Kaon physics strikes back

Seminar, December 7th, University of Geneva, Geneva, Switzerland
Speaker: Radoslav Marchevski

NA62 P326

EPFL

מכון ויצמן למדע
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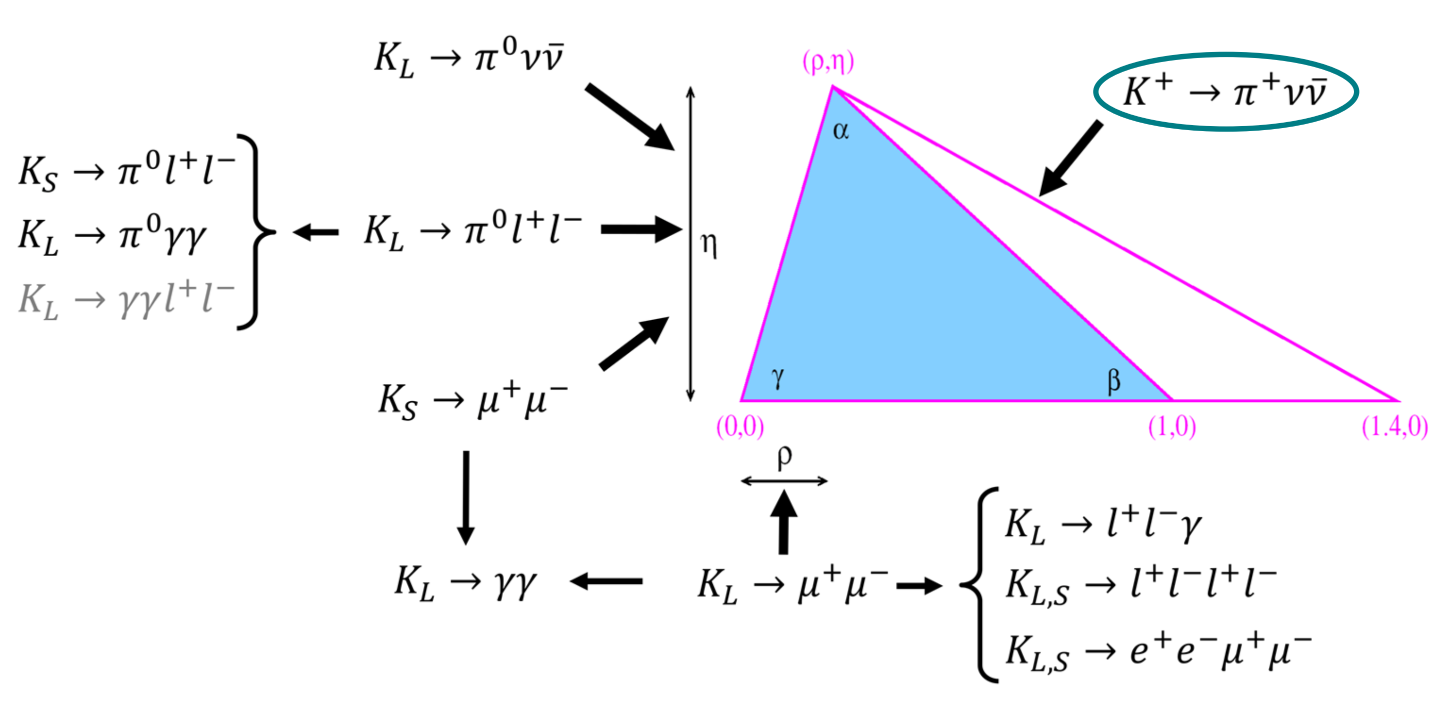
Outline

- **Why** are kaon decays important?
- **How** to measure the ultra rare $K^+ \to \pi^+ \nu\bar{\nu}$ process with NA62?
- **What** is the future of experimental kaon physics at CERN?
    - The High Intensity Kaon Experiment (HIKE) proposal
    - Ides for the far future ($K \to \mu^+\mu^-$ interference)

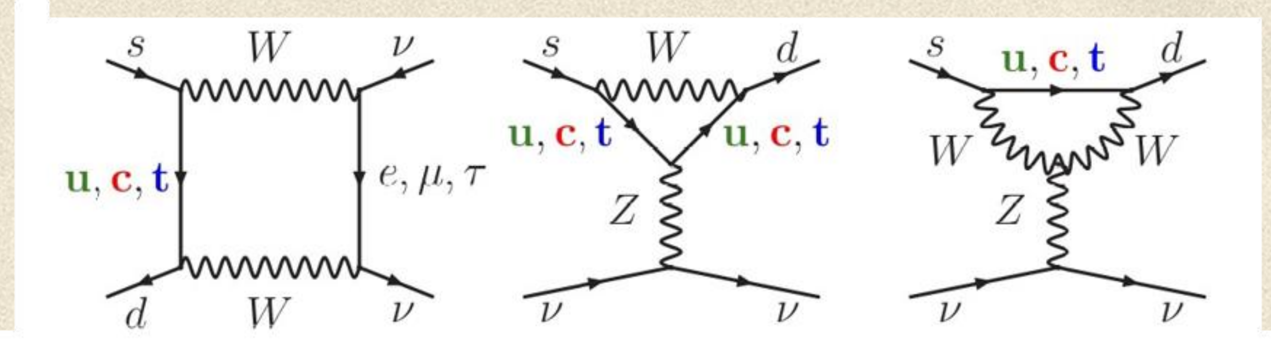
Why are kaon decays important?

Constraining the Unitarity Triangle with kaons

- Overconstraining the UT with kaons is a crucial compatibility test of the SM
- Rare kaon processes can reach unprecedented mass scales, far beyond the reach of LHC
- Measuring all charged and neutral kaon decay modes can give clear insights into the flavour structure of NP



The K→ $\pi\nu\bar{\nu}$ decay in the SM



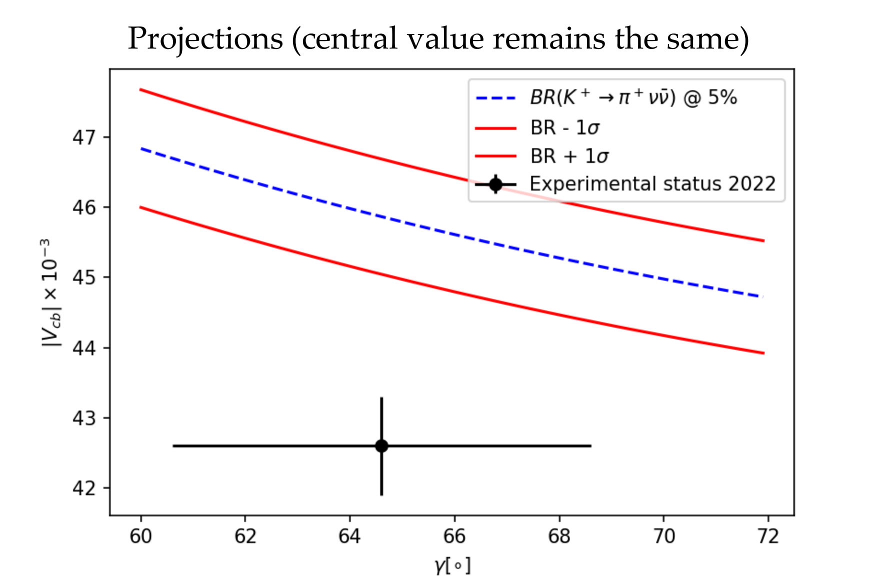
- s → d quark transition: *loop + CKM suppression, very rare in the SM*
- Decay amplitude dominated by short-distance (SD) physics: *theoretically clean*
- Hadronic matrix element measured with $K^{\pm} \rightarrow \pi^0 l^{\pm} \nu_l$ decays: *sub-% precision*
- Latest SM predictions [arXiv:2105.02868]:
  - $\boldsymbol{BR_{SM}(K^+ \rightarrow \pi^+ \nu\bar{\nu}) = \left(7.73 \pm 0.16_{SD} \pm 0.25_{LD} \pm 0.54_{param.}\right) \times 10^{-11}}$
  - $\boldsymbol{BR_{SM}\left(K_L \rightarrow \pi^0 \nu\bar{\nu}\right) = (2.59 \pm 0.06_{SD} \pm 0.02_{LD} \pm 0.28_{param.}) \times 10^{-11}}$

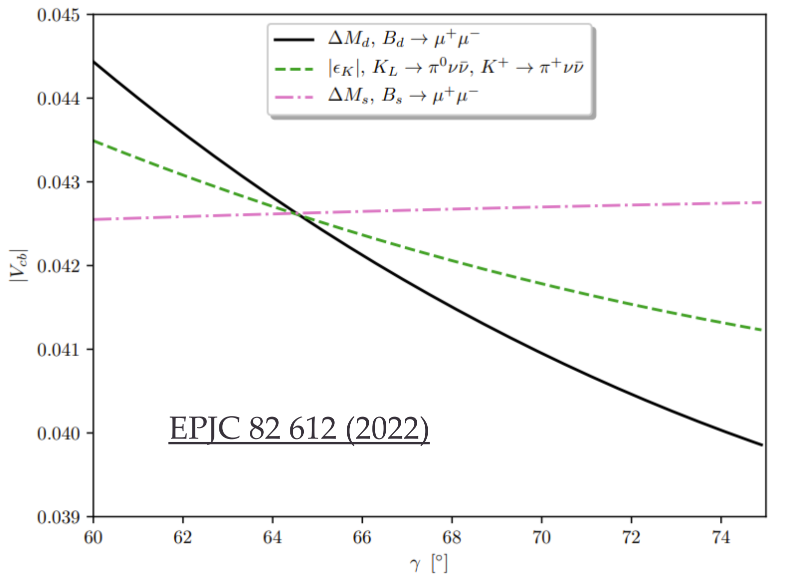
Testing the SM with FCNC: $|V_{cb}|$ and γ

- $K^+ \to \pi^+ \nu\bar{\nu}$: $|V_{cb}| = 42.6 \times 10^{-3} \left[\frac{\sin(64.6^\circ)}{\sin(\gamma)}\right]^{0.491} \left[\frac{BR\ (K^+ \to \pi^+ \nu\bar{\nu})}{(8.59 \pm 0.30) \times 10^{-11}}\right]^{0.357}$

- $K_L \to \pi^0 \nu\bar{\nu}$: $|V_{cb}| = 42.6 \times 10^{-3} \left[\frac{\sin(64.6^\circ)}{\sin(\gamma)}\right]^{0.491} \left[\frac{BR(K_L \to \pi^0 \nu\bar{\nu})}{(2.93 \pm 0.04) \times 10^{-11}}\right]^{0.25}$

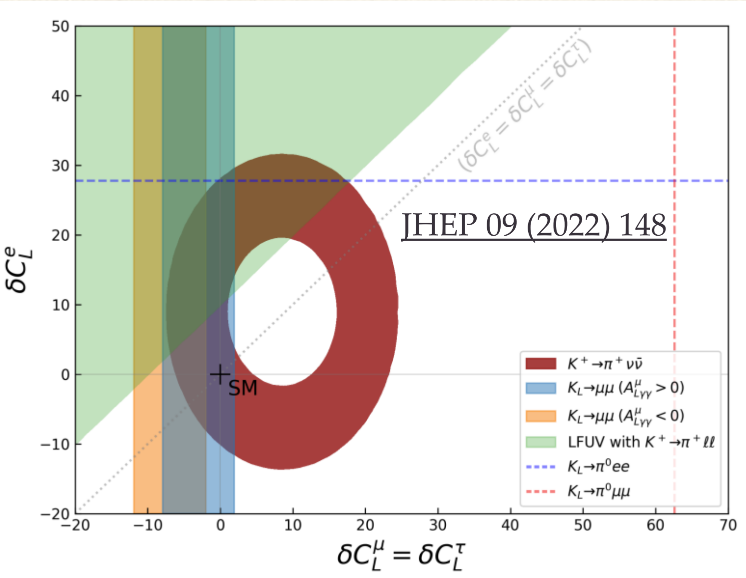
- Correlations between B and K observables can test the consistency of the CKM picture





Testing the SM with FCNC: LFUV

- Global fits to rare kaon processes can provide further tests of LFU (LH quark currents only)
- Bounds from individual observables (coloured regions 68% CL, dashed lines 90% upper limits)
- <u>Projection A:</u> upper bounds projected to SM value, measured quantities retain the observed central value
- <u>Projection B:</u> central values for all observables projected to best-fit points with existing data



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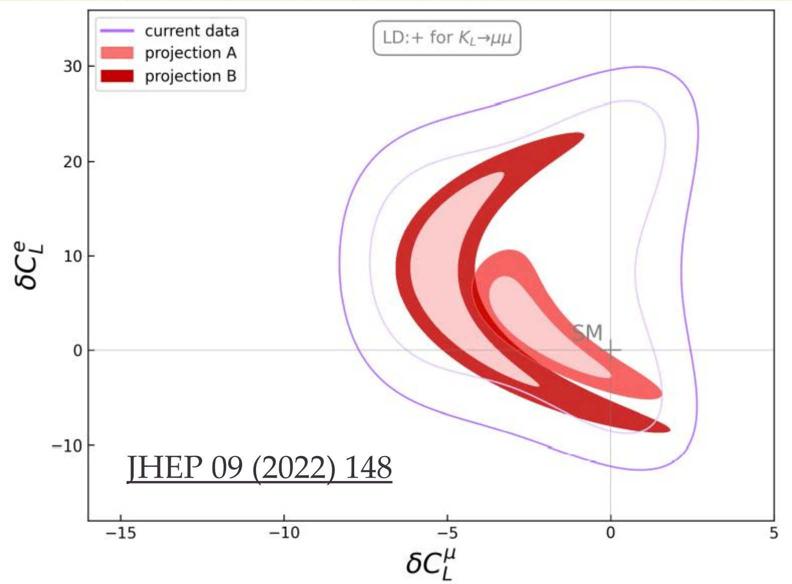

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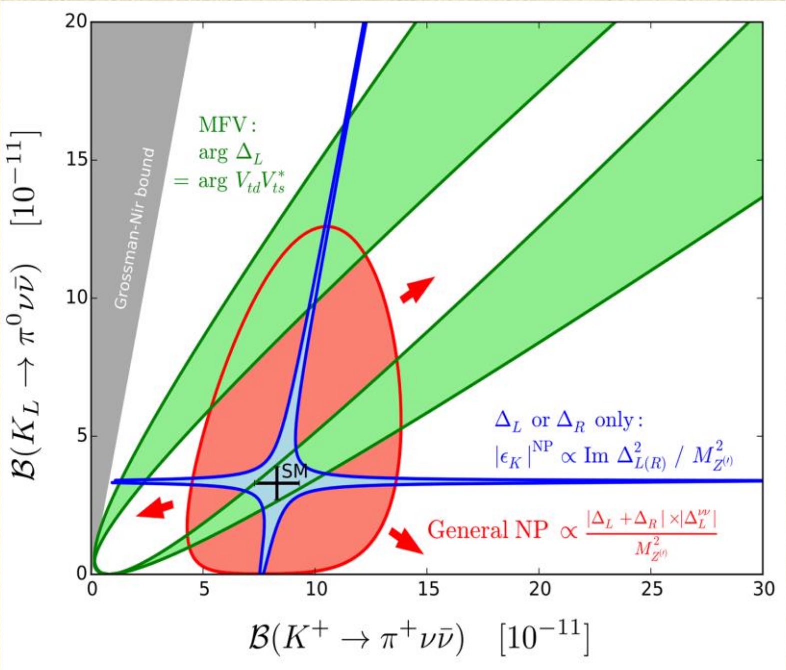
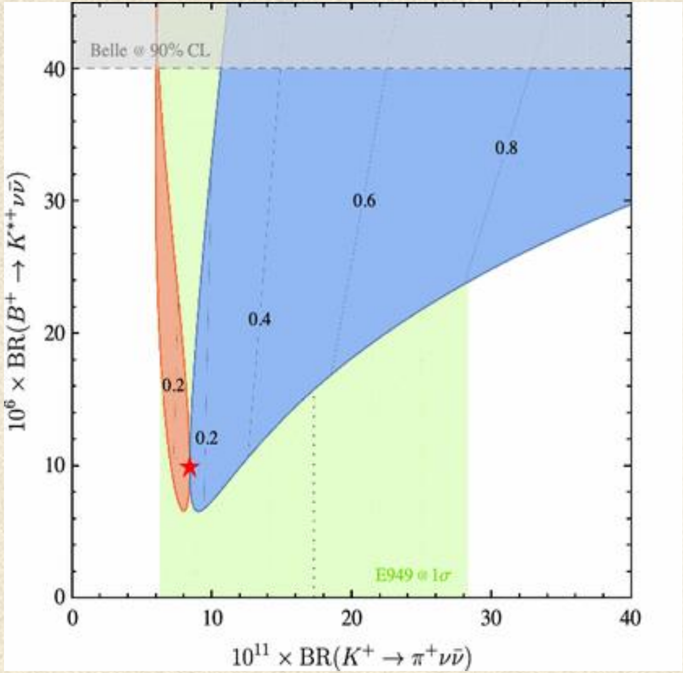
Testing the SM with FCNC: BSM models

Simplified models
[Buras et. al JHEP 1511 (2015) 166]

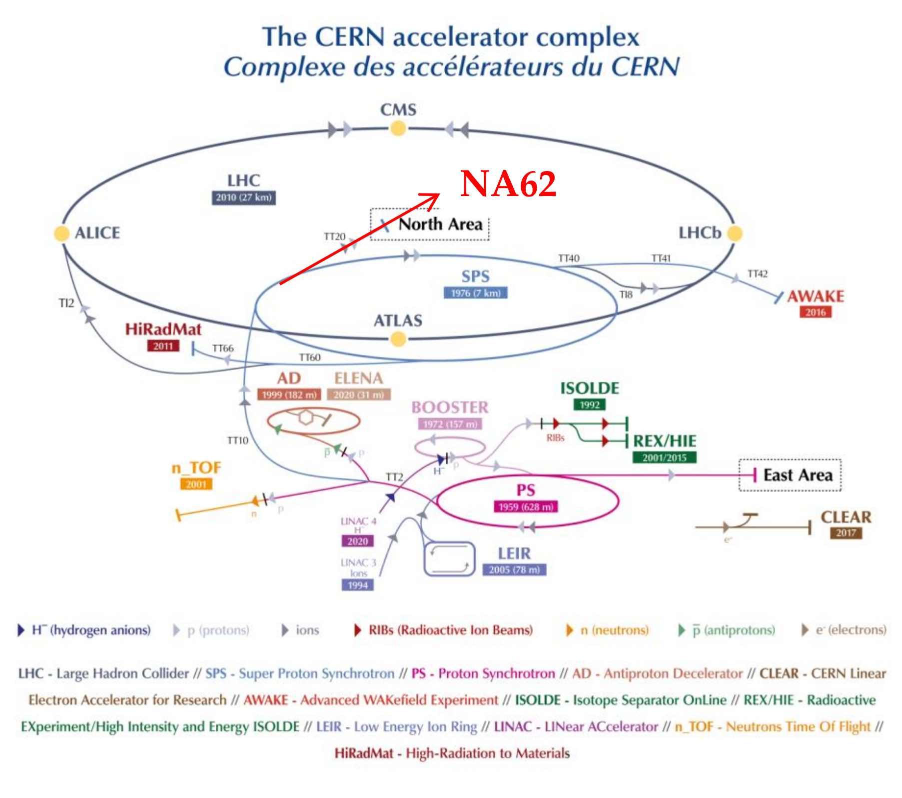


LFU violation
[Isidori et. al Eur. Phys. J. C (2017) 77: 618]



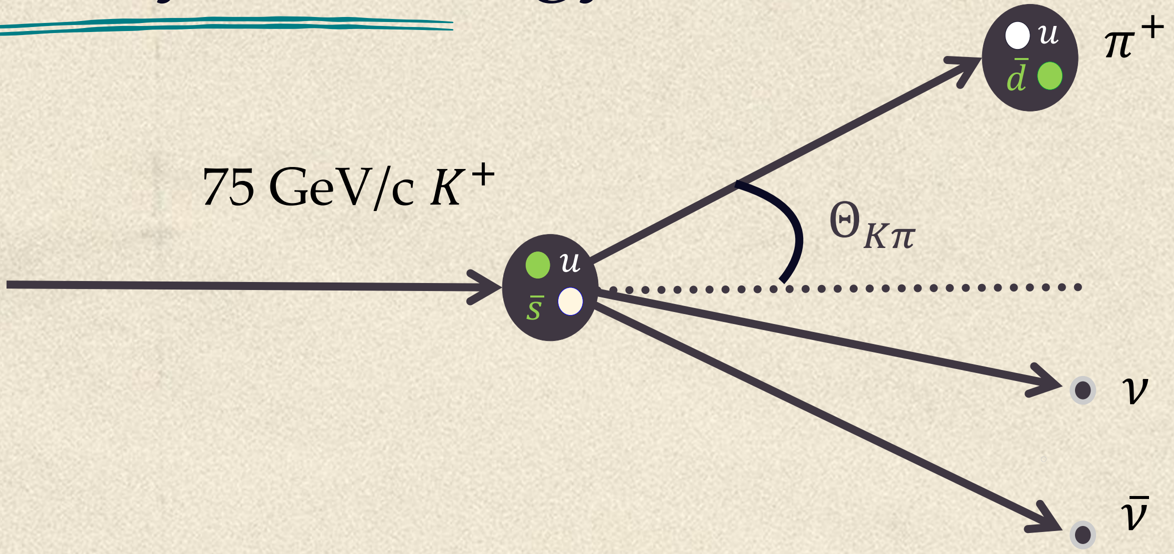
How to measure the ultra rare $K^+ \to \pi^+ \nu\bar{\nu}$ process with NA62?

The NA62 experiment @ CERN



- Fixed-target experiment at the CERN SPS
- *NA62 Run 1 (2016-18) data-taking completed*
- NA62 Run 2 (2021+) ongoing
- Main target: **$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ decay measurement**
- Broad physics program:
  - Other rare charged kaon decays
  - Precision measurements
  - LFV/LNV searches
  - Exotic searches (FIPs, Dark photon, etc…)

Analysis strategy



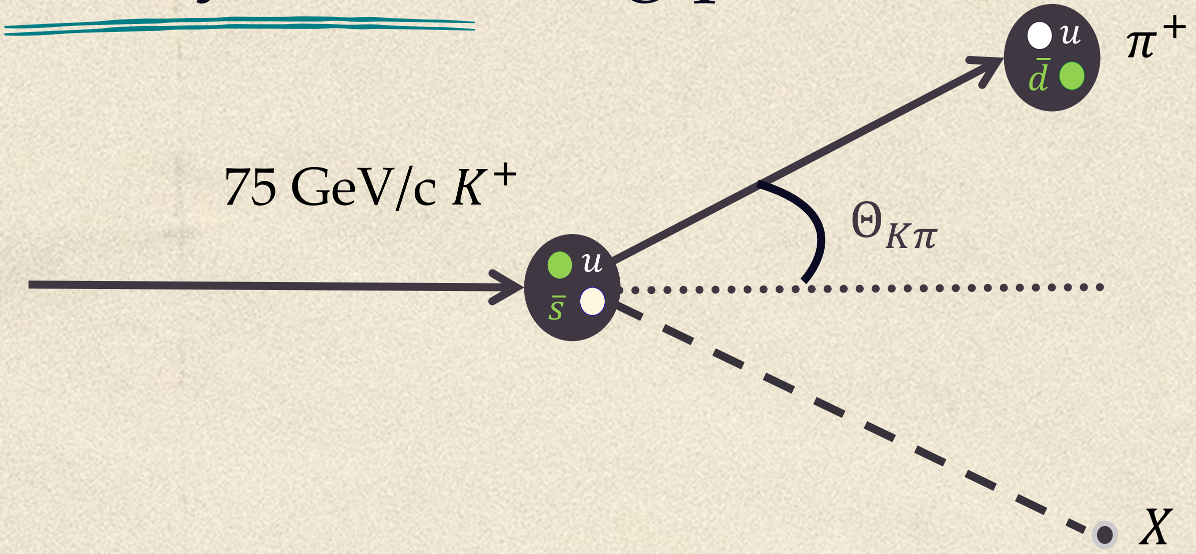
Squared missing mass (mass of the $\nu\bar{\nu}$ pair):

$$m^2_{miss} = (P_K - P_\pi)^2$$

π^+ mass hypothesis

- Highly boosted decay: (75 ± 1) GeV/c K^+ ($\gamma \sim 150$)
- Large undetectable missing energy carried away by the neutrinos
- All energy from visible particles must be detected
- π^+ momentum range 15 – 45 GeV/c ($E_{miss} > 30$ GeV)
- Hermetic detector coverage and O(100%) detector efficiency needed

Feebly interacting particles



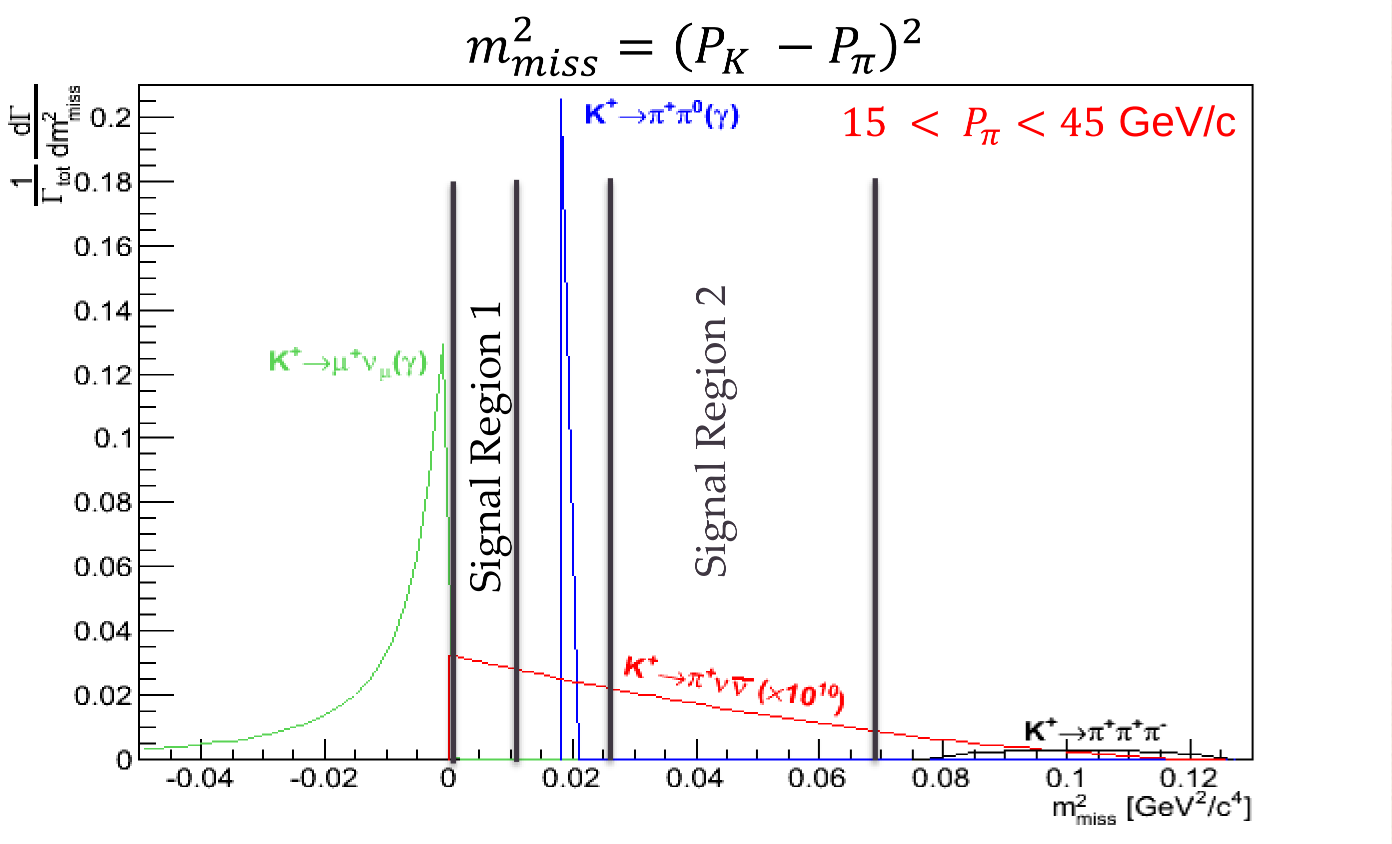
Squared missing mass
(mass of the X particle):

$$m_X^2 = (P_K - P_\pi)^2$$

π^+ mass hypothesis

- Feebly interacting scalar or pseudo-scalar particle X can be produced in $K^+ \to \pi^+ X$ decays
- Peak search inside the signal regions of the m_{miss}^2 distribution
- $O(10^{-11})$ sensitivity to a final state with a single π^+ + missing energy $(M_X = 0 - 350\ \mathrm{MeV}/c^2)$

Analysis strategy



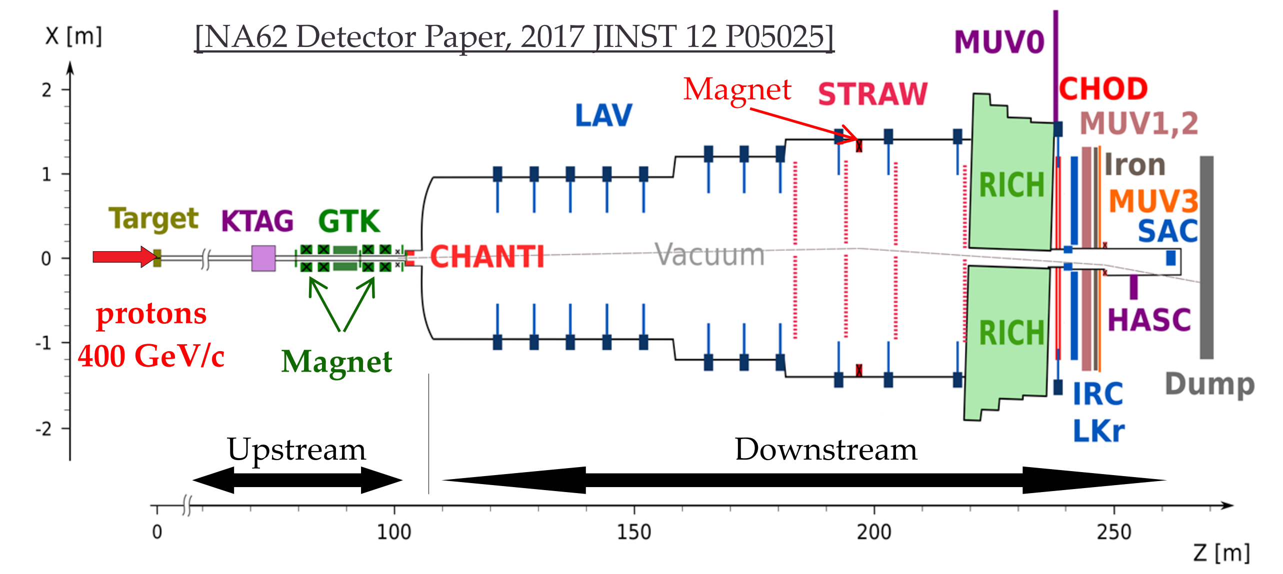
- A background suppression of $O(10^{11})$ is needed for the main K^+ decay modes

Experimental requirements

- Timing between sub-detectors $\sim \boldsymbol{O}(\mathbf{100\ ps})$
  - *Fast K^+ and π^+ tagging*
- Excellent kinematic suppression $\sim \boldsymbol{O}(\mathbf{10^4})$
  - *Precise K^+ and π^+ track reconstruction and $K - \pi$ matching*
- Muon suppression $\left(\text{e.g.}\, K^+ \to \mu^+\nu_\mu\right) \sim \boldsymbol{O}(\mathbf{10^7})$
- π^0 suppression $\sim \boldsymbol{O}(\mathbf{10^7})$
- Suppression of events with multiple charged particles $(\text{e.g.}\, K^+ \to \pi^+\pi^+\pi^-) \sim \boldsymbol{O}(\mathbf{10^7})$

The NA62 detector

- Secondary beam
  - 75 ± 1 GeV/c momentum
  - 6% K^+ component
  - 60 m long fiducial volume
  - ~ 3 MHz K^+ decay rate

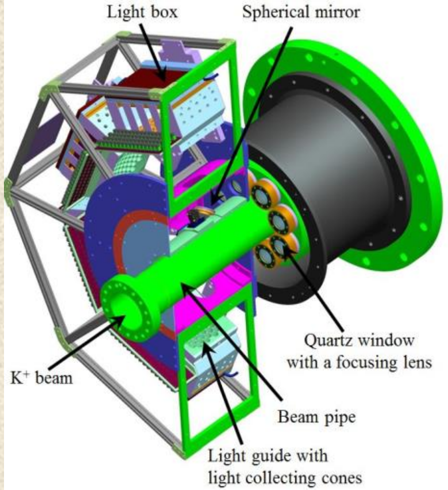


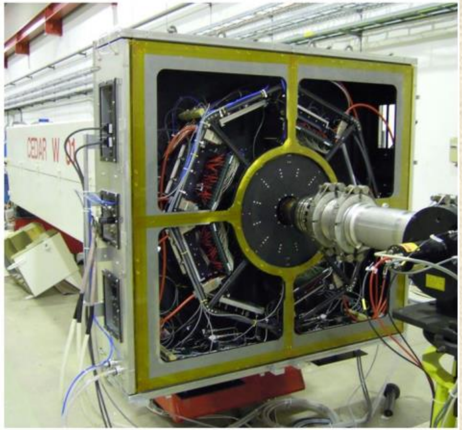
- Upstream detectors (K^+)
  - KTAG: Differential Cherenkov counter for K^+ ID
  - GTK: Silicon pixel beam tracker
  - CHANTI: Anti-counter against inelastic beam-GTK3 interactions

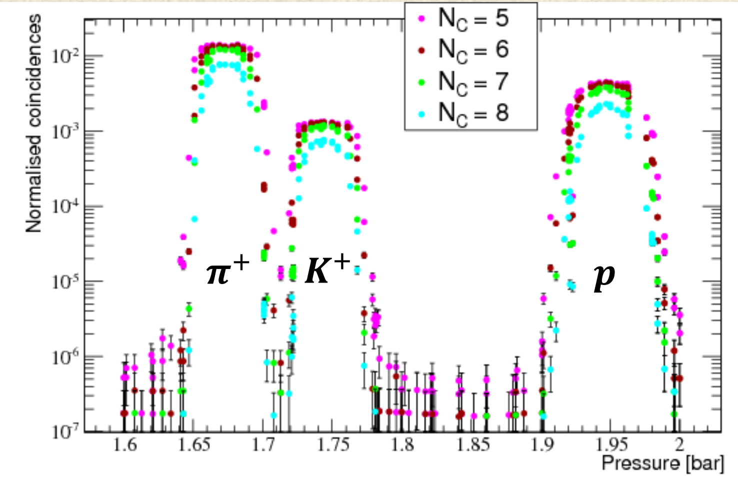
- Downstream detectors (π^+)
  - STRAW: track momentum spectrometer
  - CHOD: scintillator hodoscopes
  - LKr/MUV1/MUV2: calorimetric system
  - RICH: Cherenkov counter for $\pi/\mu/e$ ID
  - LAV/IRC/SAC: Photon veto detectors
  - MUV3: Muon veto

K^+ tagging: KTAG

- Differential Cherenkov counter geometrically aligned with the beam filled with $N_2(3.5 \times 10^{-2}\ X_0)$
  - Plans to replace the N_2 with $H_2(7 \times 10^{-3}\ X_0)$ to decrease beam emittance by ~ 9% in each plane
- Optimal working point for K^+ determined by performing a pressure scan
- PM`s time alignment and time walk corrections: $\sigma_t \sim 70$ ps
- K^+ signal from at least 5-fold coincidence: > 98% efficiency

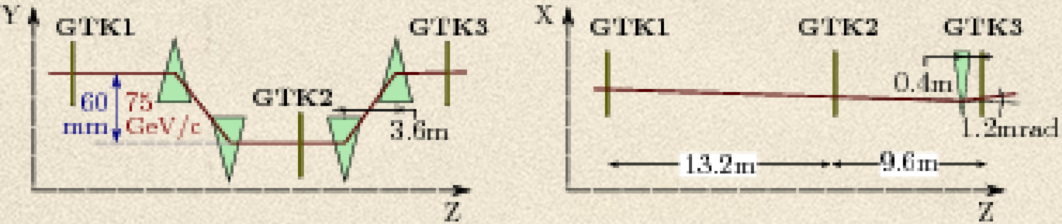


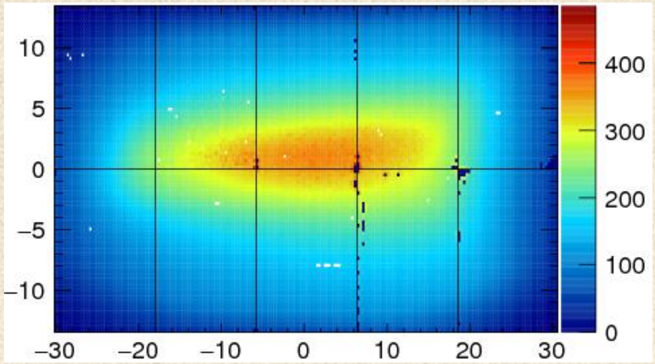




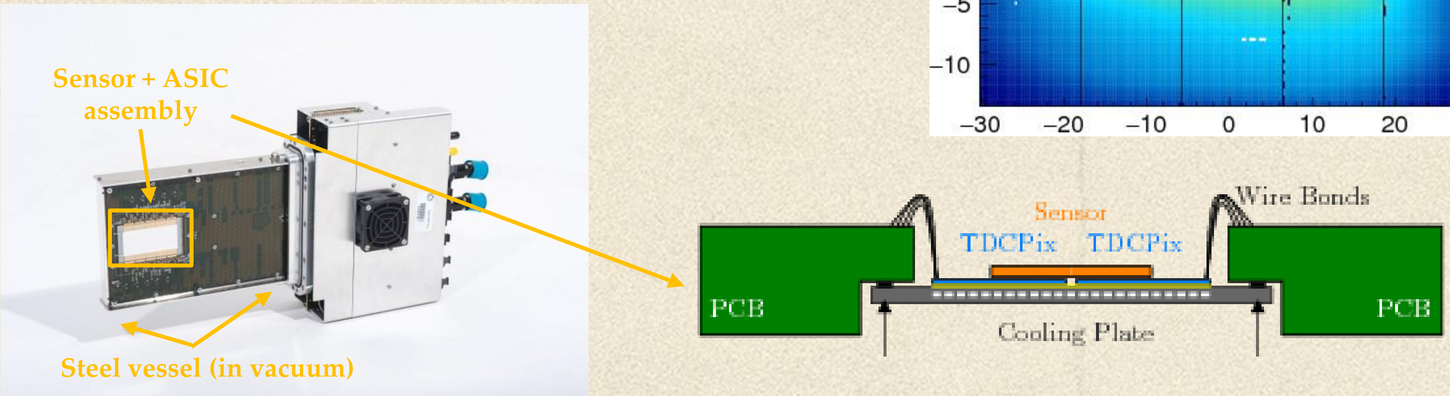
K^+ tracking: GigaTacker (GTK)

- 4D track reconstruction using trigger and KTAG as time reference: $\frac{\sigma_P}{P} \sim 0.2\%$ at 75 GeV/c
- Pixel-by-pixel time walk corrections: $\sigma_t < 150$ ps per station
- Stations aligned with the straw Spectrometer and calibrated using $K^+ \to \pi^+\pi^+\pi^-$ decays



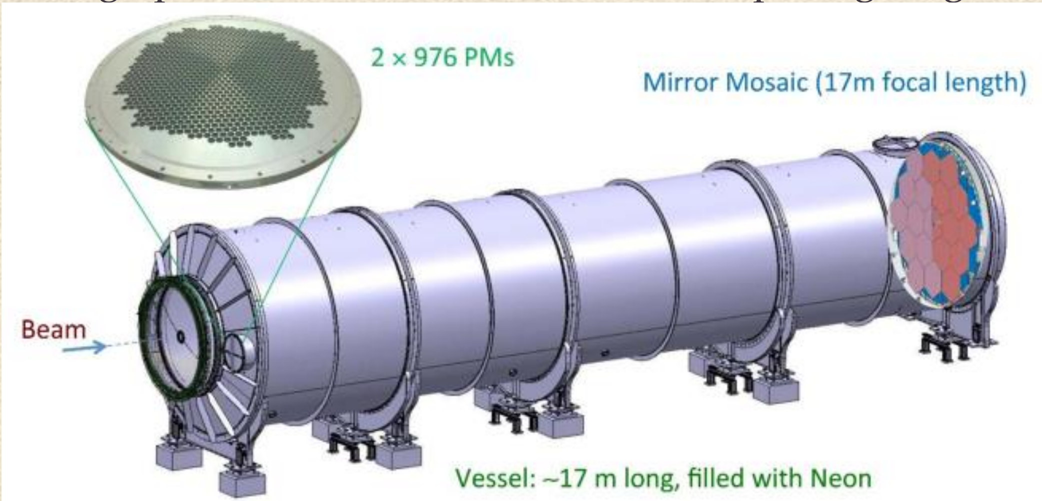


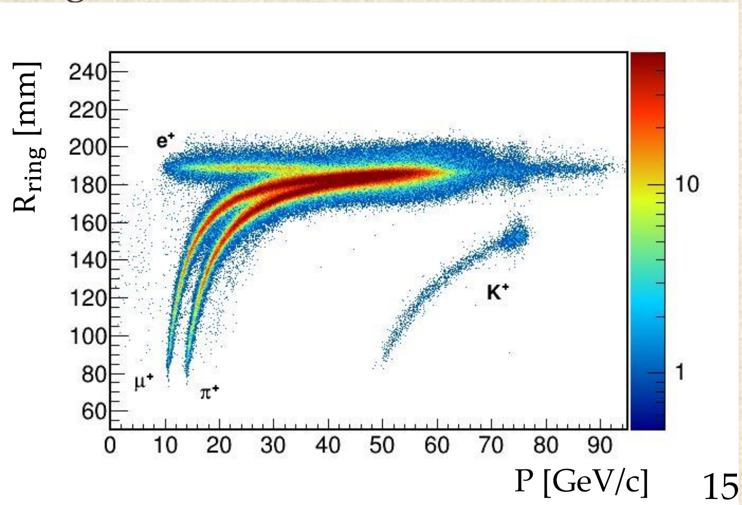
GTK station
0.5 X_0/station



π^+ tagging: RICH

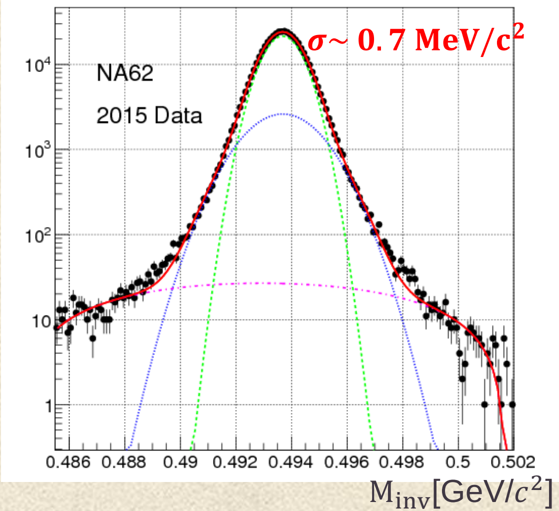
- Main task: provide timing and separate muons from pions (15-45 GeV/c range)
- Mirrors aligned using laser and tracks reconstructed with the straw spectrometer
- Monitored using e^+ ($\sim$ 16 hits per e^+ ring)
- PM`s time alignment and time walk corrections: $\sigma_t \sim 70$ ps
- Ring-spectrometer track matched comparing ring centre and flight direction

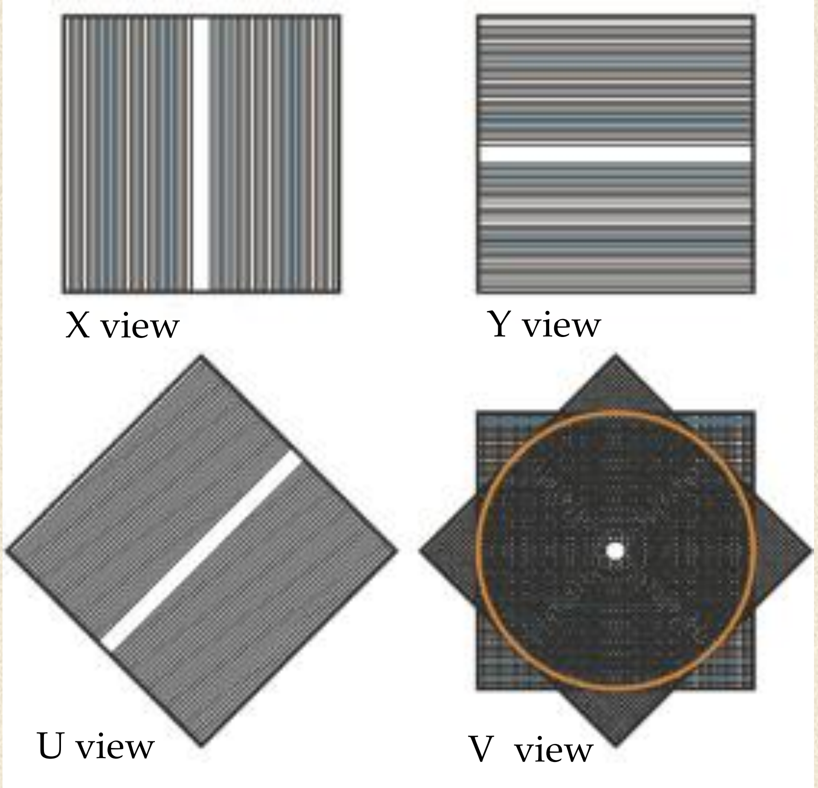




π^+ tracking: Straw spectrometer (STRAW)

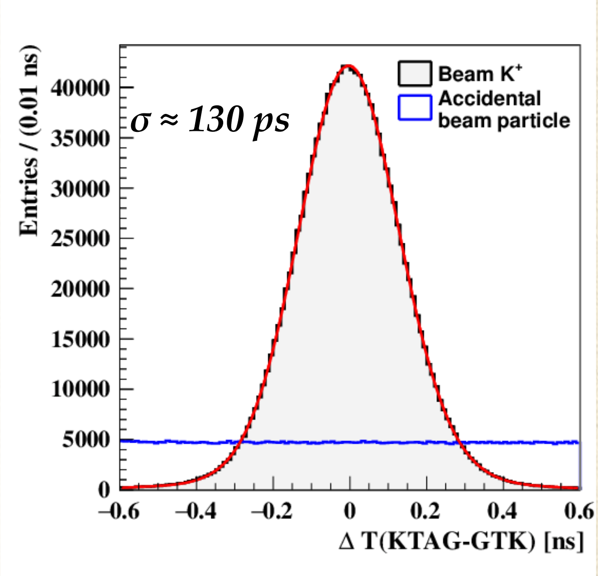
- "Massless" tracker in vacuum to minimize multiple scattering: 4 stations, total tracker mass 1.8% X_0
- Four views/station: X(0°), Y (90°), U(-45°), V(+45°)
- >95% reconstruction efficiency
- Final calibration using $K^+ \to \pi^+\pi^+\pi^-$ decays

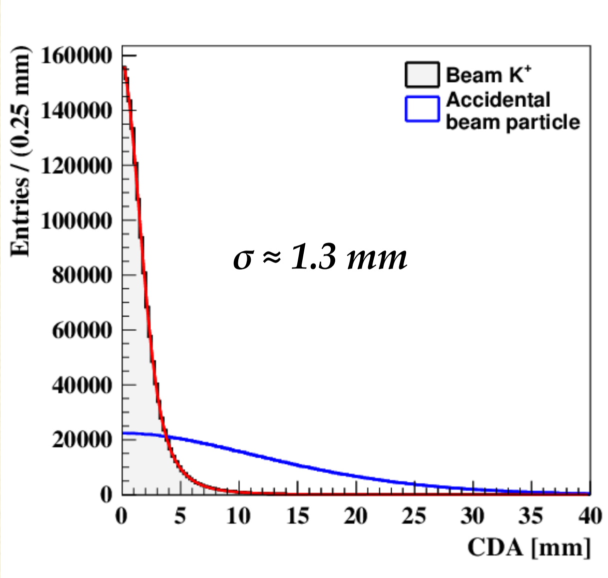




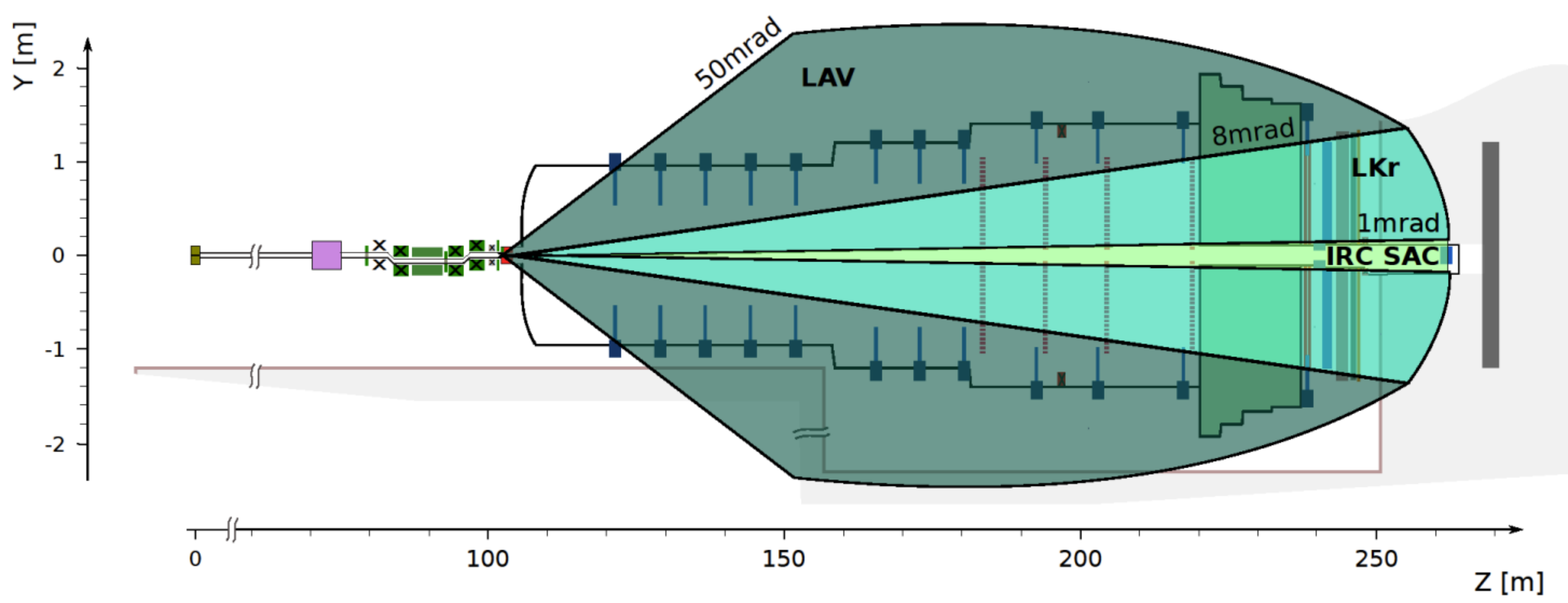
$K-\pi$ association

- KTAG – GTK – RICH time matching → Kaon decay time (t_{decay})
- GTK – STRAW spatial matching (CDA)
- 2.9% (4.0%) mis-tag if K^+ track (not) present, dependent on beam intensity
- ~ 65% K^+ reconstruction + ID efficiency (dependent on intensity)





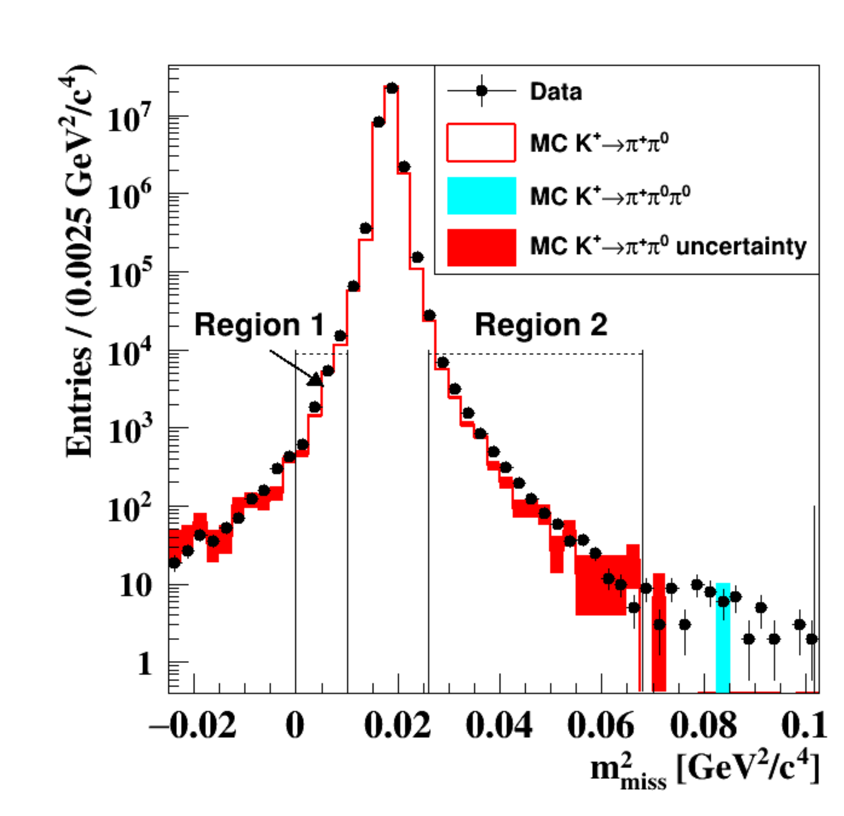
Photon rejection



- Fraction of surviving $K^+ \to \pi^+\pi^0$: $\boldsymbol{\epsilon_{\pi^0} \sim 2 \times 10^{-8}}$
- High suppression of $K^+ \to \pi^+\pi^+\pi^-, K^+ \to \pi^+\pi^-e^+\nu_e$ decays

Background from kaon decays: $K^+ \to \pi^+\pi^0$

Control $K^+ \to \pi^+\pi^0$ data used to study the tails of the m^2_{miss} distribution



Data in $\pi^+\pi^0$ region after $\pi\nu\bar{\nu}$ selection (including π^0 rejection)

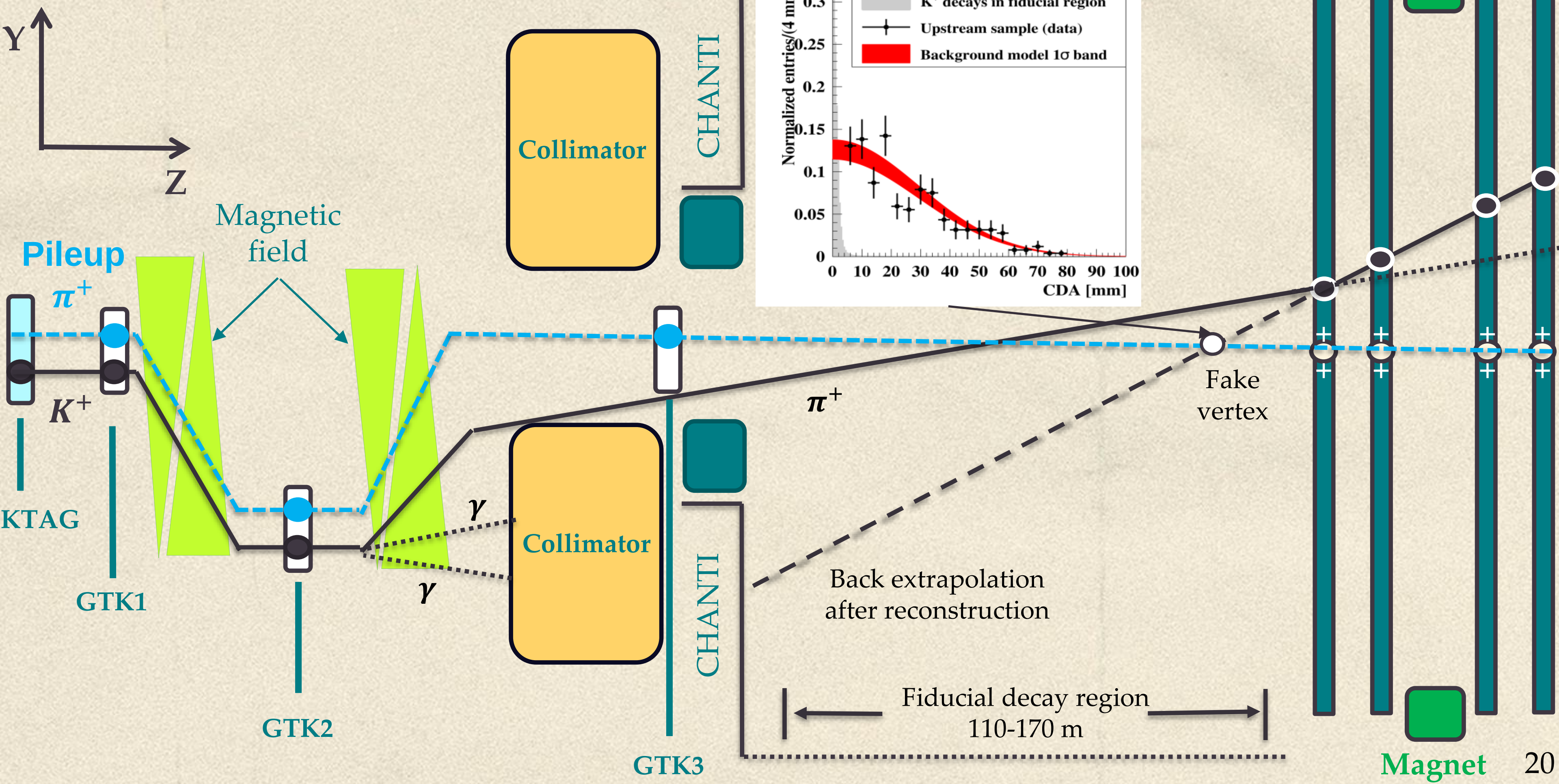
$$N^{exp}_{\pi\pi}(region) = N(\pi^+\pi^0) \cdot f_{kin}(region)$$

Expected $K^+ \to \pi^+\pi^0$ in signal regions after the $\pi\nu\bar{\nu}$ selection

Fraction of $\pi^+\pi^0$ in signal region measured on control data

- Control $K^+ \to \pi^+\pi^0$ data selected only with calorimeters (background – free)
- The same procedure used for $K^+ \to \mu^+\nu_\mu$ and $K^+ \to \pi^+\pi^+\pi^-$ background estimation
- $K^+ \to \pi^+\pi^-e^+\nu_e$ estimation entirely using MC simulations normalized to the *SES*

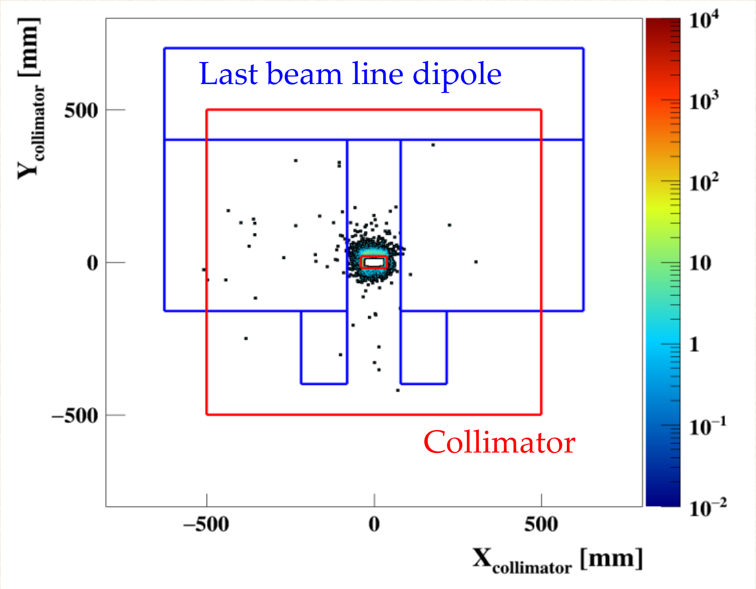
Upstream background events



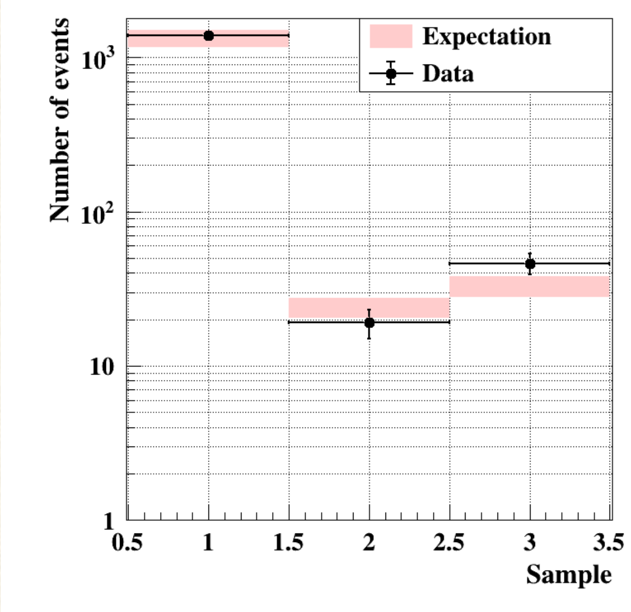
Suppressing upstream background events

- $K-\pi$ association and geometrical cuts effective against upstream events
- Data – driven background estimation
- Validation of the estimates using dedicated control samples

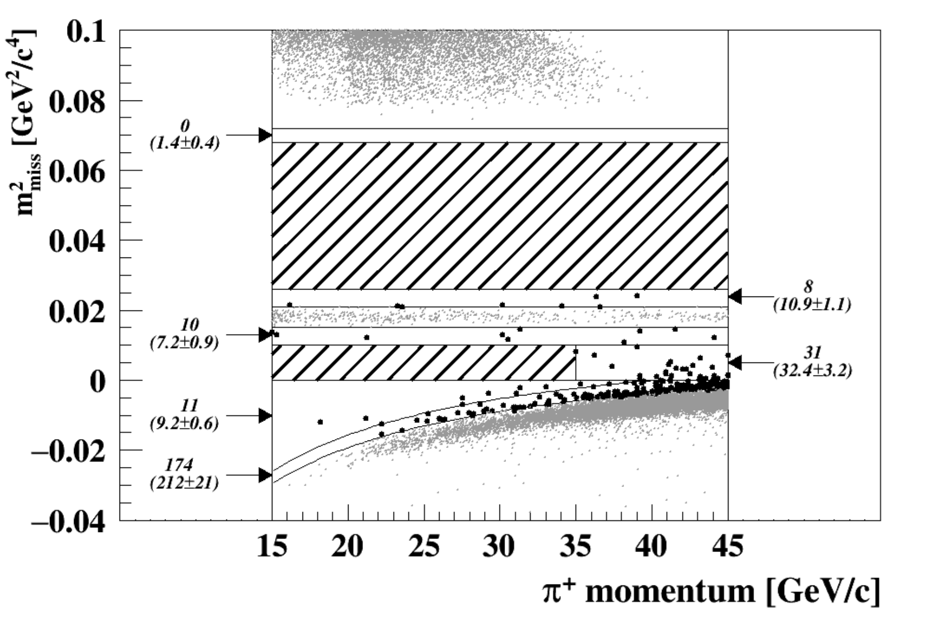
Control data



Upstream background control samples



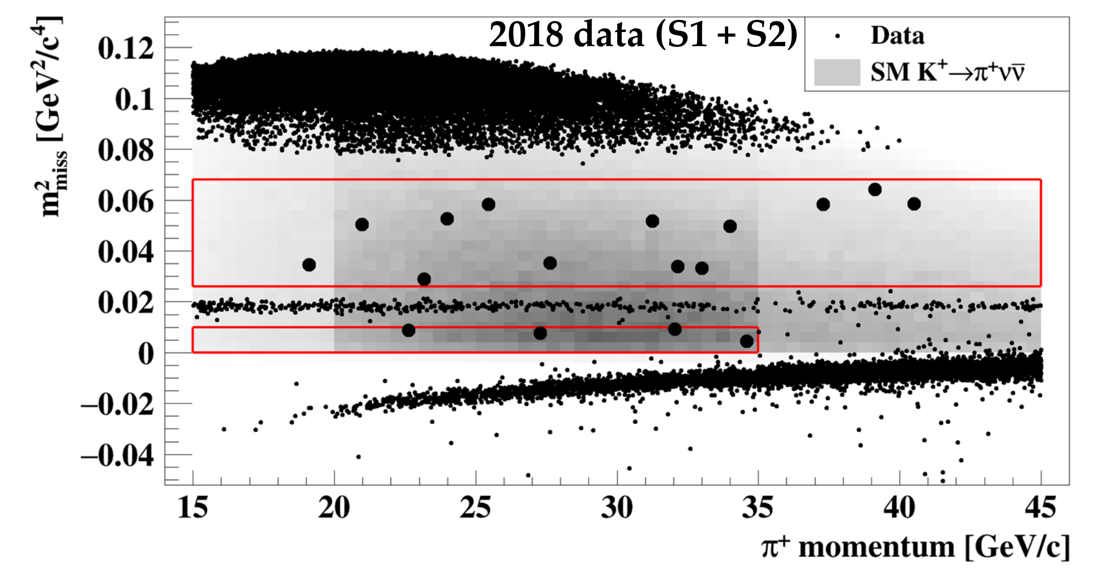
Expected signal and background contribution

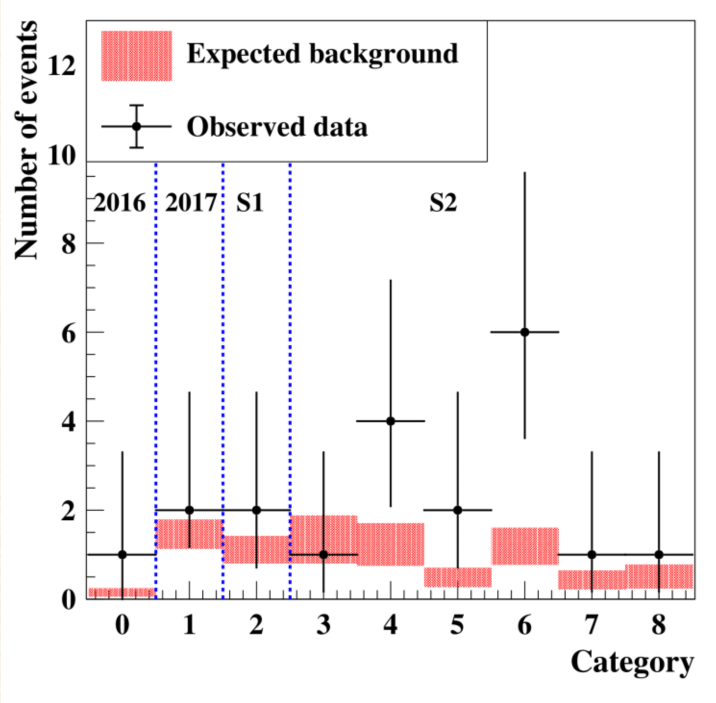


	2018 data
Expected SM signal	$7.58(40)_{syst}(75)_{ext}$
$K^+ \to \pi^+\pi^0(\gamma)$	0.75(4)
$K^+ \to \mu^+\nu(\gamma)$	0.49(5)
$K^+ \to \pi^+\pi^- e^+\nu$	0.50(11)
$K^+ \to \pi^+\pi^+\pi^-$	0.24(8)
$K^+ \to \pi^+\gamma\gamma$	< 0.01
$K^+ \to \pi^0 l^+\nu$	< 0.001
Upstream	$3.30^{+0.98}_{-0.73}$
Total background	$5.28^{+0.99}_{-0.74}$

- Combining the complete Run 1 data set (2016-18)
  - $N^{exp}_{\pi\nu\bar{\nu}} = 10.01 \pm 0.42_{syst} \pm 1.19_{ext}$
  - $N^{exp}_{bg} = 7.03^{+1.05}_{-0.82}$
  - $SES = \left(0.839 \pm 0.053_{syst}\right) \times 10^{-11}$

Results NA62 Run 1 (2016-18)

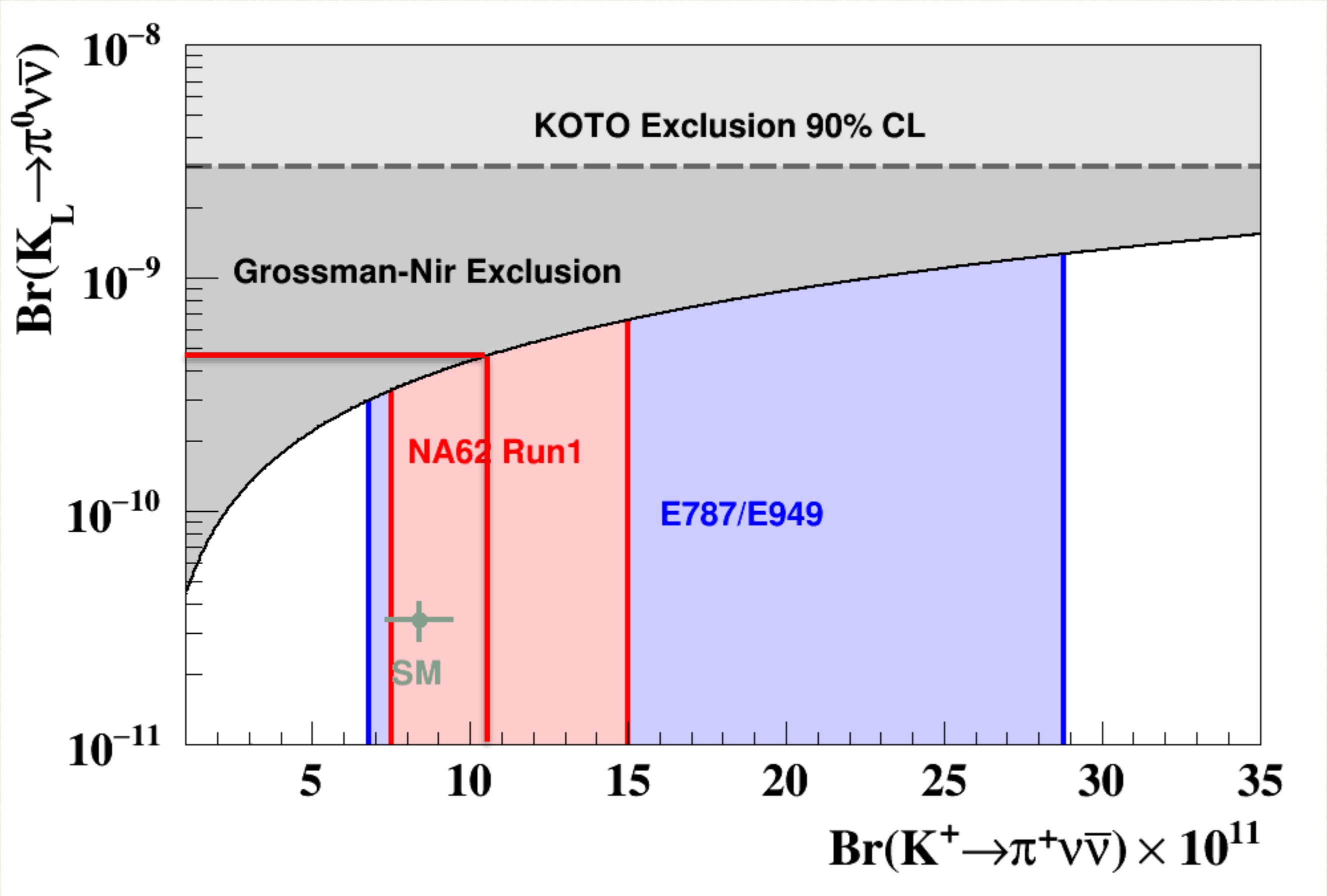




- 20 events observed in signal region in NA62 Run 1 data
- $BR(K^+ \to \pi^+ \nu\bar{\nu}) = (10.6^{+4.0}_{-3.4}|_{stat} \pm 0.9_{syst}) \times 10^{-11}$ [JHEP 06 (2021) 093]

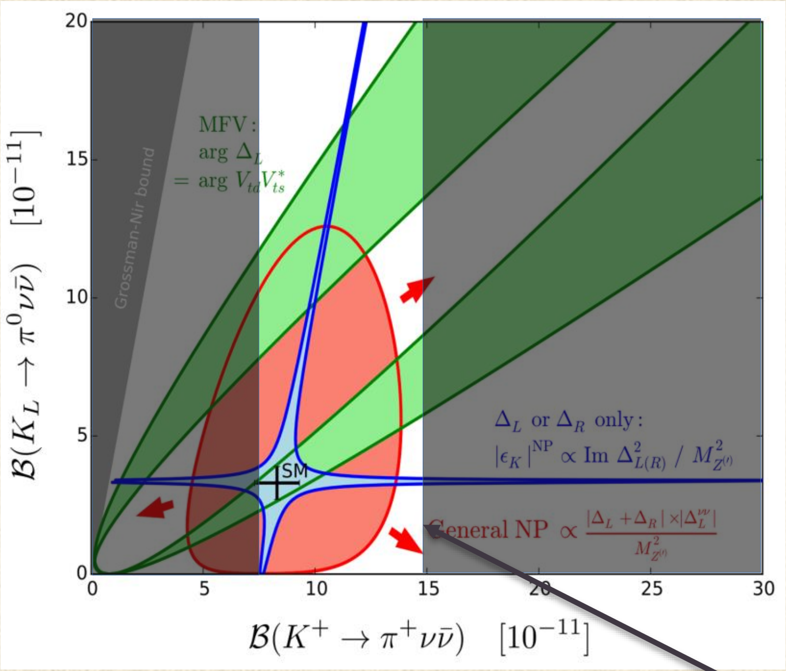
3.4σ significance

Grossman-Nir limit



Impact in the context of BSM models

Simplified models
[Buras et. al JHEP 1511 (2015) 166]



LFU violation
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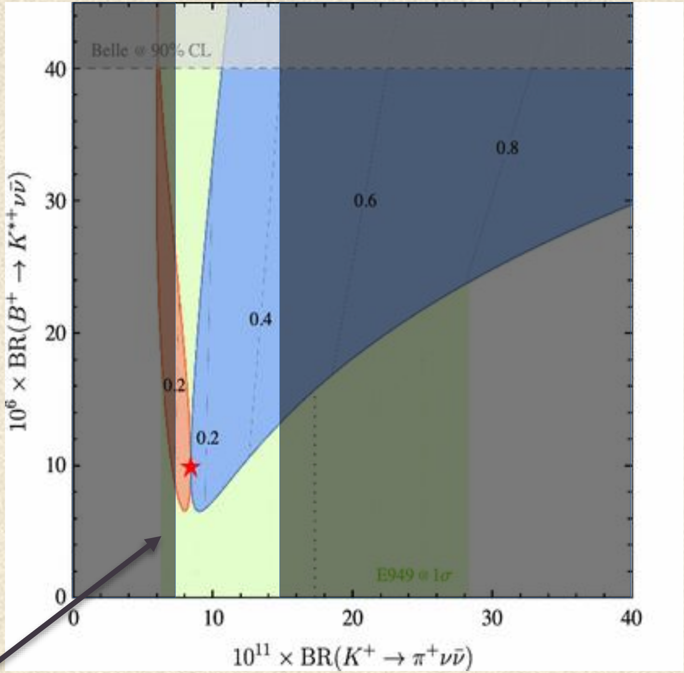
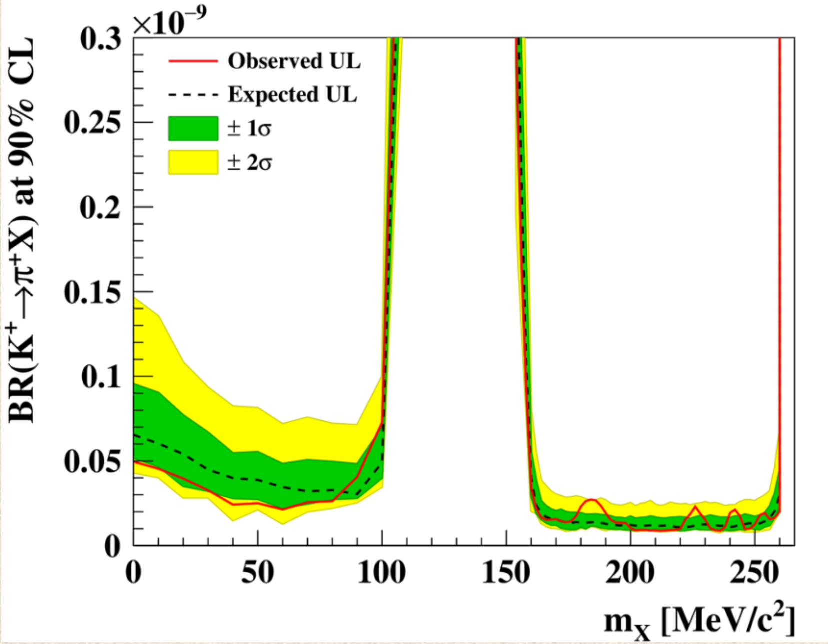
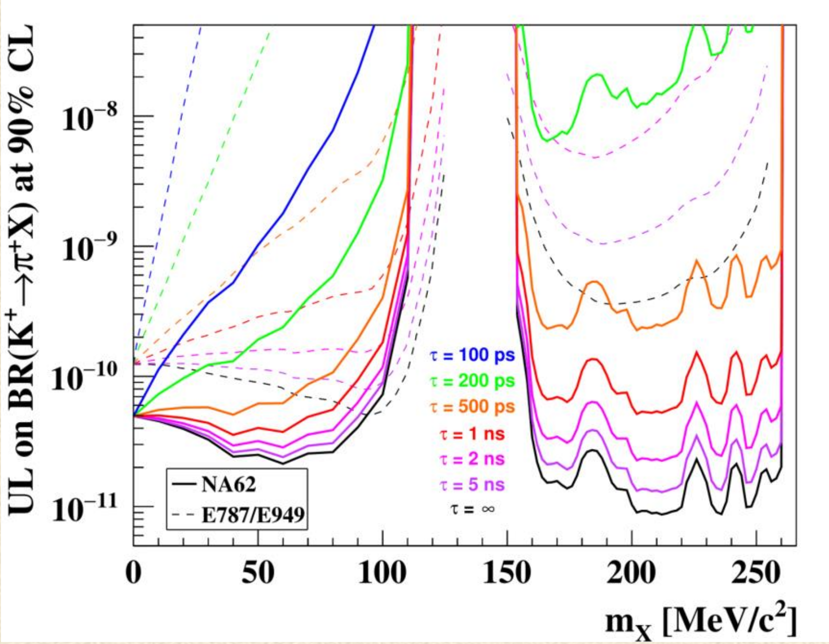


NA62 measurement

Search for $K^+ \to \pi^+ X$ decays





- Model – independent upper limits
- Limits at the order of 10^{-11} for X in the mass range up to ~ 260 MeV/c^2
- Different lifetimes considered

What is the future of experimental kaon physics at CERN?

The HIKE proposal

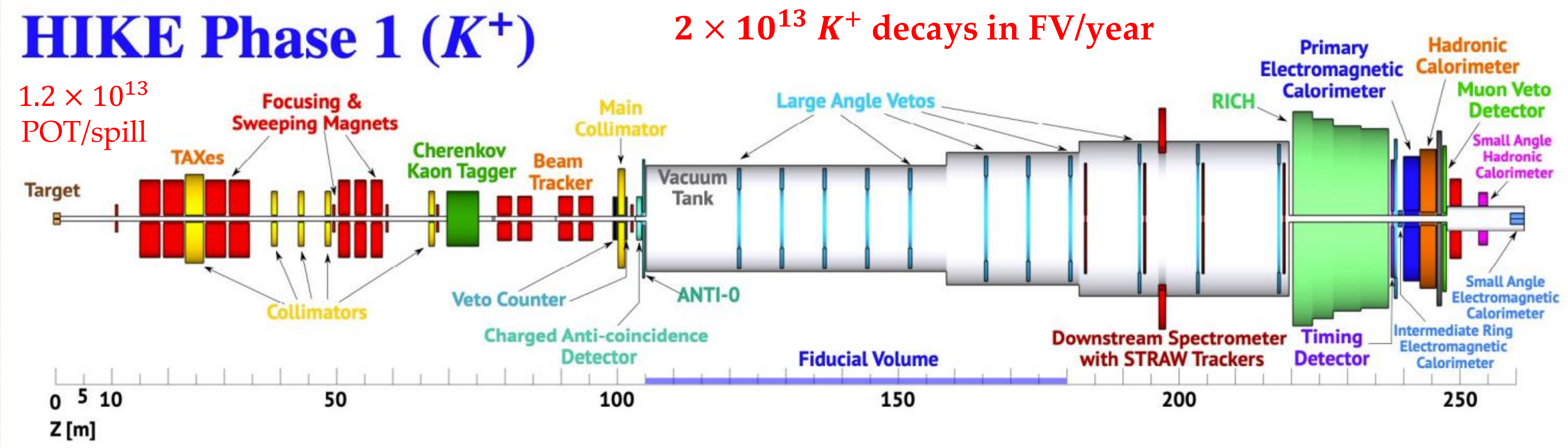
High Intensity Kaon Physics Experiments (HIKE)

- The HIKE proposal includes 3 Phases
  - Phase 1: Multi-purpose K^+ experiment ← **This seminar**
  - Phase 2: Multi-purpose K_L experiment
  - Phase 3: KLEVER – an experiment to measure the $K_L \to \pi^0 \nu \bar{\nu}$ process
- HIKE LoI published in November: https://cds.cern.ch/record/2839661

The HIKE proposal Phase 1: Physics case

- A multi-purpose K^+ experiment (after LS3)
- Measurement of the $K^+ \to \pi^+ \nu \bar{\nu}$ branching ratio to a 5% relative precision
- Precision measurements of $K^+ \to \pi^+ l^+ l^-$ decays, which also offer precision lepton universality test
- Searches for lepton flavour/number violating decays
- Measurement of the main K^+ decay modes to permille relative precision
- Improvement of other existing rare decay modes
- Searches for production of feebly-interacting particles in K^+ decays

The HIKE proposal Phase 1: Detector layout



- Decay-in-flight technique, experience from NA62 and similar layout
- High detector rates, precision tracking, time resolution $O(20\text{ps})$
- Minimize material
- High-performance PID for $\gamma,\ \pi^+,\ \mu^+,$ and e^+
- Efficient hermetic photon vetoes and high-performance EM calorimetry (σ_E, σ_t, granularity)

4xNA62 intensity

Improved timing is crucial

Technological solutions exist

Beam tracker

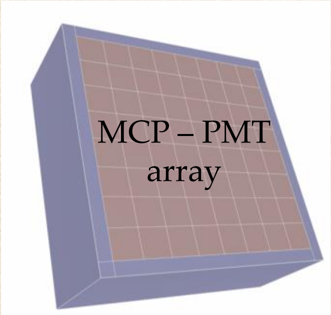
4xNA62 intensity

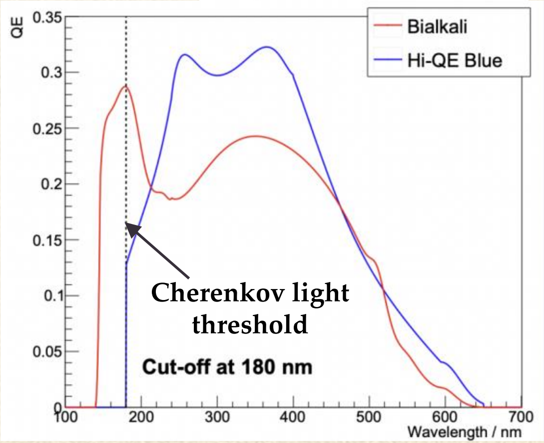
	NA62 GigaTracker	New beam tracker
Single hit time resolution	< 200 ps	< 50 ps
Track time resolution	< 100 ps	< 25 ps
Peak hit rate	2 MHz/mm^2	8 MHz/mm^2
Pixel efficiency	> 99%	> 99%
Peak fluence/1 year [10^{14} 1 MeV n_{eq}/cm^2]	4	16

- Fast timing in high-radiation environment needed across different experiments (including LHC)
- Hybrid 3D-trenched technology under study (TimeSPOT)
  - Pixel electrode geometry optimized for timing performance
  - Can withstand large irradiation
- Other solutions might also be possible (monolithic detectors, LGADs)

Cherenkov kaon tagger

- 200 MHz (10MHz/cm^2) of K^+ in HIKE Phase 1 requires: $\sigma_t \approx 15 – 20$ ps and $\epsilon_{tagging} > 95\%$
- Replacing the nitrogen radiator with hydrogen
  - Newly built ring-imaging optical components optimized for operation with hydrogen
  - Increase the number of detected photons per kaon to 30 (20 in NA62)
- Photodetection with MCP–PMTs
  - ALD coating to increase lifetime (>150 better than standard MCP–PMTS)
  - Linearity with increasing rate is under investigation
  - Rate stability can be adjusted by modifying the MCP coating
- New front-end electronics under development (fastIC, picoTDC)

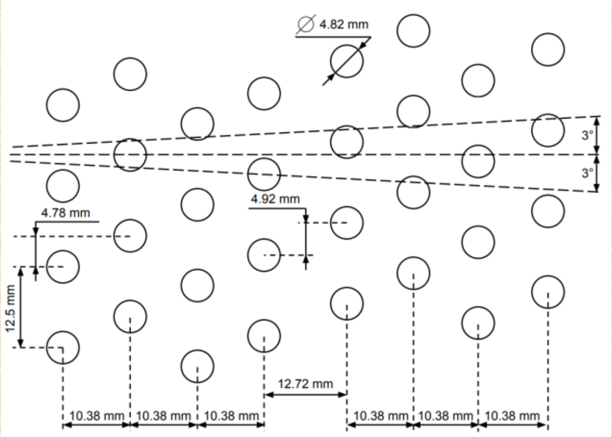




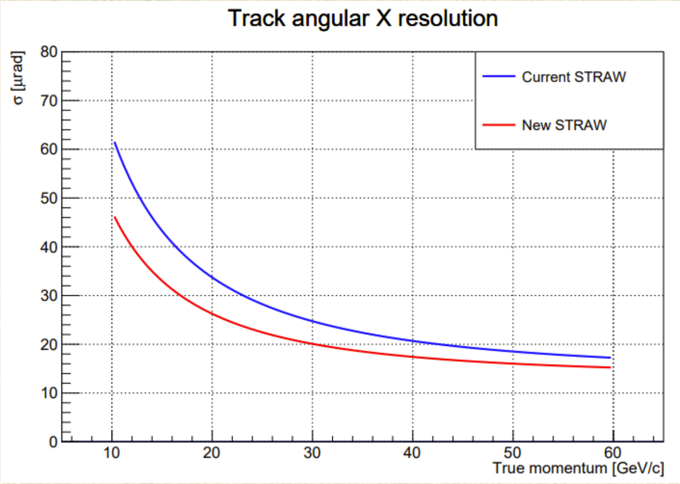
STRAW tracker

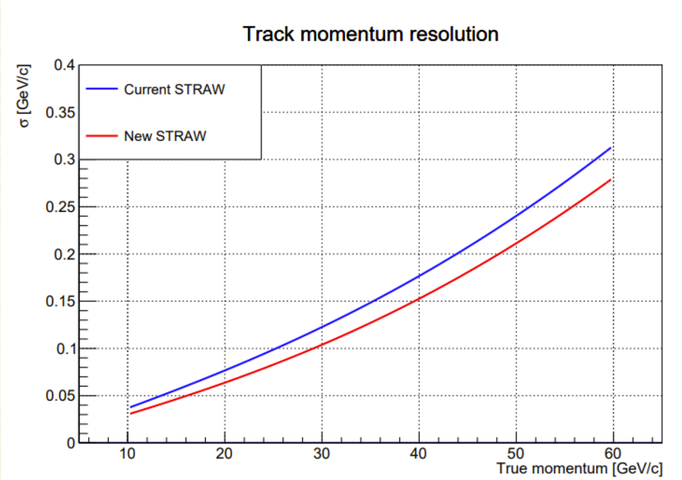
4xNA62 intensity

	Current NA62 spectrometer	New straw spectrometer
Straw diameter	9.82 mm	4.82 mm
Straw length	2100 mm	2100 mm
Planes per view	4	8
Straws per plane	112	~160
Straws per chamber	1792	~5200
Mylar thickness	36 μm	(12 or 19) μm
Anode wire diameter	30 μm	(20 or 30) μm
Total material budget	1.7% X_0	(1.0 – 1.5)% X_0
Maximum drift time	~150 ns	~80 ns
Hit leading time resolution	(3 – 4) ns	(1 – 4) ns
Hit trailing time resolution	~30 ns	~6 ns
Average number of hits hits per view	2.2	3.1



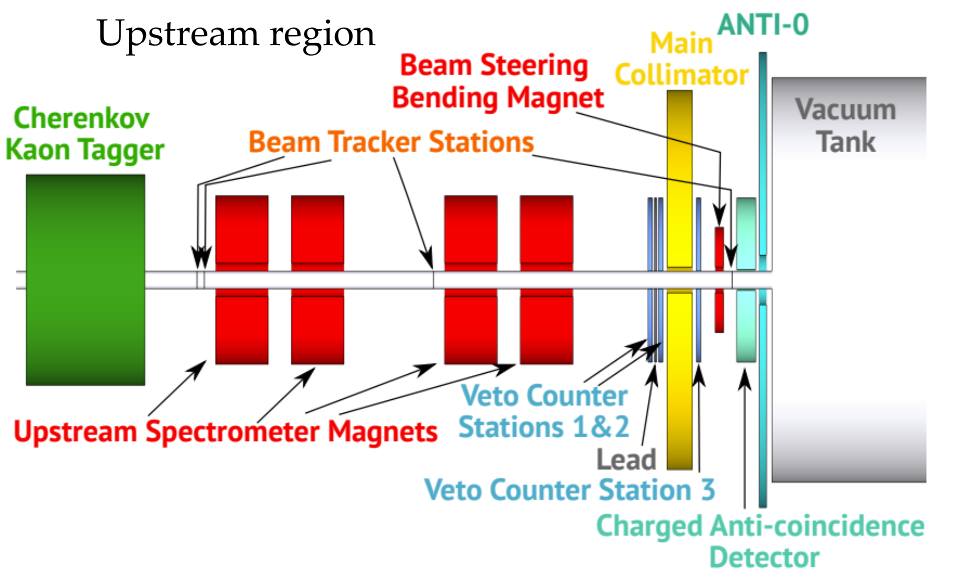
Optimized layout for new STRAW tracker





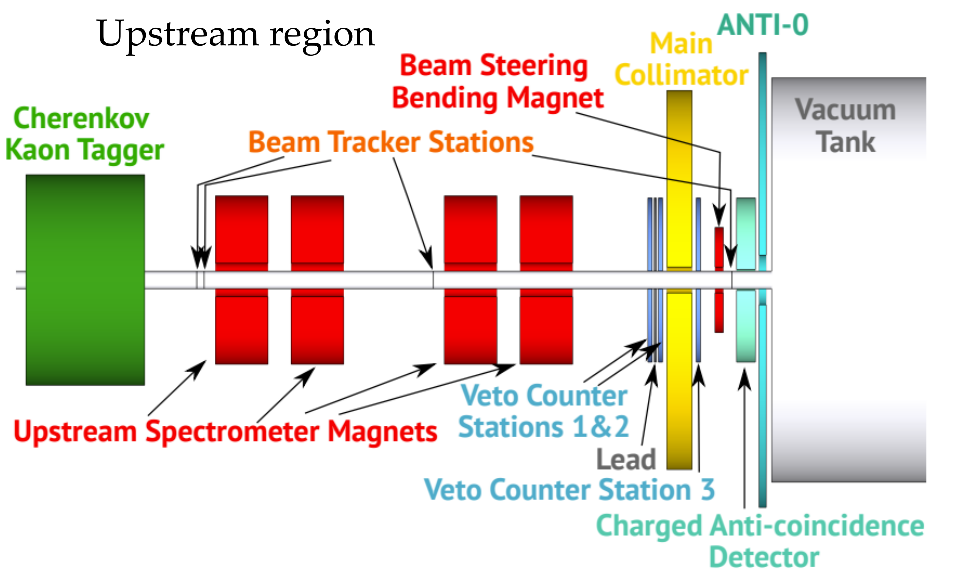
Veto counter

- Important to reject upstream decays
- Requirements:
  - $\sigma_t \sim 200$ ps per station
  - Detection efficiency > 99%
  - High-rate capabilities
- Solution already available
  - SciFi technology already used in LHCb
  - Some improvements needed on the time resolution
  - Optimize detector thickness + front-end electronics



Charged anti-coincidence detector

- Reject inelastic interactions in the beam tracker
- Requirements:
  - $\sigma_t \sim 200$ ps per station
  - Detection efficiency $> 99\%$
  - High-rate capabilities
- <u>SciFi solution possible but challenging</u>
  - Some improvements needed on the time resolution
  - The detector must be operated in vacuum – dedicated R&D is required
  - Would allow easy cooling of the SiPM at liquid nitrogen temperatures and eliminate noise
- Can be used in conjunction with the Veto Counter to separate halo muons from charged particles produced in inelastic interactions: reduce accidental veto

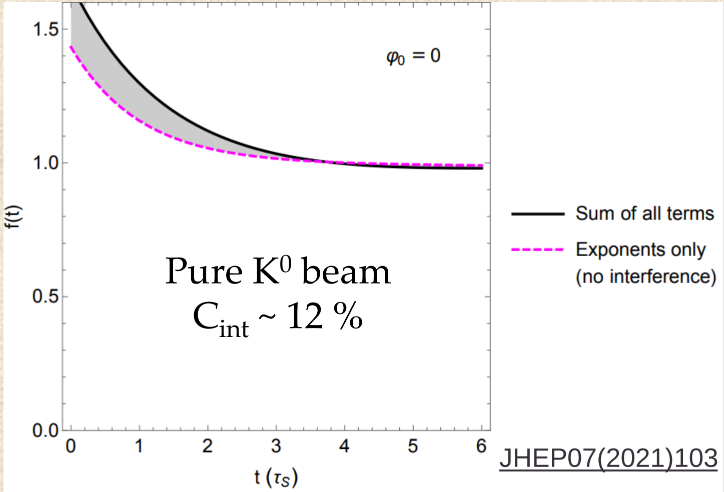


What is the future of experimental kaon physics at CERN?

Ideas for the far future ($K \to \mu^+\mu^-$ interfernece)

Experimental considerations: $K \to \mu^+ \mu^-$ interference

$$\frac{d\Gamma}{dt} \propto f(t) = C_L\, e^{-\Gamma_L t} + C_S\, e^{-\Gamma_S t} + 2[C_{sin} \sin(\Delta m t) + C_{cos} \cos(\Delta m t)]\, e^{-\Gamma t}$$



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Strong phase

$$C_{int}^2 = C_{sin}^2(D, \varphi_0) + C_{cos}^2(D, \varphi_0)$$

Dilution

$$D = \frac{N_{K^0} - N_{\overline{K^0}}}{N_{K^0} + N_{\overline{K^0}}}$$

- Asymmetric K^0 and $\overline{K^0}$ beam required: **fixed-target experiment at the SPS?**
  - QCD production with a $K^0 - \overline{K^0}$ asymmetry (D ~ 0.3 for NA48)
  - Dilution must be measured precisely (~ 1% precision or better) with $K \to \pi\pi$ decays
- At least **O(10^{14}) K decays** needed for a few % measurement (depends on φ_0) arXiv:2211.03804

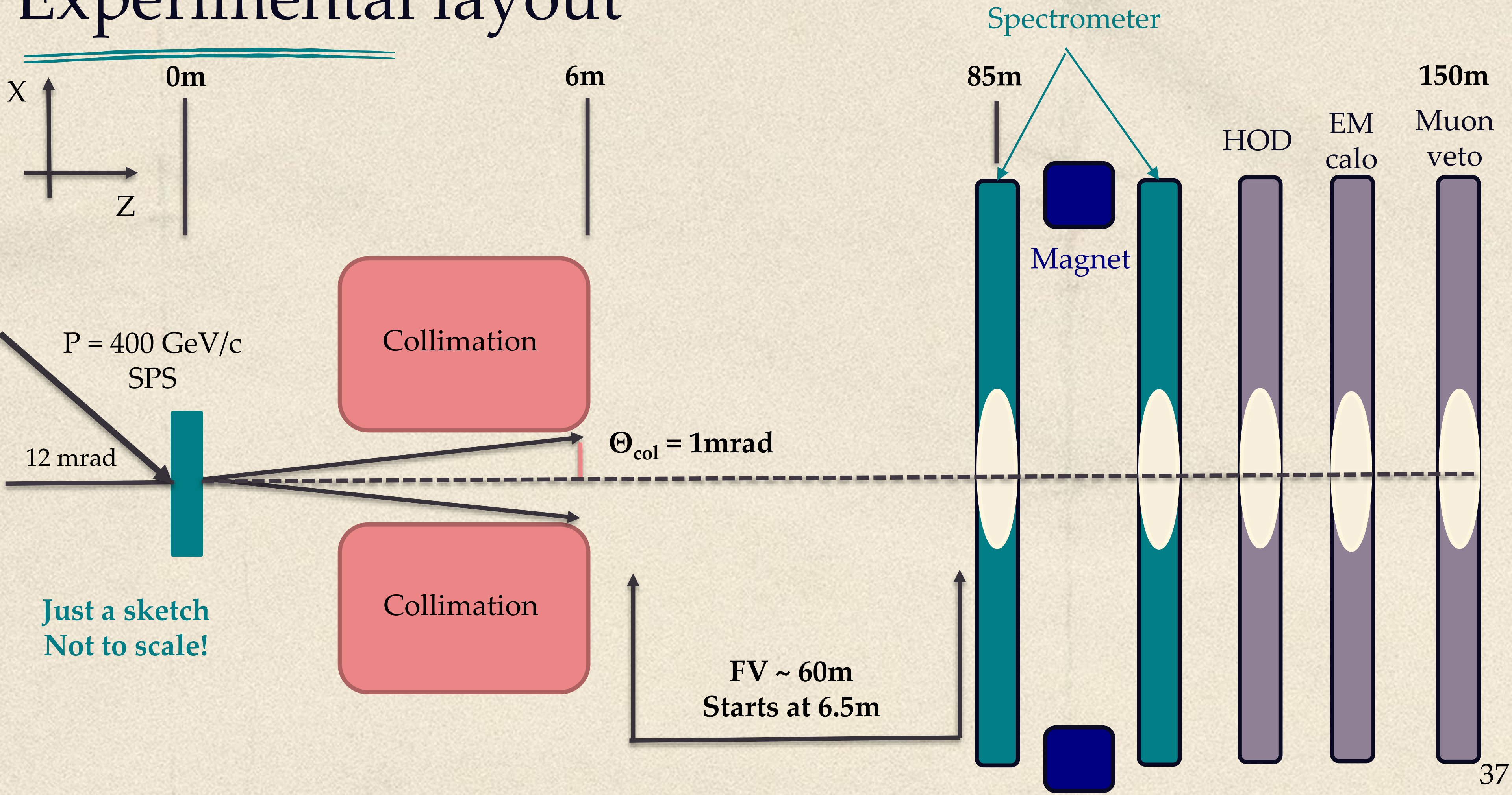
High-intensity K_S/K_L experiment

$$\boldsymbol{BR(K_S \to (\mu^+\mu^-)_{l=0})} = B(K_L \to \mu^+\mu^-) \times \frac{\tau_S}{\tau_L} \times \frac{\boldsymbol{C_{cos}^2 + C_{sin}^2}}{\boldsymbol{C_L^2}} = 1.8 \times 10^{-13} \times \frac{A^2\lambda^5\boldsymbol{\eta}}{1.3 \times 10^{-4}}$$

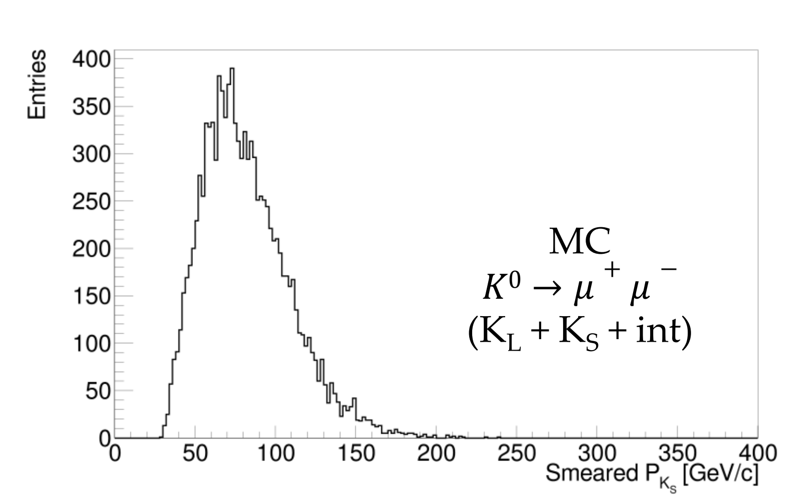
Pure CPV amplitude!

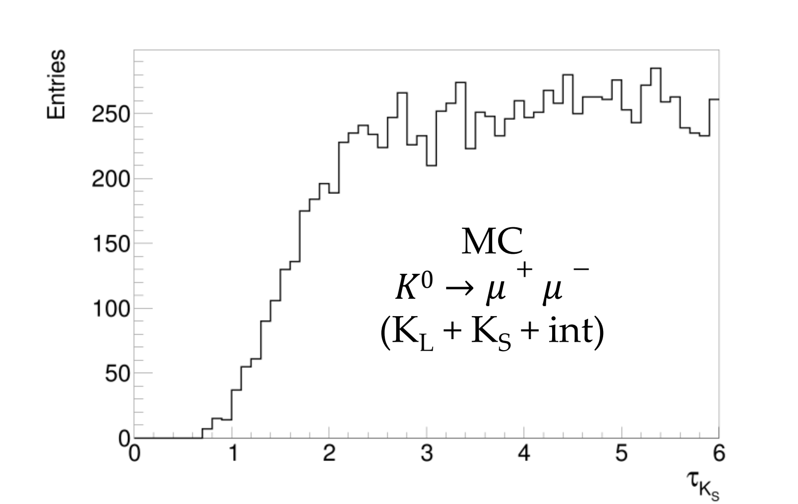
- A **golden** opportunity to get η cleanly, with **less than 1% error**
- A possibility in the long-term that should not be overlooked
- Interference mesurement is the main motivation: **PRL 119 201802(2017)**, **JHEP 07 (2021) 103**
  - Challenges on intensity, detector performance, background suppression
- **A high-intensity kaon factory that could address the interference requires a much more generic machine**
- Rewrite the PDG for K_S and K_L decays

Experimental layout



Simulation: Signal after geometrical selection



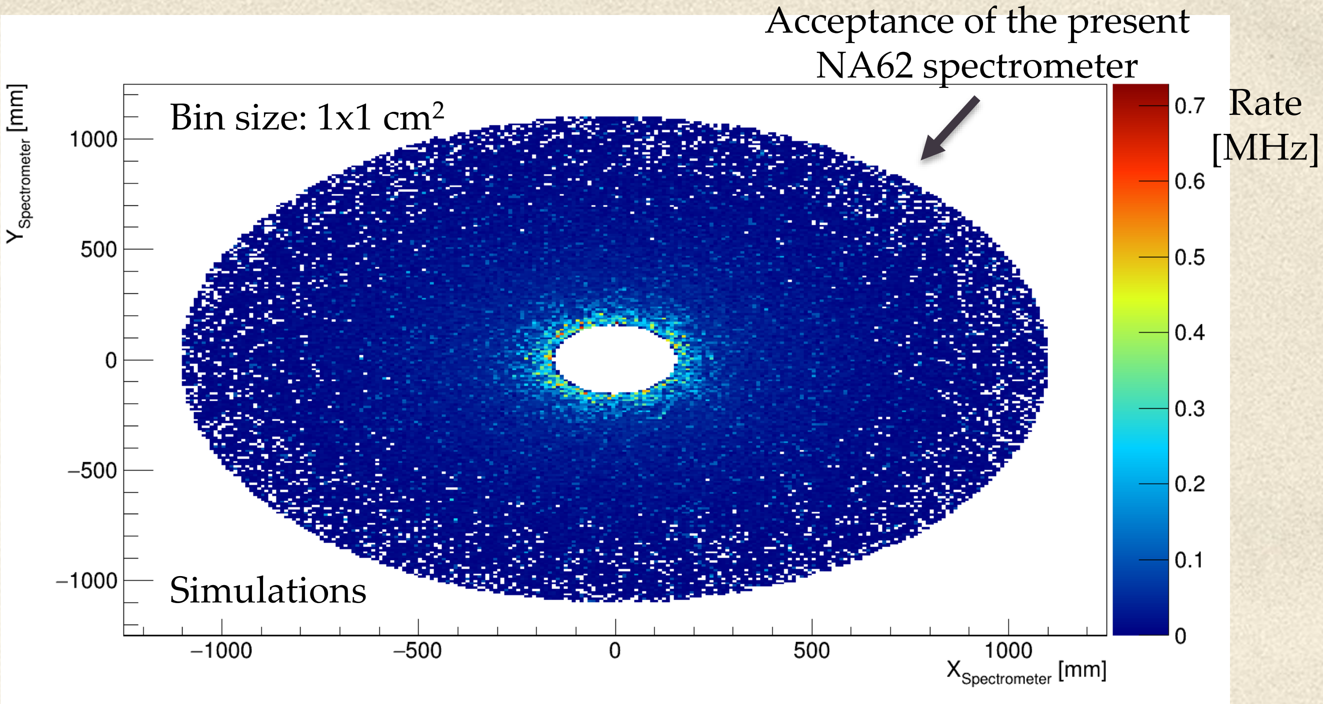


- Signal efficiency **~ 15%** (DAQ+Trigger+Detector efficiency (a la NA62)+full selection)
    - Geometrical acceptance **~ 40%**
- Statistics in the plots correspond to ~2 *years of operation* (10^{19} POT/year), *12mrad* incident angle, *1mrad* collimator opening, and $\varphi_0 = 0$ strong phase

Signal yield for 10^{19} POT/year

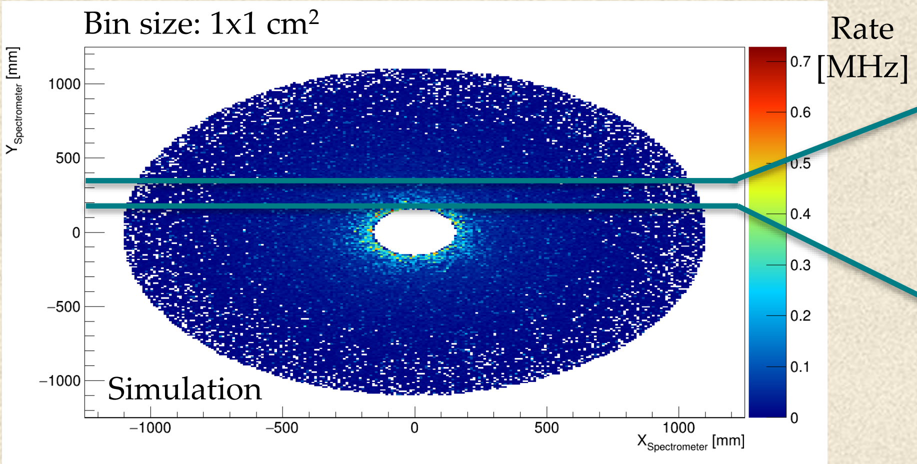
- Yield for interference events can`t reliably be computed
  - Depends heavily on the beam setup (incident angle + collimation) and the strong phase φ_0
- A particular experimental setup and φ_0 chosen
  - Expected number of interference decays in 0-6 τ_S **~ 500 – 2000 events/year (no selection)**
  - Signal efficiency ~ 15 % → **75 – 300 events/year (after full selection)**
  - Work on the signal extraction is needed to translate the expected statistics to sensitivity
  - **Optimization of the beam line essential to determine if the sensitivity will be sufficient**

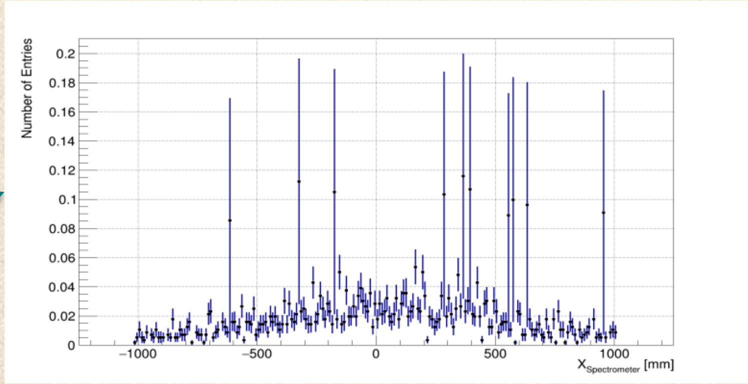
Rate of charged particles

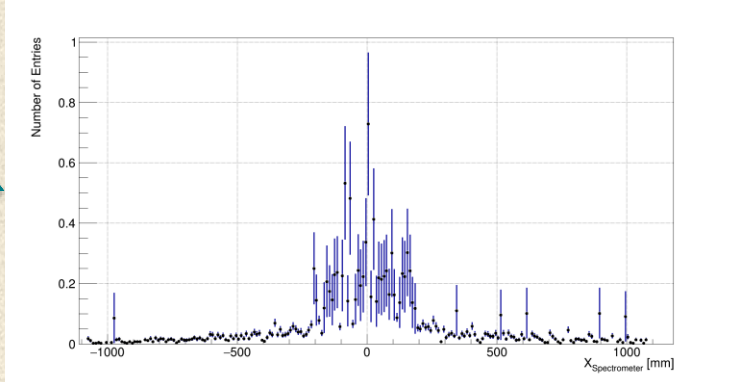


- Primary source of charged particles: **K_S and Λ decays**
  - Large integrated rates **~ 1GHz** (total surface ~ 3.7 m^2)
  - *Non-uniform rate:* hot spots can reach **~ 0.7 – 1 MHz/cm²**

Rate of charged particles







- <u>Affordable rates but technically challenging</u>
    - High granularity + different technology as a function of radius
    - Interface between different detector materials
    - Solid state detectors might be the solution
- ***Similar to the solutions required for detectors at the HL-LHC***

Areas for future study: analysis and simulations

- More serious feasibility study needed to address the $\boldsymbol{K_S - K_L \to \mu^+ \mu^-}$ **interference**

- <u>Important questions:</u>
    - Can we collect O(10^3) interference events in few years of operation
    - Background studies (accidentals and $K_L \to \mu^+ \mu^- \gamma$ background)
    - Impact of background contamination and fit procedure on the extraction of η
    - How is the sensitivity dependent on the strong phase

Areas for future study: beam and detector

- Beam line for a future high-intensity K_S experiment
  - Different options must be studied (muon rate, collimation, target, …)

- Tracking and calorimetry at the GHz regime: **dedicated R&D program required**
  - High-granularity detectors with O(100ps) time resolution
  - High detection efficiency > 95%
  - Hybrid technology (different techniques as a function of R)
  - Calorimetry essential for $K_L \to \pi^0 l^+ l^-$
  - Excellent momentum and energy resolution
  - Readout challenges

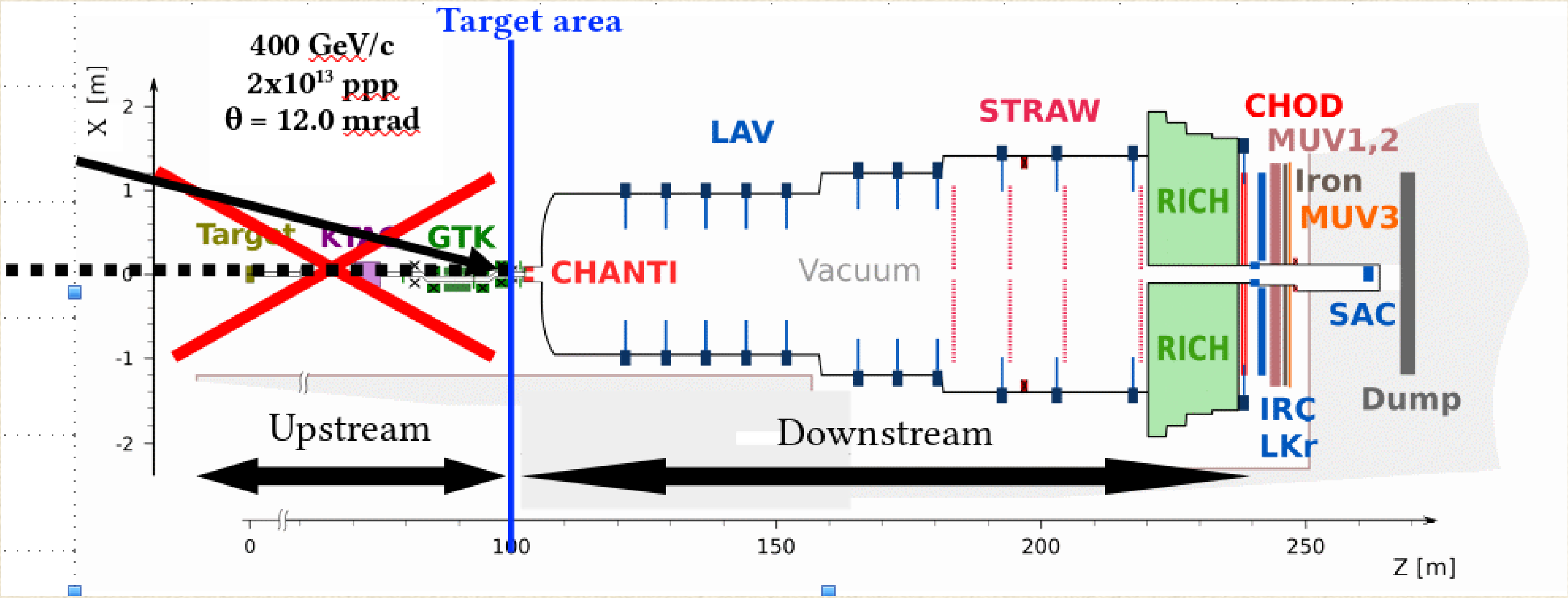
Conclusions

- Kaon physics observables: precision tests of the SM, complementary to B and D physics
- NA62 established the most precise $K^+ \to \pi^+ \nu\bar{\nu}$ measurement with its Run 1 data (Run 2 ongoing)
  - On track to reach 10% precision with Run 2 data
- Exciting prospects for the future of kaon physics at CERN (HIKE)
  - Kaon experiments at the intensity frontier = state–of–the–art detector technologies
  - Compelling physics program (rare decays, precision measurements, LFV/LNV, LFU tests, searches)
  - Detector solutions in line with the R&D required for HL–LHC
- A new idea to measure time-dependent $K_S - K_L \to \mu^+\mu^-$ interference in the future
  - Requires serious feasibility studies and many challenges

We are entering an exiting decade for kaon physics!

SPARES

Thoughts on experimental design



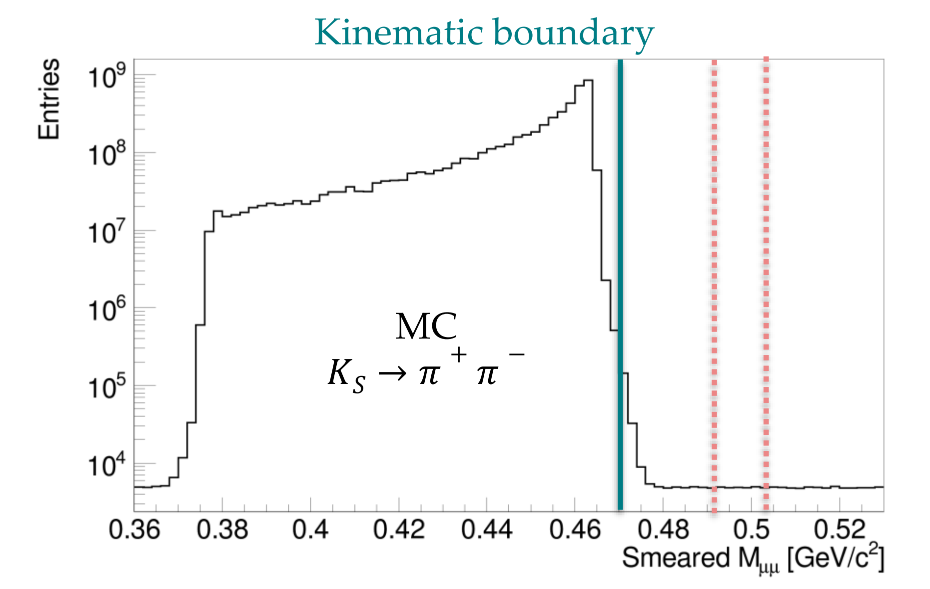
- Similar setup to NA62 but switch to neutral beamline: **6xNA62 intensity → 1019 POT/year**
- Beam much closer to the detectors: **high event rate**
- First few meters after the target will be needed for collimation
- Large incident angle → soft kaon momentum spectrum → **30-40% geometrical acceptance**

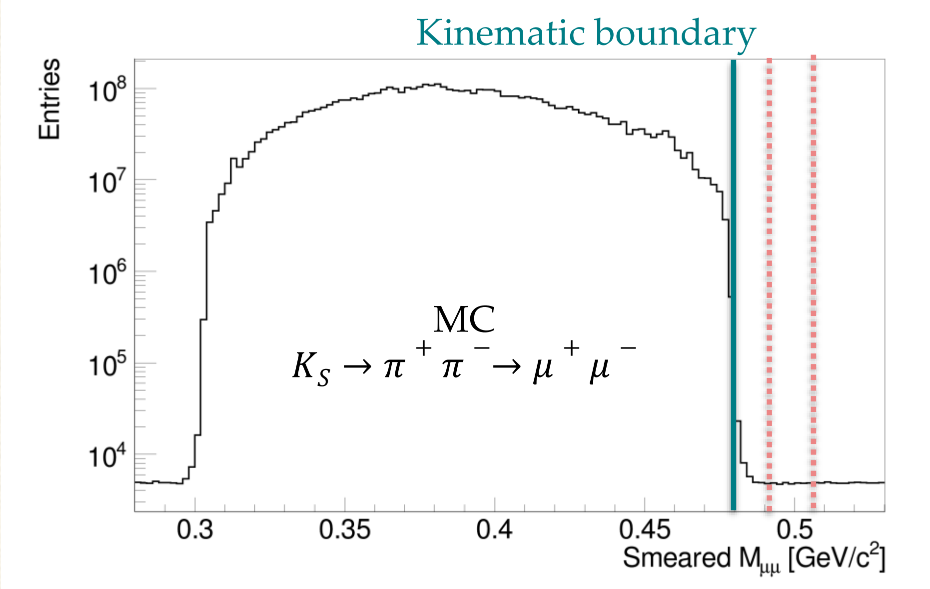
Background from kaon decays

	Effective BR	Suppression mechanism
$K^0 \to \mu^+ \mu^-$ (Signal)	**~3×10^{-10}**	**-**
$K_S \to \pi^+ \pi^-$	0.7	PID, Kinematics (wrong mass assignment)
$K_S \to \pi^+ \pi^- (\to \mu^+ \mu^-)$	1×10^{-4}	Probability for 2x $\pi \to \mu$ decays, Kinematics (P_{miss}, Vertex reconstruction, Position at primary target)
$K_L \to \mu^+ \mu^- \gamma$	3.6×10^{-7}	Branching ratio, Missing momentum, Photon rejection
Accidental muon pairs	-	Kinematic rejection, timing

- **$K^0 \to \mu^+ \mu^-$ signal signature:** two muons with invariant mass $M_{\mu\mu}$, peaking at the neutral kaon mass
- Complementary challenges as for the $K^+ \to \pi^+ \nu\bar{\nu}$ measurement:
  - **Strong PID, Kinematic, and Photon rejection**

Background: Non-gaussian kinematic tails





- Kinematic boundary for both backgrounds far from signal region (at least 10 sigma)
- Smearing as for the gaussian + non-gaussian tails from $K^+ \to \pi^+\pi^+\pi^-$ in NA62 data
- Expected kinematic tails at the level of **~ 10^{-5}**

Background contamination

	Effective BR	Suppression mechanism	Expected S/B
$K_S \to \pi^+ \pi^-$	0.7	PID, Kinematics (wrong mass assignment)	~10
$K_S \to \pi^+ \pi^- (\to \mu^+ \mu^-)$	1×10^{-4}	Probability for 2x $\pi \to \mu$ decays, Kinematics (P_{miss}, Vertex reconstruction, Position at primary target)	~2
$K_L \to \mu^+ \mu^- \gamma$	3.6×10^{-7}	Branching ratio, Missing momentum, Photon rejection	?
Accidental muon pairs	-	Kinematic rejection, timing	?

- Work required to estimate the contribution of radiative decays and accidentals
- **Accidental background will be an issue (heavily dependent on the beam line)**

Areas for future study: beyond $K \to \mu^+ \mu^-$

- Large statistics of rare processes will be available
- O(10^{14}) K_S/K_L decays will allow studies of $K_L \to \pi^0 l^+ l^-$ and $K_L \to e\mu$ decays
  - *Translates to ~ 50 (25) $K_L \to \pi^0 e^+ e^-$ ($K_L \to \pi^0 \mu^+ \mu^-$) events/year*
- O(10^{13}) Λ decays
- Sensitivity studies for a wide range of rare processes must be performed
- New ideas for observables are welcome
- Understand better the experimental requirements for a broad program!

$K^+ \to \pi^+ \nu \bar{\nu}$: Historical context