E88 Status and Plan
High-statistics $\phi \rightarrow K^+K^-$ decay measurements in p+A

E16 Collaboration at Taiwan

2024/9/9-10

Hiroyuki Sako (JAEA) for the E88 collaboration

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J-PARC E88

Study of in-medium modification of ϕ mesons inside the nucleus in $\phi \rightarrow K^+K^-$ measurements with the E16 spectrometer

Approved as Stage-I status (physics importance) in 2022

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- K. Aoki, Y. Morino, K. Ozawa (KEK/J-PARC)
- W. C. Chang, M. L. Chu (Academia Sinica, Taiwan)
- T. Chujo, S. Esumi, Y. Miake, T. Nonaka (Univ. of Tsukuba)
- M. Inaba (Tsukuba Univ. of Technology)
- M. Naruki (Kyoto Univ.)
- T. Sakaguchi (BNL)
- T. N. Takahashi (RCNP, Osaka Univ.), S. Yokkaichi (RIKEN)

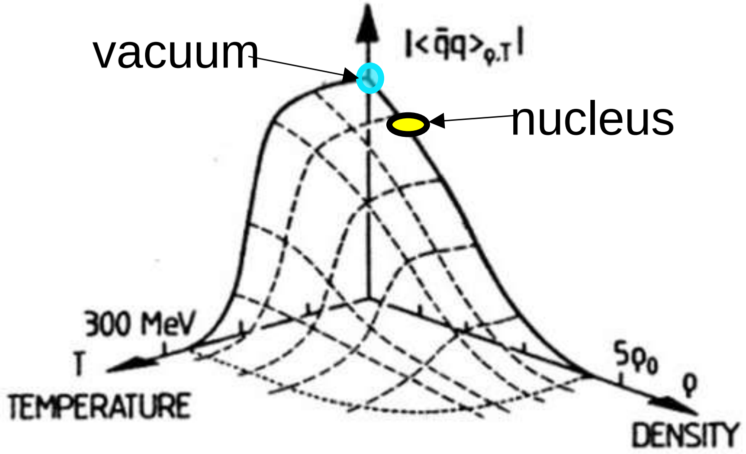
Study of ϕ meson in the nucleus

- **Goals**

  Studies of in-medium modification of ϕ mesons and its relation to $\bar{q}q$ condensate

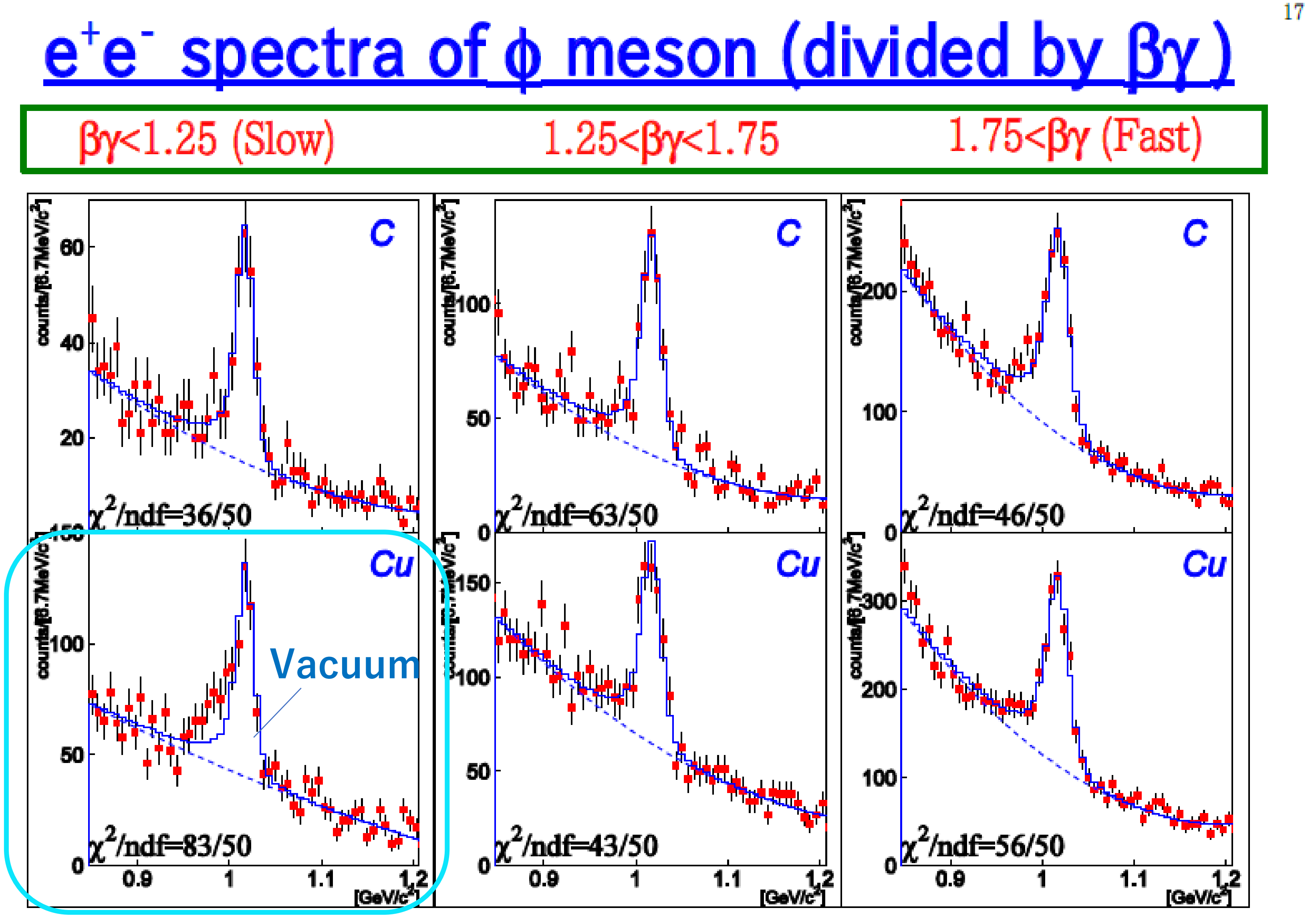
  - The mass shift of ϕ meson is sensitive to $\bar{s}s$ condensate in finite density

- **Experimental status**
  - No ϕ mass shift has been observed for ϕ→e+e- and K+K- in A+A at GSI, AGS, SPS, RHIC, LHC
  - No difference of BR betw. ϕ→e+e- and K+K- in A+A at SPS-CERES (PRL96, 152301 (2006))
  - No ϕ mass shift in ϕ→K+K- in γ+A collisions (LEPS) (Ishikawa, PLB 608 (2005) 215)
  - Only in p+A (KEK-E325), low mass excess in ϕ→e+e- observed (J-PARC E16 will measure with higher statistics)
  - ALICE pϕ femtoscopy result suggests attractive interaction between ϕ and p (S. Acharya, et al. Phys. Rev. Lett. 127(17), 172301 (2021))



P. Gubler and K. Ohtani, PRD **90**, 094002 (2014)

KEK-E325 result (ϕ→e+e-)



- E325 observed excess at lower mass at $\beta\gamma<1.25$ in p+Cu
- E325 has no ϕ→K+K- data at $\beta\gamma<1.25$

➢ E88 will focus on Low $\beta\gamma$ with extremely high statistics

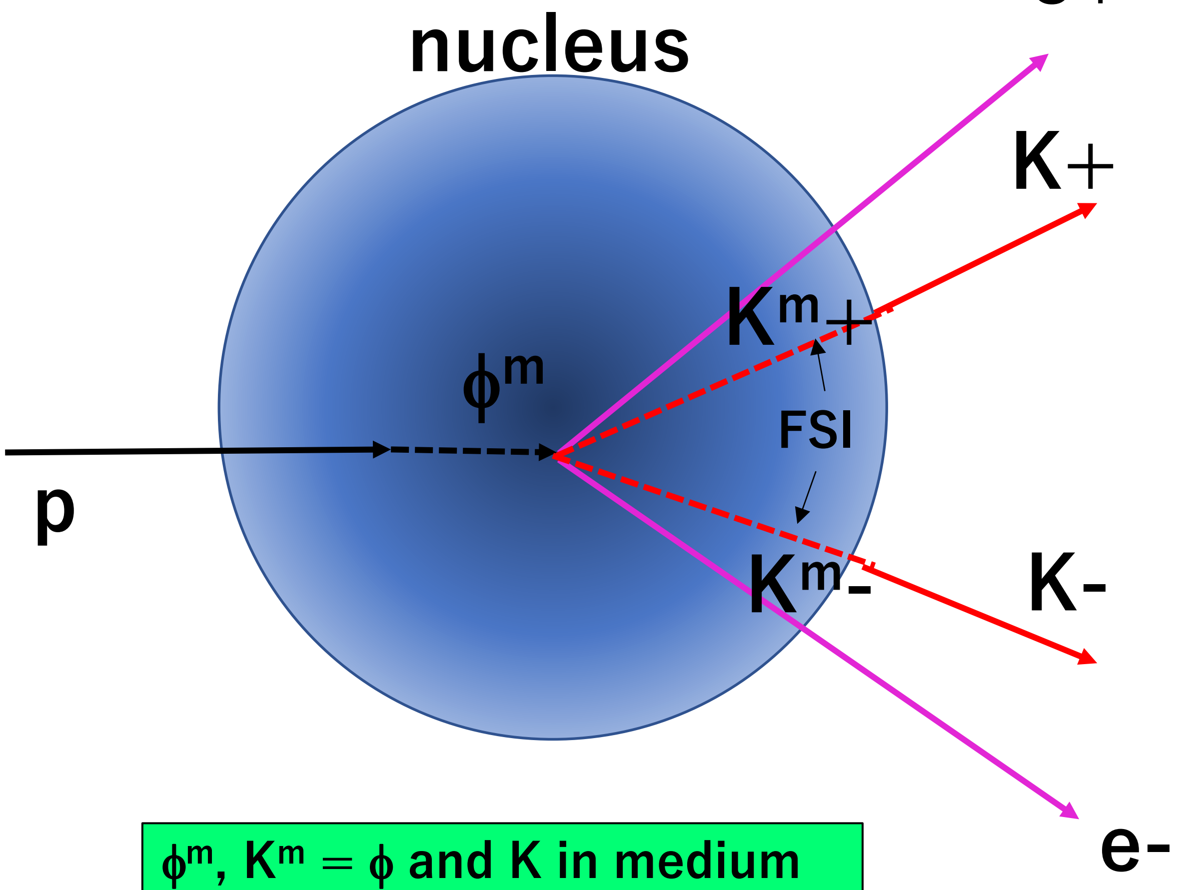
$\phi \rightarrow K^+K^-$ and $\phi \rightarrow e^+e^-$ in p+A

Advantage of $\phi \rightarrow K^+K^-$ over $\phi \rightarrow e^+e^-$

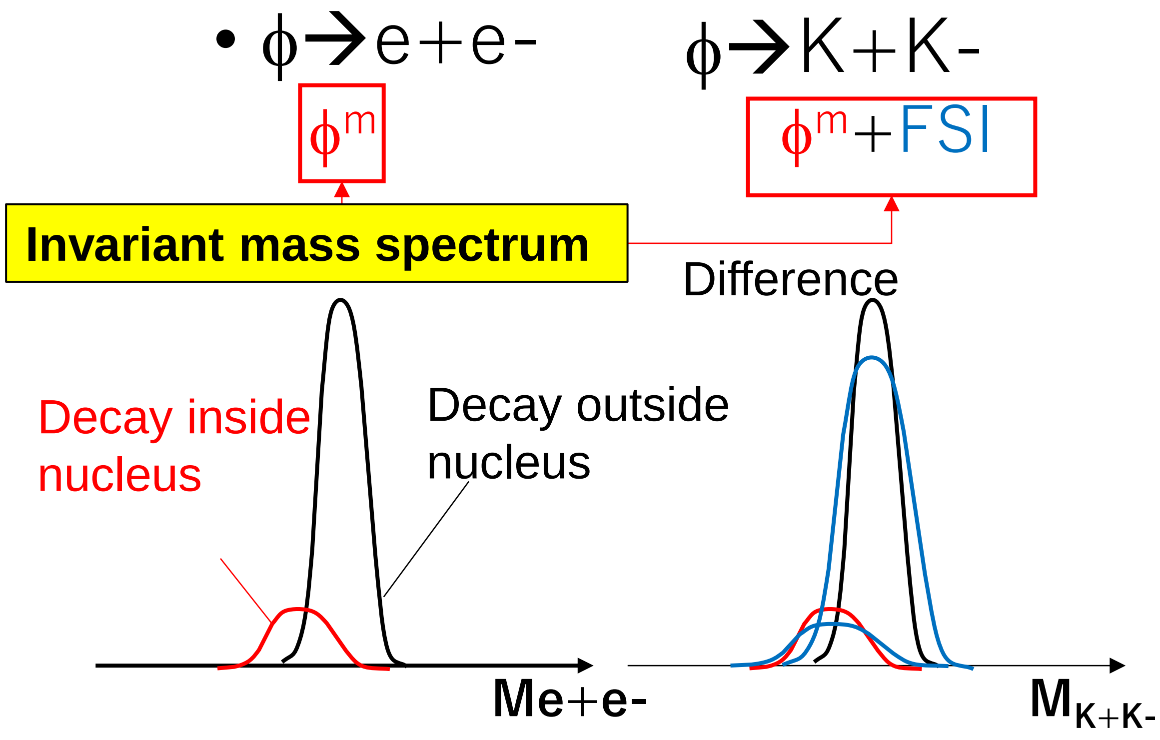
1. Much higher statistics
2. Branching ratio sensitive to ϕ mass shift

   Small Q value (32MeV) of $\phi \rightarrow K^+K^-$

However, $\phi \rightarrow K^+K^-$ is modified by FSI (KN)



ϕ^m, K^m = ϕ and K in medium



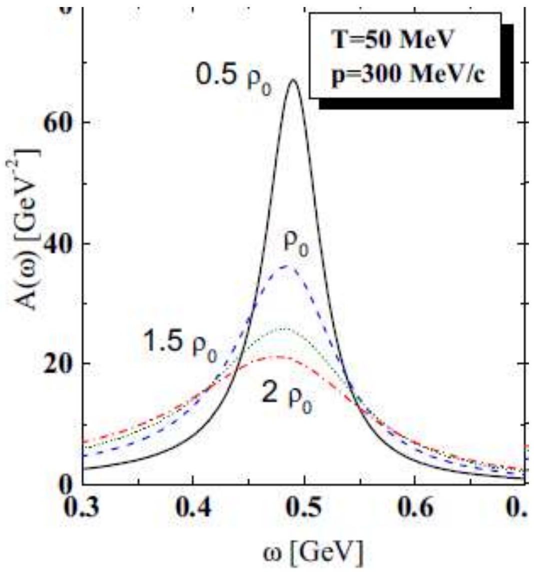
Transport model development for ϕ→KK

- HSD (Hadron-String Dynamics) model developed for ϕ→K+K- calculations

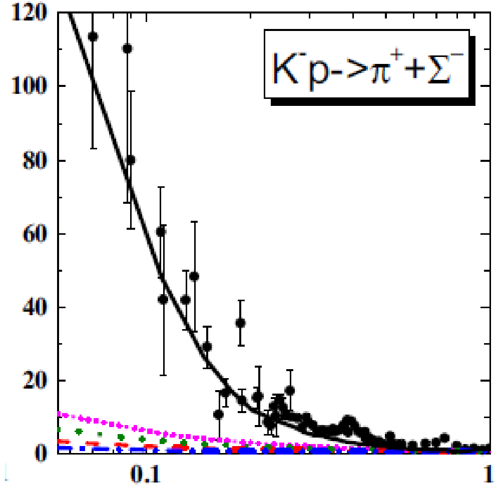
  P. Gubler (JAEA), S. H. Lee (Yonsei Univ.), E. Bratkovskaya, T. Song (Frankfurt U./GSI)

  - K-N interaction based on chiral unitary model including off-shell effects
  - $K^{\pm}$ in-medium modified spectral function
    - At high density, K- mass peak decreases and width increases
    - K+ mass increases due to repulsive potential of 20-30 MeV, while the width remains narrow
  - Scattering and absorption of $K^{\pm}$ in nucleus (e.g. to $\pi\Sigma$)
  - ϕ spectral function of Breight-Wigner shape

K- spectral function



K-N absorption cross section



T. Song et al, PRC103 044901 (2021)

p_K [GeV/c]

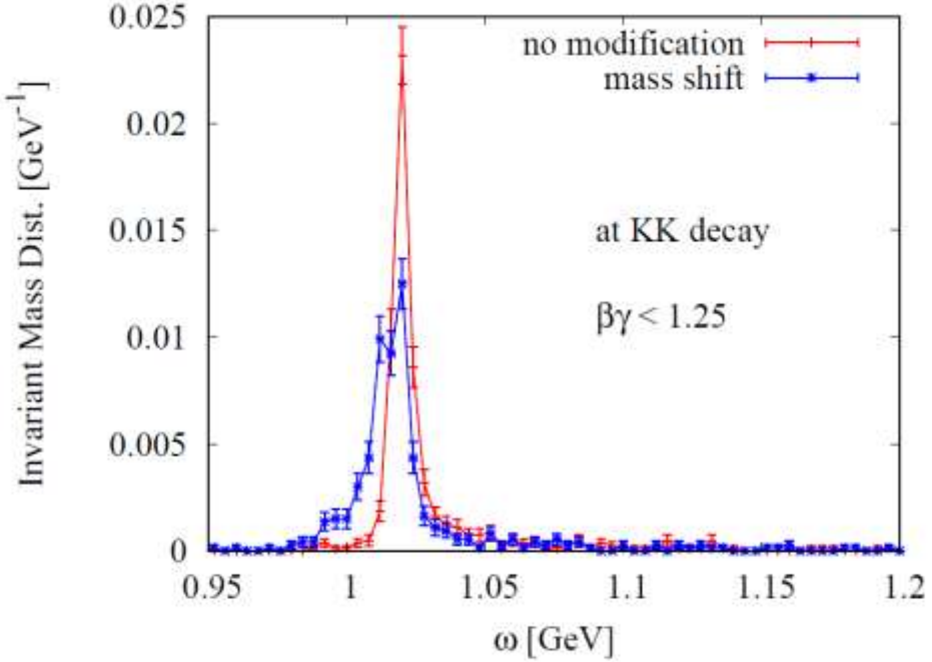
HSD calculations for $\phi \rightarrow K^+K^-$

Study in progress

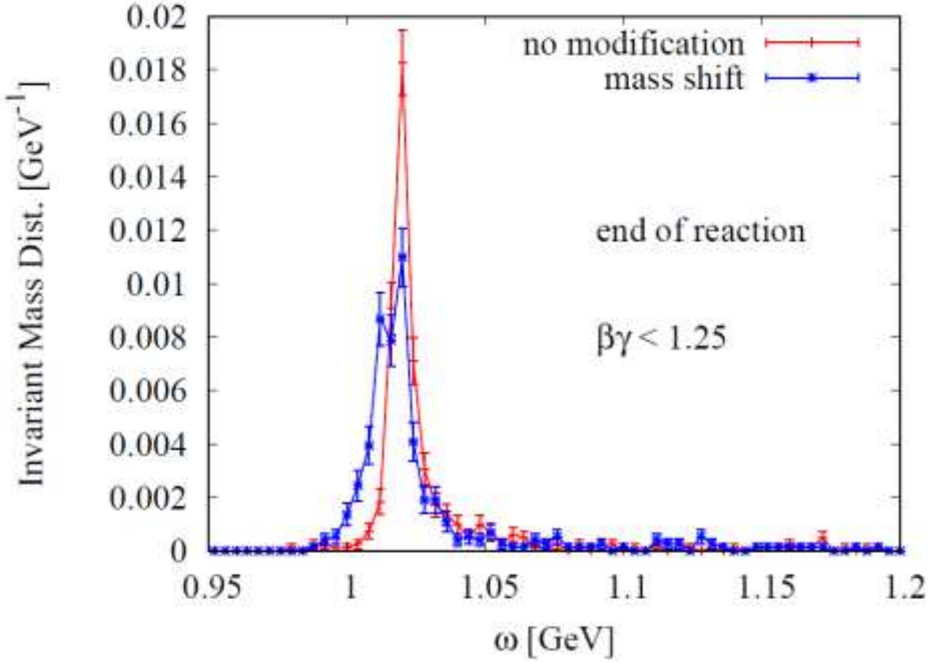
P. Gubler for E88

p+Cu, $\beta\gamma$<1.25

w/o FSI



w/ FSI

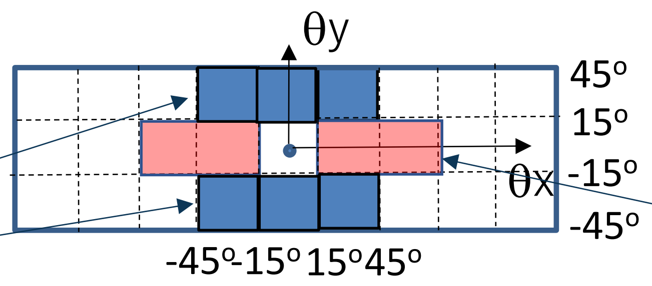


Assumed mass shift : Δm = -34MeV ρ/ρ_0 (E325)

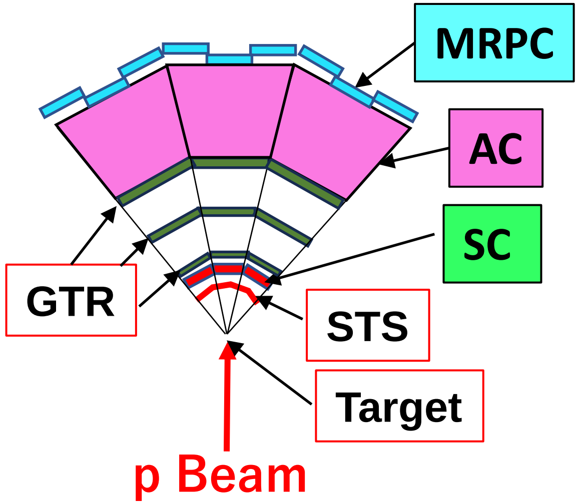
- Low mass excess remains w/ FSI
  - FSI effect is ~10% level

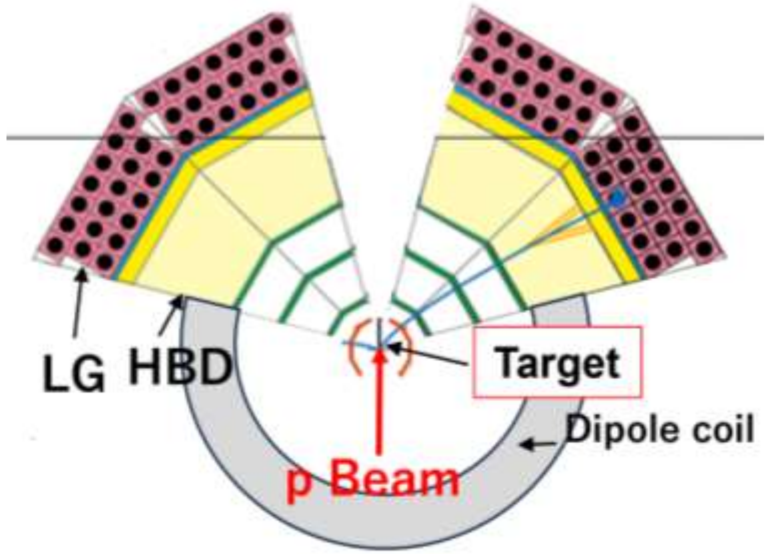
J-PARC E88 Setup

Top and bottom layers
Kaon ID detectors



Middle layer
(electron-ID detectors)



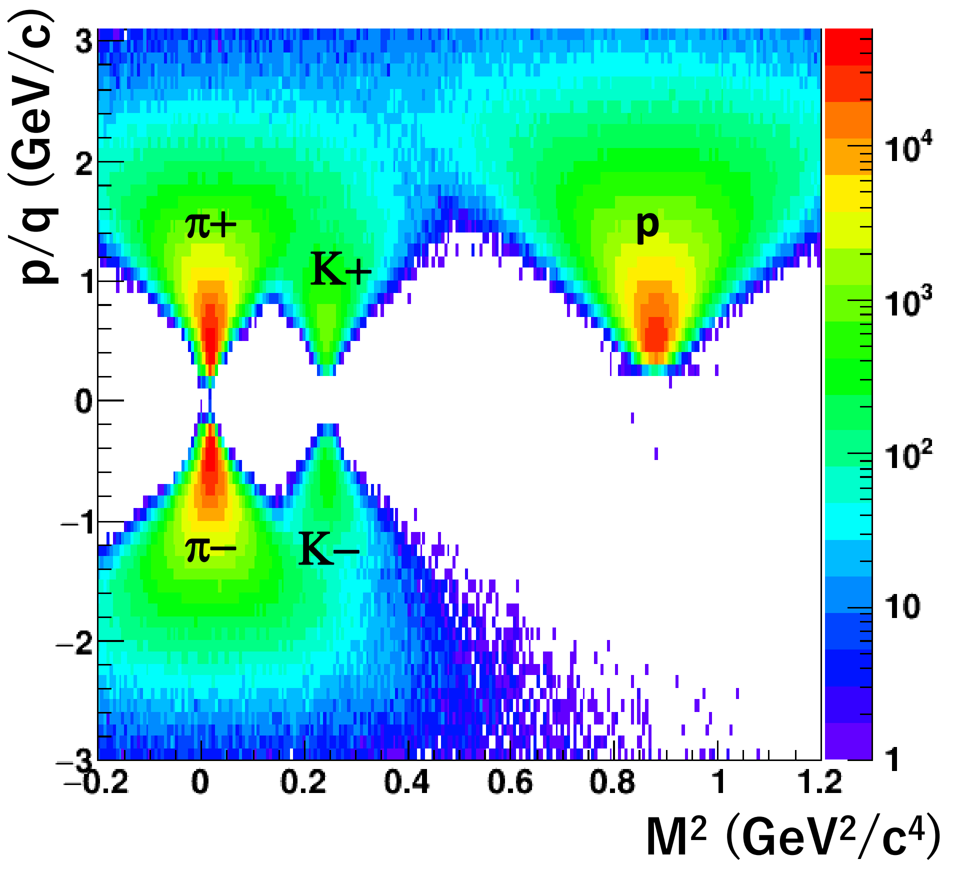


- 6 forward modules for $K^{\pm}$ identification in top and bottom layers
- **MRPC** (Mulit-gap Resistive Plate Chamber) and **SC** (Start timing counter) for Time-of-Flight measurement
- **AC** (Aerogel Cherenkov counter) for pion rejection
- **STS** (Silicon Tracking System) and **GTR** (GEM Trackers) for track reconstruction

Particle identification and acceptance

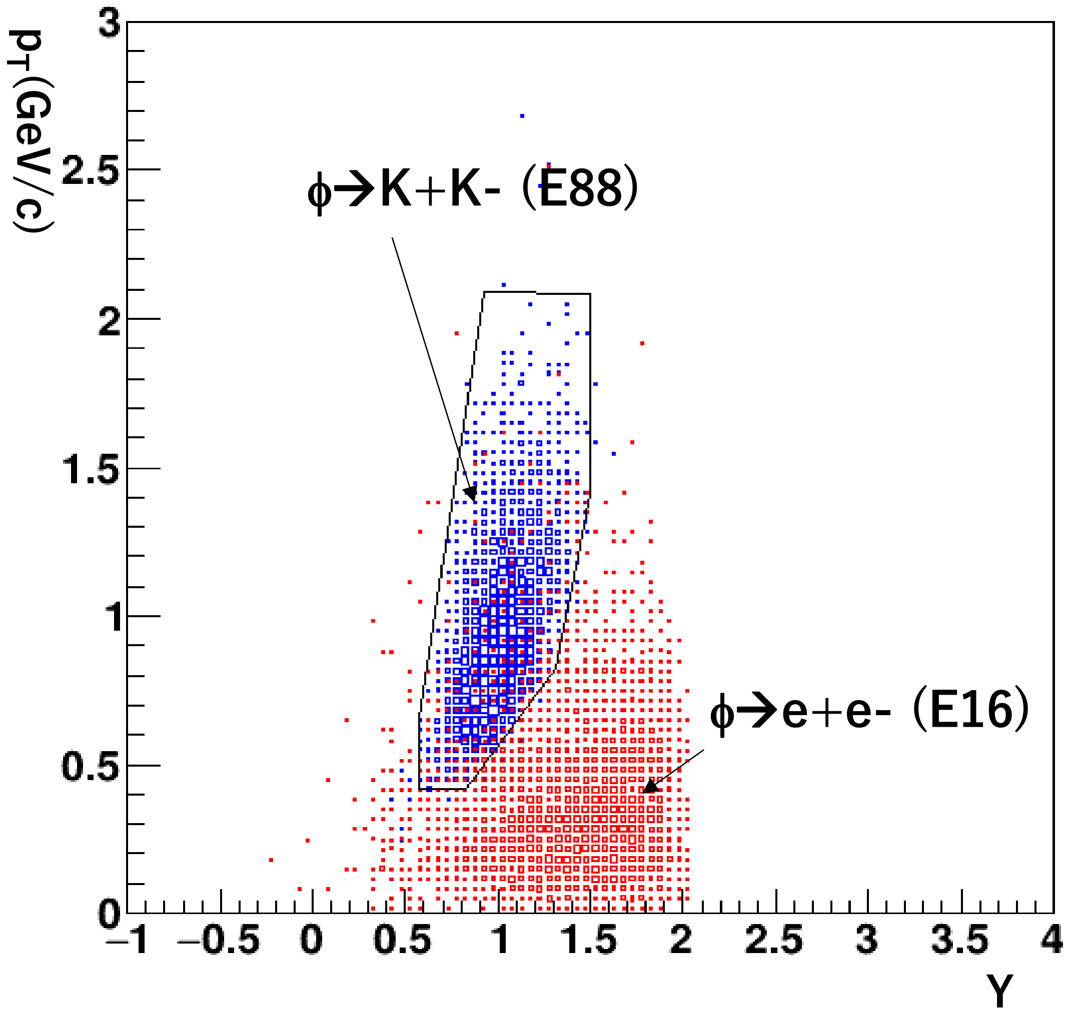
M²: calculated with TOF between MRPC and SC
→Required MRPC and SC timing resolution
~70ps, 50ps

M² vs rigidity (Simulation)



y-p_T acceptance

p+Cu (No AC veto)



Expected statistics

Beam time: 30 days with 30 GeV proton beam at 10^9 / spill

- C (0.1% int.) + Cu (0.1% int.) + Pb (0.1% int.) targets
- Statistics increased by factor of 300 (p+C) and 500 (p+Cu) from E325

$\phi \rightarrow K+K-$ at E88			
	C	Cu	Pb
ϕ ($\beta\gamma<1.25$)	72k	113k	314k
ϕ ($1.25<\beta\gamma<1.75$)	84k	146k	340k
ϕ ($1.75<\beta\gamma<2.1$)	3k	3k	8k

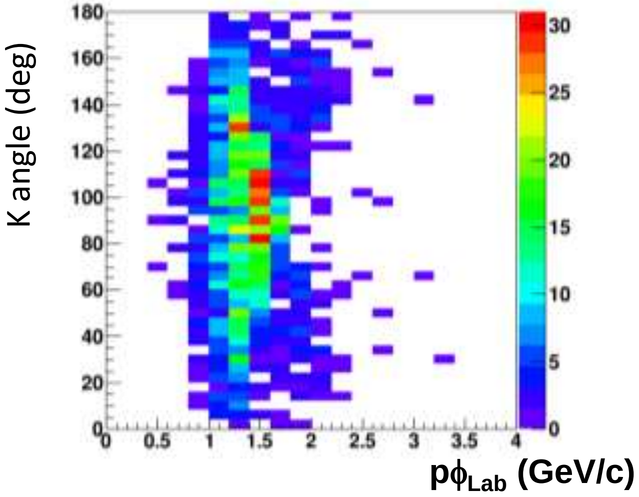
$\phi \rightarrow K+K-$ at E325		
ϕ ($1.0<\beta\gamma<1.7$)	99	285
ϕ ($1.7<\beta\gamma<2.2$)	143	279
ϕ ($2.2<\beta\gamma<3.5$)	177	269

F. Sakuma (E325)
PRL 98 152302 (2007)

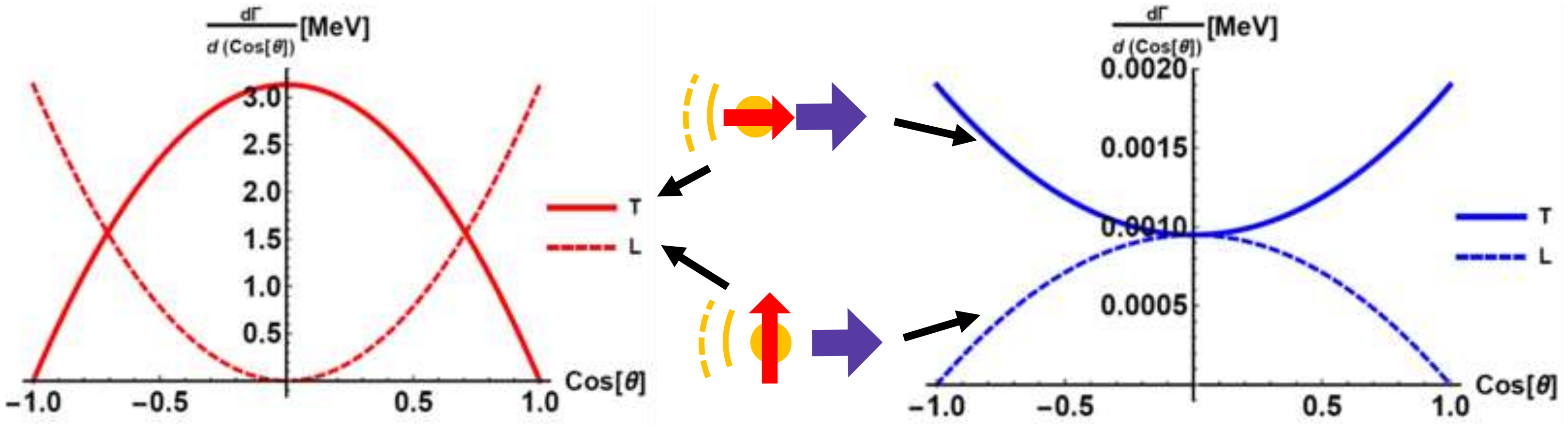
ϕ Polarization through decay angle of $\phi \rightarrow K^+K^-$ and $\phi \rightarrow e^+e^-$

I.W. Park, H. Sako, K. Aoki, P. Gubler and S.H. Lee, Phys. Rev. D **107**, 074033 (2023).

Decay angle distributions in ϕ rest frame for L/T ϕ polarizations



E88 has ~ 100% CM angle acceptance for $\phi \rightarrow KK$



$\phi \rightarrow K^+K^-$

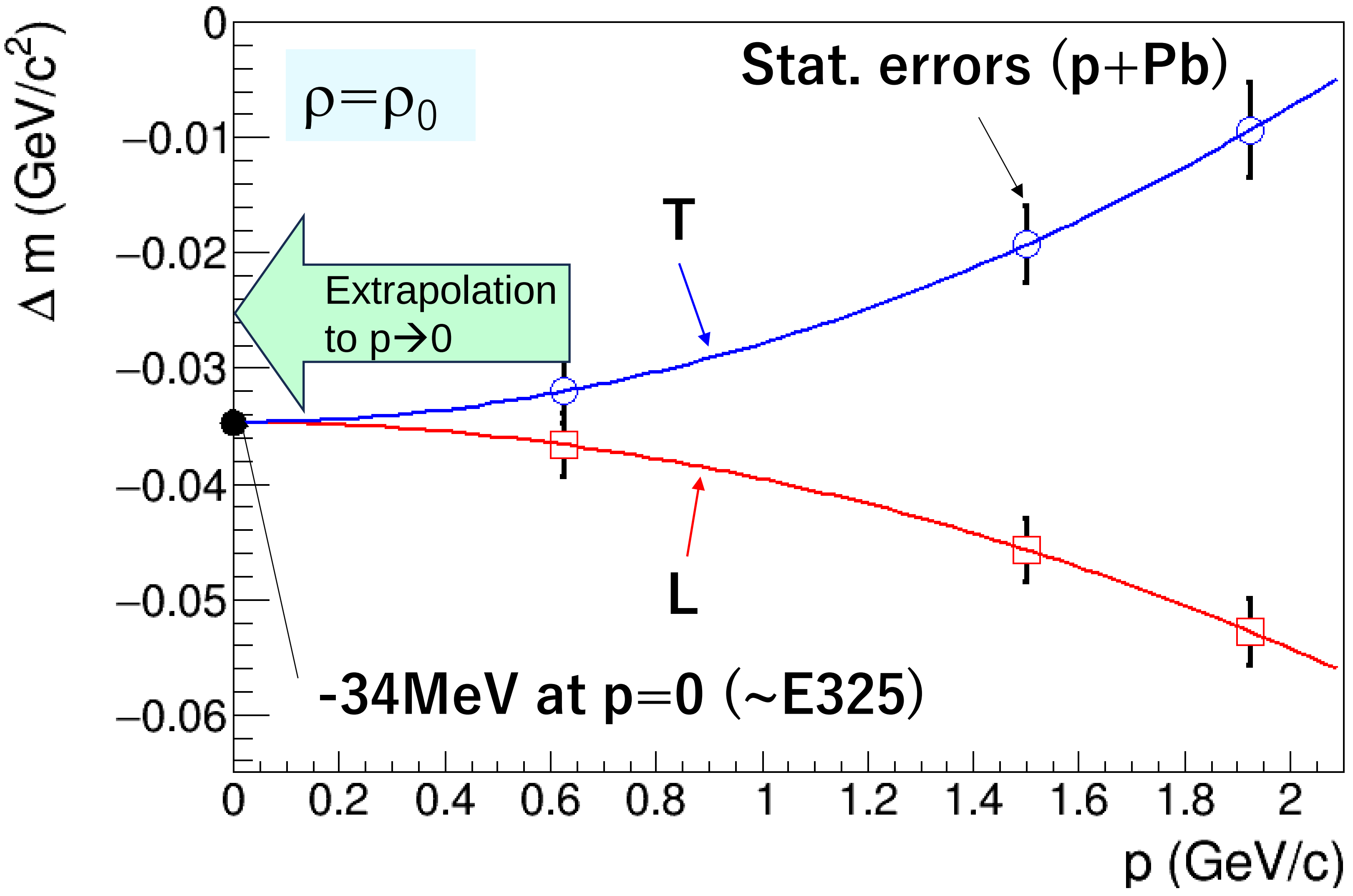
$\phi \rightarrow e^+e^-$

$\phi \rightarrow K^+ K^-$ can distinguish both T and L polarizations

$\phi \rightarrow e^+e^-$ can distinguish only L polarization

Dispersion relation

Based on QCD sum rules in H.J. Kim and P. Gubler, Phys. Lett. B **805**, 135412 (2020)



$$\frac{m(\rho)}{m(0)} - 1 = \left(a + b^{L/T} p^2\right) \frac{\rho}{\rho_0}$$

a: chrial condensate term at p=0

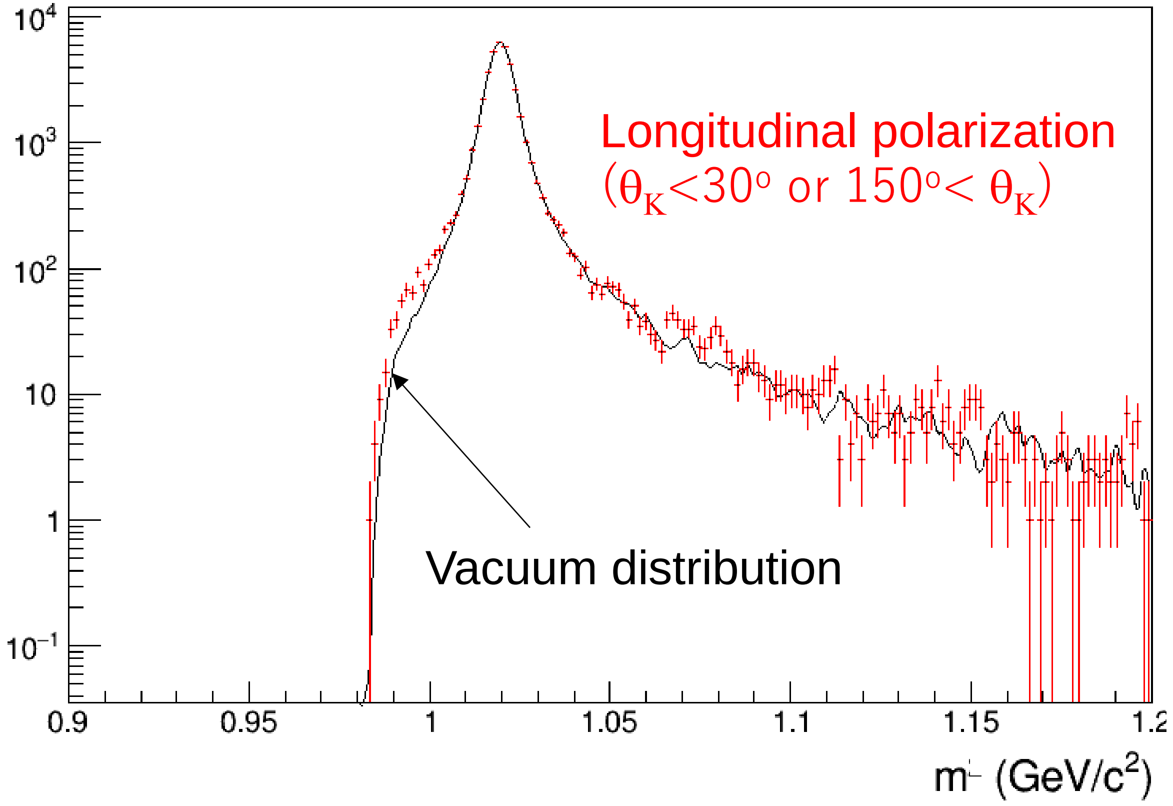
$$a = -\alpha \langle N | \bar{s}s | N \rangle \ (\alpha > 0)$$

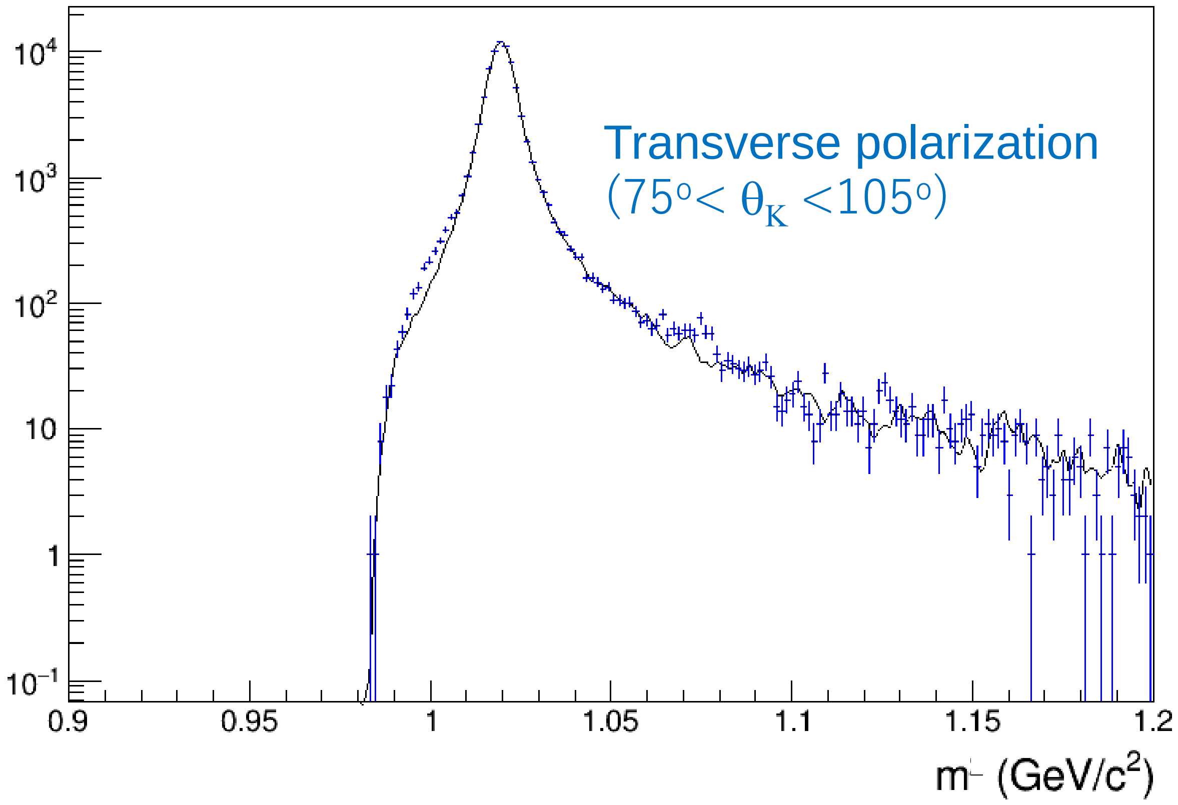
$b^{L/T}$:Lorentz symmetry breaking term (longitudinal / transverse polarized ϕ)

(momentum and polarization dependence)

p+Pb toy model

1.25<βγ<1.75





Generate ϕs with E88 statistics

ϕ kinematics based on HSD transport model

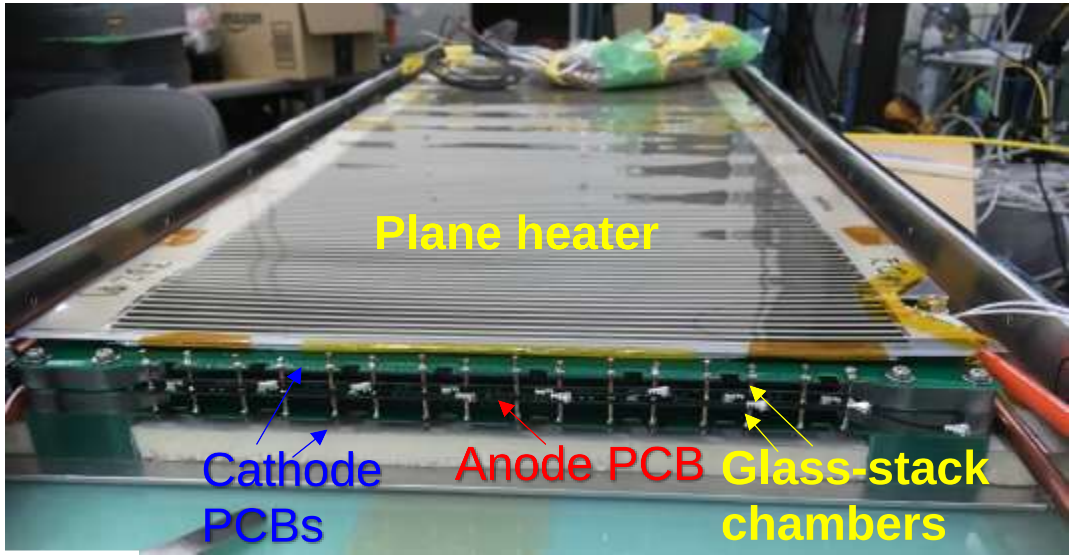
Woods-Saxon density distribution of nucleus

Dispersion relation from QCD Sum rules

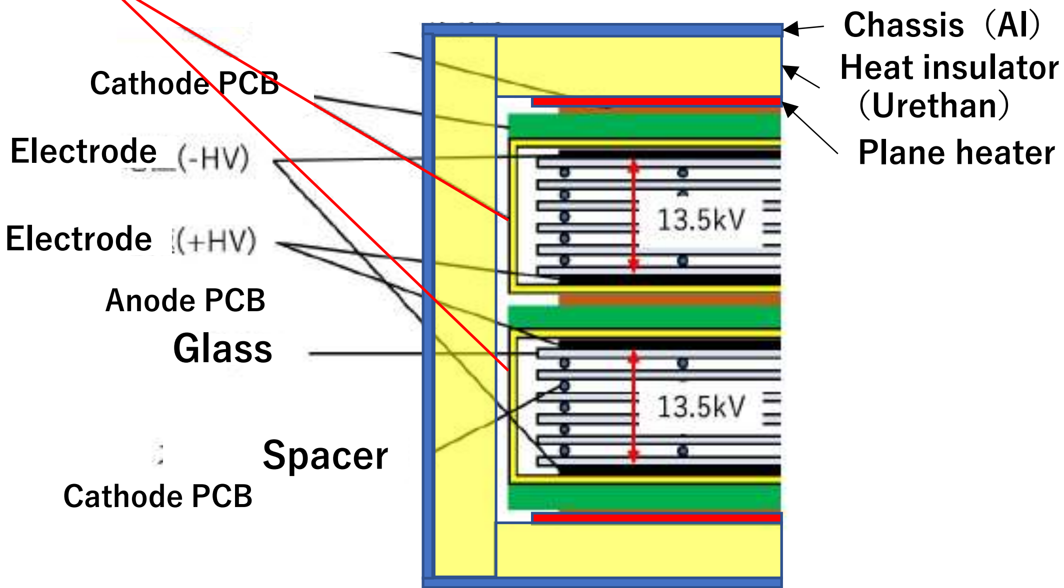
Invariant mass resolution of 2 MeV/c^2

No FSI included

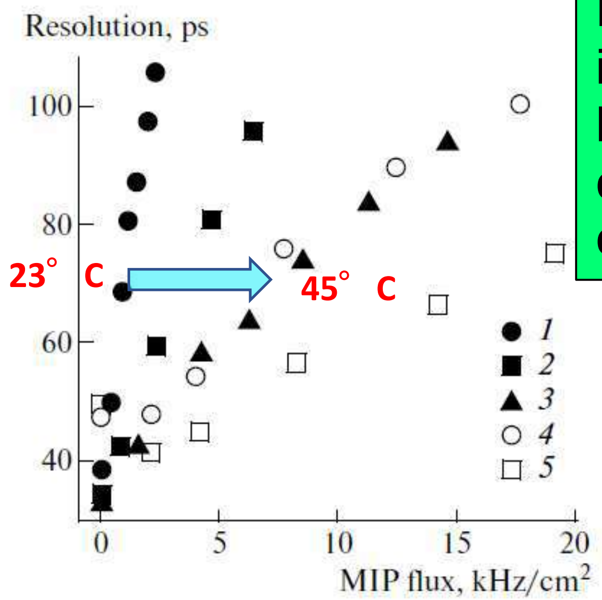
Multi-gap Resistive Plate Chamber (MRPC)



Glass stack chamber (PC or glass-epoxy)



V.A. Gapienko et al
Inst. Exp. Tech. 56 265-270 (2013)



Factor ~5 increase of high-rate capability expected

Readout : Discriminator + HUL-HRTDC

Slewing correction with TOT

Enhanced high-rate capability

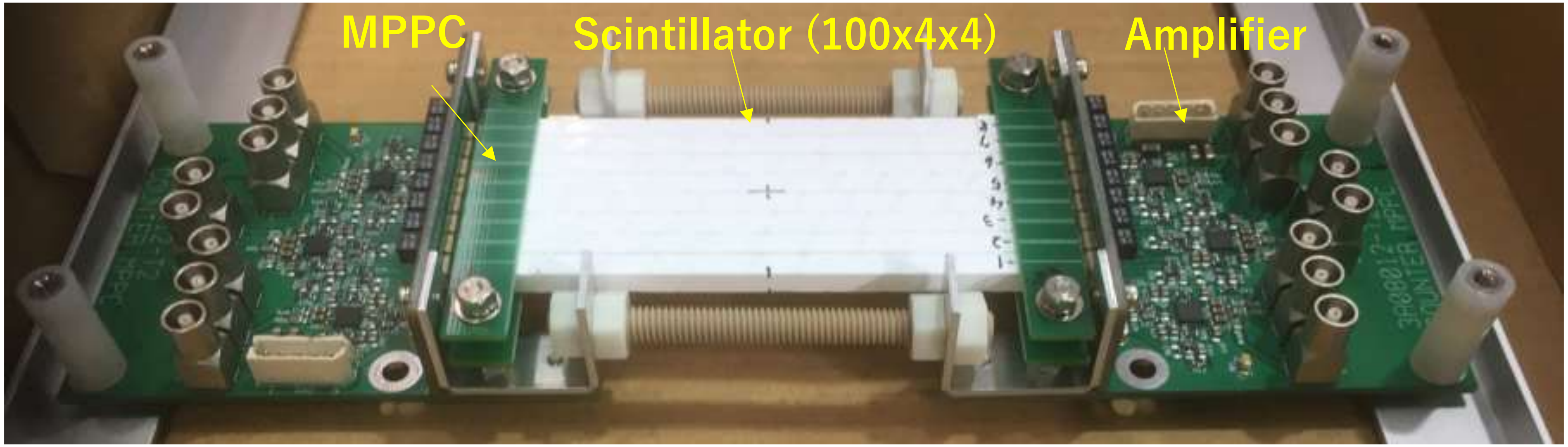
- Warming glass sheets→lower resistivity

→shorter recovery time from discharge

Start-timing Counter (SC)

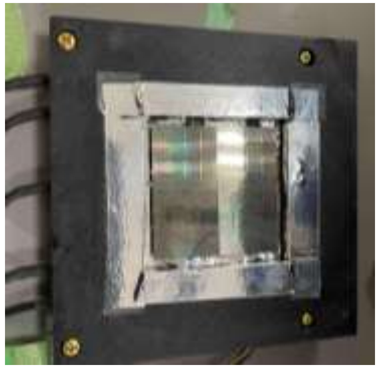
- Segmented scintillation counters
  - Slats of 4mmx4mmx100mm plastic scintillation counter (EJ-228)
  - Photon detection with SiPMs (MPPC S13360-3050, 3mmx3mm)
- Prototype test with ^{90}Sr source
  - Timing resolution : 55 ± 4 ps
- Expected hit rate in the experiment

~ 100 kHz/slat

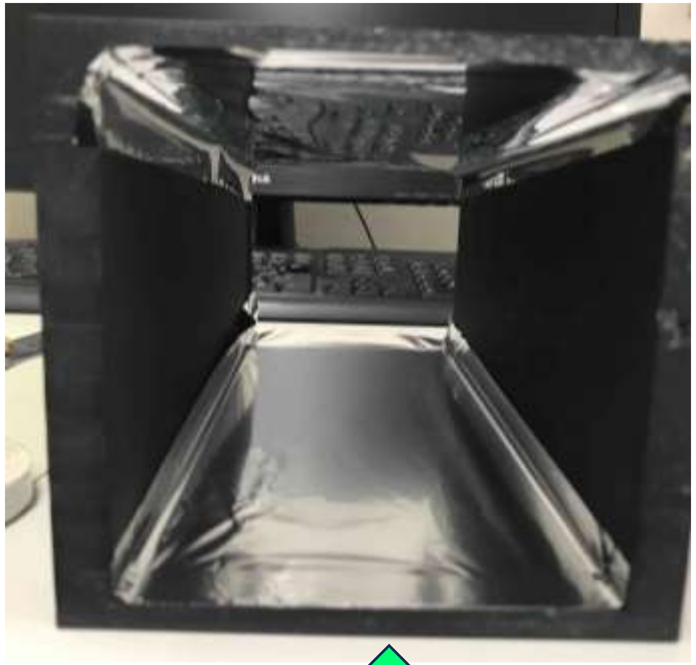


Aerogel Cherenkov Counter (AC)

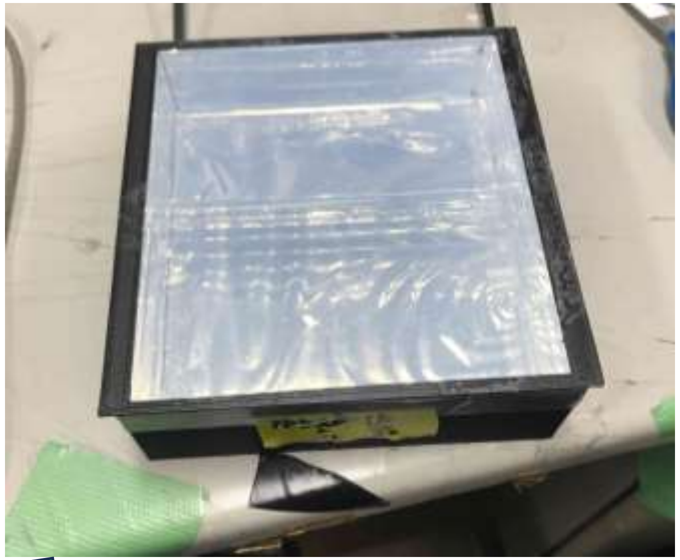
SiPM (MPPC)



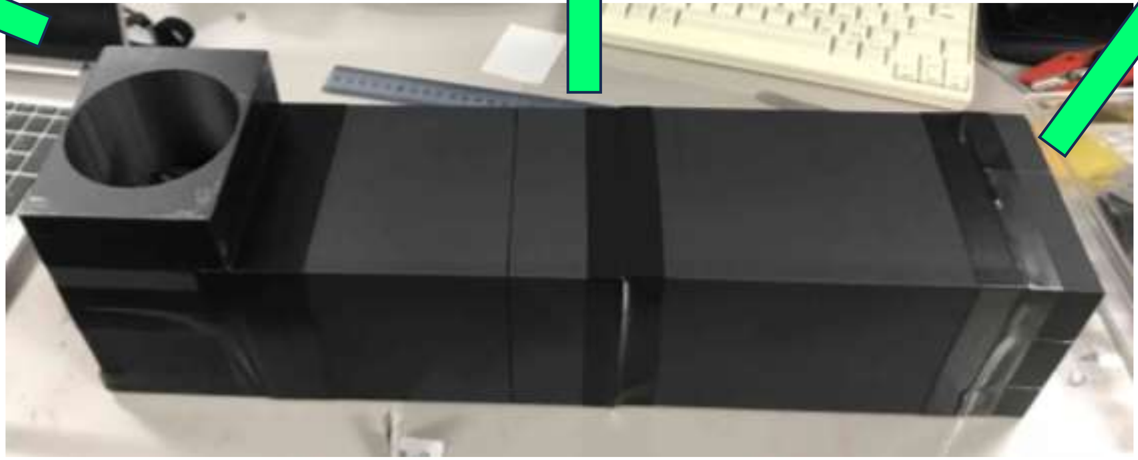
Light collection cone



Aerogel n=1.15
t=30mm



Fine-mesh PMT

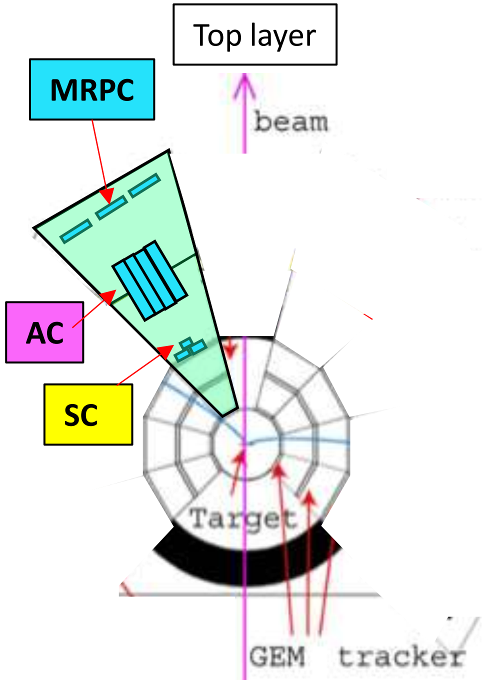


Cosmic-ray test

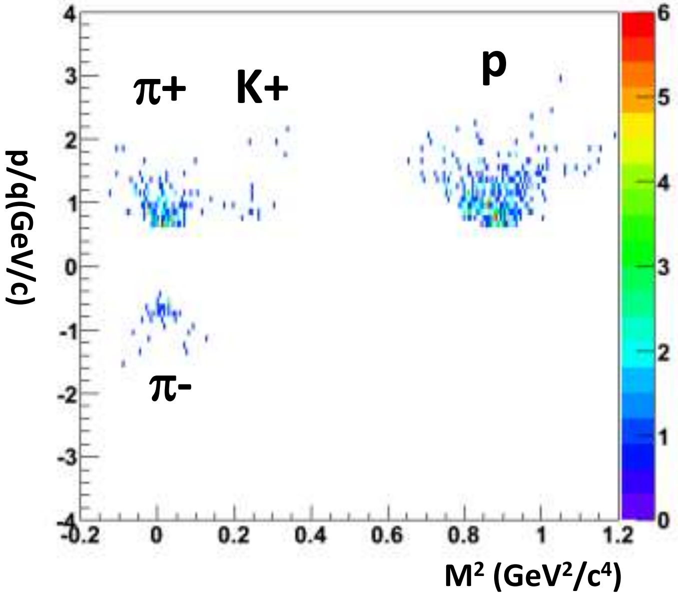
- Efficiency ~90%

Kaon ID detectors test at E16 (Apr-Jun 2024).

- 3 MRPCs, 4 ACs, and 3 SCs with 1/24 scale of a module were tested in E16 spectrometer

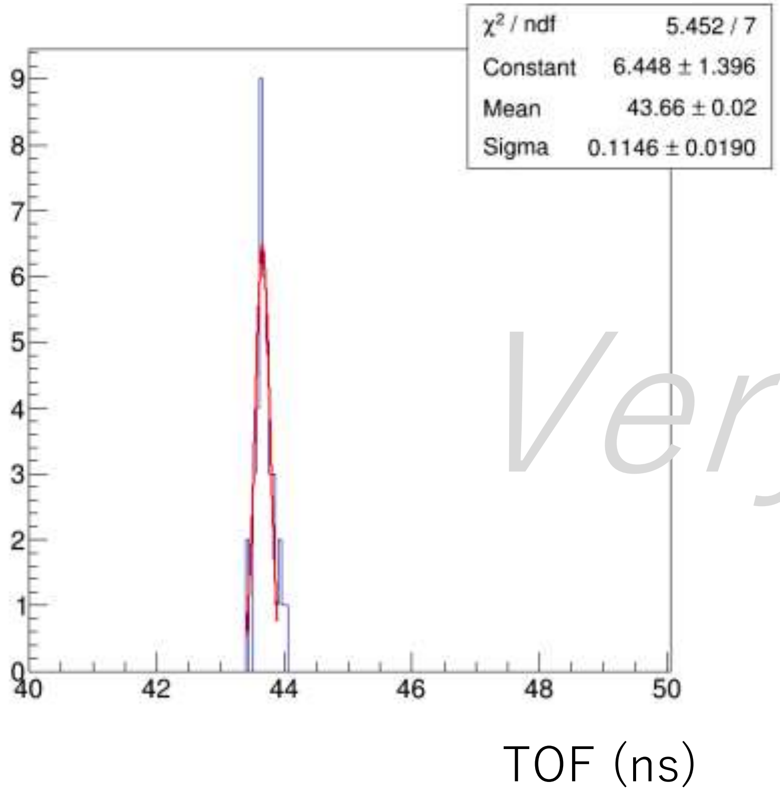


Particle identification (Simulation)

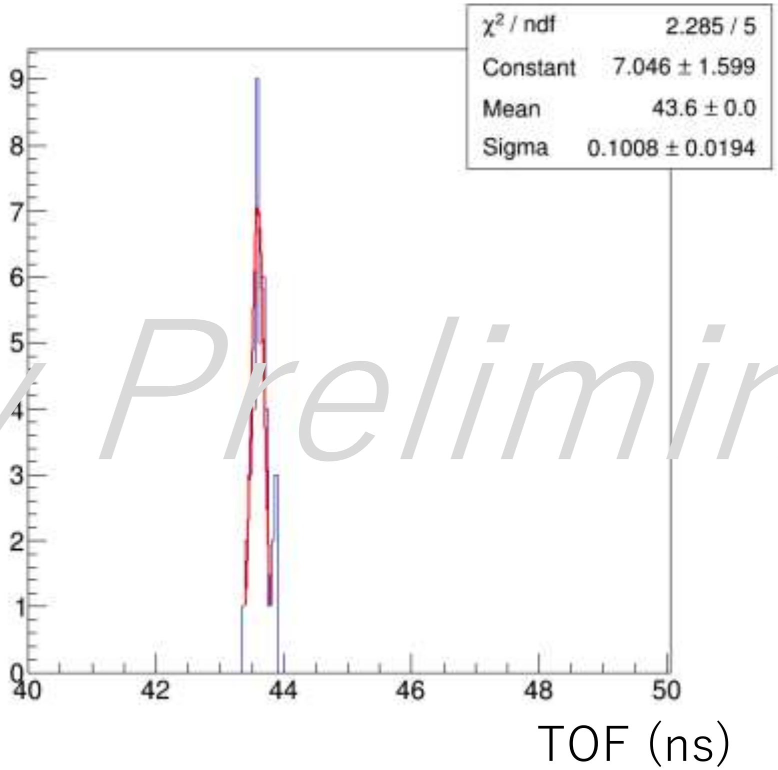


Results in Apr-Jun 2024 beam test
TOF between MRPC and reference counters

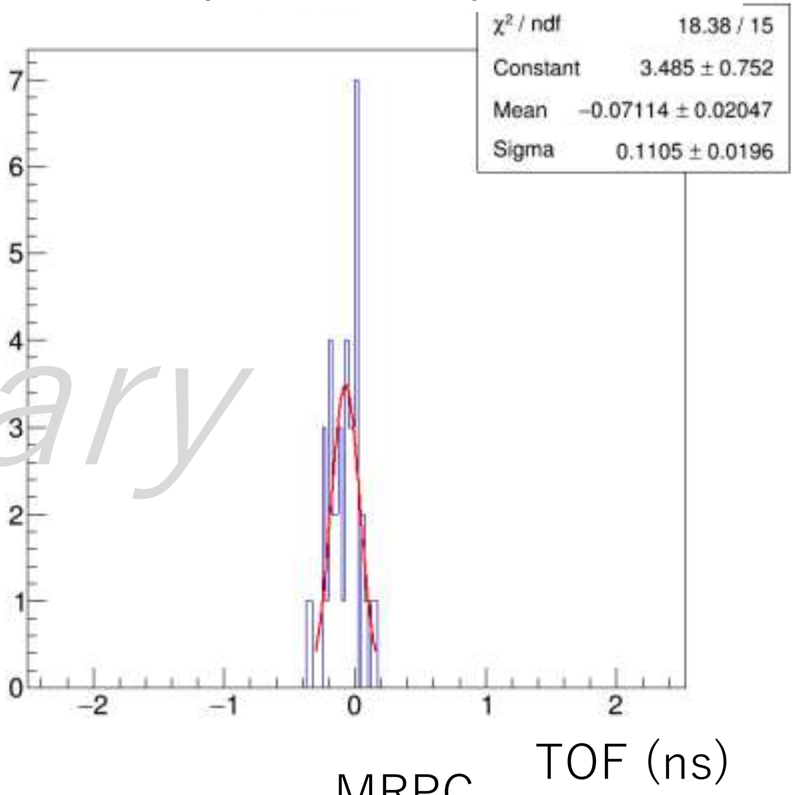
TOF(MRPC-REF1)



TOF(MRPC-REF2)



TOF(REF1-REF2)

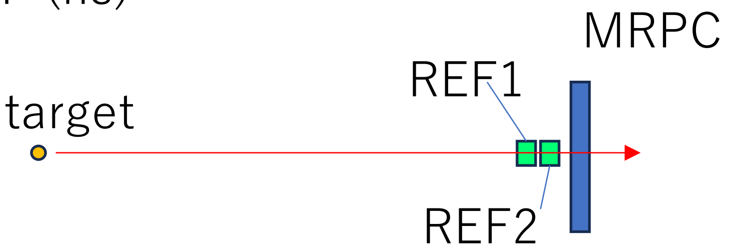


Very Preliminary

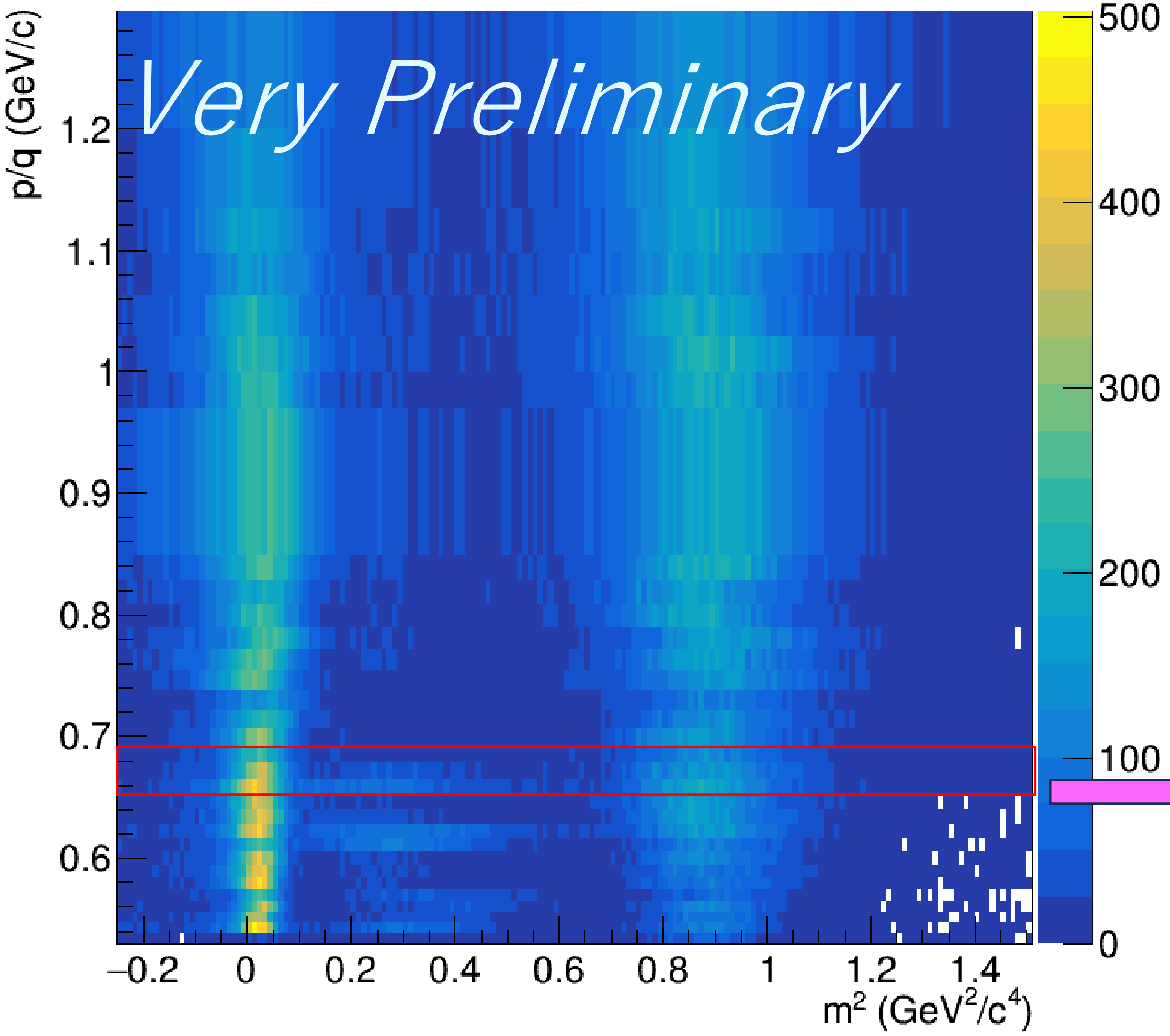
Beam rate : 8.9x10^9 /spill

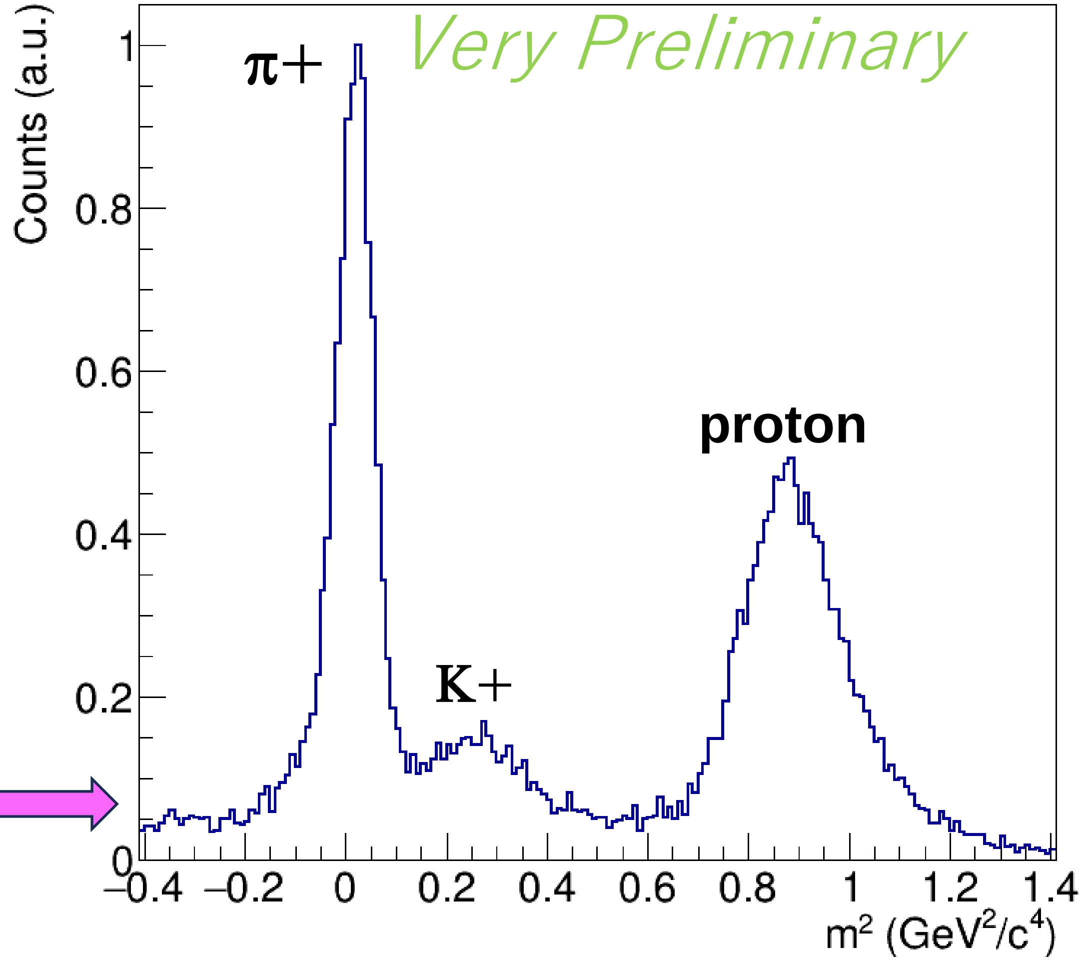
MRPC resolution: 74 ± 24 ps

Efficiency: 92.5 ± 0.5 %



Particle Identification in Apr-Jun 2024 test



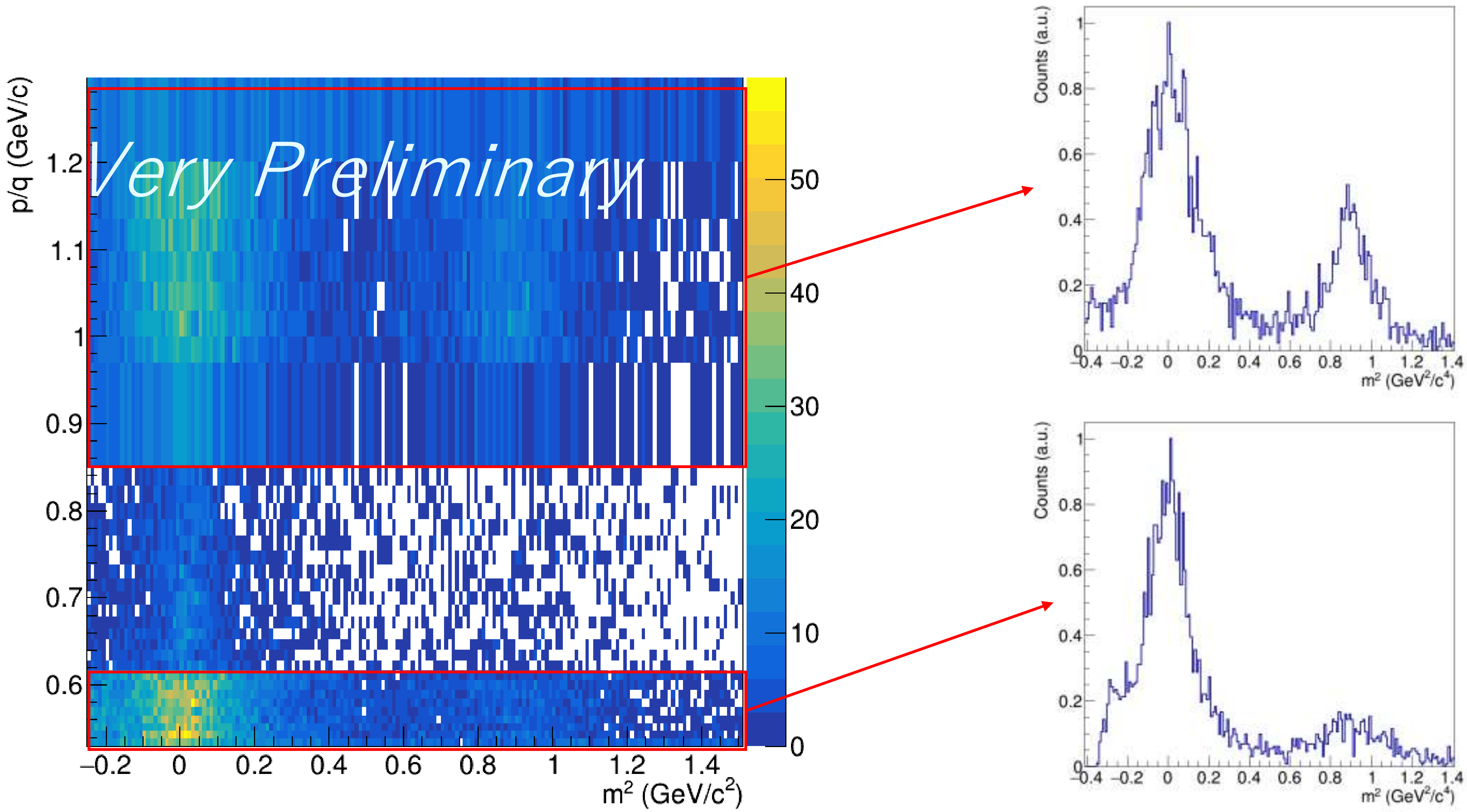


Beam rate ~ 5×10^9/spill

- TOF with SC and MRPC
- Rough momentum and path length estimation with

Horizontal positions of SC and MRPC segments assuming the particles originate from the target

Reversed B-field



Triggerless Streaming DAQ at E88?

Current plan

- K+K- trigger w/ SC, MRPC, and AC

Possible new scheme

- Triggerless continuous (streaming) readout of MRPC, SC, AC (and STS and GTR)

- Advantages
  - Much simpler system
    - No need to implement complicated K+K- trigger
    - No AC necessary?
  - We could collect data in the whole $\beta\gamma$ range (if no limit in the data rate)
  - We could measure all charged hadrons!
- Issues:
  - GTR streaming readout is not yet possible
  - High hit rates (MRPC is probably ok, SC may be ok behind GTR)
  - Event filtering in software is required to reduce the data rate to be recorded
    - Challenging development

Plan

- PID tests again in Run 1 (Apr. 2025-)
  - Possibly test of streaming readout for part of detectors
- Stage-II status request for the final experimental approval (Jan., July 2025)
- Applying for a Kakenhi budget (Kiban-S) for JFY2025
  - Mass production of AC, SC and MRPCs if approved
- Physics run in JFY2026 – 2027?

Summary

- We aim to measure $\phi \rightarrow K^+K^-$ decay in p+C, p+Cu and p+Pb with extremely high statistics to study modification of ϕ in the nucleus, focusing on low ϕ velocity.
- In 30-day beam time, we will collect ~1M $\phi \rightarrow K^+K^-$ decays at $\beta\gamma<2$, which has higher statistics than KEK-E325 by 2-orders of magnitude.
- We analyze K^+K^- invariant mass spectra in high mass resolution to evaluate mass modification depending on momentum and polarization.
- We compare the difference in the target mass dependence of the yields from $\phi \rightarrow e^+e^-$ data to evaluate FSI.

We welcome new collaborators!