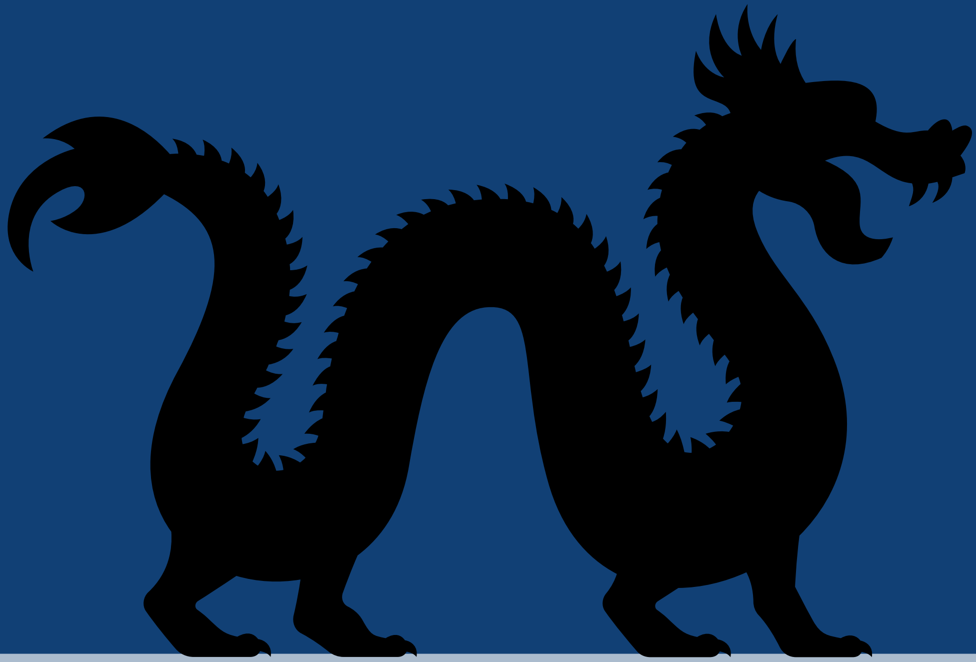
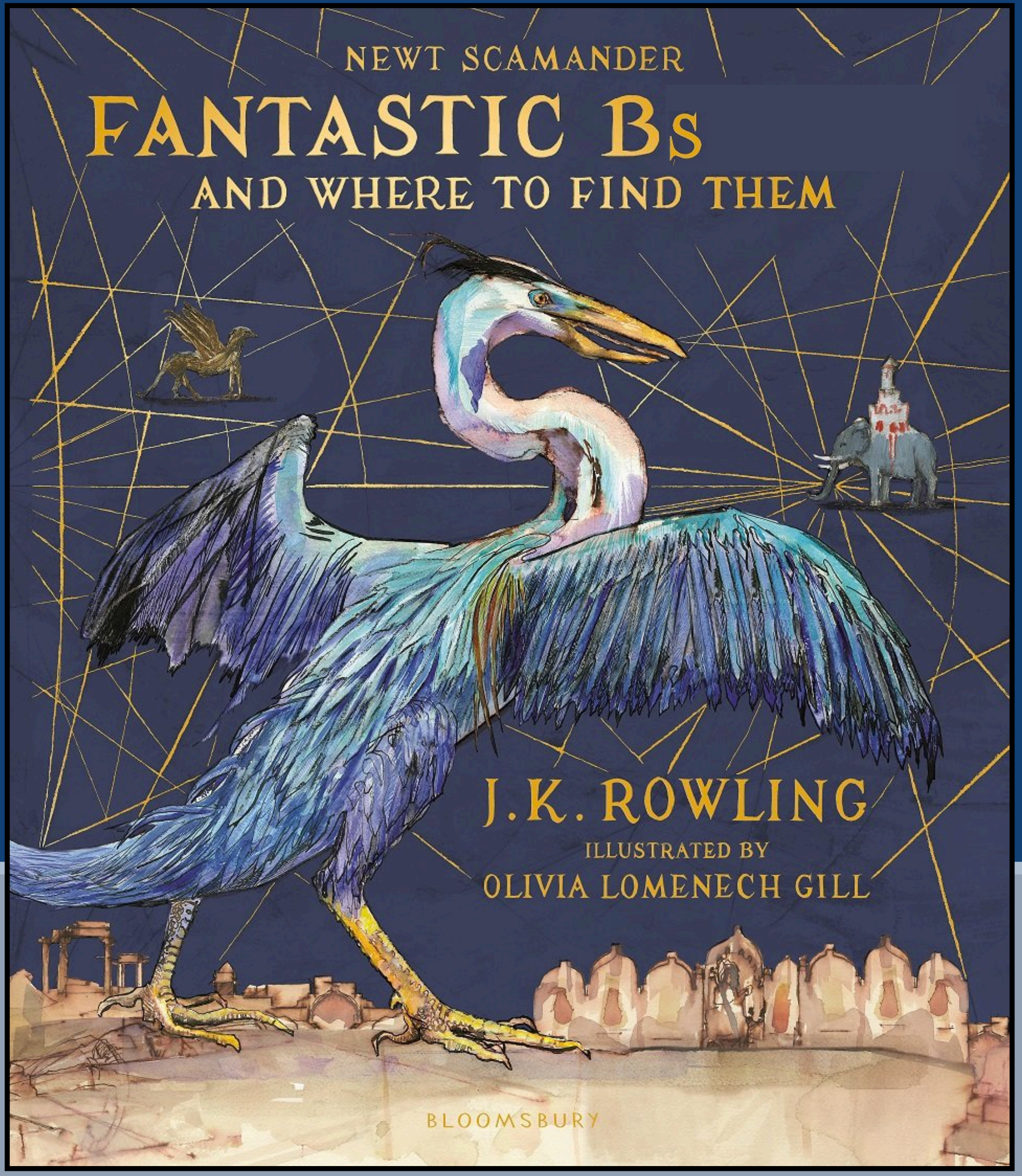
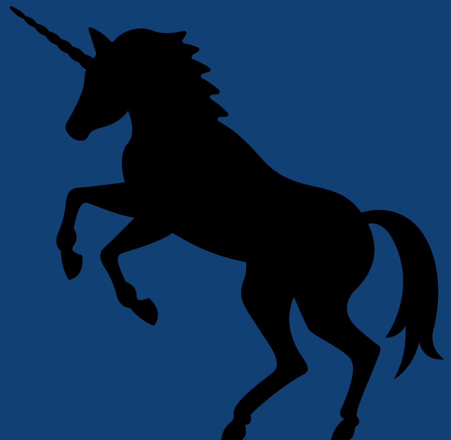


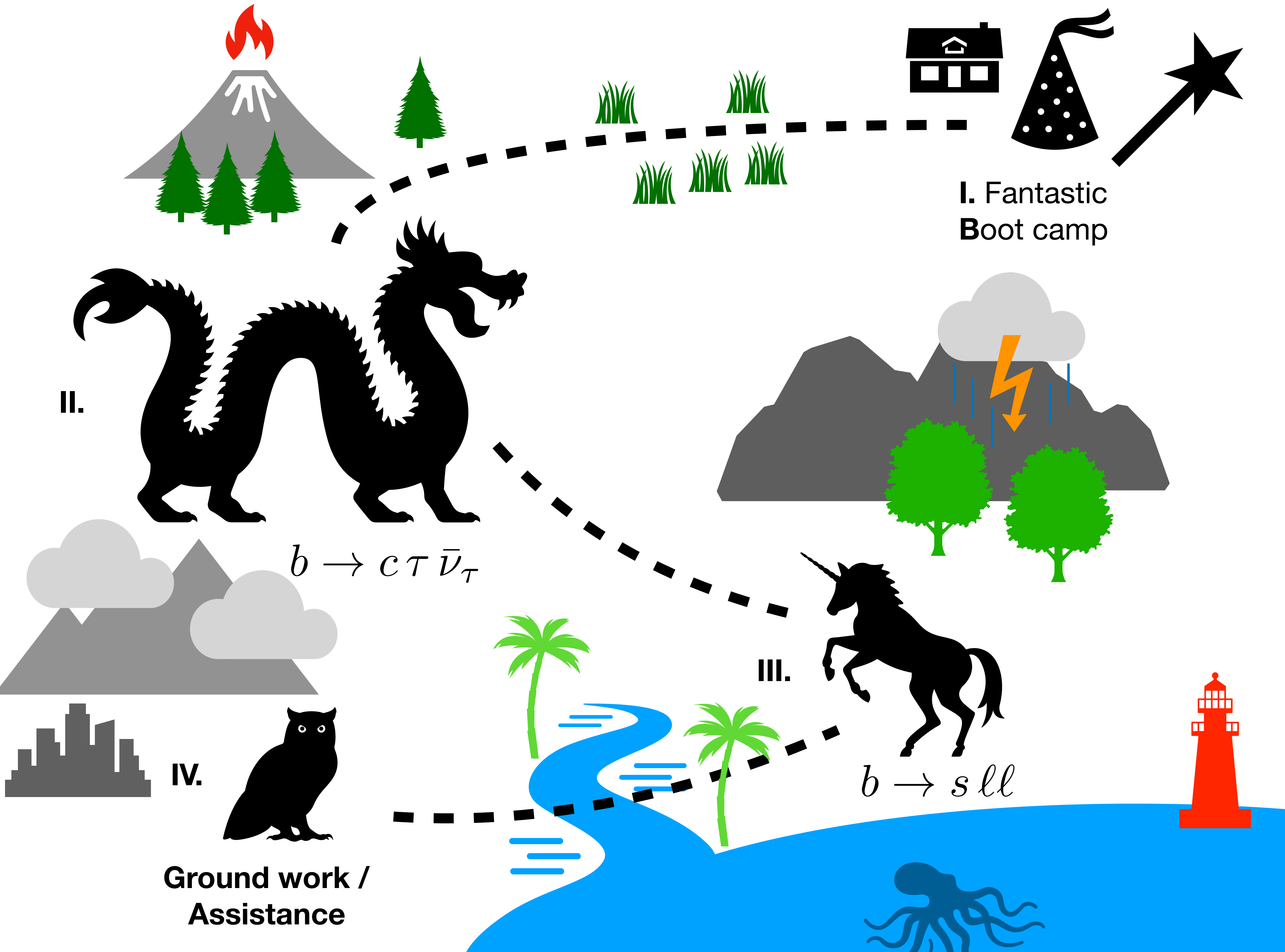


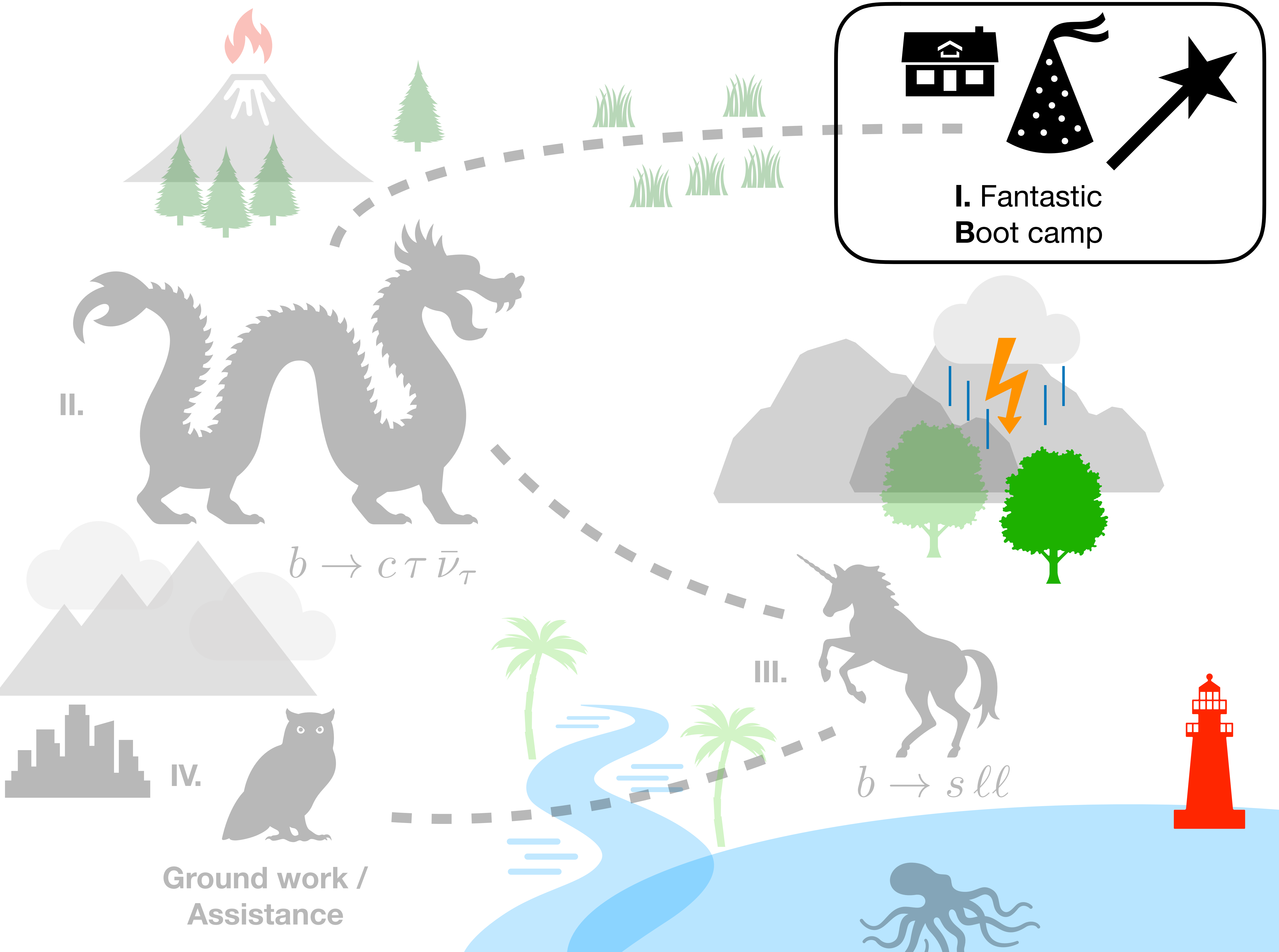
Fantastic Bs

B-Mesons & b-Baryons! ↗

... and where to find them




I. Fantastic
Boot camp
II.
$b \to c\,\tau\,\bar{\nu}_\tau$
III.
$b \to s\,\ell\ell$
IV.
Ground work /
Assistance



I. Fantastic
Boot camp
II.
$b \to c\,\tau\,\bar{\nu}_\tau$
III.
$b \to s\,\ell\ell$
IV.
Ground work /
Assistance

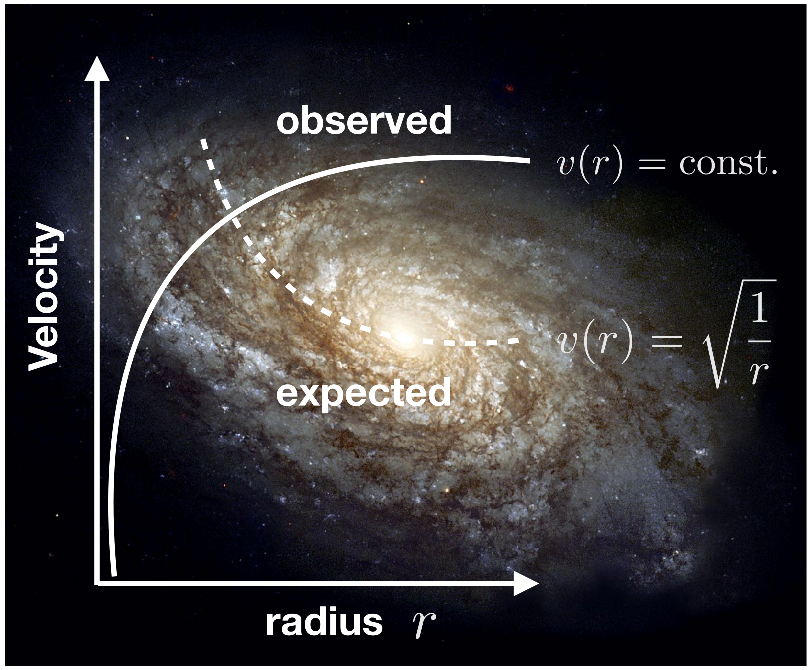
Everybody talks about new physics — why?

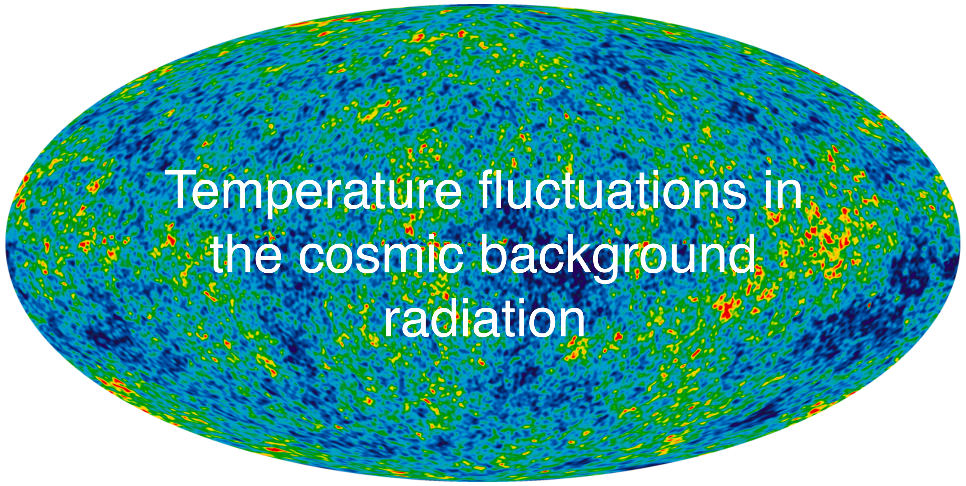
- What's wrong with "old" physics?

Successfully describes most phenomena recorded at particle physics experiments

- **The open questions:**
  - **Rotation curves** from spiral **galaxies** indicate existence of new type of matter (Dark matter or short **DM**)
    - Similar evidence for DM in the temperature fluctuations of cosmic background radiation
  - **Neutrinos** have **mass** (they oscillate)
  - **Not** a **theory of everything**: Quantum mechanics and gravity do not bond
    - Perhaps both are a limit of a more fundamental theory?

rotation curves of spiral galaxies





The Standard Model of Particle Physics (SM)

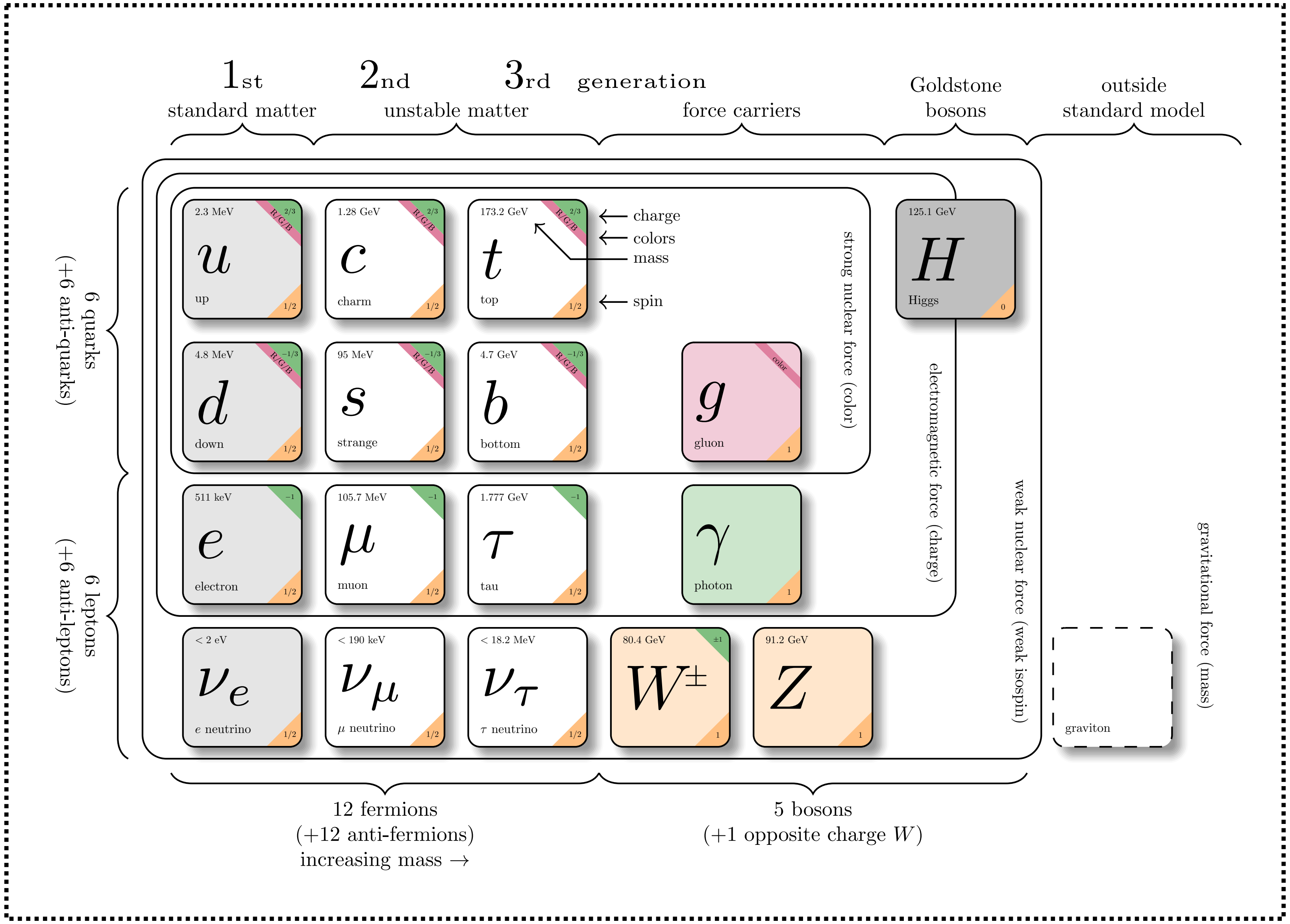
- Our **best theory** to describe particle collider phenomena

Relativistic quantum field theory, describes **3 of the 4** fundamental Forces

- Electromagnetism
- Weak Force
- Strong Force

Classifies all particles into

- 6 quarks + 6 anti-quarks
- 6 leptonen + 6 anti-leptons
- 4 Types of interaction particles
- 1 Higgs boson



The SM: a great success story with flaws

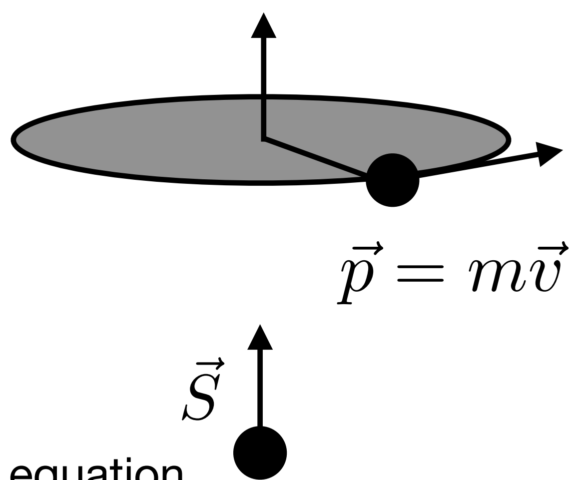
- One of the most impressive predictions: **magnetic moment of the electron**

$$\vec{L} = \vec{r} \wedge \vec{p}$$

$$M_L = -\frac{e}{2m}\vec{L}$$

in QM

$$\vec{M}_L = g_L \frac{e}{2m}\vec{S}$$



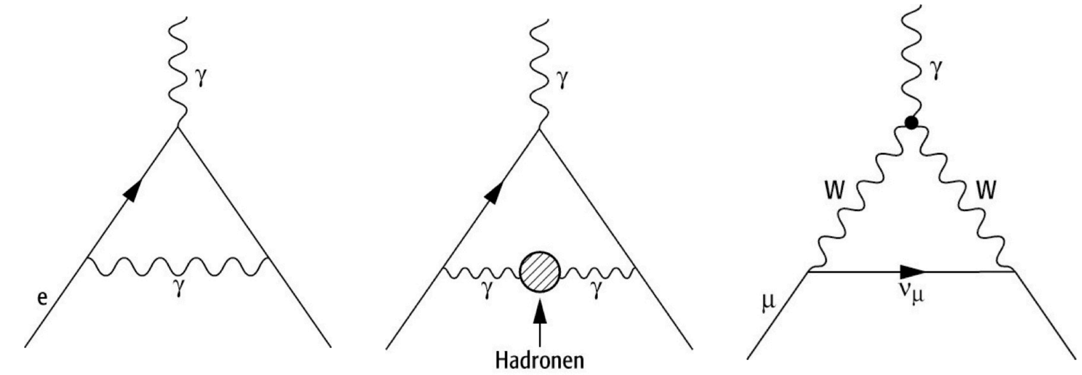
$$\vec{p} = m\vec{v}$$

$$\vec{S}$$

$$g_L = 2$$

Dirac equation, in relat. QM

Deviations of **2** through polarisation of the vacuum



$$a^e_{\text{exp}} = \frac{g_e - 2}{2} = (1'159'652'188.4 \pm 4.3) \times 10^{-12}$$

$$a^e_{\text{SM}} = \frac{g_e - 2}{2} = (1'159'652'205.4 \pm 28) \times 10^{-12}$$

Precision prediction over 8 orders of magnitudes!

The SM: a great success story with flaws

- One of the most impressive predictions: **magnetic moment of the electron**

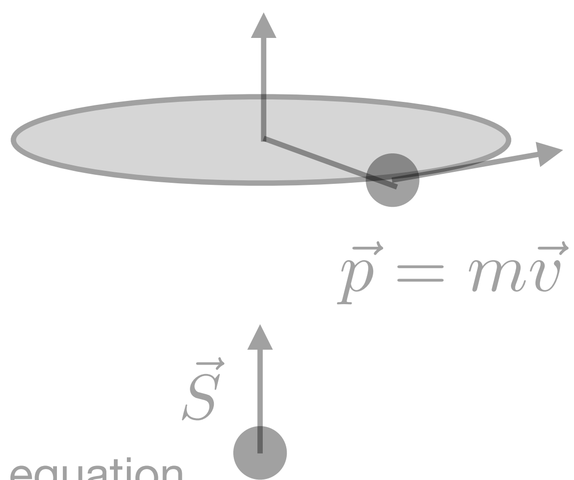
$$\vec{L} = \vec{r} \wedge \vec{p}$$

$$M_L = -\frac{e}{2m}\vec{L}$$

in QM

$$\vec{M}_L = g_L \frac{e}{2m}\vec{S}$$

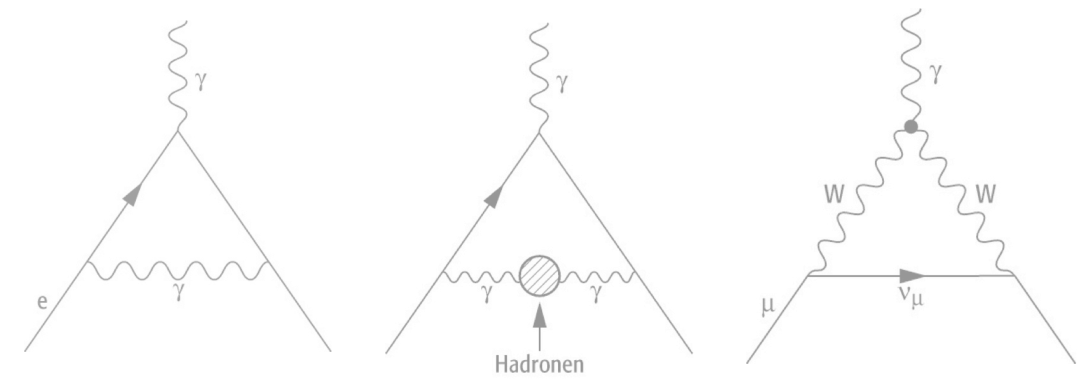
$$g_L = 2$$ Dirac equation, in relat. QM



$$\vec{p} = m\vec{v}$$

$\vec{S}$

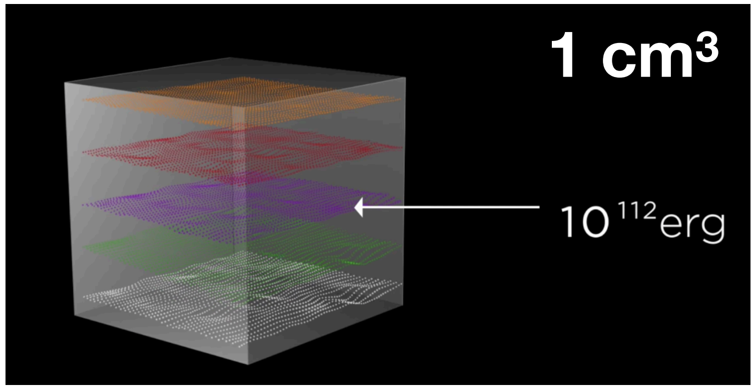
Deviations of **2** through polarisation of the vacuum



$$a^e_{\rm exp} = \frac{g_e - 2}{2} = (1'159'652'188.4 \pm 4.3) \times 10^{-12}$$
$$a^e_{\rm SM} = \frac{g_e - 2}{2} = (1'159'652'205.4 \pm 28) \times 10^{-12}$$

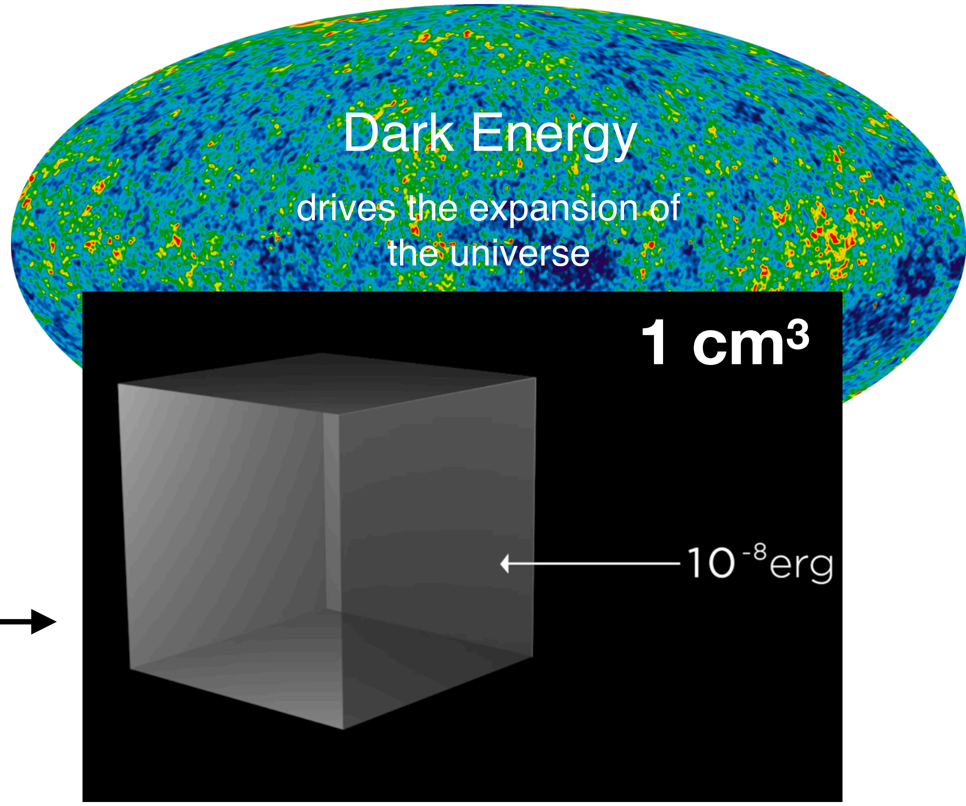
Precision prediction over 8 orders of magnitudes!

- But ask the **SM** what the energy density of the vacuum in the universe is, you get a surprise



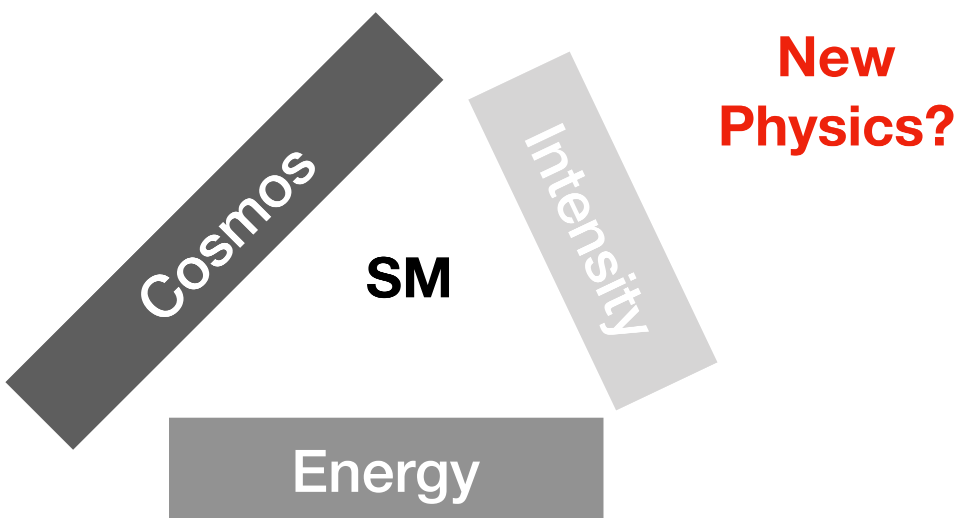
Off by 120 orders of magnitudes ?!?

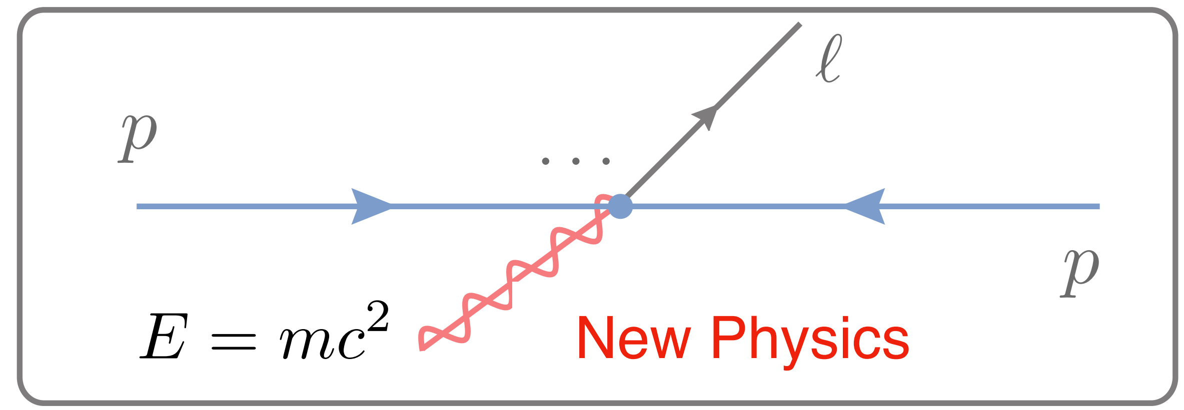
1 erg = 6.2x 10^{11} eV= 10^{-7} Joule ≈ 1 wing flap of a fly



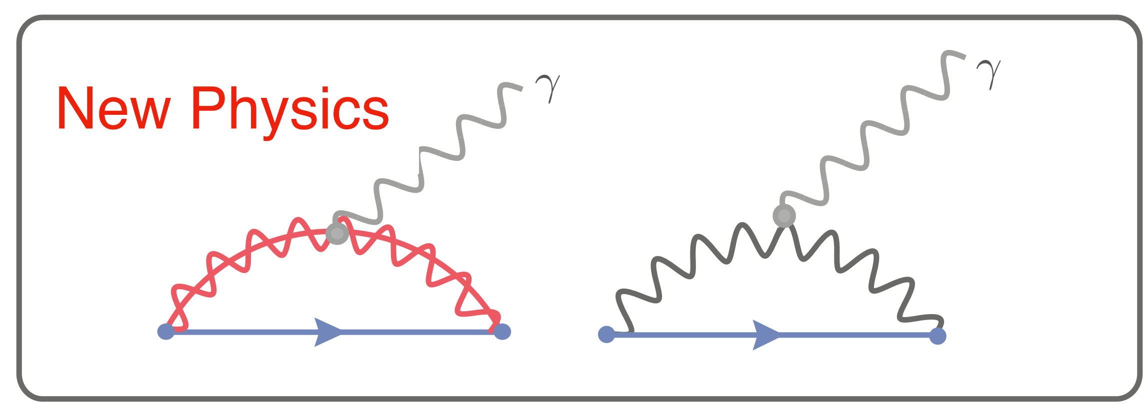
The intensity frontier and the Belle II-Experiment

- In Summary: Strong evidence that physics beyond the SM **must exist**





Search for New Physics at the LHC or HL-LHC

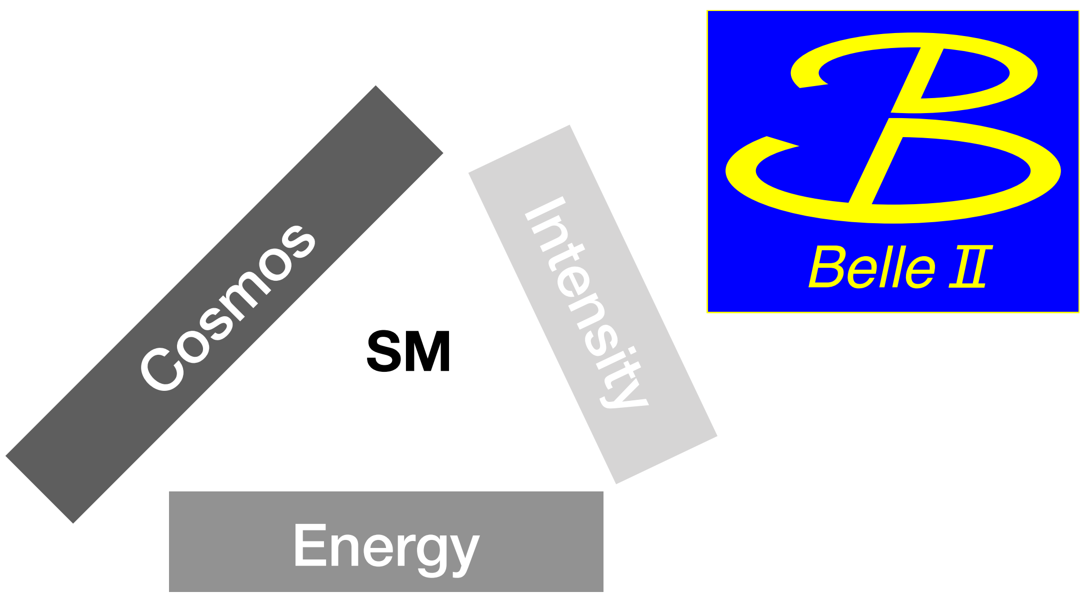


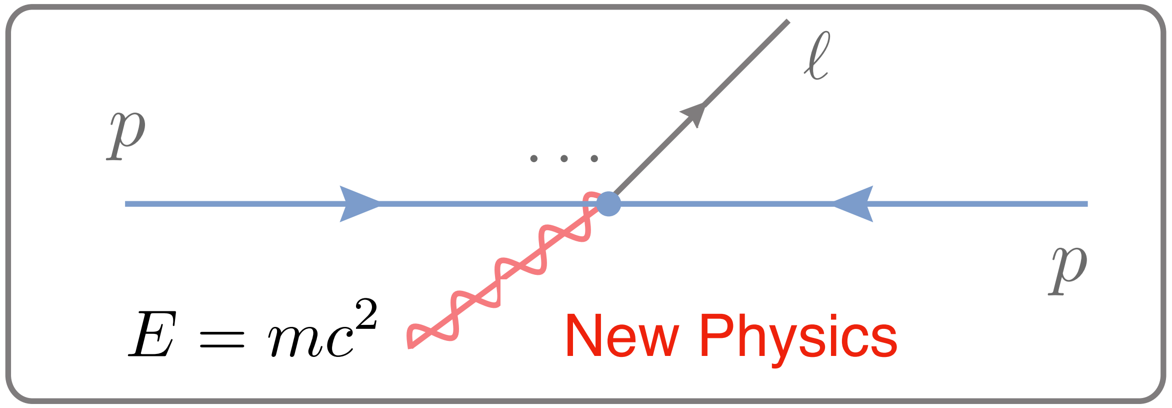
Search for New Physics at Belle II

- **Cosmos:** Use the universe as a laboratory
- **Energy:** Direct production of new physics (observe new phenomena or new particles)
- **Intensity:** Indirect Search of new physics through corrections of well known processes

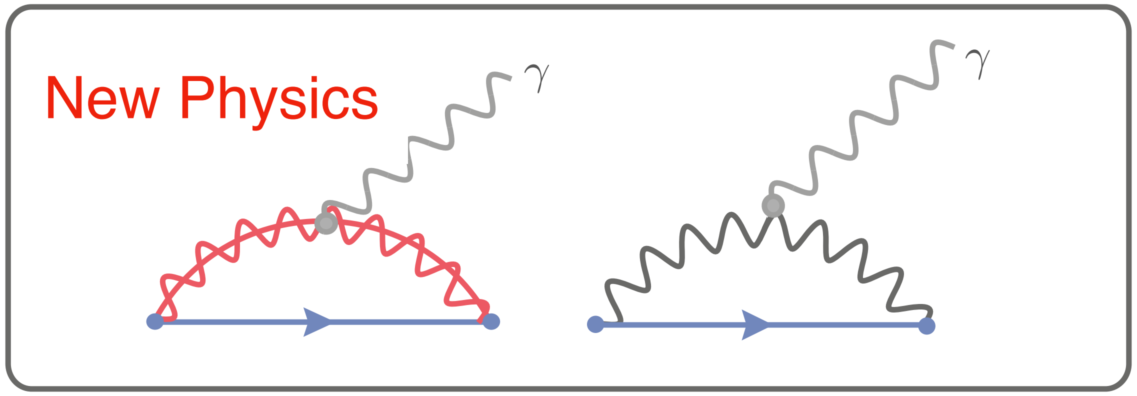
The intensity frontier and the Belle II-Experiment

- In Summary: Strong evidence that physics beyond the SM **must exist**





Search for New Physics at the LHC or HL-LHC

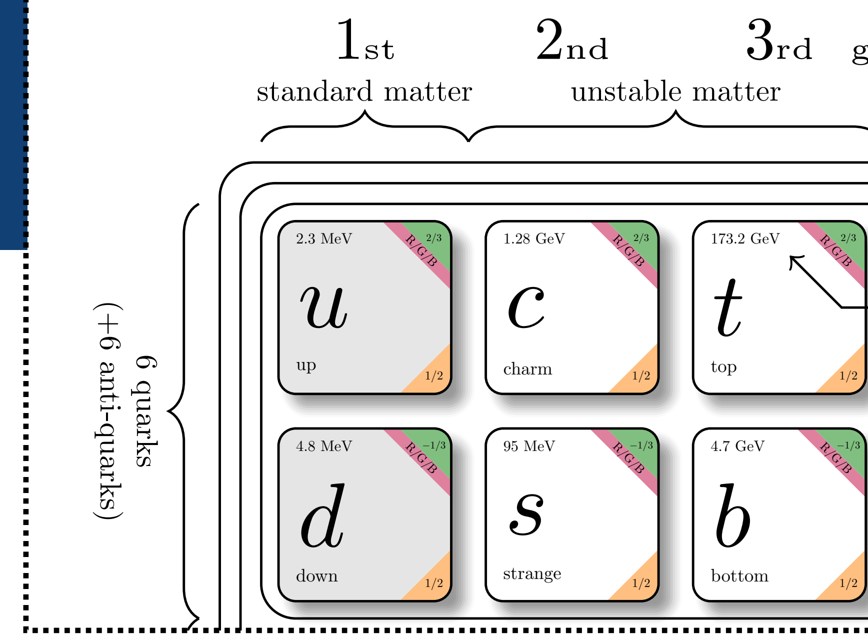


Search for New Physics at Belle II

with b quarks

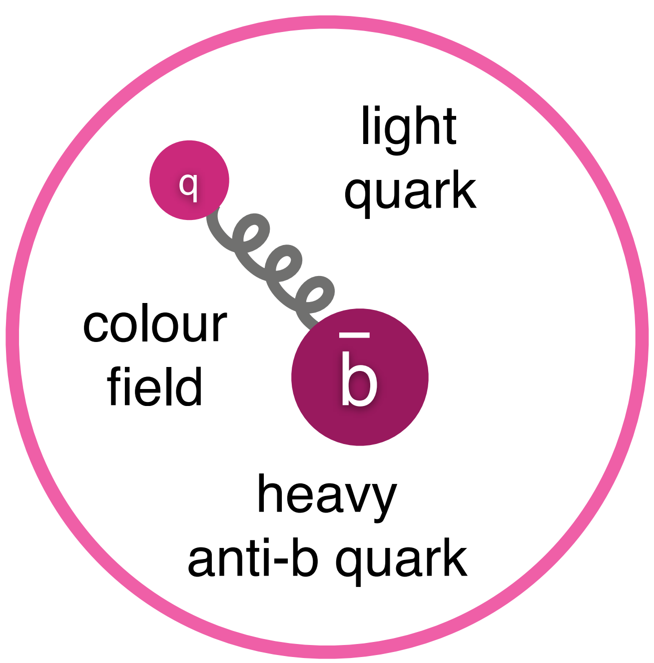
- **Cosmos:** Use the universe as a laboratory
- **Energy:** Direct production of new physics (observe new phenomena or new particles)
- **Intensity:** Indirect Search of new physics through corrections of well known processes

Beauty or Bottom Quarks

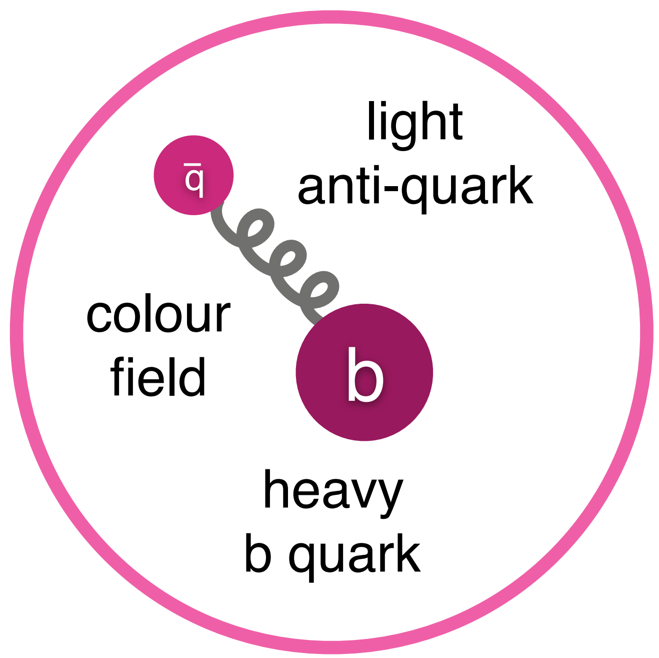


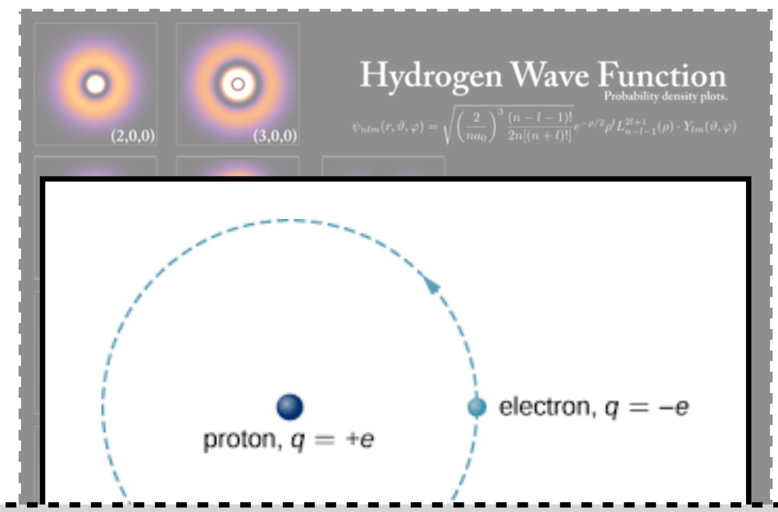
- At Belle II we search for New Physics, by producing **huge amounts** of **beauty or short b quarks**
  - All quarks carry **colour charges** and only exist as bound states (with the exception of the top quark)

B meson



anti-B meson





B meson: a **hydrogen atom for** our understanding of the strong interaction / **QCD**

$$m_Q \to \infty$$

$$i\frac{\not{p} + m_Q}{p^2 - m_Q^2 + i\epsilon} \to i\frac{1 + \not{v}}{2v \cdot k + i\epsilon}$$

v: four-velocity of the b-quarks

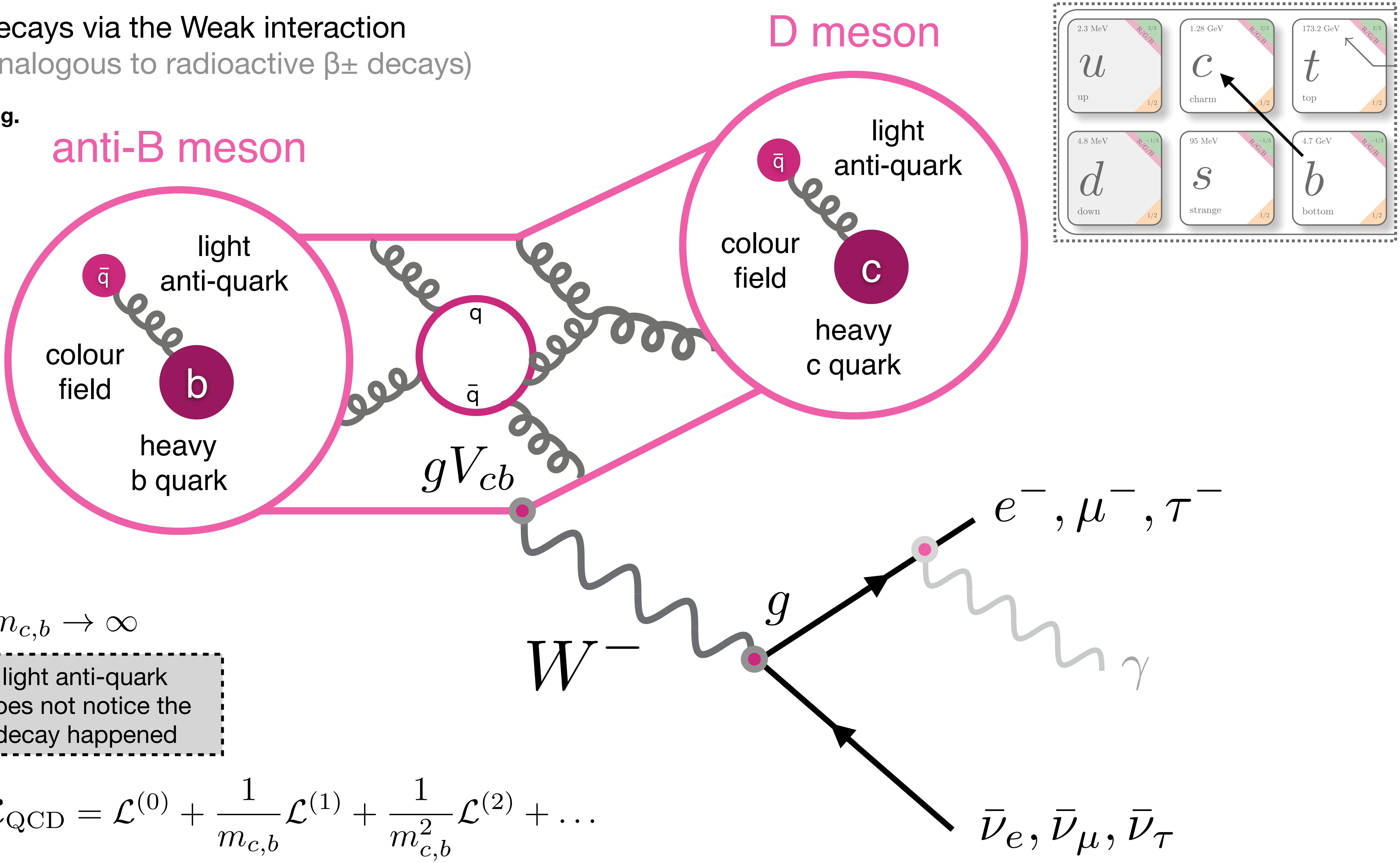
k: Measure for how far the b-quark is away from its mass-shell

Flavour

- Life time of a B meson: $\tau \approx 1.5 \times 10^{-12}$ seconds

Decays via the Weak interaction
(analogous to radioactive β± decays)

e.g.



$m_{c,b} \to \infty$

light anti-quark does not notice the decay happened

$$\mathcal{L}_{\rm QCD} = \mathcal{L}^{(0)} + \frac{1}{m_{c,b}}\mathcal{L}^{(1)} + \frac{1}{m_{c,b}^2}\mathcal{L}^{(2)} + \dots$$

The “Setup” of a B-factory

- Collide electrons and positrons at a **centre of mass energy** of about 2 x B meson mass

$$\sqrt{s} = 10.58\,\mathrm{GeV}$$

$$e^+ \longrightarrow \Upsilon(4S) \longleftarrow e^-$$

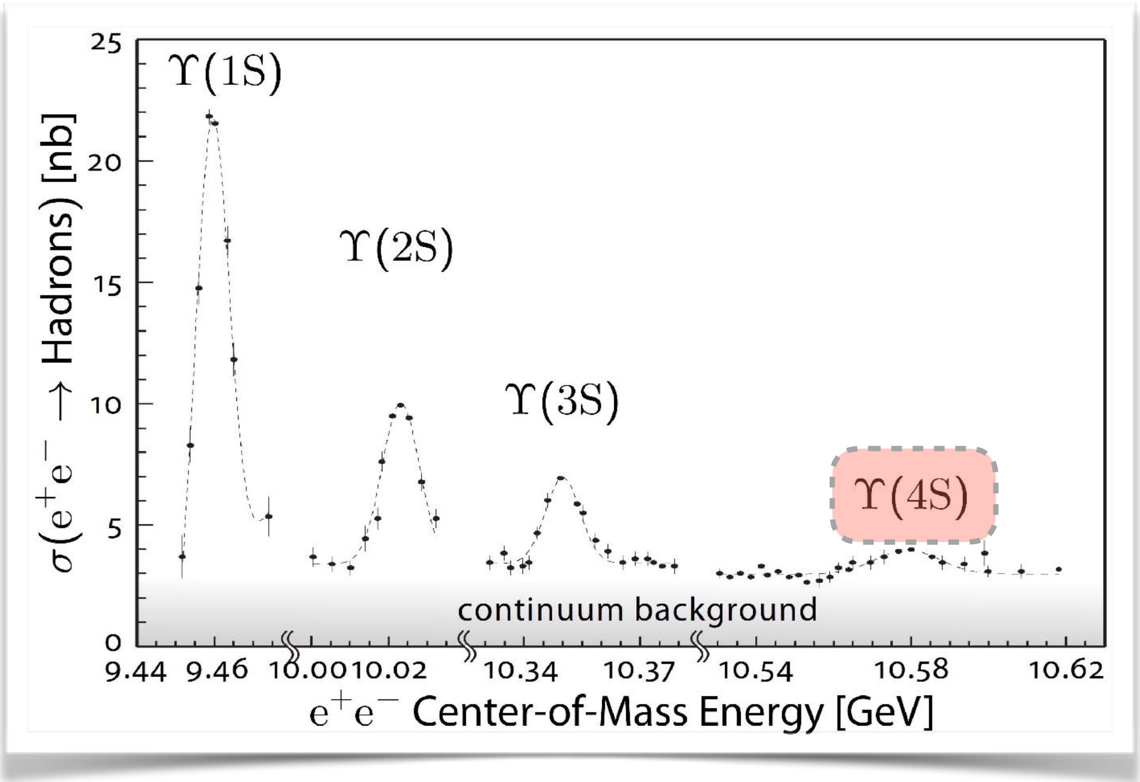
The “Setup” of a B-factory

- Collide electrons and positrons at a **centre of mass energy** of about 2 x B meson mass

$$\sqrt{s} = 10.58\,\mathrm{GeV}$$

$$e^+ \longrightarrow \Upsilon(4S) \longleftarrow e^-$$

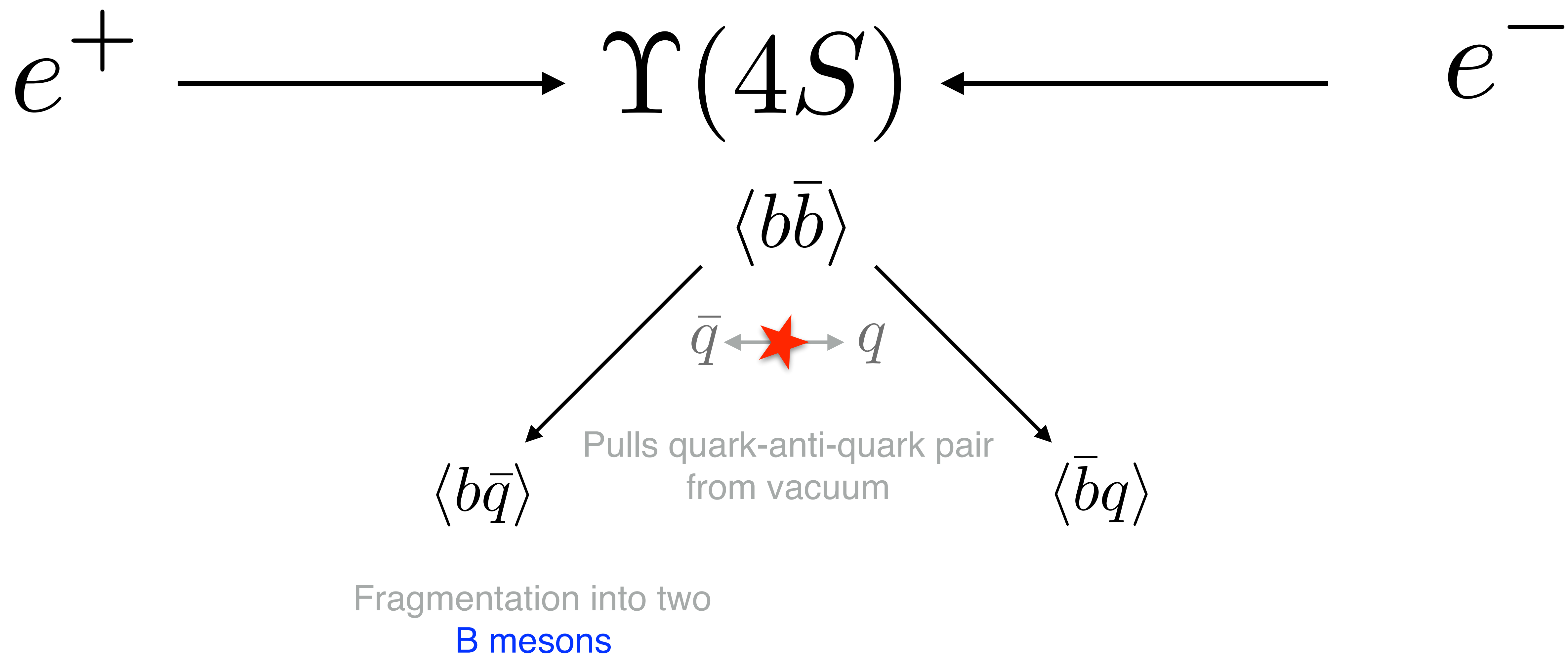
$$\langle b\bar{b}\rangle$$



Das "Setup" einer B-Fabrik

- Collide electrons and positrons at a **centre of mass energy** of about 2 x B meson mass

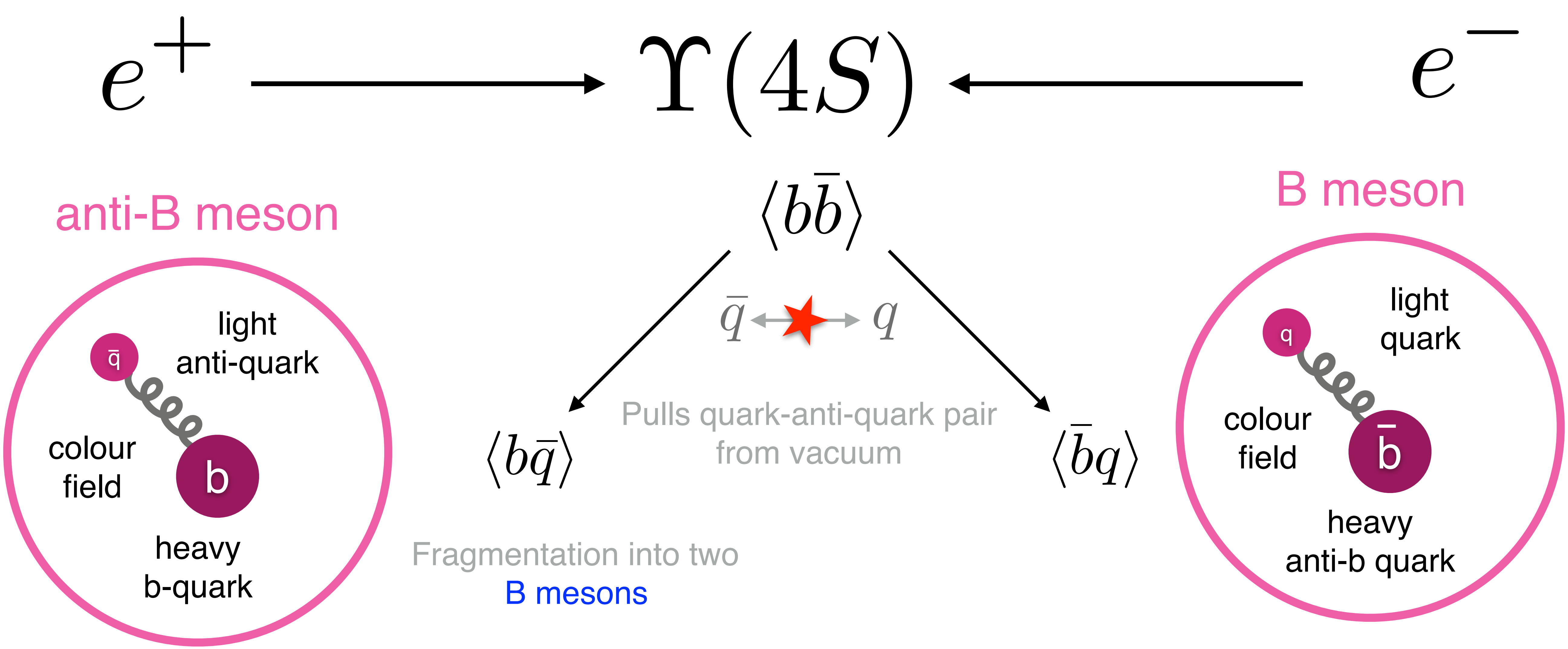
$$\sqrt{s} = 10.58\,\mathrm{GeV}$$



Das "Setup" einer B-Fabrik

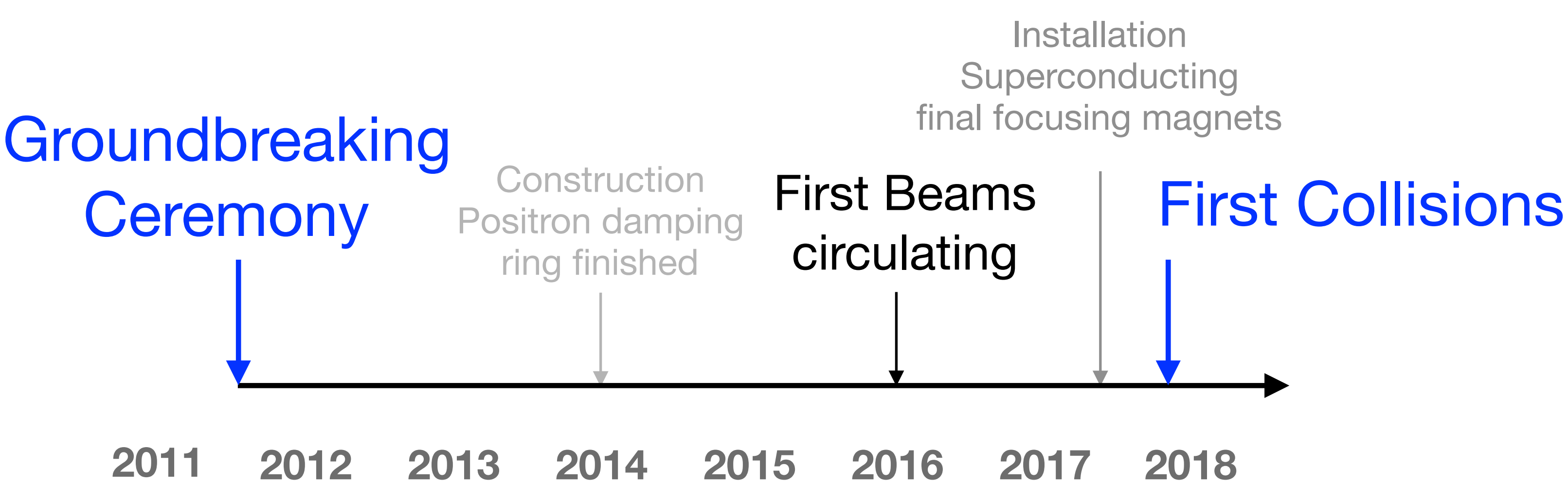
- Collide electrons and positrons at a **centre of mass energy** of about 2 x B meson mass

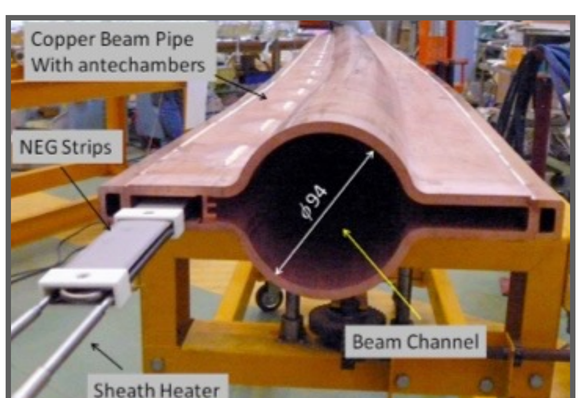
$$\sqrt{s} = 10.58\,\mathrm{GeV}$$



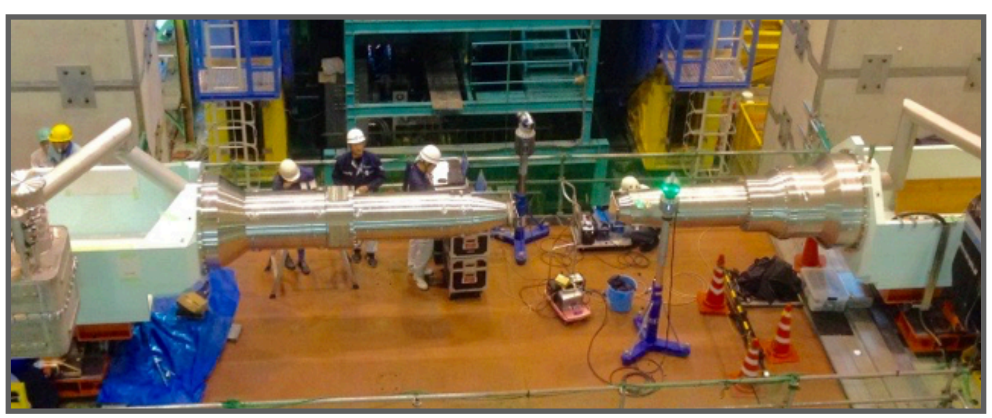
A next-generation Super-B-Factory in the making

- Integral idea: **nano-beams** P. Raimondi for SuperB
  - **50 nm** vertical spot size, reduces beam spot by factor of **20**
  - Major upgrade of existing facilities needed

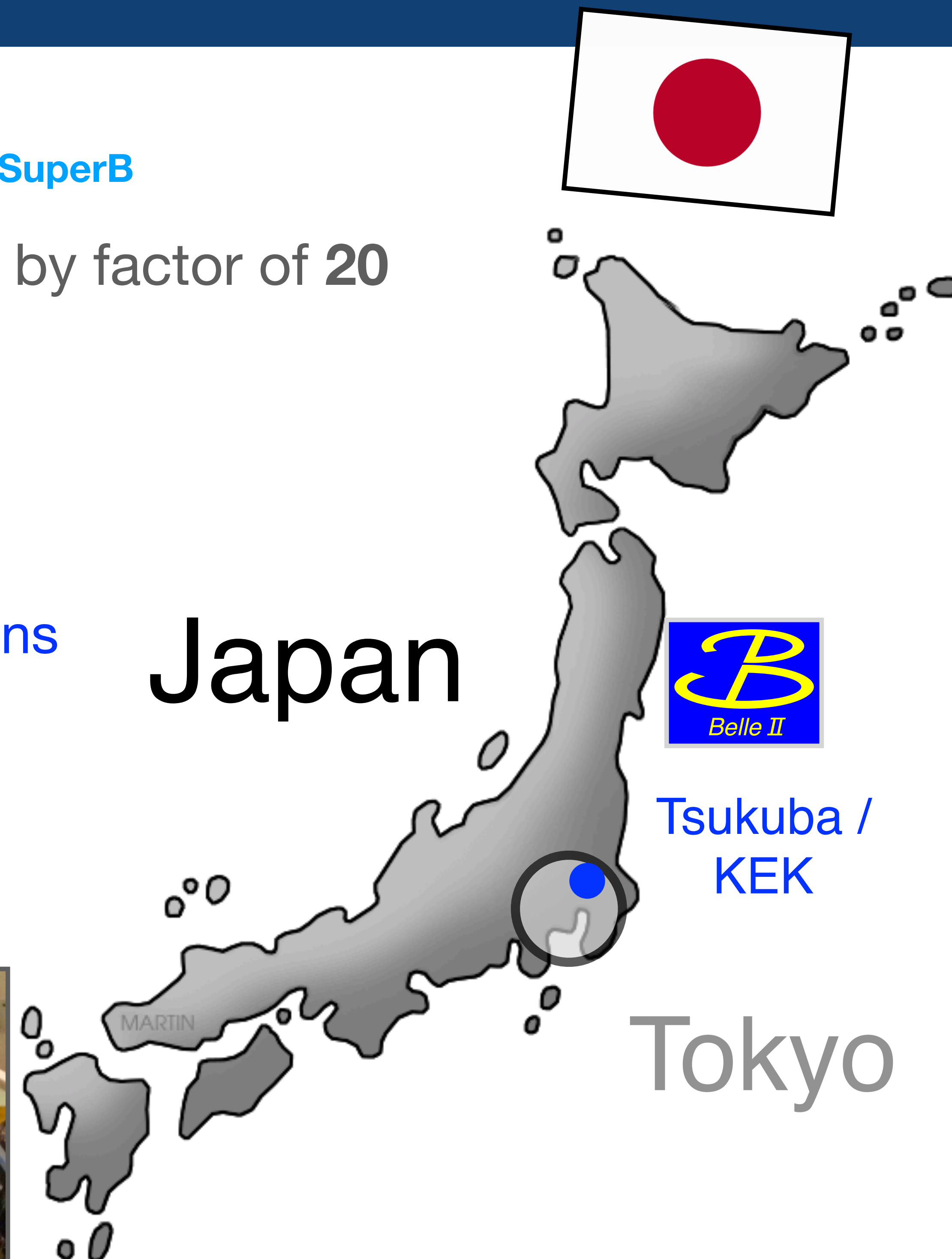




Replaced old beam pipes with TiN coated beam pipes with antechambers



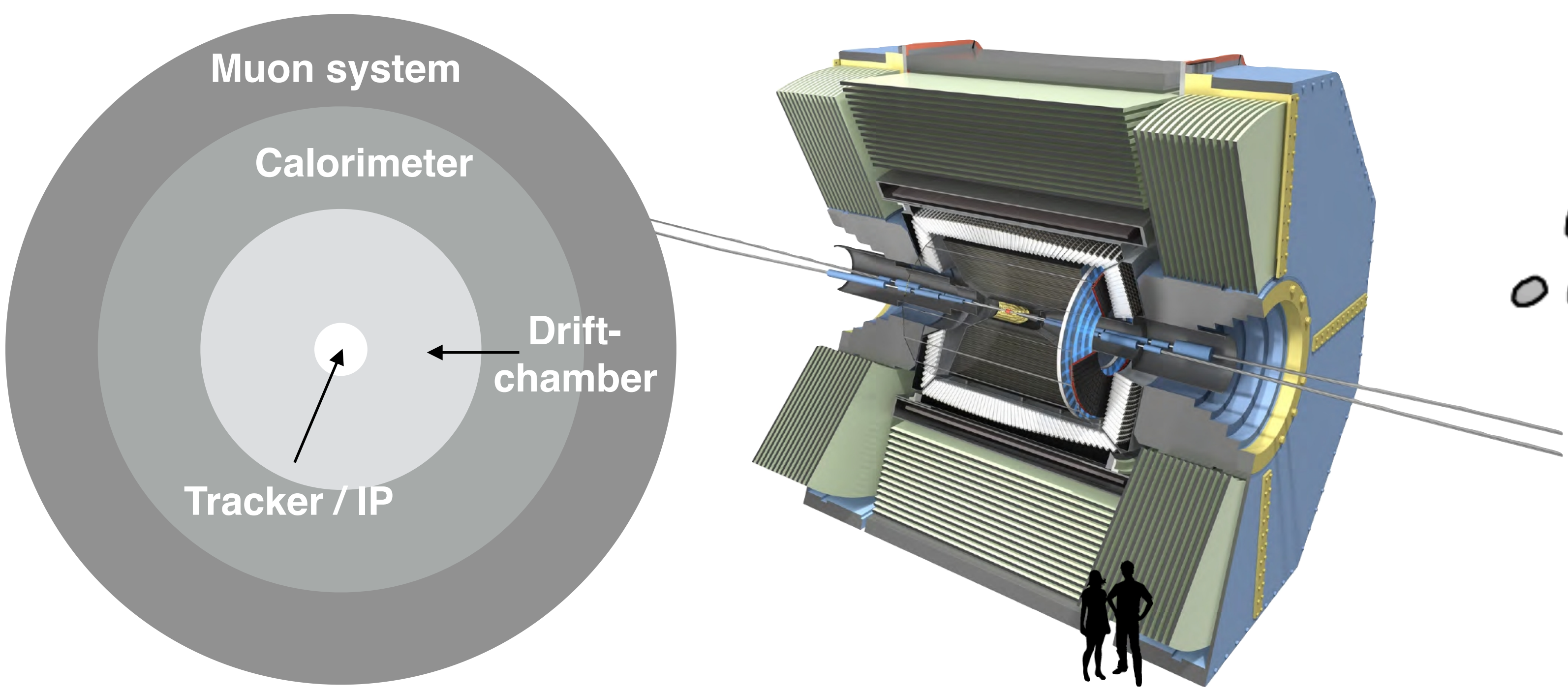
New superconducting final focusing magnets near the IP



A next-generation Super-B-Factory in the making

- Integral idea: **nano-beams** P. Raimondi for SuperB
  - **50 nm** vertical spot size, reduces beam spot by factor of **20**
  - Major upgrade of existing facilities needed

Groundbreaking Ceremony → Construction Positron damping ring finished → First Beams circulating → Installation Superconducting final focusing magnets → First Collisions

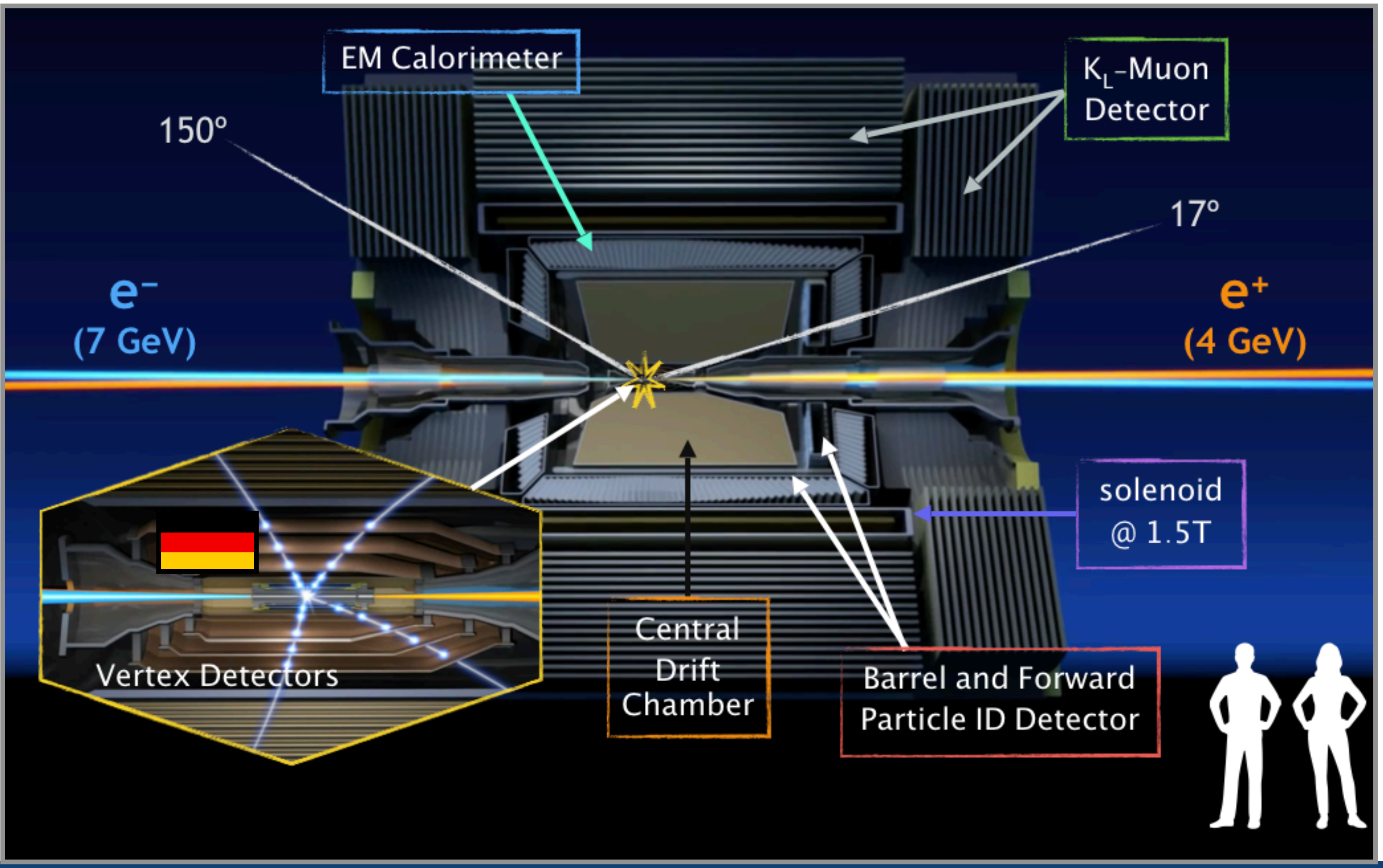


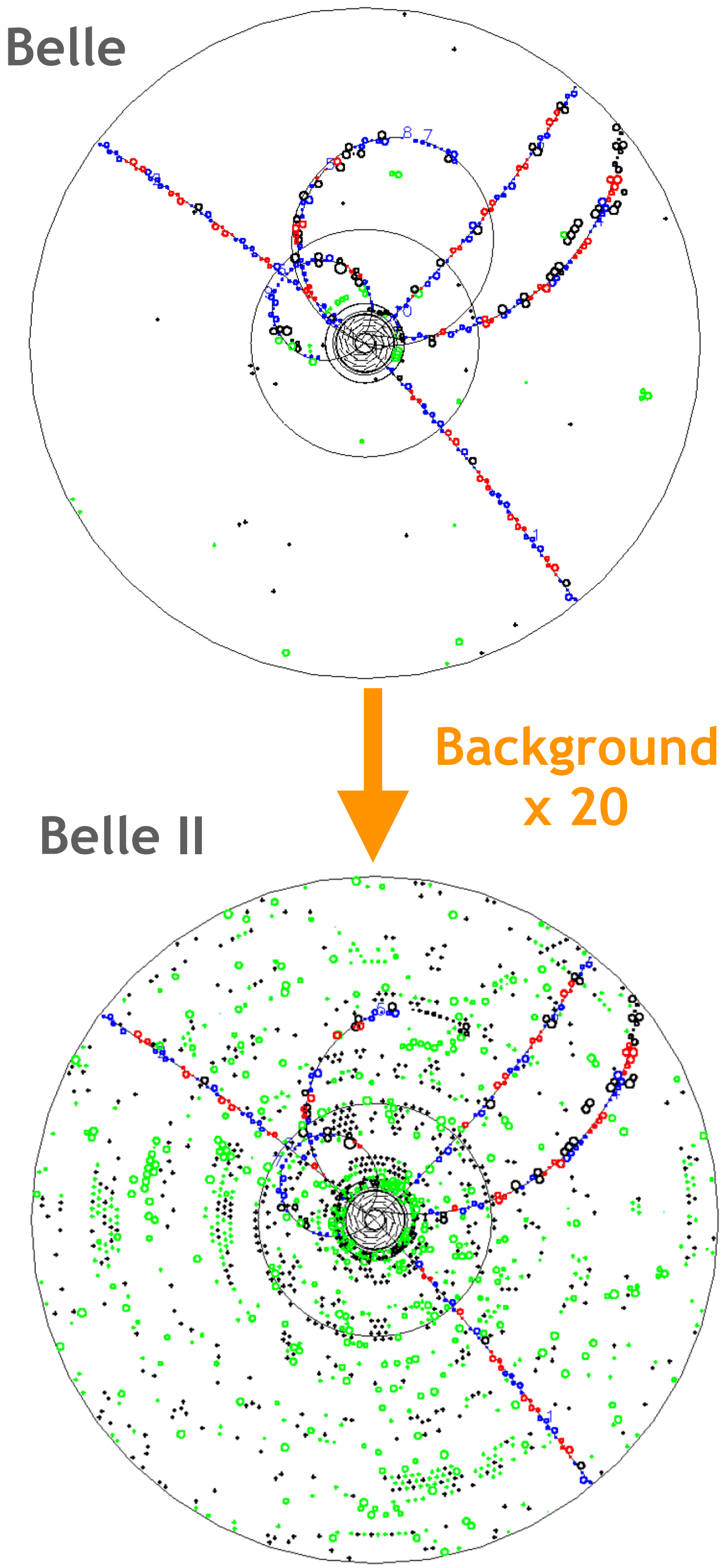

Electrons (7 GeV) - Positron (4 GeV) Accelerator
Belle II Detector
SuperKEKB-Ring (HER+LER)
Linac

The Belle II Detector

Needs to deal with **40 x higher** Luminosity:

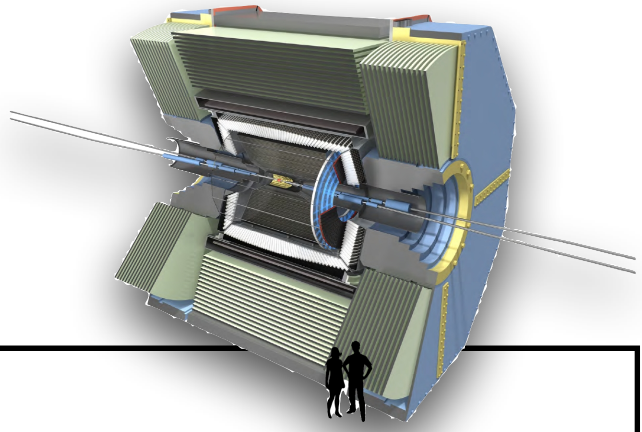
- **Higher collision rates**
  - **Higher trigger rates**
  - **Higher demands on DAQ & Computing**
- **More Background**
  - More **Radiation Damage**
  - Higher **Occupancy**, more Hits from **Background processes**

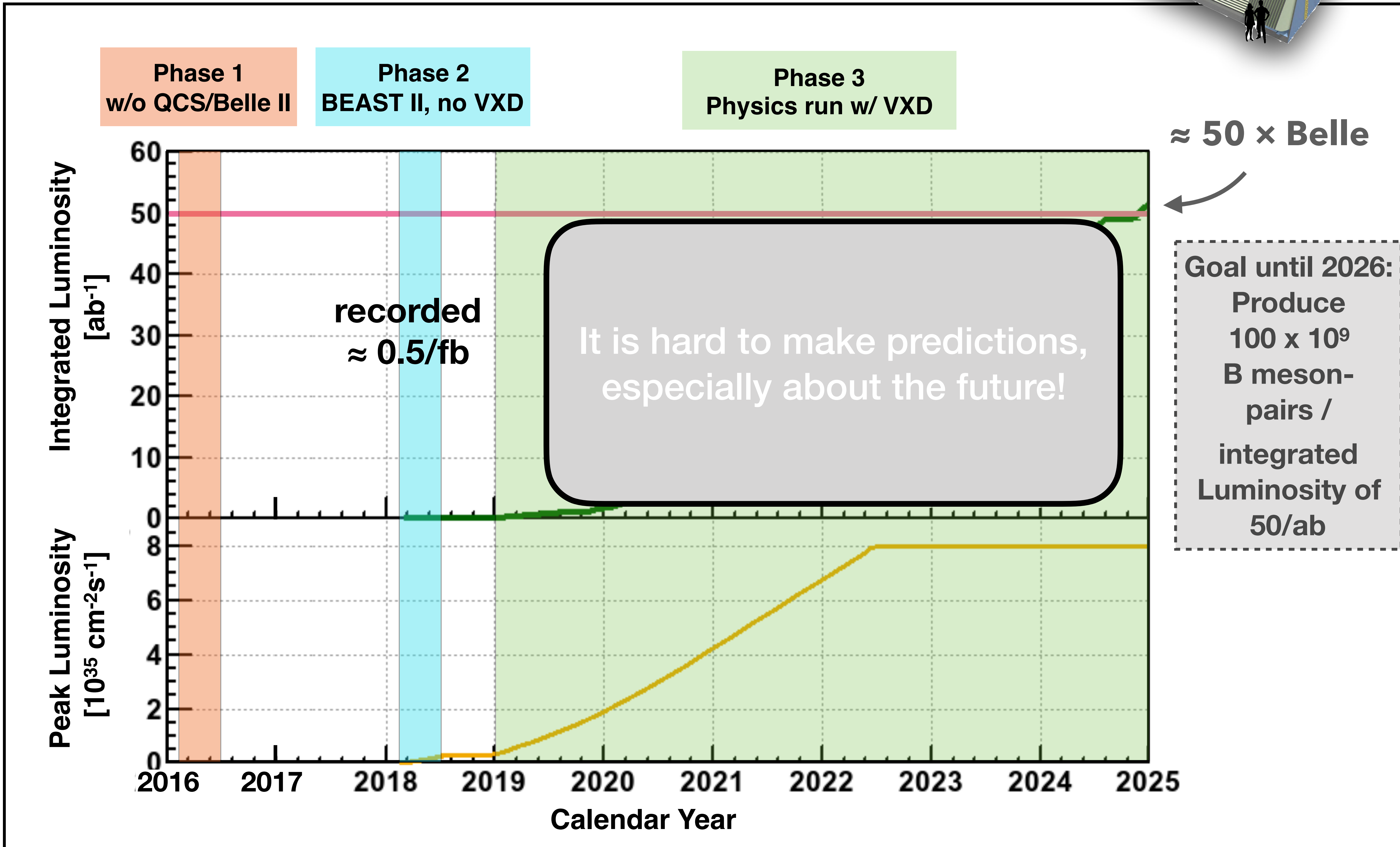




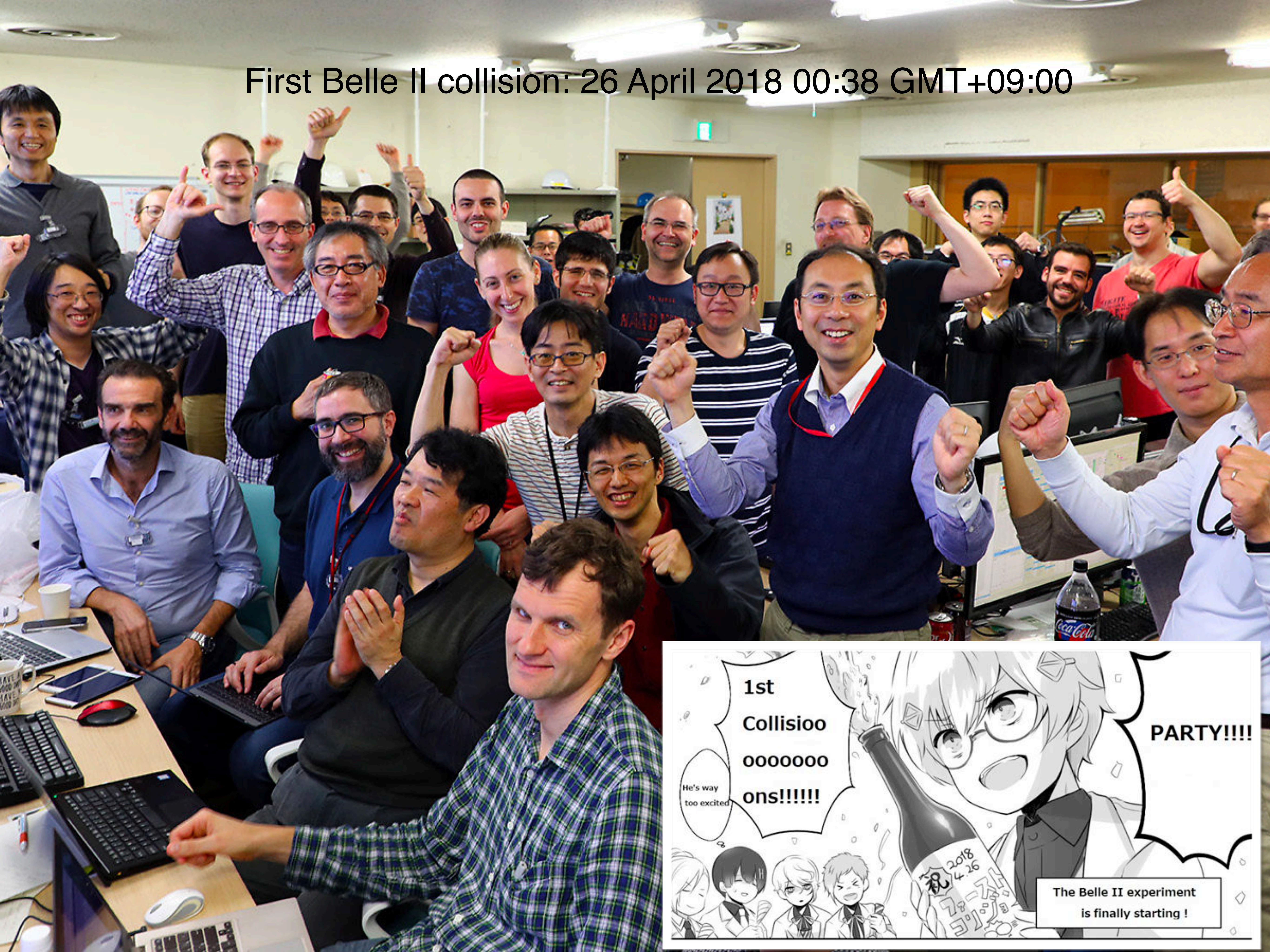
Ramp-Up

- Belle II start progresses in three phases

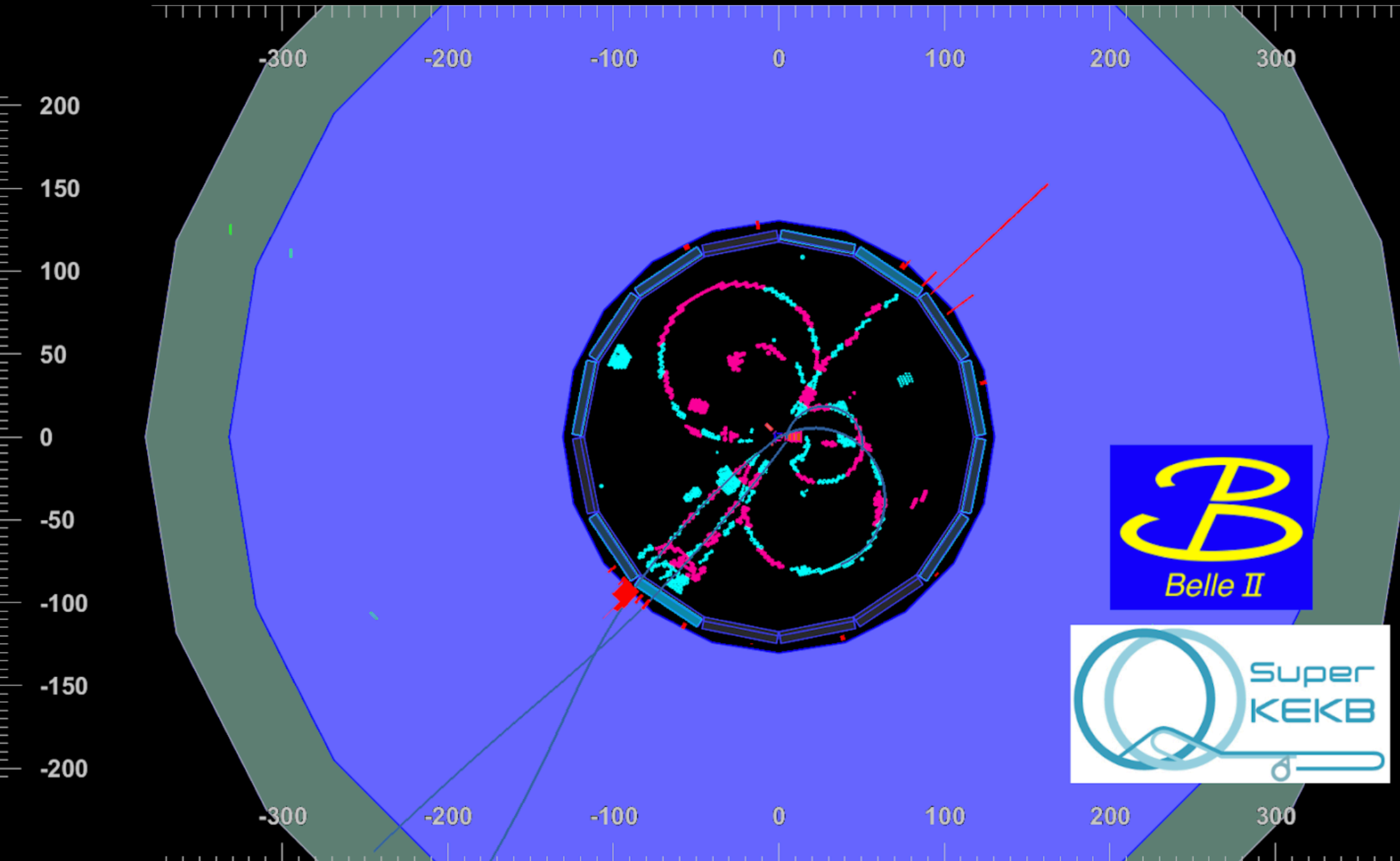




First Belle II collision: 26 April 2018 00:38 GMT+09:00



First hadronic Belle II collision

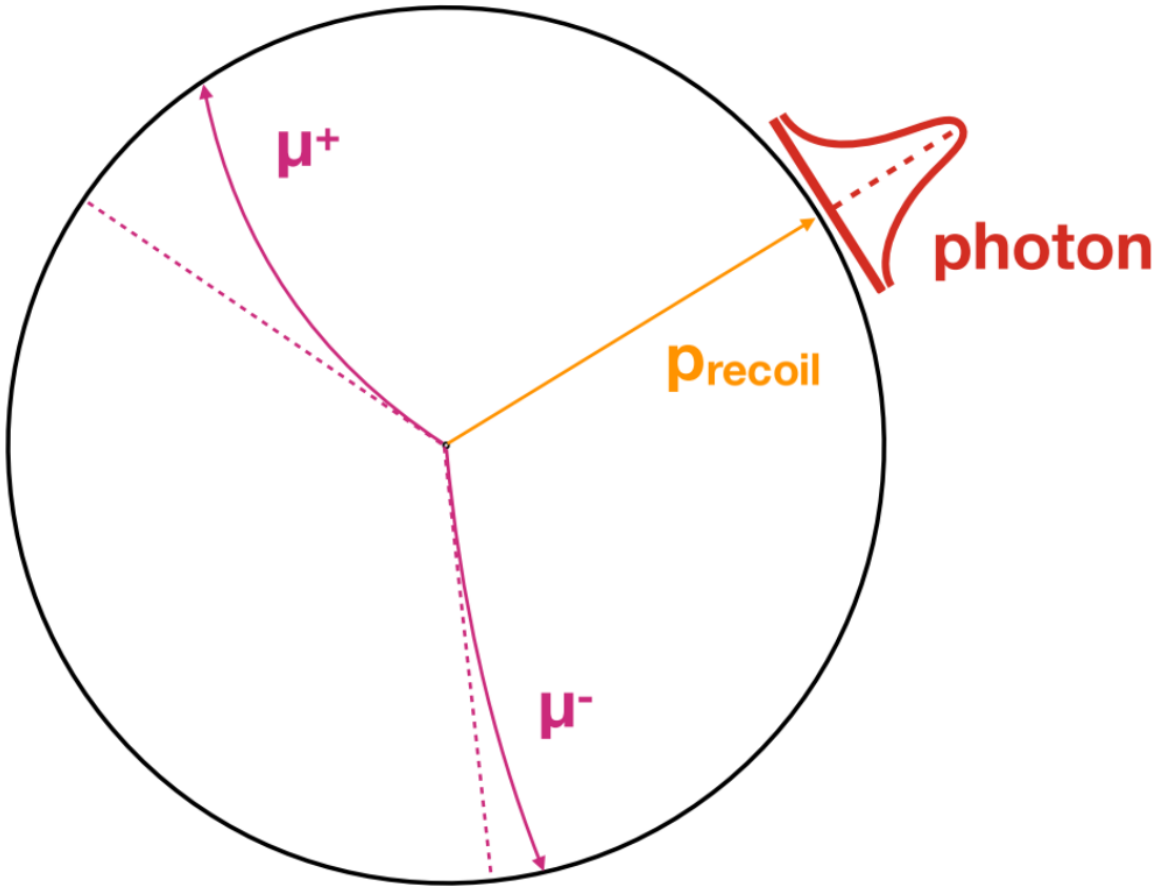


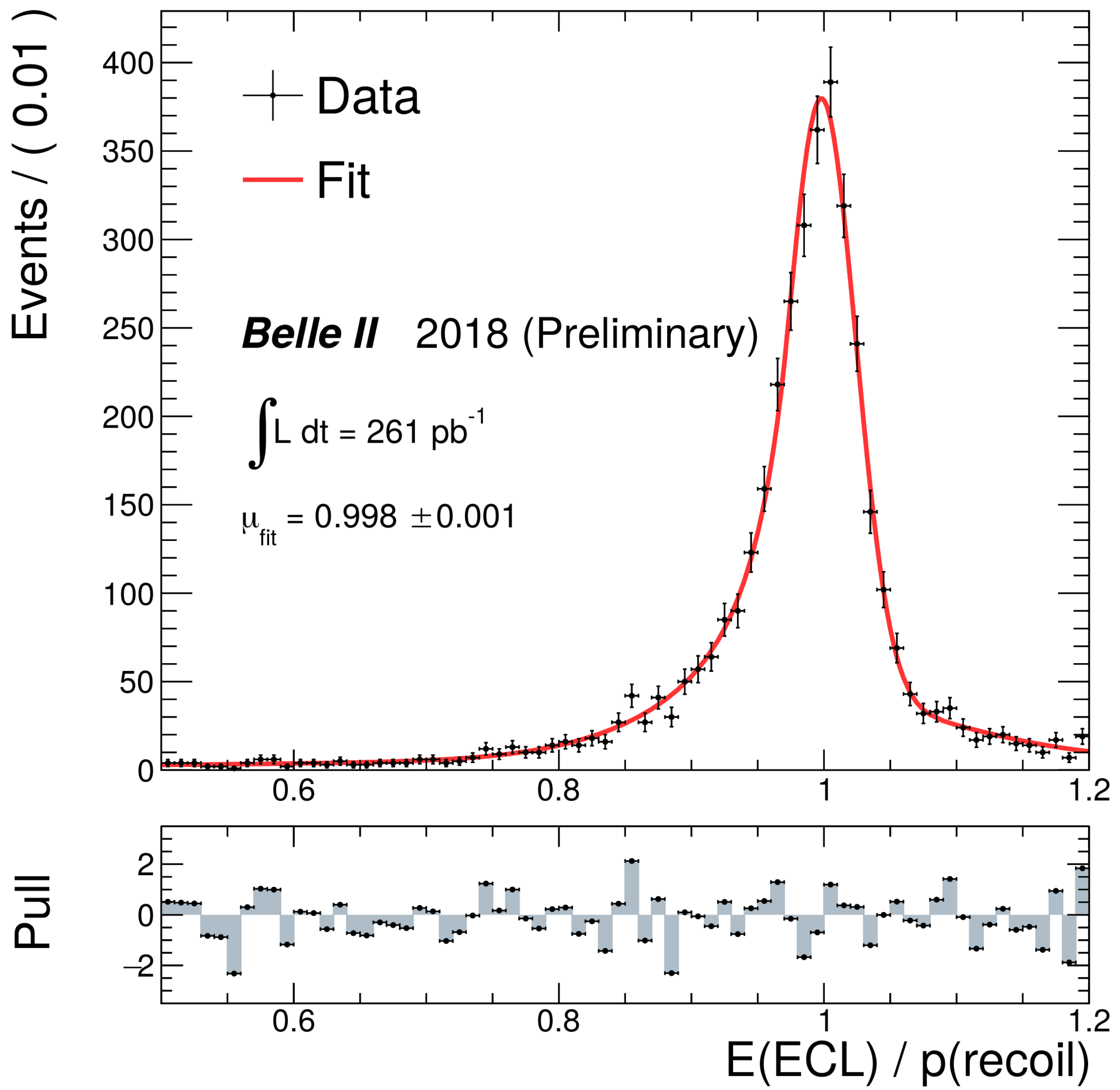
$$\mathcal{L}_{\text{peak}} = 5.5 \times 10^{33}/\text{cm}^2/\text{s} \longrightarrow \mathcal{L}_{\text{design}} = 8 \times 10^{35}/\text{cm}^2/\text{s}$$

Tracking and ECL work well

Radiative dimuon events in first data

$$e^+e^- \to \mu^+\mu^-\gamma$$

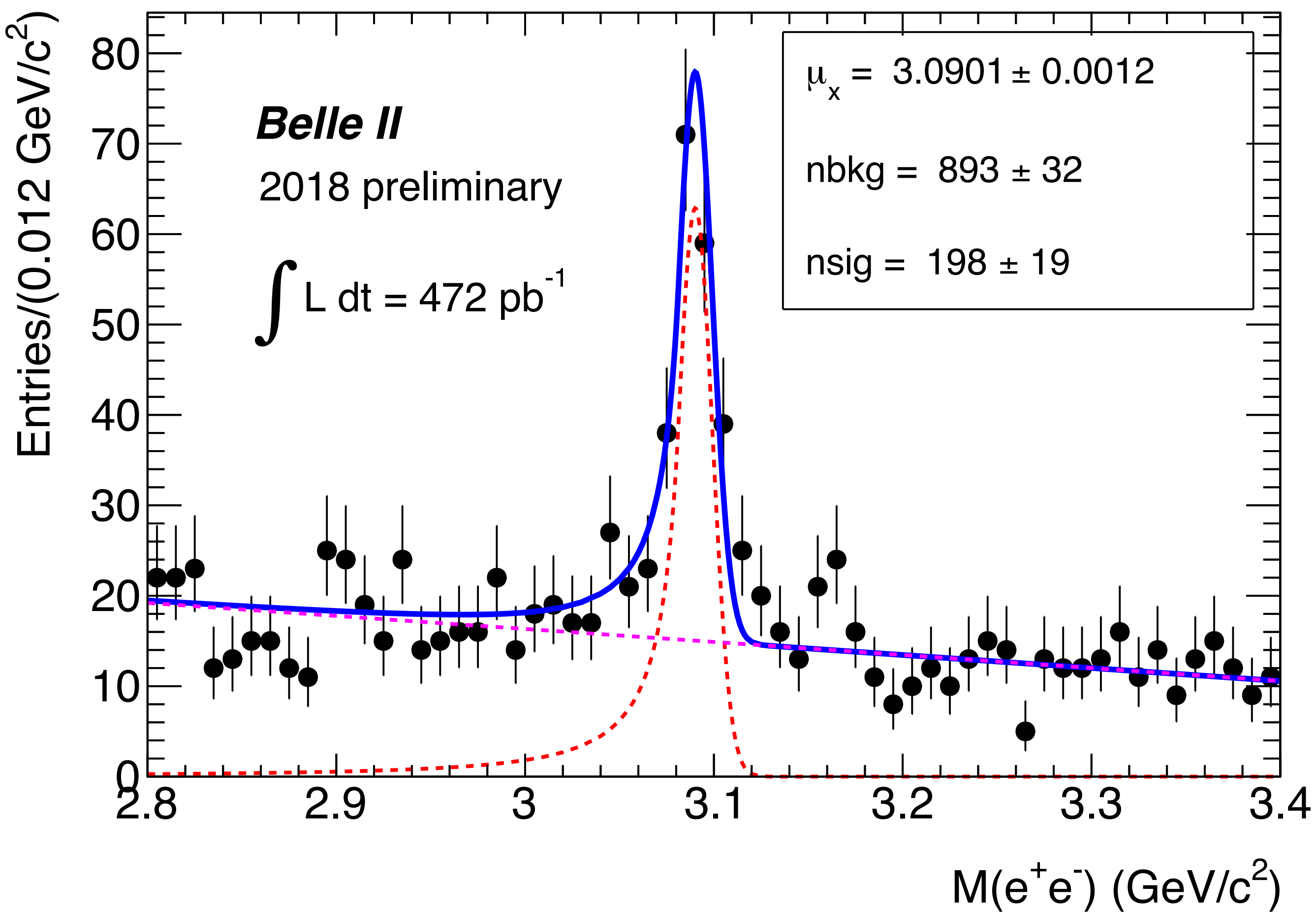




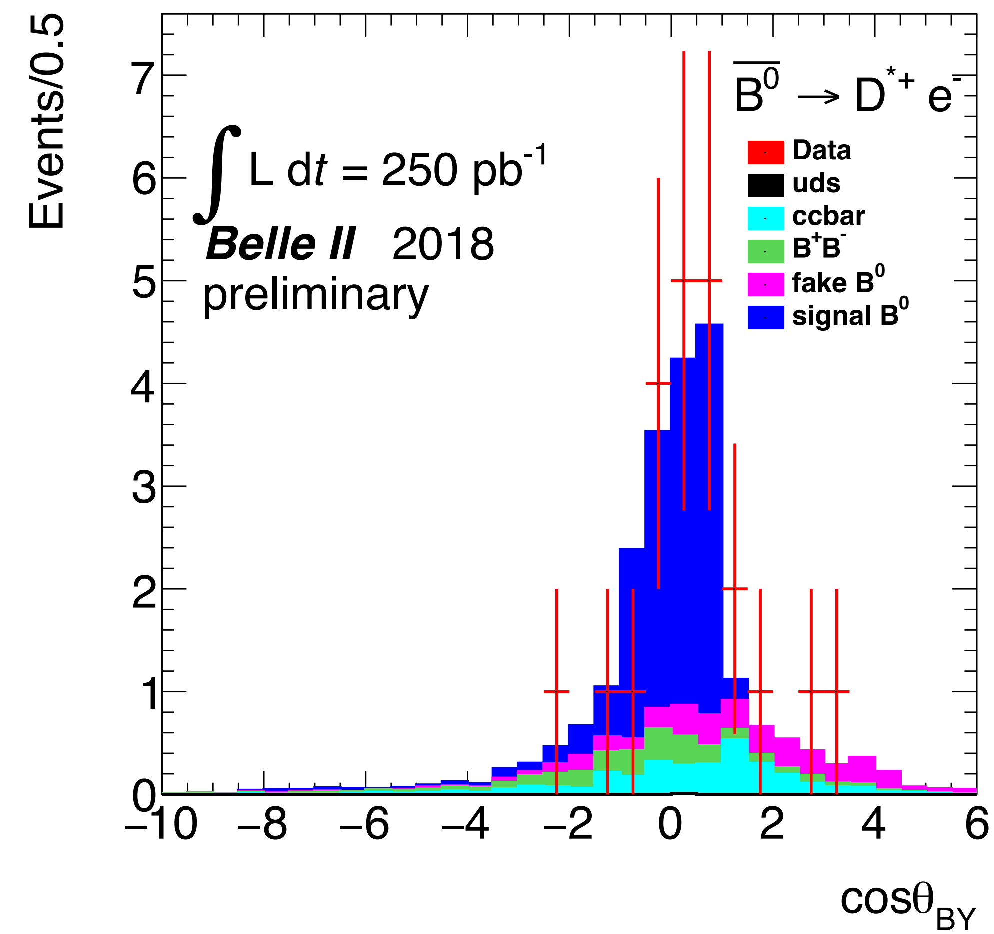
“rediscovery of the Photon”

Charmonium and SL B-Meson decays

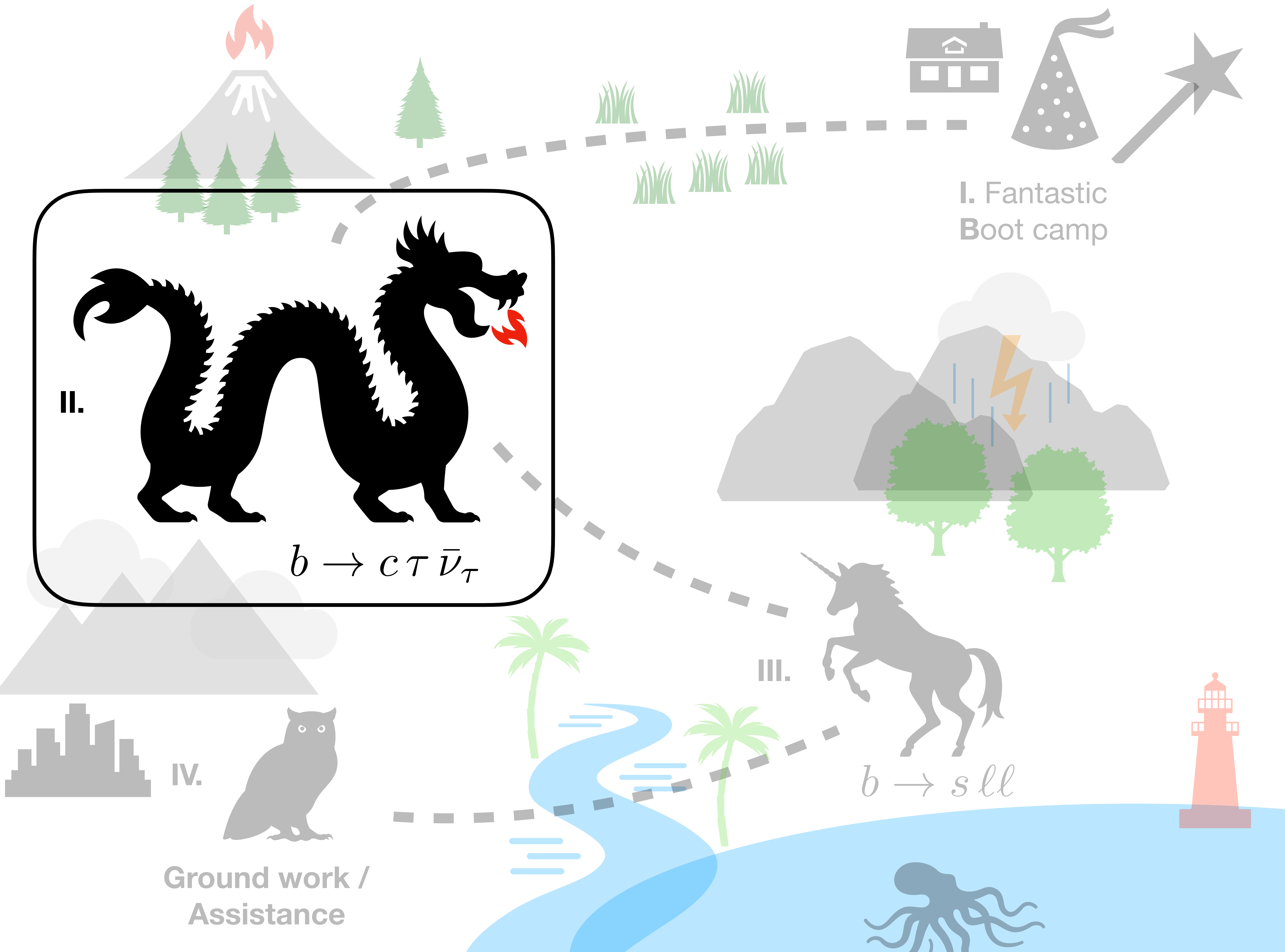
$$J/\Psi \to e^+ e^-$$



$$\bar{B}^0 \to D^{*+} e^- \bar{\nu}_e$$



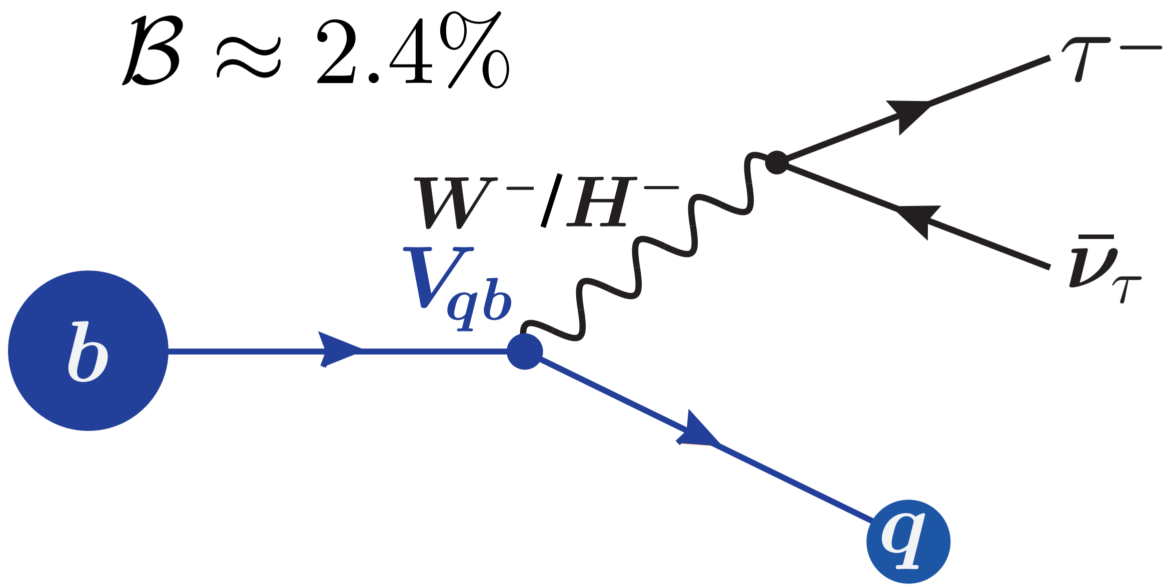
$$\cos\theta_{BY} = \frac{2E_B^* E_Y^* - M_B^2 - m_Y^2}{2p_B^* p_Y^*}$$



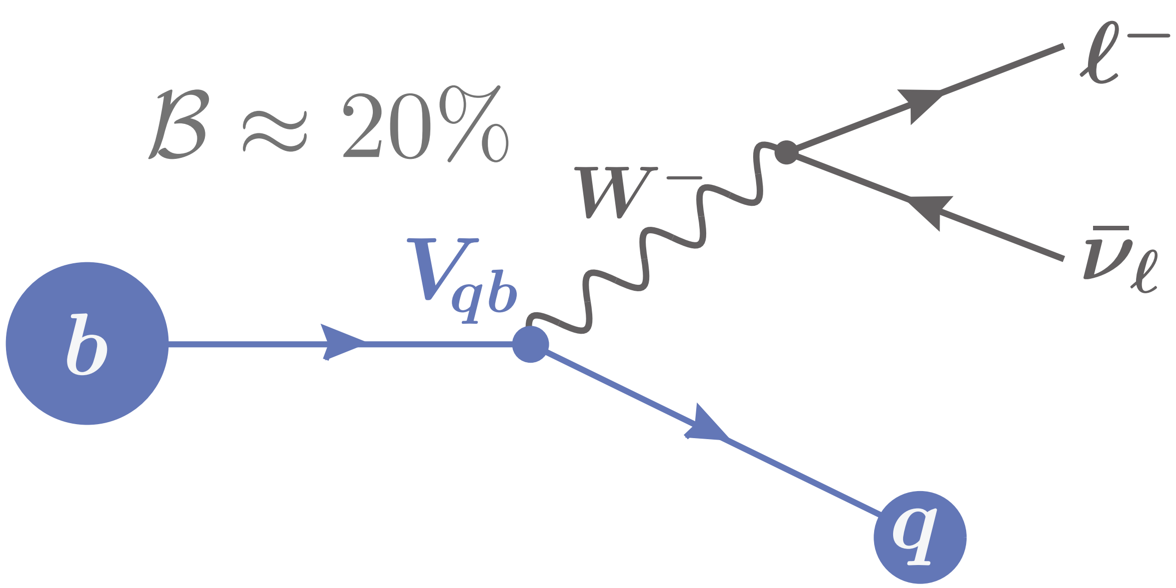
I. Fantastic
Boot camp
II.
$b \to c\,\tau\,\bar{\nu}_\tau$
III.
$b \to s\,\ell\ell$
IV.
Ground work /
Assistance

a Fantastic B: Semileptonic decays with τ

$\mathcal{B} \approx 2.4\%$



$\mathcal{B} \approx 20\%$



Observable of choice:

$$R = \frac{b \to q\,\tau\bar{\nu}_\tau}{b \to q\,\ell\bar{\nu}_\ell}$$

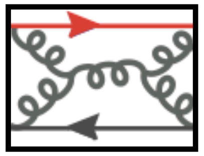
$\ell = e, \mu$

$$\downarrow$$

$$R(D^{(*)}, \pi, J/\psi)$$

Benefits:

- Experimental systematics **cancel in ratio**
- Theory uncertainties **cancel in ratio**

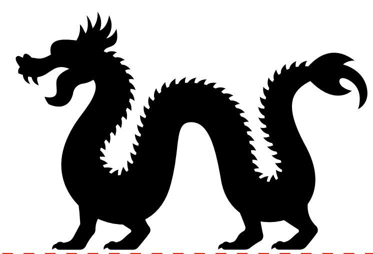
QCD: 

a Fantastic B: Semileptonic decays with τ

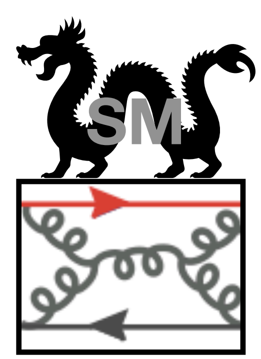
Two aspects:

1) Precise determination of R

Need **excellent understanding** of semileptonic background decays



2) Precise prediction of R in the SM



Interplay of **theory** and **experiment** to measure non-perturbative dynamics

Observable of choice:

$$R = \frac{b \to q\,\tau\bar{\nu}_\tau}{b \to q\,\ell\bar{\nu}_\ell} \qquad \ell = e, \mu$$

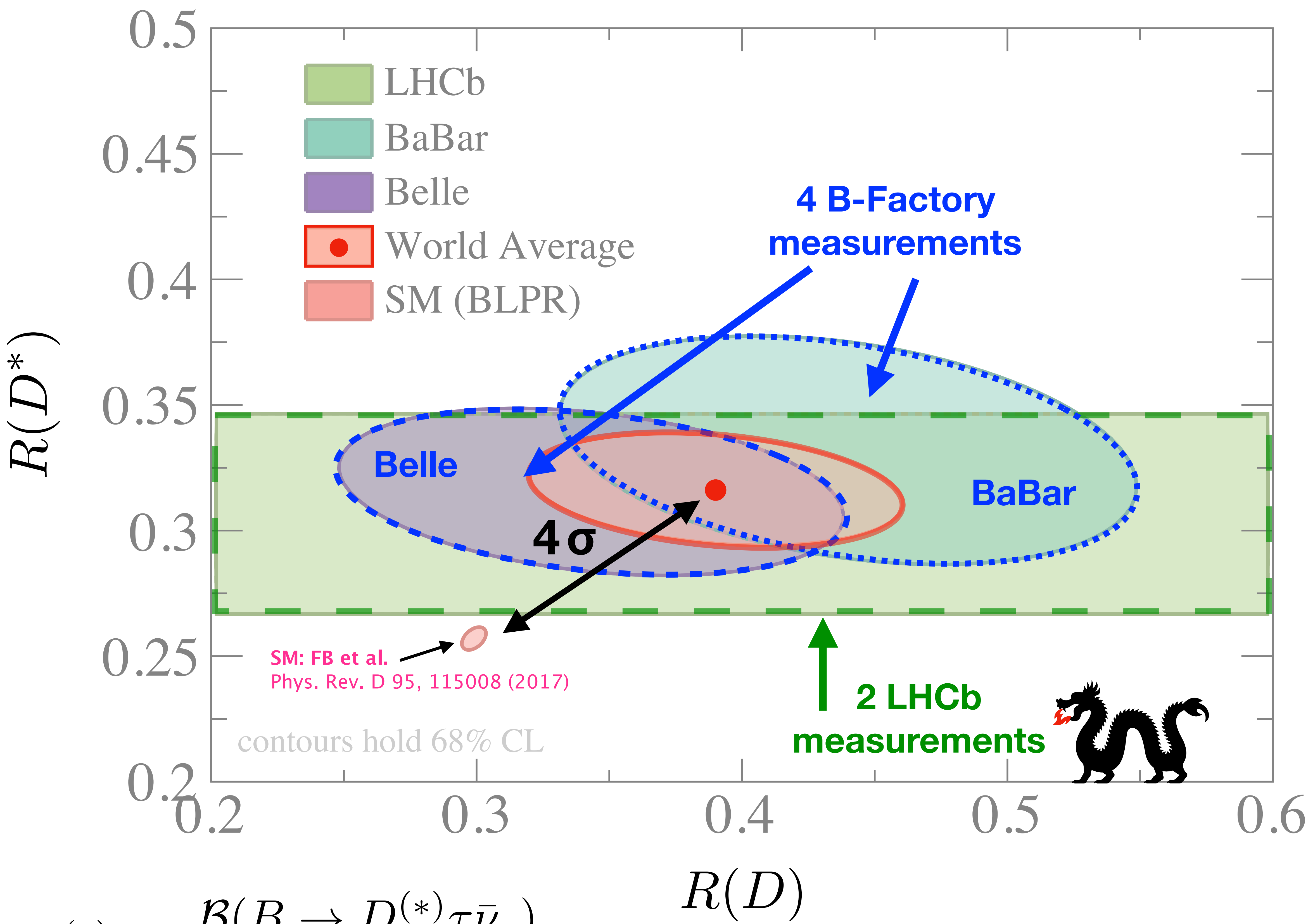
$$\downarrow$$

$$R(D^{(*)}, \pi, J/\psi)$$

Experimentally most important:

	D	D^*
Wave function	$\langle c\bar{q}\rangle \uparrow\downarrow$	$\langle c\bar{q}\rangle \uparrow\uparrow$

spin configuration



$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\bar{\nu}_\tau)}{\mathcal{B}(B \to D^{(*)}\ell\bar{\nu}_\ell)}$$

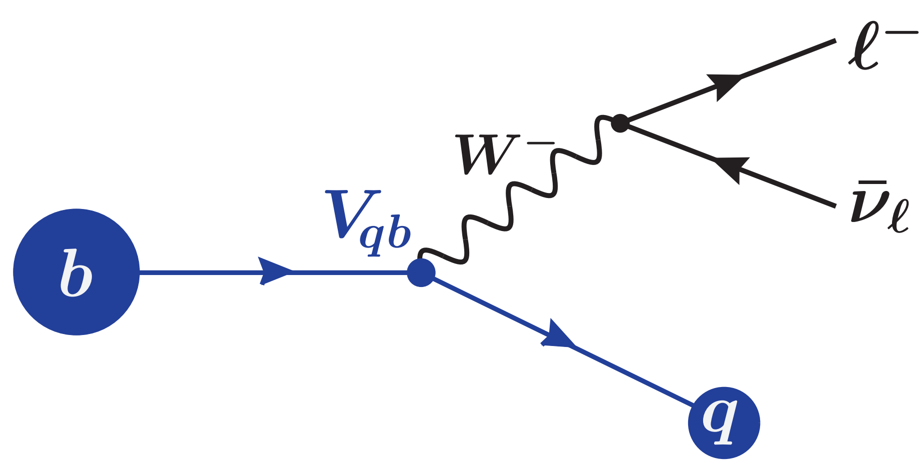
Experimental aspects

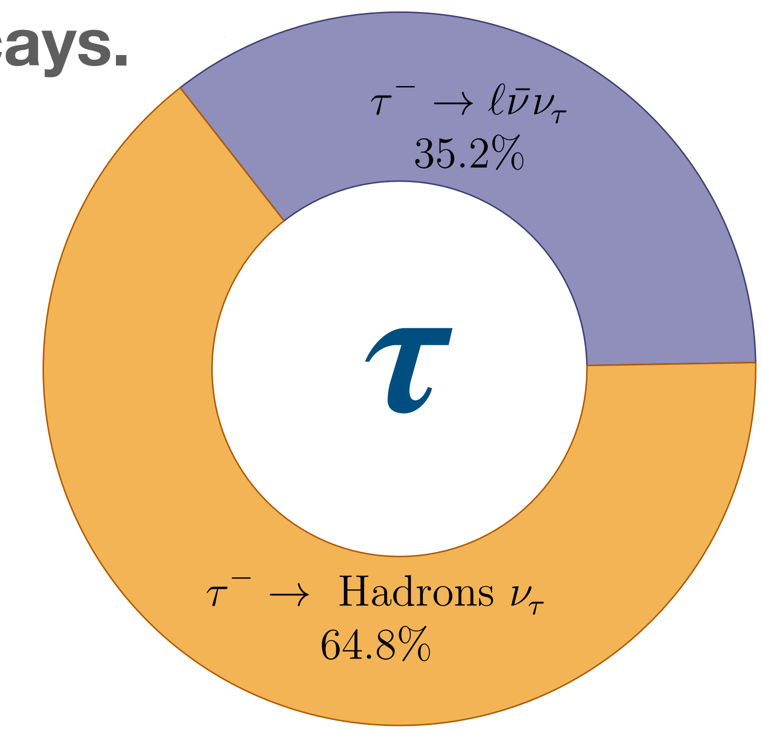
$$\frac{\mathcal{B}(B \to D^{(*)}\tau\bar{\nu}_\tau)}{\mathcal{B}(B \to D^{(*)}\ell\bar{\nu}_\ell)}$$

$\ell = e, \mu$

1. **Leptonic or Hadronic τ decays?**

Some properties (e.g. τ **polarisation**) **only accessible** in **hadronic decays.**





2. **Albeit not necessarily a rare decay of O(%) in BF, difficult to separate from normalisation and backgrounds**

LHCb: **Isolation** criteria, **displacement** of $D^{(*)}$ and τ, **kinematics**

B-Factories: Full reconstruction of event (**Tagging**), **matching topology, kinematics**

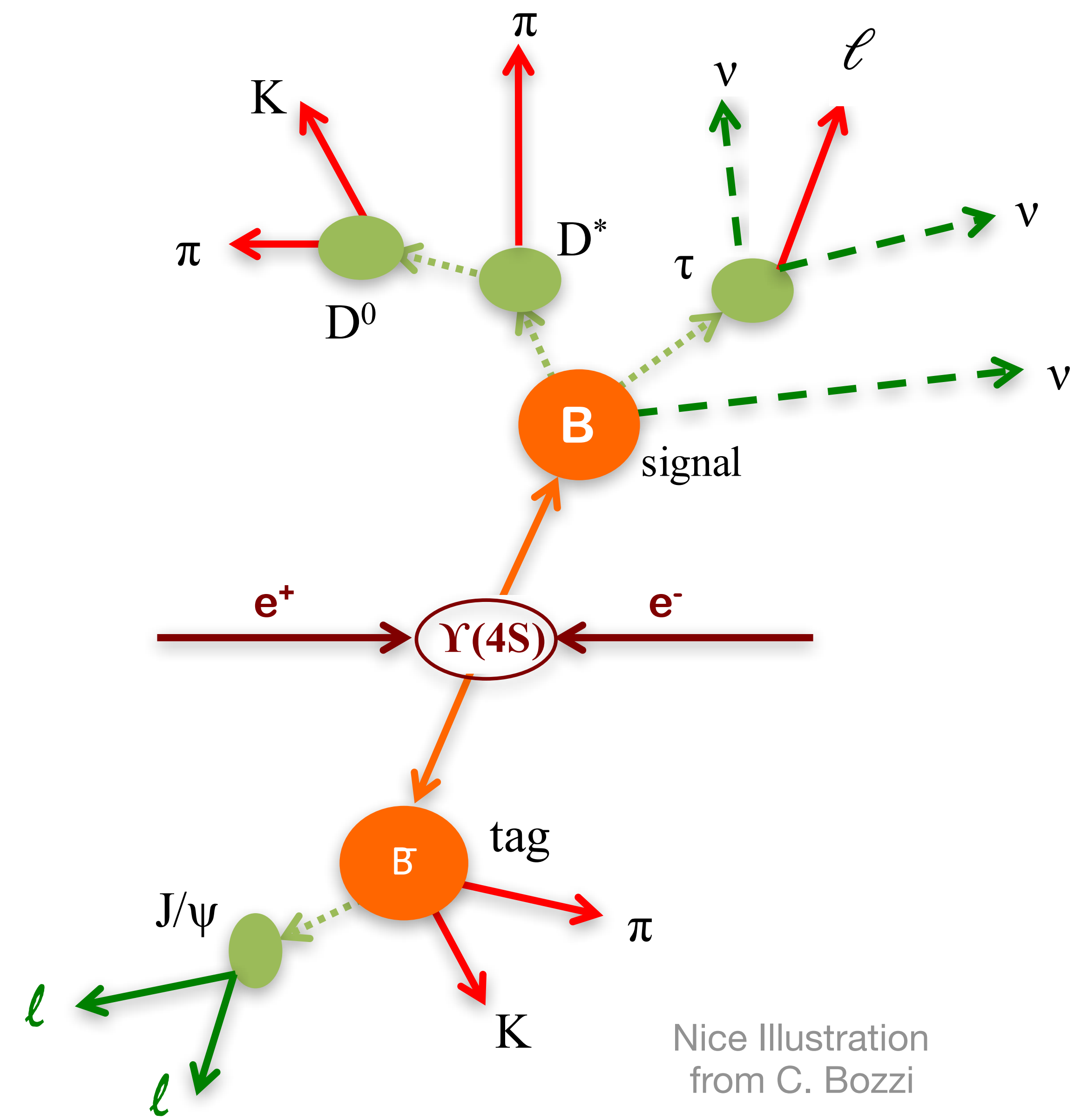
How does one measure R(D/D*) at a B-factory?

Tagging approach in a nut-shell:

- e+/e- collision produces ***Y(4S) → BB̄***
- Fully reconstruct one of the two B-mesons ('tag') → **possible** to measure **momentum** of signal B
- **Missing four-momentum** (**neutrinos**) can be reconstructed with high precision

$$p_{\mathrm{miss}} = (p_{\mathrm{beam}} - p_{B\mathrm{tag}} - p_{D^{(*)}} - p_{\ell})$$

✓ **Small efficiency (~0.2-0.4%) compensated by large integrated luminosity**



Nice Illustration from C. Bozzi

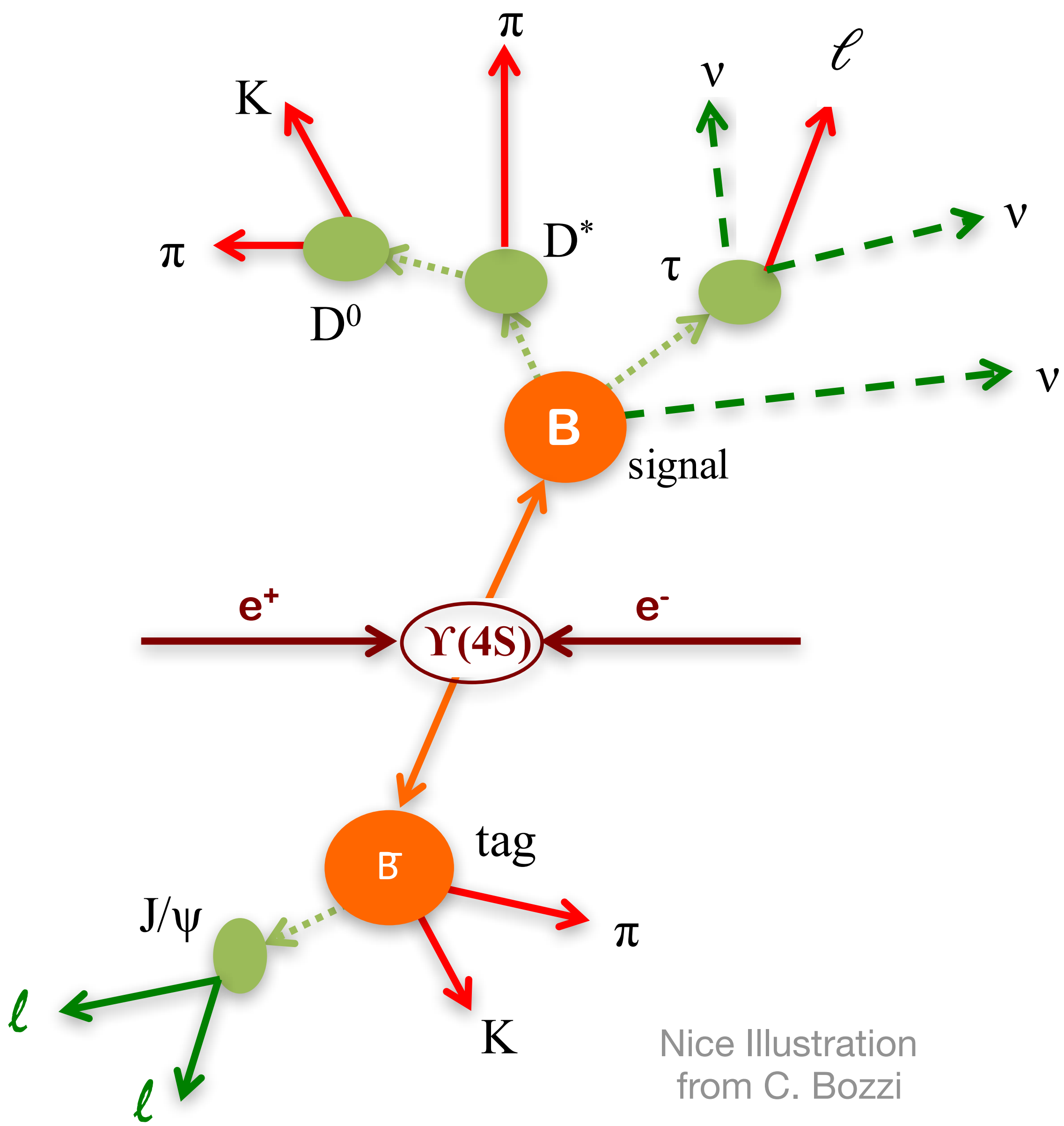
How does one measure R(D/D*) at a B-factory?

Tagging approach in a nut-shell:

- e+/e- collision produces ***Y(4S)* → *BB̄***
- Fully reconstruct one of the two B-mesons ('tag') → **possible** to measure **momentum** of signal B
- **Missing four-momentum (neutrinos)** can be reconstructed with high precision

$$p_{\rm miss} = (p_{\rm beam} - p_{B{\rm tag}} - p_{D^{(*)}} - p_{\ell})$$

✓ **Small efficiency (~0.2-0.4%) compensated by large integrated luminosity**



Nice Illustration from C. Bozzi

How does one measure R(D/D*) at a B-factory?

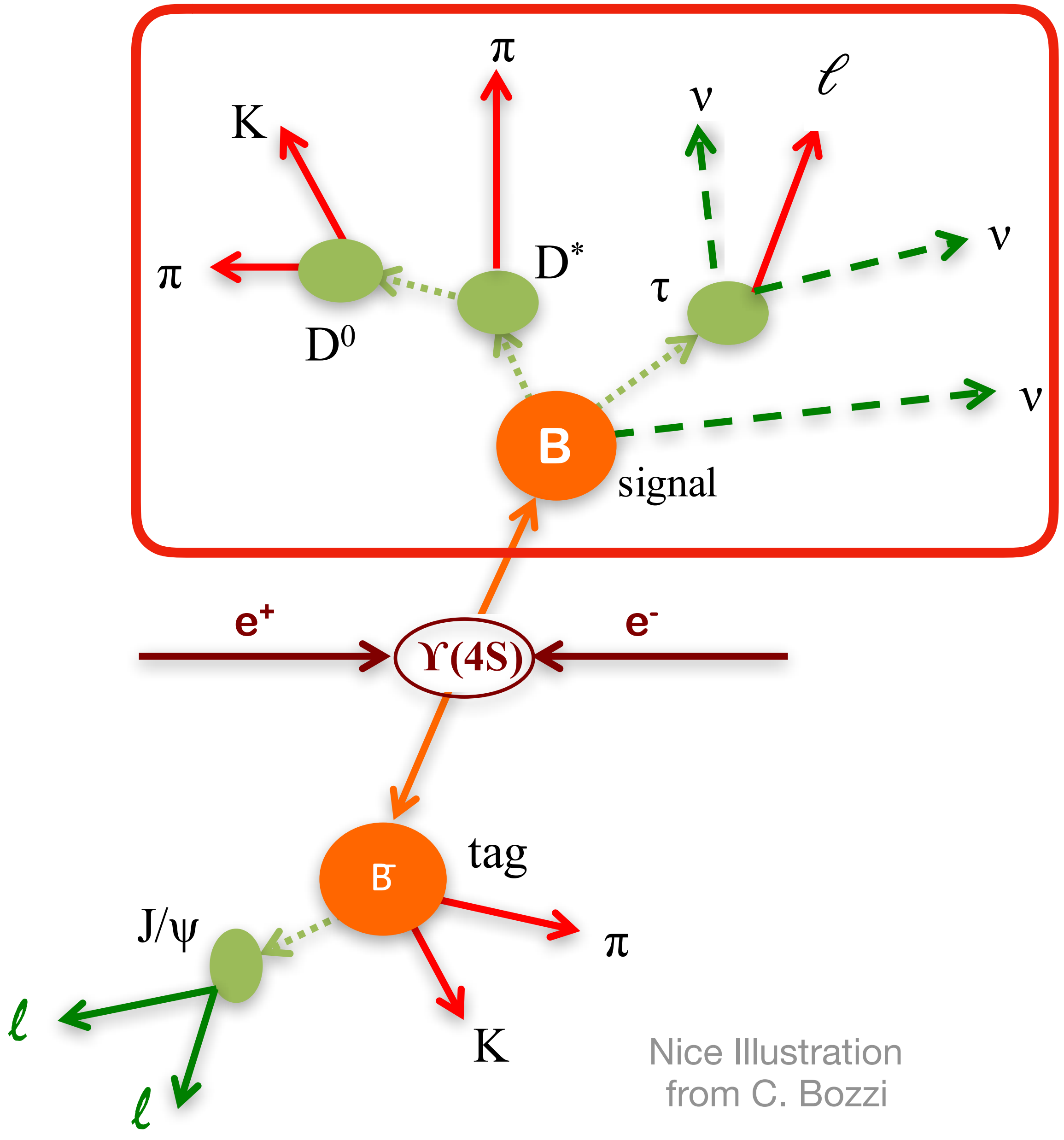
Tagging approach in a nut-shell:

- e+/e- collision produces ***Y(4S)* → *BB̄***
- Fully reconstruct one of the two B-mesons ('tag') → **possible** to measure **momentum** of signal B
- **Missing four-momentum** (**neutrinos**) can be reconstructed with high precision

$$p_{\mathrm{miss}} = (p_{\mathrm{beam}} - p_{B\mathrm{tag}} - p_{D^{(*)}} - p_\ell)$$

✓ Small efficiency (~0.2-0.4%) compensated by large integrated luminosity

✓ Demand matching topology

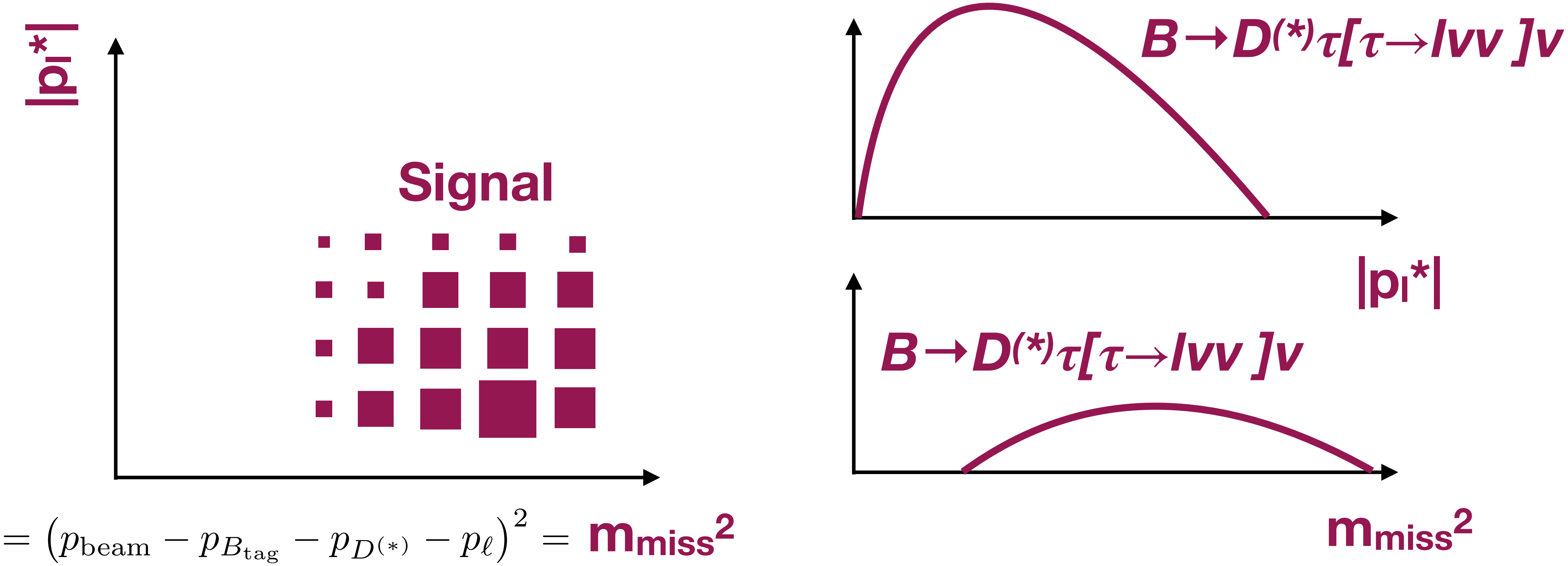


Nice Illustration from C. Bozzi

First measurement by BaBar

Phys.Rev.Lett. 109,101802 (2012)
Phys.Rev.D 88, 072012 (2013)

- Use $\tau\to e\nu\nu$ and $\tau\to\mu\nu\nu$ to reconstruct **τ-lepton**
- Simultaneous analysis of *R(D)* vs. *R(D*)* using $B^0\to D^{*-}\tau\nu$, $B^-\to D^{*0}\tau\nu$, $B^0\to D^-\tau\nu$, $B^-\to D^0\tau\nu$
- Unbinned maximum likelihood fit in 2D to m_{miss}^2 and $|p_l^*|$

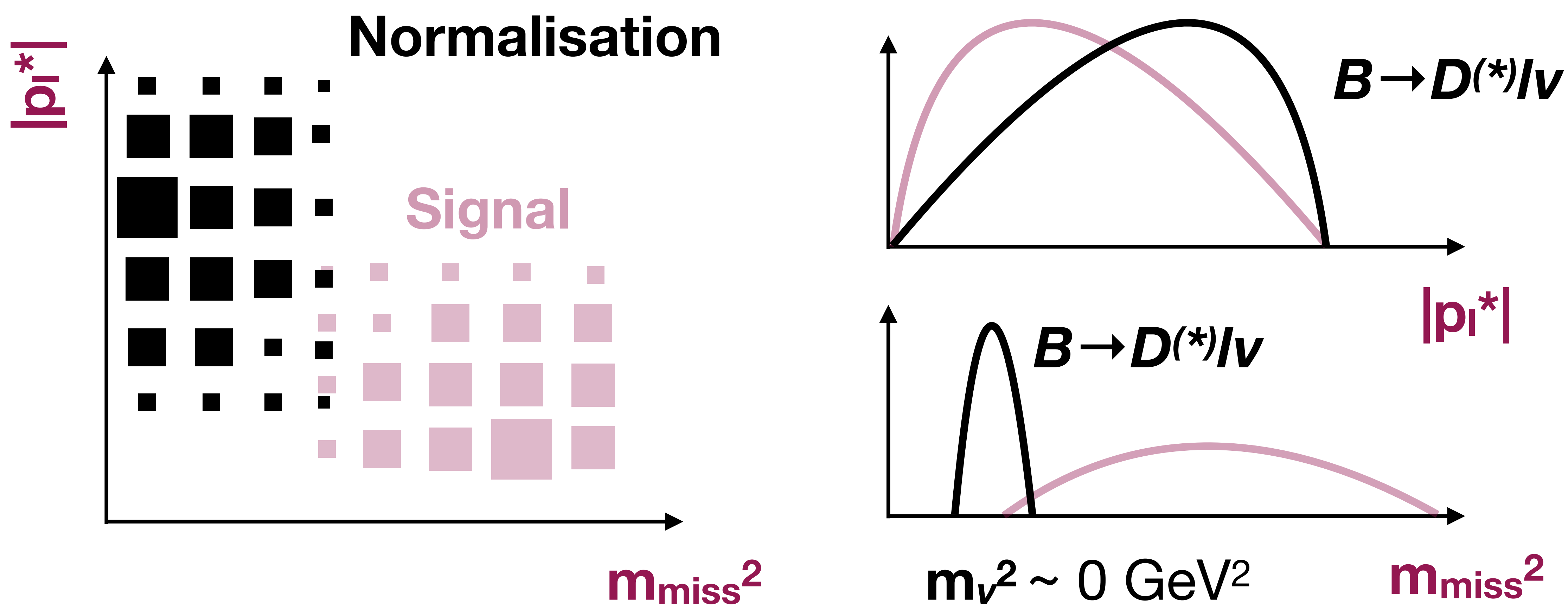


$$p_{\rm miss}^2 = \left(p_{\rm beam} - p_{B_{\rm tag}} - p_{D^{(*)}} - p_\ell\right)^2 = m_{miss}^2$$

First measurement by BaBar

Phys.Rev.Lett. 109,101802 (2012)
Phys.Rev.D 88, 072012 (2013)

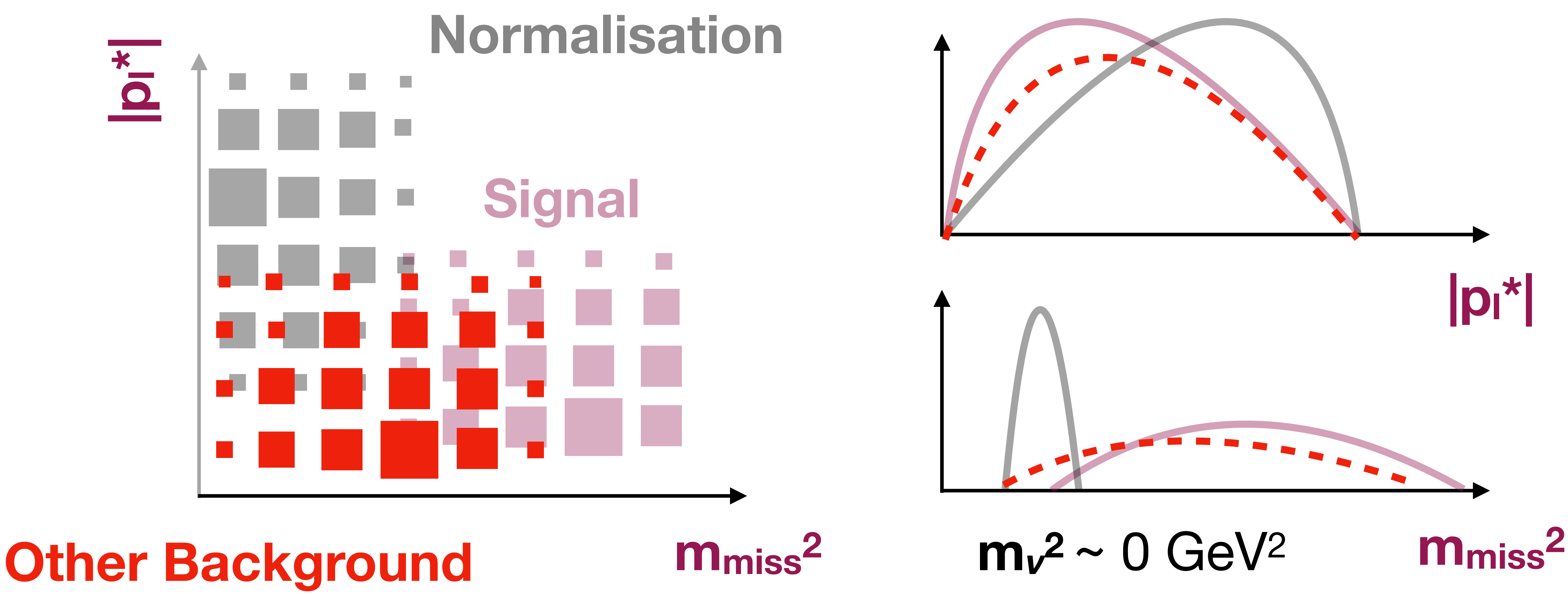
- Use $\tau \to e\nu\nu$ and $\tau \to \mu\nu\nu$ to reconstruct **τ-lepton**
- Simultaneous analysis of *R(D)* vs. *R(D*)* using $B^0 \to D^{*-}\tau\nu$, $B^- \to D^{*0}\tau\nu$, $B^0 \to D^-\tau\nu$, $B^- \to D^0\tau\nu$
- Unbinned maximum likelihood fit in 2D to m_{miss}^2 and $|p_l^*|$



First measurement by BaBar

Phys.Rev.Lett. 109,101802 (2012)
Phys.Rev.D 88, 072012 (2013)

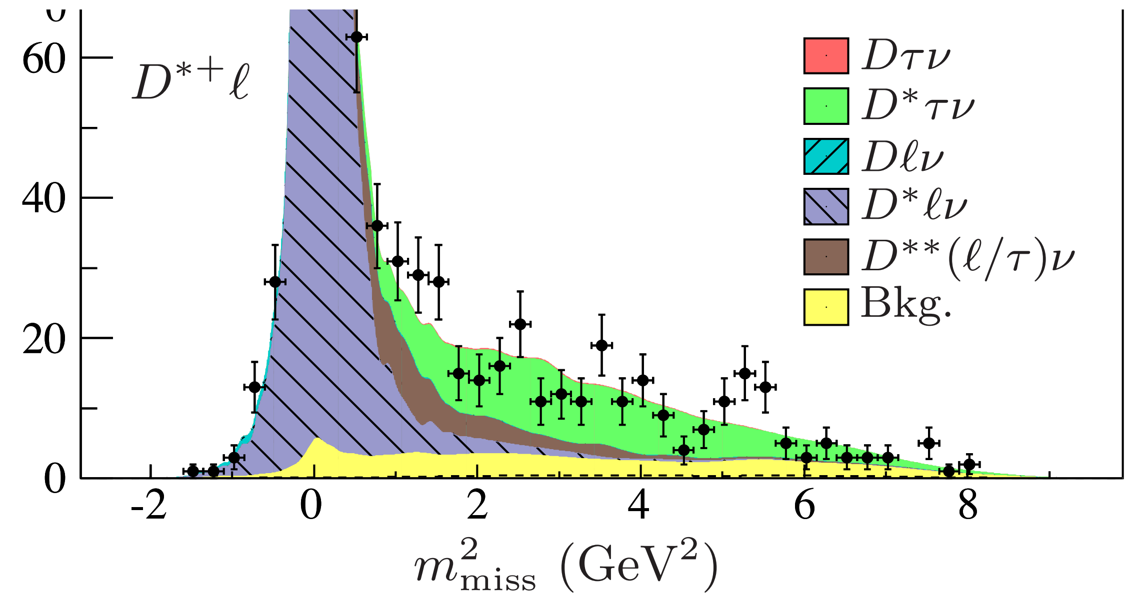
- Use $\tau \to e\nu\nu$ and $\tau \to \mu\nu\nu$ to reconstruct **τ-lepton**
- Simultaneous analysis of *R(D)* vs. *R(D*)* using $B^0 \to D^{*-}\tau\nu$, $B^- \to D^{*0}\tau\nu$, $B^0 \to D^-\tau\nu$, $B^- \to D^0\tau\nu$
- Unbinned maximum likelihood fit in 2D to m_{miss}^2 and $|p_l^*|$

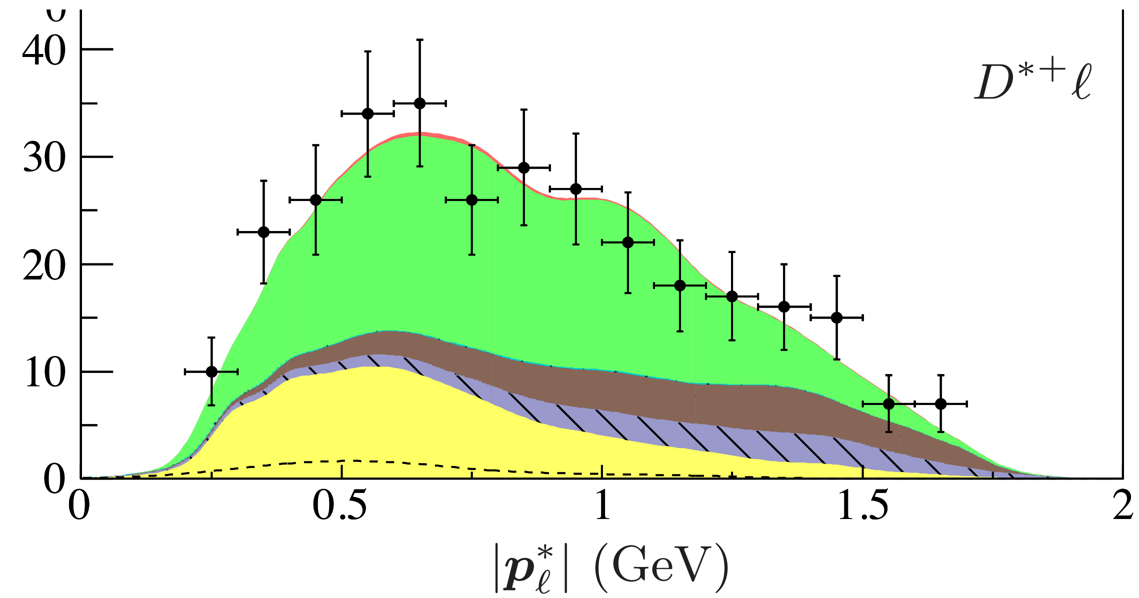


First measurement by BaBar

Phys.Rev.Lett. 109,101802 (2012)
Phys.Rev.D 88, 072012 (2013)

- Use **$\tau \to e\nu\nu$** and **$\tau \to \mu\nu\nu$** to reconstruct **τ-lepton**
- Simultaneous analysis of *R(D)* vs. *R(D*)* using **$B^0 \to D^{*-}\tau\nu$, $B^- \to D^{*0}\tau\nu$, $B^0 \to D^-\tau\nu$, $B^- \to D^0\tau\nu$**
- Unbinned maximum likelihood fit in 2D to **m_{miss}^2** and **$|p_l^*|$**





$$\mathcal{R}(D^{(*)}) = \frac{N_{\rm sig}}{N_{\rm norm}} \frac{\varepsilon_{\rm norm}}{\varepsilon_{\rm sig}},$$

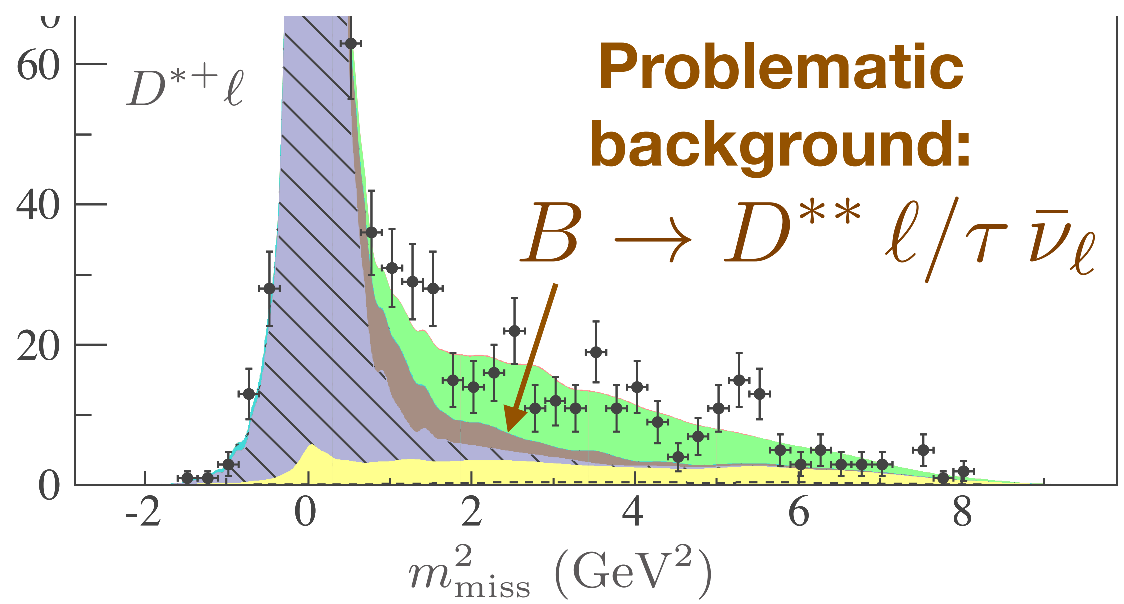
R(D) = 0.440 ± 0.058 (stat) ± 0.042 (syst) (2σ from SM)
R(D*) = 0.332 ± 0.024 (stat) ± 0.018 (syst) (2.7σ from SM)

✓ **Combination is 3.4σ from SM**

E.g. first BaBar measurement

Phys.Rev.Lett. 109,101802 (2012)
Phys.Rev.D 88, 072012 (2013)

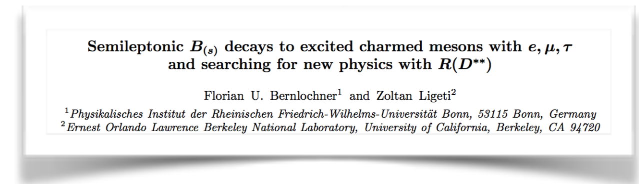
- Use **$\tau \to e\nu\nu$** and **$\tau \to \mu\nu\nu$** to reconstruct **τ-lepton**
- Simultaneous analysis of *R(D)* vs. *R(D*)* using **$B^0 \to D^{*-}\tau\nu$, $B^- \to D^{*0}\tau\nu$, $B^0 \to D^-\tau\nu$, $B^- \to D^0\tau\nu$**
- Unbinned maximum likelihood fit in 2D to **m_{miss}^2** and **$|p_l^*|$**



First model-independent prediction of $B \to D^{**}\,\tau\,\bar{\nu}_\ell$ and analysis of QCD modelling:

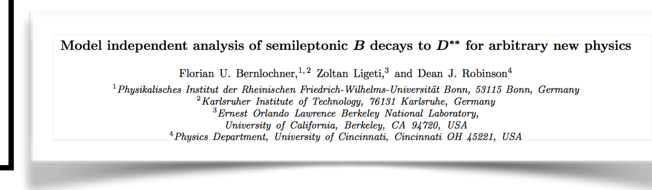
FB et al.,
Phys. Rev. D 95, 014022 (2017), Phys. Rev. D 97, 075011 (2018)

$$R(D_2^*) = 0.07 \pm 0.01\,,$$
$$R(D_1) = 0.10 \pm 0.02\,,$$
$$R(D_1^*) = 0.06 \pm 0.02\,,$$
$$R(D_0) = 0.08 \pm 0.04\,,$$


Semileptonic $B_{(s)}$ decays to excited charmed mesons with e, μ, τ and searching for new physics with $R(D^{**})$

Florian U. Bernlochner[1] and Zoltan Ligeti[2]

[1] *Physikalisches Institut der Rheinischen Friedrich-Wilhelms-Universität Bonn, 53115 Bonn, Germany*
[2] *Ernest Orlando Lawrence Berkeley National Laboratory, University of California, Berkeley, CA 94720*


Model independent analysis of semileptonic B decays to D^{**} for arbitrary new physics

Florian U. Bernlochner,[1,2] Zoltan Ligeti,[3] and Dean J. Robinson[4]

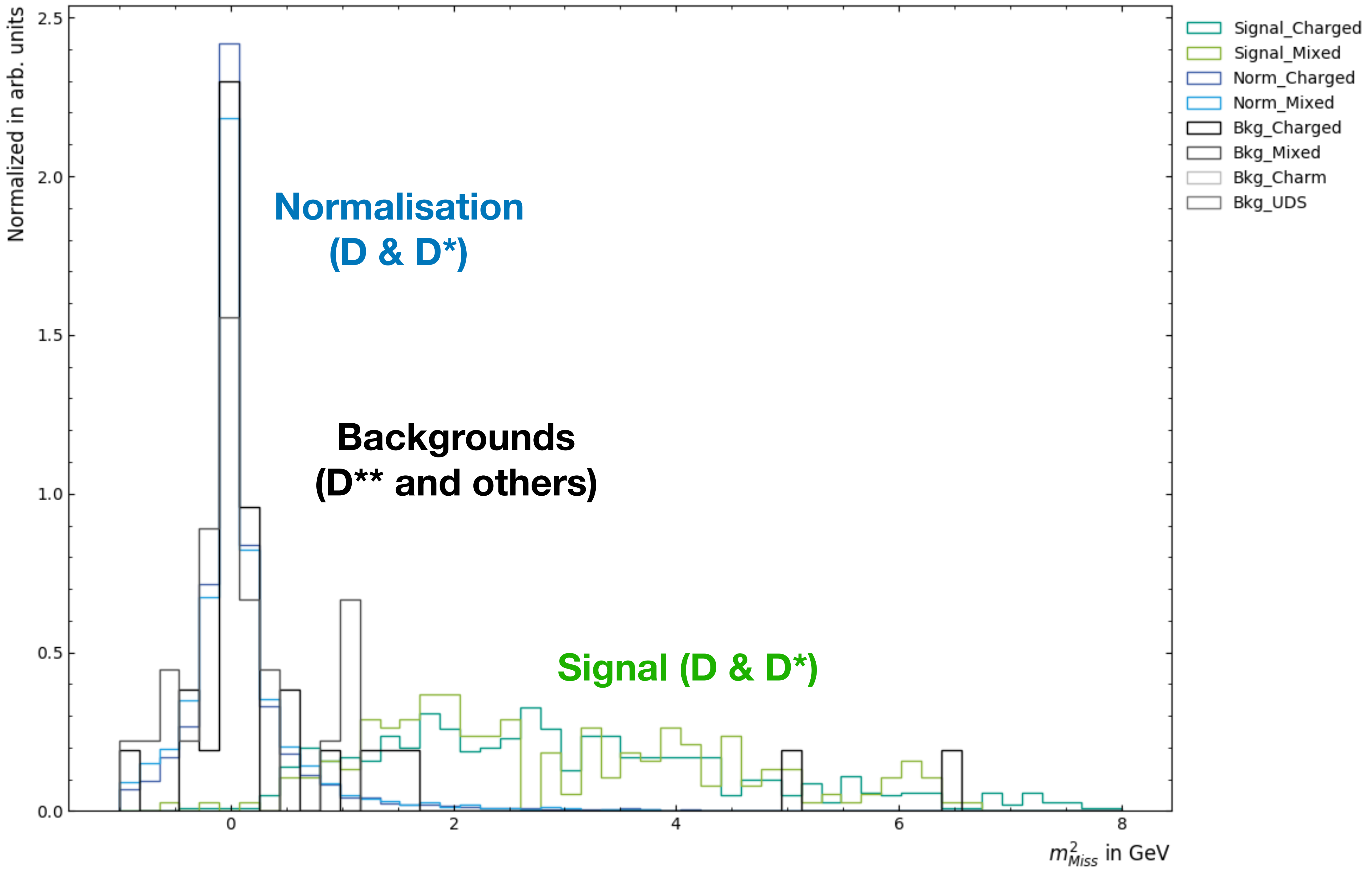
[1] *Physikalisches Institut der Rheinischen Friedrich-Wilhelms-Universität Bonn, 53115 Bonn, Germany*
[2] *Karlsruher Institute of Technology, 76131 Karlsruhe, Germany*
[3] *Ernest Orlando Lawrence Berkeley National Laboratory, University of California, Berkeley, CA 94720, USA*
[4] *Physics Department, University of Cincinnati, Cincinnati OH 45221, USA*

Belle II

Work on redoing R(D/D*) analysis with novel tagging in Karlsruhe

Felix Metzner, Max Welsch, FB

After tag reconstruction, i.e. before all the hard work



Expect factor of 2 improvement in statistical precision due to new tagging

Example:

$$B \to D\,\tau\,\bar{\nu}_\ell$$

$$f_+(q^2) \qquad\qquad f_-(q^2)$$

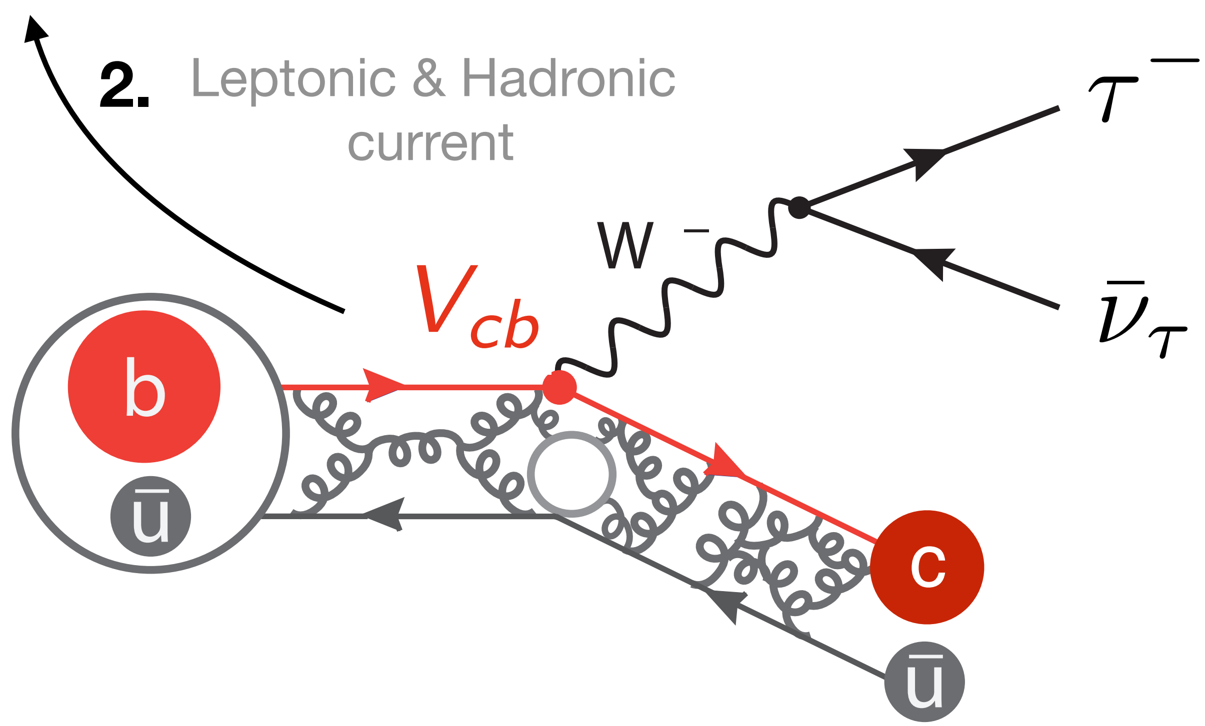
$$q^2 = (p - p')^2$$

$$\sim v(p_\ell)\,(\not{m}_\ell + \not{m}_\nu)\,\bar{u}(p_\nu)$$

Four-momentum transfer squared encodes QCD dynamics

$$H^\mu L_\mu = \langle B(p)|V^\mu - A^\mu|D(p')\rangle L_\mu = \left[f_+(q^2)\,(p+p')^\mu + f_-(q^2)\,(p-p')^\mu\right] L_\mu$$

1.



How do we predict R(D/D*) and similar ratios in the SM?

$$f_+(q^2)$$

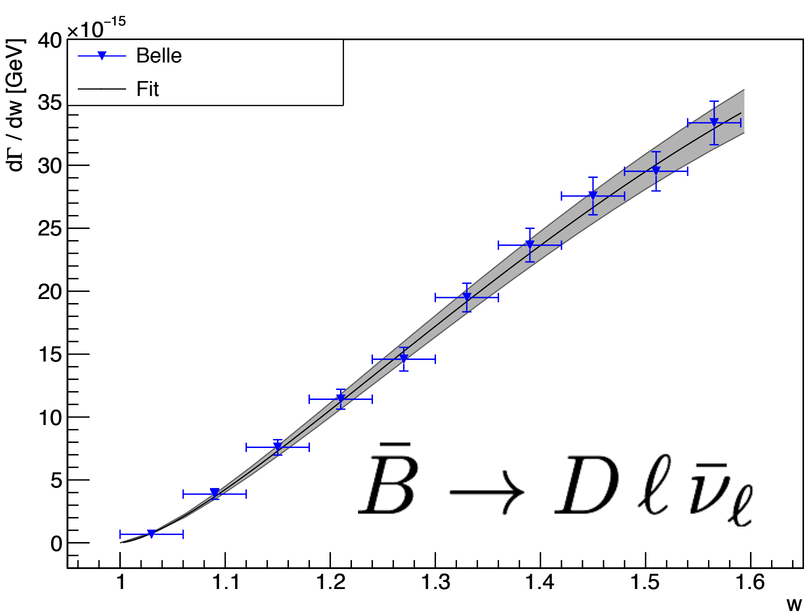
Example:

$$B \to D \tau \bar{\nu}_\ell$$

$$f_-(q^2)$$

$$\sim v(p_\ell)\,(\not{m}_\ell + \not{m}_\nu)\,\bar{u}(p_\nu)$$

Can be **studied** with **light lepton modes**, but also in **lattice (high q²)** or **sum rules**



How do we predict R(D/D*) and similar ratios in the SM?

$$f_+(q^2)$$

Example:

$$B \to D \tau \bar{\nu}_\ell$$

$$f_-(q^2)$$

$$\sim v(p_\ell)\,(\not{m}_\ell + \not{m}_\nu)\,\bar{u}(p_\nu)$$

Can be **studied** with **light lepton modes**, but also in **lattice (high q²)** or **sum rules**

Proportional to **basically ~ 0** in **light lepton modes** and cannot be constrained experimentally this way

But important for heavy leptons, **need input** from **lattice** or **HQET relations**

$m_{c,b} \to \infty$

light anti-quark does not notice the decay happened

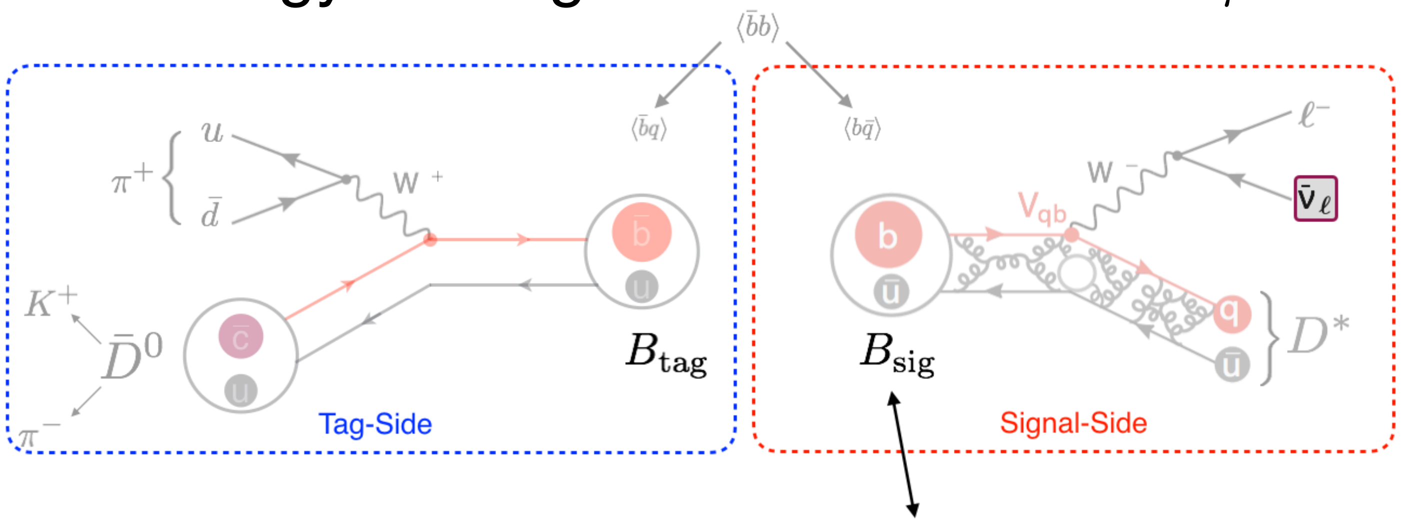
HQET = Heavy Quark Effective Theory

$$\mathcal{L}_{\mathrm{QCD}} = \mathcal{L}^{(0)} + \frac{1}{m_{c,b}}\mathcal{L}^{(1)} + \frac{1}{m_{c,b}^2}\mathcal{L}^{(2)} + \ldots$$

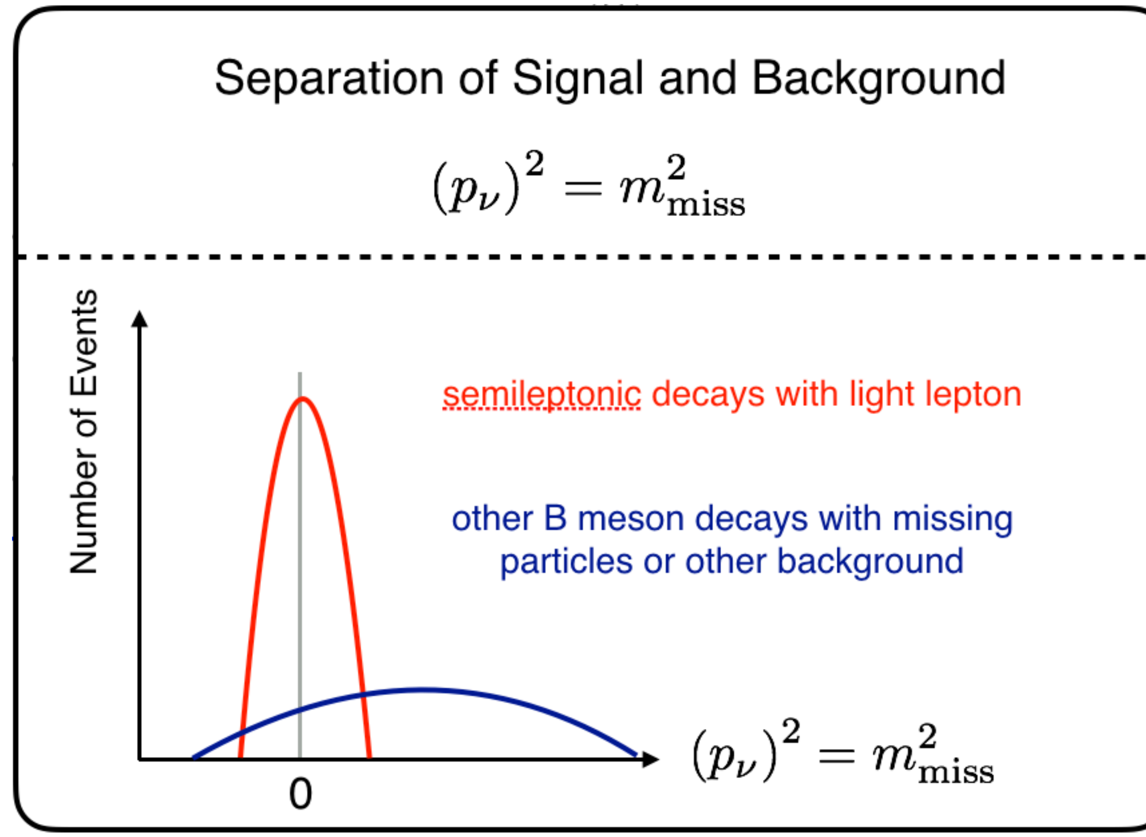
Recent measurement of $B \to D^* \ell \nu$ from Belle

Belle-Conf 1612
FB, Saskia Falke
arXiv:1702.01521

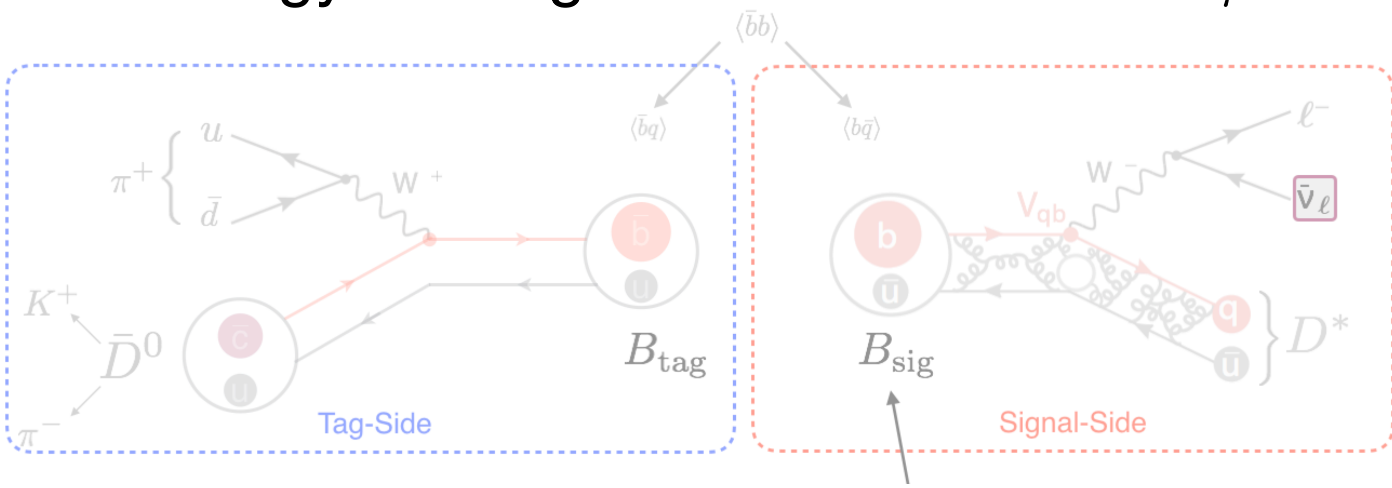
* Strategy: analogous to $B \to D^{(*)} \tau \bar{\nu}_\tau$

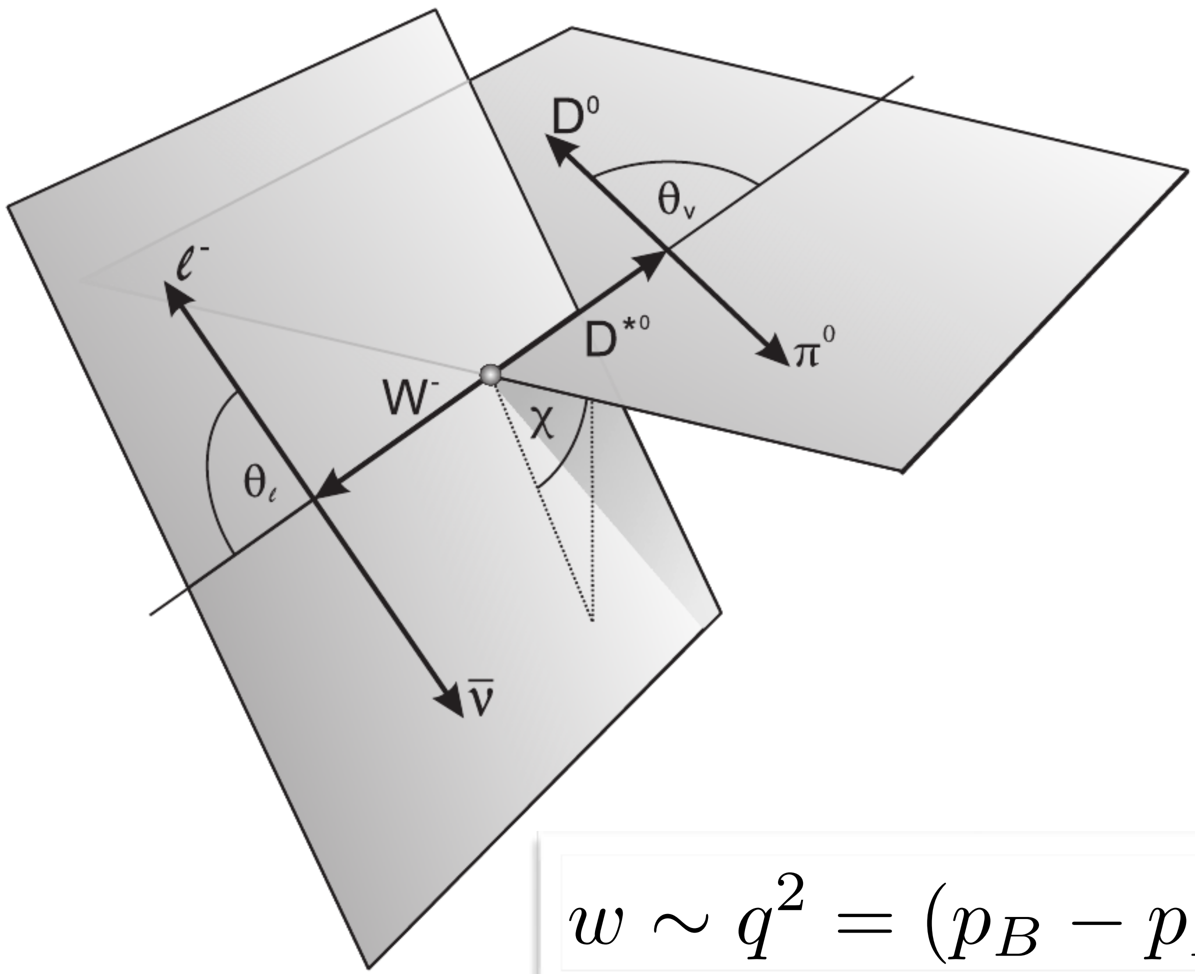


$$p_{\text{miss}} = p_\nu = \overbrace{\left(p_{e^+ e^-} - p_{\text{tag}}\right.}^{p_{B_{\text{sig}}}} - \left. p_{X_q} - p_\ell\right)$$



* Strategy: analogous to $B \to D^{(*)}\,\tau\,\bar{\nu}_\tau$





$$w \sim q^2 = (p_B - p_{D^*})^2$$

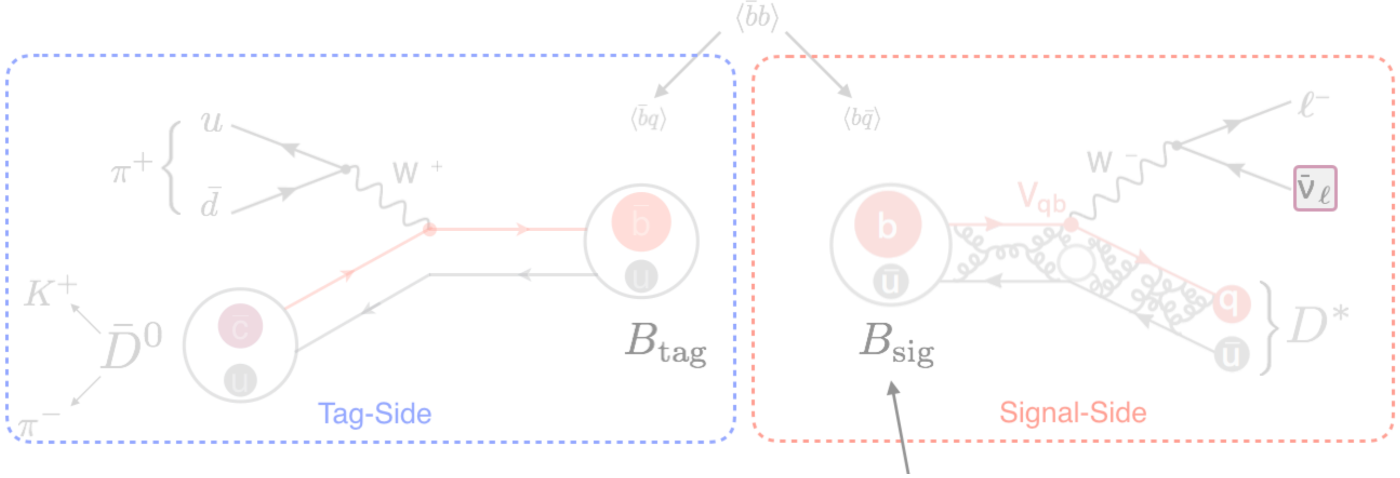
D^{*-} — $\langle \bar{c}d \rangle$ ↑↑ spin configuration

Branching fraction

68%	$\bar{D}^0\,\pi^-$	31%	$D^-\,\pi^0$
4%	$K^+\pi^-$	9%	$K^+\pi^-\pi^-$
14%	$K^+\pi^-\pi^0$		
8%	$K^+\pi^+\pi^-\pi^-$		

Belle-Conf 1612
Saskia Falke, **FB,**
arXiv:1702.01521

* Strategy: analogous to $B \to D^{(*)}\,\tau\,\bar{\nu}_\tau$

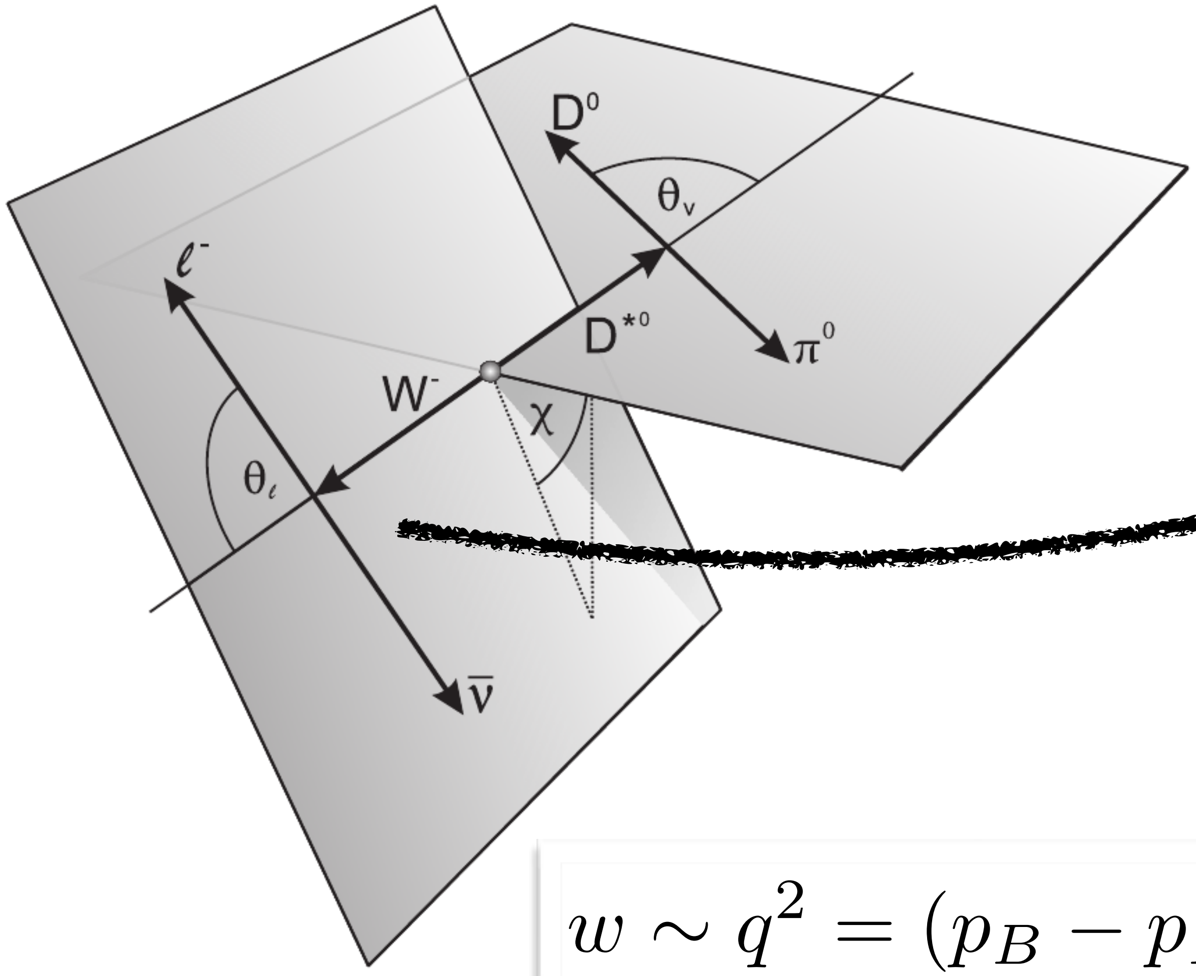


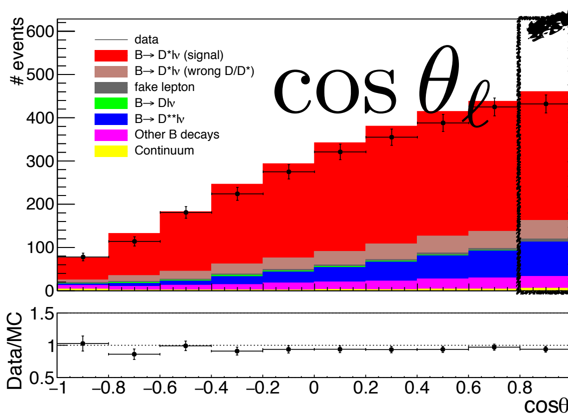
D^{*-} $\langle \bar{c}d \rangle$ ↑↑ spin configuration

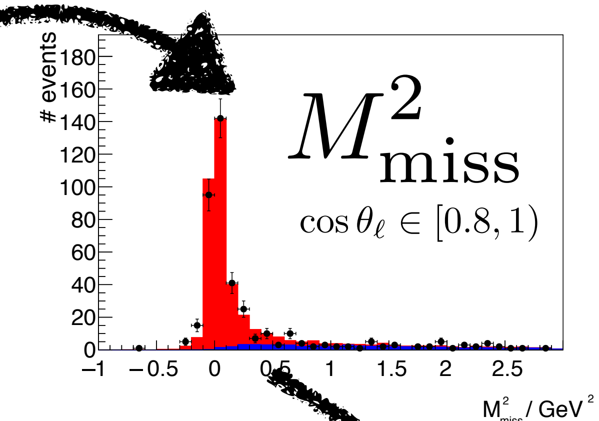
Branching fraction

68% $\bar{D}^0\,\pi^-$ → 4% $K^+\pi^-$, 14% $K^+\pi^-\pi^0$, 8% $K^+\pi^+\pi^-\pi^-$

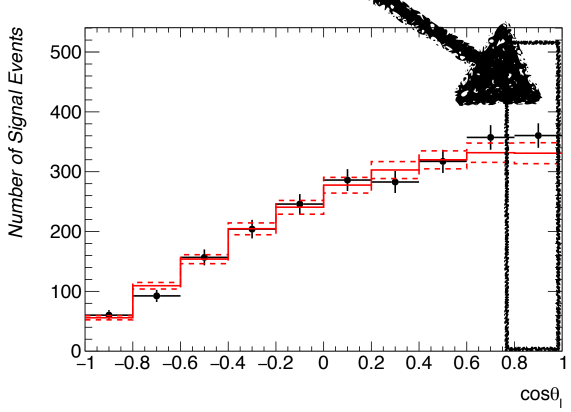
31% $D^-\,\pi^0$ → 9% $K^+\pi^-\pi^-$







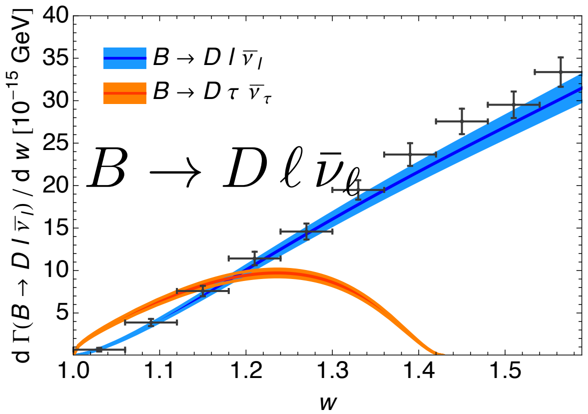
Form Factors ←



$$w \sim q^2 = (p_B - p_{D^*})^2$$

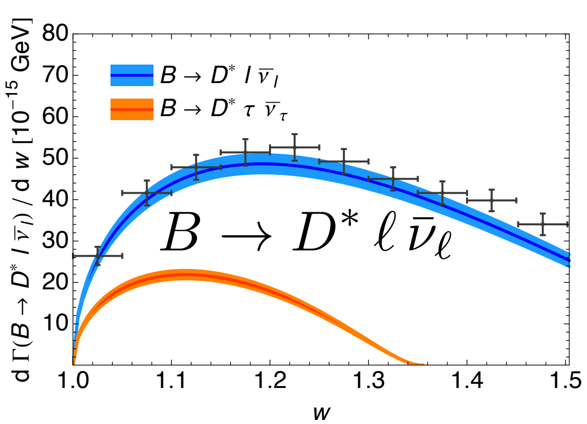
New precision prediction for R(D) / R(D*)

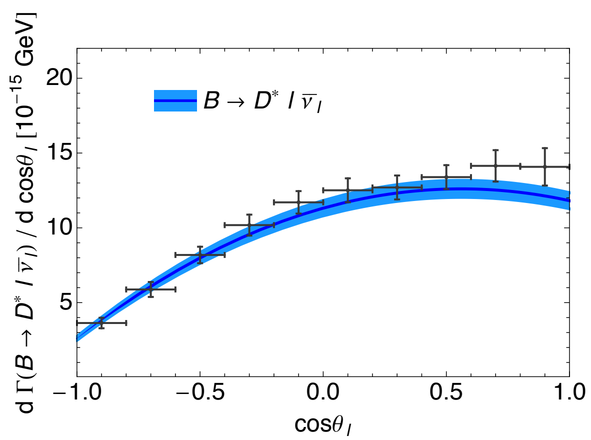
Key idea: link both channels using model independent QCD properties (HQET) of form factors

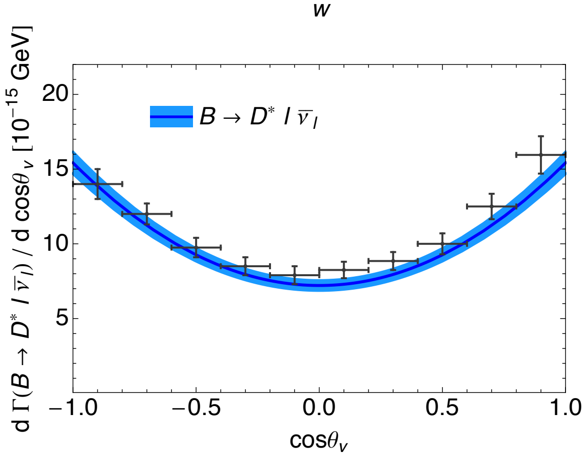


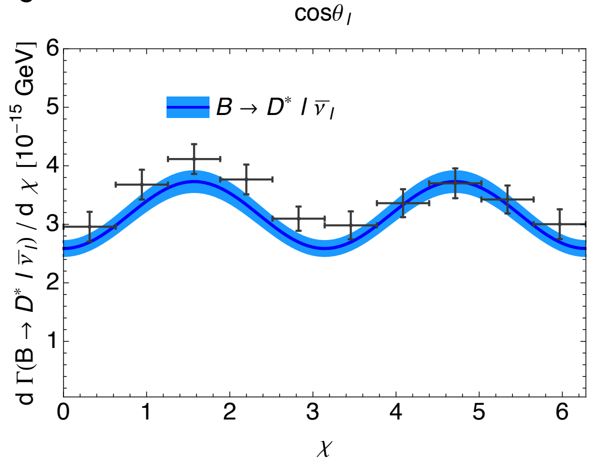
$$f = \zeta \left(1 + \alpha_s + \frac{1}{m_{c,b}} + \alpha_s \frac{1}{m_{c,b}} + \frac{1}{m_c^2} \dots \right)$$

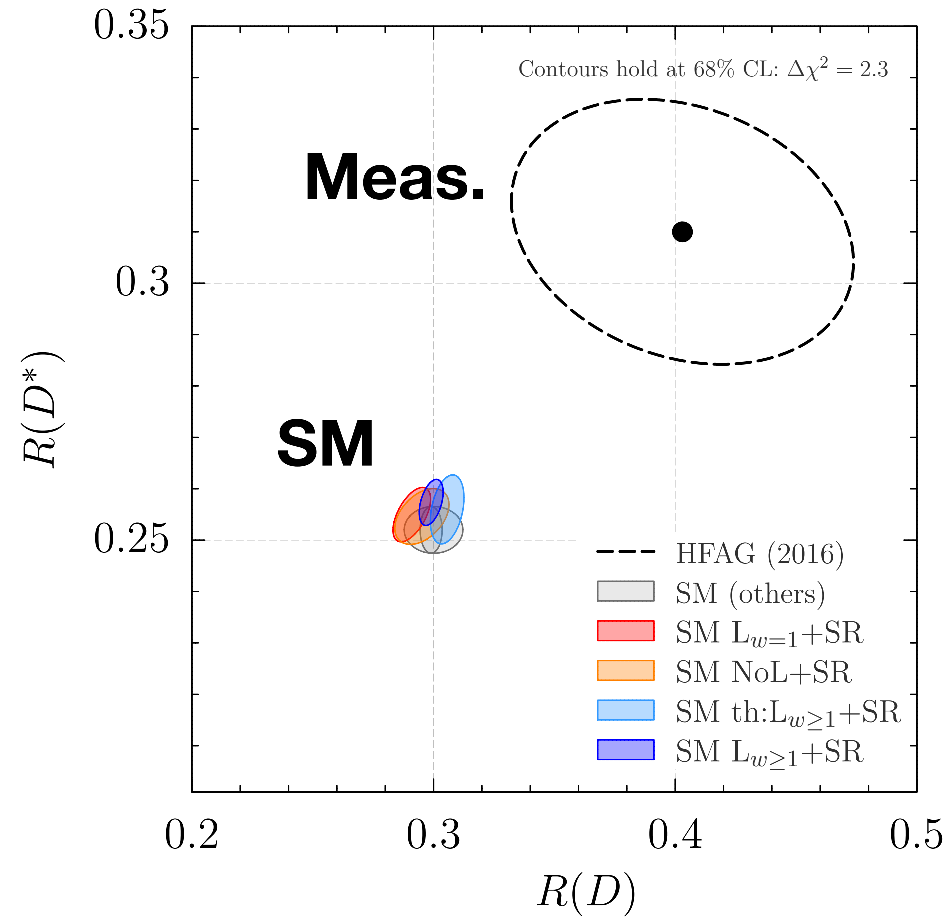
FB et al.,
Phys. Rev. D 95, 115008 (2017)









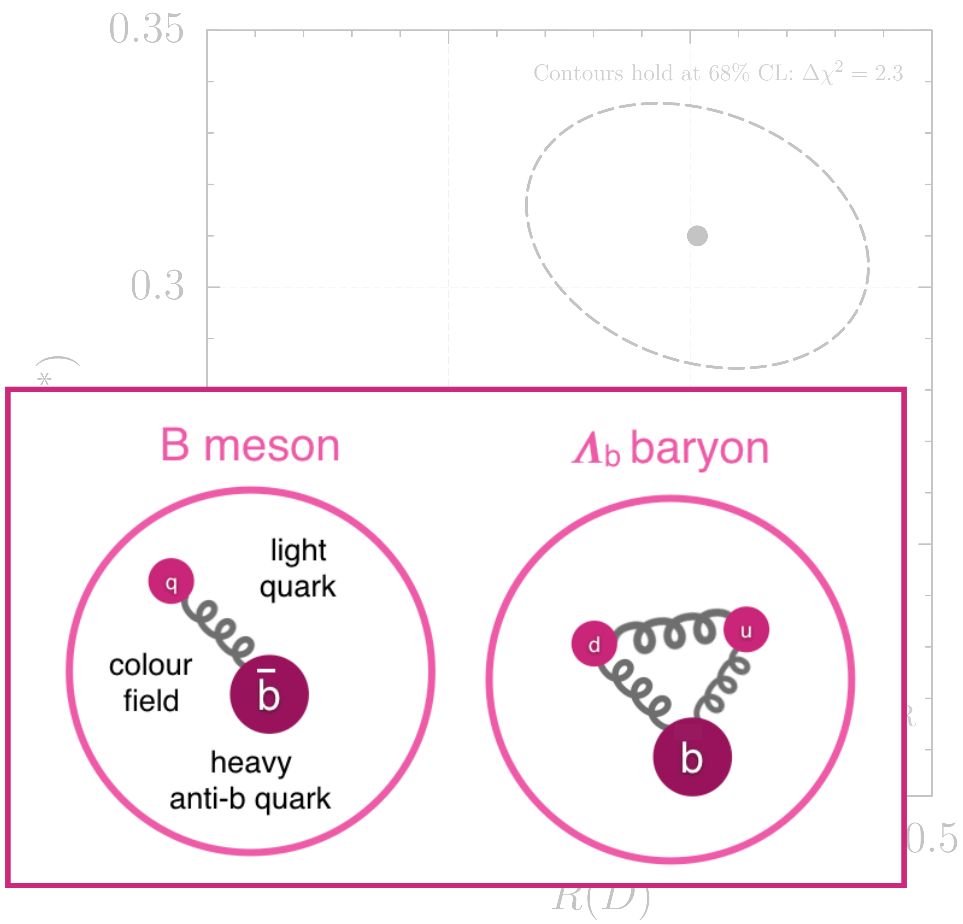


first correlated prediction!

Scenario	$R(D)$	$R(D^*)$	Correlation
$L_{w\geq1}$+SR	$\mathbf{0.299 \pm 0.003}$	$\mathbf{0.257 \pm 0.003}$	**44%**
Data [9]	0.403 ± 0.047	0.310 ± 0.017	−23%
Refs. [53, 57, 59]	0.300 ± 0.008	—	—
Ref. [58]	0.299 ± 0.003	—	—
Ref. [34]	—	0.252 ± 0.003	—

New precision prediction for R(D) / R(D*)

Key idea: link both channels using model independent QCD properties (HQET) of form factors

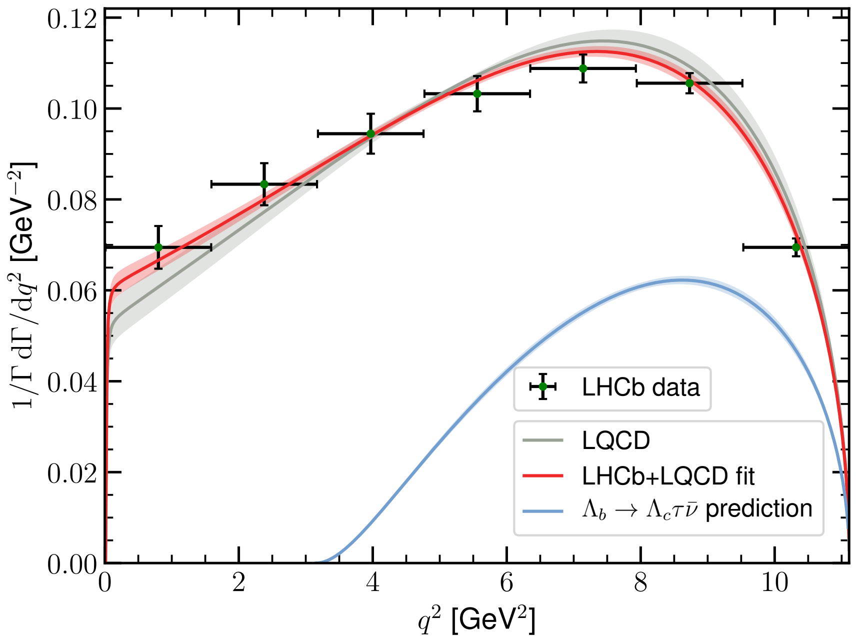


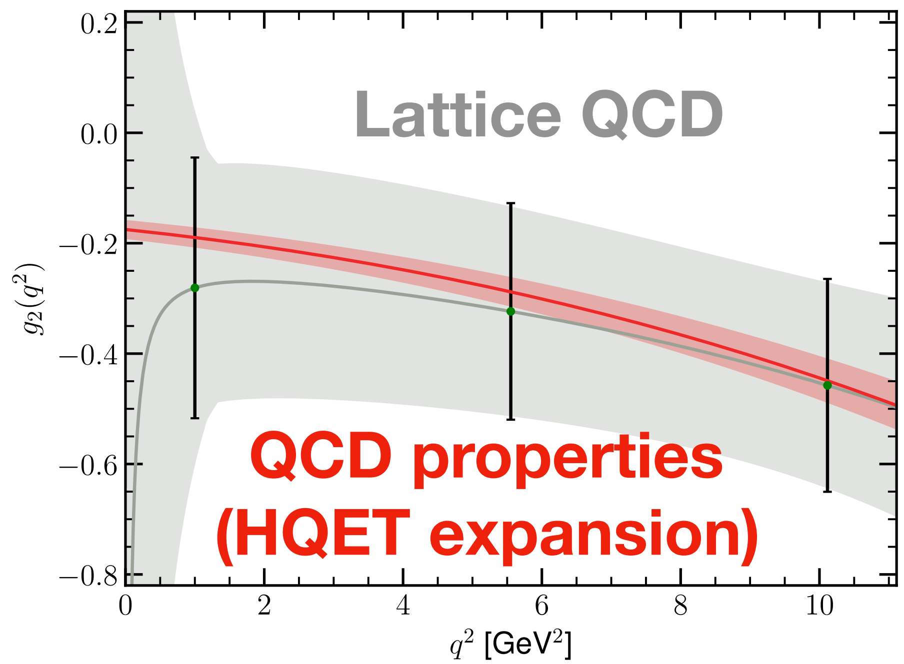
Applied similar idea to Baryons to derive most precise prediction for R(Λ_c):

New predictions for $\Lambda_b \to \Lambda_c$ semileptonic decays and tests of heavy quark symmetry

Florian U. Bernlochner,[1] Zoltan Ligeti,[2] Dean J. Robinson,[2,3] and William L. Sutcliffe[1]

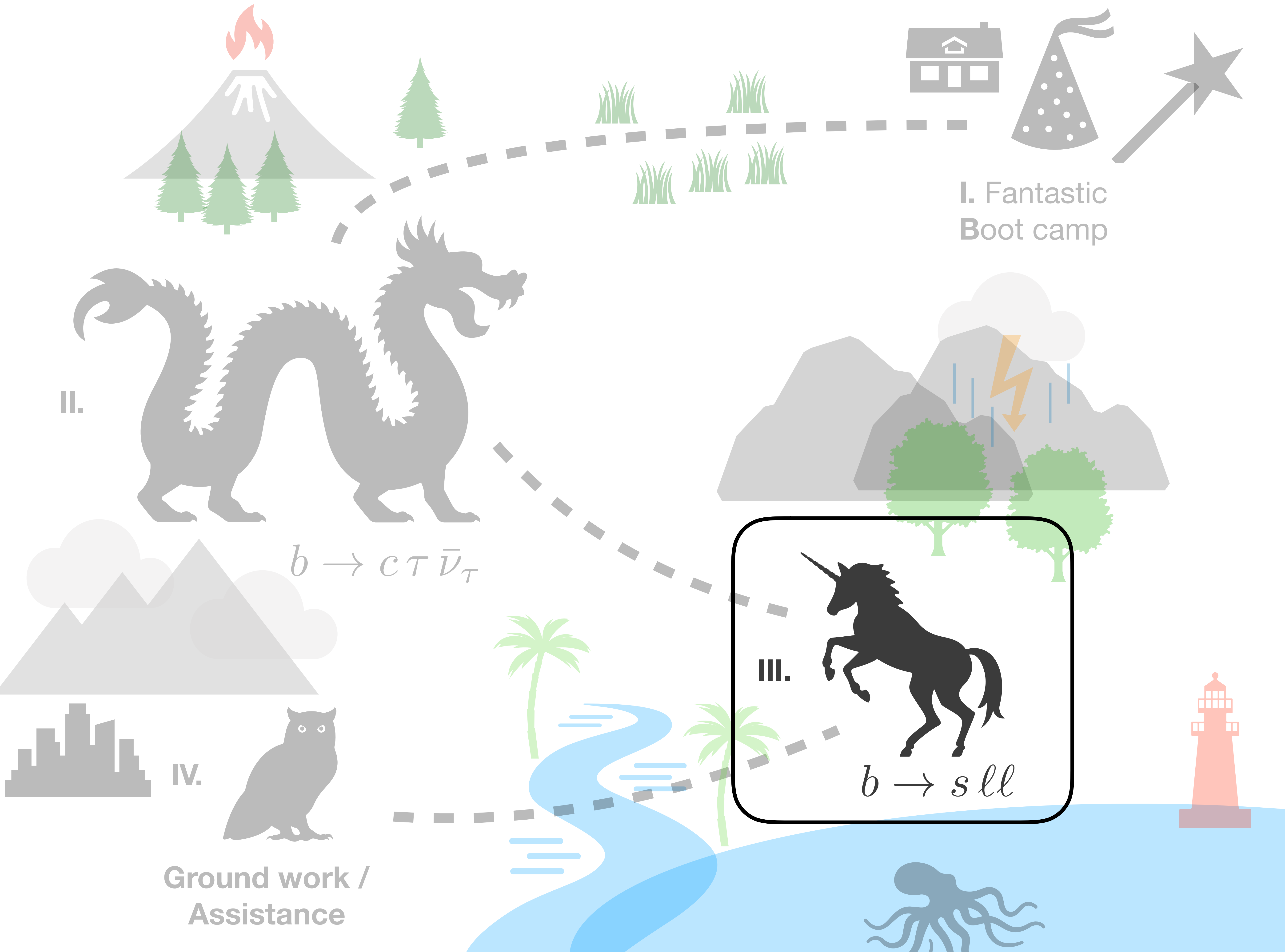
FB et al., arXiv:1808.09464
Phys. Rev. Lett. 121, 202001 (2018) plus another longer manuscript in preparation





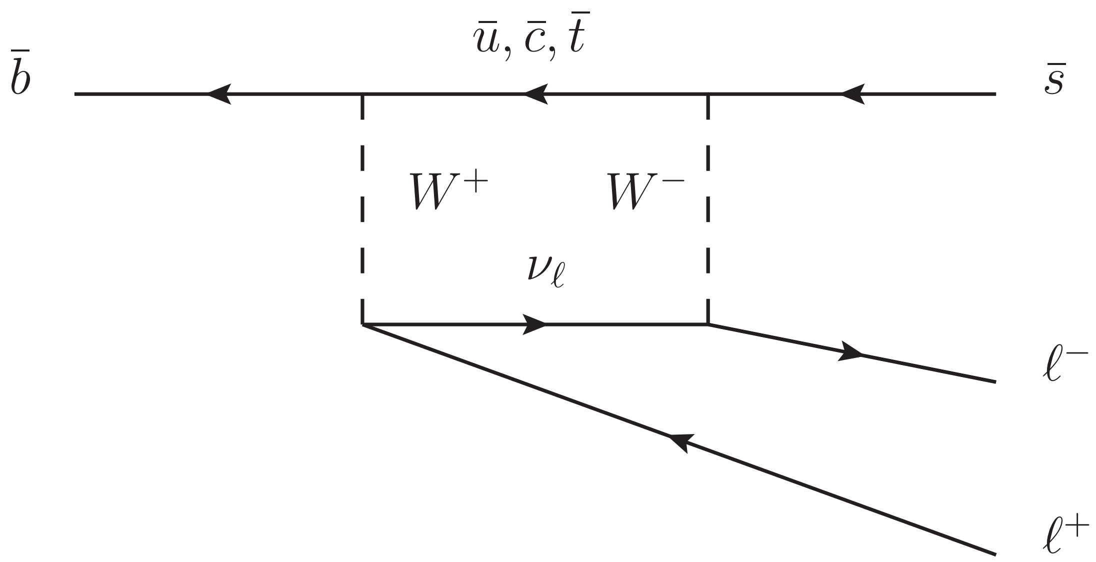
Most precise prediction to date

	LHCb + LQCD
ζ'	-2.04 ± 0.08
ζ''	3.16 ± 0.38
$\hat{b}_1/\text{GeV}^2$	-0.46 ± 0.15
$\hat{b}_2/\text{GeV}^2$	-0.39 ± 0.39
m_b^{1S}/GeV	4.72 ± 0.05
$\delta m_{bc}/\text{GeV}$	3.40 ± 0.02
χ^2/ndf	$7.20/20$
$R(\Lambda_c)$	$\mathbf{0.3237 \pm 0.0036}$

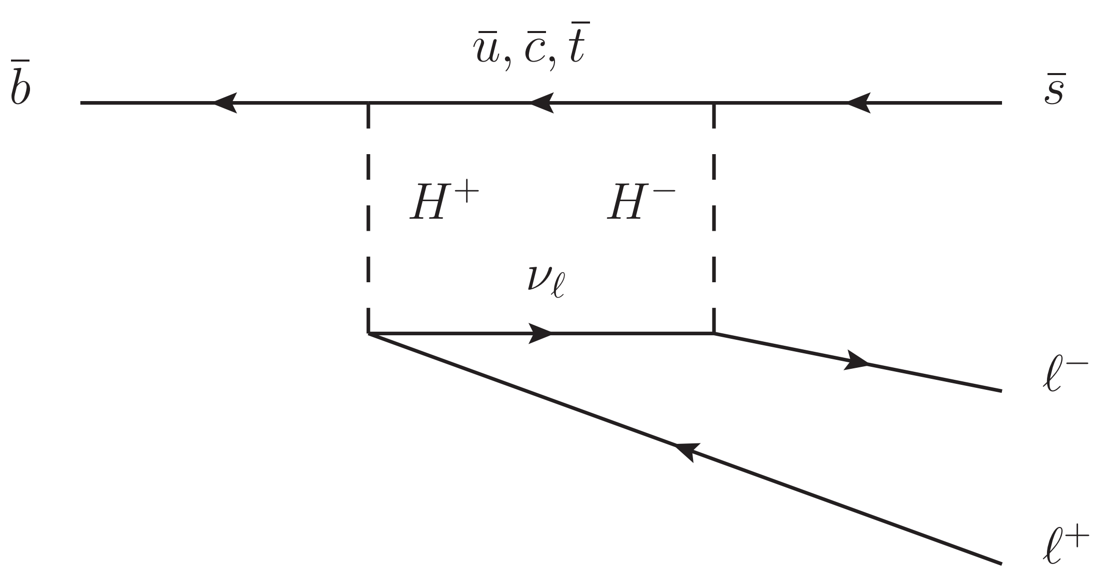

I. Fantastic
Boot camp
II.
$b \to c\,\tau\,\bar{\nu}_\tau$
III.
$b \to s\,\ell\ell$
IV.
Ground work /
Assistance

Another Fantastic B: Semileptonic decays with $\ell\ell$

SM



New Physics:



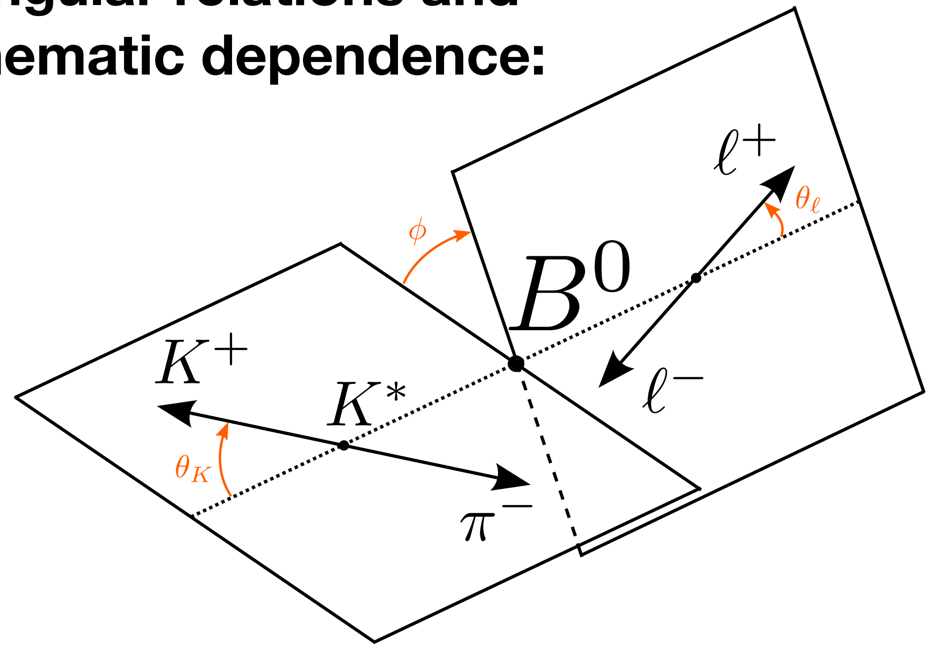
Observables of choice:

$$\mathcal{R}(K) = \frac{\mathcal{B}(B^+ \to K^+ \mu\,\mu)}{\mathcal{B}(B^+ \to K^+ e\,e)}$$

$$\mathcal{R}(K^*) = \frac{\mathcal{B}(B^0 \to K^{*0} \mu\,\mu)}{\mathcal{B}(B^0 \to K^{*0} e\,e)}$$

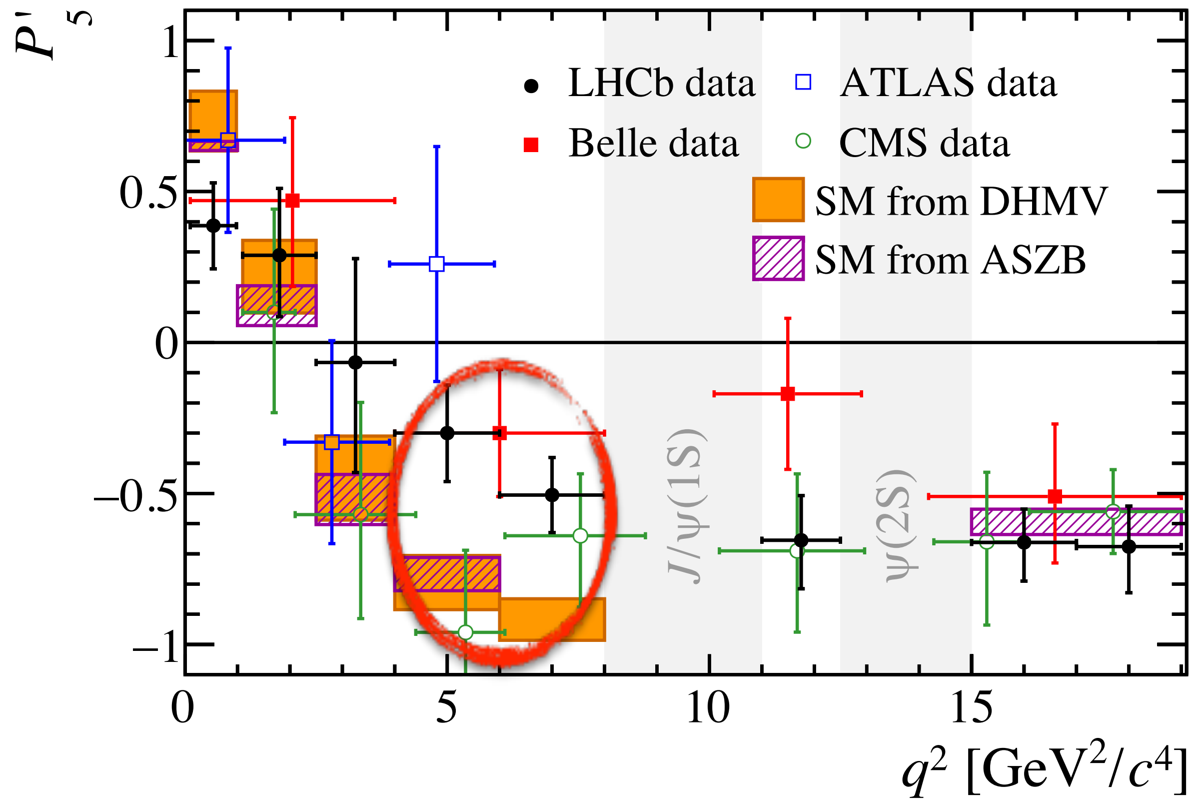
$$= 1 \pm \text{small corrections}$$

Angular relations and kinematic dependence:



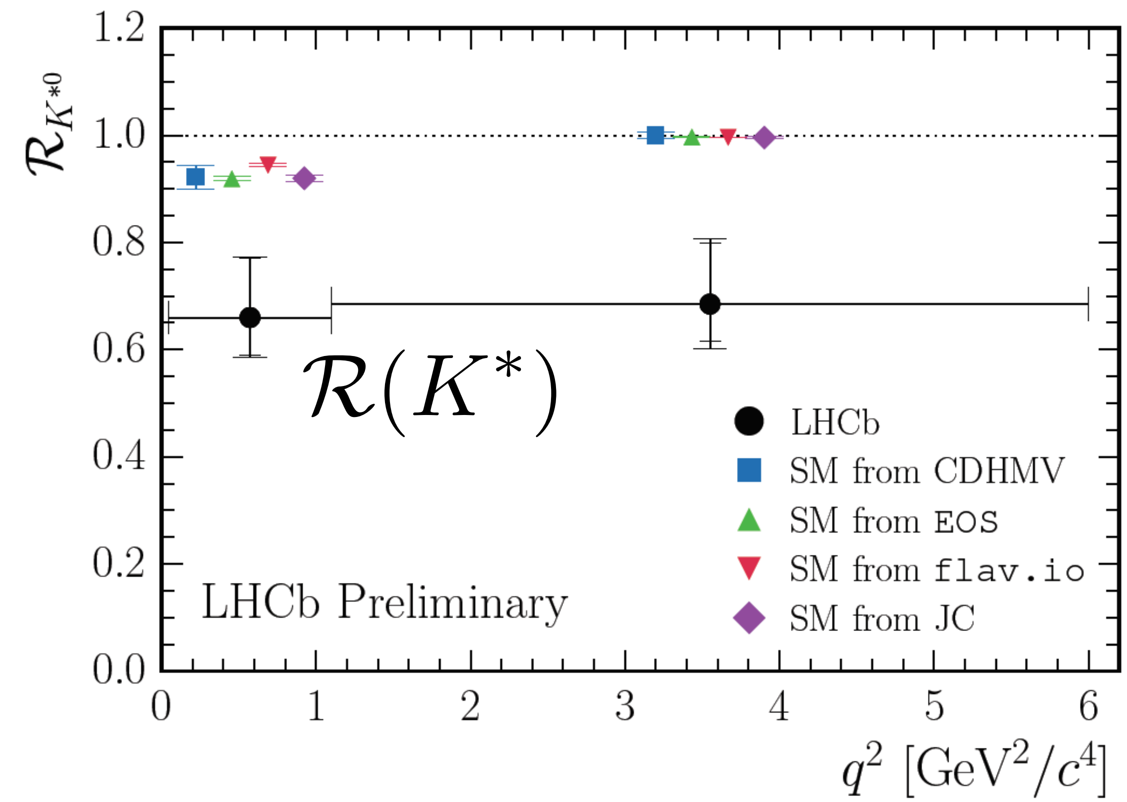
The decay is completely described by:
θ_ℓ, θ_K, ϕ and $q^2 = M^2_{\ell^+\ell^-}$

Tension with the SM **2.8-3σ**

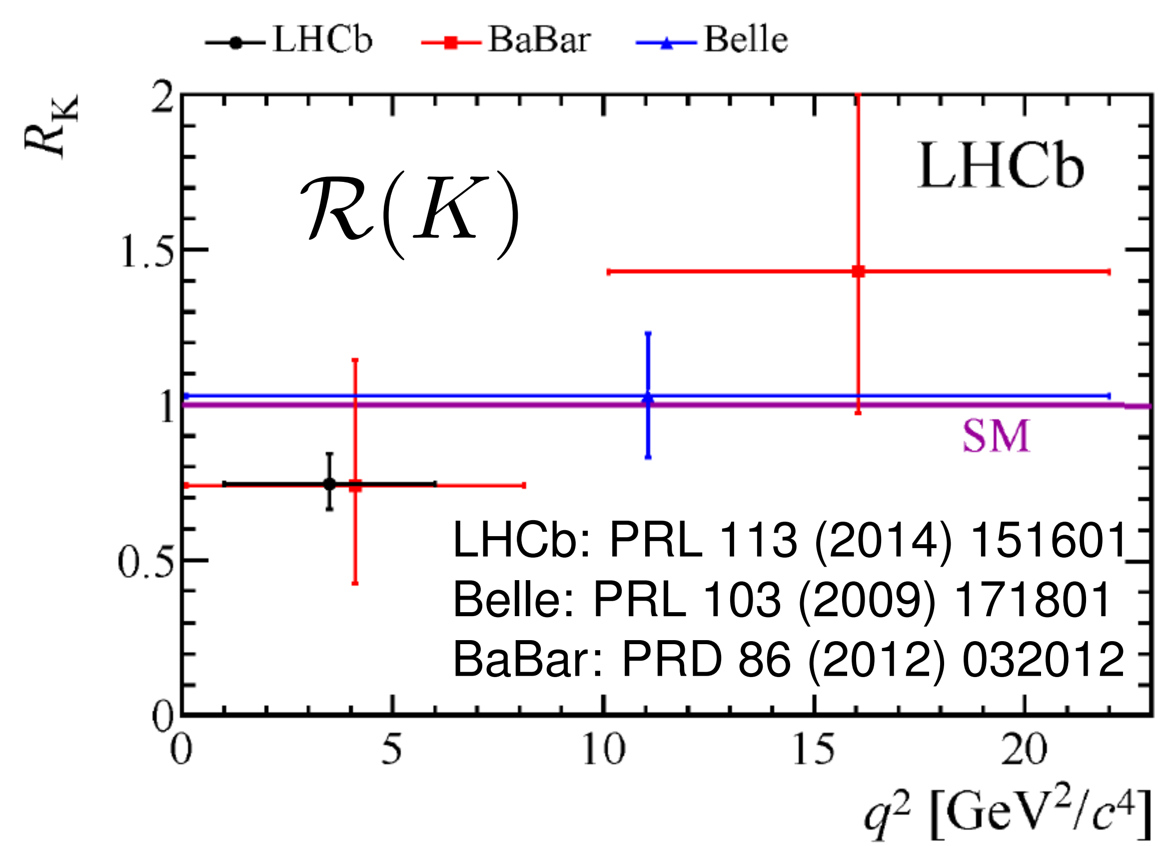


$$q^2 = m_{\ell\ell}^2$$

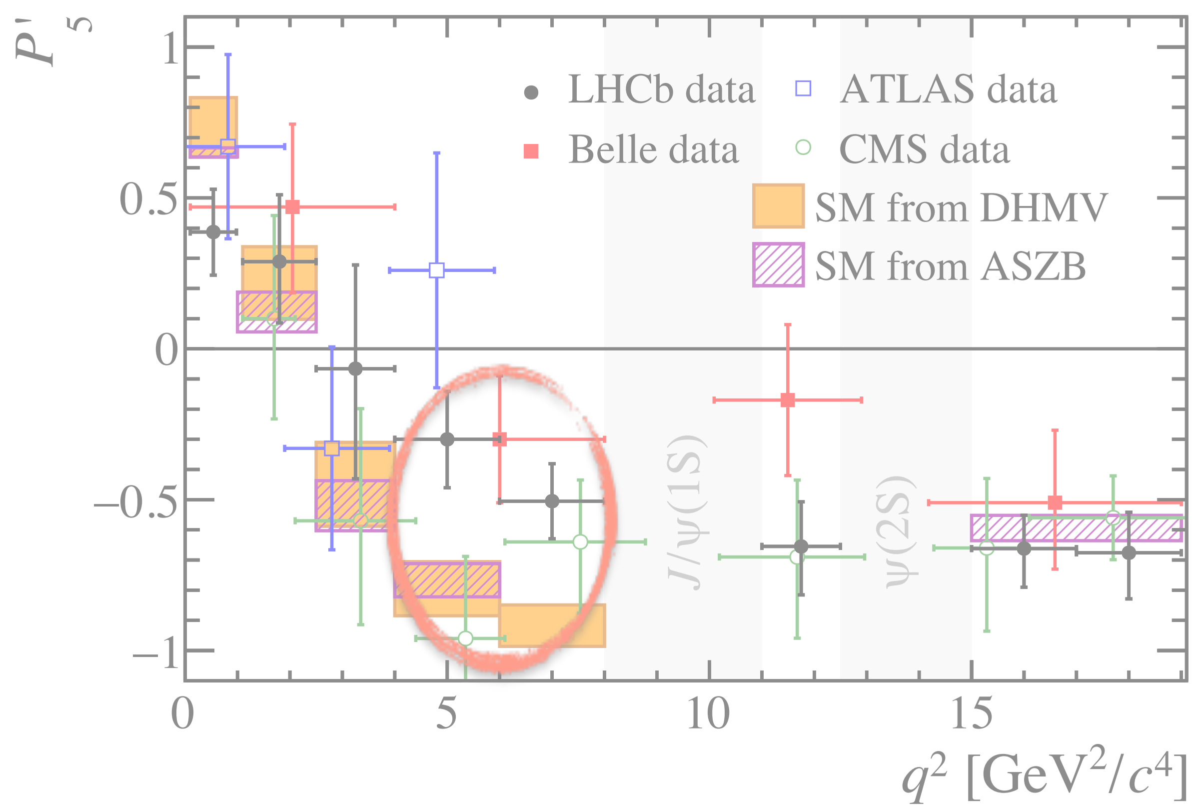
Tension with the SM **2.2-2.5σ**



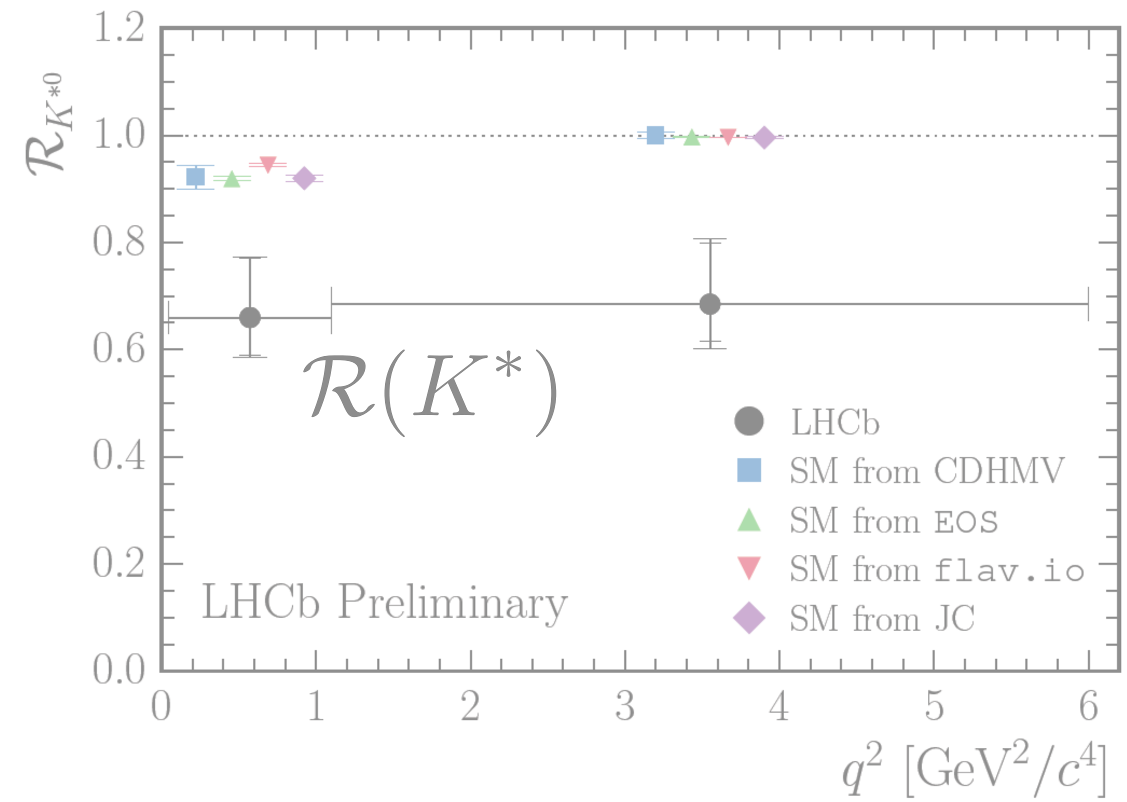
Tension with the SM **2.6σ**

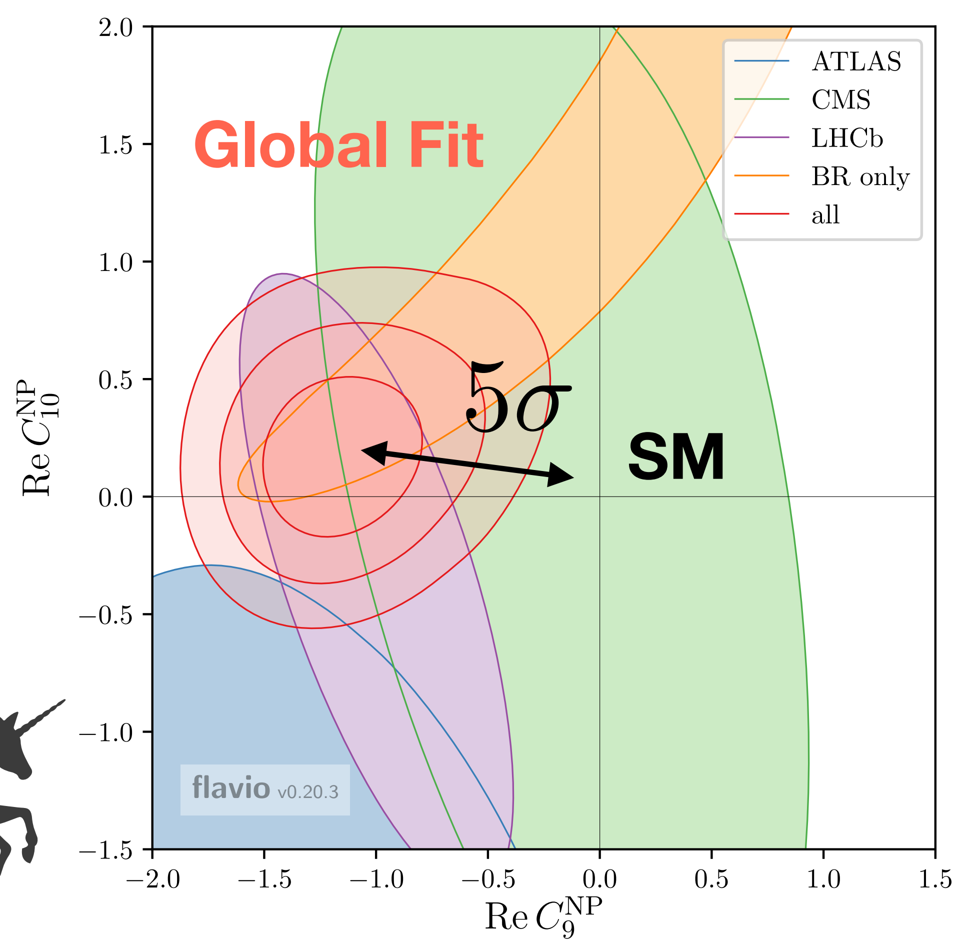


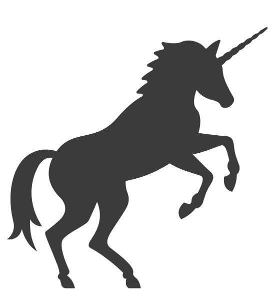
Tension with the SM **2.8-3σ**



Tension with the SM **2.2-2.5σ**



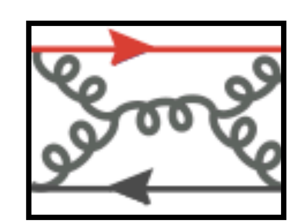




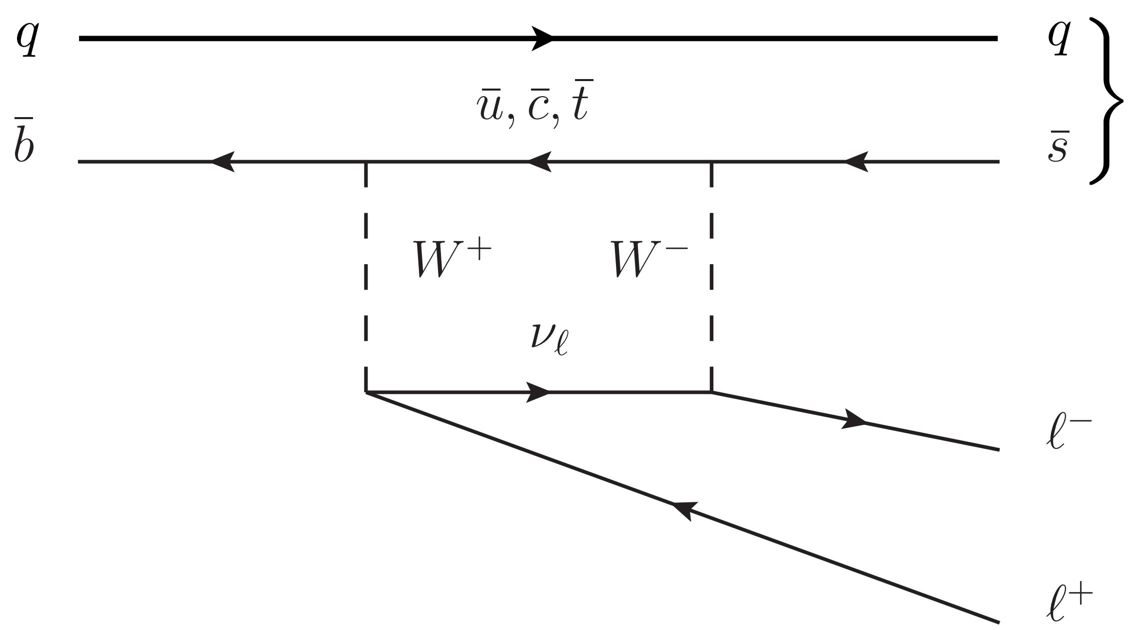
NP model independent analysis:

$$\mathcal{H}_{\rm eff} = -\frac{4\,G_F}{\sqrt{2}} V_{tb} V_{ts}^* \frac{e^2}{16\pi^2} \sum_i (C_i O_i + C_i' O_i')$$

Controversy about non-local QCD contributions in SM:



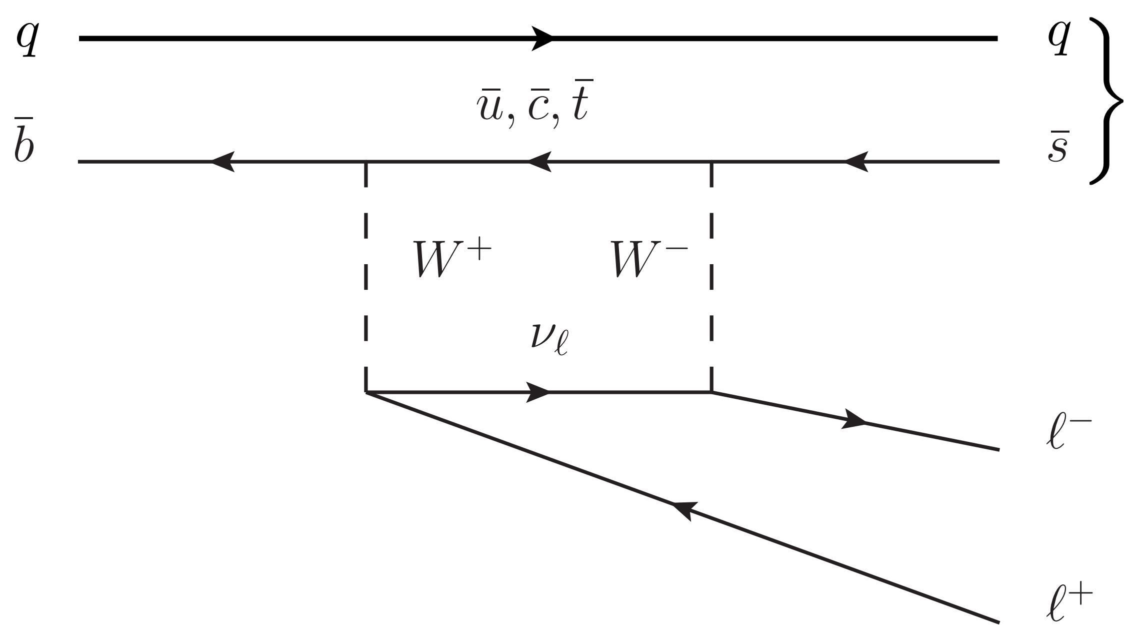
Alternative paths to that fantastic B: Inclusively



Inclusive X_s All possible final states

Exclusive $K, K^*, K\pi, \ldots$ One specific final state

Alternative paths to that fantastic B: Inclusively

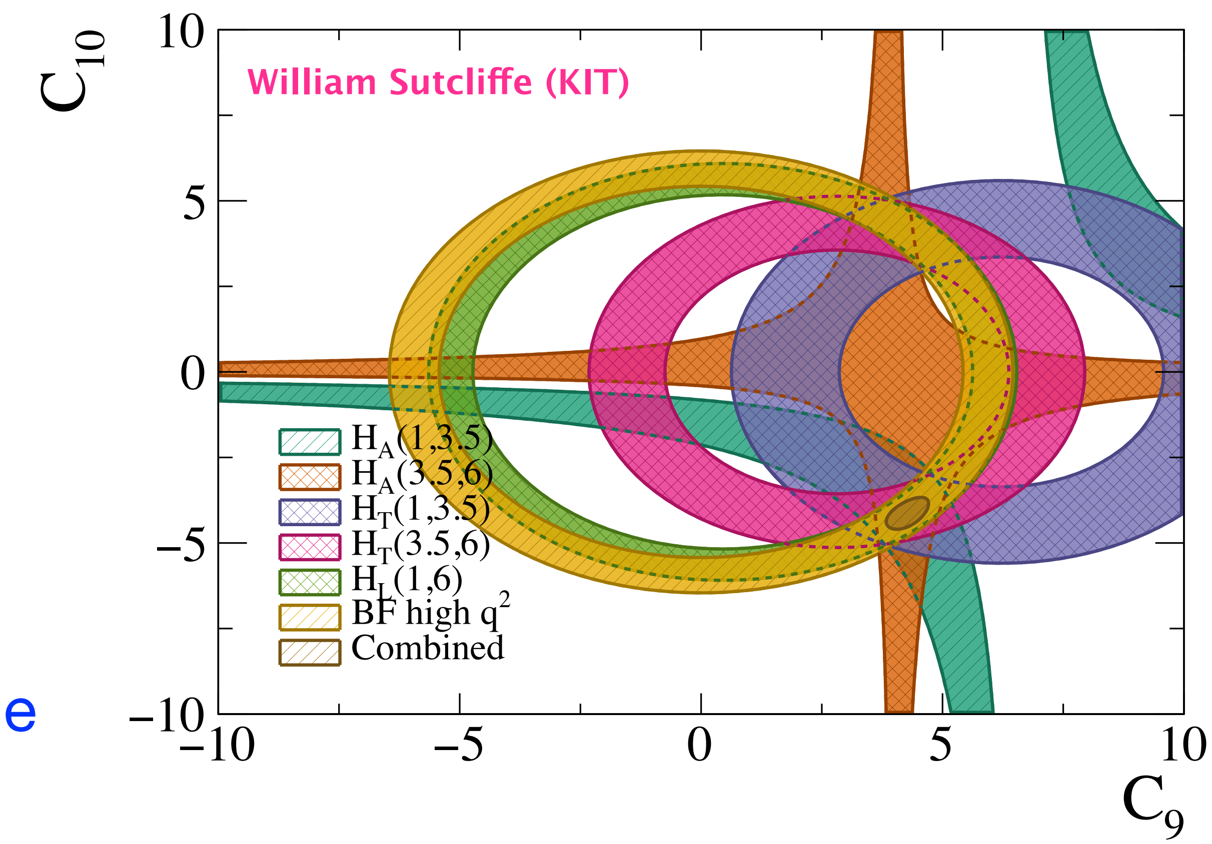


Inclusive X_s All possible final states

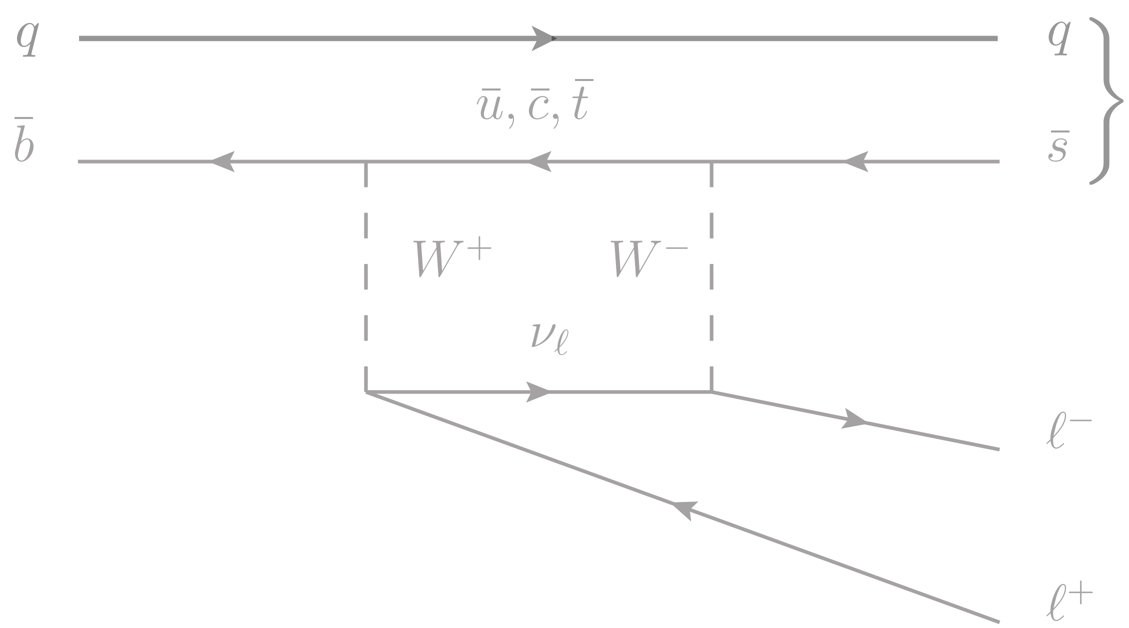
Exclusive $K, K^*, K\pi, \ldots$ One specific final state

- Benefit:
  - Theory **completely independent** for predicting inclusive decays.
  - **Alternative path** to determine **C_9** and **C_{10}** Wilson coefficients
    - Major background: semileptonic decays with $B \to D[\to K\bar{\ell}\nu]\ell\bar{\nu}$
    - Measurement only at low $q^2 = m_{ll}$ possible

Example toy fit to extract C_9 and C_{10} at low q^2 with angular information



Alternative paths to that fantastic B: Inclusively



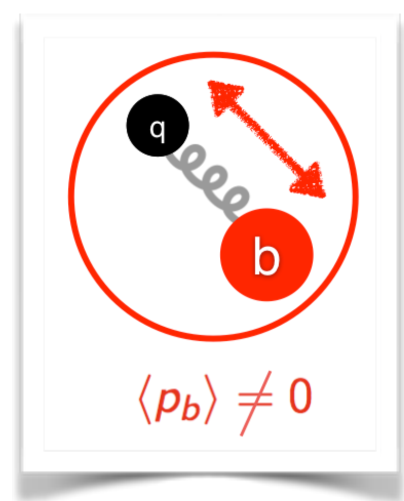
Inclusive X_s All possible final states

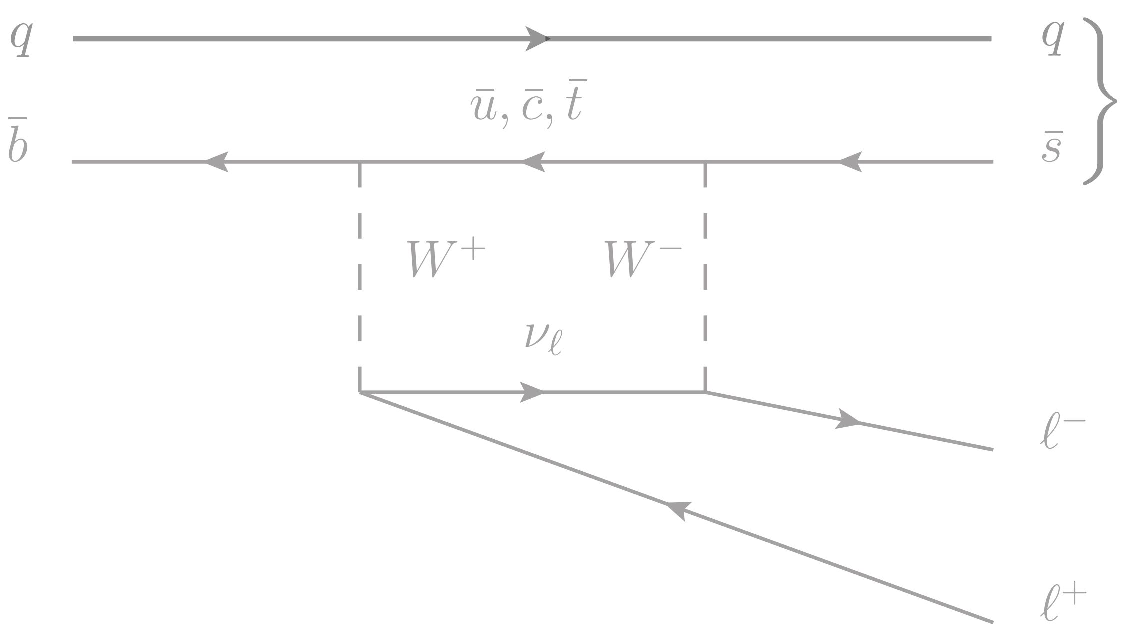
Exclusive $K, K^*, K\pi, \ldots$ One specific final state

Example toy fit to extract C_9 and C_{10} at low q^2 with angular information

- Benefit:
  - Theory **completely independent** for predicting inclusive decays.
  - **Alternative path** to determine $\mathbf{C_9}$ and $\mathbf{C_{10}}$ Wilson coefficients
    - Major background: semileptonic decays with $B \to D[\to K\bar{\ell}\nu]\ell\bar{\nu}$
    - Measurement only at low $q^2 = m_{ll}$ possible

At low q^2 SM prediction depends on b-Quark PDF inside B-Meson:





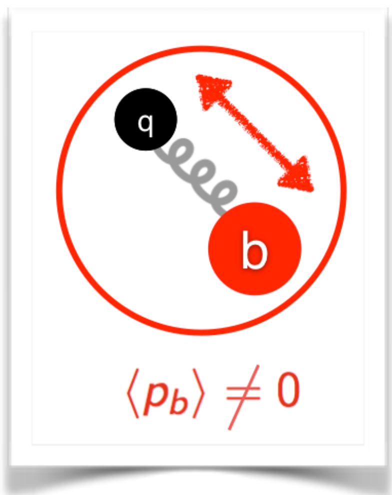
Inclusive X_s All possible final states

Exclusive $K, K^*, K\pi, \ldots$ One specific final state

Example toy fit to extract C_9 and C_{10} at low q^2 with angular information

- Benefit:
  - Theory **completely independent** for predicting inclusive decays.
  - **Alternative path** to determine **C_9** and **C_{10}** Wilson coefficients
    - Major background: semileptonic decays with $B \to D[\to K\bar{\ell}\nu]\ell\bar{\nu}$
    - Measurement only at low $q^2 = m_{ll}$ possible

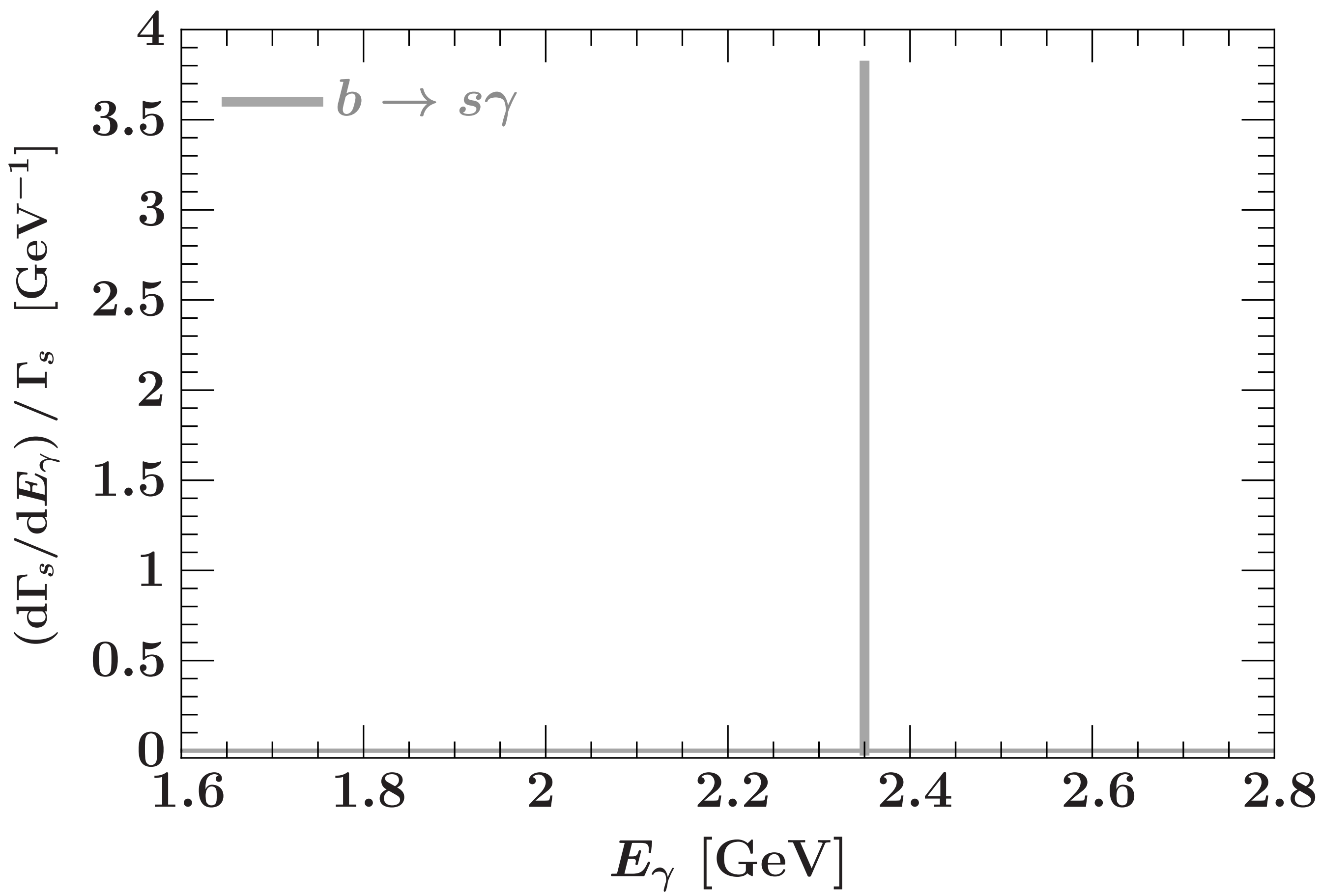
At low q^2 SM prediction depends on b-Quark PDF inside B-Meson:

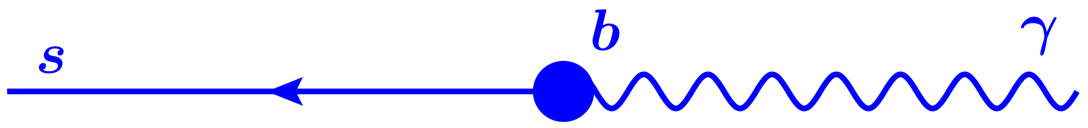


Can be constrained with two-body or other decays, e.g.

$$B \to X_s \gamma$$

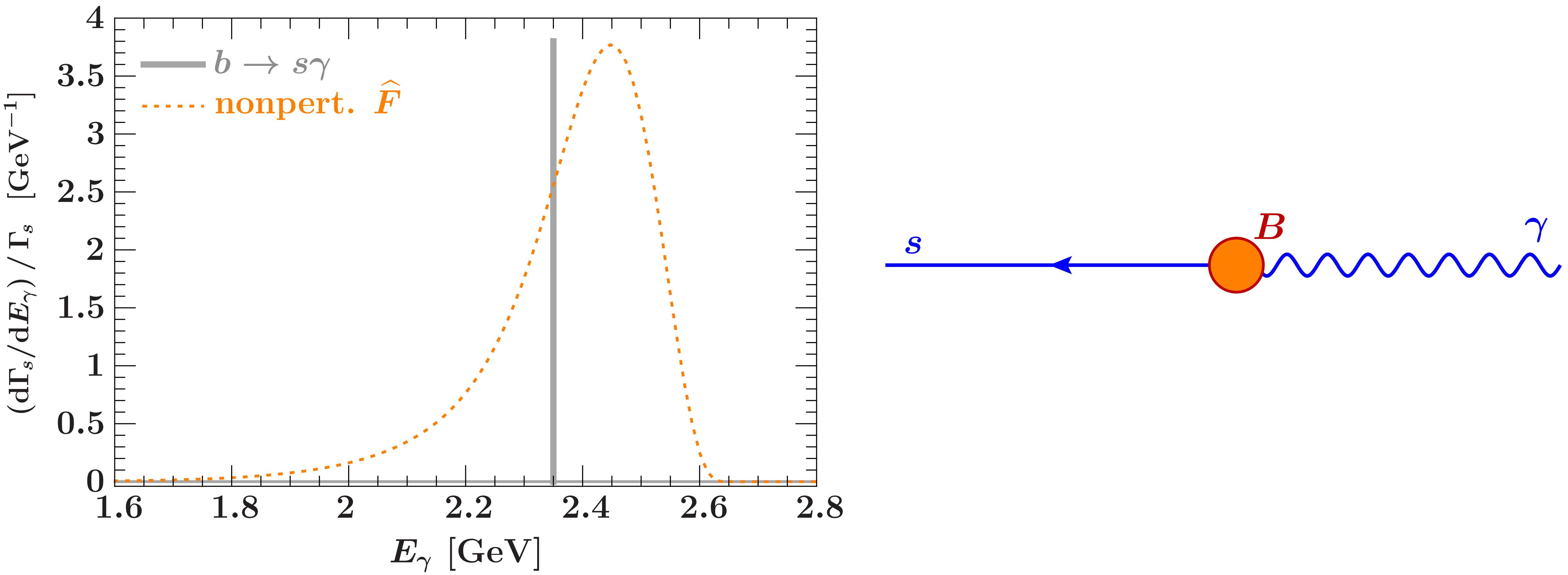
Constraining the Shape-Function





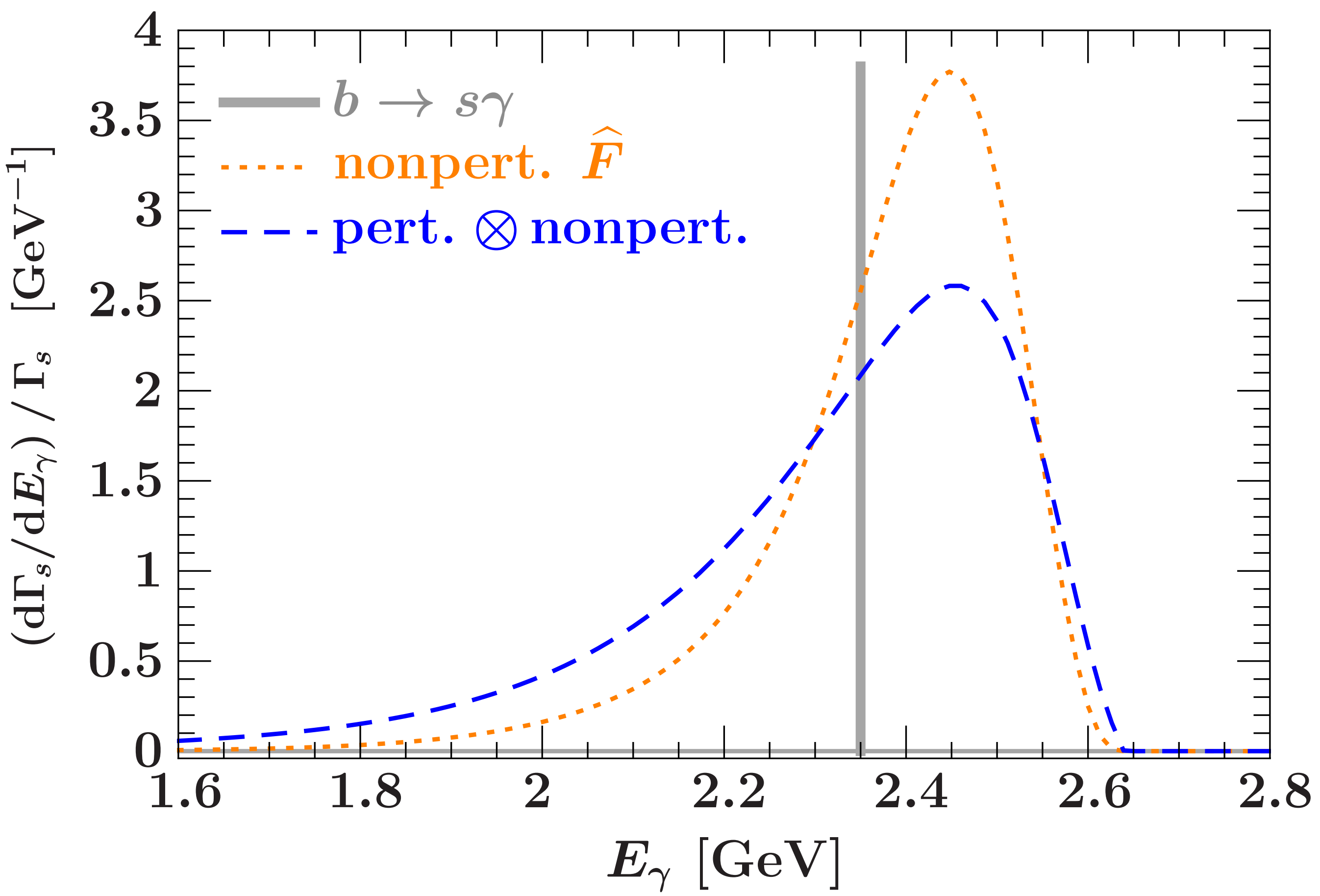
- b →s ɣ decay rate: $\mathrm{d}\Gamma/\mathrm{d}E_\gamma \sim \delta(E_\gamma - m_b/2)$

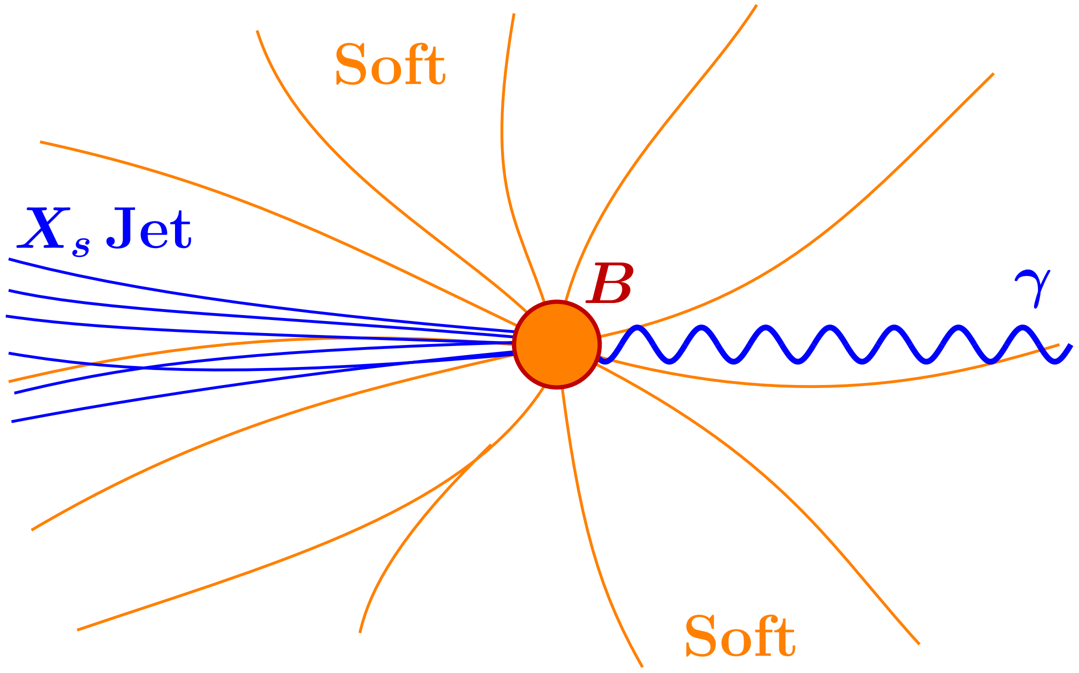
Constraining the Shape-Function



- b →s ɣ decay rate: $\mathrm{d}\Gamma/\mathrm{d}E_\gamma \sim \delta(E_\gamma - m_b/2)$
- E_γ spectrum determined by nonpert. B distribution (shape function)

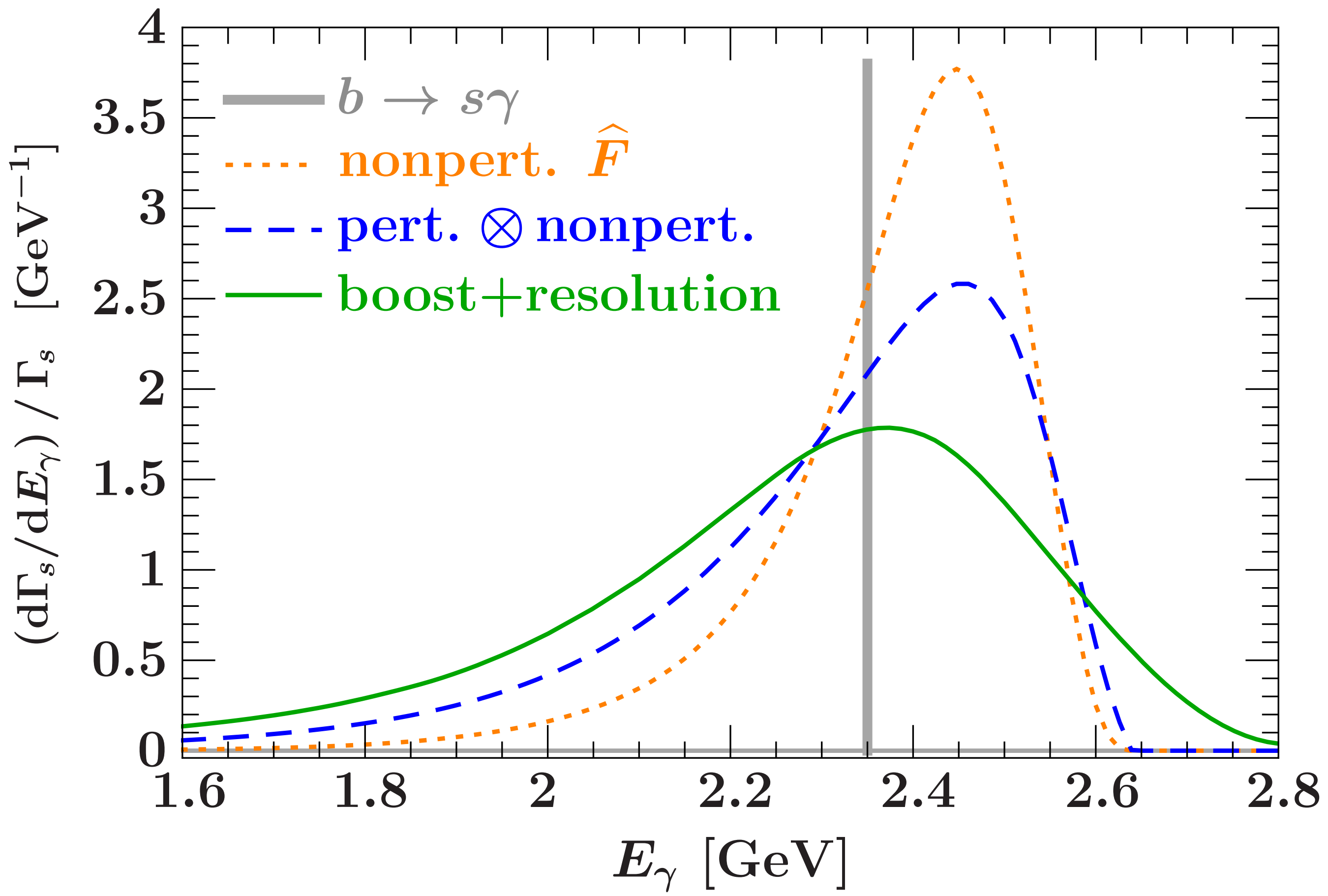
Constraining the Shape-Function

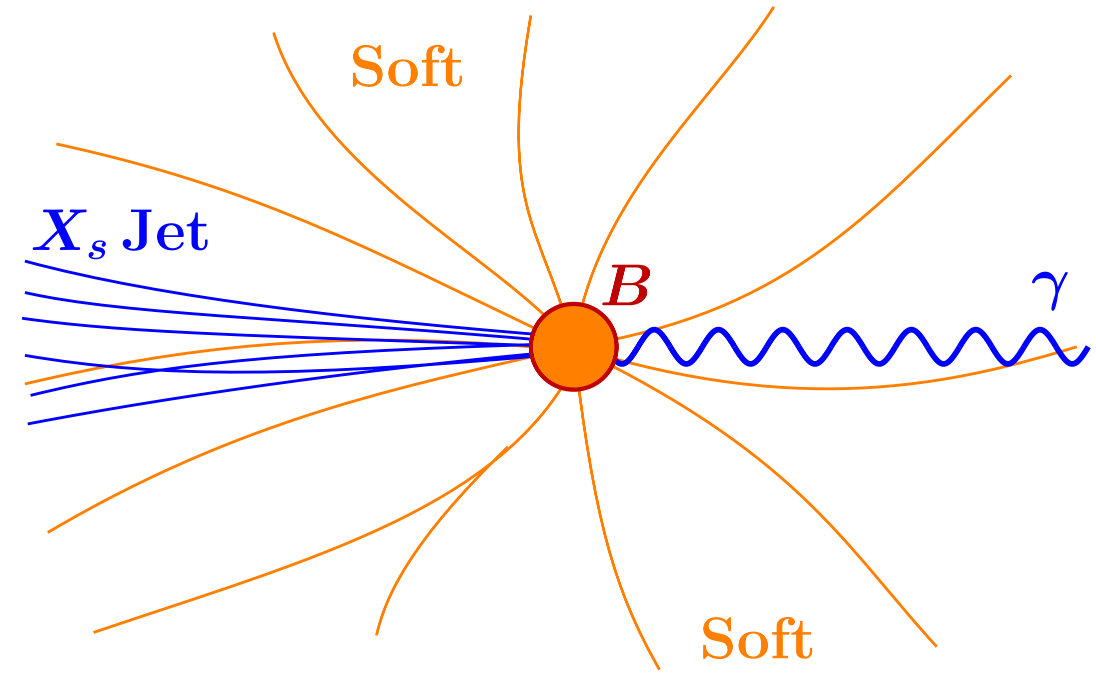




- b →s ɣ decay rate: $\mathrm{d}\Gamma/\mathrm{d}E_\gamma \sim \delta(E_\gamma - m_b/2)$
- E_γ spectrum determined by nonpert. B distribution (shape function)
- Tail for sufficiently small E_γ is mostly perturbative

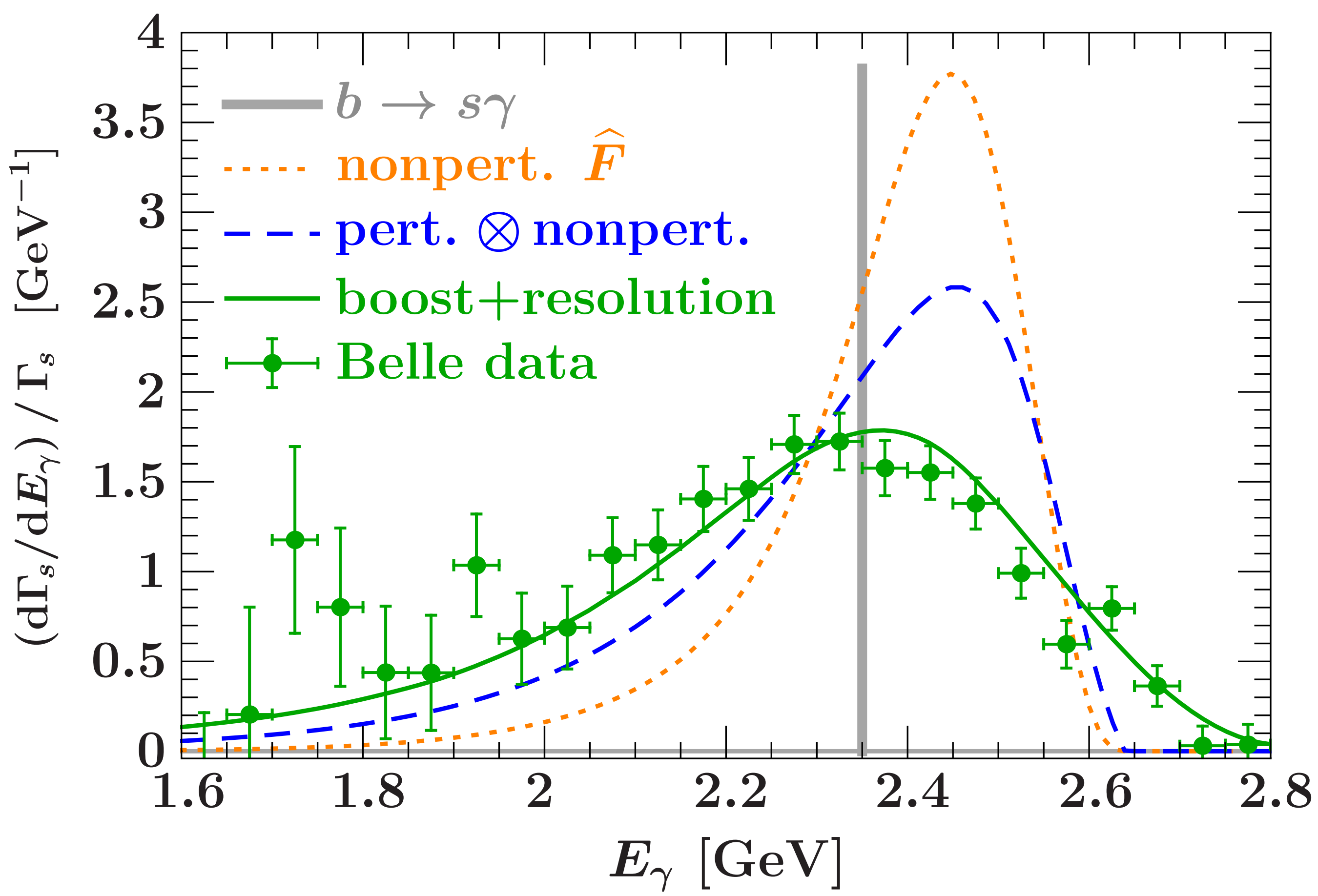
Constraining the Shape-Function





- b →s ɣ decay rate: $\mathrm{d}\Gamma/\mathrm{d}E_\gamma \sim \delta(E_\gamma - m_b/2)$
- E_γ spectrum determined by nonpert. B distribution (shape function)
- Tail for sufficiently small E_γ is mostly perturbative
- Y(4S) boost and experimental resolution further smear things out

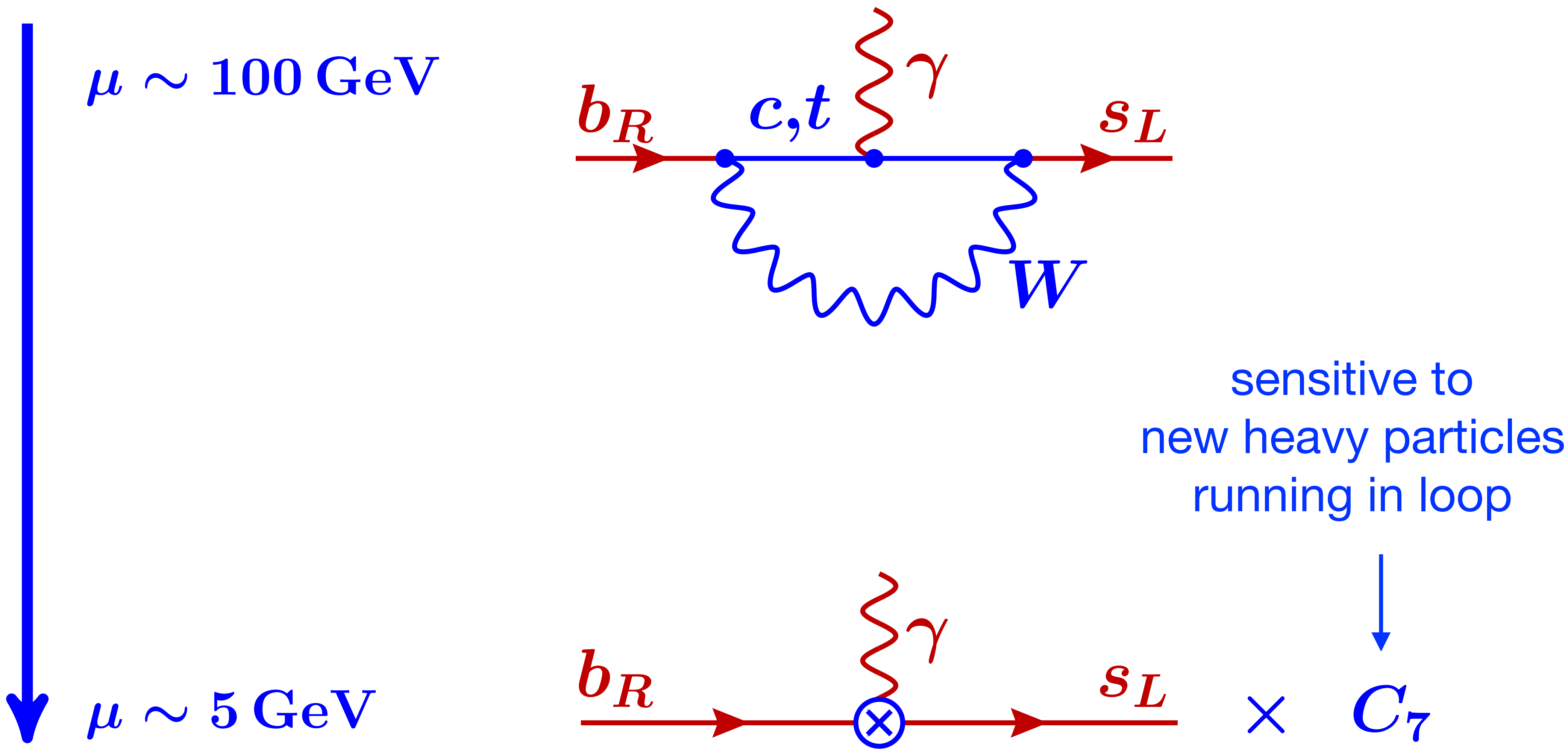
Constraining the Shape-Function



SIMBA: effort to determine nonpert. B distribution

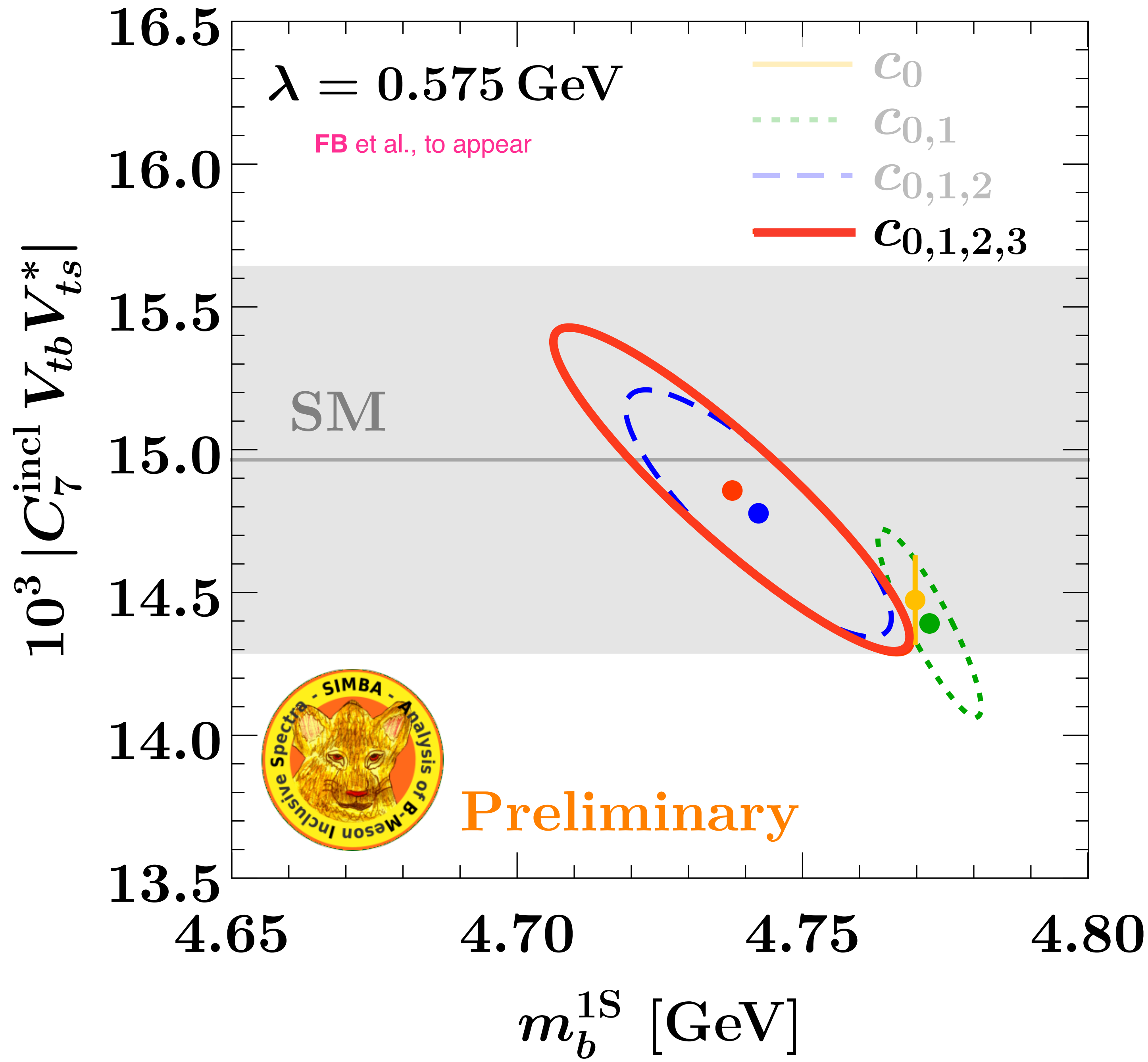
- b →s ɣ decay rate: $\mathrm{d}\Gamma/\mathrm{d}E_\gamma \sim \delta(E_\gamma - m_b/2)$
- E_γ spectrum determined by nonpert. B distribution (shape function)
- Tail for sufficiently small E_γ is mostly perturbative
- Υ(4S) boost and experimental resolution further smear things out

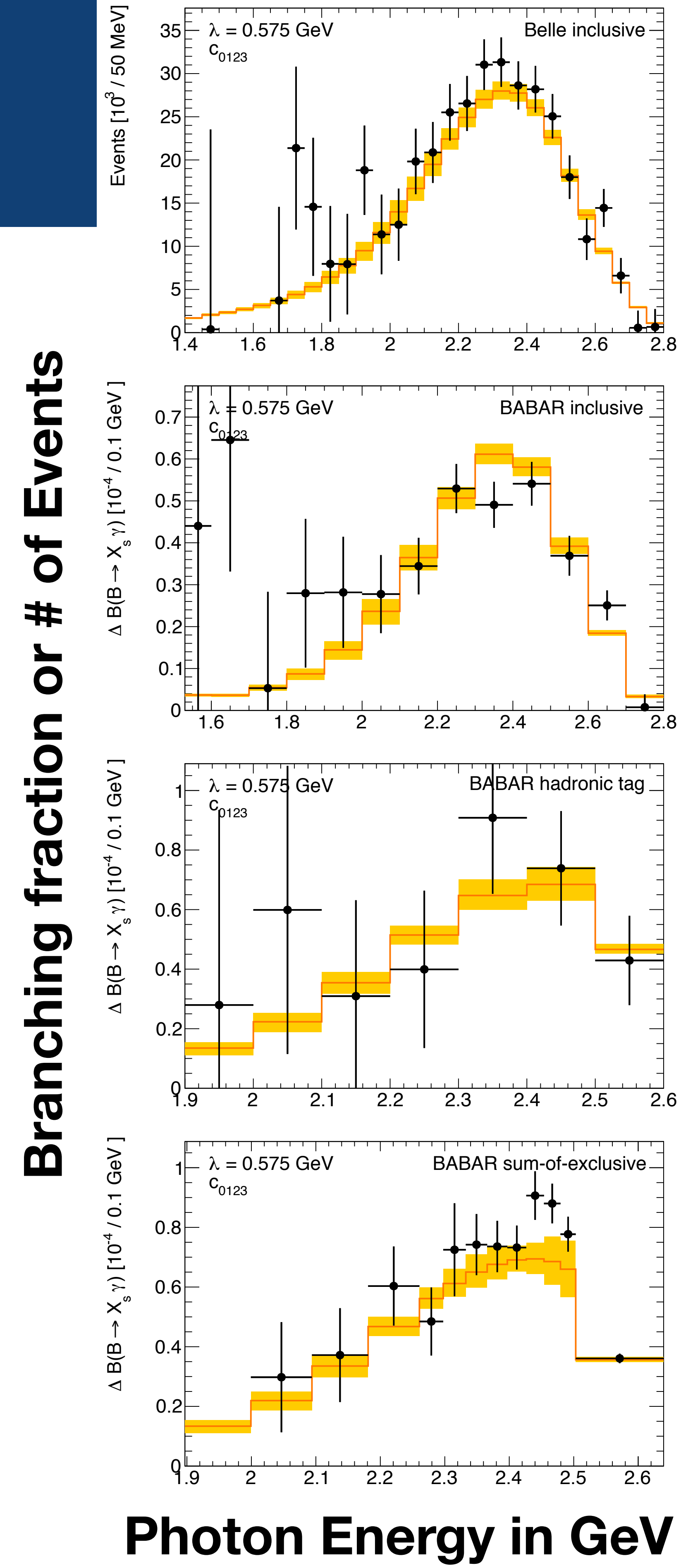
Effective Field Theories (EFTs) and New Physics



The poster child of EFT-based indirect searches for new physics

SIMBA result for $|C_7|$ and m_b





shape function encodes details
of b-quark mass

FB, Zoltan Ligeti,
Frank Tackmann,
Kerstin Tackmann,
Iain Stewart,
Heiko Lacker

FB et al, PoS ICHEP 2010, 229 (2010)
FB et al, PoS ICHEP 2012, 370 (2013)

SIMBA - Analysis of B-Meson Inclusive Spectra

Differential Information

$\bar{B} \to X_u \, \ell \, \bar{\nu}_\ell$

E_ℓ, m_X, q^2

+

$\bar{B} \to X_s \, \gamma$

E_γ

+

$\bar{B} \to X_s \, \ell\ell$

q^2

+

$\bar{B} \to X_c \, \ell \, \bar{\nu}_\ell$

E_ℓ, q^2

Global Analysis

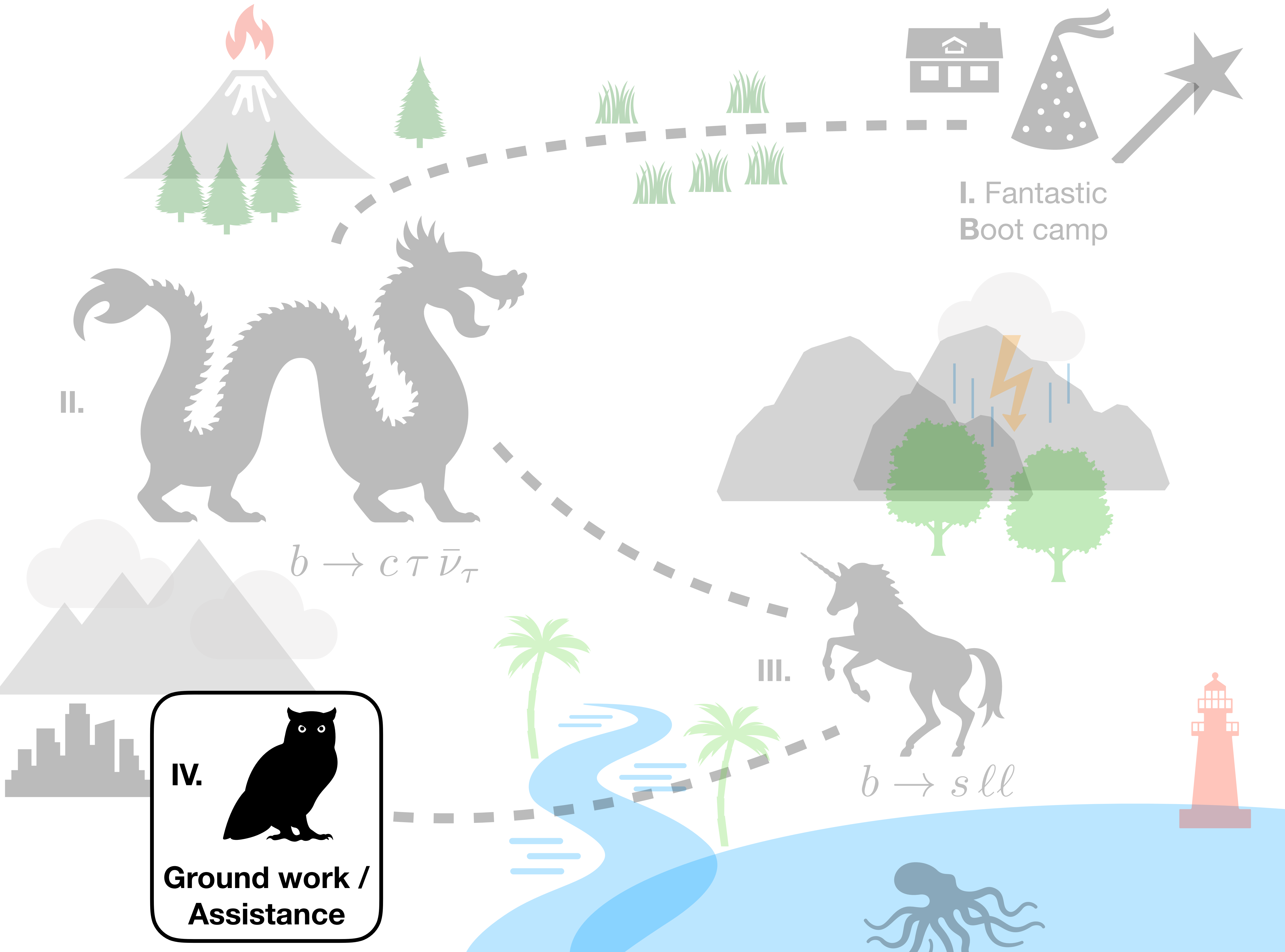
Parameters of interest:

- $|V_{ub}|$ → Incl. and Excl. Problem (3.4 σ)
- b-Quark distribution function → a priori unknown, for some applications as important as **knowing the Proton PDF at the LHC**
- $|C_7|$, $|C_9|$, $|C_{10}|$ → Search for **New Physics**
- m_b → **fundamental parameter** of the Standard Model
- $|V_{cb}|$ → Incl.. und Excl. problem (2.4 σ)

$$R(X) = \frac{\mathcal{B}(\bar{B} \to X \, \tau \, \bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to X \, \ell \, \bar{\nu}_\ell)}$$

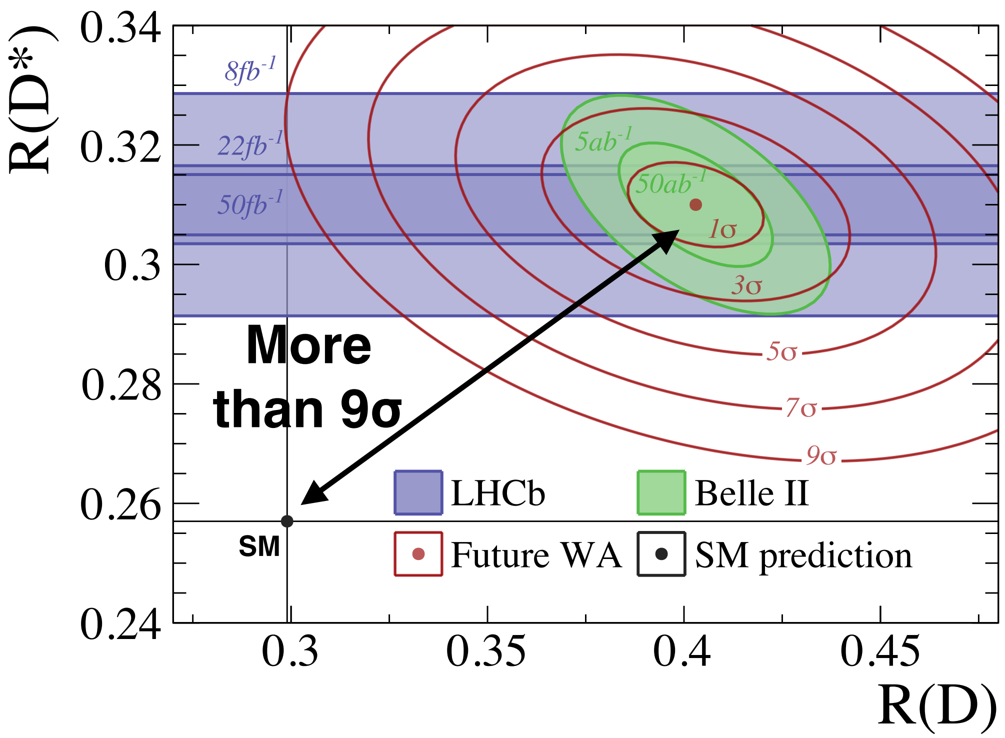
→ 4 σ difference in excl. semi-tauonic measurements

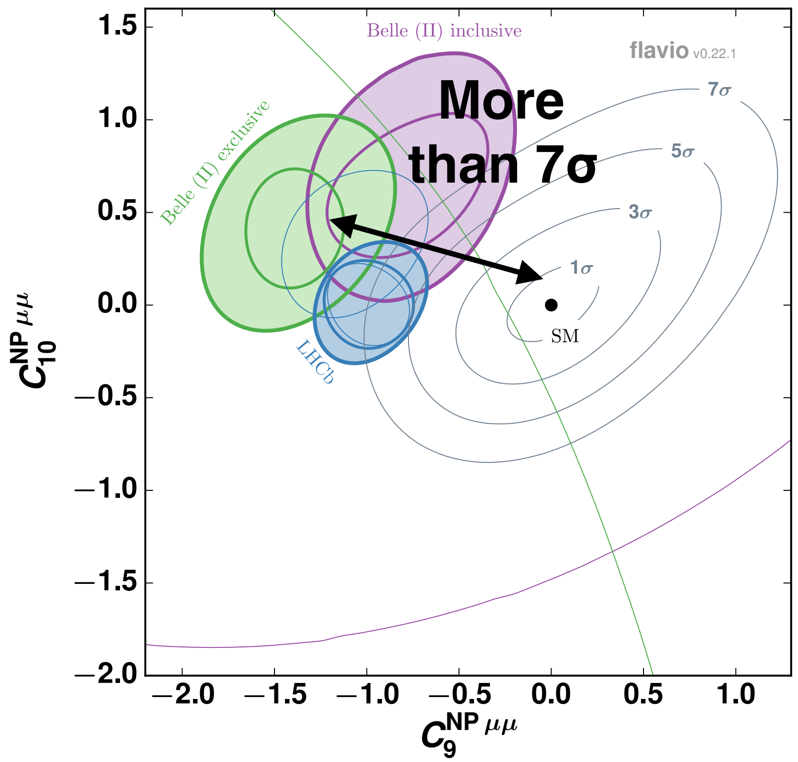
Emmy Noether-Programm
DFG Deutsche Forschungsgemeinschaft


I. Fantastic
Boot camp
II.
$b \to c \tau \bar{\nu}_\tau$
III.
$b \to s \ell\ell$
IV.
Ground work /
Assistance

There is much to do!

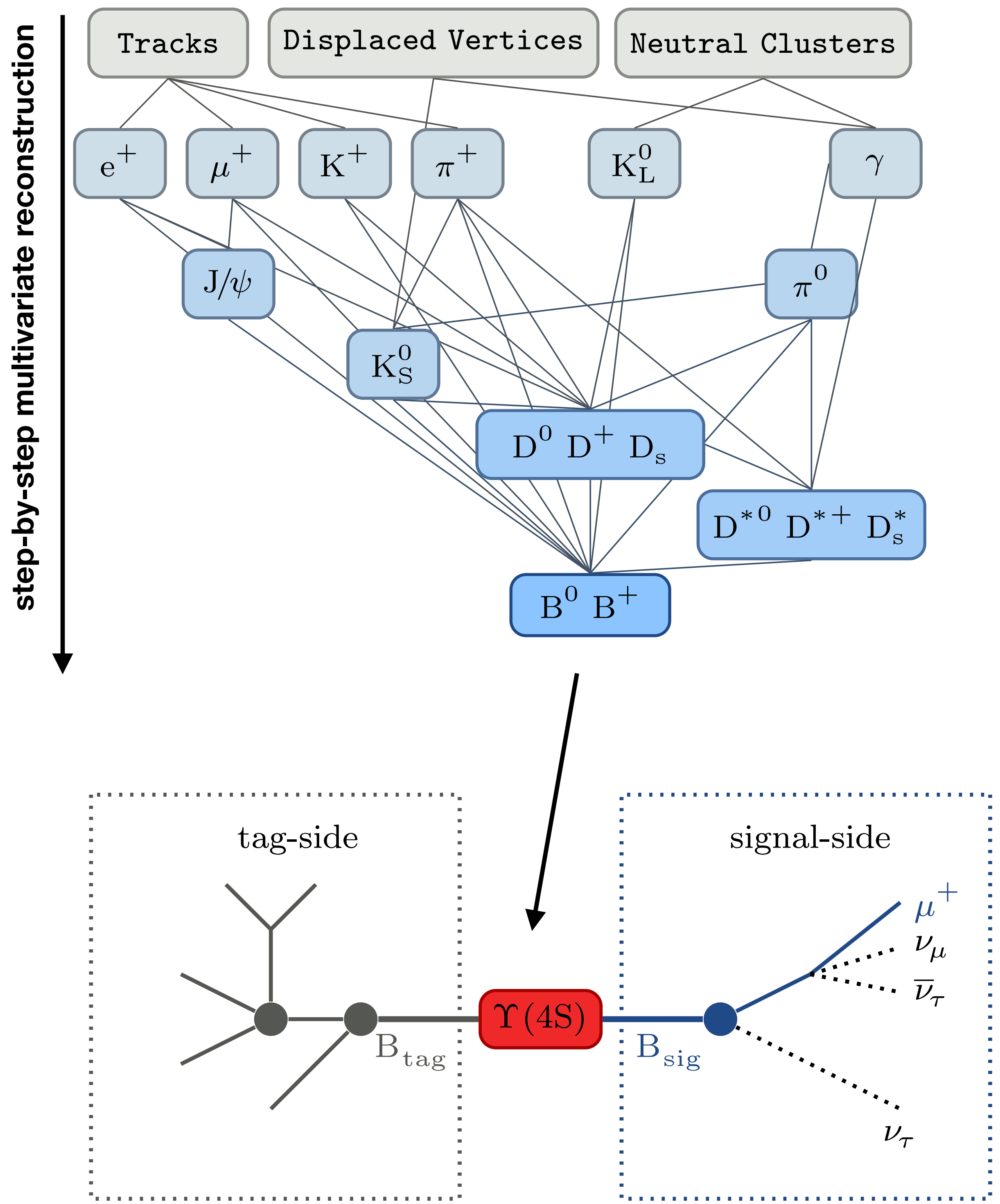
FB et al., arXiv:1709.10308



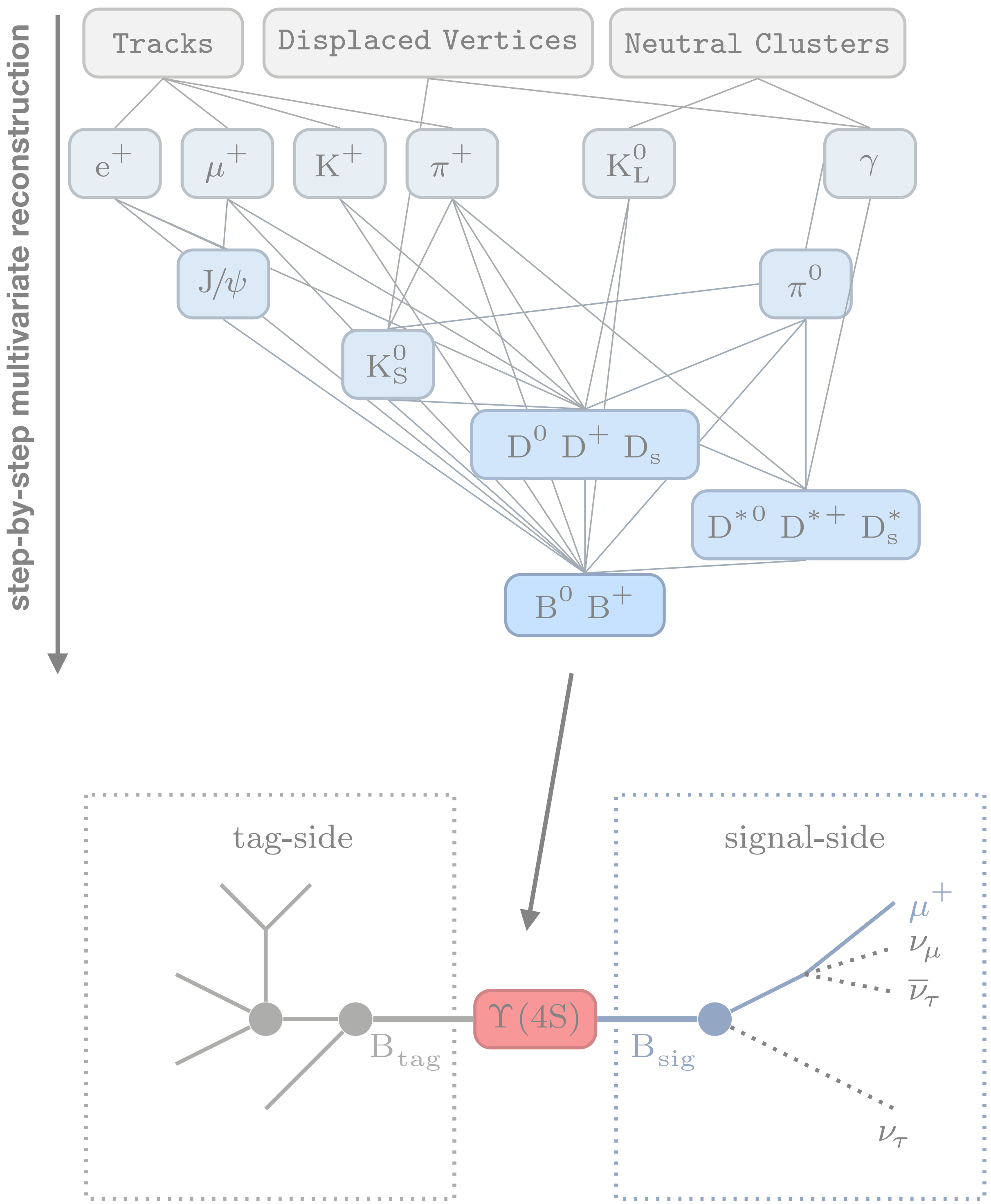


- Without necessary ground work, **no physics**:
  - Show you one example central to missing energy analyses: **Full Event Interpretation**

Full Event Interpretation or FEI



Full Event Interpretation or FEI

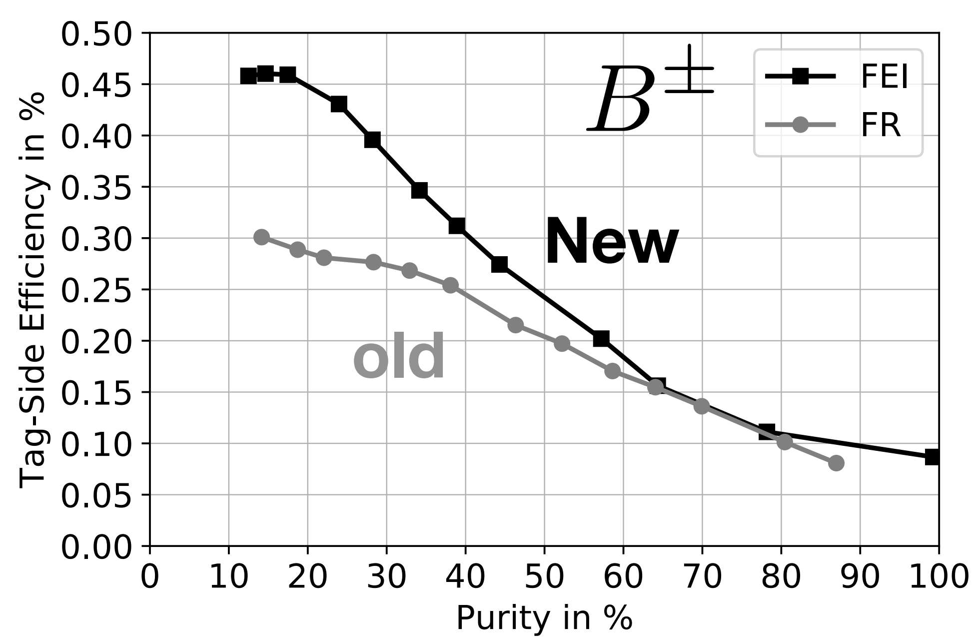


Novel multivariate algorithm for tagging:

Thomas Keck, ..., FB, ... arXiv:1807.08680
submitted to Computing and Software for Big Science

	FEI		old algorithms		
	$B^\pm$	B^0		$B^\pm$	B^0
Hadronic			Hadronic		
FEI with FR channels	0.53 %	0.33 %	FR	0.28 %	0.18 %
FEI	0.76 %	0.46 %	SER	0.4 %	0.2 %
Semileptonic			Semileptonic		
FEI	1.80 %	2.04 %	FR	0.31 %	0.34 %
			SER	0.3 %	0.6 %

- Significant improvement of performance



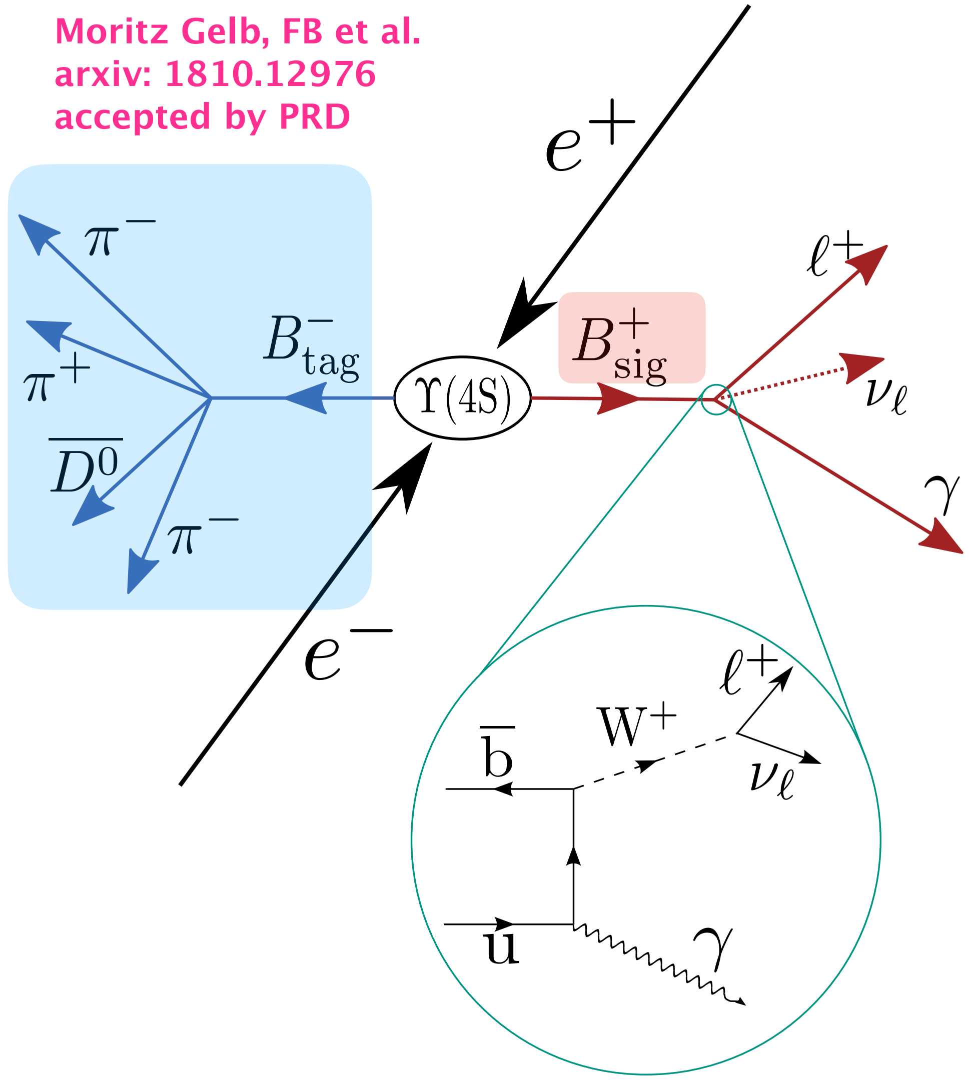
Validation using Belle data

Moritz Gelb, FB et al.
arxiv: 1810.12976
accepted by PRD

- Search for rare decay of $B^+ \to \ell^+ \bar{\nu}_\ell \gamma$
  - Belle data offers **ideal testing** ground to validate the FEI <—> **3 times higher eff.**
  - **Calibrated tagging efficiency** using $B \to D\,\ell\,\bar{\nu}_\ell$ decays
    - Measure branching fraction of $\mathcal{B}(\mathrm{B}^+ \to \pi^0 \ell^+ \nu_\ell)$

$$\mathcal{B}(\mathrm{B}^+ \to \pi^0 \ell^+ \nu_\ell) = (7.9 \pm 0.6 \pm 0.6) \times 10^{-5},$$

excellent agreement with world average



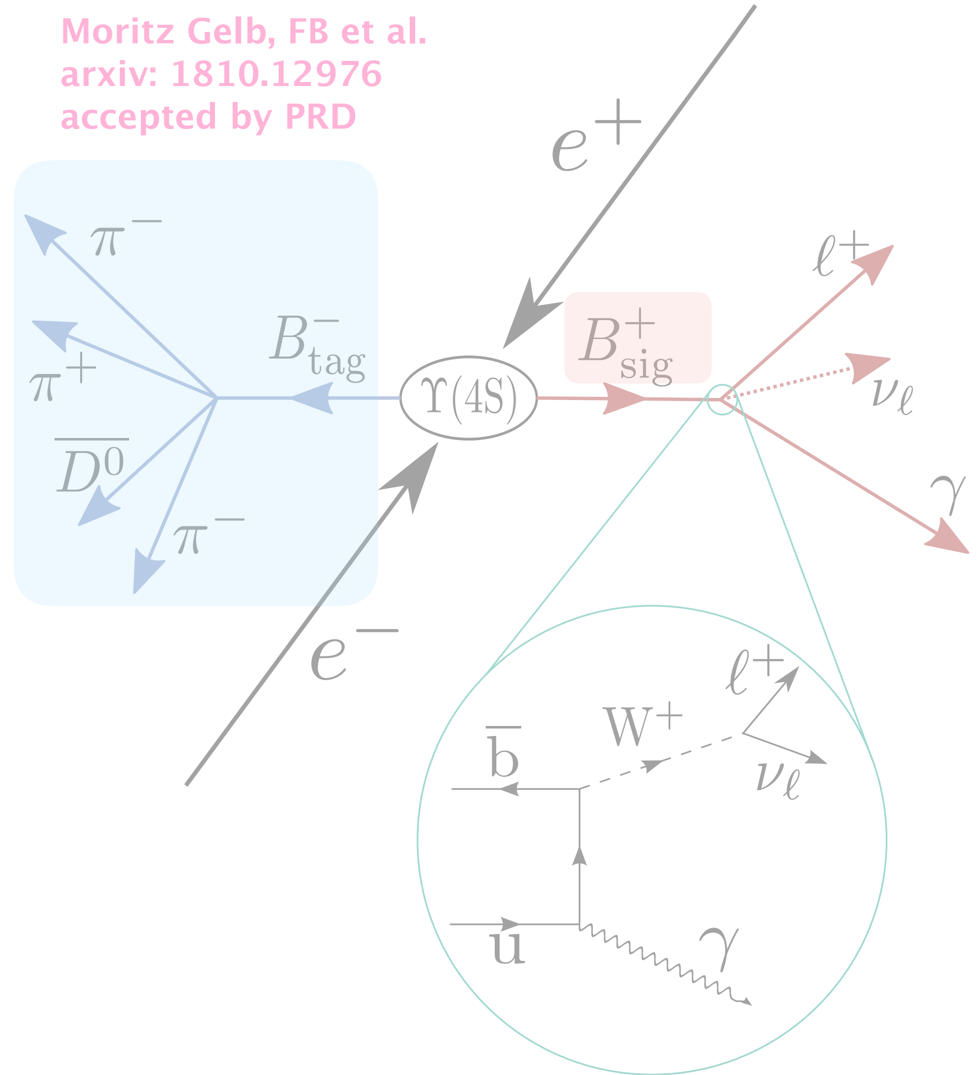
Validation using Belle data

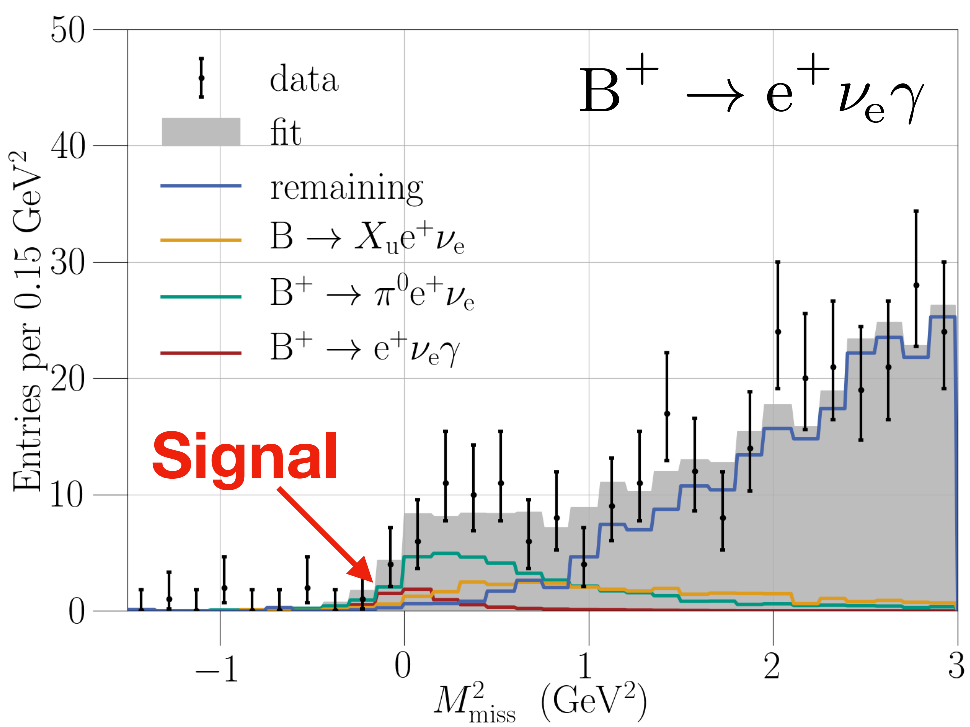
Moritz Gelb, FB et al.
arxiv: 1810.12976
accepted by PRD

- Search for rare decay of $B^+ \to \ell^+ \bar{\nu}_\ell \gamma$
  - Belle data offers **ideal testing** ground to validate the FEI <—> **3 times higher eff.**
  - **Calibrated tagging efficiency** using $B \to D \ell \bar{\nu}_\ell$ decays
    - Measure branching fraction of $\mathcal{B}(B^+ \to \pi^0 \ell^+ \nu_\ell)$

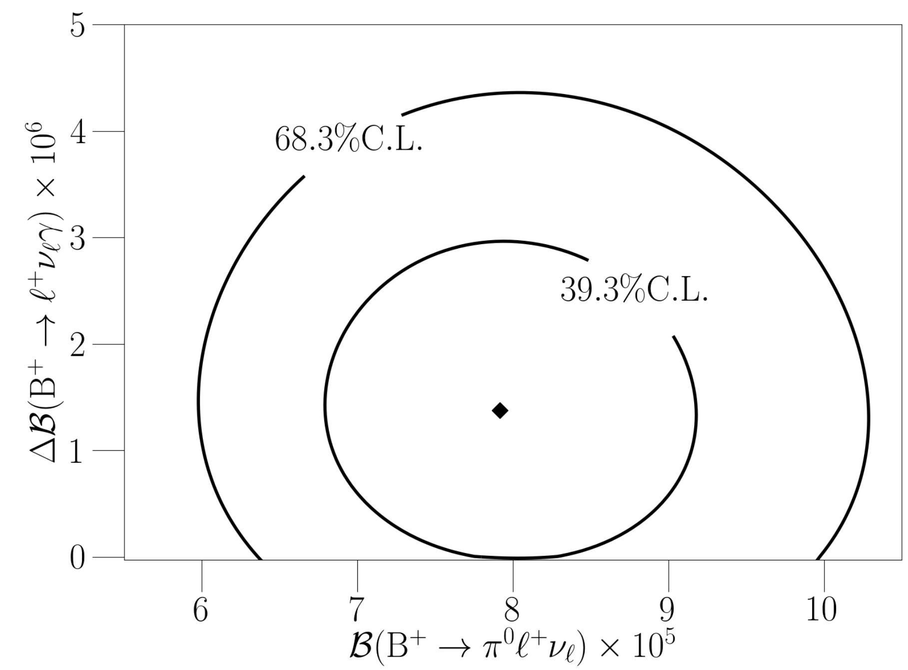
$$\mathcal{B}(B^+ \to \pi^0 \ell^+ \nu_\ell) = (7.9 \pm 0.6 \pm 0.6) \times 10^{-5},$$

excellent agreement with world average





$$\Delta\mathcal{B}(B^+ \to \ell^+ \nu_\ell \gamma) = (1.4 \pm 1.0 \pm 0.4) \times 10^{-6},$$

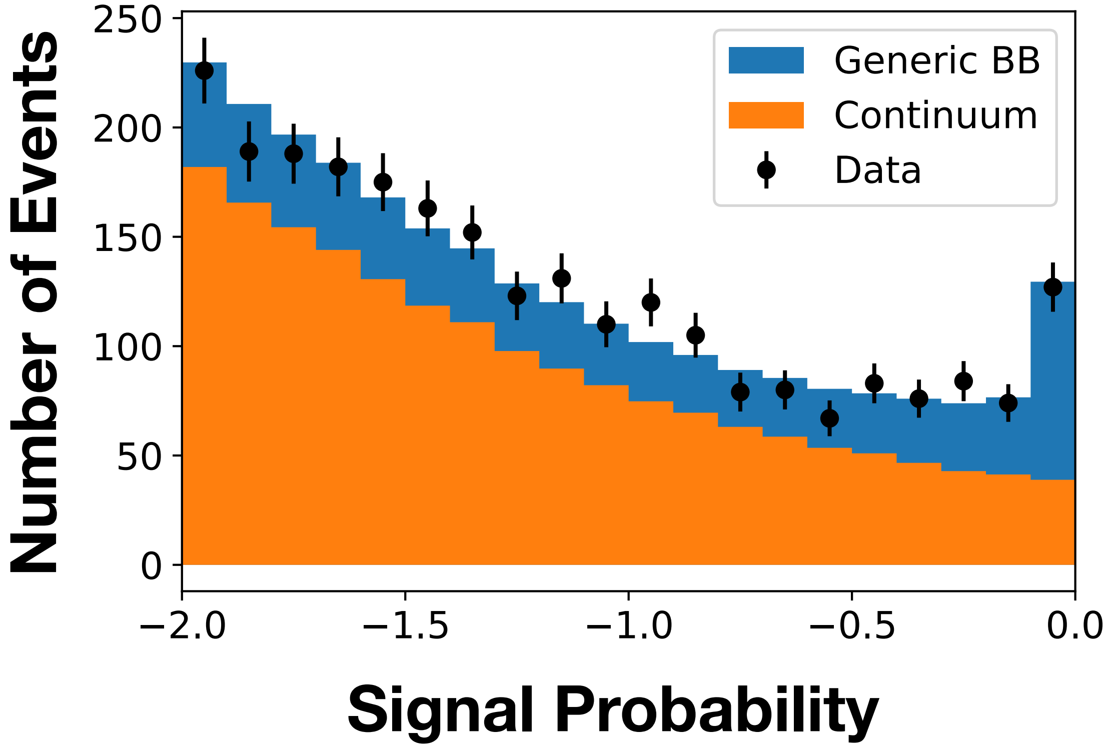


- **Upper limit:** $\Delta\mathcal{B}(B^+ \to \ell^+ \nu_\ell \gamma) < 3.0 \times 10^{-6}$ at 90% CL

Validation using Belle II data

William Sutcliffe, FB
shown at CKM 2018

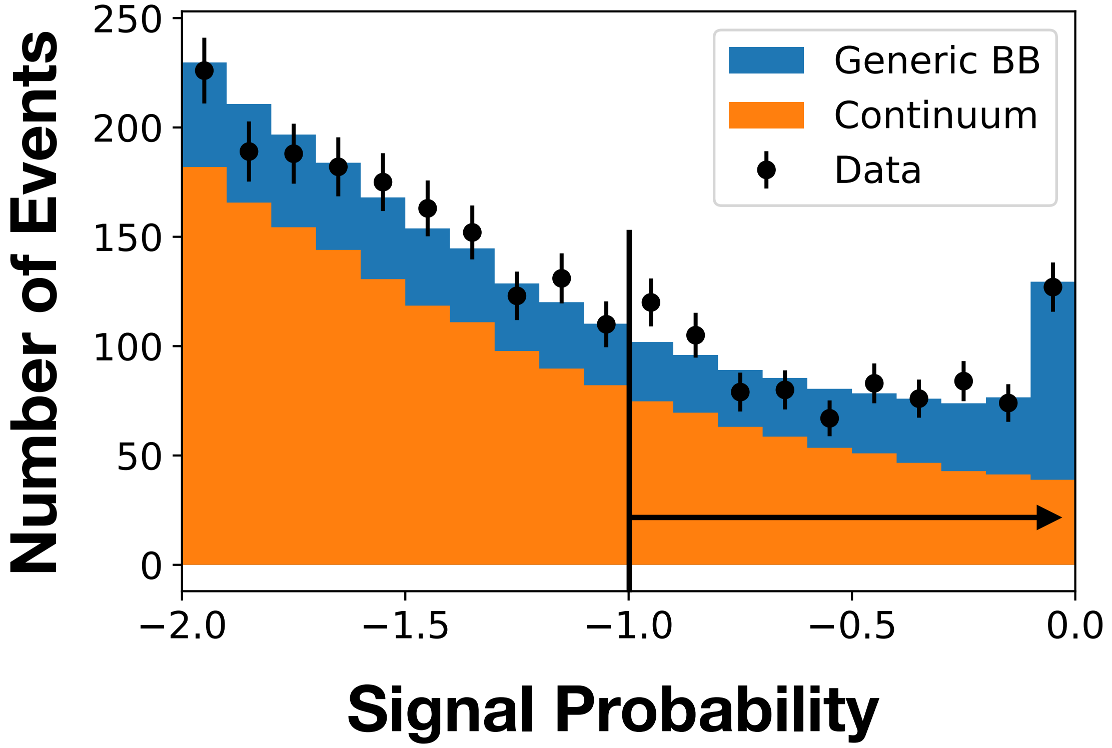
- Another great testing ground:
  - apply FEI to Belle II data and see if we can find some B mesons in hadronic modes!
- **Classifier output** of **0.5/fb** Phase II **data**
  - After applying a shape fit to generic and continuum

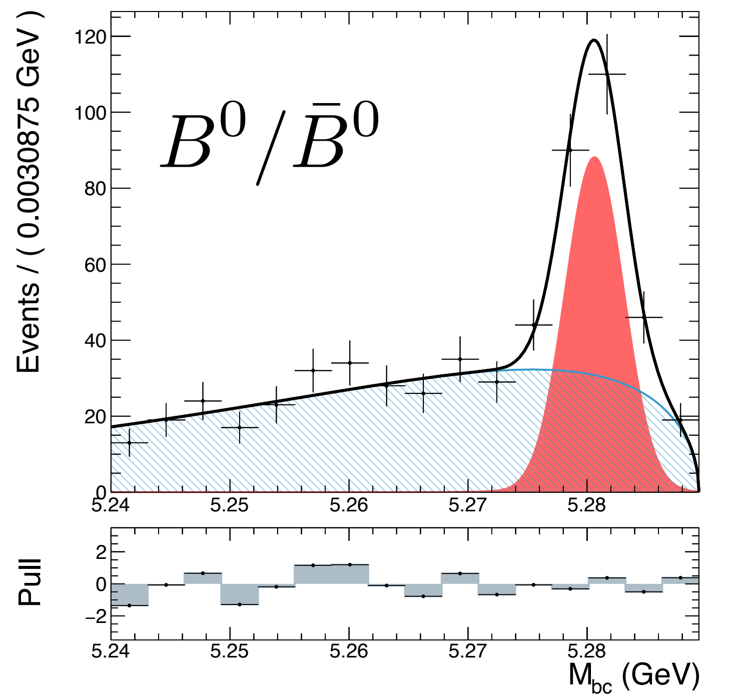


Validation using Belle II data

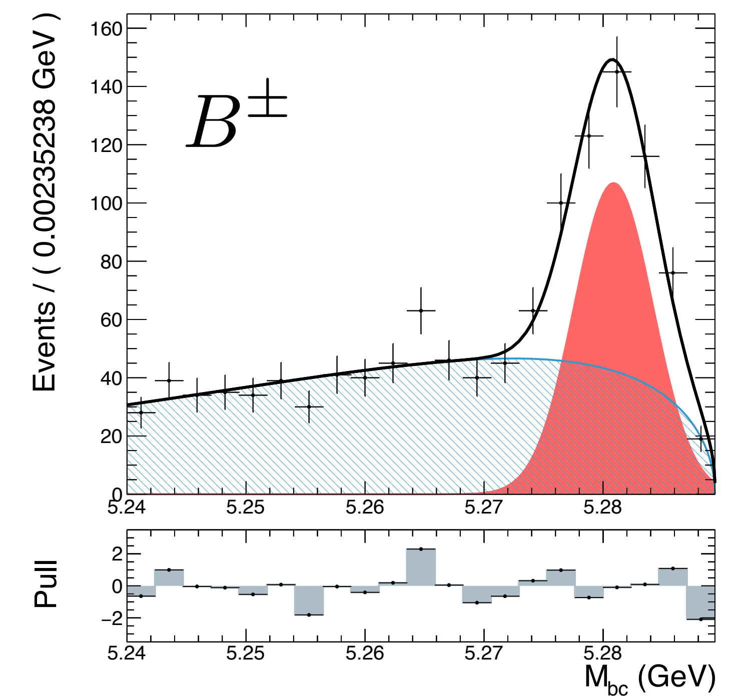
William Sutcliffe, FB
shown at CKM 2018

- Another great testing ground:
  - apply FEI to Belle II data and see if we can find some B mesons in hadronic modes!
- **Classifier output** of **0.5/fb** Phase II **data**
  - After applying a shape fit to generic and continuum



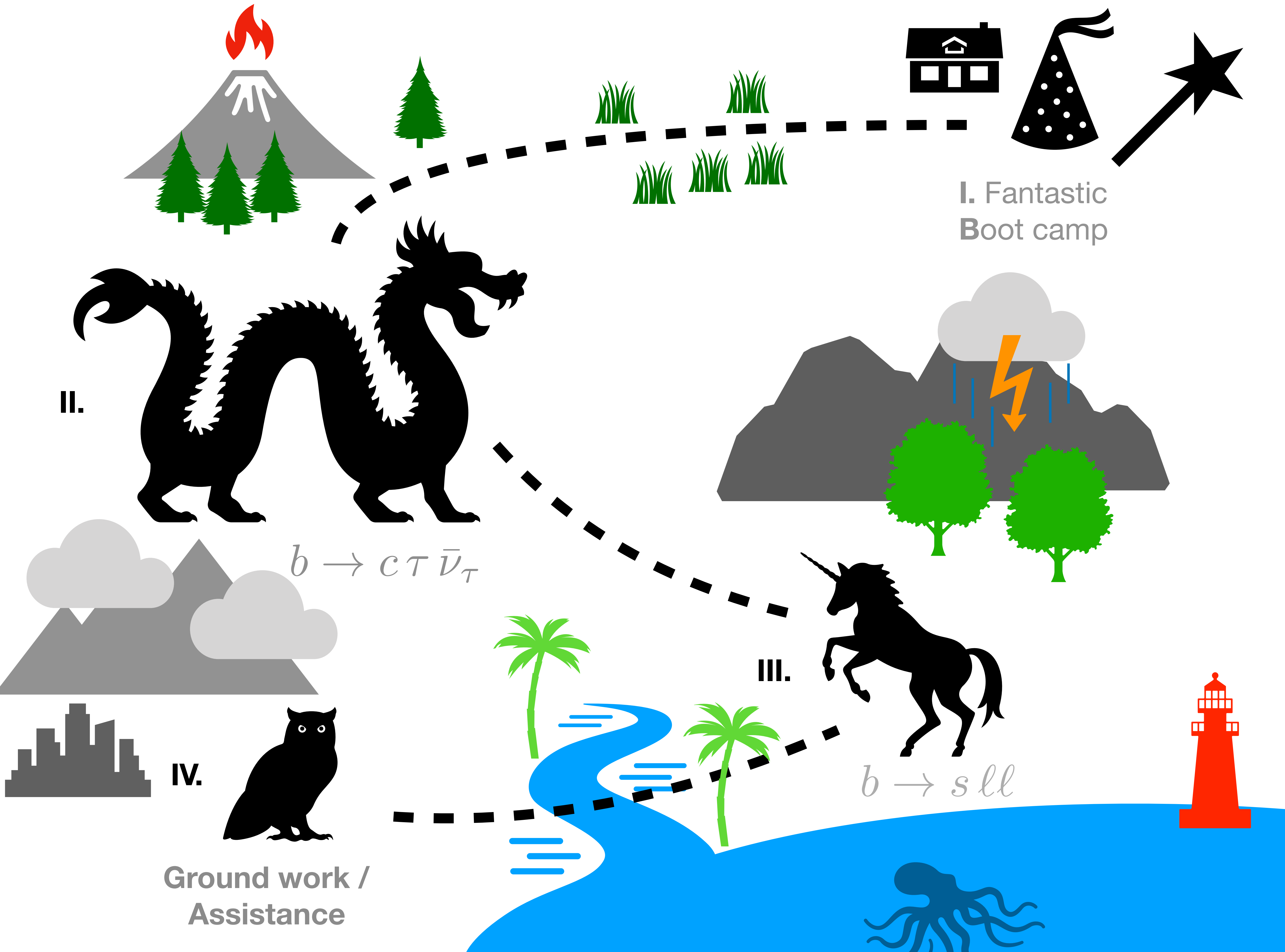


beam constrained B Meson mass

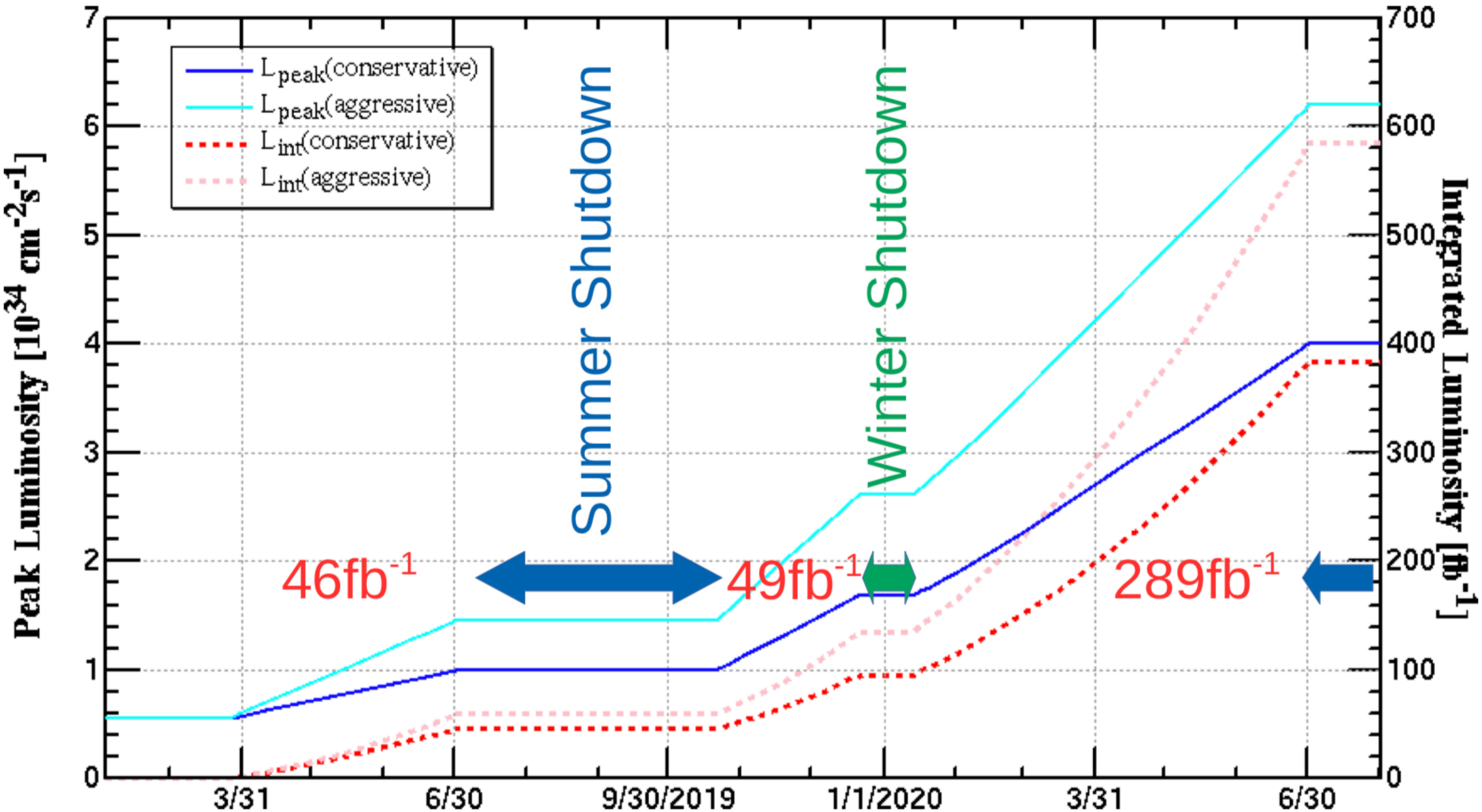


beam constrained B Meson mass

- Found **374 +/- 40** charged and **176 +/- 23** neutral B meson candidates from fitting $M_{\rm bc} = \sqrt{s/4 - |\vec{p}_B|^2}$

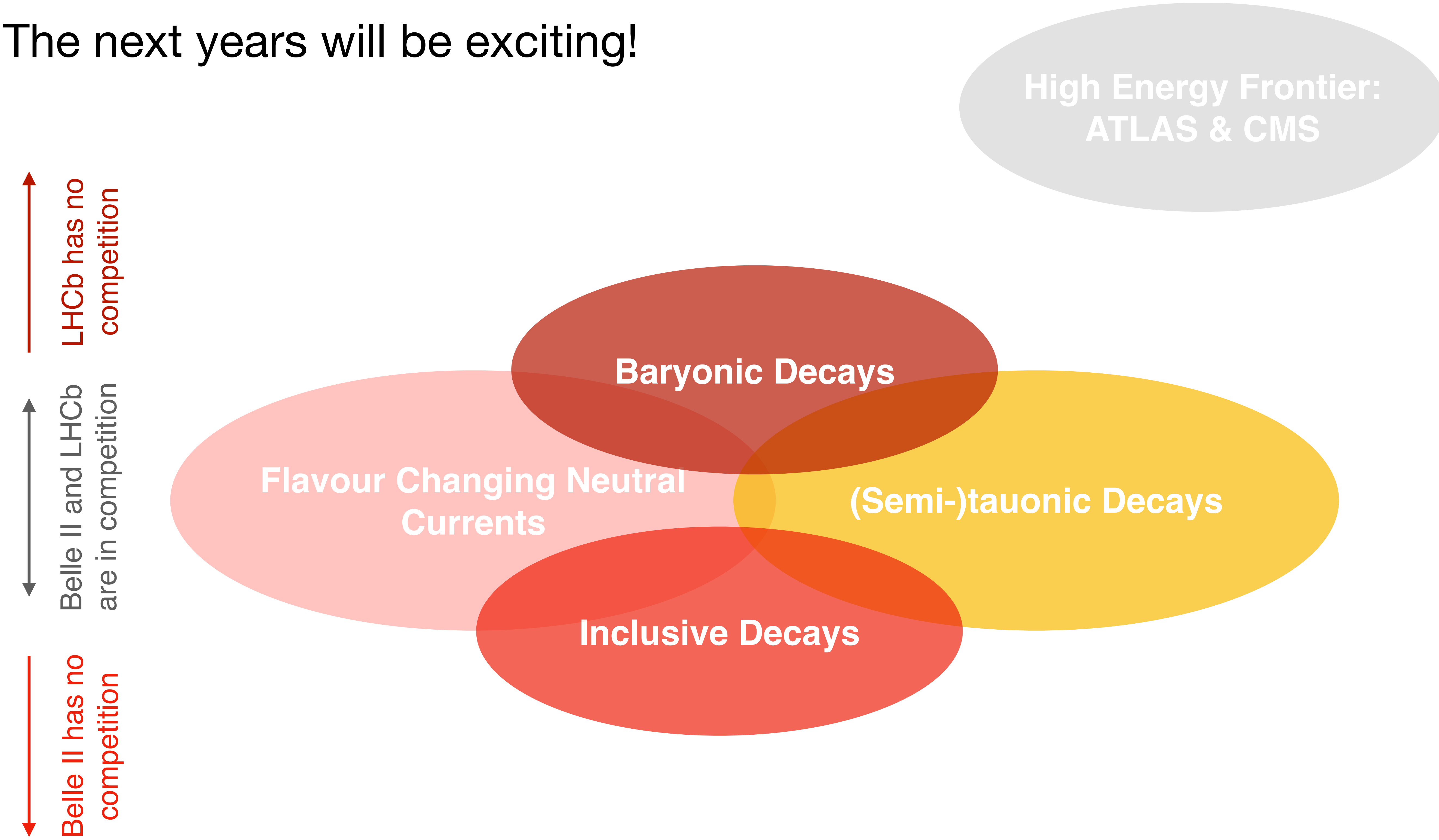

I. Fantastic
Boot camp
II.
$b \to c\,\tau\,\bar{\nu}_\tau$
III.
$b \to s\,\ell\ell$
IV.
Ground work /
Assistance

Belle II Plans 2019 and 2020: Phase III ramp-up



LHCb & Belle II: Partners in breaking out of the SM

The next years will be exciting!



Summary :

Belle II will study **many fantastic B_s** and I hope I could show you where and how we will find them!

Belle II won't operate alone: LHCb will be a formidable partner or opponent ;-)

Both experiments have unique strengths and weaknesses:

++ LHCb very rare decays with **visible final states**

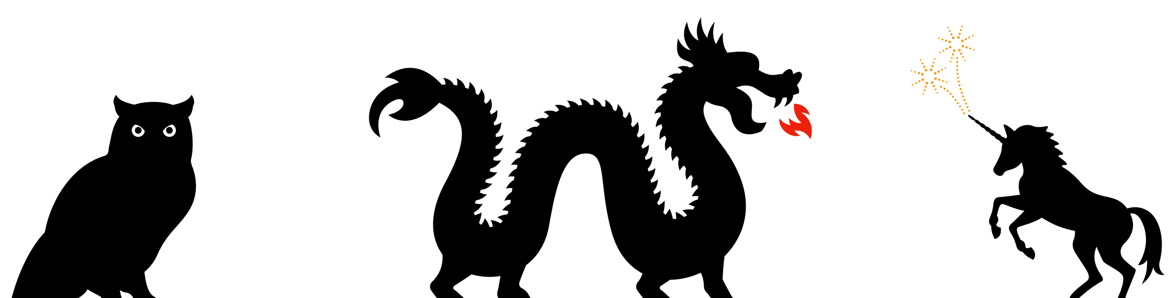
++ LHCb large sample of **Baryons with b-quarks** and **B_s mesons**

++ Belle II better detector for final states with **missing energy (hermetic design)**

++ Belle II complementary measurements using **inclusive decays**

Preparatory work crucial; without it no competitive measurements!

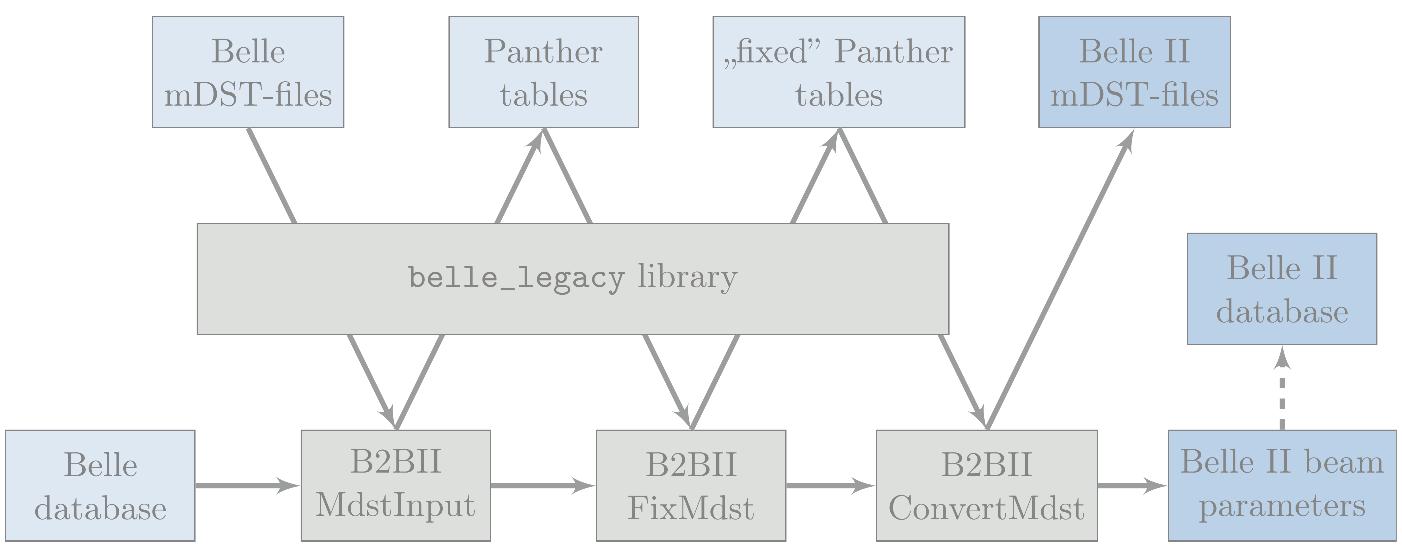
Next year and the years to come will be exciting!

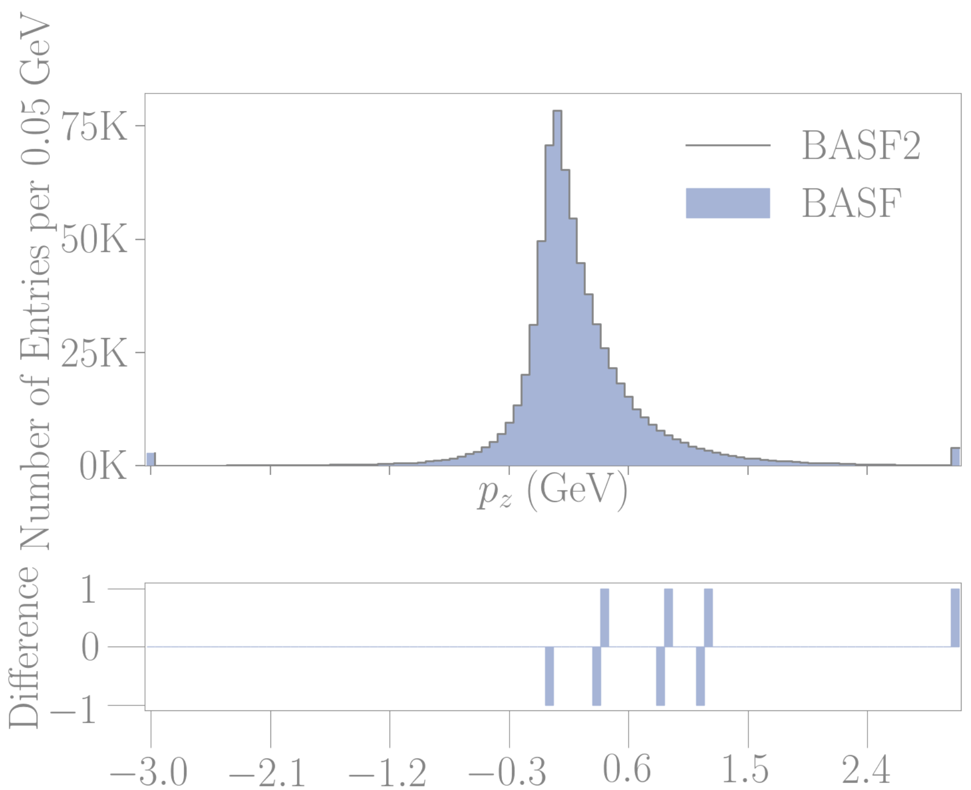


More Information

- Imagine you build a new experiment, but you have plenty of similar data lying around from a previous run.
  - But computing system completely changed; but old data invaluable tool to train PhD students and Postdoc
- B2BII: Belle to Belle II conversions made easy
  - Converts Belle files into Belle II format

Conversion flow



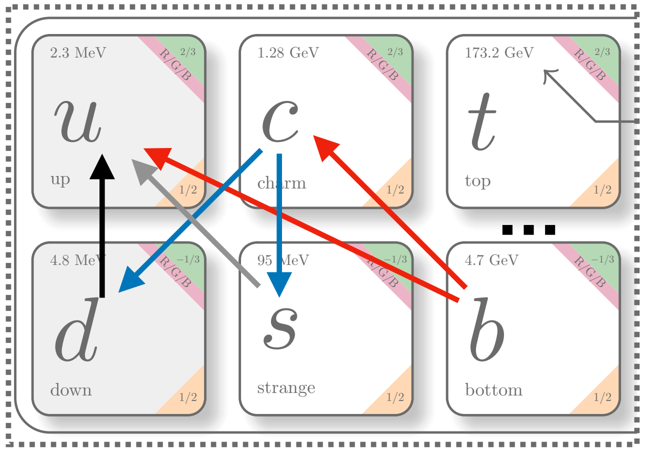


p_z of charged tracks

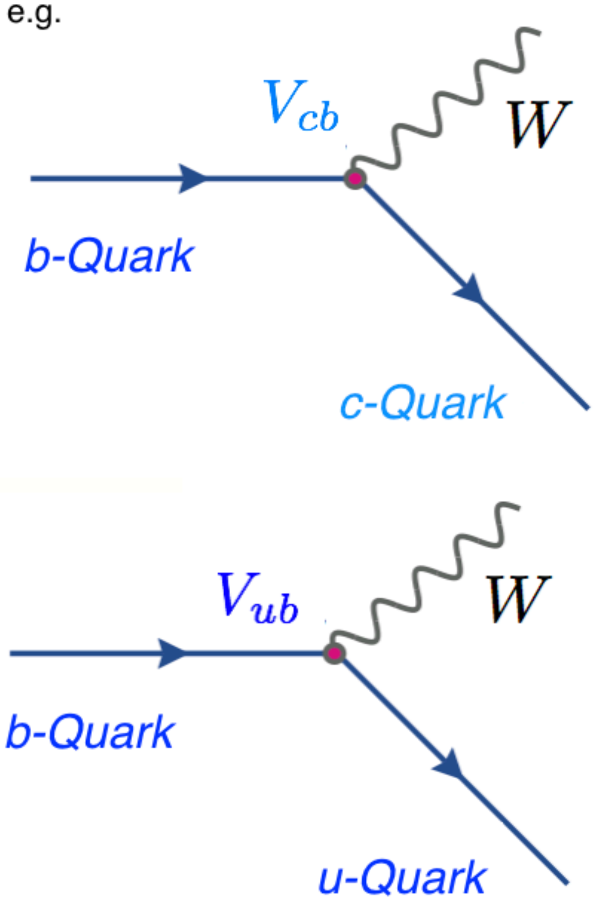
Weak decays and the CKM-Matrix

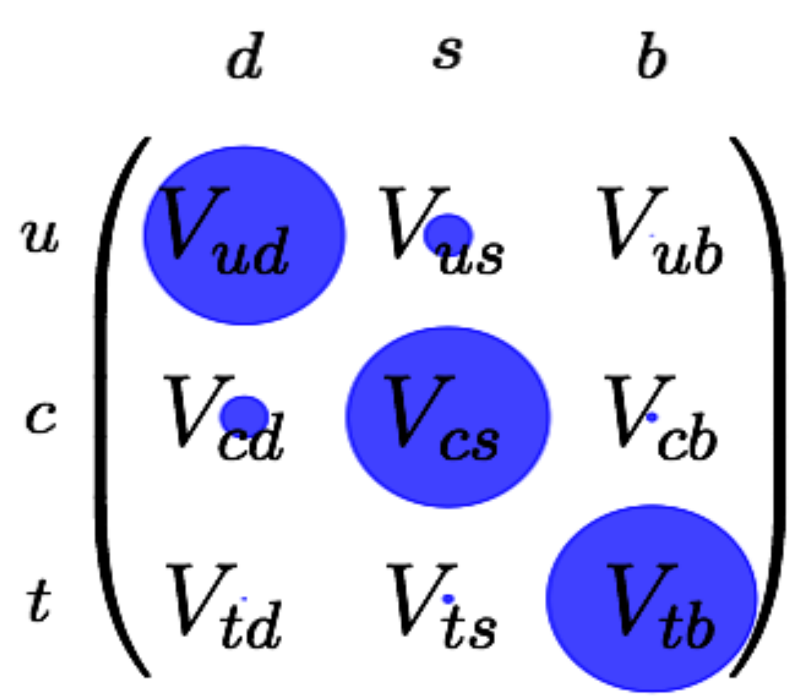
- Interaction eigenstates ≠ mass eigenstates
  - Direct consequence of massive quarks in the SM

$$\mathcal{L}_{W^\pm \text{ quark int.}} = \frac{g_2}{\sqrt{2}} W_\mu^+ \, \bar{u}'_L \, \gamma^\mu \, V_{\text{CKM}} \, d'_L + \text{h.c.} \, ,$$



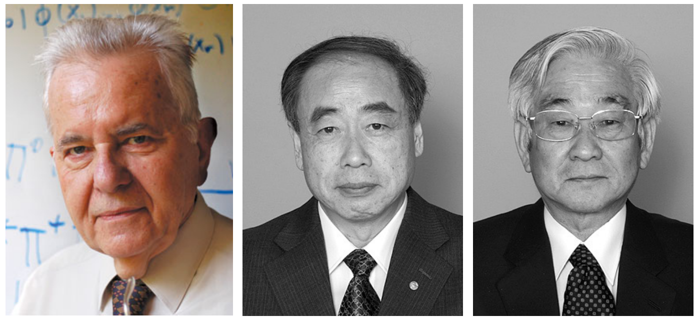
e.g.





CKM Matrix

SM: unitarity 3x3 matrix



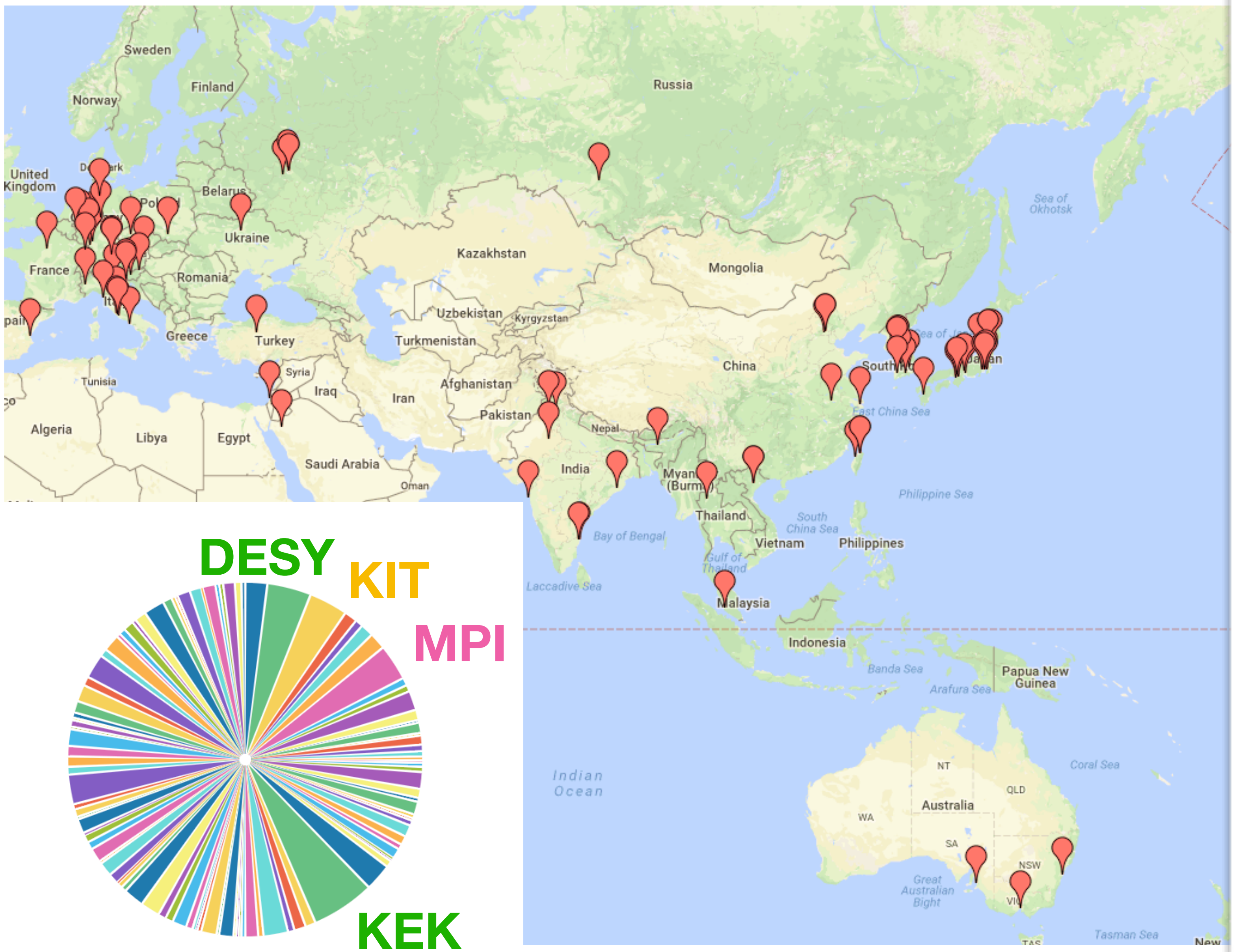
Cabibbo Kobayashi Maskawa

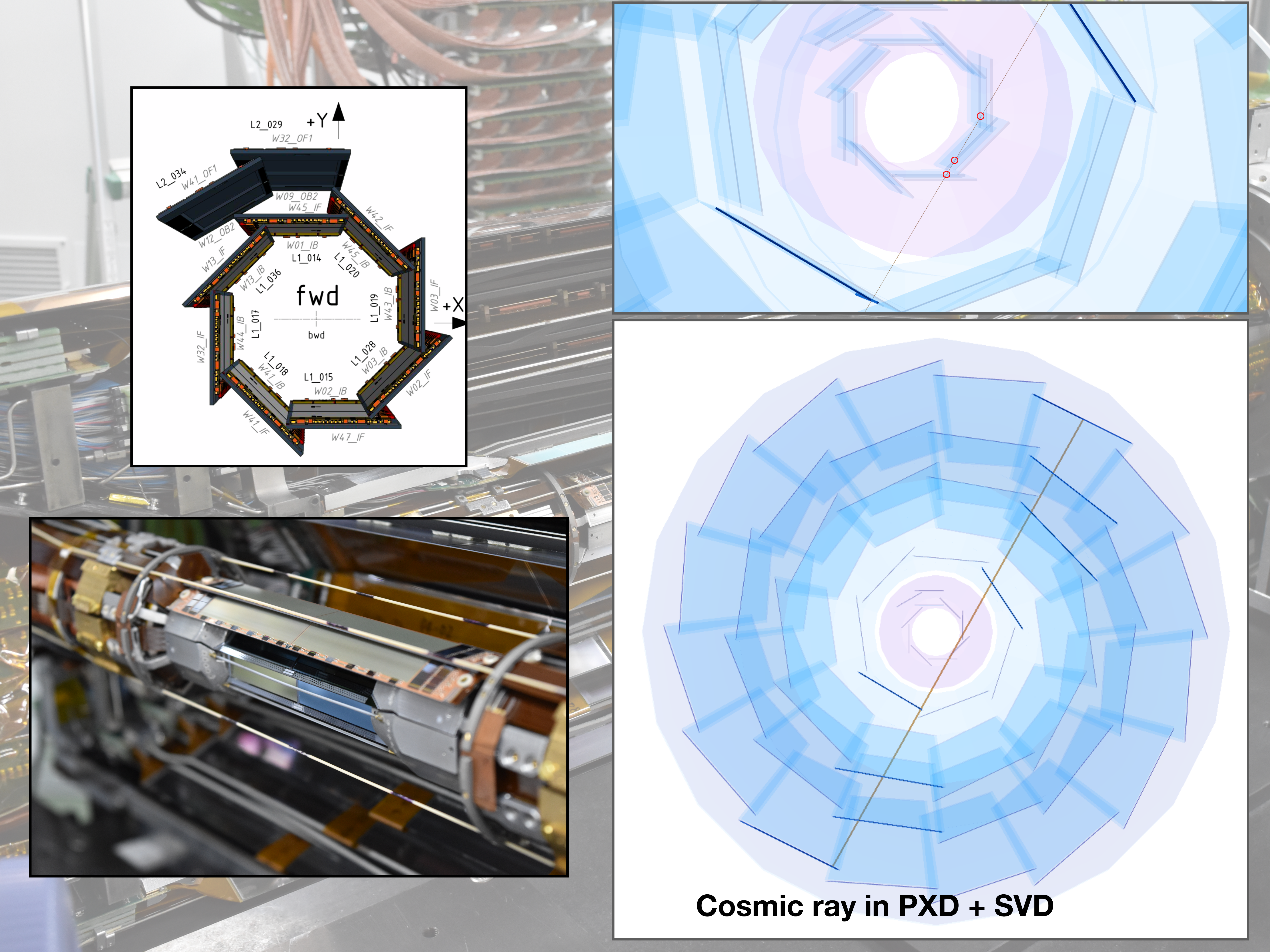
Completely determined through **4 parameters**
(3 mixing angles and 1 CP-violating phase)

A next-generation Super-B-Factory in the making

Belle II

850 Physicists
109 Institutes
25 countries

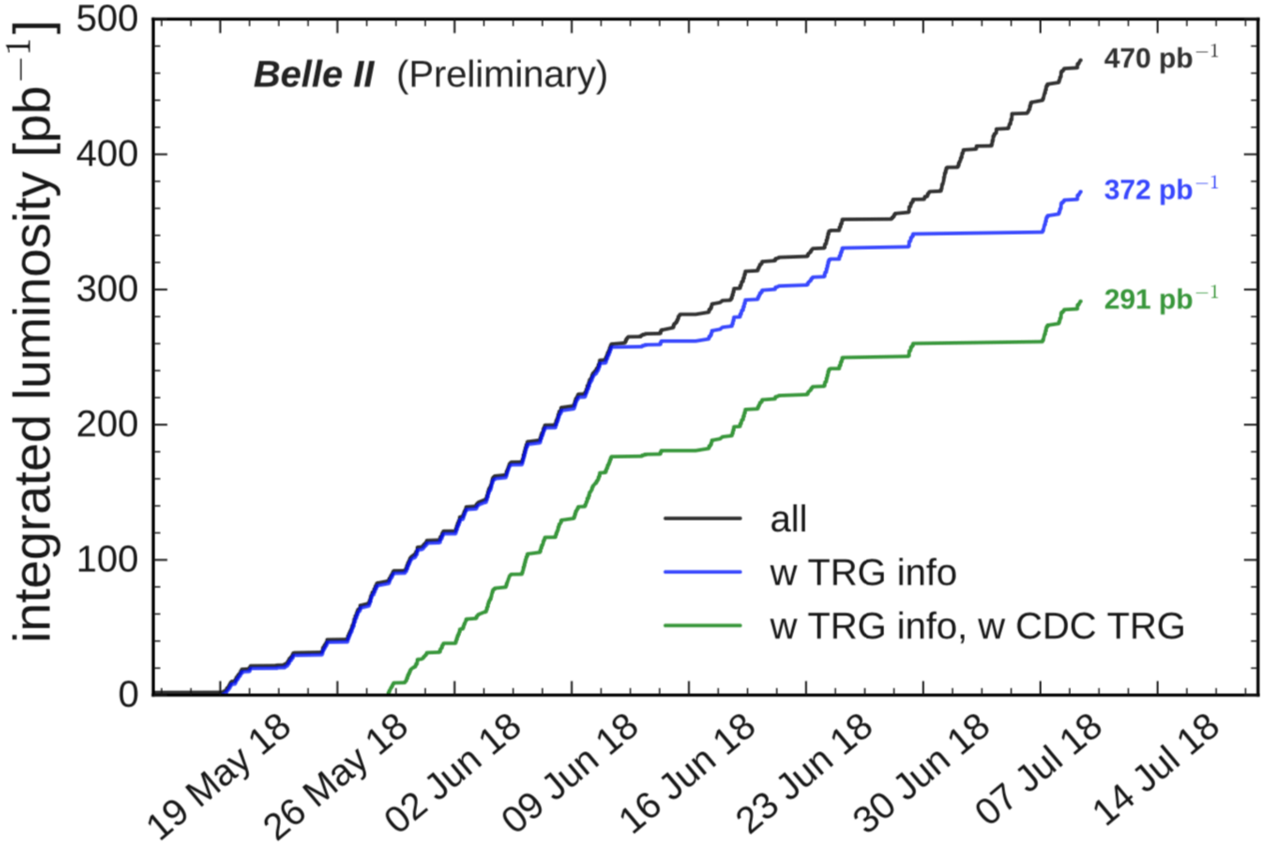


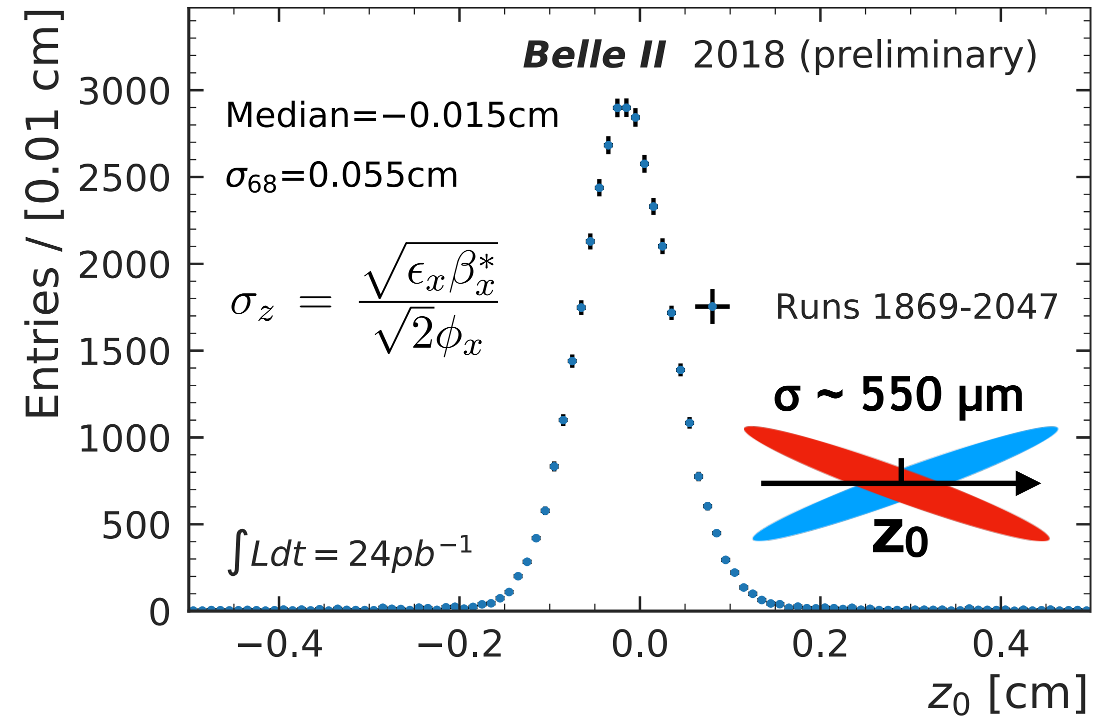

L2_029
W32_OF1
+Y
L2_034
W41_OF1
W09_OB2
W45_IF
W42_IF
W12_OB2
W13_IF
W01_IB
L1_014
W45_IB
L1_020
W13_IB
L1_036
fwd
bwd
L1_019
W43_IB
W03_IF
+X
W32_IF
W44_IB
L1_017
L1_018
W41_IB
L1_015
W02_IB
L1_028
W03_IB
W02_IF
W41_IF
W47_IF
Cosmic ray in PXD + SVD

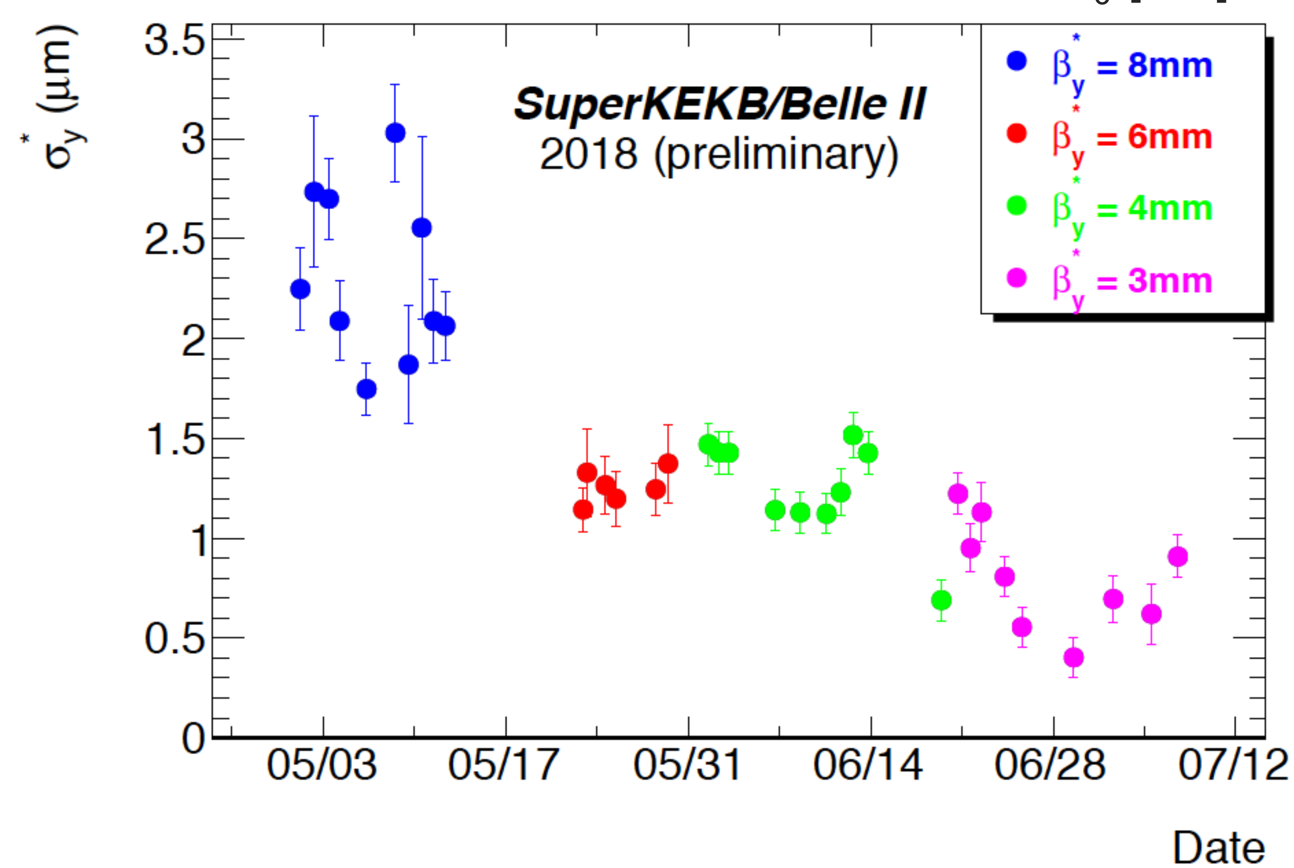
Phase II Luminosity

$\epsilon_x = 4 \times 10^{-6}$ mm, $\beta_x^* = 200$ mm,

Goals of Phase II:
- **Verification** of **nano-beam scheme**
- Achieve **inst. Luminosity** of ***O*(10^{34} cm^{-2}s^{-1})**



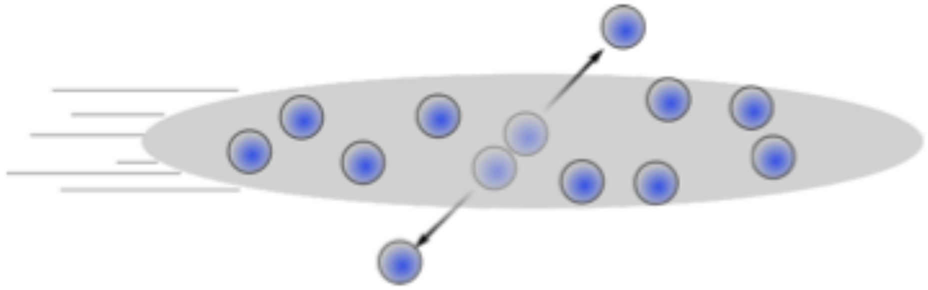




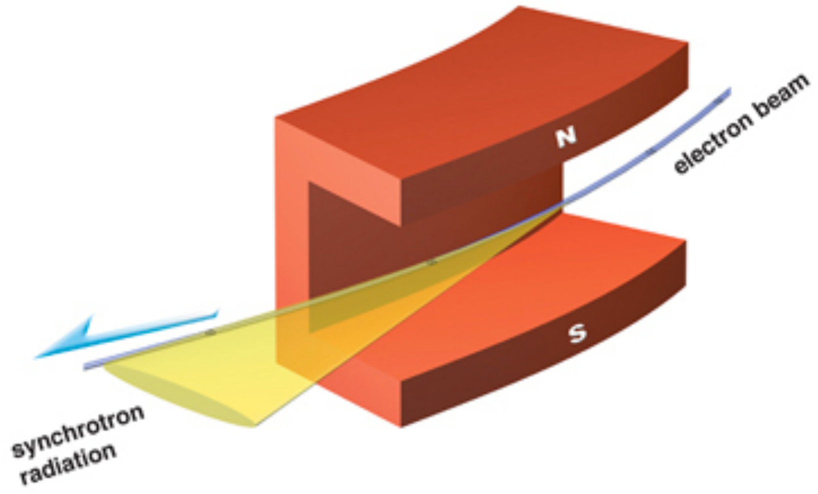
- **Peak** Luminosity**: 5.5 x 10^{33} cm^{-2} s^{-1}**
- **β^*_y = 3 mm; σ^*_y~ 333 nm** (**Goal β^*_y = 0.3 mm**)

Beam Backgrounds

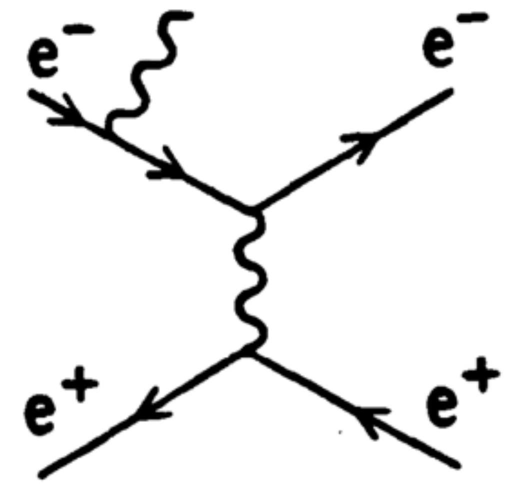
Touschek Scattering



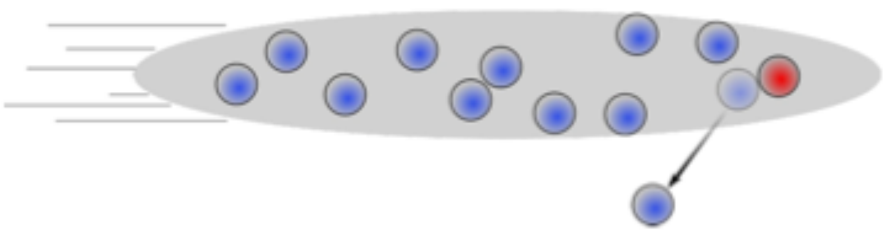
Synchrotron Radiation



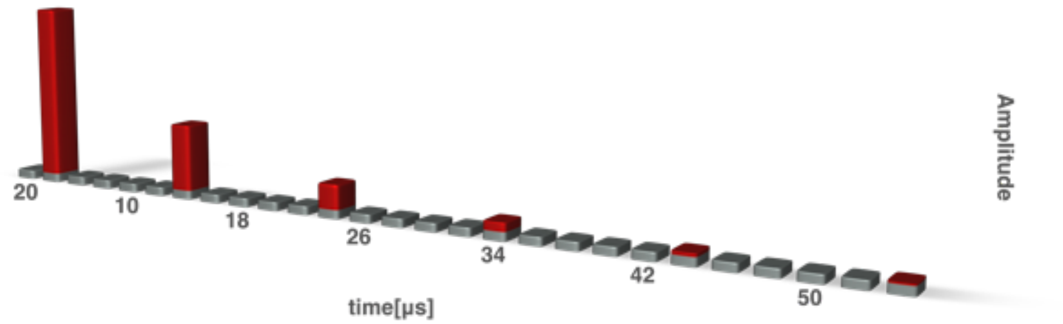
Radiative Bhabha



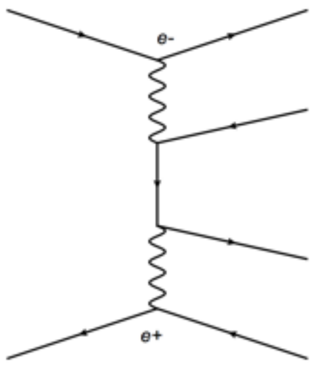
Beam-gas



Injection Background



Two photon process



Machine Parameters

To achieve the necessary sensitivity to further push the intensity frontier, the instantaneous luminosity needed to increase from **2.1×10^{34} cm^{-2} s^{-1} to 8×10^{35} cm^{-2} s^{-1}**

The key to this is a beam-configuration called the **nano-beam scheme** that squeeze the beam to have a very small vertical spot size of about 50 nm

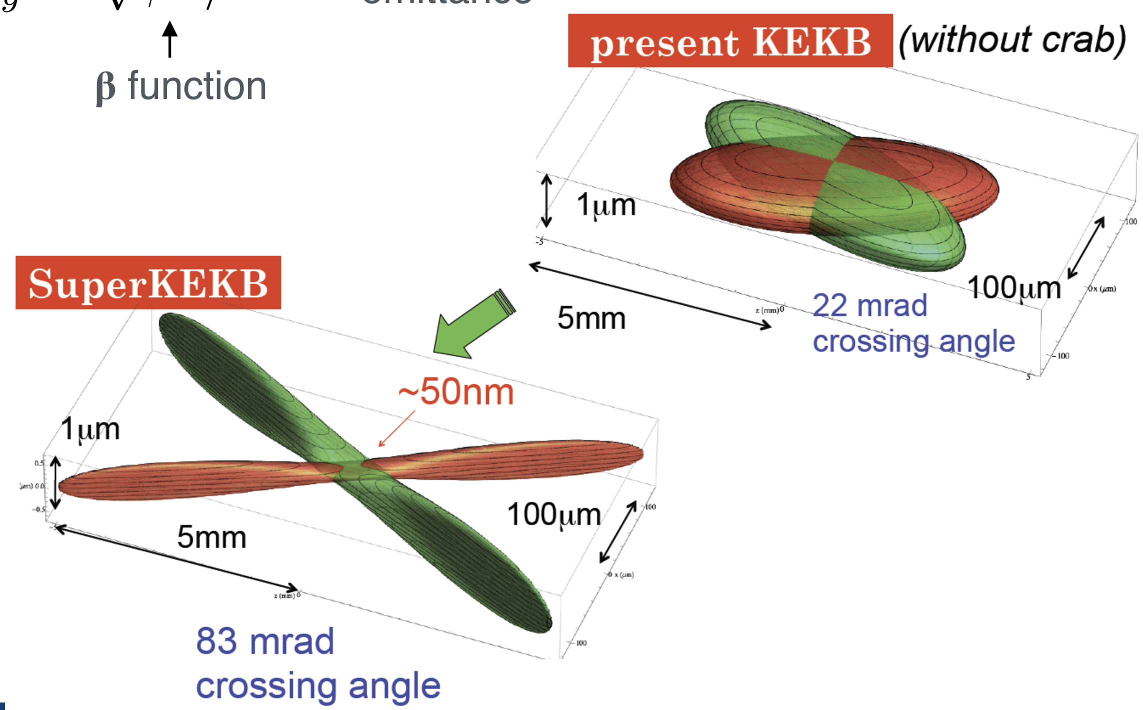
LER / HER	KEKB	SuperKEKB
Energy [GeV]	3.5 / 8	4.0 / 7.0
β_y^* [mm]	5.9 / 5.9	**0.27 / 0.30**
β_x^* [mm]	1200	**32 / 25**
$I_\pm$ [A]	1.64 / 1.19	**3.6 / 2.6**
$\zeta_{\pm y}$	0.129 / 0.09	**0.09 / 0.09**
ε [nm]	18 / 24	**3.2 / 4.6**
# of bunches	1584	2500
Luminosity [10^{34} cm^{-2} s^{-1}]	2,1	80

$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \zeta_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

Lorentz factor; beam current; beam-beam parameter; beam size aspect ratio; vertical β function; geometric factors

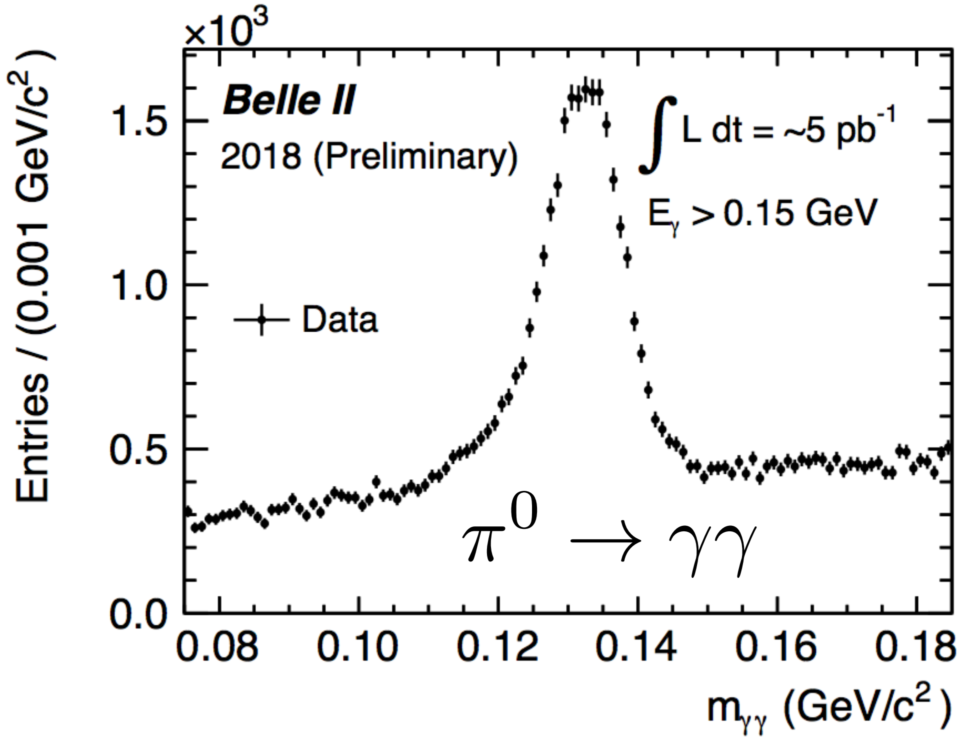
$$\zeta_{\pm y} \sim \sqrt{\beta^*/\epsilon}$$

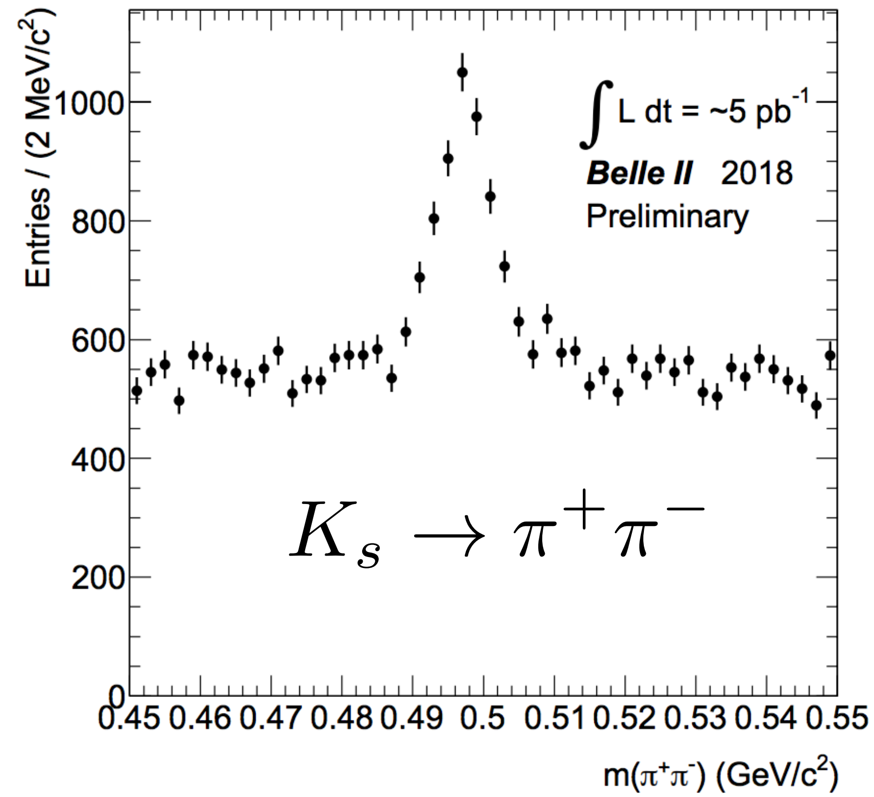
← emittance; ↑ β function

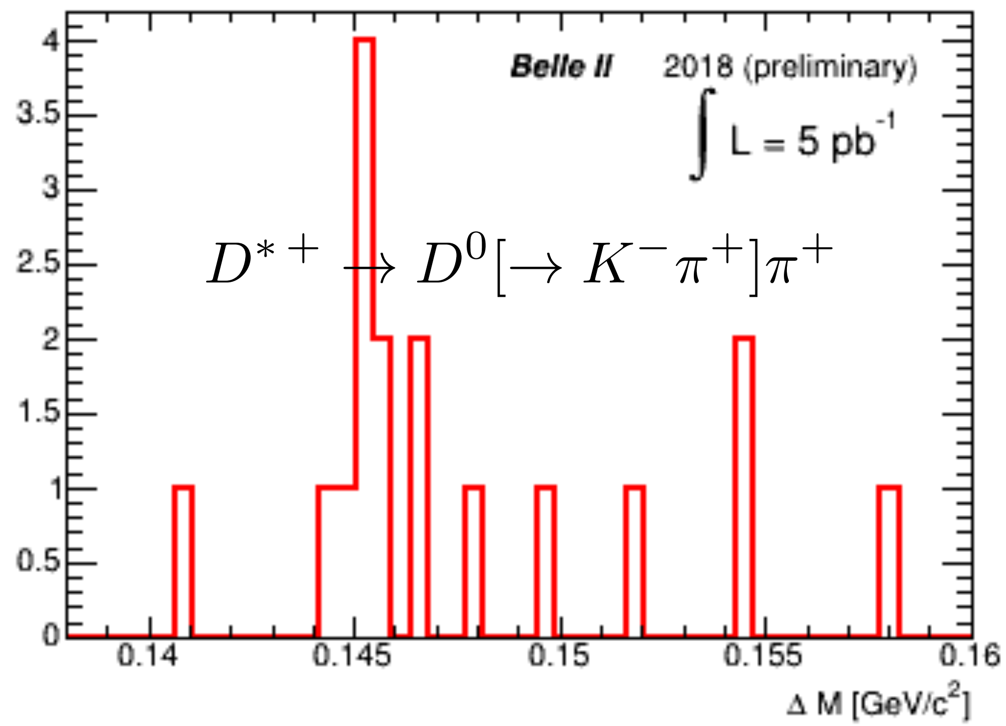


Major upgrade of existing accelerator needed

More Phase II “rediscovery plots”

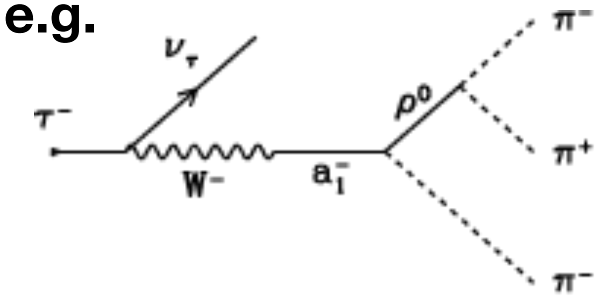




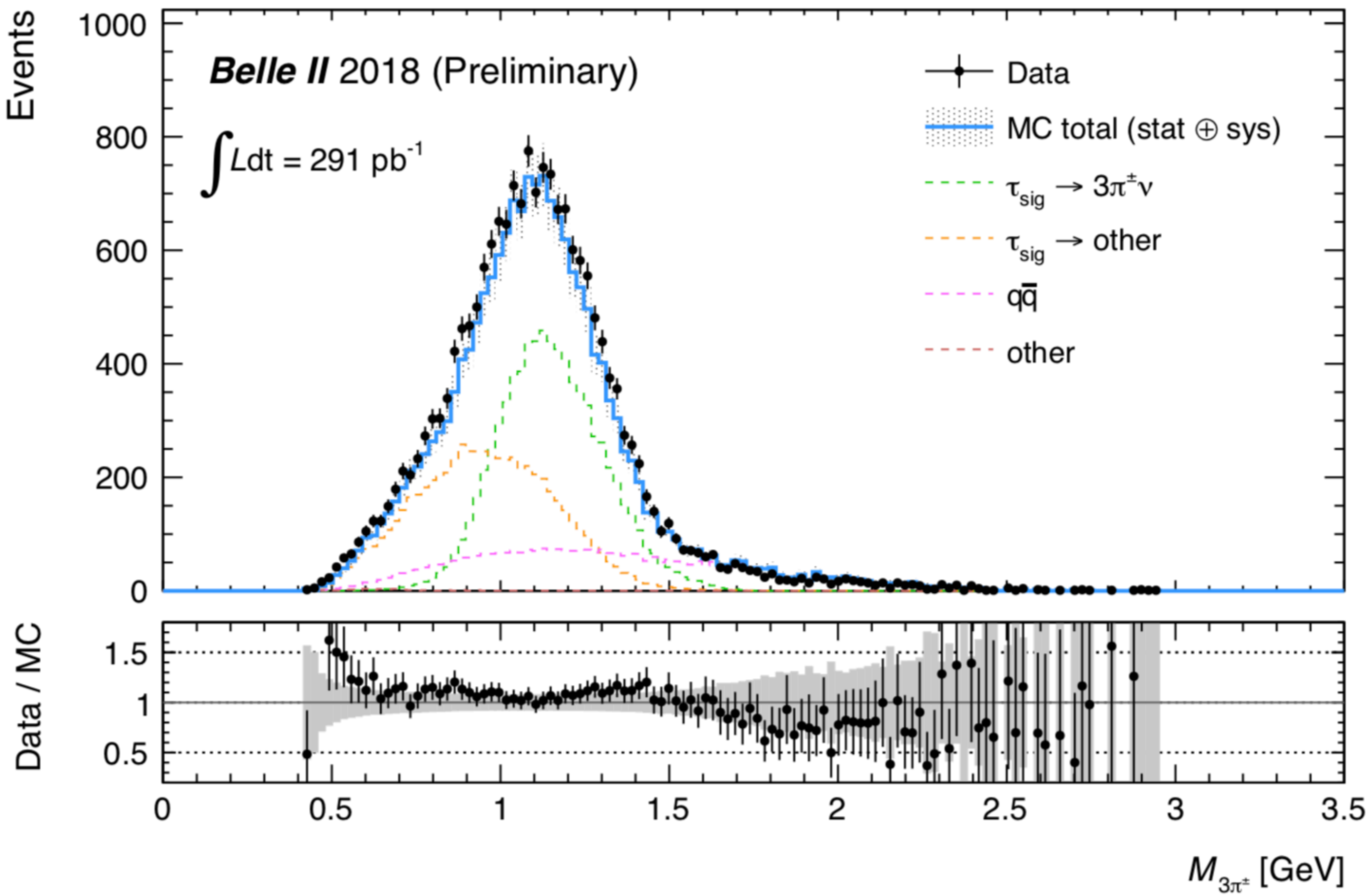


$$\Delta M = m_{D^{*+}} - m_{D^0}$$

Tau-Pair production

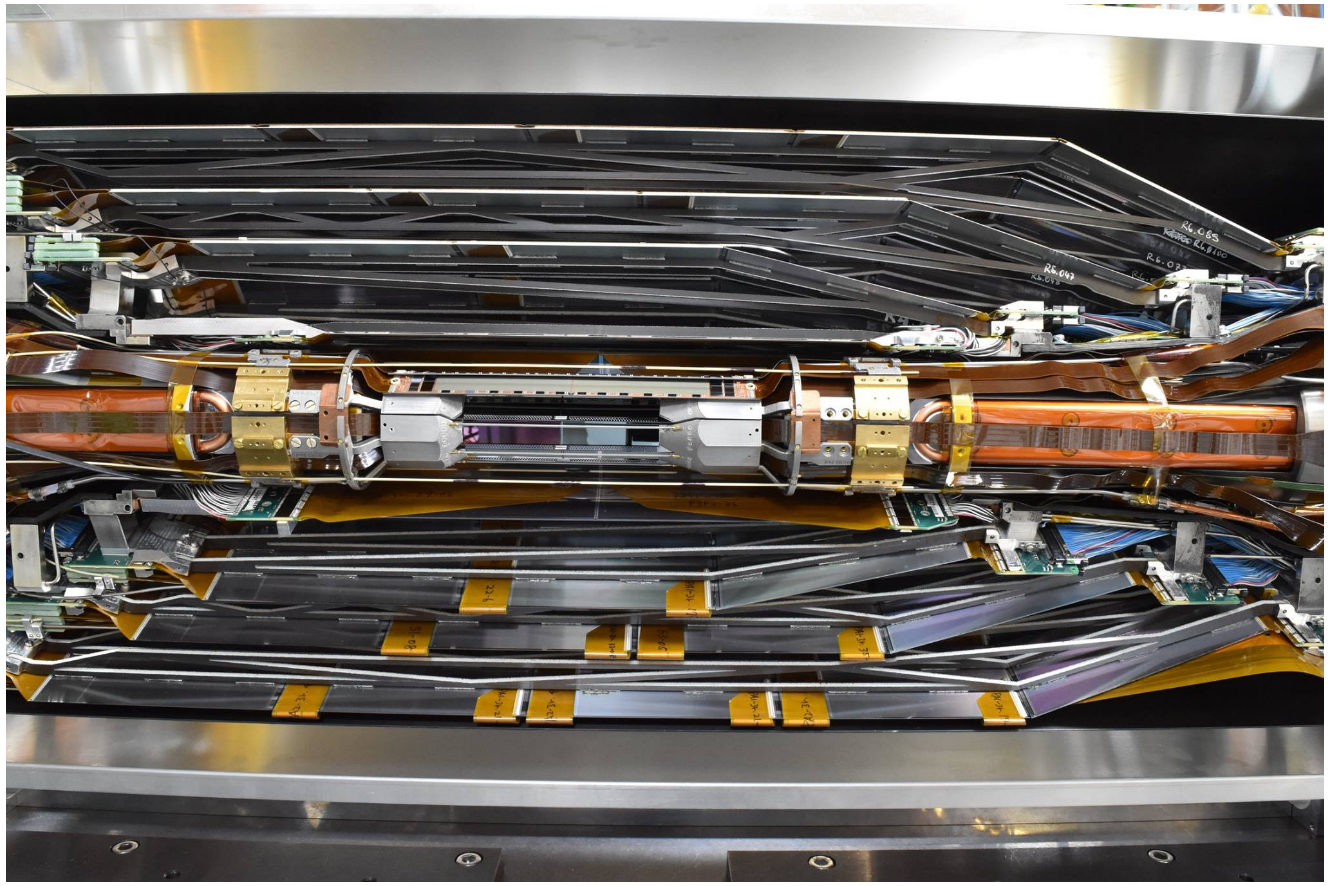


$$e^+ e^- \to \tau^+ \tau^-$$

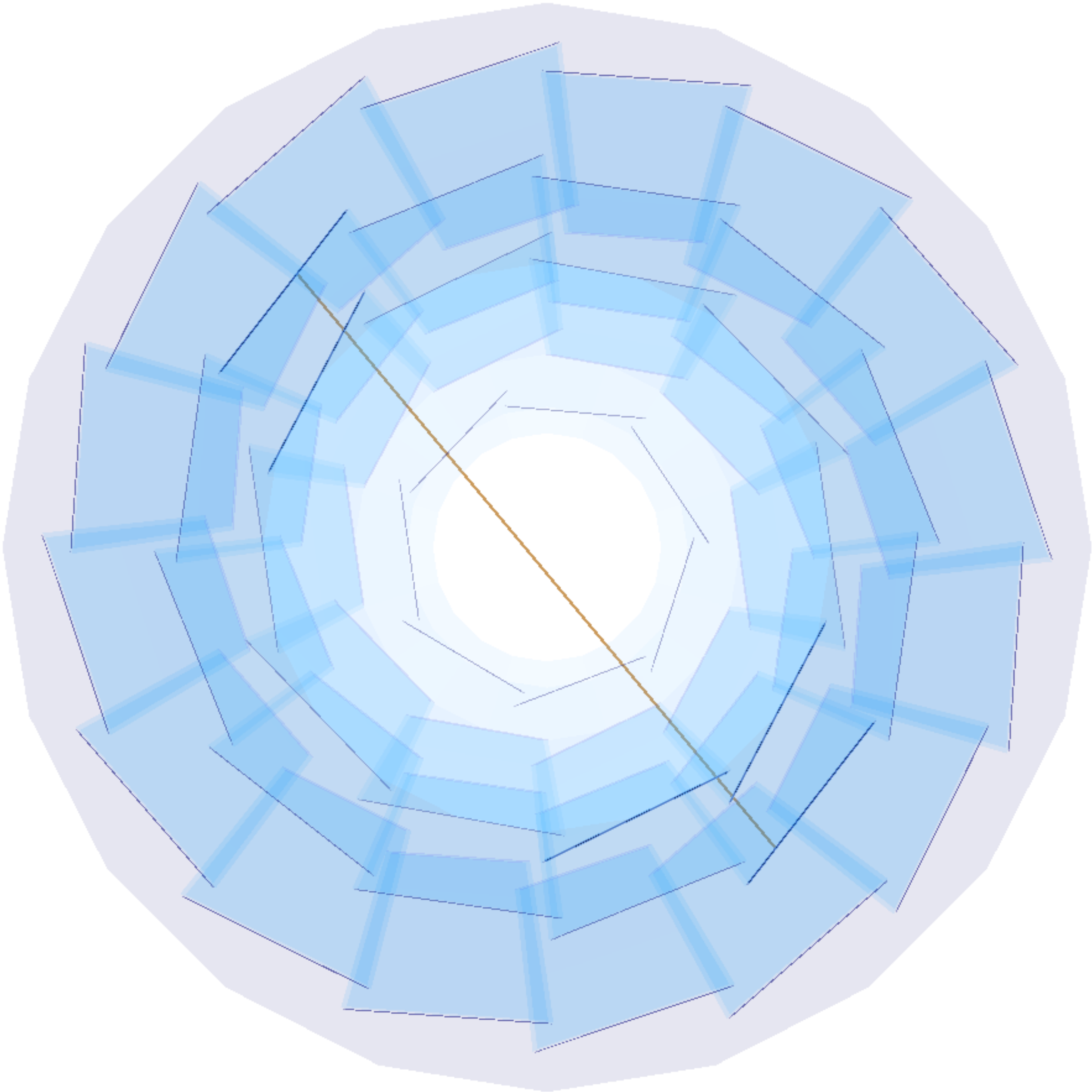


News from the Vertex detector

First recorded cosmic event



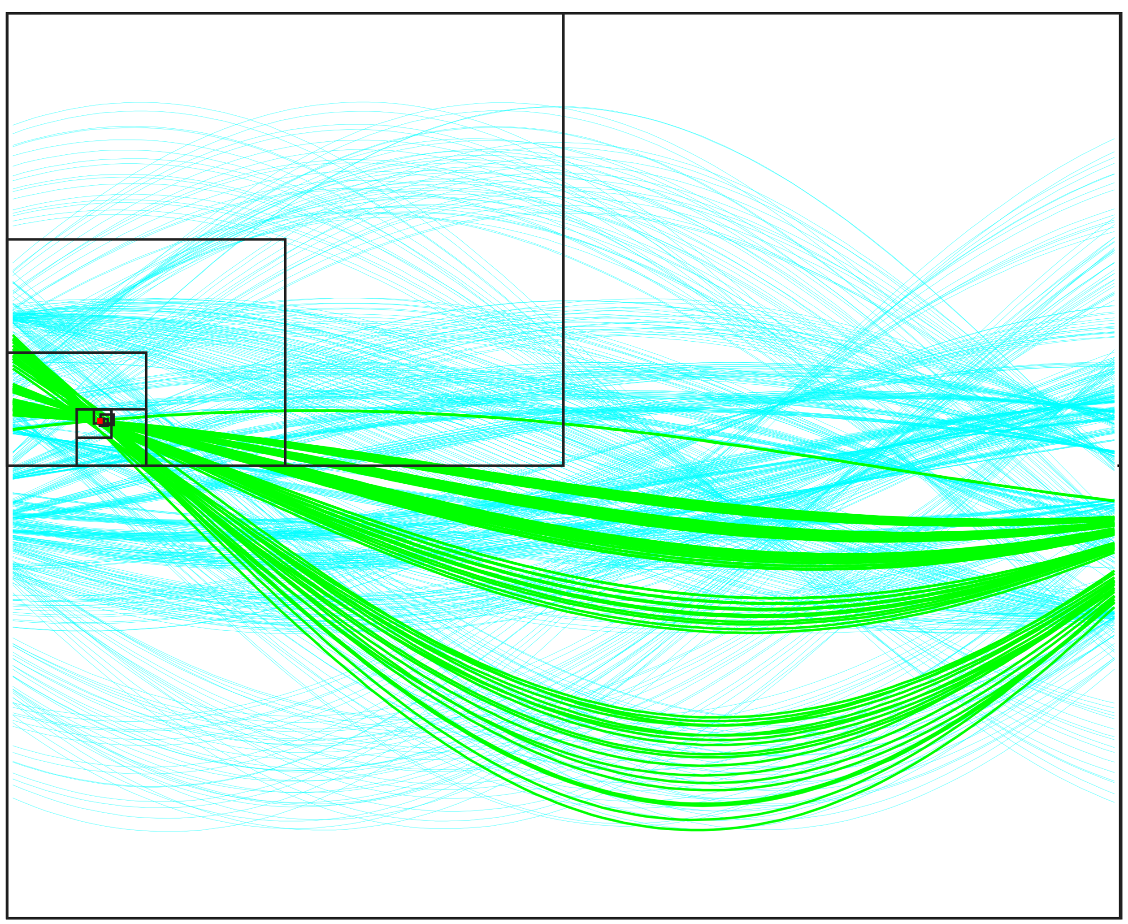
Strip-detector (4 layers) half-shells
successfully assembled and merged

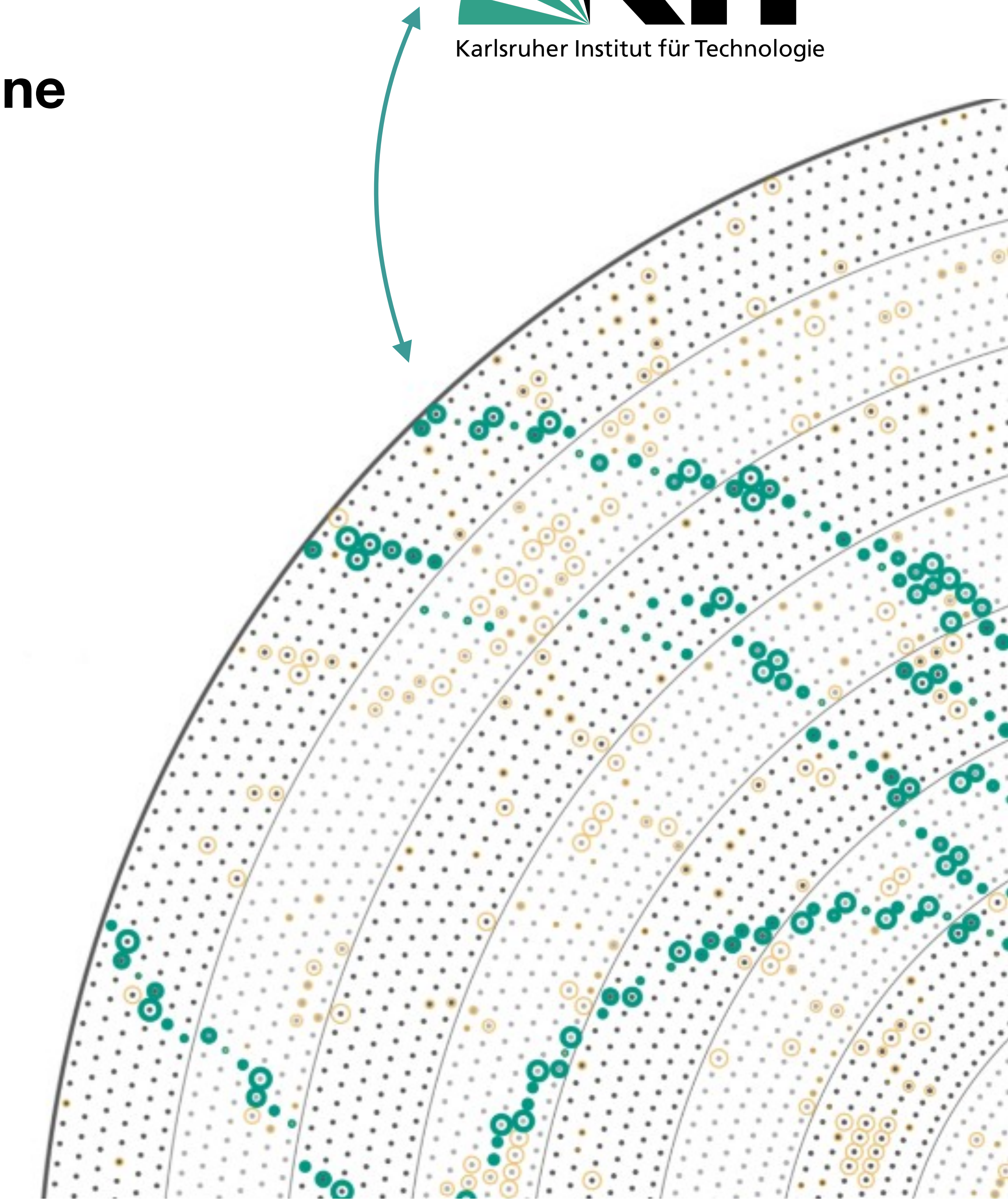


Tracking details

Karlsruher Institut für Technologie

- Newer, larger wire drift chamber. Improvements from Belle
- High luminosity: **40% of wire hits** from **machine background**.
    - **Multivariate methods used to suppress**
- **Legendre based** tracking for wire chamber.

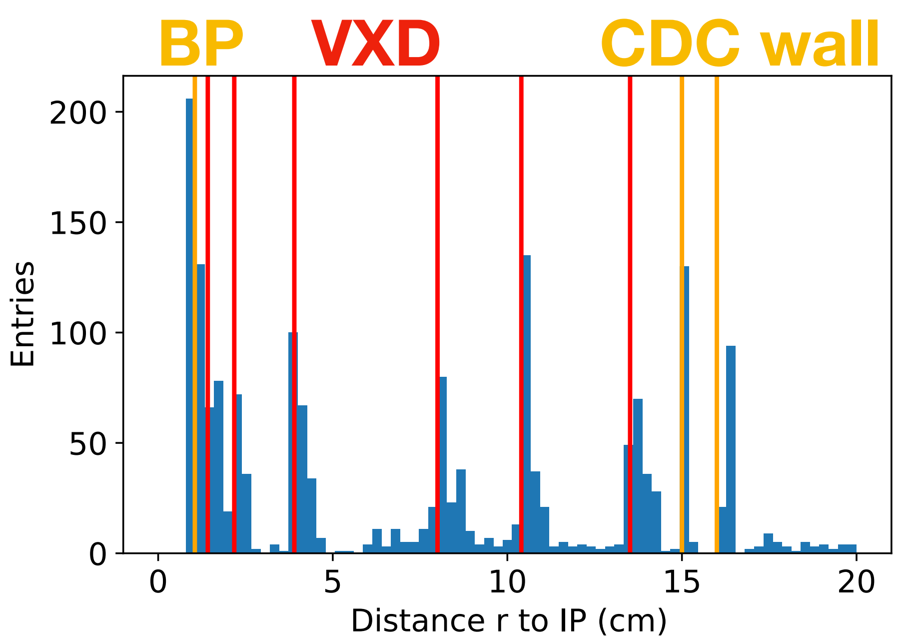


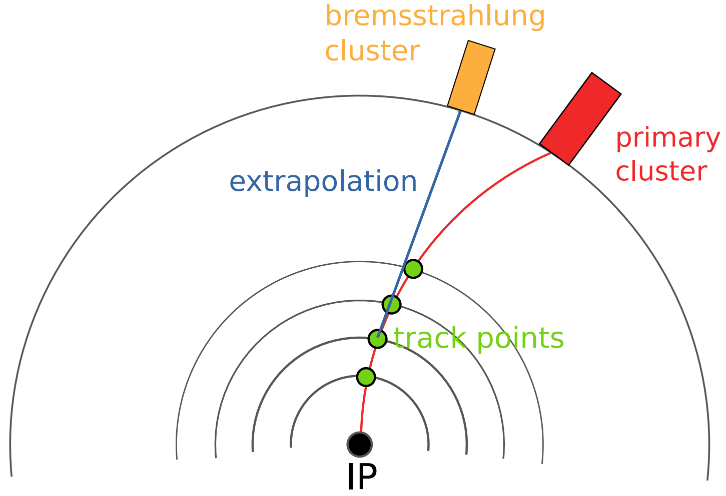


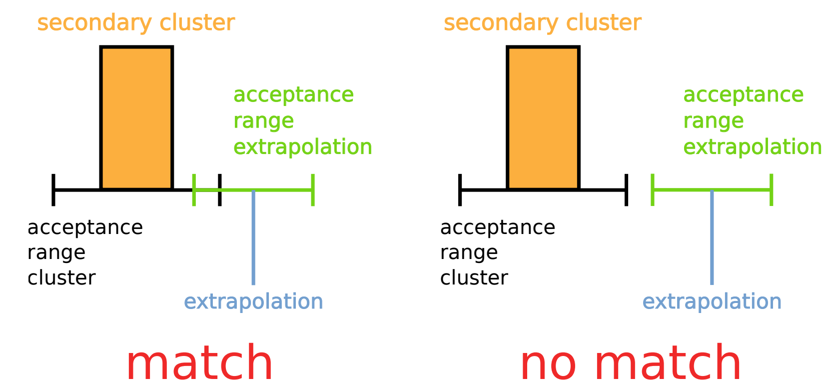
Bremsstrahlung recovery and track fitting

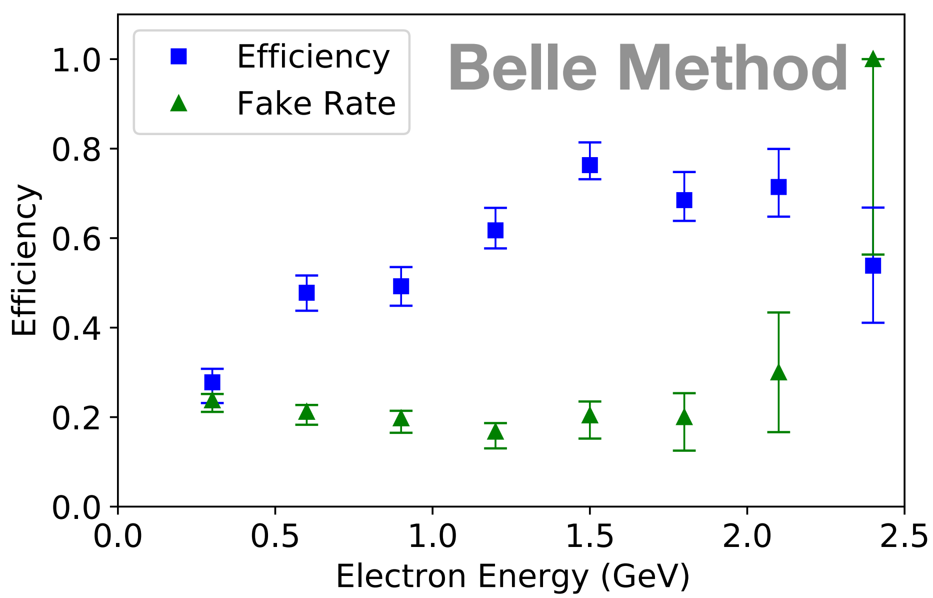
Patrick Ecker, Thomas Hauth, FB
Bachelor thesis

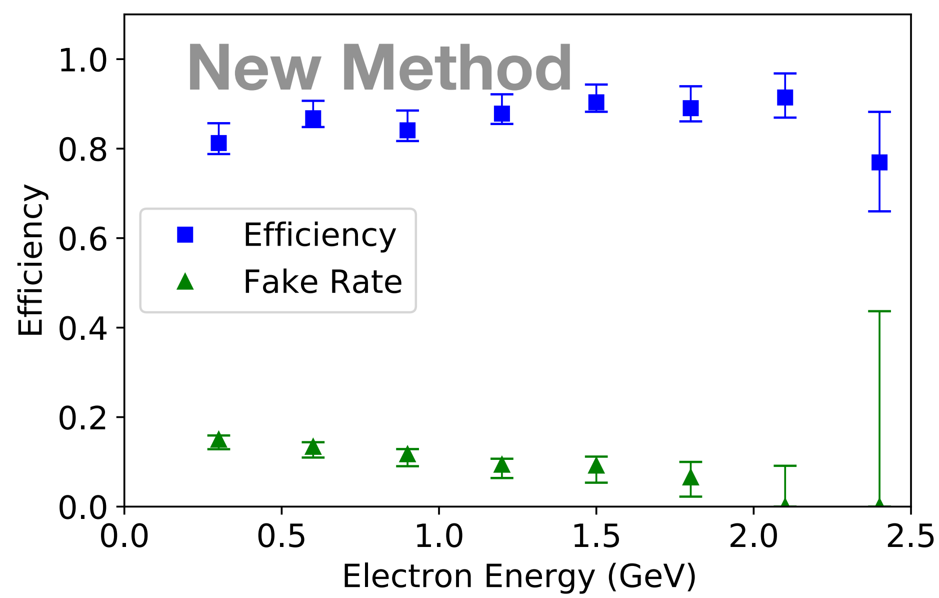
- Bremsstrahlung recovery is important to adequately measure final states with electrons, like $b \to s\,\ell\ell$
  - Belle: cone extrapolation around IP trajectory → want to do something **smarter for Belle II**



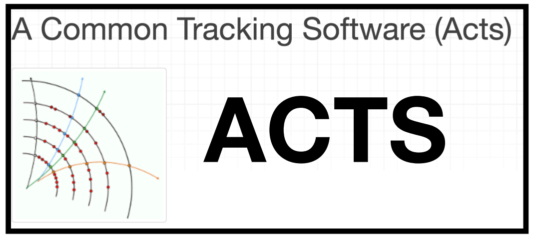






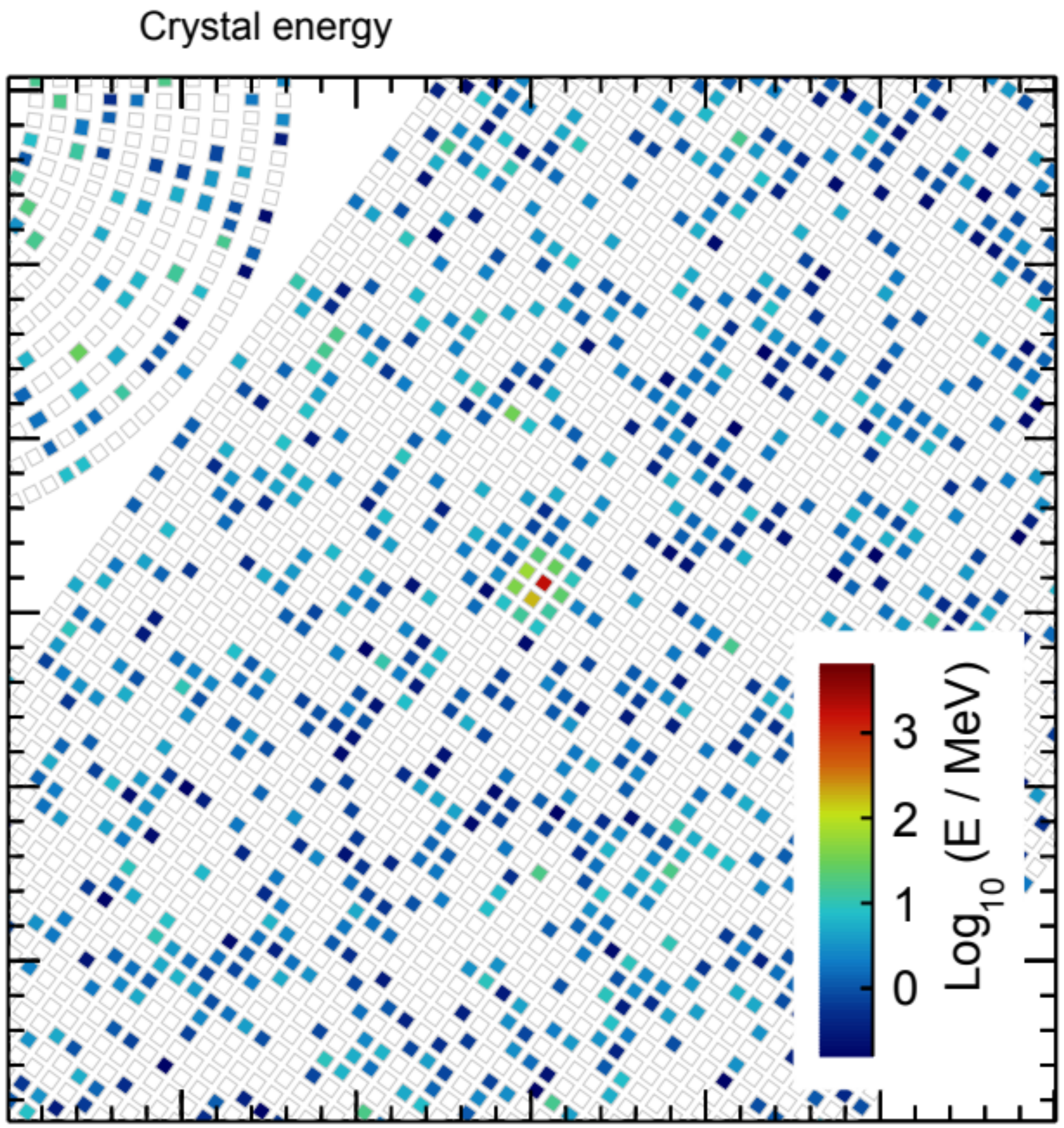


not straightforward to incorporate into track fitting



Calorimeter details

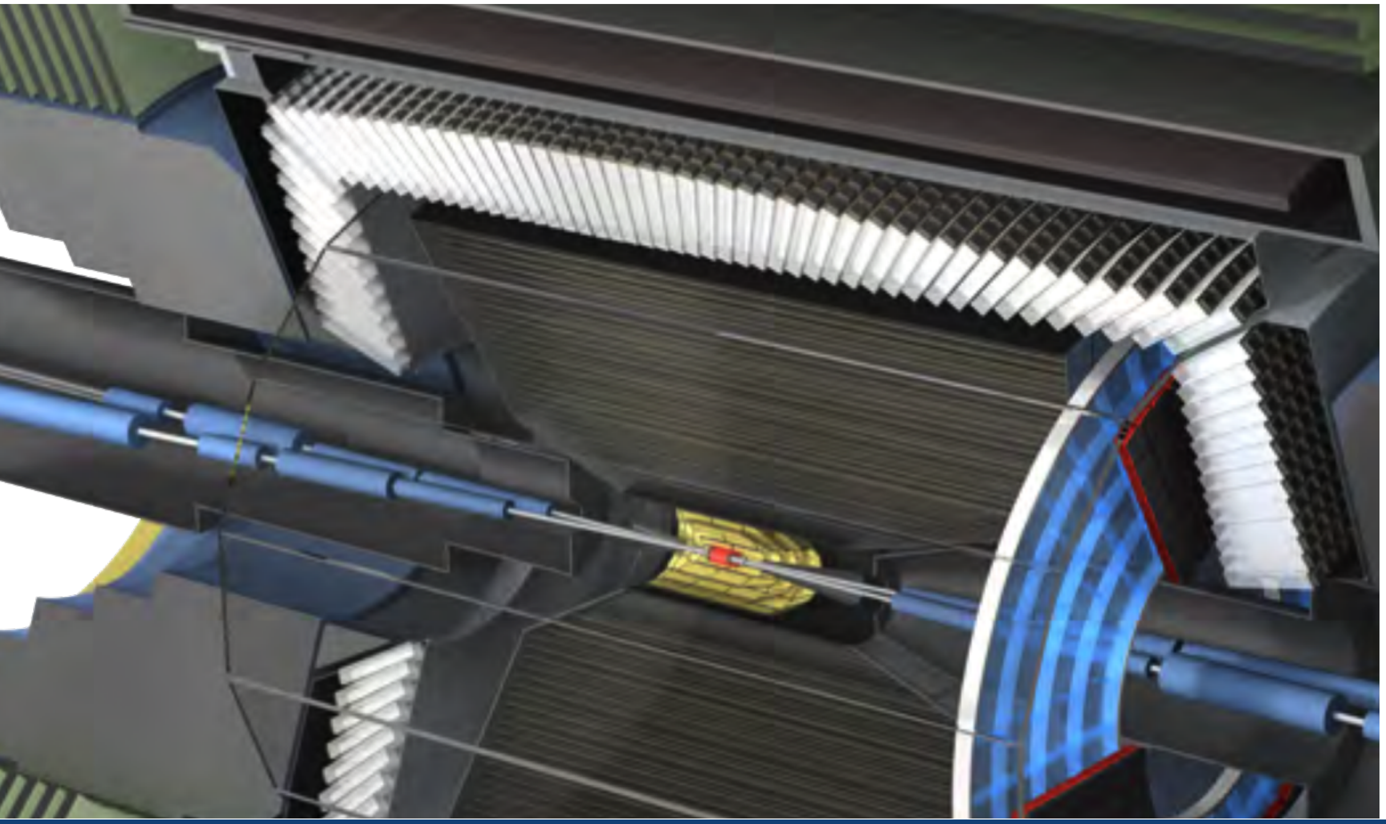
- Belle II **calorimeter crystals** are **reused from Belle**
  - **8736 CsI(Tl) crystals**
  - **New readout electronics**
- New clustering → **high luminosity environment**

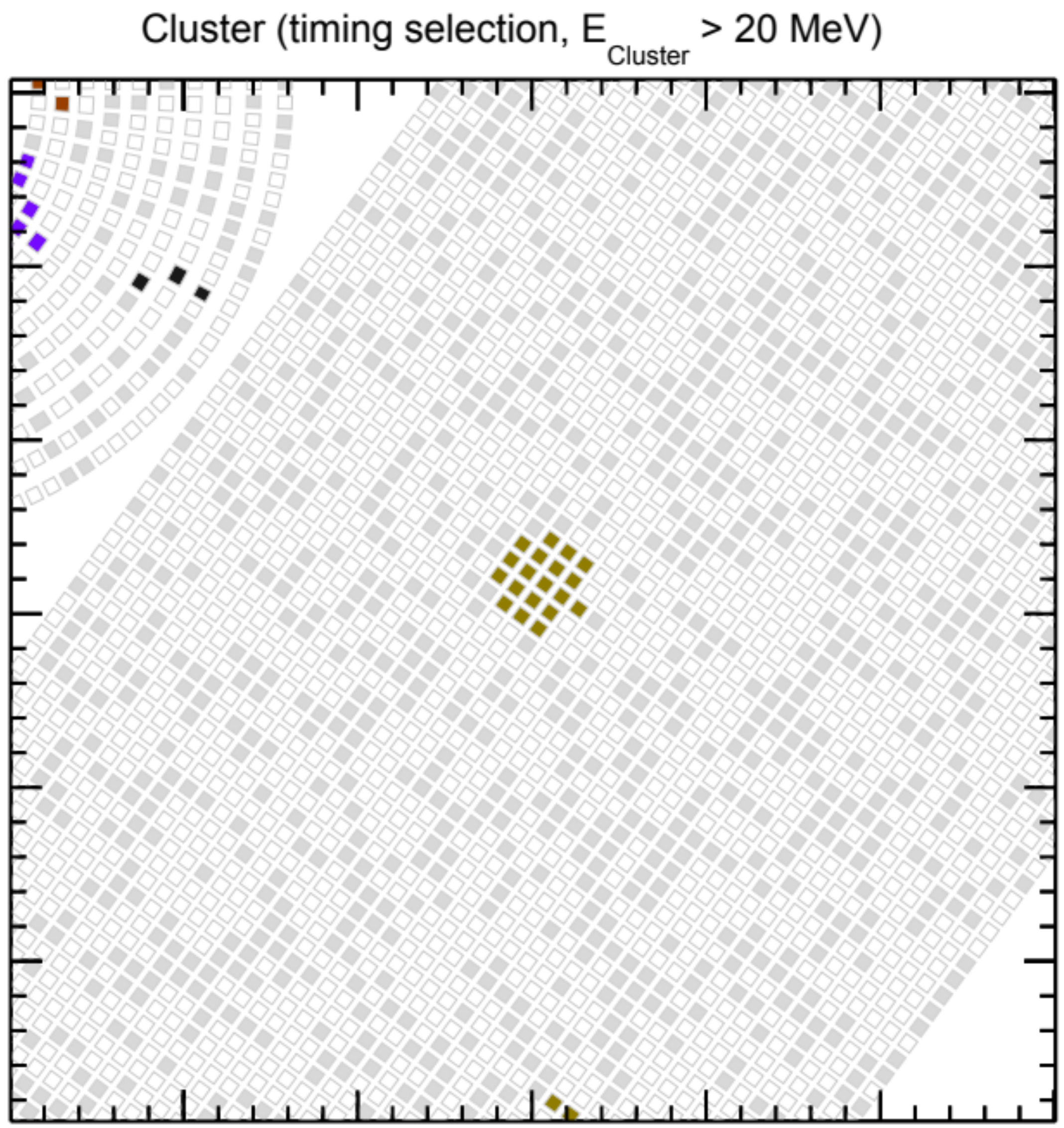


Nominal backgrounds
+ single 2.5 GeV photon

Calorimeter details

- Belle II **calorimeter crystals** are **reused from Belle**
  - **8736 CsI(TI) crystals**
  - **New readout electronics**
- New clustering → **high luminosity environment**

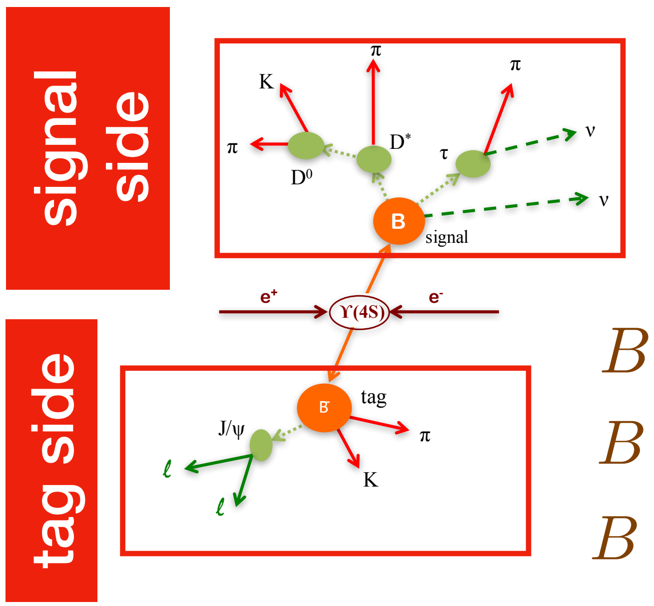




Timing and minimal cluster energy requirement

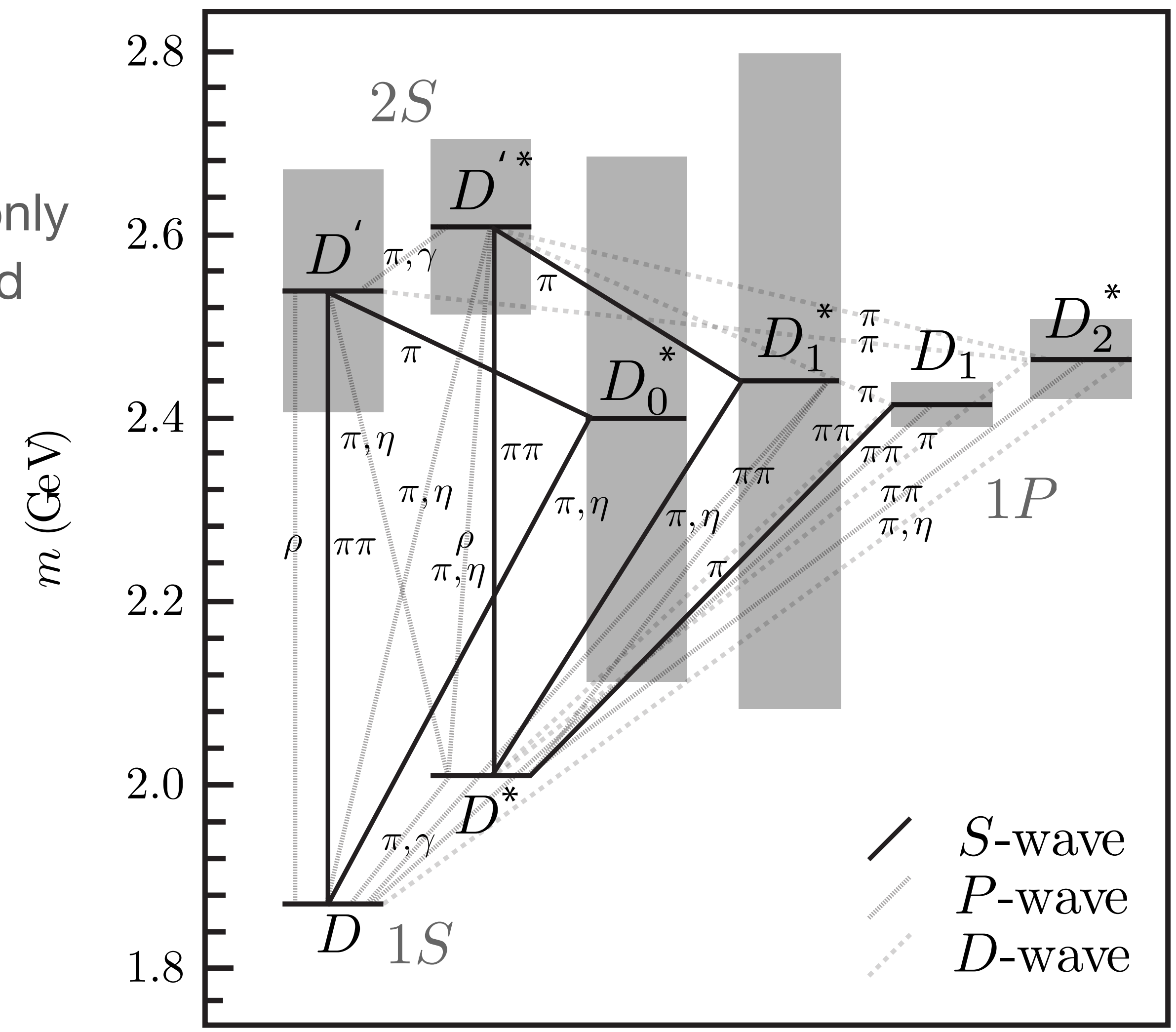
Why are D** decays selected?

- Hadronic tagging allows to enforce **matching topologies** for charged tracks
  - **Does not work well** for neutrals; typically no events or only events with a well reconstructed π^0 candidate are rejected



- Decays from higher charm resonances can sneak past

$$B \to D^{**}[\to D^{(*)}\pi^0]\,\ell/\tau\,\bar\nu_\ell$$
$$B \to D^{**}[\to D^{(*)}2\pi^0]\,\ell/\tau\,\bar\nu_\ell$$
$$B \to D^{**}[\to D^{(*)}\eta^{(\prime)}]\,\ell/\tau\,\bar\nu_\ell$$



FB et al, Phys.Rev. D85 (2012) 094033

Problem at a glance:

$$B \to D^{(*)}\,\tau\,\bar\nu_\tau \quad \hookrightarrow \ell\bar\nu_\ell\nu_\tau$$

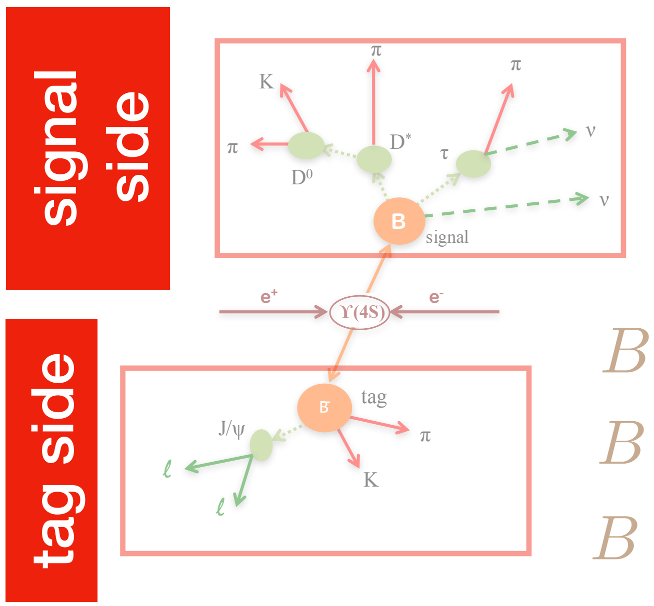
looks like

$$B \to D^{(*)}\,\pi\,\pi\,\ell\,\bar\nu_\ell$$

not reconstructed or missing particles

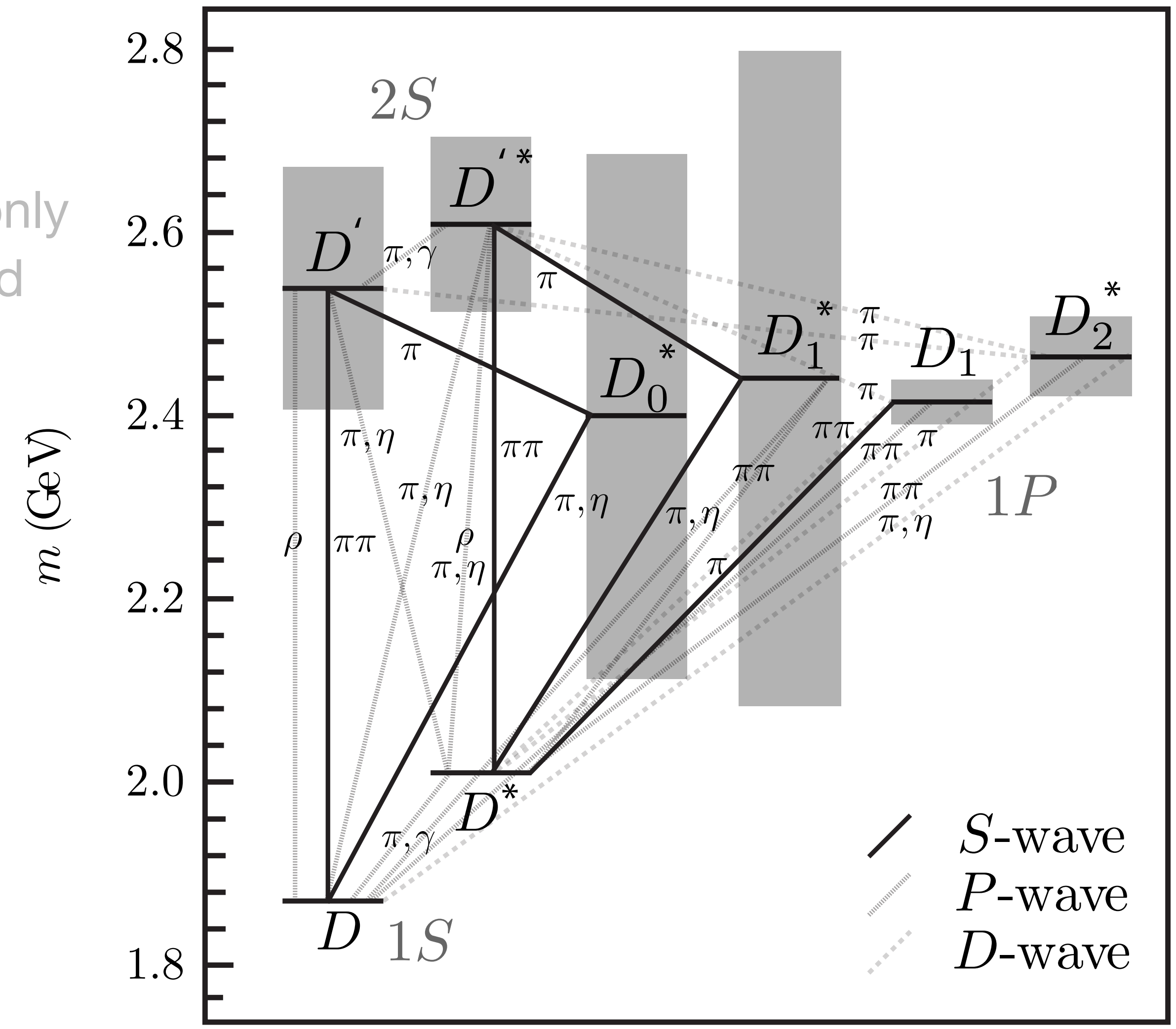
Why are D** decays selected?

- Hadronic tagging allows to enforce **matching topologies** for charged tracks
  - **Does not work well** for neutrals; typically no events or only events with a well reconstructed π^0 candidate are rejected



- ▸ Decays from higher charm resonances can sneak past

$$B \to D^{**}[\to D^{(*)}\pi^0]\,\ell/\tau\,\bar{\nu}_\ell$$
$$B \to D^{**}[\to D^{(*)}2\pi^0]\,\ell/\tau\,\bar{\nu}_\ell$$
$$B \to D^{**}[\to D^{(*)}\eta^{(\prime)}]\,\ell/\tau\,\bar{\nu}_\ell$$

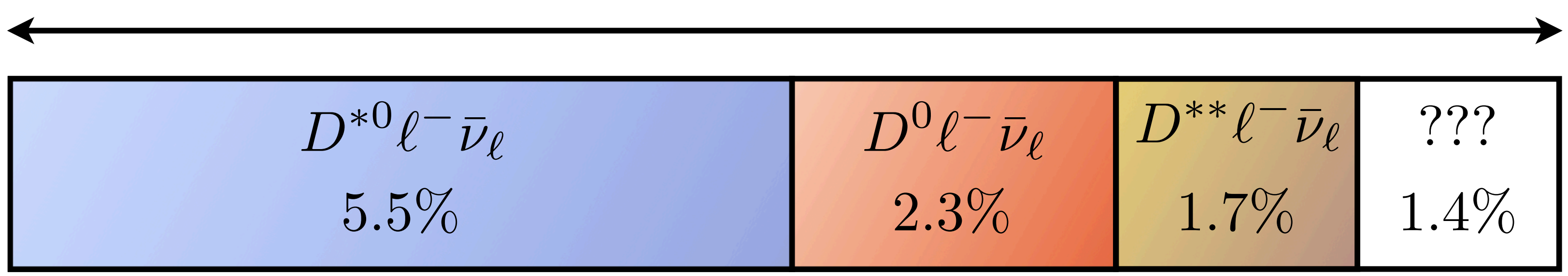


FB et al, Phys.Rev. D85 (2012) 094033

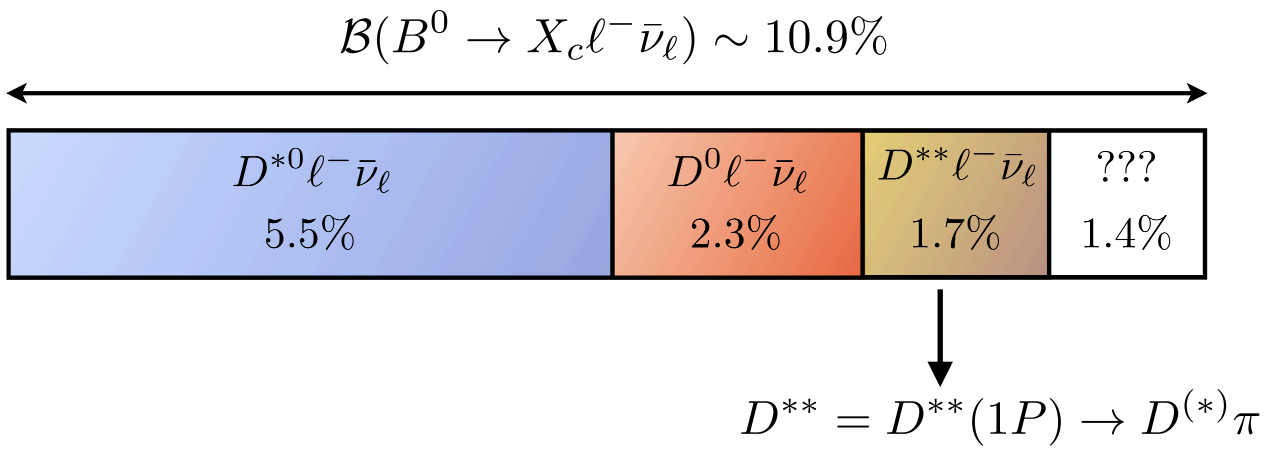
Problem at a glance:

- ▸ We don't know what is the exclusive make-up of **14%** of all semileptonic decays

$$\mathcal{B}(B^0 \to X_c \ell^- \bar{\nu}_\ell) \sim 10.9\%$$



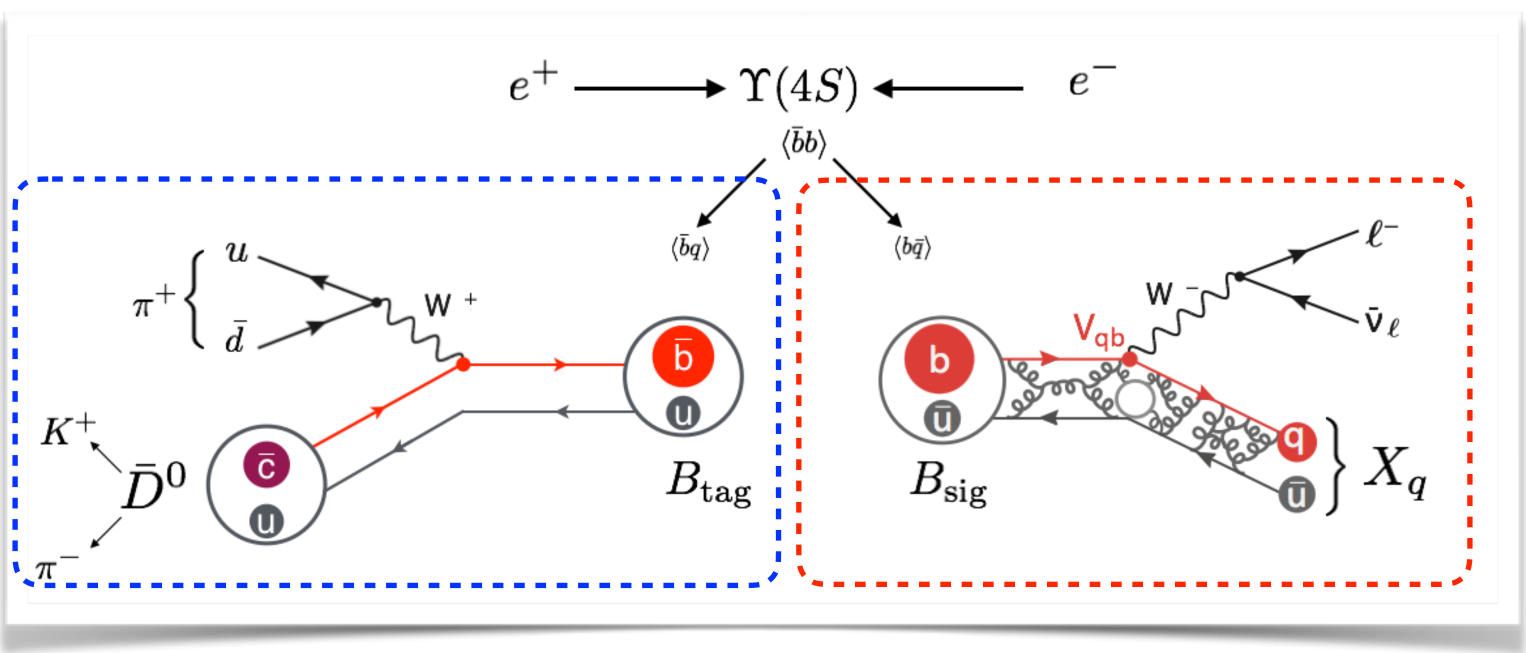
Missing contributions urgently needed

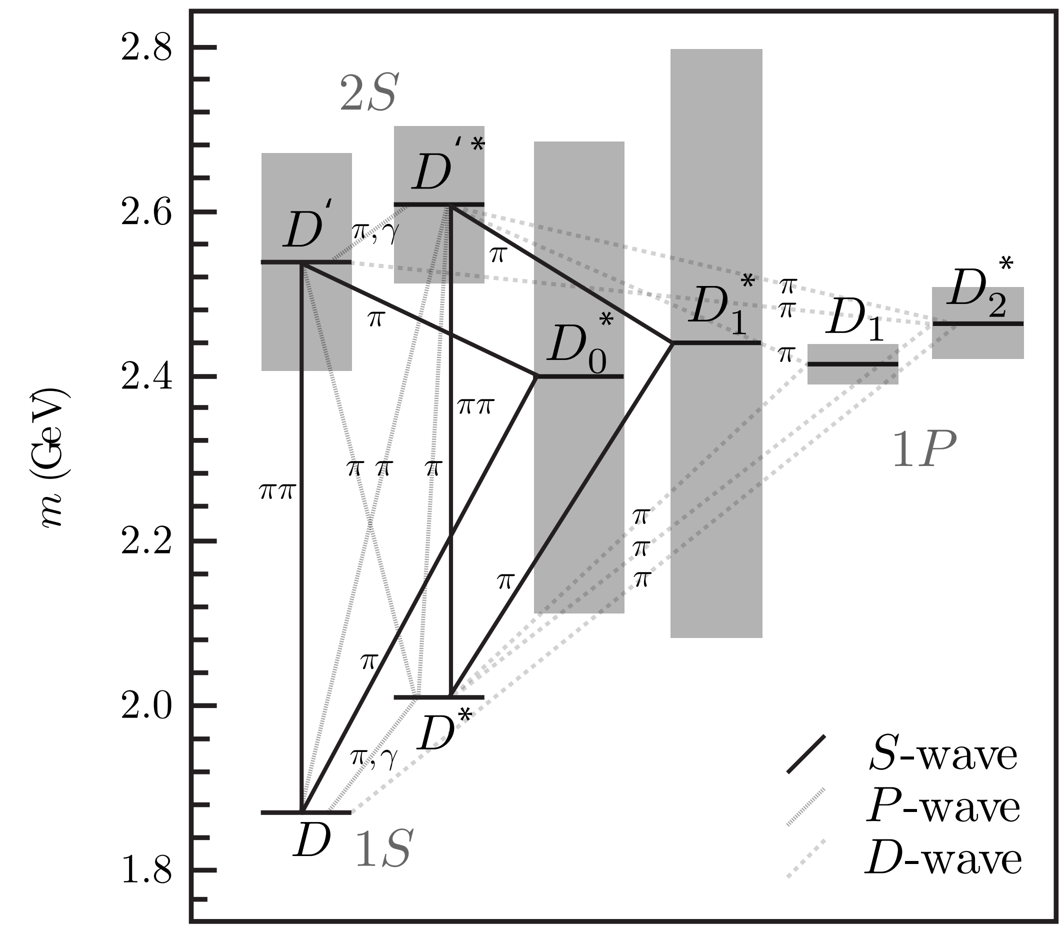


Semi-inclusive search most promising strategy

$$B \to D^{(*)}\pi^+\pi^-\ell\bar\nu_\ell$$

* Strategy: identical to $B \to D^{(*)}\tau\bar\nu_\tau$





FB et al, Phys.Rev. D85 (2012) 094033

$$p_{\text{miss}} = p_\nu = (p_{e^+e^-} - p_{\text{tag}} - p_{X_q} - p_\ell)$$

$$p_{X_q} = p_{D^{(*)}} + p_\pi + p_\pi$$

Thomas Lueck, Bob Kowalewski, FB
Phys. Rev. Lett. 116, 041801 (2016)

Background suppression via Fisher-discriminant

Background subtraction via unbinned likelihood fit in

$$E_{\mathrm{miss}} - |\vec{p}_{\mathrm{miss}}|$$

Simultaneous extraction of all channels:

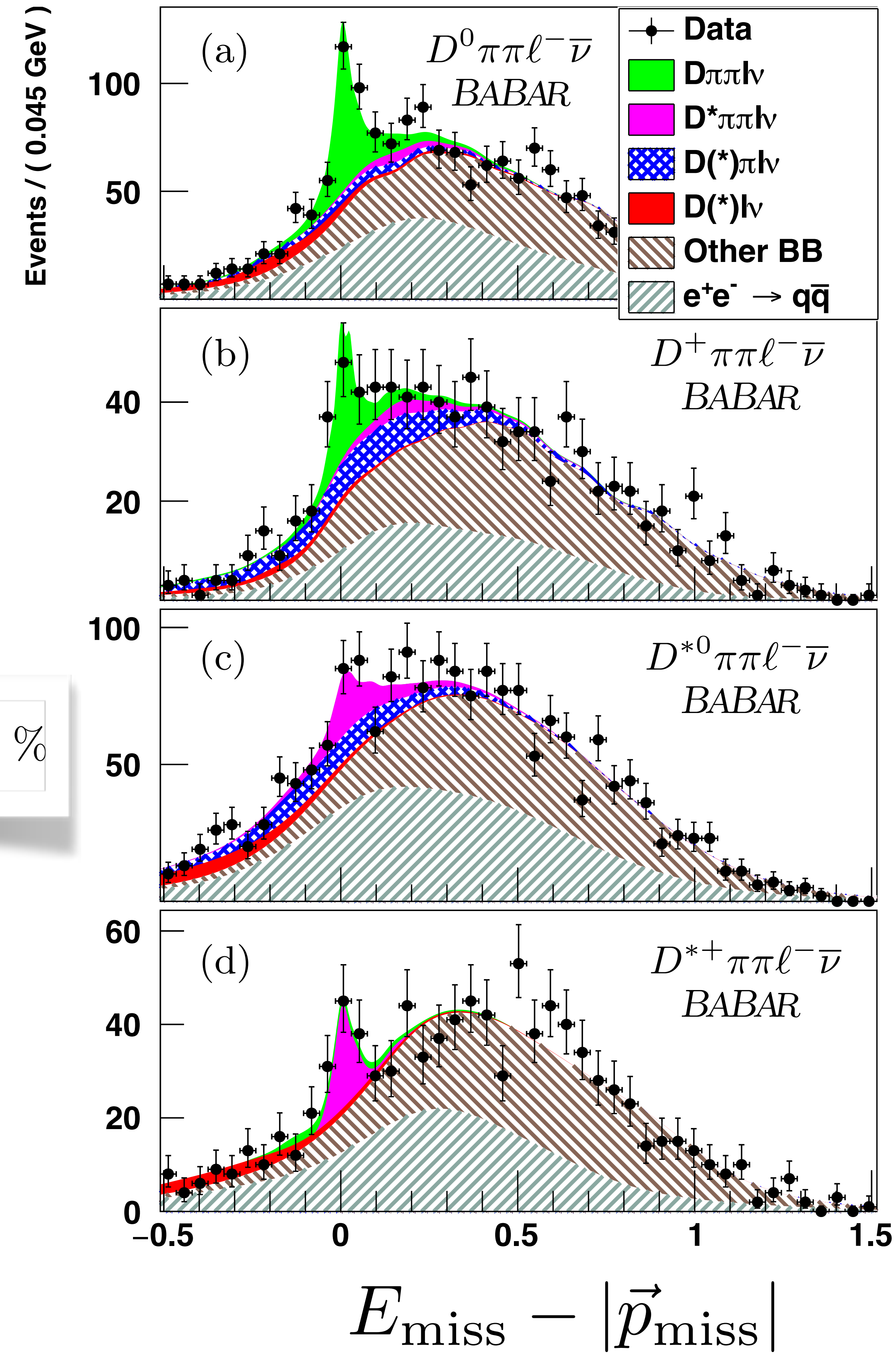
[D^0, D^+, D^{*0}, D^{*+}] $\pi^+ \pi^-$

$$\mathcal{B}(B \to D\pi\pi\,\ell\,\bar{\nu}_\ell) + \mathcal{B}(B \to D^*\pi\pi\,\ell\,\bar{\nu}_\ell) = \left(0.52^{+0.14+0.27}_{-0.07-0.13}\right)\%$$

unmeasured neutral components added via isospin extrapolation

$$\mathcal{B}(B^0 \to X_c \ell^- \bar{\nu}_\ell) \sim 10.9\%$$

~0.9% still unknown

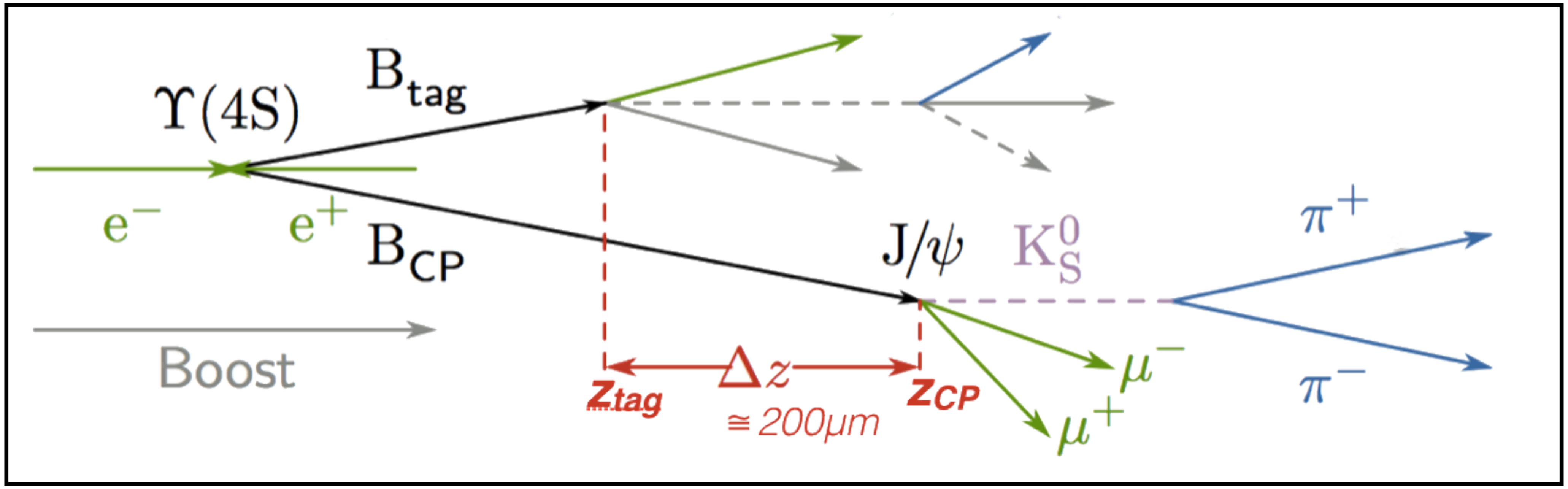


Flavour Tagger with Deep Neural Networks

- Flavour tagging:
  - important tool for time-dependent and time-integrated CPV measurements

$\sin 2\beta$

Golden mode



- Current approaches use categories

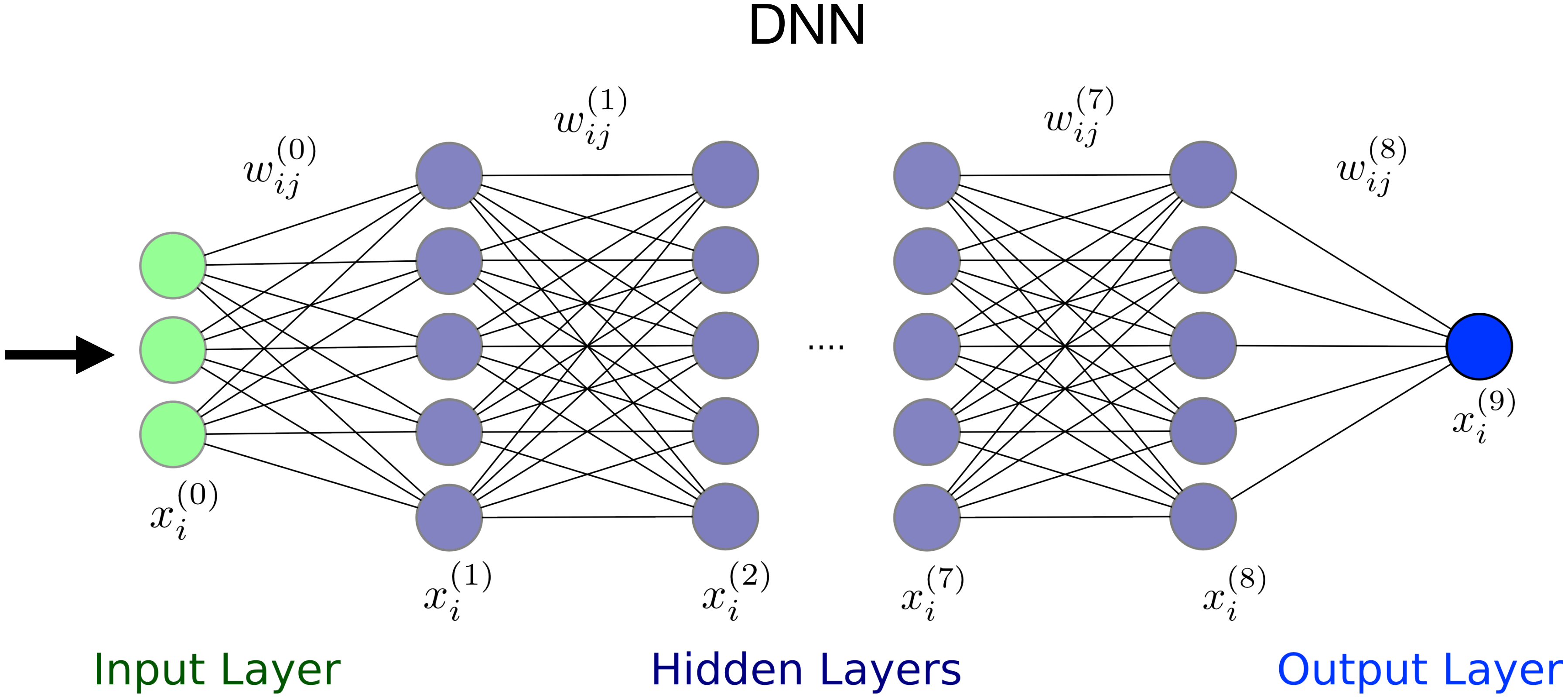
flavor-specific categories	decay processes
Primary Leptons	$\bar{b} \to \bar{c}\, \ell^{+} \nu$
Secondary Leptons	$\bar{b} \to \bar{c} \to \bar{s}\, \ell^{-} \bar{\nu}$
Slow Pion	$B^0 \to D^{*-} X, D^{*-} \to \bar{D}^0 \pi^-$
Fast Strange Particles	$B^0 \to K^+ X_{c\bar{c}}$
Slow Strange Particles	$\bar{b} \to \bar{c} \to \bar{s}$

Flavour Tagger with Deep Neural Networks

- Great playground for deep learning:
  - **Human** made **high-level categories** versus **full set of input observables**

Features

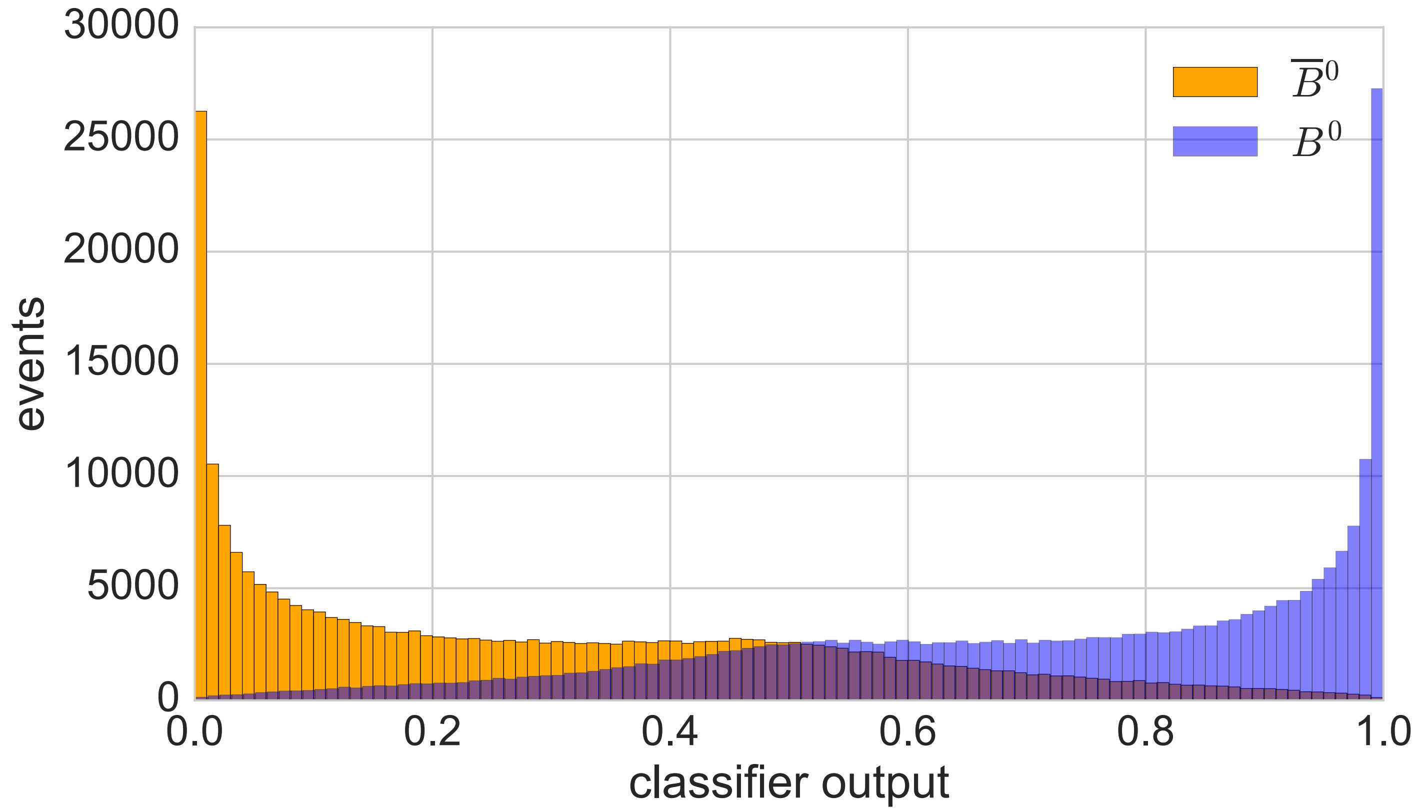
- 10 charged tracks at maximum
- sorted by momentum, grouped by charge
- p_{CMS}, $\cos(\theta_{CMS})$, ϕ_{CMS}
- electron, pion, muon, kaon, proton ID
- hit count of the Belle II-tracking detectors (3)
- track perigee (dr, dz)
- pValue
- overall 140 input features

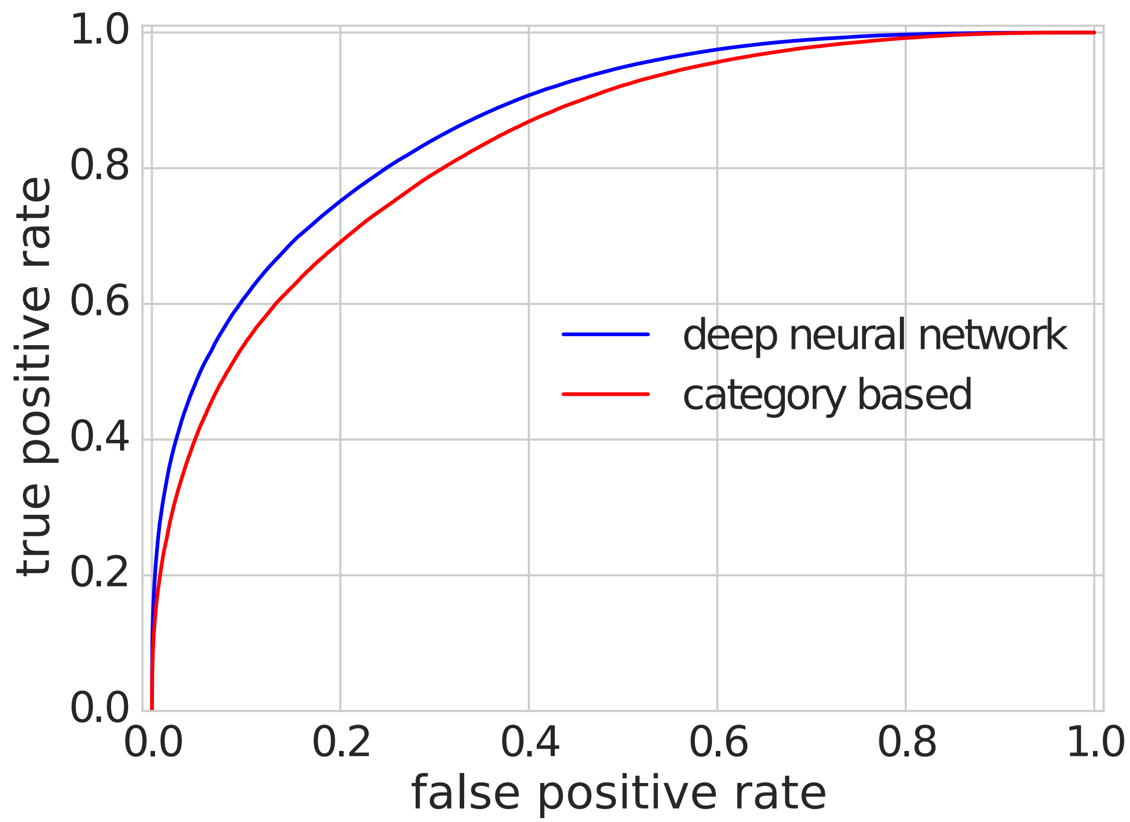


8 layers with 300 nodes each

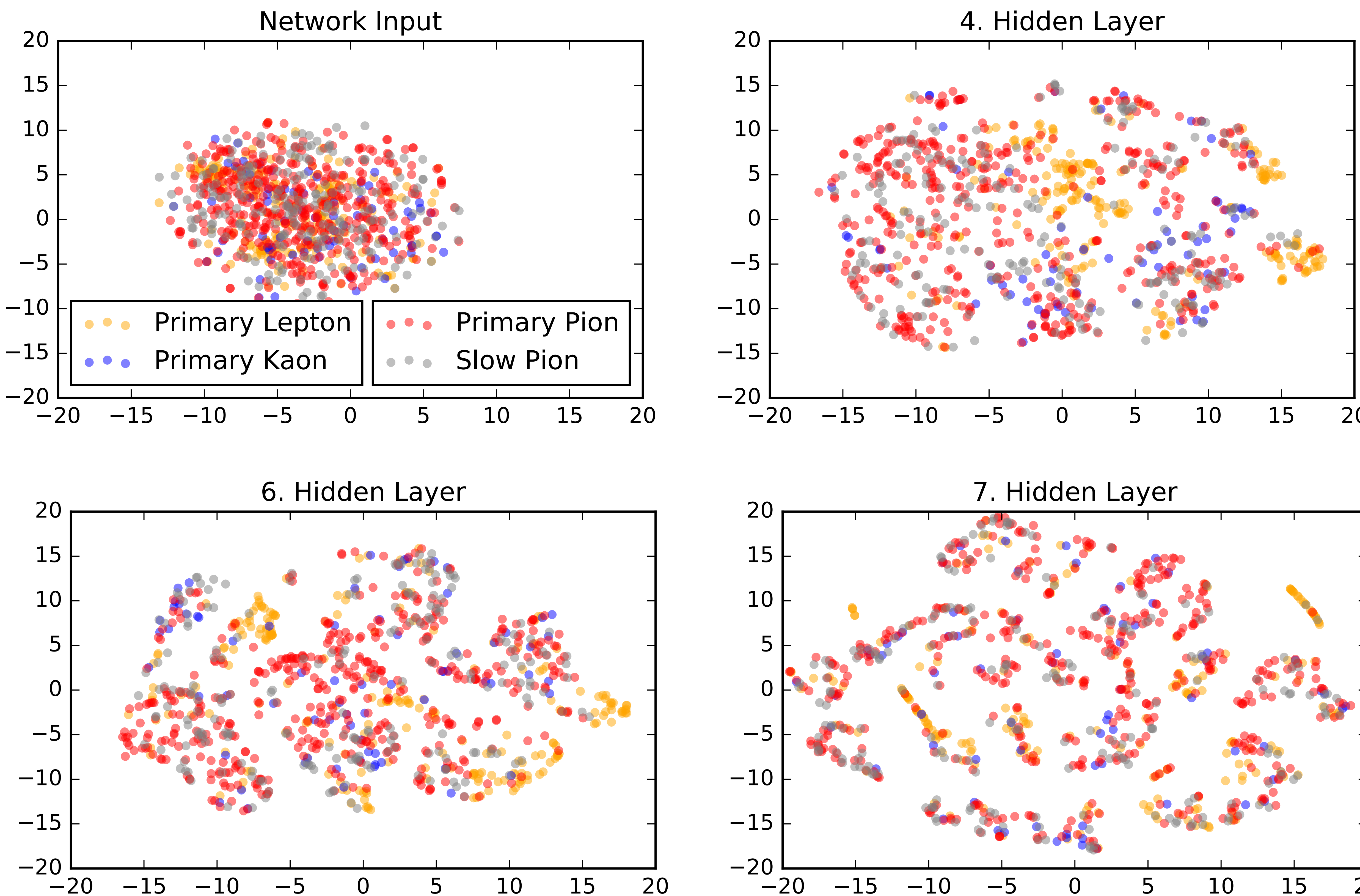
Flavour Tagger with Deep Neural Networks

- Great playground for deep learning:
  - **Human made** high-level **categories versus full set of input** observables

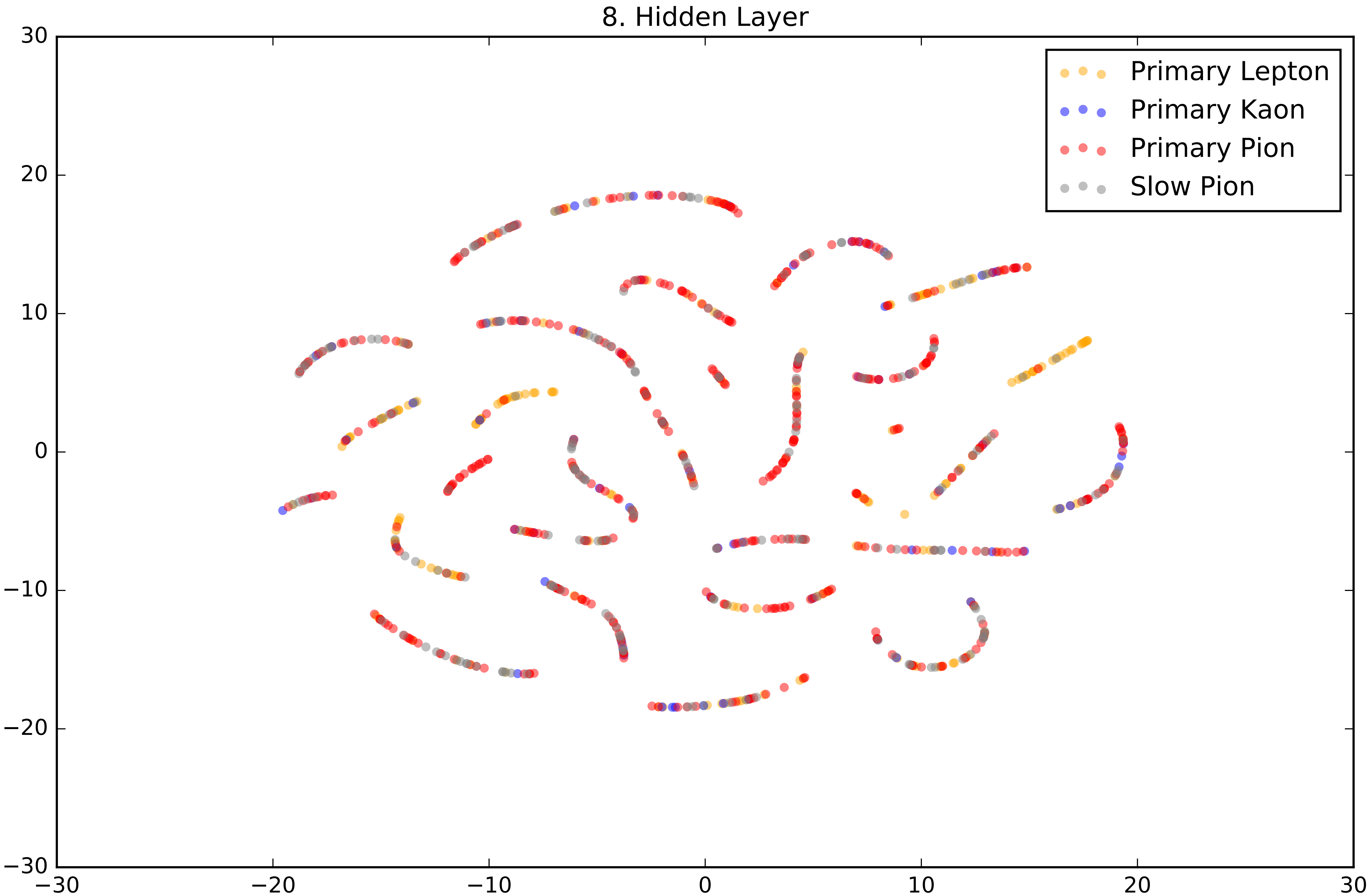


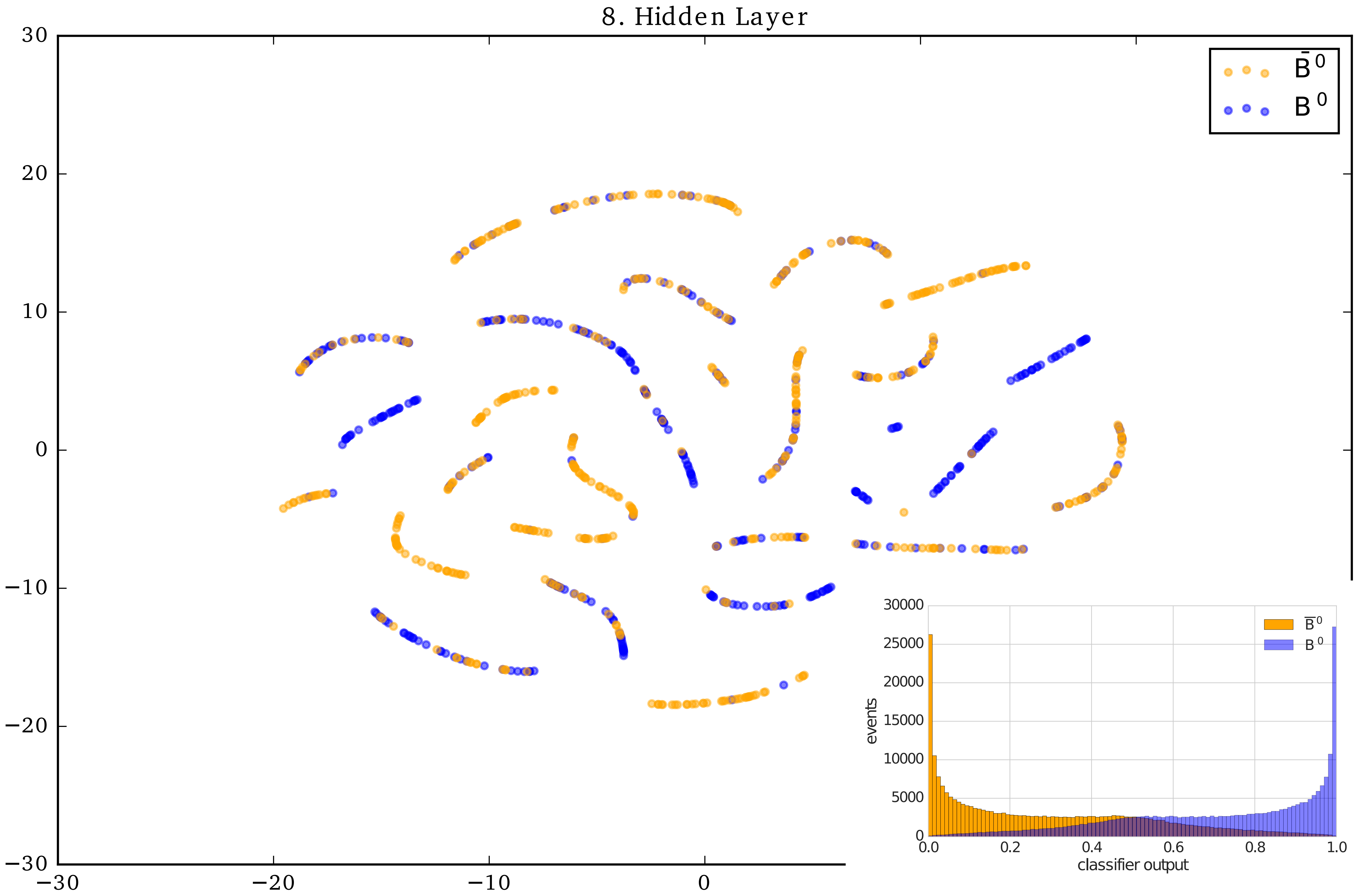


		Category Based	Deep Neural Network
Belle	$J/\Psi K_S^0$	0.293 ± 0.01 [1]	0.3442±0.0009

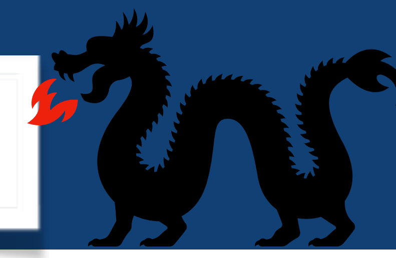


T-distributed Stochastic Neighbour Embedding (TSNE)


8. Hidden Layer
Primary Lepton
Primary Kaon
Primary Pion
Slow Pion
30
20
10
0
−10
−20
−30
−30
−20
−10
0
10
20
30


8. Hidden Layer
30
20
10
0
−10
−20
−30
−30
−20
−10
0
$\bar{B}^0$
B^0
30000
25000
20000
15000
10000
5000
0
events
0.0
0.2
0.4
0.6
0.8
1.0
classifier output
$\overline{B}^0$
B^0

Excerpt of my work on the subject of semileptonic decays:



The $B \to \pi \tau \bar{\nu}_\tau$ decay in the context of the 2HDM type II

Florian U. Bernlochner[1]
[1] *Physikalisches Institut der Rheinische Friedrich-Wilhelms-Universität Bonn, 53115 Bonn, Germany*

Phys. Rev. D 92, 115019 (2015)

A proposal to solve some puzzles in semileptonic B decays

Florian U. Bernlochner,[1] Zoltan Ligeti,[2] and Sascha Turczyk[2]
[1] *University of Victoria, Victoria, British Columbia, Canada V8W 3P*
[2] *Ernest Orlando Lawrence Berkeley National Laboratory, University of California, Berkeley, CA 94720*

Phys.Rev. D85 (2012) 094033

Constraints on exclusive branching fractions $\mathcal{B}_i(B^+ \to X_c^i l^+ \nu)$ from moment measurements in inclusive $B \to X_c l \nu$ decays

Florian U. Bernlochner
University of Victoria, Victoria, British Columbia, Canada V8W 3P

Eur.Phys.J. C74 (2014) no.6, 2914

Semileptonic $B_{(s)}$ decays to excited charmed mesons with e, μ, τ and searching for new physics with $R(D^{**})$

Florian U. Bernlochner[1] and Zoltan Ligeti[2]
[1] *Physikalisches Institut der Rheinischen Friedrich-Wilhelms-Universität Bonn, 53115 Bonn, Germany*
[2] *Ernest Orlando Lawrence Berkeley National Laboratory, University of California, Berkeley, CA 94720*

Phys. Rev. D 95, 014022 (2017)

Model independent analysis of semileptonic B decays to D^{**} for arbitrary new physics

Florian U. Bernlochner,[1,2] Zoltan Ligeti,[3] and Dean J. Robinson[4]
[1] *Physikalisches Institut der Rheinischen Friedrich-Wilhelms-Universität Bonn, 53115 Bonn, Germany*
[2] *Karlsruher Institute of Technology, 76131 Karlsruhe, Germany*
[3] *Ernest Orlando Lawrence Berkeley National Laboratory, University of California, Berkeley, CA 94720, USA*
[4] *Physics Department, University of Cincinnati, Cincinnati OH 45221, USA*

Phys. Rev. D 97, 075011 (2018)

Tensions and correlations in $|V_{cb}|$ determinations

Florian U. Bernlochner,[1,2] Zoltan Ligeti,[3] Michele Papucci,[3] and Dean J. Robinson[4]
[1] *Physikalisches Institut der Rheinischen Friedrich-Wilhelms-Universität Bonn, 53115 Bonn, Germany*
[2] *Karlsruher Institute of Technology, 76131 Karlsruhe, Germany*
[3] *Ernest Orlando Lawrence Berkeley National Laboratory, University of California, Berkeley, CA 94720, USA*
[4] *Physics Department, University of Cincinnati, Cincinnati OH 45221, USA*

Phys. Rev. D 96, 091503 (2017)

Combined analysis of semileptonic B decays to D and D^*: $R(D^{(*)})$, $|V_{cb}|$, and new physics

Florian U. Bernlochner,[1] Zoltan Ligeti,[2] Michele Papucci,[2] and Dean J. Robinson[3]

Phys. Rev. D 95, 115008 (2017)

PRL 116, 041801 (2016) PHYSICAL REVIEW LETTERS week ending 29 JANUARY 2016

Observation of $\bar{B} \to D^{(*)} \pi^+ \pi^- \ell^- \bar{\nu}$ Decays in e^+e^- Collisions at the $\Upsilon(4S)$ Resonance

J. P. Lees,[1] V. Poireau,[1] V. Tisserand,[1] E. Grauges,[2] A. Palano,[3a,3b] G. Eigen,[4] B. Stugu,[4] D. N. Brown,[5] L. T. Kerth,[5] Yu. G. Kolomensky,[5] M. J. Lee,[5] G. Lynch,[5] H. Koch,[6] T. Schroeder,[6] C. Hearty,[7] T. S. Mattison,[7] J. A. McKenna,[7] R. Y. So,[7] A. Khan,[8] V. E. Blinov,[9a,9b,9c] A. R. Buzykaev,[9a] V. P. Druzhinin,[9a,9b] V. B. Golubev,[9a,9b] E. A. Kravchenko,[9a,9b] A. P. Onuchin,[9a,9b,9c] S. I. Serednyakov,[9a,9b] Yu. I. Skovpen,[9a,9b] E. P. Solodov,[9a,9b] K. Yu. Todyshev,[9a,9b] A. J. Lankford,[10] J. W. Gary,[11] O. Long,[11] M. Franco Sevilla,[12] T. M. Hong,[12] D. Kovalskyi,[12] J. D. Richman,[12] C. A. West,[12] A. M. Eisner,[13] W. S. Lockman,[13] W. Panduro Vazquez,[13] B. A. Schumm,[13] A. Seiden,[13] D. S. Chao,[14] C. H. Cheng,[14] B. Echenard,[14] K. T. Flood,[14] D. G. Hitlin,[14] J. Kim,[14] T. S. Miyashita,[14] P. Ongmongkolkul,[14] F. C. Porter,[14] M. Röhrken,[14]

Phys. Rev. Lett. 116, 041801 (2016)

Precise determination of the CKM matrix element $|V_{cb}|$ with $\bar{B}^0 \to D^{*+} \ell^- \bar{\nu}_\ell$ decays with hadronic tagging at Belle

A. Abdesselam,[93] I. Adachi,[20,16] K. Adamczyk,[67] H. Aihara,[101] S. Al Said,[93,42]

BELLE-CONF-1612

New predictions for $\Lambda_b \to \Lambda_c$ semileptonic decays and tests of heavy quark symmetry

Florian U. Bernlochner,[1] Zoltan Ligeti,[2] Dean J. Robinson,[2,3] and William L. Sutcliffe[1]

accepted by PRL

plus more (HAMMER, other to be published projects)