Investigating the EMC effect in highly-virtual nucleons at JLab

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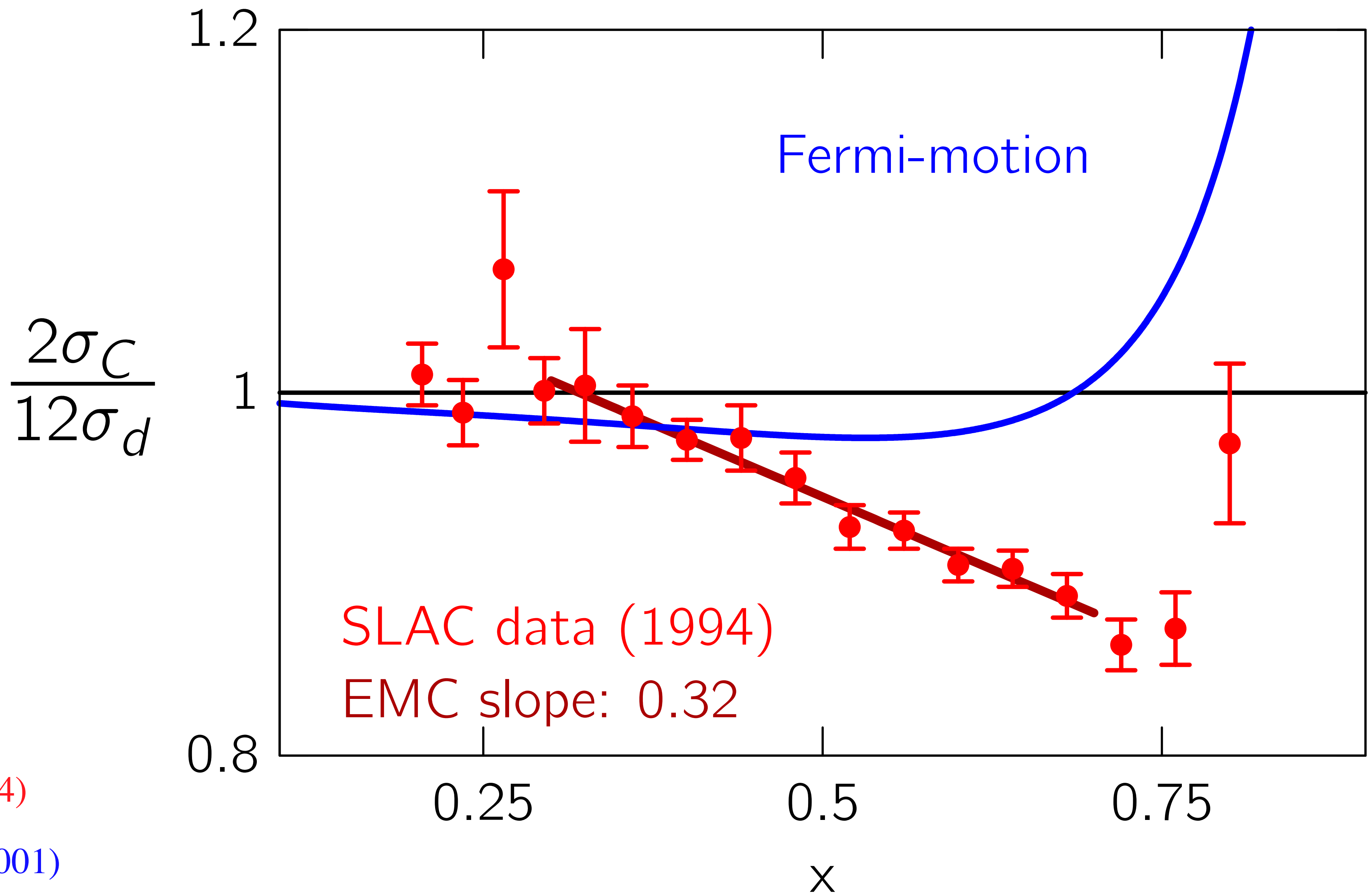
04/10/19

Outline

- EMC effect and Short Range Correlations
- Tagged DIS
- JLab Experiments
  - LAD in Hall C
  - BAND in HallB
- Very preliminary results from BAND at CLAS
- Summary and Outlook

The EMC Effect in DIS Scattering

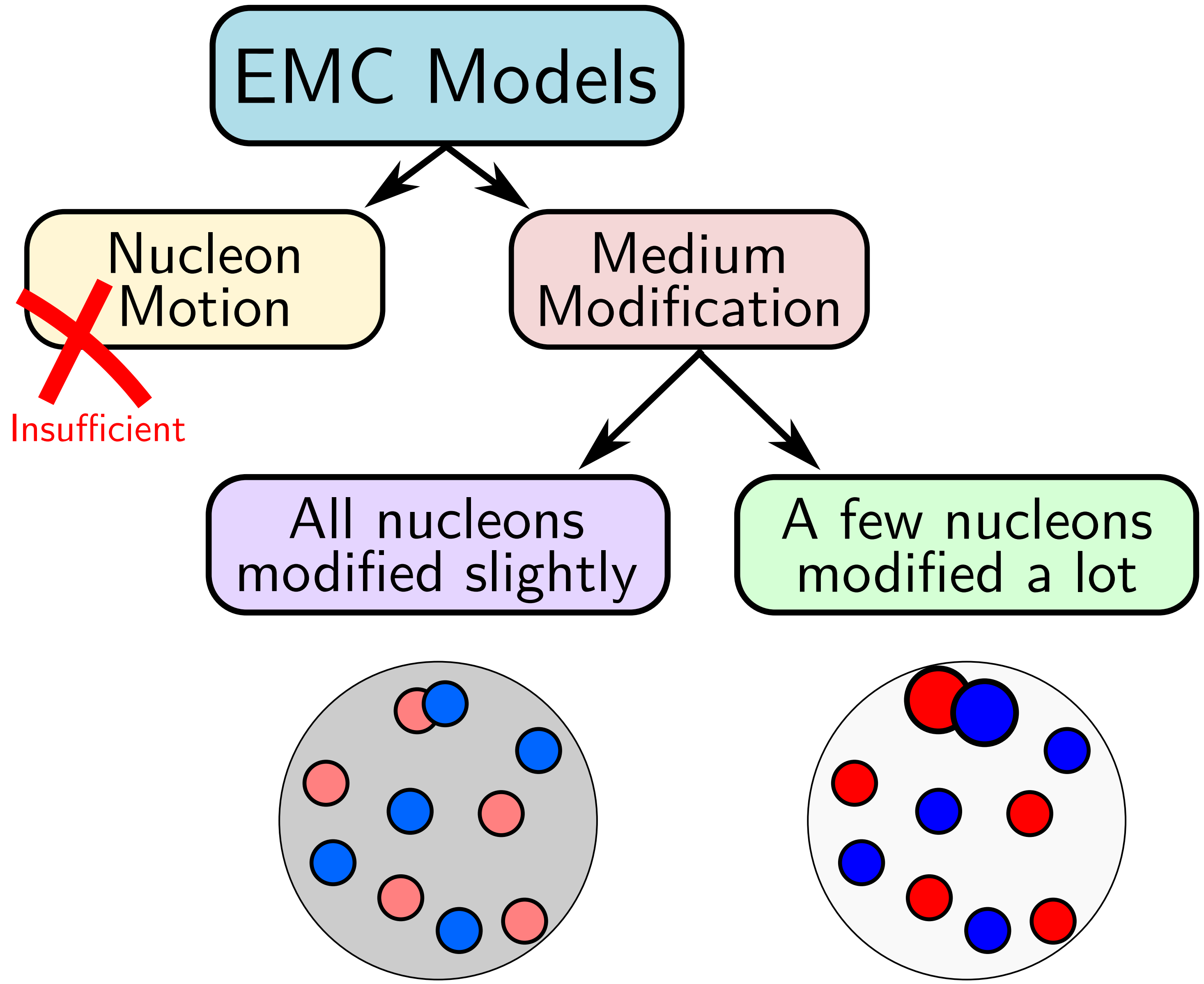


PRD 49, 4338 (1994)

PRC 65, 015211 (2001)

Quark distributions (F_2) in nucleons bound in nuclei different to distributions in free nucleons

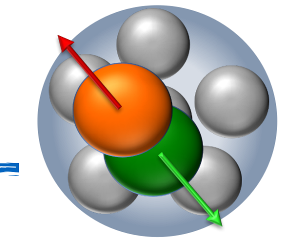
EMC Models

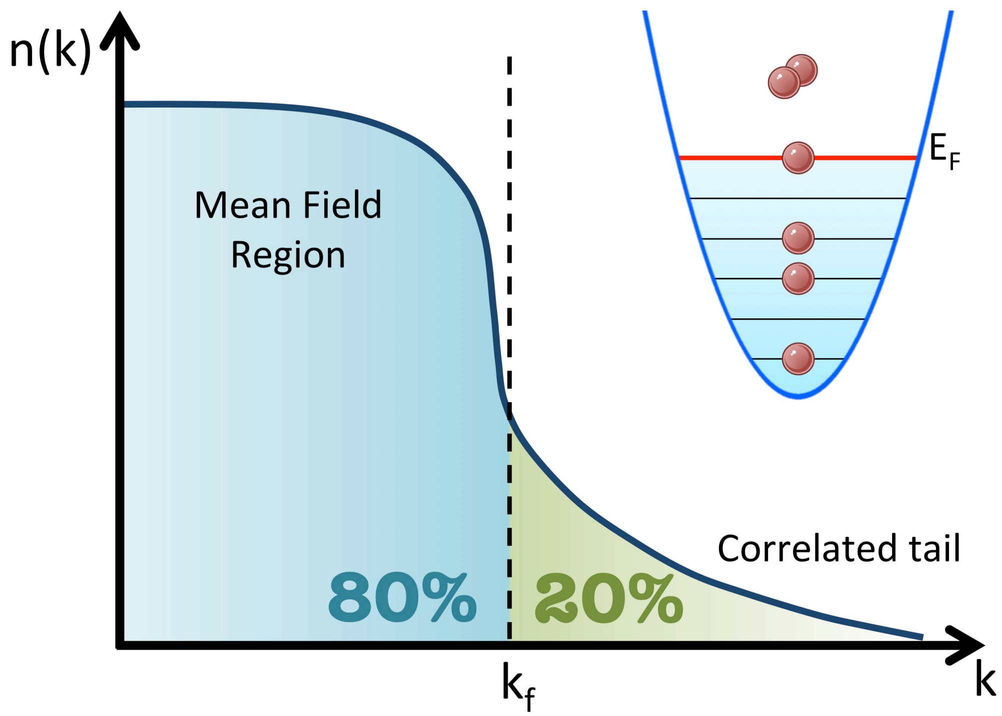


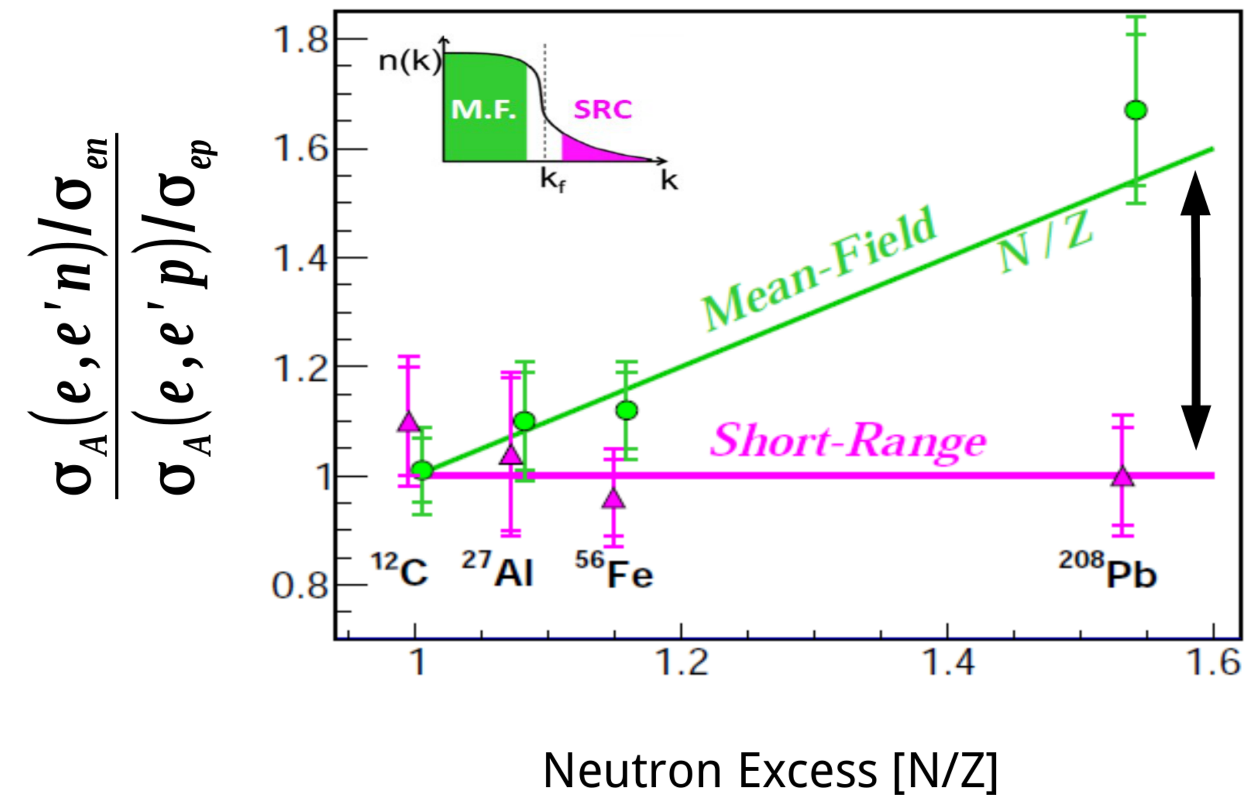
Mean Field Modifications

Short Range Correlations (SRC)

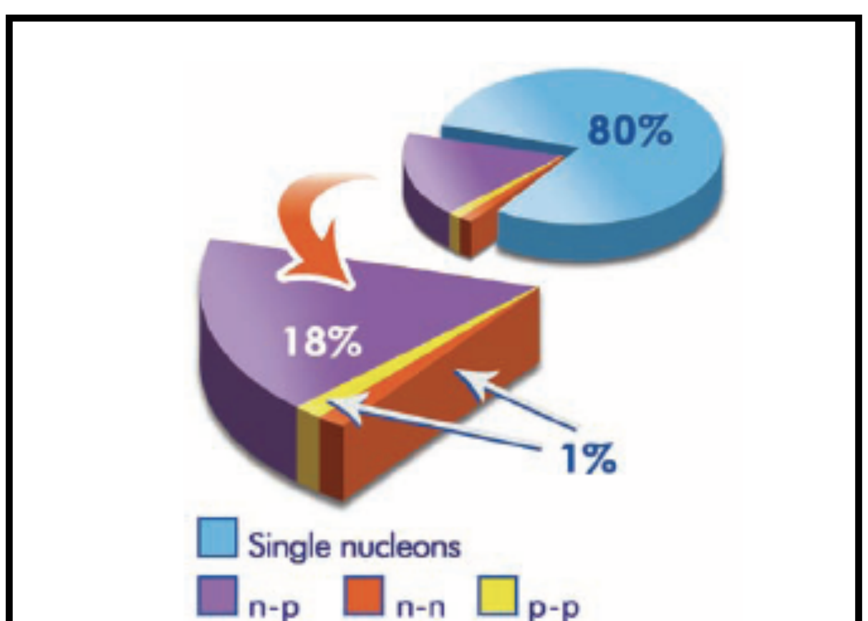
Short Range Correlations





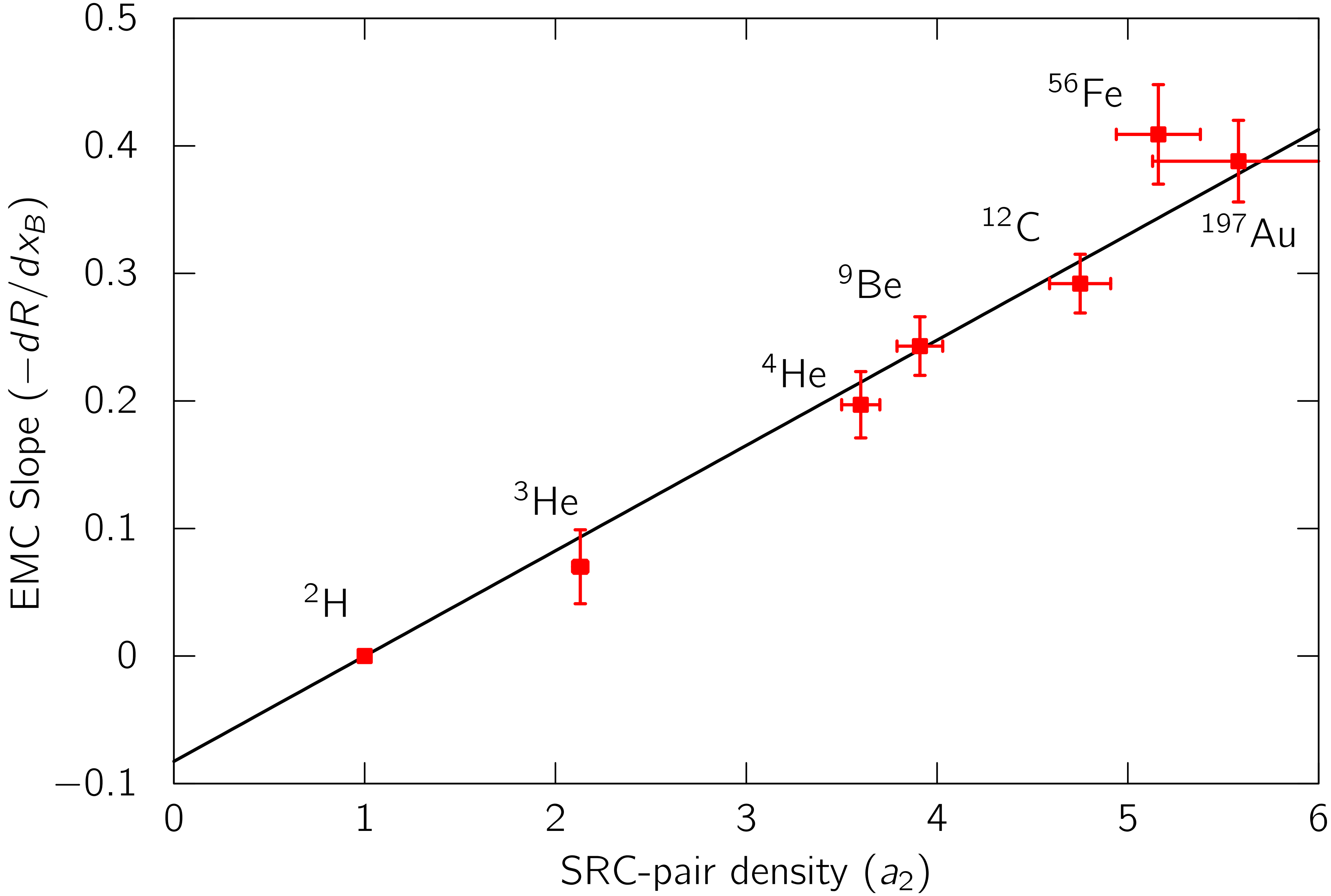


Duer et al. (CLAS collaboration), Nature 560, 617 (2018)



- NN pair with **large relative momentum and small c.m momentum**
- ~20% of nucleons in nuclei
- SRC pairs dominate nucleon momentum distribution above fermi momentum k_F
- **np dominance of SRC pairs** (about ~18 more likely than pp or nn)

EMC and SRC Correlation



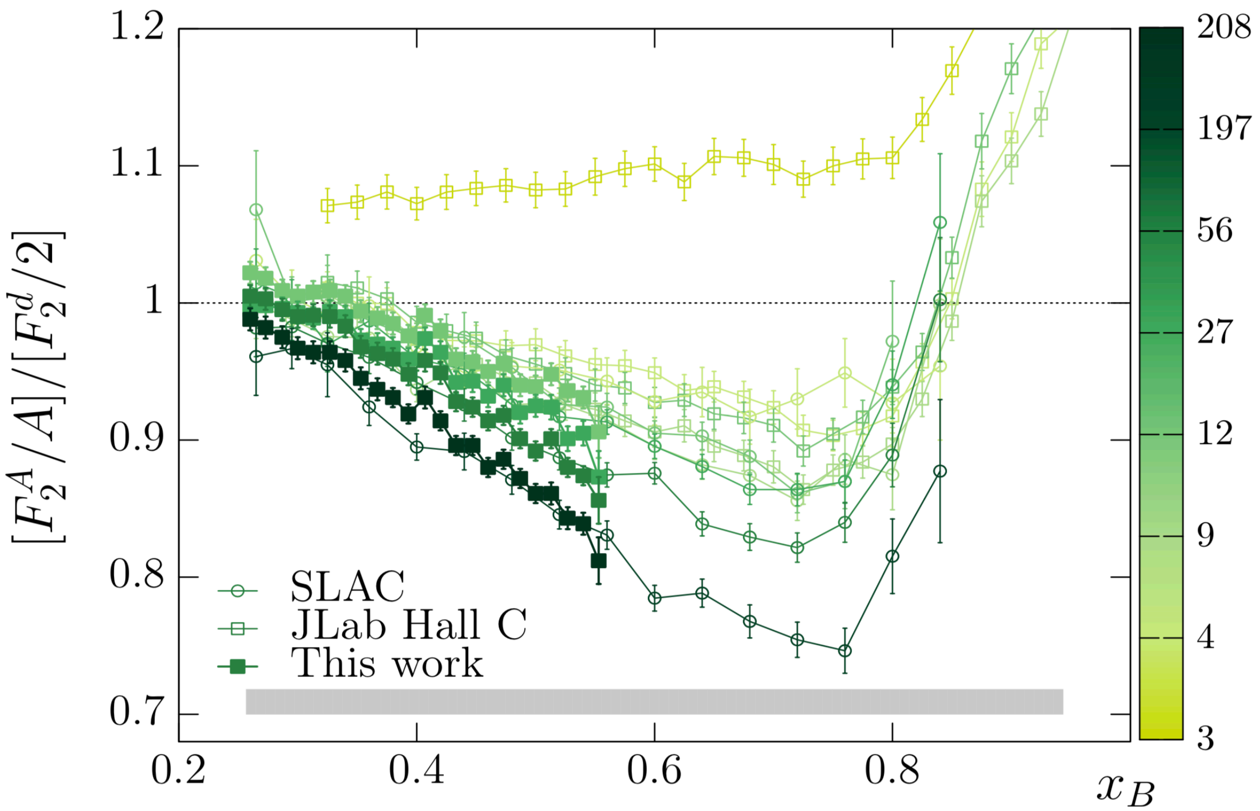
Weinstein et al., PRL 106, 052301 (2011), Hen et al.,PRC 85, 047301(2012)

EMC and SRC Correlation

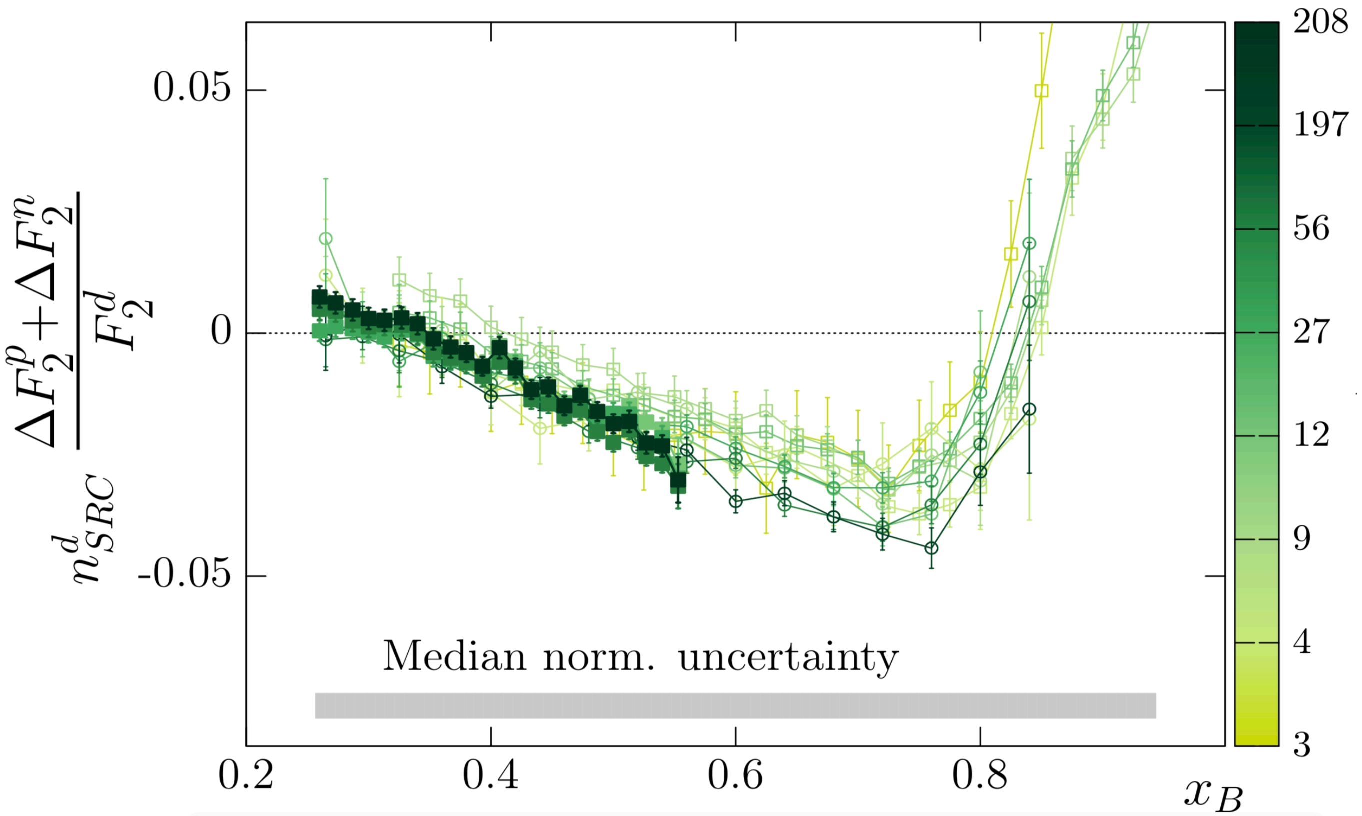
Bound = Quasi free + modified SRC

$$F_2^A = ZF_2^p + NF_2^n + n_{SRC}^A(\Delta F_2^p + \Delta F_2^n)$$

EMC effect

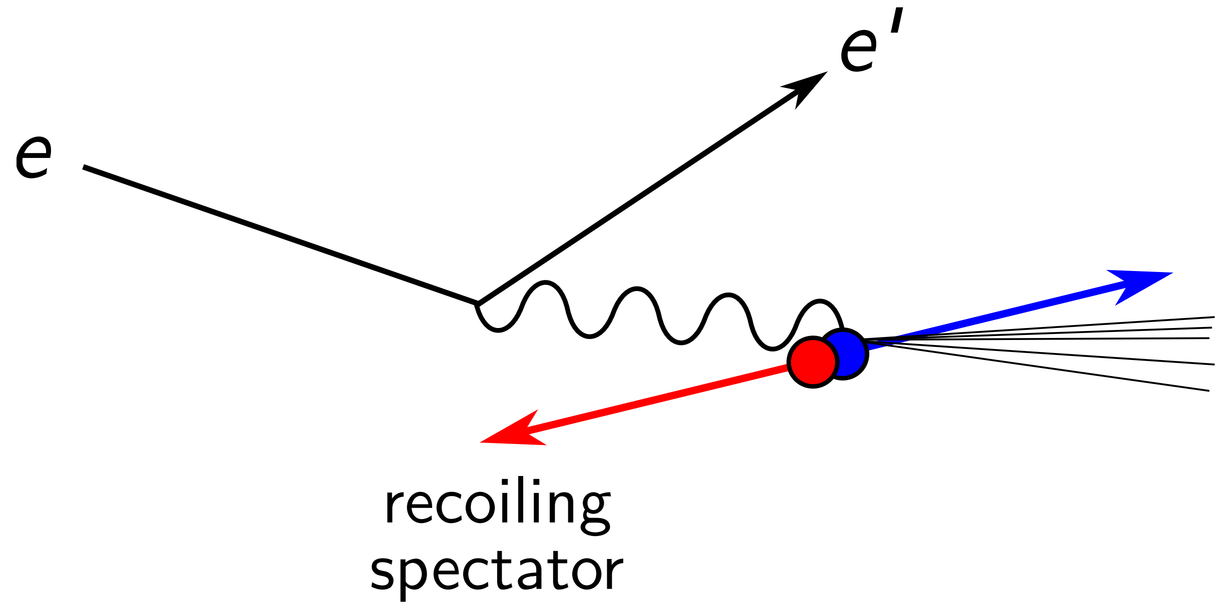


Universal Function



Schmookler et al. (CLAS collaboration), Nature 566, 354 (2019)

Tagged DIS on Deuterium



- “Tag“ interacting nucleon by measuring spectator
- How does the bound nucleon structure function depends on nucleon momentum or virtuality
- Explaining the EMC effect

What will be measured

- Measuring cross section ratios to minimize uncertainties
- Choose kinematics with minimal FSI $\theta_{rq} > 107°$

$$\frac{\sigma_{DIS}(x'_{\text{high}}, Q_1^2, \alpha_s)}{\sigma_{DIS}(x'_{\text{low}}, Q_2^2, \alpha_s)} \cdot \frac{\sigma_{DIS}^{\text{free}}(x_{\text{low}}, Q_2^2)}{\sigma_{DIS}^{\text{free}}(x_{\text{high}}, Q_1^2)} \cdot R_{FSI} = \frac{F_2^{\text{bound}}(x'_{\text{high}}, Q_1^2, \alpha_s)}{F_2^{\text{free}}(x_{\text{high}}, Q_1^2)}$$

measurement theory

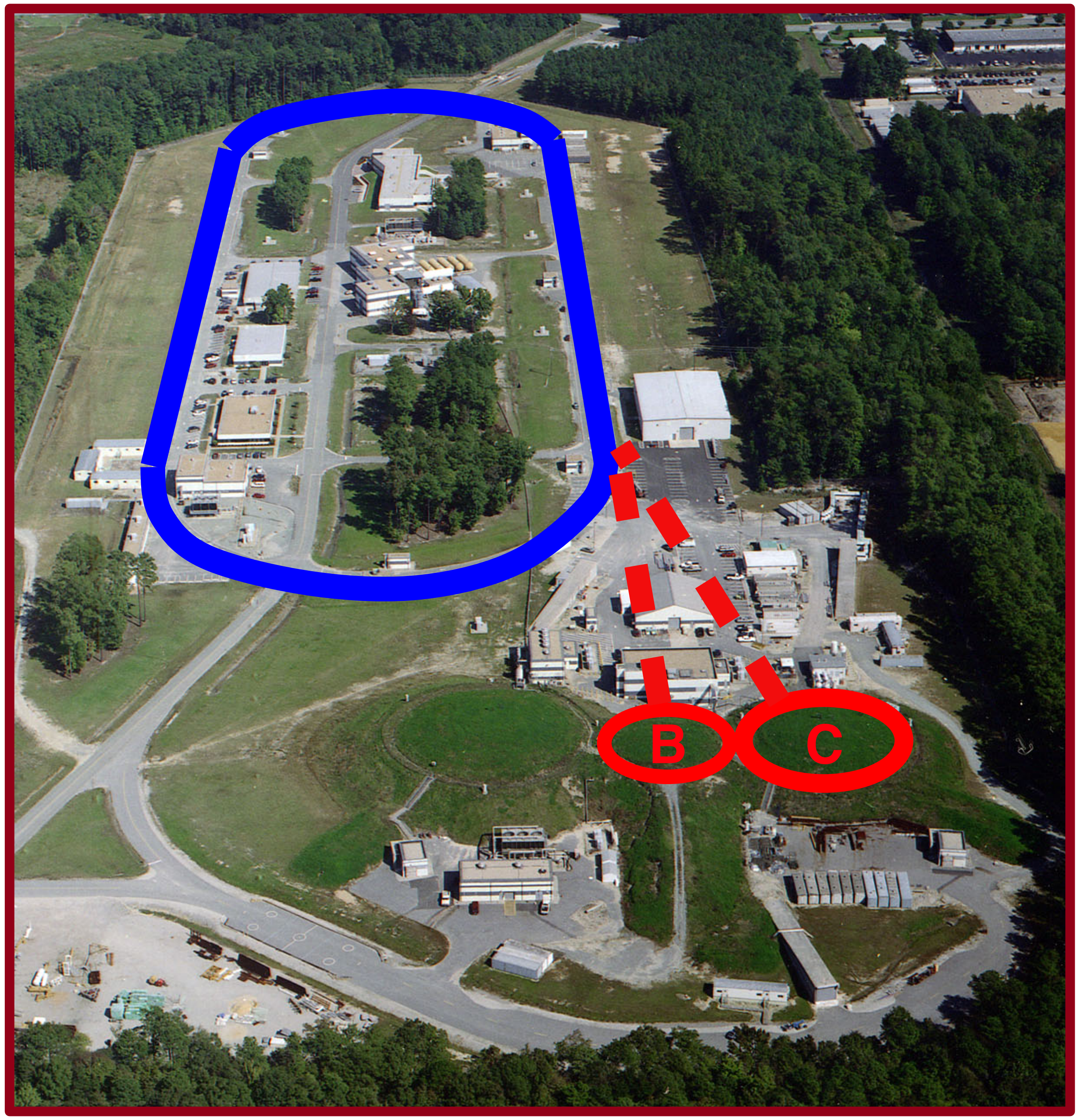
- $x' = x$ for moving nucleon
- $x'_{\text{high}} > 0.45$
- Expect no EMC effect at low x': $0.25 \leq x'_{\text{low}} \leq 0.35$

$$x'_B = \frac{Q^2}{2[(M_d - E_s)\omega + \vec{p_s} \cdot \vec{q}]}$$

$$x_B = \frac{Q^2}{2m_N\omega}$$

$$\alpha_s = (E_s - p_s^z)/m_s$$

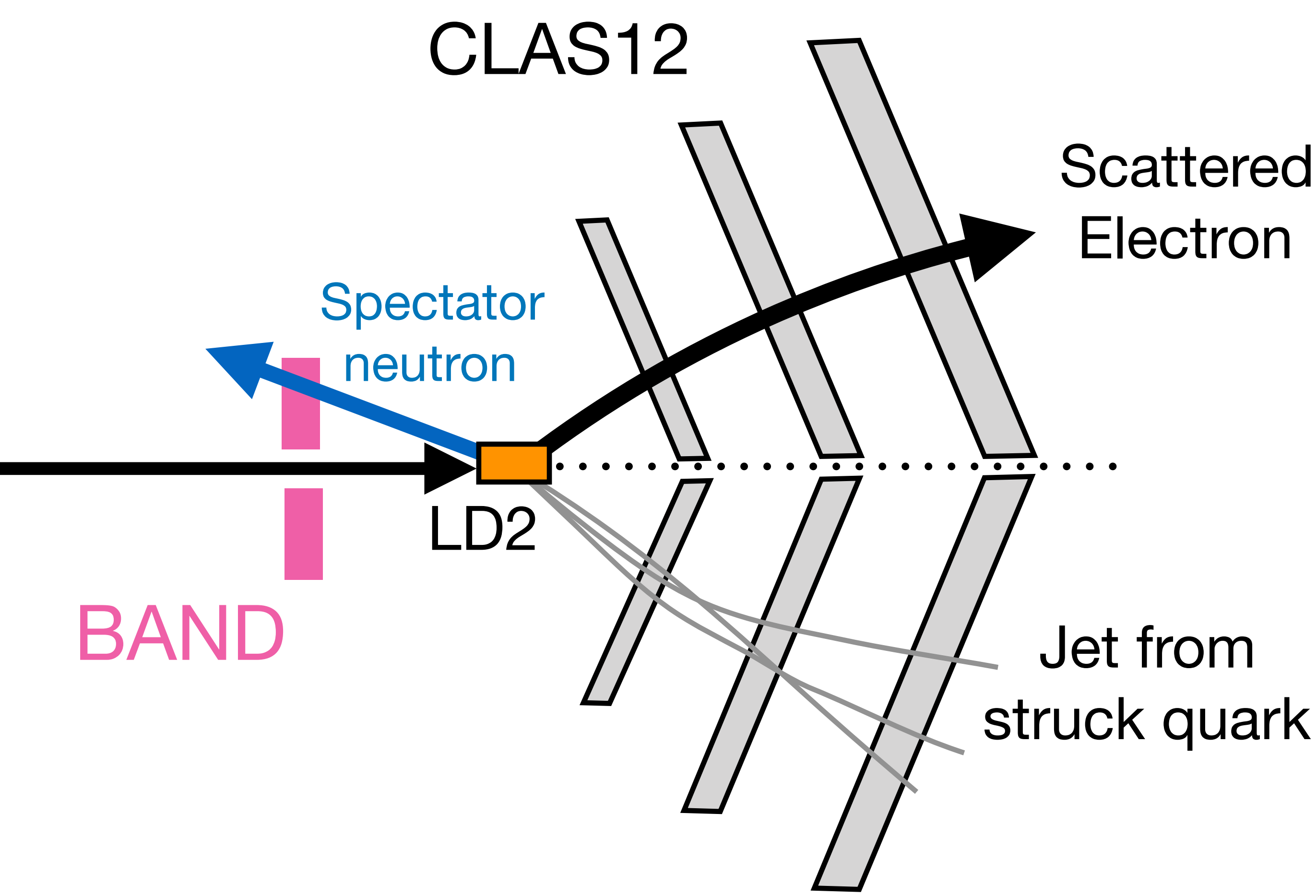
CEBAF Accelerator at JLab

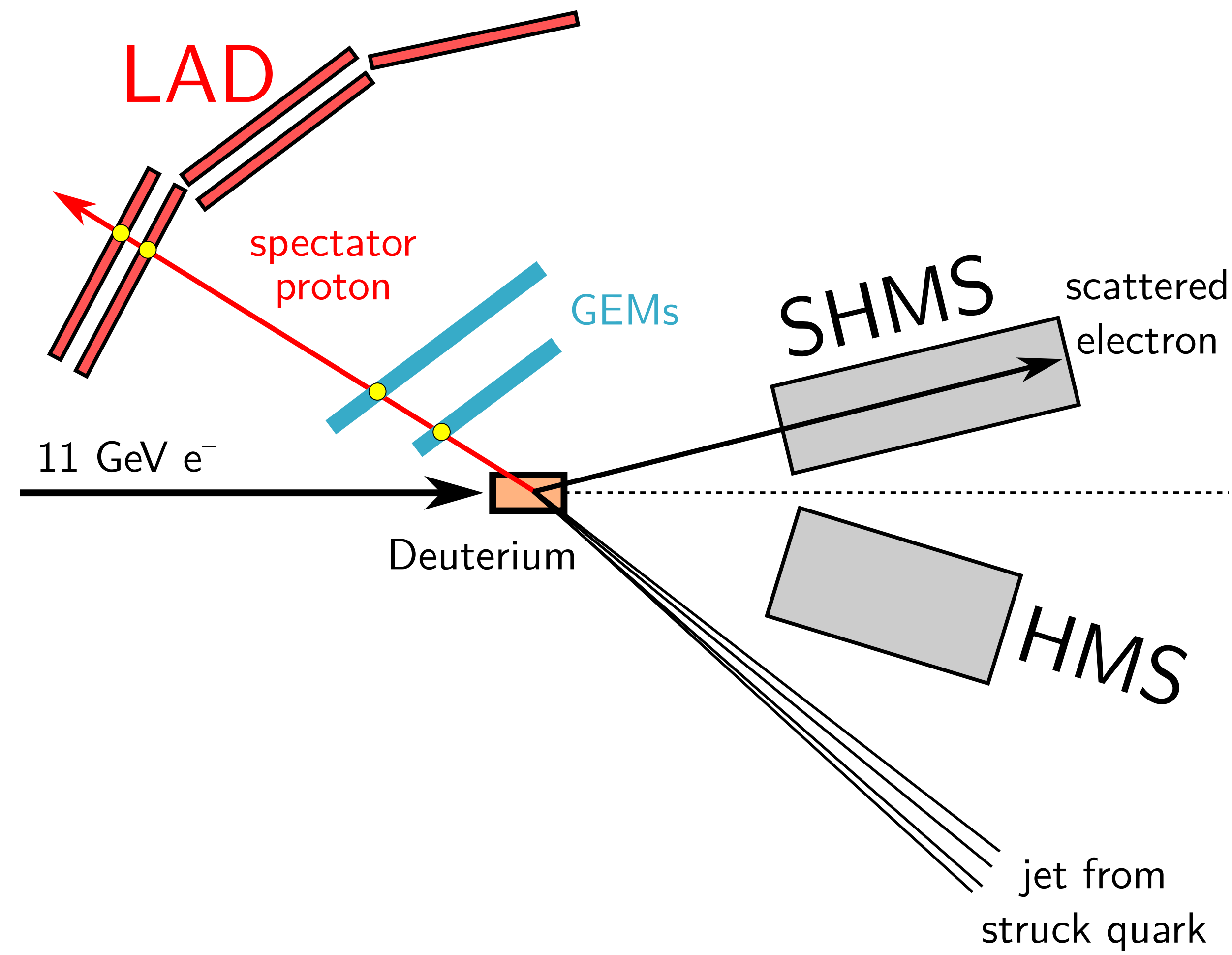


Tagged DIS at JLab

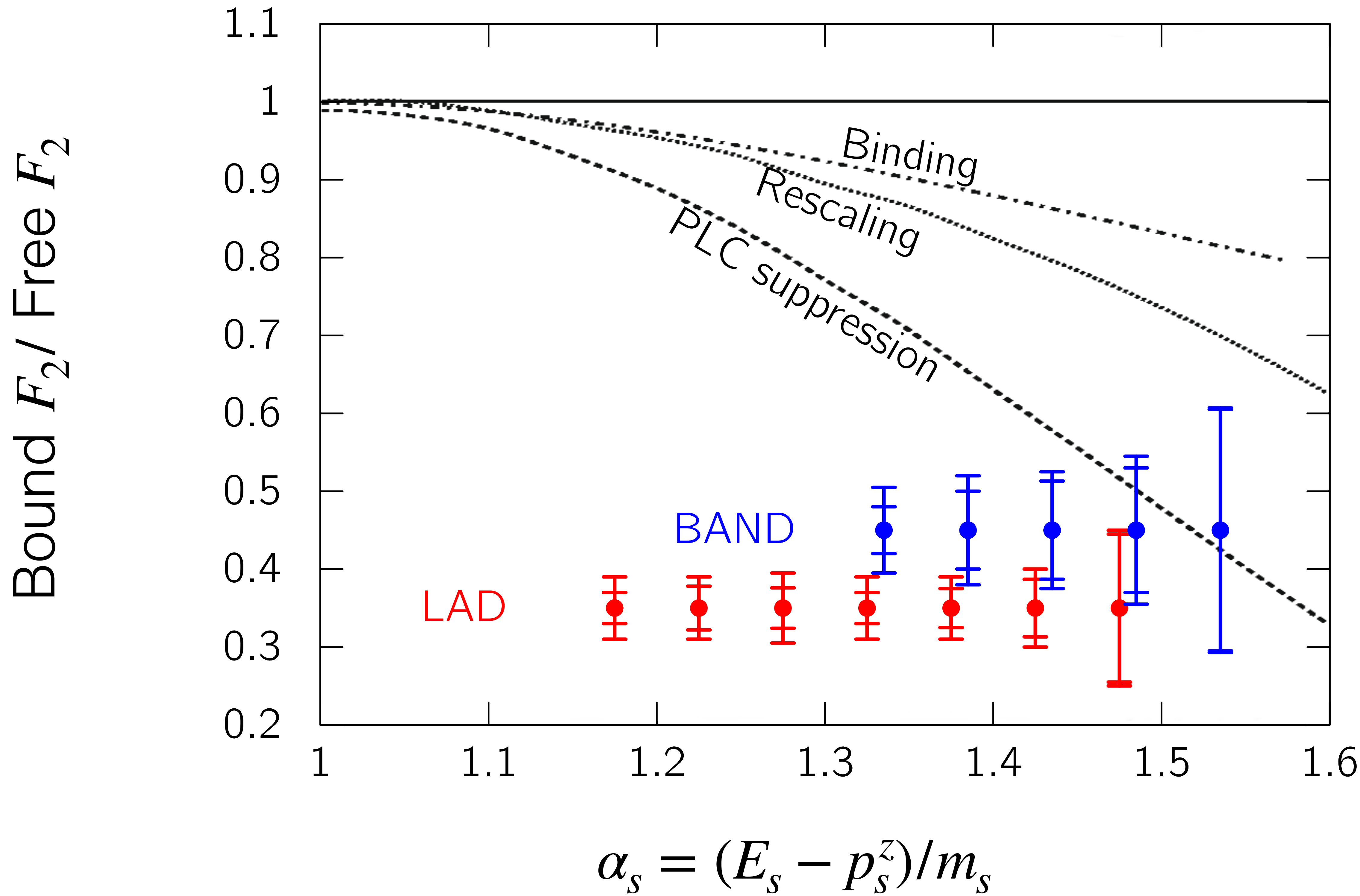
Hall B:
CLAS 12 + Backward Angle Neutron Detector (BAND)

Hall C:
SHMS/HMS + Large Angle Detector (LAD)

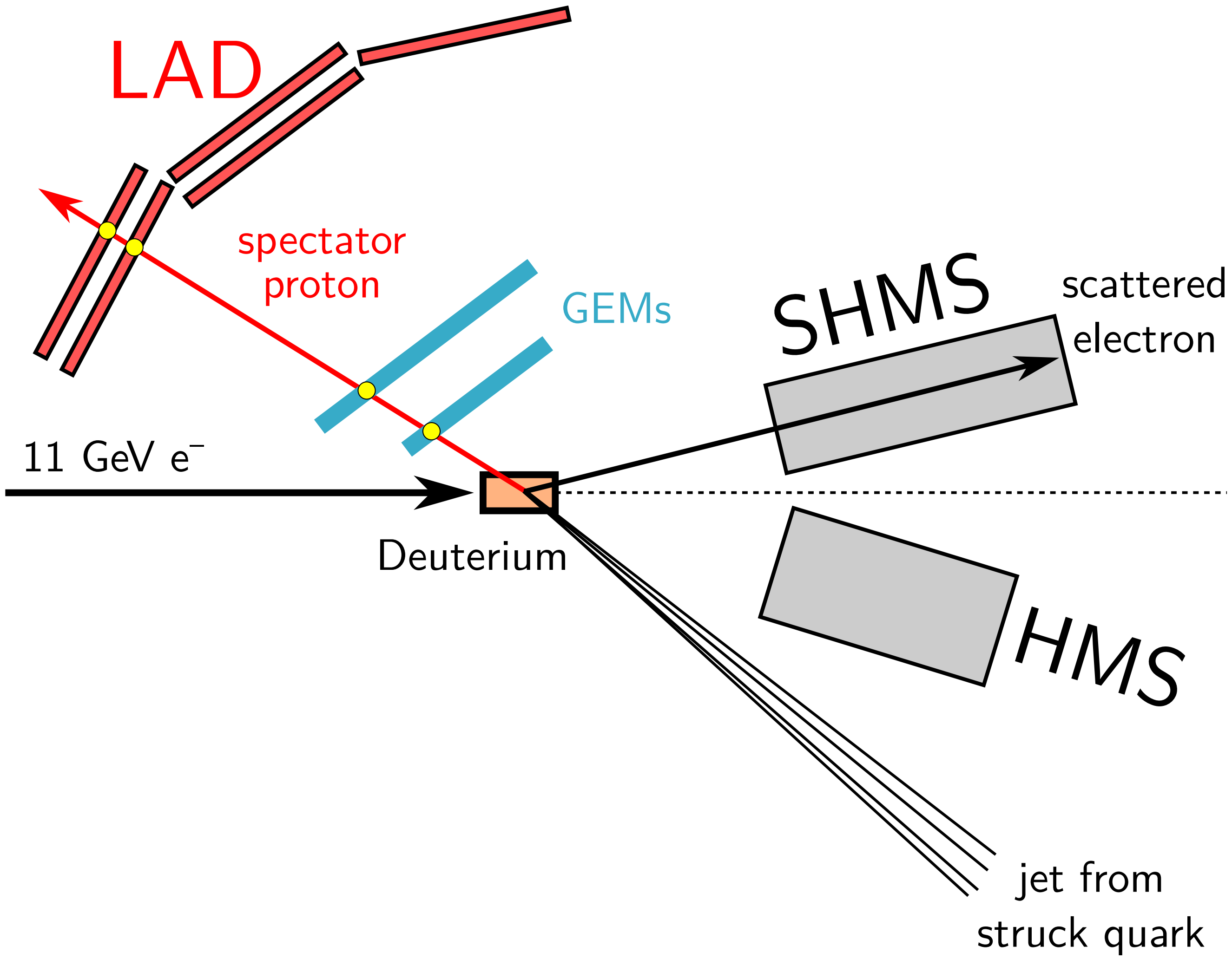


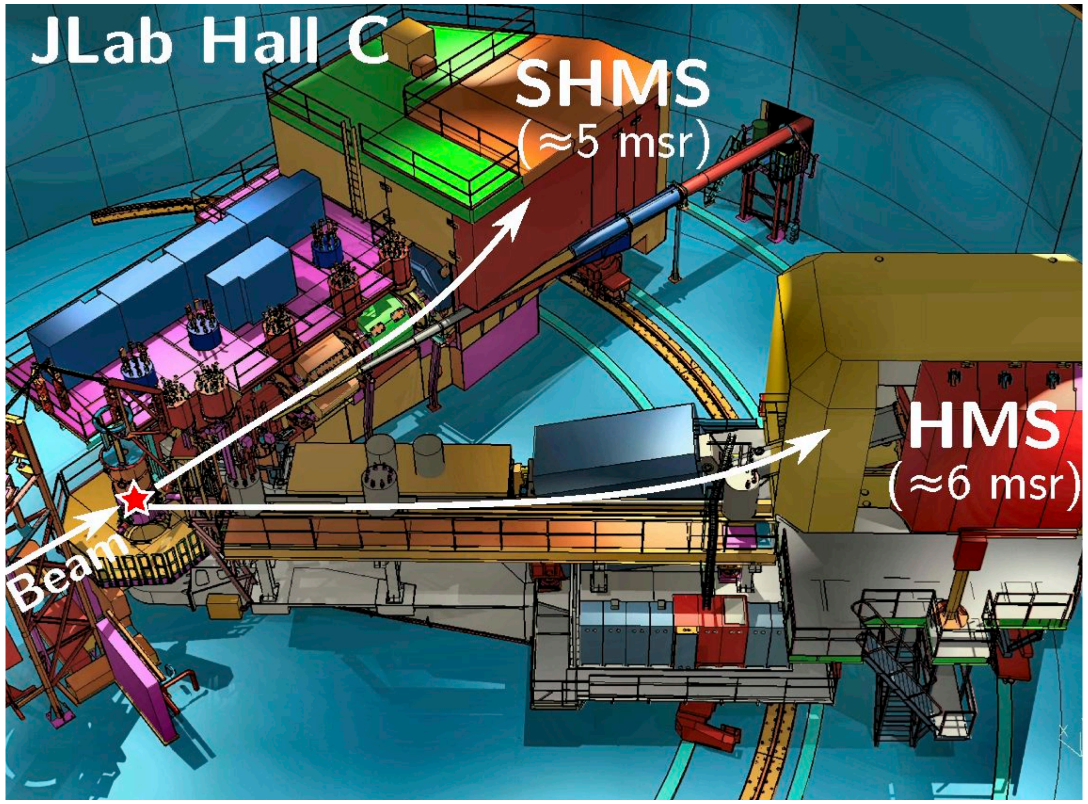


DIS Recoil Tagging d(e,e'n)X - Expected Results



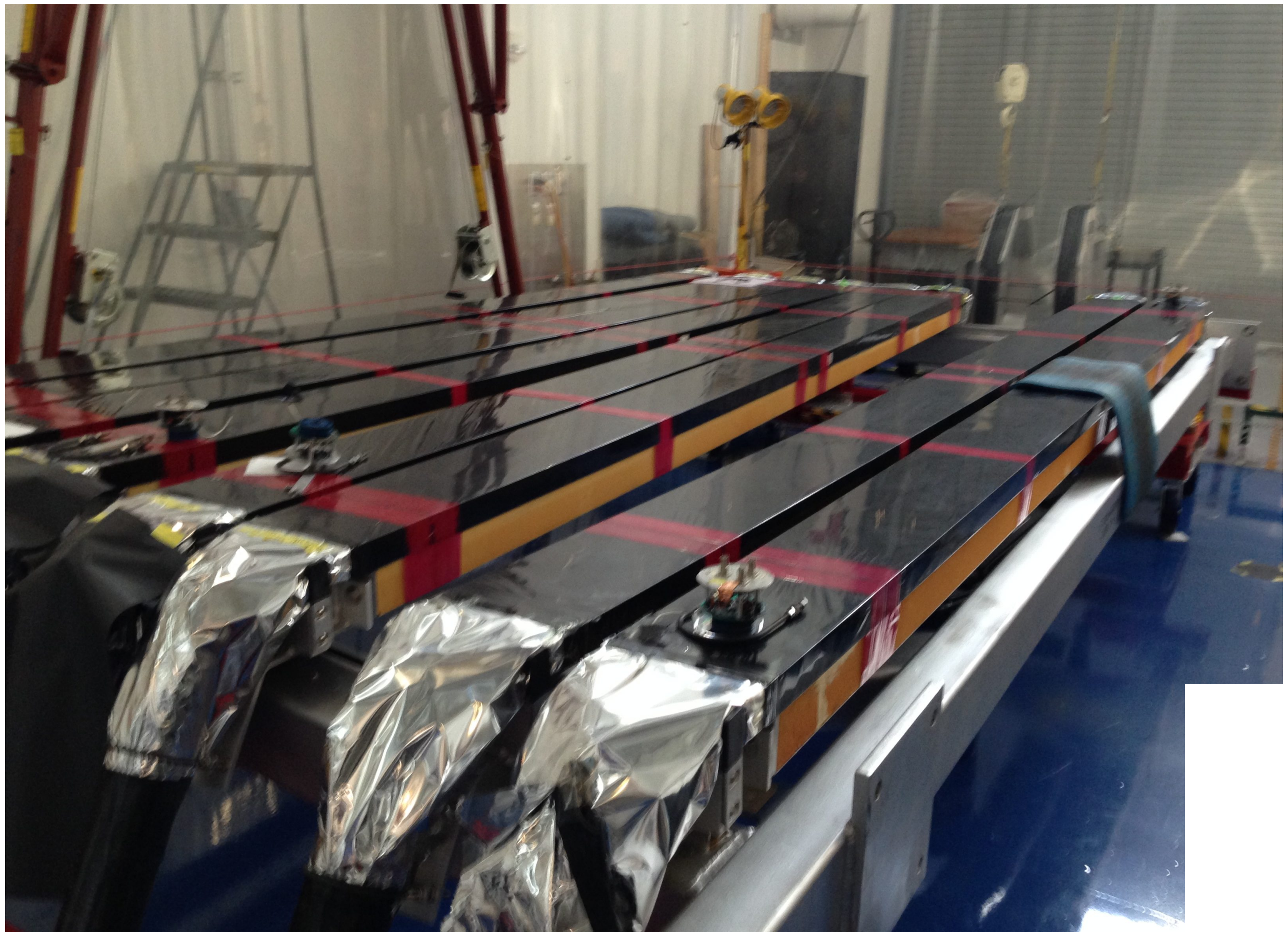
LAD in HallC





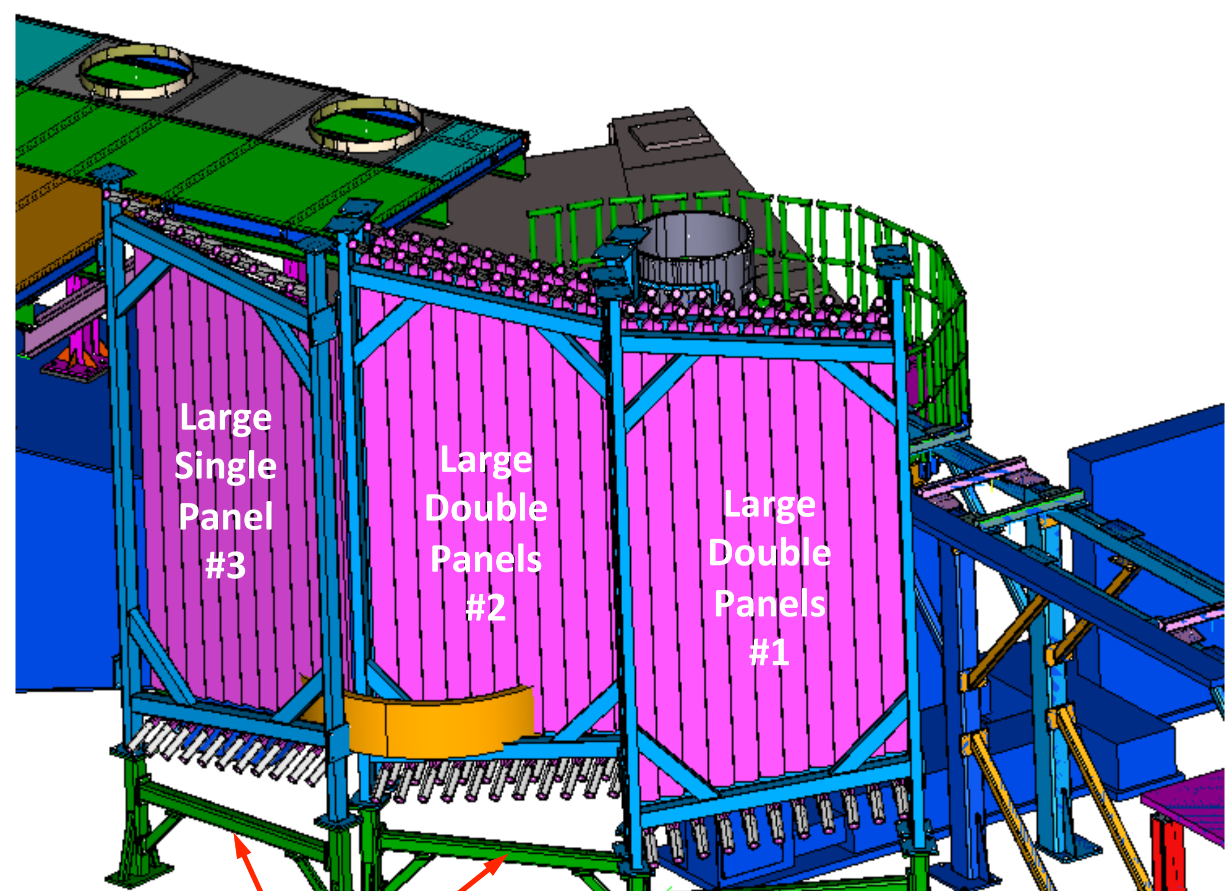
e' in (Super) High Momentum Spectrometers and Recoil nucleon in LAD

LAD - Scintillator Bars



Refurbished bars from CLAS 6 Time of Flight counters

LAD consists of 5 panels around the target



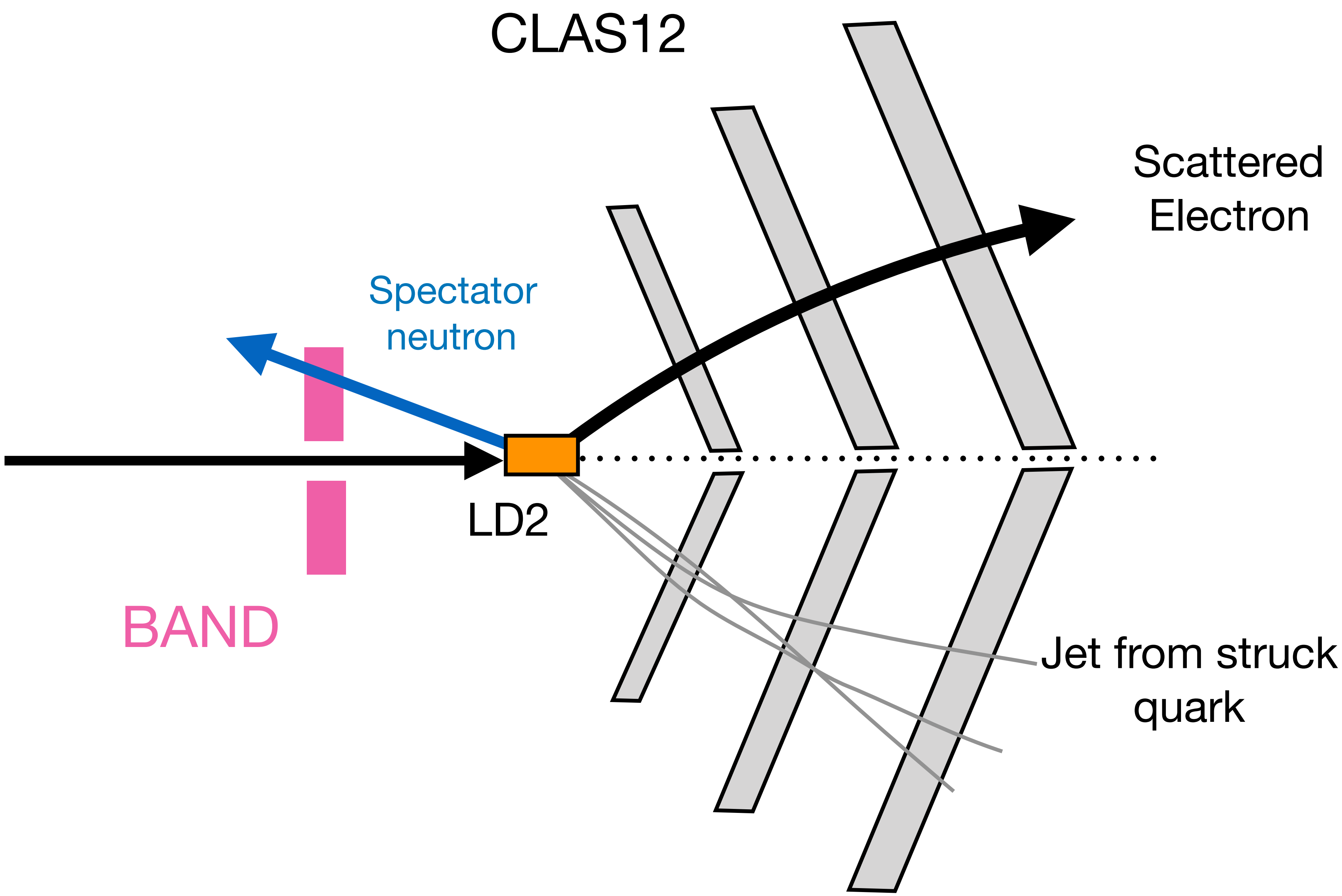
LAD Experimental Conditions

- Experiment E12-11-107
- Approved for ~34 days
- Extended LD_2 target
- 11 GeV electron beam
- 10^{36} $cm^{-2}s^{-1}$ luminosity
- Low x (x' < 0.35) and high x' (x' > 0.45) settings for e^- in HallC spectrometers SHMS and HMS

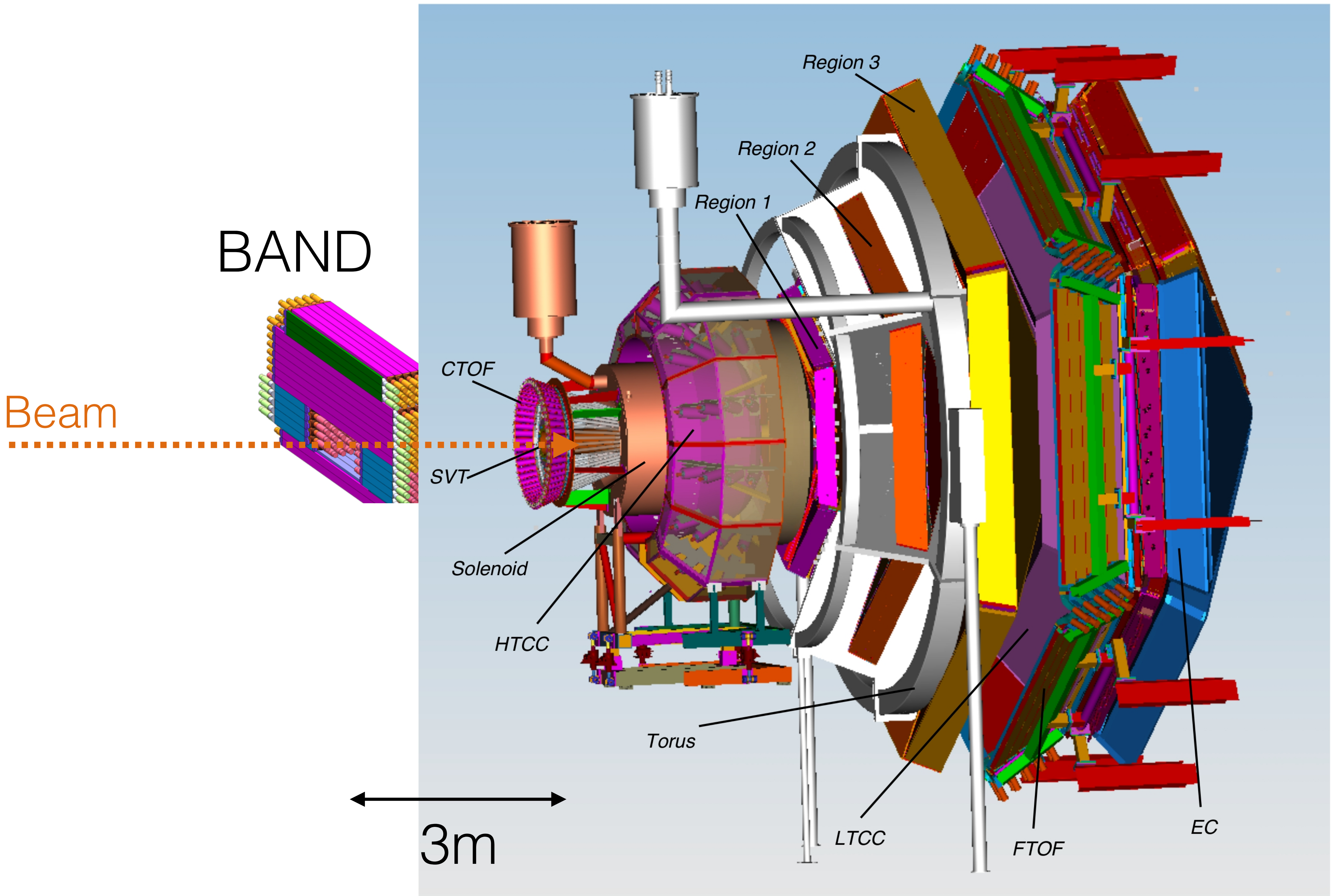
Protons in LAD

- 5 panels with 11 bars each
- 90-170 degree coverage
- +/- 20 degree out-of-plane coverage

BAND in HallB

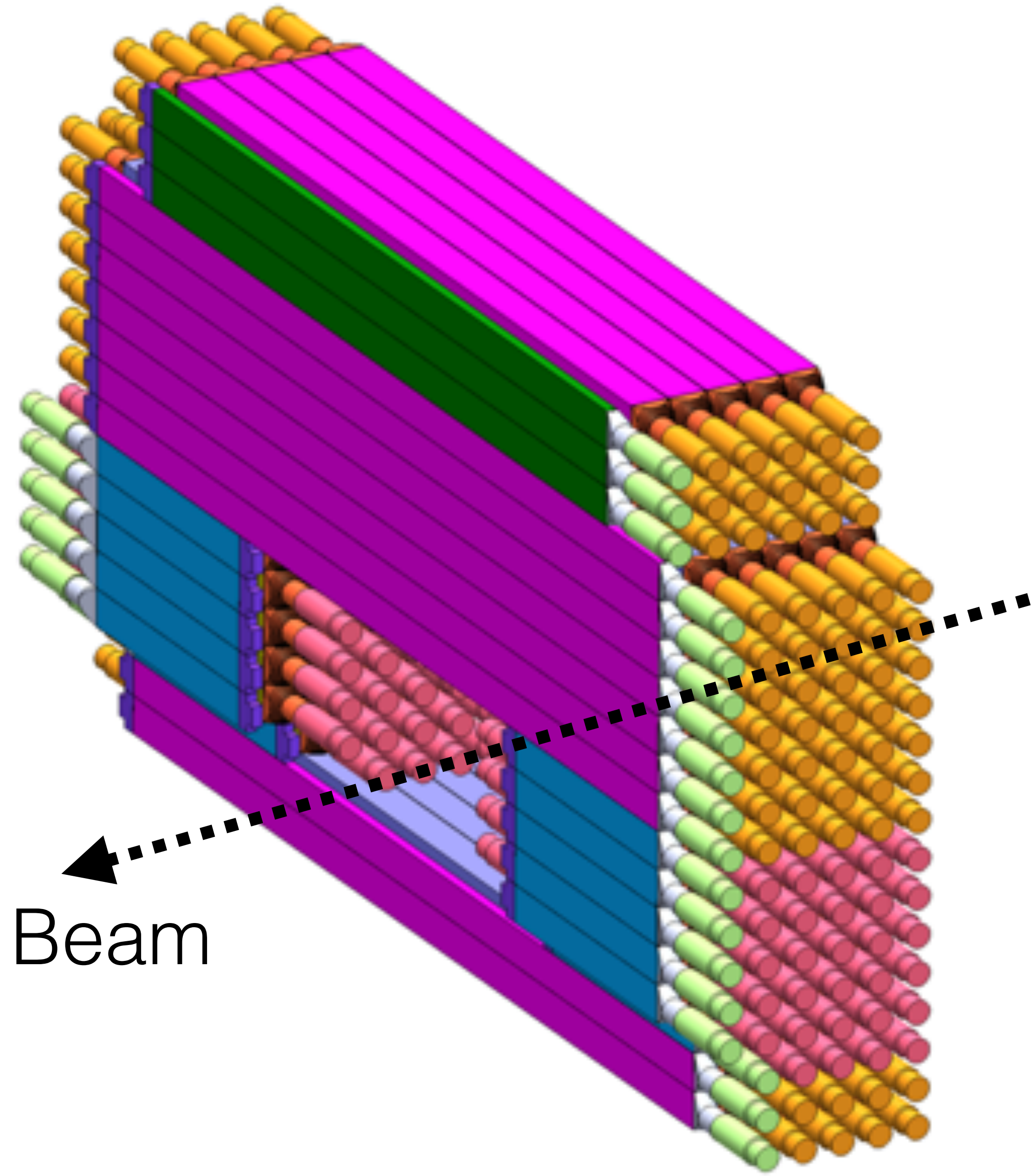


CLAS12 and BAND

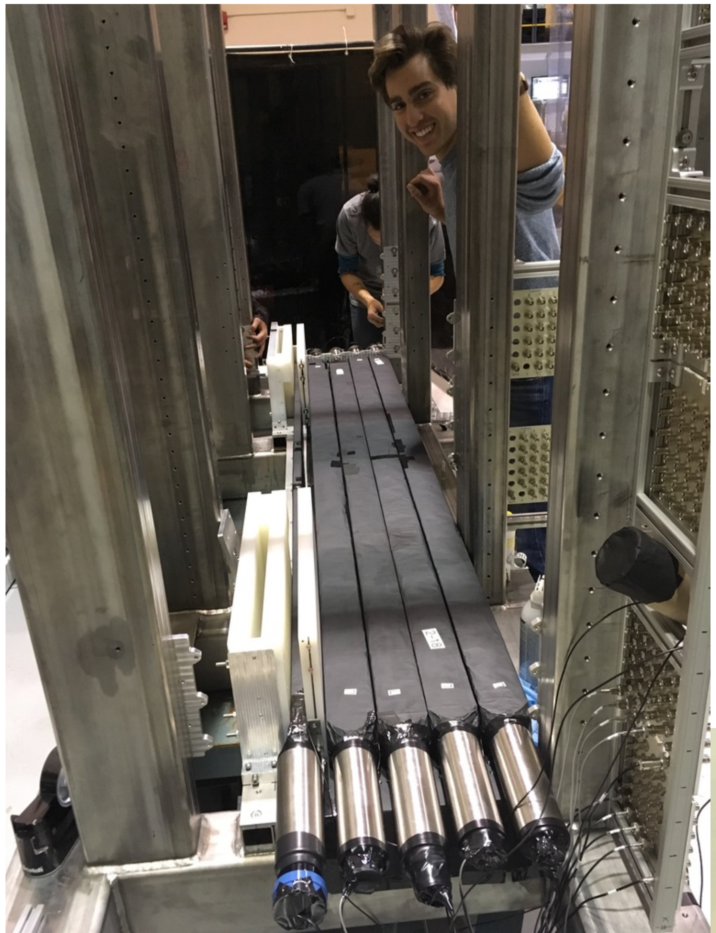


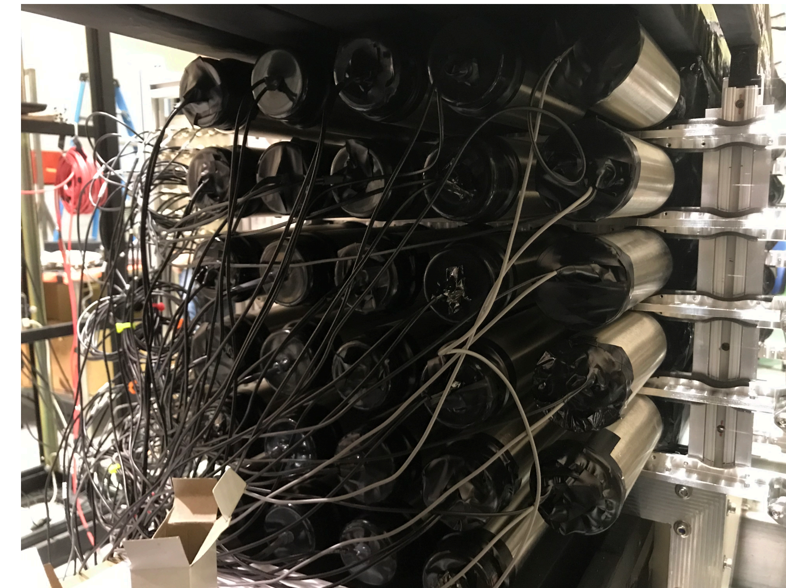
Overview of BAND

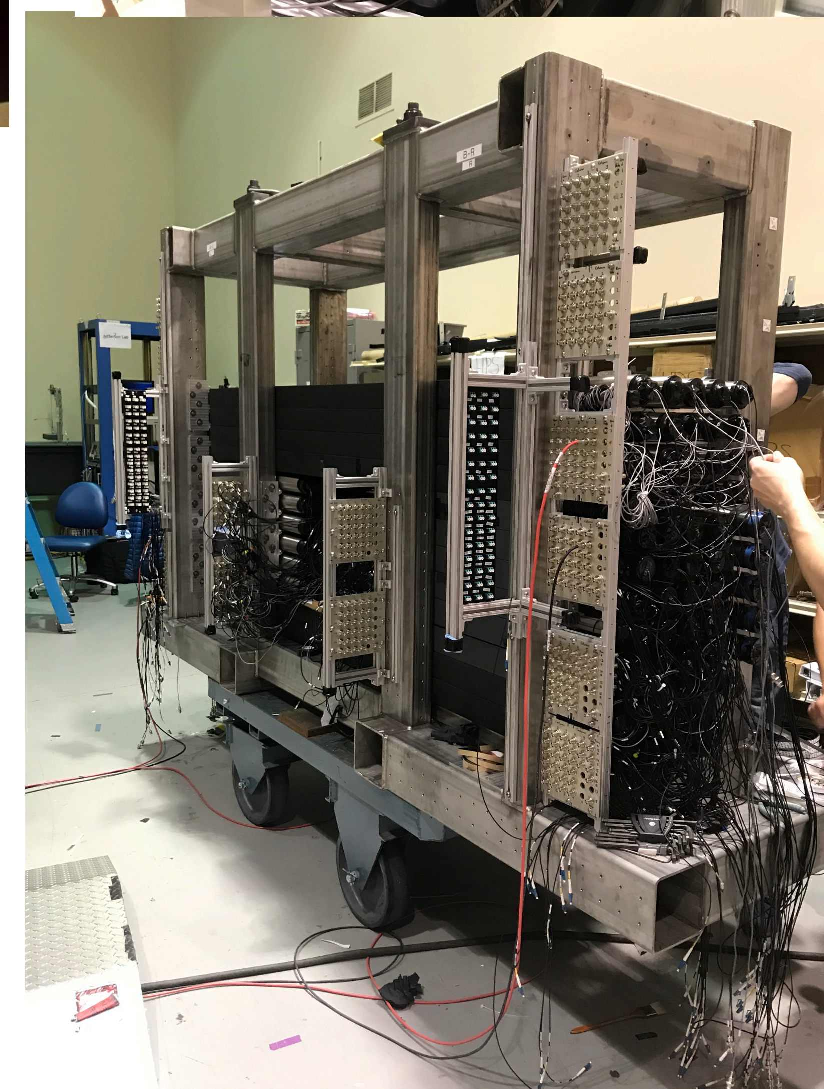
- 5 layers thick (36cm total) with veto layer (1cm thick)
- 140 scintillator bars
- Bar resolutions < 200 ps
- 3 meters upstream target cell, coverage in θ ~ 155-176°
- Design neutron efficiency ~35% and momentum resolution ~1.5% (*to be studied*)
- Laser system for calibrations



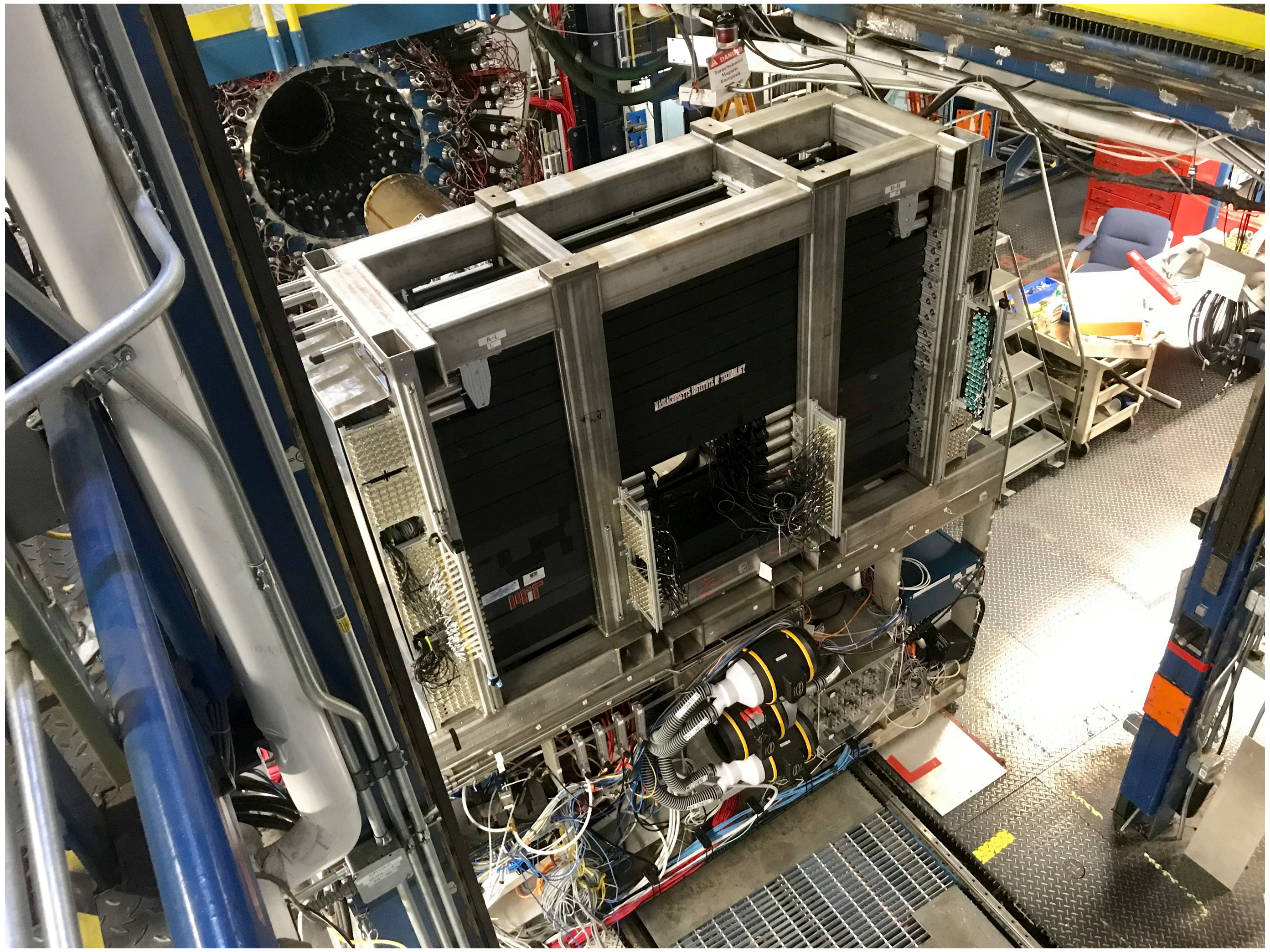
BAND Construction

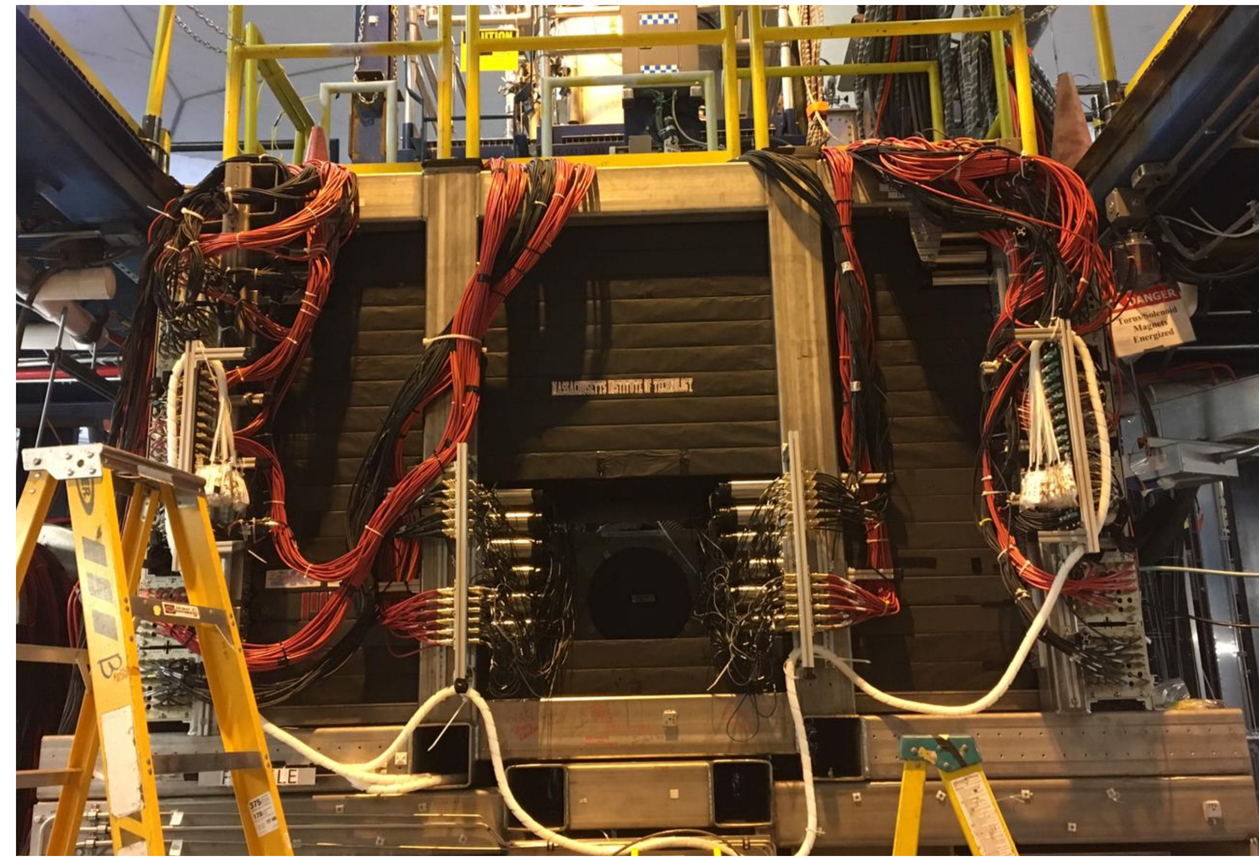






BAND in Hall B





- 256 channels
- Fiber cables from laser system for each bar
- All PMT signals split into ADC and TDC

BAND Experimental Conditions

- Data taking during Run Group B of CLAS12
- Approved for 180 days (90 PAC days)
- ~50% of approved beam time in spring and fall 2018
- 11 GeV electron beam
- 10^{35} $cm^{-2}s^{-1}$ luminosity
- Scattered e’ in CLAS12

Base Level Calibrations

Cosmic Data

Source Data

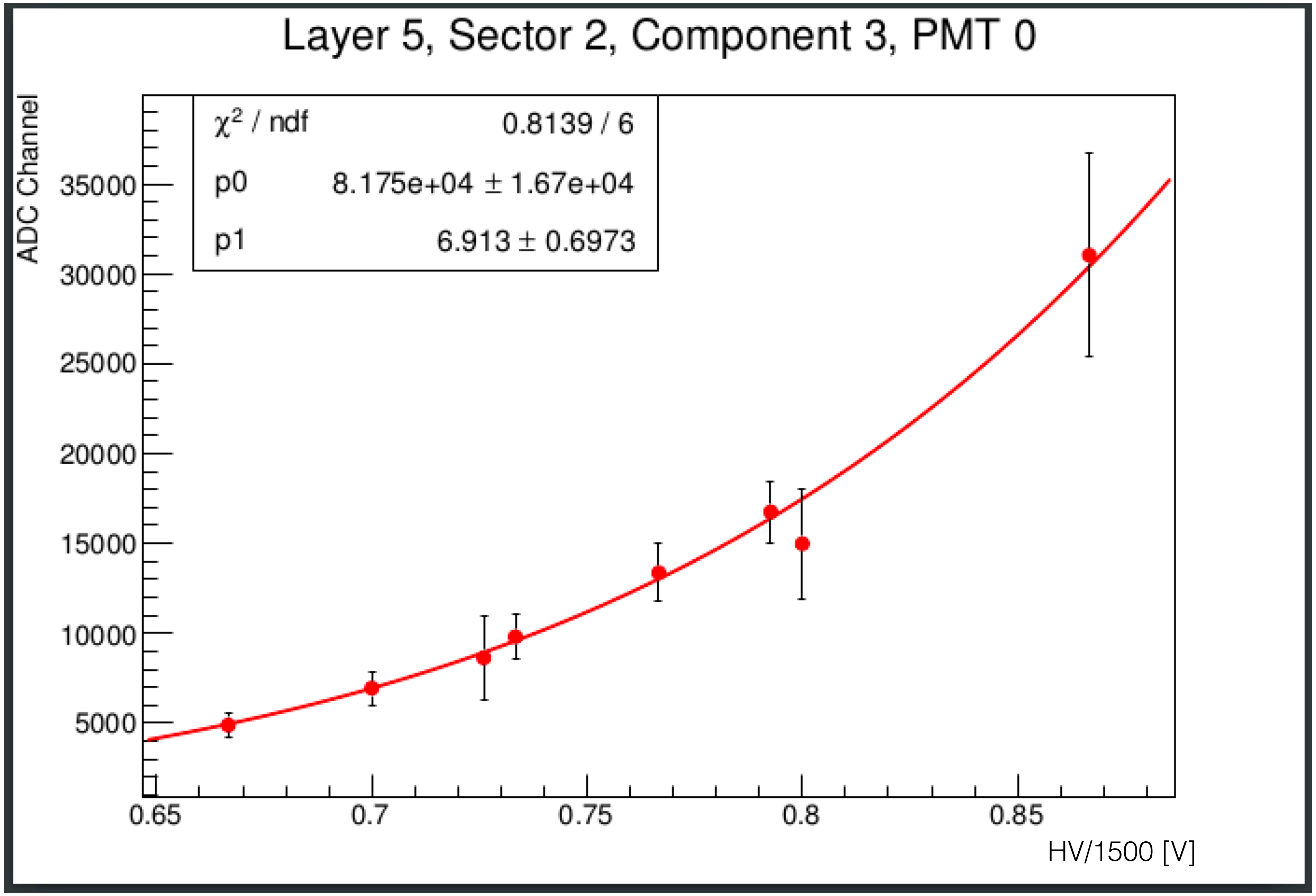
Laser Data

- TDC/FADC phase offset
- TDC time walk
- Bar attenuation
- Timing offsets
- Effective velocity

Prod Data

- Neutron efficiency
- Neutron momentum resolution

Gain Curves: Optimizing HV

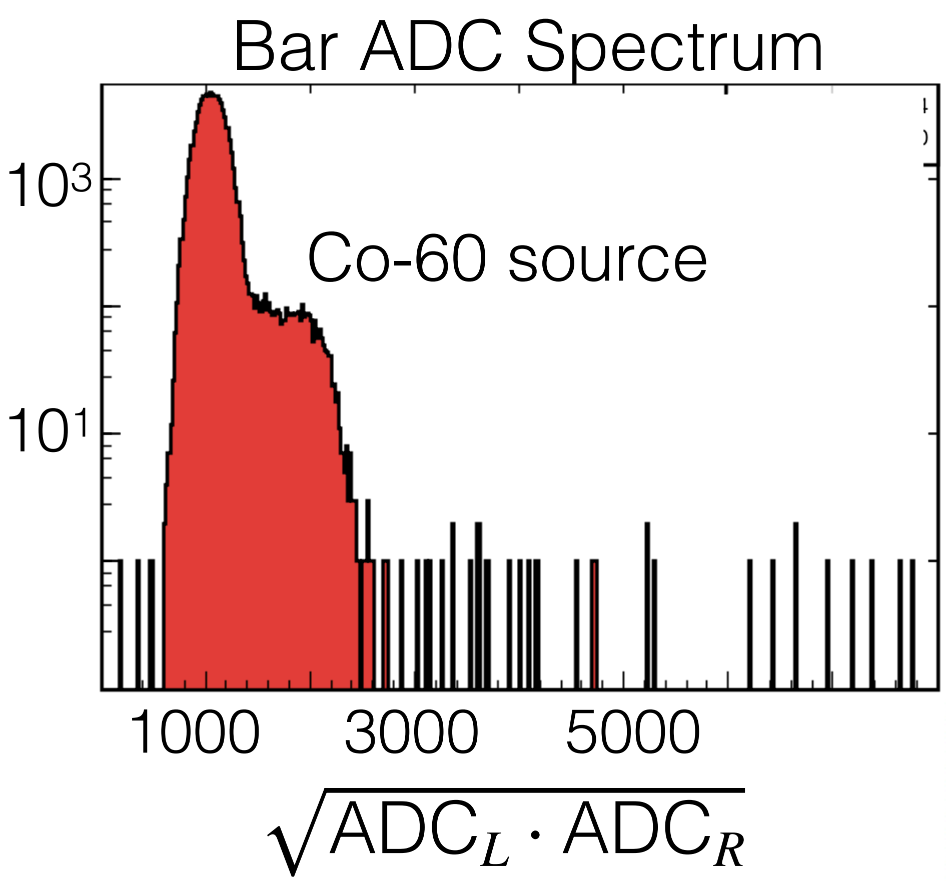


$$ADC = p_o \left(\frac{\mathrm{HV}}{1500}\right)^{p_1}$$

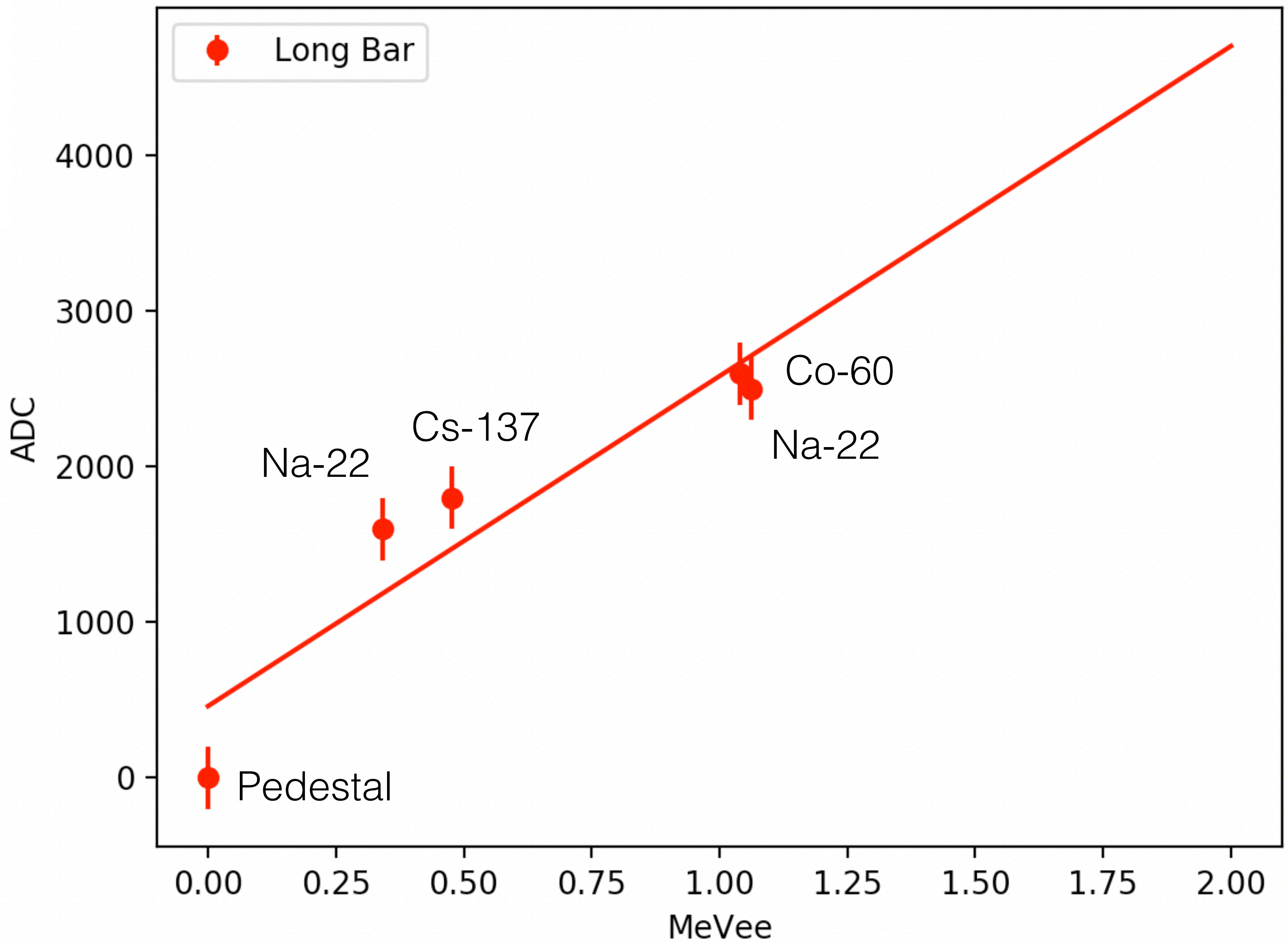
Have most ADC channels possible for neutrons while not driving PMTs into non-linearity

Calibrating ADC to MeVee

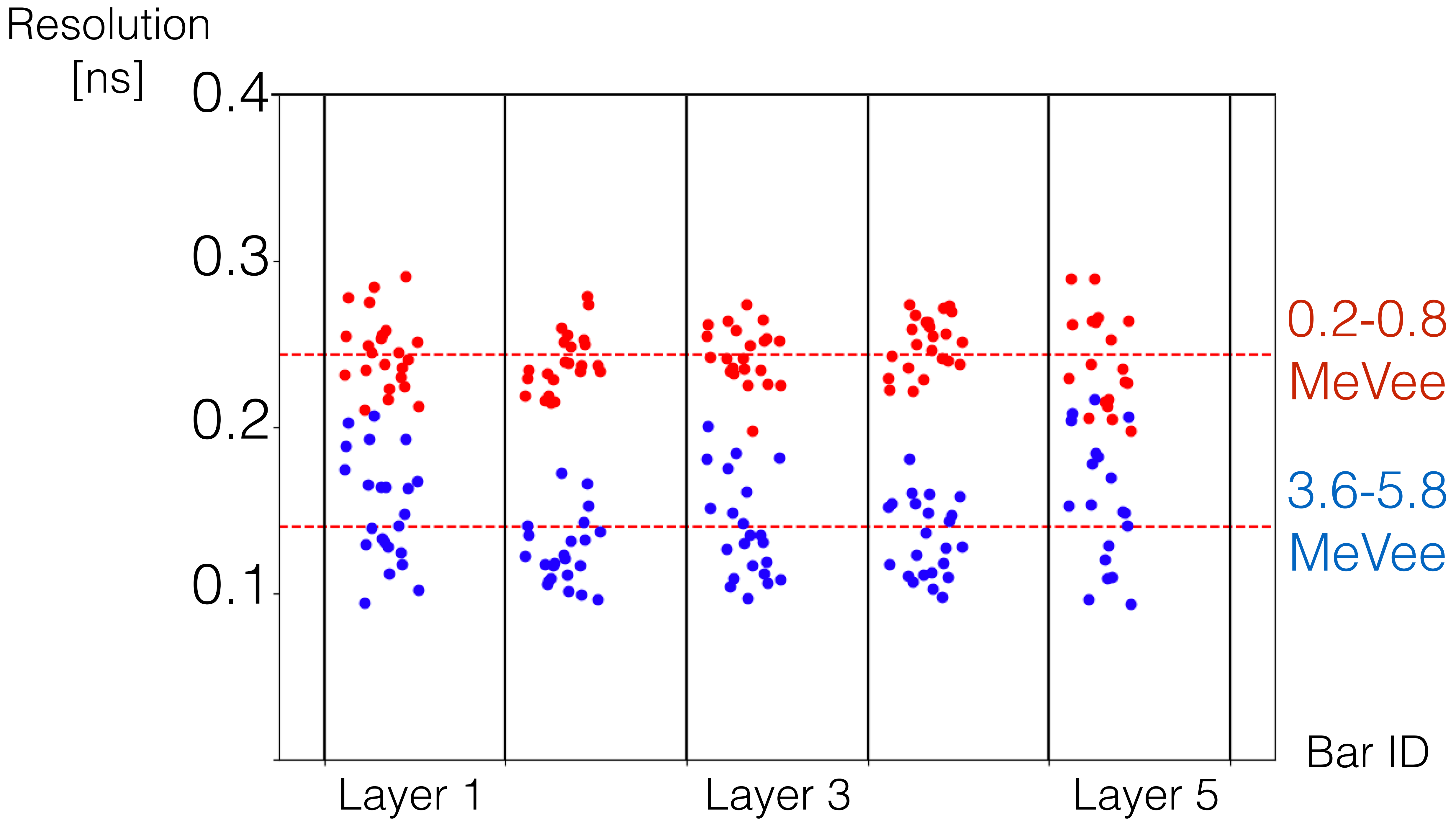
(MeVee =MeV Electron-Equivalent)



Planned software threshold of 2-3 MeVee

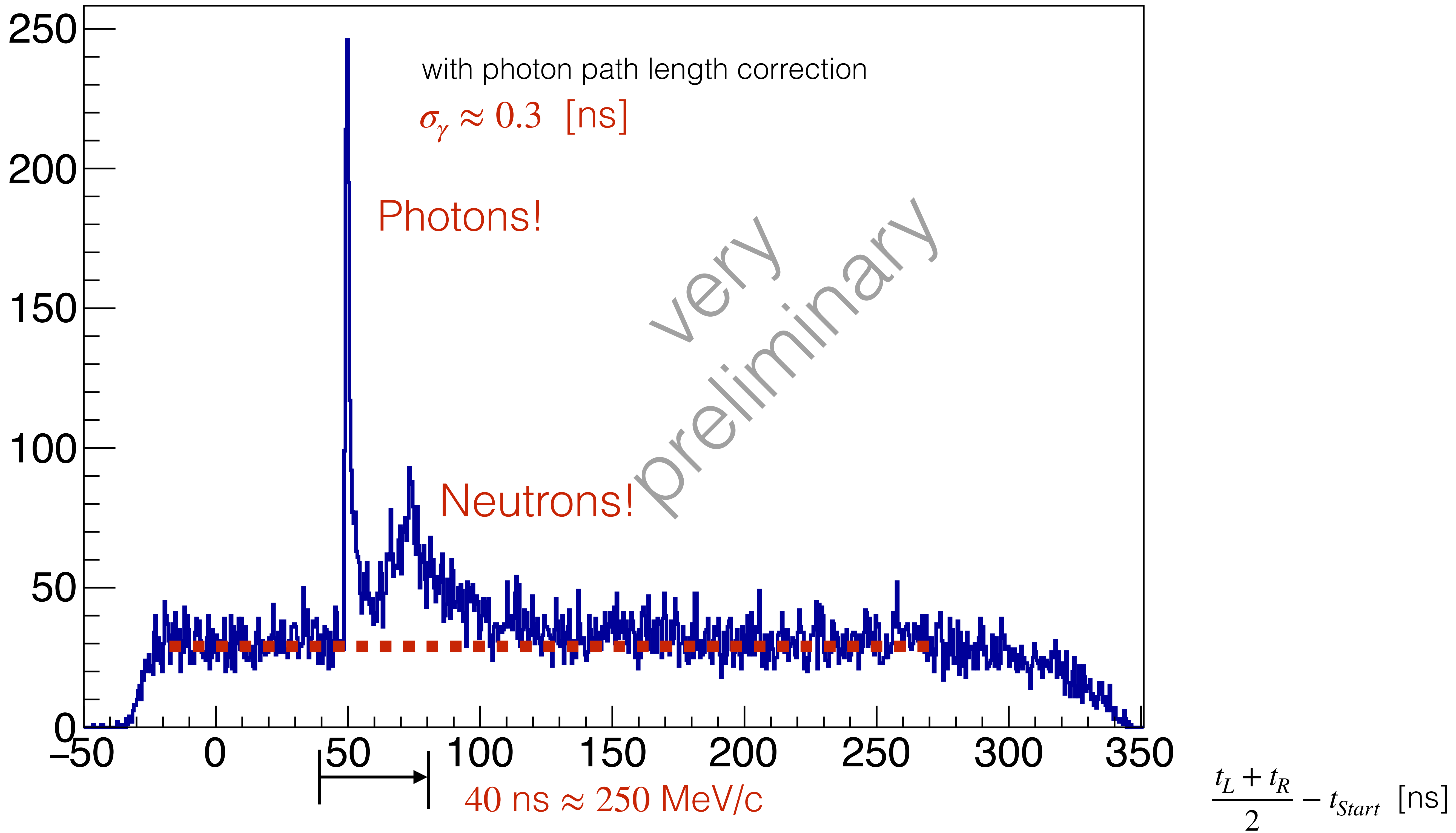


Resolutions of BAND Bars with Laser

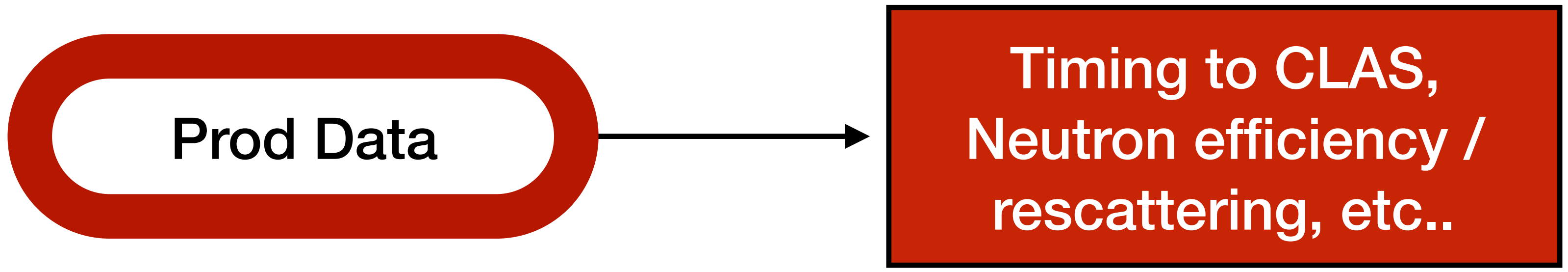


Time of Flight Distribution

All long bars in BAND, e' from CLAS, ~3h run



BAND + CLAS


Prod Data
Timing to CLAS, Neutron efficiency / rescattering, etc..

BAND + CLAS

Prod Data → Timing to CLAS, Neutron efficiency / rescattering, etc..

Calibrating with exclusive processes

$d(e, e'p)n$ (measure n efficiency)

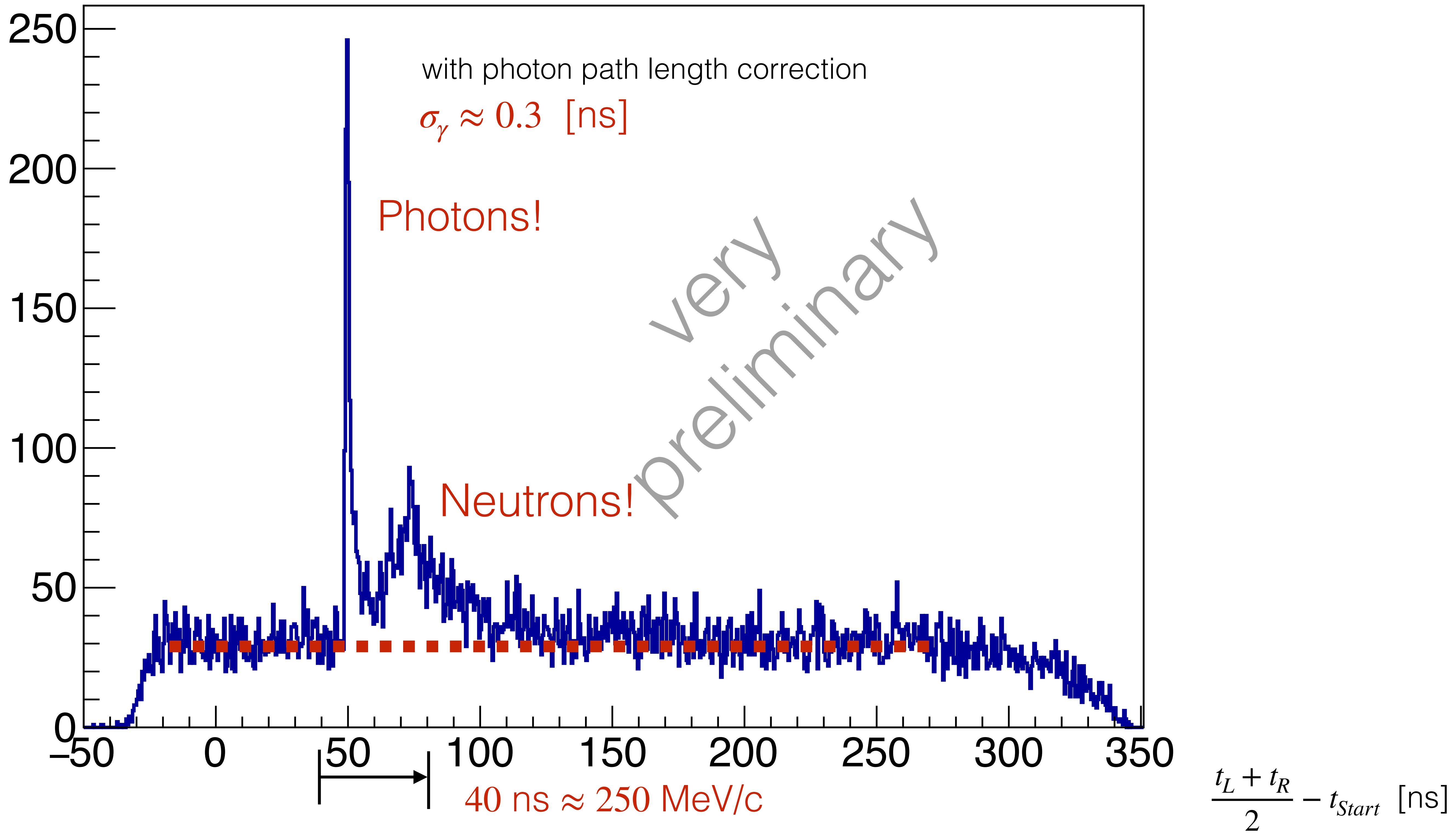
$d(e, e'p\pi^+\pi^-)n$ (measure n efficiency)

$d(e, e'pp\pi^-)$ (study resolution in CLAS)

Note 1: low energy run in fall to study neutron efficiency due to currently limited statistics
Note 2: Calibrations are too preliminary to study achievable resolution

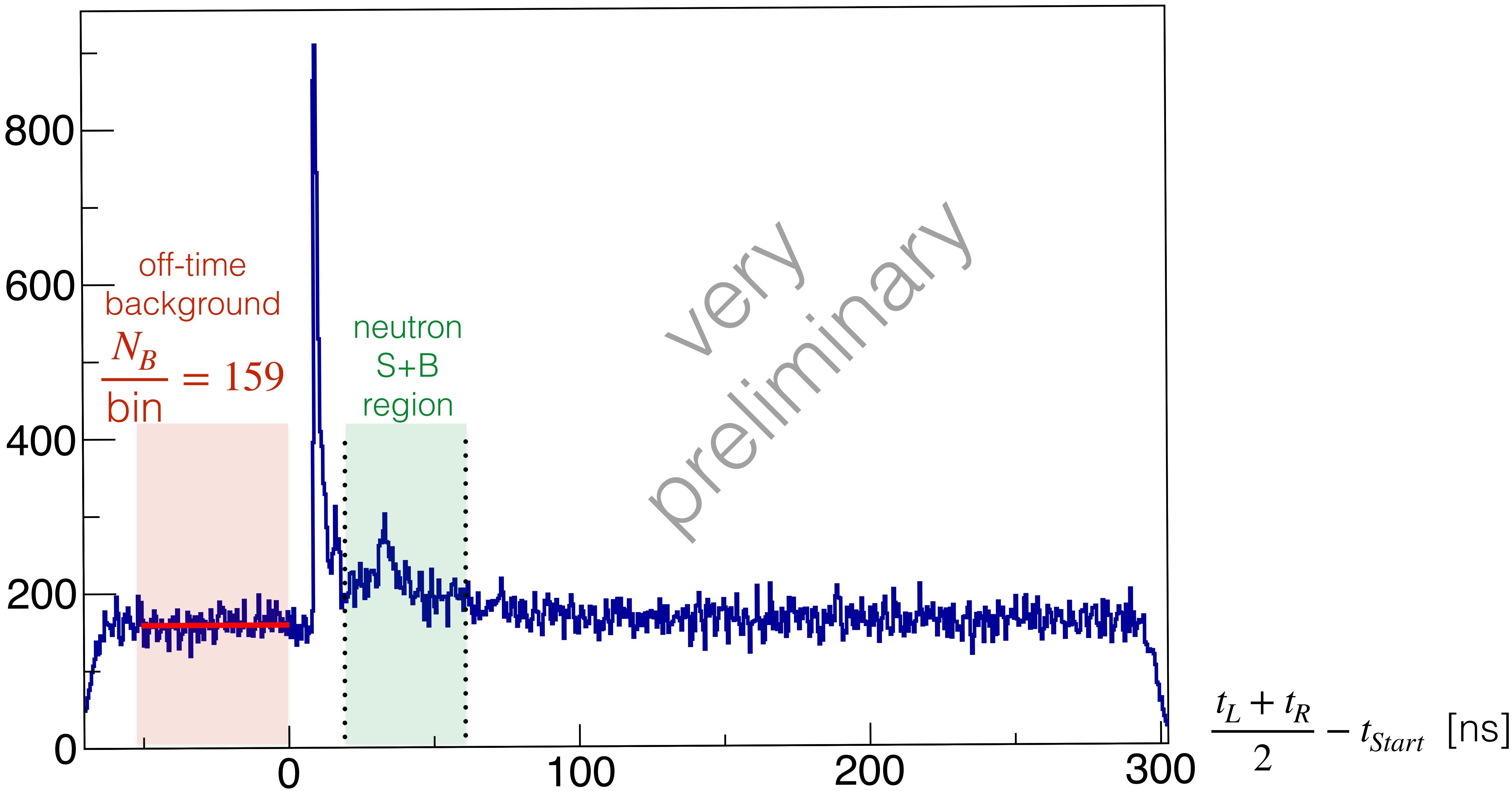
Time of Flight Distribution

All long bars in BAND, e' from CLAS, ~3h run



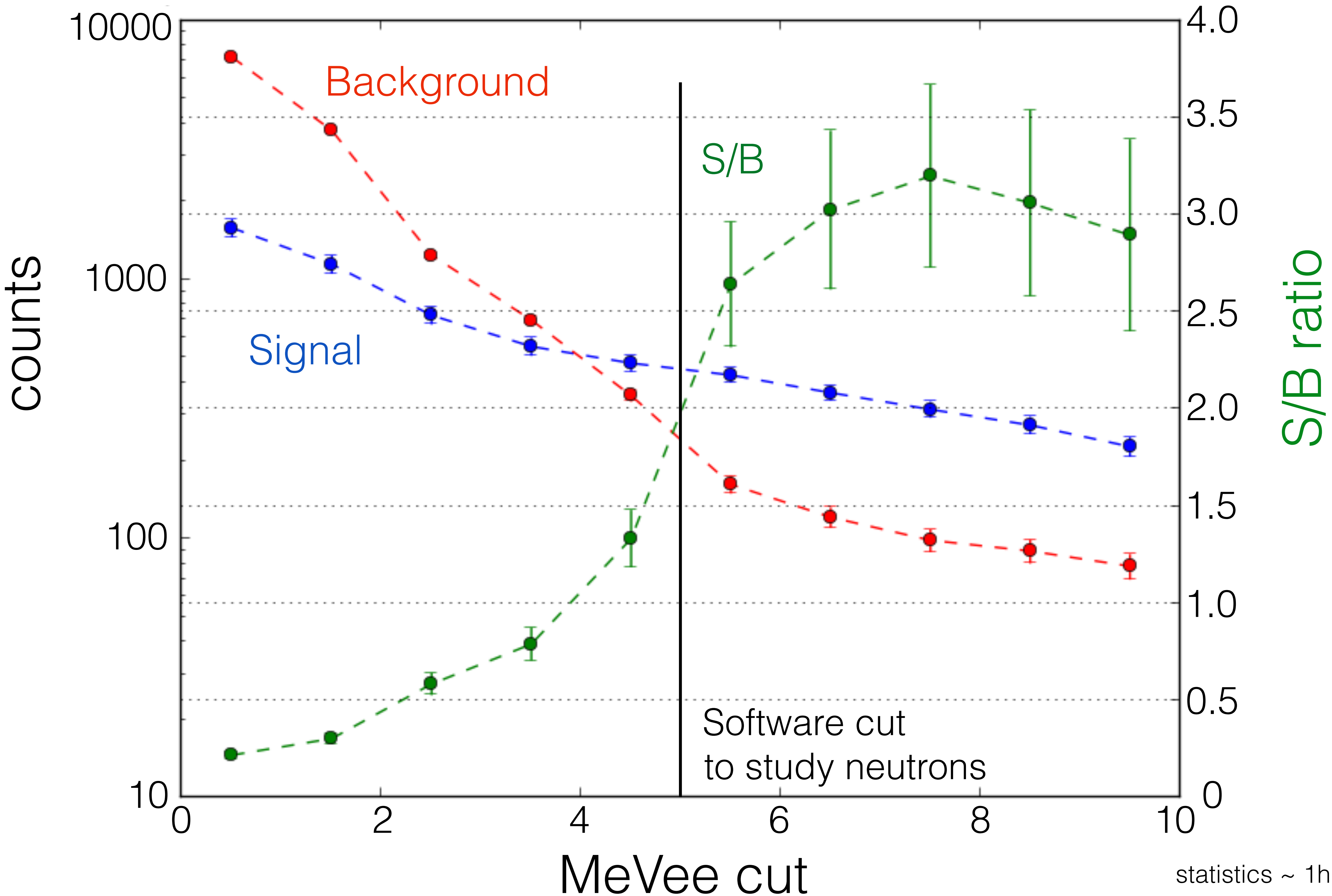
Taking S+B in 20-60ns

ToF spectrum, no cuts besides #hits = 1 for BAND & e' ID cuts



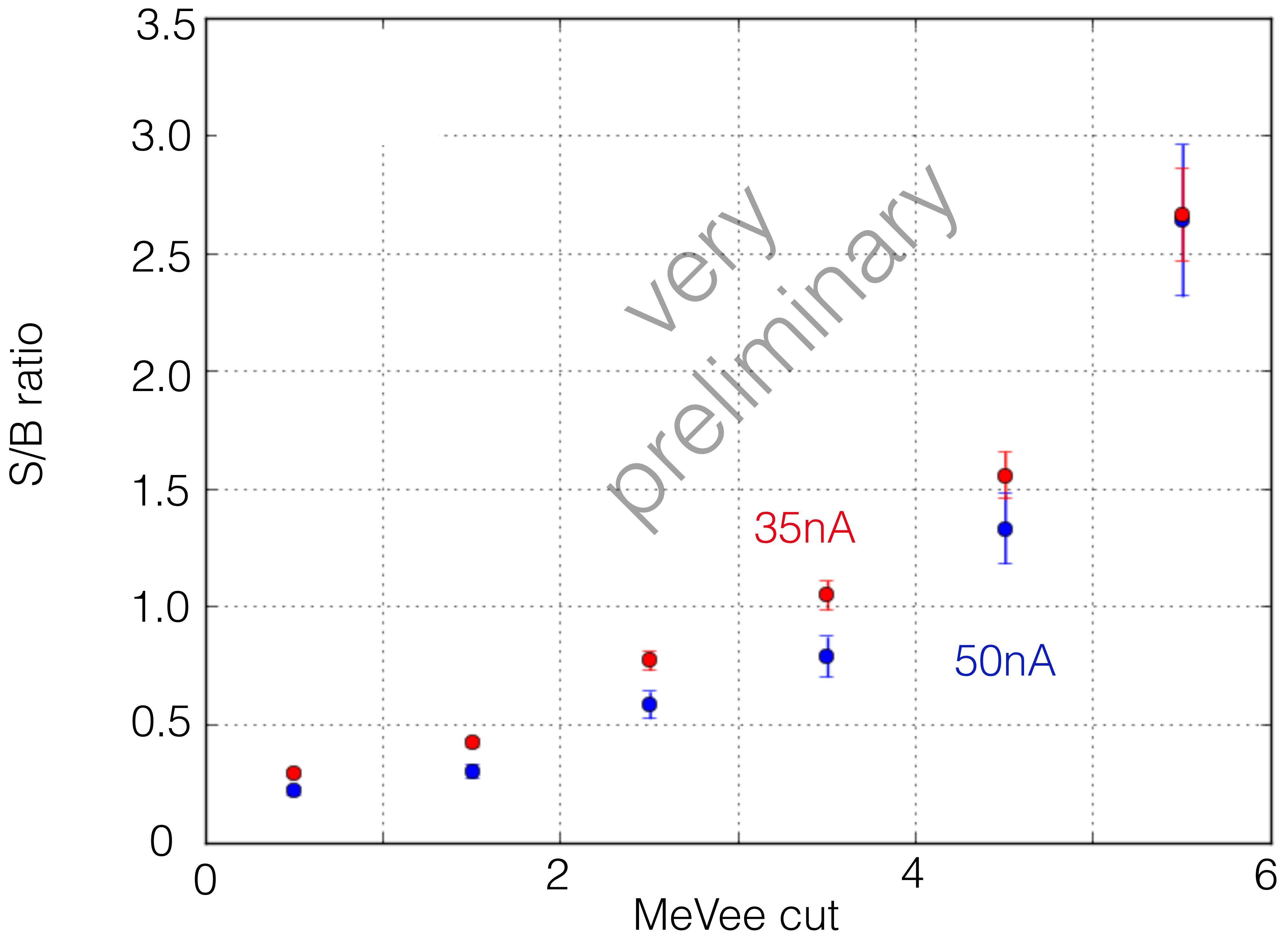
Determine S/B dependence on MeVee deposition cut on bars

Signal and Background at 50nA



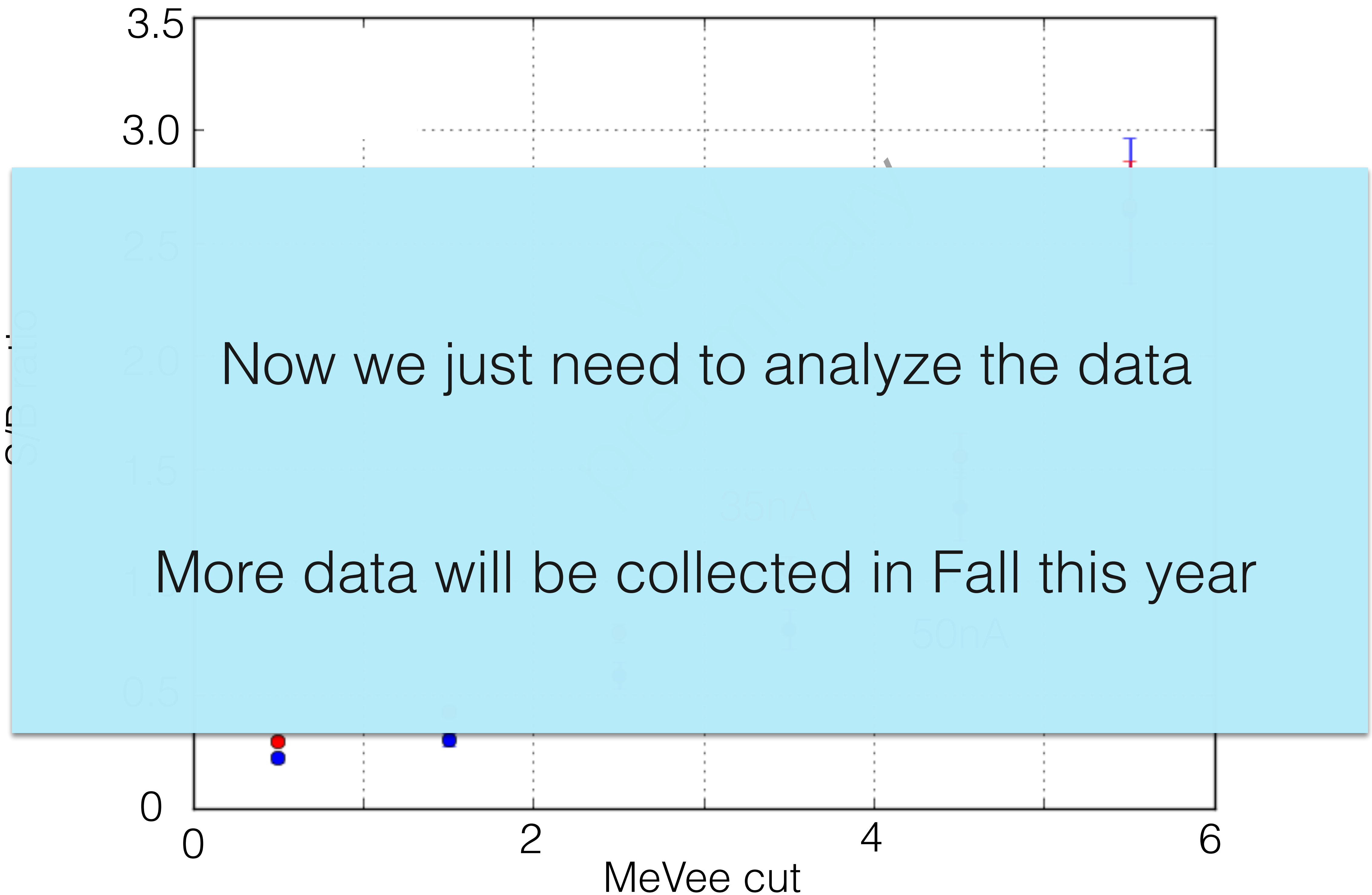
statistics ~ 1h of beam

S/B Ratio for different beam currents



Signal to Background slightly worse at higher beam current

S/B Ratio for different beam currents



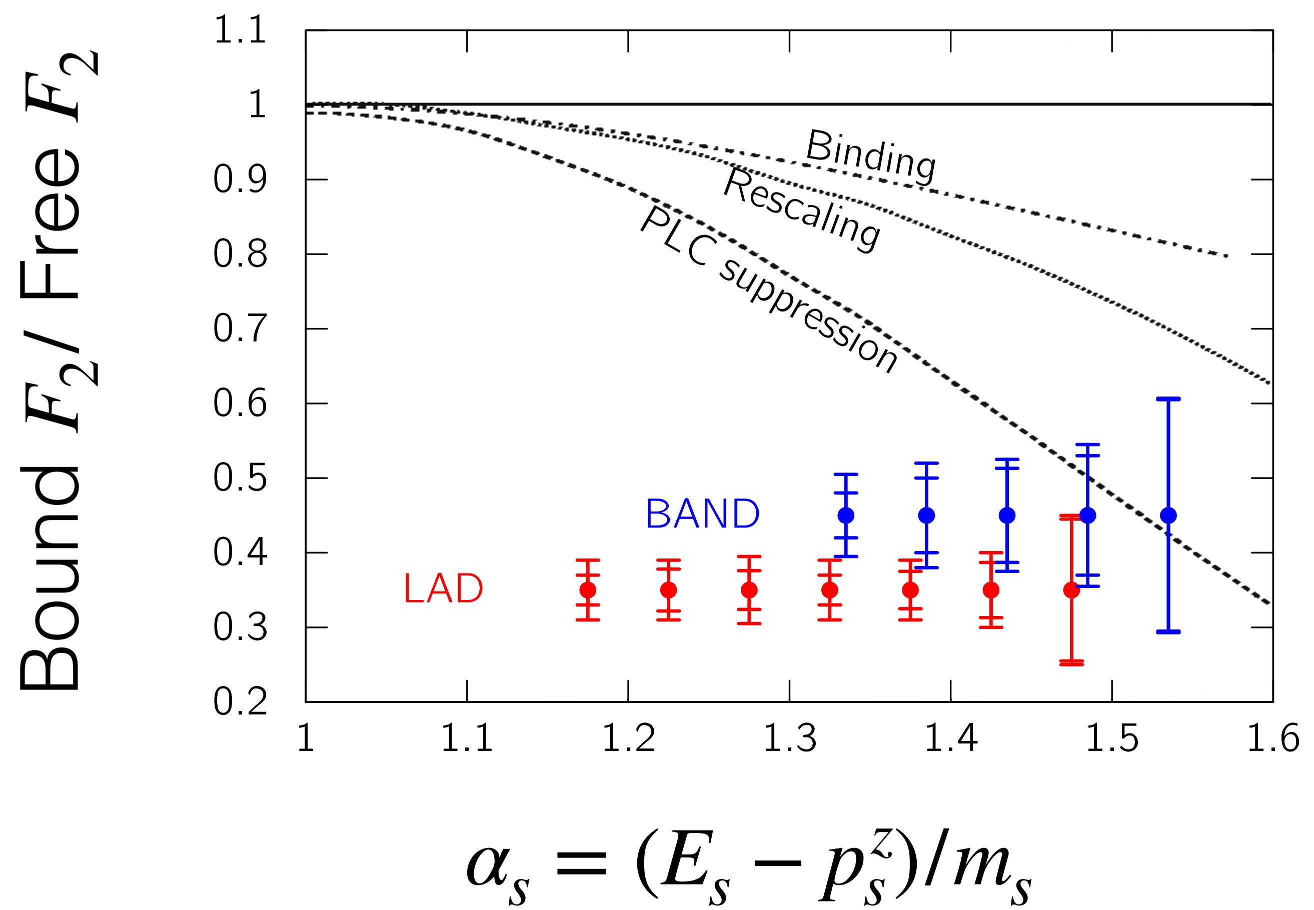
Now we just need to analyze the data

More data will be collected in Fall this year

Signal to Background slightly worse at higher beam current

Summary and Outlook

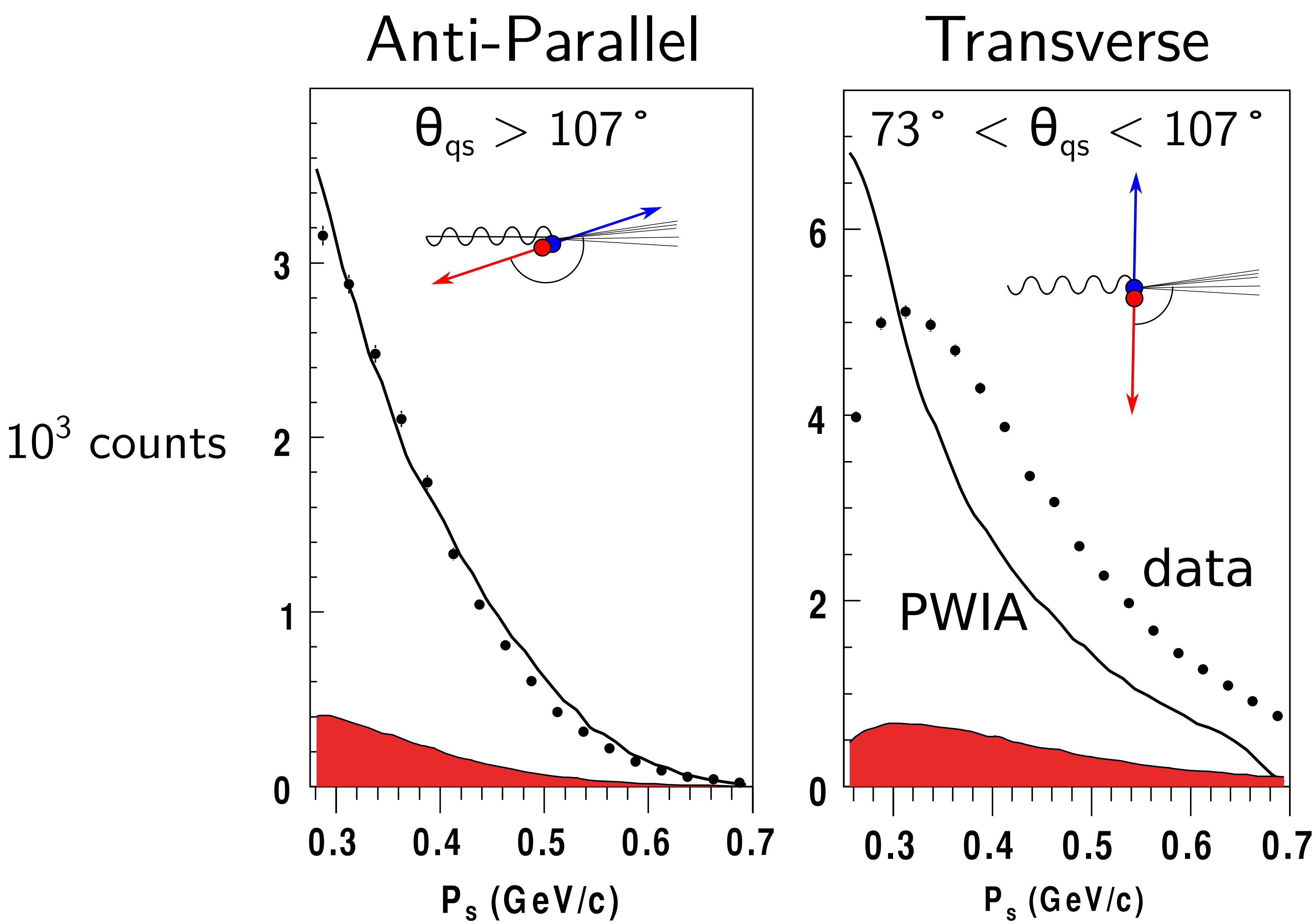
- Tagged DIS measurements to explain EMC effect
- EMC is a high virtuality effect
- EMC and SRC have same origin
- Two approved JLab experiments in HallB and HallC
- Dedicated new detectors: BAND and LAD
- First preliminary results from BAND show clearly neutron



Back up slides

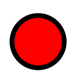
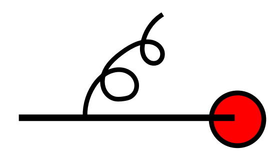
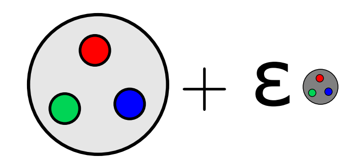
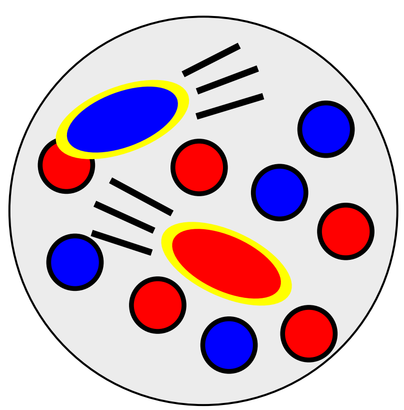
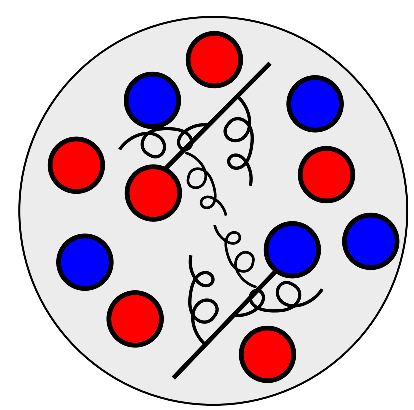
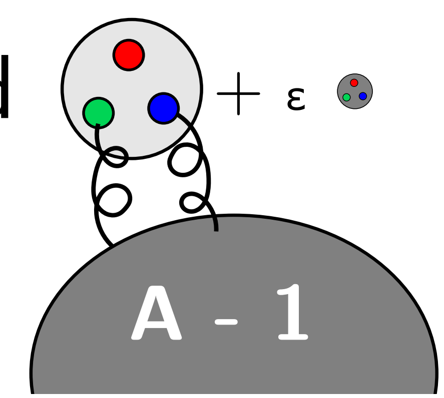
FSI in Tagged DIS

DEEPS showed little FSI at back angles.

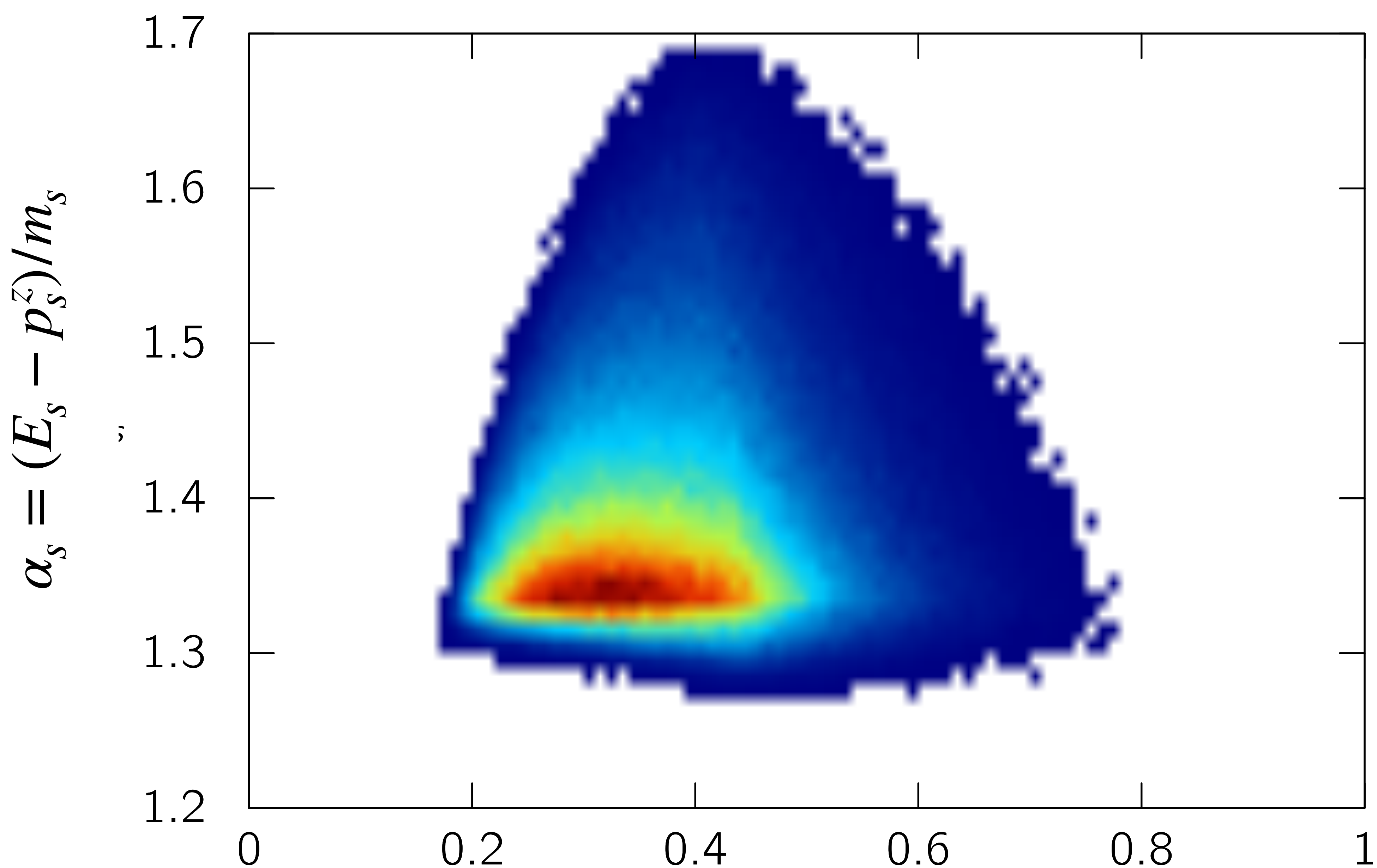


Klimenko et al., PRC 73 035212 (2006)

Theories

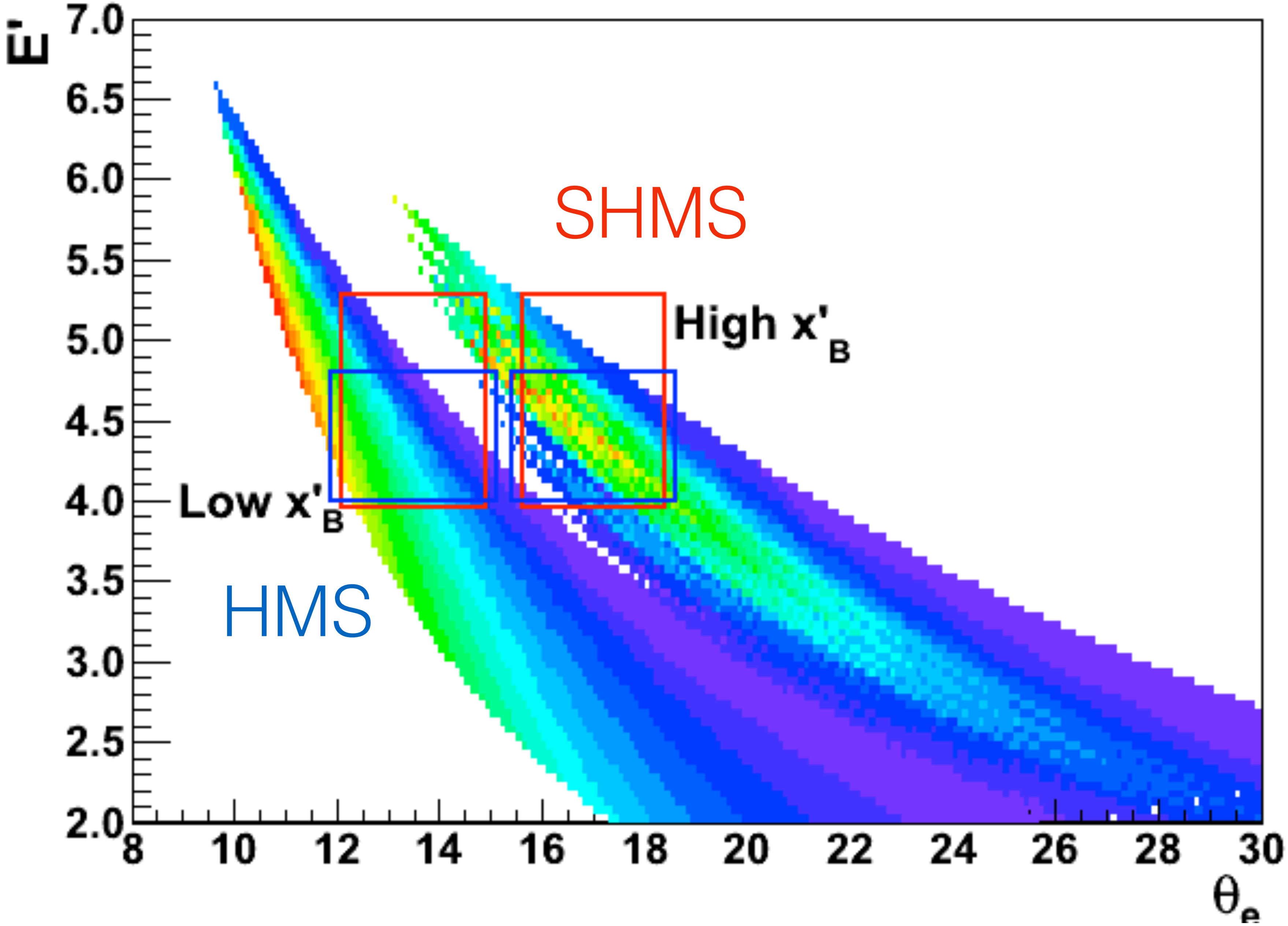
	Binding	Rescaling	Point-like Configuration Suppression
Free			
Bound			

BAND Kinematical Coverage



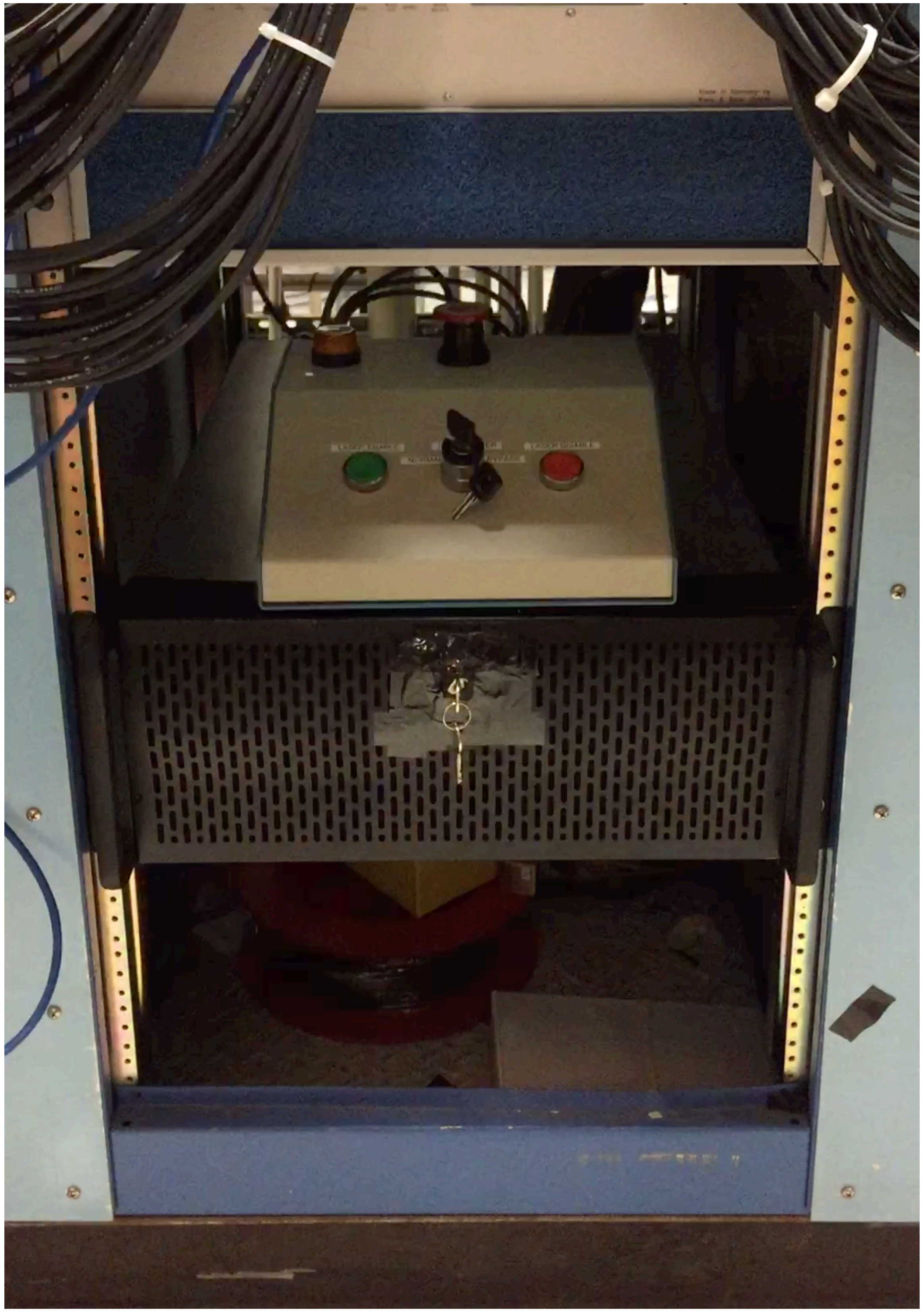
$$x_B^{'} = \frac{Q^2}{2[(M_d - E_s)\omega + \overrightarrow{p_s} \cdot \overrightarrow{q}]}$$

LAD - (S)HMS Coverage

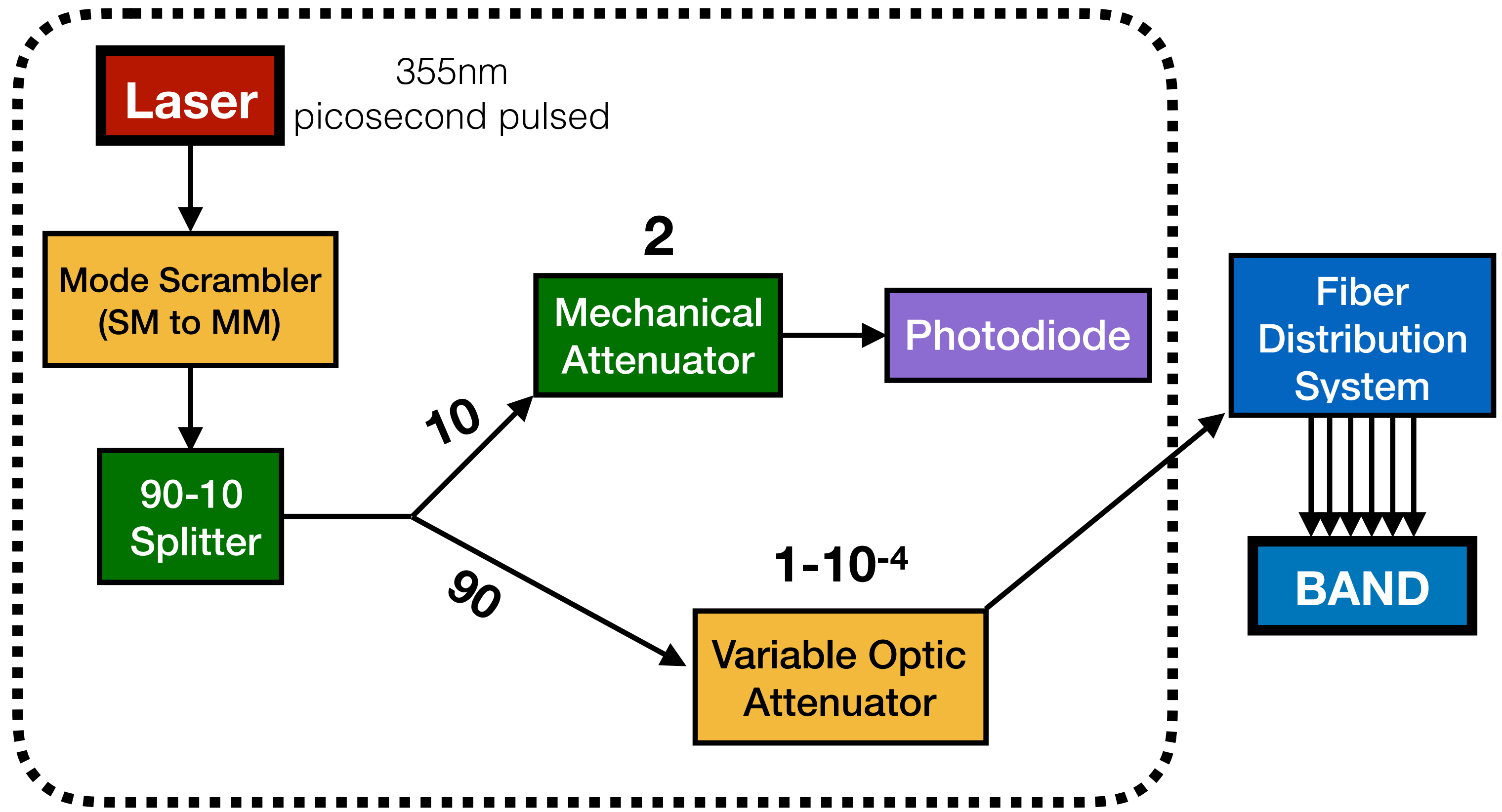


Hen et al., E12-11-107 proposal

Laser System

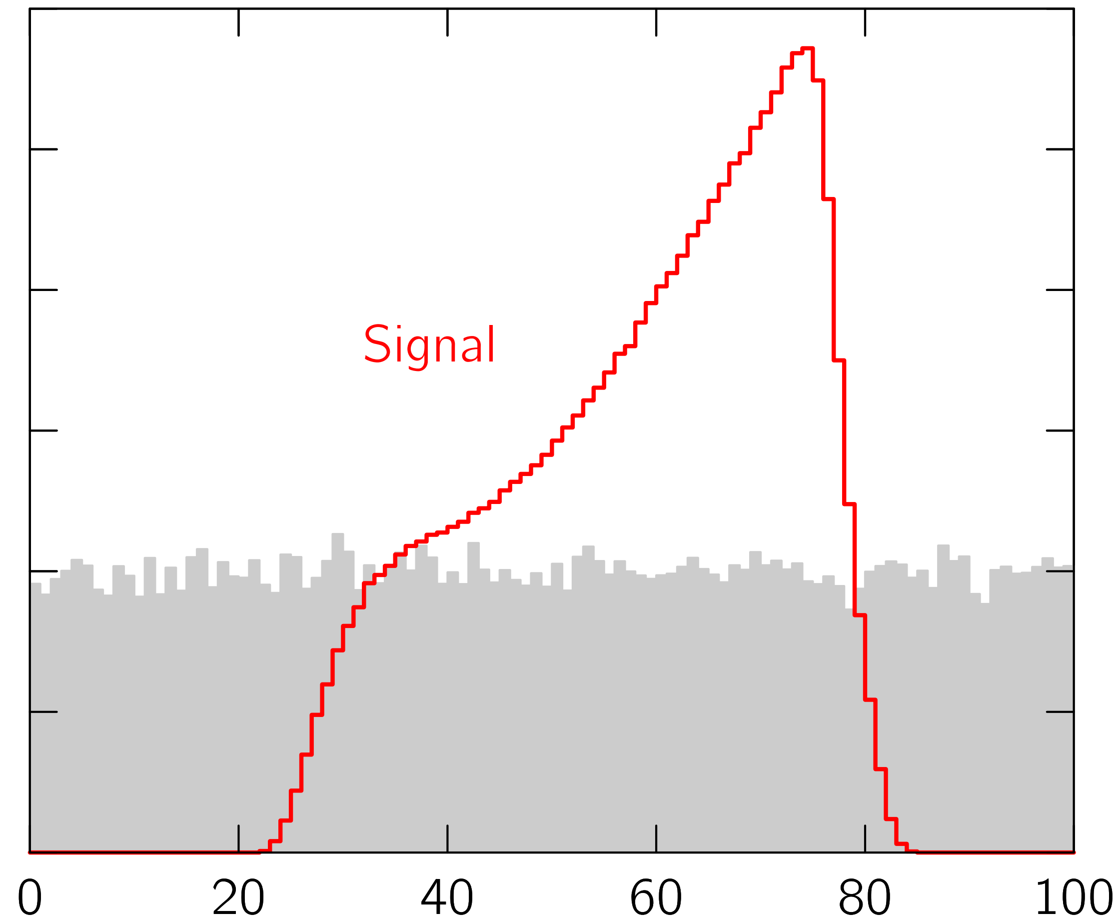


Used to monitor PMT stability



LAD : Statistical Limit - Random background

- Background subtraction by “off-time“ events
- Reduction in background gives increased statistics
- Background conditions more favorable than HallB
  - Less material between target and LAD
  - Tracking of protons with GEM detectors



Simulation by A. Schmidt

—> Higher luminosity, higher statistics, higher x’ coverage

N_{Signal} and uncertainty

Run 6164, 900 splits, 3 hours of beam

Cuts MeVee	S+B	B	S	σS	S:B	σS/S [%]
–	21499	**16596**	**4903**	195.18	0.3	3.98
1	12232	**8592**	**3640**	144.31	0.42	3.96
2	5151	**2904**	**2247**	89.75	0.77	3.99
3	3366	**1640**	**1726**	70.75	1.05	4.1
4	2253	**880**	**1373**	55.97	1.56	4.08
5	1613	**440**	**1173**	45.31	2.67	3.86

N_{Signal} and uncertainty

Run 6327, 600 splits, 1 hours of beam

Cuts MeVee	S+B	B	S	σS	S:B	σS/S [%]
-	8808	**7224**	**1584**	127	0.22	8.02
1	4914	**3767**	**1147**	93	0.3	8.11
2	1972	**1244**	**728**	57	0.59	7.83
3	1250	**698**	**552**	44	0.79	7.97
4	833	**357**	**476**	34	1.33	7.14
5	590	**162**	**428**	27	2.64	6.31
6	487	**121**	**366**	25	3.02	6.83