Measuring the Neutron Spin Asymmetry A_1^n in the Valence Quark Region in Hall C at Jefferson Lab

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On Behalf of the E12-06-110 Collaboration

Hall C Winter Collaboration Meeting
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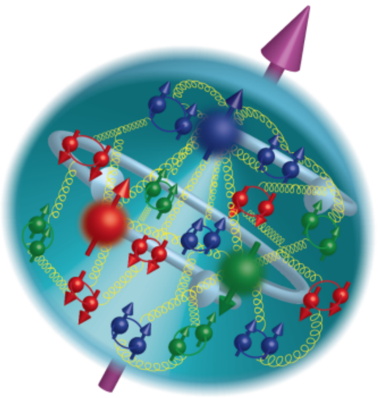
Nucleon spin structure: current status

Nucleon spin sum rule:
(Jaffe & Manohar)

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

quark intrinsic spin | gluon intrinsic spin | quark OAM | gluon OAM



Designed by Z.-E. Meziani

→ Today: **large uncertainties! in ΔG**

$\Delta\Sigma = \int (\Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s})dx \sim 30\%$

$\Delta G = \int dx\, \Delta g \sim 20\%,\ L_q \sim ??,\ L_g \sim ??$

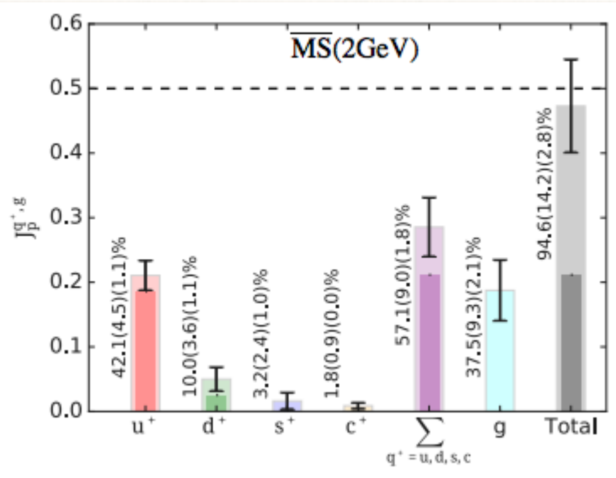
Little known about **quark OAM (L_q)**

Quark spin seems to play a smaller role in the nucleon spin decomposition than predicted by the CQM, which expected $\Delta\Sigma \sim 75\%$, $L_q \sim 25\%$

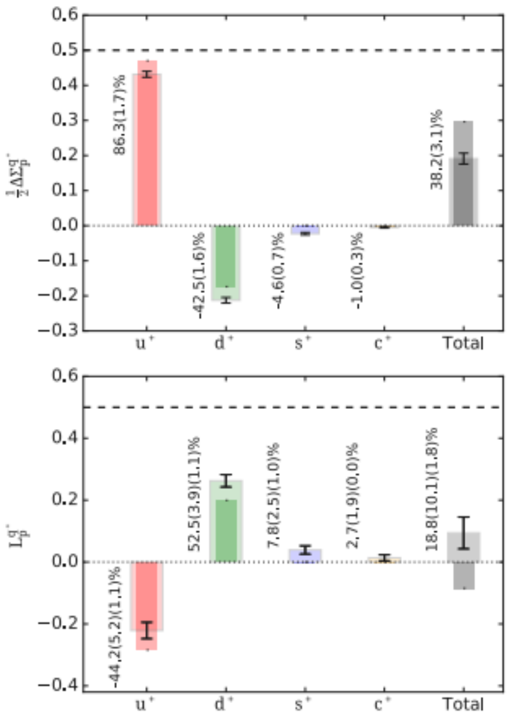
LQCD & high-*x* physics can help!

Due to the non-perturbative nature of QCD, making absolute predictions of nucleon spin structure is generally difficult, but …

→ **LQCD** can compute $L_q = J_q - \Delta\Sigma_q$, J_g (@ physical π mass!)



See *C. Alexandrou et al., Phys. Rev. D 101, 094513 (2020), arXiv:2003.08486*



→ direct calculations using **LQCD (quasi-PDFs)** promising

→ The valence domain ($\boldsymbol{x > 0.5}$) enables us to discriminate between models that include/exclude L_q

A_1^n @ high- x: a key observable for spin structure

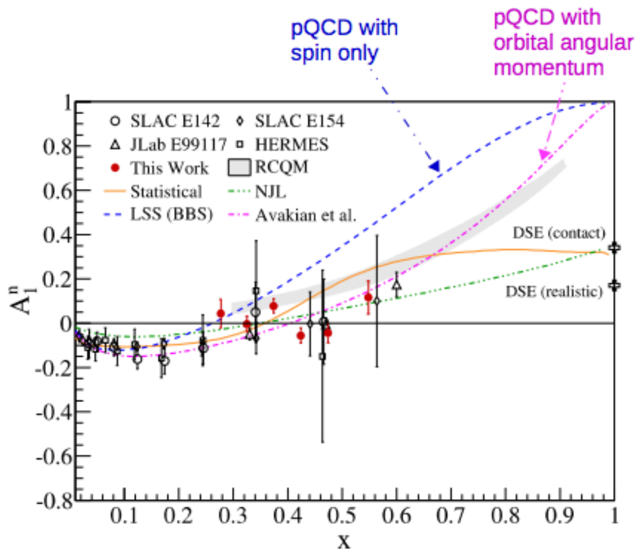
The **valence domain** ($x > 0.5$):

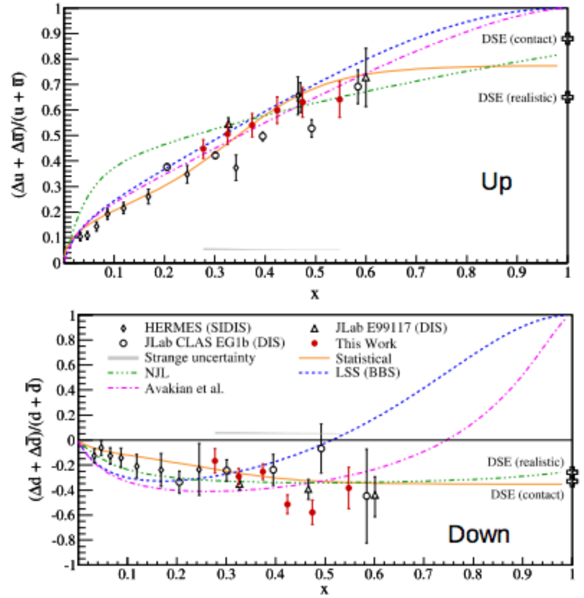
- Free of sea effects ($q\bar{q}$ pairs and hard gluons)
- Spin is assumed to be carried by the valence quarks

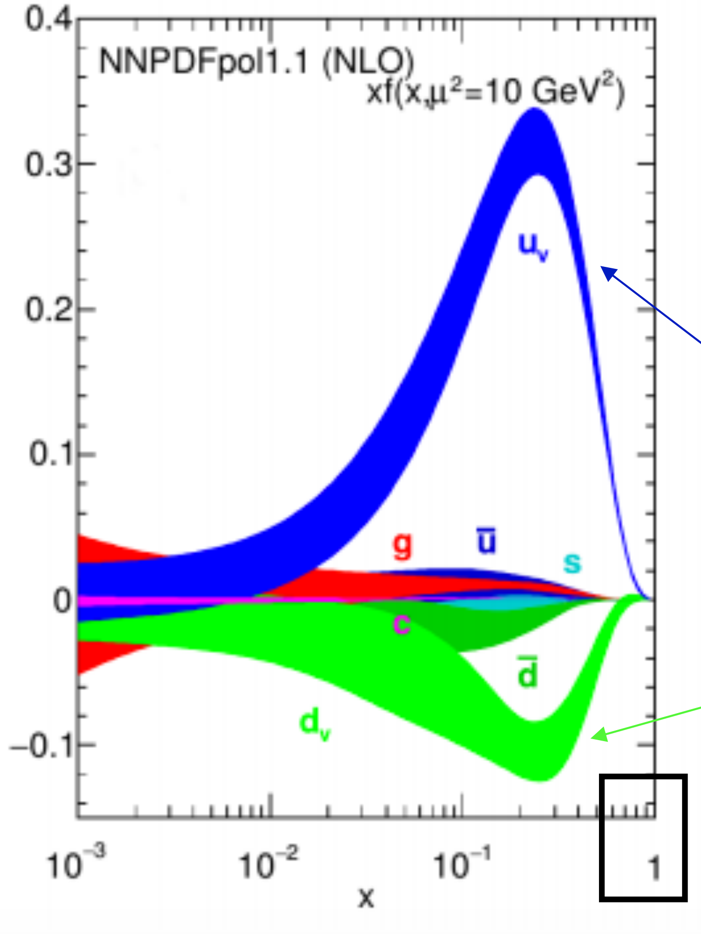
→ A poorly-explored region due to low rates at high x (need high luminosity, Hall C's 12 GeV-era polarized ^3He target reached $2\text{x}10^{36}$ cm^{-2}s^{-1}!)

- **Which models will our data agree with**? How much of a role does L_q play in forming the nucleon spin?

This experiment will provide the first precision data on A_1^n for $x > 0.61$ (went up to $x = 0.75$!)





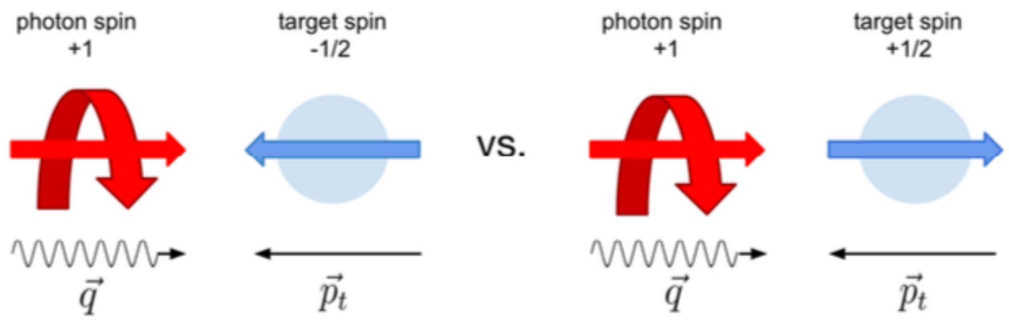


$x > 0.5$ region dominated by valence quarks

Polarized and sea quark PDFs for $Q^2 = 10\ \text{GeV}^2$ from the NNPDFpol1.1 parameterization

See *Nocera ER, et al. Nucl. Phys. B887:276 (2014).*

What is A_1? the virtual photon-nucleon asymmetry



Anti-parallel spins

$h = 1 + \frac{1}{2} = \frac{3}{2}$

Parallel spins

$h = 1 - \frac{1}{2} = \frac{1}{2}$

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{g_1(x,Q^2) - \gamma^2 g_2(x,Q^2)}{F_1(x,Q^2)}$$

where $\gamma^2 = (2Mx)^2/Q^2$ and M = nucleon mass

For large Q^2, $\boxed{A_1 \approx g_1(x)/F_1(x)}$

- Our wide Q^2 range (up to 10 GeV^2) will allow for further study of A_1's $\boldsymbol{Q^2}$ **−dependence @ a given $\boldsymbol{x}$ value in the valence region**

- We need a transverse and longitudinal component to reconstruct the asymmetry along the virtual photon direction:

$$A_{\parallel} = \frac{\sigma^{\downarrow\Uparrow} - \sigma^{\uparrow\Uparrow}}{\sigma^{\downarrow\Uparrow} + \sigma^{\uparrow\Uparrow}} \quad \text{and} \quad A_{\perp} = \frac{\sigma^{\downarrow\Rightarrow} - \sigma^{\uparrow\Rightarrow}}{\sigma^{\downarrow\Rightarrow} + \sigma^{\uparrow\Rightarrow}}$$

$$\rightarrow \boxed{A_1 = \frac{A_{\parallel}}{D(1+\eta\xi)} - \frac{\eta A_{\perp}}{d(1+\eta\xi)}}$$

- $\sigma^{\downarrow\Uparrow}(\sigma^{\uparrow\Uparrow})$ is the cross section for a **longitudinally polarized target** with the electron spin aligned antiparallel (parallel) to the target spin

- $\sigma^{\downarrow\Rightarrow}(\sigma^{\uparrow\Rightarrow})$ is the cross section for a **transversely polarized target** with the electron spin aligned antiparallel (parallel) to the beam direction

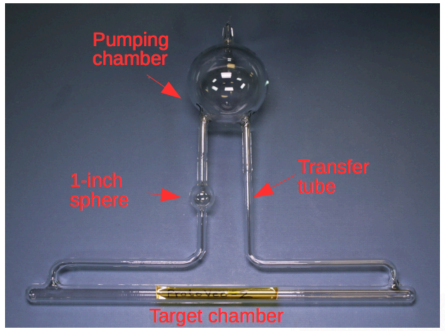
- $\eta, \xi,$ and d are kinematic factors, and D depends on the ratio of the longitudinal and transverse virtual-photon absorption cross sections $R = \sigma_L/\sigma_T$

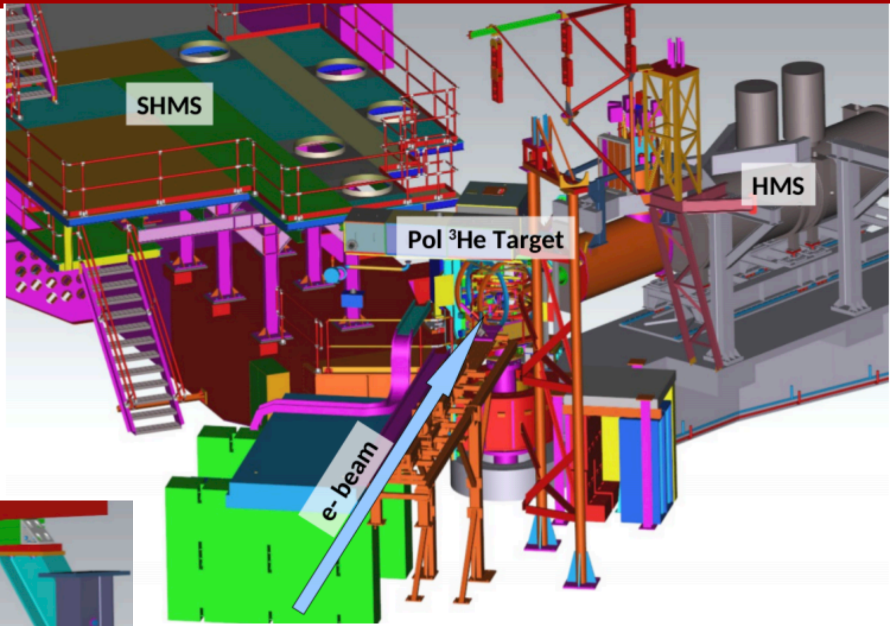
Experimental Setup

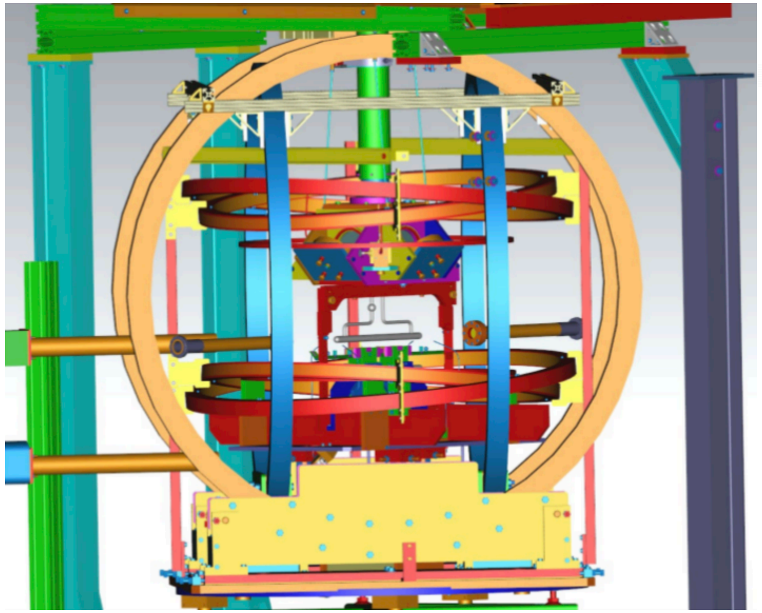
Spectrometers:
- High Momentum Spectrometer (HMS)
- Super High Momentum Spectrometer (SHMS)

Electron Beam:
- 1-pass @ 2.2 GeV (elastic, Δ(1232))
- 5-pass @ 10.5 GeV (DIS)
- Beam polarization: 85%
  (< 3% uncertainty according to Moller)
- Circular beam raster with 2.5 mm radius
- < 50 ppm avg. charge asymmetry

Polarized ^{3}He Target
- ^{3}He production cell (40 cm)
- 55 – 60% polarization without beam
- 30 uA beam current
- 3% uncertainty in polarimetry





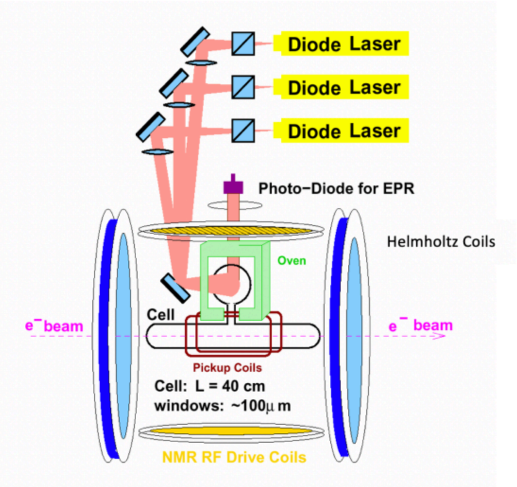


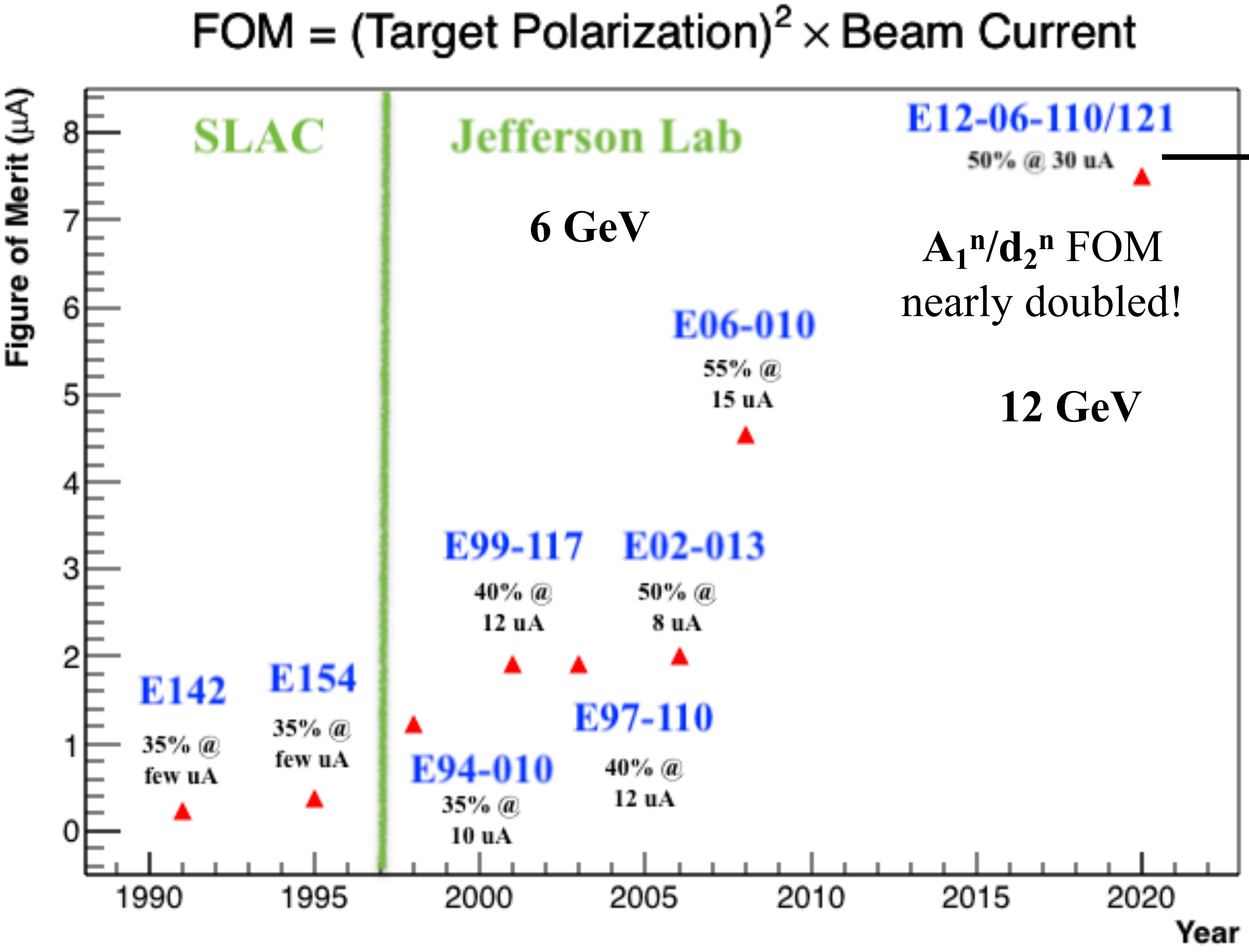
A_1^n production began on Jan. 12th and ended on March 13th, 2020

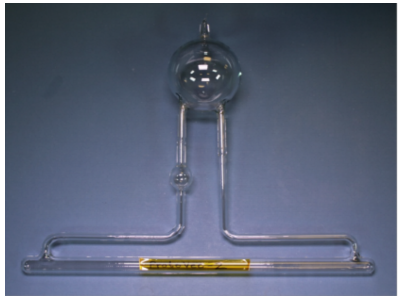
^{3}He Performance Evolution

12 GeV era achieved **double the luminosity** of $2\text{x}10^{36}$ $cm^{-2}s^{-1}$ @ 30 μA

Each laser at 795 nm @ 30 W



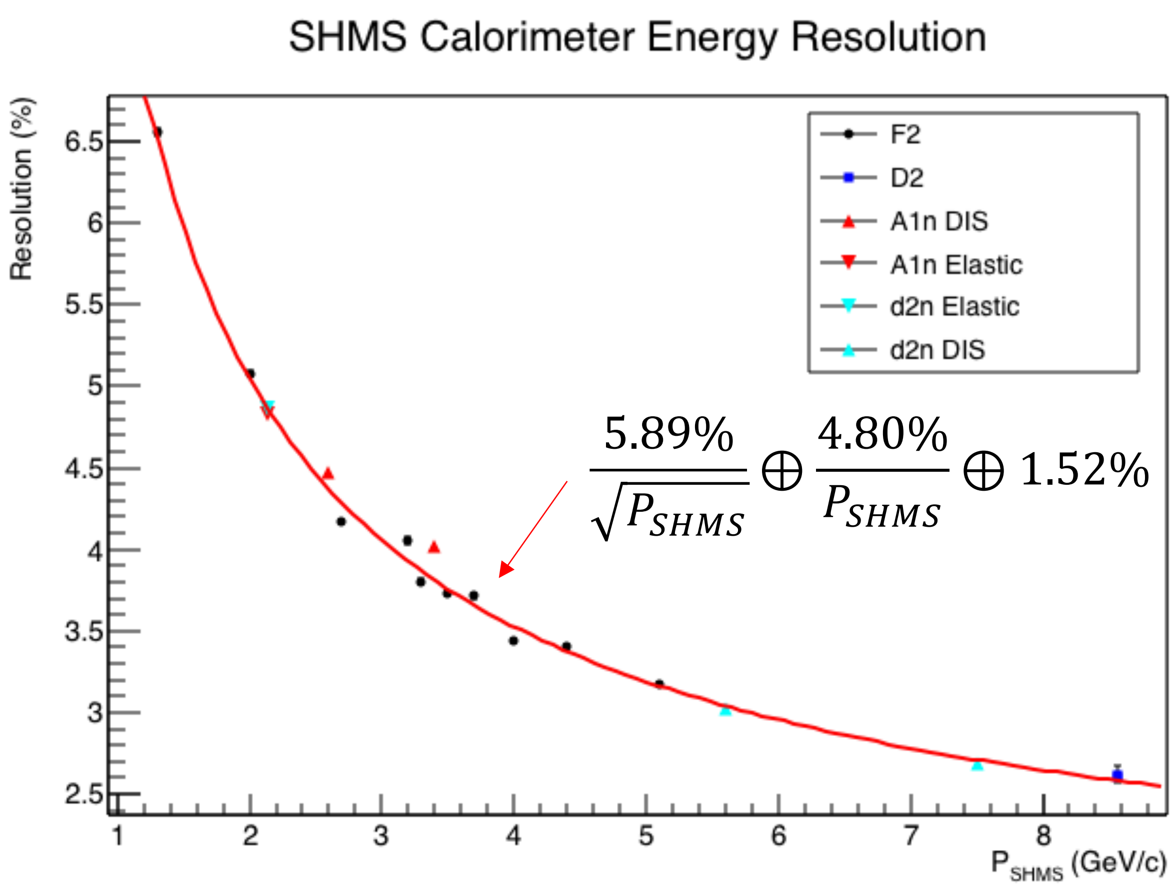


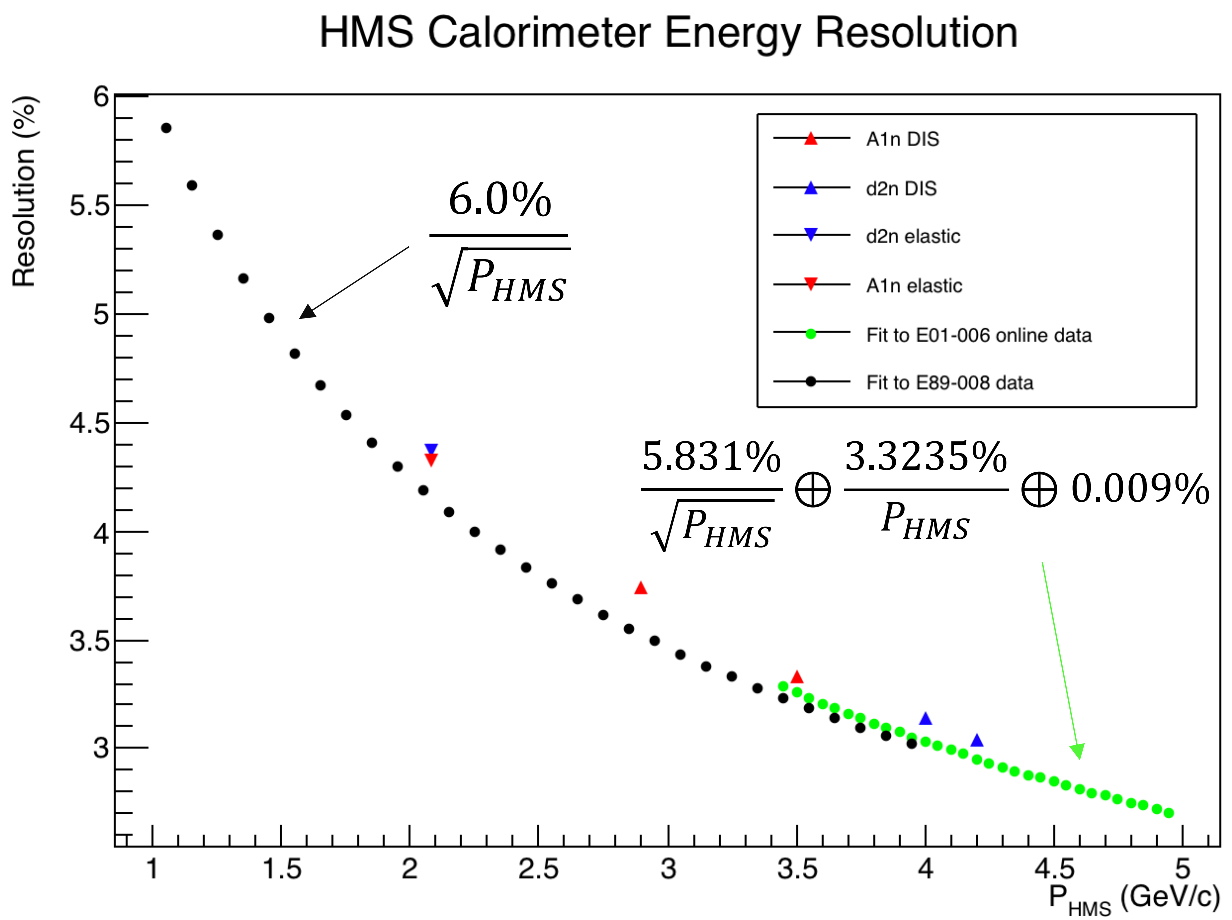


Convection-style cells (instead of diffusion cells used in the 6 GeV era) used for A1n/d2n

→ allows for more uniform polarization between target and pumping chamber

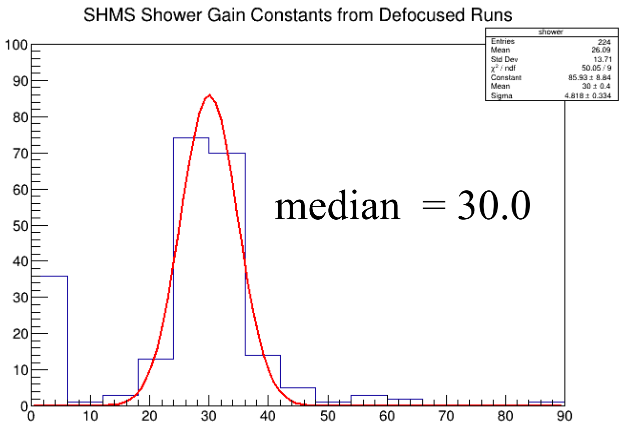
SHMS & HMS Calorimeter Energy Resolution





✓ A1n/d2n points are consistent with one another

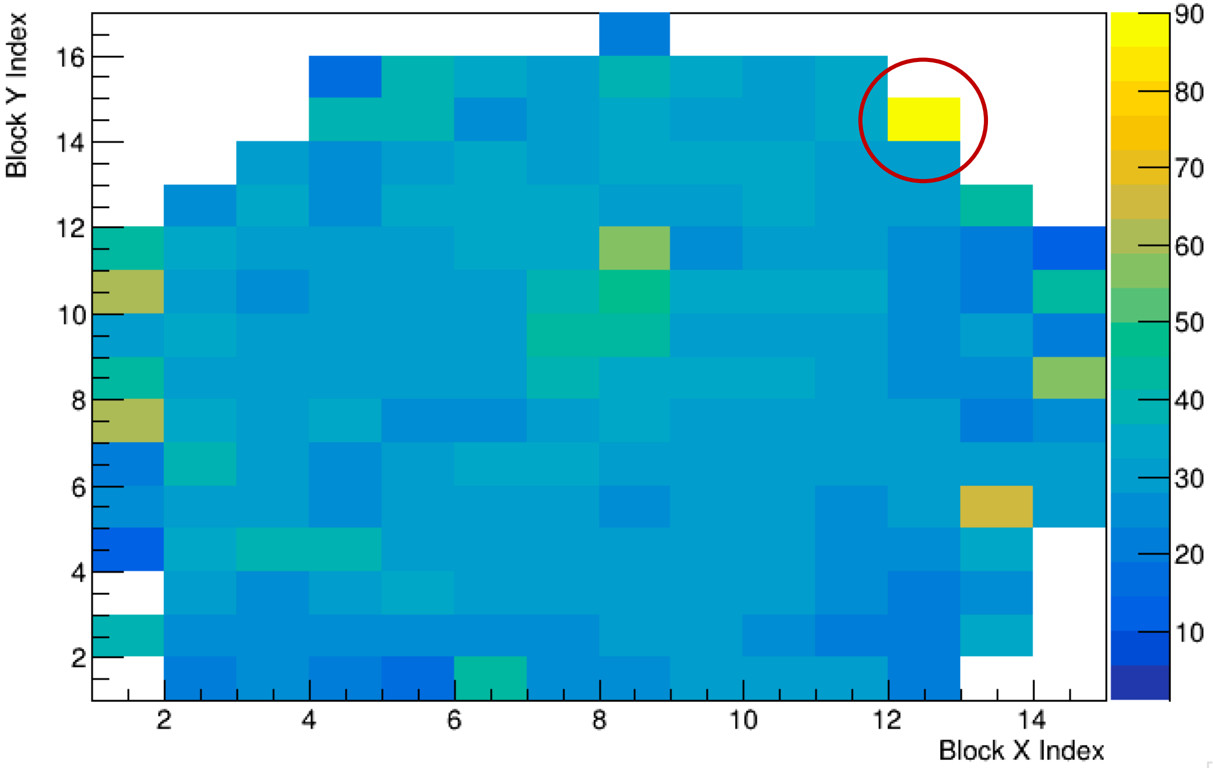
Improving the SHMS Defocused Runs Calibration

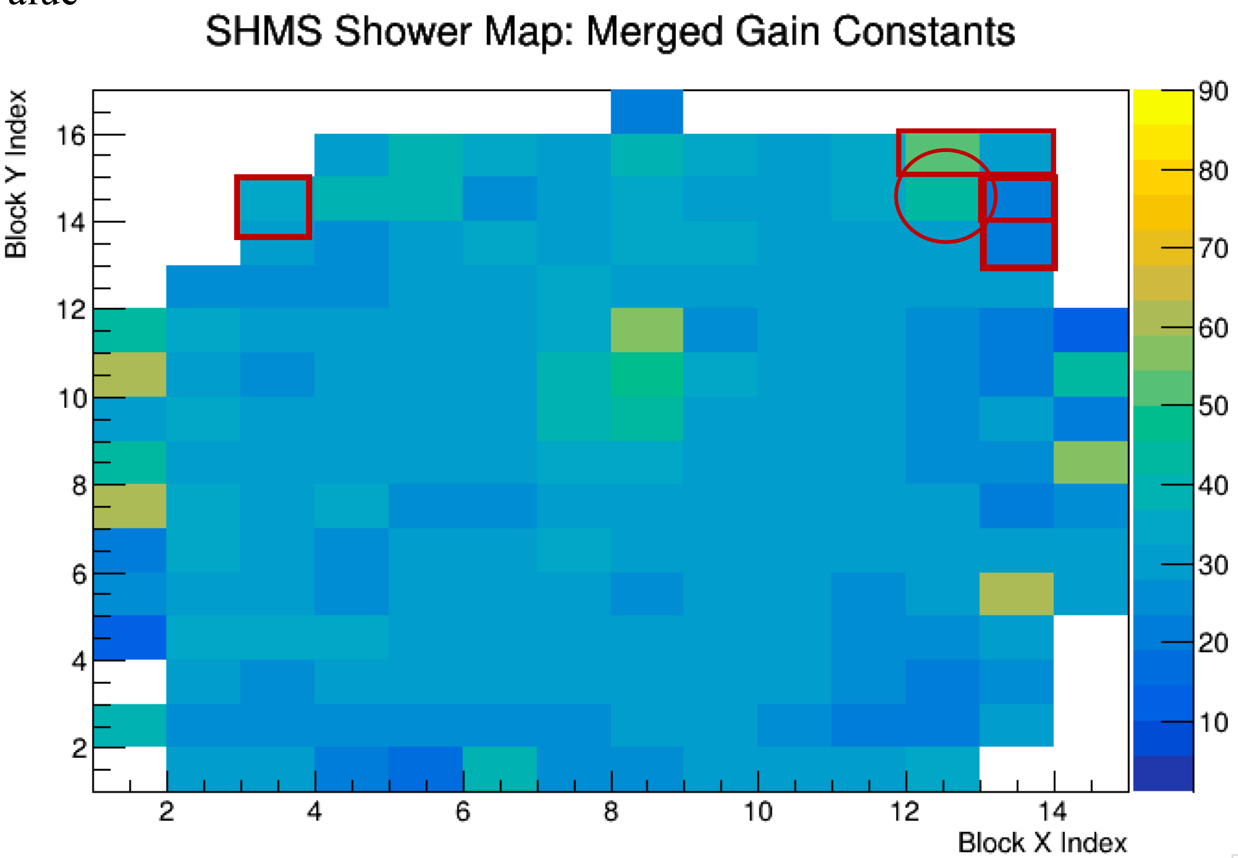


- **Defocused Runs** were taken in Dec. 2019 to illuminate as many blocks of the shower array as possible for calibration
- Gains of a few PMTs largely deviated from the median value

➢ Calibrating a large set of 2.6 GeV DIS runs provided events for some blocks not covered with the defocused runs

➢ The two sets were merged to bring the PMT gain constants towards closer agreement





Particle Identification (PID) Studies

We're measuring an asymmetry, so we need **clean electron** detection

The SHMS & HMS have two independent detectors for PID:

Combined Pion Rejection Factor = $PRF_{cherenkov} * PRF_{calorimeter}$

1. The **Gas Cherenkov**

$$Cherenkov\ Efficiency = \frac{electron\ sample\ that\ passed\ the\ Cherenkov\ cut}{electron\ sample\ selected\ with\ the\ Calorimeter}$$

$$Cherenkov\ PR\ Factor = \frac{pion\ sample\ selected\ with\ the\ Calorimeter}{pion\ sample\ that\ passed\ the\ Cherenkov\ cut}$$

→ e^-, π samples determined by the Calorimeter, Cherenkov used for PID

2. The Lead-Glass **Calorimeter**

$$Calorimeter\ Efficiency = \frac{electron\ sample\ that\ passed\ the\ etracknorm\ and\ eprtracknorm\ cut}{electron\ sample\ selected\ with\ the\ Cherenkov}$$

$$Calorimeter\ PR\ Factor = \frac{pion\ sample\ selected\ with\ the\ Cherenkov}{pion\ sample\ that\ passed\ the\ etracknorm\ and\ eprtracknorm\ cut}$$

→ e^-, π samples determined by the Cherenkov, Calorimeter used for PID

PID: Noble Gas Cherenkov (NGC) Efficiency & Pion Rejection

SHMS Runs:
10334-10347,
DIS, Long. & Trans.
E_p= -2.6 GeV, 30°

Noble Gas Cherenkov (NGC)

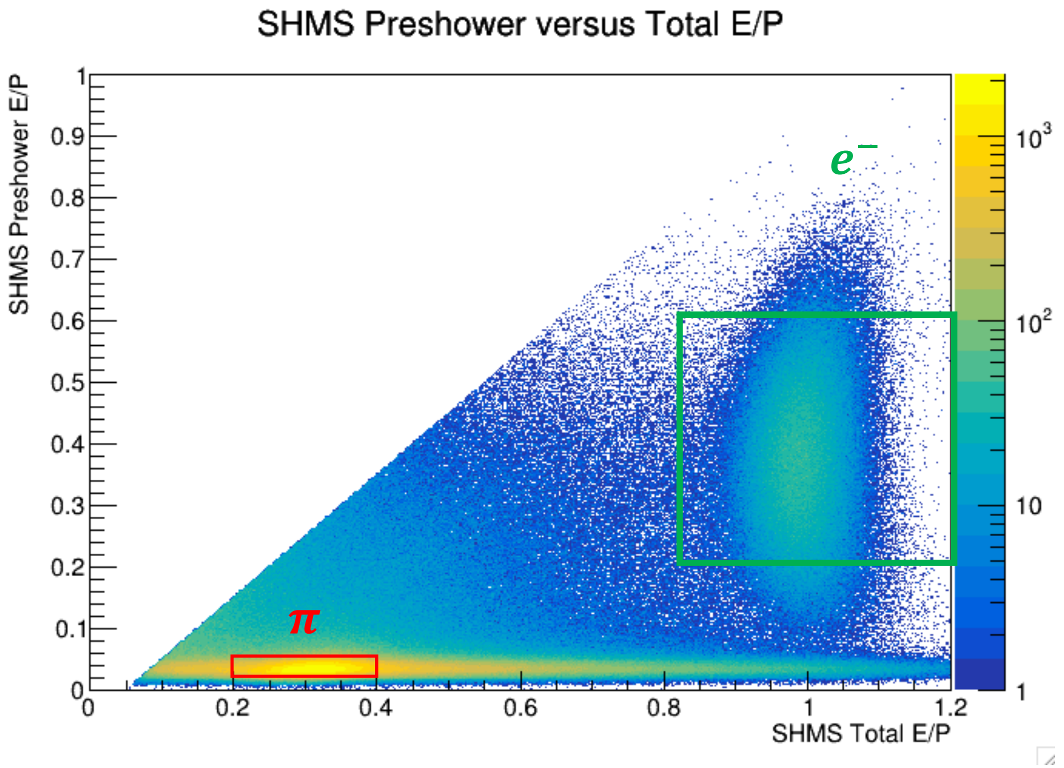
Threshold Energies
N_2 @ 1atm, 20°C
e^- : 21.6 MeV
$\pi^{+,-}$: 5.9 GeV
θ_c = 1.35°

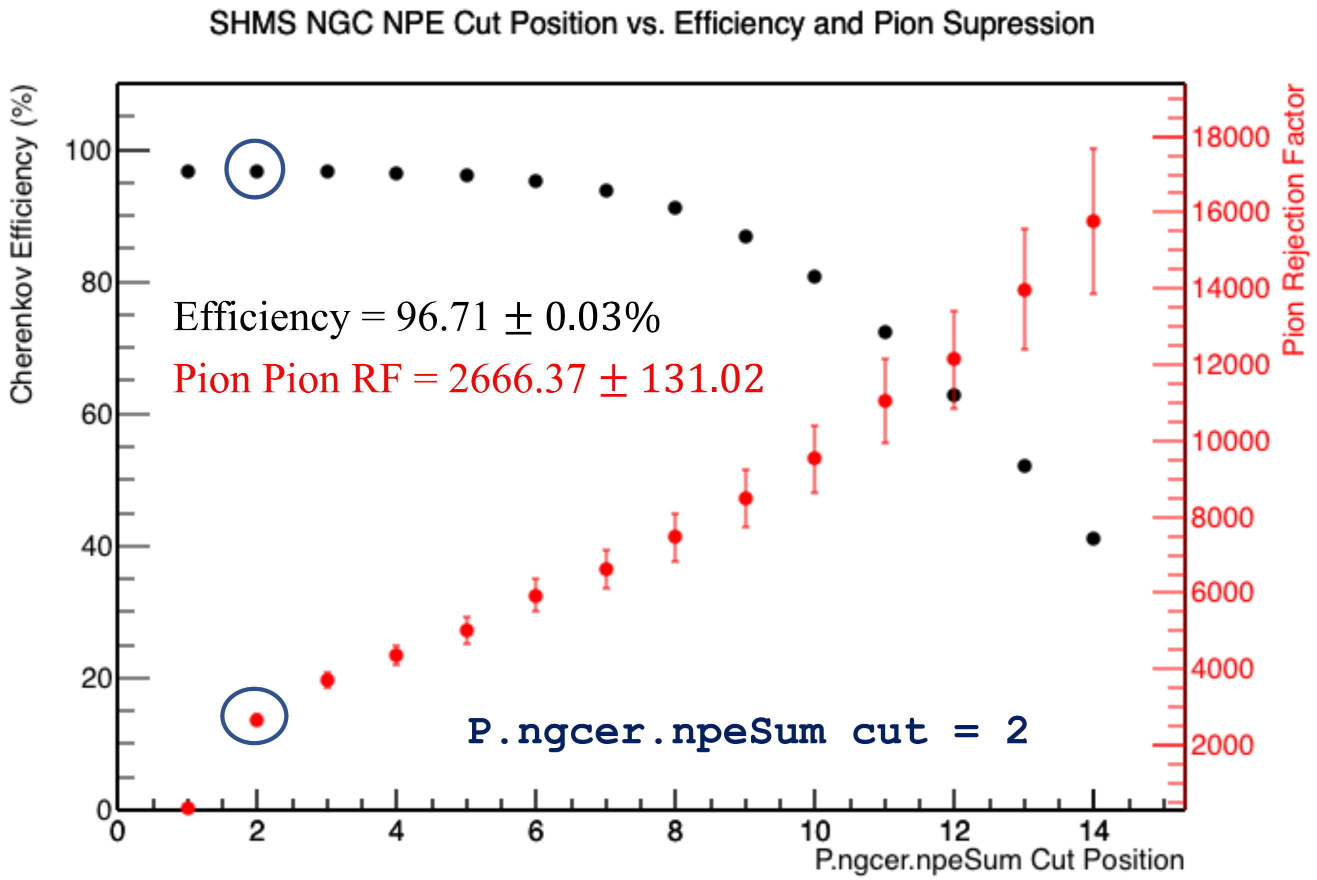
Step 1: Use 2D Graphical Cuts to determine π and e^- samples

Step 2: Determine how many e^- and π pass the NGC sum cut

```
0.80 < Total E/P < 1.20
&&
0.20 < Preshower E/P < 0.60
```

```
0.20 < Total E/P < 0.40
&&
0.02 < Preshower E/P < 0.05
```

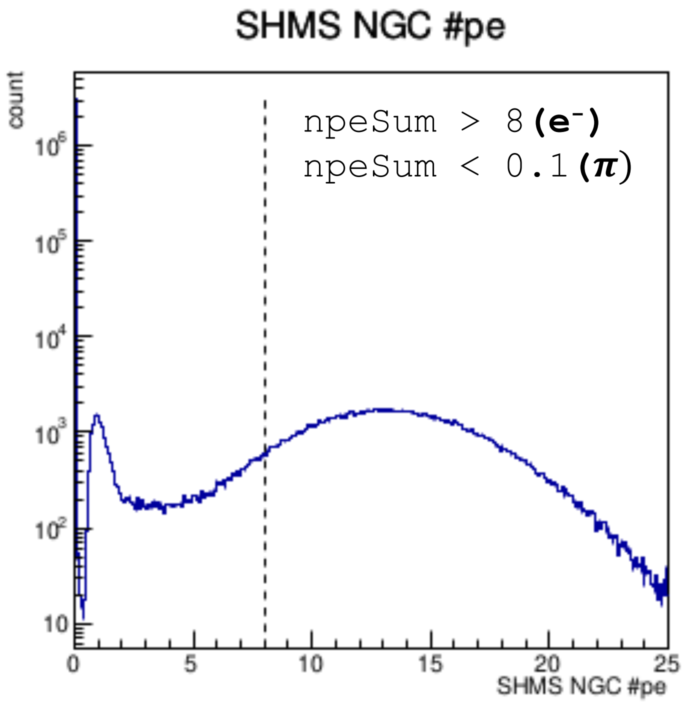




PID: Calorimeter Efficiency & Pion Rejection

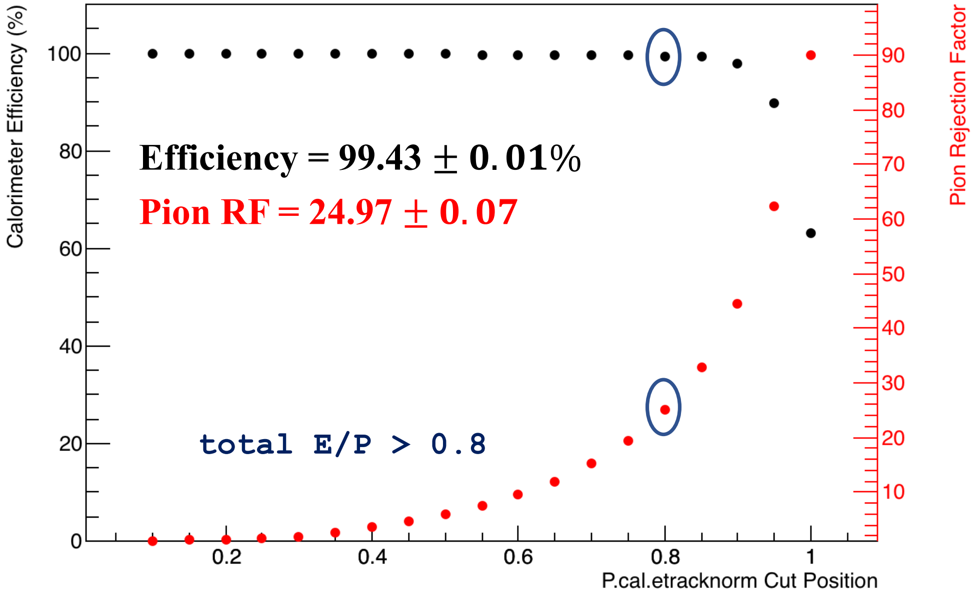
SHMS Runs:
10334-10347,
DIS, Long. & Trans.
E_p= -2.6 GeV, 30°

Calorimeter

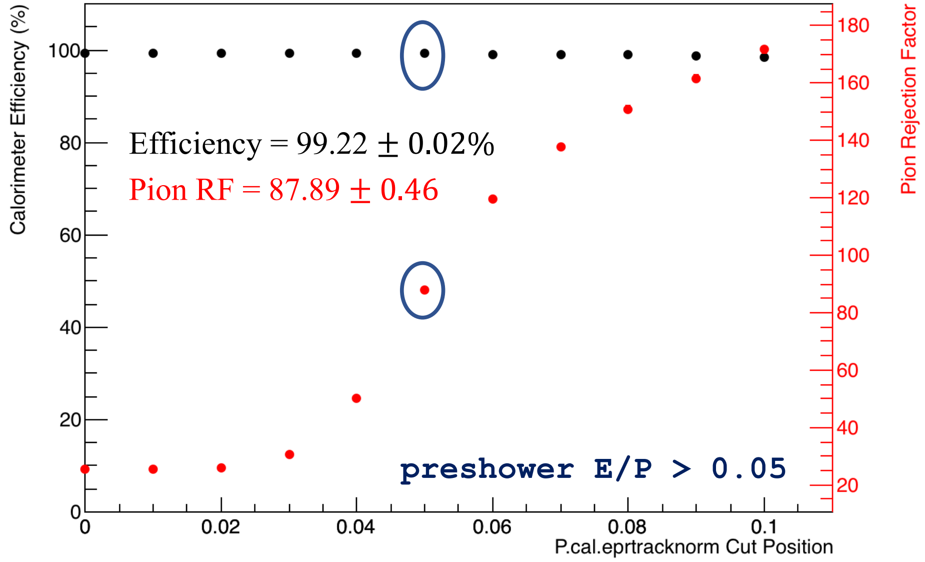


Step 1: Use the NGC npe sum cut to determine π and e^- samples

Step 2: Determine how many e^- and π pass the total E/P cut



→Add a preshower cut to the PID cut for a PRF boost



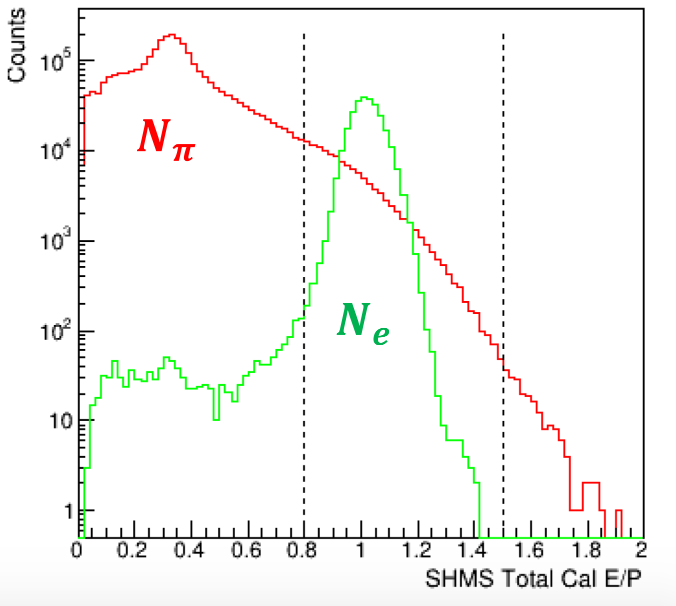
Pion Contamination with a Preshower Cut

pion contamination = N_π / N_e

PID Cuts: `Preshower E/P > 0.05`

`npeSum > 8 && shower E/P > 0`

`npeSum < 0.1`



PC from Calorimeter Only:

Histogram is integrated over `[0.80,1.50]` **to find percentage of pions in electron sample** = **12.93%**

* (1/PRF) @ 2 npeSum cut from NGC study (1/2666.25)

PC from Calorimeter + NGC: = **0.01%**

✓ goal is a contamination of < 0.4%

PID: Gas Cherenkov Efficiency & Pion Rejection

Gas Cherenkov

HMS Runs:
3181-3183
3186-3205
DIS, Long.
E_p= -2.9 GeV, 30°

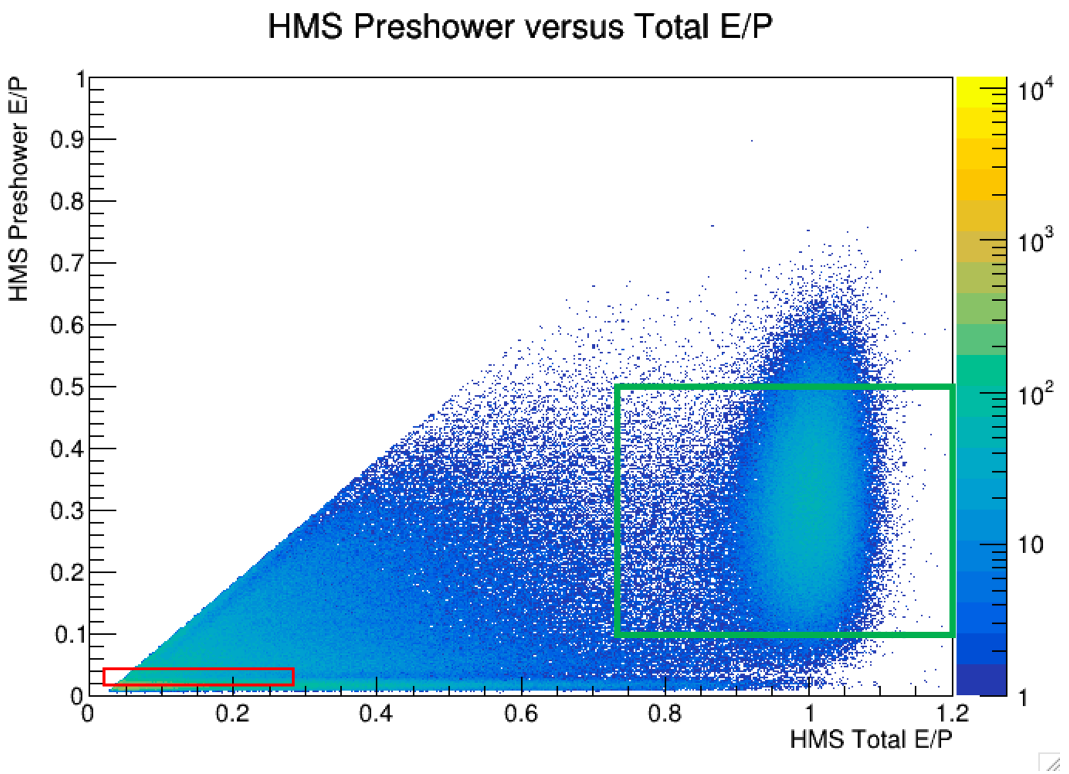
Step 1: Use 2D Graphical Cuts to determine π and e^- samples

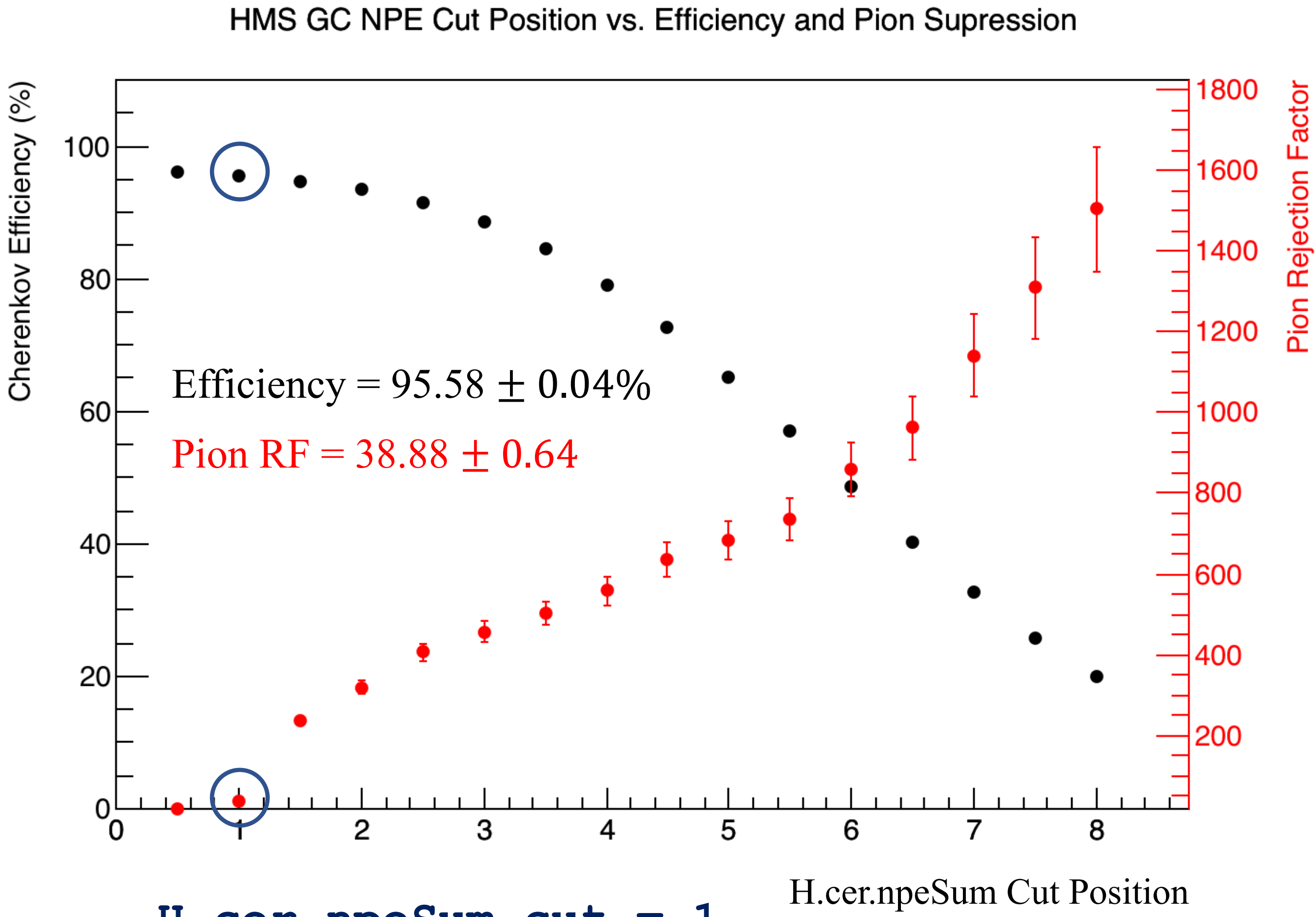
Threshold Energy
C_4F_8O @ 0.225 atm
$\pi^{+,-}$: 5.5 GeV

Step 2: Determine how many e^- and π pass the NGC sum cut

```
0.80 < Total E/P < 1.20
&&
0.10 < Preshower E/P < 0.50
```

```
0.03 < Total E/P < 0.25
&&
0.01 < Preshower E/P < 0.03
```





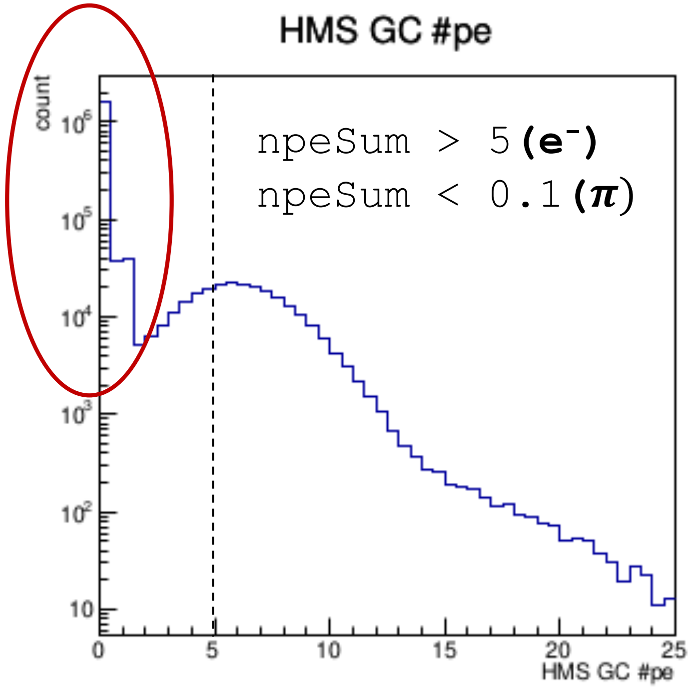

```
H.cer.npeSum cut = 1
```

PID: Calorimeter Efficiency & Pion Rejection

HMS Runs:
3181-3183
3186-3205
DIS, Long.
E_p= -2.9 GeV, 30°

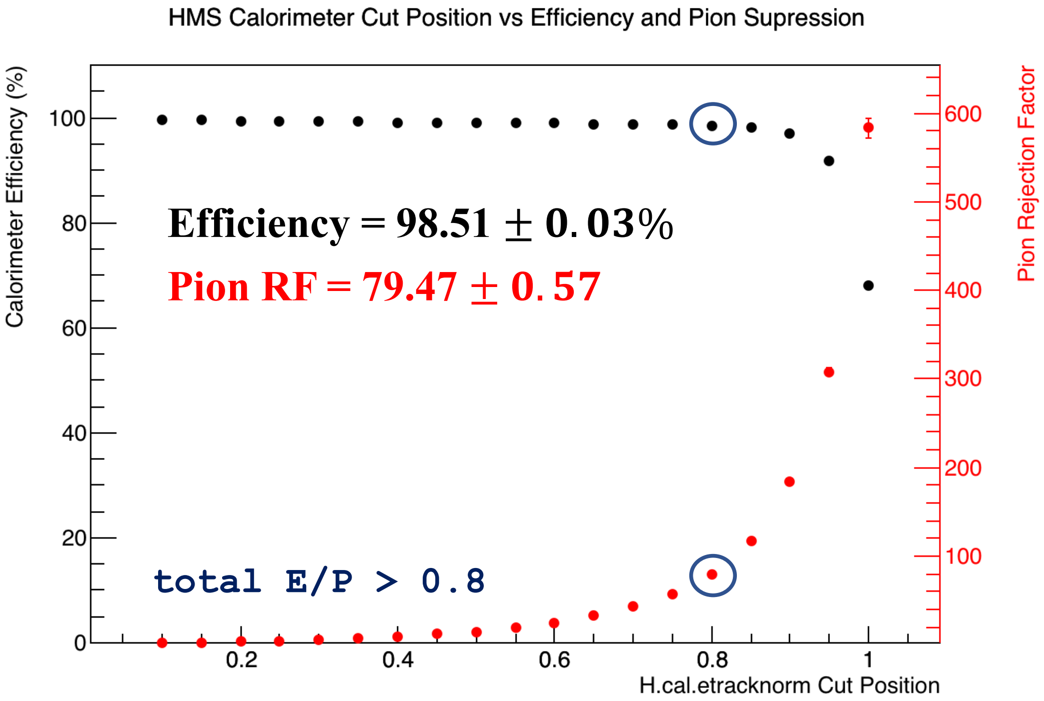
Calorimeter

(causing low cherenkov efficiency)



Step 1: Use the cherenkov npe sum cut to determine π and e^- samples

Step 2: Determine how many e^- and π pass the total E/P cut



PC from Calorimeter Only:

7.50 %

* (1/PRF) @ 1 npeSum cut from GC study (1/38.86)

PC from Calorimeter + GC:

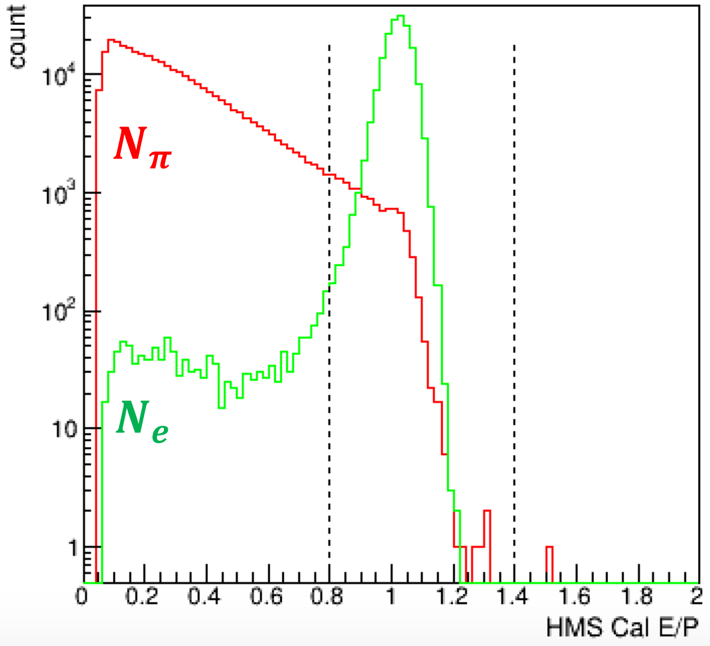
0.19 %

Step 3: Add a preshower cut, look at pion contamination to find the **percentage of pions in electron sample**

PID Cuts:
Preshower E/P > 0.05

npeSum > 5 && shower E/P > 0 (e^-)
npeSum < 0.1 (π)

pion contamination = N_π / N_e



Summary

E12-06-110 is a high-impact experiment on nucleon spin-structure

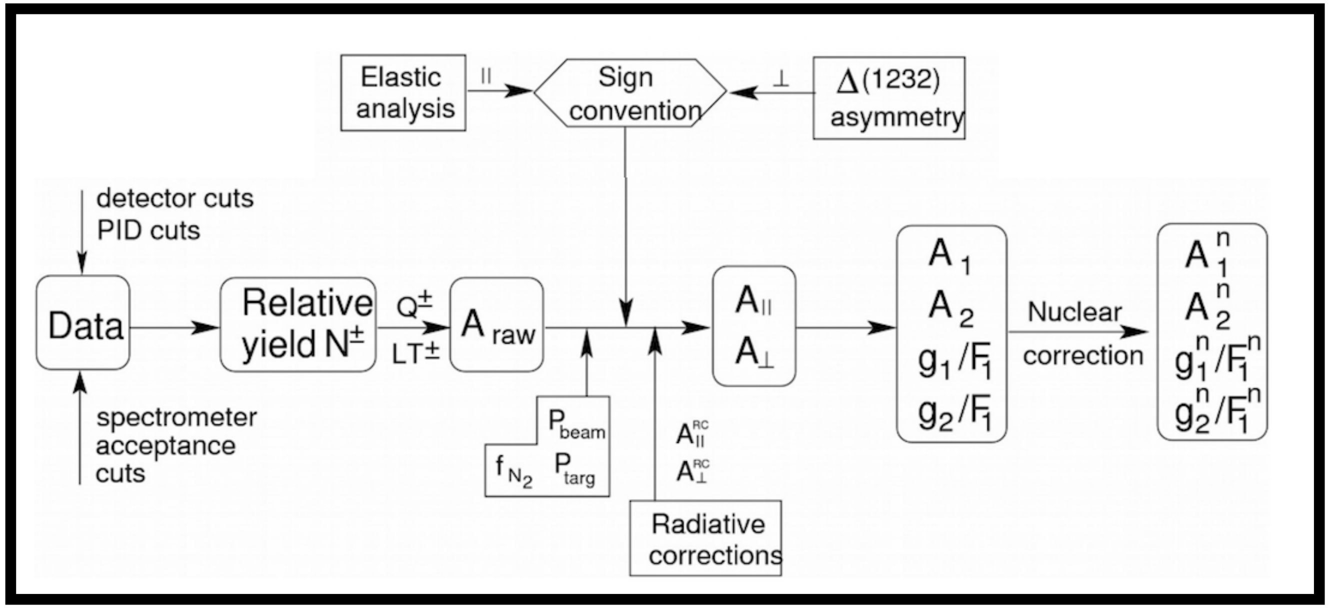
- The measurements of $\boldsymbol{A_1^n}$ **at high** $\boldsymbol{x}$ allow us to test fundamental predictions of the nucleon spin structure

- Combined with precision proton data, the high-precision neutron data will allow us to extract polarized-to-unpolarized quark PDF ratios distributions (Δq) and **spin-flavor distributions** ($\Delta u/u$) and ($\Delta d/d$)

The results will help answer questions like, **How much of a role does $\boldsymbol{L_q}$ play?** (to what degree are the quarks' spin aligned parallel to the nucleon spin?)

Thanks for listening!

Analysis Flowchart

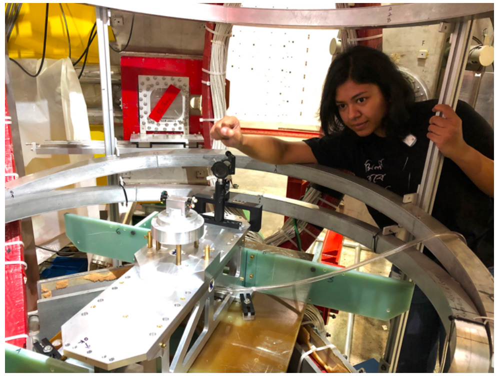


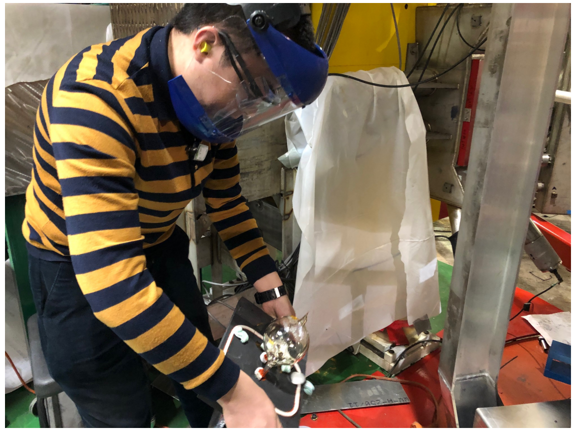
Currently at the early stages of analysis: Detector calibrations, PID, and target polarimetry work ongoing

Acknowledgements: The Polarized ^{3}He Run Group Collaboration (A_1^n/d_2^n)

D. Androic, W. Armstrong, T. Averett, X. Bai, J. Bane, S. Barcus, J. Benesch, H. Bhatt, D. Bhetuwal, D. Biswas, A. Camsonne, G. Cates, J-P. Chen, J. Chen, M. Chen, C. Cotton, M-M. Dalton, A. Deur, B. Dhital, B. Duran, S.C. Dusa, I. Fernando, E. Fuchey, B. Gamage, H. Gao, D. Gaskell, T.N. Gautam, N. Gauthier, C.A. Gayoso, O. Hansen, F. Hauenstein, W. Henry, G. Huber, C. Jantzi, S. Jia, K. Jin, M. Jones, S. Joosten, A. Karki, B. Karki, S. Katugampola, S. Kay, C. Keppel, E. King, P. King, W. Korsch, V. Kumar, R. Li, S. Li, W. Li, D. Mack, S. Malace, P. Markowitz, J. Matter, M. McCaughan, Z-E. Meziani, R. Michaels, A. Mkrtchyan, H. Mkrtchyan, C. Morean, V. Nelyubin, G. Niculescu, M. Niculescu, M. Nycz, C. Peng, S. Premathilake, A. Puckett, A. Rathnayake, M. Rehfuss, P. Reimer, G. Riley, Y. Roblin, J. Roche, M. Roy, M. Satnik, B. Sawatzky, S. Seeds, S. Sirca, G. Smith, N. Sparveris, H. Szumila-Vance, A. Tadepalli, V. Tadevosyan, Y. Tian, A. Usman, H. Voskanyan, S. Wood, B. Yale, C. Yero, A. Yoon, J. Zhang, Z. Zhao, X. Zheng, J. Zhou

PhD Candidates   Spokespeople





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