P45: 3-Body Reactions for New Aspects of Baryon Spectroscopy

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J-PARC PAC Meeting

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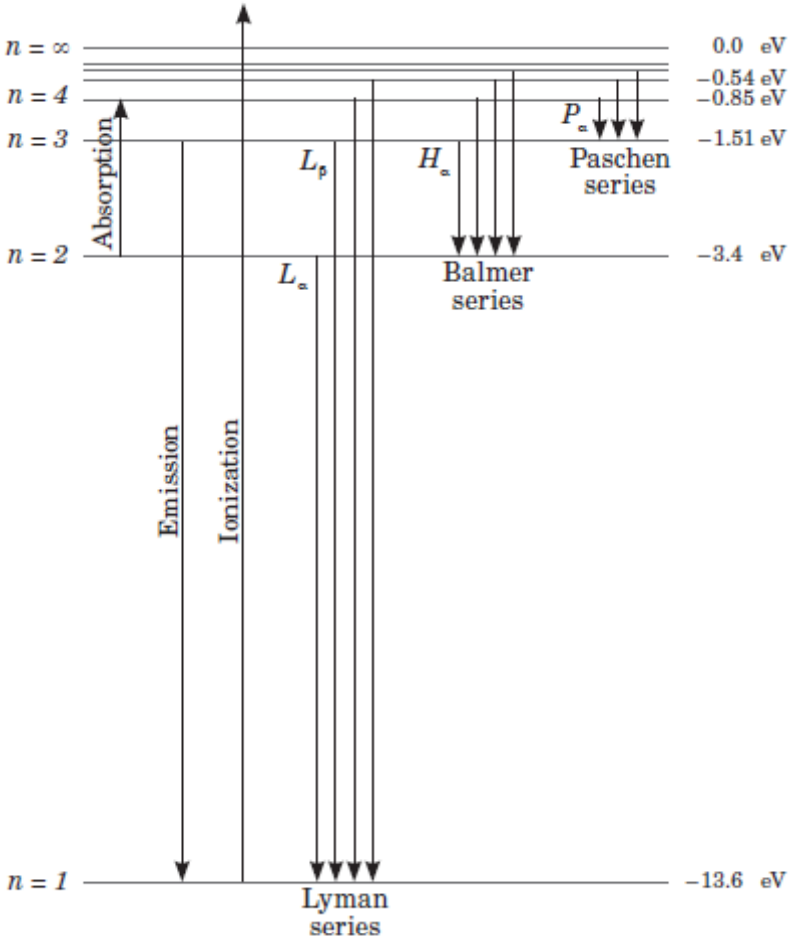
Physics Goals

- QCD is believed to be the fundamental theory of the strong force
  - At high energies, the force becomes weaker and perturbation theory can be used for calculations.
  - In the real world, energies are lower.
    - Perturbation theory fails
    - Phenomenological quark models are inadequate
    - Lattice gauge theory can now make predictions due to advances in computers and calculation techniques.

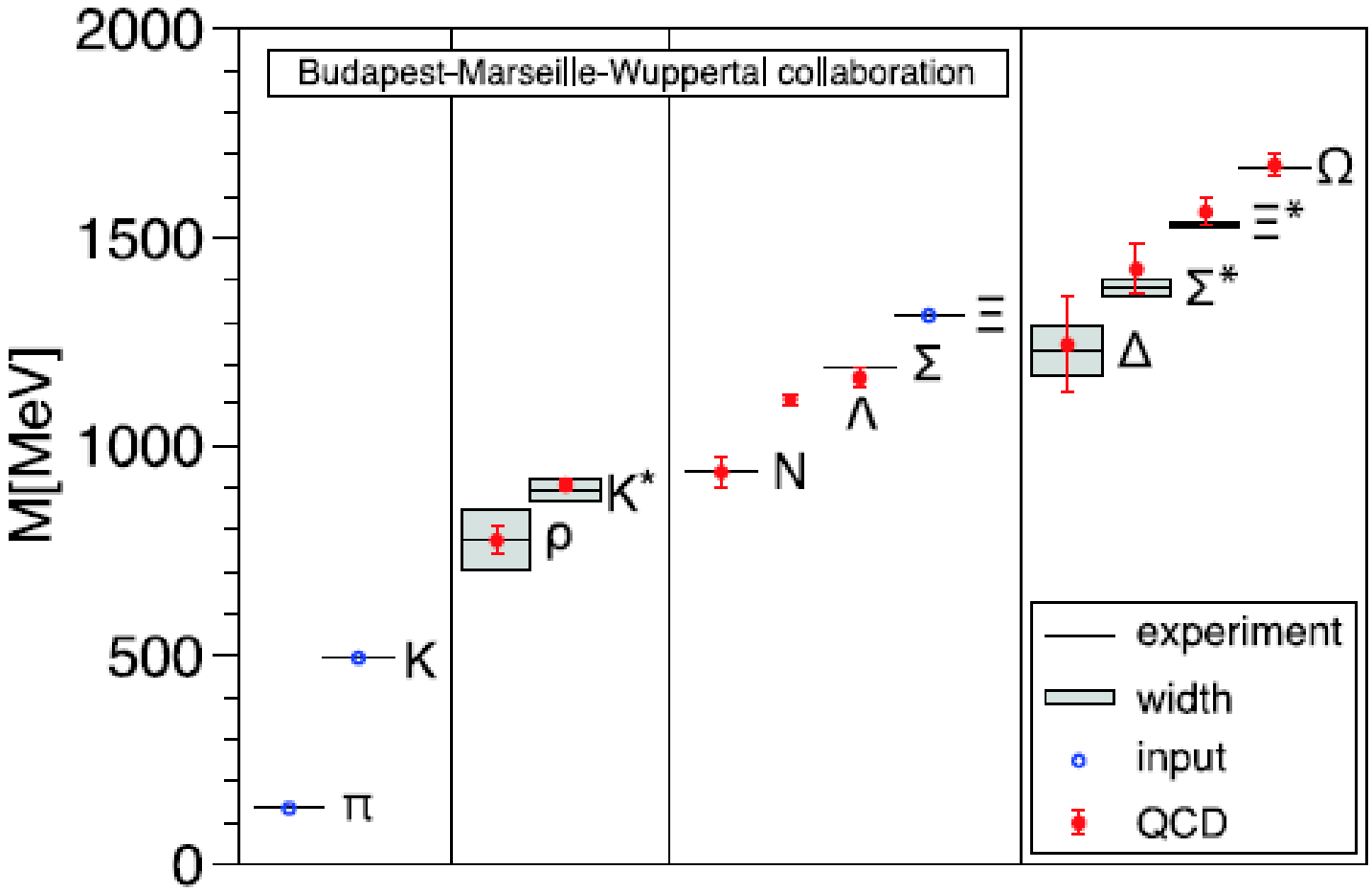
An Analogy



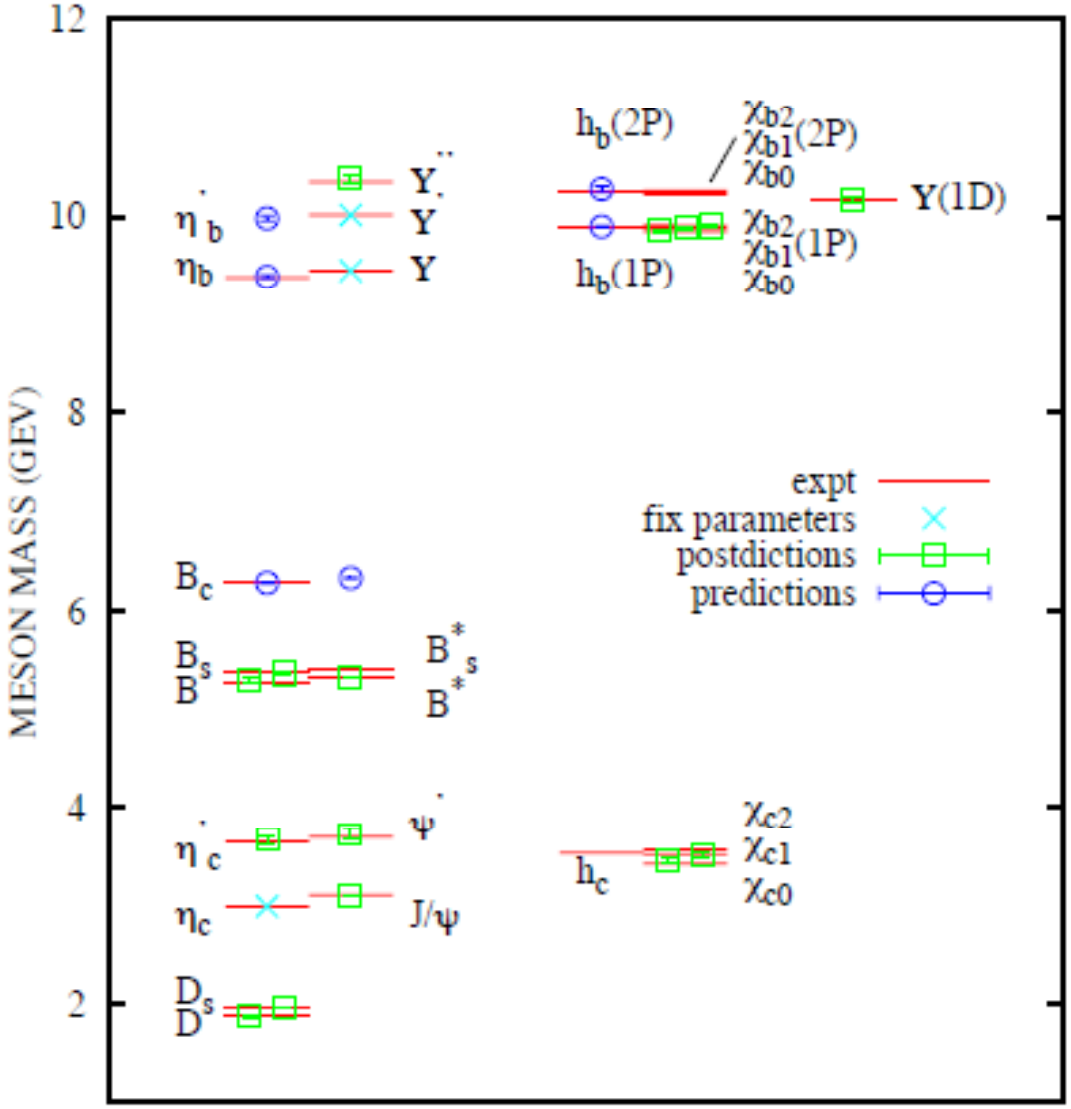
The spectrum of energy levels of the hydrogen atom provided insights into the structure of the atom from Bohr and later, with more precise data, to the theory of quantum mechanics.

Even today, the spectrum of hydrogen continues to give surprises (*e.g.* proton radius).

Lattice Gauge: Ground States

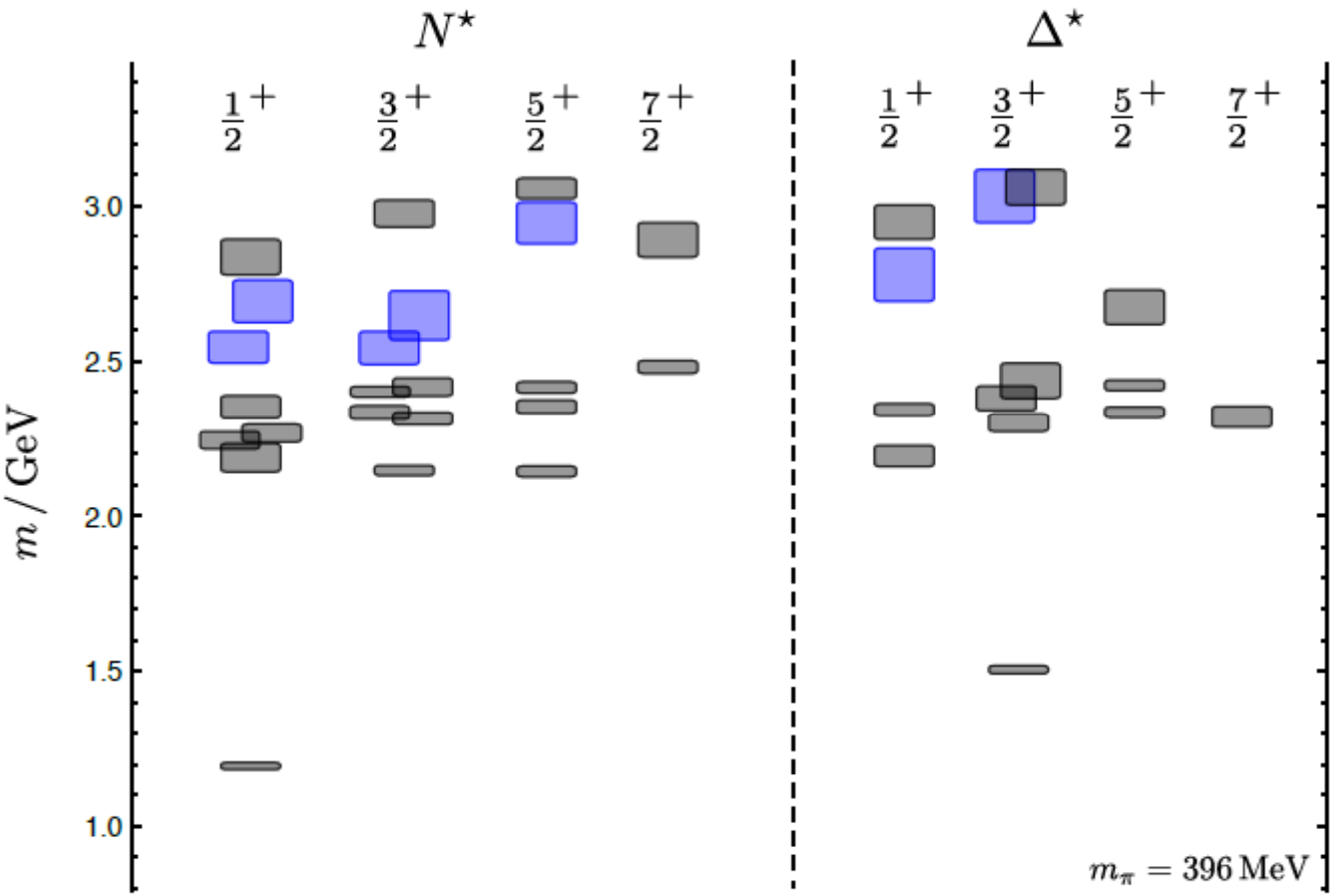


Lattice: heavy meson spectrum



The N* Spectrum (preliminary)

Hybrids



Experimental Tests: N* Spectrum

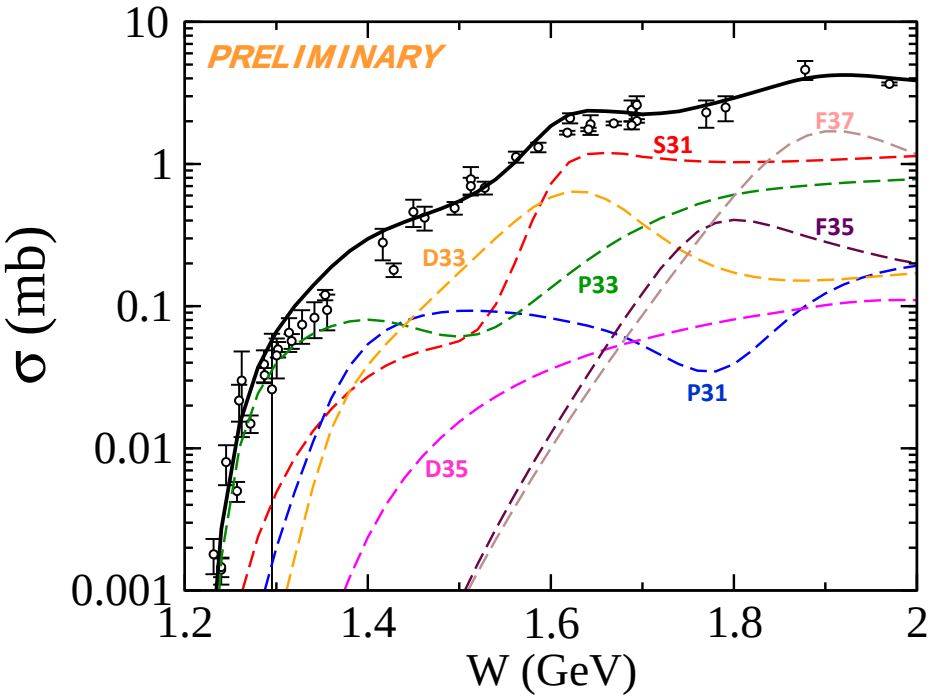
- Extracting the spectrum of nucleon resonances is not an easy task.
  - The resonances have natural widths 100-200 MeV
  - The resonances are overlapping
- However, resonances have distinct values of spin, parity and isospin.
  - Using the techniques of Partial Wave Analysis (PWA), the resonances can be separated.
  - This requires high-statistics, high-quality data.

Question 1

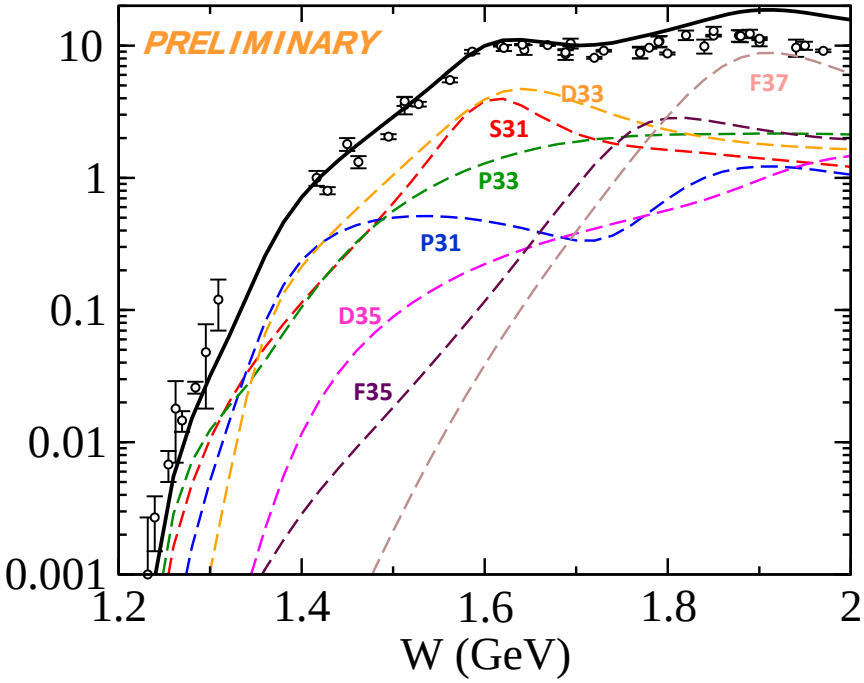
- The proponents should provide a more quantitative argument to show how the data of expected precision will contribute to the analysis of nucleon resonances.

Total Cross Sections

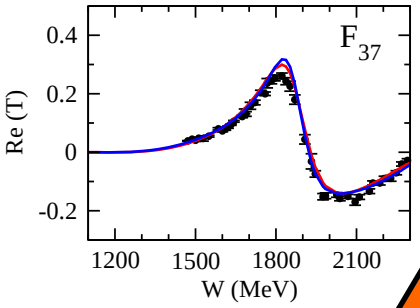
$\pi^+ p \to \pi^+ \pi^+ n$

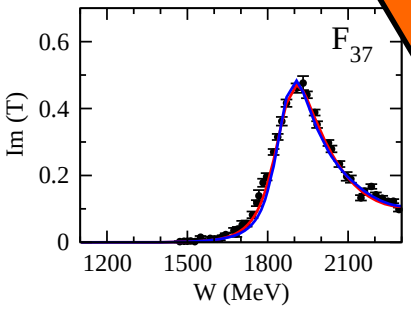


$\pi^+ p \to \pi^+ \pi^0 p$



PRELIMINARY

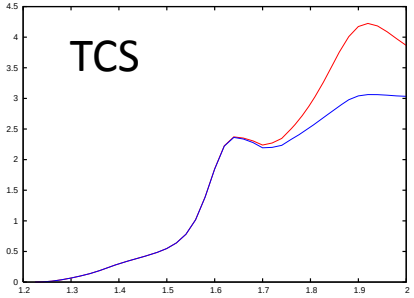




Current model

Refit F37 PWA keeping N* → πΔ off

$\pi^+ p \to \pi^+ \pi^+ n$



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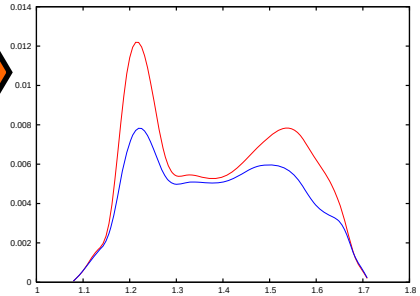
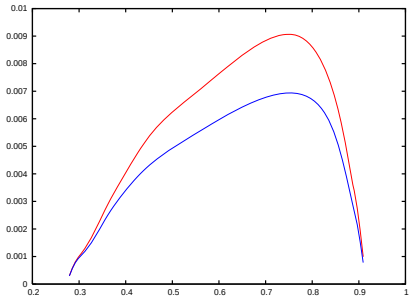
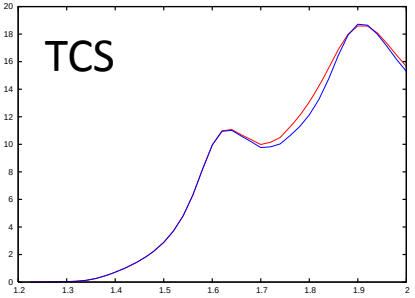


M(π+ n)



M(π+ π+)

$\pi^+ p \to \pi^+ \pi^0 p$



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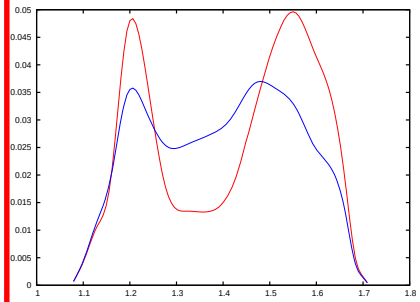
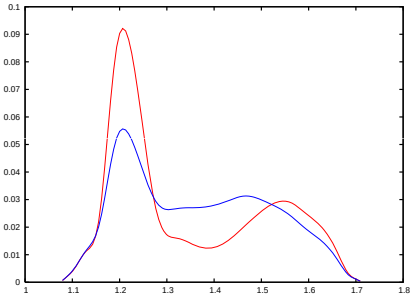
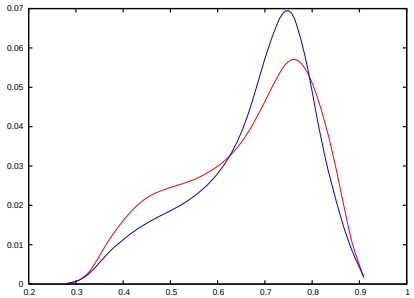


M(π0 p)



M(π+ p)

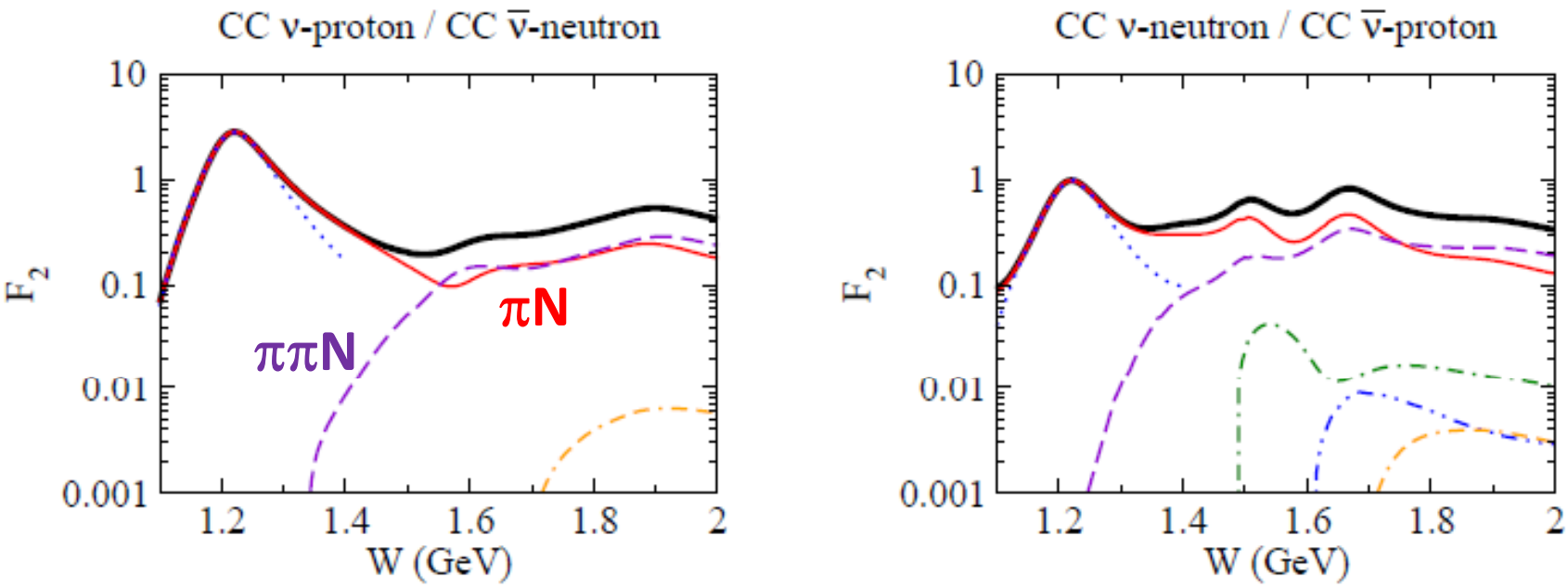


M(π+ π0)

Answer 1-a

- The previous data for the $\pi N \rightarrow \pi\pi N$ reaction is not sufficient to isolate the N* properties.
  - Ambiguities exist in the $\pi N \rightarrow \pi N$ elastic data
  - Coupled channels calculations (simultaneous fits to all πN reactions) are necessary
  - The theoretical tools now exist to do this!
- In a small amount of beamtime, J-PARC can completely re-write the $\pi N \rightarrow \pi\pi N$ database.

Answer 1-b



Charged Current neutrino scattering structure functions. For W>1.5 GeV, about half of the cross section is for the ppN final state. Knowledge of the N* resonances at higher mass helps to calculate the detector response of neutrino detectors.

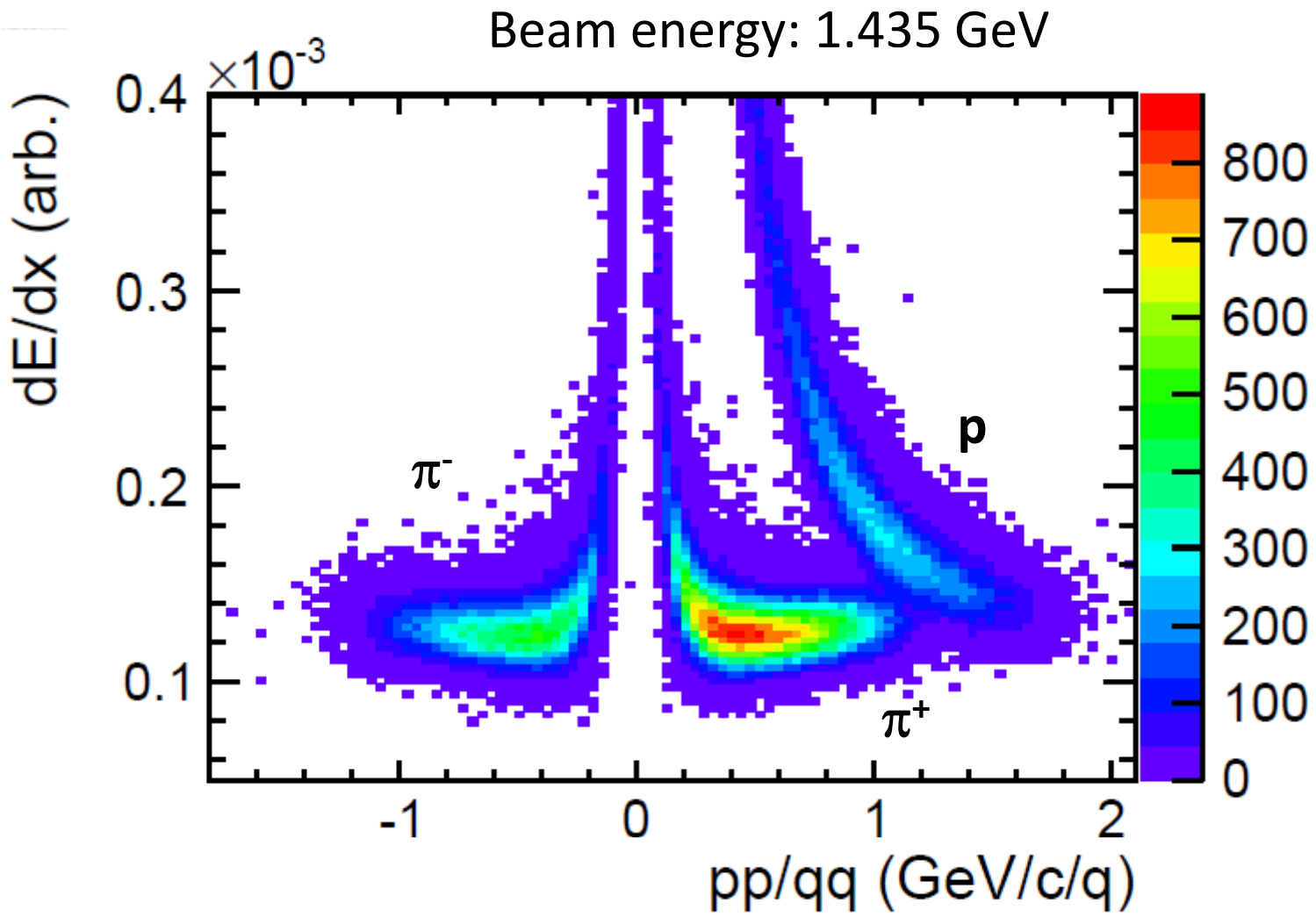
New Theoretical Collaboration

- Neutrino-nucleus reactions from MeV to GeV
  - Spokespersons S. Kumano and T. Sato
  - Goal: to study the effect of deep-inelastic scattering of neutrinos from nuclei leading to specific final states.
  - The leading-order effect is the πN final state, and the next-to-leading effect is the $\pi\pi$N final state.
  - Quantitative results are not yet available, but will be studied in the near future.

Question 2

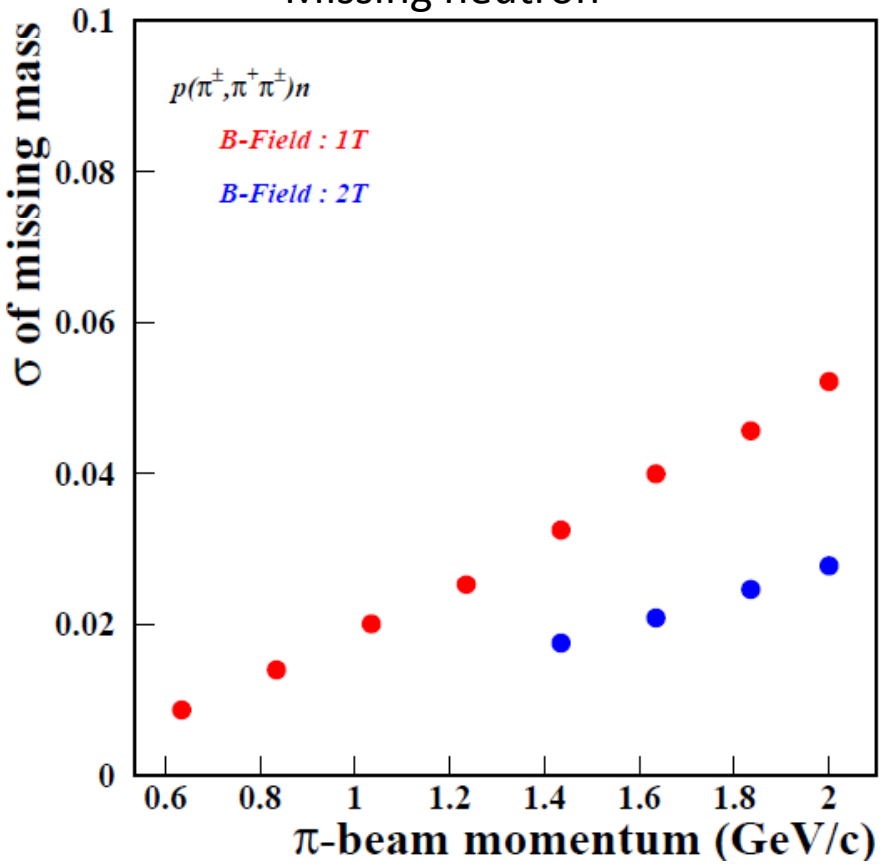
- The proponents should show how well the measurements of proposed reactions can be made in a full simulation.

Particle Identification

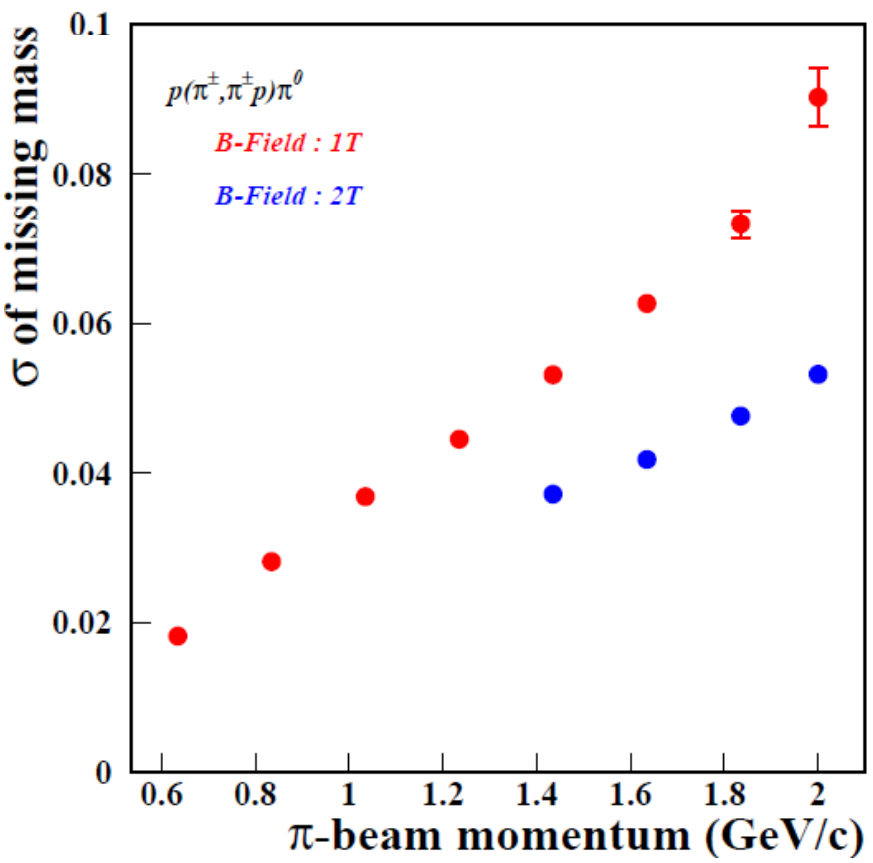


Missing Mass Resolution

Missing neutron

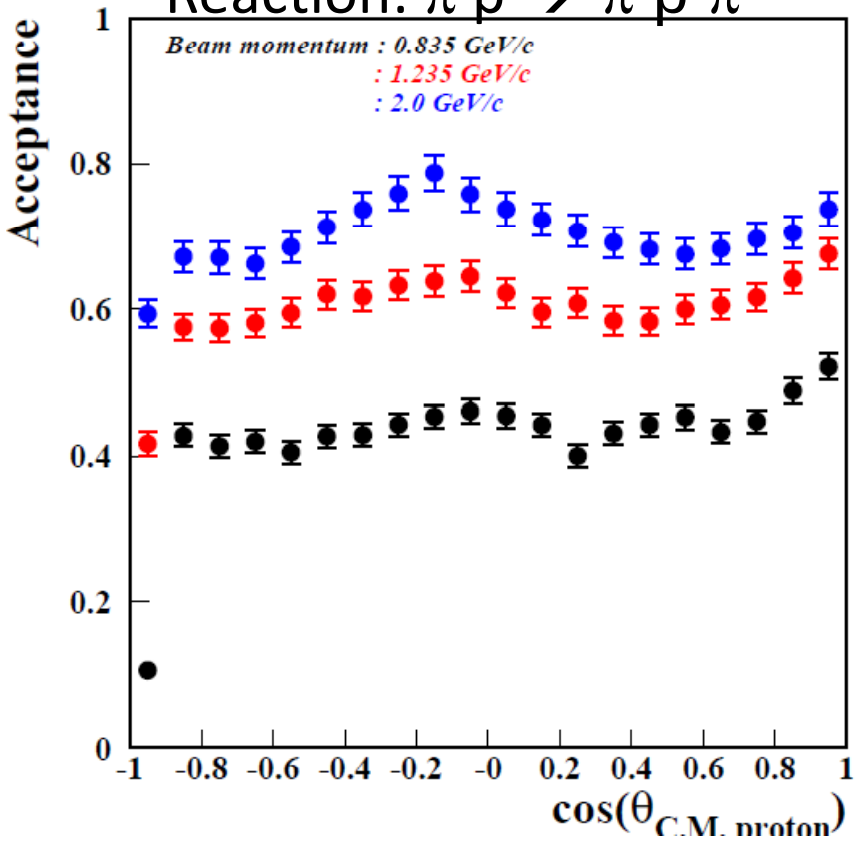


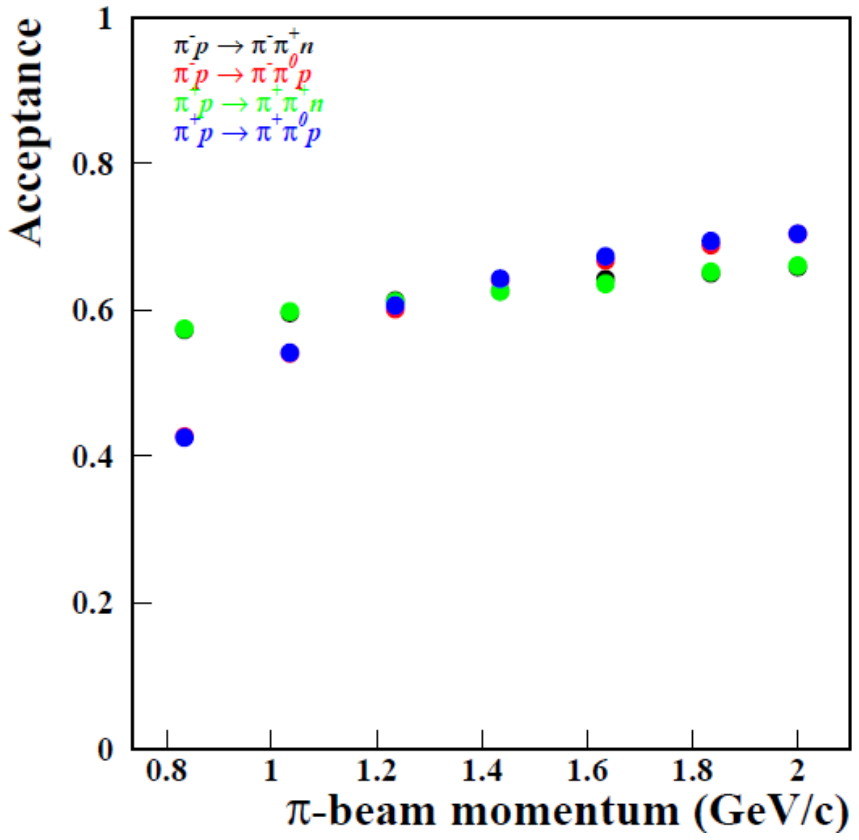
Missing pion



Acceptance

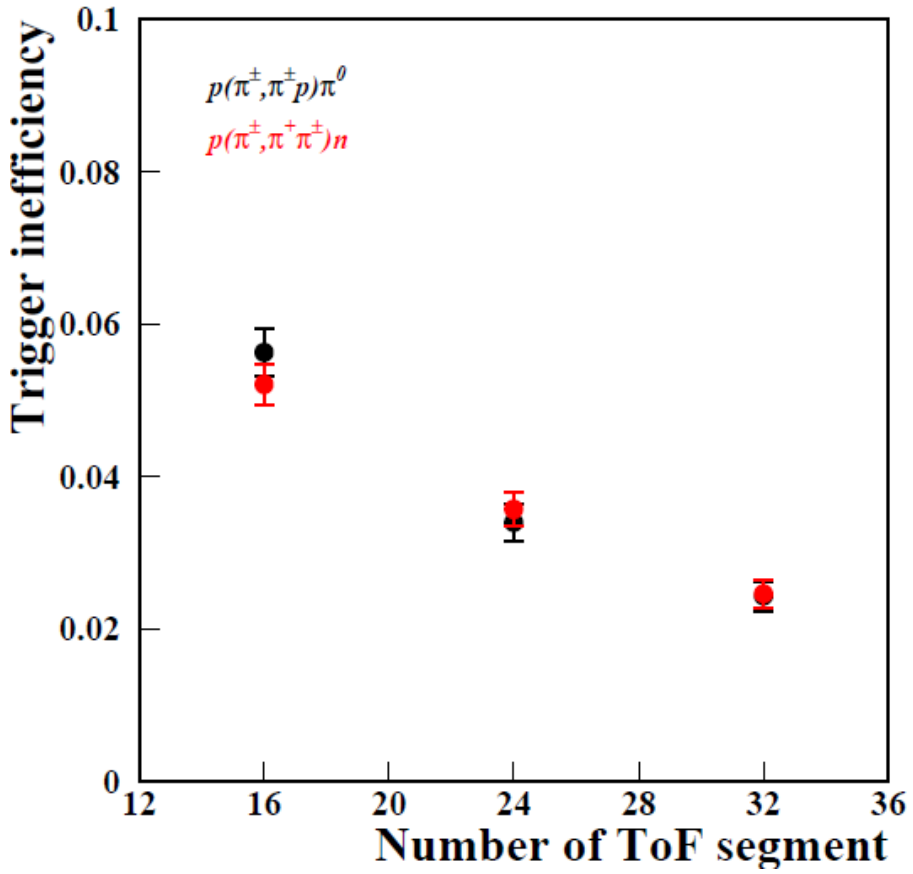
Reaction: $\pi\, p \rightarrow \pi\, p\, \pi^0$

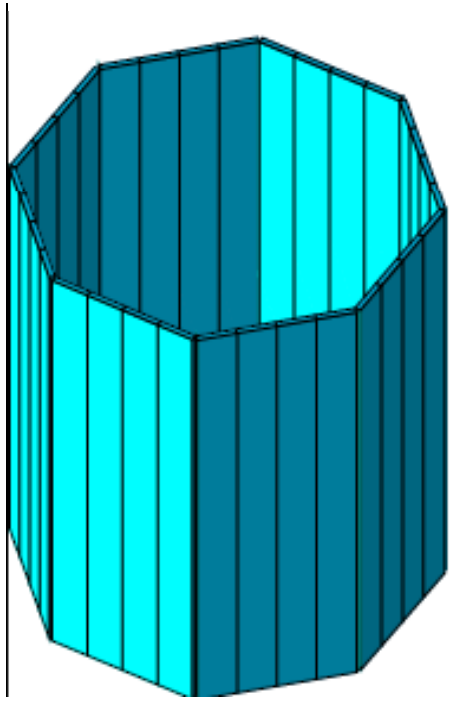




Note: for these plots, protons with momentum p < 300 MeV/c were cut out (due to energy-loss in the target).

Trigger Inefficiency





Proposed hodoscope with 32 segments.

Answer 2

- Detailed simulations have been carried out using the geant4 software with realistic resolutions for the proposed TPC for E42.
  - Particle ID is feasible
  - Missing mass resolution is OK (with 2.0 T B-field)
  - Acceptance was underestimated at low E-beam
    - We can request an additional 6-8 shifts to compensate
  - Trigger inefficiency is about 2% (32 segments)

Question 4

- The proponents should discuss with P42 how they can contribute to the detector construction.

Answer 4

- Ohio University will construct the scintillator hodoscope to be used in the trigger for both E42 and P45.
  - The geometry was already shown (32 segments)
  - We plan to use light guides and PMTs with magnetic shielding to achieve < 100 ps timing.
  - Development of an alternate design, using wave-shifting fibers and SiPM is being considered.
  - TDC readout will use existing electronics.

Question 3

The proponents should show more details about the modification of the detector system to be built in P42

Answers

3-1. Liquid-Hydrogen Target

3-2. TPC Modifications

3-3. Two-particle Trigger

- already shown

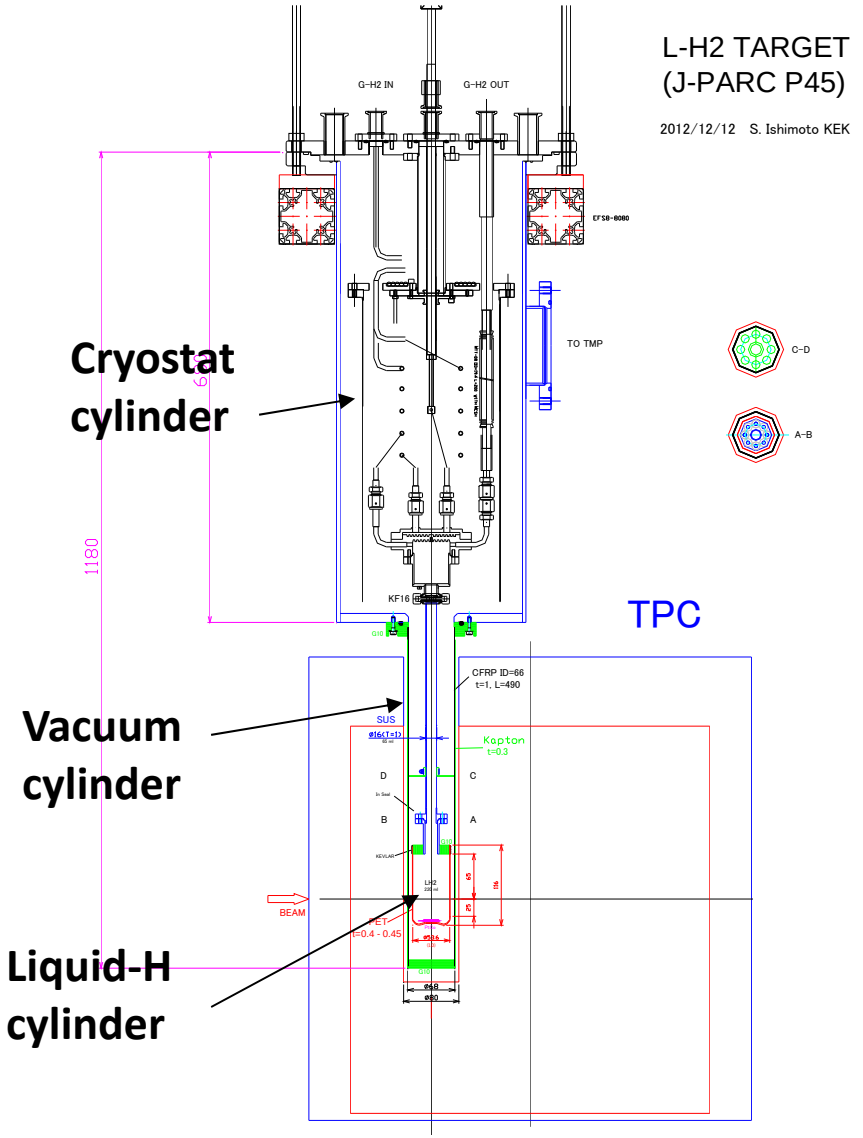
3-1. Liquid Hydrogen Target

- Basic design done with

  S. Ishimoto (KEK)
  - Fit to the TPC target holder of 8cm ϕ cylinder
- Reuse cryostat system of liquid-H target for E19 (penta-quark search)
- Need to construct newly
  - Cryostat cylinder
  - Vacuum cylinder
  - Liquid-H cylinder

  Construction

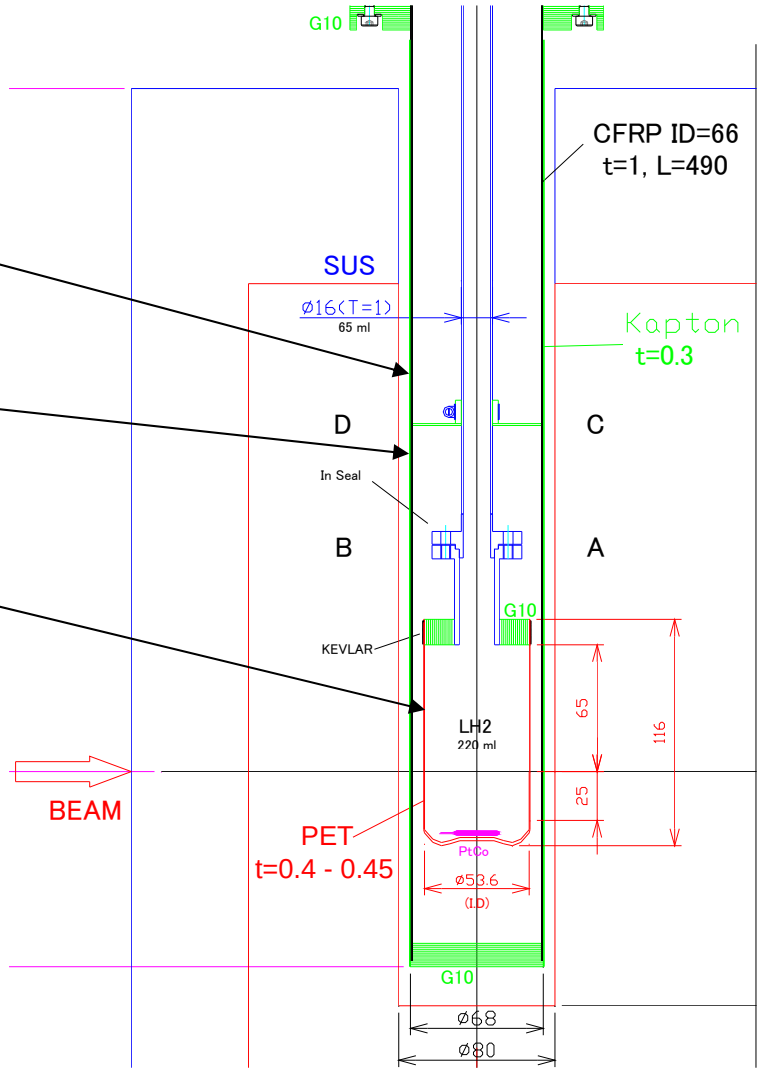
  1-2 M yen, 2 months



Liquid Hydrogen Target

Minimize material

- Vacuum cylinder
  - t=1mm CFRP (carbon fiber)
    - conductor
  - t=0.3mm Kapton
    - Insulation to field strips
- Liquid-H cylinder
  - t=0.4 mm PET(polyethylene terephthalate)
    - used in E19 successfully
- Total thickness
  - 0.28 gcm^{-2}
  - radiation length ~0.7%



3-2. TPC Modifications

P45 TPC

Modifications for target diameter

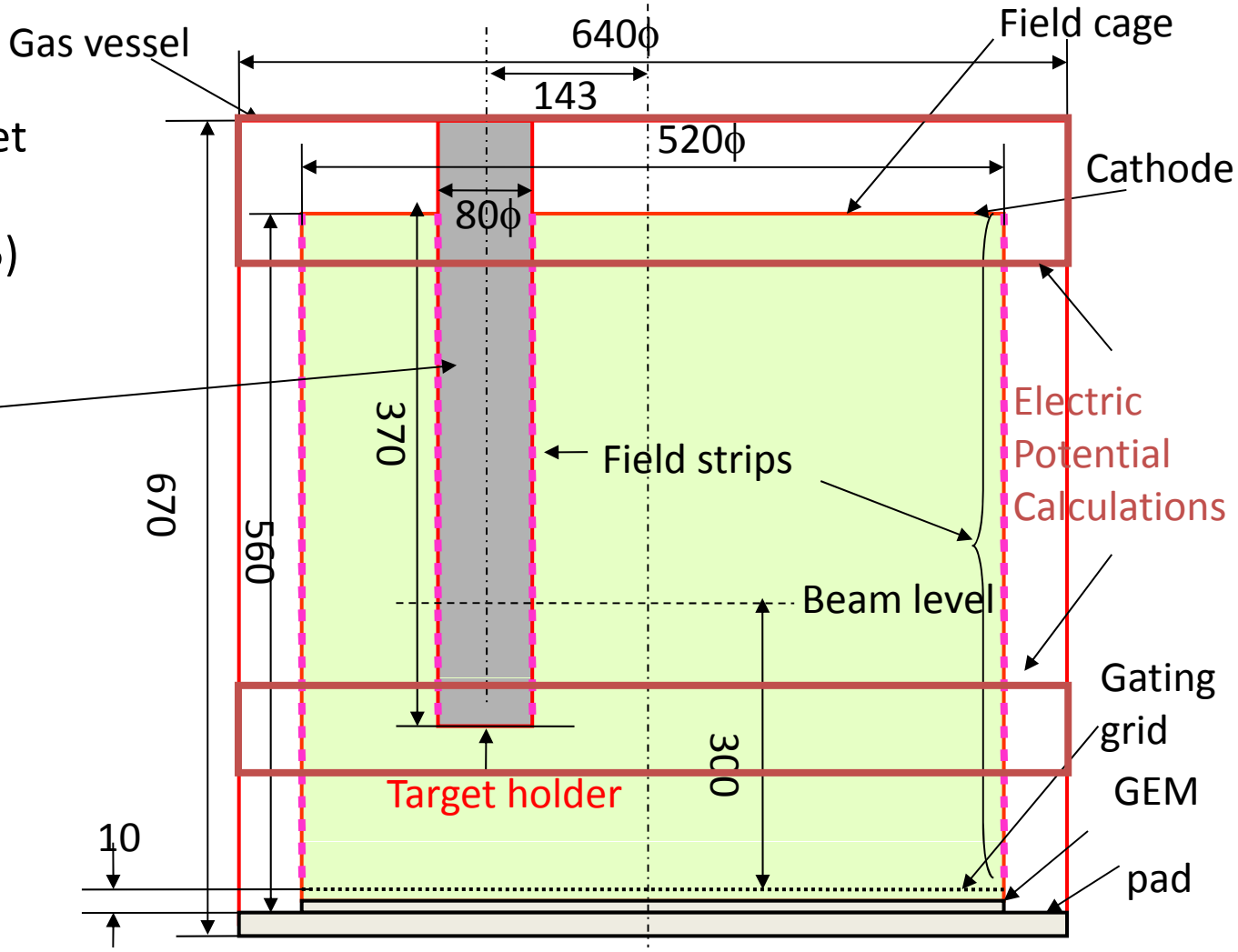
50(E42)→80mmϕ (P45)

To be replaced for P45

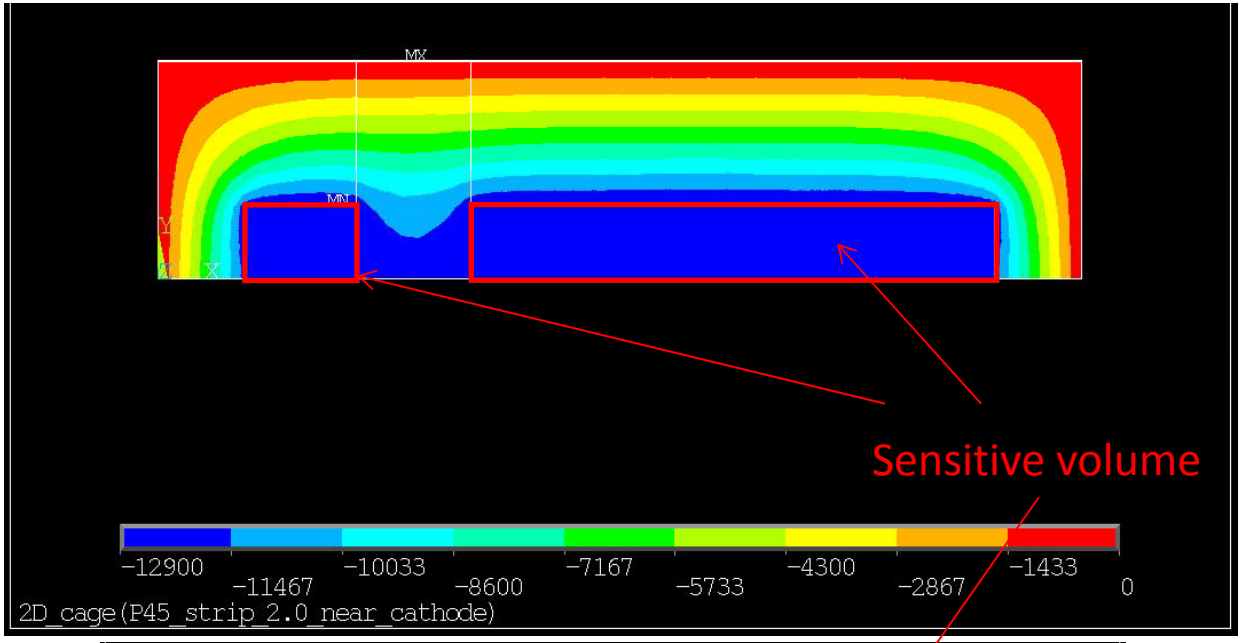
- Target holder

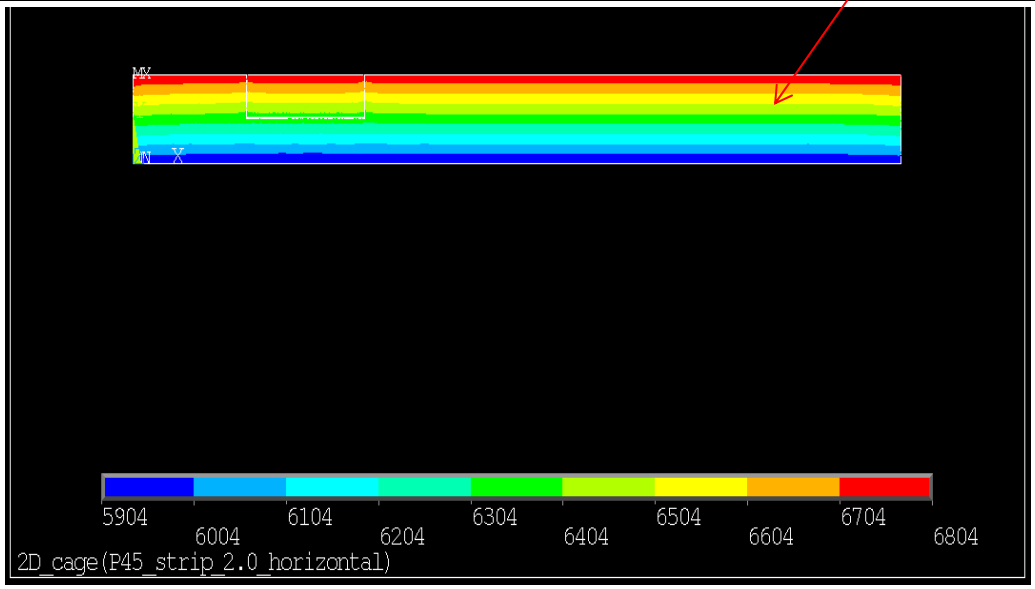
Share with E42

- Gas vessel
- Field cage
- Gating Grid
- GEM
- Pad plane
- Electronics



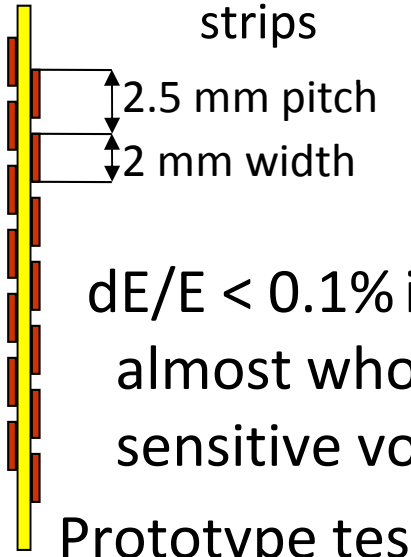
Electric potential calculations





2-d calculation

- Gas vessel
- Field cage
  - -13kV at maximum
- Target holder
- Double layer field strips



dE/E < 0.1% in the almost whole sensitive volume

Prototype test for E42 at Pusan Univ. in Jan-Feb 2013