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

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For the NA62 Collaboration

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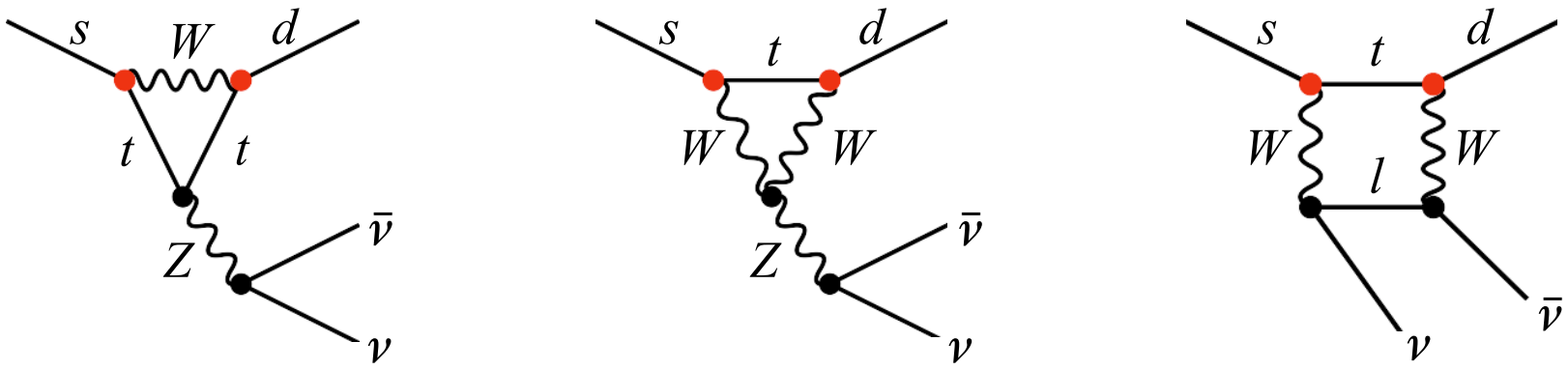
$K \to \pi\nu\bar{\nu}$ in the Standard Model

FCNC processes dominated by Z-penguin and box amplitudes:



Extremely rare decays with rates very precisely predicted in SM:

- Hard GIM suppression - loop functions favor top contribution
- No long-distance contributions from amplitudes with intermediate photons
- Hadronic matrix element obtained from BR(K_{e3}) via isospin rotation

	SM predicted rates Buras et al, JHEP 1511*	**Experimental status**
$K^+ \to \pi^+\nu\bar{\nu}$	**BR = (8.4 ± 1.0) × 10^{-11}**	**BR = (17.3 $^{+11.5}_{-10.5}$) × 10^{-11}** Stopped K^+, 7 events observed BNL 787/949, PRD79 (2009)
$K_L \to \pi^0\nu\bar{\nu}$	**BR = (3.4 ± 0.6) × 10^{-11}**	**BR < 2600 × 10^{-11} 90%CL** KEK 391a, PRD81 (2010)

* Tree-level determinations of CKM matrix elements

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

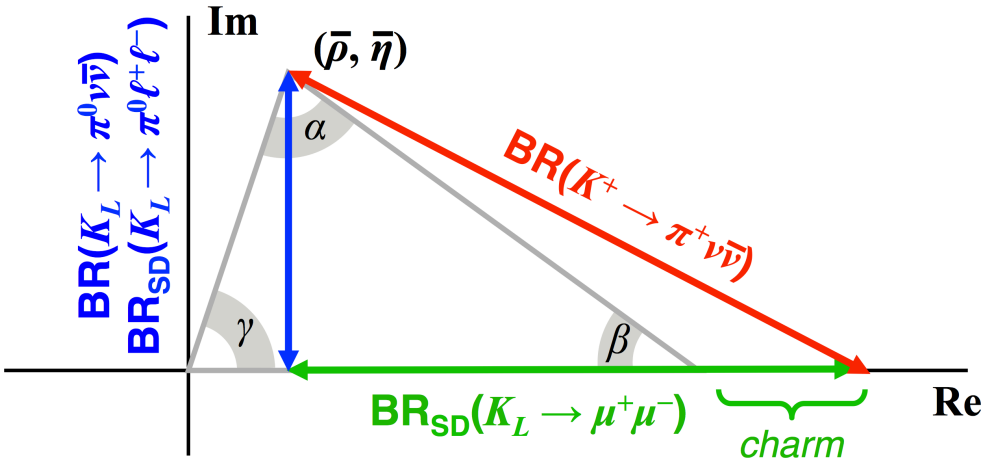
Dominant uncertainties for SM BRs are from CKM matrix elements

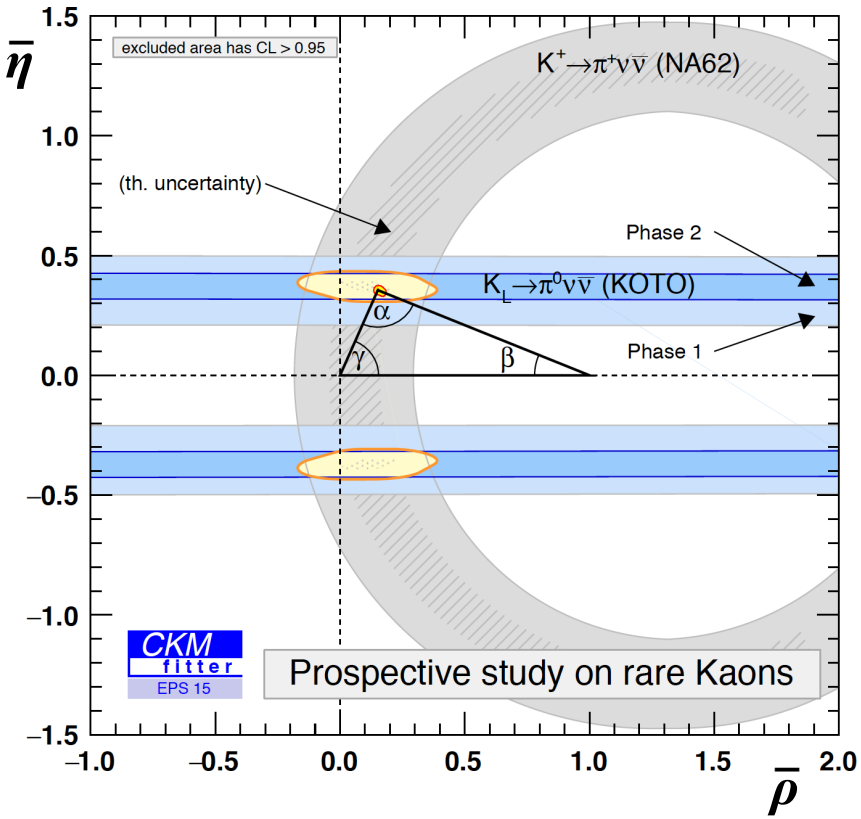
$$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu}) = (8.39 \pm 0.30) \times 10^{-11} \cdot \left[\frac{|V_{cb}|}{0.0407}\right]^{2.8} \cdot \left[\frac{\gamma}{73.2^\circ}\right]^{0.74}$$

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

Buras et al.
JHEP 1511

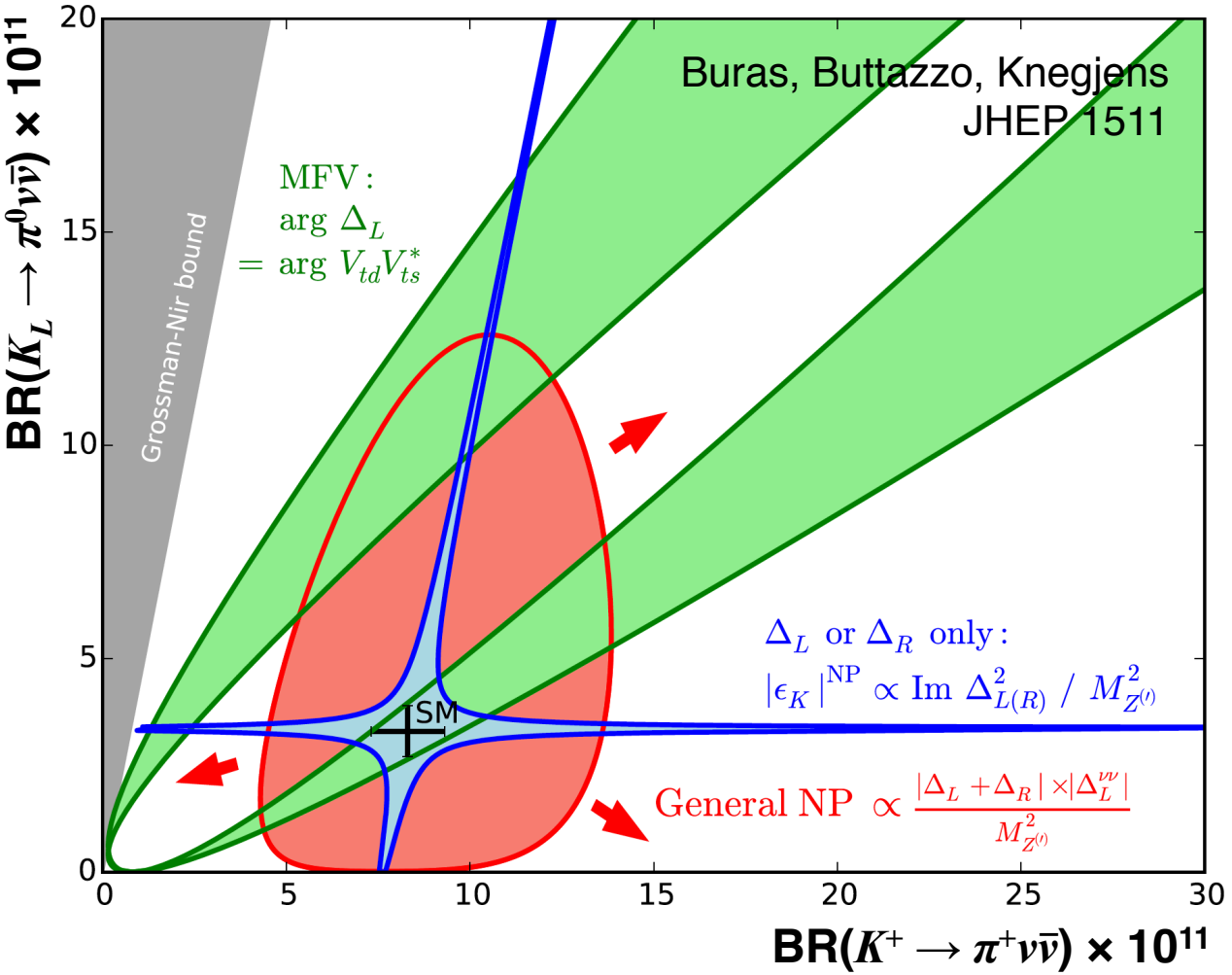
- Intrinsic theory uncertainties ~ few percent
- BR measurements overconstrain CKM matrix and may provide evidence for NP





$K \to \pi\nu\bar{\nu}$ and new physics

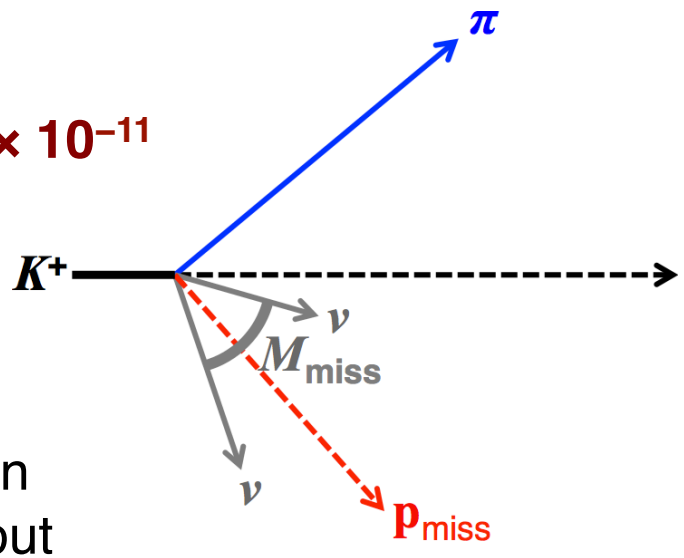
New physics affects BRs differently for different channels
Multiple measurements can discriminate among NP scenarios



- Models with CKM-like flavor structure
  - Models with MFV
- Models with new flavor-violating interactions in which either LH or RH currents dominate
  - Z/Z' models with pure LH/RH couplings
  - Little Higgs with T parity
- Models without above constraints
  - Randall-Sundrum

$K^+ \to \pi^+ \nu\bar{\nu}$: Signal and background

Signal:
$BR_{SM} \sim 8 \times 10^{-11}$



K track in
π track out
No other particles in final state
$M^2_{\text{miss}} = (p_K - p_\pi)^2$

NA62 goal:
Measure BR to 10%

100 signal events
Background < 20%

10^{13} K decays with:
- Acceptance ~10%
- Background rejection ~10^{12}
- Background known to ~10%

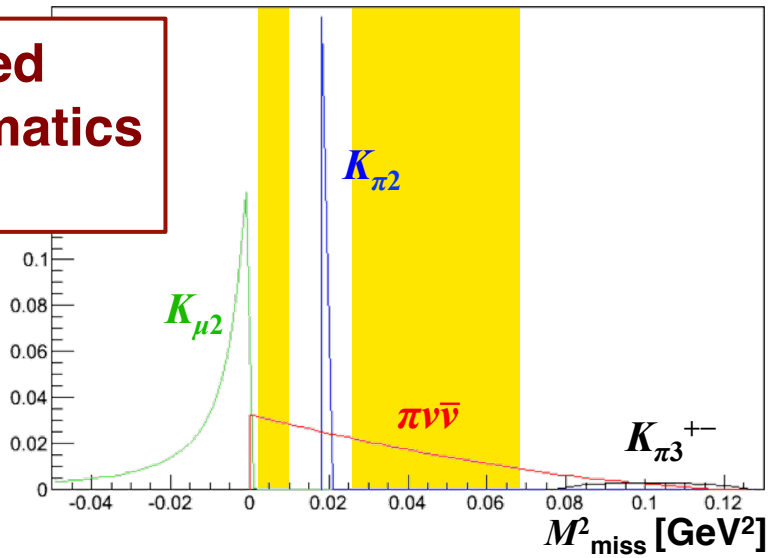
Decay backgrounds

Mode	BR
$\mu^+\nu(\gamma)$	**63.5%**
$\pi^+\pi^0(\gamma)$	**20.7%**
$\pi^+\pi^+\pi^-$	5.6%
$\pi^0 e^+\nu$	5.1%
$\pi^0\mu^+\nu$	3.3%
$\pi^+\pi^- e^+\nu$	4.1×10^{-5}
$\pi^0\pi^0 e^+\nu$	2.2×10^{-5}
$\pi^+\pi^-\mu^+\nu$	1.4×10^{-5}
$e^+\nu(\gamma)$	1.5×10^{-5}

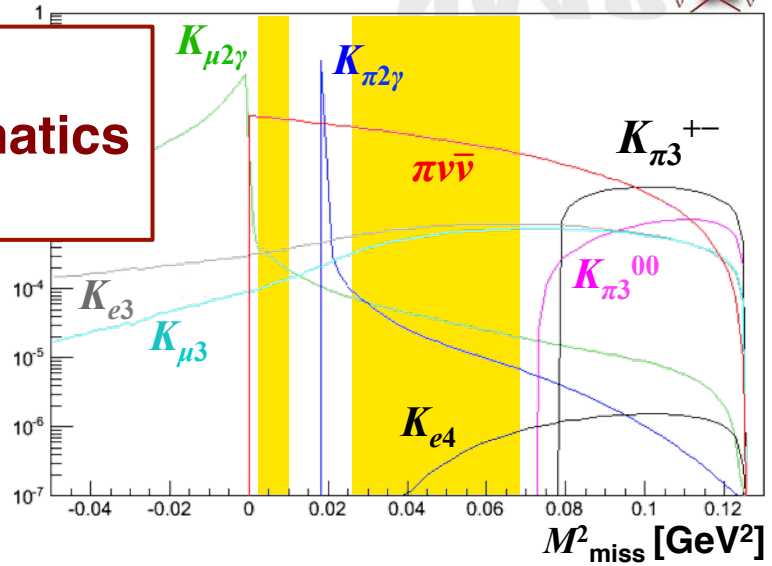
Other backgrounds
- Beam-gas interactions
- Upstream interactions

$K^+ \to \pi^+ \nu\bar{\nu}$: Background rejection

Closed kinematics 92%



Open kinematics 8%



$m^2_{miss} = 0$ or m_π^2 to reject $\mu\nu$, $\pi\pi^0$ → 2 fiducial regions in m^2_{miss}

- High resolution m^2_{miss} reconstruction
- Precise measurement of p_K and p_π
- Minimize multiple scattering

High-rate beam tracker
Low-mass spectrometer in vacuum

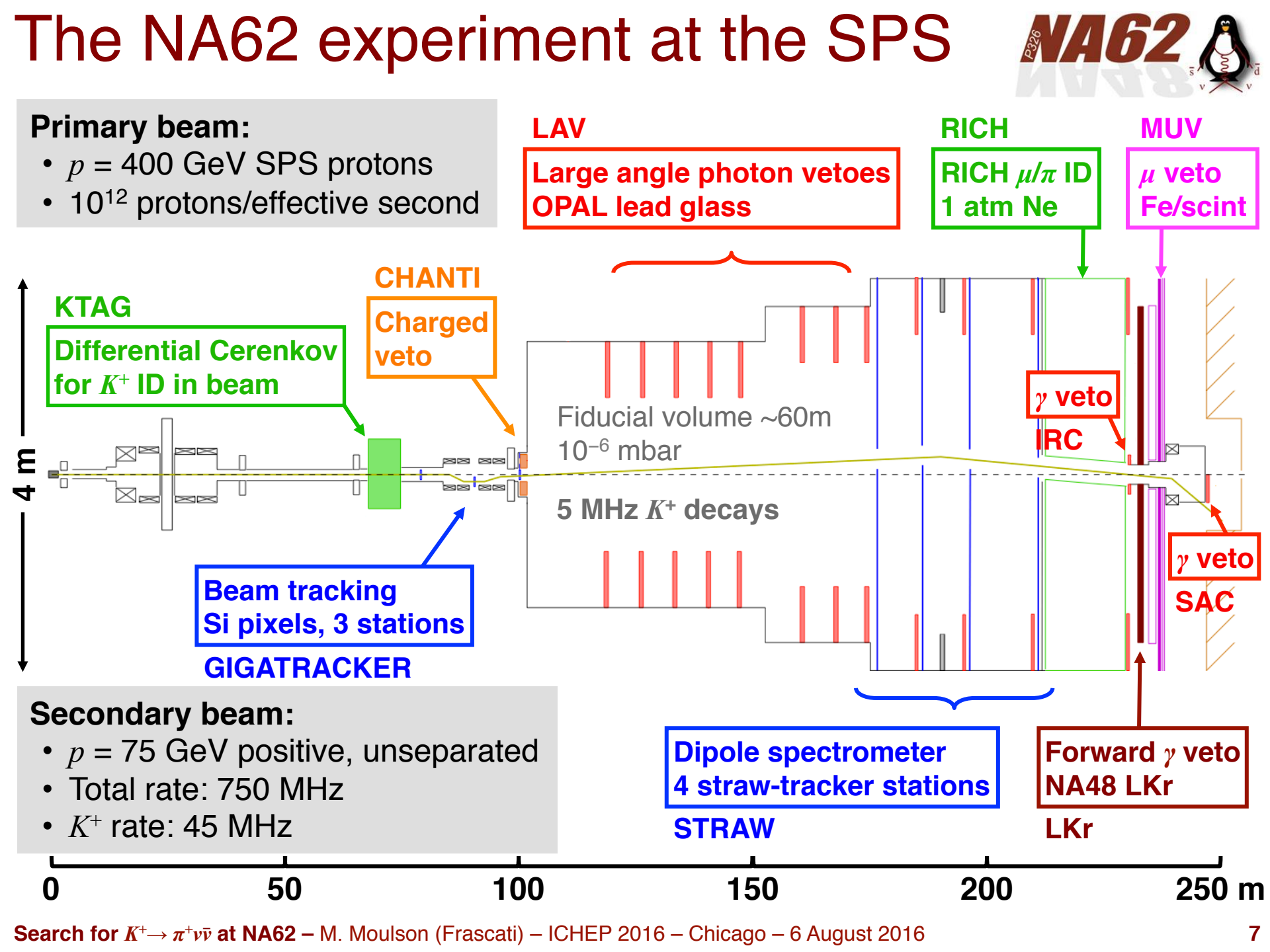
Rejection from kinematics alone: 10^5 at best

(Further) rejection relies on PID and vetoes

- Veto detectors for π^0 rejection
- K^+ identification in hadron beam
- Detectors for π/μ separation

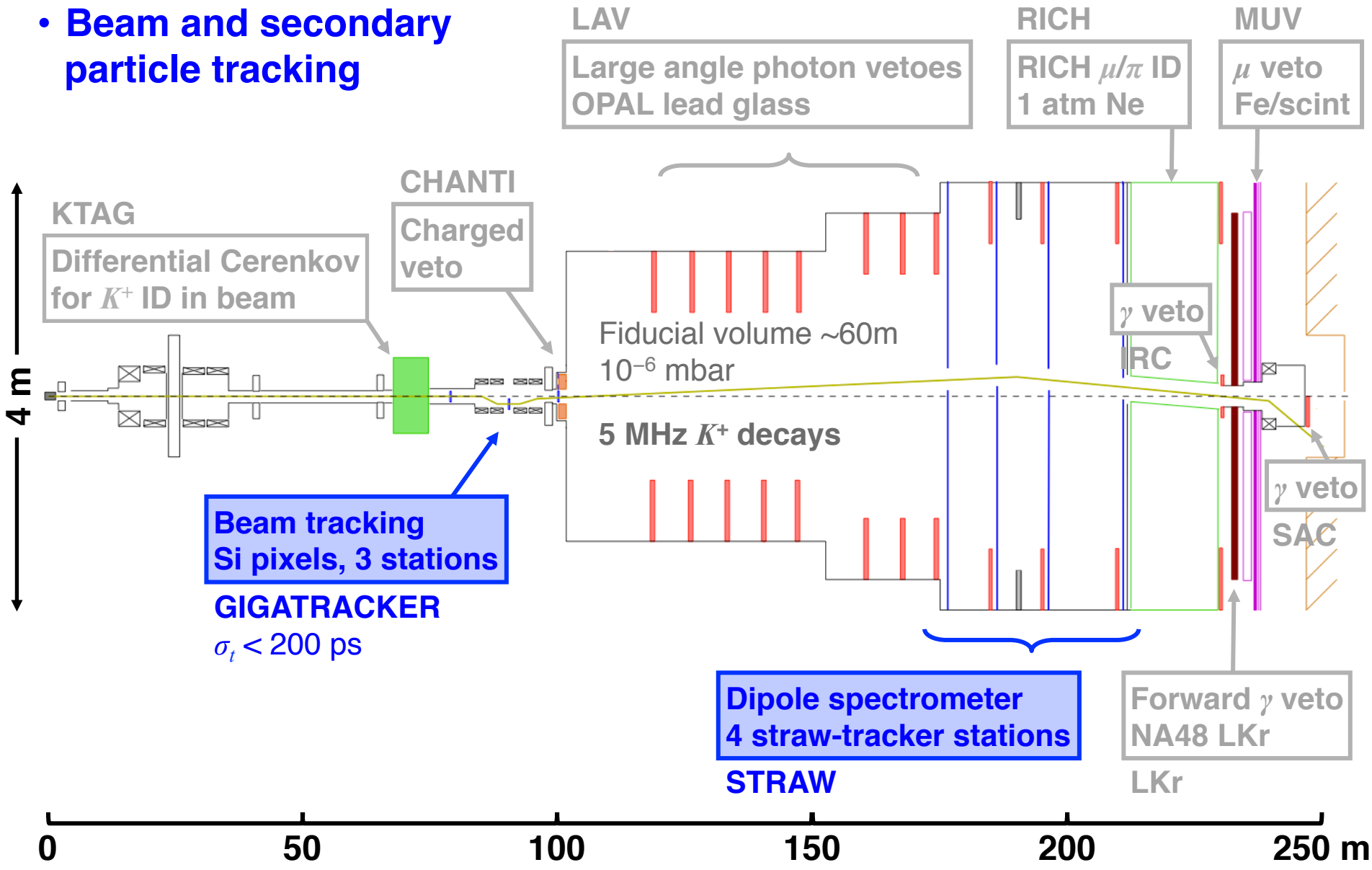
Hermetic γ vetoes
Beam & secondary particle ID
Muon vetoes

The NA62 experiment at the SPS



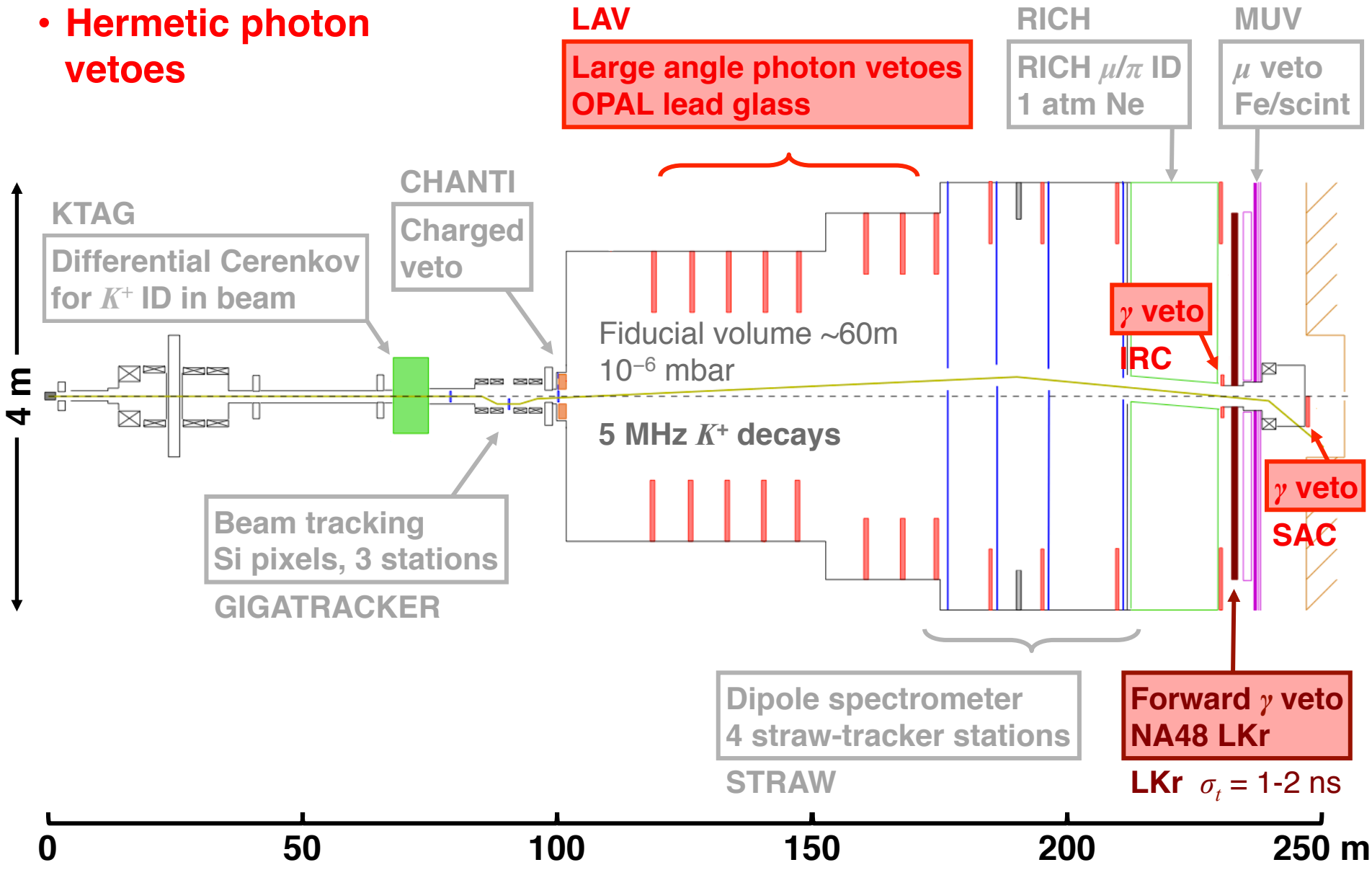
The NA62 experiment at the SPS

- **Beam and secondary particle tracking**



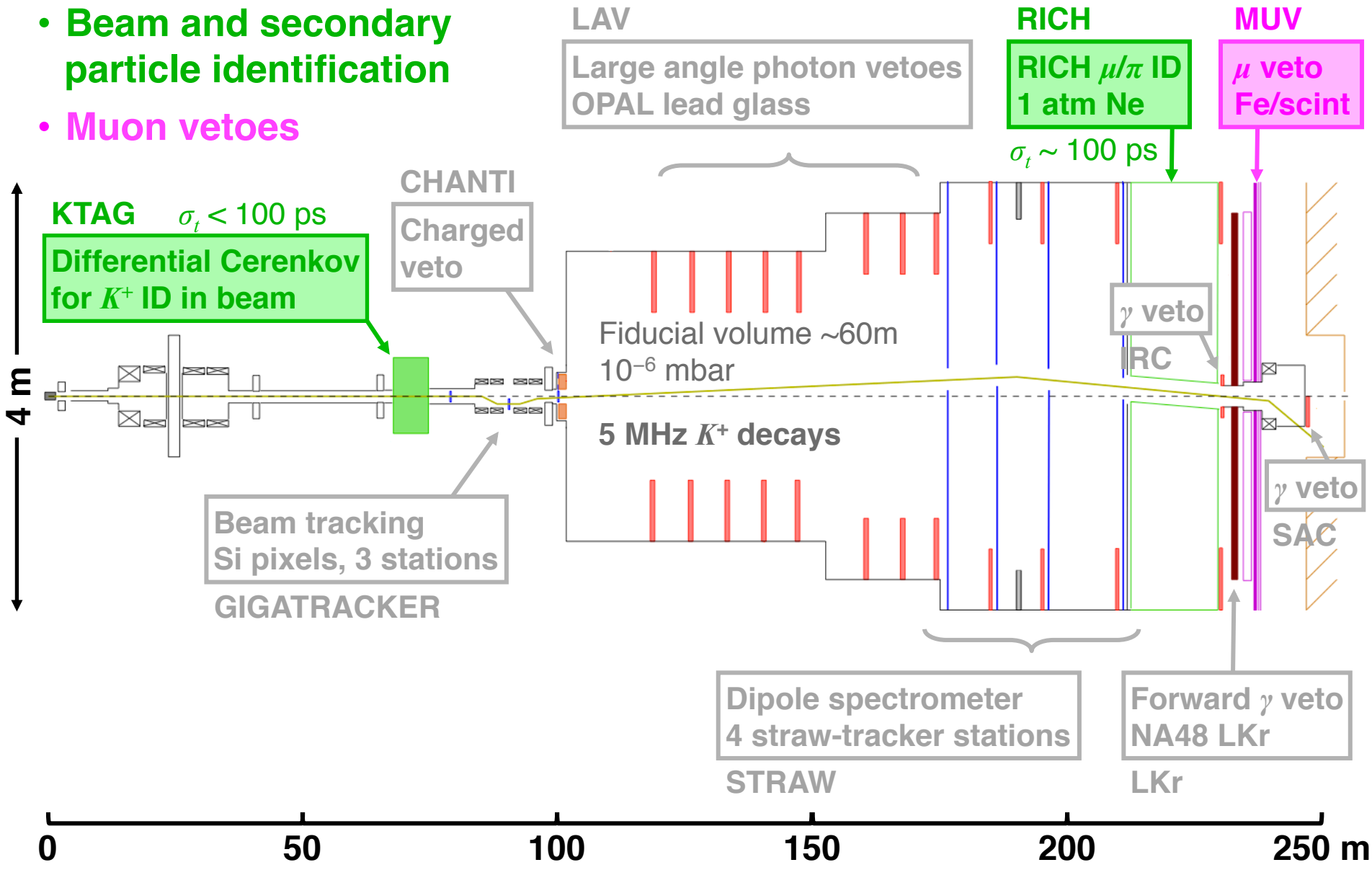
The NA62 experiment at the SPS

- **Hermetic photon vetoes**

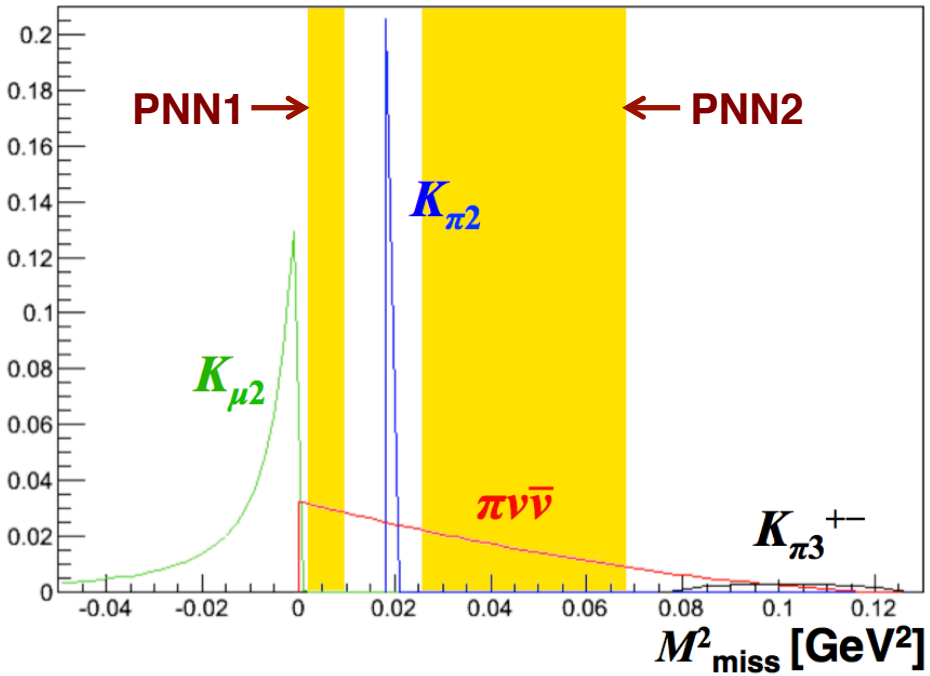


The NA62 experiment at the SPS

- **Beam and secondary particle identification**
- **Muon vetoes**



Expected performance



Acceptance: ~12%

3% in PNN1 region

9% in PNN2 region

50% loss from momentum cut

Detector inefficiencies included

45 signal events/yr

- 1 track with $15 < p_\pi < 35$ GeV and π PID in RICH
- No γs in LAV, LKr, IRC, SAC
- No μs in MUVs
- 1 beam particle in Gigatracker with K PID by KTAG
- z_{vtx} in 60 m fiducial volume

Expected backgrounds	
$K^+ \to \pi^+\pi^0$	10%
$K^+ \to \pi^+\pi^0\gamma_{IB}$	3%
$K^+ \to \mu^+\nu$	2%
$K^+ \to \mu^+\nu\gamma_{IB}$	1%
$K^+ \to \pi^+\pi^+\pi^-$	< 1%
K^+_{e4}, other 3 track decays	< 1%
K^+_{e3}, $K^+_{\mu 3}$	negligible
Total	**< 20%**

Experimental status

NA62 data taking:

- First data from pilot run in fall 2014
- First physics run June-November 2015
- 2016 run in progress (April-November)
- Expect to take data through 2018 (until LS2)

Beamline commissioned up to full intensity

Detector status:

- Gigatracker partially commissioned
- Spectrometer, PID detectors, photon vetoes all fully operational

Trigger and data acquistion status:

- Level-0 trigger fully operational
- Level-1 and level-2 triggers partially commissioned

Data and reconstruction quality under study using 2015 data:

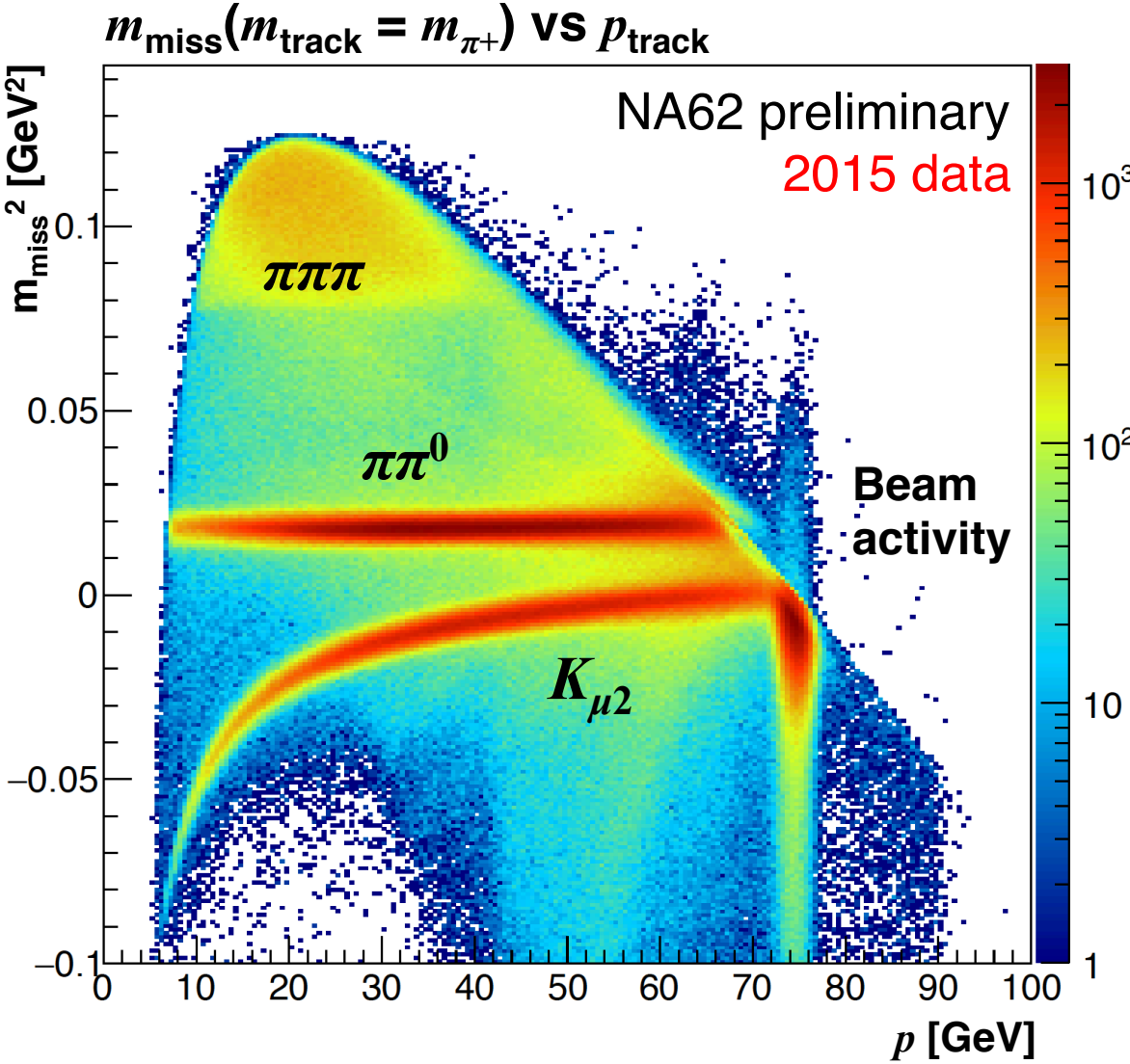
- Minimum-bias data at 1% beam intensity – *this talk*
- Data with preliminary LKr $\pi\nu\bar{\nu}$ trigger at 50-100% intensity – under study

Reconstruction & signal selection

Minimum-bias data at 1% beam intensity

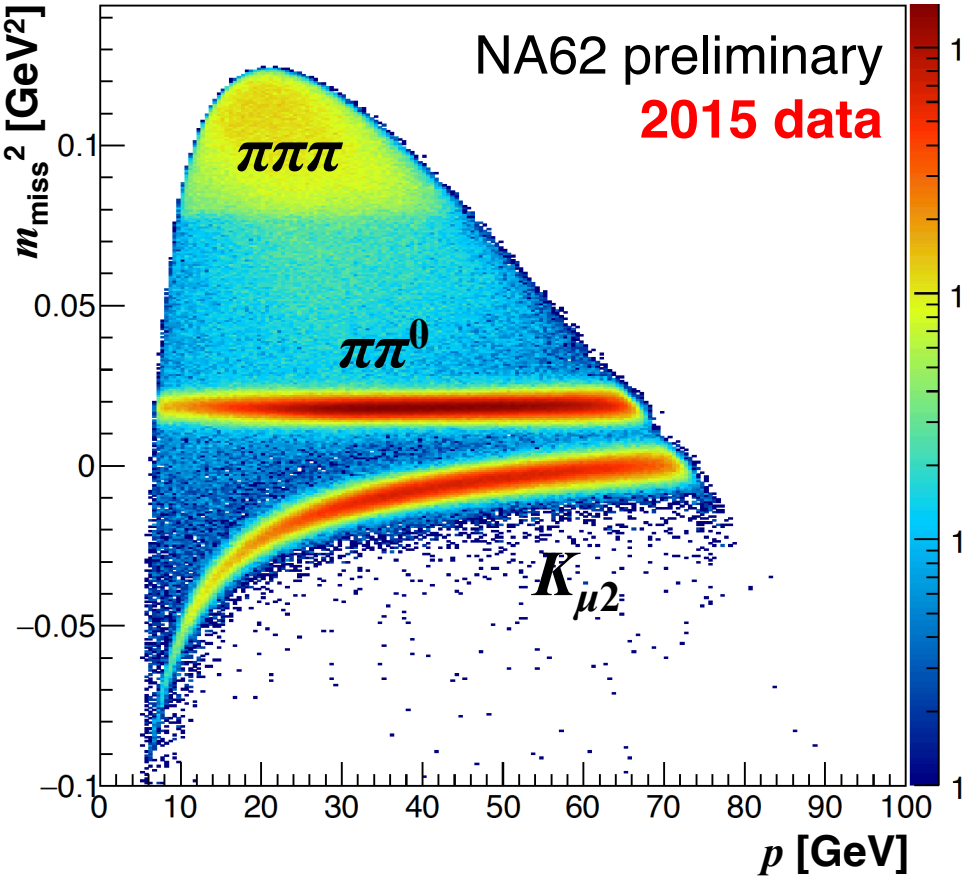
1-track selection:

- 1 positive track
- Acceptance/quality cuts
- Track origin in fiducial region
- Matched to hit on CHOD
  ($\sigma_t \sim 200$ ps)
- Matched to KTAG beam ID
  ($\sigma_t \sim 100$ ps)
- Forming vertex with beam track from GTK
- Further associated to hits on LKr, RICH, muon vetoes

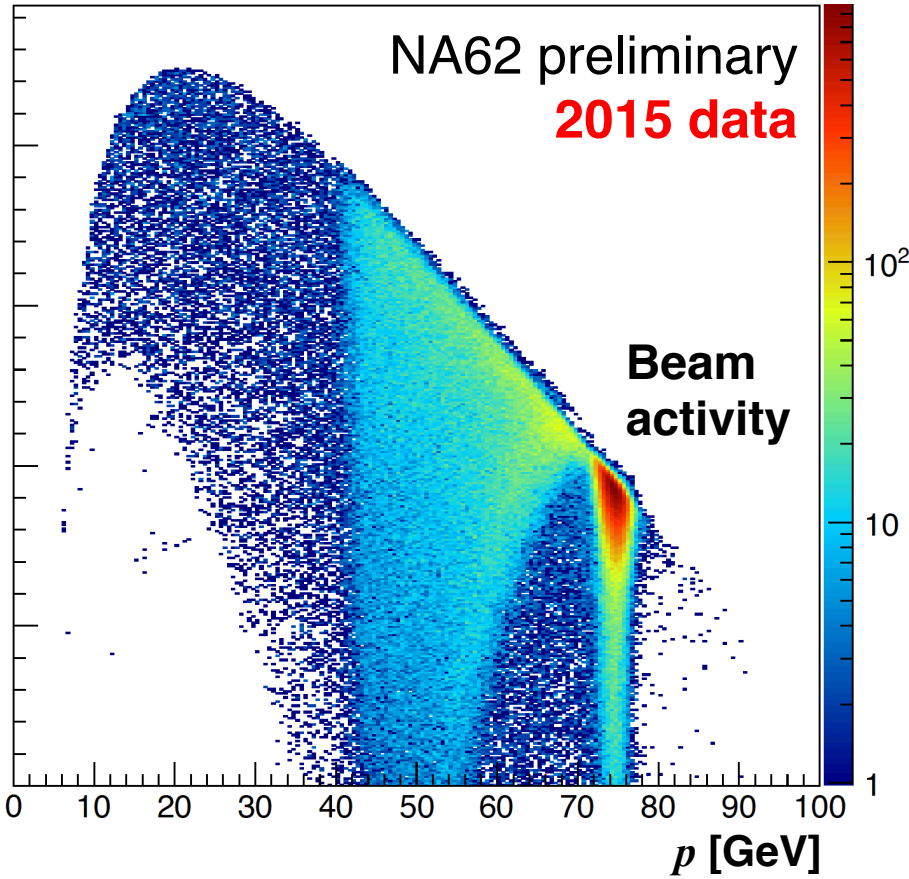


Signal selection and kaon ID

1-track selection
K^+ ID in KTAG



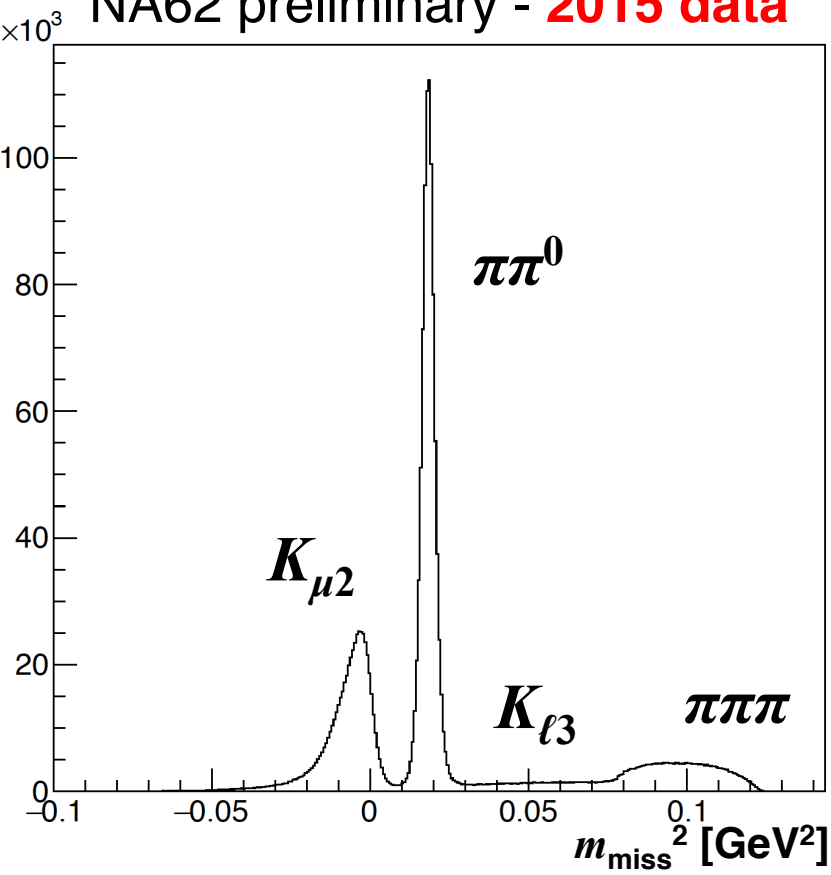
1-track selection
No K^+ ID in KTAG

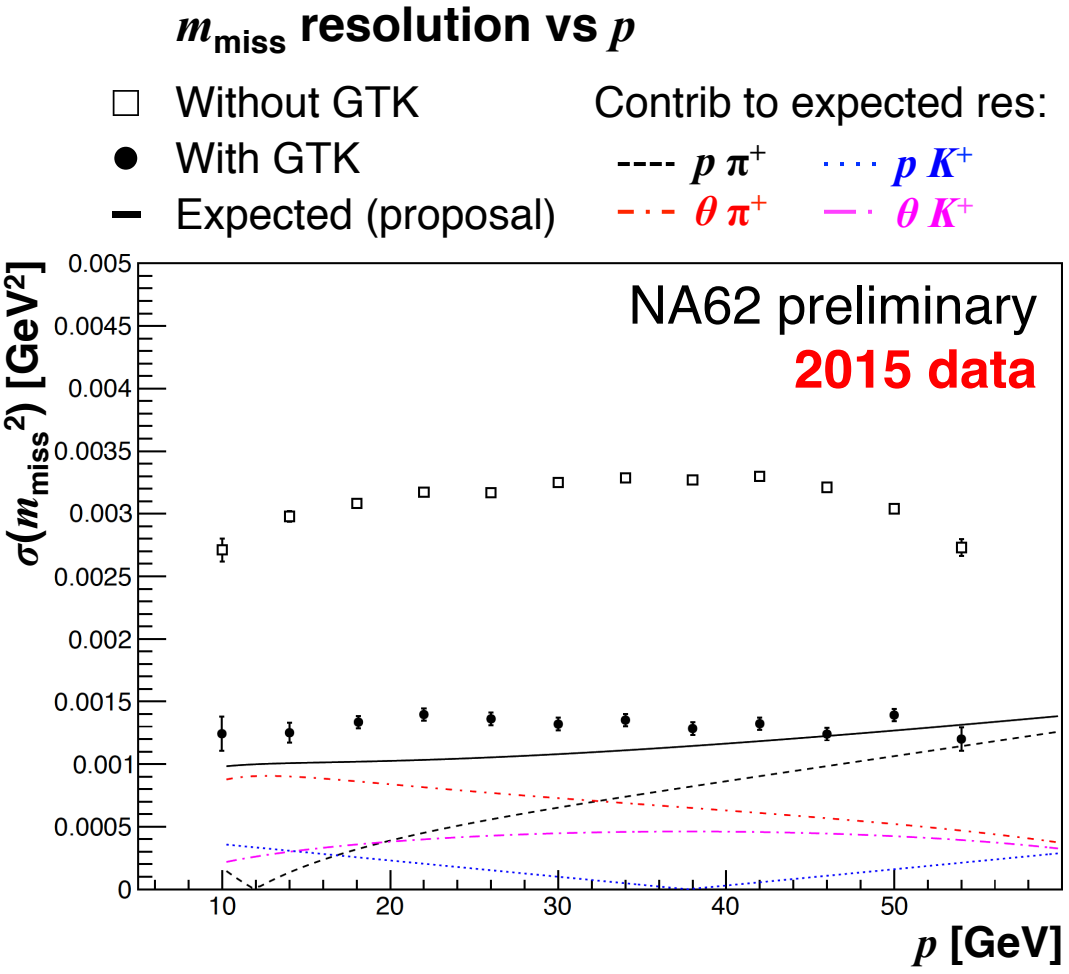


Reconstruction of kinematics

Goal: 10^4-10^5 rejection for 2-body decays

Use LKr to obtain clean sample of $\pi\pi^0$ events to study m_{miss} resolution



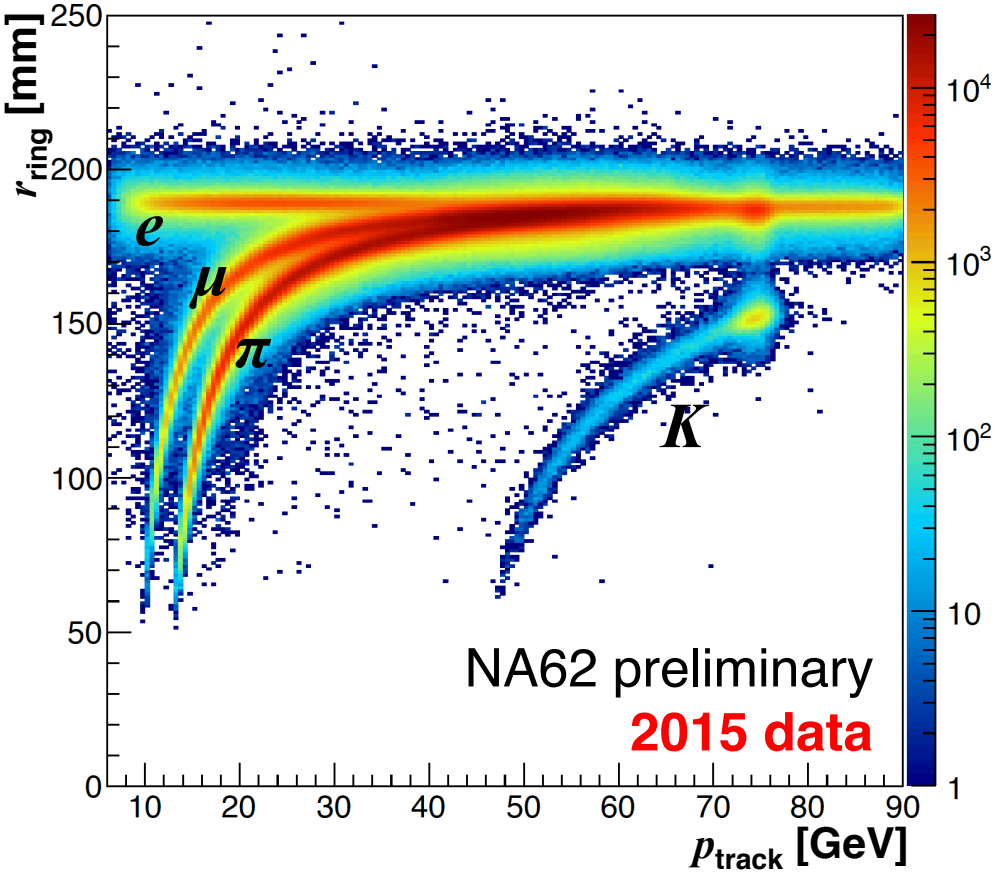


m_{miss} resolution in 2015 near to design value: O(10^3) $\pi\pi^0$ suppression obtained

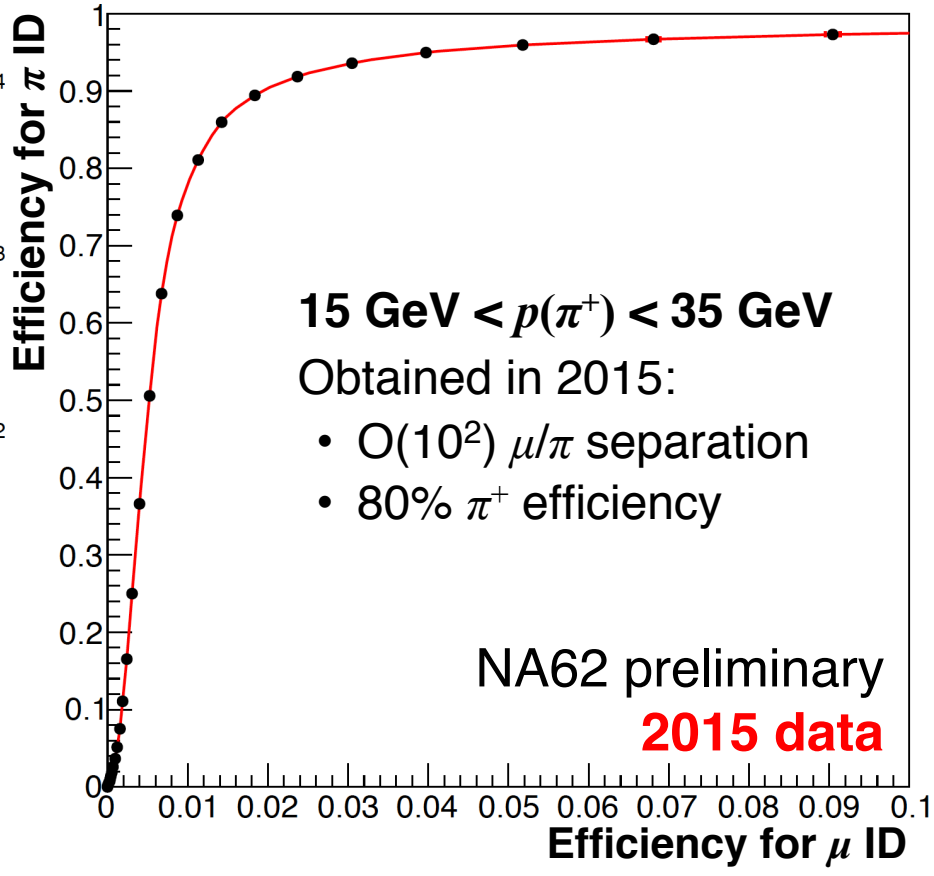
Secondary particle identification

Goal: 10^7 μ/π separation, mainly for rejection of $K_{\mu 2}$
Study with pure kinematic selection of $K_{\mu 2}$ and $\pi\pi^0$ events

RICH ring radius vs track momentum

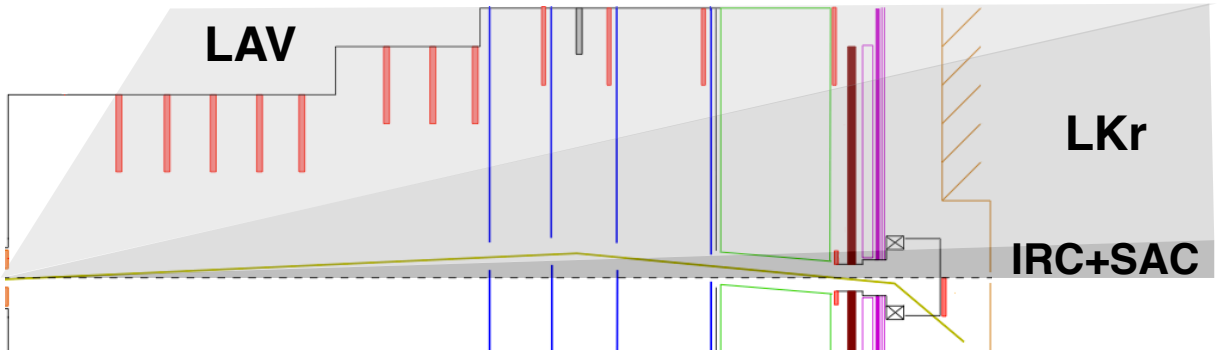


RICH π ID efficiency vs μ ID efficiency

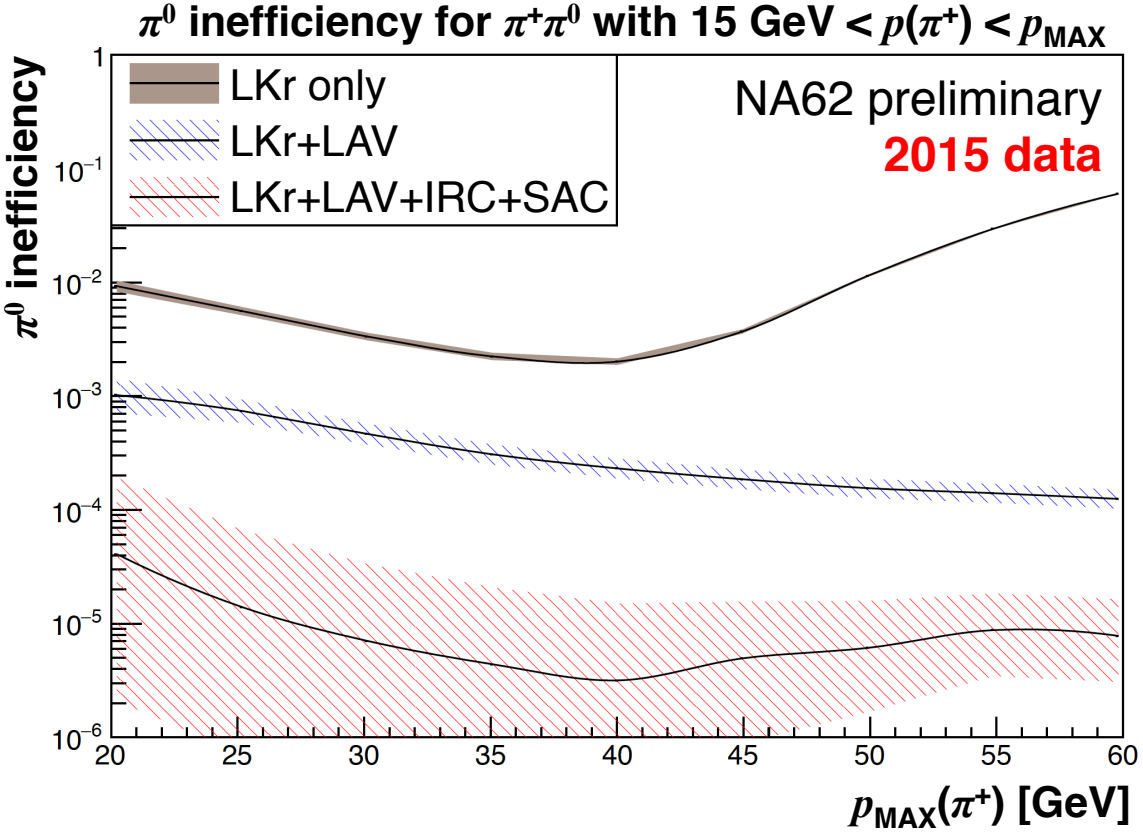


LKr + muon vetoes: Preliminary results from cut analysis with 2015 data
O(10^6) μ rejection at 50% π^+ efficiency (efficiency expected to improve)

Photon rejection



Detector	θ [mrad]
LAV	8.5 - 50
LKr	1 - 8.5
IRC+SAC	< 1



- **Goal:** 10^8 rejection of $\pi^0 \to \gamma\gamma$
- Requiring $p(\pi^+) < 35$ GeV ensures $E(\pi^0) > 40$ GeV
- Use tracking/PID to obtain clean sample of $K \to \pi\pi^0$ events to study
- **O(10^6) rejection obtained in 2015**

  Measurement with minimum-bias data limited by statistics

NA62 physics besides $K^+ \to \pi^+ \nu\bar{\nu}$

Standard kaon physics

- Precision measurements of dominant K^+ BRs
- ChPT studies: $K^+ \to \pi^+\gamma\gamma$, $K^+ \to \pi^+\pi^0 e^+ e^-$, K_{e4}
- Precision test of lepton universality: $R_K = \Gamma(K \to e\nu(\gamma))/\Gamma(K \to \mu\nu(\gamma))$

Searches for lepton-flavor or -number violating decays

- $K^+ \to \pi^+\mu e$, $K^+ \to \pi^-\mu^+ e^+$, $K^+ \to \pi^-\ell^+\ell^+$

Searches for heavy neutrinos

- $K^+ \to \ell^+ \nu_h$ (inclusive)
- ν_h from upstream K, D decays with $\nu_h \to \pi\ell$

Searches for long-lived dark sector particles

- Dark photon γ' produced in π/ρ decays in target, with $\gamma' \to \ell^+\ell^-$
- Axion-like particle A^0 produced in target/beam dump, with $A^0 \to \gamma\gamma$

π^0 decays

- $\pi^0 \to$ invisible; $\pi^0 \to 3\gamma$, 4γ; $\pi^0 \to \gamma\gamma'$

Summary and outlook

NA62 beamline and detector commissioned up to full program intensity

First physics run in 2015:

- Minimum bias data collected at low intensity used for data quality studies
- Data and reconstruction quality consistent with design expectations for measurement of $K^+ \to \pi^+ \nu\bar{\nu}$

NA62 physics runs 2016-2018:

- Currently running at 20% intensity; will go to 50% soon
- Expect to collect a few SM $K^+ \to \pi^+ \nu\bar{\nu}$ events by end of 2016 run
- On track to collect O(100) SM $K^+ \to \pi^+ \nu\bar{\nu}$ events and measure BR to ~10% by 2018

NA62 will pursue a broad array of measurements as a side program

- Traditional K physics, LFNV searches, exotic long-lived particle searches, and more