HypTPC for high-rate beams

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新学術領域「中性子星核物質」

第2回検出器ワークショップ

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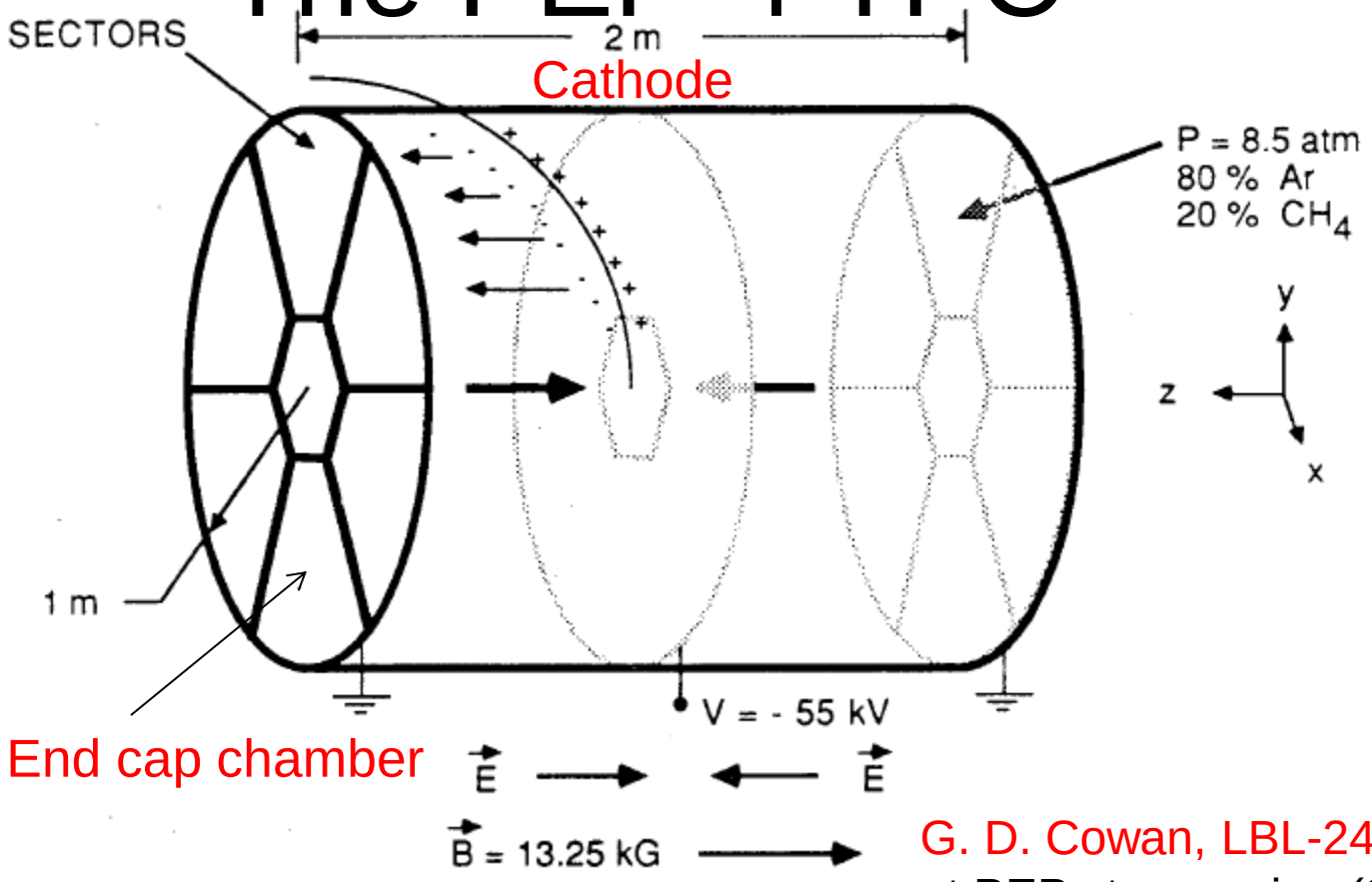
Outline

- HypTPCの設計
  - The TPC vs HypTPC
- High rateへの対応
- Field cageの帯電対策
- HypTPC,TPCの応用

TPC

- The best three-dimensional imaging tracker
  - Pad position (x,z) and drift time (y)
  - Easy for 3-d pattern recognition
  - dE/dx can be measured with large number of layers
  - Big detector possible
- Disadvantage: high-rate capability
  - Limited primarily by electron drift time
    - e.g. Drift length(L)=50cm, Drift velocity(v)=5cm/μs
    - t = 10μs (10^5Hz)
    - If the rate is higher, events overlap
  - Field distortion due to positive ions

The PEP-4 TPC

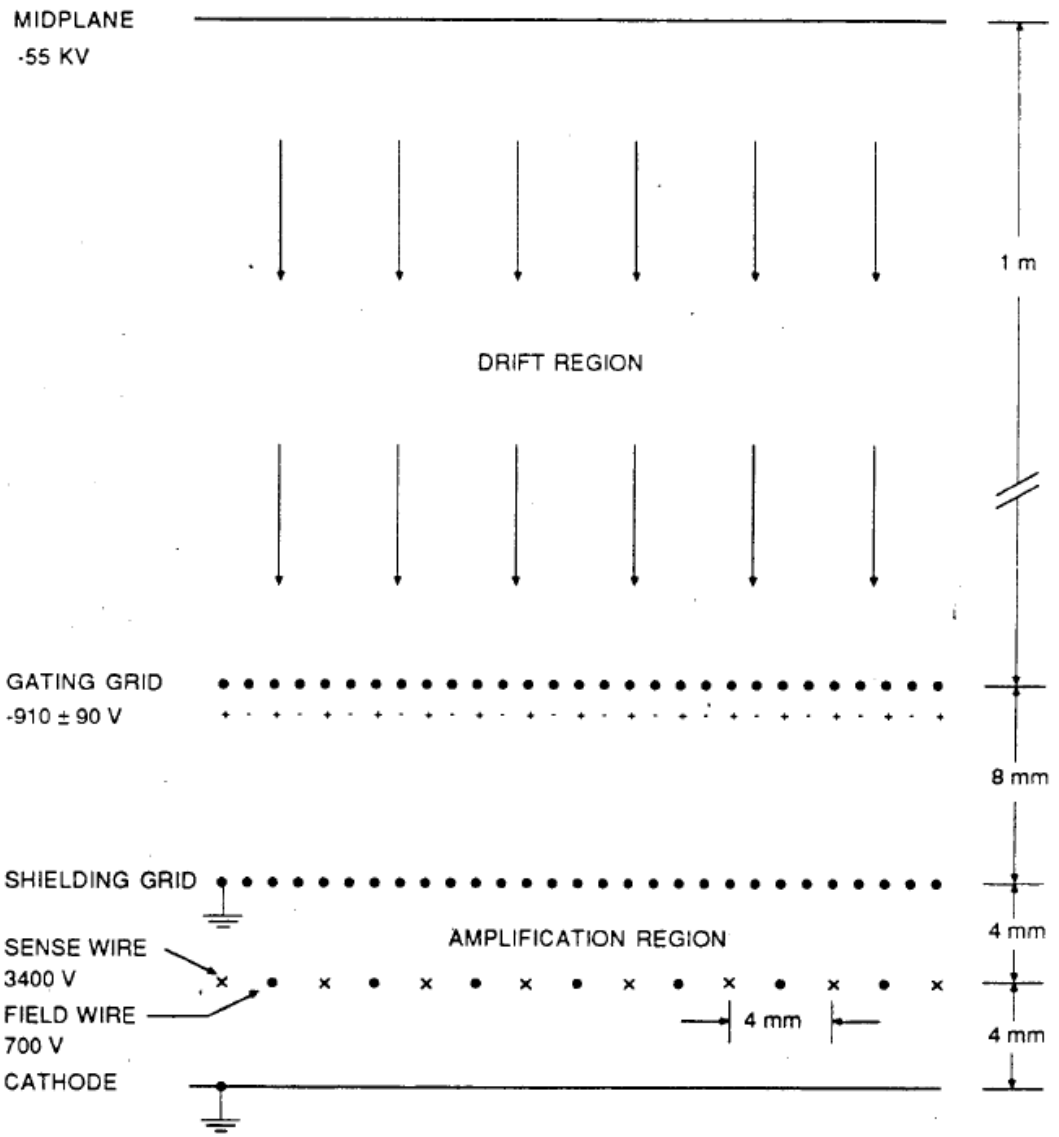


G. D. Cowan, LBL-24715 (1988)
at PEP storage ring (SLAC)

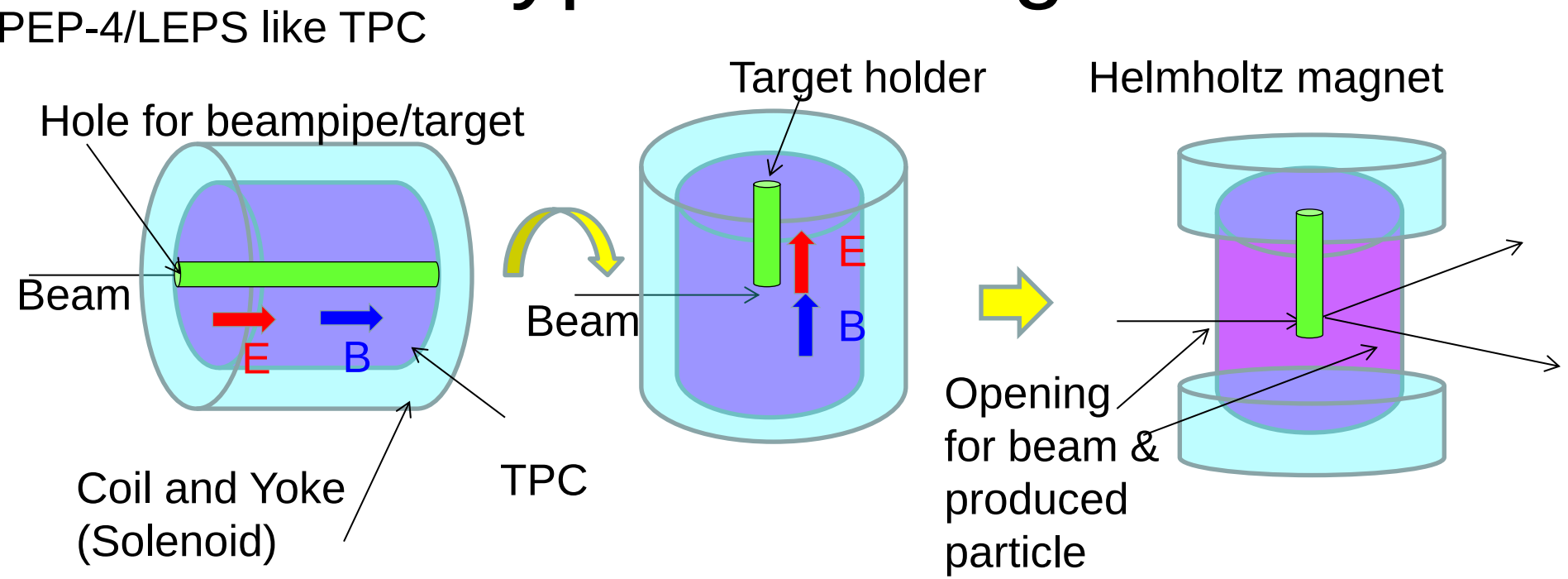
- Drift volume : uniform E
- End cap chamber for signal amplification
- B parallel to E
  - Smaller diffusion size → higher resolution

The PEP-4 TPC

- Gating grid
- Amplification with anode wires
  - Ion backflow ~ 100%



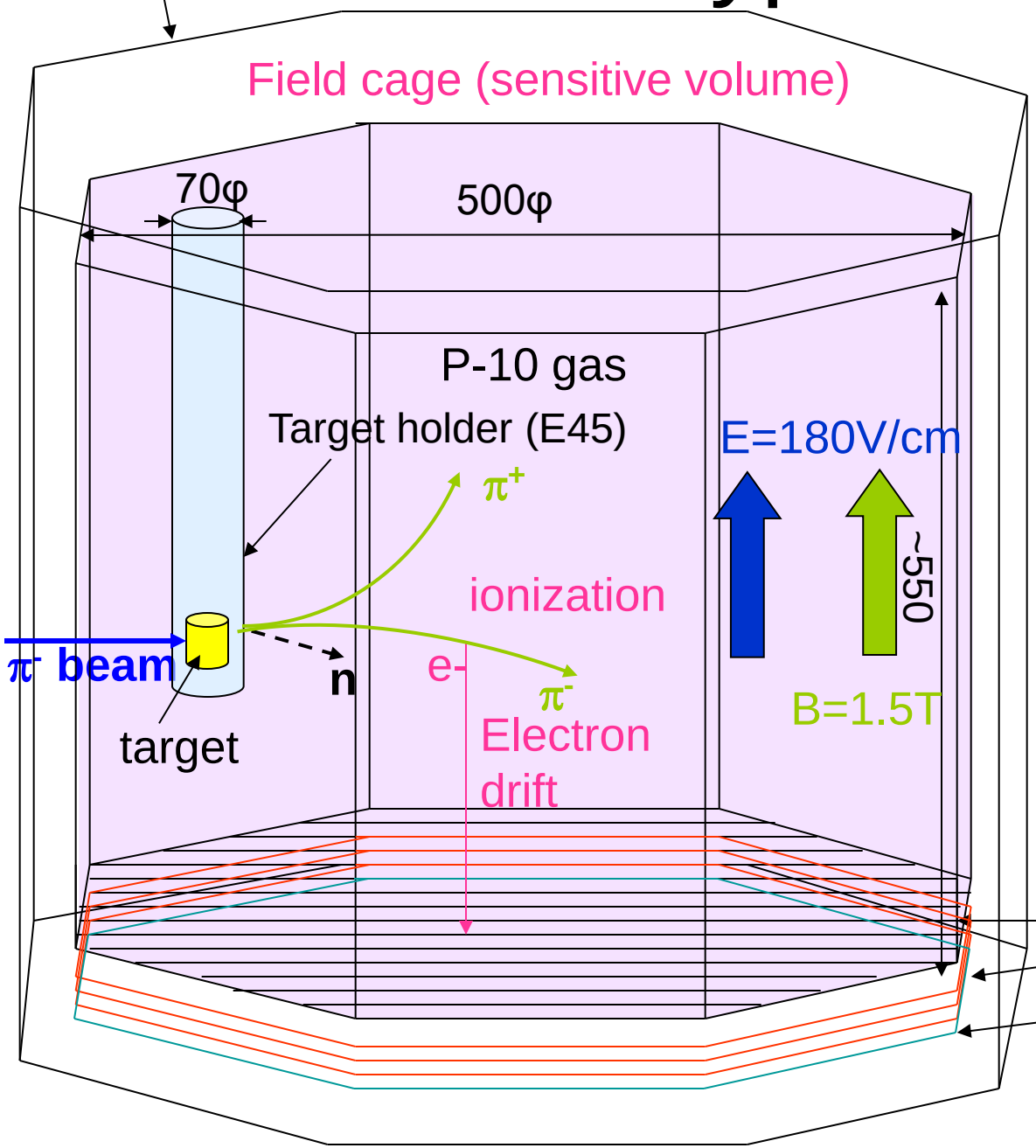
HypTPC design



- Large acceptance
  - Target “inside” drift volume
- Good position and decay vertex resolution
  - B//E
  - Solenoid: poor momentum resolution in the forward direction

  →Vertical B field (good resolution in the forward direction)

HypTPC



Design for high-rate capability

Double suppression of ion backflow

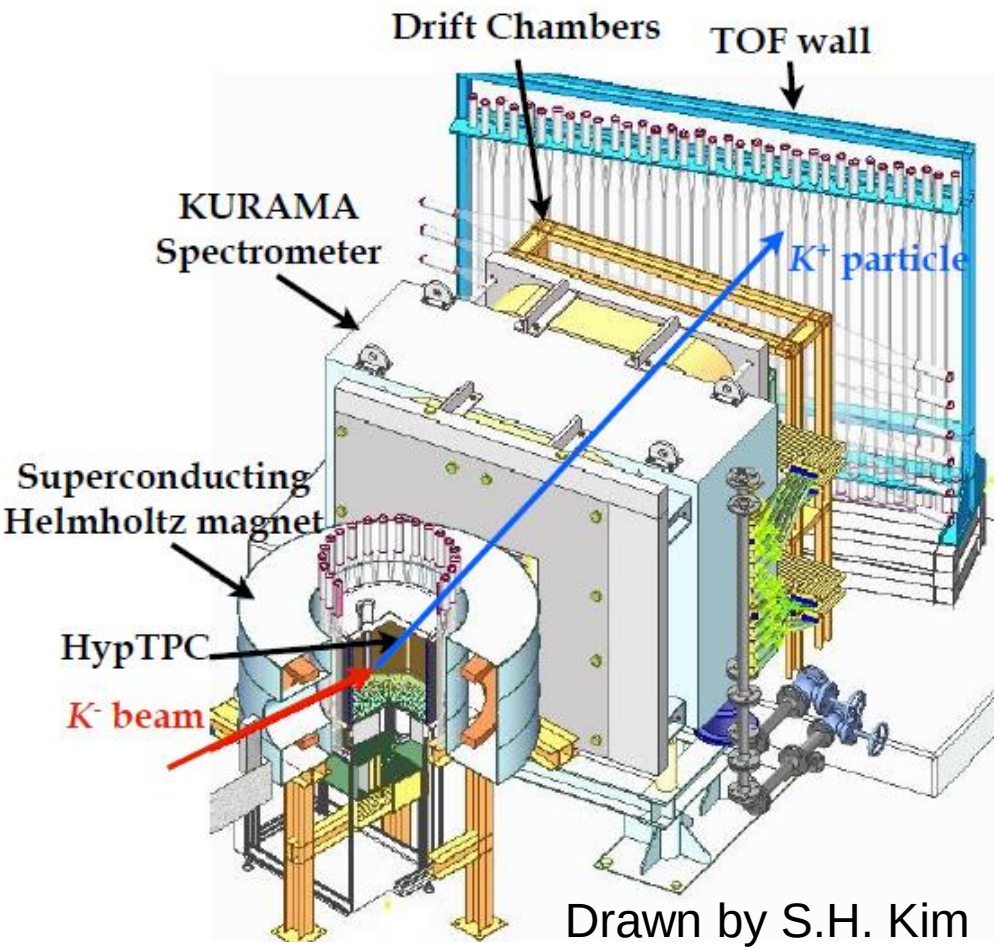
- Gating Grid
- GEM(Gas Electron Multiplier)
  Suppression of positive-ion backflow causing field distortion
- Mask GEM

- Exchange of the target holder possible for various targets

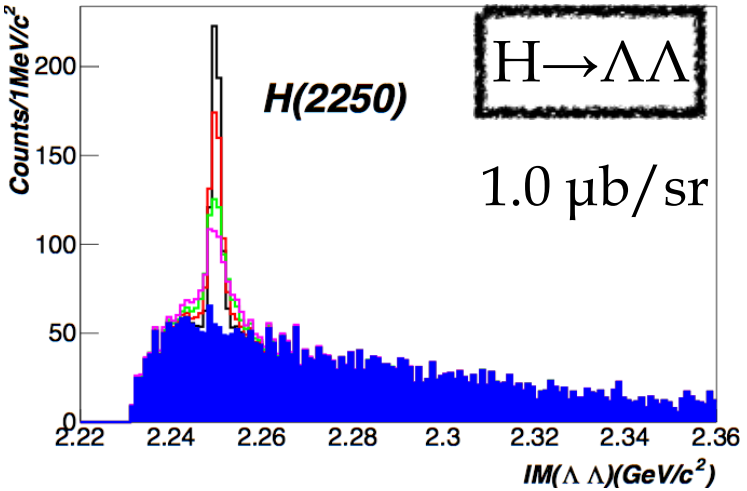
Gating grid wires
GEMs (electron amplification)
Pad plane

J-PARC E42 setup

- 1.8 GeV/c K^- beam at 10^6 / spill on a diamond target
- (K^-,K^+) tagged by KURAMA Spectrometer
- Search for $H \to \Lambda\Lambda \to \pi^-\pi^- pp$, $H \to \Lambda\pi^- p \to \pi^-\pi^- pp$ in HypTPC (Hyperon-TPC)



Drawn by S.H. Kim



ΛΛ invariant mass resolution
=1.5 MeV/c^2

11000 ΛΛ events
and 1440 H-dibaryons
in 33-day experiment

E45 setup

Measure (π,2π) in HypTPC

$\pi^- p \rightarrow \pi^+ \pi^- n$, $\pi^0 \pi^- p$

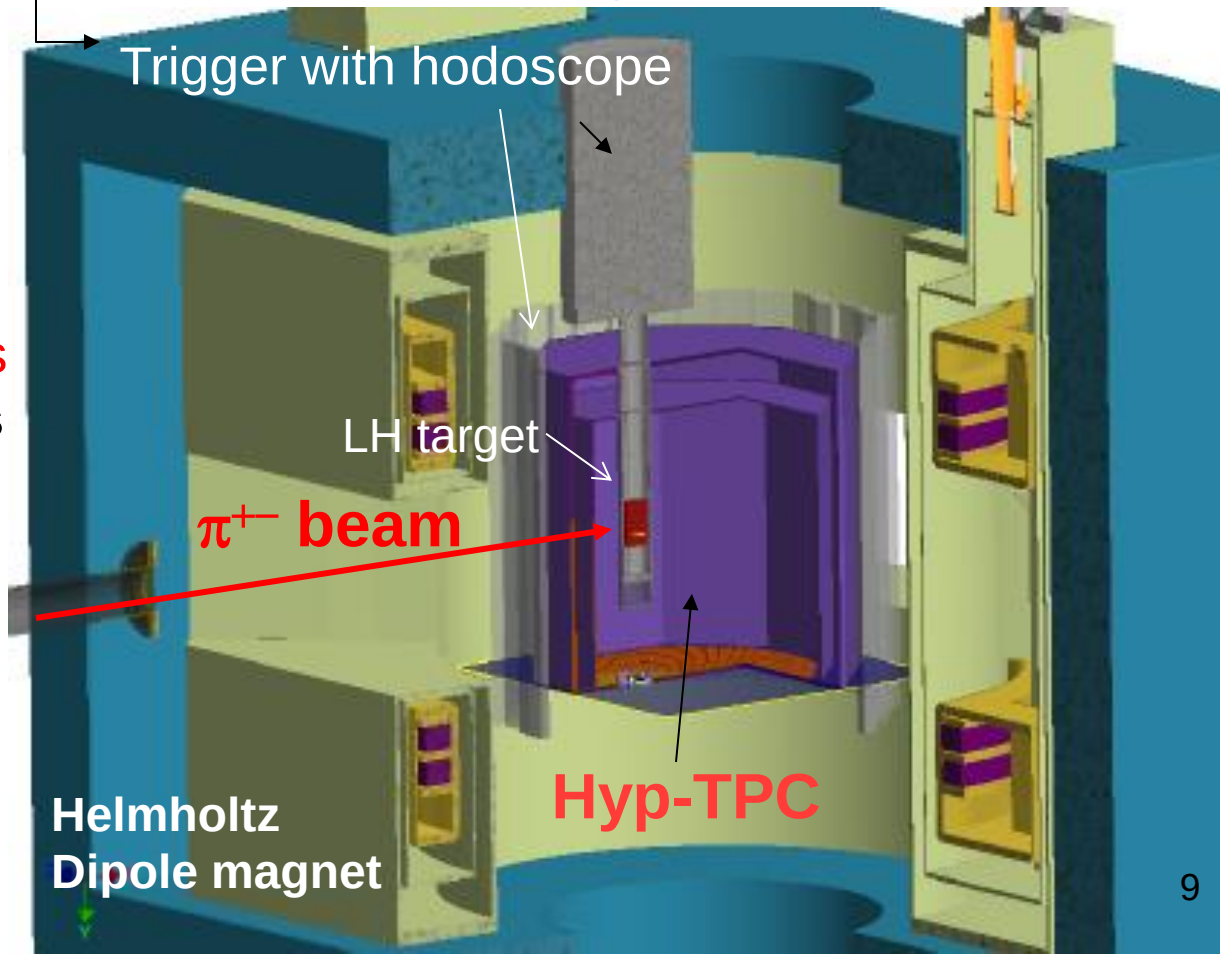
$\pi^+ p \rightarrow \pi^0 \pi^+ p$, $\pi^+ \pi^+ n$

2 charged particles + *1 neutral particle*

→*missing mass*

π^{+-} beam at 10^6 / spill
on liquid-H target
(p=0.73 – 2.0 GeV/c)

E45 : 30M events in 15 days
Enhance statistics of world's data by factor of 130

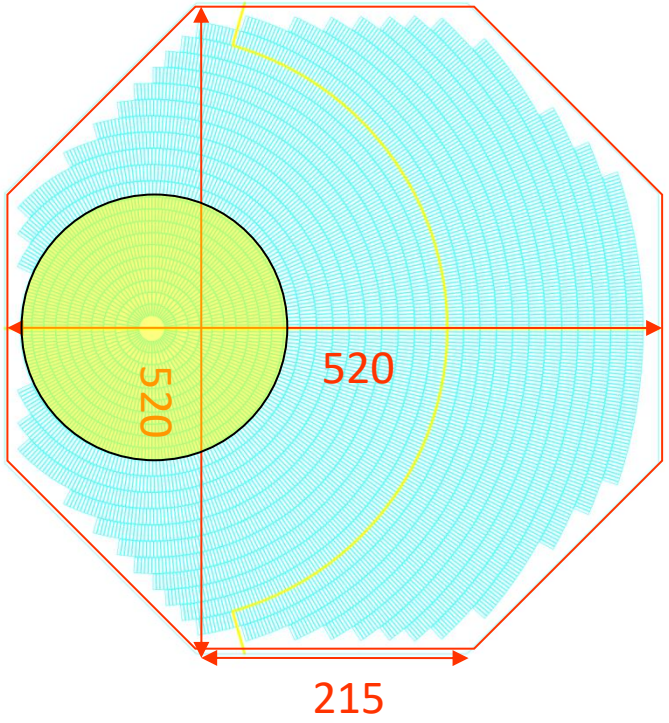


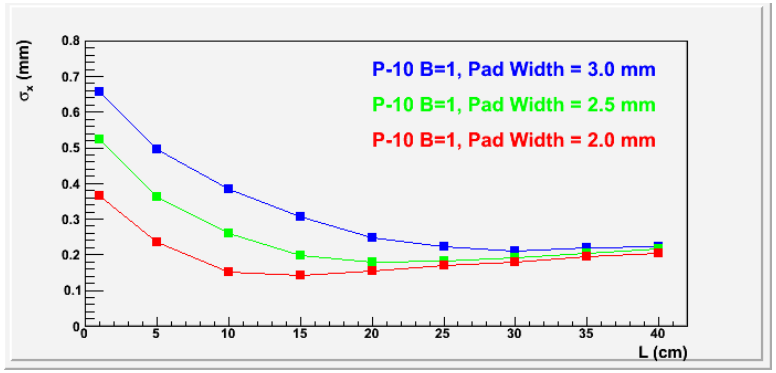
Readout pads

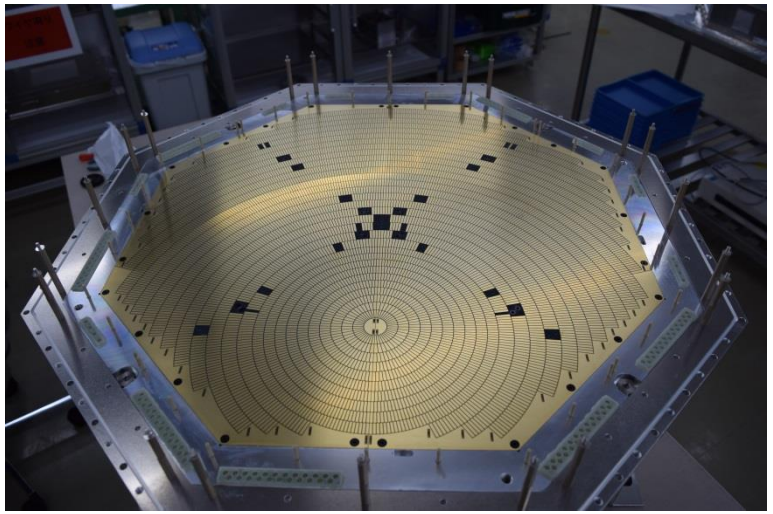
Pad size
2.4 x 9 mm^2 (inner layer)
2.4 x 13 mm^2 (outer layer)
32 pad rows (rings)
No. of pads = 5768

Position resolution <300μm
(L>10cm)

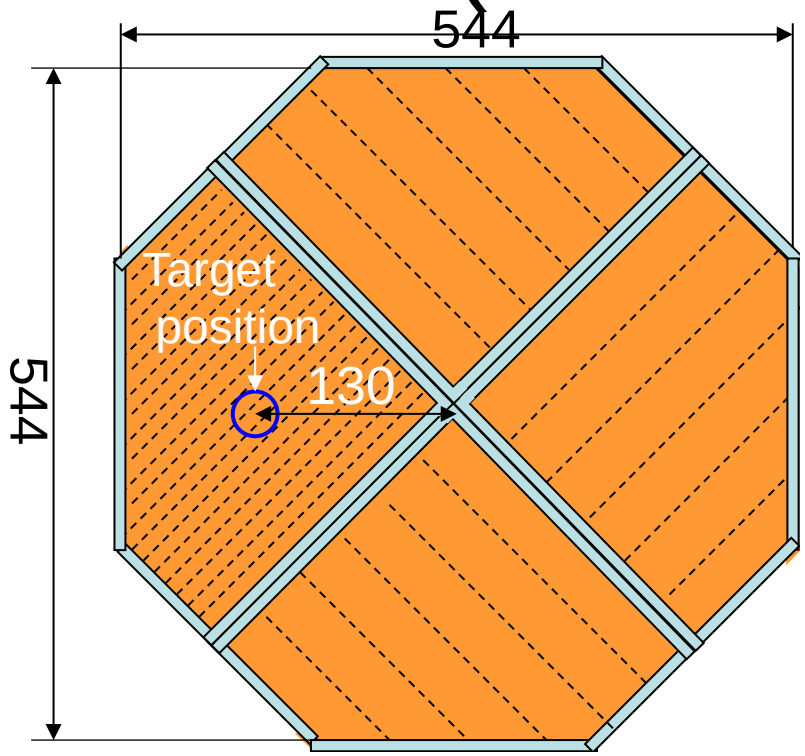
$\Delta p/p$=1-3% (π,p)







GEM (Gas Electron Multiplier)

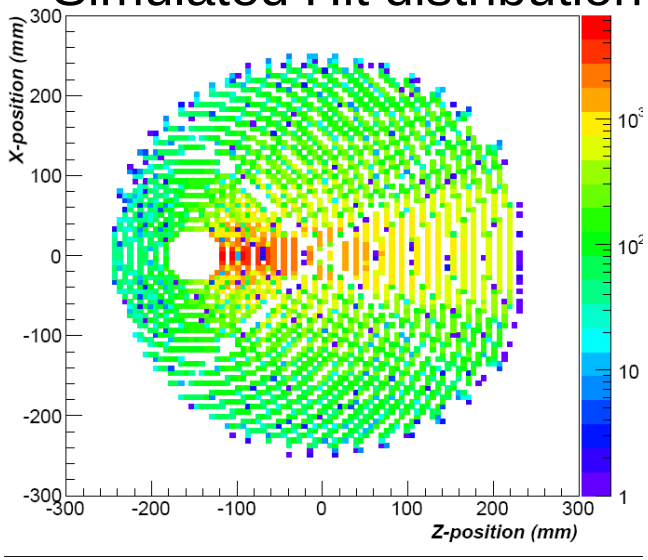


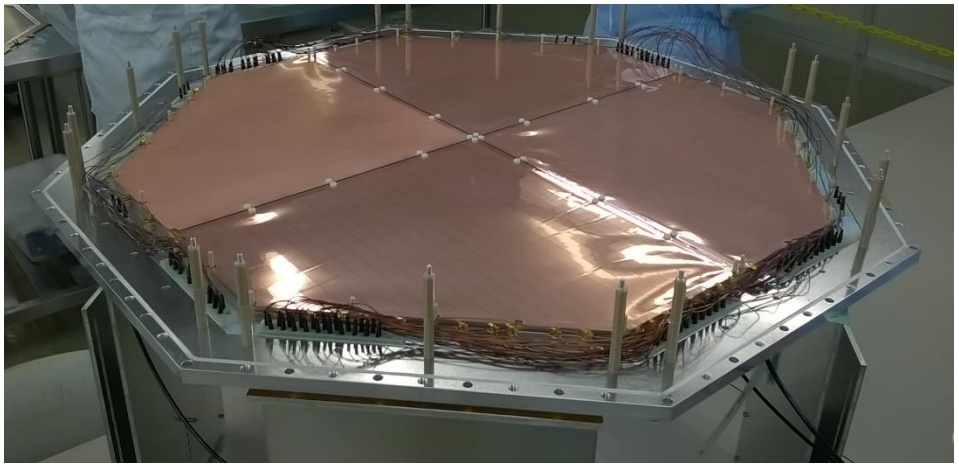
- 4 GEM (250mmx250mm) sheets
- 3-GEM layers

50μm + 50μm +100μm thick

Gain ~ 10^4

Simulated Hit distribution





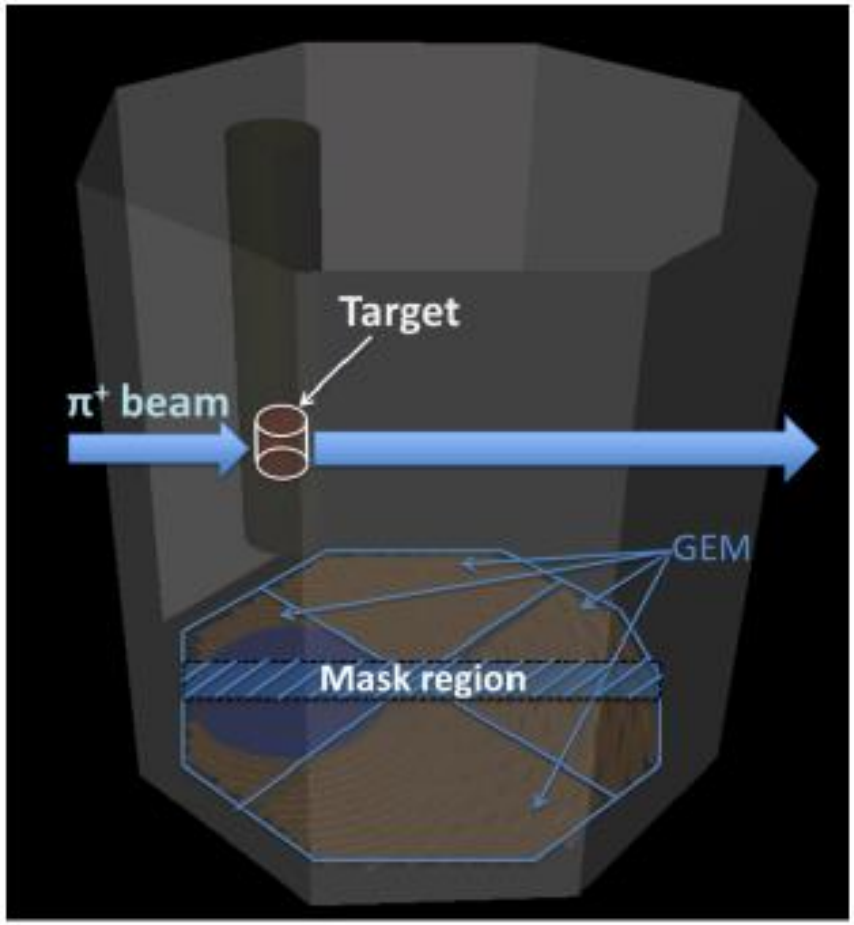
Segmented electrodes

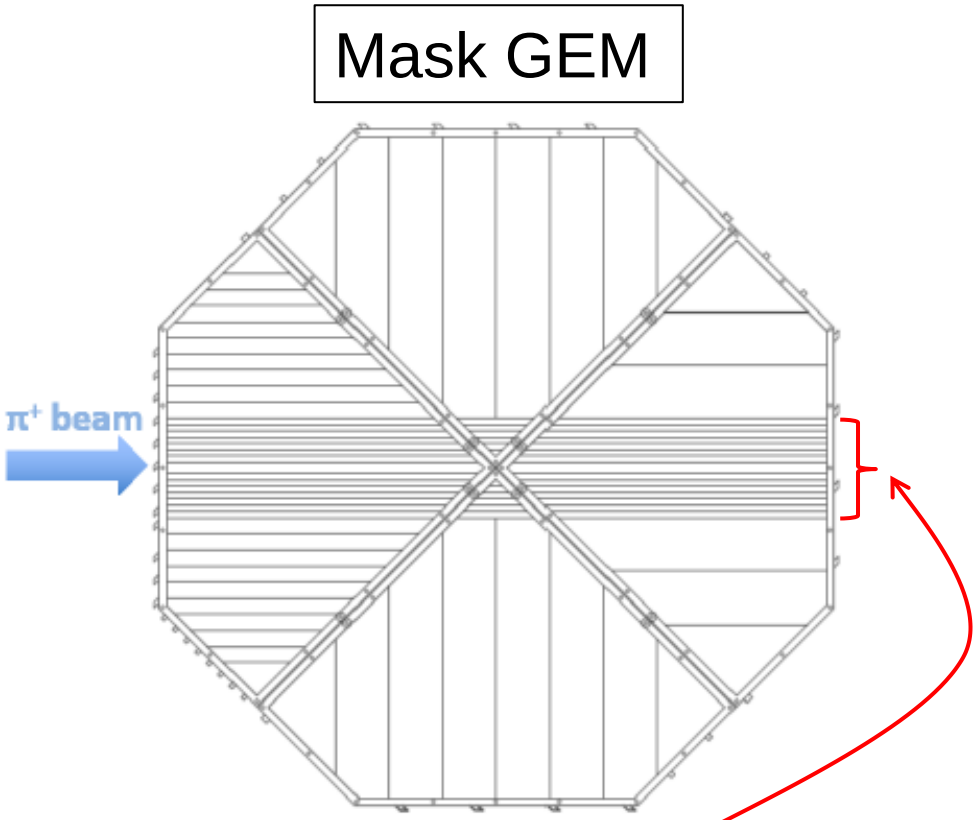
- to reduce spark rate / electrode
- to minimize acceptance loss when an electrode is broken due to discharge

Mask GEM for >10^6 Hz beam

Reduce GEM HV in the beam trajectory region to make beam trajectories invisible

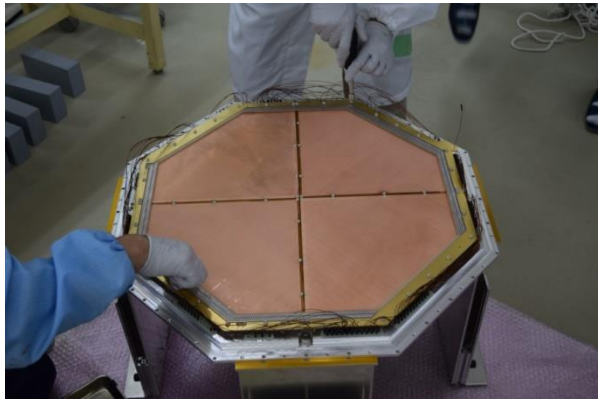
"Mask region" is adjustable (5mm pitch).



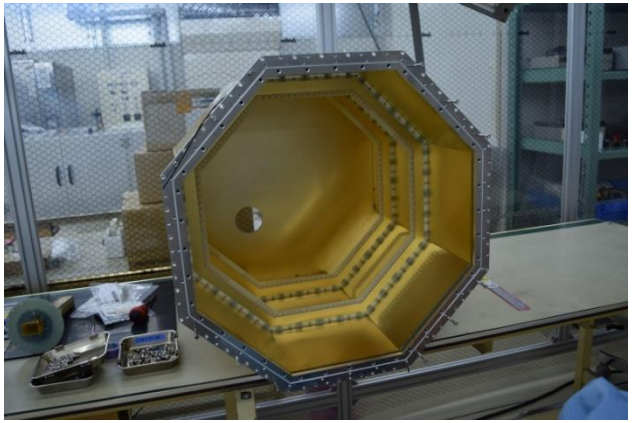


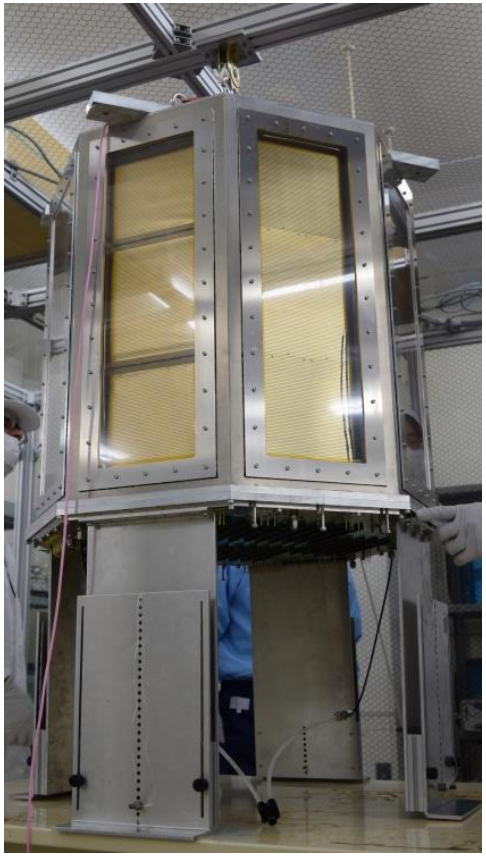
HypTPC

GEMs

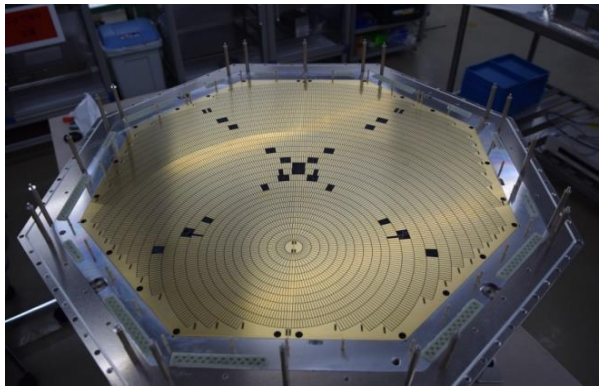


Field cage

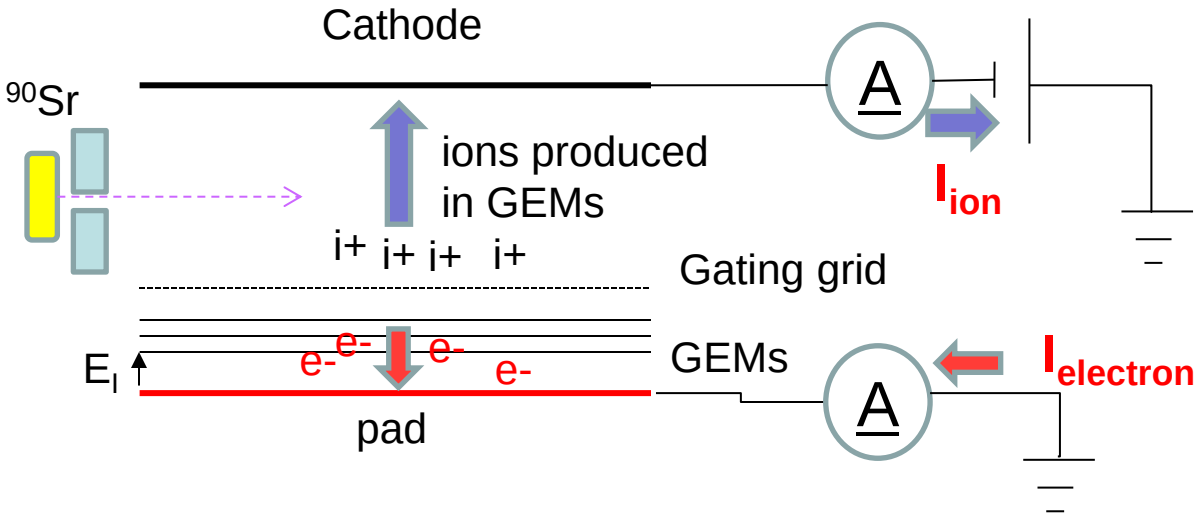




Readout pads

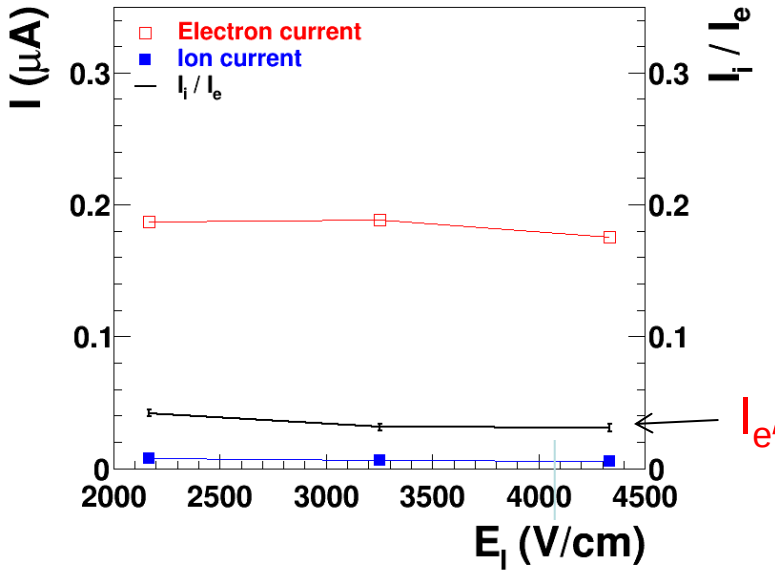


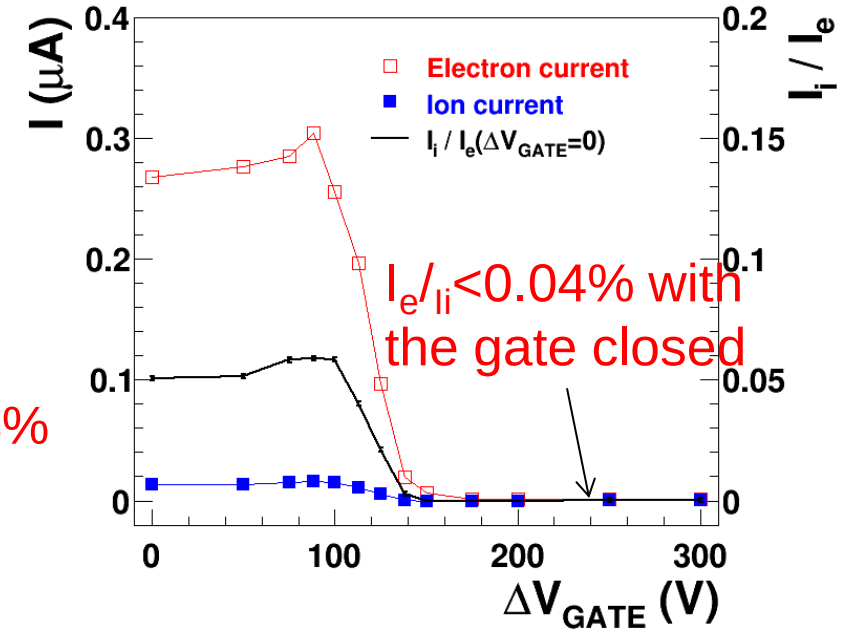
Ion backflow



Backflow ratio

BR= $I_{ion}/I_{electron}$

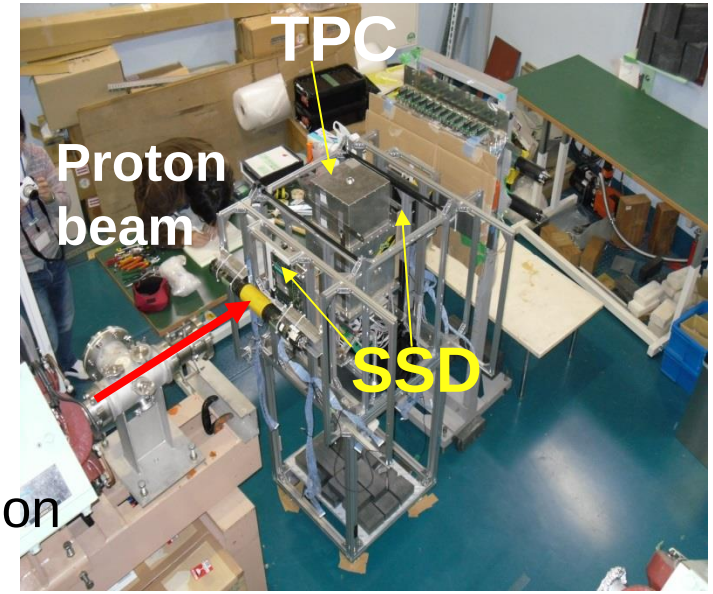




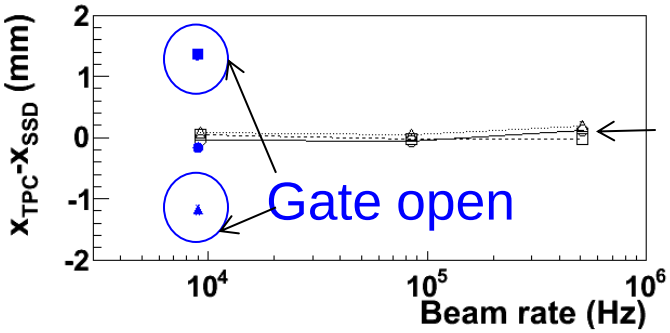
TPC prototype test

NIMA763(2014)65-81

- Beam test at RCNP
  - Proton beam at 400 MeV
  - Beam rate up to 10^6 Hz /cm^2



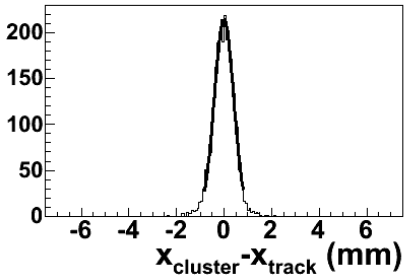
Hit position distortion<0.1mm with GG



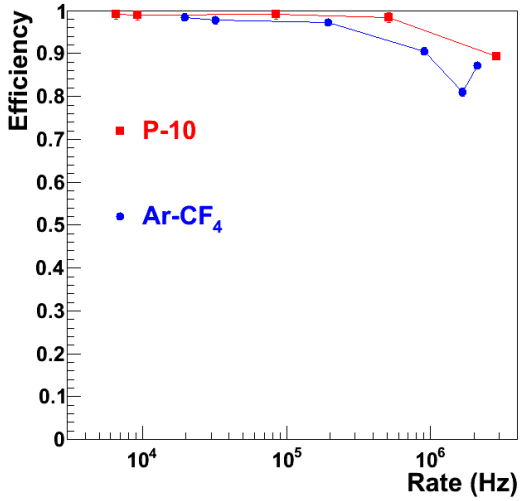
at gate operation

Position resolution (B=0)

σ_x=0.40mm (4mm pad)

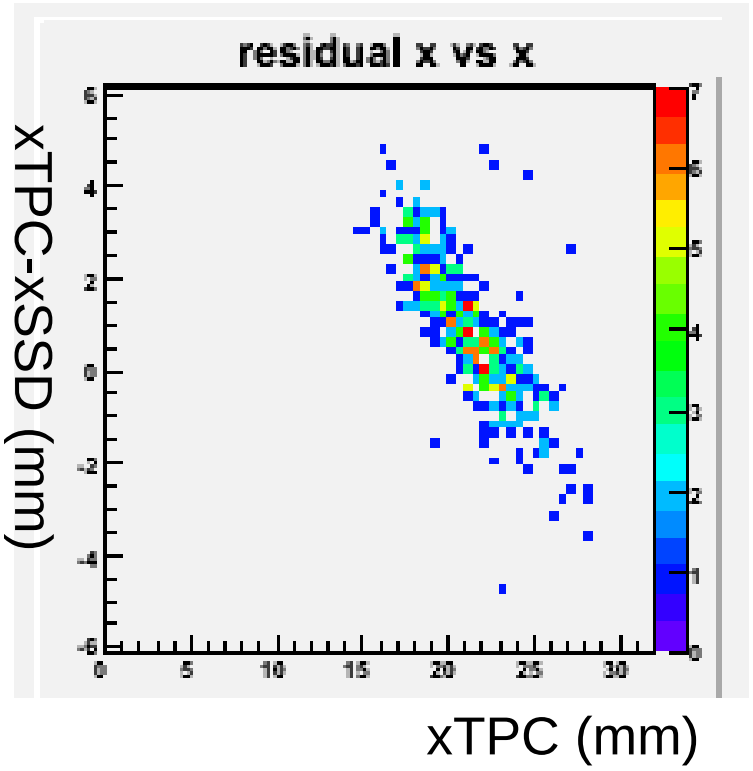


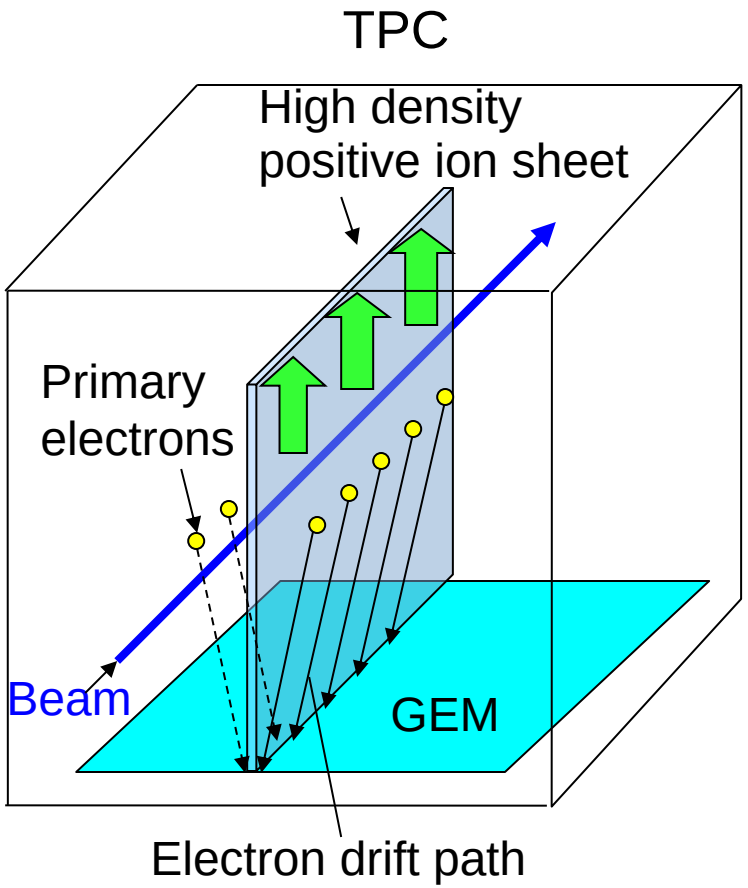
Efficiency vs beam rate



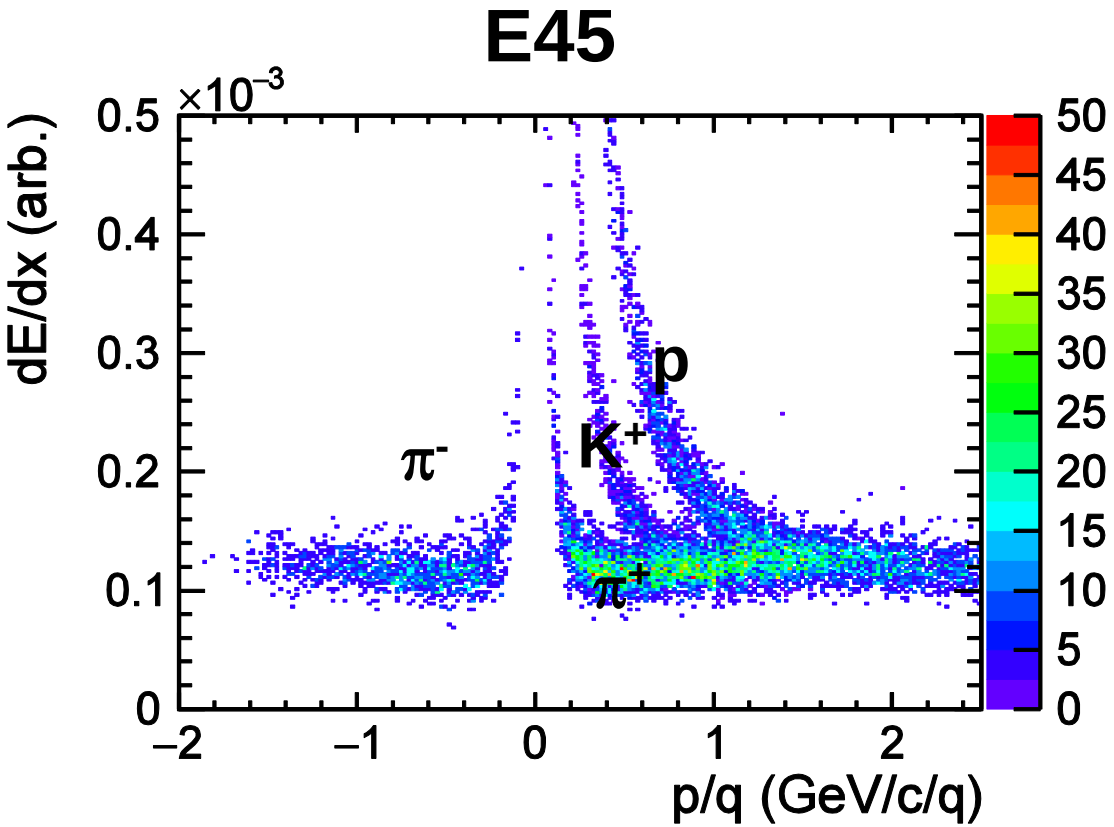
TPC hit distortions

GATE open Beam rate = $9x10^3/cm^2$





Particle identification with TPC



π/K : p<=0.5 GeV/c
π/p : p<=1.1 GeV/c

Courtesy of S.H. Hwang

Modification of the strip pattern (field cage and target holder)

Original

Modified

1.5

1

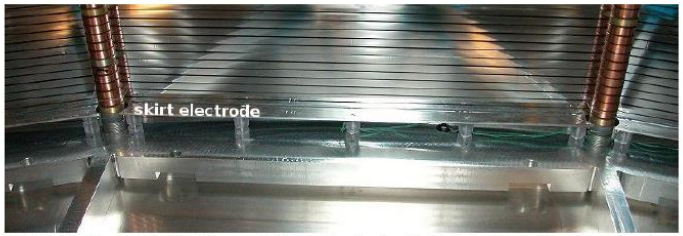
2

0.5

The place where positive Ions can be attached

Remove Insulator (ALICE-TPC Like solution)

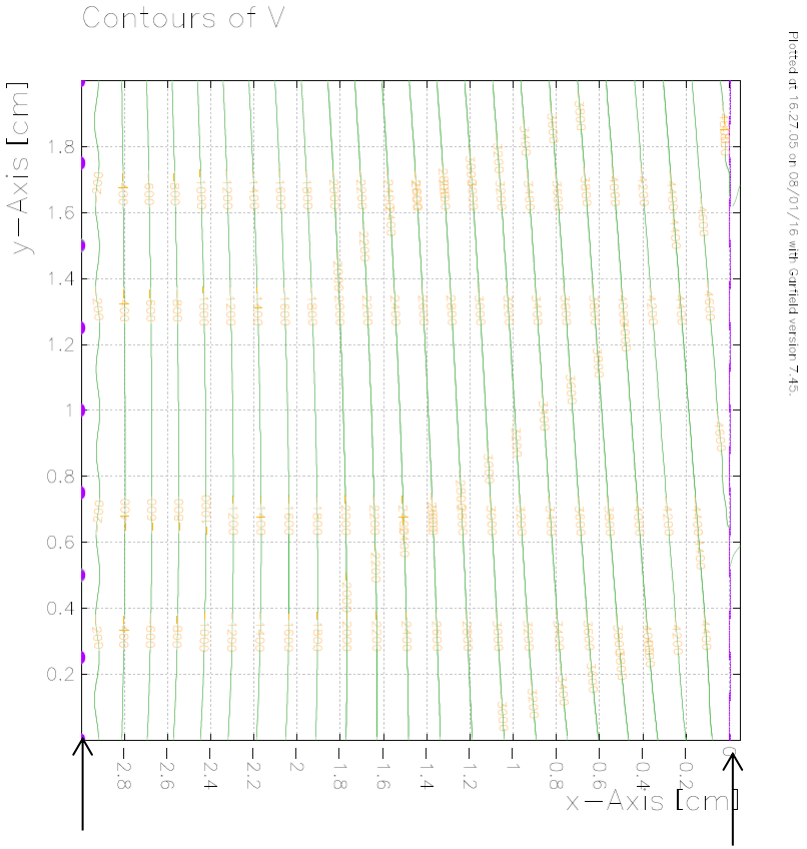
ALICE-TPC field strips



Ion drift outside the field cage

- Most serious problem
- All the positive ions hit the field cage wall

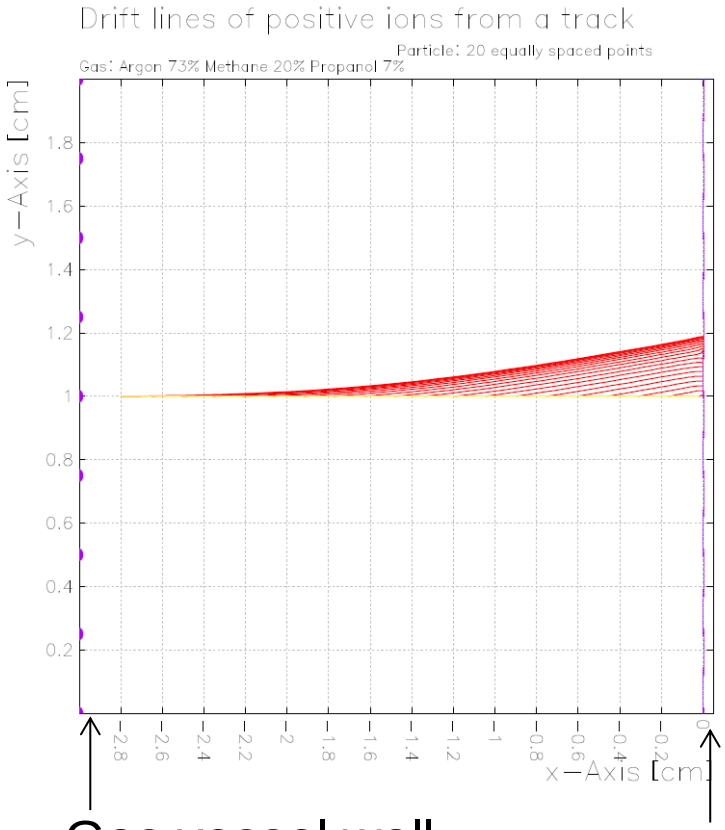
Equipotential lines



Gas vessel wall
(actual a metal plate)

Field strip wall
(printed circuit on polyimide)

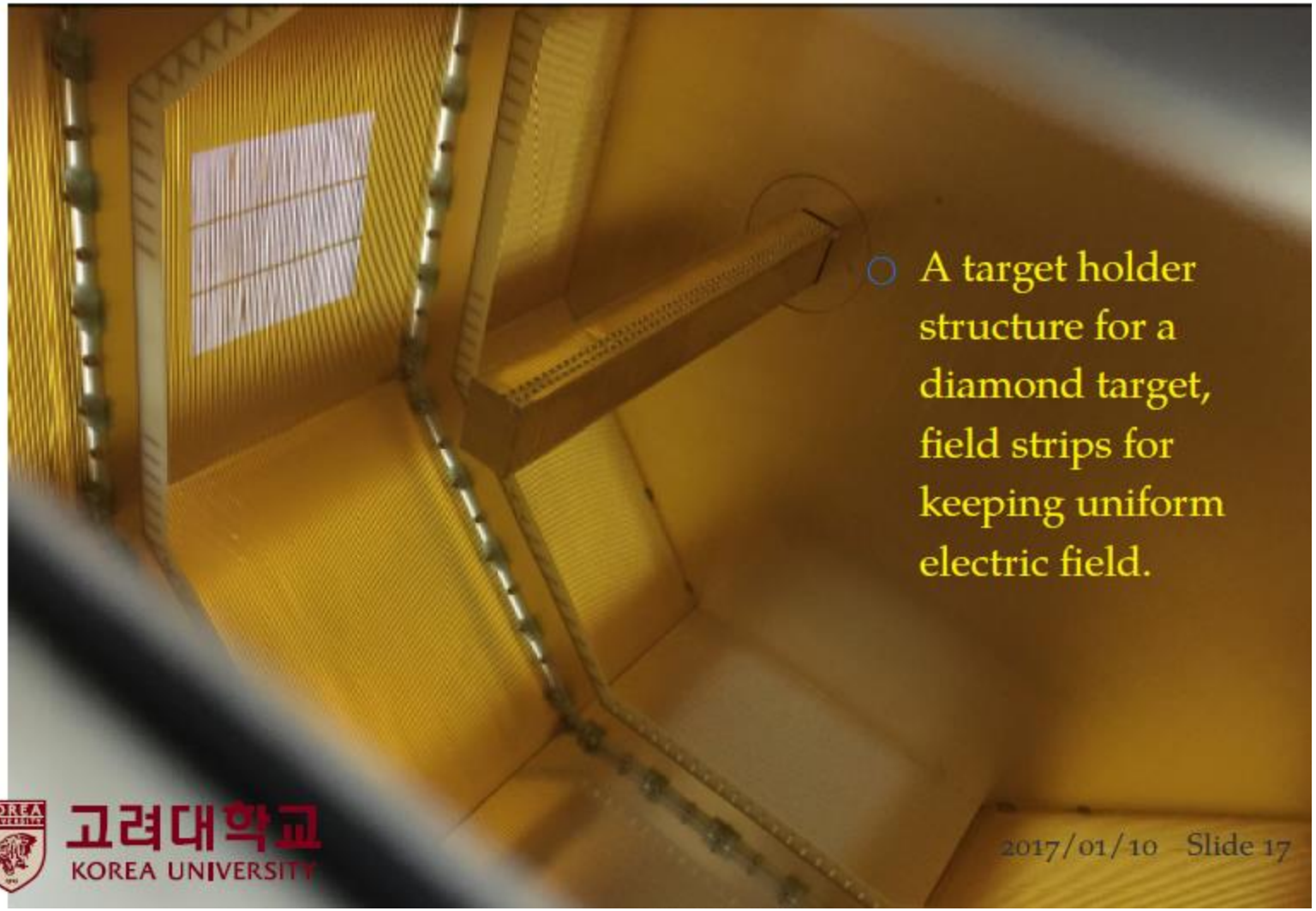
Drift lines of positive ions
along a beam particle



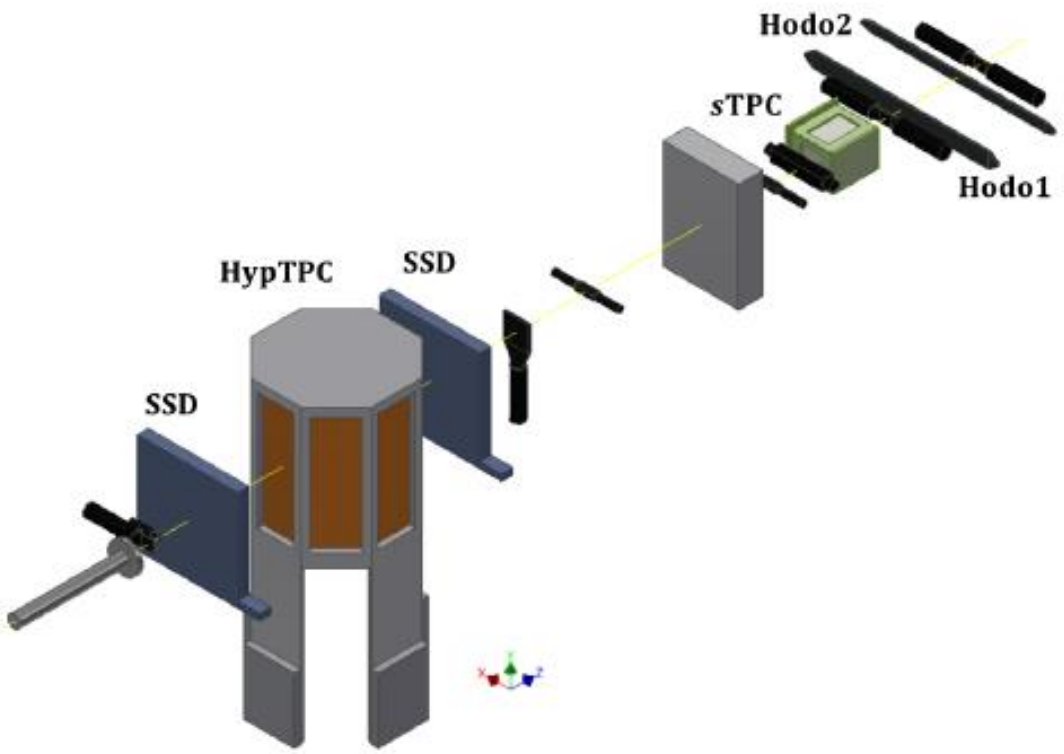
Gas vessel wall

Field strip wall

Inside the HypTPC

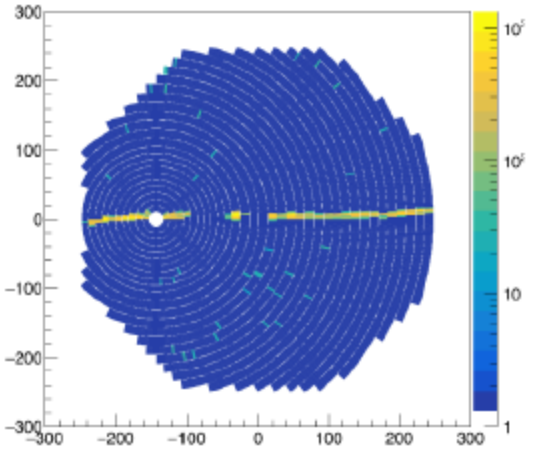


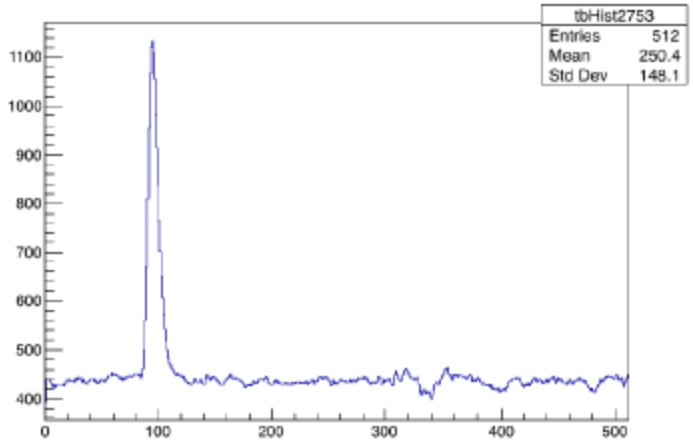
First Beam Test with HypTPC at ELPH



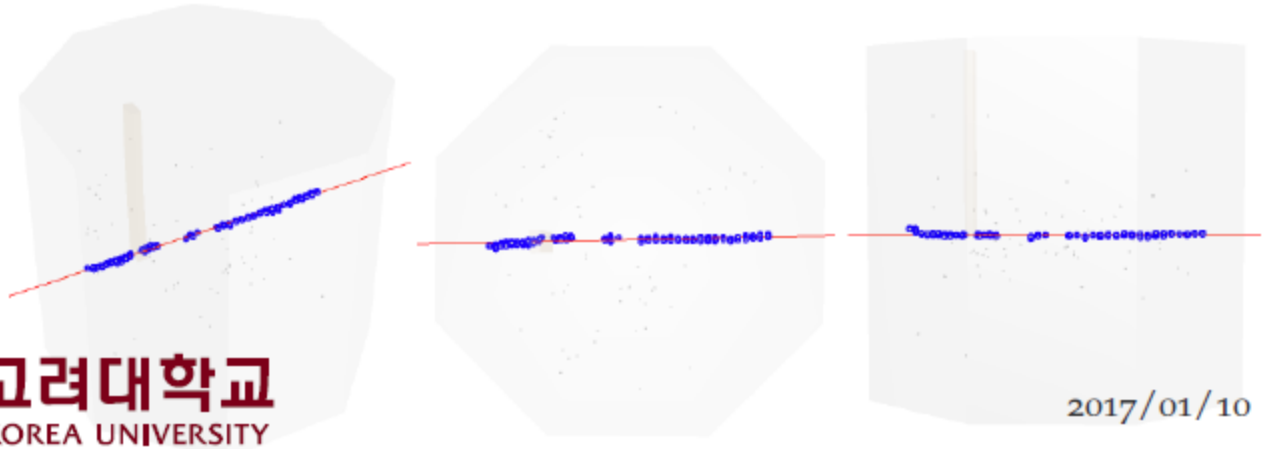
- A 460-MeV/c positron beam was exposed to HypTPC on November 7-9, 2016 at ELPH, Tohoku University.

Preliminary ELPH Test Results





- A positron beam track is clearly reconstructed.



Physics possibilities with HypTPC

- $\Lambda(1405)$: $\pi^- p \rightarrow K^0 \Lambda(1405)$

  $\Lambda(1405) \rightarrow \Lambda\gamma$ ($\bar{K}N$ compositeness, T. Sekihara, *PR*C89 (2014) 025202)

- Λ^*, Σ^* studies in $K^- p$ reactions with PWA

  – $K^- p \rightarrow K^0 n, \pi\Sigma, \pi\Lambda, \eta\Lambda, \pi\pi\Lambda, \pi K n, \ldots$

- $K^- pp$: $\pi^+ d \rightarrow K^+ K^- pp$

  $K^- pp \rightarrow \Lambda p, \Sigma^0 p, \Lambda\pi^0 p, \Sigma^0\pi^0 p$

- Ξ excited states:

  $K^- p \rightarrow K^+ \Xi^{-*}$, $\Xi^{-*} \rightarrow \Lambda K^-, \Sigma^0 K^-, \Sigma^- K^0, \Xi^-\pi^0, \Xi^0\pi^-, \Xi^-\gamma$

  $K^- p \rightarrow K^0 \Xi^{0*}$, $\Xi^{0*} \rightarrow \Lambda K^0, \Sigma^0 K^0, \Sigma^+ K^-, \Xi^-\pi^+$

- Ξ-C atom (E42) : $K^- C \rightarrow K^+ \Xi^- X$, Ξ^- capture in C

  X-ray detection in TPC? (Ar gas)

Application of TPCs

- High multiplicity events in HI collisions
  - RHIC-STAR, LHC-ALICE(50kHz,continuous readout)
- TPCs with various gas
  - X-ray detection (X-ray polarization) (DME, C_2H_6O)
    - e from photoelectron effect
  - γ detection (Ar)
    - Compton camera (e from Compton scattering)
  - neutron detection (^{3}He)
- Liquid Argon TPC
  - Neutrino, dark matter search (good dE/dx resolution)
- Liquid Xe TPC
  - High resolution gamma detection

Summary

- TPC is an excellent detector for 3-d imaging
- However,TPC has a disadvantage for high particle rate
- A large acceptance TPC for E42 (H-dibaryon search) and E45 (baryon resonance study) experiments at J-PARC for high rate beams has been developed
  - Target inside drift volume with a target holder
  - GEMs and gating grid to suppress field distortion
- Applications of HypTPC to other hadron physics possible with various targets (and gas?)