Status and latest results from the NA62 Experiment at CERN

PATRIZIA CENCI

INFN, Perugia (Italy)

BEACH 2012

X International Conference on Hyperons, Charm and Beauty Hadrons

Wichita, KS

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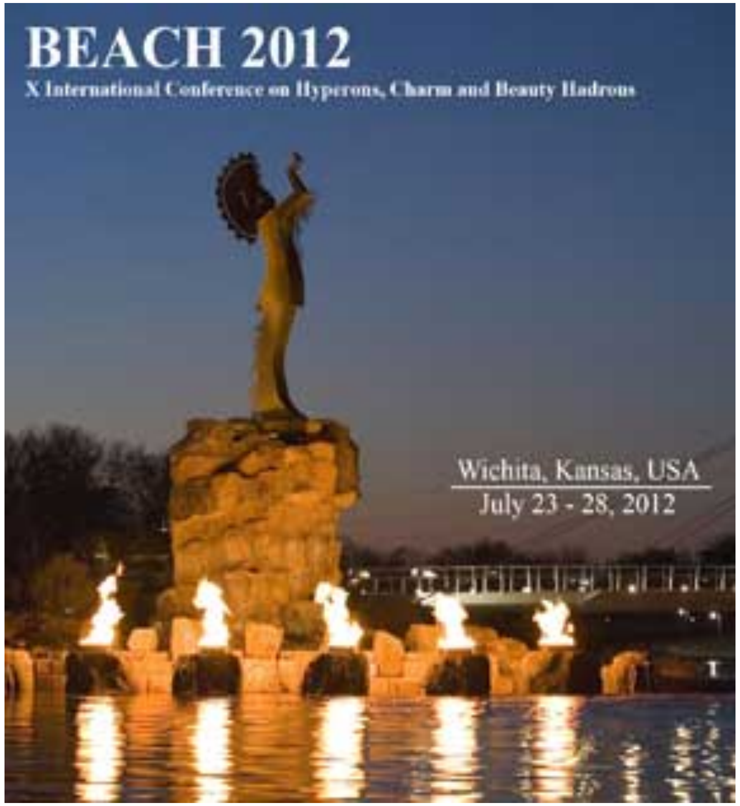
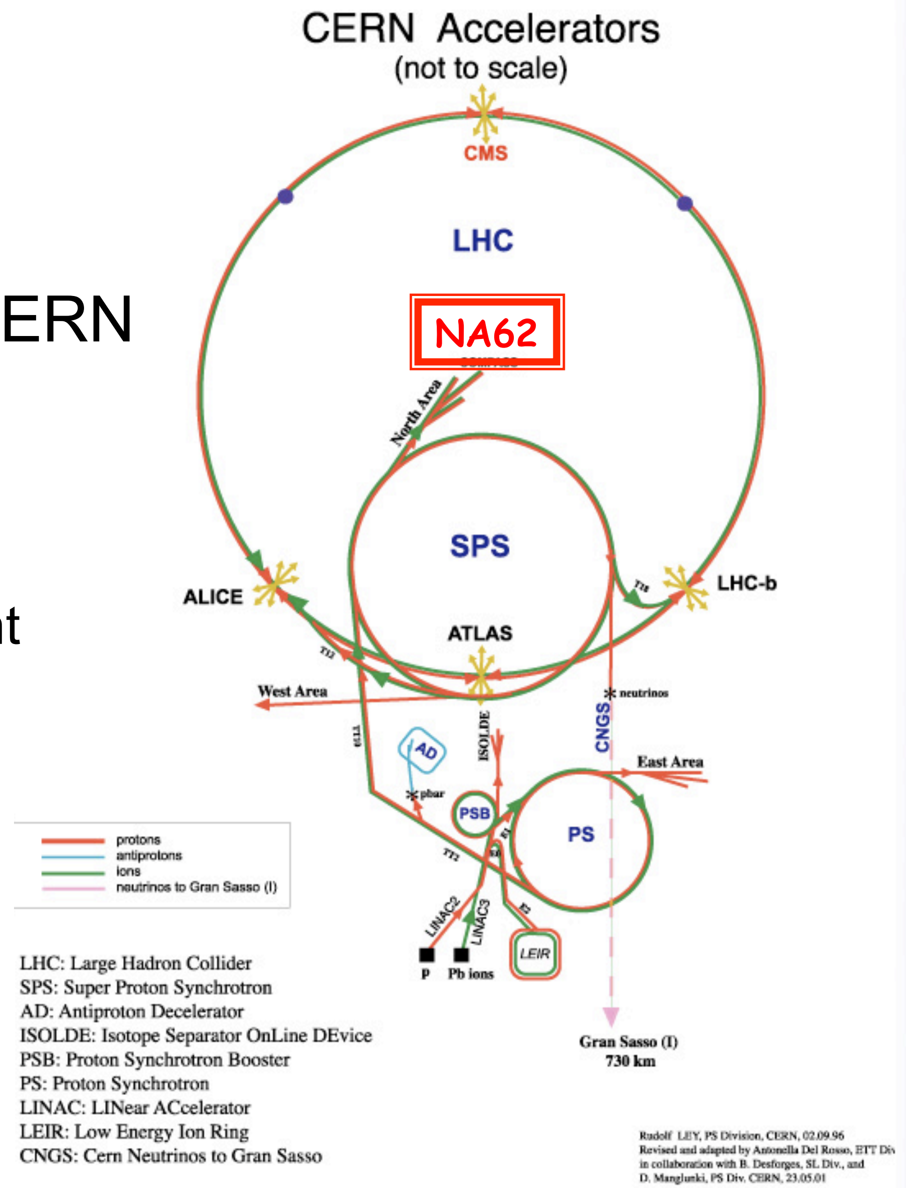
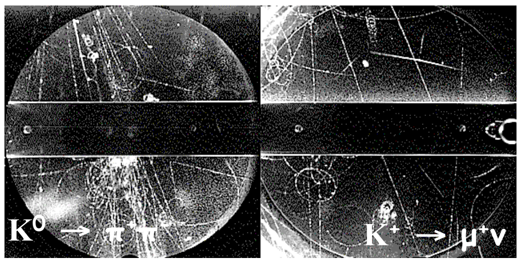


On behalf of the NA62 Collaboration

Outline

- Kaons and New Physics
- The NA62 experiment at CERN
  - Experimental technique
  - Beam and detector
  - Final $R_K = K_{e2}/K_{\mu 2}$ measurement
- Summary and outlook





Flavor physics: the golden observables

G. Isidori – Implications of LHC results — *CERN, 30th March 2012*

▶ Minimal list of key (*or better classes of*) observables

• γ from tree ($B \to DK$, ...)	(S)LHCb
• $\|V_{ub}\|$ from semi-leptonic B decays	SuperB's
• $B_{s,d} \to l^+l^-$	(S)LHCb
• CPV in B_s mixing	(S)LHCb
• $B \to K^{(*)}\, l^+l^-$, $\nu\nu$	(S)LHCb , SuperB's
• $B \to \tau\nu$, $\mu\nu$	SuperB's
• $K \to \pi\nu\nu$	Kaon beams (NA62,...)
• CPV in charm	(S)LHCb , SuperB's
• LFV in charged leptons	Muon beams, (S)LHCb, SuperB's

Gino Isidori

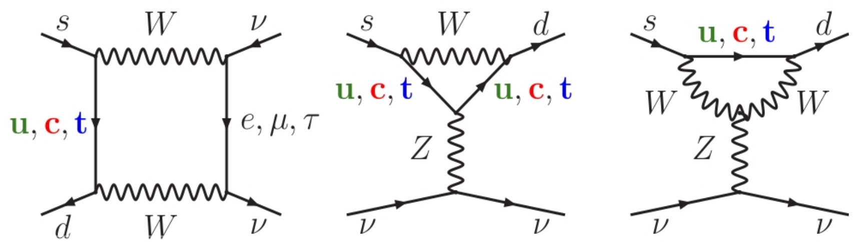
The K → πνν̄ decays in the SM

Decay (BR × 10^{10})	Theory (SM Prediction)	Experiments
$K^+ \to \pi^+ \nu \bar{\nu}$	0.781 ± 0.075 ± 0.029 [1]	1.73 + 1.15 – 1.05 [2]
$K^0 \to \pi^0 \nu \bar{\nu}$	0.243 ± 0.039 ± 0.006 [1]	< 260 [3]

[1] Brod, Gorbahn, Stamou: PRD83(2011) 034030, arXiv 1009.0947
[2] BNL E787/E949: PRL101 (2008) 191802, arXiv 0808.2459
[3] KEK E391a: PR D81 (2010) 072004, arXiv 0911.4789

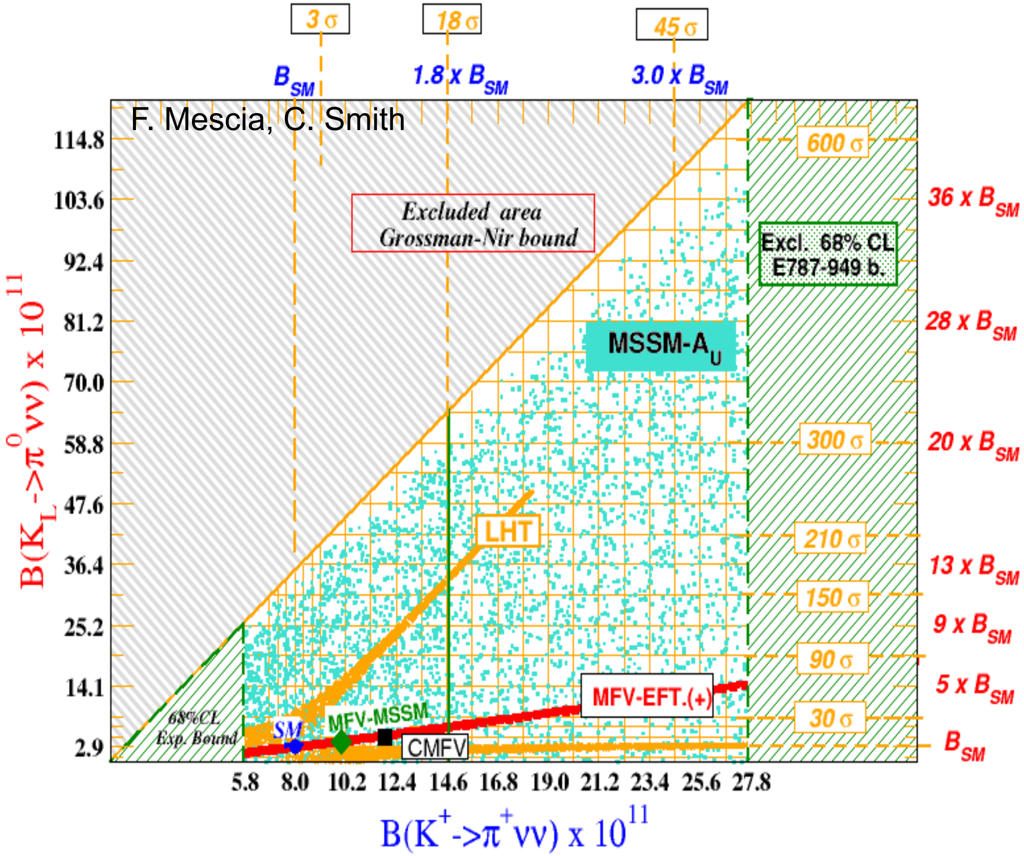
SM predictions are extremely clean

- Short Distance dynamics dominates:
  - FCNC processes only arising at loop level (Z penguins and box diagrams)
- Hadronic matrix element known from K_{e3} semileptonic decays BR via isospin rotation
- Uncertainty dominated by CKM matrix elements
- Amplitude very well predicted:
  - *clean V_{td} dependence*
  - *the BR measurement determines V_{td} without input from Lattice QCD ($\delta BR/BR \approx 10\% \longrightarrow \delta V_{td}/V_{td} \approx 7\%$)*
- Strongly suppressed in SM ($<10^{-10}$):
  - *Key role in seeking NP beyond SM*



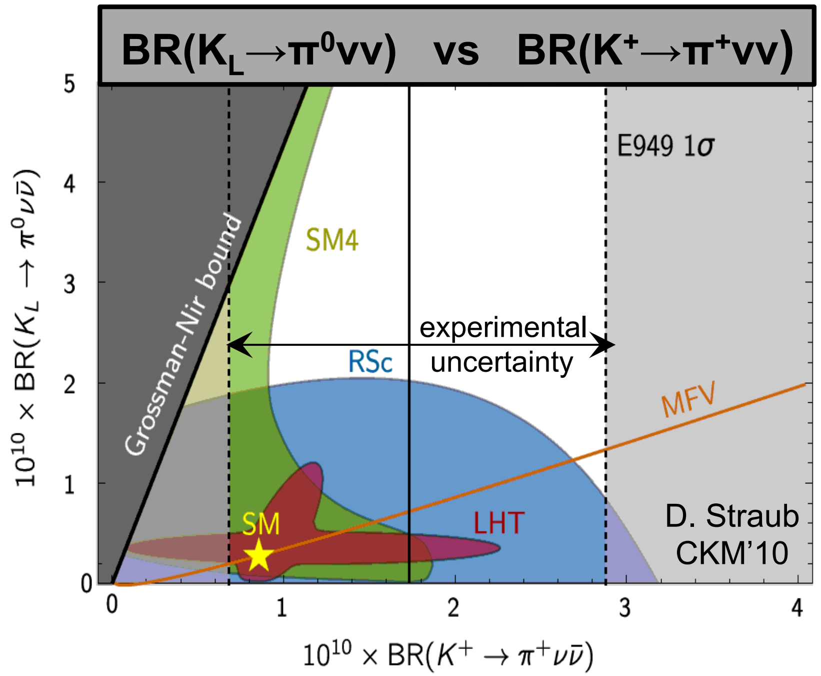
The K → πνν̄ decays beyond SM

- Rare K decays are highly suppressed (CKM) → highly predictive for SM extensions
- Many SM extensions predict sizeable deviations from the BR_{SM} value
- Possibility to distinguish among many different models:
  - *Chargino/H± loops (MSSM at low/large tanβ), R-parity violation (non MFV), enhanced EW Penguins, Little Higgs, extra dimensions, 4th generation, …*



NP models predicting deviations from MFV:

- *Randall-Sudrum,*
- *Littlest Higgs with T-parity,*
- *SM 4th generation*



The NA62 experiment at CERN

The CERN Accelerator Complex

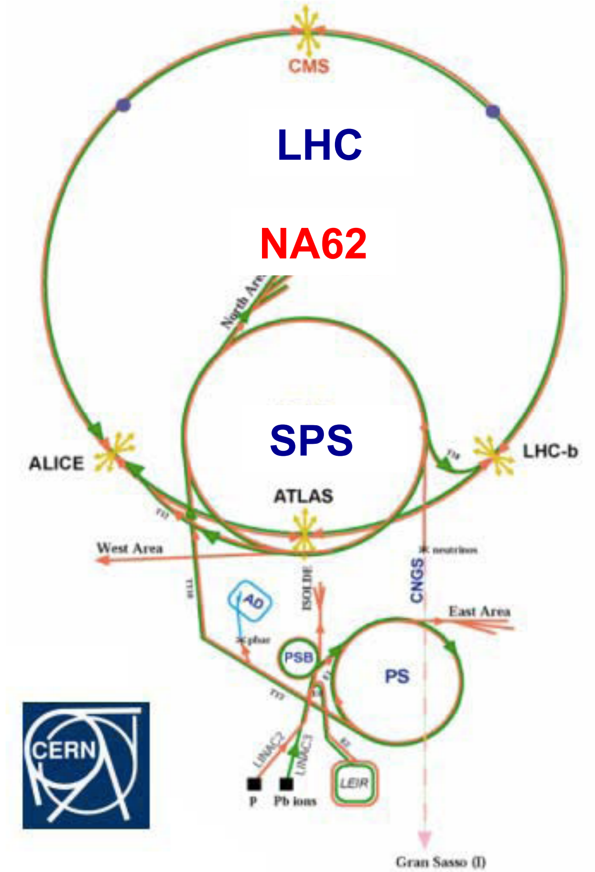
The SPS at CERN:

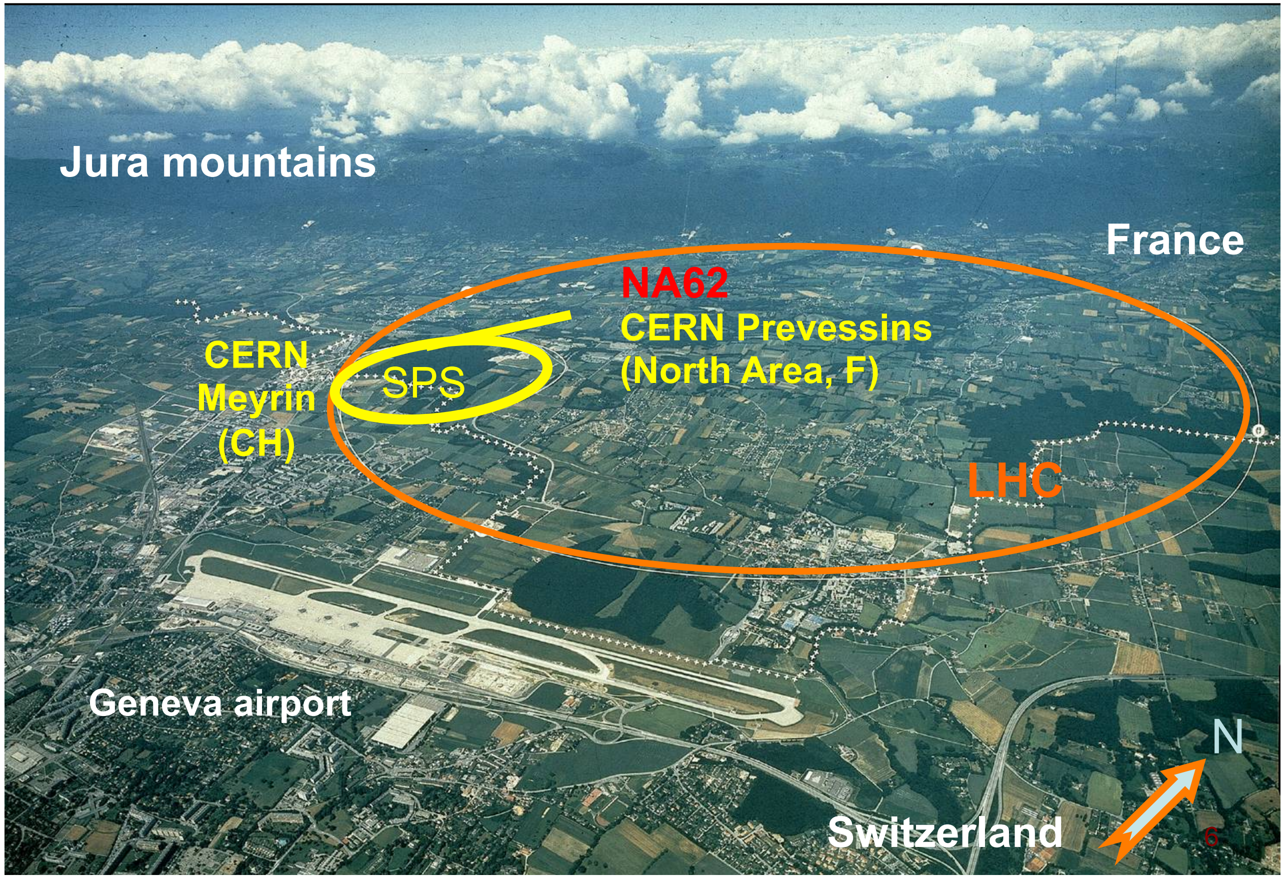
- 400 GeV/c protons
- used as injector for the LHC
- multi-turn fast/slow extraction system

The NA62 experimental program

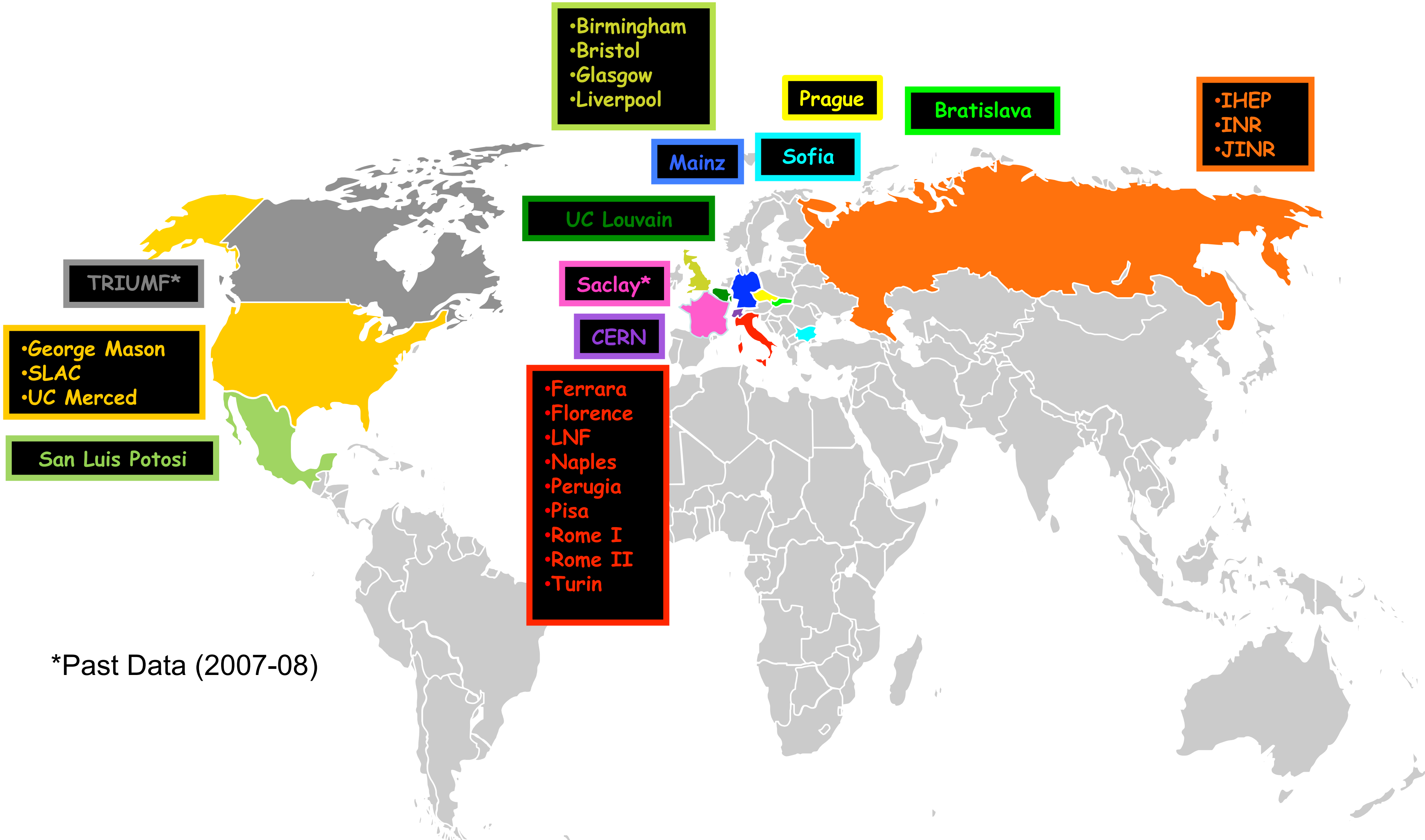
Main goal: measurement of $K^+ \to \pi^+ \nu\bar{\nu}$
(O(100) events, S/B≈10; physics runs: 2014-15, commissioning run with partial detector in 2012)

Early stage: measurement of $R_K = \Gamma(K_{e2})/\Gamma(K_{\mu2})$ with precision <1% (physics runs: 2007-08)





The NA62 Collaboration



*Past Data (2007-08)

The NA62 Collaboration: Birmingham, Bratislava, Bristol, CERN, Dubna, Fairfax, Ferrara, Florence, Frascati, Glasgow, Liverpool, Louvain, Mainz, Merced, Moskow, Napoli, Perugia, Pisa, Prague, Protvino, Rome I, Rome II, San Luis Potosí, SLAC, Sofia, Turin

NA62: the experimental technique

Decay-in-flight technique:

Advantages
(wrt decay at rest)

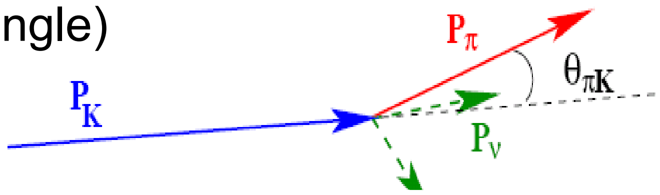
- ➔ easy to have high intensity beam
- ➔ easy to veto high energy photons

Disadvantages

- ➔ long detector and decay region
- ➔ event by event measurement of K momentum
- ➔ unseparated hadron beam

Signal signature:

1 track (momenta+angle)
+ nothing



Background:

All K decays + accidental charged particles
(beam particle interactions)

➔ A challenging experiment with weak signal signature (BR_{SM} = 8 x 10^{-11}) and huge background from kaon decays

Decay	BR
$\mu^+\nu$ ($K_{\mu 2}$)	63.5%
$\pi^+\pi^0$ ($K_{\pi 2}$)	20.7%
$\pi^+\pi^+\pi^-$	5.6%
$\pi^0 e^+\nu$ (K_{e3})	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_{e4})	4.1×10^{-5}
$\pi^0\pi^0 e^+\nu$ (K_{e4}^{00})	2.2×10^{-5}
$e^+\nu$ (K_{e2})	1.5×10^{-5}
$\pi^+\pi^-\mu^+\nu$ ($K_{\mu 4}$)	1.4×10^{-5}

NA62: guiding principles

GOAL: 10% precision measurement of BR($K^+ \to \pi^+ \nu\bar{\nu}$)

O(100) $K^+ \to \pi^+ \nu\bar{\nu}$ decays with ~10% background in 2 years data taking

Requirements:

Statistics:

- BR(SM) ~ 8 x 10^{-11}
- Acceptance: 10%
- K decays: ~10^{13}

Kaon intensity, signal efficiency

Systematics:

- ≥10^{12} background rejection
- ~10% precision on background measurement

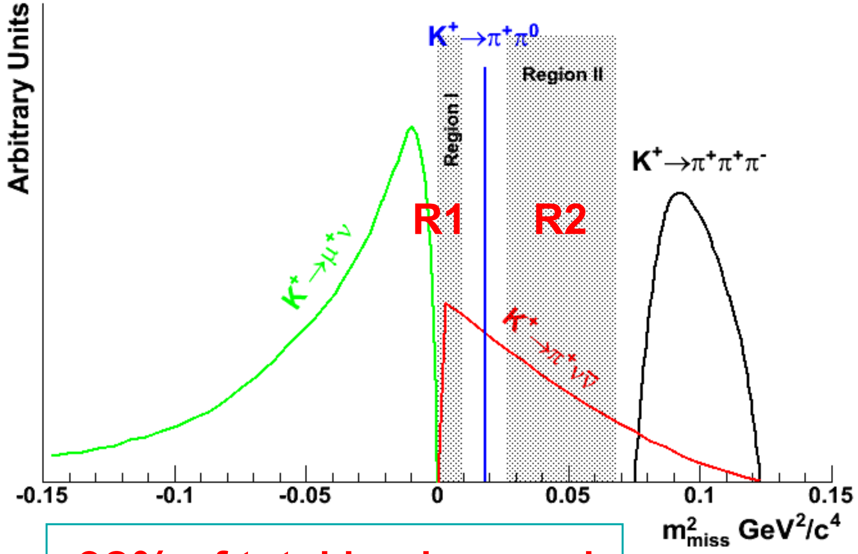
Signal purity, detector redudancy

- high-rate environment ➔ precise high resolution timing
- kinematic rejection, by cutting on the missing mass squared of the observed decay particles
  - ➔ fast tracking to measure the incoming K momentum
  - ➔ high resolution tracking to measure daughter particles momenta
- rejection of background processes
  - ➔ precise identification of kaons, pions, muons, electrons and photons
  - ➔ hermetic vetoing of photons out to large angles and of muons within the acceptance
- redundancy of information

NA62: background rejection

$$m^2_{miss} = (P_K - P_\pi)^2 = m_K^2 + m_\pi^2 - 2(E_K E_\pi - p_K p_\pi \cos\theta_{K\pi})$$

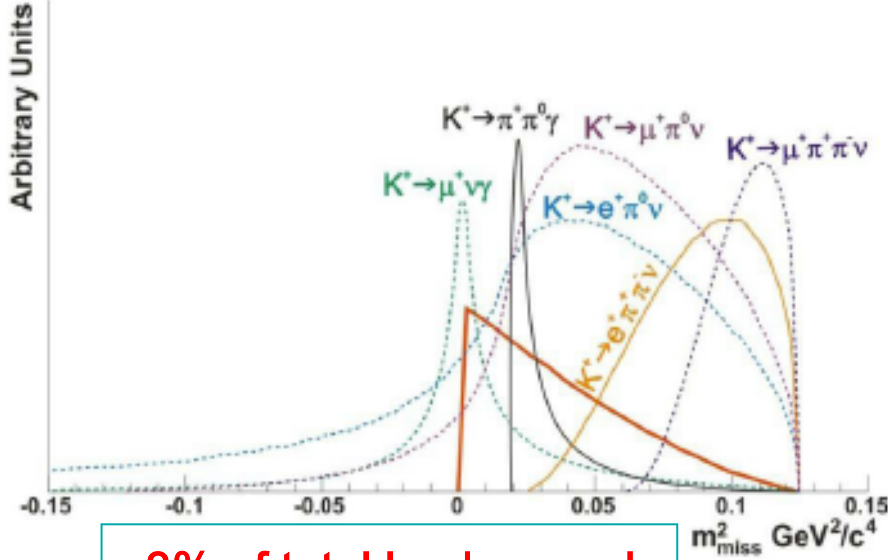
Background separated by kinematic cuts



92% of total background

- Definition of the signal region with low background:
  - ➔ $K^+ \to \pi^+\pi^0$ forces to split it into 2 parts: R1 and R2
- Achievable kinematic rejection power (MC):
  - ➔ ~10^4 ($K^\pm_{2\pi}$), ~10^5 ($K^\pm_{\mu 2}$)
- Rejection relies on high resolution m^2_{miss} reconstruction
  - ➔ low mass/high resolution tracking in vacuum

Background NOT separated by kinematic cuts



8% of total background

- Radiative decays or ν final states
- Span across the signal region
- Rejection relies on efficient vetoes and PID

NA62: $K^+ \to \pi^+ \nu\bar{\nu}$ signal acceptance

Analysis:

- Simulation based on G3, G4, Fluka
- **Main cut: 15 < $P_{\pi+}$ < 35 GeV/c**
  - for RICH operational reasons
  - better photon and muon rejection

Signal Acceptance:

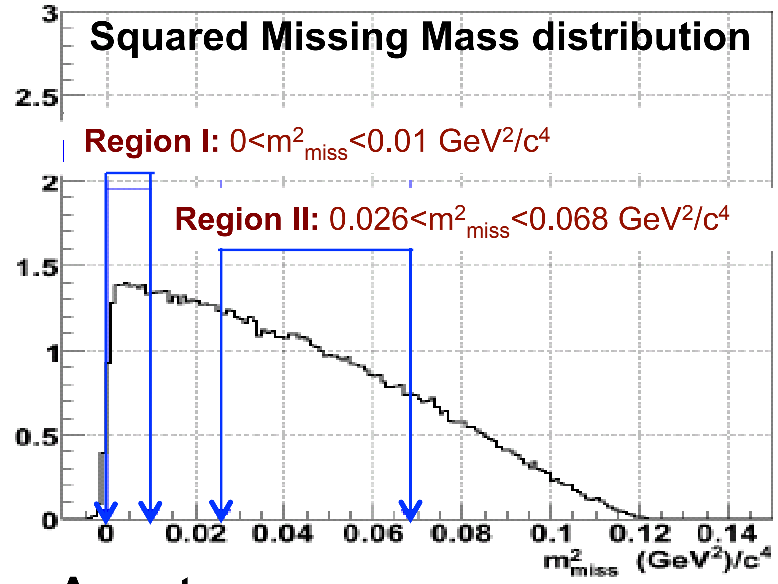
- 3.5 % in region I
- 10.9% in region II
- 50% signal loss due to **$P_{\pi+}$** cut
- expected detector inefficiencies

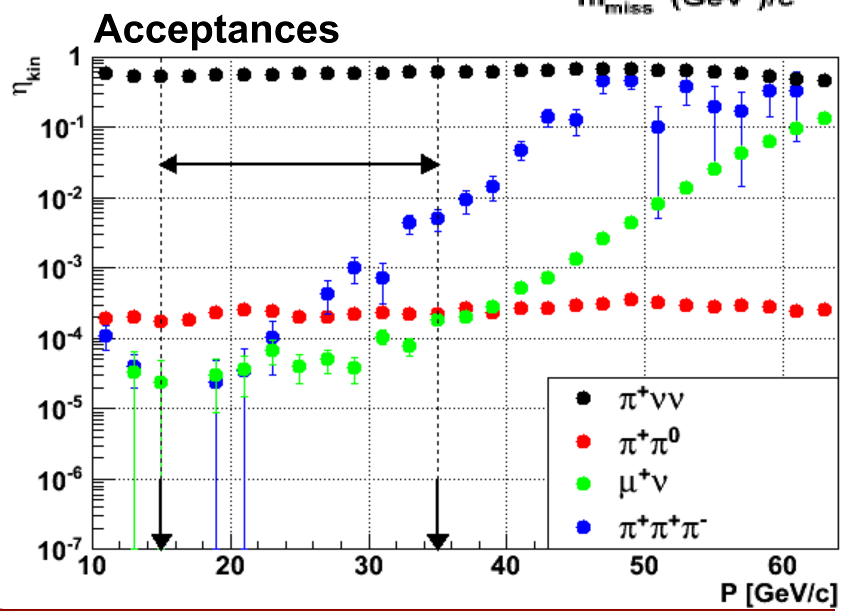
taken under consideration

Channel	M^2_{miss} cut	Overall acceptance
$\pi^+\nu\bar{\nu}$	~ 0.57	~ 0.147
$\pi^+\pi^0$	$(2.2 \pm 0.5) \times 10^{-4}$	$(4.4 \pm 1.0) \times 10^{-5}$
$\mu^+\nu_\mu$	$(0.7 \pm 0.1) \times 10^{-4}$	$(1.0 \pm 0.1) \times 10^{-5}$
$\pi^+\pi^+\pi^-$	$(1.4 \pm 0.2) \times 10^{-4}$	$(6.9 \pm 2.0) \times 10^{-7}$

➔Acceptance: ~ 14.7 % (NA62 goal: 10%)

(to be taken into account additional losses due to dead time, further inefficiencies, …)





NA62: sensitivity

Decay mode	Events / year
Signal: $K^+ \rightarrow \pi^+ \nu\nu$ ***(Flux = 4.8 ×10^{12} decays/year)***	**55 events/year**
$K^+ \rightarrow \pi^+ \pi^0$	4.3% (2.3 evts)
$K^+ \rightarrow \mu^+ \nu$	2.2% (1.2 evts)
$K^+ \rightarrow \pi^+ \pi^- e\ \nu$	<3% (1.7 evts)
Other 3-track decays	<1.5% (0.8 evts)
$K^+ \rightarrow \pi^+ \pi^0\ \gamma$	~ 2% (1.1 evts)
$K^+ \rightarrow \mu^+ \nu\ \gamma$	~ 0.7% (0.4 evts)
others	negligible
Expected background	**<13.5% (7.4 evts)**

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

- Kinematic rejection → Gigatracker (K), Straw Chambers (π)
- Particle identification
  - K identification → CEDAR (KTAG)
  - π/μ separation and μ suppression → RICH, MUV
  - charged particles detection/rejection → CHANTI, CHOD, MUV
- Photon rejection → Large Angle Veto, LKr calorimeter, Inner Ring Calorimeter, Small Angle Veto

General Theme:
maintain a good signal/background ratio while preserving as much as possible the signal acceptance

NA62: Beam & Detectors

Primary SPS beam: p = 400 GeV/c

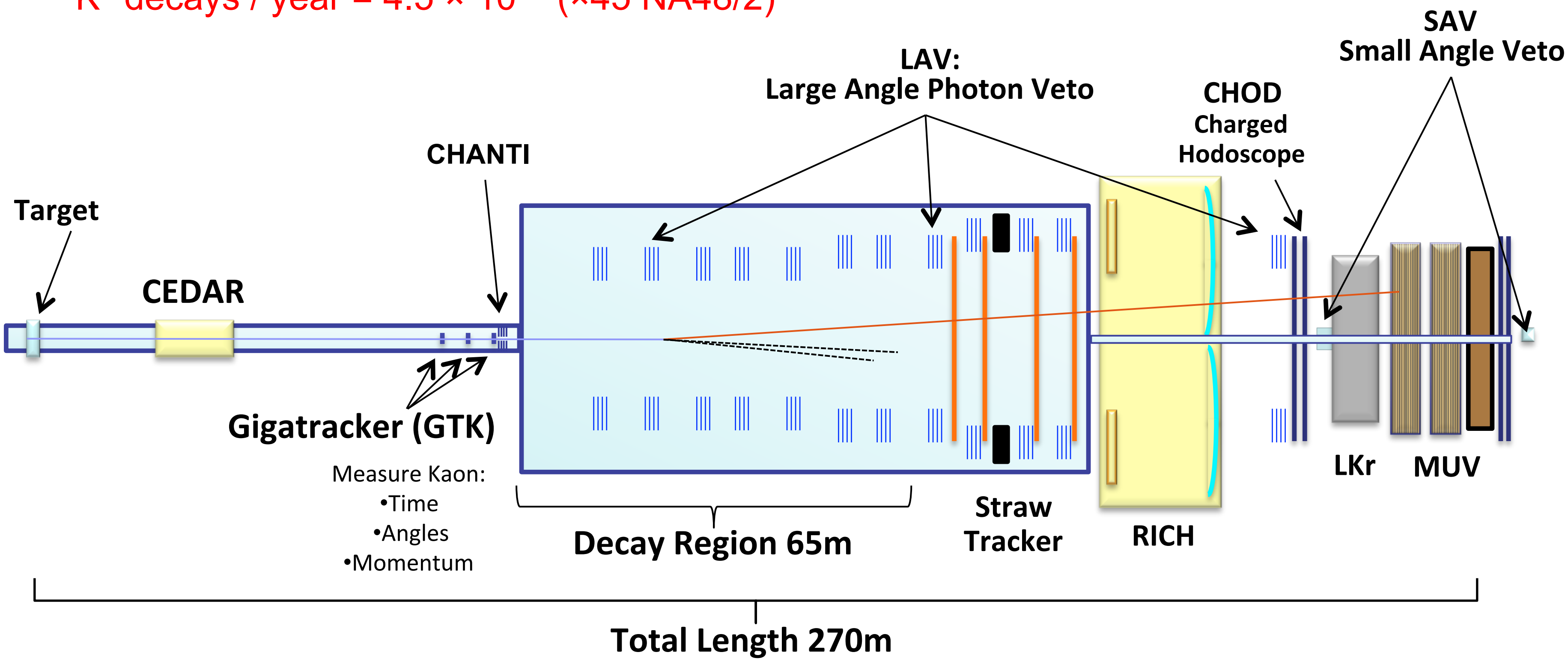
- proton/pulse 3×10^{12} (×3 NA48/2)
- duty cycle 4.8 s / 16.8 s

Secondary unseparated positive beam:

- p_K = 75 GeV/c ($\Delta p/p \sim 1.1\%$)
- π/K/p ($K^+ \sim 6\%$, positron free)
- K^+ decays / year = 4.5×10^{12} (×45 NA48/2)

Beam acceptance = 12 mstr (×25 NA48/2)
Area @ beam tracker = 16 cm^2
Integrated average rate = 750 MHz
Average rate @ detectors ≈ 10 MHz

Vacuum at 10^{-6} mbar to reduce beam-gas interaction (use existing NA48 decay tank)

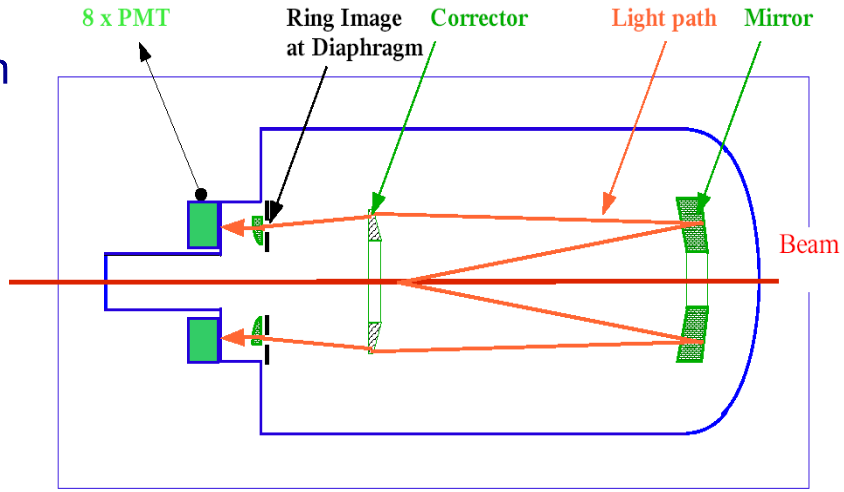


CEDAR

CEDAR: Cherenkov Differential Counter with Achromatic Ring Focus

CEDAR detectors have been designed and used at CERN since early 80's for particle identification in the SPS secondary hadron beams.

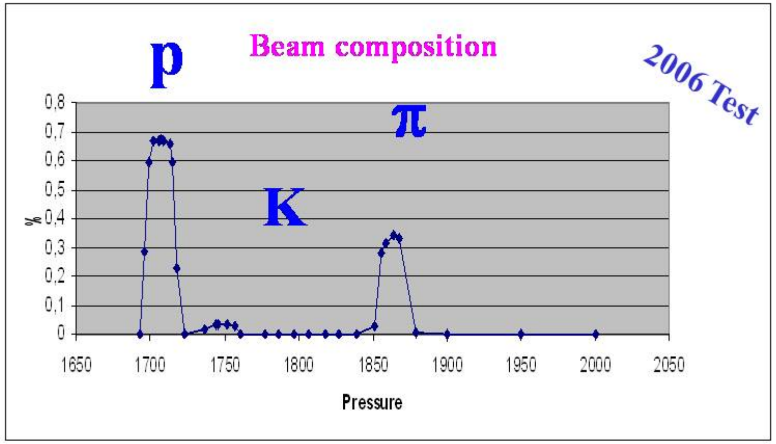
Gas pressure and diaphragm aperture are varied to select different beam particles (K, p, π)

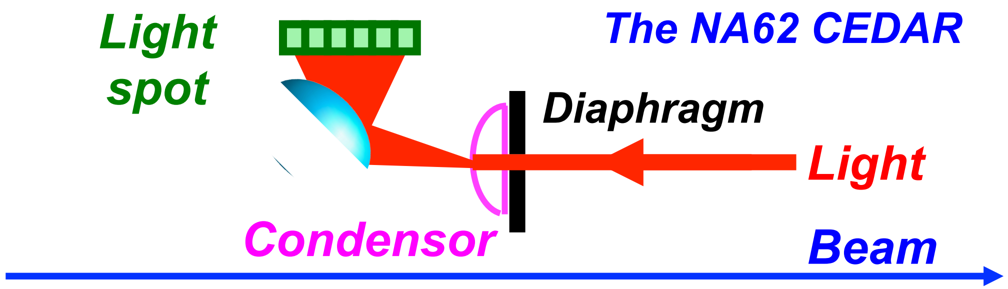


Original CEDAR (CERN 82-13)

Requirement for a CEDAR in NA62:

- positive K identification in a 800 MHz hadron beam, insensitive to π and p
- ~50 MHz K^+ rate (6% of total)
- photon rate = ~2 MHz/mm^2:
  - ➜ *~30 photons per Kaon detected on 8 spots*
  - ➜ *light to be diluted on many PMs (condensor)*



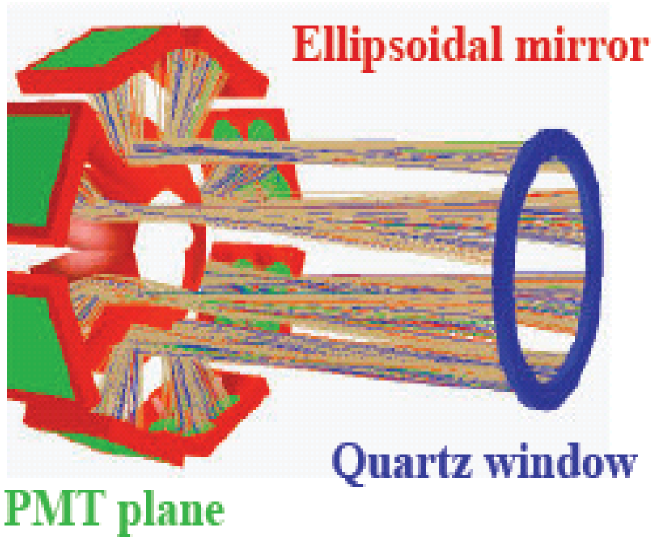


CEDAR: the Kaon Tagger (KTAG)

KTAG: a CEDAR counter filled with H_2 gas to stand 50 MHz K rate

KTAG: CEDAR adapted to the NA62 need

- ➔ H_2 instead of N_2 gas to minimize multiple scattering
- ➔ nominal pressure for Kaons: 3.85 bar
- ➔ photon rate spread on many photo-detectors (PMs): 64 PMs (Hamamatsu R7400U-03) per light spot
- ➔ new deflecting mirrors system to decrease the rate per single channel on the readout
- ➔ modified mechanics/optics
- ➔ new front-end and readout electronics



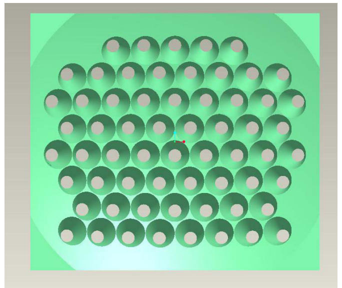
CEDAR detector commissioning for NA62 successfully completed (2011 CERN test beam)

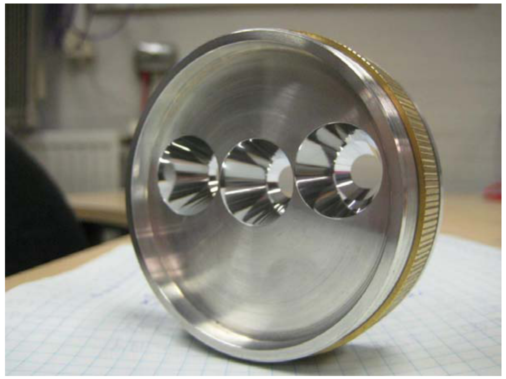
- ➔ new PMs and light guide prototype show adequate efficiency and timing performance
- ➔ different options of new front-end and read-out electronics were tested to validate the final choice

2012 Technical Run:

full enclosure available; 4 out of 8 light spots instrumented (read out by 32 out of 64 PMs)

Light spot (64 PMs)

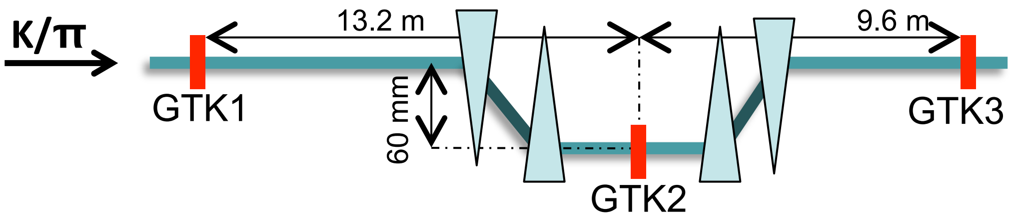


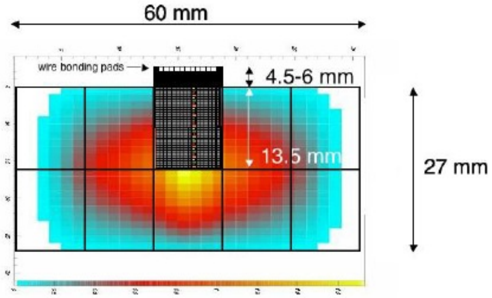


Aluminum light-guide (prototype)

Gigatracker (GTK)

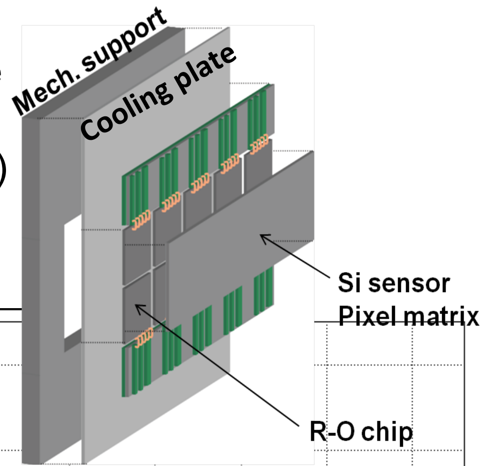
GTK: beam spectrometer to measure time, direction and momentum of all the particle tracks in a 800 MHz beam





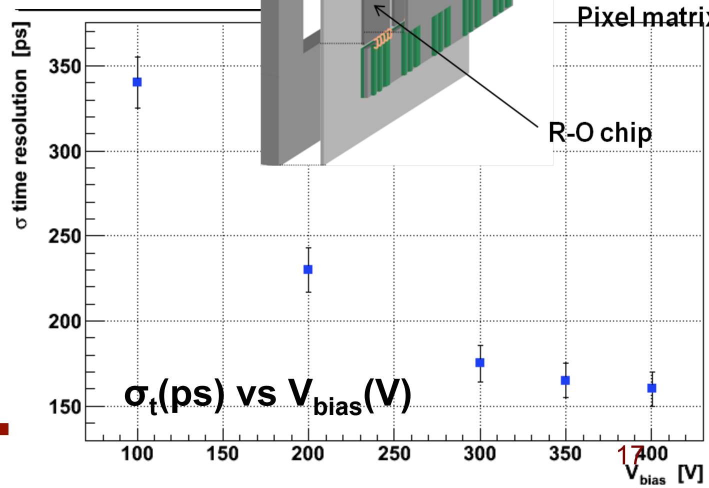
Three hydrid Si-pixel stations before the decay volume

- 200 μm thick Si sensor (60 x 27mm^2), dimensions matching the beam shape
- 18000 pixel/station, 300 x 300 μm^2 pixel size
- thin detector: 200 μm sensor + ~100 μm readout chip (<0.5%X/X_0 per station)
- 10 readout chips bump-bonded to the sensor (0.13 μm technology)
- high radiation levels, comparable to inner layers of LHC trackers in 10 years: expected fluence (100 days/year) ~ $2x10^{14}$ (1 MeV n_{eq}/cm^2)
- Micro-channel technology chosen as cooling system to control the leakage current: 150 mm thick cooling plate (0.013% X_0), two-inlet and two-outlet pipe and appropriate geometry



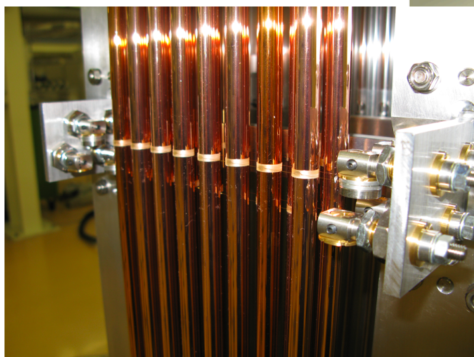
Detector performances (prototype tests):

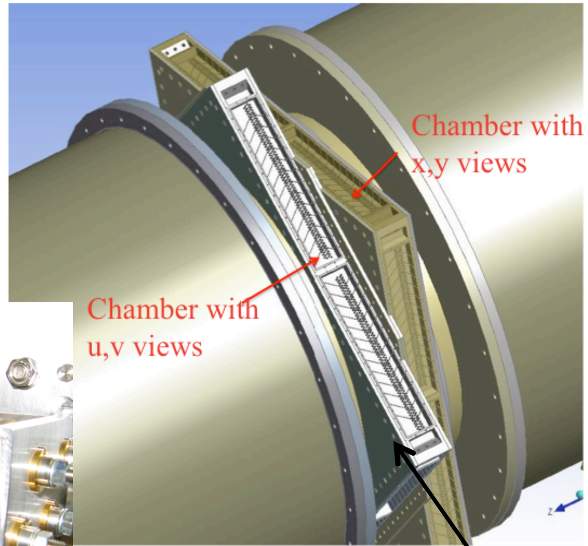
→ direction: $\sigma_{RMS}(\theta_K)$ ~16 μrad
→ momentum: $\sigma_{RMS}(p_K)$ /p ~0.2%
→ track time: $\sigma_{RMS}(t)$ ~150 ps on single tracks



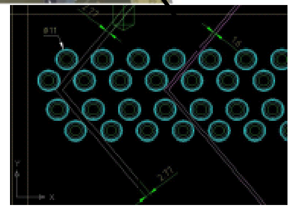
Straw Spectrometer

The Straw Tracker: large acceptance spectrometer to reconstructs coordinates and momentum of charged particles in the decay region with: $\Delta p/p<0.5\%$ and $\sigma_{xy}<120\mu m$

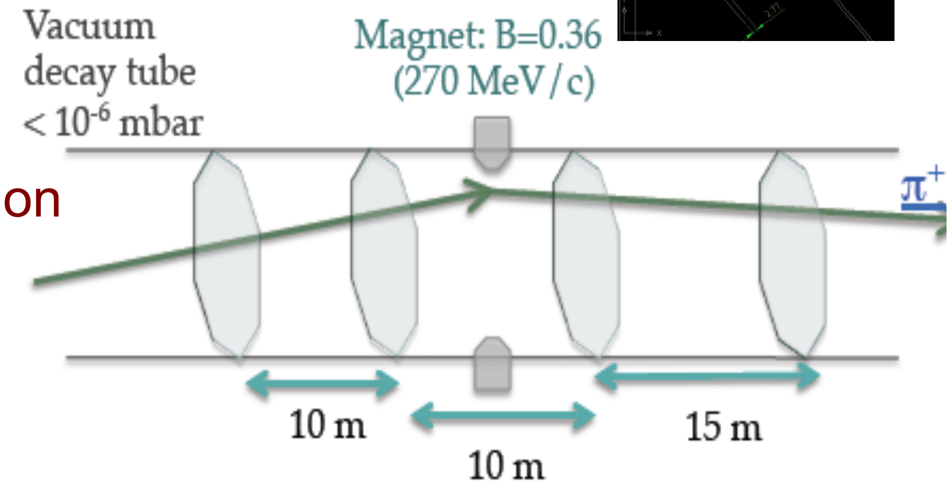




Straw layout in one view



- 4 stations of straw tubes:
  - → 36 µm Cu/Au-plated mylar foils
  - → lenght 2.1 m, diameter 9.6 mm
  - → ~1800 tubes per station
- 4 views (XYUV) per station
- 4 staggered layers of straws per view
- mechanically independent straws
- central “hole” (6 cm radius)
- minimum material: ~0.5% X_0 per station
  - → working in vacuum (10^{-6} mbar)
  - → no windows or He gas
- gas mixture: Ar(70%) + CO_2 (30%)



Straw Spectrometer

Full length prototype built and tested in vacuum in 2007 and 2010 at SPS@CERN

Momentum and angular resolutions

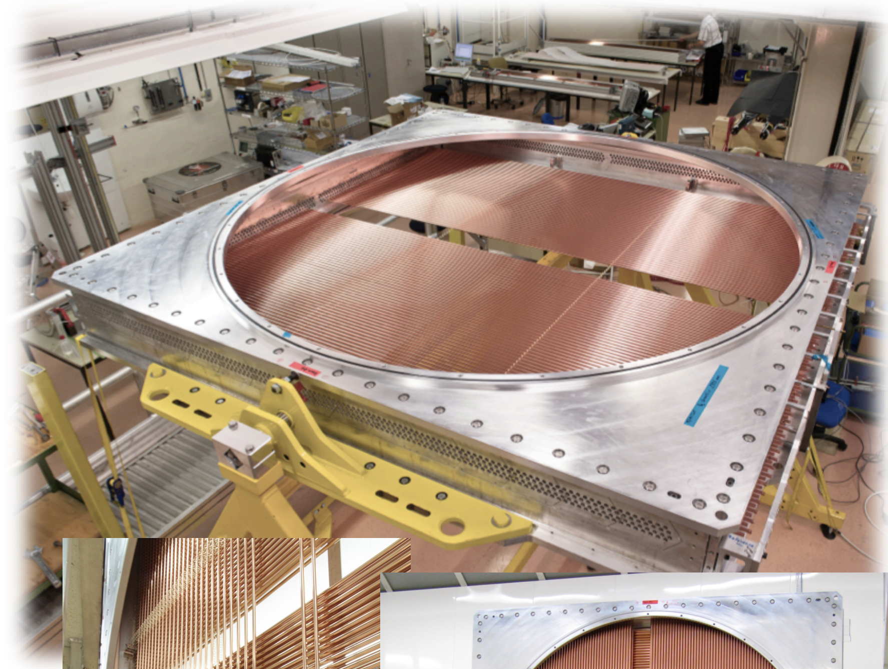
- → $\sigma(P_p)/P_p \sim 0.3\% \oplus 0.007\% * P_p$ (GeV/c)
- → $\sigma(dX/dZ)/(dX/dZ) \sim 45\text{-}15\ \mu rad$
- → $\sigma < 130\ \mu m$ per view

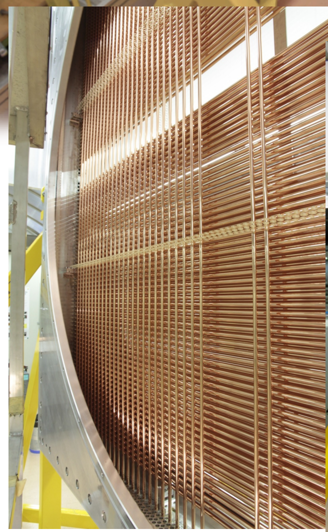
Efficiency > 99% on single hit (straw center at low rate)

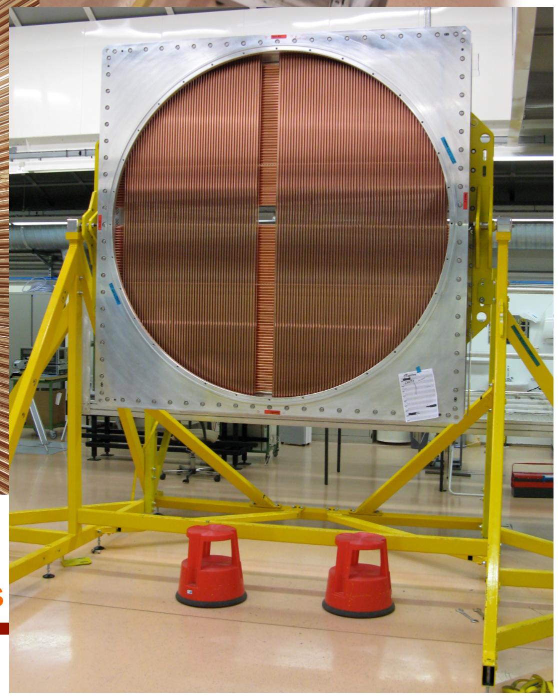
High rate: 0.5 MHz maximum with < 3% lost efficiency

Vertex extrapolation: $\sigma_{CDA} \sim 1$ mm

Kinematic rejection power (MC): $\sim 10^4$ ($K^{\pm}_{2\pi}$), $\sim 10^5$ ($K^{\pm}_{2\mu}$)





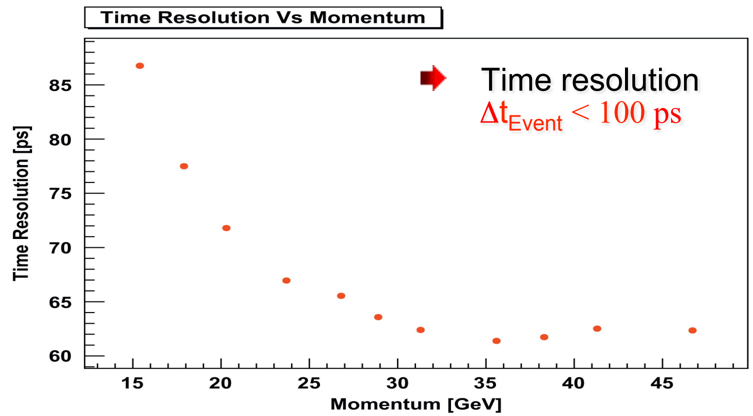


Module 1, 896 straw tubes

RICH

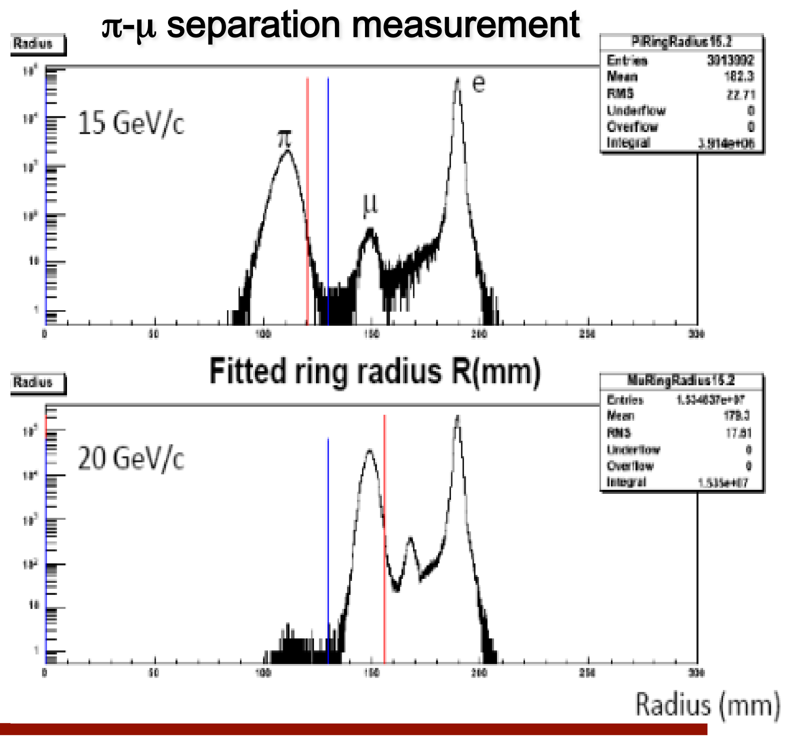
REQUIREMENTS:

- Separate π-μ in 15 < p < 35 GeV/c with μ suppression factor ≤ 10^{-2}
- Measure the π crossing time with a resolution < 100 ps
- Provide a L0 trigger for charged tracks



The NA62 RICH:

- 17 m long, 3 m diameter vessel
- Neon gas radiator at atmosferic pressure
  - → *(n-1) = 62.8 10^{-6} at λ=300 nm (small dispersion)*
  - → *low atomic number: small X_0*
  - → *$(\theta_{Ch})max$ = 11.2 mrad*
  - → *$p_{threshold}$ = 12 GeV/c for π*
- Cherenkov light collected in 2 spots each of ~1000 Hamamatsu R7400 U03 PM
- Mosaic of mirrors with 17 m focal lenght
- Design validated in full length prototype tests at CERN



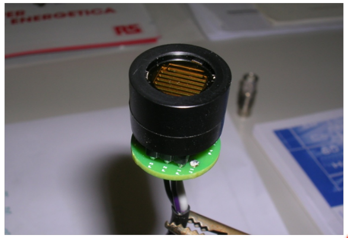
TEST BEAM RESULTS (2007, 2009)

[NIM A 593, 2008; NIM A621, 2010]

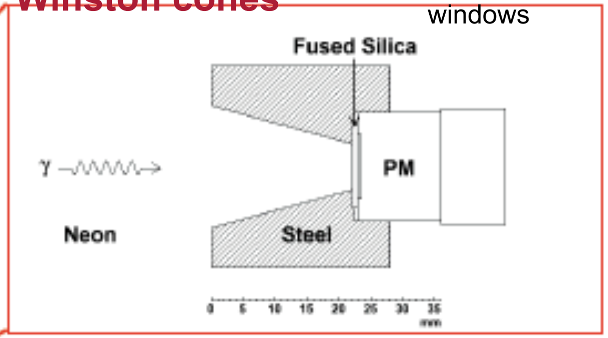
- Average time resolution: ~70 ps
- Integrated π-μ mis-identification probability: ~5x10^{-3}
- θ_{Ch} resolution ~60 mrad

RICH Final Design

Hamamatsu R7400 U03 PMs

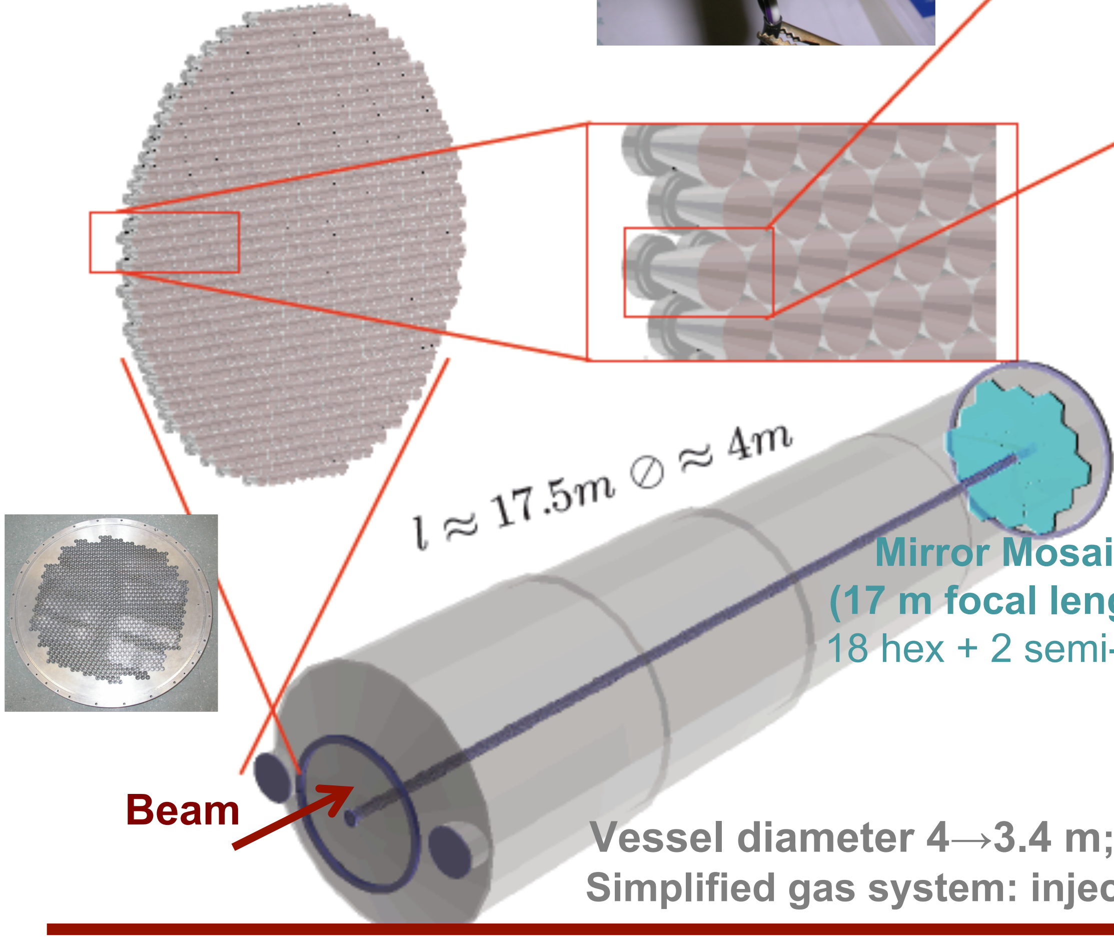


Winston cones

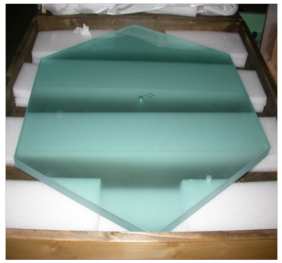


PM lodging disk

$2\times \approx 1000PM$



- Ne @ 1 atm ($\approx 5\% X_0$)
- Vacuum proof vessel
- 20 mirror segments ($\approx 20\% X_0$)
- $15 < \frac{p_{tr}}{GeV/c} < 35$
- Contamination of $\mu < 1\%$
- Level 0 Trigger
- $\sigma_t < 100ps$



Vessel diameter 4→3.4 m; volume ~ 200 m^3

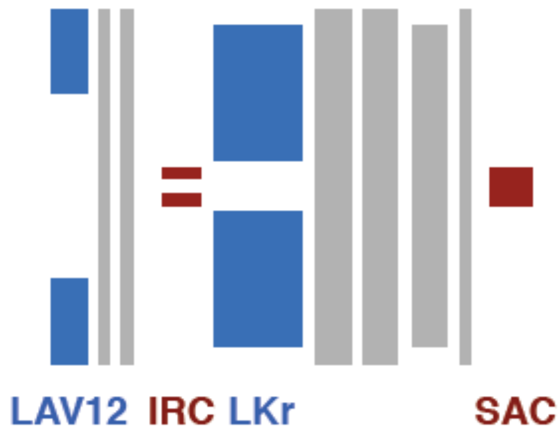
Simplified gas system: inject pure Ne into an evacuated vessel

The NA62 Photon Veto

BR($K^+ \rightarrow \pi^+\pi^0$) = 21% ➔ Kinematic rejection: 10^{-4}

Photon Veto Detectors inefficiency requirements:

Detector	θ(mrad)	Maximum 1-ε	
LAV	8.5 - 50	10^{-4} at 200 MeV	Large angle, new system
LKr	1 – 8.5	10^{-3} at 1 GeV 10^{-5} at 10 GeV	Medium angle, re-use NA48 LKr calorimeter
SAV (SAC+IRC)	< 1	10^{-5}	Small angle, new system of compact calorimeters



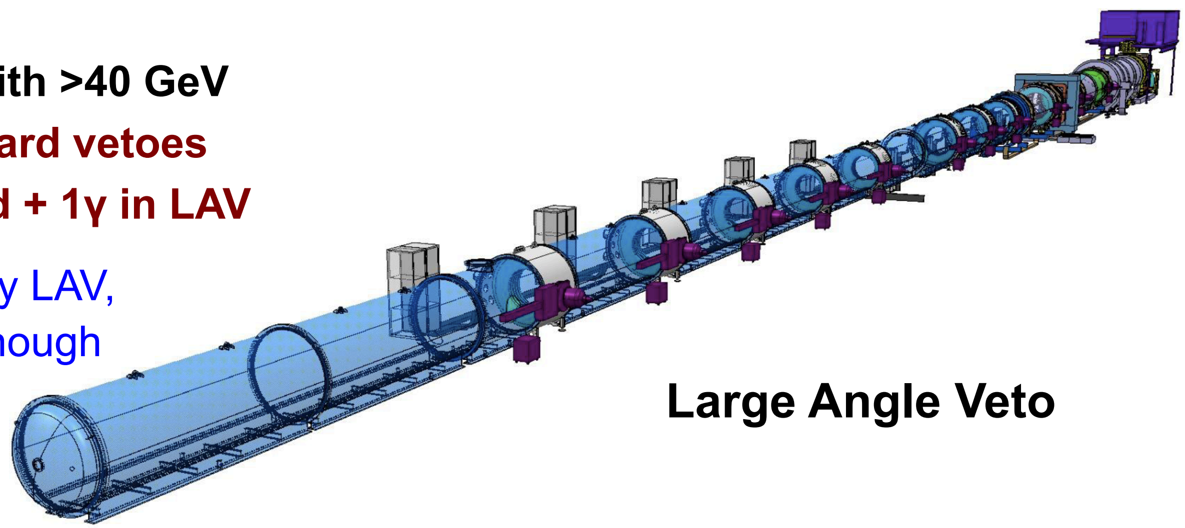
Forward Vetoes

Cut $p_{\pi+}$< 35 GeV gives $\pi^0 \rightarrow \gamma\gamma$ with >40 GeV

→ **85% of events have 2γ in forward vetoes**

→ **15% of events have 1γ forward + 1γ in LAV**

→ In case of undetected photons by LAV, the other γ from π^0 decay has enough energy to be detected efficiently by LKr & SAC (**LAV simulation**)

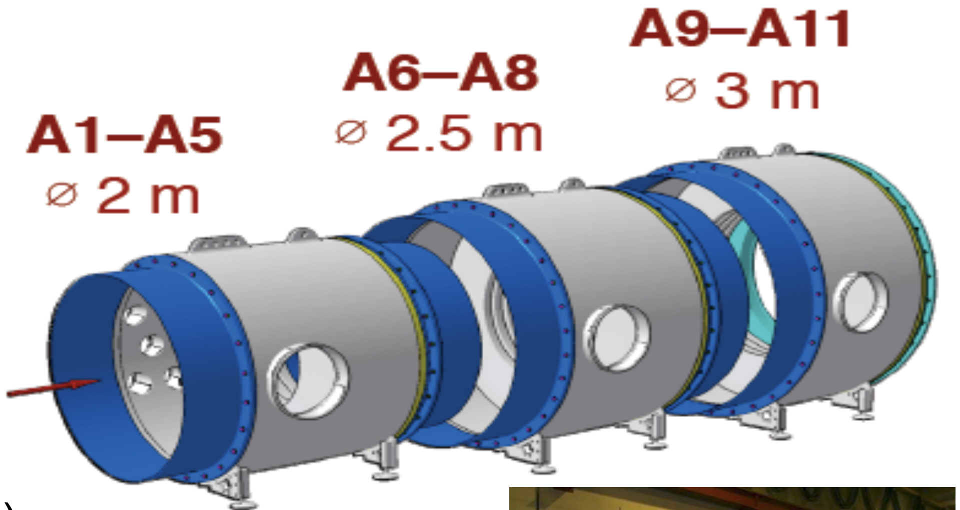


Large Angle Veto

Large Angle Veto (LAV)

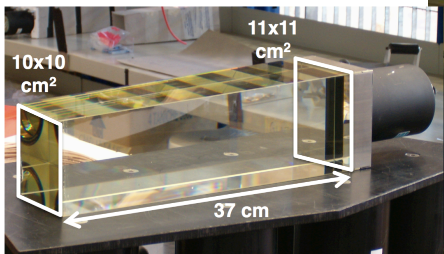
LAV system requirements:

- Efficiency 10^{-4} for E_γ>200 MeV
- Operation in vacuum (10^{-6} mbar)
- Dynamic range 10 MeV – 10 GeV
- Energy resolution ~ 10% at 1 GeV
- Time resolution ~ 1 ns



Technology:

lead-glass (Schott SF57) modules
(OPAL: 3600 crystals, different geometries)
read with R2238 76-mm PMs
(12 stages, gain: $5x10^5$@1250V)



LAV System Design

- hermetic coverage in the 8.5-50 mrad range
- 12 ring stations of increasing diameter along the decay volume
  ➔ suppress γ between 105 m to 170 m after the target
- spaced by 6 m in the upstream region and by 12 m downstream
- stations A1-A11 operated in vacuum, station A12 operated in air (design not final yet)
- 4 or 5 staggered rings of lead-glass crystals per station, 32 to 48 crystals/layer, total depth of 29 to 37 X_0 (>2500 crystals used in total)
- Incident particles hit at least 3 rings (21 X_0), most particles traverse 4 rings (27 X_0)

Large Angle Veto (LAV)

Test beam results (CERN 2010):

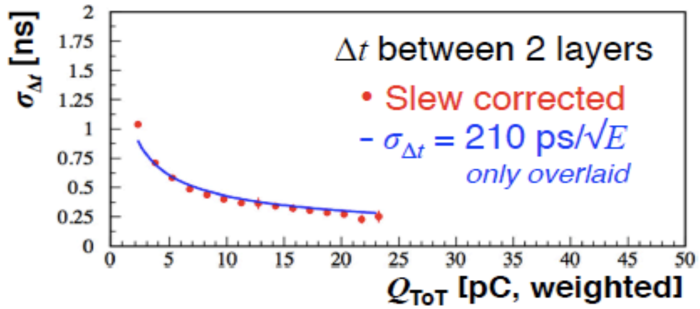
Energy resolution:

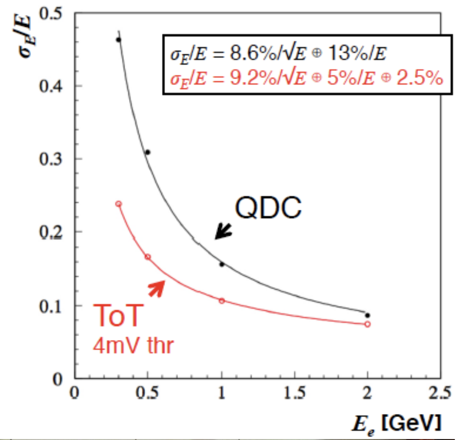
$\sigma_E/E = 0.092/\sqrt{E} \oplus 0.05/E \oplus 0.025$ [GeV]

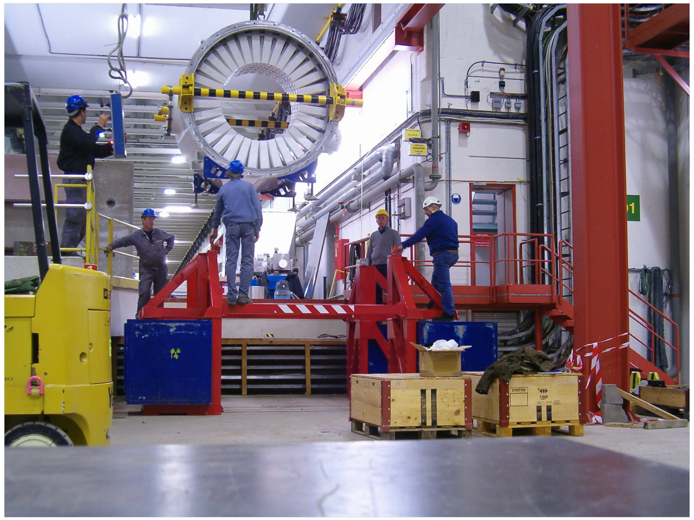
Time resolution (slewing corrected):

$\sigma_t = 300$ ps/$\sqrt{E(\mathrm{GeV})}$

Inefficiency within expectation (LAV simulation)







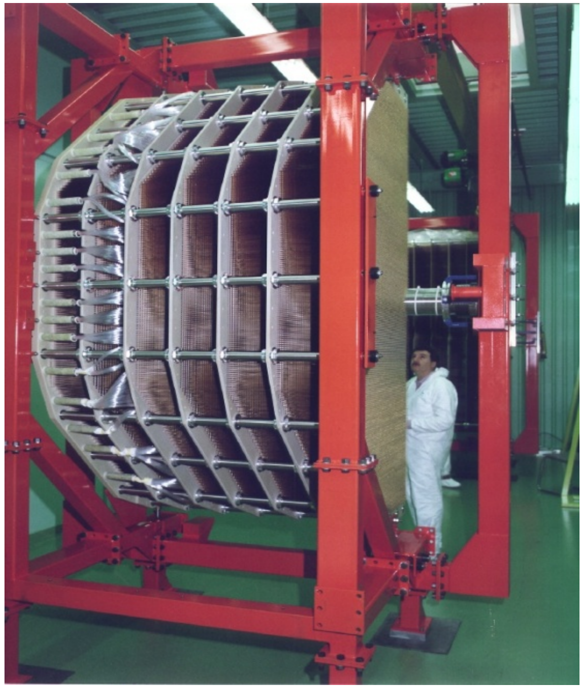
Status: first 8 stations completed and installed along the beam line, available for the 2012 technical run

LKr: medium angle veto

Medium angle veto (1-8 mrad) → inefficiency $<10^{-5}$ for E_γ > 10 GeV

Liquid Krypton NA48 electromagnetic calorimeter

- Quasi homogeneous ionization chamber
- More than 13000 channels, 2x2 cm^2 granularity
- Depth 1.25 m, 27 X_0
- Excellent energy resolution:
  $\Delta E/E = 3.2\%/\sqrt{E} \oplus 9\%/E \oplus 0.42\%$ [GeV]
- Very good time resolution: 100 ps
- New readout electronics: 14 bits 40 MHz FADC with large data buffering, 14 bit resolution:
  - 5 prototypes (CAEN) available in 2012



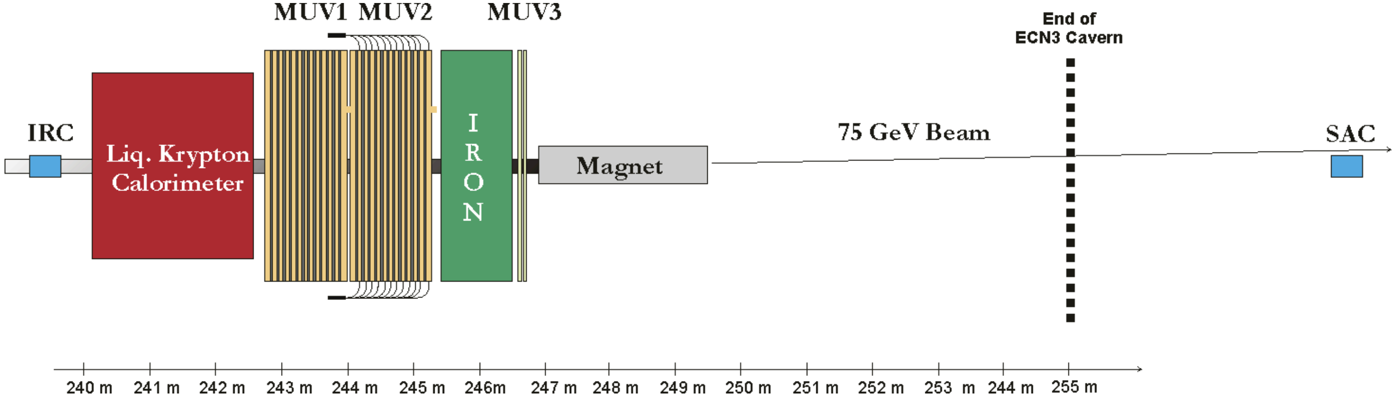
Performance of LKr as photon veto

→ measured using NA48 data @75 GeV
→ $K^+ \rightarrow \pi^+\pi^0$ selected using kinematics only
→ π^+ and lower energy γ are used to predict the position of the other γ

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

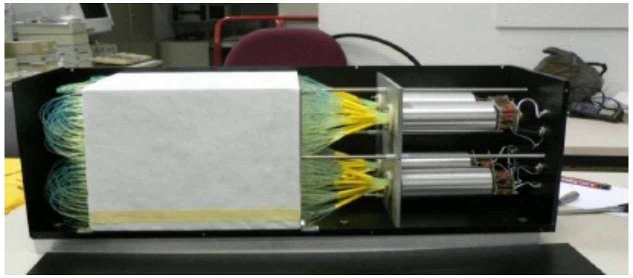
Small Angle Veto

Small Angle Veto (<1 mrad): two small calorimeters made of layers of lead and scintillators with wavelength shifting fibers ("shashlyk")



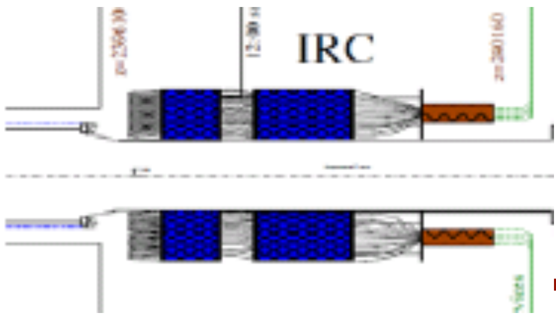
SAC: Small Angle Calorimeter

- close to the beam dump, at the very end of the experiment, in the prolongation of the beam pipe region, to detect γ down to 0 degrees.
- a magnet will deflect charged particles before it



IRC: Inner Ring Calorimeter

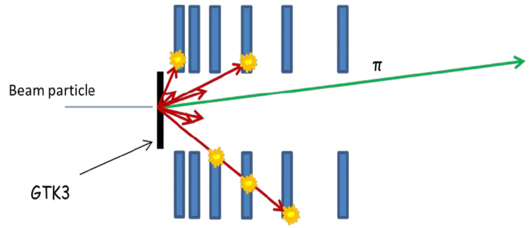
- located around the beam pipe, in front of LKr, cover the angular region close to the inner LKr radius (radial coverage: 7 cm < R < 14 cm)



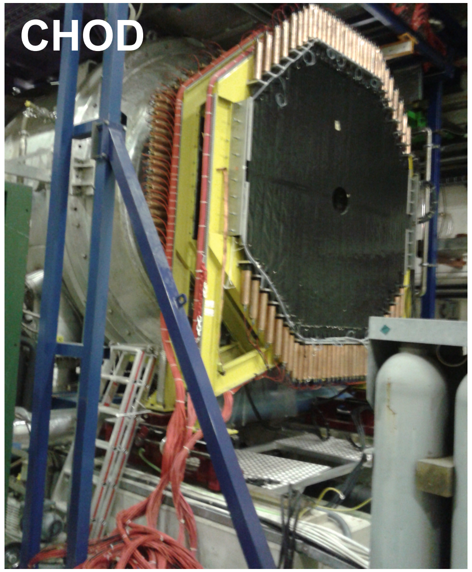
CHANTI and CHOD

CHANTI and CHOD: tracks detection ➔ charged particles veto

CHANTI: identify inelastic interactions in the collimator and the GTK by detecting particles at higher angles w.r.t. the beam; identify beam halo μ in the region closest to the beam



- ➔ *guard counters placed right immediately after GTK3*
- ➔ *triangular scintillator bars/layer read out by SiPM*
- ➔ *6 stations, 2 scintillator layers per station:*
- ➔ *first station completed, second station test started*



CHOD: provide a fast L0 trigger signal for charged particle final states and veto multiple charged particle events:

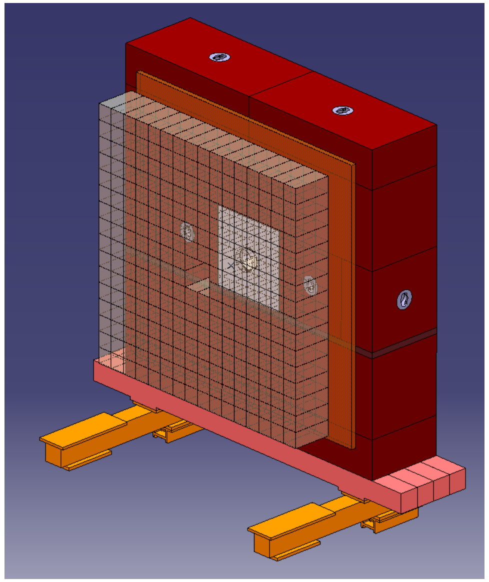
- ➔ *stand a rate of about 11 MHz*
- ➔ *provide fast timing capability also at the online level: accuracy < 1 ns*
  - *suppress accidental events*
  - *complement RICH informations in identifying charged tracks (L0)*
- ➔ *effective vetoing of photon conversions or photonuclear interactions producing low energy hadrons in the detector material*
  - *complement the LKr photon detection capability at low energy (also at L0)*
- ➔ *acceptance adequate to complement MUV and RICH detectors in identifying μ at L0 trigger*
- ➔ *re-use NA48 CHOD in 2012 with the new NA62 TDAQ electronics*
- ➔ *prototype of new detector based on scintillator pads and SiPM*

MUV: the Muon Veto

MUV: 3 muon veto stations to reach a factor of 10^6 in muon rejection (combined with the RICH)

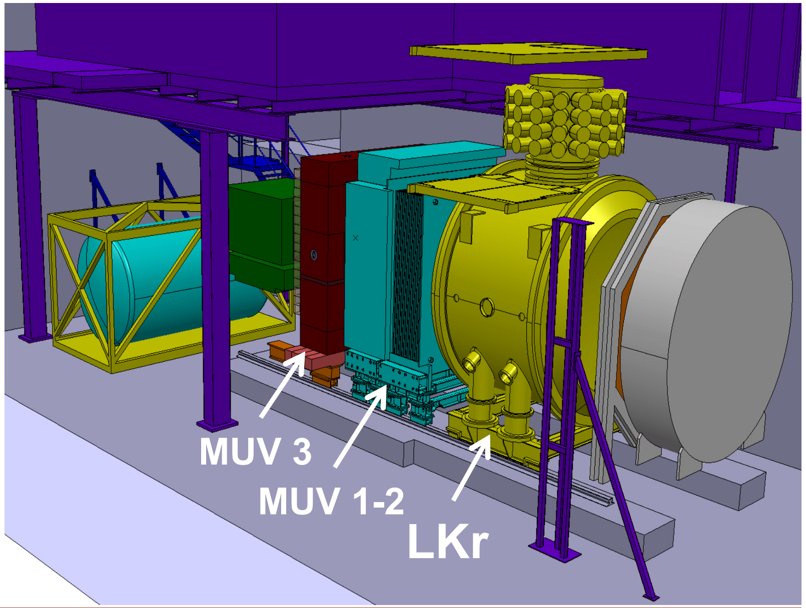
MUV1-2 :

- NA48 Hadron calorimeter partially reused
- 24 (MUV1) and 22 (MUV2) iron/scintillator layers
- alternating horizontal and vertical scintillator strips coupled to PMs



MUV3:

- fast muon identification plane for trigger (L0)
- after 80 cm of iron, 5 cm thick single layer of scintillator tiles readout with 2 PMs
- < 1 ns time resolution (test beam result)
- crucial to cope with 10 MHz integrated rate

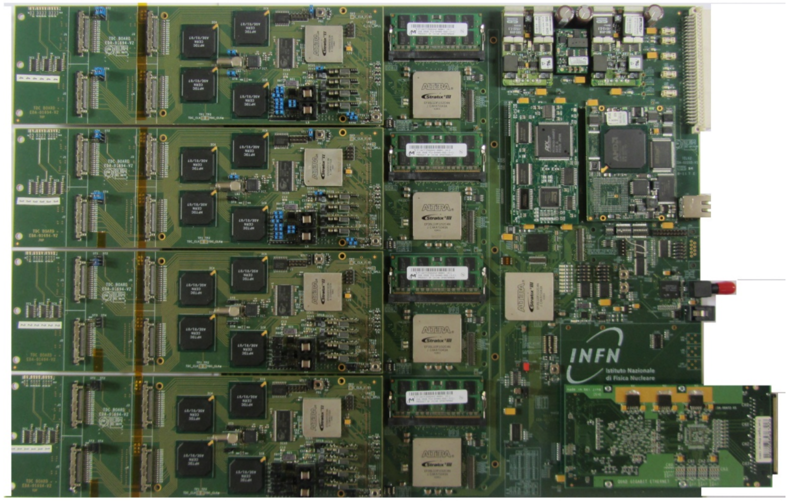


Present status

- MUV1 construction completed in 2012
- MUV2 reinstallation and commissioning done for participation in technical runs
- MUV3 assembled and tested with cosmics, installation and commissioning planned for participation in technical runs

NA62 readout: TEL62

- The TEL62 is a main board to digitize (using daughter boards) buffer data and to build trigger primitives. It's an evolution of the LHCb TELL1 board.
- A board (TDCB) equipped with 128 ch. of TDC (HPTDC, 100 ps LSB) has been developed.
- One TEL62 mother board houses 4 TDCB (512 ch.).
- The trigger primitives are built in parallel with the readout on the same TEL62 board (implemented in firmware using the board's FPGA's)
- Technical run 2012: 13 TEL62 boards will be available, with special crates



Detector	TEL62 (2012)
CEDAR	1
CHANTI	1
LAV	3
STRAW	1
CHOD	1
LKR/L0	3
MUV2	1
MUV3	1
SAC/IRC	1

Trigger and Data Acquisition

Requirements:

- Reduce 10 MHz rate/detector to 10 kHz
- High data bandwidth
- No zero suppression (for candidate events)
- Very good online time resolution (< 1 ns) to avoid random veto (< 1%)

Solution:

- Integrated system Trigger + DAQ (based on TEL62)
- Completely digital data stream from FE to TDAQ
- Fully monitored system
- Uniformity for most subdetectors
- Custom hardware minimized
- L0 hardware, L1/L2 software
- Flexibility (for additional physics program)

L0: Hardware level

➔ synchronous; decision based on primitives produced in the readout boards of the detectors partecipating to trigger

L1: Software level

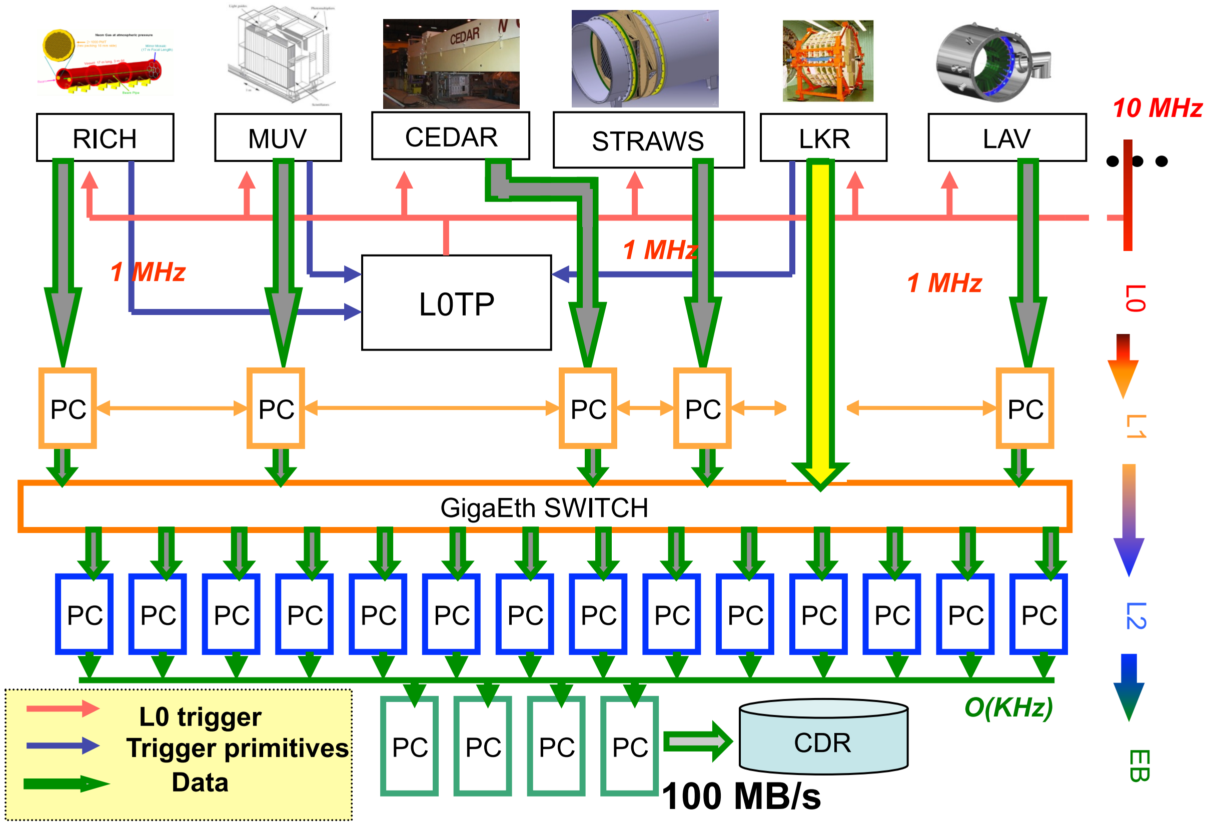
➔ asynchronous (ethernet); "Single detector" PCs

L2: Software level

➔ asynchronous; the informations coming from different detectors are merged together

On-line sub-nanosecond time resolution of Veto detectors and RICH is crucial for high efficiency (>95%)

Trigger/Daq General Overview

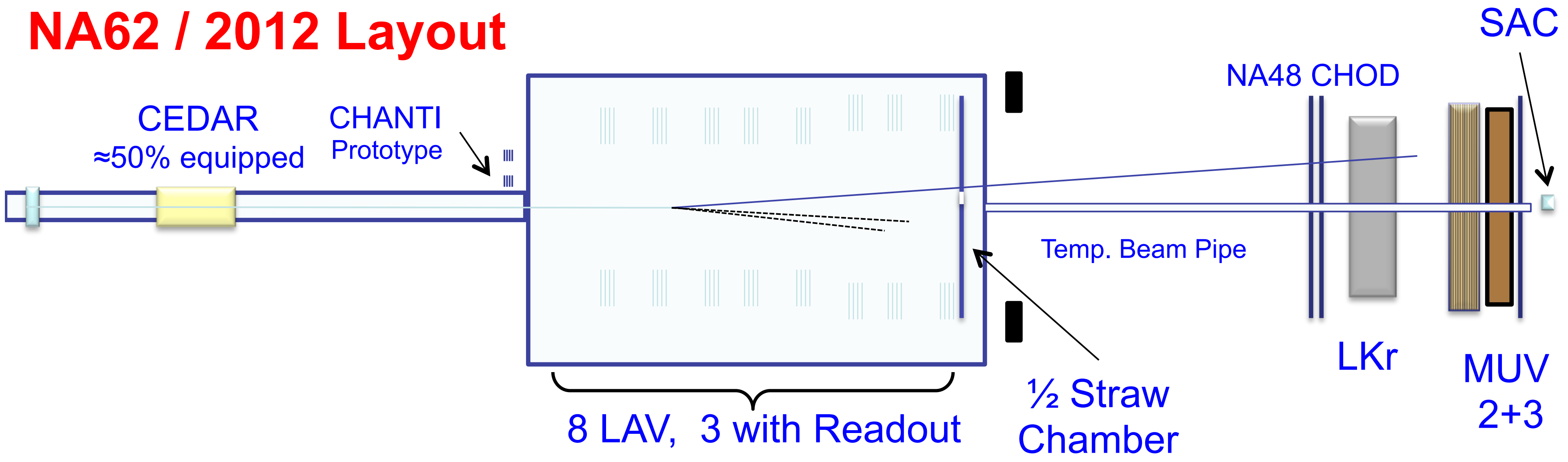


Detector	Rate (MHz)
CEDAR	50
GTK	800
LAV (total)	9.5
STRAW (each)	8
RICH	8.6
LKR	10.5
MUV	9.2
SAC	1.5

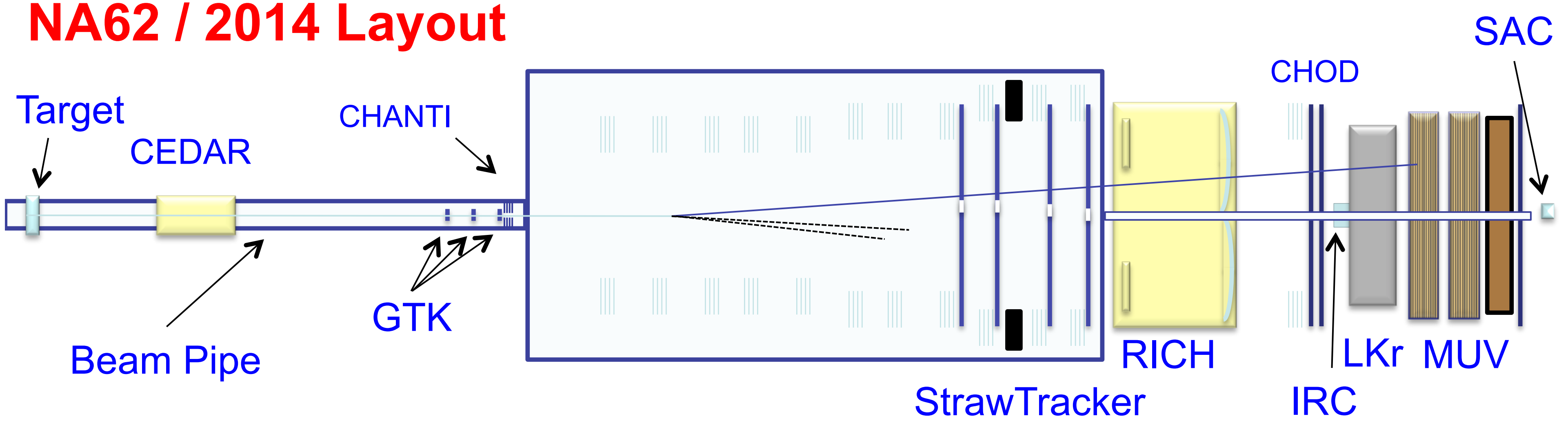
		Input rate (max)	Output rate (max)	latency
L0	hw, syncronous	~10 MHz	~ 1 MHz	1 ms
L1	sw, asyncronous	~ 1 MHz	~ 100 kHz	O(s)
L2	sw, asyncronous	~ 100 kHz	O(kHz)	undefined

Commissioning run in 2012

NA62 / 2012 Layout



NA62 / 2014 Layout



Final $R_K = K_{e2}/K_{\mu 2}$ measurement

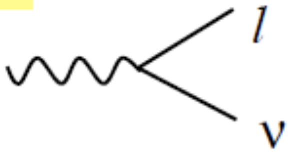
Lepton Universality

In Standard Model (SM) e-μ-τ have identical EW gauge interactions:

- ⇨ identical coupling constants for different lepton flavours
- ⇨ very accurate theoretical predictions
- ⇨ only difference in mass and coupling to the Higgs boson

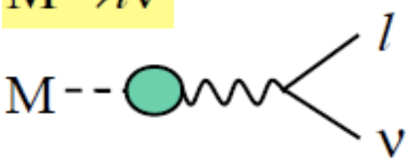
…unless New Physics (NP) violates Universality

W



$$R^{W}_{e/\mu} = \frac{\Gamma(W\to e\nu)}{\Gamma(W\to \mu\nu)} \propto \frac{g_e^2}{g_\mu^2}$$

$M \to l\nu$



$$R^{\pi}_{e/\mu} = \frac{\Gamma(\pi\to e\nu)}{\Gamma(\pi\to \mu\nu)} \propto \frac{g_e^2}{g_\mu^2}\frac{m_e^2}{m_\mu^2}$$

Measurements of Ratios of Weak Coupling Constants

MODE	g_e/g_μ	
π→eν/π→μν	0.9985±0.0016	PRL 68 (1992), PR D49 (1994), PRL 70 (1993)
K → eν/K→μν	1.0018±0.0026	➔ THIS TALK
τ→eνν/τ→μνν	0.9998±0.0020	EPJ C57 (2008)
νe-νμ	1.10±0.05	PL B179 (1986)
W decays	1.001±0.011	EPJ C57 (2008)
K → πeν/K→πμν	0.998±0.002	NP Proc. Suppl. 181-182 (2008)

The ratio R_K

Very accurate Standard Model prediction of R_k (as well as R_π): theoretical uncertainties on individual decay rates due to hadronic contributions cancel in the ratio

$$R_K = \frac{\Gamma(K^\pm \to e^\pm \nu_e)}{\Gamma(K^\pm \to \mu^\pm \nu_\mu)} = \frac{m_e^2}{m_\mu^2}\left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 (1 + \delta R_{QED}) = (2.477 \pm 0.001) \times 10^{-5}$$

Helicity suppression

Radiative corrections

ChPT, $O(m^2/p^4)$

[V. Cirigliano and I Rosell, PRL 99, 231801 (2007), JHEP 0710, 005 (2007)]

➡ Sub-permille (0.04%) accuracy of the SM prediction of R_K

Helicity suppression of R_K might enhance the sensitivity to non-SM effects to a level experimentally accessible

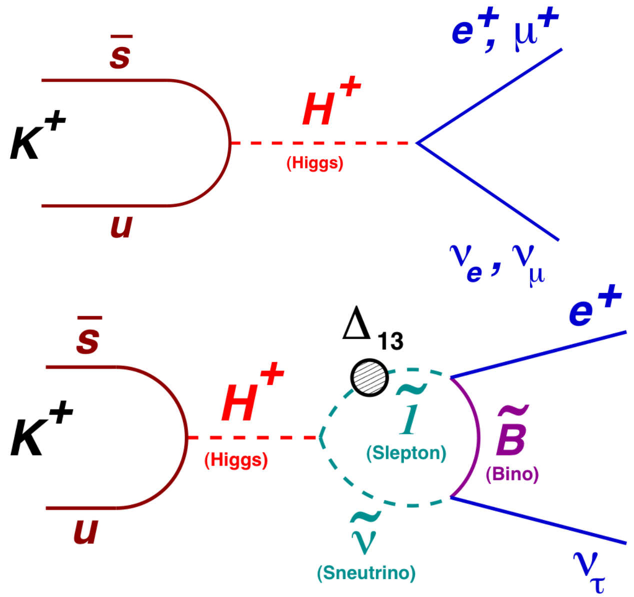
A precise measurement of R_K probes μ–e Universality providing a powerful test of SM

R_K beyond the SM: SUSY

SUSY (MSSM framework) produces sizeable effects to R_K**(SM)**

➔ R-parity is the source of Lepton Universality violating effects

➔ 2 Higgs Doublets Model (A. Masiero, P. Paradisi, R. Petronzio, PRD74 (2006) 011701, JHEP 0811 (2008) 042)



2HDM – tree level: K_{l2} proceeds via exchange of sizeable charged Higgs $H^\pm$ instead of $W^\pm$

2HDM – one-loop level: $H^\pm$ mediated LFV terms with emission of ν_τ are the dominant contribution to ΔR_K

$$R_K^{LFV} \approx R_K^{SM}\left[1+\left(\frac{m_K^4}{m_{H^\pm}^4}\right)\left(\frac{m_\tau^2}{m_e^2}\right)\left|\Delta_{13}\right|^2 \tan^6\beta\right]$$

Δ_{13} ➔ mixing parameter of superpartners of right-handed leptons

➔ LFV term connected to Helicity suppression in K_{e2}

$\tan\beta$ ➔ ratio of the two Higgs vacuum expectation values

At large $\tan\beta$ values with a massive $H^\pm$, LFV contributions dominate and produce sizable O(1%) effects to R_K

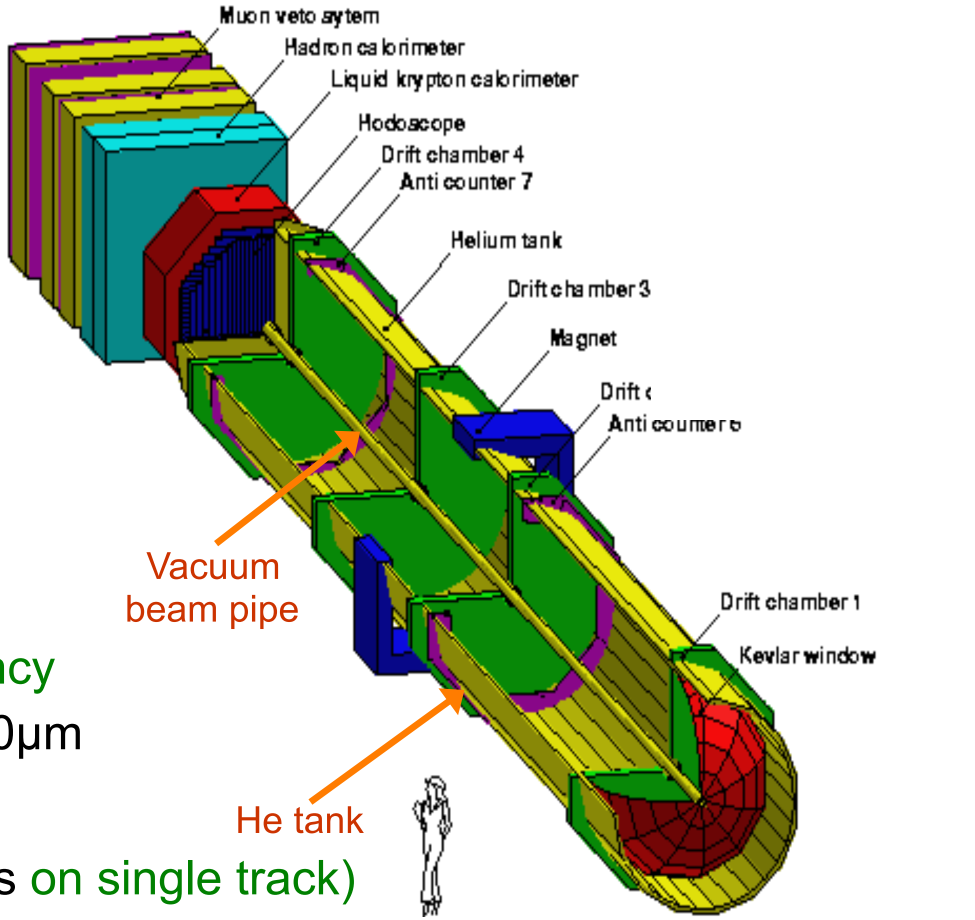
(Ex.: $\Delta_{31}=5\times10^{-4}$, $\tan\beta=40$ and $M_H=500$ GeV/c^2 → $R_K^{LFV} = R_K^{SM}$ (1+0.013)

The NA62 Data Taking for R_K

Running periods:

• 2007: 4 months (~400K SPS spills)
~300TB of raw data, ~90TB recorded;

• 2008 : 2 weeks
special data sets collected to optimize and reduce systematic uncertainties.



Detector: the NA48 detector

(C. Lazzeroni talk)

Magnetic spectrometer
(4 DCHs, 4 view each): redundancy ⇒ efficiency
$\sigma(p)/p = 0.48\% + 0.009\%\ p$ [GeV/c]; $\sigma_{x,y} = 90\mu m$

Hodoscope
fast trigger and good time resolution (σ_t~200ps on single track)

Liquid Krypton calorimeter (LKr)
high granularity, quasi-homogeneous ⇒ γ veto
$\sigma(E)/E = 3.2\%/\sqrt{E} + 9\%/E + 0.42\%$ [GeV]; $\sigma_{x,y} = (0.42/\sqrt{E} + 0.6)$ mm

Decay volume is upstream

Analysis strategy

NA62

Count reconstructed $K_{e2}/K_{\mu 2}$ candidates collected concurrently

- ➔ Fluxes cancel in the ratio: analysis does not rely on absolute K flux measurement
- ➔ Several systematic effects cancel at first order in the ratio
  (e.g. reconstruction/trigger efficiencies, time-dependent effects, beam simulation)

$$R_K = \frac{1}{D} \cdot \frac{N(K_{e2}) - N_B(K_{e2})}{N(K_{\mu 2}) - N_B(K_{\mu 2})} \cdot \frac{A(K_{\mu 2}) \times f_\mu \times \varepsilon(K_{\mu 2})}{A(K_{e2}) \times f_e \times \varepsilon(K_{e2})} \cdot \frac{1}{f_{LKr}}$$

$N(K_{e2})$, $N(K_{\mu 2})$:	numbers of selected K_{l2} candidates
$N_B(K_{e2})$, $N_B(K_{\mu 2})$:	numbers of background events;
$A(K_{e2})$, $A(K_{\mu 2})$:	geometric acceptances (MC, no ID);
f_e, f_μ:	particle ID efficiency (measured, no MC);
$\varepsilon(K_{e2})/\varepsilon(K_{\mu 2})$:	trigger efficiency;
f_{LKr}:	global LKr readout efficiency (only K_{e2});
D:	downscaling factor of the $K_{\mu 2}$ trigger (D=150).

⇒ $N_B(K_{e2})$: the **main source of systematic errors** comes from the K_{e2} background subtraction

- ➔ count of events done independently in 10 lepton momentum bins
  (due to strong dependence of backgrounds and acceptance on lepton momentum)
- ➔ MC simulations (Geant3) used for the geometric acceptance correction
- ➔ PID, trigger, readout efficiencies are measured directly from data

The K_{e2} and $K_{\mu2}$ event selections

Large common part (similar topologies):

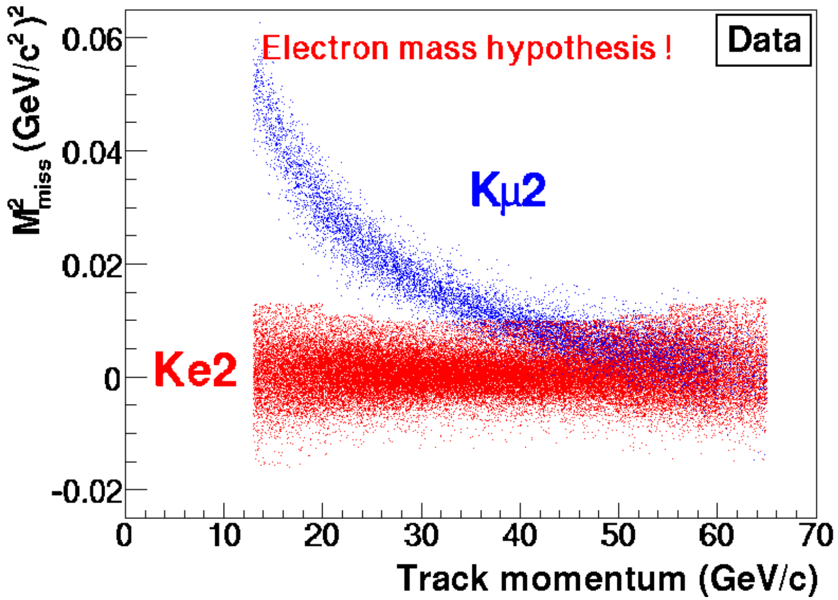
- one reconstructed track (lepton candidate);
- track momentum: 13GeV/c < p < 65GeV/c;
- geometrical acceptance cuts;
- K decay vertex: minimum distance between the lepton track & the nominal kaon axis;
- veto extra LKr energy deposition clusters.

Kinematic identification: M_{miss}^2 vs p_l

Missing mass $M_{miss}^2 = (p_K - p_l)^2$

p_K: average value measured with $K_{3\pi}$ decays

→ $K_{e2}/K_{\mu2}$ samples separation at p_{track}<25 GeV/c



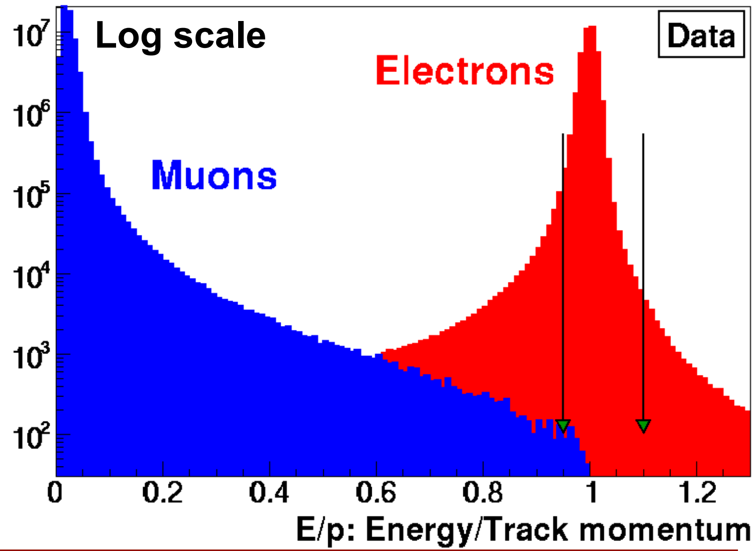
Particle ID: E/p

E/p = LKr energy/track momentum

(0.90 to 0.95) < E/p < 1.10 for **electrons**

E/p < 0.85 for **muons**

→ Powerful $\mu^\pm$ suppression in $e^\pm$ sample (~10^6)



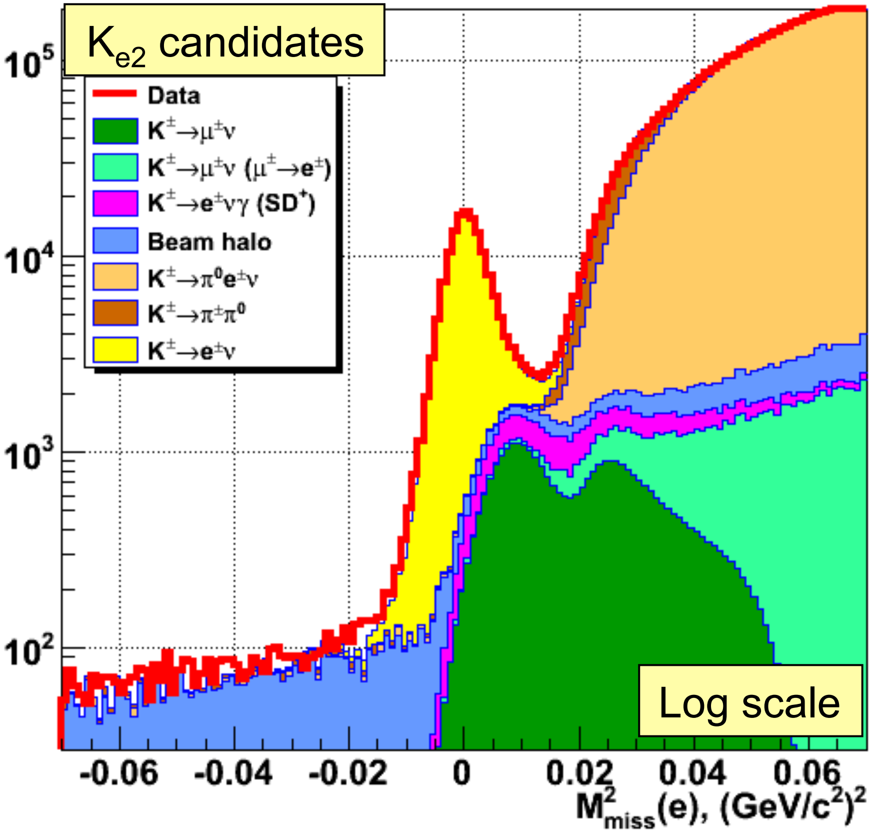
Background to the K_{e2} sample

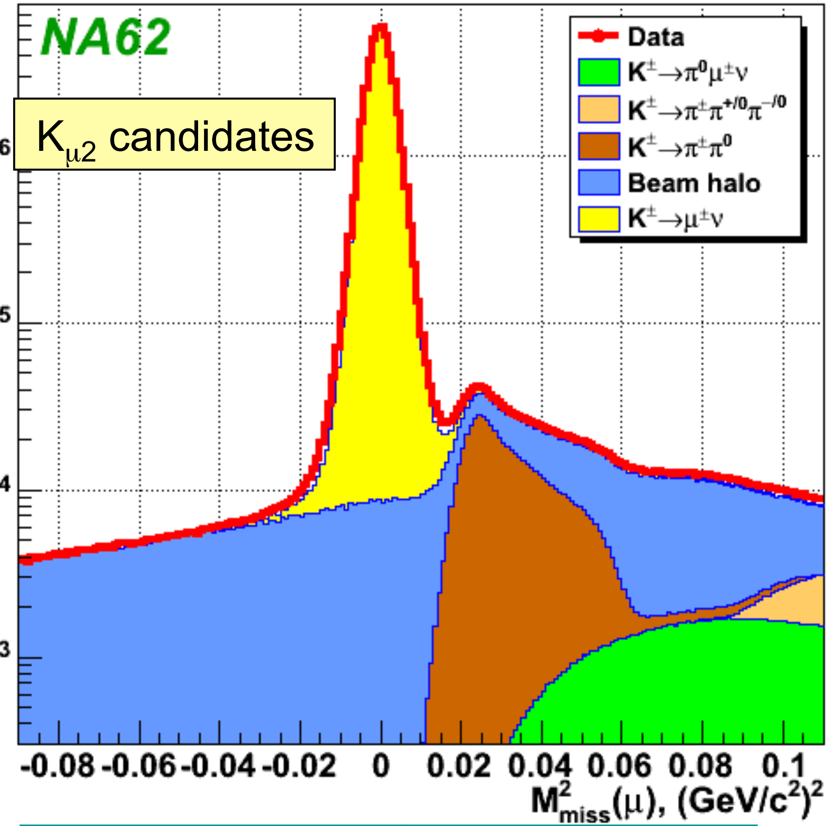
- $K^+ \to \mu^+\nu$ with a μ^+ mis-identified as a e^+
  - *μ bremsstrahlung* ← **MAIN CONTRIBUTION**
  - *$\mu \to e$ decay in flight*
- $K^+ \to e^+\nu\gamma$, SD+ component
- Beam halo muons
- $K^+ \to \pi^0 e^+\nu$ with a non-identified π^0
- $K^+ \to \pi^+\pi^0$ with a π^+ mis-identified as e^+ or followed by a Dalitz decay $\pi^0 \to ee\gamma$

Lower contributions: B/(S+B) < per-mille

- After the events selection:
  - **146K K_{e2}** candidates
  - **43M $K_{\mu2}$** candidates (beam halo muons: only background)

The final K_{e2} and $K_{\mu2}$ data samples





145.958 $K^\pm \to e^\pm \nu$ candidates
10.95% background
Electron ID efficiency: (99.28±0.05)%

42,817 x 10^6 $K^\pm \to \mu^\pm \nu$ candidates
0.50% background

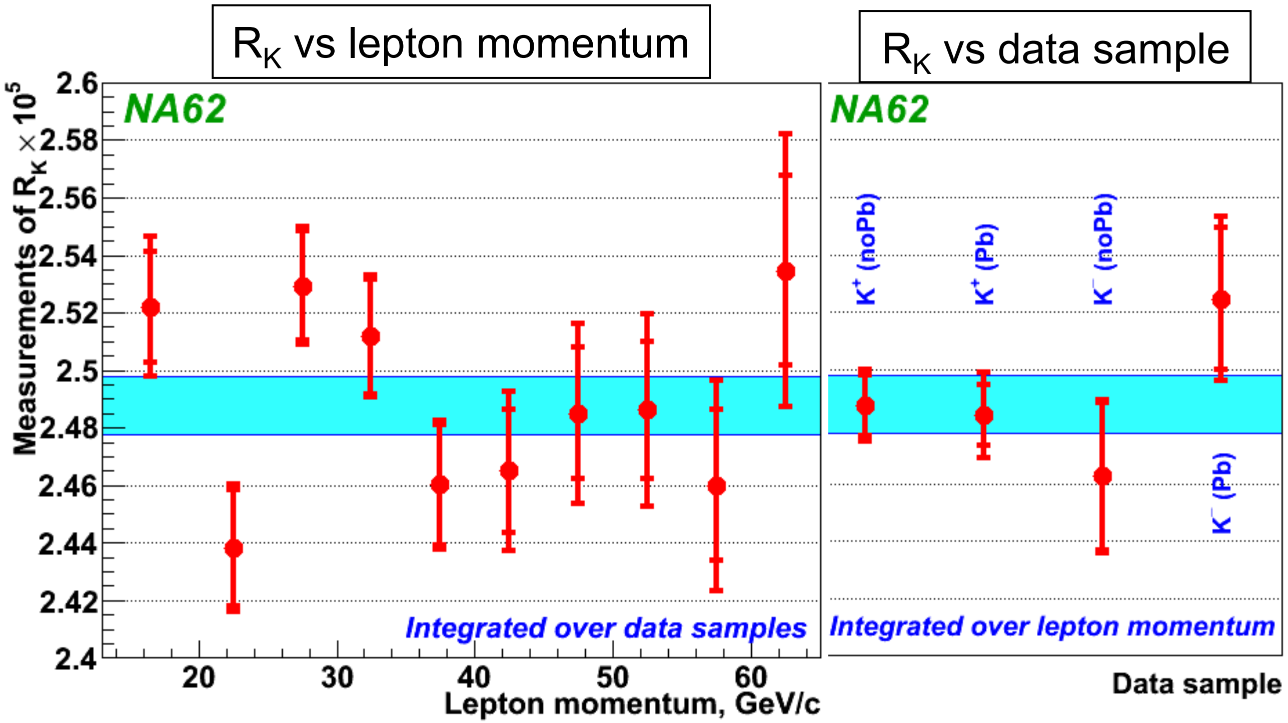
Background source	B/(S+B)
$K_{\mu2}$	(5.64±0.20)%
$K_{\mu2}$ ($\mu \to e$)	(0.26±0.03)%
$K_{e2\gamma}$ (SD+)	(2.60±0.11)%
$K_{e3(D)}$	(0.18±0.09)%
$K_{2\pi(D)}$	(0.12±0.06)%
Wrong sign K	(0.04±0.02)%
Muon halo	(2.11±0.09)%
Total	(10.95±0.27)%

The NA62 final result (full data set)

$$R_K = (2.488 \pm 0.007_{stat} \pm 0.007_{syst}) \times 10^{-5}$$

$$R_K = (2.488 \pm 0.010) \times 10^{-5}$$

Fit over 40 measurements (4 data samples × 10 momentum bins) including correlations: $\chi^2/ndf=47/39$



Uncertainty source	$\delta R_K \times 10^5$
Statistical	0.007
$K_{\mu 2}$ background	0.004
$K^\pm \to e^\pm \nu \gamma$ (SD^+)	0.002
$K^\pm \to \pi^0 e^\pm \nu$, $K^\pm \to \pi^\pm \pi^0$	0.003
Beam halo background	0.002
Thickness of spectrom.	0.003
Acceptance correction	0.002
DCH alignment	0.001
Electron identification	0.001
1TRK trigger efficiency	0.001
LKr readout efficiency	0.001
Total uncertainty	0.010

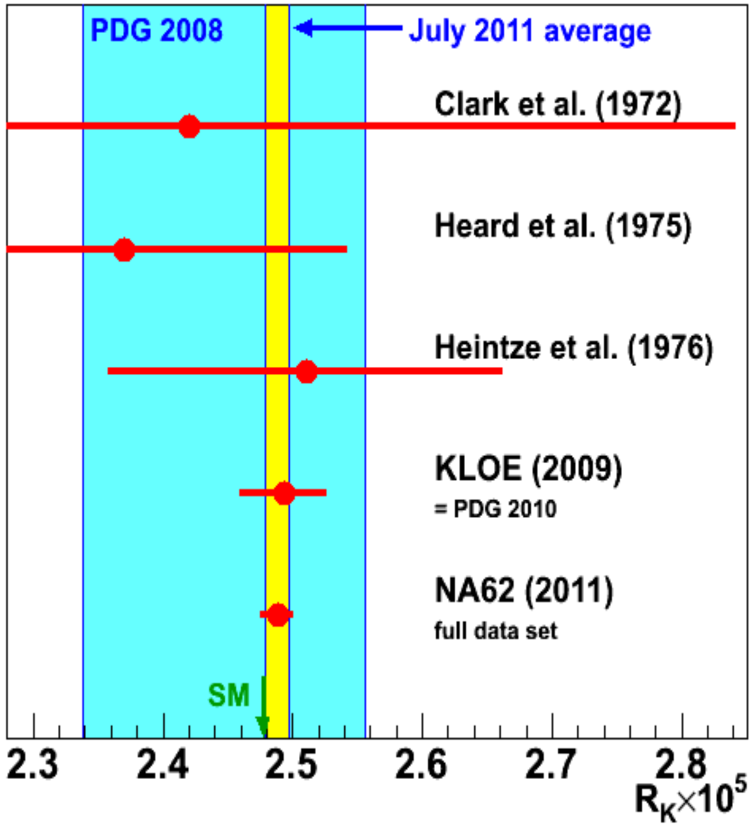
R_K World Average

PDG'08 (1970s measurements): $R_K=(2.45\pm0.11)\times10^{-5}$ $(\delta R_K/R_K=4.5\%)$

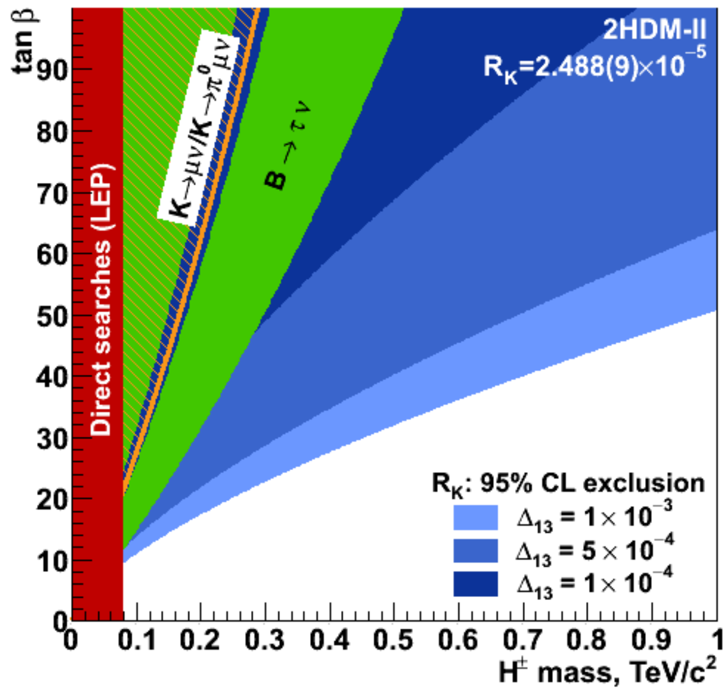
KLOE (LNF), 2009 (13.8K K_{e2}, 15% bkgd): $R_K=(2.493 \pm 0.031)\times10^{-5}$ $(\delta R_K/R_K=1.3\%)$

NA62 (CERN), 2011 (≈60K K_{e2}, ≈9% bkgd): $R_K=(2.487 \pm 0.013)\times10^{-5}$ $(\delta R_K/R_K=0.7\%)$

July 2011 World Average: $R_K=(2.488\pm0.009)\times10^{-5}$ $(\delta R_K/R_K=0.4\%)$



Constraints to 2 Higgs Doublets Model

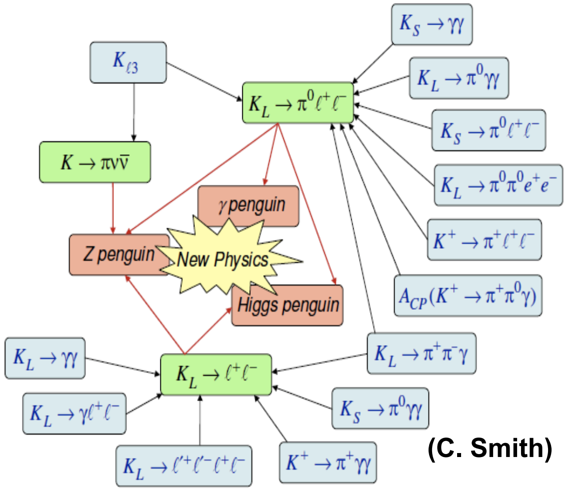


➔ for non-tiny values of the LFV slepton mixing Δ_{13}, the sensitivity to $H^{\pm}$ in R_K is better than in $B\rightarrow\tau\nu$

Summary

A challenging experimental program is going on in NA62 at CERN

- **$K^+ \to \pi^+\nu\bar{\nu}$ decays:** main purpose of NA62, golden quality precision physics complementary to the high-energy approach for NP searches
  - ➜ collect O(100) events in two years to provide a 10% precision on BR
  - ➜ key points: high intensity beams, excellent resolutions, hermetic coverage, particle Identification, redundancy of information
  - ➜ schedule: physics run in 2014-15
    - *Construction in progress*
    - *Technical runs in summer/falls 2012*
    - *Ready to take data after CERN accelerators shutdown*



(C. Smith)

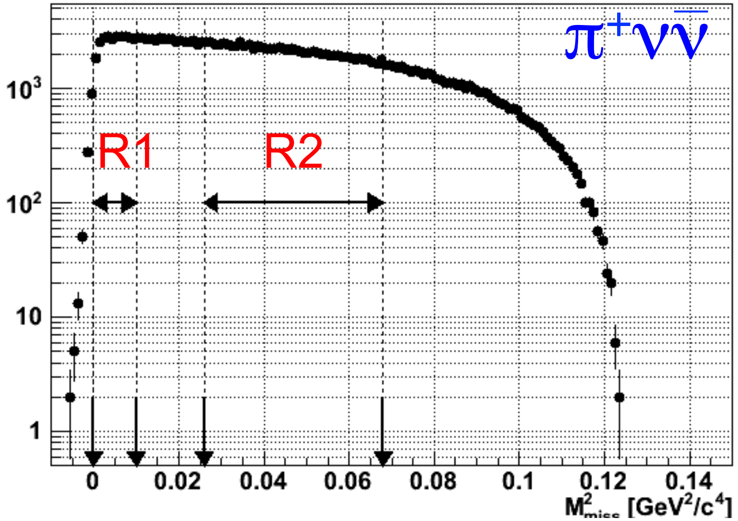
- **R_K ratio:** a record precision of 0.4% has been achieved
  - ➜ still one order of magnitude bigger that SM prediction
  - ➜ further improvement expected with physics run data

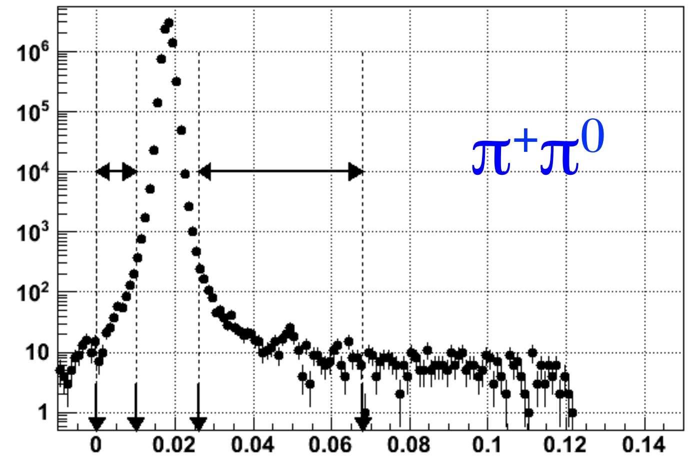
The high performance of NA62 detector is a building blocks for a further challenging physics program, in addition to the main goal (as in NA48):

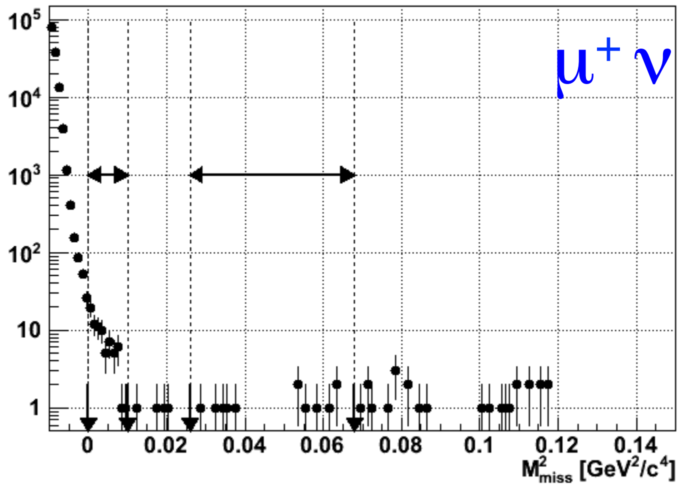
➜ **a rich physics program is expected in the near future** spare

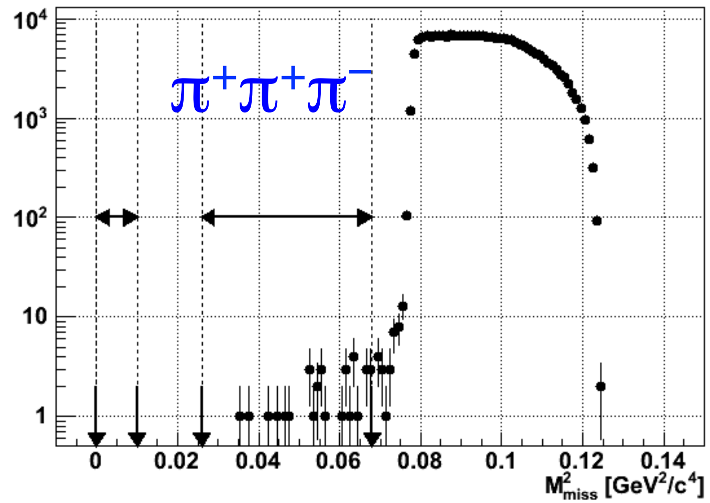
Kinematic Selection: cuts on M^2_{miss}

M^2_{miss} resolution: non-gaussian tails



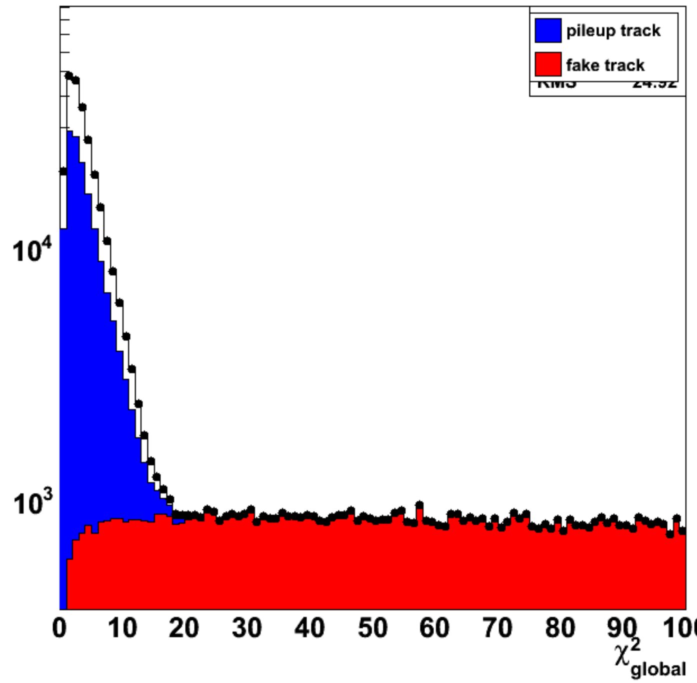






Beam Pileup and GTK reconstruction

- Pileup simulation: Rate=750 MHz in GTK
  - Average tracks in GTK per event: 2.5 (1 K, 1.5 pileup)
- All possible GTK hit combinations considered
  - Real tracks: GTK hits from the same track (Pileup tracks, Kaon tracks).
  - Fake tracks: GTK hits from different beam tracks
- Before selection cuts:
  - Average reconstructed track per event: 27
  - Fraction of: Kaons 3.6%, Pileup 5.3%, Fake 91%



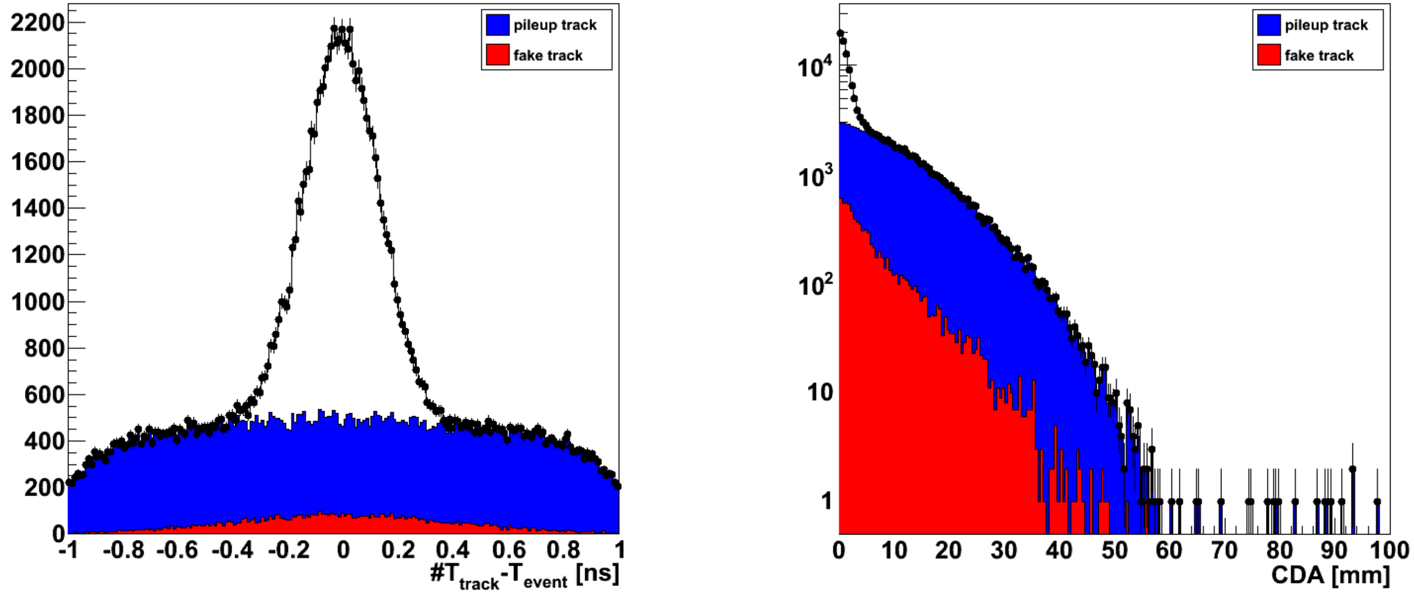
- Real Track Recognition:
- Discriminant variable: global χ^2
- Track recognition: global $\chi^2 < 20$.
- After track recognition:
  - Average reconstructed track per event: 2.6
  - Fraction of: Kaons 38% , Pileup 56%, Fake 6.1%.

Beam Pileup and Kaon-ID

- Inputs for Kaon track identification: $\Delta T = T_{track} - T_{event}$, CDA.

ΔT for all the tracks

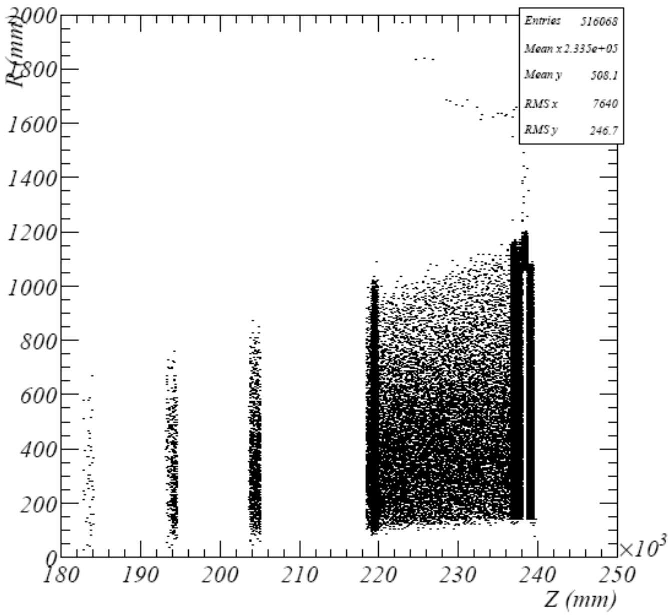
CDA for all the tracks



- Results after Kaon - ID:
- Fraction of: Kaons 99.4%, Pileup 0.6%, Fake <0.1%

Photons in the Forward Region

- Evaluate the effect of the material in front of the LKr on the photon rejection inefficiency (straw chambers and RICH).
- Reminder: the LKr intrinsic inefficiency was evaluated on data (NA48 in 2007) .



- Probability of γ interaction: 20%
  - Most part of the interactions are simple photon conversions (e^+e^- pairs detected as well in the LKr).
- Probability of γ nuclear interaction: 10^{-3}
- Multiplicity cuts in LAV9,10,11,12 and in the detectors downstream to the RICH have been applied.

Energy	< 1 GeV	1 – 5.5 GeV	5.5 – 7.5 GeV	7.5 – 10 GeV	>10 GeV
LKr Inefficiency	1	10^{-3}	10^{-4}	5×10^{-5}	8×10^{-6}
Effect of the material	-	$(2.1\pm0.5)\times10^{-4}$	$(1.4\pm0.5)\times10^{-4}$	$(5\pm2)\times10^{-5}$	$(3.7\pm1.6)\times10^{-6}$

Status of the installation

- The new beam dump is completed
- The beam line is being installed
- In progress tendering process for the vacuum system
- The surface building is being refurbished
- The detector is being installed in ECN3

ECN3 hall (same as NA48)