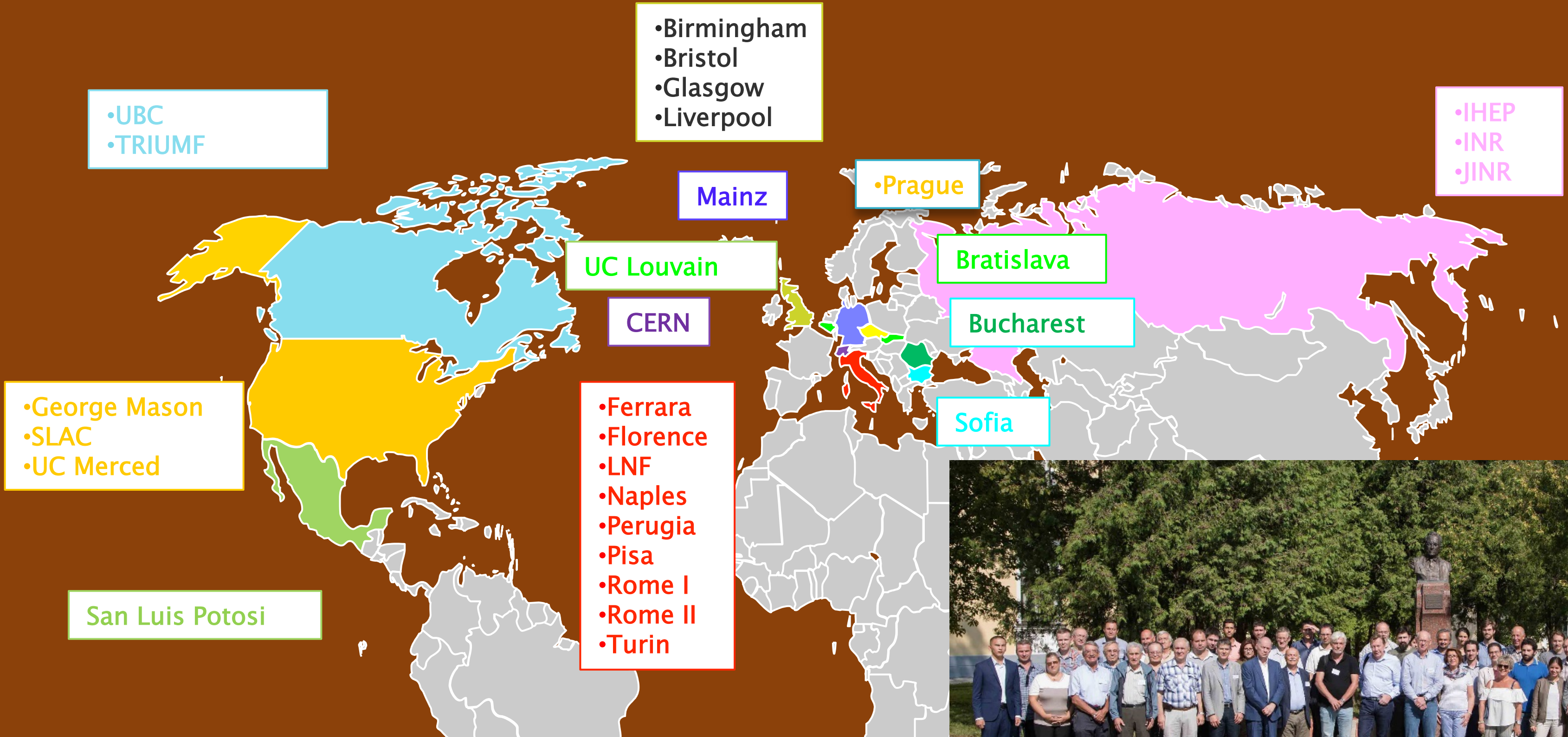
Invisibles17

Augusto Ceccucci / CERN

Zurich, June 13, 2017

STATUS AND PLANS OF NA62

NA62 COLLABORATION



29 Institutes, 230 Collaborators

Why Kaon Physics in the 3rd Millennium?

- The Standard Model (SM) was largely built from kaons…
  - Theta-tau puzzle and the fall of Parity Conservation
  - Strangeness and flavour conservation in Strong Interactions
  - Universality of the Weak Interaction
  - Absence of Flavour Changing Neutral Currents (FCNC) and GIM Mechanism → prediction of charm
  - CP-Violation: ε and ε'/ε

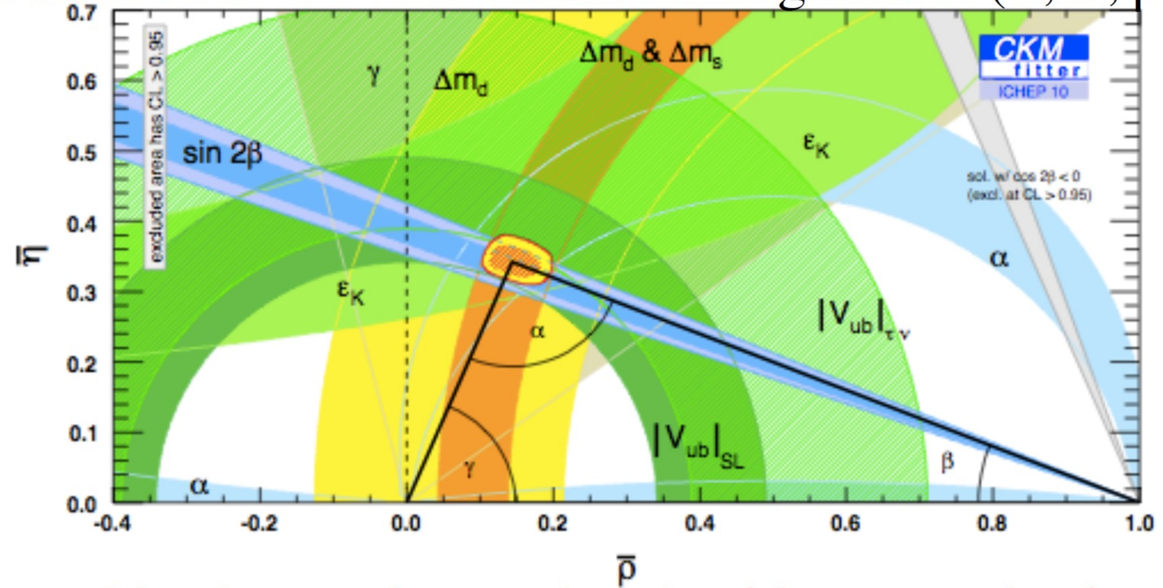
- …Kaon decays are a powerful tool to:
  - Go beyond the SM looking for New Physics in rare decays
  - Study non-perturbative aspects of the Strong Interaction: $\pi-\pi$ scattering, CHPT, hadron structure
  - Look for non-universal lepton couplings
  - CKM unitarity tests & flavour mixing
  - Search for long-lived low energy neutral particles

From I. Shipsey ICHEP 2016
"Vision and Outlook"

Quark flavor physics

Triumph of the CKM description

- All the flavour changing processes are described by the four parameters of the CKM mass mixing matrix (λ, A, ρ, η)



- From this plot, we know already either new physics energy scale is >> TeV (far beyond LHC) or the flavour structure of new physics is very special.

ICHEP 2016 -- I. Shipsey

$K \to \pi\nu\bar{\nu}$ and the unitarity triangle

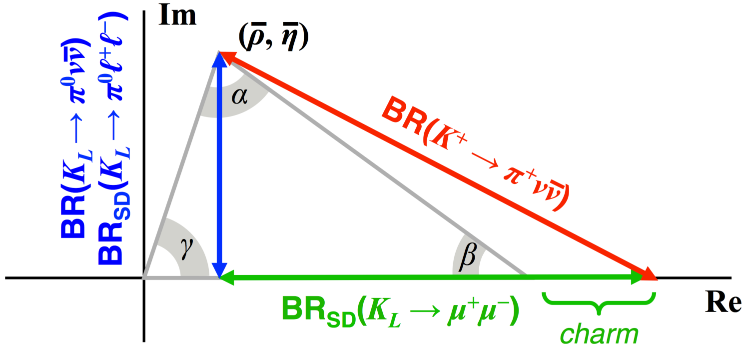
Dominant uncertainties for SM BRs are from CKM matrix elements

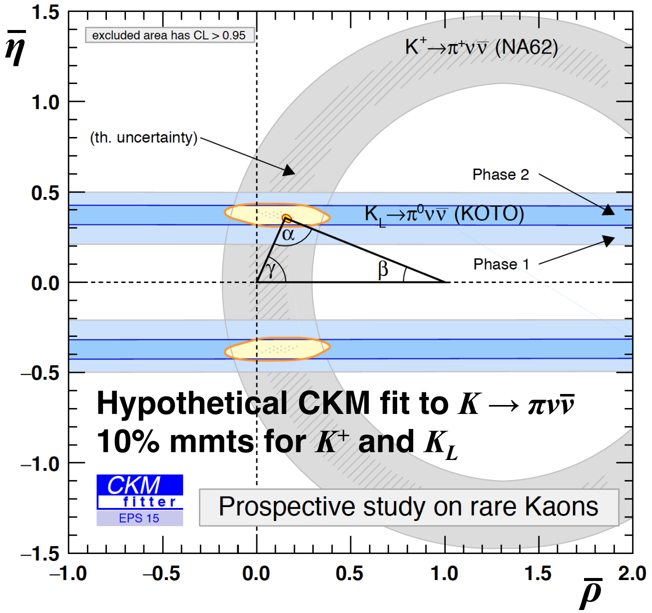
$$\mathrm{BR}(K^+ \to \pi^+\nu\bar{\nu}) = (8.39 \pm 0.30) \times 10^{-11} \cdot \left[\frac{|V_{cb}|}{0.0407}\right]^{2.8} \cdot \left[\frac{\gamma}{73.2^\circ}\right]^{0.74}$$

Buras et al., JHEP 1511

$$\mathrm{BR}(K_L \to \pi^0\nu\bar{\nu}) = (3.36 \pm 0.05) \times 10^{-11} \cdot \left[\frac{|V_{ub}|}{3.88 \times 10^{-3}}\right]^{2} \cdot \left[\frac{|V_{cb}|}{0.0407}\right]^{2} \cdot \left[\frac{\sin\gamma}{\sin 73.2^\circ}\right]^{2}$$

- Intrinsic theory uncertainties ~ few percent
- BR measurements for both K^+ and K_L determine the unitarity triangle independently from B inputs
  - Overconstrain CKM matrix → reveal NP?





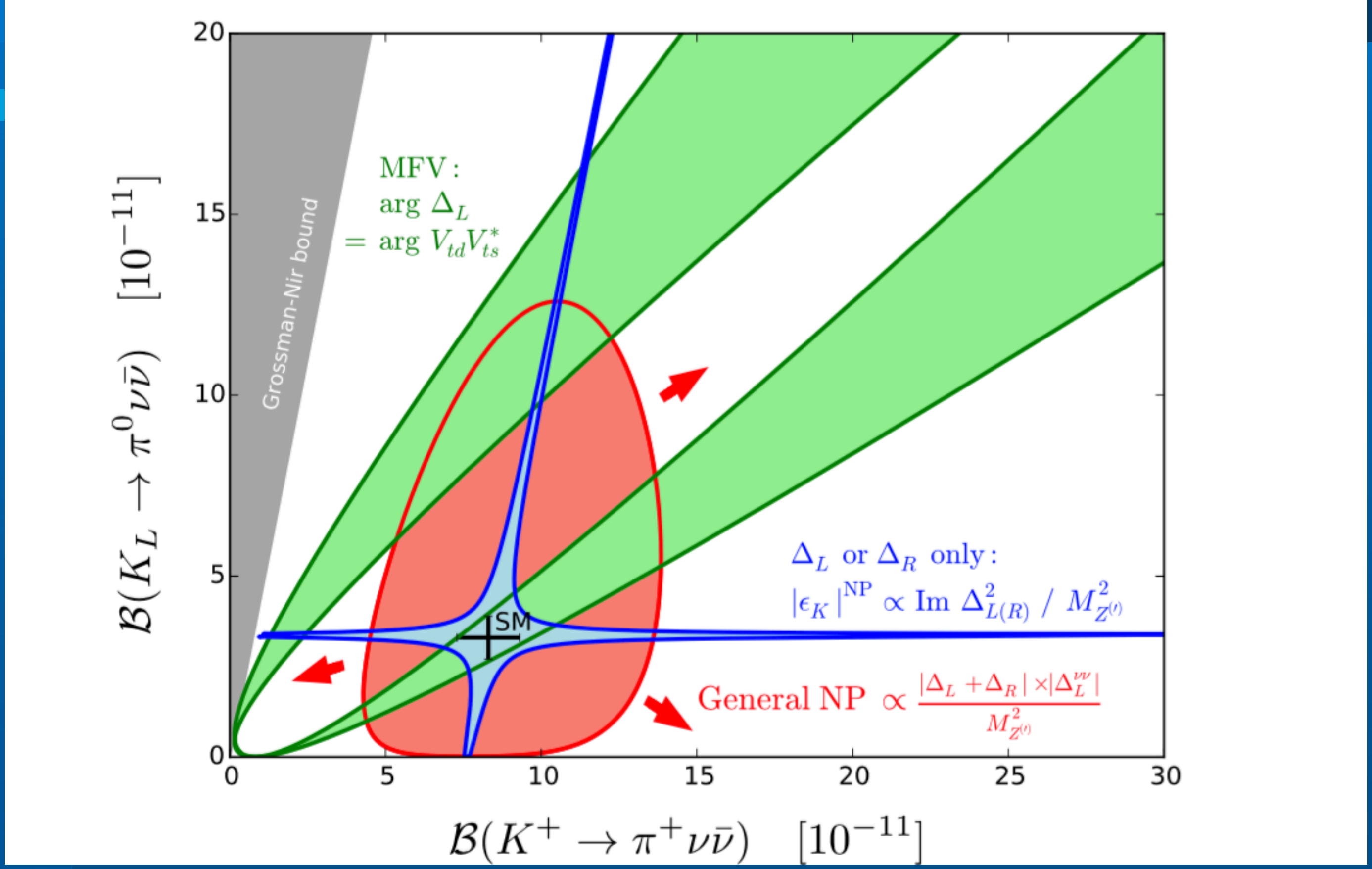
K^+

SM prediction [Buras et al. JHEP 1511 (2015) 33] $\mathrm{BR}(K^+ \to \pi^+\nu\bar{\nu}) = (8.4 \pm 1.0) \cdot 10^{-11}$

Experimental status (E787, E949) $\mathrm{BR}(K^+ \to \pi^+\nu\bar{\nu}) = (17.3^{+11.5}_{-10.5}) \times 10^{-11}$

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

Simplified New Physics Models



Simplified New Physics Models   Buras, Buttazzo, Knegjens, JHEP1511

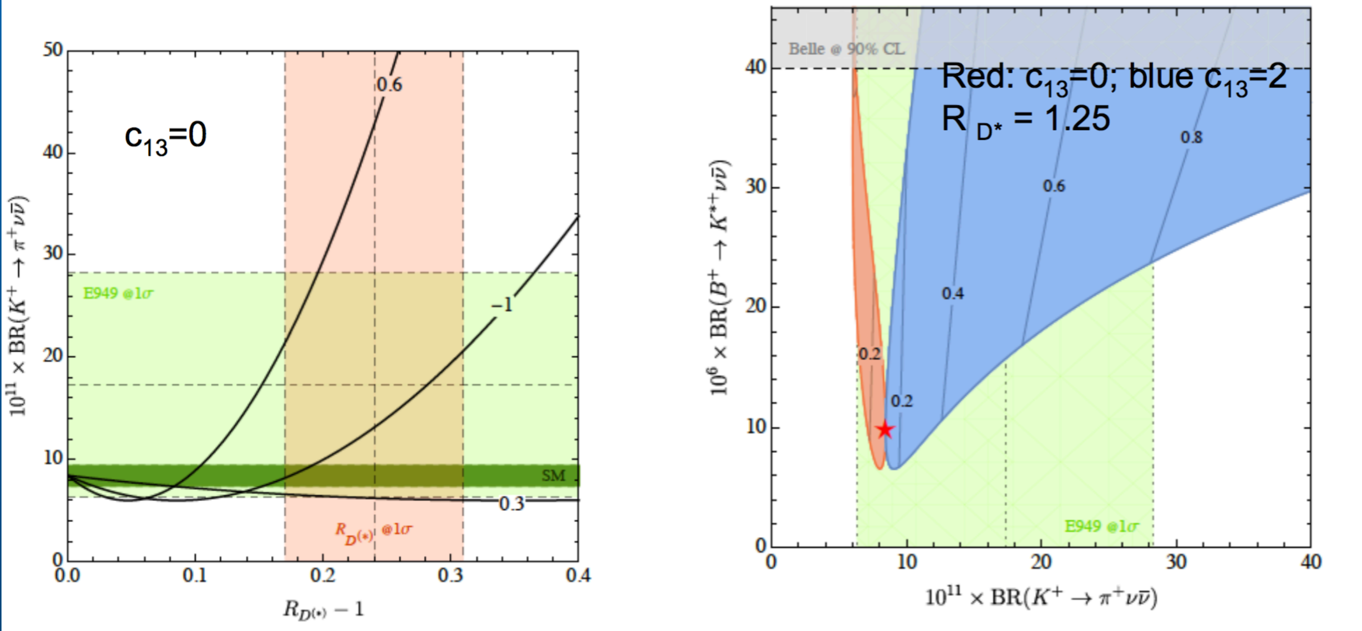
Probing Lepton Flavour Universality with $K \rightarrow \pi\, \nu\nu$ decays

Bordone, Buttazzo, Isidori, Monnard

$$\mathcal{B}(B \to D^{(*)}\tau\bar{\nu}) = \mathcal{B}(B \to D^{(*)}\tau\bar{\nu})_{\rm SM} \left|1 + R_0 \left(1 - \theta_q e^{-i\phi_q}\right)\right|^2 \qquad R_0 = \frac{1}{\Lambda^2}\frac{1}{\sqrt{2}G_F}$$

$$\mathcal{B}(K_L \to \pi^0\nu\bar{\nu}) = 2\mathcal{B}(K_L \to \pi^0\nu_e\bar{\nu}_e)_{\rm SM} + \mathcal{B}(K_L \to \pi^0\nu_\tau\bar{\nu}_\tau)_{\rm SM}\left|1 - \frac{R_0\,\theta_q^2(1-c_{13})}{(\alpha/\pi)(X_t/s_w^2)}\right|^2$$

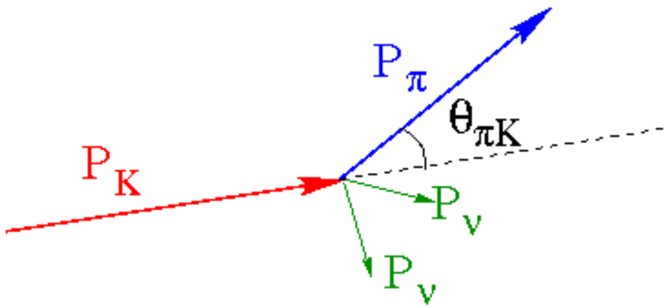
Varying θ_q :

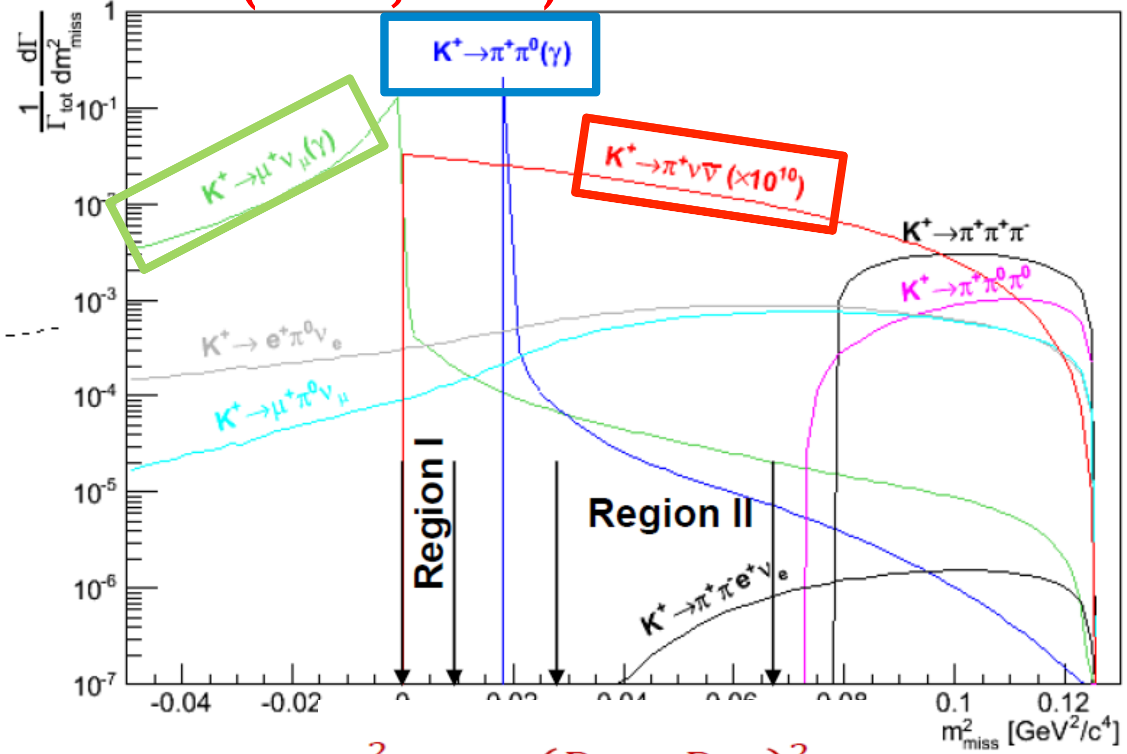


arXiv:1705.10729v1

NA62 NOVEL IN-FLIGHT TECHNIQUE TO MEASURE $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

- ~100 ps timing for K^+ – π^+ association **(KTAG, GTK, RICH)**
- EM Calorimeters to veto photons **(LAV, LKr, SAC, IRC)**, hadron calorimeters **(MUV1, MUV2, HASC)** and hodoscopes to veto muons **(MUV0, MUV3)**, extra particles **(CHOD, NewCHOD)** and interactions **(CHANTI)**
- Very light, high rate trackers to reconstruct the K^+ and the π^+ momenta **(GTK, STRAW)**
- Full particle identification **(KTAG, RICH)**

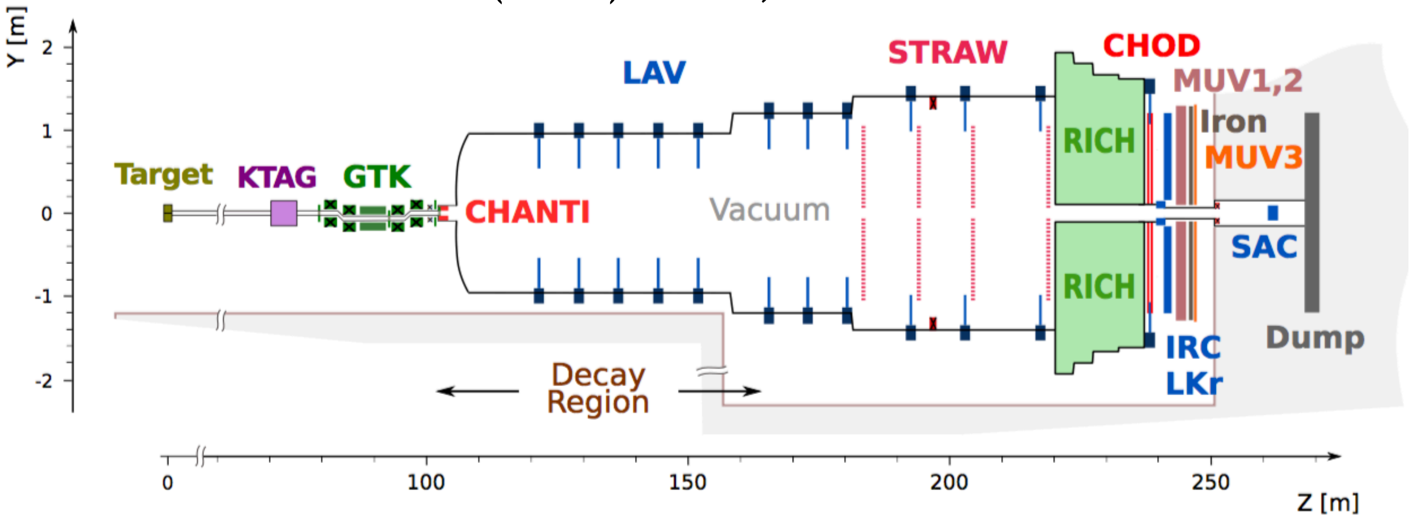


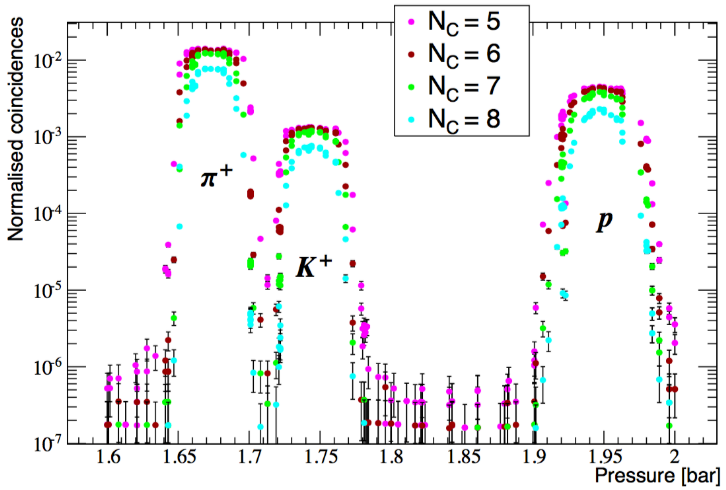


$$m^2_{miss} = (P_K - P_{\pi^+})^2$$

NA62 SCHEMATIC LAYOUT

JINST 12 (2017) no.05, P05025





10^{12} / s protons from SPS (400 GeV/c) on Be target (~1 λ)

SPS K12 Beam: 750 MHz, 75 GeV/c
- Positive polarity
- Kaon fraction ~6%
- Δ p/p ~ 1%
- Useful kaon decays ~10% (5 MHz)

Residual pressure in decay tank ~10^{-6} mbar

NA62 is built for a specific "silver bullet" measurement. This requires high beam rate, full PID, hermetic coverage, very light, high-rate tracking and state-of-the-art trigger and DAQ

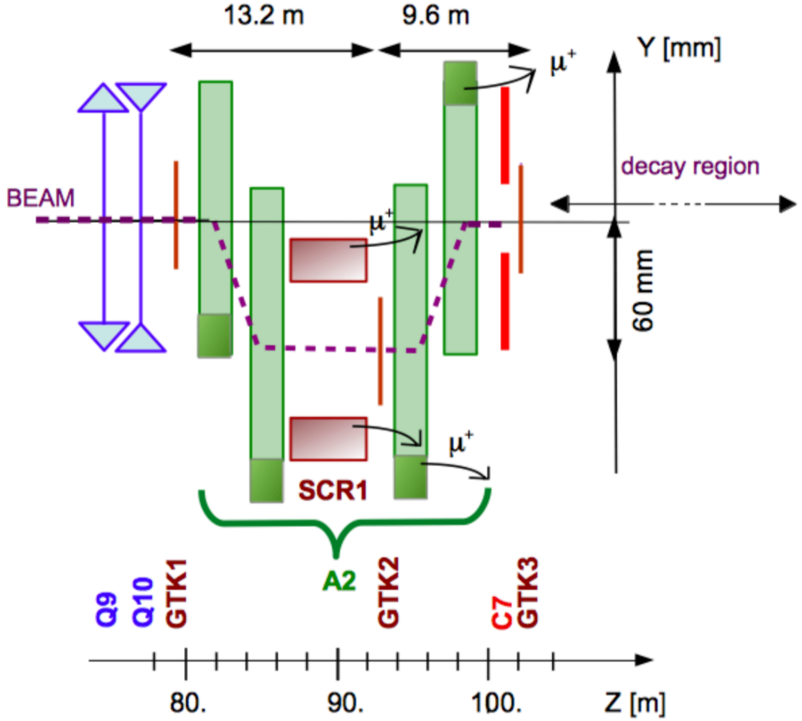
It paves the way to a broad physics program in kaon decays (LFV, LU, CHPT) and beyond (HNL, Exotics, Dark Sector etc.)

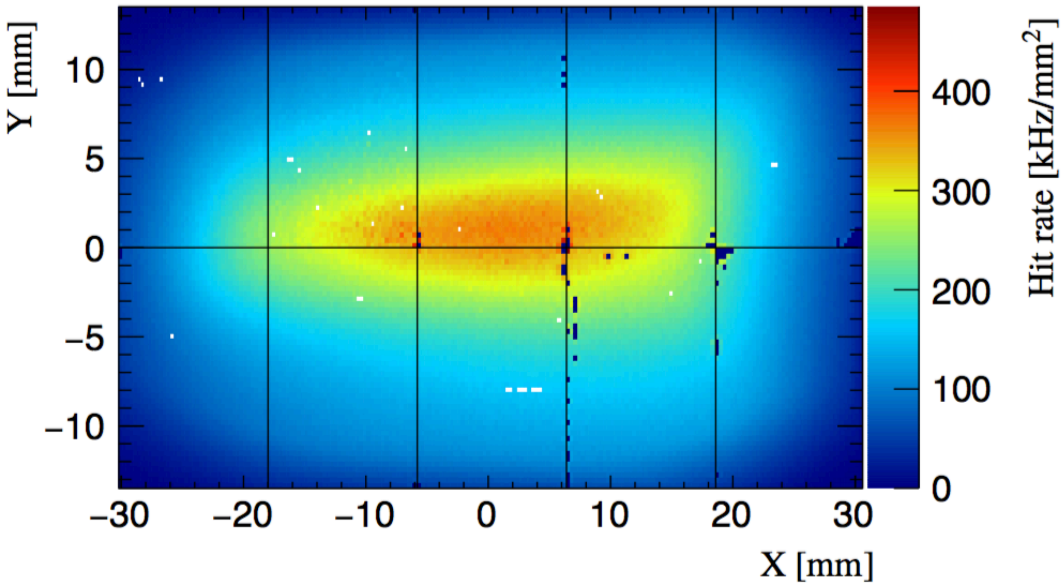
STATUS OF NA62 IN A NUTSHELL

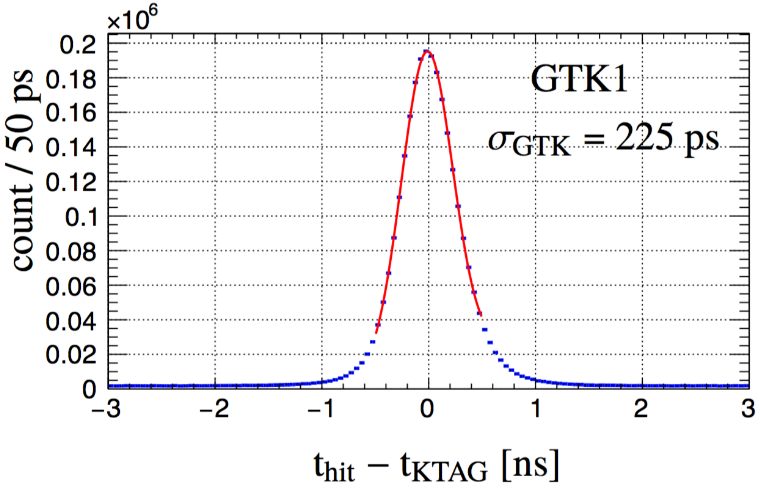
- 2016: Commissioning + Physics Data Taking
- **Collected ~ 5 10^{11} K^+ decays "good for PNN" in 2016**
- 5% of the 2016 statistics analyzed (presented here)
- 2017 Run under way, take data until October 22
- Extrapolating from 2016, **we expect ~ 15 PNN Standard Model events in 2017**
- With usual end-of-the-year break, data taking will resume in 2018 until CERN Long-Shutdown 2 (2019-2020)
- We are planning to extend data beyond LS2 to complete the proposed programme and to implement new ideas (see later)
- Technical details on NA62 can be found in the recently published Beam and Detector paper: JINST 12 P50025, arXiv:1703.08501

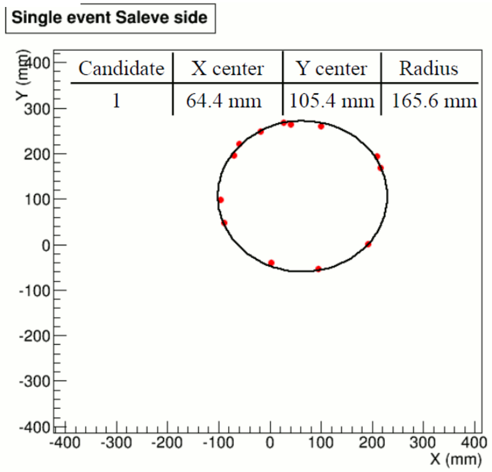
NA62 TIMING

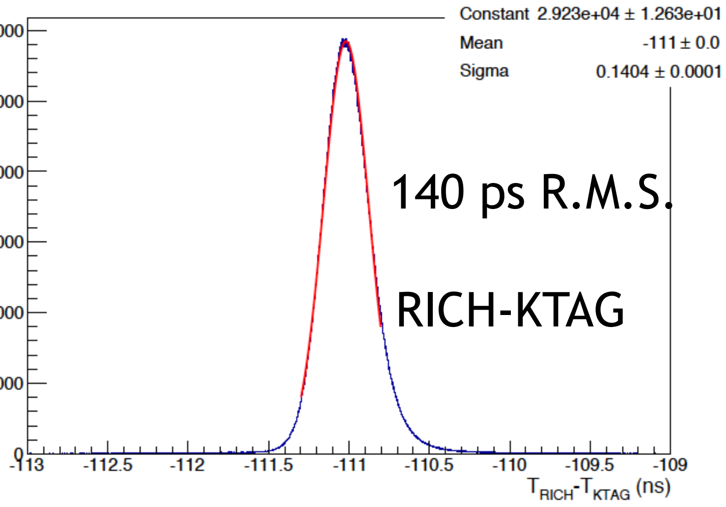
For NA62 is essential to have a flat SPS slow extraction: both microscopically and macroscopically



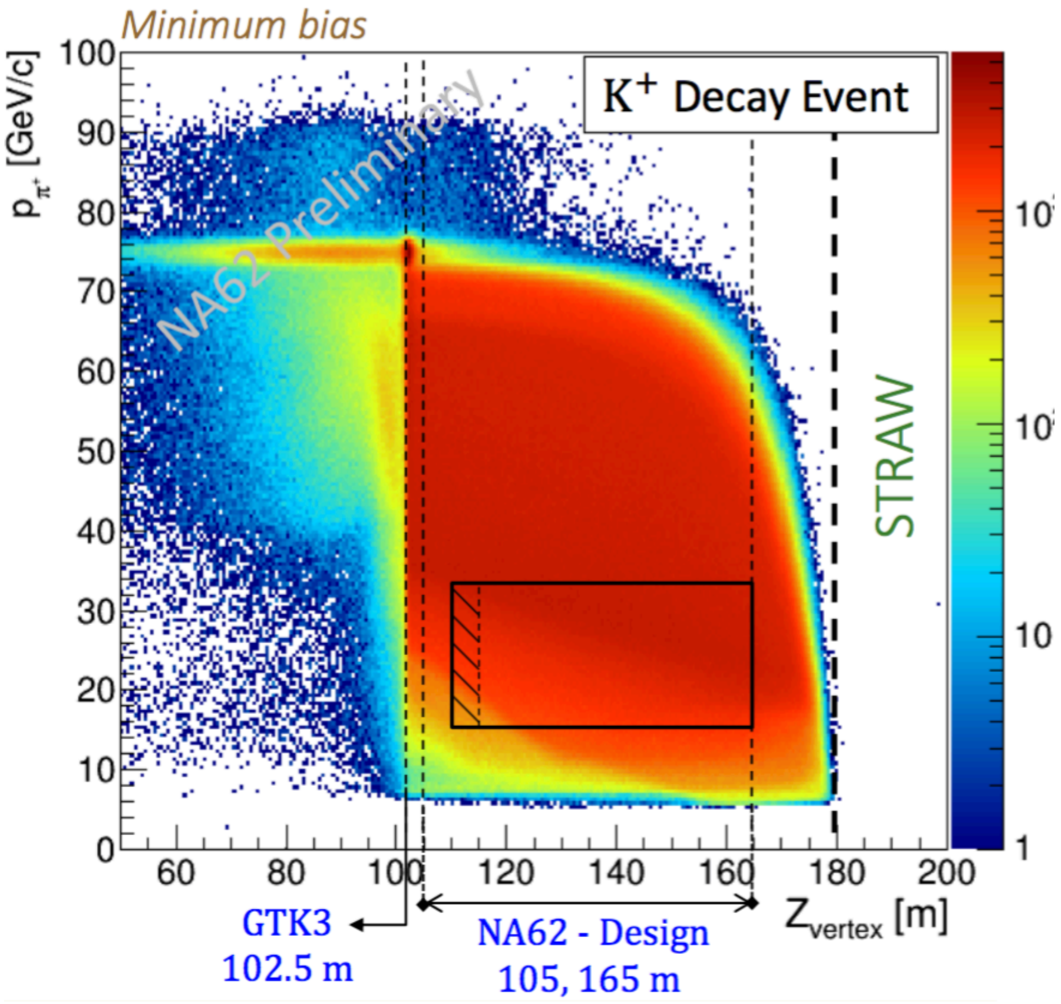








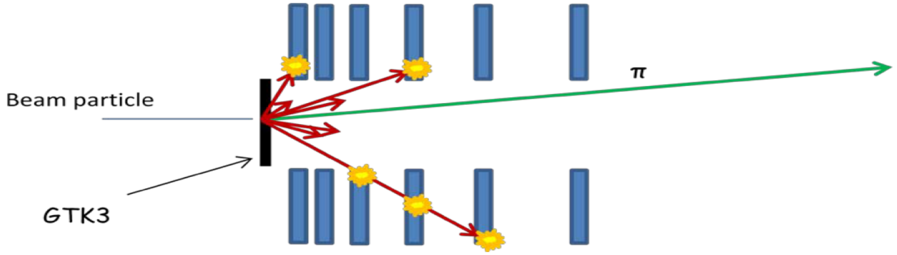
DECAY REGION



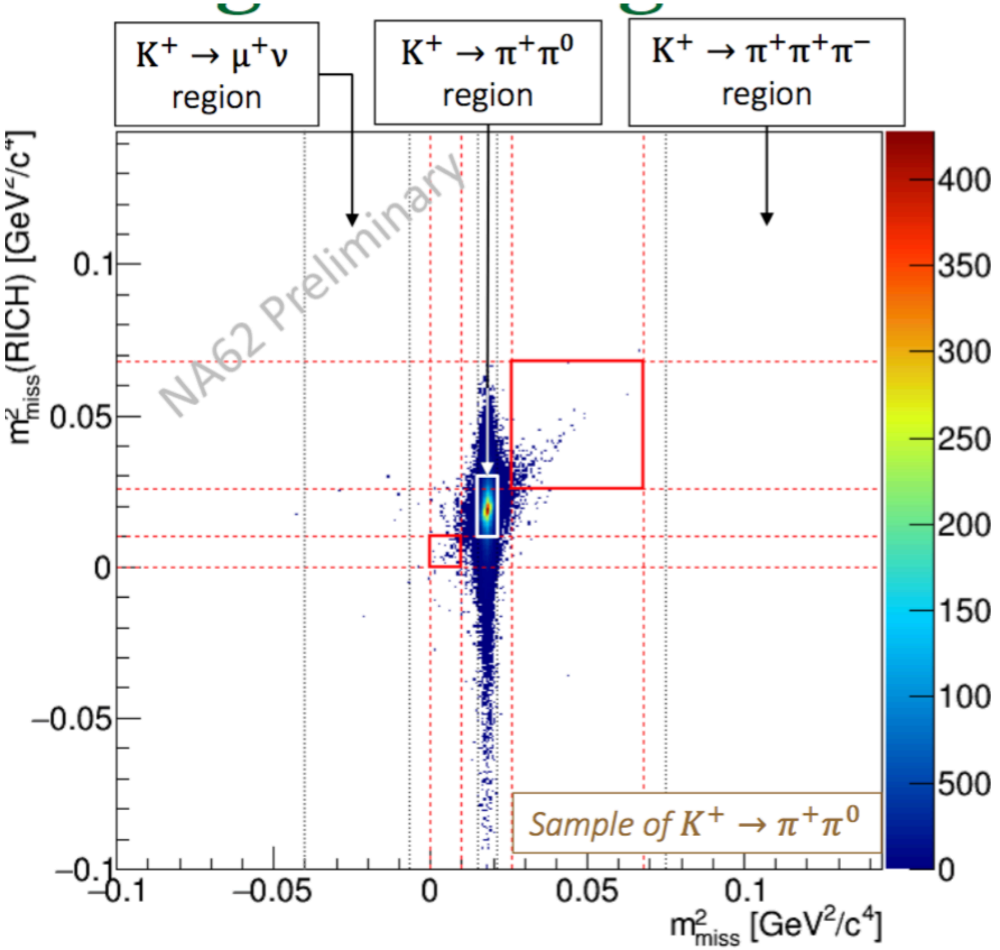
- The plot shows tracks from tagged kaon decays
- The sharp edge is the position of the last GTK station
- The signal region in momentum is limited from 15 to 35 in order to:

1. Have at least 40 GeV of EM energy associated to a $K^+ \rightarrow \pi^+ \pi^0$ decay
2. Have excellent pi/mu separation with a RICH with Neon as radiator at atmospheric pressure

- The fiducial region starts several meters downstream of the GTK3 position to control early decays and inelastic interactions producing (e.g.) K^0_S

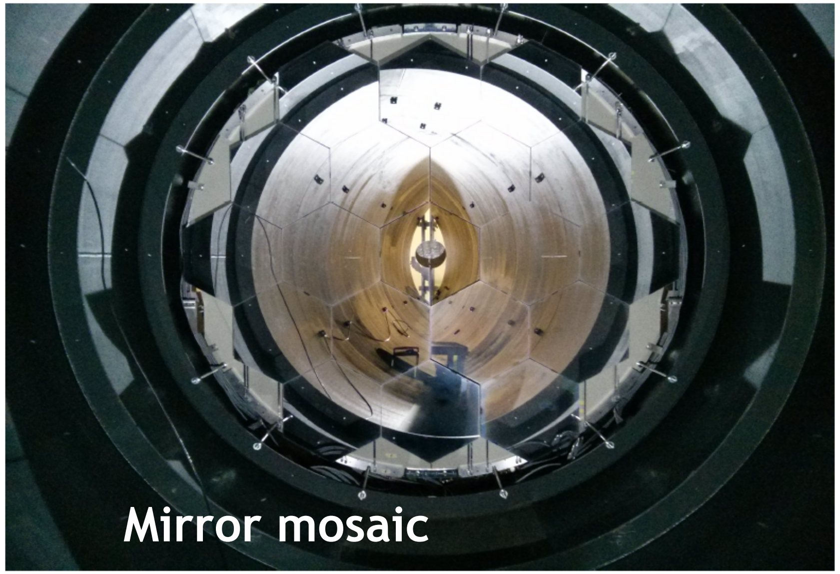


VELOCITY AND MAGNETIC SPECTROMETERS

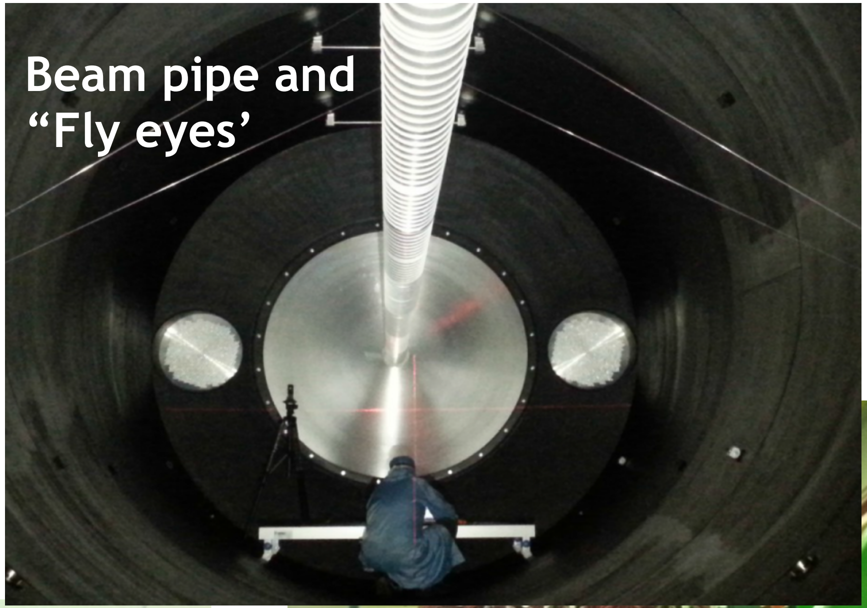


- The missing mass can be computed using the momentum determined either by the magnetic spectrometer or by the RICH assuming the pion mass
- This allows one to measure $K^+ \rightarrow \pi^+ \pi^0$ tails due to angular measurements

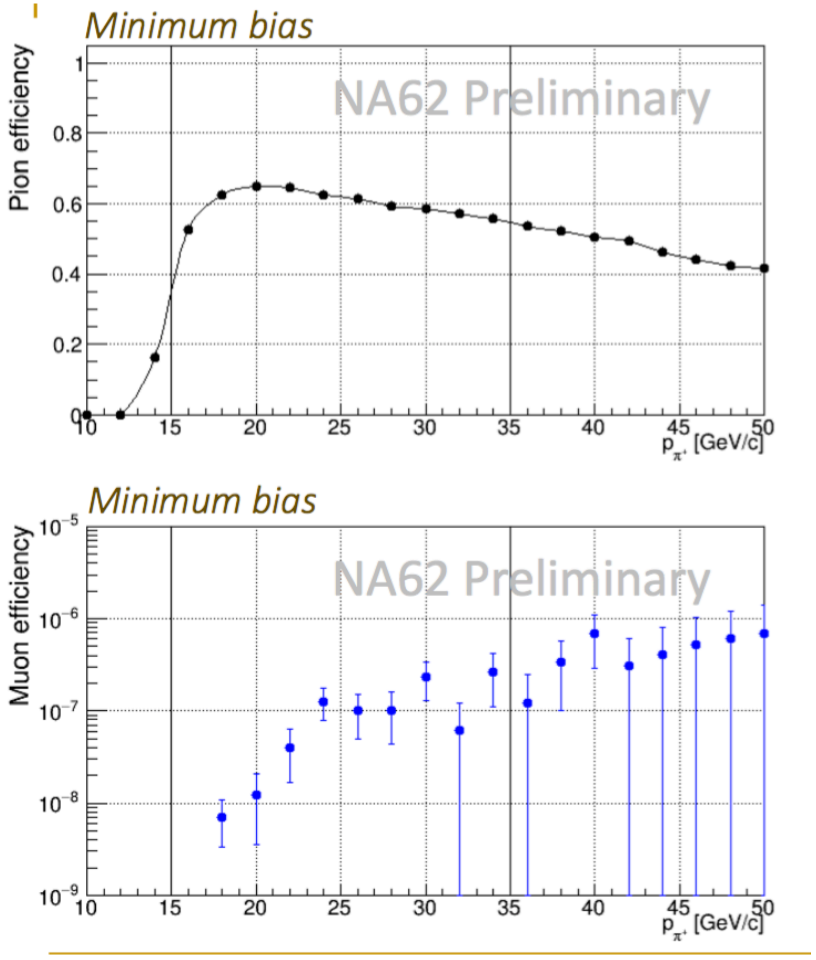
NA62 RICH



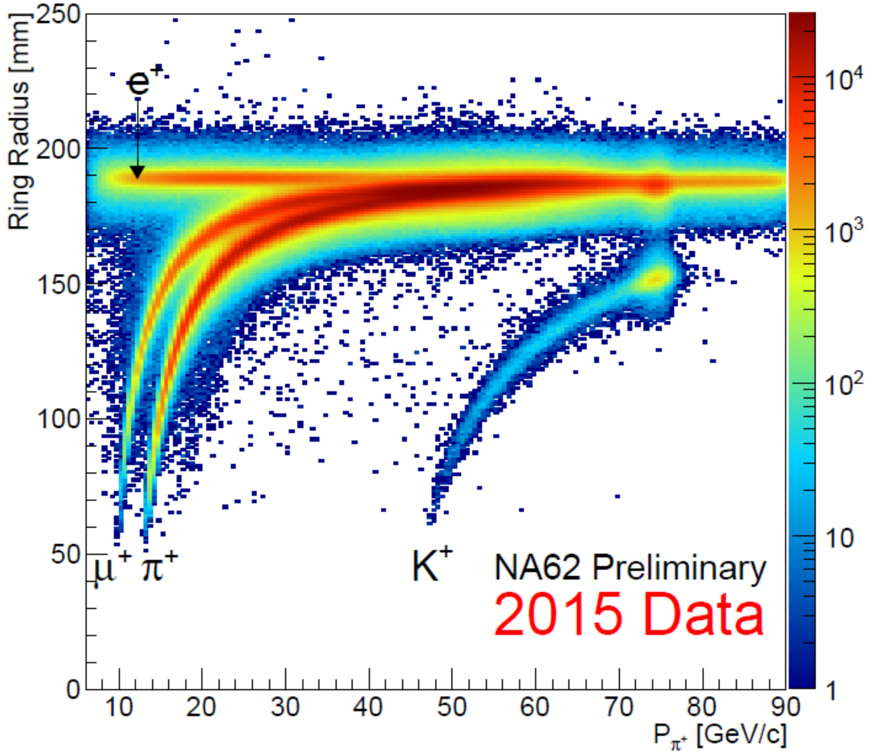
Vessel being pumped for Neon filling



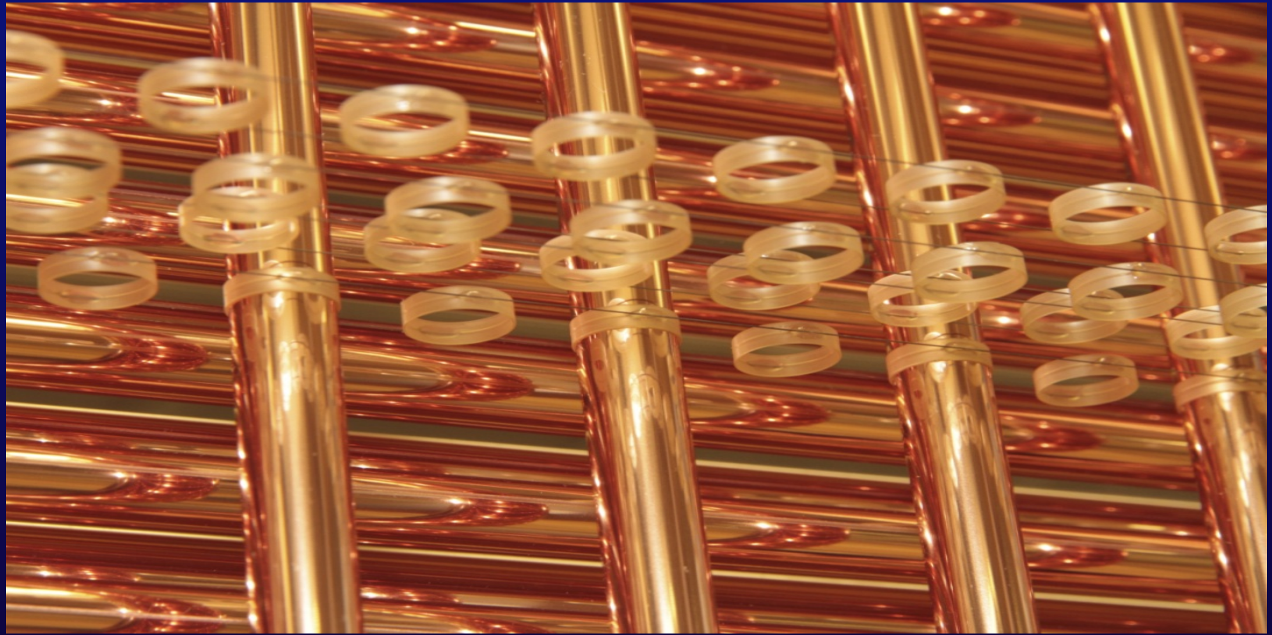
PI-MU SEPARATION



- 2/3 of Kaons decay in μ ν
- Calorimetry and RICH are orthogonal techniques to reject muons
- Combined together they provide a very strong muon suppression



π^+ Detection



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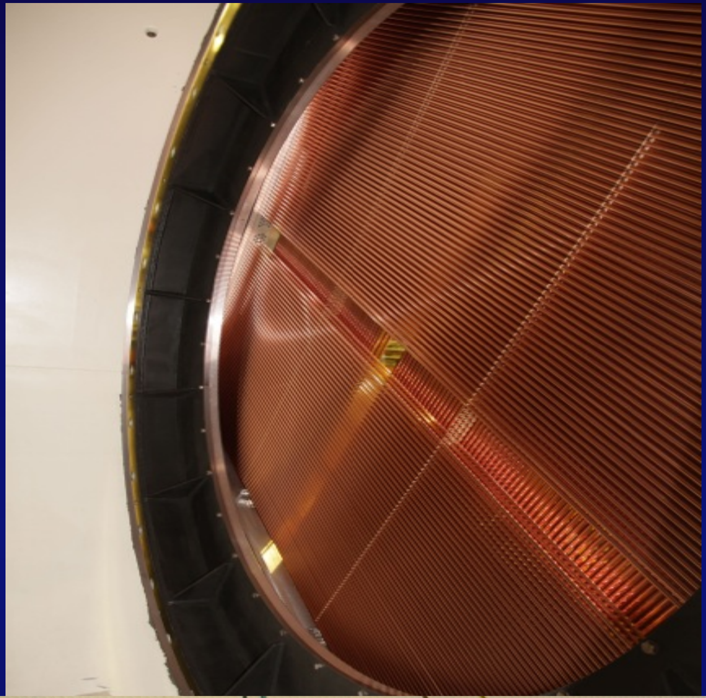
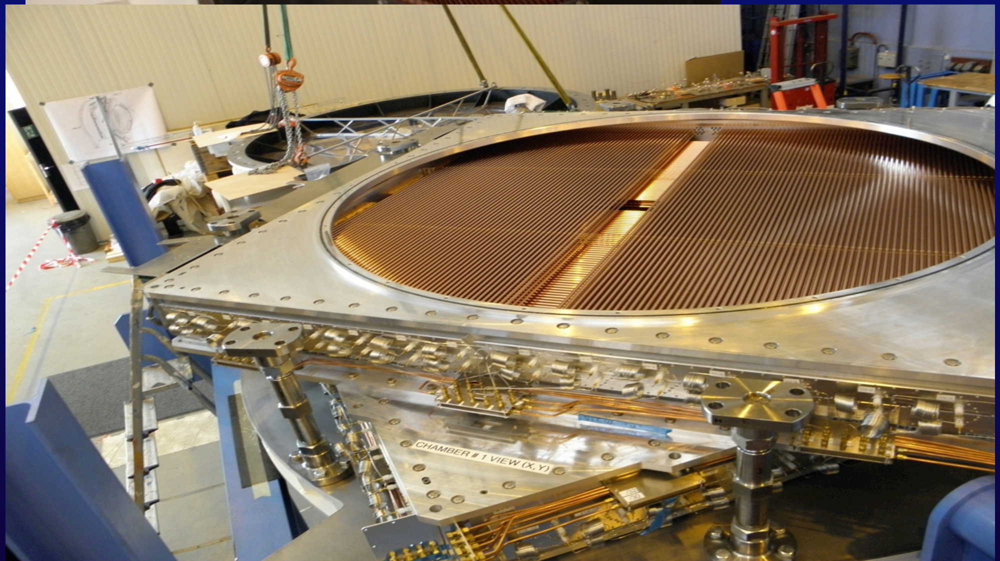
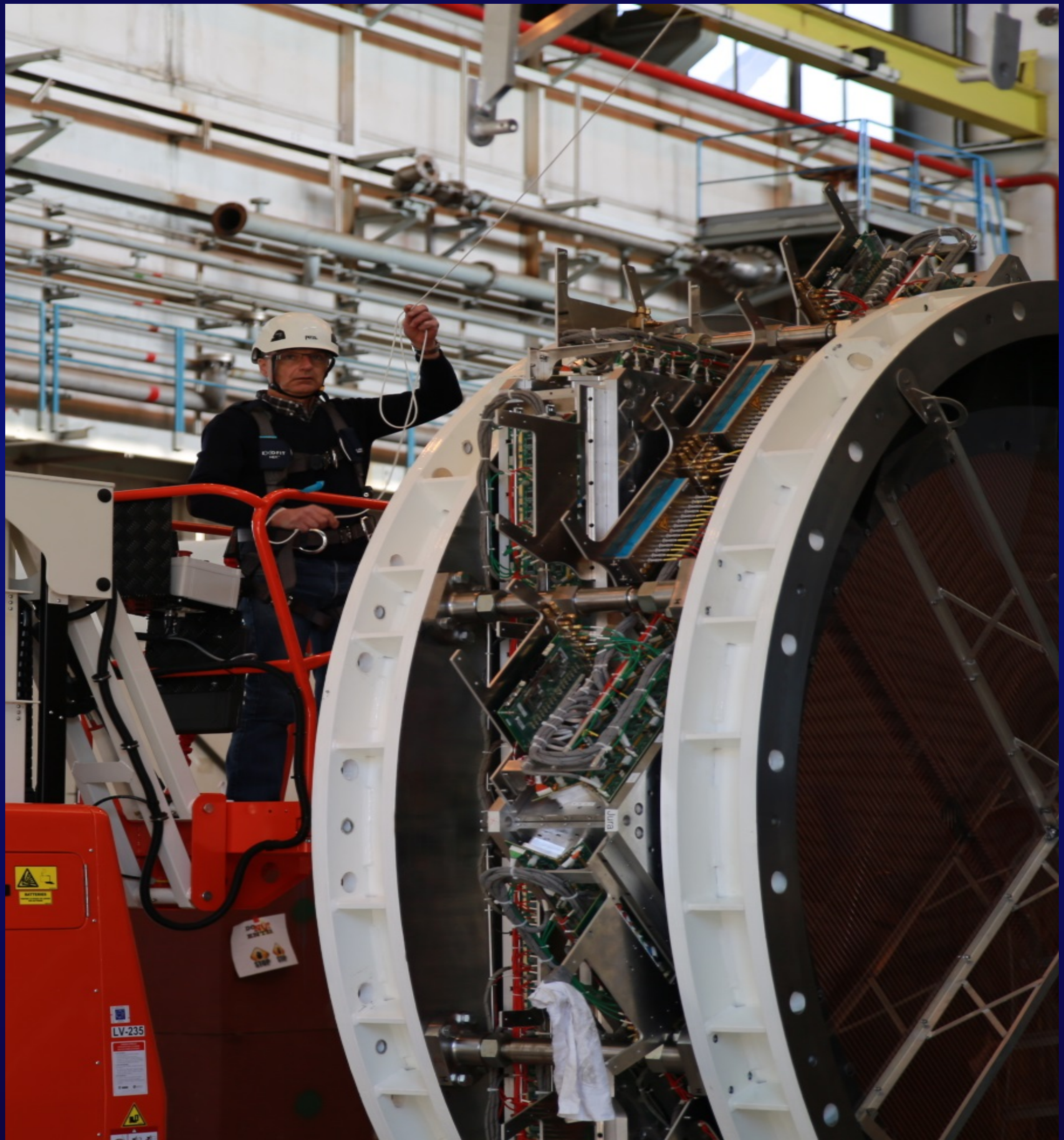
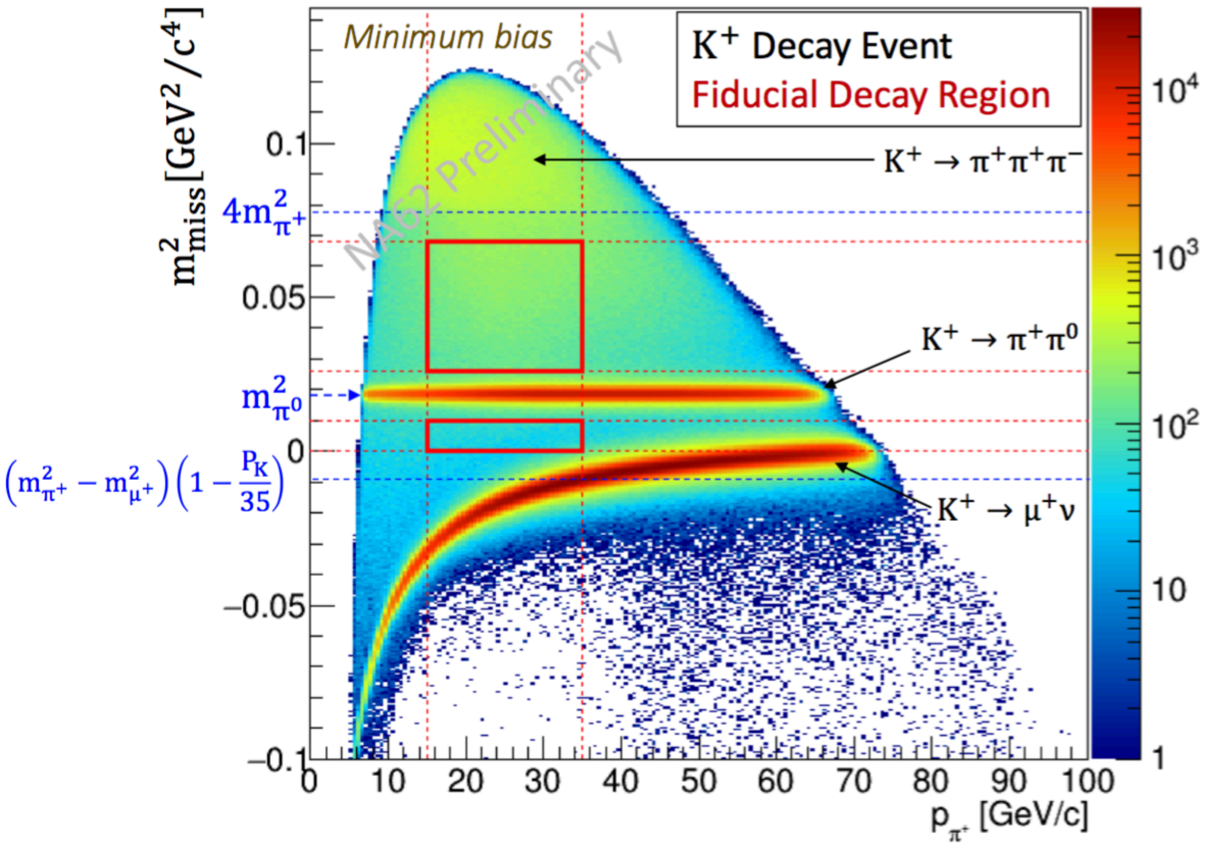
NA62 STRAW TRACKER



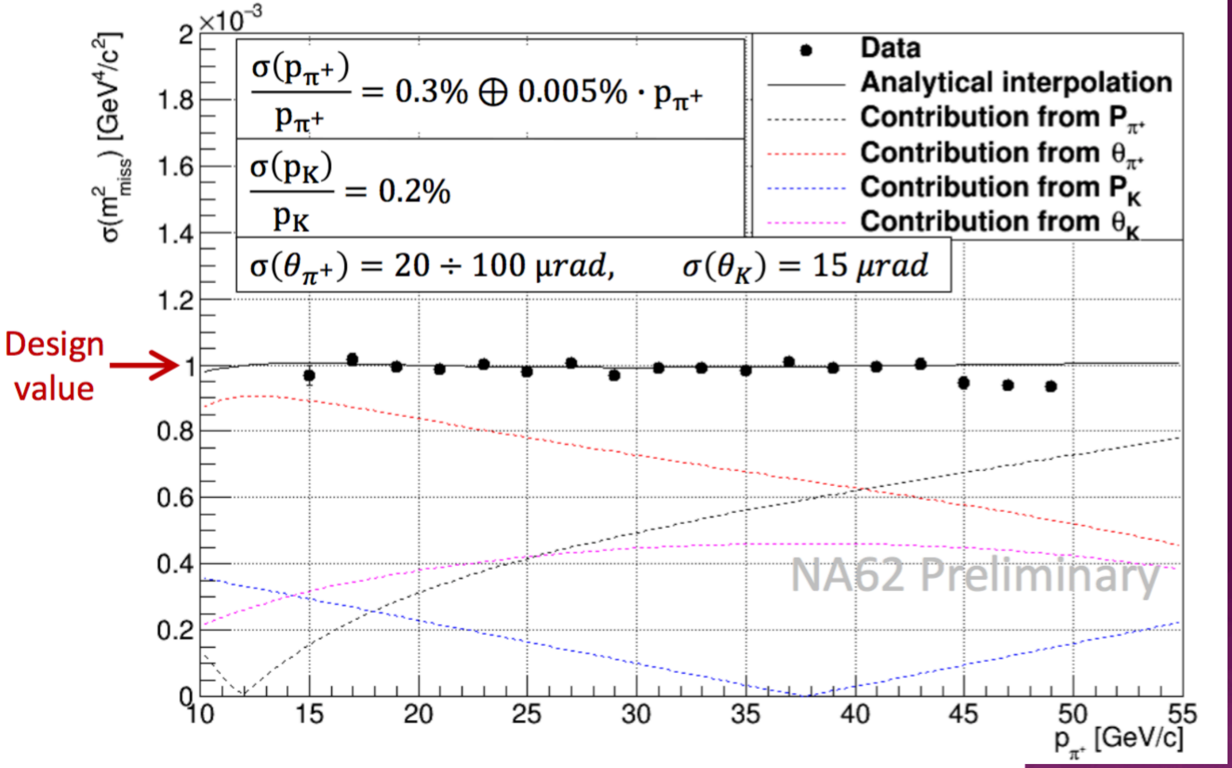




NA62 KINEMATICS



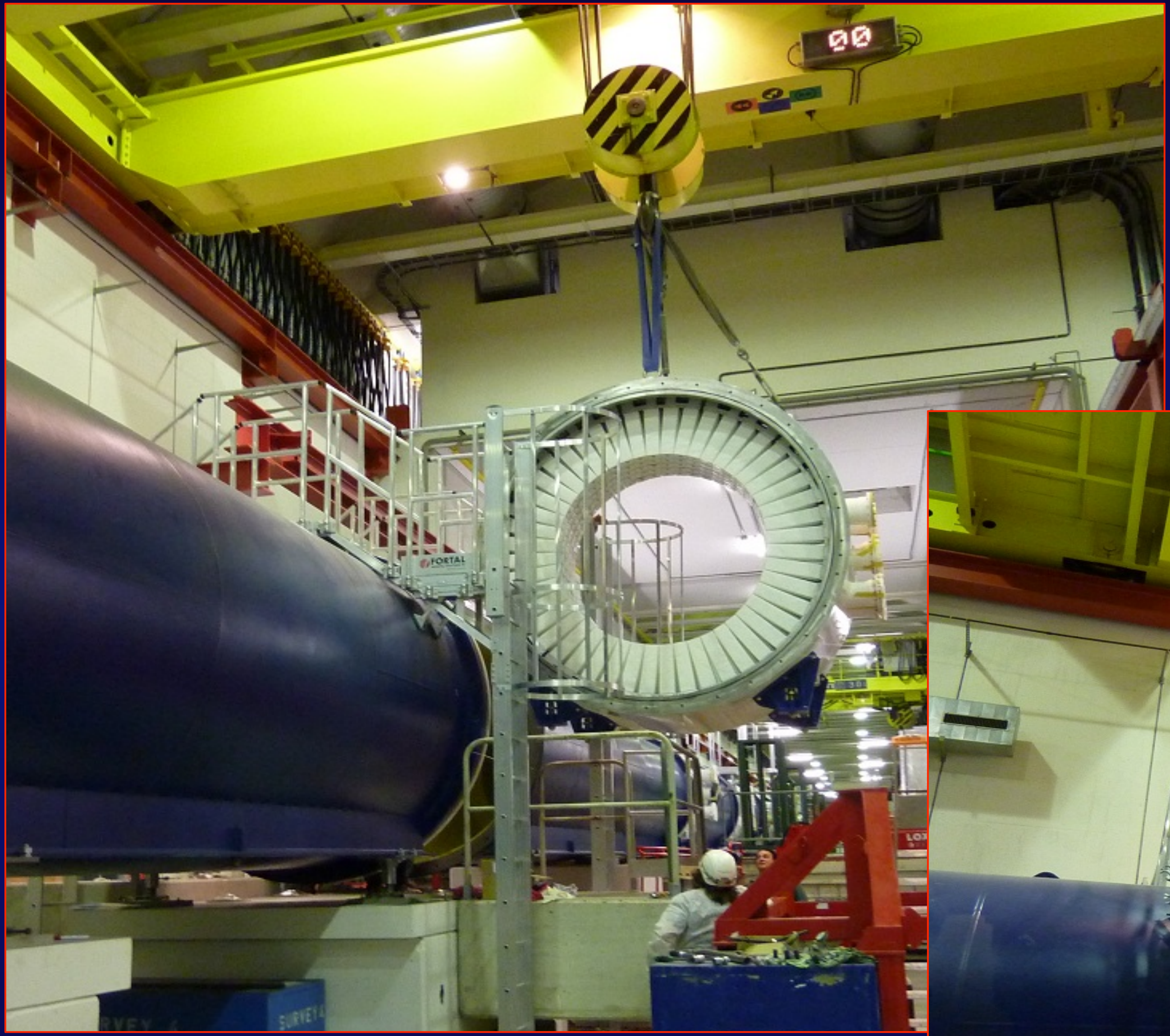
2016 Data, Preliminary



Single track events tagged to originate from a kaon decay

Missing Mass Resolution for single track events

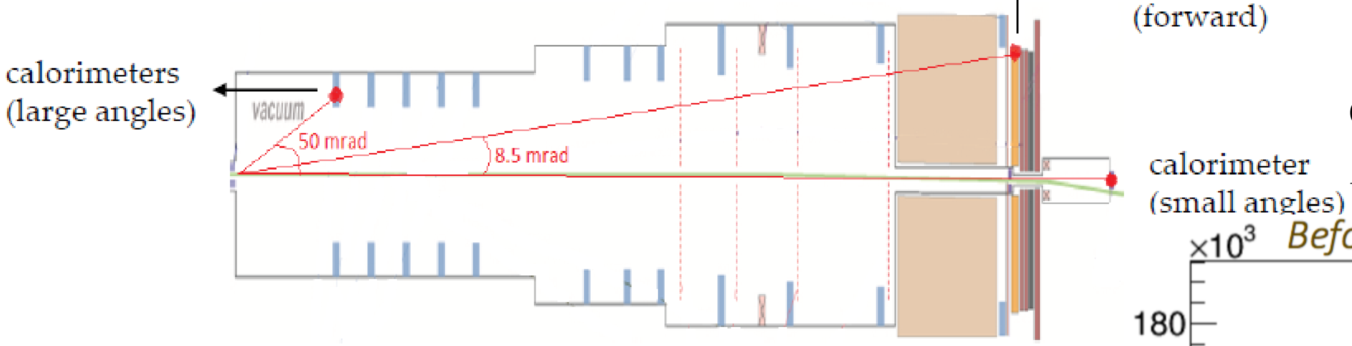
π^0 Suppression



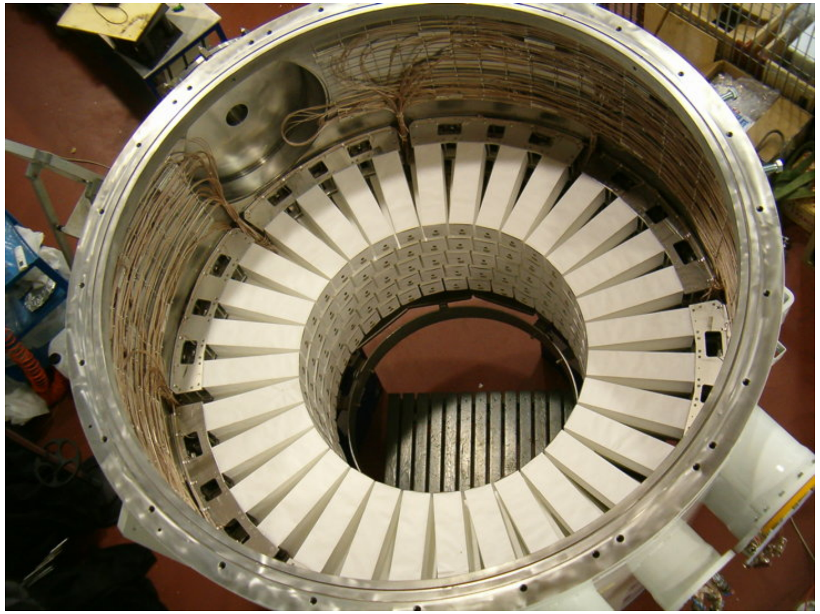

NA62 PI0 REJECTION

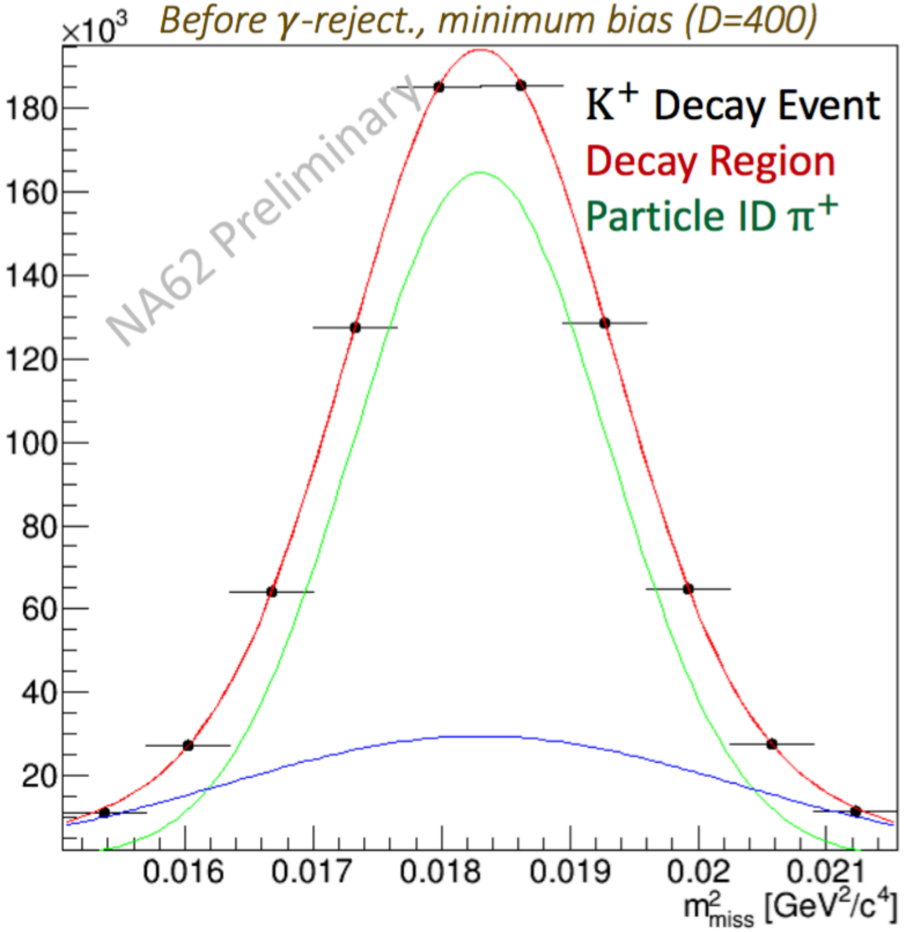
LAV (OPAL barrel Lead Glass)

LKr (Liquid Krypton) IRC SAC



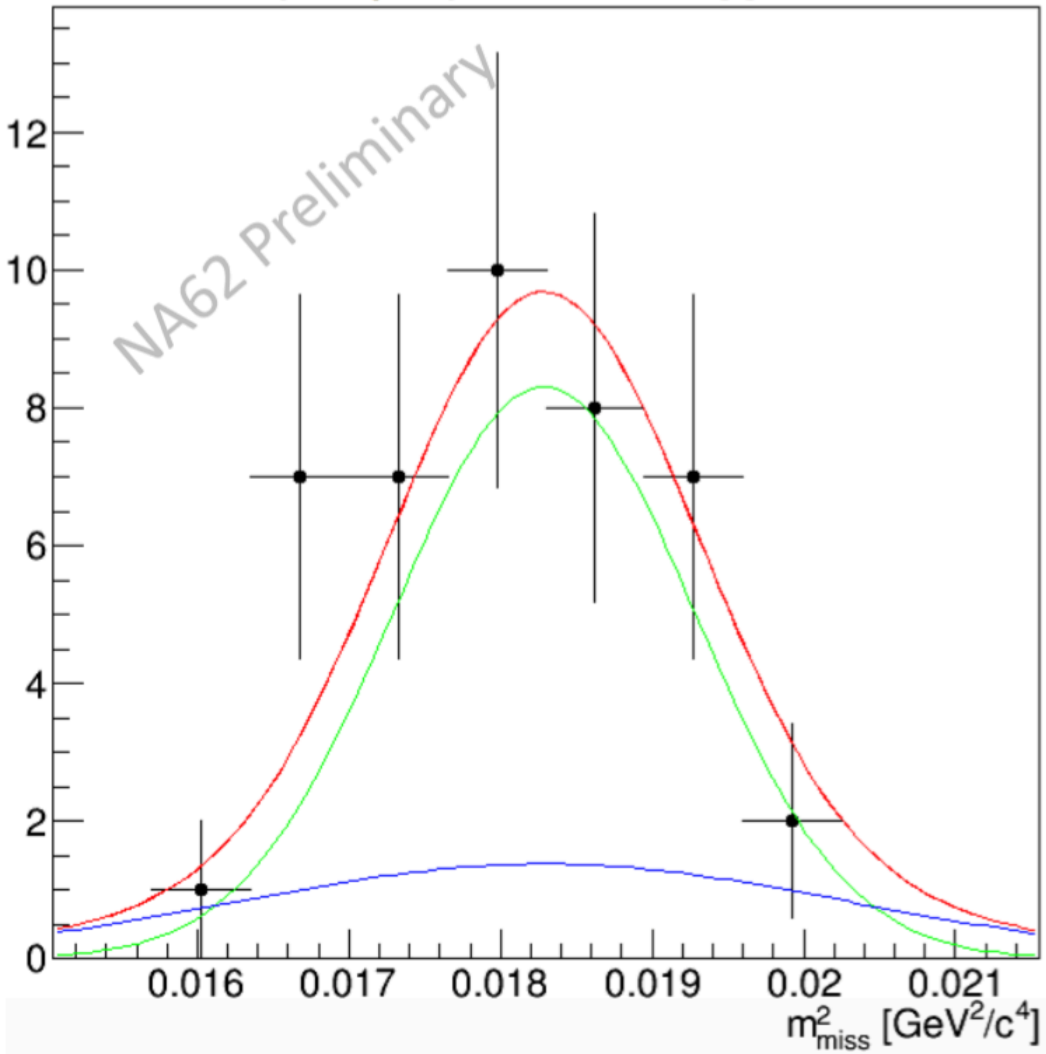
In situ/continuous monitor of π^0 rejection performed selecting $K^+ \rightarrow \pi^+ \pi^0$ events purely on kinematics





PI0 REJECTION

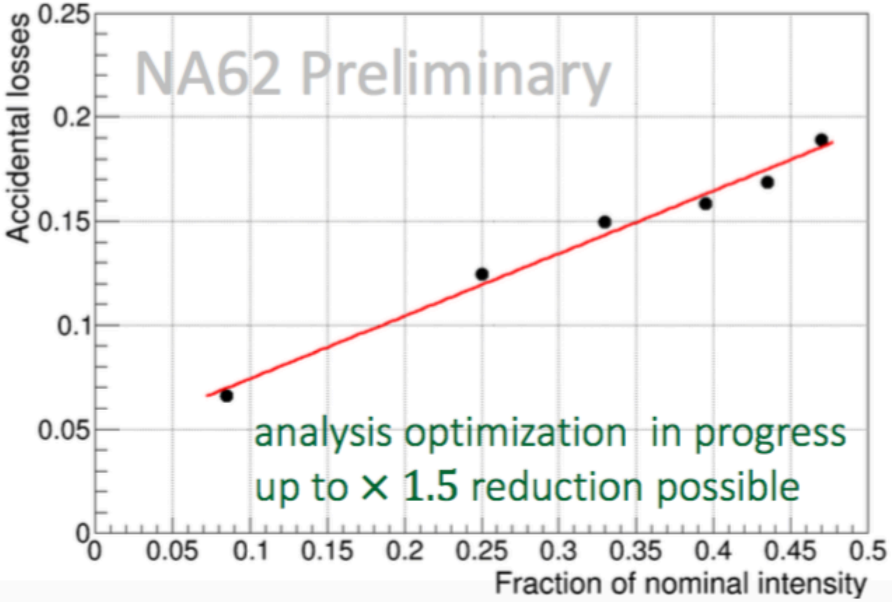
After γ-reject., PNN Trigger



Gaussian RMS and mean from fit before γ-reject.

$$\epsilon_{\pi^0} = (1.2 \pm 0.2) \times 10^{-7}$$

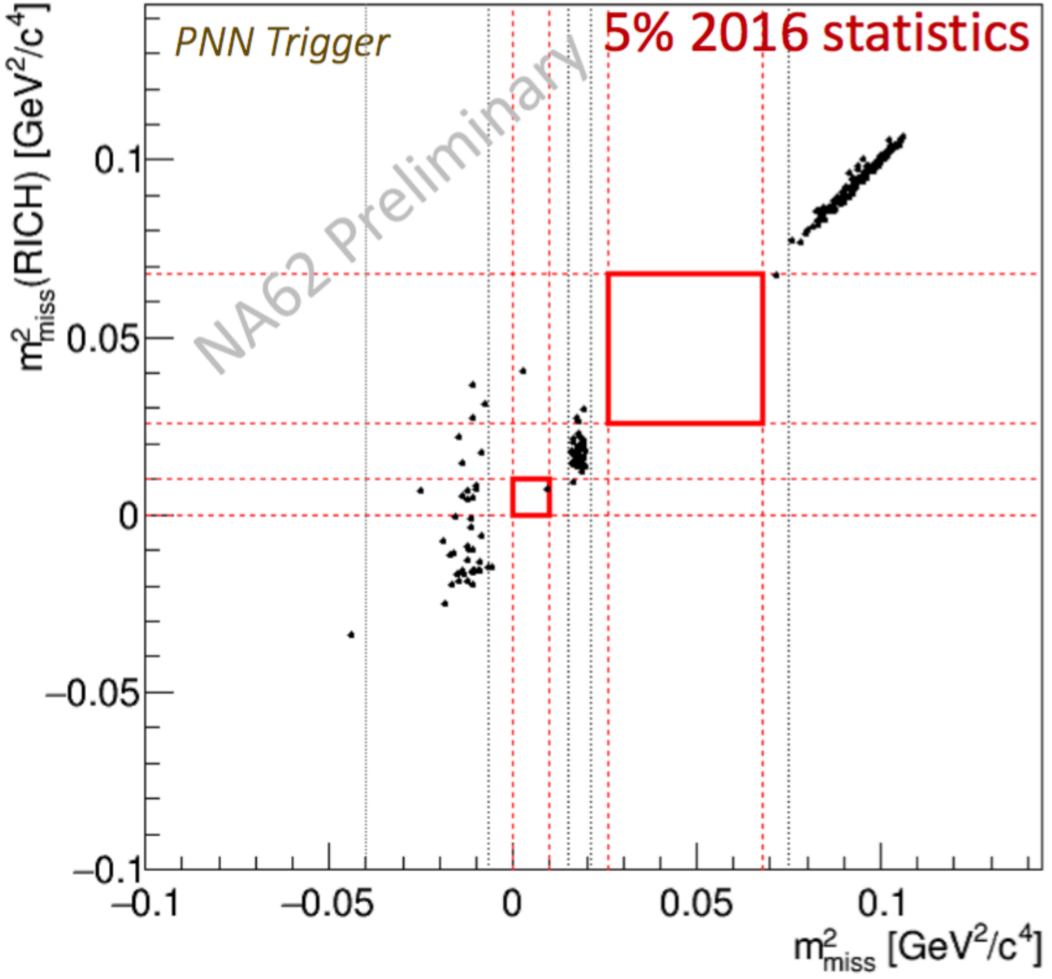
$\pi\nu\nu$ accidental losses



analysis optimization in progress
up to × 1.5 reduction possible

5% 2016 STATISTICS

$K^+ \to \pi^+ \nu\nu$



- Flux: 2.3 x 10^{10} K^+
- Expected Backgrounds:
  - $K^+ \to \pi^+ \pi^0$ 0.024
  - $K^+ \to \mu^+ \nu$ 0.011
  - $K^+ \to \pi^+ \pi^+ \pi^-$ 0.017
  - Early decays < 0.005

- Expected SM signal:0.064 [Acceptance 3.3% to be improved]

- Observed 0

[the event in the box has m^2_{miss}(no GTK) outside signal region]

EXOTIC SEARCHES

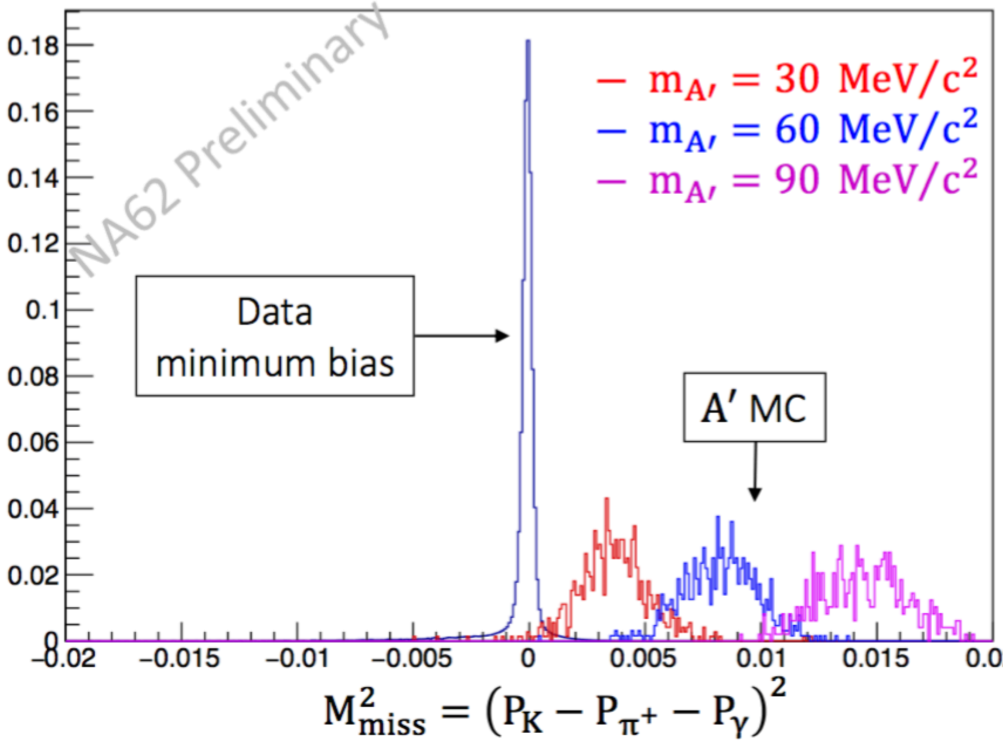
- Dark Photons (A'), Heavy Neutral Leptons (HNL), Axion-like particles (ALP)

- Production and decays:
  - Protons on target → mesons → A' / HNL; A'→ l^+l^-, HNL → $\pi\mu$
  - Protons on Dump (Copper) →ALP→ $\gamma\gamma$

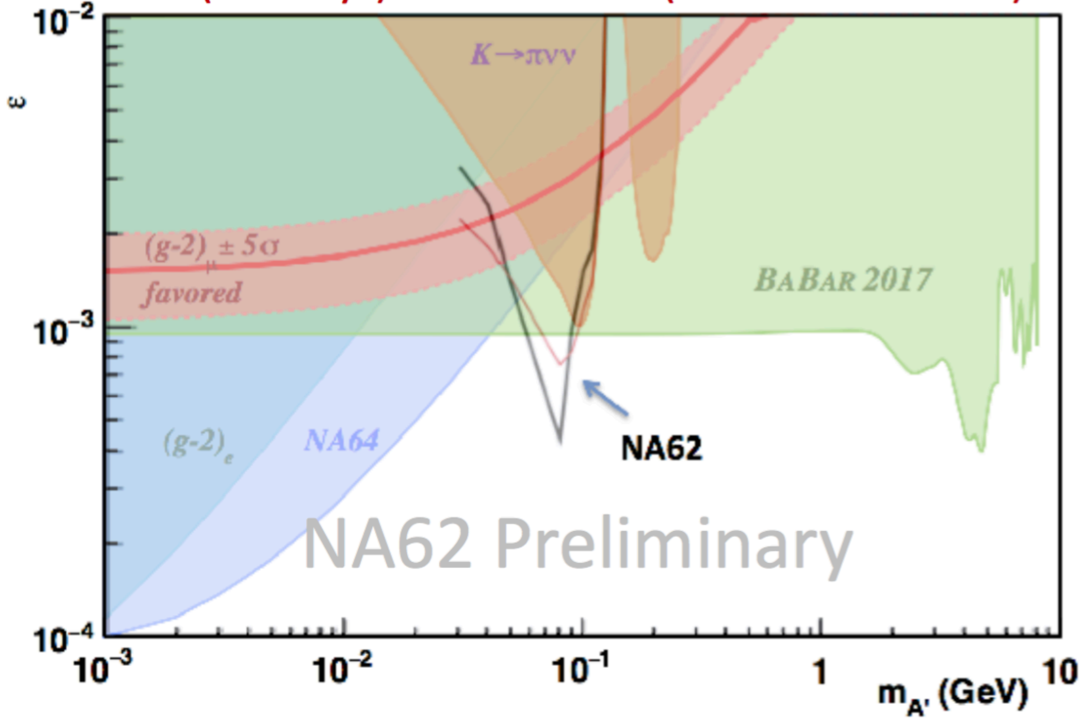
- Run 2016
  - A'/HNL: Triggers for 2-body final states taken concurrently with PNN (10^{17} POT)
  - ALP: A few hours special run (dump) to improve existing 2-photon limits

INVISIBLE VECTOR BOSON

$K^+ \rightarrow \pi^+\pi^0, \pi^0 \rightarrow A'\gamma, A' \rightarrow Invisible$



N(K decays) ~ 1.5×10^{10} (4% 2016 statistics)



NA62 sensitivity for LFNV decays

Decays in FV in 2 years of data: 1×10^{13} K^+ decays, 2×10^{12} π^0 decays

Single-event sensitivity 1/(decays × acceptance)

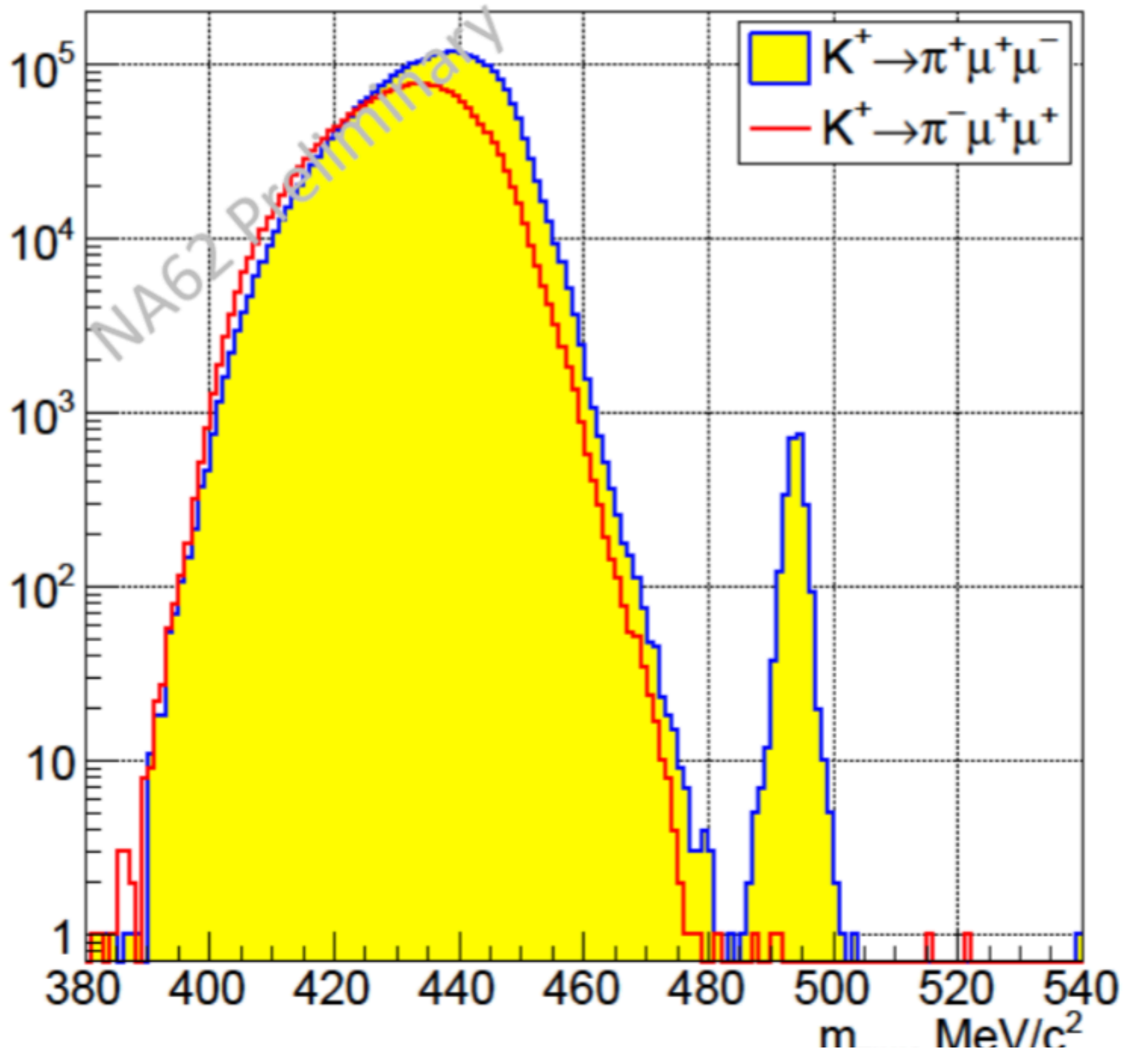
Mode	UL at 90% CL	Experiment	NA62 acceptance*
$K^+ \to \pi^+\mu^+e^-$	1.3×10^{-11}	BNL 777/865	~10%
$K^+ \to \pi^+\mu^-e^+$	5.2×10^{-10}	BNL 865	
$K^+ \to \pi^-\mu^+e^+$	5.0×10^{-10}	BNL 865	~10%
$K^+ \to \pi^-e^+e^+$	6.4×10^{-10}	BNL 865	~5%
$K^+ \to \pi^-\mu^+\mu^+$	1.1×10^{-9}	NA48/2	~20%
$K^+ \to \mu^-\nu e^+e^+$	2.0×10^{-8}	Geneva Saclay	~2%
$K^+ \to e^-\nu\mu^+\mu^+$	no data		~10%
$\pi^0 \to \mu^+e^-$	3.6×10^{-10}	KTeV	~2%
$\pi^0 \to \mu^-e^+$			

* From fast Monte Carlo simulation with flat phase-space distribution. Includes trigger efficiency.

NA62 single-event sensitivities: **~10^{-12} for K^+ decays**, **~10^{-11} for π^0 decays**

RARE AND FORBIDDEN DECAYS

- 2016 Data
- Trigger: multi-track, di-lepton
- >1000 $K^+ \rightarrow \pi^+ l^+ l^-$
- <1% background
- Competitive limits on Lepton Number Violation



Rare π^0 decays in NA62

2×10^{12} π^0 decays in FV in 2 years of data will allow substantial improvement of results in many channels

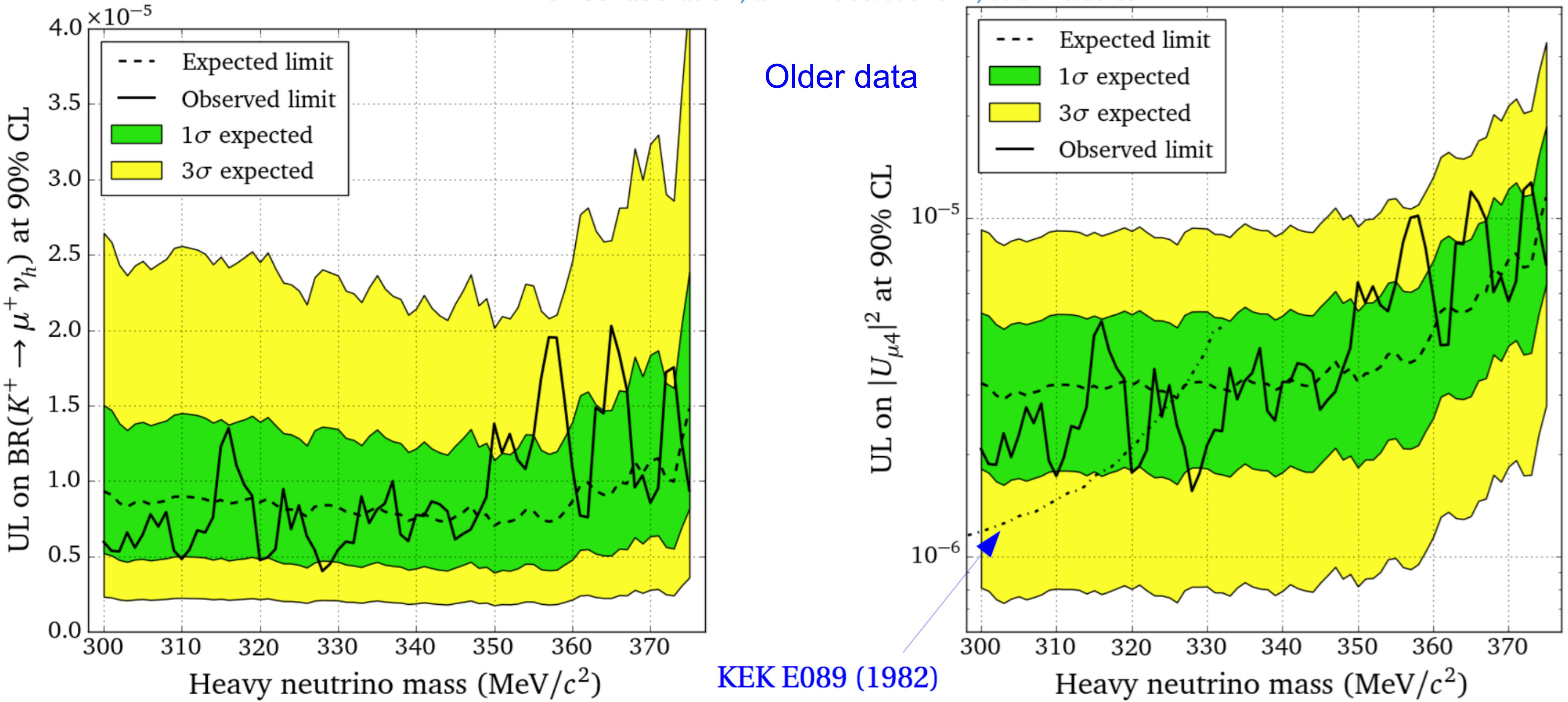
Mode	Current knowledge	Experiment	Expectation in SM	Physics interest
Neutral modes				
$\pi^0 \to 3\gamma$	$BR_{90CL} < 3.1\times10^{-8}$	Crystal Box	Forbidden	Violates C
$\pi^0 \to 4\gamma$	$BR_{90CL} < 2\times10^{-8}$	Crystal Box	$BR \sim 10^{-11}$	Scalar states $\pi^0 \to SS$
$\pi^0 \to$ inv	$BR_{90CL} < 2.7\times10^{-7}$	BNL 949	$BR < 10^{-13}$ (cosm. limit)	N_ν, LFV
Charged modes				
$\pi^0 \to e^+e^-e^+e^-$	$BR = 3.34(16)\times10^{-5}$	KTeV	$3.26(18) \times10^{-5}$	Off-shell vectors
$\pi^0 \to e^+e^-\gamma$	$BR_{95CL}(\pi^0 \to U\gamma)$: $< 1\times10^{5}$, $M_U = 30$ MeV $< 3\times10^{6}$, $M_U = 100$ MeV	WASA/COSY	Null result	Dark forces

Search for $K^+ \rightarrow \mu^+ \nu_h$

$$B_{UL}\left(K^+ \rightarrow \mu^+\nu_h\right) = \frac{n_{UL}}{N_K \times A(m_h)}$$

$$|U_{\mu 4}|^2 = \frac{\mathcal{B}\left(K^+ \rightarrow \mu^+\nu_h\right)}{\mathcal{B}\left(K^+ \rightarrow \mu^+\nu_\mu\right)} \times \frac{1}{f\left(m_h\right)}$$

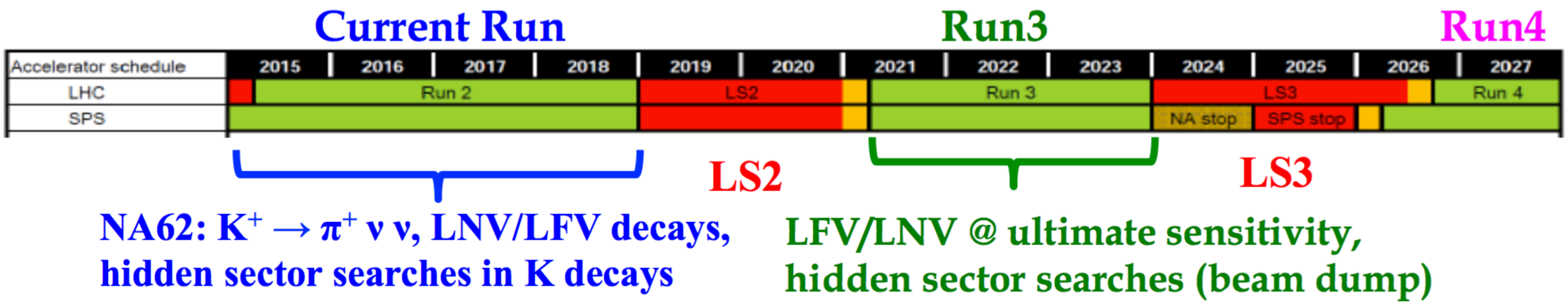
NA62 Collaboration, arXiv:1705.07510v1, submitted to PLB



Physics at NA62 in Run 3

A rich field to be explored with minimal/no upgrades to the present setup

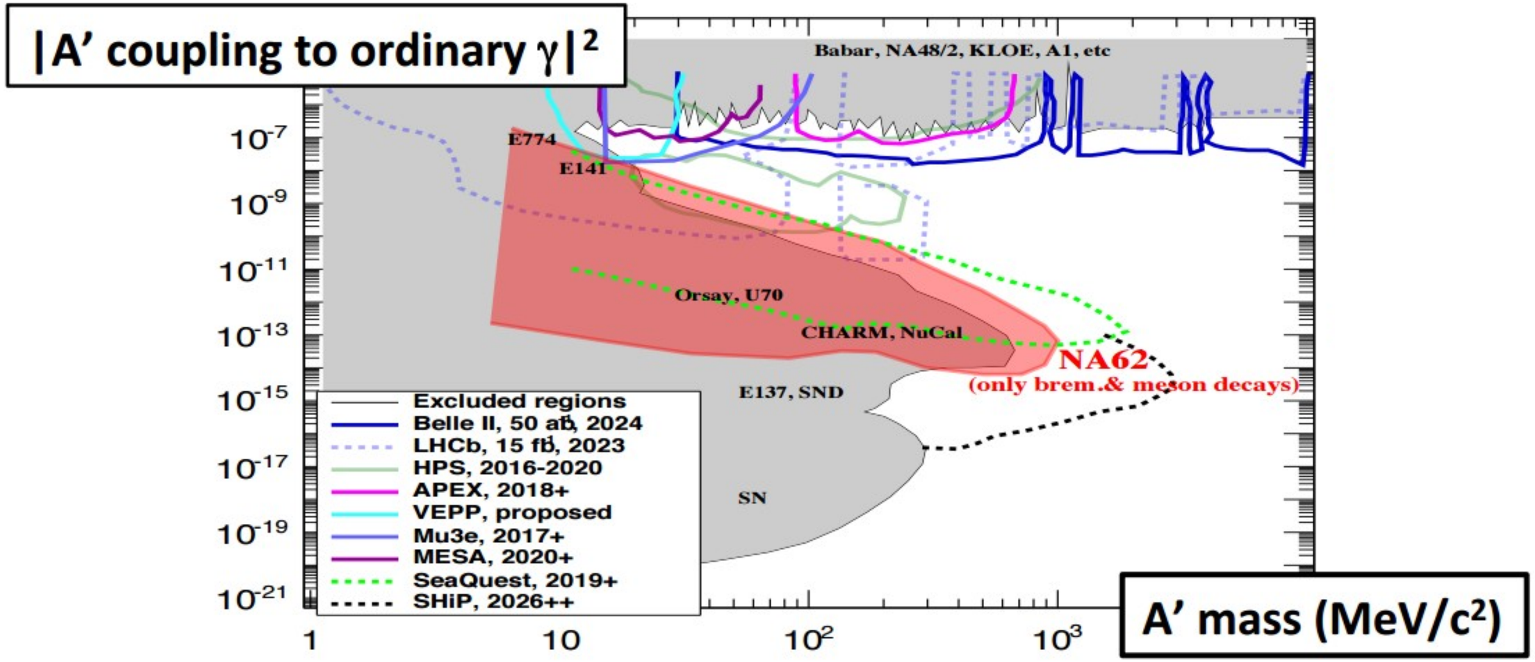
0. **If needed, run for refining $\pi\nu\nu$ measurement**
1. **Present K^+ beam setup + dedicated runs: unprecedented LFV/LNV sensitivities from K^+/π^0**
2. **Year-long run in “beam-dump” mode, new program of NP searches for MeV-GeV mass hidden-sector candidates: Dark photons, Heavy neutral leptons, Axions/ALP’s, etc.**



Search for visible decays of long-lived A’

- Search for displaced dilepton decays of dark photons, A’→ee, μμ
- Expected 90% CL plot evaluation:

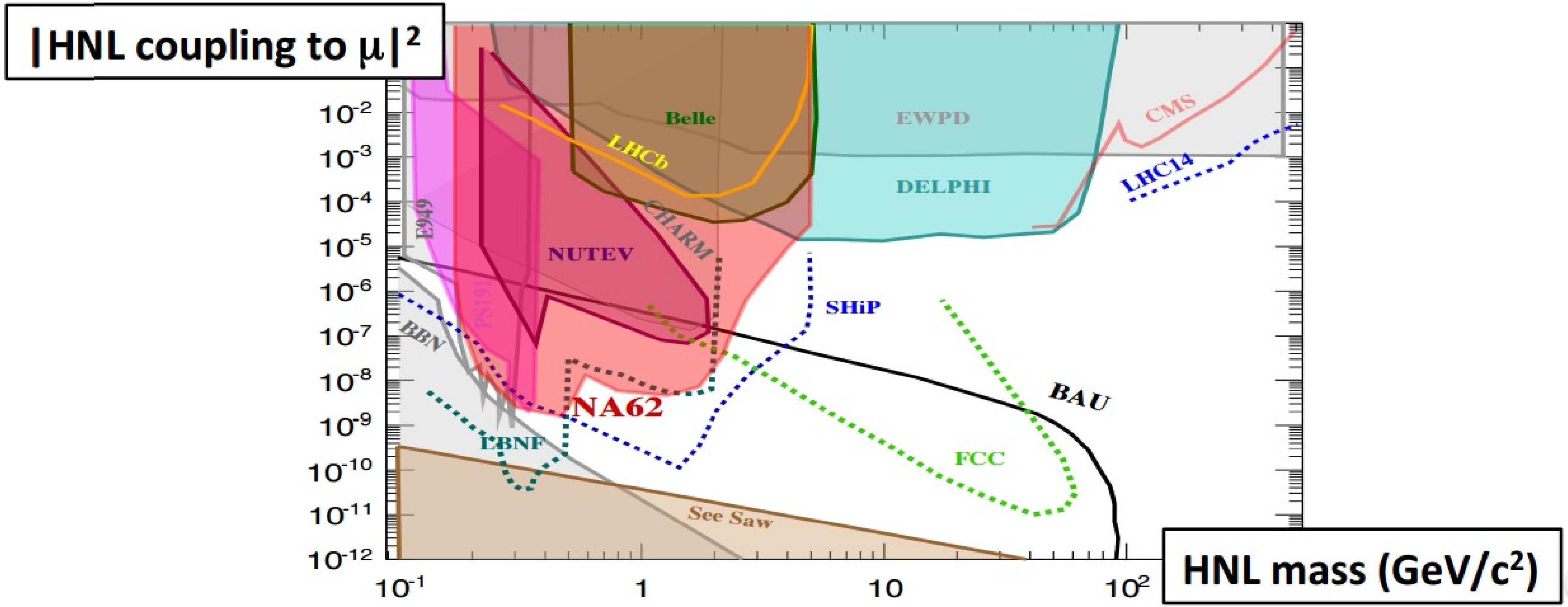
  assuming 2×10^{18} 400 GeV POT; zero background; trigger, acceptance and selection efficiency



- Sensitivity expected to be even higher: including direct QCD production of A’; production in the TAX (only target considered here)

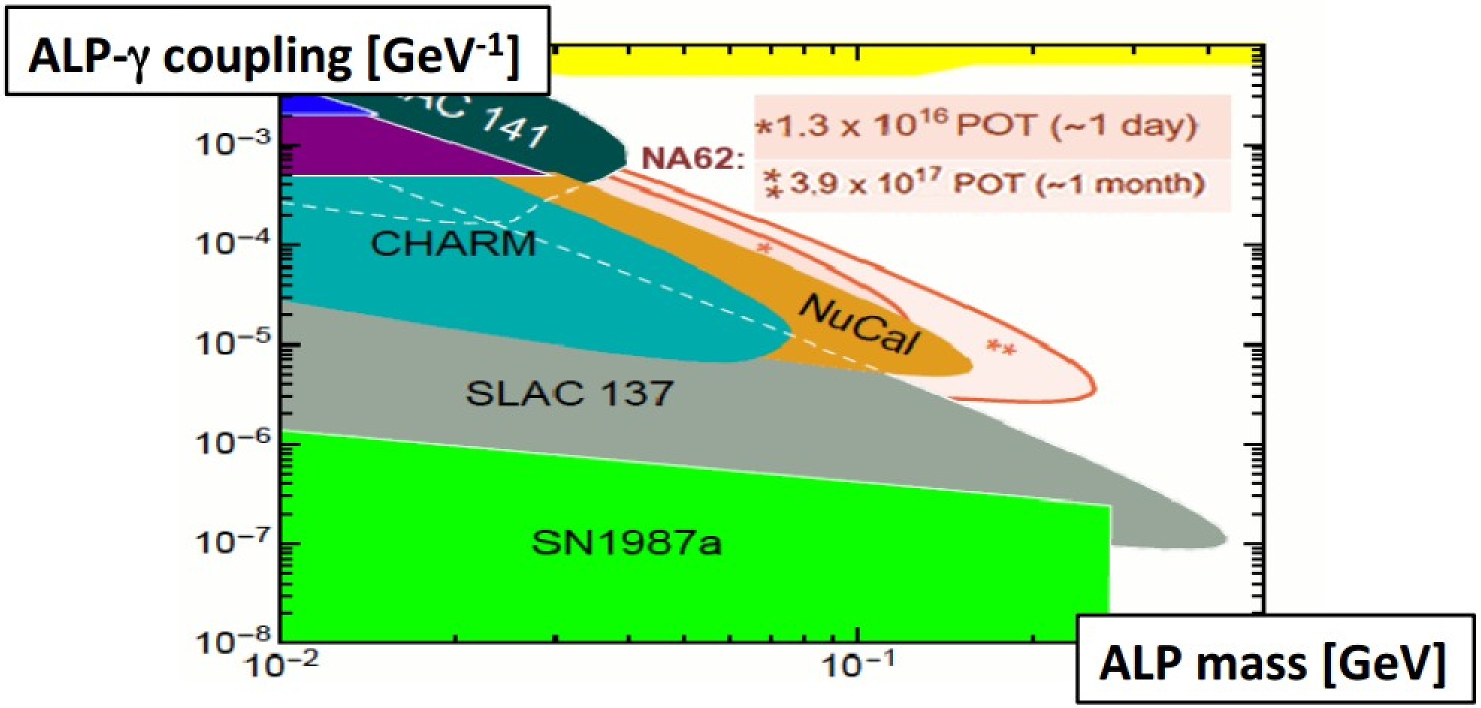
Search for visible decays of HNL

- Search for displaced decays of HNL→πe, πμ
- Expected 90% CL plot evaluation:
  assuming 2×10^{18} 400 GeV POT; zero background; trigger, acceptance and selection efficiency



Search for visible decays of ALPs

- Search for decays of ALP→γγ in the NA62 fiducial volume
- Expected 90% CL plot evaluation:
  assuming 1.3×10^{16} (3.9×10^{17}) 400 GeV POT corresponding to 1 day (1 month) runs;
  zero background; geometrical acceptance;



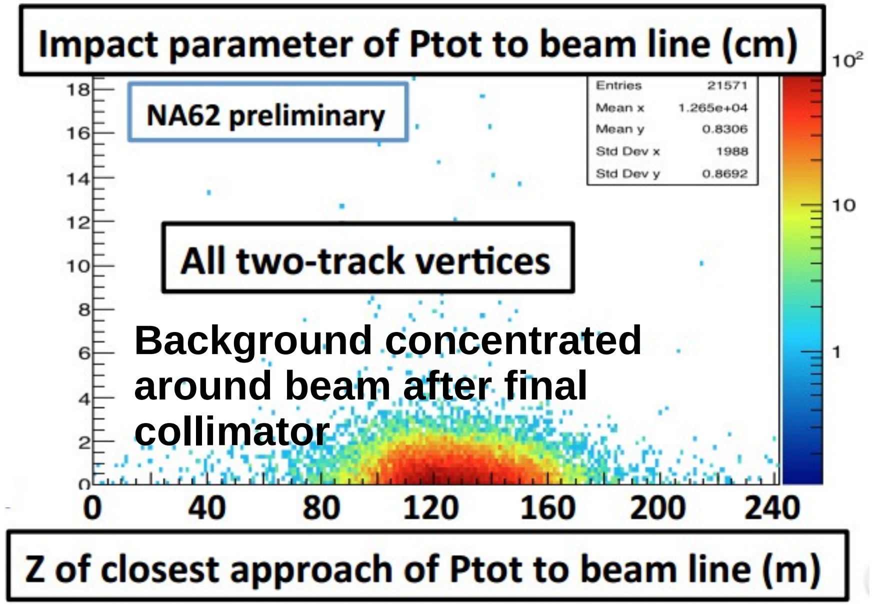
Test of the zero background assumption

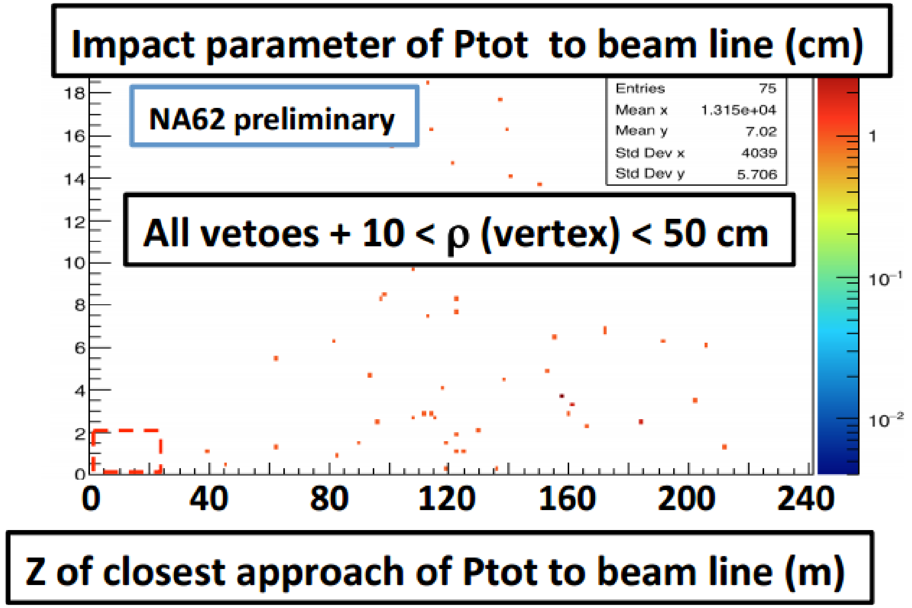
[In "Beam" Mode, result in "Dump" mode in preparation]

- Event selection: track quality + acceptance cuts
  - two track vertex: cda < 1 cm
  - position 105 < Z < 165 m

  Stat. corresponds to ~10^{15} POT

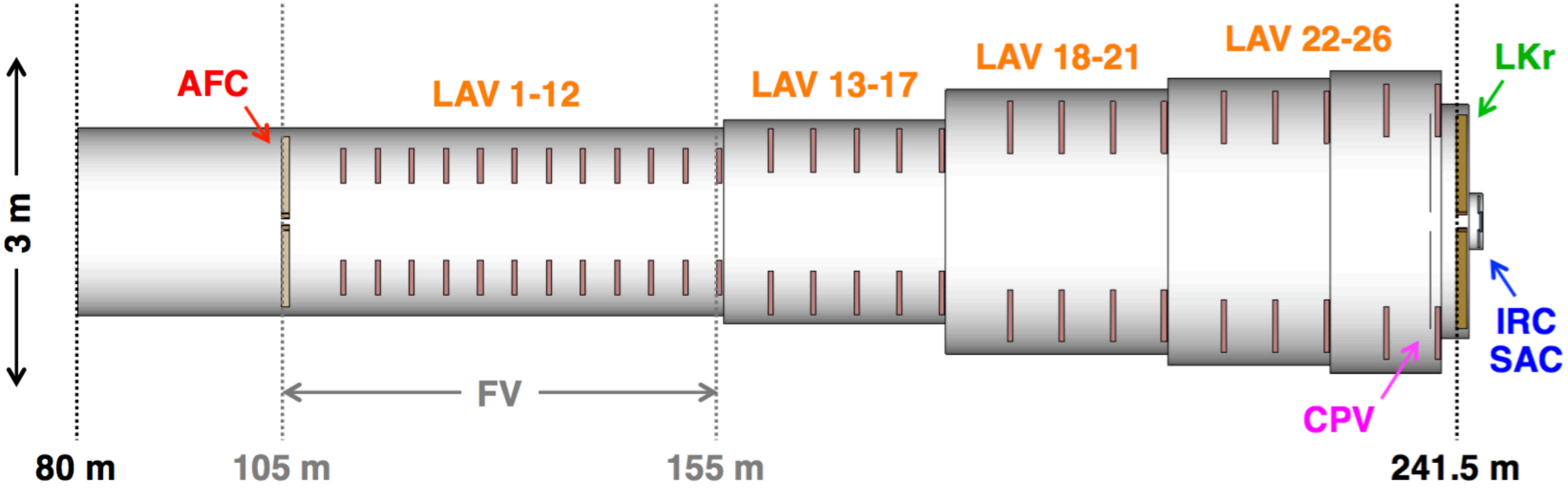
- Event-level veto conditions:
  - energy in LKr <2 GeV
  - veto on forward/large angle calorimeters
  - veto on charged anti-counter
- Total momentum stems from target





No events selected in the signal region!

An experiment to measure $K_L \to \pi^0 \nu \bar{\nu}$ KLEVER



For 60 SM events, need:

5×10^{19} pot

E.g. 2×10^{13} ppp/16.8 s × 5 yrs

$\langle p_K \rangle$ = **70 GeV** for decays in FV

Photons from $K_L \to \pi^0\pi^0$ boosted forward for easier vetoing

Much higher energy than KOTO: Complementary approach

Main detector/veto systems:

AFC	Active final collimator/upstream veto
LAV1-26	Large-angle vetoes (26 stations)
LKr	NA48 liquid-krypton calorimeter
IRC/SAC	Small-angle vetoes
CPV	Charged-particle veto

SUMMARY

- In 2016 NA62 performed the transition from commissioning to data taking/analysis
- Run 2017 well under way
- Incremental improvements to data taking efficiency, trigger and beam intensity planned for 2017 in order to fulfil our objective to collecting approx. 10^{13} kaon decays before LS2
- **Broad road physics portfolio**
- **There are plans to extend the experiment after LS2 to also explore the "Invisibles" using the NA62 detector and ideas to go even further!**

LHC roadmap: according to MTP 2016-2020

LS2 starting in 2019 => 24 months + 3 months BC
LS3 LHC: starting in 2024 => 30 months + 3 months BC
Injectors: in 2025 => 13 months + 3 months BC