Possibility to explore short range correlation with hyperon at LEPS2

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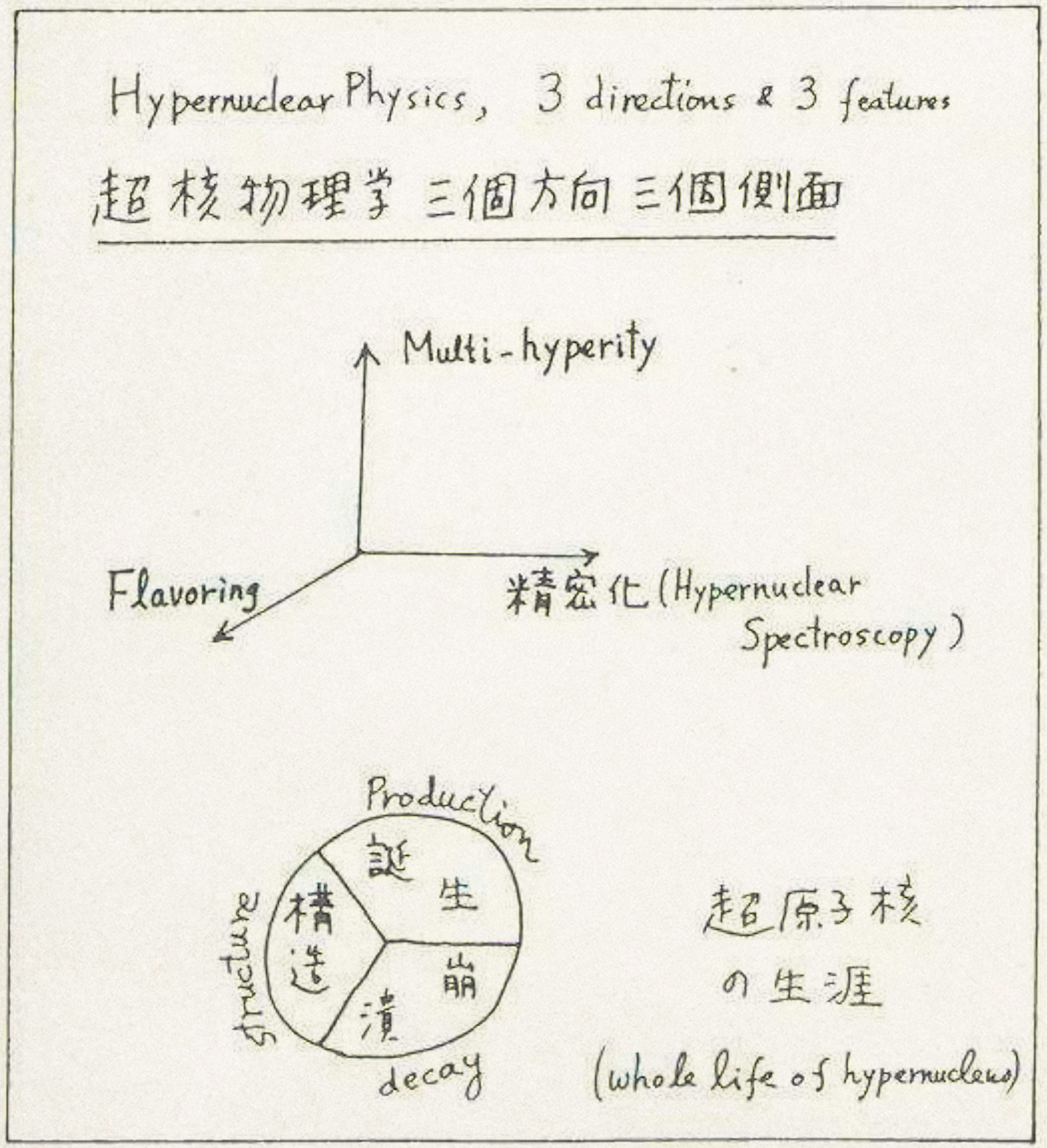
August 9th, 2024

Outline

- Introduction & Motivation
    - Hypernuclear bound vs unbound states
- Experiment concept
    - LEPS2 + observables
- Summary

Overview of hypernuclear physics



An overview of hypernuclear physics by H. Bando san in 1990

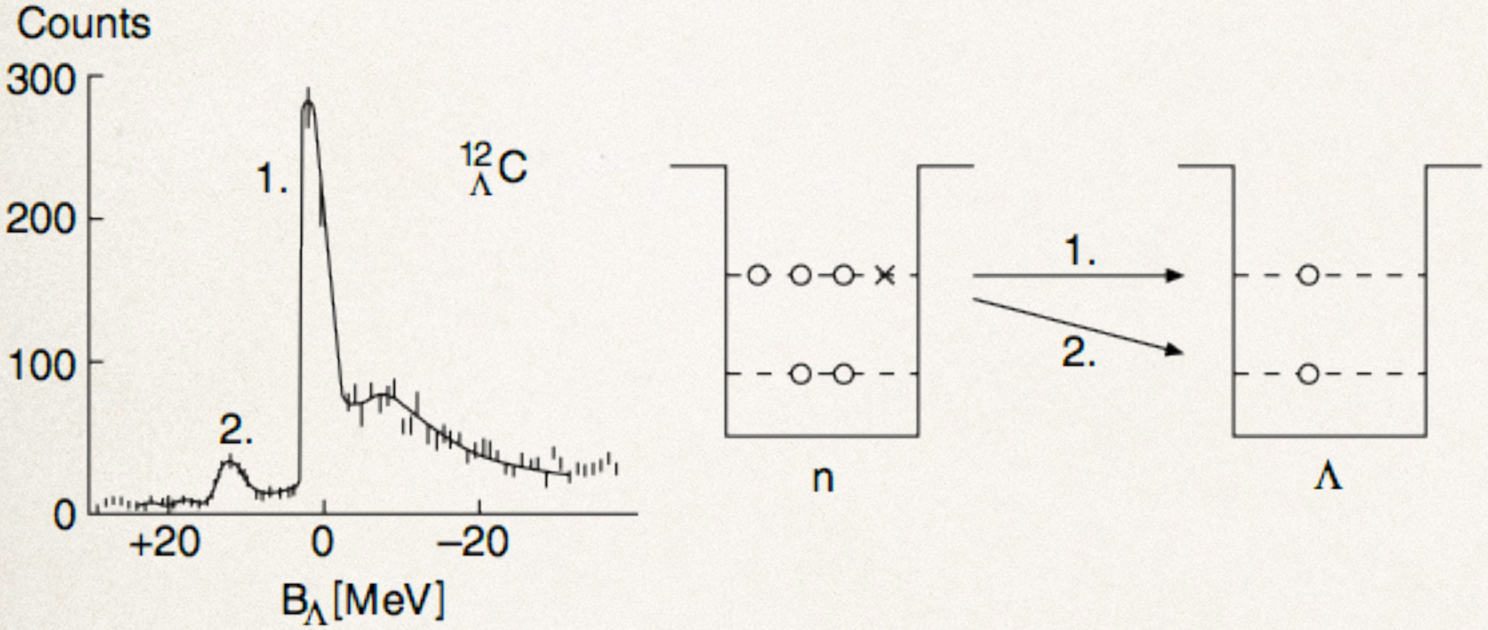
- Flavor Baryon with s, c, b
- Multi strangeness: double Λ, Ξ
- Hypernuclear Spectroscopy:
  - γ-ray spectroscopy
  - sub-MeV program at J-PARC and JLab

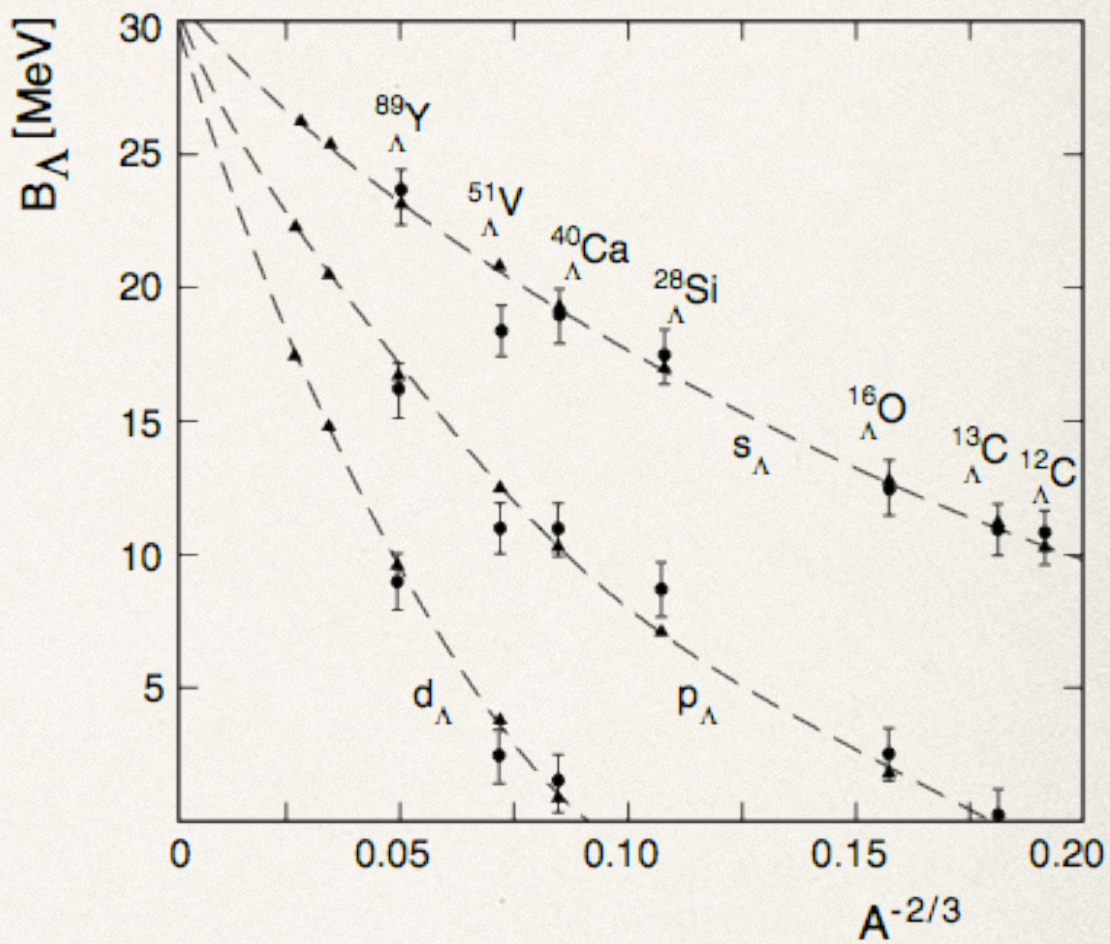
All these are based on bound state or mean field + hyperon picture

Illustration stolen from H. Bando san's proceeding at Changchun, PRC (?)

Probing nuclear structure: soft probe

$^{12}\mathrm{C}(K^-, \pi^-)^{12}_{\Lambda}\mathrm{C}$ reaction



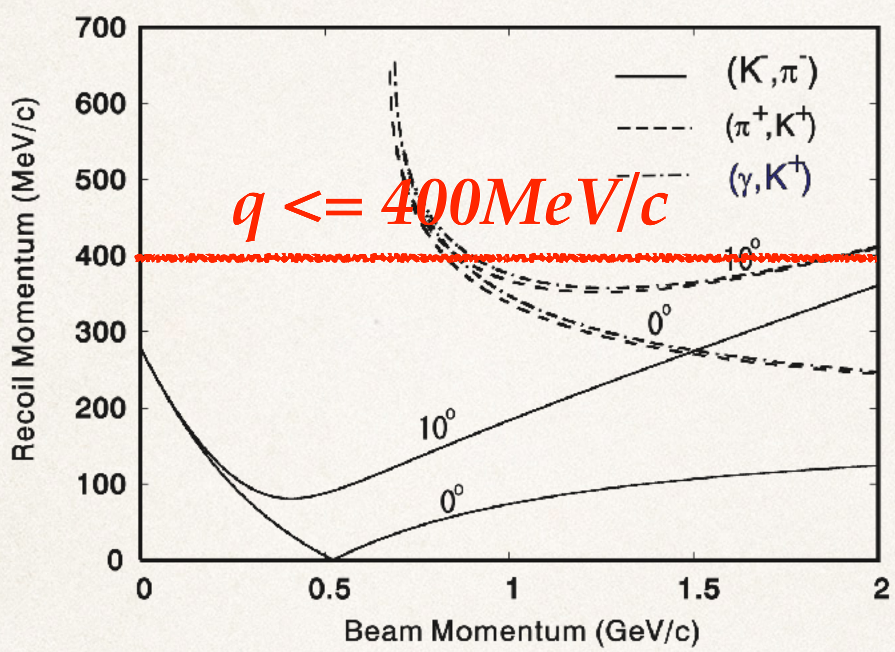


$$B_{\Lambda} = M_{A-1} + M_{\Lambda} - M_{HY}$$

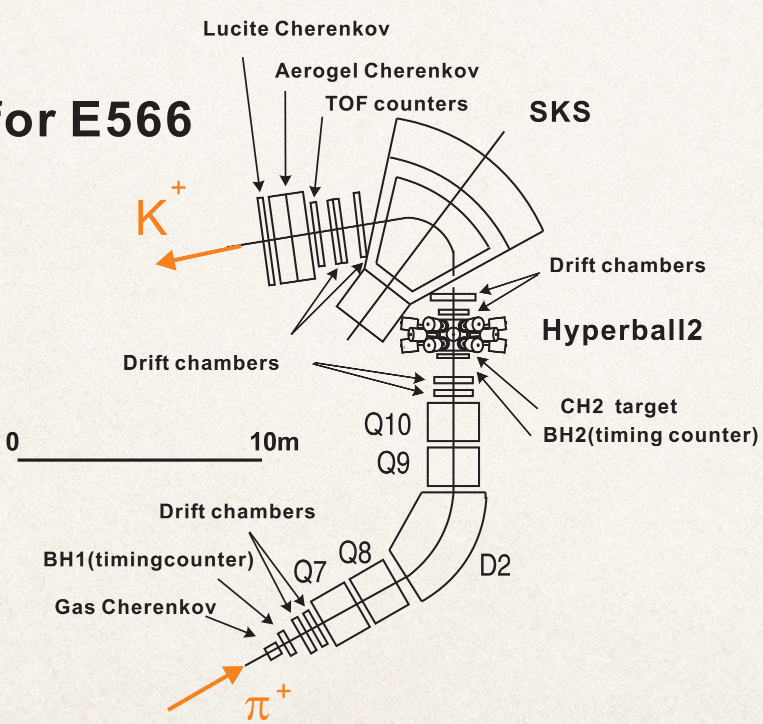
$$M_{HY} = \sqrt{(E_K + M_A - E_{\pi})^2 - (P_K^2 + P_{\pi}^2 - 2P_K P_{\pi} cos\theta_{K\pi})}$$

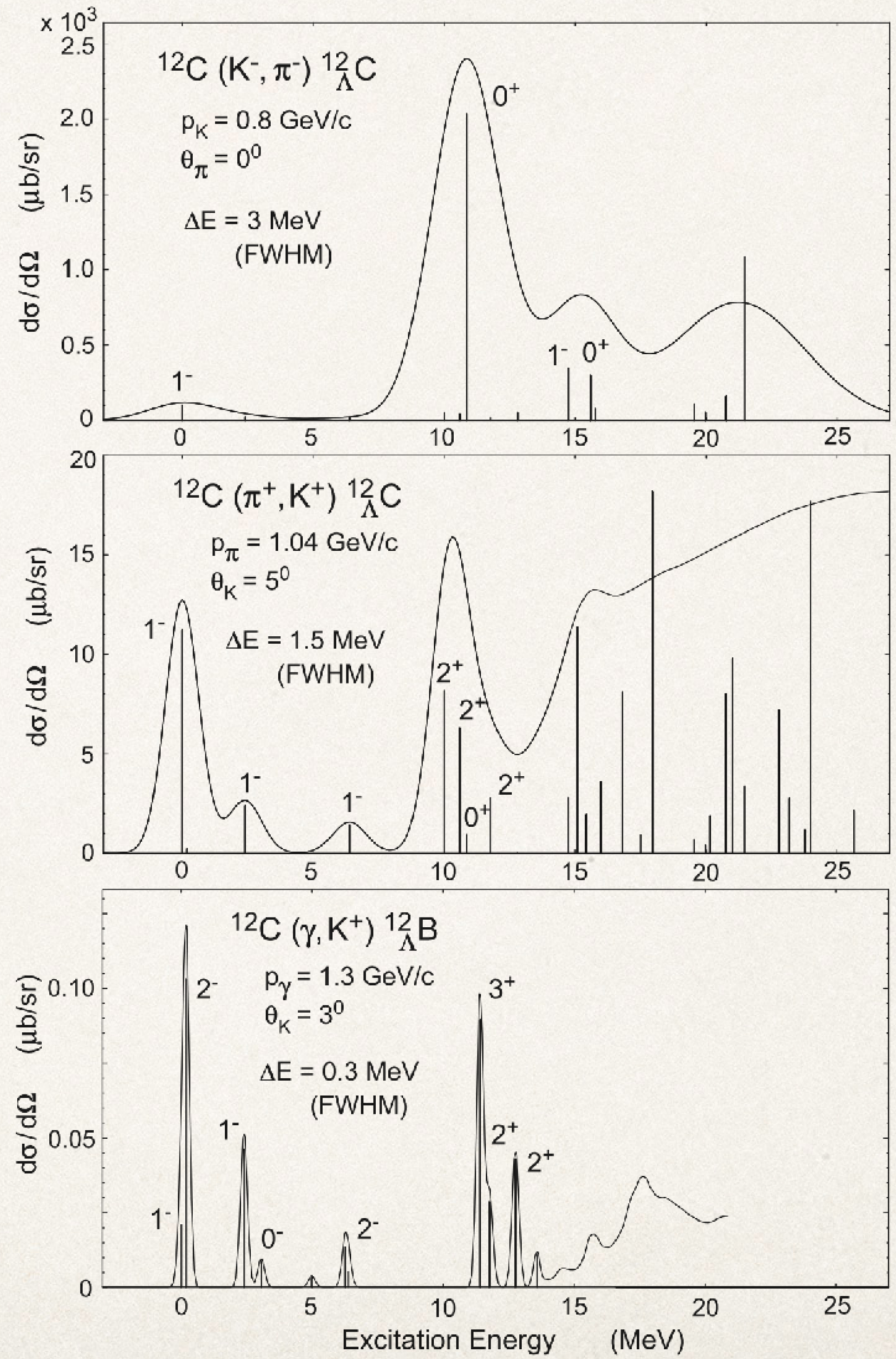
First direct evidence for the nuclear mean field potential!

Probing nuclear structure: soft probe



Setup for E566



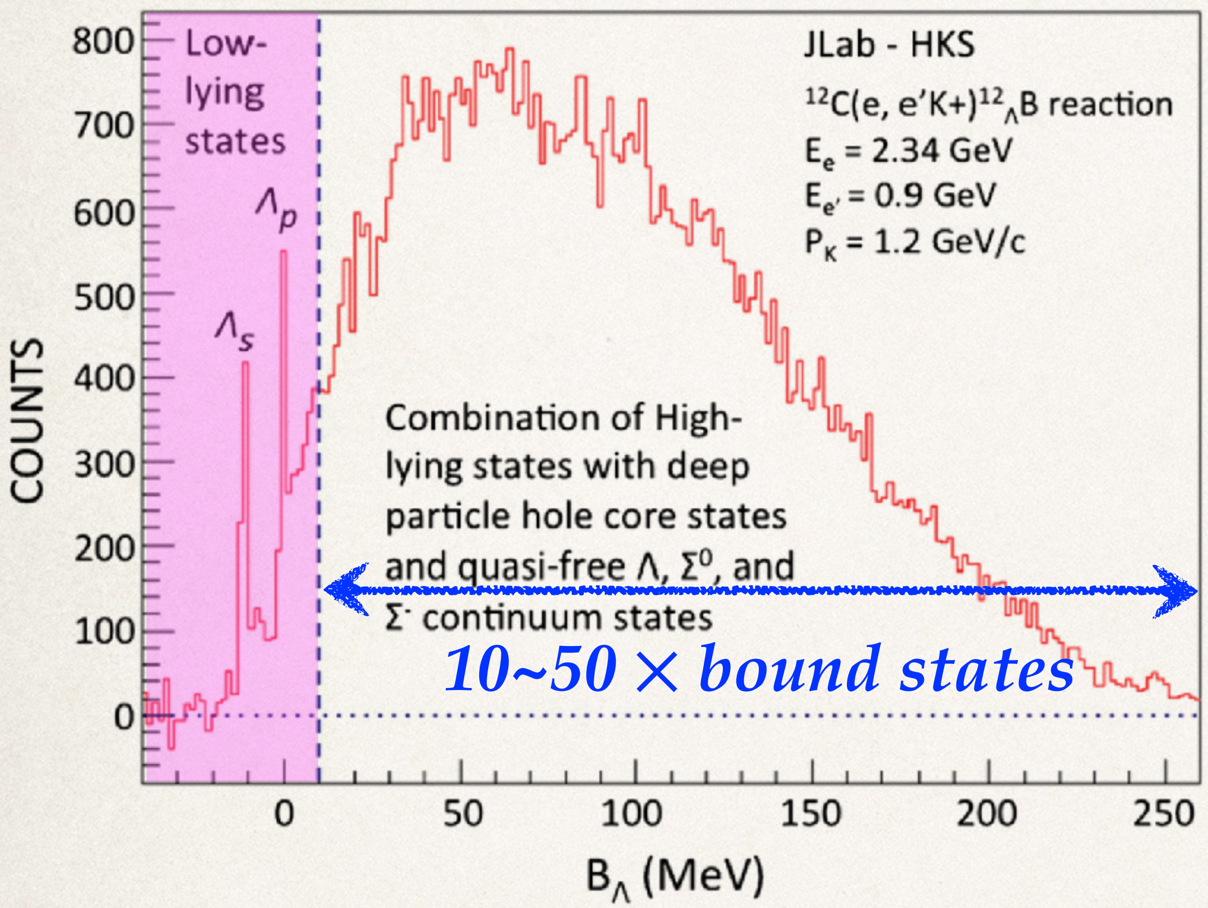


O. Hashimoto and H. Tamura, doi:10.1016/j.ppnp.2005.07.001

Probing nuclear structure: *hard probe?*

- Given the success of **Λ** as a ***soft probe*** for nuclear potential, an important assumption, ***weak coupling***, is assumed:
  - ***soft probe***: most data and theoretical calculations are for small momentum transfer events (q <= 400MeV/c)
  - ***weak coupling***: elementary **Λ** hyperon production + Woods-Saxon potential works pretty well
- What about ***large momentum*** transfer events? **Λ** as a ***hard probe*** for ***beyond the mean field*** effects such as short range YN interaction?

Probing nuclear structure: *hard probe?*



- Most efforts have been invested to the bound states region to study Λ hyperon within nuclear mean filed potential.
- Our question: what is inside the unexplored unbound region? core excited states + quasi free Λ/Σ + ***one more thing***?

- Hypernucleus is famously known as a probe for nuclear mean field by studying the bound states.
- Can we use Λ hyperon as a ***hard probe*** for nuclear structure beyond the mean field assumption?

https://doi.org/10.1016/j.nuclphysa.2018.03.001

What happens inside nucleus?

- Good old days: Fermi gas model, liquid-drop model, shell model, Relativistic Mean Field theory...

- Updated: some peculiar phenomena can not be explained by "averaging out" the multi-body interactions

  - short range correlation (SRC): EMC effect

  - ultra sub-threshold $\pi/\bar{p}$ production

Short range correlation: $\Delta p \Delta x \sim \hbar$

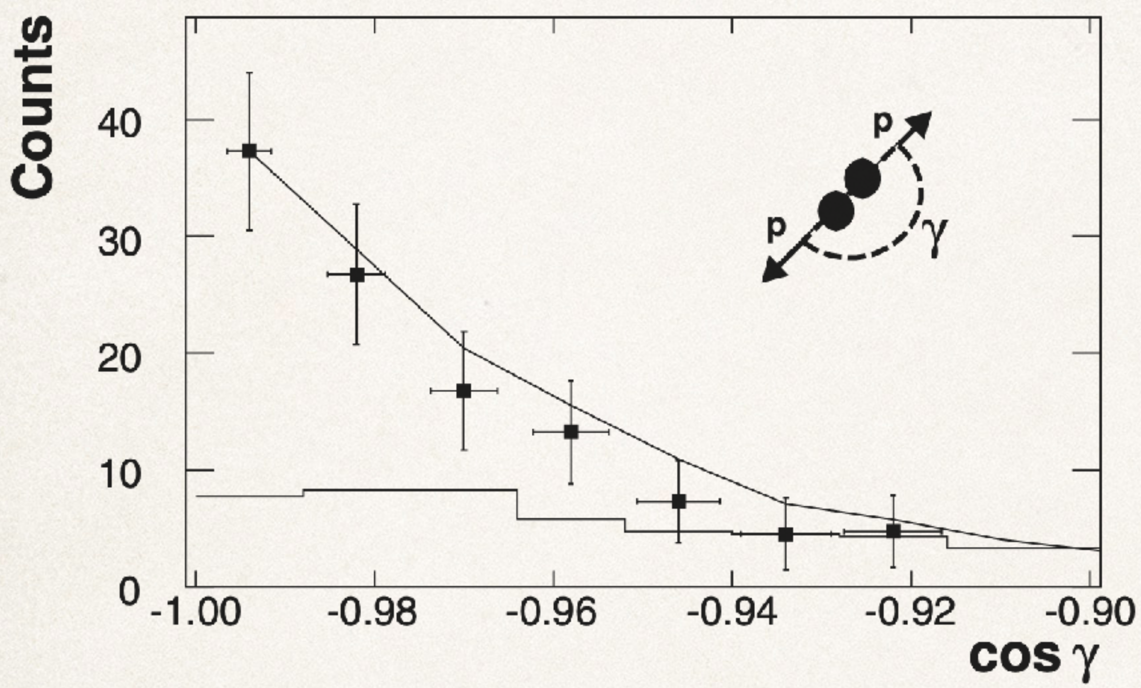
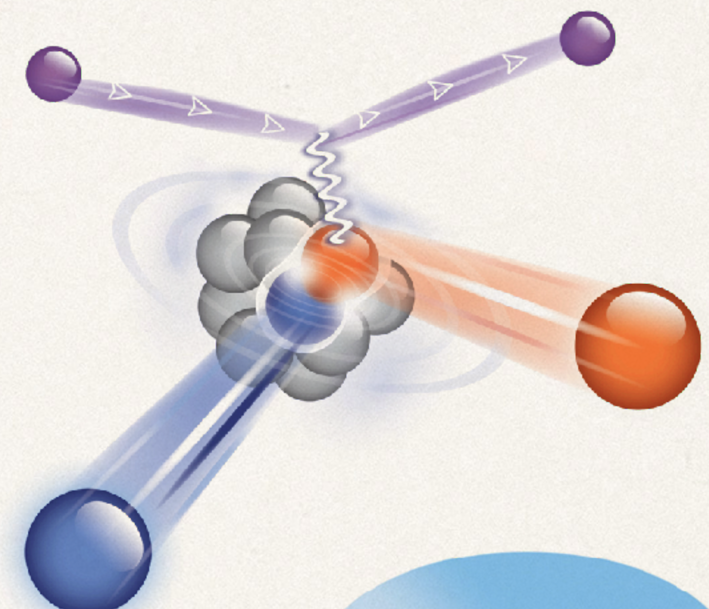
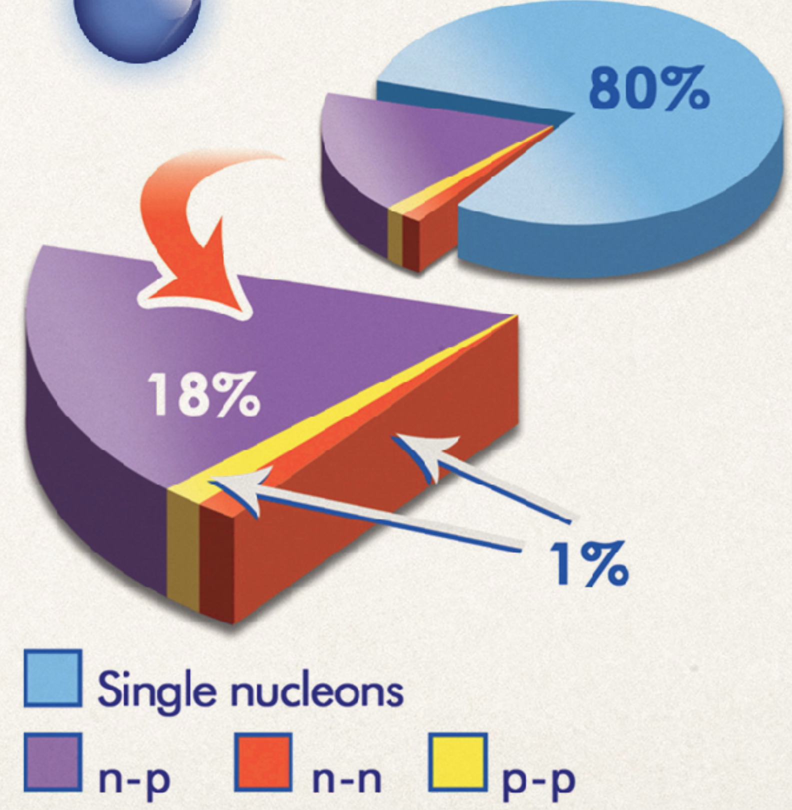


FIG. 3. The distribution of the cosine of the opening angle between the $\vec{p}_{\text{miss}}$ and $\vec{p}_{\text{rec}}$ for the $p_{\text{miss}} = 0.55$ GeV/c kinematics. The histogram shows the distribution of random events. The curve is a simulation of the scattering off a moving pair with a width of 0.136 GeV/c for the pair c.m. momentum.

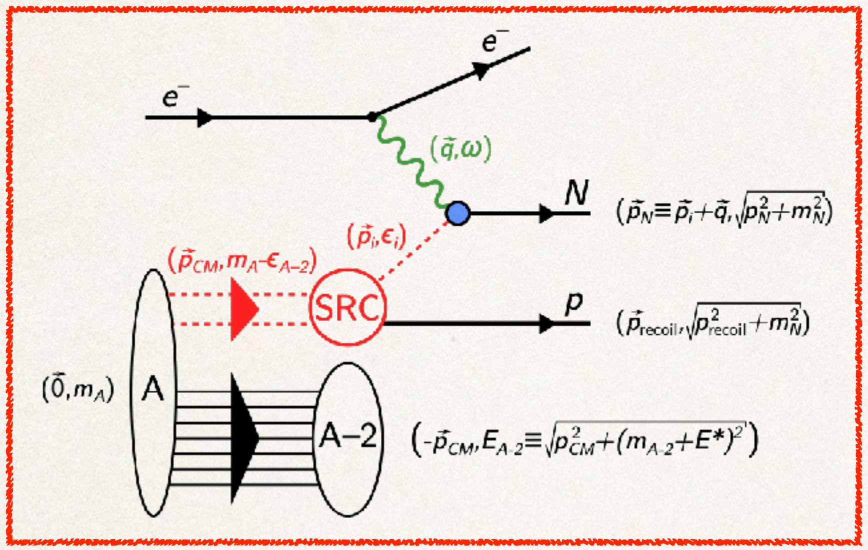


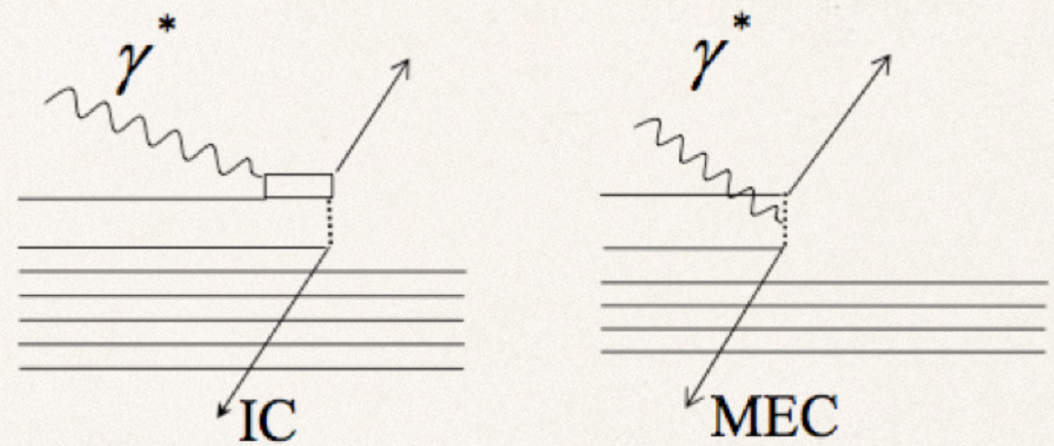


10~20% of nucleons form very closed pair with large $\Delta p \geq p_F$

DOI: 10.1126/science.1156675
https://doi.org/10.1103/PhysRevLett.99.072501

JLab $A(e, e'pp)$ example: background channels





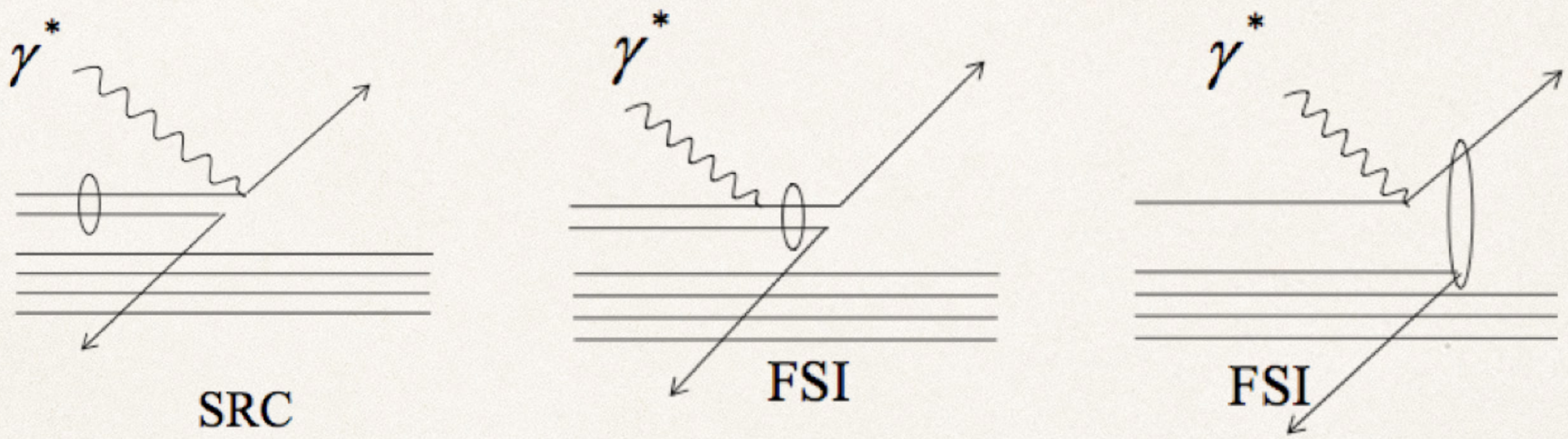


Figure 9: The reaction mechanisms for electron-induced two nucleon knockout. The virtual photon can be absorbed on one nucleon of an SRC pair, leading to the emission of both nucleons (SRC). The virtual photon can excite a nucleon to a Δ, which deexcite by exchanging a pion, resulting in the emission of two nucleons (IC). The virtual photon can be absorbed on a pion-in-flight (MEC). The virtual photon can be absorbed on one nucleon of an SRC pair which rescatters from the other nucleon in the pair (FSI (left)). The virtual photon can be absorbed on an uncorrelated nucleon which rescatters from another nucleon (FSI (right)).

https://doi.org/10.48550/arXiv.2009.09617

What we can do with Λ hyperon for SRC?

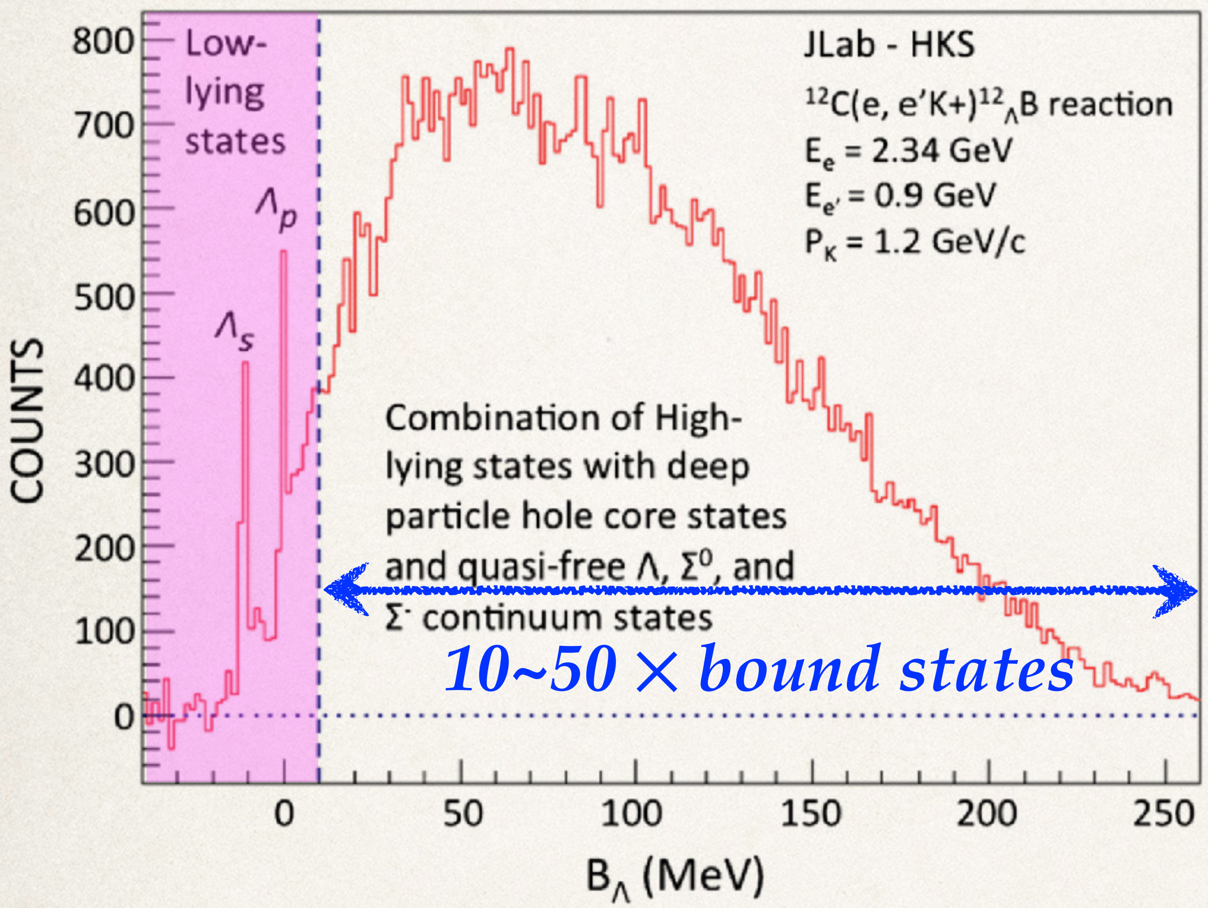
- ${}^{Z}A(\gamma, K^0 + p + \Lambda)^{Z-1}(A-2)$: exclusive final state measurement

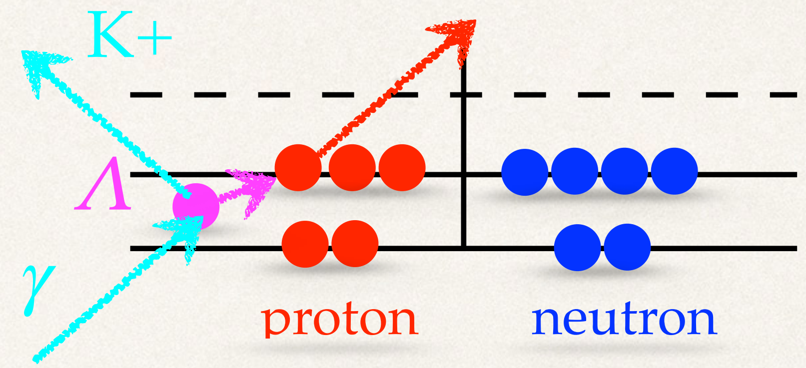
- Different dynamics and background processes from electron scattering experiments at JLab

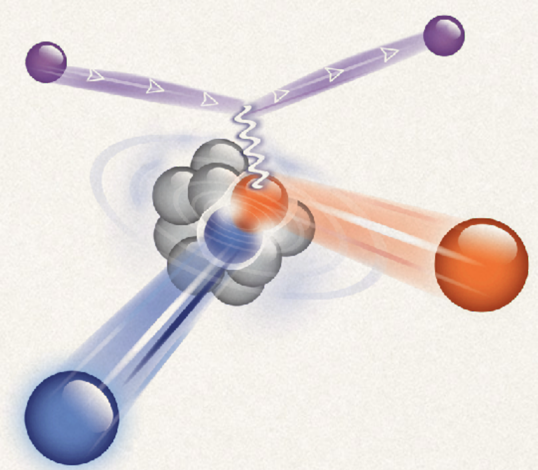
- Λ hyperon isospin = 0: allow us to switch off tensor in final state and identify its contribution, *tensor origin??*

- Elementary process with Deuteron target to calibrate background contributions by comparing with elementary process together with Fermi motion

Λ vs Short Range Correlation

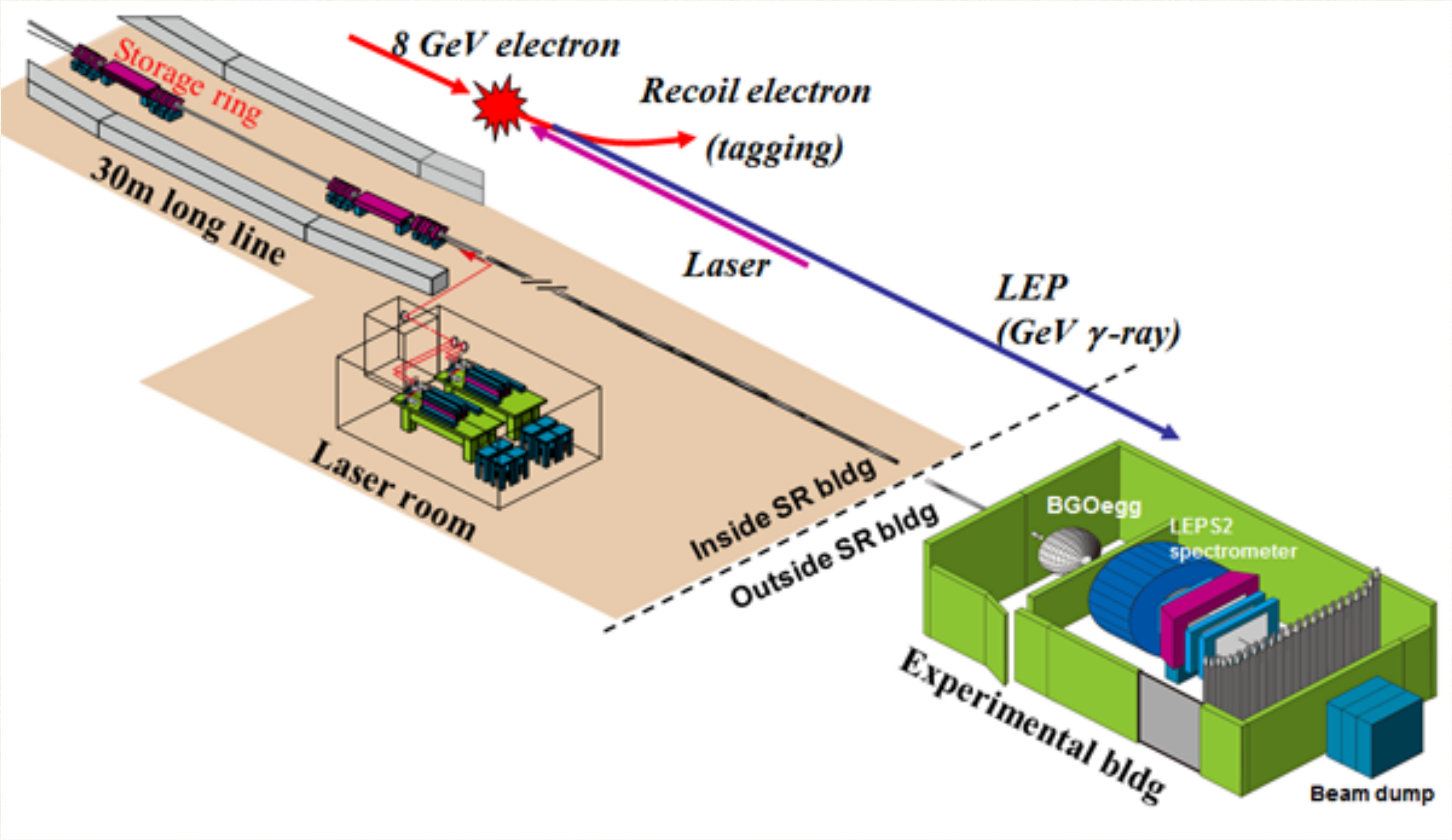






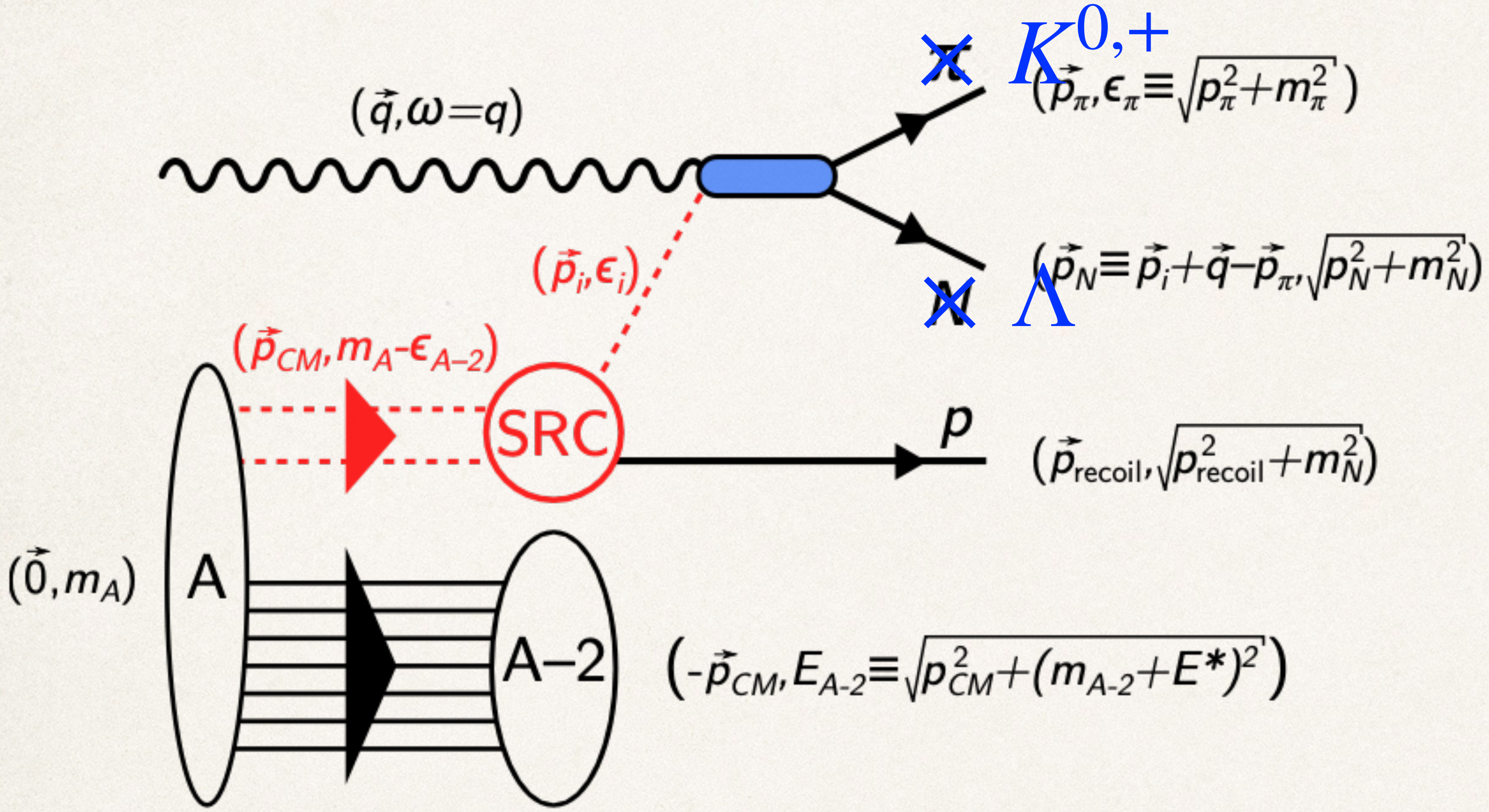
- Reaction: ${}^{Z}A(\gamma, K^0 + p + \Lambda)^{Z-1}(A-2)$
  - select $(A-2)$ spectator nucleus with missing mass
  - tracking for both $n-p$ and $p-p$ mode: only possible with $n(\gamma, K^0)\Lambda$ reaction not $(e, e'pn)$ at JLab

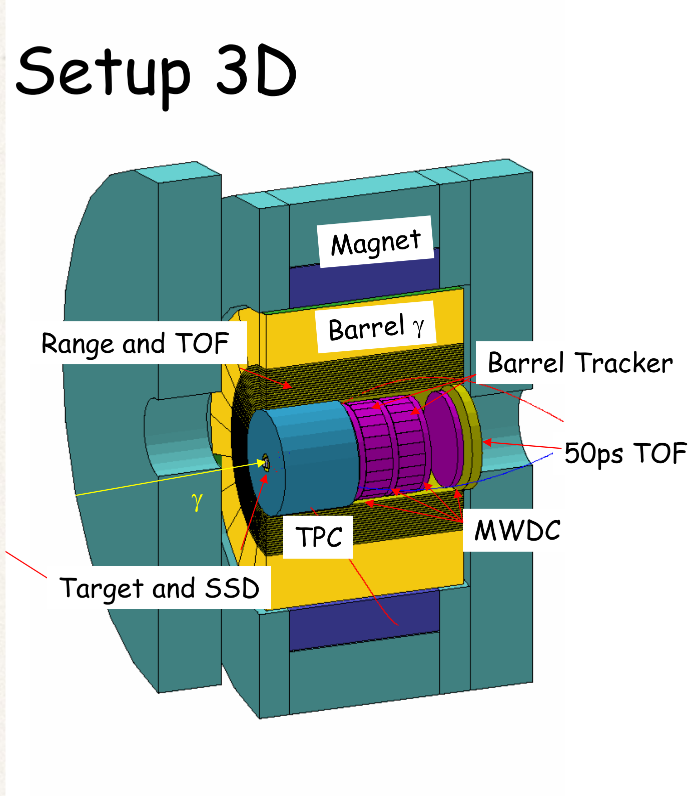
Why LEPS2?



- LEPS2: Laser Electron Photon Experiment at SPring-8
- Reverse Compton scattering is used to populate high energy gamma ray beam: 1.5 ~2.4 GeV;
- Large Acceptance Solenoid Spectrometer + TPC

Why LEPS2?





SRC event generator implementation:

1, γ beam is always real photon

2, SRC NN pair in Lab. frame with $P\sigma_{CM} \sim$ 136 MeV/c

3, $P \sim 1/k^4$ in SRC CM frame $\in$ [0.2, 0.6] GeV/c

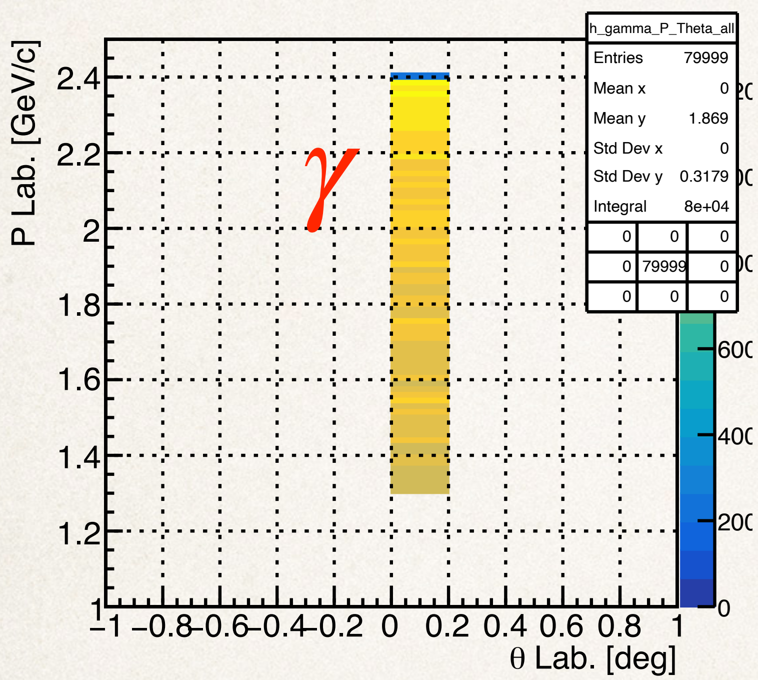
4, n_{SRC} is off-shell to balance recoil proton and (A-2) system

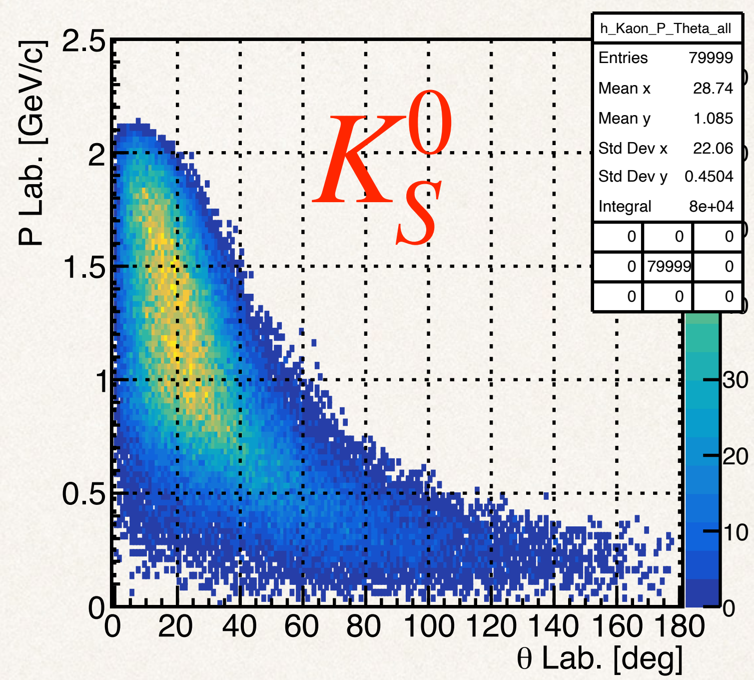
https://doi.org/10.48550/arXiv.2009.09617

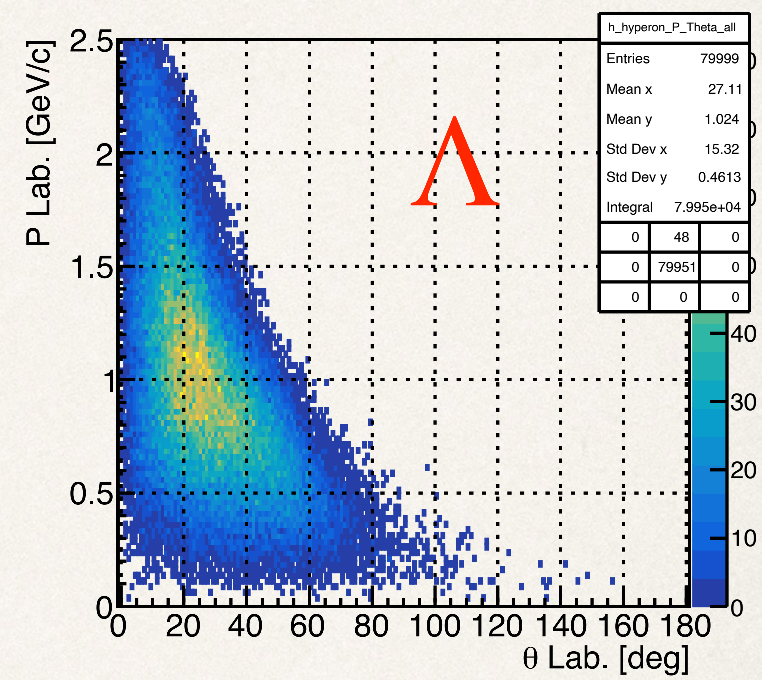
Statistics estimation for SRC events

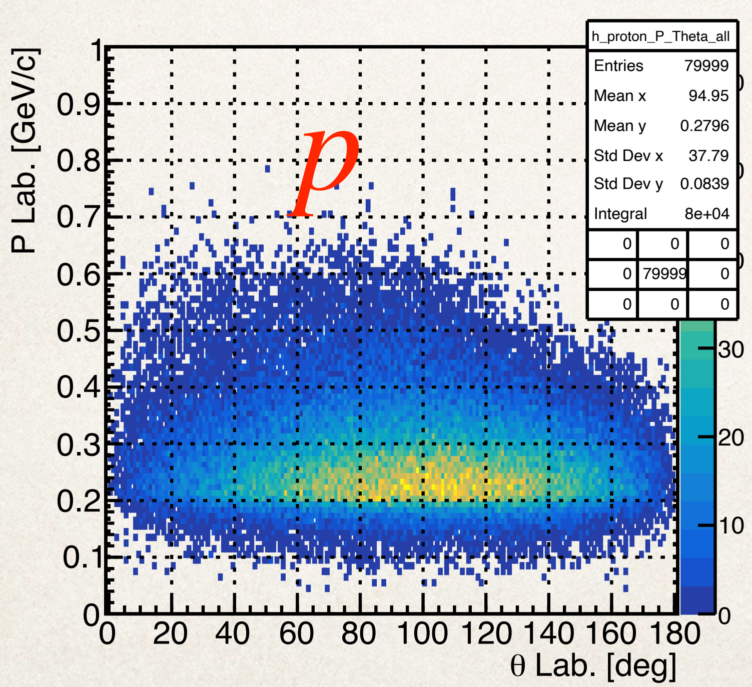
- total Λ events ~8×10^5 in SC and CFRP (100days)
- branching ratio: $\Lambda \rightarrow p + \pi^-$
- branching ratio: K^0 : K_S^0 / K_L^0 ~ 0.5, $K_S^0 \rightarrow \pi^+ + \pi^-$
  - --> 50% of $\Lambda + K_S^0$ physics events
- SRC ~20% of nucleons
- $8 \times 10^5 \times 20\% \times 50\,\% = 8 \times 10^4$ SRC events as input for GEANT4 to study LEPS2 performance

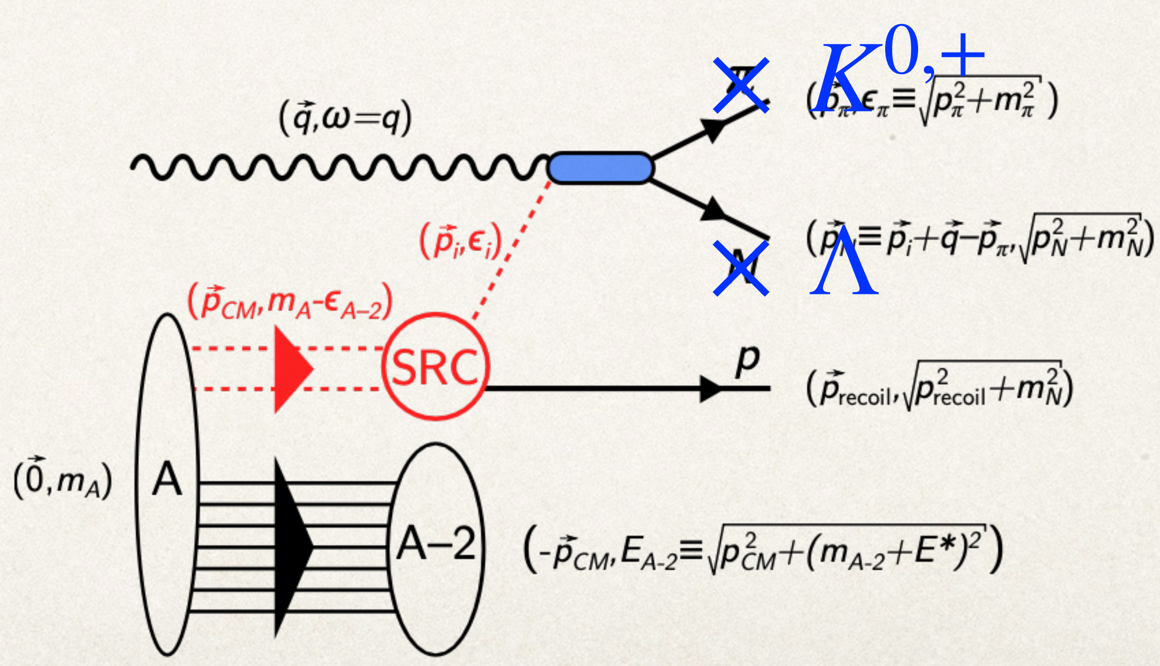
Simulation: input = 8×10^4



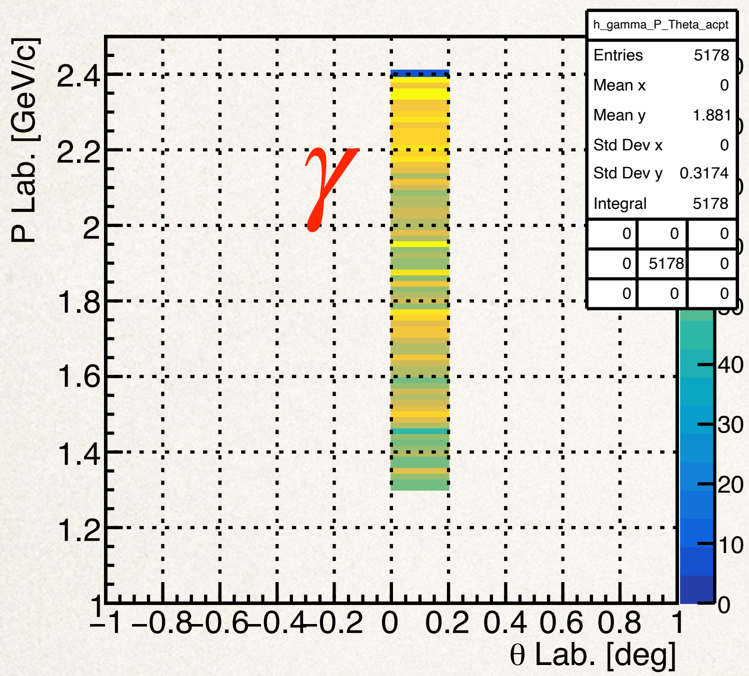


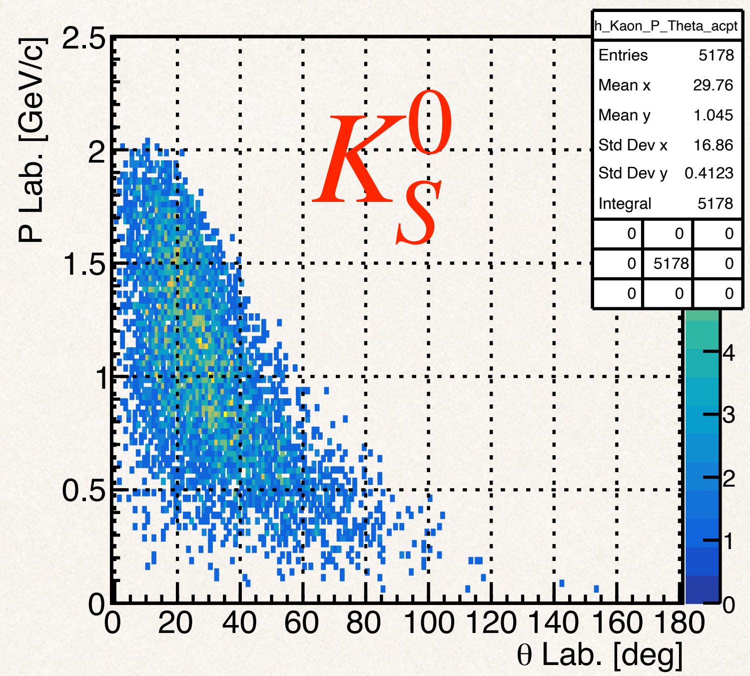


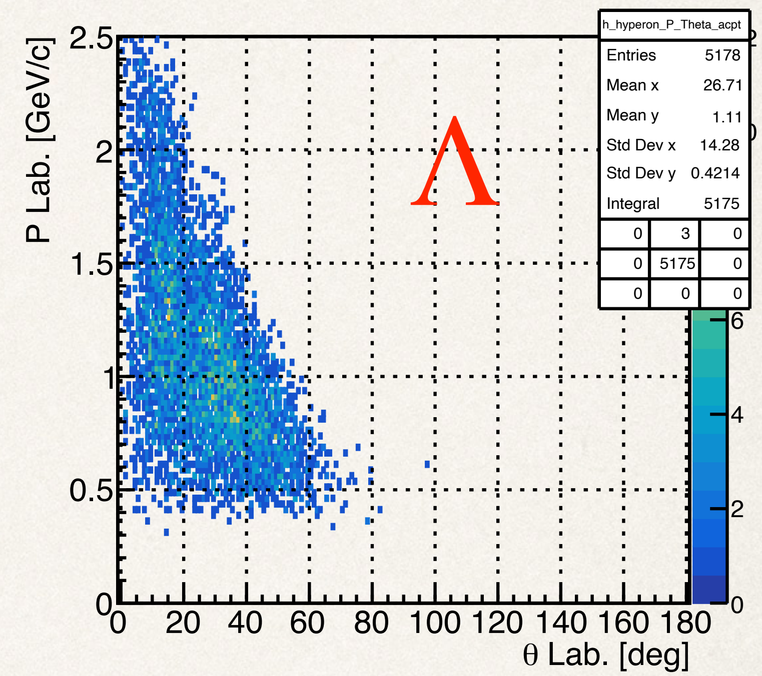


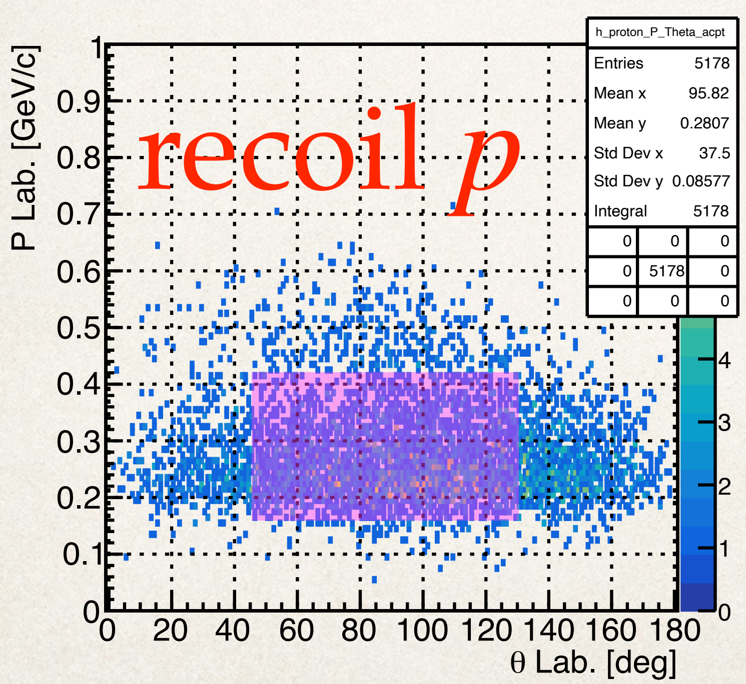


Simulation: W/O requesting recoil proton



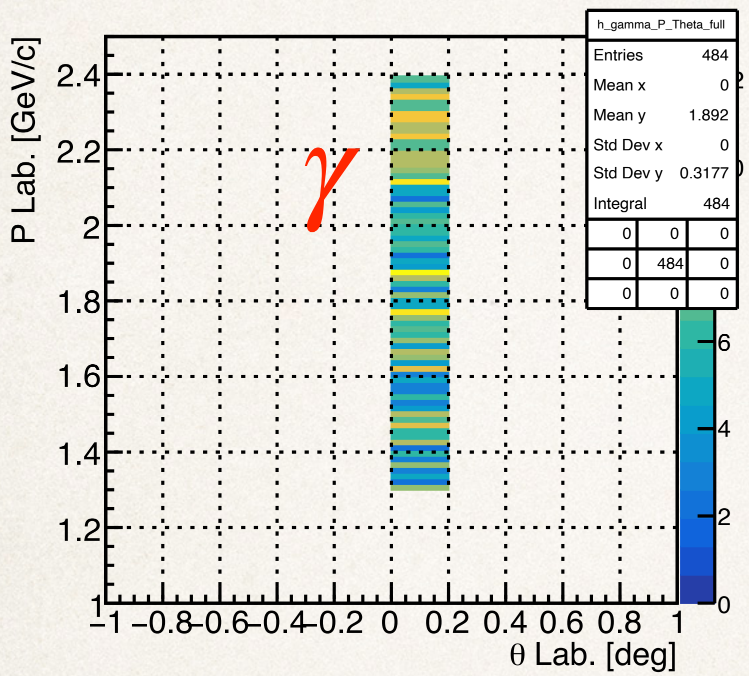


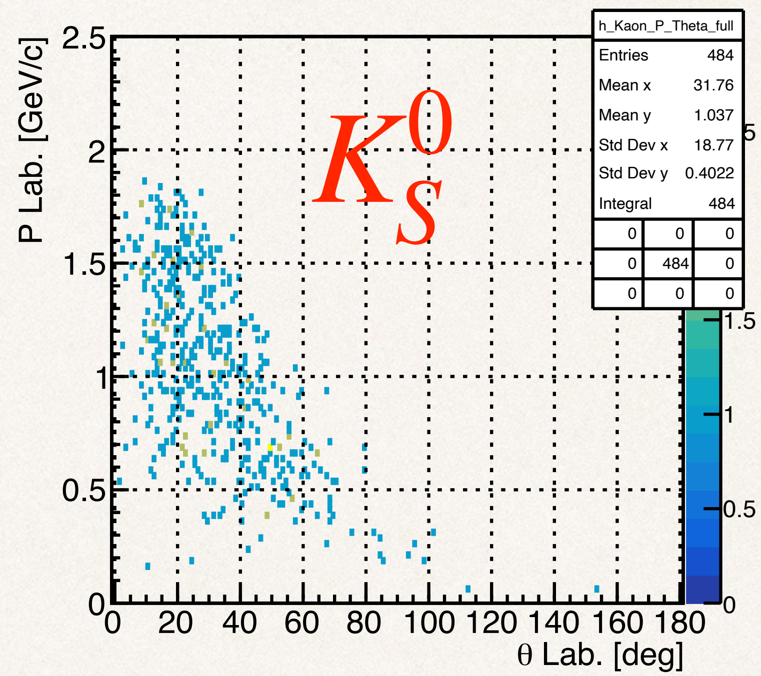


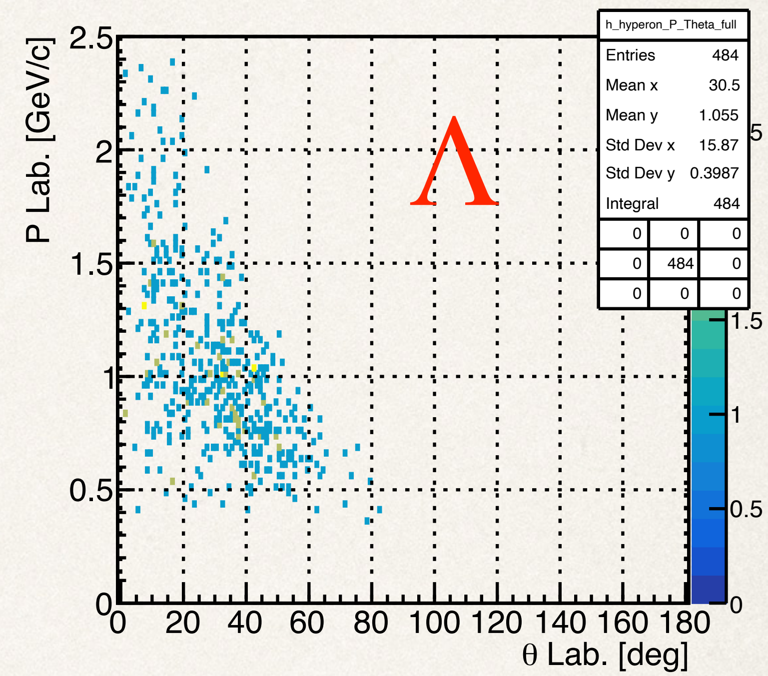


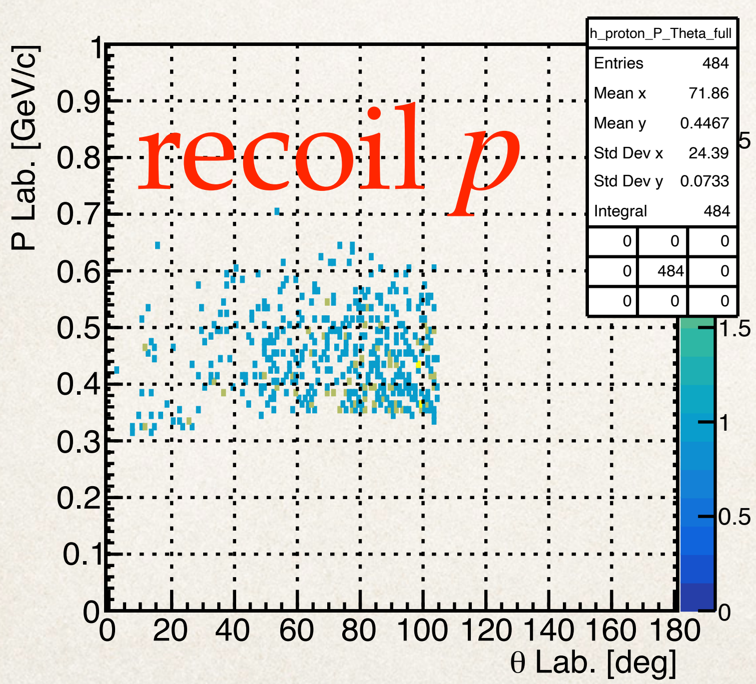
~5k events fall into
acceptance of FRPC/BRPC
W/O analysis efficiency
W/O requiring recoil proton on BRPC
TPC dE/dx for recoil proton PID
--> TPC acceptance 45~135deg?

Simulation: W/ proton









~200 events fall into acceptance of FRPC/BRPC

W/O analysis efficiency

W/ requesting recoil proton on BRPC

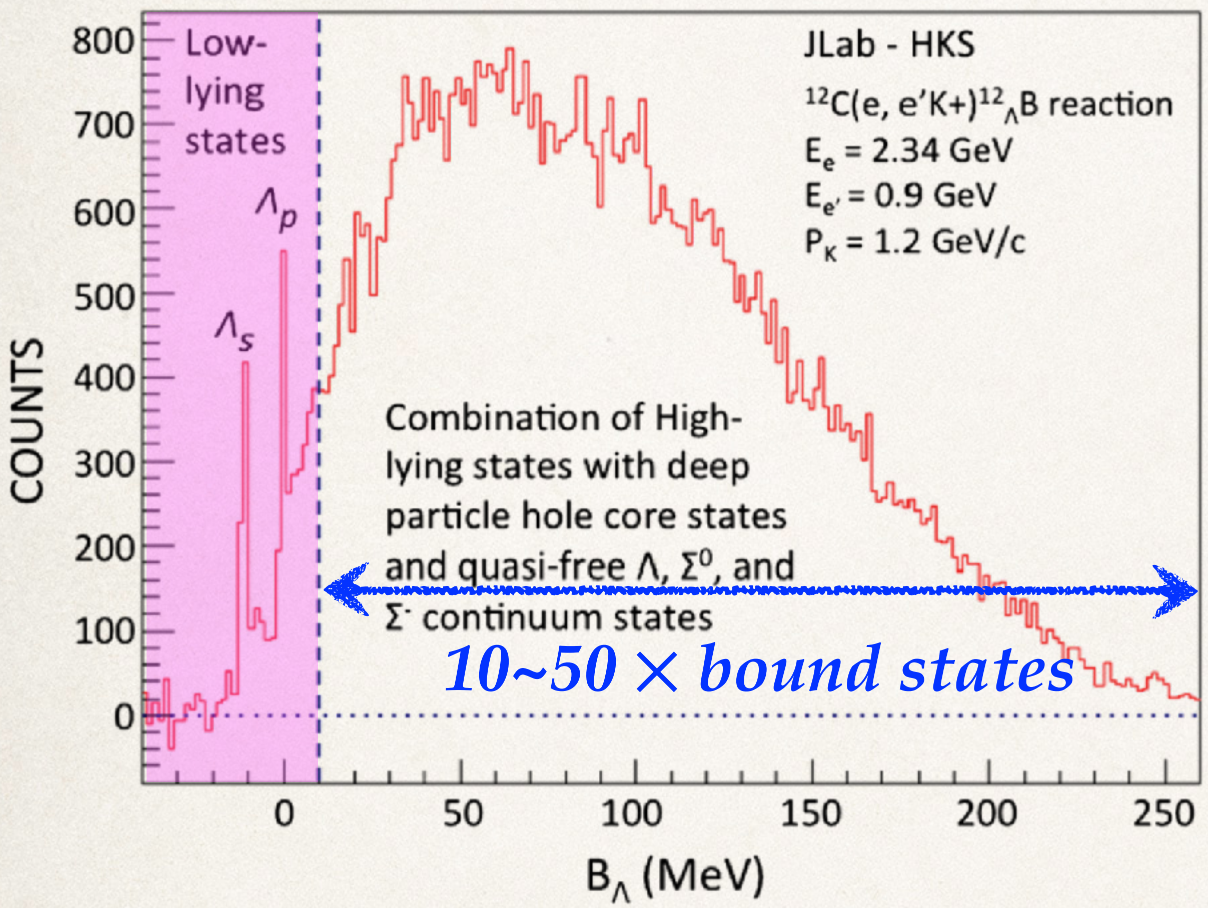
Current status

- As a by product of the on-going LEPS2 experiment to search for Kpp deeply bound state as $d(\gamma, \Lambda p)K^0$ at SPring8 facility, we have enough calibration data for D2 target to verify the FSI and other backgrounds

- Official proposal for dedicated beam time to study short range correlation with various nucleus targets will be submitted to Q-PAC

- Data analysis will start very soon

Summary



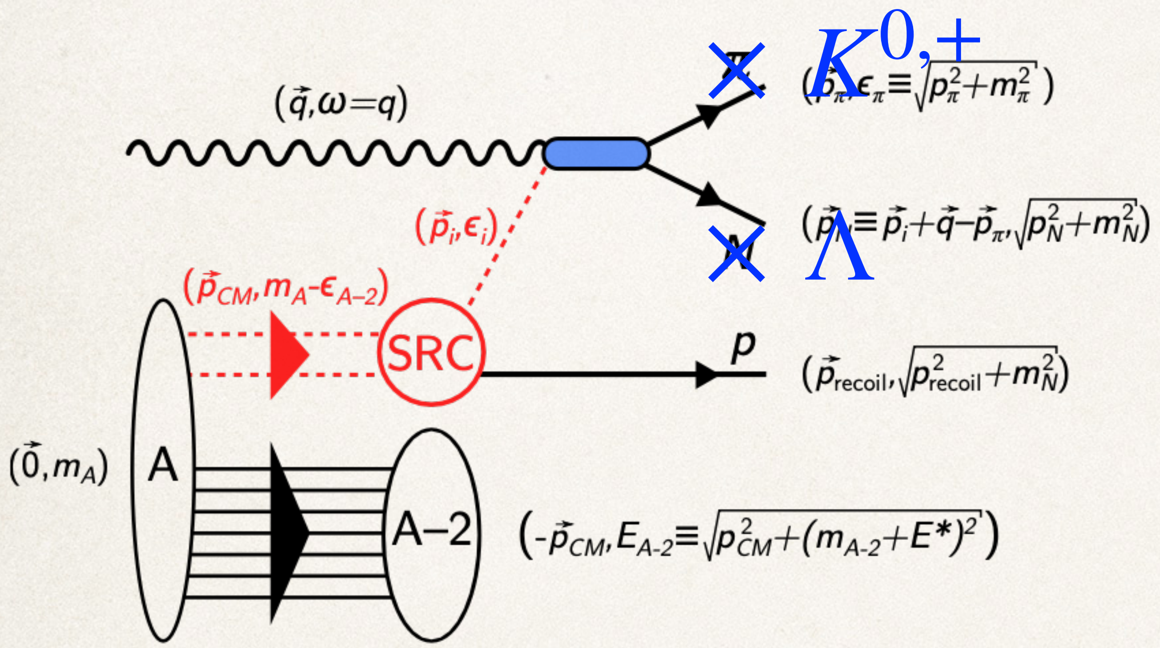
Let's explore the unexplored:
it is more exciting than excited.

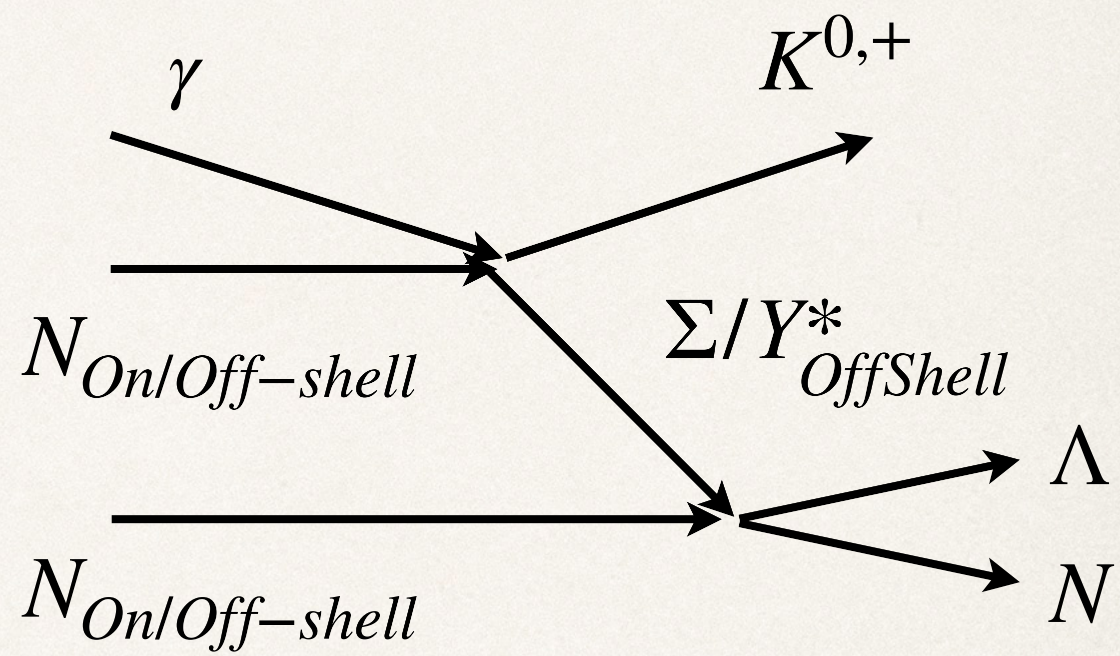
- LEPS2 provides unique chance for probing nuclear structure with Λ hyperon as a hard probe for short range correlation study

- backup

Pseudo-analysis: how to tell our story?

- SRC vs $YN \to \Lambda N$ conversion ($\Delta N \to NN$)





  - For SRC process, $\gamma + n_{SRC} \to K^0 + \Lambda$ should have the same (or similar) $K^{0,+}$ angular distribution as the elementary reaction, which is different from $\gamma + n \to K^0 + Y^*$?!
  - Can this help us to estimate contributions from background channels, such as $YN \to \Lambda N$? FSI smearing?