SRCs @ EIC: Challenges in Forward Detection and Simulation

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Sept 6, 2018

Challenges in ePb: an example

(w/ V. Morozov, et. al & E. Aschenauer et al.)

Challenges in eD

(w/ Z. Tu, T. Ullrich)

SRCs: e"D" embedded in ePb?

(w/ D. Higinbotham et al.)

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Collaborators and Advisors

& plot providers

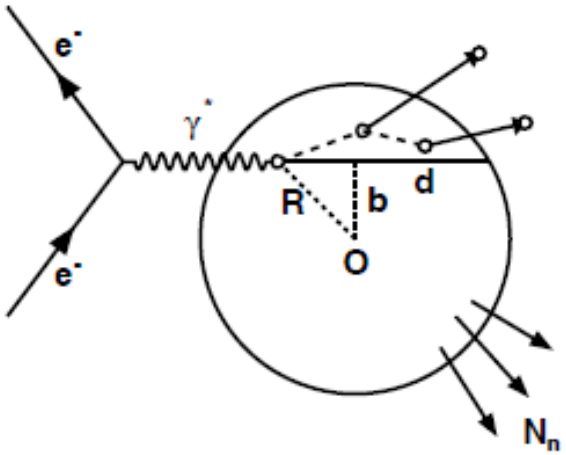
- eA @ eRHIC: E. Aschenauer, W.Chang, A. Kiselev, J.H. Lee, T. Ullrich, L. Zheng
- eA @ JLEIC: A. Accardi, R. Dupre, M. Erhart, C. Fogler, C. Hyde, V. Morozov, P. Nadel-Turonski, K. Park, A. Sy, T. Toll, G. Wei, L. Zheng
- eD @ eRHIC: Z Tu, T. Ullrich
- SRC @ JLEIC: F. Hauenstein, O.Hen, D. Higinbotham, C. Hyde, P. Nadel-Turonski, G. Wei, L. Zheng

- Advice from: N. Fomin, W. Schmidke, M. Sievert, R. Venugopalan, C. Weiss, M.P. Zurita

BeAGLE – Benchmark eA Generator for LEptoproduction

- Aschenauer, MDB, Lee, Zheng (+Armesto+Dupré)
- Merger of
  - Pythia – hard interaction (adding RAPGAP option)
  - Glauber + optional multinucleon shadowing
  - Optional (radiative) jet quenching PyQM (off today)
  - DPMJET3-F (DPMJET3+Fluka) – nuclear response
- Tuned to ZEUS forward nucleons, FNAL E665 slow neutrons, + HERMES
  - Working on E665 e-by-e charged hadrons (SC)

Key Features of BeAGLE



<u>Multistep process.</u>

Hard interaction (DIS or diffractive) involving one or more nucleons.

Intra Nuclear Cascade w/ Formation Zone

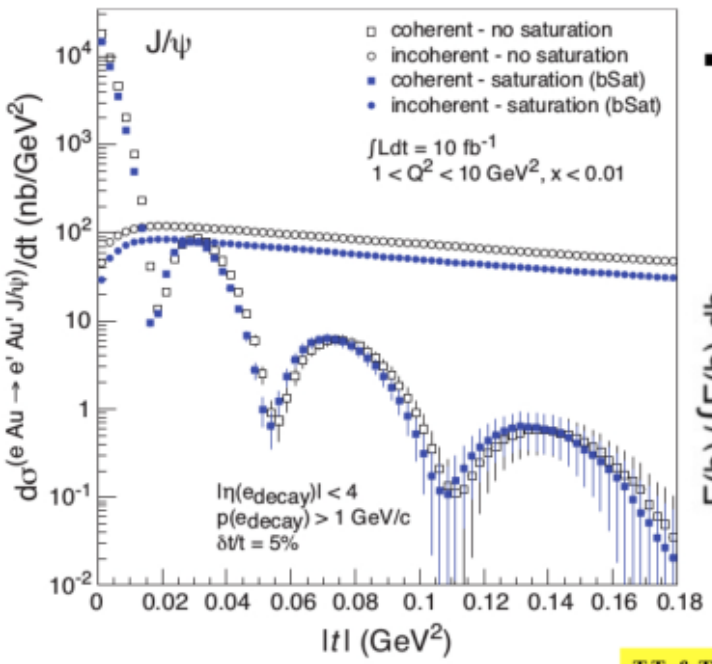
Excited nuclear remnant will decay:
Fission &/or evaporation of nucleons
De-excitation by gamma emission.

Try to model both hard process AND nuclear interaction.

It helps if A is big enough (12?) to leave a substantial remnant which can be modeled in the ion rest frame as a collection of on-mass-shell nucleons with Fermi motion sitting in a mean field.

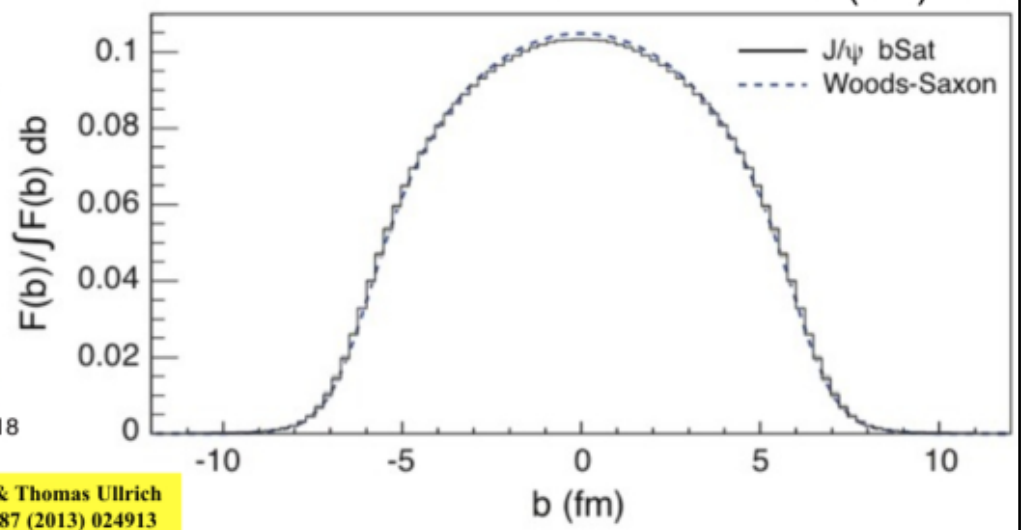
Probing the spatial gluon distribution at EIC

Momentum transfer t conjugate to transverse coordinate b



$$F(b) \propto \int \mathrm{d}\Delta \Delta J_0(\Delta b) \sqrt{\frac{\mathrm{d}\sigma}{\mathrm{d}t}}$$

$t = \Delta^2/(1-x) \approx \Delta^2$

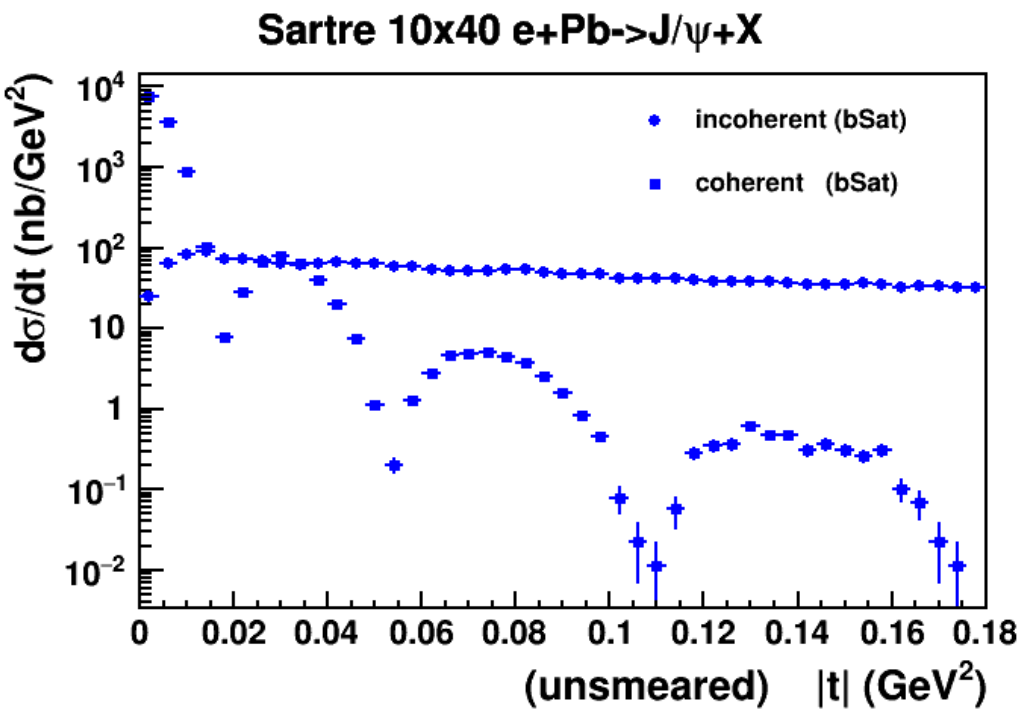


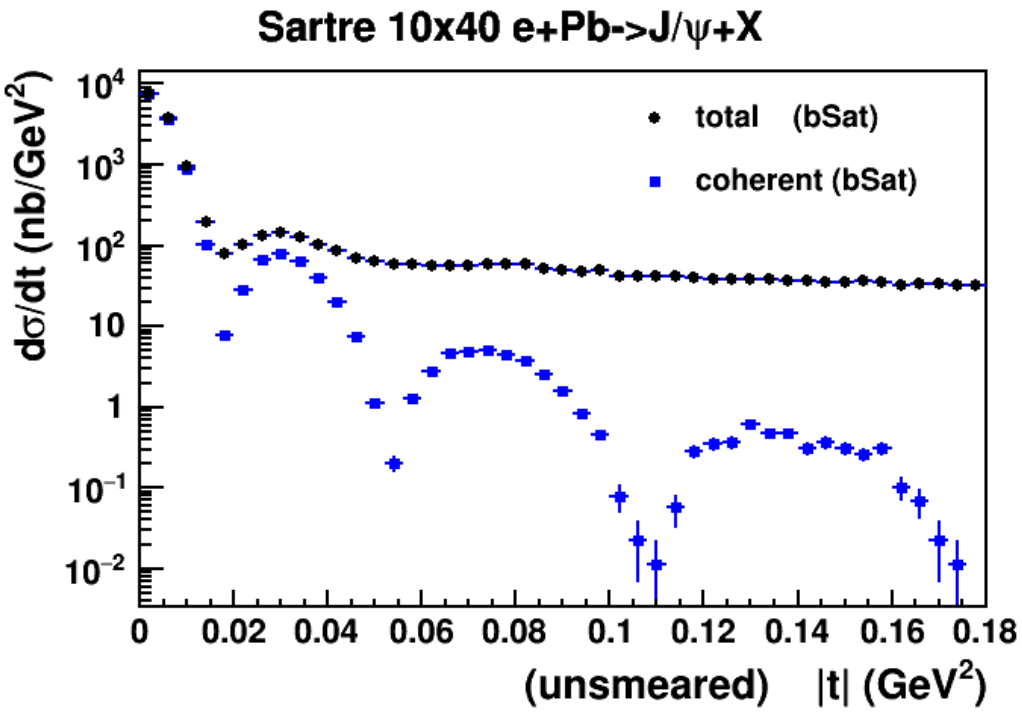
T.T. & Thomas Ullrich
PRC 87 (2013) 024913

EIC will be able to retrieve the spatial gluon distribution with high precision.

IF we can extract the coherent diffraction pattern

Importance of veto tagging





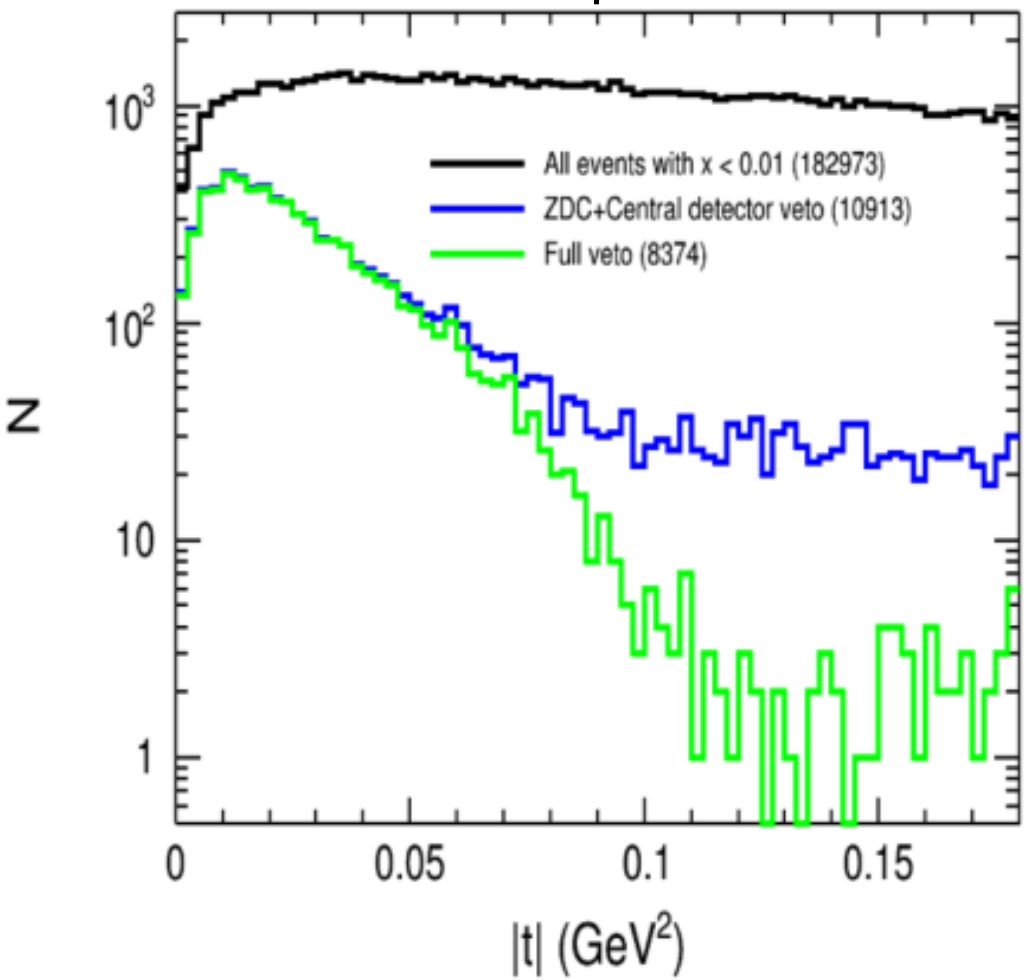
$1<Q^2<10$ GeV^2 & $x<0.01$
Yield is ~ 50% of that at 20x100 (18x110)

For experts: old Sartre (eAu) tune
Similar to White paper, but JLEIC energy.
Low statistics MC run.

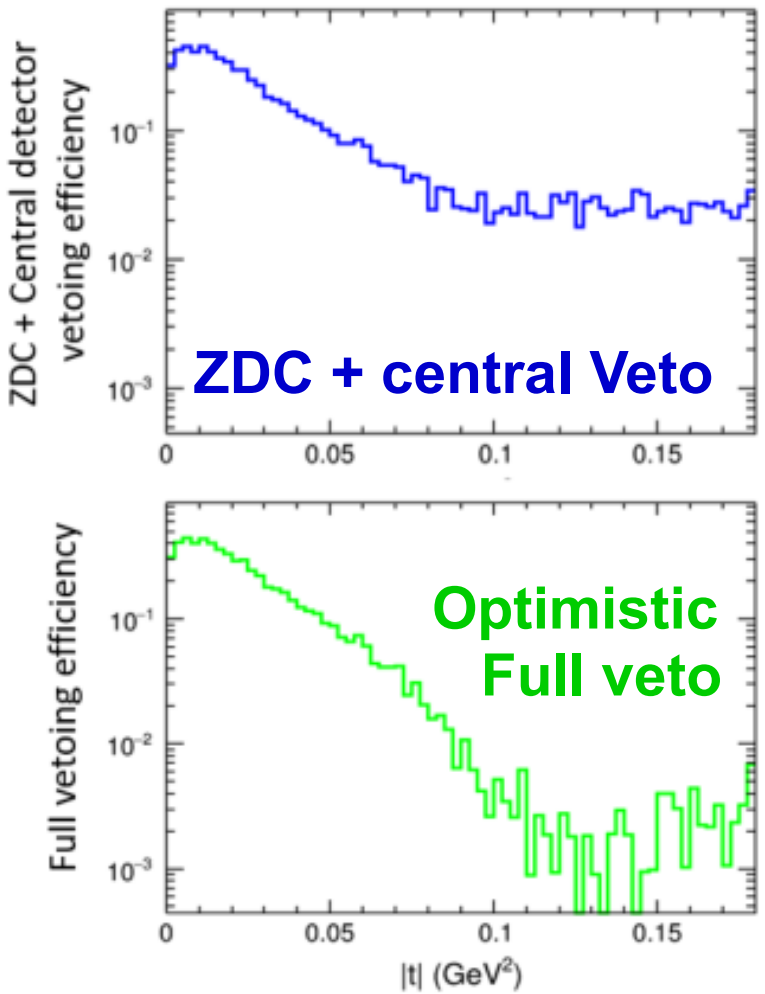
We definitely need to tag (VETO) the incoherent data or we have no information.

V.S.Morozov et al. DIS2018 proc.

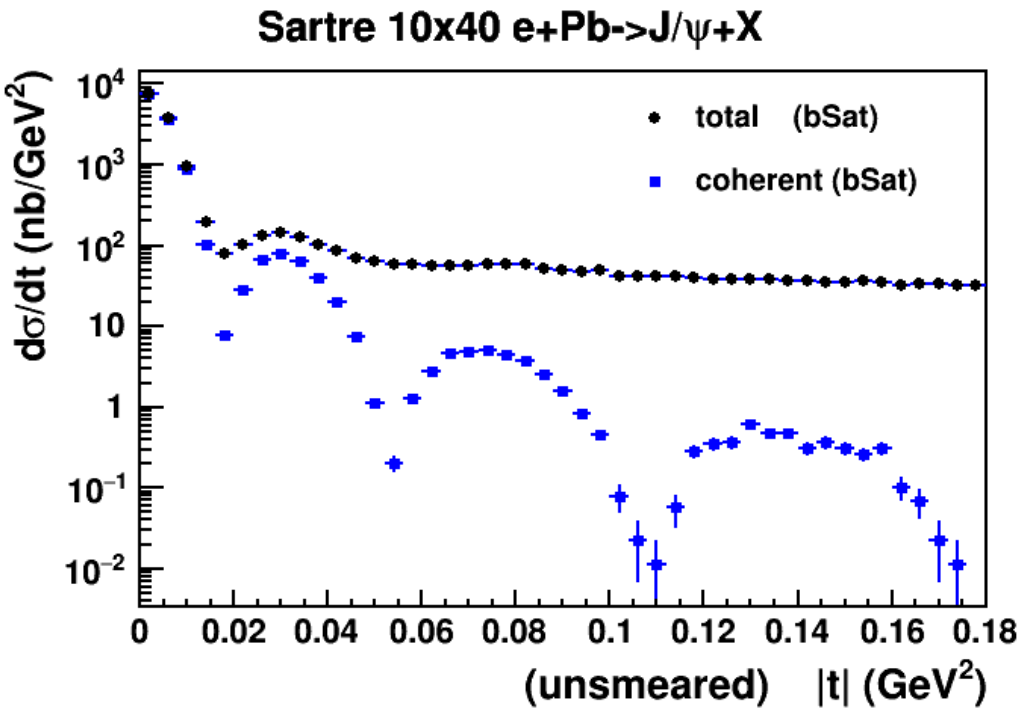
Incoherent J/ψ from e+Pb

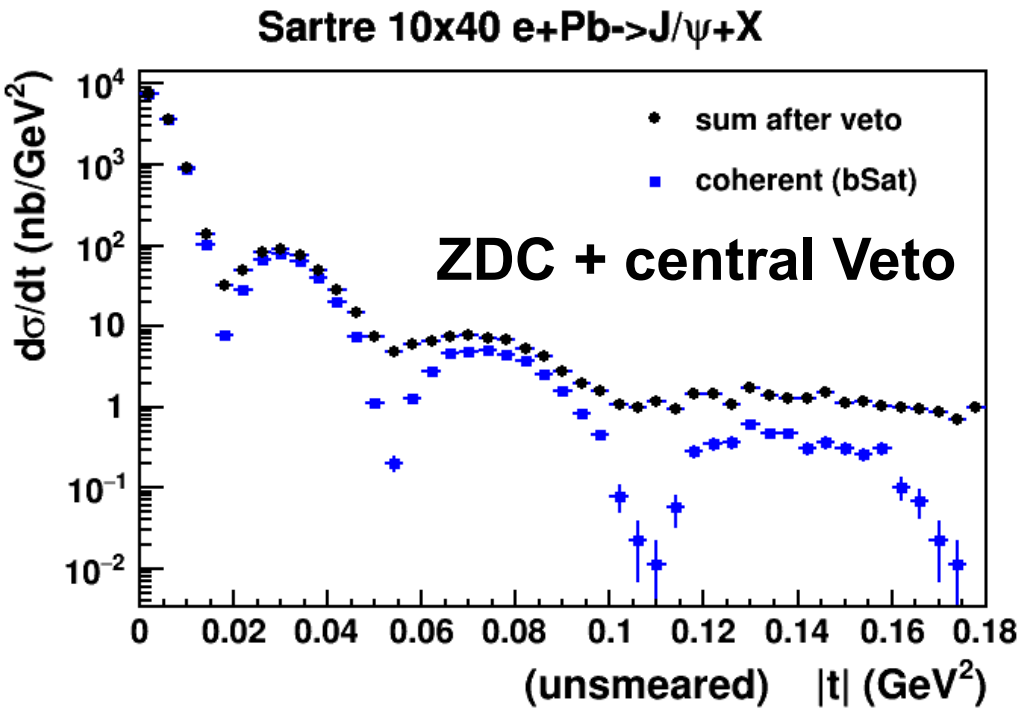


Tagging inefficiency



Challenge of veto tagging



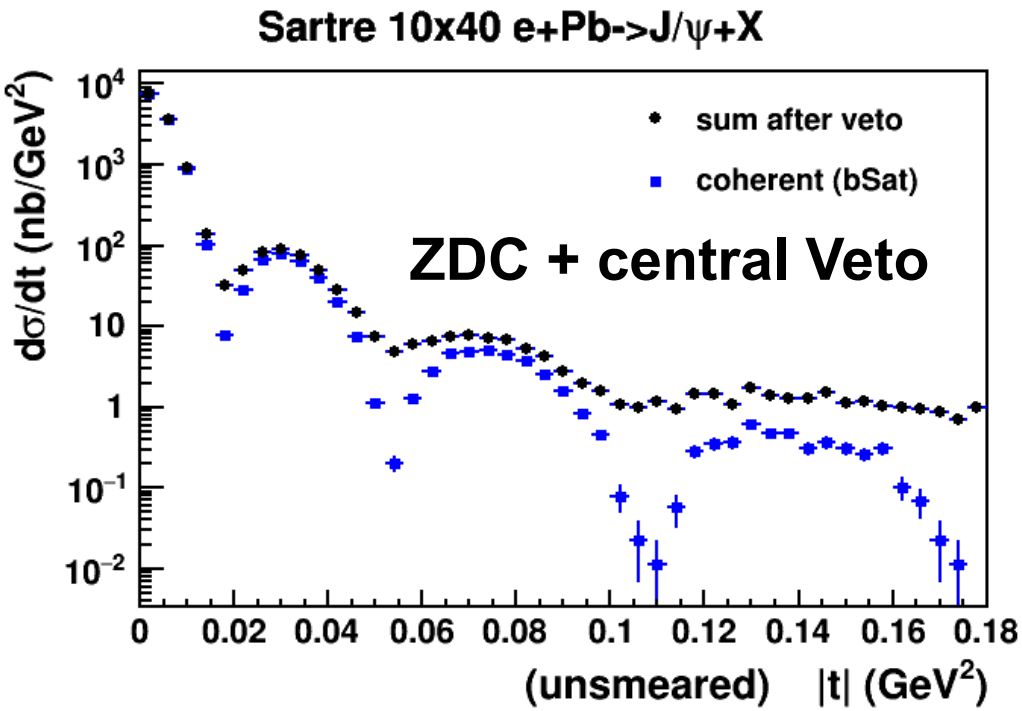


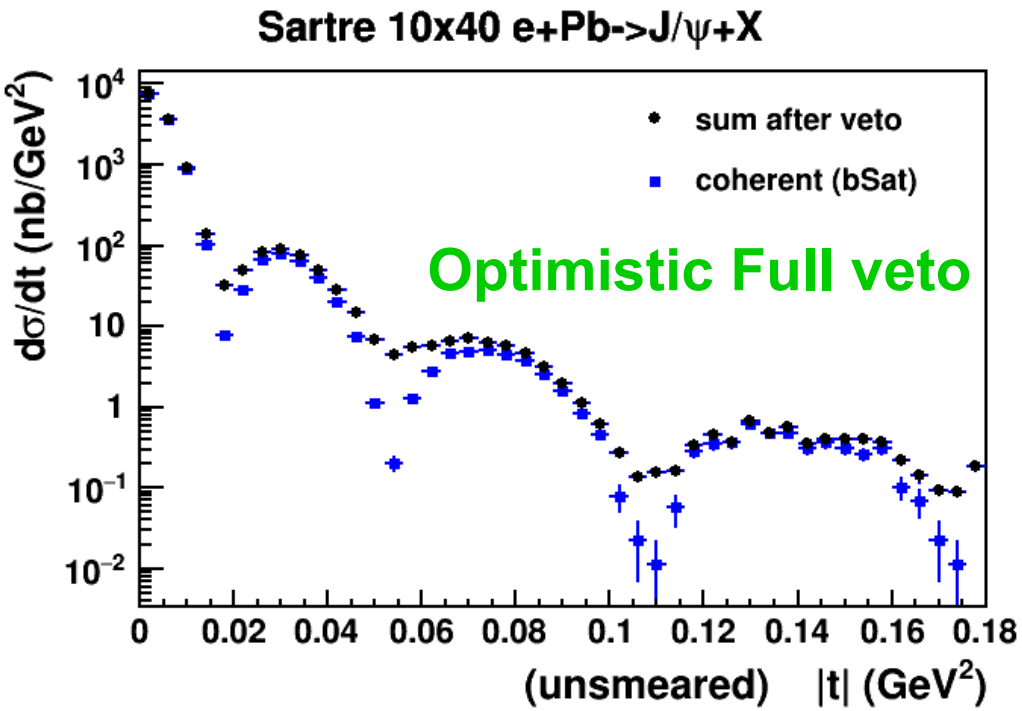
No tagging

Remove events with:

- n or >40 MeV γ w/ θ<10mr
- or hadronic activity w/ θ>100mr
- or >500 MeV γ w/ θ>100mr

Challenge of veto tagging





Remove events with:

- n or >40 MeV γ w/ θ<10mr
- or hadronic activity w/ θ>100mr
- or >500 MeV γ w/ θ>100mr

Also remove events with:

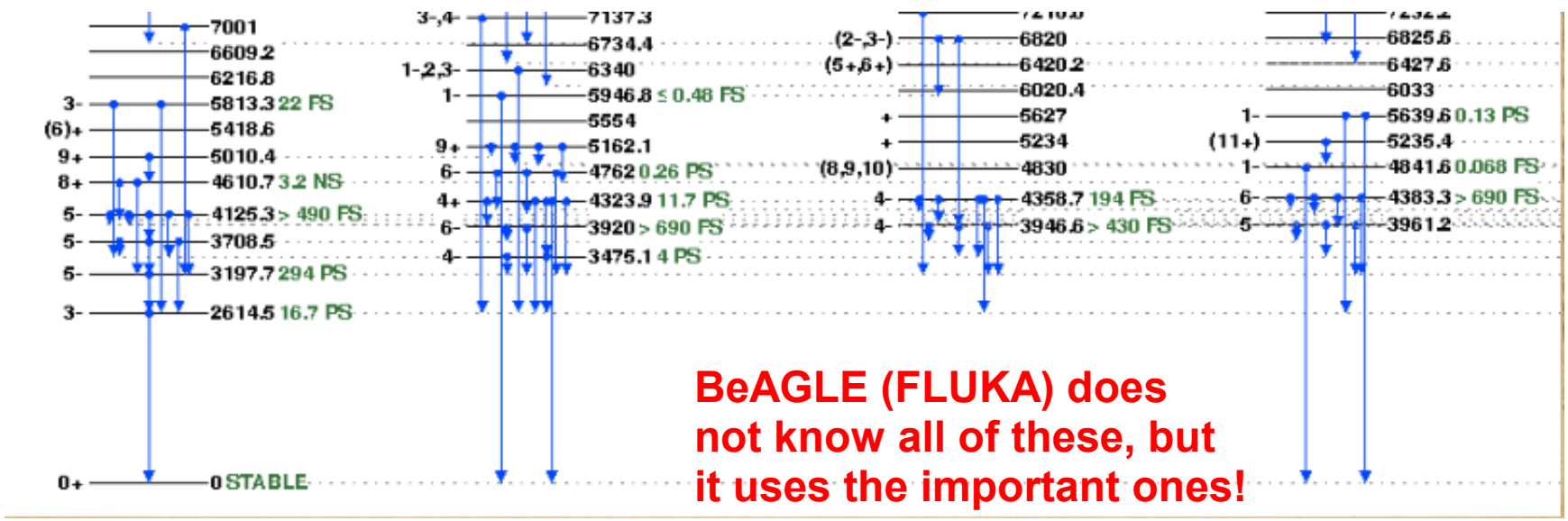
- p w/ θ<10mr

Good enough??

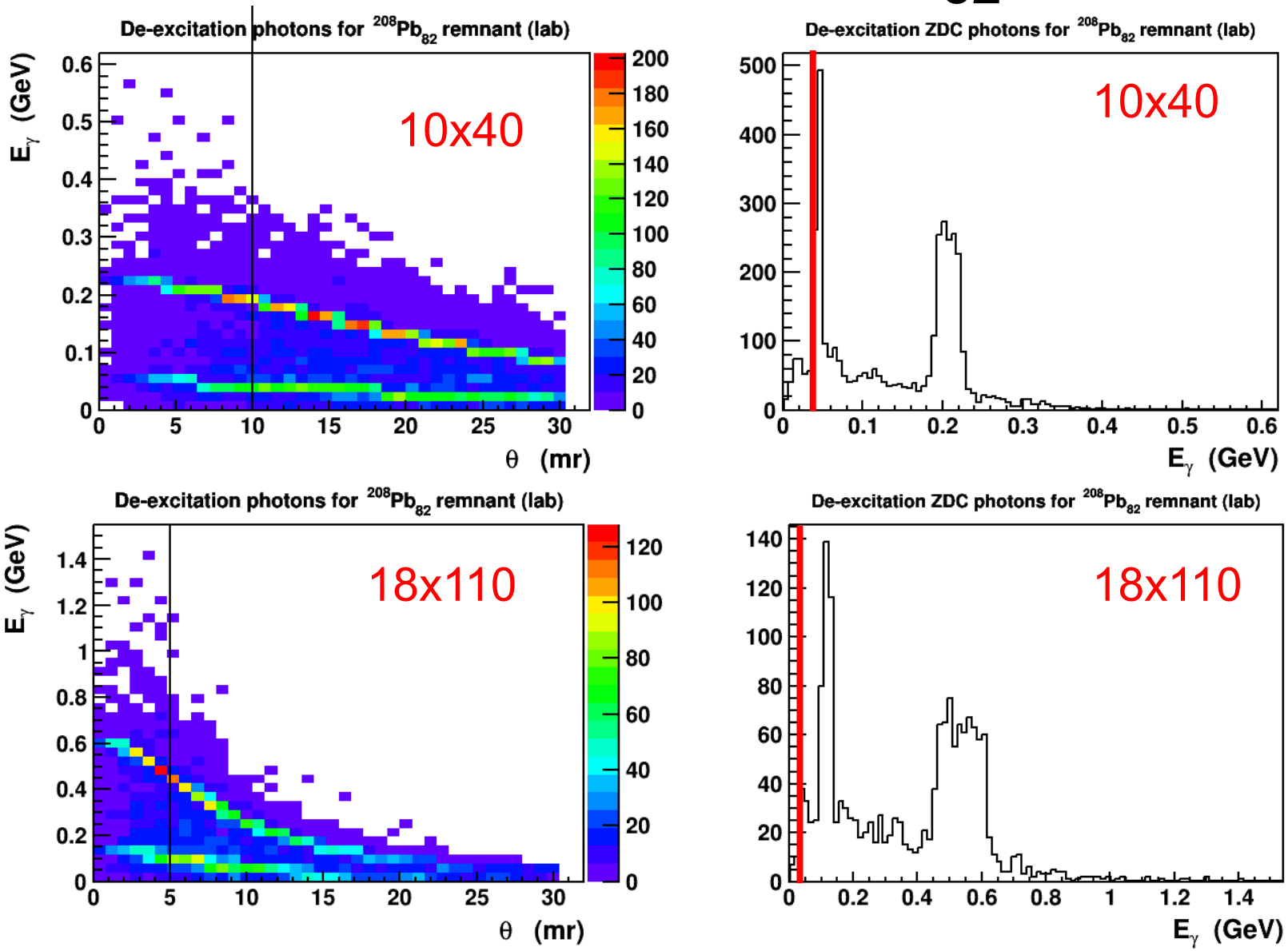
Simulation Challenge: nuclear detail

- Veto problems for $|t|<0.07$ GeV^2 are due to events where the struck nucleon and any further INC nucleons are reabsorbed: $e + {}^{208}Pb_{82} \rightarrow e' + {}^{208}Pb_{82} + J/\psi + \gamma + \gamma + \gamma ...$
- Excited Pb decays usually include a γ w/ $E \geq 2.6$ MeV
- Au decays are more challenging to detect!

Pb:



Photons from $^{208}Pb_{82}$ in lab frame

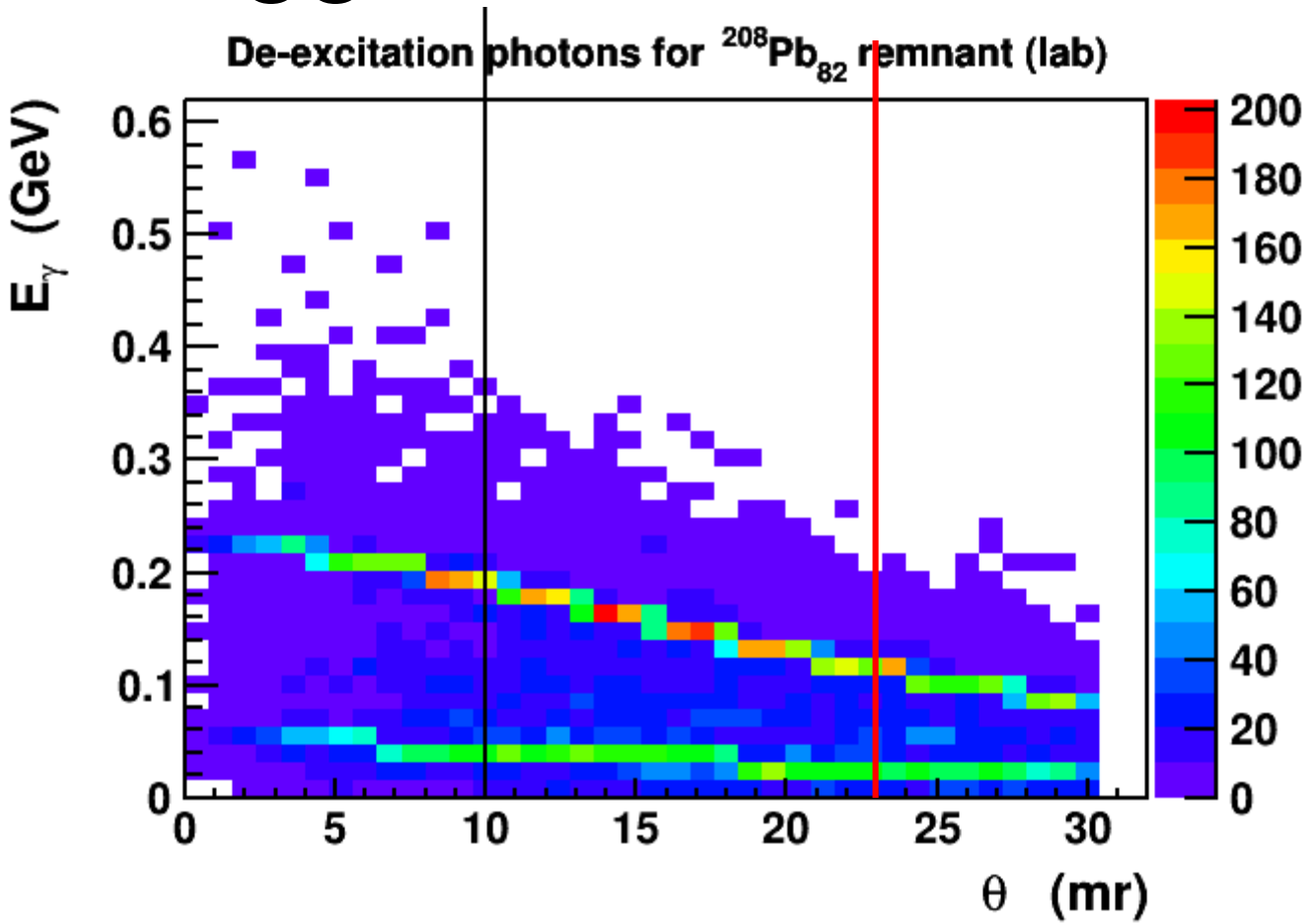


Detailed studies ongoing.

It is clear that γ's will be needed for low |t|!

w/ Morozov, Hyde, Turonski et al.

Bigger forward cone?



2-3 photons / per event. Half are in the forward TRF hemisphere:
$\theta<1/\gamma_{Pb}$ in lab or 23 mr for 10x40 (8.5 mr for 18x110). By momentum conservation:
WE EXPECT AT LEAST ONE SUCH PHOTON PER EVENT!

BeAGLE for eA summary

- Forward neutrons <u>and</u> protons <u>and</u> photons are ALL needed in order to veto incoherent diffraction and measure coherent diffraction.
- Still to determine:
  - Is our current forward detector suite adequate?
  - Can we subtract the remaining background?
  - If we invert what we can measure, how well do we reconstruct the input G(b)?
  - Is BeAGLE correct?
    - Add RAPGAP & tune to E665 SC data.

BeAGLE not optimized for e+D!

Main problem – Everything lives on mass shell.
No remnant to absorb energy-momentum imbalance.

$W^{\mu} = \{\nu+M_d; 0, 0, \mathrm{sqrt}(\nu^2+Q^2)\}$

$W^{\mu} = \{\nu+E_n+E_p; 0, 0, \mathrm{sqrt}(\nu^2+Q^2)\}$

Note: DPMJET3-F has the same problem. Minimized due to minimal p_F.
So DPMJET3-F is not ideal for detector optimization for SRC.

Solutions

- First attempt (for today) using upgraded BeAGLE
  - Impulse approximation (struck + spectator)
  - All relative p,n momentum from the initial state
  - Ad hoc adjustment of final state particle 4-momenta to match correct total 4-momentum of original γ^*+D
- Next steps: input from Christian Weiss
  - Conserve p^+,p_T adjust only p^- of non-spectators
  - Get spectator p^+, p^-,p_T from light-cone wavefunction?
- Then?: FS effects? Non-impulse approximation...

Fermi momentum at a collider

BeAGLE (& DPMJET & Pythia) use on-mass-shell nucleons which sit in a mean-field nuclear binding + Coulomb potential.

In nuclear target rest frame:

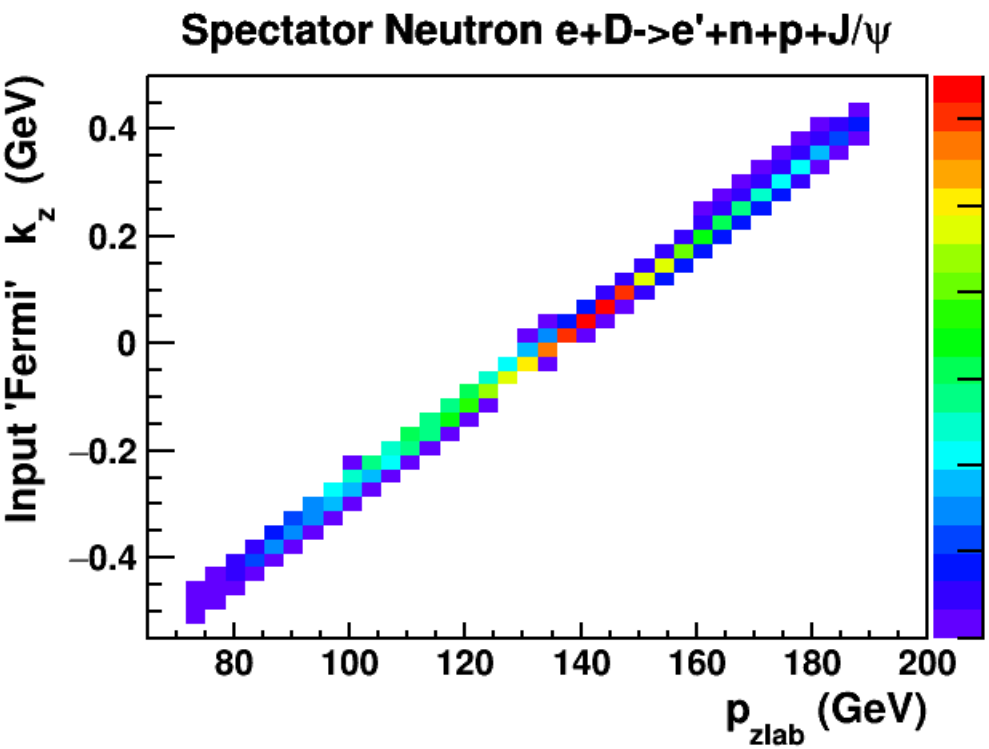
$P^{\mu} = \{M; 0, 0, 0\}$ OR $\{M+E_{kinF}; k_{xF}, k_{yF}, k_{zF}\}$

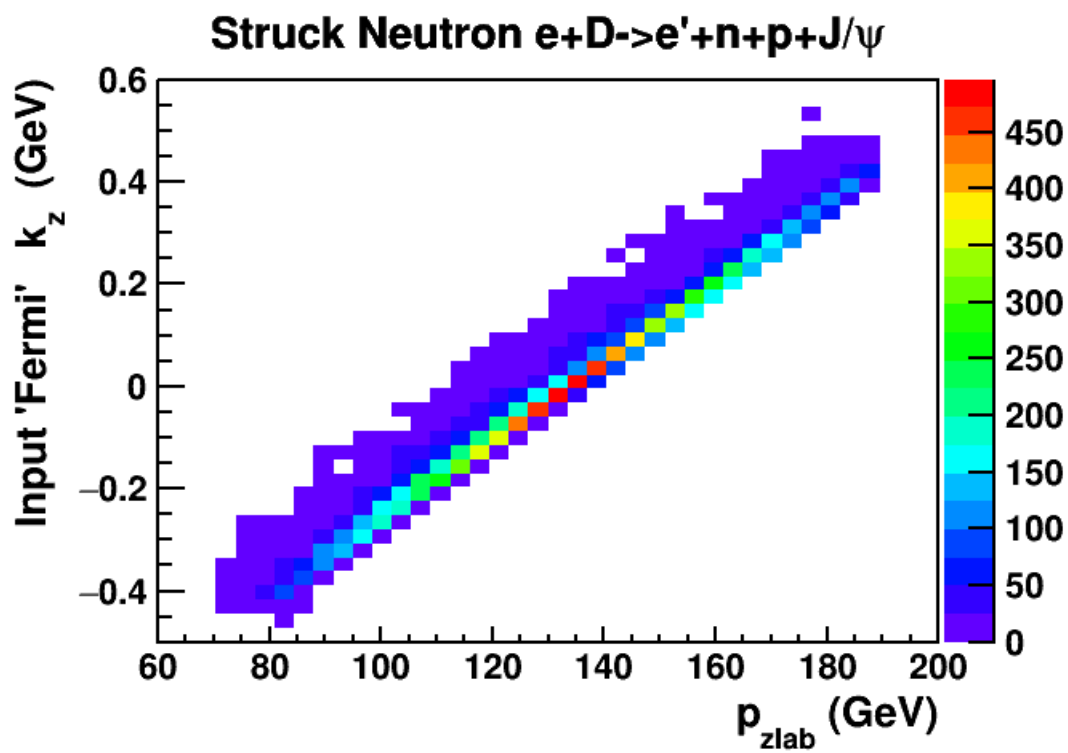
In lab collider frame:
$P^{\mu} = \{\gamma M; 0, 0, \gamma\beta M\}$ OR $\{\gamma M+\gamma\beta k_{zF}+\gamma E_{kinF}; k_{xF}, k_{yF}, \gamma\beta M+\gamma k_{zF}\}$

Since $\beta \sim 1$ and $E_{kinF} << k_{zF}$:

$E \sim p_z \sim E_{beam} (1 + k_{zF}/M)$

18x135 e+D "Fermi" effect

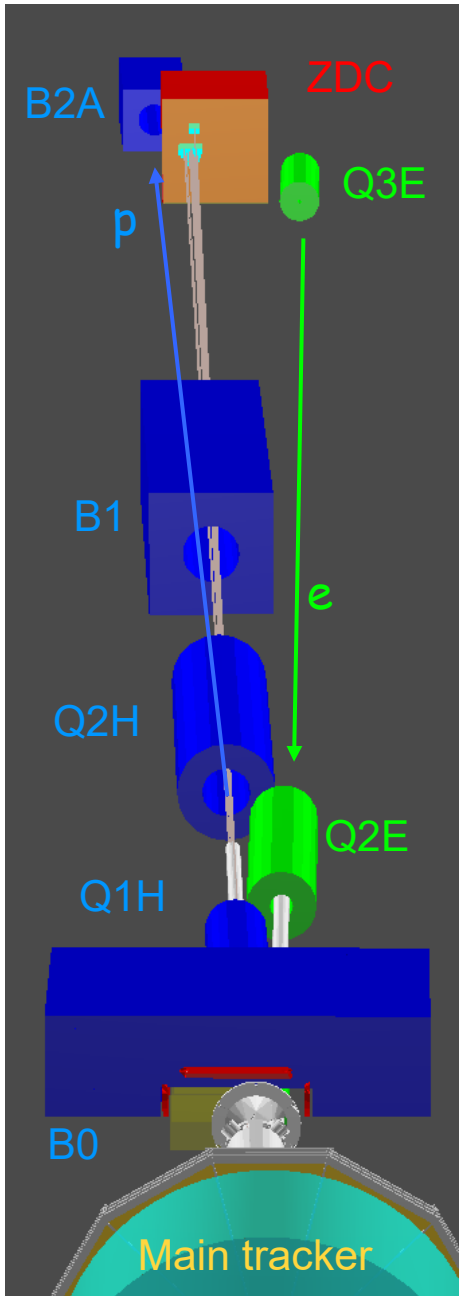




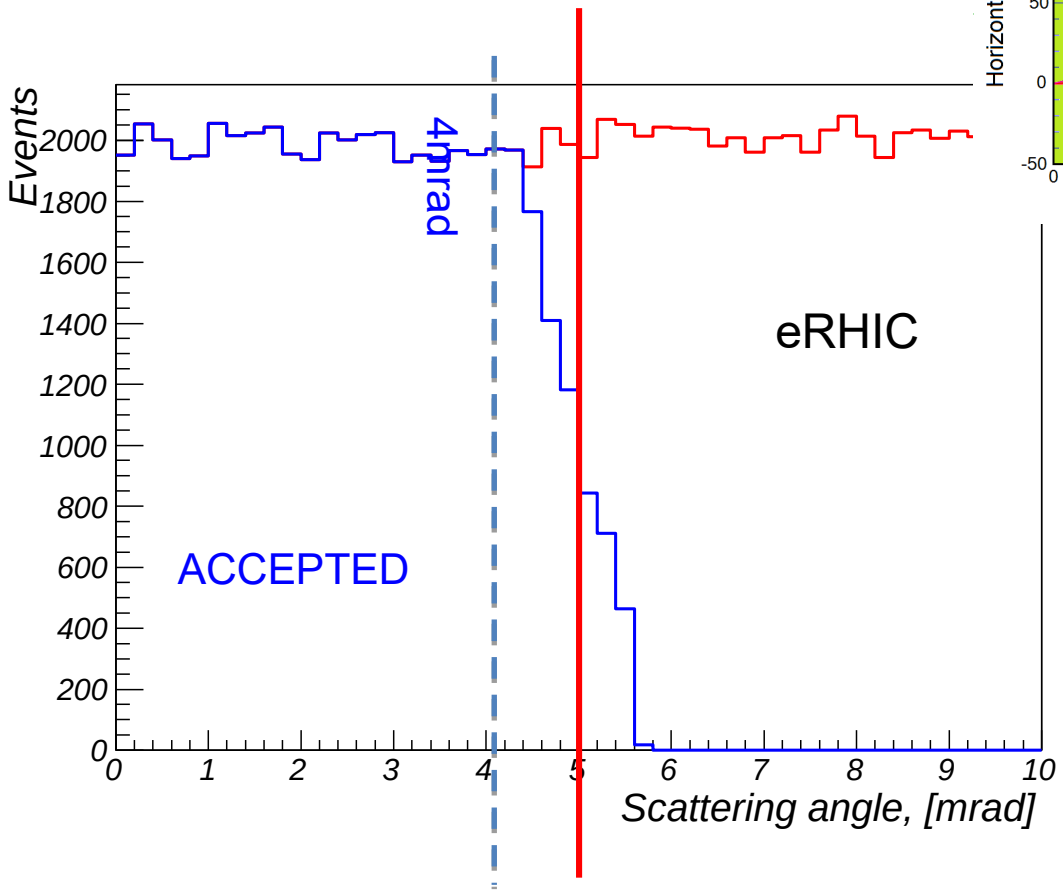
Any p-kick (IS or FS) along the “z” direction in the ion rest frame is magnified!

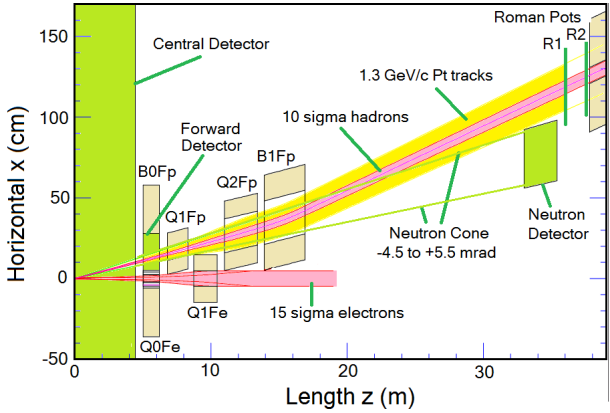
Minor point: z in this plot is defined along γ*D axis not eD axis.

Angular acceptance for neutrons



→ NB: here particles generated flat in θ
→ ZDC is handled as a "black hole" volume



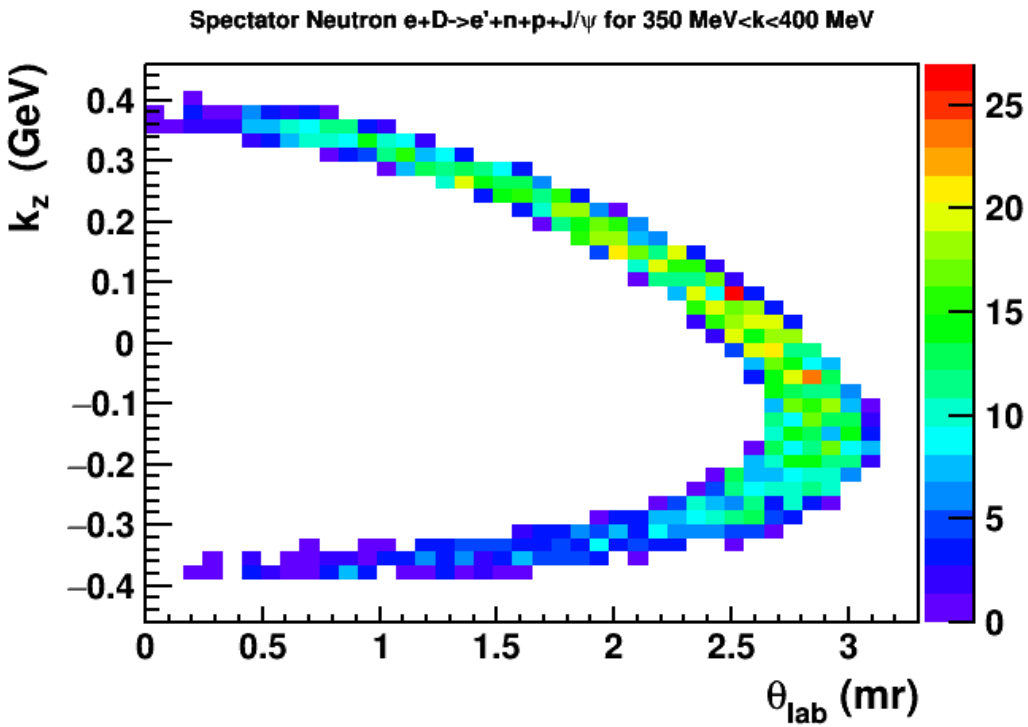


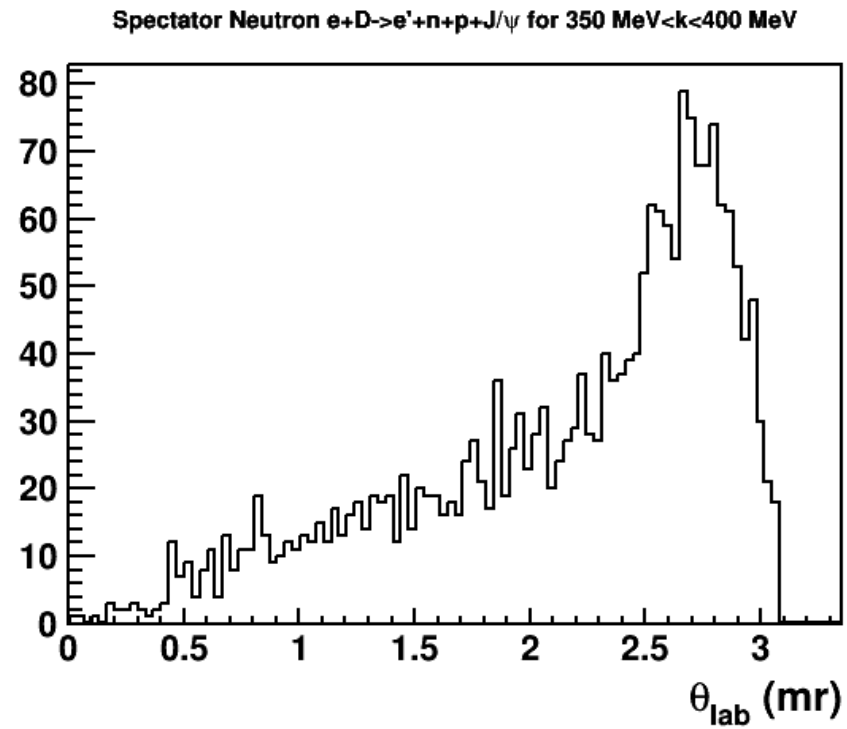
→ NB: space for ZDC needs to be increased for better hadronic shower containment

Achieve the 4 mrad acceptance requirement

From A. Kiselev

Spectator neutrons for k~375 MeV



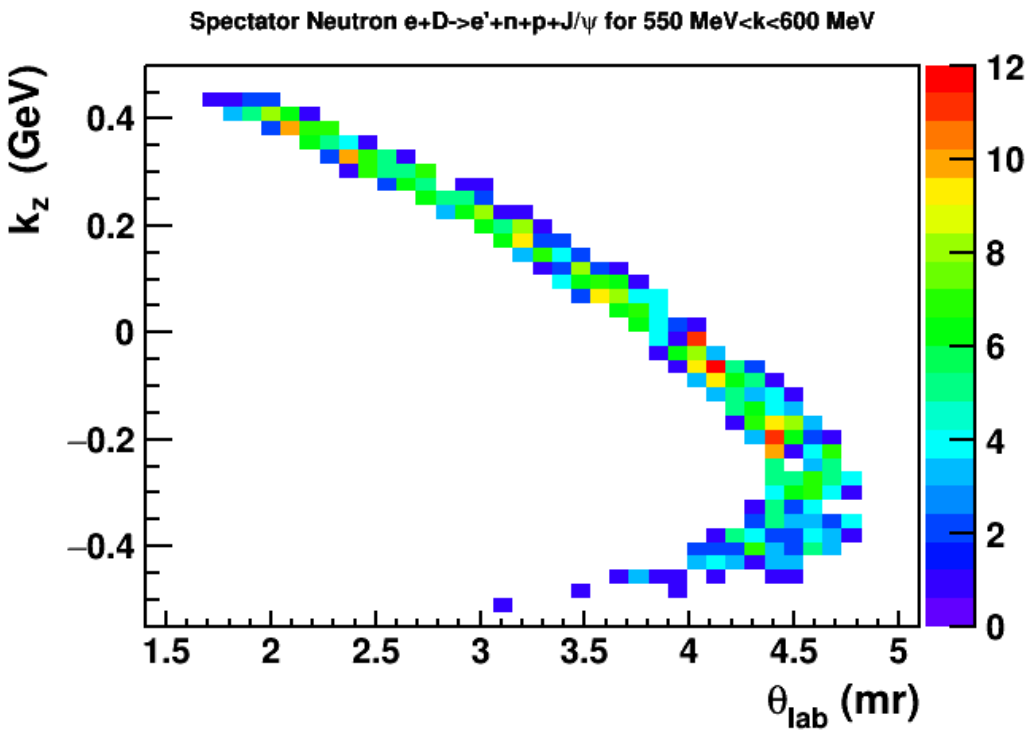


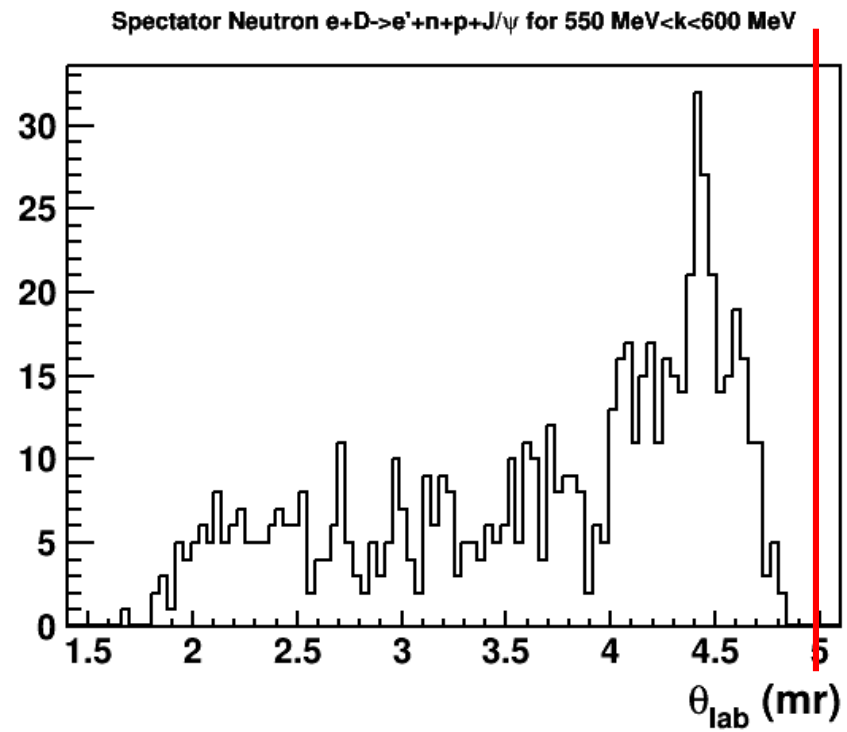
Spectator neutrons are easy to detect

Spectator protons look similar to neutrons – also easy??

Spectator neutrons for k~575 MeV

(but $|k_z|$ < ~450 MeV)



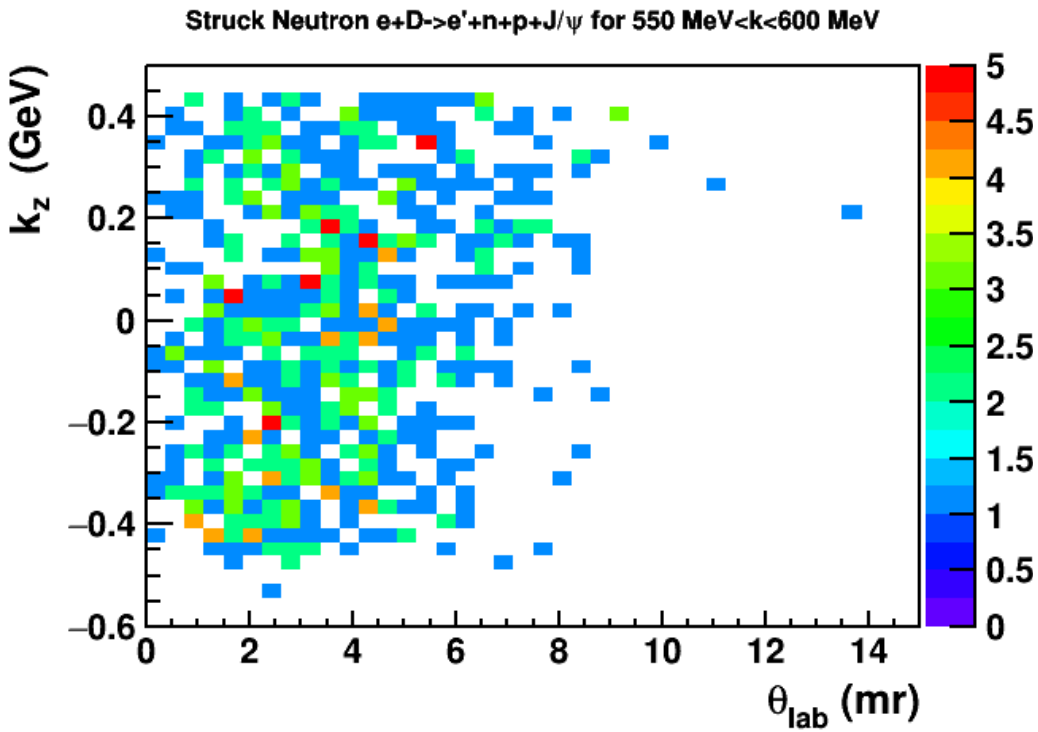


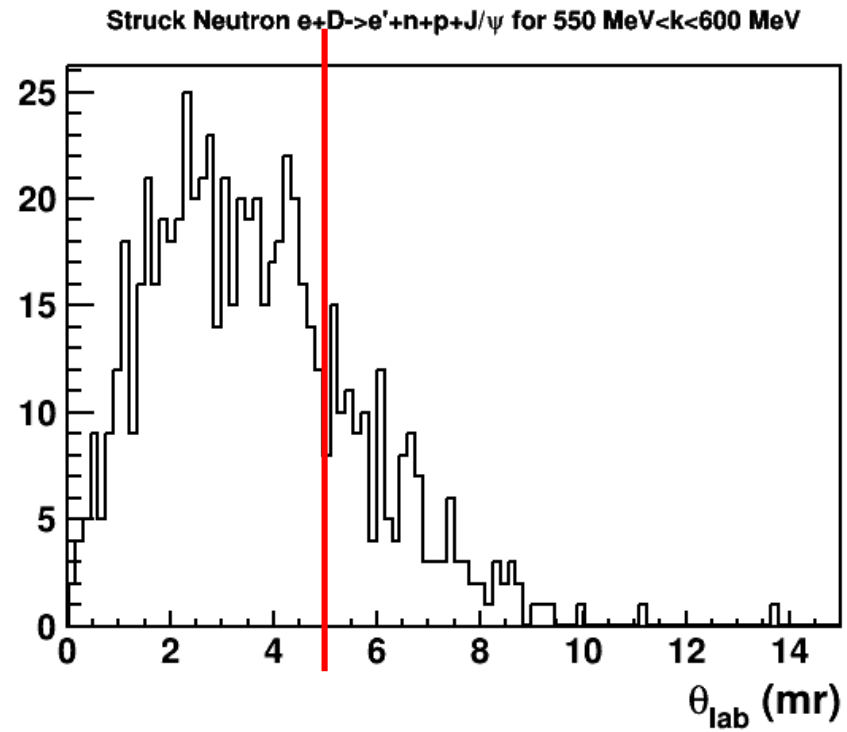
Spectator neutrons still detectable

Spectator protons?

Struck neutrons for k~575 MeV

(but $|k_z| < \sim 450$ MeV)



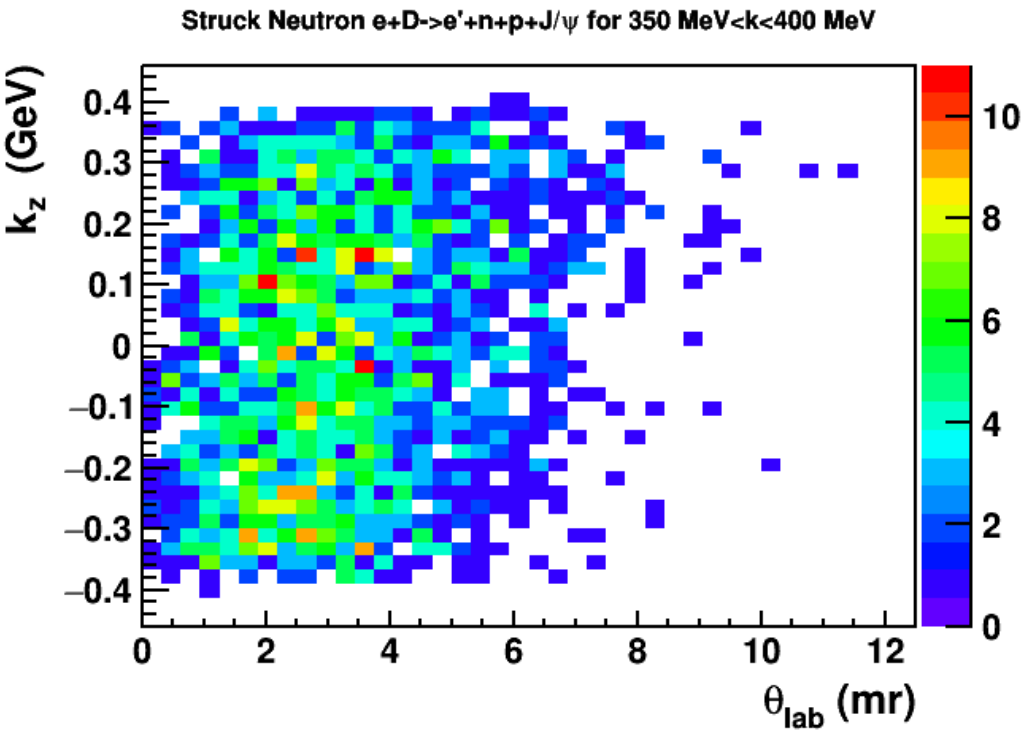


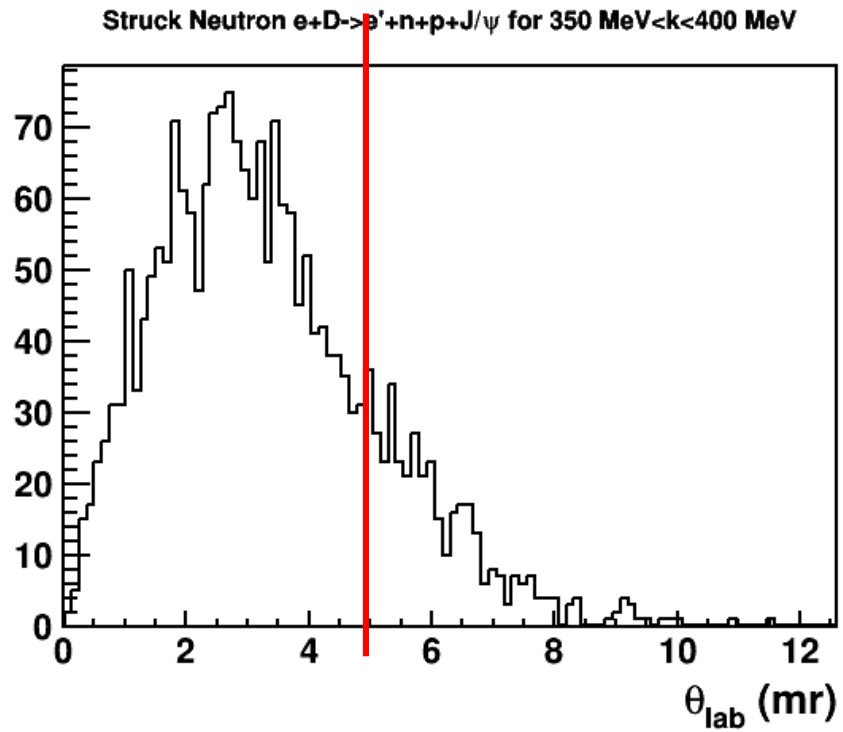
Struck neutrons not fully contained in ZDC

Again, struck protons have a similar distribution

Struck neutrons for k~375 MeV

(but $|k_z|$<450 MeV)

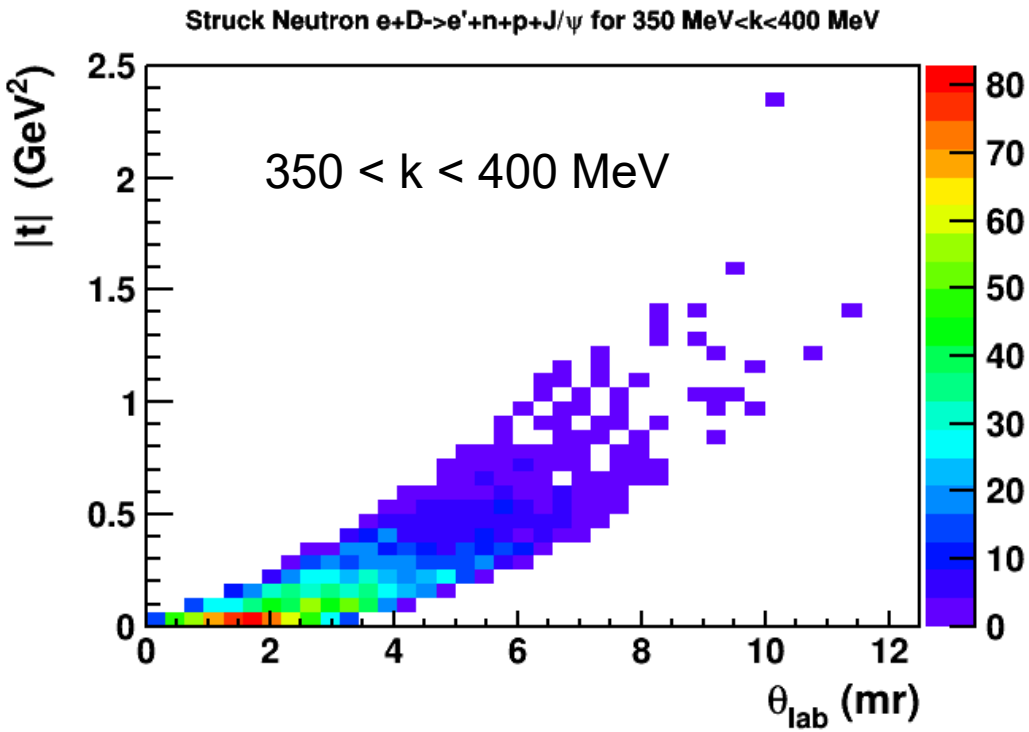


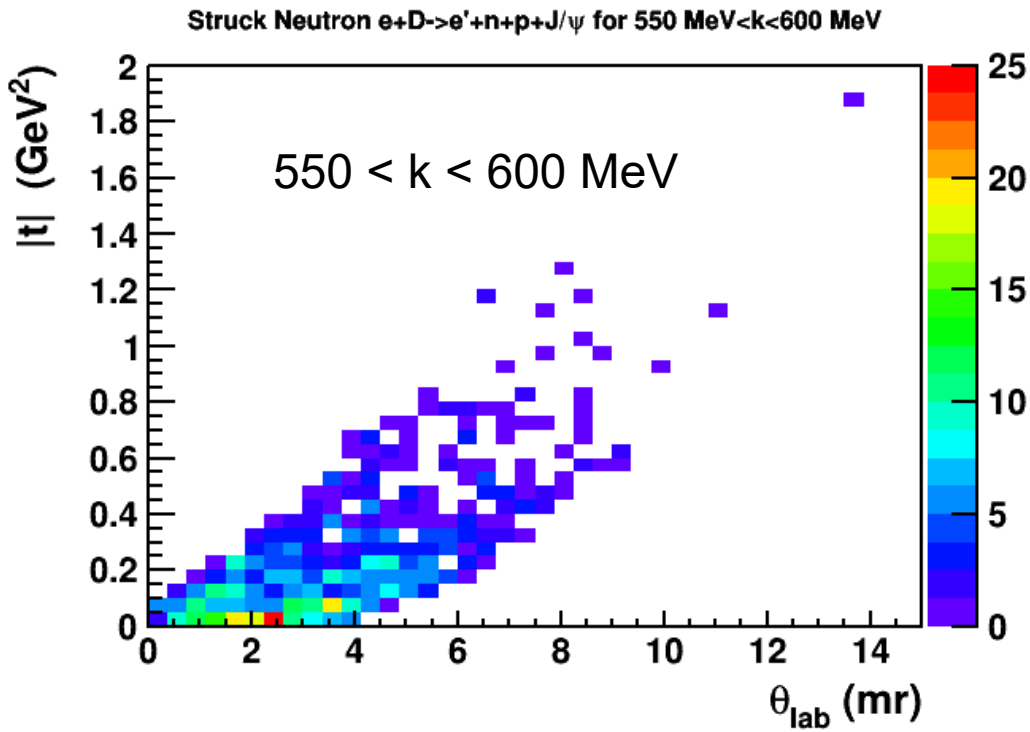


Struck neutrons still not fully contained in ZDC

Struck protons have a similar distribution

Struck neutrons affected by collision



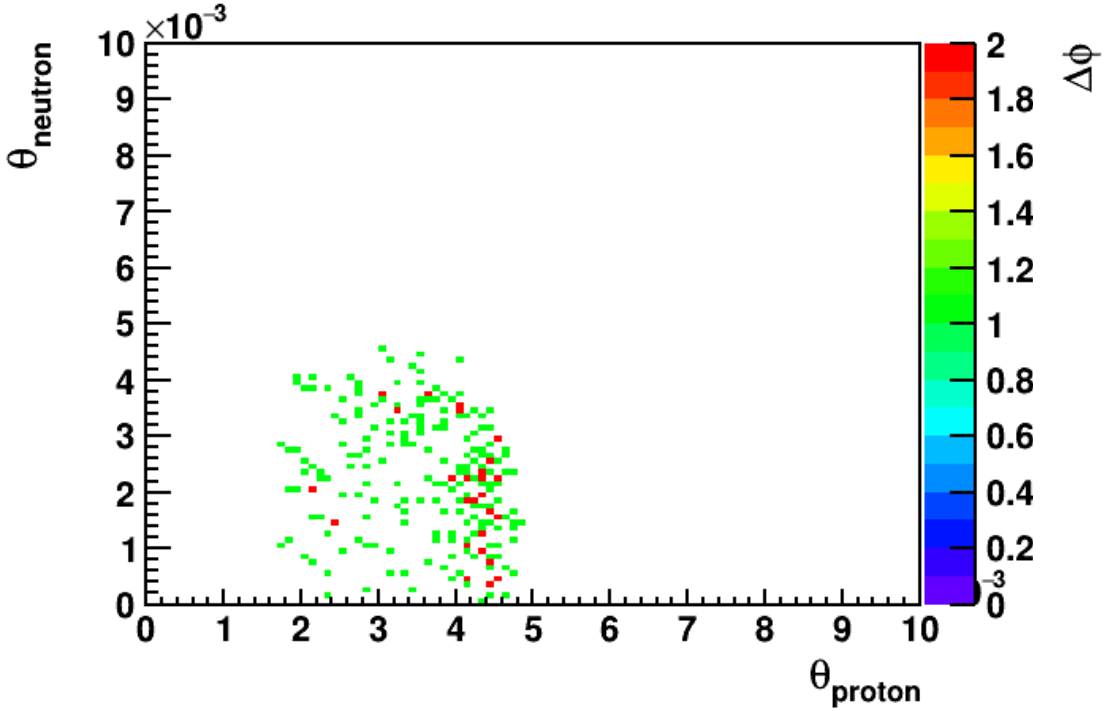


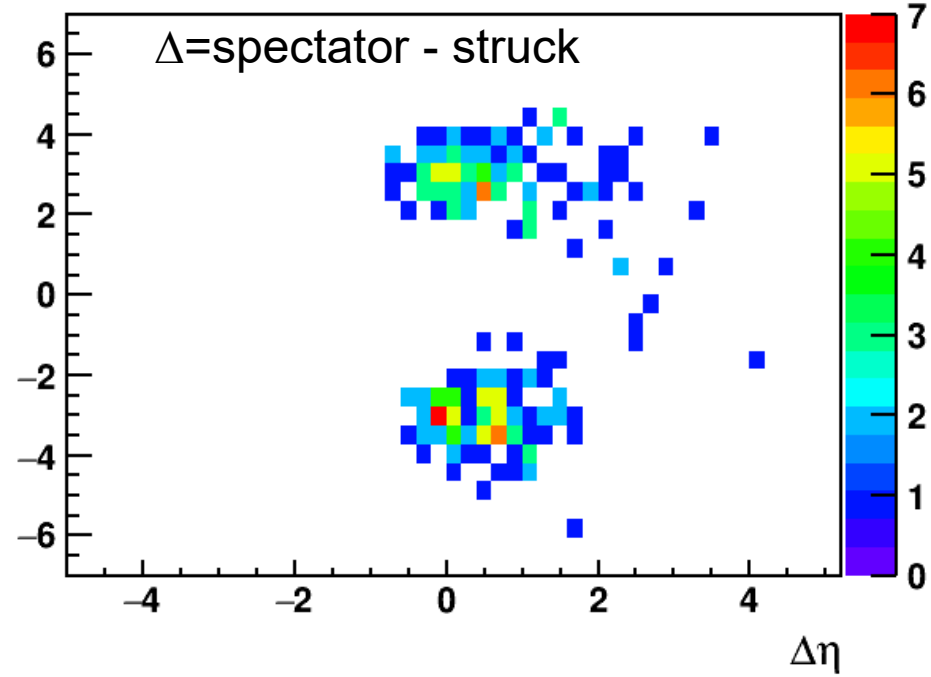
Keeping $|t|<0.1$ GeV^2 should contain neutrons in ZDC

Should also keep nucleon breakup in check.

Correlations

For struck neutron, spectator proton – lab variables
$|t|<0.1$ GeV^2, $550 < k < 600$ MeV $|k_z|<450$ MeV





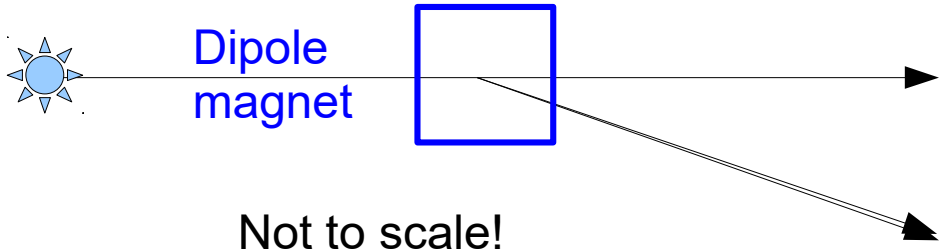
Recall η=-ln tan (θ/2)

Keeping $|t|<0.1$ GeV^2 contains forward nucleons in $\theta<5$ mr!

Nucleons are back to back (in this simulation!)

Forward acceptance at a collider

Forward proton acceptance in e+p is DIFFERENT from e+A



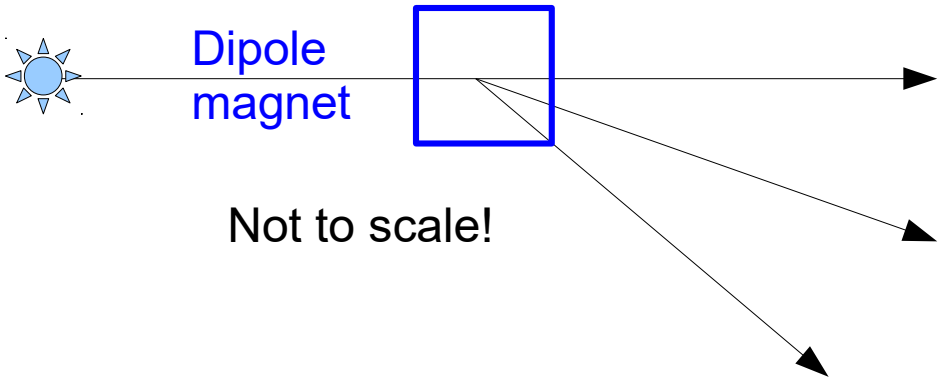
Not to scale!

n (θ=0)

p (beam or $p_z=p_{zbeam}$ & θ=0)

Main ep→p challenge:
AVOID BEAM

Don't use proton acceptance plots from e+p for e+A!



Not to scale!

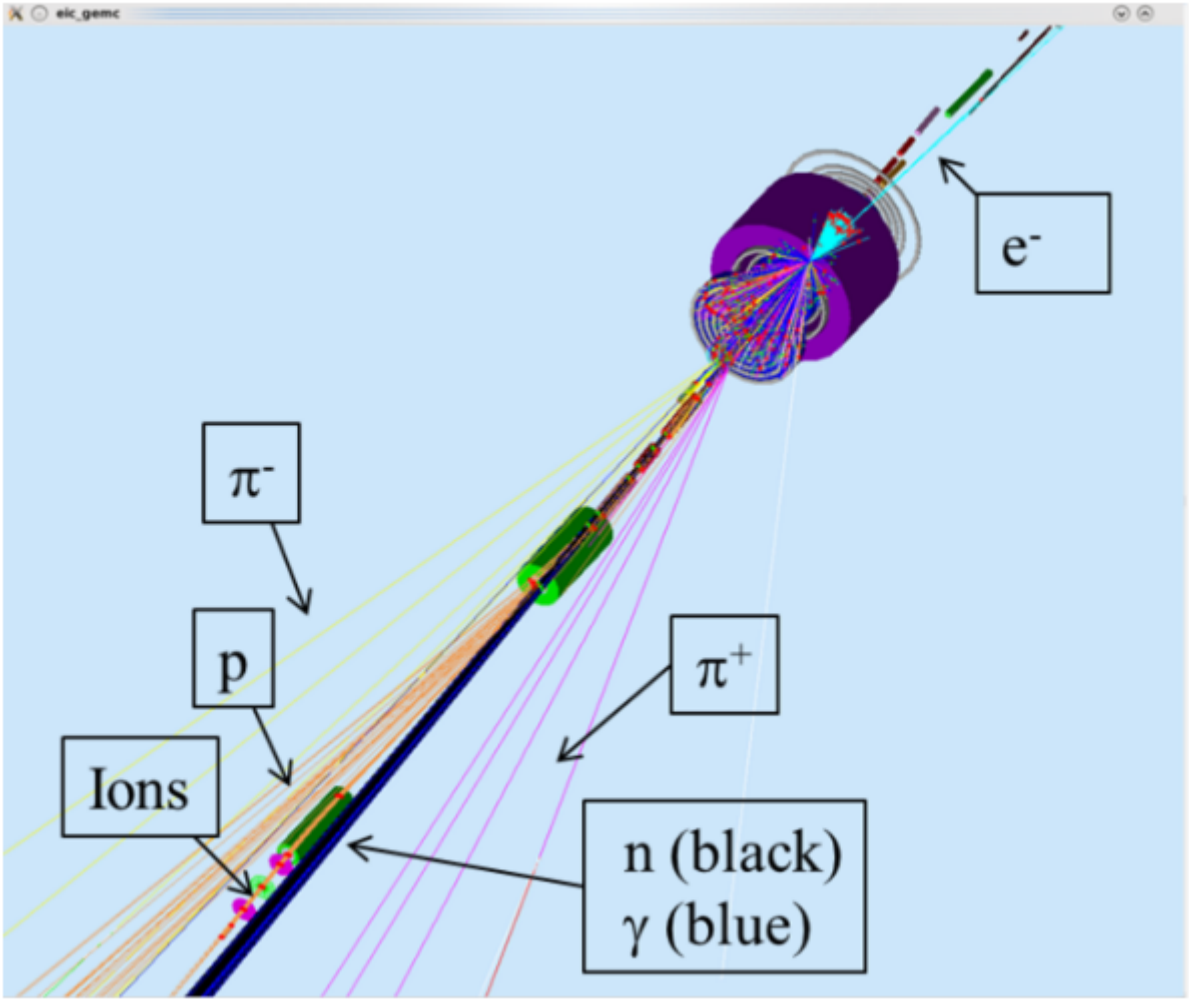
n (θ=0)

A (beam)

p ($p_z=p_{zbeam}/A$ & θ=0)

Main eA→p challenge:
MAGNET APERTURE

Full JLEIC e+Pb simulation



Multiple events superimposed.

BeAGLE+GEMC

e+D will not look too different in the forward direction.

Similar plots from eRHIC coming soon.

SRC simulation: e+"D" inside of Pb?

Proposed JLAB LDRD FY2019-2020:

Tagged Short Range Correlations for Medium to Heavy Ions at JLEIC

MDB, F. Hauenstein, O.Hen, D. Higinbotham (PI), C. Hyde, P. Nadel-Turonski, G. Wei, L. Zheng

- If approved, we plan to extend BeAGLE to simulate SRCs in e+C and higher, as well as refine the e+D simulation further.
- Today, just a couple of "back of the envelope" calculations from our proposal.

JLEIC Nuclear DIS Statistics at high x_{Bj}

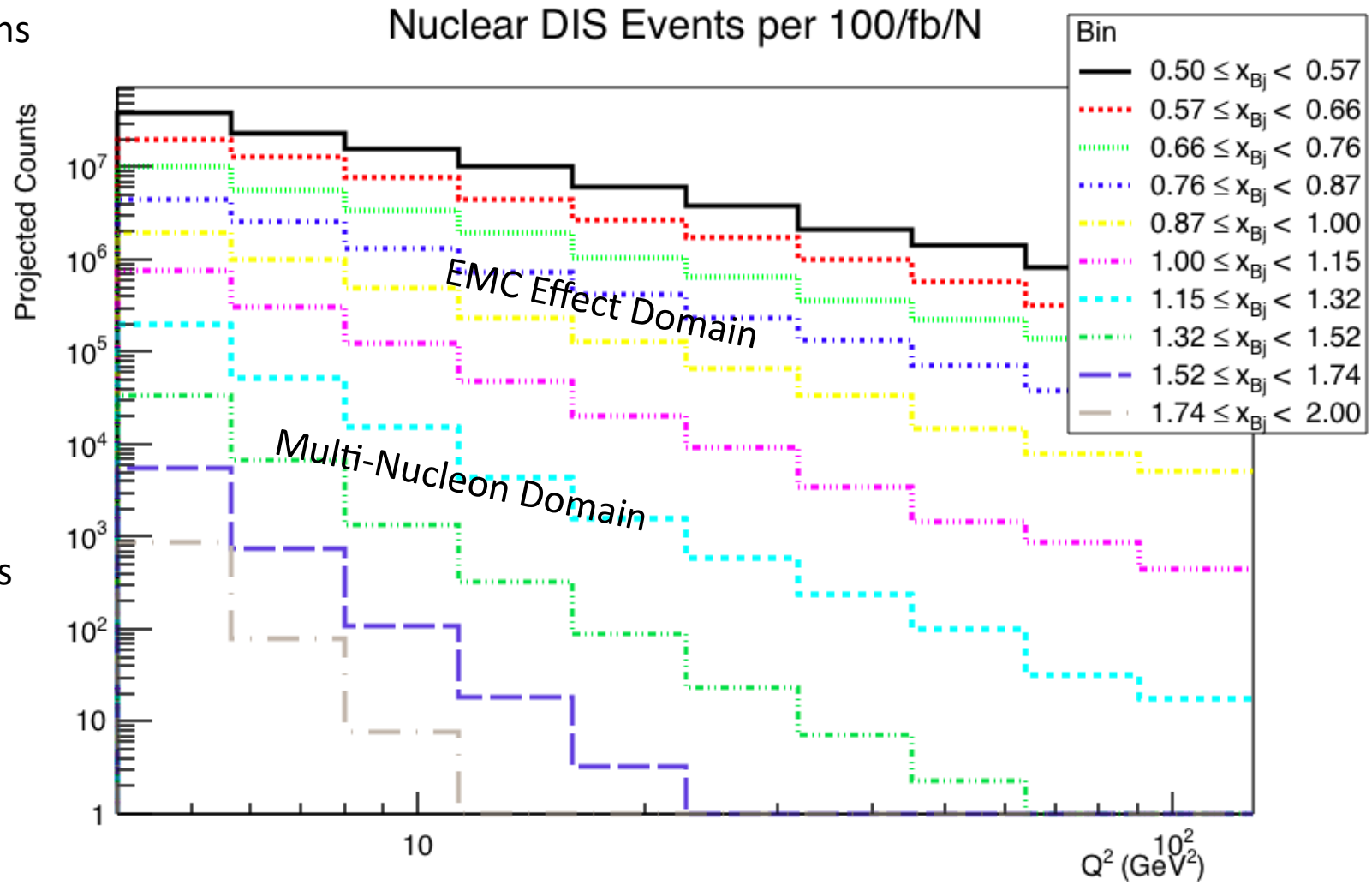
~Universal to different nuclei, beam energy configurations

eA Beam Configurations & 10^7 s Luminosity:

- 10x100(Z/A): 90/fb/nucleon
- 5x100(Z/A): 300/fb/nucleon
- 3x 40 (Z/A) 90 /fb/nucleon
- 3x 20 (Z/A) 15/fb/nucleon

Project Goals:

- Evaluate electron vs hadron jet reconstruction: Acceptance, resolution



5x50 GeV e+C: Plot is ~ 6 weeks @ 100% eff.

Projections based on parameterization of N. Fomin *et al.*, PRL **105** (2010) 212502

Kinematics in e+A (w/ p_F)

- Q^2 is well-defined based on ee'γ* vertex
- W^2 (or x_B or ν) definition depends on your assumption about the incoming nucleon motion.
  - At rest in ion rest frame: Measure using e,e'.
  - Actual motion with nonzero k in ion rest frame: measure using hadronic subevent (IF YOU CAN!)
  - Fractional difference ΔW^2 (or Δx or $\Delta\nu$) ~ k_z/M
    - We can have x=1.5 measured by leptons and x=0.9 measured by γ*N subevent (if we can pick it out!).

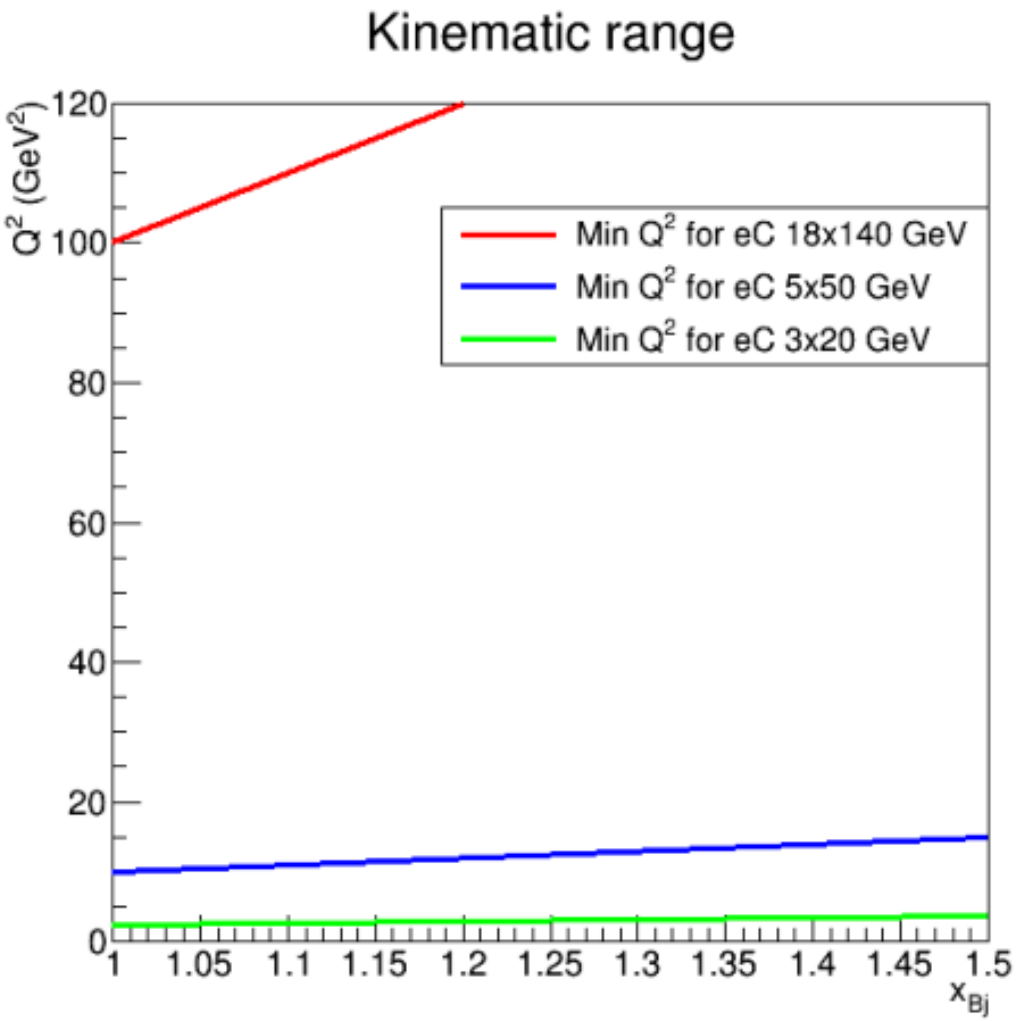
Lepton limitations

- Problem
  - Note $x = Q^2/y(s-M^2) = Q^2/4E_eE_py$, so high x is low y.
  - $\sigma_x/x \sim \sigma_y/y \sim (1/y)\ \sigma(E_e')/E_e'$ gets ugly fast @ low y!
- Approach:
  - For e+p colliders: mix of leptonic and hadronic information at low y especially.
  - E665 e+A mostly restricted to y>0.2.
  - For collider e+A this is a research project!
    - Nuclear debris & mismatch of meaning ($\Delta \sim k_z/M$)

Kinematic reconstruction → lower s

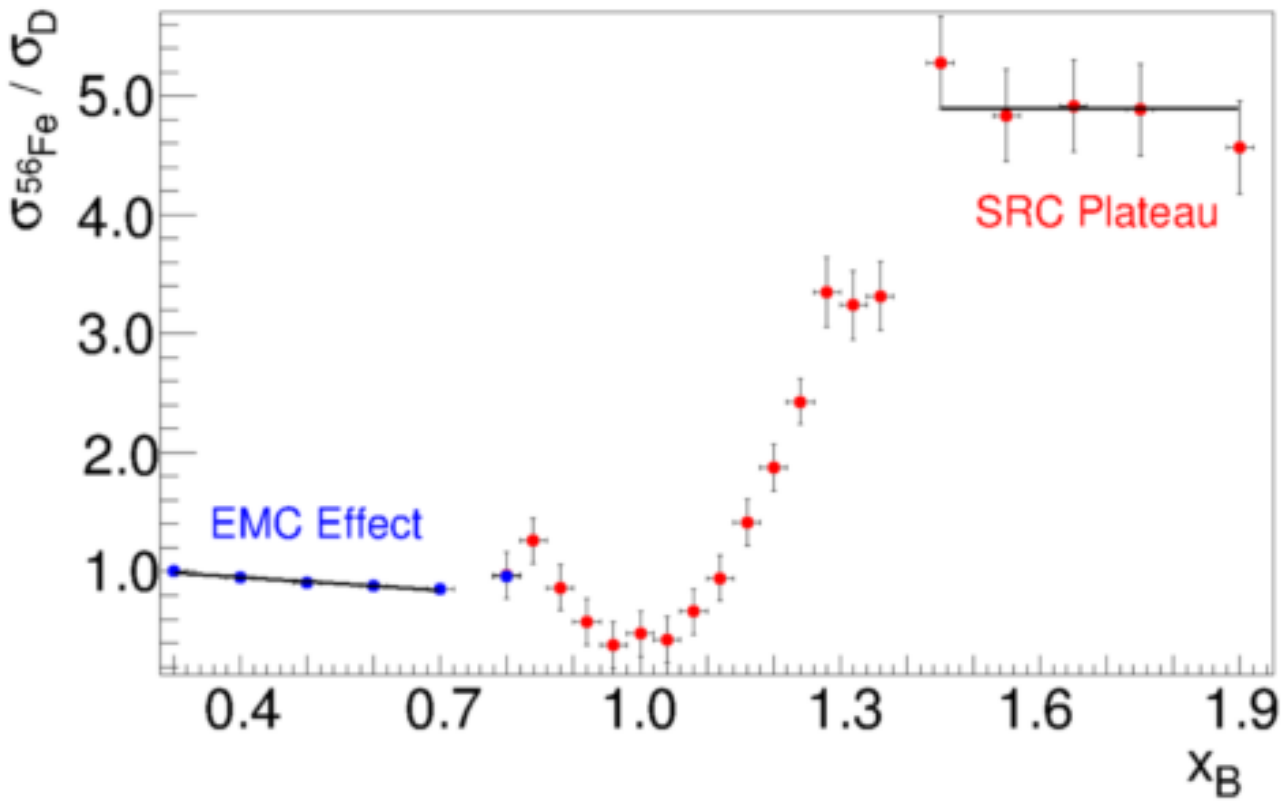
- $Q^2 = 4E_eE_N\,xy$
  where E_N=ion energy/nucleon
- So $Q^2_{min} = 4E_eE_N x\, y_{min}$

- Optimistically assume y>0.01
- $Q^2 > xE_eE_N/25$



Conclusions

- SRCs @ an EIC present exciting possibilities
  - Good Q^2 reach at high x (x>0.1)
  - Good forward detection (we hope!?)
- Short-range correlations in e+A present big (coupled) challenges to:
  - Simulation
  - Reconstruction
  - Forward Detector Design
- We have our work cut out for us...

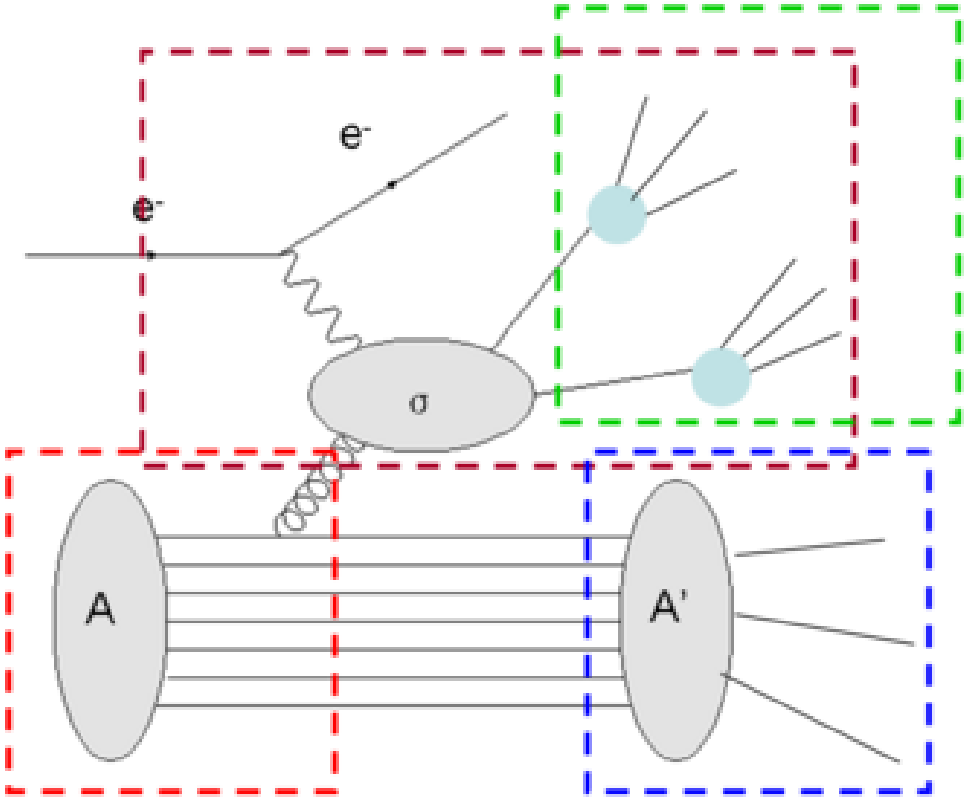


D. Higinbotham, G. A. Miller, O. Hen and K. Rith, CERN Cour. 53N4 (2013) 24.

BeAGLE Structure

Elke Aschenauer + MDB + J.H.Lee + Liang Zheng

From: https://wiki.bnl.gov/eic/index.php/BeAGLE



A hybrid model consisting of DPMJet and PYTHIA with nPDF EPS09.

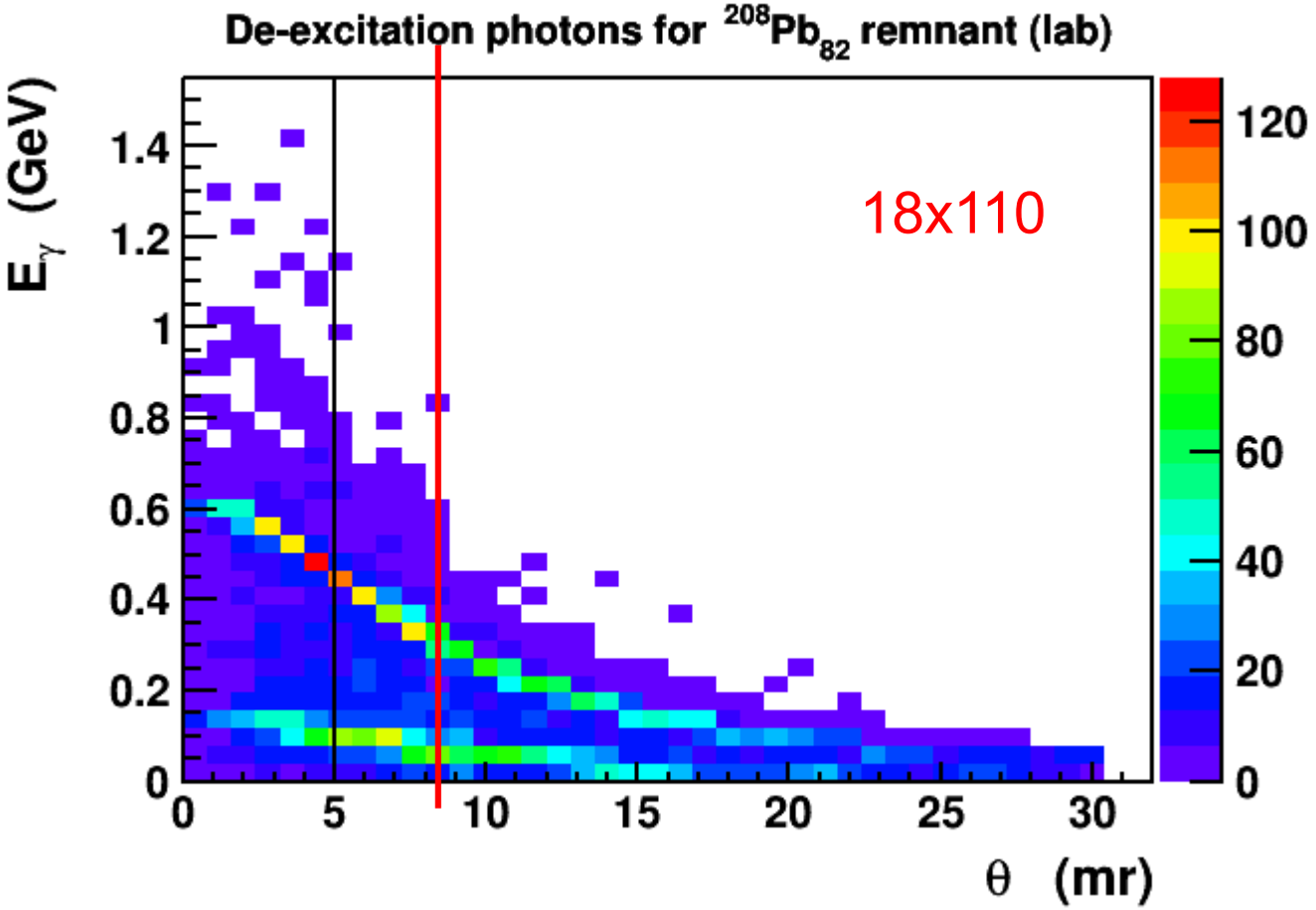
Nuclear geometry by DPMJet and nPDF provided by EPS09.

Parton level interaction and jet fragmentation completed **in Pythia** in PYTHIA

Intra Nuclear Cascade & Nuclear evaporation (gamma dexcitation/nuclear fission/fermi break up) treated by DPMJet **(Fluka)**

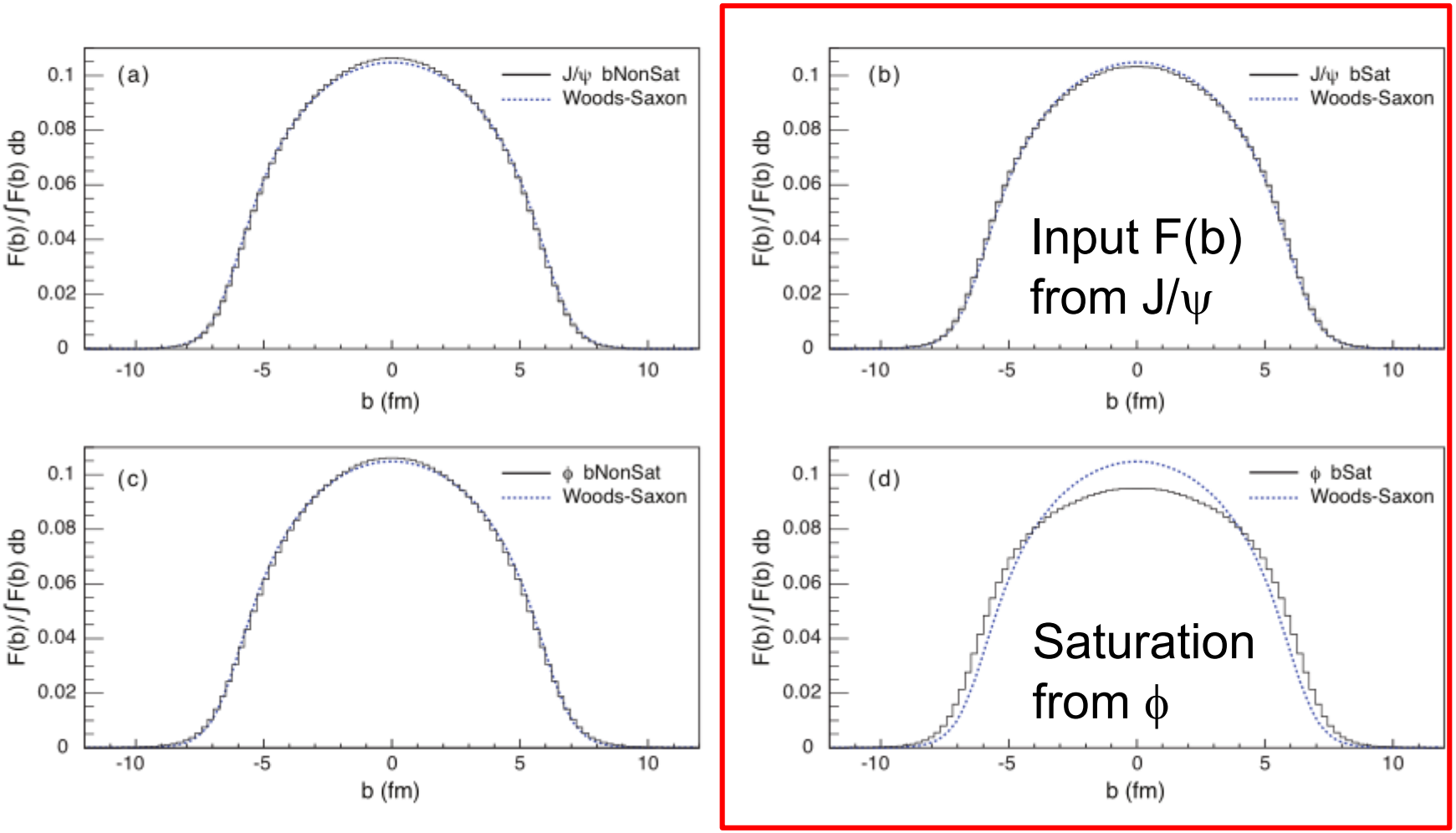
Energy loss effect from routine by **Accardi, Dupré** Salgado&Wiedemann to simulate the nuclear fragmentation effect in cold nuclear matter **is available.**

Bigger forward cone?



2-3 photons / per event. Half are in the forward TRF hemisphere:
$\theta<1/\gamma_{Pb}$ in lab or 8.5 mr for 18x110 (23 mr for 10x40). By momentum conservation: :
WE EXPECT AT LEAST ONE SUCH PHOTON PER EVENT!

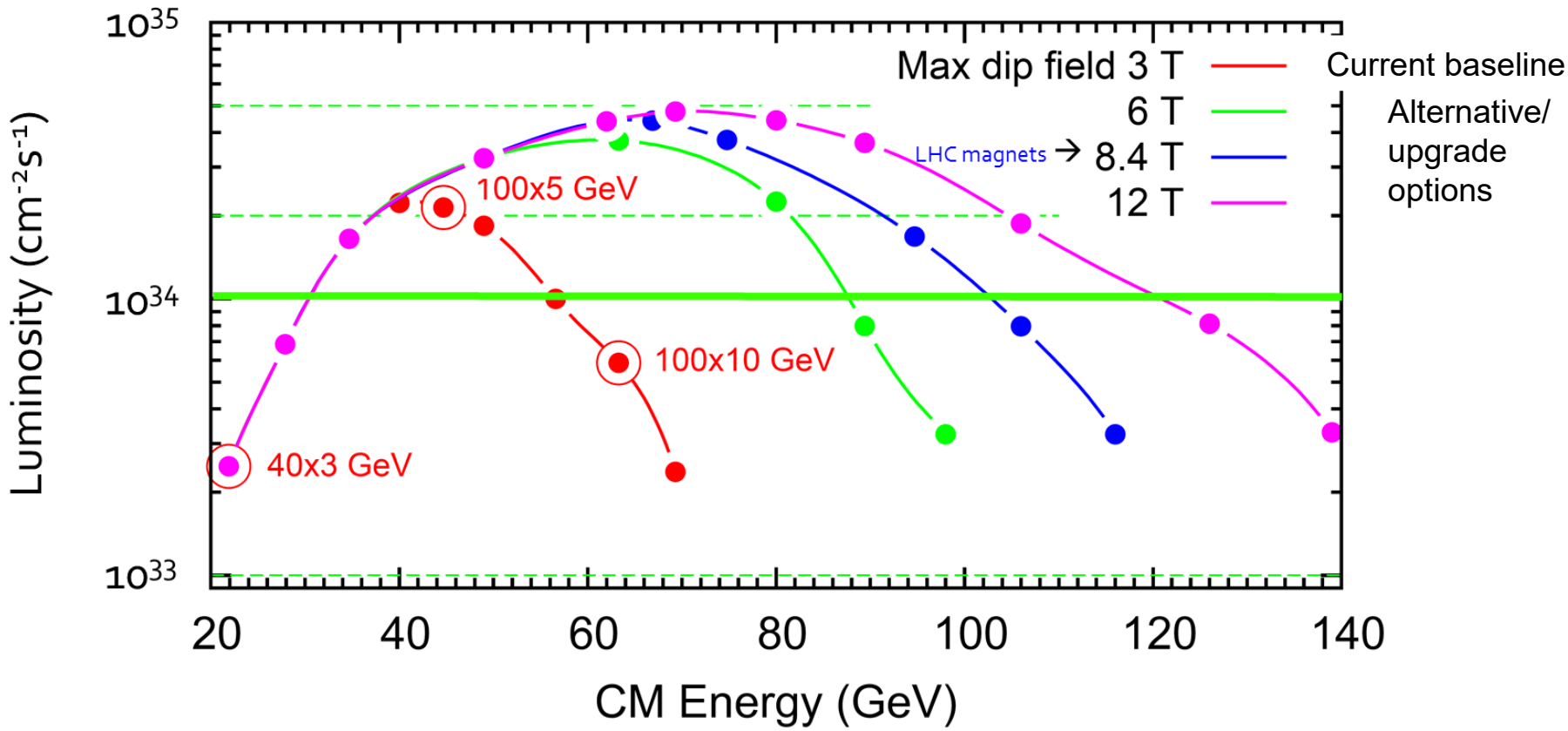
Results for all Data Sets



Toll, Ullrich PRC 87 (2013) 024913

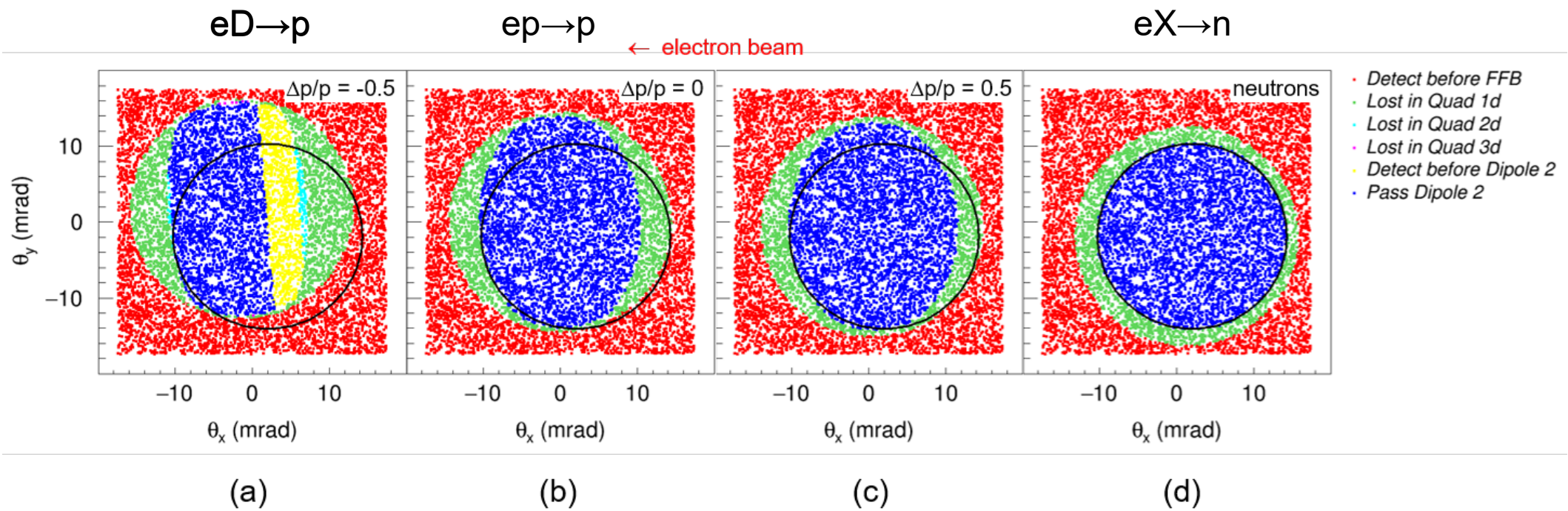
JLEIC Luminosity vs CM Energy

Plot is for ep
For eA the per-nucleon luminosity is 1.5 x ep luminosity at E/A = E_p*Z/A

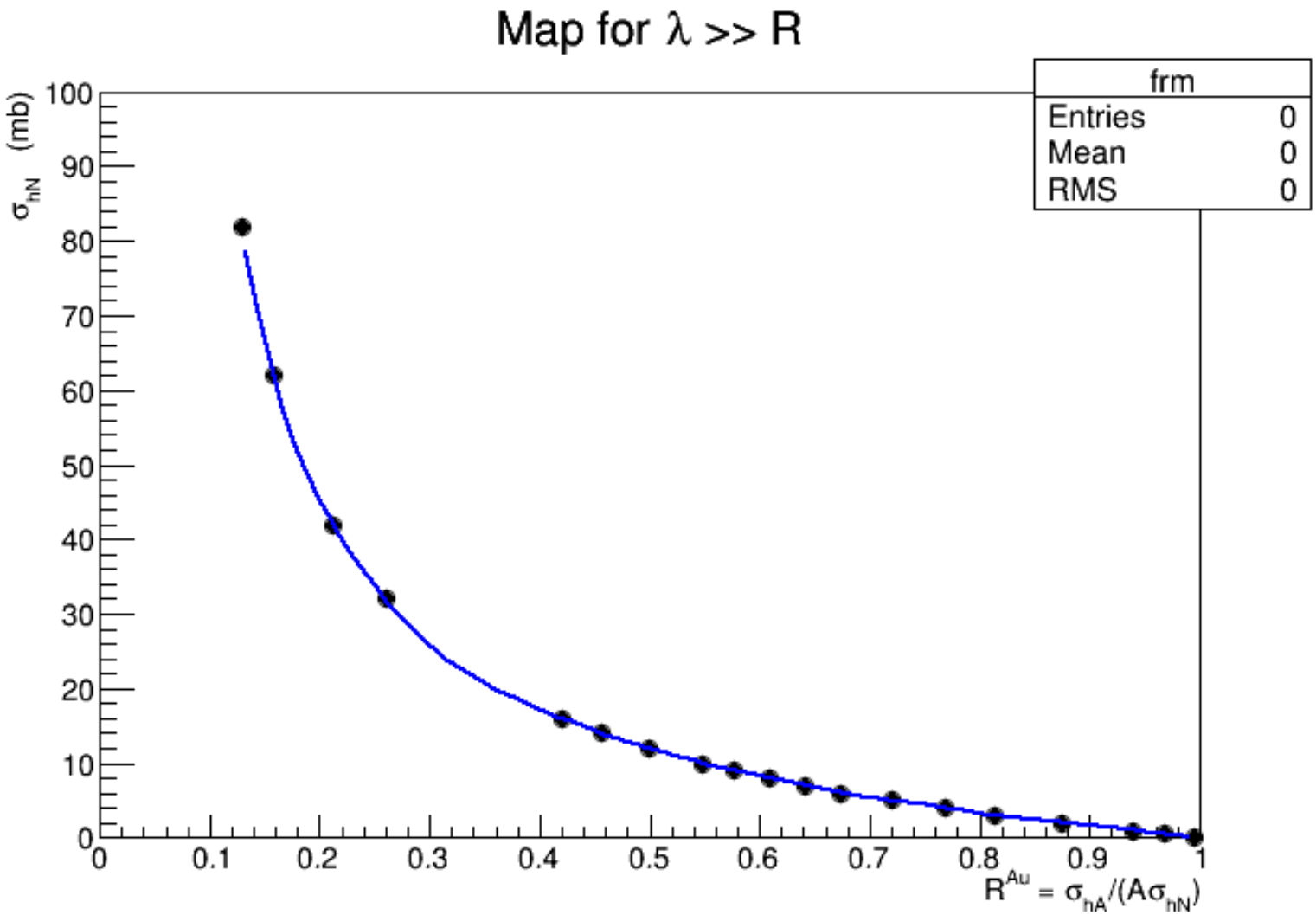


Forward protons @ JLEIC

From V. Morozov



Glauber Map


Map for λ >> R
frm
Entries 0
Mean 0
RMS 0
σ_hN (mb)
100
90
80
70
60
50
40
30
20
10
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
R^Au = σ_hA/(Aσ_hN)