Search for a ϕ–N Bound State from ϕ Production in a Nuclear Medium

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CLAS Collaboration meeting

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A CLAS Collaboration Proposal to PAC47

Search for a $\phi - N$ Bound State from ϕ Production in a Nuclear Medium

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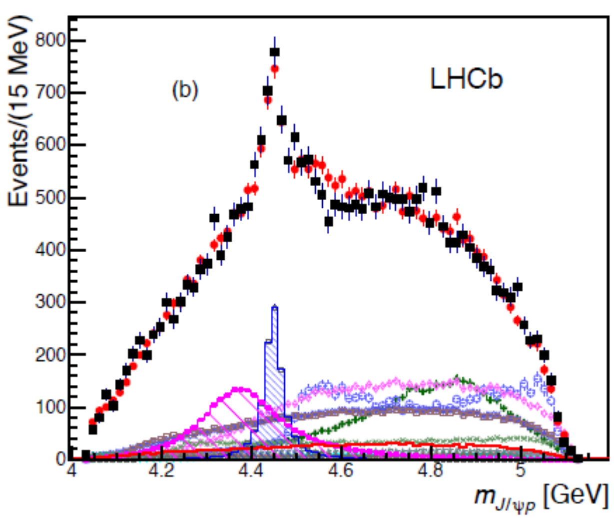
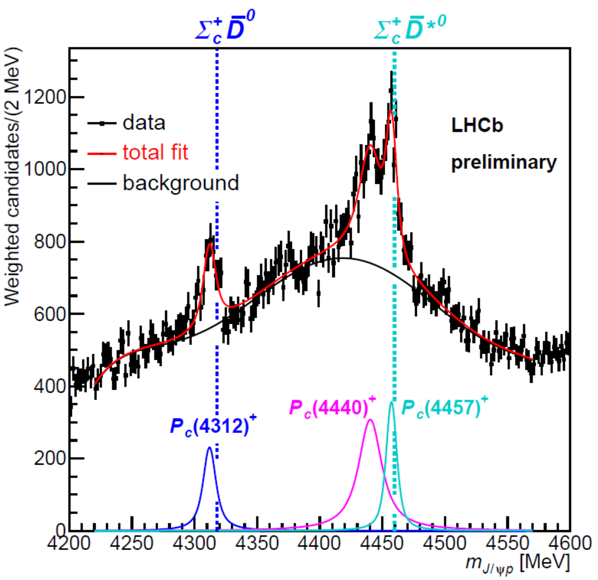
Why ϕ-N bound state?

- The multiquark state has been one of the active frontiers since the establishment of the quark model
- The study of multiquark states is an approach to understand the dynamics of the strong interaction at the hadron level
- LHCb pentaquark with hidden charm in 2015 and in 2019 with 10 times more statistics
- What about strangeness?



2015



2019

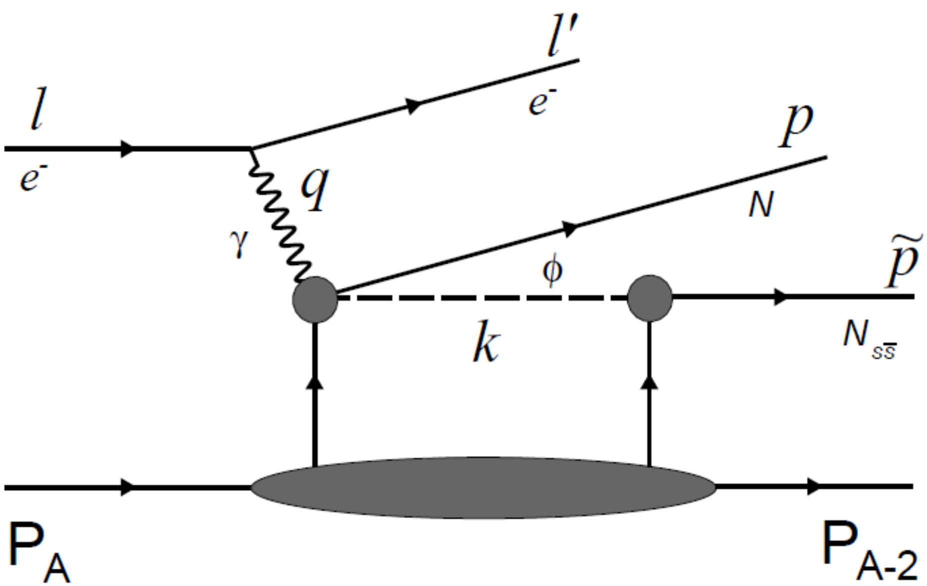
ϕ-N bound state prediction

- QCD van der 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:
  - ϕ meson could also be bound to a nucleon/nucleus. Theoretical studies predict the existence of a ϕ-N bound state.
  - A recent Quark Delocalization Color Screening Model 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, Bethe-Salpeter equation calculation and lattice QCD calculation also support the existence of such a kind of bound state

- **H. Gao et al "Search for a hidden strange baryon-meson bound state from ϕ production in a nuclear medium", Phys. Rev. C 95, 055202 (2017)**
- H. Gao, T. S. H. Lee, and V. Marinov, Phys. Rev. C 63, 022201 (2001)
- F. Huang, Z. Y. Zhang, and Y. W. Yu, Phys. Rev. C 73, 025207 (2006)
- S. Liska, H. Gao, W. Chen, and X. Qian, Phys. Rev. C75, 058201 (2007)
- J. He, H. Huang, D.-Y. Chen, and X. Zhu, Phys. Rev. D 98, 094019 (2018)
- S. R. Beane et. al., Phys. Rev. D 91, 114503 (2015)

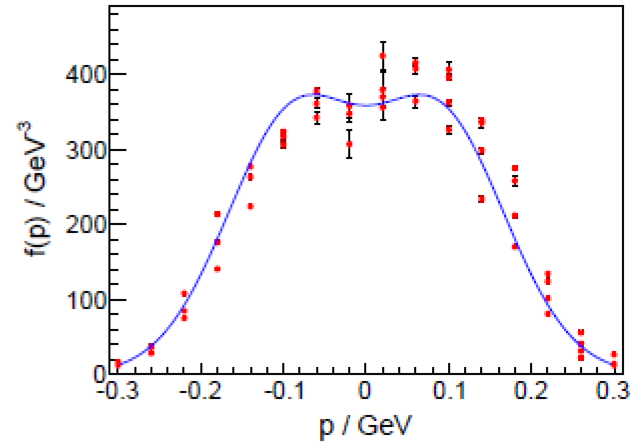
How to produce it

- Two step
  - Sub-threshold and near-threshold production of ϕ meson inside a nuclear medium
  - Then ϕ combine with a nearby slow nucleon

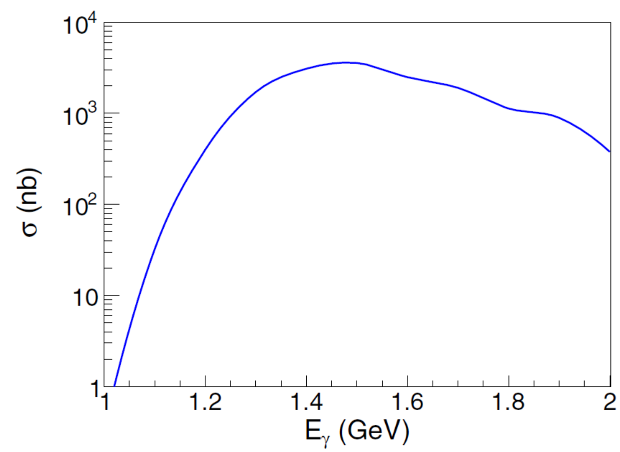


Phys. Rev. C 95, 055202 (2017)

Nucleon mom in gold

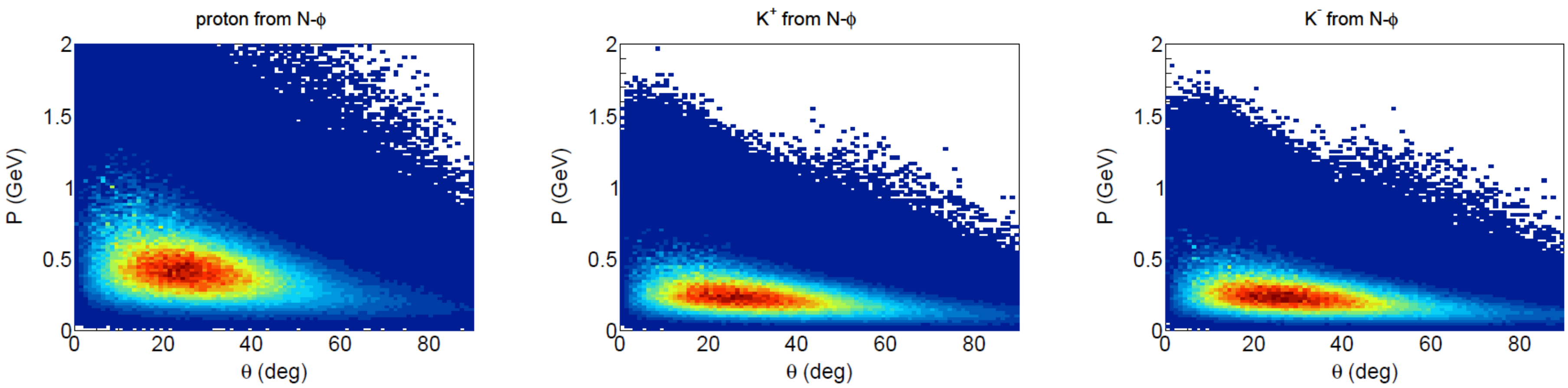


ϕ-N photoproduction total crosssection on gold



How to detect it

- Dominate decay channel (46%) pK^+K^- of 4MeV width
- Prefer photon beam or quasi-real electron beam for better yield
- Need to detect low mom pK^+K^- 100-1000MeV at forward angle and check invariant mass
- Detection is not dependent on any particular model, even though rate estimation is.

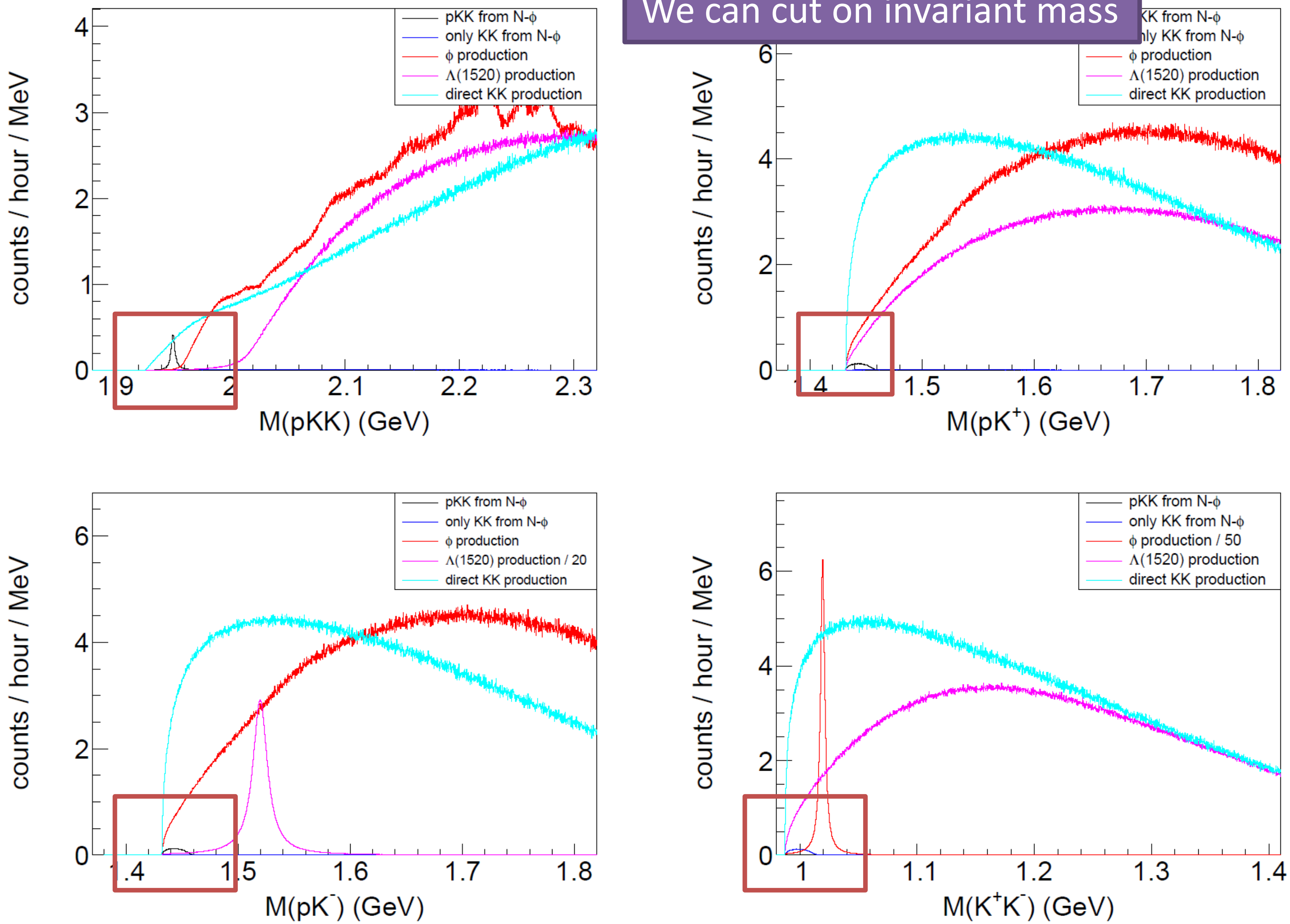


Event generation condition:

- 4.4GeV 42nA electron beam on 0.1mm gold target, 3e34/cm2/s nucleon luminosity
- Quasi-real scattered electron (2.5-4.5deg, 1-4GeV)

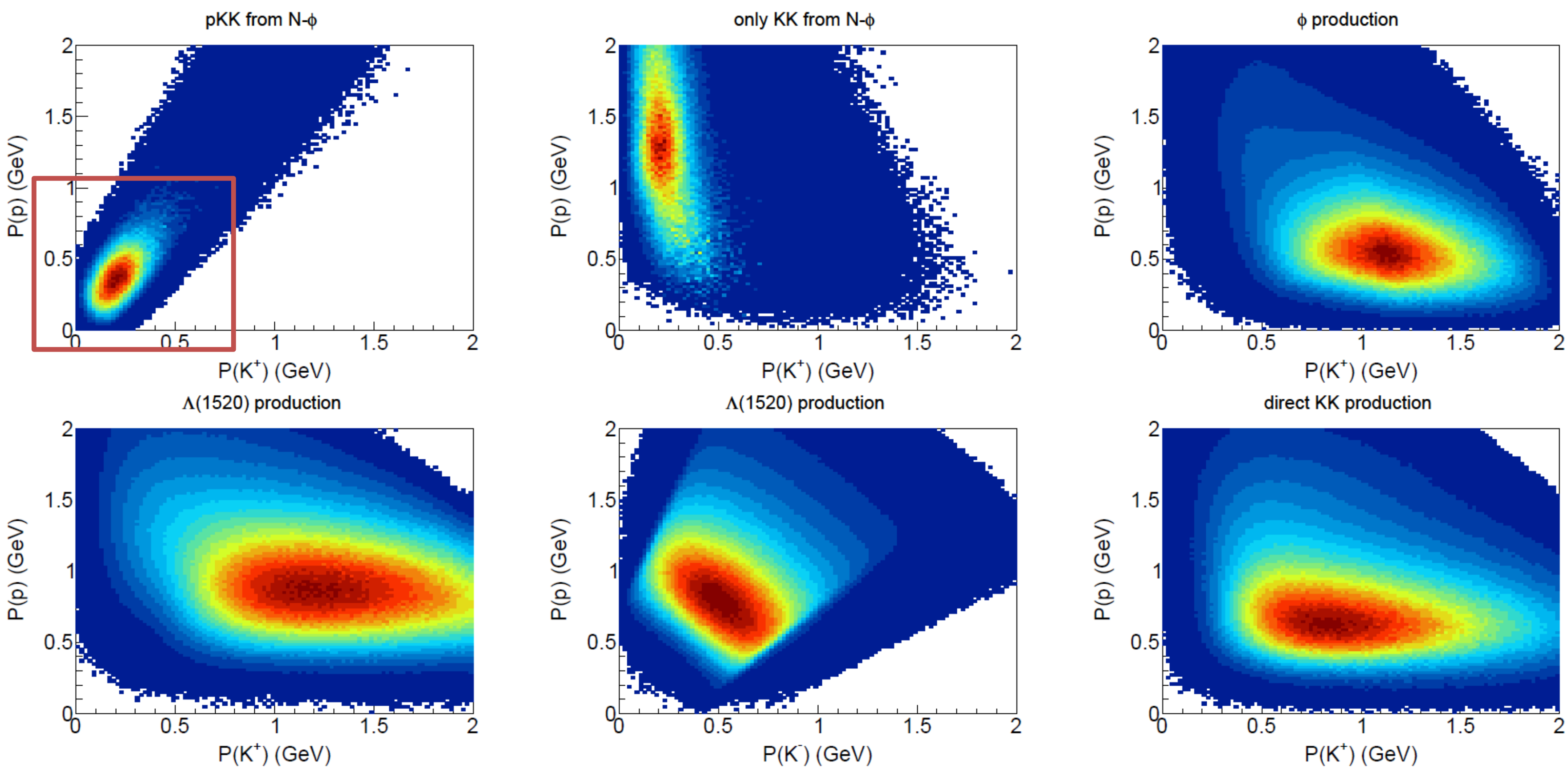
How is background (with same final state)

We can cut on invariant mass



How is background (with same final state)

We can cut on mom



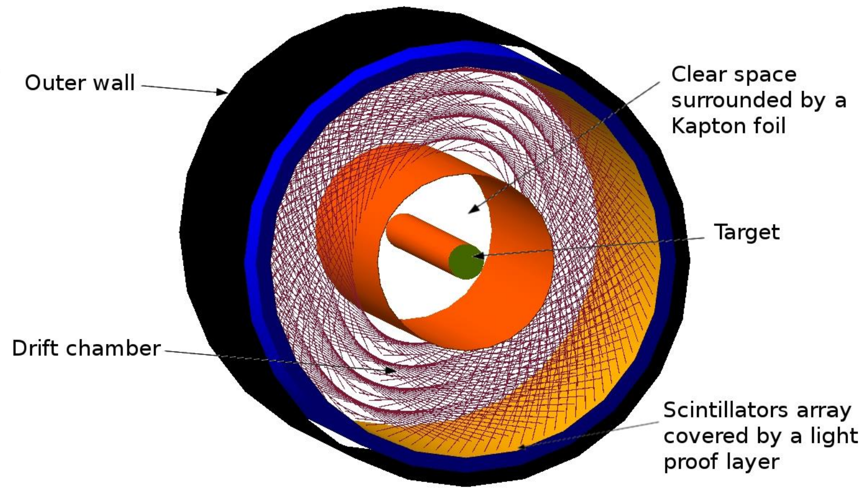
Experimental Setup

- CLAS12+ALERT
  - 4.4GeV 42nA electron beam, 0.1mm gold foil target, 3e34/cm2/s nucleon luminosity
  - Forward Tagger (2.5-4.5deg, 1-4GeV) detect scattered e-
  - ALERT detects $pK^{+}K^{-}$ with 100<P<350 MeV
  - CLAS12 forward angle detects $pK^{+}K^{-}$ depending on torus field

CLAS12 detector

Parameters	Forward Detector	Central Detector	Forward Tagger
Charged Particles:			
Polar Angular Range (θ)	5° to 35°	35° to 125°	2.5° to 4.5°
Resolution:			
Polar Angle ($\delta\theta$)	< 1 mrad	< 10 mrad to 20 mrad	$< 1.5\%$
Azimuthal Angle ($\delta\phi$)	< 4 mrad	< 5 mrad	$< 2^\circ$
Momentum (δp/p)	$< 1\%$ at 5 GeV/c	$< 5\%$ at 1.5 GeV/c	$< 0.02/\sqrt{(E)}$
Neutral Particles:			
Polar Angular Range (θ)	5° to 40°	40° to 125° (neutrons)	
Resolution:			
Polar angle ($\delta\theta$)	< 4 mrad	< 10 mrad	
Energy	$< 0.1/\sqrt{(E)}$	$< 5\%$	
PID:			
e/π	full momentum range	N/A	full momentum range
π/p	full momentum range	< 1.25 GeV/c	
K/π	< 3 GeV/c	< 0.65 GeV/c	
K/p	< 4 GeV/c	< 1 GeV/c	

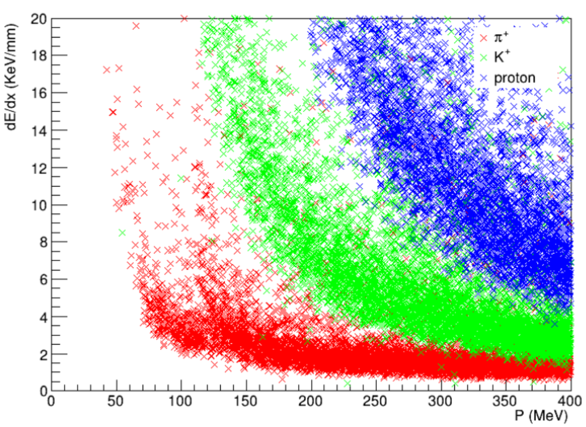
ALERT detector for this proposal

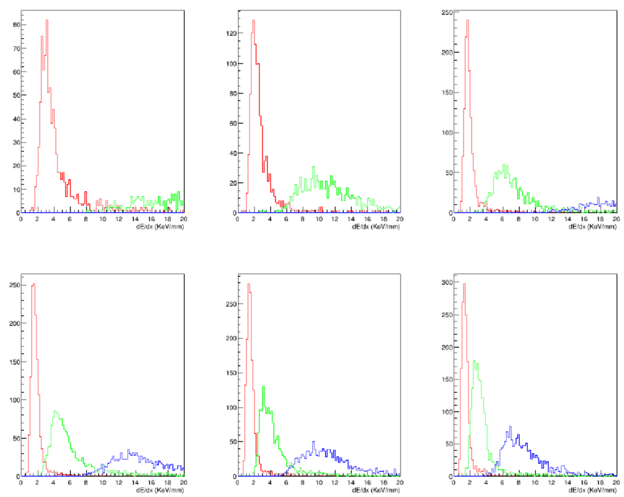


ALERT approved PR12-17-012
Inside CLAS12 5T solenoid
Gas target, DC for tracking and scintillator for TOF
Detect proton and heavier ions
ERR review in Fall 2019

Changes for this proposal:

1. Replace gas target with 0.1mm gold foil at upstream entrance
2. Replace DC gas He with Ar
3. ALERT has coincidence trigger with FT



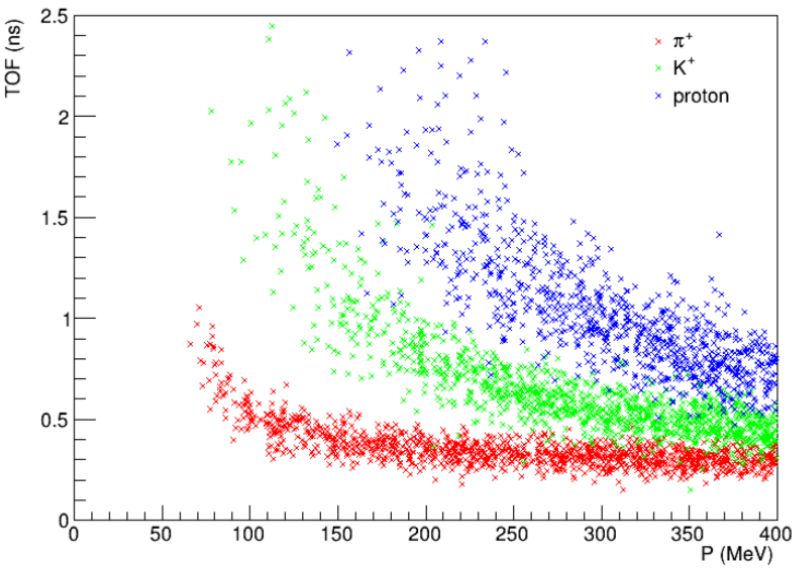


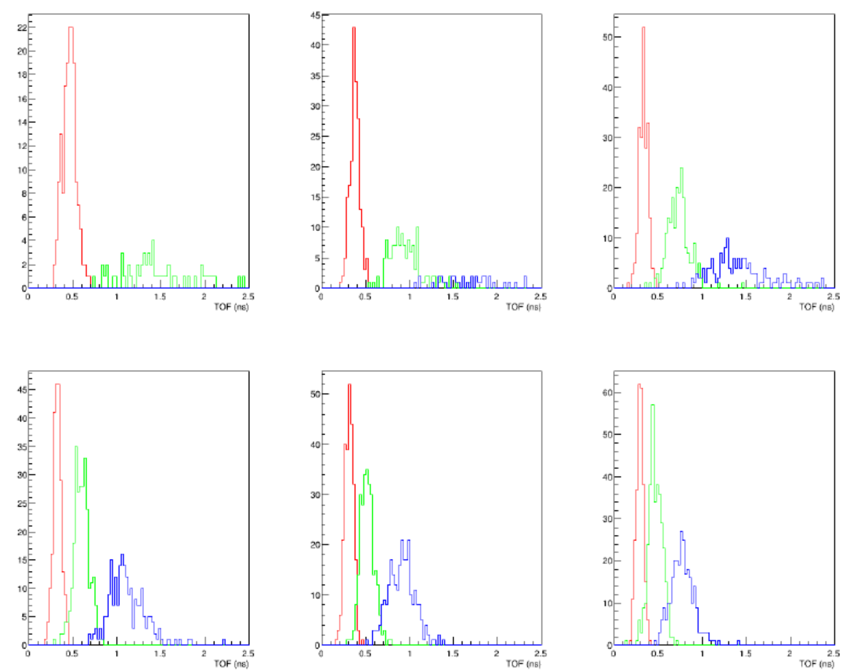
100-400 MeV, 50MeV bin

DC gas Ar+C4H10 shows better dE/dx separation between kaon and pion

ALERT TOF PID for p, kaon

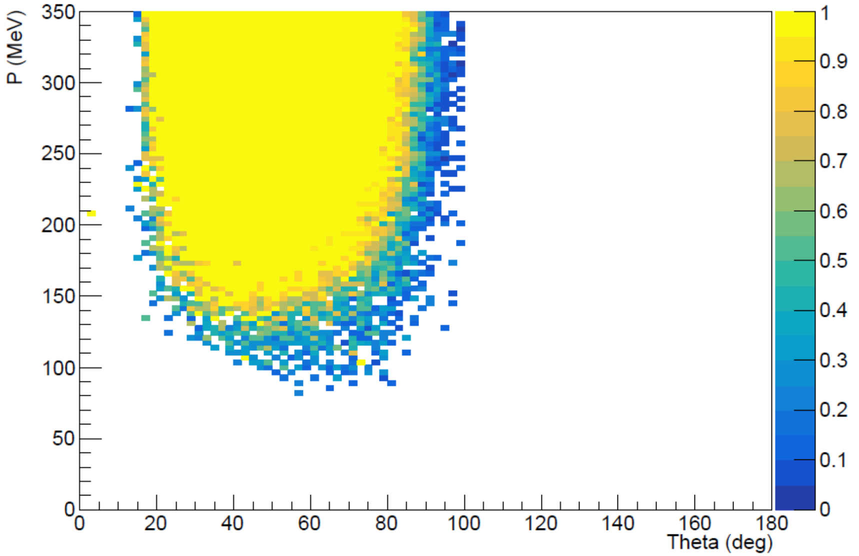
- Polar angle 75-85 deg with shortest path length
- 150ps scintillator time resolution
- below mom 350MeV, proton and kaon >90% efficiency and pion rejection > 50



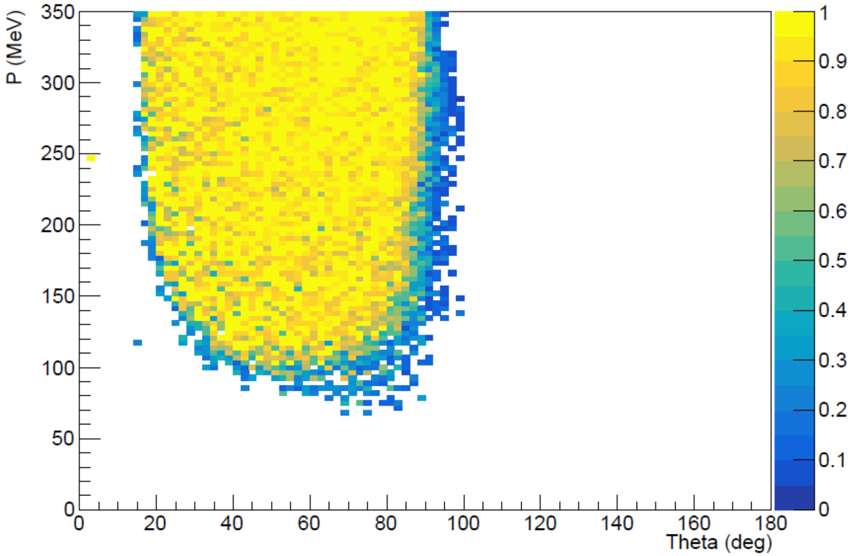


100-400 MeV, 50MeV bin

ALERT acceptance



(a) Proton acceptance



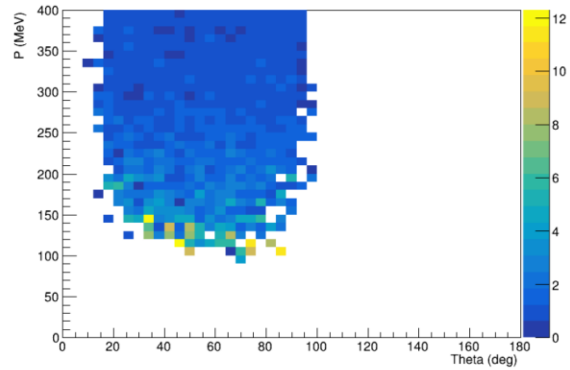
(b) K^+ acceptance

Proton > 130 MeV and Kaon > 100 MeV

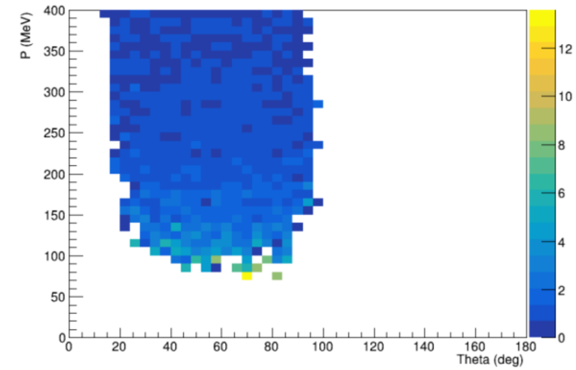
Both polar angle 20-90 deg

ALERT resolution

mom 2%

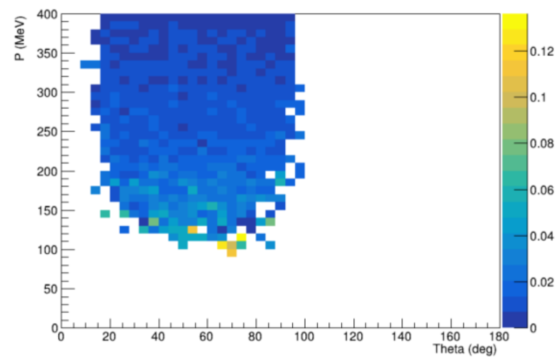


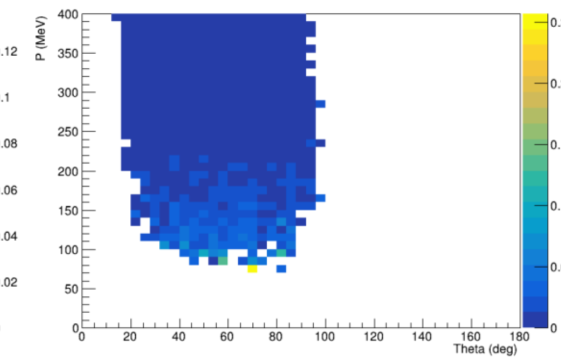
(a) Proton momentum resolution in percentage



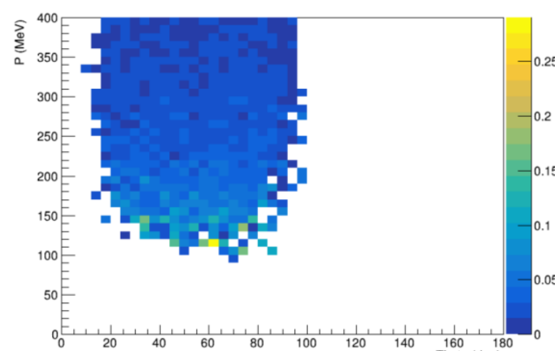
(b) K^+ momentum resolution in percentage

Polar angle 20mrad

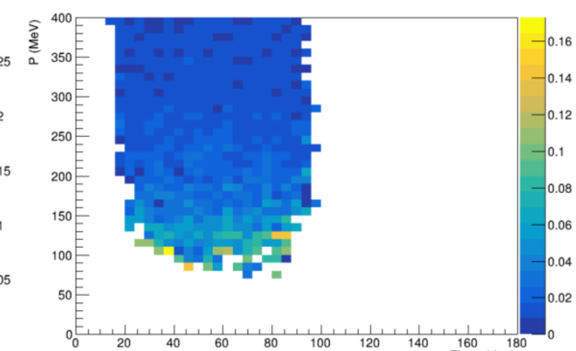




Azimuthal angle 20mrad



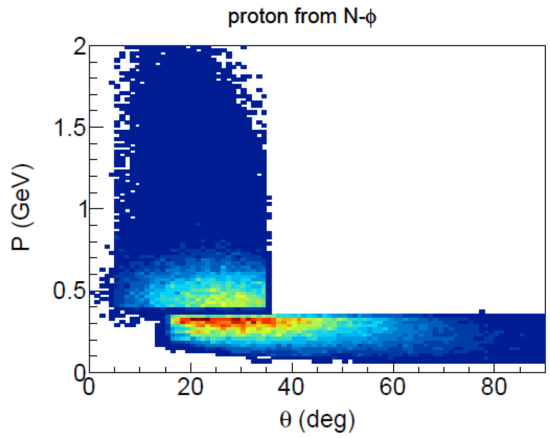
(a) Proton azimuthal angle resolution in rad

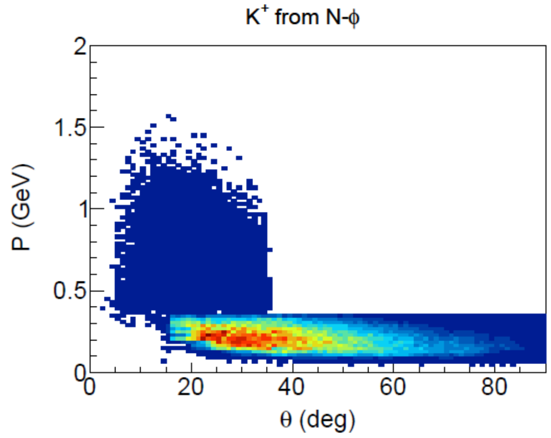


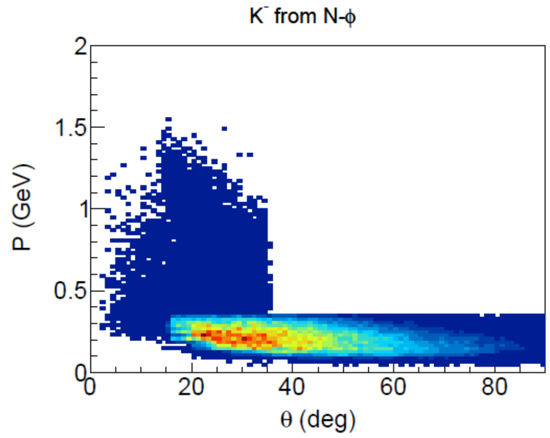
(b) K^+ azimuthal angle resolution in rad

Detected signal pK$^+$K$^-$ from ϕ-N

- CLAS12 + ALERT acceptance and resolution applied to generated events

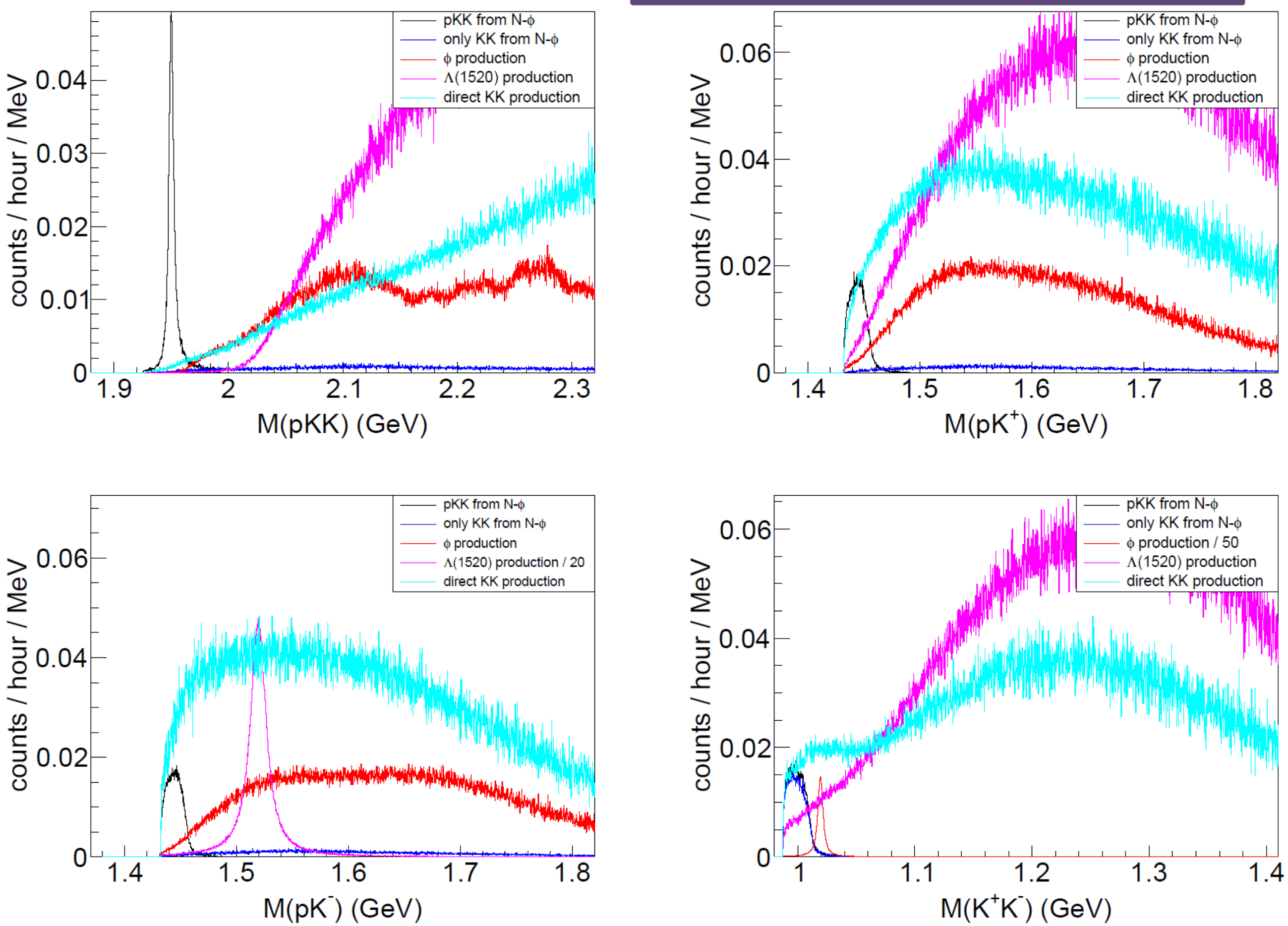






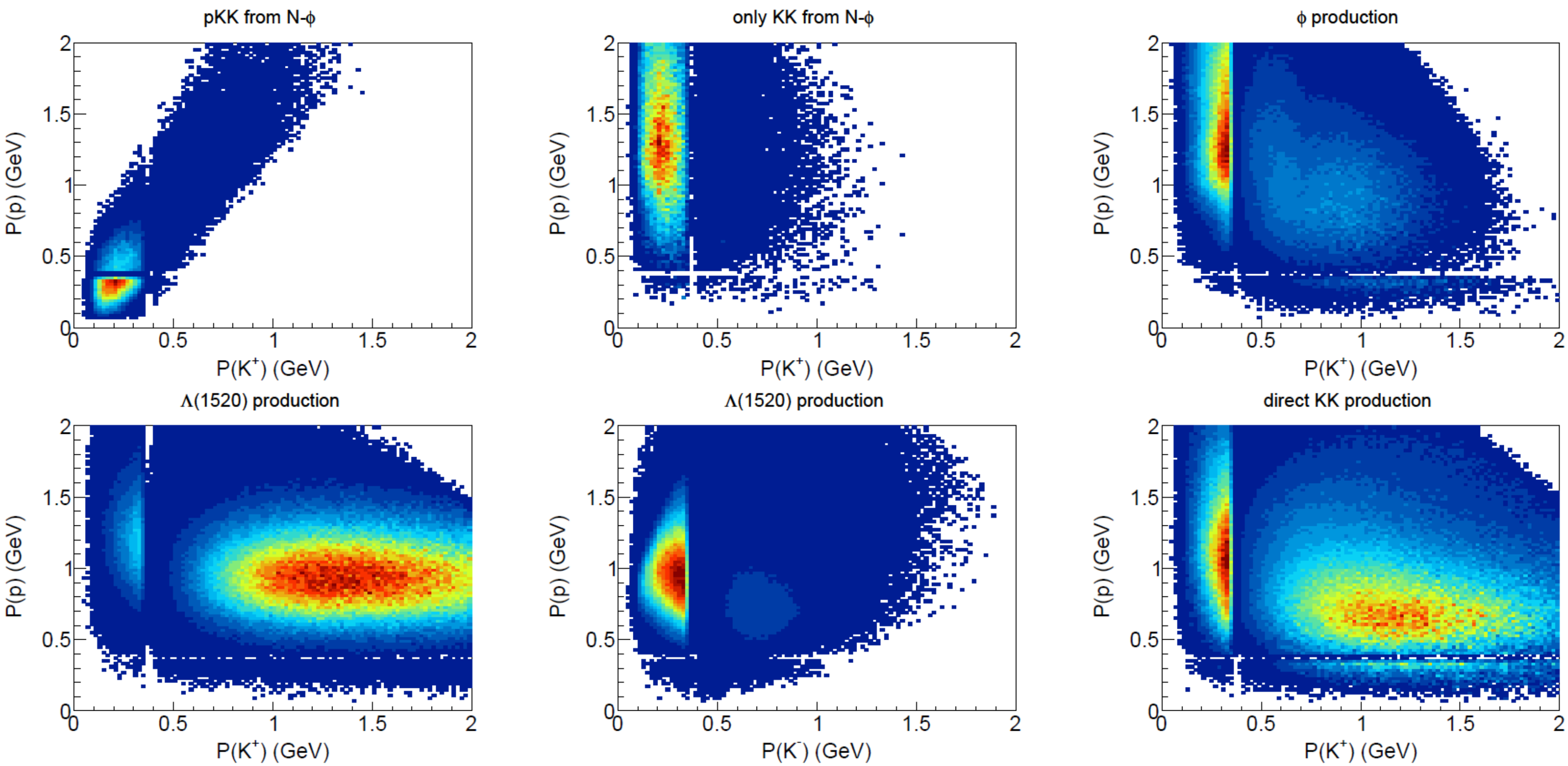
Detected background (with same final state)

We can cut on invariant mass



Detected background (with same final state)

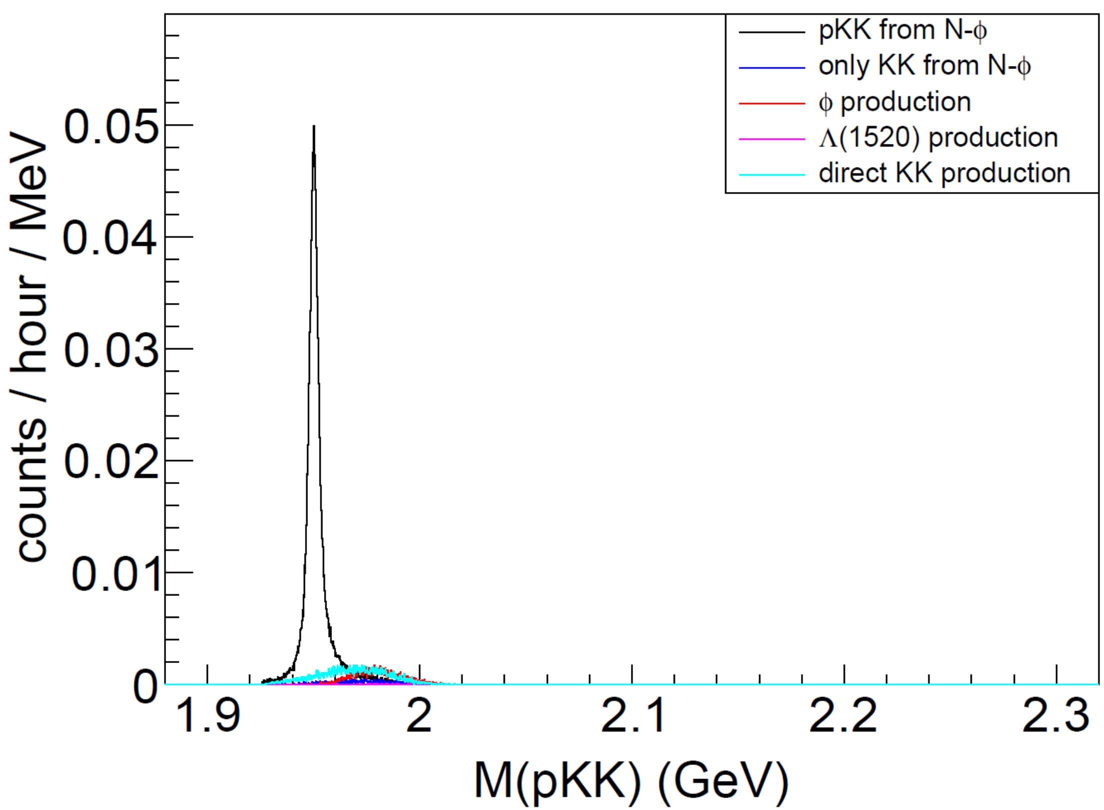
We can cut on mom



Detected signal and background (with same final state)

After cuts $P(p) < 0.8$ GeV, $P(K^{\pm}) < 0.5$ GeV

$$M(pK^{\pm}) < 1.48 \text{ GeV, and } M(K^+K^-) < 1.04 \text{ GeV.}$$

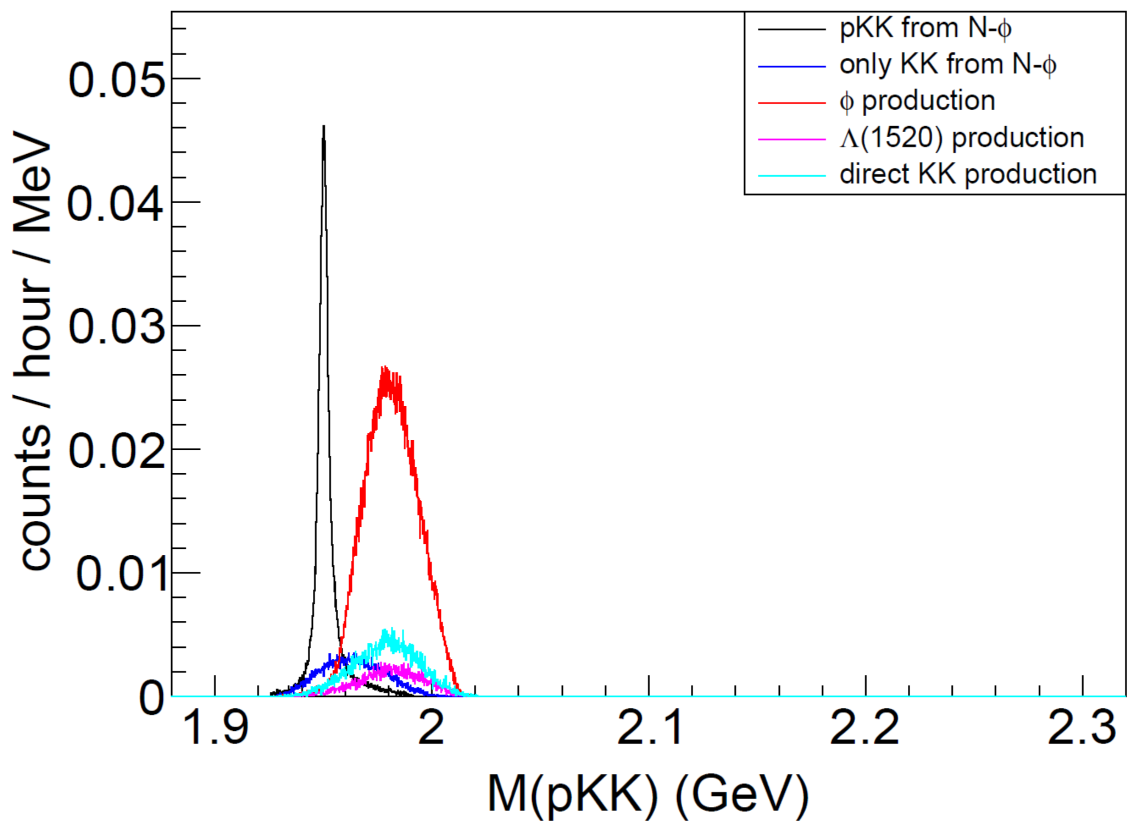


Detected signal and uncorrelated background (with same final state, but spectator proton)

After additional cut proton polar angle < 60deg

Signal only reduced by 5%

35% from uncorrelated background over signal

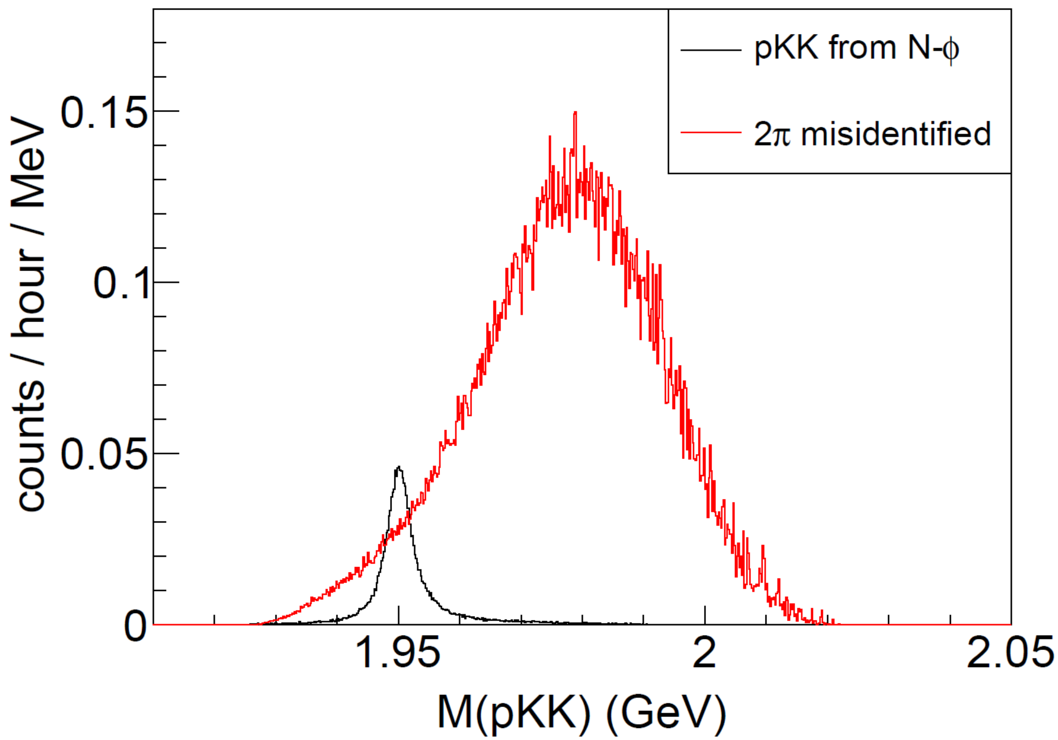


Detected signal and uncorrelated background (with different final state)

2 pion exclusive generator **TWOPEG**
CLAS12 Note 2017-001

Assume single pion rejection 50

210% from 2 pion background over signal



Projection and Beam time

- 4.4 GeV 42 nA beam on 0.1mm gold foil target with nucleon luminosity 3e34/cm2/s (same as ALERT experiment)
- CLAS12+ALERT
- 3sigma of pK^+K^- invariant mass range from 1940MeV to 1960MeV
- Apply all kinematic cuts
- Assume 0.7 overall detection efficiency
- Rate
  - signal pK^+K^- from ϕ-N, 0.2/h
  - correlated background, negligible
  - uncorrelated background, 0.07/h
  - two pion background, 0.43/h
- Beam time request 40+5 days
  - 192 events of signal and 480 events of all background
  - 7.4sigma =192/sqrt(192+480)

Summary

- Search for a ϕ−N Bound State from ϕ Production in a Nuclear Medium by using CLAS12 + ALERT detector
- It could open a new way of QCD study in strangeness sector
- We need to use ALERT with different DC gas, gold foil target and coincidence trigger
- We request 45 days of 4.4GeV 42nA beam

backup

ALERT experiment

background rejection, while keeping the material budget as low as possible for low energy particle detection. ALERT will be installed inside the solenoid magnet instead of the CLAS12 Silicon Vertex Tracker and Micromegas tracker. We will use an 11 GeV longitudinally polarized electron beam (80% polarization) of up to 1000 nA on a gas target straw filled with deuterium or ^{4}He at 3 atm to obtain a luminosity up to 6×10^{34} nucleon cm^{-2}s^{-1}. In addition we will need to run hydrogen and ^{4}He targets at different beam energies for detector calibration. The following table summarizes our beam time request:

Configurations	**Proposals**	**Targets**	**Beam time request**	**Beam current**	**Luminosity***
			days	nA	n/cm^2/s
Commissioning	All†	^{1}H, ^{4}He	5	Various	Various
A	Nuclear GPDs	^{4}He	10	1000	6×10^{34}
B	Tagged EMC & DVCS	^{2}H	20	500	3×10^{34}
C	All†	^{4}He	20	500	3×10^{34}
TOTAL			**55**		

trigger rate estimation

- CLAS12 run 3048 has 70 kHz FT single-cluster trigger rate with
  - 6.4 GeV electron beams
  - 15 nA on 5cm long liquid hydrogen target with 2e34/cm2/s lumi
  - FCAL > 0.5 GeV
  - Q2_min = 0.006GeV^2
- This proposal
  - 4.4 GeV electron beam
  - 42nA on 0.1mm gold foil target with 3e34/cm2/s
  - 4GeV>FCAL>1GeV
  - Q2_min=0.008GeV^2

- Estimation for this proposal
  - Assume FT single-cluster rate is proportional to virtual photon flux (E'/Q^{2}E)
  - This proposal could have FT single-cluster trigger rate

    70 * (0.006/0.008)*(1/4.4)/(0.5/6.4)*(3e34/2e34) = 238 kHz
  - To have random coincidence trigger rate below CLAS12 limit 12kHz, assume 50ns time window, ALERT and CLAS12 forward angle detector need to provide a trigger below

    12/50/238 = 1MHz

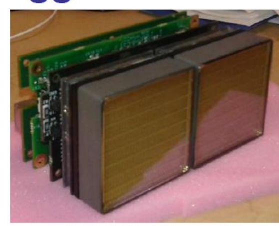
Petiroc2A in the Trigger

FPGA Readout board hasn't yet been used in the trigger, but supports it

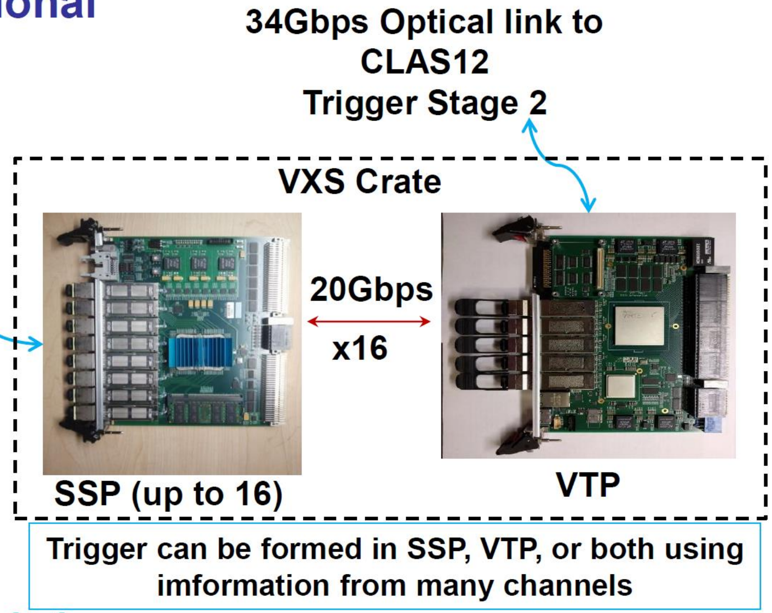
- FPGA Readout to SSP optical link is bidirectional
  - SSP -> FPGA readout
    - 2.5Gbps
    - fixed latency clock, sync, & trigger
    - Register access commands
  - FPGA readout -> SSP
    - 2.5Gbps up to 6.25Gbps
    - 20% encoding overhead
    - 1Gbps for readout
    - 1Gbps for control
    - Up to 3Gbps for trigger

      Full 64bit channel pattern with 32ns timing resolution

      Timing can improved by grouping channels or by knowing dead-time due to shaping



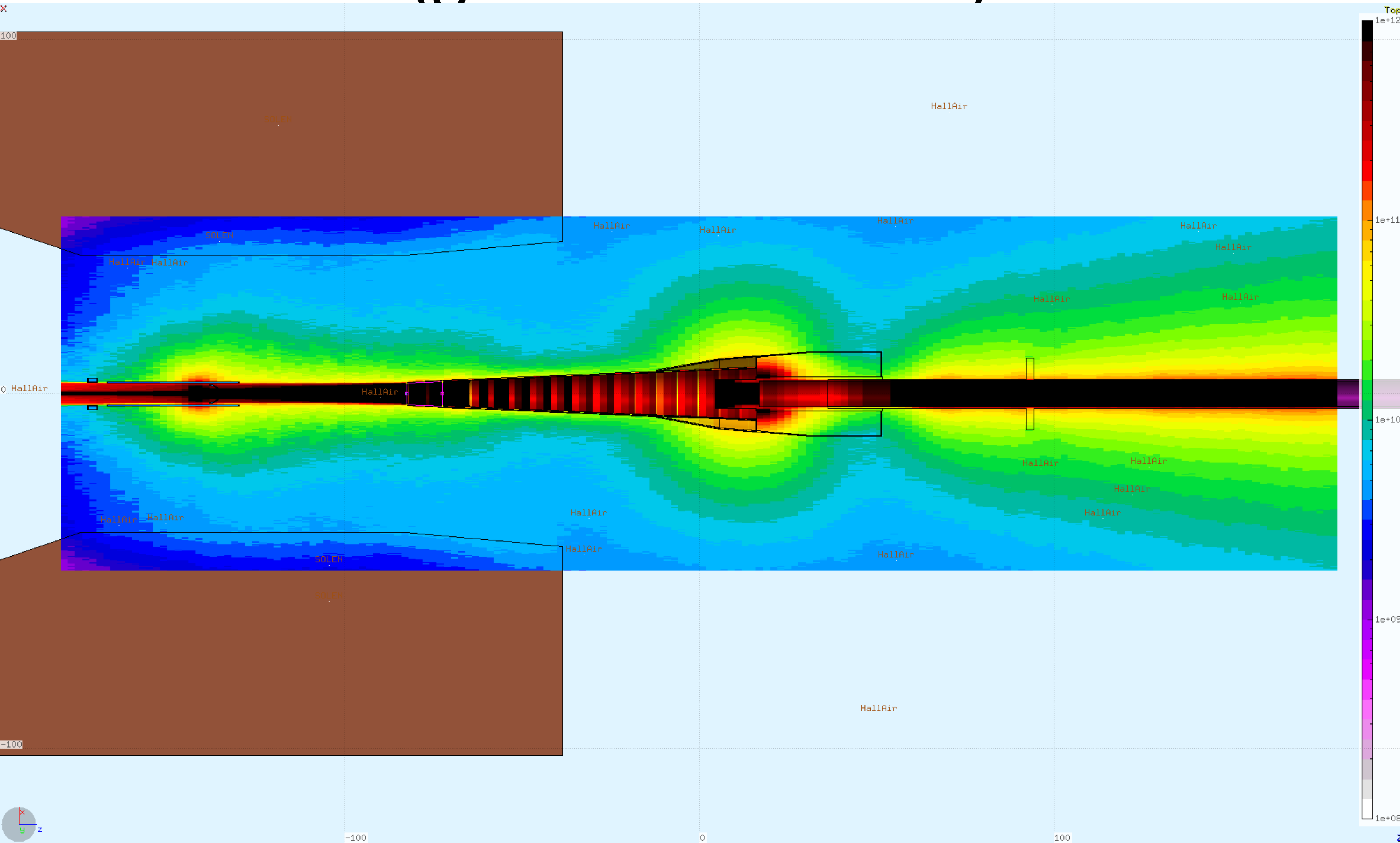
FPGA Readout
(32 per SSP)



CLAS12 radiation background with gold foil target

- Fluka simulation by Lorenzo Zana
- Its geometry and materials include 0.1mm (3% RL) gold foil, Moller cone, 5T solenoid field and nothing else
  - The rest of the target is not there. I have changed the material of the USM target cell to air (that is the simulation that I have used). So, the border are there, but in reality is air as anywhere else.
  - The Moller cone is there, since it helps on shielding. It is the version with solid targets with Hall-B (same as run group M.)
- Simulation for 40 days at 40nA (8.64E17 electrons on target)
- For the rest for the simulation refer to https://userweb.jlab.org/~zana/Documents/Hall-B_USM/

1MeV equivalent neutron damage (gold foil z=-15cm)



Dose in rad
(gold foil z=-15cm)