

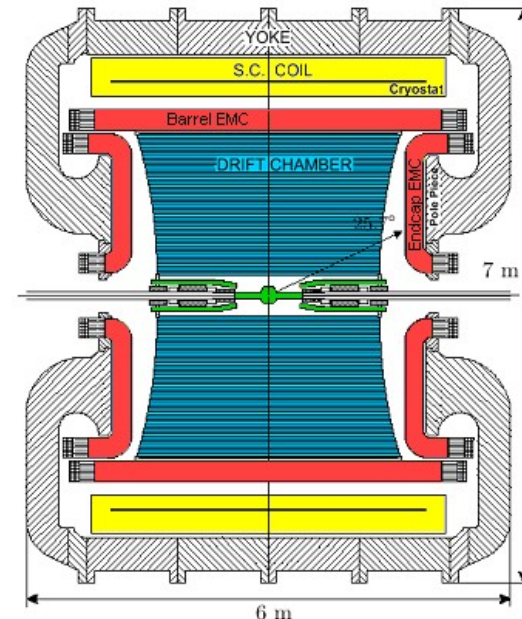
Kaon Experiments in Europe: KLOE-2 and NA62

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KLOE-2

- Extend KLOE physics at upgraded DAΦNE
- Phase 0 (2012): $\mathcal{L} \sim 5 \text{ fb}^{-1}$ with new tagging system for $\gamma\gamma$ physics
- Phase 1 (2013-2016/7?): collect $\mathcal{L} \sim 25 \text{ fb}^{-1}$ with upgraded detector

-lead/scintillating fiber calorimeter
-drift chamber



DAΦNE Upgrade

- Crab waist interaction region (P. Raimondi)
- Luminosity increase of factor 3



Detector Upgrade

- $\gamma\gamma$ tagging system (ready)
- Inner tracker (construction started)
- Small angle and quad calorimeters (construction started)
- FEE
- Computing and networking
- Trigger, software, etc.



Inner tracker construction

Physics Program

- Neutral kaon interferometry, CPT symmetry & QM tests
- Kaon physics, CKM, LFV, rare K_S decays
- η , η' physics
- Light scalars, $\gamma\gamma$ physics
- Hadron cross-section at low energy, muon anomaly

(see EPJC 68 (2010) 619-681)

Neutral Kaons at a Φ Factory

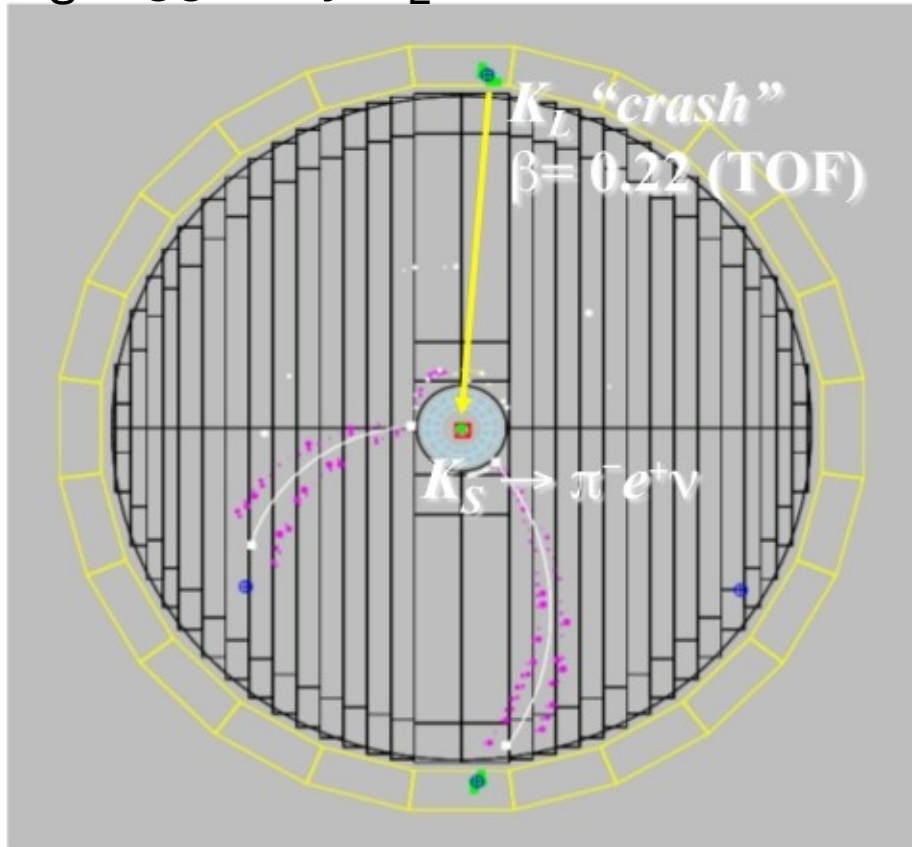
- $\sigma_{e^+e^- \rightarrow \phi(1020)} \approx 3\mu\text{b}$
- $\text{BR}(\phi \rightarrow K^0 \overline{K}^0) \approx 34\%$
- $\sim 10^6$ neutral kaon pairs / pb^{-1}
- Pairs produced in an antisymmetric quantum state with $J^{PC} = 1^{--}$
- $p_K = 110 \text{ MeV}$; $\lambda_S = 6 \text{ mm}$; $\lambda_L = 3.5 \text{ m}$

Kaon detection at large (small) times tags a K_S (K_L) \Rightarrow
possibility to select a pure K_S sample

unique at a Φ -factory

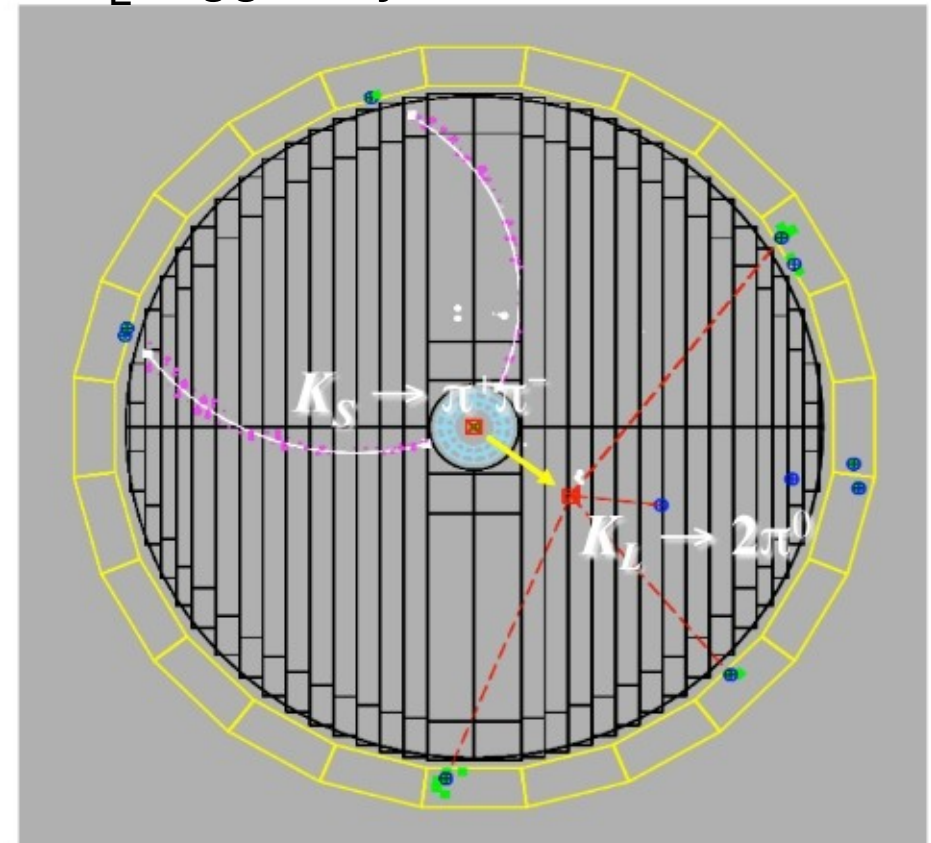
Tagging with KLOE

K_S tagged by K_L interaction in EmC



Efficiency $\sim 30\%$ (mainly geometrical)
 K_S angular resolution: $\sim 1^\circ$ (0.3° in φ)
 K_S momentum resolution: ~ 2 MeV

K_L tagged by $\pi^+ \pi^-$ vertex at IP



Efficiency $\sim 70\%$ (mainly geometrical)
 K_L angular resolution: $\sim 1^\circ$
 K_L momentum resolution: ~ 2 MeV

Analysis of $K_S \rightarrow \pi^0 \pi^0 \pi^0$

- KLOE [PLB619(2005)61] with 450 pb⁻¹
 - BR < 1.2 x 10⁻⁷ at 90% CL
 - $|\eta_{000}| < 0.018$ at 90% CL
- Update with more KLOE data, ~2.5 fb⁻¹
 - Reduce split clusters with better algorithm
 - Stiffer K_S tagging requirements
 - PRELIMINARY
 - BR < 2.7 x 10⁻⁸ at 90% CL
 - $|\eta_{000}| < 0.009$ at 90% CL

Suggests KLOE-2 discovery potential ($\sim 2 \times 10^{-9}$)

Neutral Kaon Interferometry

- Double differential time distribution:

$$I(f_1, t_1; f_2, t_2) = C_{12} \left\{ |\eta_1|^2 e^{-\Gamma_L t_1 - \Gamma_S t_2} + |\eta_2|^2 e^{-\Gamma_S t_1 - \Gamma_L t_2} - 2|\eta_1||\eta_2| e^{-(\Gamma_L + \Gamma_S)(t_2 + t_1)/2} \times \cos[\Delta m(t_2 - t_1) + \phi_1 - \phi_2] \right\}$$

Φ-factory
interference
term

- With various final states, can measure

$$\Gamma_L, \Gamma_S, \Delta m, |\eta_i|, \phi_i \equiv \arg(\eta_i)$$

Prospects

Mode	Test of	Param.	Present best published measurement	KLOE-2 L=25 fb ⁻¹
$K_S \rightarrow \pi e \nu$	CP, CPT	A_S	$(1.5 \pm 11) \times 10^{-3}$	$\pm 1 \times 10^{-3}$
$\pi^+ \pi^- \pi e \nu$	CP, CPT	A_L	$(332.2 \pm 5.8 \pm 4.7) \times 10^{-5}$	$\pm 4 \times 10^{-5}$
$\pi^+ \pi^- \pi^0 \pi^0$	CP	$\text{Re}(\epsilon'/\epsilon)$	$(1.65 \pm 0.26) \times 10^{-3}$ (*)	$\pm 0.3 \times 10^{-3}$
$\pi^+ \pi^- \pi^0 \pi^0$	CP, CPT	$\text{Im}(\epsilon'/\epsilon)$	$(-1.2 \pm 2.3) \times 10^{-3}$ (*)	$\pm 4 \times 10^{-3}$
$\pi e \nu \pi e \nu$	CPT	$\text{Re}(\delta) + \text{Re}(x_-)$	$\text{Re}(\delta) = (0.25 \pm 0.23) \times 10^{-3}$ (*) $\text{Re}(x_-) = (-4.2 \pm 1.7) \times 10^{-3}$ (*)	$\pm 0.3 \times 10^{-3}$
$\pi e \nu \pi e \nu$	CPT	$\text{Im}(\delta) + \text{Im}(x_+)$	$\text{Im}(\delta) = (-0.6 \pm 1.9) \times 10^{-5}$ (*) $\text{Im}(x_+) = (0.2 \pm 2.2) \times 10^{-3}$ (*)	$\pm 4 \times 10^{-3}$
$\pi^+ \pi^- \pi^+ \pi^-$		Δm	$(5.288 \pm 0.043) \times 10^9 \text{ s}^{-1}$	$\pm 0.05 \times 10^9 \text{ s}^{-1}$

(*) = PDG 2008 fit

Prospects, cont.

Mode	Test of	Param.	Present best published measurement	KLOE-2 L=25 fb ⁻¹
$\pi^+\pi^- \quad \pi^+\pi^-$	QM	ξ_{00}	$(0.1 \pm 1.0) \times 10^{-6}$	$\pm 0.1 \times 10^{-6}$
$\pi^+\pi^- \quad \pi^+\pi^-$	QM	ξ_{SL}	$(0.3 \pm 1.9) \times 10^{-2}$	$\pm 0.2 \times 10^{-2}$
$\pi^+\pi^- \quad \pi^+\pi^-$	CPT & QM	α	$(-0.5 \pm 2.8) \times 10^{-17} \text{ GeV}$	$\pm 2 \times 10^{-17} \text{ GeV}$
$\pi^+\pi^- \quad \pi^+\pi^-$	CPT & QM	β	$(2.5 \pm 2.3) \times 10^{-19} \text{ GeV}$	$\pm 0.2 \times 10^{-19} \text{ GeV}$
$\pi^+\pi^- \quad \pi^+\pi^-$	CPT & QM	γ	$(1.1 \pm 2.5) \times 10^{-21} \text{ GeV}$ compl. pos. hyp. $(0.7 \pm 1.2) \times 10^{-21} \text{ GeV}$	$\pm 0.3 \times 10^{-21} \text{ GeV}$ compl. pos. hyp. $\pm 0.2 \times 10^{-21} \text{ GeV}$
$\pi^+\pi^- \quad \pi^+\pi^-$	CPT & EPR corr.	Re(ω)	$(-1.6 \pm 2.6) \times 10^{-4}$	$\pm 3 \times 10^{-5}$
$\pi^+\pi^- \quad \pi^+\pi^-$	CPT & EPR corr.	Im(ω)	$(-1.7 \pm 3.4) \times 10^{-4}$	$\pm 4 \times 10^{-5}$
$K_{S,L} \rightarrow \pi e \nu$	CPT & Lorentz	Δa_0	$[(0.4 \pm 1.8) \times 10^{-17} \text{ GeV}]$	$\pm 2 \times 10^{-18} \text{ GeV}$
$\pi^+\pi^- \quad \pi^+\pi^-$	CPT & Lorentz	Δa_Z	$[(2.4 \pm 9.7) \times 10^{-18} \text{ GeV}]$	$\pm 1 \times 10^{-18} \text{ GeV}$
$\pi^+\pi^- \quad \pi e \nu$	CPT & Lorentz	$\Delta a_{X,Y}$	$[<10^{-21} \text{ GeV}]$	$\pm 6 \times 10^{-19} \text{ GeV}$

[...] = preliminary

NA62

- 2005: Proposal Submitted
- 2007-2008: $R_K = \frac{\Gamma(K^\pm \rightarrow e^\pm \nu)}{\Gamma(K^\pm \rightarrow \mu^\pm \nu)}$ Running
- 2008: Proposal Approved by CERN
- 2007-2013: Design & Construction
- 2012: Technical Run
- 2014: Data Taking

Goals

- $K^+ \rightarrow \pi^+ \nu \bar{\nu}$
- $K^+ \rightarrow \pi^+ \ell^+ \ell^-$
- R_K
- Lepton number violation
- Heavy neutrinos
- Low energy QCD
- $K^0 \rightarrow \pi^0 \nu \bar{\nu}$
- ...

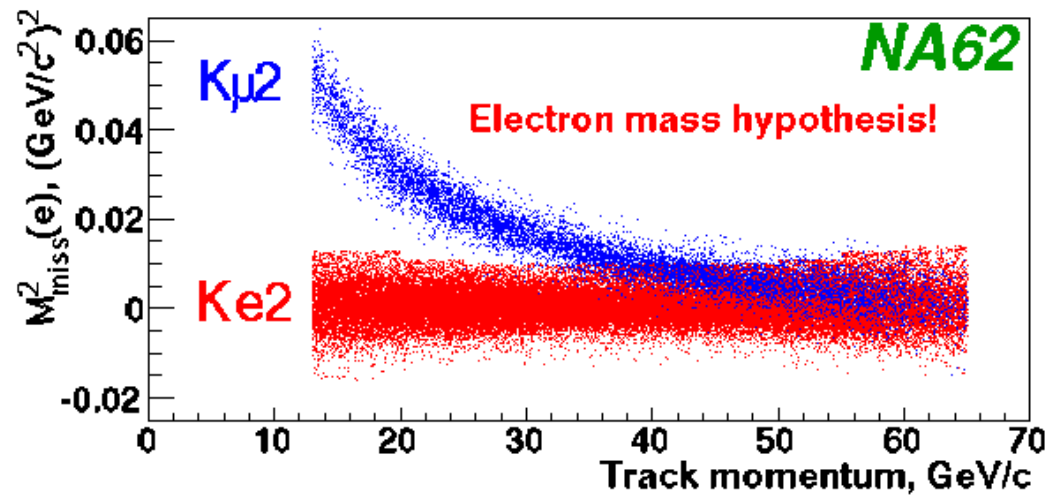
Collaboration

Birmingham, Bristol, CERN, Comenius, Dubna,
Ferrara, Florence, Frascati, Glasgow, GMU, Horia
Hulubei, IHEP Protvino, INR Moscow, Liverpool,
Louvain, Mainz, Merced, Naples, Perugia, Pisa,
Roma I, Roma Tor Vergata, San Luis Potosí,
SLAC, Sofia, Turin

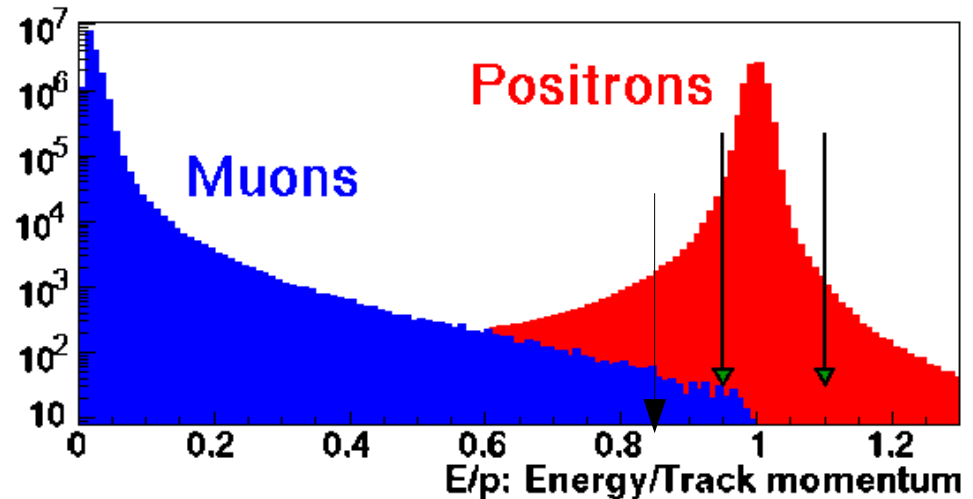
[Belgium, Bulgaria, Germany, Italy, Mexico,
Romania, Russia, Slovakia, United Kingdom,
U.S.A.]

R_K Event Selection

$$M_{\text{missing}}^2 = (P_K - P_\ell)^2$$



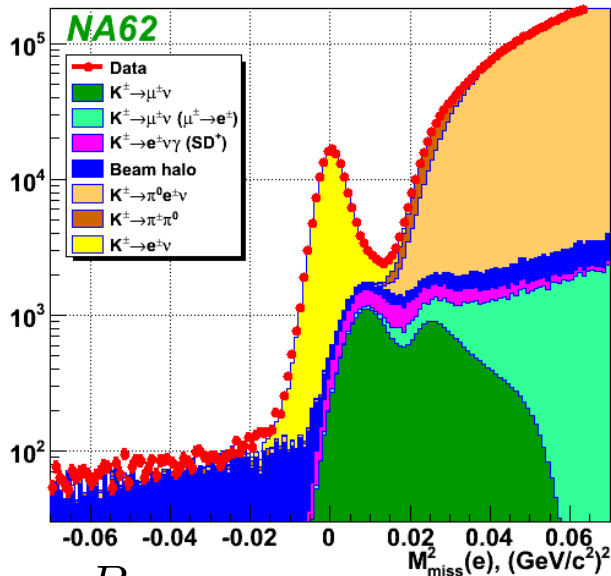
E from LKr Calorimeter
P from Spectrometer



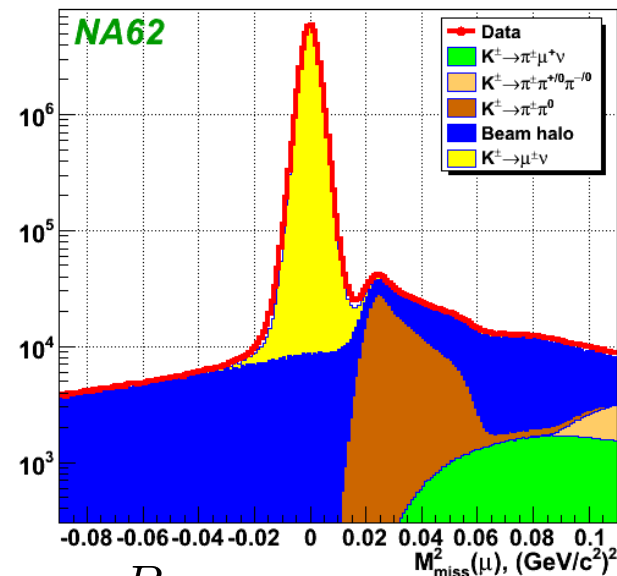
R_K Selected Events

145958 Ke2 Events

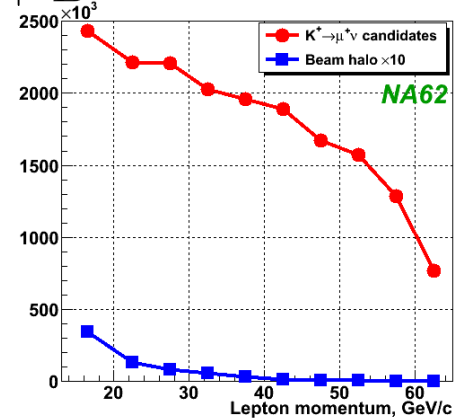
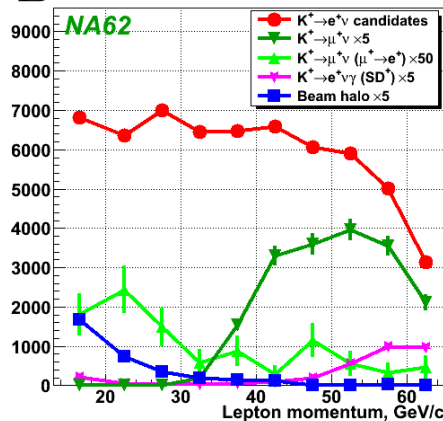
42.817×10^6 $K\mu 2$ Events



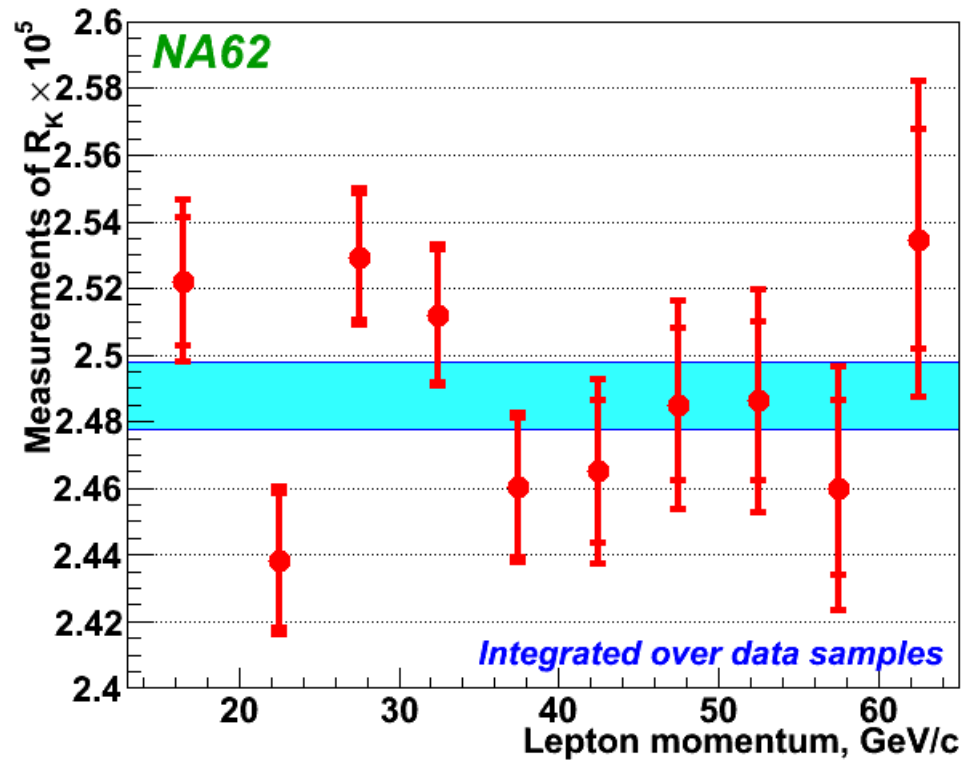
$$\frac{B}{S + B} = (10.95 \pm 0.27)\%$$



$$\frac{B}{S + B} = (0.50 \pm 0.01)\%$$

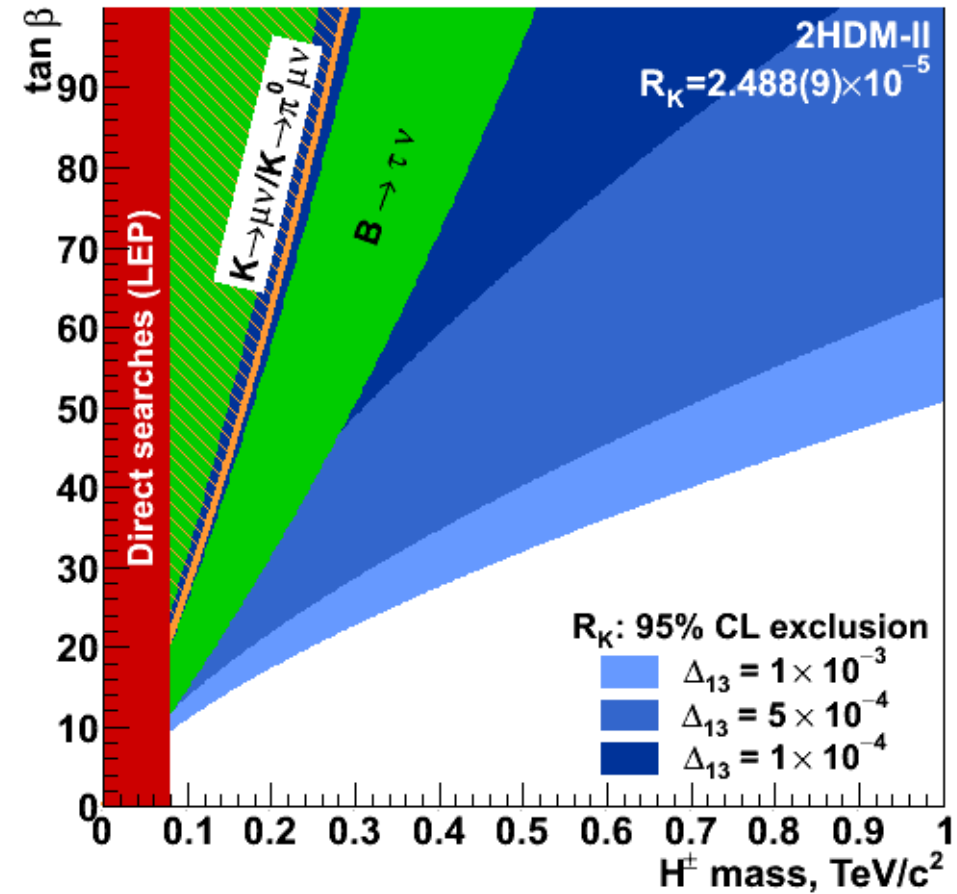
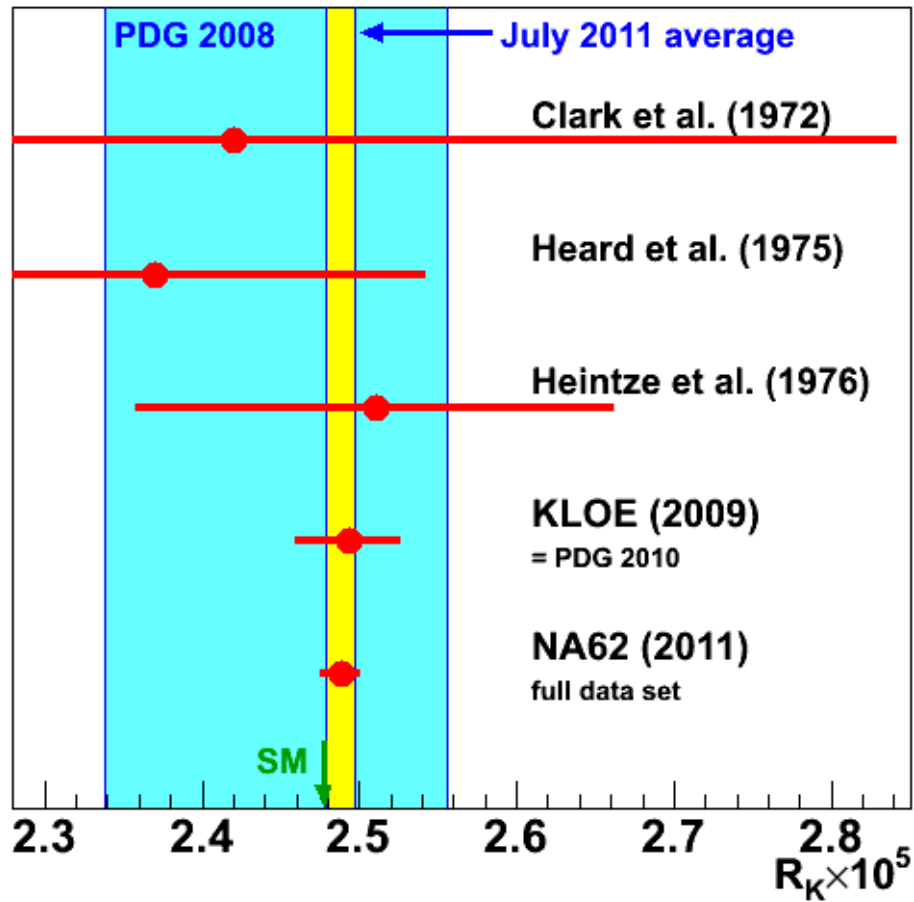


R_K Results

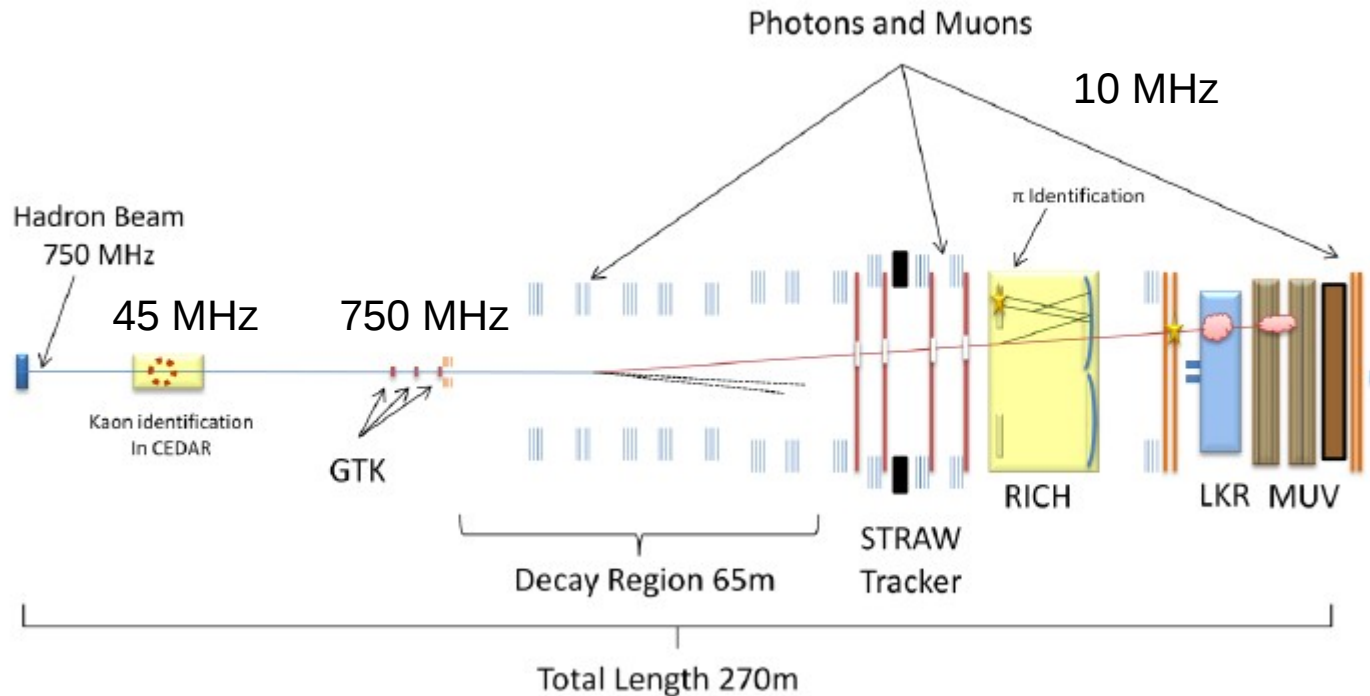


$$\begin{aligned} R_K &= (2.488 \pm 0.007_{stat} \pm 0.007_{syst}) \times 10^{-5} \\ &= (2.488 \pm 0.010) \times 10^{-5} \end{aligned}$$

R_K World Average



NA62



- Primary Beam

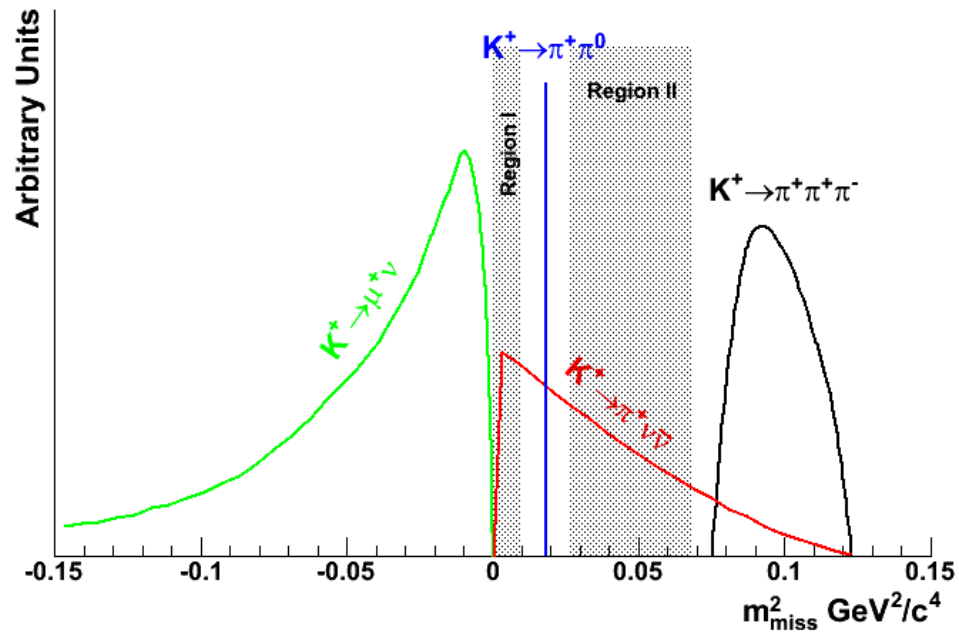
- 400 GeV/c protons
- 3×10^{12} protons/spill
- 4.8 s/16.8 s duty cycle

- Secondary Beam

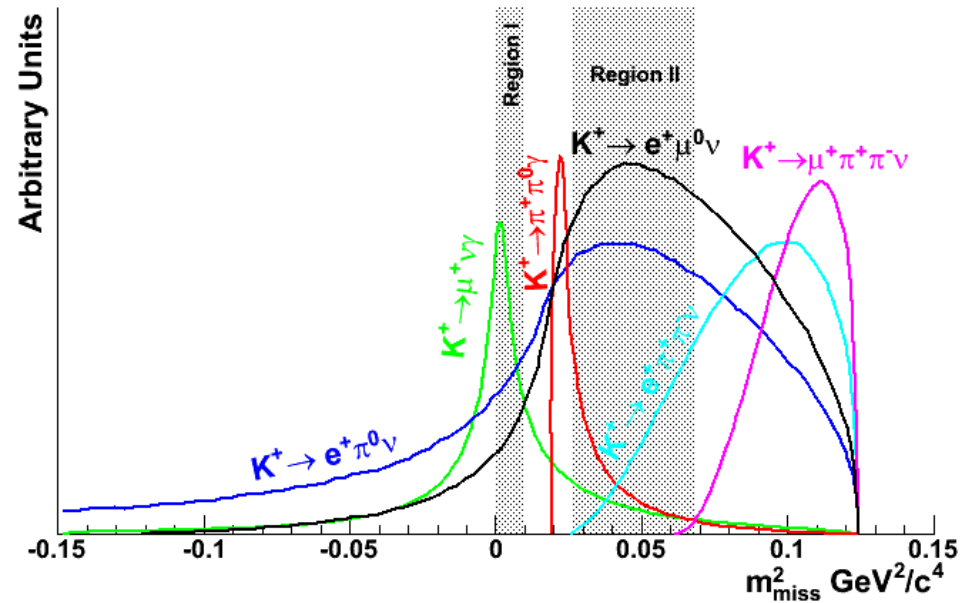
- $p = 75$ GeV/c ($\Delta p/p \approx 1\%$)
- Acc. = 12.7 μ str
- $K^+ \approx 6\%$
- 4.5×10^{12} K^+ decays/year

Kinematics

92%



8%



$$M_{\text{missing}}^2 = (P_K - P_{\pi})^2$$

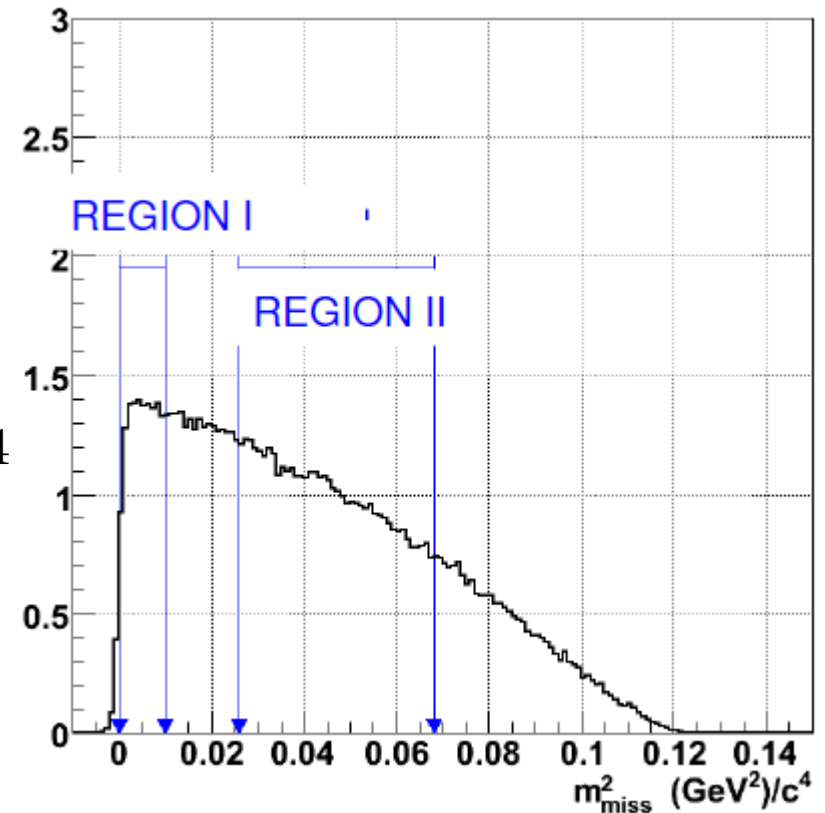
Kinematic Acceptance

- Region I

- $0 < M_{\text{miss}}^2 < 0.01 \text{ GeV}^2/c^4$
- 3.5%

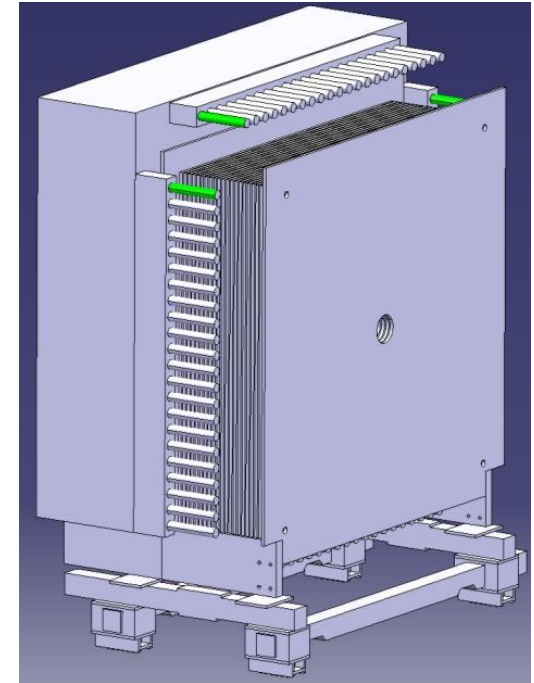
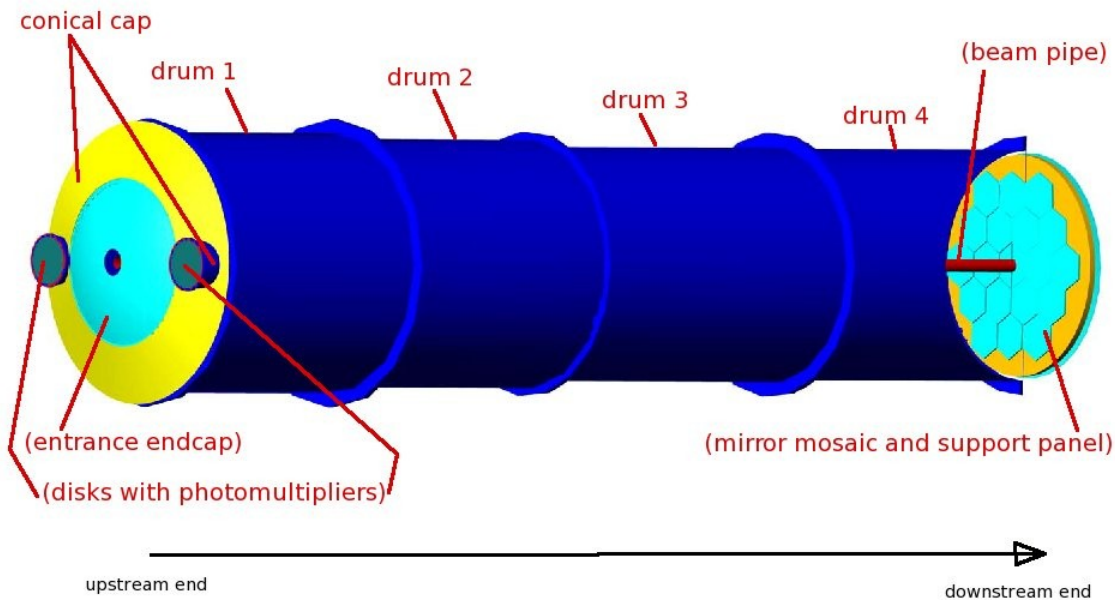
- Region II

- $0.026 < M_{\text{miss}}^2 < 0.068 \text{ GeV}^2/c^4$
- 10.9%



$K_{\mu 2}$ Background

- Kinematics: 5×10^{-6}
- Muon Veto: 10^{-5}
- Particle ID: 10^{-2}



MuV

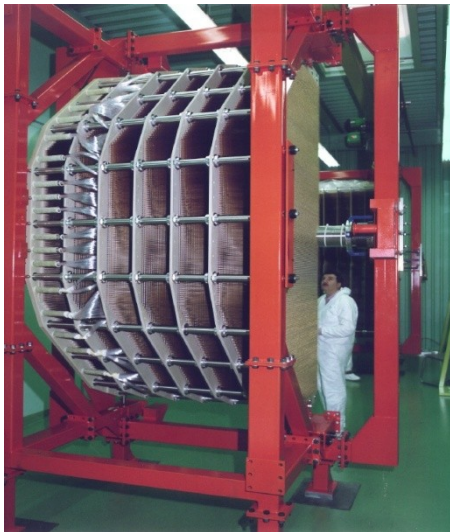
RICH

$K_{\pi 2}$ Background

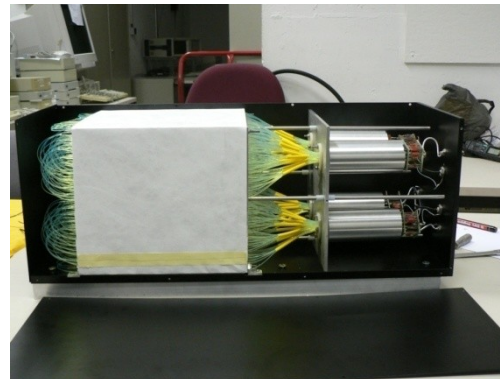
- Kinematics: 5×10^{-5}
- Muon Veto: 10^{-5} per photon; 10^{-8} per π^0



LAV $8.5 < \text{acc} < 50$ mrad

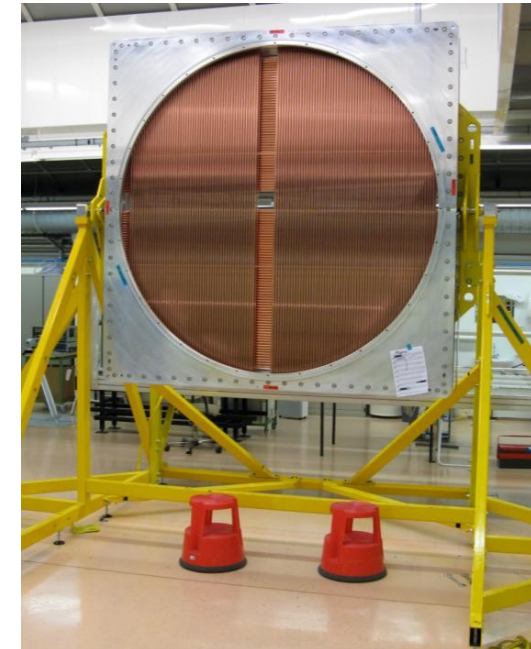
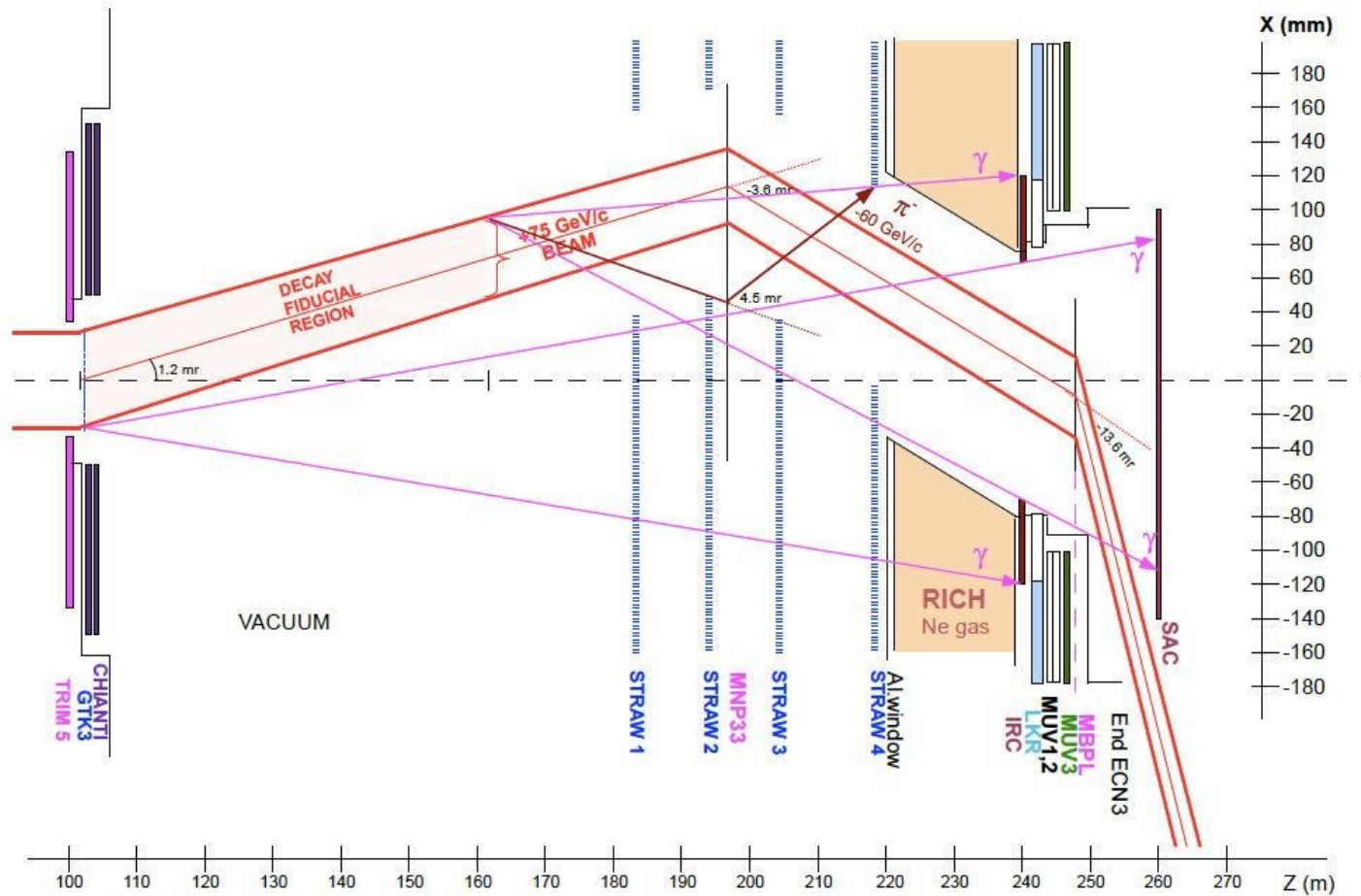


LKr $1 < \text{acc} < 8.5$ mrad



SAV $\text{acc} < 1$ mrad

Multi-body Background



Hermetic for π^- up to 60 GeV/c

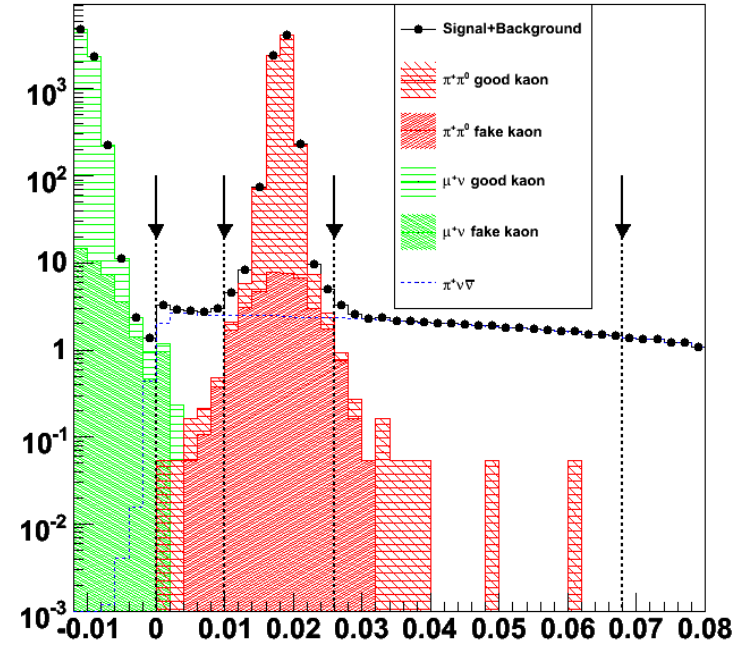
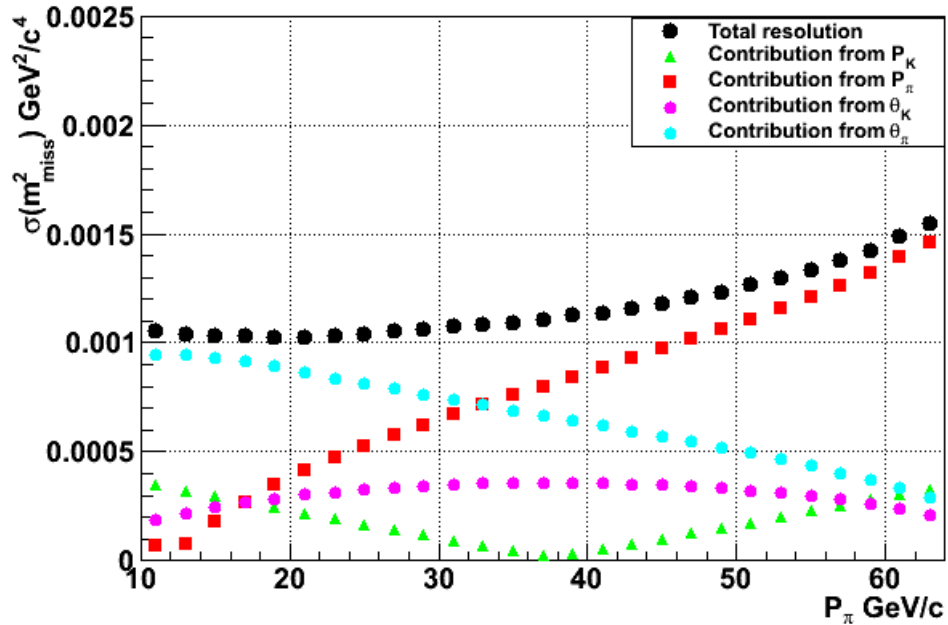
Schedule and Sensitivity

- Technical run in 2012
- Data taking in 2014

Source	Events/yr
Signal	55
Background	7.5-9.4
Channel	Fraction (%)
$\pi^+ \pi^0$	4.3-7.5
$\mu^+ \nu$	2.2
$\pi^+ \pi^- e^+ \nu$	≤ 3
other 3 – track modes	≤ 1.5
$\pi^+ \pi^0 \gamma$	~ 2
$\mu^+ \nu \gamma$	~ 0.7

SPARES

Reconstruction Resolution



Resolution limited by angle between Kaon and Pion

Backgrounds

Mode	Branching Fraction
$\mu^+ \nu (K_{\mu 2})$	63.5%
$\pi^+ \pi^0 (K_{\pi 2})$	20.7%
$\pi^+ \pi^+ \pi^-$	5.6%
$\pi^0 e^+ \nu (K_{e 3})$	5.1%
$\pi^0 \mu^+ \nu (K_{\mu 3})$	3.3%
$\pi^+ \pi^0 \pi^0$	1.8%
$\mu^+ \nu \gamma (K_{\mu 2 \gamma})$	0.62%
$\pi^+ \pi^0 \gamma$	2.7×10^{-4}
$\pi^+ \pi^- e^+ \nu (K_{e 4})$	4.1×10^{-5}
$\pi^0 \pi^0 e^+ \nu (K_{e 4}^{00})$	2.2×10^{-5}
$e^+ \nu (K_{e 2})$	1.5×10^{-5}
$\pi^+ \pi^- \mu^+ \nu (K_{\mu 4})$	1.4×10^{-5}