Search for $K^+ \to \pi^+ \nu\nu$ at NA62

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on behalf of the NA62 Collaboration

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MENU 2016 KYOTO

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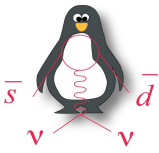
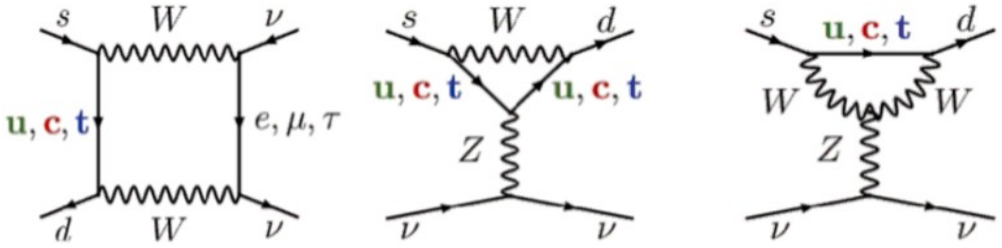
Outlines



- Theoretical introduction to the $K^+ \to \pi^+ \upsilon\upsilon$ rare decay
- The NA62 experiment at CERN SPS: aim and strategy
- Experimental setup
- Data quality from 2015 data
- Conclusions

Theoretical Motivations

- **FCNC loop process**



- **BR suppressed** by hierarchical structure of the CKM matrix

$$BR(K^+ \to \pi^+ \nu\bar{\nu}) = \kappa_+ [1 + \Delta_{EM}] \left[\left(\frac{\Im\lambda_t}{\lambda^5} X(x_t) \right)^2 + \left(\frac{\Re\lambda_c}{\lambda} (P_c + \delta P_{c,u}) + \frac{\Re\lambda_t}{\lambda^5} X_t \right)^2 \right]$$

Loops favor top contribution

$x_q \equiv m_q^2/m_W^2$

$\lambda = V_{us}$
$\lambda_c = V_{cs}^* V_{cd}$
$\lambda_t = V_{ts}^* V_{td}$

Hadronic matrix element
from Ke3 via isospin rotation

Charm contributes to theory errors

$\mathcal{B}_{SM}(K^+ \to \pi^+ \upsilon\upsilon) = (9.11 \pm 0.72)\ 10^{-11}$

$\mathcal{B}_{SM}(K_L \to \pi^0 \upsilon\upsilon) = (3.00 \pm 0.30)\ 10^{-11}$

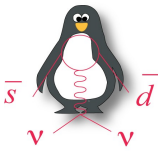
[JHEP 1511 (2015) 033]

Very clear SM prediction

extraction of V_{td} without hadronic uncertainties

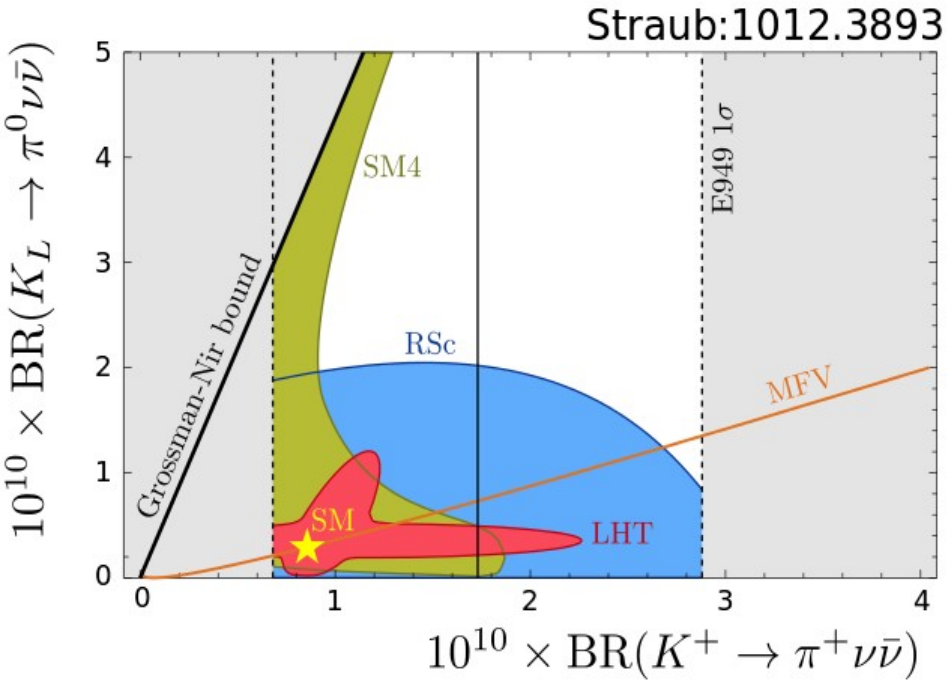
and...

Sensitive probe to New Physics



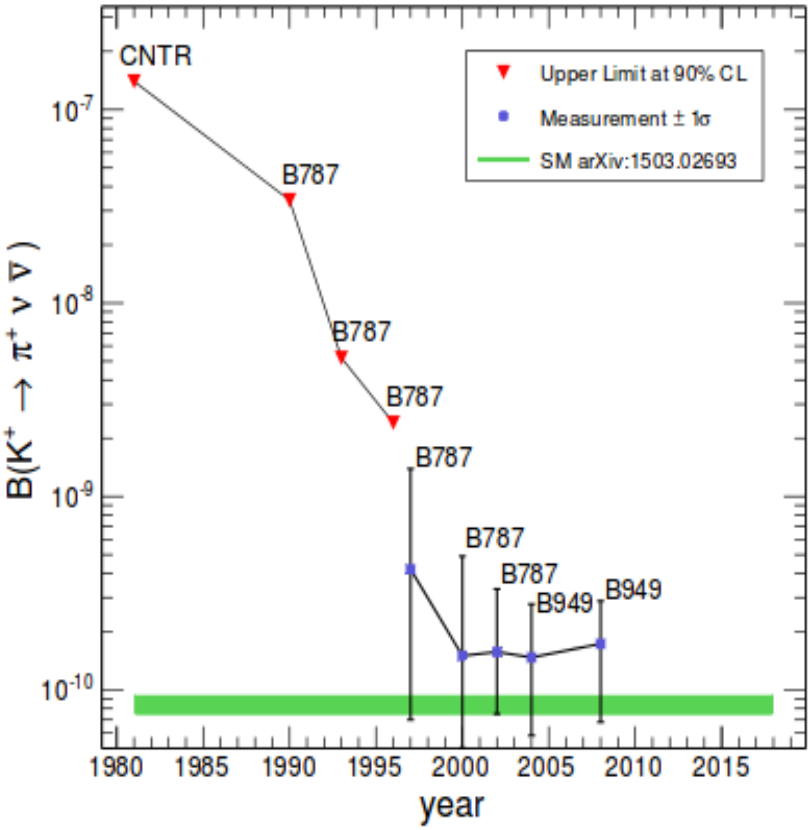
Deviation from $\mathcal{B}_{SM}$ → signal of New Physics process

- 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]



Present experimental knowledge

Experimental status



	SM prediction ($\times 10^{-11}$)	Experiment ($\times 10^{-11}$)
$K^+ \to \pi^+ \nu\bar{\nu}$	9.11 ± 0.72	$17.3^{+11.5}_{-10.5}$
$K^0 \to \pi^0 \nu\bar{\nu}$	3.00 ± 0.30	<2600

PAST :

Stopped kaon technique

E787
E949
} @ BNL

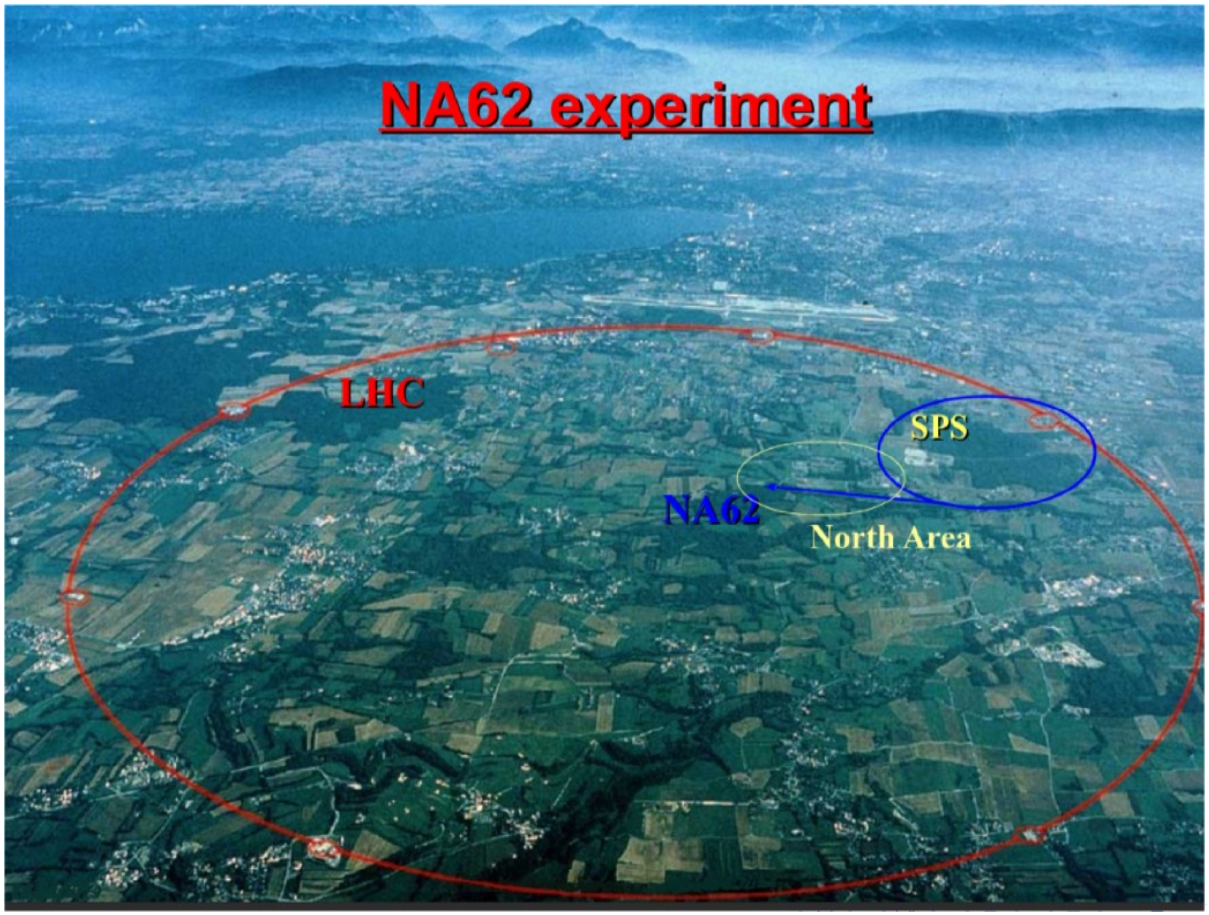
Phys. Rev. D 77, 052003 (2008)
Phys. Rev. D 79, 092004 (2009)

NOW

NA62 in-flight-decay technique → 10% precision

NA62 at CERN SPS

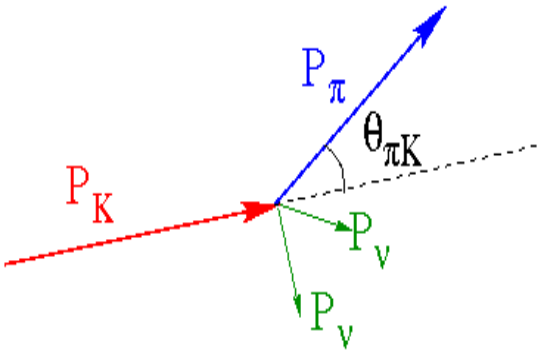
Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna(JINR), Fairfax, Ferrara, Florence, Frascati, Glasgow, Liverpool,Louvain-la-Neuve, Mainz, Merced, Moscow (INR), Naples, Perugia, Pisa, Prague, Protvino (IHEP) , Rome I, Rome II, San Luis Potosi, SLAC, Sofia, TRIUMF, Turin, Vancouver (UBC)



- ✔ '06 Proposal
- ✔ '09-'12 R&D and construction for πνν
- ✔ '12 technical run
- ✔ '14-'15 commissioning runs
- ✔ '16 run started in May
- ☐ Physics runs ('16-'18)

Analysis strategy

Measuring the $\mathcal{B}(K^+ \to \pi^+ \upsilon\upsilon)$ with 10% precision



Ultra rare decay O(10^{-11})

↓

High intensity beam → 10^{13} decays in two years of data taking

Large signal acceptance → 10%

Large background rejection → 10^{12}

Clear signal signature: K^+ track + π^+ track

↓

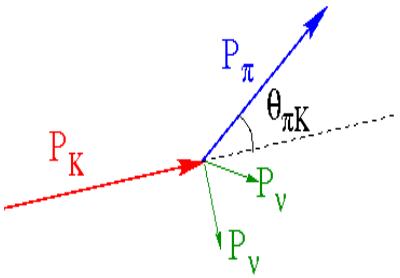
Precise timing → 100-150 ps

Kinematics cut → low mass tracking

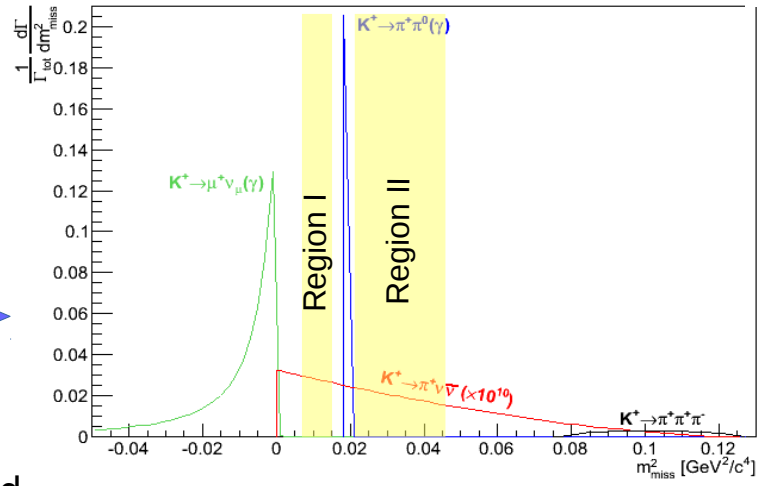
High efficiency photon and muon vetos

Analysis strategy

Large background rejection → 10^{12}



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



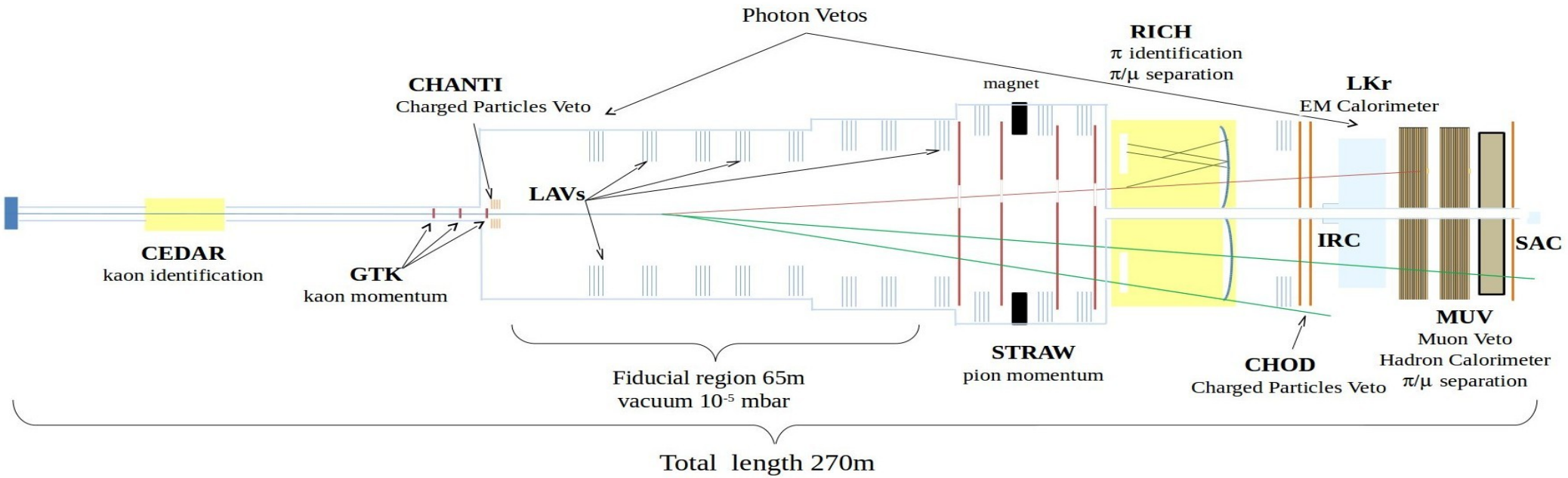
92% separated
by kinematic cut

Decay	BR	Rejection Tools
$K^+ \to \mu^+\nu$	63%	μ-ID + kinematics
$K^+ \to \pi^+\pi^0$	21%	γ-veto + kinemtics
$K^+ \to \pi^+\pi^+\pi^-$	6%	multi-tracks +kinematics
$K^+ \to \pi^+\pi^0\pi^0$	2%	γ-veto + kinemtics
$K^+ \to e^+\pi^0\nu$	5%	e-ID + γ-veto
$K^+ \to \mu^+\pi^0\nu$	3%	μ-ID + γ-veto

Decay	event/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
$K^+\to\pi^+\pi^-e^+\nu$ + other 3 tracks decays	< 1
$K^+\to\pi^+\pi^0\gamma$(IB)	1.5
$K^+\to\mu^+\nu\gamma$(IB)	0.5
$K^+\to\pi^0e^+(\mu^+)\nu$, others	negligible
Total background	< 10

NA62 experimental setup

High intensity Beam



Secondary beam from SPS: 750 MHz

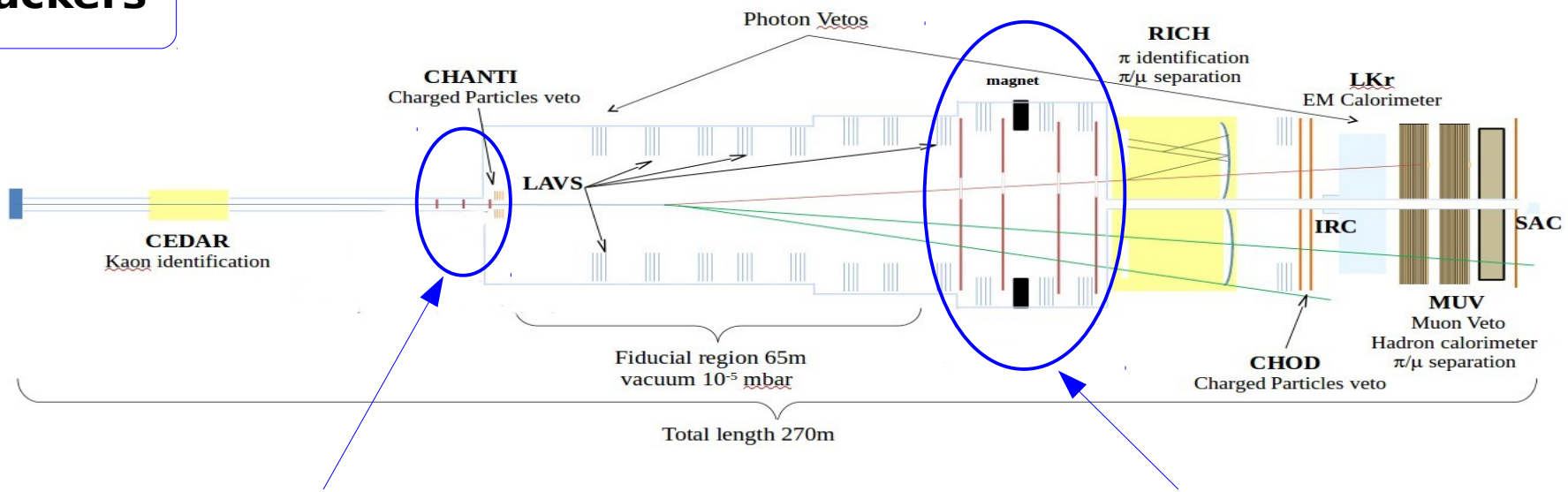
75 GeV/c with δp/p=1%

Composition:
6% K^+
23% p
70% π^+

Beam and detector commissioned up to nominal intensity (2015)

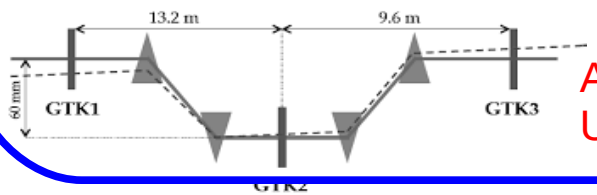
NA62 experimental setup

Trackers



GTK

3 station of Si-Pixel detector (60.8x27mm²)
Low material budget: 0.5 X_0
Momentum Resolution ~δp/p= 0.2%
Fast Timing: σ=200 ps (hit time resolution)
From 2015: σ~230-250 ps



All Station 2015
Under commissioning

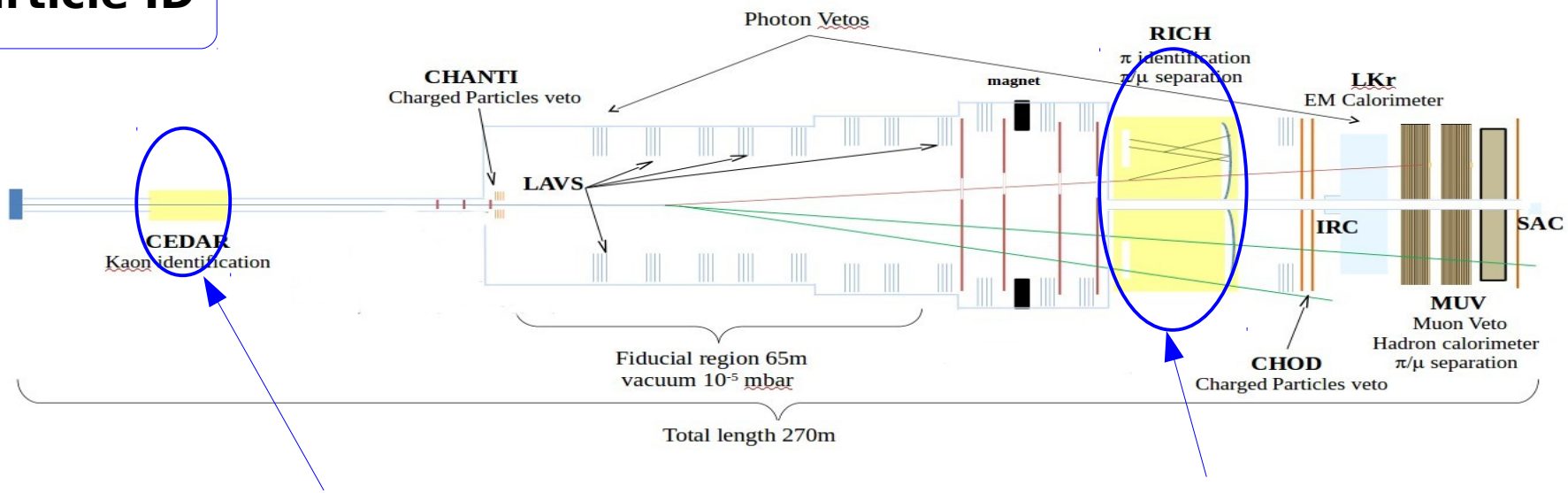
STRAW

Low material budget: <0.5% X_0(per chamber
Vertical magnetic field: P_{T_kick}=270 MeV/c
Angular resolution < 60 μrad
Momentum resolution ~δp/p= 1%

From 2015: σ~5 ns

NA62 experimental setup

Particle ID

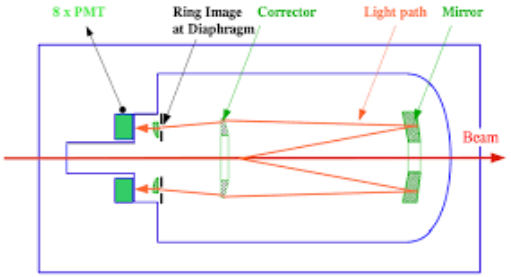


KTAG

45 MHz K^+

Fast Timing: σ<100 ps

0.1% mis-ID → from 2015 data



RICH

Vessel: 17m long & ∅ 4 m
Neon gas @ ~1atm

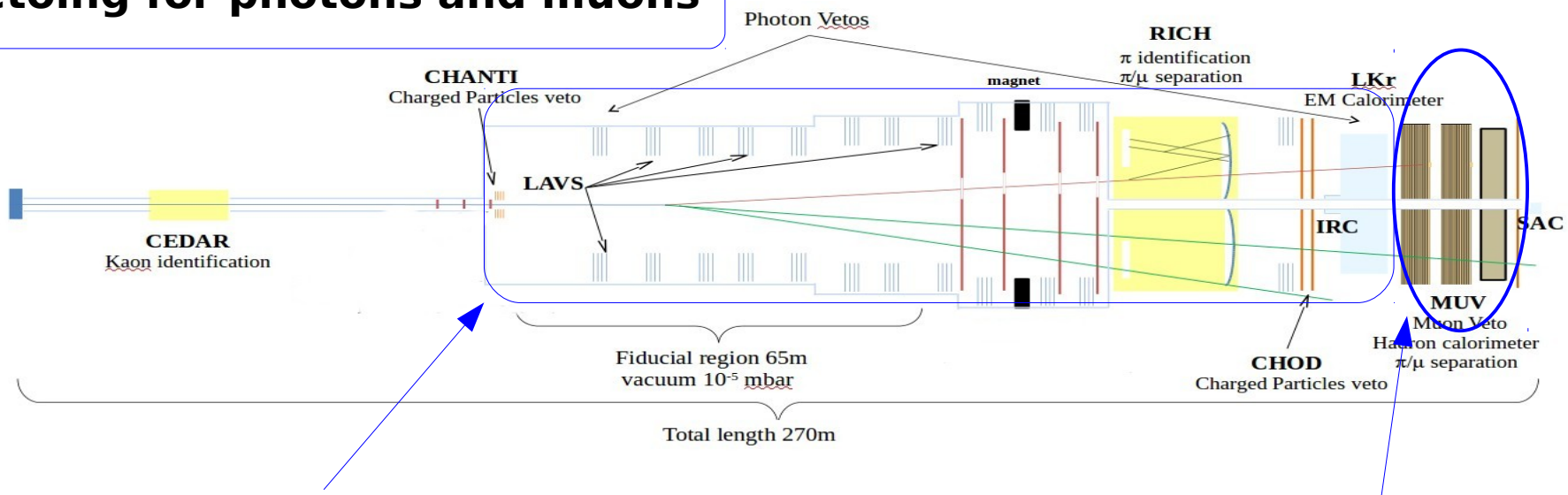
Mirrors: curvature 34m
Reflectivity > 90%

Pion ID efficiency ~80%
Muon mis-ID ~ 1%

@ 15 < p < 35 GeV/c from 2015 data

NA62 experimental setup

Vetoing for photons and muons



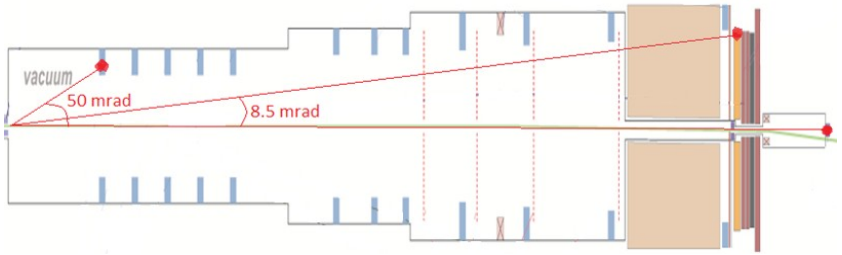
Photon veto system

LAVs: 8.5-50 mrad, $\varepsilon=10^{-4}$ $E_\gamma>200$ MeV

LKr: 1-8.5 mrad, $\varepsilon=10^{-5}$ $E_\gamma>10$ GeV

IRC&SAC: <1 mrad, $\varepsilon=10^{-4}$ $E_\gamma>5$ GeV

Target: π^0 rejection O(10^8)



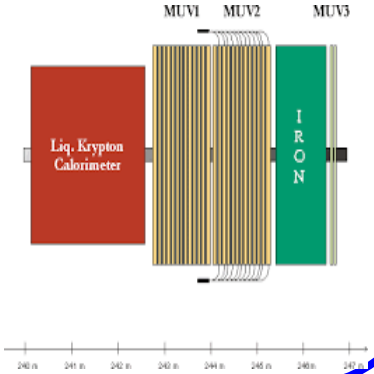
Muon veto system

MUV1&MUV2:

hadronic calorimer

iron-scintillator plate sandwiches

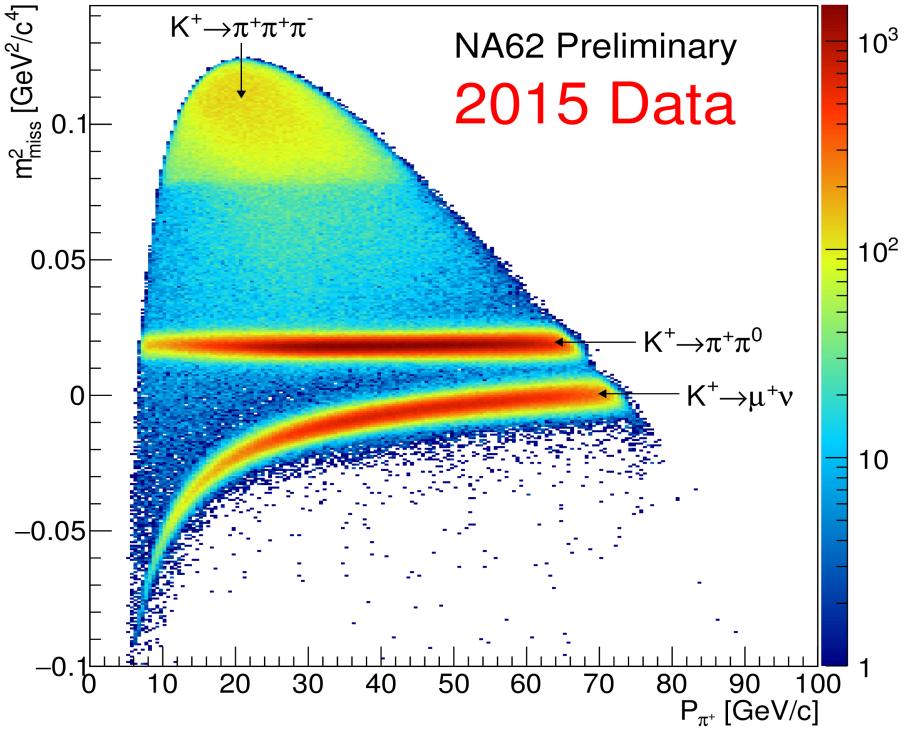
MUV3:
Efficient fast μ-veto



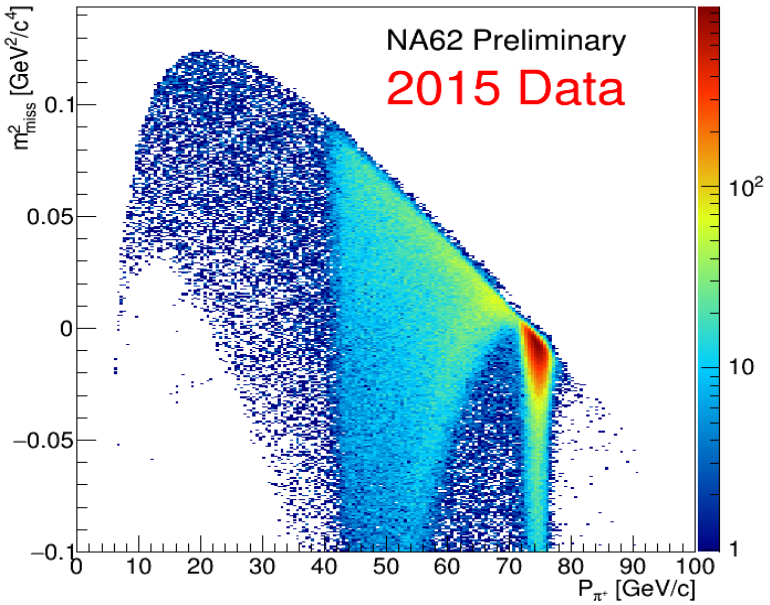
Signal topology and Kaon ID

2015 Data sample: **Low intensity data taken with a minimum bias trigger (this talk)**
Samples at half and full intensity taken with a calorimeter trigger

Single Track Selection
Beam Track: matching kaon in KTAG
Matching Kaon – Downstream track



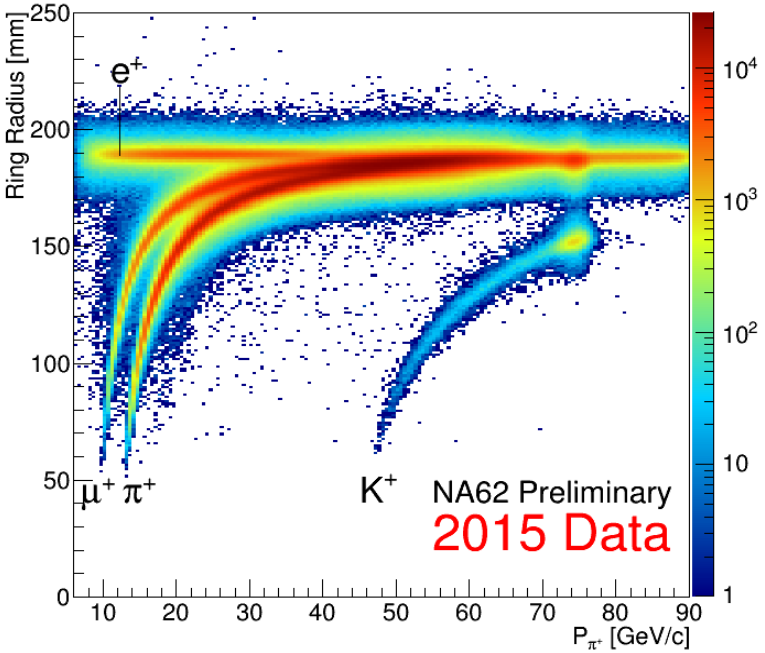
Beam track: no matching
Kaon in KTAG



Downstream Particle Identification

GOAL: O(10^7) π/μ separation, to reject $K^+ \to \mu^+ \nu$

Pure sample of pion and muon selected using kinematics cuts



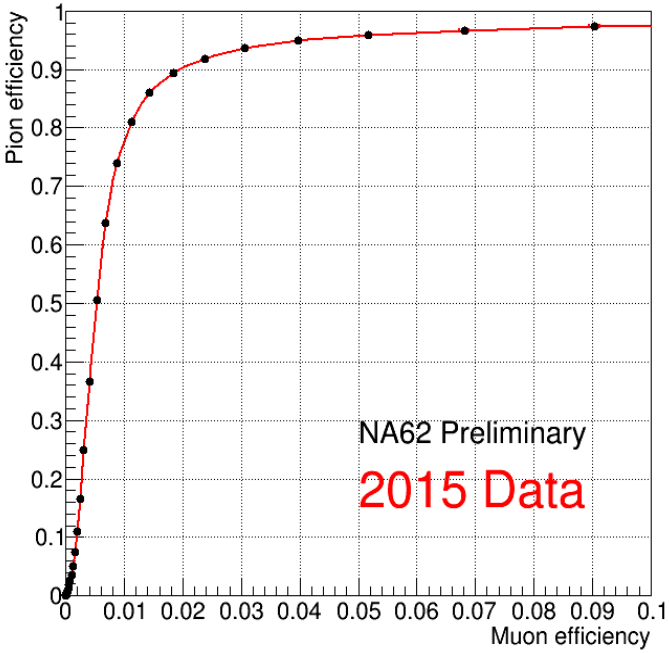
RICH

Best π/μ separation

@ 15 < P_π < 35 GeV/c

O(10^2) μ suppression

80% π^+ efficiency in 2015.



CALORIMETERS

10^4 - 10^6 μ^+ suppression for 90% - 40% π^+ efficiency in 2015 using a cut analysis.

Photon rejection

Technique: EM calorimeters exploiting correlation 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

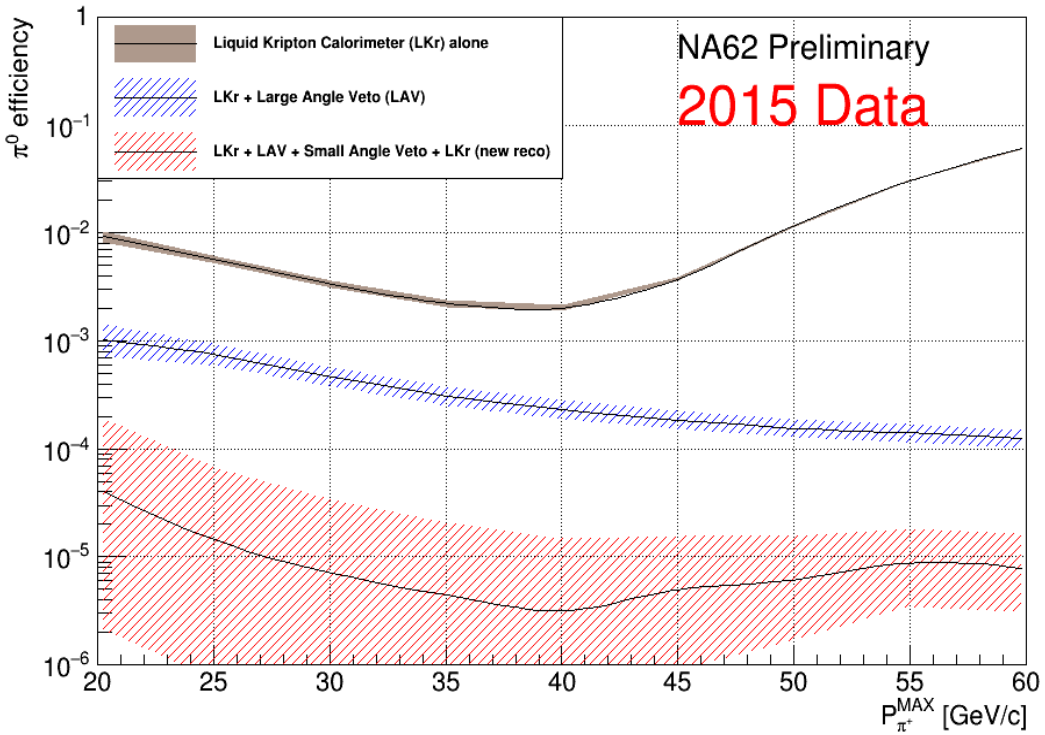
Measured on data using $K^+ \to \pi^+\pi^0$

selected kinematically

O(10^6) π^0 rejection already obtained.

More statistics needed to push the study

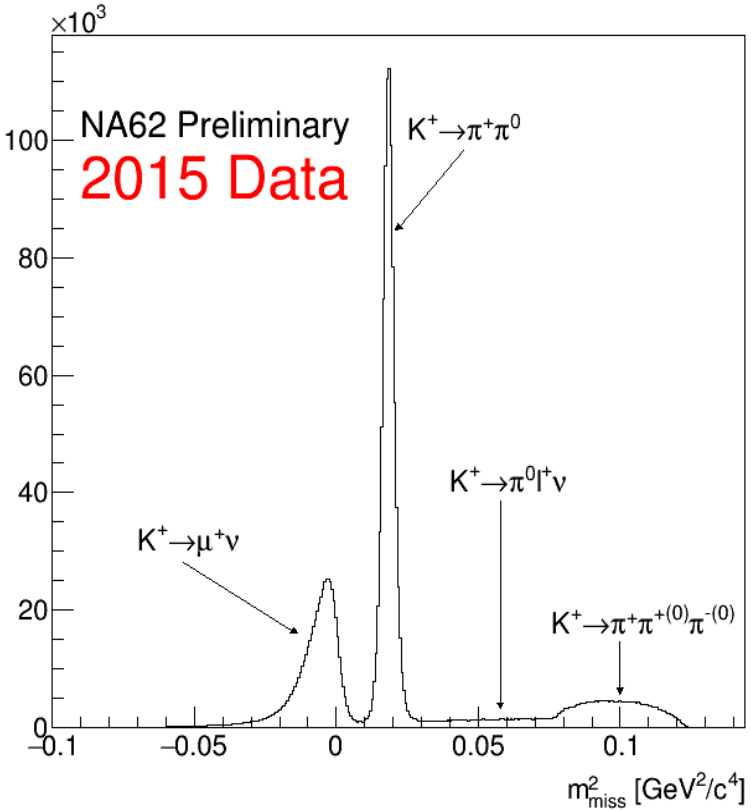
at the design sensitivity.

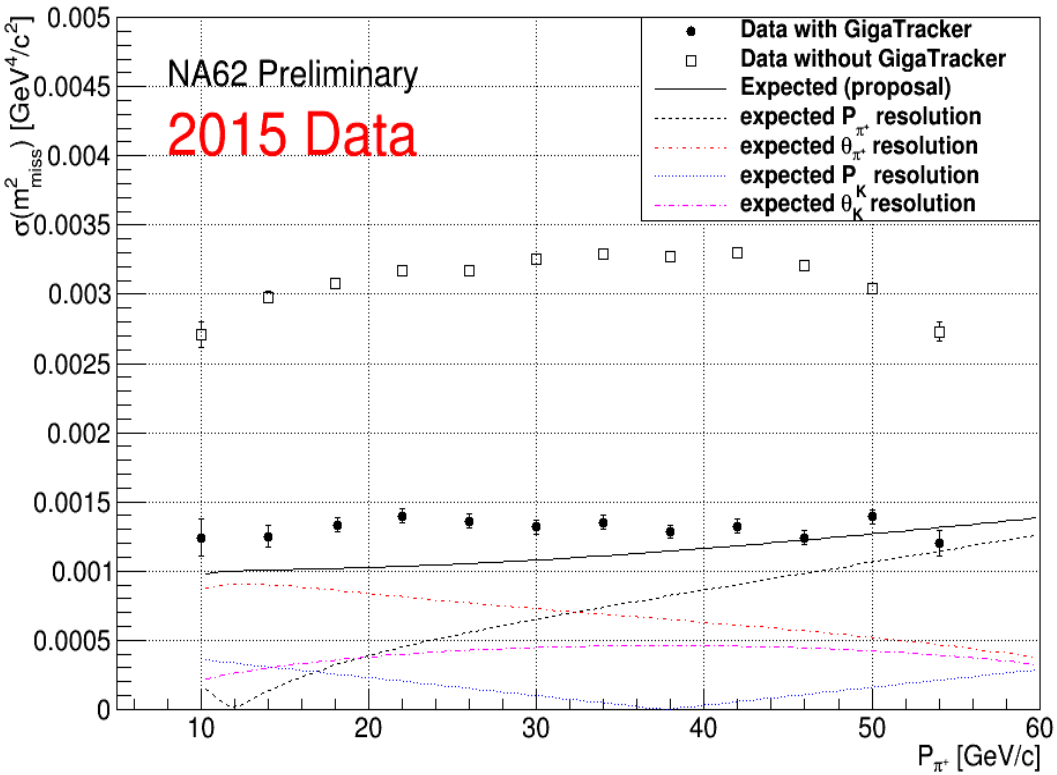


Kinematics

Goal: O(10^{4}) suppression factor of the main kaon decay modes

Single track selection + Kaon ID + vertex cut





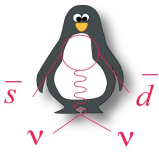
Resolution close to the design

O(10^{3}) suppression factor from 2015 data.

Further opportunities

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}
$\mu^+\nu_h, \nu_h \rightarrow \nu\gamma$	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	-	$O(10^5)$

Conclusions



✔ Commissioning of the detector has been completed

✔ Physics sensitivity for $K^+ \to \pi^+ \upsilon\upsilon$ measurement in line with the design:

- Time resolution close to the design
- Kinematics Resolution close to the design.
  Prospects to reach the designed signal – background separation.
- Pion – muon ID Separation with RICH close to expectations.
  Study of the separation with calorimeters on going. Results from simple cut analysis promising.
- Photon veto: 2015 measurement statistically limited

NA62 started to collect data in April 2016

and will continue in 2017 and 2018


Thanks for your attention