Status of the NA62 Experiment

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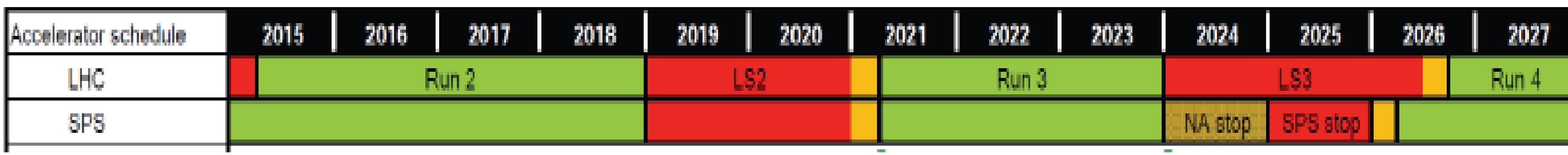
Introduction

- NA62: kaon experiment at CERN SPS
  - Main goal: precise measurement of BR($K^+ \to \pi^+ \nu \bar{\nu}$)
  - Broader physics program: LFV / LNV in K^+ decays, hidden sector particles searches.



- NA62 is taking data. Approved until LS2
- Proposed runs after LS2 under discussion*

*see P.Petrov and M. Moulson talks on Saturday

Kaon @ CERN - SPS

'97-'01 NA48: ε'/ε

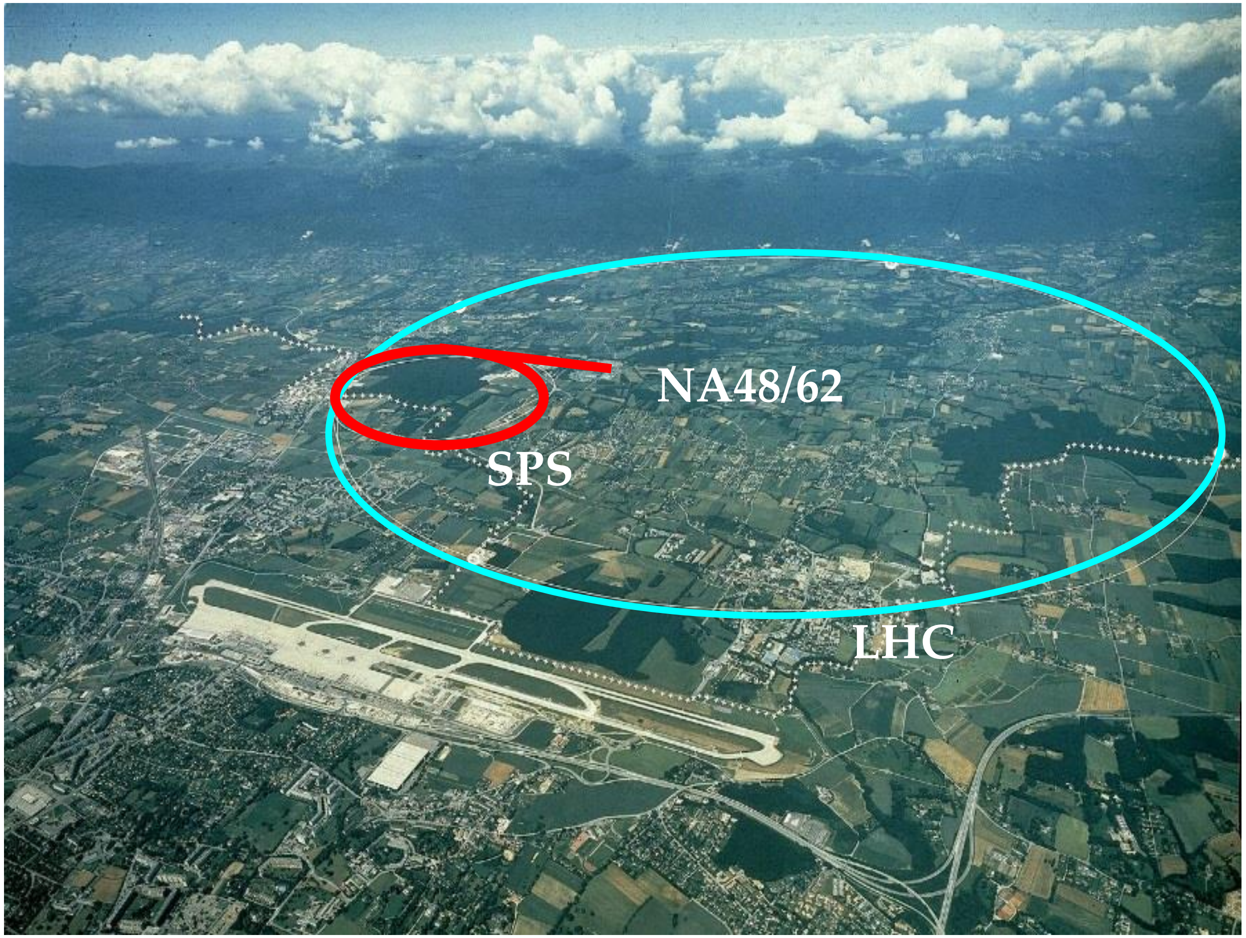
'02 NA48/1: K_S rare decays

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

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

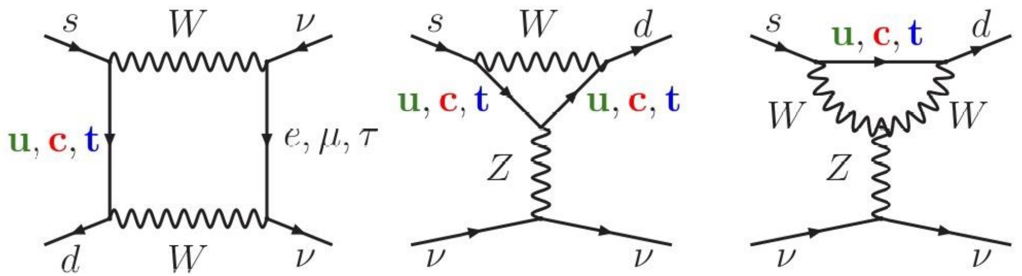
'14 - NA62: $K^+ \to \pi^+ \nu\bar{\nu}$

- Installation complete
- Runs from 2014
- Detector commissioning
- Data quality studies



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. JHEP 1511 (2015) 33]

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

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

- 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)

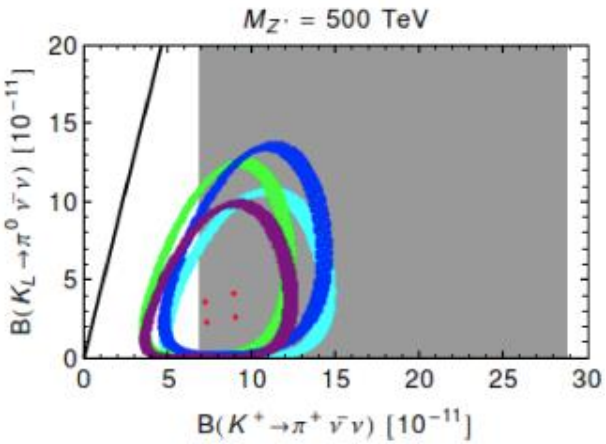
$BR(K_L \to \pi^0\nu\bar{\nu}) < 2.6 \times 10^{-8}$ (90% C. L.) Phys. Rev. D 81, 072004 (2010)

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

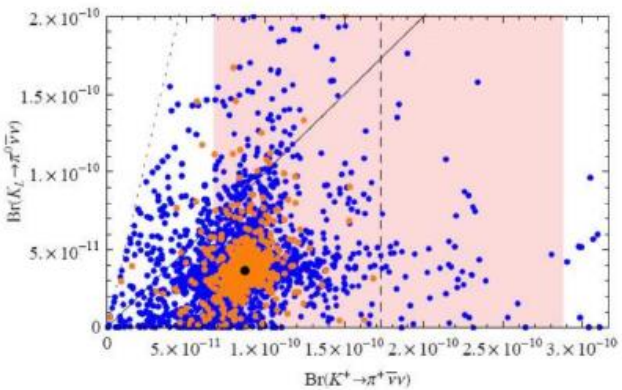
- Simplified Z, Z′ models [Buras, Buttazzo,Knegjens, JHEP 1511 (2015) 166]
- Littlest Higgs with T-parity [Blanke, Buras, Recksiegel, EPJ C76 (2016) no.4 182]
- Custodial Randall-Sundrum [Blanke, Buras, Duling, Gemmler, Gori, JHEP 0903 (2009) 108]
- MSSM non-MFV [Tanimoto, Yamamoto arXiv:1603.0796, Isidori 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

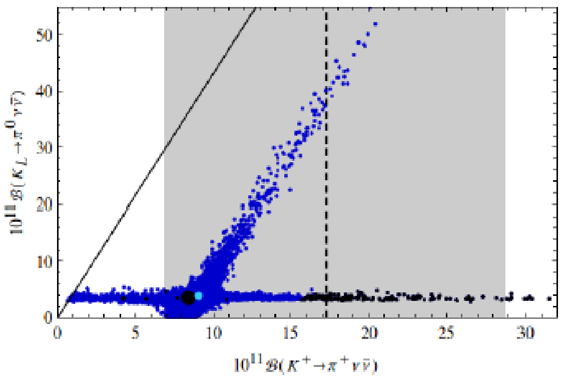
Z′ model



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:

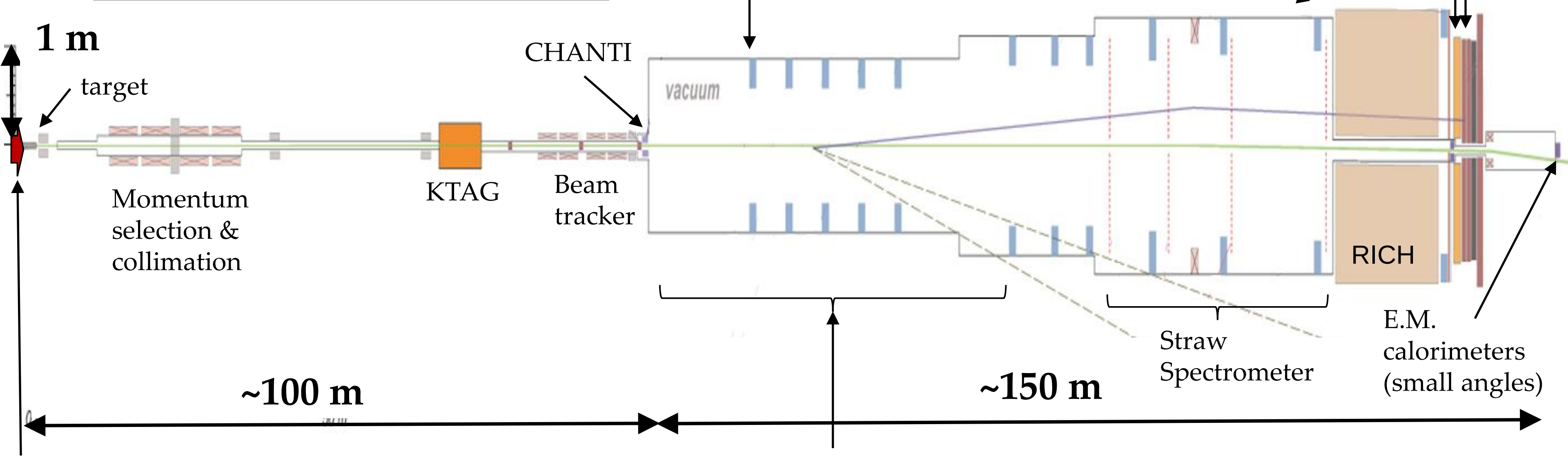
  10% precision BR($K^+ \to \pi^+ \nu \bar{\nu}$)

- Requirements:
  - Statistics: O(100) events
  - K decays 10^{13} , Signal acceptance ~ 10%
  - Systematics: <10% precision background measurement
  - >10^{12} background rejection (<20% background)

- Technique:
  - K Decay – in – flight

NA62 Layout

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



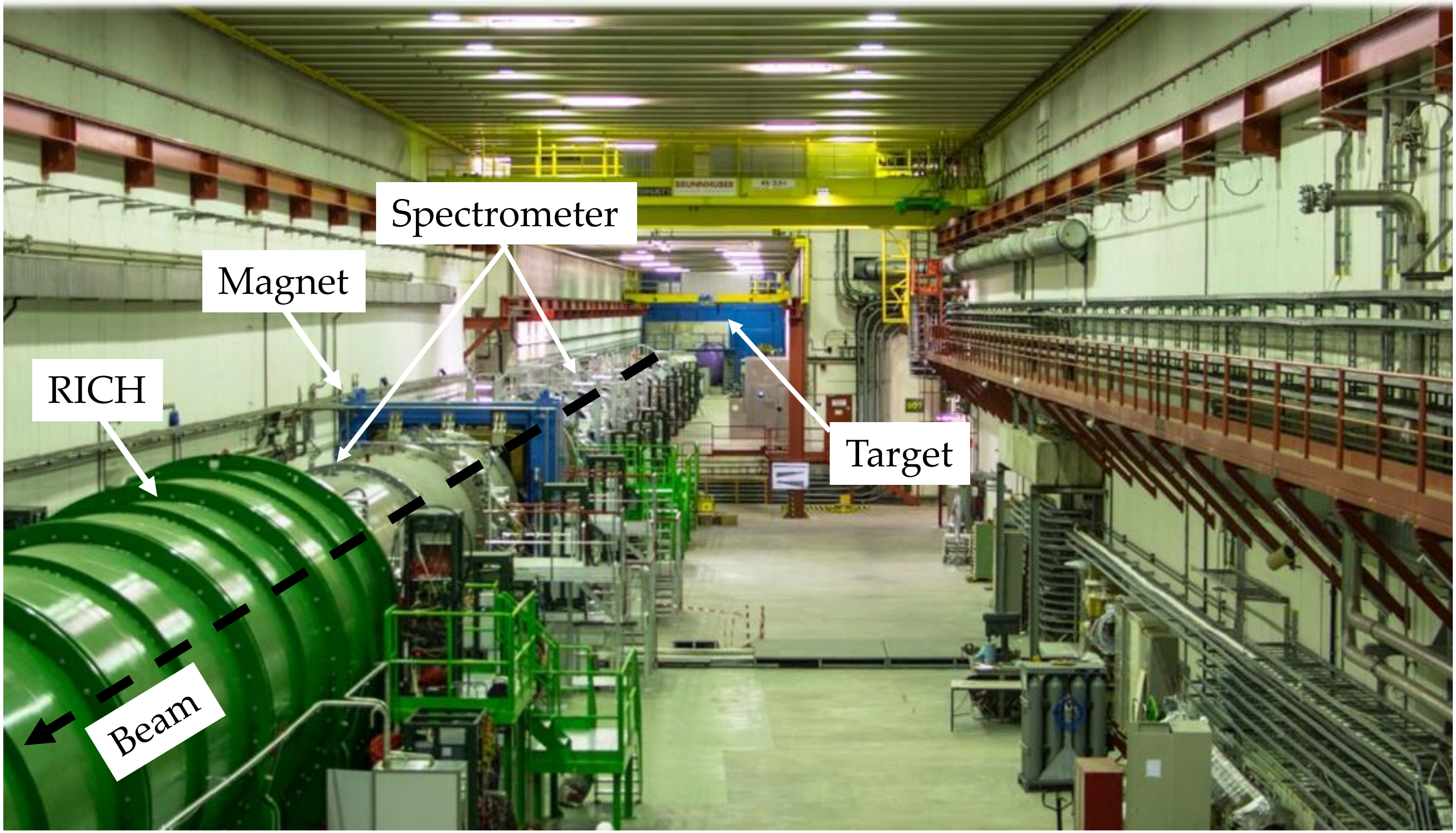
SPS proton
400 GeV
10^{12} p/s
3.5 s spill

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

The Apparatus



Present Status

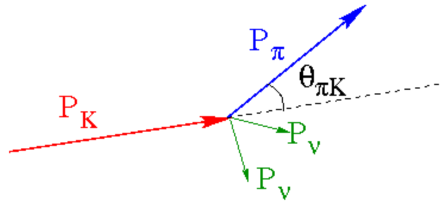
- Beam line, detectors, trigger and DAQ fully commissioned

- NA62 data taking periods
  - 2014: detector commissioning
  - 2015: trigger commissioning, detector quality studies, beam line commissioning up to nominal intensity
  - 2016: high level trigger commissioning (done), full beam tracker commissioning (done), physics (on - going)

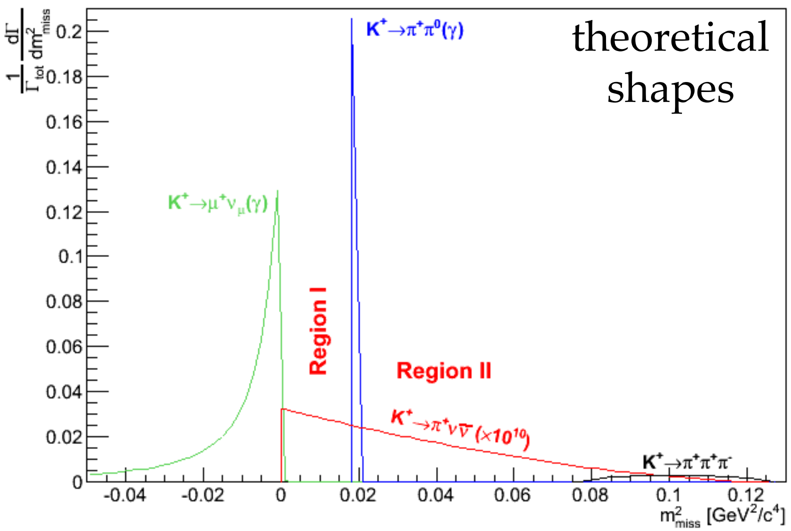
- Data samples for analysis:
  - 2015:
    - Low intensity data with minimum bias trigger for detector quality studies (this talk)
  - 2016:
    - $\pi\nu\nu$ data (up to 30% of nominal intensity)
    - not – $\pi\nu\nu$ data (up to 30% of nominal intensity)

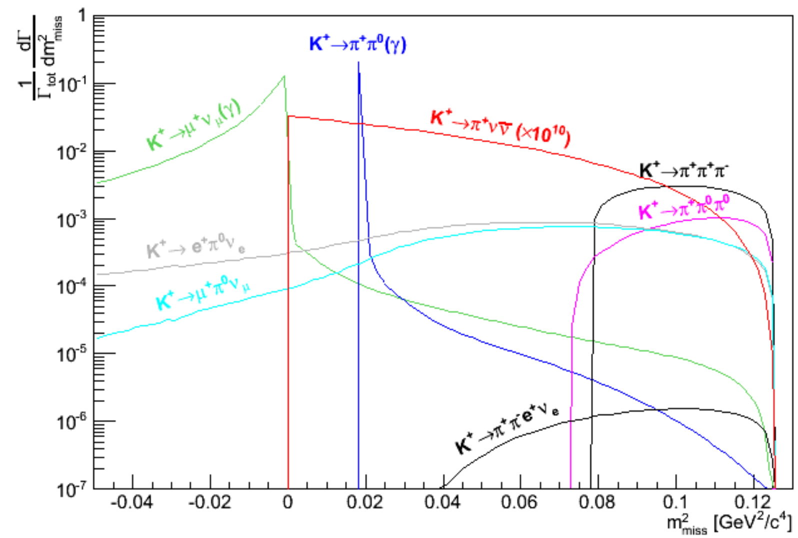
$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ Analysis Principles

- 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 Performances and Sensitivity

- Required background suppression

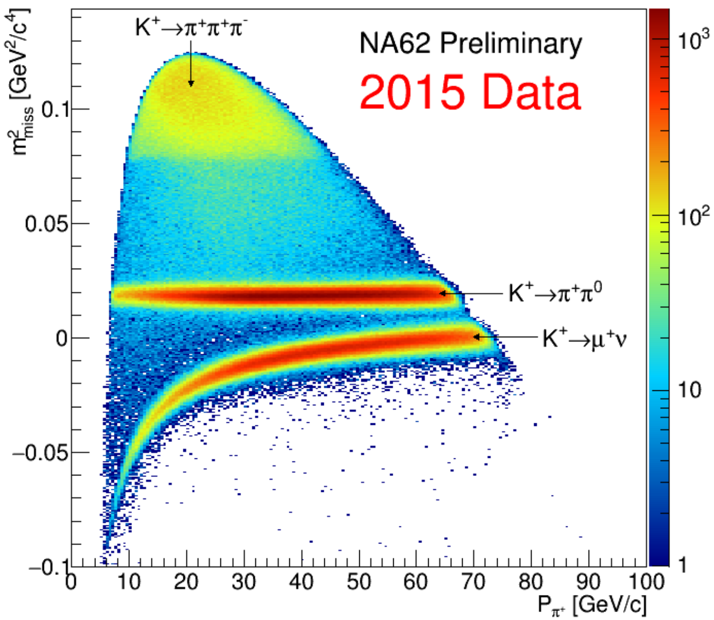
Kinematics	$O(10^4\text{-}10^5)$
Charged Particle ID	$O(10^7)$
γ detection	$O(10^8)$
Timing	$O(10^2)$

- Sensitivity

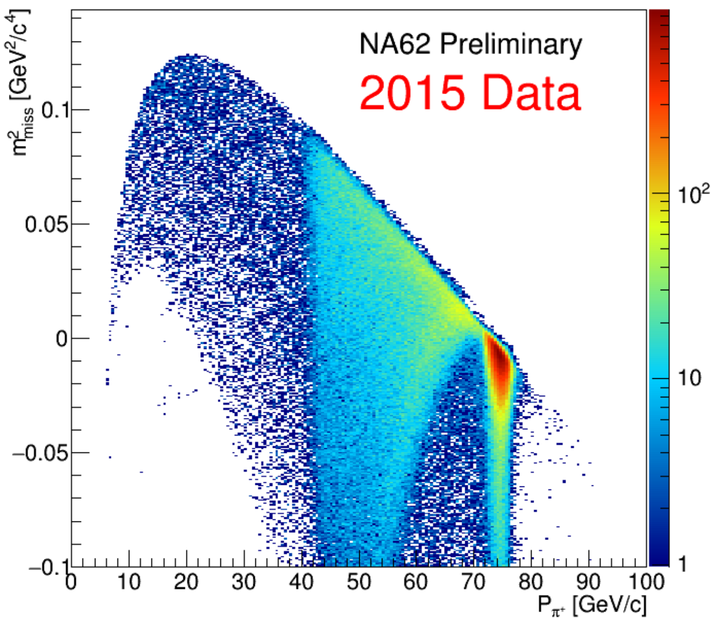
Decay	ev/year
$K^+ \to \pi^+ \nu\nu$ [SM] (flux 4.5×10^{12})	45
$K^+ \to \pi^+ \pi^0$	5
$K^+ \to \mu^+ \nu$	1
$K^+ \to \pi^+ \pi^+ \pi^-$	< 1
3 tracks decays	< 1
$K^+ \to \pi^+ \pi^0 \gamma$(IB)	1.5
$K^+ \to \mu^+ \nu \gamma$(IB)	0.5
$K^+ \to \pi^0 e^+ (\mu^+) \nu$, others	< 1
Total background	< 10

Signal Topology and Kaon ID

OTS + Kaon ID



OTS + no - Kaon ID



One – track selection (OTS)

- Single downstream track topology
- Downstream track matching energy in calorimeters
- Beam track matching the downstream track

Kaon ID

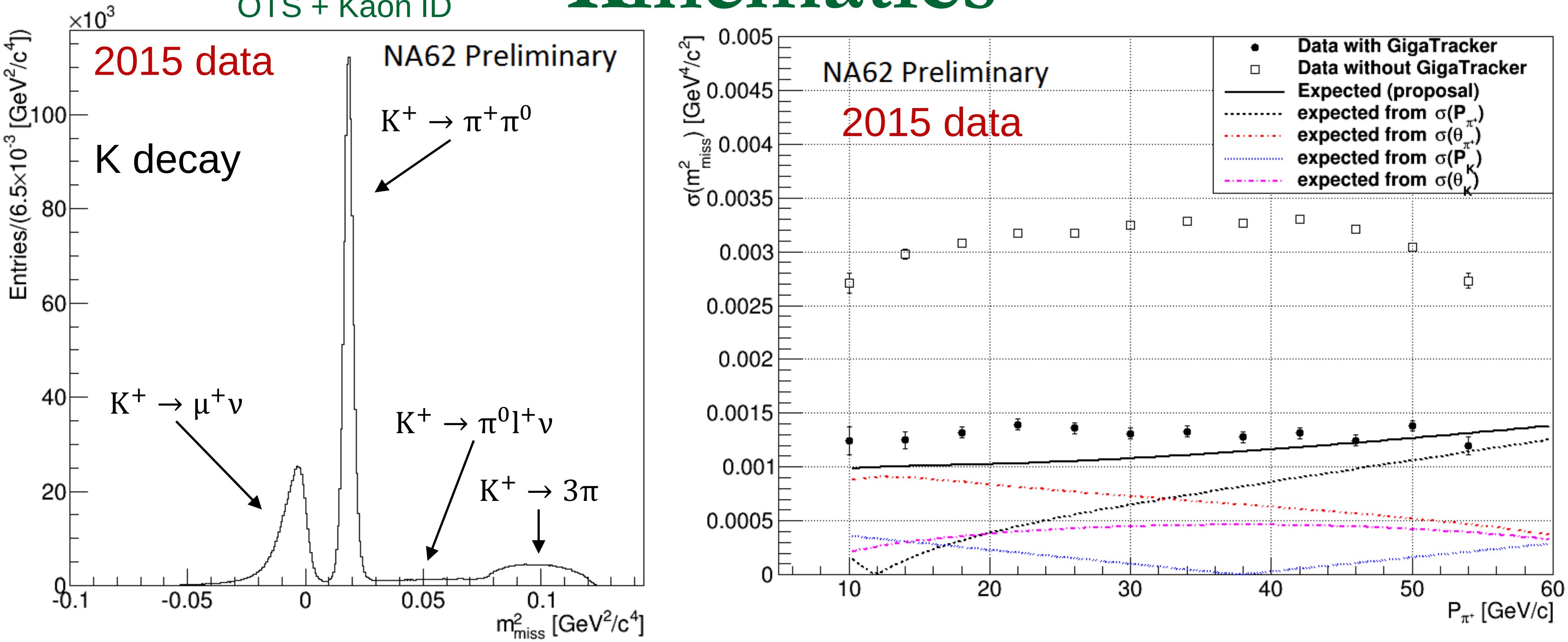
- Beam track matching a K signal in Kaon ID
- Decay vertex in the fiducial region (65 m).

Time resolutions:

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

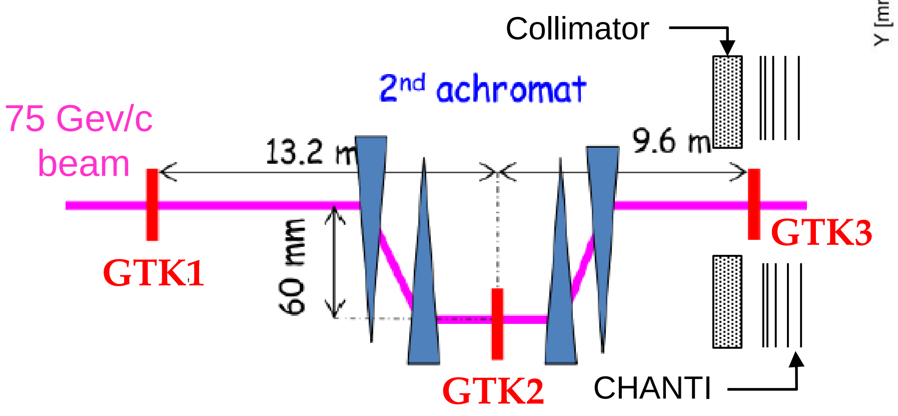
Kinematics

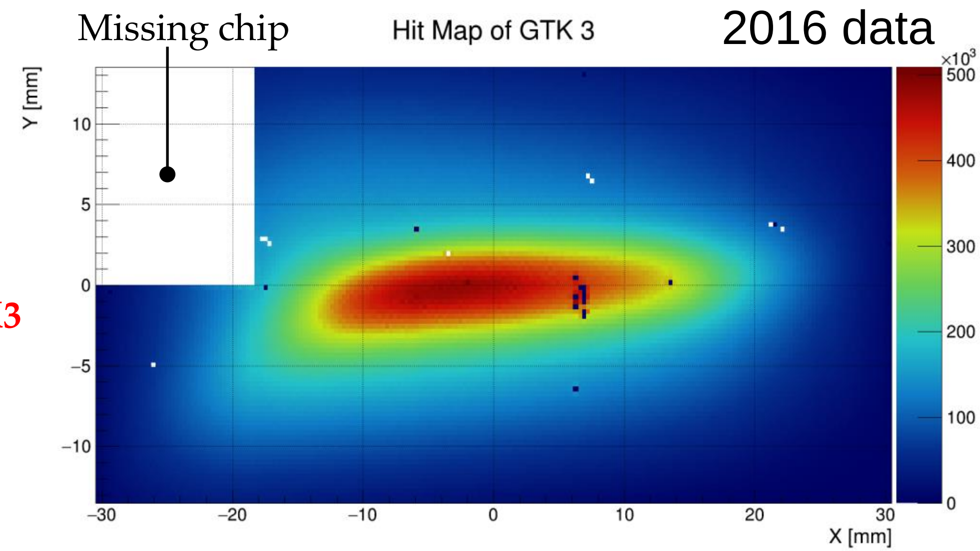
OTS + Kaon ID

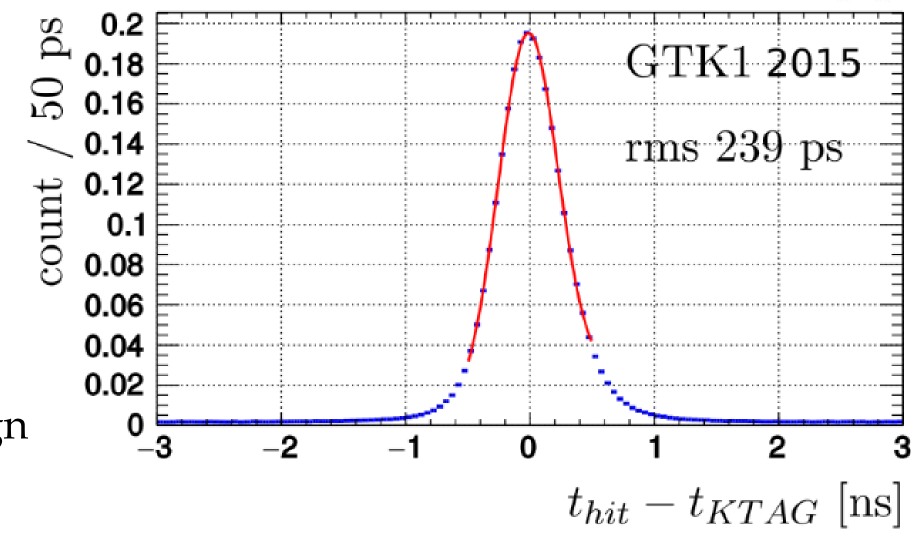


- Tracking Techniques: Si - pixel tracker (beam); Straw tube tracker in vacuum (downstream)
- Goal: O($10^4 \div 10^5$) suppression factor of the main kaon decay modes
- $P_{\pi^+} < 35$ GeV/c: best $K^+ \to \mu^+\nu$ suppression.
- Kinematics studied on $K^+ \to \pi^+\pi^0$ selected using LKr calorimeter.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

Beam Tracker (GigaTracker)



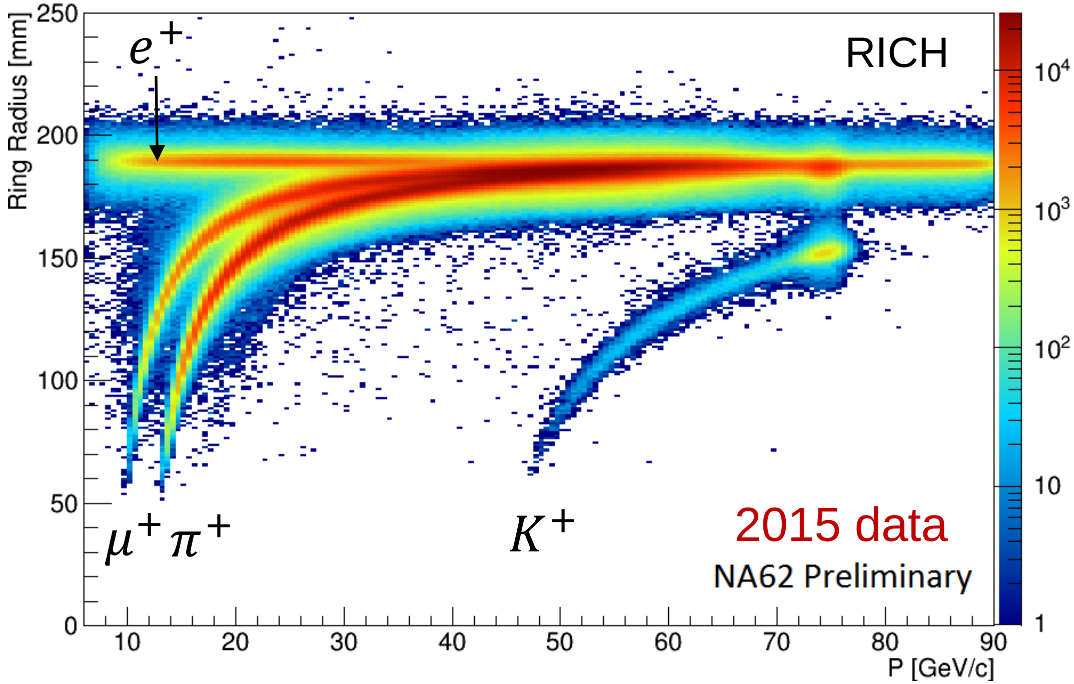


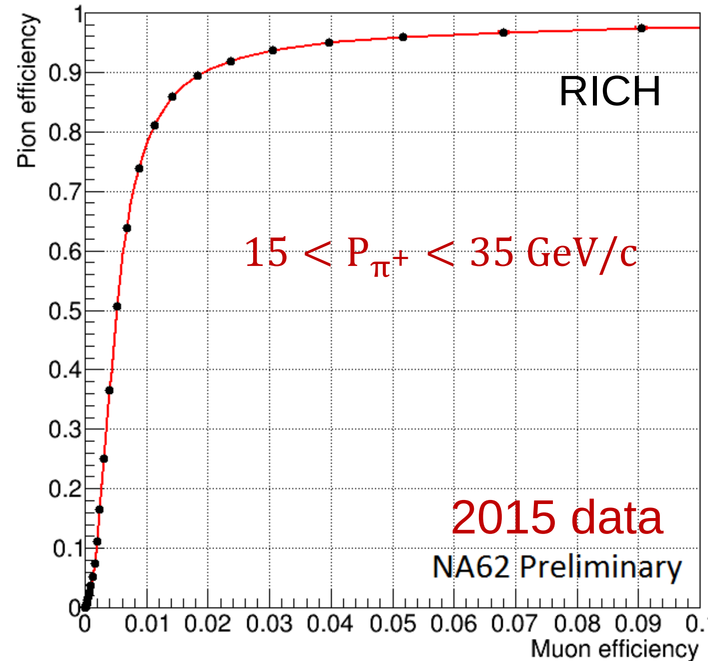


- 3 Si pixel stations on the beam
- 300 × 300 μm² pixels, ~54000 pixels
- Cooling using microchannel technique
- On-sensor TDC readout chip
- $X/X_0 < 0.5\%$ / station
- Commissioned in 2015-2016
- Measured performances match the design
  - $\sigma(t_{beam\ track}) \leq 200$ ps

Downstream Particle Identification

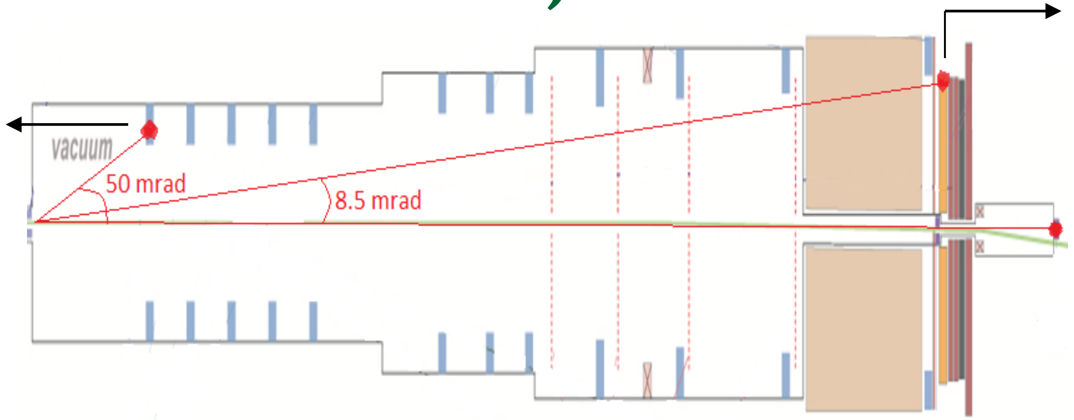
OTS





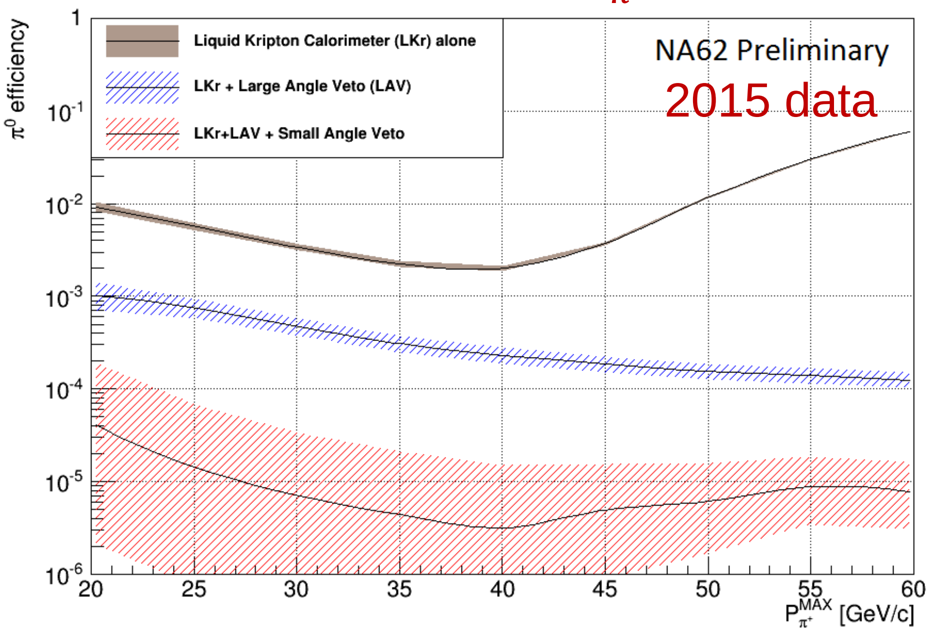
- Technique: RICH and calorimeters
- Goal: O(10^7) μ/π separation to suppress mainly $K^+ \rightarrow \mu^+ \nu$
- $15 < P_{\pi^+} < 35$ GeV/c: best μ/π separation in RICH
- Pure samples of pions and muons selected using kinematics
- RICH: O(10^2) π/μ separation, 80% (90%) π^+efficiency in 2015 (2016)
- 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 → $E_{\pi^0} > 40$ GeV
- Measured on data using $K^+ \to \pi^+\pi^0$ selected kinematically
- 2015 measurement statistically and background limited

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



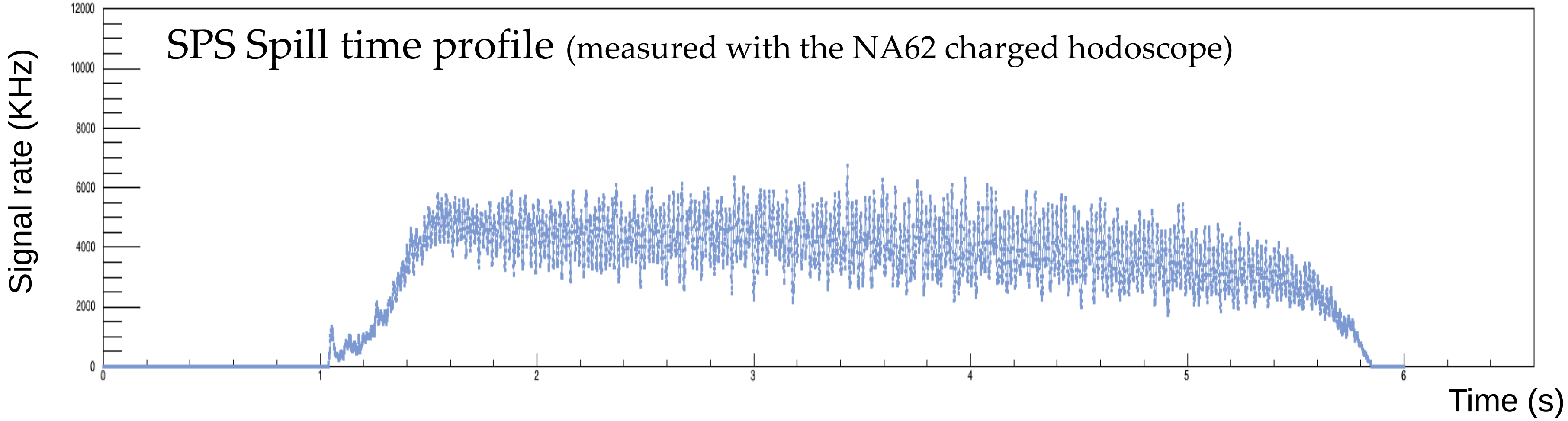
Summary from data quality studies

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. Statistically limited. 2016 already enough to address the 10^8 rejection level (analysis on - going).

Broader NA62 Physics Program

- LFV with Kaons:
  - $K^+ \to \pi^+\mu^\pm e^\mp$, $K^+ \to \pi^-\mu^+e^+$, $K^+ \to \pi^- l^+ l^+$
- π^0 decays rare and forbidden/LFV, dark photon production:
  - $\pi^0 \to$ invisible, $\pi^0 \to 3/4\gamma$, $\pi^0 \to ee, eee$, $\pi^0 \to \mu e$, $\pi^0 \to U\gamma$
- Heavy neutral lepton production searches in K decays:
  - $K^+ \to l^+\nu_h$ (already under analysis with 2015 data), $K^+ \to l^+X$
- Dark sector particles searches:
  - Long living dark photon decaying in l^+l^- and produced by $\pi^0/\eta/\eta'/\Phi/\varrho/\omega$ decays
  - Long living heavy neutral lepton decaying in πe, $\pi\mu$
  - Long living axion-like decaying in $\gamma\gamma$ produced in a beam-dump configuration

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)

Timescale

- $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ program until LS2
- End 2016: reach the SM sensitivity for $K^+ \rightarrow \pi^+ \nu\bar{\nu}$
- End 2017: improve (by much) the present status of the art (BNL measurement).
- End 2018: reach the 10% precision.

- Broader physics program until LS2 (see P.Petrov talk on Saturday)
- LFV / LNV decays, heavy neutrinos, π^0 rare decays, ...
- as many decay modes as possible to take simultaneously with πνν

- Broader physics program beyond LS2 (see P.Petrov talk on Saturday)
- LFV / LNV decays, heavy neutrinos, π^0 rare decays, hidden sector particles searches

Conclusions

- The NA62 experiment is running in stable conditions.
- Data quality studies:
  - Physics sensitivity for $K^+ \to \pi^+ \nu\bar{\nu}$ measurement in line with the design.
- Analysis of the 2016 data on – going.
- $K^+ \to \pi^+ \nu\bar{\nu}$ program to get the 10% design precision under way.
- Broader physics program for short/medium term plan established.