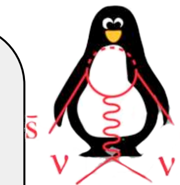
High Sensitivity Experiments Beyond the Standard Model

XIIth Rencontres du Vietnam



Search for $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ and exotics at NA62

Angela Romano, on behalf of the NA62 collaboration

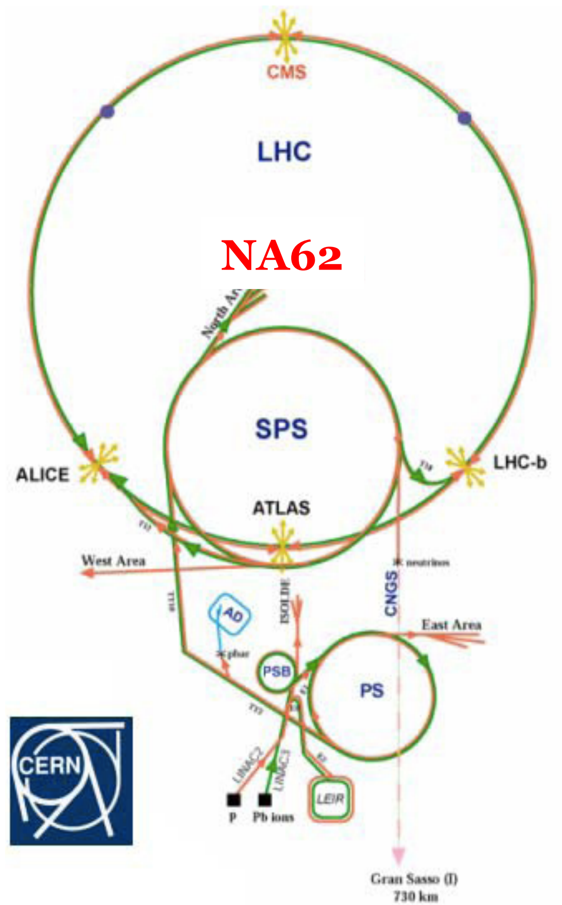
Quy Nhon, Vietnam, July 31 – August 7, 2016

Angela Romano, University of Birmingham (axr@hep.ph.bham.ac.uk)

The NA62 experiment

High precision fixed-target Kaon experiment at CERN SPS

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)



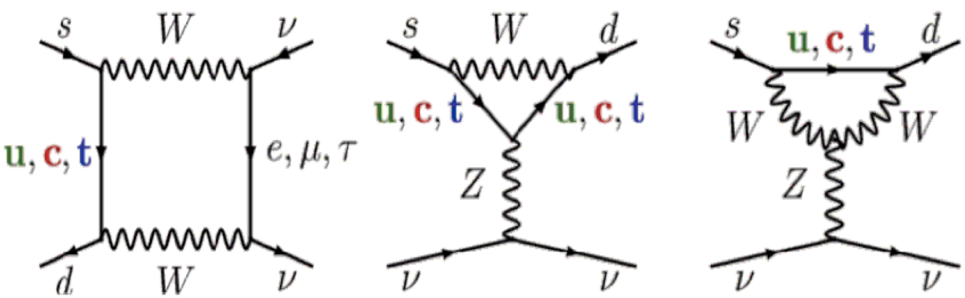
NA62 Timeline

- **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($K^+ \to \pi^0 e^+ \nu$))

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

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

error: CKM parametric, dominated by V_{cb}

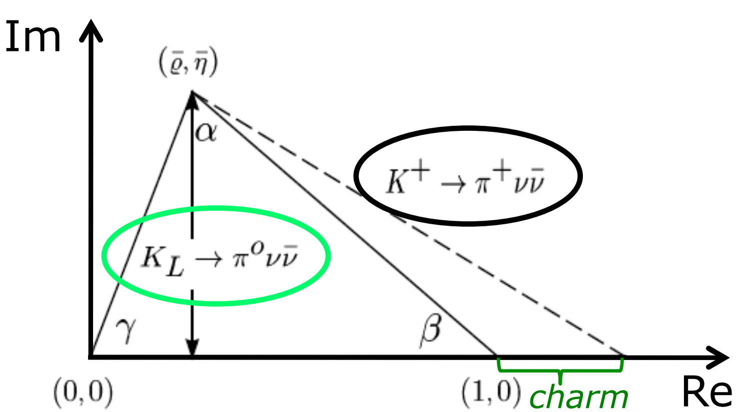
Indirect searches of NP with high precision studies of rare K decays

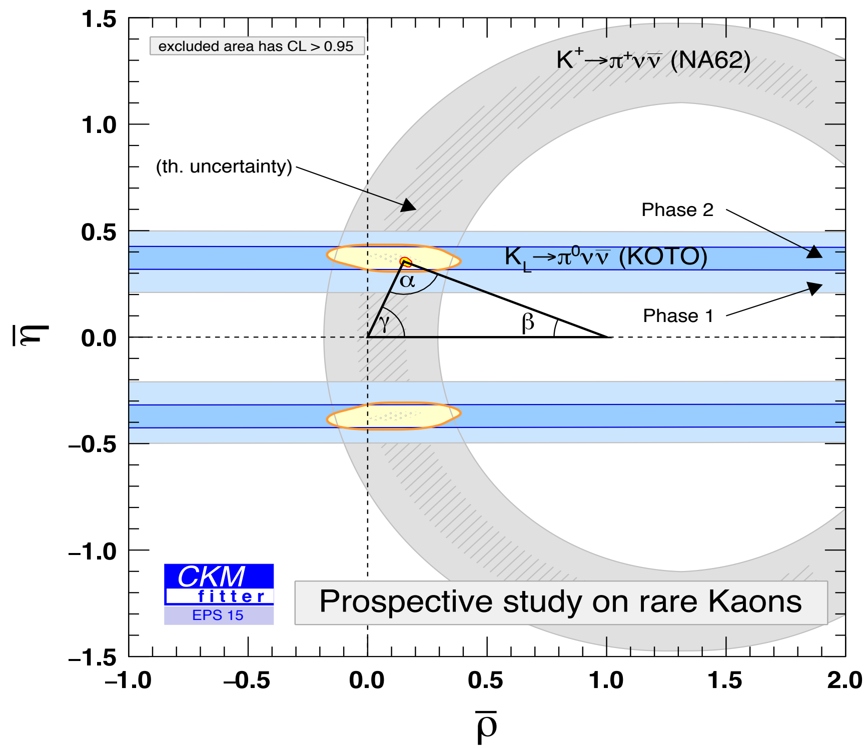
$K \to \pi\nu\nu$: Experiment vs Theory

BR($K^+ \to \pi^+\nu\bar{\nu}$) with 10% uncertainty allows to determine $|V_{td}|$ at 9%
[Buras 0405132]

With BR($K^+ \to \pi^+\nu\bar{\nu}$) , BR($K_L \to \pi^0\nu\bar{\nu}$) the CKM unitarity triangle can be built independently from B observables

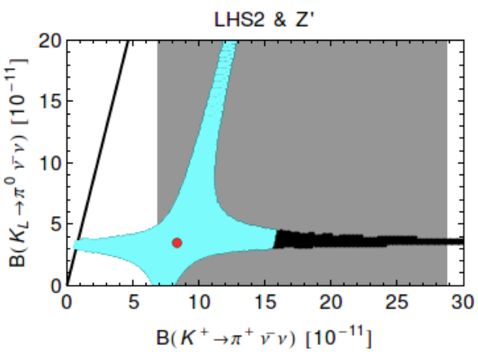
Testing the CKM unitarity triangle with Kaons

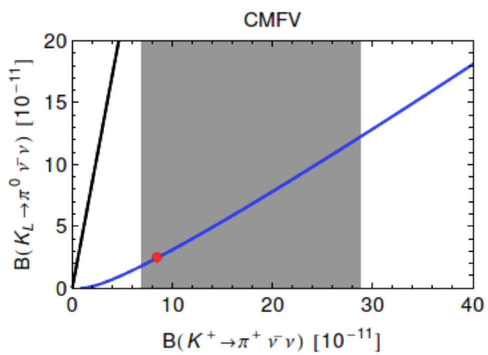


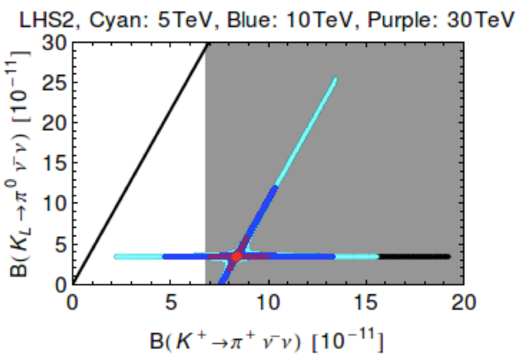


K→ πνν: NP Sensitivity

Measurement of charged ($K^+ \to \pi^+\nu\bar{\nu}$) and neutral ($K_L \to \pi^0\nu\bar{\nu}$) modes can discriminate among different NP scenarios

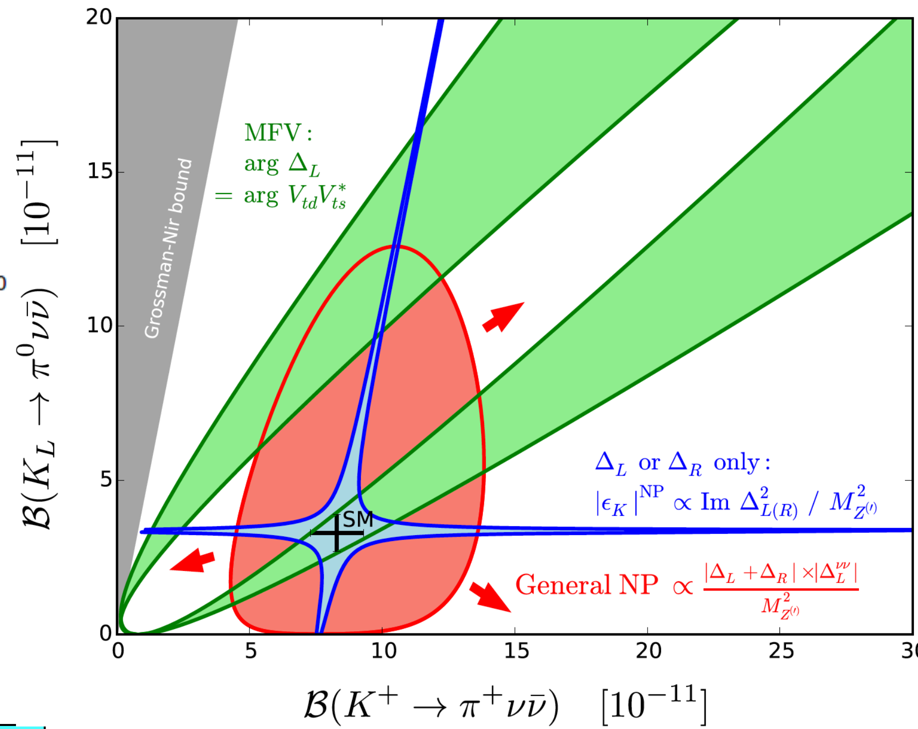






Sensitivity to $M_{Z'}$ beyond the LHC

Buras et al., JHEP 1302 (2013) 116



K→ πνν̄ probes of unique sensitivity for NP models among B and K decays

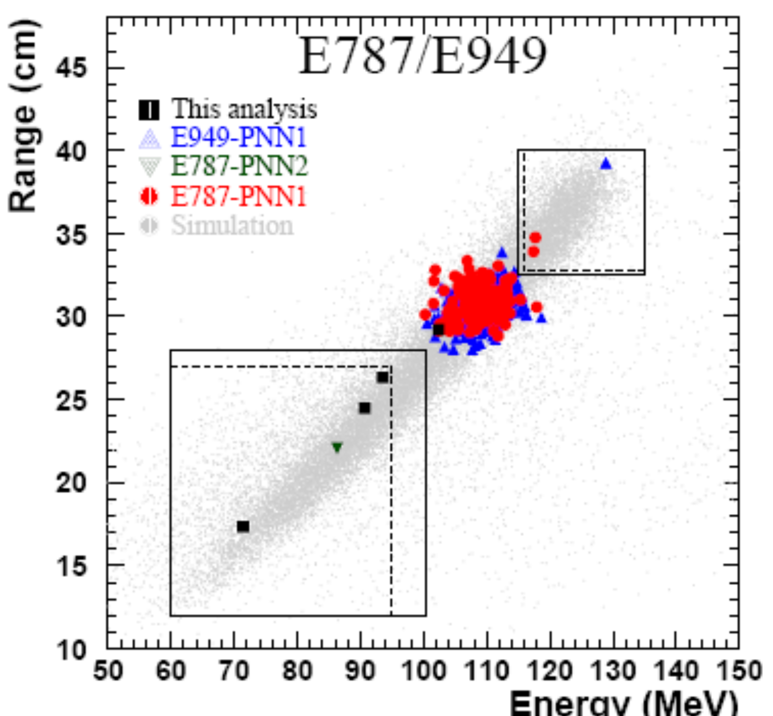
(NP searches complementary/alternative to LHC)

Correlations significantly change for different classes of NP models

[Buras et al., JHEP 1511 (2015) 166]

Experimental Status

The only measurement has been obtained by E787/E949 experiments at BNL by studying stopped Kaon decays



(7 candidates E787+E949)

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

$BR(K^+ \to \pi^+ \nu\bar{\nu})_{EXP} = 1.73^{+1.15}_{-1.05} \times 10^{-10}$

[E787/E949, Phys.Rev.Lett.101, 191802, 2008]

- based on 7 candidates
- stopped Kaon technique

Large experimental error motivates a strong experimental effort

NA62 with decay-in-flight technique aims at $BR(K^+ \to \pi^+ \nu\bar{\nu})$ measurement with 10% accuracy

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

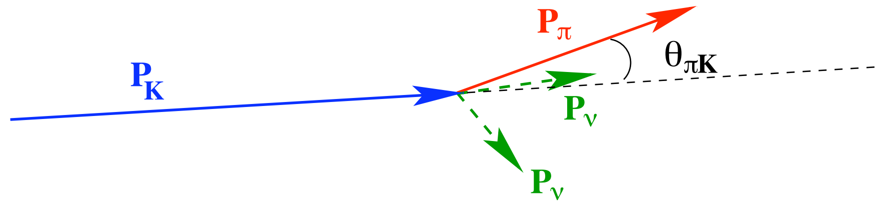
- 75 GeV/c momentum beam - K/π/p

→ Help in background rejection (vetoes - PID)

Signal and Backgrounds

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

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



Backgrounds: Kaon decays & Interactions

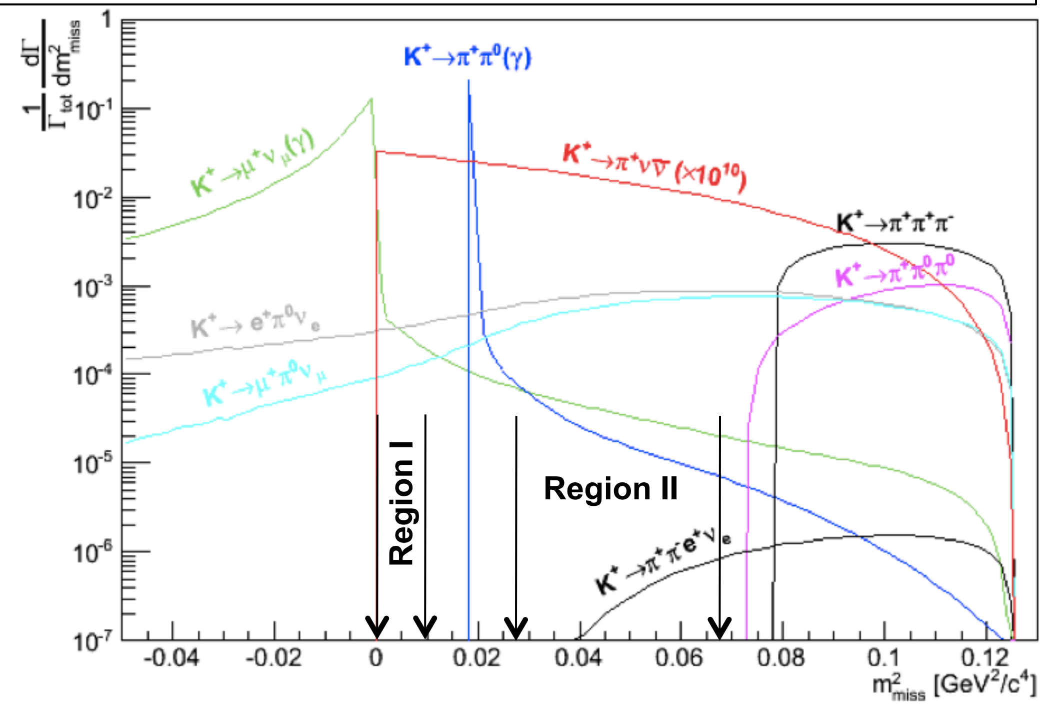
Decay backgrounds

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 Beam line

Primary SPS protons on beryllium target

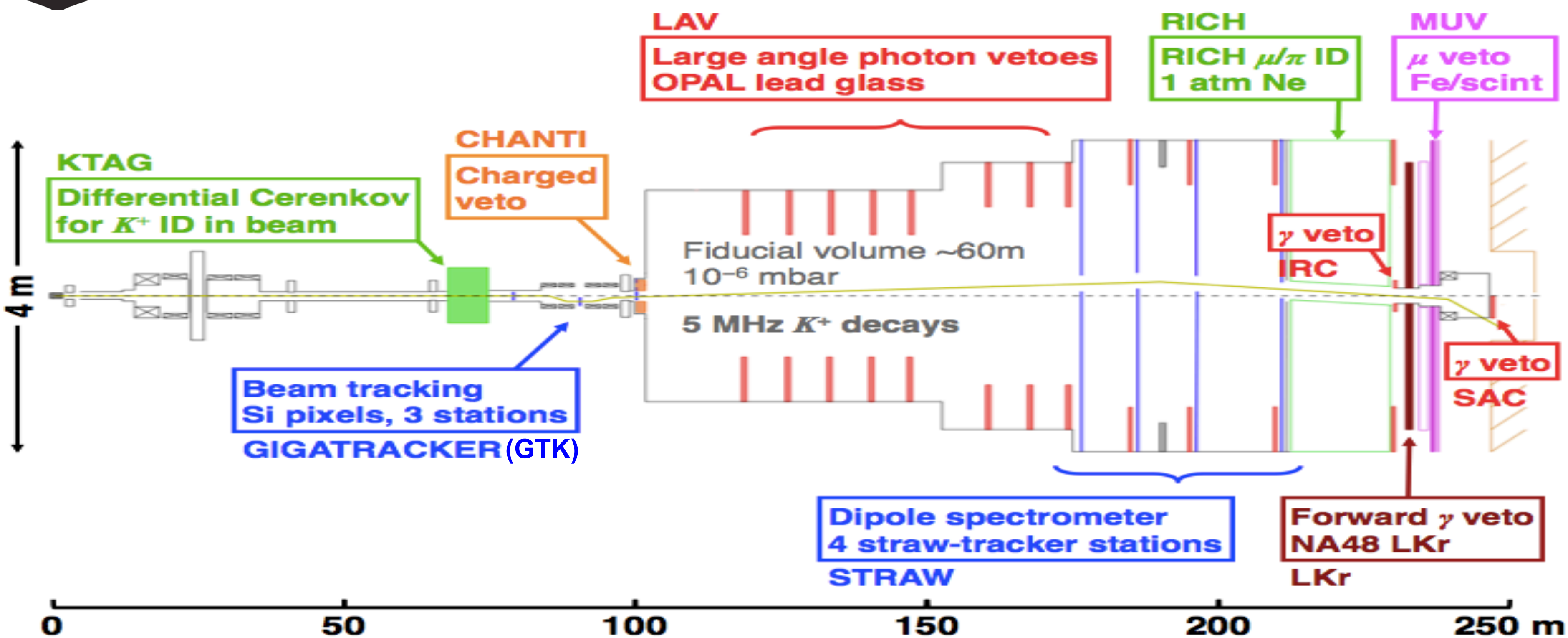
- ✓ P = 400 GeV/c
- ✓ ~ 3 x 10^{12} protons/pulse (3.5 s effective spill)

Secondary (unseparated) hadron beam π / K / p

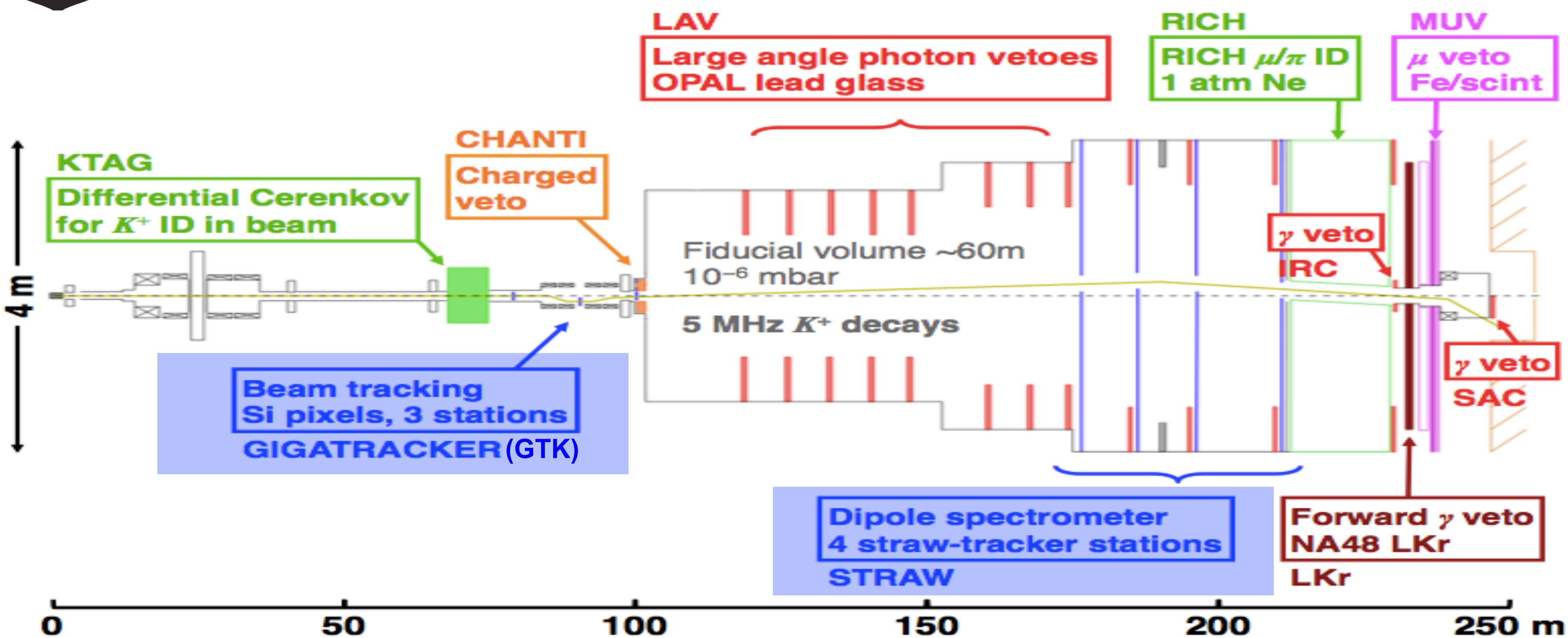
- ✓ p = 75(±1%) GeV/c
- ✓ X,Y divergence < 100 μrad
- ✓ Total rate ~750MHz (K component ~ 6%)
- ✓ 10% of K decays in 60 m fiducial volume
- ✓ 4.5 x 10^{12} K^+ decays/year

Secondary beam line fully commissioned

The NA62 Detector

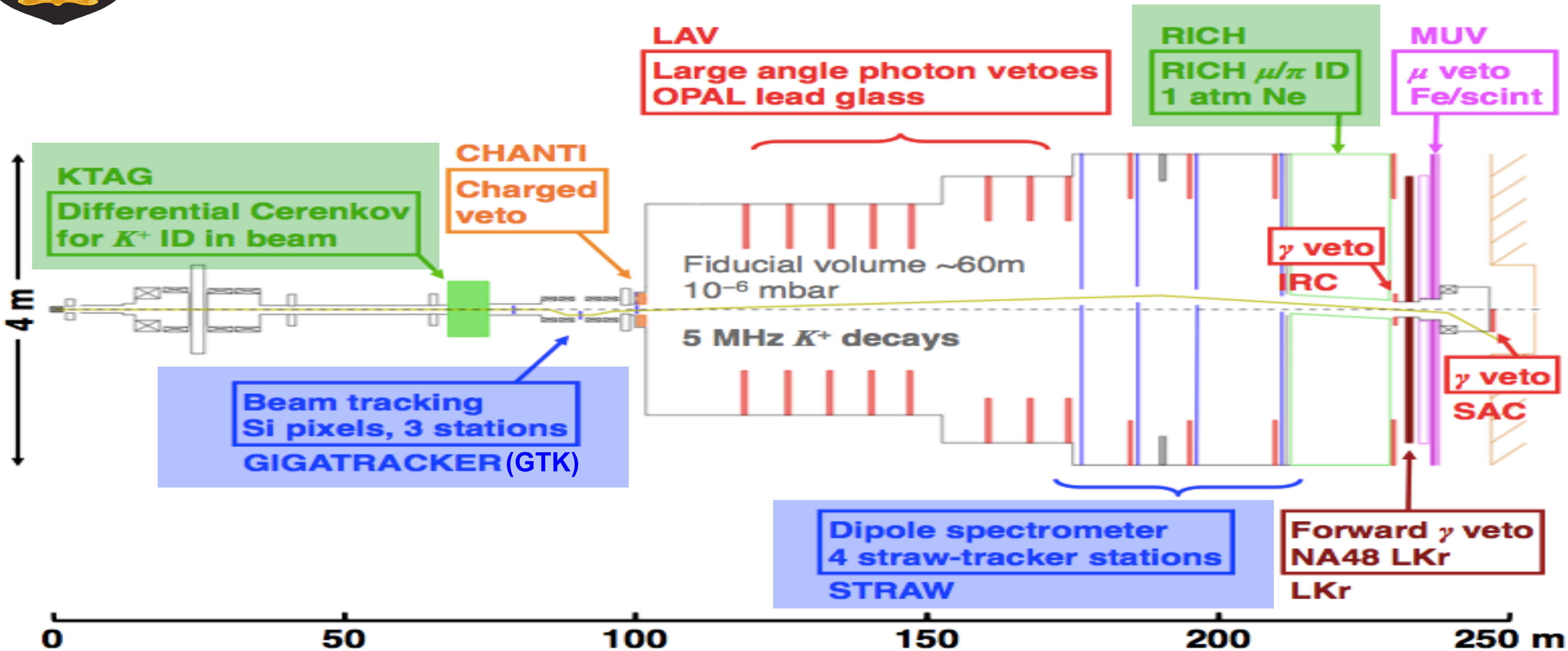


The NA62 Detector



Track reconstruction: $\mathbf{P_K}$ (**GIGATRACKER**, also called **GTK**), $\mathbf{P_\pi}$ (**STRAW**)

The NA62 Detector

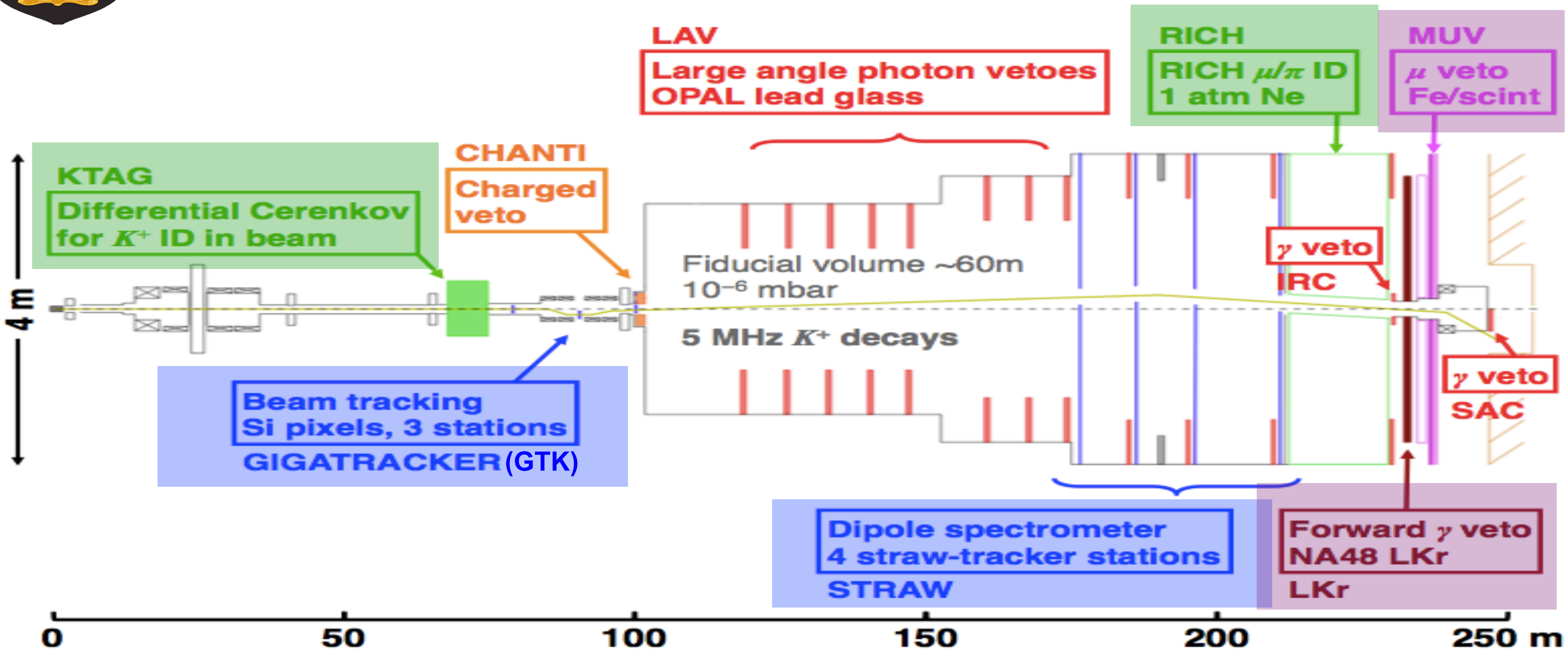


Track reconstruction: P_K (**GIGATRACKER**, also called **GTK**), P_π (**STRAW**)

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

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

The NA62 Detector



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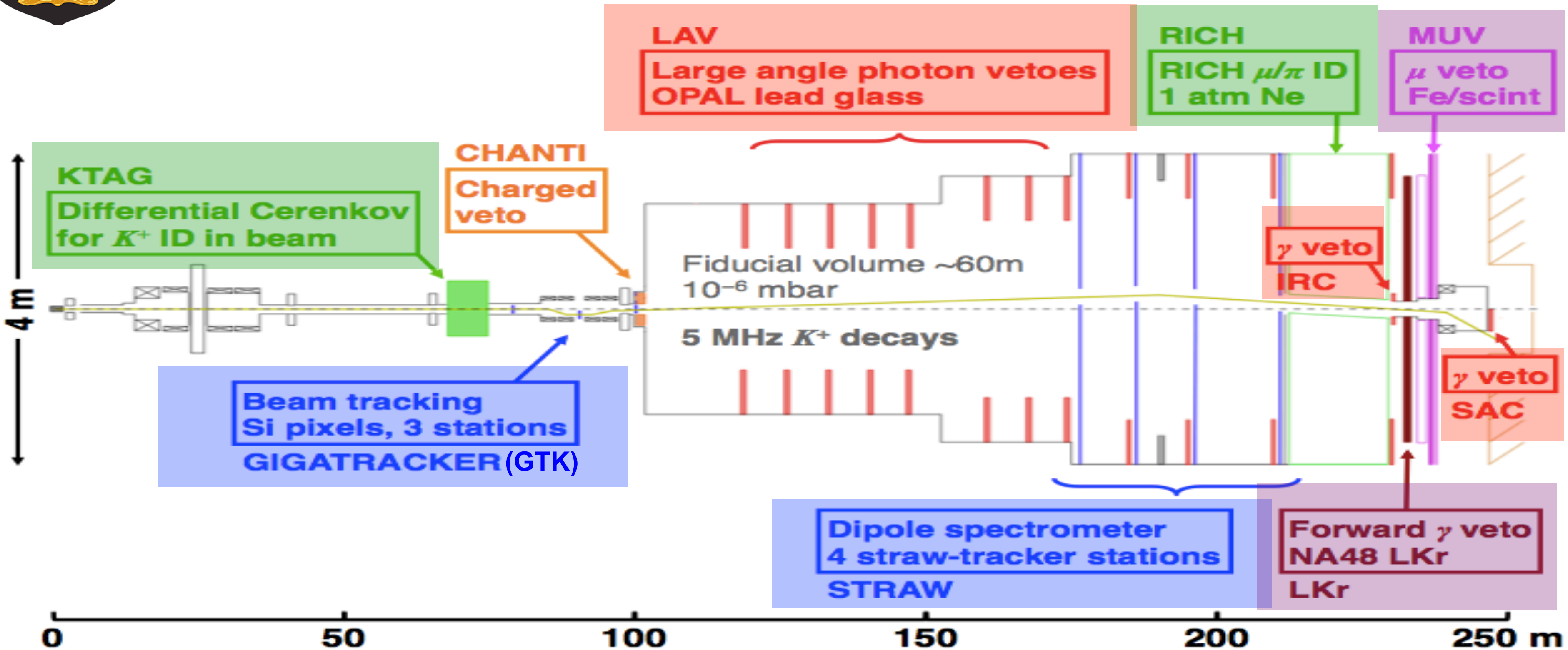
$\pi/\mu/e$ separation for bkg with leptons in final state (**LKr, MUV**)

The NA62 Detector



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

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

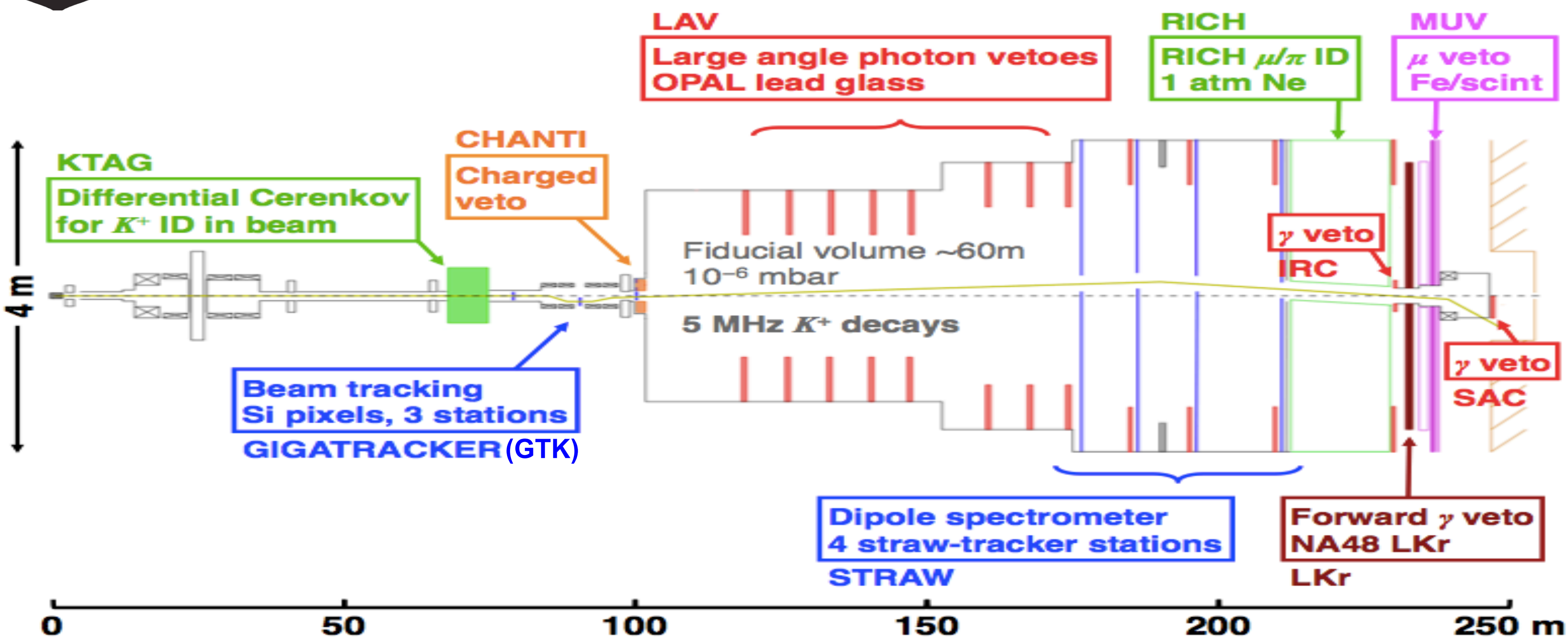
PID π/μ for main (BR~64%) bkg $K^+ \to \mu^+ \nu$ (**RICH**)

π/μ/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 $K^+ \to \pi^+ \nu \bar{\nu}$ 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

NA62 Status & 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

Data taking in 2015 - samples for quality study:

- **minimum bias run** at 1% beam intensity (this talk)
- half and full beam intensity data with calorimetric trigger (under study)

Data taking in 2016 currently at 20% beam intensity:

- focused on $\mathbf{K}_{\pi\nu\nu}$ measurement
- proof of principle for **broader rare/forbidden decay programme**
- planning ~50% intensity later in the year (max intensity is currently limited by SPS capabilities)

KTAG: Kaon ID Detector

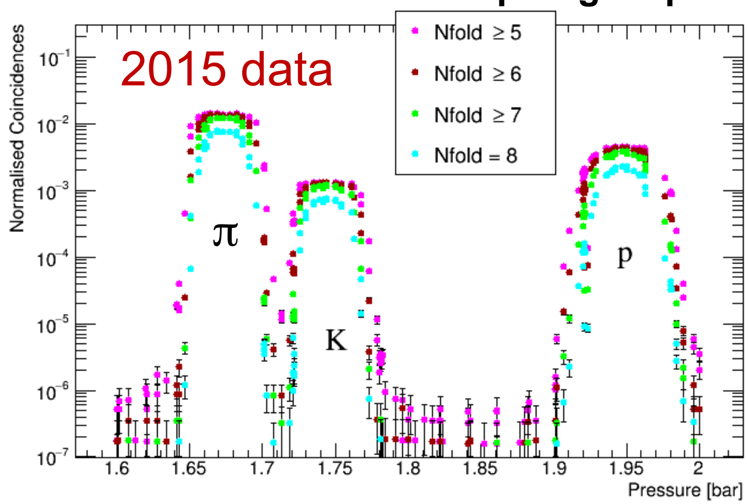
Commissioning

- 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}

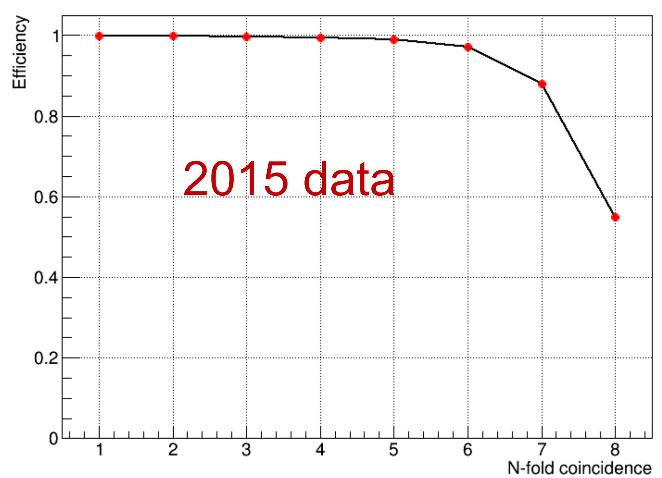
Analysis with 2015 data

- 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

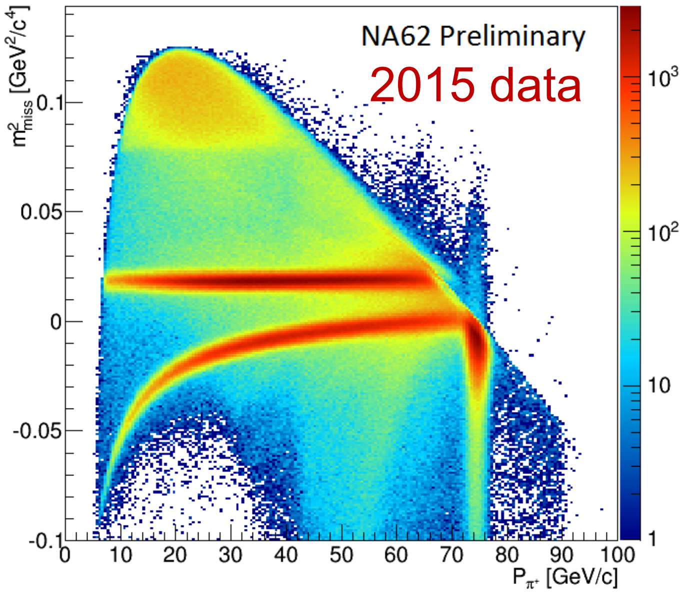


Analysis of data at higher intensity with more control samples on going

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

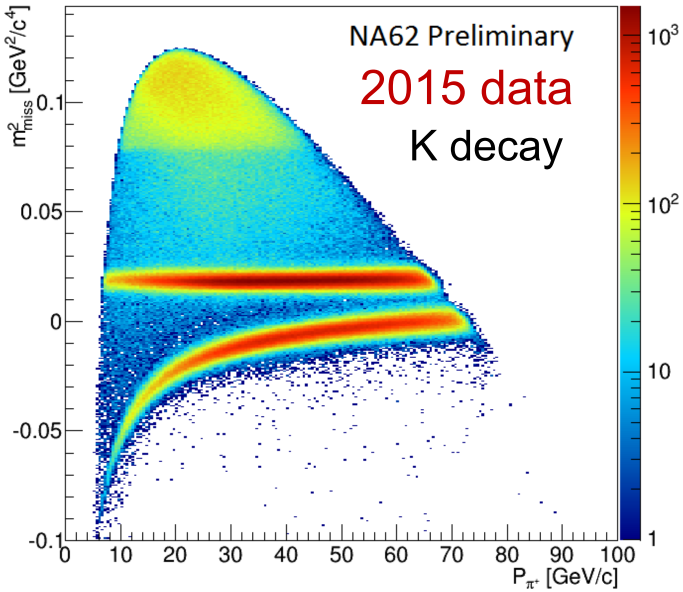
Signal Topology

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



Kaon ID

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



Signal selection:

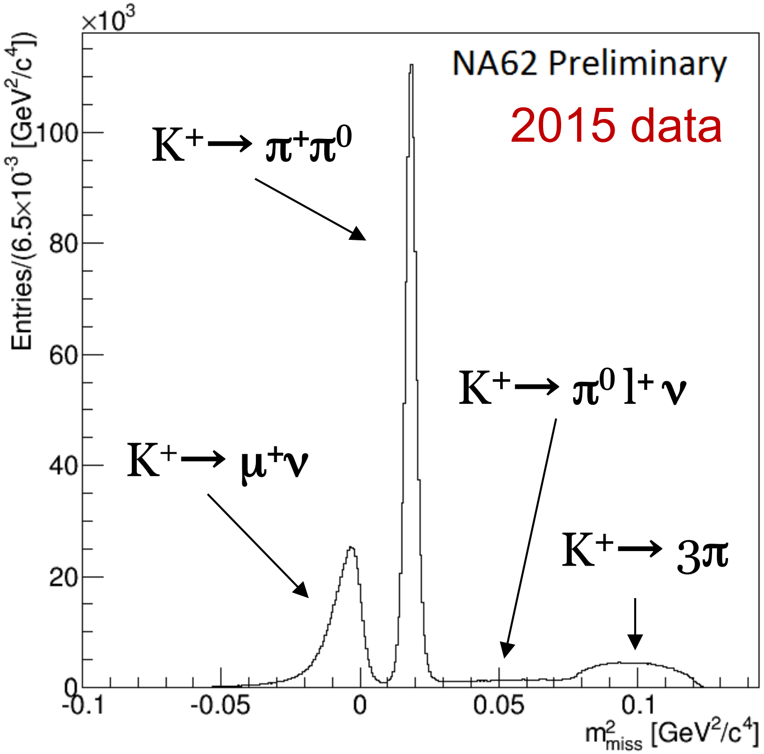
- Single downstream track
- Beam track matching the downstream track
- Kaon ID
- Downstream track matching energy in calorimeters
- Track origin in the fiducial region

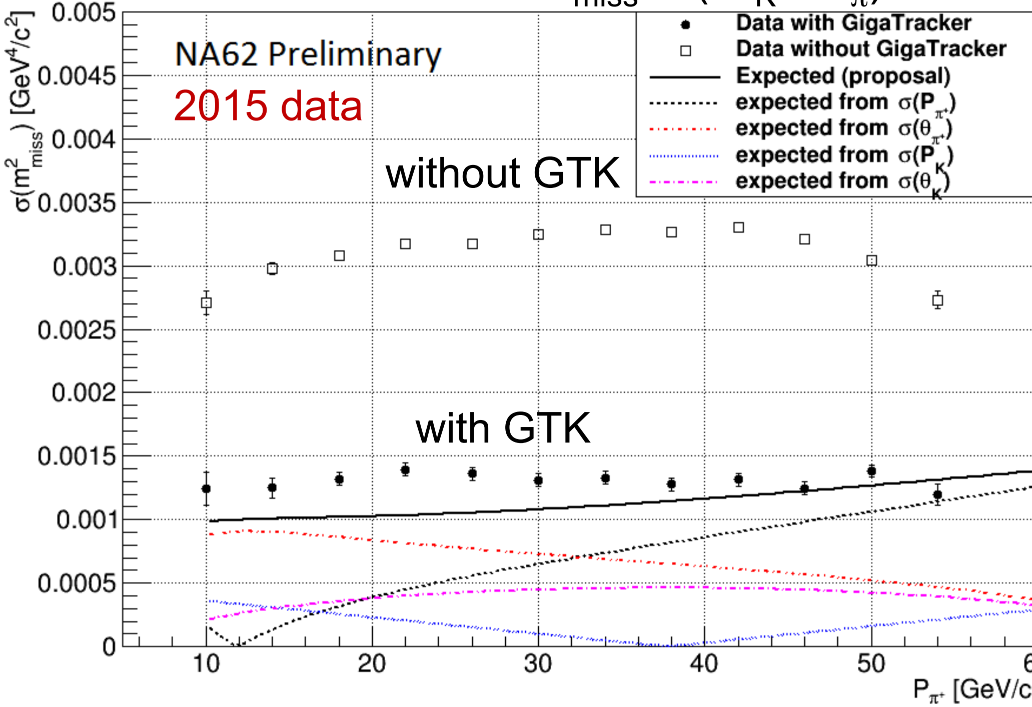
Measured time resolutions (close to design):

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

Signal Kinematics

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





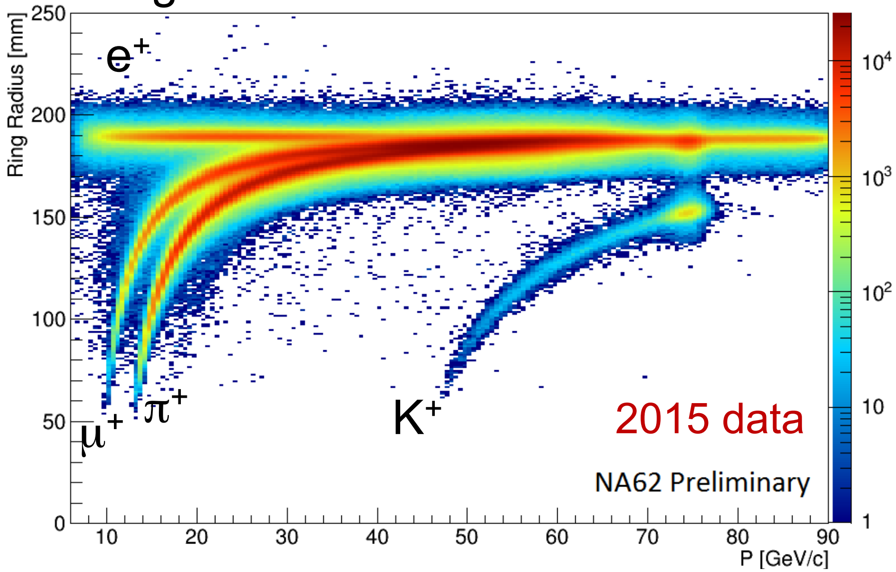
- **Aim at O(10⁴ ÷ 10⁵) rejection factor of main decay modes**
- $P_{\pi^+} < 35$ GeV/c for best $K^+ \rightarrow \mu^+\nu$ suppression
- Kinematics computed on $K^+ \rightarrow \pi^+\pi^0$ events, collected with LKr calorimeter selection
- O(10³) suppression factor achieved in 2015

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

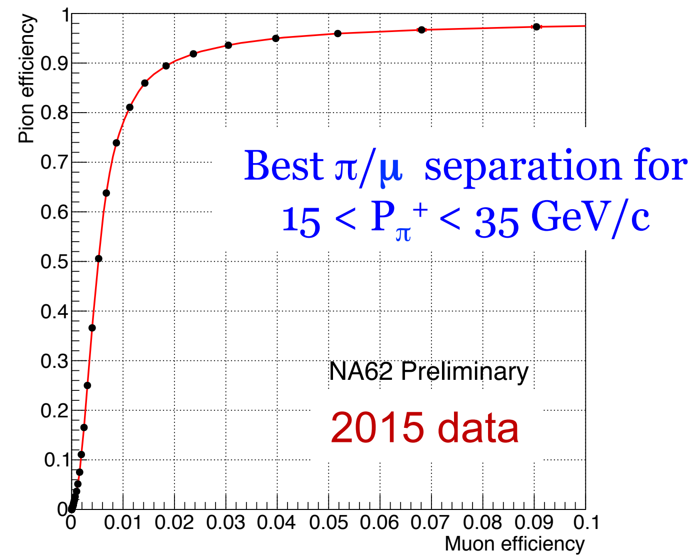
Background Suppression

Downstream PID

Ring radius in RICH vs Momentum



π^+ efficiency in RICH vs μ^+ efficiency



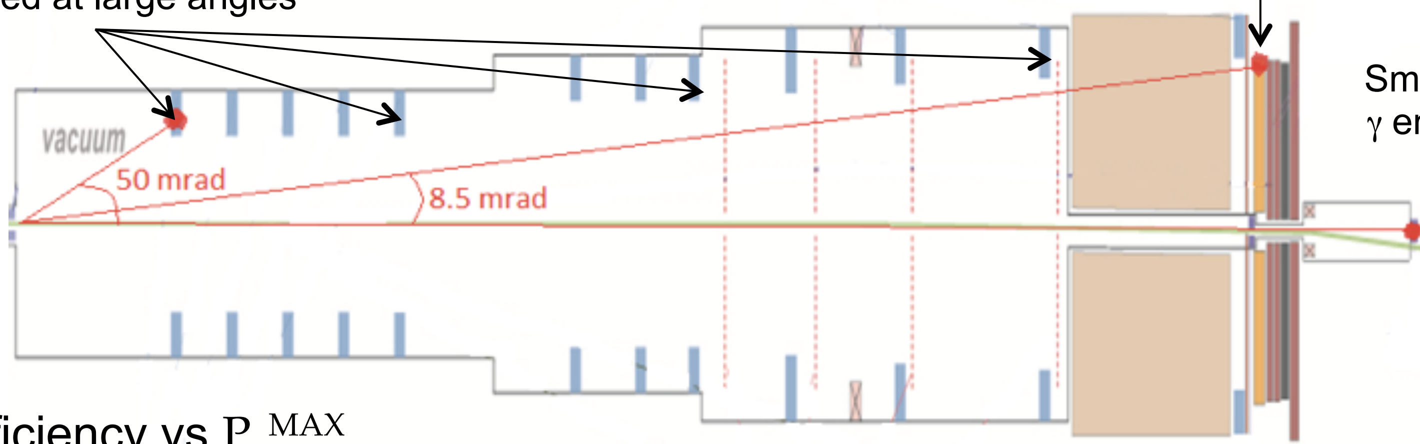
- **Aim at O(10^7) π/μ separation for $K^+ \to \mu^+\nu$ bkg**
- Use RICH, Calorimeters and Kinematics to select pure samples of pions and muons
- RICH: O(10^2) **π/μ** separation with 80% π^+ efficiency achieved for $15 < P_{\pi}^{+} < 35$ GeV/c
- Calorimeter: ($10^4 \div 10^6$) μ suppression with (90%÷40%) π^+ efficiency using a cut analysis (Room for improvements)

Separation with RICH close to expectations

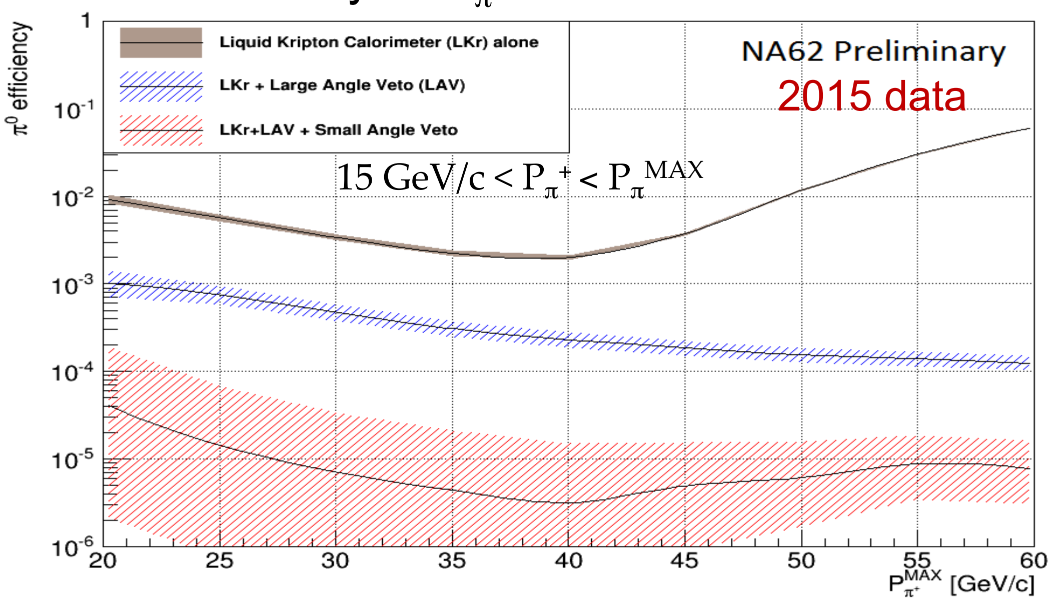
Separation with MUV, ongoing analysis

Background Suppression

Photon Rejection



π^0 efficiency vs P_π^{MAX}



- **Aim at O(10^8) π^0 rejection for $K^+ \to \pi^+\pi^0$ bkg**
- $E(\pi^0) > 40$GeV for $P_{\pi^+} < 35$ GeV/c
- Efficiency measured on data using $K^+ \to \pi^+\pi^0$ selected kinematically

O(10^6) π^0 rejection obtained in 2015

Need more stats to reach design sensitivity

Broader Physics Programme @ NA62

- **Standard Kaon Physics**
  - Measurements of the BR of all the main K+ decay modes
  - χPT studies: $K^+ \to \pi^+\gamma\gamma$, $K^+ \to \pi^+\pi^0 e^+ e^-$, $K^+ \to \pi^0(^+)\pi^0(^-) l^+\nu$
  - Precision measurement of $R_K = \Gamma(K^+ \to e^+\nu_e)/(K^+ \to \mu^+\nu_\mu)$
- **LFV with Kaons**
  - $K^+ \to \pi^+\mu^\pm e^\mp$, $K^+ \to \pi^-\mu^+ e^+$, $K^+ \to \pi^- l^+ l^+$ searches
- **π⁰ decays**
  - $\pi^0 \to$ invisible, $\pi^0 \to \gamma\gamma\gamma(\gamma)$
- **Heavy neutrino searches**
  - $K^+ \to l^+\nu_h$
  - ν_h from K,D decays and $\nu_h \to \pi^\pm l^\mp$
- **Dark sector searches**
  - Long living dark photon decaying in l^+l^- and produced by $\pi^0/\eta/\eta'/\Phi/\boldsymbol{\rho}/\omega$

NA62 Triggers for more Physics..

Test of L0 triggers for exotics data streams in 2016:

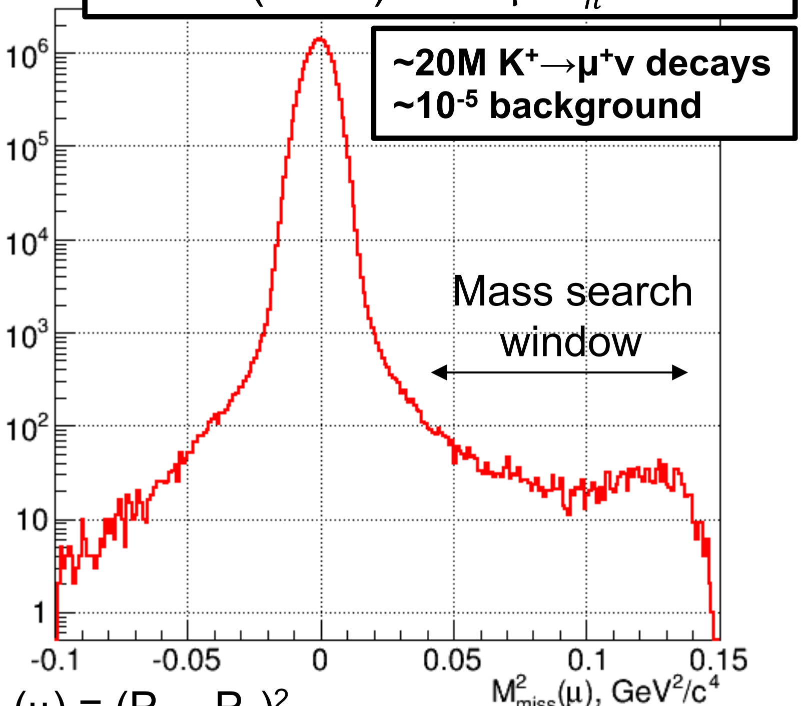
- **Multiple track trigger** (**MT**) built requiring signals in 10 RICH PMTs and two (NA62) CHOD quadrants
- **Dielectron trigger: MT** + more than 10GeV of energy in the LKr
- **Dimuon trigger: MT** + signals in two MUV3 tiles
- **LFV (muon-electron) trigger**: **MT** + more than 10GeV of energy in the LKr and signal in one MUV3 tile (selects **$K^+ \rightarrow \pi\mu e$** decays)

- From simulations total rate from above L0 triggers ~ **few 100 kHz**
- Feasible to run in parallel to the $K^+ \rightarrow \pi^+ \nu\nu$ trigger
- Validation of trigger rates with data is **currently underway**

Heavy Neutrino Searches

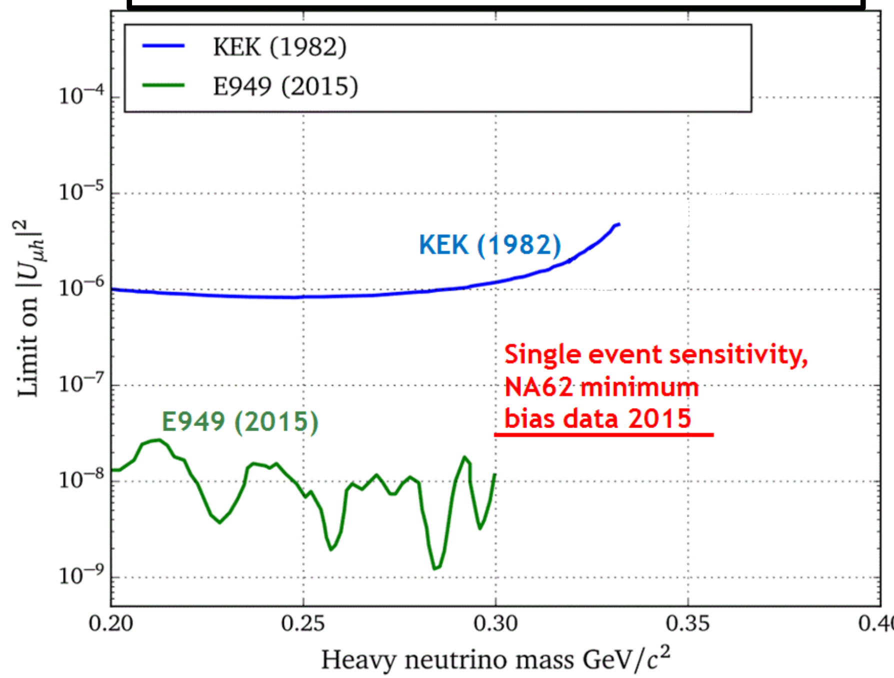
- Search for heavy neutrinos (HNL) produced in $K^+ \to \mu^+ \nu_h$ and $K^+ \to e^+ \nu_h$
- NA62 perfectly suited to search for ν_h in (100 –380) MeV/c² mass range:
  - $K^+ \to l^+ \nu_h$ decays kinematically enhanced wrt to $K^+ \to \mu^+ \nu_{SM}$
  - Background in the mass search region ~5 order of magnitude below the $K^+ \to l^+ \nu_{SM}$ peak

NA62 (2015): $K^+ \to \mu^+ \nu_h$ search



$M^2_{miss}(\mu) = (P_K - P_\mu)^2$

Direct Experimental Constraints

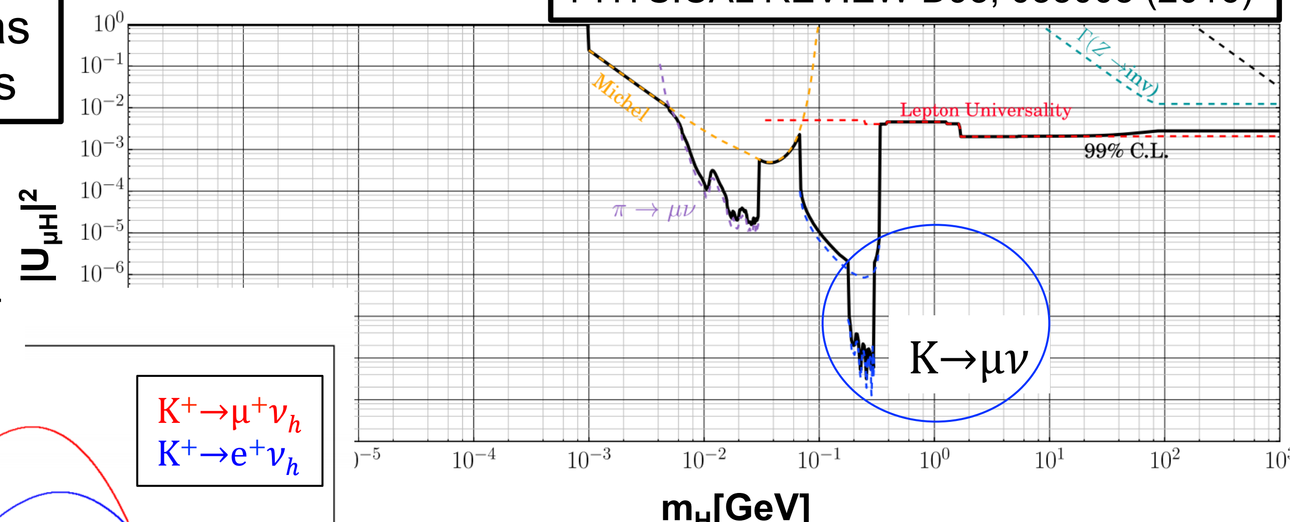


Heavy Neutrino Searches

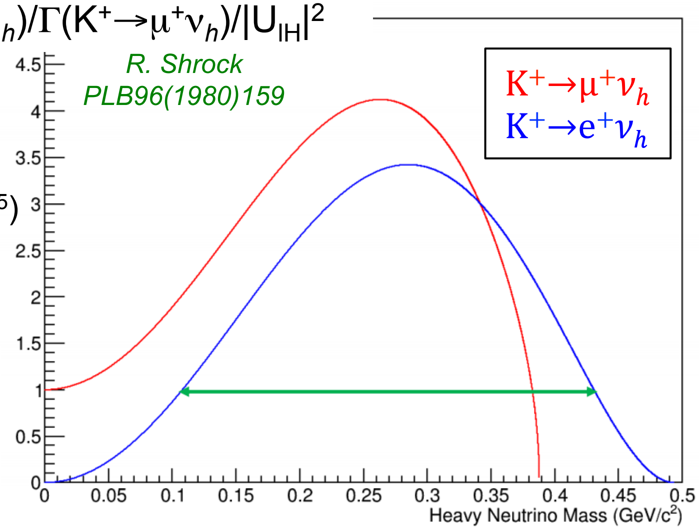
- Search for heavy neutrinos (HNL) produced in $K^+ \to \mu^+ \nu_h$ and $K^+ \to e^+ \nu_h$
- Production searches are model-independent
- Most stringent limits are set by Kaon decay measurements

Global limits on $|U_{\mu H}|^2$ as a function of HNL mass

PHYSICAL REVIEW D93, 033005 (2016)



HNL production, kinematic factor $\Gamma(K^+ \to l^+ \nu_h)/\Gamma(K^+ \to \mu^+ \nu_h)/|U_{lH}|^2$



$K^+ \to e^+ \nu_h$ helicity suppressed (~10^{-5}) for m(ν_h)→0
PLB698 (2011) 10

Lifting of the suppression by the HNL (for m(ν_h) ~0.1GeV) means there could be a similar number of $K^+ \to e^+ \nu_h$ events as $K^+ \to \mu^+ \nu_h$

LFV with Kaons

Search for forbidden states with lepton pair (ee, μμ, μe):

$$K^+ \to \pi^+\mu^+e^-$$
$$K^+ \to \pi^+\mu^-e^+$$
$$K^+ \to \pi^-\mu^+e^+$$
$$K^+ \to \pi^-e^+e^+$$
$$K^+ \to \pi^-\mu^+\mu^+$$

$$K^+ \to \mu^-\nu e^+e^+$$
$$K^+ \to e^-\nu\mu^+\mu^+$$

$$K^+ \to \pi^+\pi^0, \ \pi^0 \to \mu^+e^-$$
$$K^+ \to \pi^+\pi^0, \ \pi^0 \to \mu^-e^+$$

New Physics scenarios involving LFV:

- ✓ Neutrino is a **Maiorana fermion** (identical to antineutrino)
- ✓ Heavy (possible sterile) neutrino states
- ✓ **Supersymmetry** with R-parity violation or RH neutrinos

Astrophysical consequences:

- ✓ **Dark matter**, nucleosynthesis, Supernova evolution, …

LFV with Kaons

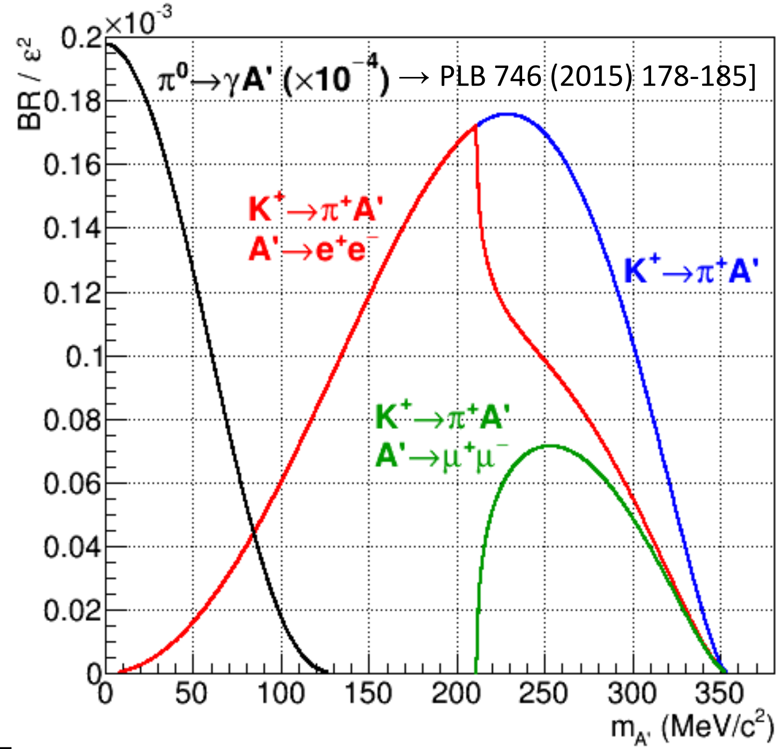
Searches for **K⁺→πμe** have potential to probe to 10^{-12}

Mode	UL at 90% CL	Experiment	Reference
$K^+ \to \pi^+\mu^+e^-$	1.3×10^{-11}	E777/E865	PRD 72 (2005) 012005
$K^+ \to \pi^+\mu^-e^+$	5.2×10^{-10}	E865	PRL 85 (2000) 2877
$K^+ \to \pi^-\mu^+e^+$	5.0×10^{-10}		

Searches for **K⁺→πμe** might be sensitive to dark photons with LFV couplings, masses from 100 to 350 MeV

NA62 perfectly suited to search LFV

L0, L1 specific triggers validation with data currently under way



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 $K^+ \to \pi^+ \nu \bar{\nu}$ measurement in line with design
- Further compelling physics program is going to be addressed
    - Rare decays, searches for LFV, HNL,...

NA62 physics runs 2016-2018

- run at 20% intensity now, going to 50% soon
    - Expect few SM $K_{\pi\nu\nu}$ events by end of 2016

Ultimate Goals:

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

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

Conclusions

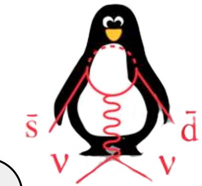
nominal intensity

d for data quality studies

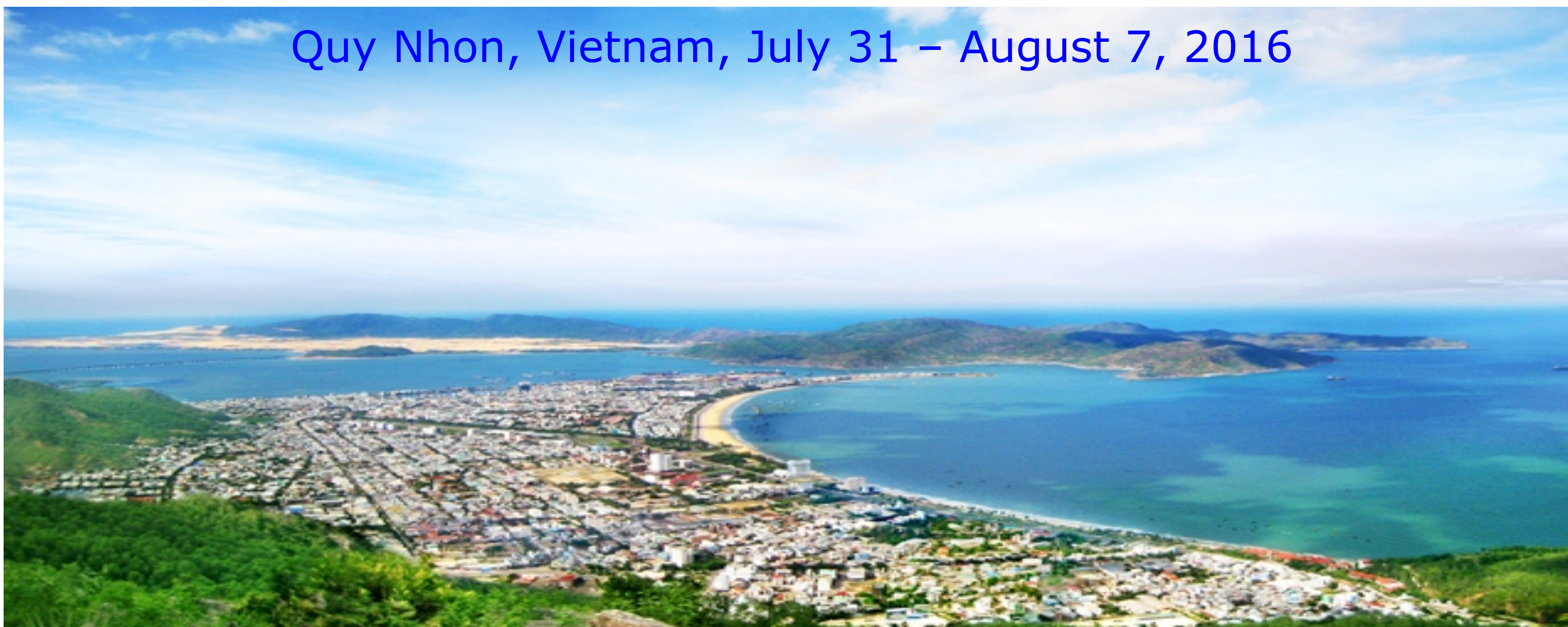
line with design

e addressed

✓ measure BR(K → π νν) with ~10% accuracy

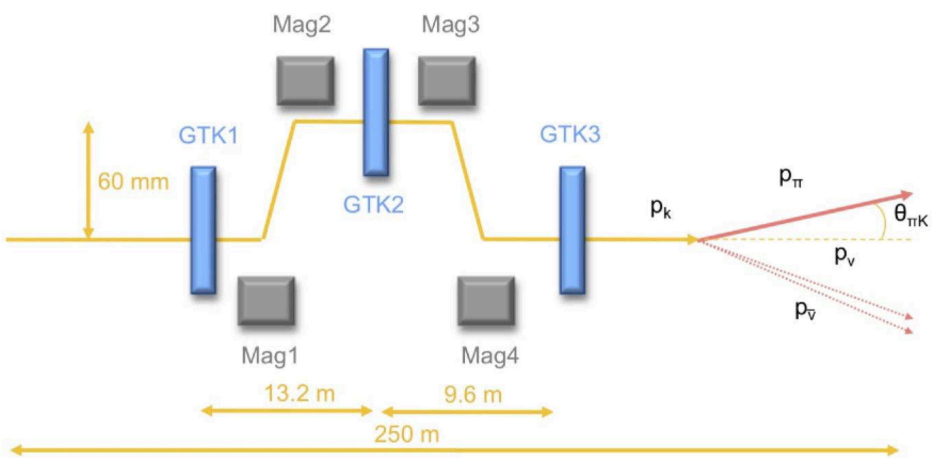


Spares



Beam Reconstruction

GIGATRACKER (GTK)



Spectrometer layout

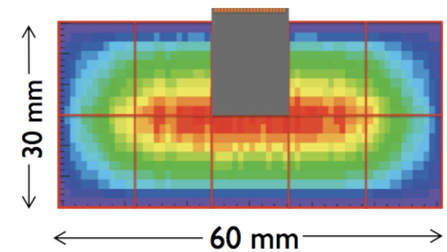
- 3 stations of hybrid silicon pixel detectors
- 4 achromat magnets (beam displacement ~60mm)
- 18, 000 pixels/station of size 300 × 300 μm²

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

Partially commissioned in 2015

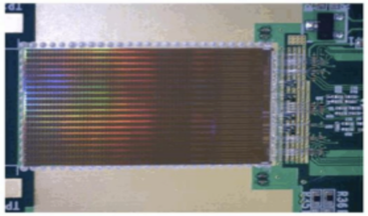
Tracking of K^+:

- High non-uniform nominal beam rate @ GTK (750 MHz)



- minimal amount of material $X/X_0 < 0.5\%$/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 $\sigma_\theta = 16\ \mu rad$

Pion Reconstruction

STRAW

Tracking of secondary charged particles:

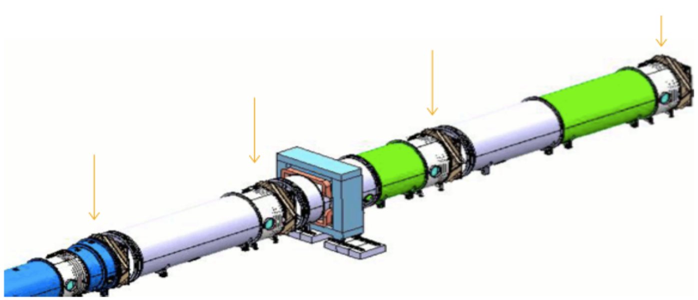
- operation in vacuum;
- ultra-light material X/X0 ~ 0.1%/"View"
- spatial resolution $\sigma \leq 130\mu m$ (1 "View")
- $\sigma_p/p \sim 0.32\% \oplus 0.008\%\, p$ [GeV/c]
- $\sigma_{\theta(K\pi)}$ = 20-50 μrad

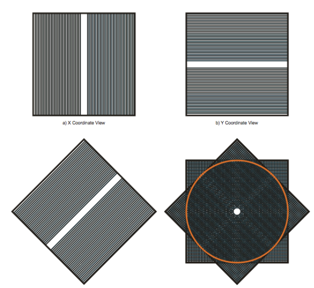
P_π momentum and position: **STRAW**
π^+ timing: **RICH**

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)

Fully commissioned in 2015

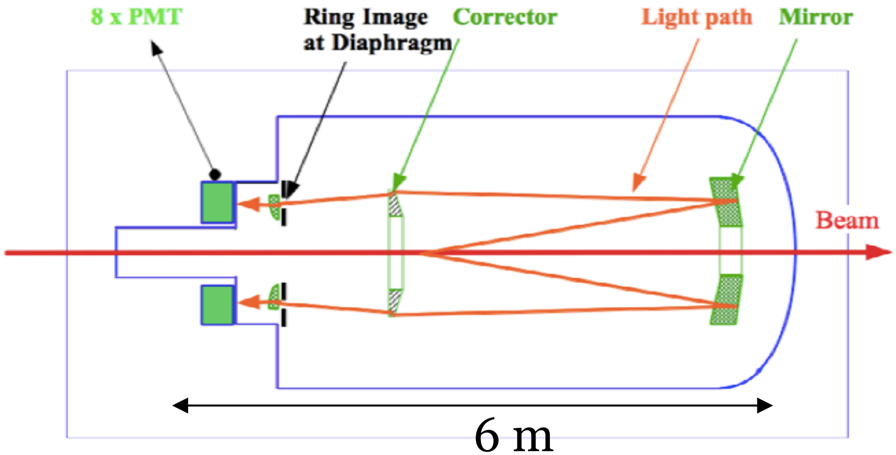




- 1,792 straw tubes/chamber (16 layers - 4 "Views")

Kaon ID – Beam Timing

Suppress background from particle interactions with material on the beam line
Match upstream info from GTK (~750MHz) with downstream π detection(~10MHz)



K⁺ ID and tagging under conditions:

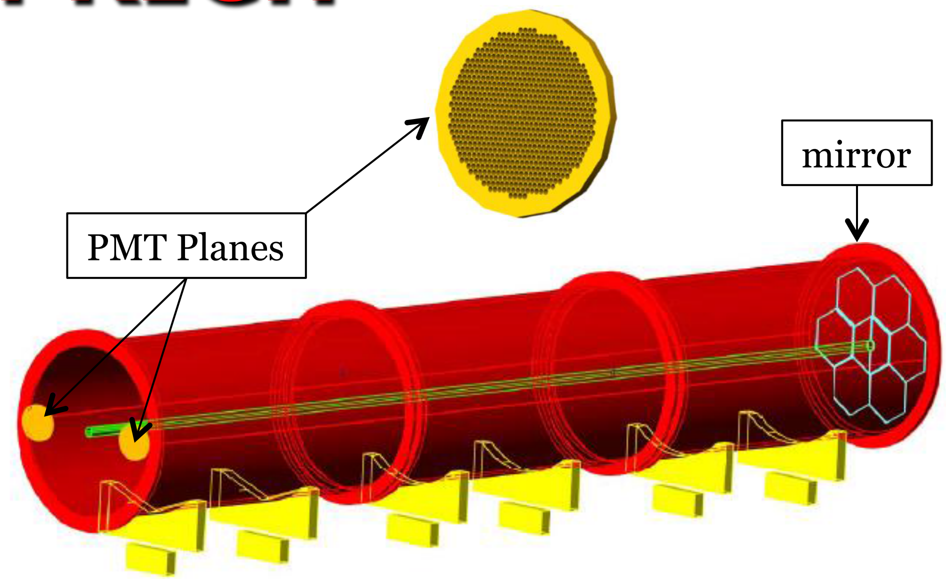
- Nominal hadron beam rate (~750 MHz)
- K beam composition ~ 6% (~45MHz)
- Cherenkov light yield ~ 200 γ /K (~ few MHz/mm²)

KTAG layout & principles:

- Original CEDAR counter used at CERN SPS
- Vessel filled with N2 gas of controlled pressure
- Insensitive to pion and protons
- New external optics, PMTs, FE and RO
- Kaon tagging with σ_t < 100 ps time resolution

Fully commissioned in 2015

Pion ID: RICH



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

Requirements:

π^+/μ^+ separation > 10^2 up to 35 GeV/c

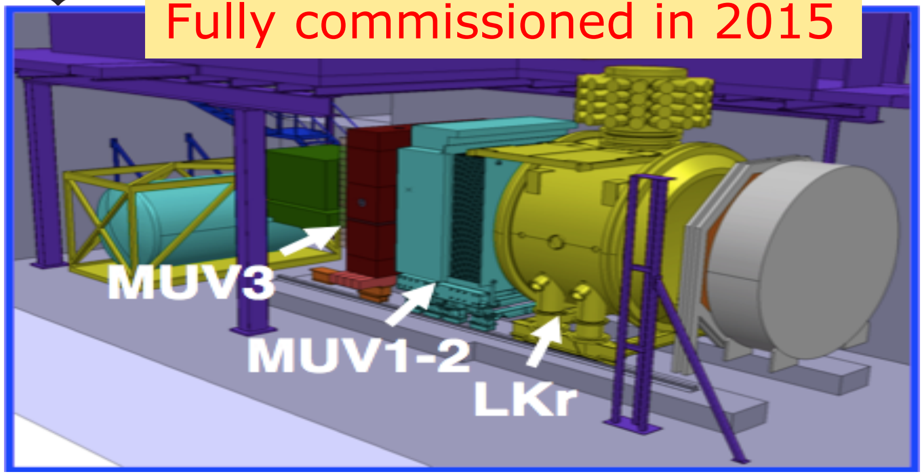
Resolution on π crossing time $\sigma_t < 100$ ps

RICH layout & principles

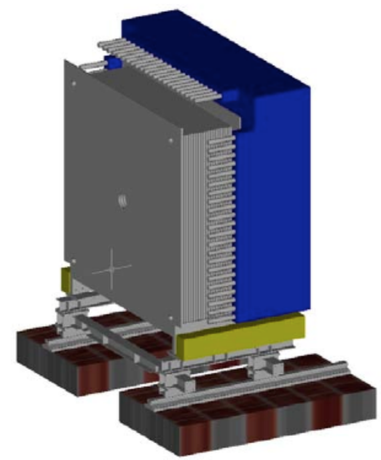
- Cherenkov light ring radius proportional to β of particle
- Ne gas at 1 atm;
- 14 GeV/c threshold for π
- High granularity γ detector (2000 PMTs)

PID: LKr, MUV

Fully commissioned in 2015



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

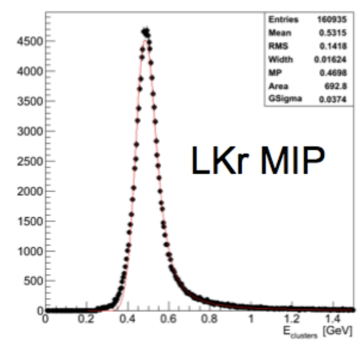


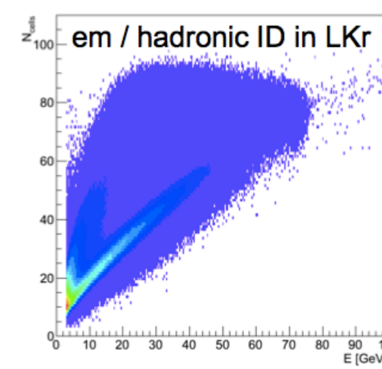
$\pi/\mu/e$ separation

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

Fully commissioned in 2015

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 $\pi^0 \rightarrow \gamma\gamma$
- Kinematic cut on $p_\pi < 35$ GeV gives $\pi^0 \rightarrow \gamma\gamma$ with > 40 GeV

First LAV station

LKr

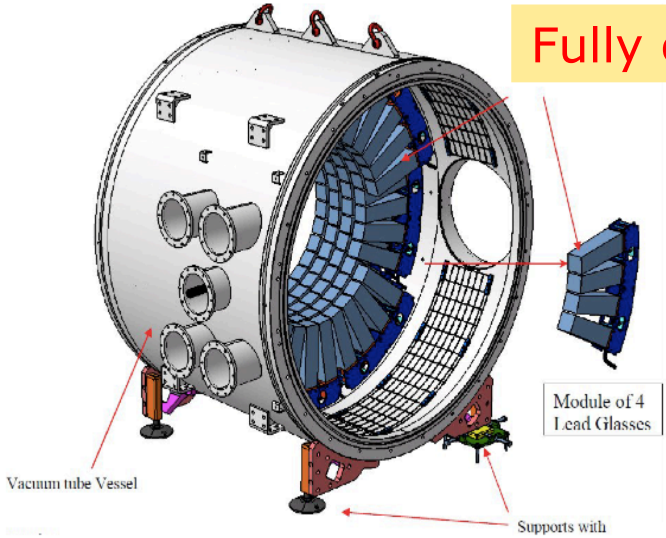
Simulations showed:

- $K^+ \rightarrow \pi^+\pi^0$ 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)

Detector	Technology	θ [mrad]	Max. (1-e)
LAV (12 Stations)	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

Fully commissioned in 2015



-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);

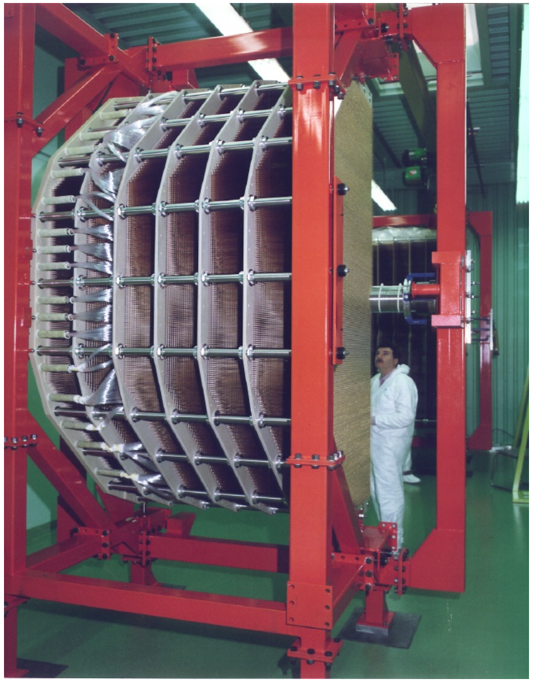
- quasi-homogeneous ionization chamber;

- 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 ~2×2 cm^2 each and no longitudinal segmentation;

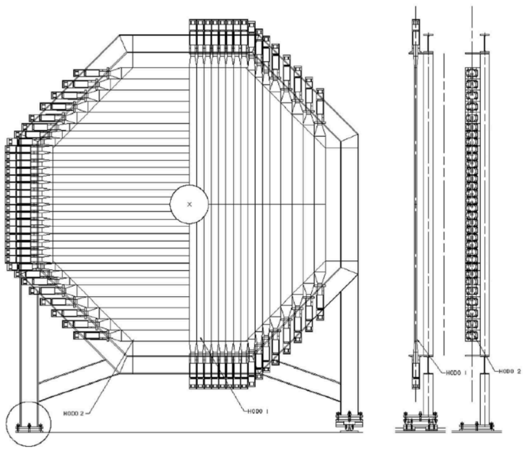
- from studies with e^- at E>10GeV -> $(1-\varepsilon) \sim 8 \times 10^{-6}$

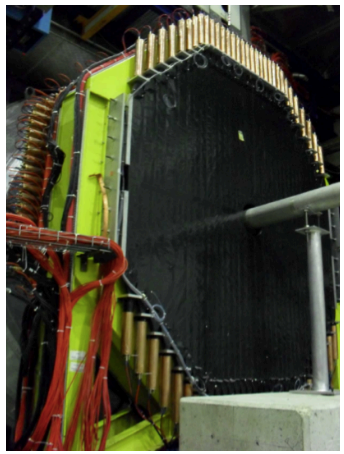


Charged Tracks Veto System

Fully commissioned in 2015

CHOD (NA48 Charged Hodoscope)

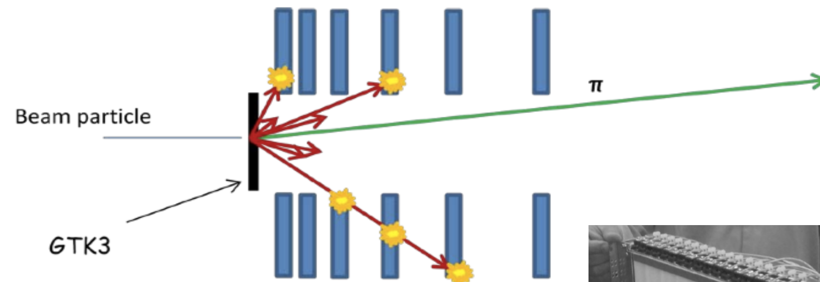


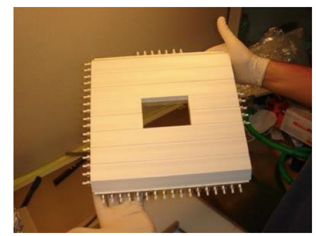


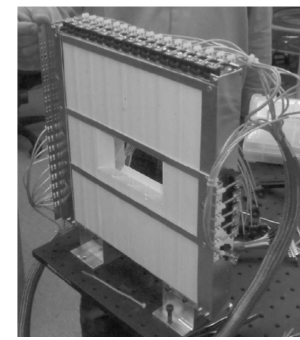
- 2 planes of plastic scintillation counters (horizontal & vertical)
- ~ 0.05 X0 each plane
- time resolution $\sigma_t \sim 200$ ps;

Fast charged particles signal for trigger

CHANTI



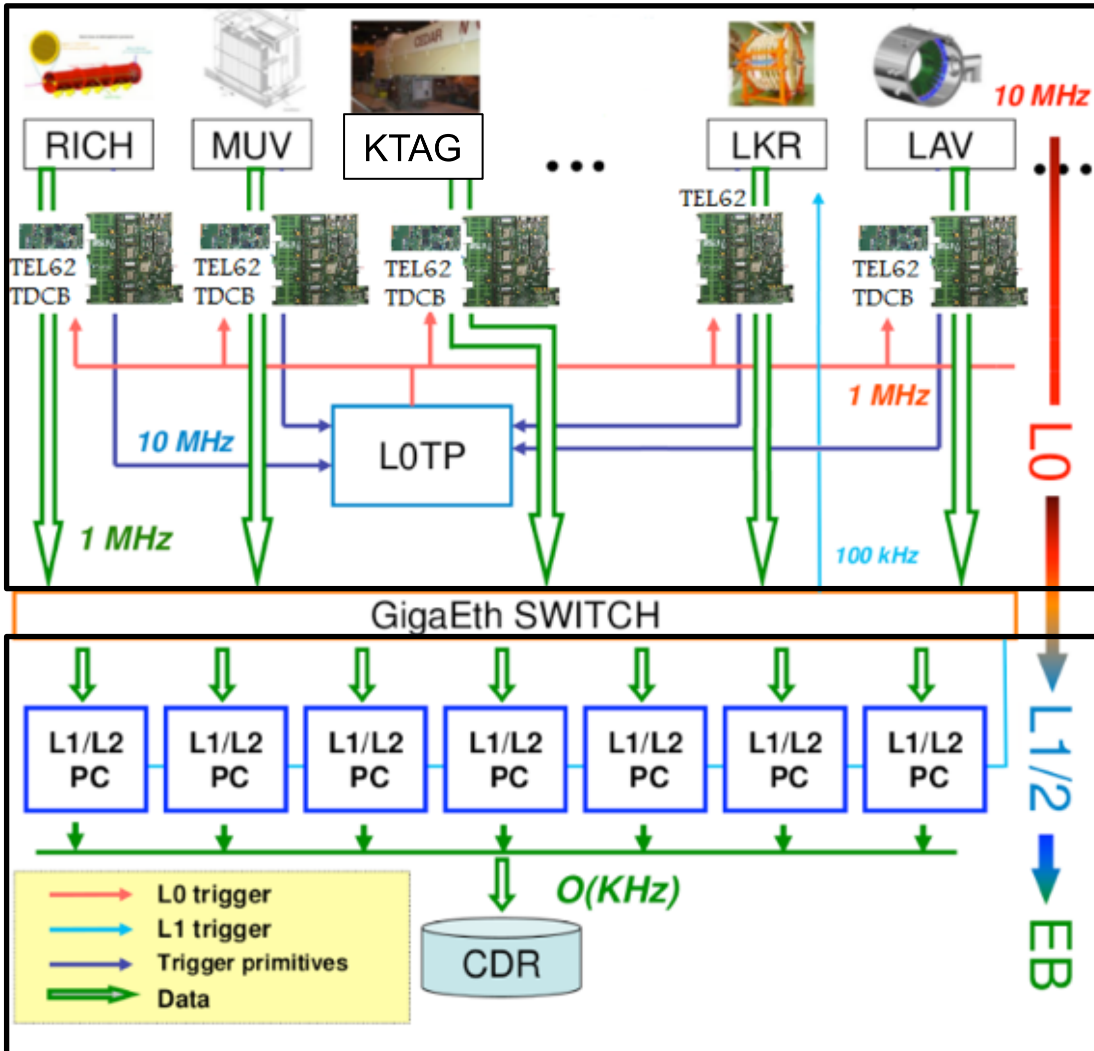




- 6 scintillator stations in vacuum
- WLS + SiPM readout
- angle coverage (1.3-4.9) mrad

Veto for charged particles from inelastic interactions in GTK3

The NA62 Trigger&DAQ System



L0 Trigger hardware implemented (FPGAs) from 10MHz to 1MHz

L0 for $K\pi\nu\nu$ evt selection
RICH & !MUV3 & !LKr & !LAV(12th)

L1/2 Trigger software implemented on PCfarms from 1MHz to O(KHz)

L1 for $K\pi\nu\nu$ evt selection
KTAG & !LAV(All) & Straw
(ongoing validation with data)