MC Event Generator BeAGLE for Forward Physics at the EIC

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Oct. 17, 2018

BeAGLE Monte Carlo

(w/ E. Aschenauer et al.)

Example 1: e+Pb @ JLEIC: forward physics

(w/ V. Morozov et. al.)

Example 2: e+D @ eRHIC: forward physics

(w/ Z. Tu et al.)

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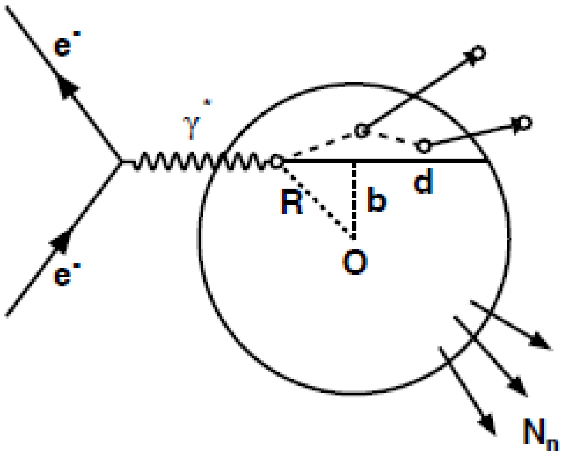
Collaborators and Advisors & plot providers

- BeAGLE: E. Aschenauer, J.H. Lee, L. Zheng
  (+ R. Dupré, N. Armesto, M.Ehrhart)
  (+DPMJET team + Fluka team + Pythia team!)
- ePb @ JLEIC: A. Accardi, R. Dupré, M. Erhart, C. Fogler, C. Hyde, V. Morozov, P. Nadel-Turonski, K. Park, J. Stukes, A. Sy, T. Toll, G. Wei, L. Zheng
- eD @ eRHIC: Z Tu, T. Ullrich, C. Weiss
- Advice from: R. Venugopalan

BeAGLE – Benchmark eA Generator for LEptoproduction

- Aschenauer, MDB, Lee, Zheng (+DPMJET+Fluka+...)
- Merger of
  - Pythia6: hard interaction (adding RAPGAP option)
  - Glauber + multinucleon shadowing
  - PyQM: Optional radiative jet quenching (off today)
  - DPMJET3-F (DPMJET3+Fluka) – nuclear response
- Tuned to ZEUS forward nucleons, FNAL E665 (FixTarg) 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 (Glauber).

Intra Nuclear Cascade w/ Formation Zone

Excited nuclear remnant decays by:
- 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.

Substantial BeAGLE+Sar*t*re effort for JLEIC

Geometry tagging for heavy ions at JLEIC*

(DIS 2018 meeting)

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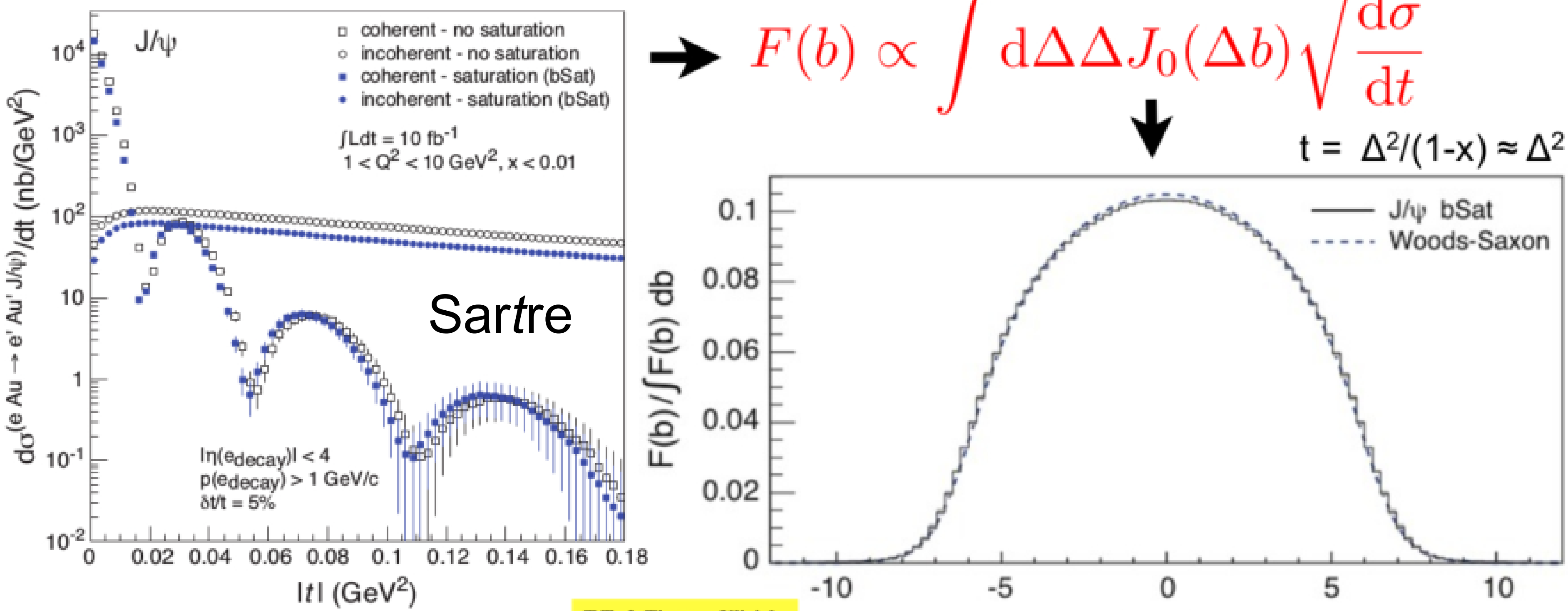
Probing the spatial gluon distribution at EIC

Momentum transfer t conjugate to transverse coordinate b

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

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

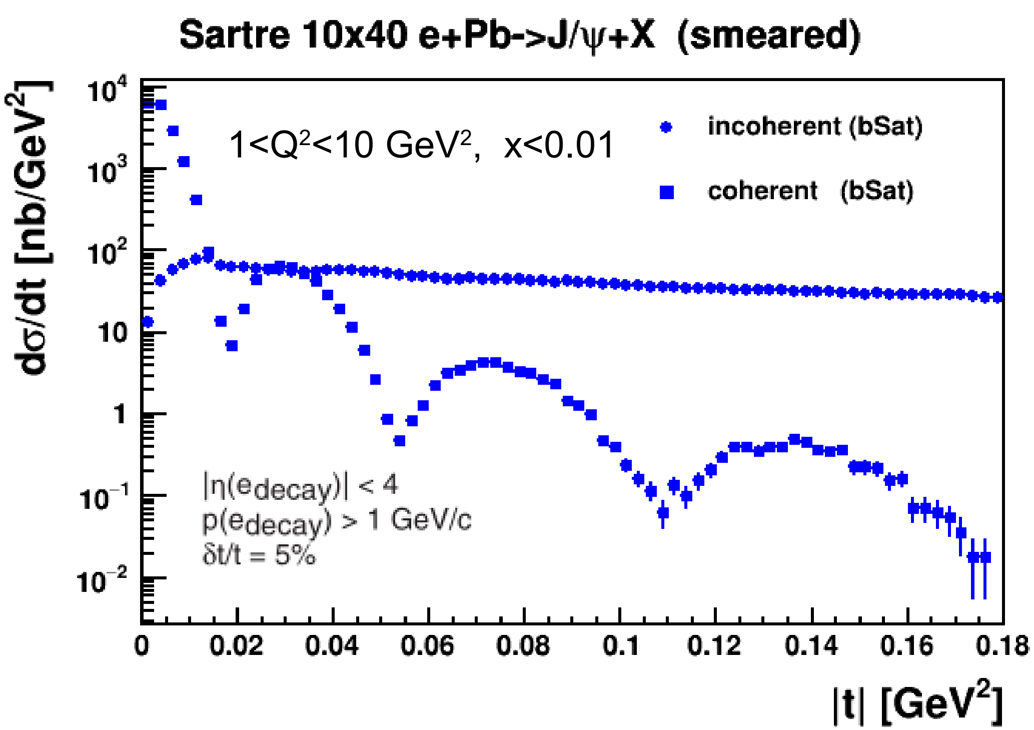


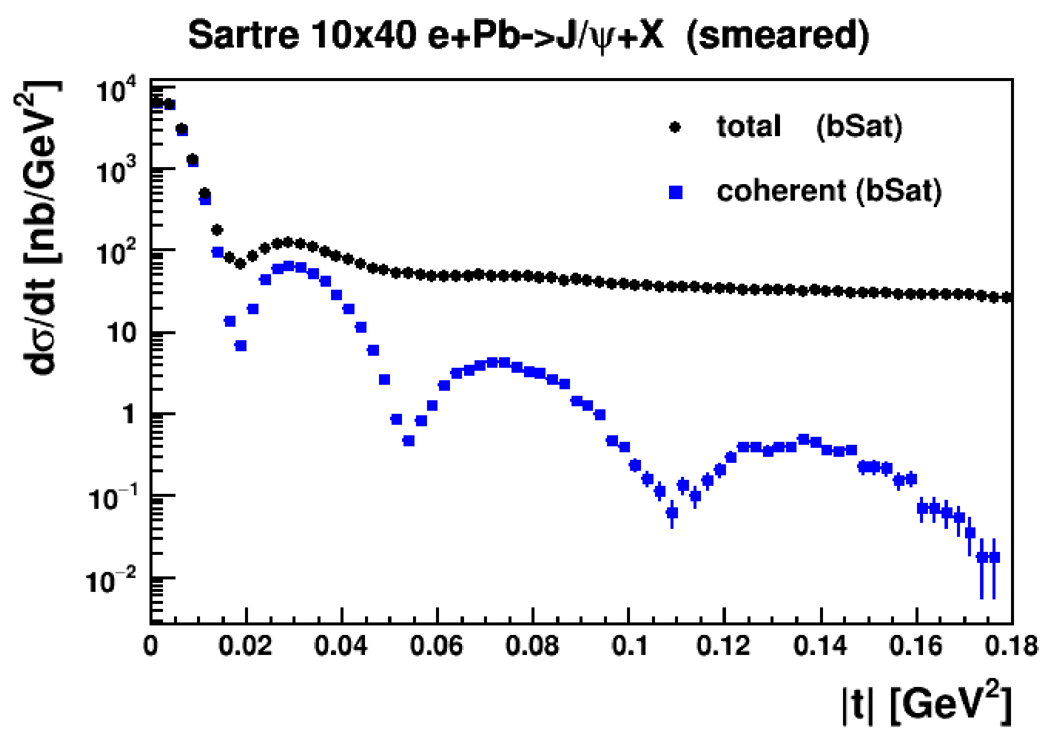
T.T. & Thomas Ullrich
PRC 87 (2013) 024913

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



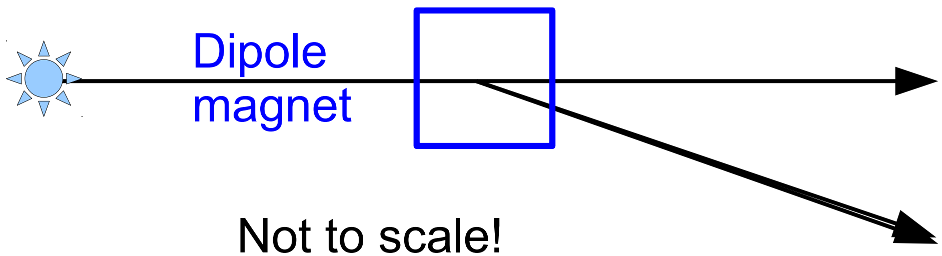


We must veto incoherent data
or we have no information!

Only keep events with e'+^{208}Pb+J/ψ alone
Veto on forward p, n, γ etc.

Forward acceptance at a collider

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



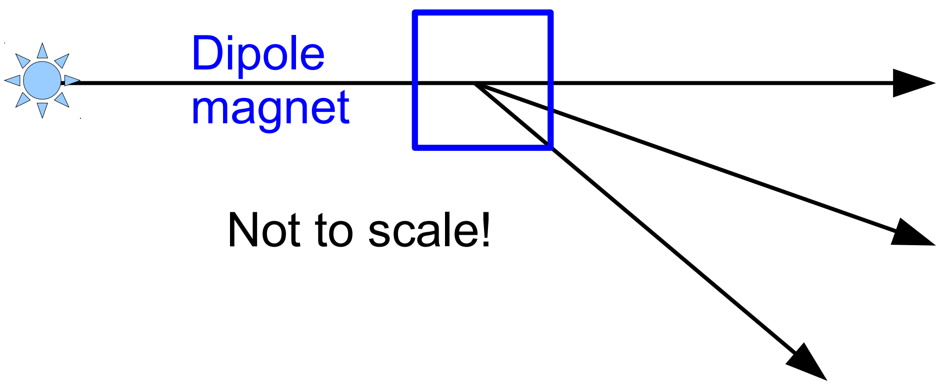
Not to scale!

n (θ=0)

p (beam or
$p_z=p_{zbeam}$ & θ=0)

Main ep$\rightarrow$p challenge:
AVOID BEAM

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



Not to scale!

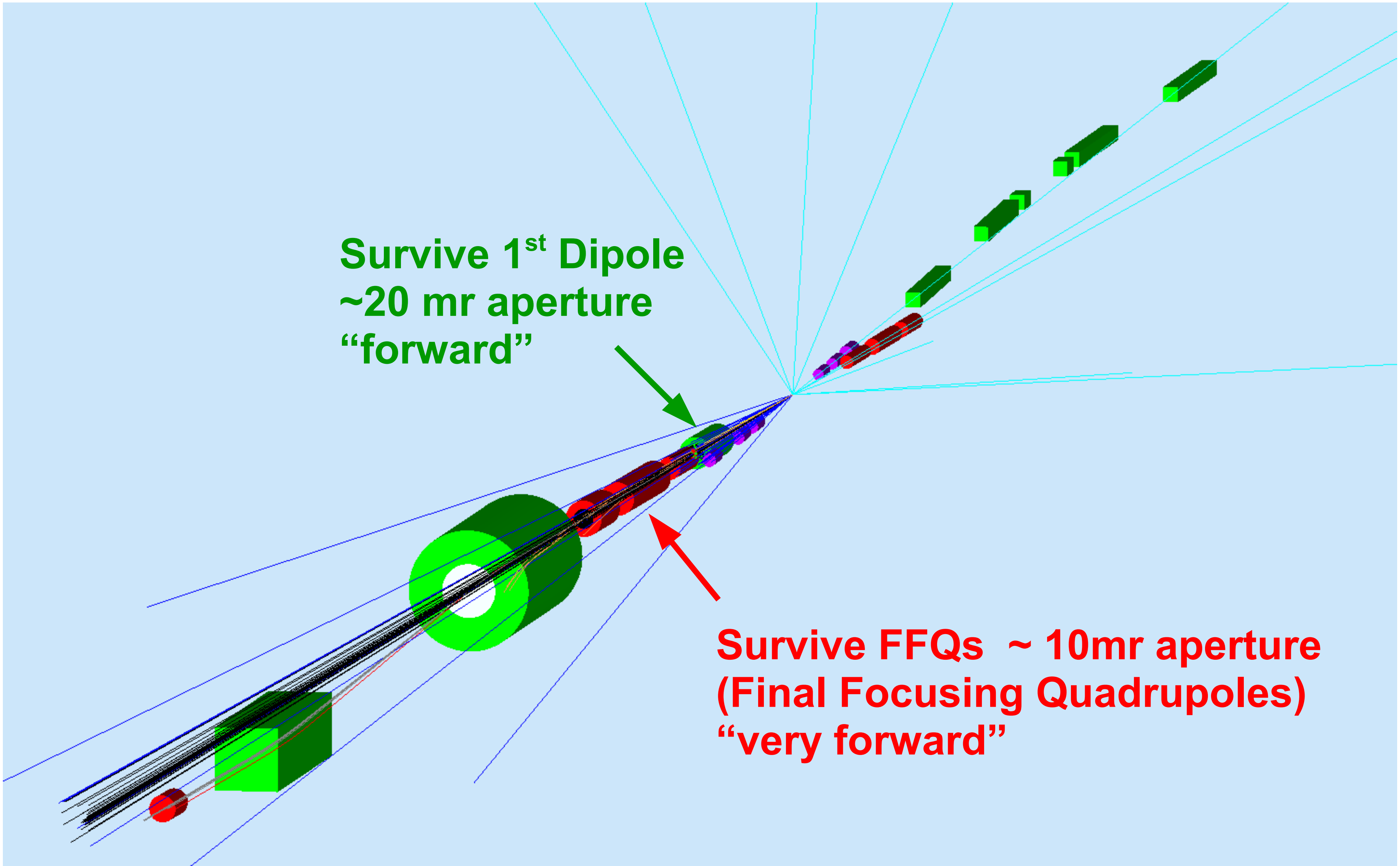
n (θ=0)

A (beam)

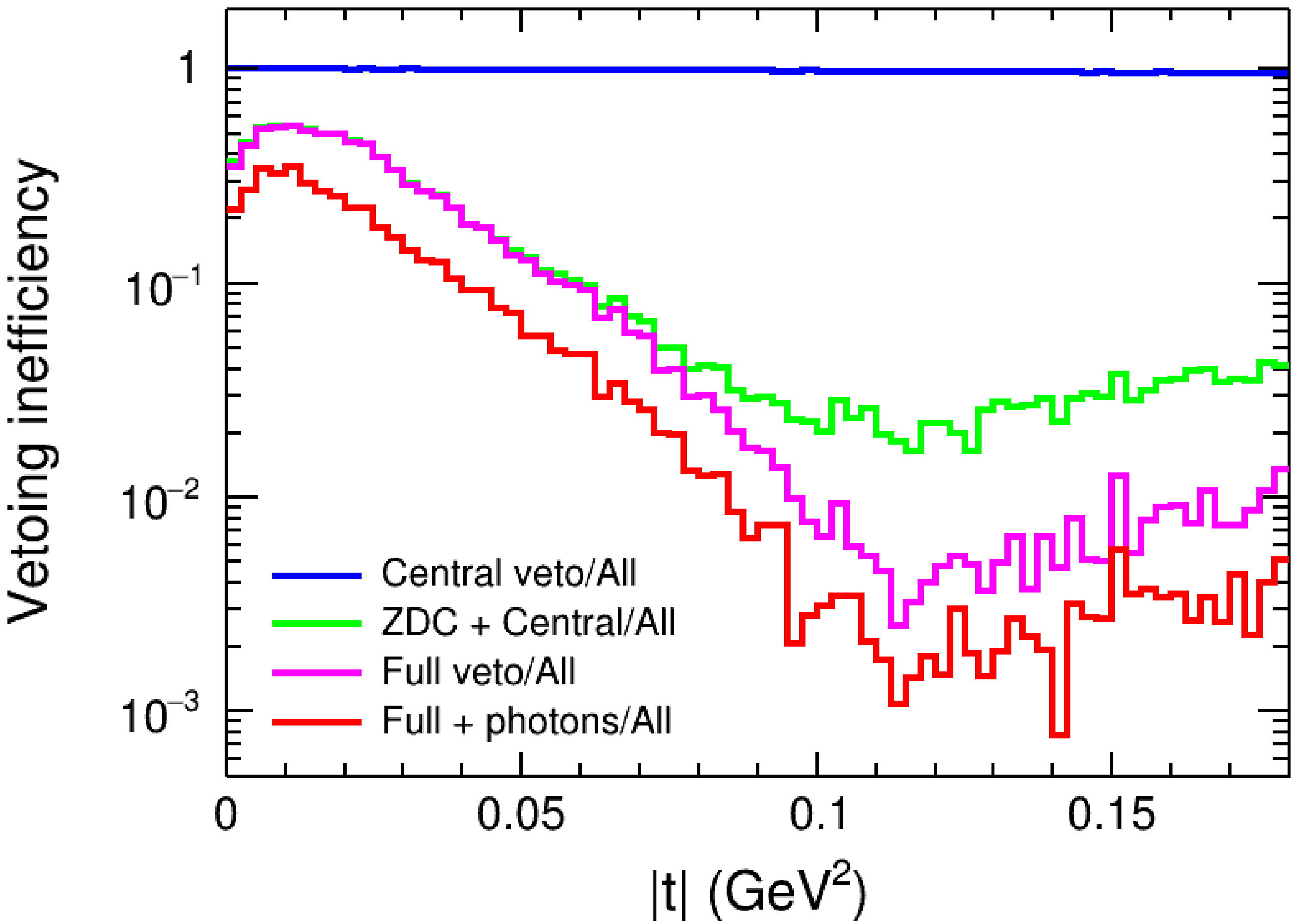
p ($p_z=p_{zbeam}/A$ & θ=0)

Main eA$\rightarrow$p challenge:
MAGNET APERTURE

GEMC (Geant): JLEIC Simulation Setup



Veto inefficiency: BeAGLE + GEMC



VETO USING:

Non-forward particles
θ>100 mr (E$_\gamma$>500 MeV)

w/ very forward particles
(E$_\gamma$>40 MeV)

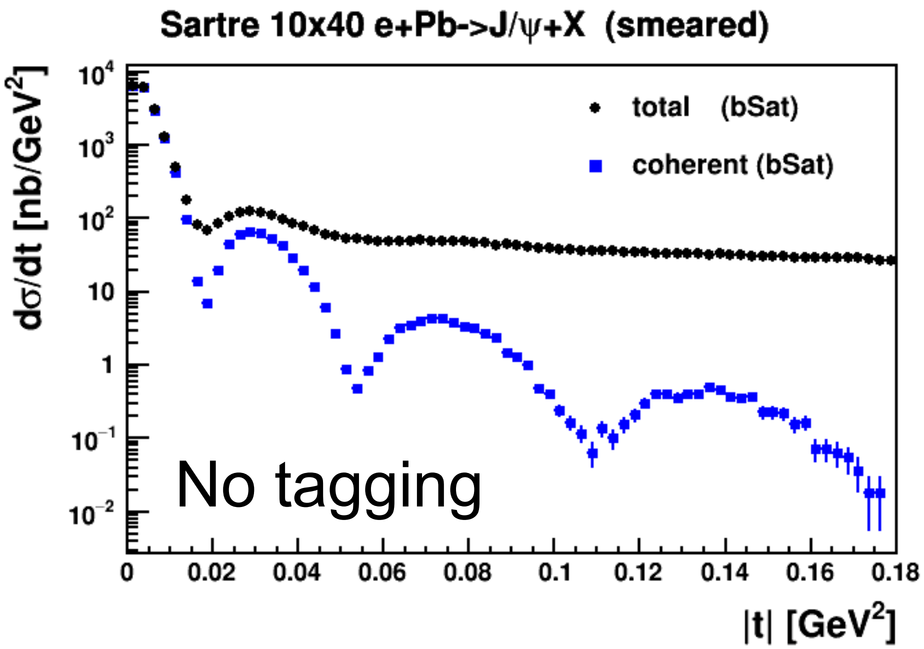
(w/ very forward neutrals
or forward charged)

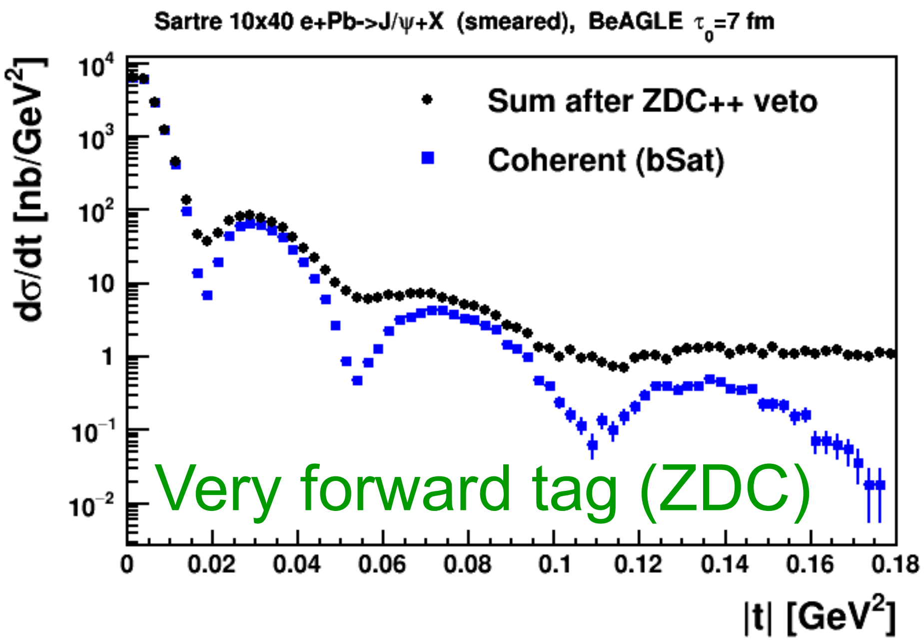
w/ forward particles
(E$_\gamma$>40 MeV)

BeAGLE models incoherent e+A diffraction as Glauber Σ e+N

Full + photons means we veto on all forward particles
which make it through the first spectrometer dipole.

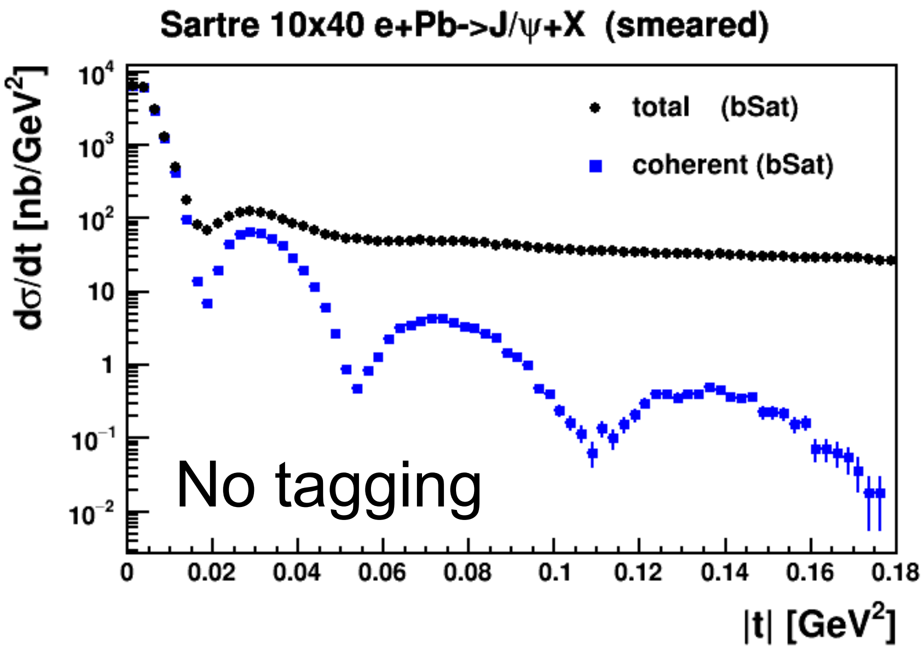
JLEIC veto tagging results (e+Pb)

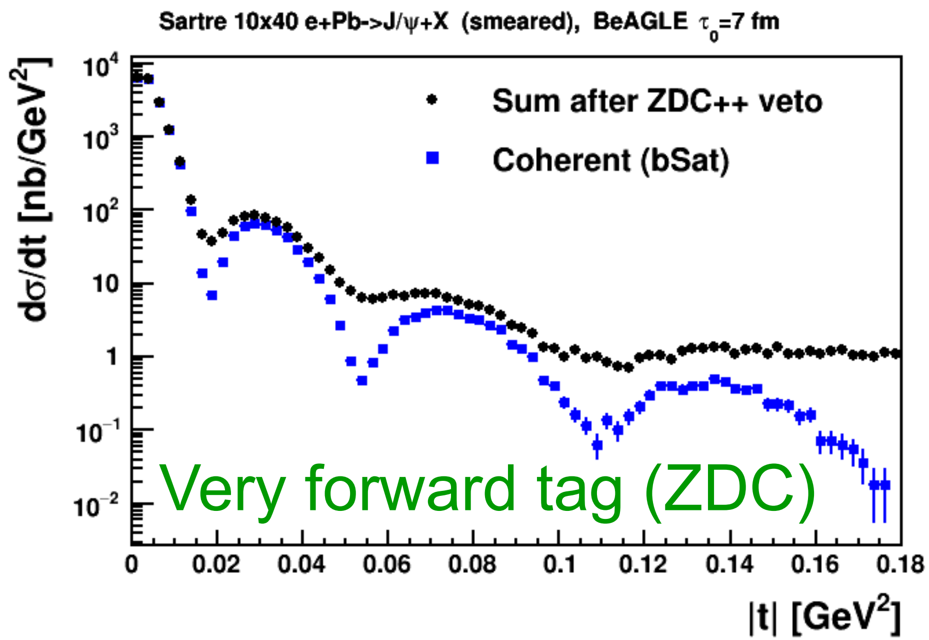




- Veto tagging helps.
- Very forward tag alone is questionable (need 3 dips).

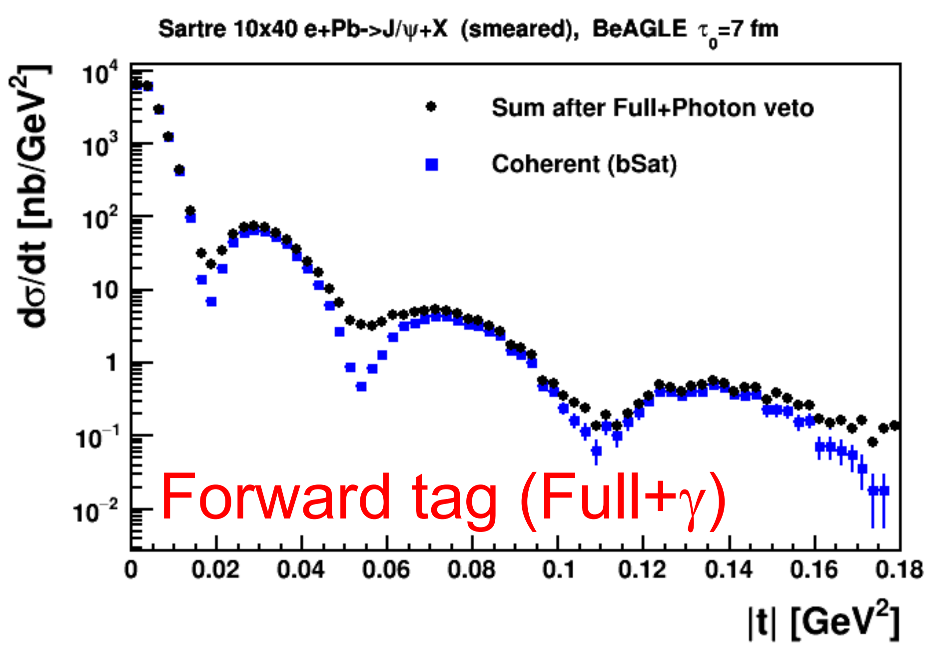
JLEIC veto tagging results (e+Pb)





- Veto tagging helps.
- Very forward tag alone is questionable (need 3 dips).

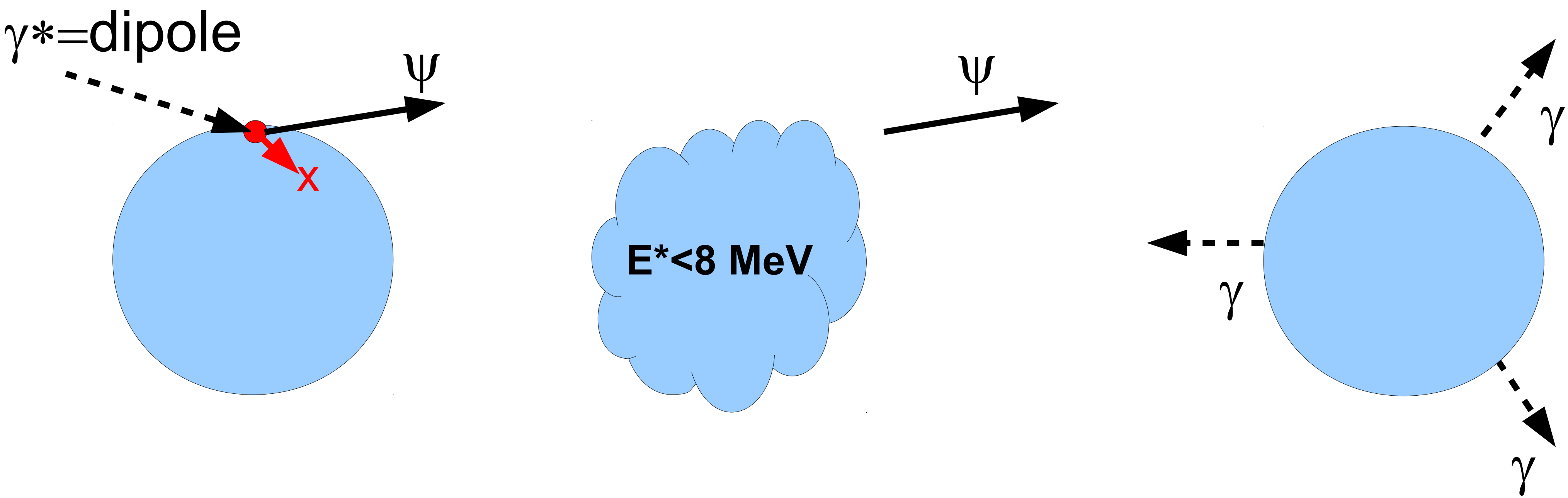
- Forward tag better. Not ideal…
- Still studying impact on G(b) reconstruction.



Challenge of veto tagging: Why so hard?

- Veto problems for $|t|<0.06\ \mathrm{GeV}^2$ are due to events where the struck nucleon is reabsorbed:

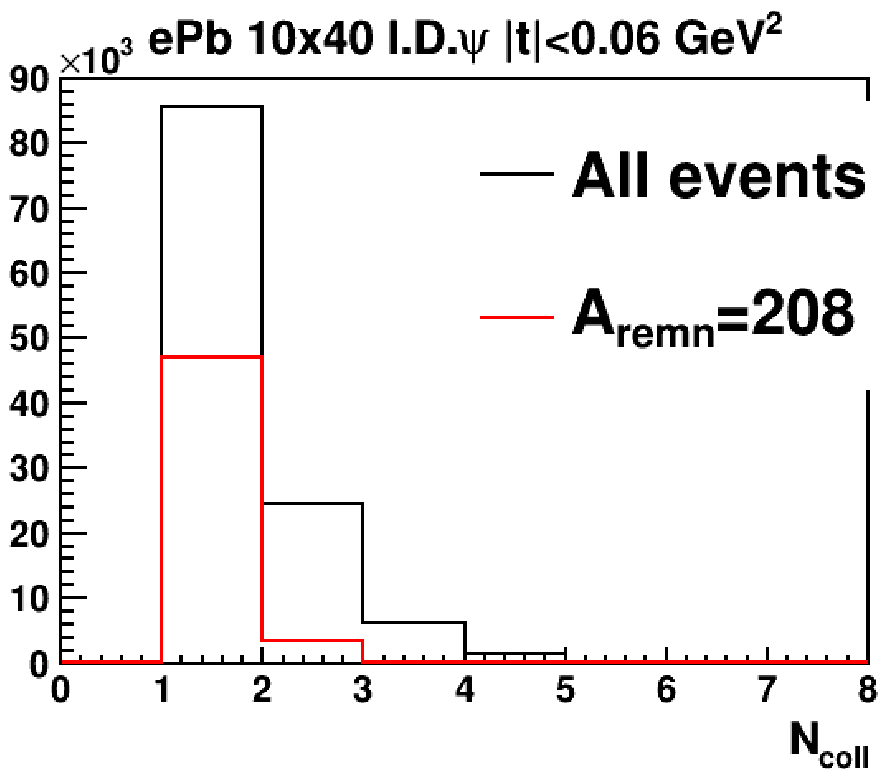
$$e + {}^{208}Pb_{82} \rightarrow e' + {}^{208}Pb_{82} + J/\psi + \gamma + \gamma + \gamma \ldots$$



Cartoons in Ion Rest Frame

There are just a lot of events with N_{coll}=1

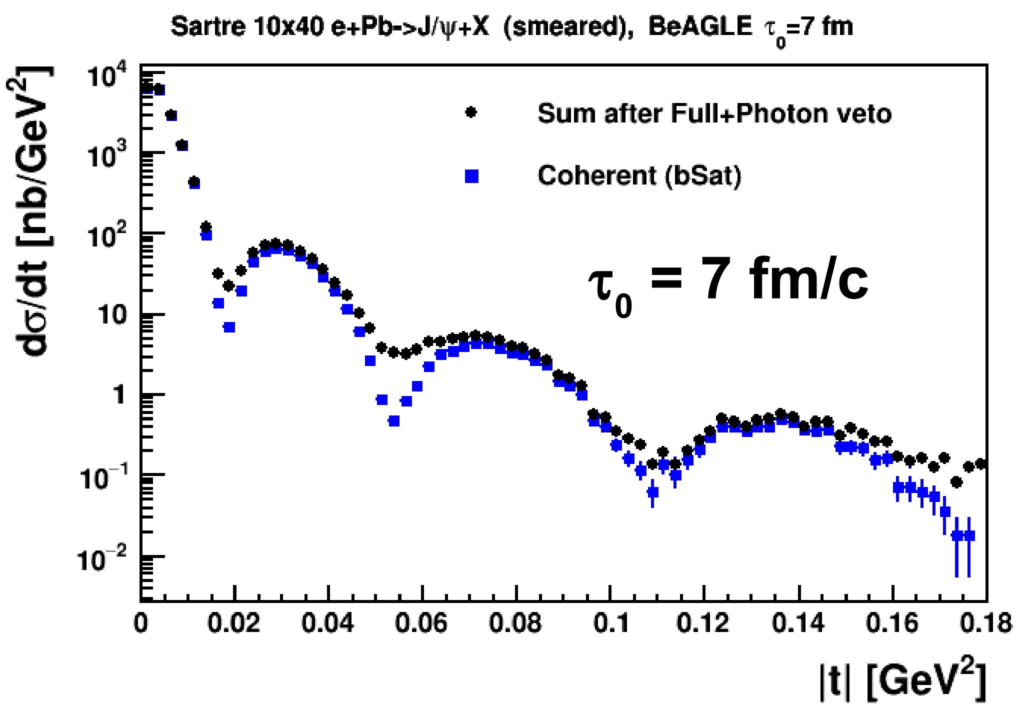
One small kick to the nucleus doesn't excite it very much!

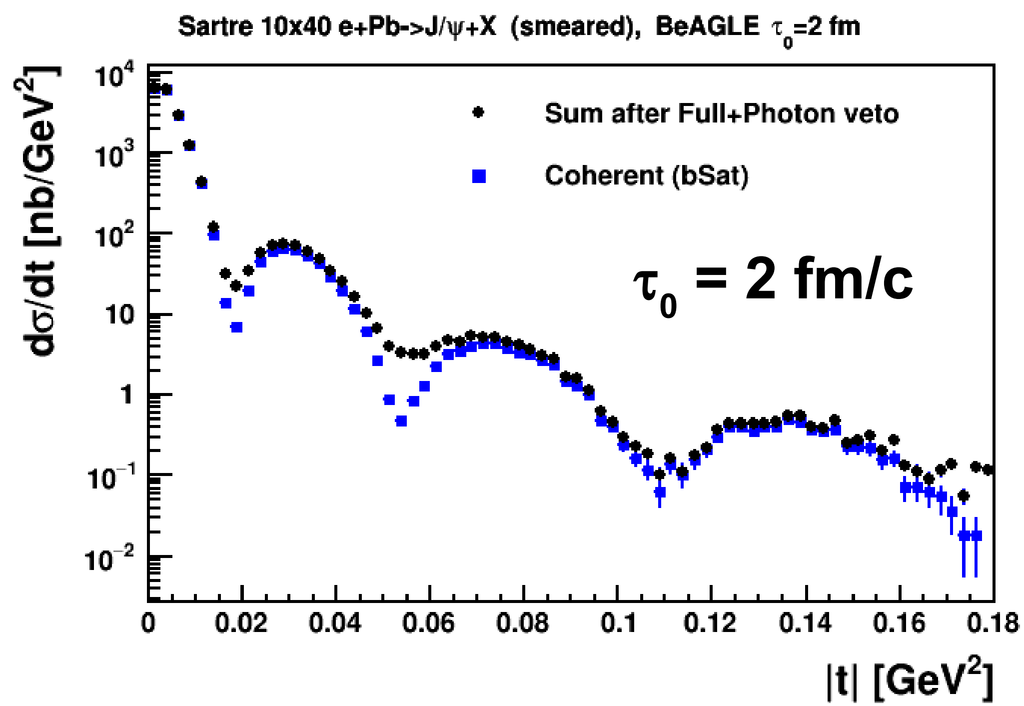


- σ("dipole") modest for dipoles that become a J/ψ.
- Therefore small <N_{coll}>
- Glauber nucleon description affects only fluctuations:
  - **Small hard sphere (BeAGLE)**
  - Large diffuse sphere
  - Hard vs. fuzzy edges
  - Glauber-Gribov σ fluct.
- Any change drives:
  - Slightly MORE N_{coll}=1
  - Tails to higher N_{coll}

Very weak dependence on INC details

- DPMJET Intranuclear cascade parameter τ_0
  - Mean formation time in hadron rest frame: $\exp(-\tau/\tau_0)$
  - E665 neutron data tune led to long τ_0 =7 fm/c





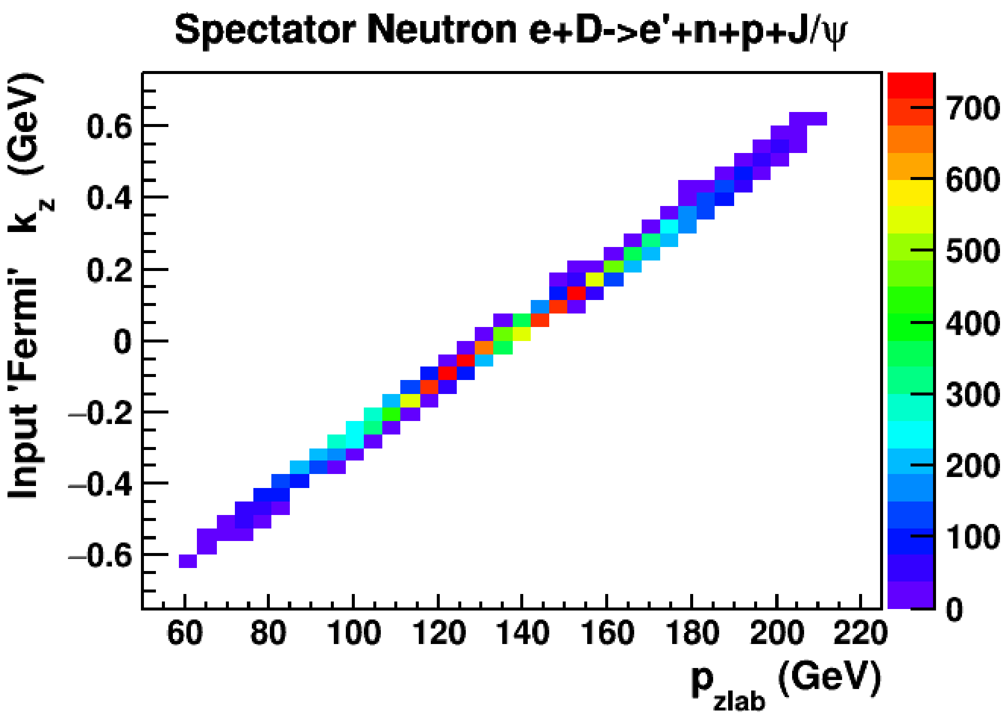
BeAGLE for eA summary

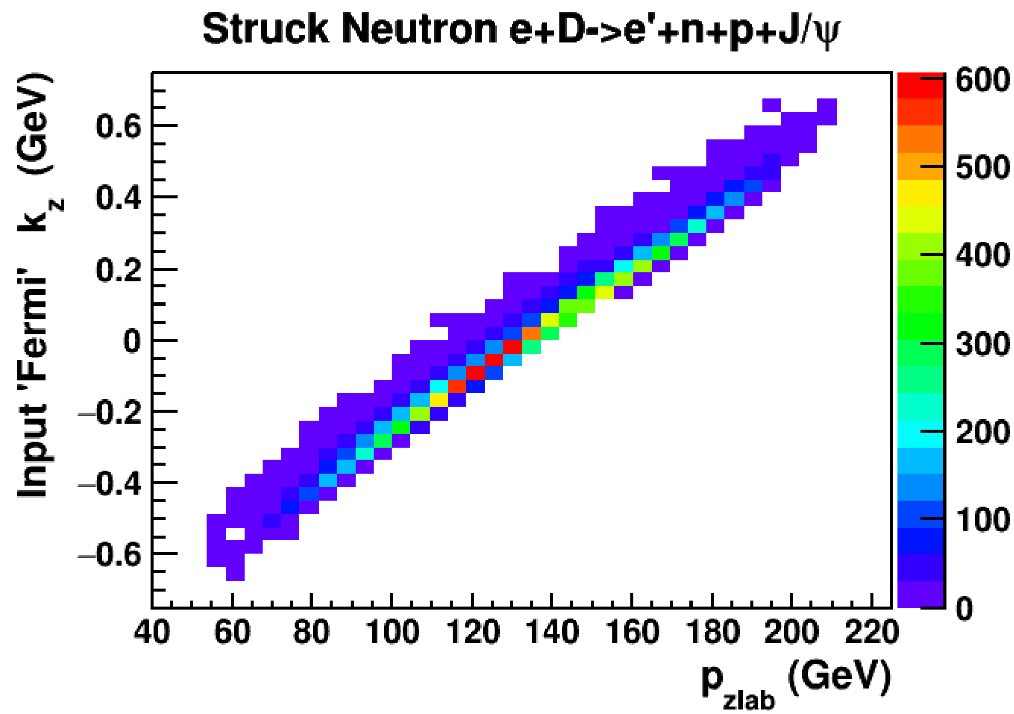
- Forward neutrons and protons and photons are ALL needed in order to veto incoherent diffraction and measure coherent diffraction.
- This statement is NOT very model dependent.
  - Glauber improvements → vetoing slightly harder!
- Can we live with the current detector?
  - Can we subtract the remaining background?
  - If we invert what we can measure, how well do we reconstruct the input G(b)?

BeAGLE e+D project is just getting started

- MDB, Z. Tu, T. Ullrich, C. Weiss
- Current version
  - 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 involve light-cone (+z along γ^*):
  - Conserve p^-, p_T adjust only p^+ of non-spectators.
  - Get spectator p^+, p^-, p_T from light-cone wavefunction.
- Then: Better FS effects, Non-impulse approximation...

18x135 e+D momentum tail effect



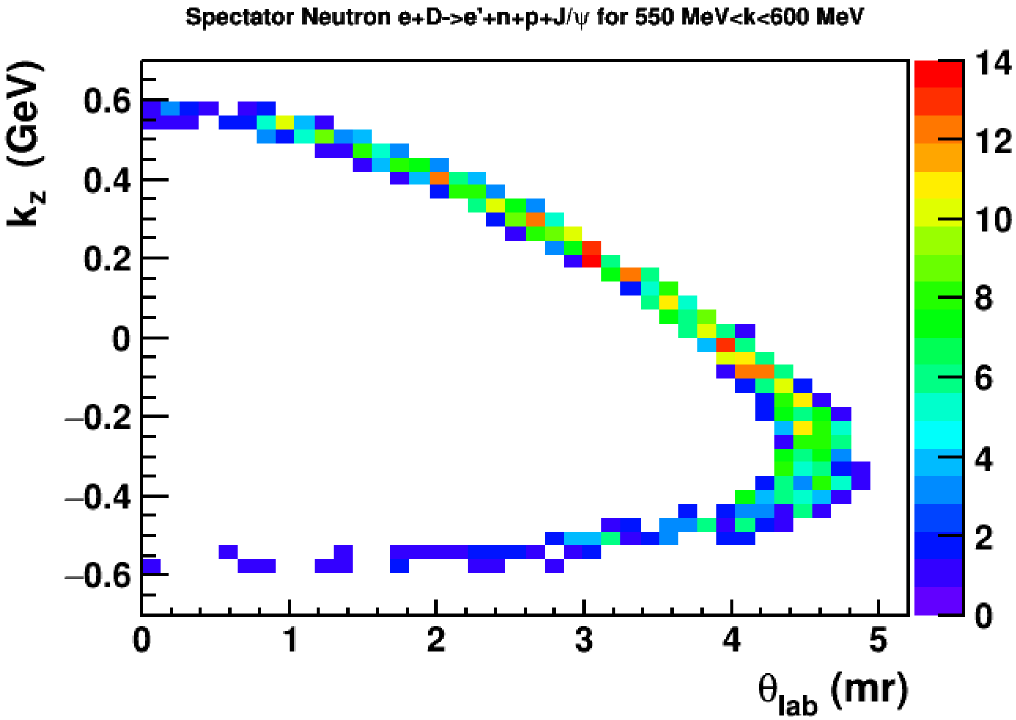


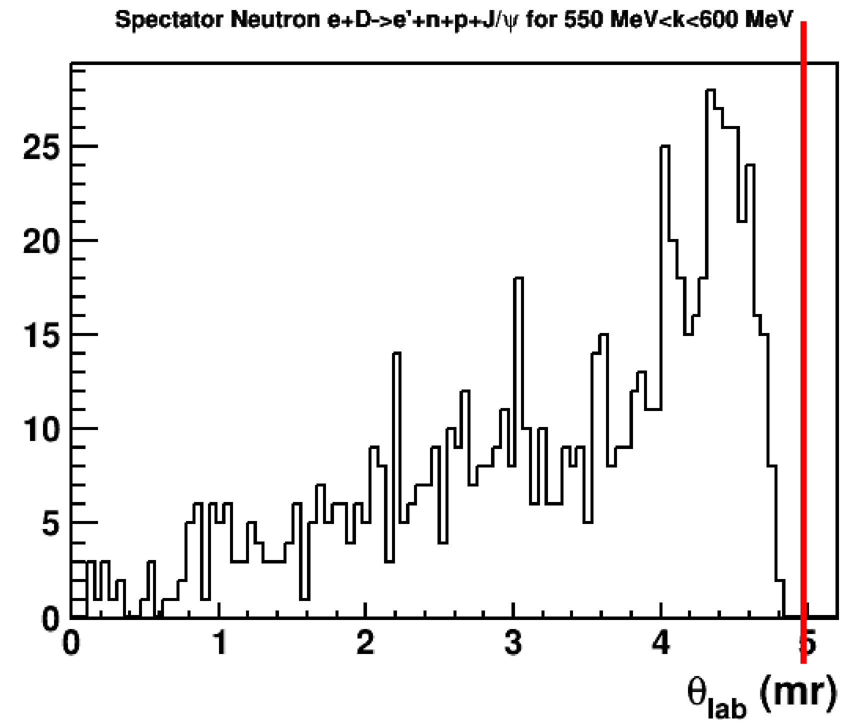
Any p-kick (IS or FS) along the “z” direction in the ion rest frame is magnified!
High p_z tails will be easy to pick out and measure.

Note: k is the relative momentum of n wrt D (arbitrary distribution)
k_z wrt z along γ*D axis in IonRF. p_{zlab} has z along eD axis in lab.

Spectator neutrons (or p's) for k~575 MeV

18x135 GeV e+D→e'+n+p+J/ψ

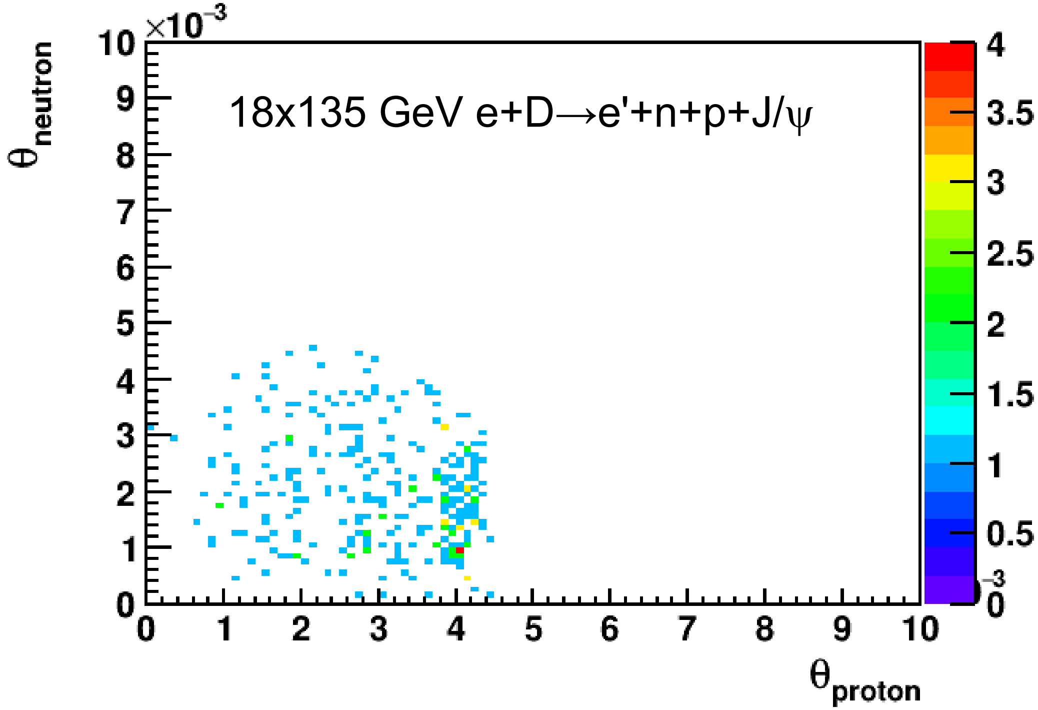




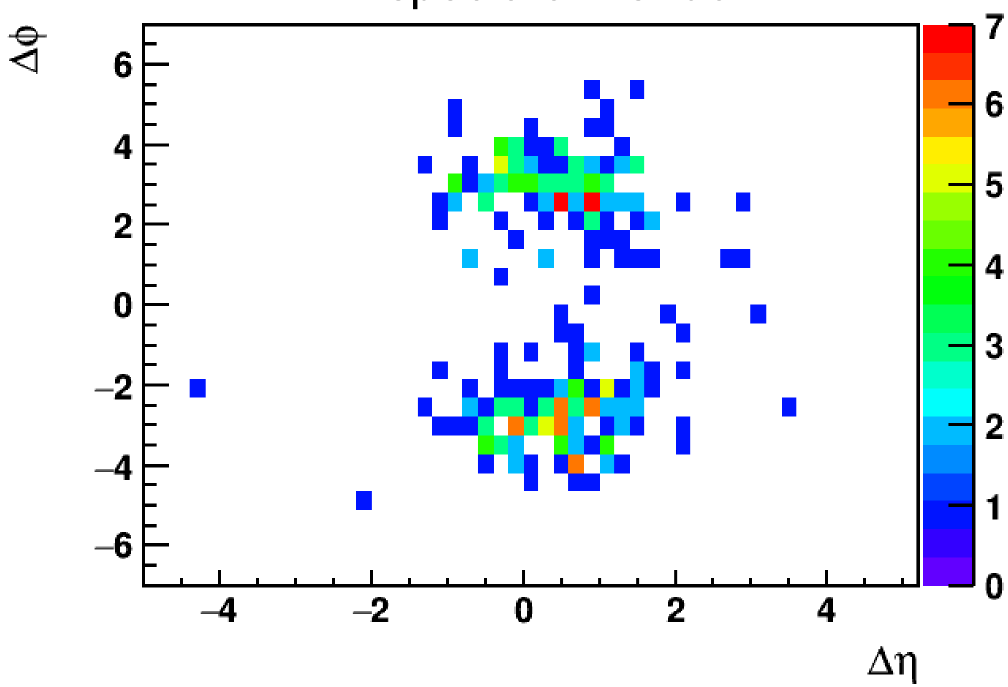
Spectators are very forward, even for 550<k<600 MeV
Neutrons basically contained in ZDC.
Protons need study, but the prognosis is good.

Correlations

For struck neutron, spectator proton – lab variables
$|t|<0.1\ \mathrm{GeV}^2$, $550 < k < 600$ MeV



Δ=spectator - struck



Recall $\eta = -\ln \tan(\theta/2)$

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

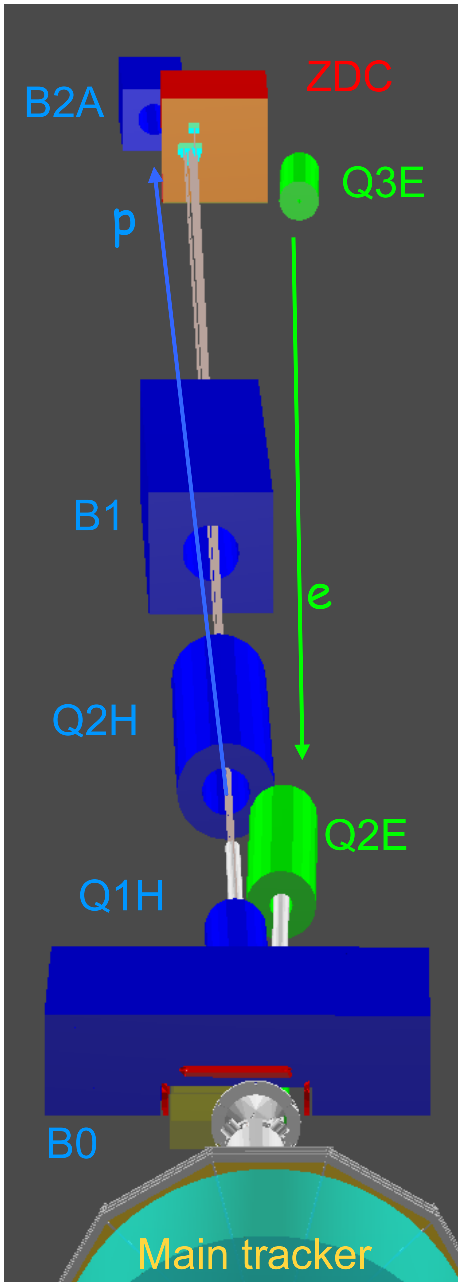
Nucleons are back to back (in this simulation)

Conclusions

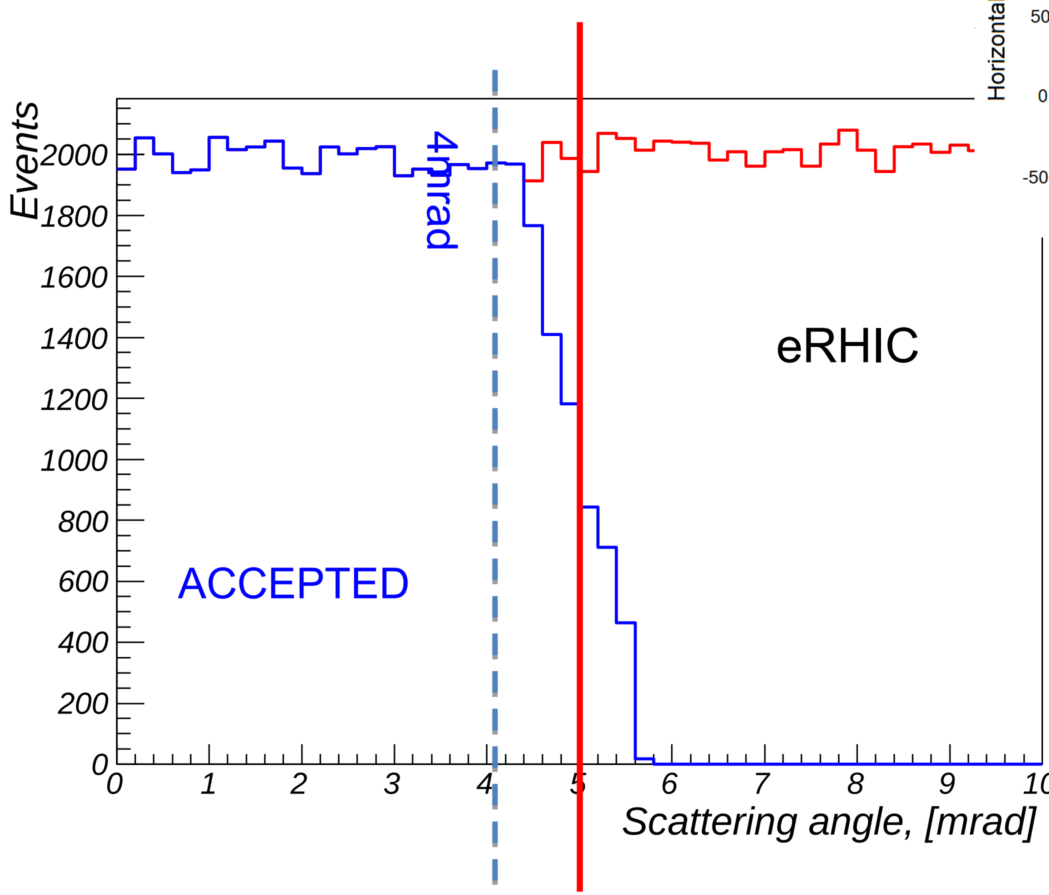
- BeAGLE is a Benchmark eA Generator for LEptoproduction
  - Available to estimate rates & acceptance for many eA or ep processes (but not coherent diffraction).
    - Note: ep is basically just EIC-tuned Pythia 6.
    - For coherent diffraction, use Sar*t*re
  - Can be compared with any new eA generators as they come online.
- We can clearly see that the forward detector suite will be crucial for eA physics at an EIC.
  - BeAGLE is helping to quantify that statement.

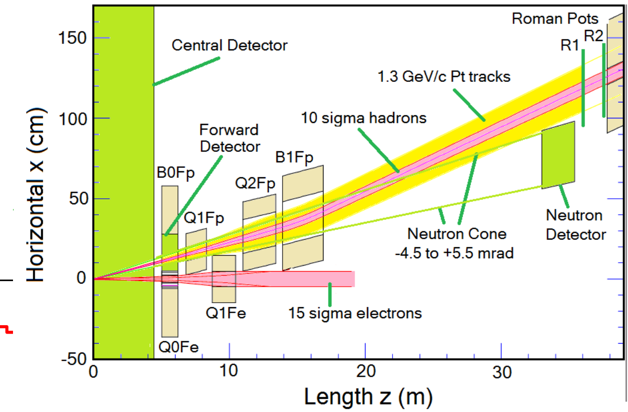
Extras

Angular acceptance for neutrons



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





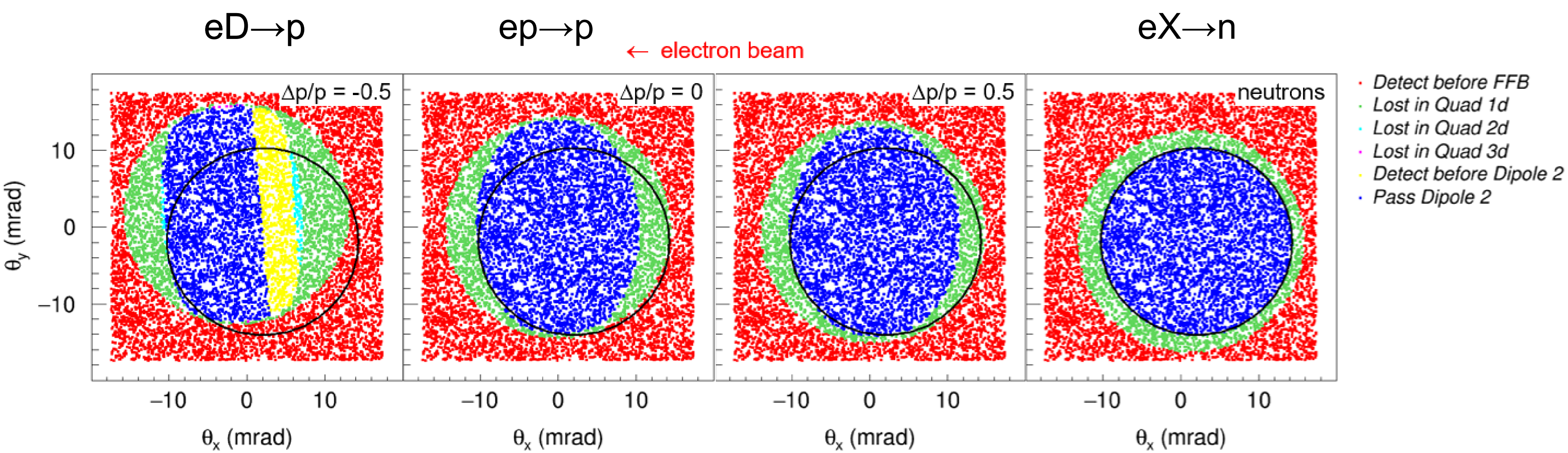
→ NB: space for ZDC needs to be increased for better hadronic shower containment

Achieve the 4 mrad acceptance requirement

From A. Kiselev

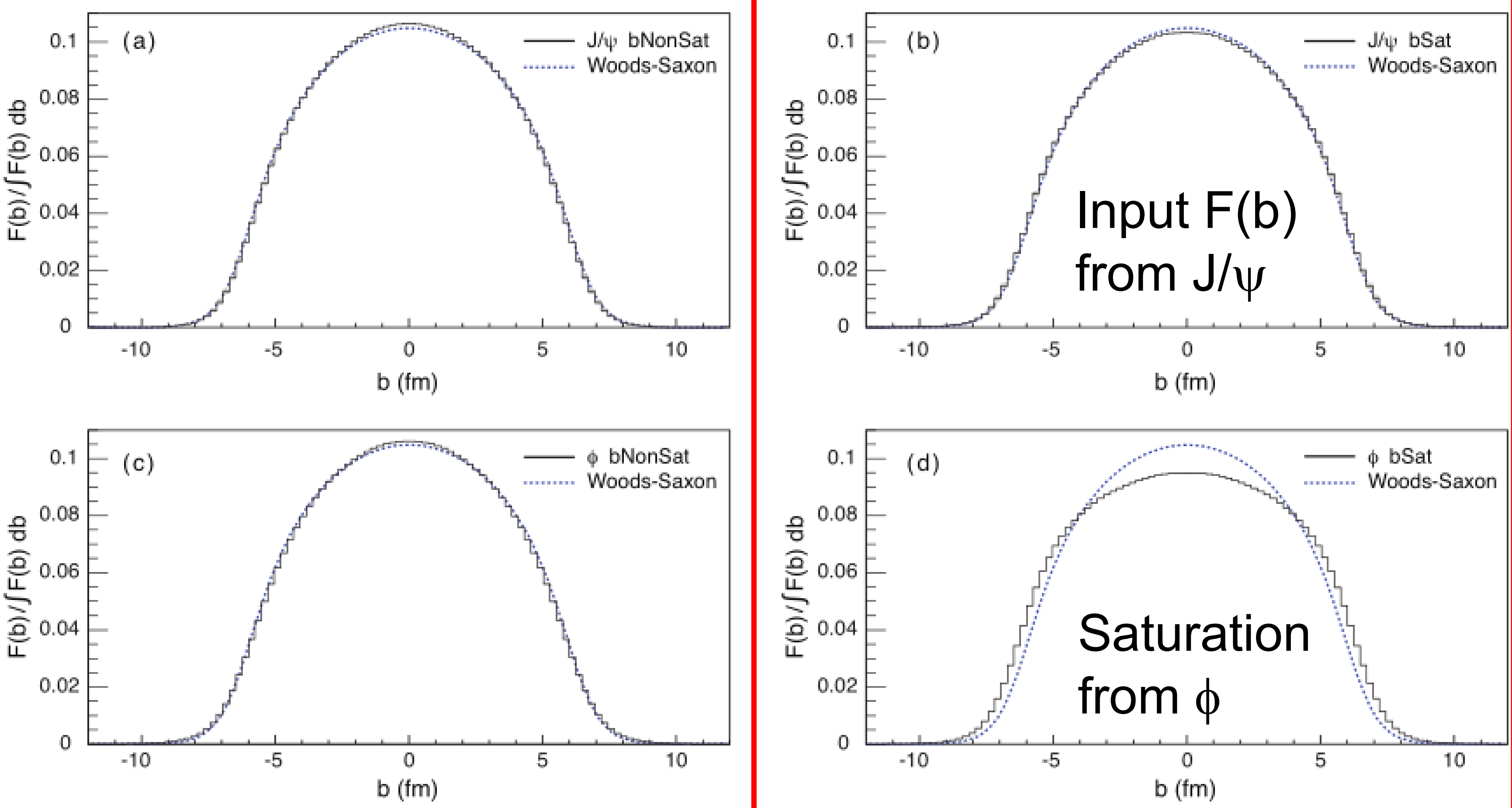
Forward protons @ JLEIC

From V. Morozov



(a) (b) (c) (d)

Results for all Data Sets

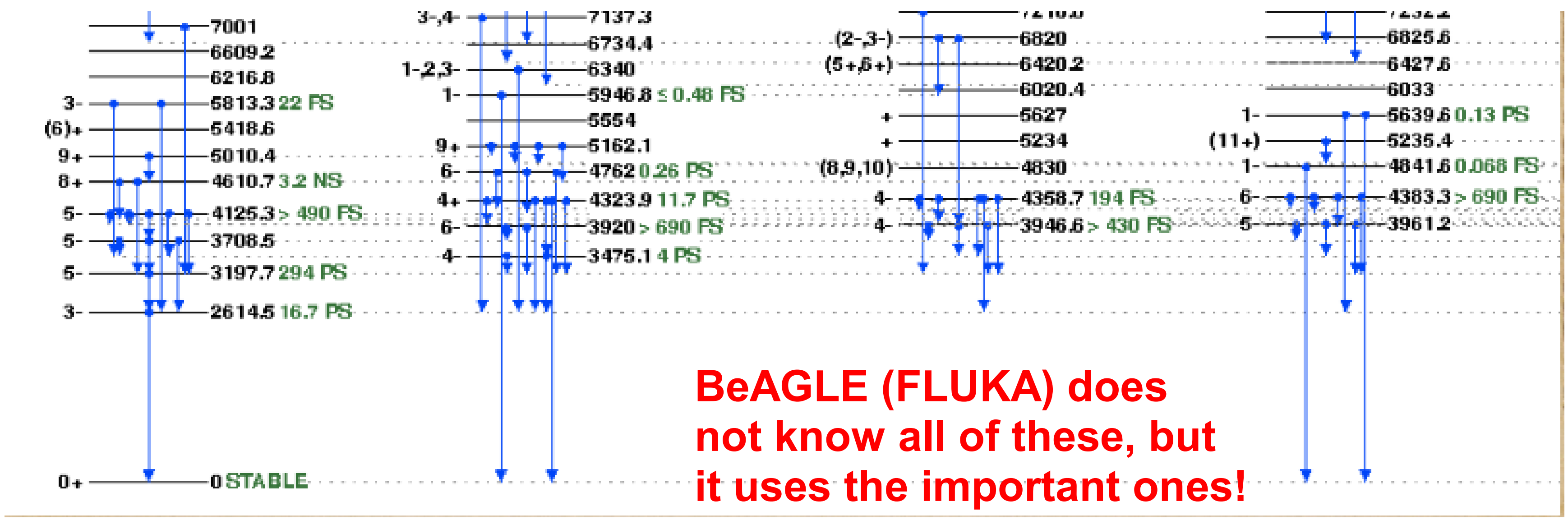


Toll, Ullrich PRC 87 (2013) 024913

Simulation Challenge: nuclear detail

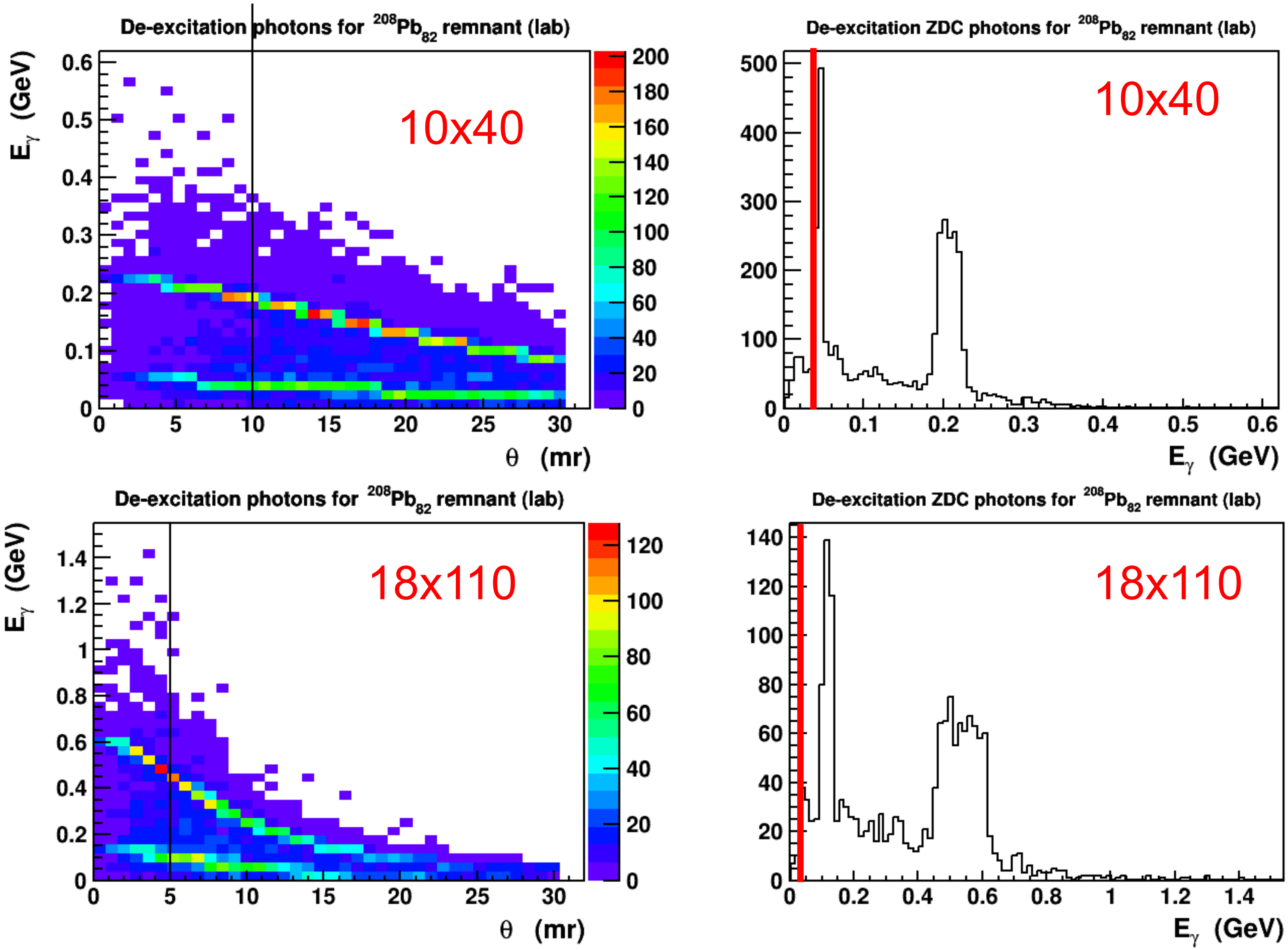
- Veto problems for $|t|<0.07$ GeV^2 are due to events where the struck nucleon and any further INC nucleons are reabsorbed: $e + {}^{208}Pb_{82} \rightarrow e' + {}^{208}Pb_{82} + J/\psi + \gamma + \gamma + \gamma ...$
- Excited Pb decays usually include a γ w/ $E \geq 2.6$ MeV
- Au decays are more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

Pb:



BeAGLE (FLUKA) does not know all of these, but it uses the important ones!

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.

Fermi momentum at a collider

Longitudinal momentum in the ion rest frame gets magnified by γ

In ion 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 $E_{kinF} << k_{zF}$:

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

Conceptual problem for e+D w/ large k

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

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

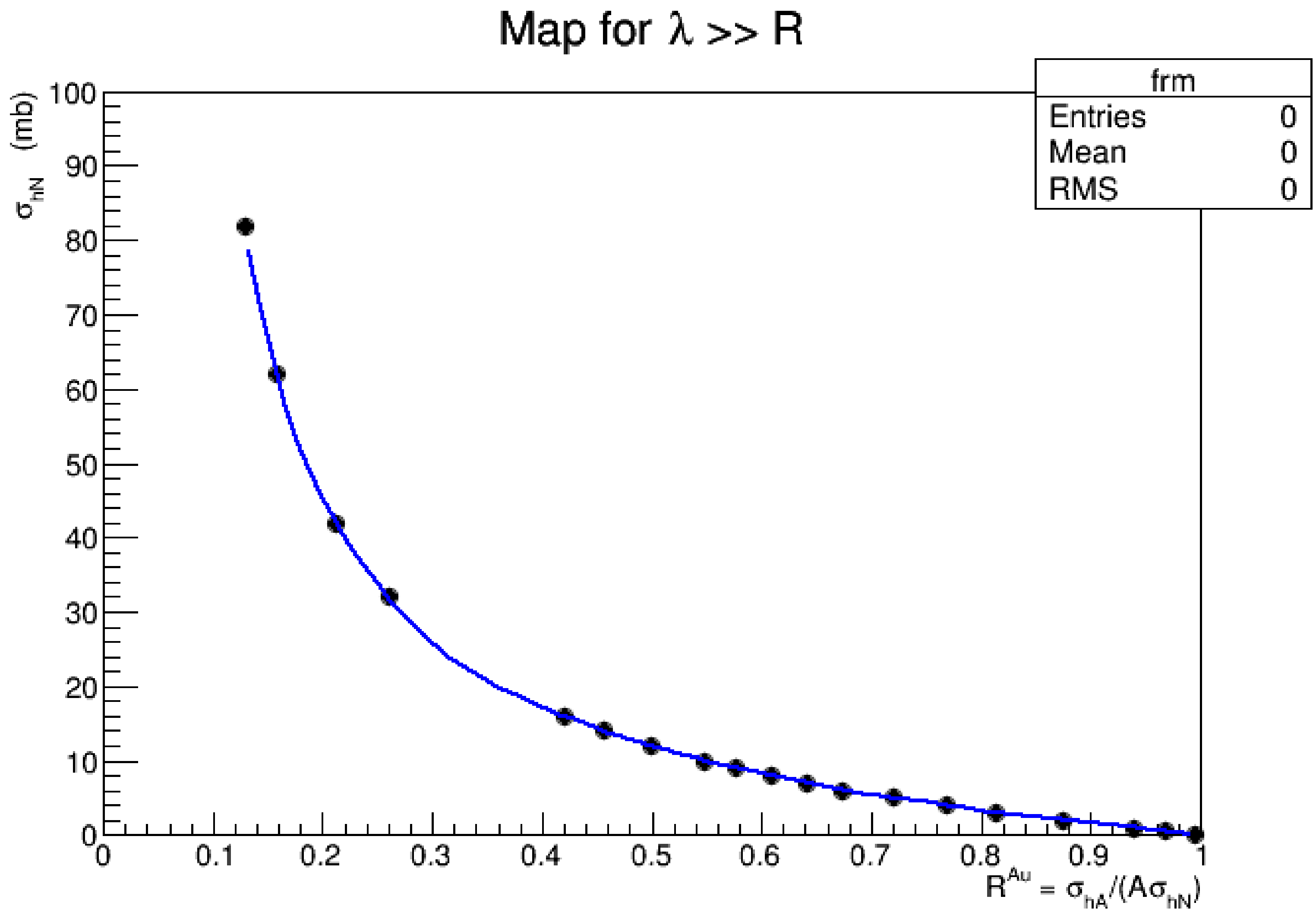
$W^\mu = \{\nu+E_n+E_p;\ 0,\ 0,\ \mathrm{sqrt}(\nu^2+Q^2)\}$

Energy not conserved in the ion rest frame (E & p_z fail in other frames)

Note: DPMJET3-F has the same problem. Minimized due to minimal p_F.

Must adjust 4-momenta of final state.

Glauber Map



Map for λ >> R
frm
Entries 0
Mean 0
RMS 0
σ_hN (mb)
0
10
20
30
40
50
60
70
80
90
100
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)