eRD17: BeAGLE

A Tool to Refine Detector Requirements for eA in the Saturation Regime

M.D. Baker*
MDBPADS Consulting

E.C. Aschenauer, J.H. Lee*
Brookhaven National Laboratory

L. Zheng
Central China Normal University

14-July-2017

*-co-PIs

You Were Right!

<u>From the Jan. 2017 EIC R&D Committee Report:</u>

The statement is made that BeAGLE has ‘over-excited’ the nucleus. This sounds potentially serious but the authors seem confident that they can easily fix it.

FIXED

The outline for future work and manpower on it seem realistic

ORIGINAL PROJECT ~ ON TRACK

[L]ine 11 of the Table hides potential challenges since it involves the role of diffractive processes as A increases. This will need better data ... to sort out, hence elements of this work will be an ongoing project for a considerable time.

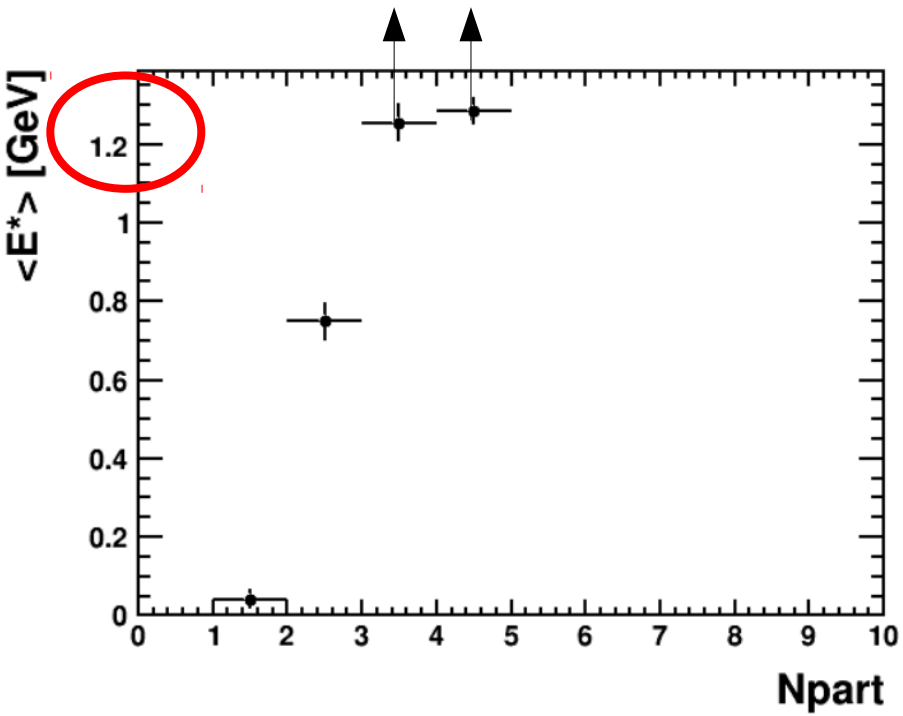
INDEED!
See extended proposal

Status of eRD17 Project

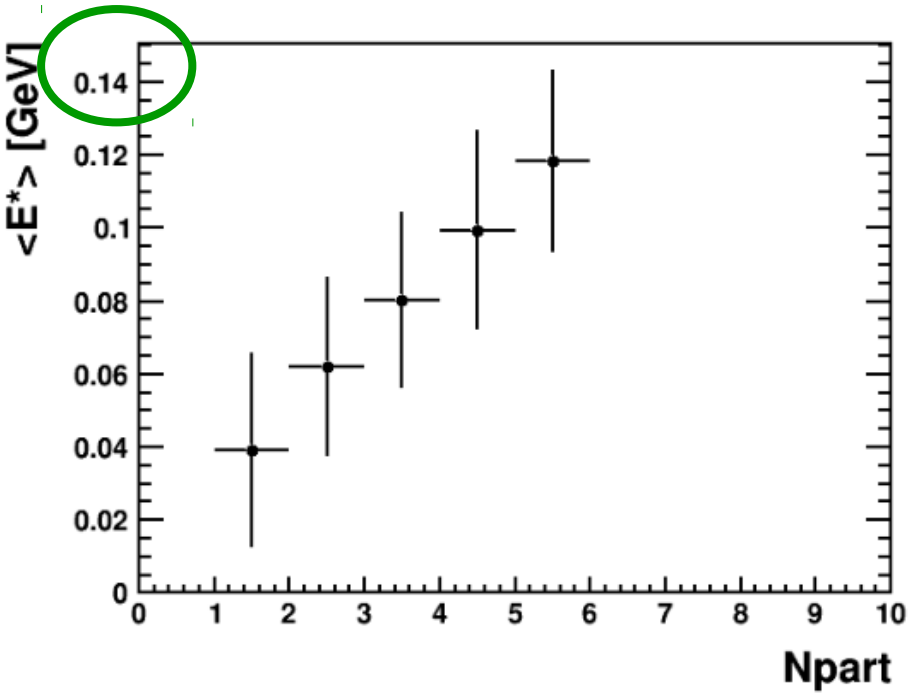
Feature added or error corrected	DPMJet Hybrid	BeAGLE 1/2017	BeAGLE 6/2017	BeAGLE 7/2017	BeAGLE (planned)
1. Hard processes correct.	YES	YES	YES	YES	YES
2. Tuned to ZEUS ep→p+X data	YES	YES	YES	YES	YES
3. IntraNuclear Cascade	YES	YES	YES	YES	YES
4. Nuclear evaporation/breakup	YES	YES	YES	YES	YES
5a. Multinucleon shadowing	NO	YES	YES	YES	YES
5b. Debug multinucleon shadow.	NO	NO	YES	YES	YES
6a. Correct nucleon remnant (n/p)	NO	YES	YES	YES	YES
6b. Debug M_n vs. M_p	NO	NO	YES	YES	YES
7. Correct eA target rest frame	NO	YES	YES	YES	YES
8. Tuned to E665 μPb→n+X data	YES	YES/NO	YES	YES	YES
9. Shadowing coherence length	NO	NO	NO	NO	YES
10. Partial shadowing effect	NO	NO	NO	YES	YES
11. Process-specific A dependence	NO	NO	Next Year	Next Year	FY2018
12. Tuned to more E665 μA data	NO	NO	Progress	Progress	FY2019
13. FS p_F for hard process correct	NO	NO	NO	NO	YES

Excitation energy makes sense now

BUGGY (from January)

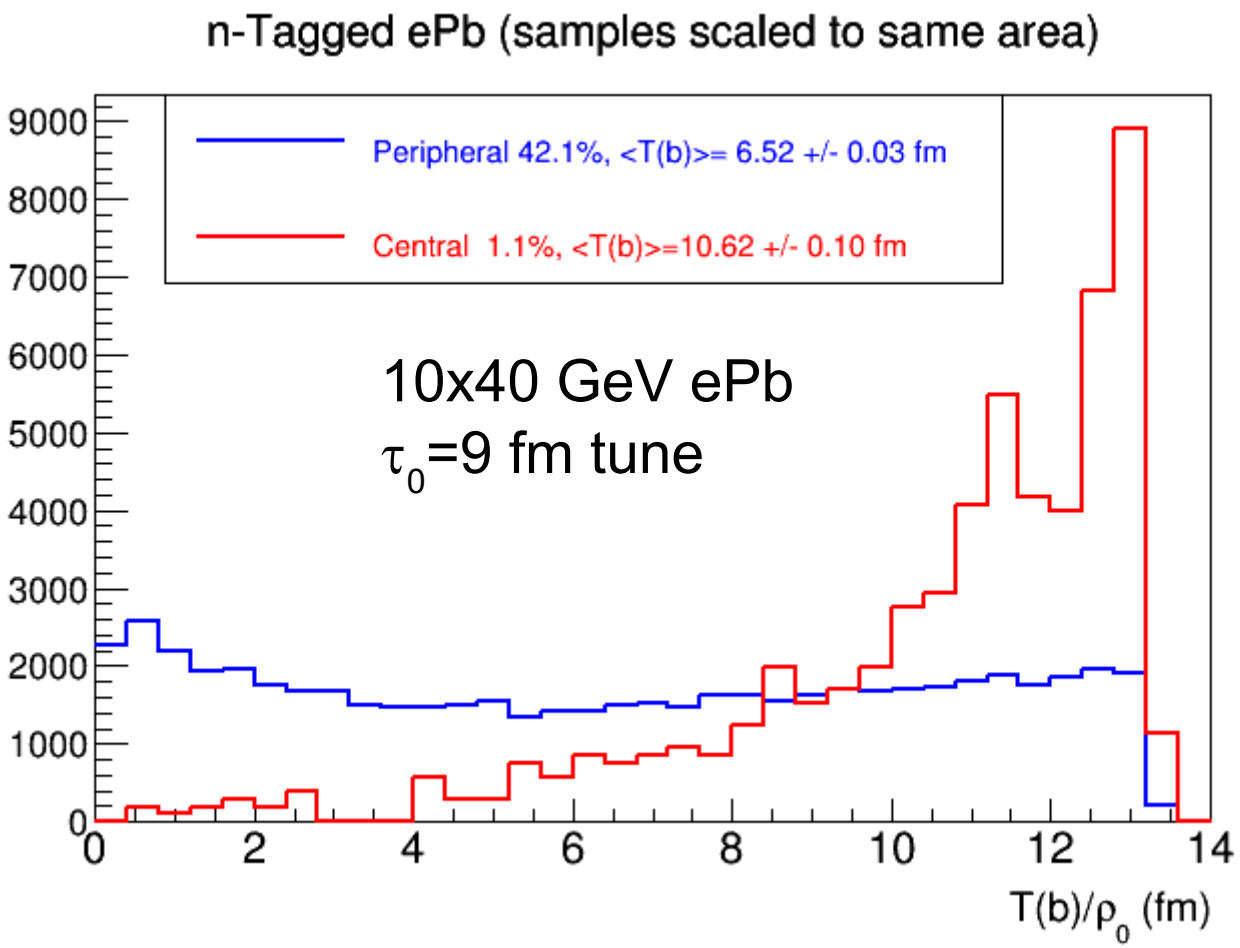


Current Result (genShd=3)



e+Au 10x100 GeV

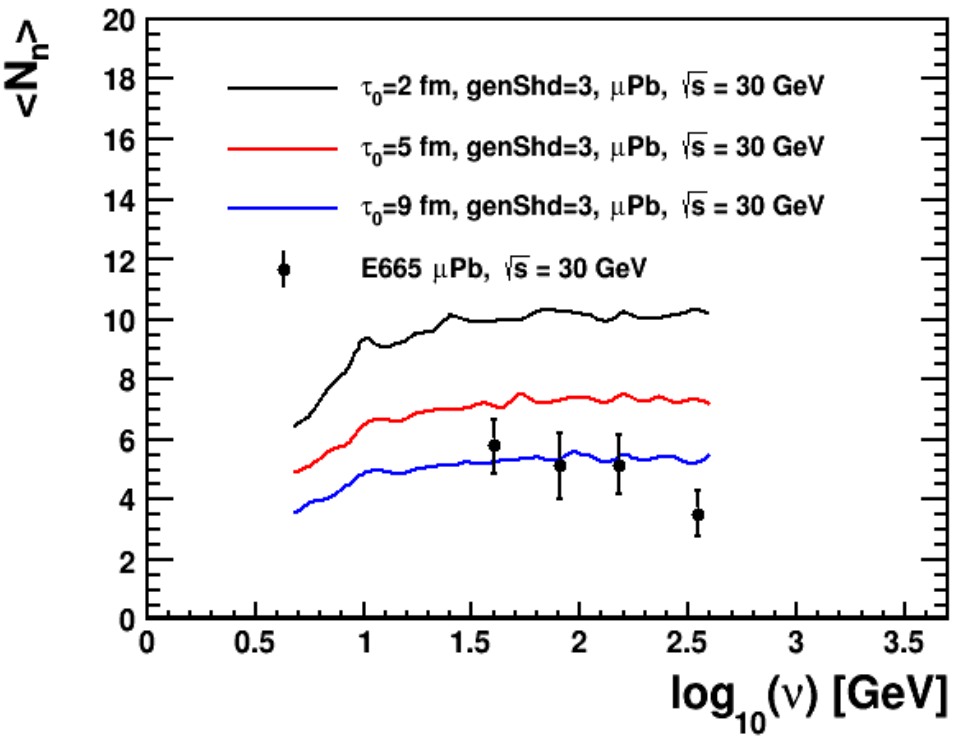
Geometry tagging works

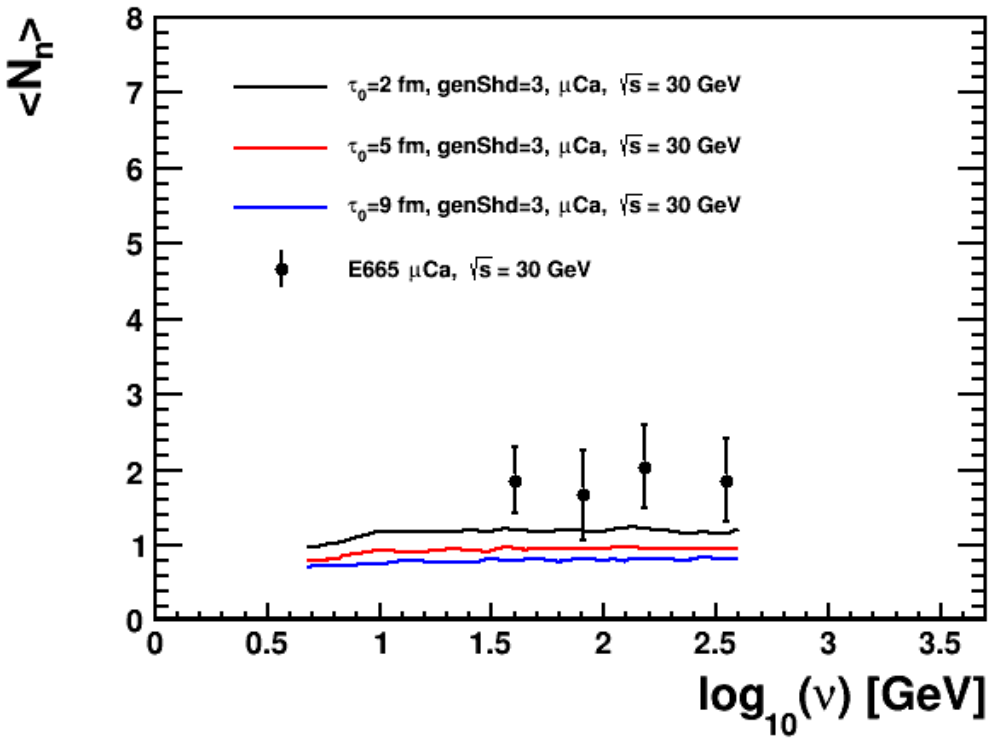


Room for improvement with charged particle detection

Tune to E665 neutron data

E665, PRL 74 (1995) 5198



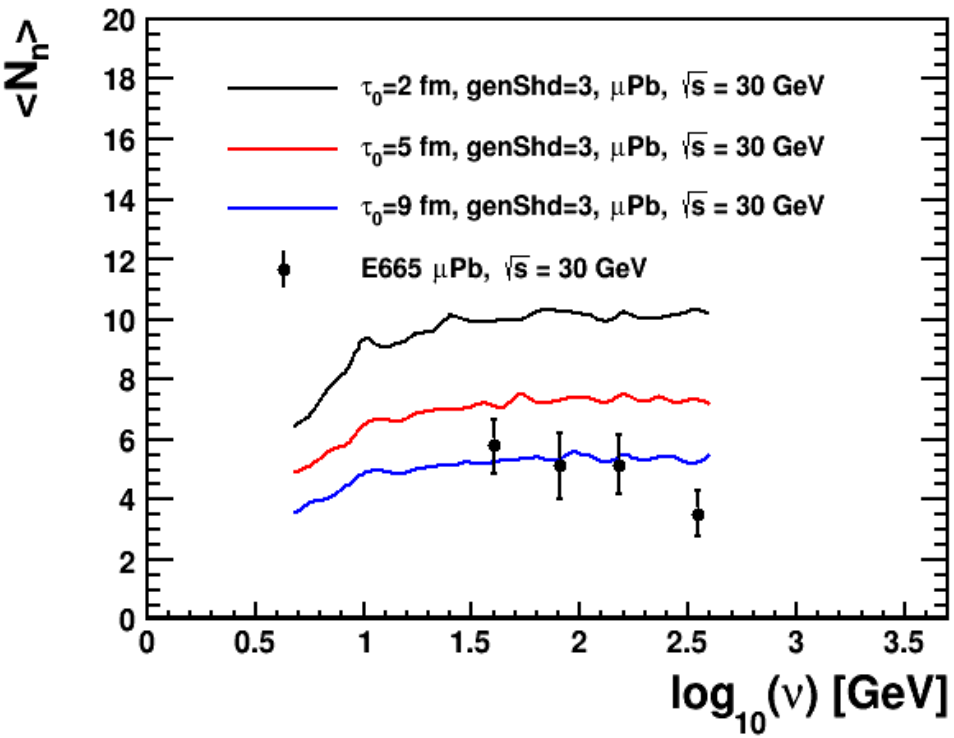


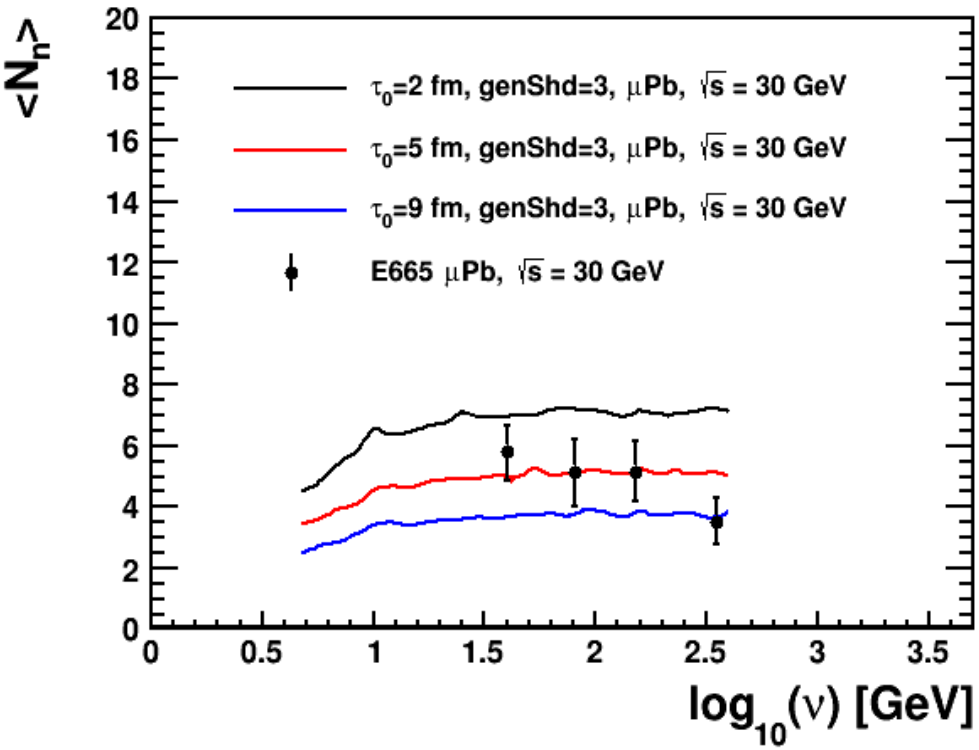
E665 ePb prefers τ_0= 9fm. eCa τ_0< 2 fm

But this assumes no coherent diffraction e+Pb→ e+Pb+V

Revisit tune to E665 neutron data

E665 estimates coherent diffraction/total of 13% in μXe





0% CD/total
ePb prefers τ_0= 9fm.

30% CD/total
ePb prefers τ_0= 5 fm

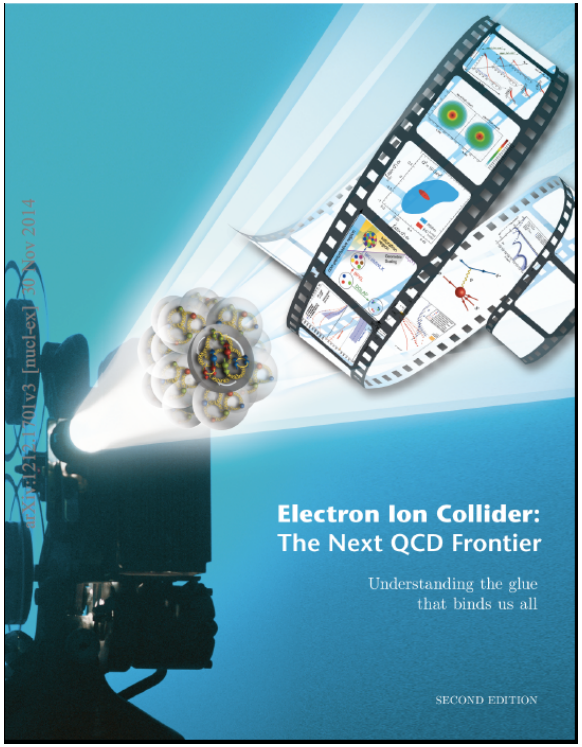
Really tuning BeAGLE

- Trigger/event selection similar in E665 Streamer Chamber and neutron papers.
- A real understanding of this data would require a better model of eN diffraction in BeAGLE as well as mixing in of Sar*t*re coherent eA diffractive events.

Status & Proposal in a nutshell

- Original idea from July 2015 mostly fulfilled
  - BeAGLE in use at JLAB & BNL
  - Minor tweaks remain for DIS
  - Tuning difficult due to paucity/complexity of data.
- Extended proposal
  - Extend BeAGLE to handle incoherent diffraction
  - Then tune to E665 charged+neutral & pA/AA UPC
  - Essential for optimizing forward detection for a key EIC e+A observable: spatial gluon distribution.

Diffraction in the White Paper



"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."

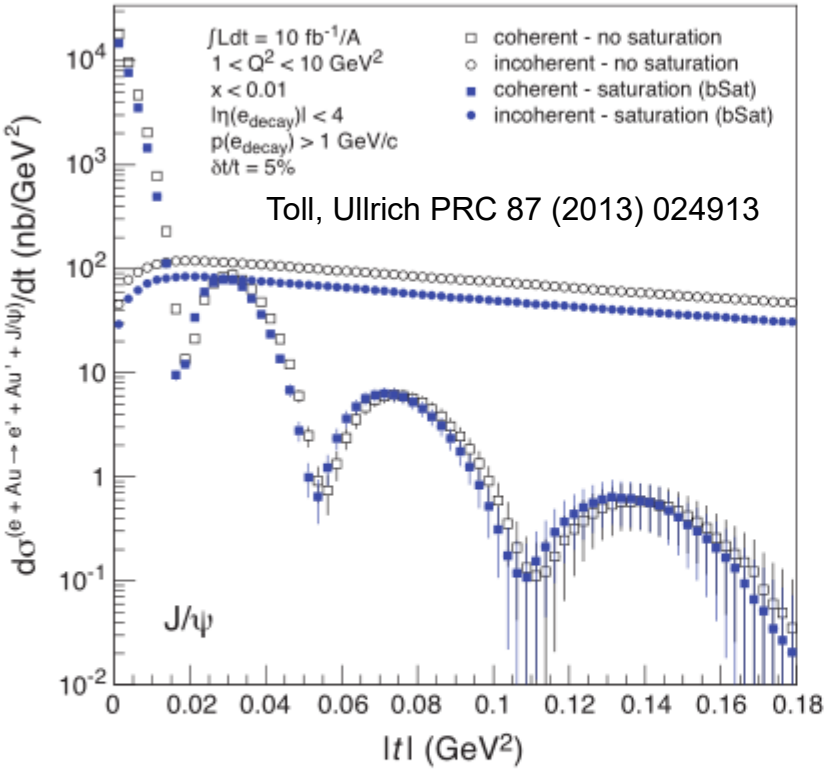
So exactly the type of problem that BeAGLE was designed to study and very well aligned with EIC R&D goals.

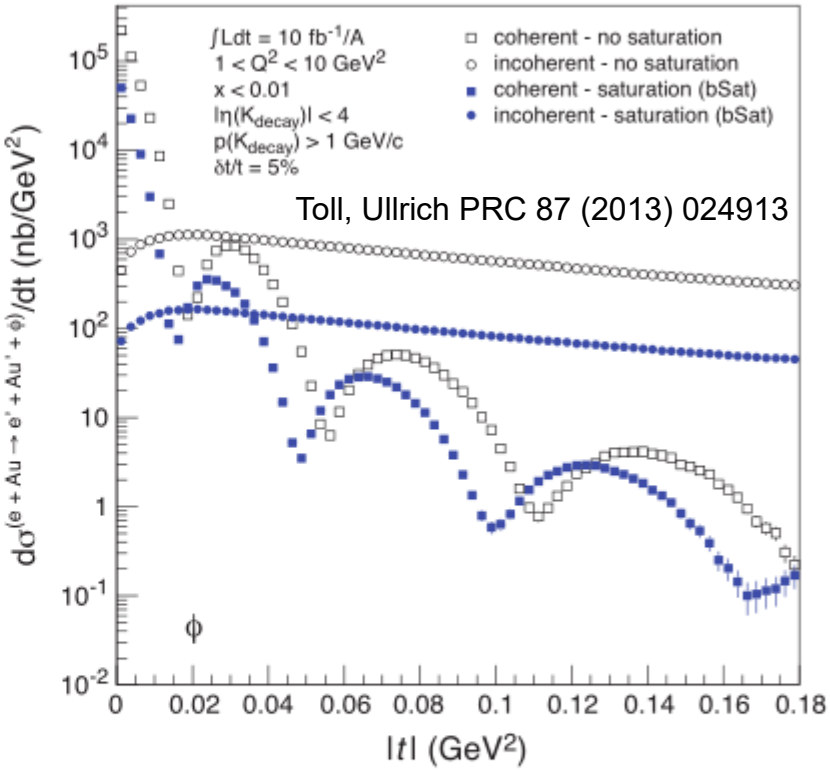
But BeAGLE needs upgrading to meet this challenge.

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

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

Starting Point

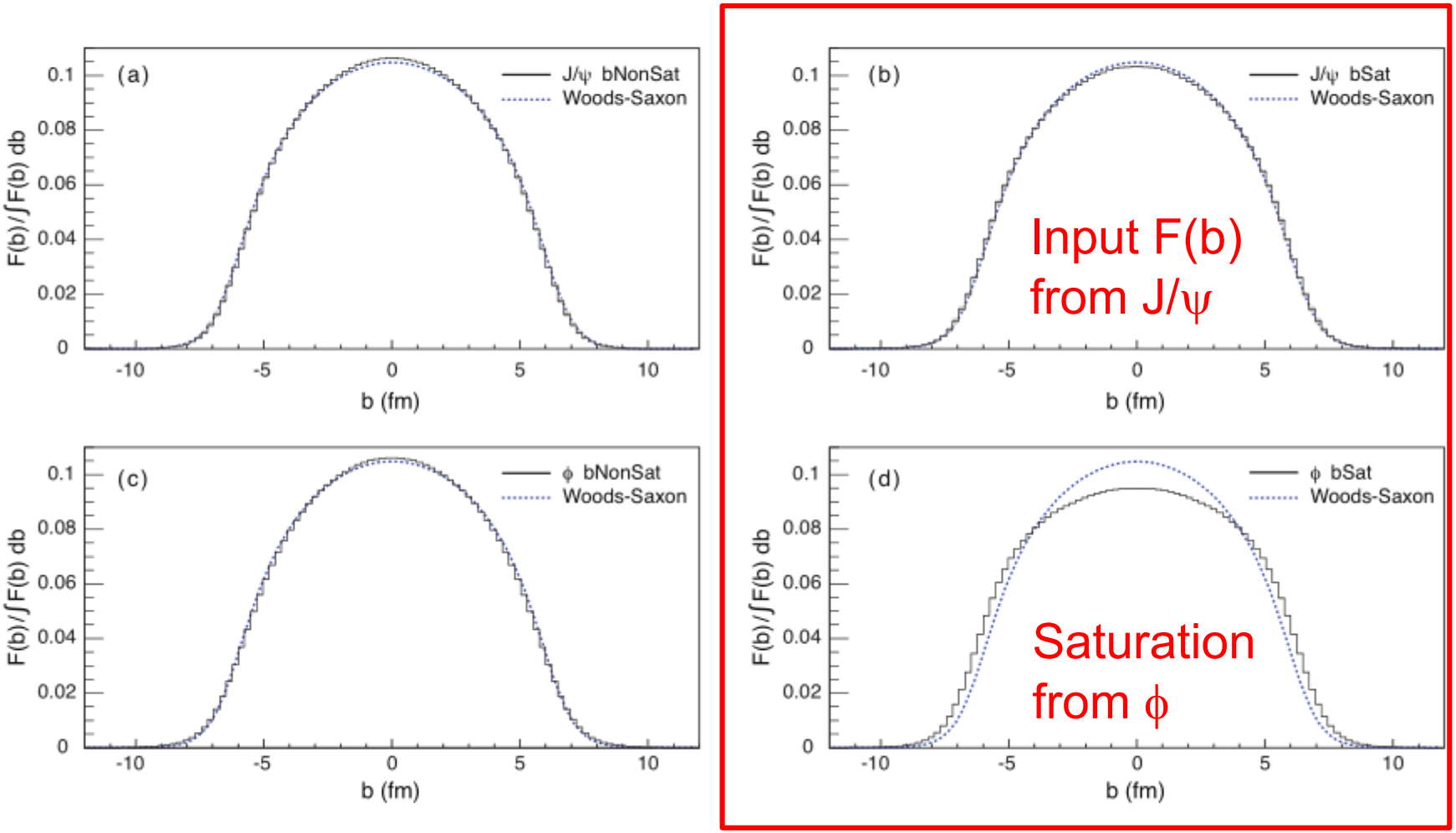




Reminder:

- 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

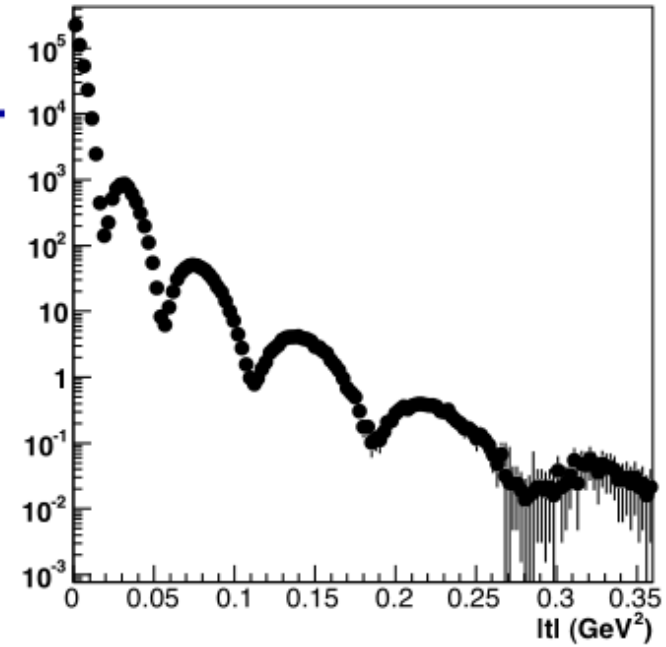


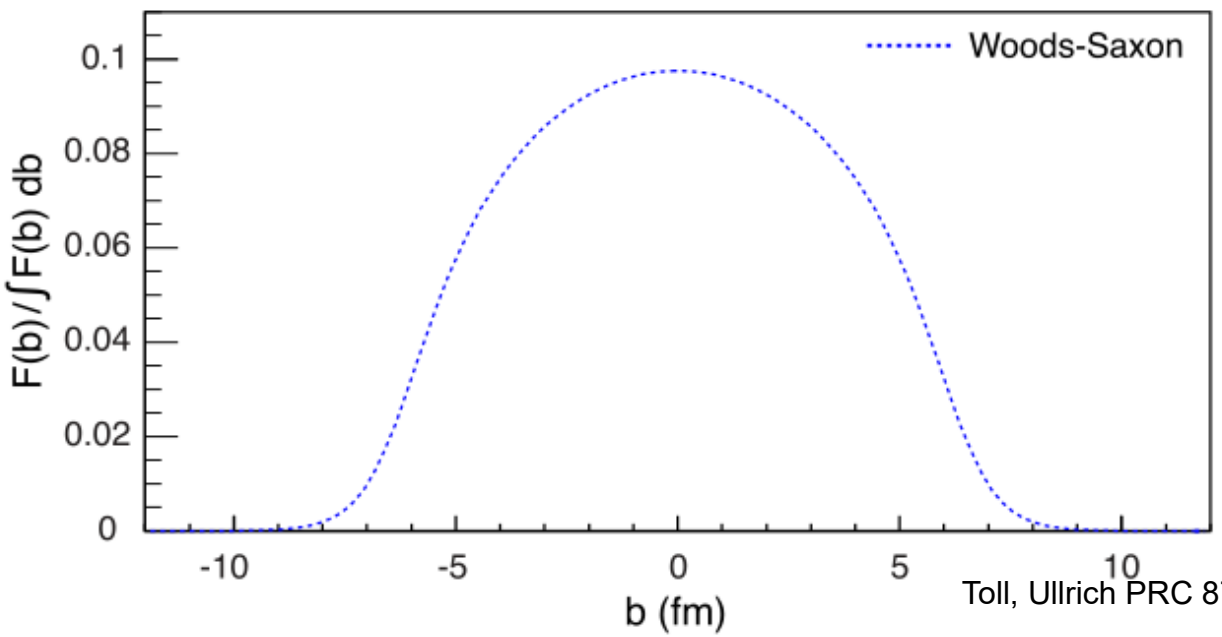
Toll, Ullrich PRC 87 (2013) 024913

t-Range

ϕ bNonSat:

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



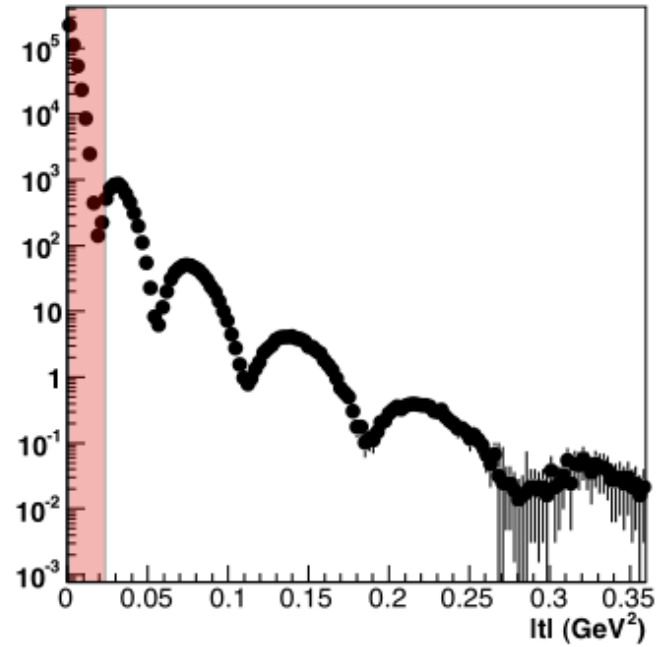


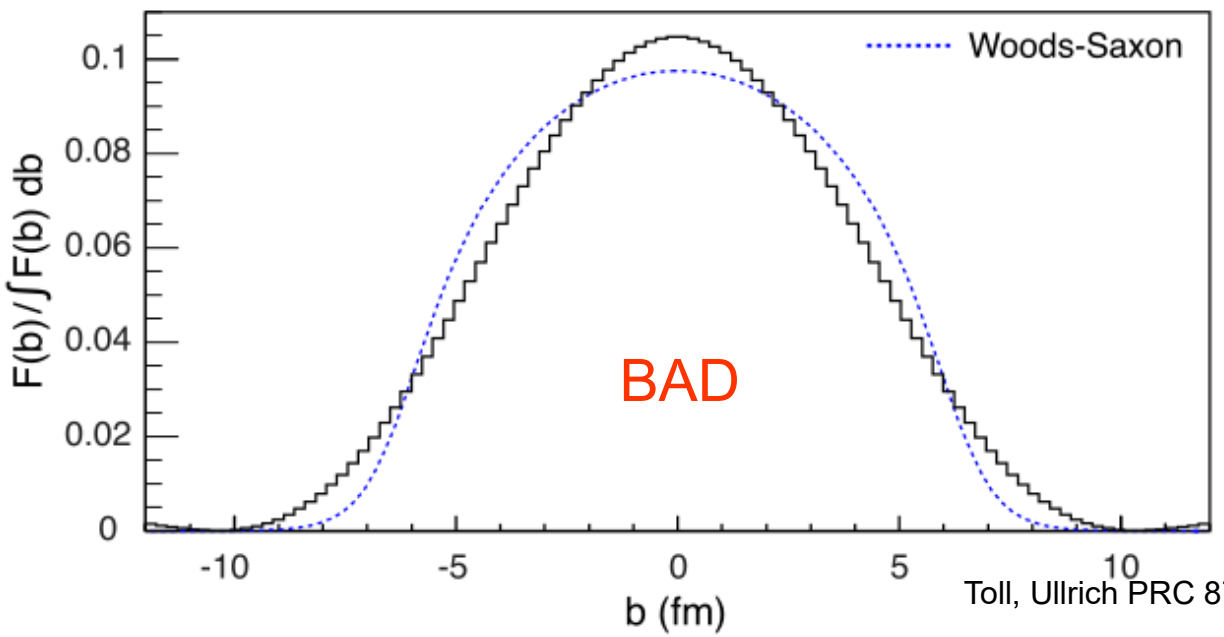
Toll, Ullrich PRC 87 (2013) 024913

t-Range

ϕ bNonSat:

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





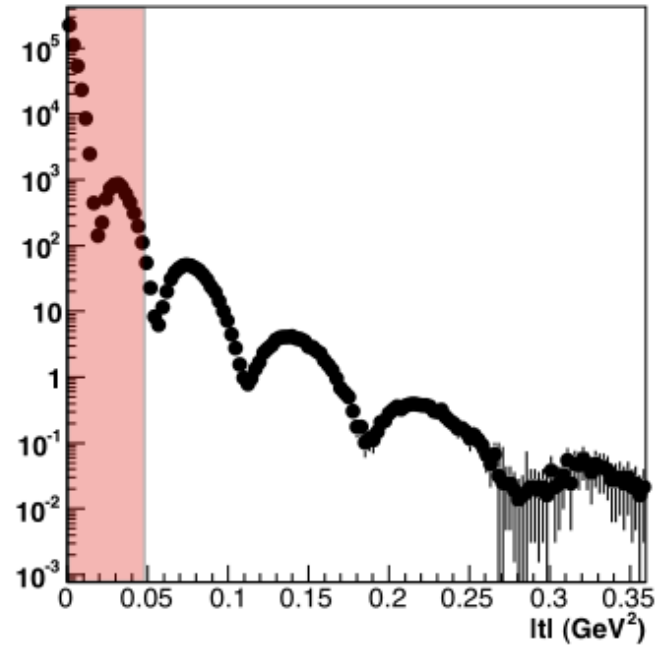
Toll, Ullrich PRC 87 (2013) 024913

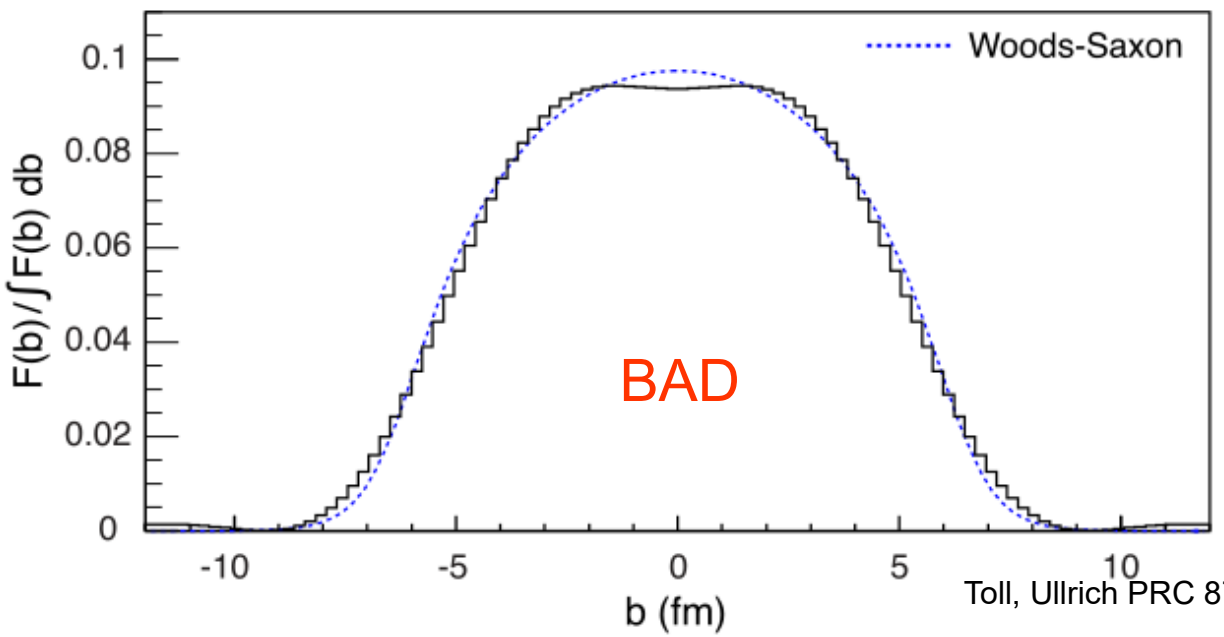
7

t-Range

ϕ bNonSat:

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





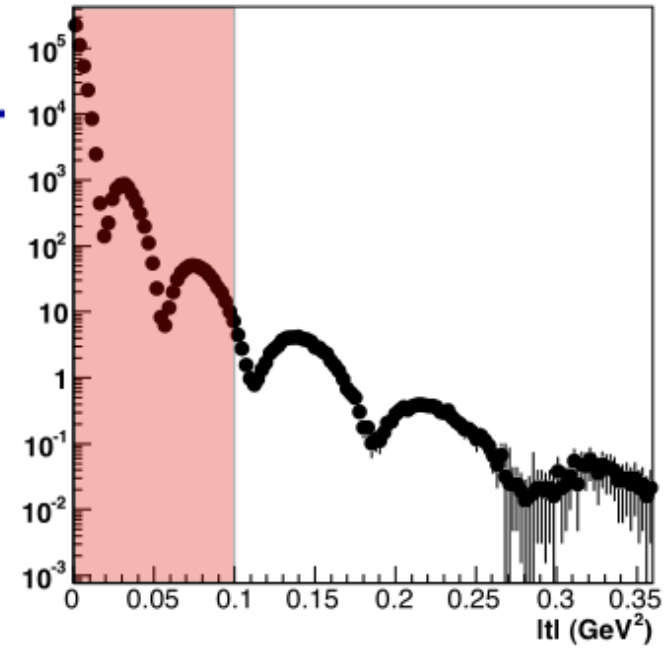
Toll, Ullrich PRC 87 (2013) 024913

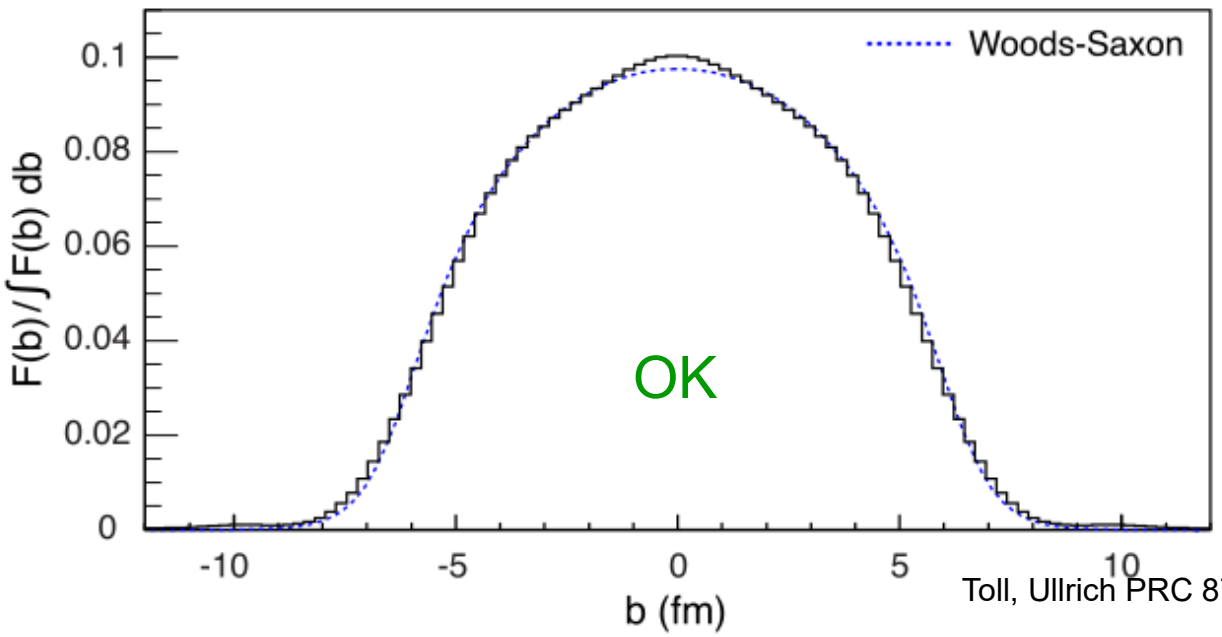
7

t-Range

ϕ bNonSat:

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





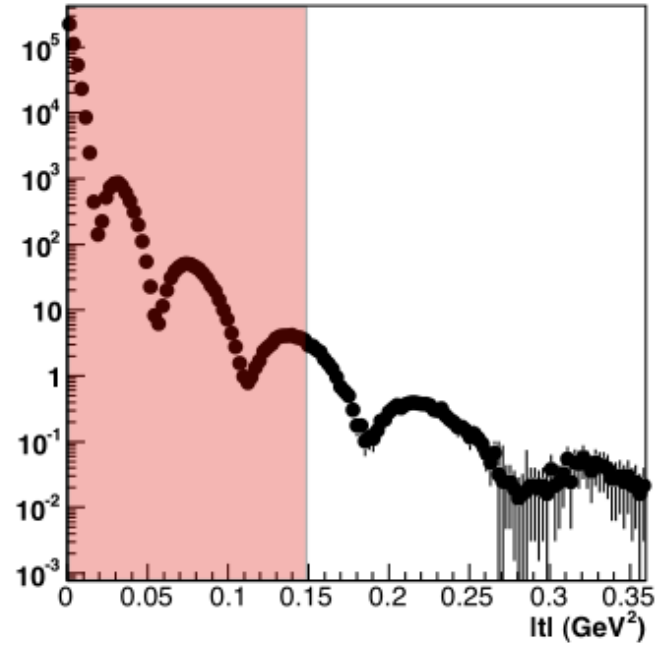
Toll, Ullrich PRC 87 (2013) 024913

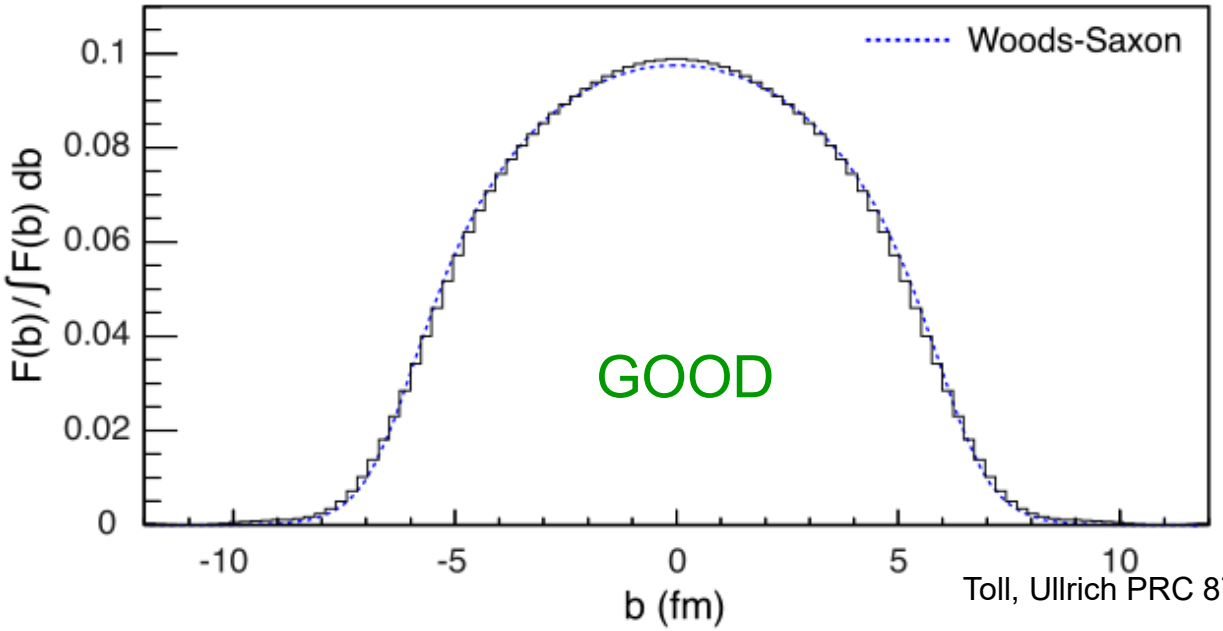
7

t-Range

ϕ bNonSat:

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





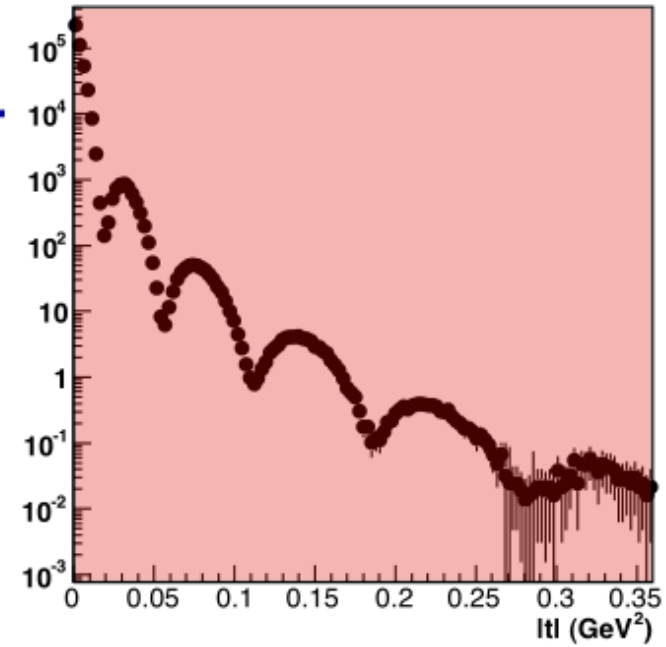
Toll, Ullrich PRC 87 (2013) 024913

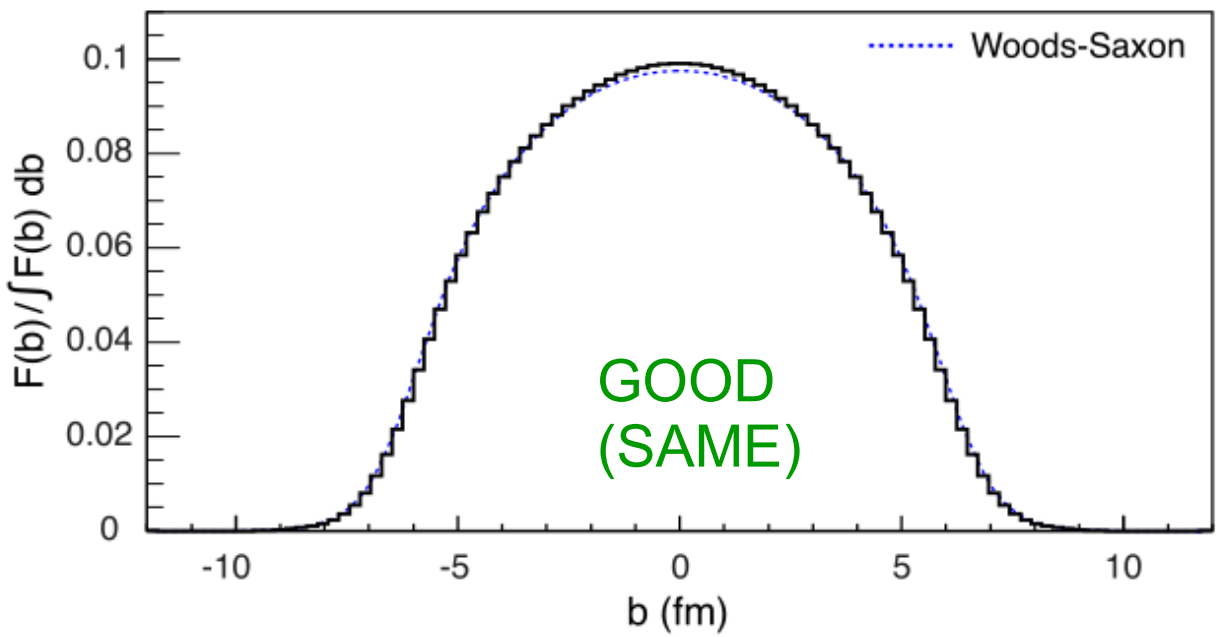
7

t-Range

ϕ bNonSat:

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



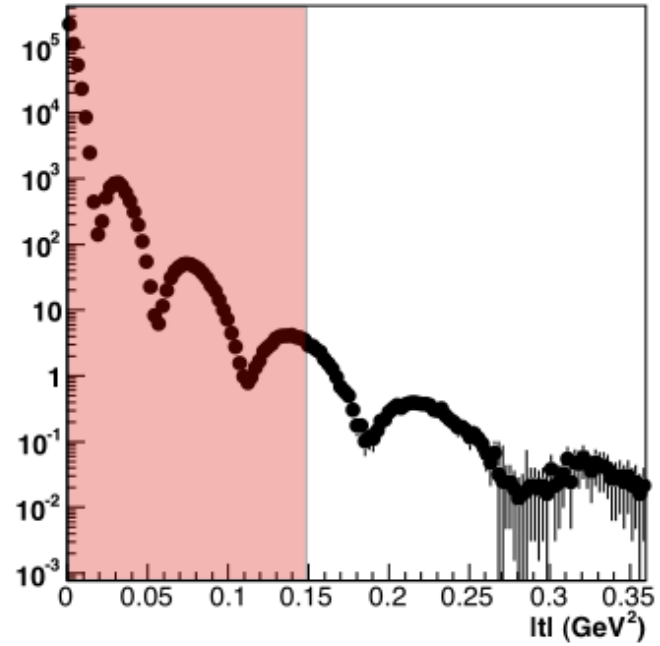


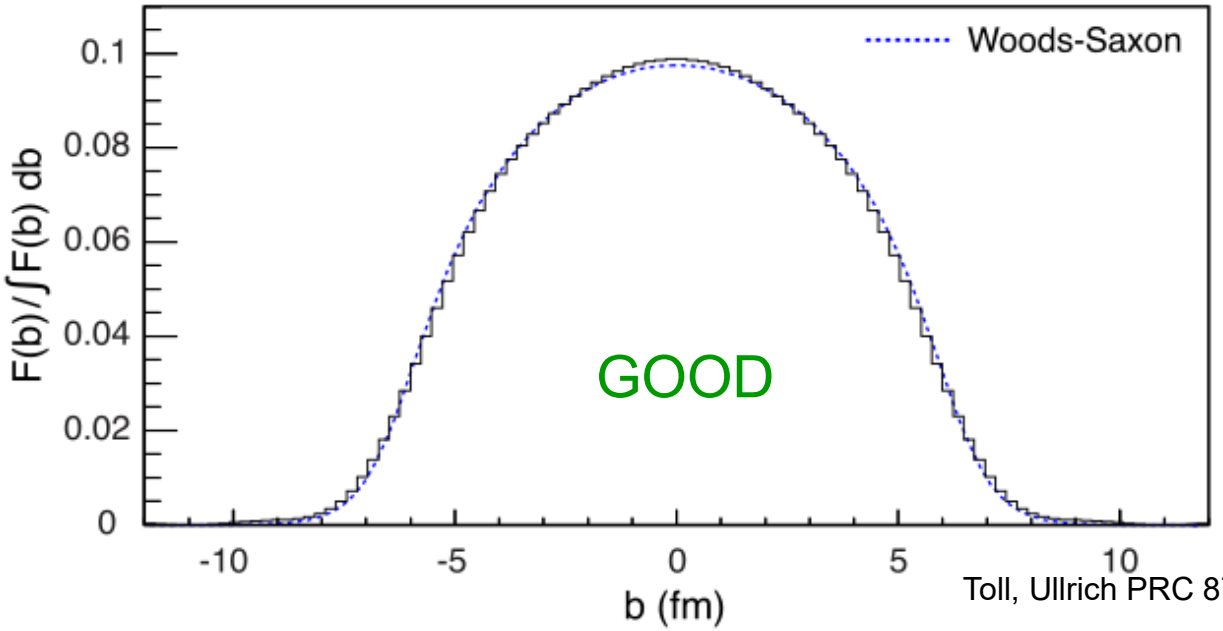
7

t-Range

ϕ bNonSat:

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

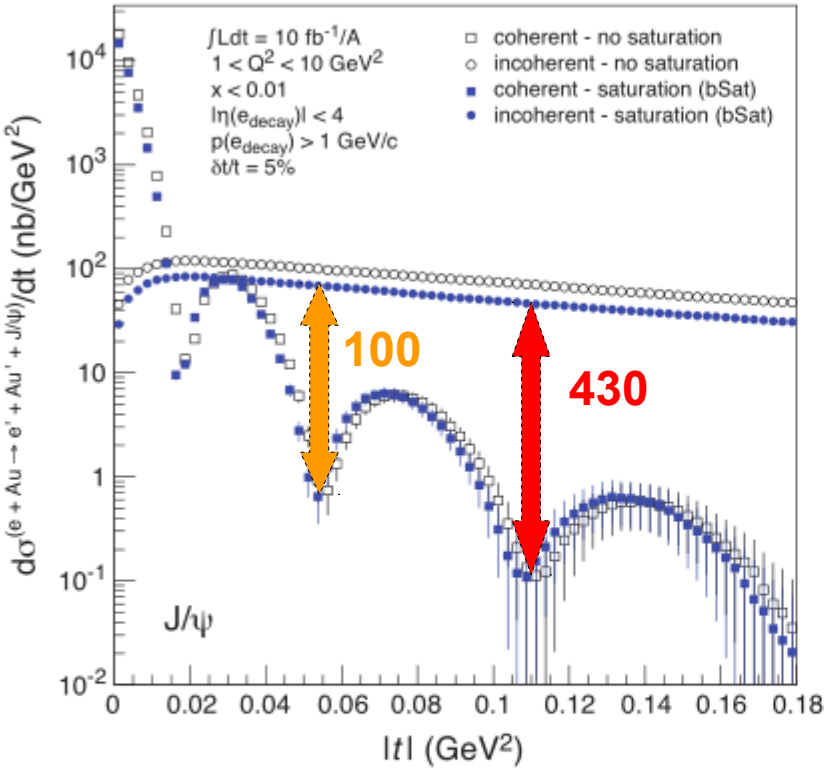


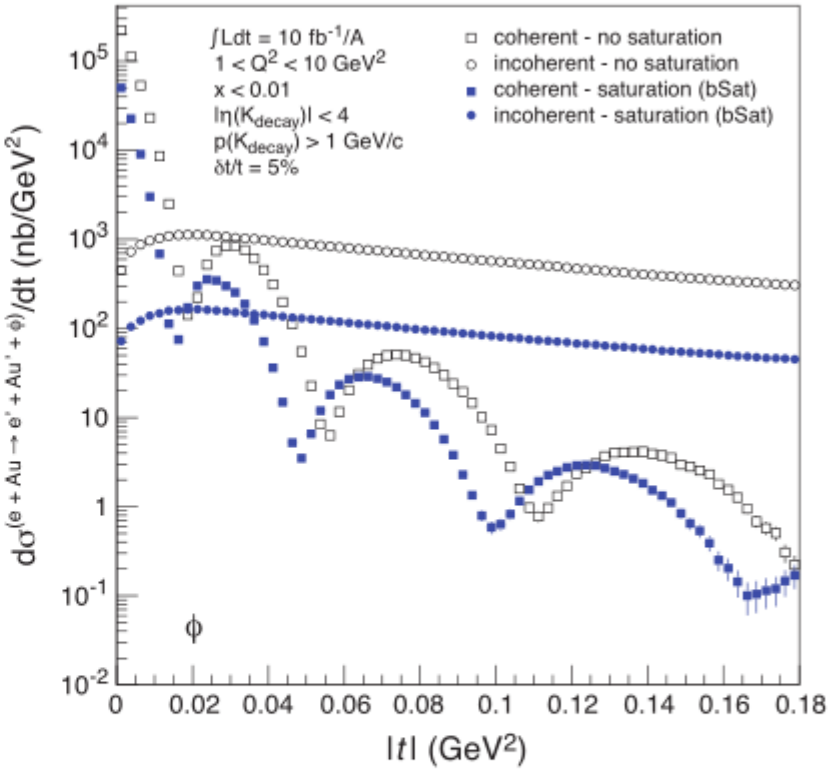


Toll, Ullrich PRC 87 (2013) 024913

7

Starting Point





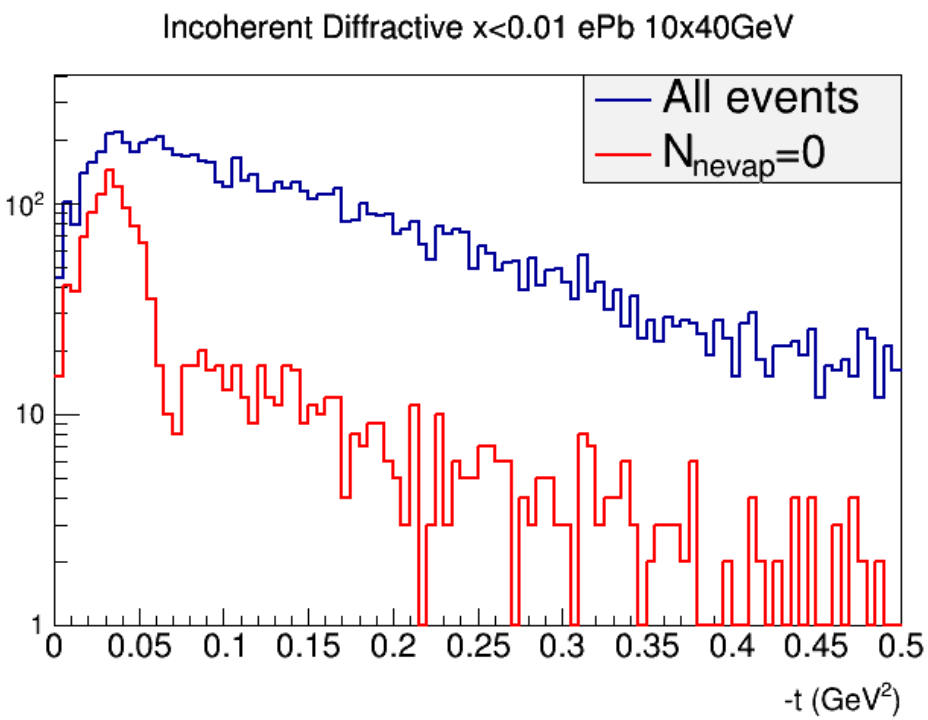
Toll, Ullrich PRC 87 (2013) 024913

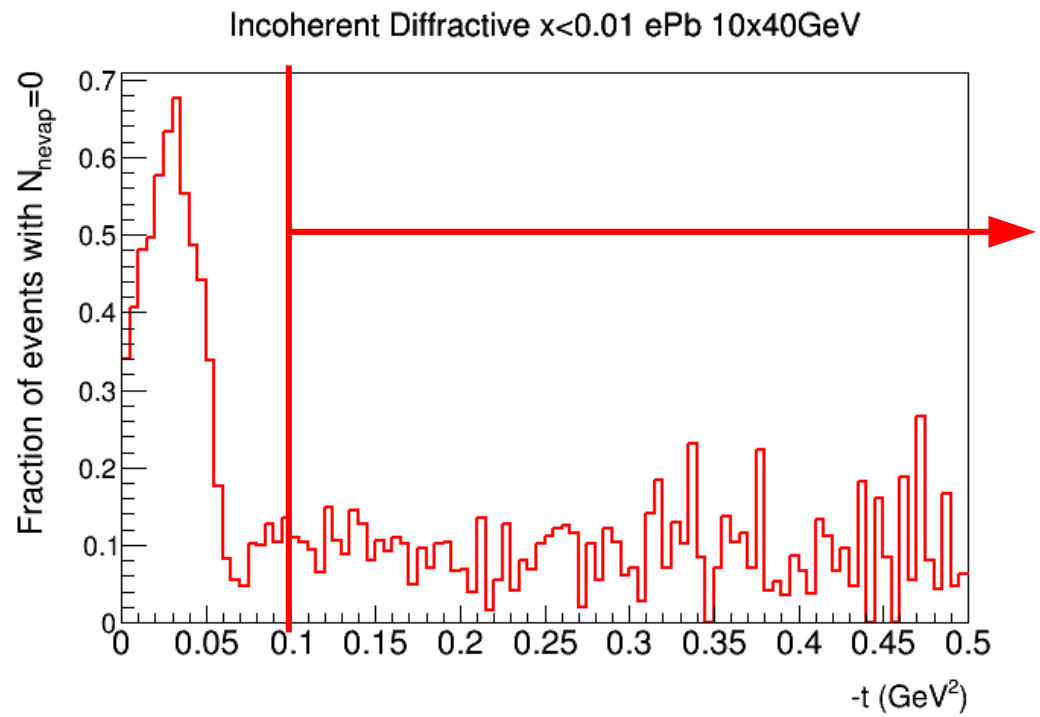
Reminder:

- 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

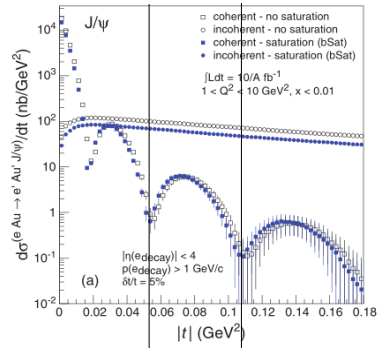
N_{nevap} veto inefficiency

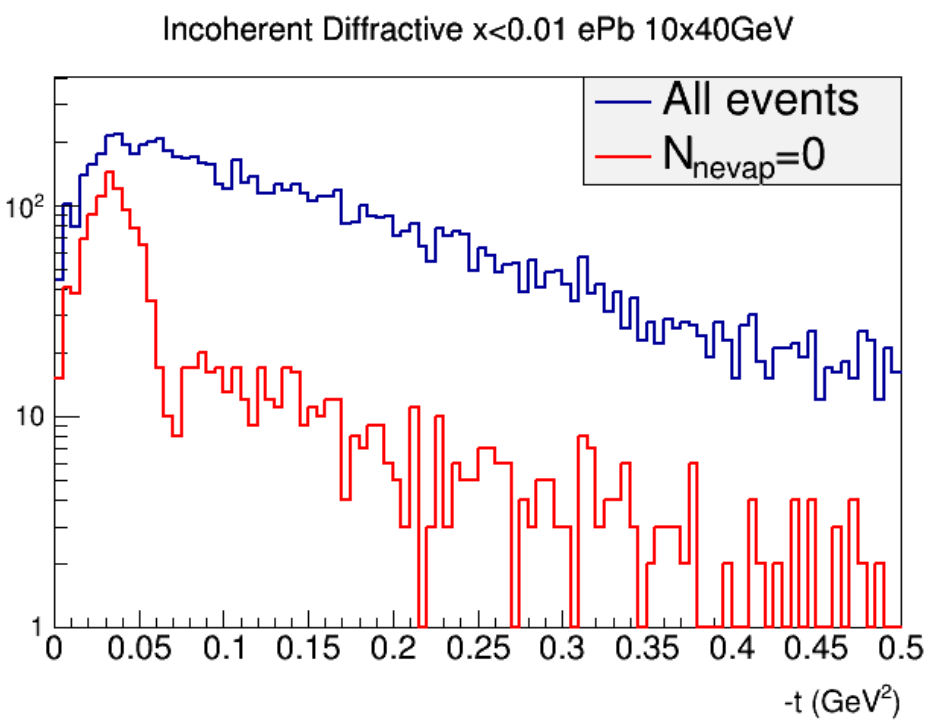
Target Fraction < 1/1300 = 0.00077

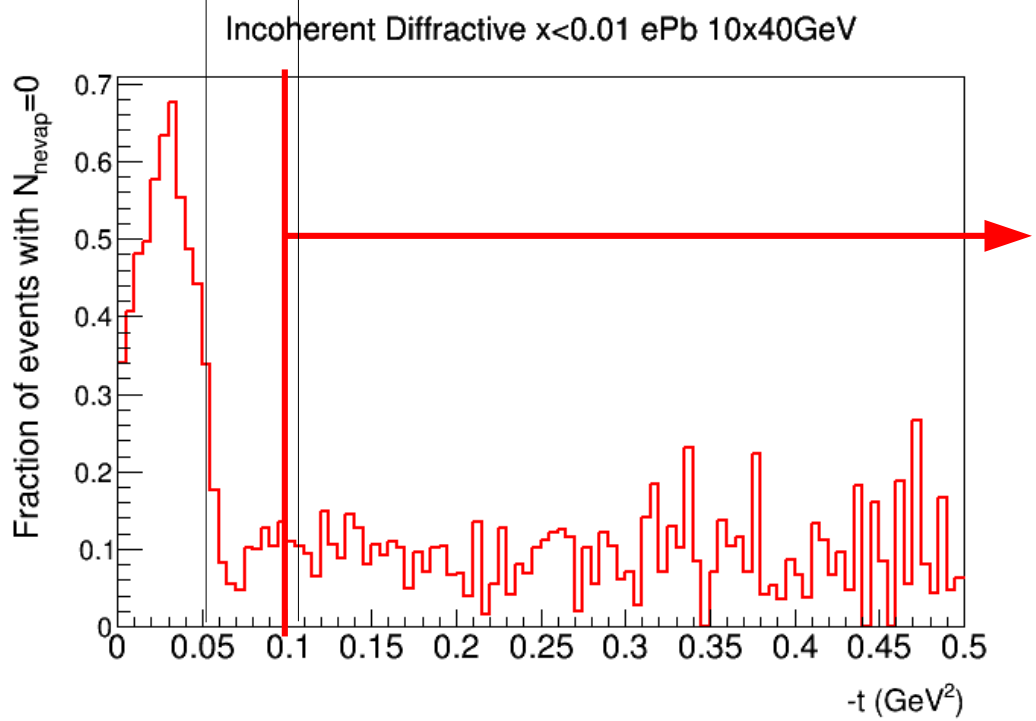




N_{nevap} veto inefficiency

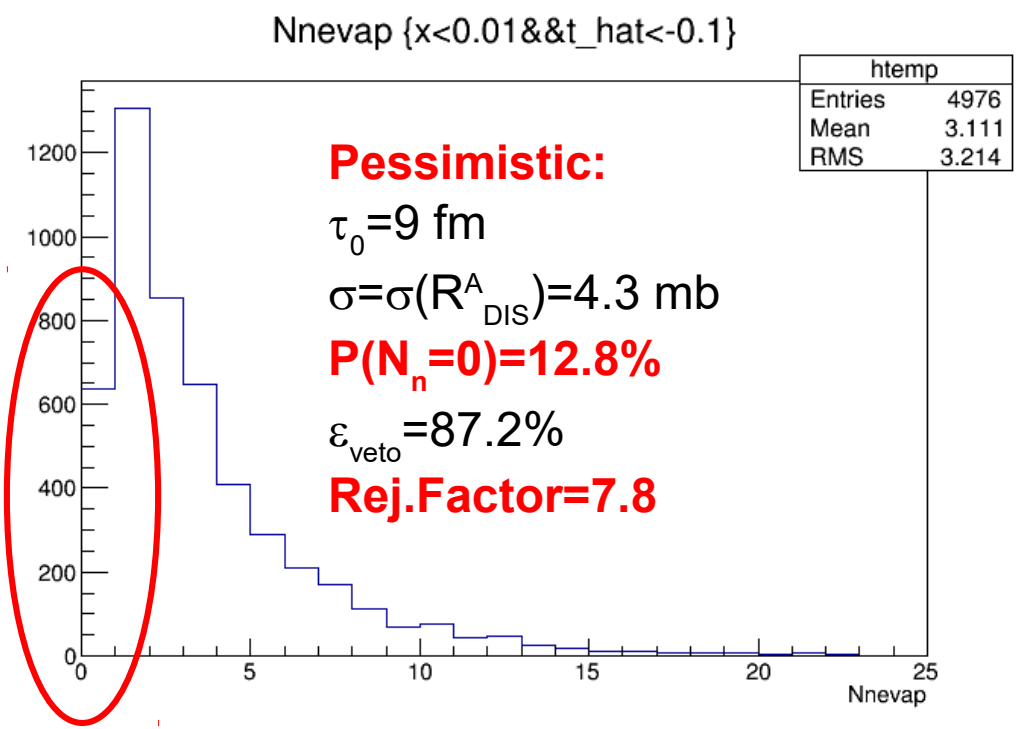


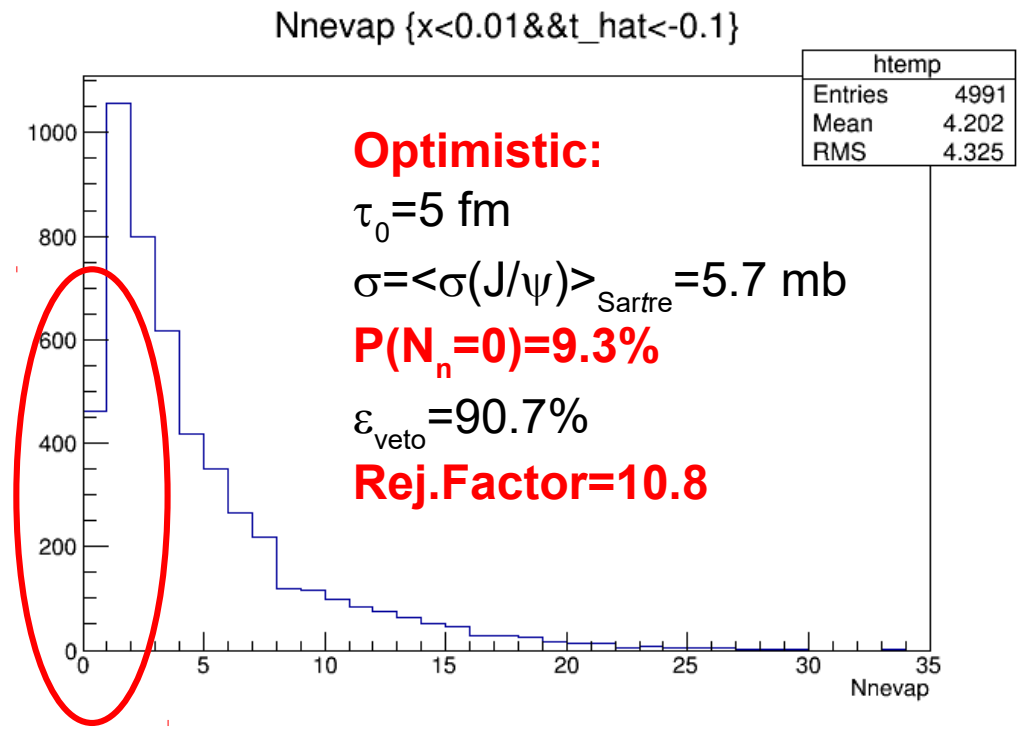




Veto (In-)efficiency

Exclusive vector meson incoherent diffraction for 10x40 GeV ePb in BeAGLE





Rejection factor goal: 100-1300 (S:N 1:1 @ 2nd dip to S:N 3:1 @ 3rd dip)

Evaporation neutrons alone are not sufficient to veto incoherent diffraction.

The key issue

- From the white paper:
  - Coherent diffraction in eA is a "golden" channel.
  - But to realize it we'll need a good, and well understood detector (RejFac up to 1300!).
  - May be a key driver for forward detector/IR design.
- BeAGLE – with a better description of diffraction – is essential for properly evaluating the design of the forward detectors/IRs.

FY2018 milestones

- FY2018 – improve diffractive description
  - Qtr1: Process-dependent cross-section:
    - (eN) diffractive events =(incoherent eA) are different than DIS in A-dependence and in multinucleon shadowing
  - RAPGAP in BeAGLE (as Pythia alternative)
    - Qtr2: Alpha release (code runs without crashing and results aren't obviously nuts)
    - Qtr3: Beta release (code appears to work but needs more testing)
    - Qtr4: Release – ready for prime time

FY2018 milestones

- FY2018 – improve diffractive description
  - Qtr1: Process-dependent cross-section:
    - (eN) diffractive events =(incoherent eA) are different than DIS in A-dependence and in multinucleon shadowing
  - RAPGAP in BeAGLE (as Pythia alternative)
    - Qtr2: Alpha release (code runs without crashing and results aren't obviously nuts)

60%

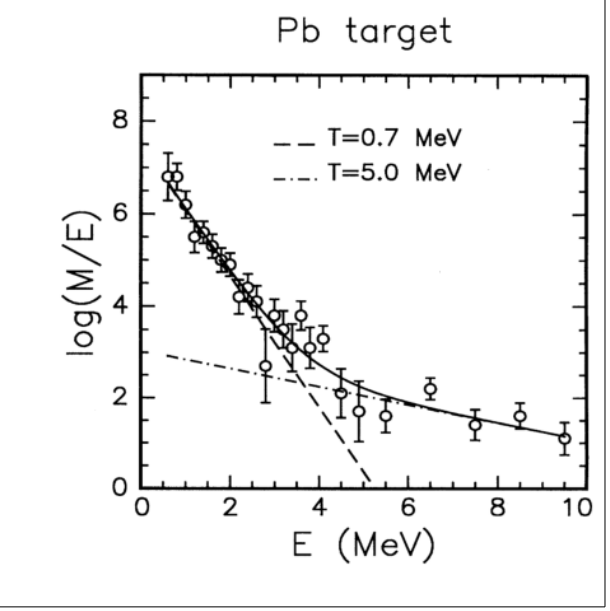
    - Qtr3: Beta release (code appears to work but needs more testing)

80%

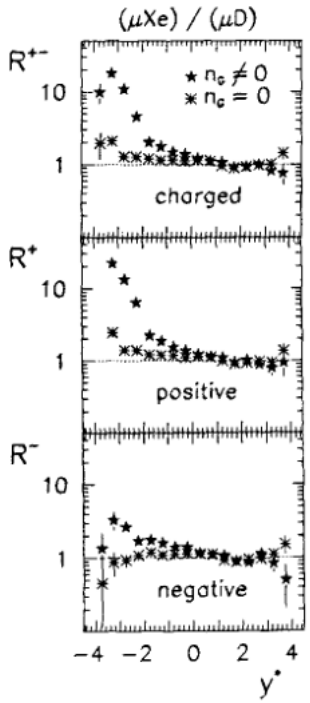
    - Qtr4: Release – ready for prime time

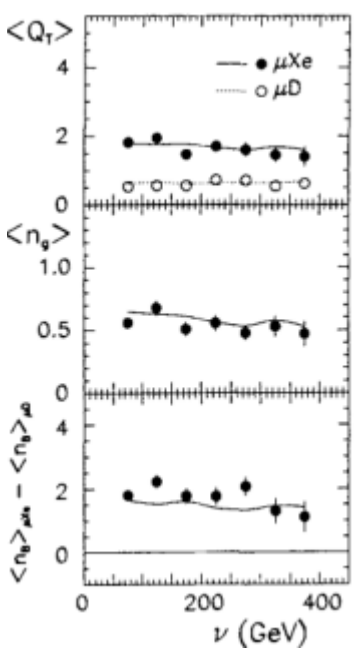
There's actually a lot of data

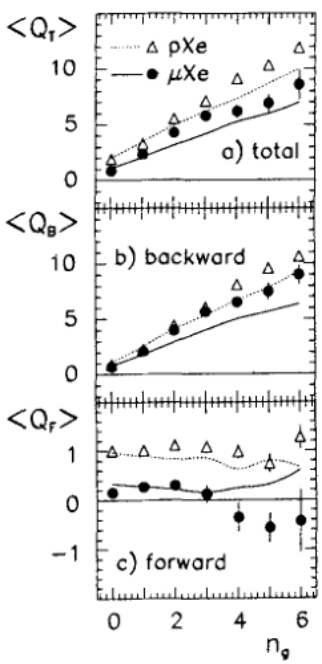
E665, PRL 74 (1995) 5198

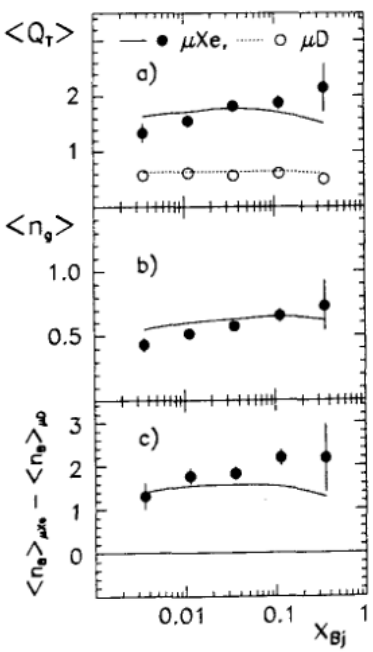


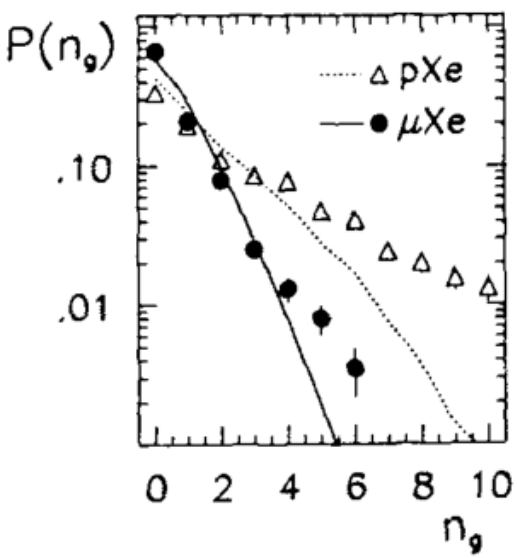
E665, ZPC 65 (1995) 225

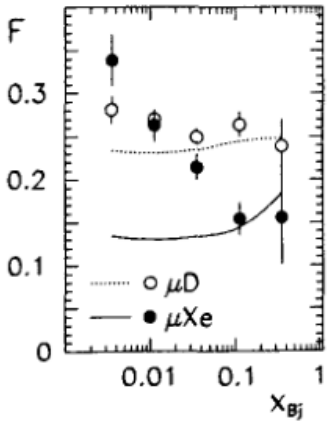






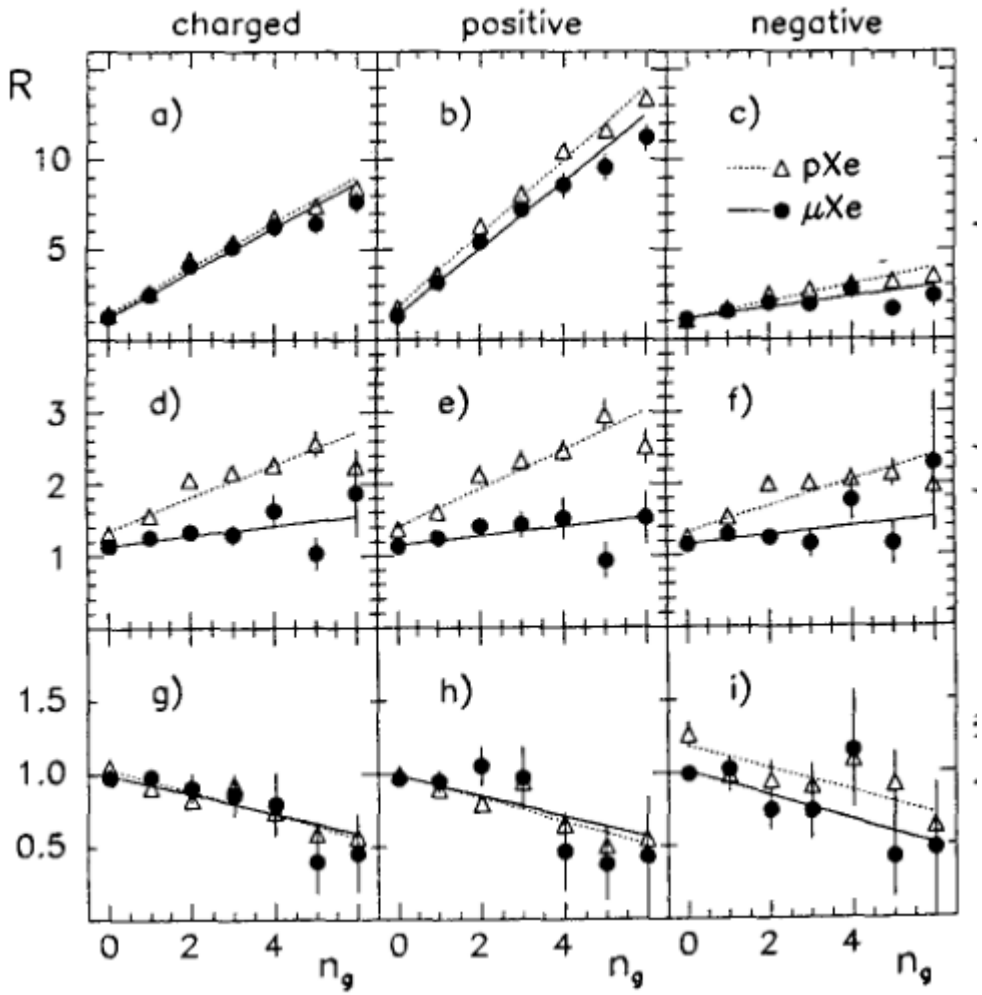


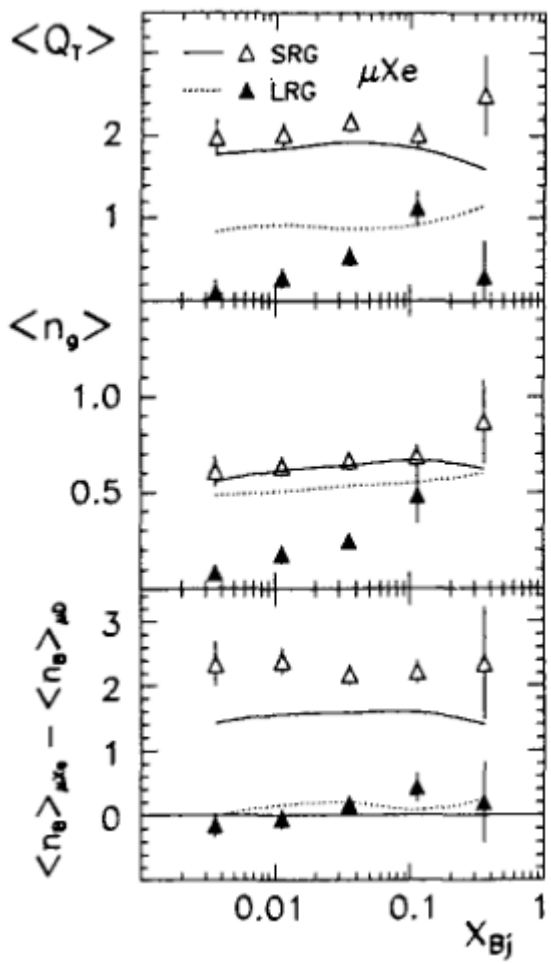


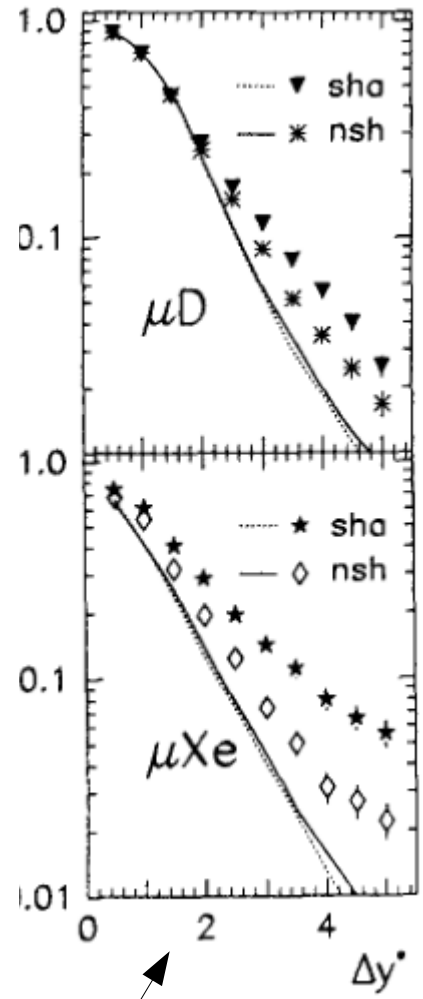


And ...

E665, ZPC 65 (1995) 225







But you need to simulate diffractive + DIS

FY2019

- FY2019 – Tune BeAGLE (+Sar*t*re)
  - Tune to E665
    - As many observables as possible from Streamer Chamber and neutron detectors.
  - Tune to Ultraperipheral Heavy Ion Data
    - Atlas: proof-of-principle. They run Pythia6, weighted for UltraPeriperal. But no Nuclear effects and no RAPGAP.
    - CMS: Sees evidence of incoherent diffraction in "0n" events.
  - And finally – an optimal tool to refine detector requirements for *incoherent diffraction veto* at EIC

100%:80%:60% Budgets

Person	Institution	Effort (FTE-year)	Cost to Proposal	Remarks
E. Aschenauer	BNL	0.05	$0	cost covered by BNL
M.D. Baker	MDBPADS[15]	0.25	$60,000	
J.H. Lee	BNL	0.05	$0	cost covered by BNL
L. Zheng	CCNU	0.10	$0	cost covered by CCNU
TOTAL:		0.45	$60,000	

Table 2: Personnel Budget Breakdown for FY2018

Funding Level	%Funding	% Project	Impact
$60,000	100%	100%	Full results for FY2018
$48,000	80%	75%	First three milestones stretch out over the whole year
$36,000	60%	50%	First two milestones stretch out over the whole year

Table 3: Impact of Reduced Funding in FY2018

Status & Proposal in a nutshell

- Original idea from July 2015 mostly fulfilled
  - BeAGLE in use at JLAB & BNL
  - Minor tweaks remain for DIS
  - Tuning difficult due to paucity/complexity of data.
- Extended proposal
  - Extend BeAGLE to handle incoherent diffraction
  - Then tune to E665 charged+neutral & pA/AA UPC
  - Essential for optimizing forward detection for a key EIC e+A observable: spatial gluon distribution.

Extras

Bug Fixes

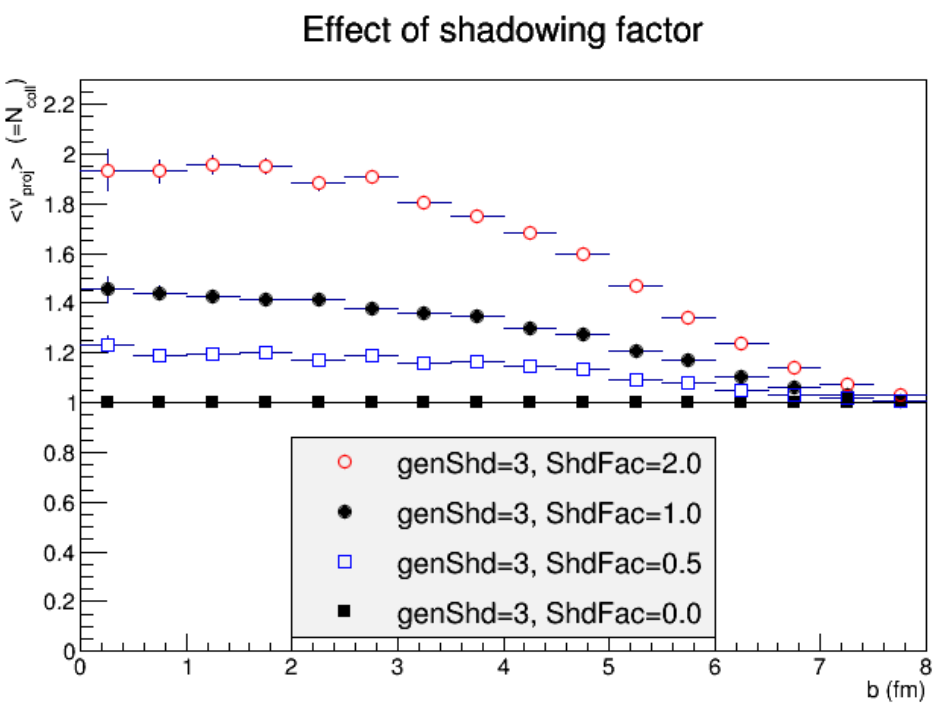
- Problem 1: Over-excited nucleus (E* too big)
  - Complicated logic → bad accounting
  - Added $(N_{coll} -1) * m_N$ to E* (huge!)
- Problem 2: Illegal E* (E*<0)
  - Hard-coded m_p (instead of m_p or m_n as appropriate)
  - Error x50000 due to small Δ big #s...
- Issue 3: Decay π^0s after INC (14% effect on E*)
- Careful audit: a few more small logic bugs.

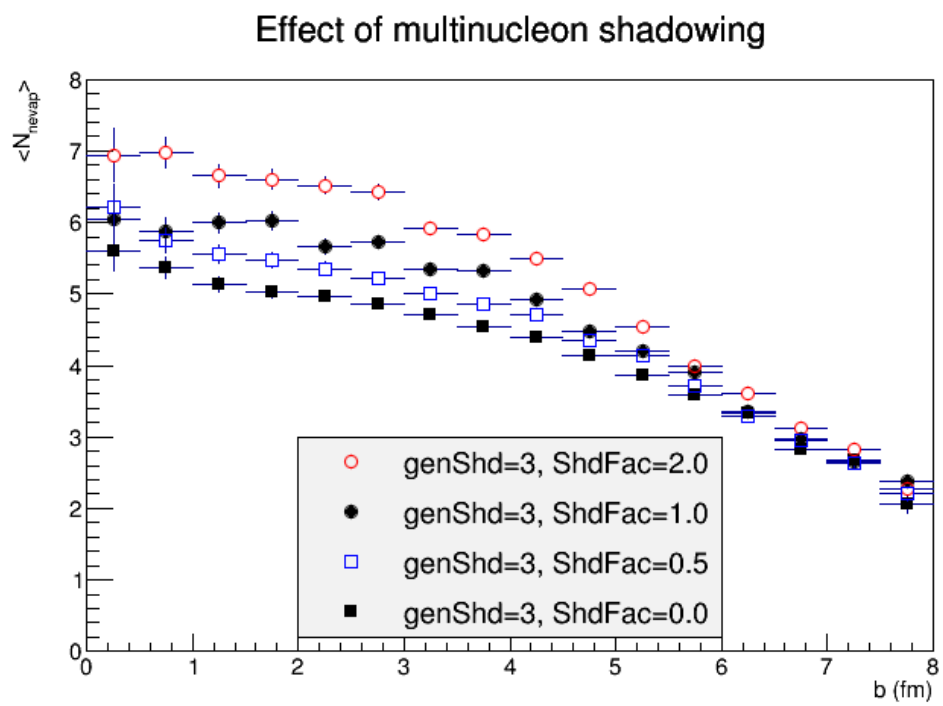
Issue 3: Correct handling of π^0

- Recall that $c\tau$ for π^0 is 25 nm = 25,000,000 fm
- Usually decay it "promptly" since the detectors don't resolve it (at JLAB/RHIC energies).
- But the π^0 should participate in INC before decaying into photons.
- Increases E* by ~14%

Added more control over $\sigma_{\text{"dipole"}}$

"Dipole" $\sigma = f_s * \sigma(R^{(A)}(x,Q^2))$

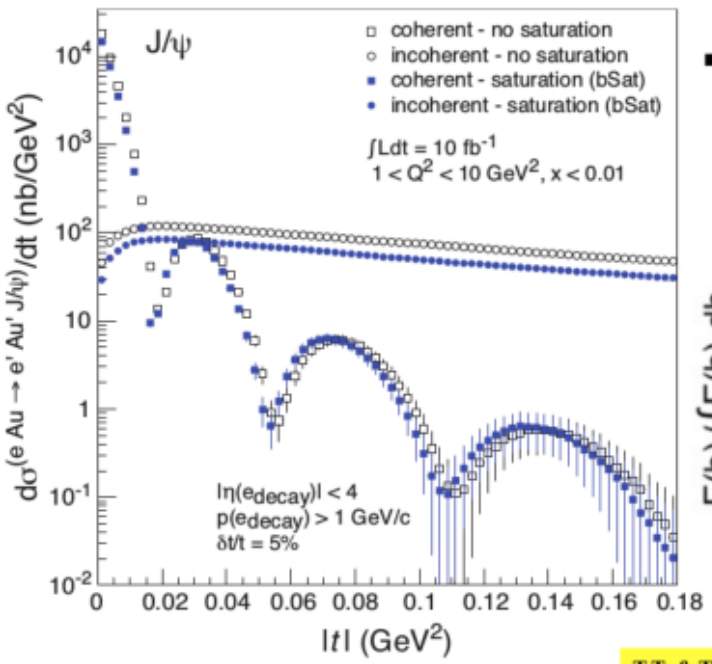




e+Au 10x100 GeV

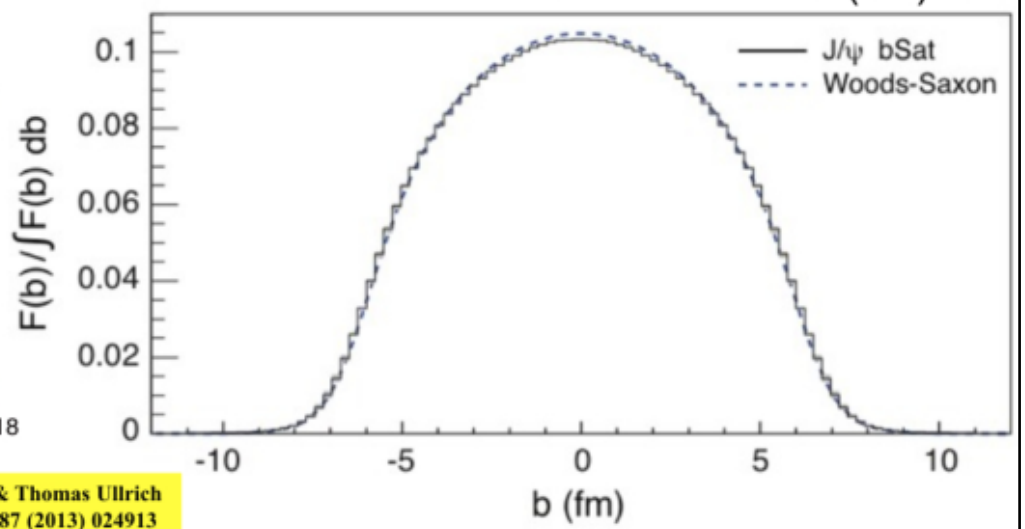
Probing the spatial gluon distribution at EIC

Momentum transfer t conjugate to transverse coordinate b



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

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



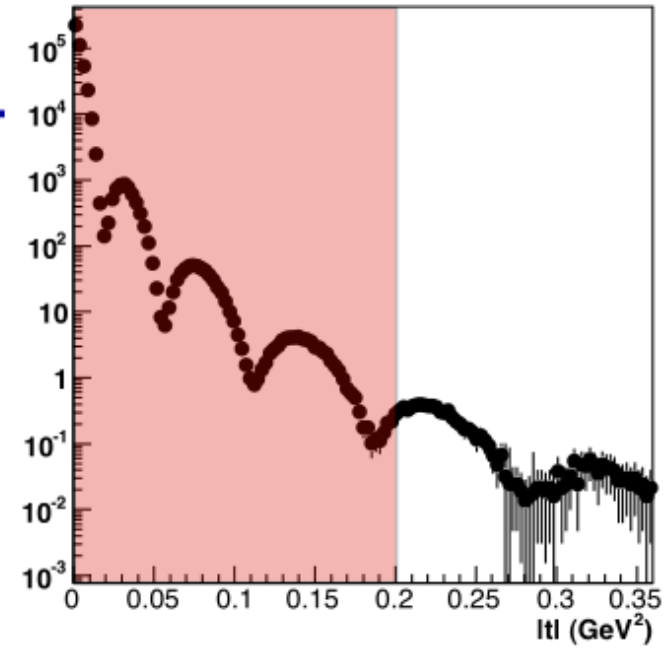
T.T. & Thomas Ullrich
PRC 87 (2013) 024913

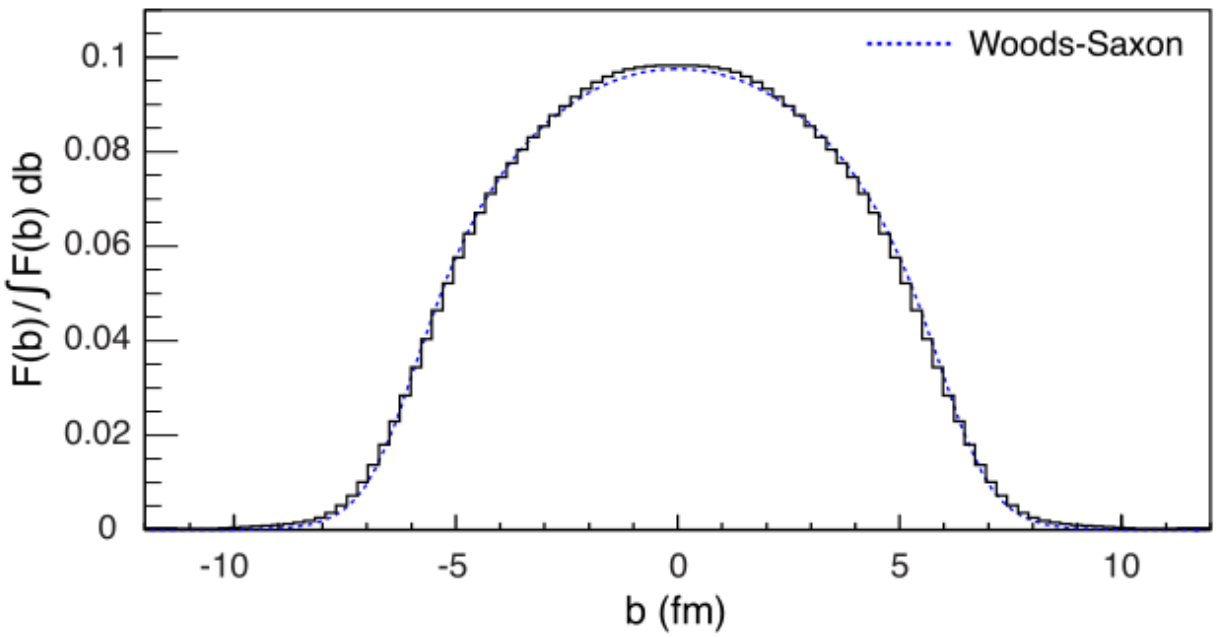
EIC will be able to retrieve the spatial gluon distribution with high precision.

t-Range

ϕ bNonSat:

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



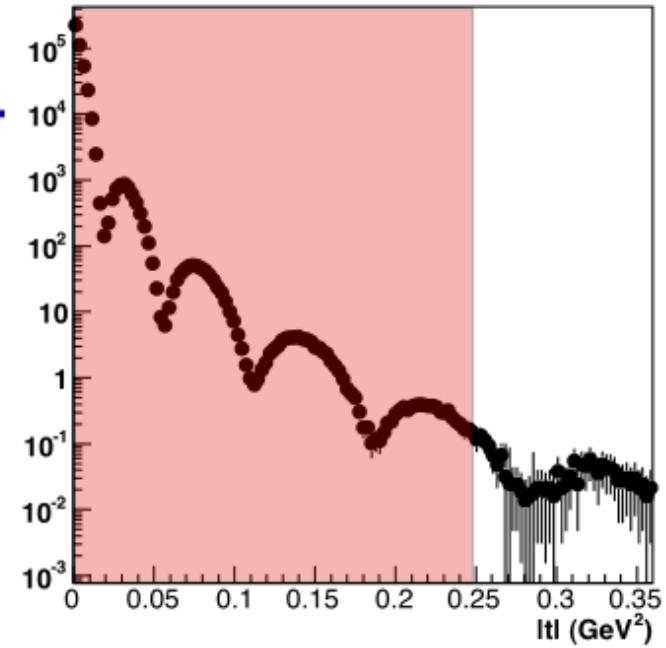


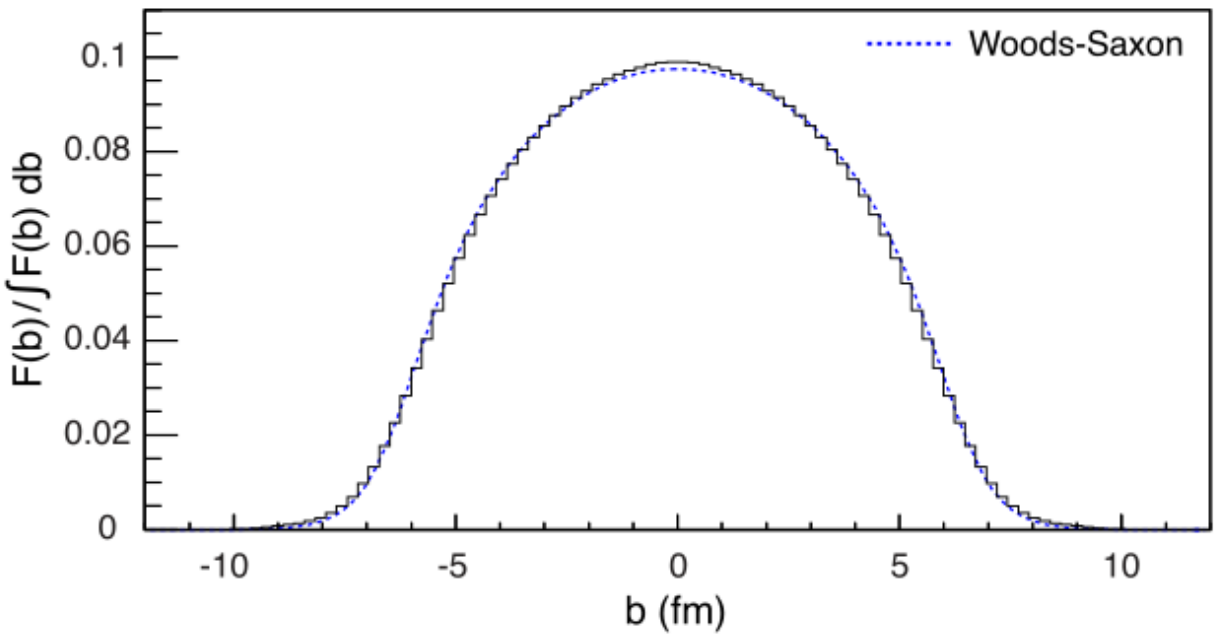
7

t-Range

ϕ bNonSat:

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

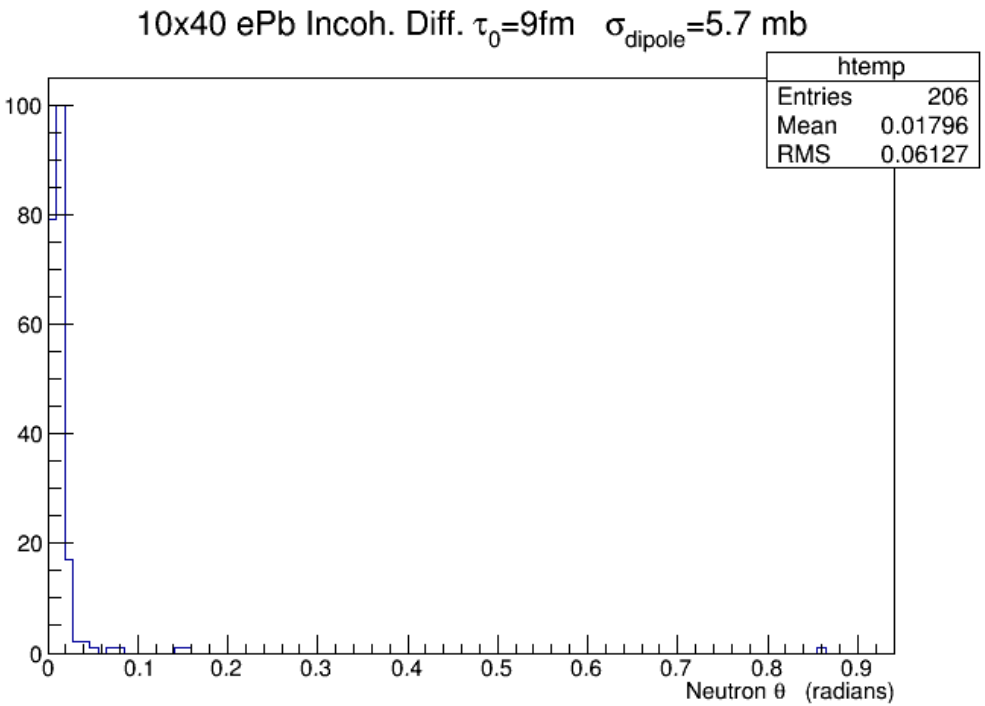


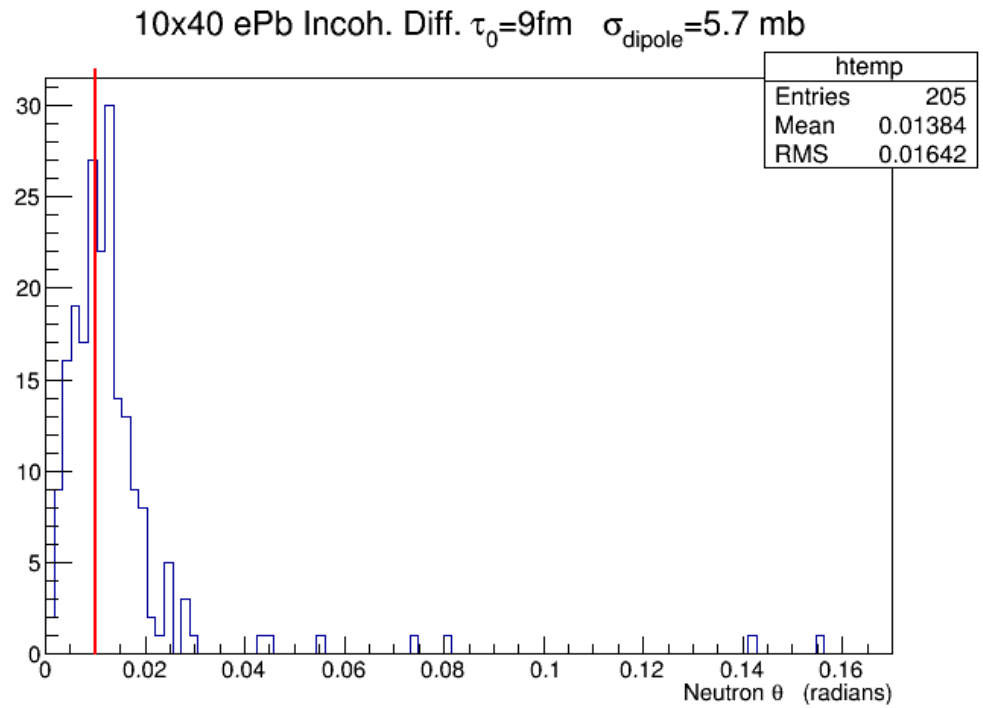


7

What about "knockout" neutrons?

544 events with no evaporation neutrons.
206 knockout neutrons.
86 in 10mr ZDC.





Incoh.Diff. Veto w/ ZDC

- Using BeAGLE: ePb 10x40 GeV
- Use any vector meson (J/ψ, ρ, ϕ, ω)
  - Multiple interaction probability uses $\sigma_{J/\psi}$ = 5.7 mb
- $x<0.01$ and $|t|>0.1$ GeV^2
- 4809 sample events: Target of RejFac=1300:
- Inefficiency budget: ~4 events
- Unvetoed events: 544-86 = 458 RF=10.5
- NOT GOOD ENOUGH

544/4809 events w/ N_{nevap}=0, t<-0.1

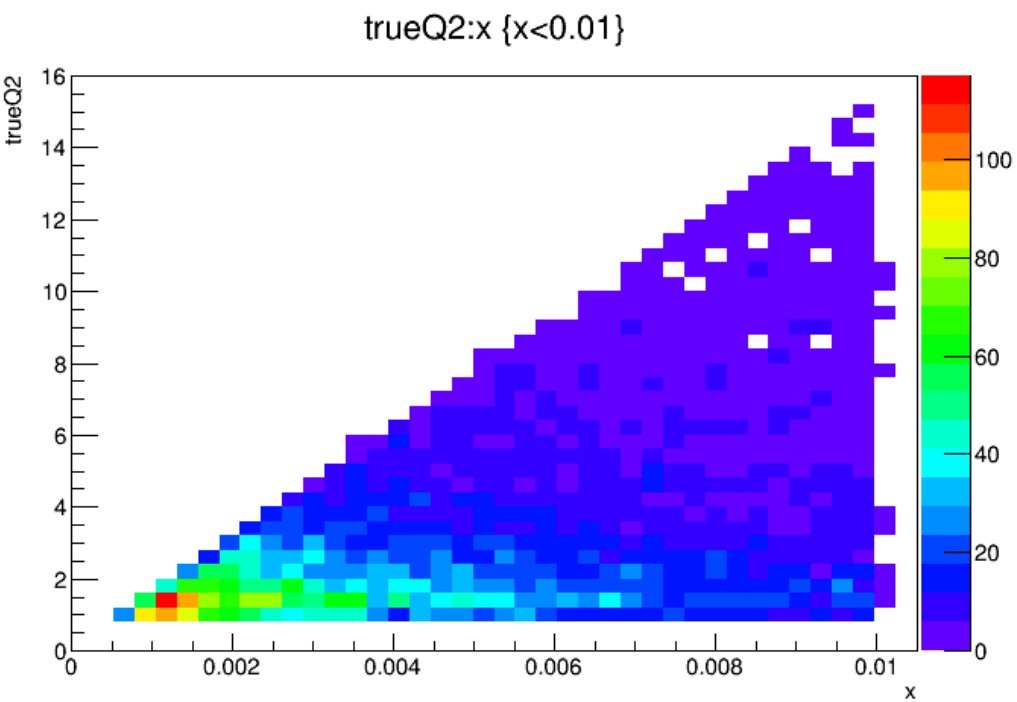
Beam Remnant	Z=80 Hg	Z=81 Tl	Z=82 Pb	Z=83 Bi
A=208		1 Tl-208	**6** **Pb-208**	3 Bi-208
A=207	1 Hg-207	**303** **Tl-207**	**226** **Pb-207**	
A=206	1 Hg-206	3 Tl-206		

p

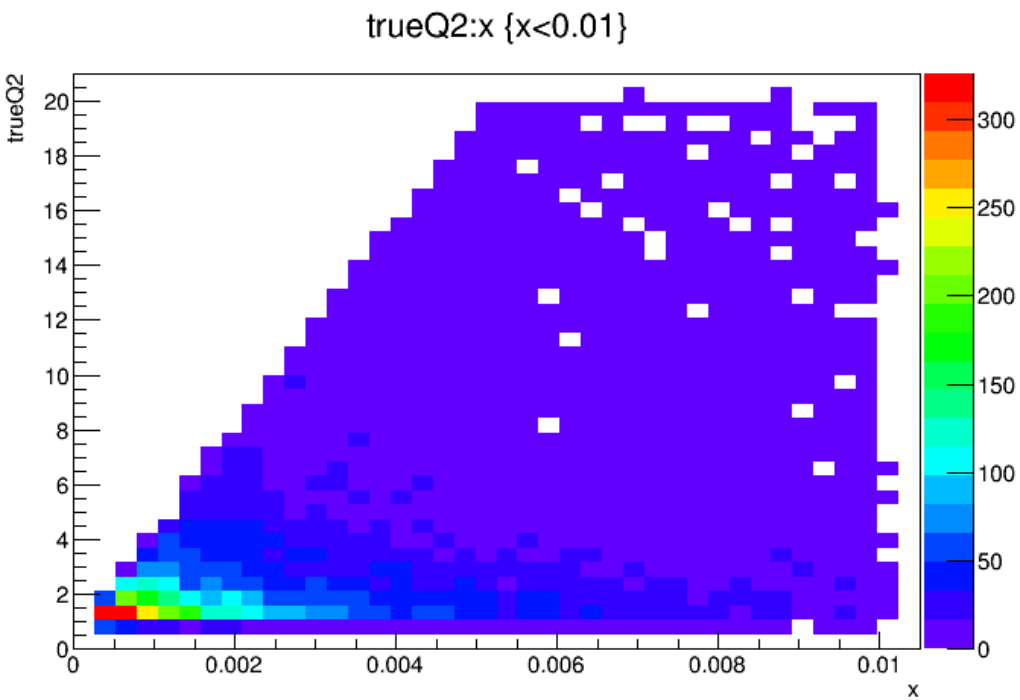
n

Advantages of higher energy

Cross-section is 2-3x larger for 20x100 vs. 10x40
Slightly better kinematic reach. Lower x for given Q^2 range.
Can try to turn ON/OFF saturation in ϕ alone rather than using ϕ vs. J/ψ.



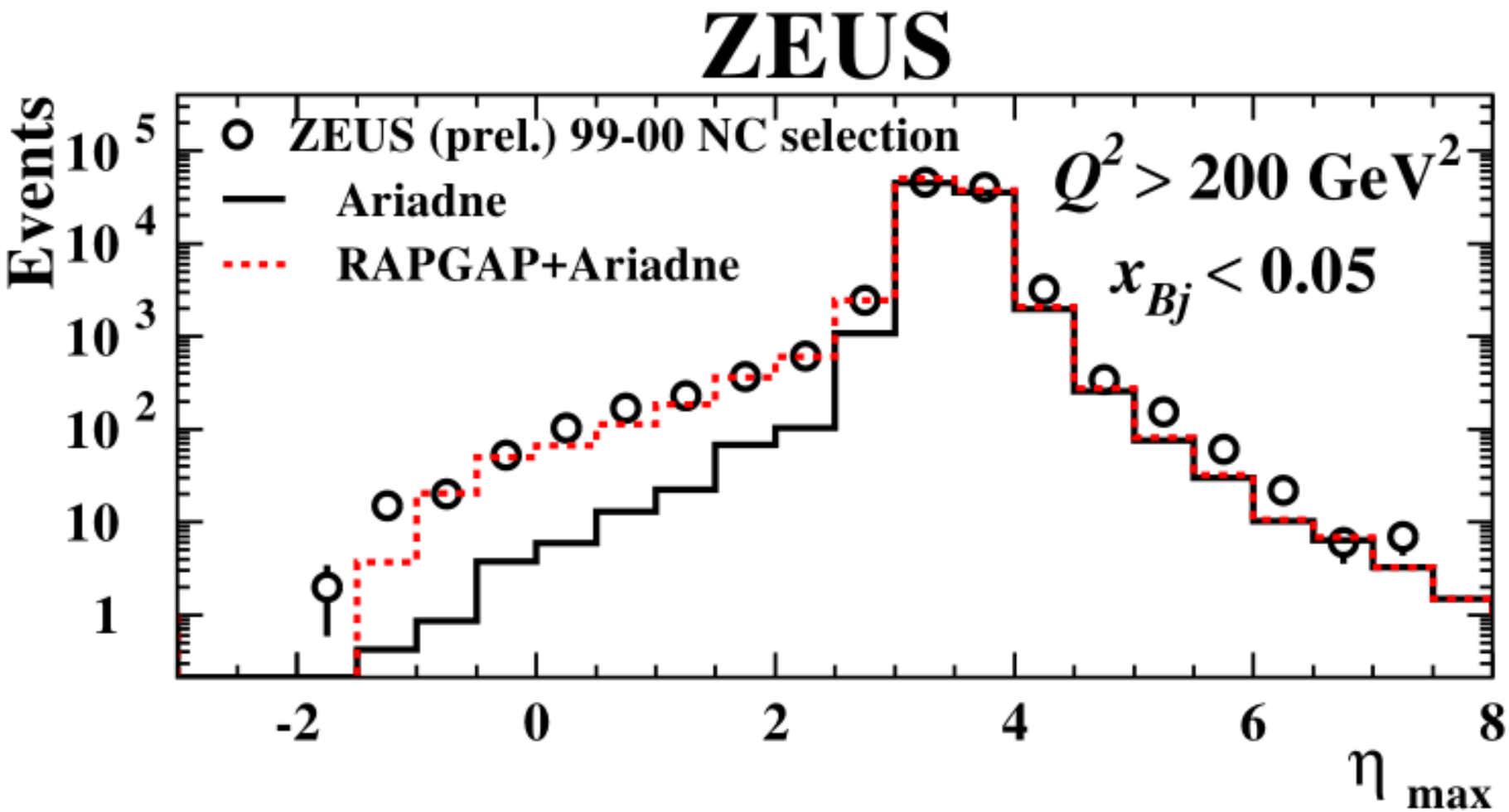
ePb 10x40 incoherent diffractive



ePb 10x100 incoherent diffractive

@x=0.001: 1 GeV^2<Q^2<1.6 GeV^2 vs. 1 GeV^2<Q^2<4 GeV^2

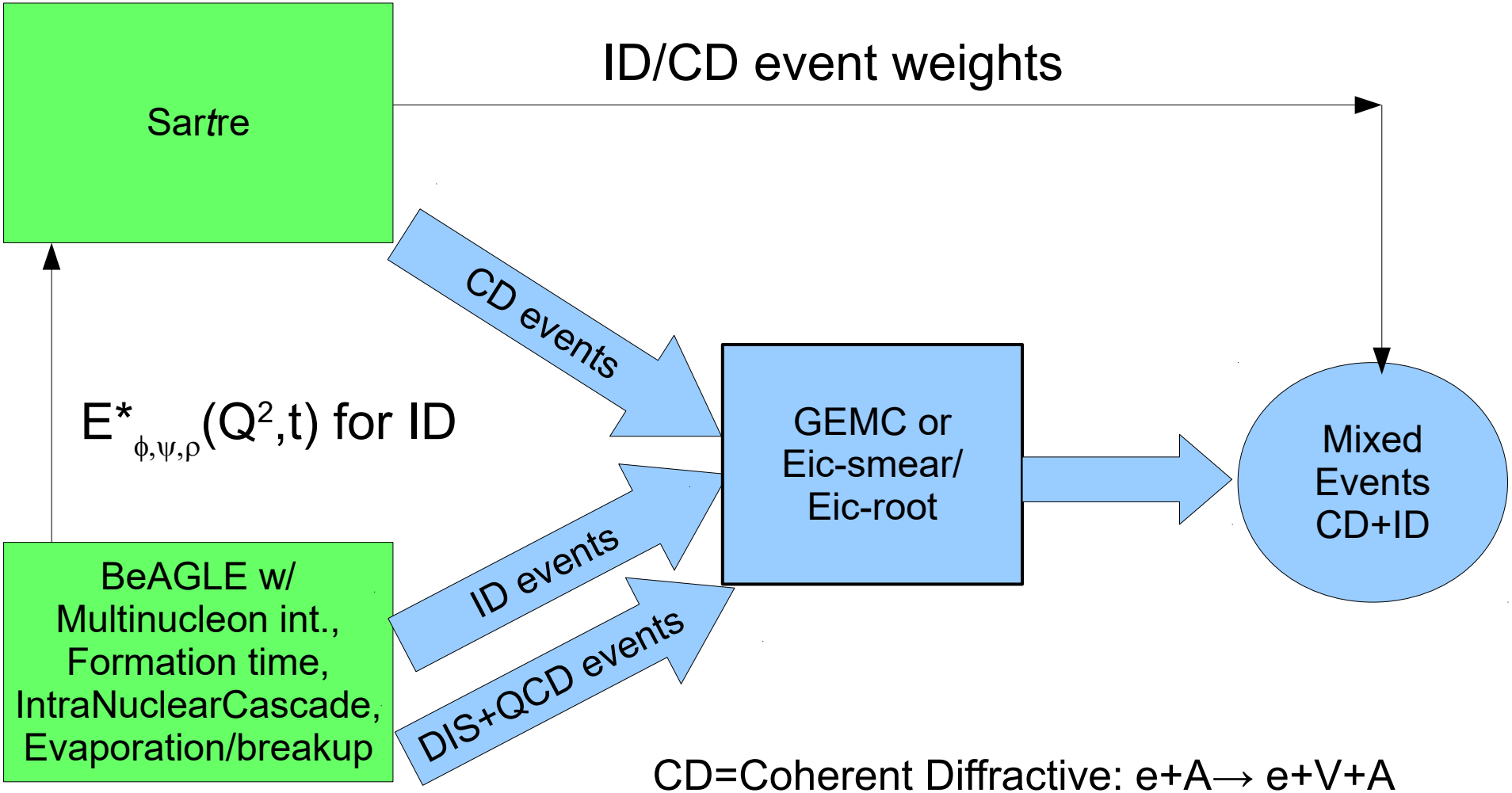
RAPGAP needed to describe Rapidity Gaps...



2018-LDRD-4:
Geometry Tagging for Heavy Ions at JLEIC
(Continuation of 2017-LDRD-6)

A. Accardi, M. Baker, W. Brooks, R. Dupre, M. Ehrhart, C. Fogler, K. Hafidi, C. Hyde, V. Morozov (PI), P. Nadel-Turonski, K. Park, T. Toll, G. Wei, L. Zheng

Event mixing: BeAGLE+Sar*t*re



CD=Coherent Diffractive: e+A→ e+V+A
ID = Incoherent Diffractive e+A→ e+V+X
DIS+QCD = Pythia (LO + QCDC + PGF)