The NA62 Experiment at CERN

Giuseppe Ruggiero - Scuola Normale Superiore & INFN (Pisa)

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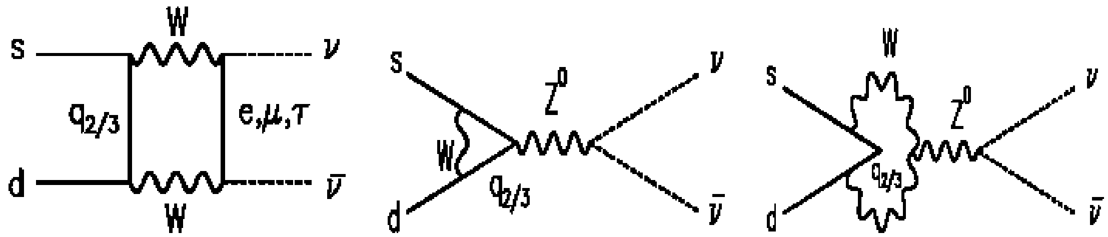
The $K \to \pi \nu \bar{\nu}$ decays: a clean theoretical environment

- NA62 Physics goal: study of the $K^+ \to \pi^+ \nu \bar{\nu}$ decay mode
- FCNC loop processes: s→d coupling and highest CKM suppression



- Very clean theoretically: SD contributions dominate, hadronic matrix element related to precisely measured quantities
- SM predictions (main uncertainties from CKM matrix elements):

$$BR(K^+ \to \pi^+ \nu \bar{\nu}) = (8.5 \pm 0.7) \times 10^{-11}, \quad BR(K_L \to \pi^0 \nu \bar{\nu}) = (2.6 \pm 0.4) \times 10^{-11}$$

- Experimental results:

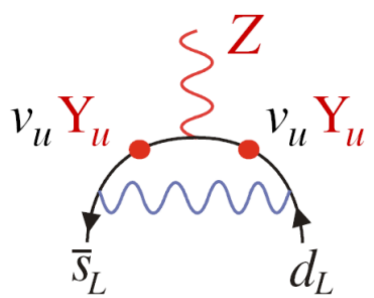
$$BR(K^+ \to \pi^+ \nu \bar{\nu}) = (1.73^{+1.15}_{-1.05}) \times 10^{-10} \ [E787, E959]$$

$$BR(K_L \to \pi^0 \nu \bar{\nu}) \leq 2.6 \times 10^{-8} [E391a]$$

NP and The $K \to \pi \nu \bar{\nu}$ decays

(courtesy by C. Smith)

C. The Z penguin (and its associated W box)

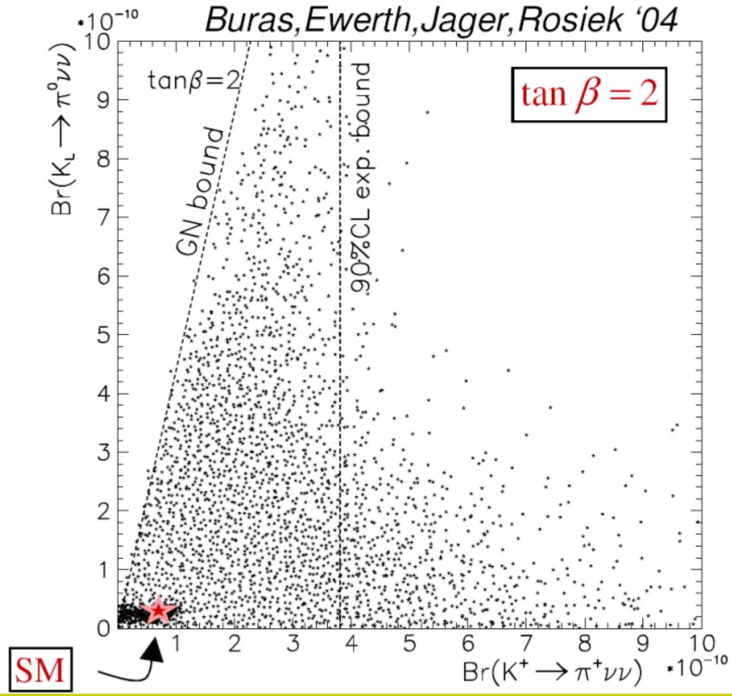


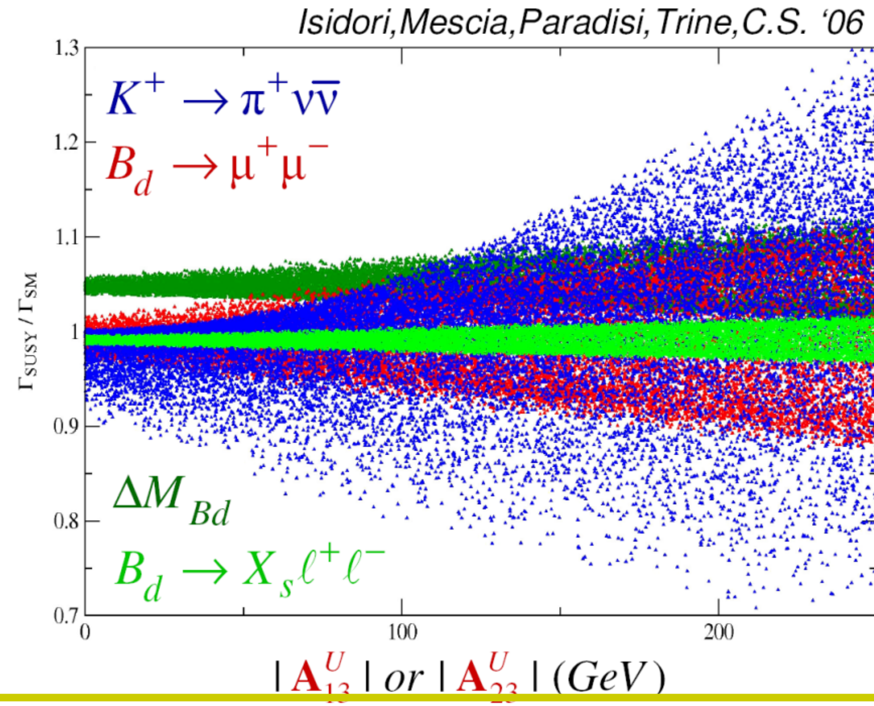
- $SU(2)_L$ breaking: $SM : v_u^2 Y_u^{*32} Y_u^{31} \sim m_t^2 V_{ts}^* V_{td}$

$$MSSM : v_u^2 A_{\tilde{u}}^{*32} A_{\tilde{u}}^{31} \sim m_t^2 \times O(1)\,?$$

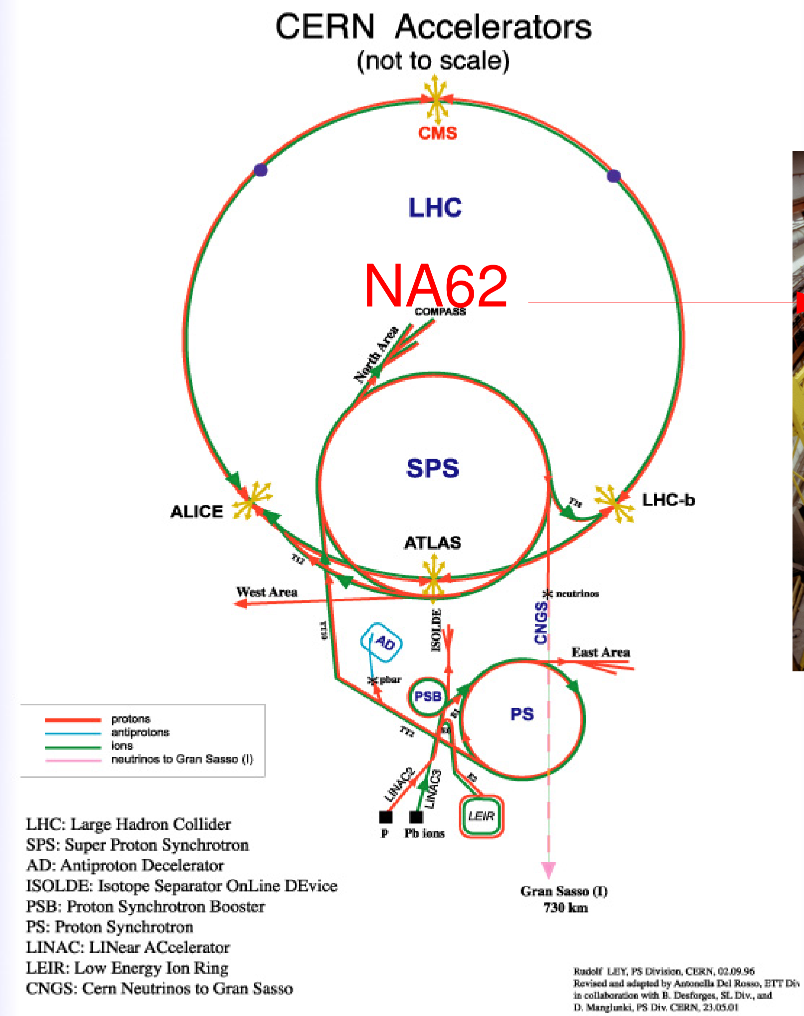
$$MFV : v_u^2 A_{\tilde{u}}^{*32} A_{\tilde{u}}^{31} \sim m_t^2 V_{ts}^* V_{td} \left|A_0 a_2^* - \cot\beta\mu\right|^2 .$$

- Relatively slow decoupling (w.r.t. boxes or tree).





The NA62 Experiment



former NA48 exp hall

NA62 Collaboration: Bern ITP, Birmingham, Bristol, CERN, Dubna, Ferrara, Fairfax, Florence, Frascati, Glasgow, IHEP, INR, Liverpool, Louvain, Mainz, Merced, Naples, Perugia, Pisa, Rome I, Rome II, San Luis Potosi, SLAC, Sofia, TRIUMF, Turin

Experimental Principles of NA62

- Goal: 10% precision branching ratio measurement
  - $O(100)\, K^+ \to \pi^+ \nu \bar{\nu}$ events
  - % level Systematics
- Requirements
  - Statistics:
    - BR(SM) ~ 8.5×10^{-11}
    - Acceptance: 10%
    - K decays: 10^{13}
  - Systematics
    - $\geq 10^{12}$ background rejection (i.e. $\leq$10% background)
    - $\leq$10% precision background measurement

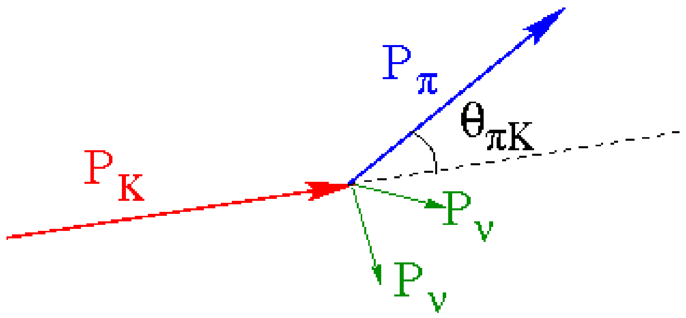
Kaon intensity - Signal efficiency

Signal purity & Detector Redundancy

- Principles:
  - "High" momentum K^+ beam
  - Decay in-flight technique

Experimental Principles of NA62

- Signal signature:

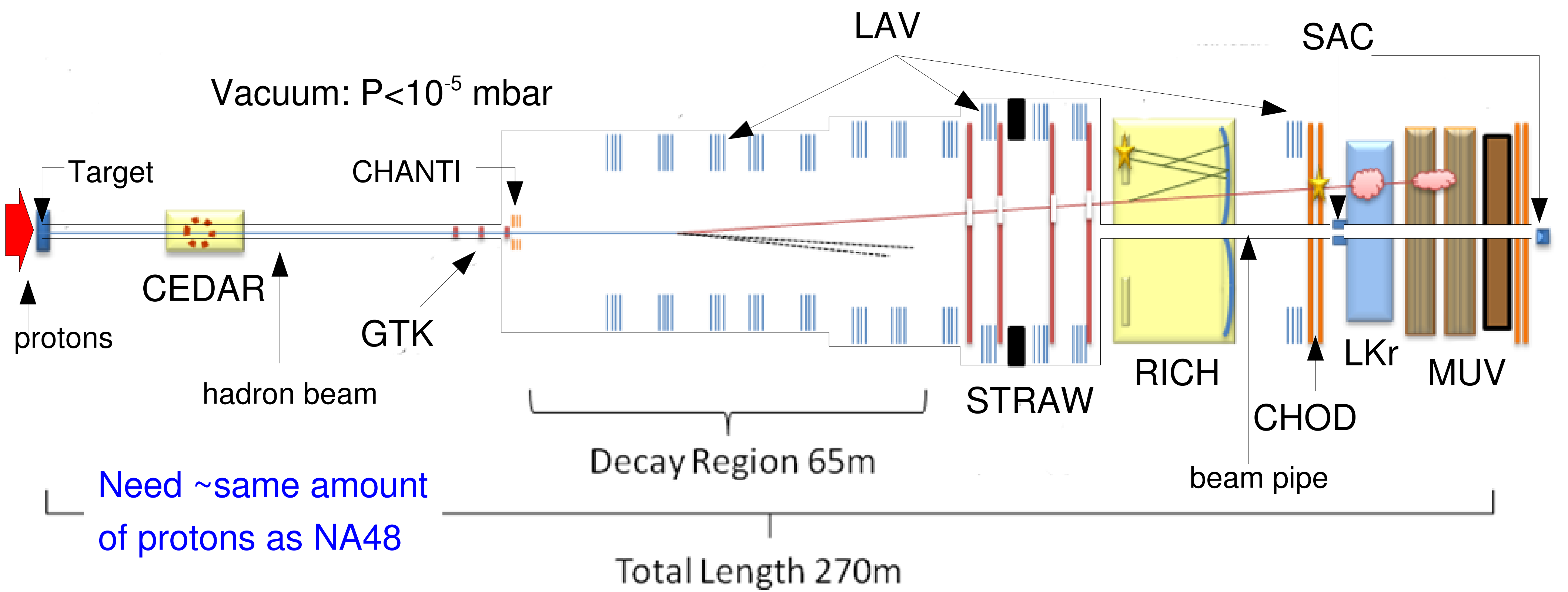


- Background:
  - All the K^+ decay modes.
  - Accidental charged particles (beam particle interactions).

- Experimental technique:
  (1) Kinematic rejection
  (2) Precise timing
  (3) Vetoes
  (4) Particle Identification

Detector Layout

- SPS primary protons @ 400 GeV/c ⇨ Unseparated secondary charged beam
- 75 GeV/c ($\Delta P/P \sim 1\%$)
- p/π/K (positron free, fraction of K ~6%)
- Area @ beam tracker 16 cm^2
- Integrated average rate @ beam tracker 750 MHz
- Kaon decays/year 4.8×10^{12}

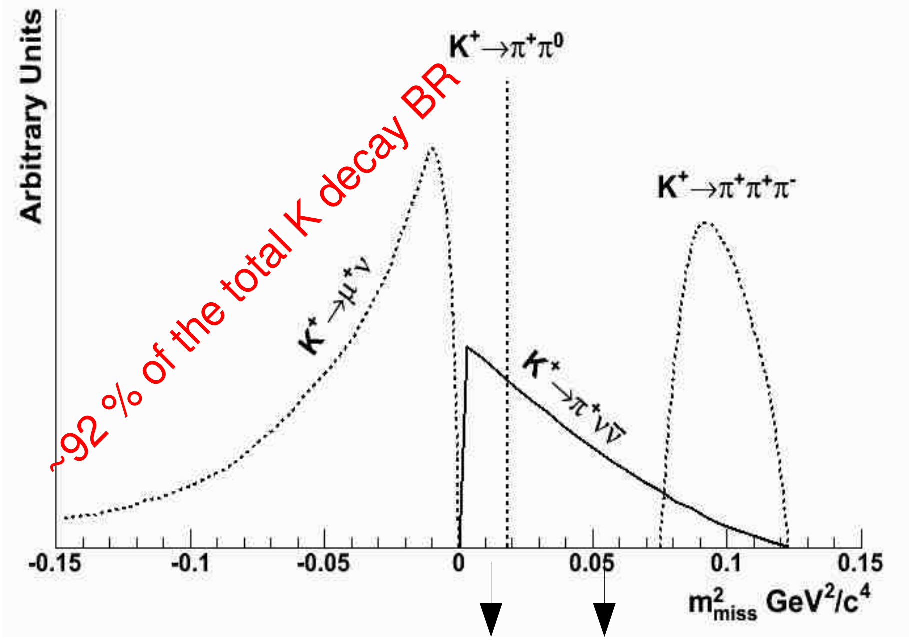


Need ~same amount of protons as NA48

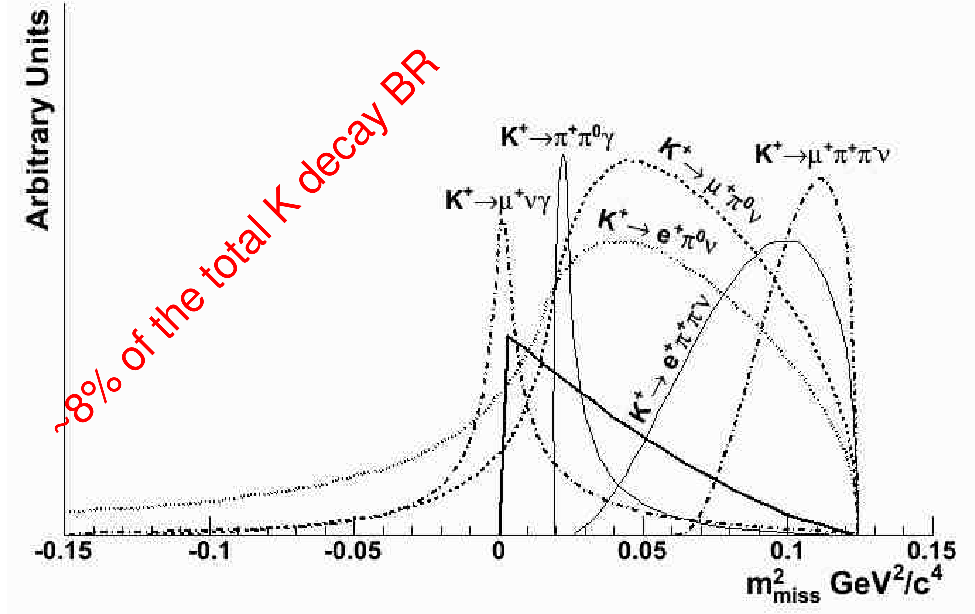
1) Kinematic Rejection

- Background from K⁺ decays: $m^2_{miss} = (P_K - P_\pi)^2$

Background constrained by kinematic



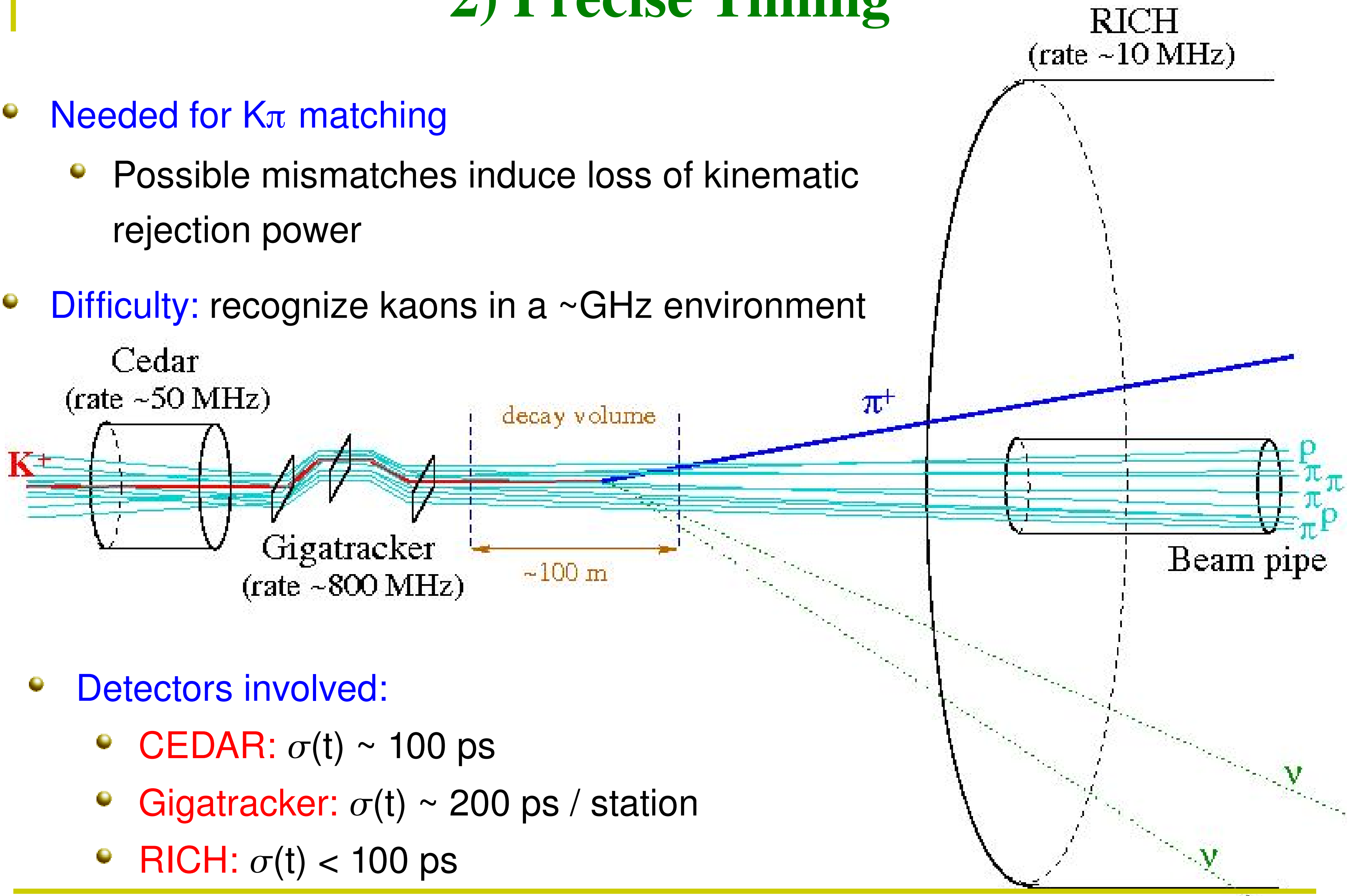
Background not constrained



- Two signal regions with a minimum of background, separated by the $K^+ \rightarrow \pi^+\pi^0$
- Background from 1) Kinematic resolution 2) Decays "not constrained".
- Requirements: low mass / high resolution trackers → Gigatracker (kaon), Straw chambers (pion)
  - tracking in vacuum, σ ~100 μm per coordinates

2) Precise Timing

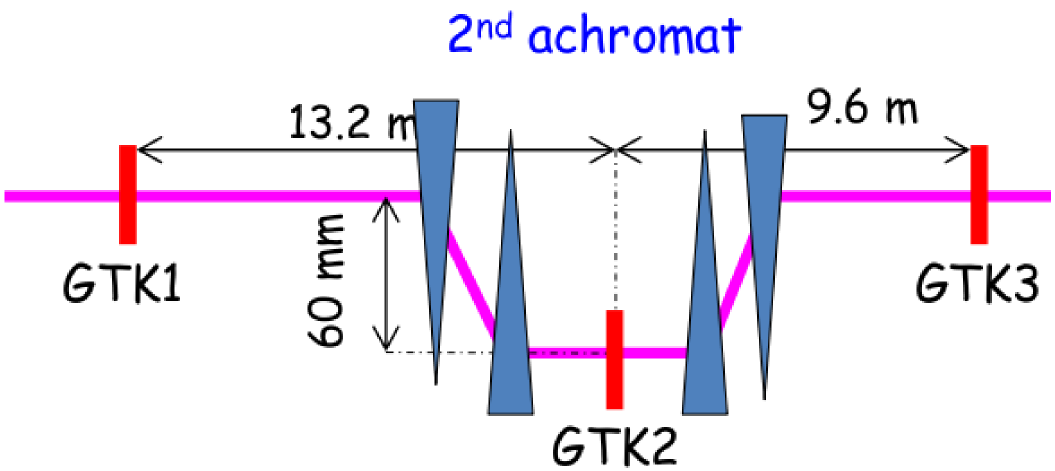
- Needed for Kπ matching
  - Possible mismatches induce loss of kinematic rejection power
- Difficulty: recognize kaons in a ~GHz environment



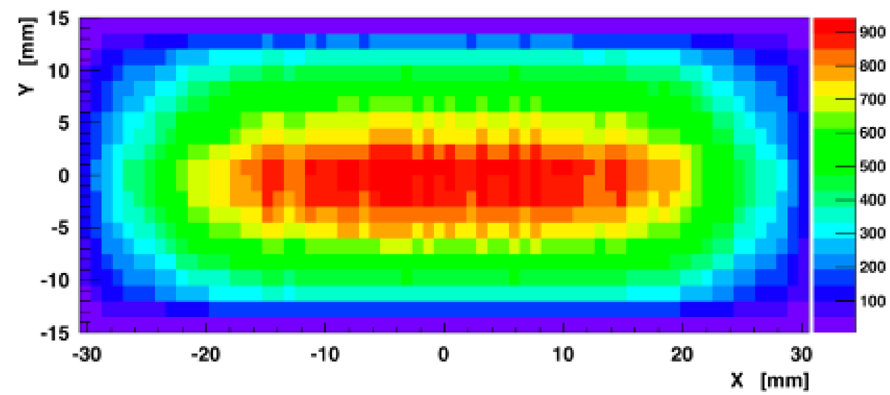
- Detectors involved:
  - CEDAR: σ(t) ~ 100 ps
  - Gigatracker: σ(t) ~ 200 ps / station
  - RICH: σ(t) < 100 ps

Gigatracker

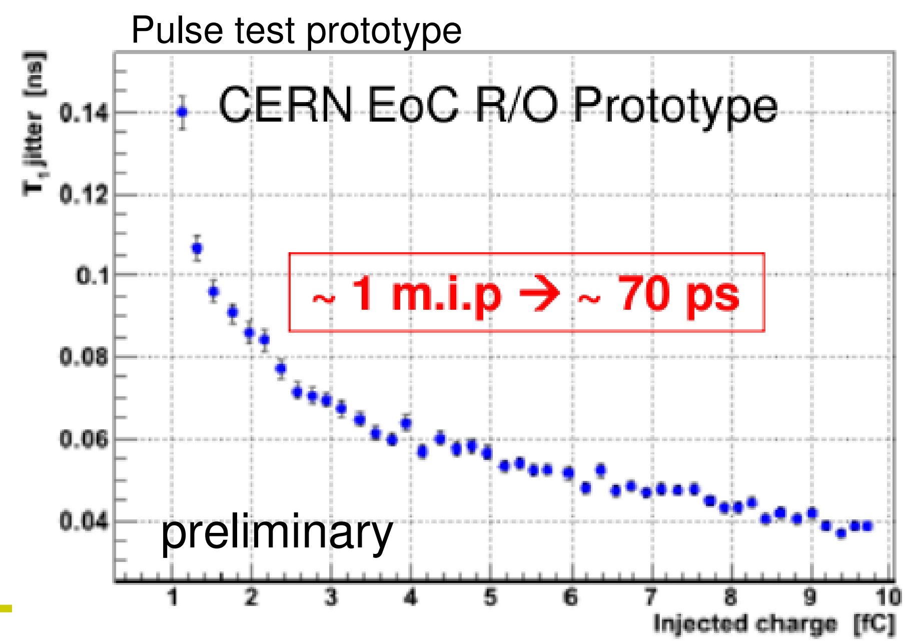
- 3 Si pixel stations before the decay volume



- Geometry matching the beam shape

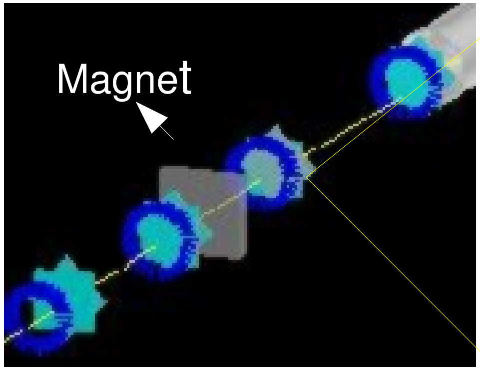


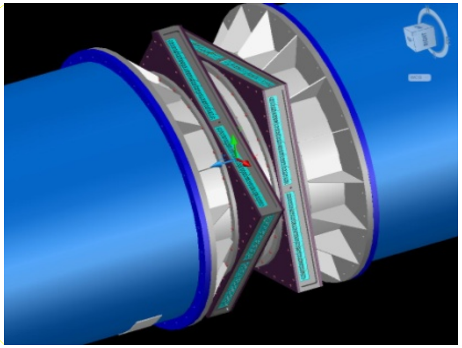
- Requirements:
- High space resolution: 300x300 μm pixels
- Low X/X_0: 200 μm sensor+100 μm chip (<0.5% X/X_0 per station)
- Excellent time resolution: sophysticated RO chip bump bonded on the sensor (0.13 μm technology)



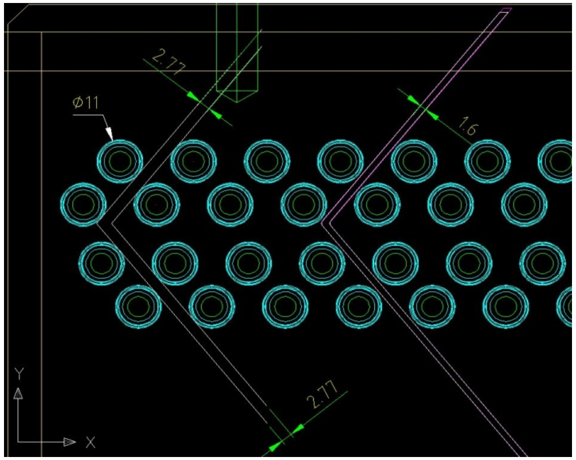
Straw Chamber Spectrometer

- 4 straw chambers in vacuum + 1 magnet (NA48 magnet, 256 MeV/c P_t kick)

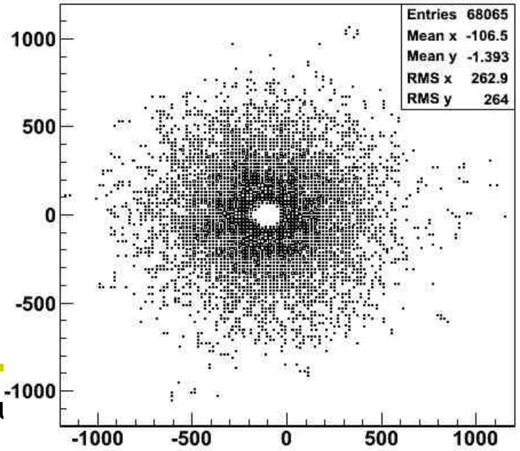




- 4 views per chamber (XYUV)
- 4 staggered layers of tubes per view
- 9.6 mm mylar tubes
- 2.1 m long
- Total X/X_0 ~0.1% per view

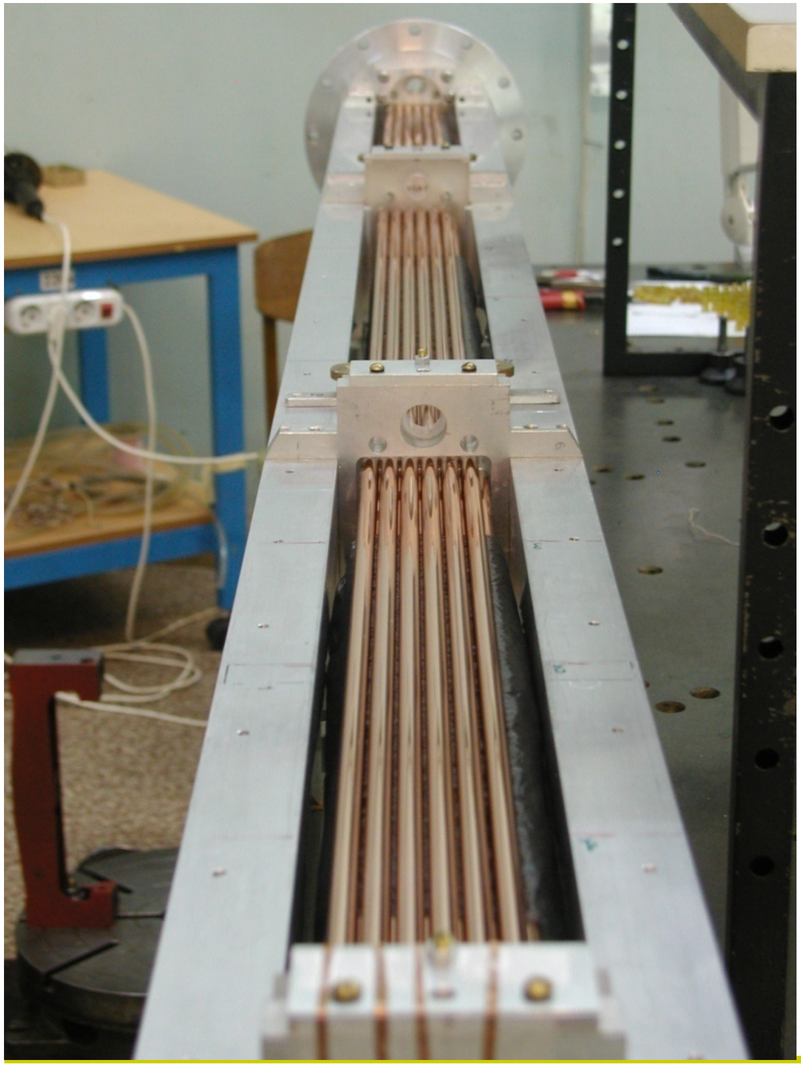


- 6 cm ”radius” beam hole displaced in the bending plane according to the 75 GeV/c beam path



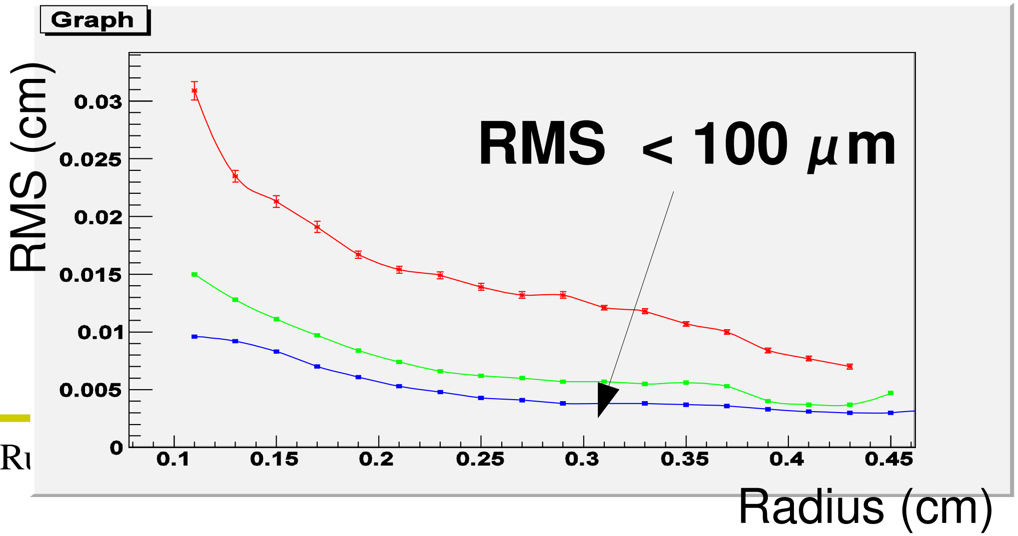
Straw Chamber Spectrometers R&D

- Full length prototipes built in 2007 and 2010. Tests on beam in 2007 and 2010.



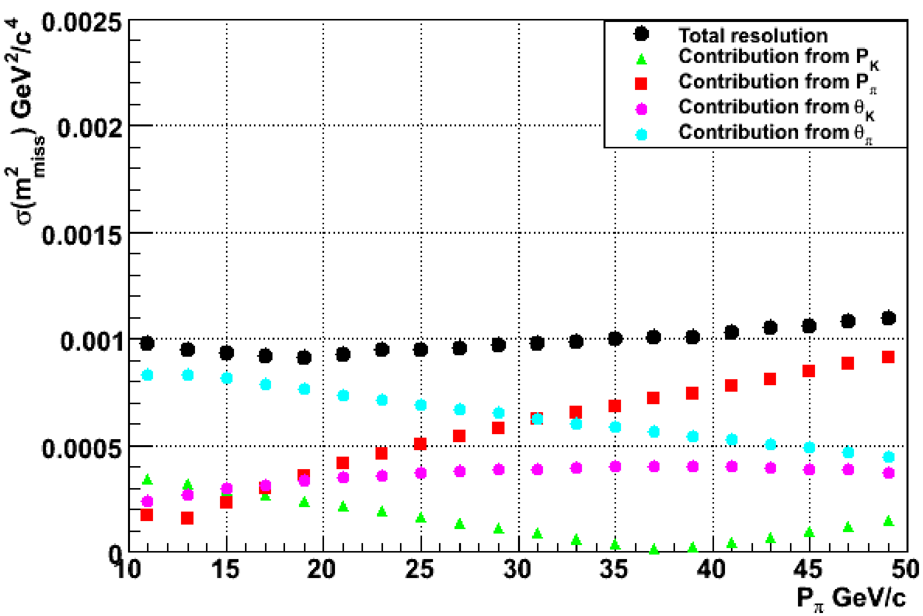
- Placed in vacuum on the beam

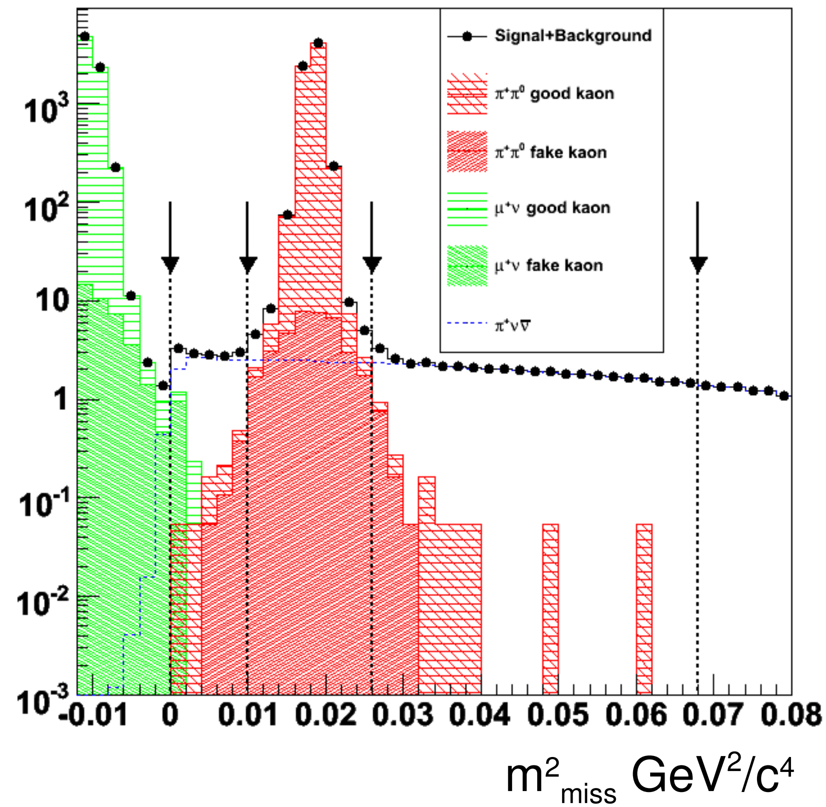
- Resolution from 2007 test beam (blue points). 2010 test beam just in this week



Kinematic rejection capabilities

- Performance of the new tracking system (Geant4 MC):
  - $\sigma(P_K)/P_K$ ~0.2%, σ(dX,Y/dZ)~16 μrad
  - $\sigma(P_\pi)/P_\pi$ ~0.3%$\pm$0.007% P_π, σ(dX,Y/dZ)~45 – 15 μrad
- 2-body rejection power
  - 10^4 ($K^+ \to \pi^+\pi^0$), 10^5($K^+ \to \mu^+\nu$)
- Sources of inefficiency:
  - MS non guassian tails
  - Kπ mis-match



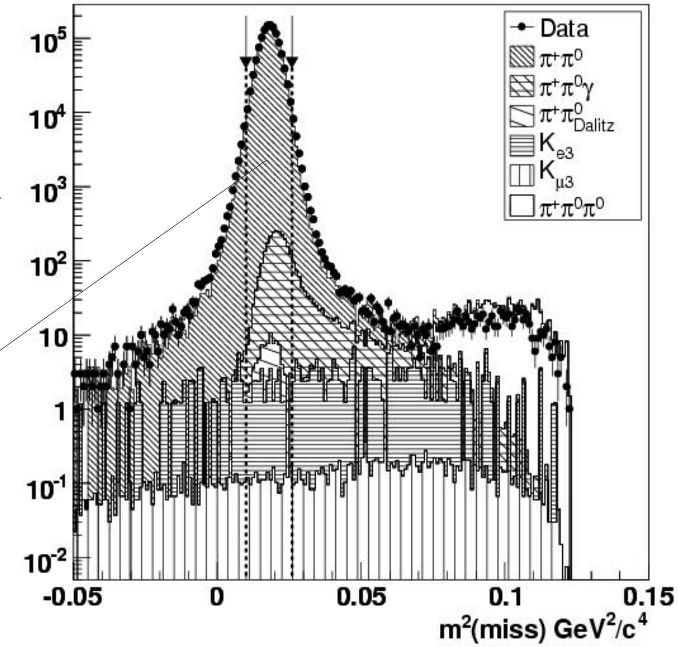


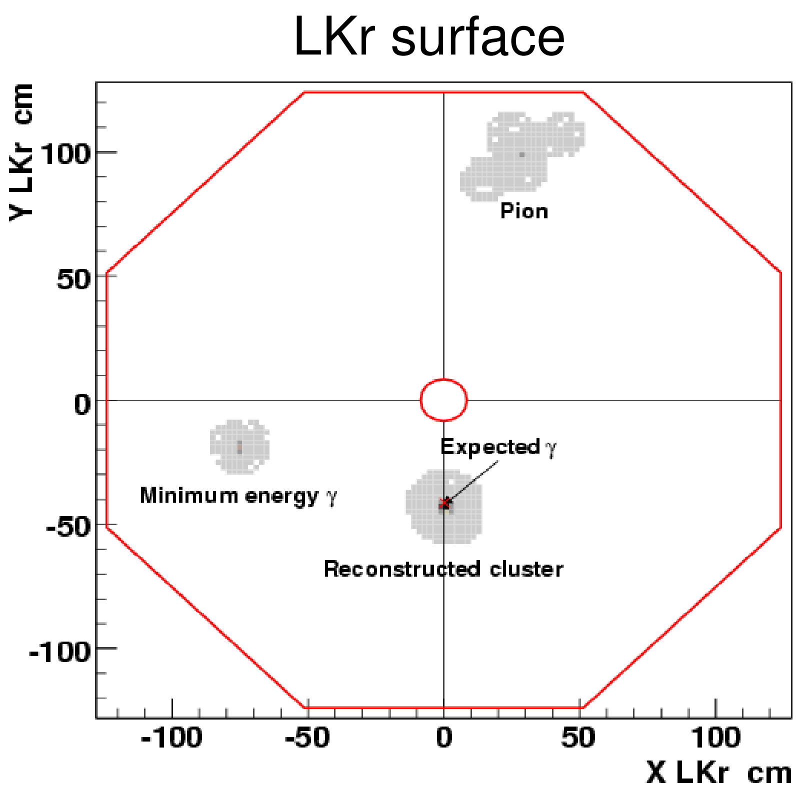
3) Photon Vetoes

- Principle:
  - Detectors designed to reject $K^+ \rightarrow \pi^+\pi^0$ together with the kinematic rejection.
- Detectors:
  - EM calorimeters (LAV, LKr, SAC)
  - 0-50 mrad
- Key points:
  - Analysis request: $P(\pi^+)$<35 GeV/c $\Rightarrow$ $P(\pi^0)$> 40 GeV/c it can hardly be missed in calorimeters!
  - >1 GeV photons hit the liquid Kripton calorimeter.
  - 10^{-5} inefficiency of the liquid Kripton calorimeter for >10 GeV photons .
- Rejection Capability:
  - $2 \div 3.5 \times 10^{-8}$ π^0 rejection inefficiency from $K^+ \rightarrow \pi^+\pi^0$

NA48 Liquid Kripton em calorimetry inefficiency

- Inefficiency measured on data
- NA48 data @ 75 GeV
  - $K^+ \rightarrow \pi^+\pi^0$ selected using kinematic only

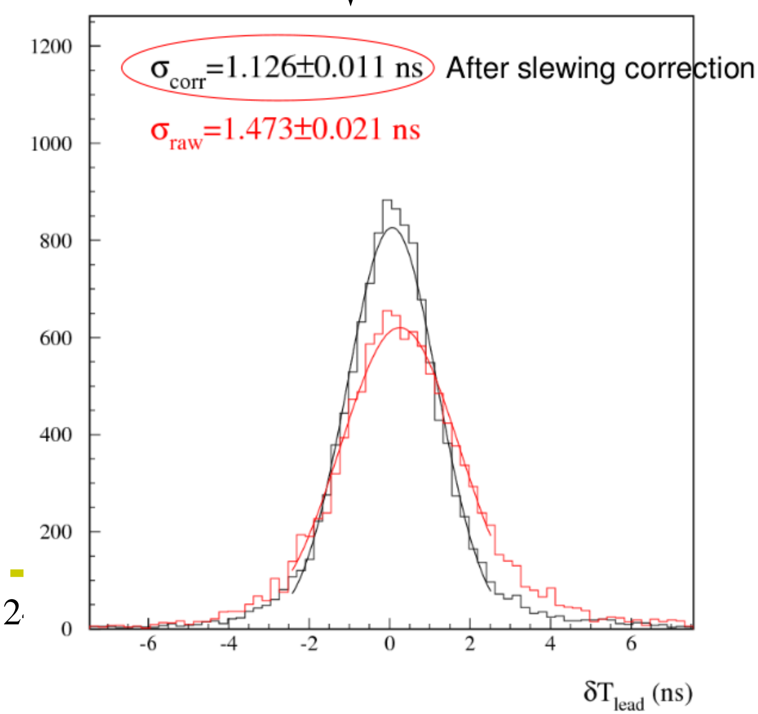


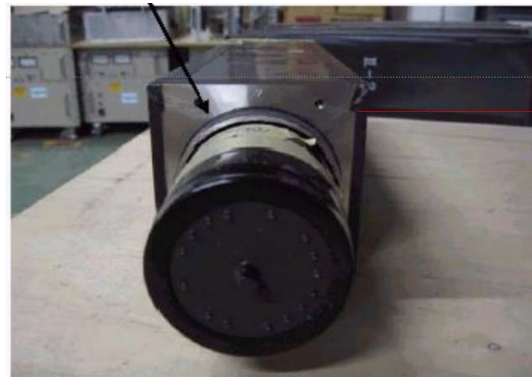


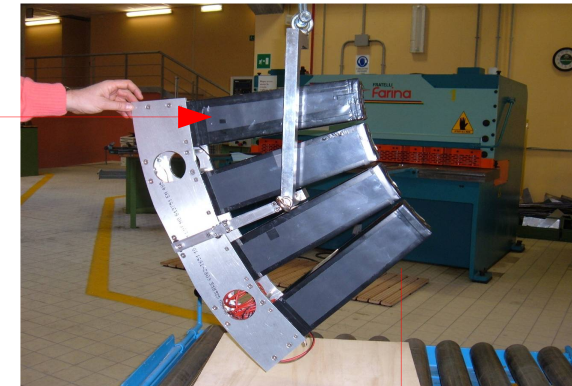
E (GeV)	Inefficiency
2.5 – 5.5	$< 10^{-3}$
5.5 – 7.5	$< 10^{-4}$
7.5 – 10	$< 5x10^{-5}$
> 10	$< 8x10^{-6}$

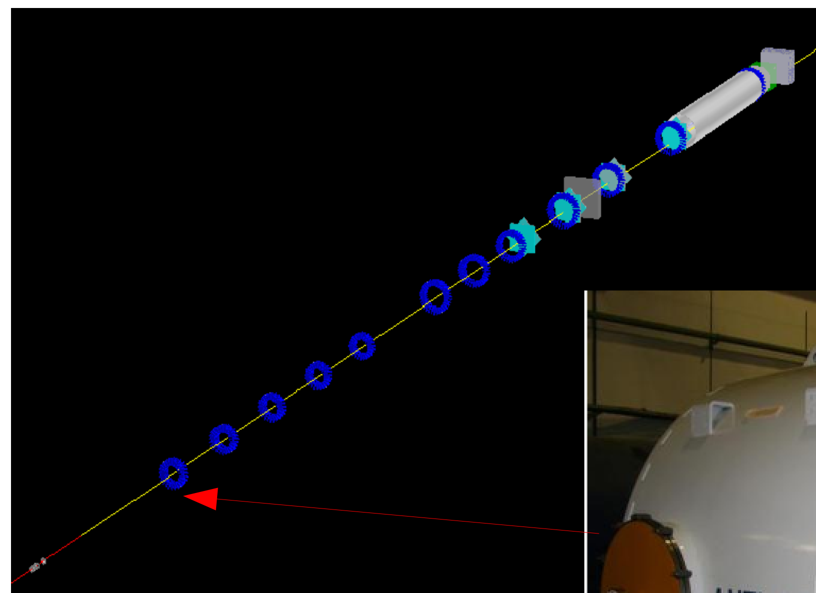
Large Angle Veto (LAV)

- OPAL lead glass:
- 12 rings in vacuum
  - 5 staggered planes per ring
- Blocks tested @ BTF (Frascati):
  - Inefficiency @ 471 MeV e^+:
    ~10^{-4} on the whole surface
- First ring built and tested in 2009 at CERN SPS









3) Muon Vetoes

- Principle:
  - Detectors designed to reject $K^+ \to \mu^+\nu(\gamma)$ together with the kinematic rejection.
- Detector
  - Sampling hadronic calorimeter with scintillator planes
- Key points:
  - Sensitivity to MIP
  - EM/Hadronic showers separation (LKr/Hadronic calorimeter)
- Rejection Capability:
  - $O(10^{-5})$ muon rejection inefficiency.

Still not enough against the $K^+ \to \mu^+\nu(\gamma)$ background

4) Particle Identification

- Against K^+ decays:
- Principle:
  - Detectors designed to reject $K^+ \rightarrow \mu^+ \nu(\gamma)$ together with the kinematic rejection and MUV
- Detector:
  - RICH for π/μ separation
- Performances:
  - $\sim 10^{-3}$ / 10^{-2} muon mis-identiication probability up to 35 GeV/c
- Redundancy
  - Kinematic rejection, muon rejection, positron rejection.

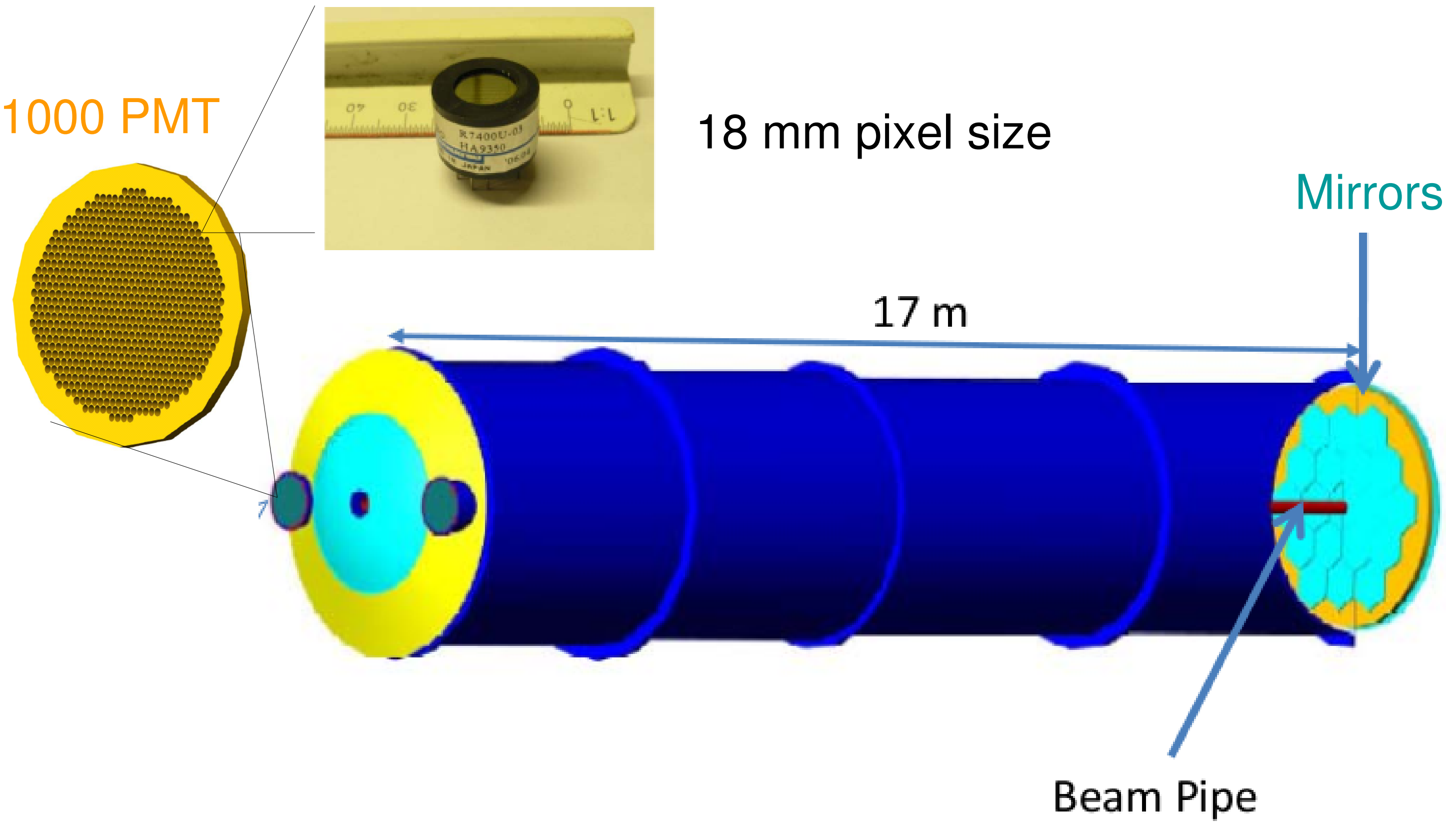
- Against accidentals:
- Principle:
  - Veto of events with π^+/protons interacting with the beam tracker or with the residual gas in the decay volume.
- Detector:
  - CEDAR for K^+ identification.

RICH

- Purposes:
  - → π/μ separation
  - → Event time

Radiator: Ne (1atm)

→ P_{π} > 15 GeV/c (Cerenkov threshold).

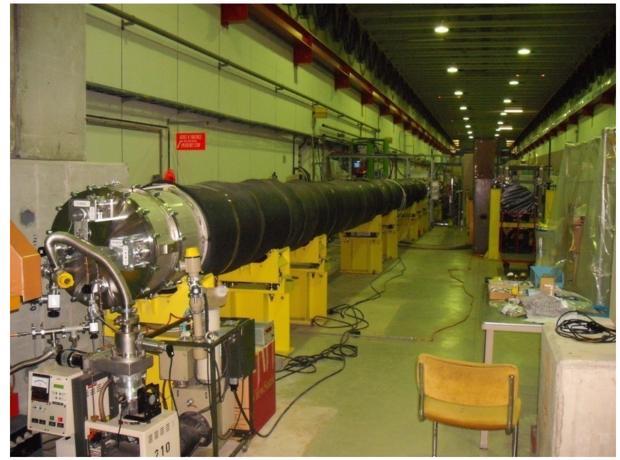


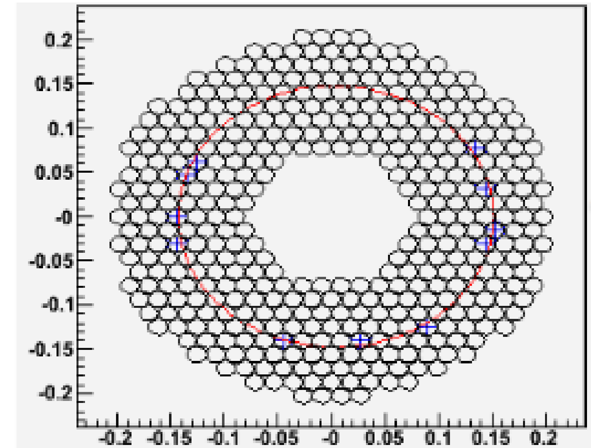
- Test beam 2007
- ECN3 (NA48 cavern) @ CERN
- 200 GeV hadron beam (pion/K)
- Full length prototipe (0.5 m radius)
- 96 PMT Hamamtsu R7400

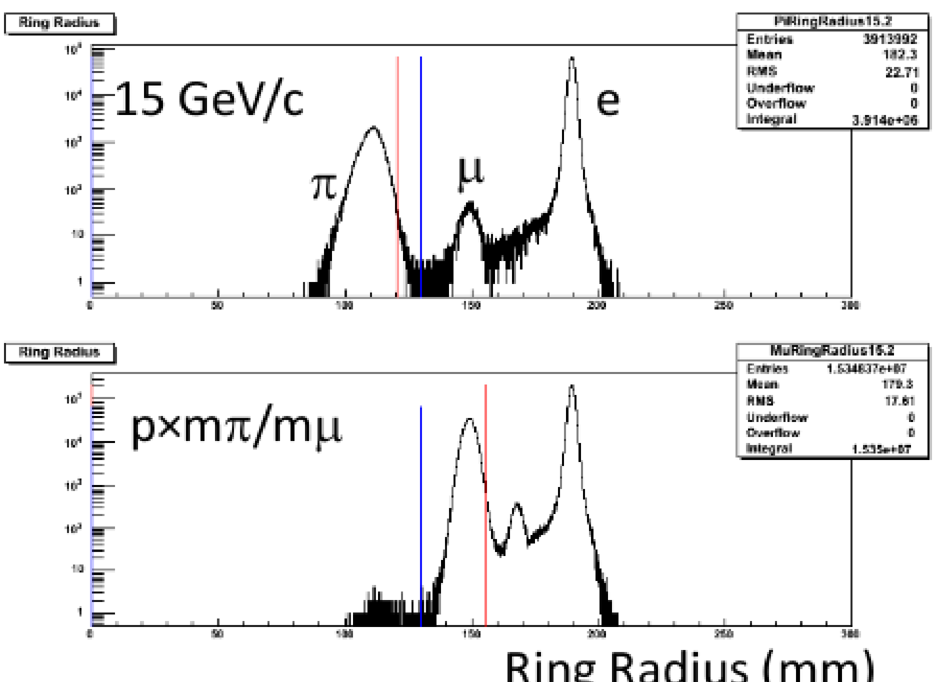
- Results [NIM A 593, 2008]
- N_{hits} ~ 17/event
- Δt_{event} ~ 70 ps
- $\Delta\theta_c$ ~ 50 μrad (biased by PM Geometry)

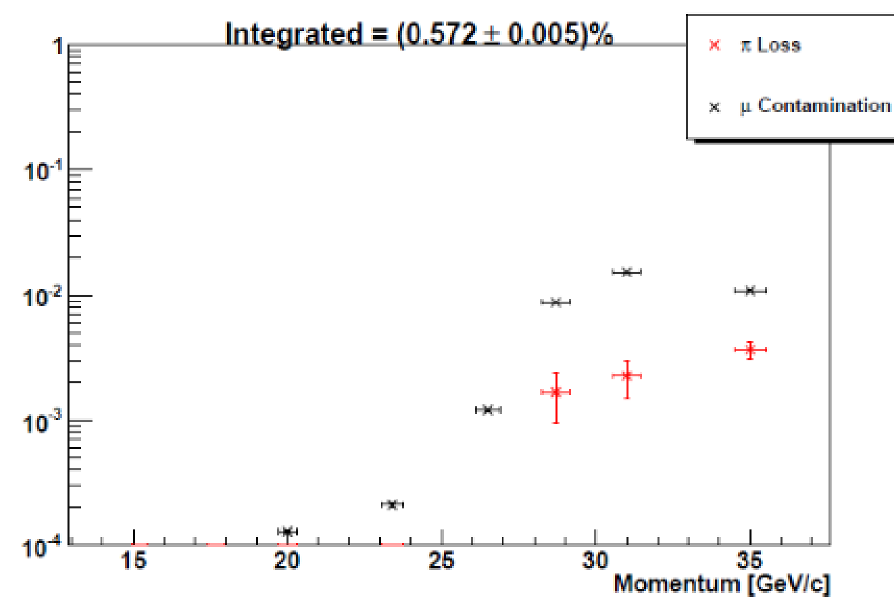
Rich Test Beam '09

- Full length prototype tested on a charged beam at CERN SPS
- ~400 PMT installed
- HPTDC + TELL1 for readout (project developed within the collaboration in the framework of the Trigger R&D)



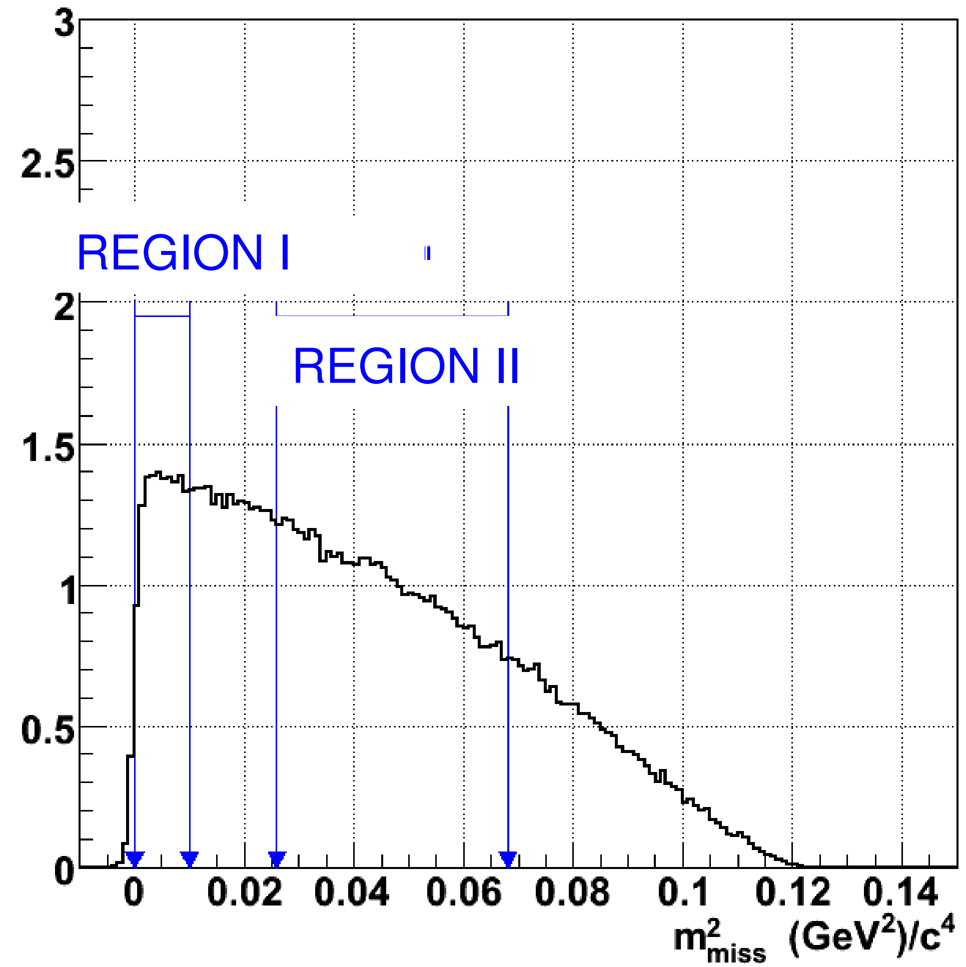






NA62 Sensitivity: signal acceptance

- Simulation of the NA62 apparatus
  - interactions in the trackers simulated using GEANT4
- Most important cut in the analysis: $15 < P_\pi < 35$ GeV/c
  - For photon and muon rejection
  - RICH operational reasons
- Acceptance: ~14.4%
  - 3.5% "region 1", 10.9% "region 2"
  - 50% loss due to P_π cut
  - Expected detector inefficiencies considered



- To be reduced because of losses due to dead time, additional inefficiencies...

The NA62 experiment matches the goal of 10% acceptance

NA62 Sensitivity

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

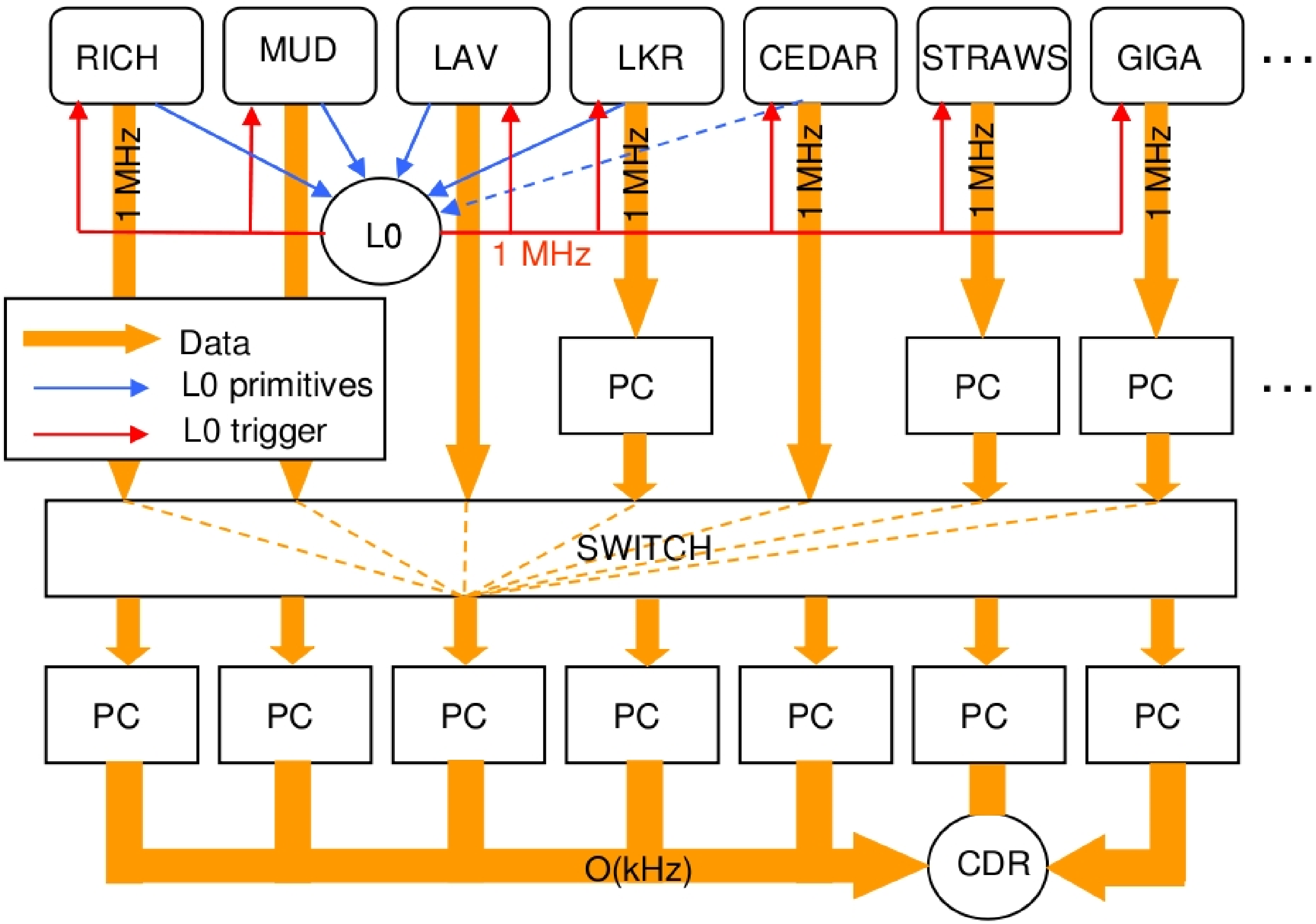
Conclusions

- NA62 is approved and financed.
- With 2(+1) years of data taking NA62 will provide a 10% measurement of the BR of the $K^+ \rightarrow \pi^+ \nu \bar{\nu}$
  - x50 Kaon flux with respect to NA48 with ~same amount of protons from SPS.
  - Key points: Excellent resolutions, hermetic coverage, strong particle ID.
  - The R&D is close to the end and the construction is already started.
- The high performances of the detectors can also be the building blocks for a further rich physics program.

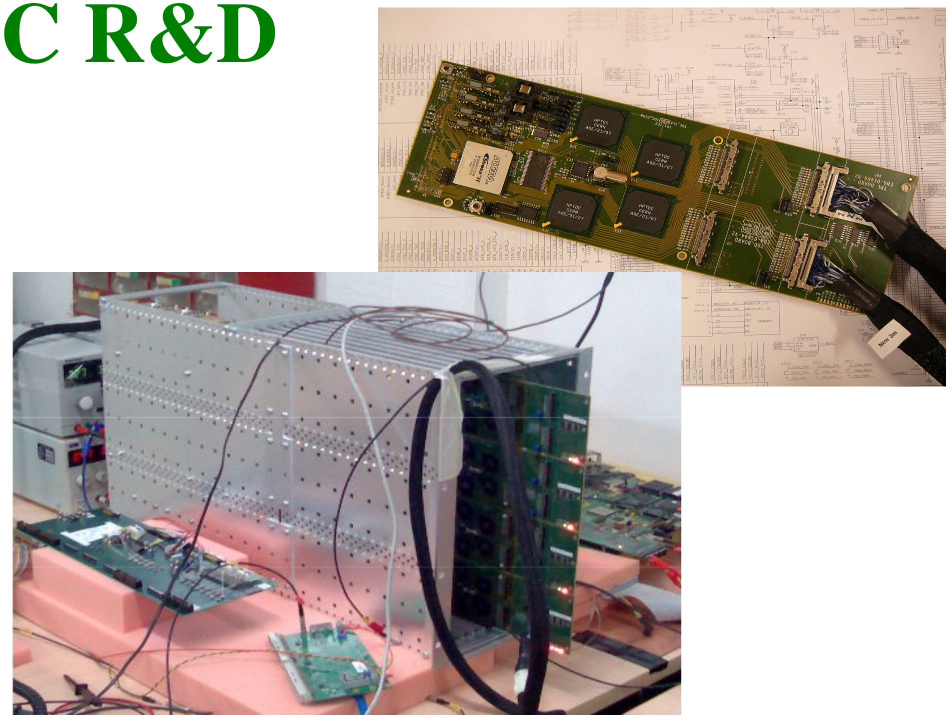
Spares

Trigger system

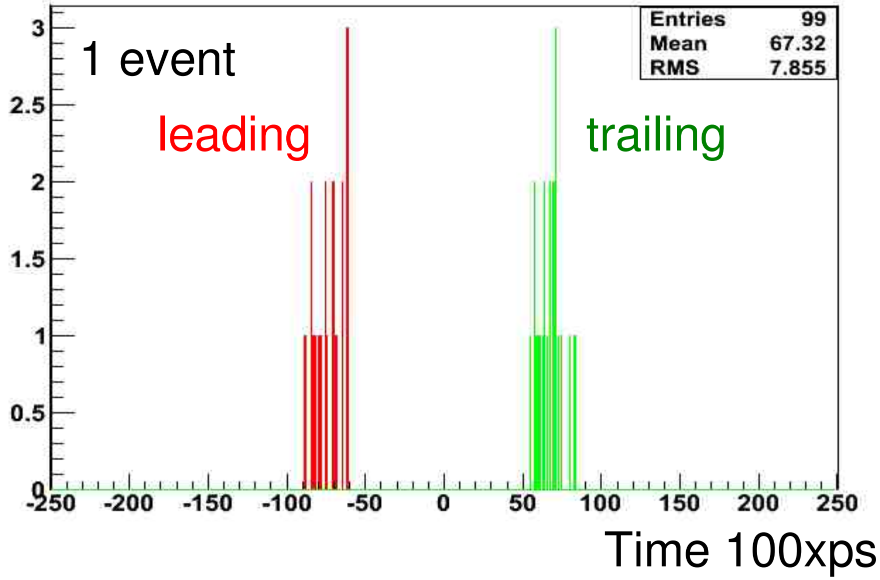
- Sub-detectors R/O and integrated L0 trigger: TELL1/TDC project
  - RICH, MUD, LAV, Straws
  - Gigatracker, LKr , CEDAR: dedicated projects for R/O and L0 trigger
- L0 processor: receives O(40 MB/s), takes a decision delivered to all the detectors.
- L1 (subdetectors), L2 (event) triggers: online farm. Output O(kHz).



TELL1/TDC R&D



- LHCb TELL1 as underlying carrier board
- High integration TDC daughter card with HPTDCs developed (512ch/TELL1)
- Linear fast preamp/discriminator gives PH information with time-over-threshold
- Local processing and power storage
- TELL1/TDC based R/O system tested successfully during the '09 RICH test



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