PSI2019, Villigen, Switzerland, Oct. 20-25, 2019

Test of lepton universality and search for light neutral bosons with TREK/E36 at J-PARC

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on behalf of the TREK/E36 Collaboration

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Outline

- Lepton non-universality?
- TREK Program
  - E06: Search for Time Reversal Symmetry Violation
  - E36: Test of Lepton Universality
  - Search for Heavy Neutrinos
  - Search for Light Bosons

Lower intensity

- TREK Apparatus
- Status

E36 data taking completed in 2015

http://trek.kek.jp

Limits of lepton universality (LU)

- e, μ, and τ: Different masses, same gauge couplings
- Lepton universality has been rather well established at 10^{-3} – 10^{-2} level
- Summary by A. Pich, arXiv:1201.0537v1 [hep-ph] (2012)

	$\Gamma_{\tau\to\nu_\tau e\bar\nu_e}/\Gamma_{\mu\to\nu_\mu e\bar\nu_e}$	$\Gamma_{\tau\to\nu_\tau\pi}/\Gamma_{\pi\to\mu\bar\nu_\mu}$	$\Gamma_{\tau\to\nu_\tau K}/\Gamma_{K\to\mu\bar\nu_\mu}$	$\Gamma_{W\to\tau\bar\nu_\tau}/\Gamma_{W\to\mu\bar\nu_\mu}$
$\vert g_\tau/g_\mu\vert$	1.0007 ± 0.0022	0.992 ± 0.004	0.982 ± 0.008	1.032 ± 0.012
	$\Gamma_{\tau\to\nu_\tau\mu\bar\nu_\mu}/\Gamma_{\tau\to\nu_\tau e\bar\nu_e}$	$\Gamma_{\pi\to\mu\bar\nu_\mu}/\Gamma_{\pi\to e\bar\nu_e}$	$\Gamma_{K\to\mu\bar\nu_\mu}/\Gamma_{K\to e\bar\nu_e}$	$\Gamma_{K\to\pi\mu\bar\nu_\mu}/\Gamma_{K\to\pi e\bar\nu_e}$
$\vert g_\mu/g_e\vert$	1.0018 ± 0.0014	1.0021 ± 0.0016	0.998 ± 0.002	1.001 ± 0.002
	$\Gamma_{W\to\mu\bar\nu_\mu}/\Gamma_{W\to e\bar\nu_e}$		$\Gamma_{\tau\to\nu_\tau\mu\bar\nu_\mu}/\Gamma_{\mu\to\nu_\mu e\bar\nu_e}$	$\Gamma_{W\to\tau\bar\nu_\tau}/\Gamma_{W\to e\bar\nu_e}$
$\vert g_\mu/g_e\vert$	0.991 ± 0.009	$\vert g_\tau/g_e\vert$	1.0016 ± 0.0021	1.023 ± 0.011

- Couplings to *W* and Z^0 (LEP-II [PDG 2010])

$$R^W_{\tau\ell} = \frac{2\,\mathrm{BR}\,(W\to\tau\,\overline{\nu}_\tau)}{\mathrm{BR}\,(W\to e\,\overline{\nu}_e)+\mathrm{BR}\,(W\to\mu\,\overline{\nu}_\mu)} = 1.055(23)$$

2.4σ dev.

- Belle, Babar, LHCb (HFLAV 2019)

$$\mathcal{R}(D^{(*)}) = \mathcal{B}(\overline{B}\to D^{(*)}\tau^-\overline{\nu}_\tau)/\mathcal{B}(\overline{B}\to D^{(*)}\ell^-\overline{\nu}_\ell)$$

3.6σ dev.

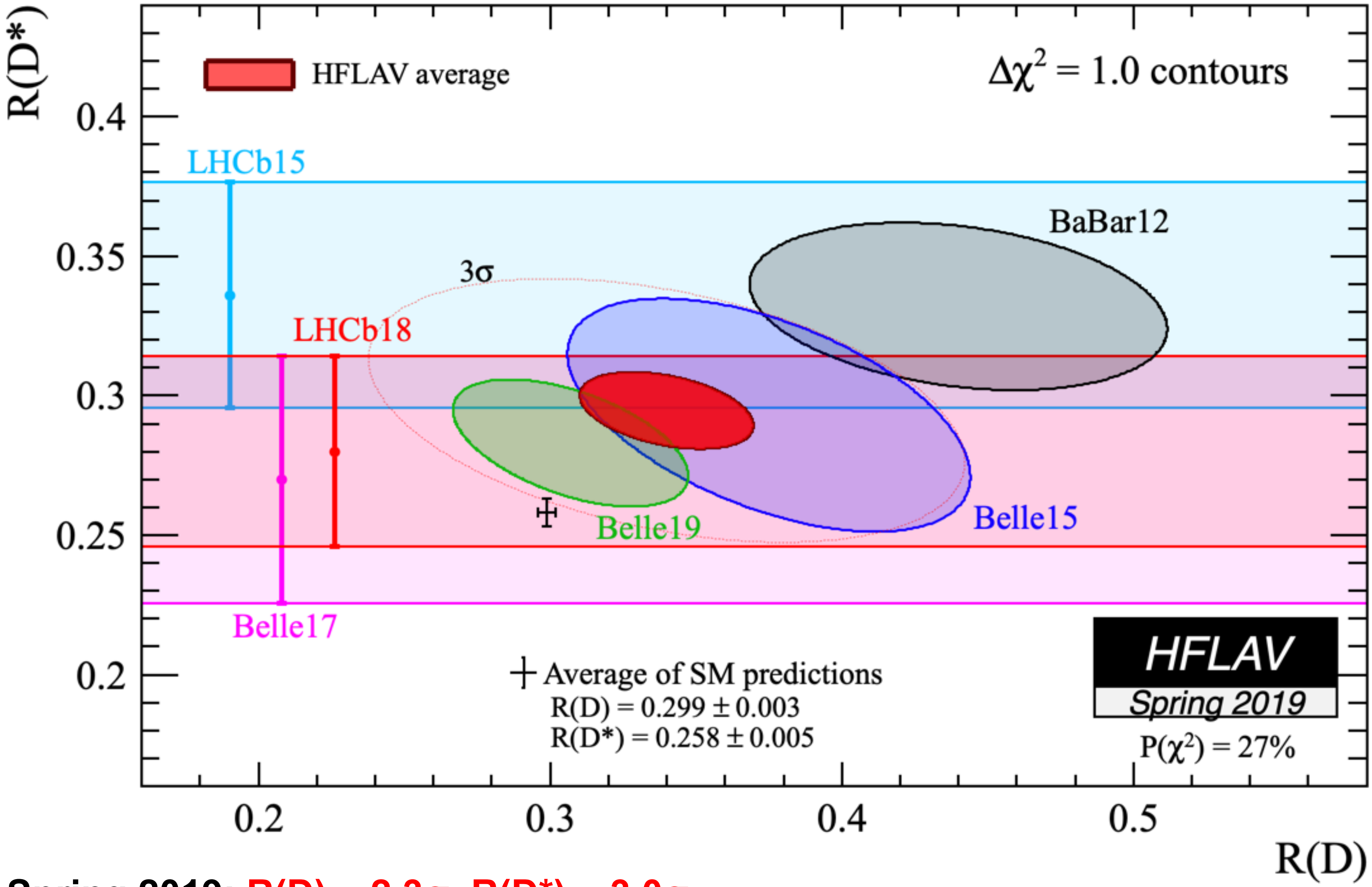
- LHCb (update from March 22, 2019)
  $\mathrm{BR}(B^+\to K^+\mu^+\mu^-) / \mathrm{BR}(B^+\to K^+e^+e^-) = 0.846^{+0.060}_{-0.054}{}^{+0.016}_{-0.014}$

2.5σ dev.

- Possible link to proton charge radius puzzle
  r_e (μH) = 0.84087 ± 0.00039 fm, r_e (CODATA2014) = 0.8751 ± 0.0061 fm

5.6σ dev.

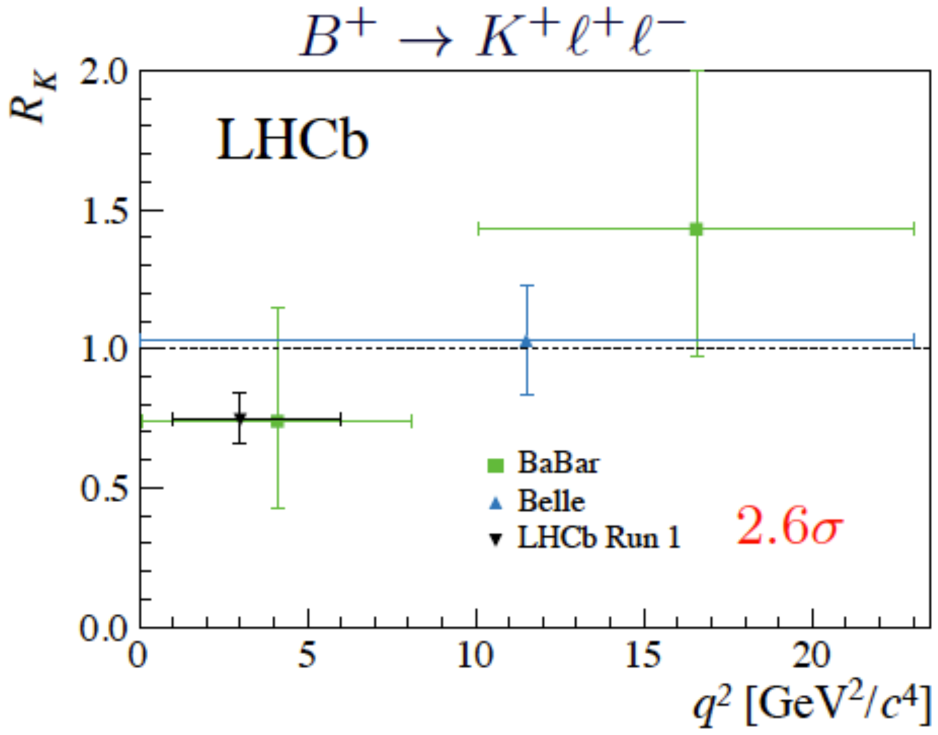
Lepton non-universality in B-decays (τ-μ)

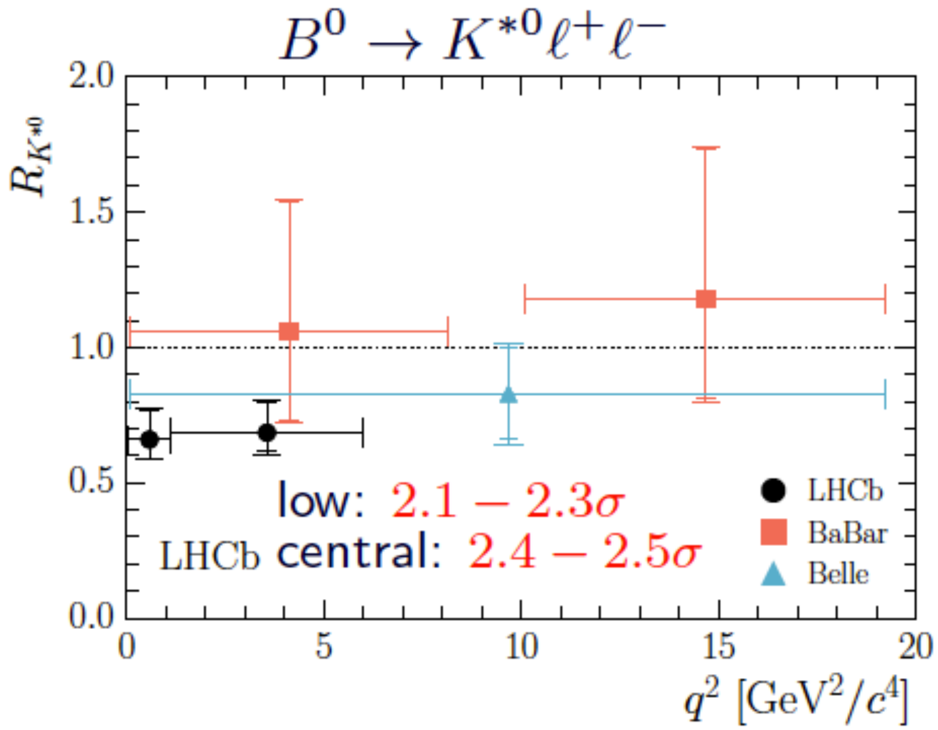


- **Spring 2019:** R(D) ~ 2.3σ, R(D*) ~ 3.0σ
  Combined at 3.62σ

Lepton non-universality in B-decays (μ-e)

- **LHCb: $R(K^{(+,*)}) = \Gamma(B^{(+,0)} \rightarrow K^{(+,*)} \mu^+\mu^-) / \Gamma(B^{(+,0)} \rightarrow K^{(+,*)} e^+e^-)$**
- **Summer 2018: $R(K^{(+,*)})$ different from SM at the 2.5σ level**



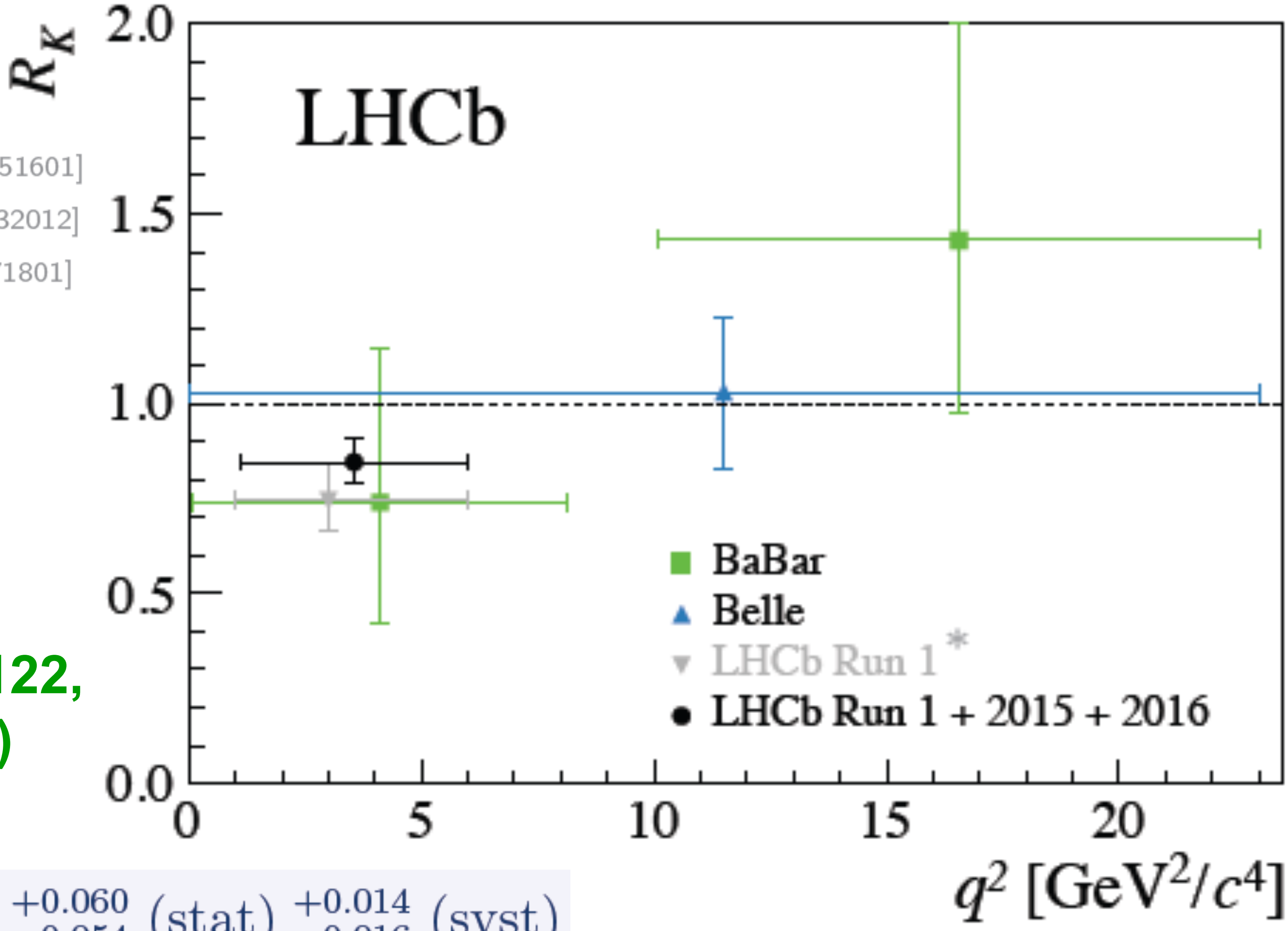


[LHCb, PRL 113 (2014) 151601]
[LHCb, JHEP 08 (2017) 055]
[BaBar, PRD 86 (2012) 032012]
[Belle, PRL 103 (2009) 171801]

Lepton non-universality in B-decays (μ-e)

- **LHCb: R(K$^+$) = Γ(B$^+$→K$^+$ μ$^+$μ$^-$) / Γ(B$^+$ → K$^+$ e$^+$e$^-$)**
- **Spring 2019: R(K$^+$) different from SM at 2.5σ level**

[LHCb, PRL 113 (2014) 151601]
[BaBar, PRD 86 (2012) 032012]
[Belle, PRL 103 (2009) 171801]



R. Aaji, PRL 122, 191801 (2019)

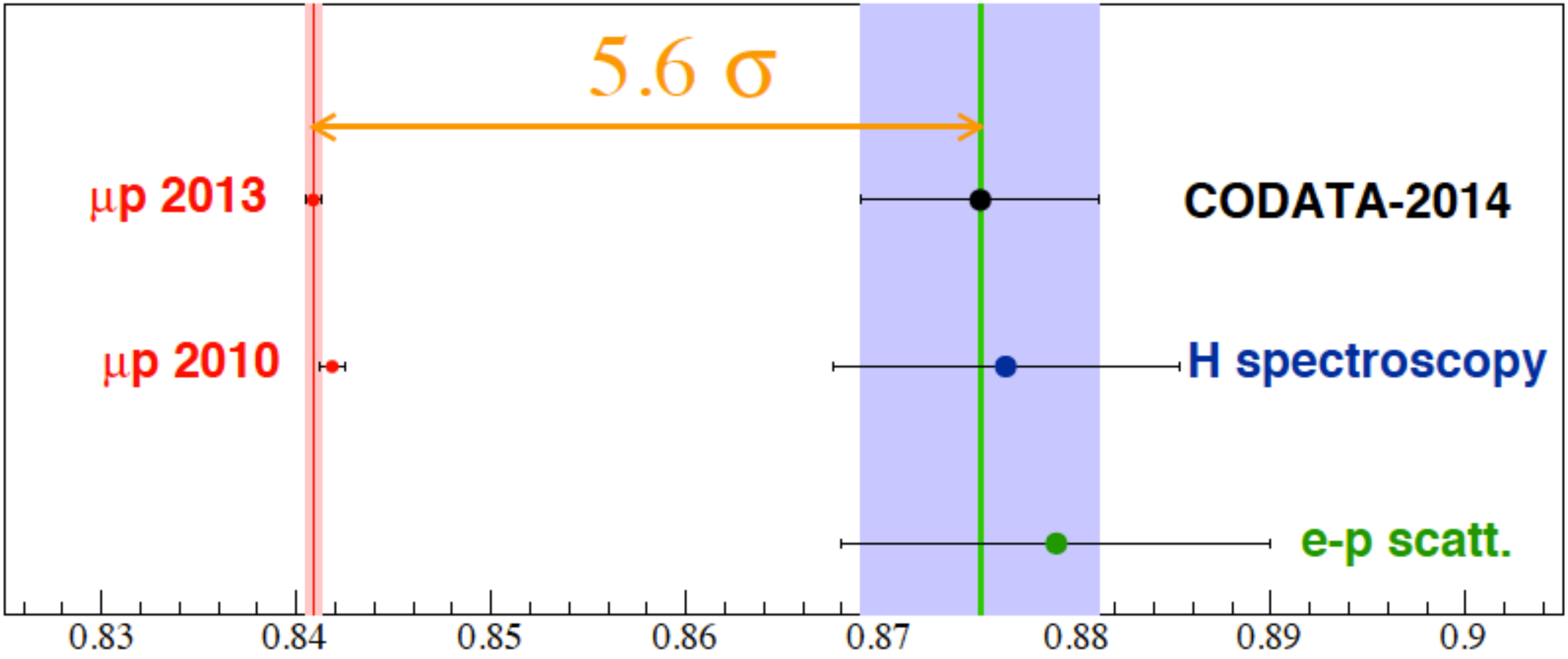
$$R_K = 0.846\ ^{+0.060}_{-0.054}\ (\text{stat})\ ^{+0.014}_{-0.016}\ (\text{syst})$$

The proton radius puzzle

The proton rms charge radius measured with

electrons: (0.8751 ± 0.0061) fm **(CODATA2014)**

muons: (0.8409 ± 0.0004) fm

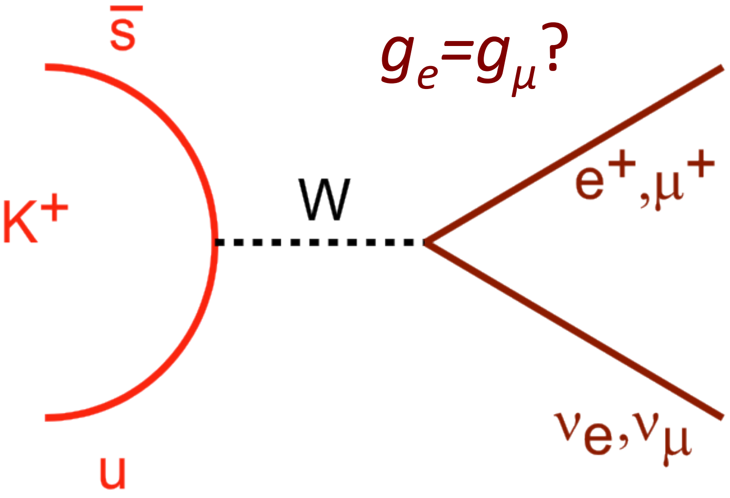


Proton charge radius (fm)

R. Pohl et al., Nature 466, 213 (2010)
A. Antognini et al., Science 339, 417 (2013)

Lepton universality in Standard Model K_{l2}

Standard Model:



- $\Gamma(K_{l2}) = g_l^2 \frac{G^2}{8\pi} f_K^2 m_K m_l^2 \left(1 - \frac{m_l^2}{m_K^2}\right)^2$
- **In the ratio of $\Gamma(K_{e2})$ to $\Gamma(K_{\mu 2})$, hadronic form factors are cancelled**
- $R_K^{SM} = \frac{\Gamma(K^+ \to e^+\nu)}{\Gamma(K^+ \to \mu^+\nu)} = \underline{\frac{m_e^2}{m_\mu^2}} \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 \underline{(1+\delta_r)}$

  helicity suppression

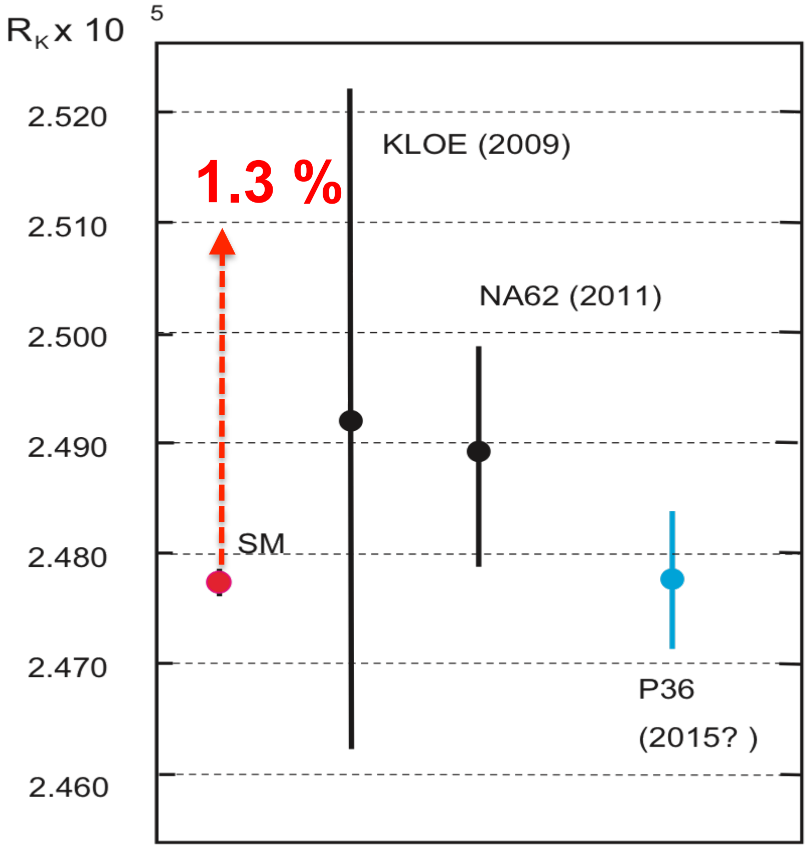
  radiative correction (Internal Brems.)
- **Strong helicity suppression of the electronic channel enhances sensitivity to effects beyond the SM**
- **Highly precise SM value**

  R_K^{SM}= (2.477±0.001) x 10^{-5} with δ_r = -0.036; (→ $\delta R_K/R_K$=0.04%)

  V. Cirigliano, I. Rosell, Phys. Rev. Lett. 99, 231801 (2007)

Experimental status of R_K

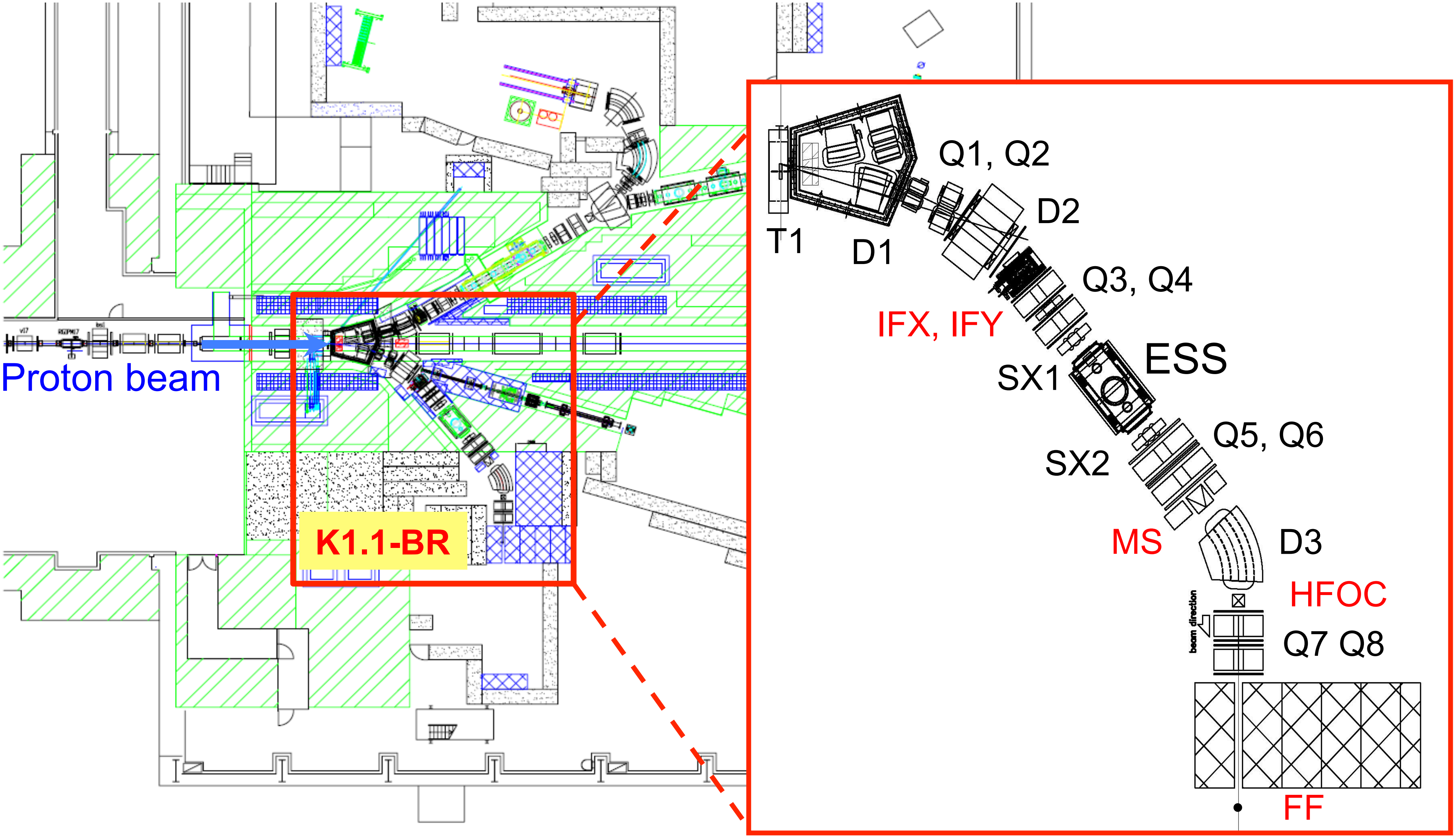
- **Highly precise SM value**
  $R_K = (2.477 \pm 0.001) \times 10^{-5}$ (with $\delta_r = -0.036$), $\delta R_K/R_K$=0.04%
  V. Cirigliano, I. Rosell, Phys. Rev. Lett. 99, 231801 (2007)
- **KLOE @ DAΦNE (in-flight decay)**
  $R_K = (2.493 \pm 0.025 \pm 0.019) \times 10^{-5}$
  F. Ambrosino et al., Eur. Phys. J. C64, 627 (2009)
- **NA62 @ CERN-SPS (in-flight decay)**
  $R_K = (2.488 \pm 0.007 \pm 0.007) \times 10^{-5}$
  C. Lazzeroni et al., PLB719, 105 (2013)
- **World average (2012)**
  $R_K = (2.488 \pm 0.009) \times 10^{-5}$, $\delta R_K/R_K$=0.4%
- **Dominant systematics:**
  - **In-flight-decay experiments: kinematics overlap**
  - **E36 stopped K^+: detector acceptance and target**
  - **E36 complementary to in-flight experiments**



- **E36 orig. goal: $\delta R_K/R_K = \pm 0.2\%$ (stat) $\pm 0.15\%$ (sys) [0.25% total]**

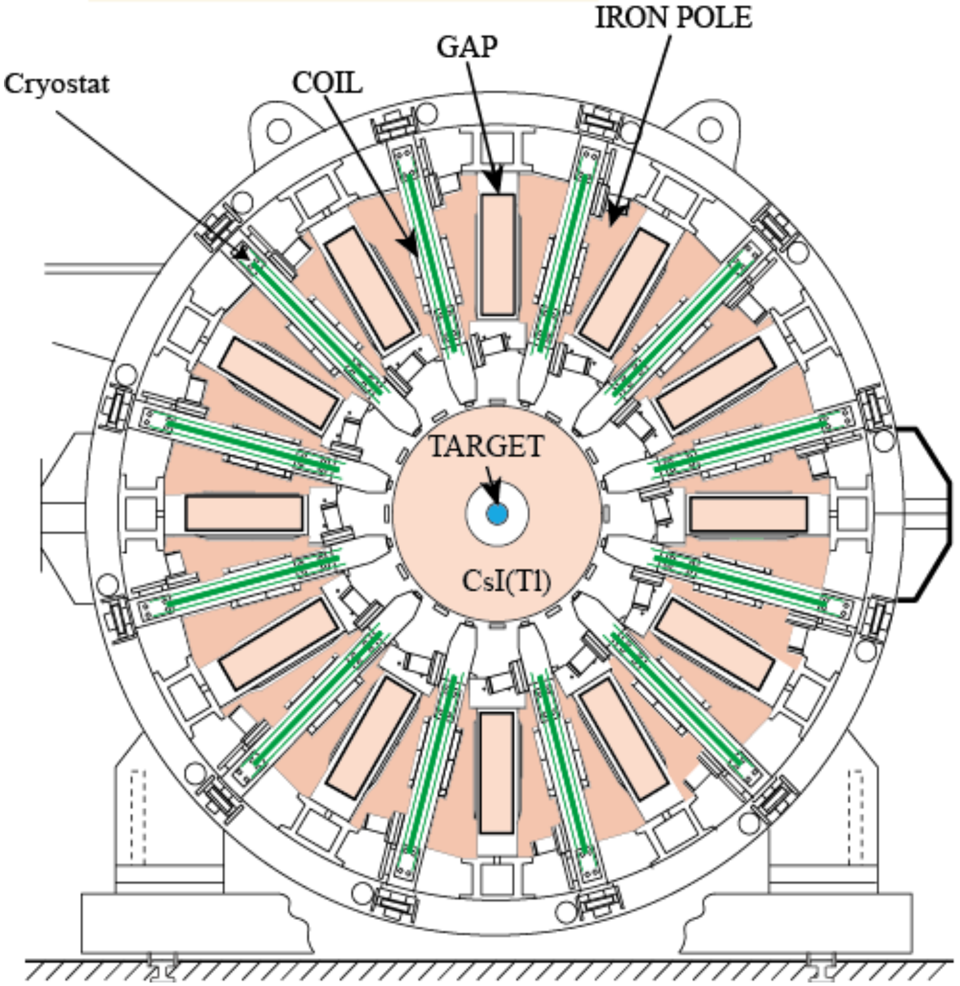
K1.1BR beamline

- **K1.1BR constructed in 2009/10, commissioned by TREK Coll. in Oct. 2010**
- **Re-aligned after 3/11 earthquake, re-commissioned June 2012, paused 2013/14**
- **J-PARC Hadron Hall operations restarted in April 2015**
  π/K ratio ~1.3, av. kaon flux 2.3x10^{5} Hz at 40 kW   [1.4x10^{6}/(2s-spill) at 6s-rep.]

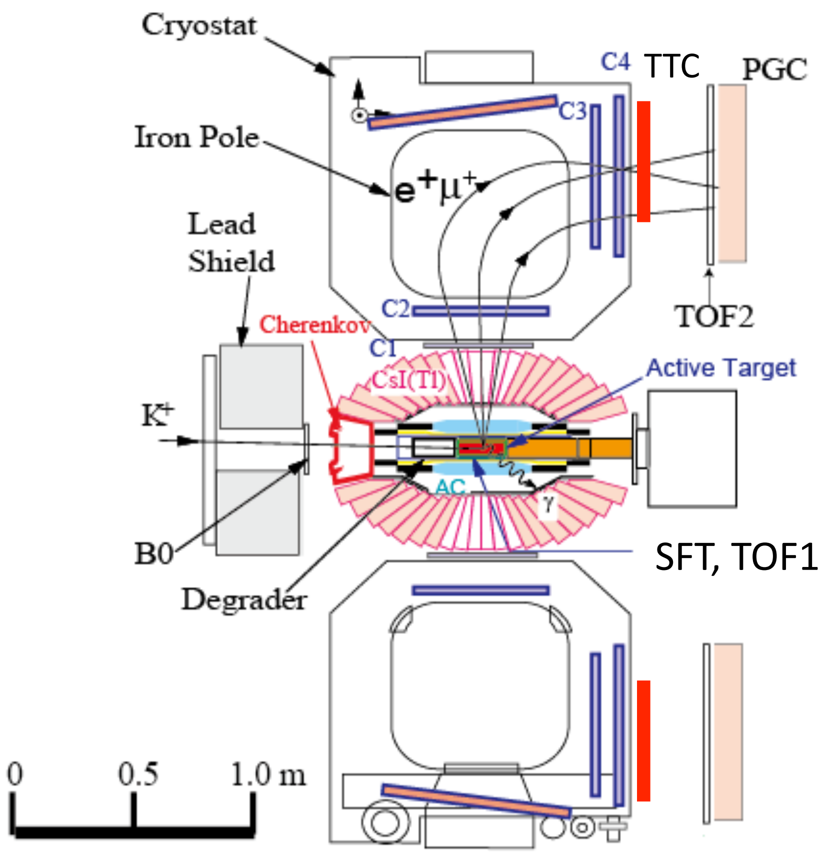


The TREK apparatus for E36

End View



Side View



Modest upgrade of KEK-PS E246

Stopped K^+
- K1.1BR beamline
- Fitch Cherenkov
- K^+ stopping target (TGT)

Tracking (π,μ,e)
- MWPC (C2, C3, C4)
- Spiral Fiber Tracker (SFT)
- TGT, TOF1,2, TTC

PID
- TOF2-TOF1 (TOF)
- Aerogel Che. (AC)
- Pb glass (PGC)

Gamma
- CsI(Tl)
- Gap veto

The TREK apparatus for E36

Stopped K^+
- K1.1BR beamline
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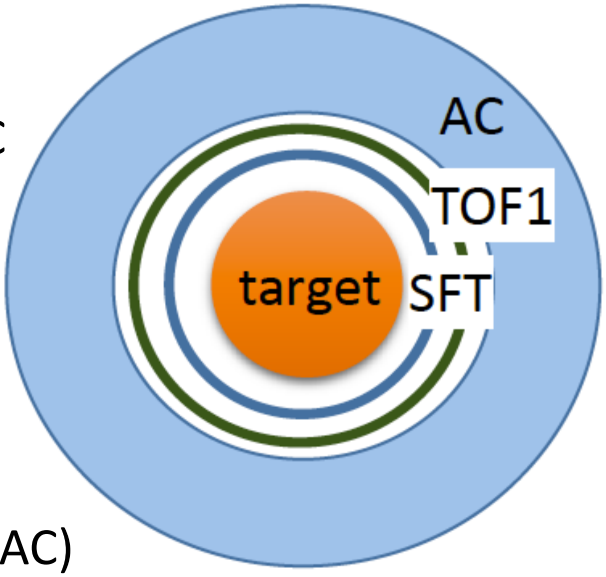
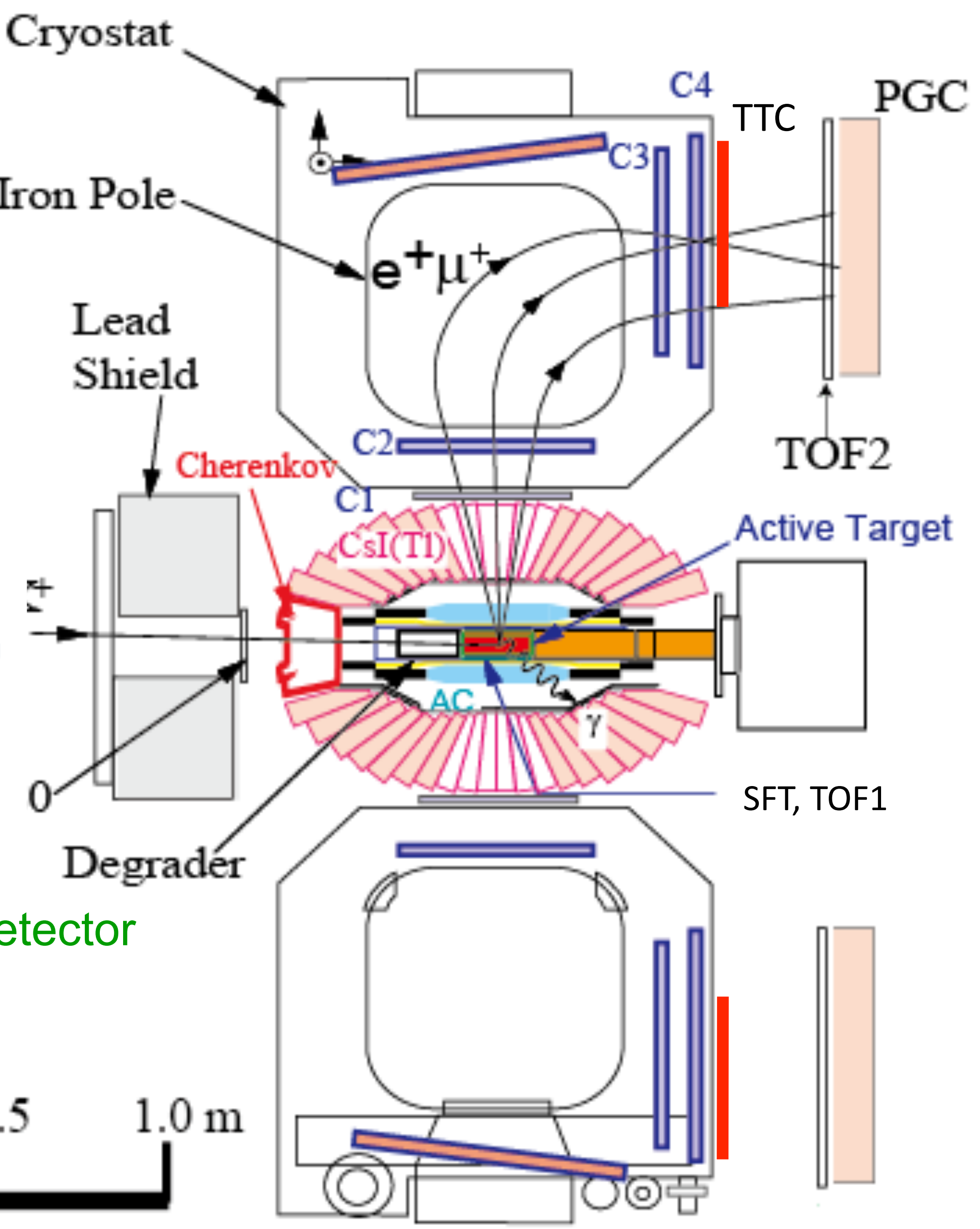
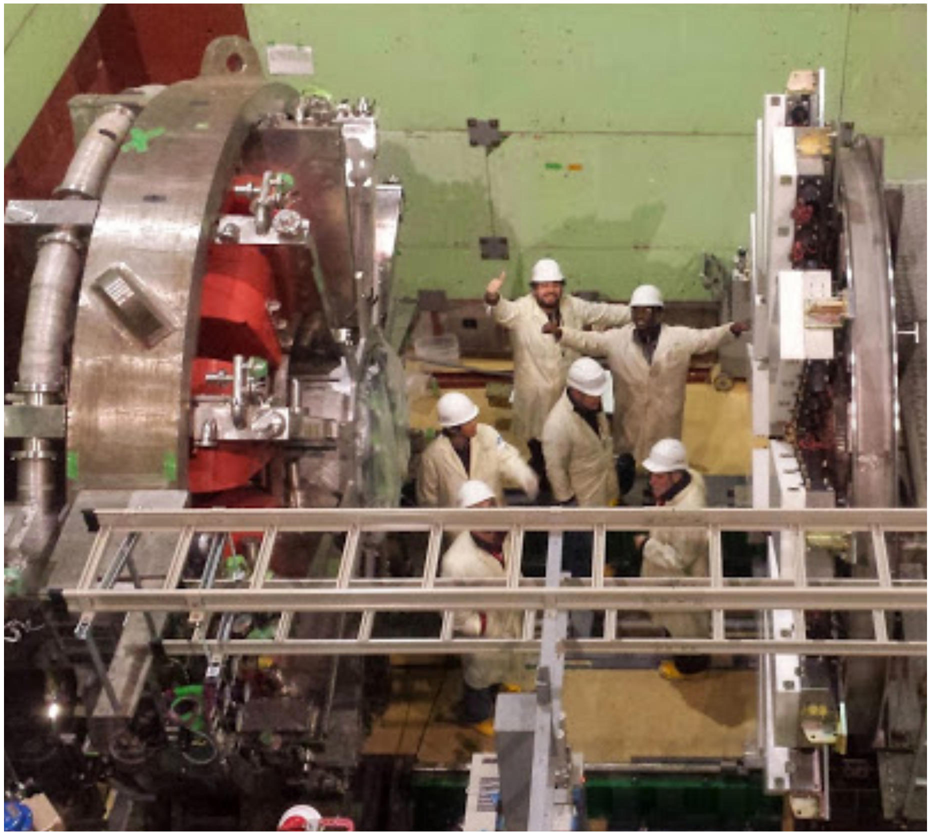


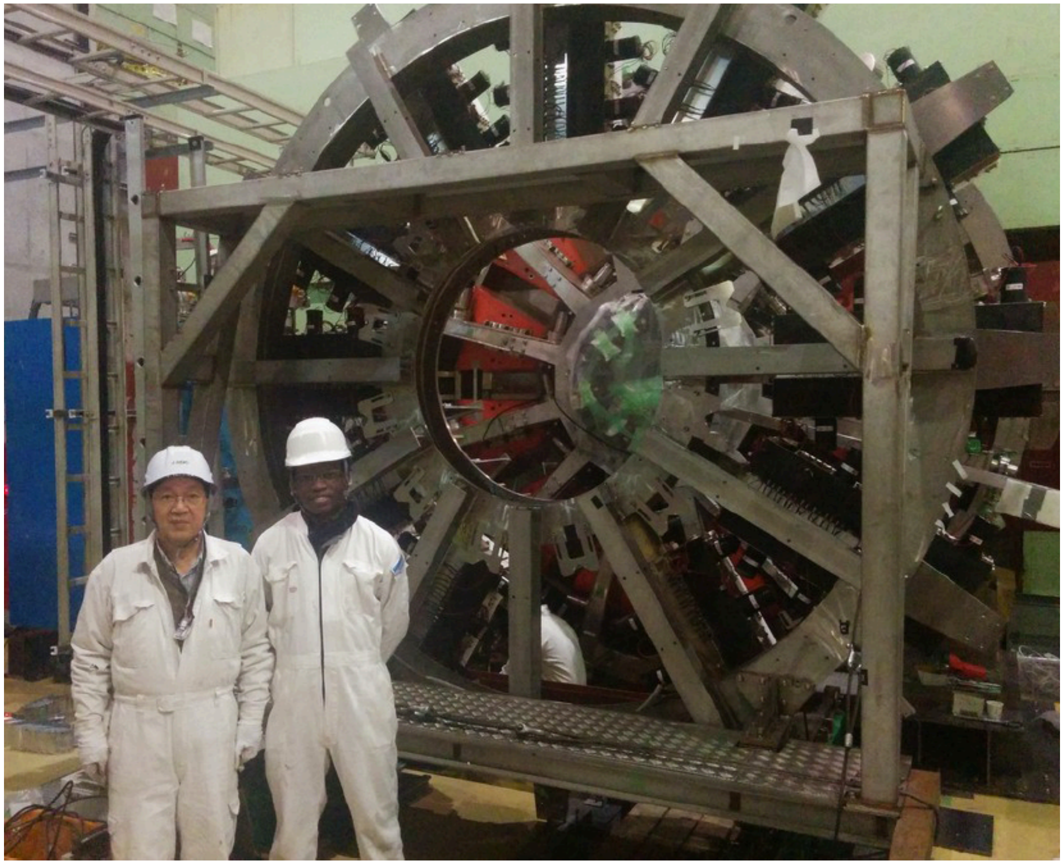
Zoomed inner detector (schematically)



TREK/E36 installation and commissioning

- **Completed detector installation April 2015**
- **Electronics and DAQ set up and tested (area available only mid-January)**
- **Conditioning of MWPCs**





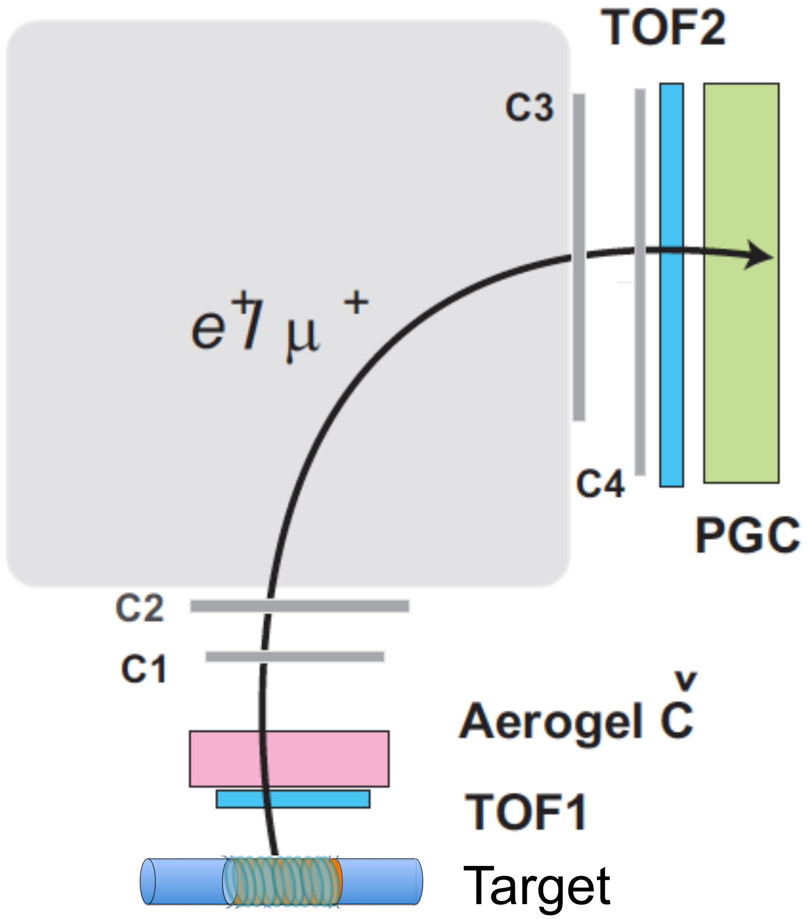
Bishoy Dongwi (Hampton U.)

- **Commissioning of TGT+TOF1+SFT with cosmic rays**
- **Check-out of all detectors with beam**
- **Commissioning of toroidal magnet including cryogenics**

μ^+/e^+ identification (designed)

PID with:

- **TOF**
- **Aerogel Č**
- **Lead glass**

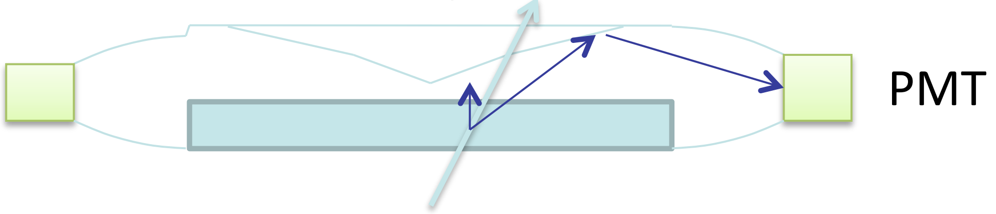


TOF

Flight length	250 cm
Time resolution	<100 ps
Mis-ID probability	7x 10^{-4}

Aerogel Č counter

Radiator thickness	4.0 cm
Refraction index	1.08
e^+ efficiency	>98%
Mis-ID probability	3%



Lead glass (PGC)

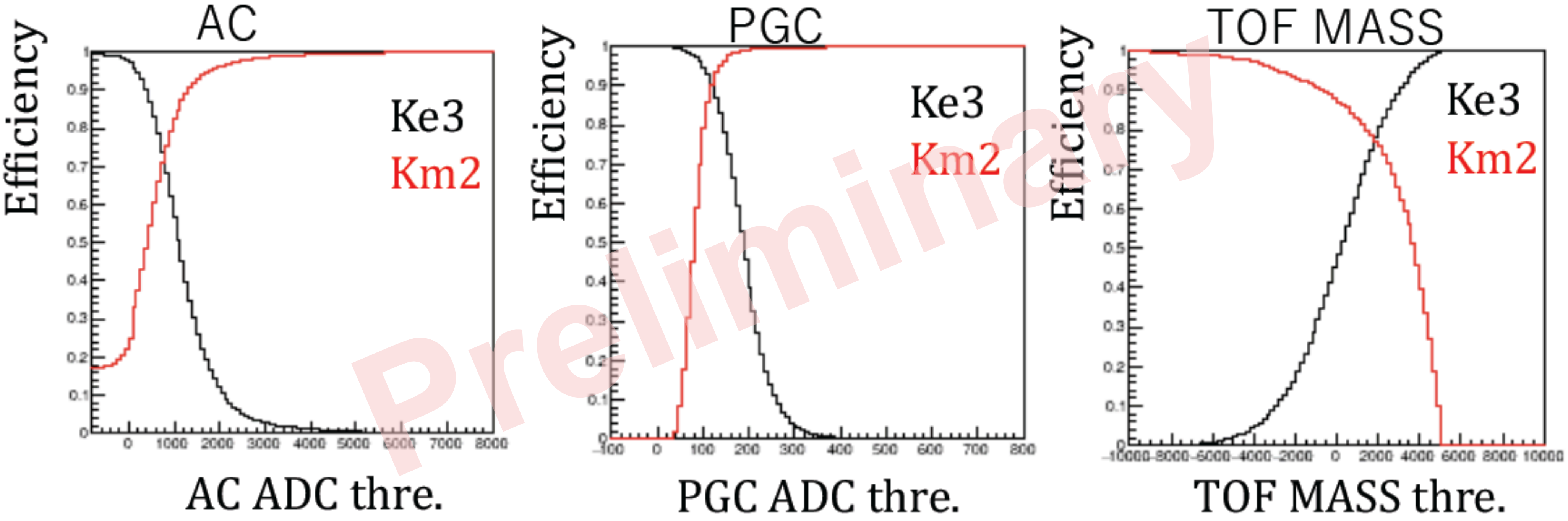
Material	SF6W
Refraction index	1.05
e^+ efficiency	98%
Mis-ID probability	4%

$$\boxed{P_{mis}\text{ (total)} = P_{mis}\text{ (TOF)} \times P_{mis}\text{ (AČ)} \times P_{mis}\text{ (LG)} = 8 \times 10^{-7} < O(10^{-6})}$$

μ^+/e^+ identification (typical performance)

- **Redundant PID to maximize e^+ efficiency and minimize μ^+ mis-ID**
- **PID with:**

Aerogel Cherenkov (AC)
Lead glass (PGC)
Time of flight (TOF)



— e^+ efficiency — μ^+ rejection

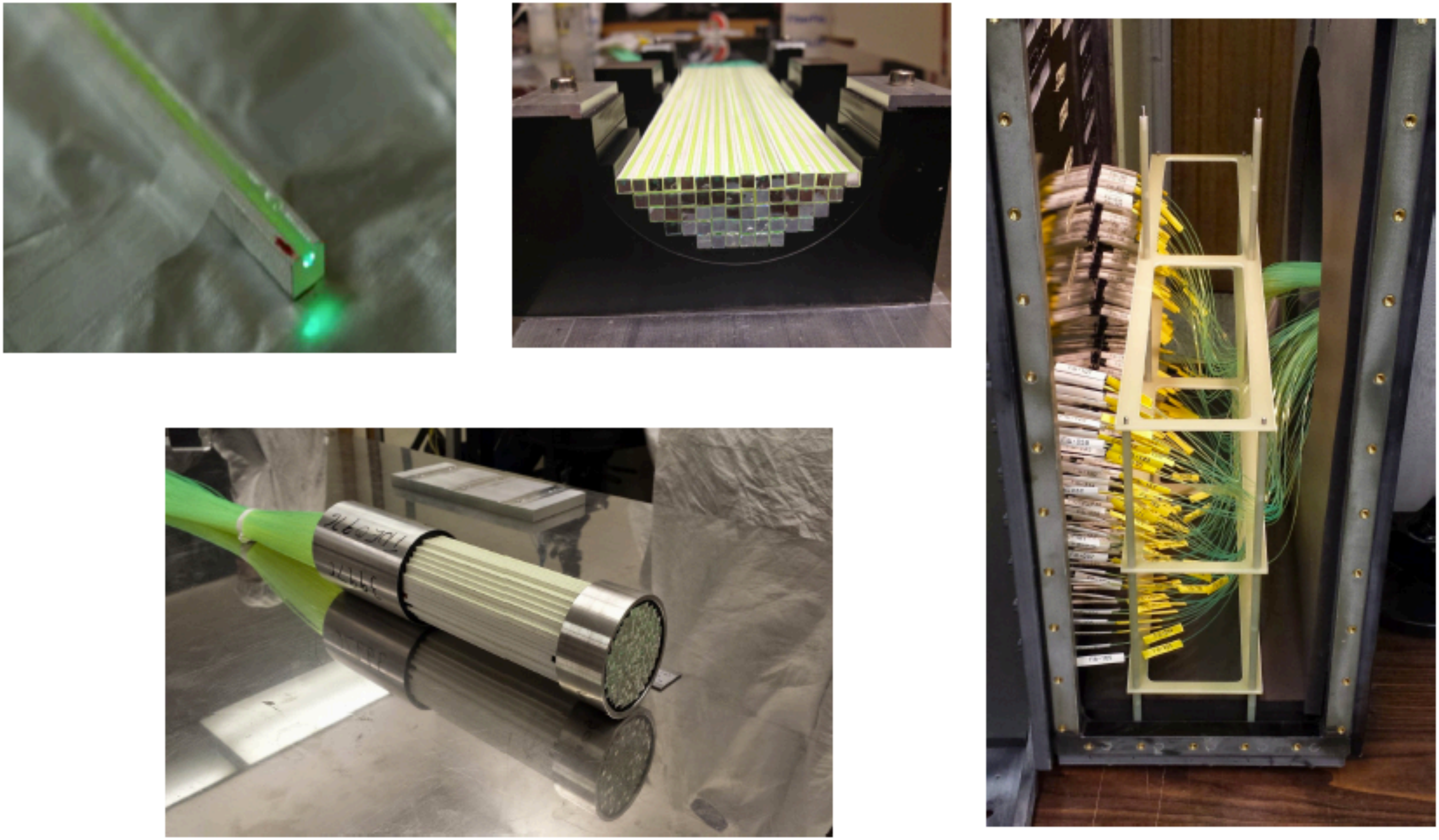
H. Ito, K. Horie, S. Shimizu

PID performance limitation mandates subtraction of residual muon background

Scintillating-fiber kaon stopping target

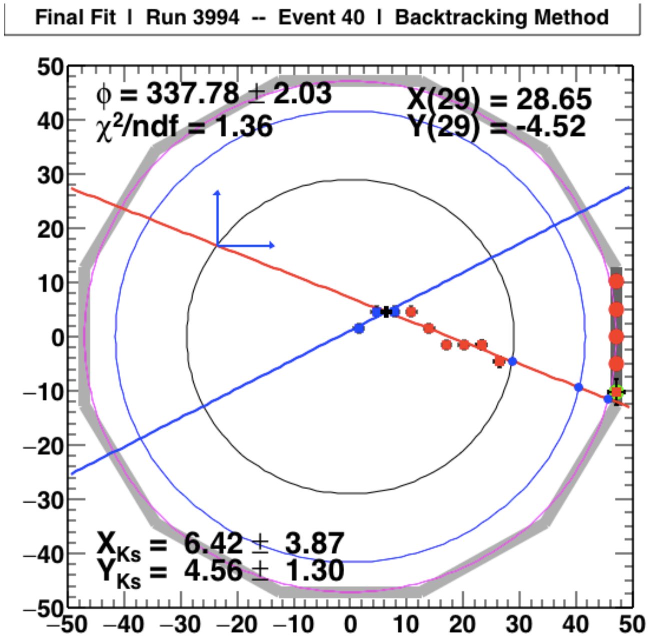
- Built at TRIUMF (delivered to J-PARC in September 2014)
- 256 scintillating fibers (3x3 mm^2), WLS fiber in groove, diameter 6 cm
- MPPC readout with VF-48 FADC

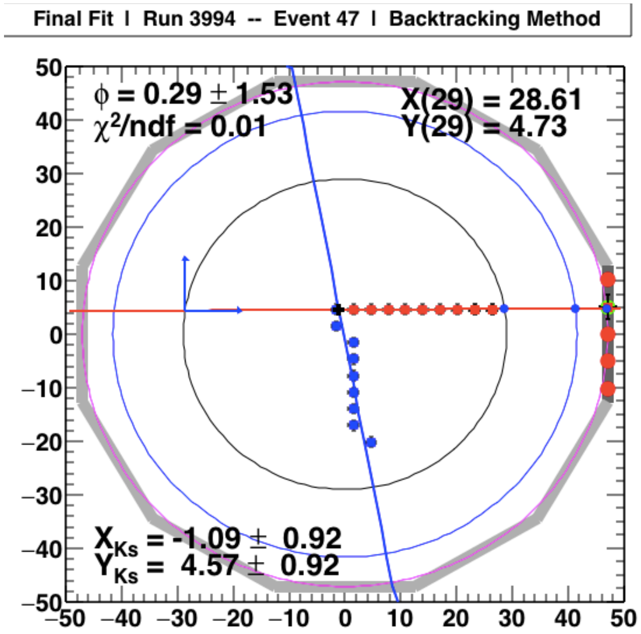
M. Hasinoff, S. Bianchin



Target performance

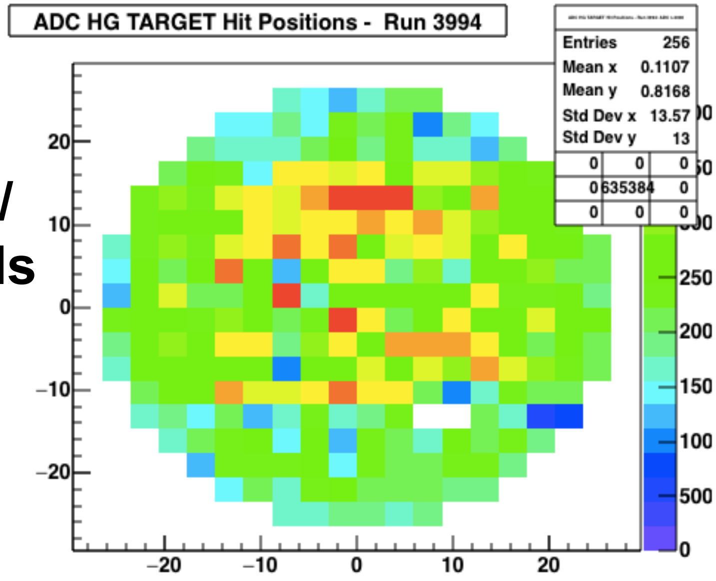
Kaon stop + decay particle



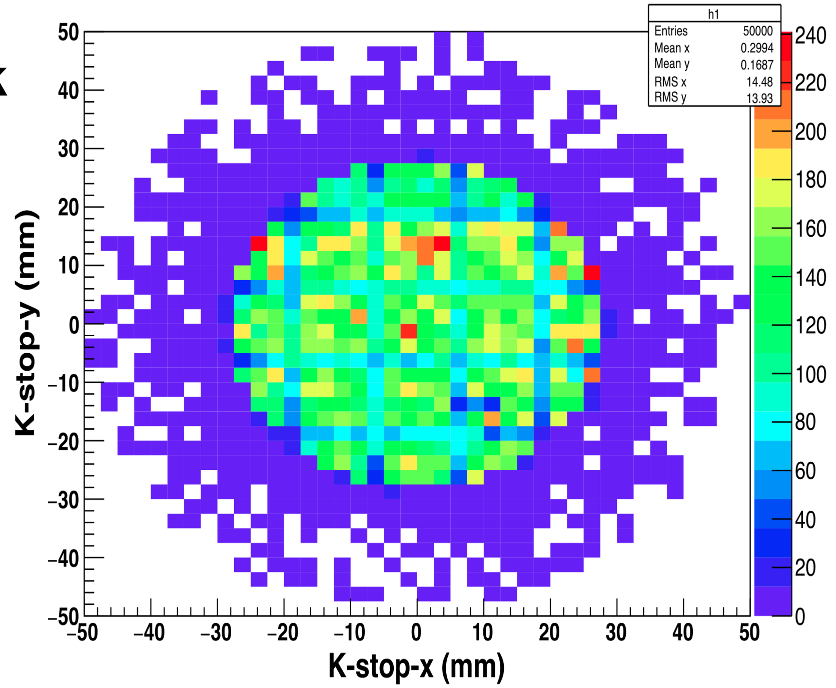


Kaon beam profiles

From fibers w/ highest signals



From track intercepts

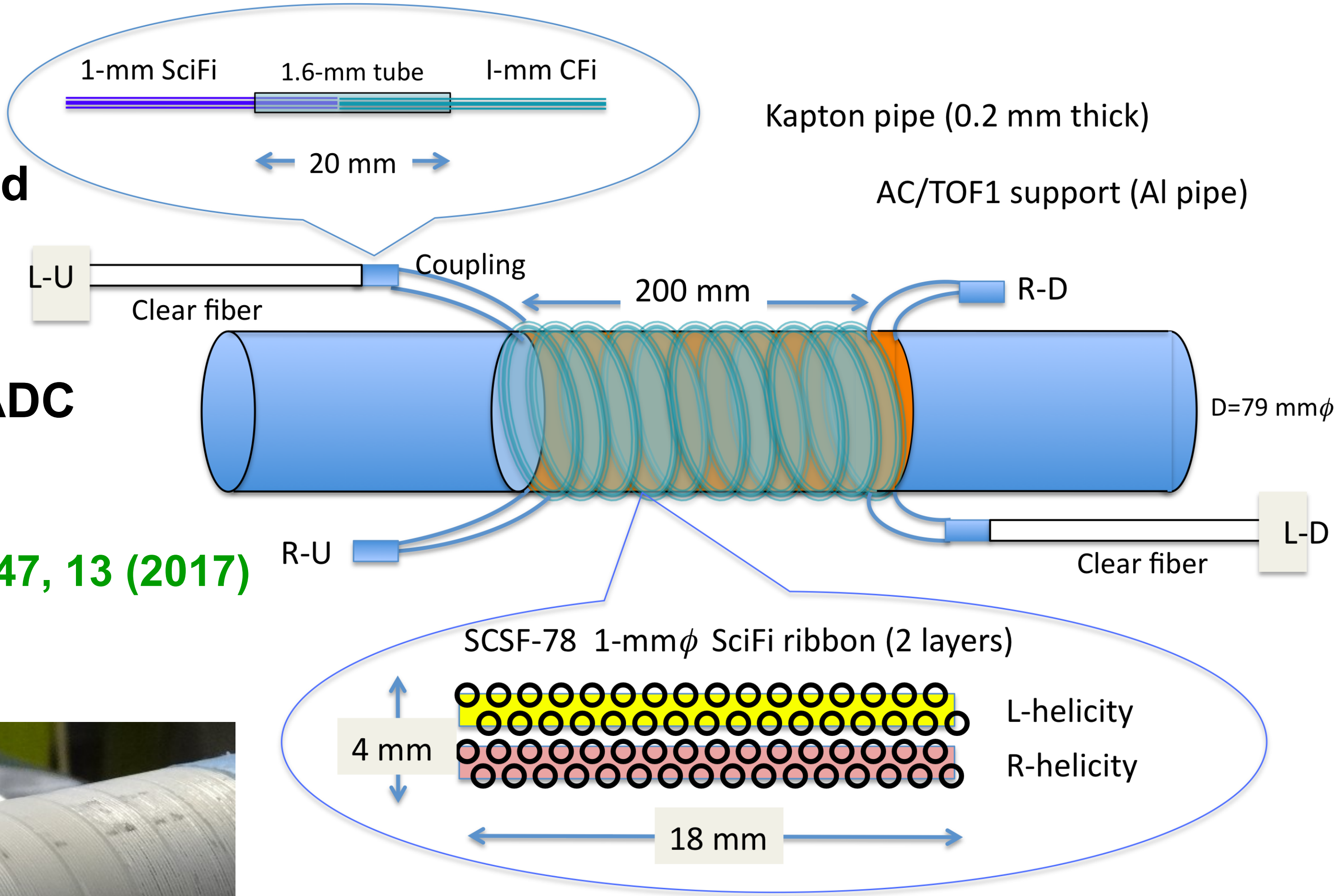


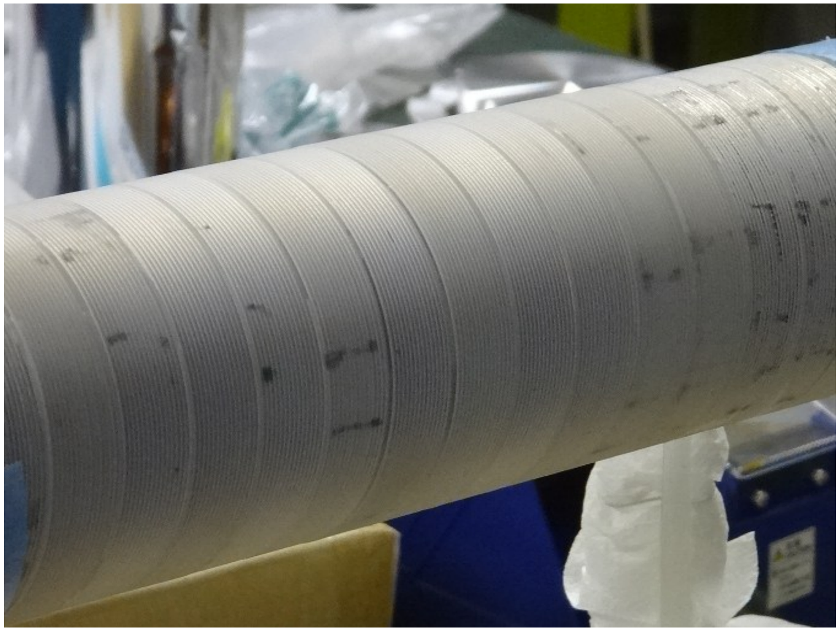
Preliminary

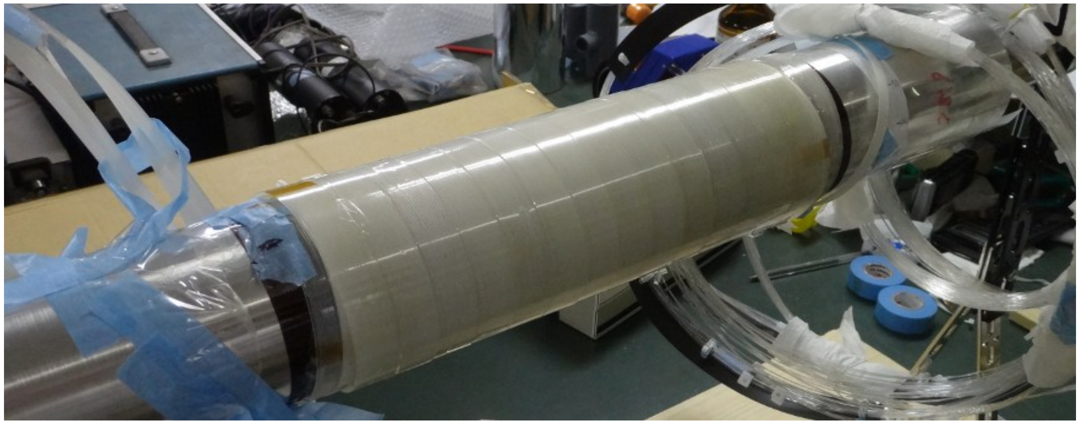
S. Bianchin

Spiral fiber tracker (SFT)

- **Double-layer fibers in 2 helicities wrapped around target bundle for near target vertex**
- **Using same VF-48 FADC as for fiber target**
- **V. Mineev *et al.*, NIM A847, 13 (2017)**

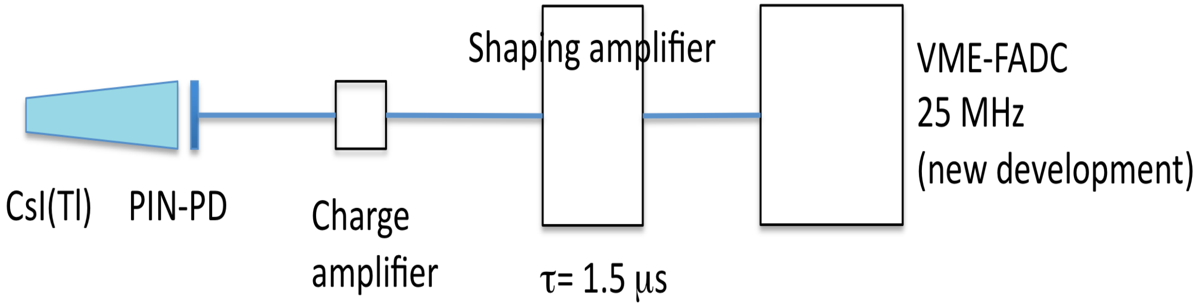




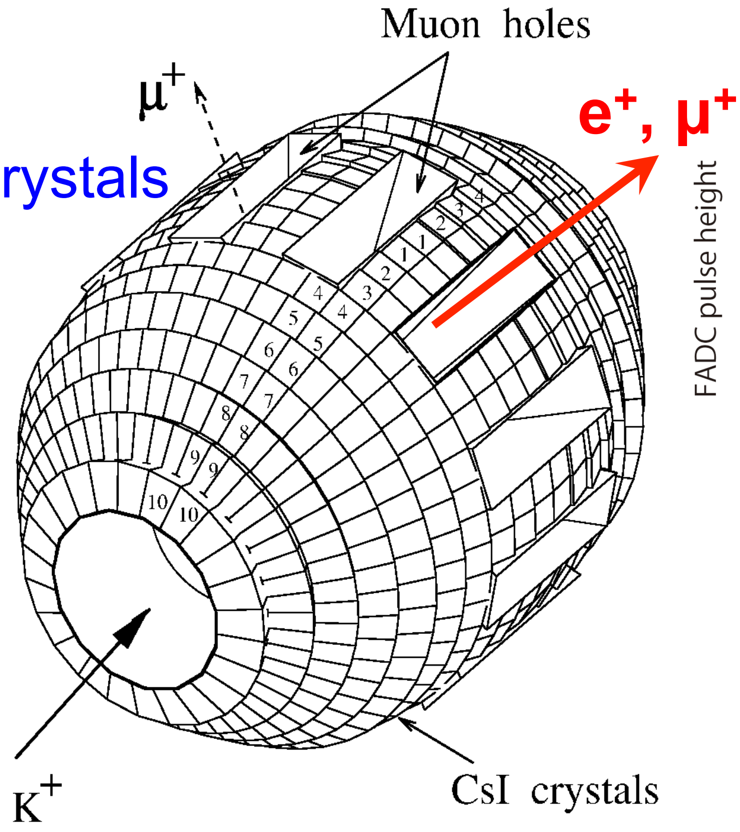


CsI(Tl) calorimeter

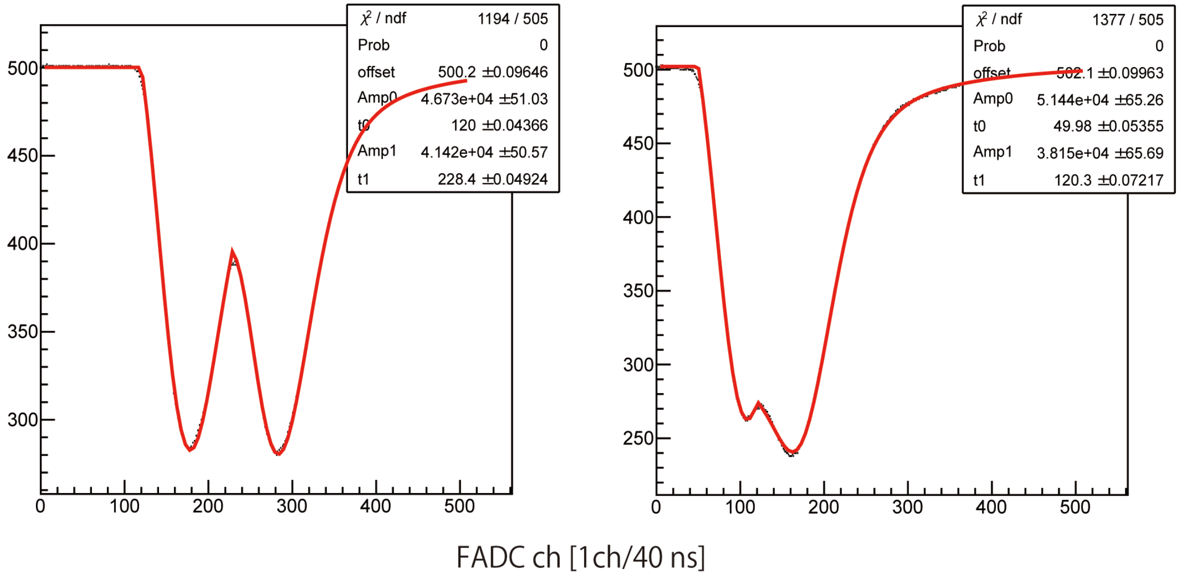
Crystal length	**250 mm**
Number of crystals	**768**
Segmentation	**7.5°**
Coverage	**~75%**
Readout	**PIN diodes**
Maximum rate	**~200 kHz**



768 crystals



Typical pileup events

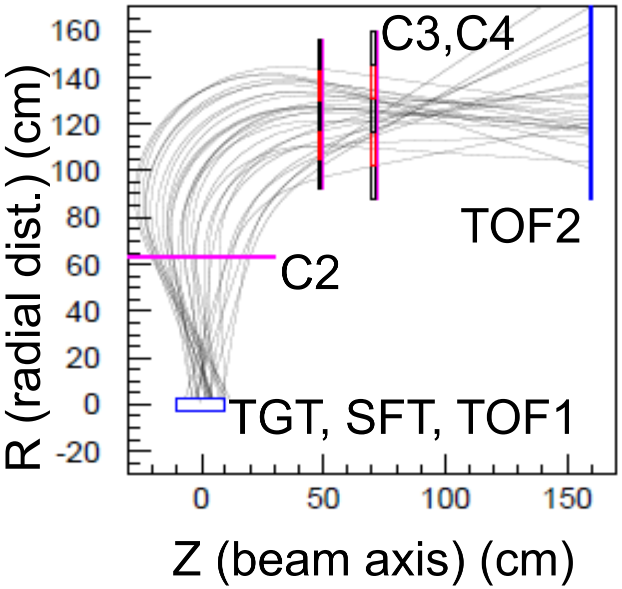


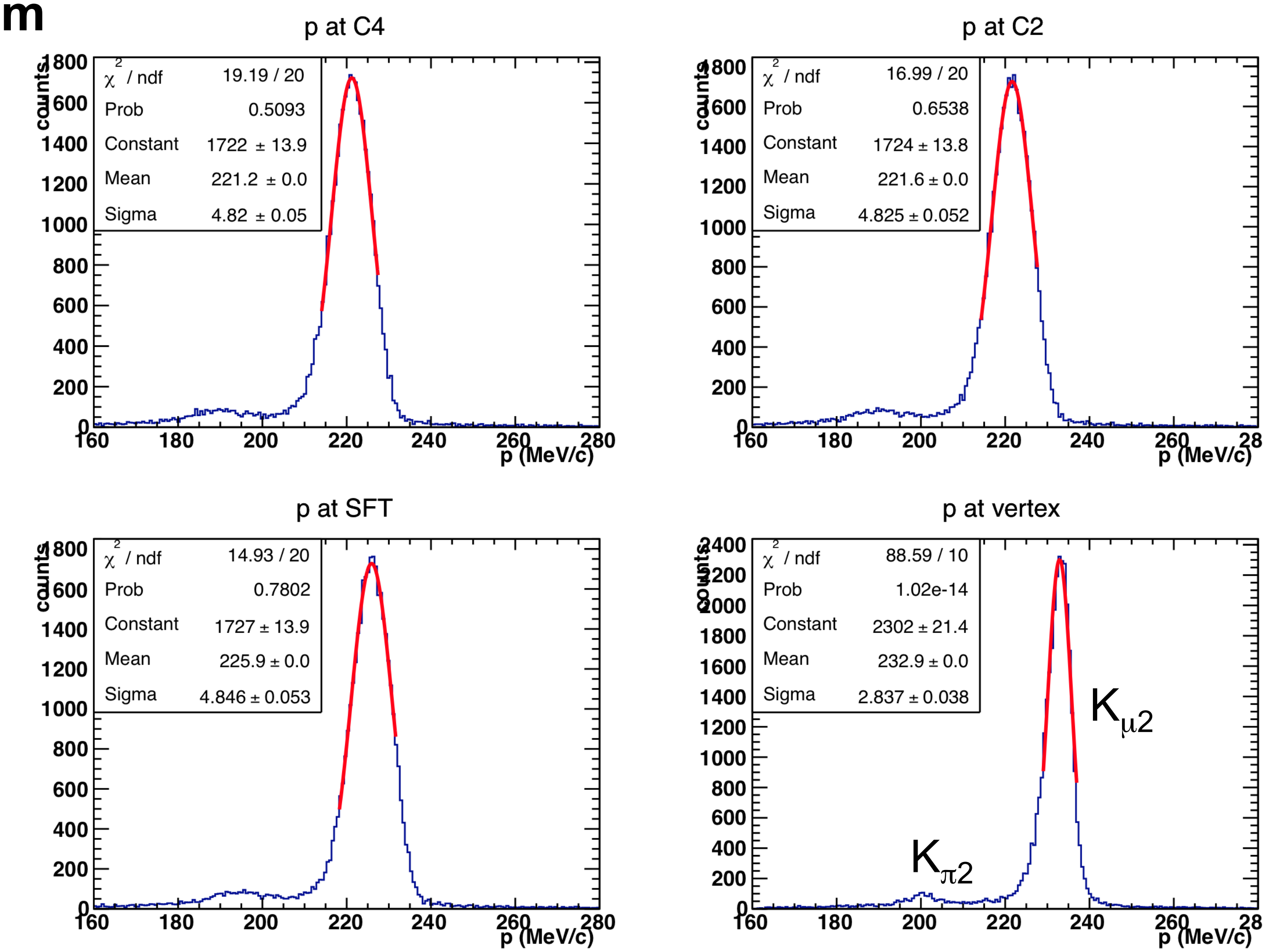
- *possible to separate with FADC*
- *has been implemented successfully*
- ***H. Ito et al., NIM A901, 1 (2018)***

Detection of photons from ***$K^+ \to \mu^+(e^+)\ \nu\ \gamma$ from IB+SD***
Detection of ***e^+, e^- from A' decay***

Momentum determination

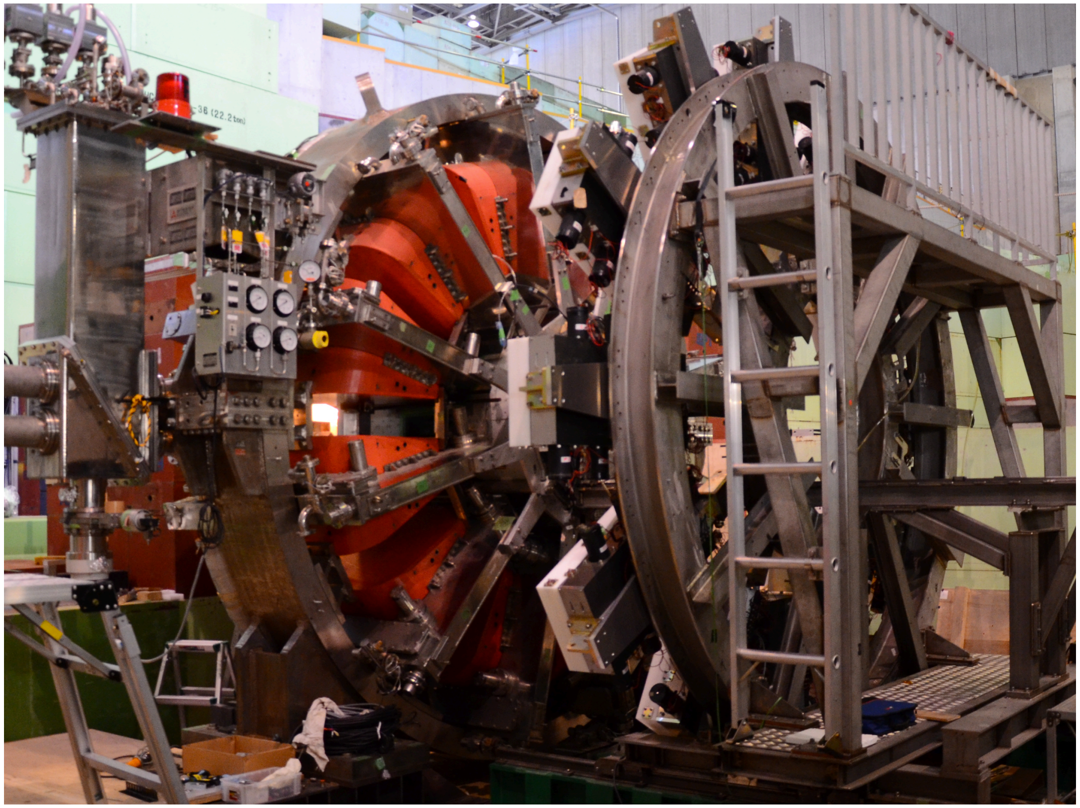
- **Charged particle momentum from tracking with C2, C3, C4 based on Kalman Filter technique (Tongtong Cao)**
- **Momentum evaluated at C4, C2, SFT, and vertex, corrected for energy loss, shifted from expected value by O(1%) (mag. field and vertex uncertainty)**
- **Monochromatic peaks from $K_{\mu2}$ and $K_{\pi2}$ observed**
- **Momentum resol. ~1.2%, improve to ~1% with target and SFT in KF for more accurate vertex**

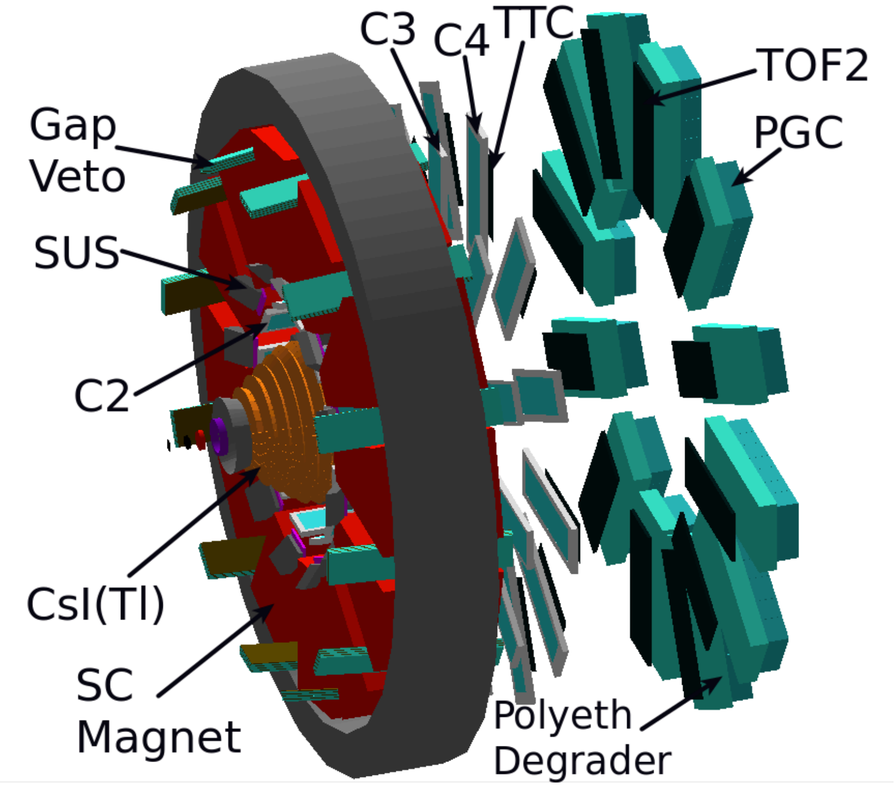


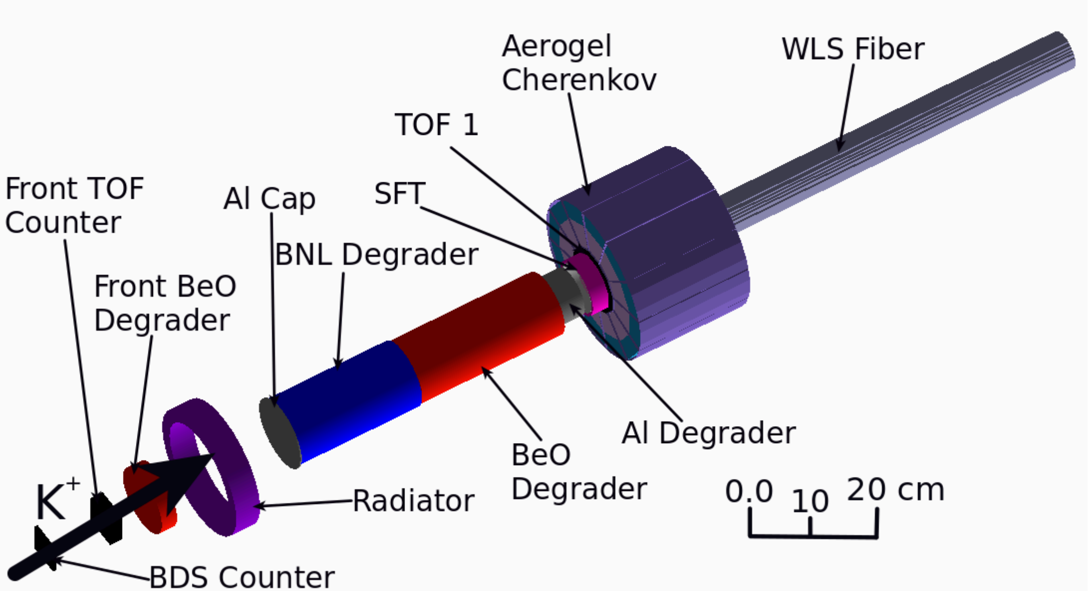


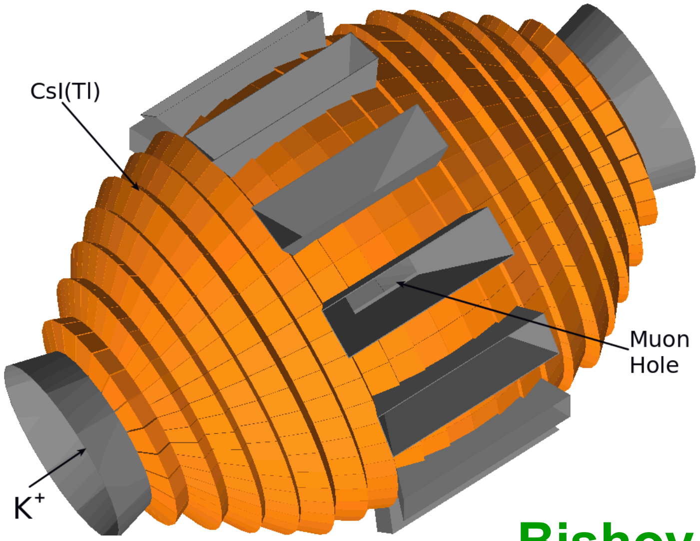
Preliminary

Geant4 description of TREK/E36





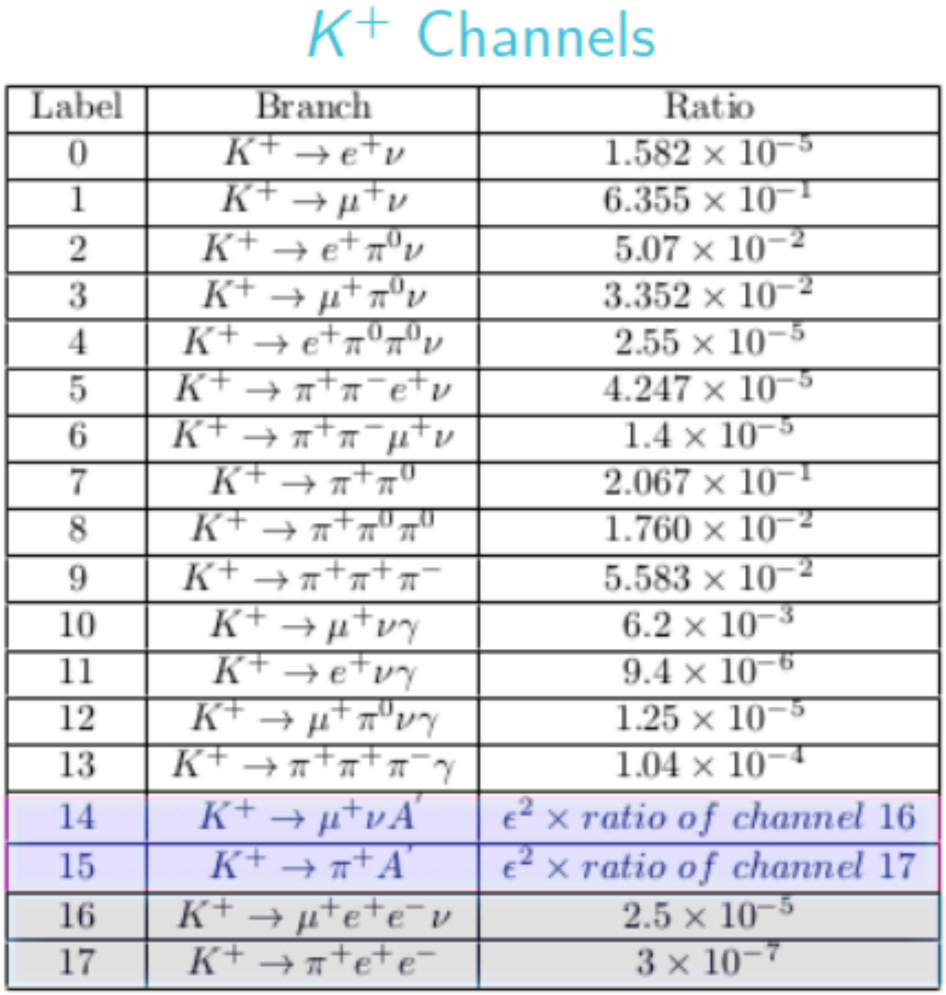




CsI(Tl)

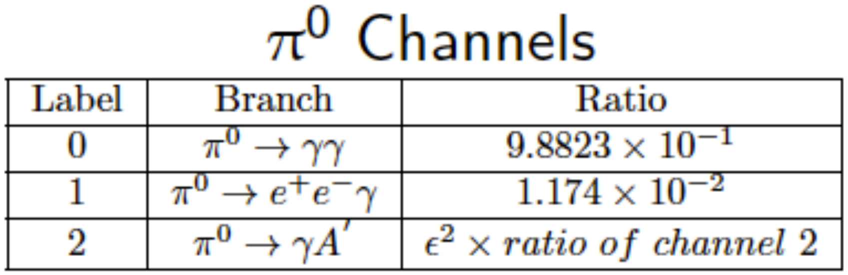
Bishoy Dongwi

Geant4 description of TREK/E36



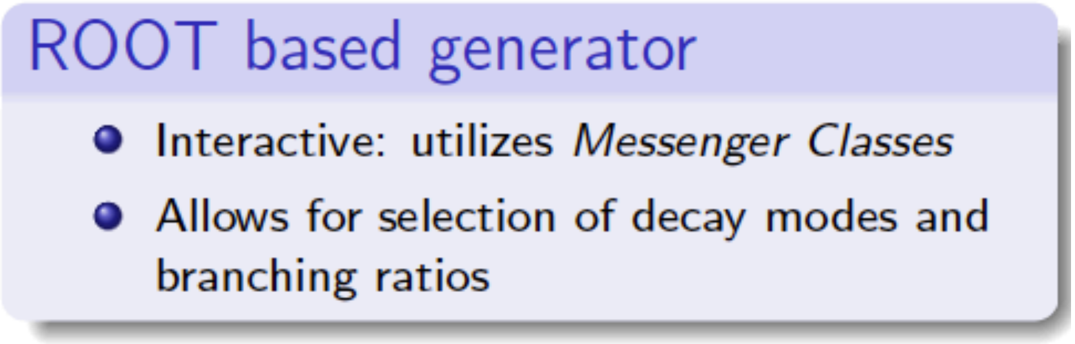
K^+ Channels

Label	Branch	Ratio
0	$K^+ \to e^+\nu$	1.582×10^{-5}
1	$K^+ \to \mu^+\nu$	6.355×10^{-1}
2	$K^+ \to e^+\pi^0\nu$	5.07×10^{-2}
3	$K^+ \to \mu^+\pi^0\nu$	3.352×10^{-2}
4	$K^+ \to e^+\pi^0\pi^0\nu$	2.55×10^{-5}
5	$K^+ \to \pi^+\pi^-e^+\nu$	4.247×10^{-5}
6	$K^+ \to \pi^+\pi^-\mu^+\nu$	1.4×10^{-5}
7	$K^+ \to \pi^+\pi^0$	2.067×10^{-1}
8	$K^+ \to \pi^+\pi^0\pi^0$	1.760×10^{-2}
9	$K^+ \to \pi^+\pi^+\pi^-$	5.583×10^{-2}
10	$K^+ \to \mu^+\nu\gamma$	6.2×10^{-3}
11	$K^+ \to e^+\nu\gamma$	9.4×10^{-6}
12	$K^+ \to \mu^+\pi^0\nu\gamma$	1.25×10^{-5}
13	$K^+ \to \pi^+\pi^+\pi^-\gamma$	1.04×10^{-4}
14	$K^+ \to \mu^+\nu A'$	$\epsilon^2 \times ratio\ of\ channel\ 16$
15	$K^+ \to \pi^+A'$	$\epsilon^2 \times ratio\ of\ channel\ 17$
16	$K^+ \to \mu^+e^+e^-\nu$	2.5×10^{-5}
17	$K^+ \to \pi^+e^+e^-$	3×10^{-7}



π^0 Channels

Label	Branch	Ratio
0	$\pi^0 \to \gamma\gamma$	9.8823×10^{-1}
1	$\pi^0 \to e^+e^-\gamma$	1.174×10^{-2}
2	$\pi^0 \to \gamma A'$	$\epsilon^2 \times ratio\ of\ channel\ 2$



ROOT based generator

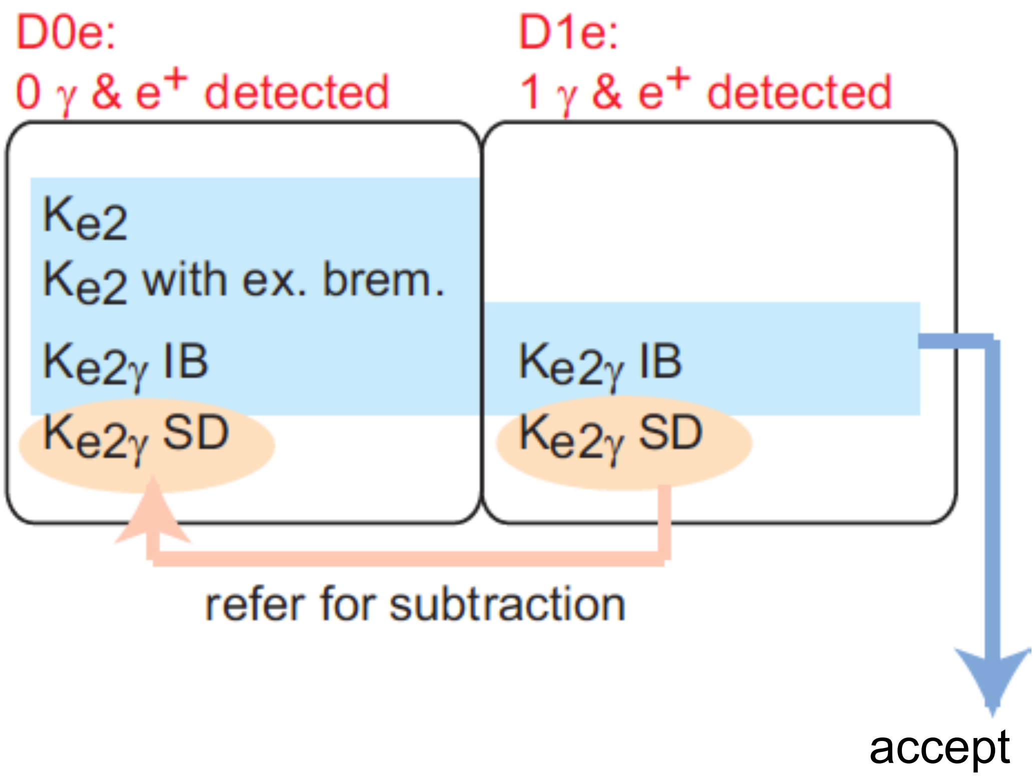
- Interactive: utilizes *Messenger Classes*
- Allows for selection of decay modes and branching ratios

Bishoy Dongwi
Tongtong Cao

Extraction of $K_{e2\gamma}$(SD) and K_{e2}

- **Subtraction of structure dependent $K_{e2\gamma}$ (SD) required**
- **E36 and KLOE can measure the SD events**
- **BR($K_{e2\gamma}$) is important input for NA62 analysis ($\Delta R_K/R_K$=0.4%)**

K. Horie, S. Shimizu



D0e:
0 γ & e⁺ detected

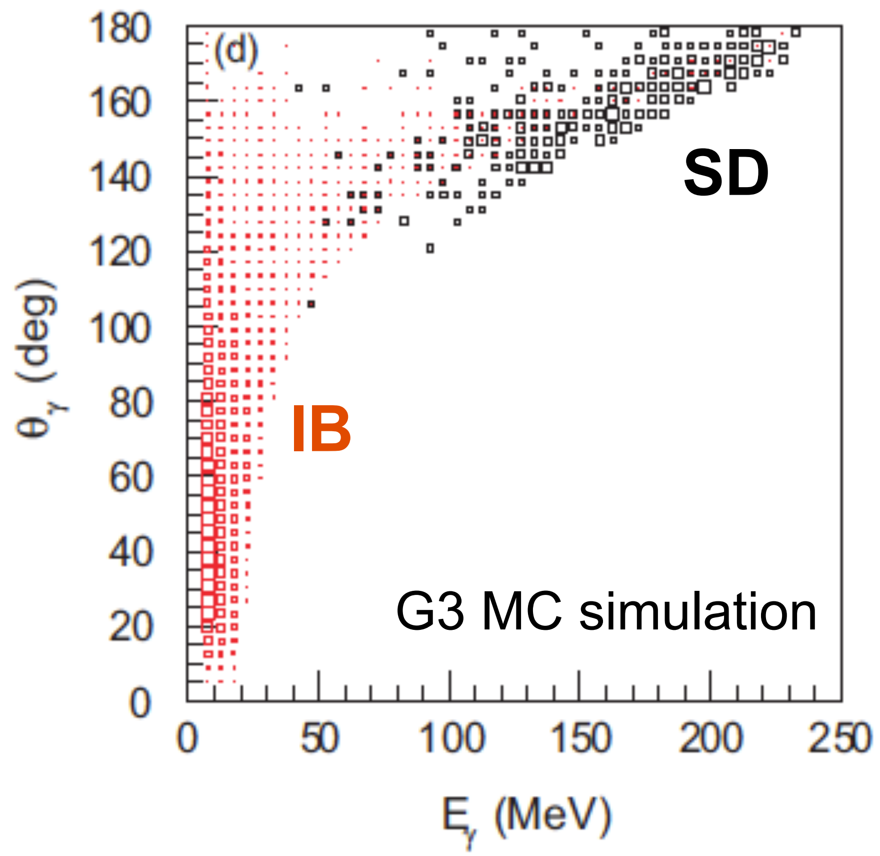
D1e:
1 γ & e⁺ detected

Ke2
Ke2 with ex. brem.
Ke2γ IB
Ke2γ SD

Ke2γ IB
Ke2γ SD

refer for subtraction

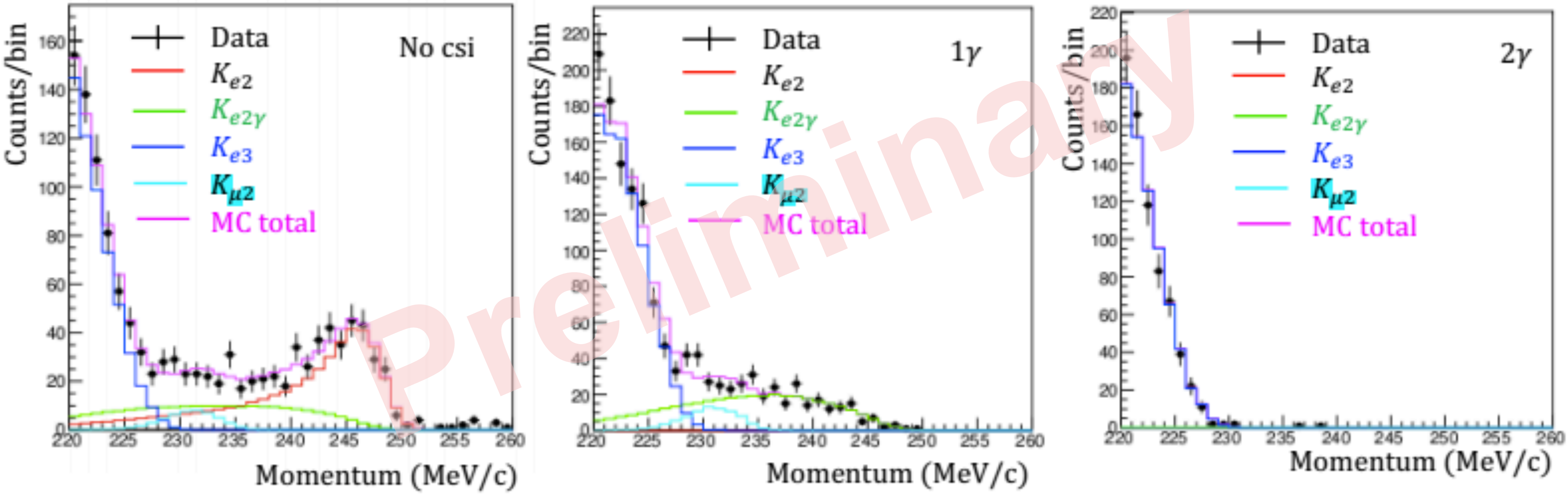
accept



Extraction of $K_{e2\gamma}$(SD) and K_{e2}

- **Positron momentum spectrum (900 runs)**
- **PID applied with AC, PGC, TOF**
- **Decomposition of *Ke2, Ke2γ, Ke3 yields***
- **Competitive E36 result for Ke2γ almost final**

K. Horie, S. Shimizu



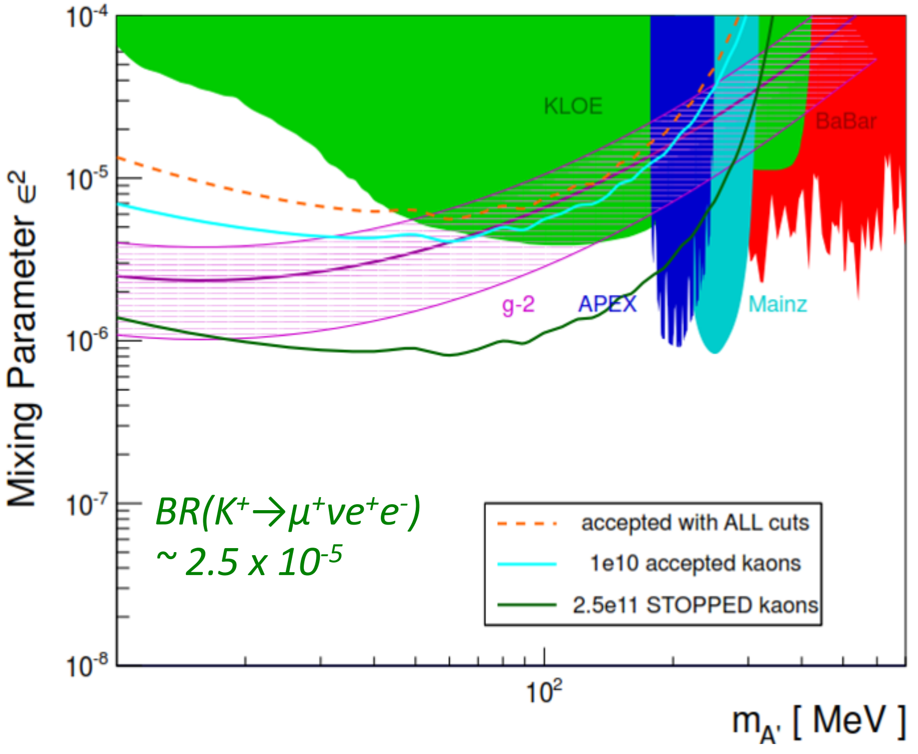
KLOE: BR($K_{e2\gamma}$) = $(1.37\pm0.06)\times10^{-5} = [1.37\times(1\pm0.044)]\times10^{-5}$

F. Ambrosino *et al.*, Eur. Phys. J. C64, 627 (2009); C. Lazzeroni, PANIC 2011

Dark photon / light neutral boson search

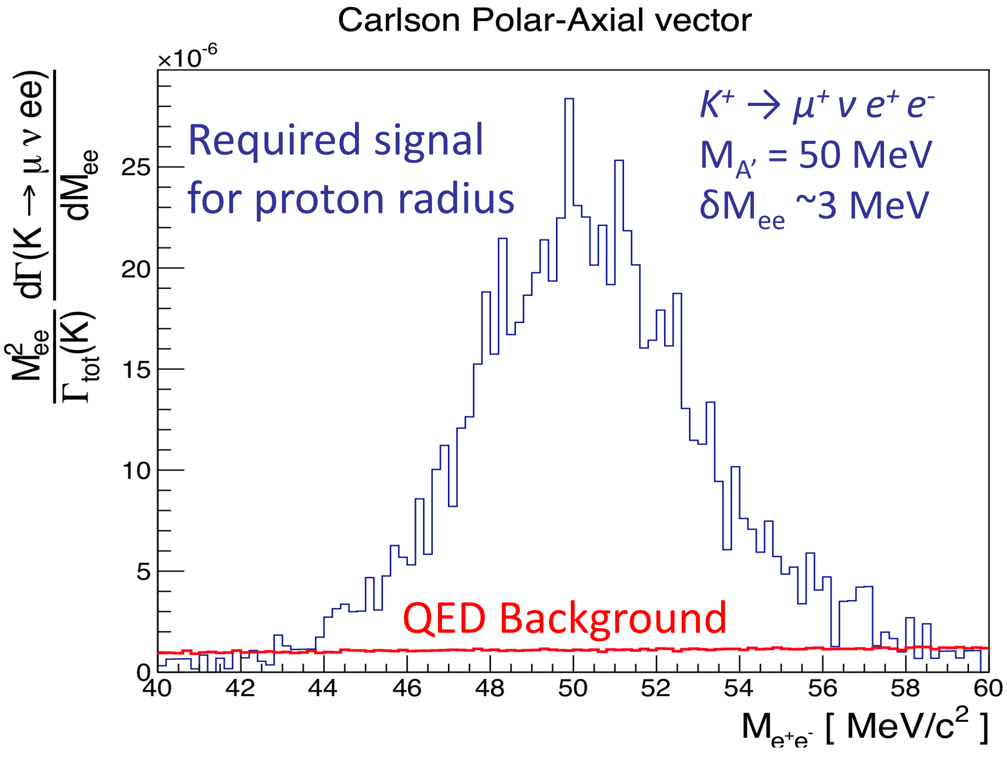
- **Dark photons (universal coupling) well motivated by dark matter observations (astronomical, direct, positron excess) and g_μ-2 anomaly**
- **Light neutral bosons (selective coupling) for proton radius puzzle**
- **Search for visible decay mode of *A’* → e^+e^- in K^+ decays**
  Kaons: $K^+ \rightarrow \mu^+ \nu A'$; $K^+ \rightarrow \pi^+ A'$ (also invisible decay);
  Pions: $\pi^0 \rightarrow \gamma A'$, using $K^+ \rightarrow \pi^+\pi^0$ (21.13%) and $K^+ \rightarrow \mu^+ \nu \pi^0$ (3.27%)

E36: Dark photon exclusion limit



$BR(K^+ \rightarrow \mu^+ \nu e^+ e^-)$
$\sim 2.5 \times 10^{-5}$

E36: Light boson expected signal



Required signal for proton radius

$K^+ \rightarrow \mu^+ \nu e^+ e^-$
$M_{A'}$ = 50 MeV
δM_{ee} ~3 MeV

QED Background

Possible A’ decay channels in TREK/E36

K^+ decays ~ 10^{10}

Signal 1a: $K^+ \rightarrow \pi^+ A’,\ A’ \rightarrow e^+e^-$

Signal 1b: $K^+ \rightarrow \pi^+ A’,\ A’ \rightarrow \gamma\,\gamma$ *(electrophobic scalar boson)*

Signal 1c: $K^+ \rightarrow \pi^+ A’$ *(via missing mass)*

SM Background: BR($K^+ \rightarrow \pi^+ e^+ e^-$) ~ 2.9×10^{-7} ~ 2,900 ev.

Signal 2: $K^+ \rightarrow \mu^+ \nu A’,\ A’ \rightarrow e^+e^-$

SM Background: BR($K^+ \rightarrow \mu^+ \nu\ e^+ e^-$) ~ 2.5×10^{-5} ~ 250k ev.

Add. background from $K^+ \rightarrow \mu^+ \nu \pi^0 \rightarrow \mu^+ \nu\ e^+ e^- (\gamma)$

π^0 decays 1) 3×10^8 2) 2×10^9

π^0 production: $K^+ \rightarrow \mu^+ \nu \pi^0$ (3.3%) $K^+ \rightarrow \pi^+ \pi^0$ (21.1%)

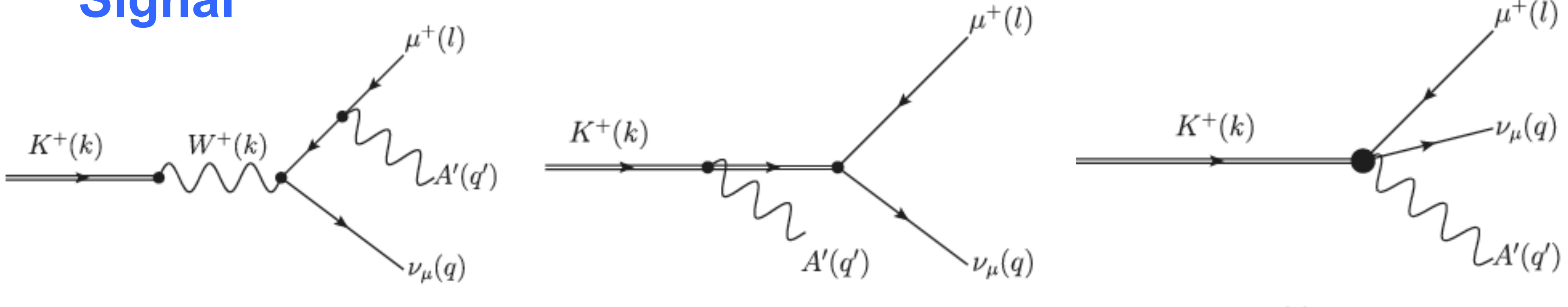
Signal 3: $\pi^0 \rightarrow \gamma A’,\ A’ \rightarrow e^+e^-$

SM Background: BR($\pi^0 \rightarrow \gamma\ e^+ e^-$) ~1.2% ~ 0.3 (2.3) $\times 10^7$ ev.

The rare kaon decay $K^+ \rightarrow \mu^+\nu A' \rightarrow \mu^+\nu e^+ e^-$

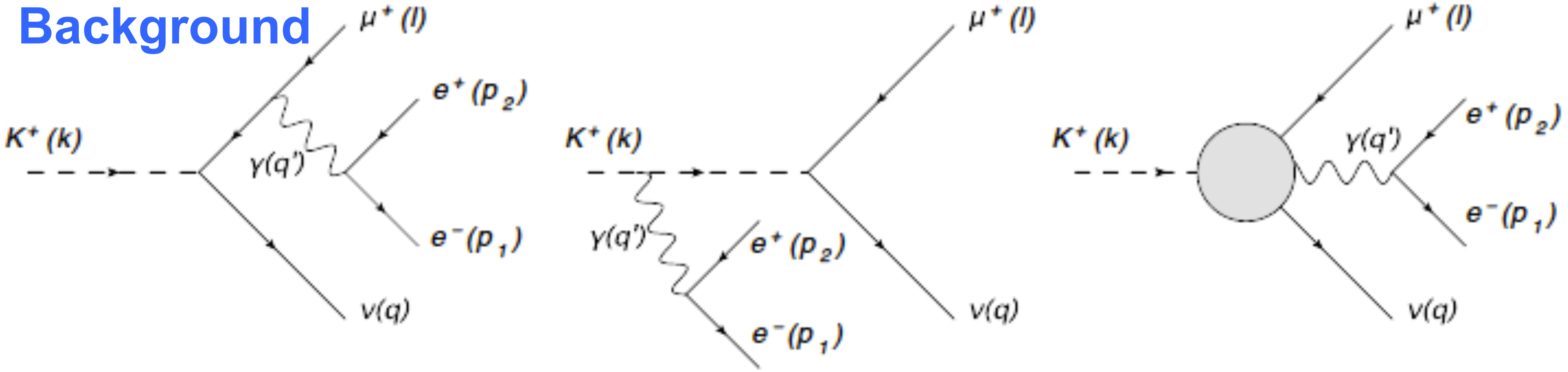
C. Carlson & B. Rislow; T. Beranek

Signal



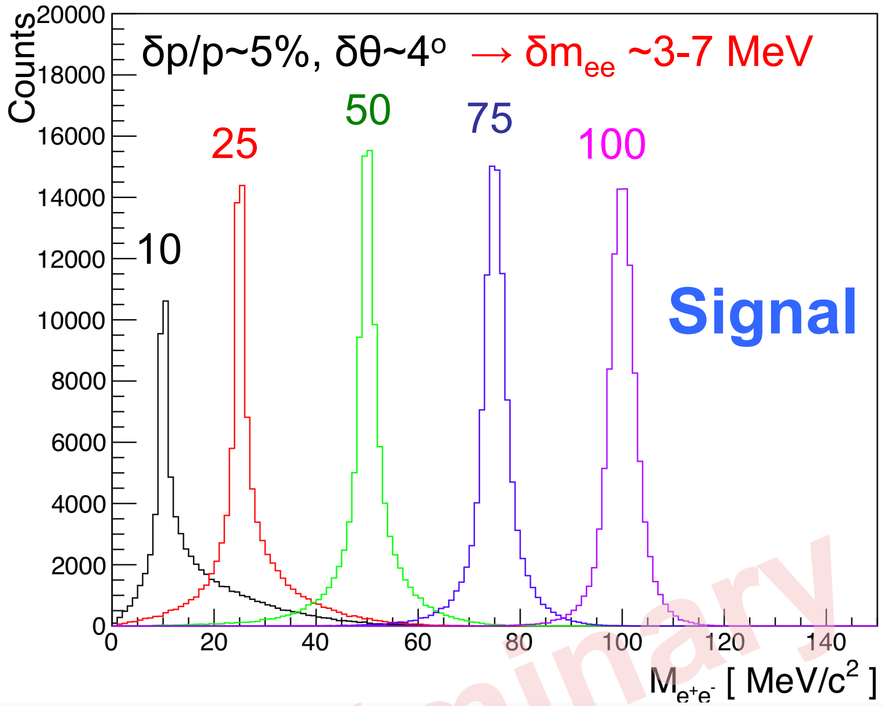
(a) (b) (c)

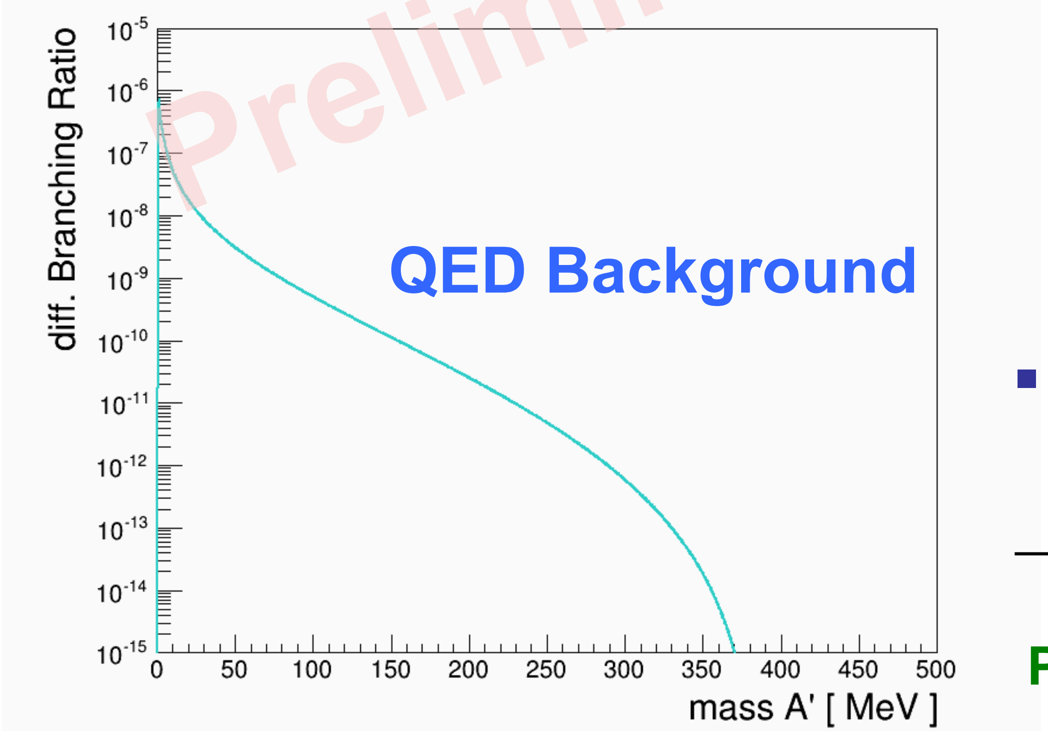
Background



- **Background: SM process with time-like (virtual) photon exchange**
  - **Calculable in QED, BR($K^+ \rightarrow \mu^+ \nu\ e^+ e^-$) = 2.49 x 10^{-5}**
    J. Bijnens et al., Nucl. Phys. B396, 81 (1993), hep-ph/9209261
  - **Measured for m_{ee} > 145 MeV/c^2**
    A. Poblaguev et al., Phys. Rev. Lett. 89, 061803 (2002), hep-ex/0204006

Search for a new particle in $K^+ \rightarrow \mu^+ \nu\, e^+ e^-$





E36:

- **Detect μ^+ in toroid, e^+e^- in CsI(Tl)**
- **Simulate achievable resolution for invariant mass m_{ee}**
- **Simulate QED background (radiative decay $K^+ \rightarrow \mu^+ \nu\ \ e^+ e^-$) and experimental backgrounds, e.g. $K^+ \rightarrow \mu^+ \pi^0 \nu \rightarrow \mu^+ \nu\, e^+ e^- (\gamma)$**
- **Sensitivity from QED background fluctuation**

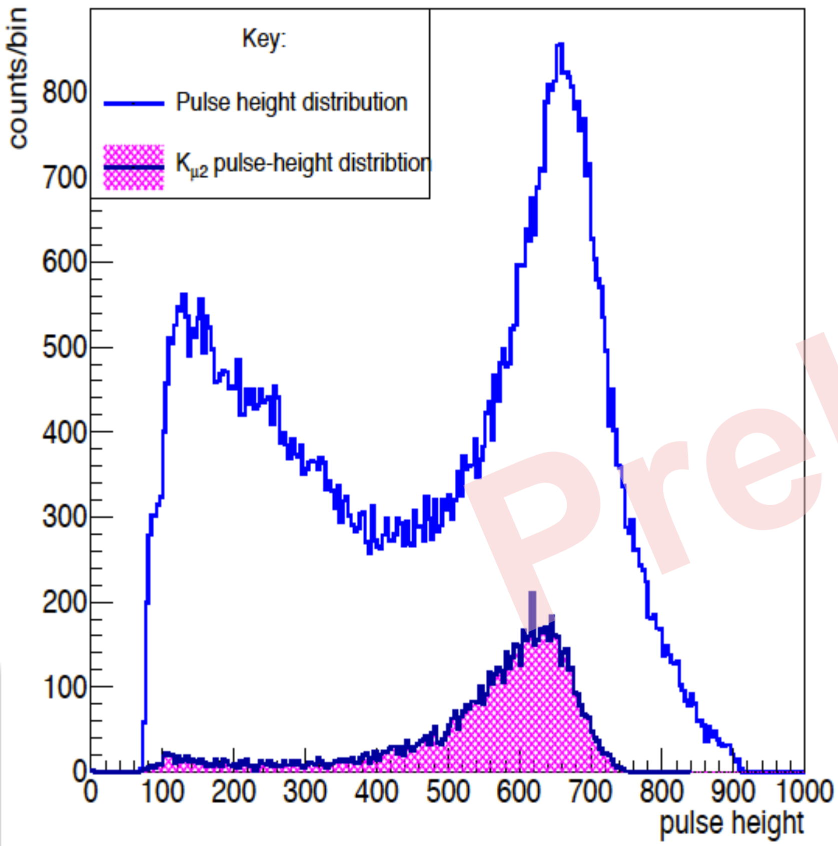
→ Exclusion limits ε^2 versus m_{ee}

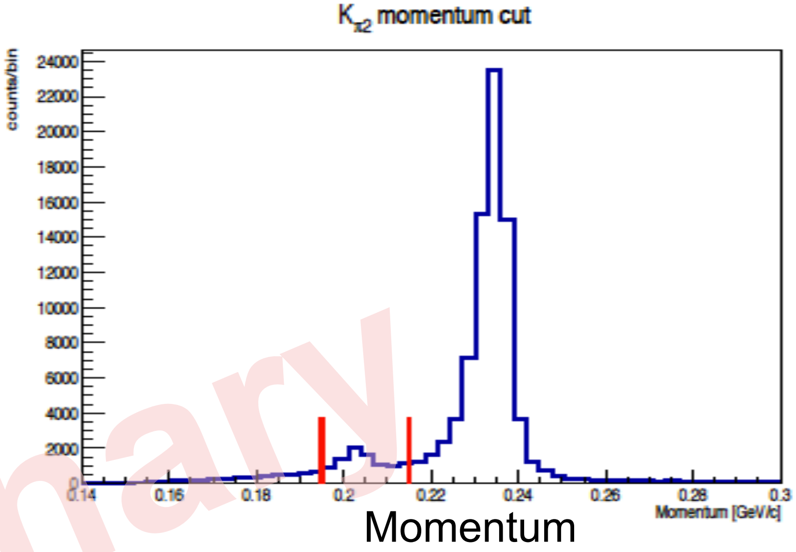
P. Monaghan, T. Cao, B. Dongwi (HU)

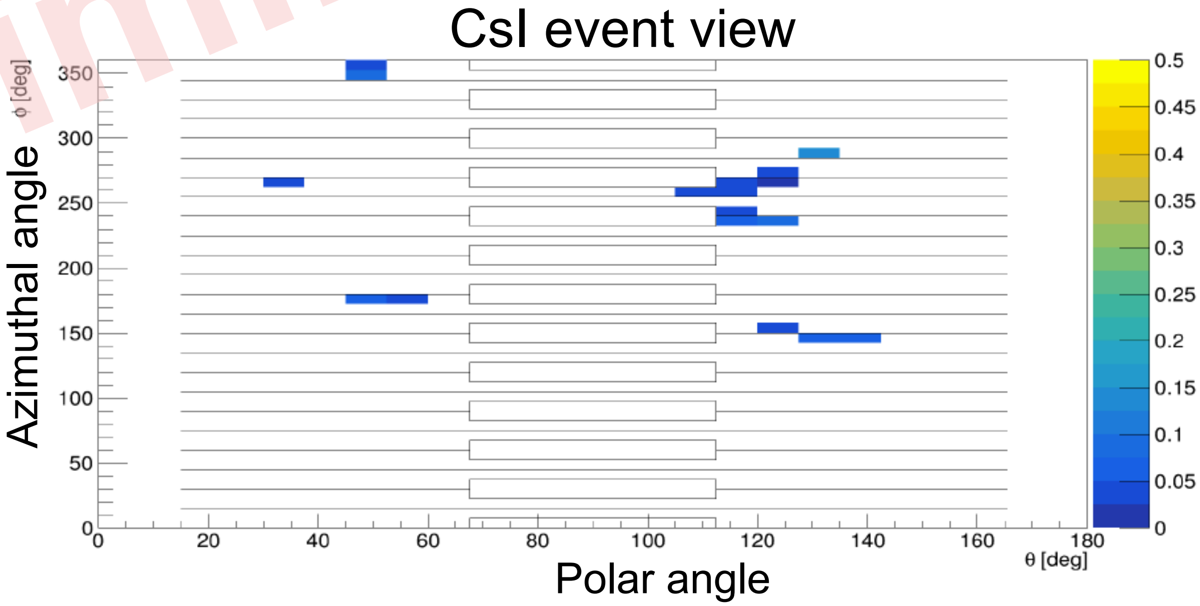
CsI cluster analysis

- Energy calibration w/ single-crystal $K_{\mu 2}$
- Robust wave form analysis
- Require μ^+ timing and secondary e^+
- Pulse height distribution
- Energy loss in target (Geant4)

- Use $K_{\pi 2}$ events to develop and validate cluster finding with $\pi^0 \rightarrow \gamma\gamma$





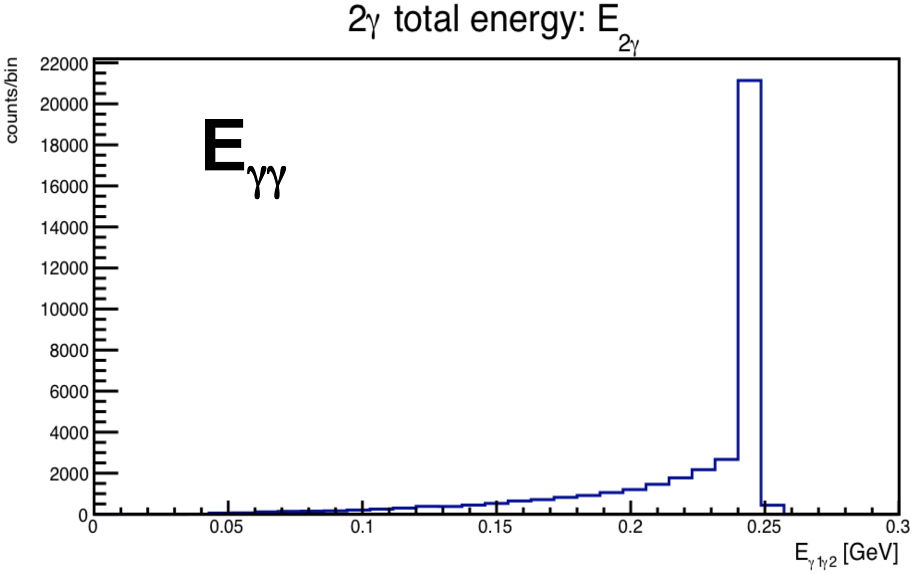


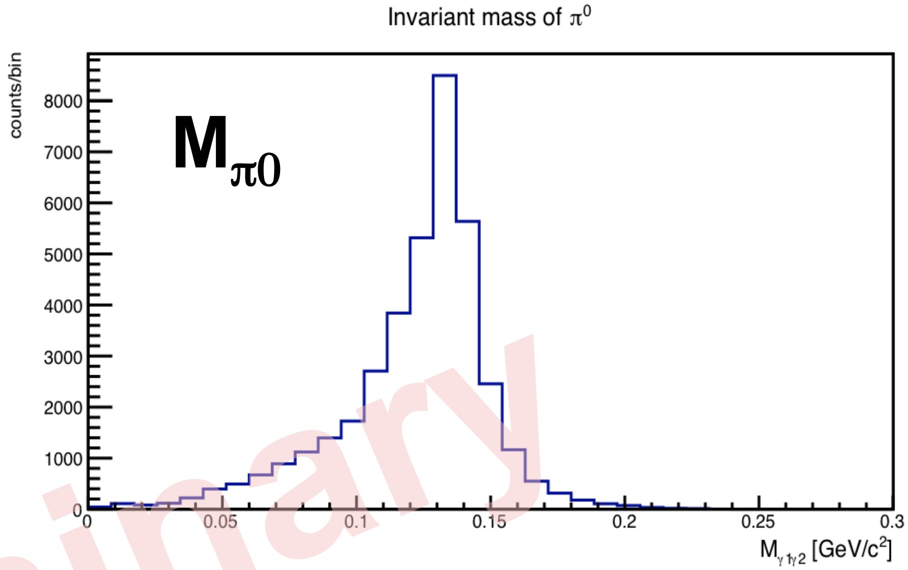
H. Ito et al., NIM A 901, 1 (2018)

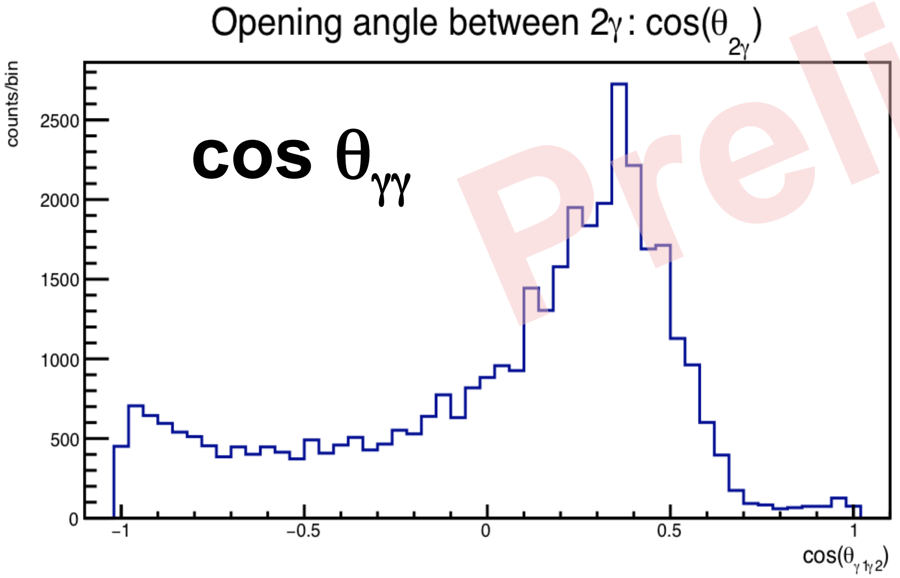
Bishoy Dongwi

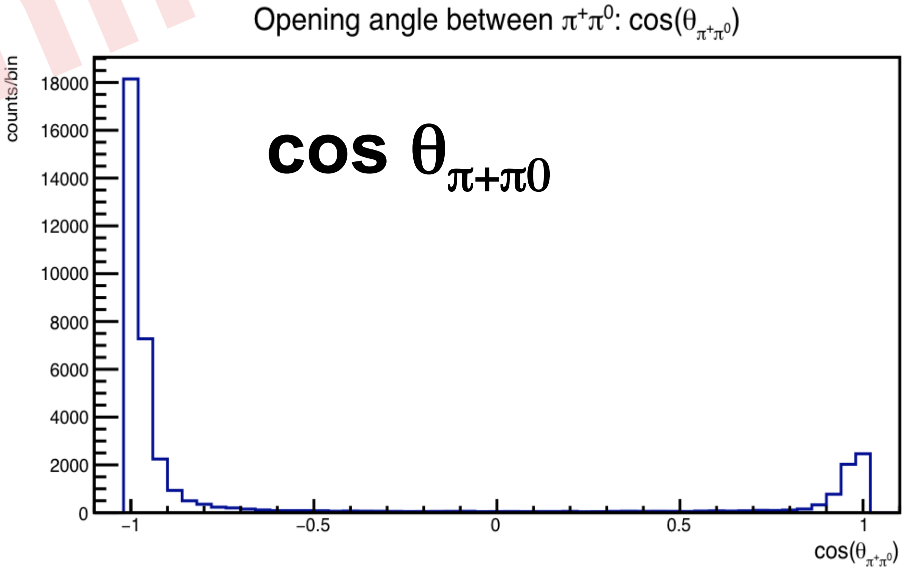
CsI cluster analysis

Generator (e36g4MC): $K^+ \rightarrow \pi^+ \pi^0$ (w/o detector resolution)





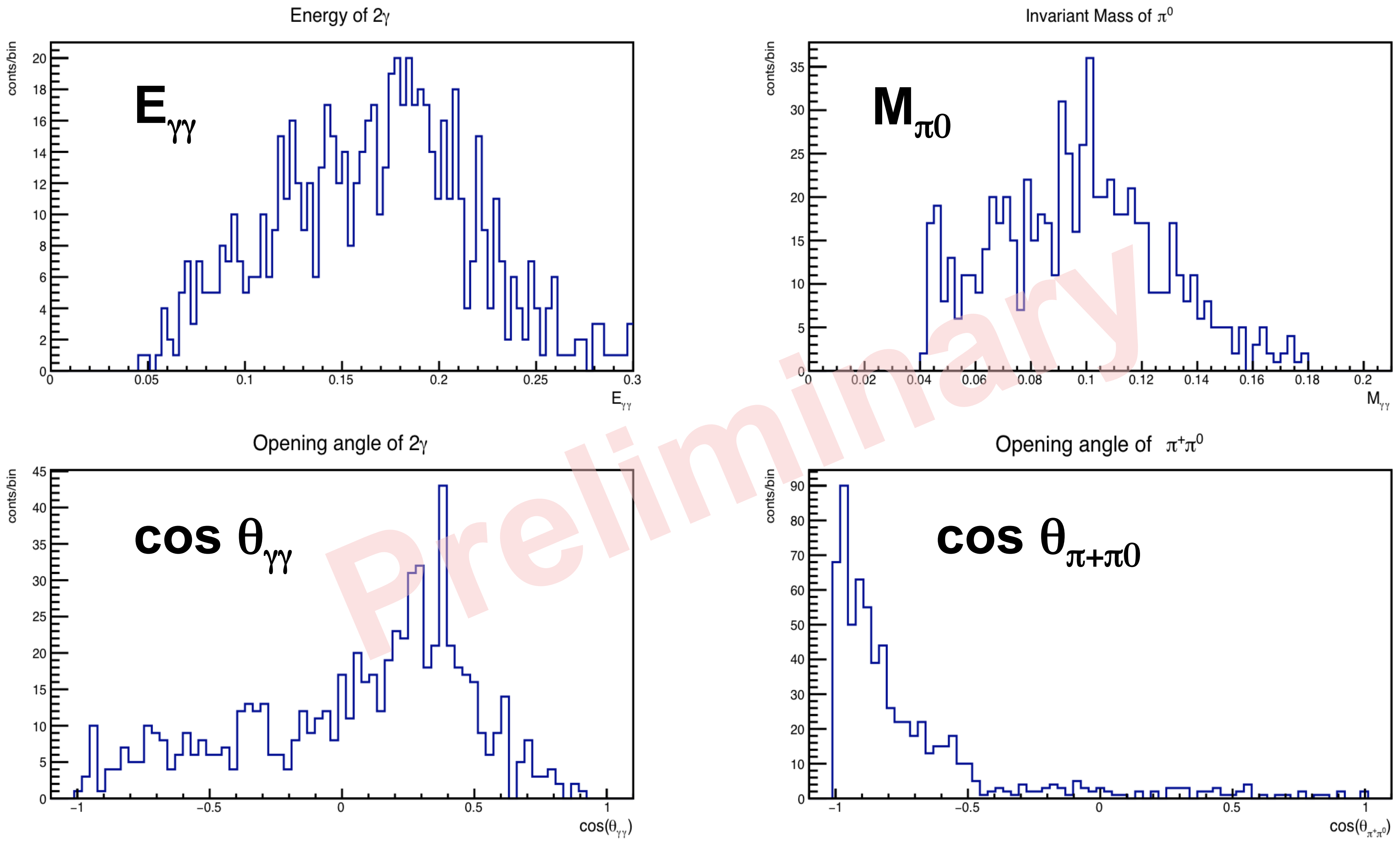




Bishoy Dongwi

CsI cluster analysis

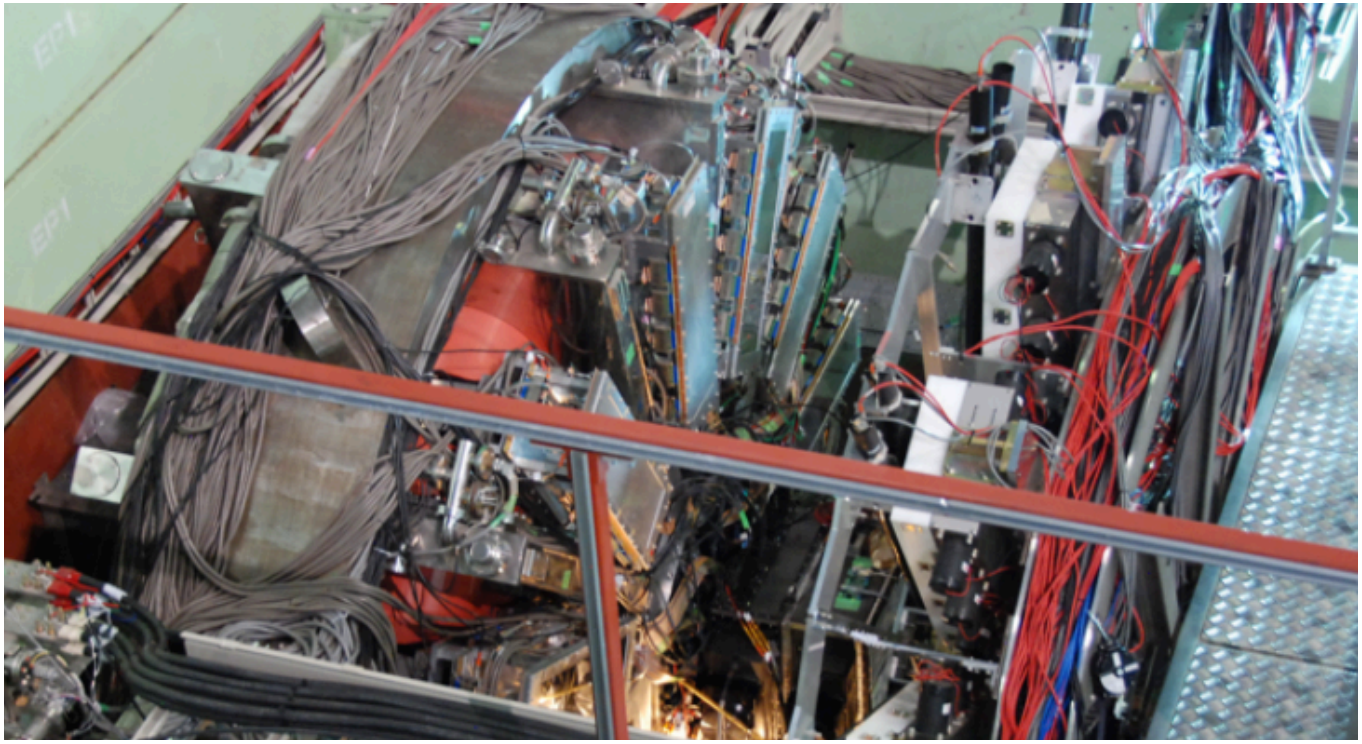
$K^+ \rightarrow \pi^+ \pi^0$ ($K_{\pi 2}$) event candidates w/ 2 clusters in CsI(Tl)



Bishoy Dongwi

Summary

- Lepton universality is challenged (BaBar, Belle, LHCb)
- **TREK/E36:** Measurement of $K_{e2}/K_{\mu 2}$ ratio – test of lepton universality; Measurement of structure-dependent BR($K_{e2\gamma}$)
- Search for dark photon/light boson
- Production running has been completed (Oct. 14 – Dec. 18, 2015)
- Analysis underway (calibration, simulation, systematic error studies); expect results in the near future
- TREK/E06 (T-violation) in the future



TREK (E36/E06) collaboration

~30 collaborators

Spokespeople:
M.K., S. Shimizu

CANADA

University of British Columbia
Department of Physics and Astronomy

TRIUMF

USA

University of South Carolina
Department of Physics and Astronomy

University of Iowa
Department of Physics

Hampton University
Department of Physics

JAPAN

Osaka University
Department of Physics

Chiba University
Department of Physics

Rikkyo University
Department of Physics

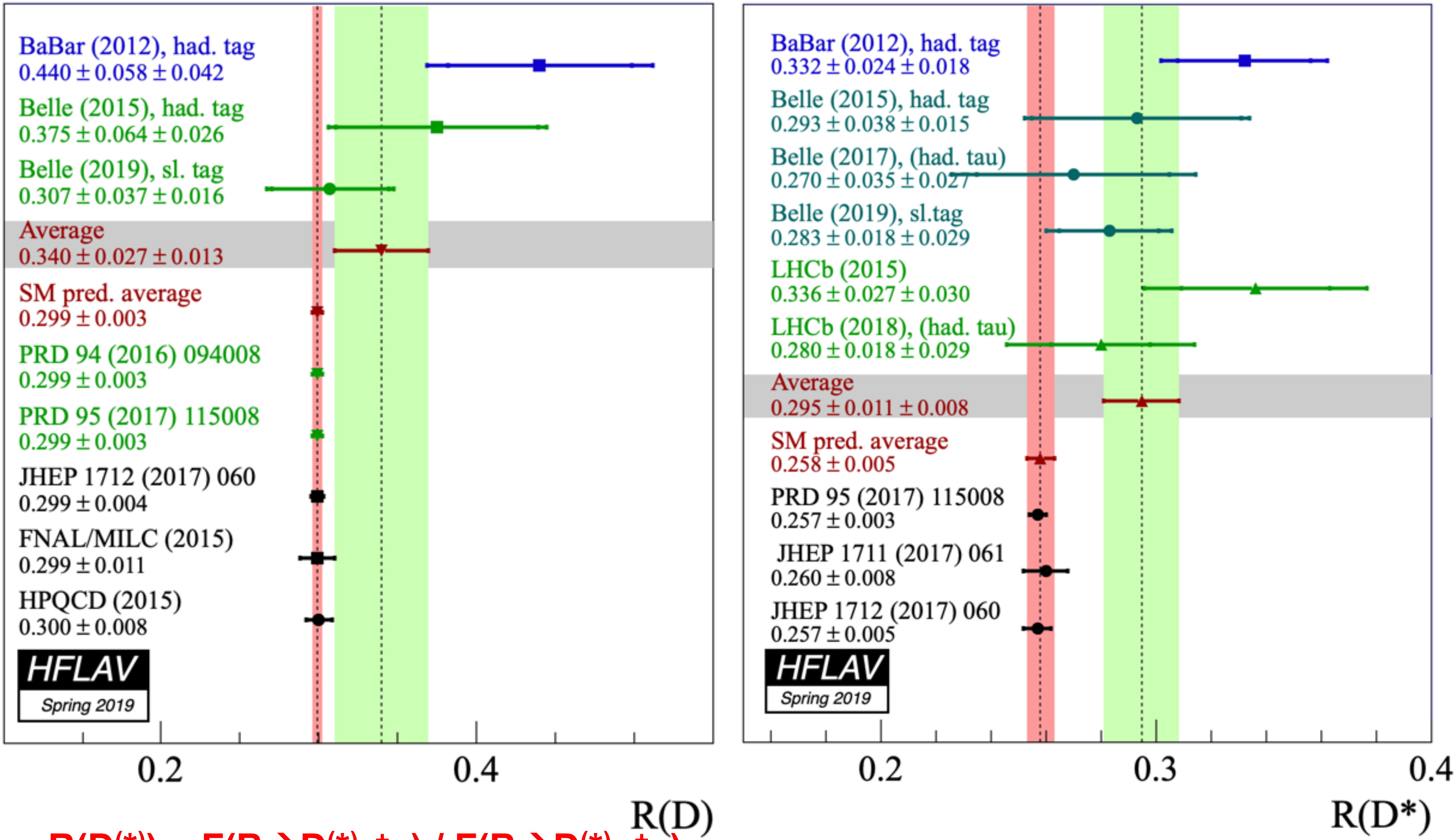
High Energy Accelerator Research Organization (KEK)
Institute of Particle and Nuclear Studies

RUSSIA

Russian Academy of Sciences (RAS)
Institute for Nuclear Research (INR)

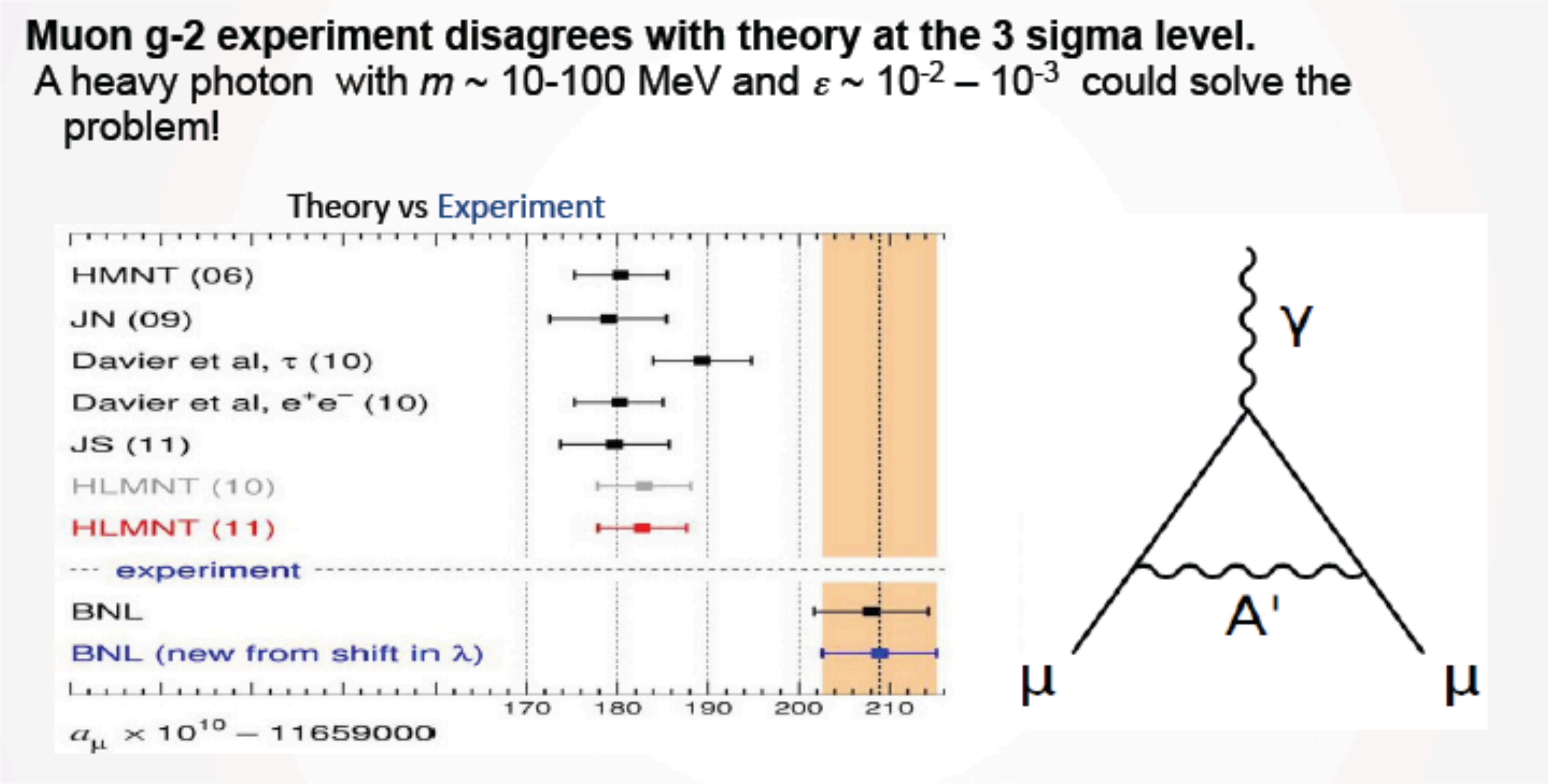
Backup

Lepton non-universality in B-decays (τ-μ)



- $R(D^{(*)}) = \Gamma(B \to D^{(*)}\tau^+\nu) / \Gamma(B \to D^{(*)}\mu^+\nu)$
- **Spring 2019:** R(D) ~ 2.3σ, R(D*) ~ 3.0σ
  Combined at 3.62σ

Muon anomalous magnetic moment



Muon g-2 experiment disagrees with theory at the 3 sigma level.

A heavy photon with m ~ 10-100 MeV and $\varepsilon \sim 10^{-2} - 10^{-3}$ could solve the problem!

Anomaly ‘usually’ explained by SUSY with large tanβ
-> no evidence
Anomaly can be explained with dark photon or light boson

The TREK program

- **E06**
  (Time Reversal Experiment with Kaons, TREK)

“ **Measurement of T-violating transverse muon polarization (P_T) in $K^+ \to \pi^0 \mu^+ \nu$ decays** ”

Proposal to PAC 1 (2006) 100-270 kW

Stage-1 approved since July 2006

Spokespeople: Jun Imazato and M.K.

- **E36** (Test of Lepton Universality, Search for Heavy Neutrinos and Light Bosons)

“ **Measurement of $\Gamma(K^+ \to e^+ \nu)$ / $\Gamma(K^+ \to \mu^+ \nu)$ and search for heavy sterile neutrinos using the TREK detector system** ”

Proposal to PACs 10 (2010), 11,13-18 30-50 kW

Stage-1 approved since August 2012

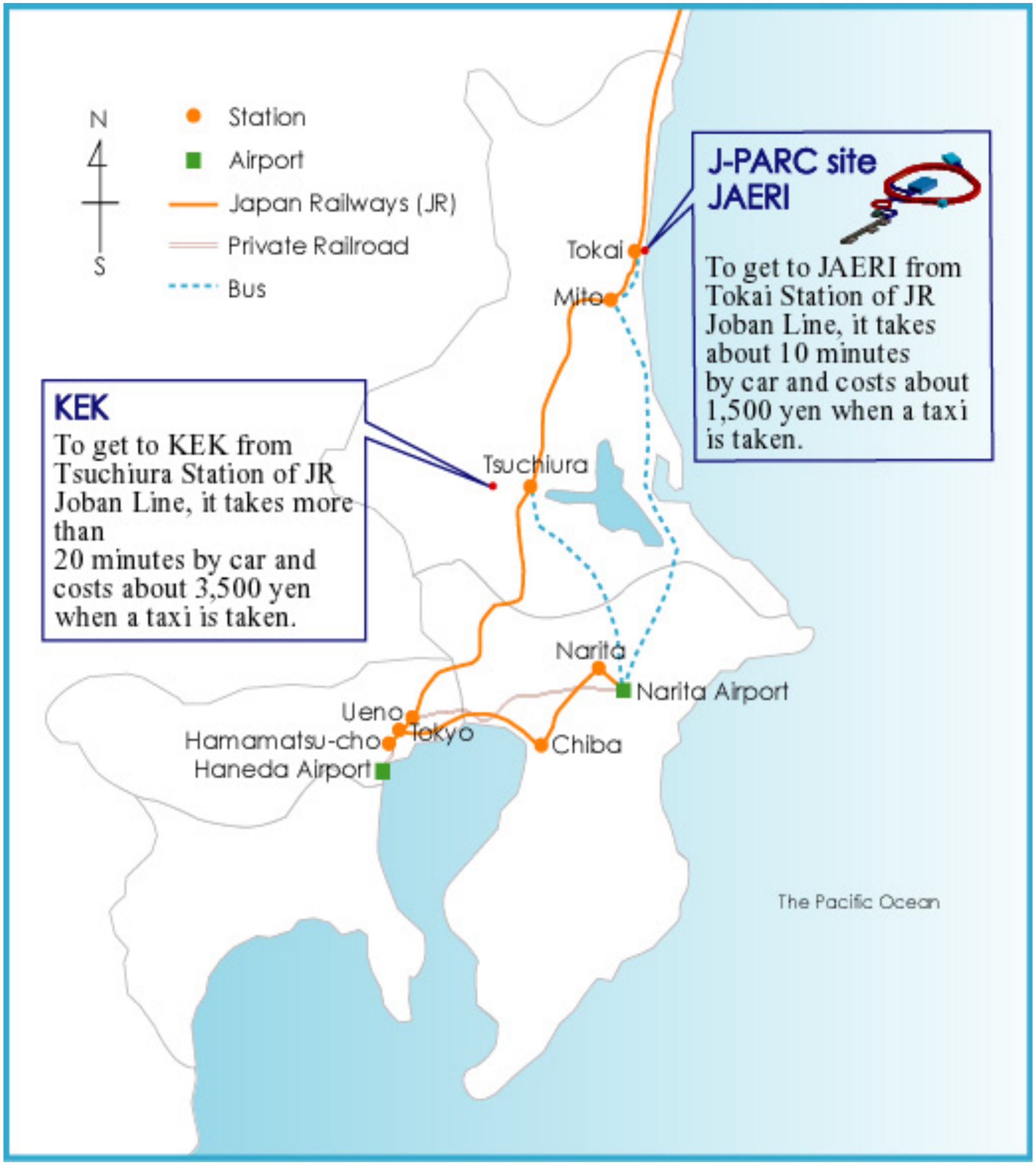
Stage-2 approved since September 2013

Spokespeople: M.K. and Suguru Shimizu

Timeline of TREK

- **2006: E06 (T-violation) Proposal (PAC1)**
- **2009: J-PARC PS and HF start operating**
- **2010: E36 (LFU/HNS) Proposal (PAC10)**
- **2011: E36 stage-1 recommended (PAC11)**
- **2012: E36 stage-1 approved (PAC15)**
- **2013: E36 stage-2 recommended (PAC17)**
- **2014: E36 stage-2 approved (PAC18)**
- **Detector preparation November 2014 – April 2015**
- **First commissioning run April 8 (24) – May 7, 2015**
- **Second commissioning run June 3 – 26, 2015**
- **Implemented improvements in summer 2015**
- **Production run October 14 – November 24, 2015**
- **Run extended until December 18, 2015**
- **2016-2019: Analysis in progress**

Location of J-PARC



J-PARC site
JAERI

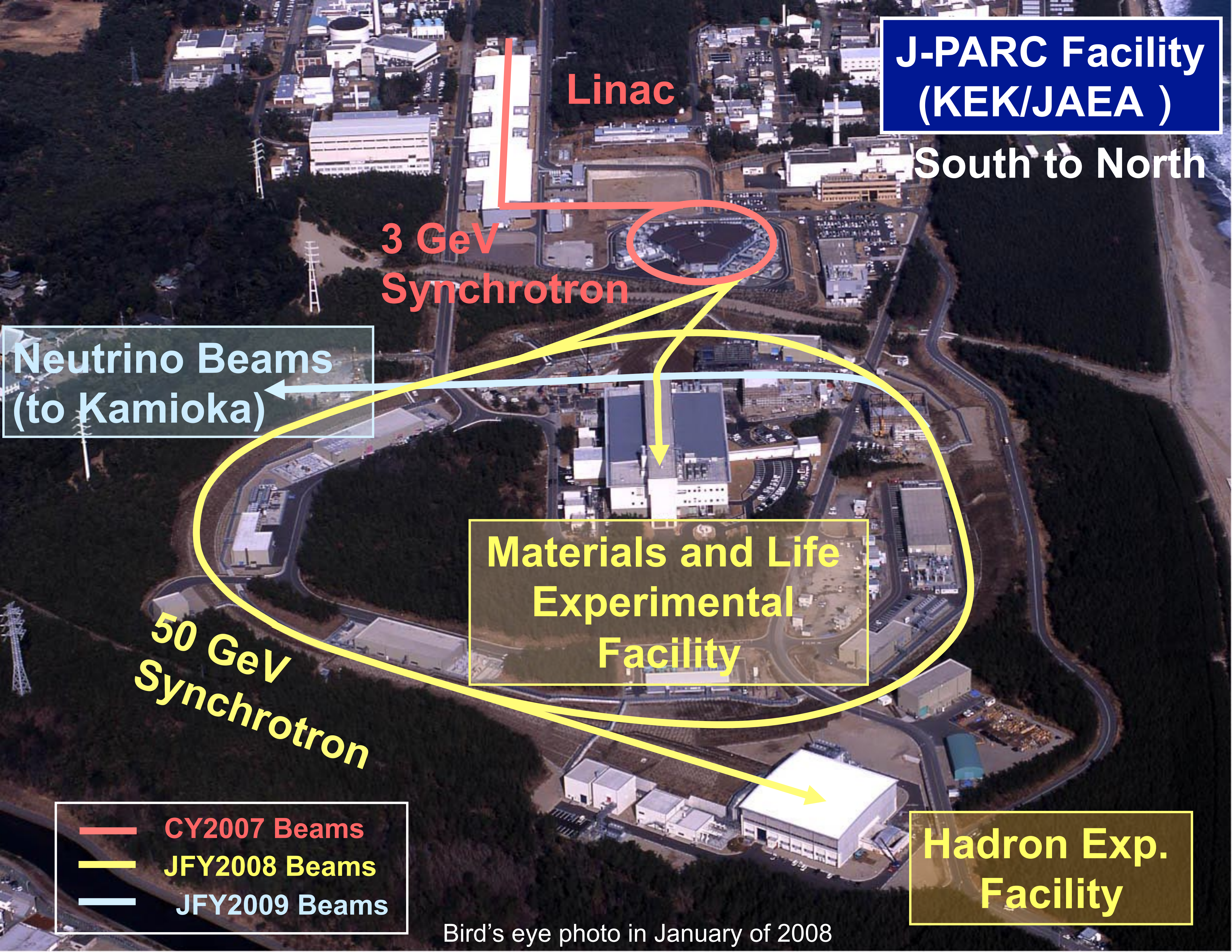
To get to JAERI from Tokai Station of JR Joban Line, it takes about 10 minutes by car and costs about 1,500 yen when a taxi is taken.

KEK

To get to KEK from Tsuchiura Station of JR Joban Line, it takes more than
20 minutes by car and costs about 3,500 yen when a taxi is taken.

J-PARC Facility (KEK/JAEA)

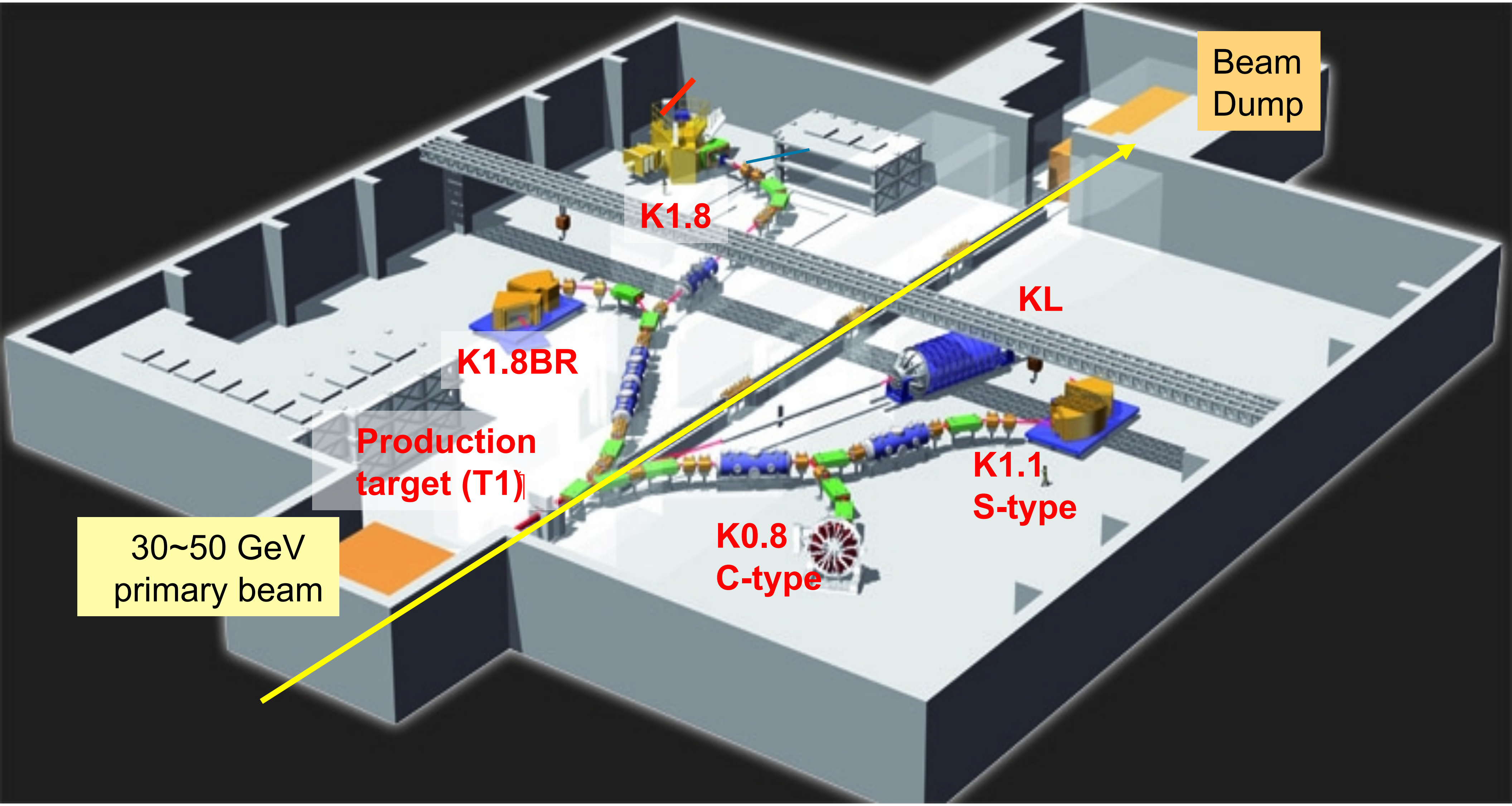
South to North



- CY2007 Beams
- JFY2008 Beams
- JFY2009 Beams

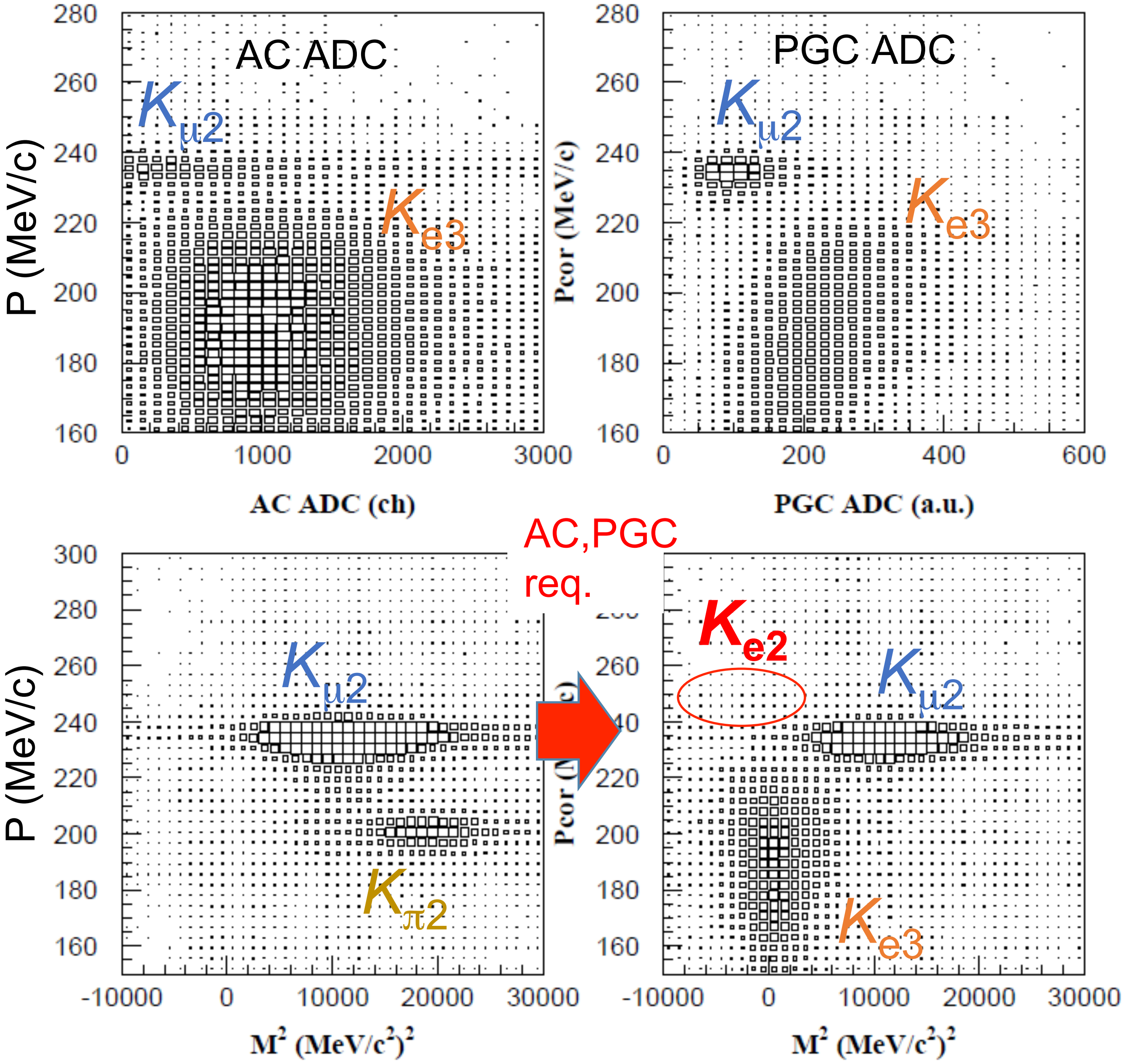
Bird’s eye photo in January of 2008

J-PARC Hadron Experimental Hall



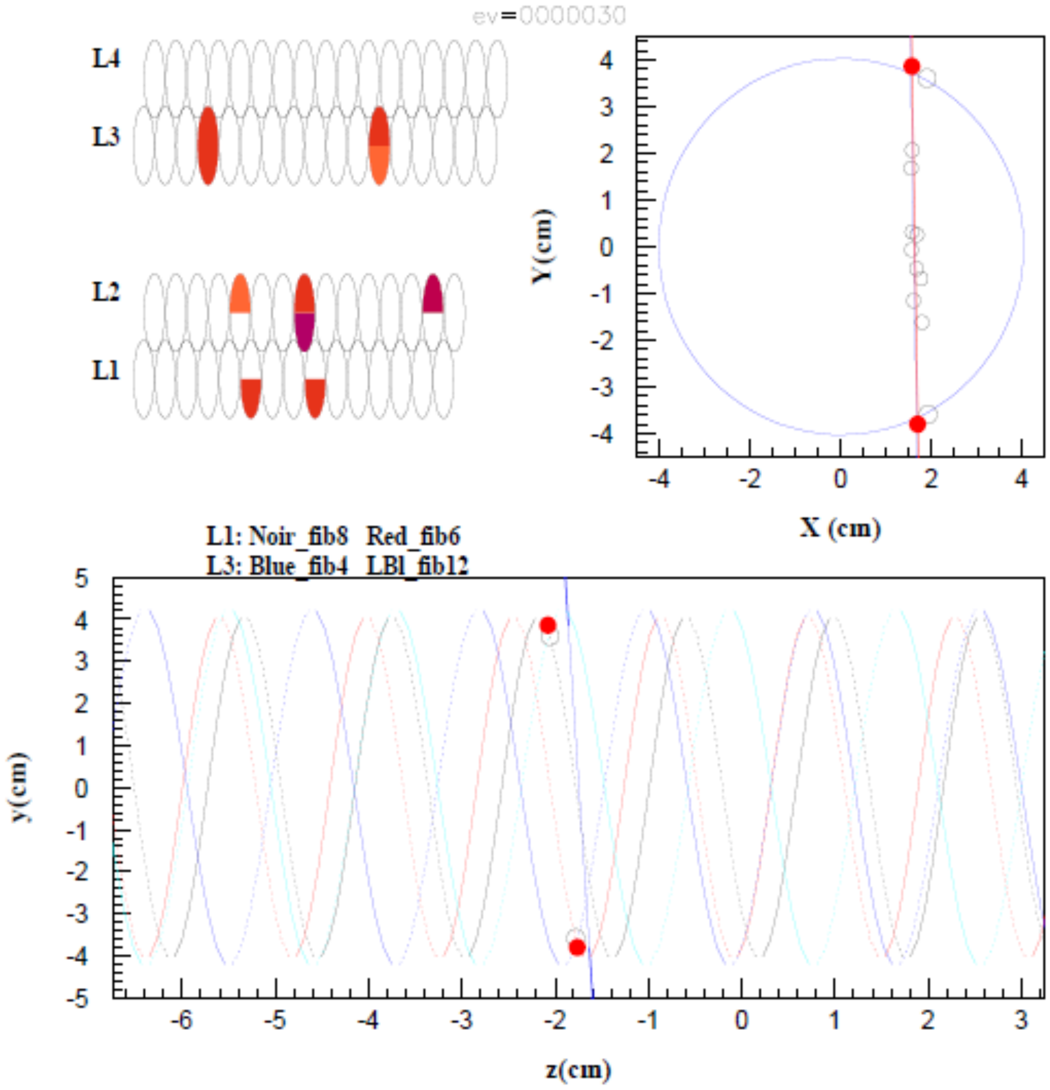
Particle identification by AC, PGC, and TOF

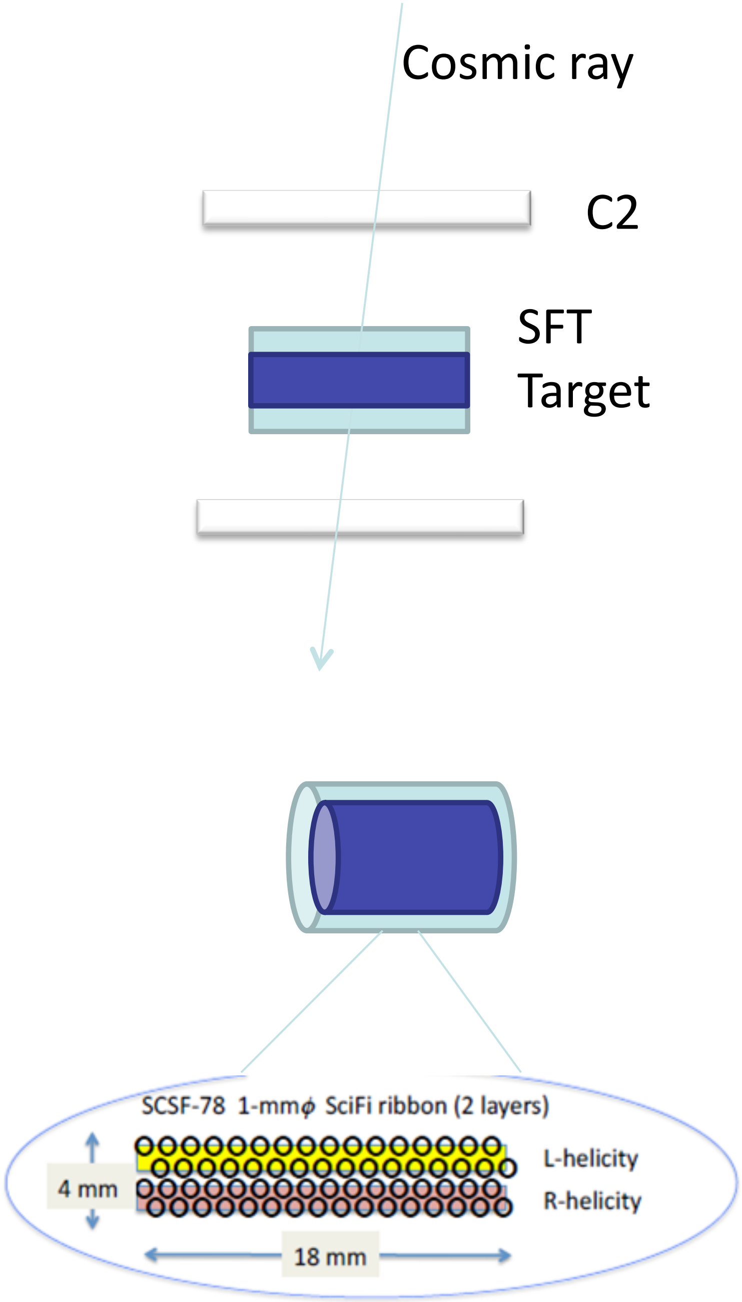
- **Positrons are selected by AC, PGC and TOF**
- **PID performance by combining the three detectors is now being optimized**
- **Suppression of muon mis-identification below O(10^{-8}) level achievable with refined analysis**
- **Refined analysis of PID performance in progress**



Preliminary

Track identification by central detector





SFT+Target consistency established with cosmic rays

Simulation and analysis

Team: Hampton (T. Cao, B. Dongwi, M.K.)

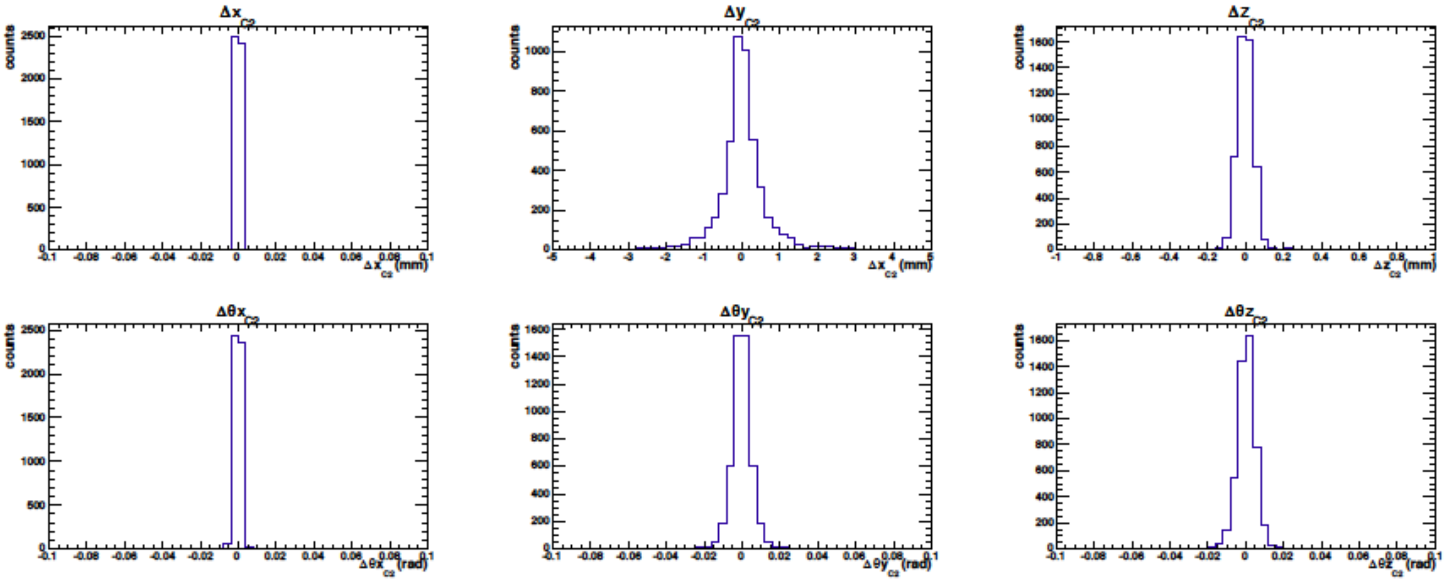
Accomplishments

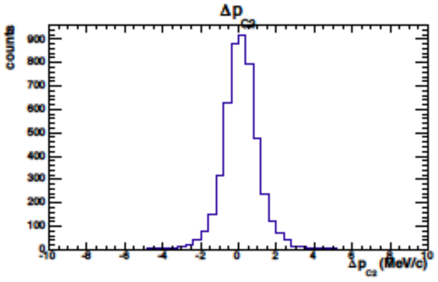
- Geant4: Completed geometry, now including target, SFT, CsI
- Established, tested Kalman Filter for tracking, fully consistent with G4
- Kaon decay generator developed and implemented into Geant4

Plans

- Acceptance ratio for K_{l2}
- Simulation of DP signal and bkg processes for realistic reach
- DP analysis: CsI clustering

Diff. between tracking results and true values for the state vector at C2

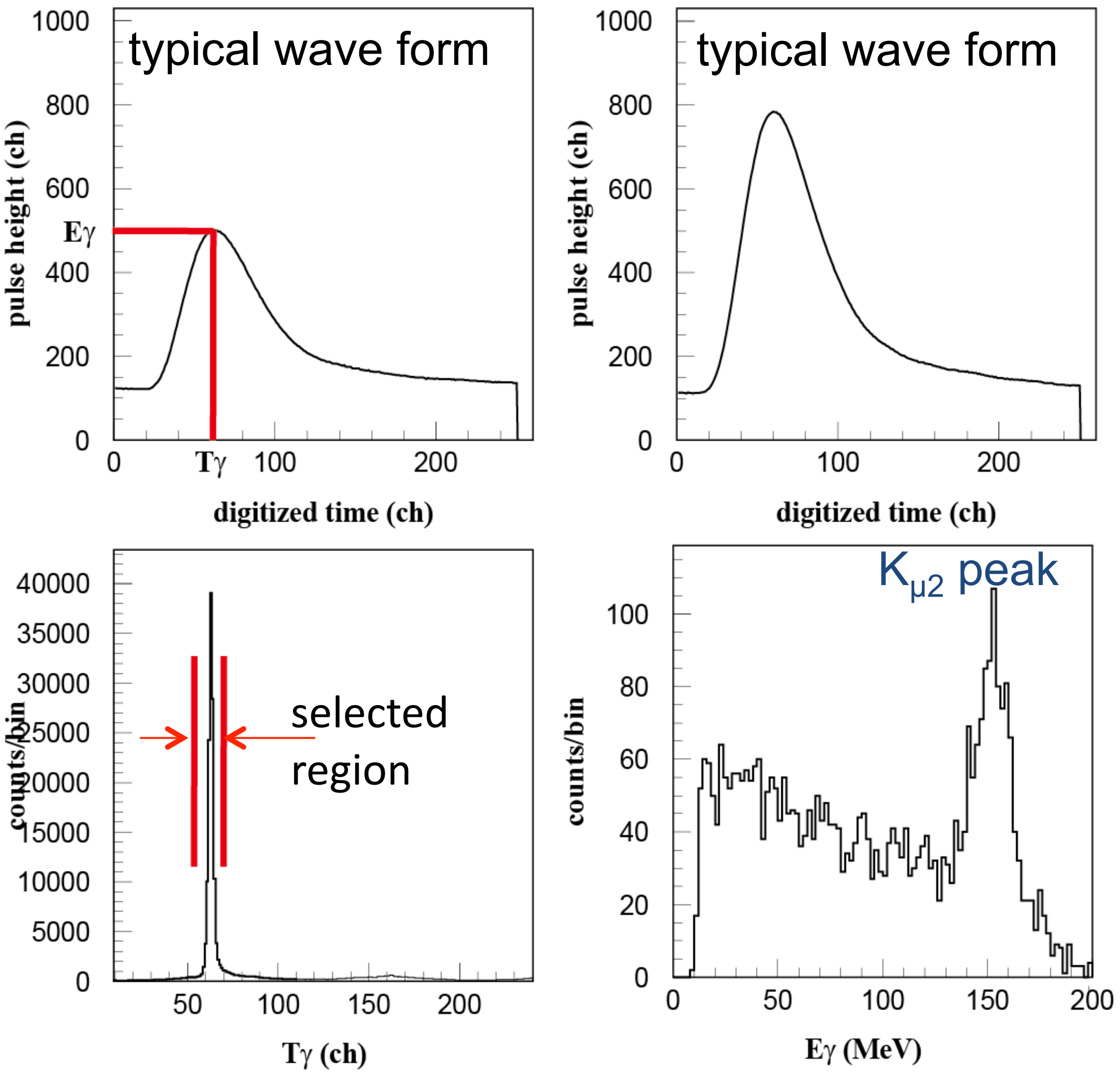




- Simulated data: propagated and reconstructed tracks
- Tracking efficiency ~100%
- No bias, narrow resolutions

CsI(Tl) calorimeter analysis

- **Energy and timing obtained by pulse shape data from FADC (VF48)**
- **Events from the K^+ decays were selected**
- **$K_{\mu 2}$ events with single crystal hit used for the energy calibration**
- **Deposited muon energy used for energy calibration of each crystal**



H. Ito et al., NIM A 901, 1 (2018)

Combining spectrometer + calorimeter

- $K_{\pi 2}$ events selected by analyzing momentum and TOF (M^2)
- π^0 invariant mass reconstructed by selecting two-cluster events
- Large π^+ / π^0 opening angle observed to select $K_{\pi 2}$
- Confirmed that the total E36 system works correctly and is consistent with E246

Preliminary