Sep. 16, 2021

Measurement of radiative $K^+ \to e^+\nu\gamma$ decays at J-PARC E36

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for the J-PARC E36 collaboration

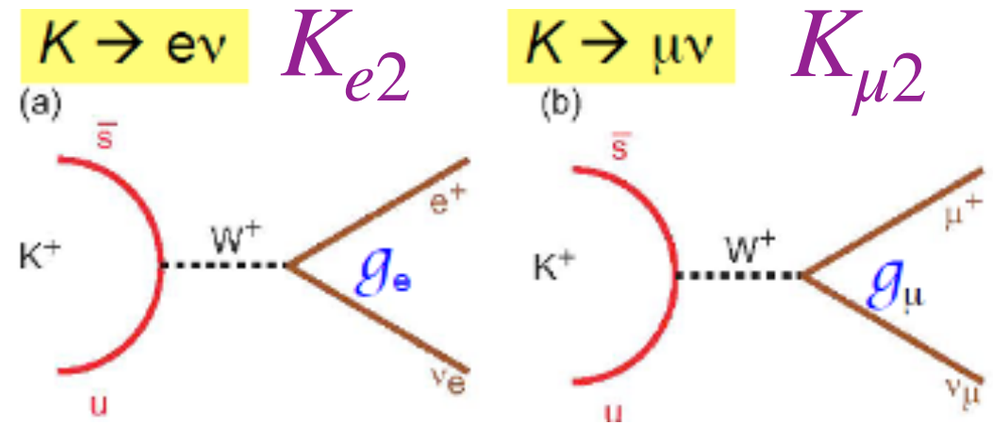
Search for Lepton universality violation in K_{l2} decay and importance of radiative $K^{SD}_{e2\gamma}$ decay

- Since hadronic form factors are canceled out, R_K^{SM} can be precisely calculated

$$R_K^{SM} = \frac{\Gamma(K^+ \to e^+\nu)}{\Gamma(K^+ \to \mu^+\nu)} = \frac{m_e^2}{m_\mu^2}\left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 (1+\delta_r)$$

$=(2.477\pm0.001)\times10^{-5}$

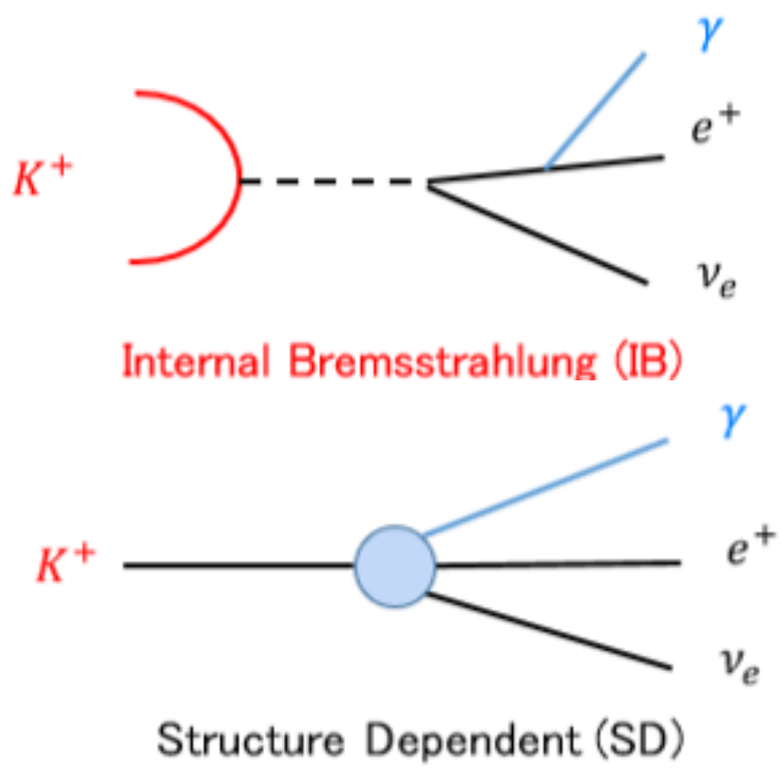
Helicity suppression



- Radiative $K^+ \to e^+\nu\gamma$ $(K_{e2\gamma})$ decay
  - (1) IB : Internal bremsstrahlung process
  - (2) SD : Structure dependent process

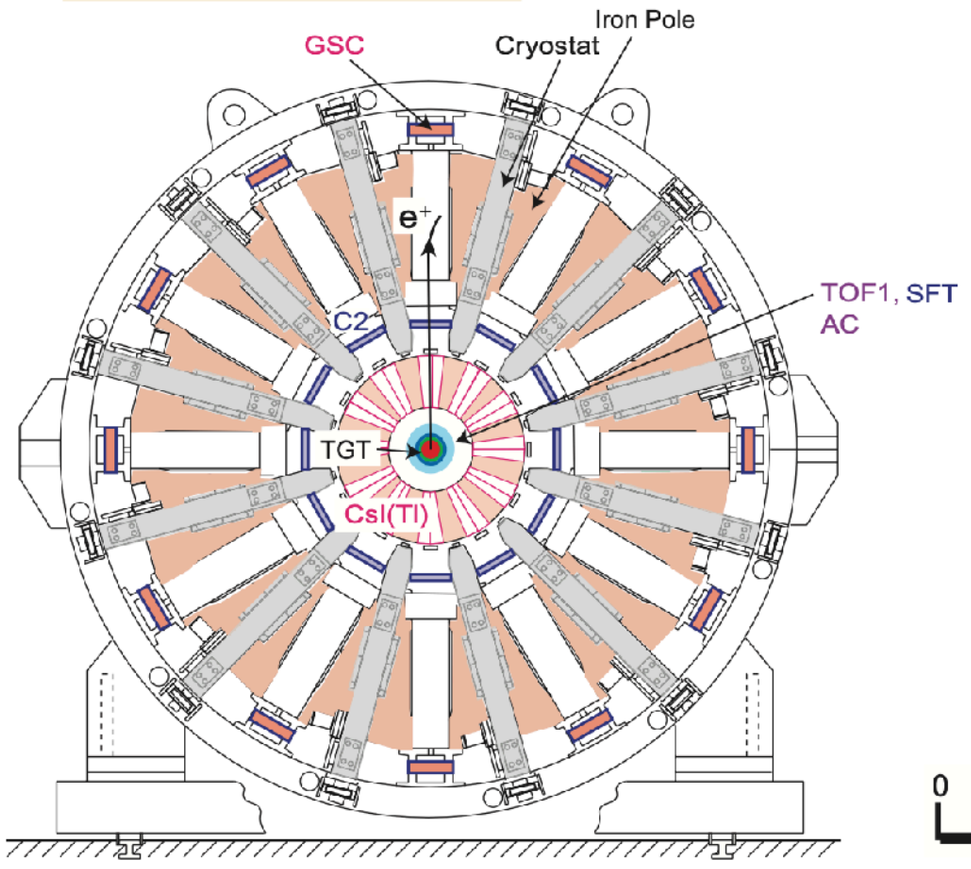
$$R_K = \frac{N(K_{e2} + K^{IB}_{e2\gamma})}{N(K_{\mu2} + K^{IB}_{\mu2\gamma})} \frac{\Omega(K_{\mu2} + K^{IB}_{\mu2\gamma})}{\Omega(K_{e2} + K^{IB}_{e\gamma})}$$

- IB is added to K_{e2} for R_k
- SD is background and has to be subtracted

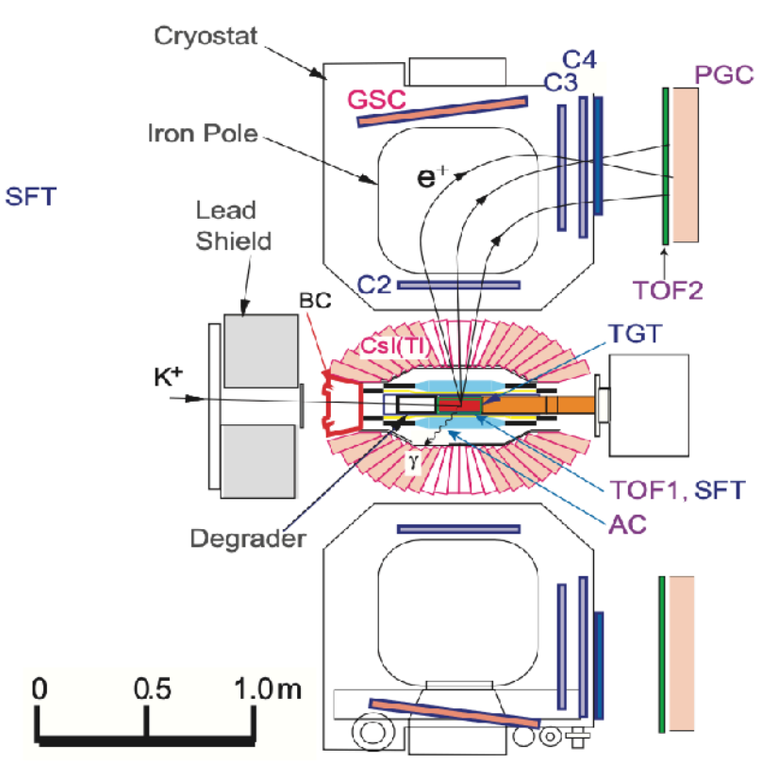


J-PARC E36 detector configuration

End View



Side View



Stopped K method

- K1.1BR beamline
- Beam Cherenkov
- K^+ stopping target

Tracking

- MWPC (C2, C3, C4)
- Spiral Fiber Tracker (SFT)
- Active target

PID

- TOF (TOF1, TOF2)
- Aerogel Cherenkov (AC)
- Pb glass counter (PGC)

Gamma ray

- CsI(Tl)
- GSC

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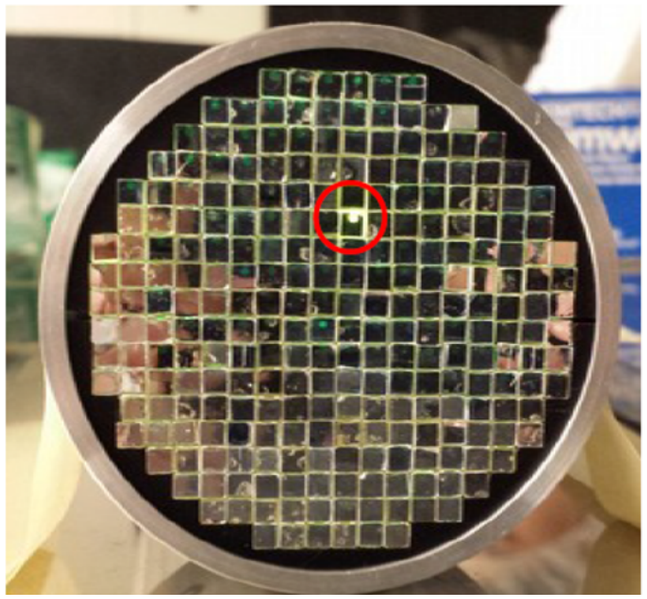

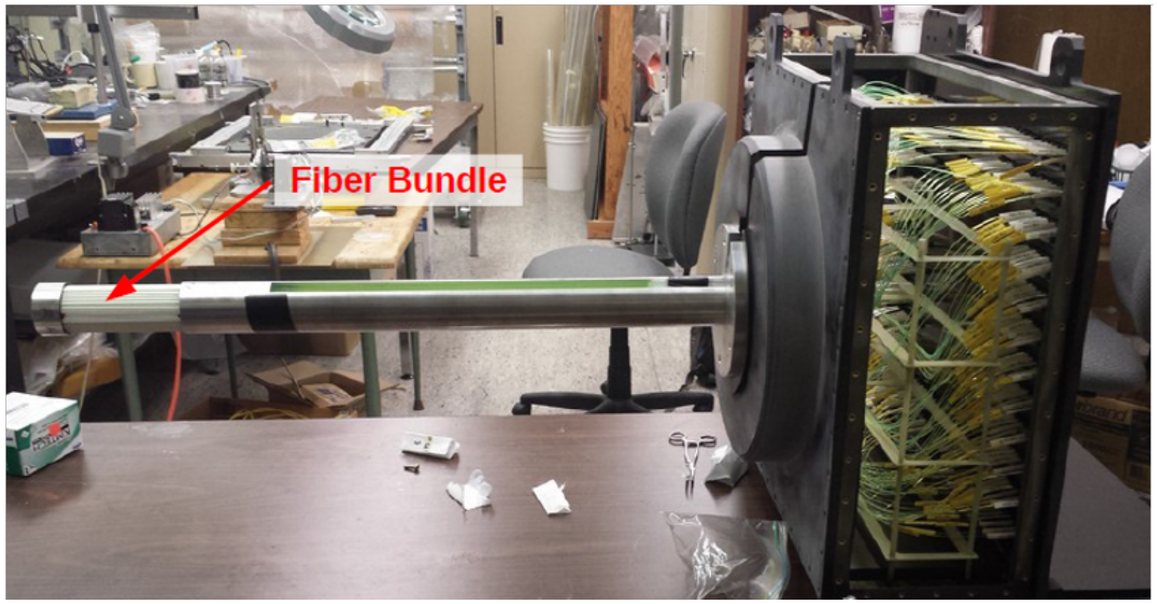

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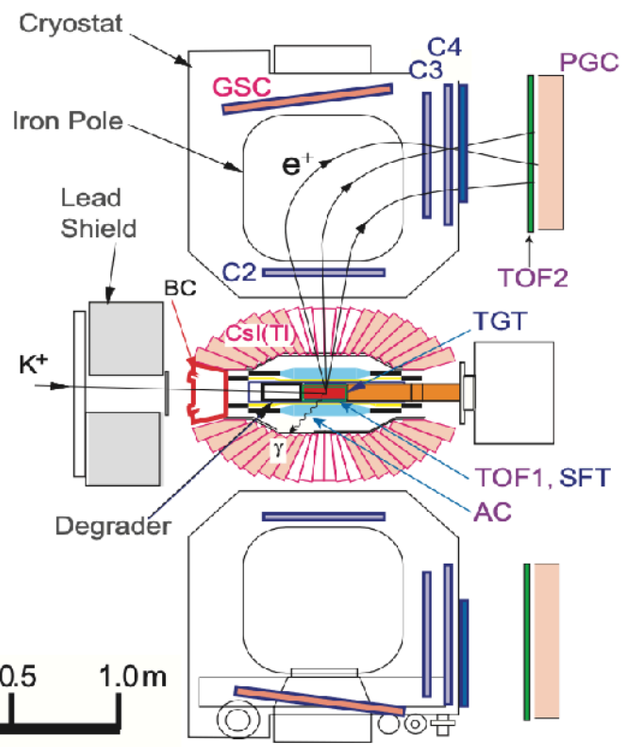

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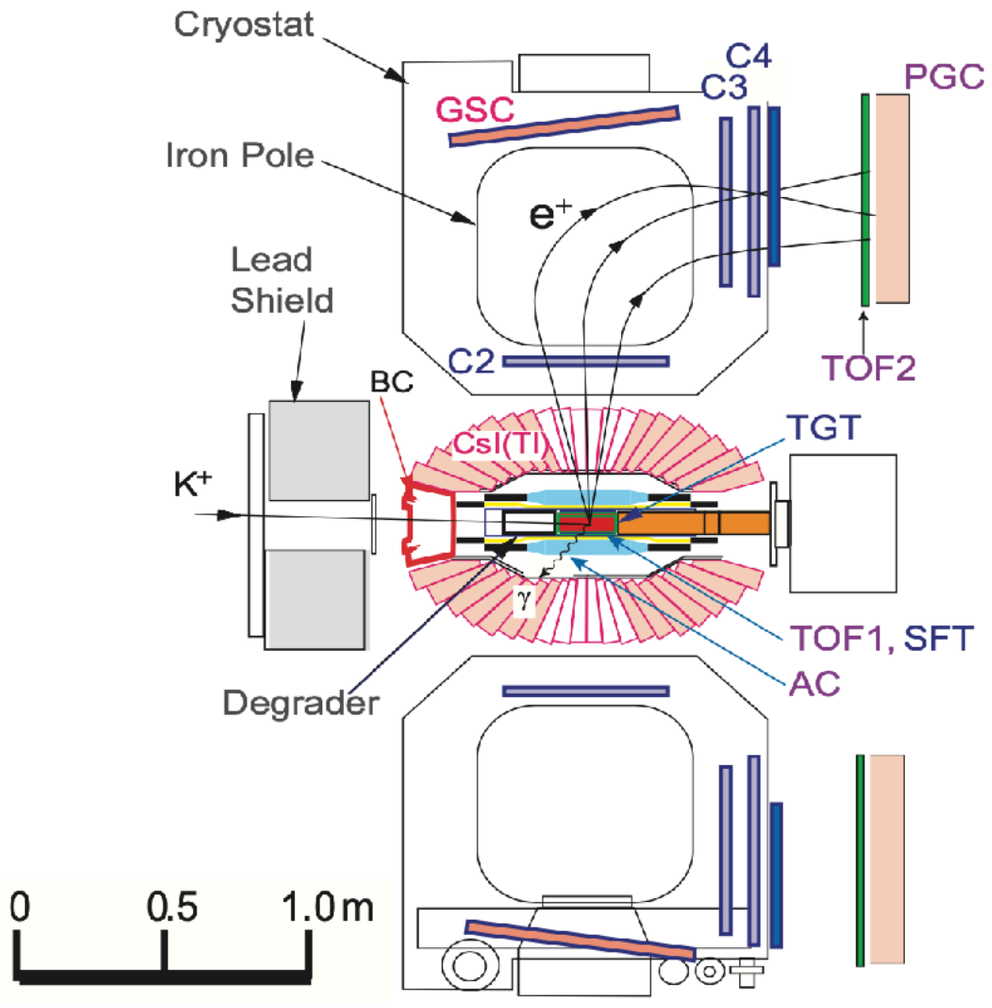

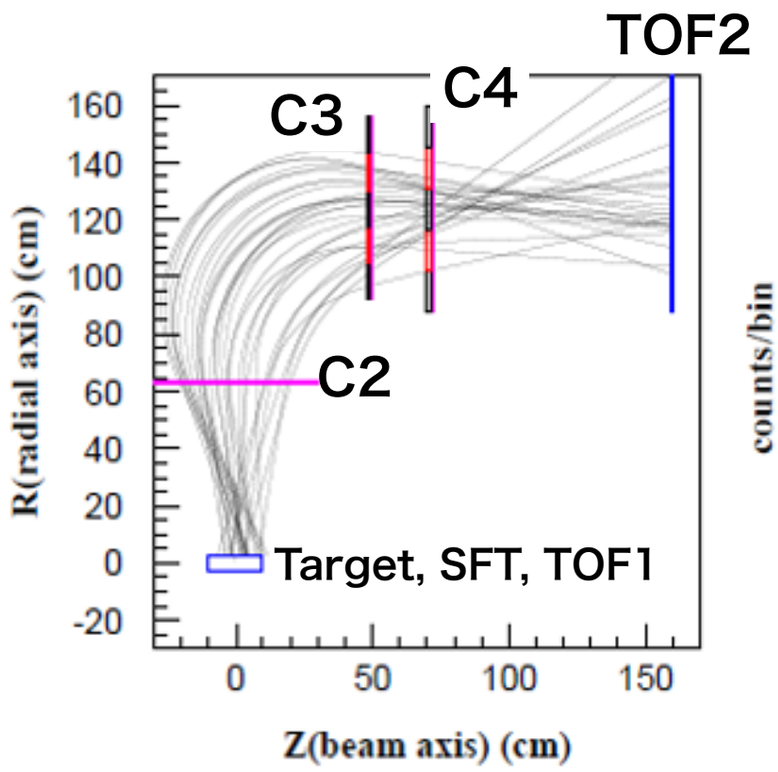

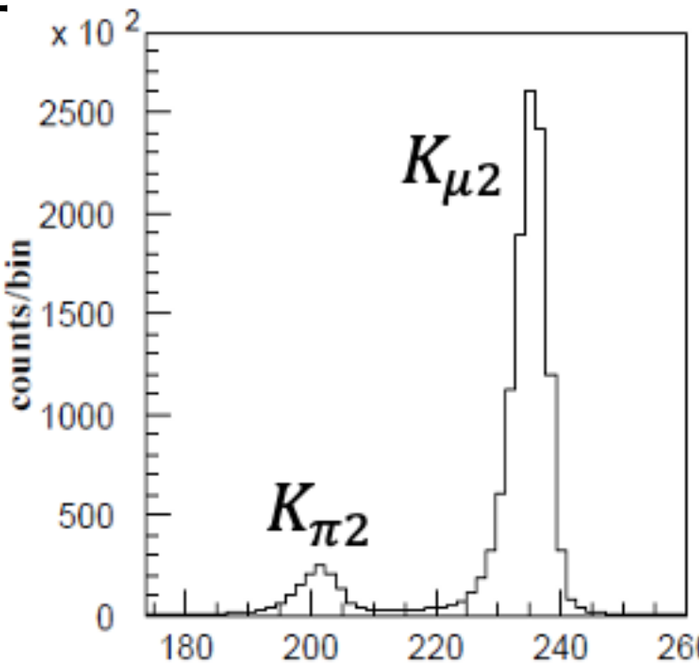

※ $K_{\pi 2} : K^+ \rightarrow \pi^+ \pi^0$
$K_{\mu 2} : K^+ \rightarrow \mu^+ \nu$

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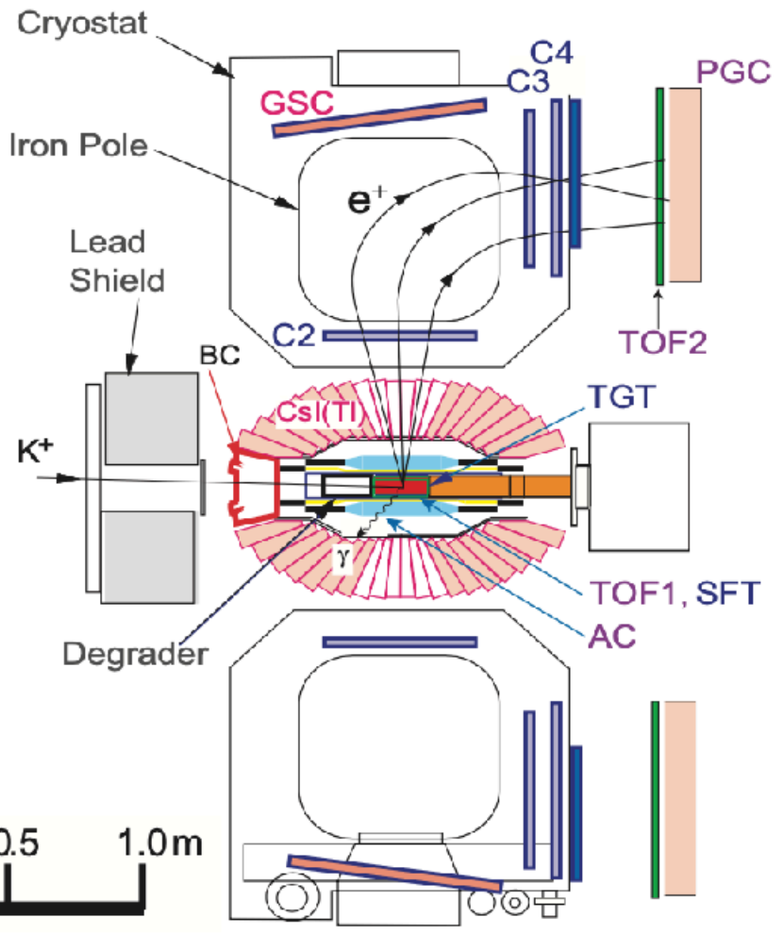

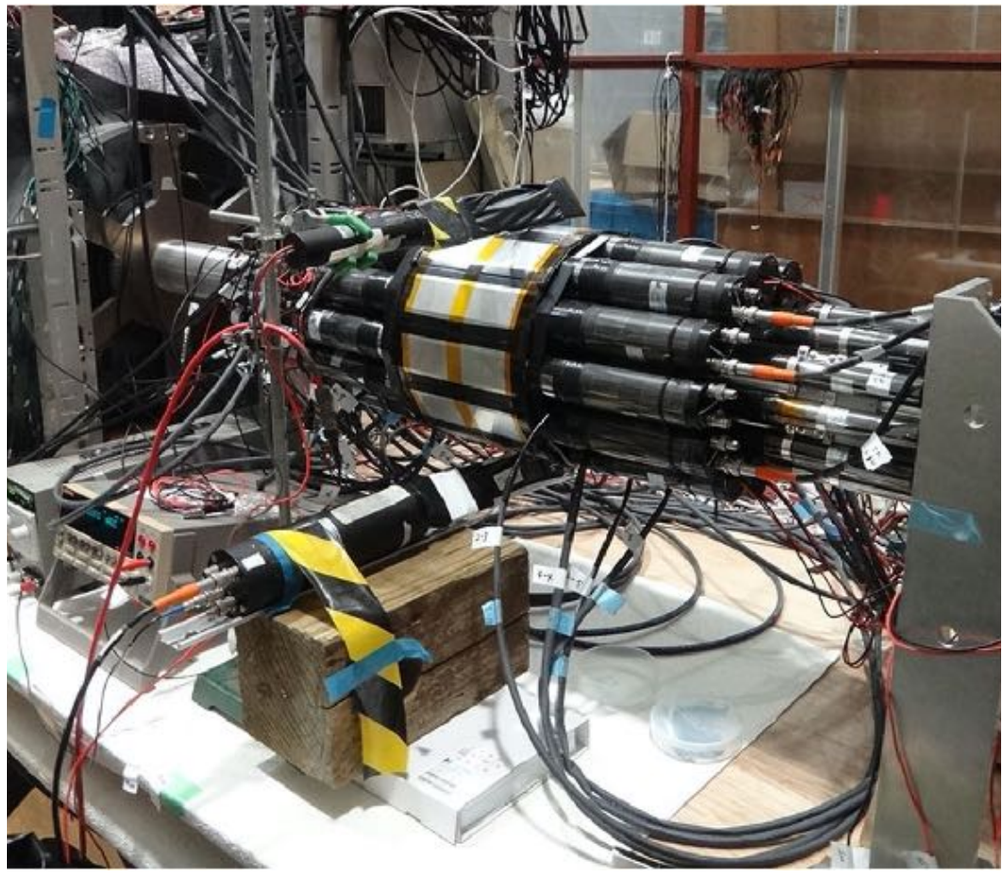

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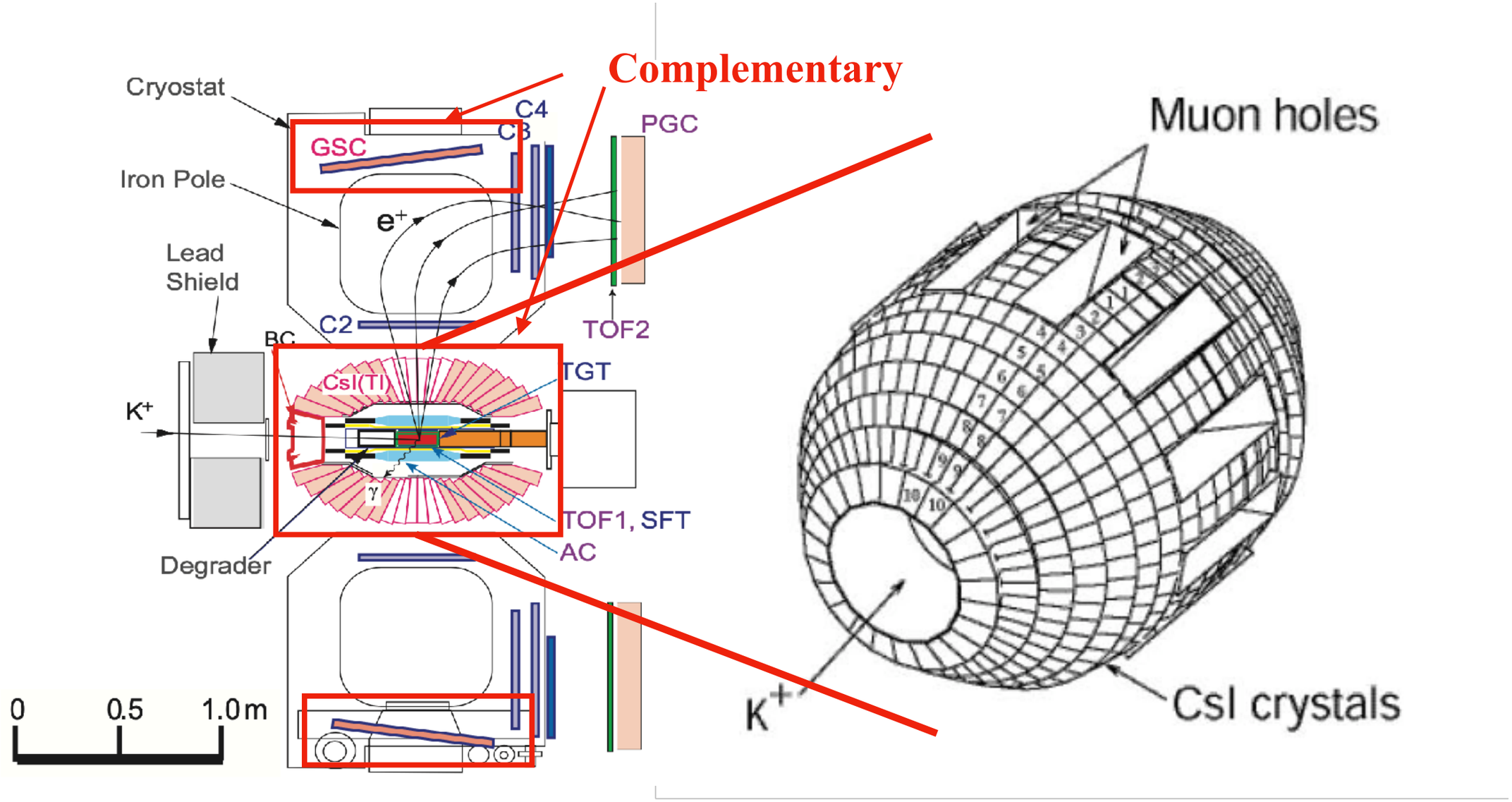

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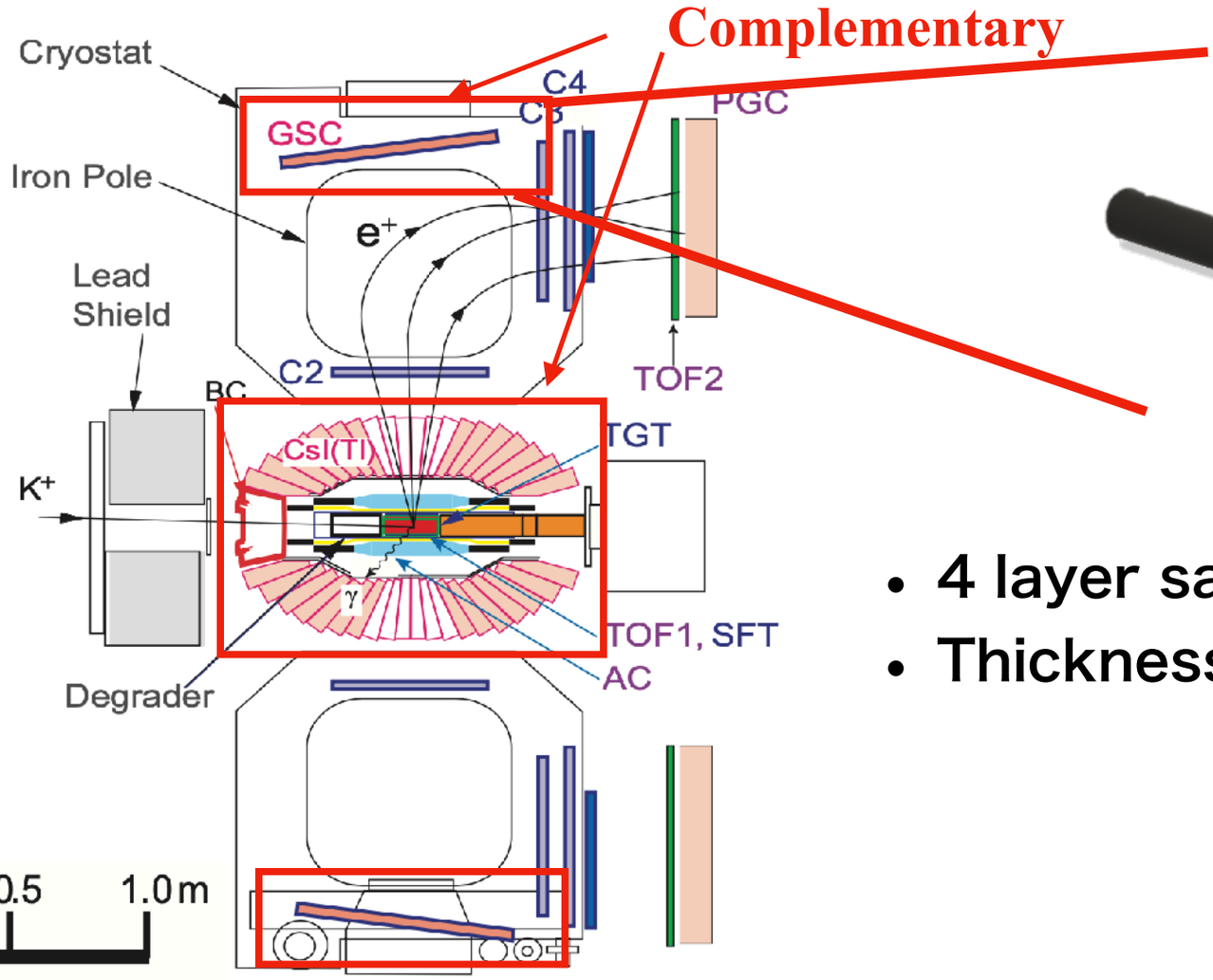

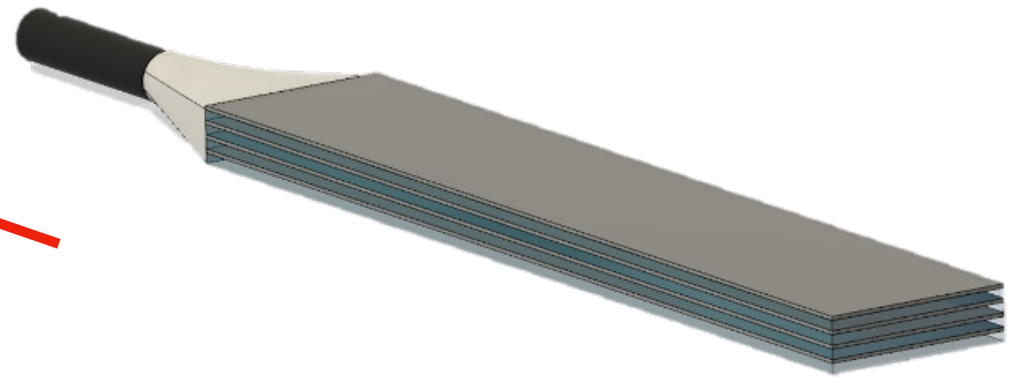

- 4 layer sandwich structure
- Thickness of Pb (Plastic) is 3.7mm (10mm)

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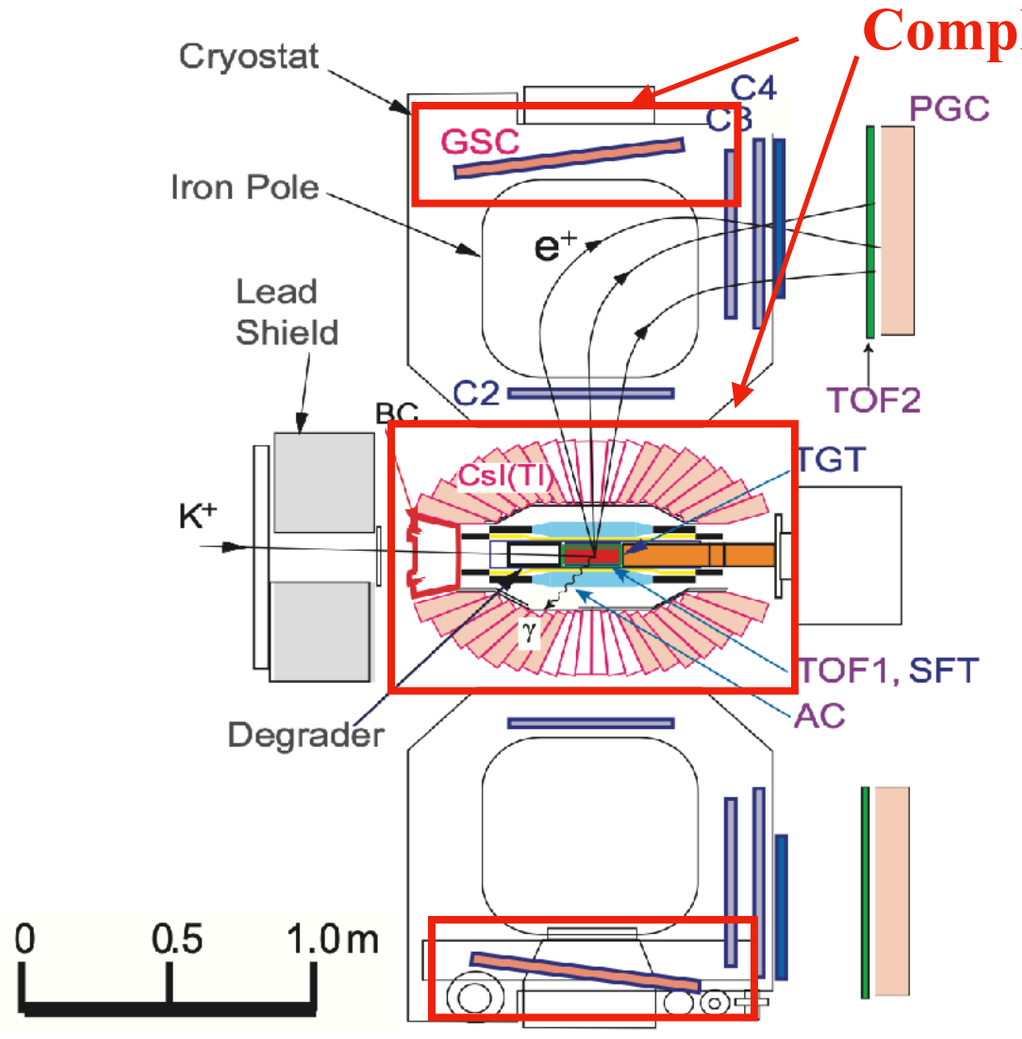

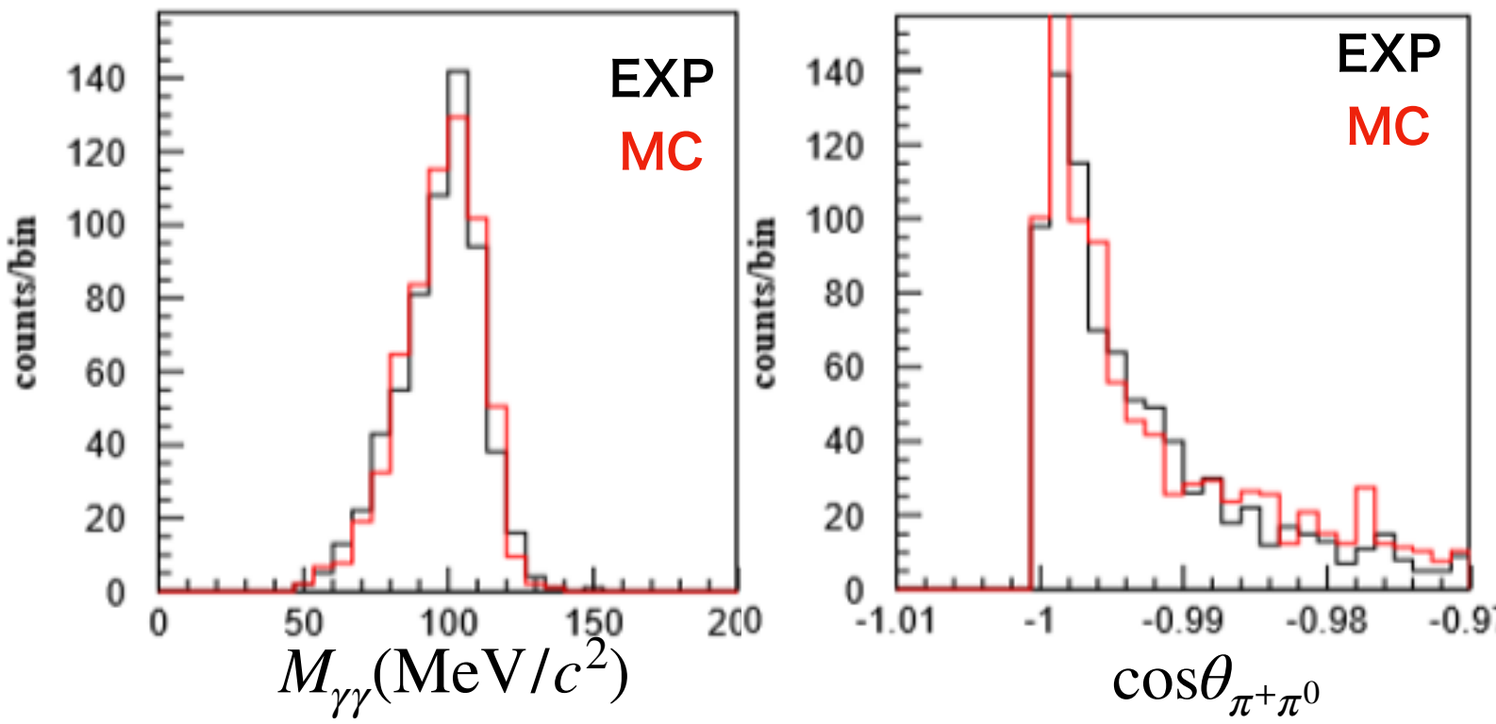

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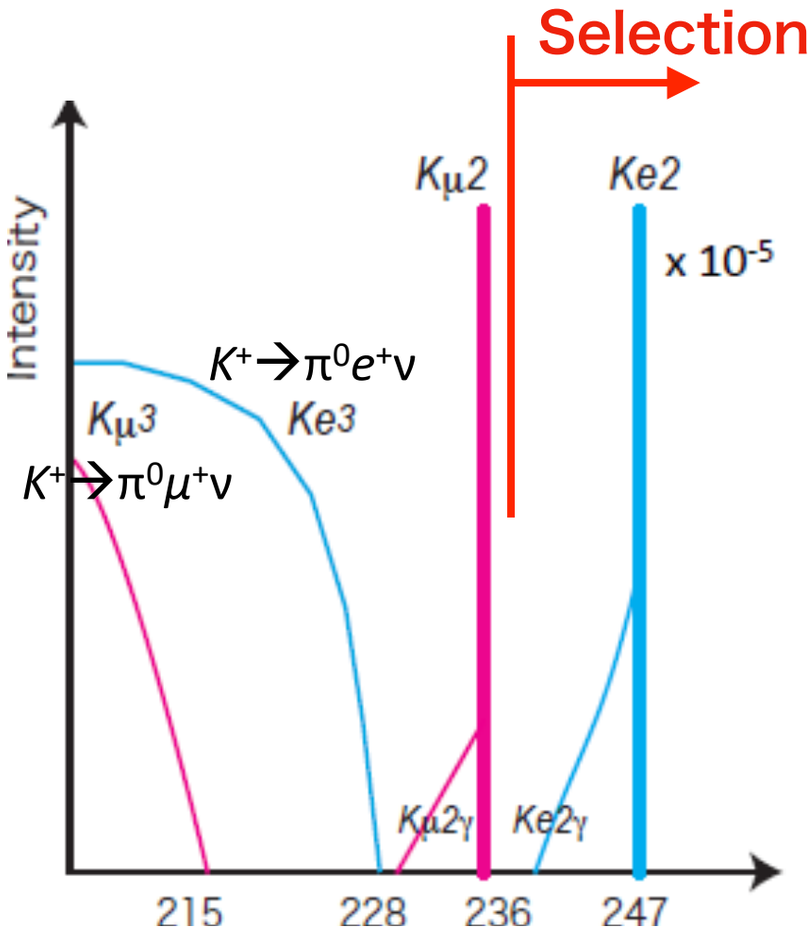
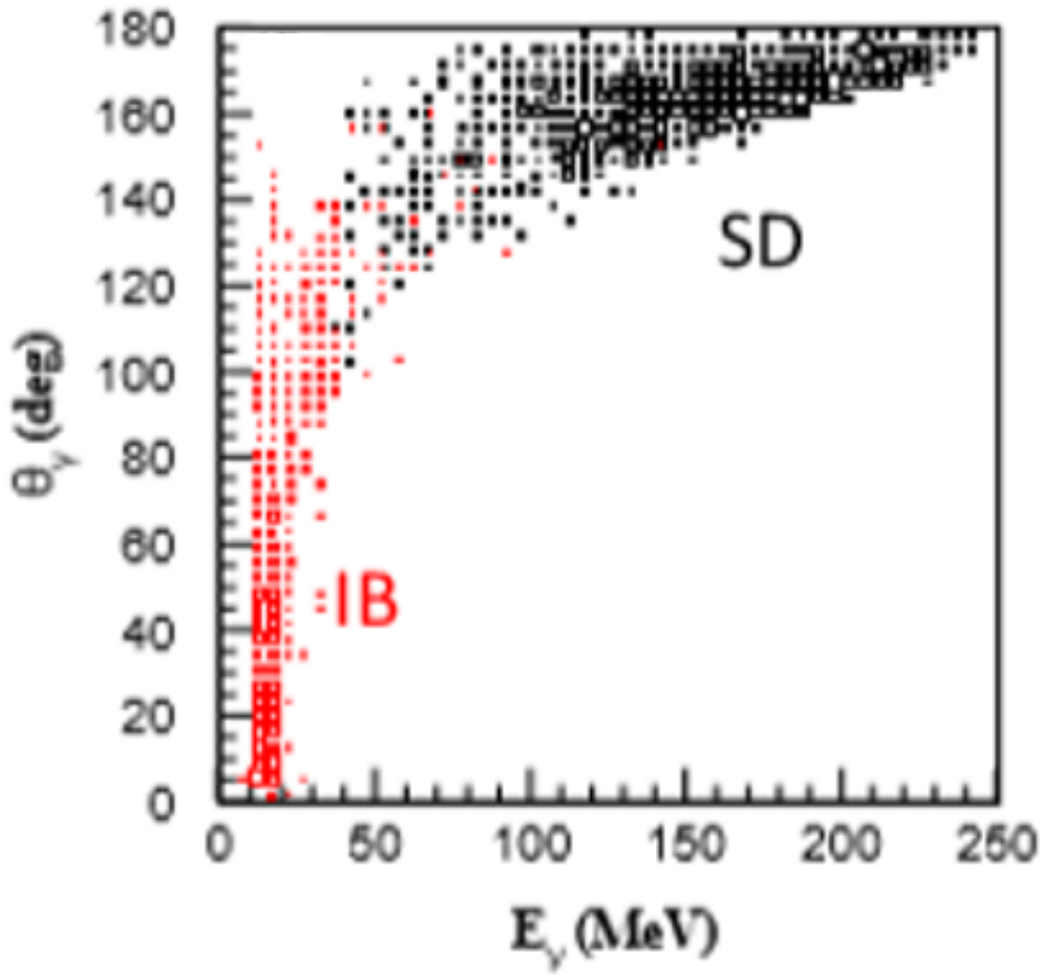
Analysis method of $K^{SD}_{e2\gamma}$

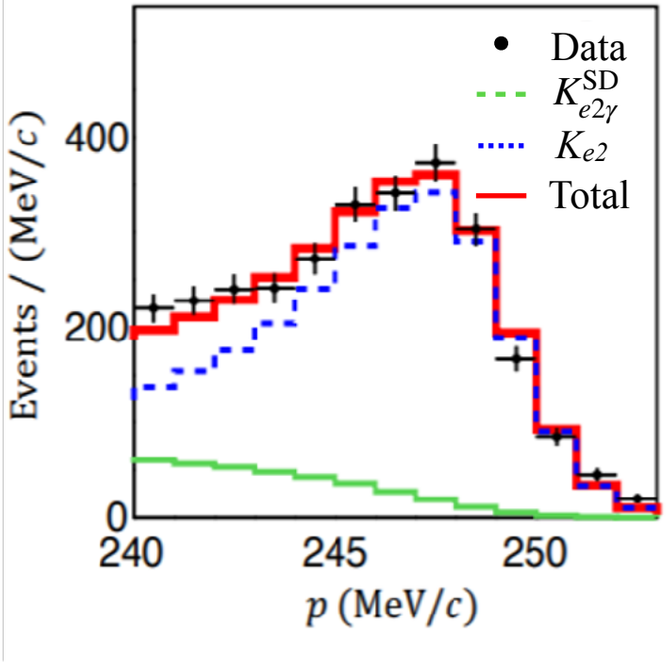
- $K^{SD}_{e2\gamma}$ can be discriminated clearly
  - (1) $K_{e2\gamma}$ and K_{e2} were extracted by PID and momentum selection
  - (2) Requiring photon separate $K_{e2\gamma}$ and K_{e2}
  - (3) $K^{SD}_{e2\gamma}$ was discriminated using its kinematical difference from $K^{IB}_{e2\gamma}$
  - (4) $Br(K^{SD}_{e2\gamma})$ relative to $Br(K_{e2(\gamma)}) = Br(K_{e2} + K^{IB}_{e2\gamma})$ was obtained.



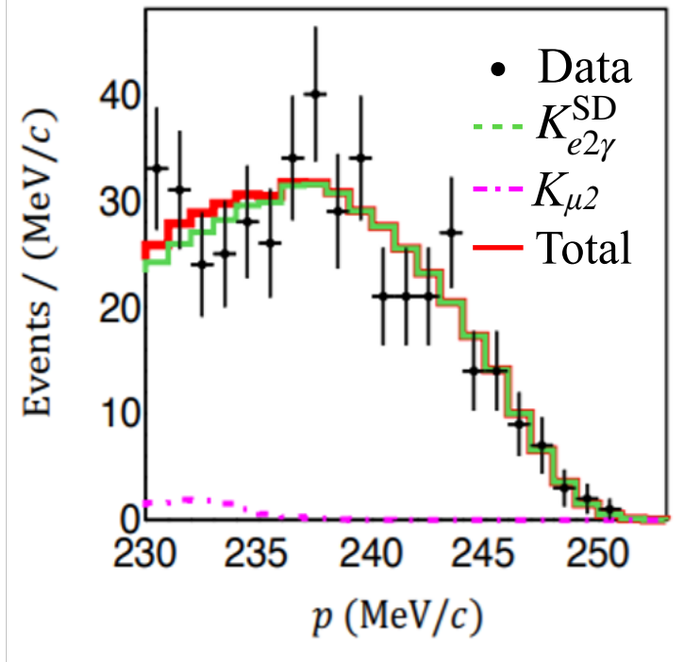


Analysis results of the $K^{SD}_{e2\gamma}$ and K_{e2}

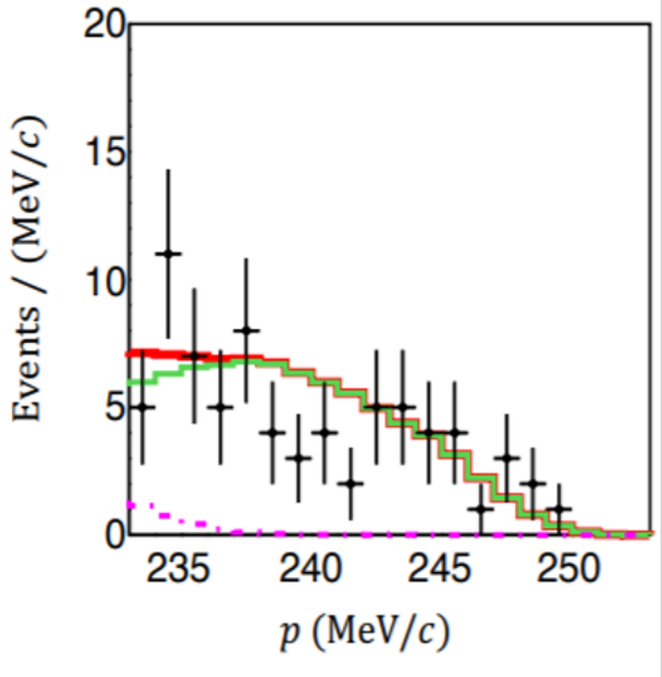
Without gamma requiring

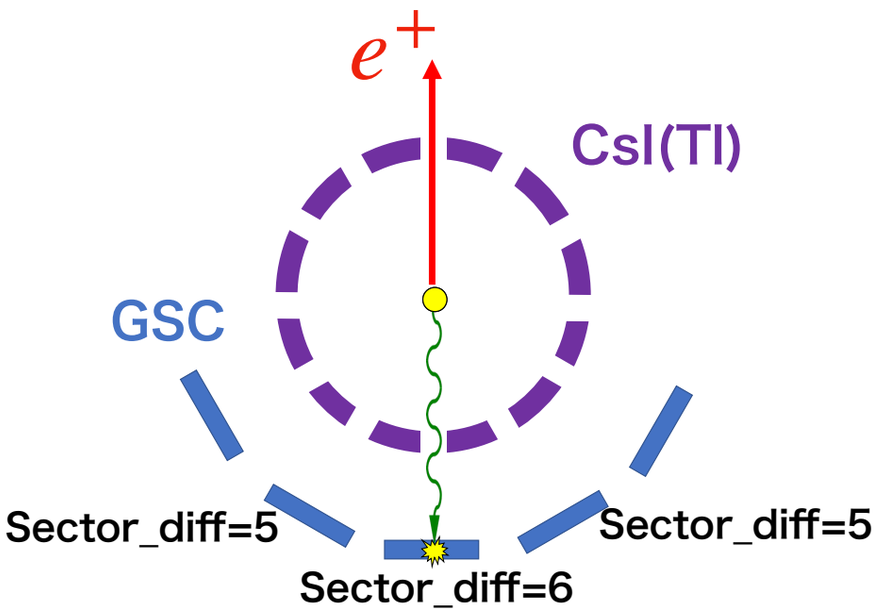


1 hit in CsI(Tl)

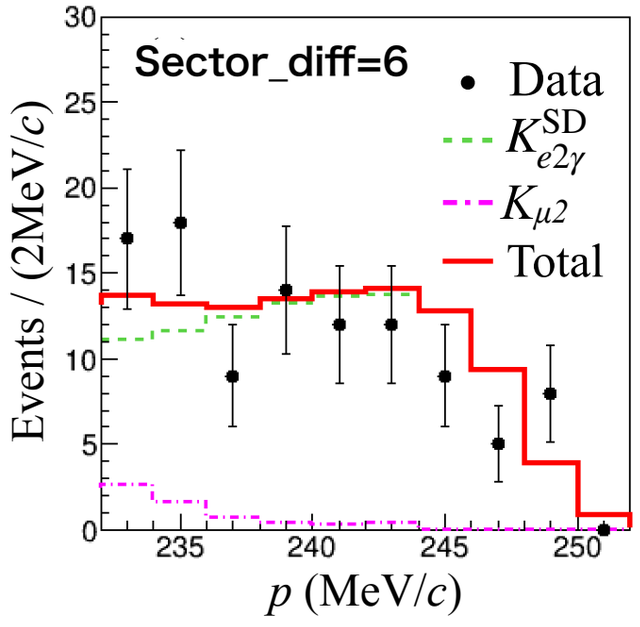


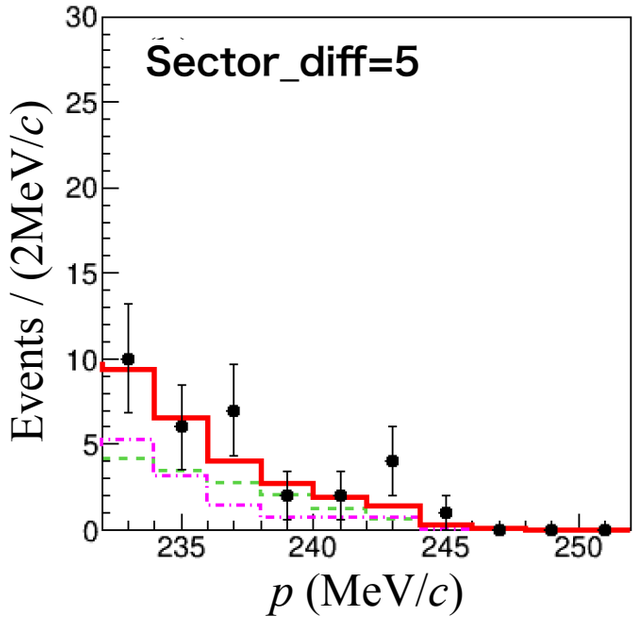
2 hits in CsI(Tl)





1 hit in GSC

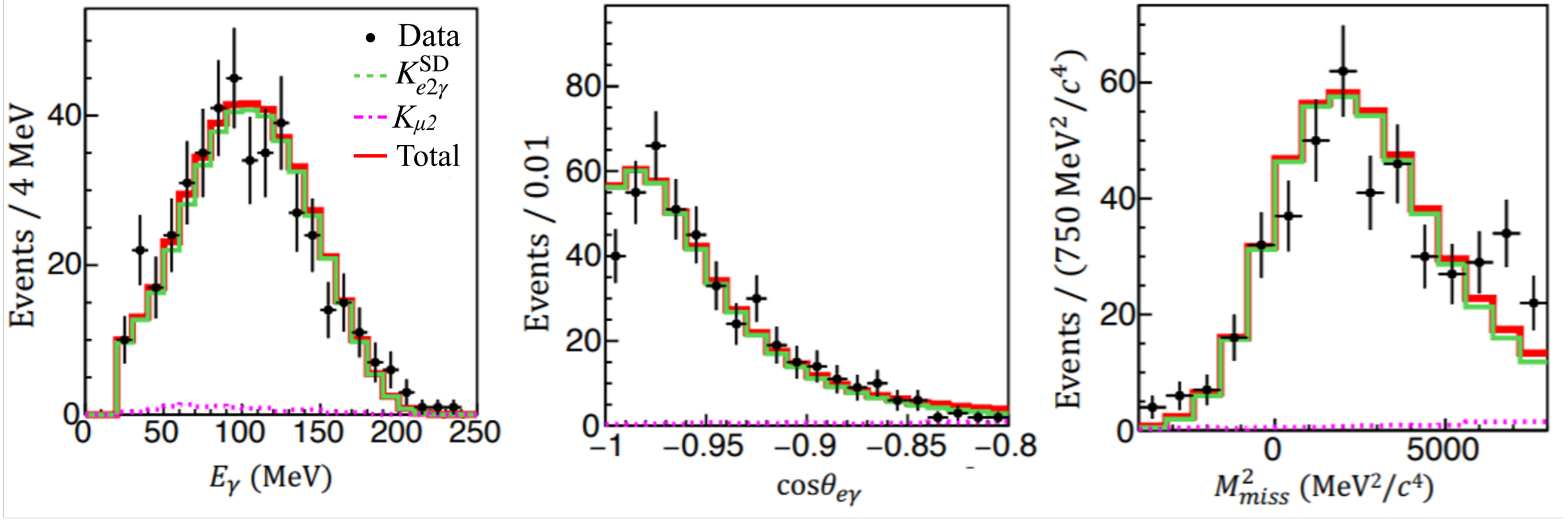




$K_{e2\gamma}^{SD}$ spectra with the photon hits in CsI(Tl)

- A photon hit in CsI(Tl) and $\mathrm{p}>230$ MeV/c were required.
- $E_\gamma, \cos\theta_{e\gamma}, M_{miss}^2$ are in good agreement with the MC simulation

  ※ $M_{miss}^2 = (M_K - E_e - E_\gamma)^2 - |\overrightarrow{P_e} + \overrightarrow{P_\gamma}|^2$
- The simulation has reproduced $K_{e2\gamma}^{SD}$ kinematics correctly.



Systematic uncertainties

The CsI(Tl) analysis

Source	Systematic uncertainty
Hole size of CsI(Tl) calorimeter	0.017
CsI(Tl) misalignment	< 0.001
Imperfect reproducibility of photon angular distribution	< 0.001
Accidental backgrounds in CsI(Tl)	0.004
Photon energy threshold of CsI(Tl)	0.007
Photon energy calibration of CsI(Tl)	< 0.001
Photon timing window	0.009
CsI(Tl) detection efficiency	0.012
AC detection efficiency	0.007
PGC detection efficiency	0.007
TOF detection efficiency	0.019
$K_{\mu 2}$ background subtraction	0.015
$K^{\mathrm{SD}}_{e2\gamma}$ form factor	0.011
K^+ stopping distribution	0.003
Material thickness in the central parts	< 0.001
Positron momentum resolution	0.002
Magnetic field	0.002
In-flight kaon decay	0.002
Total	0.036

The GSC analysis

Source	Uncertainty
GSC misalignment	< 0.001
GSC timing window	0.025
GSC detection efficiency	0.060
AC detection efficiency	0.008
PGC detection efficiency	0.010
TOF detection efficiency	0.013
$K_{\mu 2}$ background subtraction	0.042
$K^{\mathrm{SD}}_{e2\gamma}$ form factor	0.001
K^+ stopping distribution	0.009
Material thickness in the central parts	< 0.001
Positron momentum resolution	0.002
Magnetic field	0.002
In-flight kaon decay	0.002
Total	0.080

Results of the $K_{e2\gamma}^{SD}$ analysis

- CsI(Tl) analysis : $\frac{Br(K_{e2\gamma}^{SD})}{Br(K_{e2})} = 1.22 \pm 0.07_{stat} \pm 0.04_{syst}$ Preliminary

- GSC analysis : $\frac{Br(K_{e2\gamma}^{SD})}{Br(K_{e2})} = 1.22 \pm 0.13_{stat} \pm 0.08_{syst}$ Preliminary

- These results are consistent within the experimental uncertainties.

- $Br(K_{e2})$ should be corrected to be $Br(K_{e2} + K_{e2\gamma}^{IB})$.
  This correction is in progress and it will make the ratios smaller.

Summary

- The J-PARC E36 aims at searching for lepton universality violation by precisely measuring the ratio of the branching ratio of $K^+ \to \mu^+\nu$ and $K^+ \to e^+\nu$.

- Structure dependent radiative $K^+ \to e^+\nu\gamma(K^{SD}_{e2\gamma})$ decay is a background and has to be subtracted.

- We successfully observed the $K^{SD}_{e2\gamma}$ events using the Toroidal spectrometer with the CsI(Tl) calorimeter and the GSC counter.

- $\dfrac{Br(K^{SD}_{e2\gamma})}{Br(K_{e2})}$ has been obtained and the IB correction is in progress.