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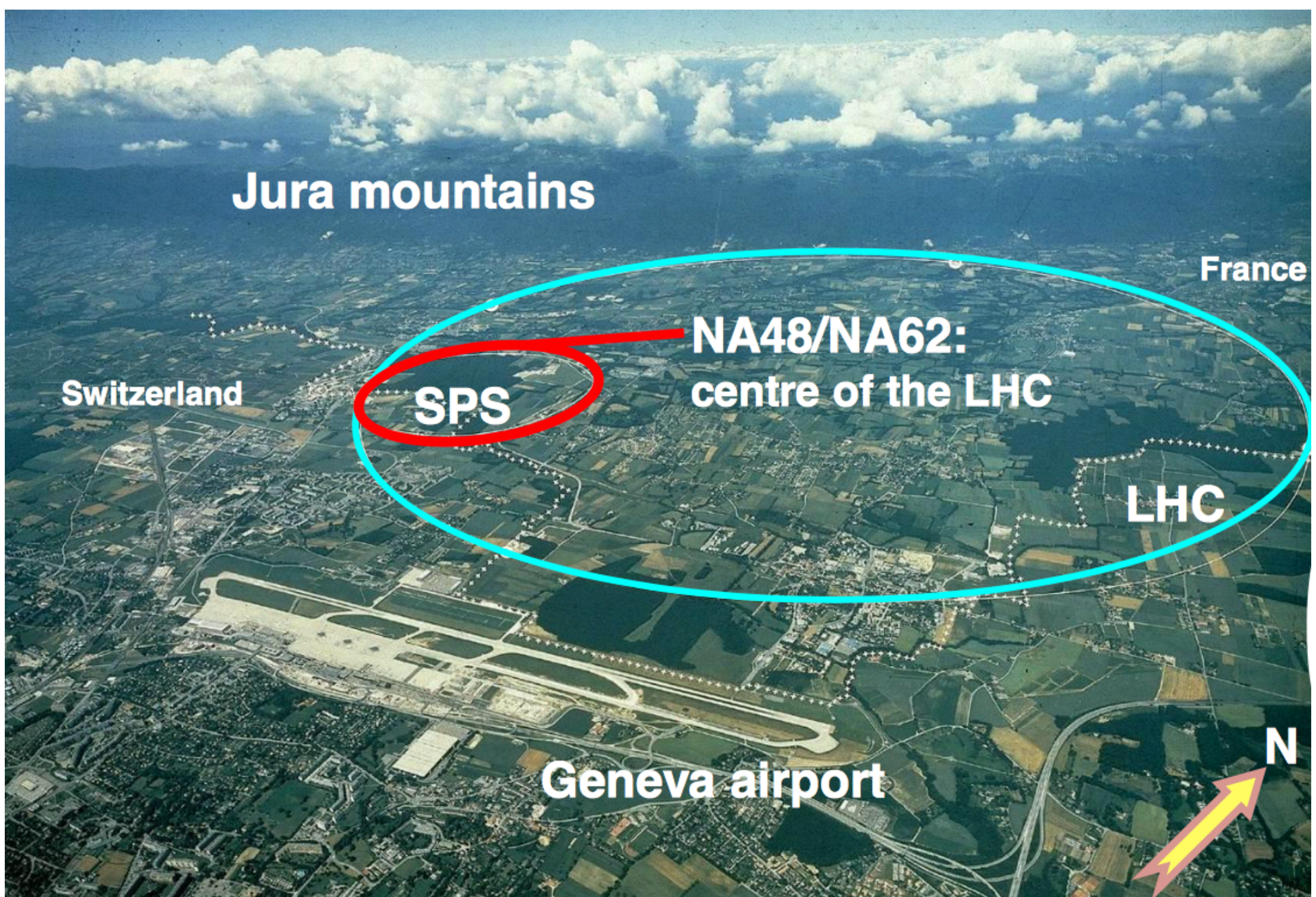
THE NA62 EXPERIMENT AT CERN: STATUS AND RECENT RESULTS

THE NA62 COLLABORATION

~30 institutes, ~200 participants form:

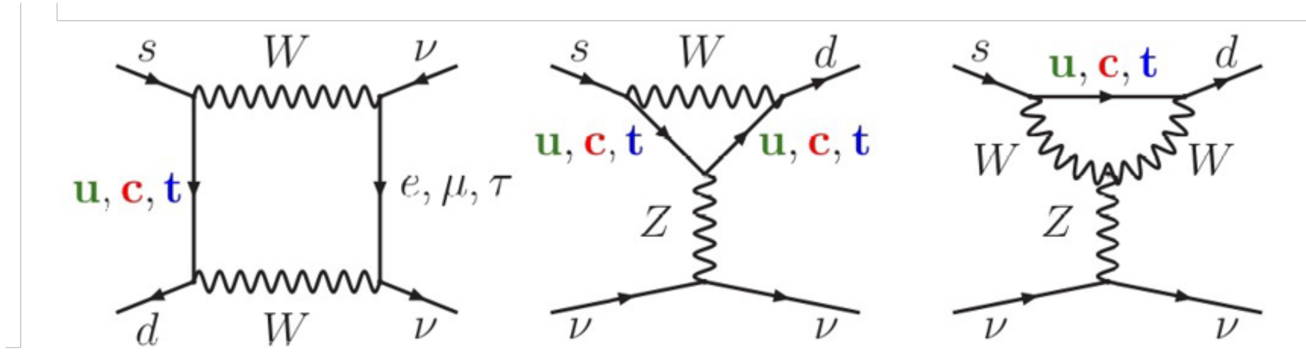
Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna, Fairfax, Ferrara, Firenze, Frascati, Glasgow, Liverpool, Louvain, Mainz, Merced, Moscow, Napoli, Perugia, Pisa, Prague, Protvino, Roma I, Roma II, San Luis Potosi, Sofia, Torino, TRIUMF, Vancouver UBC



NA62 experiment is located at north area(NA) of CERN. Protons are extracted from the SPS with p=400 GeV/c producing a secondary beam of hadrons (~6% are kaons).

Main goal is to measure the $K^+ \to \pi^+ \nu\nu$ branching fraction with high precision

MOTIVATION



- Ultra rare kaon decay with very clean theoretical prediction within the SM framework: $BR(K^+ \to \pi^+ \nu \bar{\nu}) = (9.11 \pm 0.72) \times 10^{-11}$ Buras et al., JHEP 1511 (2015) 033

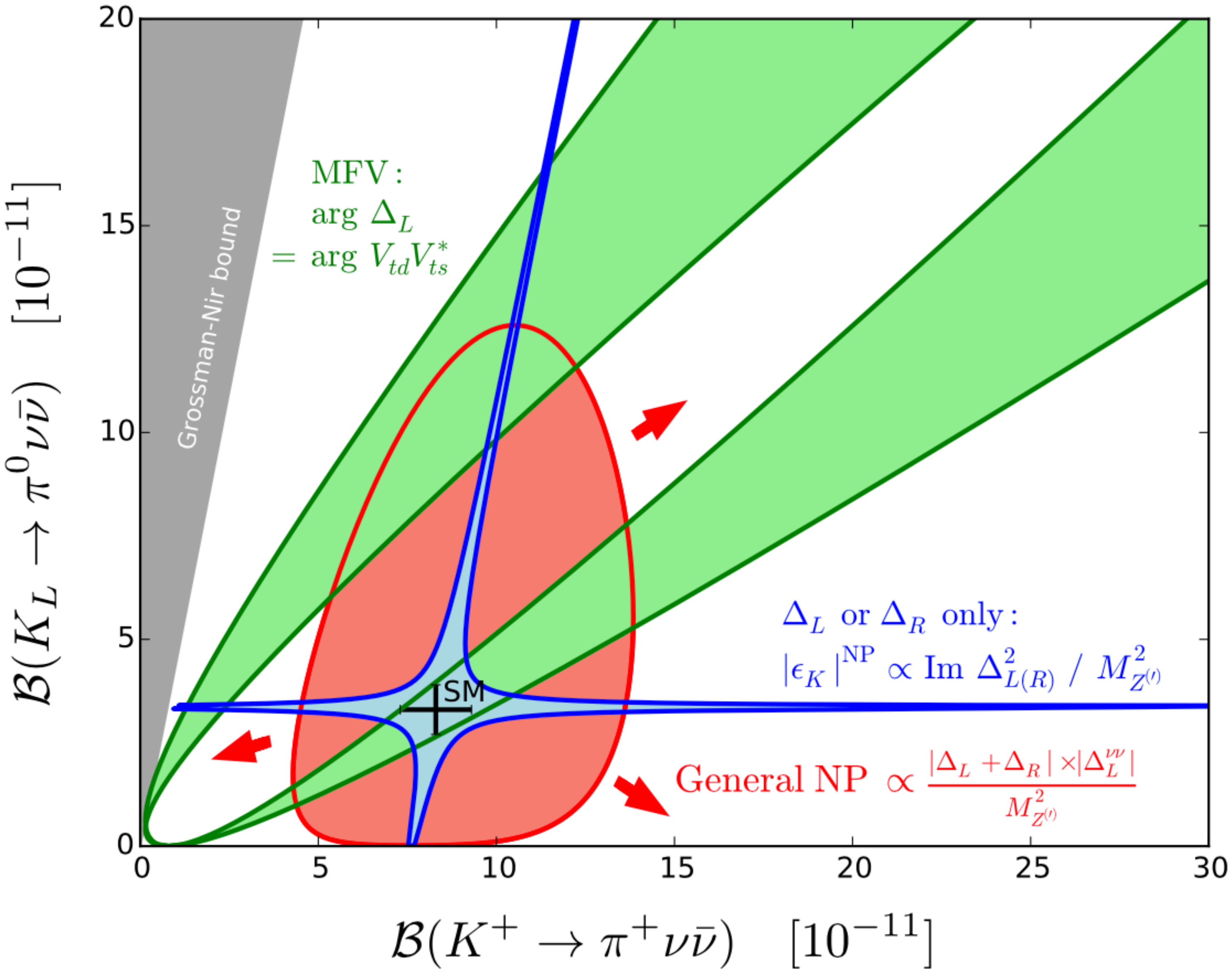
- The only experimental measurement from E787/E949 has large uncertainty: PRL101 (2008) 191802

$$BR(K^+ \to \pi^+ \nu \bar{\nu}) = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$$

- Sensitive to new physics effects… (see next slide)

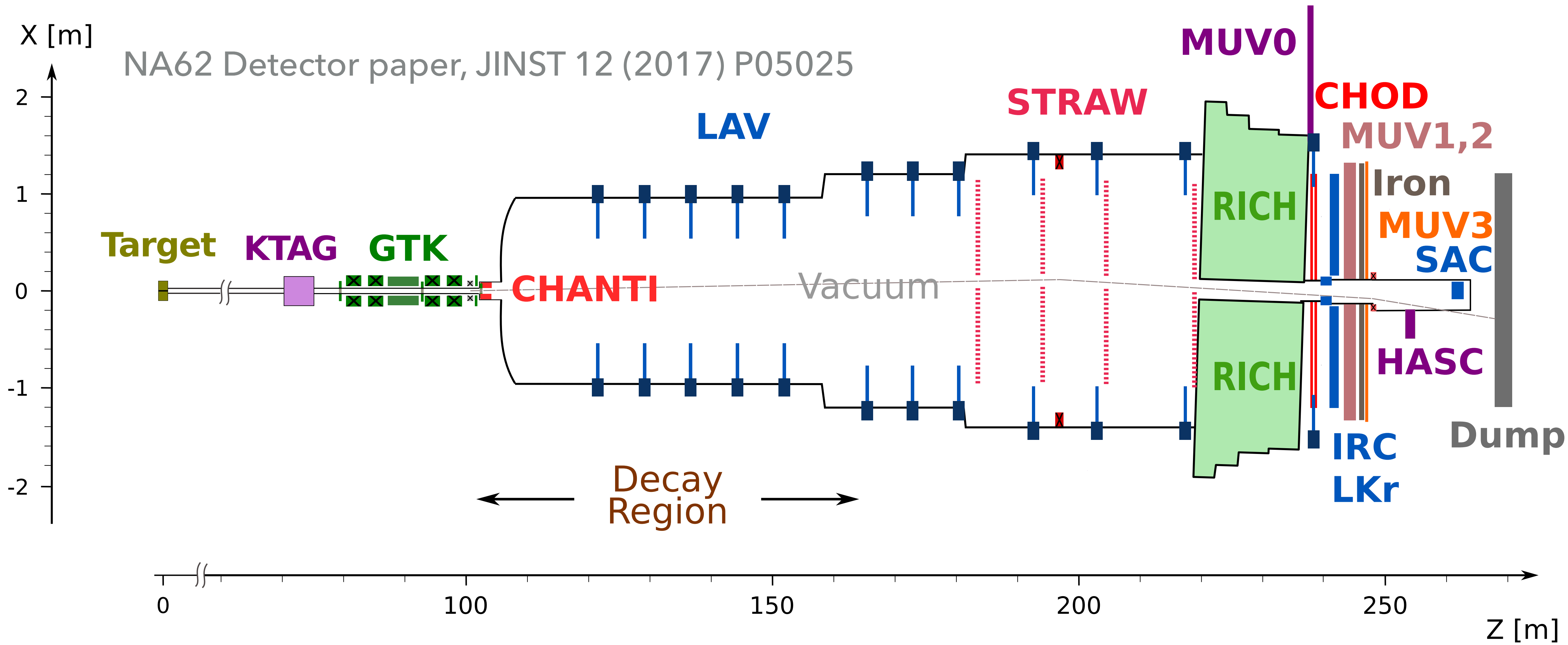
BEYOND THE SM

Buras et al., JHEP 1511 (2015) 166



- Models with general LH and RH NP couplings
- Models obeying CMFV
- Constraint from ε_K if only RH or LH couplings are present

THE NA62 DETECTOR



- Kaon ID and direction (KTAG, GTK, CHANTI)
- Pion ID and direction (STRAW, CHOD, RICH)
- Photon veto (LAV, LKr, IRC, SAC)
- Muon veto (MUV1,2,3)

Secondary beam

- Momentum 75 GeV/c
- Composition: K^+(6%), π^+(70%), p(24%)

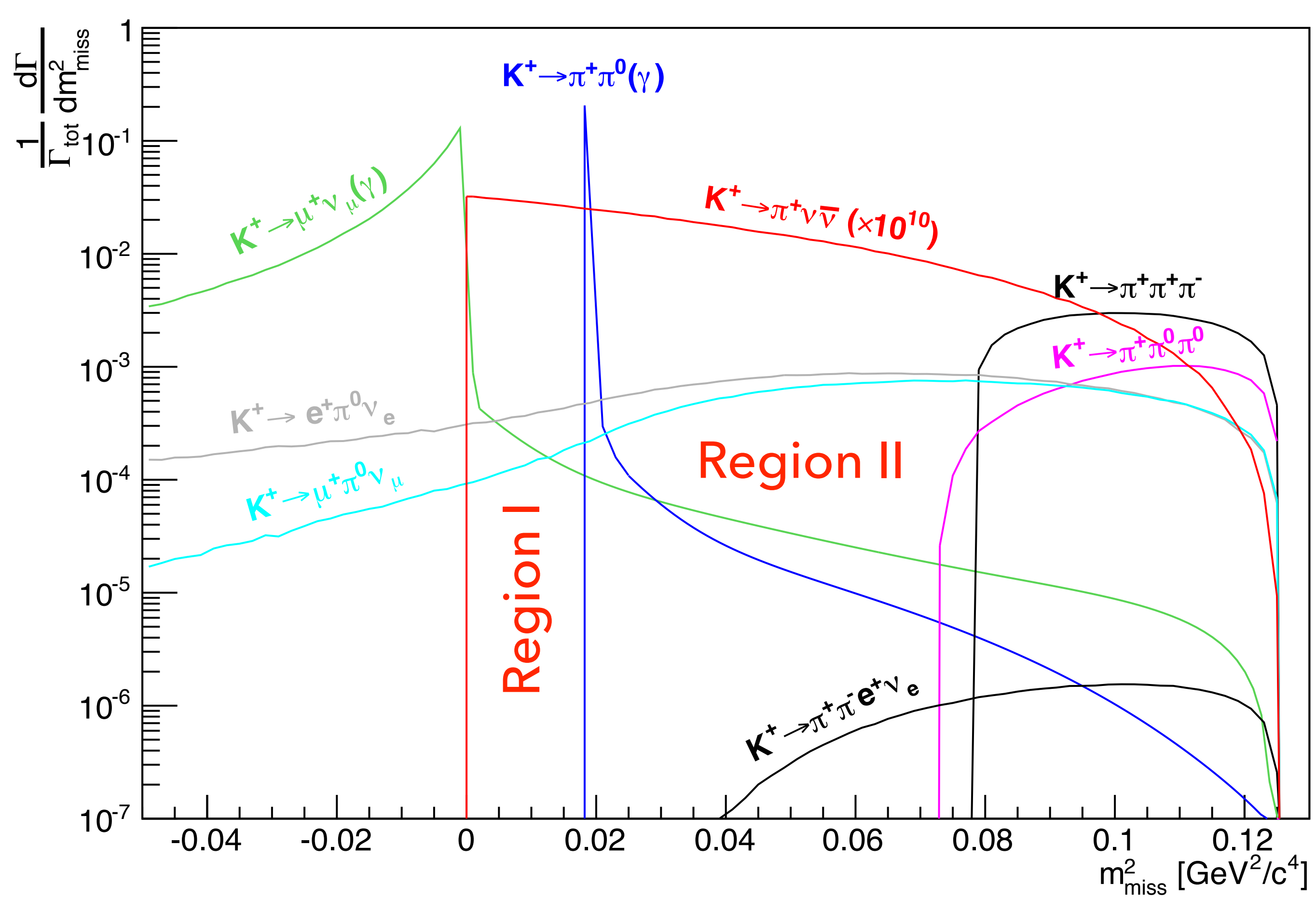
DATA COLLECTION

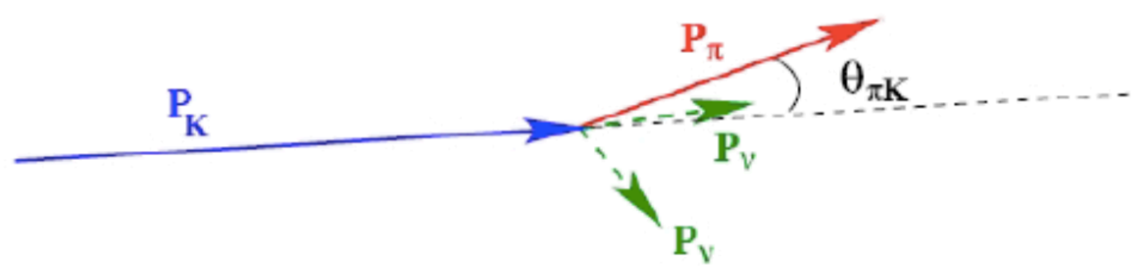
- 2015: minimum bias (~1% intensity) and test data: most systems commissioned and meet the design requirement
- 2016: 3 May - 14 Nov. (~40% of nominal intensity). Focused on the main decay mode $K^+ \to \pi^+ \nu\nu$, but can be used also for other rare/forbidden decays: $K^+ \to \pi ll$ ($l = e, \mu$), $\pi^0 \to \nu\nu$, $K^+ \to l^+ N$, $K^+ \to \pi^+ A'$,…
- 2017: May - Oct. (~50% of nominal intensity).
- 2018: data taking approved

THE STRATEGY

NA62 is expected to collect O(100) SM events (BR measurement with O(10%) precision) in three years of data taking ⇒ must have order of 10^{12} background rejection:

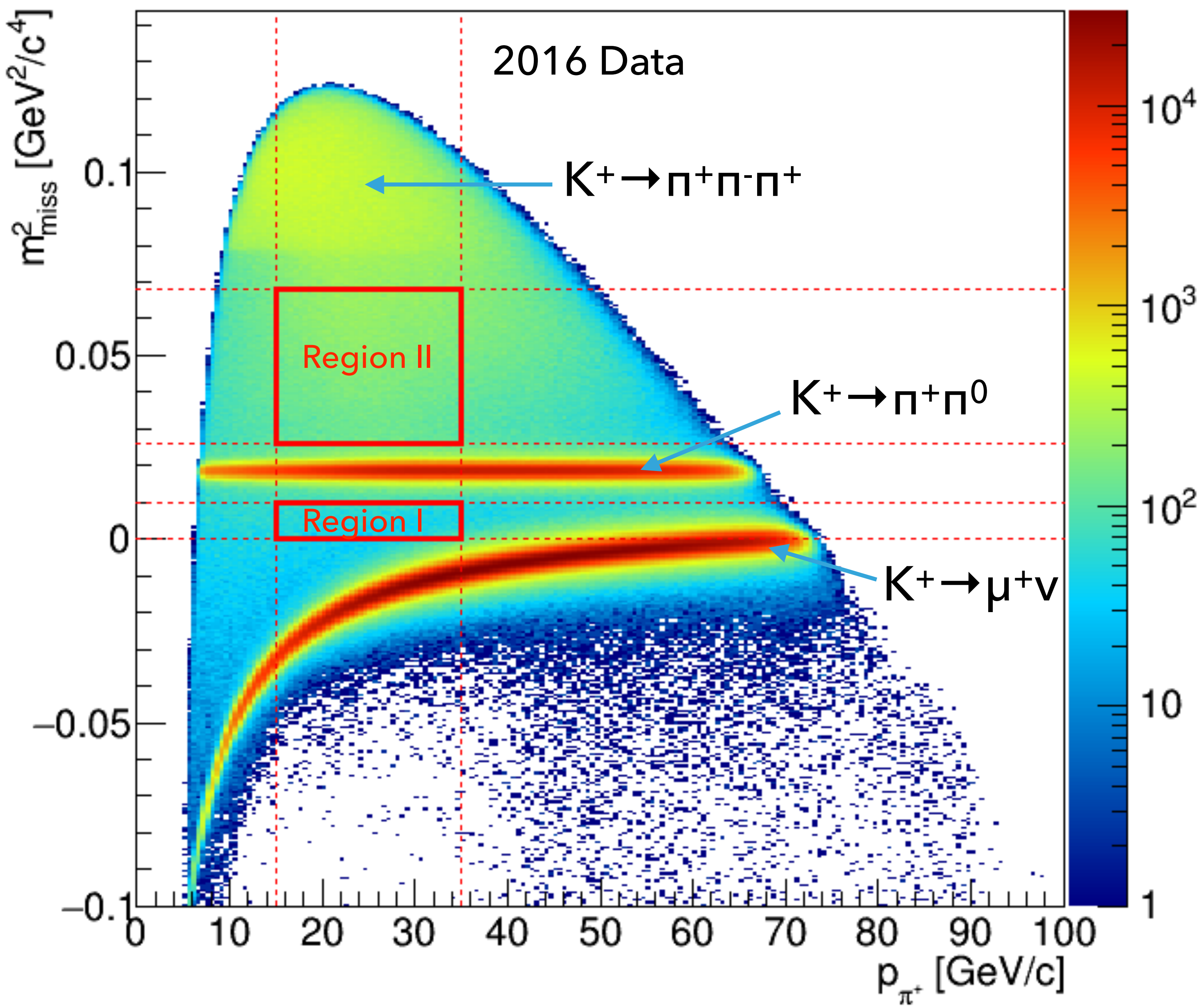
- Isolate signal decays based on missing mass (high rejection by kinematics)
- Use veto to reject other background





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

SIGNAL REGIONS



- Design kinematical resolution on m_{miss}^2 has been achieved (10^{-3} GeV^2/c^4)
- Measured kinematical background suppression: 6×10^{-4} ($K^+ \to \pi^+\pi^0$), 3×10^{-4} ($K^+ \to \mu^+\nu$)
- Further background suppression:
  - PID (calorimeters/cherenkov detectors): μ suppression < 10^{-7}
  - Hermetic photon veto: $\pi 0 \to \gamma\gamma$ suppression < 10^{-7}

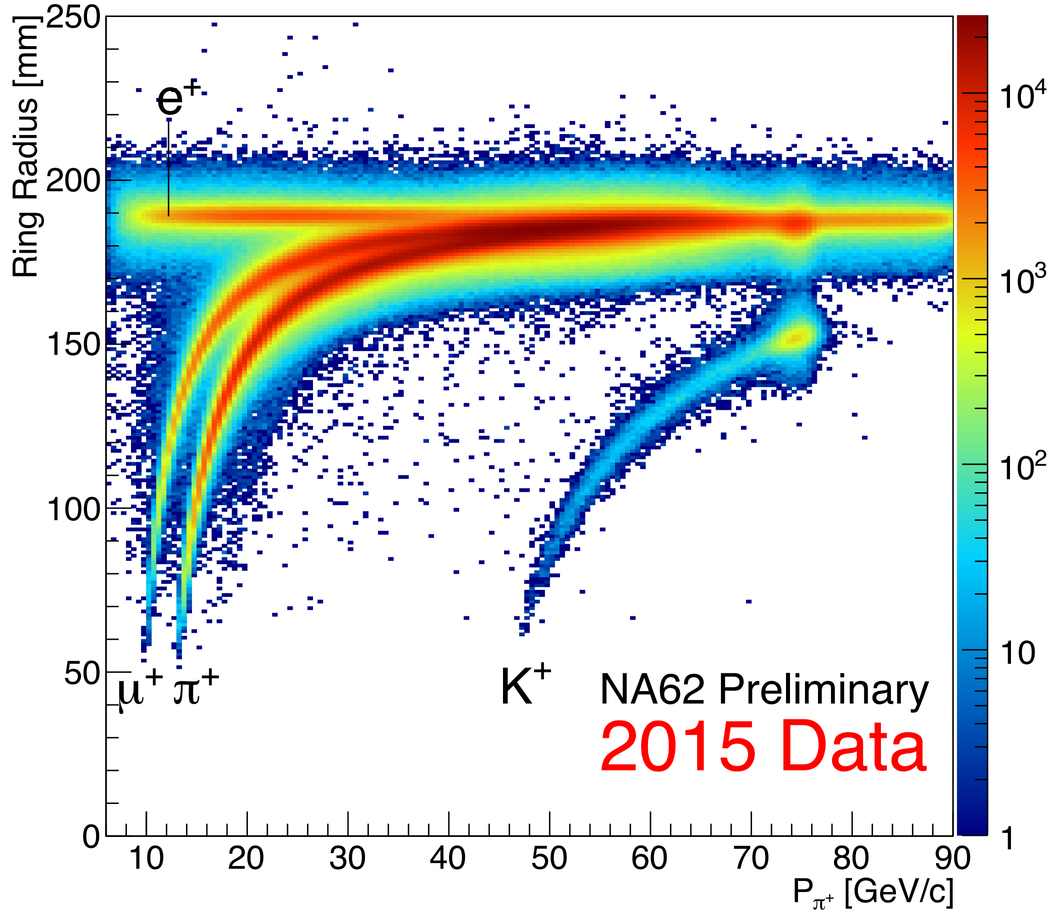
Analysis done in 3D space:

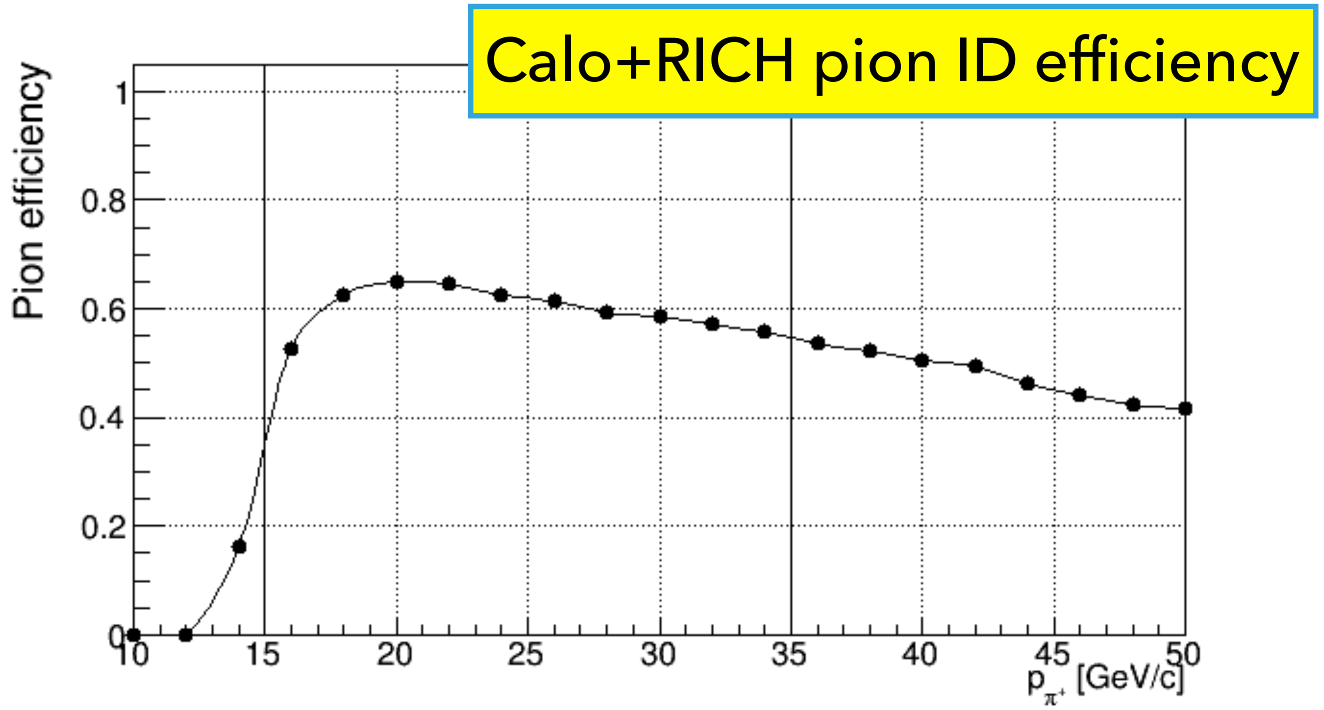
m^2_{miss}, p_{π^+}

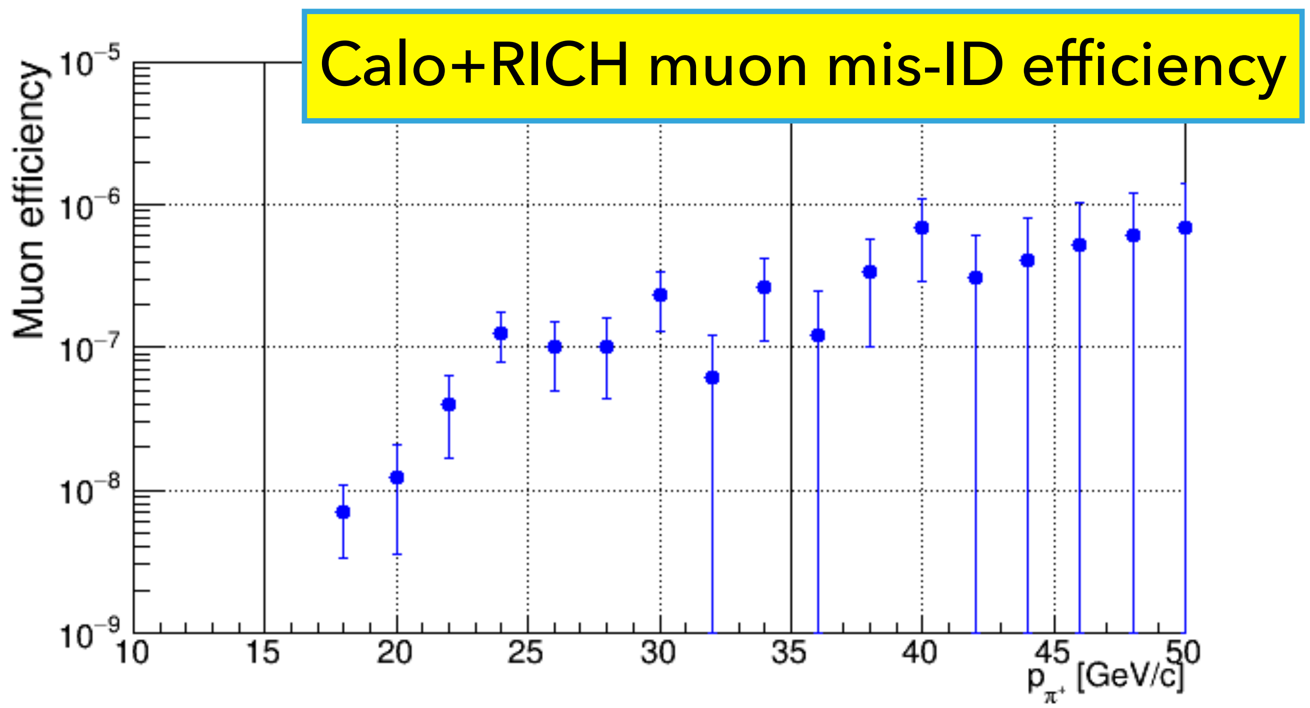
m^2_{miss}(RICH) p_{π^+} RICH (m_{π^+})

m^2_{miss}(No GTK) p_{K^+} nominal

PARTICLE ID: PION – MUON SEPARATION







<u>Two independent PID measurements:</u>

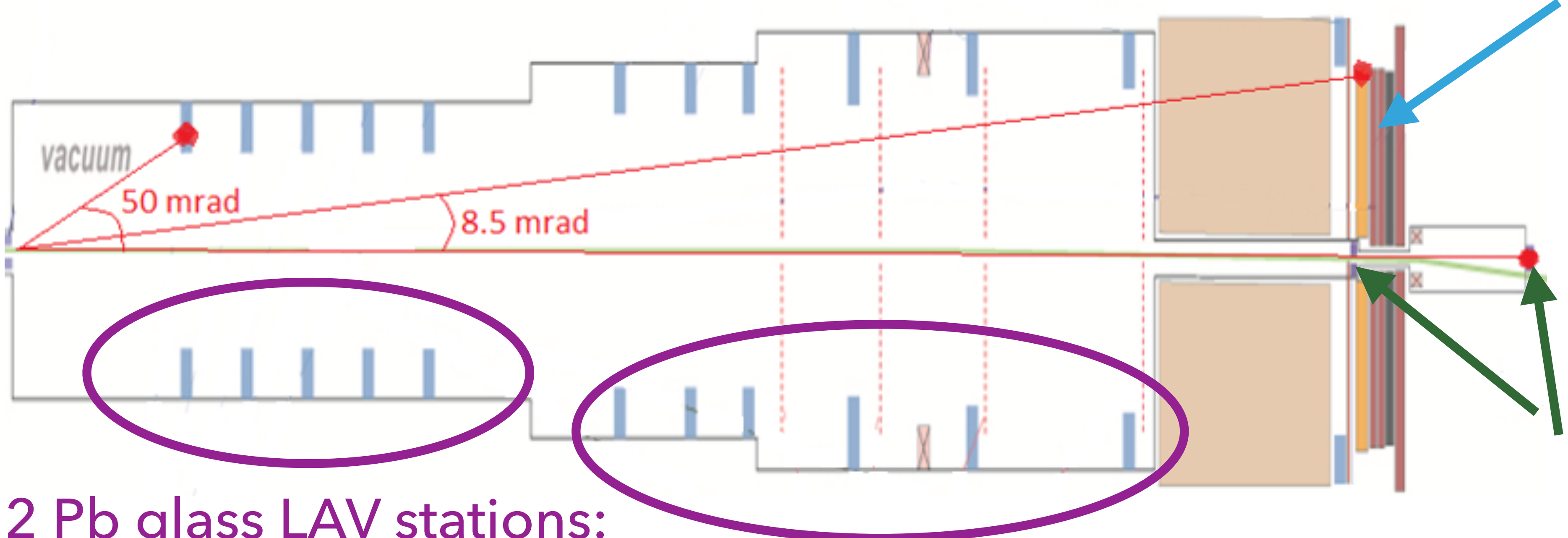
1) with calorimeters & muon detector: MVA technique used; $\varepsilon_\mu \div \varepsilon_\pi = 10^{-5} \div 80\%$,

2) with RICH: $\varepsilon_\mu \div \varepsilon_\pi = 10^{-2} \div 80\%$

in the signal momentum region.

Performance measured with $K^+ \to \pi^+\pi^0$, $K^+ \to \mu^+\nu$.

PHOTON VETO

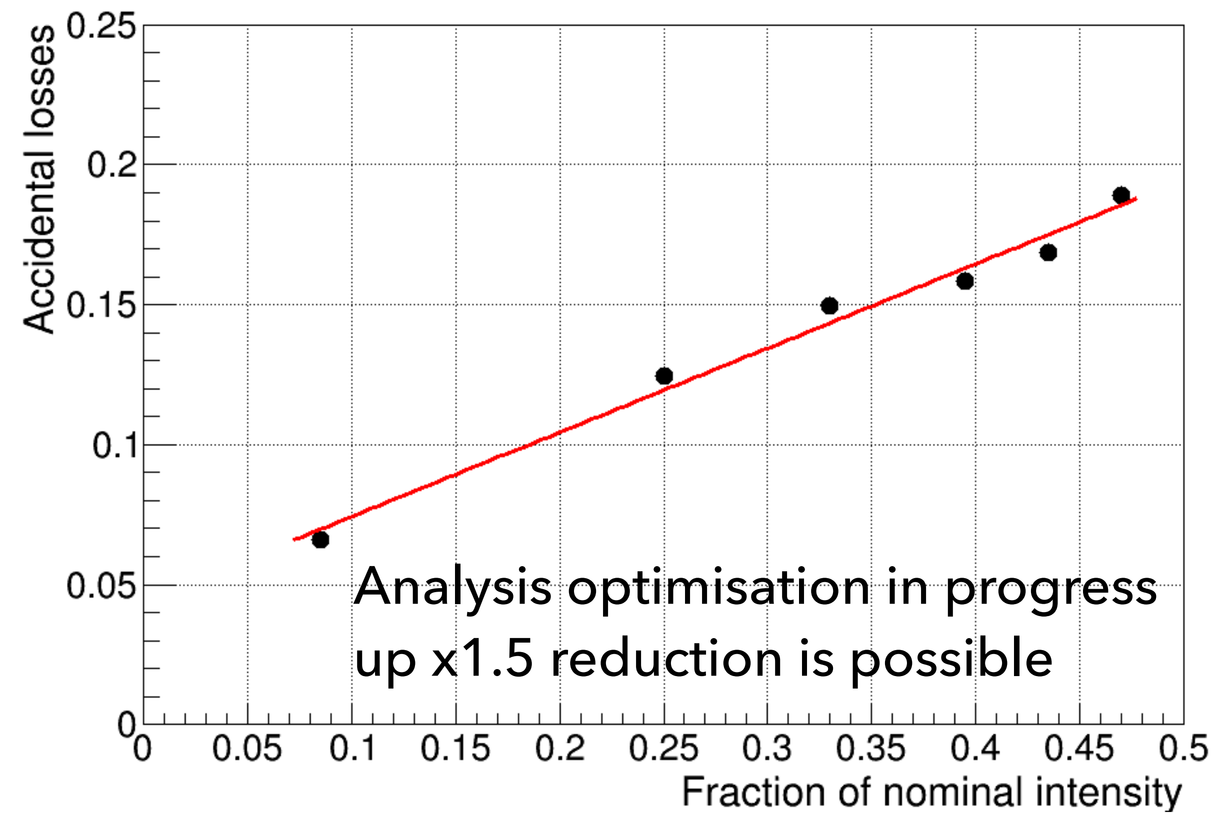


LKr calorimeter: forward veto

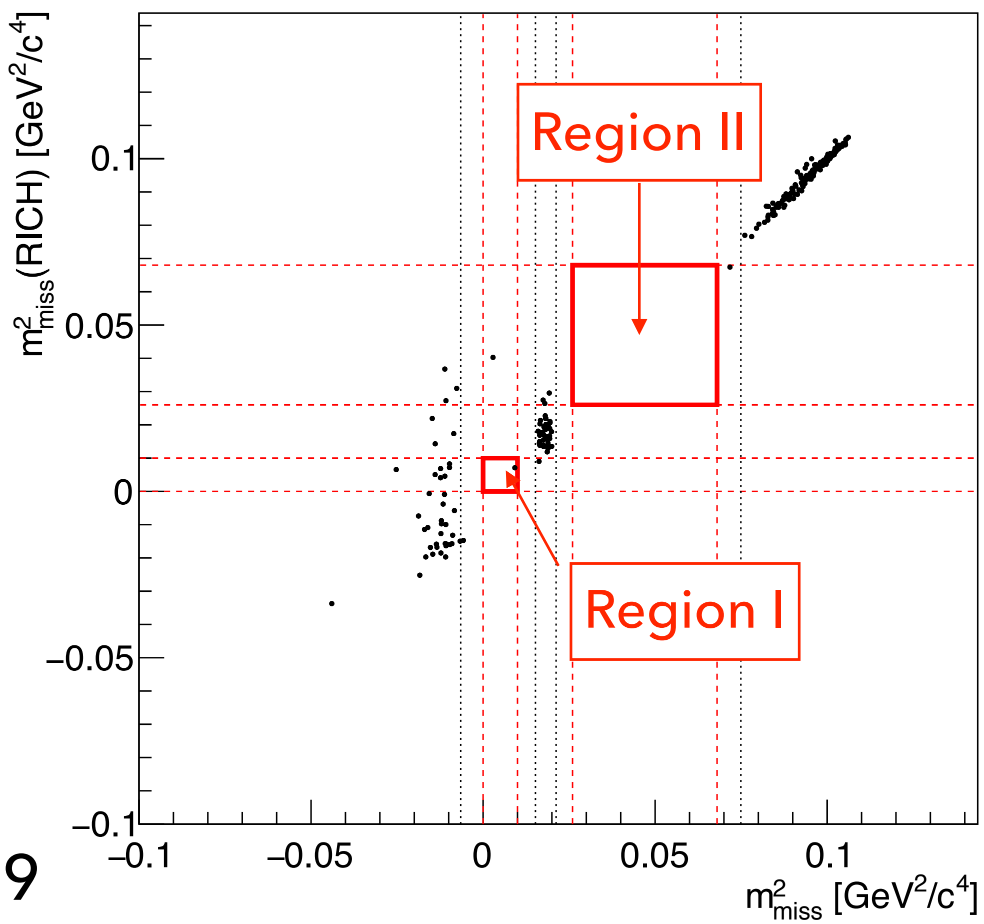
SAV: small angle veto

12 Pb glass LAV stations: hermetic up 50 mrad

- Technique: EM calorimetry exploiting correlations between photons from $\pi^0 \to \gamma\gamma$ decays.
- Signal region: $p(\pi^+)<35$ GeV/c, therefore $p(\pi^0)>40$ GeV/c.
- Goal: $O(10^{-7})$ to $O(10^{-8})$ rejection of π^0 from $K^+ \to \pi^+\pi^0$ decays.
- Measured π^0 rejection factor with the $K_{\pi\nu\nu}$ selection: $\varepsilon = (1.2 \pm 0.2) \times 10^{-7}$. Accidental loss measured with $K_{\mu 2}$: 16% at 40% intensity, can be improved.



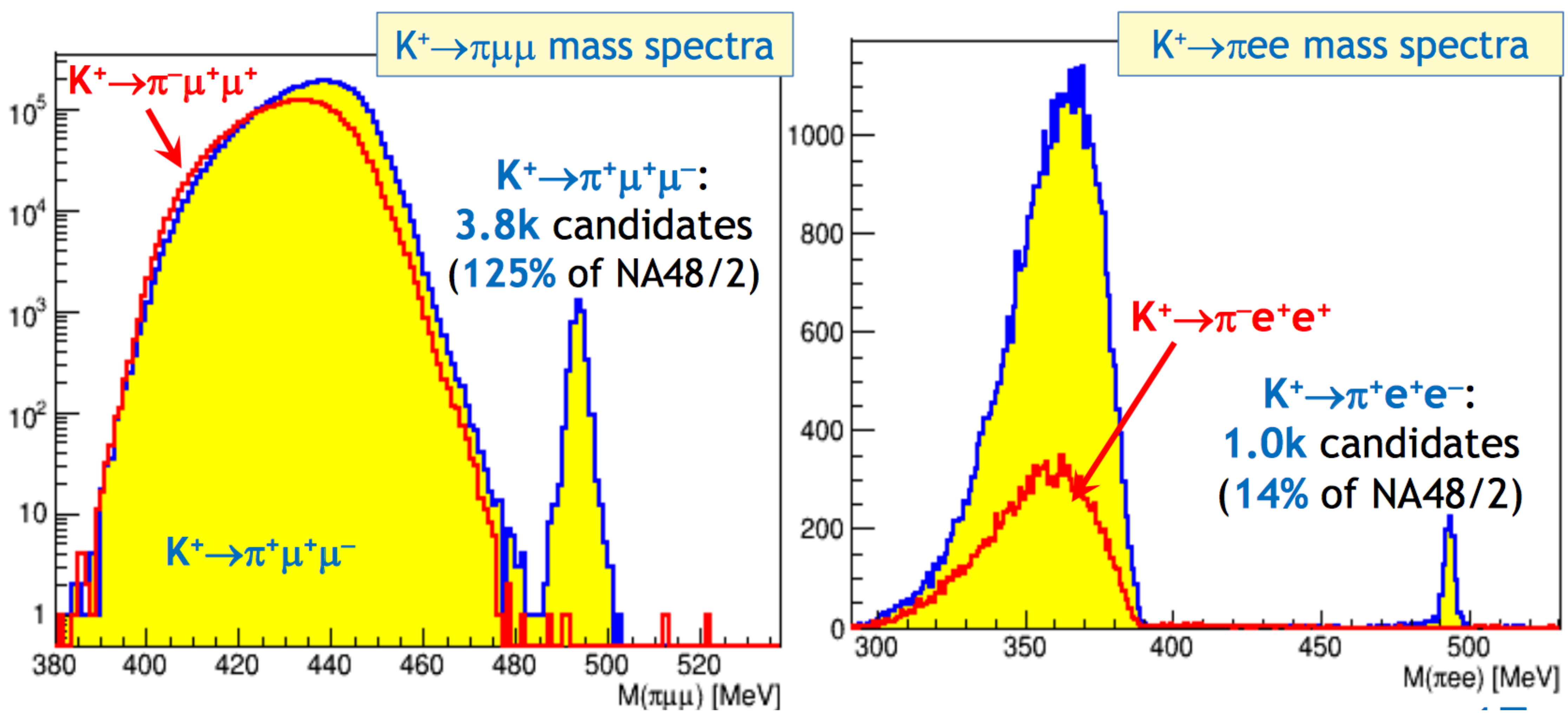
PRELIMINARY RESULTS



- 5% of 2016 data: 2.3x10^{10} kaon decays
- No events found in the signal regions
- Expect 1.3 SM events from full 2016 data set
- Preliminary statements on background: B/S < 0.9
- Analysis in progress to increase signal acceptance and improve background suppression

2016 DATA BEYOND THE "GOLDEN" MODE

- Dedicated triggers for 3-track decays with leptons
- Expect to improve world limits on LFV/LNV K^+ and π^0 decays



SEARCH FOR HEAVY NEUTRINO WITH 2015 DATA

WHY DO WE NEED HNL?

Neutrino oscillation

Baryon asymmetry of the Universe

Dark matter and dark energy

νMSM: SM + 3 right-handed neutrinos
$m_1 \sim 10$ keV
$m_{2,3} \sim 100$ MeV - 100 GeV

T. Asaka and M. Shaposhnikov
Phys. Lett. B620, 17 (2005).

There is new physics beyond the Standard Model, but we don't know exactly what is it

HOW TO FIND HNL?

- Meson decays ✓

Search for extra peaks in lepton distributions (momentum, energy, missing mass, ...)

$$\Gamma(M^+ \to l^+ \nu_H) = \rho \times \Gamma(M^+ \to l^+ \nu_l) \times |U_{lH}|^2$$

R.E. Shrock, Phys. Rev. D24, 1232 (1981)

- Heavy neutrino decays

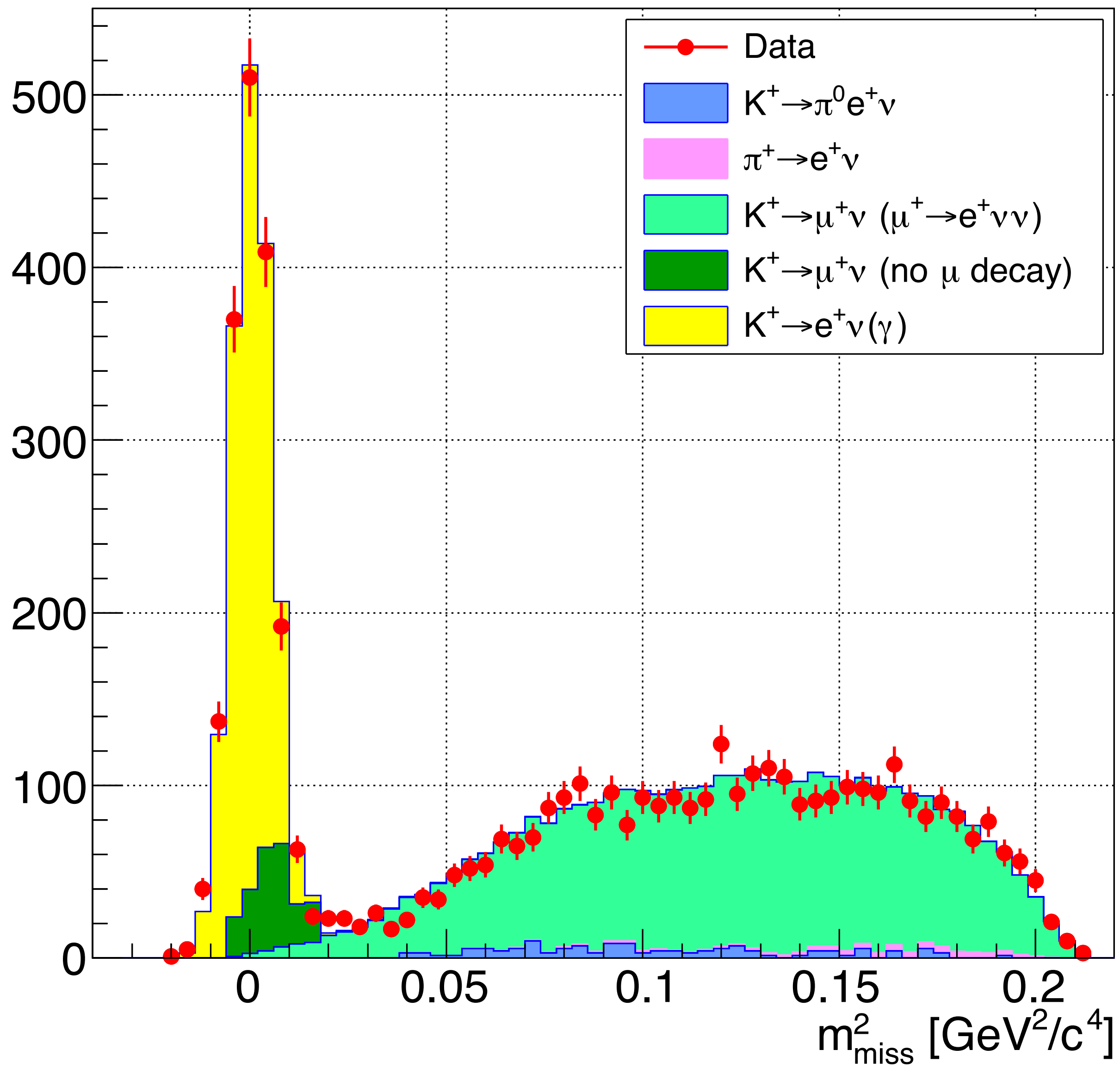
"Nothing" ➛ leptons and hadrons

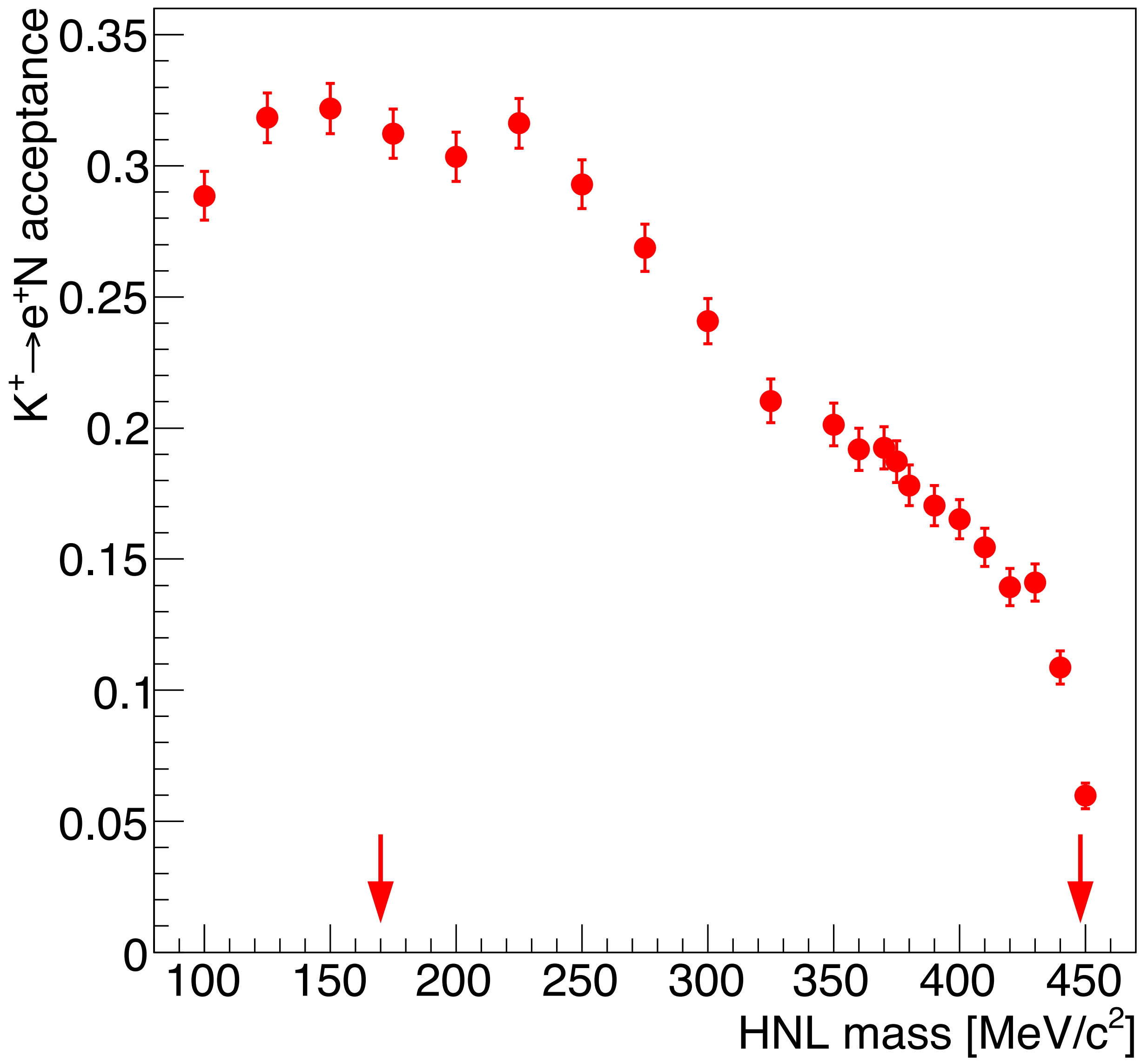
$$\nu_H \to e^+ e^- \nu_\alpha, \nu_H \to \mu^\pm e^\mp \nu_\alpha, \nu_H \to \mu^+ \mu^- \nu_\alpha,$$

$$\nu_H \to \pi^0 \nu, \pi e, \pi \mu, K e, K \mu, \ldots$$

DATA SAMPLE

- Minimum bias (~1% intensity) in 2015
- Kaon decays in FV: $(3.01\pm0.11)\times10^8$
- Beam tracker is not available: kaon momentum is estimated as beam average

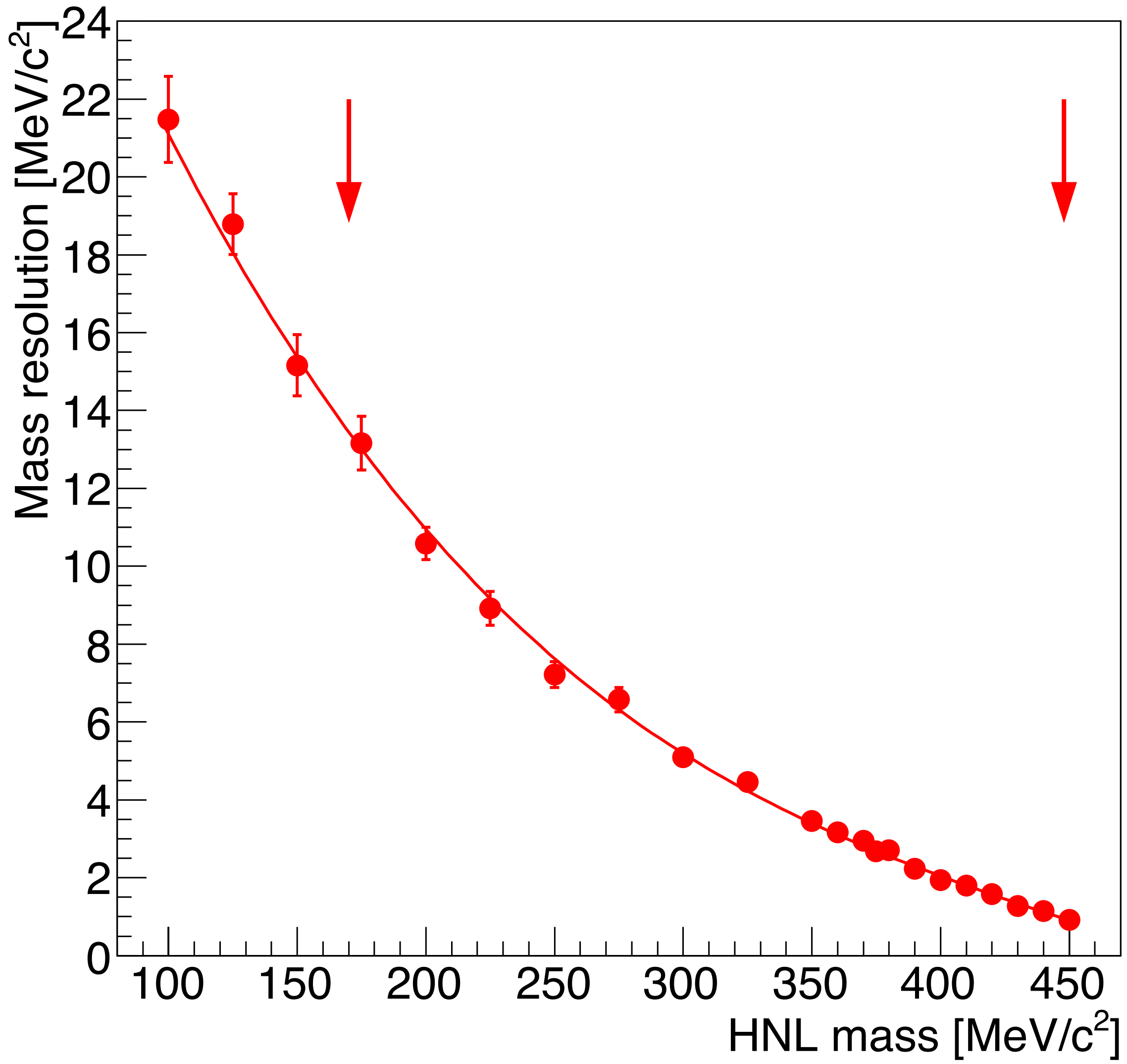


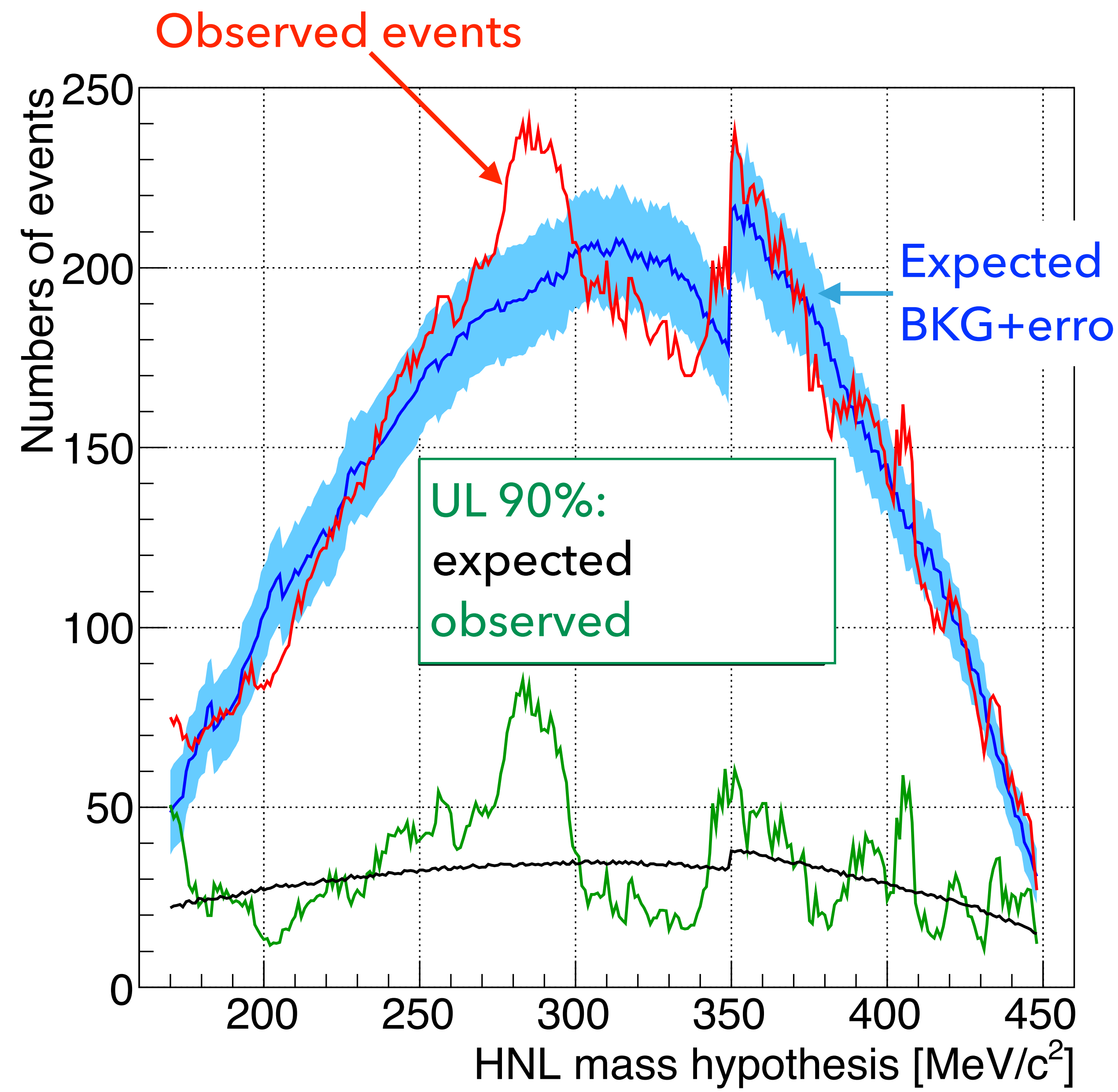


PEAK SEARCH

- Scan region 170<m<448 MeV/c^2, mass step = 1 MeV/c2
- Signal search window for each mass hypothesis ±1.5σ
- Background estimate: polynomial fit outside signal window
- Background stat. errors are estimated with MC
- Upper limit for each mass is obtained from numbers of observed and expected events and their uncertainties

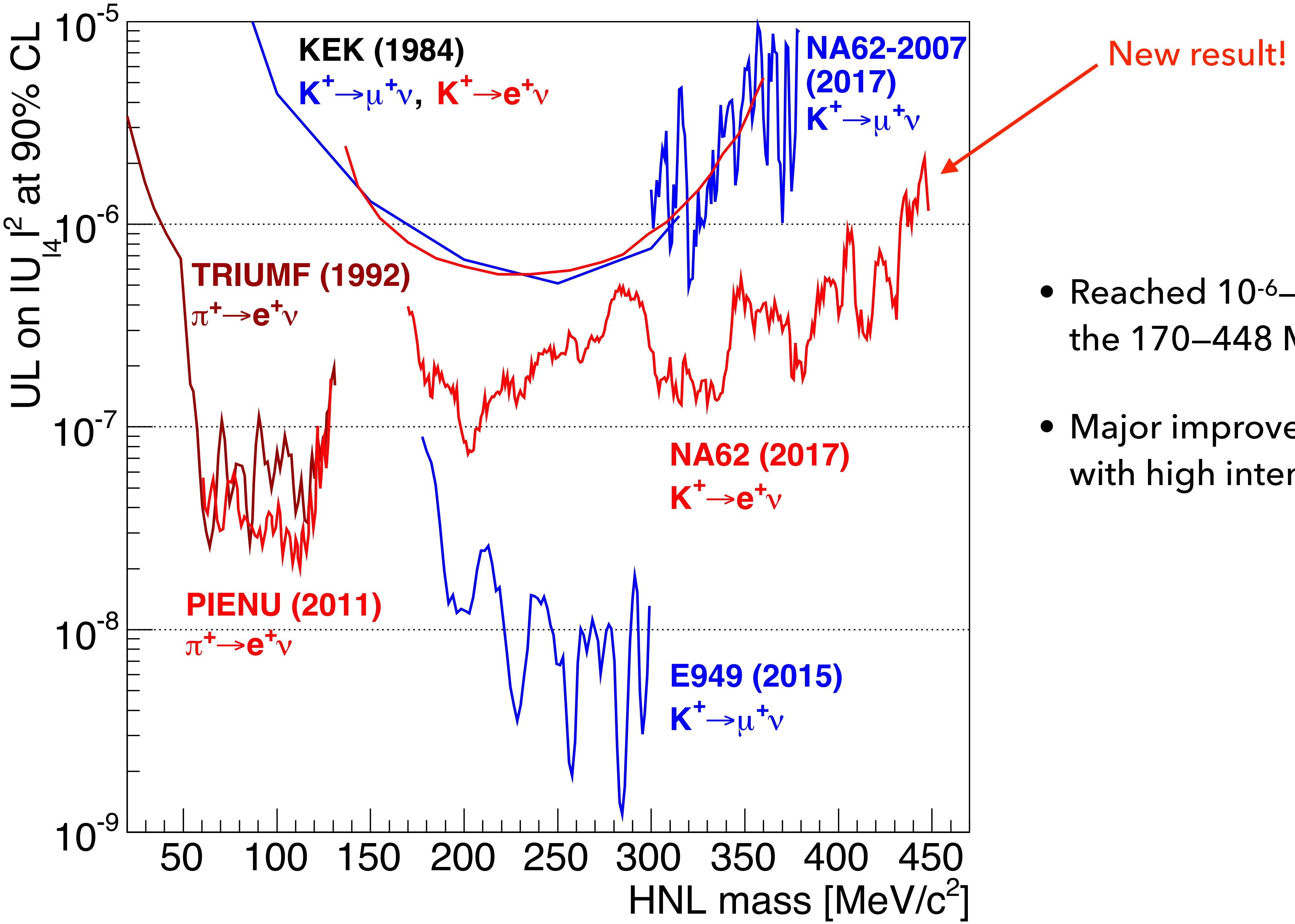
RESULTS





Local signal significance never exceeds 3σ: no heavy neutrino signal is observed

RESULTS



- Reached 10^{-6}–10^{-7} limits on $|U_{e4}|^2$ in the 170–448 MeV/c2 mass range
- Major improvements are expected with high intensity 2016 data

NA62 BROAD PHYSICS PROGRAM

NA62 approach allows for a broad physics programme:

Signature: high momentum K^+ (75GeV/c) → low momentum π^+ (15–35 GeV/c).

Advantages: max detected K^+ decays/proton ($p_K/p_0 \approx 0.2$);
efficient photon veto (>40 GeV missing energy)

Un-separated beam (6% kaons) → higher rates, additional background sources.

❖ **NA62 Run 2016–2018: focused on the "golden mode" $K^+ \to \pi^+ \nu\nu$.**

- ✓ Several measurements at nominal SES~10^{-12}: $K^+ \to \pi^+ A'$, $\pi^0 \to \nu\nu$.
- ✓ A few measurements do not require extreme SES: $K^+ \to \ell^+ N$, …
- ✓ Sensitivities to most rare/forbidden decays are limited but still often world-leading (~10^{-10} to ~10^{-11}).
- ✓ Proof of principle for a broad rare & forbidden decay programme.

NA62 BROAD PHYSICS PROGRAM

❖ **NA62 Run 2021–2024**:

- ✓ Existing apparatus with improved trigger logic.
- ✓ Evaluate incremental changes for optimal efficiency.
- ✓ Further $K^+ \to \pi^+ \nu\nu$ data collection.
- ✓ Rare/forbidden K^+ and π^0 decays at SES~10^{-12}:
  - K^+ physics: $K^+ \to \pi^+ \ell^+ \ell^-$, $K^+ \to \pi^+ \gamma \ell^+ \ell^-$, $K^+ \to \ell^+ \nu \gamma$, $K^+ \to \pi^+ \gamma\gamma$, …
  - π^0 physics: $\pi^0 \to e^+ e^-$, $\pi^0 \to e^+ e^- e^+ e^-$, $\pi^0 \to 3\gamma$, $\pi^0 \to 4\gamma$, …
  - Searches for LFV/LNV: $K^+ \to \pi^- \ell^+ \ell^+$, $K^+ \to \pi^+ \mu e$, $\pi^0 \to \mu e$, …
- ✓ Beam dump with ~10^{18} POT: hidden sector (long-lived HNL, DP, ALP).

CONCLUSION

- Detector is fully operated since Sept.2016 and data is taking now @50% of nominal intensity
- ~10^{11} kaon decays has already collected in 2016
- The $K^+ \to \pi^+ \nu\nu$ analysis is on-going and O(1) SM events are expected from total 2016 data sample
- First physics result from 2015 minimum bias data: search for heavy neutrino production in $K^+ \to e^+ N$ decays in mass range 170–448 MeV/c^2: no observed signal, set upper limits at 10^{-6}–10^{-7} level