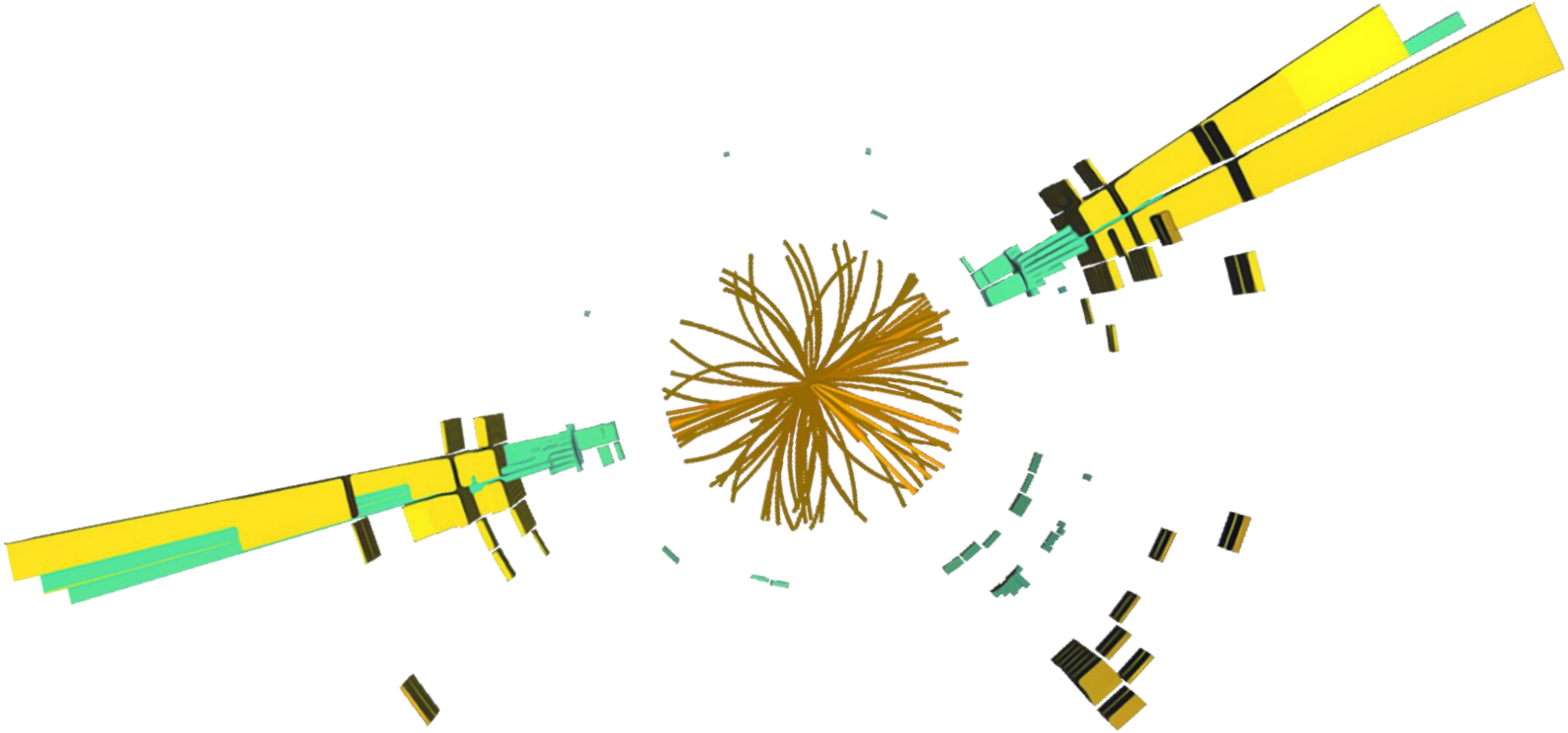


Probing the Energy Frontier with ATLAS

Séminaire du DPNC

Roland Jansky
University of Geneva

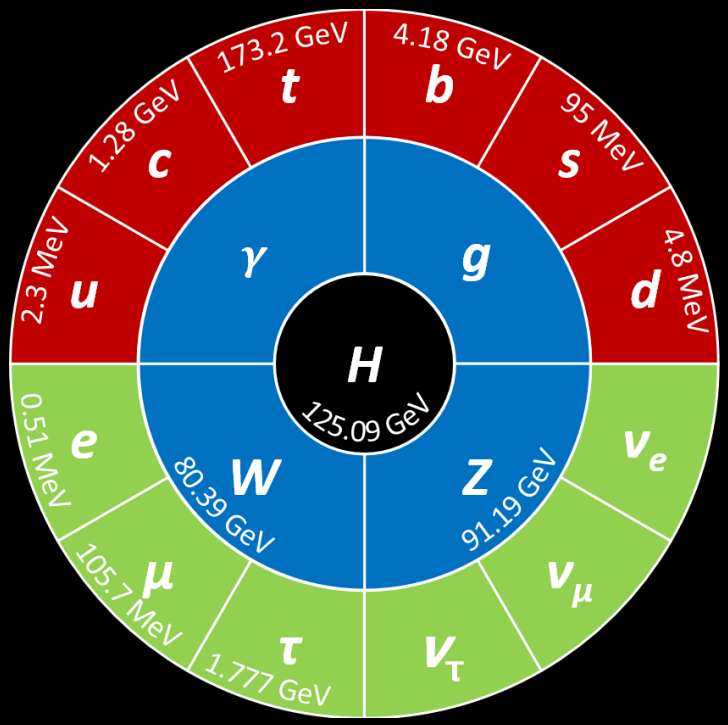
3rd May 2017

UNIVERSITÉ DE GENÈVE

ATLAS EXPERIMENT

Particle Physics

- These particles we know, and they are the building blocks of the 5% of the universe we roughly understand.
- Described by the Standard Model.

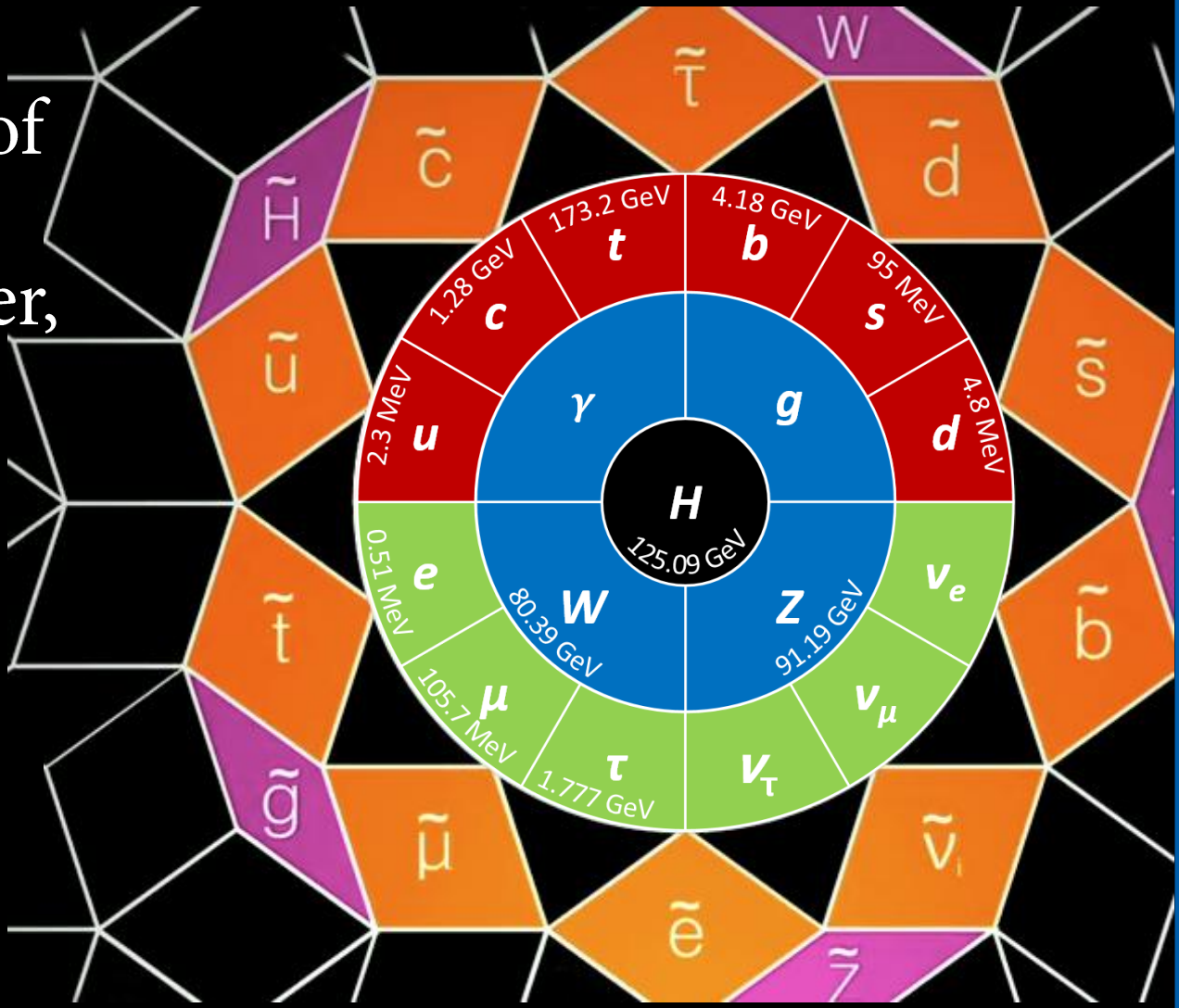


Expanding the Standard Model

Many open questions:

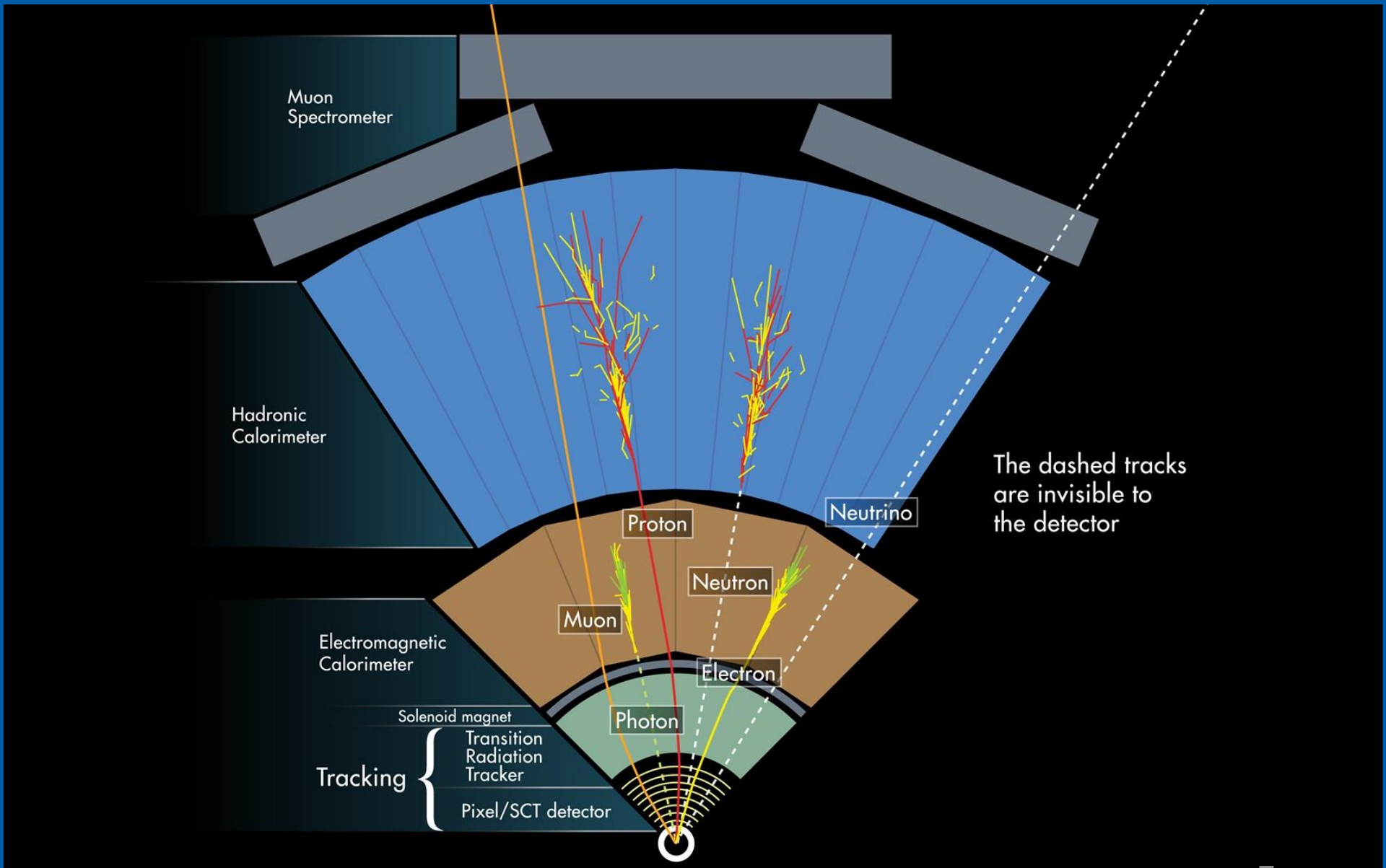
- What explains the other 95% of the universe? (i.e. Dark Matter, Dark Energy?)
- Why is gravity so weak?

⋮

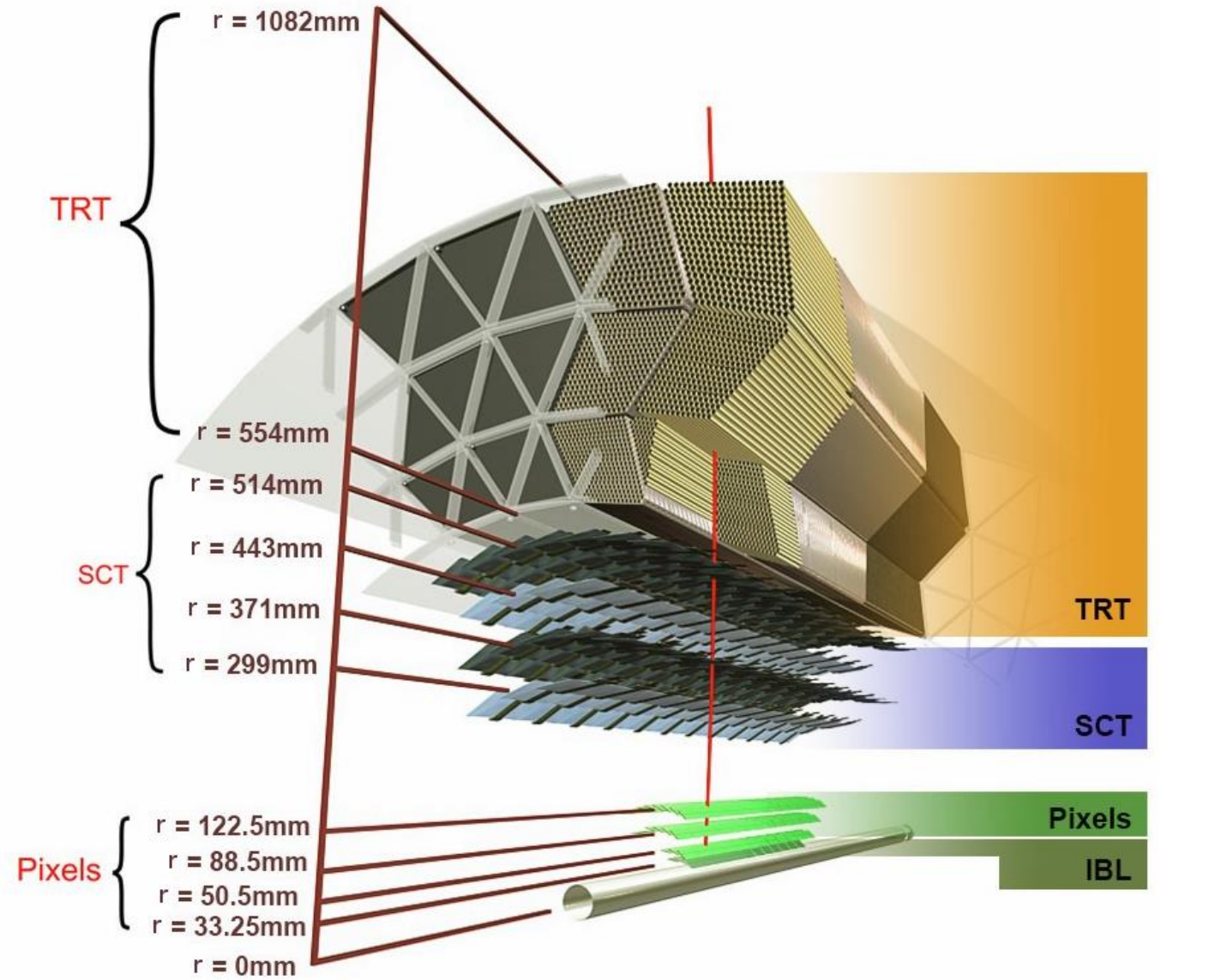


Large Hadron Collider

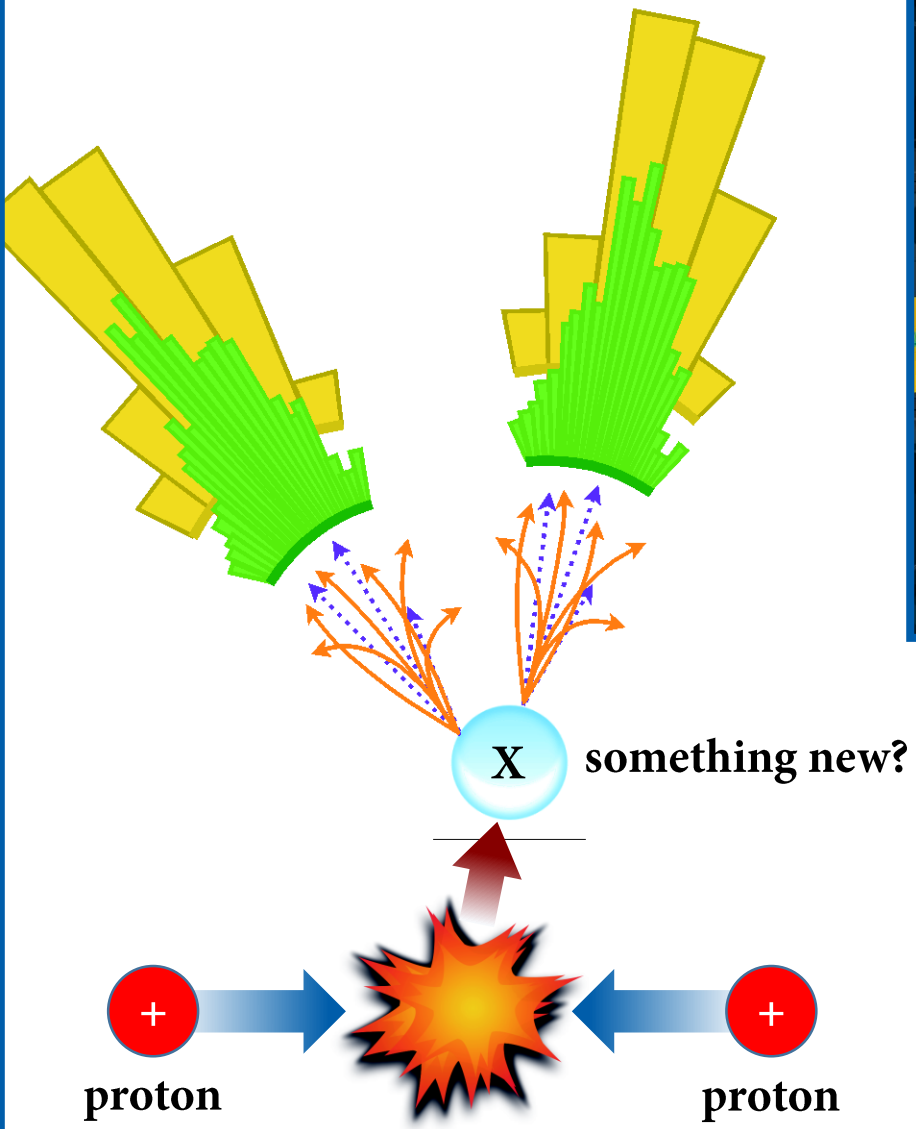
ATLAS Detector



ATLAS Inner Detector



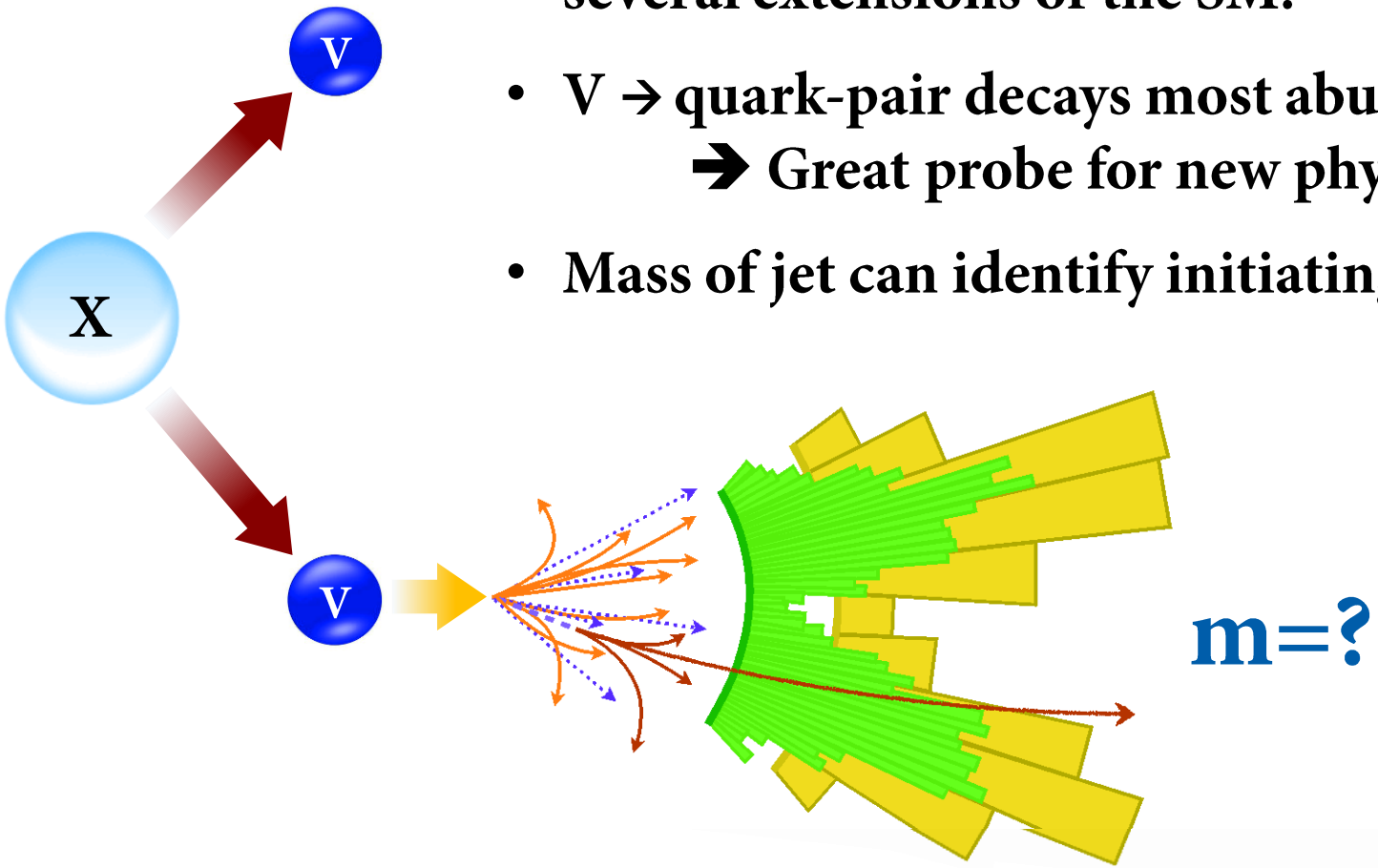
Energy Frontier: Jets



- **Newly opened energy regime: $\sqrt{s} = 13$ TeV.**

Motivation

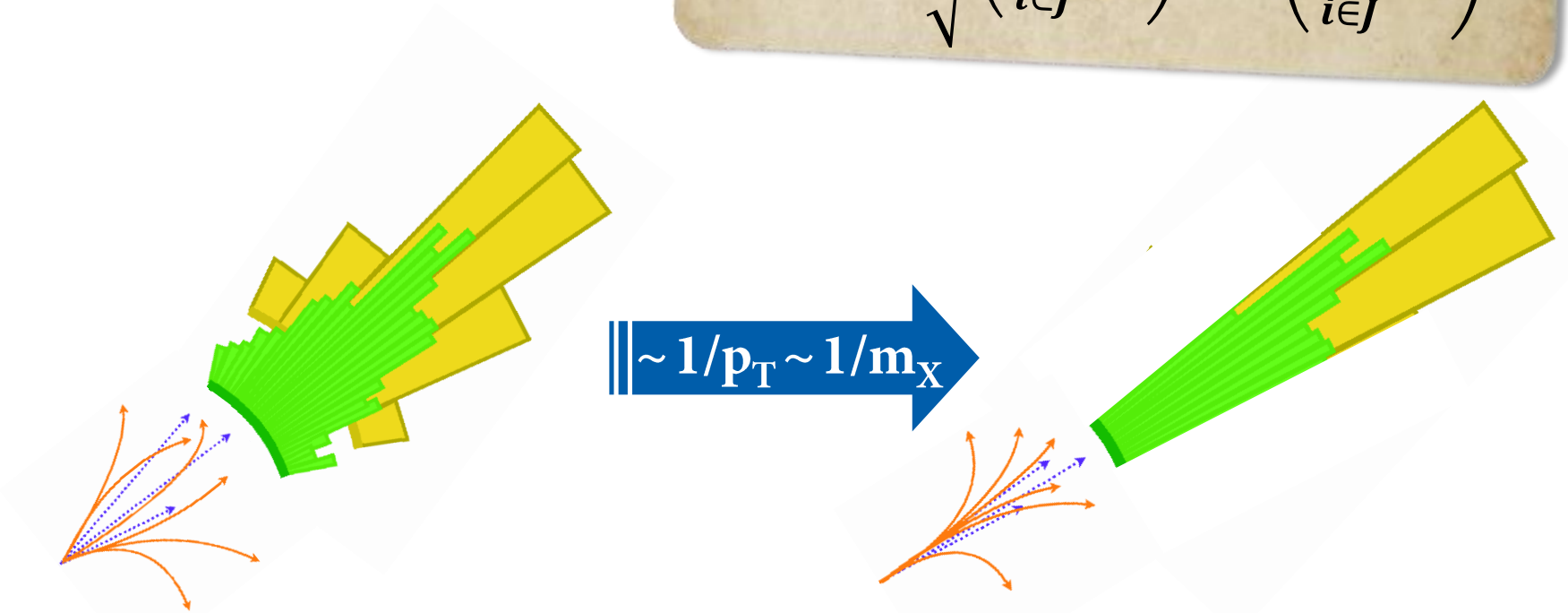
- Heavy (>1 TeV) resonances to pairs of vector bosons (V=W/Z) predicted by several extensions of the SM.
- V → quark-pair decays most abundant.
  ➔ Great probe for new physics!
- Mass of jet can identify initiating particle.



Jet Mass Definition (1)

calorimeter-based jet mass:

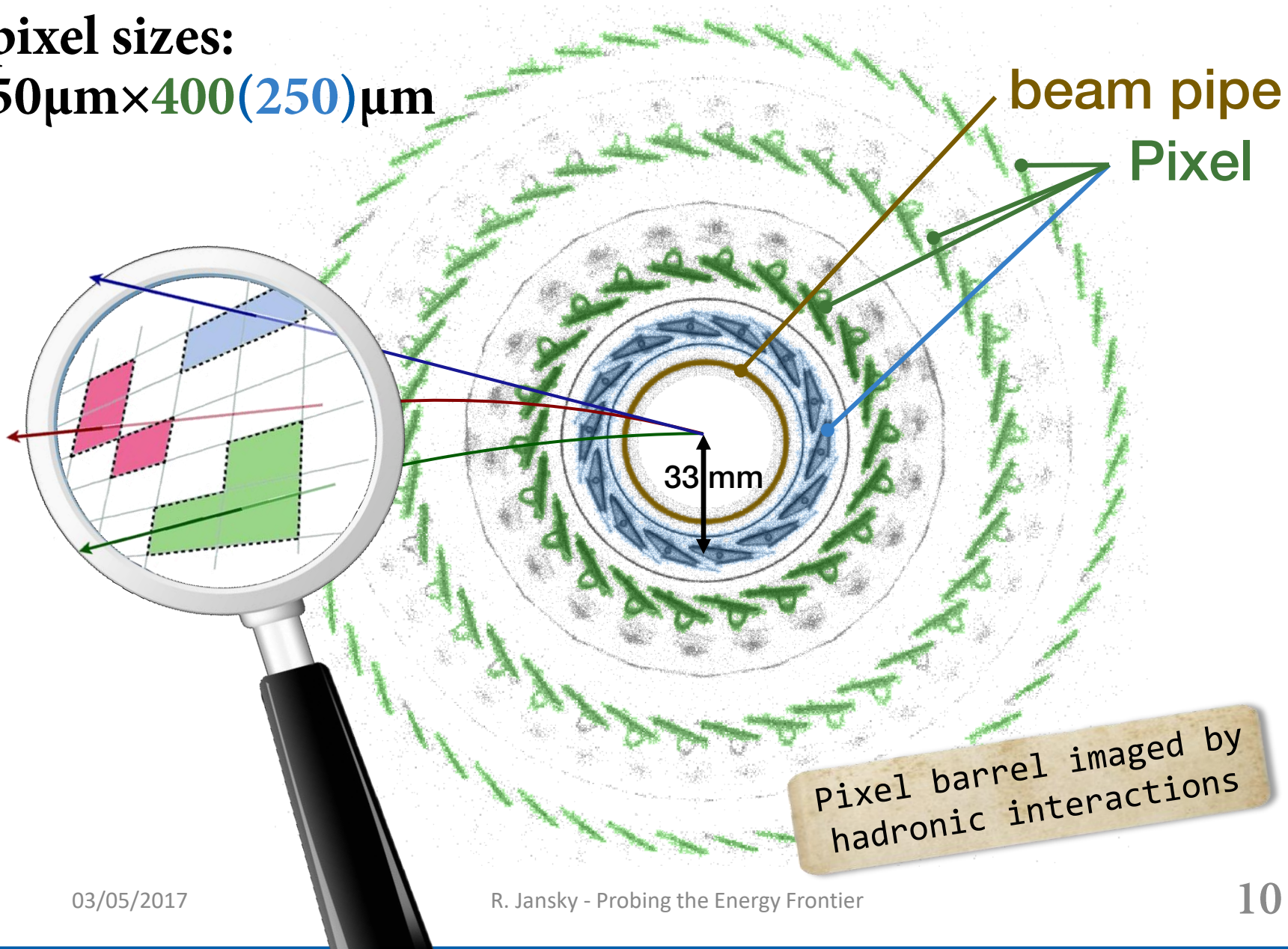
$$m^{\text{calo}} = \sqrt{\left(\sum_{i \in J} E_i\right)^2 - \left(\sum_{i \in J} \vec{p}_i\right)^2}$$



- Tracker granularity superior to calorimeter.
  - ➔ **Use tracker in reconstruction of jet mass.**

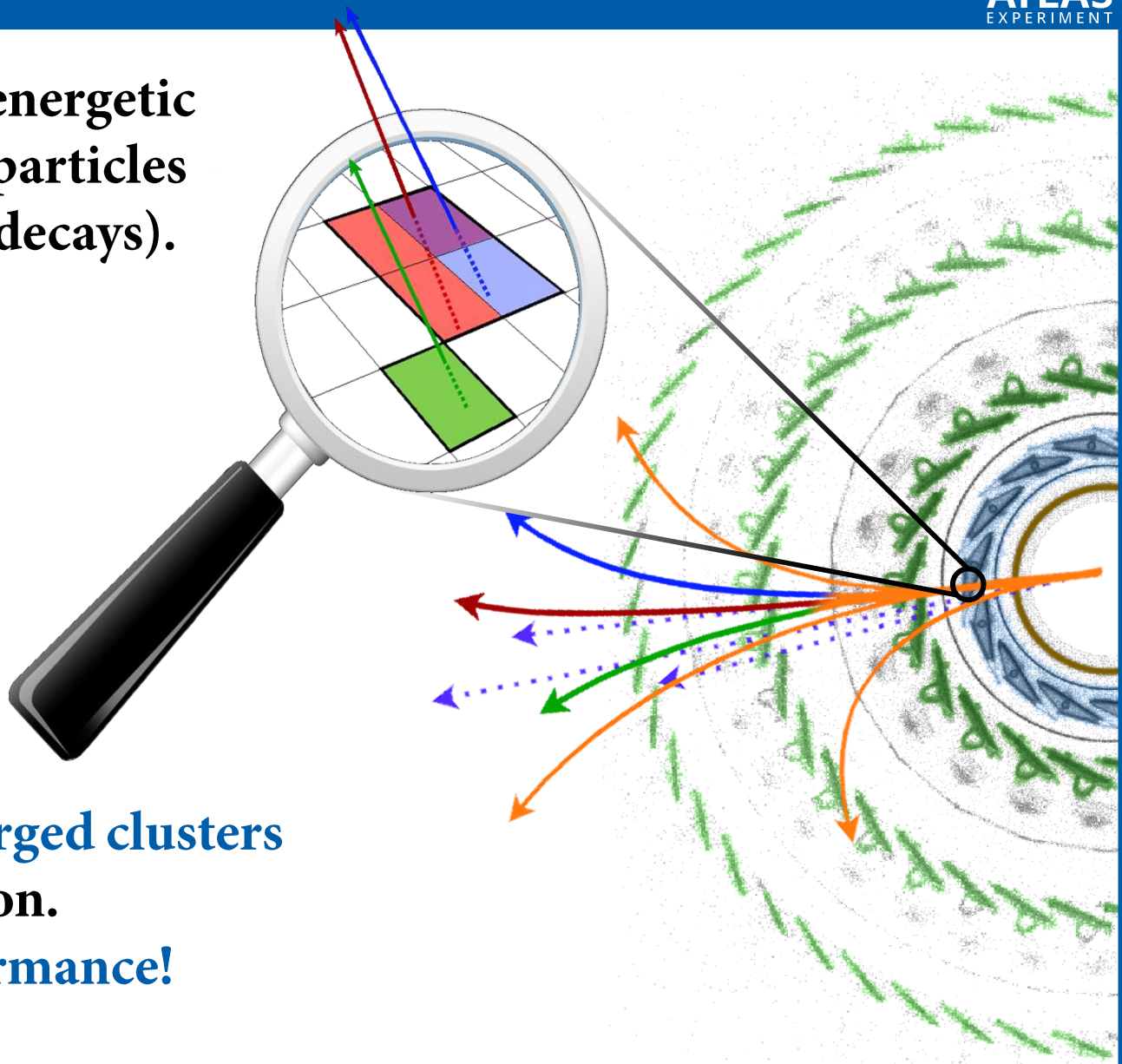
Tracking with Pixel Detectors

pixel sizes:
50μm×400(250)μm



Tracking in Dense Environments

- Common in high energetic jets and decays of particles (e.g. hadronic tau decays).



- Collimation & merged clusters can create confusion.

  ➔ Bad performance!

Tracking in Dense Environments

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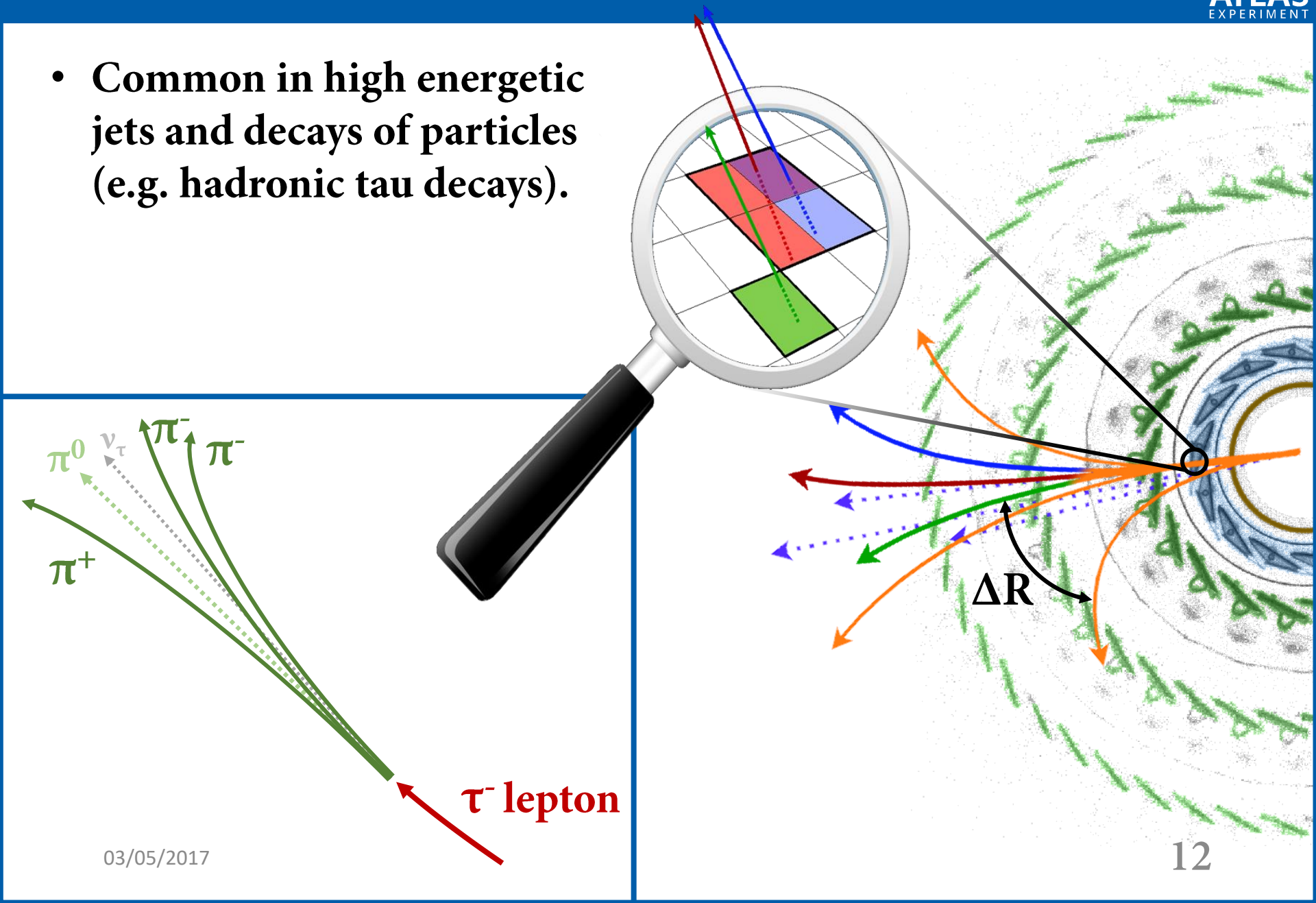
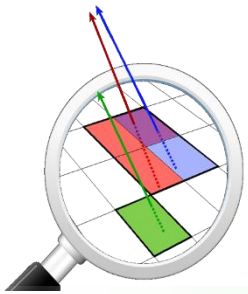
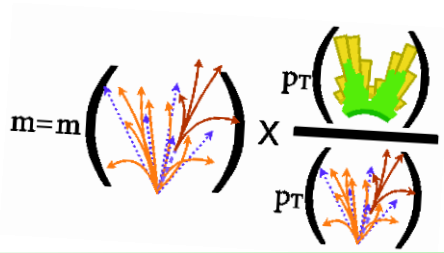
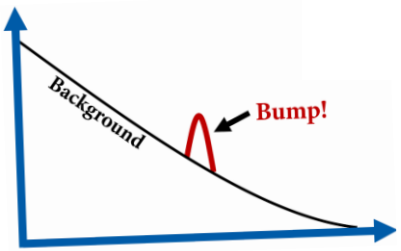
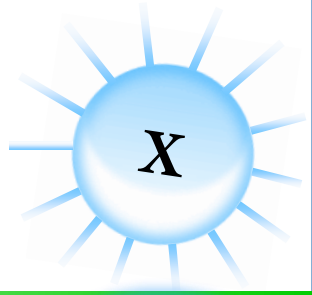


Overview







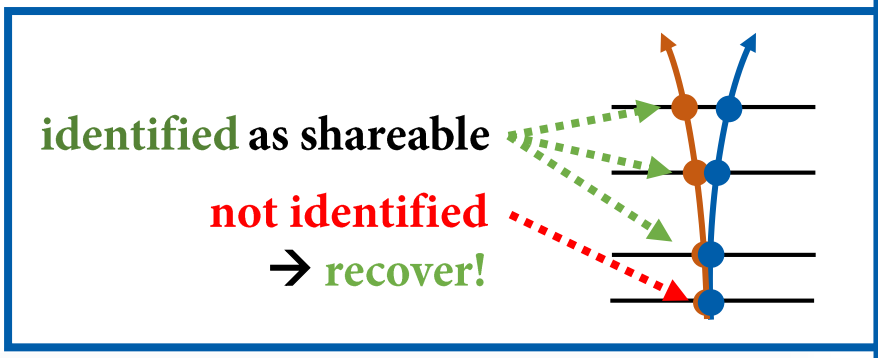


Performant Tracking + Performant Jet Mass + High Sensitivity Search ⇒ Potential Discovery!

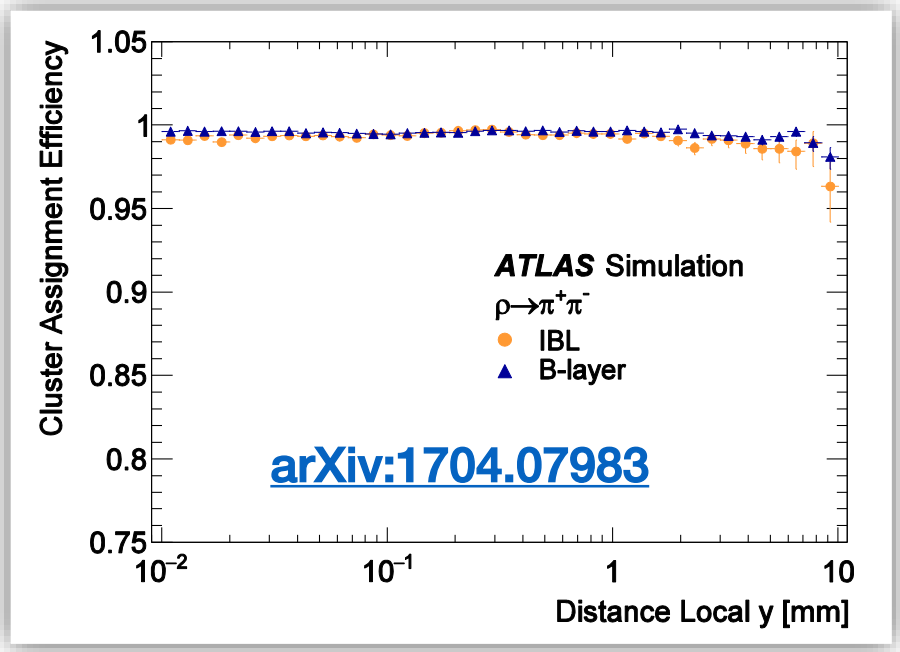
Improving Tracking Performance

- Study of previous performance led to algorithmic improvements and novel developments:
  - Use artificial neural network for analysing clusters.
    → identifies merged clusters.
    → predicts particles position.
  - Exploit global information.
  - Optimize algorithm and tune parameters.

⋮



- **Increases:**
  accuracy of measurement
  efficiency of assignment!



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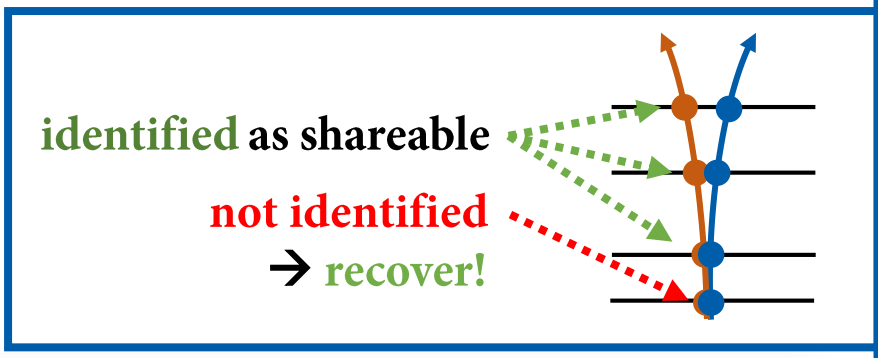

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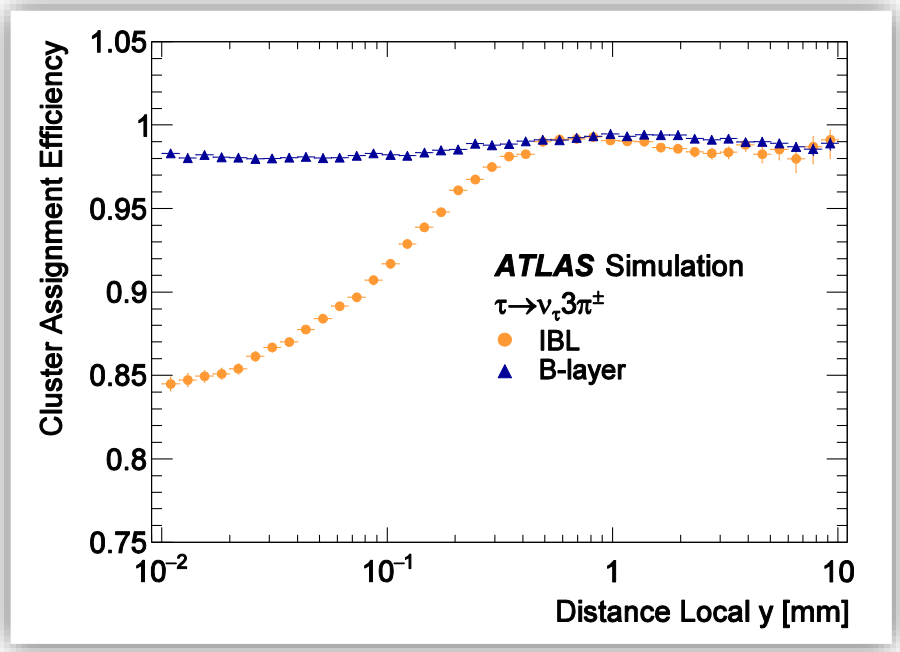

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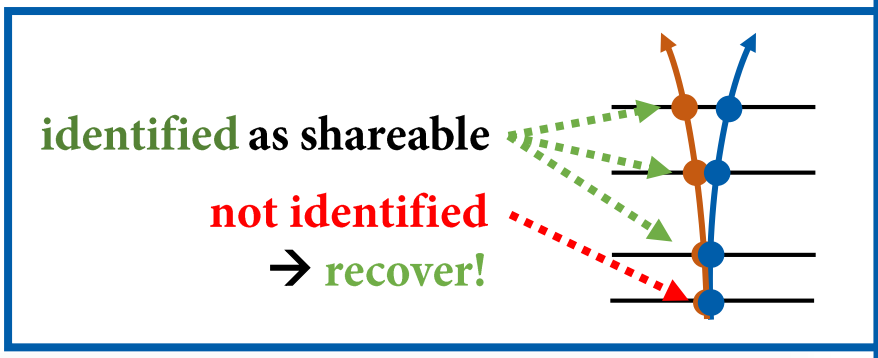

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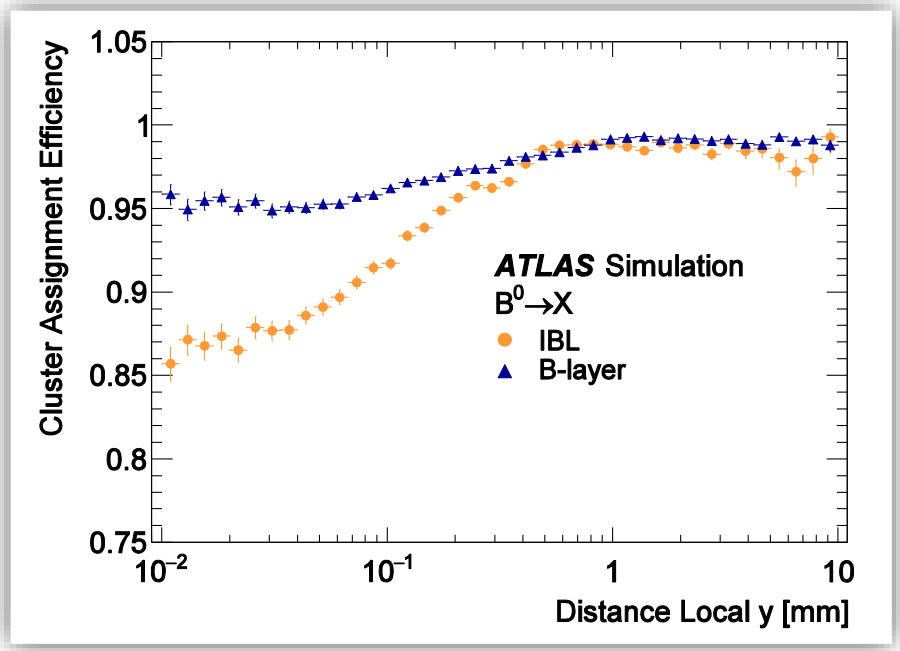
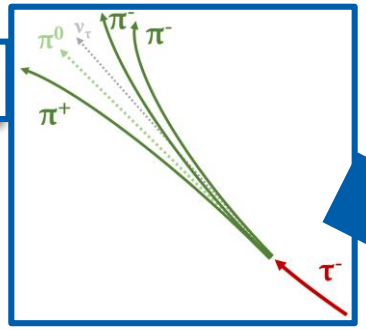
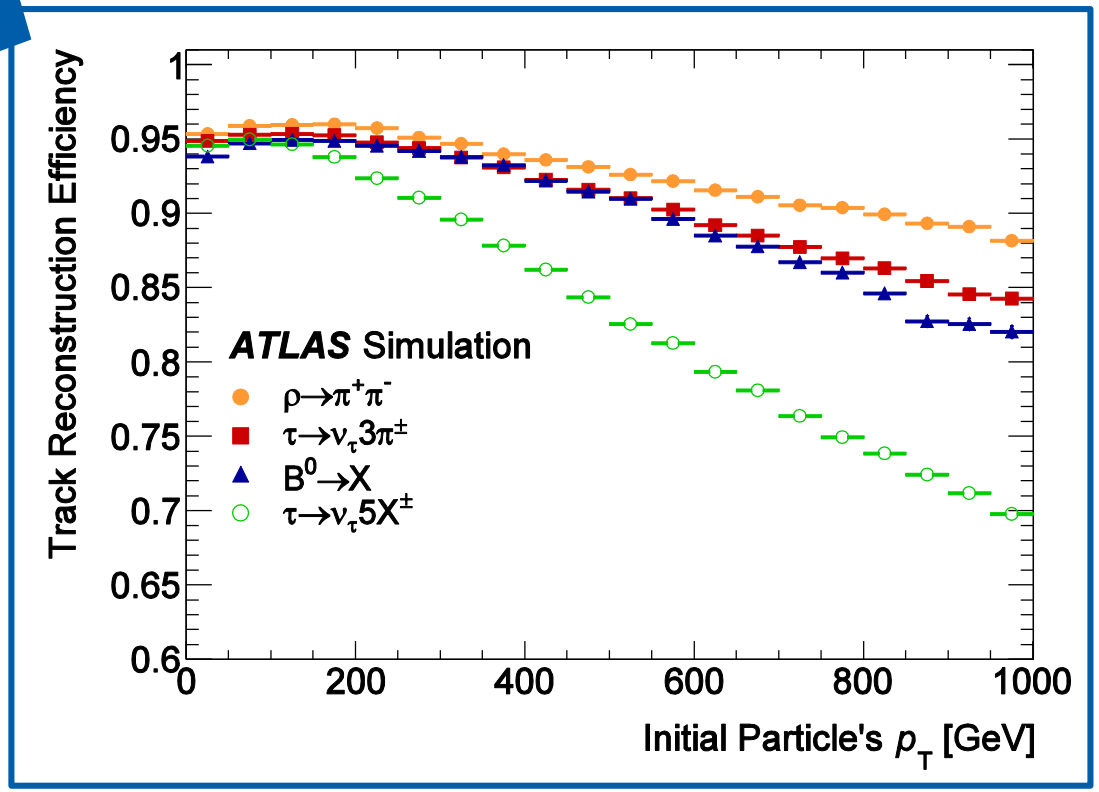


Optimized Performance

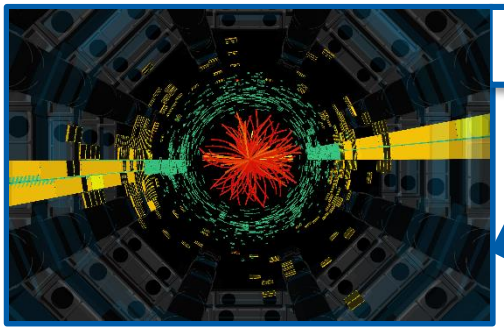
Taus



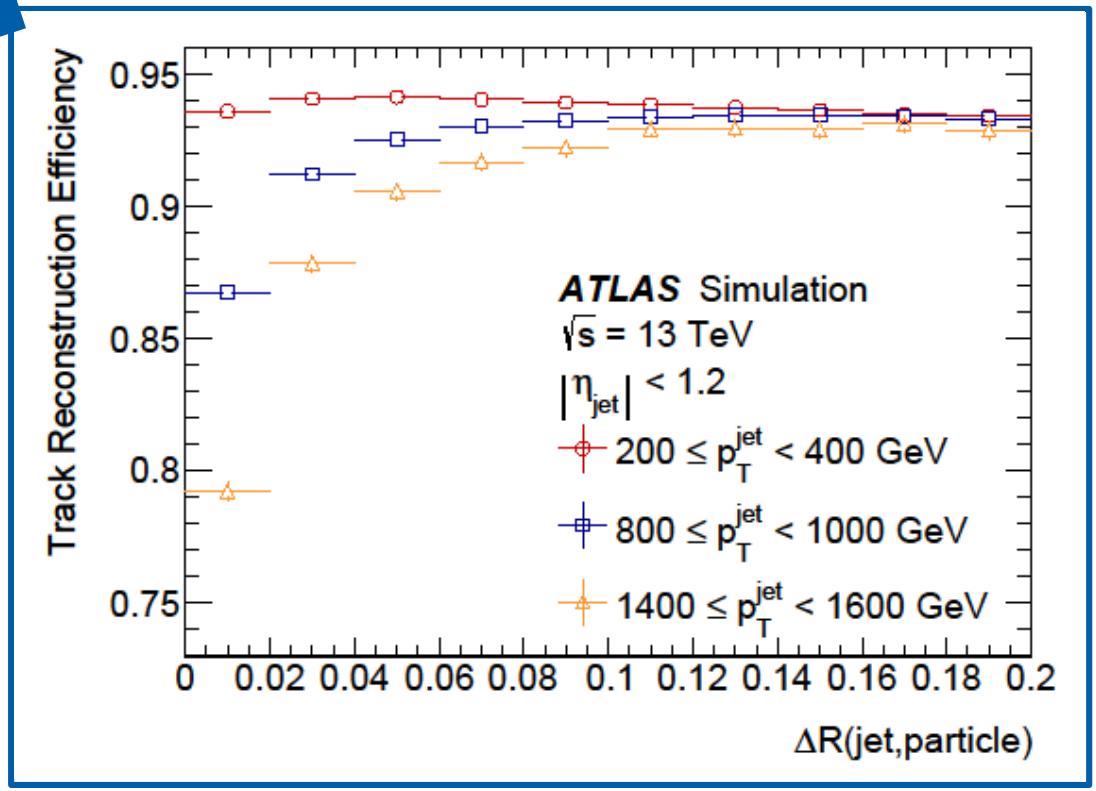


- Efficient hit assignment leads to better performance for physics objects.

Optimized Performance



Jets

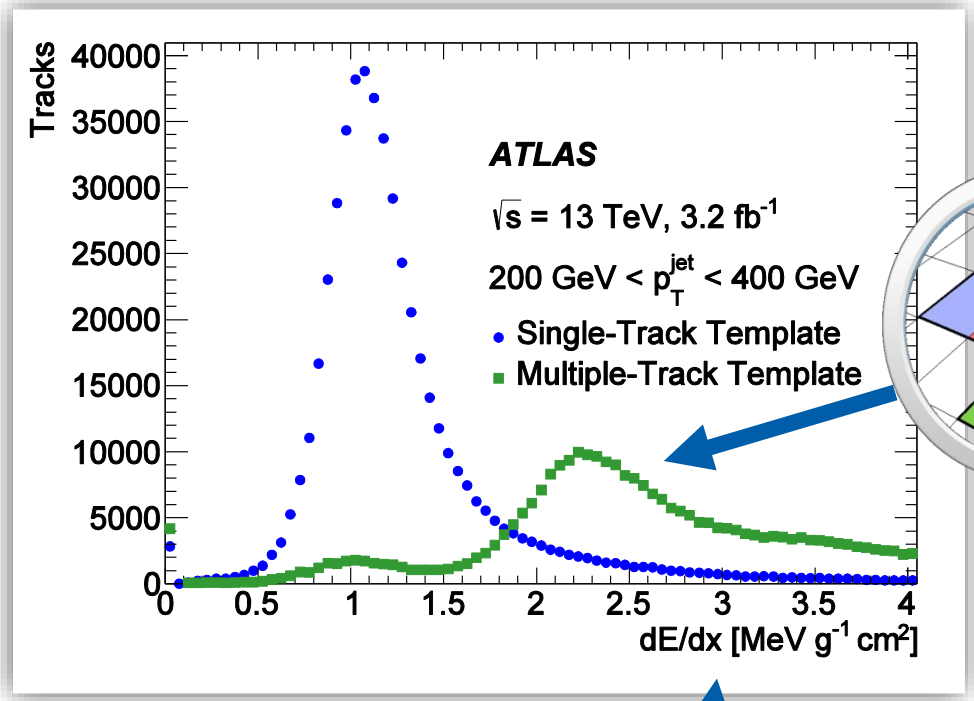


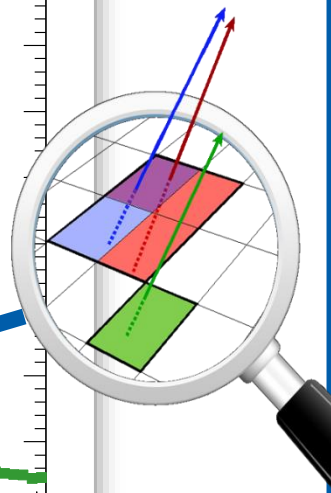
- Efficient hit assignment leads to better performance for physics objects.

Tracking Performance in Data

- Previous results were on simulation
  ➔ **performed several studies to measure performance in data!**

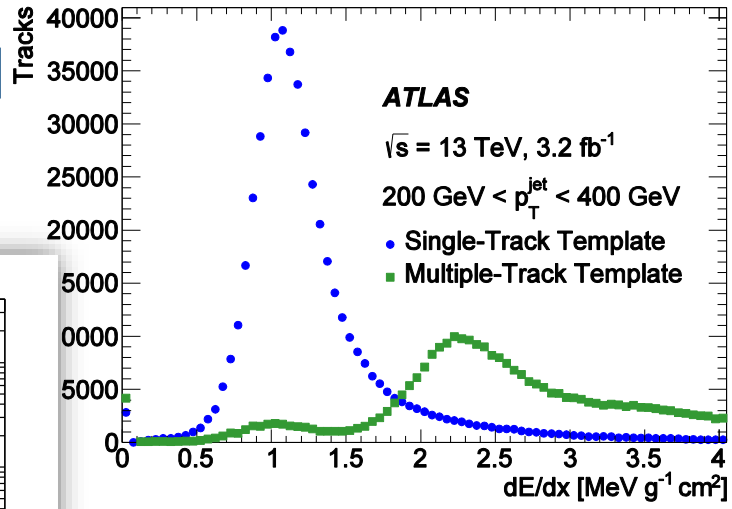
- **Example: novel method to measure efficiency of tracking in dense environments in data.**

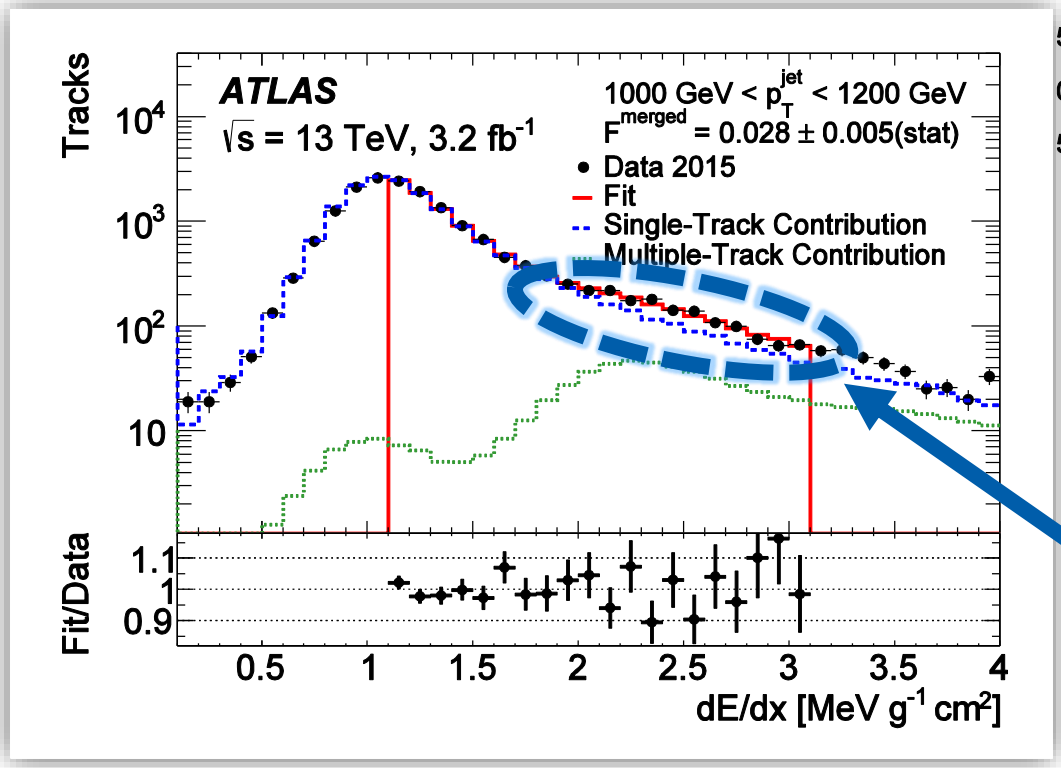




~Energy loss in cluster

Tracking Performance in Data

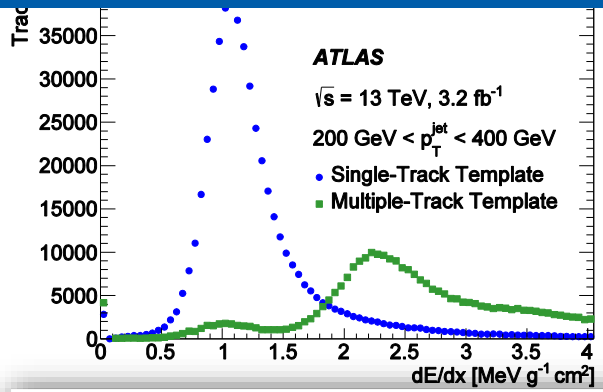


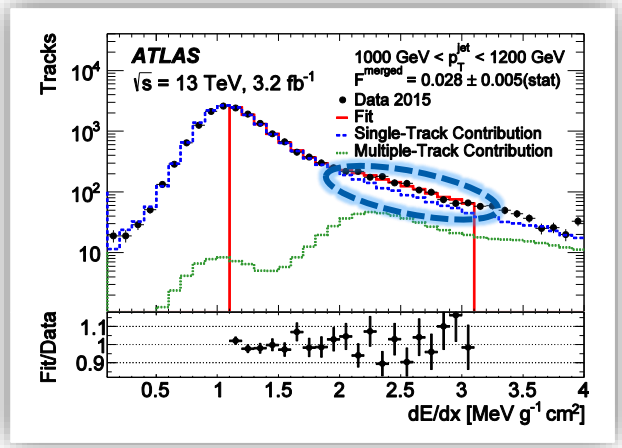


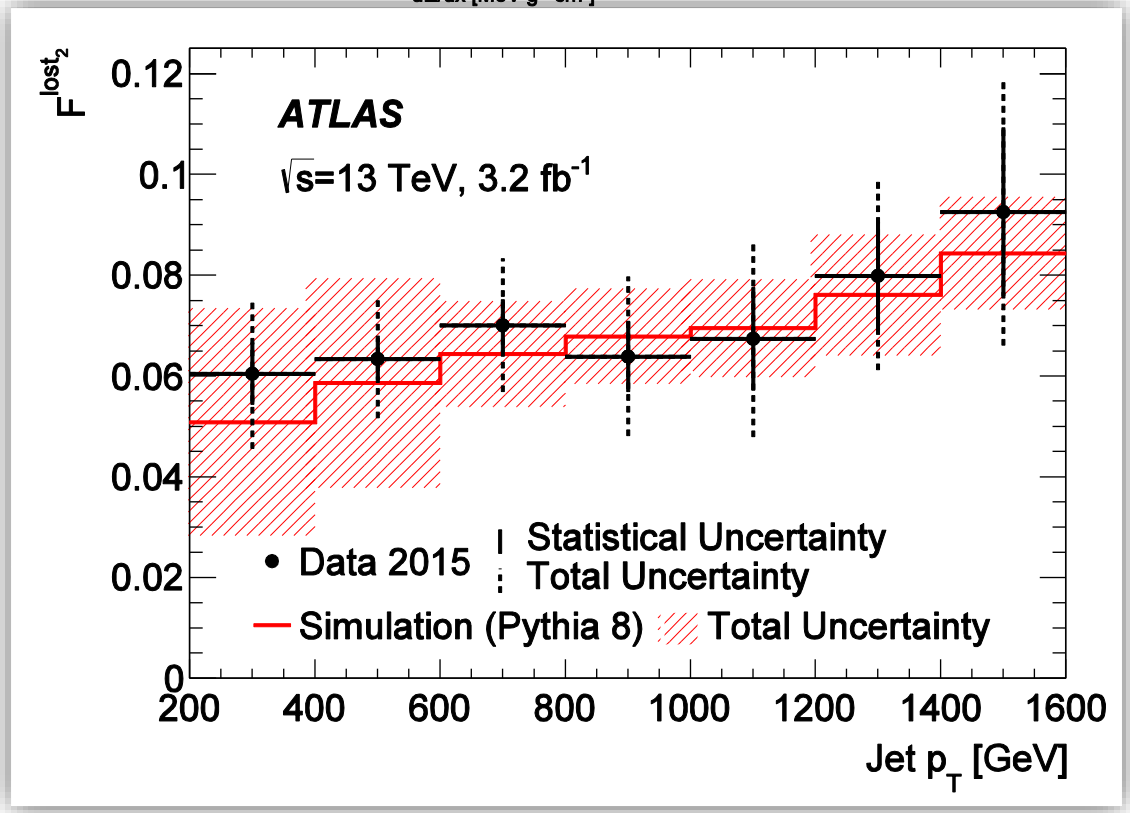
- **Fit fraction of lost tracks with templates.**

Second peak = Inefficiency

Tracking Performance in Data



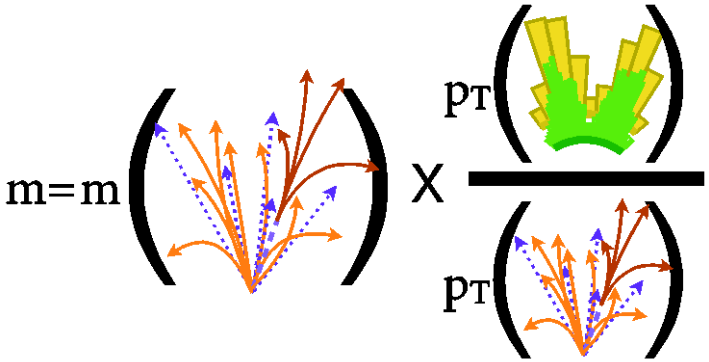




- **Results reduce uncertainty from 50% to ~15%.**

Jet Mass Definition (2)

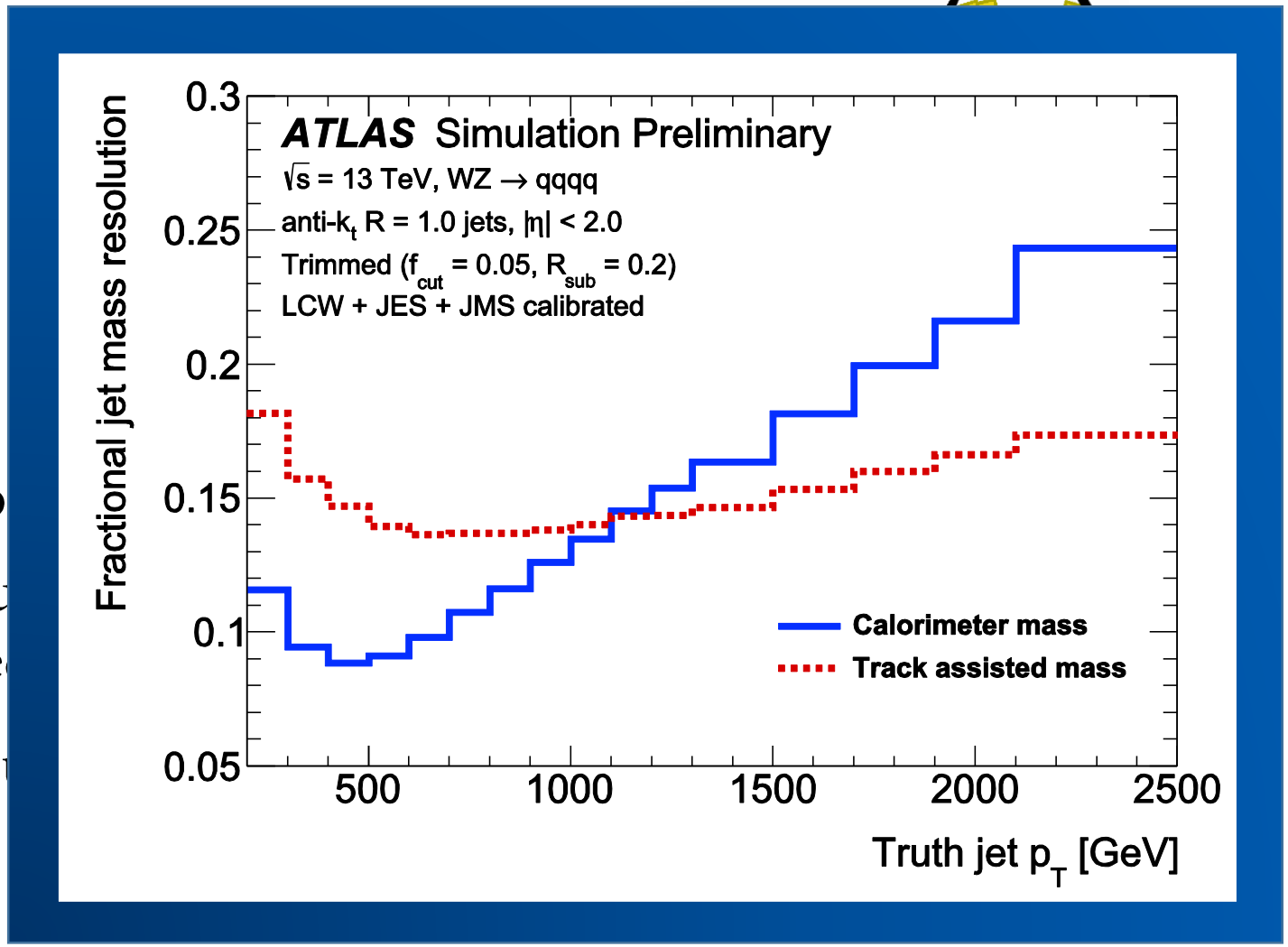
track-assisted jet mass:



- Ratio $\frac{p_T^{calo}}{p_T^{track}}$ corrects for charged-to-neutral fluctuations, improving resolution with respect to track-only jet mass.
- m^{TA} uncertainties factor 2 smaller than m^{calo}.

Jet Mass Definition (2)

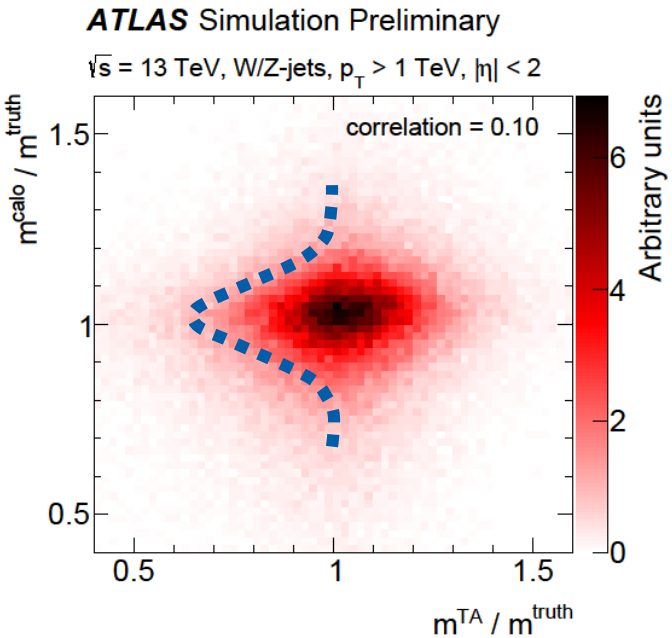
- Ratio
  fluctu
  respe
- m^{TA}



Combined Mass: $m^{\mathrm{TA}} \oplus m^{\mathrm{calo}}$

- m^{calo} not used explicitly in construction of m^{TA}

  ➡ Reduce resolution by combining both mass definitions.



- Approximate independence and Gaussian nature of responses.

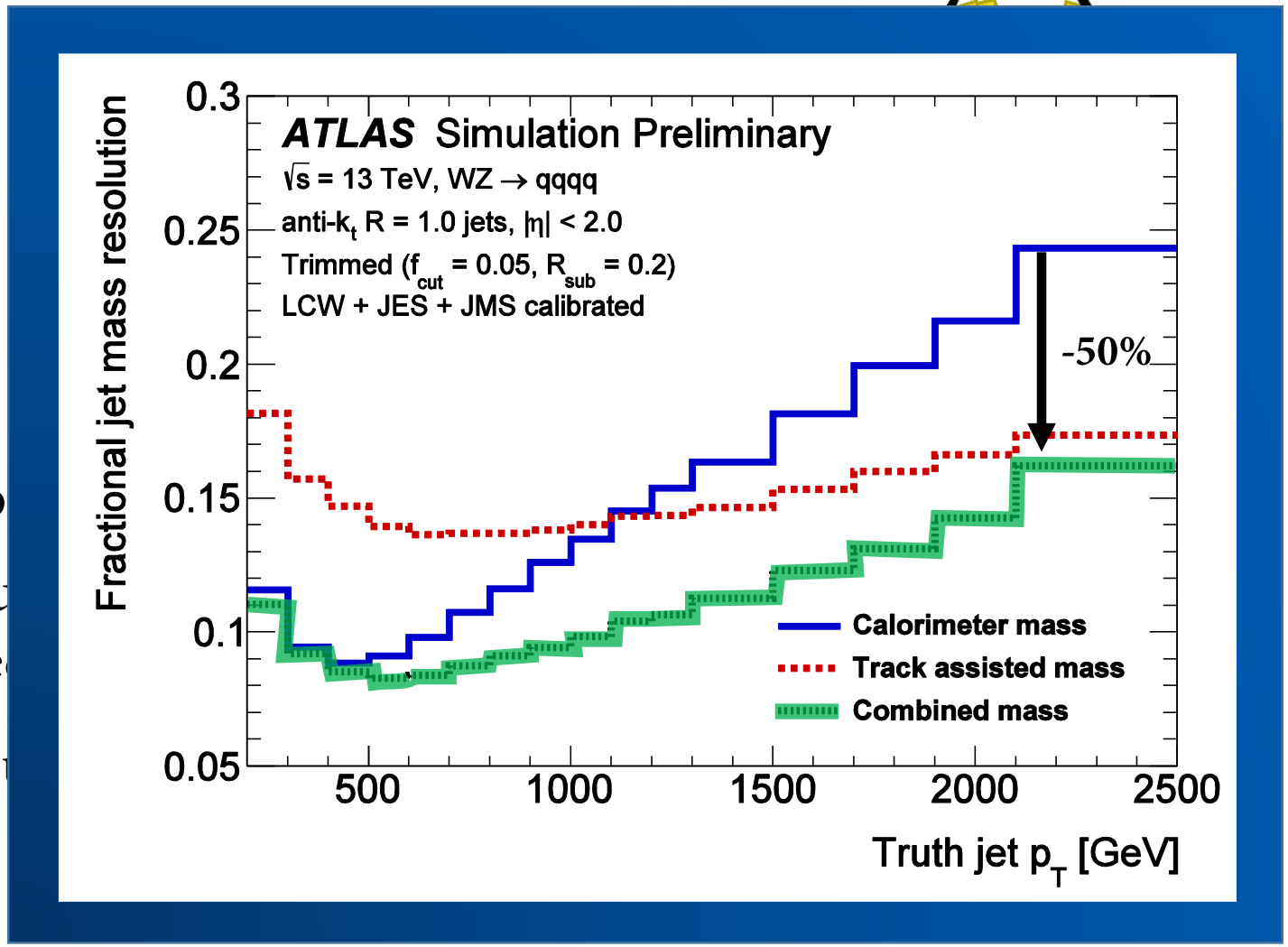
  ➡ (Nearly) optimal combination of variables is linear.

$$m^{\mathrm{comb}} = a \times m^{\mathrm{calo}} + b \times m^{\mathrm{TA}}$$

- Choose a and b mass according to individual mass resolutions.

Jet Mass Definition (2)

- Ratio
  fluctu
  respe
- m^{TA}



Analysis Overview

- Sear
  to W
- Resu
  ➔
  ➔
- Fin
  ➔
  ➔

Z/W

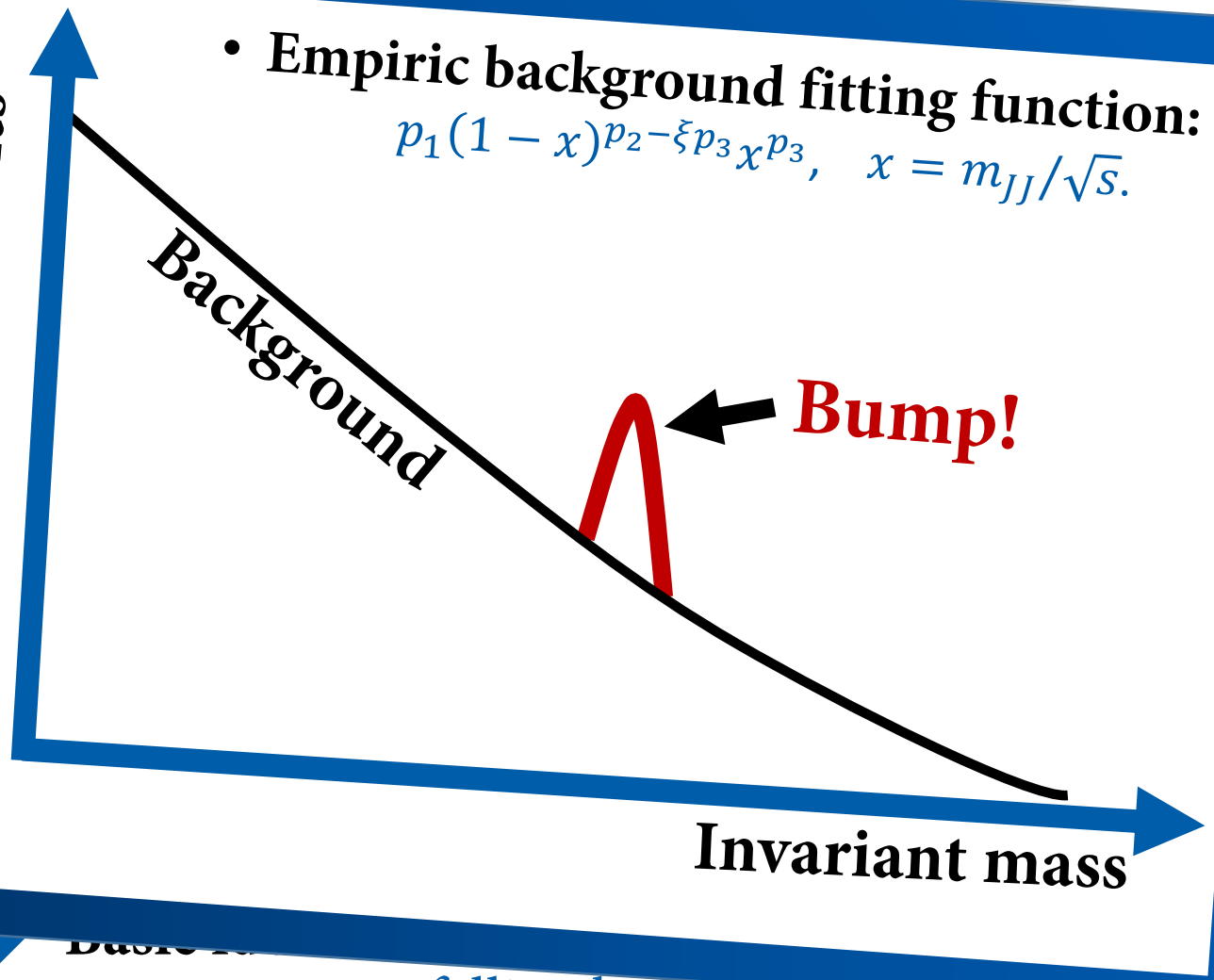
Z/W

ns.

R-S graviton

- **Empiric background fitting function:**

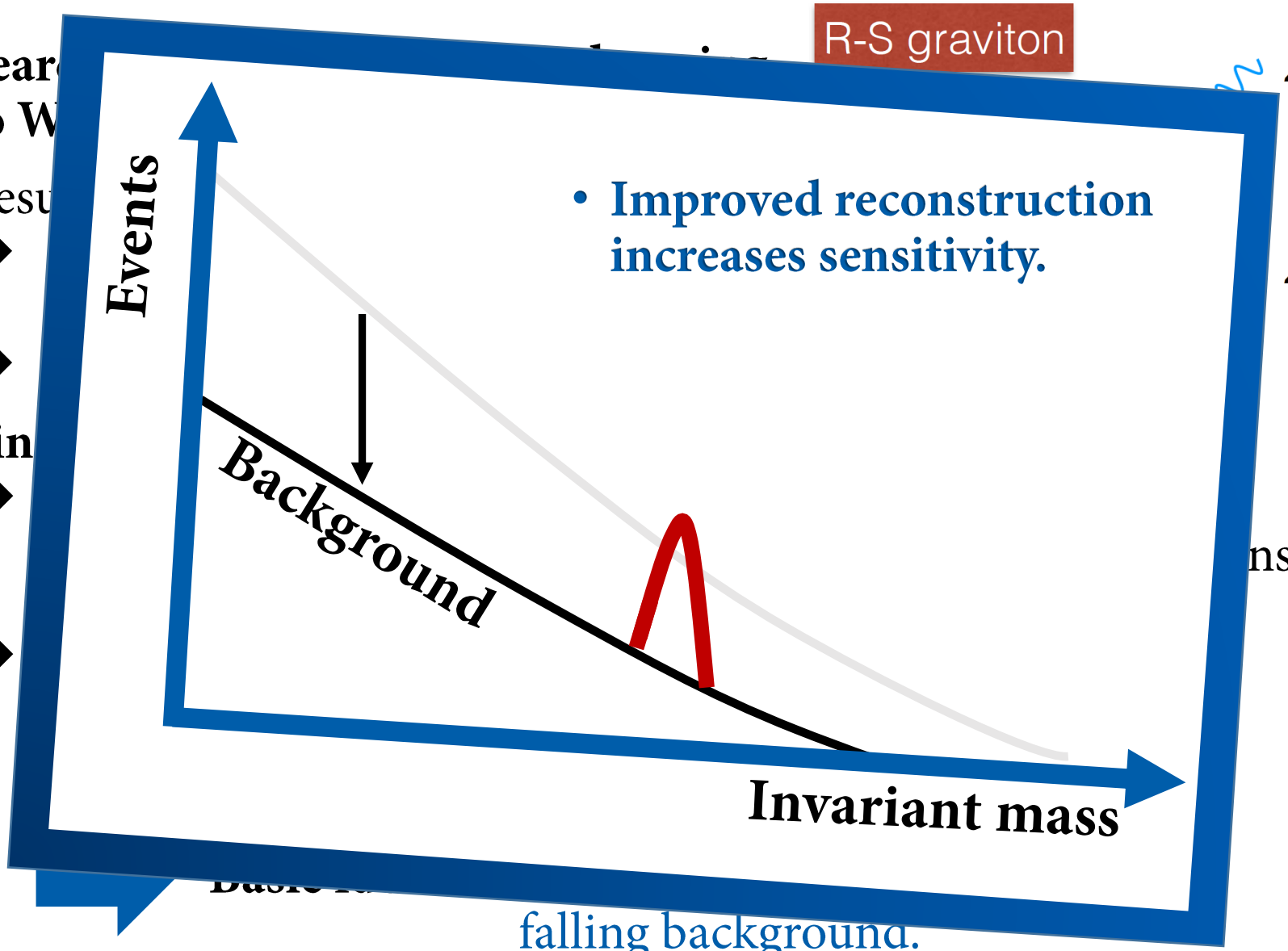
$$p_1(1-x)^{p_2-\xi p_3}x^{p_3}, \quad x = m_{JJ}/\sqrt{s}.$$



falling background.

Analysis Overview

- Sear
  to W
- Resu
  ➔
  ➔
- Fin
  ➔
  ➔



Z/W

Z/W

ns.

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Z/W

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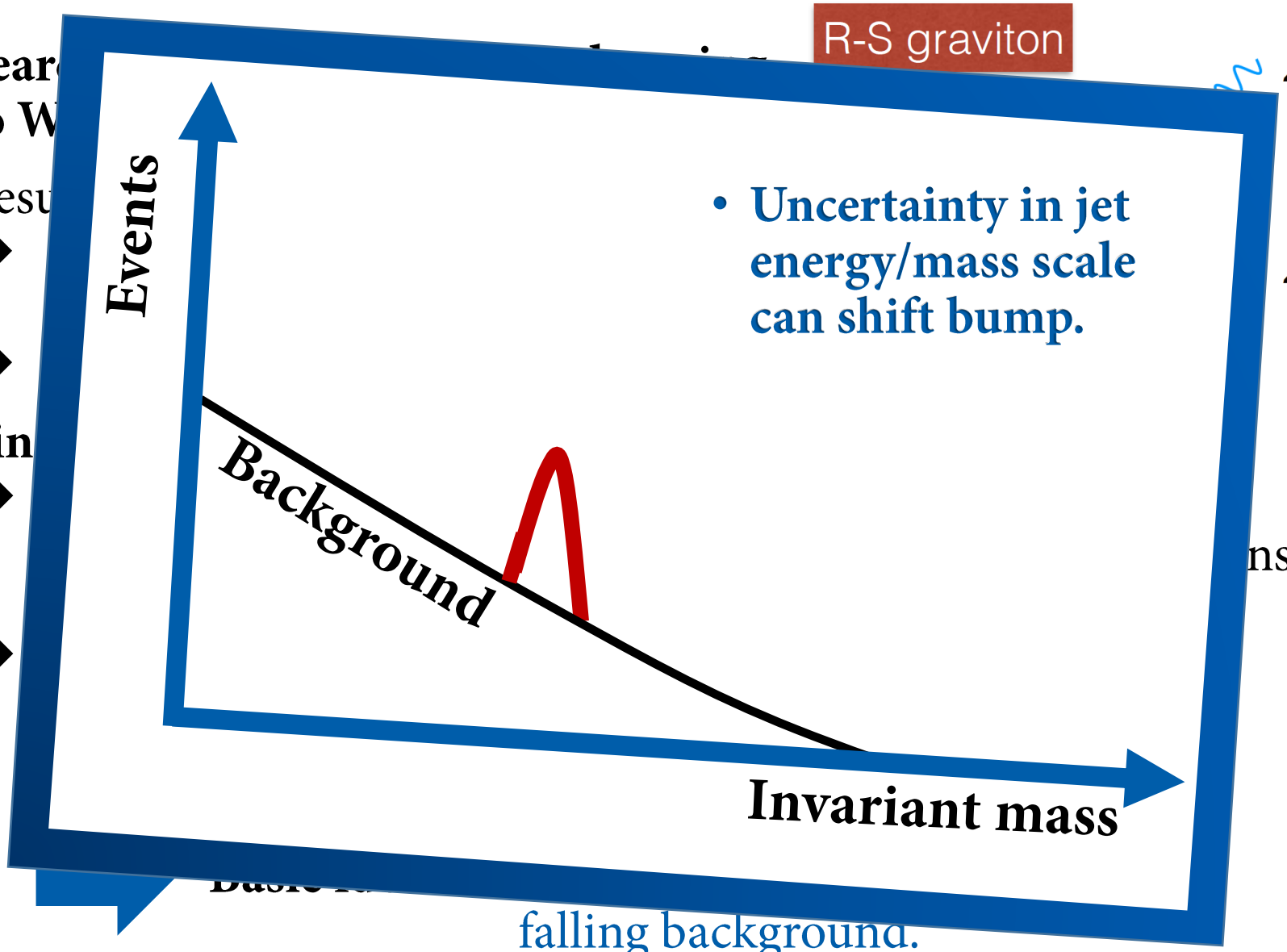

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Analysis Overview

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- Fin
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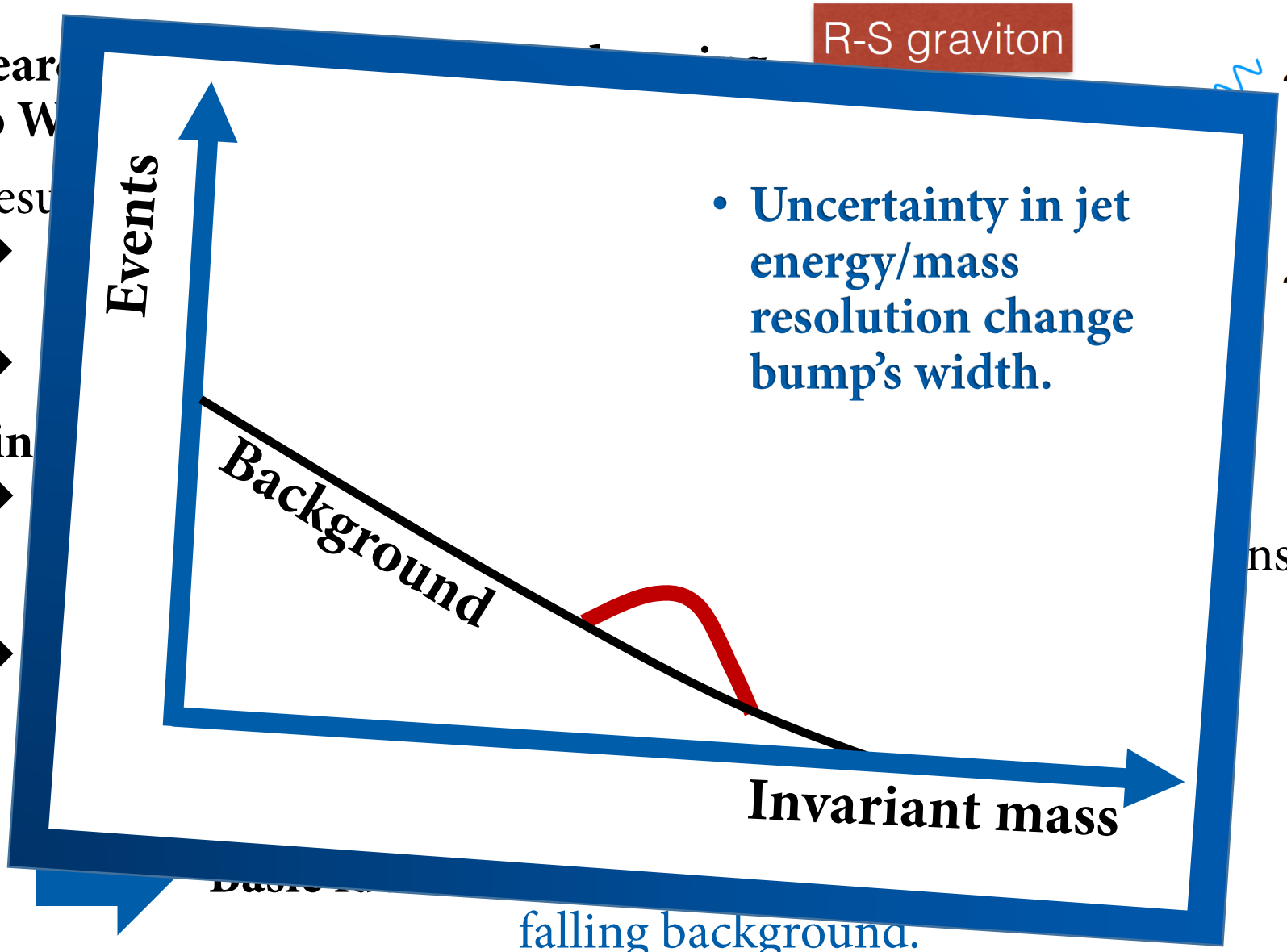


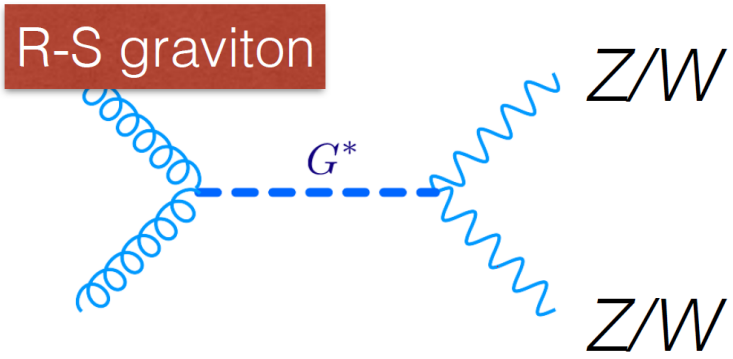
Z/W

Z/W

ns.

falling background.

Analysis Overview

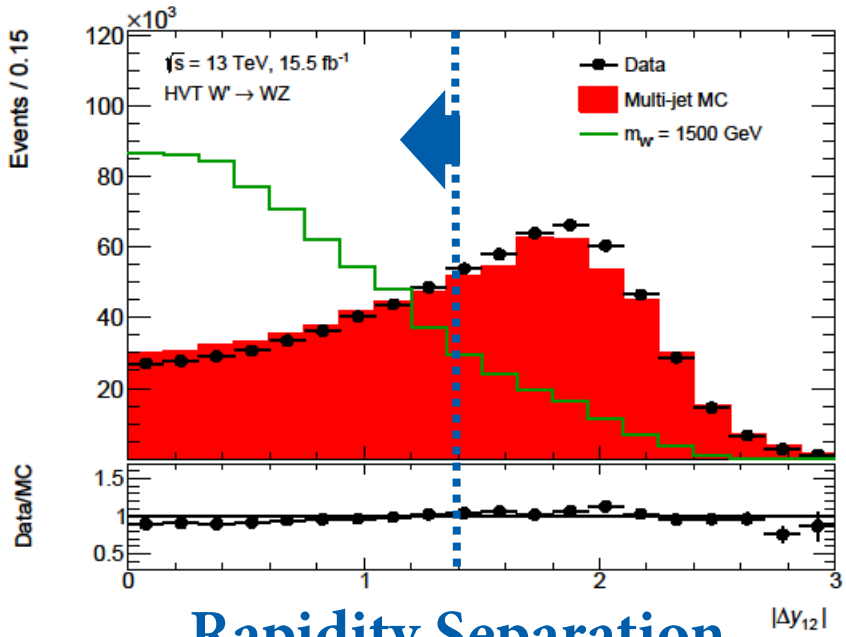


- **Search for heavy resonances decaying to WZ, ZZ and WW.**
- Results interpreted in terms of:
  - ➔ bulk Randall-Sundrum graviton decaying to WW/ZZ.
  - ➔ Heavy Vector Triplet (W′, Z′) decaying to WZ and WW.
- **Final state oriented analysis.**
  - ➔ Hadronic decays are important.
    →3/10× more hadronic W/Z decays than into light leptons.
  - ➔ High-p_T region.
    →hadronic decays can provide great sensitivity.
    →QCD dijet background low or can be supressed.

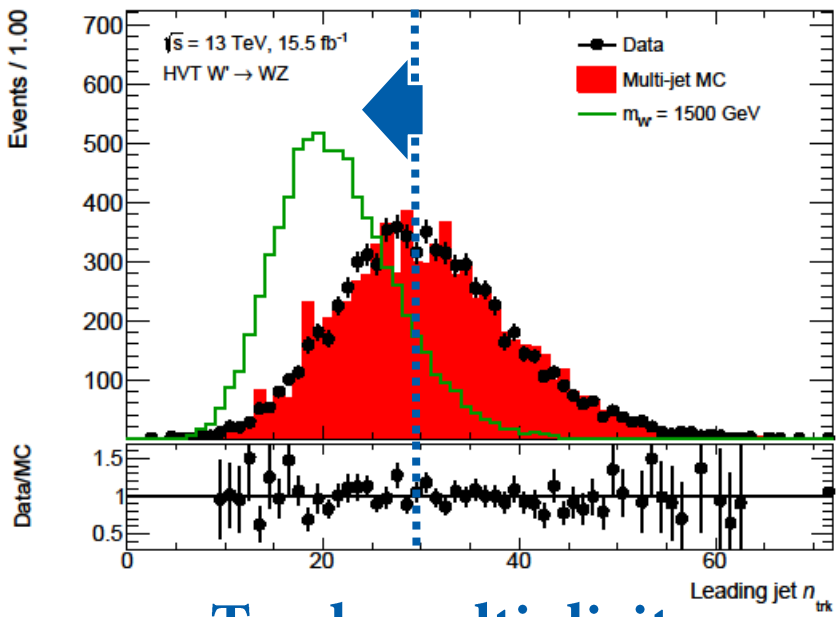
Basic idea: Bump-Hunting in smoothly falling background.

Analysis Selections

- **Kinematic selections enhance diboson signal over background. Example:**
  - **Rapidity separation:** signal events more central than QCD background.



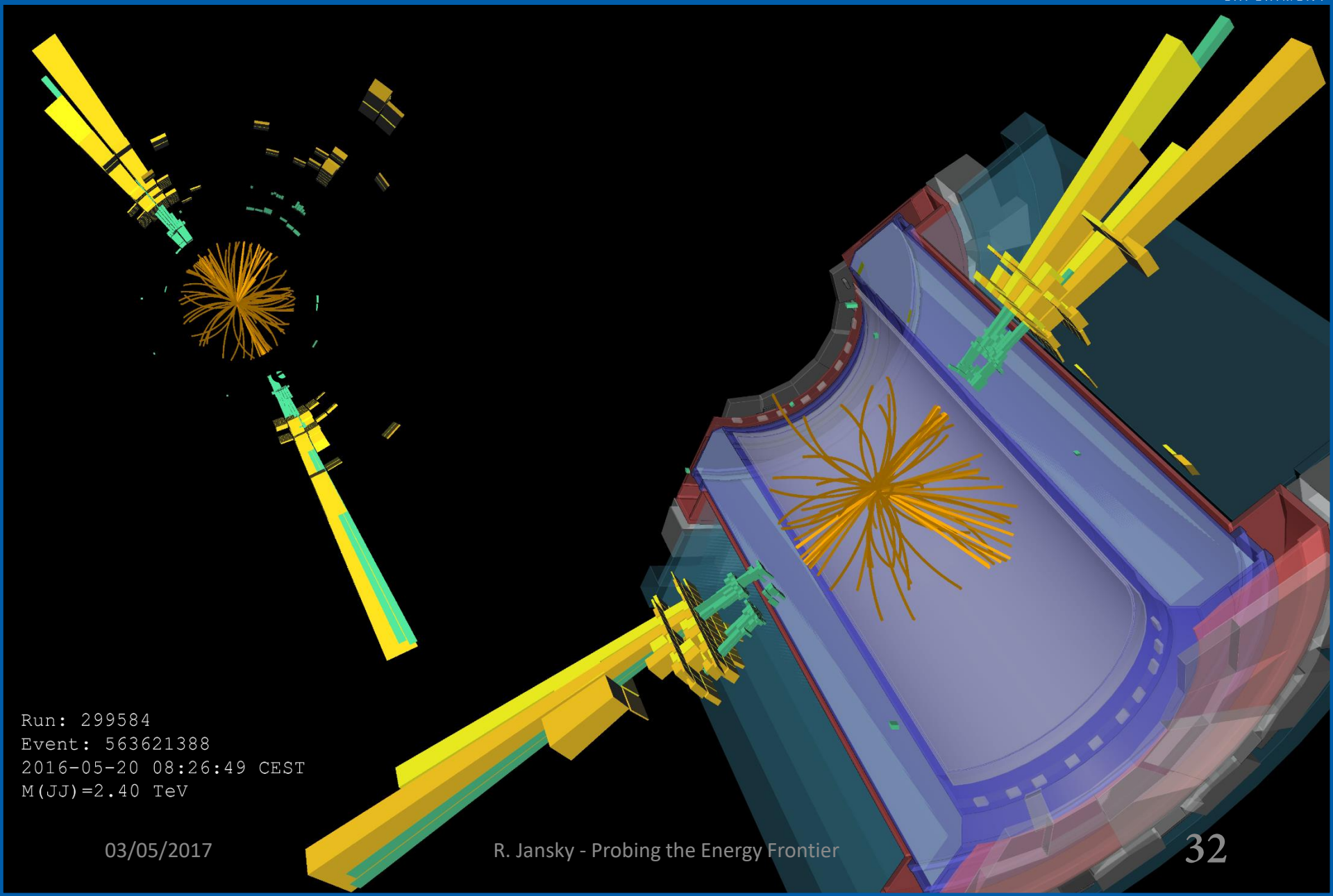
Rapidity Separation



Track-multiplicity.

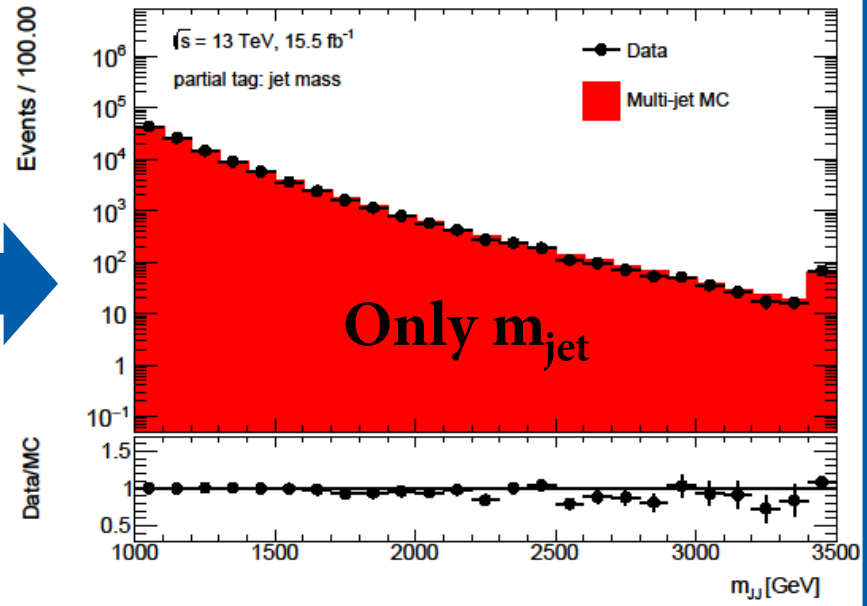
- **Identify jets as Boson-like:**
  - **Jet mass.**
  - Substructure (D_2).
  - Track-multiplicity.
- **Signal regions:**
  WZ, WW and ZZ.

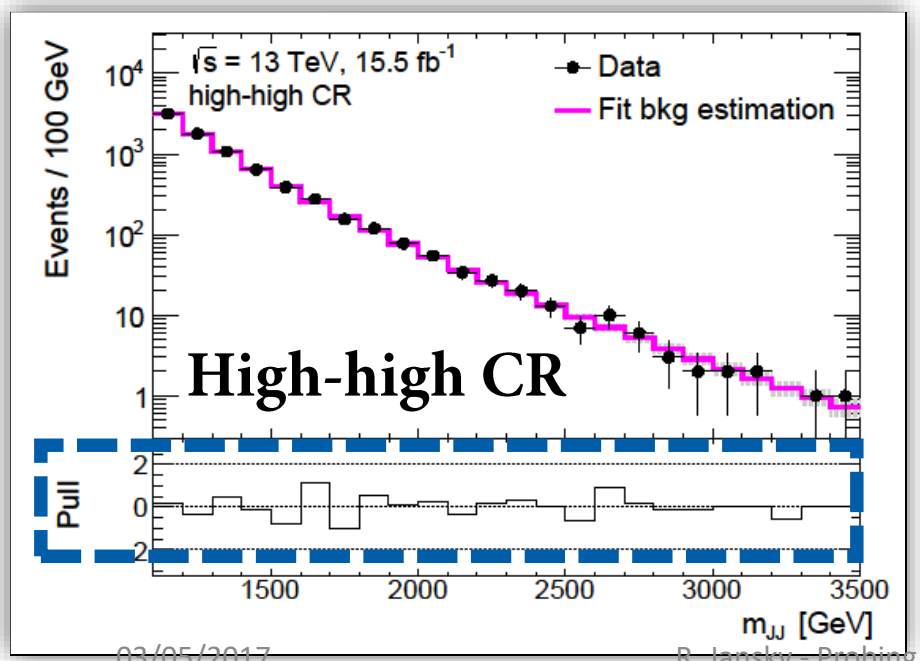
Signal-like Event



Control Regions

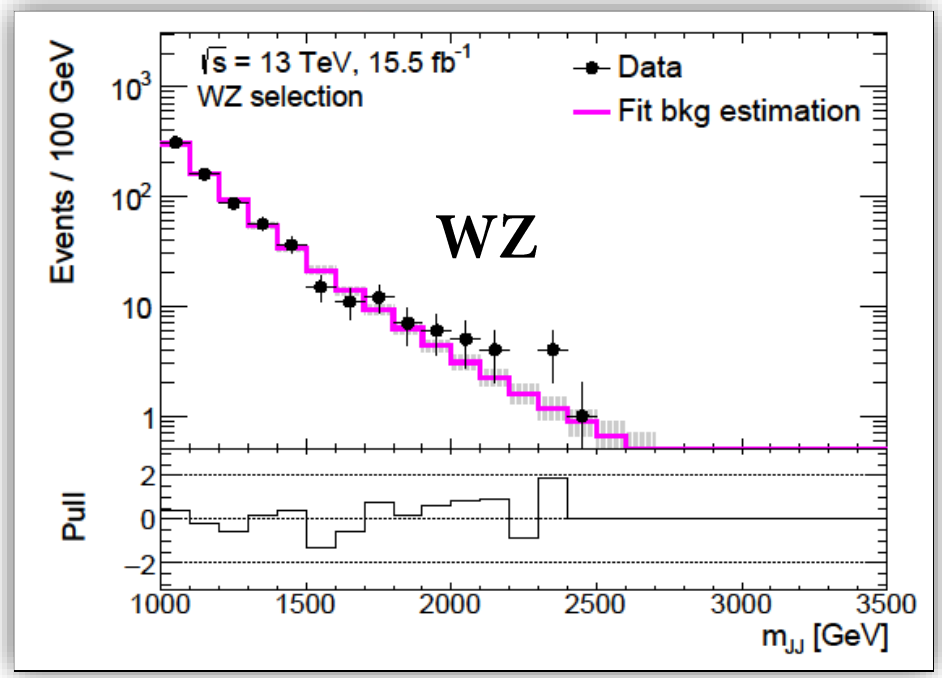
- **Following CRs used:**
  - Jets in a low (50-65 GeV) or high (110-140 GeV) mass sideband.
  - Partial boson selection(only mass, D_2, or track-multiplicity).
  - V+jets CR allows for derivation of uncertainty on track-multiplicity.

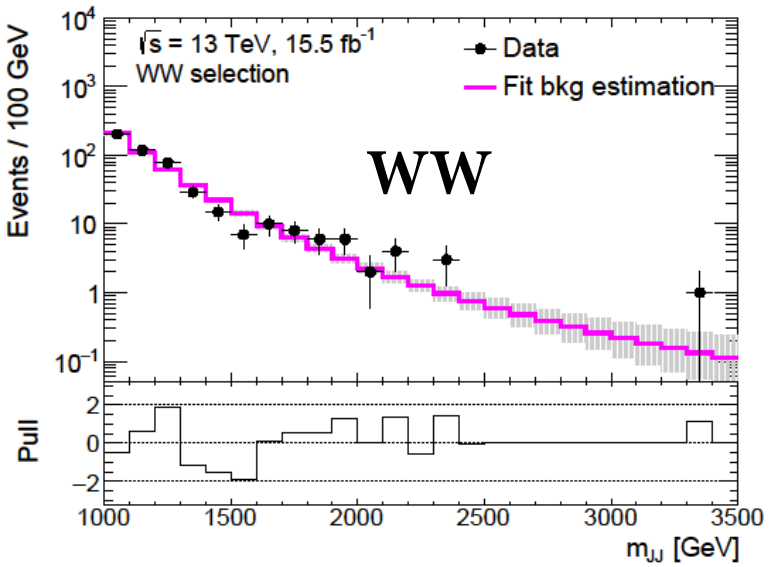


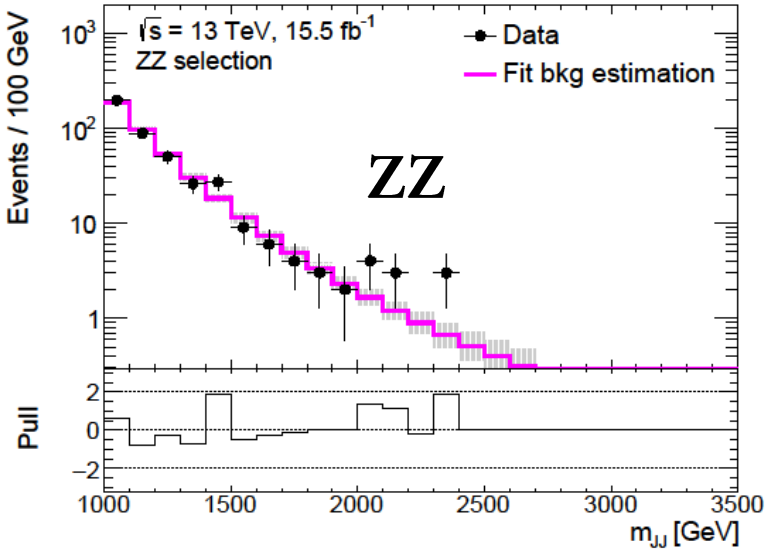


- **Why CRs for data-driven analysis?**
  - Ensure selections are not sculpting the background.
  - Test the robustness of fitting function.

Results: Fitted Signal Regions

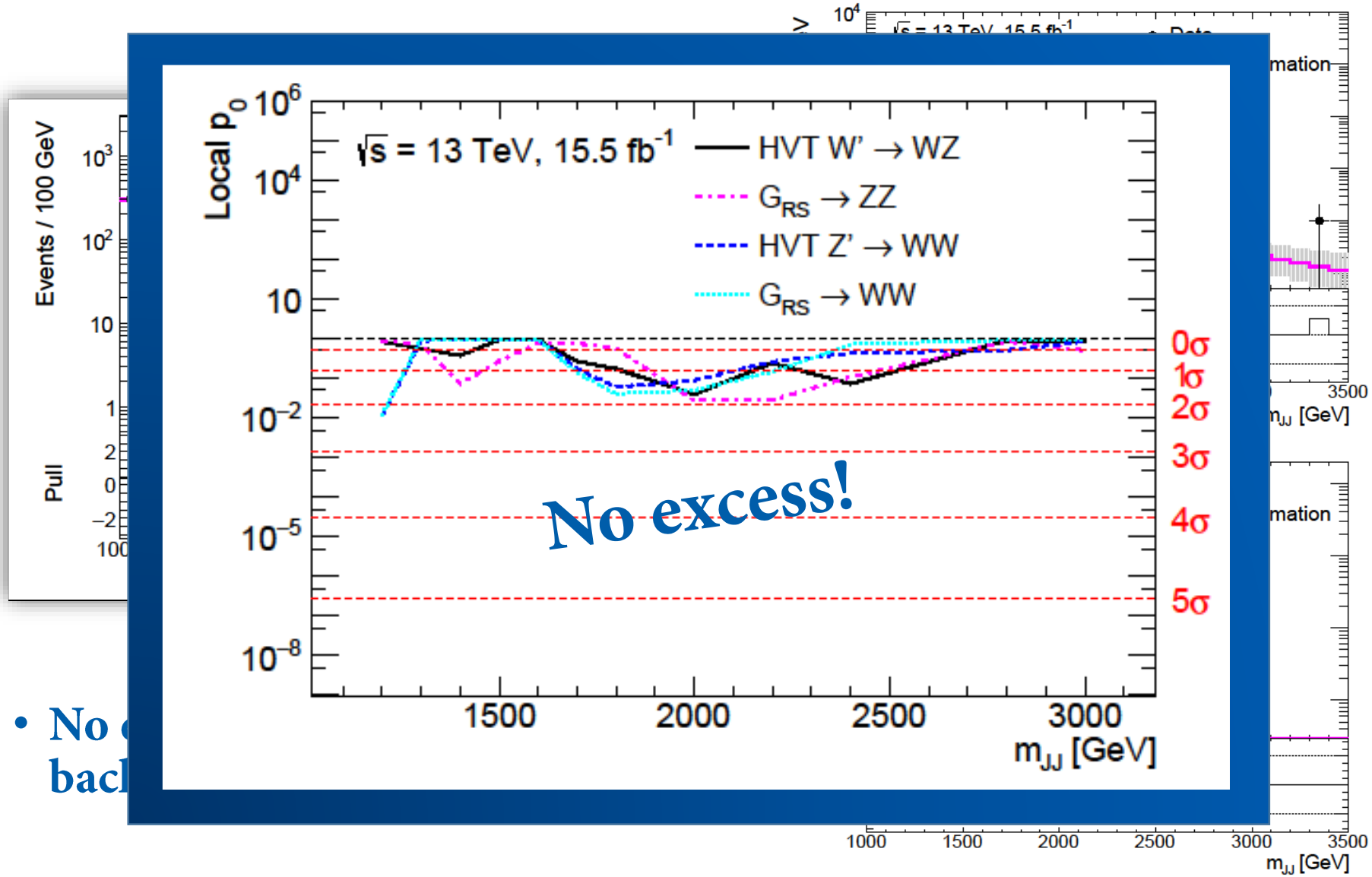






- **No excess over fitted background observed in any signal region.**

Results: Fitted Signal Regions

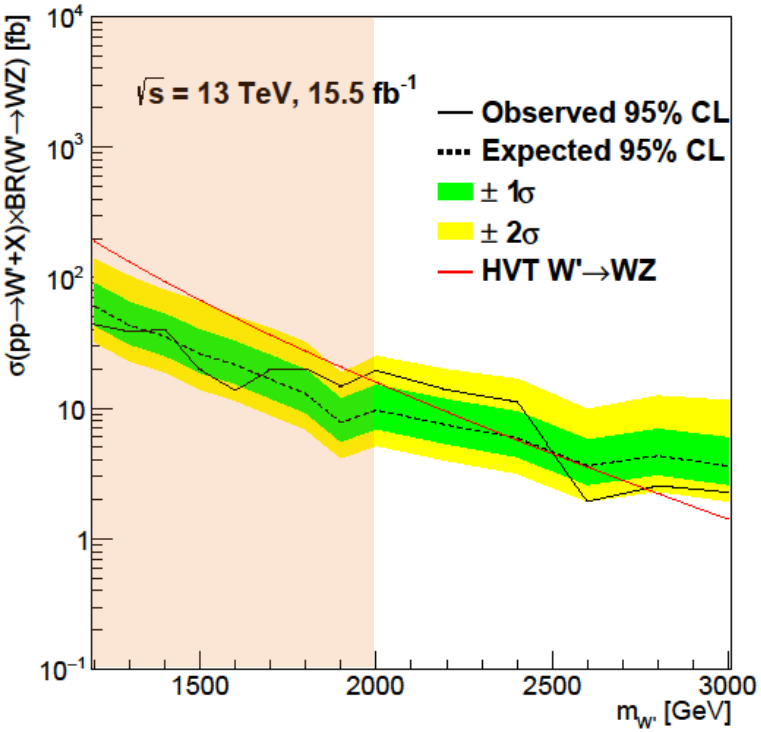


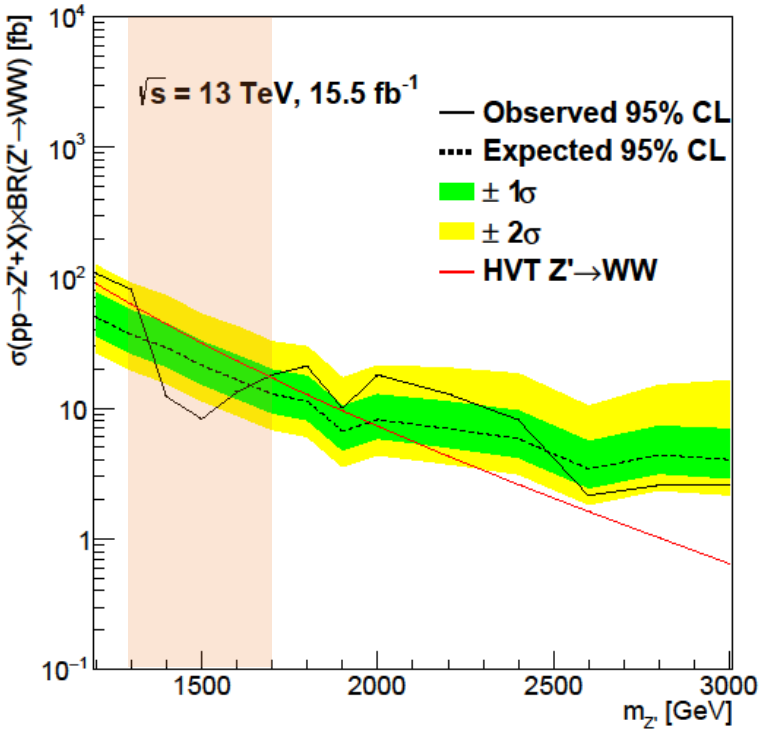
- No e
bacl

Results: Limits for Benchmark Models

Previous HVT limit:
W′→WZ 1.38 - 1.6 TeV

- Able to set best exclusion limits on new resonances of HVT model with 95% confidence level :
  - W′→WZ:
    masses between 1.2 - 2.0 TeV.
  - Z′→WW:
    masses between 1.3 - 1.7 TeV.





- Not able to exclude bulk RS graviton with current sensitivity.

Summary

- Developments provide excellent performance of track reconstruction in dense environments.
  - ➔ New studies helped vastly reduce tracking related uncertainties.
- Improved tracking performance and uncertainties allow for novel methods of jet mass reconstruction.
  - ➔ Provides superior performance and reduces related uncertainties.
- Utilizing these performance optimizations a search for heavy diboson resonances was performed.
- No excess observed.
  - ➔ But best exclusion limits yet set!