Diffraction: A killer app for IP8?

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19 May 2021

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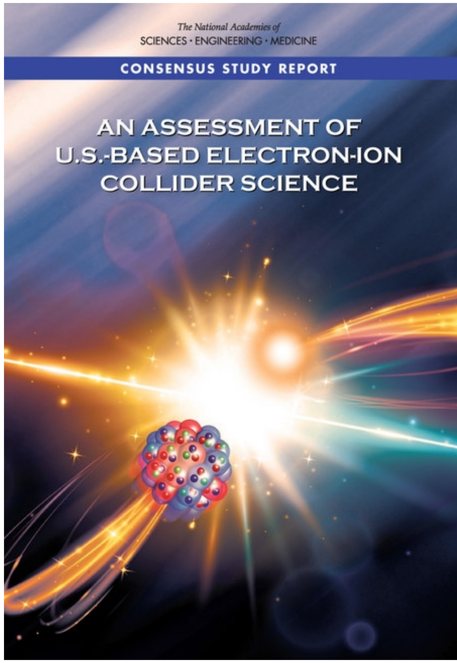
Collaborators

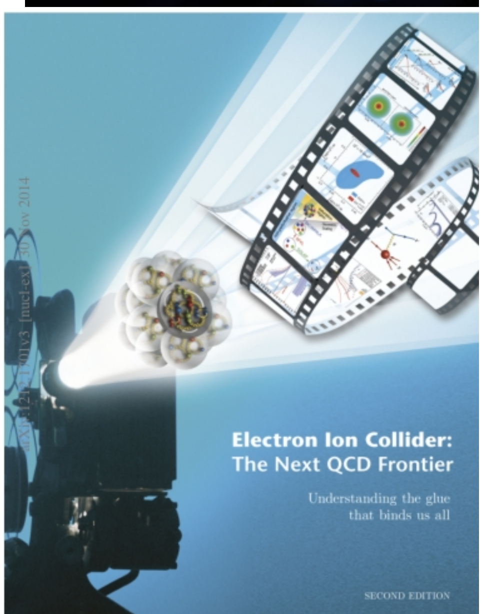
- Originators
  - T. Toll, T. Ullrich
- BNL/IP6 effort:
  - E.Aschenauer, MDB, W. Chang, A. Jentsch, J.H. Lee, Z. Tu, L. Zheng
- JLAB LDRD effort
  - MDB, C. Hyde, V. Morozov, P. Nadel-Turonski, et al....

Executive Summary

- White paper and NAS report show e+Pb coherent diffractive vector meson production as a key measurement.
  - Naively assume that it is easy to tag coherent vs. Incoherent events. But it is not!
- Yellow report does not REQUIRE it
  - "More study is needed to understand..."
- Extensive IP6 studies show that it is not possible to veto the incoherent e+A events without a secondary focus (such as at IP8).
- Is it possible at IP8??

Prominent in NAS & WP physics case





THE SCIENTIFIC CASE FOR AN ELECTRON-ION COLLIDER 41

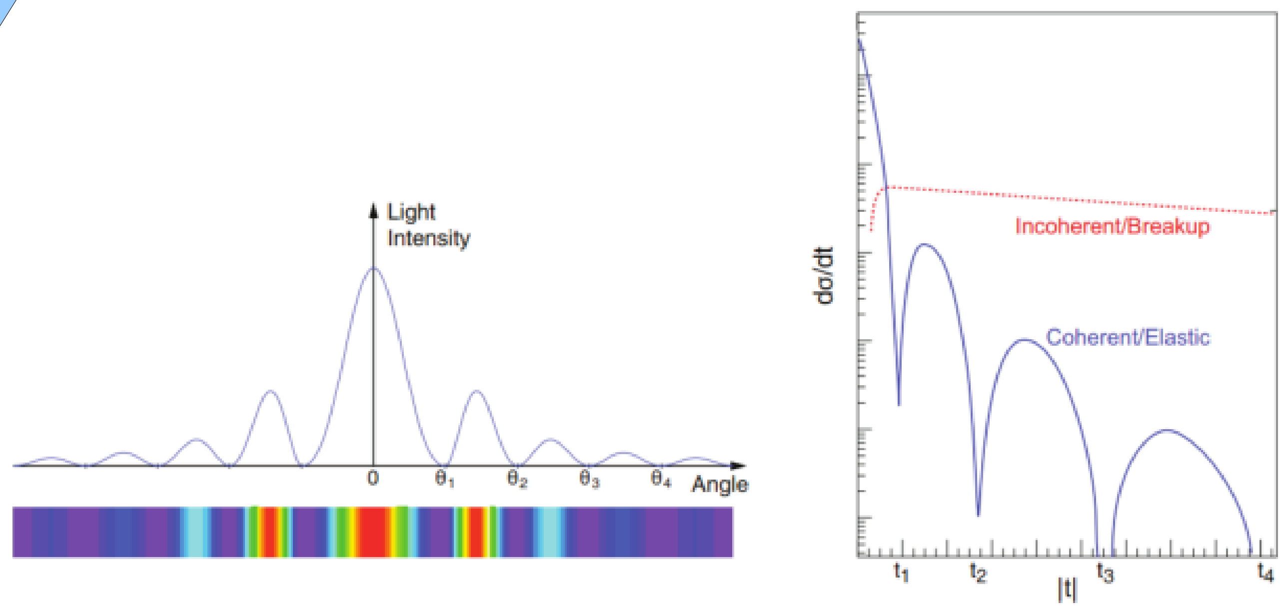
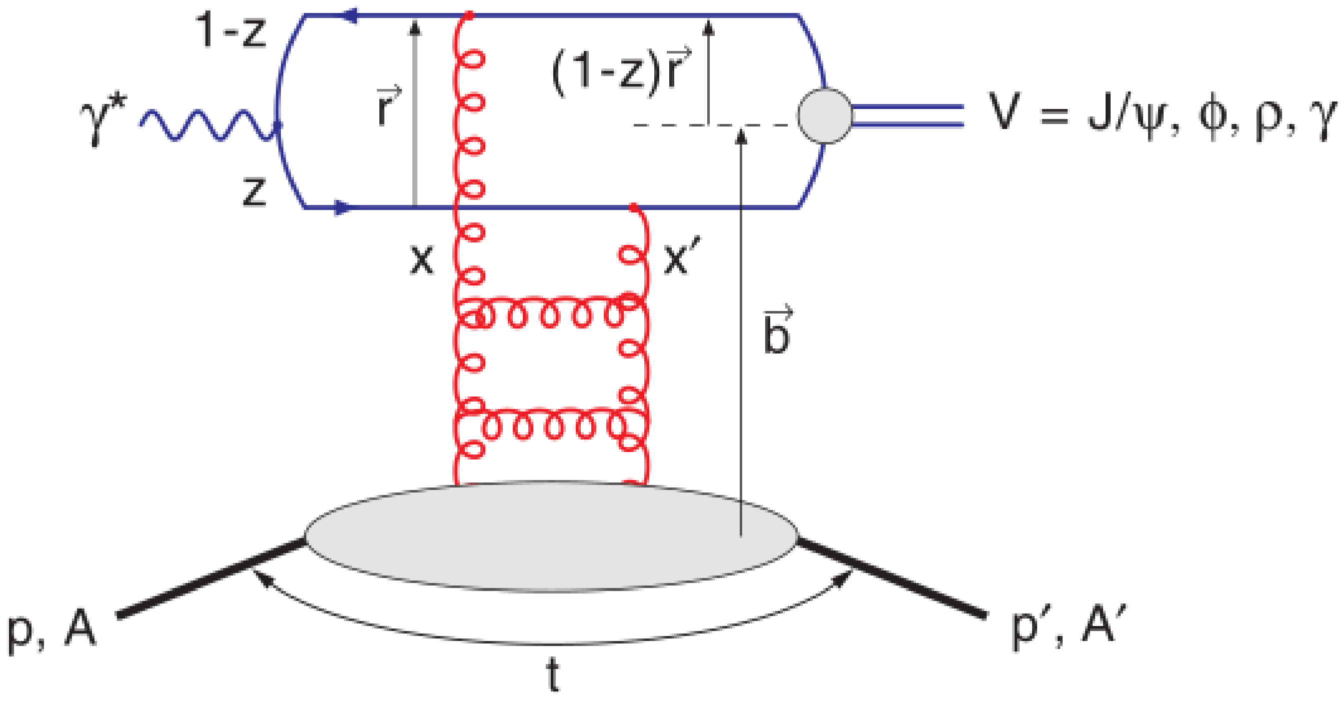


FIGURE 2.9 *Left:* Diffraction pattern in optics, showing the light intensity landing on a screen behind a circular obstacle. *Right:* The expected differential cross section for coherent and incoherent diffractive production of J/ψ particles on nuclei. The variable *t* is related to the momentum carried by the scattered proton, which provides a measure of the scattering angle. The incoherent/breakup curve is explained in the text. SOURCE: *Reaching for the Horizon,* 2015 DOE/NSF Long Range Plan for U.S. Nuclear Science.

Schematic view of diffraction

Coherent means e+A→e'+V+A' and nothing else
Incoherent is e+A→e'+V+X where X is not just A'
X can include, heavy & light ions, p, n, γ, π, K



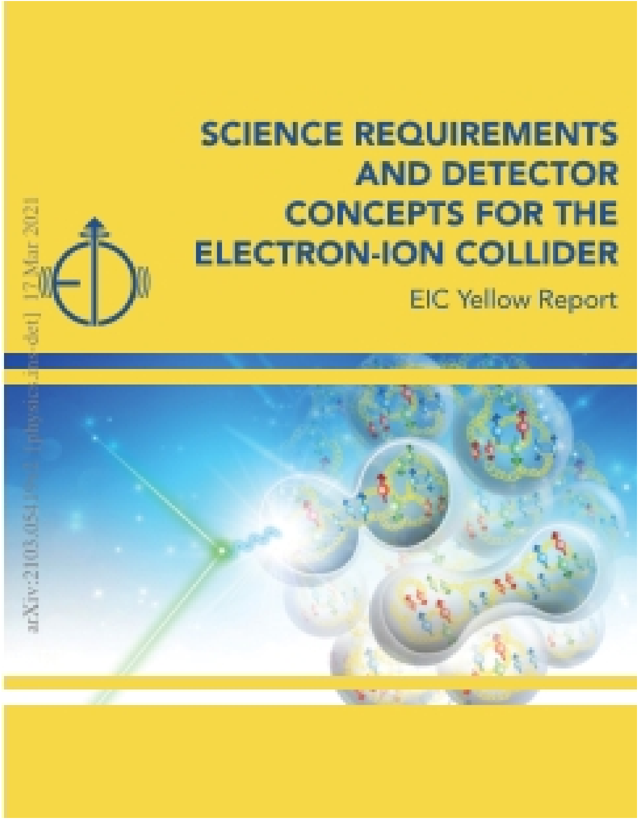
From Toll, Ullrich, PRC 87, 024913 (2013)

"A key e+A measurement" in the white paper

Deliverables	Observables	What we learn	Low energy option	High energy option
Integrated gluon momentum distributions $G_A(x,Q^2)$	F_2, F_L, and $F_2^{c\bar{c}}$	Nuclear wave function; saturation	Gluons at $10^{-3} \lesssim x \lesssim 1$	Exploration of the saturation regime
k_T-dependent gluons $f(x,k_T)$; gluon correlations	Di-hadron correlations	Non-linear QCD evolution/universality; saturation scale Q_s	Onset of saturation; Q_s measurement	Non-linear small-x evolution
Spatial gluon distributions $f(x,b_T)$; gluon correlations	Diffractive dissociation $\sigma_{diff}/\sigma_{tot}$ vector mesons & DVCS $d\sigma/dt$, $d\sigma/dQ^2$	Non-linear small-x evolution; saturation dynamics; black disk limit	saturation vs. non-saturation models	Spatial gluon distribution; Q_s vs centrality

Table 3.1: Key measurements in e+A collisions at an EIC with two energy options, as shown in Fig. 3.1, addressing the physics of high gluon densities.

The Yellow Report makes no promises



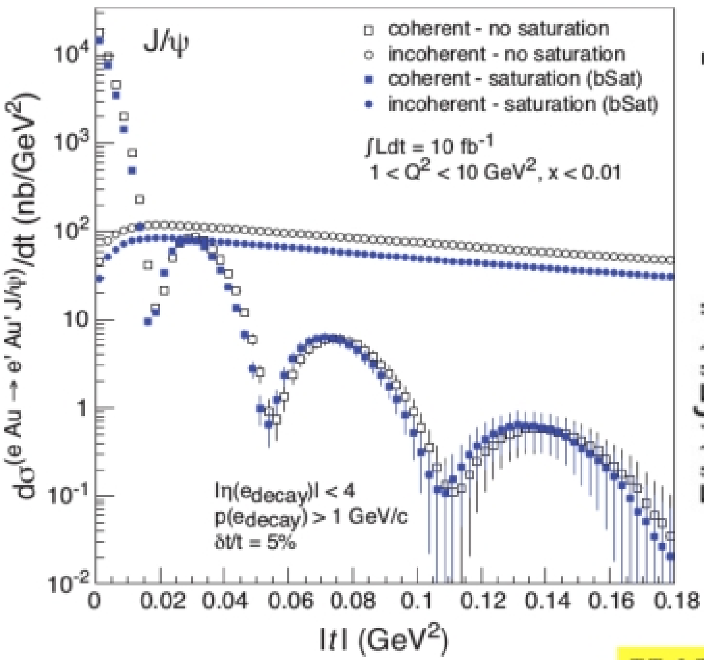
p. 14
An early measurement of coherent diffraction in e+A collisions at the EIC would provide the first unambiguous evidence for gluon saturation.

Section 7.3: Several theoretical & experimental concerns were discussed & then:

p.185: “More study is needed to understand the severity of all of these issues.”

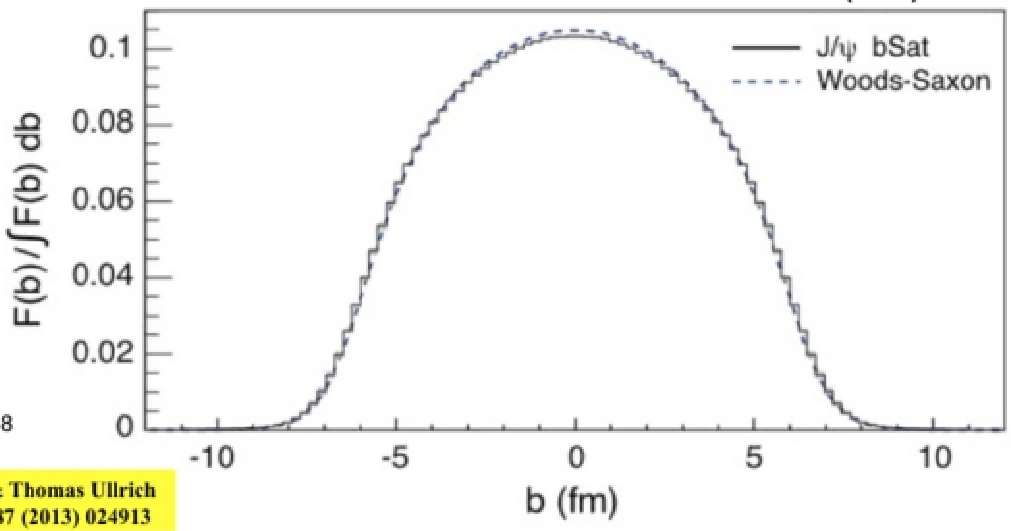
Probing the spatial gluon distribution at EIC

Momentum transfer t conjugate to transverse coordinate b



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

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



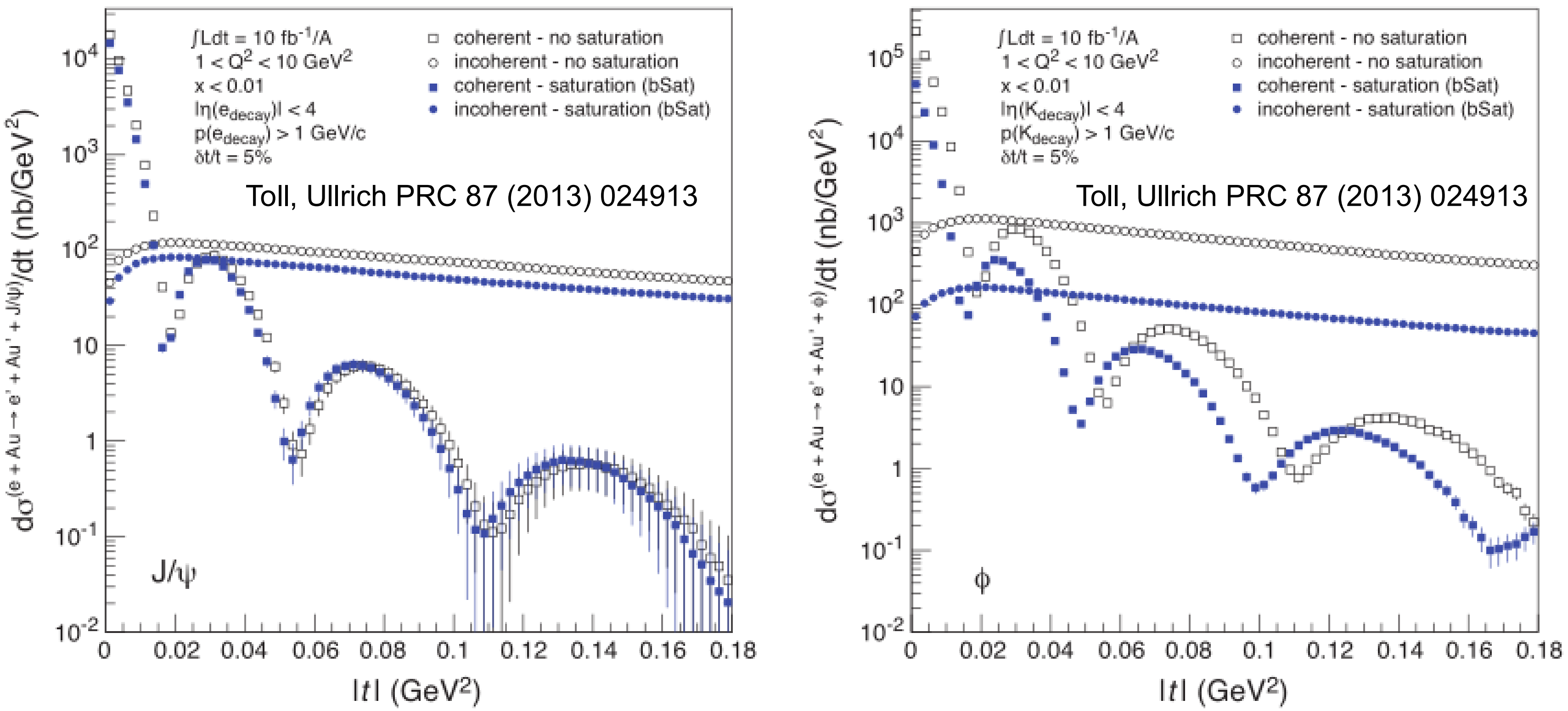
T.T. & Thomas Ullrich
PRC 87 (2013) 024913

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

T. Ullrich, 2012-10-04 BNL EIC TaskForce Meeting

https://wiki.bnl.gov/eic/upload/FourierSummary.pdf

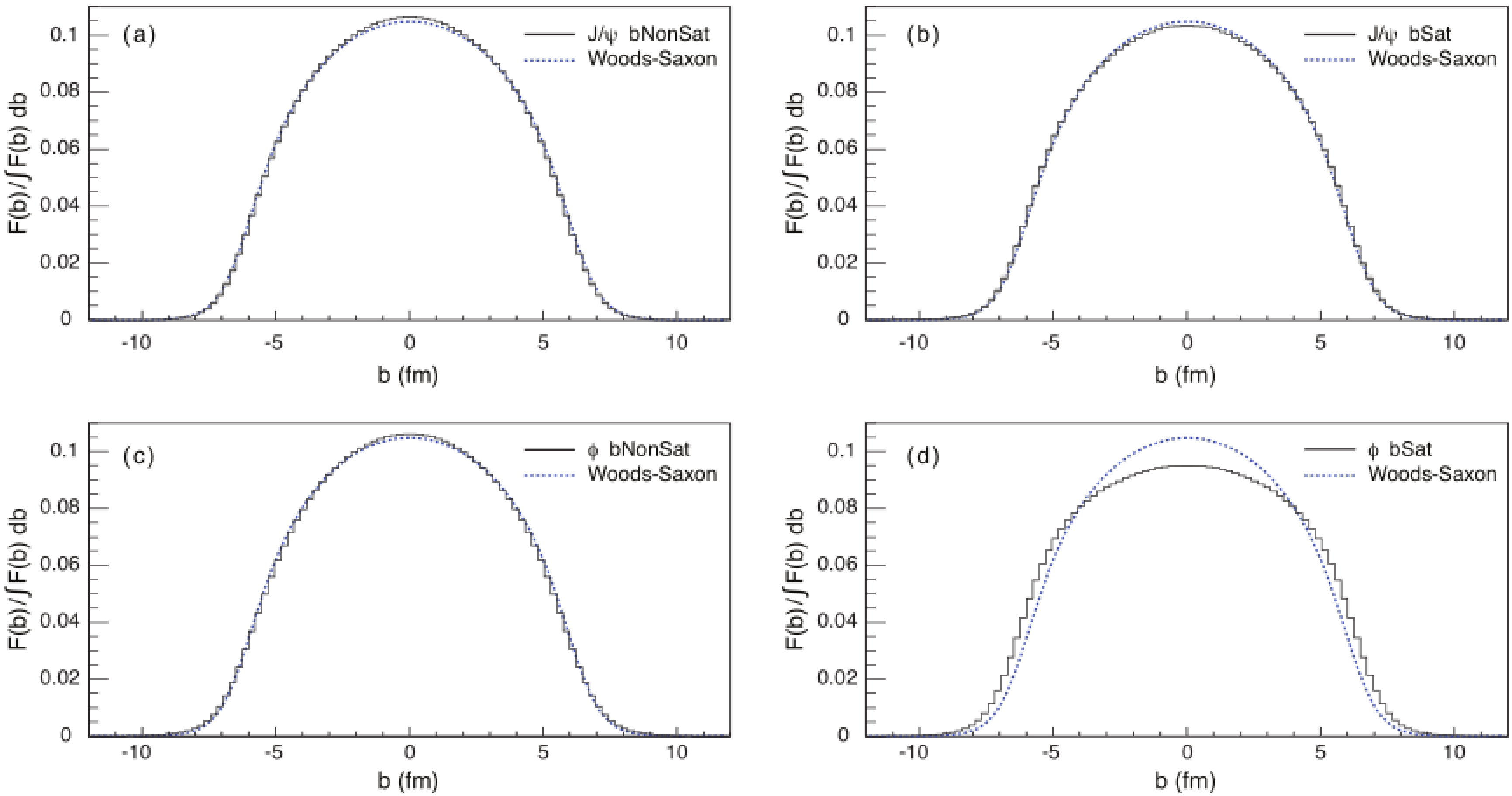
Starting Point



Reminder:

- e + Au → e' + Au + J/ψ: not sensitive to sat. effects
- e + Au → e' + Au + φ: larger wf ⇒ sensitive to sat. effects
- Sartre: uses Woods-Saxon to generate nuclei

Results for all Data Sets



Toll, Ullrich PRC 87 (2013) 024913

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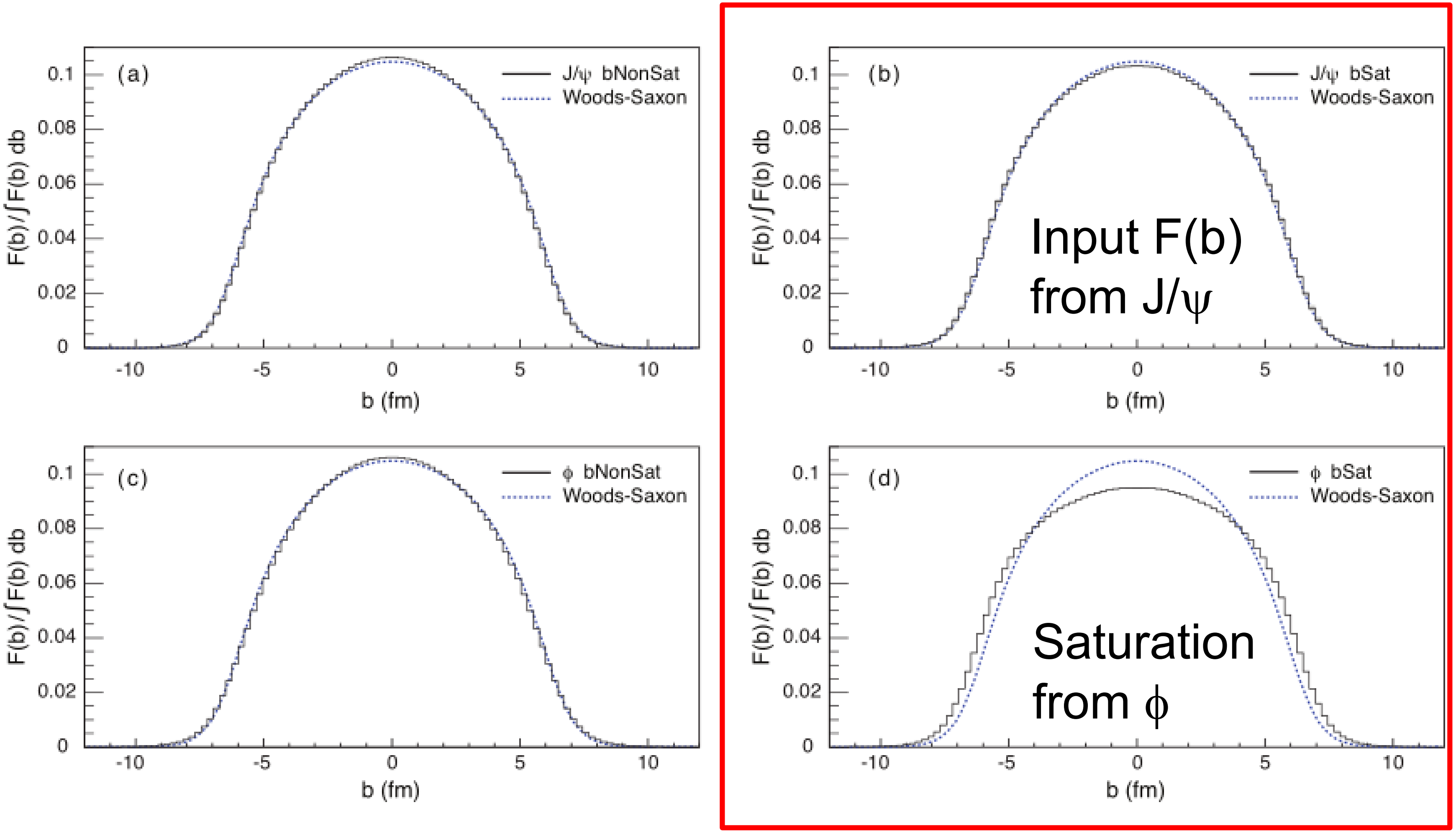

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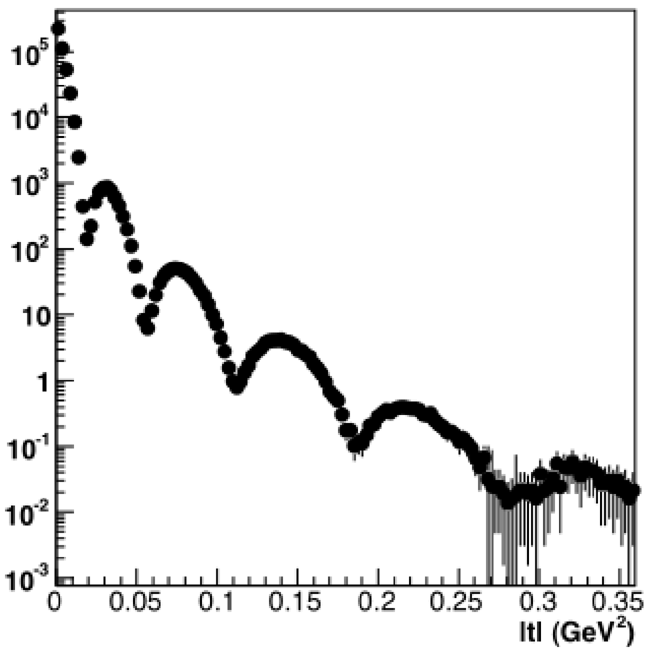
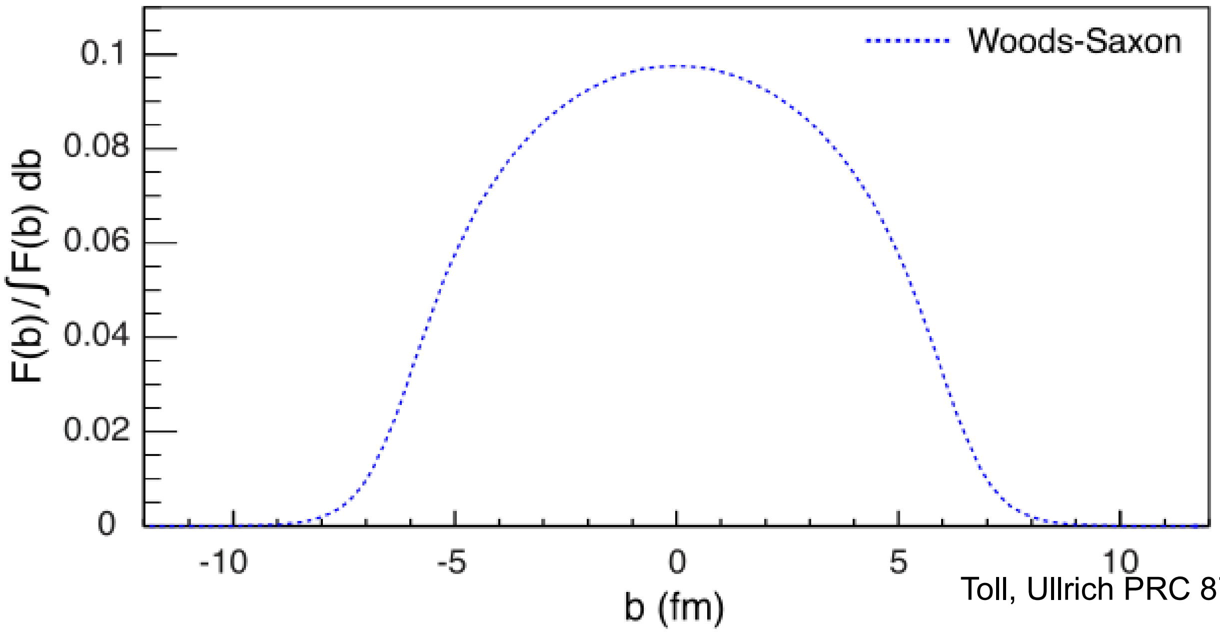
t-Range

ϕ bNonSat:

- No saturation effects expected
- In ideal world: should get original Woods-Saxon back





Toll, Ullrich PRC 87 (2013) 024913

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t-Range

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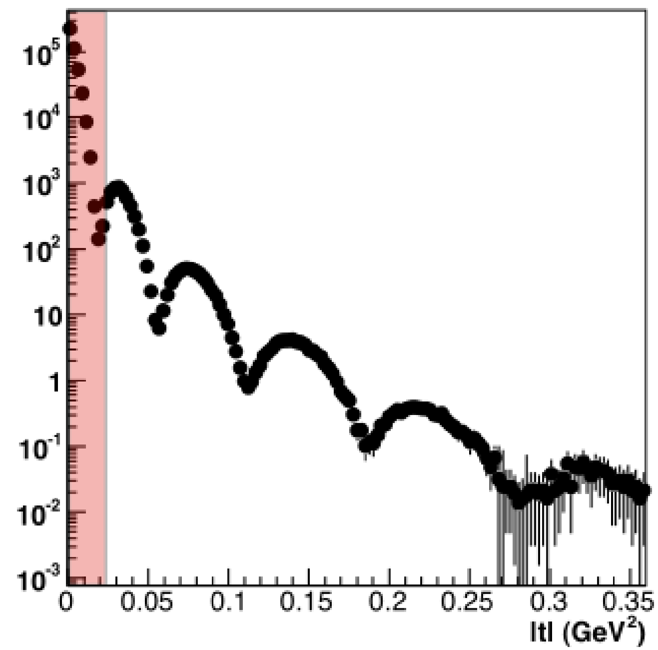

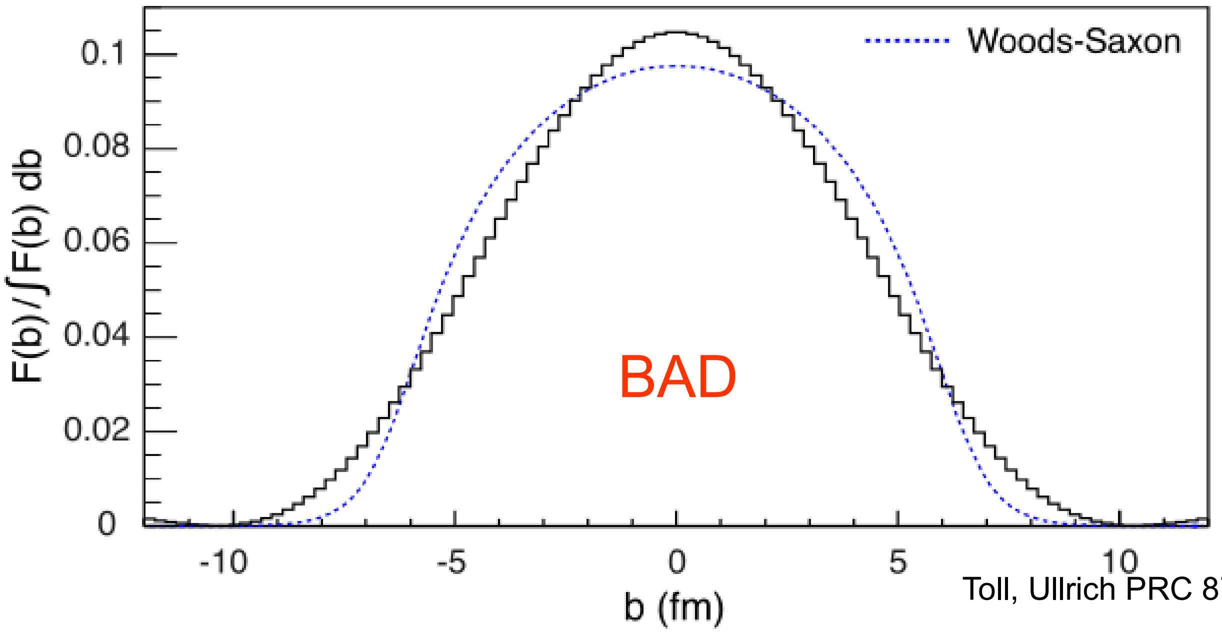

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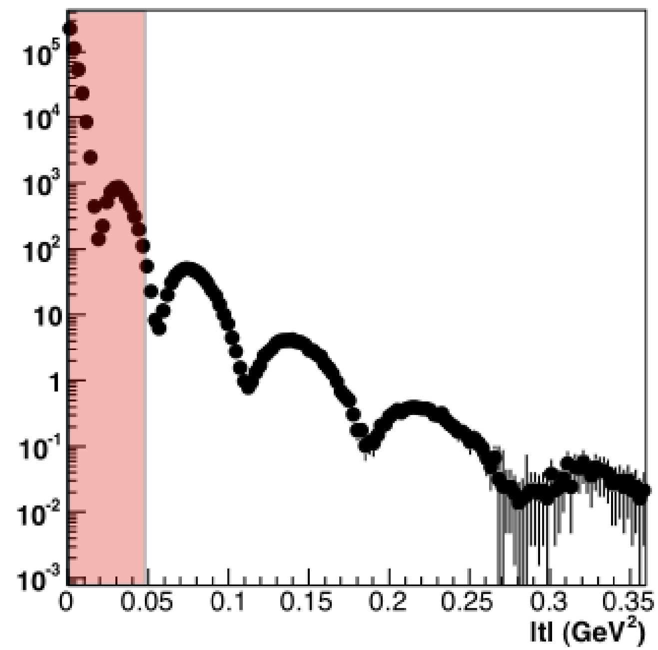

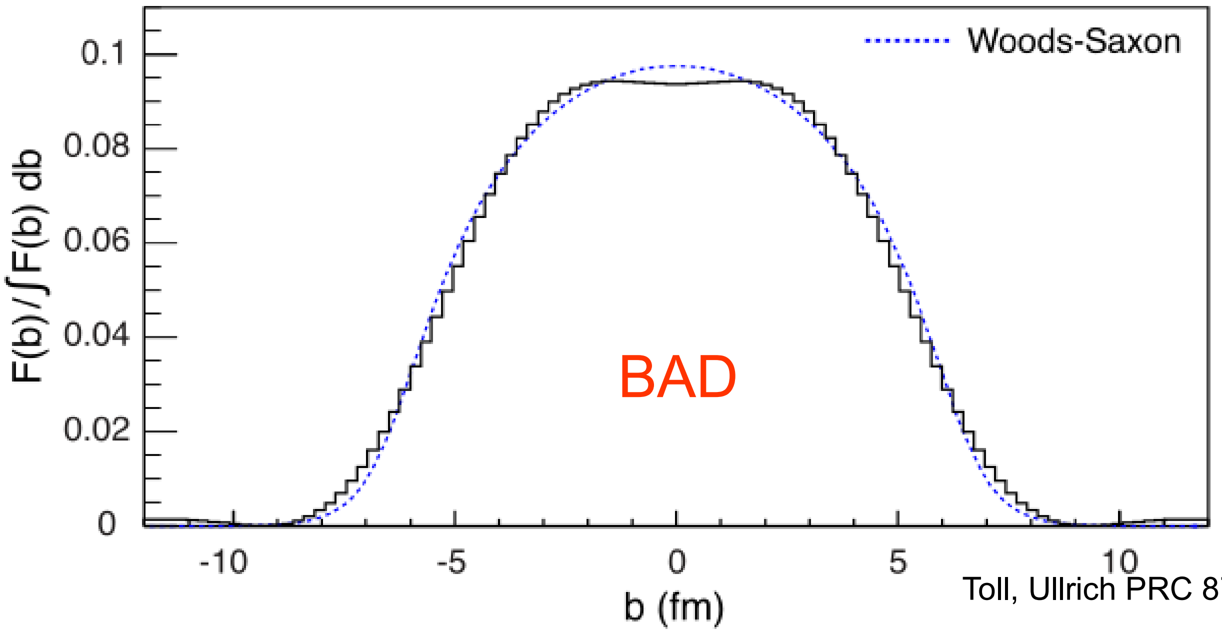

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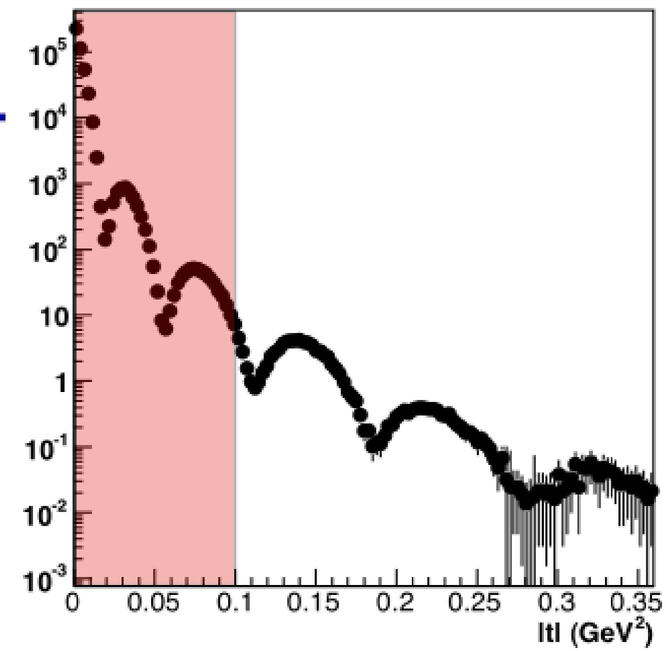

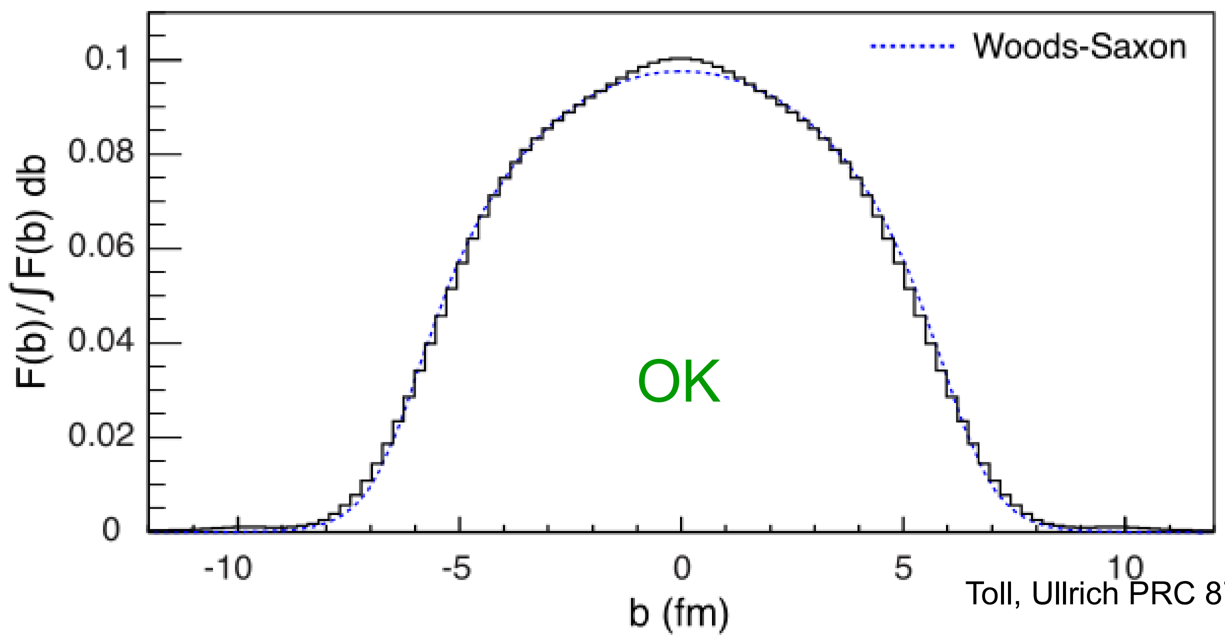

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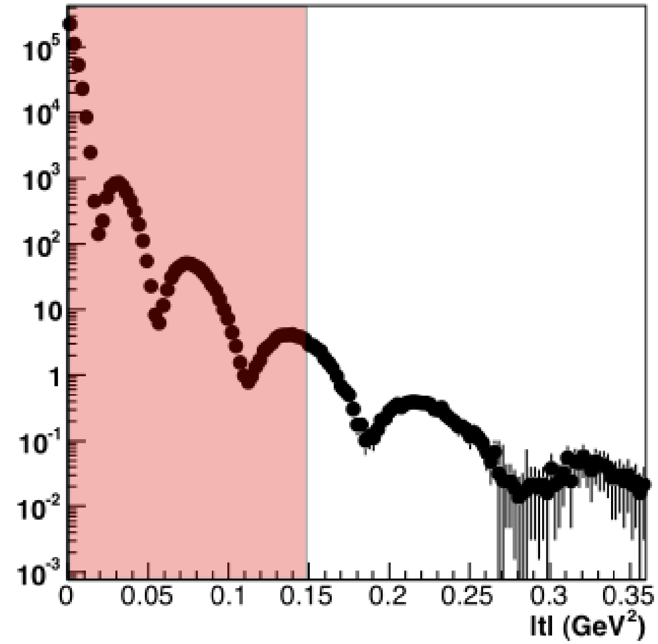

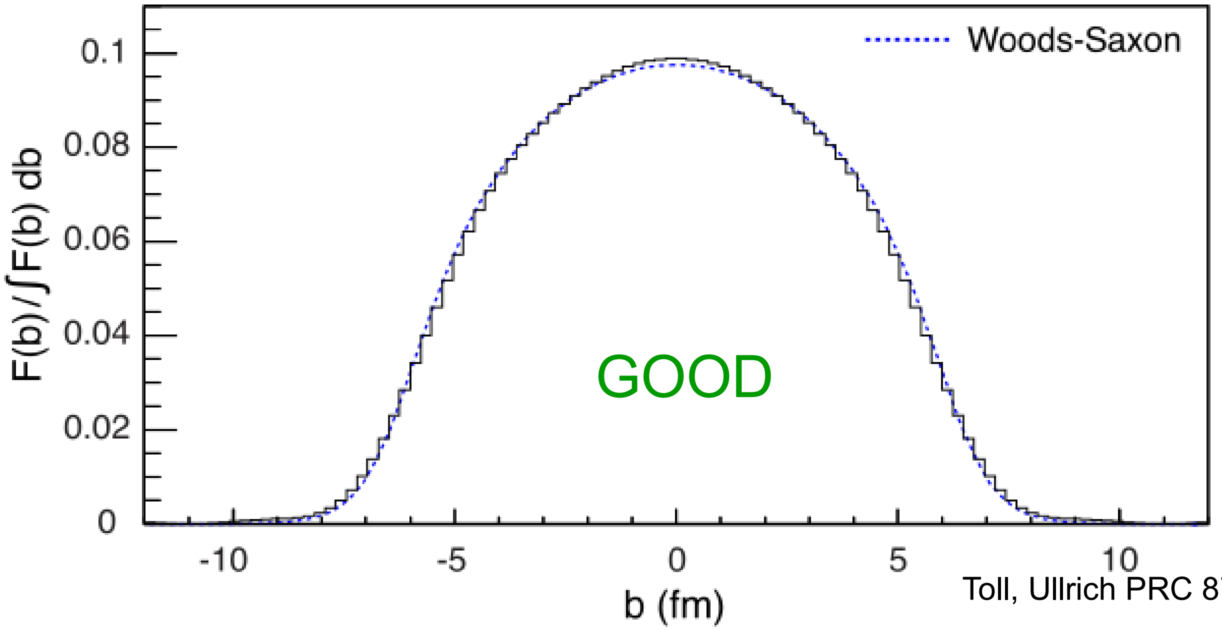

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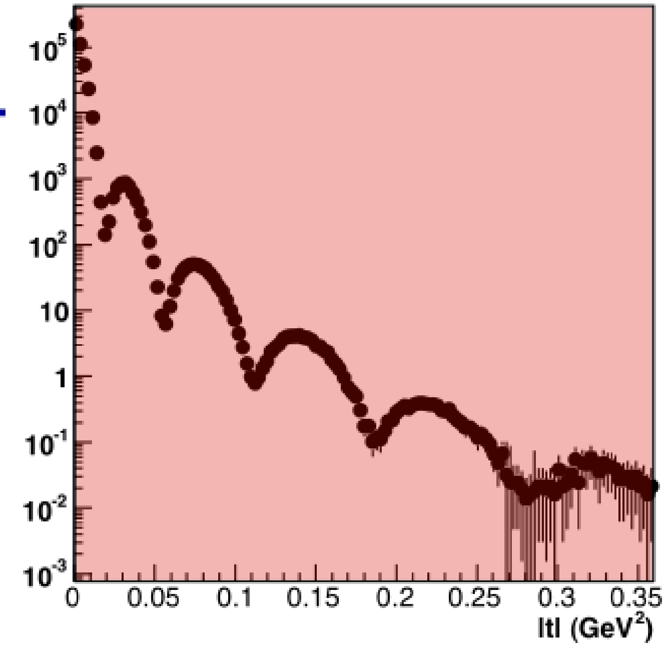

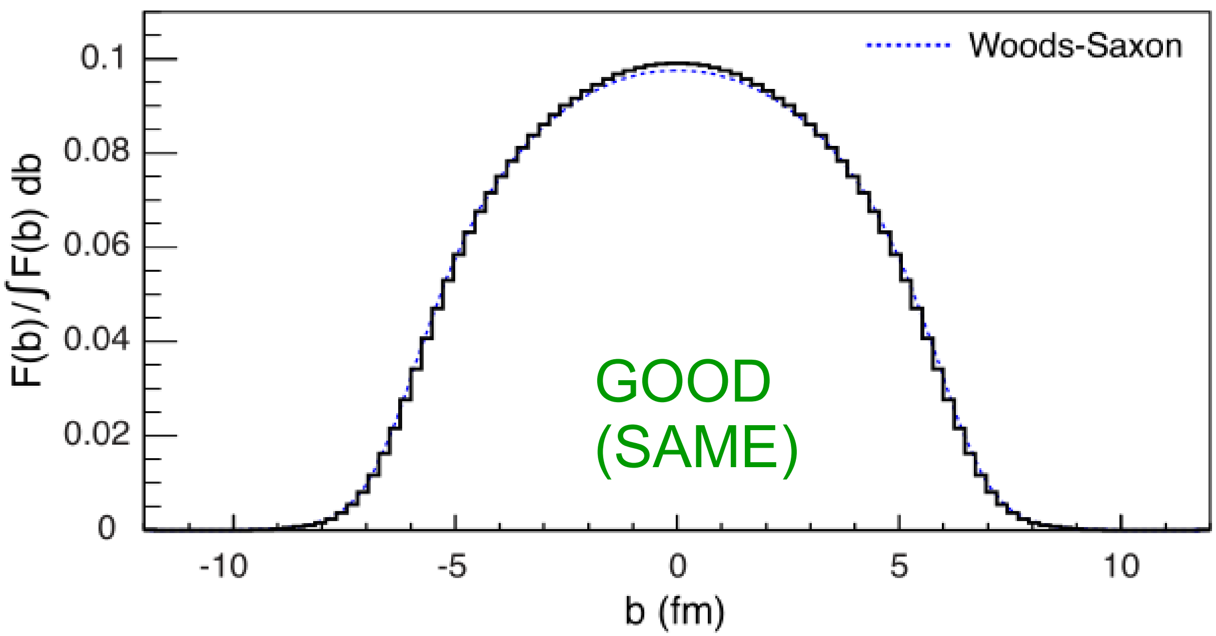

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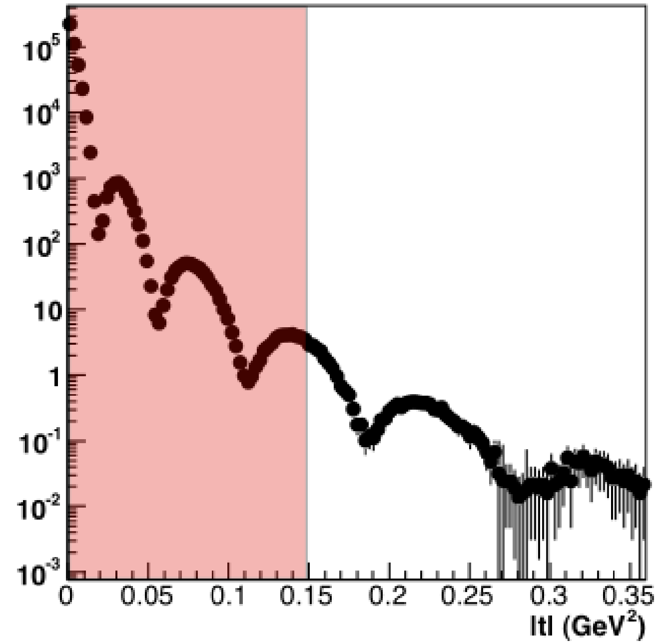

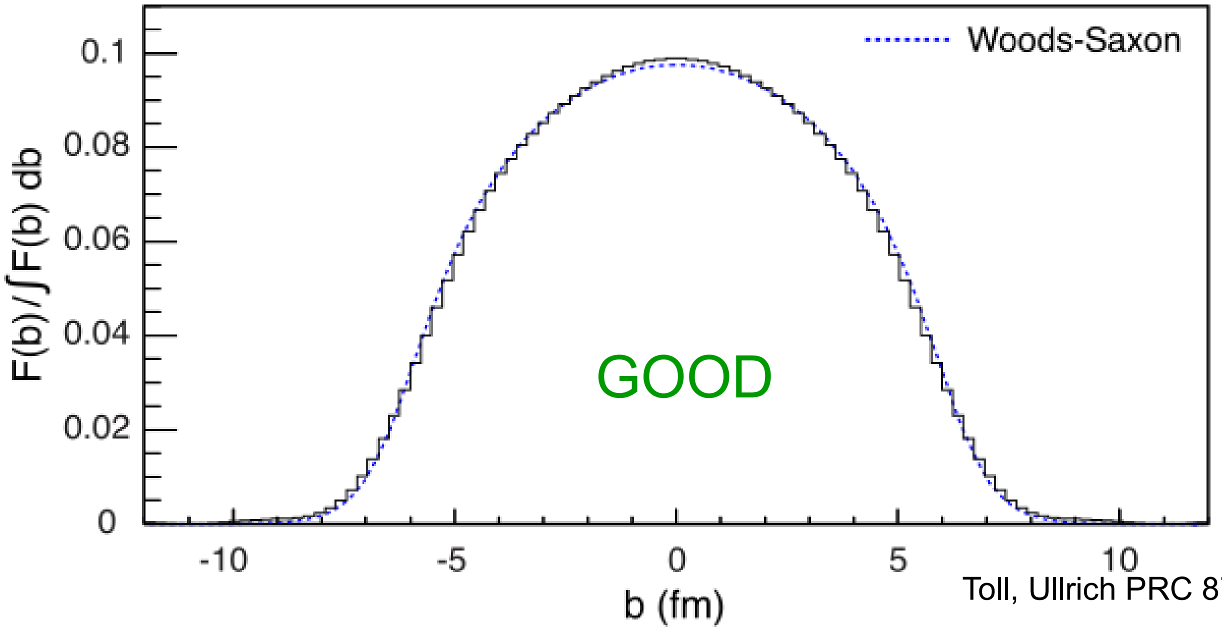

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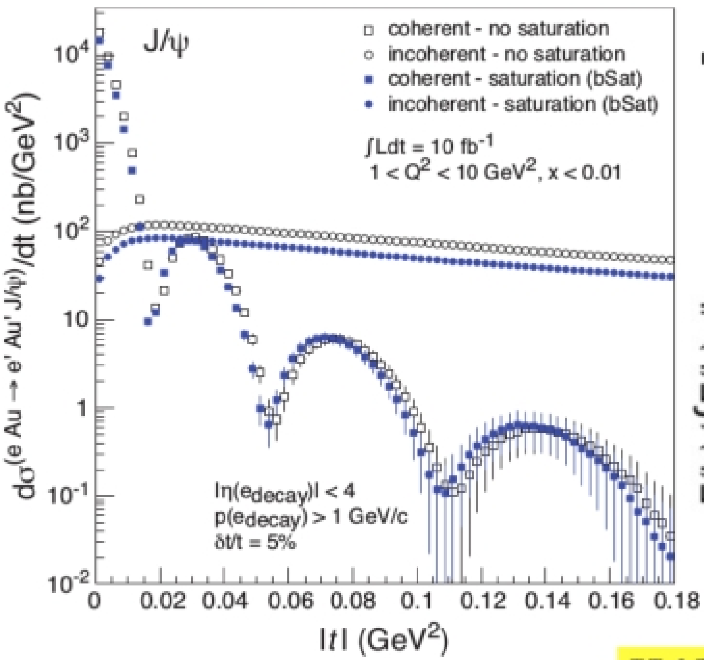
The Rest of the Story...

Probing the spatial gluon distribution at EIC

Momentum transfer t conjugate to transverse coordinate b



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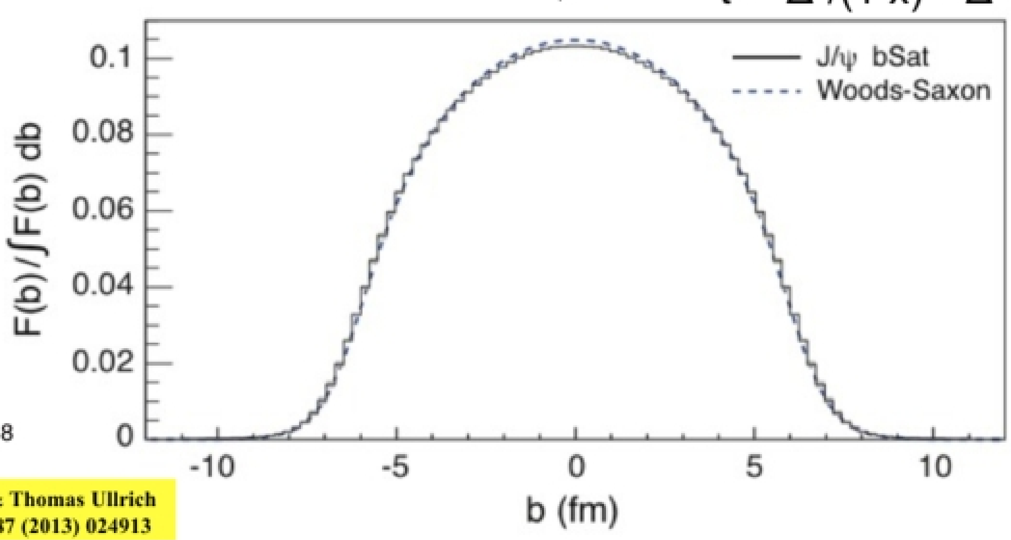

T.T. & Thomas Ullrich
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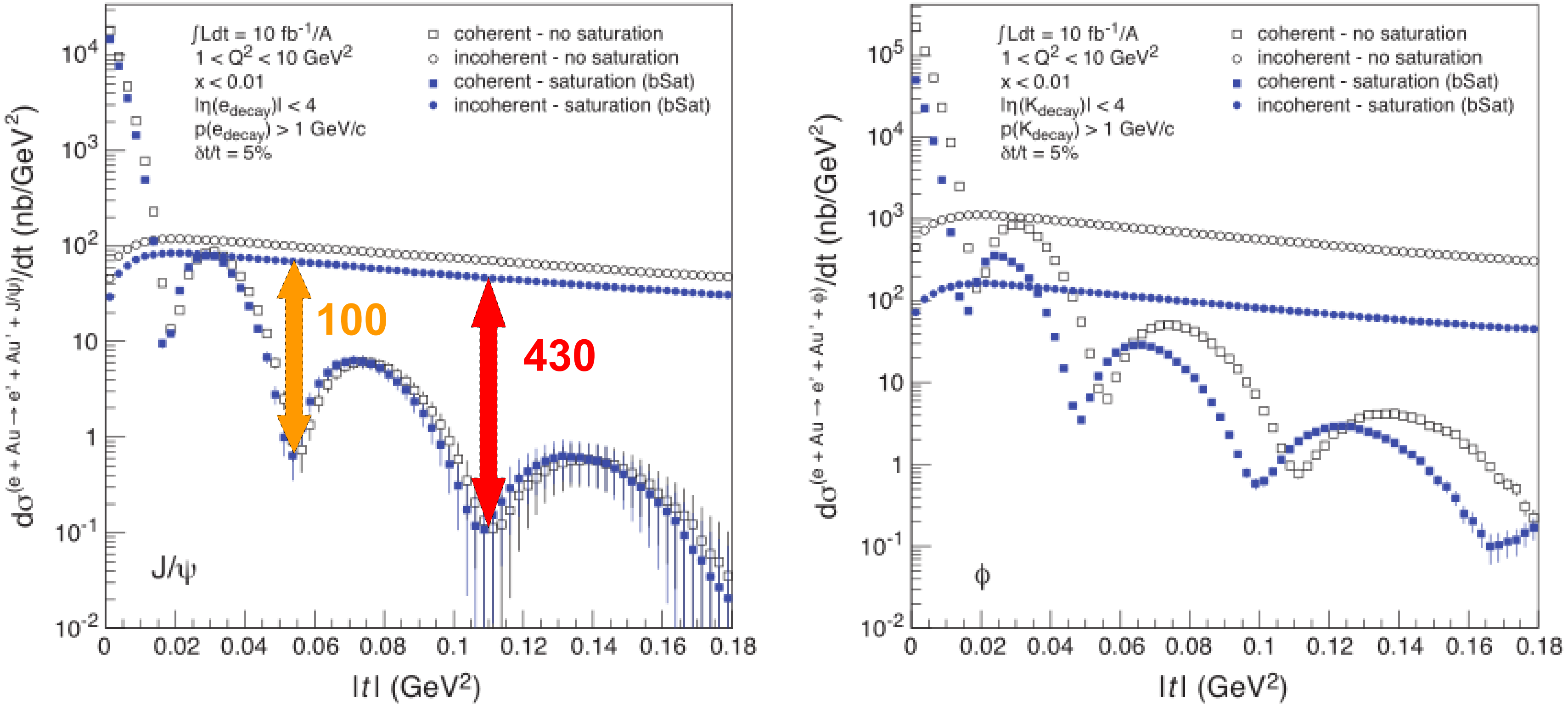
EIC will be able to retrieve the spatial gluon distribution with high precision.

IF we can extract the coherent diffraction pattern

Starting Point



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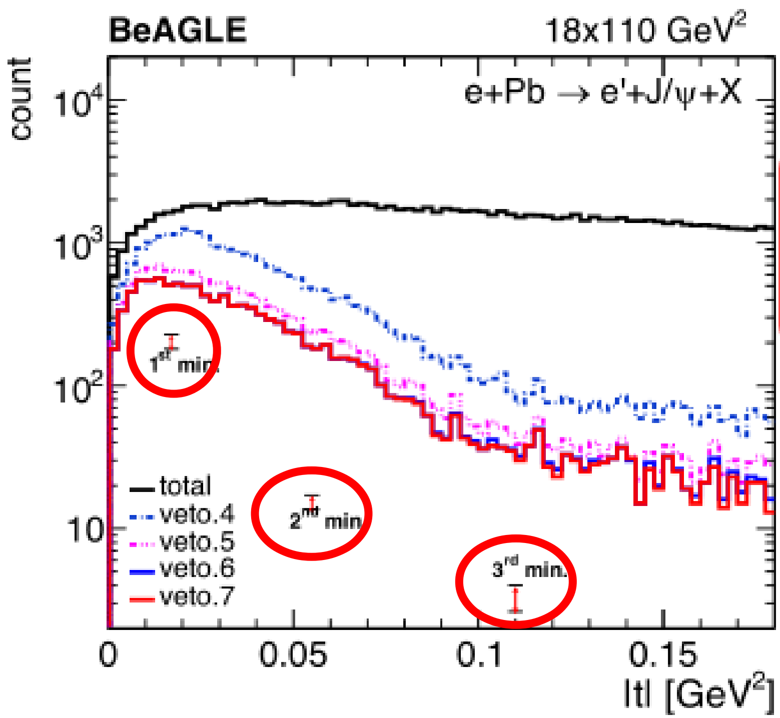
From W. Chang @ DIS2021

Vetoing Incoherent Events: Main detectors

Veto on forward:
protons
neutrons
photons

Also on main detector (other than e'+J/ψ)



Veto.5:
- Veto4 + no anything in preshower

Veto.6:
- Veto5 + no photon *E>50MeV* in ZDC

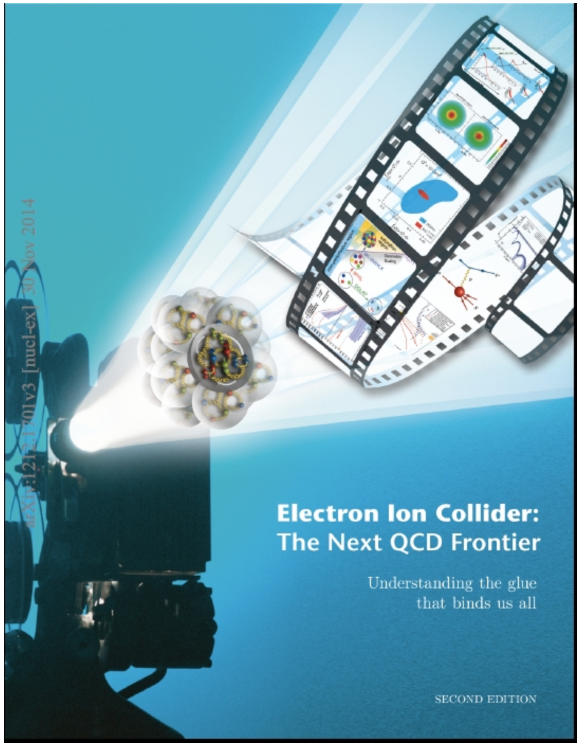
Veto.7:
- Veto6 + no activities ($|\eta| < 4.0$ & $p_T > 100$ MeV/c & $E > 50$ MeV) other than e- and J/ψ in the main detector (generator level)

With these requirements, the rejection power is found to be not enough to reach the three minimum positions.

Survived event count			
Total events	250000	100%	
Cut1	42026	16.81%	n
Cut2	42026	16.81%	p
Cut3	40734	16.29%	p
Cut4	39415	15.77%	p
Cut5	18324	7.33%	γ
Cut6	14551	5.82%	γ
Cut7	14203	5.68%	

12 Wan Chang 2021/04/14

Diffraction in the White Paper



Eur.Phys.J. A52 (2016) no.9, 268

"What makes the diffractive processes so interesting is that they are most sensitive to the underlying gluon distribution, and that they are the only known class of events that allows us to gain insight into the spatial distribution of gluons in nuclei.

However, while the physics goals are golden, the technical challenges are formidable but not insurmountable, and require careful planning of the detector and interaction region."

IP6 did not do the trick
Narrow window to test & influence the IP8 design!
No guarantee that the technical challenges are surmountable though.

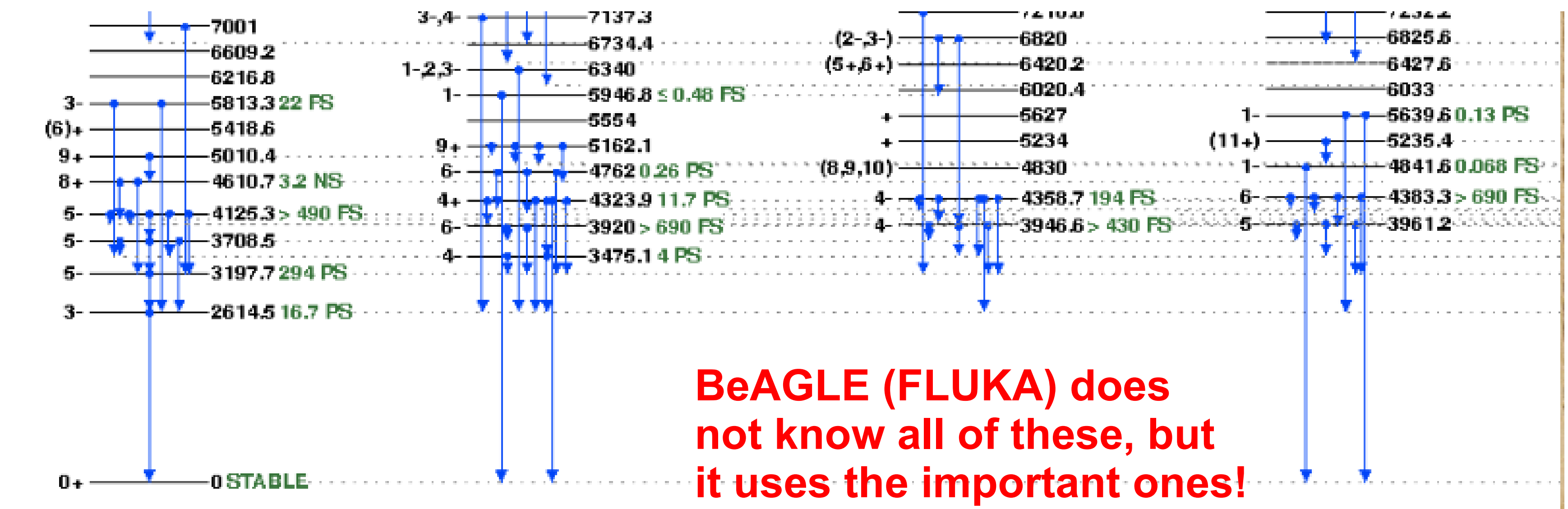
An aside on photons and on Pb vs. Au

- When |t|<0.07 GeV^2 the collision may be too soft to free a nucleon. We may just get photons from Pb* decay, e.g.

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

- Excited Pb decays usually include a γ w/ E≥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!

γ-based veto promising for ePb

Veto Bound Excited States on gamma-decay

- Boost factor from Ion-Rest Frame to Detector Frame:
  - $\gamma \approx 40 \approx 100$ GeV(Z/A)/M_N , $\beta \approx 0.9997$
  - Decay distribution ≈ uniform in ion rest frame
  - $$\cos(\theta_{\mathrm{Det}}) = \frac{\cos(\theta_{\mathrm{Ion}}) + \beta}{1 + \cos(\theta_{\mathrm{Ion}})\,\beta}$$
  - 50% of decay photons are in a cone (around ion-direction) of ±25 mad. This is inside Dipole-1 acceptance.
  - Photon energy ≈ (2.6MeV) $[1+\cos_{\mathrm{Ion}}\beta]\gamma$.
    - Same 50% of photons have $E_\gamma \geq 104$ MeV.

From Charles Hyde

Every $^{208}Pb_{82}{}^*$ event should have a gamma. Typically a few._

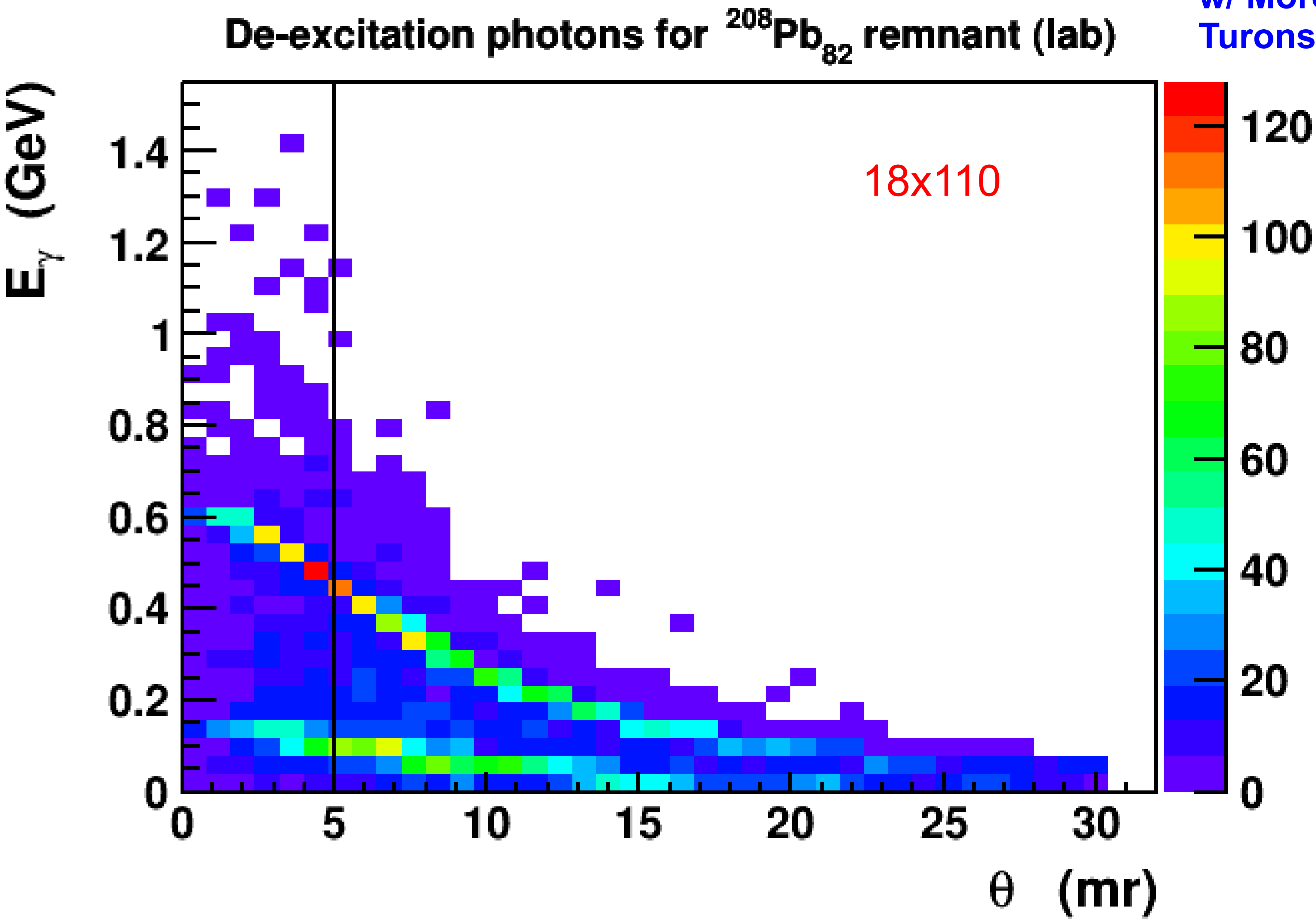
<u>At eRHIC (100):</u>

50% of γ's:

$\theta<10$ mrad w/
E>260 MeV

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

w/ Morozov, Hyde, Turonski et al.



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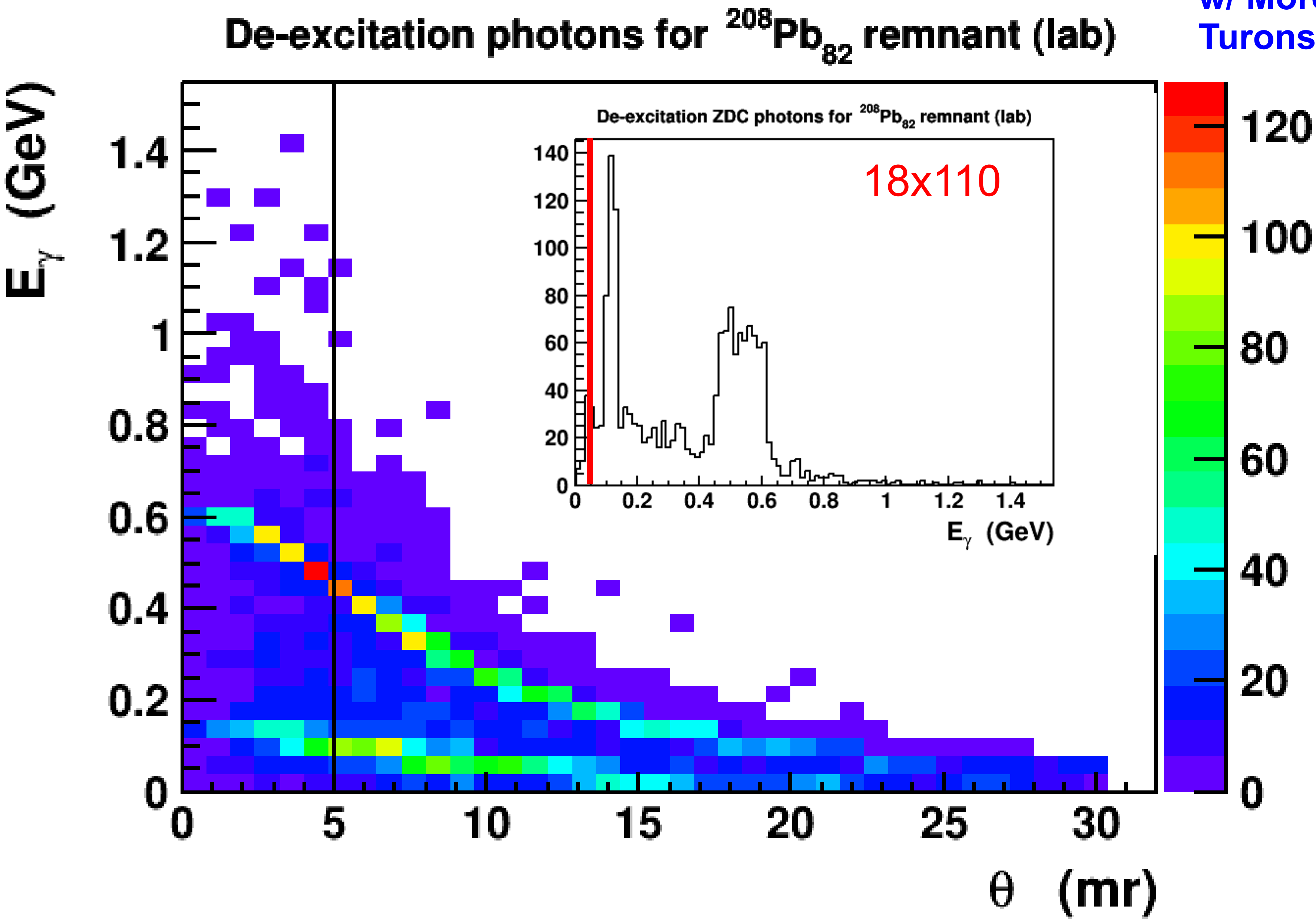
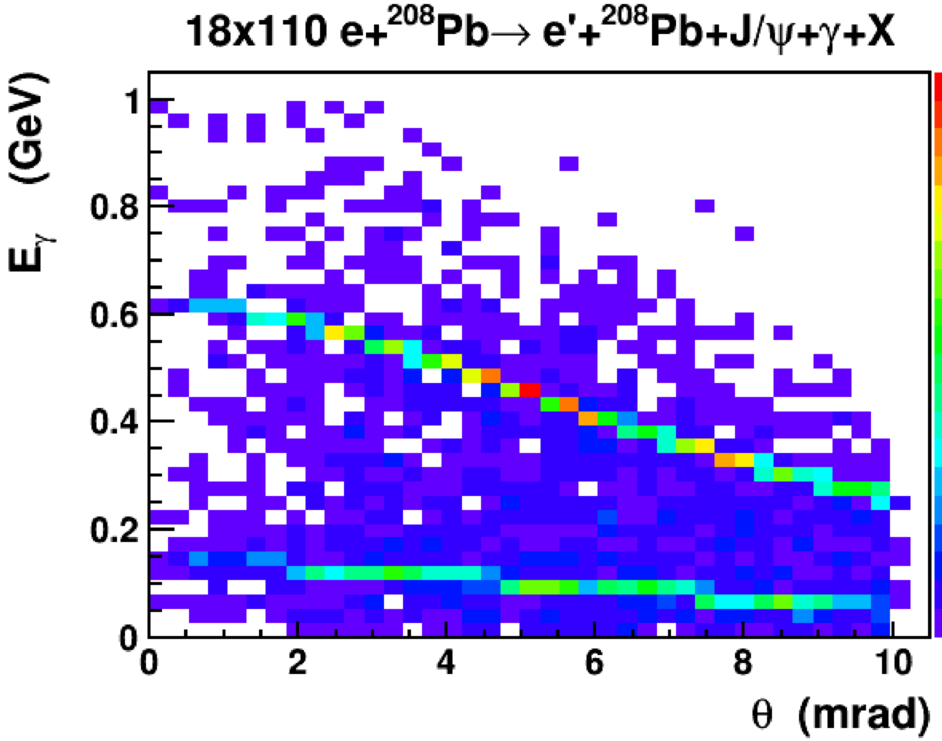
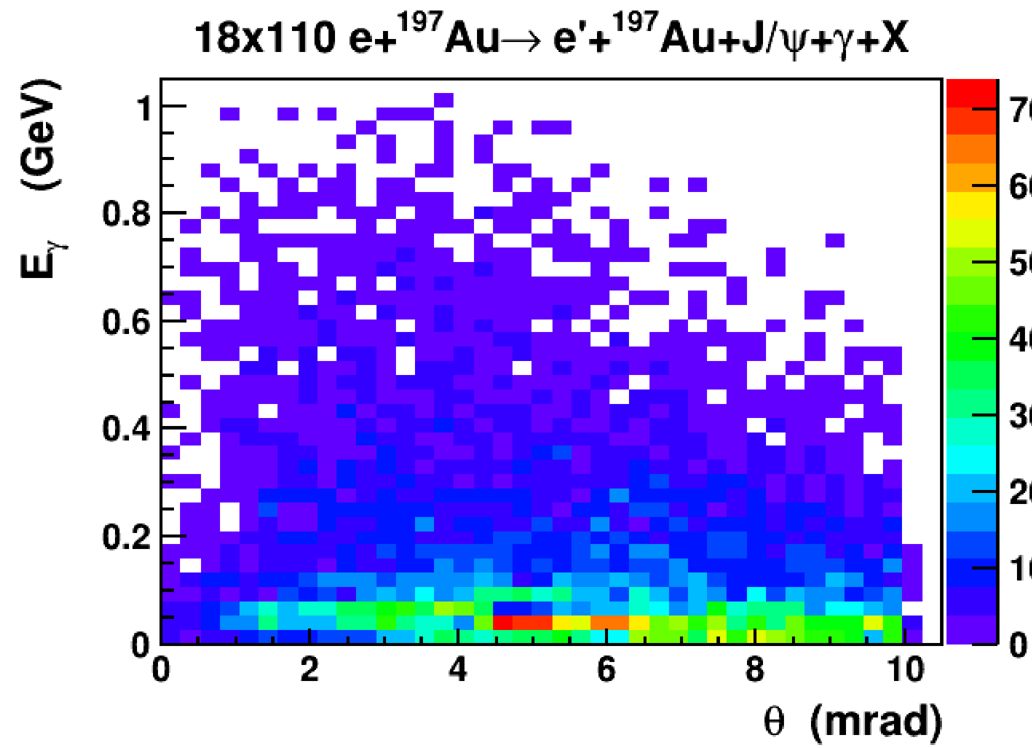


Photons from $^{208}Pb_{82}$ vs. $^{197}Au_{79}$

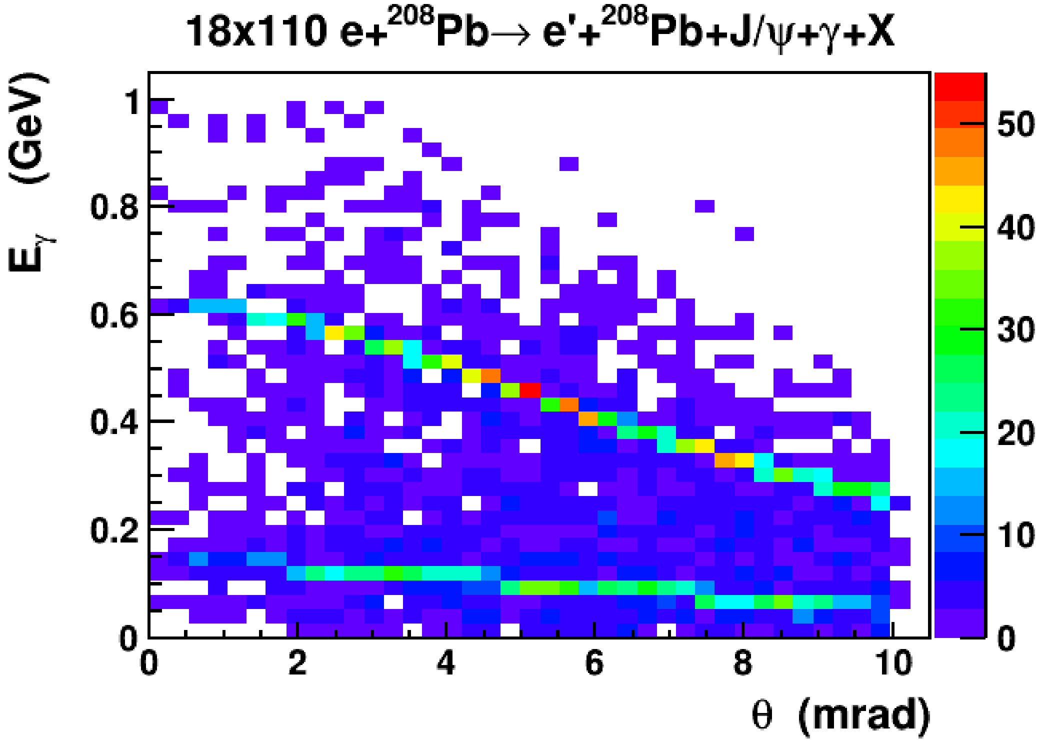


Pb much better than Au!

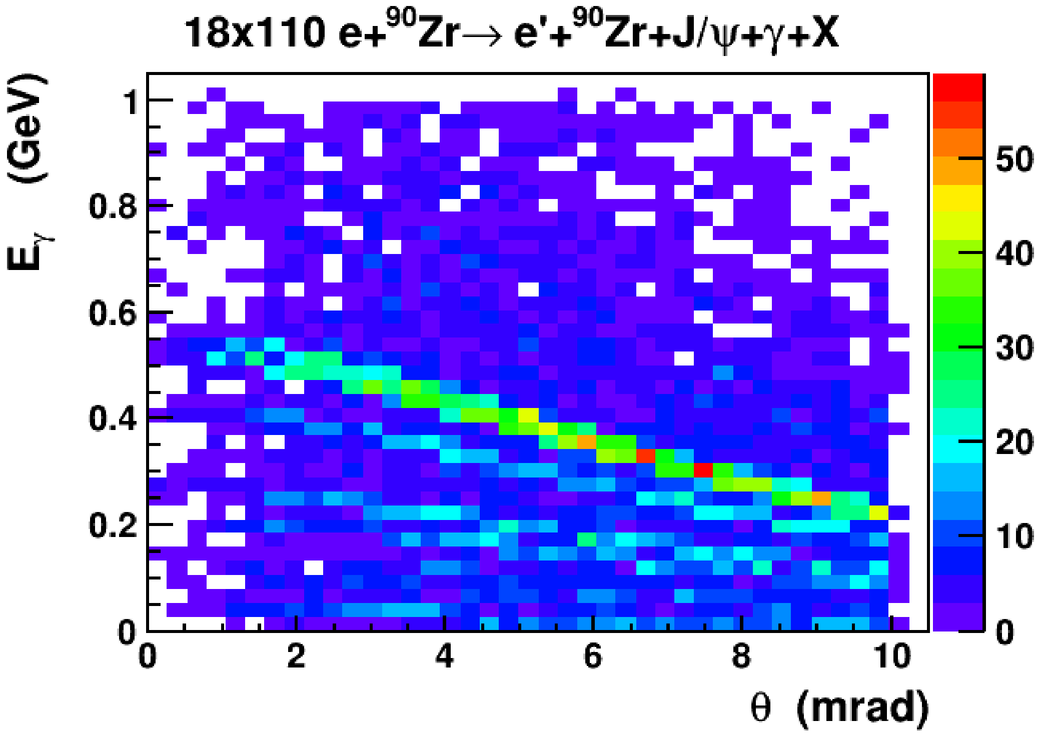
Bigger acceptance than 4.5mr would be valuable.



Photons from $^{208}Pb_{82}$ vs. $^{90}Zr_{40}$

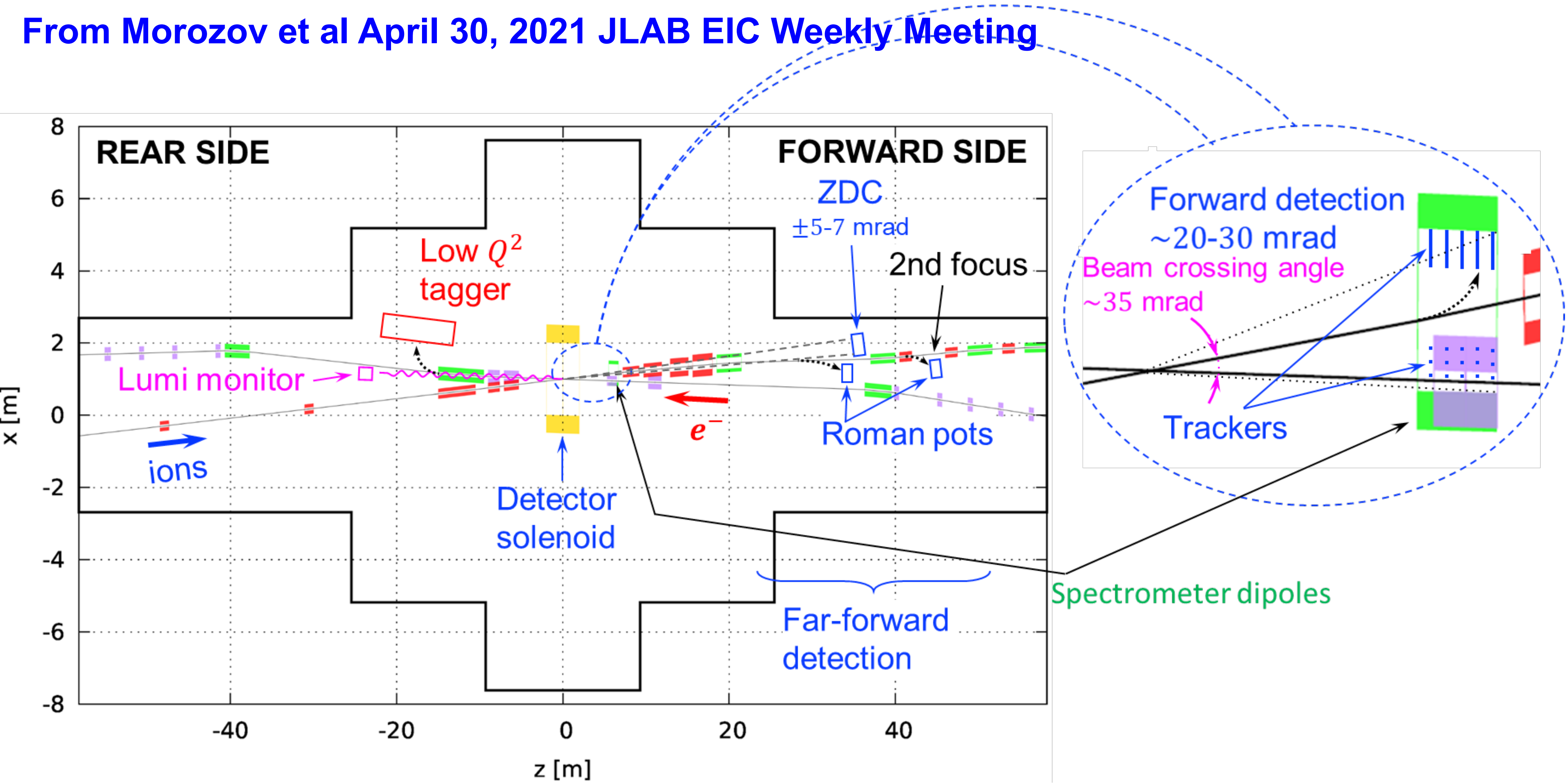


Pawel suggested that ^{90}Zr might be similar to Pb… Yes.



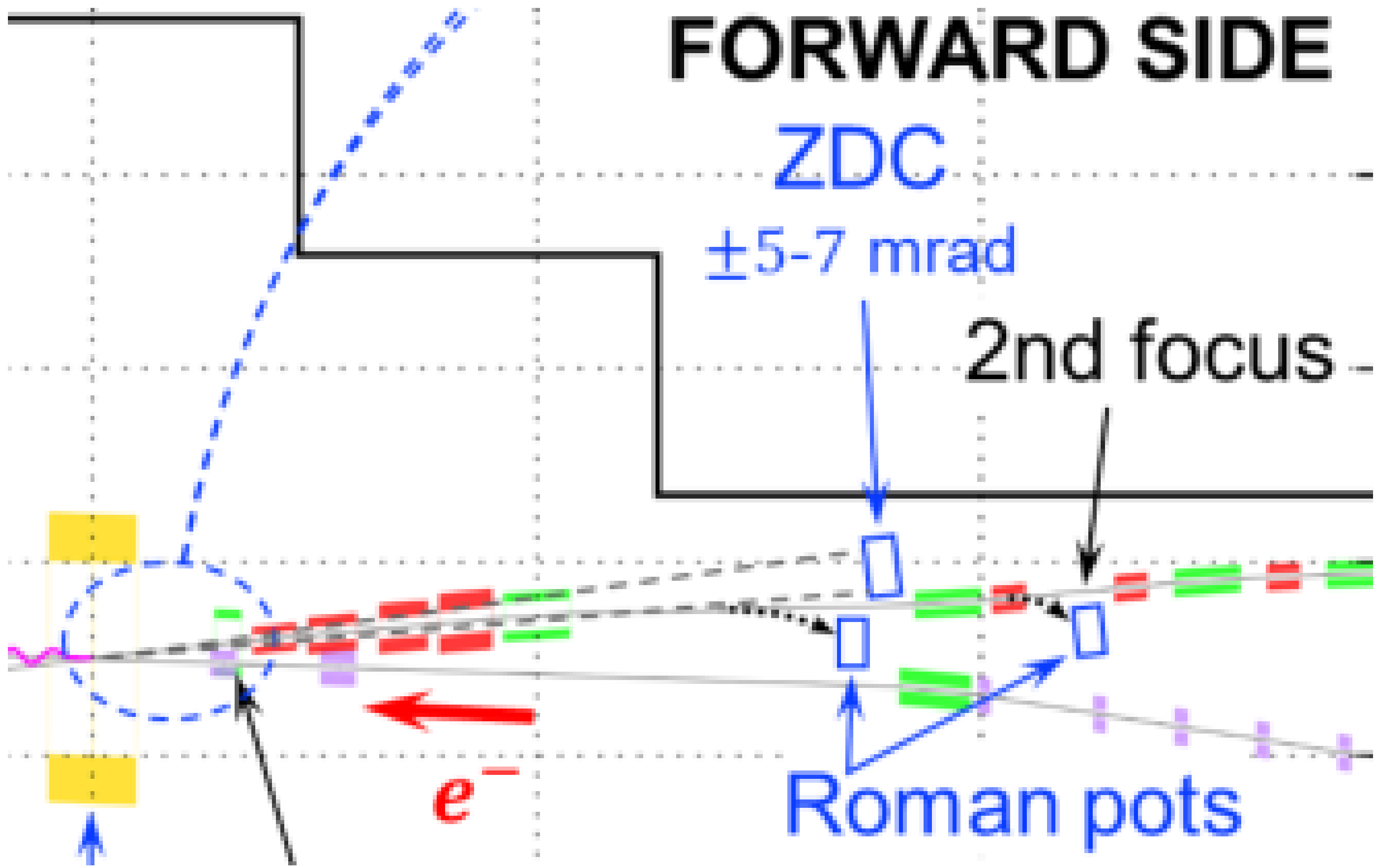
IP8 has a secondary focus point

From Morozov et al April 30, 2021 JLAB EIC Weekly Meeting



Secondary focus

Allows the detection of particles with rigidity, Z/p, near the beam.
Dispersion path to cause separation of particles.
Focus to allow the Roman pot to be close to pick up the separation.



What about IP8?

- Can we detect beam remnants with ΔA=1 to improve the veto tagging of incoh. diffraction?
  - $^{208}Pb_{82}$ vs. $^{207}Pb_{82}$ rigidity difference of ~0.5%
  - $^{208}Pb_{82}$ vs. $^{207}Tl_{81}$ rigidity difference of ~0.75%
- Fallback (from Pawel) – what about $^{90}Zr_{40}$?
  - A-1 Rigidity differences 1.1% & 1.4%
- Caveat, even if we succeed in A-1 tagging, the first two minima also require good γ tagging. Larger than 4.5mr would help...

What needs doing?

1) Full GEANT simulation of IP8.

2) Particle gun with ^{208}Pb with p_T=0 and p/A ranging ±2% from nominal value: 110 GeV.

3) What is the acceptance vs. p/A? (equiv. Z/p)?

4) If it looks promising, try BeAGLE e+Pb incoherent diffractive simulation and measure veto efficiency vs. -t.

5) If it looks more borderline, perhaps think about sar*t*re & BeAGLE study of ^{90}Zr; or push on design.

Conclusion

- Veto tagging of incoherent J/ψ production in e+Pb was considered important for physics in the WP & NAS document.
- Difficult @ IP6, so downplayed in the YR.
- Possible killer app for IP8 (ECCE?) due to secondary focus.
- Narrow window of time to study / affect the IP8 design. IP6 is pretty much frozen.