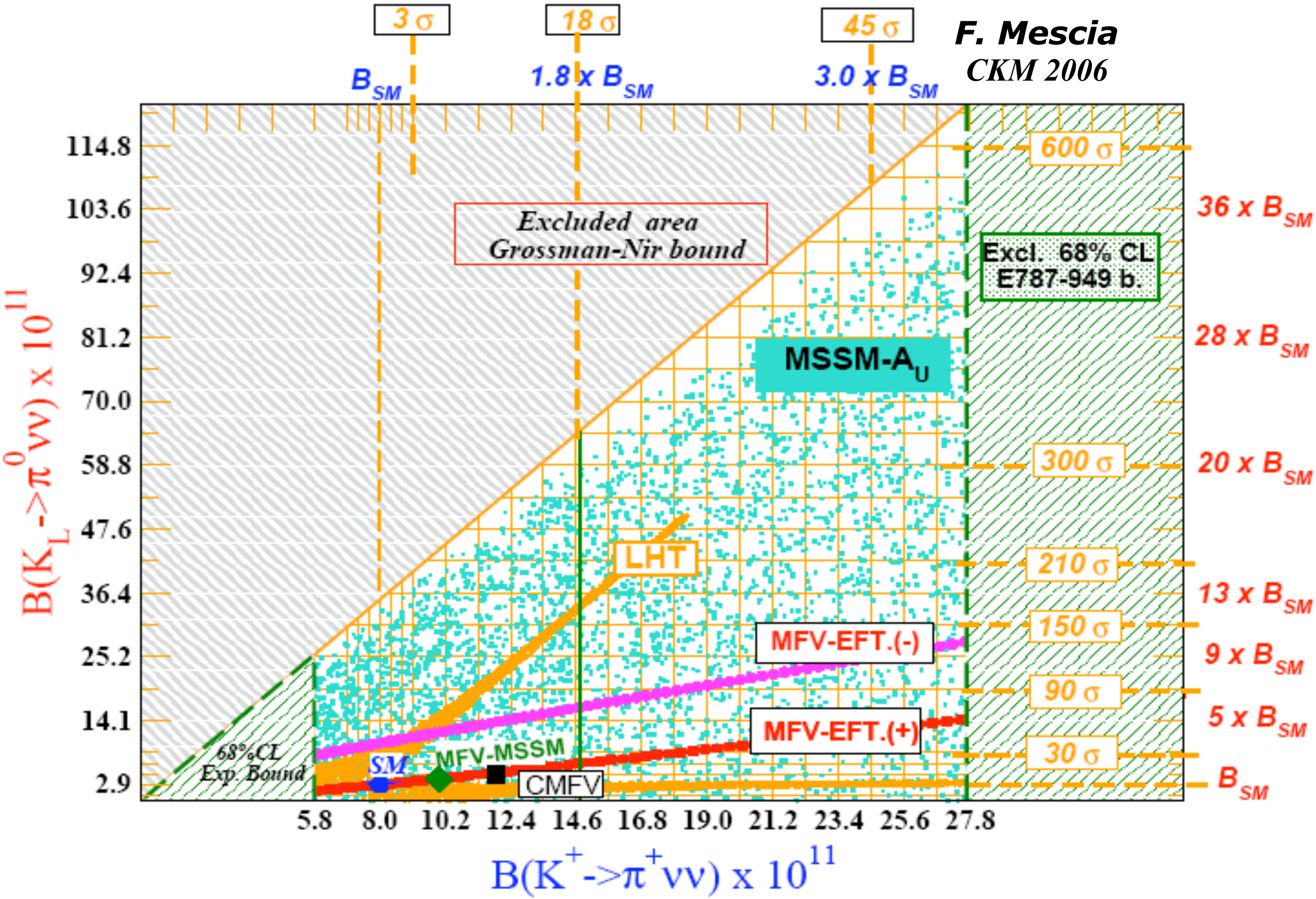
Rare Kaon Decays: Experimental Prospects

Augusto Ceccucci/CERN

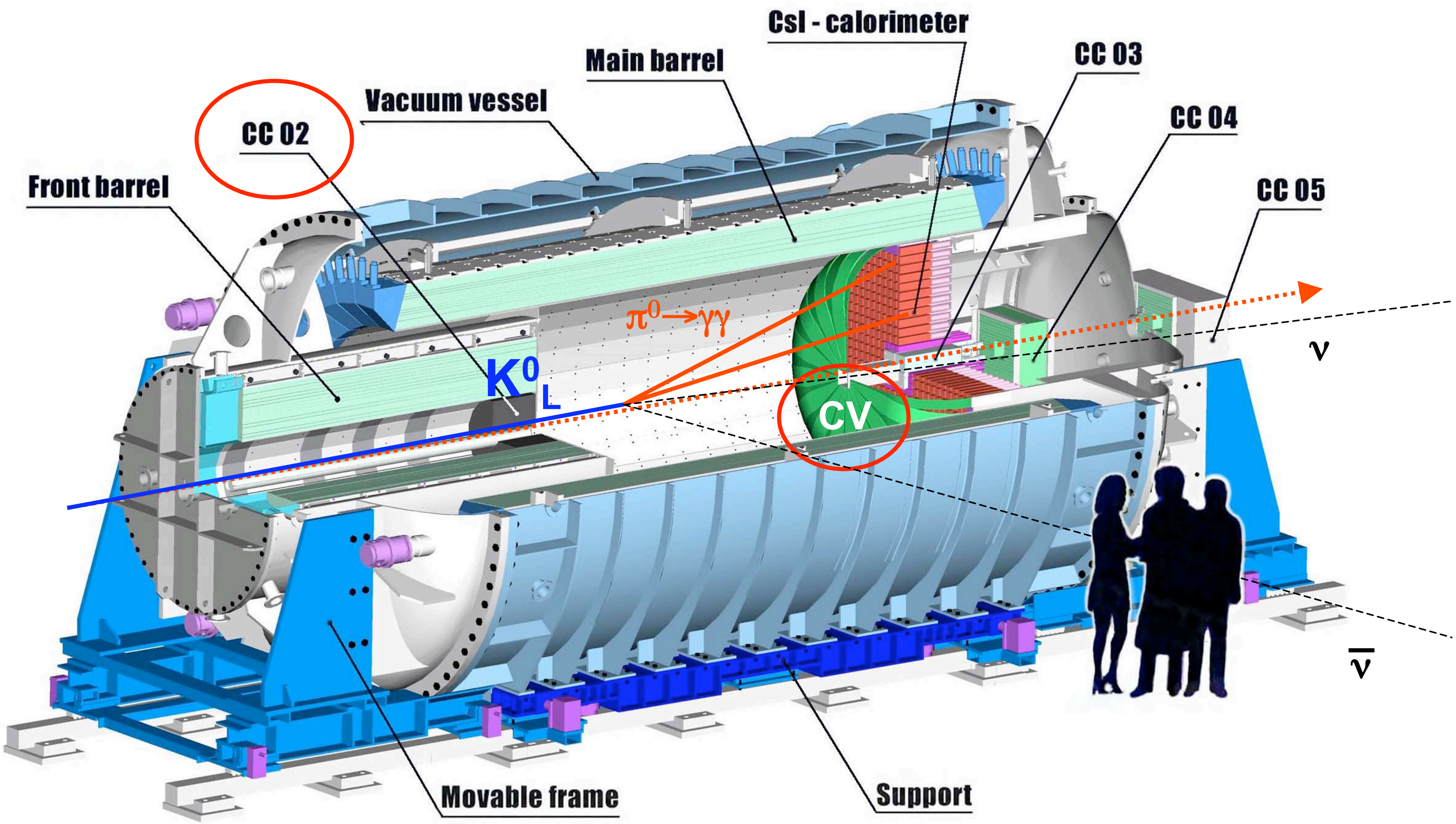
New Physics Reach of the K → π νν decays



Outlook

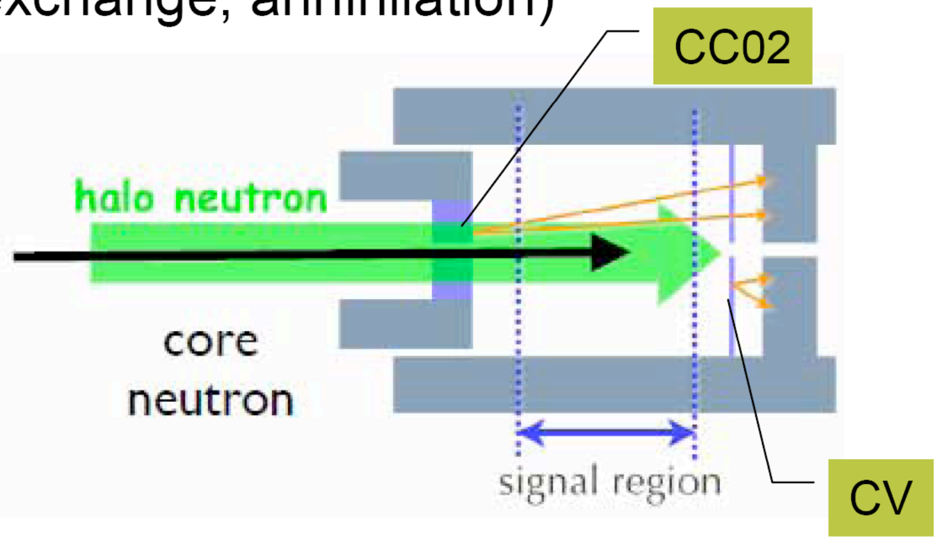
- $K^0_L \rightarrow \pi^0 \nu\nu$
  - State of the art: KEK E391a
  - Prospects (short term) : J-PARC E14;
  - Prospects (long term) : KLOD@U70, Project X (à la KOPIO), CERN
- $K^+ \rightarrow \pi^+ \nu\nu$
  - State of the art: BNL E787/E949
  - An In flight experiment at Fermilab (CKM) was cancelled
  - Prospects (short term): in-flight CERN P-326/NA62
  - Prospects (long term): Project X (?)

State of the art: KEK E391a



E391a: technique

- Kaon Decay
  - $K_L \rightarrow \pi^0\pi^0$ (2γ missed; due to inefficiency or fusion)
  - $K_L \rightarrow \pi^+\pi^-\pi^0$ (2 charged pion missed)
  - $K_L \rightarrow \pi^- e^+ \nu$ (charge exchange, annihilation)
- Halo neutron
  - Interact with "CC02","CV"
  - Produce π^0, η

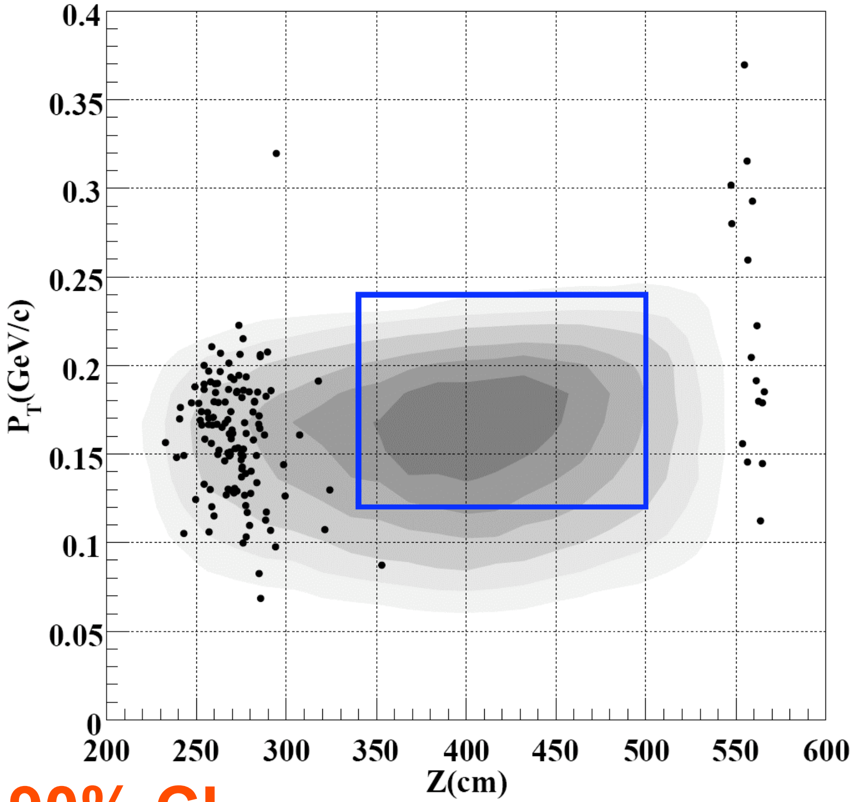


Slide from T. Nomura

E391a: Run II

PRL 100, 201802 (2008) [arXiv:0712.4164]

Background Source	Estimated # BG
$K^0_L \to \pi^0 \pi^0$	0.11 ± 0.09
CC02	0.16 ± 0.05
CV	0.08 ± 0.04
CV-η	0.06 ± 0.02
Total	**0.41± 0.11**

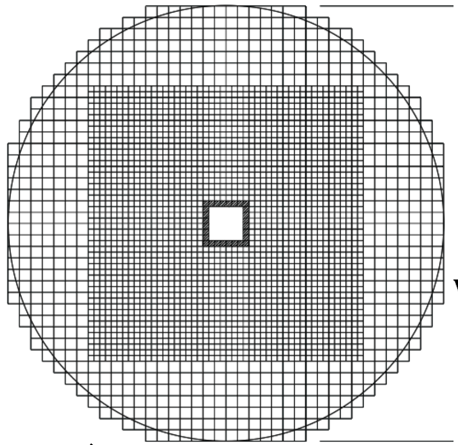


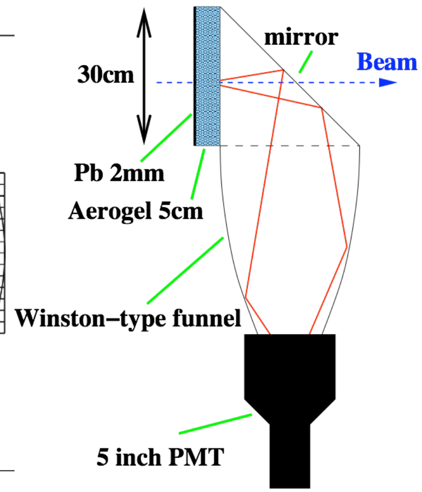
$BR(K^0_L \to \pi^0 \nu\nu) < 6.7 \times 10^{-8}$ 90% CL

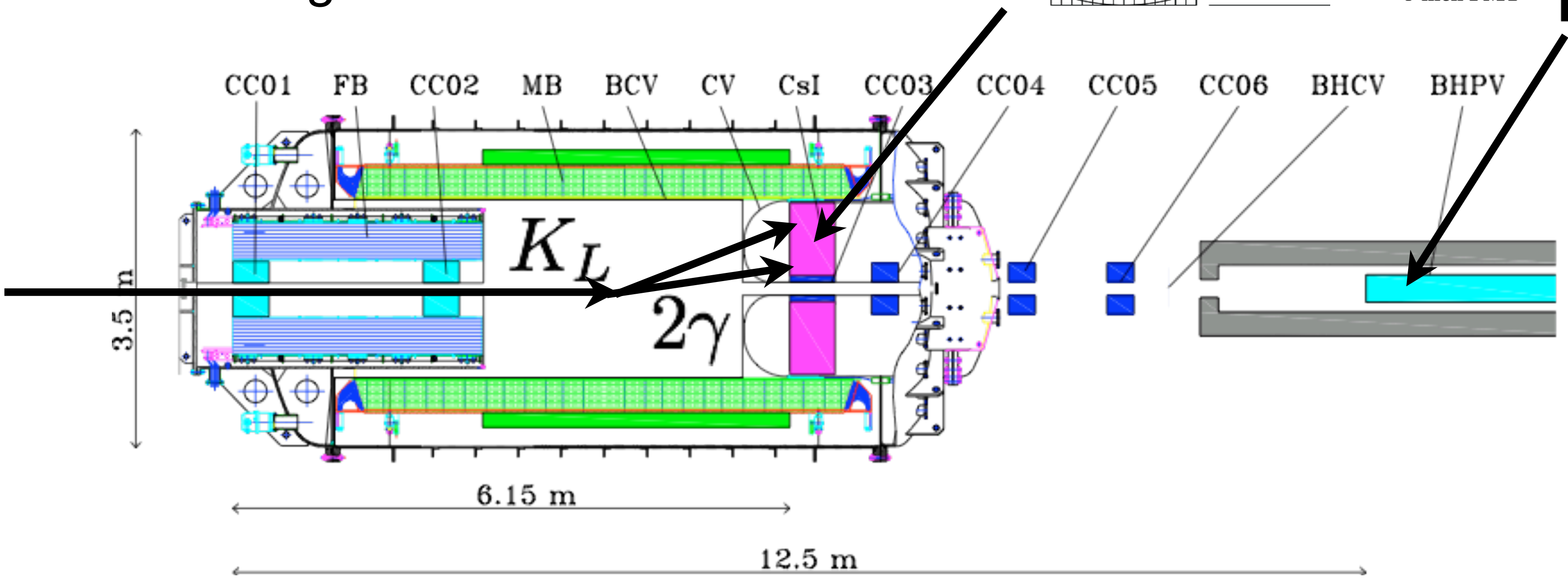
Improvement by about a factor of three w.r.t. previous best limit

Upgrades for E14 (J-Parc Step 1)

- CsI calorimeter with a finer granularity
- New photon veto in the beam
- Waveform digitization for higher rates







E14@J-PARC Stage 1

- 3 snowmass years
- "KL alone" beamline

(KL yield based on GEANT4/QGSP)

		standard cuts	CsI cluster shape cut	acceptance loss (50%)
Signal	$K_L \to \pi^0 \nu \overline{\nu}$	6.0 ± 0.1	5.4 ± 0.1	2.70 ± 0.05
K_L BG	$K_L \to \pi^0 \pi^0$	3.7 ± 0.2	3.3 ± 0.2	1.7 ± 0.1
	$K_L \to \pi^+ \pi^- \pi^0$	0.18 ± 0.08	0.16 ± 0.07	0.08 ± 0.04
	$K_L \to \pi^- e^+ \nu_e$	0.13 ± 0.01	0.03 ± 0.003	0.02 ± 0.001
halo n BG	CV	—	—	0.08
	η	8.1	0.6	0.3

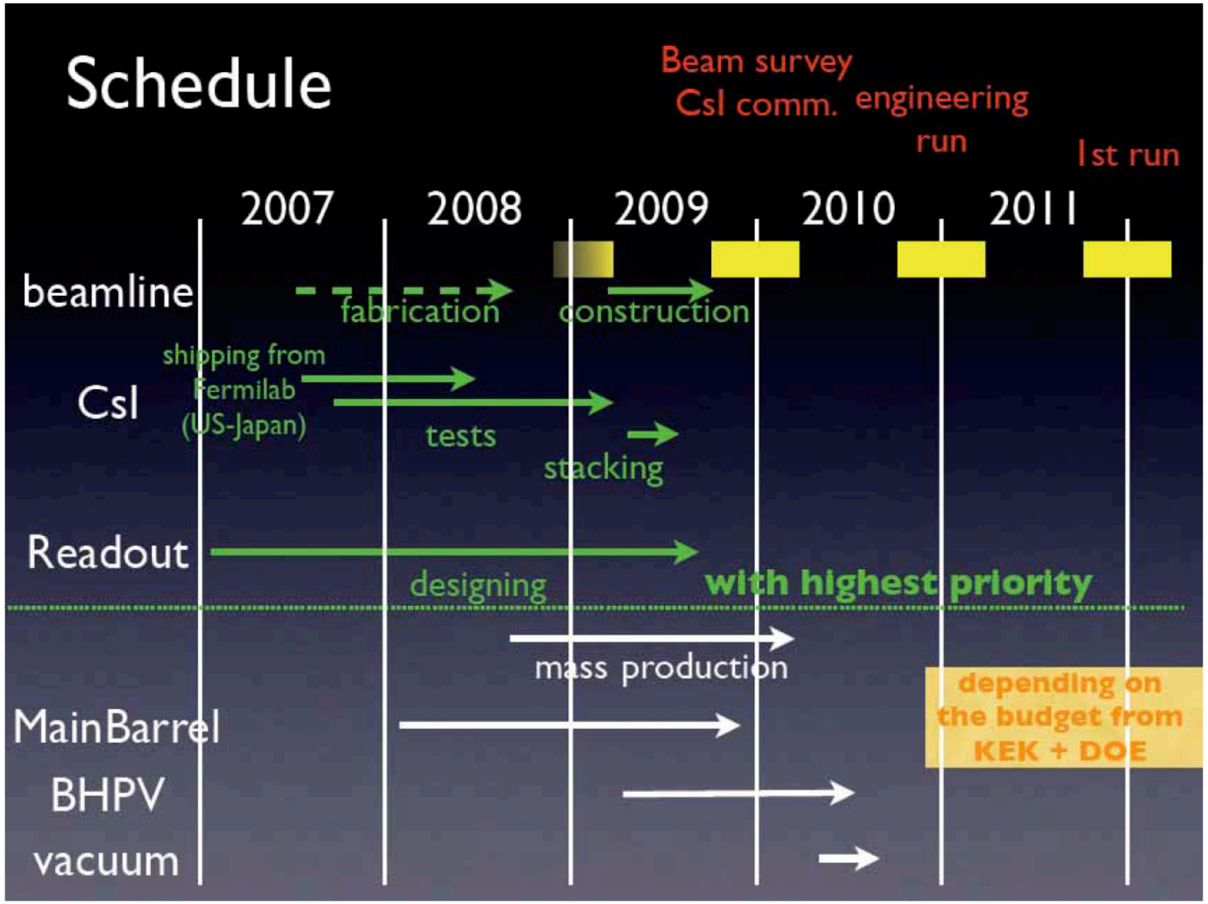
Note:
Detailed simulation of CV/CC02 BG in progress

Slide from T. Nomura

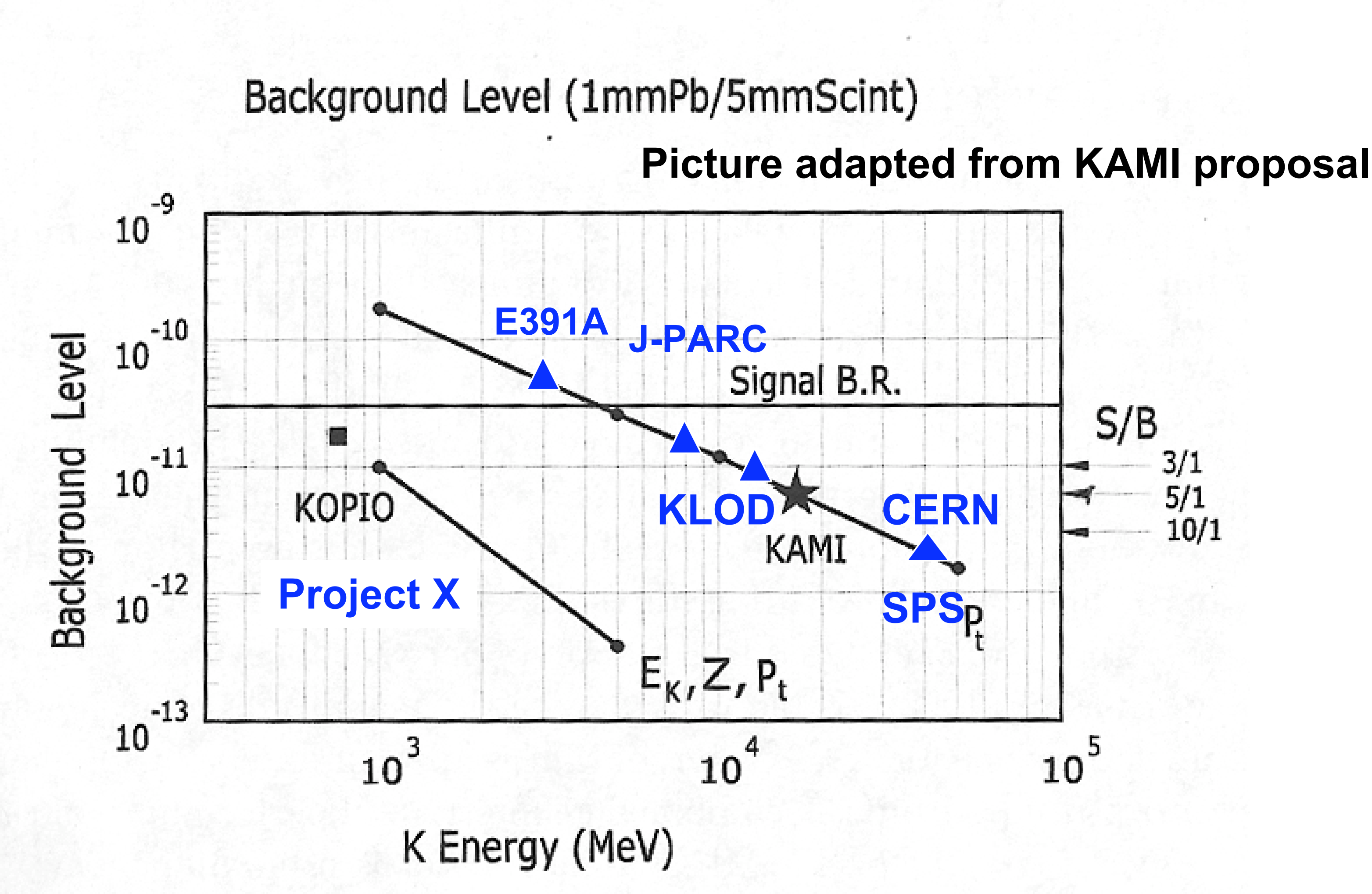
Status of E14

- Stage I Approved
- Recommended for stage II approval by J-PARC PAC
- Significant resources already secured

Schedule from T. Nomura



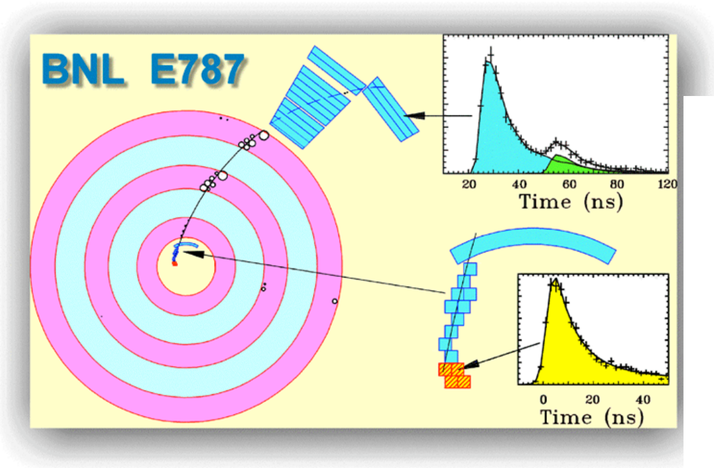
$K_L \to \pi^0 \nu\nu$ Long Time Prospects

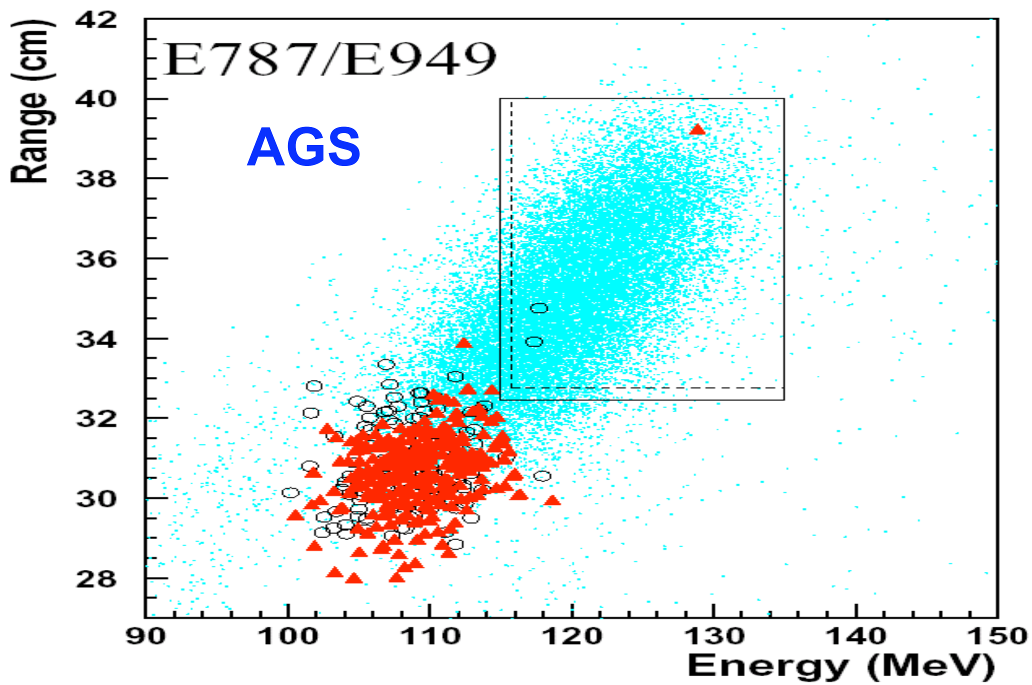


CERN is competitive if the E391A technique is established

$K^+ \rightarrow \pi^+ \nu\nu$: State of the art

hep-ex/0403036 PRL93 (2004)
See also long article just printed:
PRD 77, 052003 (2008)





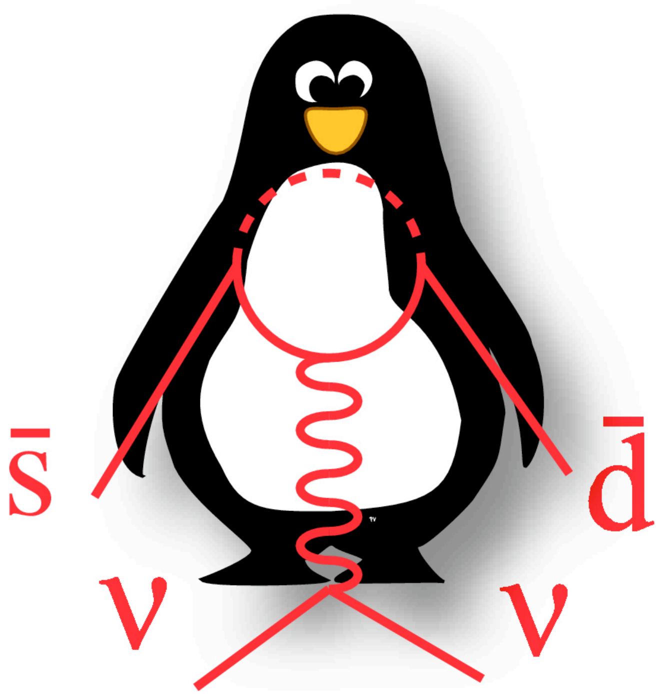
Stopped K
~0.1 % acceptance

$BR(K^+ \rightarrow \pi^+ \nu\nu) = 1.47^{+1.30}_{-0.89} \times 10^{-10}$

- Three candidates
- Compatible with SM within large errors

Proposal to Measure the Rare Decay $K^+ \rightarrow \pi^+ \nu \nu$ at the CERN SPS

P-326/NA62



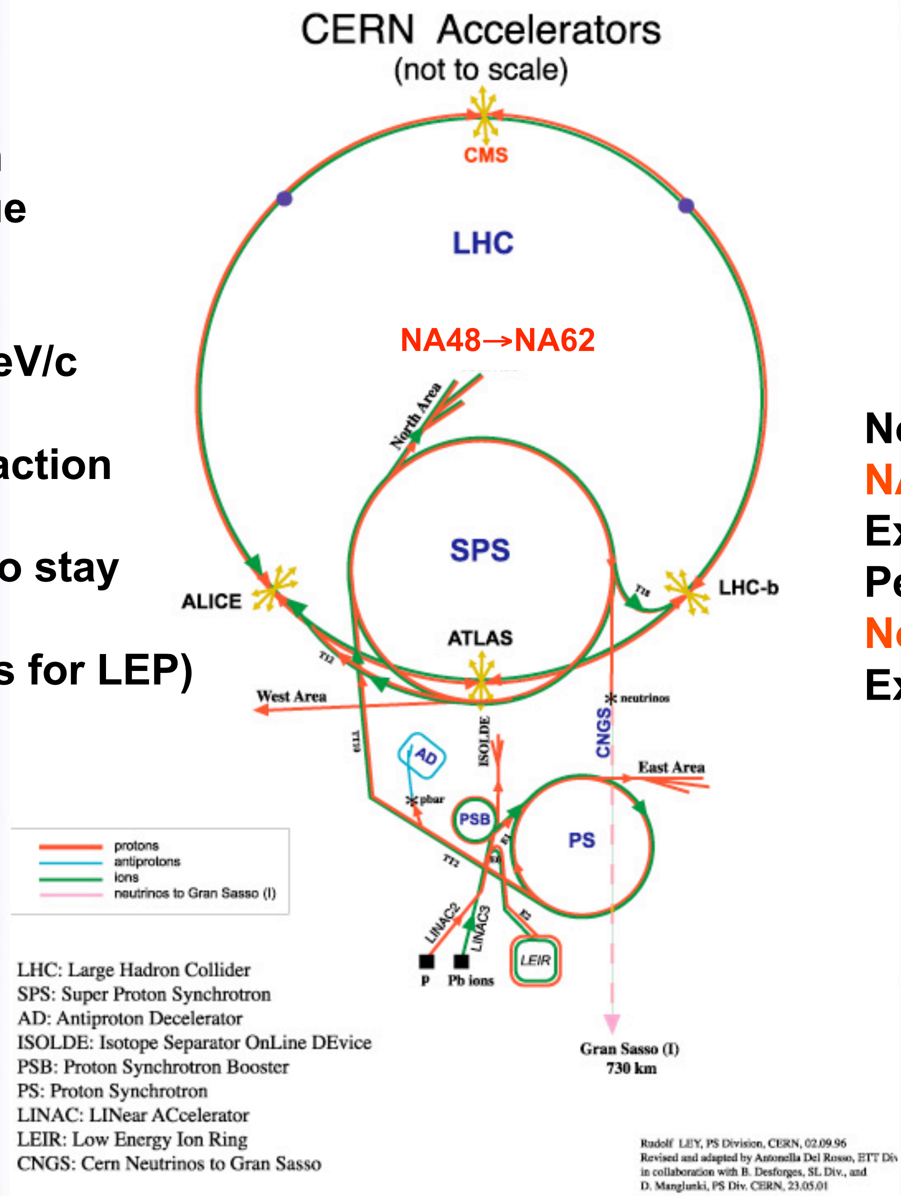
CERN-SPSC-2005-013
SPSC-P-326

Bern, Birmingham, CERN, Dubna, Ferrara, Fairfax, Florence, Frascati, IHEP, INR, Louvain, Mainz, Merced, Naples, Perugia, Pisa, Rome I, Rome II, Saclay, San Luis Potosi, SLAC, Sofia, Triumf, Turin

The CERN proton
Complex is unique

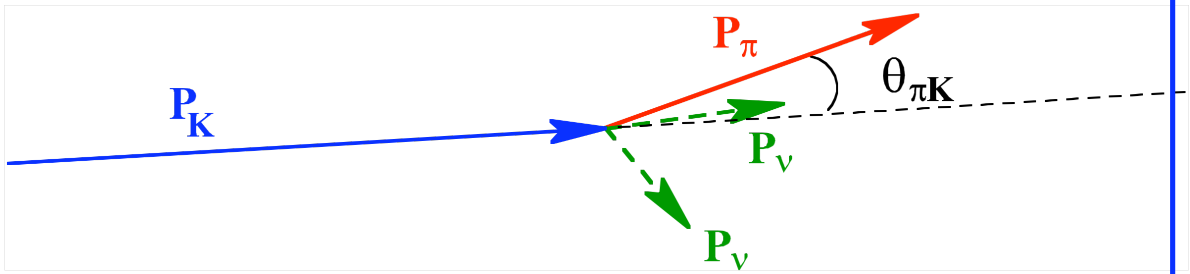
The SPS delivers
Protons of 400 GeV/c
Momentum with
Fast or slow extraction

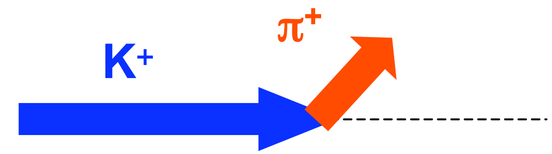
The SPS is here to stay
as injector to
the LHC (as it was for LEP)



Nota Bene:
NAYY ≡ YYth
Experiment
Performed at the
North Area SPS
Extraction site

Principle of the Experiment



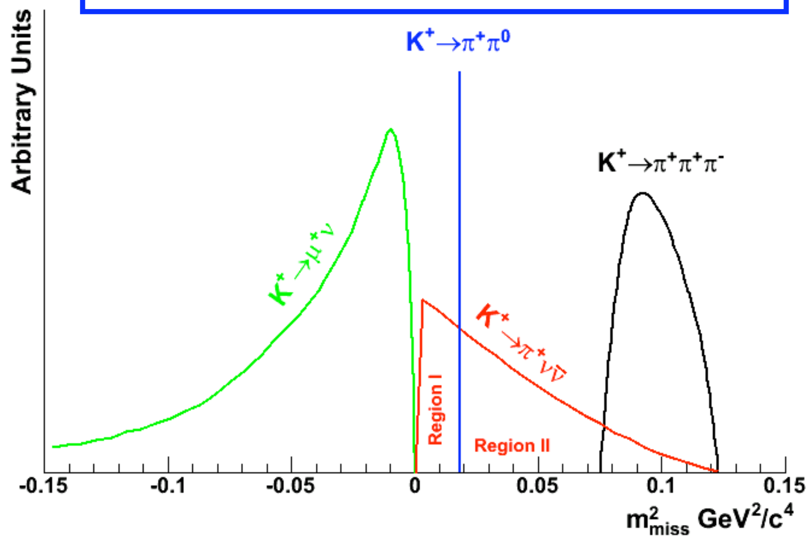


Signature:

- Incoming **high** momentum K^+
- Outgoing **low** momentum π^+

1) Kinematical Rejection

$$m^2_{miss} \approx m^2_K \left(1 - \frac{|P_\pi|}{|P_K|}\right) + m^2_\pi \left(1 - \frac{|P_K|}{|P_\pi|}\right) - |P_K||P_\pi|\vartheta^2_{\pi K}$$



2) Photon vetoes to reject $K^+ \to \pi^+ \pi^0$:

P(K^+) = 75 GeV/c

Requiring P(π^+) < 35 GeV/c

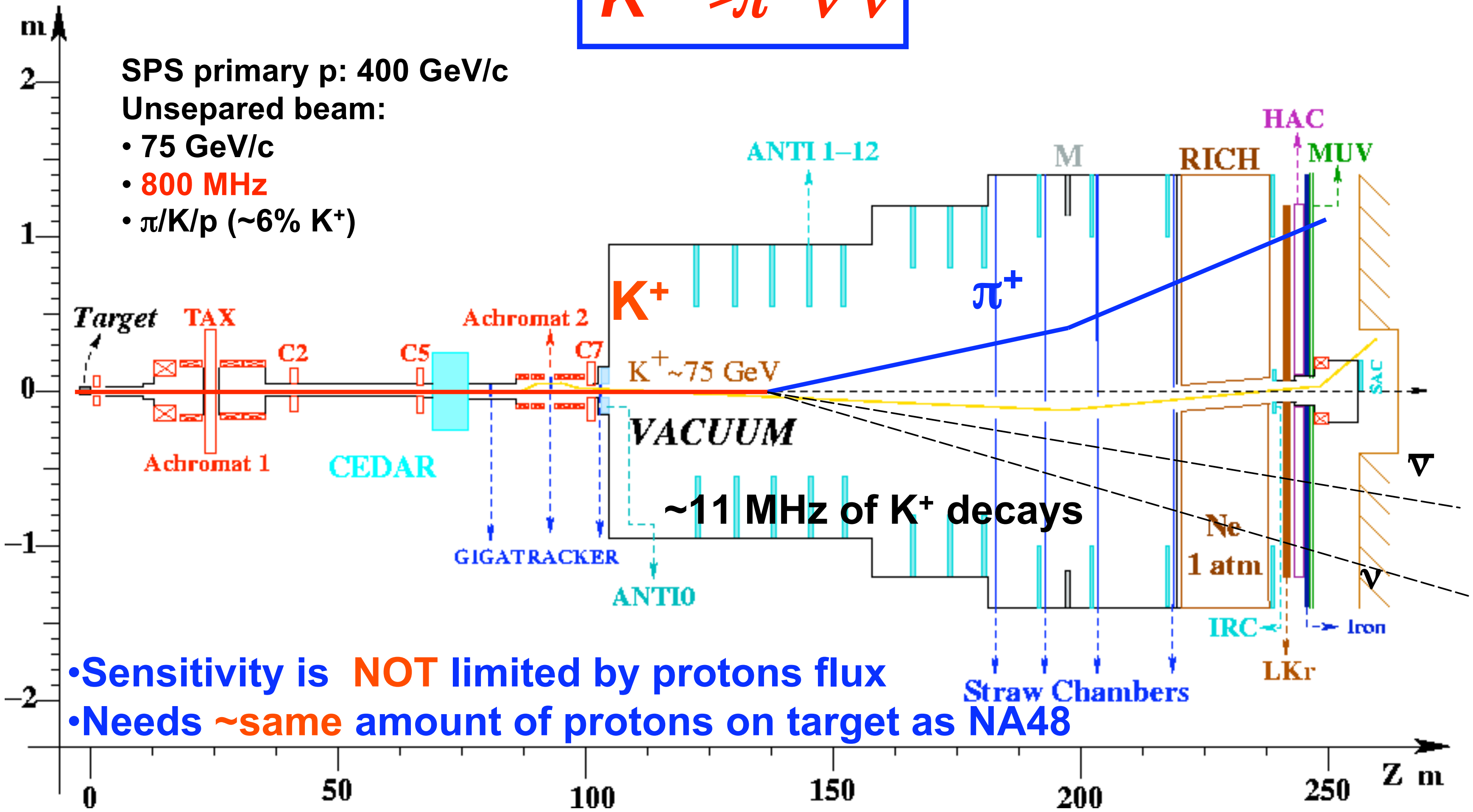
P(π^0) > 40 GeV/c ➡ It can hardly be missed in the calorimeters

3) PID (RICH) for $K^+ \to \mu^+ \nu$ rejection (à la FNAL-CKM)

Proposed Detector Layout

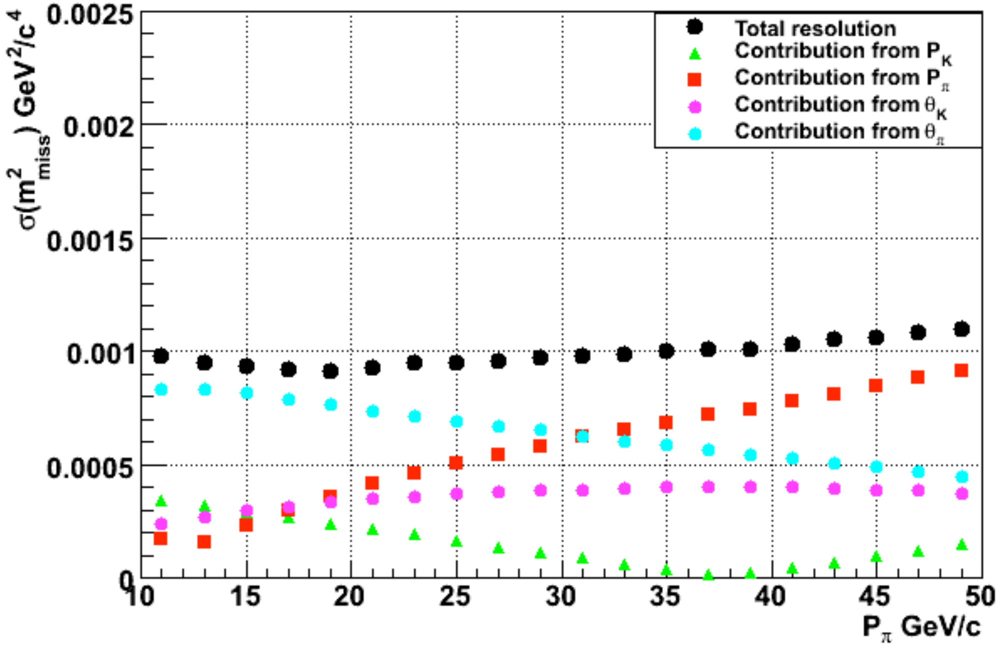
$K^+ \rightarrow \pi^+ \nu \bar{\nu}$

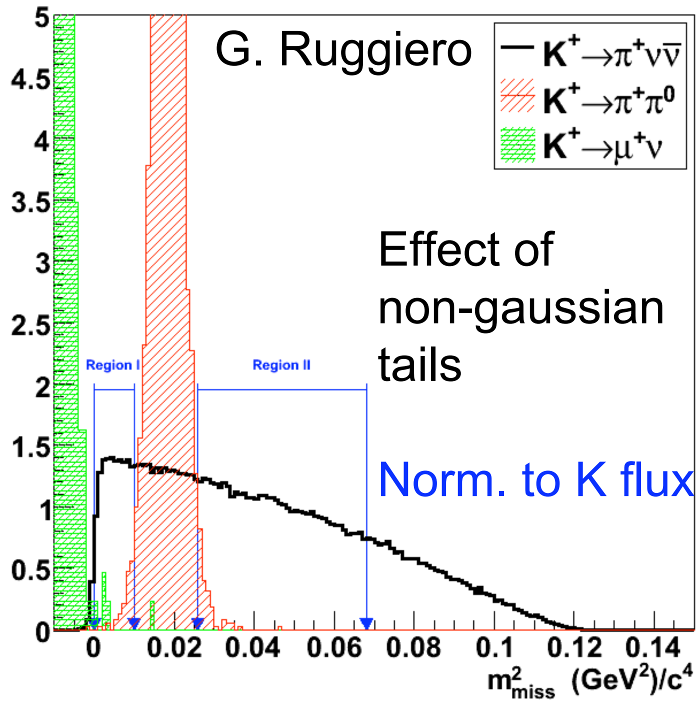
SPS primary p: 400 GeV/c
Unsepared beam:
- 75 GeV/c
- 800 MHz
- π/K/p (~6% K^+)



- Sensitivity is NOT limited by protons flux
- Needs ~same amount of protons on target as NA48

Missing Mass Resolution





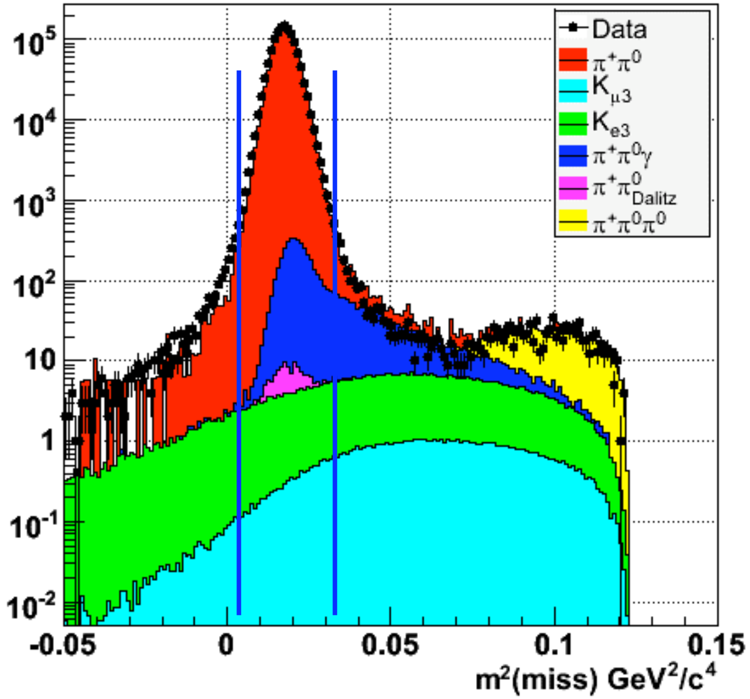
Non-gaussian tails can be induced, for instance, by the wrong association between the incoming kaon and the pion

➡ 200 ps time resolution In gigatracker is required

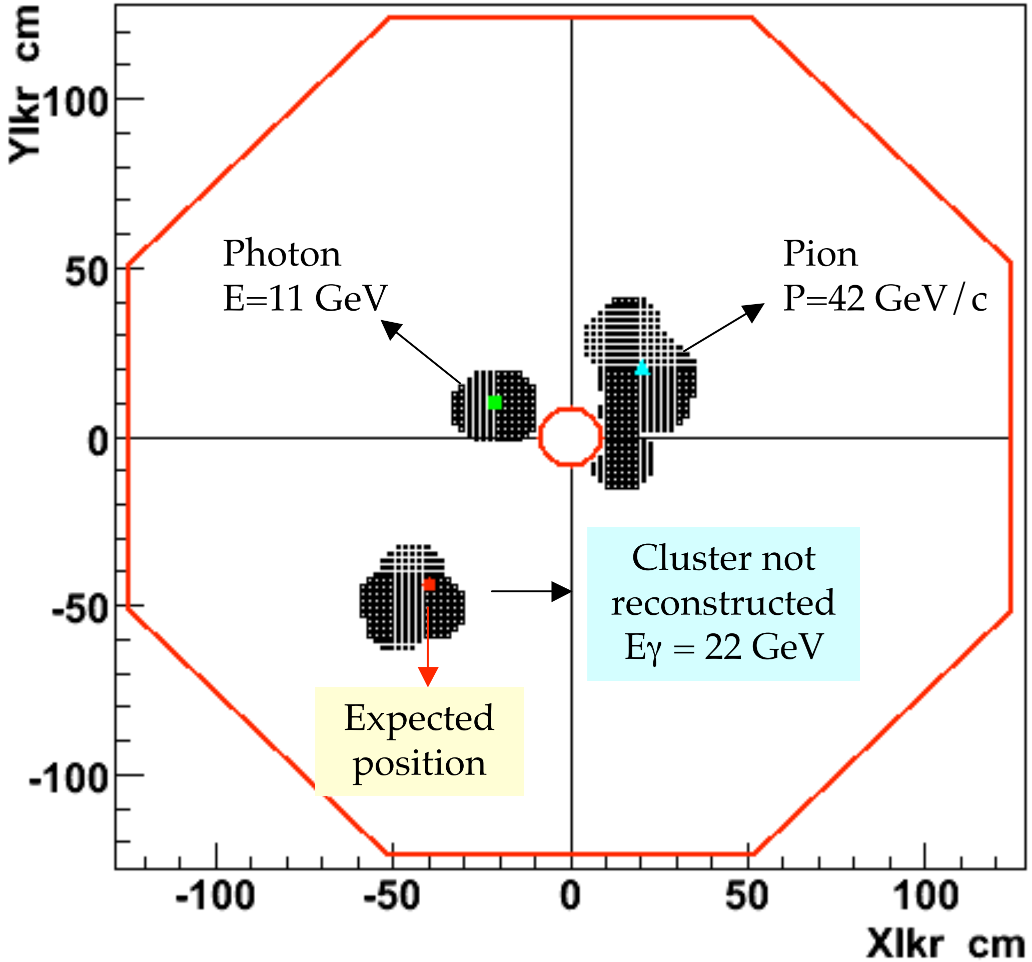
LKr inefficiency measured with data

LKr ineff. per γ (E_γ > 10 GeV):
$\eta \sim 7 \times 10^{-6}$ (preliminary)

$K^+ \rightarrow \pi^+ \pi^0$ selected kinematically

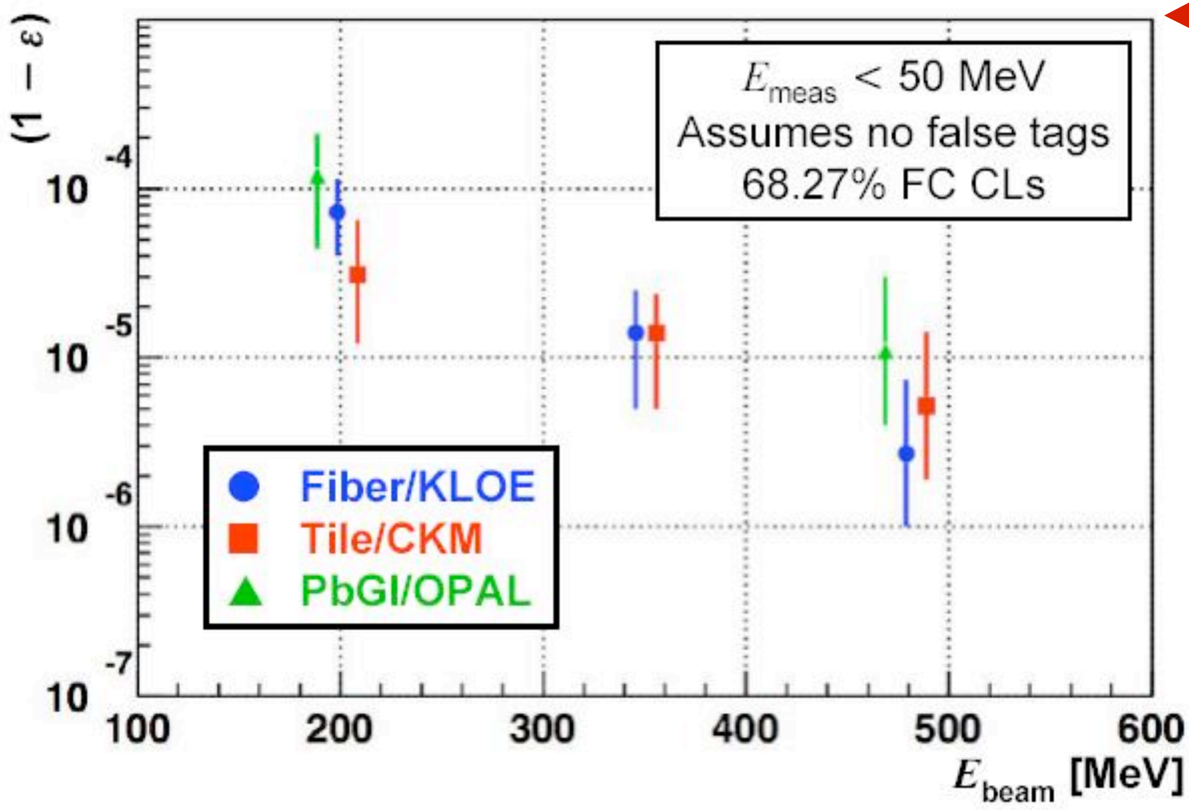


π^+ track and lower energy γ are use to predict the position of the other γ



Large Angle Photon Vetos

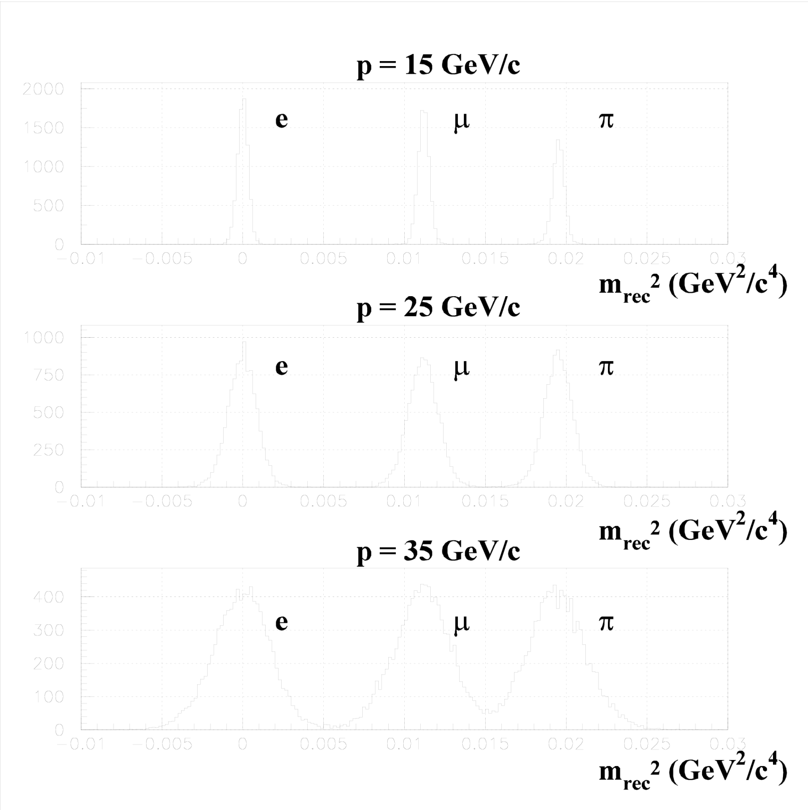
Efficiencies for electron detection similar for all 3 technologies

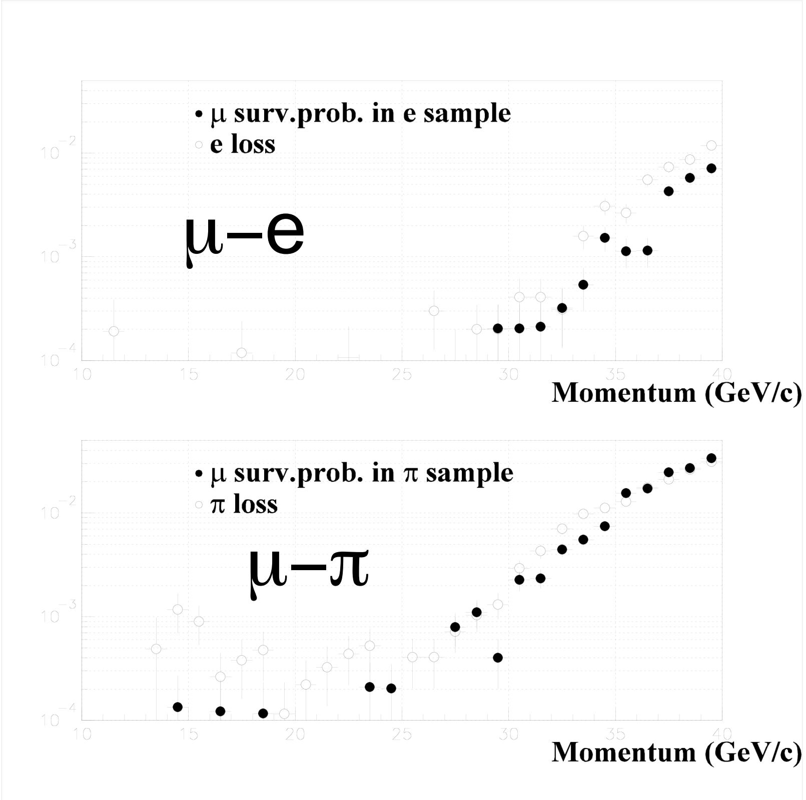


With inefficiency at this level, the LAV contribution to the average inefficiency is $0.2 \cdot 10^{-8}$

Tile (CKM) and lead glass (OPAL) results are preliminary

The RICH: μ suppression (MC)





Muon contamination in π sample (15<p<35 GeV/c): **1.3×10^{-3}**

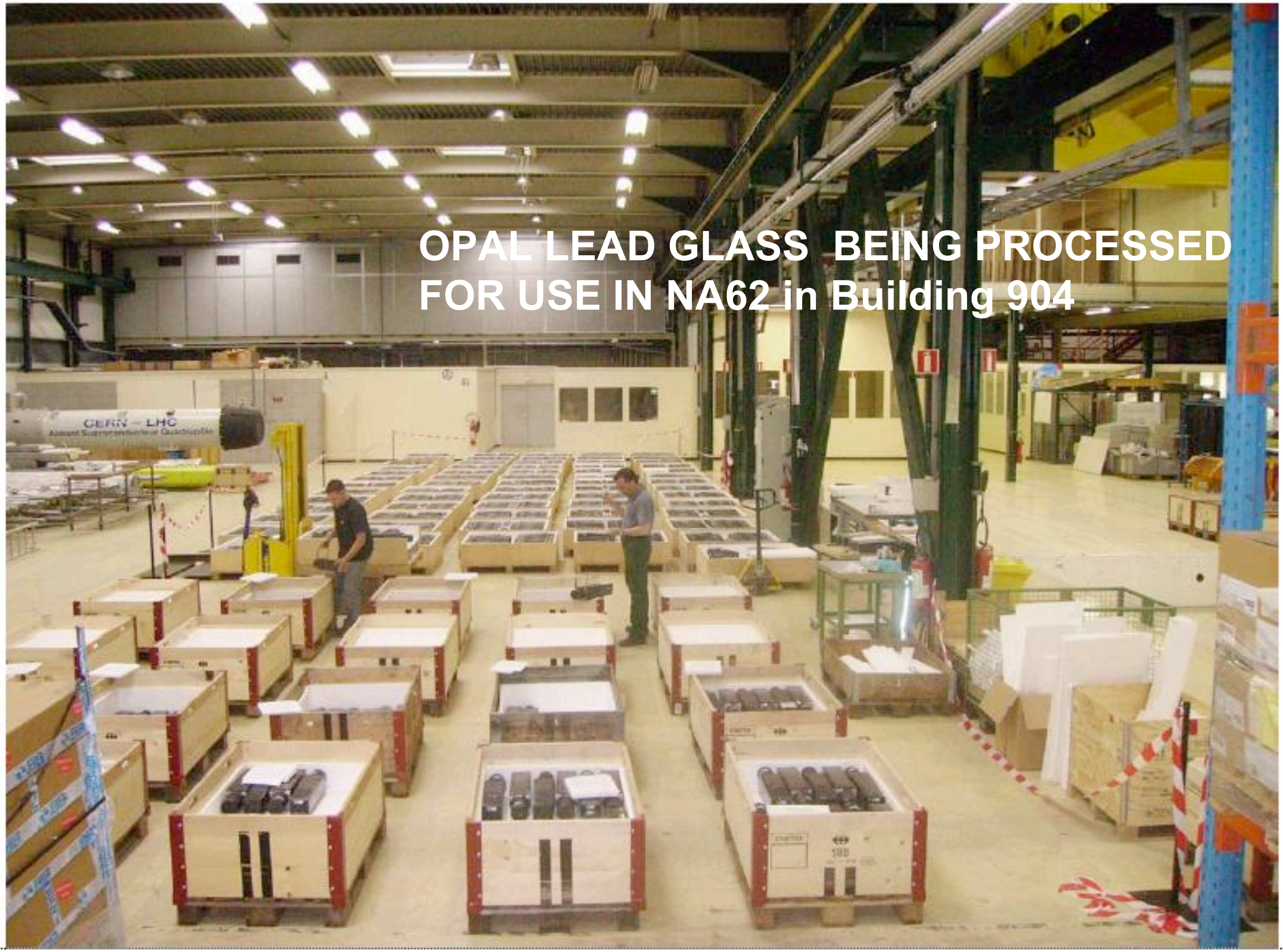
P-326/NA62 Sensitivity

Decay Mode	Events
Signal: $K^+ \rightarrow \pi^+ \nu\nu$ *[flux = 4.8×10^{12} decay/year]*	55 *evt/year*
$K^+ \rightarrow \pi^+ \pi^0$ $[\eta_{\pi 0} = 2\times10^{-8}$ (3.5×10^{-8})]	4.3% (7.5%)
$K^+ \rightarrow \mu^+ \nu$	2.2%
$K^+ \rightarrow e^+ \pi^+ \pi^- \nu$	≤3%
Other 3 – track decays	≤1.5%
$K^+ \rightarrow \pi^+ \pi^0 \gamma$	~2%
$K^+ \rightarrow \mu^+ \nu \gamma$	~0.7%
$K^+ \rightarrow e^+(\mu^+)\ \pi^0 \nu$, others	negligible
Expected background	≤13.5% (≤17%)

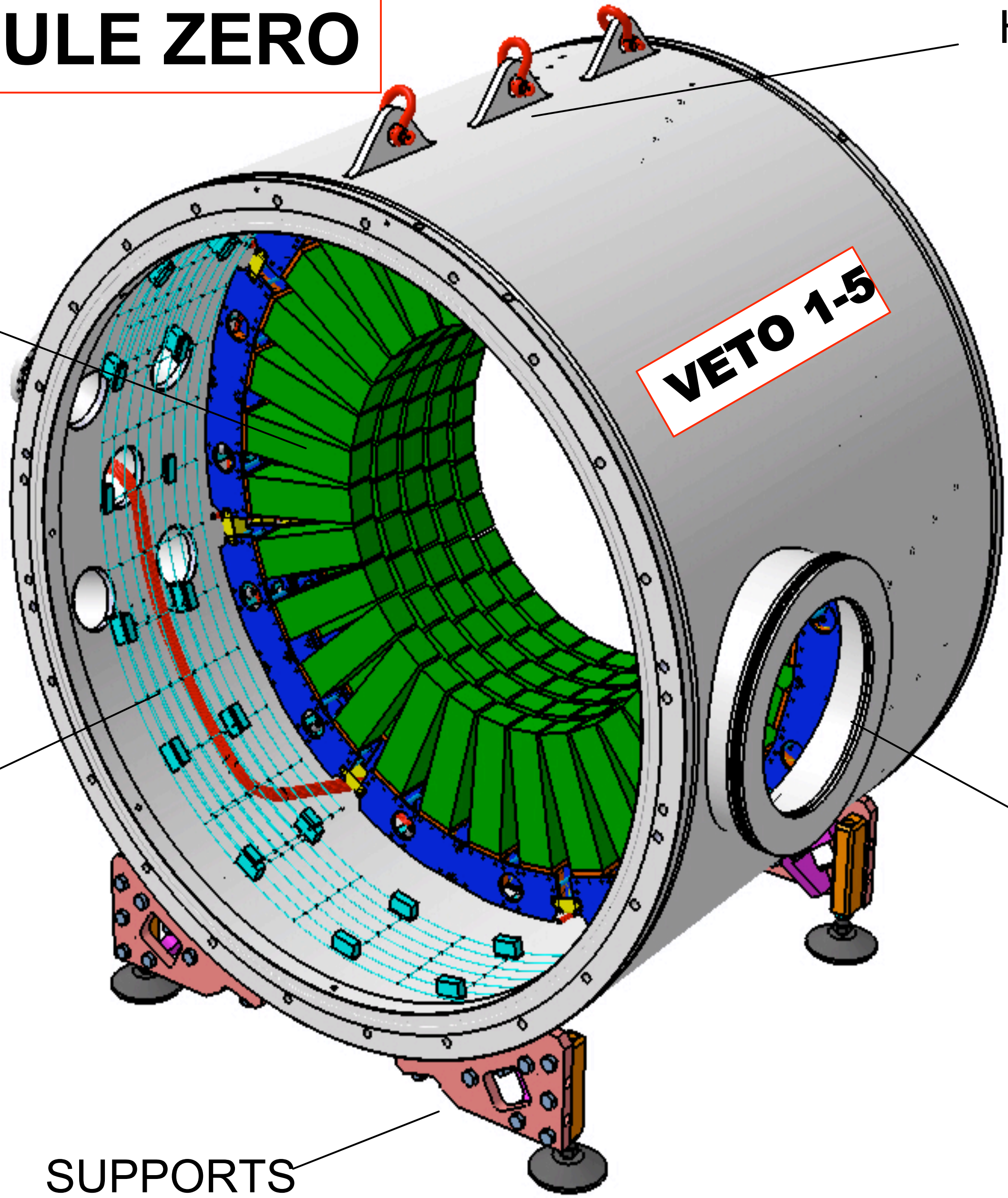
Definition of "year" and running efficiencies based on NA48 experience

Status of the R&D

Large Angle Photon Vetoes

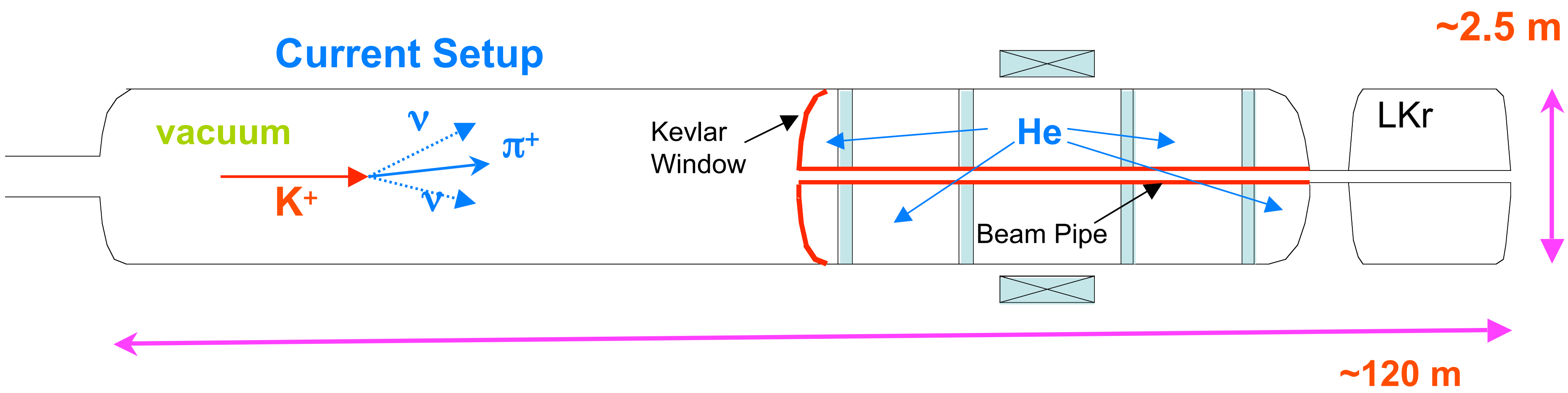


NA62 MODULE ZERO



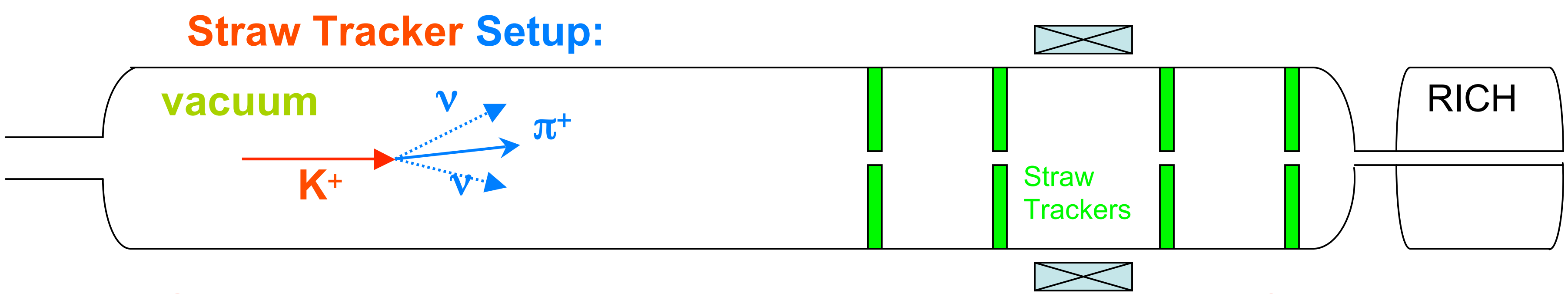
LNF-SPAS
C.Capoccia

NA62 Experimental Challenge: Straw Tracker



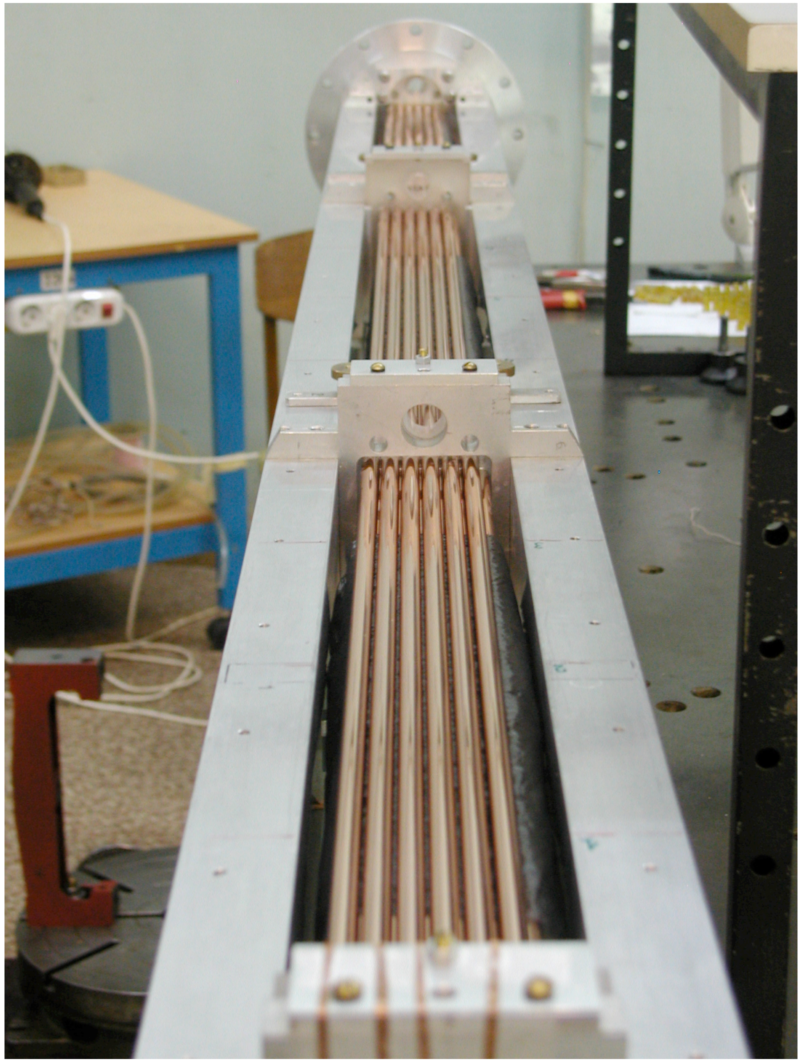
Straw Trackers operated in vacuum would enable us to:

- **Remove the multiple scattering due to the Kevlar Window**
- **Remove the acceptance limitations due to the beam-pipe**
- **Remove the helium between the chambers**



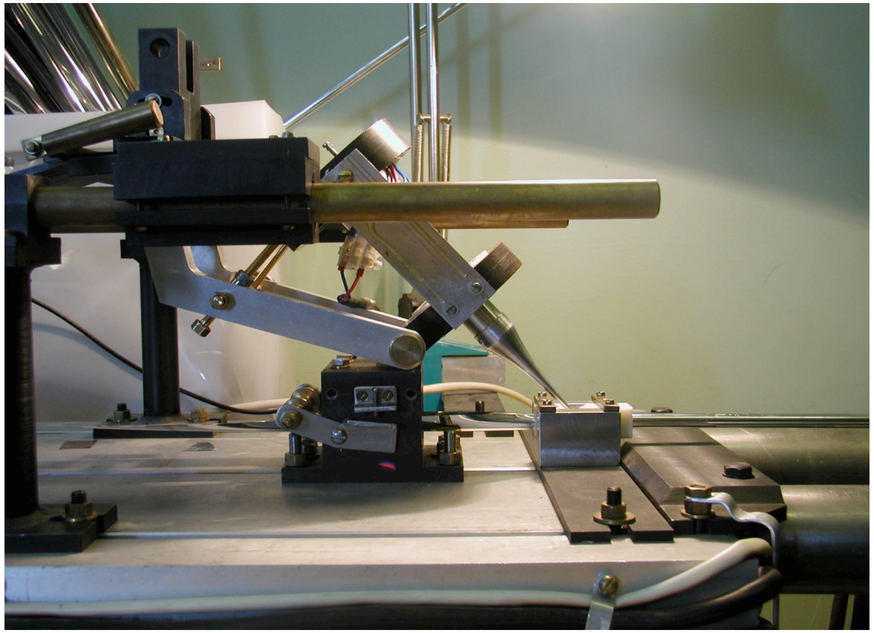
- **The Straw Tracker is essential to study ultra-rare-decays in flight**

STRAW Prototype built in 2007

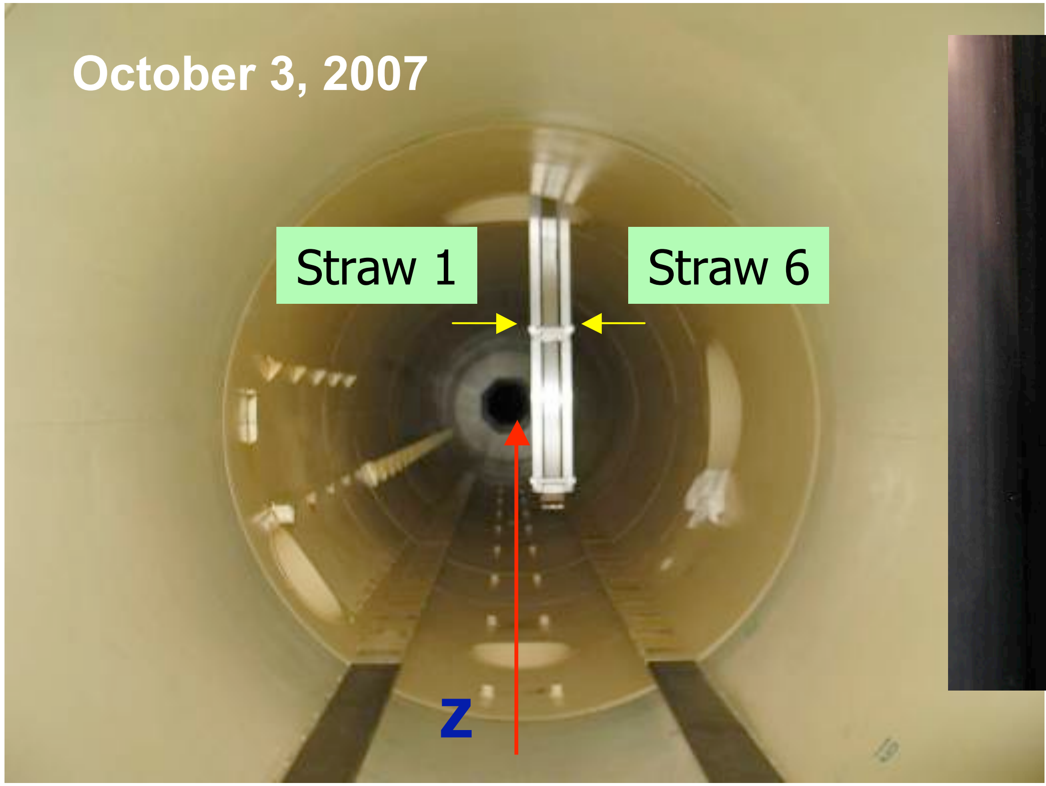


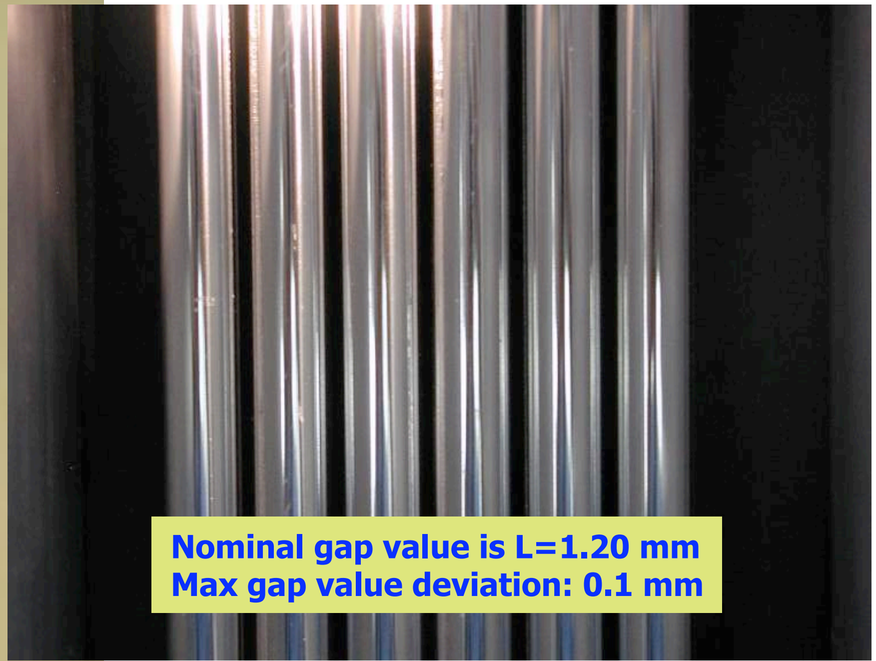
Ultrasound Welded mylar (linear weld, no glue!)

- 36 Al
- 12 (Cu+Au) mylar straws



Straw Prototype inside the Vacuum Tube

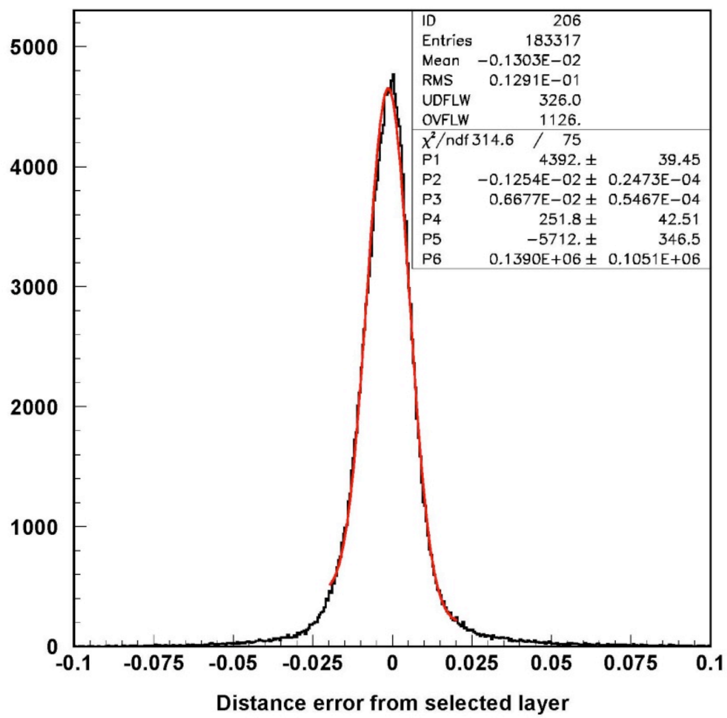




- Data were collected with hadron, muon and kaon decays
- The test in the actual vacuum tank enabled one to address realistic issues

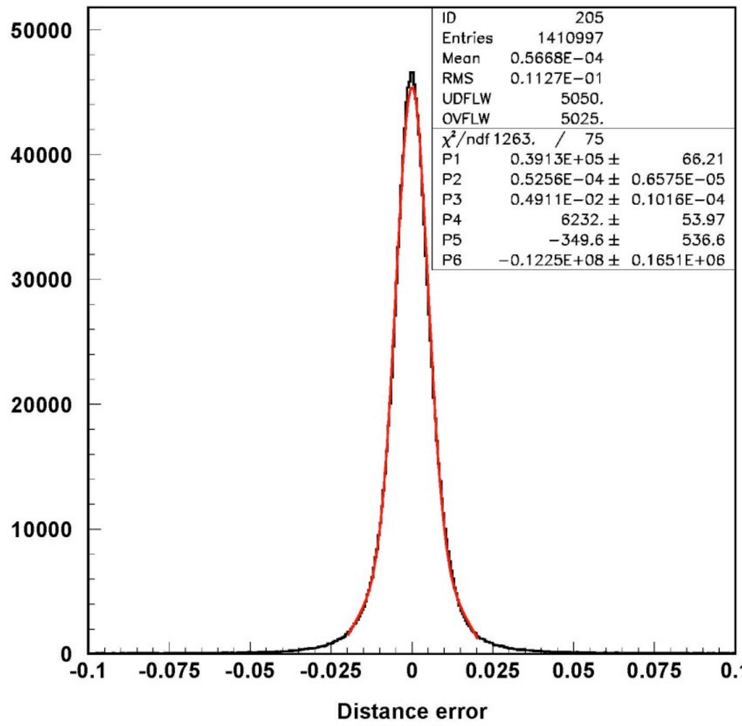
Aluminum straws (preliminary)

Resolution



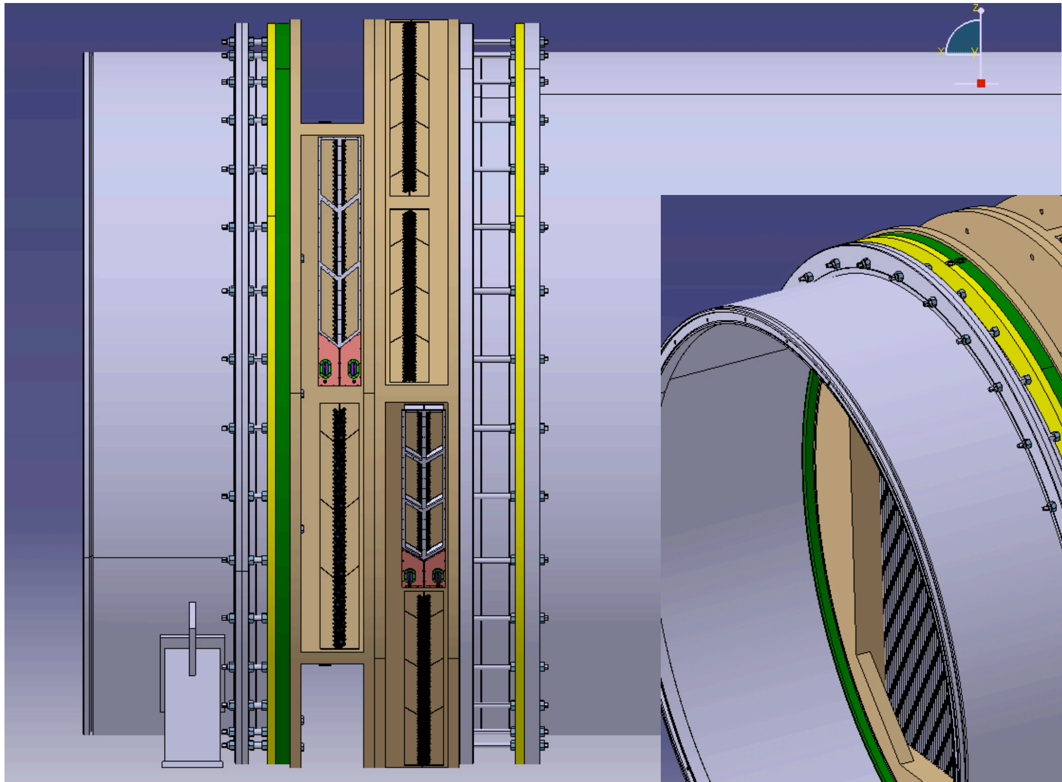
R.M.S.=130 μm
sigma=67 μm

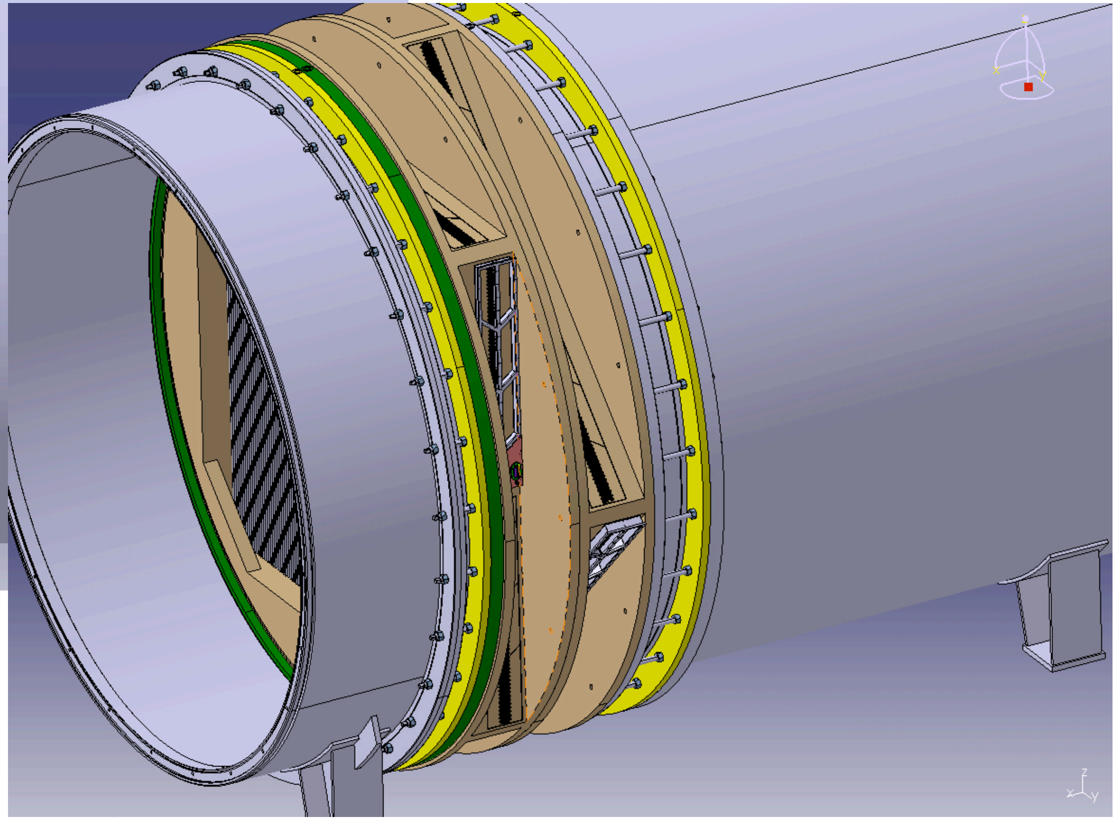
Residuals



R.M.S.=113 μm
sigma=49 μm

NA62 Straw Chamber design





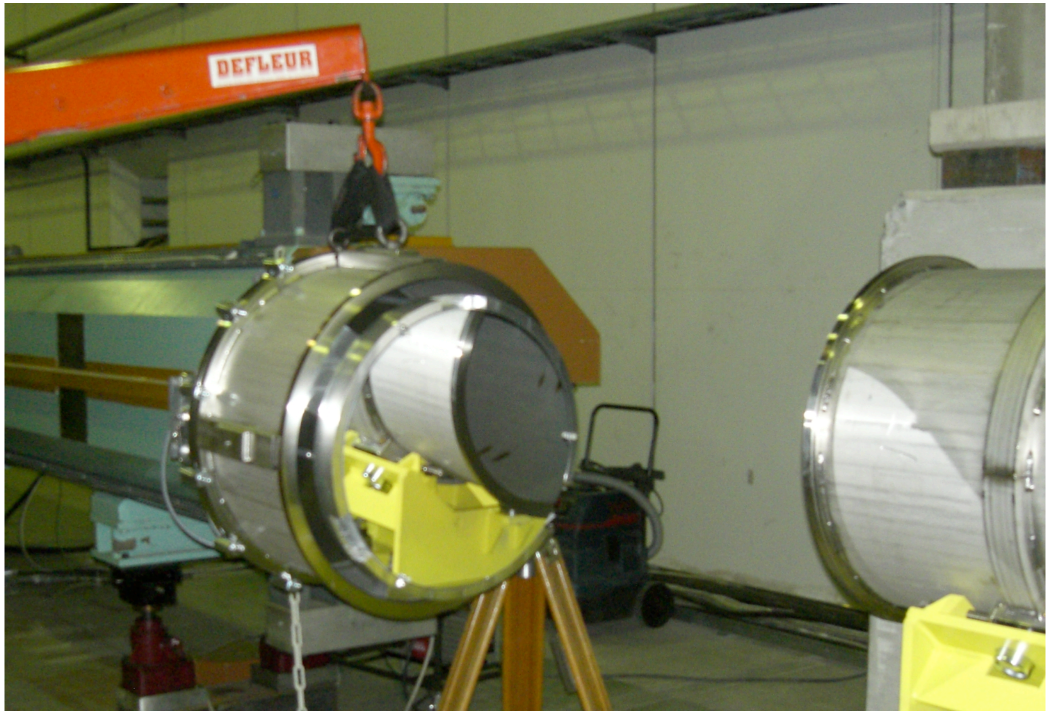
June 2, 2008

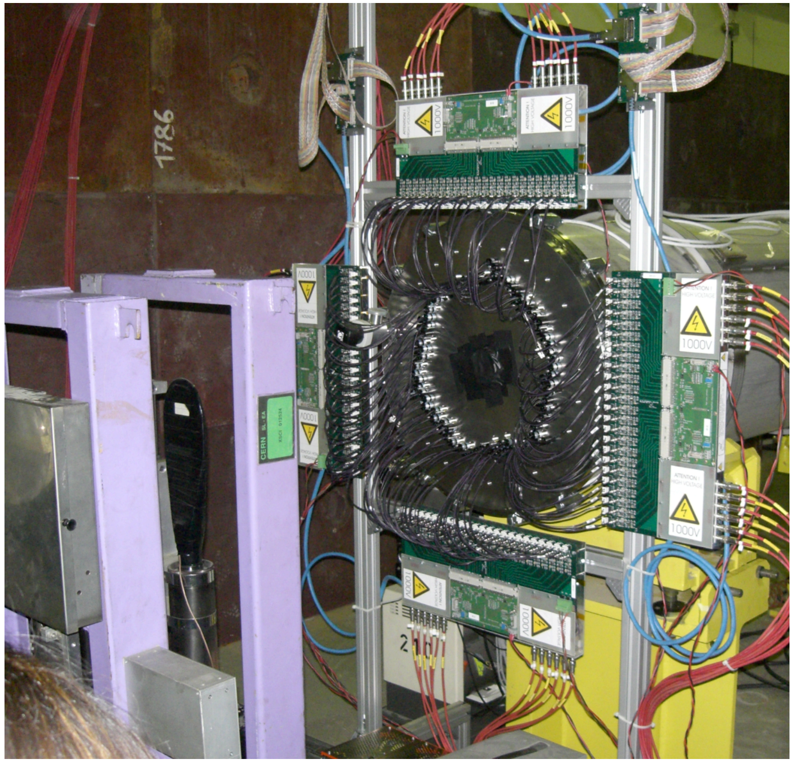
The RICH prototype

- Full scale (longitudinal) RICH prototype
- 18 m long tube, vacuum resistant
- Mirror: ϕ=50cm, f=17.01m
- 96 PMs Hamamatsu R 7400 U
- Test: negative beam from SPS@200 GeV/c

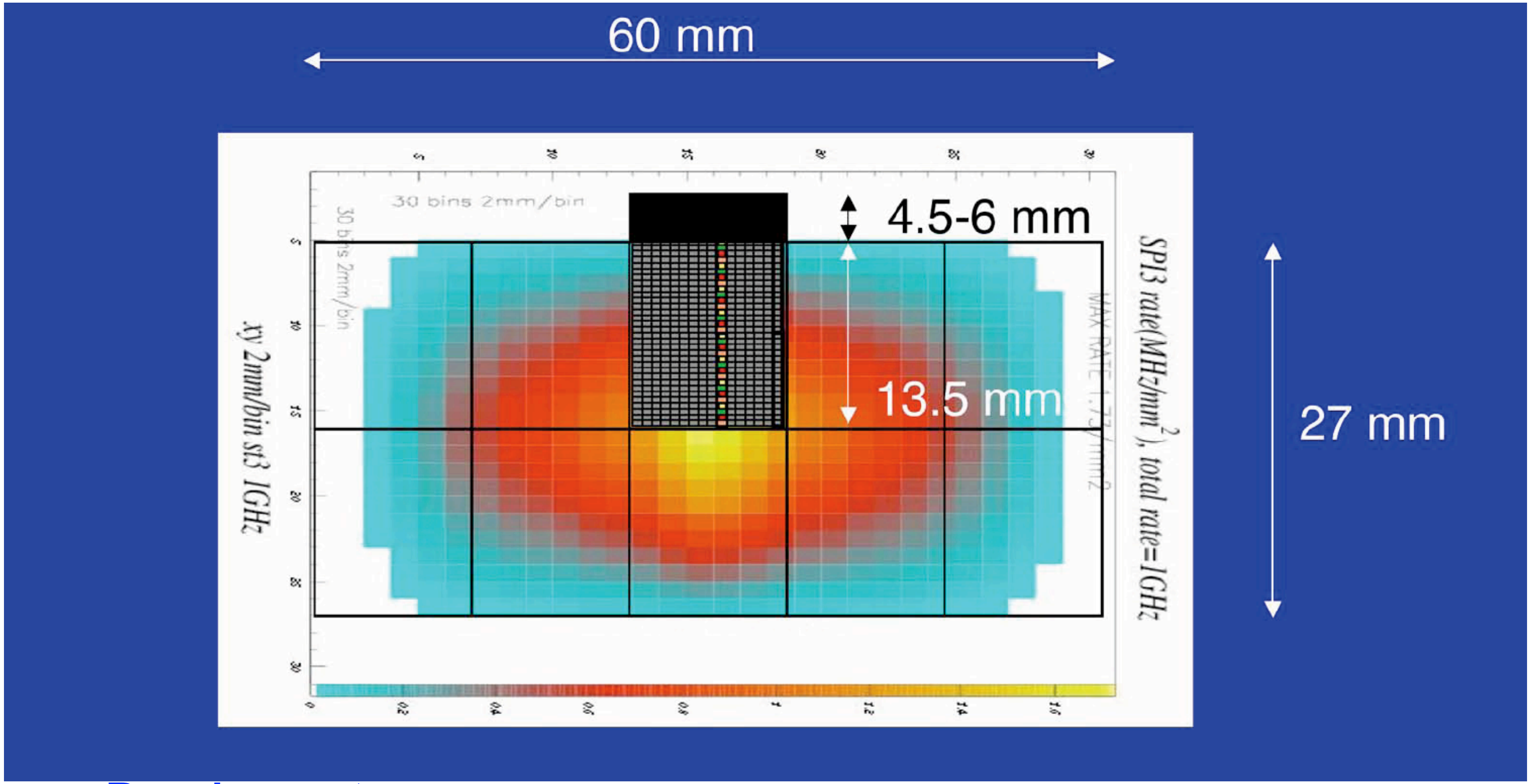
Achieved time resolution:
75 ps per event

In 2008 the prototype
Will be equipped with
~400 PMTs





Gigatracker (Silicon μ–pixel)



Requirements:

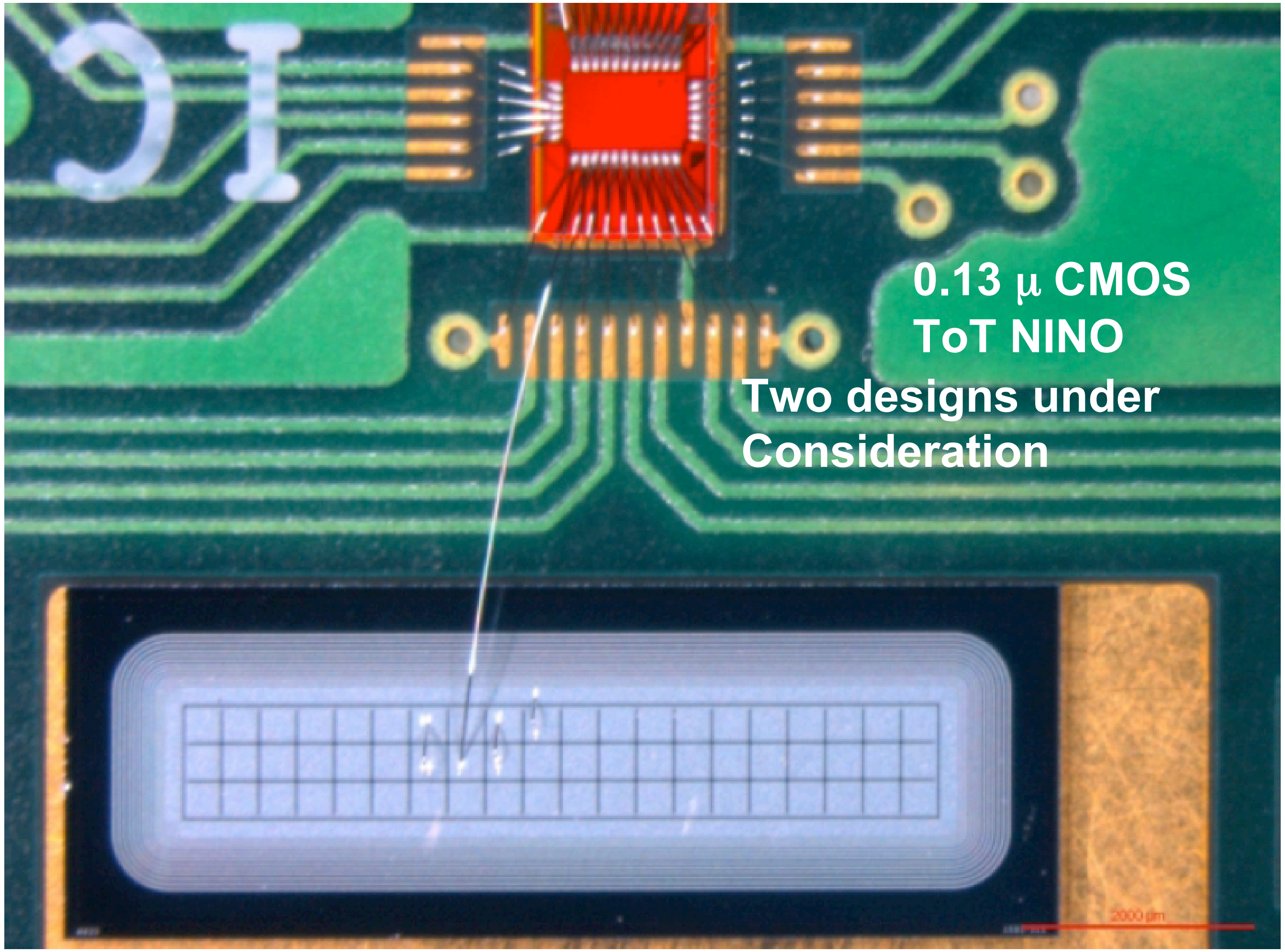
Time resolution: 200 ps / station

Material Budget: < 0.5 % X_0 / station

Driven by the experience with the thin hybrids of the ALICE SPD

IRST Diode with NINO chip

Next step::
~8 x 8 matrix prototype
Bump-bonded to R/O chip for Beam Test



Fadmar Osmić – P326 GTK Meeting, September 10, 2007 -7-

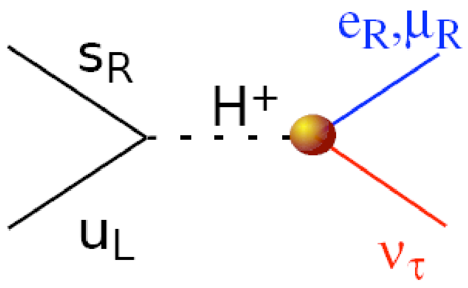
Status of P-326 / NA62

- The Collaboration is in the phase of completing the R&D and preparing the construction
- Some Funding agency, and notably INFN, have already approved the programme
- Construction is foresee during the 2009-2011 period and data taking for $K^+ \to \pi^+ \nu \nu$ should start in 2011-2012
- The New Collaboration is growing and the best way to blend the new groups is to do physics together
- In 2007 the New Collaboration NA62 has collected 5 months of proton data at the SPS to study lepton universality in kaon leptonic decays

$R_K = \Gamma(K \to e\nu) / \Gamma(K \to \mu\nu)$

$$R_K^{LFV} = \frac{\sum_i K \to e\nu_i}{\sum_i K \to \mu\nu_i} \simeq \frac{\Gamma_{SM}(K \to e\nu_e) + \Gamma(K \to e\nu_\tau)}{\Gamma_{SM}(K \to \mu\nu_\mu)}, \quad i = e, \mu, \tau$$

Masiero, Paradisi, Petronzio, hep-ph/0511289 PRD74,(2006)



$$eH^\pm\nu_\tau \to \frac{g_2}{\sqrt{2}}\frac{m_\tau}{M_W}\Delta_R^{31}\tan^2\beta$$

$$\Delta_R^{31} \sim \frac{\alpha_2}{4\pi}\delta_{RR}^{31}$$

$$\Delta_R^{31} \sim 5\cdot 10^{-4} \quad t_\beta = 40 \quad M_{H^\pm} = 500\text{GeV}$$

$$\Downarrow$$

$$\Delta r_{K\,SUSY}^{e-\mu} \simeq \left(\frac{m_K^4}{M_{H^\pm}^4}\right)\left(\frac{m_\tau^2}{m_e^2}\right)|\Delta_R^{31}|^2\tan^6\beta \approx 10^{-2}$$

$R_K(SM) = (2.472 \pm 0.001) \times 10^{-5}$

Variations of the order of 1% to with respect to **$R_K(SM)$** may be present from breaking of μ-e universality in SUSY (maximum effect possible -3.2%)

World average (PDG): $R_K = (2.44 \pm 0.11) \times 10^{-5}$

from three experiments: 1972 (112 evts); 1975 (534 evts); 1976 (404 evts)

From the analysis of NA48/2 2003 data (~ 4000 events):

$R_K = (2.416 \pm 0.043 \pm 0.024) \times 10^{-5}$ (~ 4000 evts) presented at HEP2005, Lisbon

Ratio of Leptonic Meson Decays

$$R_M = \frac{\Gamma(M \to e\nu(\gamma))}{\Gamma(M \to \mu\nu(\gamma))} = \left(\frac{m_e}{m_\mu}\right)^2 \left(\frac{1-\left(\frac{m_e}{m_M}\right)^2}{1-\left(\frac{m_\mu}{m_M}\right)^2}\right)^2 \times (1+\delta R_M)$$

The latest theoretical predictions give:

R_π= (1.2352 ± 0.0001) × 10^{-4}

R_K= (2.477 ± 0.001) × 10^{-5}

Experimental Situation

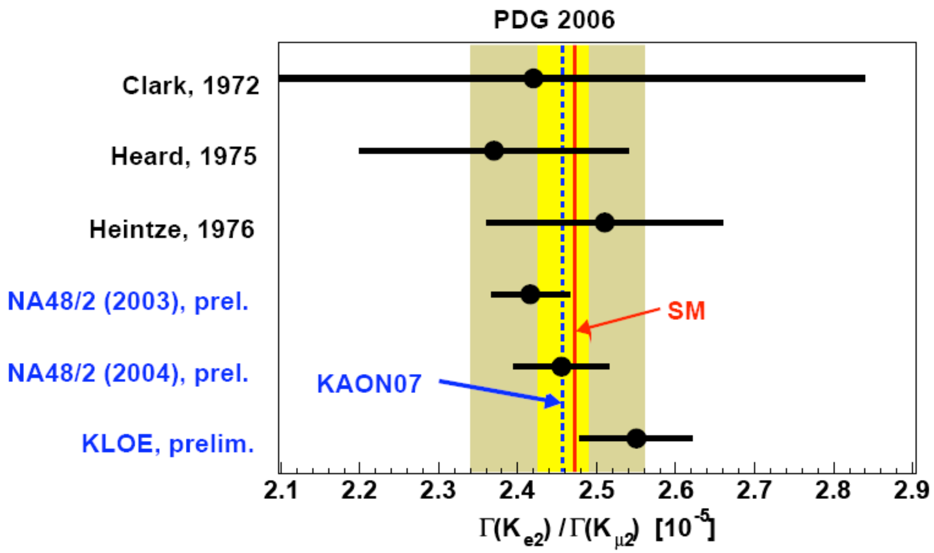
$\pi \to e\nu$

$$R_K = 2.457 \pm 0.032 \times 10^{-5}$$

$R^{\exp\pi}_{e/\mu}$ $(\pm 0.4\%)$

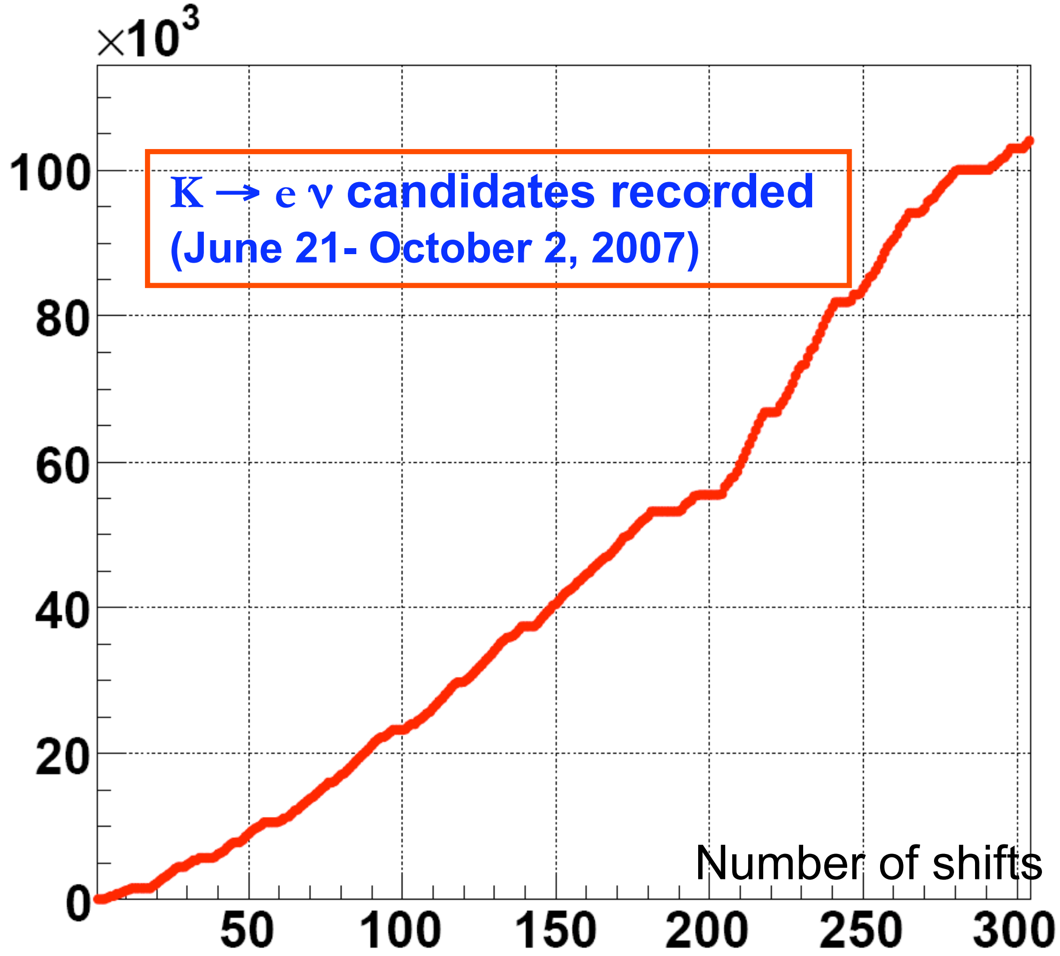
$1.2265(34)(44)x10^{-4}$ TRIUMF (1992)

$1.2346(35)(36)x10^{-4}$ PSI (1993)



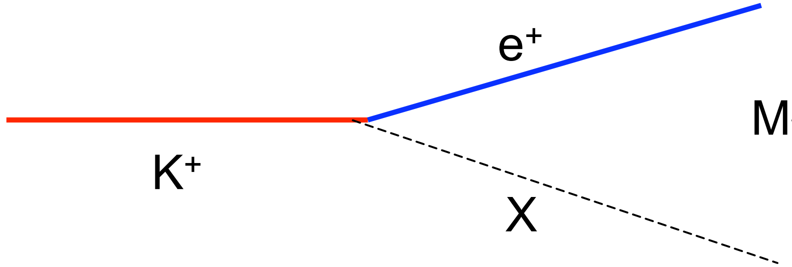
New experiments planned at TRIUMF and PSI to reach <0.1% on R_π

NA62: 2007 data taking for R_K

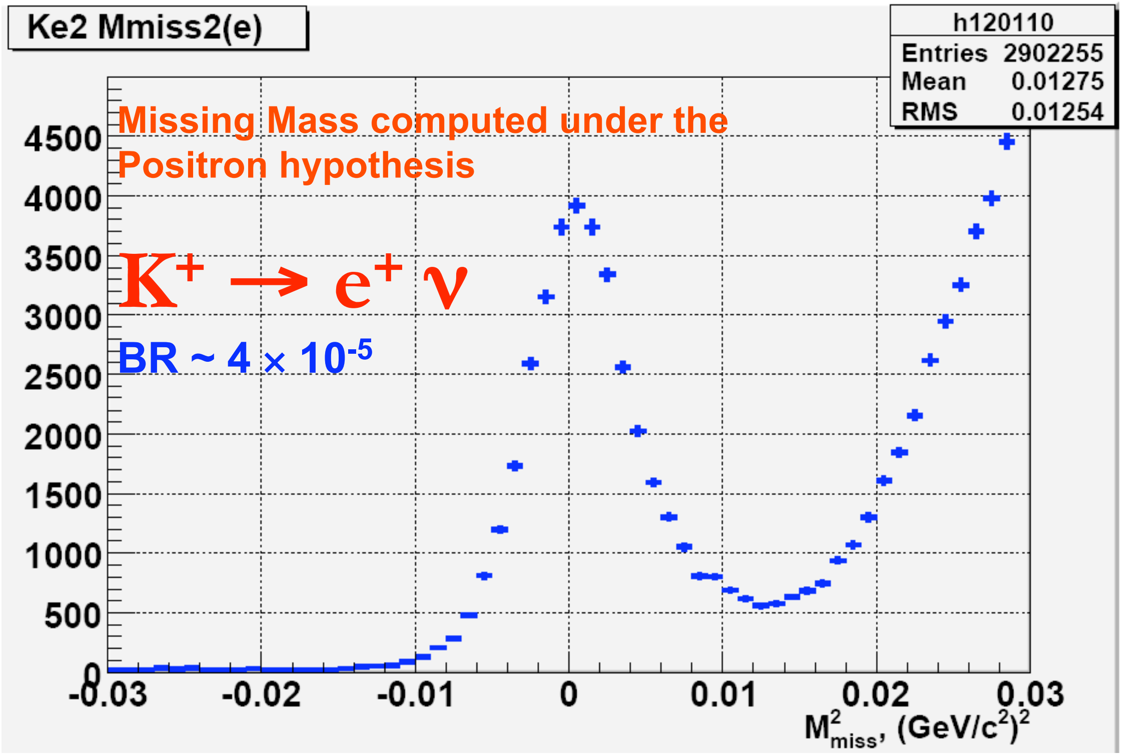


NA62 has accumulated more than 100 k $K \to e\,\nu$ events in 2007 to push the error on R_K from ~2% to ~0.3%

Subset of the NA62 data (2007)



$M^2_{miss} = 0$ for $X=\nu$



Fermilab Plan

with a High Intensity Proton Source

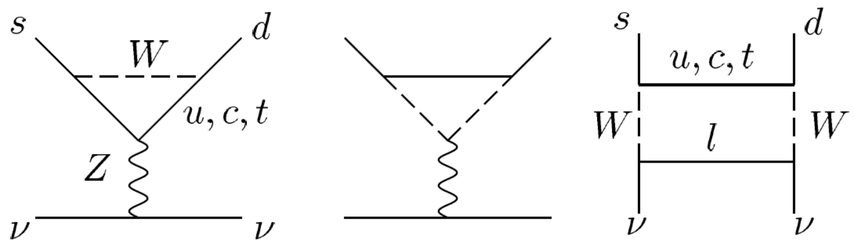
Project X

Young-Kee Kim
Fermilab and University of Chicago

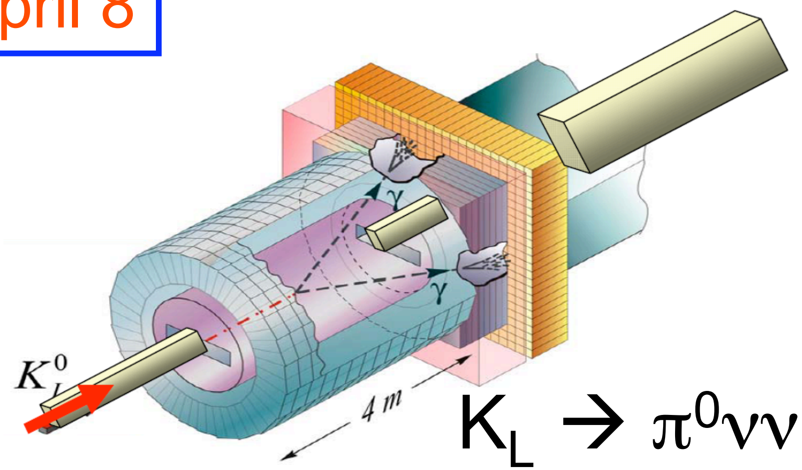
CERN
April 8, 2008

Kaons: Rare Decays $K^+ \to \pi^+\nu\nu$, $K_L \to \pi^0\nu\nu$

SM Leading diagrams



Young-Kee Kim, April 8



$K_L \to \pi^0\nu\nu$
Experiment Concept

an almost-MFV World

Kaons: Rare Decays

Young-Kee Kim, April 8

- an almost-Minimal Flavor Violation World
  - Measuring small deviations from SM – of great importance.
    - SUSY breaking scale, Flavor symmetries related to unification, Compositeness, extra dimensions, etc.
  - Directly complementary to central physics program at LHC.
  - Experimental focus – theoretically & experimentally clean
    - Small errors: ~ a few %; require ~1,000 clean Kaon events

$K^+ \rightarrow \pi^+\nu\nu$	#evnts	$K_L \rightarrow \pi^0\nu\nu$	#evnts
CERN NA48 (by 2012)	~160	J-PARC I (by 2012)	~4
		J-PARC II (by ~2016)	~100
Potential FNAL (w/o Proj.X)	~600	Potential FNAL (w/o Proj.X)	~200
Potential FNAL (w/ Proj.X)	~1500	Potential FNAL (w/ Proj.X)	~1000

(FNAL: 5 year running)

HEPAP-P5 Report May 29, 2008

From C. Baltay presentation

Budget re-instated at 2007level and adjusted for inflation

- The more favorable funding scenario, scenario C, would allow for pursuing a program in rare K decay experiments at Fermilab as well.

Doubling the 2007 budget Over 10 years

Personal Concluding Remarks

- The precise SM predictions and the sensitivity to New Physics makes the continuation of rare kaon decays measurements compelling
- The Community should focus on the most promising approach and to consolidate globally into one or two collaborations.
- The rare kaon decay experimental programme has to be considered within a coherent flavour effort complementary to the high energy frontier
- Like the epsilon'/epsilon endeavor in the past, these experiments can produce a variety of physics results
- To avoid limitations to the physics output, resources for triggering, read-out and data handling have to be planned carefully