Joint Annual HEPP and APP Conference

Status of the NA62 experiment at CERN

Angela Romano, on behalf of the NA62 collaboration

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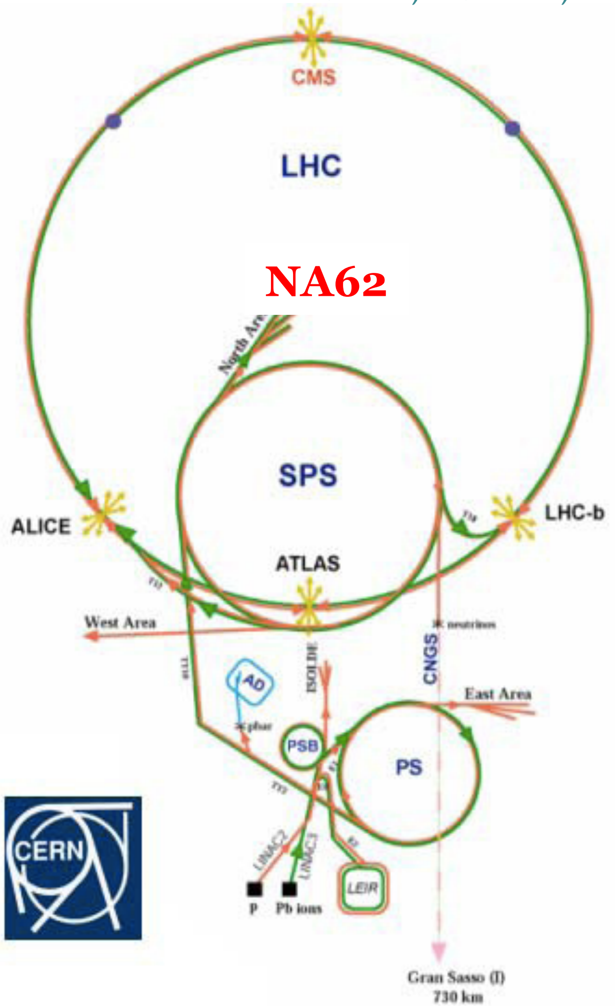
The NA62 experiment

Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna (JINR), Fairfax, Ferrara, Florence, Frascati, Glasgow, Liverpool, Louvain-la-Neuve, Mainz, Merced, Moscow (INR), Naples, Perugia, Pisa, Prague, Protvino (IHEP), Rome I, Rome II, San Luis Potosi, SLAC, Sofia, TRIUMF, Turin, Vancouver (UBC)



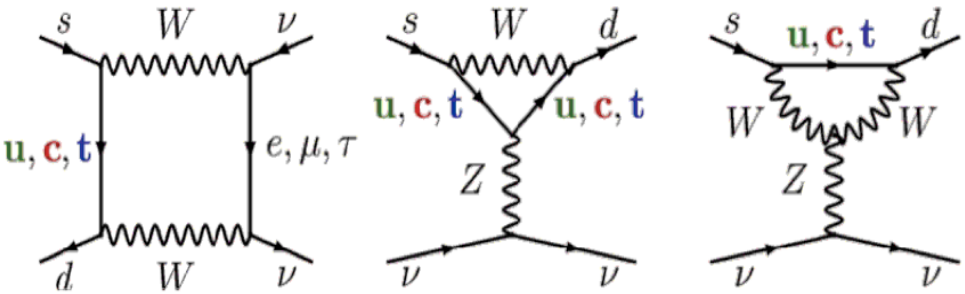
NA62 Timeline

- **Dec 2008 - NA62 Approval**
- **2009 - 2012: detector R&D**
  Oct 2012 - NA62 Technical Run (partial layout)
- **2013 - 2014: Installation/Commissioning**
  Oct 2014 - NA62 Pilot Run (partial layout)
- **2015 - 2018: Physics Runs**

NA62 primary goal: Measure BR($K^+ \rightarrow \pi^+\nu\bar{\nu}$) with 10% accuracy

Motivations for $K^+ \to \pi^+ \nu\bar{\nu}$

Box & Penguin (one-loop) diagrams



✓High sensitivity to New Physics

✓FCNC process forbidden at tree level

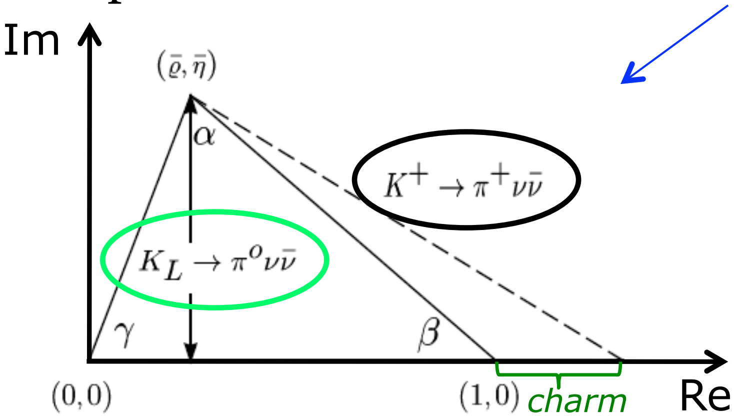
✓ Highly CKM suppressed (BR ~ $|V_{ts}^* V_{td}|^2$)

✓Extraction of V_{td} with minimal (few %) non-parametric uncertainty

Theoretically very clean:

- (dominant) short-distance t quark part: NLO QCD and 2-loop EW corrections
- (small) c quark part: NNLO QCD and NLO EW corrections
- correction for long-distance contributions
- hadronic matrix element extracted from precisely measured BR($K^+ \to \pi^0 e^+ \nu$)

Independent determination of unitary triangle for K meson system (with neutral mode)



$BR(K^+ \to \pi^+ \nu\bar{\nu}) = (9.11 \pm 0.72) \times 10^{-11}$

[Buras et al., JHEP 1511 (2015) 033]

error: CKM parametric, dominated by V_{cb}

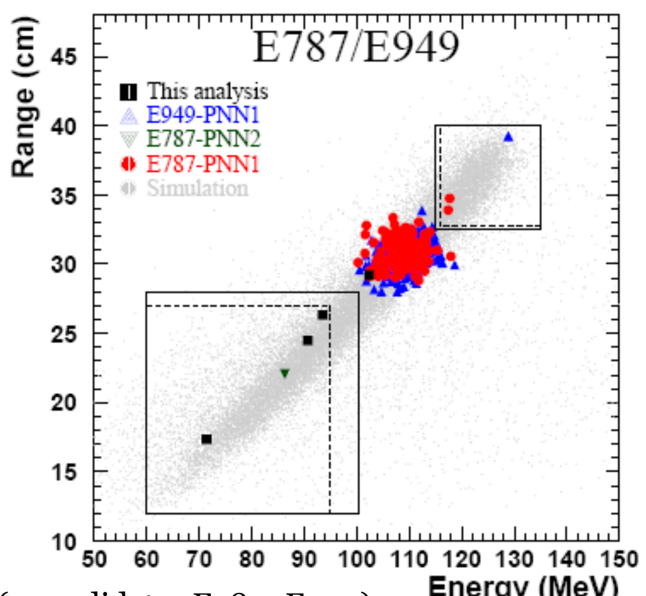
Indirect searches of NP with high precision studies of rare K decays

Experimental Status & NP Sensitivity

$BR(K^+ \rightarrow \pi^+ \nu\bar{\nu})_{THEORY} = (0.91 \pm 0.07) \times 10^{-10}$

$BR(K^+ \rightarrow \pi^+ \nu\bar{\nu})_{EXP} = 1.73^{+1.15}_{-1.05} \times 10^{-10}$
[E787/E949, Phys.Rev.Lett.101, 191802, 2008]

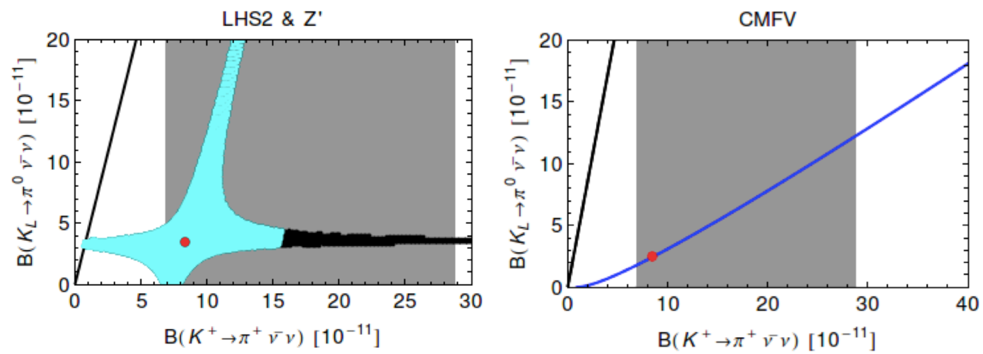
- based on 7 candidates
- stopped Kaon technique

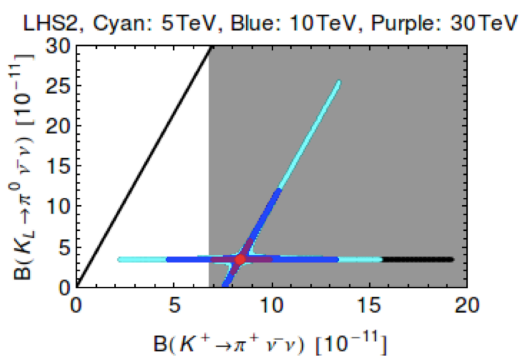


(7 candidates E787+E949)

Discrimination among NP scenarios

[Buras et al., JHEP 1302 (2013) 116]





Sensitivity to $M_{Z'}$ beyond the LHC

$K \rightarrow \pi\nu\bar{\nu}$ probes of unique sensitivity for NP models among B and K decays

(NP searches complementary/alternative to LHC)

The NA62 challenge

SM BR($K^+ \rightarrow \pi^+ \nu \bar{\nu}$) ~ 9 x 10^{-11}

Requirements

KAON INTENSITY
- At least 10^{13} K^+ decays

SIGNAL EFFICIENCY
- Detector acceptance ~ 10%

→ Detect O(100) $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ events in 2(3) years of data taking

SIGNAL PURITY
- Background rejection > 10^{12}

DETECTOR REDUNDANCY
- Background measurement <10% precision

→ Signal/Bkg ~ 10
Measure BR($K^+ \rightarrow \pi^+ \nu \bar{\nu}$) with a 10% accuracy

Technique

DECAY-IN-FLIGHT TECHNIQUE
- 75 GeV/c momentum beam - K/π/p

→ Help in background rejection (vetoes - PID)

The NA62 Beam line

Primary SPS protons on beryllium target

- ✓ P = 400 GeV/c
- ✓ ~ 3 x 10^{12} protons/pulse (3.5 s effective spill)

Secondary (unseparated) hadron beam π / K / p

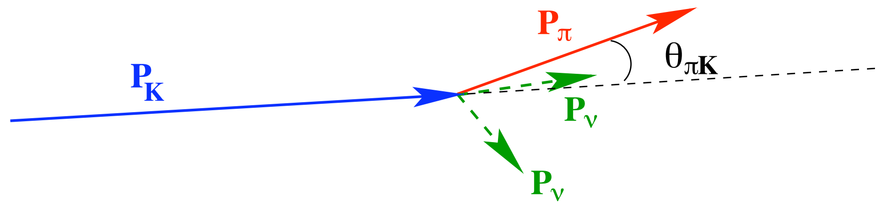
- ✓ p = 75(±1%) GeV/c
- ✓ X,Y divergence < 100 μrad
- ✓ Total rate ~750MHz (K component ~ 6%)
- ✓ 10% of K decays in 60 m fiducial volume
- ✓ 4.5 x 10^{12} K^+ decays/year

Secondary beam line fully commissioned

Signal and Backgrounds

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

$$m^2_{miss} \cong m_K^2\left(1-\frac{|P_\pi|}{|P_K|}\right) + m_\pi^2\left(1-\frac{|P_K|}{|P_\pi|}\right) - |P_K||P_\pi|\theta^2_{\pi K}$$



Backgrounds: Kaon decays & Interactions

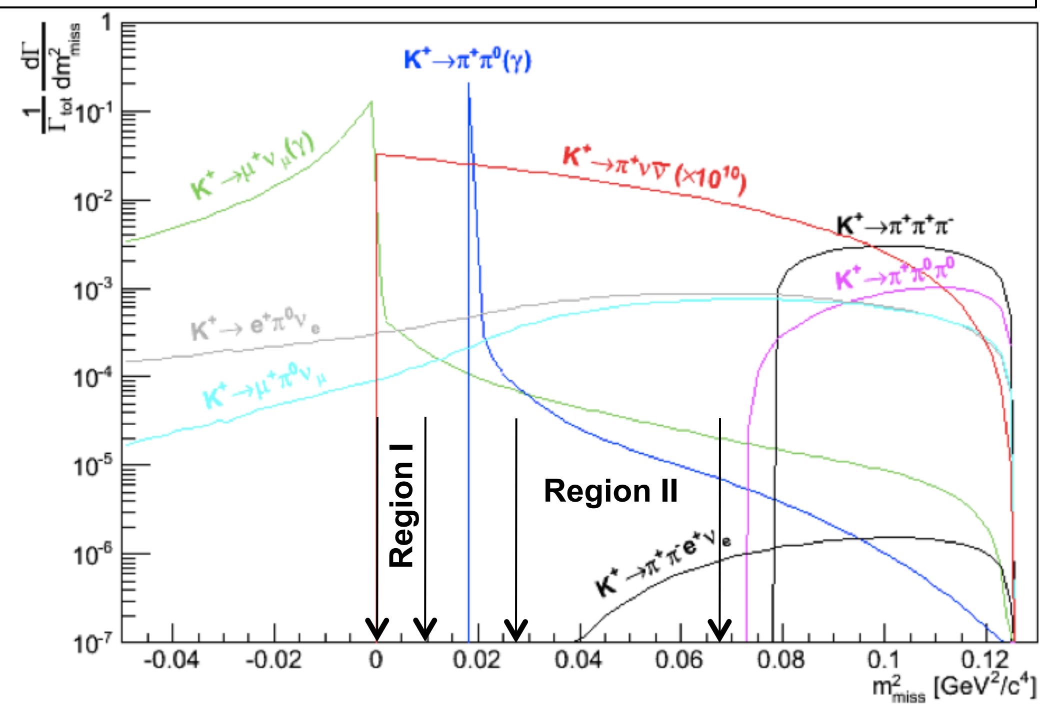
Decay backgrounds

Mode	BR
$\mu^+\nu(\gamma)$	63.5%
$\pi^+\pi^0(\gamma)$	20.7%
$\pi^+\pi^+\pi^-$	5.6%
$\pi^0 e^+\nu$	5.1%
$\pi^0\mu^+\nu$	3.3%
$\pi^+\pi^- e^+\nu$	4.1×10^{-5}
$\pi^0\pi^0 e^+\nu$	2.2×10^{-5}
$\pi^+\pi^-\mu^+\nu$	1.4×10^{-5}
$e^+\nu(\gamma)$	1.5×10^{-5}

Other backgrounds

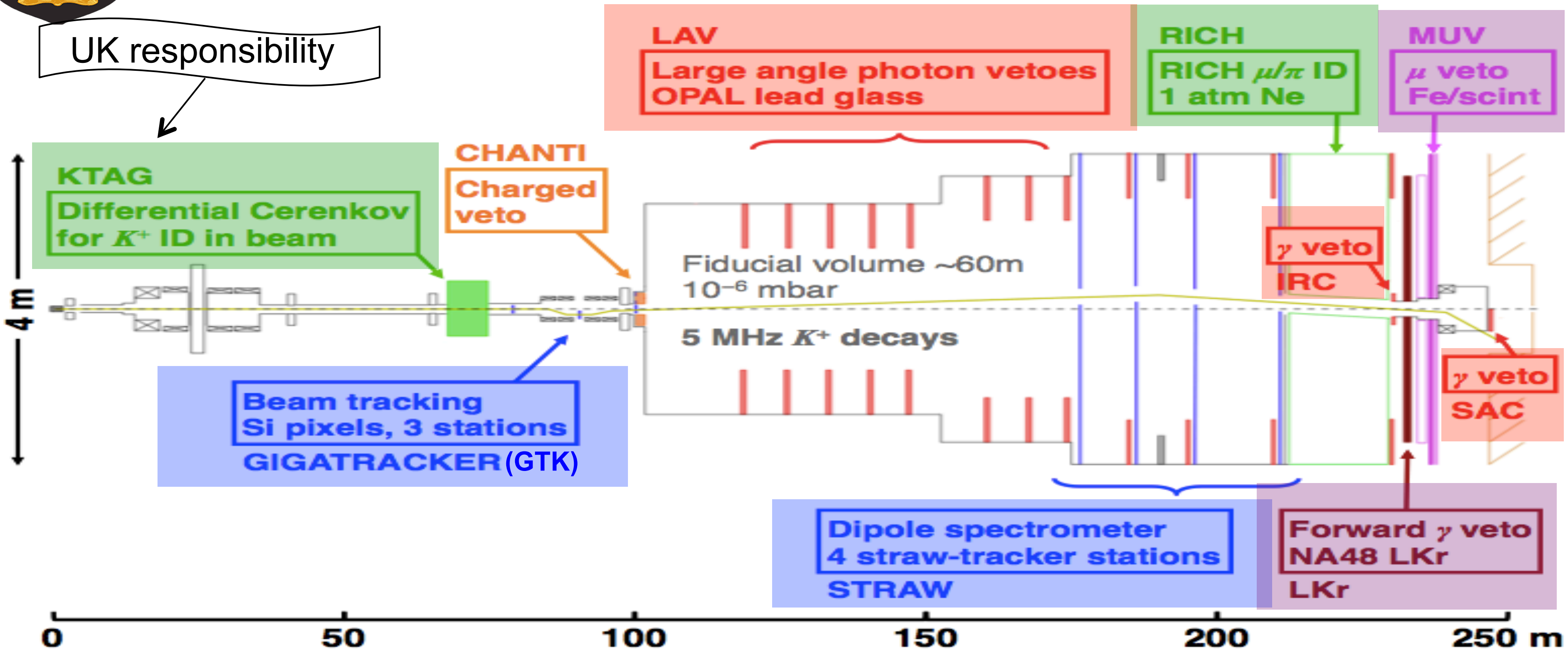
Beam-gas interactions

Upstream interactions



Rejection relies on kinematic reconstruction (m^2_{miss}) used in conjunction with PID and veto systems.

The NA62 Detector



Track reconstruction: P_K (**GIGATRACKER**, also called **GTK**), P_π (**STRAW**)

PID K for bkg coming from non-kaon components (**KTAG**)

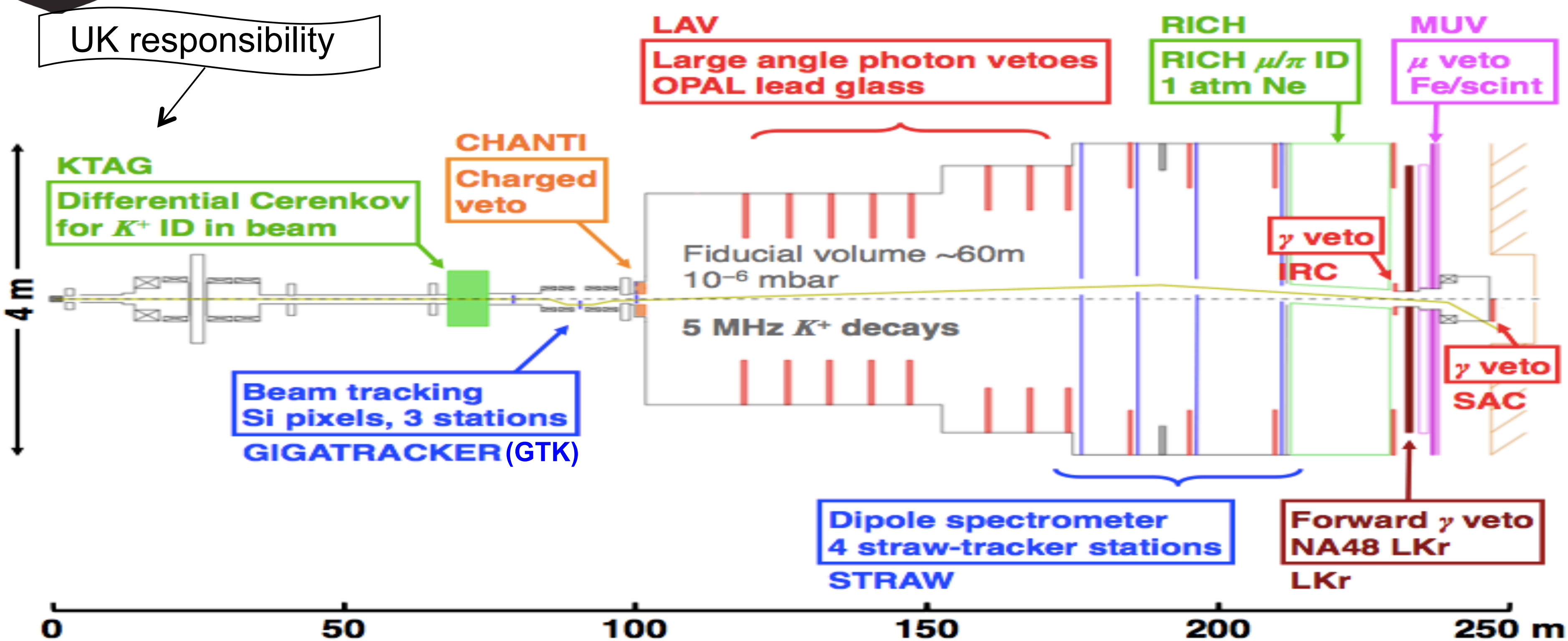
PID π/μ for main (BR~64%) bkg $K^+ \to \mu^+\nu$ (**RICH**)

$\pi/\mu/e$ separation for bkg with leptons in final state (**LKr, MUV**)

Photon rejection for $K^+ \to \pi^+\pi^0$ (BR~21%) and all bkgs with γs in final state (**LAV, IRC, SAC**)

} **Hermetic Veto Systems**

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



Event reconstruction:

- ✓ single π^+ in final state (STRAW, RICH, LKr, MUV)
- ✓ K^+ - π^+ sub-ns time association (RICH, KTAG),
- ✓ m^2_{miss} reconstruction for signal definition,
- ✓ 15 GeV/c < P_{π^+} < 35 GeV/c (>40GeV missing energy)

NA62 Physics Sensitivity

Decay	events / year
$K^+ \to \pi^+\nu\bar{\nu}$ [SM]	45
$K^+ \to \pi^+\pi^0$	5
$K^+ \to \mu^+\nu$	1
$K^+ \to \pi^+\pi^-\pi^+$	< 1
$K^+ \to \pi^+\pi^- e^+\nu$ + other 3-track decays	< 1
$K^+ \to \pi^+\pi^0\gamma$ (IB)	1.5
$K^+ \to \mu^+\nu\gamma$ (IB)	0.5
$K^+ \to \mu^+(e^+)\pi^0\nu$, others	negligible
Total background	< 10

At nominal beam intensity: 4.5×10^{12} K^+ decays/year

Cut & count analysis without any optimization

Detector Commissioning and Data Taking

Secondary beam line:

- commissioned up to fully intensity

Detectors:

- Trackers: GTK partially commissioned, STRAW commissioned
- PID: Cherenkov detectors KTAG, RICH commissioned
- Veto: all Calorimeters and other detectors commissioned

Trigger:

- L0 commissioned
- L1-L2 partially commissioned

Collection (mainly in 2015) of **samples for data quality study**:

- minimum bias run at low beam intensity (this talk)
- half and full beam intensity data with calorimetric trigger

KTAG: Kaon ID Detector

(UK responsibility)

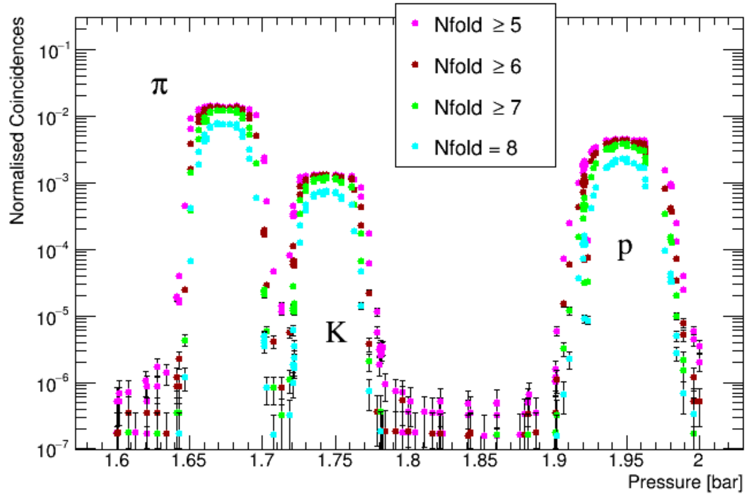
Commissioning

- Optical axis aligned with the beam axis
- **Pressure scan** performed for different diaphragm aperture (nominal at 1.5mm)
- Tune KTAG to Kaon peak to maximise Kaon ID efficiency
- Pion mis-ID probability: ~10^{-4}

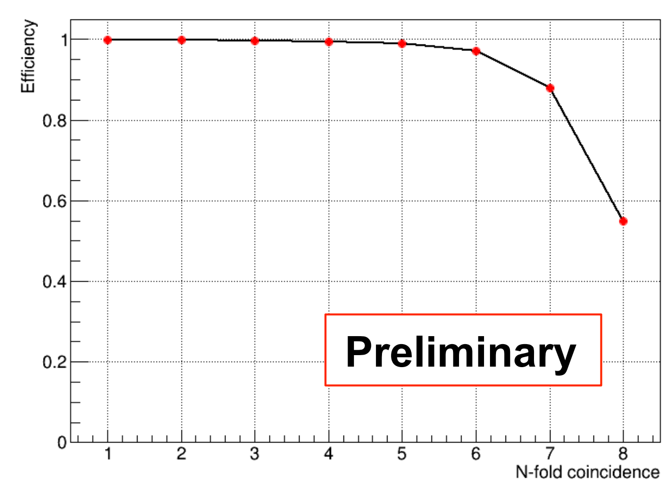
Analysis with 2015 data

- Kaons tagged by selecting $\pi^+\pi^0$ with downstream detectors (LKr)
- Selected sample used for **Kaon ID efficiency** studies at low beam intensity
- Confirmed performances: $\sigma_t(K)$<70 ps

Pressure scan at 1.5mm diaphragm aperture



KTAG Efficiency vs N-fold (Sector) coincidence



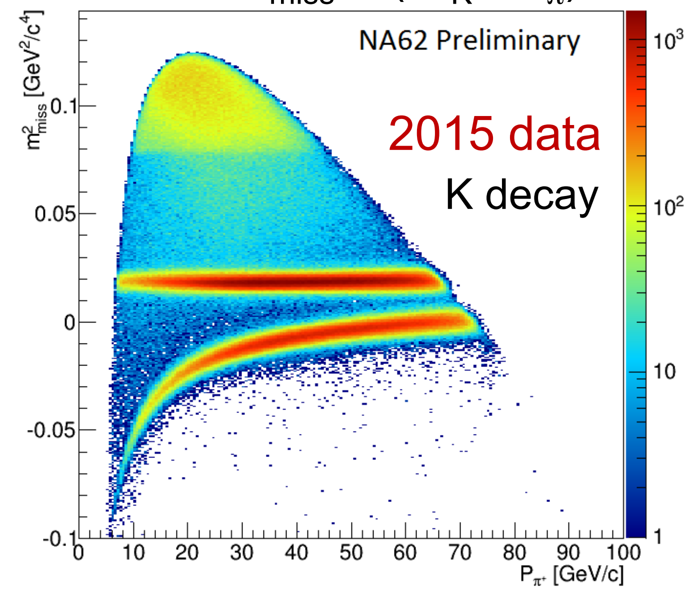
Analysis of data at higher intensity with more control samples on going

KTAG Efficiency > 98% when requiring N-fold ≥ 5

Signal Topology and Kinematics

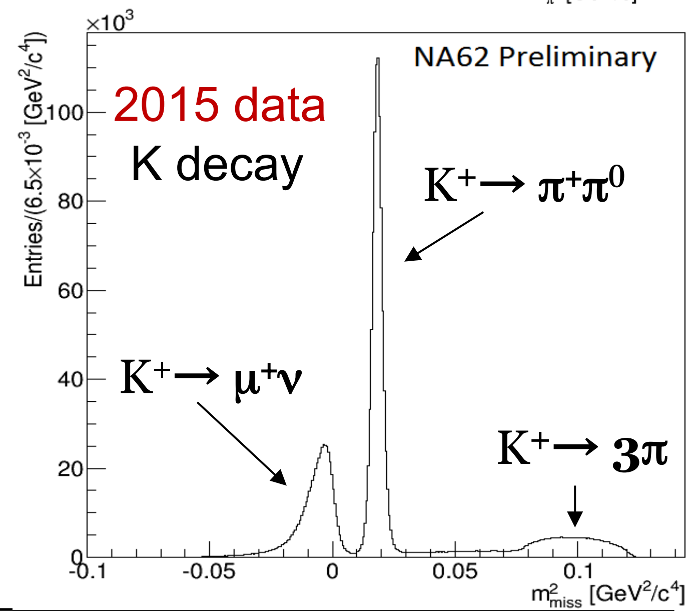
- Single downstream track topology
- Beam track matching the downstream track
- Beam track matching a K signal in Kaon ID
- Downstream track matching energy in calorimeters
- Track origin in the fiducial region

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



Measured time resolutions (close to design):

- Kaon ID < 100 ps
- Beam track < 200 ps
- Downstream track < 200 ps
- Calorimeters 1-2 ns



Kinematics:

Aim at $O(10^4 \div 10^5)$ rejection factor of main decay modes

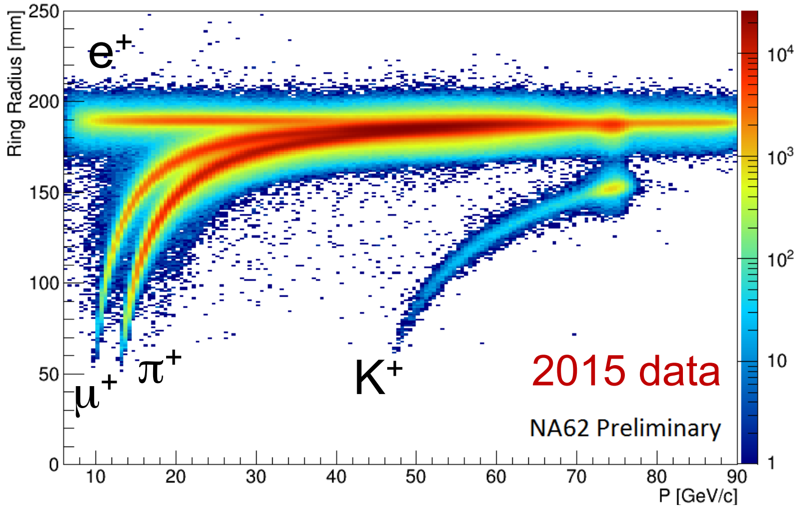
Best $K^+ \rightarrow \mu^+\nu$ suppression for $P_\pi^+ < 35$ GeV/c

Resolution on m^2_{miss} close to design

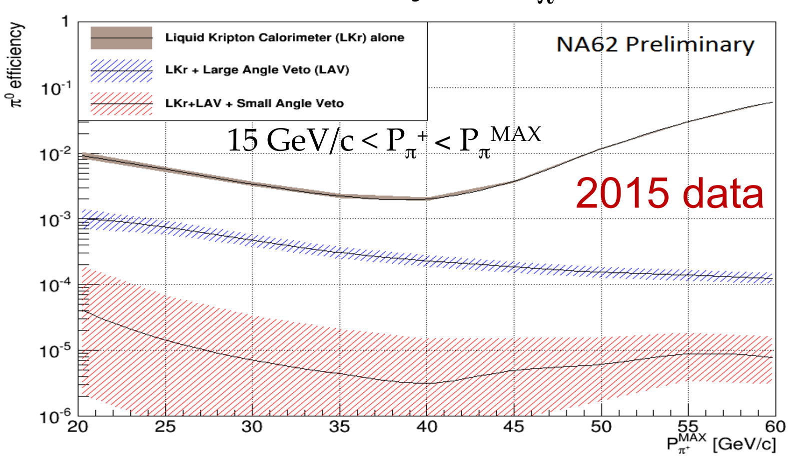
Prospects to reach design with fully commissioned GTK

Background Suppression

Ring radius in RICH vs Momentum



π^0 efficiency vs P_π^{MAX}



Downstream PID

- Aim at $O(10^7)$ **π/μ** separation for K^+**->**$\mu^+\nu$ bkg
- $O(10^2)$ **π/μ** separation with 80% π^+ efficiency achieved for 15 GeV/c < P_π^+ < 35 GeV/c (RICH)

Separation with RICH close to expectations
Separation with MUV, ongoing analysis

Photon Rejection

- Aim at $O(10^8)$ π^o rejection for K^+**->**$\pi^+\pi^0$ bkg
- $E(\pi^0)$ > 40GeV for P_π^+ < 35 GeV/c

$O(10^5)$ π^o rejection obtained
Need more stats to reach design sensitivity

Conclusions

NA62 Beam line and Detector commissioned up to nominal intensity

First Physics run in 2015:

- Minimum bias data collected at low intensity used for data quality studies
- Physics sensitivity for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ measurement in line with design
- Further compelling physics program is going to be addressed
  - Rare decays, searches for LFV, HNL,...
- Analysis of data at higher intensity ongoing

High intensity beam in 2016-2018 for physics runs (next run ~200days starting in April)

Goals:

✓ collect O(100) SM $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ events

✓ measure BR($K^+ \rightarrow \pi^+ \nu \bar{\nu}$) with ~10% accuracy

Conclusions

N… to nominal intensity ✔

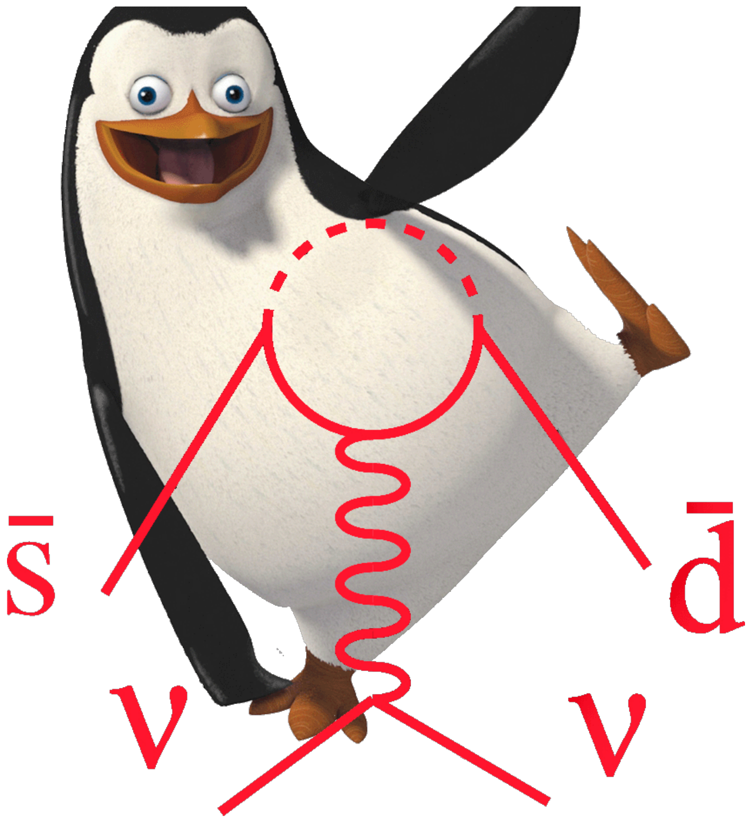
…d for data quality studies

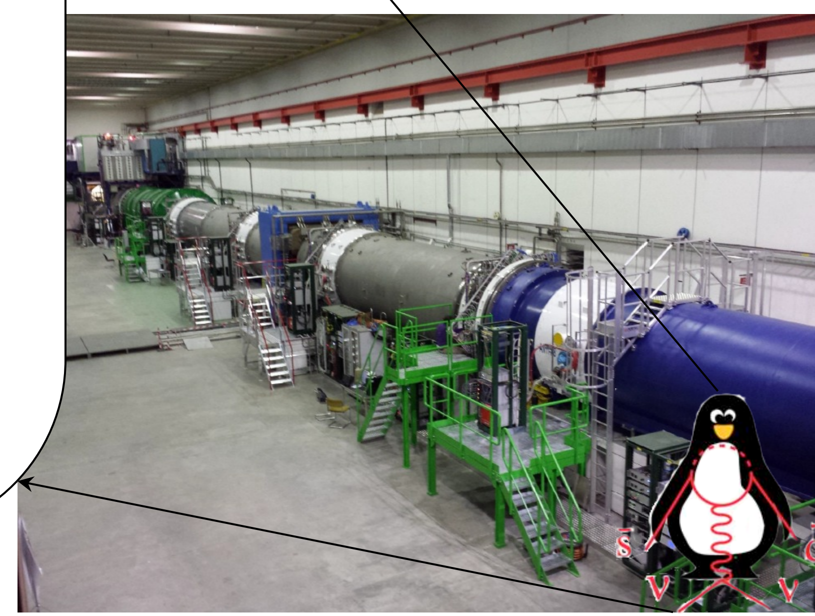
…line with design

…e addressed

✓ mea…

Stay Tuned !



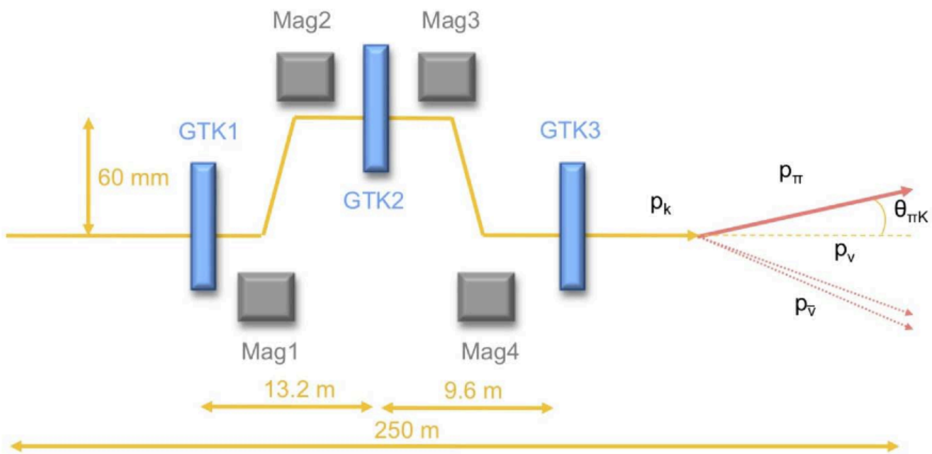


Spares

21-23 March 2016, University of Sussex, Brighton

Beam Reconstruction

GIGATRACKER (GTK)



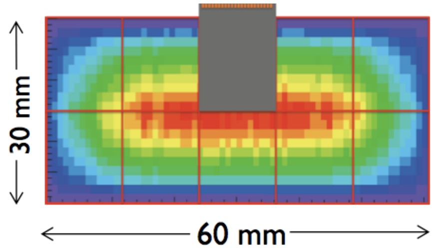
Spectrometer layout

- 3 stations of hybrid silicon pixel detectors
- 4 achromat magnets (beam displacement ~60mm)
- 18, 000 pixels/station of size 300 × 300 μm²

P_K momentum and position: **GTK**
K^+ timing: **GTK** and **KTAG**

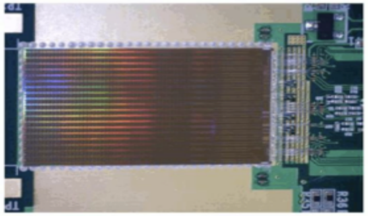
Tracking of K^+:

- high and non-uniform beam rate @ GTK (750 MHz)



- minimal amount of material X/X0 < 0.5%/station
- σ_t~ 200 ps match the π tracking info from downstream detectors

bump-bonded chips on sensor



- $\sigma_p/p \sim 0.2\%$ and $\sigma_\theta = 16$ μrad

Pion Reconstruction

STRAW

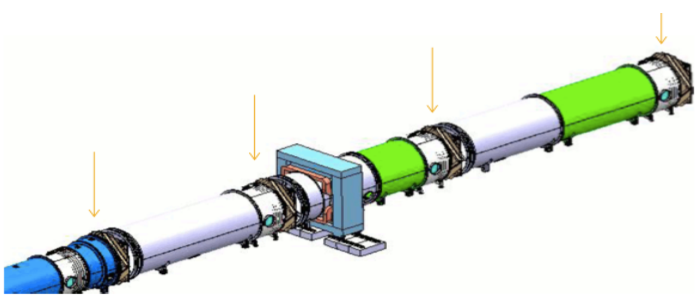
Tracking of secondary charged particles:

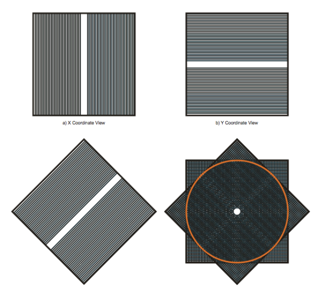
- operation in vacuum;
- ultra-light material X/X0 ~ 0.1%/"View"
- spatial resolution $\sigma \leq 130\mu m$ (1 "View")
- $\sigma_p/p \sim 0.32\% \oplus 0.008\%\ p$ [GeV/c]
- $\sigma_{\theta(K\pi)}$ = 20-50 μrad

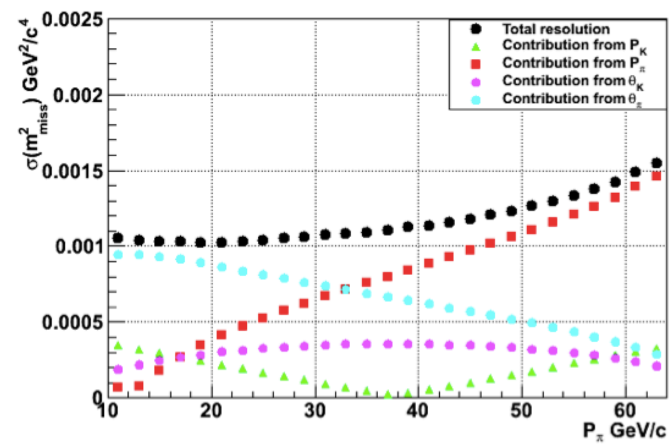
P_π momentum and position: **STRAW**
π^+ timing: **RICH**

Spectrometer layout

- high aperture dipole magnet (B-field ~ 0.36 T; $\Delta p_\perp$ = 270 MeV)
- 4 straw-tube chambers (2.1 m in diameter)

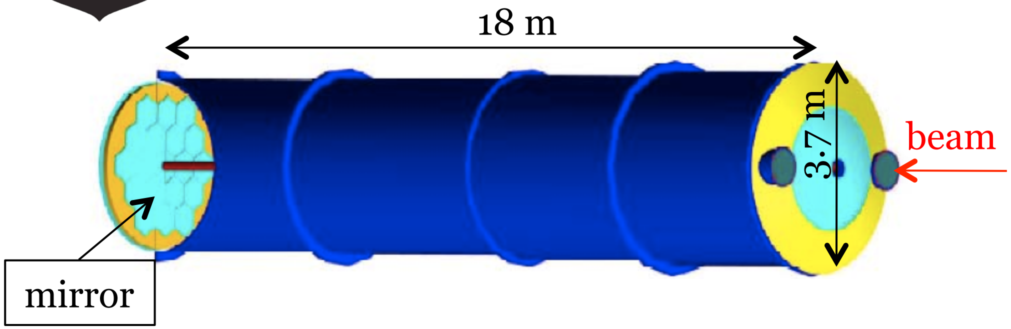






- 1,792 straw tubes/chamber (16 layers - 4 "Views")

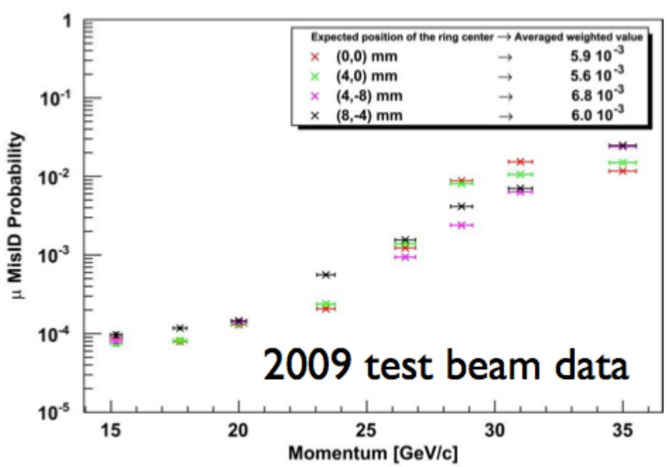
Pion ID: RICH



Suppression of $K^+ \to \mu^+\nu$ (BR ~ 63%)
- L0 trigger for charged particles
- μ suppression better than 1%

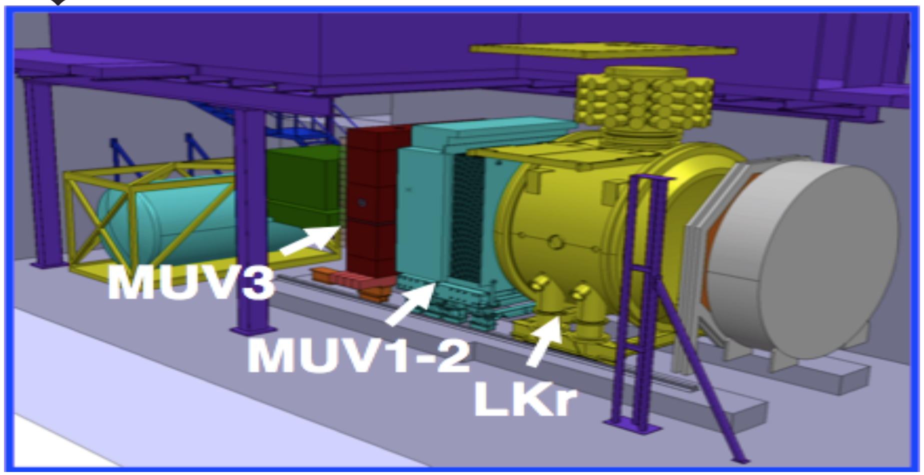
RICH layout and principles

- Cherenkov light ring radius prop to β of particle
- Ne gas at 1 atm;
- 14 GeV/c threshold for π
- High granularity γ detector (2000 PMTs)

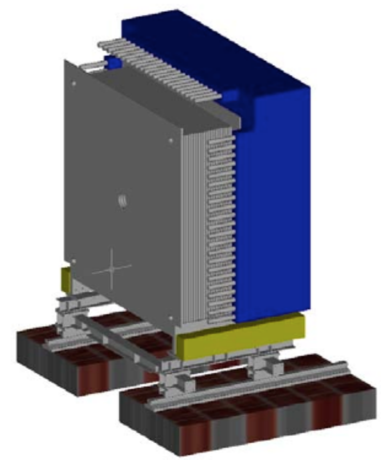


- Full length prototype tested in 2009 (test beam)
- Final detector installed on beam line in 2014
- π^+/μ^+ separation > 10^2 up to 35 GeV/c
- Resolution on π crossing time $\sigma_t < 100$ ps

PID: LKr, MUV



Suppression of $K^+ \rightarrow \mu^+ \nu$ (BR ~ 63%)
- μ mis-ID as a π -> down to ~10^{-5}
- muon crossing time with $\sigma_t < 1$ns

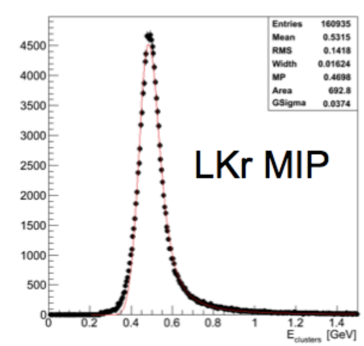


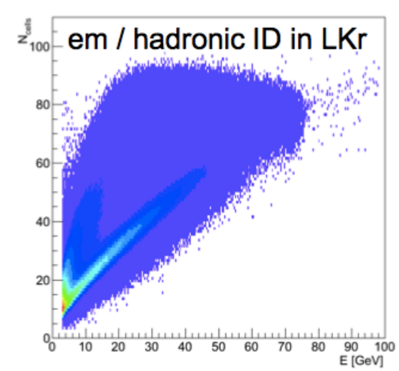
$\pi/\mu/e$ separation

NA48 LKr em calorimeter:
- em/hadr/mip cluster ID

MUV1-2:
- Fe-scintillators calorimeter
- hadr/mip cluster ID
- suppress μ "catastrophic" energy loss

MUV3:
- scintillation tiles counter
- detect non-showering muons (<% ineff)
- used in L0 trigger (10MHz)





Photon Veto Systems - I

Photon Veto system: LAV, LKr, IRC, SAC

- Suppression of $K^+ \rightarrow \pi^+\pi^0$ (BR ~ 21%)
- Hermetic photon coverage up to 50 mrad
- $O(10^8)$ on rejection of $\pi^0 \to \gamma\gamma$
- Kinematic cut on $p_\pi < 35$ GeV gives $\pi^0 \to \gamma\gamma$ with > 40 GeV

Simulations showed:

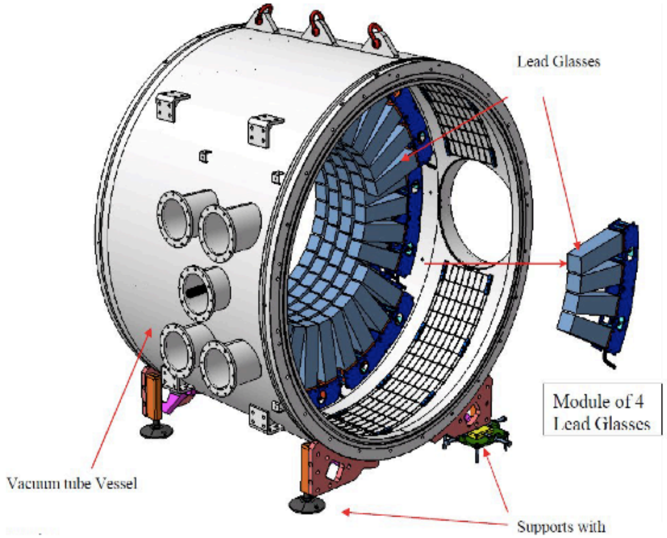
- $K^+ \rightarrow \pi^+\pi^0$ kinematic rejection (m^2_{miss}) ~ 10^{-4}
- 81.2% - 2γs in forward region (LKr/SAC)
- 18.6% - 1γ in LKr/SAC, 1γ at large angle (LAV)
- 0.2% - 1γ in LAV, 1 γ out of acceptance (>50mrad)

First LAV station

LKr

Detector	Technology	θ [mrad]	Max. (1-e)
LAV	Lead-glass block from OPAL	8.5 - 50	10^{-4} at 200MeV
LKr	NA48 EM calorimeter	1 - 8.5	10^{-3} at 1 GeV 10^{-5} at 10 GeV (data)
IRC+SAC	Shashlik	< 1	10^{-4} at 5 GeV

Photon Veto Systems - II



-12 **LAV** stations distributed along the decay volume and covering the angular region: (8.5÷50) mrad;

- Photon energy range (10MeV÷30GeV);

- each **LAV**: 4/5 staggered layers of lead-glass crystals from OPAL EM barrel calorimeter;

- test beam with e^- at 200MeV showed $(1-\varepsilon) \sim 10^{-4}$

- **LKr** fundamental detector constructed for the studies of direct CP-violation in the neutral kaon system (NA48);

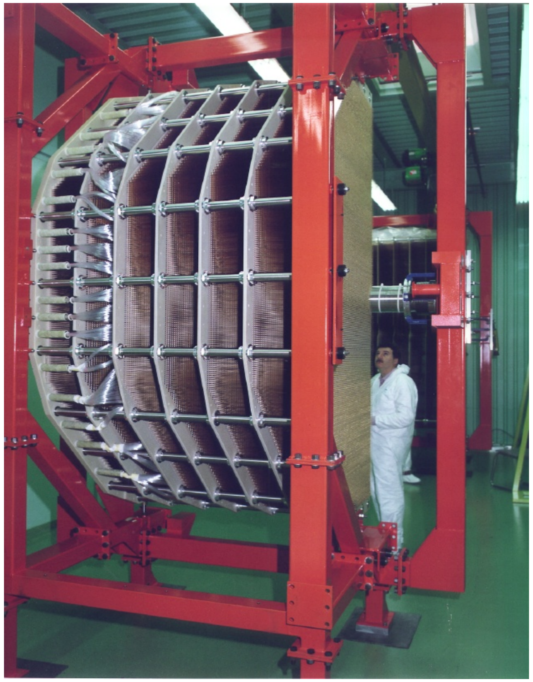
- quasi-homogeneous ionization chamber;

- Photon energy range (>1GeV);

- high energy (>10GeV) EM showers contained in compact detector (27 X_0);

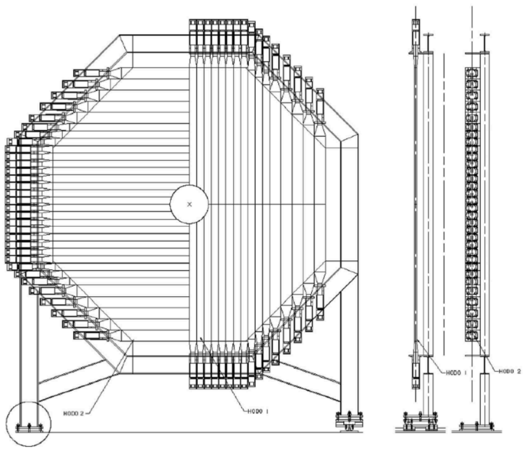
- 13, 248 readout cells with a transverse size of $\sim 2\times 2$ cm^2 each and no longitudinal segmentation;

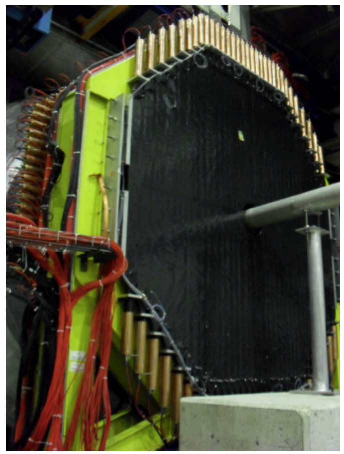
- from studies with e^- at E>10GeV -> $(1-\varepsilon) \sim 8\times 10^{-6}$



Charged Tracks Veto System

CHOD
(NA48 Charged Hodoscope)

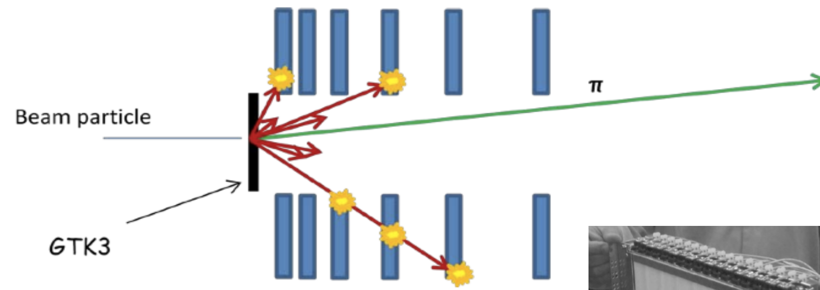


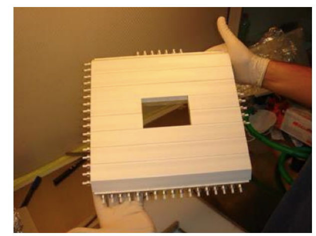


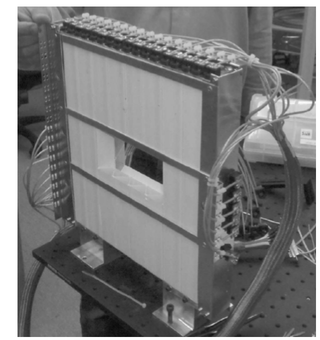
- 2 planes of plastic scintillation counters (horizontal & vertical)
- ~ 0.05 X0 each plane
- time resolution σ_t ~ 200 ps;

Fast charged particles signal for trigger

CHANTI



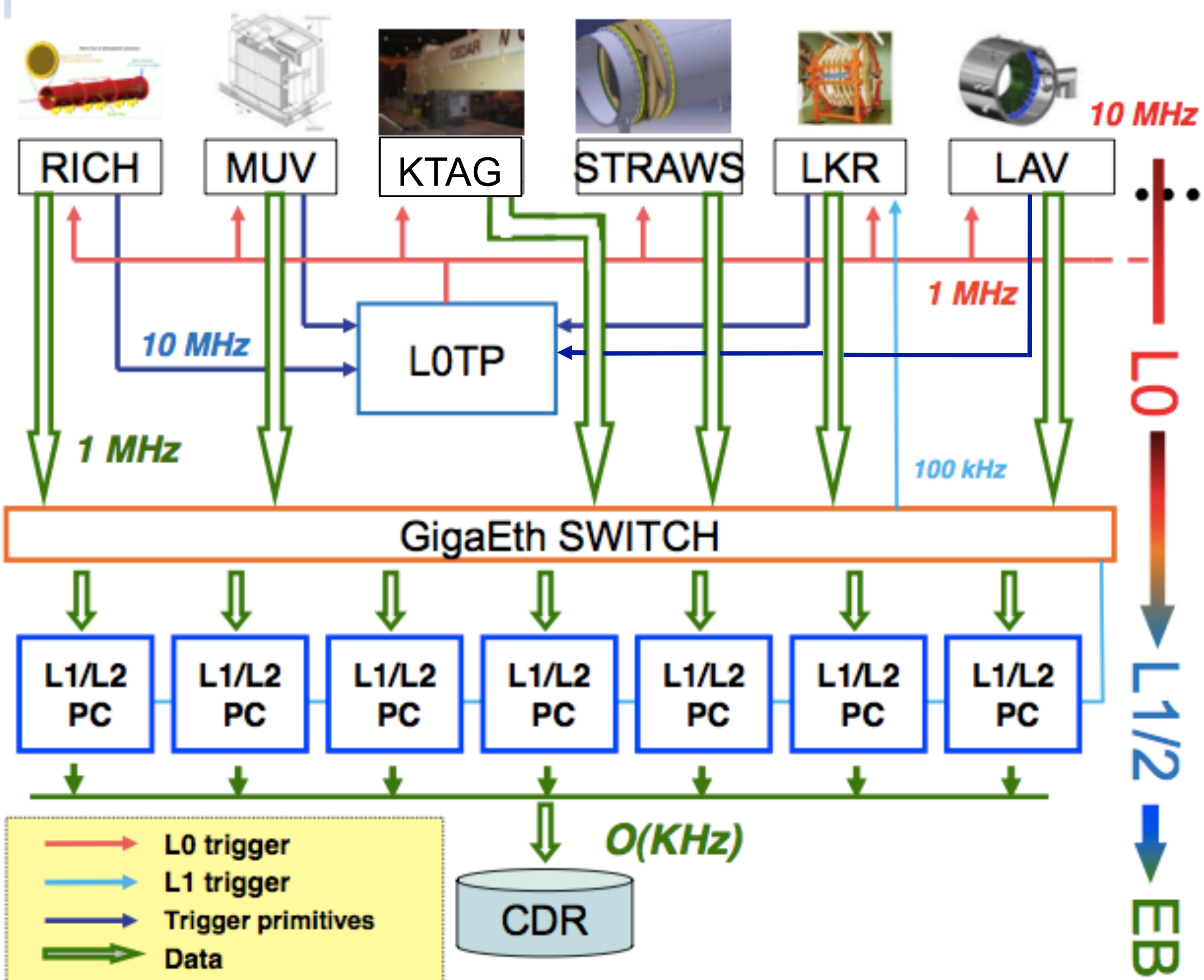




- 6 scintillator stations in vacuum
- WLS + SiPM readout
- angle coverage (1.3-4.9) mrad

Veto for charged particles from inelastic interactions in GTK3

NA62 Trigger Technique: The TDAQ System



L0: Hardware synchronous level. 10 MHz to 1 MHz. Max latency 1 ms.

L1: Software level. "Single detector". 1 MHz to 100 kHz

L2: Software level. "Complete information level". 100 kHz to few kHz.