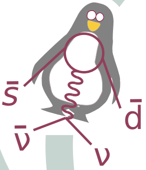
Searching for New Physics with the NA62 Experiment

Seminar at CPPM, Marseille, France



Mathieu PERRIN-TERRIN

Université Catholique de Louvain, Belgium.

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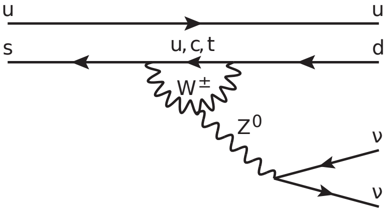
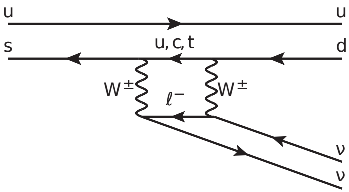
Outline

- **Physics Case** ~10min
  - Exploring NP with $K^+ \to \pi^+ \nu \bar{\nu}$
  - And with many more channels (axion, dark photon etc...)
- **The NA62 Experiment** ~20min
  - General Description
  - A close up on the GigaTracker
- **Analysis of the 2015 Data** ~15min
  - Performances for the $K^+ \to \pi^+ \nu \bar{\nu}$ analysis
- **Conclusions and Prospects**

$K^+ \to \pi^+ \nu \bar{\nu}$: a rare and clean decay

- Flavour Changing Neutral Current: no tree diagrams, hard GIM suppression





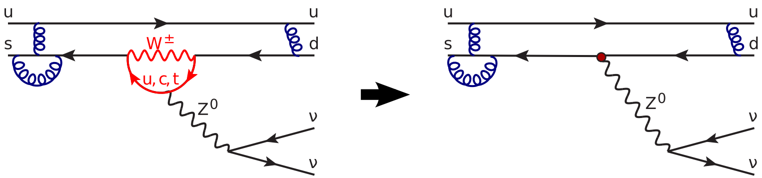
- Very rare SM process [Buras, 1503.02693]

$$\mathcal{B}(K^+ \to \pi^+ \nu \bar{\nu}) = (8.4 \pm 1.0) \times 10^{-11}$$

- Diagrams with new particles could modify decay properties
- Resulting deviations easily detectable as theory is very clean...

Theoretical Interlude...

- Must describe the hadronic initial and final states



- Use EFT to separate short and long range physics: [Buras 9806471]

$$\mathcal{A}(M \to F) \quad = \quad \frac{G_F}{2} \sum_i V^i_{CKM} C_i(\mu) \langle F | Q_i(\mu) | M \rangle$$

$\langle F | Q_i(\mu) | M \rangle$ long range, matrix elements, **large uncertainties**
$C_i(\mu)$ short range, Wilson coefficients

Theoretical Uncertainties

Matrix Elements: $\langle F|Q_i(\mu)|M\rangle$

- Normally large uncertainties
- Derived from $K^+ \to \pi^0 e^+ \nu$ using isospin symmetry:

$$\langle \pi^+|(\bar{s}d)_{V-A}|K^+\rangle = \sqrt{2}\langle \pi^0|(\bar{s}u)_{V-A}|K^+\rangle$$

Wilson Coefficients: $C_i(\mu)$

- NLO QCD correction for top, NNLO for charm
- NLO EW correction for top & charm

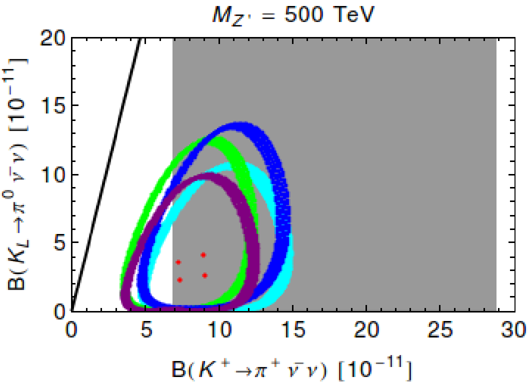
SM Predictions [Buras 1503.02693]

$$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}) = (8.4 \pm 0.3 \pm 1.0_{CKM}) \times 10^{-11}$$

- Dominant uncertainty from CKM inputs (V_{cb}, γ)

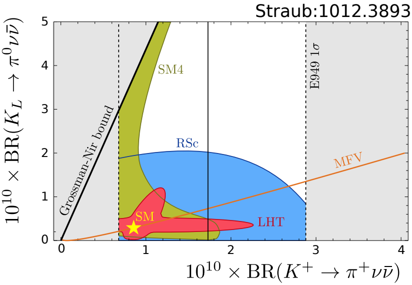
Testing the SM and the Physics Beyond (1/2)

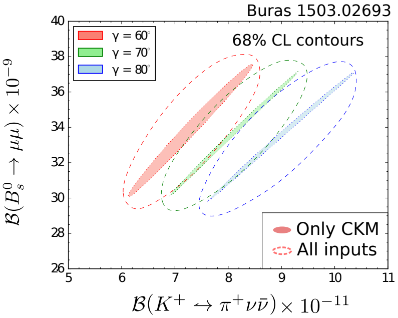
- Deviation from $\mathcal{B}_{SM}$ would signal new particles (e.g. vector boson) contributions
- One example: Simplified Z-Z' models [Buras 1408.0728]



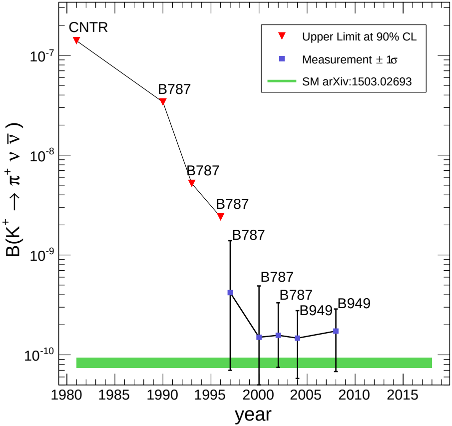
Testing the SM and the Physics Beyond (2/2)

- Enhanced NP sensitivity (MFV) when using correlations with $\mathcal{B}(K_L \to \pi^0 \nu\bar{\nu})$, $\mathcal{B}(B_s^0 \to \mu^+\mu^-)$, γ, $B \to K(K^\star)\mu\mu$, ϵ'/ϵ
- A key observable for the LHC era





State of the Searches



E949 Measurements – 2008

- Stopping kaon technique

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

[Phys. Rev. D 77, 052003 (2008)]
[Phys. Rev. D 79, 092004 (2009)]

Related Decay $K_L \to \pi^0 \nu\bar{\nu}$

- KOTO at JPARC: single SM event sensitivity by 2020
- $\mathcal{B}(K_L \to \pi^0 \nu\bar{\nu}) = (3.0 \pm 0.3) \times 10^{-11}$

[Buras 1503.02693]

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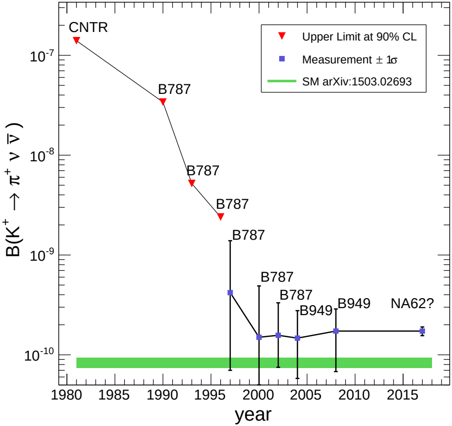

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[Buras 1503.02693]

NA62 Main Goal

- Measuring $\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu})$ with 10% uncertainty in 2 years
  - $O(100)$ signal events
  - Sig/Bkg $O(10)$
- With a signal efficiency of $\sim$10%, it implies:
  - 10^{13} kaons in 2 years
  - Background rejection of 10^{12}
    Main background $K^+ \to \pi^+\pi^0$, $\mathcal{B}$= 20%
- Use SPS for decay in flight technique experiment
  - Large integrated kaon flux achievable
  - 400 $\mathrm{GeV/c}$ SPS proton beam favorable to K production

A Broad Physics Program(1/2)

NA62 Potential

- High beam intensity: 10^{13} K^+ and 10^{11} π^0 by 2018
- Excellent PID and hermetic photon coverage
- Long O(100m) decay region

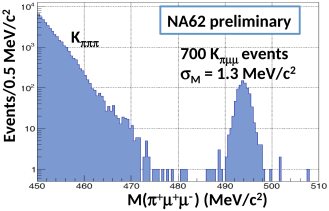
Rare K^+ and π^0 Decay, improve present SES by $O(10^{-2})$

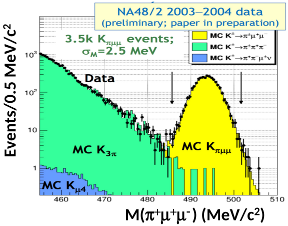
- LFV and LNV e.g. $K^+ \to \pi^- \mu^+ \mu^+$ or $K^+ \to \pi^\pm e^\pm \mu^\mp$ etc
- Chiral perturbation theory e.g. $K^+ \to \pi^+ \gamma\gamma$
- π^0 from factor [NA62 1612.08162]

A Broad Physics Program (2/2)

Dark Sector

- Search axion, dark photon, inflaton, HNL with K^+ and π^0 decays e.g. $K^+ \to \pi^+ X$ or $K^+ \to \ell^+ X$ or $\pi^0 \to \gamma X$
- Search new particles in beam dump mode

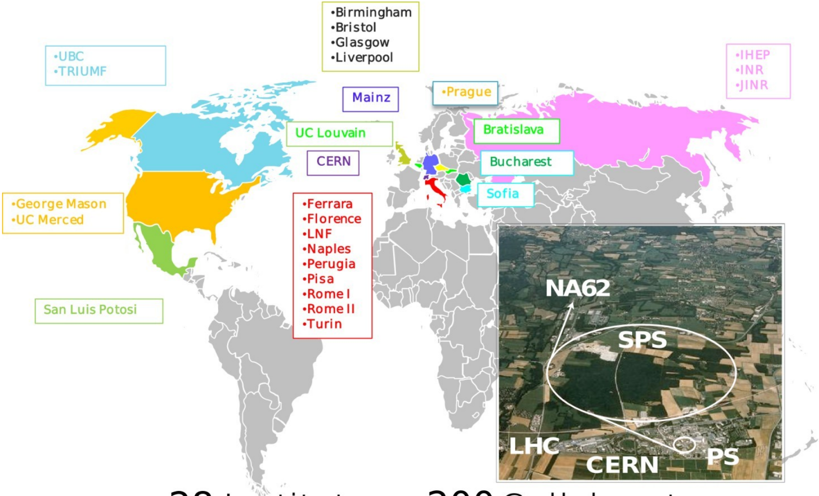




Post $K^+ \to \pi^+ \nu\bar{\nu}$ Phase

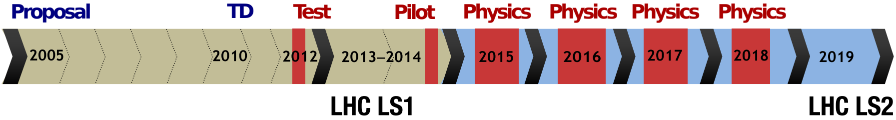
- Untill 2018 limited trigger bandwidth ($K^+ \to \pi^+ \nu\bar{\nu}$ priority)
- Physics Beyond Collider Workshop see T. Spadaro's Talk

NA62 Collaboration



28 Institutes, ~200 Collaborators

NA62 Time Line



Reference Documents

2005 Proposal

[CERN-SPSC-2005-013]

2010 Technical Design

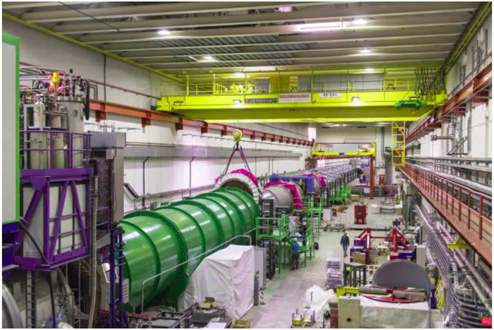
[NA62-10-07]

2015 Analysis Sensitivity

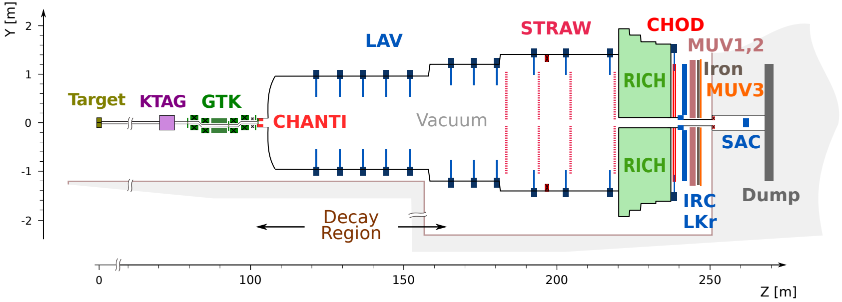
[G. Ruggiero, KAON 2016]

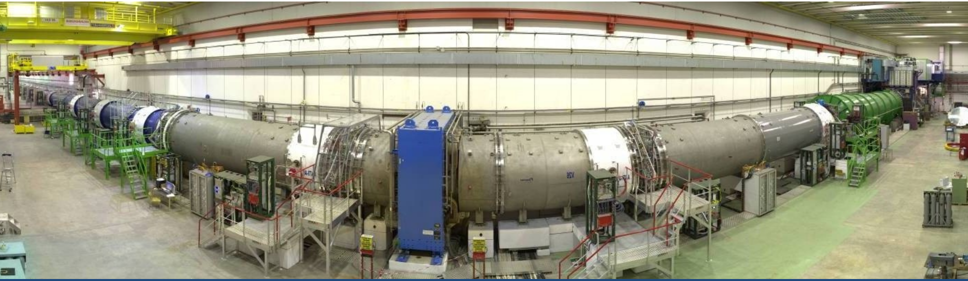
[Detector Paper, To Be Submitted]

2021 PBC Wokshop



NA62 Apparatus





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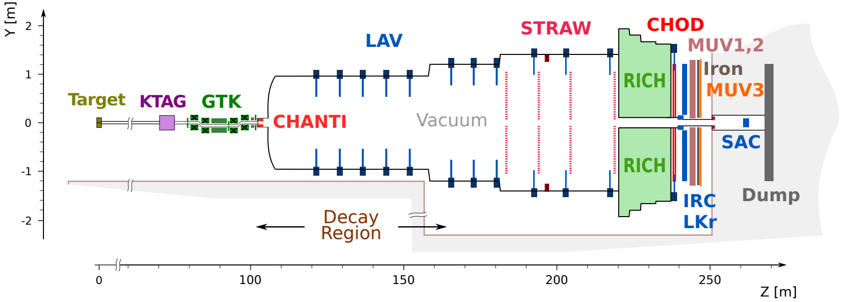


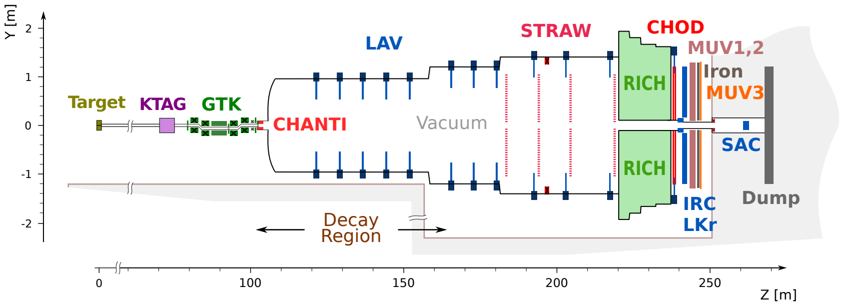
Secondary Beam from SPS

- 5s spill at 750 MHz (not bunched)
- Composition:

p	π^+	K^+
70	24	6%

- 75 GeV/c with $\delta p/p = 1\%$

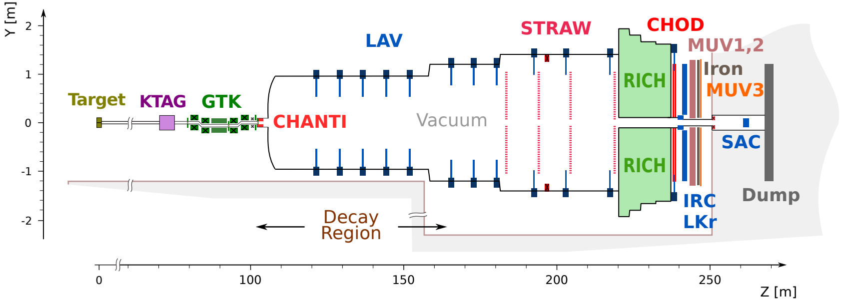
NA62 Apparatus



Beam Instrumentation

- Kaon Tagging (KTAG, Differential Cerenkov N_2 or H_2)
- Kinematics (GigaTracker, Silicon hybrid pixels)
- Beam particle scattering detection (Guard Ring CHANTI)
- Arrival time measurement

NA62 Apparatus

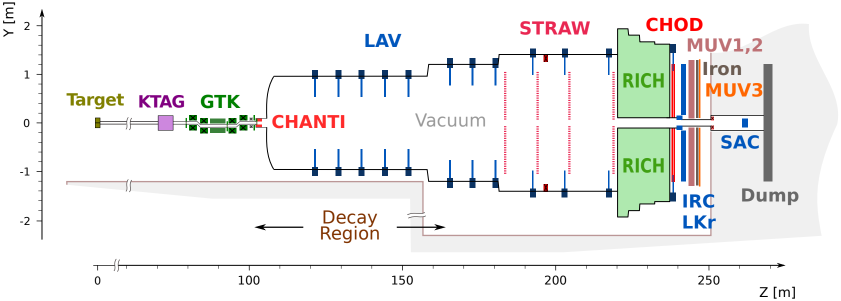


Decay Region

- 120m long, in vacuum (500 m^3 at 10^{-6} mbar)
- 10% of K^+ decay in the first 65m:

5MHz of K^+ decay, 4.5×10^{12}/year

NA62 Apparatus



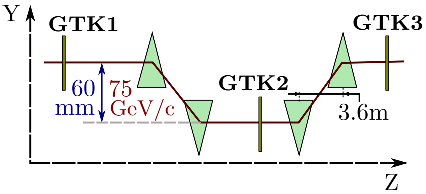
Decay Products Instrumentation

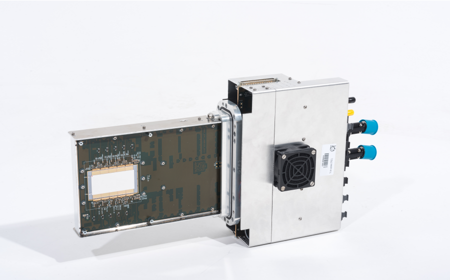
- Kinematics (STRAW Spectrometer, in vacuum!)
- Photon Detection (LAV, IRC, LKr, SAC)
- π and μ identification (RICH, Hadronic Calo MUV's)
- Arrival time measurement (all + CHOD for charged particles)

A Special Detector: The GigaTracker

Beam 4D Tracker Principle

- 3 time resolved pixel arrays installed in the beam





A Special Detector: The GigaTracker

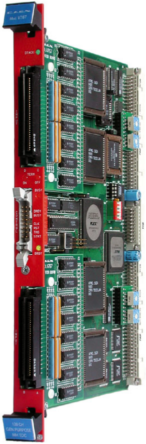
Demanding Specifications

- 10^9 particles / s over $3\times6\ \mathrm{cm}^2$, peak intensity 1.5 MHits/s/mm^2
- Fluence 2×10^{14} 1MeVn_{eq} per 100 days of run
- $\delta p/p = 0.2\%$ and $\delta\theta_x = \delta\theta_y = 16\mu\mathrm{rad}$
- Track time resolution required: < 150 ps
- Material budget required: $< 0.5\%$ X_0 per station

The GigaTracker Design

Technical Challenge 1: Particle Rate

- Kinematics needs $300 \times 300\ \mu\text{m}^2$ pixels
  i.e. 54,000 pixels to be read with TDC!!
- Dedicated chips (TDCPix):
  -720 TDCs per $7 \times 12\text{mm}^2$
  -4 serialisers running at 3.2 GBit/s
  -10 chips per station
- Station replaced after 100 days
  in the beam



Std VME 128 Channels
Chip HPTDC 28 Channels

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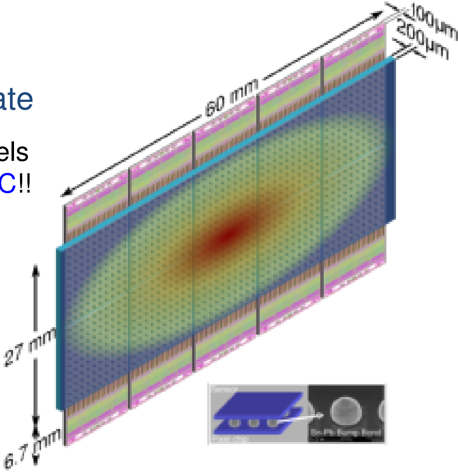
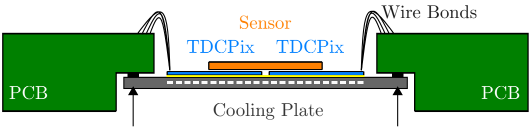


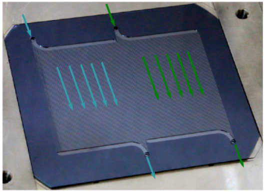
Hybrid Pixels, chip compliant with
both p-in-n and n-in-p sensors

The GigaTracker Design

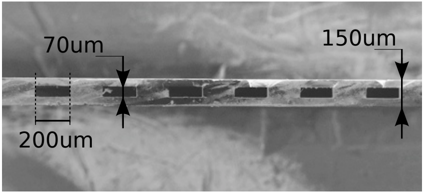
Technical Challenge 2: Material Budget

- Detector operated in vacuum (10^{-6} mbar)
- Cool TDCPix's (3.5W each) with less than 0.2% X_0 of material
- Develop (HEP first) micro-channel cooling (liquid C_6F_{14}, 3g/s)



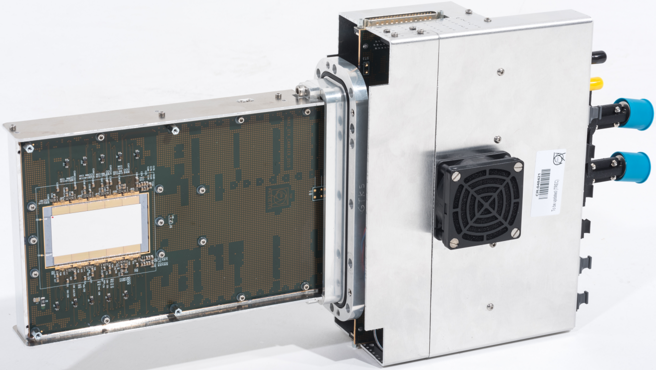


Cooling Plate (glassed closed)

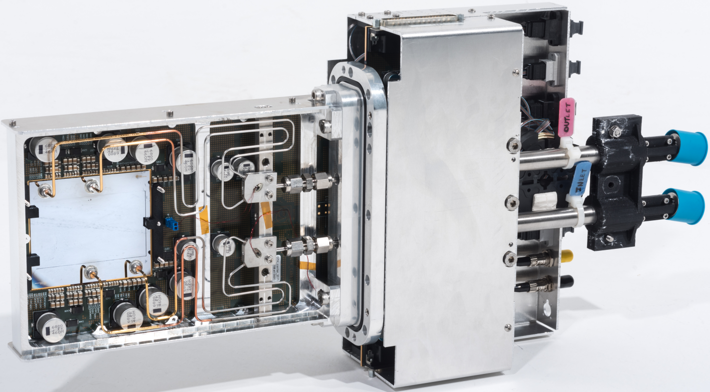


Cooling Plate (crossed view)

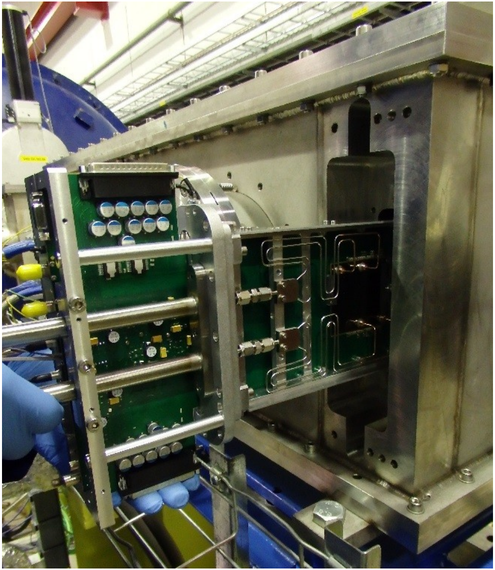
GigaTracker Sensor Side



GigaTracker Cooling Plate Side

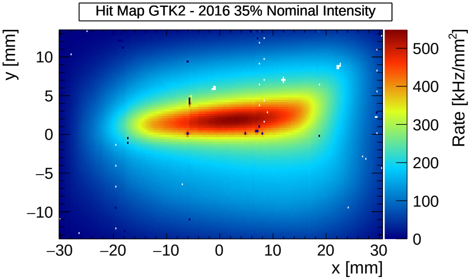


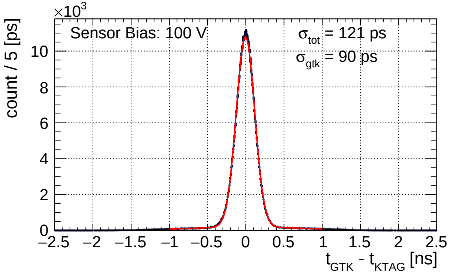
GigaTracker being installed



GigaTracker Performance

- Fully commissioned in 2016

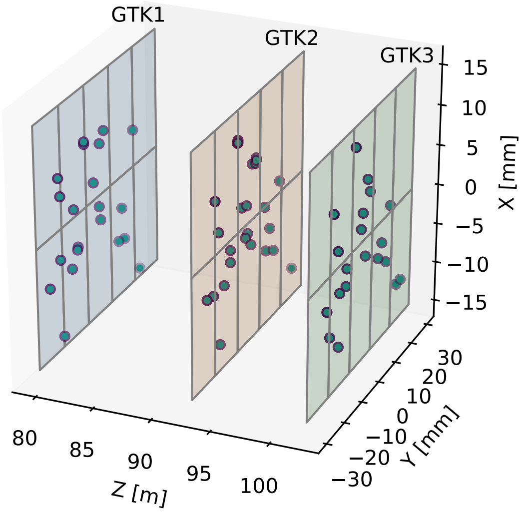




- Time Resolution ($\sim$ 100ps) better than specifications (150ps)!
- Dose accumulated in 2016: 6% of a nominal year (6 MRad)
- Kinematics performance (see 2015 data analysis)

4D Tracking: One Typical Event

Beam Intensity: 35% of nominal



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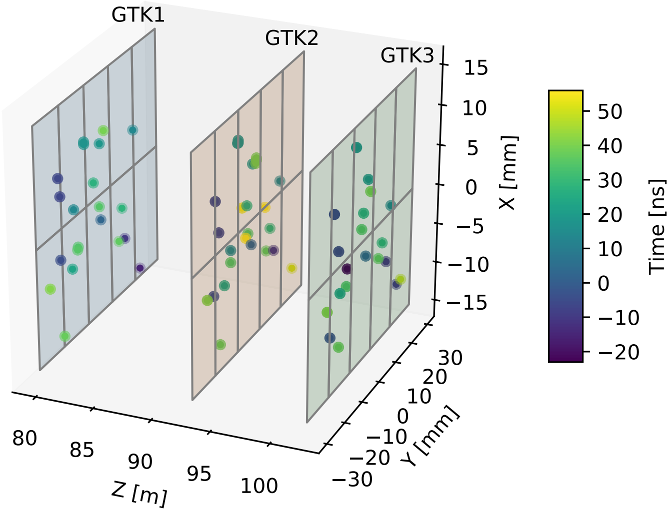

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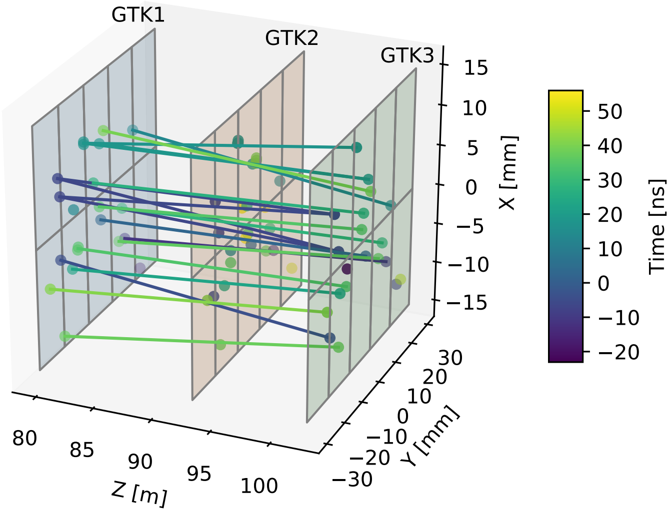
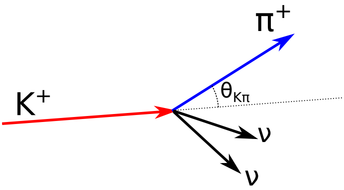


$K^+ \to \pi^+ \nu \bar{\nu}$ Analysis Principles

Signal Topology



Backgrounds

- Dominantly mis-reconstructed K^+decays

	$\mathcal{B}$[%]
$K^+ \to \mu^+ \nu$	63
$K^+ \to \pi^+ \pi^0$	21
$K^+ \to \pi^+ \pi^+ \pi^-$	5.6
$K^+ \to \pi^0 \mu^+ \nu$	3.3
$K^+ \to \pi^+ \pi^0 \pi^0$	1.7

- Early decays or inelastic scatterings

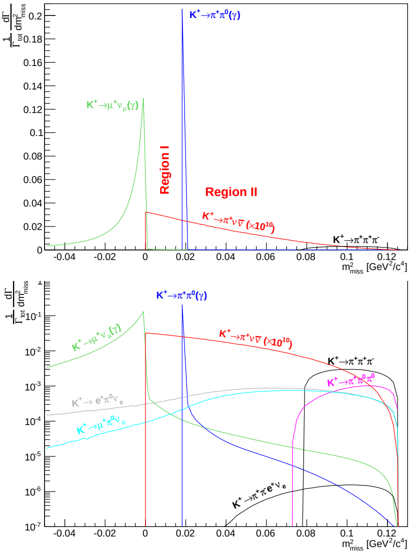
$K^+ \to \pi^+ \nu \bar{\nu}$ Analysis Principles

Key Detector Performance

- PID: K and π, μ, e
- Hermetic Photon detection
- Sub ns timing
- Precise kinematics

Key Analysis Elements

- two $m_m^2 = |\mathbf{p}_K - \mathbf{p}_\pi|^2$ regions
- $15 < p_\pi < 75\ \mathrm{GeV/c}$
- 65m fiducial decay region



Analysis Sensitivity (MC)

Expected Bkg Rejetion

- Kinematics
  $O(10^{-4}$–$10^{-5})$
- Charged PID
  $O(10^{-7})$
- Photon Detection
  $O(10^{-8})$
- Timing
  $O(10^{-2})$

Expected Nb of Candidates

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

Minimum bias data taken in 2015 to evaluate our bkg rejection (this talk)

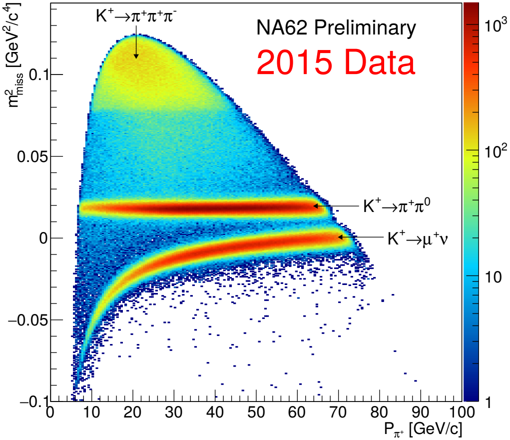
Sensitivity Study - 2015 Minimum Bias Data

Data (control) Sample

- Isolated downstream track (DT)
- DT matching energy deposits in calorimeters
- DT matching a beam track (BT)
- BT tagged as Kaon
- Vertex in fiducial region

Timing

- Kaon ID $\leq$ 100 ps
- Beam Track $\leq$ 100 ps
- Downstream Track $\leq$ 200 ps
- Calorimeters $\simeq$ 1-2 ns



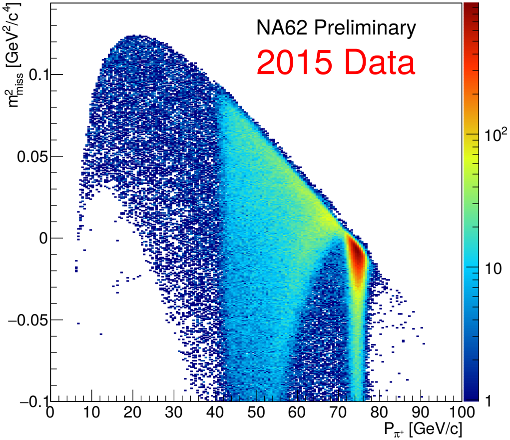
Sensitivity Study - 2015 Minimum Bias Data

Data (control) Sample

- Isolated downstream track (DT)
- DT matching energy deposits in calorimeters
- DT matching a beam track (BT)
- BT NOT tagged as Kaon
- Vertex in fiducial region

Timing

- Kaon ID $\leq$ 100 ps
- Beam Track $\leq$ 100 ps
- Downstream Track $\leq$ 200 ps
- Calorimeters $\simeq$ 1-2 ns



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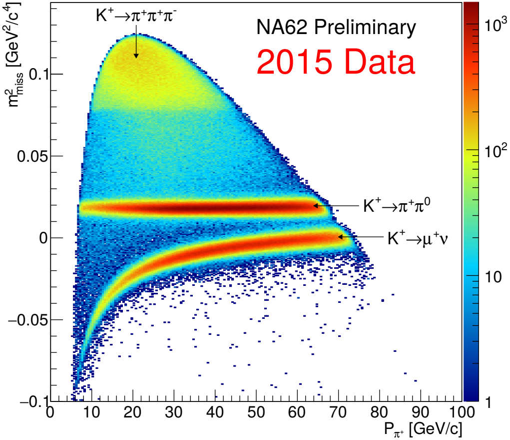
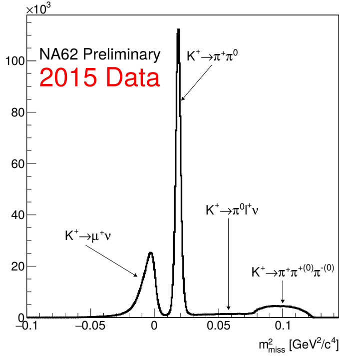
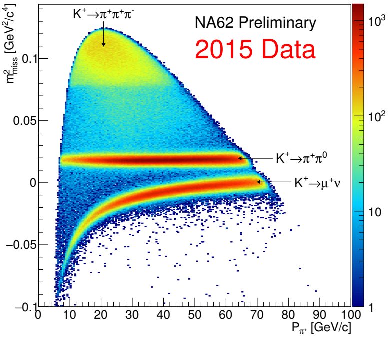


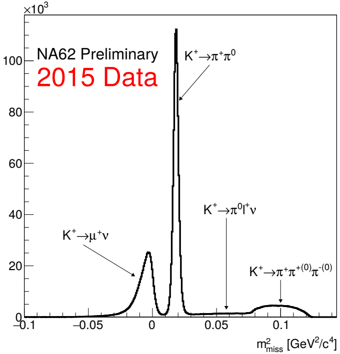
Kinematics in view of 2015 Data

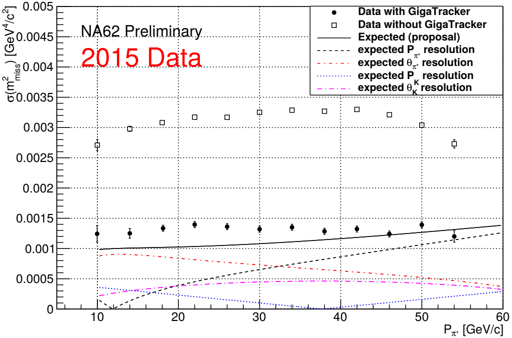




- $15 \leq p_\pi \leq 35\,\mathrm{GeV/c}$ to suppress $K^+ \to \mu^+\nu$
- $K^+ \to \pi^+\pi^0$ selected using LKr
- Resolution close to design
- Background rejection aimed: $10^4 - 10^5$, measured: 10^3

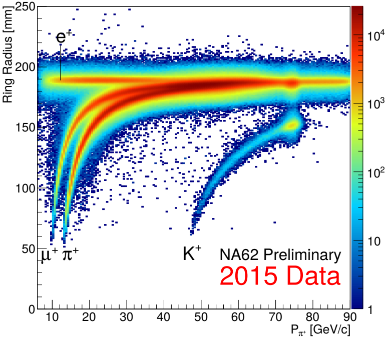
Kinematics in view of 2015 Data

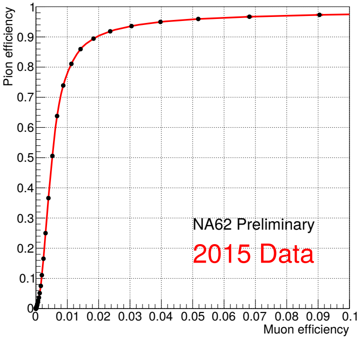




- $15 \leq p_\pi \leq 35\ \mathrm{GeV/c}$ to suppress $K^+ \to \mu^+\nu$
- $K^+ \to \pi^+\pi^0$ selected using LKr
- Resolution close to design
- Background rejection aimed: $10^4 - 10^5$, measured: 10^3

PID in view of 2015 Data

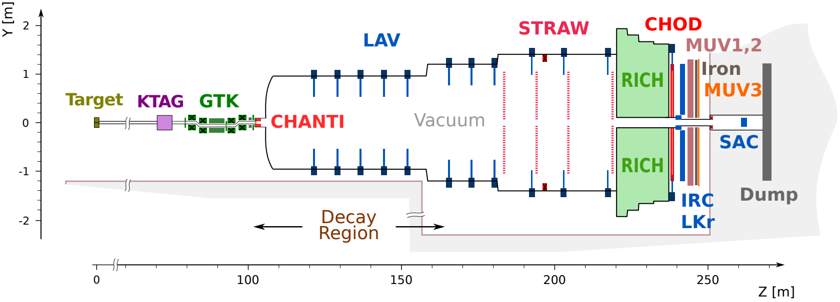




- Goal: 10^7 muon rejection to reduce $K^+ \to \mu^+\nu$
- $15 \leq p_\pi \leq 35\,\mathrm{GeV/c}$: best RICH performance
- Pure sample of pion and muon selected using kinematics
- RICH: 10^2 μ^+ rejection for 80 (90) % π^+ efficiency in 2015 (2016)
- Calorimeter: $10^4 - 10^6$ μ^+ rejection for 90-40% π^+ efficiency (cut)

Photon rejection in view of 2015 Data

- Goal: 10^8 rejection on π^0 from $K^+ \rightarrow \pi^+\pi^0$
- As 15 $\leq p_\pi \leq$ 35 $\mathrm{GeV/c}$ we have $E_{\pi^0} > 40\mathrm{GeV}$
- Hermetic to photon from 50 mard to 0 ($\eta \in [3.7, \infty]$)



Photon rejection in view of 2015 Data

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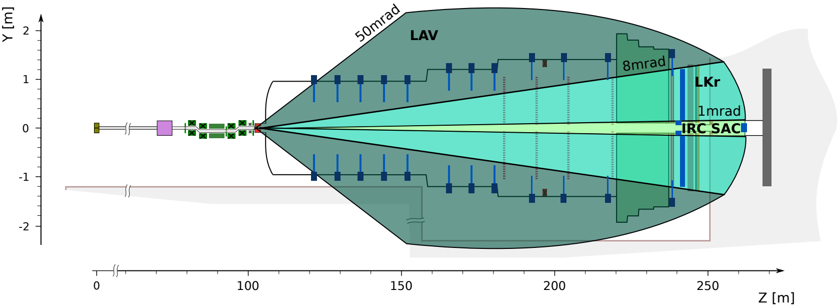
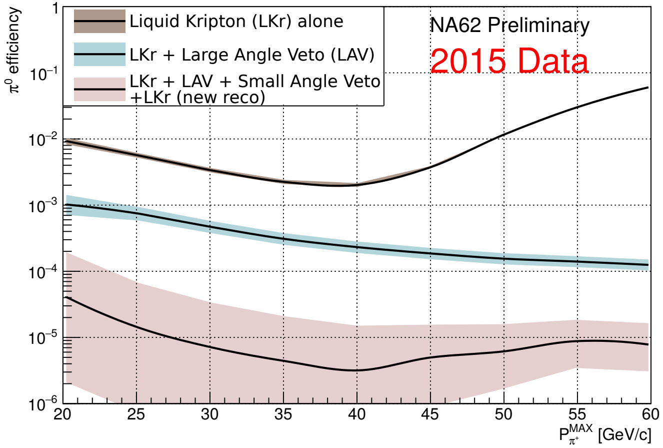


Photon rejection in view of 2015 Data

- π^0 rejection measured selecting $K^+ \to \pi^+\pi^0$ using kinematics
- Results limited by statistics



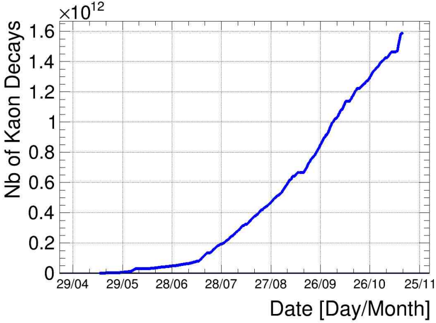
Performances Summary

Time Reso	- All detectors reach design specs
Kinematics	- Performance close to design specs - Improved in 2016
$\pi-\mu$ ID	- RICH reaches design specs - Calorimeter first results are promising, refined studies (MVA) on going
Photon Veto	- 10^{-6} rejection achieved, results limited by statistics - More news in 2016.

Glimpse at 2016 and Beyond

Data Collected

- Ran at 40% nominal intensity
- Limiting beam time structures (30Hz, 50Hz...)
- Triggers: PNN + EXOTICS
- Full GTK from 15/09
- 8×10^{11} usable K decays



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

2016 Reach SM SES

2017 Improved on BNL results

2018 Reach 10% precision on $\mathcal{B}$

Conclusion and Prospects

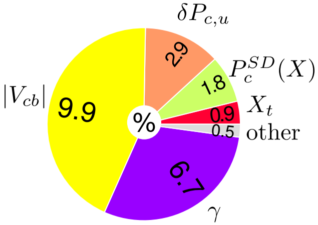
- NA62 is tailored to look for new physics
  - flagship analysis: $K^+ \to \pi^+ \nu \bar{\nu}$
  - many other searches (rare decays, LNFV, dark sector)
- NA62 pioneered 4-D tracking and micro-channel cooling
- Experiment running in stable conditions
- 2015 data quality shows performances in line with design
- 2016 data analysis on going
- 10% precision measurement of $\mathcal{B}(K^+ \to \pi^+ \nu \bar{\nu})$ on its way...

Thanks you for your attention!
Questions?

Extra Slides

5. $K^+ \to \pi^+ \nu \bar{\nu}$
6. Beyond $K^+ \to \pi^+ \nu \bar{\nu}$
7. More on Detectors
8. Recent Results

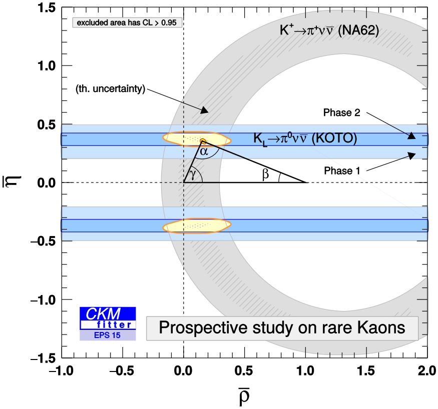
Uncertainty budget



- $\delta P_{c,u}$ long range contribution to charm
- P_c^{SD} short range contribution to charm

Unitarity Triangles

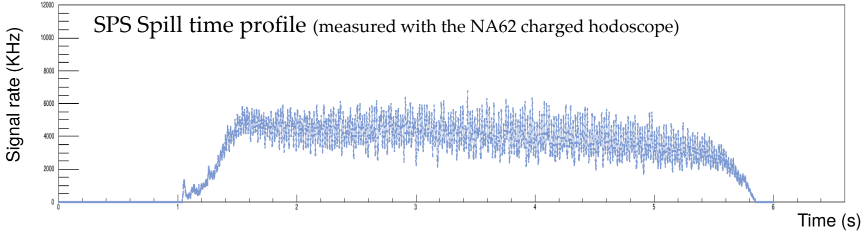
- $\mathcal{B}(K^+ \to \pi^+ \nu \bar{\nu})$ with 10% uncertainties allows to determine $|V_{td}|$ at 9% [Buras 0405132]
- With $\mathcal{B}(K^+ \to \pi^+ \nu \bar{\nu})$, $\mathcal{B}(K_L \to \pi^0 \nu \bar{\nu})$ the CKM unitarity triangle can be built independently from B observables:



Beyond $K^+ \to \pi^+ \nu\bar{\nu}$

Decay	Physics	Present limit (90% C.L.) / Result	NA62
$\pi^+\mu^+e^-$	LFV	1.3×10^{-11}	0.7×10^{-12}
$\pi^+\mu^-e^+$	LFV	5.2×10^{-10}	0.7×10^{-12}
$\pi^-\mu^+e^+$	LNV	5.0×10^{-10}	0.7×10^{-12}
$\pi^-e^+e^+$	LNV	6.4×10^{-10}	2×10^{-12}
$\pi^-\mu^+\mu^+$	LNV	1.1×10^{-9}	0.4×10^{-12}
$\mu^-\nu e^+e^+$	LNV/LFV	2.0×10^{-8}	4×10^{-12}
$e^-\nu\mu^+\mu^+$	LNV	No data	10^{-12}
π^+X^0	New Particle	$5.9 \times 10^{-11}\ m_{X^0} = 0$	10^{-12}
$\pi^+\chi\chi$	New Particle	–	10^{-12}
$\pi^+\pi^+e^-\nu$	$\Delta S \neq \Delta Q$	1.2×10^{-8}	10^{-11}
$\pi^+\pi^+\mu^-\nu$	$\Delta S \neq \Delta Q$	3.0×10^{-6}	10^{-11}
$\pi^+\gamma$	Angular Mom.	2.3×10^{-9}	10^{-12}
$\mu^+\nu_h, \nu_h \to \nu\gamma$	Heavy neutrino	Limits up to $m_{\nu_h} = 350\ MeV$	
R_K	LU	$(2.488 \pm 0.010) \times 10^{-5}$	>×2 better
$\pi^+\gamma\gamma$	χPT	< 500 events	10^5 events
$\pi^0\pi^0e^+\nu$	χPT	66000 events	$O(10^6)$
$\pi^0\pi^0\mu^+\nu$	χPT	-	$O(10^5)$

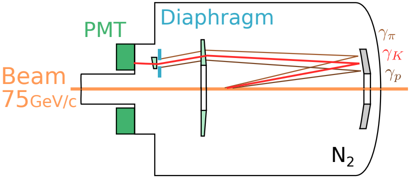
A glance to the on-going 2016 run



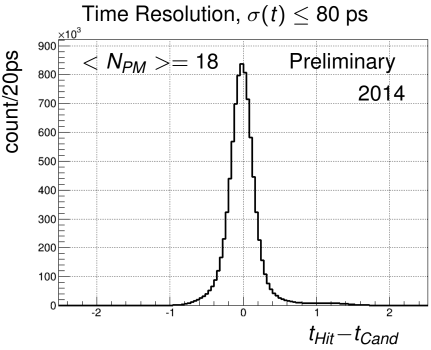
- Stable data taking since beginning of August at 20 – 30 % of nominal intensity
- L0 πνν trigger: hits in RICH & CHOD, !muons, E(LKr) < 20 GeV
- L1 πνν trigger: KTAG, LAV, Straw (P < 50 GeV/c)
- Data type (simultaneously): πνν (no downscaling), di-lepton, minimum bias
- Average rate at L0 (25% of nominal beam intensity): 500 KHz
- Average rate after L1 (25% of nominal beam intensity): 60 KHz
- On – line $\pi^+\pi^0$ reduction factor (πνν trigger): 6 (room for improvements ×2 at least)
- On – line muon reduction factor (πνν trigger): O(100)
- Data collected so far: πνν sensitivitiy below 10^{-9} (assuming O(10%) signal acceptance)

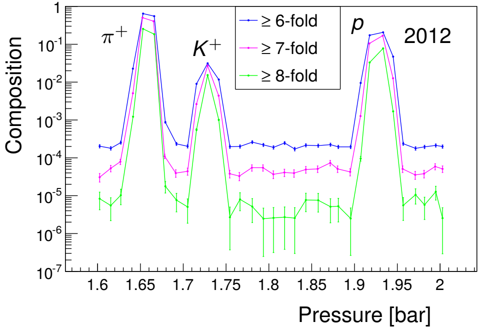
KTAG - Kaon Identification and Timing

Differential Cerenkov Detector



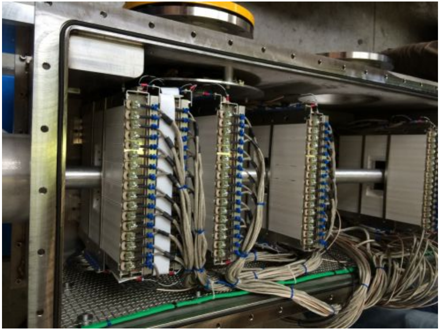
KTAG - Performance



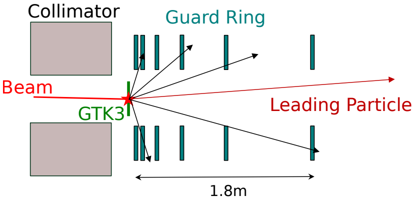


- K^+Identification $> 95\%$
- π^+, p Rejection $> 99.9\%$

Guard Ring - GTK3 Scattered Particle Detection



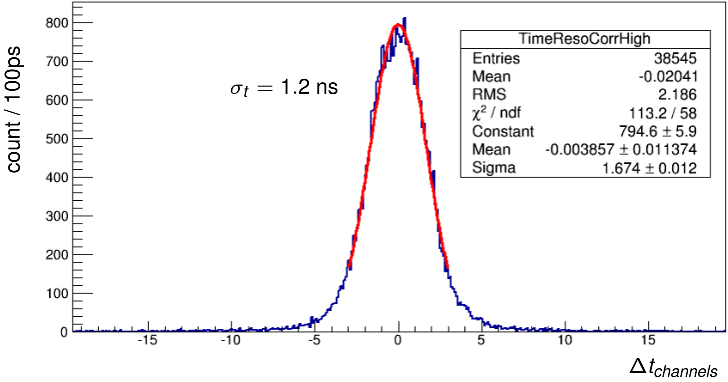
Five first Guard Ring stations during installation



Specifications	
Rate	10-100kHz
Time Reso	1 ns

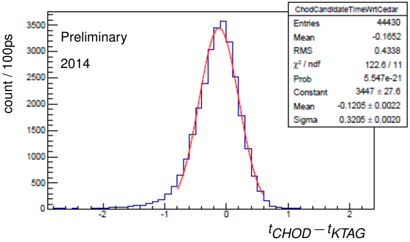
CHANTI - Design and Performance

- 6 stations of scintillator+WLS fibres read with SiPMs
- Signal processed with TDC



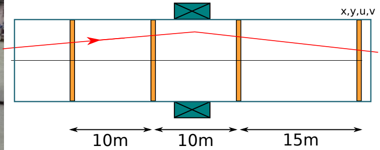
CHOD - Charged Decay Product Timing

Time Resolution, $\sigma(t) \simeq 300$ ps



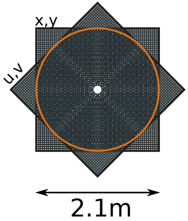
- 2 layers (X-Y) of scintillator read each by 64 PMT
- Used for time reference

Spectrometer - Decay Products Kinematics



Spectrometer - Design and Status

Specifications	
Rate	15 MHz
Momentum Reso	1%
Angular Reso	20-60 μrad
Material	$4\times0.5\%X_0$
Size	2.1 m diameter



- 2.1m long straw filled wilt Ar+CO_2 at 1 atm ran in vacuum
- 7168 straws arranged in 4 chambers of 4 views (x,y,u,v)
- Readout up to 700kHz per straw with TDCs
- See performance in First Data

Photon Detection ($K^+ \rightarrow \pi^+ \pi^0$)

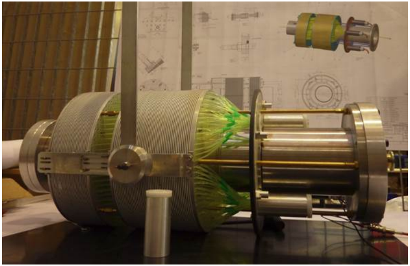
LAV Pb Glass - OPAL

$8.5 \rightarrow 50$ mrad

LKr NA48

$1 \rightarrow 8.5$ mrad

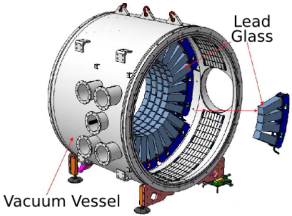
IRC (+ SAC) Shashlik type



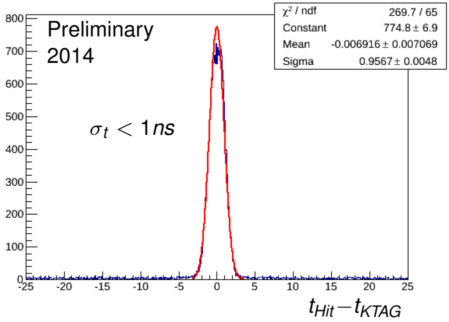
< 1 mrad: angular coverage

LAV: 8.5 → 50 mrad

Specifications	
Eff.	99.8 - 99.99%
Time Reso	< 1 ns
Tot Rate	1MHz

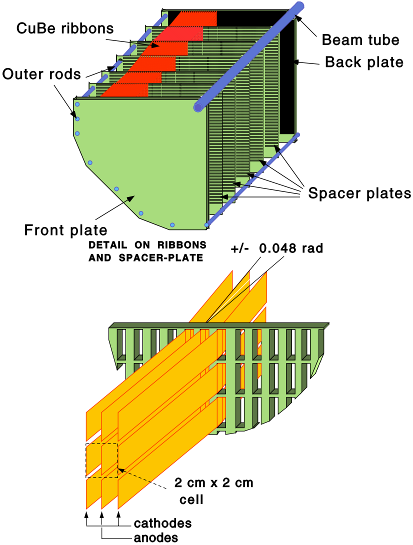


- 12 stations of 4-5 rings of staggered lead glass blocks

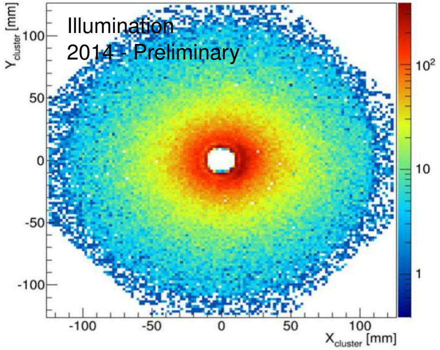


LKr: 1 $\to$ 8.5 mrad

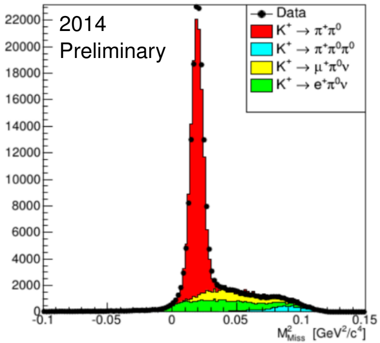
- Quasi homogenous liquid Kripton calorimeter from NA48
- Inefficiency measured in 2004 at 10^{-5} for $E > 10$ GeV
- Major RO upgrade: full LKr sampled at 40MHz with 14bits FADC



LKr - Performance

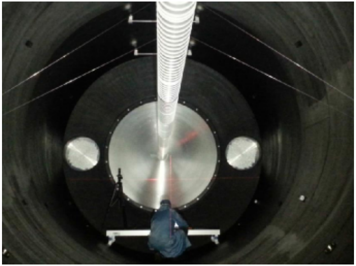


$|p_K - p_{\pi^0}|^2$



- $K^+ \to \pi^+\pi^0$ event reconstructed with LKr only
- p_K set to it nominal value
- π^0 reconstructed from two EM clusters, constrained to m_{π^0}

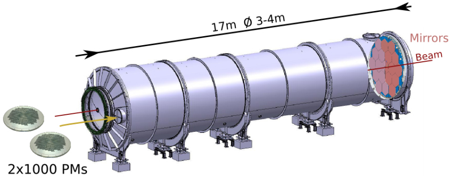
RICH - $\pi, \ \mu$ Identification

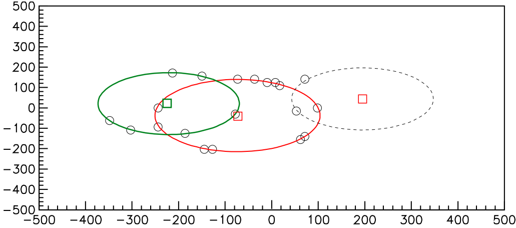


RICH - Design

Specifications	
$\pi \to \mu$	$<$ 1% for $p \in [15, 35]$ GeV
Angular Reso	$< 100\mu\text{rad}$
Time Reso	$<$ 100 ps RMS
Rate	10 MHz

- Neon at 1 atm: $p^{\pi}_{Th} = 13 GeV/c$
- 17m long vessel: $\sim$20 hits per ring
- Light reflected on two 1000 PM arrays read with TDC

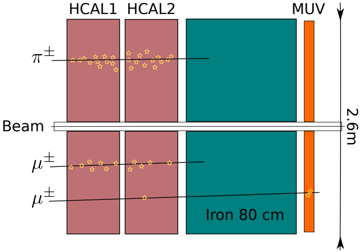




HCAL and MUV - π, μ Identification

HCAL 1 and 2

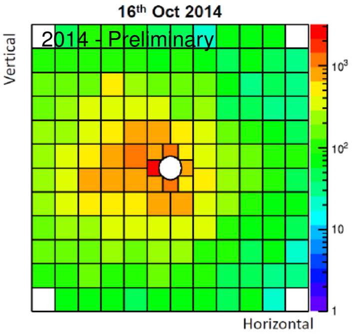
MUV - back

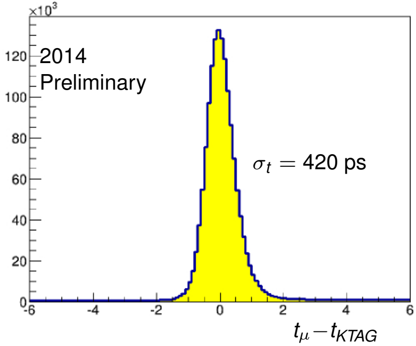


MUV - Design and Performance

- MUV made of scintillator 22x22 cm^2 tiles read with 2 PMs and CFDs

Specifications	
$\pi \to \mu$	$< 10^{-2}$
Time Reso	$< 1ns$ RMS
Rate	10 MHz



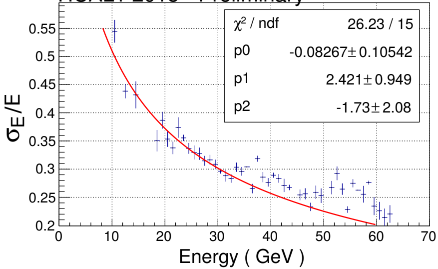


HCAL 1 and 2 - Design and Performance

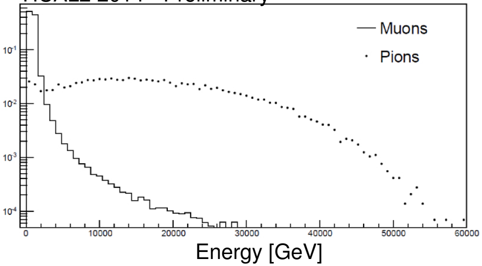
- HCAL1 (HCAL2) made of alternating layers of iron and 6 (12) cm scintillator strip read with PMs and TDCs

Specifications	
$\pi \to \mu$	$< 10^{-3}$
Time Reso	$< 1ns$ RMS
Rate	10 MHz

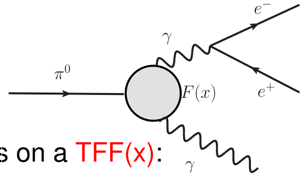
HCAL1 2015 - Preliminary



HCAL2 2014 - Preliminary



Recent Results: $\pi^0{}_D$ Transition Form Factor - NA62



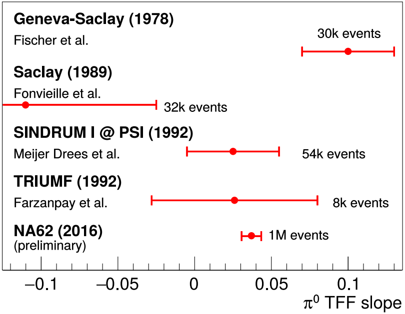
More details on M. Koval Talk at La Thuile

- NA62-R_K had 5×10^9 π^0 from $K^+ \to \pi^+\pi^0$ to study $\pi^0 \to e^+e^-\gamma$
- Diff decay rate wrt $x = (m_{ee}/m_{\pi^0})$, depends on a TFF(x):

$$\frac{1}{\Gamma(\pi^0_{2\gamma})}\frac{d\Gamma(\pi^0_D)}{dx} = \frac{2\alpha}{3\pi}\frac{(1-x)^3}{x}\left(1+\frac{r^2}{2x}\right)\sqrt{1-\frac{r^2}{x}}\,(1+\delta(x))\,(1+a\,x)^2$$

- TFF used for hadronic light by light scattering contribution to $(g-2)_\mu$
- Extract a by comparing x spectrum to MC:

$$a = (3.70\pm0.53_{\text{stat}}\pm0.36_{\text{syst}})\times10^{-2}$$



Recent Results: NP searches with $K^{\pm} \to \pi\mu\mu$ - NA48/2

More details in Talk by K.Massri at La Thuile

More details in K. Massri Talk at La Thuile

Same Sign Muon Pair

- World Best Limit: $\mathcal{B}(K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm}) < 8.6\times10^{-11}$ at 90% C.L. (LNV)
- Resonances search $K^{\pm} \to \mu^{\pm}N(\pi^{\mp}\mu^{\pm})$ with N a majorana neutrino