π^0 form factor and $K^+ \to \pi^+ \nu\bar{\nu}$ at NA62

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51 st Rencontres de Moriond EW 2016

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Outline

- Measurement of the π^0 transition form factor on 2007 data.
- Status and prospects for $K^+ \to \pi^+ \nu \bar{\nu}$.

Kaon @ CERN - SPS

’97-’01 NA48: ε’/ε

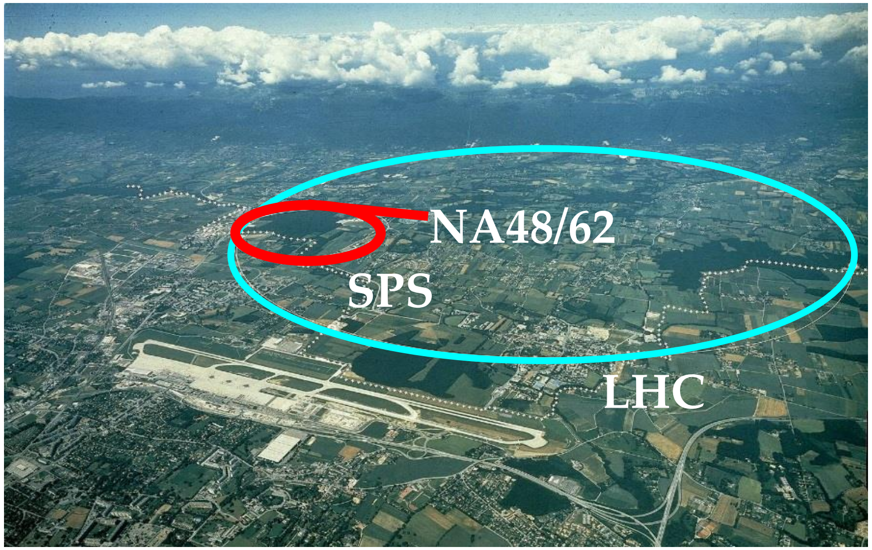
’02 NA48/1: K_S rare decays

’03-’04 NA48/2: $K^{\pm}$ CP violation, semileptonic, low energy QCD

’07-’08 NA62: Lepton universality (using the NA48 apparatus)

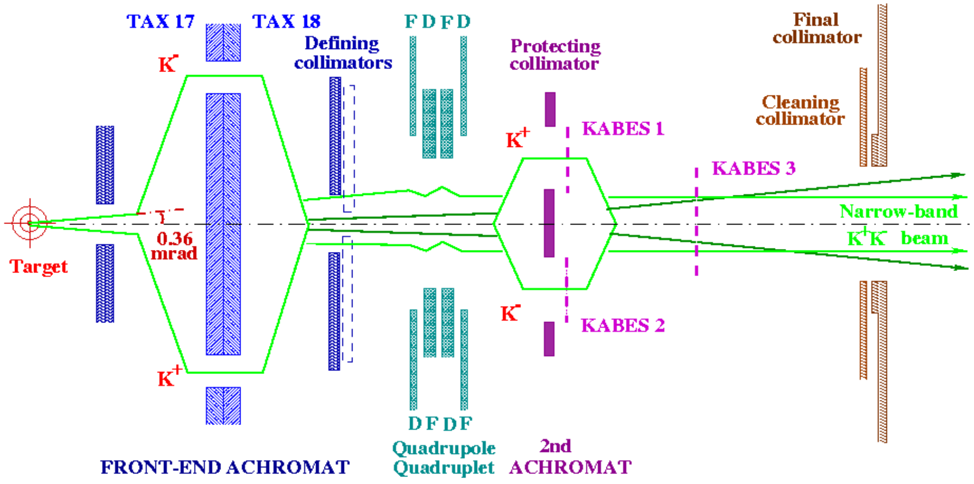
‘14 - NA62: $K^+ \rightarrow \pi^+ \nu\bar{\nu}$

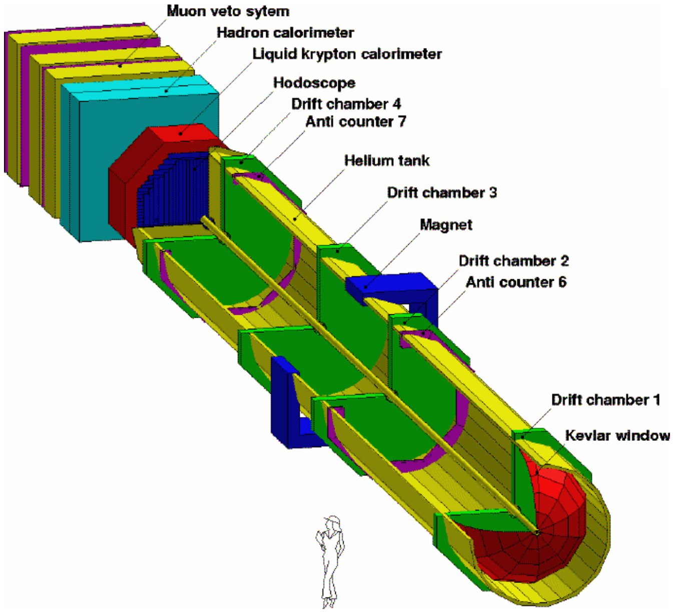
- Installation complete
- Runs in 2014 - 2015
- Detector commissioning
- Data quality studies



NA62 2007 Layout

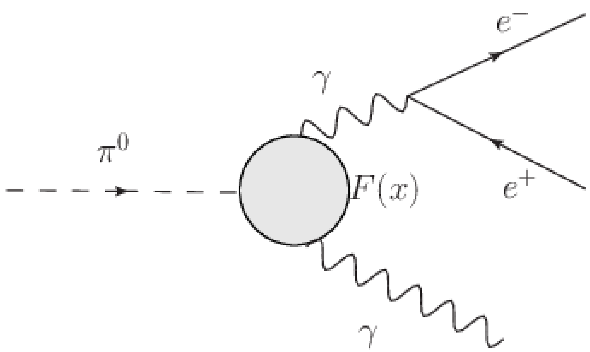
- K± beams:
  - $P_K = 75 \pm 2$ GeV/c





- Main Detectors (NA48):
  - Magnetic Spectrometer: $\sigma(P)/P = 0.48\% \oplus 0.009\, P(\mathrm{GeV/c})\%$
  - Hodoscope: Fast trigger for charged particles and timing for the event ($\sigma(t) = 200$ ps)
  - Liquid Kripton e.m. calorimeter (LKr): $\sigma(E)/E = 3.2\%/\sqrt{E} \oplus 9\%/E \oplus 0.42\%$ (GeV)

$\pi^0 \to \gamma\gamma^*$ Transition Form Factor



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

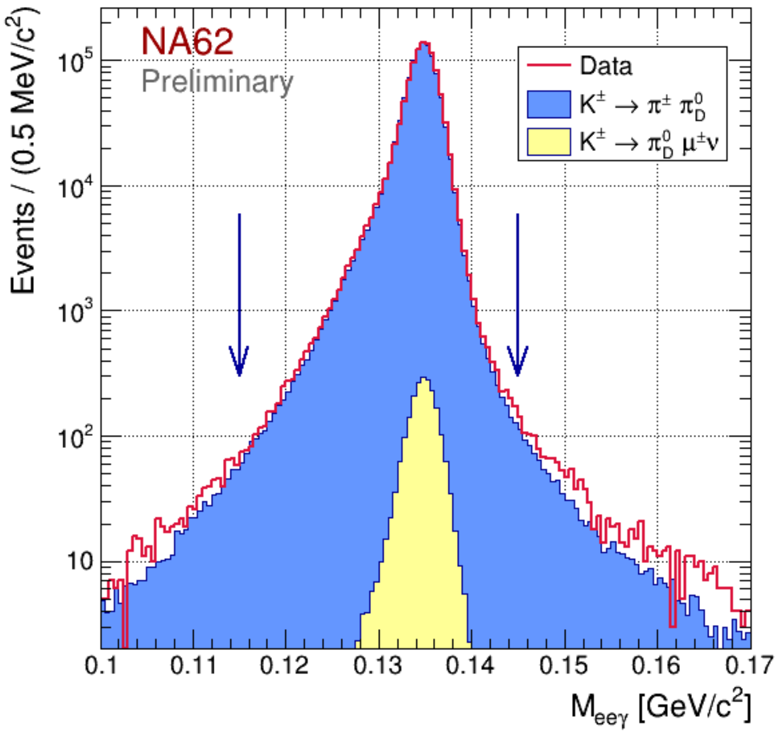
$x = \frac{(p_{e^+}+p_{e^-})^2}{m^2_{\pi^0}}$ $r^2 = (2m_e/m_{\pi^0})^2$ $\delta(x)$ radiative correction $F(x) \approx 1 + a\,x$

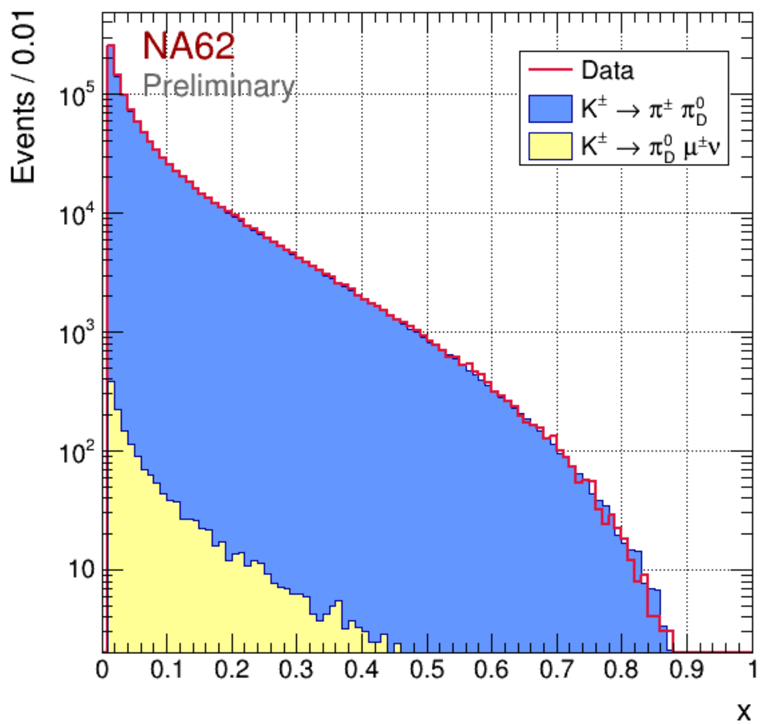
- TFF measurement: test prediction from theoretical models
- TFF models used for the hadronic light by light scattering contribution to $(g-2)_\mu$

- NA62 2007 data
- Data taking conditions optimized for $K^\pm \to e^\pm\nu$ [Phys. Lett. B 719 (2013) 326]
- $K^\pm \to \pi^\pm\pi^0$, $\pi^0 \to \gamma e^+e^-$

$\pi^0 \to \gamma e^+ e^-$ TFF: Selection

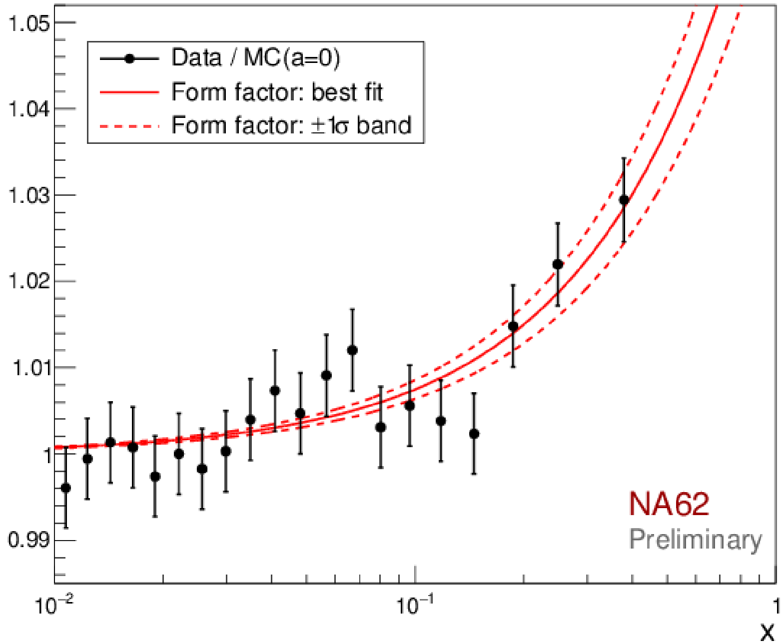
- Selection: 3-track topology, photon in LKr, full kinematic closure, x > 0.01
- 1.05×10^6 fully reconstructed $\pi^0 \to \gamma e^+ e^-$
- TFF obtained by adjusting the simulation to the data x spectrum.

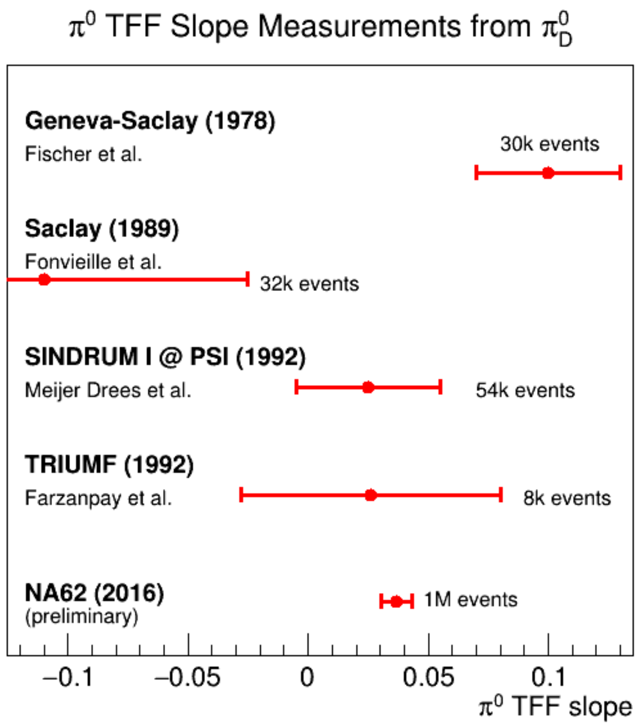




$\pi^0 \to \gamma e^+ e^-$ TFF: Preliminary Result

$$a = (3.70 \pm 0.53_{stat} \pm 0.36_{syst}) \times 10^{-2}$$

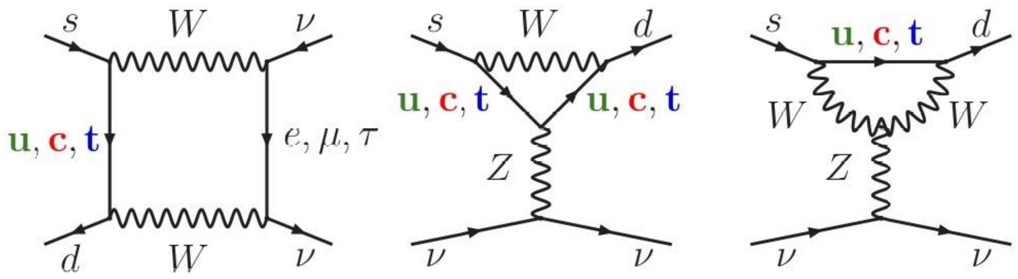




- TFF Theory expectations:
- $a = (2.90 \pm 0.50) \times 10^{-2}$, χPT, [K. Kampf et al. EPJ C46 (2006), 191]
- $a = (3.07 \pm 0.06) \times 10^{-2}$, dispersion theory, [M. Hoferichter et al. EPJ C74 (2014), 3180]
- $a = (2.92 \pm 0.04) \times 10^{-2}$, two-hadron saturation, [T. Husek et al. EPJ C75 (2015) 12, 586]

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

- FCNC loop processes: s→d coupling and highest CKM suppression



- Very clean theoretically: Short distance contribution. No hadronic uncertainties.
- SM predictions [Buras et al. arXiv:1503.02693], [Brod, Gorbahn, Stamou, Phys. Rev.D 83, 034030 (2011)]

$$BR(K^+ \to \pi^+\nu\bar{\nu}) = (8.39 \pm 0.30)\cdot 10^{-11}\left(\frac{|V_{cb}|}{0.0407}\right)^{2.8}\left(\frac{\gamma}{73.2°}\right)^{0.74} = (8.4 \pm 1.0)\cdot 10^{-11}$$

$$BR(K_L \to \pi^0\nu\bar{\nu}) = (3.36 \pm 0.05)\cdot 10^{-11}\left(\frac{|V_{ub}|}{0.00388}\right)^{2}\left(\frac{|V_{cb}|}{0.0407}\right)^{2}\left(\frac{\sin\gamma}{\sin 73.2}\right)^{2} = (3.4 \pm 0.6)\cdot 10^{-11}$$

- Experiments:

$BR(K^+ \to \pi^+\nu\bar{\nu}) = \left(17.3^{+11.5}_{-10.5}\right)\times 10^{-11}$ Phys. Rev. D 77, 052003 (2008), Phys. Rev. D 79, 092004 (2009)

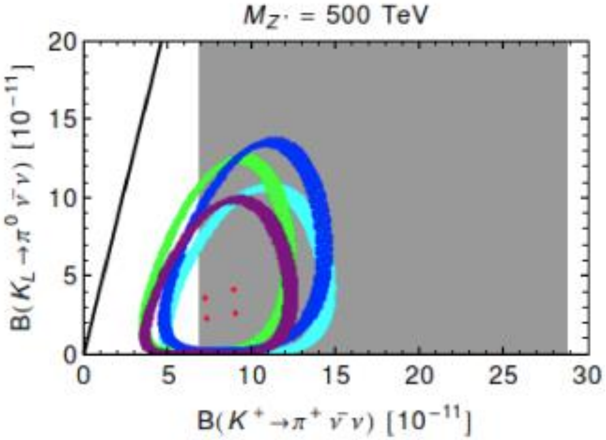
$BR(K_L \to \pi^0\nu\bar{\nu}) < 2.6\times 10^{-8}$ (90% C.L.) Phys. Rev. D 81, 072004 (2010)

$K \to \pi\nu\bar{\nu}$ NP Sensitivity

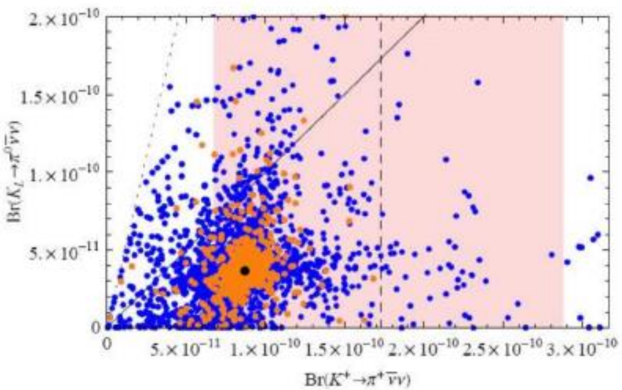
- Simplified Z, Z′ models [Buras, Buttazzo,Knegjens, arXiv:1507.08672 (2015)]
- Littlest Higgs with T-parity [Blanke, Buras, Recksiegel, arXiv:1507.06316 (2015)]
- Custodial Randall-Sundrum [Blanke, Buras, Duling, Gemmler, Gori, JHEP 0903 (2009) 108]
- MSSM non-MFV [Tanimoto, Yamamoto arXiv:1503.06270, Isidori et al. JHEP 0608 (2006) 064]

- Constraints from existing measurements (correlations model dependent):
  - Kaon mixing and CPV, CKM fit, K,B rare meson decays, NP limits from direct searches

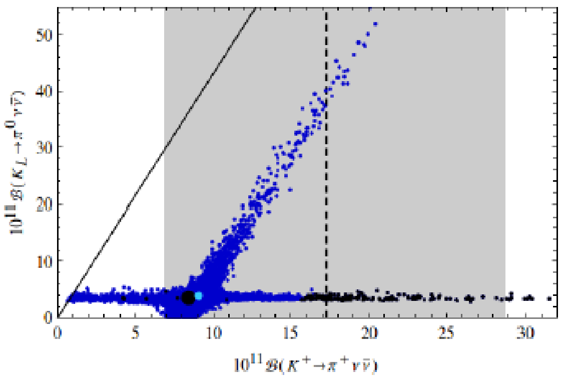
Z′ model



Randall - Sundrum



Littlest Higgs



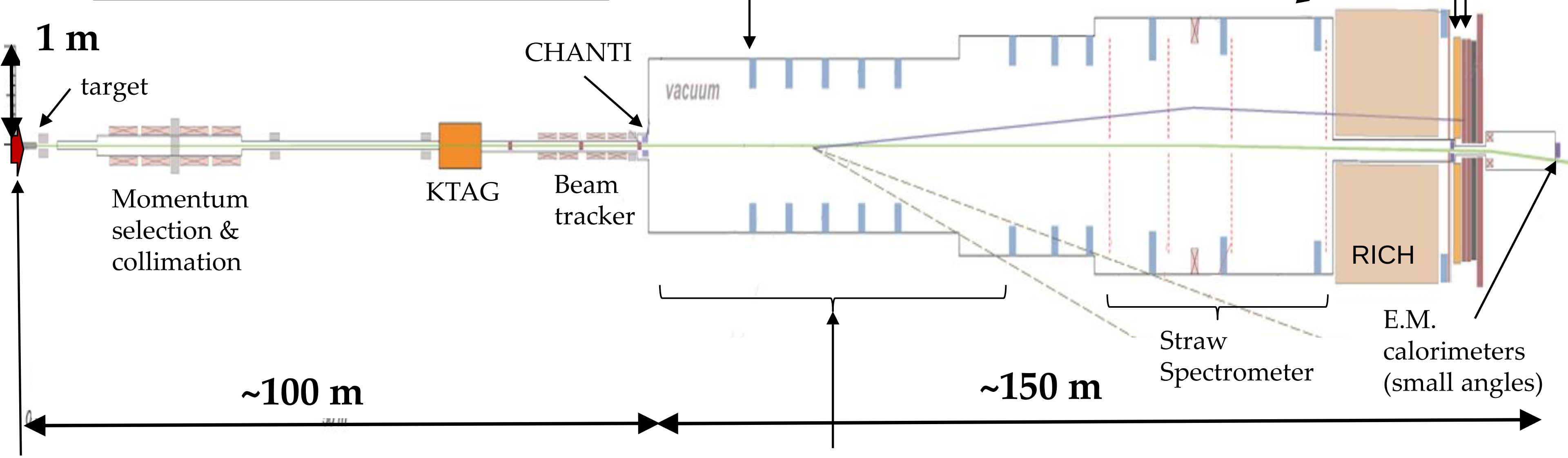
The NA62 Experiment for $K^+ \to \pi^+ \nu \bar{\nu}$

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)

- Primary goal:
  10% precision BR($K^+ \to \pi^+ \nu \bar{\nu}$)
- Requirements:
  - Statistics: O(100) events
  - K decays (2 years) 10^{13} , Signal acceptance ~ 10%
  - Systematics: <10% precision background measurement
  - >10^{12} background rejection (<20% background)
- Technique:
  - K Decay – in – flight

NA62 Apparatus

Detectors for Secondary Beam
- Kaon ID (KTAG)
- Beam Tracker
- Beam guard ring (CHANTI)



SPS proton
400 GeV
10^{12} p/s
3.5 s spill

Secondary Beam
75 GeV/c, $\Delta p/p \sim 1\%$
X,Y Divergence < 100 μrad
K(6%), π(70%), p(23%)
Total rate: 750 MHz
Beam size: 6.0 × 2.7 cm^2

Kaon Decay
~5 MHz
$4.5 \times 10^{12}/year$
60 m length
10^{-6} mbar vacuum

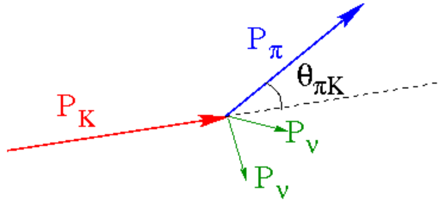
Detectors for decay products
- Charged particle tracking
- Charged particle time stamping
- Photon detection
- Particle ID

Experimental Status

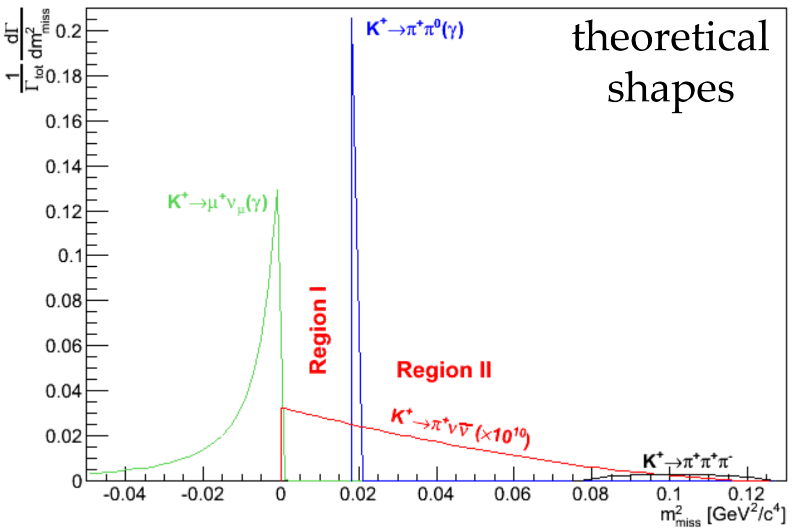
- NA62 took data in 2014 and 2015
- Beam commissioned up to nominal intensity
- Tracker:
  - Beam tracker (Gigatracker) partially commissioned.
  - Straw spectrometer commissioned
- Cherenkov detectors:
  - Beam Kaon ID (KTAG) commissioned.
  - RICH commissioned.
- All the other detectors commissioned
- Trigger:
  - L0 commissioned; L1(2) partially commissioned.
- Data samples for data quality study (mainly from 2015):
  - Low intensity data taken with a minimum bias trigger (this talk).
  - Samples at half and full intensity taken with a calorimeter trigger.

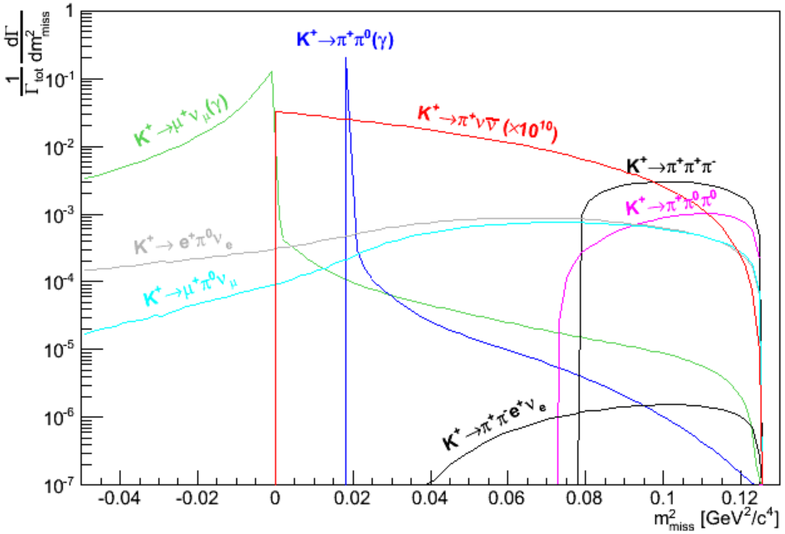
Scheme for $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ Analysis

- Signal



- Background: K^+ decay modes; beam activity
- Kinematics: $m^2_{miss} = (P_K - P_{\pi^+})^2$



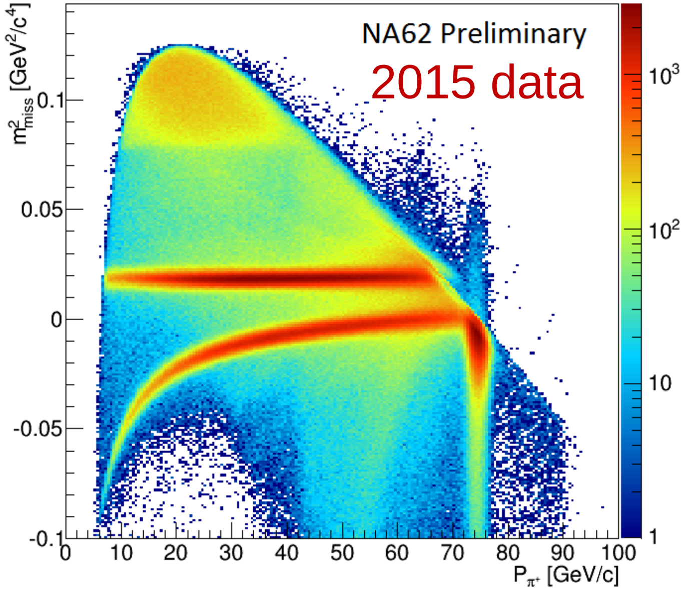


- Experimental principles:
  1) Precise kinematic reconstruction
  2) PID: K upstream, $e/\mu/\pi$ downstream
  3) Hermetic γ detection
  4) Sub-ns timing

- Key analysis requirements
  - 2 signal regions in m^2_{miss}
  - $15 < P_\pi < 35$ GeV/c
  - 65 m long decay region

Expected 45 SM signal events / year with < 10 background [$O(10^{-12})$ SES]

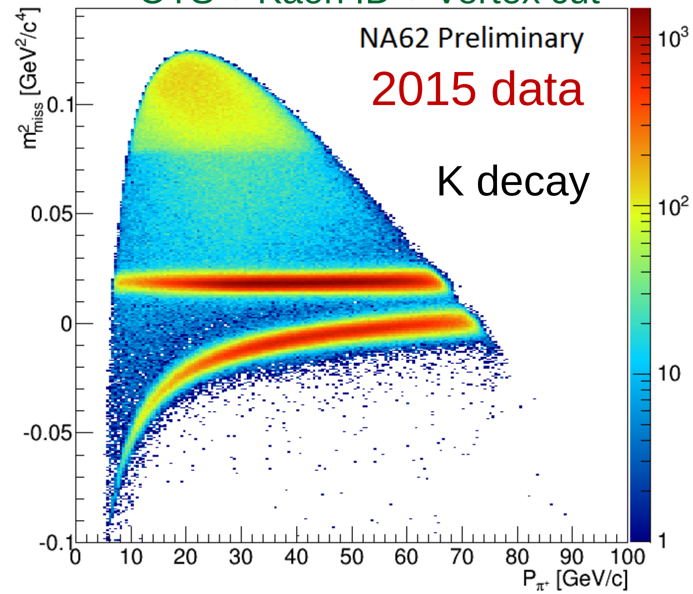
Signal Topology and Kaon ID



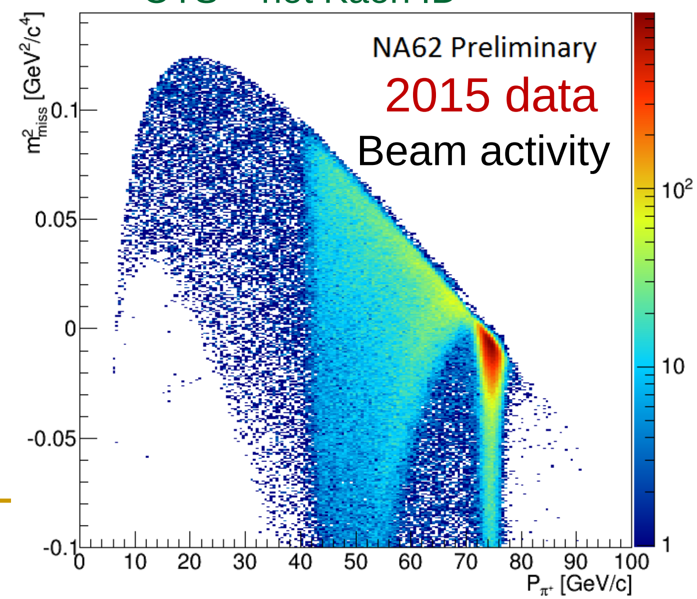
Kaon ID
Track origin in the fiducial region

Not Kaon ID

OTS + Kaon ID + Vertex cut



OTS + not Kaon ID



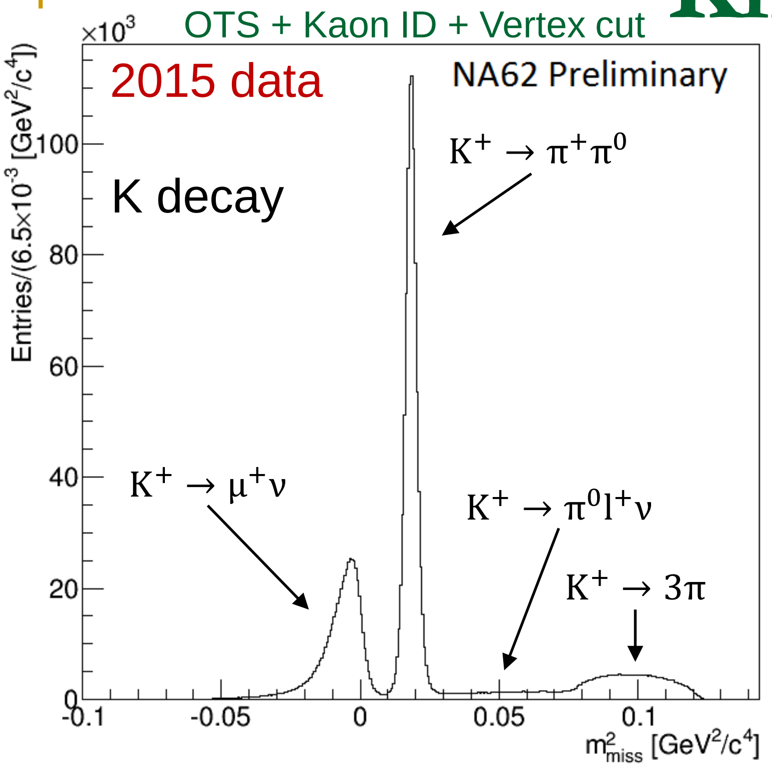
One – track selection (OTS)

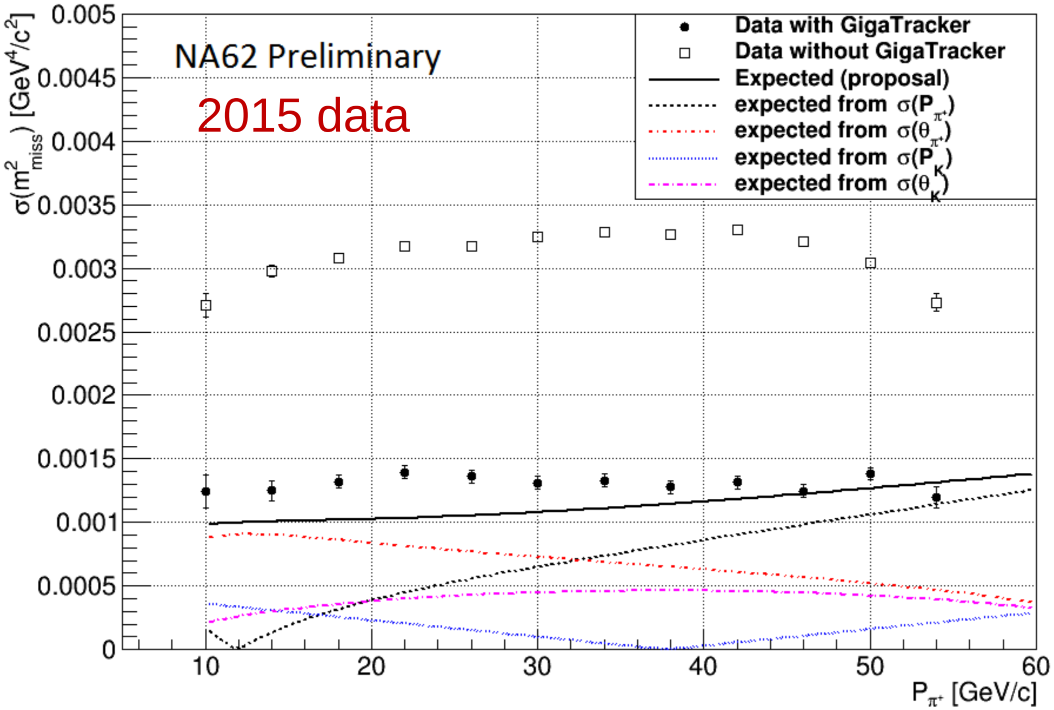
- Single downstream track topology
- Beam track matching the downstream track
- Beam track matching a K signal in Kaon ID
- Downstream track matching energy in calorimeters

Time resolutions:

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

Kinematics

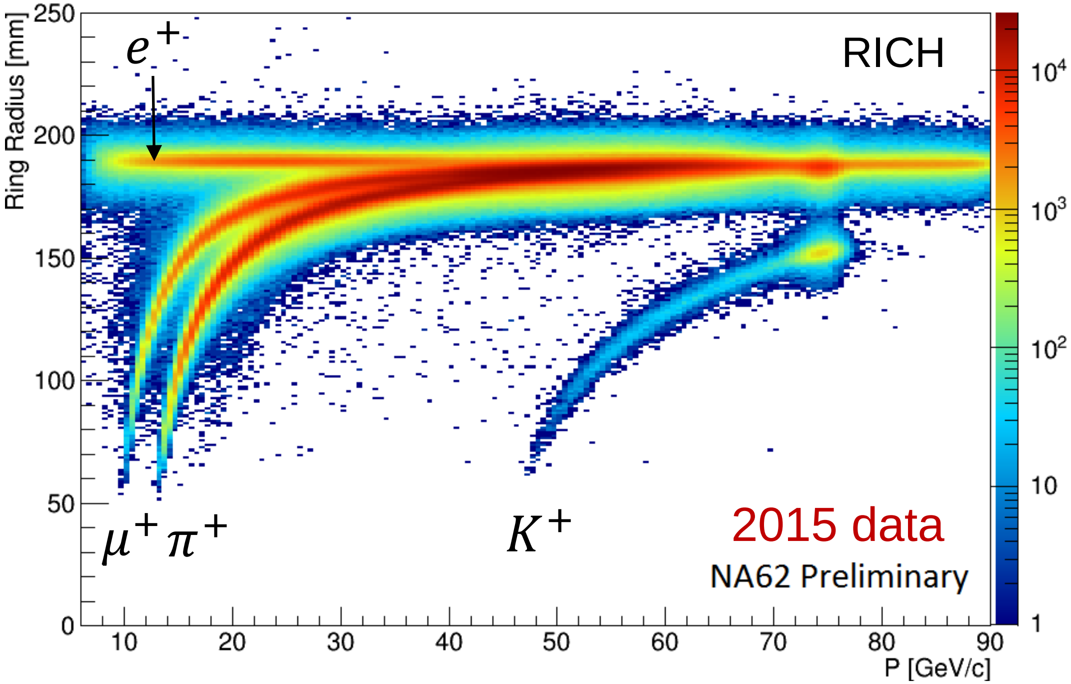


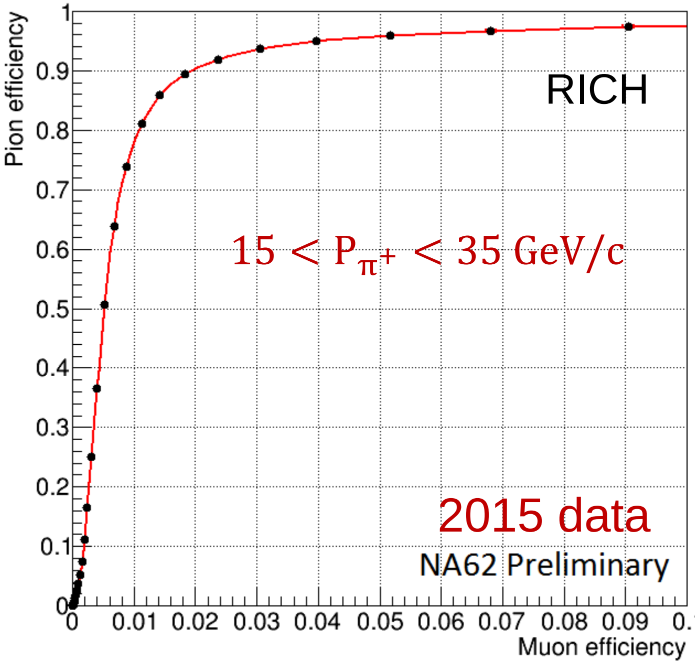


- Technique: Si - pixel tracker; Straw tube tracker in vacuum
- Goal: $O(10^4 \div 10^5)$ suppression factor of the main kaon decay modes
- $P_{\pi^+} < 35$ GeV/c: best $K^+ \to \mu^+\nu$ suppression.
- Kinematics studied on $K^+ \to \pi^+\pi^0$ selected using LKr calorimeter.
- Resolutions close to the design.
- $O(10^3)$ kinematic suppression factor in 2015.

Downstream Particle Identification

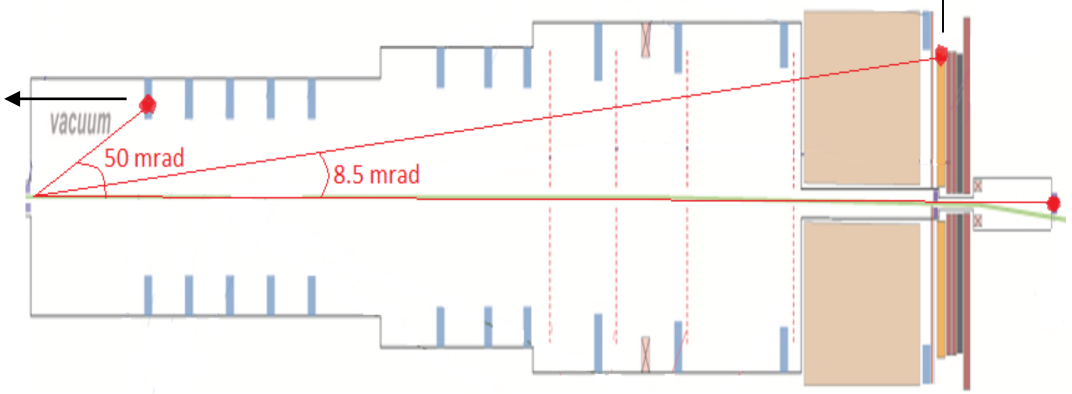
OTS





- Technique: RICH and calorimeters
- Goal: O(10^7) μ/π separation to suppress mainly $K^+ \to \mu^+ \nu$
- $15 < P_{\pi^+} < 35$ GeV/c: best μ/π separation in RICH
- Pure samples of pions and muons selected using kinematics
- RICH: O(10^2) π/μ separation, 80% π^+efficiency in 2015.
- Calorimeters: ($10^4 \div 10^6$) μ suppression, (90% ÷ 40%) π^+efficiency in 2015 using a cut analysis. Room for improvements.

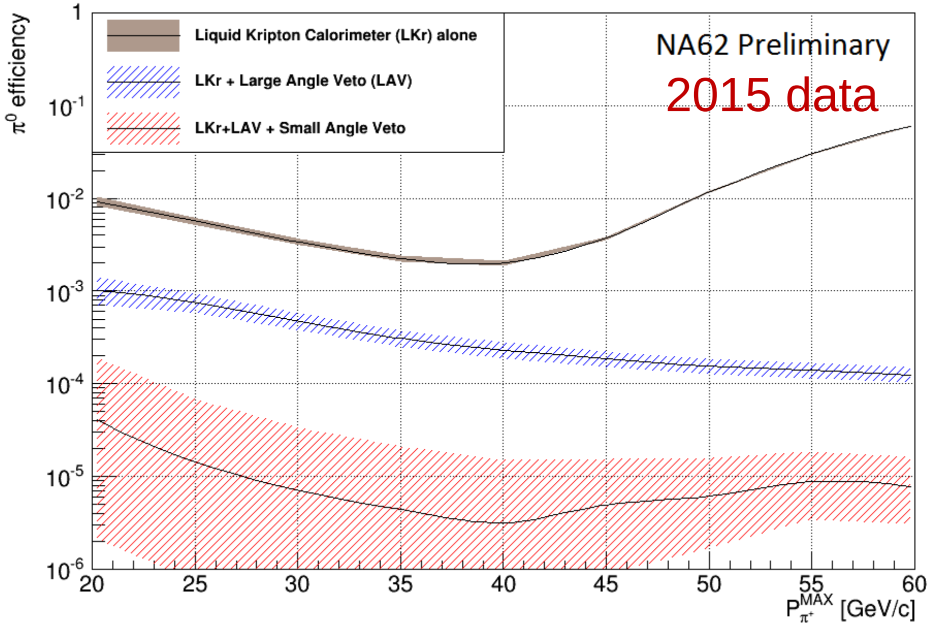
Photon rejection



- Technique: EM calorimeters exploiting correlations between γs' from π^0.
- Goal: $O(10^8)$ rejection π^0 from $K^+ \to \pi^+\pi^0$
- $P_{\pi^+} < 35$ GeV/c $\to E_{\pi^0} > 40$ GeV

- Measured on data using $K^+ \to \pi^+\pi^0$ selected kinematically
- 2015 measurement statistically limited

$15 < P_{\pi^+} < P_{\pi^+}^{MAX}$



Summary from (low intensity) data quality studies

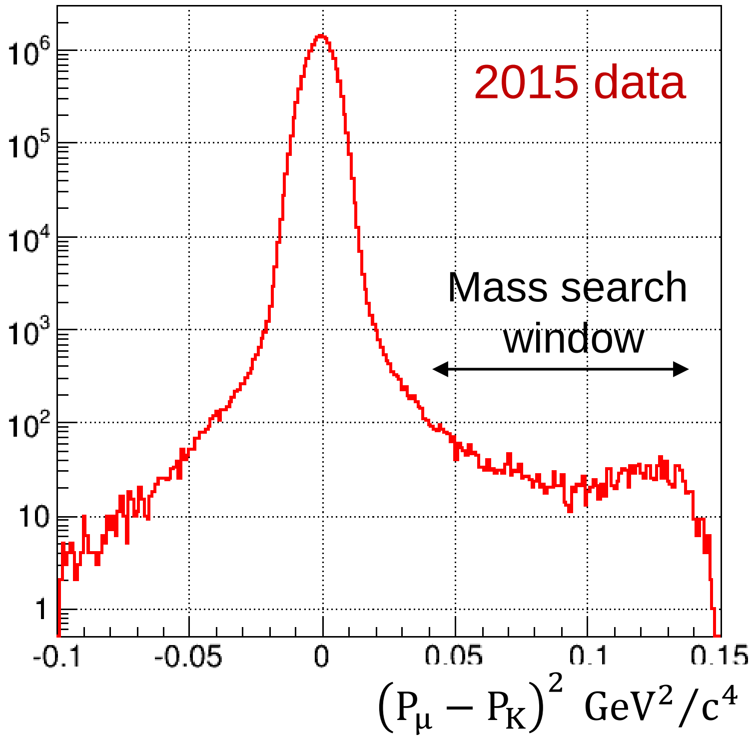
1) Time resolution
   - Close to the design
2) Kinematics
   - Resolution close to the design.
   - Prospects to reach the designed signal – background separation.
3) Pion – muon ID
   - Separation with RICH close to expectations.
   - Study of the separation with calorimeters on going. Results from simple cut analysis promising.
4) Photon veto:
   - $O(10^6)$ π^0 rejection already obtained. More statistics needed to push the study at the design sensitivity.

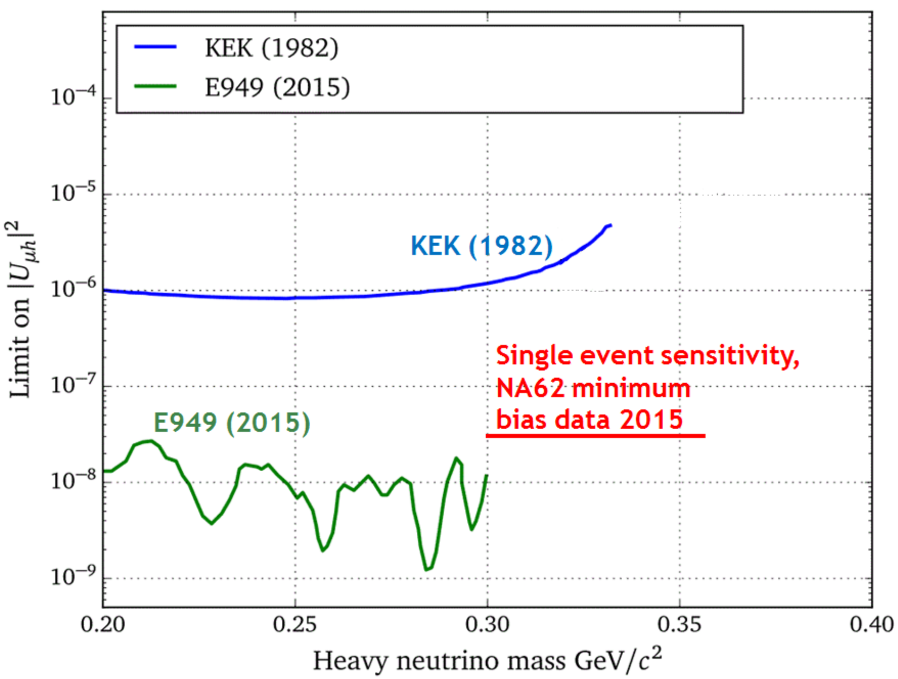
Further NA62 Physics Program

- Standard Kaon Physics
  - Precision measurements of the branching ratio of all the main K decay modes
  - χPT studies: $K^+ \to \pi^+\gamma\gamma$, $K^+ \to \pi^+\pi^0 e^+ e^-$, $K^+ \to \pi^{0(+)}\pi^{0(-)} l^+\nu$
  - LU study with the precision measurement of $R_K = \Gamma(K^+ \to e^+\nu)/\Gamma(K^+ \to \mu^+\nu)$
- LFV with Kaons:
  - $K^+ \to \pi^+\mu^\pm e^\mp$, $K^+ \to \pi^-\mu^+ e^+$, $K^+ \to \pi^- l^+ l^+$
- Heavy neutrino searches:
  - $K^+ \to l^+\nu_h$
  - ν_h from K, D decays and $\nu_h \to \pi l$
- π^0 decays:
  - $\pi^0 \to$ invisible, $\pi^0 \to 3/4\gamma$, $\pi^0 \to U\gamma$
- Dark sector searches:
  - Long living dark photon decaying in l^+l^- and produced by $\pi^0/\eta/\eta'/\Phi/\varrho/\omega$ decays
  - Long living axion-like decaying in $\gamma\gamma$ produced in a beam-dump configuration

NA62 and Heavy Neutrino

- Search for heavy neutrinos produced in $K^+ \to \mu^+ \nu_h$ and $K^+ \to e^+ \nu_h$
- NA62 is perfectly suited to search for ν_h in 100 – 380 MeV/c^2 mass range:
  - $K^+ \to l^+ \nu_h$ decays kinematically enhanced wrt to $K^+ \to \mu^+ \nu_{SM}$
  - Background in the mass region search ~5 order of magnitude below the $K^+ \to l^+ \nu_{SM}$ peak





Conclusions

- Preliminary world best measurement of the π^0 transition form factor slope (NA62 2007 data):

$$a = (3.70 \pm 0.53_{stat} \pm 0.36_{syst}) \times 10^{-2} = (3.70 \pm 0.64) \times 10^{-2}$$

- The NA62 experiment for $K^+ \to \pi^+ \nu\bar{\nu}$ commissioned. Tested up to nominal intensity

- Preliminary study of the quality of the data taken at low intensity:
  - Physics sensitivity for $K^+ \to \pi^+ \nu\bar{\nu}$ measurement in line with the design.
  - A further compelling physics program is going to be addressed.
  - Analysis of data at higher intensity on going.

- NA62 will resume data taking end of April 2016 (~200 days run in 2016).