Study of Baryon Excited States in High-statistics (π, 2π) Reactions at J-PARC

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for J-PARC E45 Collaboration
ECT* Workshop, Space-like and time-like electromagnetic baryonic transitions
12 May 2017, Trento

J-PARC E45 Collaboration

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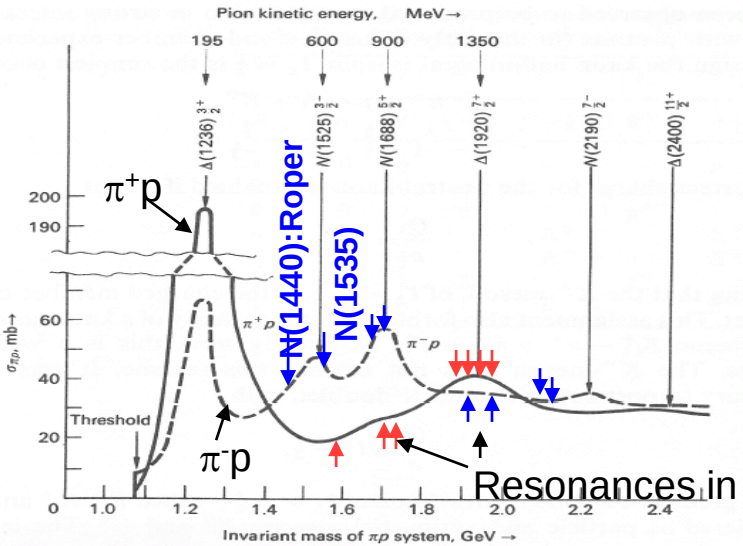
Baryon spectroscopy :
Physics of broad and overlapping resonances



Resonances in PDG

- ✓ **Width: a few hundred MeV.**
- ✓ **Resonances are highly overlapped in energy except Δ(1232).**

→Complicated Partial Wave Analysis to extract hidden resonances

Measure cross sections as a function of
- **Incident pion energy**
- **Scattering angle**

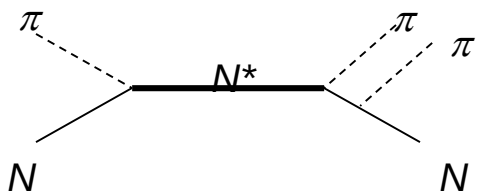
In broad range (with fine bins) to extract resonance poles

D.H.Perkins, Introduction to High Energy Physics

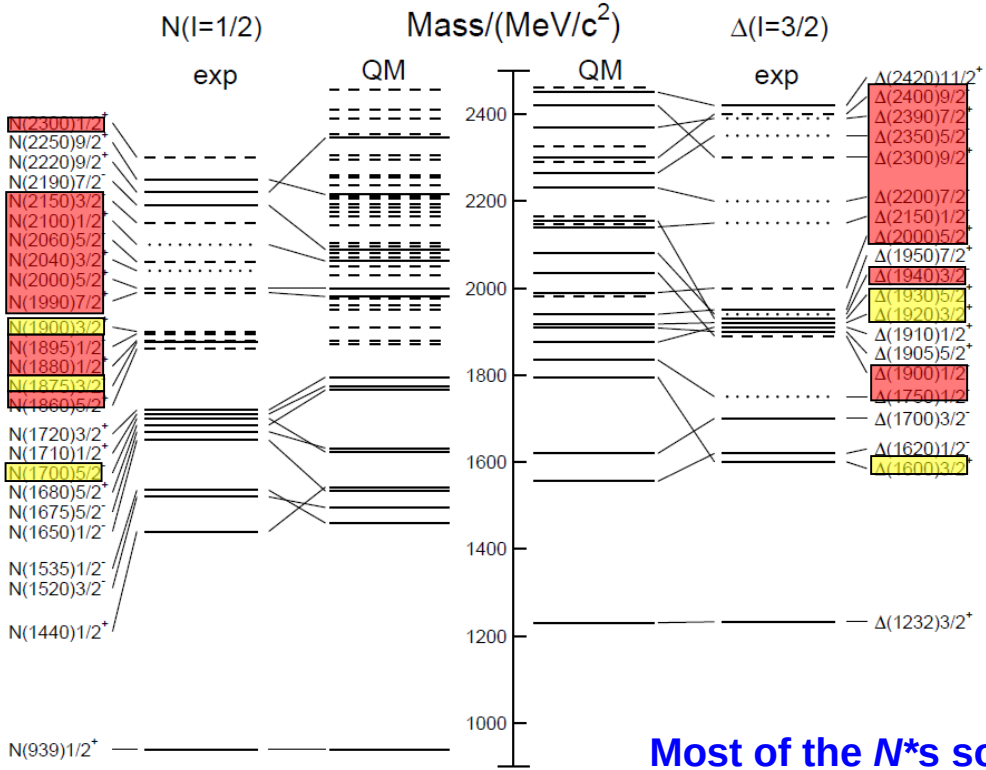
J-PARC E45

Proposed to study baryon resonances in (π,2π) reactions.

- Precise measurements of baryon resonance properties
- Deeper understanding of non-perturbative QCD
- Search for new baryon states
  - *e.g.* hybrid baryons (*qqqg*)



Baryon mass: Experiment vs Quark Model



PDG 2016

Many baryon resonances have not been established experimentally.

**** established
***
* **

Most of the *Ns so far were measured from**

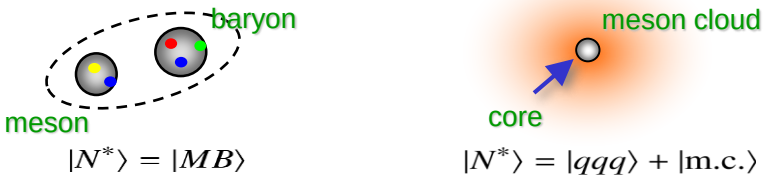
$$\pi N \to \pi N\ ,\quad \gamma N \to \pi N$$

Dynamical Coupled-Channels model (ANL-Osaka)

Matsuyama, Sato, Lee, Phys. Rep. 439 193 (2007)

✓

Physical N^*s will be a "mixture" of the two pictures:



✓

$$V_{a,b} = v_{a,b} + \sum_{N^*} \frac{\Gamma^{\dagger}_{N^*,a}\Gamma_{N^*,b}}{E - M_{N^*}}$$

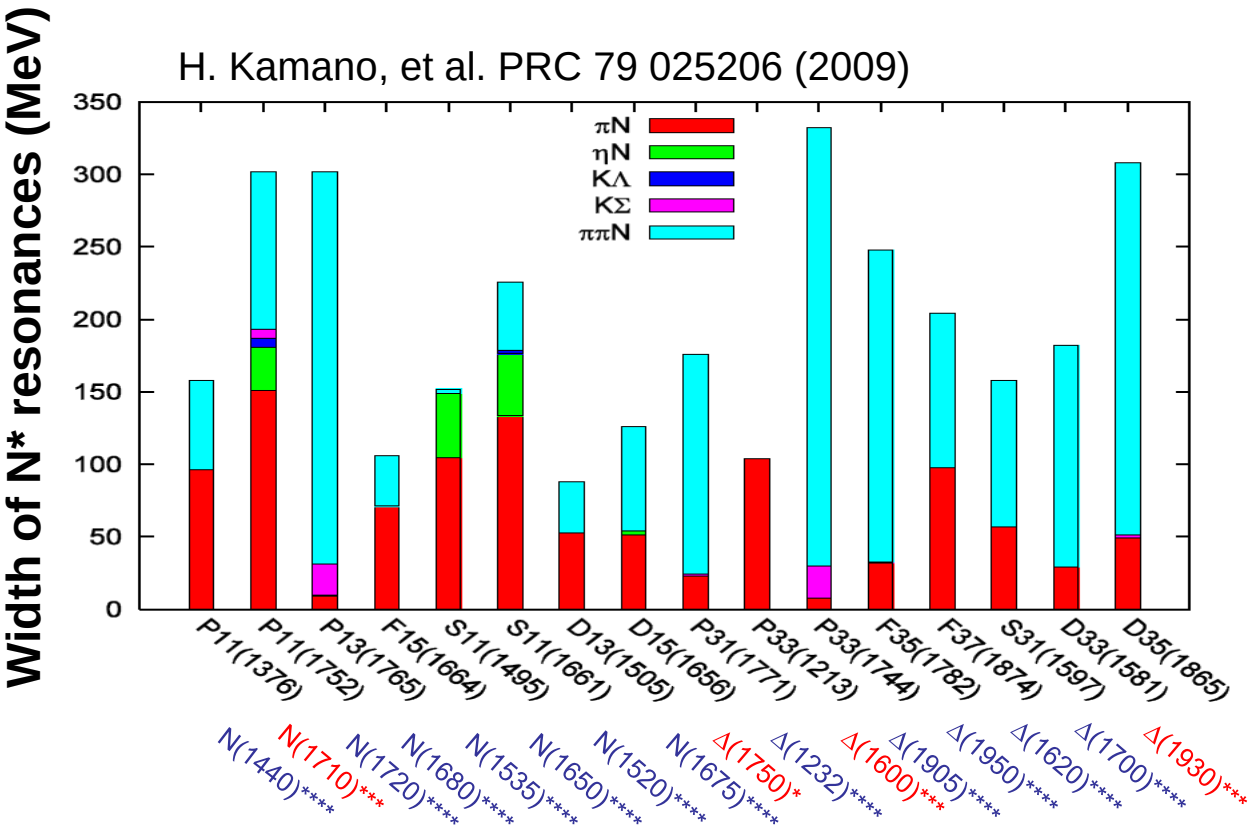
✓ Transition potentials:

exchange potentials of ground state mesons and baryons

bare N^* states

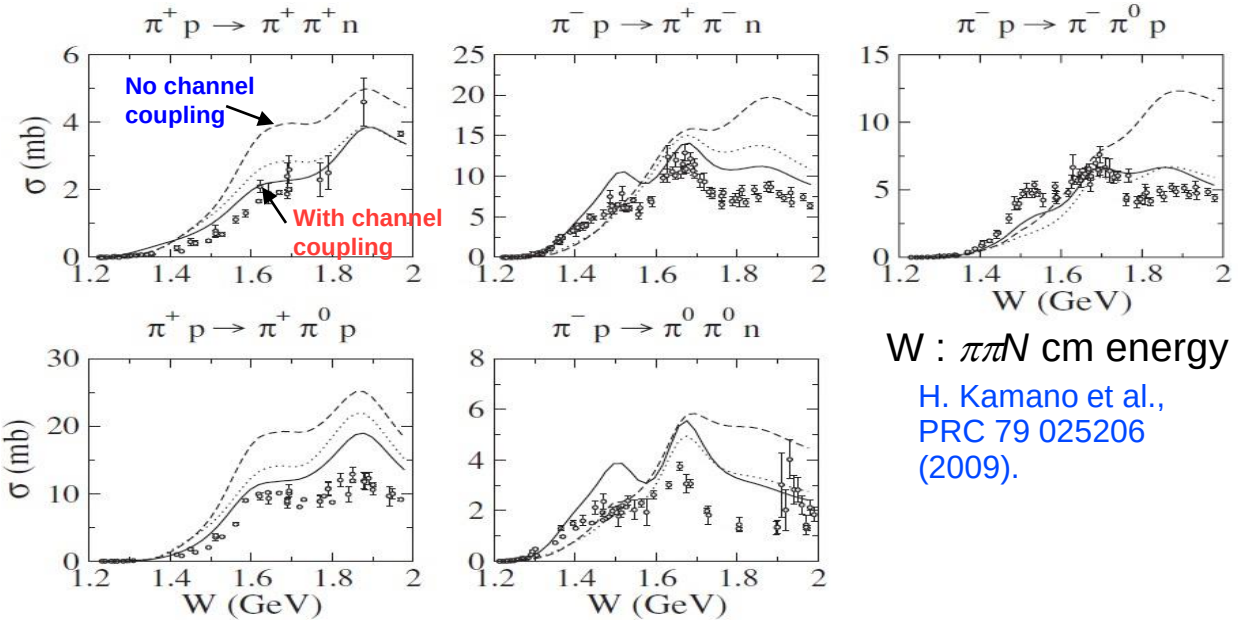
H. Kamano, JAEA seminar

Importance of $N\pi\pi$ Decay



World's $\pi N \to \pi\pi N$ data

Only 240K events measured in 1970's

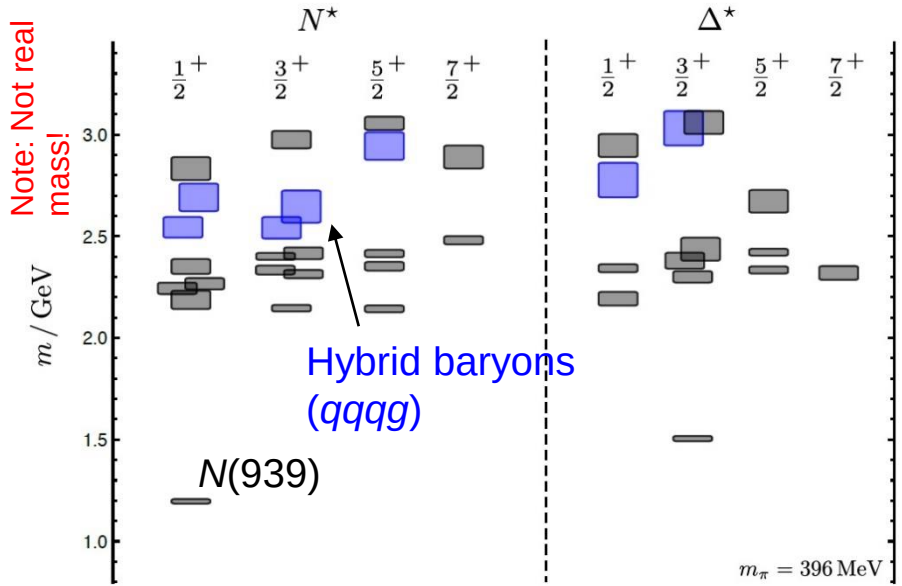


W : $\pi\pi N$ cm energy

H. Kamano et al., PRC 79 025206 (2009).

Recent Lattice QCD calculations

J. Dudek et al., PRD85 (2012) 054016



J-PARC E45 spectrometer

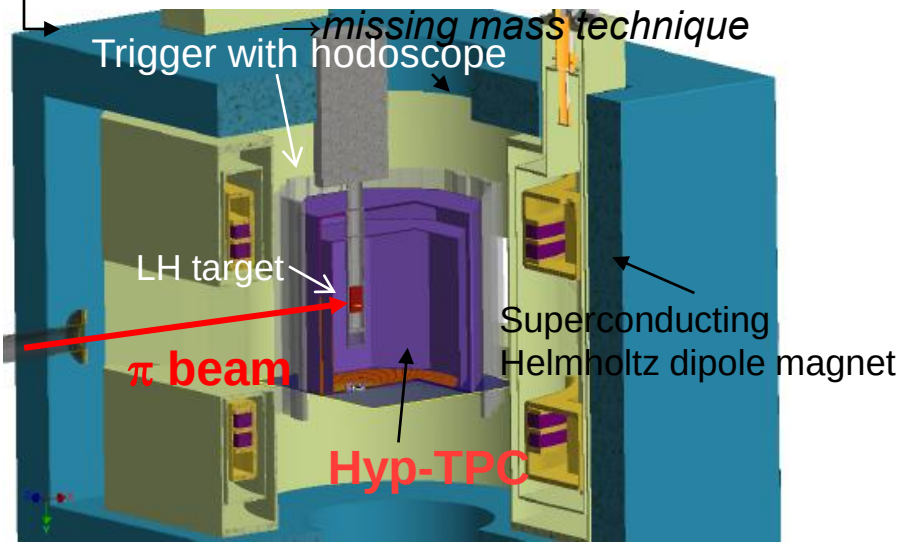
Measuring (π,2π) in large acceptance TPC (HypTPC)

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

2 charged particles + *1 neutral particle*
→missing mass technique

$\pi N \rightarrow KY$ *(2-body reaction)*
$\pi p \rightarrow K^0 \Lambda$,
$\pi^+ p \rightarrow K^+ \Sigma^+$ (I=3/2, Δ*)

π^{+-} beam on liquid-H target
p= 0.73 – 2.0 GeV/c



Expected statistics at E45

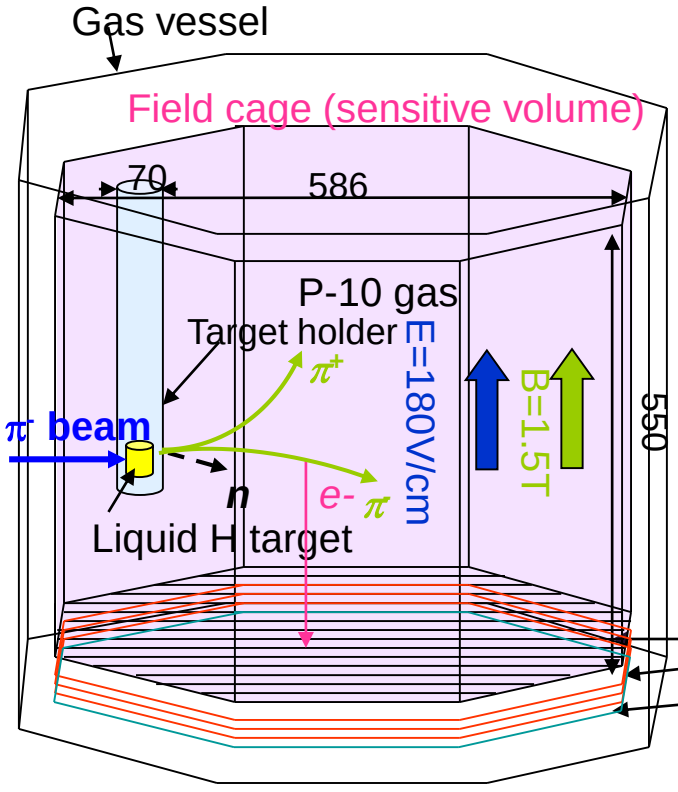
- π beam rate : ~10^6 / cycle (6s)
- Liquid H target : 5 cm thickness
- TPC acceptance : 40%
- (π,2π) cross section : ~2 mb
- ⇨ 160 events / cycle (6 s)
- Background : elastic scattering
  3200 events / cycle

- πp CM energy range : 1.50 – 2.15 GeV
- No. of bins : π^- beam : 24 (energy) x 20 (angle)
  π^+ beam : 23 (energy) x 20 (angle)
- No. of events / bin : 32 K

⇨ 30M events in 15 days

Increase world's $\pi\pi N$ data (240K) by a factor of 130

HypTPC

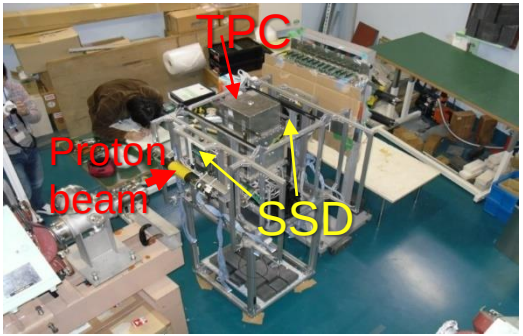


- Large acceptance
  - Liquid-Hydrogen target inside
- High-rate capability with suppression of positive-ion backflow causing distortion of trajectories
  - Gating Grid
  - GEM (Gas Electron Multiplier)
- Good momentum resolution (1-3%) with B-field and fine-segmented pads
  - 2.5 mm x 10 mm pad
  - No. of pads = 5800

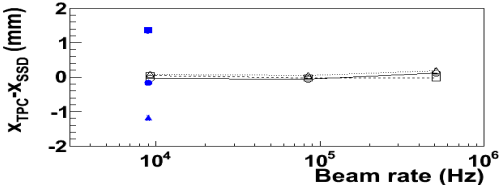
Prototype TPC test

- Beam test at RCNP (Osaka Univ.)
  - Proton beam at 400 MeV
  - Beam rate up to 10^6 Hz/cm^2

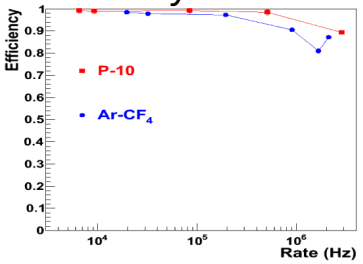
NIMA763(2014)65-81



Hit position distortion <0.1mm

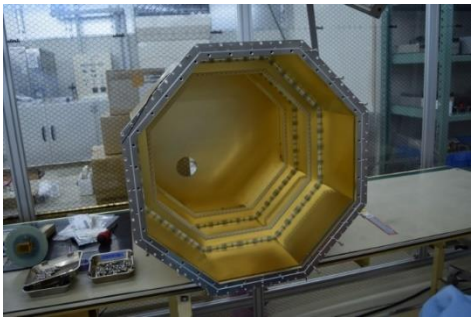


Efficiency>95% at 10^6Hz

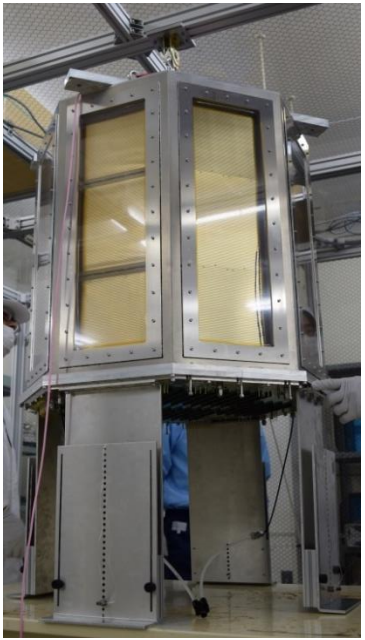


HypTPC

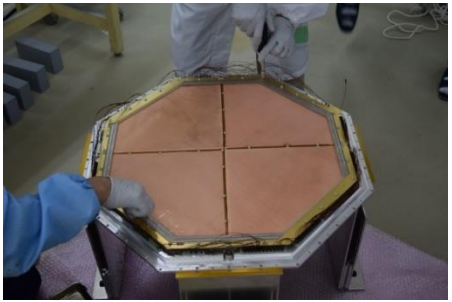
Field cage

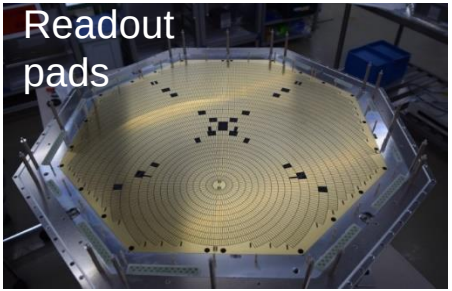


Completed
Beam test at ELPH in Nov 2016



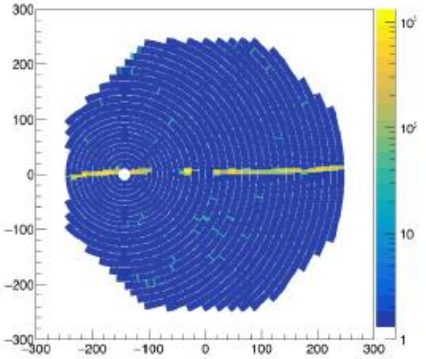
GEM

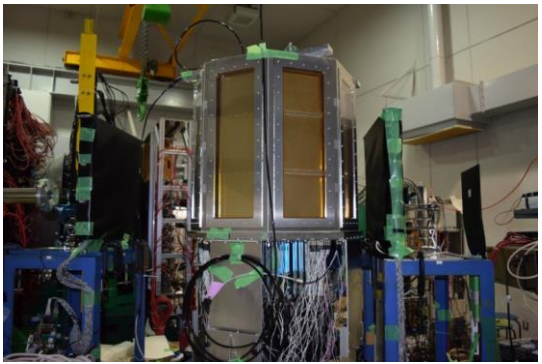


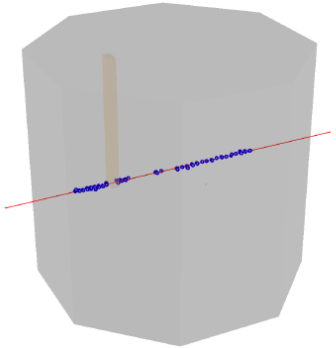


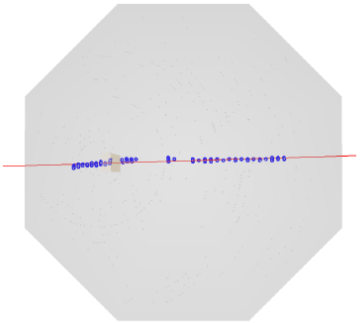
Beam test at ELPH (U. Tohoku) Nov. 2016

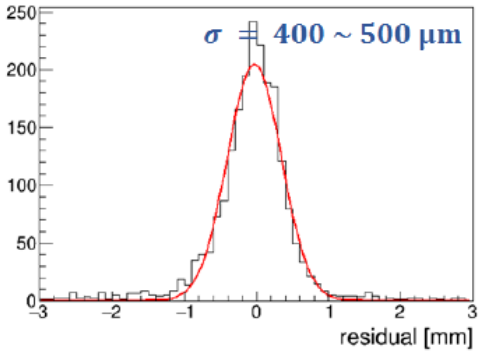
- TPC efficiency and position resolution similar to the designed values



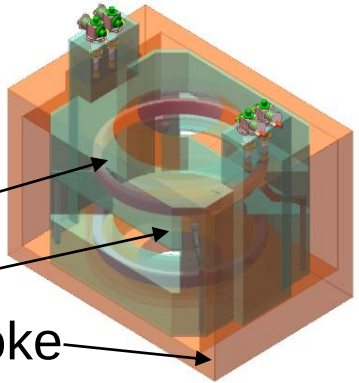






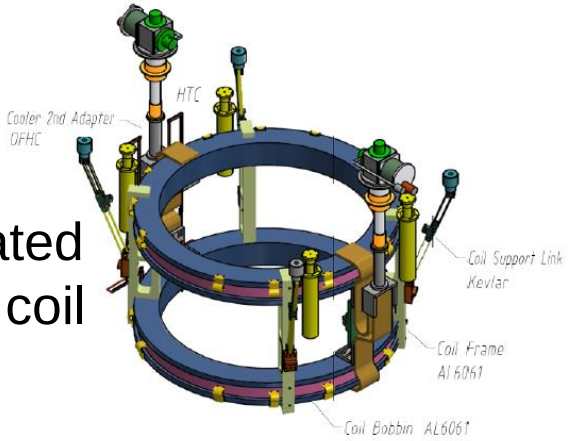


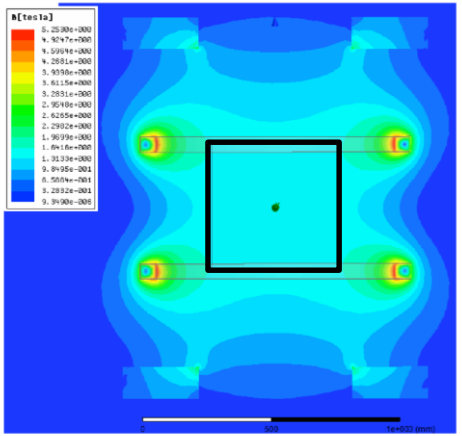
Superconducting Helmholtz magnet

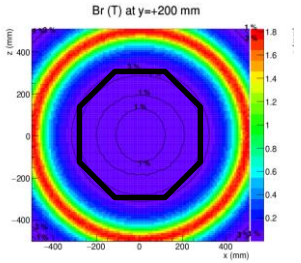


Coils
Cryostat
Return yoke

2 coils separated by the coil radius



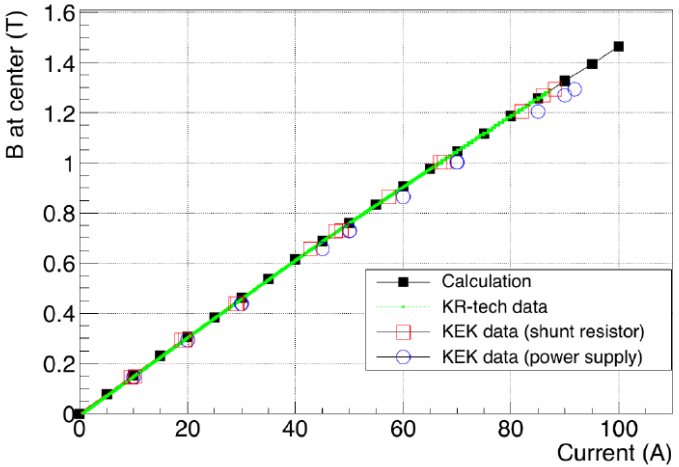




Br in TPC field cage <1%

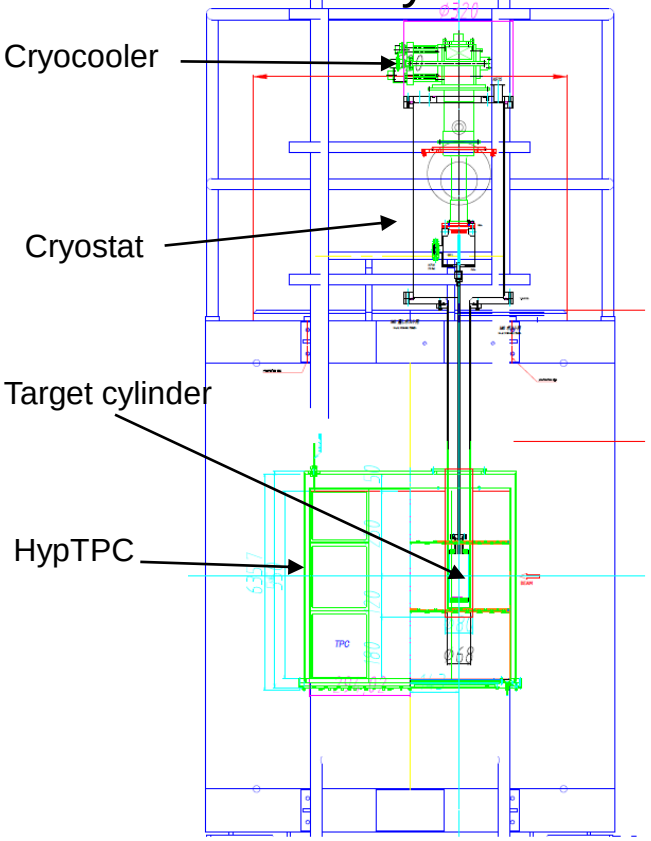
Excitation test of Helmholtz magnet

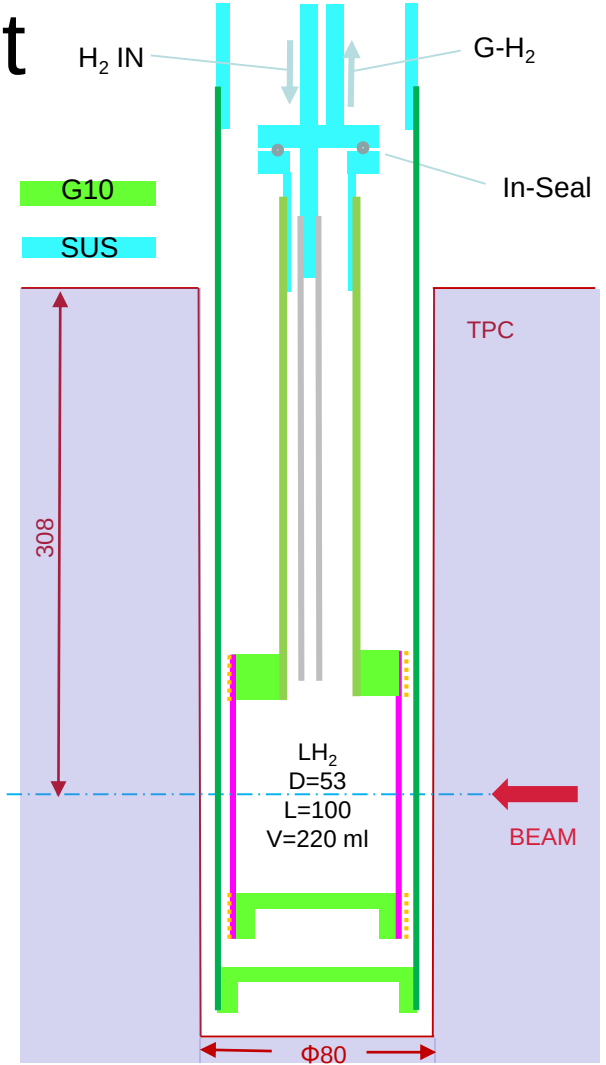
- Excitation test at KEK since Nov. 2016
  - B reached 1.3 T (design value = 1.5T)
- Cosmic ray test with HypTPC planned in 2017



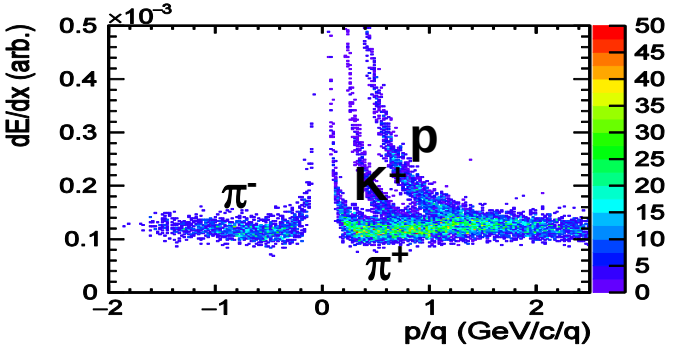
L-H_2 target

Design underway
Construction by Mar 2018





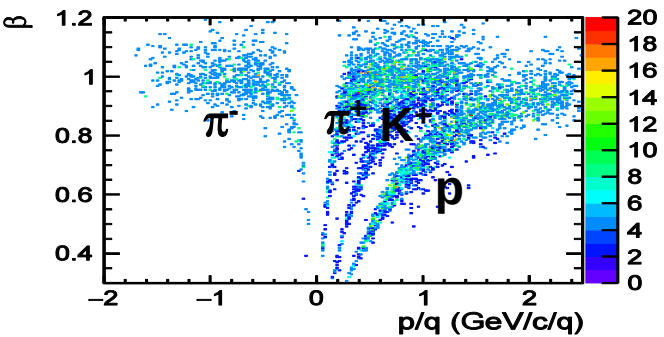
Particle identification (GEANT)



TPC dE/dx

π/K : p<=0.5 GeV/c

π/p : p<=1.1 GeV/c



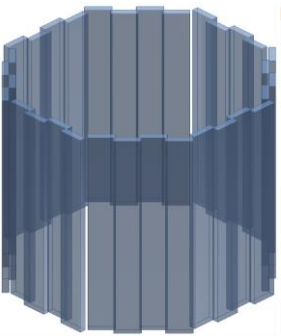
Hodoscope TOF

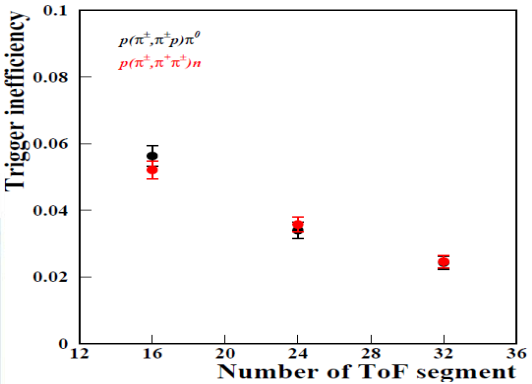
σ_T = 100ps

Trigger efficiency and acceptance

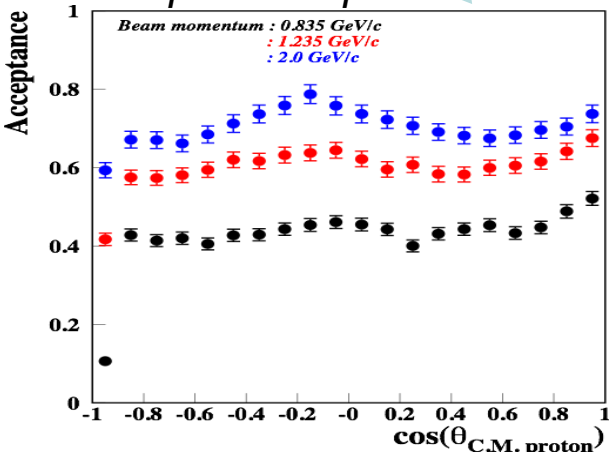
2-charged particle trigger
(inefficiency due to double hit)

hodoscope



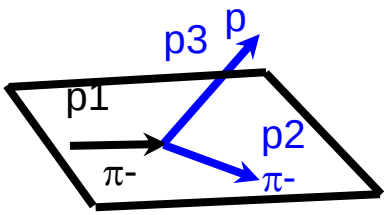


$\pi^+p \rightarrow \pi^+\pi^0p$ reaction



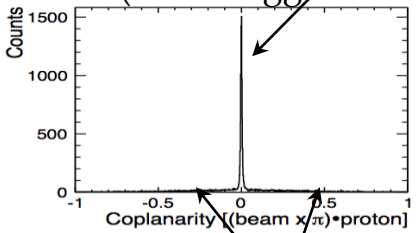
Proton momentum > 300 MeV/c

Rejection of elastic scattering



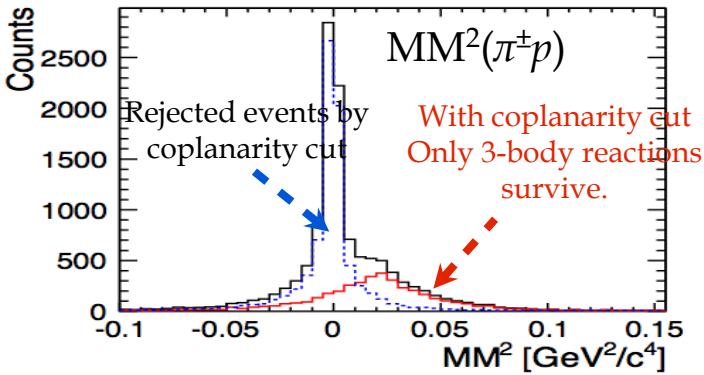
Coplanarity
=cosine of angle between p1 and (p2xp3)

Elastic scattering
(Same trigger condition)



3-body reaction

$\pi^- p \rightarrow \pi^- \pi^0 p$ reaction



Physics possibilities with HypTPC

- *H*-dibaryon (E42) : $K^-C \rightarrow K^+ H X$, $H \rightarrow \Lambda\Lambda, \Lambda\pi p, \Xi^- p$
- $\Lambda(1405)$: $\pi^- p \rightarrow K^0 \Lambda(1405)$

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

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

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

Summary and prospect

- J-PARC E45 was proposed to establish baryon excited states up to 2 GeV/c^2 in (π,2π) reactions, which will increase previous data statistics by two-orders of magnitude.
- Large acceptance E45 spectrometer was designed based on Helmholtz magnet and TPC to measure (π,2π) reactions with 10^6Hz pion beams.
- The spectrometer will be ready in Mar 2018.
- Final review by J-PARC PAC in Jan. 2018.
- Approval expected in Jul. 2018→Ready for beam!