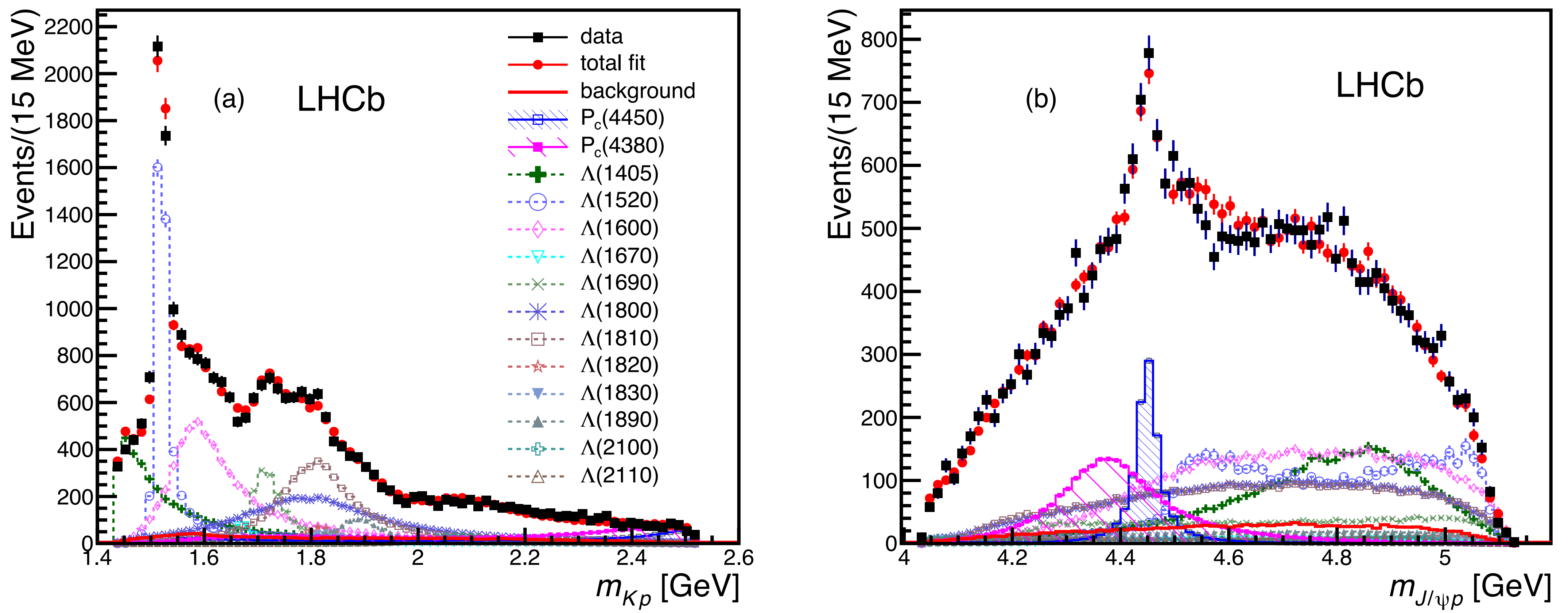
# Search for $\phi$-N bound state

Chao Gu

Duke Medium Energy Physics Group

# Why $\phi$-N bound state?

- The multiquark state is one of the active frontiers since the establishment of the quark model:
    - Recently observed hidden charm pentaquark candidates $P_C(4380)$ and $P_C(4450)$ by LHCb
- The study of multiquark states is an approach to understand the dynamics of the strong interaction at the hadronic scale.




Phys. Rev. Lett. 115(2015)072001

# Why $\phi$-N bound state?

- QCD van de Waals force: the dominant (attractive) interaction between two hadrons when they have no common quarks
    - Strong enough to bind a charmonium to a nucleus
    - Enhanced at low relative velocities between the two hadrons, which supports the prediction that a nucleon/nucleus-charmonium bound state can be produced near the charm production threshold
- Extension to strangeness:
    - $\phi$ meson could also be bound to a nucleon/nucleus
    - Theoretical studies predict the existence of a $\phi$-N bound state, a recent study shows the mass of 1950 MeV and the width of 4 MeV, and the feasibility to search for this bound state at Jefferson Lab
    - Some chiral quark model calculation and lattice QCD calculation also support the existence of such a kind of bound state


✳ **Our paper "Search for a hidden strange baryon-meson bound state from $\phi$ production in a nuclear medium", Phys. Rev. C 95(2017)055202**

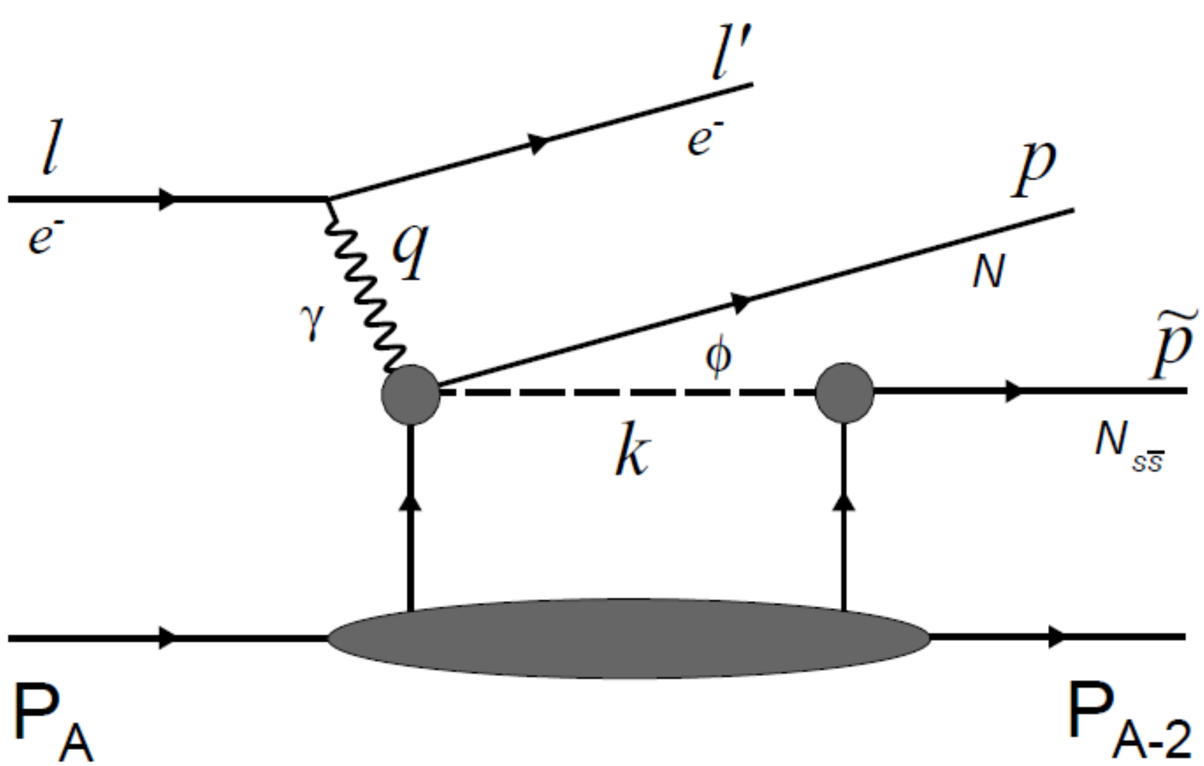
✳ **H. Gao, T. S. H. Lee, and V. Marinov, Phys. Rev. C 63(2001)022201**

✳ **F. Huang, Z. Y. Zhang, and Y. W. Yu, Phys. Rev. C 73(2006)025207**

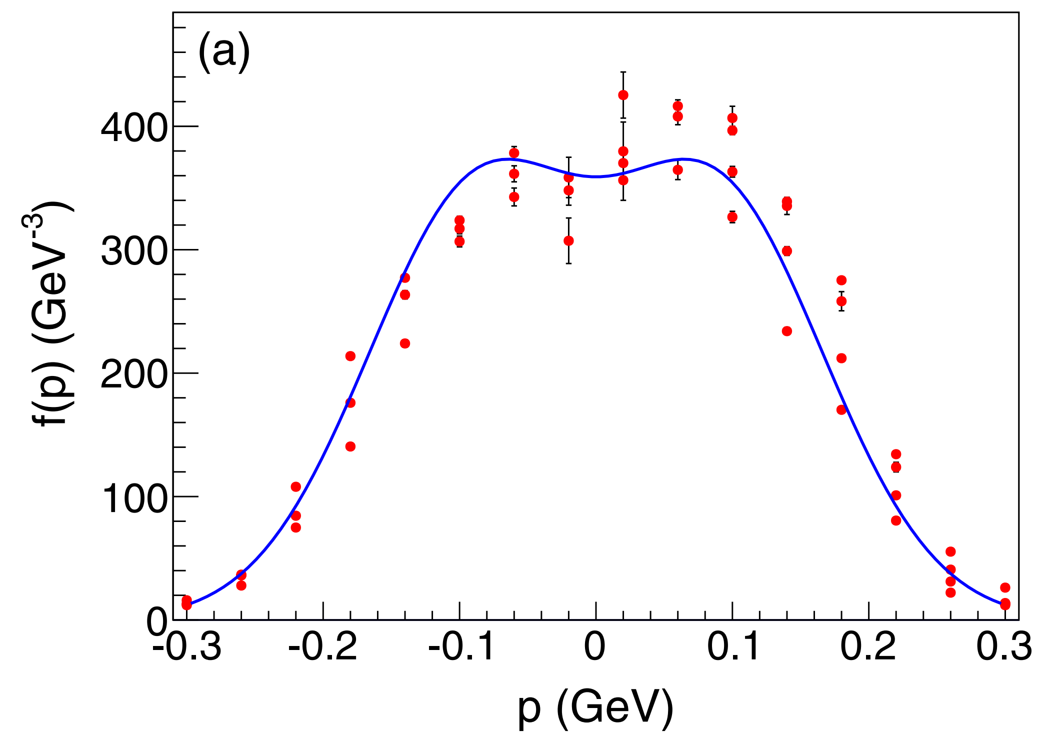
✳ **S. R. Beane et. al., Phys. Rev. D 91(2015)114503**

# Production of $\phi$-N bound state

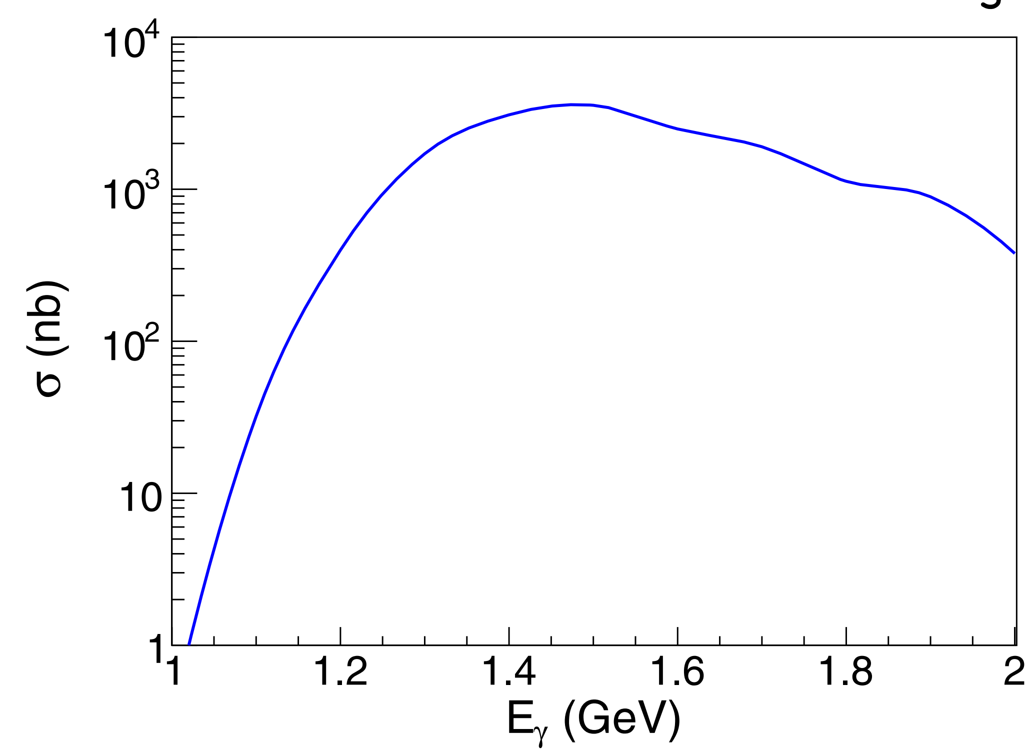
- Sub-threshold and near-threshold production of $\phi$ meson inside a nuclear medium
- Then $\phi$ interacts with a nearby slow nucleon




The mechanism of $\phi$-N bound state electro-production on a nuclear target



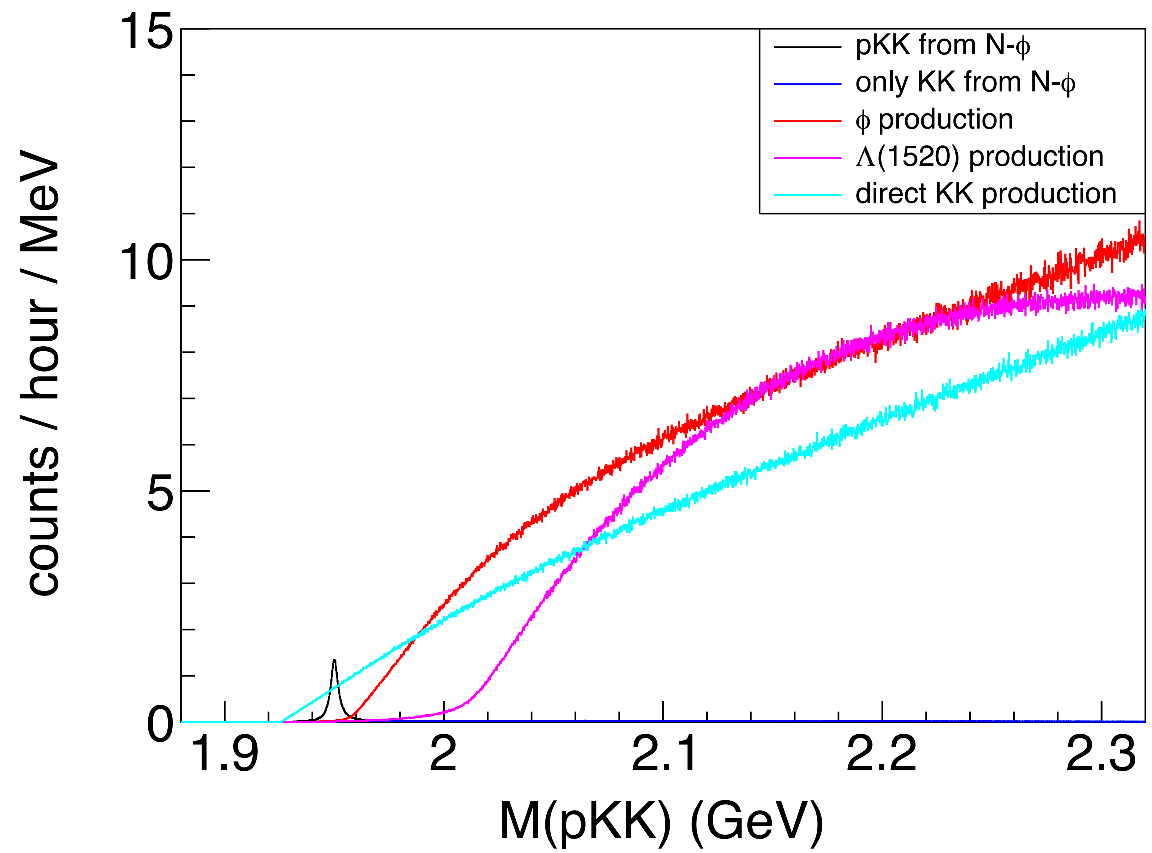

The nucleon momentum distribution of gold




The photo-production cross section of the $\phi$-N bound state on gold

# How to detect it

- Dominate decay channel NKK ($pK^+K^-$) with 4MeV width
- Prefer photon beam or quasi-real electron beam for better yield
- Need to detect $pK^+K^-$ below 500 MeV and down to 50 MeV to optimize the signal detection and we can cut away high energy particles to suppress the background

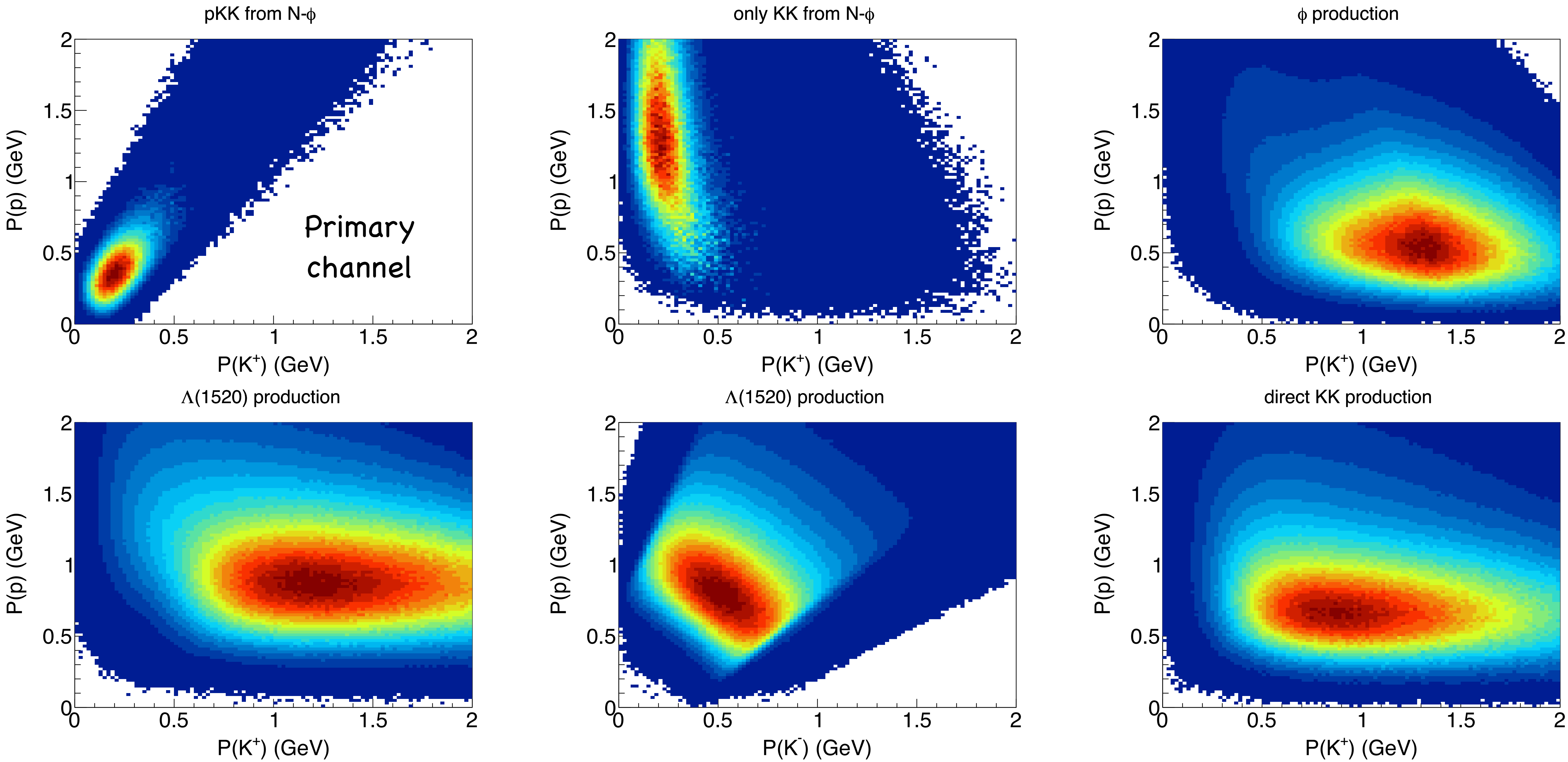



The invariant mass spectra of $pK^+K^-$ from different channels

| Decay channel | QDCSM1 | | QDCSM2 | | QDCSM3 | |
|---|---|---|---|---|---|---|
| | $\Gamma_i$(MeV) | $\Gamma_i/\Gamma$(%) | $\Gamma_i$(MeV) | $\Gamma_i/\Gamma$(%) | $\Gamma_i$(MeV) | $\Gamma_i/\Gamma$(%) |
| $N\eta'$ | 0.002 | 0.1 | 0.022 | 0.5 | 0.009 | 0.2 |
| $\Lambda K$ | 0.011 | 0.3 | 0.120 | 2.9 | 0.055 | 1.2 |
| $\Sigma K$ | – | 0.0 | 0.060 | 1.5 | – | 0.0 |
| $\phi$ decays | 3.619 | 99.6 | 3.892 | 95.1 | 4.616 | 98.6 |

The decay widths and branch ratios of each decay channel of $\phi$-N bound state

# How to detect it



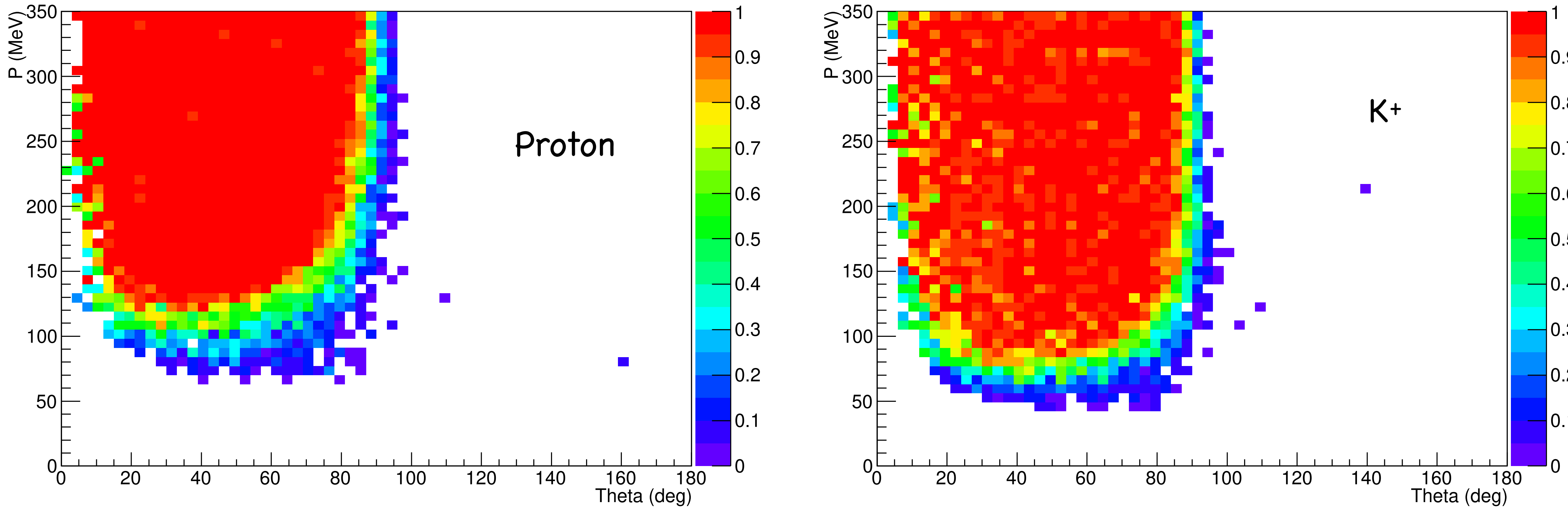

The proton-kaon momenta distributions from different channels, the proton and the kaons which are decay products from the bound state concentrate in the low momentum region

# Proposed experiment

- Perform this measurement in Hall B using a gold foil target (LOI12-17-002)
    - 4.4GeV 100nA electron beam on a 0.138mm gold foil target: 1e35 nucleon luminosity
    - The scattered electron would be detected by the forward tagger (2.5 - 4.5 deg)
    - Use BONUS12 to detect the proton, $K^+$, and $K^-$ in the final state with momentum from 50 MeV to 250 MeV (proton up to 300 MeV)
    - Use CLAS12 to detect the proton, $K^+$, and $K^-$ in the final state with momentum larger than 300 MeV (depending on torus field)
    - Use momentum cut to suppress out background

# BONUS12

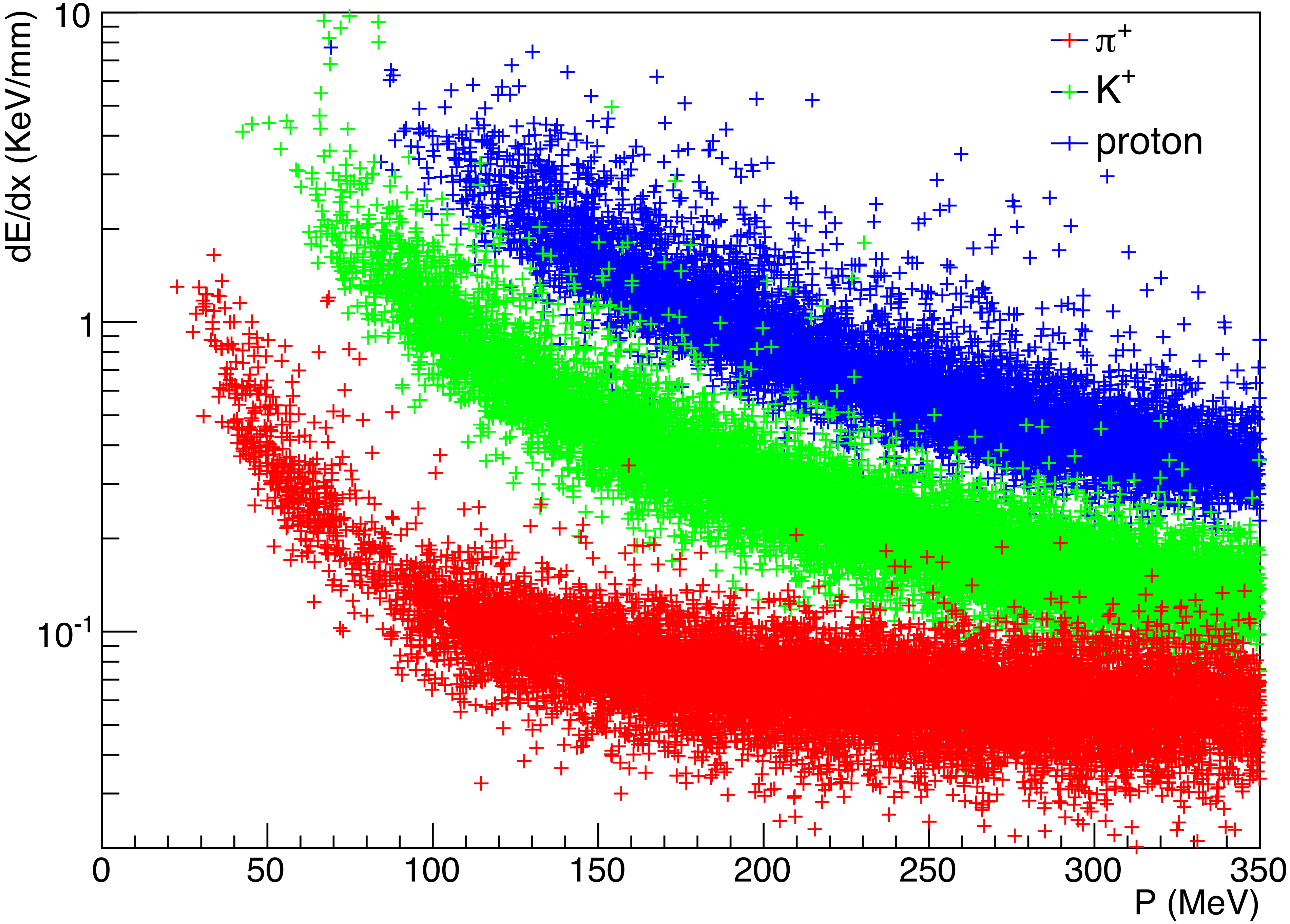
- Use BONUS12 detector to detect low energy kaons and protons
- The gold foil target is located at the upstream entrance to maximize the forward angle acceptance
- New: Use BONUS12 to do Kaon PID
    - Simple study: A Geant4 simulation for the BONUS12 detector (by J. Zhang)



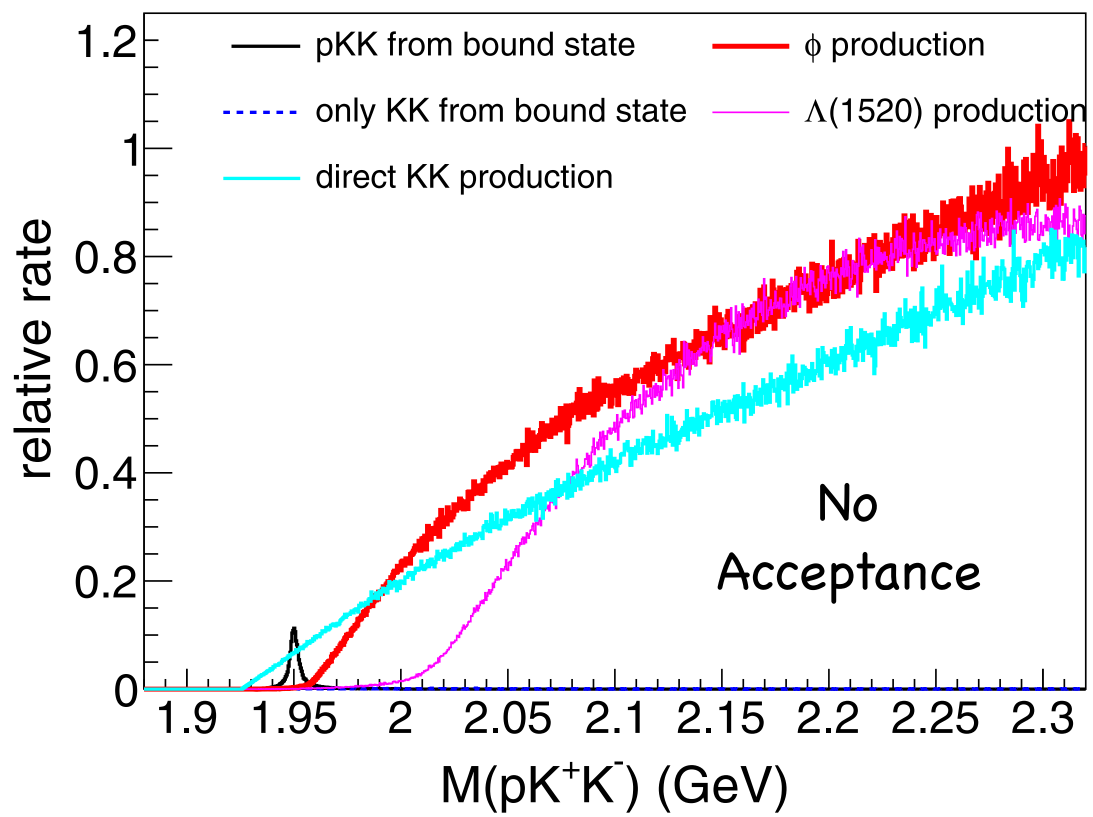

BONUS12 acceptance for proton and $K^{+}$

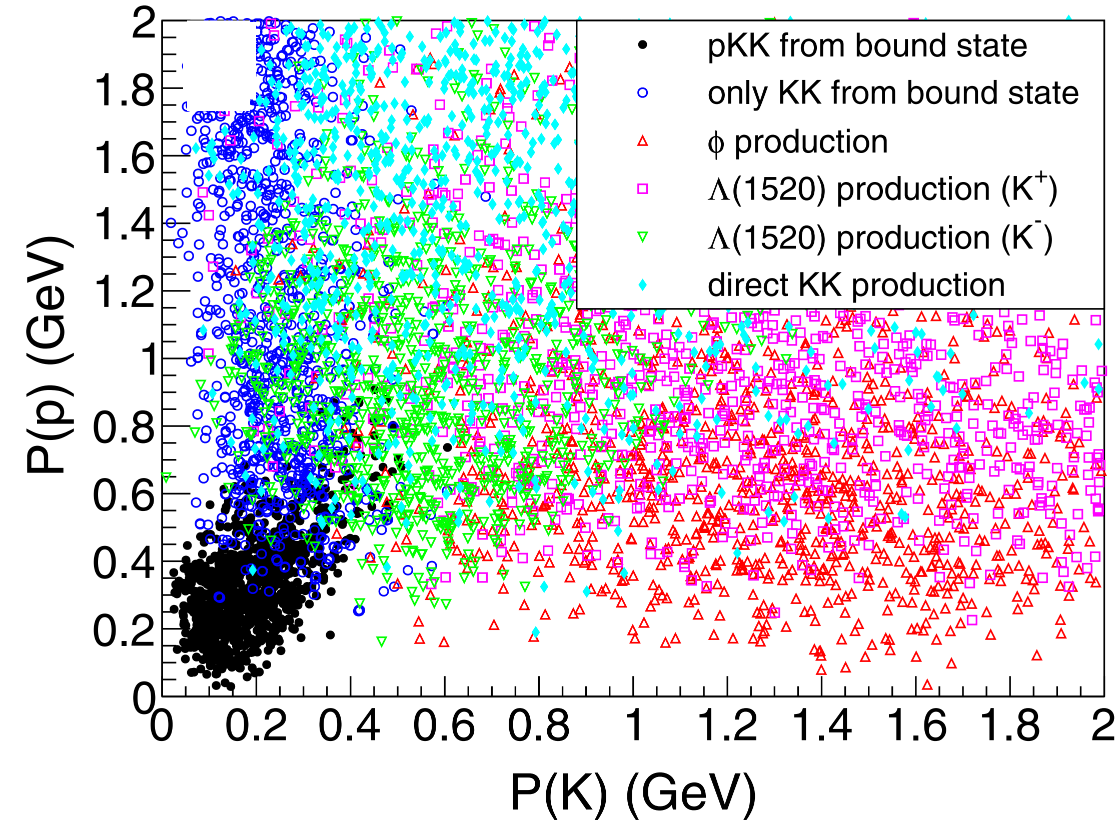
# BONUS12

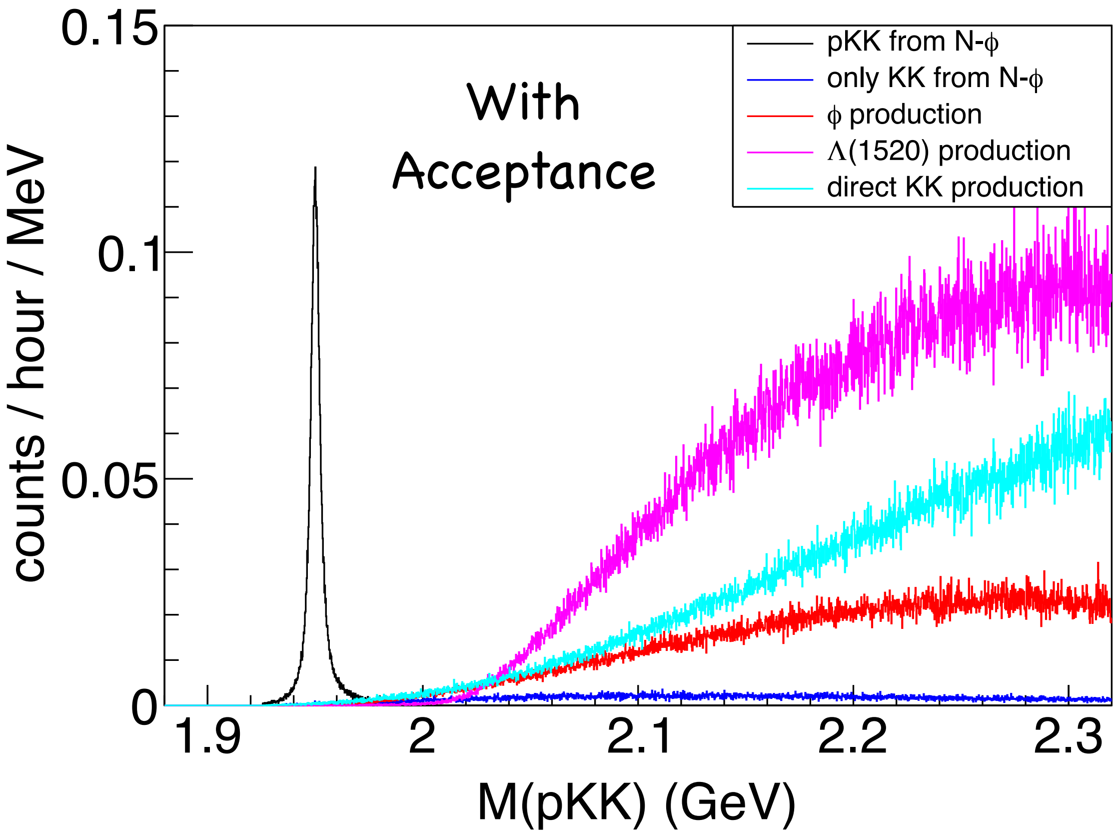
- We expect kaons and protons can be identified below 250 MeV and pions can be suppressed with at least a factor of 10
- Further study is needed to verify its performance.



# Hall B Projection

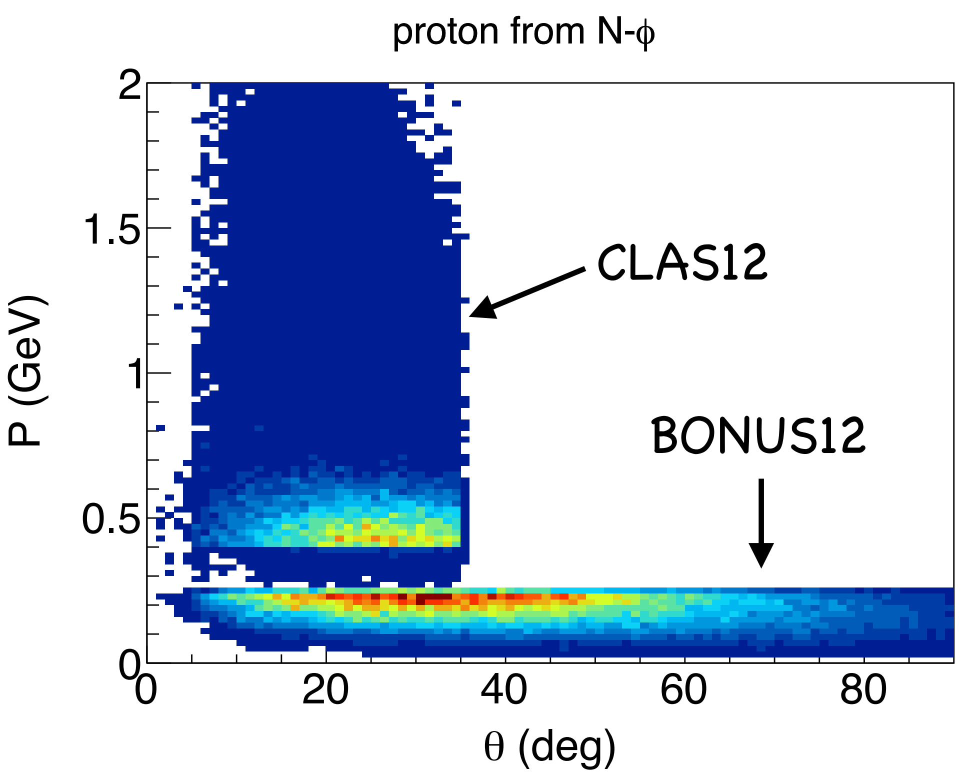


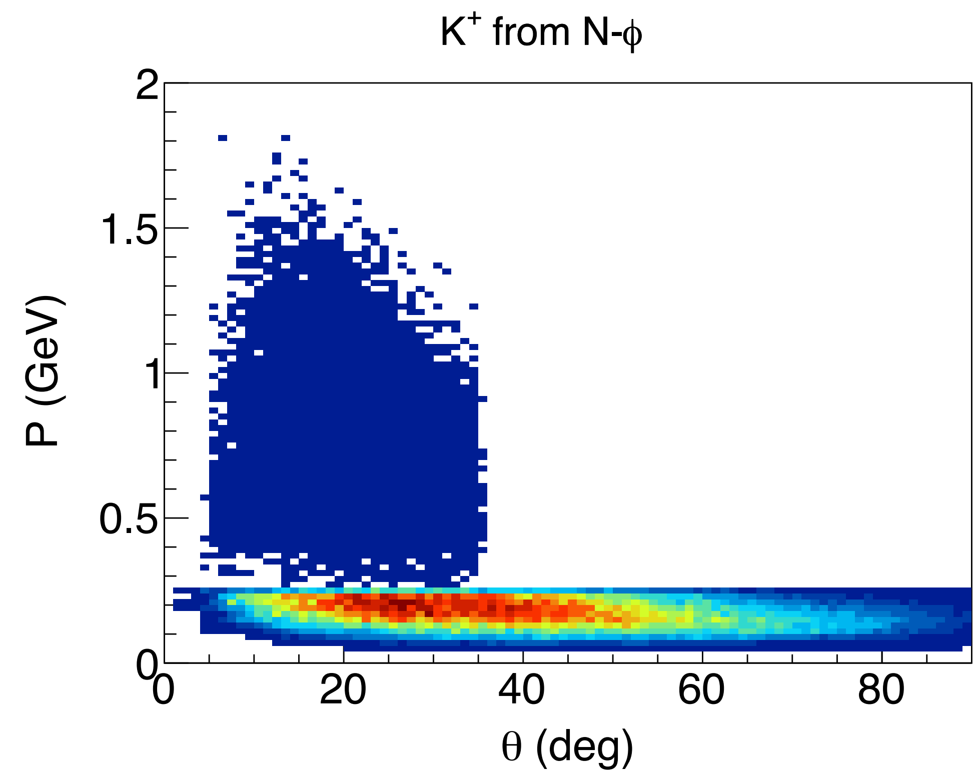



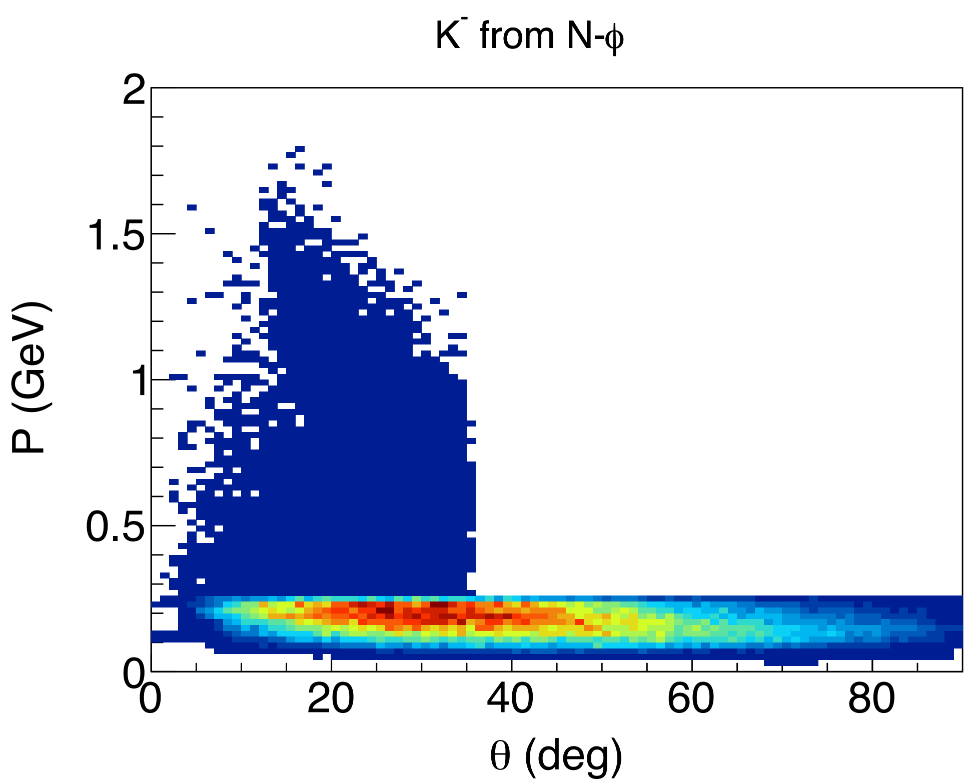




- The top left plot shows the invariant mass spectra of $pK^+K^-$ from pure model prediction
- The top right plot shows the proton-kaon momentum distribution from different channel
- The bottom left plot shows the invariant mass spectra of detected $pK^+K^-$ with BONUS12 and CLAS12

# Hall B Projection



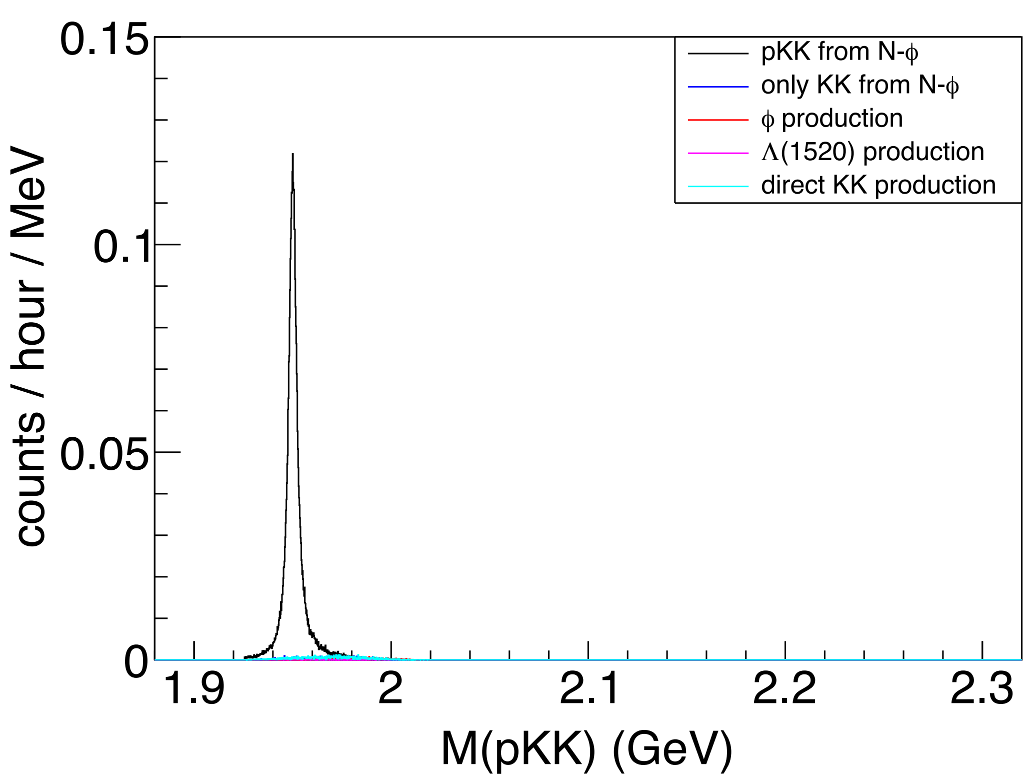



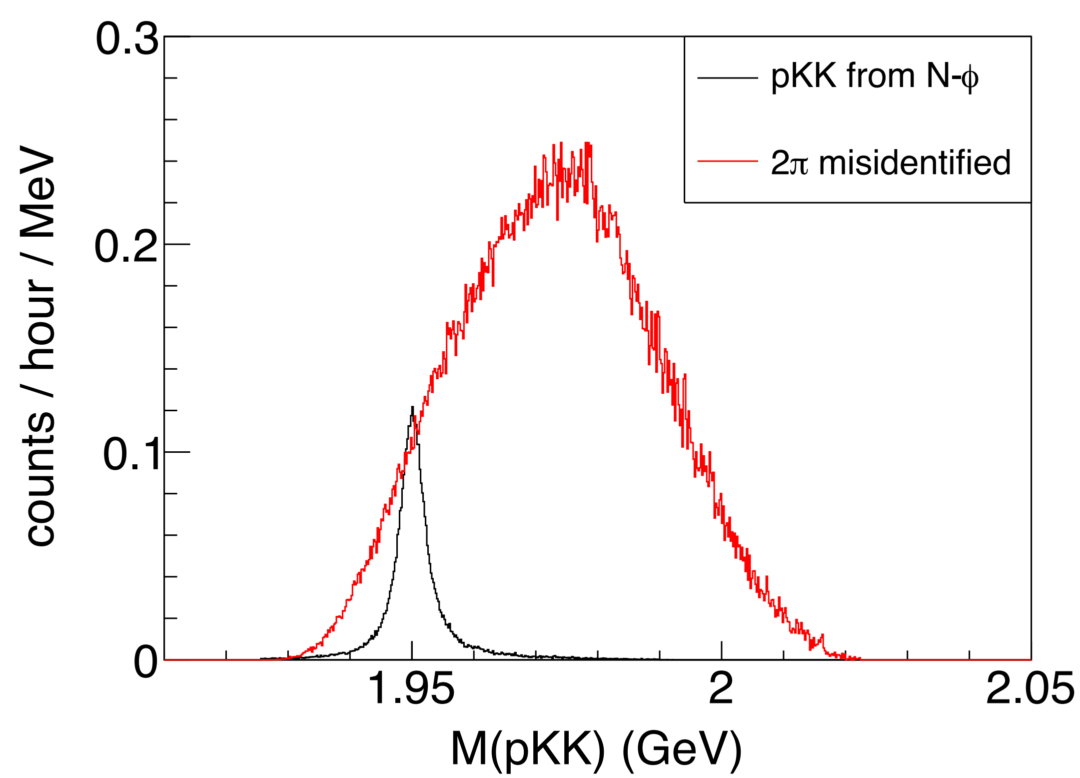

- The momentum-polar angle distributions of the detected proton and kaons from the bound state

# Projected Results

- Momentum cuts are applied to suppress the backgrounds
  - $M(pK^{\pm}) < 1.48$ GeV, $M(K^+K^-) < 1.04$ GeV, $P(p) < 0.8$ GeV, and $P(K^{\pm}) < 0.5$ GeV
- Also simulate the $p\pi^+\pi^-$ channel to account for the background due to $\pi/K$ misidentifications
  - Assume that 10% pions are misidentified as kaons
- The signal rate is 0.75/h
- We propose 200 hours beam time for 150 signal events (25 days, 20 days for production and 5 days for calibration, need further evaluation at proposal time later)




The invariant mass spectra of $pK^+K^-$ with momentum cuts




The comparison between the invariant mass distribution of the $pK^+K^-$ and the one of the $p\pi^+\pi^-$ misidentification

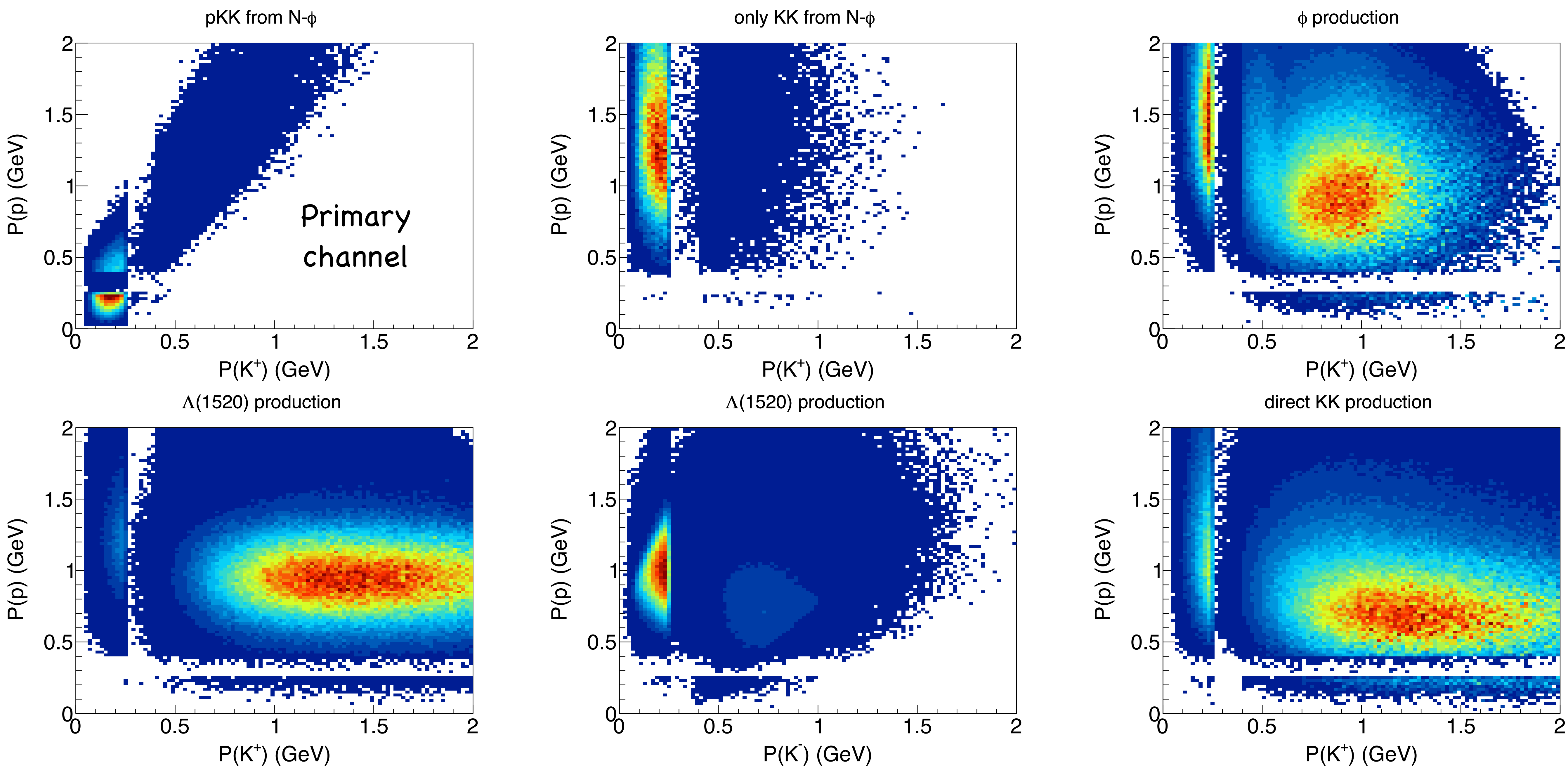
# Conclusion

- The LOI for searching hidden strange pentaquark candidate at Hall B was submitted to PAC45 and received positive feedback from the PAC
- The CLAS12 main detector and the forward tagger together with the BONUS12 detector should be the best configuration for this proposed experiment.
- The experiment is challenging in a number of aspects. In particular, using BONUS12 detector to do kaon PID is new. We will work closely with its design and hardware groups to study this.
- More detailed background studies will be conducted also with the valuable input from the upcoming CLAS12 and forward tagger data taking.
- We plan to submit a full proposal to the PAC in the near future.

Thanks

# Backups

# How to detect it

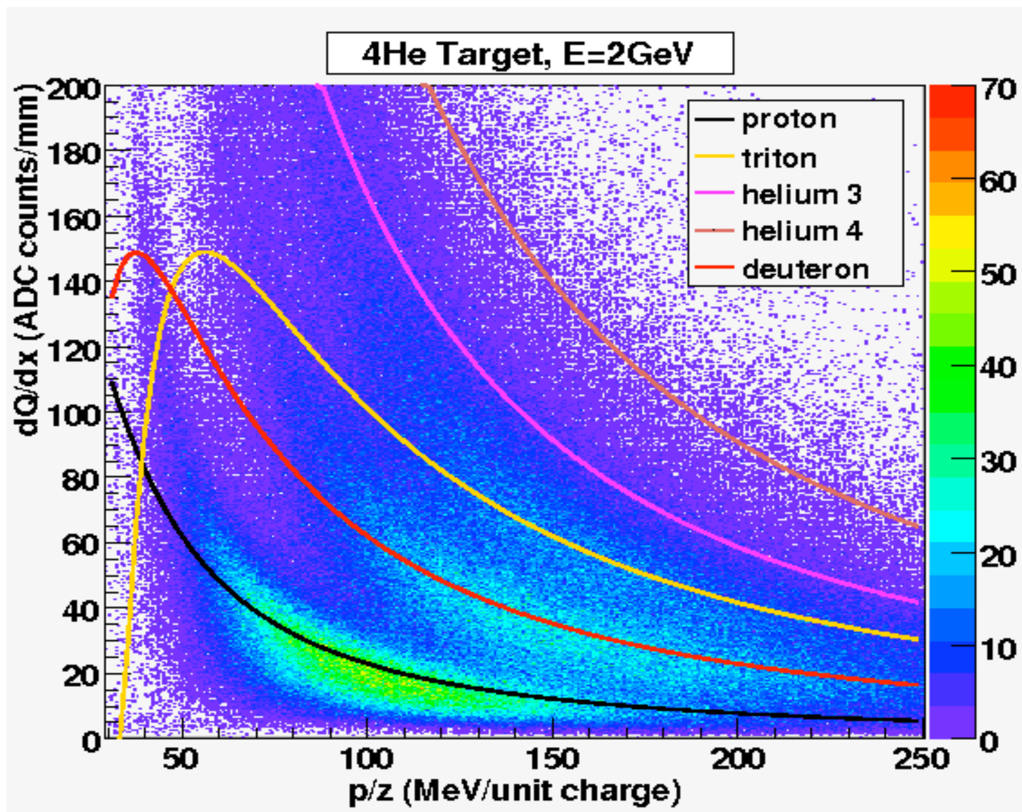



The proton-kaon momenta distributions from different channels, the proton and the kaons which are decay products from the bound state concentrate in the low momentum region

Slide from Keith Griffioen's old Talk

The College of WILLIAM & MARY

# BoNuS RTPC Performance




- upper left: dE/dx vs. p/Z for He target
- lower left: dE/dx vs. p for deuterium target
- below RTPC+CLAS resolution for common $e^-$ events