# eA vs pA: Similarities and Differences, An Experimentalist's Perspective

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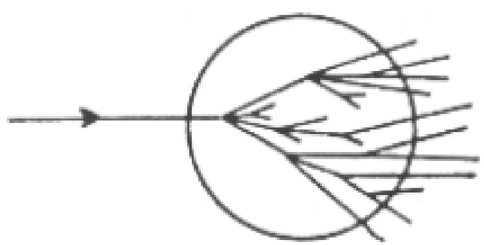
June 28, 2017

# Geometry: $N_{part}$ – an old idea...

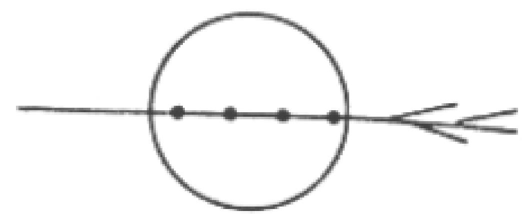
## Questions From The 1970's

- Mechanism of the Particle Production
- Space-Time Evolution of Production Process



$\langle n\rangle_A \sim \langle n\rangle_p A^{1/3}$

or



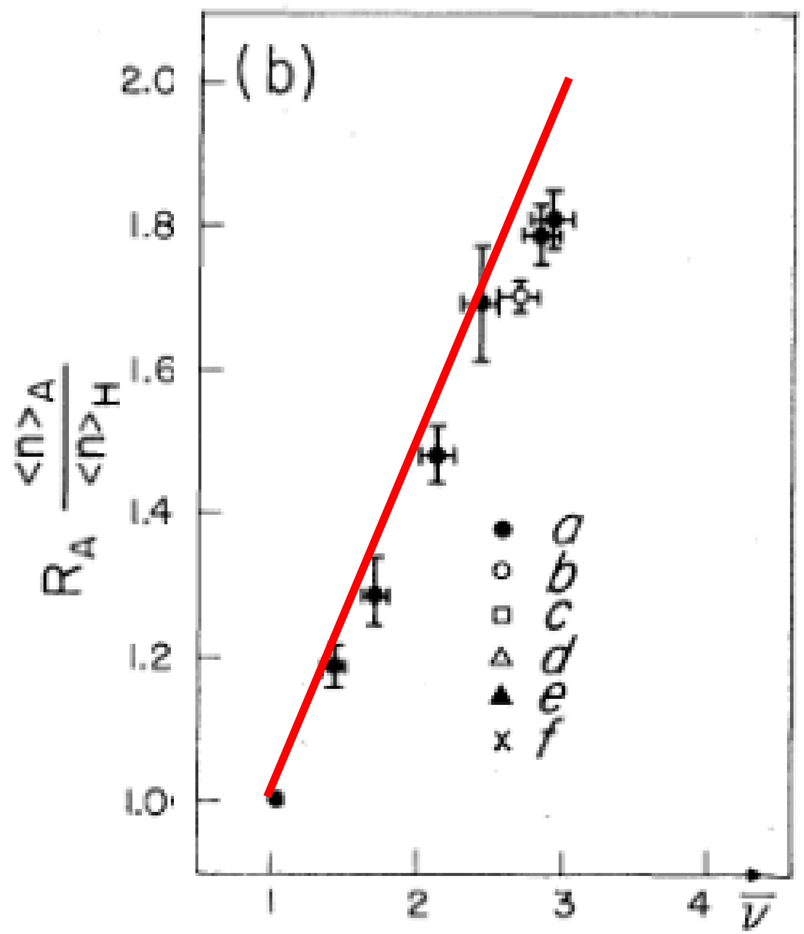
$\langle n\rangle_A \sim \langle n\rangle_p$ or
$\langle n(A,s)\rangle \sim \langle n(p,\bar{\nu}s)\rangle$

$$N_{part} = \bar{\nu} + 1 \qquad \bar{\nu} = \frac{A\sigma_{pp}}{\sigma_{pA}} =$$

Average number of mean free paths encountered by inc. particle when crossing the nucleus

W. Busza, 24th Winter Workshop on Nuclear Dynamics (2008)

# Mix of pA & $\pi$A




W. Busza et al., (E178 A) PRL 34 (1975) 836

$$N_{part} = \bar{\nu} + 1$$

$R_A = N_{part}/2 = ½(1+\bar{\nu})$

# 200 GeV p+A (fixed target)

DeMarzo et al., PRD 29 (1984) 2476

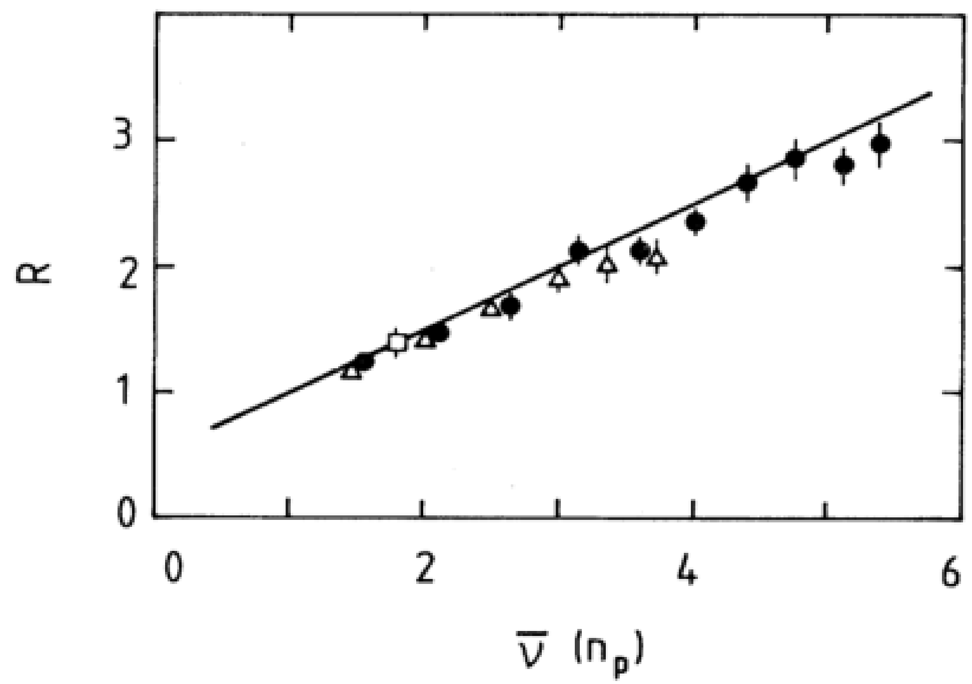



FIG. 4. The ratio $R = \langle n \rangle_{pA} / \langle n \rangle_{pp}$ versus the average number $\bar{\nu}(n_p)$ of projectile collisions for $p$Xe (circles), $p$Ar (triangles), and $p$Ne (squares) collisions. A line of the form $R = 0.5[\bar{\nu}(n_p) + 1]$ is shown for comparison.

# Can also measure $<\nu_{tot}>$

DeMarzo et al., PRD 29 (1984) 2476

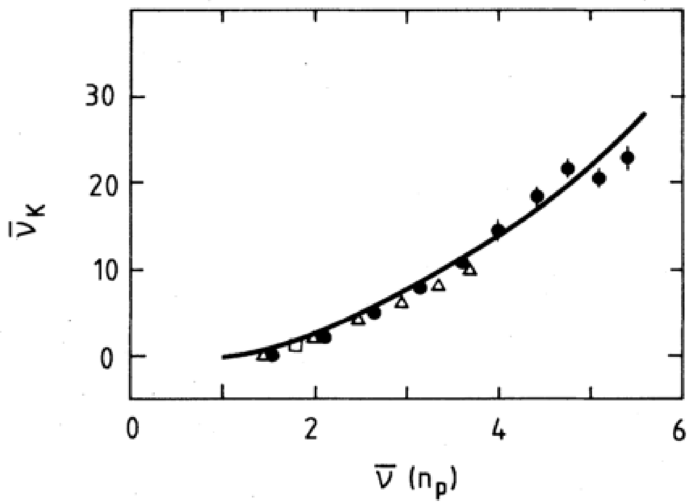


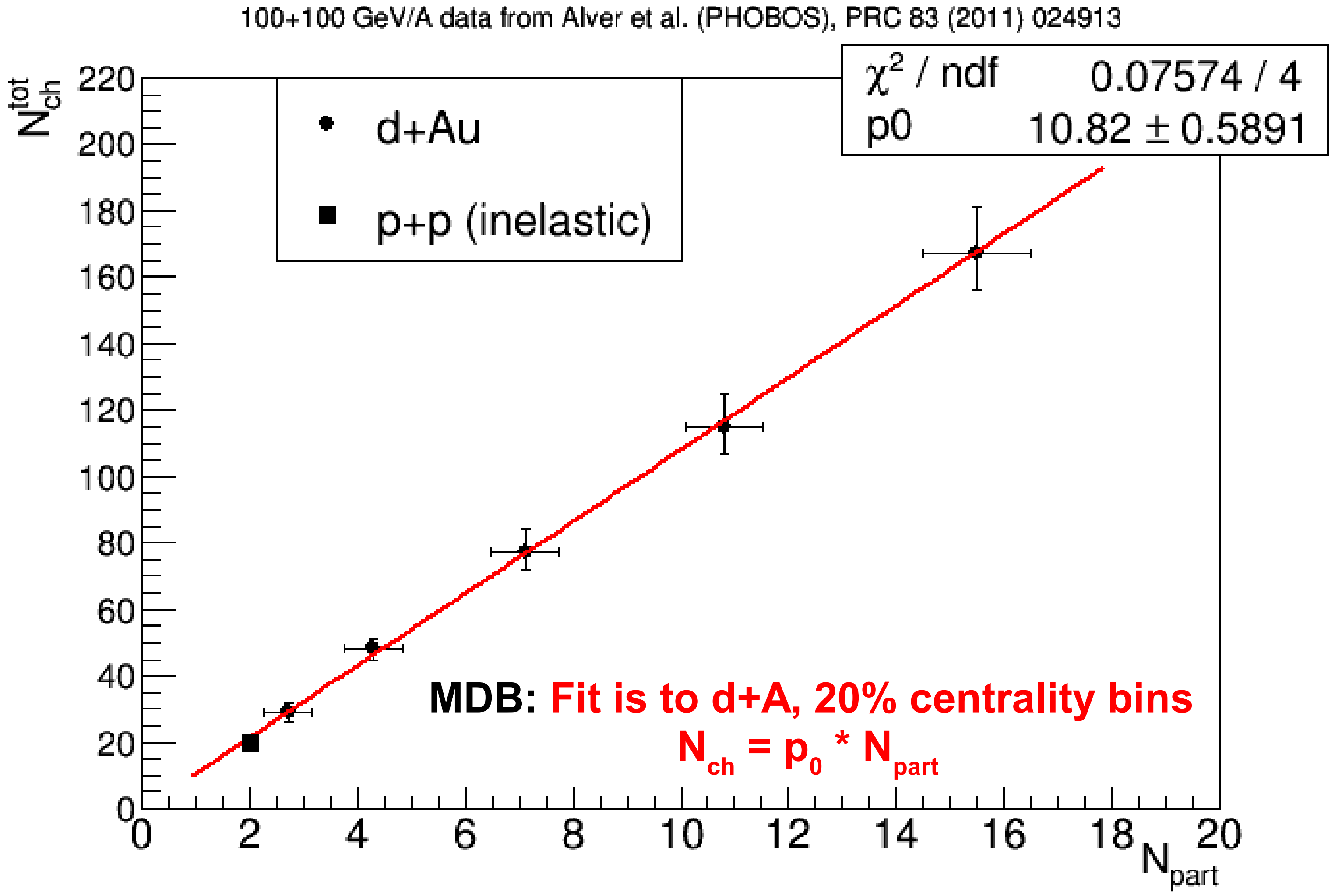

FIG. 10. Average number $\bar{\nu}_K$ of secondary collisions in the intranuclear cascade versus the number $\bar{\nu}(n_p)$ of projectile collisions for *p*Xe (circles), *p*Ar (triangles), and *p*Ne (squares) collisions. The curve of the form $(\nu^{1.95}-1)$ is shown for comparison.

- Intranuclear cascading leads to additional collisions:

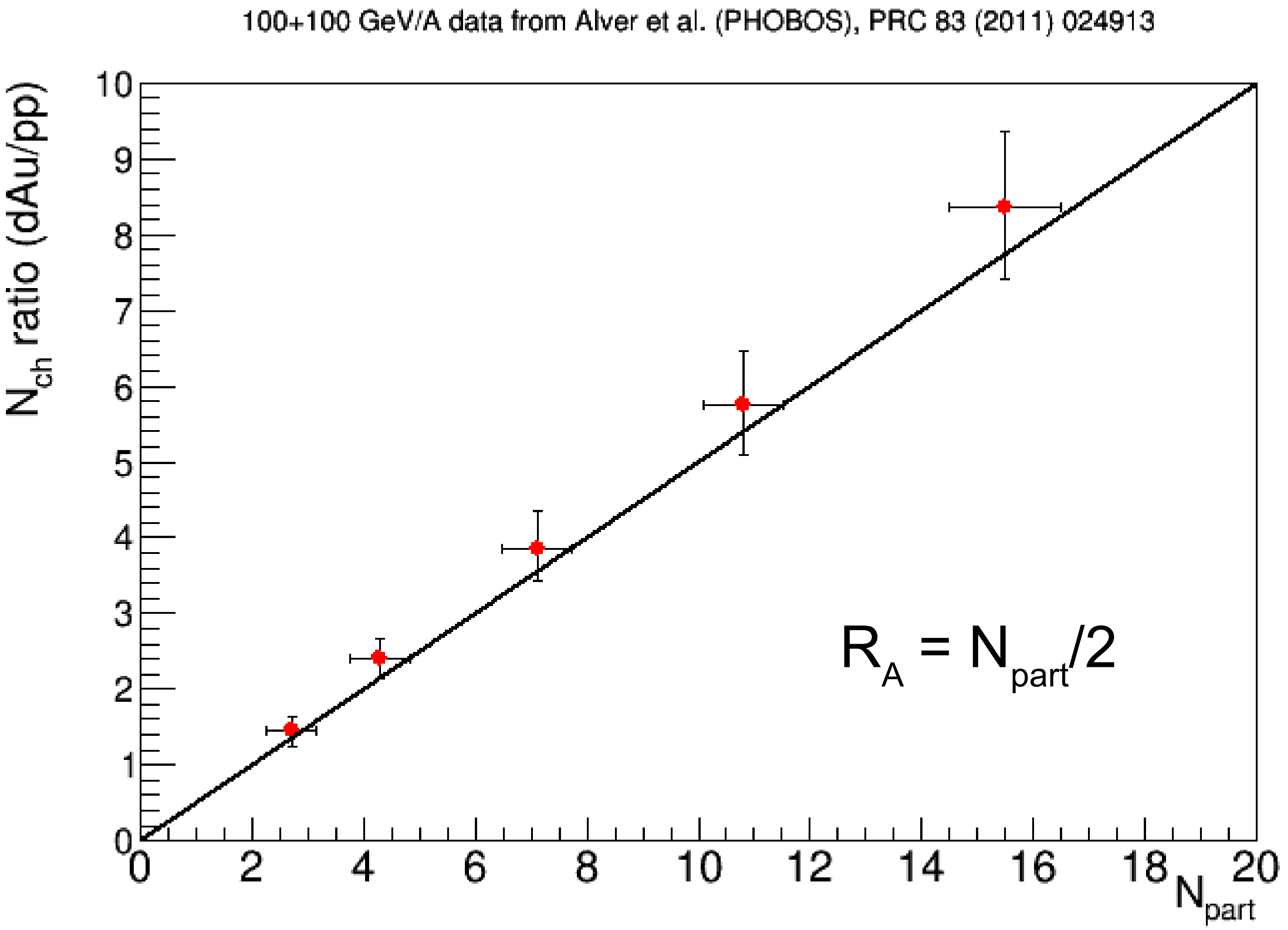
  $<\nu_{tot}>=<\nu_{proj}>+<\nu_{sec}>$

- Measure with net charge: $<Q_T> = <\nu_{tot}>Z/A + Z_{proj}$

# RHIC: 10x the $\sqrt{s}_{NN}$



# 0-parameter prediction

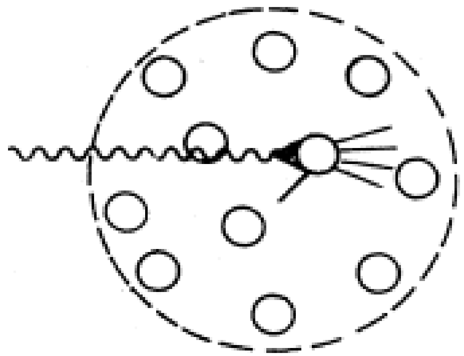


# eA: Basic Quantum Mechanics

$\hbar=c=1$ $\quad r=0.88$ fm $\quad 1/(2Mr) = 0.12 \quad \Delta p_z \Delta z = 1/2$

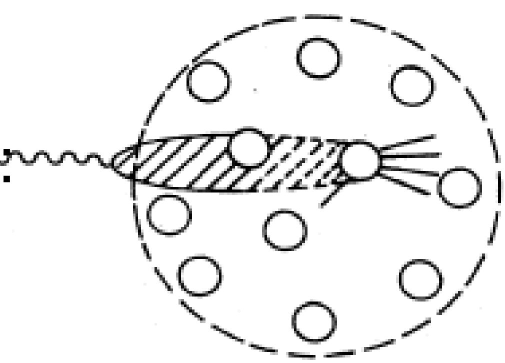
Bauer, Spital, Yennie, Pipkin
Rev. Mod. Phys. 50 (1978) 261

High $x_{Bj}$:



Nucleus Rest Frame (b)

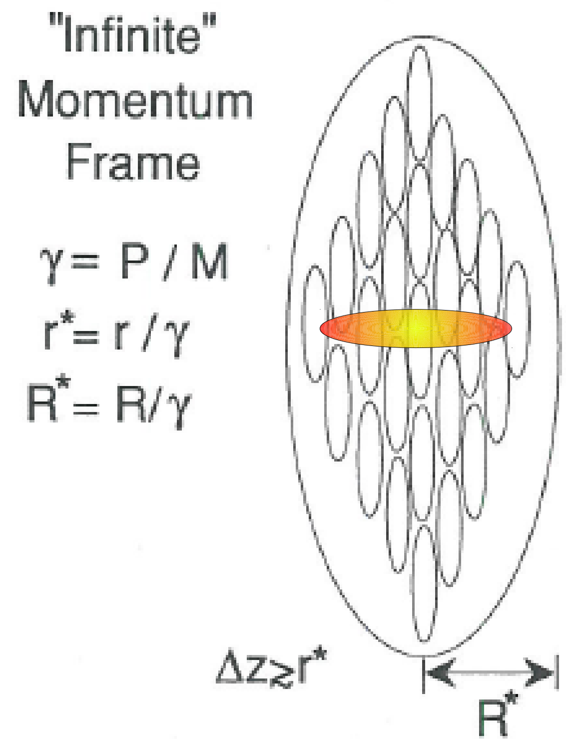
Low $x_{Bj}$:



(c)

$\boxed{\lambda_h/r \approx 1/(2Mxr) = 0.12/x_{Bj}}$

See e.g. Nikolaev, Zakharov, ZPC 49 (1991) 607



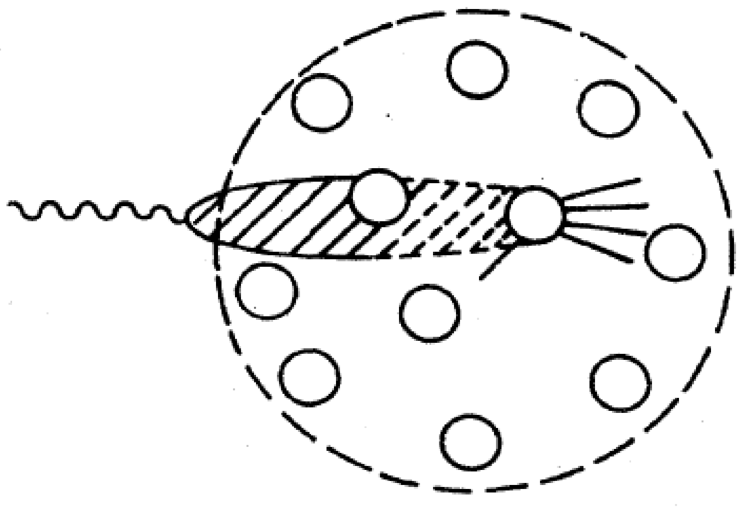

$p_z^{quark} = Mx\gamma$

$\Delta z = 1/(2Mx\gamma)$

$\Delta z/r^* = 1/(2Mxr)$
$= 0.12/x_{Bj}$

**For $x_{Bj} << 0.12$, parton wavefunctions and/or interaction cannot be localized.**

# Low x eA is $\gamma^*$A which is ~ like pA



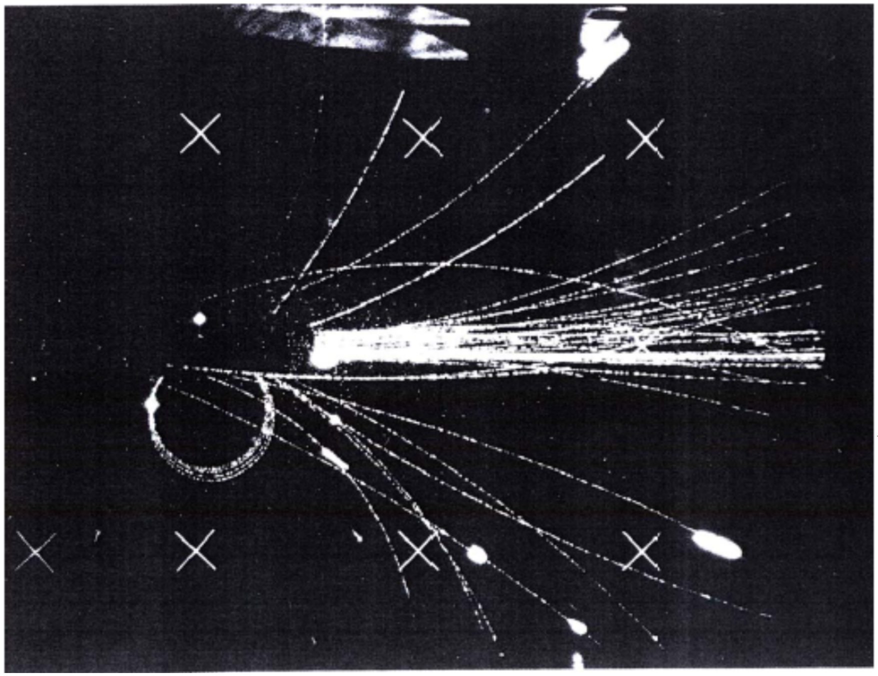

In the nuclear rest frame:
$\gamma^*$ alternates between point-like $\sigma$~0
& a hadronic object ("dipole") $\sigma$ ~few mb
lasting for length $\lambda$~1/(2Mx)

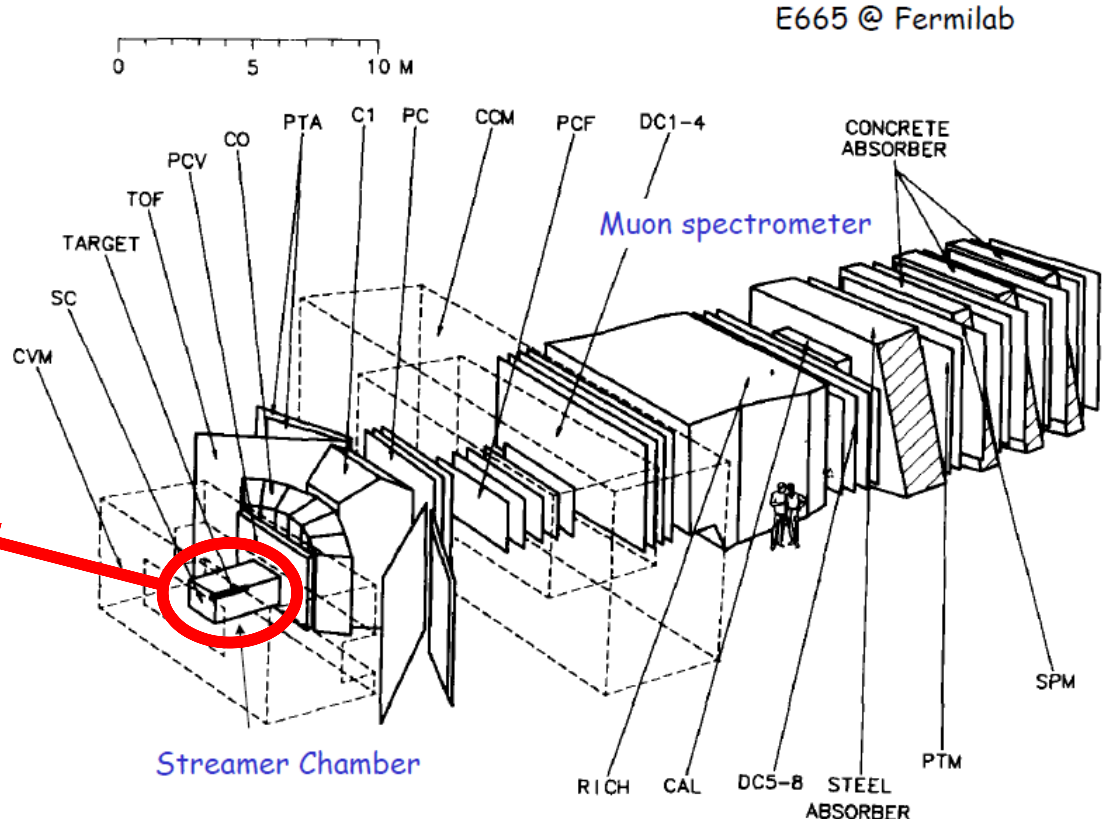
Great! So if the $\gamma^*$ is hadronic, we can do Glauber like in pA or dA and do geometry tagging to pick out "central" events.

Let's look at $N_{part}$, $N_{coll}=\bar{\nu}=\langle\nu_{proj}\rangle$, $\langle\nu_{tot}\rangle$

# FNAL E665: 490GeV μ+A FixedTgt

Streamer chamber in FT ideal for this.






- Streamer chamber
  - Blind to large slow remnants (absorbed in target)
  - Sees charged produced particles, evaporated particles, Intranuclear Cascade
  - Slow tracks $0.3<\beta<0.7$ are grey (evaporation, INC)
  - Data taking rate 1.5 Hz

# NA5@CERN: p+Xe 200GeV FixTgt

C. DeMarzo et al. PRD 26 (1982) 1019

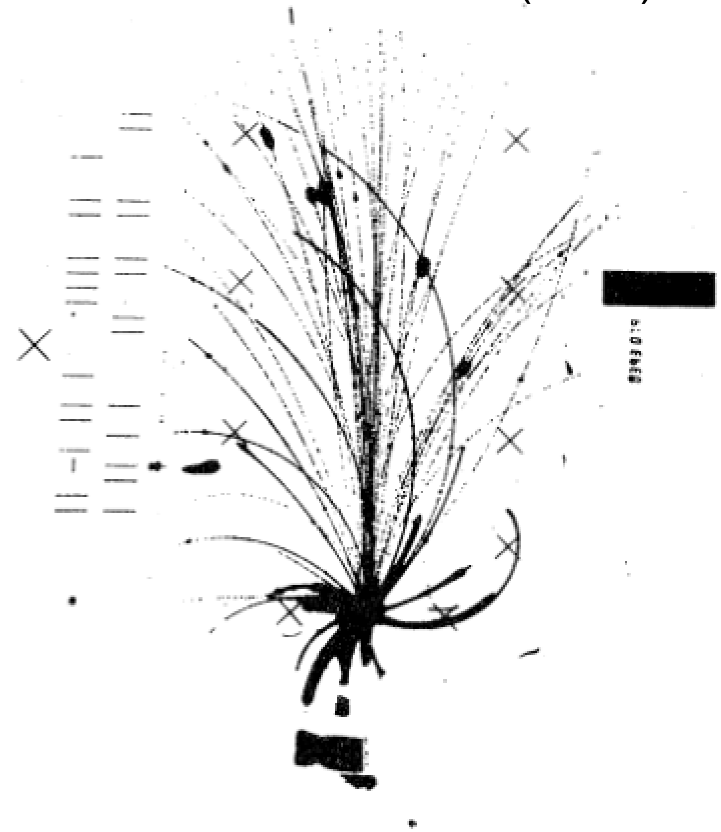
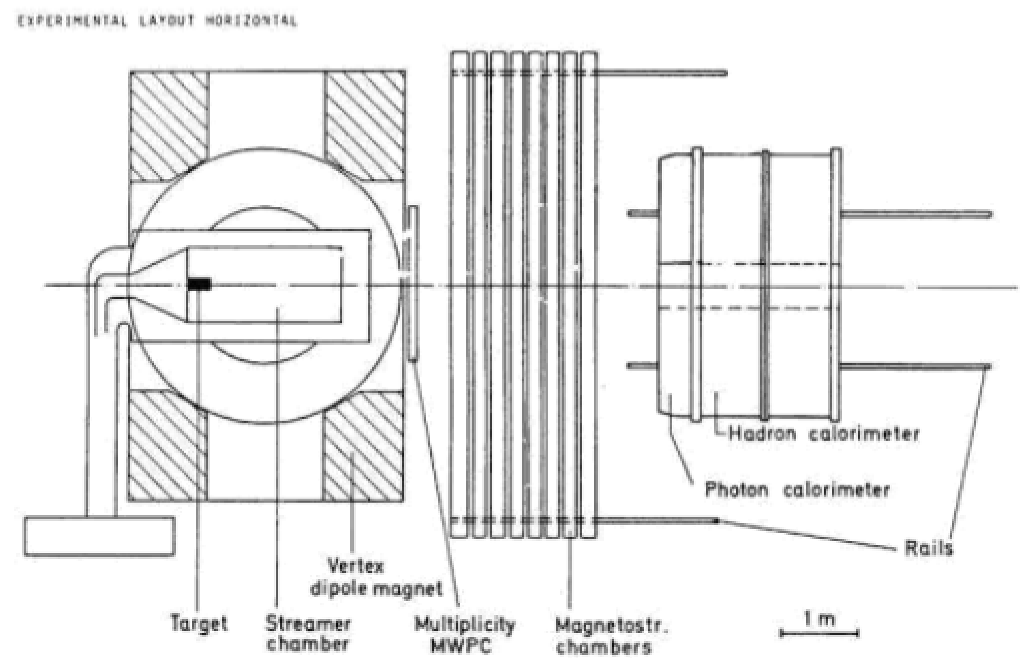


FIG. 2. Photograph of a $pXe$ interaction at 200 GeV/$c$ incident momentum.

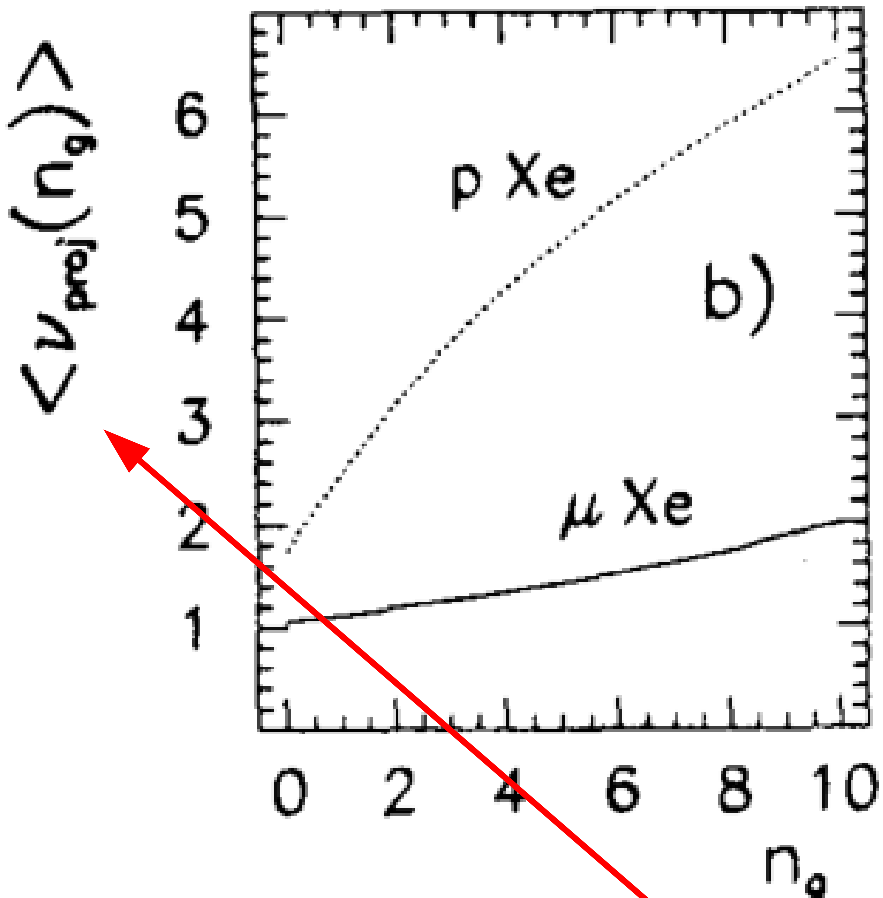
Very similar Streamer Chamber as E665,
Made by the SAME group at MPI,Munich

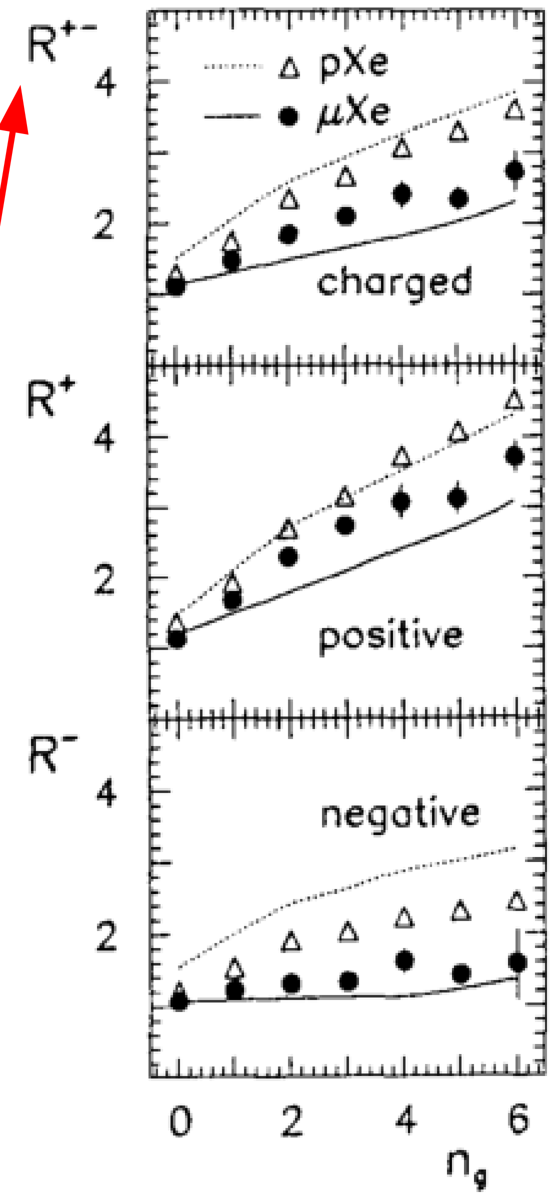
NA5 s ≈ E665 <$W^2$>



# Centrality select by grey tracks

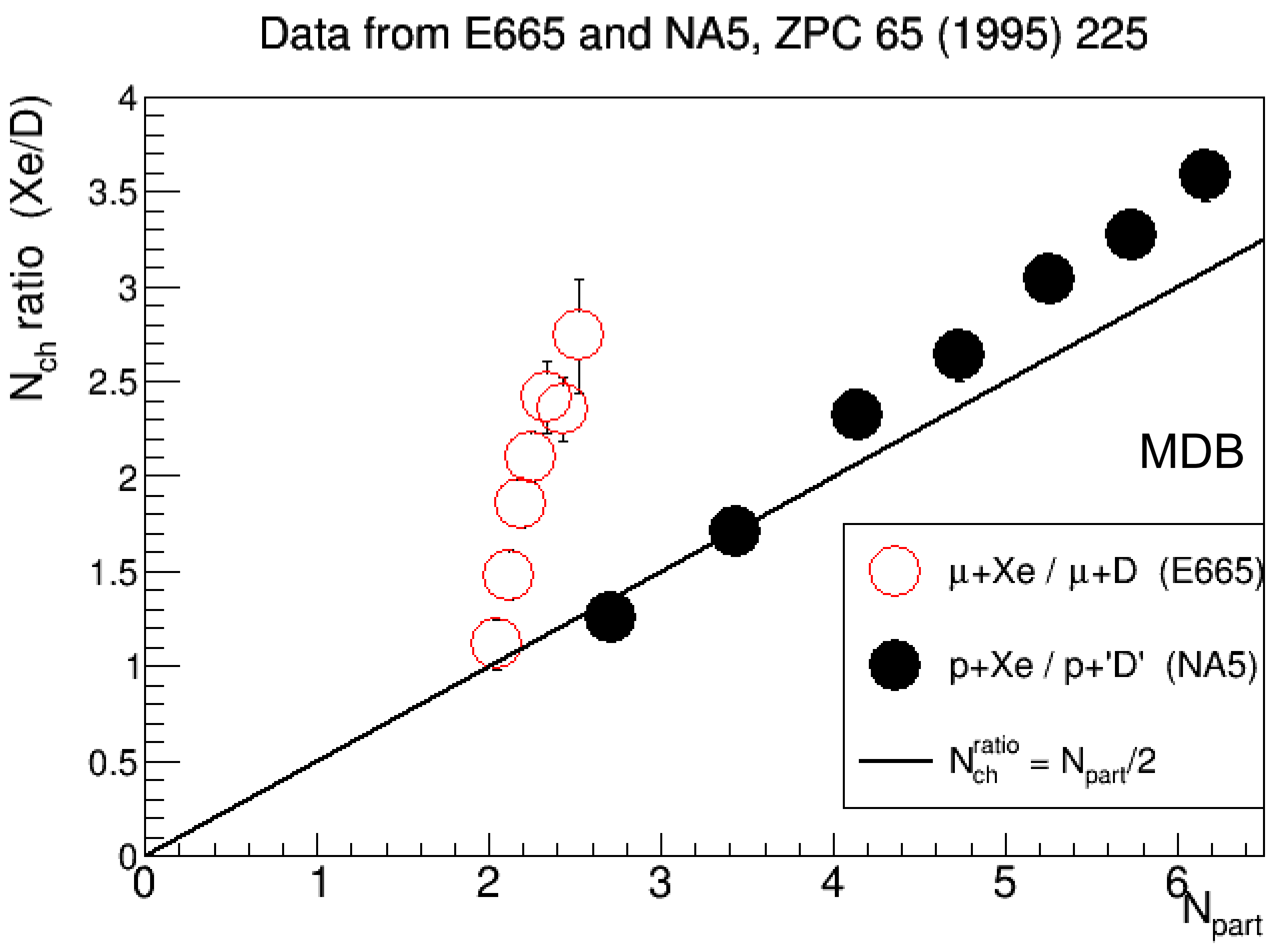
E665, ZPC 65 (1995) 225



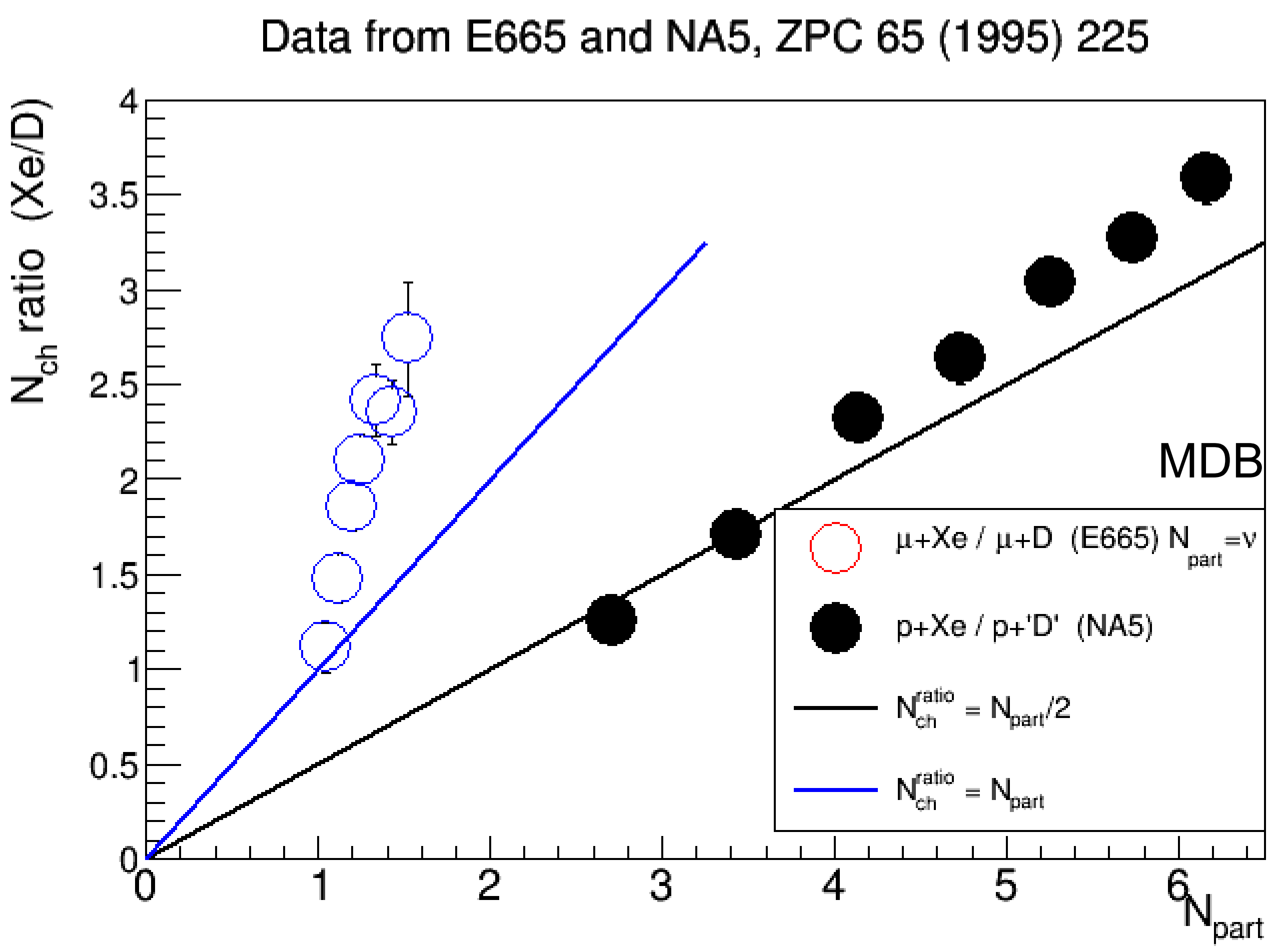




We want $R^{+-}$ vs. ½(1+ $\langle \nu_{proj} \rangle$)

# Try $N_{part}(\mu A)=½(1+<\nu_{proj}>)$



# Try $N_{part}(\mu A)=<\nu_{proj}>$



# What about total collisions?

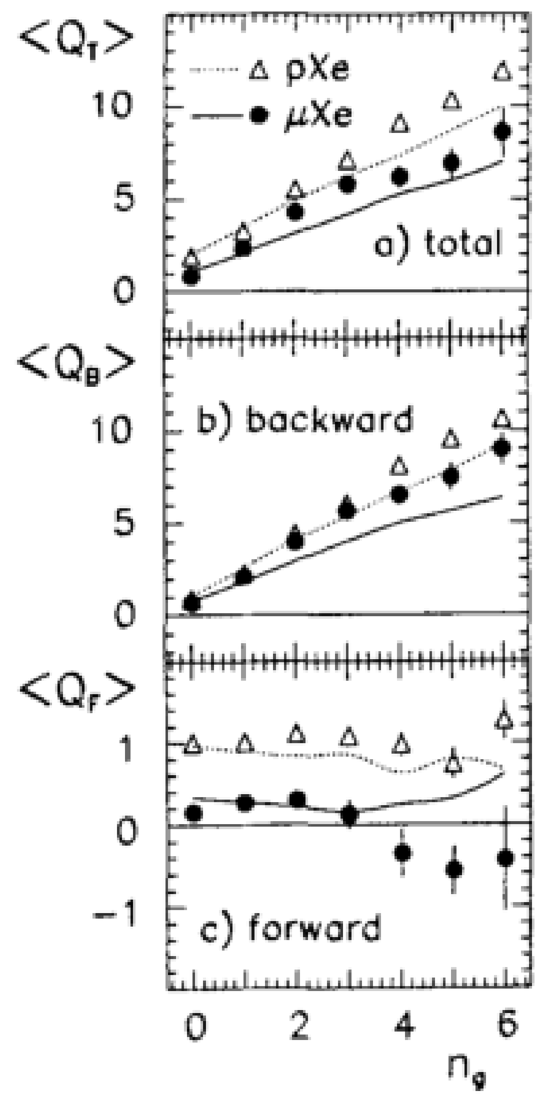
Recall:

$<Q_T> = <\nu_{tot}>Z/A$

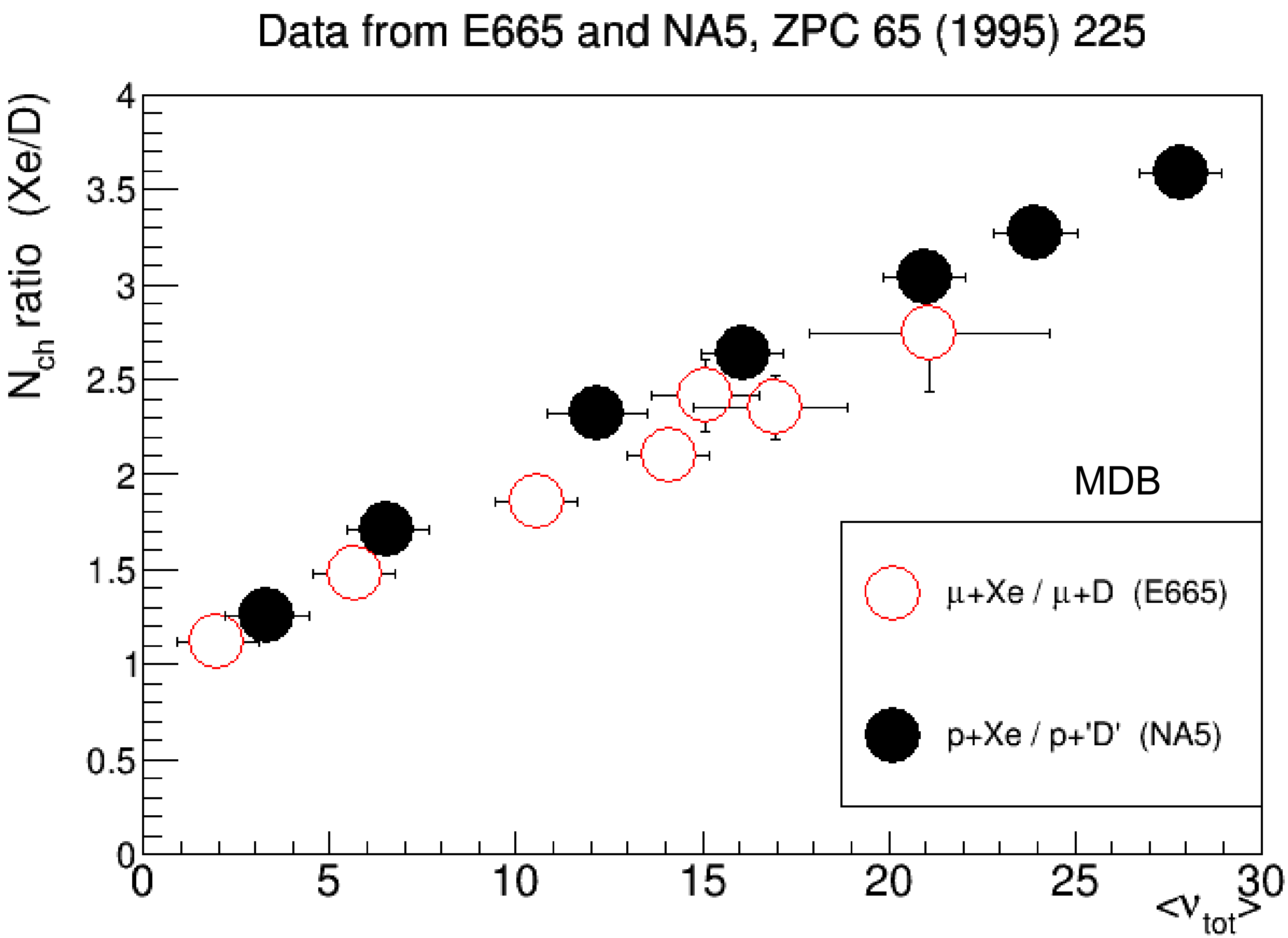
So $<\nu_{tot}>=(A/Z)_{Xe}(<Q_T> - Z_{proj})$

$=2.43\ (<Q_T> - Z_{proj})$

E665, ZPC 65 (1995) 225



# Multiplicity driven by Total collisions



# E665 & Neutron Detection

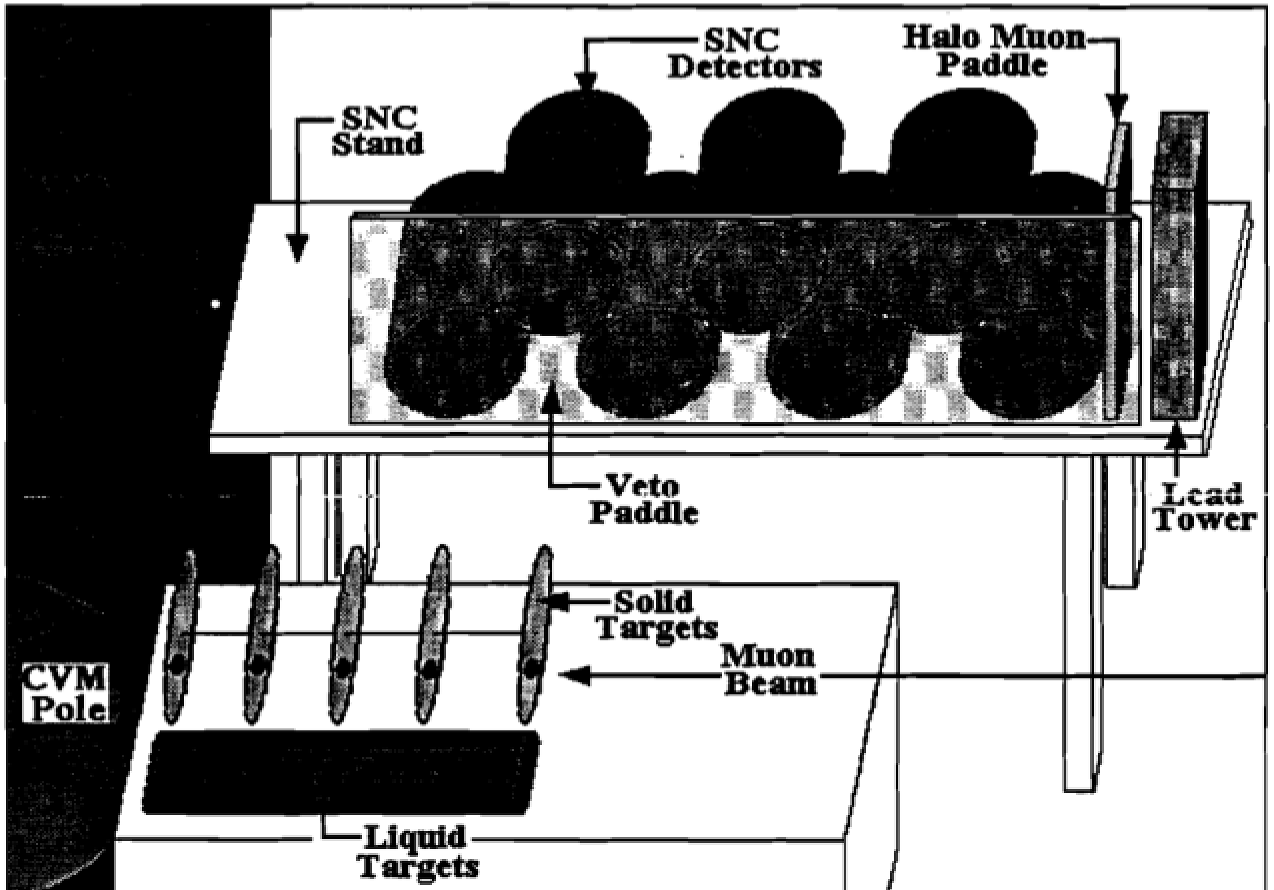



Figure 5.1: Location of the SNC experimental setup with respect to the target-vertex area.

Unlike at an EIC, E665 neutron detector had small relative coverage.

Not event-by-event

Warning: E665 data is usually a mix of DIS & diffractive...

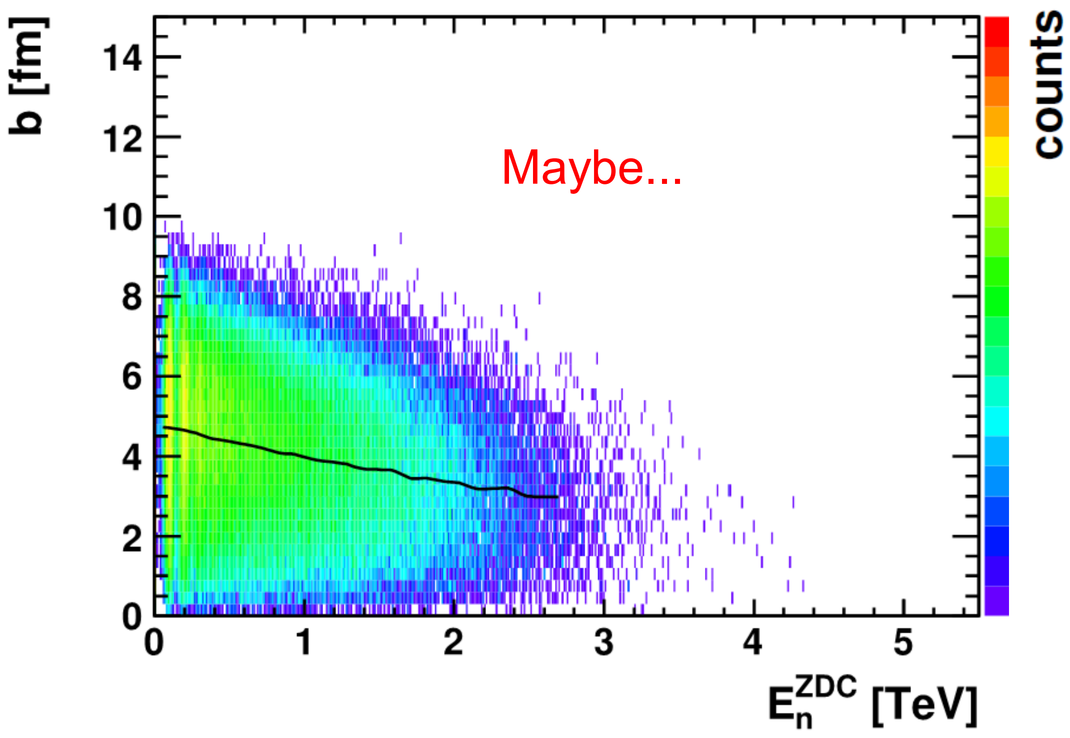
PhD Thesis, Henry Clark, Ohio University (1993)

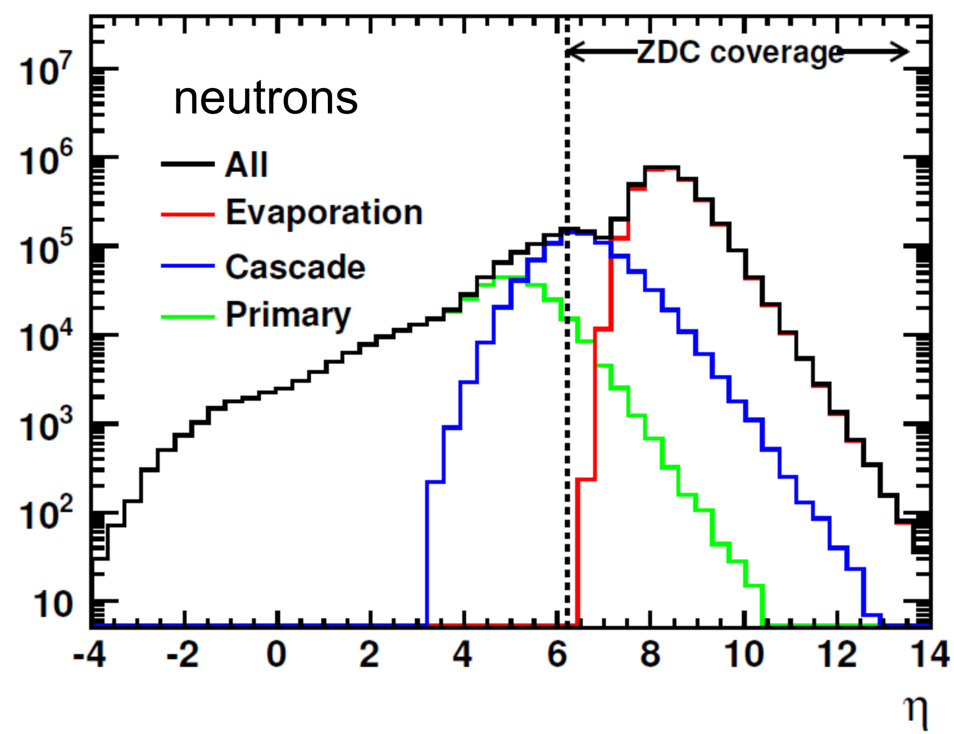
# Tag eA w/ Neutrons?

First look:

Zheng, Aschenauer, Lee, Eur.Phys.J.**A50** (2014) 189

10x100 GeV e+Au using DPMJET



# BeAGLE – Benchmark eA Generator for LEptoproduction

mdbaker@eic0004:BeAGLE

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File Edit Options Buffers Tools Help

+-------------------------------------------------------------------------+
| Welcome to BeAGLE - Benchmark eA Generator for LEptoproduction          |

|         BBBBBB  EEEEEEE     A     GGGGGG  LL        EEEEEEE           |
|         BB   B  EE         A A    GG      LL        EE                |
|         BB  B   EE        A   A   GG      LL        EE                |
|         BBBBB   EEEEE     AAAAA   GG  GG  LL        EEEEE             |
|         BB  B   EE       A     A  GG   G  LL        EE                |
|         BB   B  EE       A     A  GG   G  LL        EE                |
|         BBBBBB  EEEEEEE  A     A  GGGGGG  LLLLLLL   EEEEEEE           |

| Pre-release version                                                     |
|                                                                         |
| Authors: Elke Aschenauer, Mark D. Baker, J.H. Lee, Liang Zheng          |
| Contact: liangzhphy@gmail.com or mdbaker@mdbpads.com                    |
|                                                                         |
| This program (previously called DPMJetHybrid) links to:                 |
| DPMJET, PHOJET, & PYTHIA (see version #s below) including also          |
| LHAPDF for pdfs, and FLUKA & PyQM for conventional nuclear effects      |
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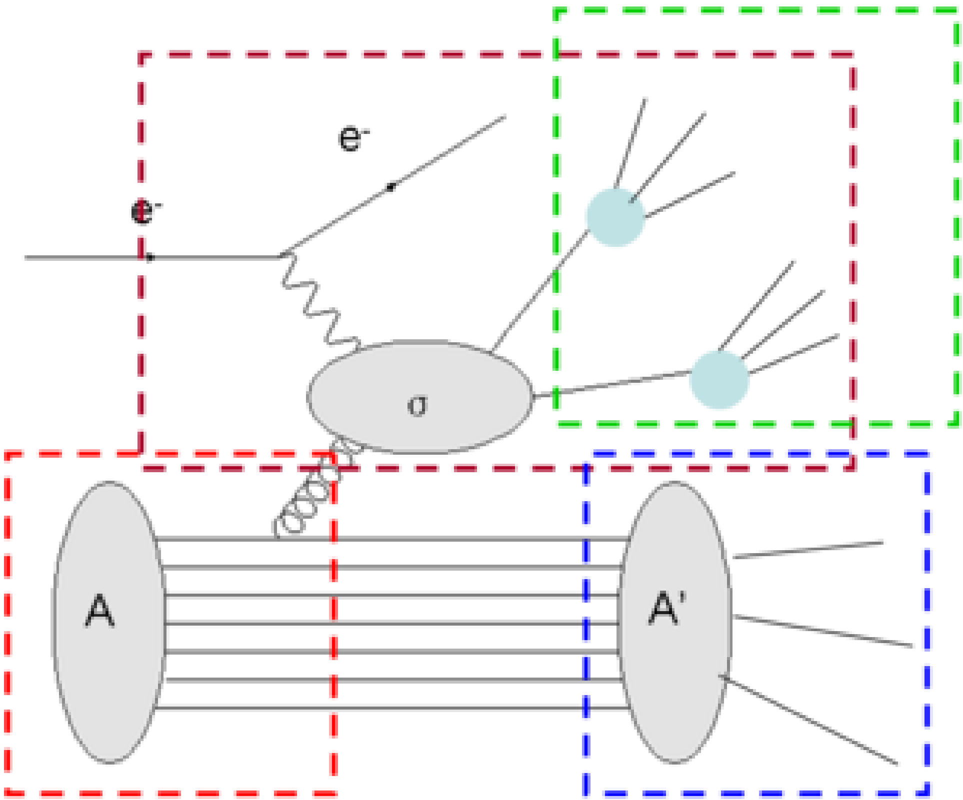
# BeAGLE

## **B**enchmark **eA G**enerator for **LE**ptoproduction

# BeAGLE Structure

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.

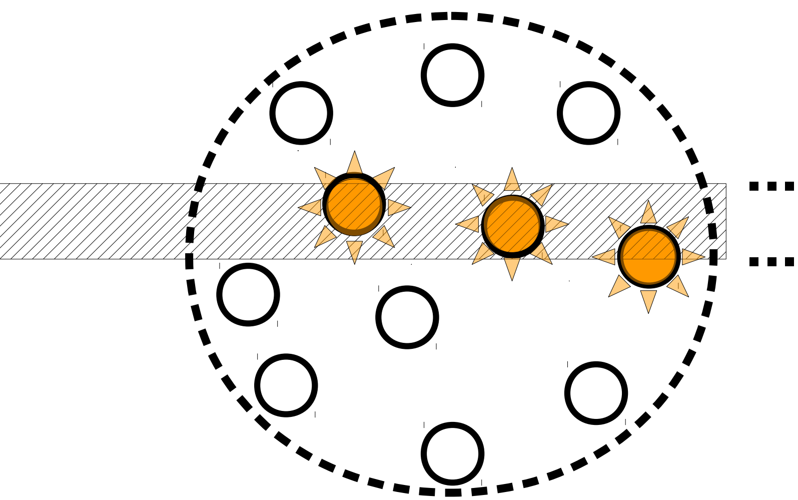
Nuclear evaporation ( gamma dexcitation/nuclear fission/fermi break up ) treated by DPMJet **& INCascade**

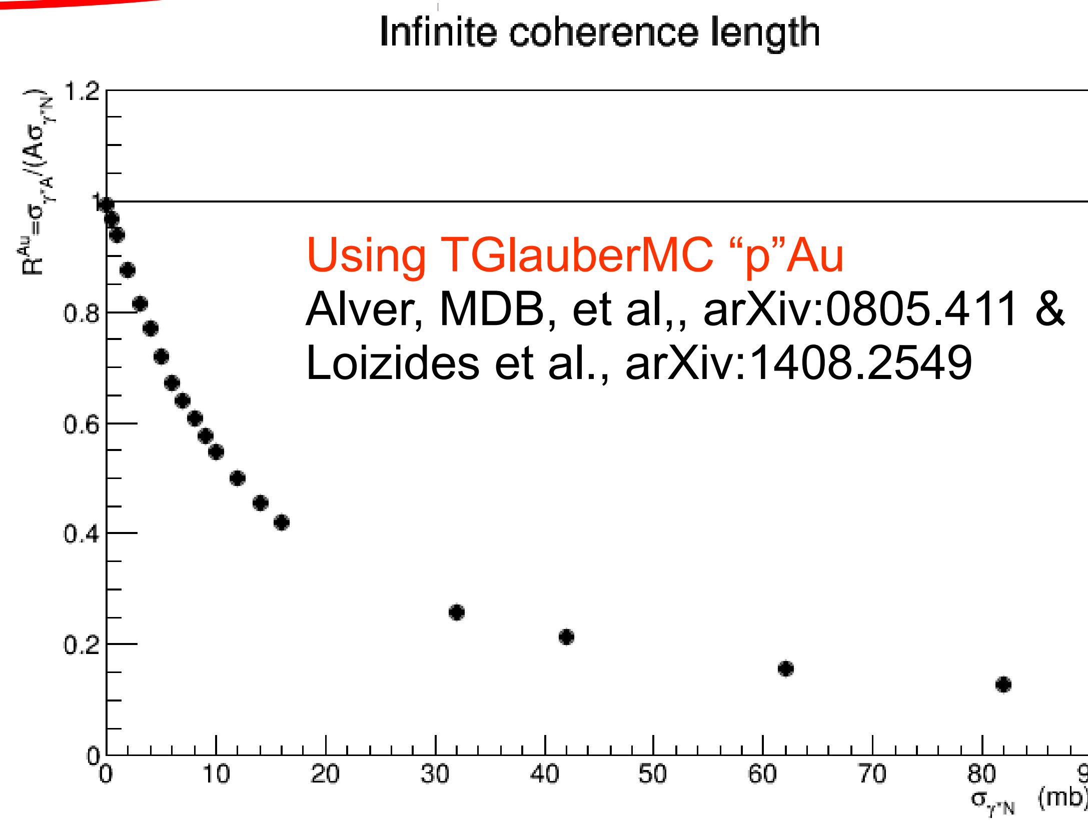
Energy loss effect from routine by **Accardi, Dupré** Salgado&Wiedemann to simulate the nuclear fragmentation effect in cold nuclear matter

# Making the map for $\lambda \gg R$

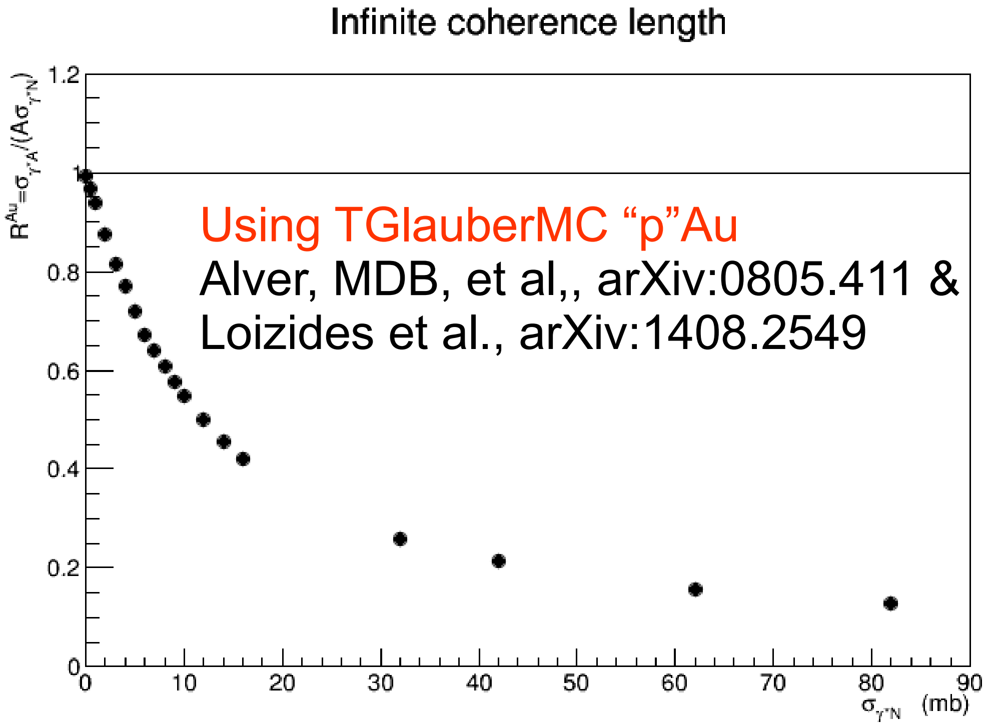
Most of the complications in saturation theory are in predicting the dependence on x, $Q^2$. With Glauber, we can make a simple map:

$\sigma^A/\sigma^N(x,Q^2) \longleftrightarrow \sigma_{\text{“dipole”}}(x,Q^2) \longleftrightarrow P(N_{coll},b)$

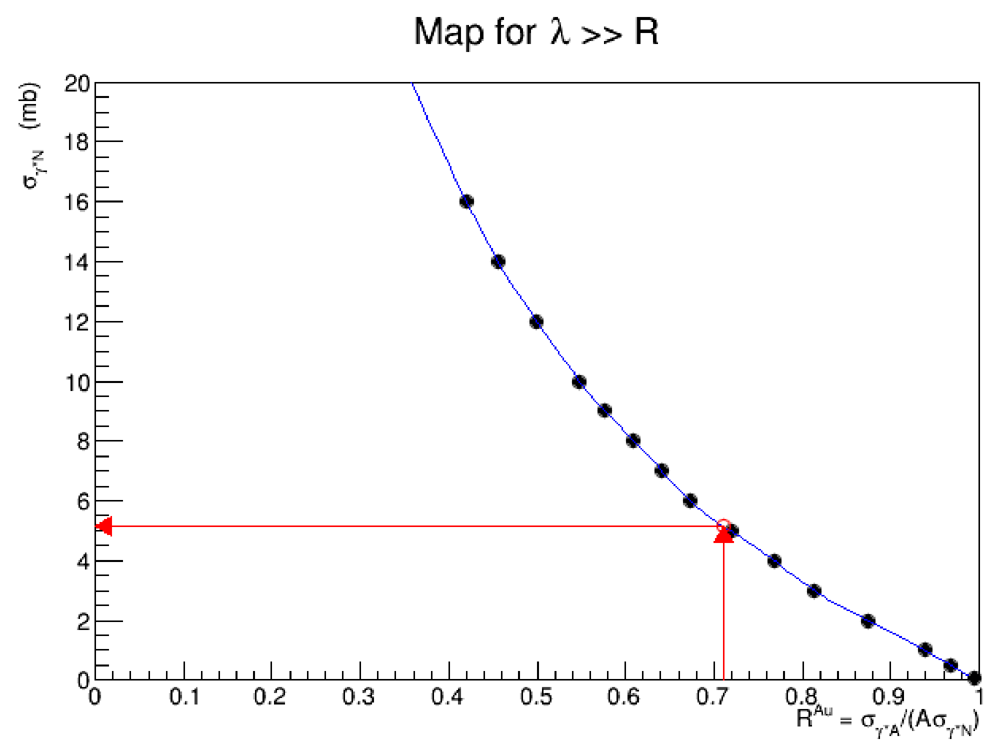




# Looking up the appropriate $\sigma_{\gamma^*N}(x,Q^2)$




Flip axes to make map.




Event-by-event, given x & $Q^2$:

E.g. for $x=0.001$, $Q^2=1.69$ GeV$^2$

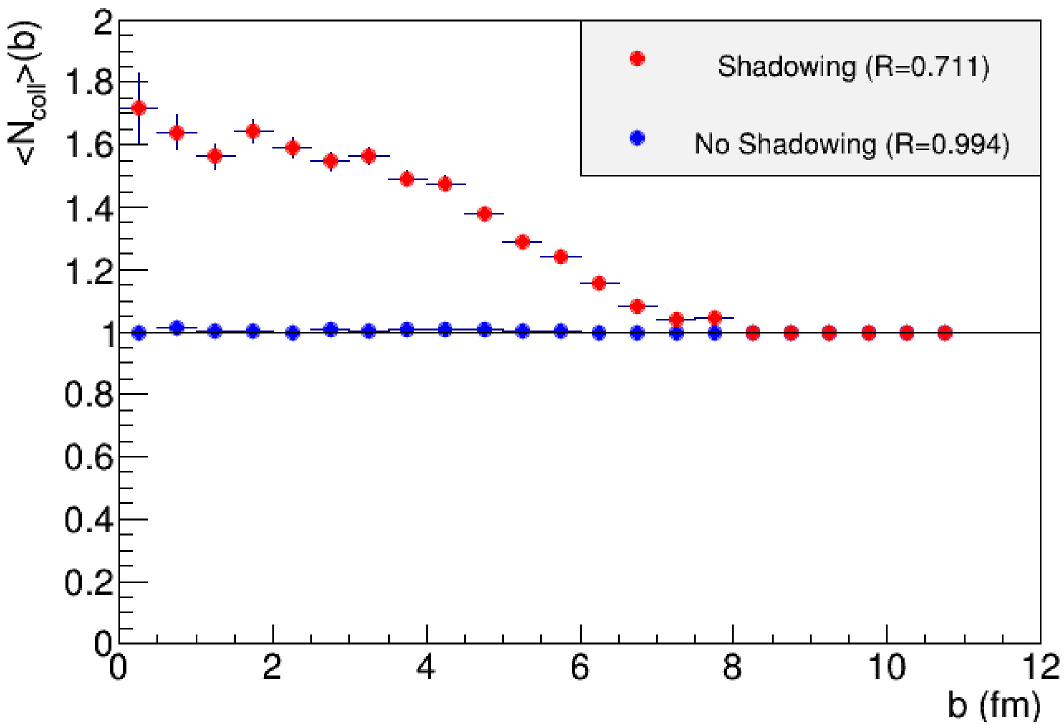
$R^{(Au/N)}(x\rightarrow 0, Q^2=1.69\text{GeV}^2) \approx 0.711$

$\sigma_{\text{"dipole"}} = 5.16$ mb

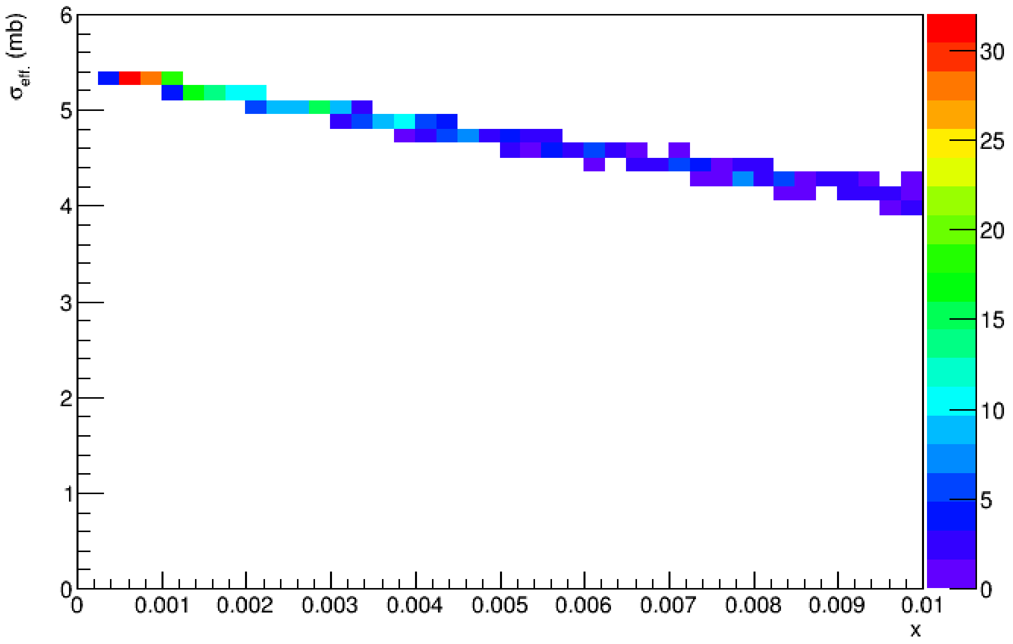
# $N_{coll}(b)$ for $Q^2$=1.69 GeV$^2$,x<<1

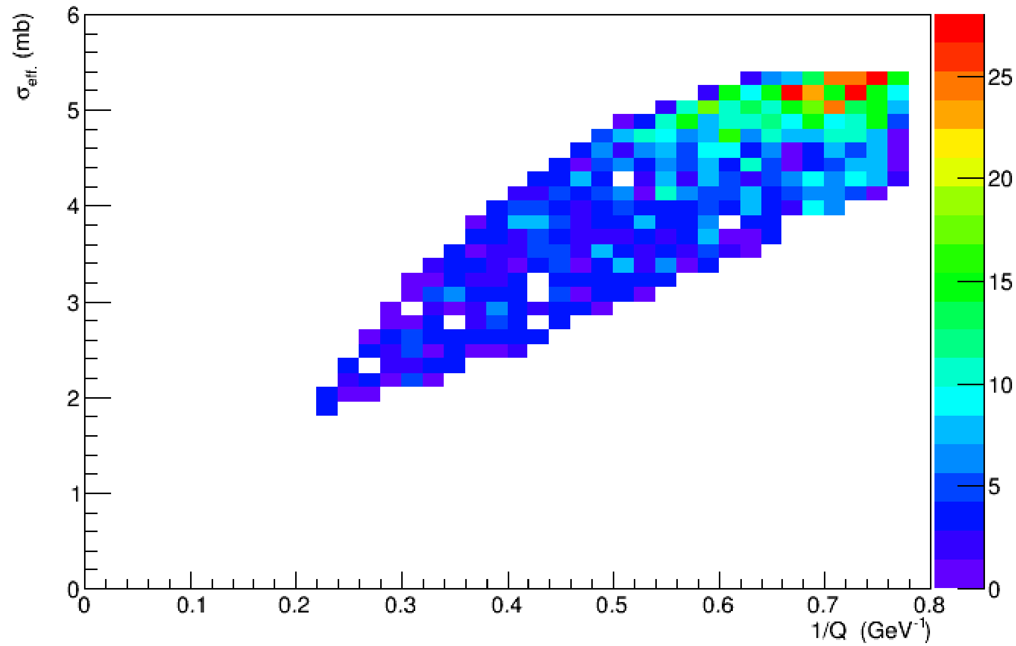
$\sigma^A/\sigma^N(x,Q^2)$ ⟷ $\sigma_{dipole}(x,Q^2)$ ⟷ $P(N_{coll},b)$

- **Big difference between b=0 & b= $R_{Au}$=6.38 fm at low x,$Q^2$**
- **Geometry tagging easier. Now b is <u>directly</u> correlated with measurable activity**
- **Enhanced shadowing (& saturation?) at b=0 (recall $R=1/N_{coll}$).**



# Effective $\sigma_{dip}$ from $R_{(A)}^{(EPS09LO)}(x,Q^2)$




Effective **σ:**

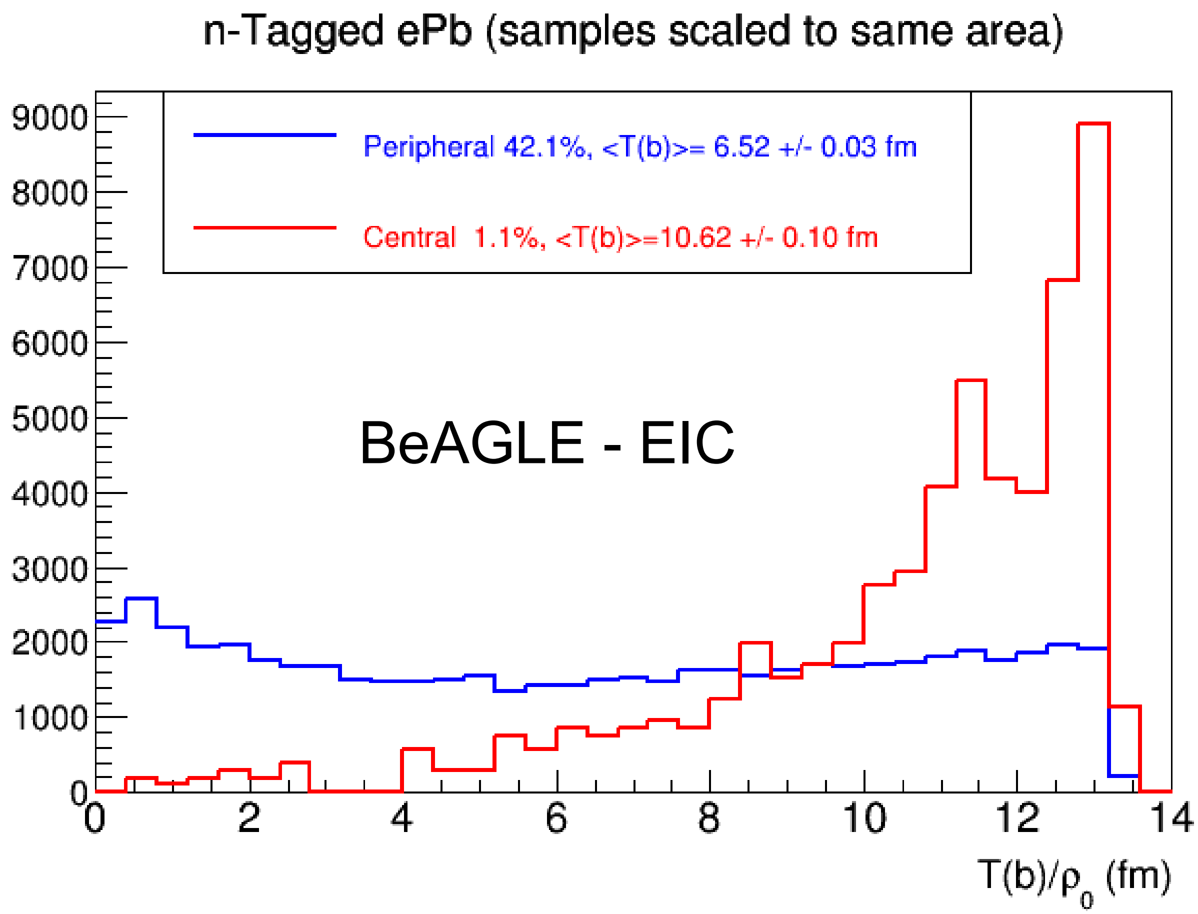
Includes possible effects of λ/R<∞

Weak function of x for x<0.01

Effective **σ**~1/Q rather than $1/Q^2$

Note: EPS09LO only valid for Q>1.3 GeV

# Geometry (b) tagging for e+Pb




e+Pb$^{208}$ collisions at 10 x 40 GeV, $Q^2$ > 1 GeV$^2$, y < 0.95, x < 0.002
w/ JLAB 2017-LDRD-6 collaboration V. Morozov et al.

# What do we need? (I)

- AA/pA/eA experimentalists: EIC planning as well as trying out forward detection now!
  - eA is NOT cut and dried. Lots of room for applying analysis & detector techniques from pA.
    - Not just measuring 39 "fundamental" structure functions for the theorists.
  - Forward detectors are the "streamer chamber" of a collider. How hermetic can we get?
    - Can we measure net charge $\langle Q_T \rangle$, $n_{grey}$, A'?
    - Something more clever: YOUR IDEA HERE?

# What do we need? (II)

- Better e+A simulations.
- BeAGLE plans:
  - Improve handling of (transverse) Fermi momentum
    - May affect dijets / monojets comparison e+A vs e+p
  - Improve description of incoherent: e+A→e+V+X
    - Better dipole cross-section for diffraction
    - Add RAPGAP option (vs. Pythia)
  - Allow handling of UltraPeripheral events
  - Better tune to E665 and current UPC data

# What do we need? (III)

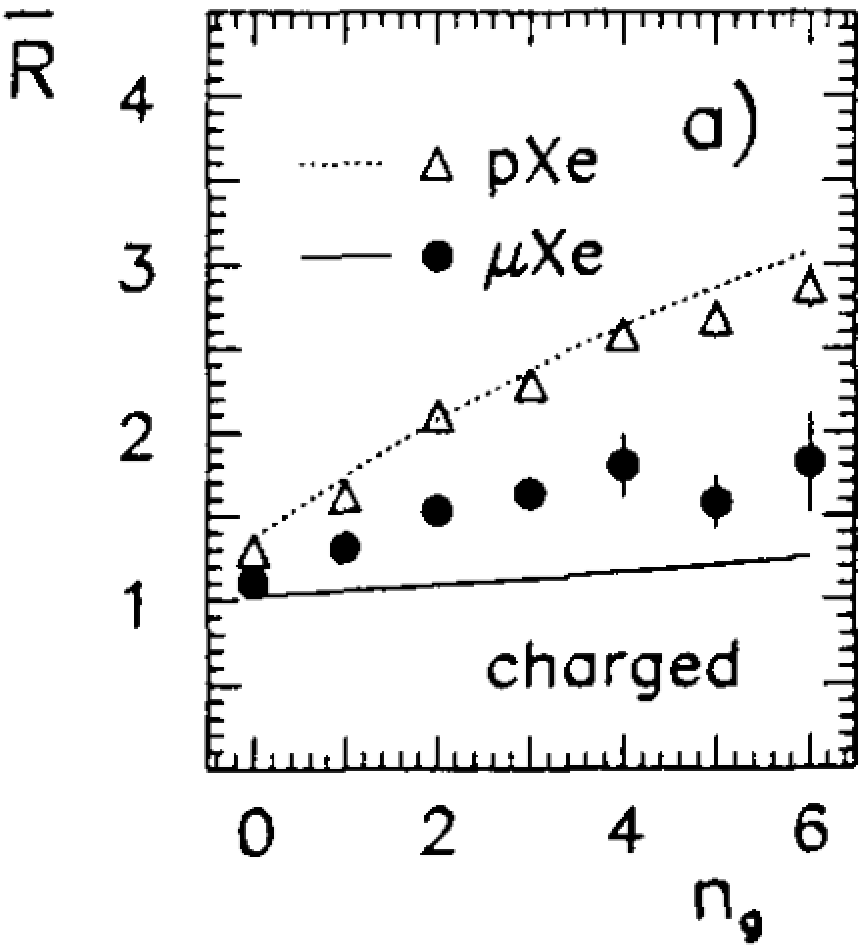
- Pedestrian guides to the theory
  - Maps between:
    - Dipole & IMF & light-front approaches
    - Parton saturation & dipole saturation & confinement
    - Shadowing (leading or higher twist) & saturation
  - What is known vs. conjectured?
    - Widely believed vs. controversial
    - What are we trying to prove with our measurements?
      - Is there a "Find the QGP!"-like slogan?

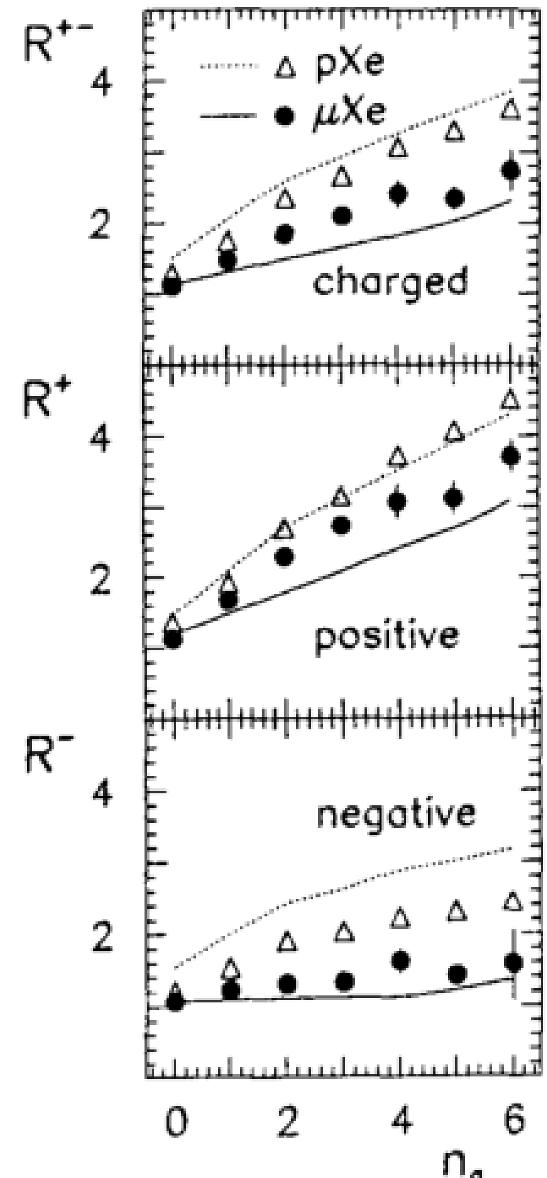
# Conclusions

- Lots of interesting work for:
  - Experimentalists of all stripes (AA/pA/$p\uparrow p\uparrow$/ep/eA)
  - Model-builders
  - Theorists
- Geometry tagging is potentially powerful, but not straightforward (i.e. fun!)
  - Challenging to model
  - Challenging to build optimal detectors

# BACKUPS

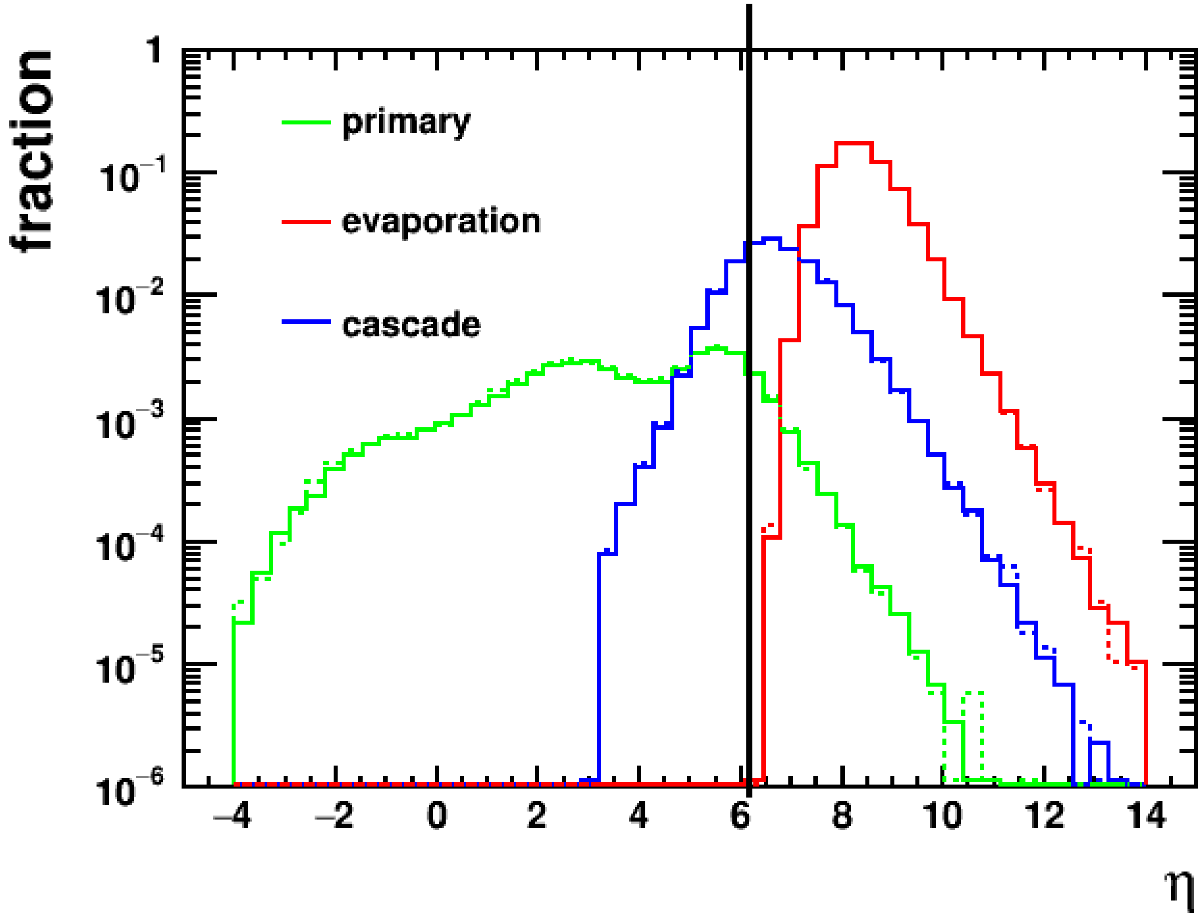
E665, ZPC 65 (1995) 225



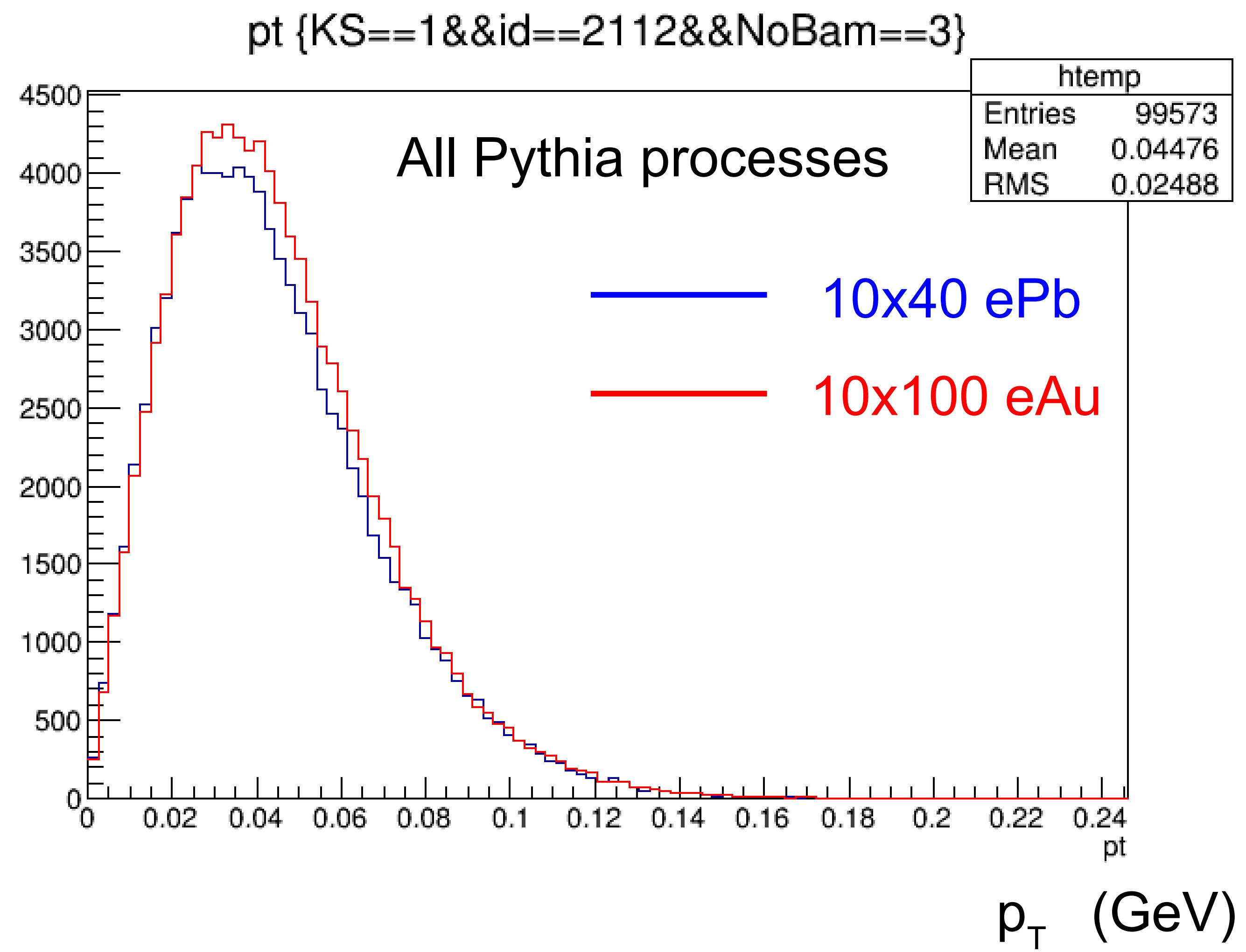
# Impact of PARP(91)=$k_T^{rms}$

**Solid: 0.24 GeV** **Dotted: 0.11 GeV**

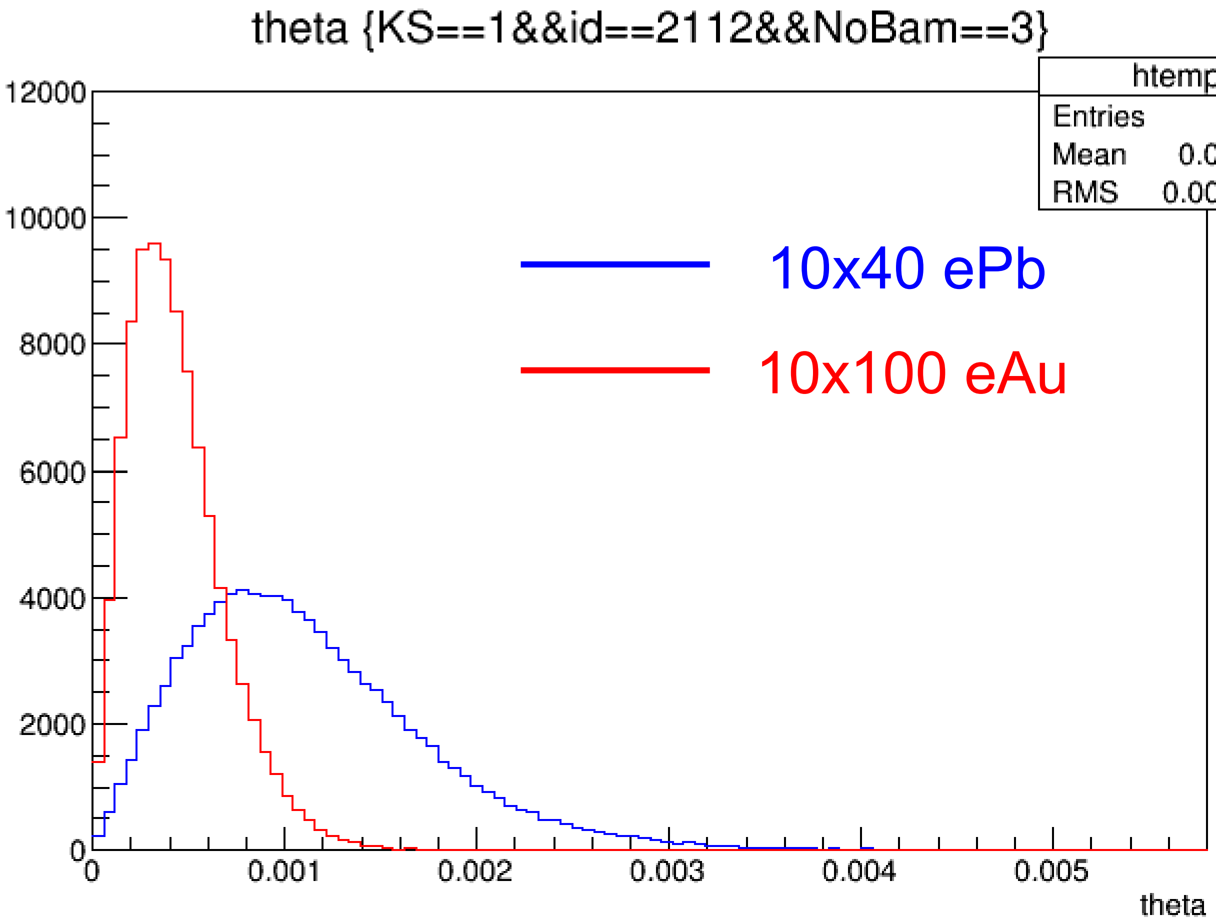



**Modest changes in PARP(91) are barely visible.**

# Evaporation neutrons in BeAGLE



# Evaporation neutrons in BeAGLE




θ (radians)

10mr ZDC @ JLEIC
=
4mr ZDC @ eRHIC

& more than cover evaporation neutrons @ full energy.

eRHIC OK for 10x40 (&JLEIC for 10x16)