Results from NA62 and KOTO

On behalf of the NA62 collaboration

UCLouvain
Institut de recherche en mathématique et physique

Artur Shaikhiev (artur.shaikhiev@cern.ch)
Institute for Nuclear Research, Moscow
Université catholique de Louvain, Belgium

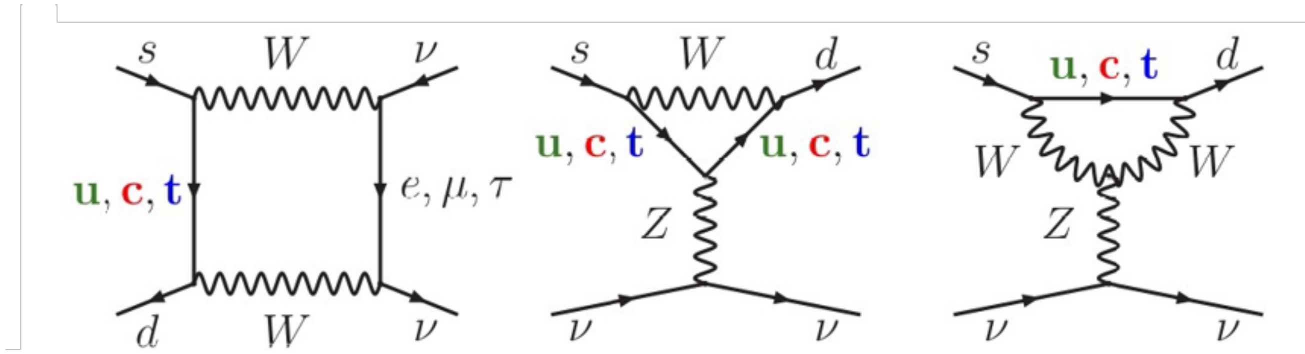
Outline

- $K^+ \to \pi^+ \nu \bar{\nu}$: first result from NA62 at CERN
- $K_L \to \pi^0 \nu \bar{\nu}$: KOTO experiment at J-PARC

"Golden" mode $K \to \pi\nu\nu$

- FCNC process forbidden at tree level
- Highly CKM suppressed: BR~ $|V_{ts}^* V_{td}|^2$
- Extraction of Vtd with minimal (few %) non-parametric uncertainty
- Theoretically very clean:
  - dominant short-distance contribution
  - hadronic matrix element extracted from precisely measured BR($K^+ \to e^+\pi^0\nu$)
- Sensitive to New Physics effects (next slide for details)

Box and penguin diagrams



The Standard Model predictions

(Buras et al., JHEP 1511(2015) 033)

$$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu}) = (8.4 \pm 1.0) \times 10^{-11}$$

$$\mathcal{B}(K_L \to \pi^0\nu\bar{\nu}) = (3.4 \pm 0.6) \times 10^{-11}$$

Experimental status:

E787/E949: $\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu}) = (17.3^{+11.5}_{-10.5}) \times 10^{-11}$

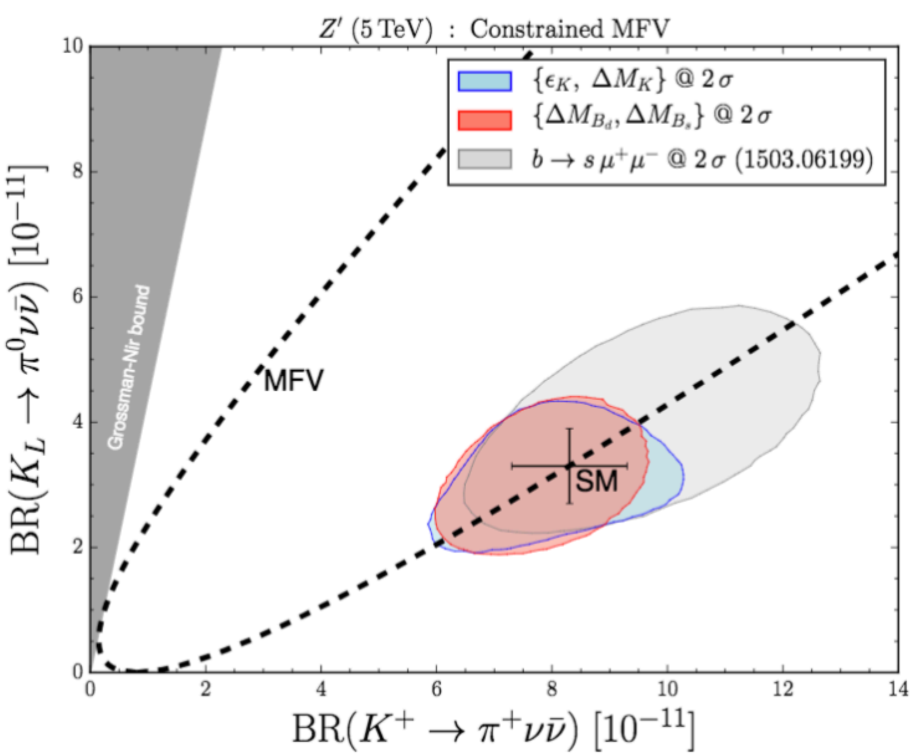
Phys.Rev.D77, 052003 (2008); Phys.Rev.D79, 092004 (2009)

E391a: $\mathcal{B}(K_L \to \pi^0\nu\bar{\nu}) < 2.6 \times 10^{-8} (90\% CL)$

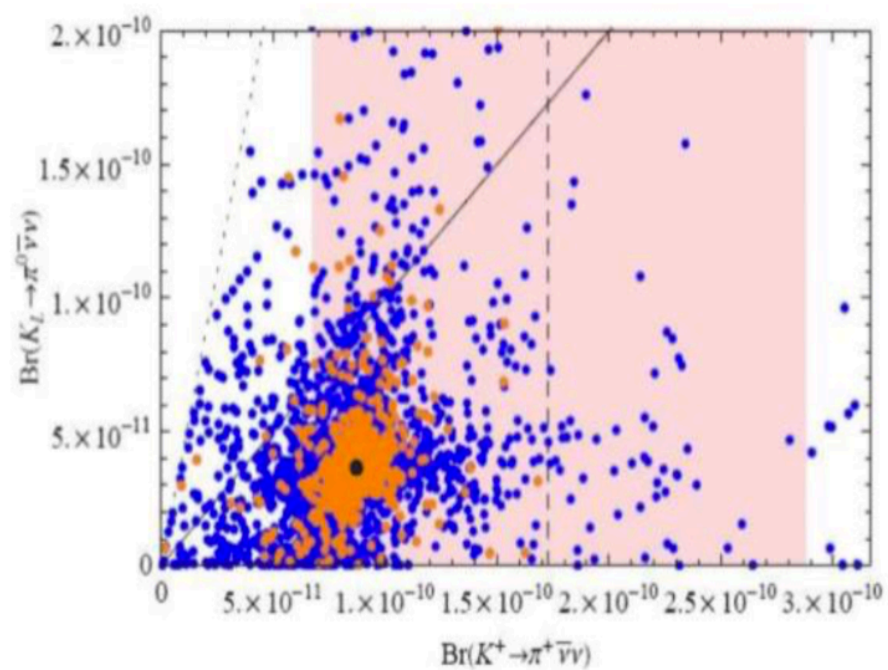
Phys.Rev.D81, 072004(2010)

Beyond the Standard Model

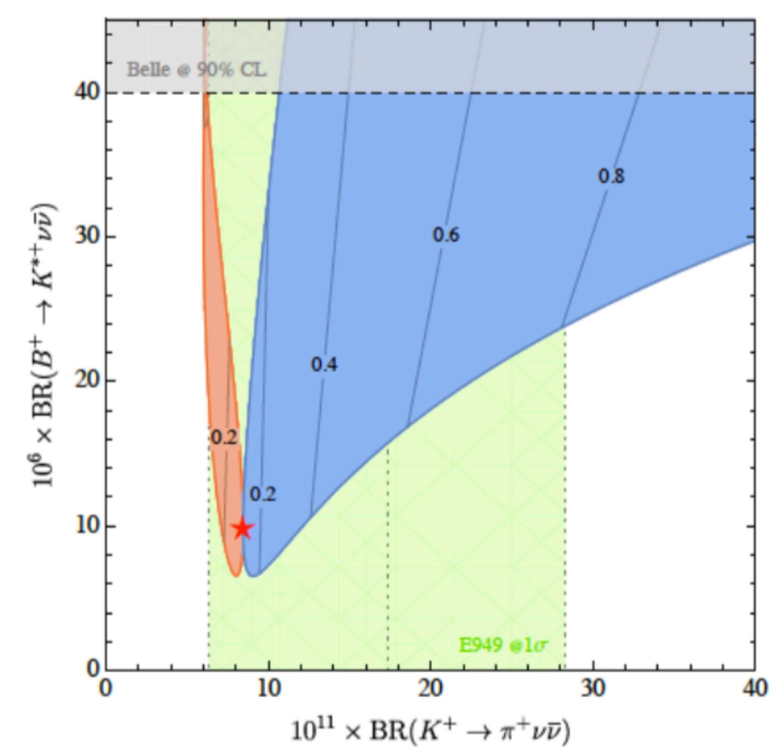
- Simplified Z, Z′ models [Buras, Buttazzo, Knegjens, JHEP 1511 (2015) 166]
- Littlest Higgs with T-parity [Blanke, Buras, Recksiegel, EPJ C76 (2016) n.4 182]
- Custodial Randall-Sundrum [Blanke, Buras, Duling, Gemmler, Gori, JHEP 0903 (2009 108)]
- MSSM analyses [Tanimoto, Yamamoto, PTEP 2016 (2016) no.12, 123B02; Blazek, Matak, IntlJModPhys.A29 (2014), 1450162; Isidori et al., JHEP 0608 (2006) 064]
- LFU violation models [Isidori et al., Eur.Phys.J C (2017) 77]



Z'(5 TeV) in Constrained MFV



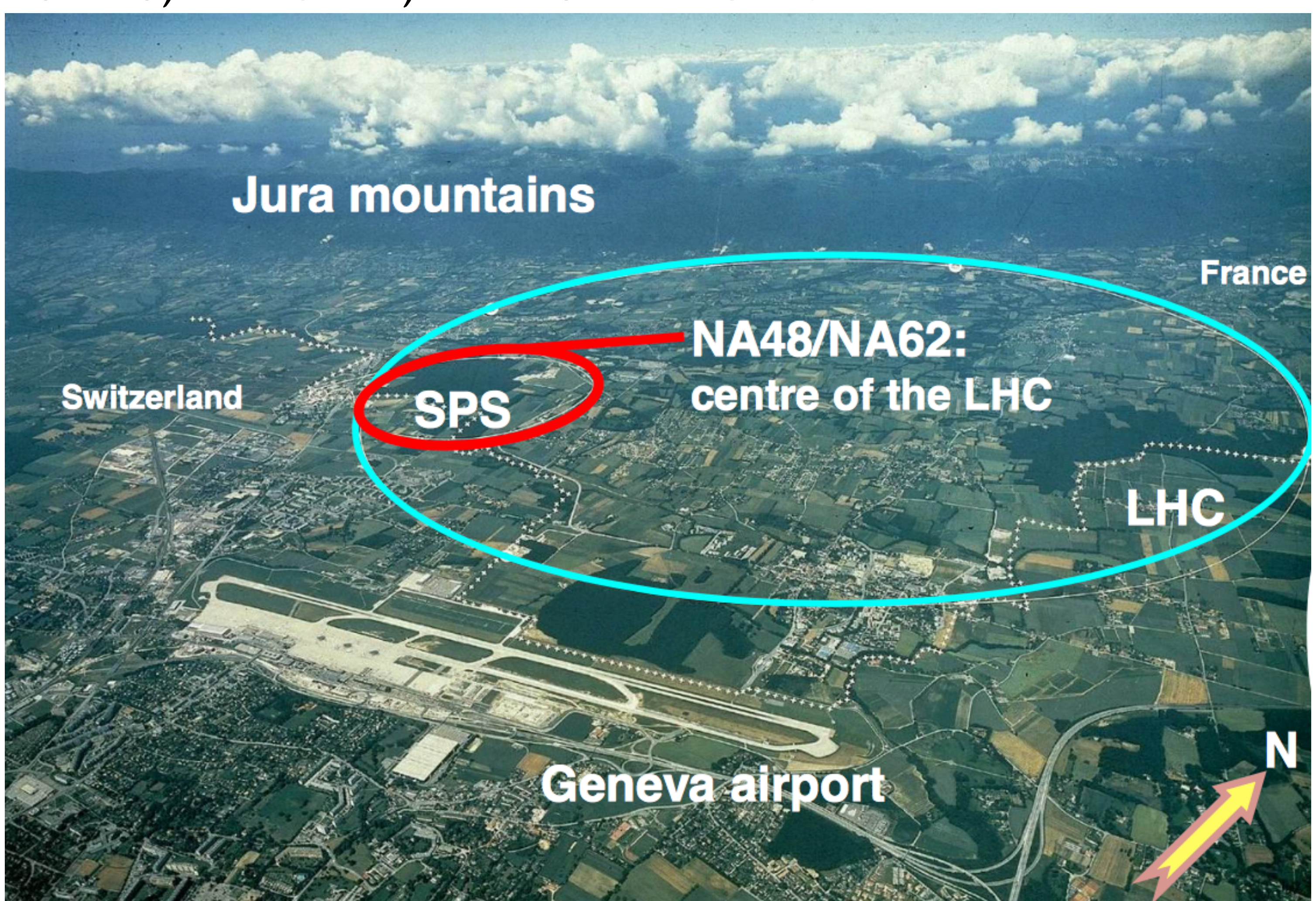
Randall Sundrum



LFU violation

NA62 experiment at CERN

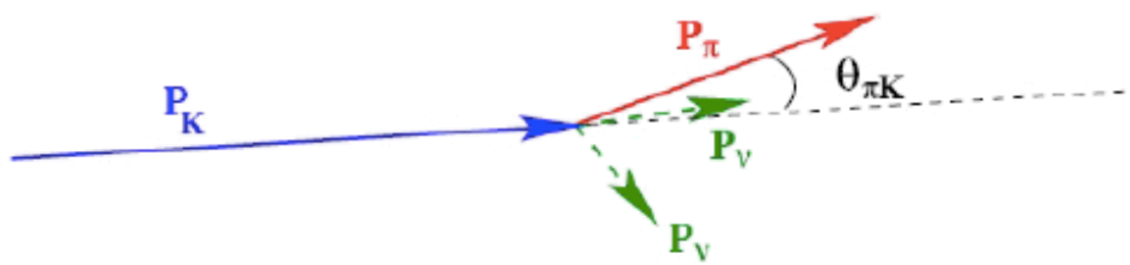
~30 institutes, ~200 participants form: Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna, Fairfax, Ferrara, Firenze, Frascati, Glasgow, Liverpool, Louvain, Mainz, Merced, Moscow, Napoli, Perugia, Pisa, Prague, Protvino, Roma I, Roma II, San Luis Potosi, Sofia, Torino, TRIUMF, Vancouver UBC



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). Kaon decay-in-flight technique.

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

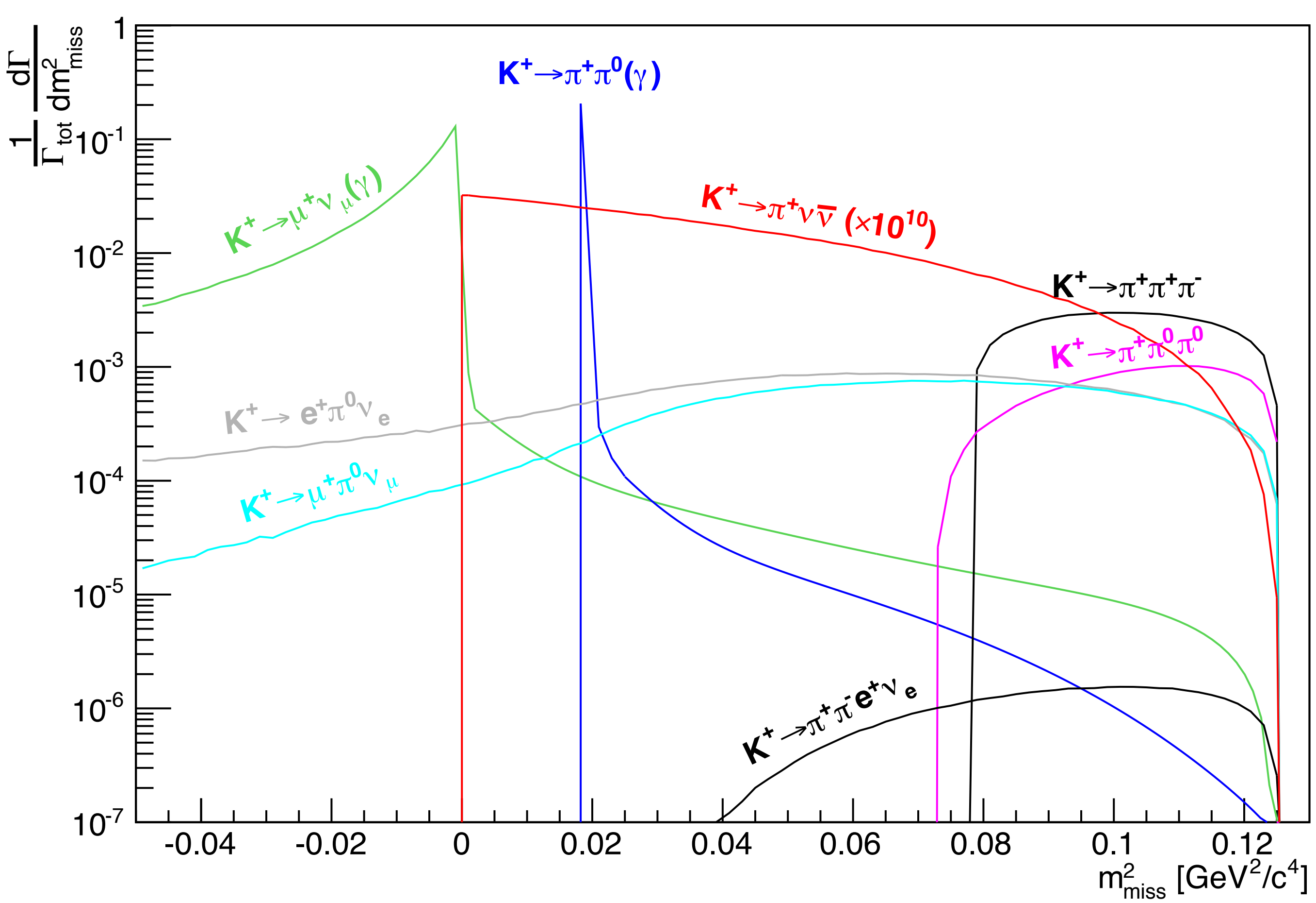
Measurement strategy



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

Keystones of the analysis:

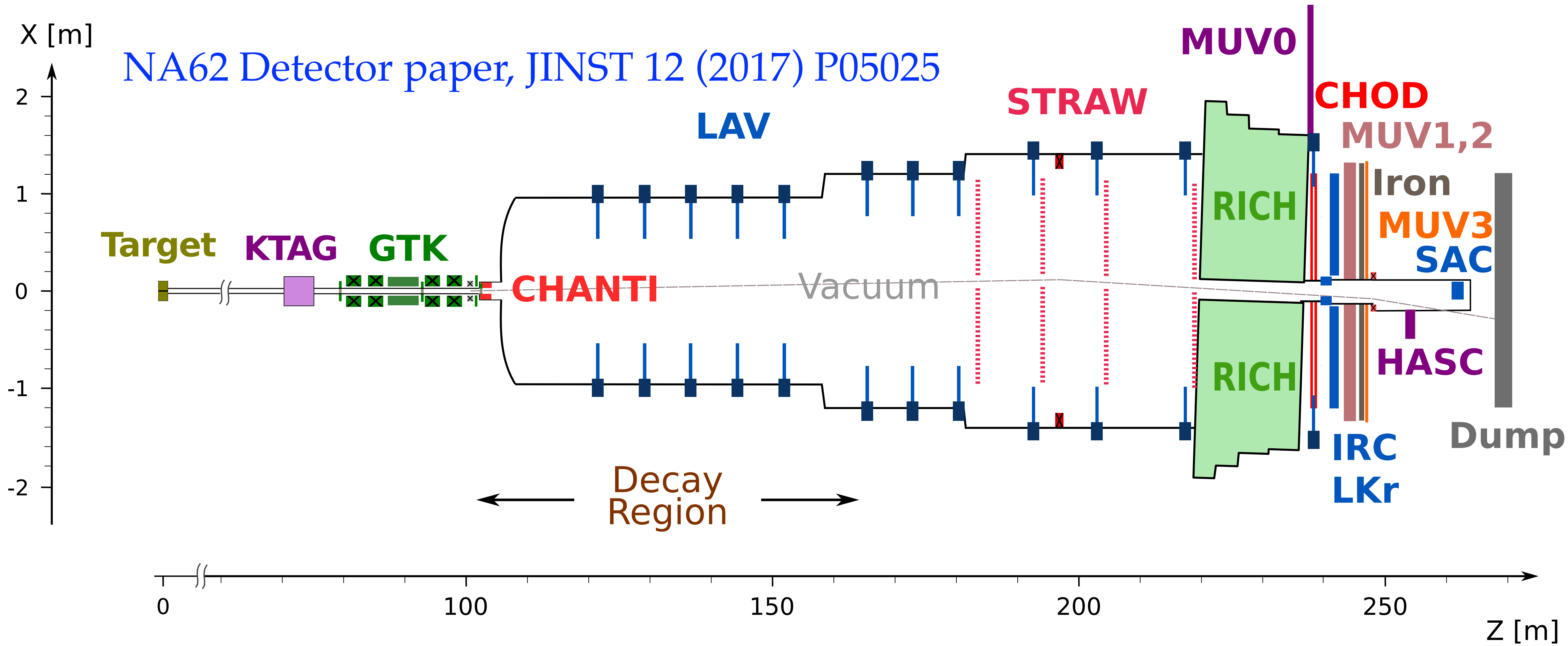
- Timing between subdetectors ~O(100ps)
- Kinematic suppression ~O(10^4)
- Muon suppression > 10^7
- π^0 suppression > 10^7



Background suppression:

- 15<p_π<35 GeV/c
- Particle ID (Cherenkov detectors)
- Particle ID (calorimeters)
- Photon veto

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

2014	2015	2016	2017	2018	2019-2020
Pilot Run	Commissioning	Commissioning + Physics Run	Physics Run	Physics Run	LS2 Long shutdown 2

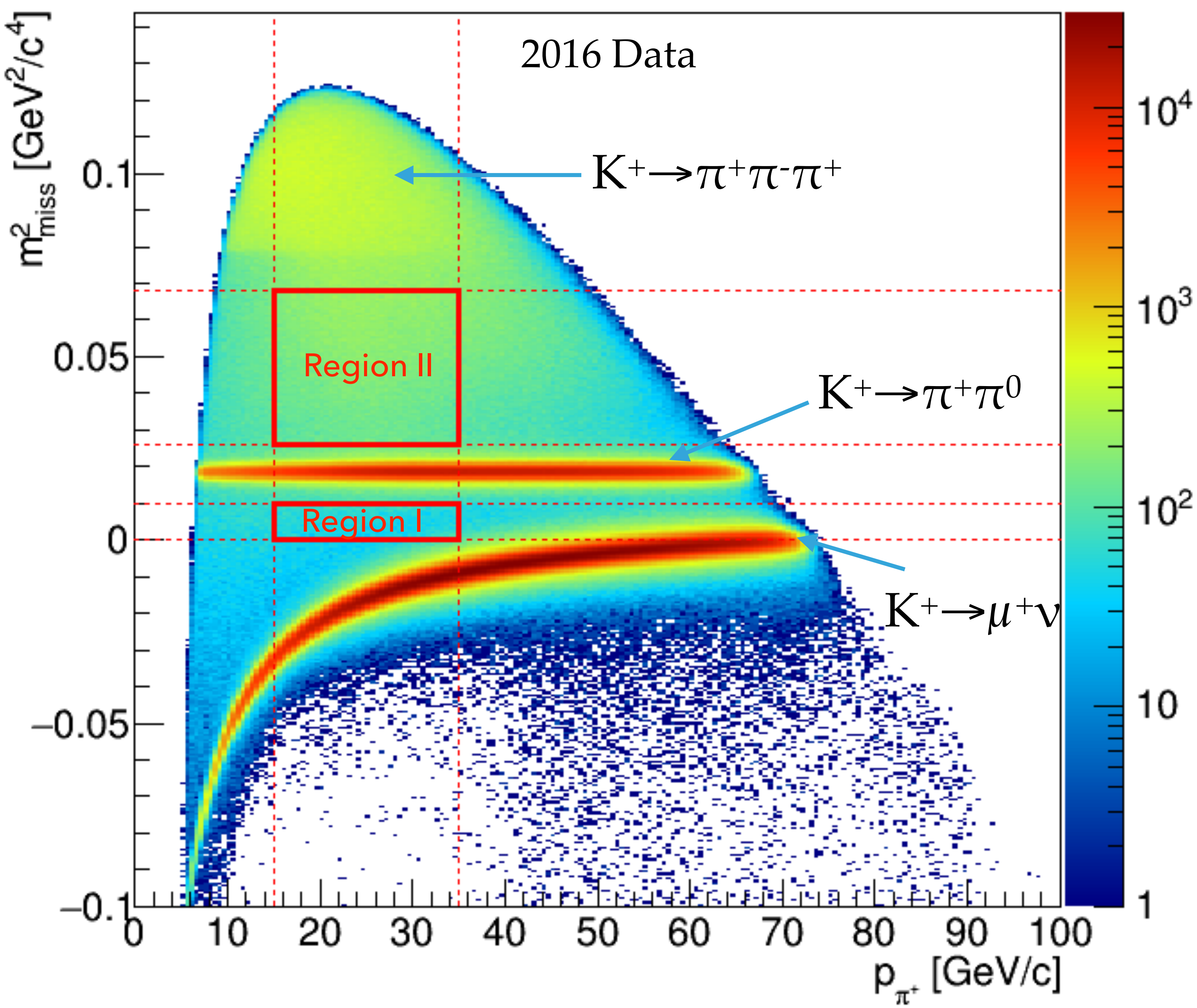
2016: 40% of nominal intensity, ~5×10^{11} kaon decays recorded
2017+2018: 60% of nominal intensity, > 8×10^{12} kaon decays on the tape

— better data quality assessment
— higher data taking efficiency

Trigger streams:

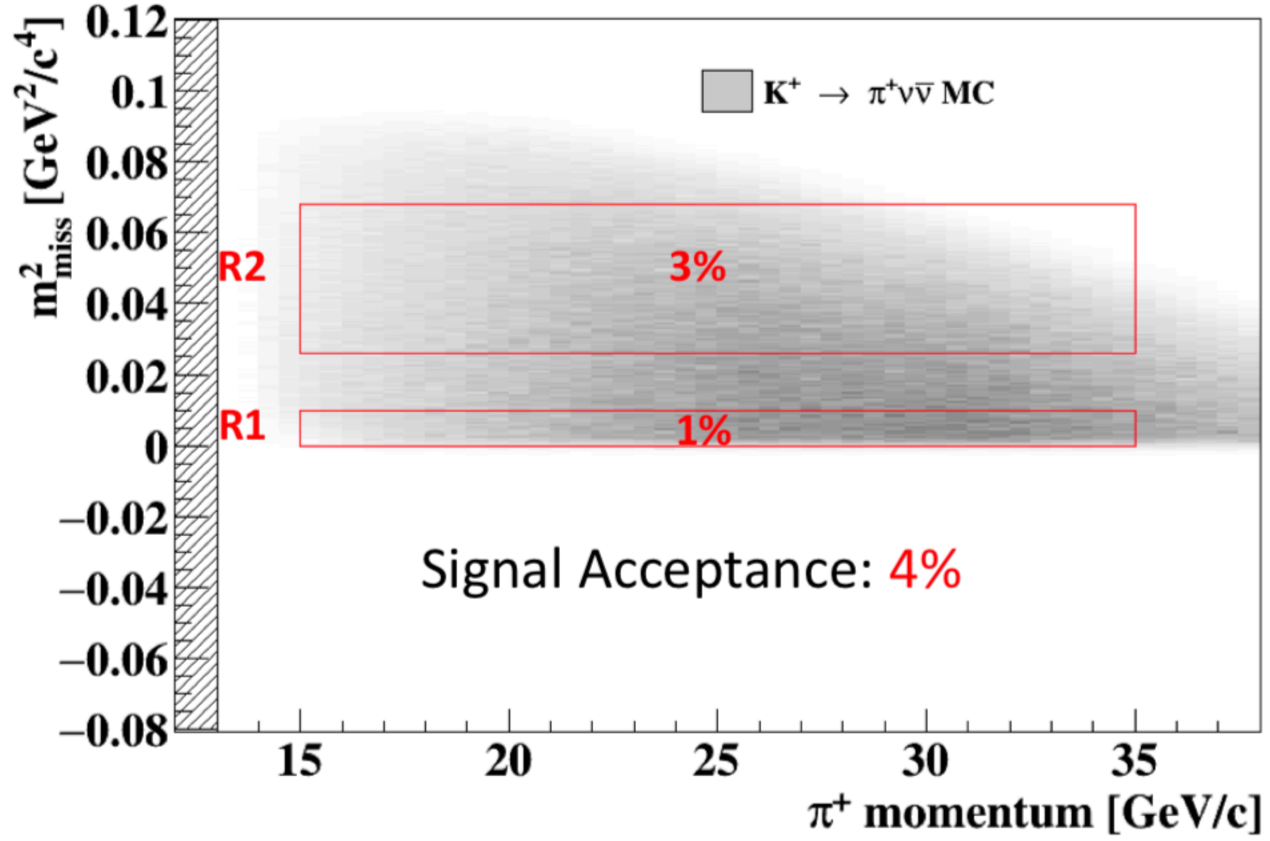
- $\pi\nu\nu$ trigger: 1 track, γ/μ veto
- Control trigger: samples for normalization, background estimation

Signal regions



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

Single event sensitivity



Source	δSES (10^{-10})
Random Veto	± 0.17
N_K	± 0.05
Trigger efficiency	± 0.04
Definition of $\pi^+\pi^0$ region	± 0.10
Momentum spectrum	± 0.01
Simulation of $\pi+$ interactions	± 0.09
Extra activity	± 0.02
GTK Pileup simulation	± 0.02
Total	± 0.24

- Control trigger $K^+ \rightarrow \pi^+\pi^0$ used for normalization
- Normalization acceptance: 10%
- Number of kaon decays (N_K) in fiducial volume $N_K = 1.21(2) \times 10^{11}$

Single Event Sensitivity: $SES = (3.15 \pm 0.01_{stat} \pm 0.24_{syst}) \times 10^{-10}$

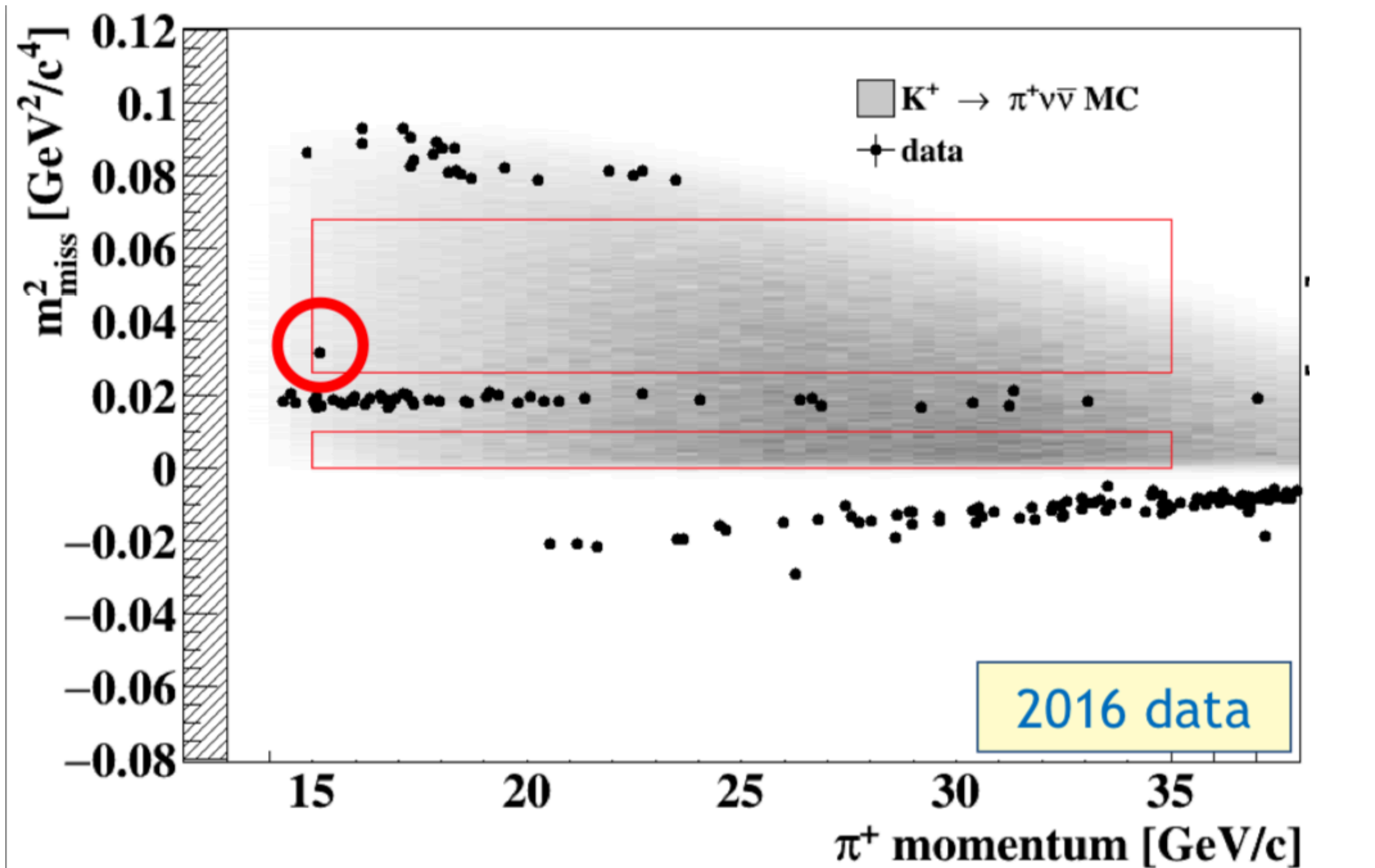
Background summary

Process	Expected events in R1+R2
$K^+ \to \pi^+ \nu\bar{\nu}$ (SM)	$0.267 \pm 0.001_{stat} \pm 0.020_{syst} \pm 0.032_{ext}$
Total Background	$0.15 \pm 0.09_{\mathbf{stat}} \pm 0.01_{\mathbf{syst}}$
$K^+ \to \pi^+\pi^0(\gamma)$ IB	$0.064 \pm 0.007_{stat} \pm 0.006_{syst}$
$K^+ \to \mu^+\nu(\gamma)$ IB	$0.020 \pm 0.003_{stat} \pm 0.003_{syst}$
$K^+ \to \pi^+\pi^-e^+\nu$	$0.018^{+0.024}_{-0.017}\|_{stat} \pm 0.009_{syst}$
$K^+ \to \pi^+\pi^+\pi^-$	$0.002 \pm 0.001_{stat} \pm 0.002_{syst}$
Upstream Background	$0.050^{+0.090}_{-0.030}\|_{stat}$

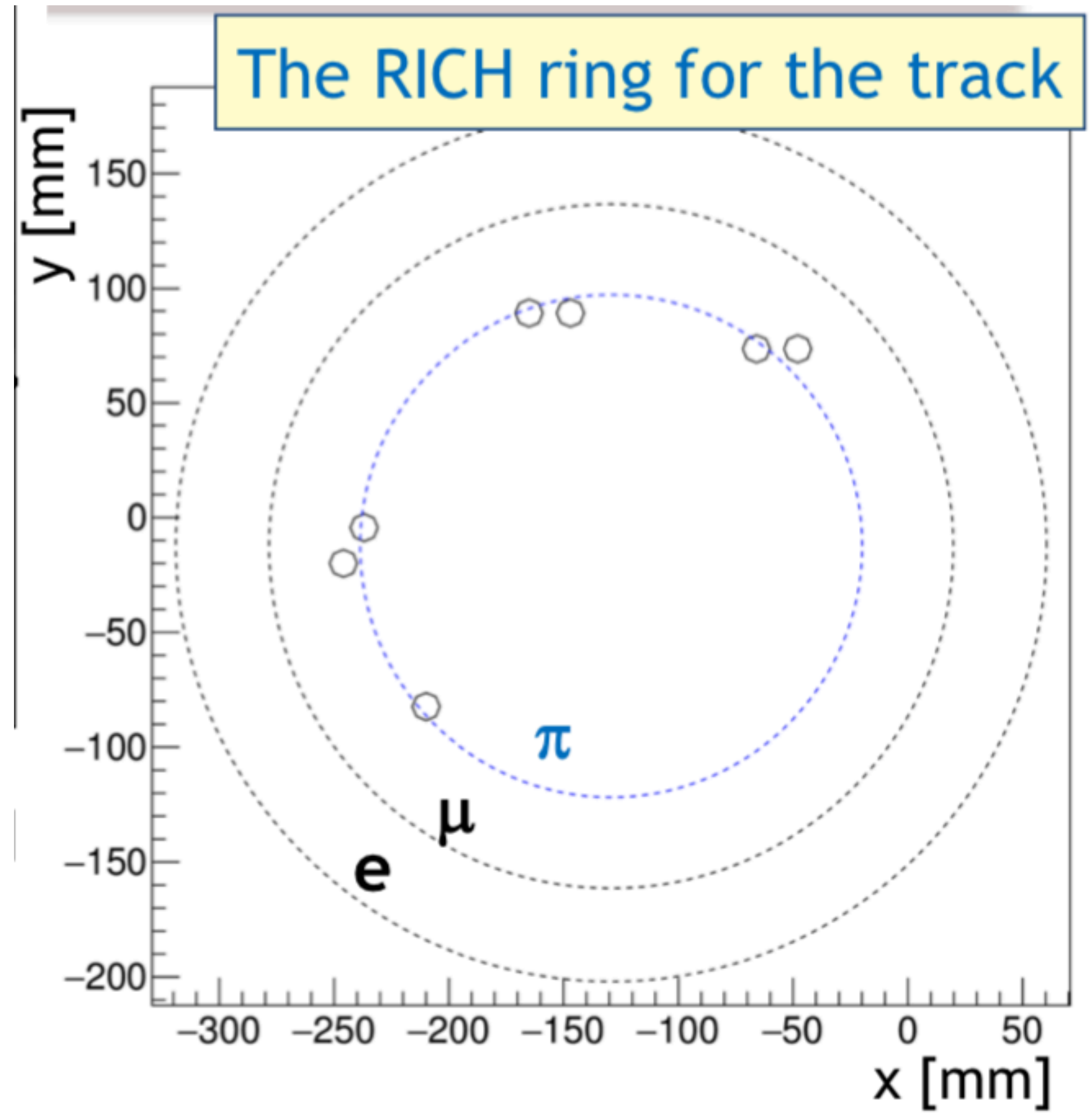
Background estimates are mostly data driven

Signal acceptance:
$A_{\pi\nu\nu}$=(4.0±0.1)%.

2016 result



One $K^+ \to \pi^+ \nu\nu$ candidate observed:
$BR(K^+ \to \pi^+ \nu\nu) < 11 \times 10^{-10}$ at 90% CL.



BNL 949 (K^+ decay at rest): $BR(K^+ \to \pi^+ \nu\nu) = (1.73^{+1.15}_{-1.05}) \times 10^{-10}$

SM prediction: $BR(K^+ \to \pi^+ \nu\nu) = (0.84 \pm 0.10) \times 10^{-10}$

- ❖ The NA62 decay-in-flight technique works!
- ❖ Competitive sensitivity obtained with ~1% of the total expected statistics.

NA62 $K^+ \to \pi^+ \nu\nu$ prospects

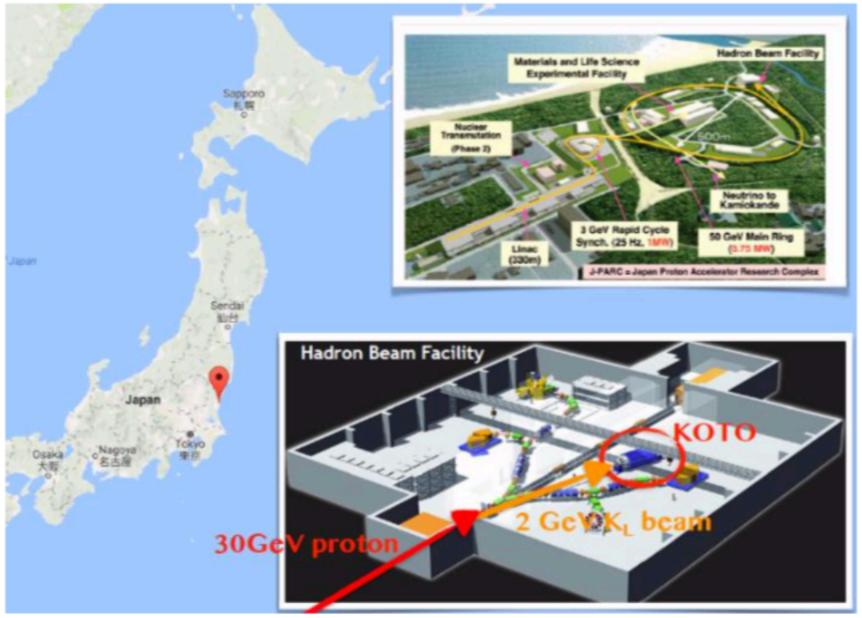
- Analysis of data collected in 2017 is in progress
  - Data sample x20 larger than presented statistics
  - Expect improvements on signal acceptance, efficiency and S/B ratio
- Data taking is finished in Nov. 2018
- Expect ~20 SM events before LS2
- Data taking after LS2 in approval stage

KOTO experiment at J-PARC

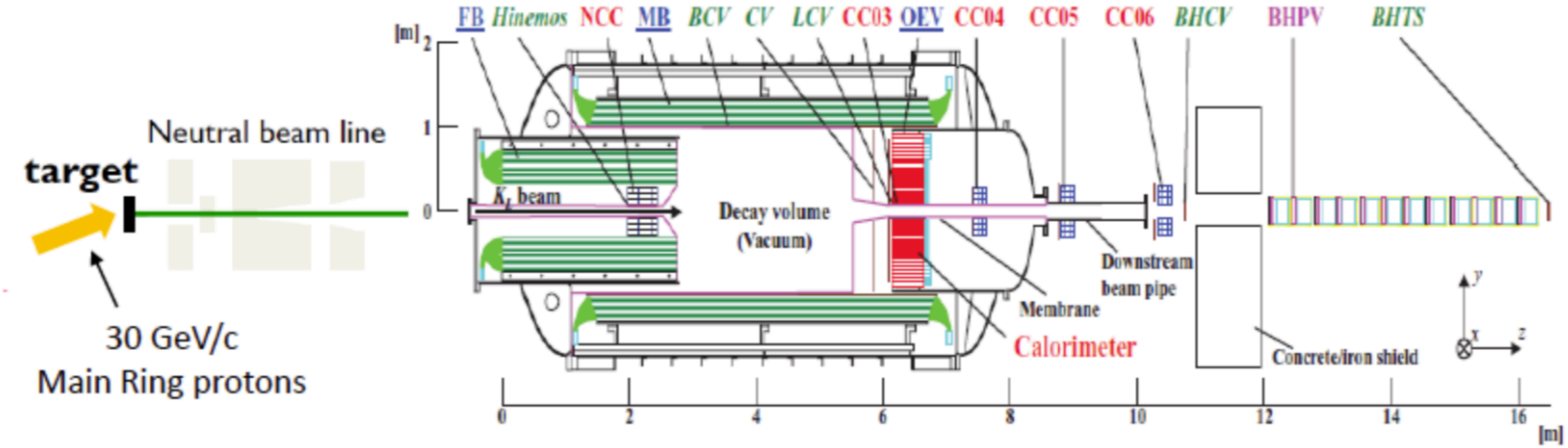
Study of $K_L \to \pi^0 \nu\bar{\nu}$ @ JPARC 30GeV Main Ring
Goal is to search for New Physics at $BR \sim 10^{-11}$

Primary 30 GeV/c protons on gold target
Secondary neutral beam (K_L , neutrons, photons)

- P = 1.4 GeV/c peak
- Transverse size: 80 x 80 mm^2
- Fiducial decay region ~ 2 m



Arizona, Chicago, Chonbuk, Hanyang, Jeju, JINR, KEK, Kyoto, Michigan, NDA, NTU, Okayama, Osaka, Pusan, Saga & Yamagata

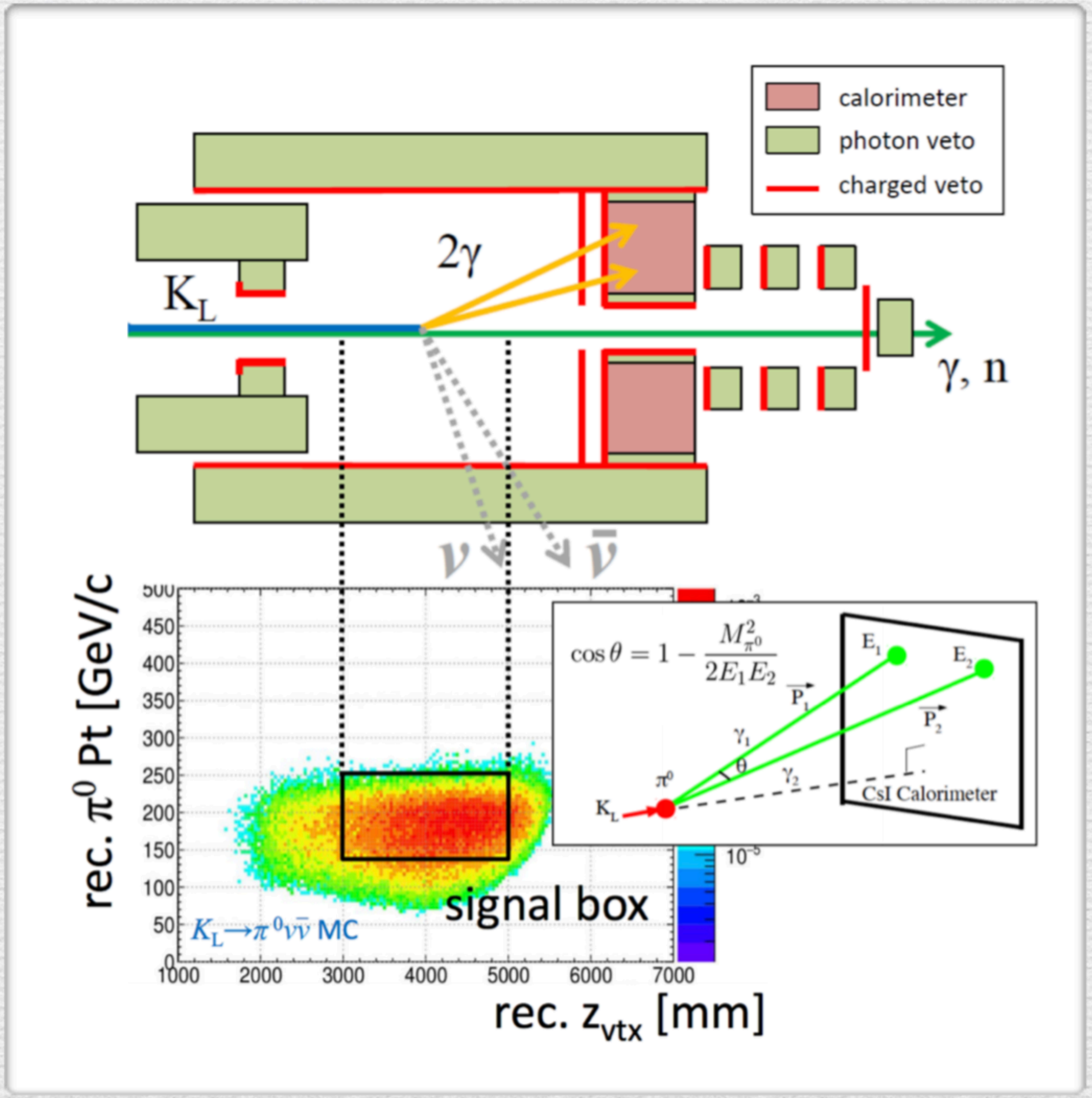


CsI Calorimeter from KTeV + **Hermetic Veto Systems** ⟶ To suppress $K_L \to \pi^0\pi^0$background

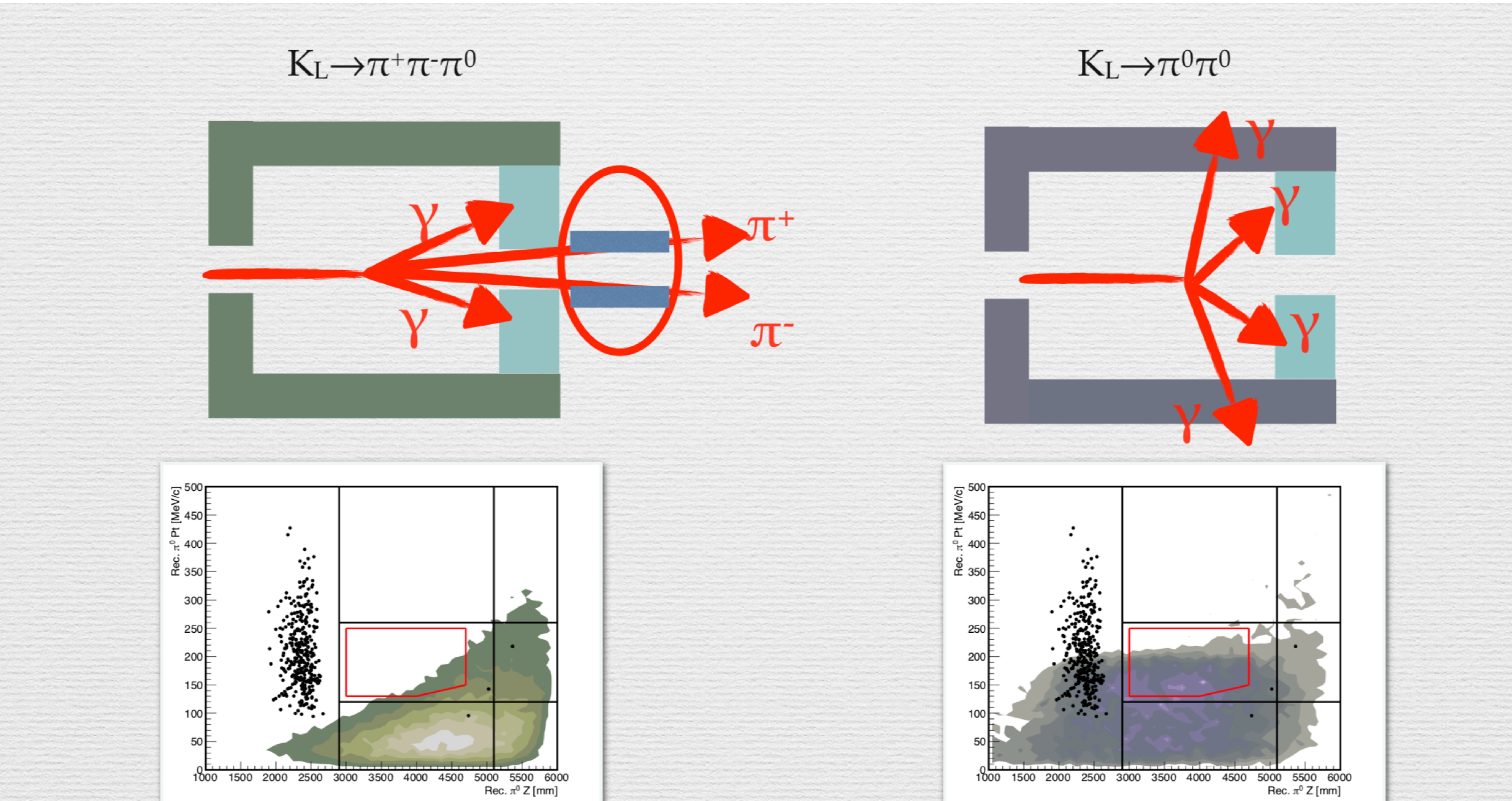
Experimental principle

- $K_L \to \pi^0 \nu \nu$ (Invisible)
  - 2γ with high P_T = signal
- Hermetic Detector
  - no signal in veto detectors

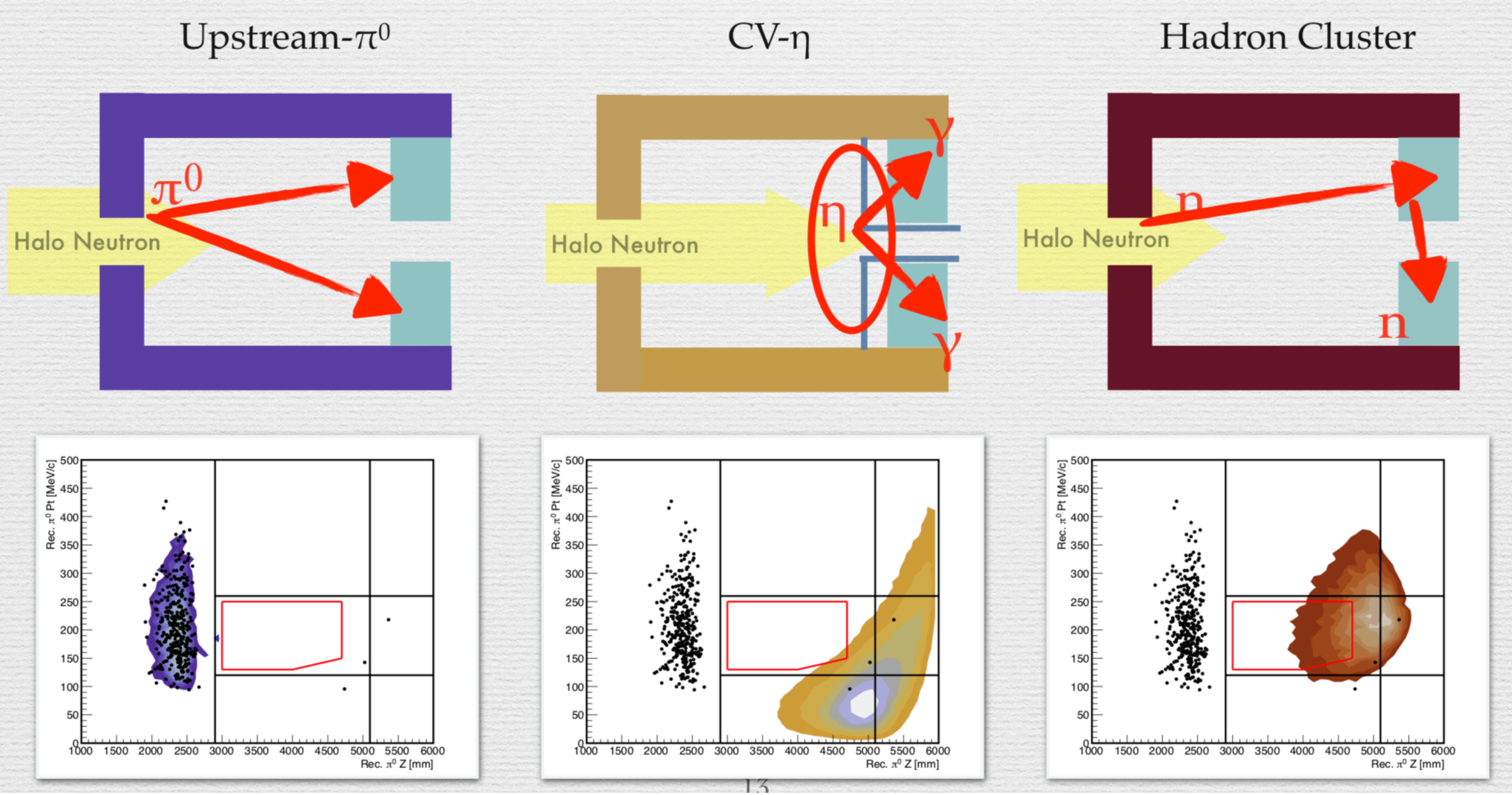
Mode	BR	Handles
$K_L \to \pi^{\pm} e^{\mp} \nu$	40.6%	charged (x2), non-EM (x1)
$K_L \to \pi^{\pm} \mu^{\mp} \nu$	27.0%	charged (x2), non-EM (x1)
$K_L \to \pi^+ \pi^- \pi^0$	12.5%	charged (x2), low π^0 Pt
$K_L \to \pi^0 \pi^0 \pi^0$	19.5%	extra photon (x4)
$K_L \to \gamma\gamma$	5.5x10-4	low Pt, back-to-back symmetry
$K_L \to \pi^+ \pi^-$	2.0x10-3	charged (x2), non-EM (x2)
$K_L \to \pi^0 \pi^0$	8.6x10-4	extra photon (x2)



Background – Kaon decays



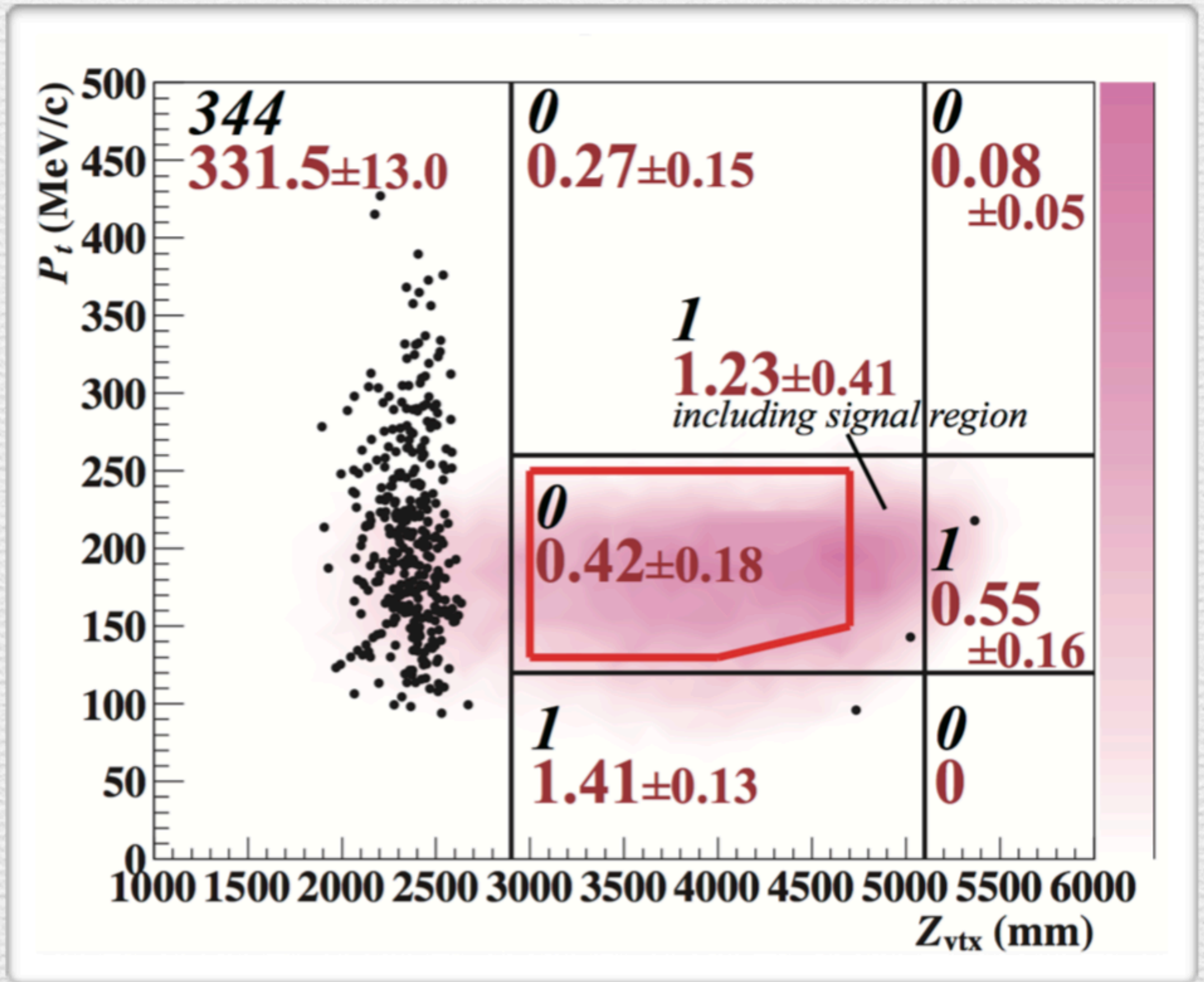
Background – Neutrons



KOTO 2015 result

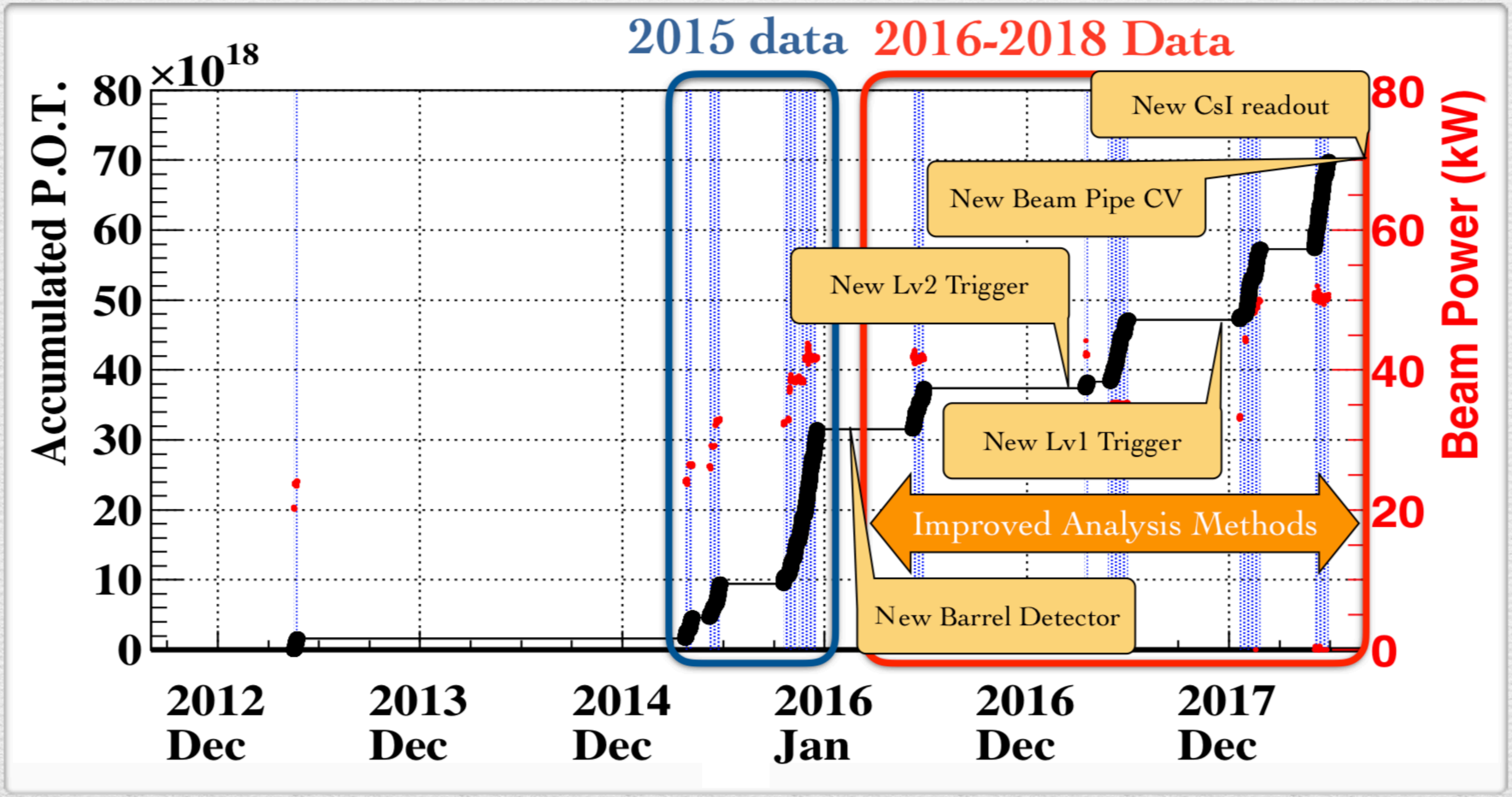
- Based on 40% data collected before major upgrades
  - SES = 1.3×10^{-9}
  - BR[$K_L\to\pi^0\nu\nu$] < 3.0×10^{-9}
  - Published in PRL.122.021802

source		Number of events
K_L decay	$K_L\to\pi^+\pi^-\pi^0$	0.05 ± 0.02
	$K_L\to2\pi^0$	0.02 ± 0.02
	other K_L decays	0.03 ± 0.01
neutron-induced	hadron-cluster	0.24 ± 0.17
	upstream-π^0	0.04 ± 0.03
	CV-η	0.04 ± 0.02
total		0.42 ± 0.18



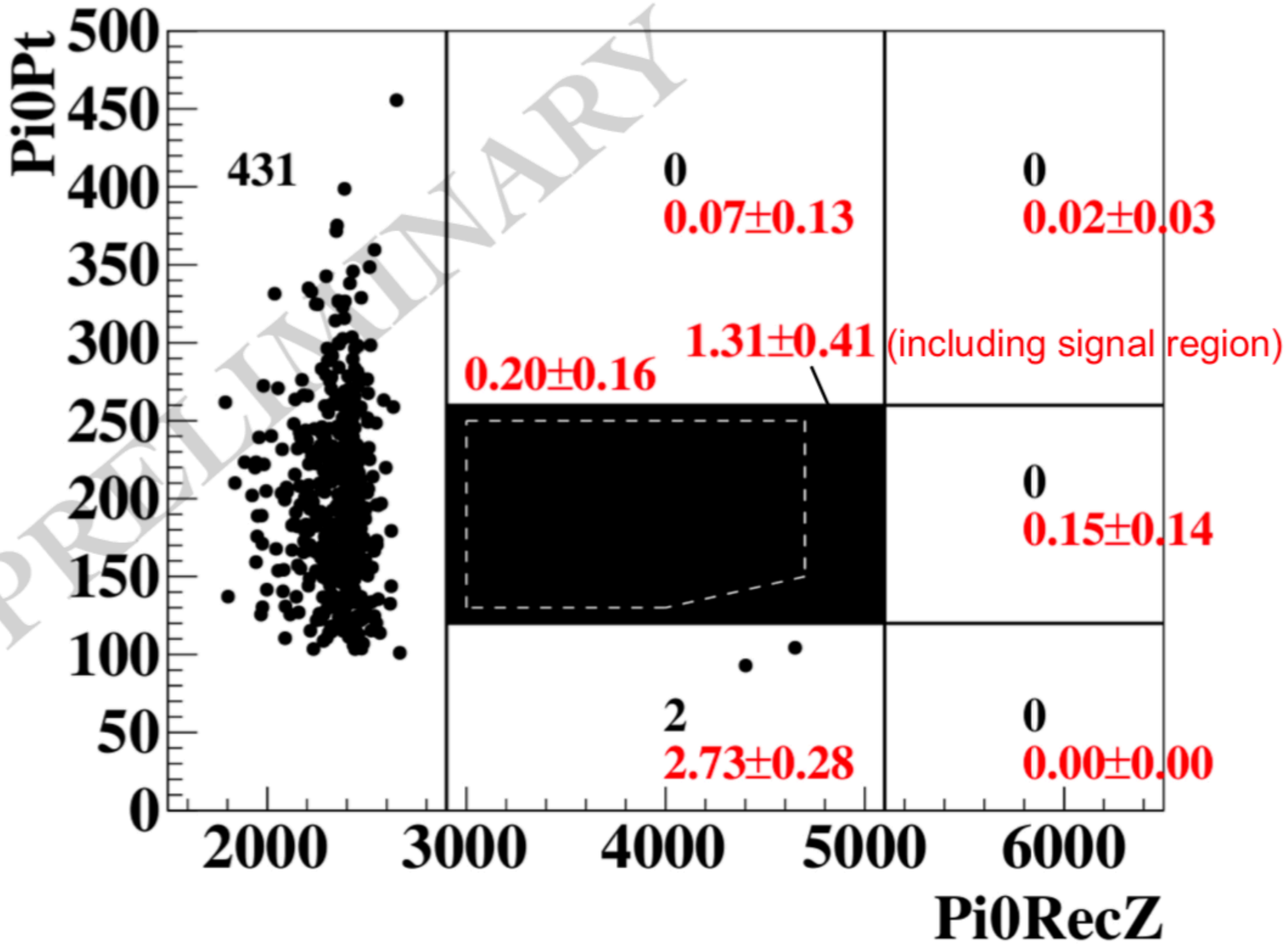
KOTO data taking

- Several major upgrades after 2015
- 2016-2018 result is coming out this summer
  - expect combined U.L. to cross G-N limit



Analysis status 2016–2018

- S.E.S. = 8.2×10^{-10} (without new veto window)
- Background under control
- Results coming soon in summer 2019

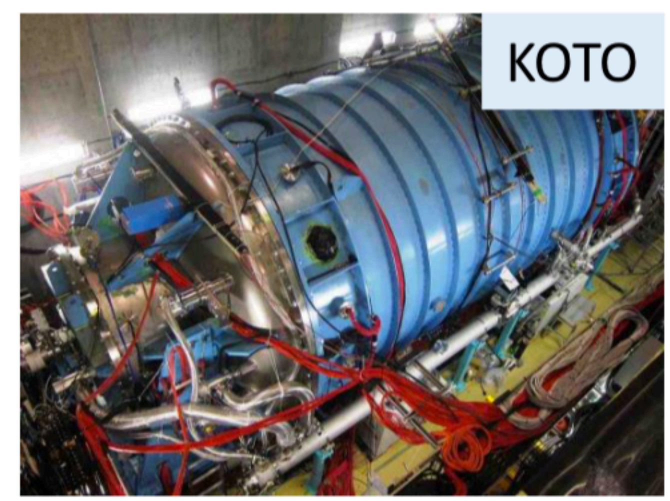


	# of BG inside signal region
$K_L \to 2\pi^0$	0.09±0.09
$K_L \to \pi^+\pi^-\pi^0$	0.02±0.02
Hadron cluster	0.07±0.13
CV-pi0	< 0.19
CV-eta	0.02±0.01
Total	**0.20±0.16**

Conclusion

- The novel NA62 decay-in-flight technique works
- SM sensitivity for $K^+ \to \pi^+ \nu\bar{\nu}$ reached with the completion of 2016 data analysis
- One event observed in 2016 data (0.3 SM expected in R1+R2)

$$BR(K^+ \to \pi^+ \nu\bar{\nu}) < 14.0 \times 10^{-10} \text{ @ } 95\%\ CL$$



- $K^+ \to \pi^+ \nu\bar{\nu}$: NA62
  - BR measurement expected in the next few years
- $K_L \to \pi^0 \nu\bar{\nu}$: KOTO
  - New result (2015 data): $BR(K_L \to \pi^0 \nu\bar{\nu}) < 3.0 \times 10^{-9} \text{ @ } 90\%\ CL$
  - O(10^{-11}) sensitivity expected with with runs after 2018
- **Both experiments are running and data analyses are ongoing**