K^+ nucleus interaction at DAFNE

Research Center for Electron Photon Science
Tohoku University
Hiroaki Ohnishi

K^+ nucleus interaction at DAFNE

Research Center for Electron Photon Science
Tohoku University
Hiroaki Ohnishi
Yuta Sada and Kairo Toho

The KN interaction

- The KN interaction is known to be repulsive.
- No resonance exist below KN threshold (not the case for $\bar{K}N$ interaction)
- Therefore, bare interaction between kaon and nucleon can be accessible via KN scattering at low energy.

- Moreover, for the reasons mentioned above, Kaons can penetrate the nucleus, making Kaon-nucleus interactions accessible under finite density conditions through Kaon nucleus scattering.

Kaon-nucleon elastic scattering

- In case of Kaon nucleon scattering, quark condensate with strangeness component can be written with isospin averaged kaon-nucleon scattering amplitude T_{KN} as

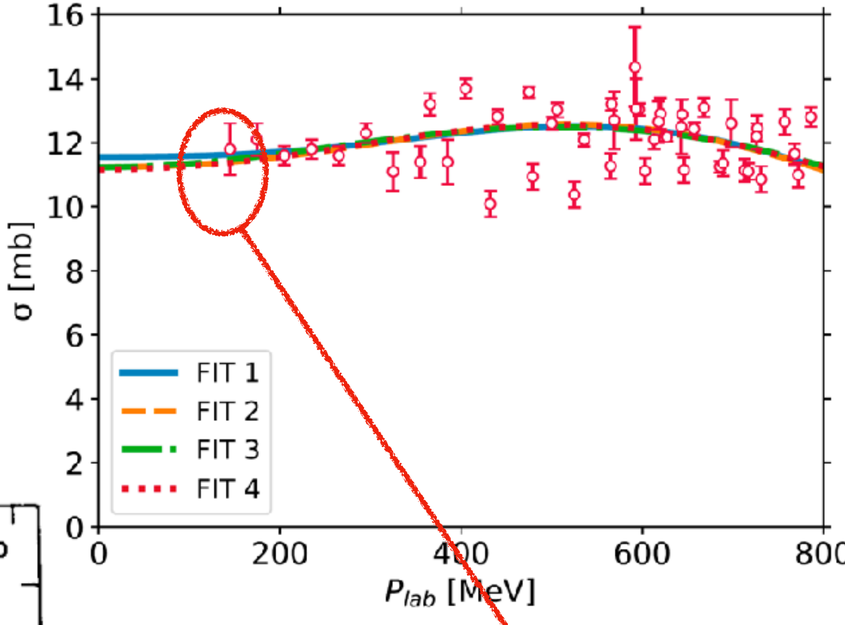
$$\frac{\langle \bar{u}u + \bar{s}s \rangle^*}{\langle \bar{u}u + \bar{s}s \rangle_0} = \left(1 + \frac{\rho}{M_K^2} \frac{T_{KN}(q=0)}{2M_N} \right)$$

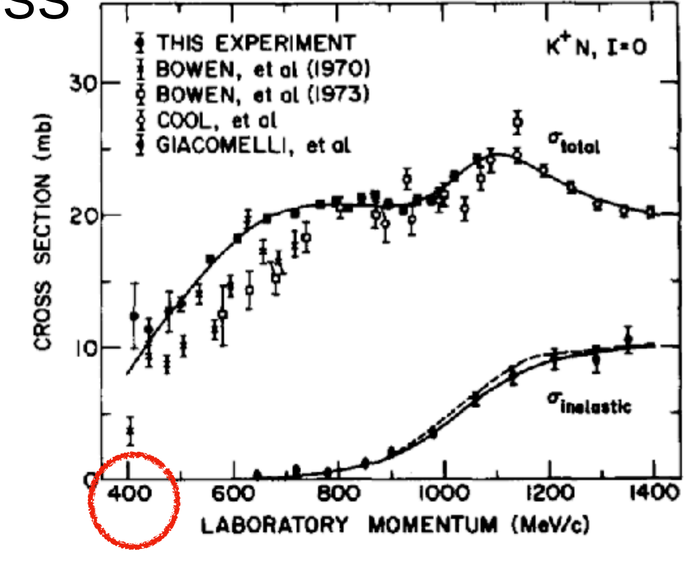
Y. Iizawa, D. Jido and S. Hubsch
arXiv:2308.09397v1 [hep-ph] 18 Aug 2023

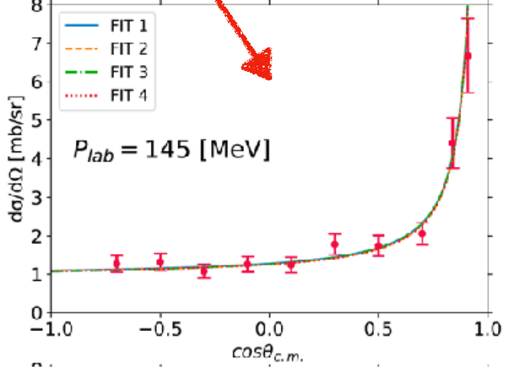
- So, the KN scattering amplitude will be a key measurement in revealing quark condensation with strangeness.

Experimental data from past experiment

- For I=1 K^+N interaction, data of K+ momentum down to 145 MeV/c already exist. ($K^+p \to K^+p$).
- On the other hand, no data for Kaon momentum lower than 400 MeV/c exist for I=0 KN scattering.
- K^+ scattering data with $P_K < 400$ MeV/c will be a unique measurement to access KN interaction.
- I =0 KN scattering channel at low energy is essential for KN scattering,





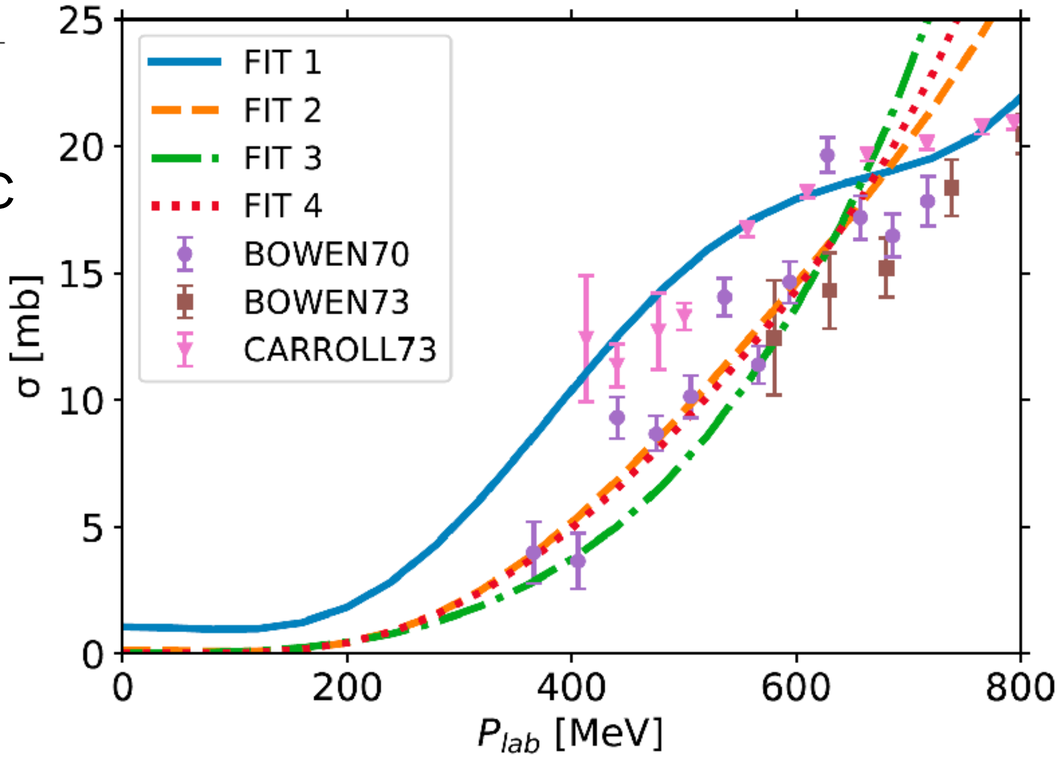


Theoretical work for I=0 KN interaction

- I=0 K+N total cross section data have been investigated by Y. Iizawa, D. Jido and S. Hubsch discussed in arXiv:2308.09397v1
  They include some resonances which strongly coupled with K+p

Solution	Resonance (J^P)	mass [MeV]	width [MeV]	coupling strength [10^{-3} MeV^{-1}]
Solution 1	P_{01} ($\frac{1}{2}^+$)	1617	305	$5.26 - 2.62i$
Solution 2	P_{03} ($\frac{3}{2}^+$)	1678	463	$4.64 - 2.62i$

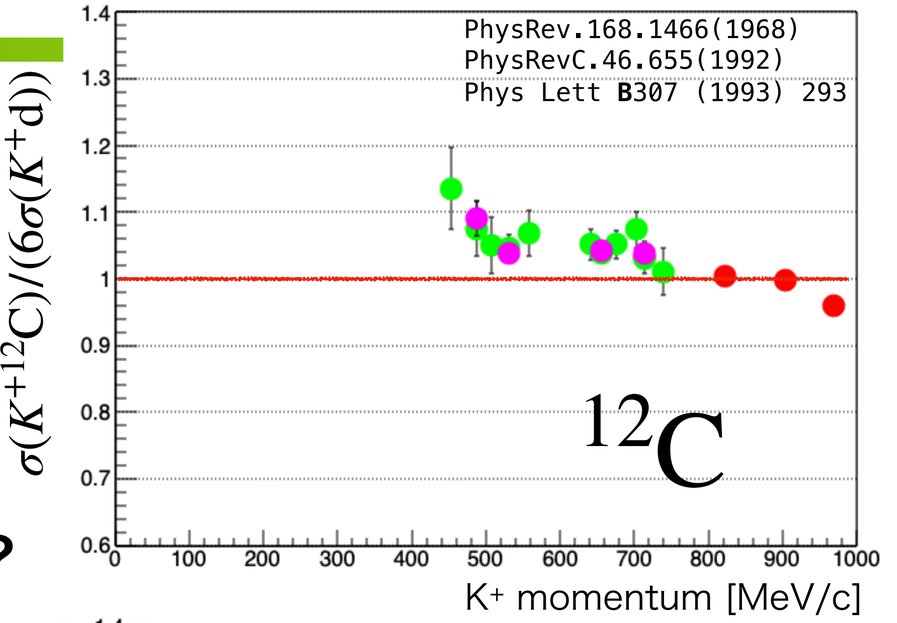
- The effect appeared around $P_K \sim 500$ MeV/c
- In other words, low-energy K+N scattering data may only provide information about the KN interaction
  (free from the effect of the possible resonance state.)

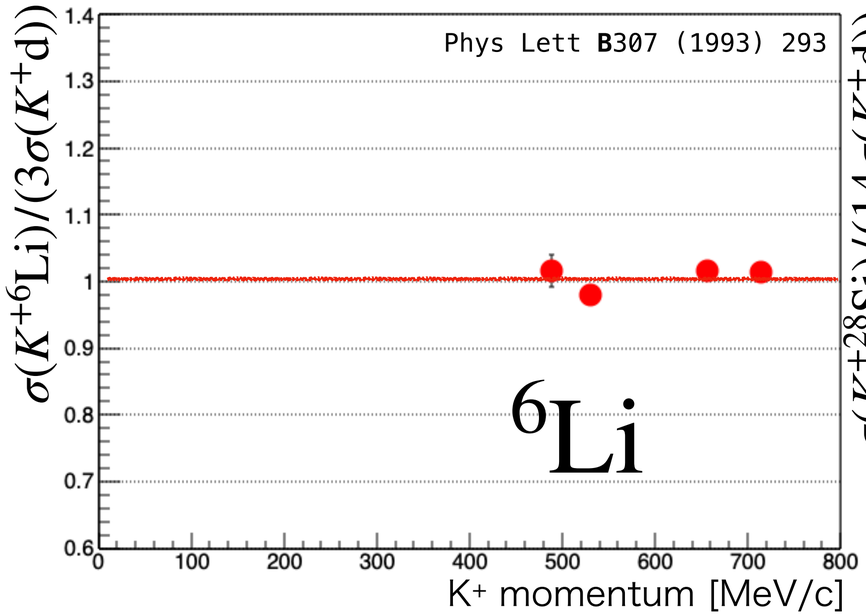


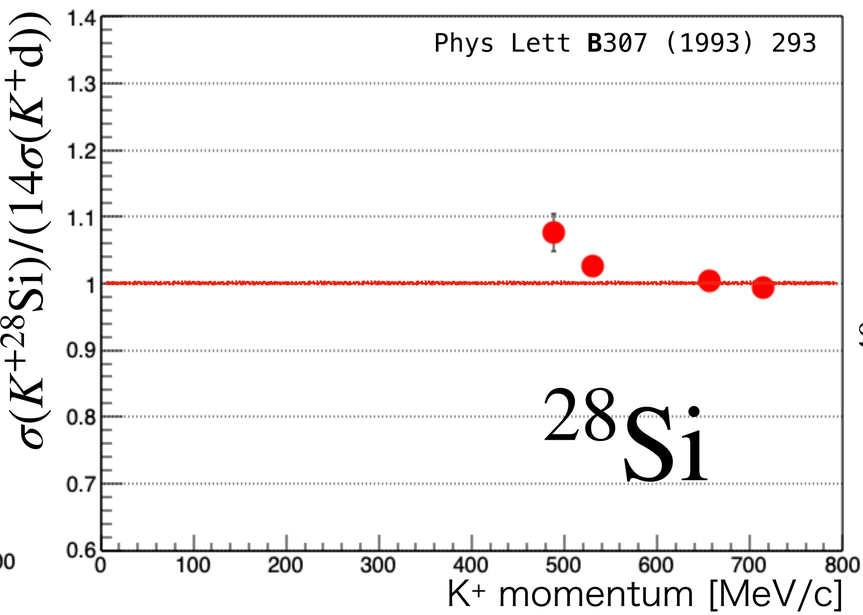
Kaon scattering on nuclei

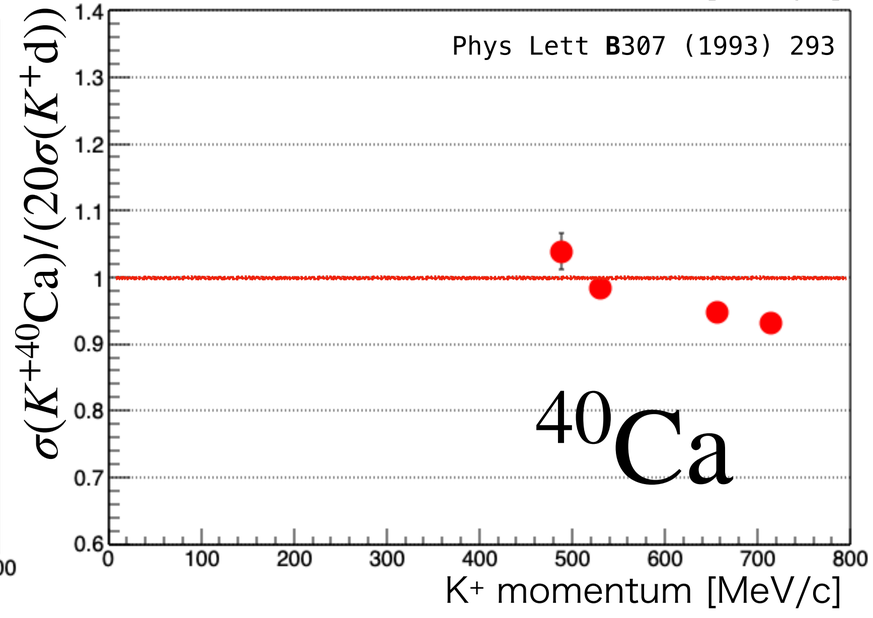
- The ratio $[\sigma(A,Z))/A]$ / $[\sigma(d)/2]$ increases, a little, at low energy.
- There isn't much data available, especially in the very low momentum region, where the matter effect is expected to be significant.

Is it possible to conduct the measurement at DAFNE?







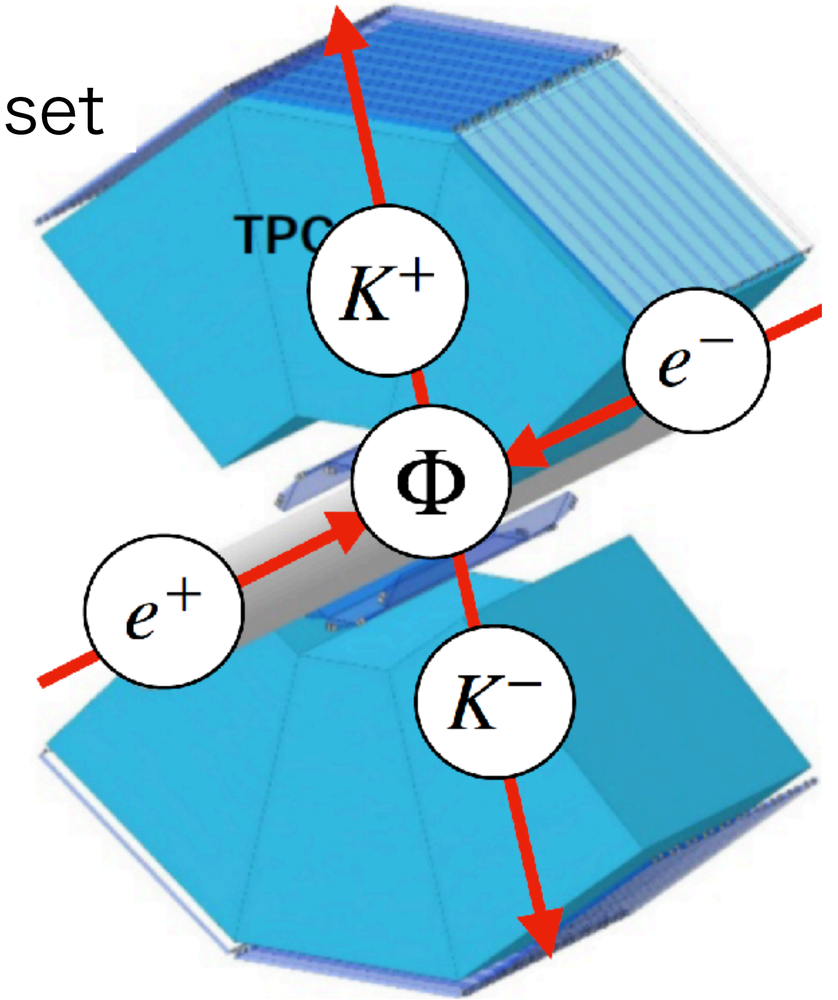


New experiment?

K^+ scattering experiment at DAFNE

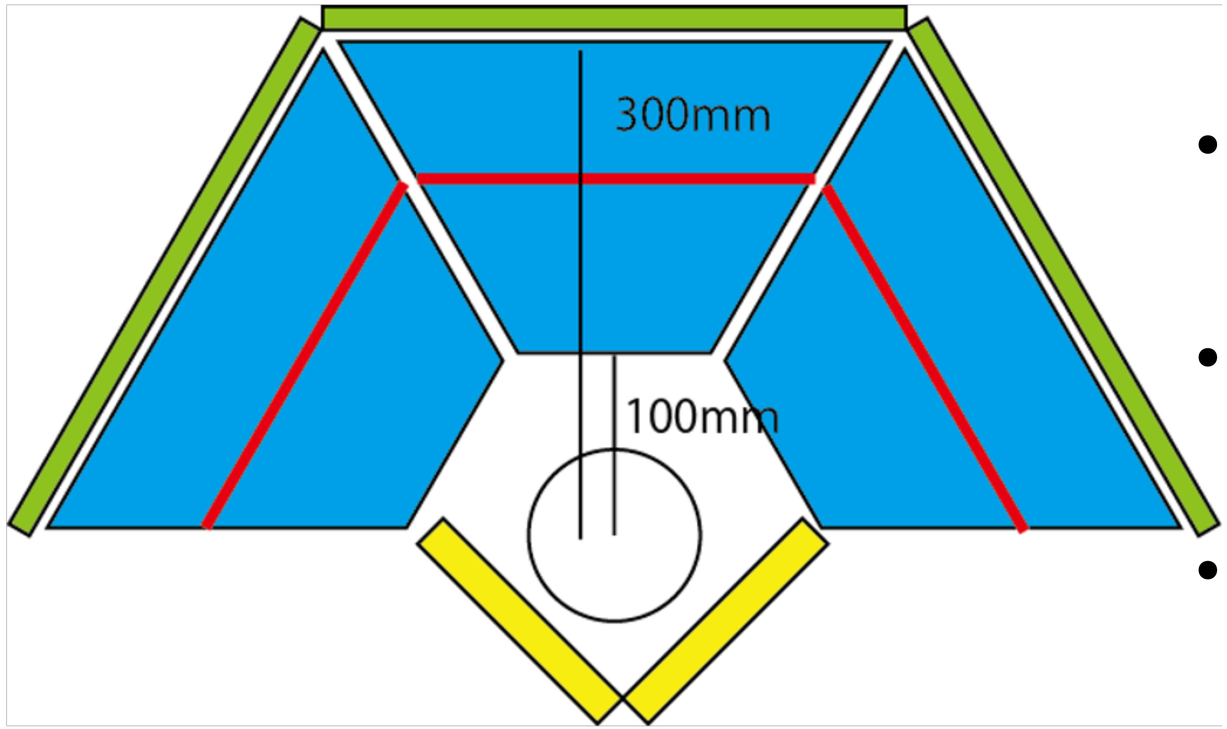
Conceptual design of the detector

- The detector will be placed surrounding the beam pipe.
- The full detector will be segmented into 8-10 subset detectors (1/8 to 1/10 in the phi direction.)
- The number of segments required for the experiment depends on the detector construction budget.



Detail design (in progress)

Kaon ID detector



Kaon monitor & identifier

- Total 3 segments (for first step experiment)
  → Acceptance ~ 25%
- Define start timing and detect beam Kaon with the Kaon monitor.
- Identify K+/K- with stopped K inside the Kaon ID detector
- Film target inside TPC.
  Target thickness ~ an order of 100 μm
- Target Materials:
  → Carbon, CH2, CD2, Al(?)

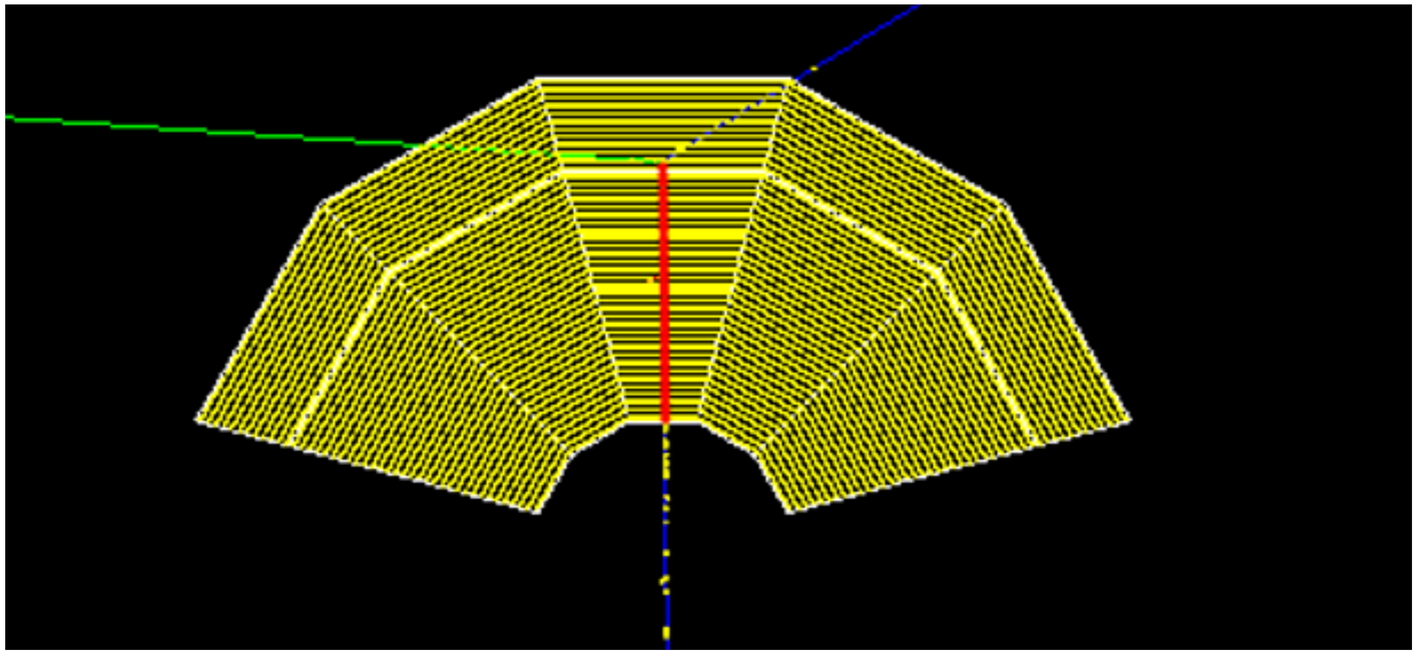
Expected statistics

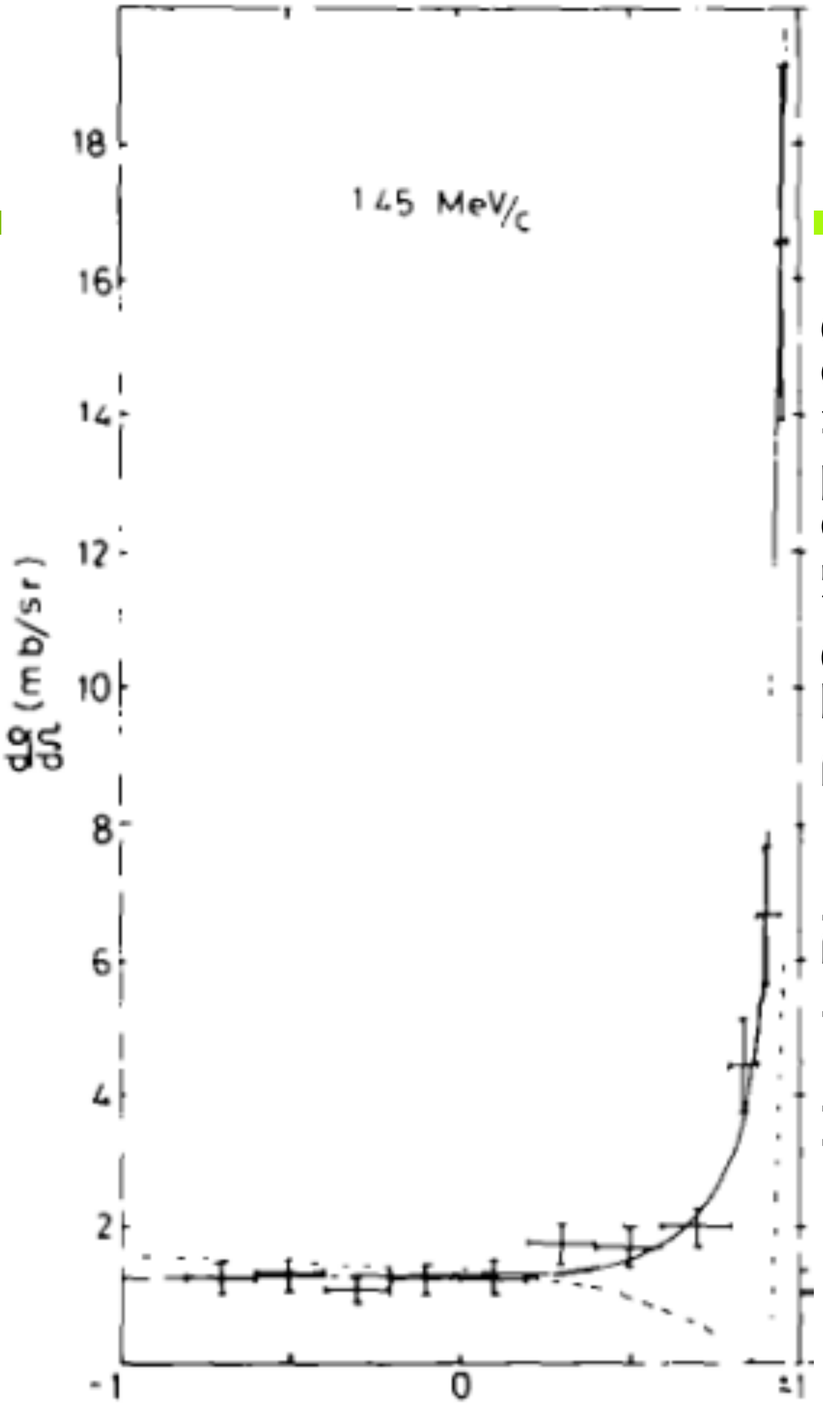
- $N_{event/sec}$ = 500(K beam/s) x σ_{Kp} x N_{target} x ε_{acc} x ε_{eff} x ε_{decay}
- σ_{Kp} : 12 mb
- N_{target} : 1.0 g/cm^3 x film thickness (200 μm) x N_A x 2/A_{CH2}
  =0.02 x10^{23}
- ε_{acc} **~ 0.25**
- ε_{eff} : tracking (0.8) x e K^+/K^-(0.7) x $\varepsilon_{detector}$(0.9) = **0.5**
- ε_{decay}: 0.8 ($\beta\gamma$ of K~0.26)
- N_{event} /sec =~1.2 x 10^{-3}
- N_{event} /20 day ~2.4 x10^3

i.e. ~ month / Target?

Simulation

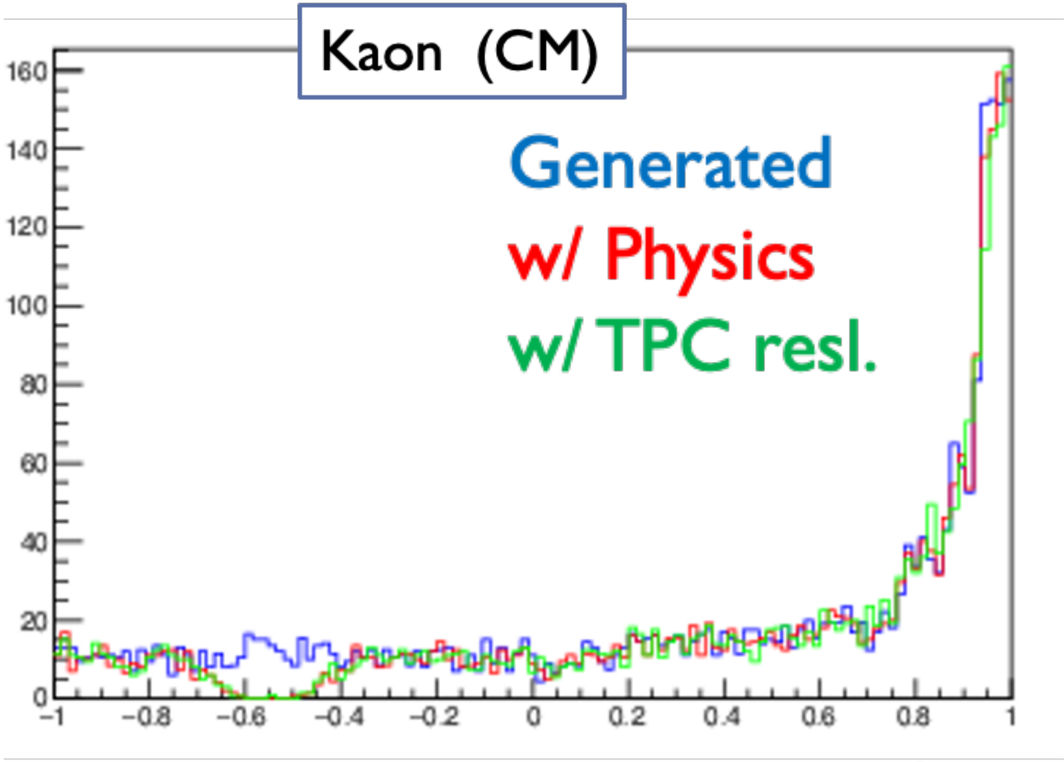
- GEANT4 simulation has been proceeded.
- A differential cross-section of the K+p reaction has been taken from the old Bubble chamber's data (Nucl. Phys B 78 (1974)93), where K+ momentum =145 MeV/c.





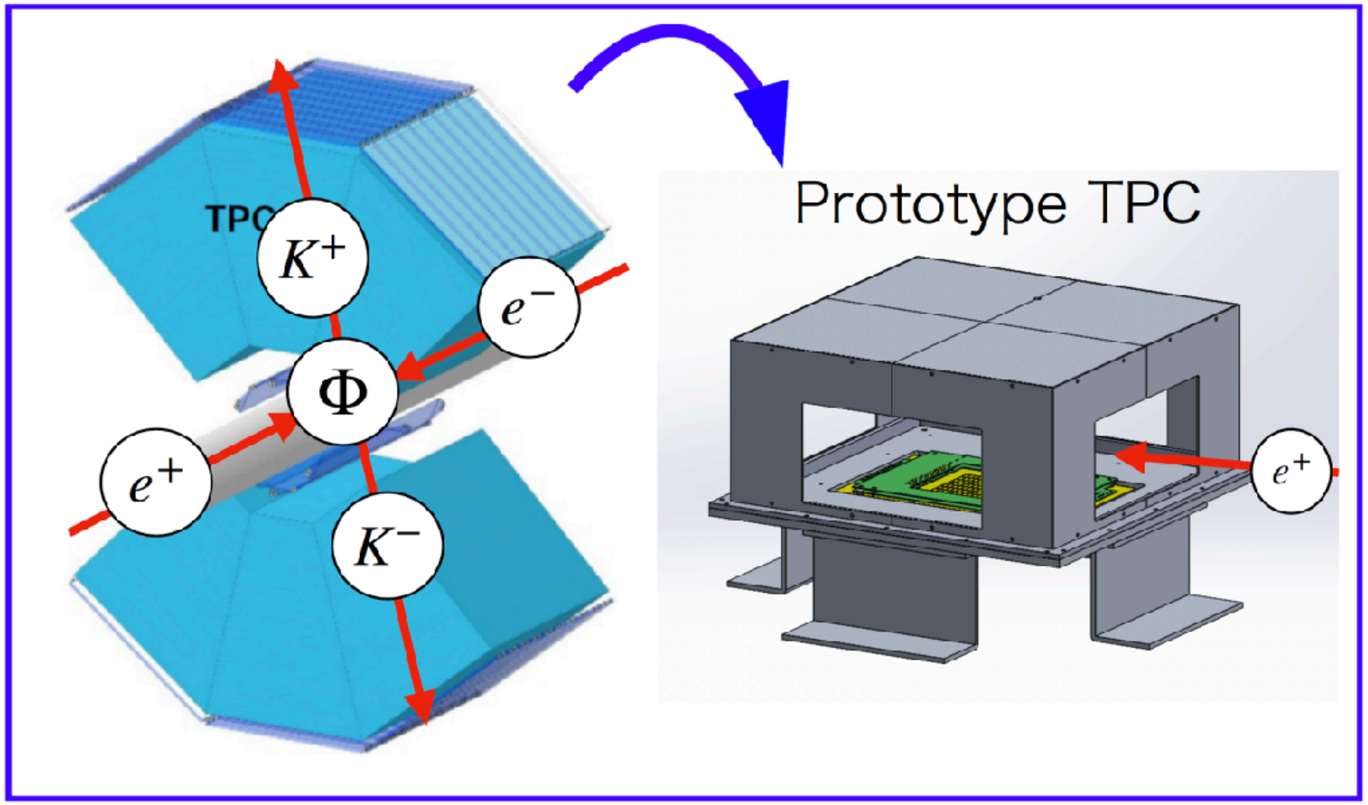
Simulation

- Evaluate the expected signal with a 20-day data-taking situation.
- The lack of data around $\cos\theta_{\mathrm{CM}}$ = -0.5 is due to inefficient acceptance.
- The TPC resolutions, i.e. σ_z, σ_{xy} , are now set to ~ 200 μm
- “w/ Physics” means include multiple scattering effects.
- Evaluations of the precision of extracted parameters, cross-sections, low energy constants, etc., are underway.



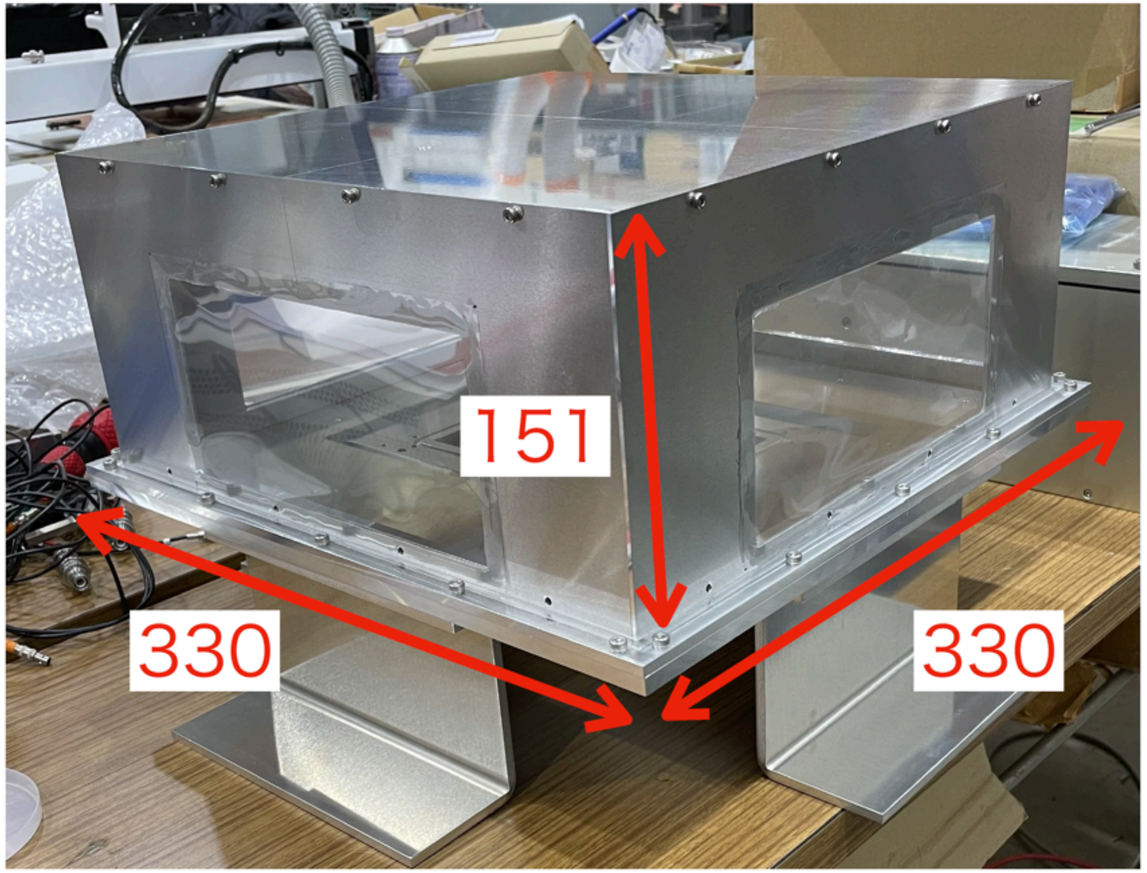
Preparation status

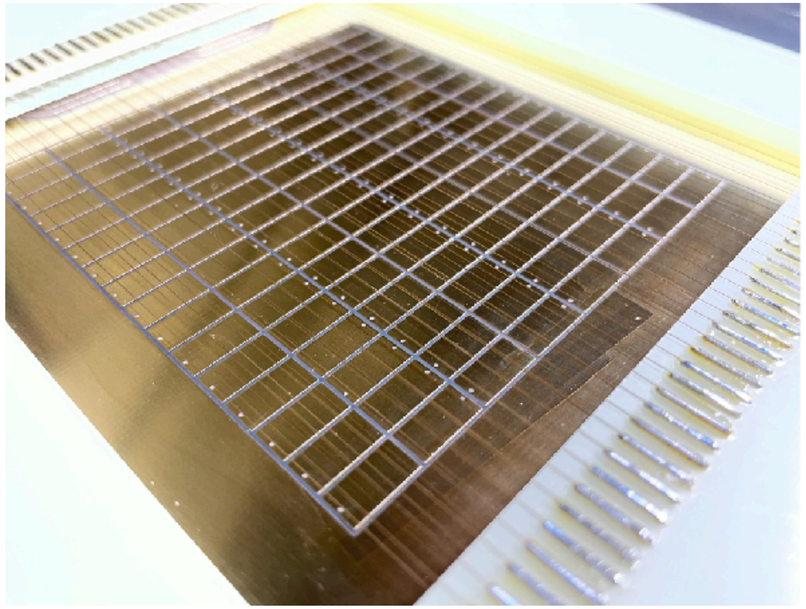
Prototype TPC development

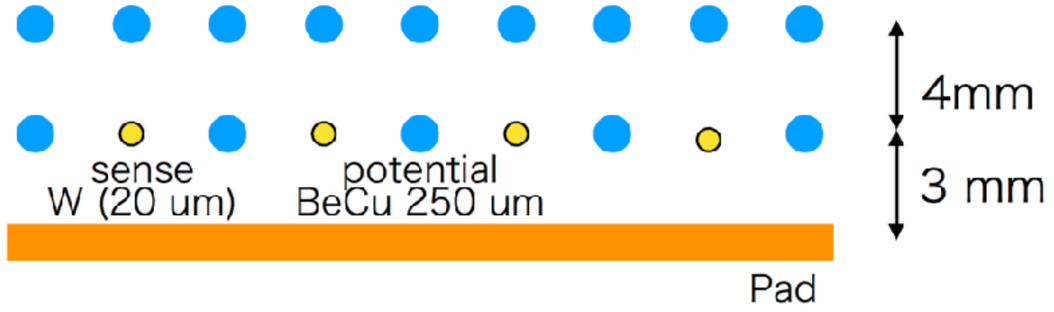


- Gas for TPC ; Ar(90%) + CH4(10%)
- Readout configuration;
  → Pad readout.
- Signal amplification:
  → sense wire and potential
- A field cage, which will create a uniform electric field,
  will be constructed by wire.

Prototype TPC development







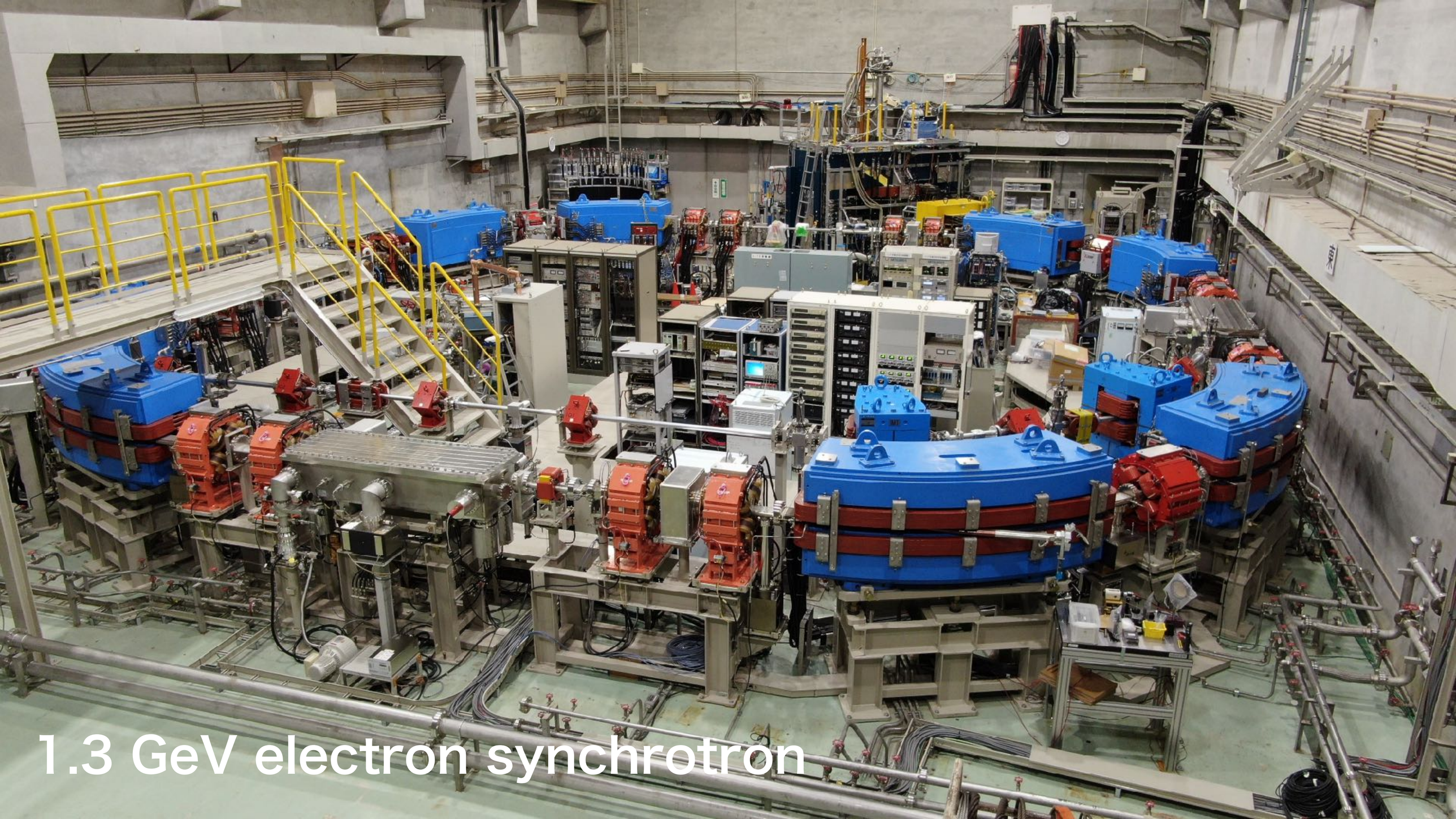
Test experiment at ELPH, Tohoku Univ.

- Tohoku University is located in Sendai, Miyagi, about 350 km away from Tokyo.
- The Research Center for Electron Photon Science (ELPH) is situated at a distance of 6 km from the center of the city.


ELPH, Tohoku University

Test experiment at ELPH, Tohoku Univ.

- Tohoku University is located in Sendai, Miyagi, about 350 km away from Tokyo.
- The Research Center for Electron Photon Science (ELPH) is situated at a distance of 6 km from the center of the city.
- ELPH has a 1.3 GeV electron synchrotron on its campus.


1.3 GeV electron synchrotron

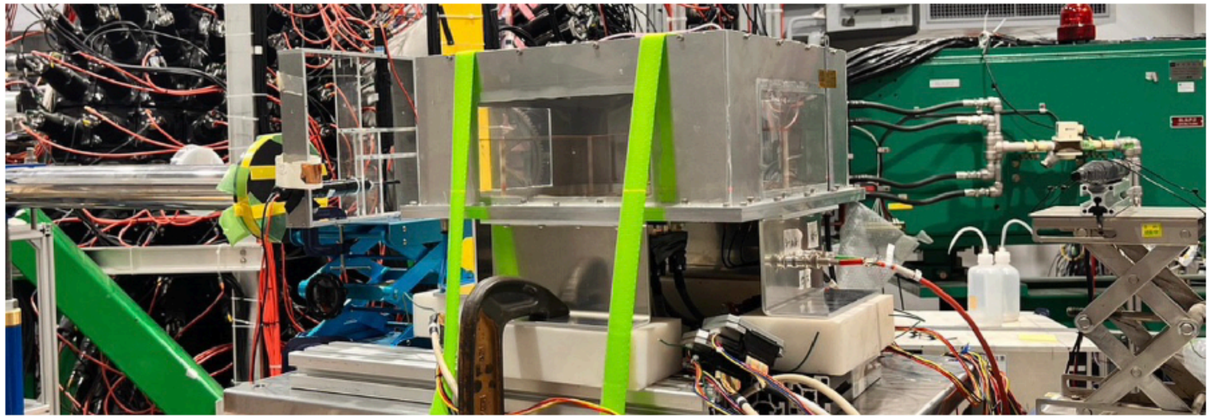
Test experiment at ELPH, Tohoku Univ.

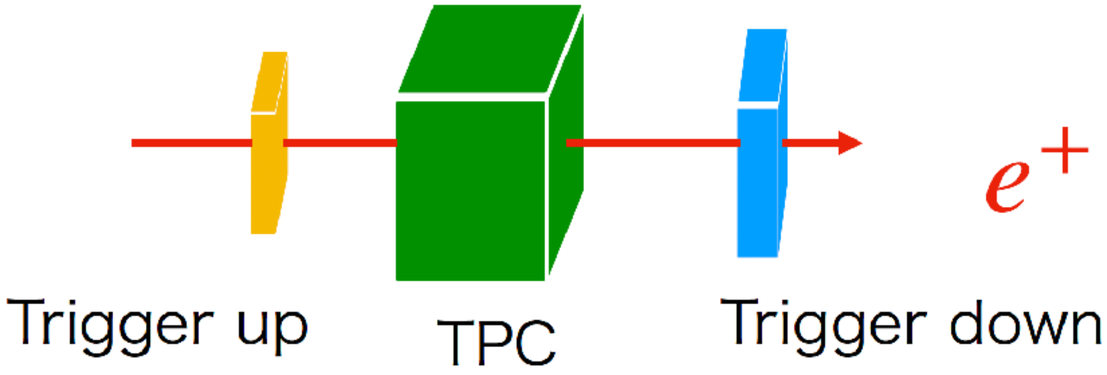
- Tohoku University is located in Sendai, Miyagi, about 350 km away from Tokyo.
- The Research Center for Electron Photon Science (ELPH) is situated at a distance of 6 km from the center of the city.
- ELPH has a 1.3 GeV electron synchrotron on its campus.
- By utilizing 1.3 GeV electron, we produced photons by Bremsstrahlung.
- Tagged photon available on beam energy 0.9 GeV < Eγ < 1.26 GeV
- By inserting a metal target into the photon beamline, we can produce an electron-positron beam through pair creation.
- Those positions will be used for the detector test experiment.
- 50 MeV - 1.1 GeV positron can be used for the detector test at ELPH.

Test experiment at ELPH, Tohoku Univ.

- Prototype TPC tests with a positron beam have already been performed.

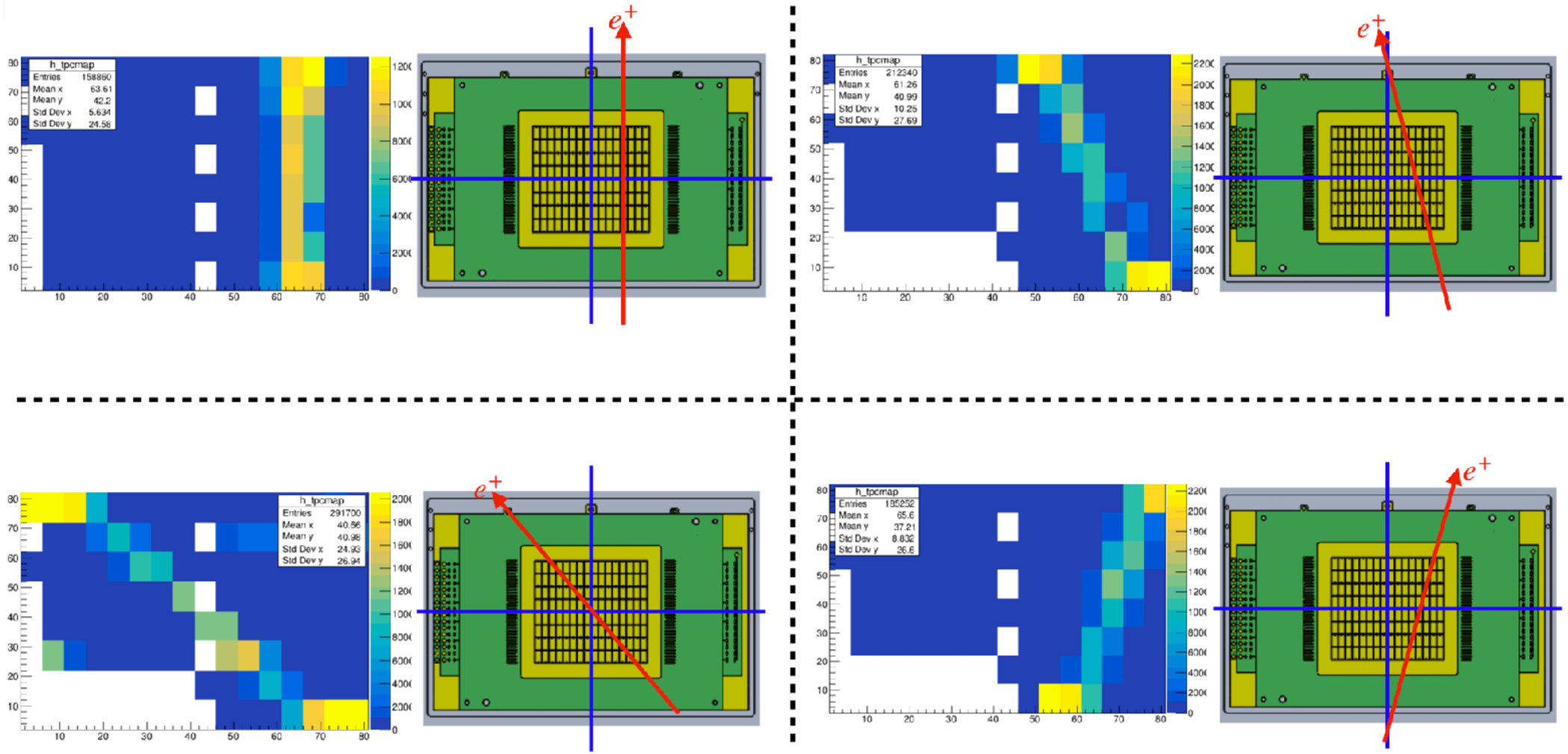
Set up





- Signal readout electronics are used the same as the CDC of the E15 experiment at J-PARC
  → not optimized for the TPC
- Field cage is also not optimized for this test experiment

Test experiment at ELPH

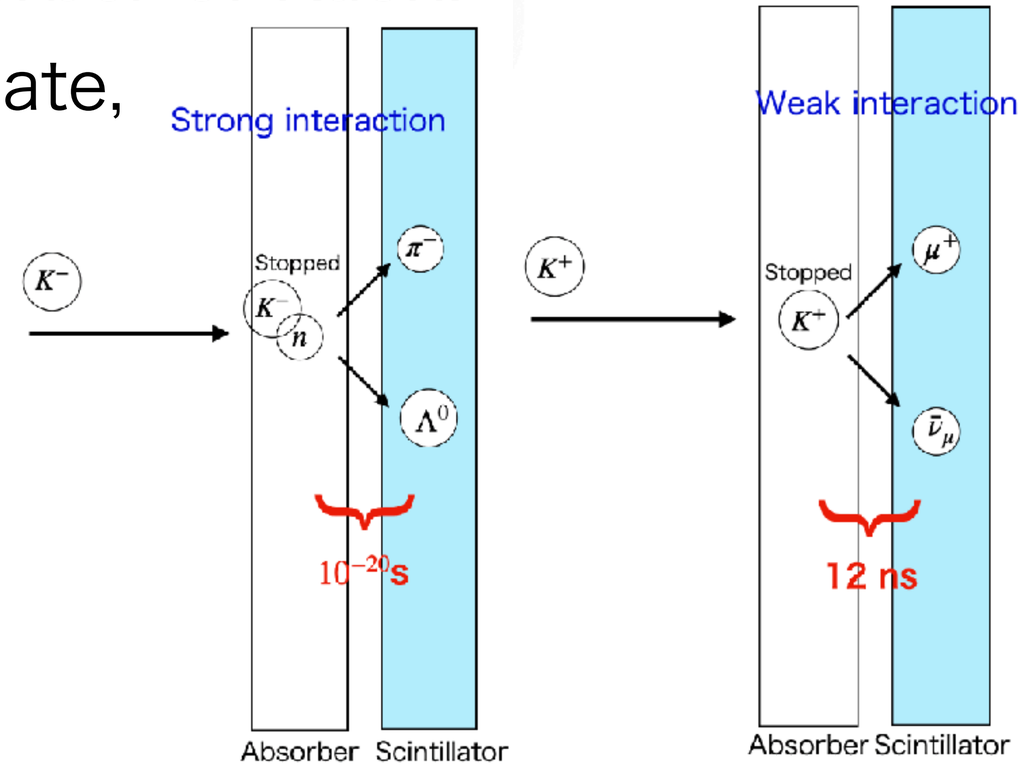


- Just for event display. detail analysis is under the way.

KaonID detector

- The detector consists of a Teflon plate together with a scintillator.
- Incoming K^+/K^- will be stopped inside the Teflon plate.

  → the Teflon plate works as an absorber of Kaon.
- Once K^+/K^- stopped inside the Teflon plate,
  - K^- will be absorbed immediately via strong interaction, emitting multi-charged particles.
  - K^+ will decay via the weak interaction with a lifetime of 12 ns, producing charged particles.



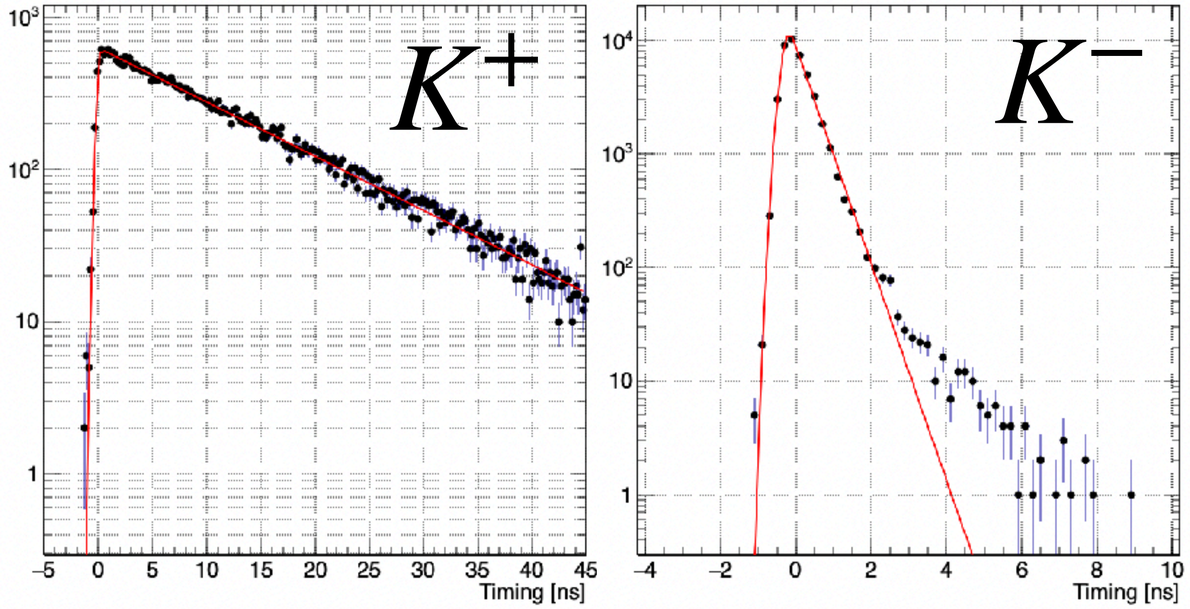
- The thickness of the absorber is adjusted using MC → we choose 6mm.

KaonID detector

- The detector consists of a Teflon plate together with a scintillator.
- Incoming K^+/K^- will be stopped inside the Teflon plate.

  → the Teflon plate works as an absorber of Kaon.
- Once K^+/K^- stopped inside the Teflon plate,
  - K^- will be absorbed immediately via strong interaction, emitting multi-charged particles.
  - K^+ will decay via the weak interaction with a lifetime of 12 ns, producing charged particles.

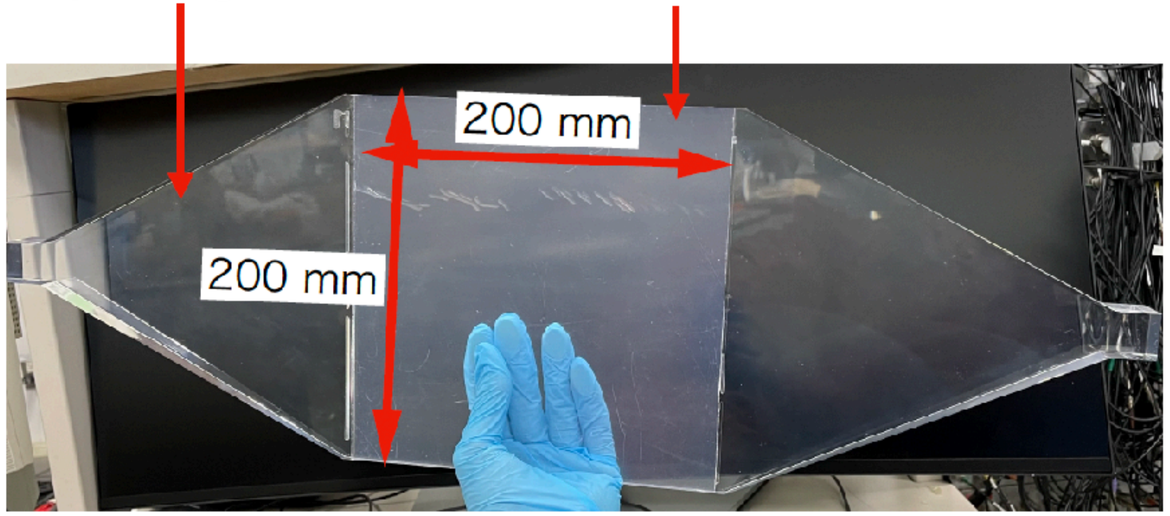
Decay time distribution in Simulation



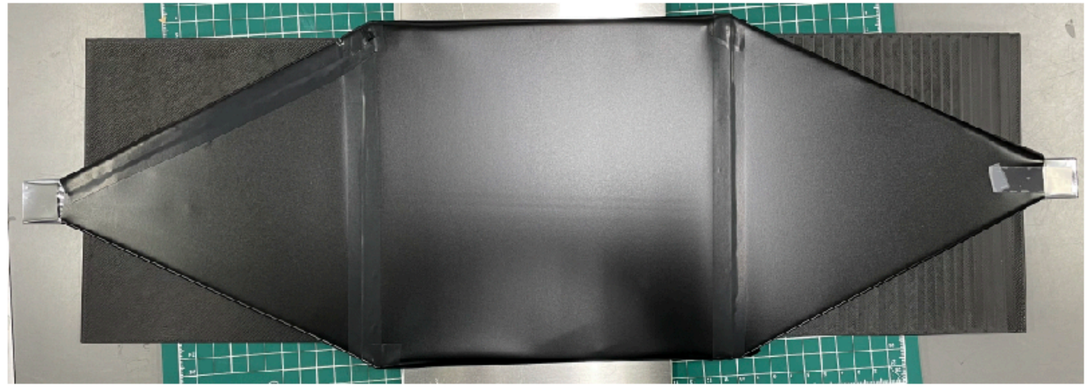
- The thickness of the absorber is adjusted using MC → we choose 6mm.

Detector construction

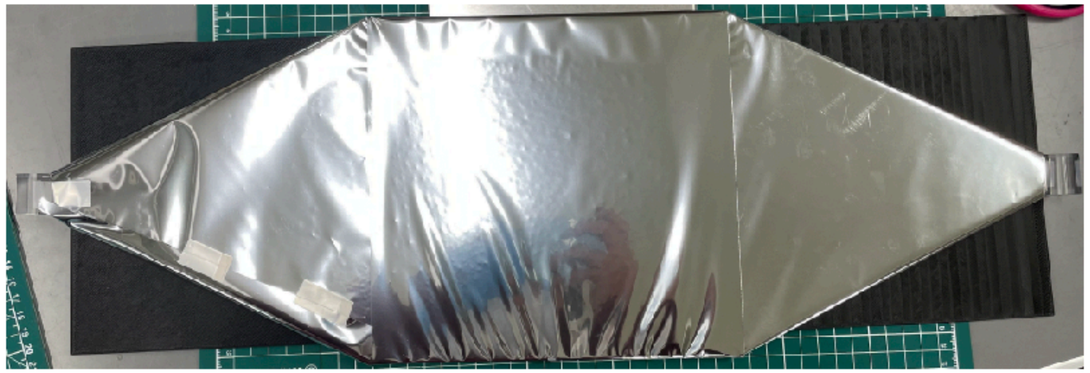
Acrylic Light Guide Plastic scintillator



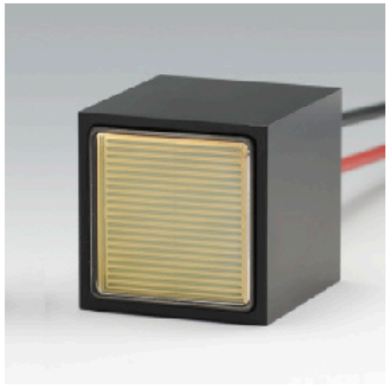
Kaon detector wrapped with black sheet



Kaon detector wrapped with aluminized mylar

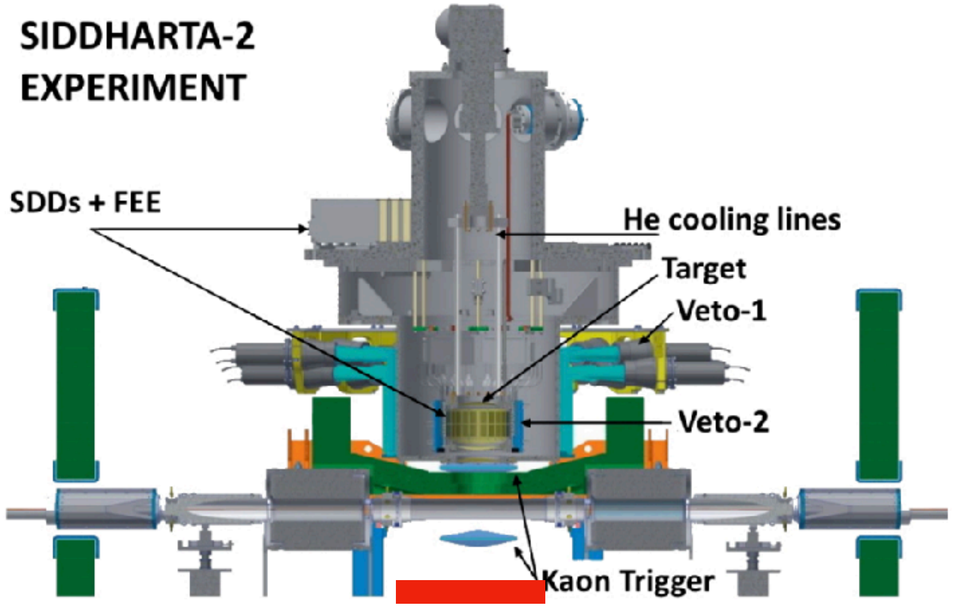


Used Photo multiple Tube
H11934, HAMAMATSU

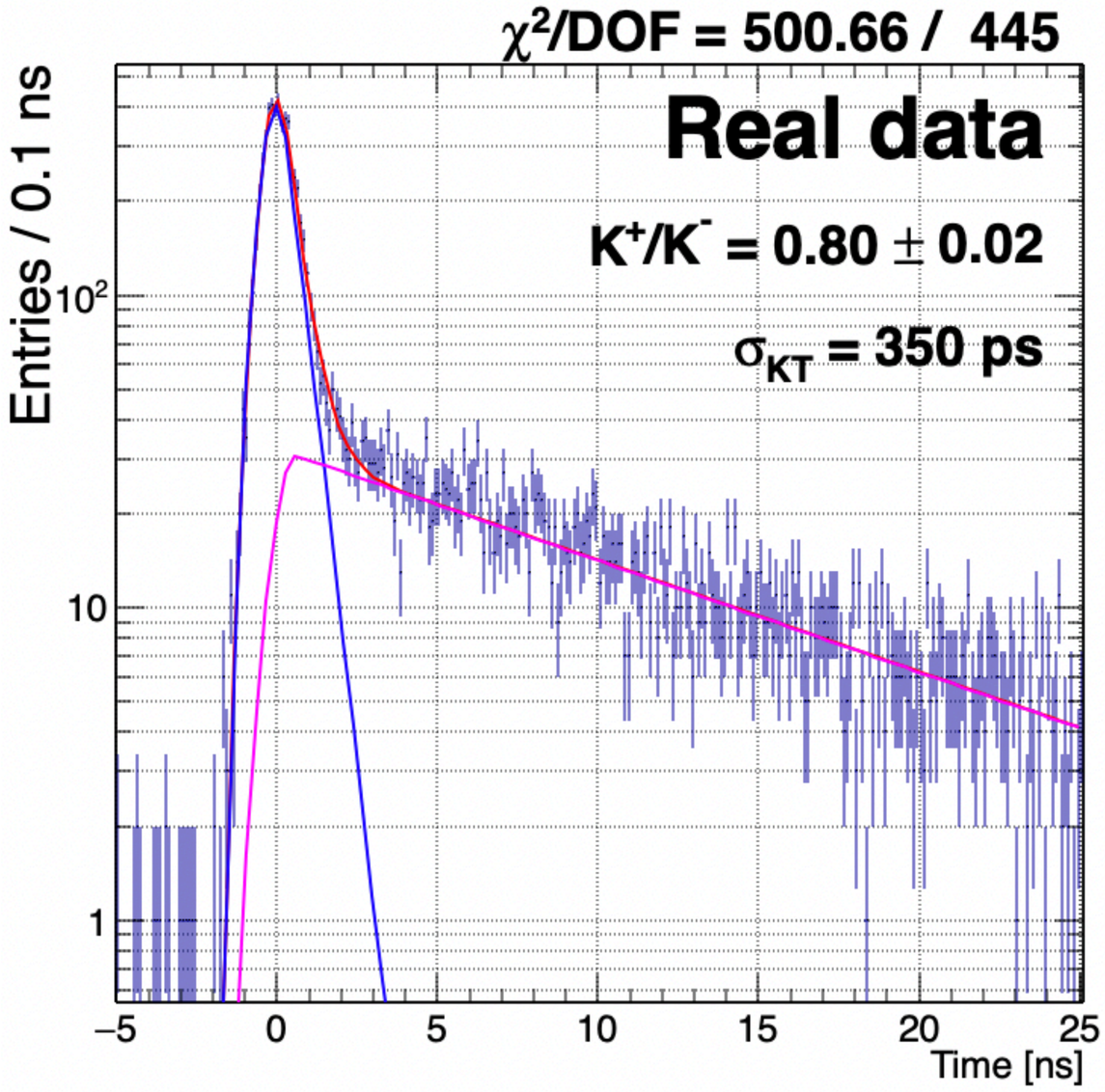


Kaon detector integrated in SIDDHARTA-2

- The Kaon detector was installed just below the Kaon Trigger. (opposite side of the Target)



Kaon Detector



Summary

- K+ scattering may provide valuable information about the quark condensate of the strangeness sector under finite-density matter conditions.
- Currently, there is a shortage of available data for K+ N and K+A, especially at low energies. DAFNE, therefore, presents a unique opportunity to conduct these experiments.
- On the other hand, I believe that AMADEUS data should encompass not only K- scattering but also K+ scattering. This aspect needs further examination.
- Detector development has recently commenced, and there are still many challenges to address, particularly concerning the readout electronics for the TPC. Collaboration with experienced individuals is essential.