Search for ϕ-N Bound State in Jefferson Lab Hall-B

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For Short Range Correlation Workshop

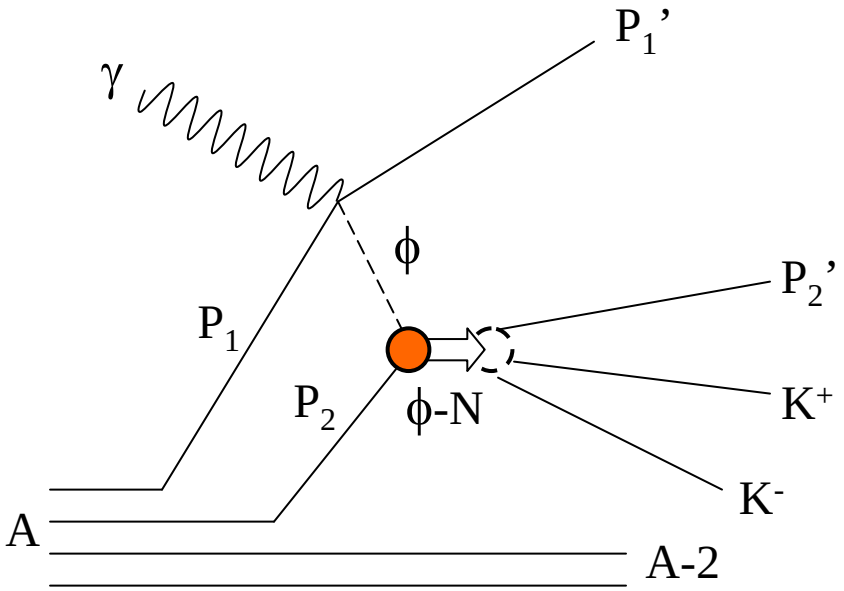
Nuclear-Bound Quarkonium

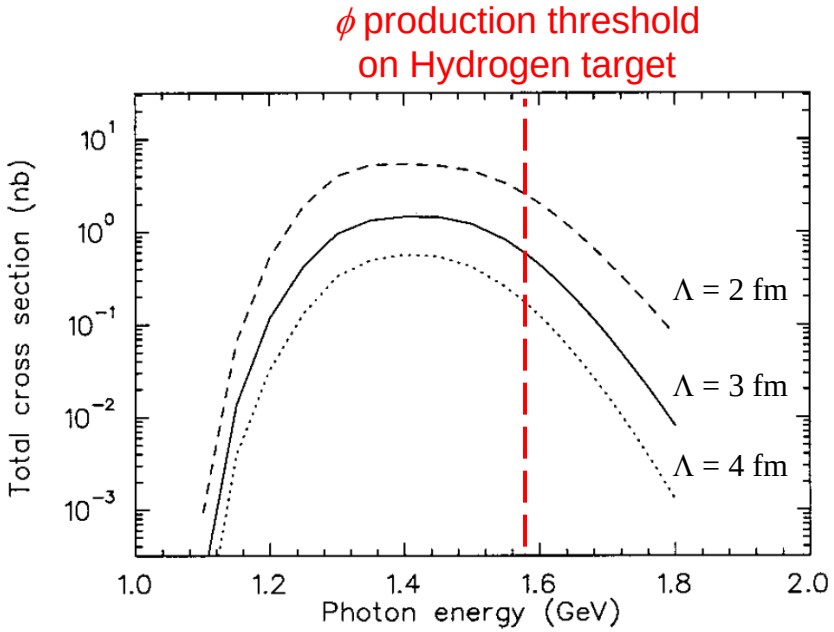
- S. J. Brodsky, I. A. Schmidt, and G.F. de Teramond, Phys. Rev. Lett. **64**, 1011 (1990).
- D. A. Wasson, Phys. Rev. Lett. **67**, 2237 (1991).
- **QCD van der Walls interaction**, mediated by *multi-gluon exchanges*, is dominant when the two interacting color singlet hadrons have **no common quarks**.
- Suggested a bound state of charm quarkonium to ^{3}He nucleus: η_c-^{3}He.
- Binding energy ~ 20 MeV, width ~ tens of keV.

ϕ-N Bound State

- H. Gao, T.-S. H. Lee, and V. Marinov, Phys. Rev. C **63**, 022201 (2001).
  - The interaction is expected to be enhanced by $(m_c/m_s)^3$.
  - ϕ-N can be formed inside heavy nuclei through quasi-free ϕ photoproduction.
- F. Huang, Z. Y. Zhang, and Y. W. Yu, Phys. Rev. C **73**, 025207 (2006).
  - Chiral SU(3) quark model.
  - The model has good description of baryon ground states, deuteron binding energy, etc.
- Binding energy 2 ~ 9 MeV.

Creation of ϕ-N Bound State in Heavy Nuclei





H. Gao, T.-S. H. Lee, and V. Marinov, Phys. Rev. C **63**, 022201 (2001)

- "Sub-threshold" generated ϕ is slow enough to bound with nucleon.
- $\sigma^{tot} \sim 1.4$ nb on ^{12}C nucleus.

Possible Way to Detect ϕ-N

- "Sub-threshold" ϕ production in nuclei.
  - Can use real photon, electron or proton beam.
  - Need to tag energy of real/virtual photon.
- Detect all final states of ϕ-N bound state decay to reconstruct its invariant mass.
  - $\phi - N \rightarrow p_2' + K^+ + K^-$: triple coincidence.
- Jefferson Lab Hall B is a possible place to search for such particle:
  - Large acceptance detector and tagged photon beam.
  - Good particle identification.

Background Channels

- 3 major background channels
  - Direct production:

$$\gamma + p_1 \rightarrow p_1' + K^+ + K^-$$

  - No Bound State:

$$\gamma + p_1 \rightarrow p_1' + \phi \rightarrow p_1' + K^+ + K^-$$

  - $\Lambda(1520)$ Production:

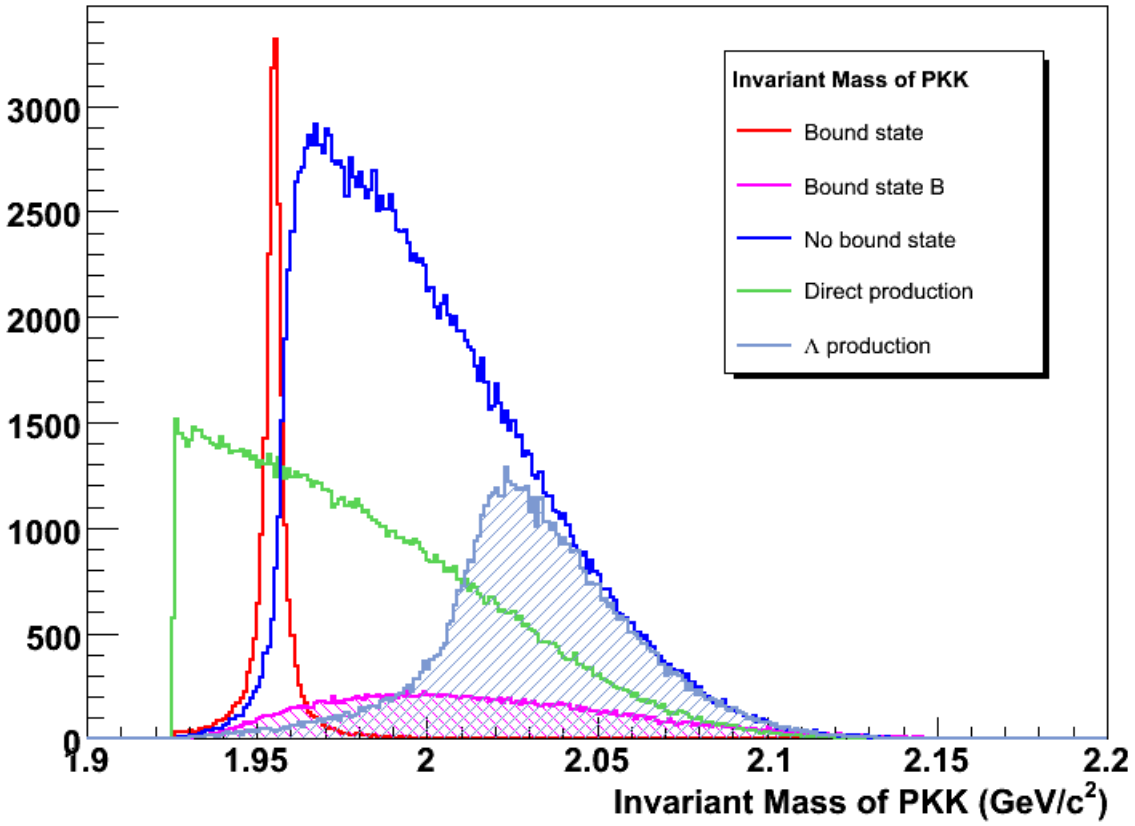
$$\gamma + p_1 \rightarrow \Lambda(1520) + K^+ \rightarrow p_1' + K^- + K^+$$

- Bound state formed but K^+ K^- coincide with the recoil proton p_1'.

Phase Space Simulation

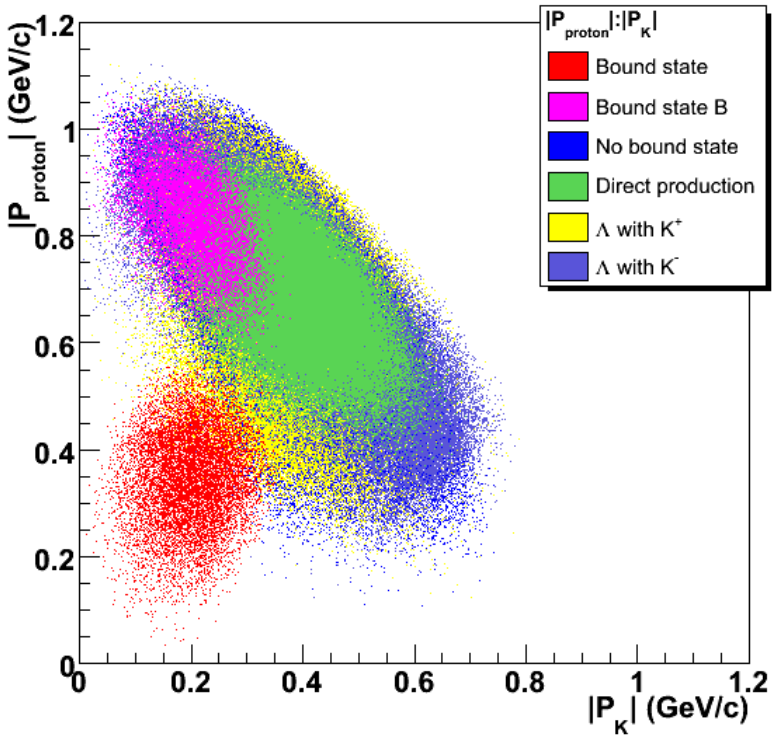
- Done by S. Liska and Y. Qiang.
- On four nuclear targets: ^{12}C, ^{56}Fe, ^{63}Cu and ^{197}Au.
- Fermi motion and missing energy distributions were taken into account in the simulation of quasi-free process.
- The following results were from ^{63}Cu target with photon energy $E\gamma = 1.45 \sim 1.55$ GeV.

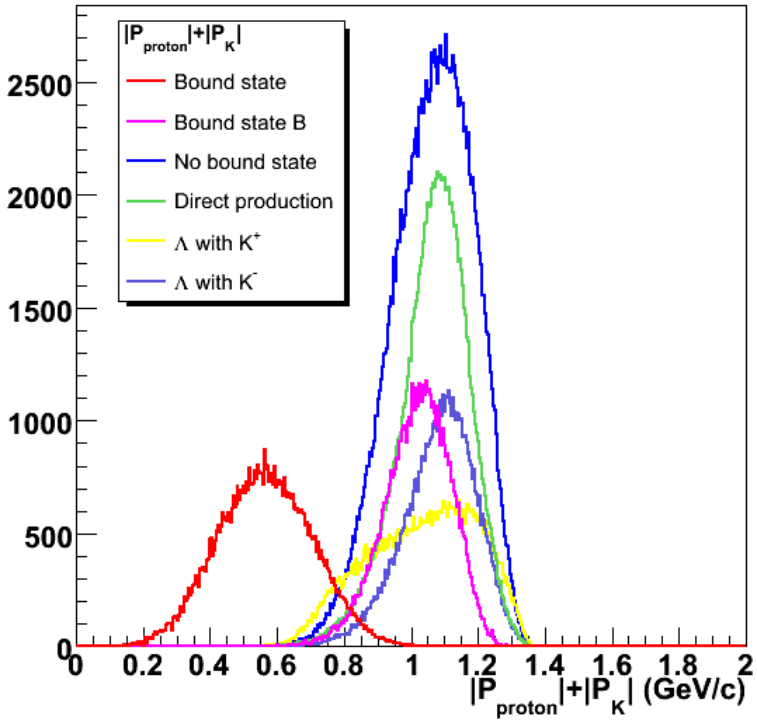
Invariant Mass of $p\ K^+\ K^-$



- ϕ-N bound state is mixed with other channels.

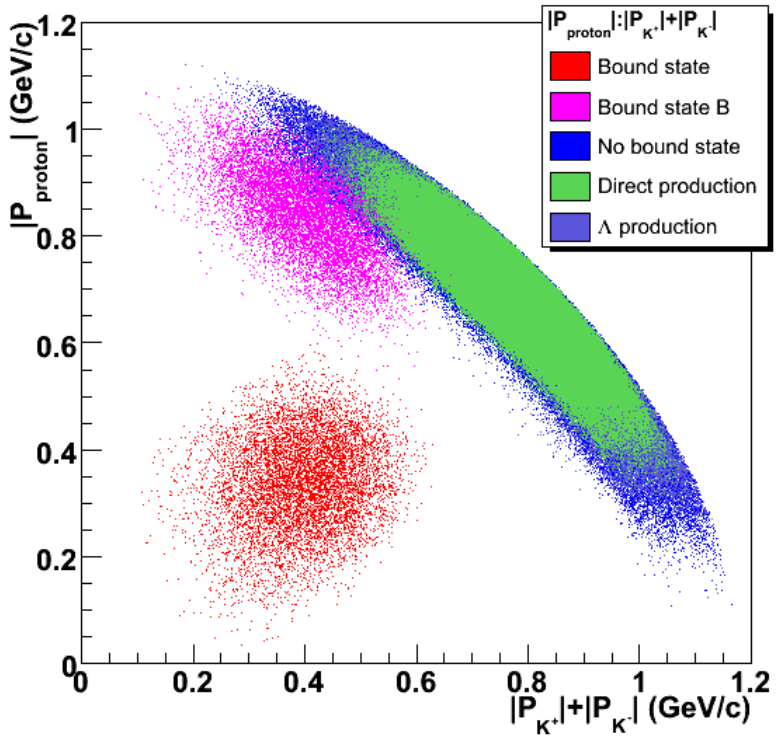
Cut in Momentum Distribution

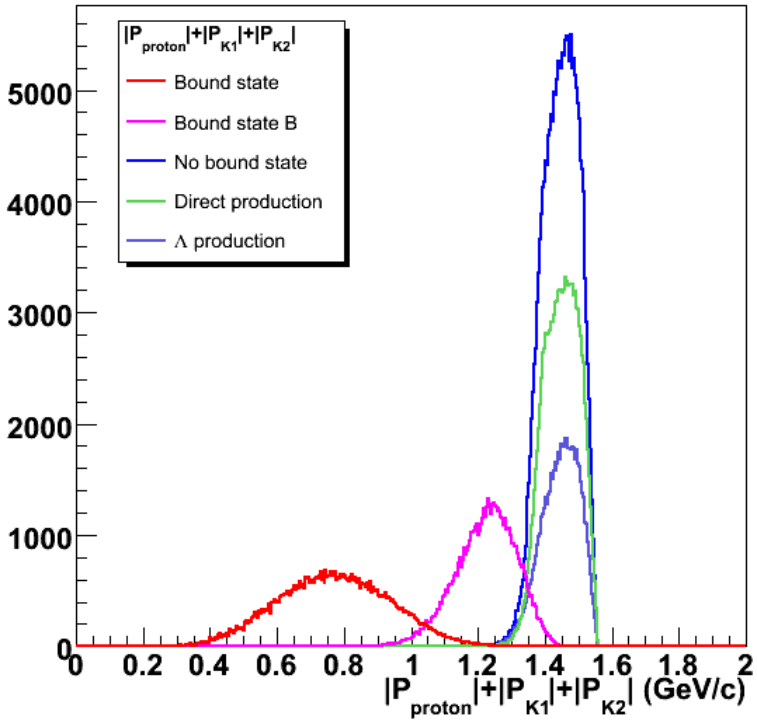




- ϕ-N bound state can be separated, but not clean.

Improved Cut in Momentum Distribution

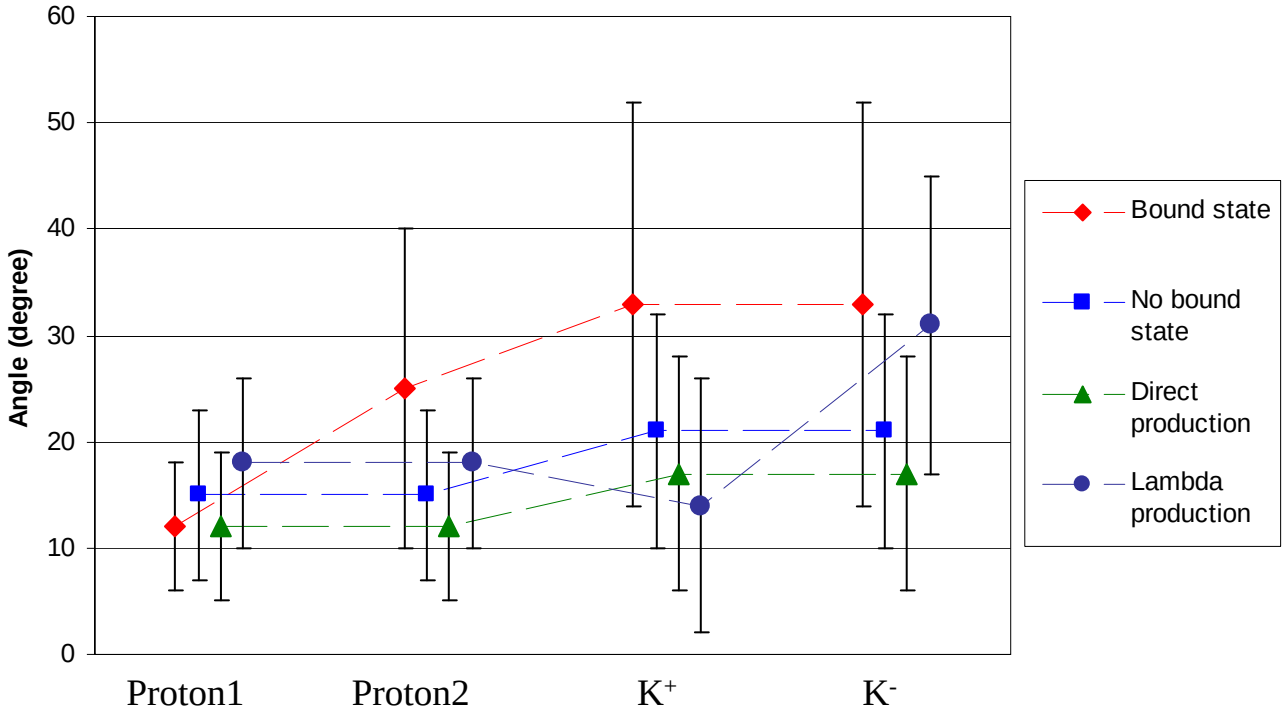




- ϕ-N bound state can be clearly identified.

Angles of Final States

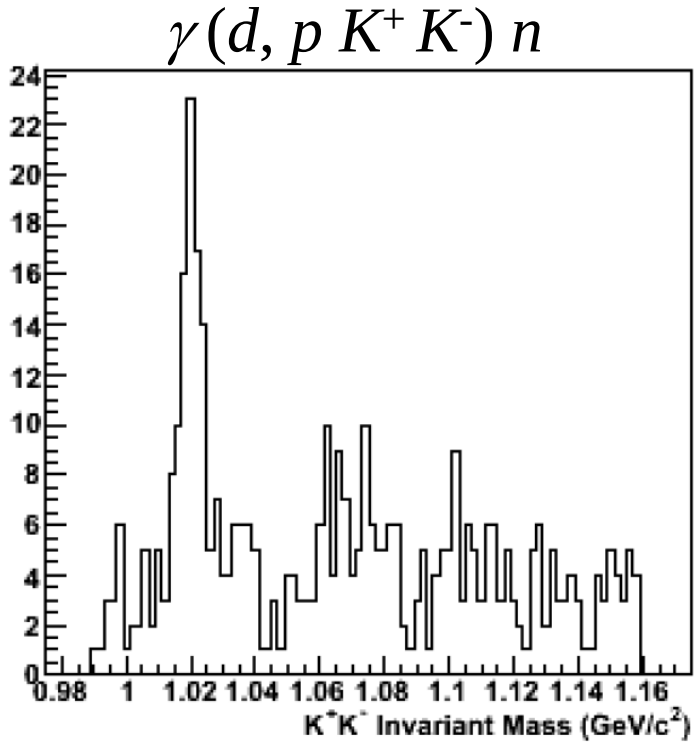
- All particles are produced forward while the final states of ϕ-N bound state have the largest angles.

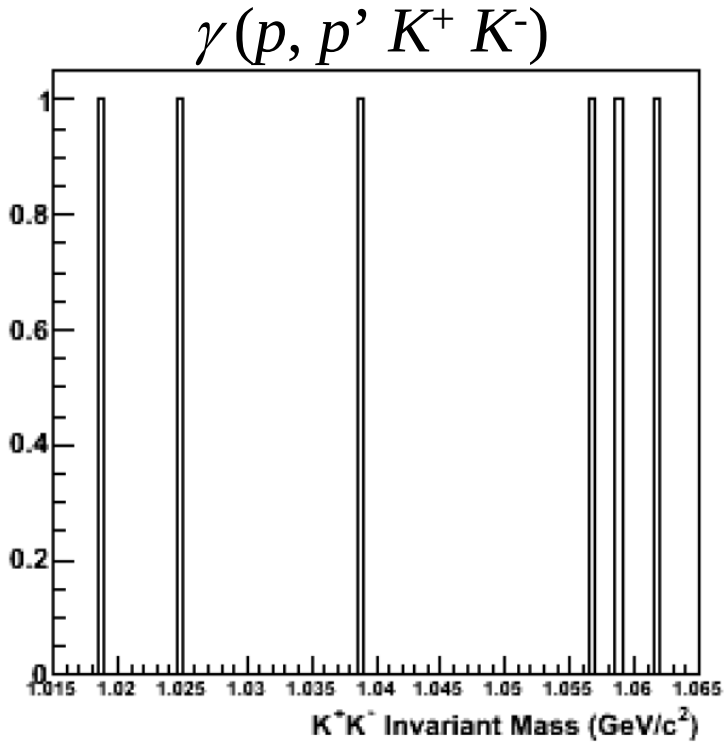


Summary of ϕ-N Final States

- $\phi - N \rightarrow p_2' + K^+ + K^-$
  - p_2' : 200 ~ 500 MeV/c 10^o ~ 40^o
  - K^+ : 100 ~ 300 MeV/c 13^o ~ 52^o
  - K^- : 100 ~ 300 MeV/c 13^o ~ 52^o

Evidence of ϕ Production from Fermi Motion

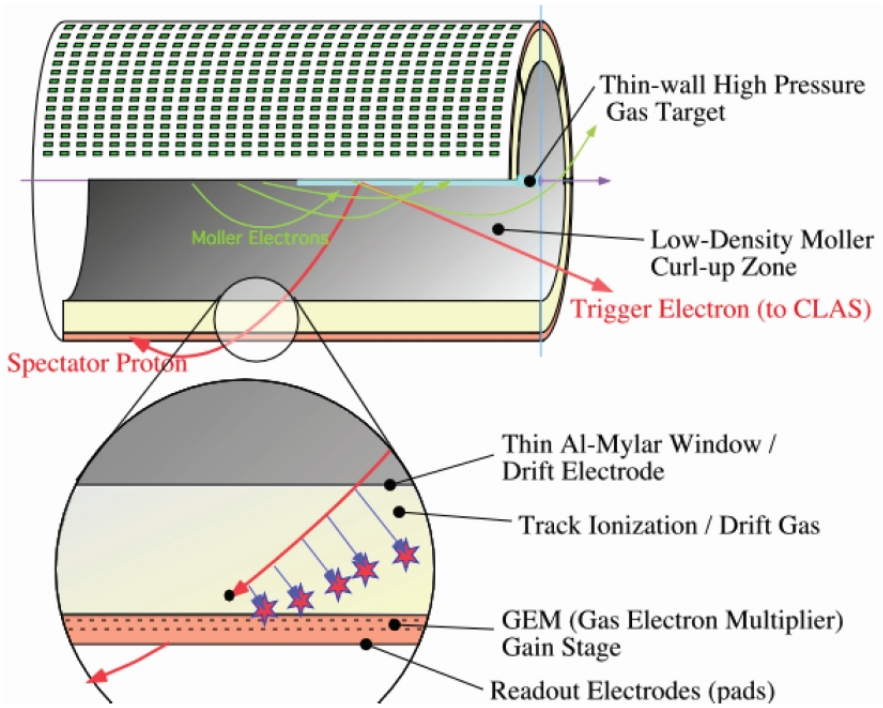




- Analyzed by X. Qian using CLAS g10 data, Eγ = 1.65~1.75 GeV.

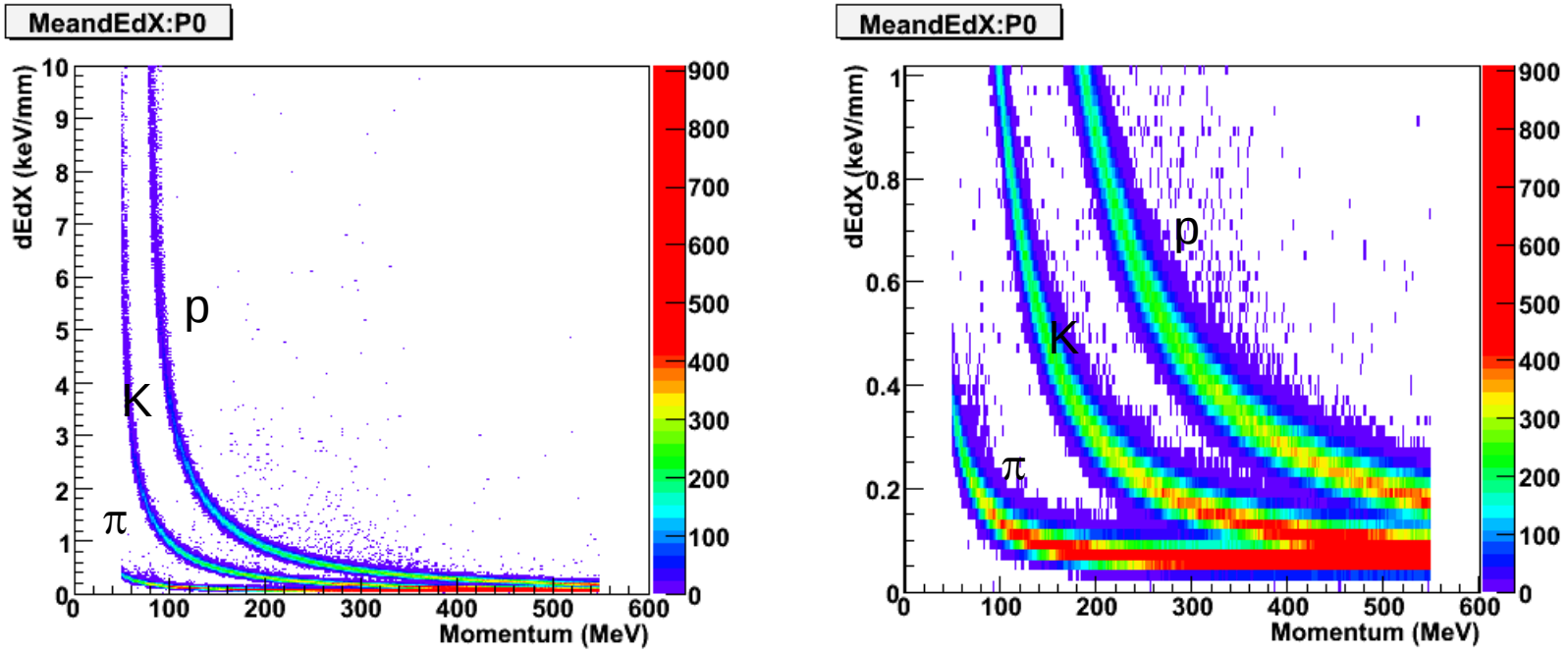
Study on BoNuS Detector

- Radial Time Projection Chamber (RTPC) using GEM foils.
- Active drifting volume: L=20 cm, R=3 cm.
- Longitudinal field is generated by Møller solenoid (2~7 T).



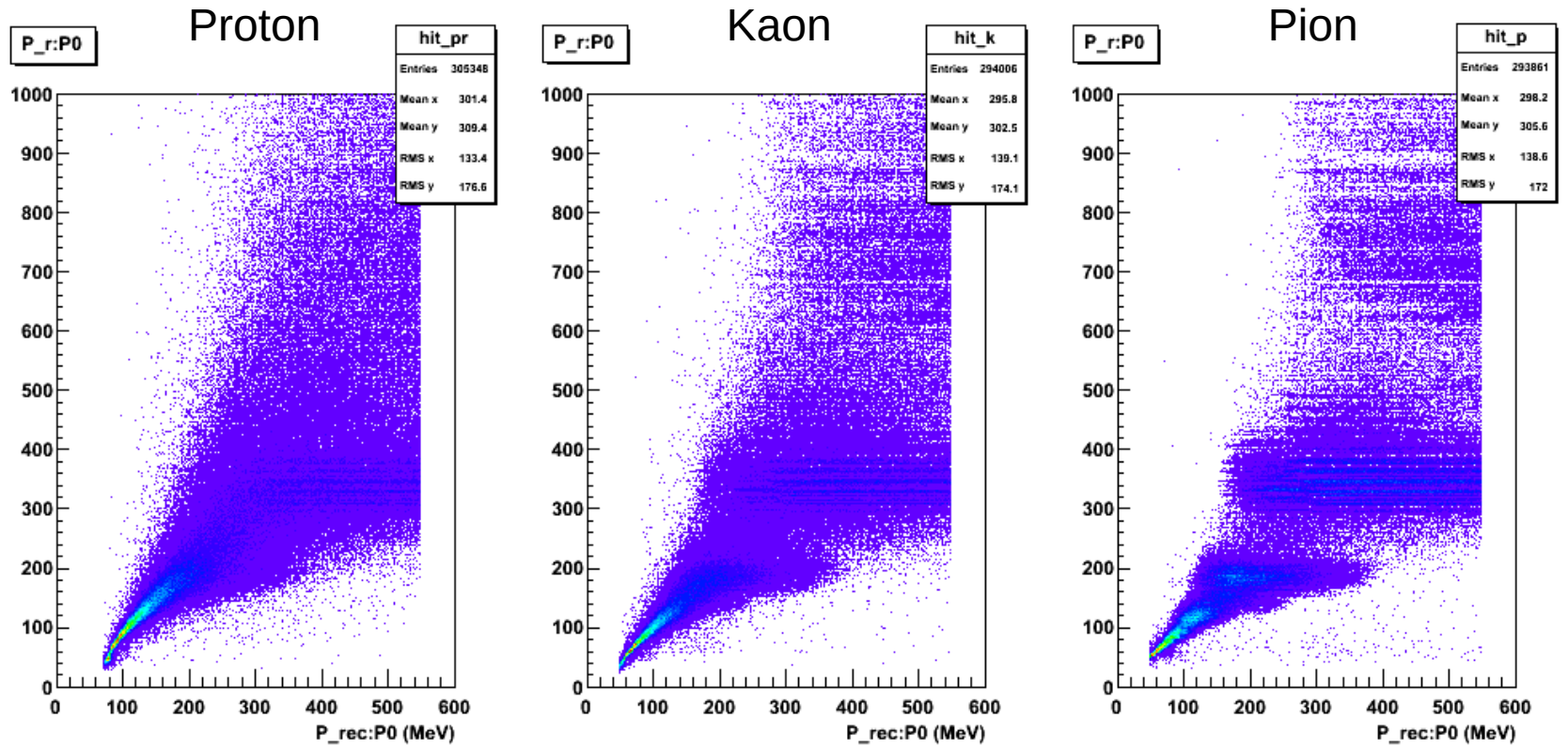
- Can be used to detected low momentum charged particles (< 250 MeV/*c*).
- GEANT4 simulation code by J. Zhang.

Average dE/dX in BoNuS



- BoNuS uses energy loss **dE/dX** and **momentum** reconstructed from measured curvature to identify charged particles.

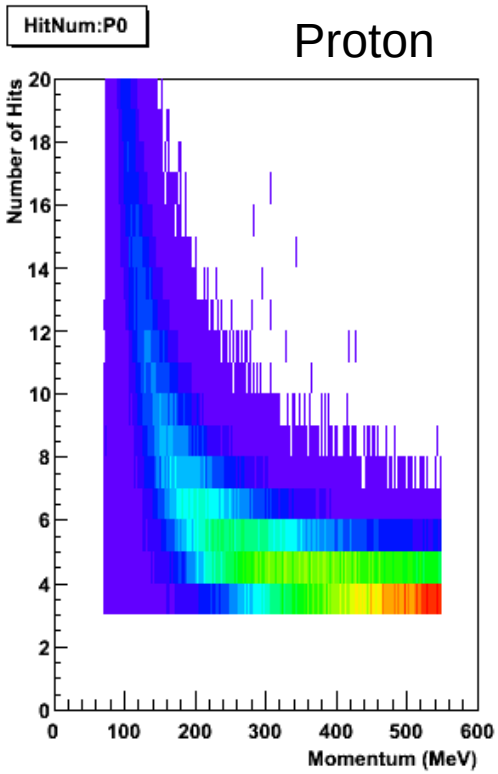
Momentum Reconstruction

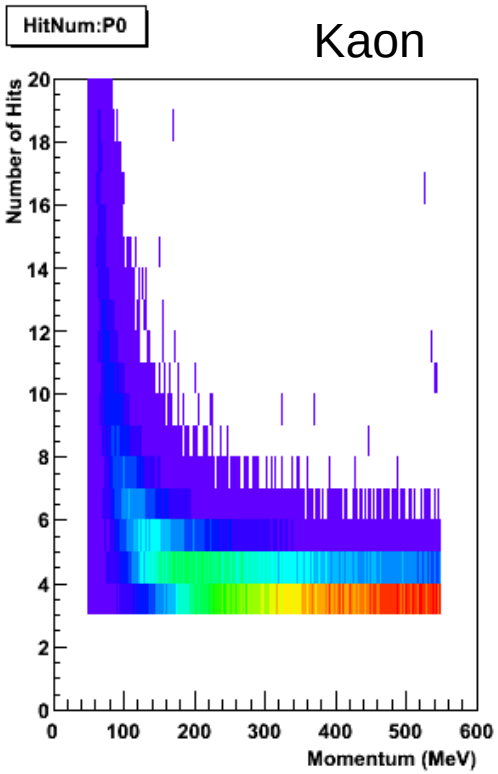


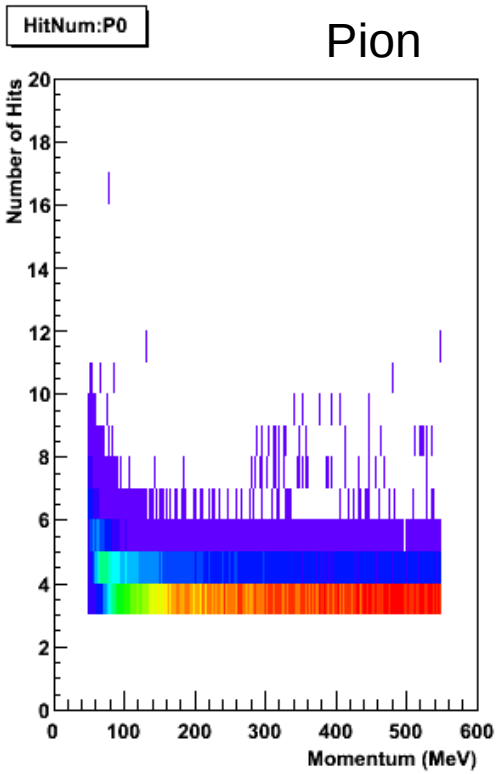
- Only low momentum (<200MeV/*c*) could be reconstructed correctly.

Number of Hits

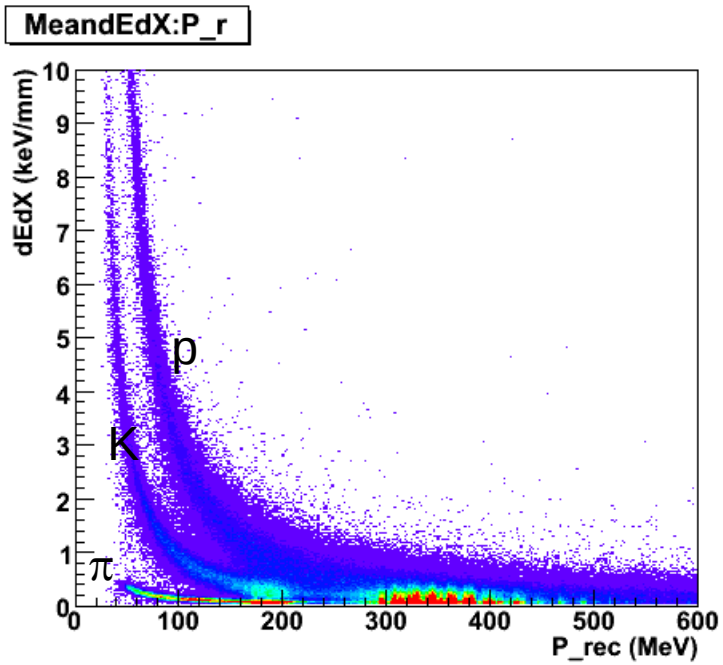
- More than 3 hits are required to define a track:

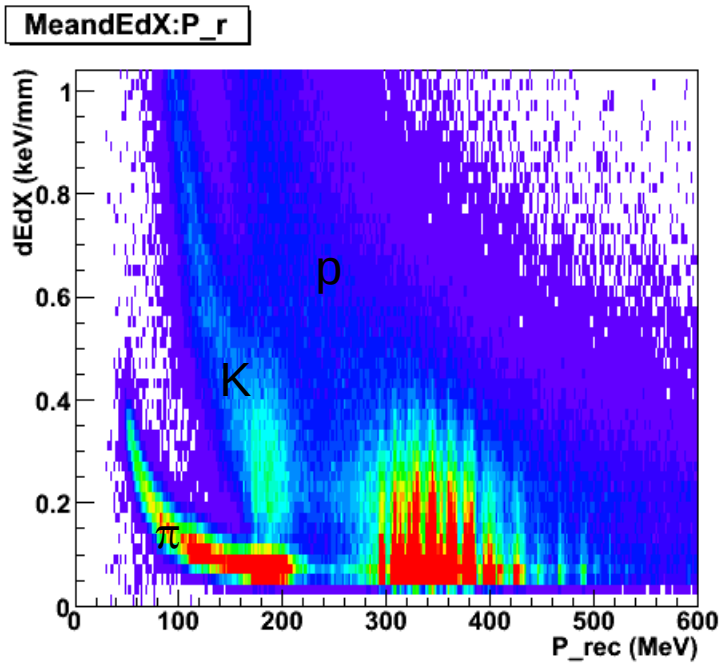






dE/dX vs. Reconstructed Momentum





- The BoNuS RTPC can identify charged particles with momentum below 200 MeV/*c*.
- The use of CLAS seems to be necessary.

Summary

- The search of ϕ-N bound state (QCD molecular state) is important and exciting.
- ϕ-N bound state has moderate cross section to be detected in sub-threshold ϕ photo-production.
- Background channels can be clearly excluded with momentum cut.
- Jefferson Lab Hall B may be a good place to carry out the search.
- Our study on the BoNuS RTPC has been done.
- Study on CLAS detector is still underway.

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