Hadron spectroscopy with HypTPC at J-PARC

Kiyoshi Tanida

(Advanced Science Research Center,
Japan Atomic Energy Agency)

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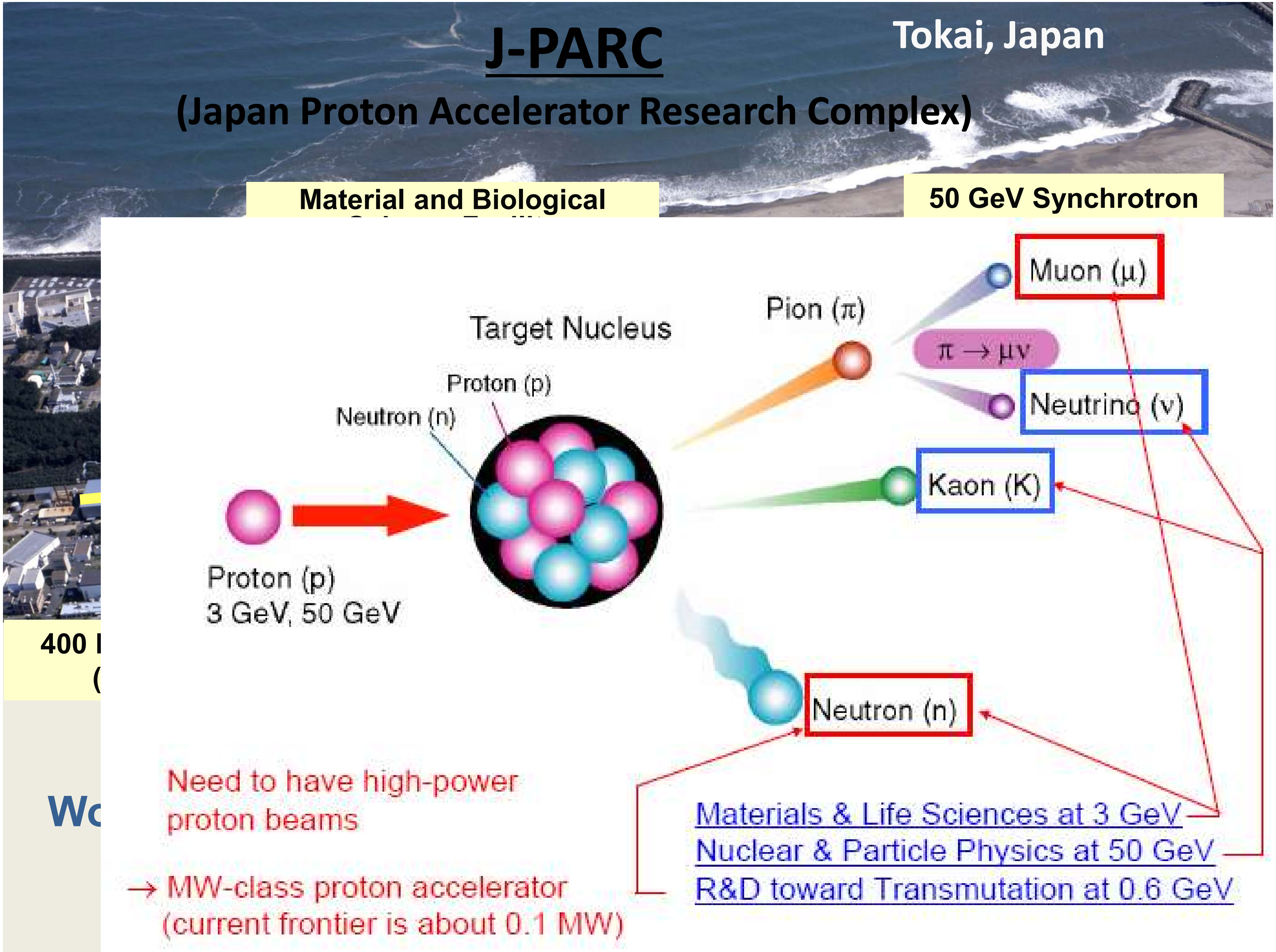
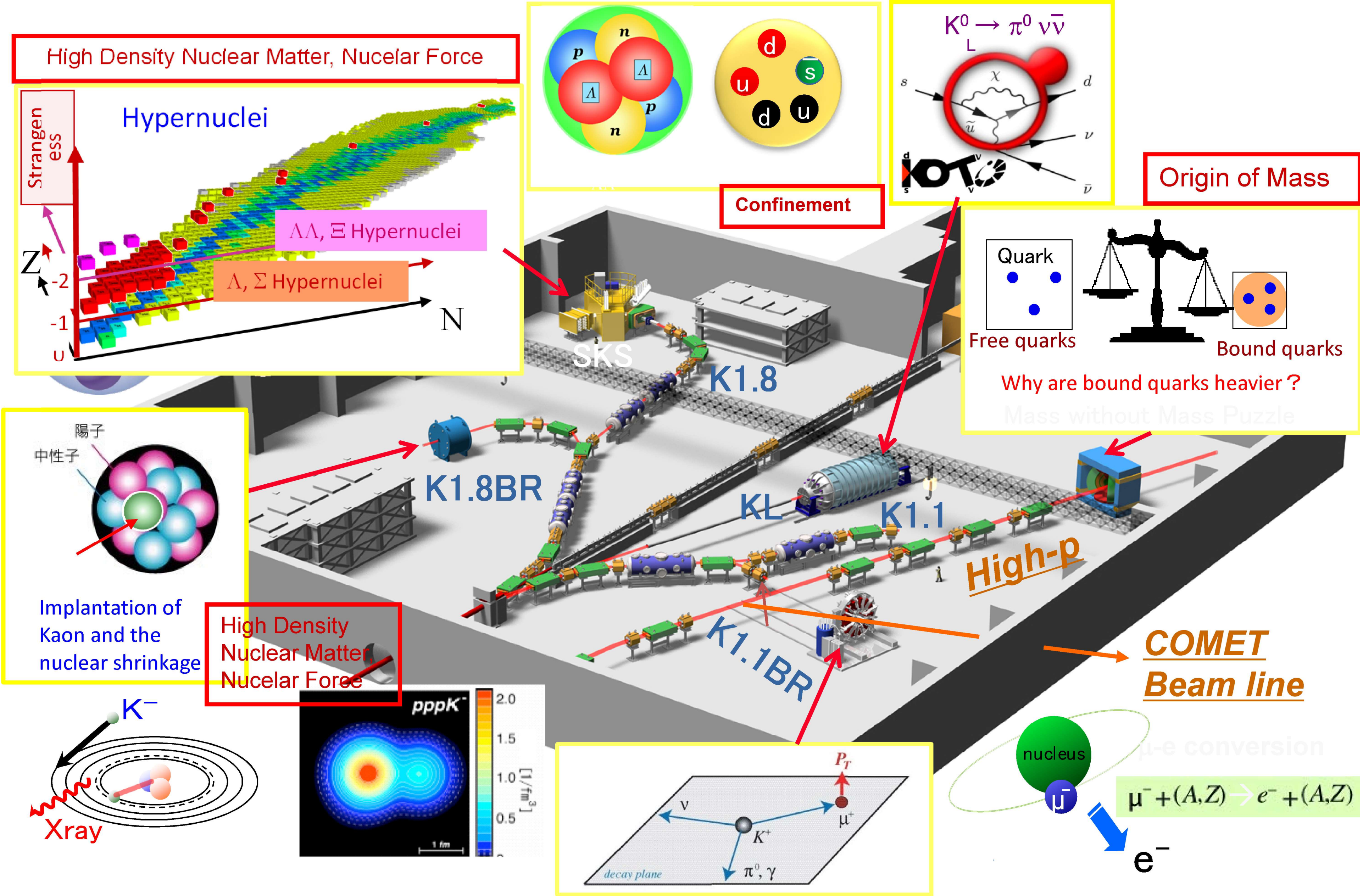
Part I.
Introduction of J-PARC


J-PARC
Tokai, Japan
(Japan Proton Accelerator Research Complex)
Material and Biological
50 GeV Synchrotron
Muon (μ)
Pion (π)
π → μν
Target Nucleus
Neutrino (ν)
Proton (p)
Neutron (n)
Kaon (K)
Proton (p)
3 GeV, 50 GeV
Neutron (n)
Need to have high-power proton beams
→ MW-class proton accelerator (current frontier is about 0.1 MW)
Materials & Life Sciences at 3 GeV
Nuclear & Particle Physics at 50 GeV
R&D toward Transmutation at 0.6 GeV

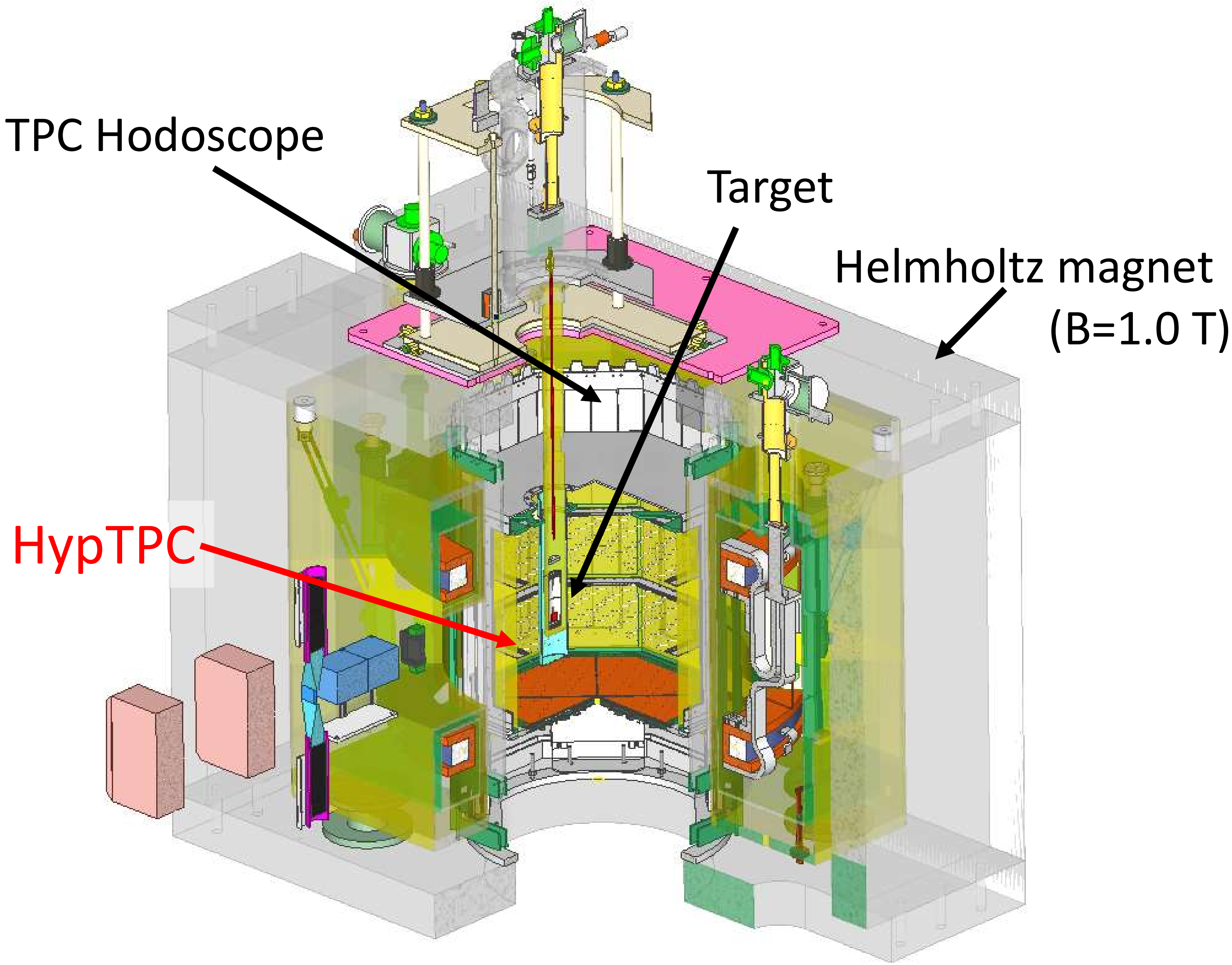
Nuclear & Hadron Physics in J-PARC

Experiments at a glance (not all)



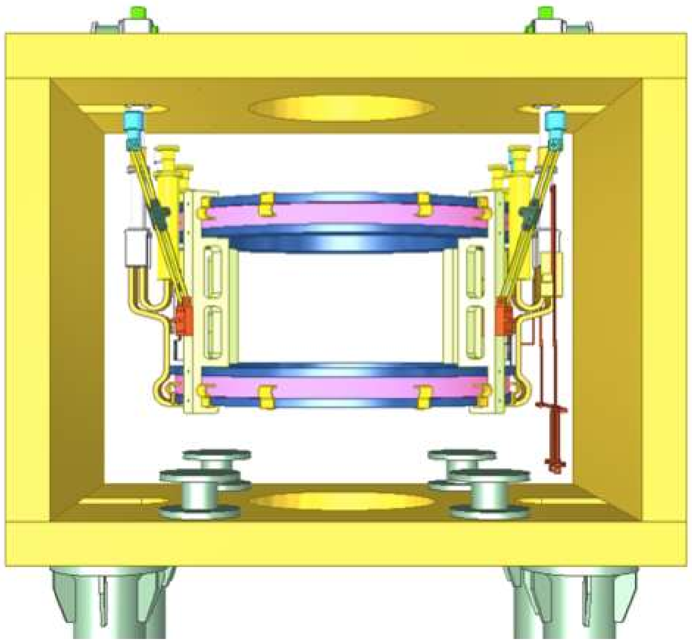
Part II.
Hyperon Spectrometer & HypTPC

Overview of Hyperon Spectrometer

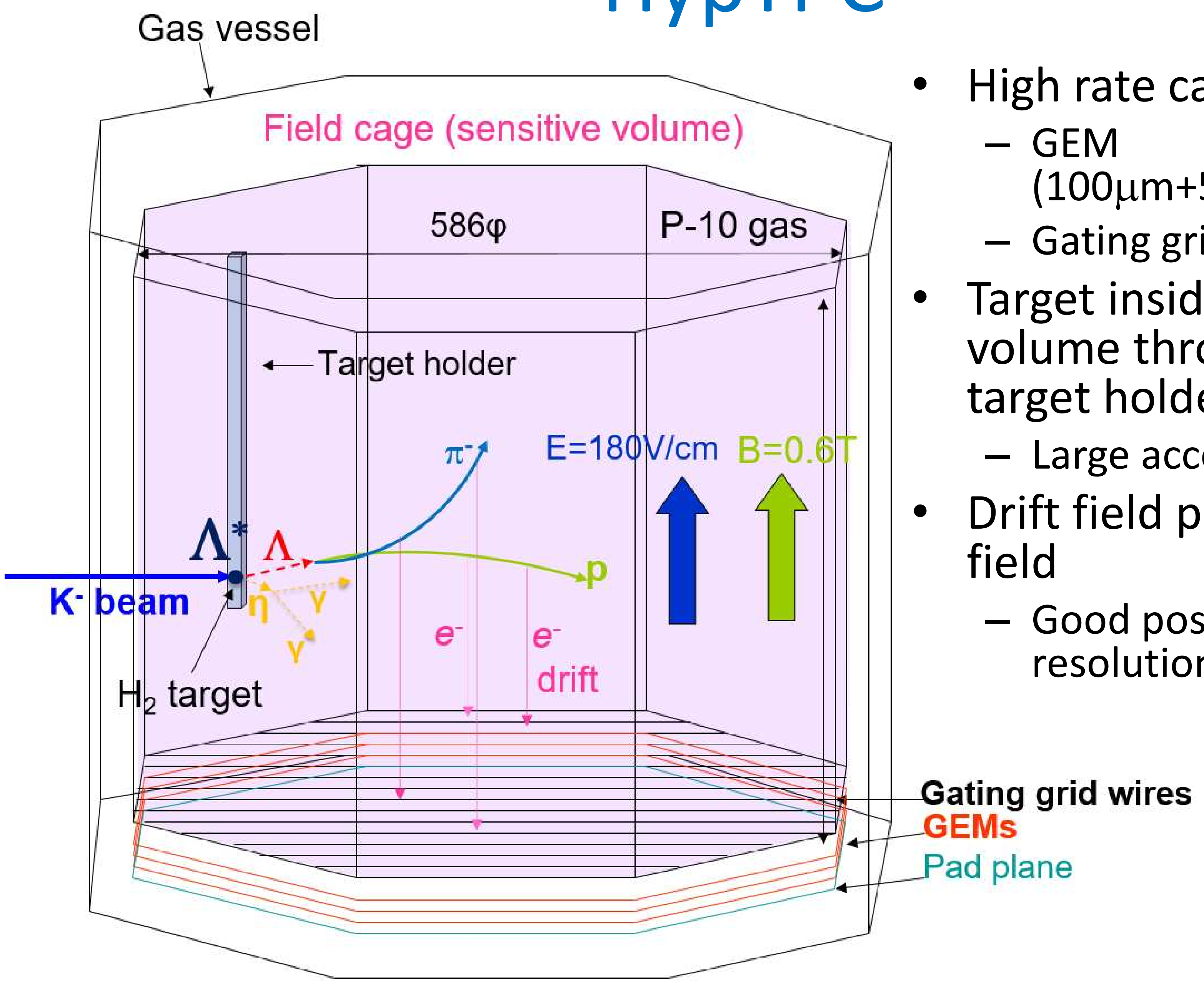


The Superconducting magnet

- Helmholz type, design maximum field : 1.5 T
- Conduction cooling with 2 GM cryocoolers
- Coil diameter : 1.0m
- Field uniformity : Br/By<1% in the TPC volume to achieve the good momentum resolution



HypTPC

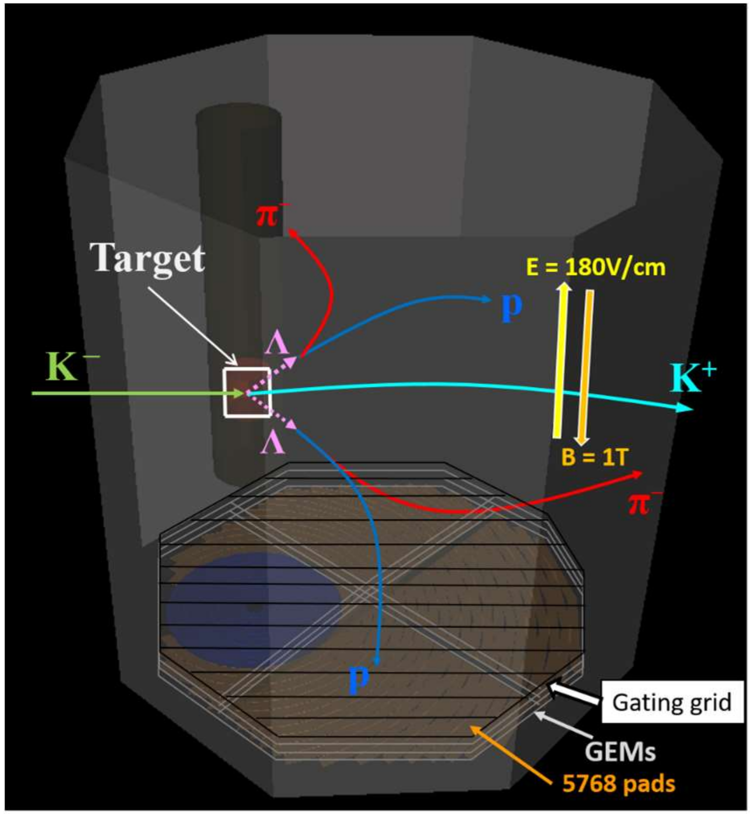


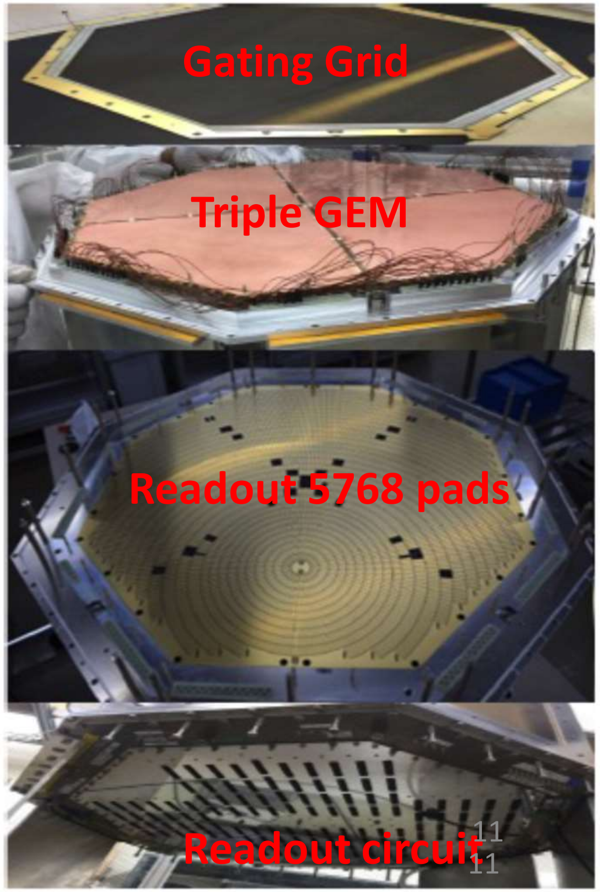
- High rate capability
  - GEM (100μm+50μm+50μm)
  - Gating grid
- Target inside the drift volume through the target holder
  - Large acceptance
- Drift field parallel to B-field
  - Good position resolution

More on HypTPC

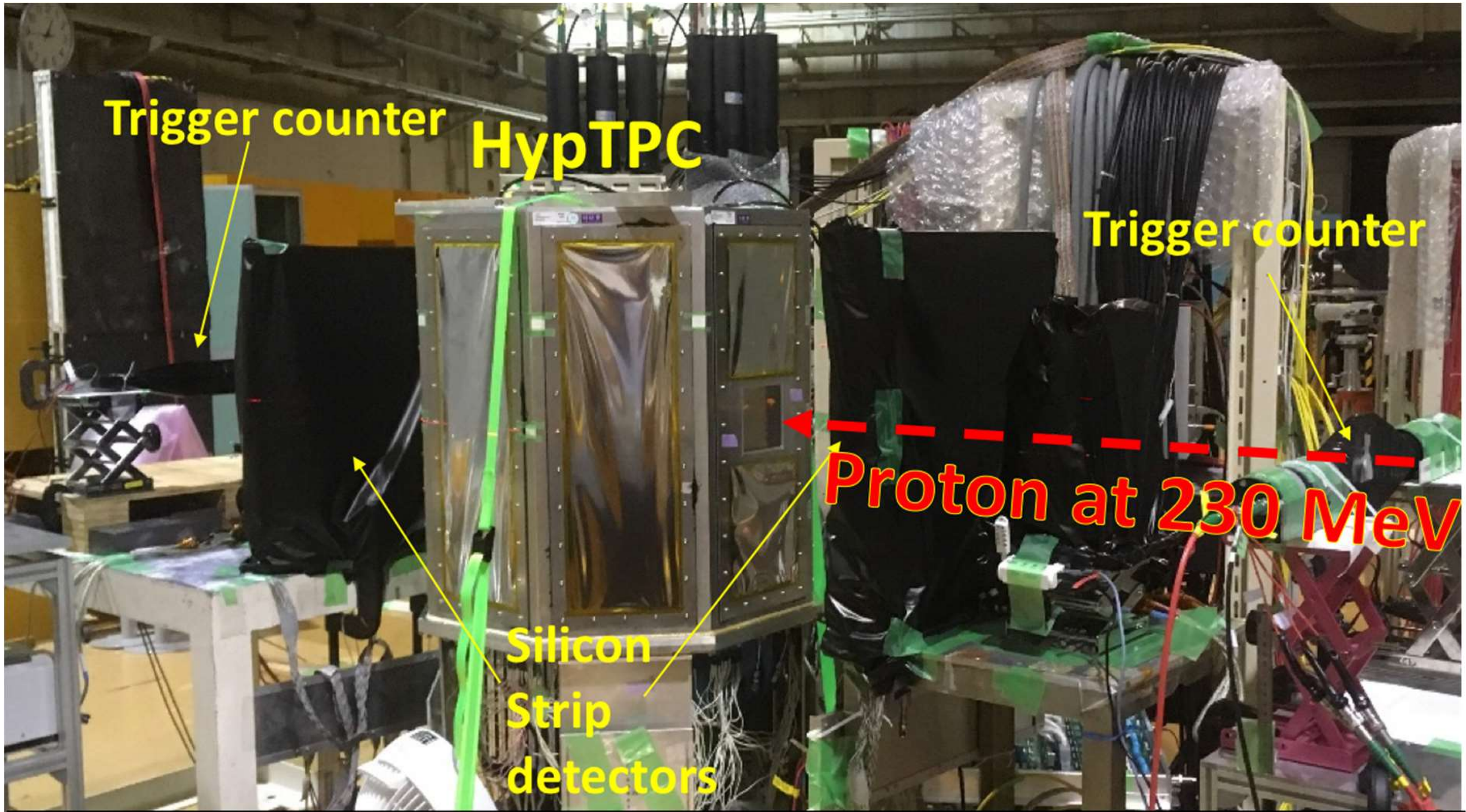
- ○ Octagonal prism field cage
- ○ 5768 readout pads
  - Inner(10 rows): 2.1-2.7 × 9 mm^2
  - Outer(22 rows): 2.3-2.4 × 12.5 mm^2
- ○ Gating grid: ϕ50 μm, 1mm space

- ○ Gas: P-10 (v_{max} ~ 5.3 cm /s)
- ○ Gain ~ 10^4
- ○ Position resolution < 300 μm
- ○ Δp/p = 1-3% for π and p





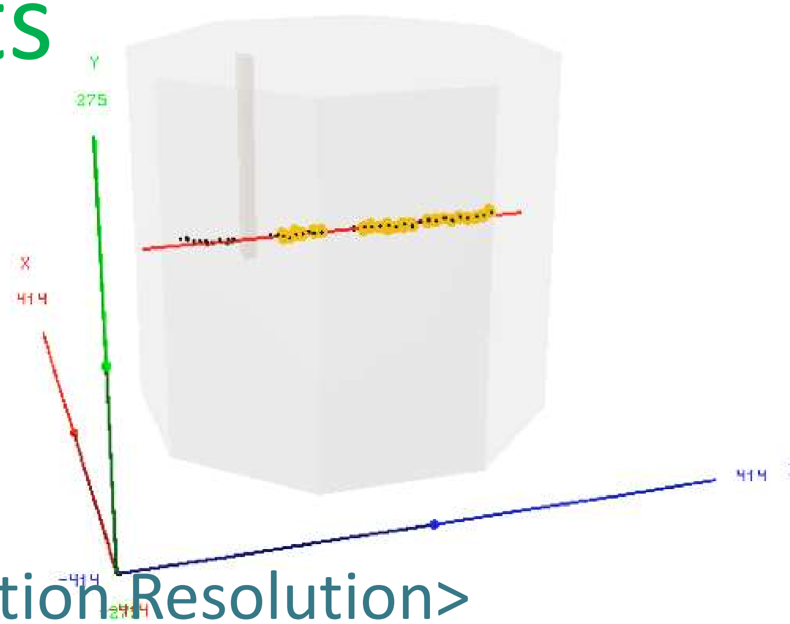
Test experiment at HIMAC



Test experiment at HIMAC (July 2018)

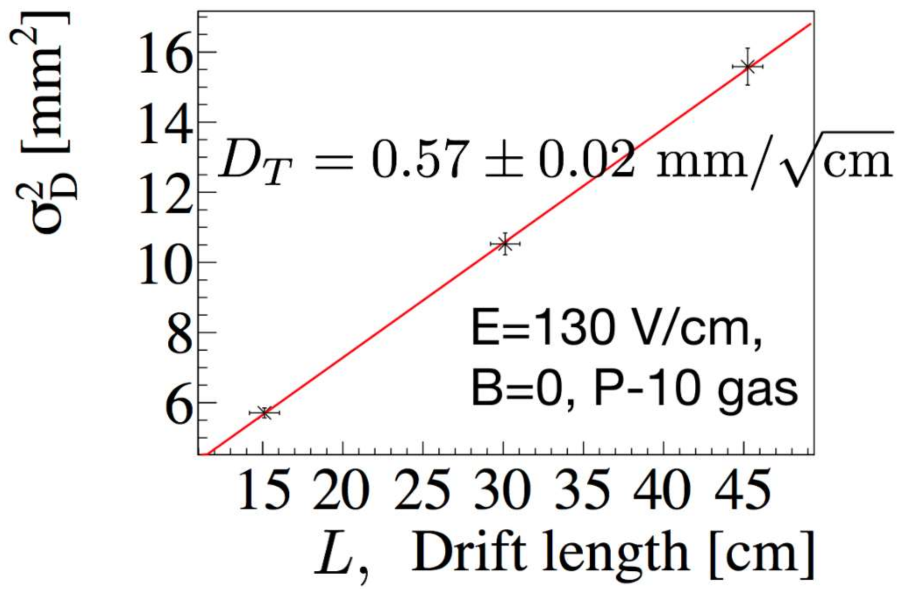
Test Results

Good resolution
obtained w/o magnetic field



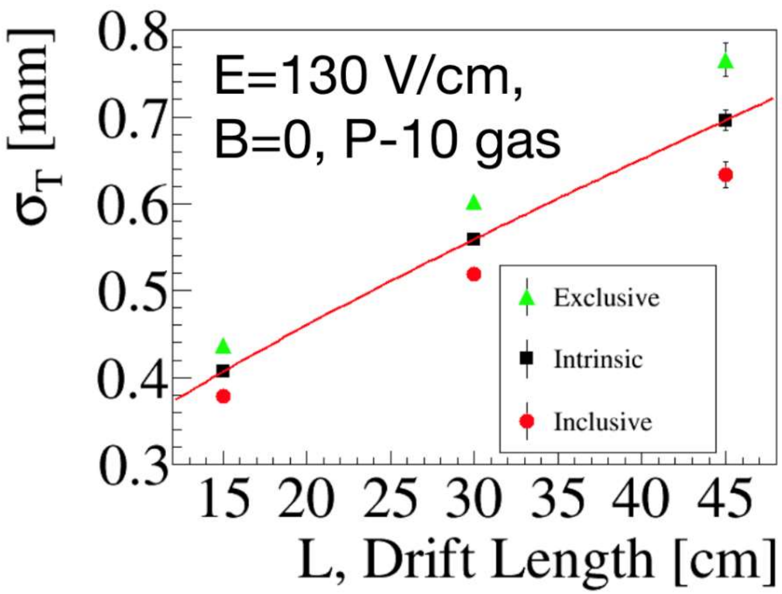
<Transverse Diffusion>

$$\sigma_T(L) = \sqrt{\sigma_0^2 + D_T^2 L}$$

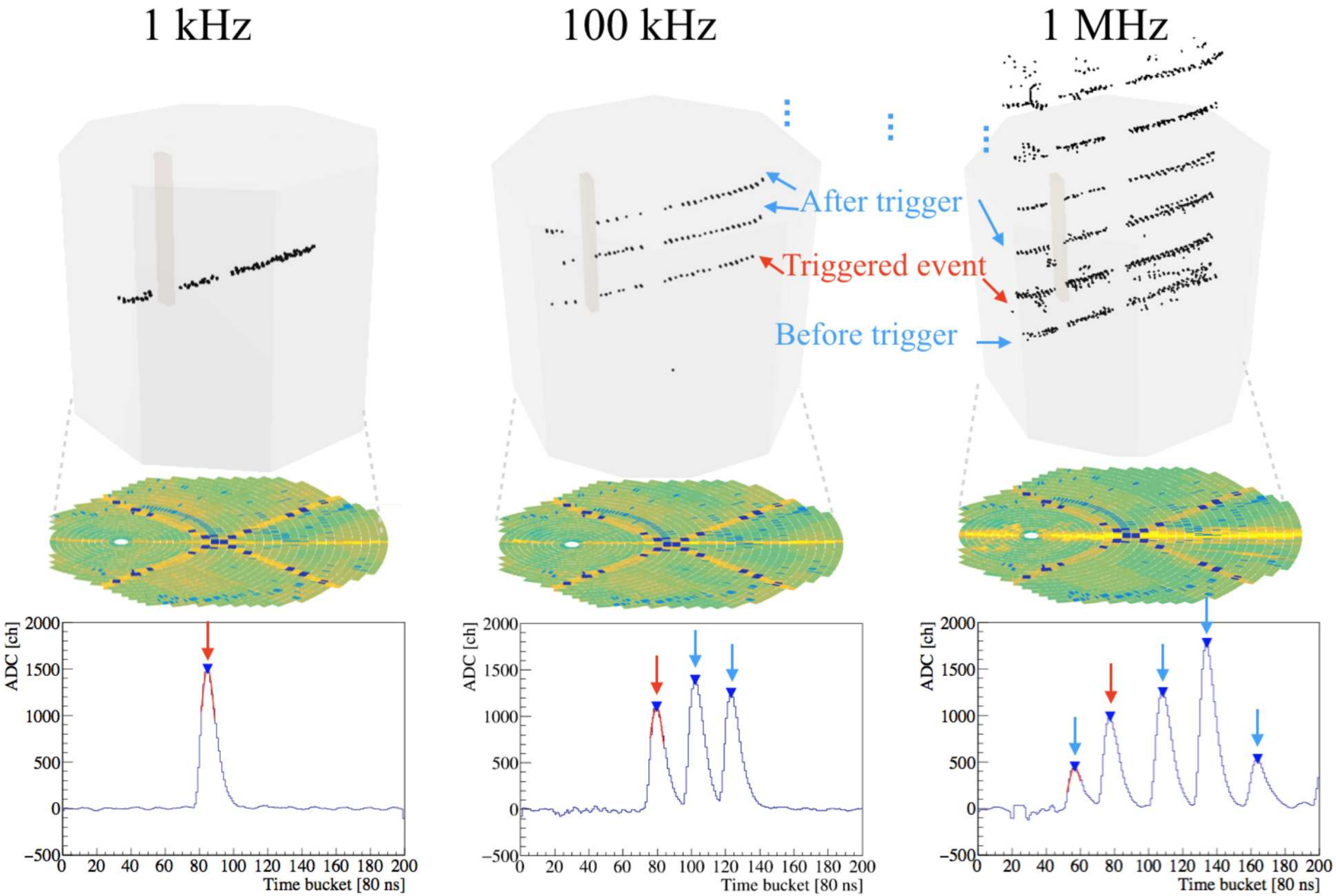


<Position Resolution>

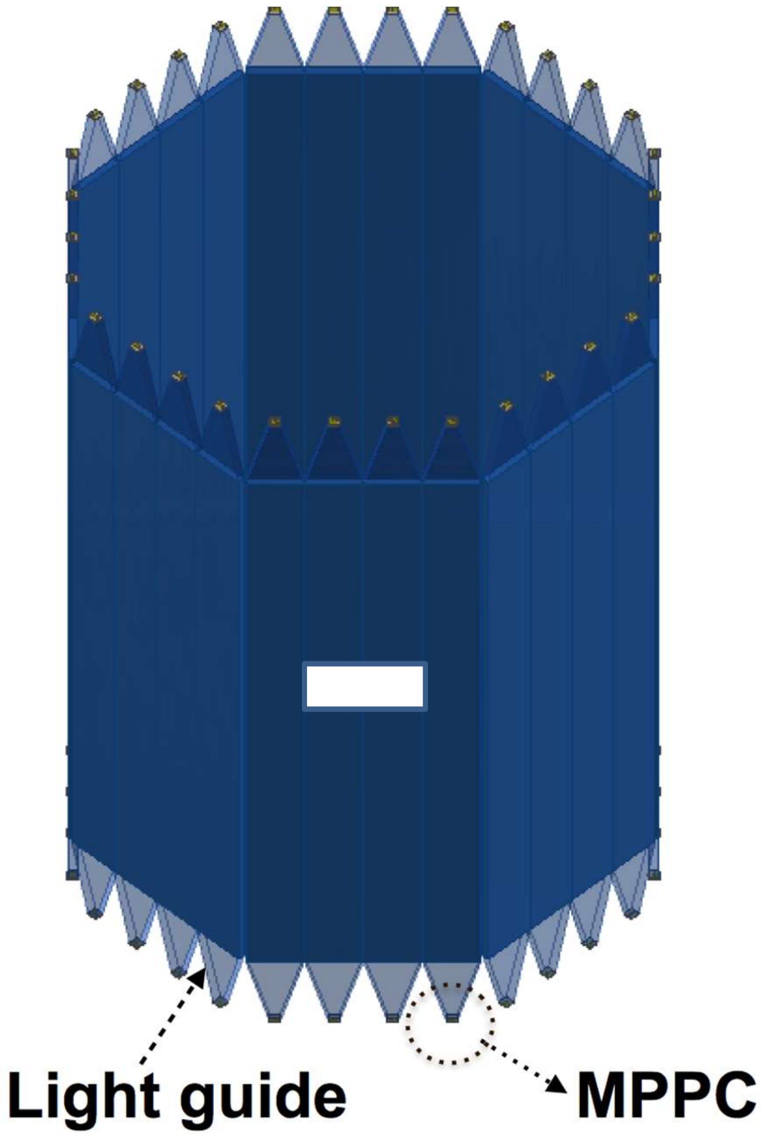
Expected to have 200-250 μm resolution under the B field of 1 T



High rate capability



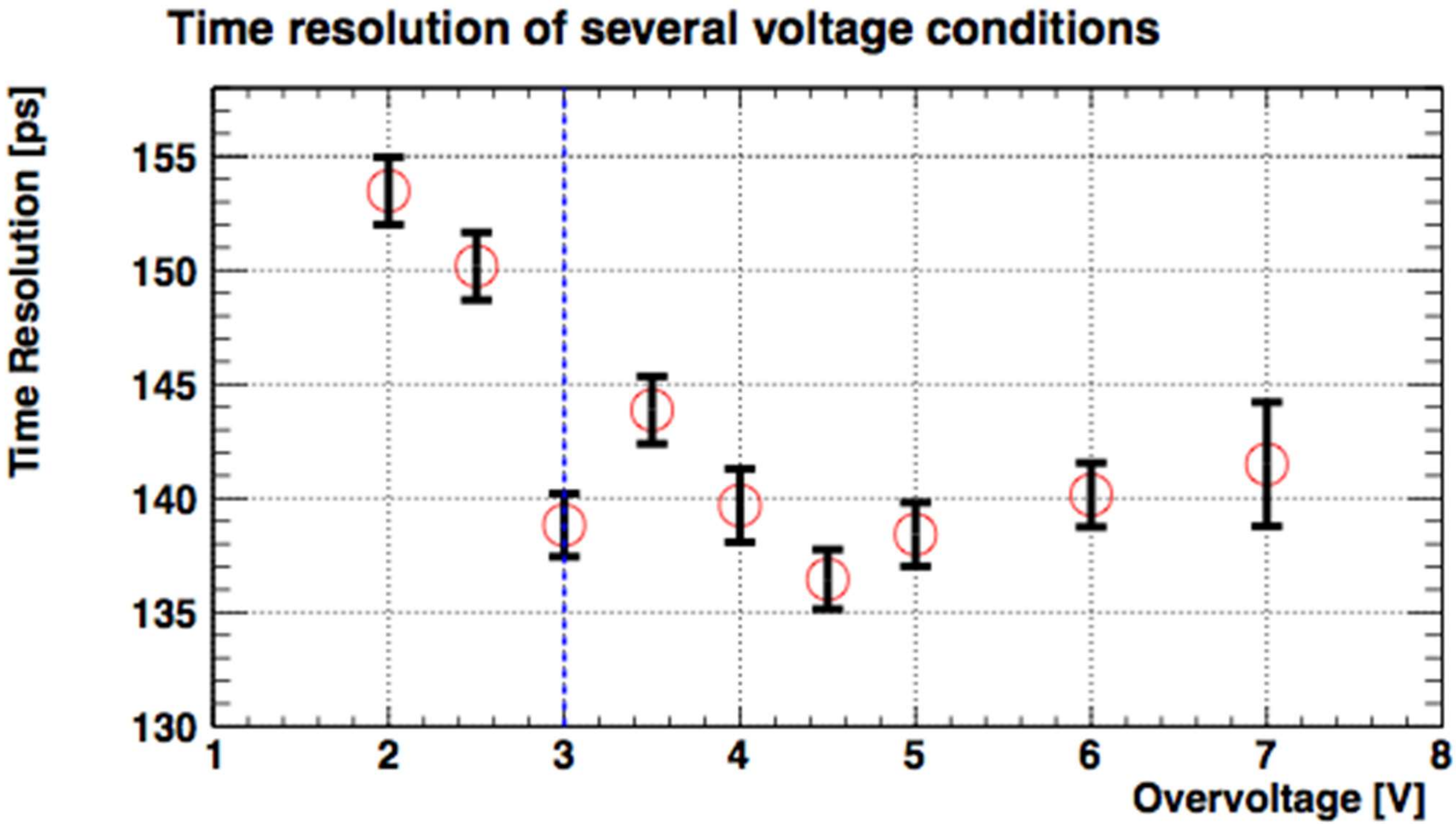
TPC Hodoscope



- Used for trigger/TOF
- 32 segments of plastic scintillator array surrounding HypTPC.
- Plastic scintillator of 80cm x 7cm x 1cm
- MPPCs on both ends
  - PMTs not used due to the strong magnetic field.

TOF resolution

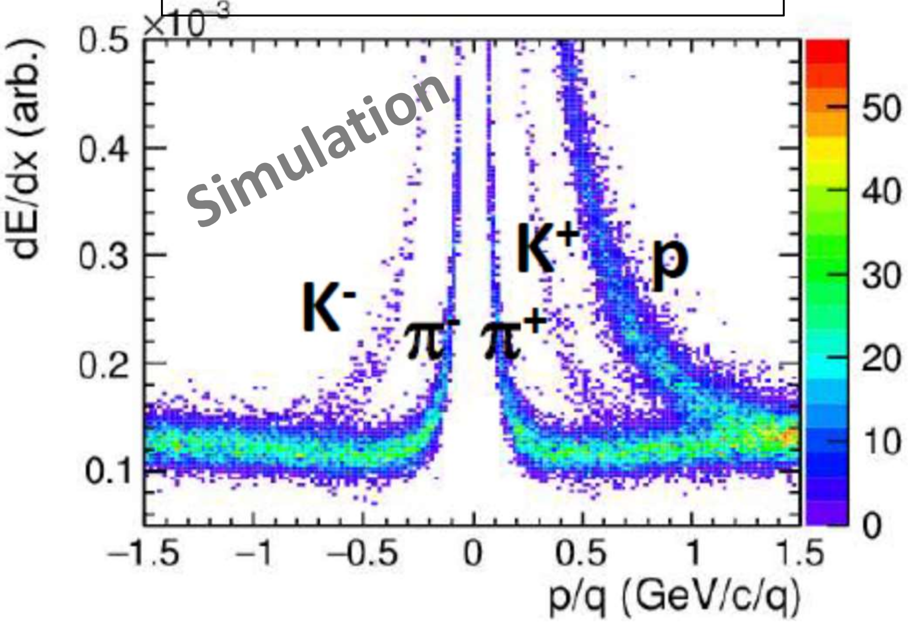
- Achieved ~140 ps resolution with a real size bar.



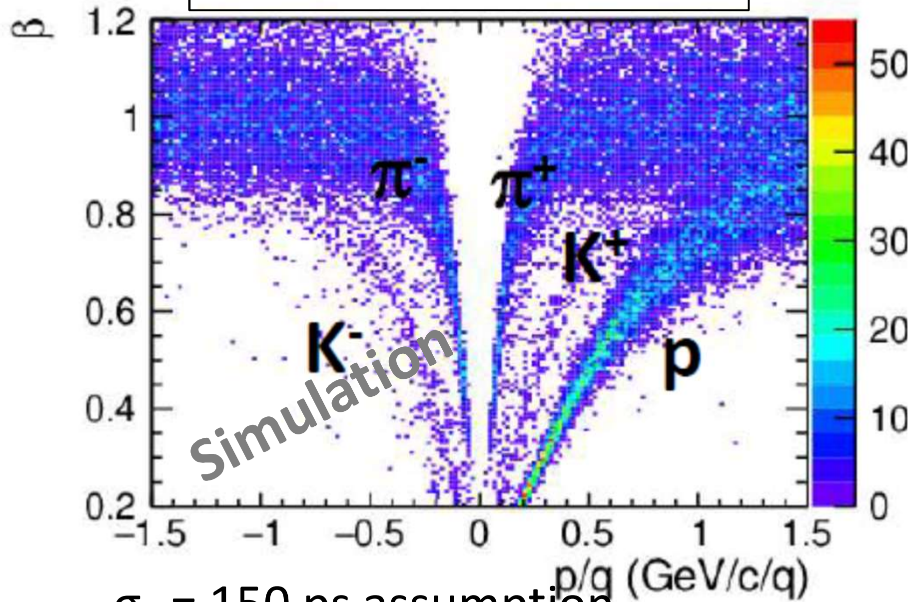
PID capability

- By dE/dx in TPC & TOF with the Hodoscope
  - π-p separation up to 0.9 GeV/c
  - K-π separation up to 0.5 GeV/c

PID: dE/dx(TPC) vs p/q



PID: TOF(β) vs p/q



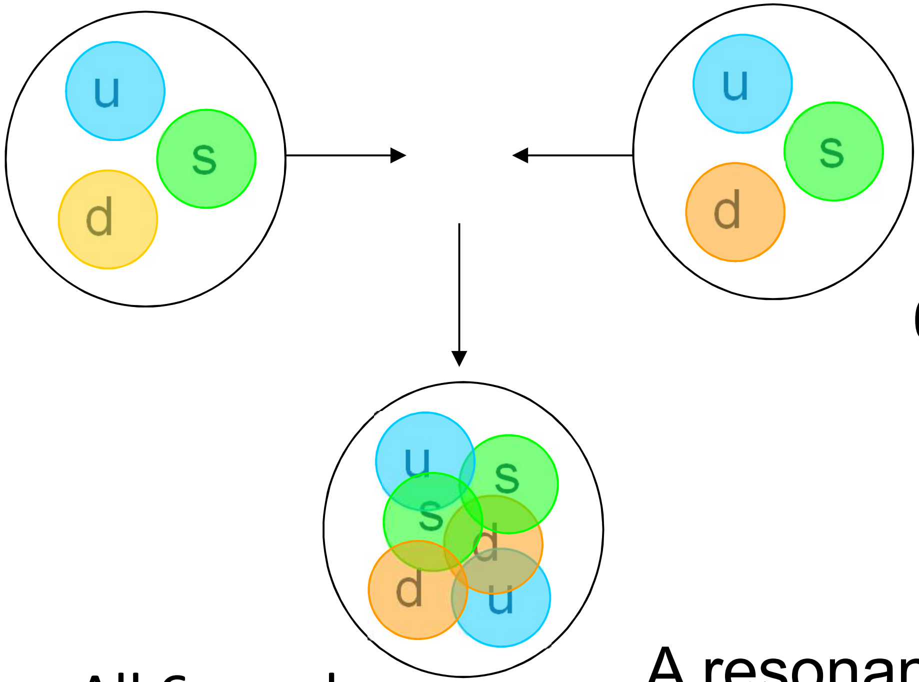
σ_T = 150 ps assumption

Part III.
Planned experiments using HypTPC

J-PARC E42 experiment ~Search for H dibaryon~

H dibaryon

Flavor-singlet (00) state (strangeness -2, isospin 0, or $^1S_0$ state in $\Lambda\Lambda - \Xi N - \Sigma\Sigma$ system)



All 6 quarks in s-state

Color-magnetic force is not repulsive, but attractive

6 quark state may exist

→ H dibaryon

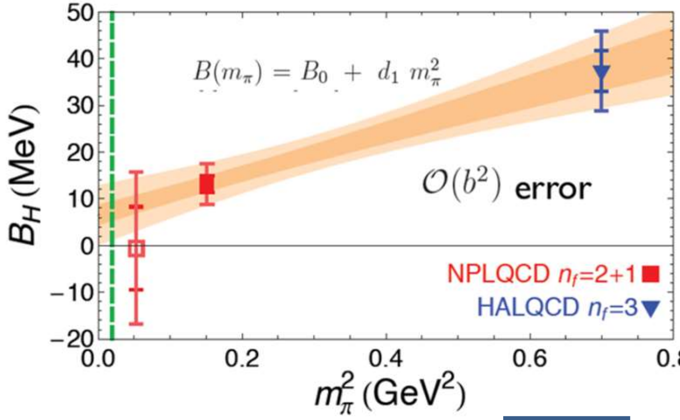
but not found so far

A resonant state just above $\Lambda\Lambda$ threshold?

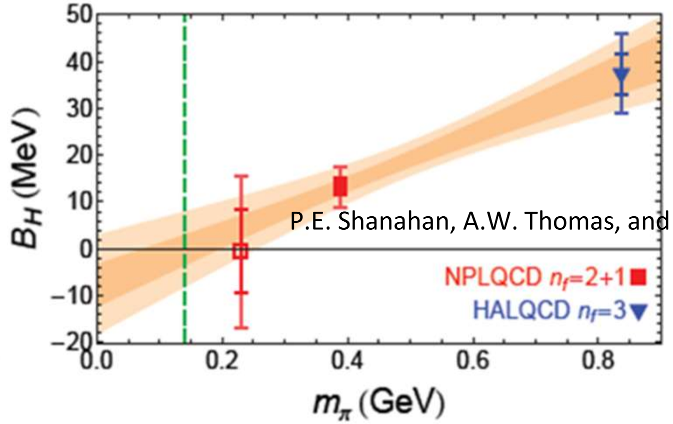
⇒ Still an open and important question

Lattice QCD calculation for H dinaryon

Physical π mass



Physical π mass

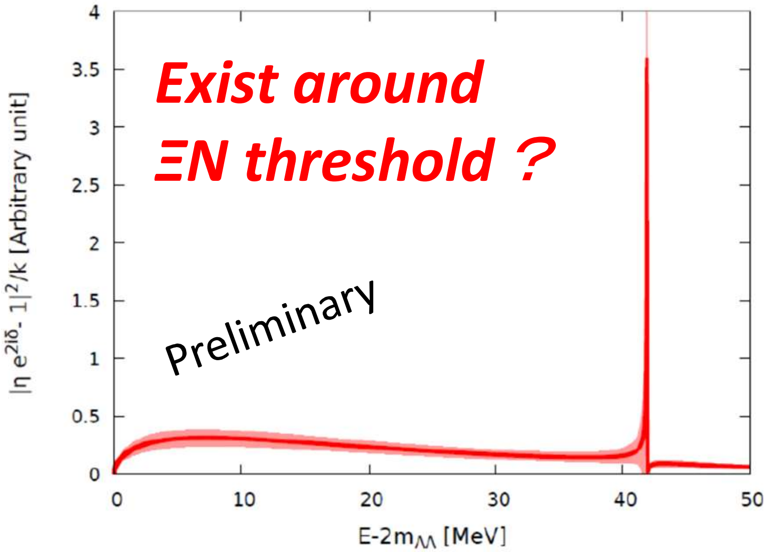


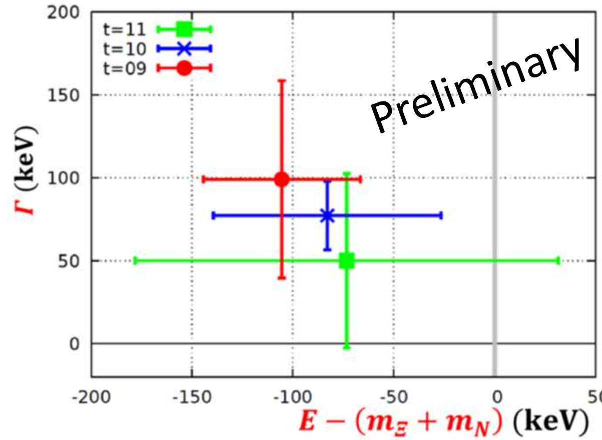
P.E. Shanahan, A.W. Thomas, and R.D. Young, PRL 107 (2011).

Calculation at almost physics point

K. Sasaki for the HAL Collab., Reimei 2016, Inha (2016).

	Mass [MeV]
π	146
K	525
m_π/m_K	0.28
N	956±12
Λ	1121±4
Σ	1201±3
Ξ	1328±3





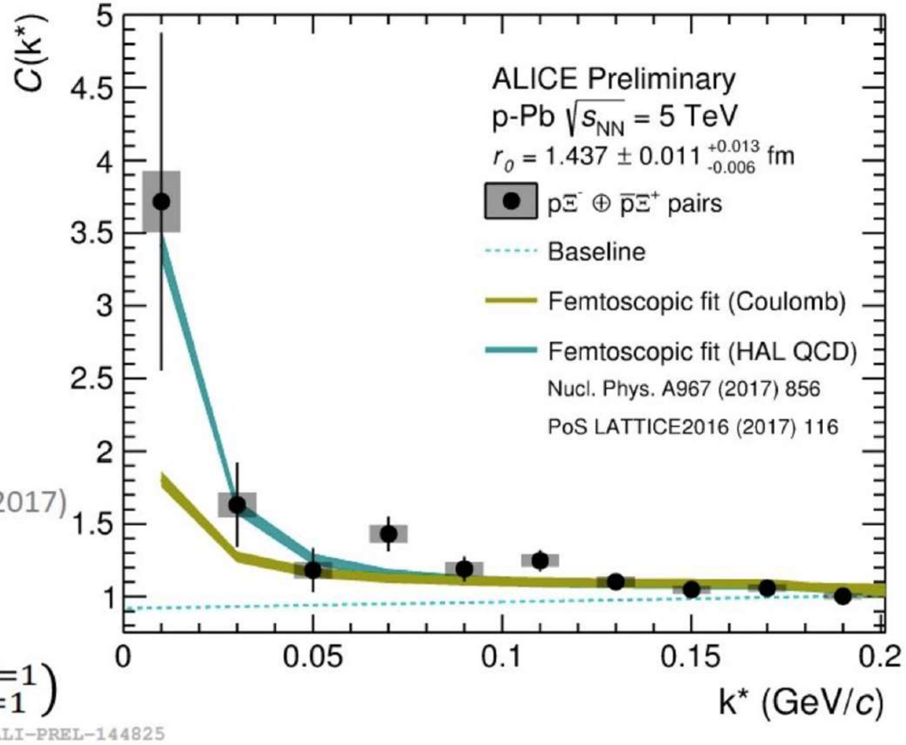
Lattice QCD vs ALICE data

p-Ξ⁻ Correlation Function in p-Pb 5.02 TeV

- **First observation of strong attractive interaction in p-Ξ⁻**
  - p-Value with and without strong potential (Coulomb only): 0.055 vs. 0.004
- modeled with preliminary QCD strong potential by the HAL QCD collaboration

(Hatsuda et al., NPA967 (2017) 856, PoS Lattice2016 (2017) 116)

$$C(k^*) = \frac{1}{8}\left(C_{I=0}^{S=0} + C_{I=1}^{S=0}\right) + \frac{3}{8}\left(C_{I=0}^{S=1} + C_{I=1}^{S=1}\right)$$

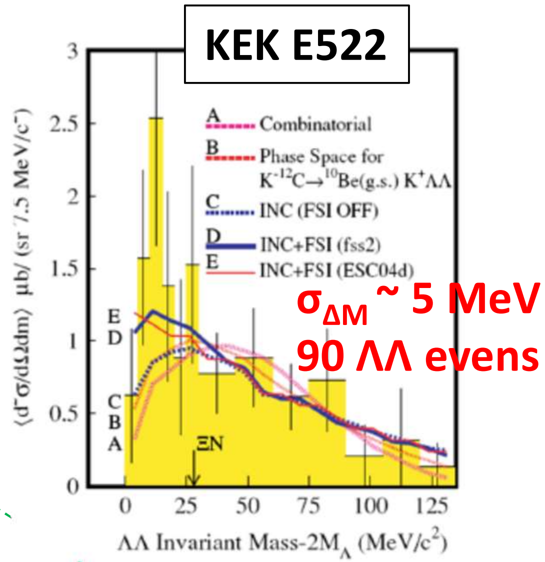


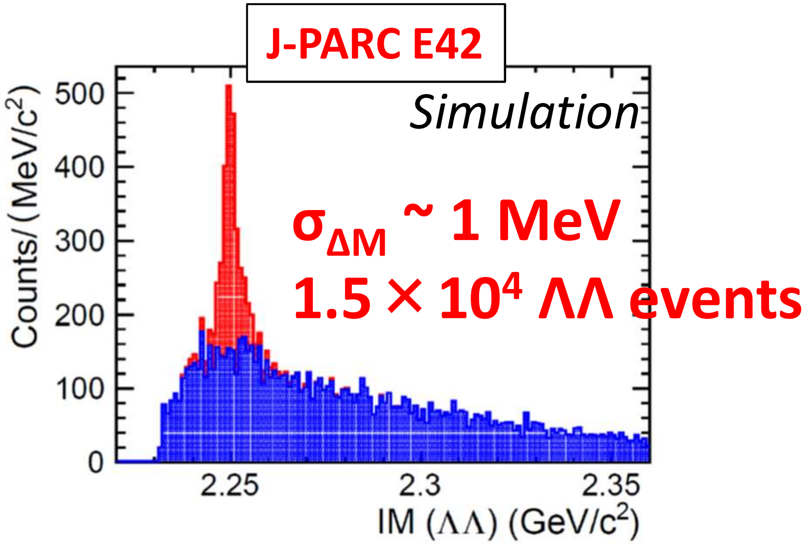
Valentina Mantovani Sarti (TUM Physics Department – E62) 10

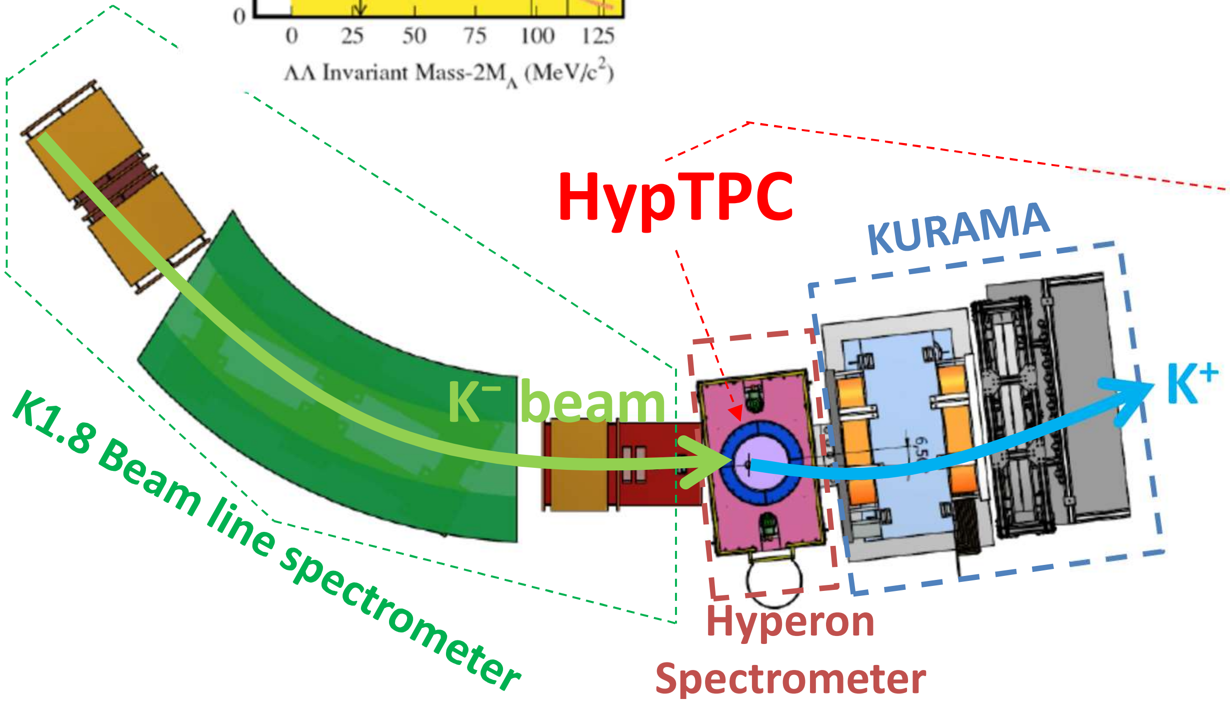
Talk by Valentina Mantovani Sarti (TUM) at MESON2018 (June 8, 2018)

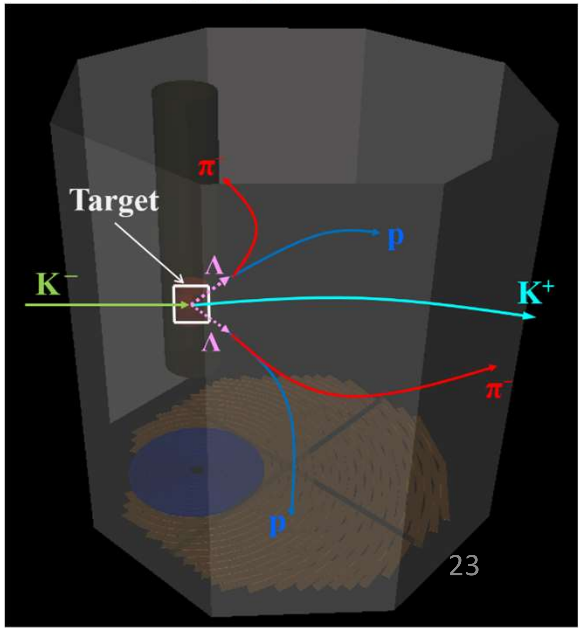
J-PARC E42 experiment

H-dibaryon search by using (K^-, K^+) reaction with diamond target.







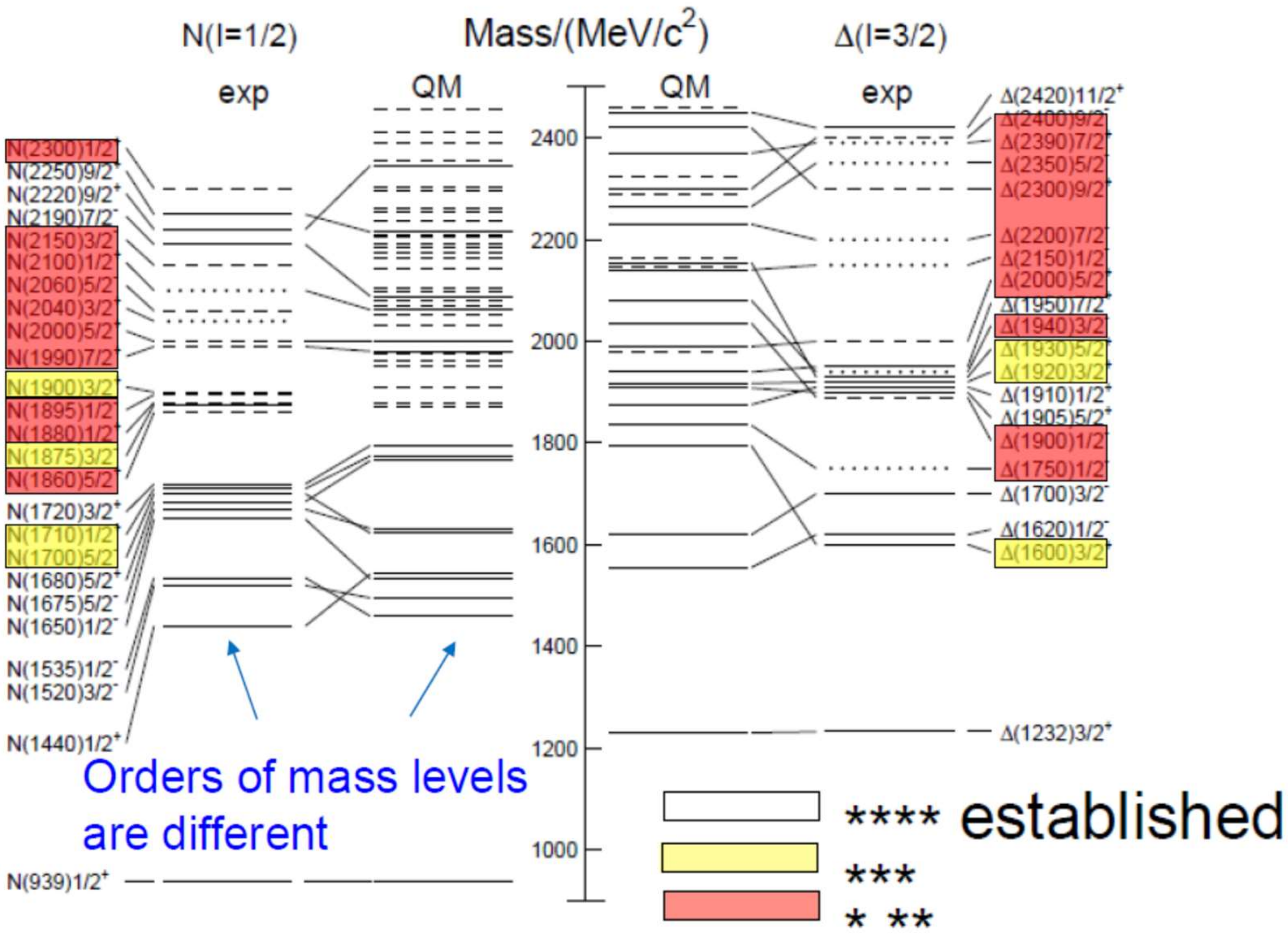


J-PARC E45 experiment

~Baryon spectroscopy by using p(π, 2π) reaction~

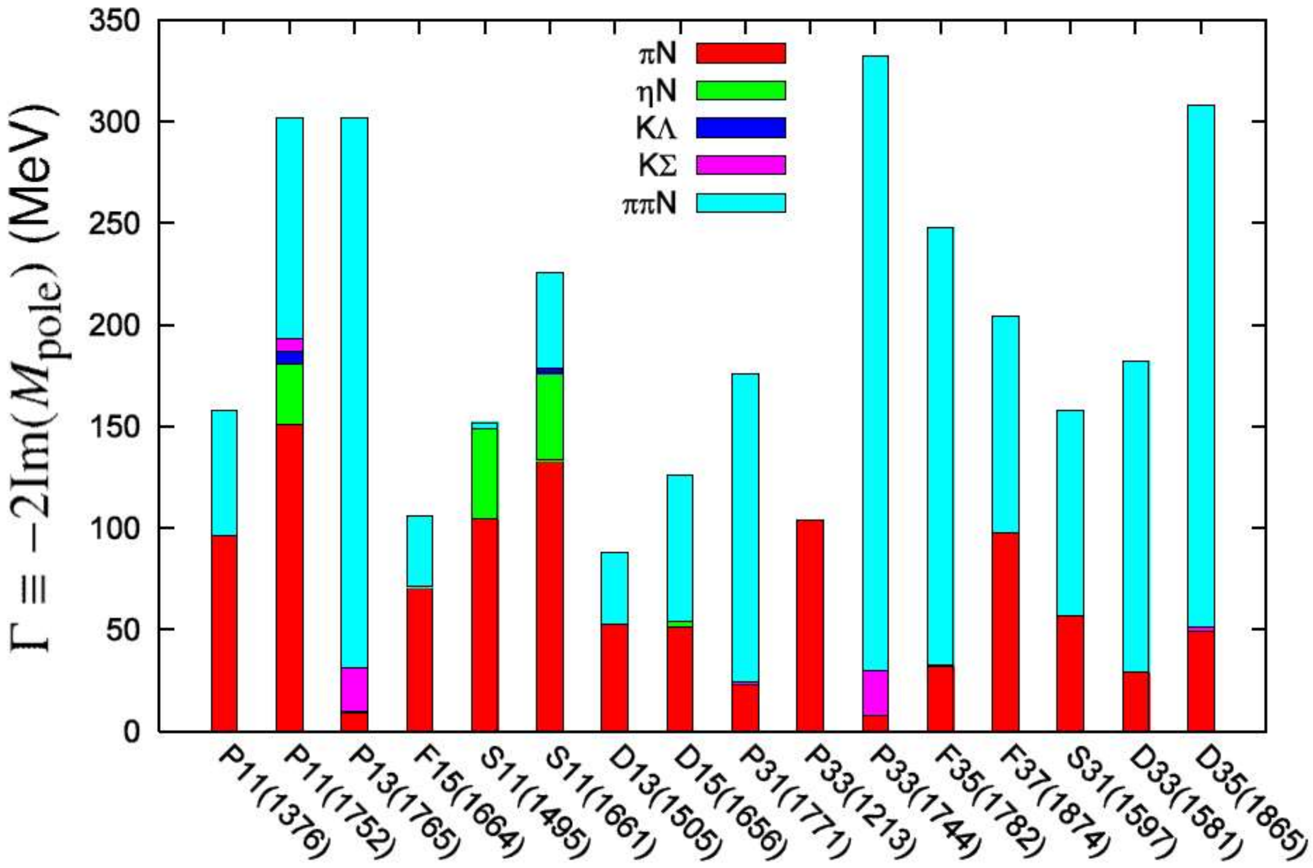
Missing resonances

- A lot of states are predicted by QM, but not observed
- Measured by using mainly πN → πN, γN → πN reactions



Importance of $\pi\pi$N (Width of N^* resonances)

Over half of the decay branchig fraction goes into 2π channel.



Kamano, Nakamura, Lee, Sato, 2012

E45 setup

Measure $(\pi,2\pi)$ in large acceptance TPC in dipole magnetic field

$\pi^- p \rightarrow \pi^+ \pi^- n,\ \pi^0 \pi^- p$ 2 charged particles + 1 neutral particle

$\pi^+ p \rightarrow \pi^0 \pi^+ p,\ \pi^+ \pi^+ n$ →*missing mass technique*

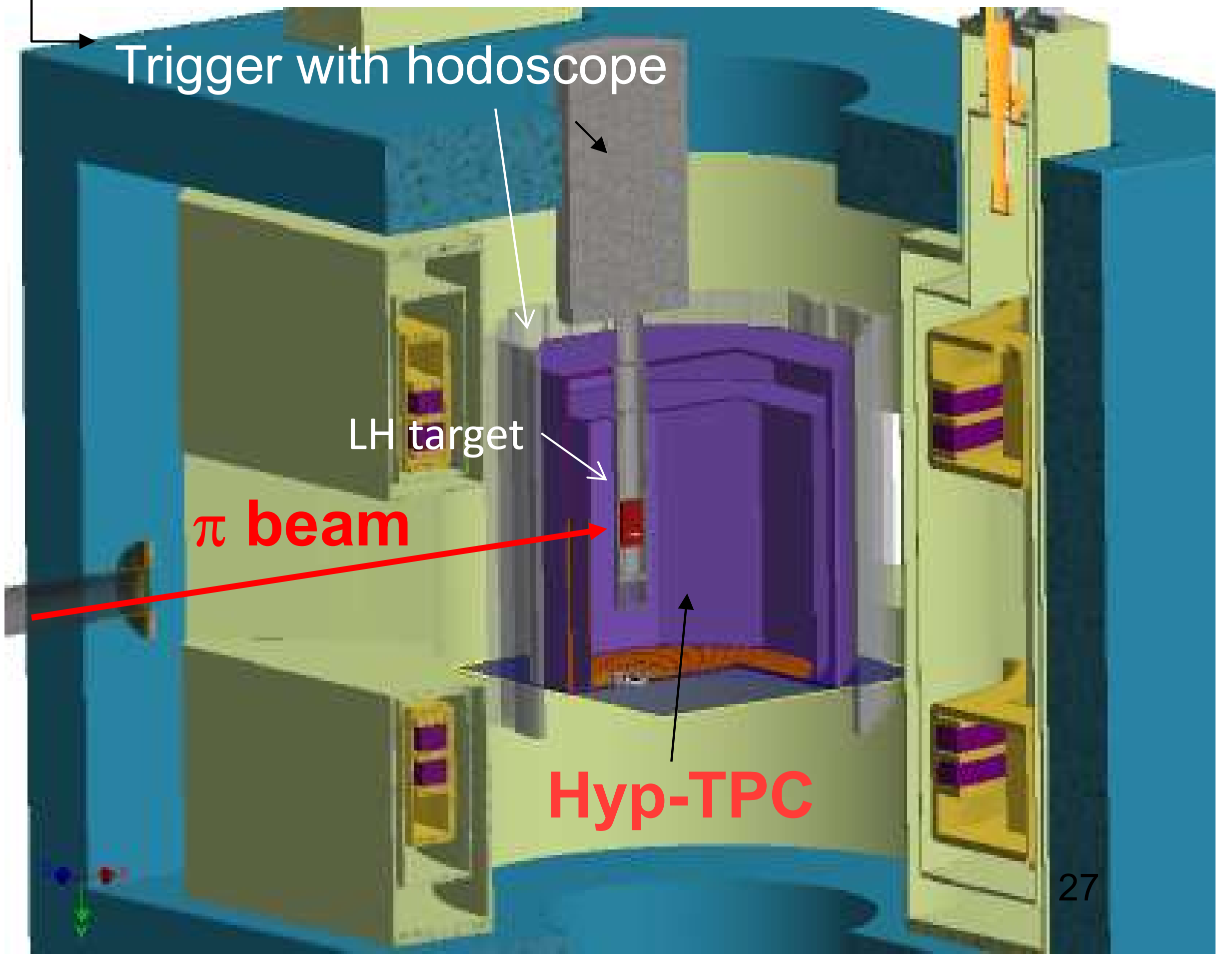
$\pi N \rightarrow KY$ *(2-body reaction)*

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

$\pi^+ p \rightarrow K^+ \Sigma^+$ *(I=3/2, Δ*)*

π^{+-} beam on liquid-H target
(p= 0.73 – 2.0 GeV/c
W=1.5-2.15 GeV)

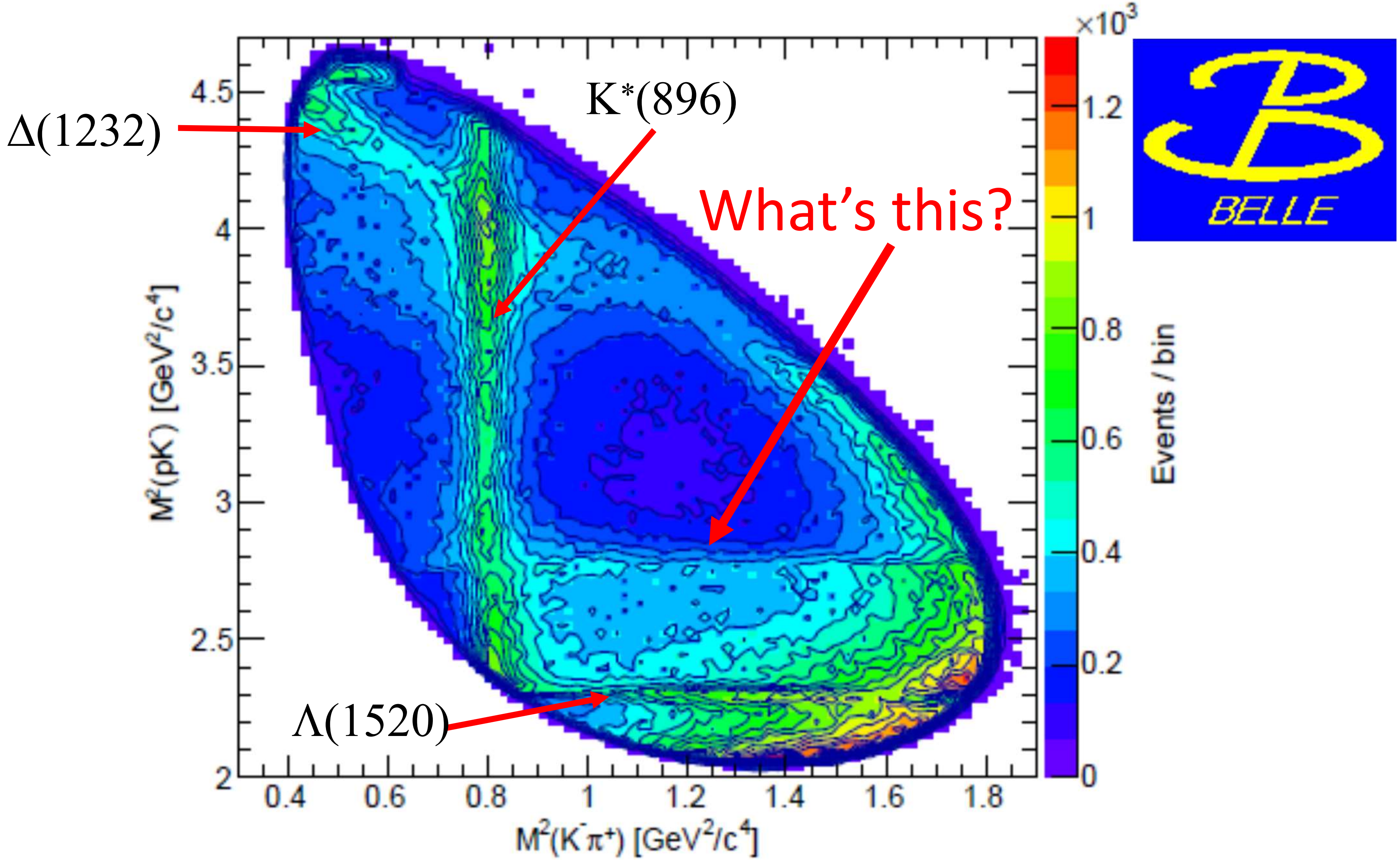
x100 more statistics than ever



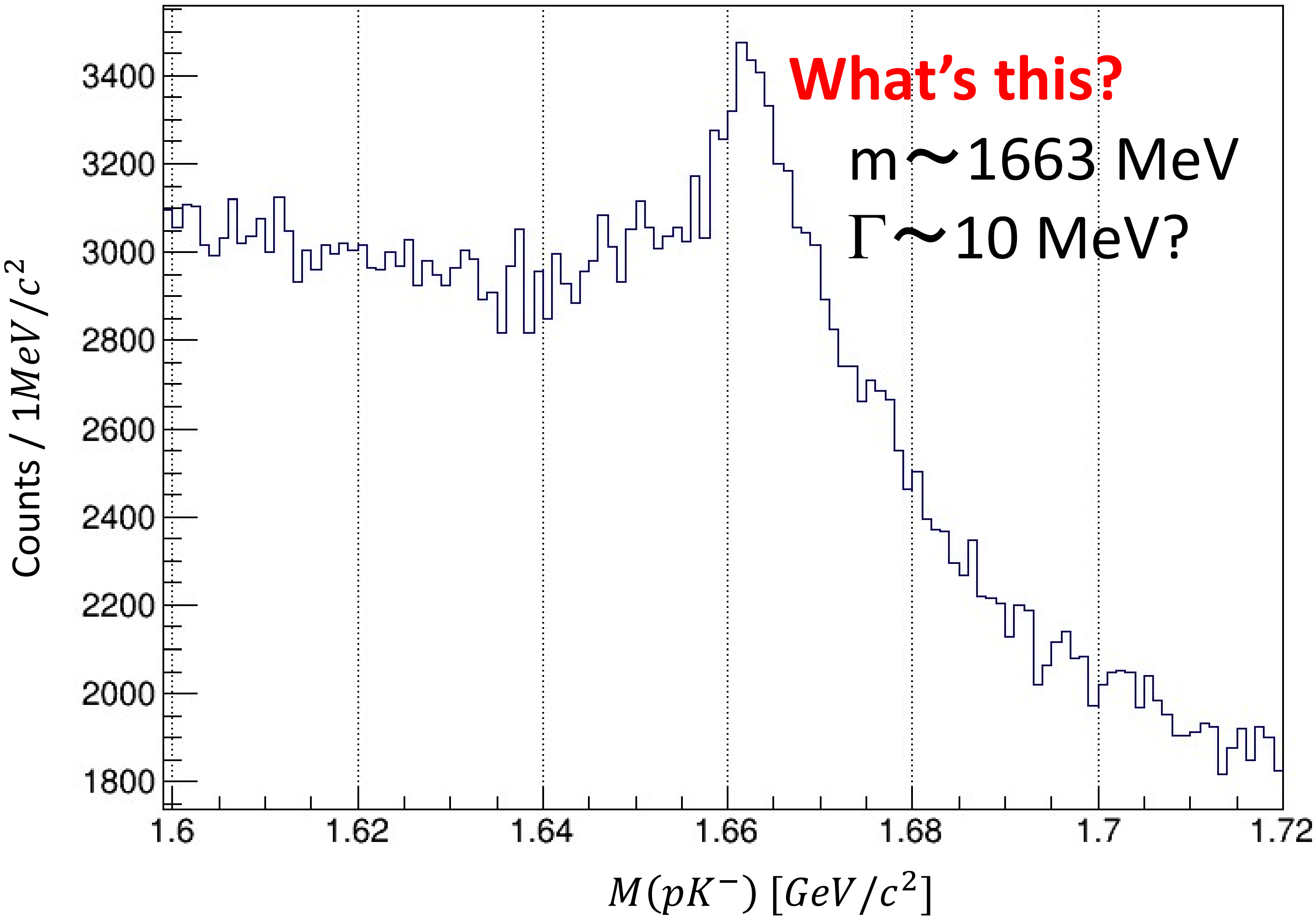
J-PARC E72 experiment

*~Search for new Λ**
by using $K^-p \rightarrow \Lambda\eta$ reaction~

Dalitz plot: $\Lambda_c^+ \to pK^-\pi^+$ [PRL117.011801]



■ **1D projection --** $M(pK^-)$



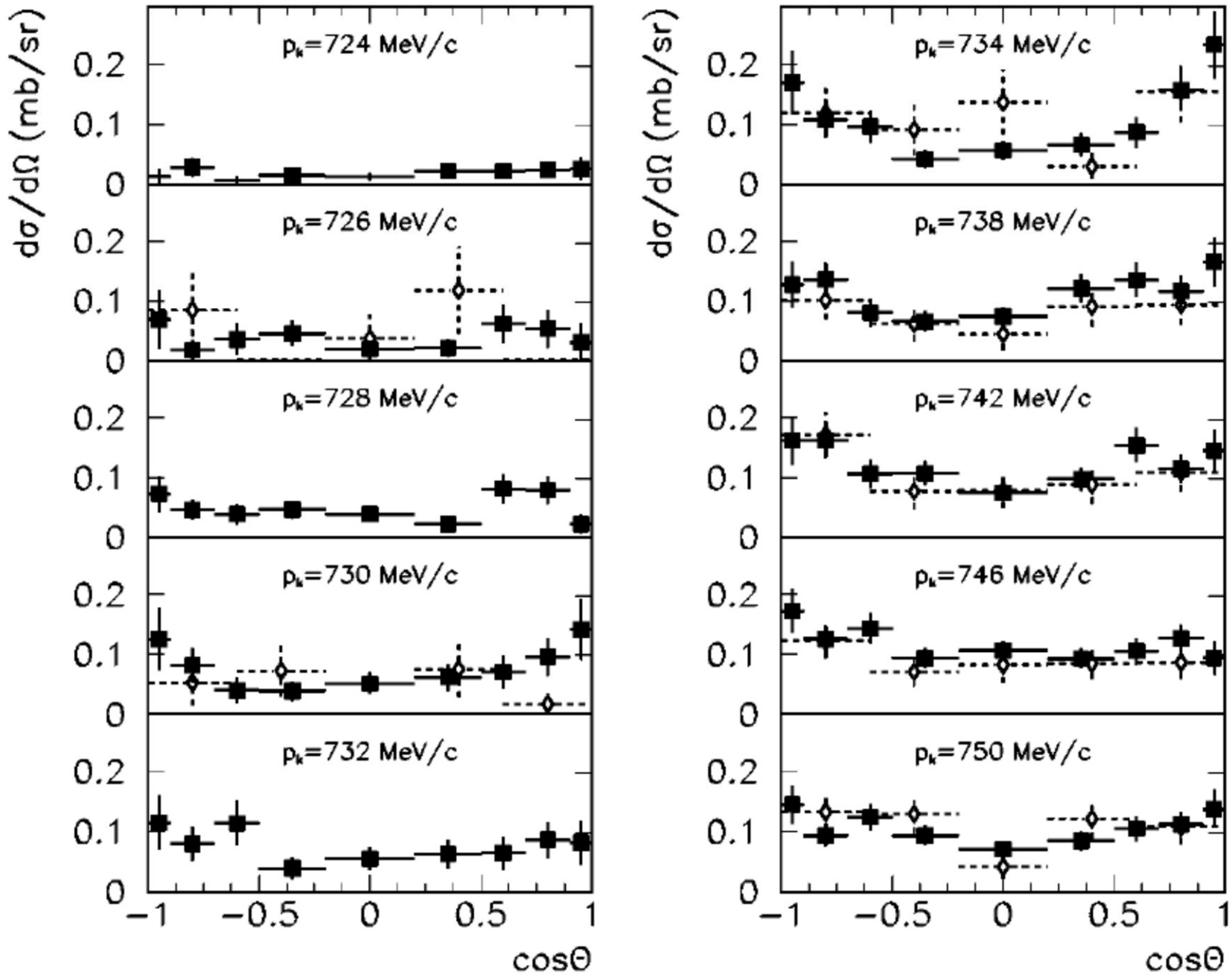
What's this?

- The peak position is ~1663 MeV, near the $\Lambda\eta$ threshold (1663.5 MeV)
- Width is ~10 MeV, significantly narrower than Λ, Σ resonances in this region
  - Λ(1670): 25-50 MeV
  - Σ(1660): 40-200 MeV
  - Σ(1670): 40-80 MeV
  - Λ(1690): ~60 MeV
- No such narrow states are theoretically predicted in this region – exotic?

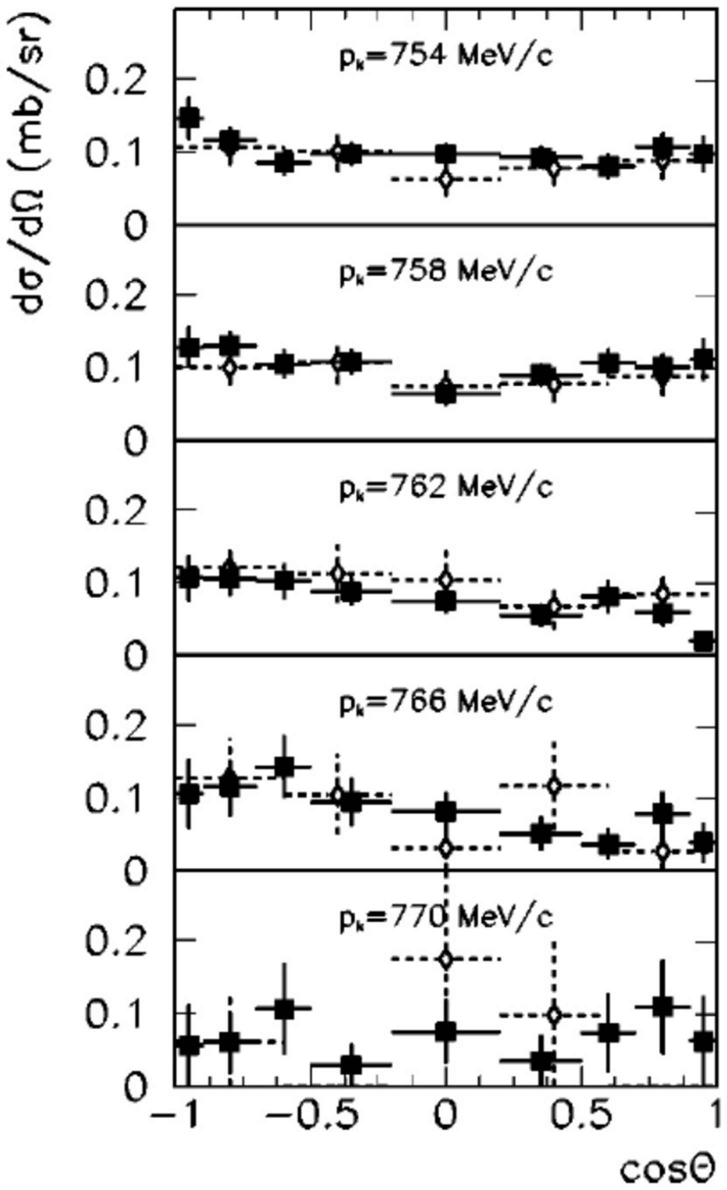
An idea

- 2 independent groups claim there is a new narrow Λ^* resonance at this energy with J=3/2
  - Kamano et al. [PRC90.065204, PRC92.025205]
    $J^P=3/2^+$ (P_{03}), M=1671+2-8 MeV, Γ=10+22-4 MeV
  - Liu & Xie [PRC85.038201, PRC86.055202]
    $J^P=3/2^-$ (D_{03}), M=1668.5±0.5 MeV, Γ=1.5±0.5 MeV
- The reason is the same
  - From $K^-p \rightarrow \Lambda\eta$ measurement near the threshold by Crystal Ball collaboration at BNL [PRC64.055205]
  - Model independent

Differential cross sections (1)



Differential cross sections (2)



- Flat near the threshold
  - Expected for J=1/2 (S-wave)
- Concave-up around p_K=734 MeV/c (√s=1669 MeV)
- Flat again for p_K > 750 MeV/c (√s=1677 MeV)

- Concave shape requires J=3/2 amplitude → reason for a narrow resonance; model independent

What can it be?

- The experimental data suggest the existence of a new Λ^* resonance with spin 3/2 (P_{03} or D_{03}), $\Lambda(1665)$:

  Q: What is the nature of $\Lambda(1665)$, if it really exists?

  A: We have few ideas at the moment, aside from that it must be exotic, and thus very interesting.

- It is near the $\Lambda\eta$ threshold, but threshold cusp is unlikely.
  – Visible cusp appears only in S wave
- A molecular state in P or D? Then, where is the S state?
  – Cf. X(3872) & $\Lambda(1405)$ are in S wave.

→ **It may be a new type of exotic state!**

  – Mixture of a molecular state and a 3-quark state???
  – $uds s\bar{s}$ pentaquark???

J-PARC E72

- Repeat the Kp → $\Lambda\eta$ experiment again with a large acceptance detector, i.e., TPC (HypTPC)
  - Confirm angular distribution & the new resonance
  - Determine parity by Λ polarization measurement
- Principle
  - K beam momentum: 720-770 MeV/c
  - Momentum resolution: 1 MeV/c or better
    → Can identify narrow resonance of Γ=1.5 MeV
  - Detect Λ → $p\pi^-$, identify η by missing mass

Summary

- We are developing a powerful multi-purpose time-projection-chamber, HypTPC.
  - Internal target – 4π acceptance
  - High-rate capability, good momentum resolution
  - Will open new possibilities of hadron physics at J-PARC.
- Three experiments are proposed to J-PARC
  - E42: Search for H-dibaryon by using (K^-, K^+) reaction
  - E45: Baryon spectroscopy by using $p(\pi, 2\pi)$ reaction
  - E72: Search for new Λ^* resonance via $p(K^-, \Lambda)\eta$
  - More are coming.