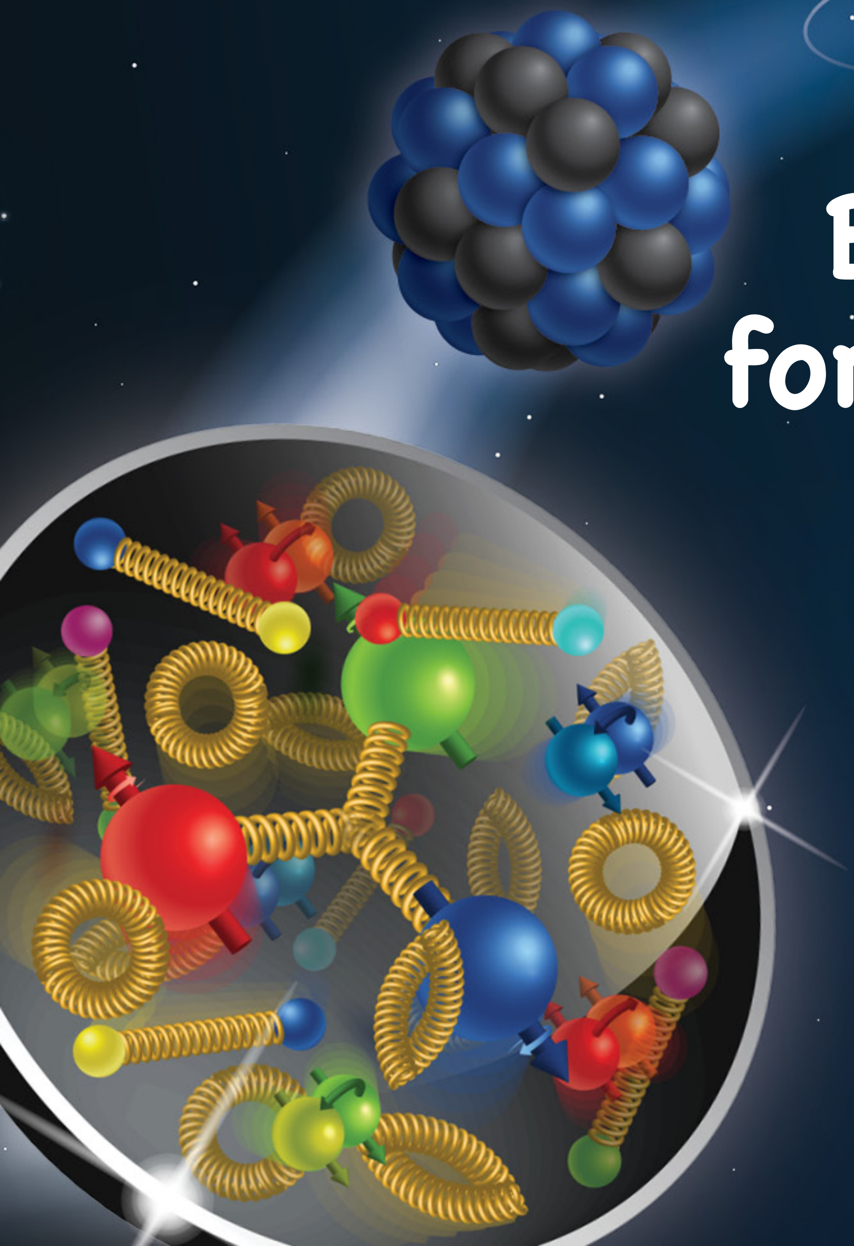

BeAGLE generator for nuclear breakup

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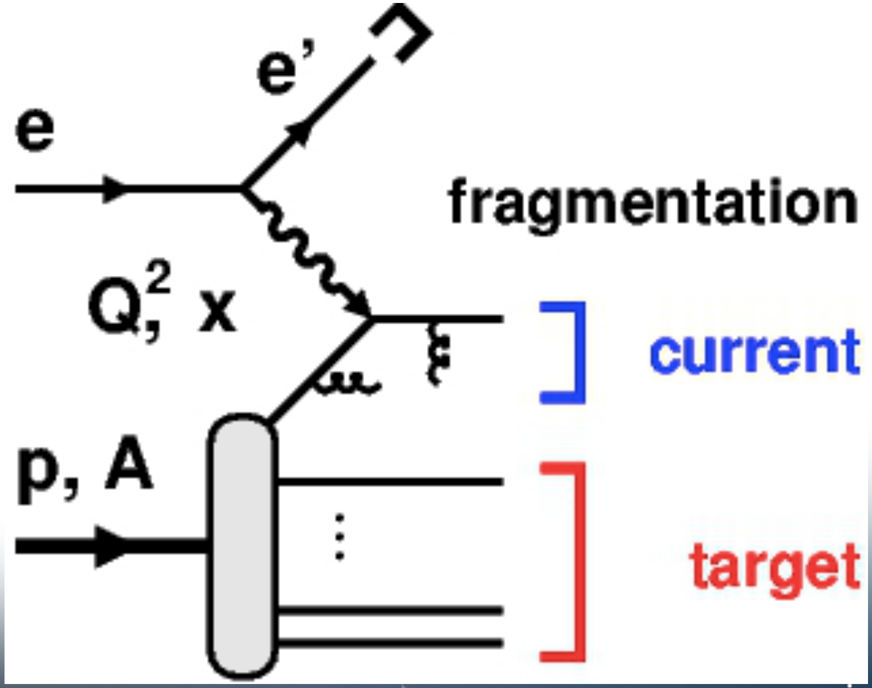
Outlook

- Motivation
- Tuning PYTHIA for e+p
- BeAGLE simulation framework
- BeAGLE parameter tuning
- Summary



Motivation

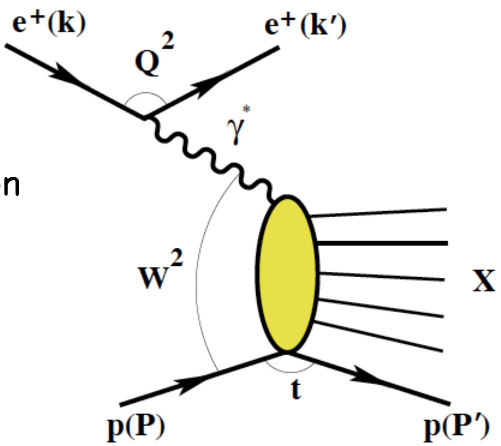
The BeAGLE (**B**enchmark **eA** **G**enerator for **LE**ptoproduction) program for simulating e+A collisions, largely developed as an EIC R&D project, used to optimize the detector and IR integration requirements, particularly in the forward region. Many topics with demanding requirements on forward detection.

BeAGLE helps us to describe the target fragmentation better.

BeAGLE is currently the main general purpose e+A simulation tool used to understand the physics and detector design for e+A collisions at EIC.

Tuning PYTHIA with e+p@ZEUS

$e^+p \rightarrow e^+Xp$ (27.5 GeV x 820 GeV)



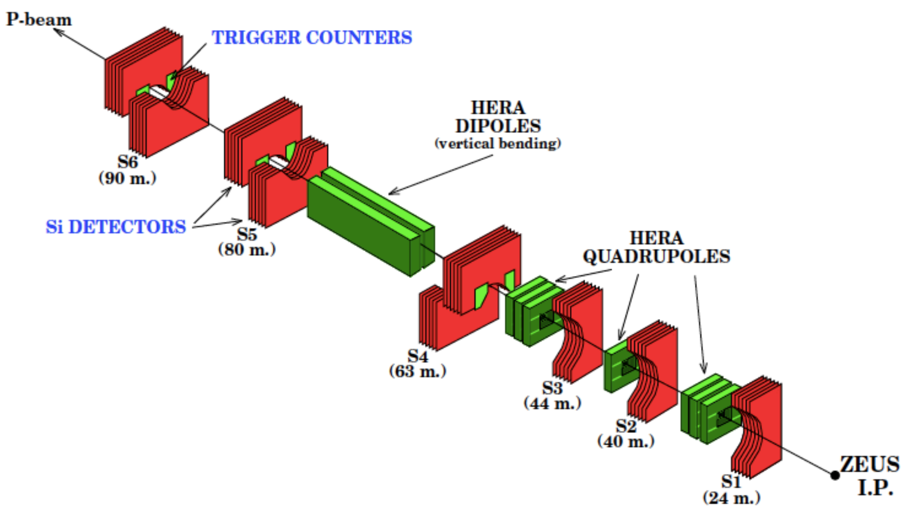
Event:

$x_L > 0.32$
$p_T^2 < 0.5\ \mathrm{GeV}^2$
$Q^2 > 3\ \mathrm{GeV}^2$
$45 < W < 225\ GeV$

x_L is the momentum fraction carried by the outgoing leading proton:

$$x_L = \frac{P' \cdot k}{P \cdot k}$$

The final-state proton was detected with the ZEUS leading proton spectrometer (LPS).



six detector stations: s1 to s6

the minimum distance between the track and the beampipe: 0.25 cm for s123 & 0.04 cm for s456

the minimum distance of the track from the edge of any LPS detector: 0.02cm

Tuning of P(χ)

MSTP(94): controls the energy partitioning in beam remnant cluster decay. The default value of 3 uses the regular fragmentation function
→ MSTP(94)=2: $P(\chi) = (k+1)(1-\chi)^k$ where χ is the energy fraction taken by the hadron or diquark.

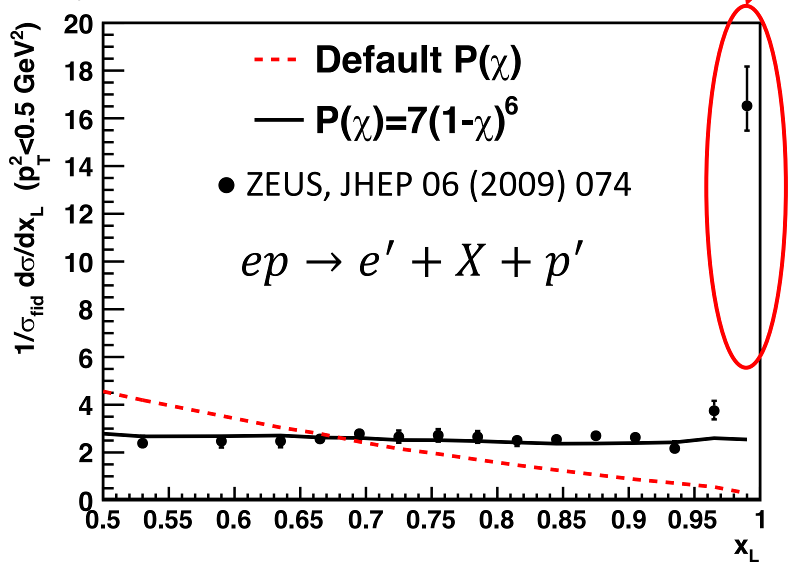
PARP(97): the value of parameter k for MSTP(94)=2

We tuned P(χ) to better match ZEUS data.

	MSTP(94)	PARP(97)	P(χ)
Default	3	-	Frag. function
Peaked	2	6	$7(1-\chi)^6$

Diffractive Peak

$\sigma_{fid} = \sigma$ for h^+ $0.5 < x_L < 0.89, p_T^2 < 0.5$ GeV^2



PARJ(21): the standard fragmentation p_{T} width.
PARP(91): (D=2) the width of Gaussian intrinsic k_{T} distribution.

We also lowered k_T to better match ZEUS data.

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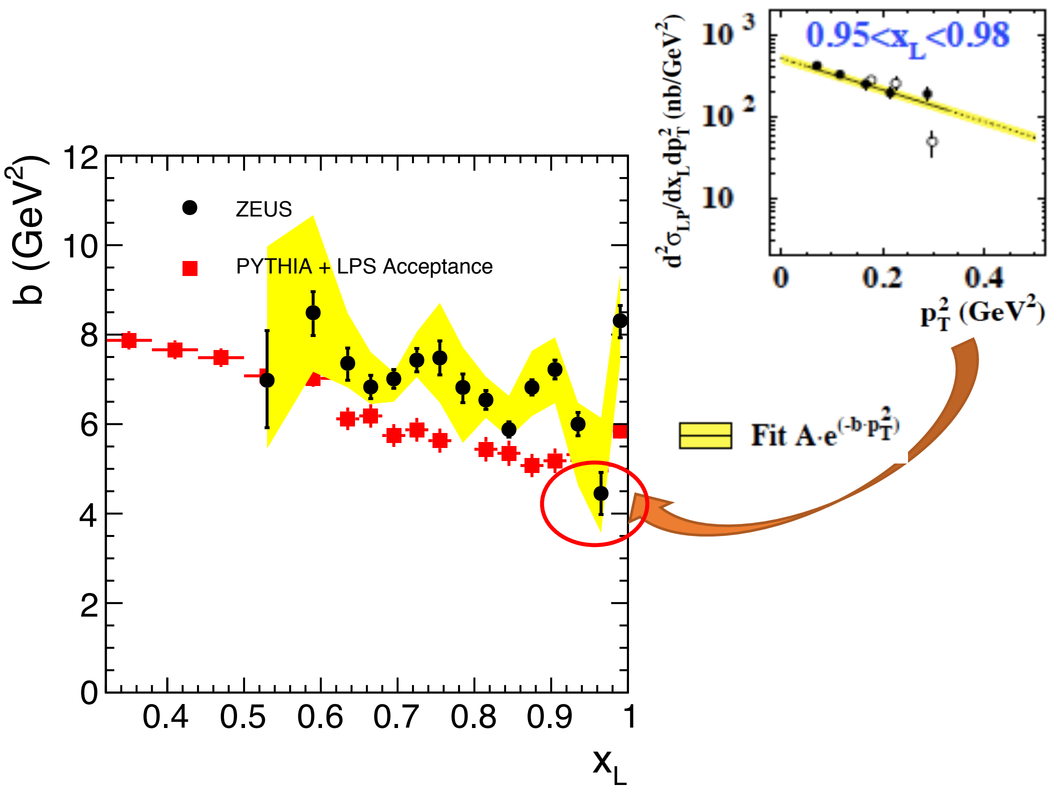
NOTE: In the end used:

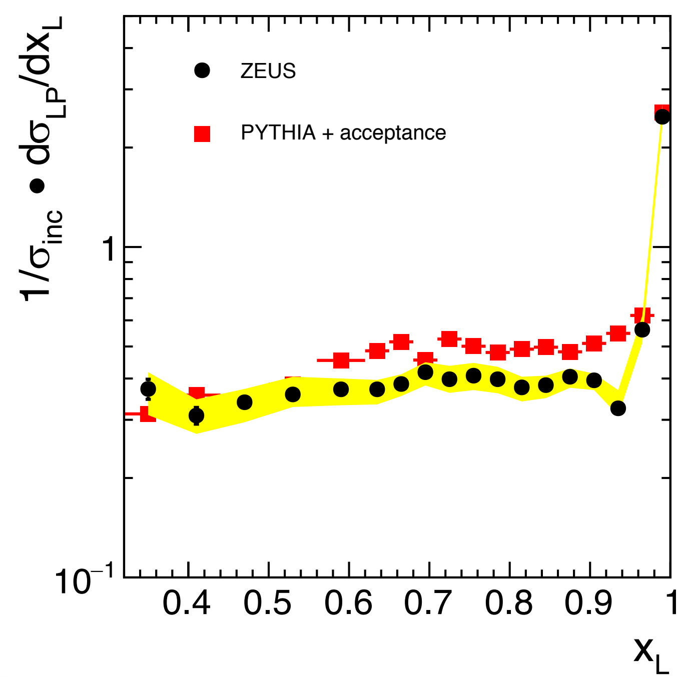
MSTP(94)	PARP(97)	PARP(91)	PARJ(21)
2	6	0.32	0.32

PYTHIA tune for ZEUS e+p

LPS trigger conditions and acceptance were required, dropped tracks very close to beamline or the edge of LPS detectors.



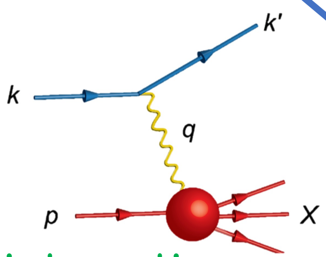
The leading proton production rate:



We have a good PYTHIA tune for target fragmentation for ep.
Remaining improvement would require a full GEANT simulation

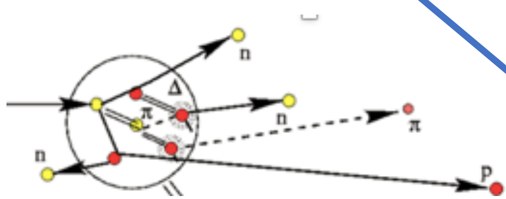
BeAGLE framework for eA

BeAGLE (**B**enchmark ***eA*** **G**enerator for **LE**ptoproduction): A hybrid model consisting of DPMJet and PYTHIA with nPDF EPS09.



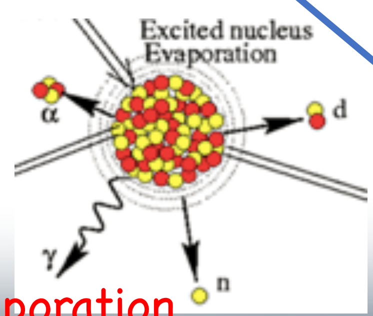
Primary interaction

Primary interaction treated by **PYTHIA** hard collision.



Intra-nuclear cascade

Cascade process handled by **DPMJET**.



Nuclear remnant evaporation

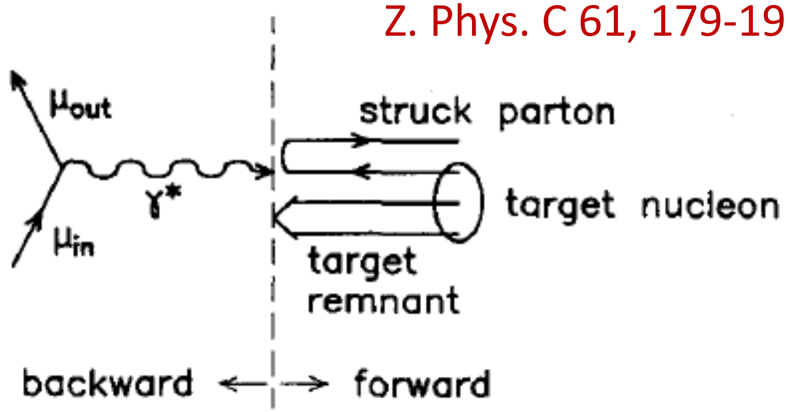
Target remnant evaporation and break up included by **FLUKA**.

BeAGLE tune for E665 muXe

Z. Phys. C 61, 179-198(1994)

E665 fixed target experiment
Data sample: μ^{+}+Xe
Beam momentum: 490 GeV

$0.1 < y < 0.85$
$1.0 < Q^2 < 100$
0.0035 rad < θ < 6.29 rad
8<W<30 GeV
X>0.002



The struck parton is emitted into the forward direction, while the target remnant travels into the backward direction. The hadronic CMS frame is defined by the system formed by the virtual photon and the target nucleon.

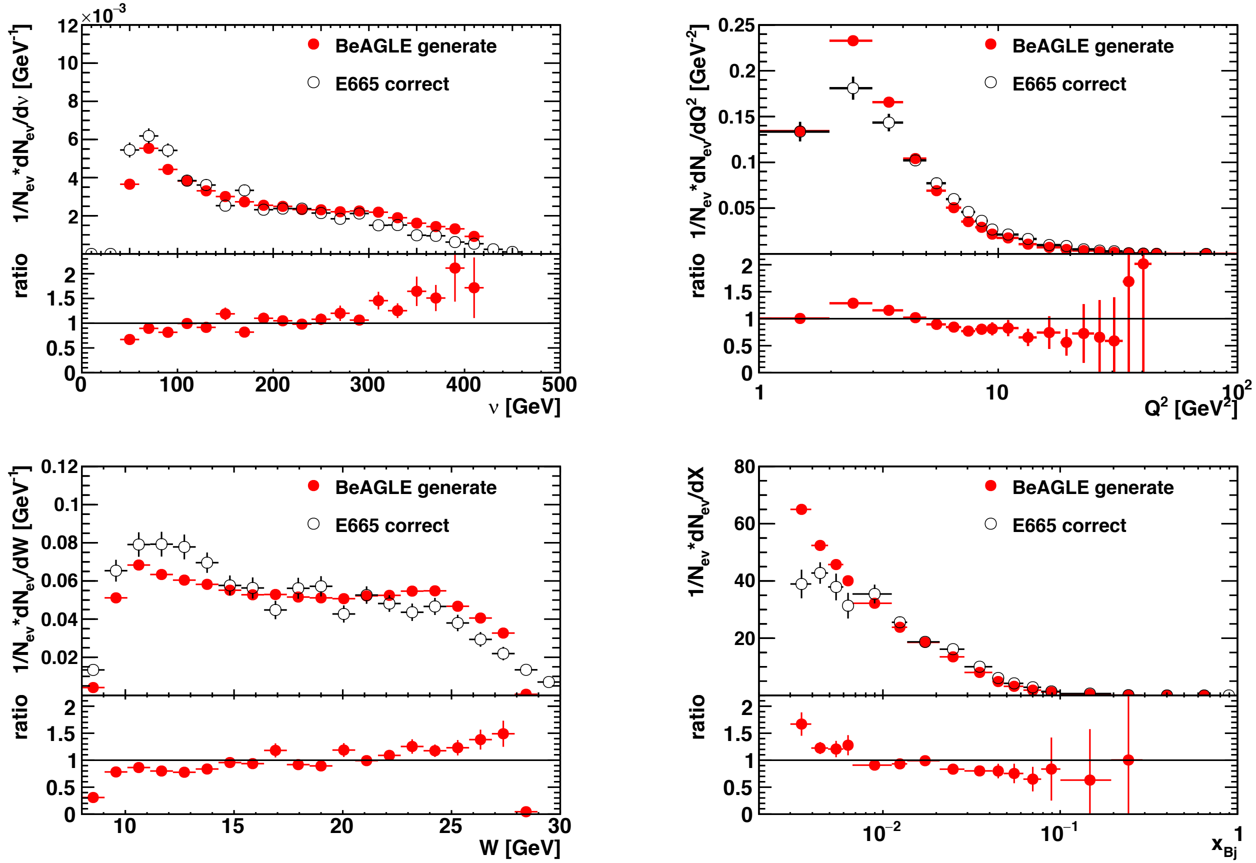
A streamer chamber (SC) provides momentum measurement of nearly all low momentum charged hadrons (0.2 < p < 10 GeV/c).
The scattered muon and high momentum (p ≥ 10 GeV/c) charged hadrons are measured in a forward spectrometer.

All positive hadrons in the data with $x_F(m_\pi)$ < -0.2 are assigned the proton mass, all other hadrons are treated as pions.

BeAGLE tune for E665 muXe

Z. Phys. C 61, 179-198(1994)

Kinematics distributions:



PYTHIA and nuclear PDF EPS09 implemented in BeAGLE describe the E665 data.

Tuning of formation time τ_0

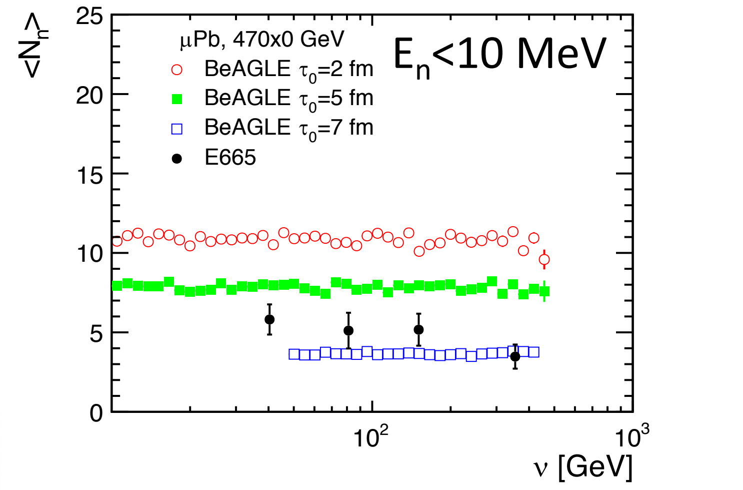
In DIS , the formation time τ is defined as the time before newly created particles can be re-interact with the nucleons:

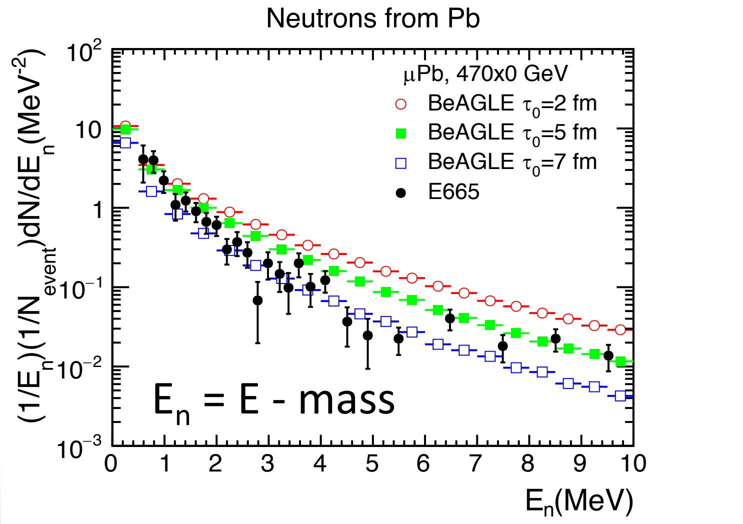
$$\tau = \tau_0 \frac{E}{m} \frac{m^2}{m^2 + p_\perp^2}$$

τ_0 is a free formation length
E, m, $p_\perp$ are the energy, mass and transverse momentum

The longer τ_0, the less number of particles can be created during the nucleus.

Results of different formation length parameters as a function of ν and E_n in the simulation compared with the E665 data: M. Adams et al. (E665 Collaboration), Phys.Rev.Lett. 74, 5198 (1995)

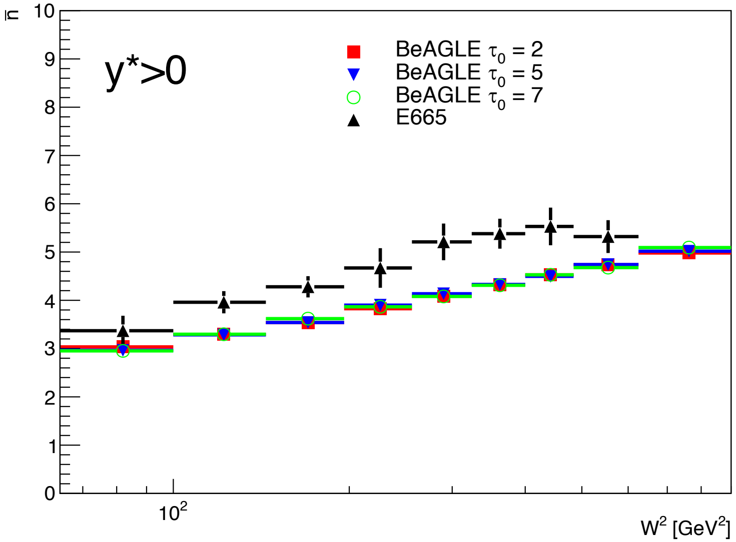




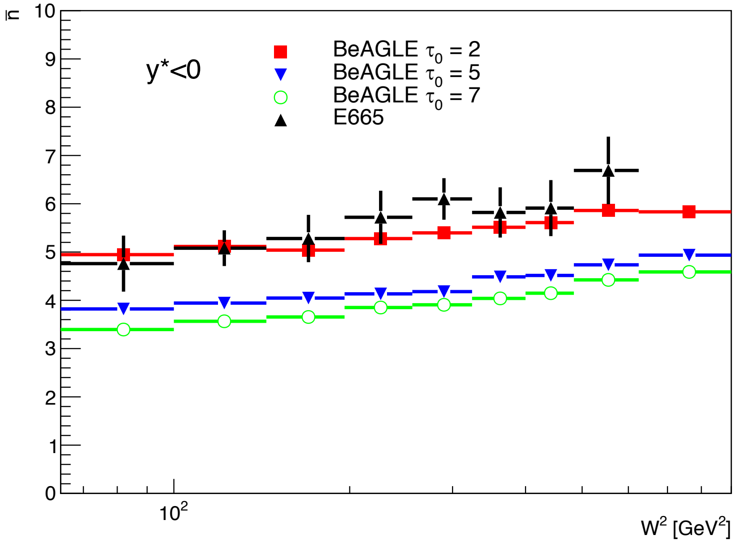
The results with $\tau_0 = 7$ fm are closest to the E665 result.

Average multiplicity distribution vs. τ_0

current fragmentation



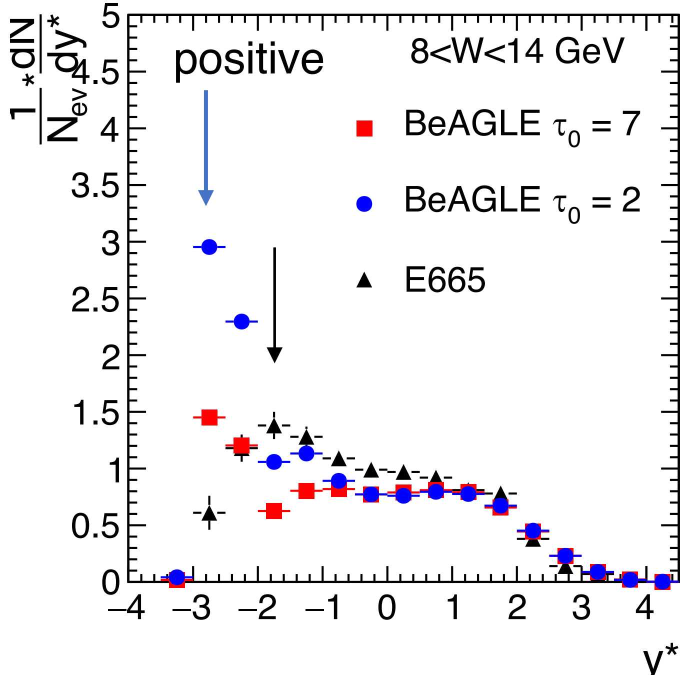
target fragmentation

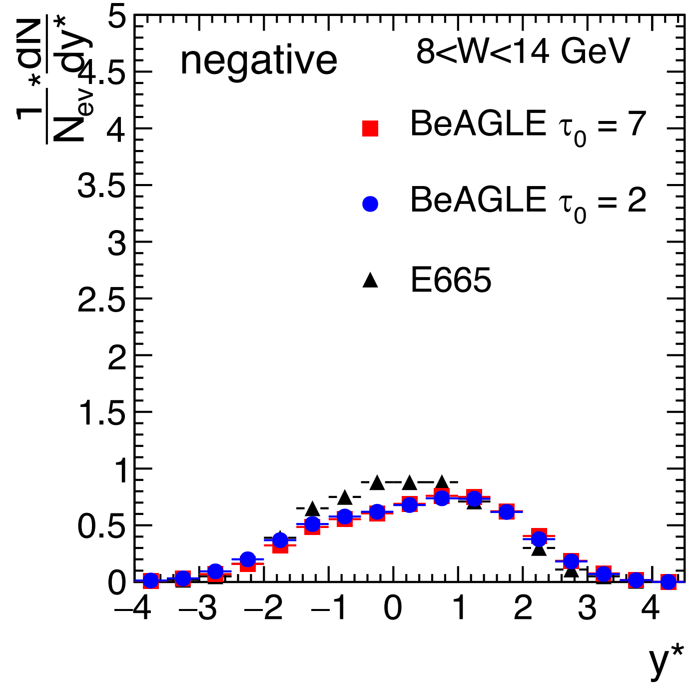


- The distribution for charged hadrons for current fragmentation has no τ_0 dependence.
- With lower τ_0, the average multiplicity distributions for charged hadrons in the target fragmentation region improve.
- τ_0=2 fm matches the data, which is a discrepancy to the τ_0=7 fm obtained from the neutron.

Rapidity distribution of muXe

The normalized cms-rapidity distribution for positive and negative charged hadrons are studied in three W-bins: 8<W<14 GeV, 14<W<20 GeV, 20<W<30 GeV.

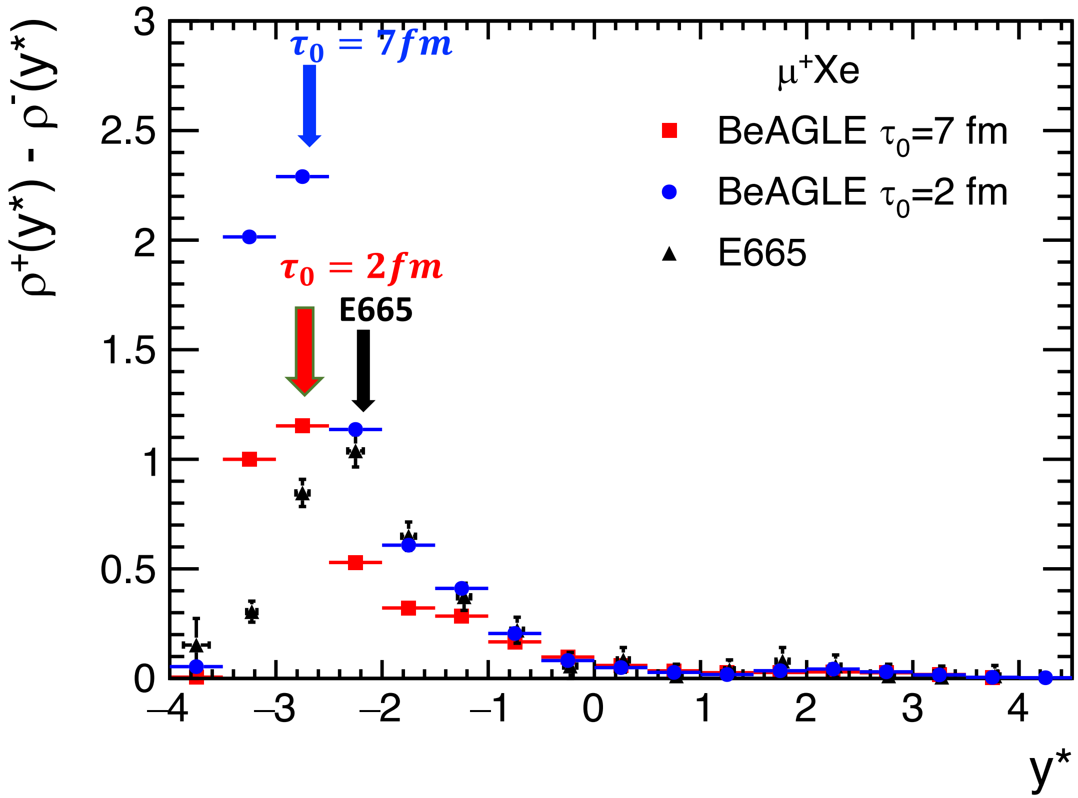




- positive charged hadrons:
  - no τ_0 dependence at forward y* and data are matched well.
  - But backward peak position different for MC and E665 data.
- negative charged hadrons:
  - distributions are almost identical for different τ_0. Agree all well with E665.

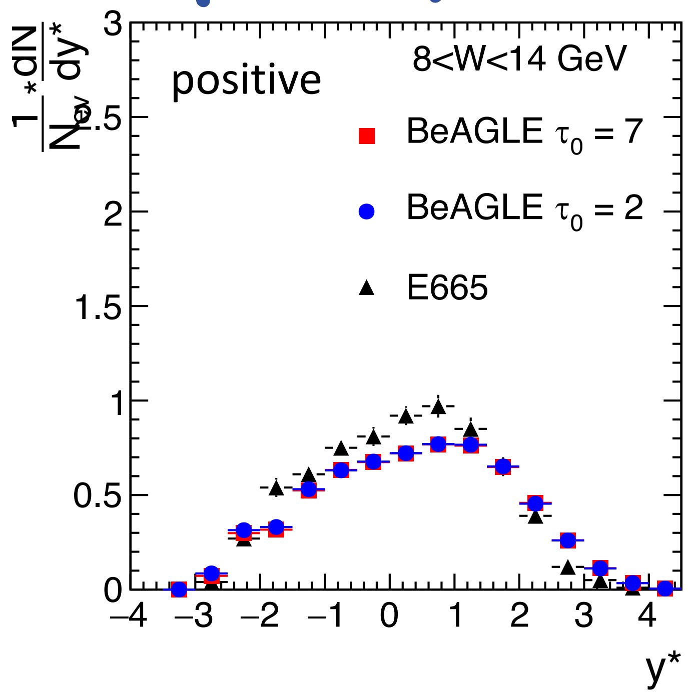
Rapidity distribution of muXe

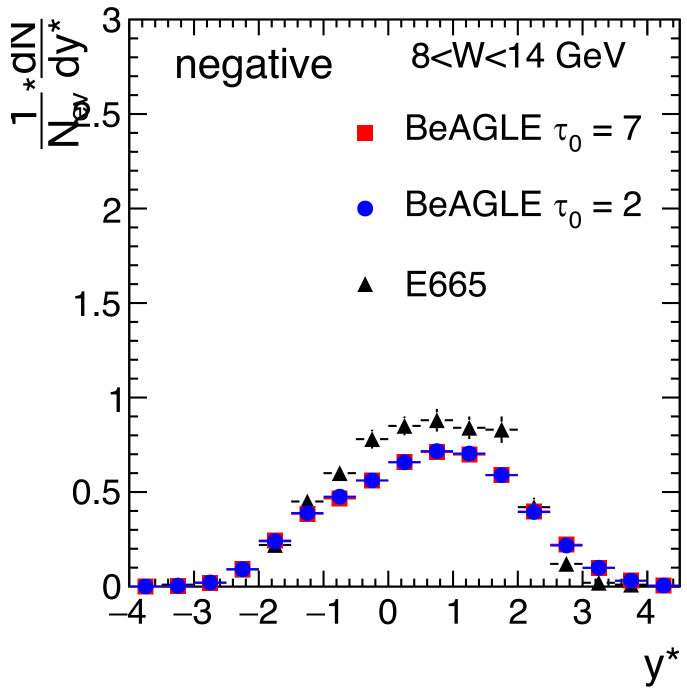
The normalized cms-rapidity distribution of hadronic net charge for muXe:

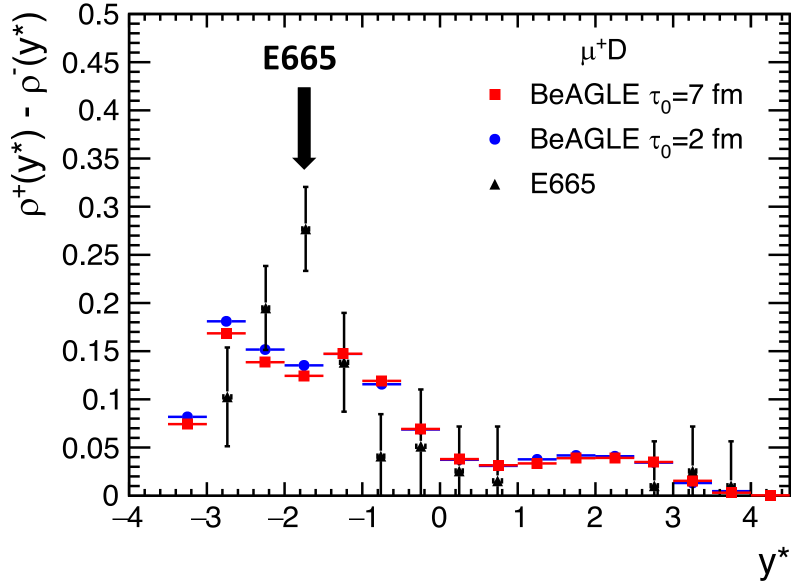


- Hadronic net charge: peak position of BeAGLE y*=-2.8, but E665 y*=-2.2

Rapidity distribution of muD





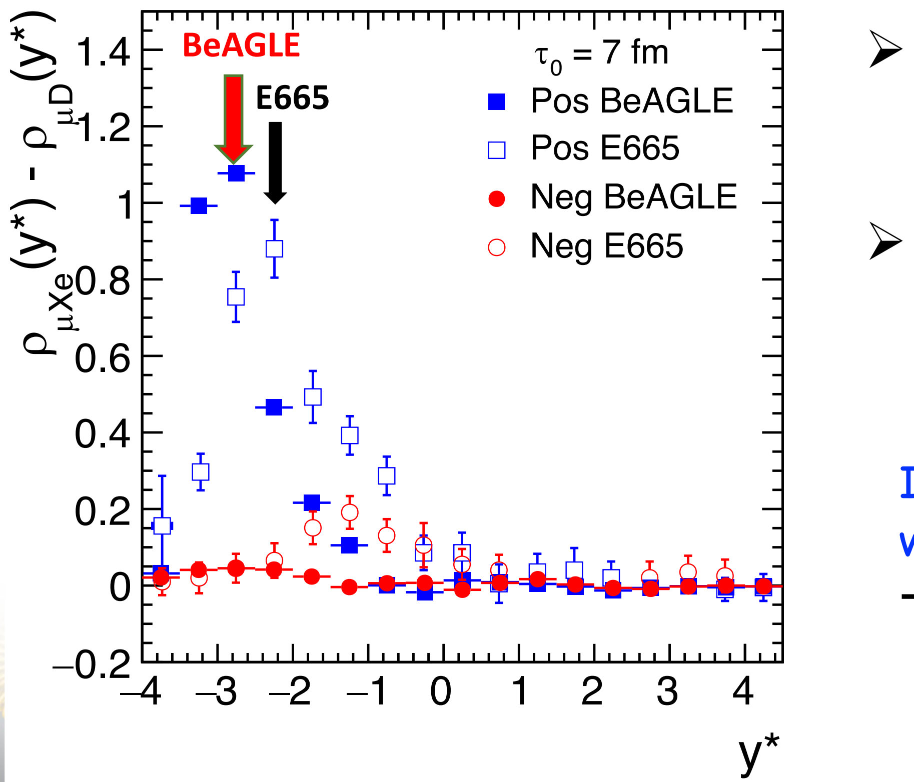


- positive and negative charged hadrons are almost the same.
- no τ_0 dependence for both positive and negative charged hadrons.

- For the hadronic net charge, the peak of BeAGLE and E665 seem to be in different positions.

$\rho_{\mu Xe}(y^*) - \rho_{\mu D}(y^*)$

Difference of the normalized cms-rapidity distributions between muXe and muD scattering, for positive (blue) and negative hadrons (red) with different τ_0:



- match well for both positive and negative charged hadrons at forward y*
- don't agree backward y*, peak for Beagle at more negative y*

Is E665 data wrong or is something wrong in BeAGLE?

→ test BeAGLE / DPMJET with different observable/data

BeAGLE muXe/muP vs. SPS pXe/pp

BeAGLE: fixed target muXe/muP
$E\mu$= 490 GeV
17<W<23 GeV

VS.

SPS: pXe/pp
E_p = 200GeV/c
($\sqrt{s_{NN}}$ = 19.4 GeV ~W)

$$\rho(y) = \frac{1}{N_{ev}}\frac{dN}{dy} \qquad R(y) = \rho_{Xe}(y)/\rho_p(y)$$

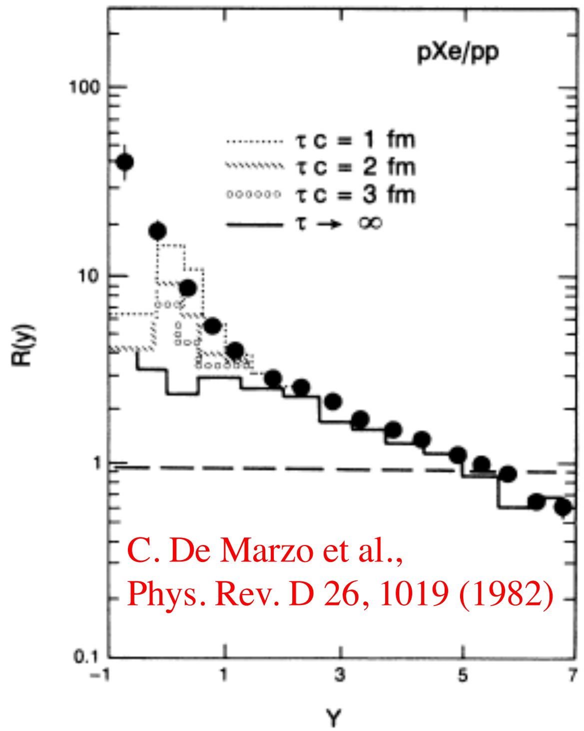
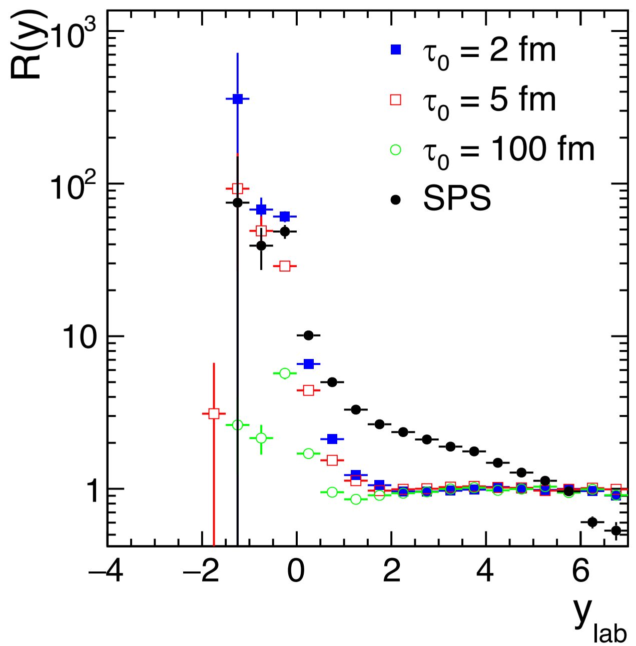


FIG. 6. Rapidity ratios $R(y)=[dN/dy(p\text{-Xe})]/[dN/dy(p\text{-p})]$ for all charged particles at proton energies in the laboratory frame $p_{lab}=200$ GeV/c. The Monte Carlo results represented by histograms are compared to data from Ref. 22. The lowest histogram corresponding to $\tau\rightarrow\infty$ was already calculated in Ref. 8.



BeAGLE/DPMJET: show that the "nuclear response" is centered at same y_{lab} as SPS pA data.

Summary

- ✓ We have a good PYTHIA tune for target fragmentation for ep
- ✓ PYTHIA and nuclear PDF EPS09 implemented in BeAGLE describe the E665 data sensitive to hard interaction
- ✓ BeAGLE does reproduce the negative charged hadrons of E665 over all y^*
- ✓ BeAGLE doesn't reproduce E665 data for positive charged hadrons at backward hemisphere.
  - ✓ **Possible Explanations:**

    E665 data: rapidity has been somehow mis-measured?

    E665 data: big detection inefficiency for $-1<y<+0.5$?

    BeAGLE/DPMJET: INC and Evaporation physics not fully covered for DIS

Collaborators

Special acknowledgement:

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Brookhaven National Laboratory

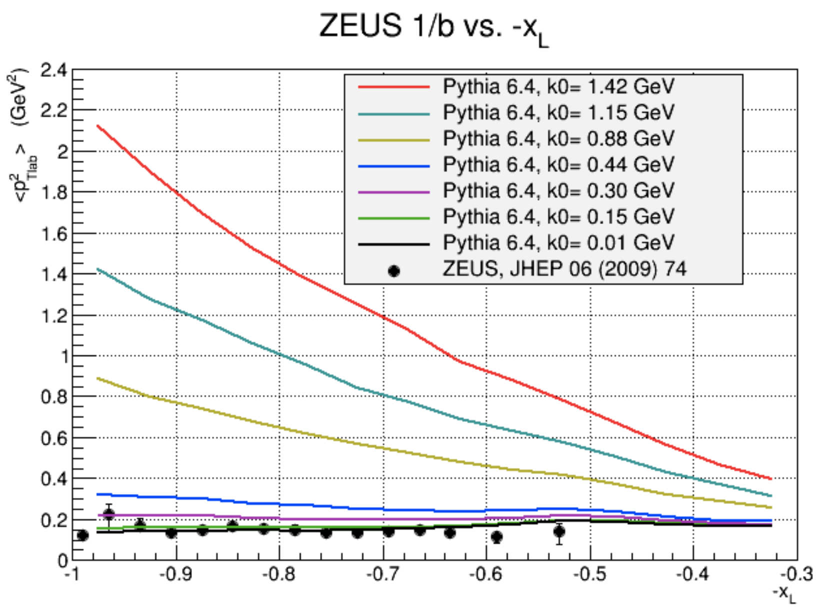
Liang Zheng
China University of Geosciences (Wuhan)

Thank you!

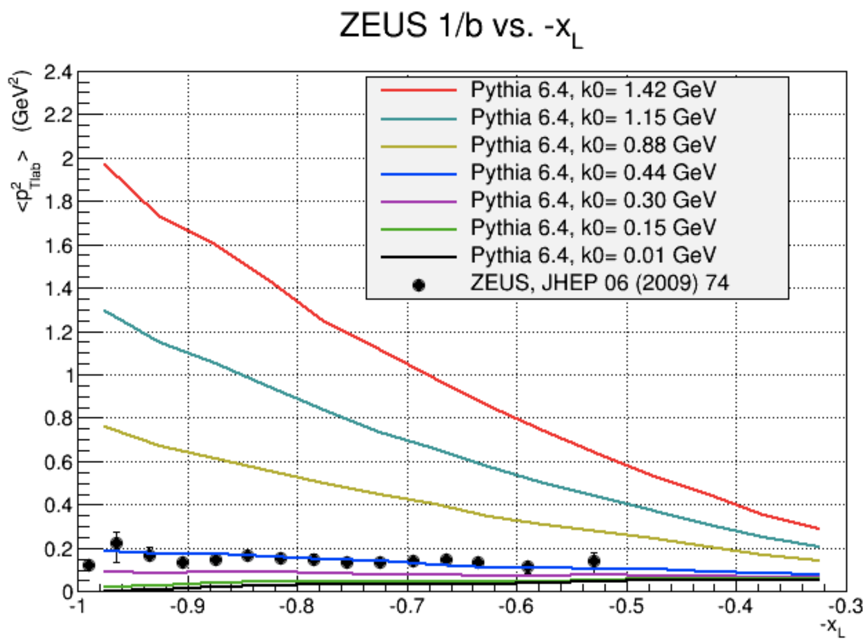
Backup

Fragmentation p_{T} vs. intrinsic k_{T}

PARJ(21): the standard fragmentation p_{T} width.
PARP(91): (D=2) the width of Gaussian intrinsic k_{T} distribution.



PARJ(21) = 0.36 GeV(default)
Data favors k_0 = PARP(91) = 0.01 GeV



PARJ(21) = 0.01 GeV (TINY!)
Data favors k_0 = PARP(91) = 0.44 GeV

NOTE: In the end used PARJ(21)= PARP(91) = 0.32

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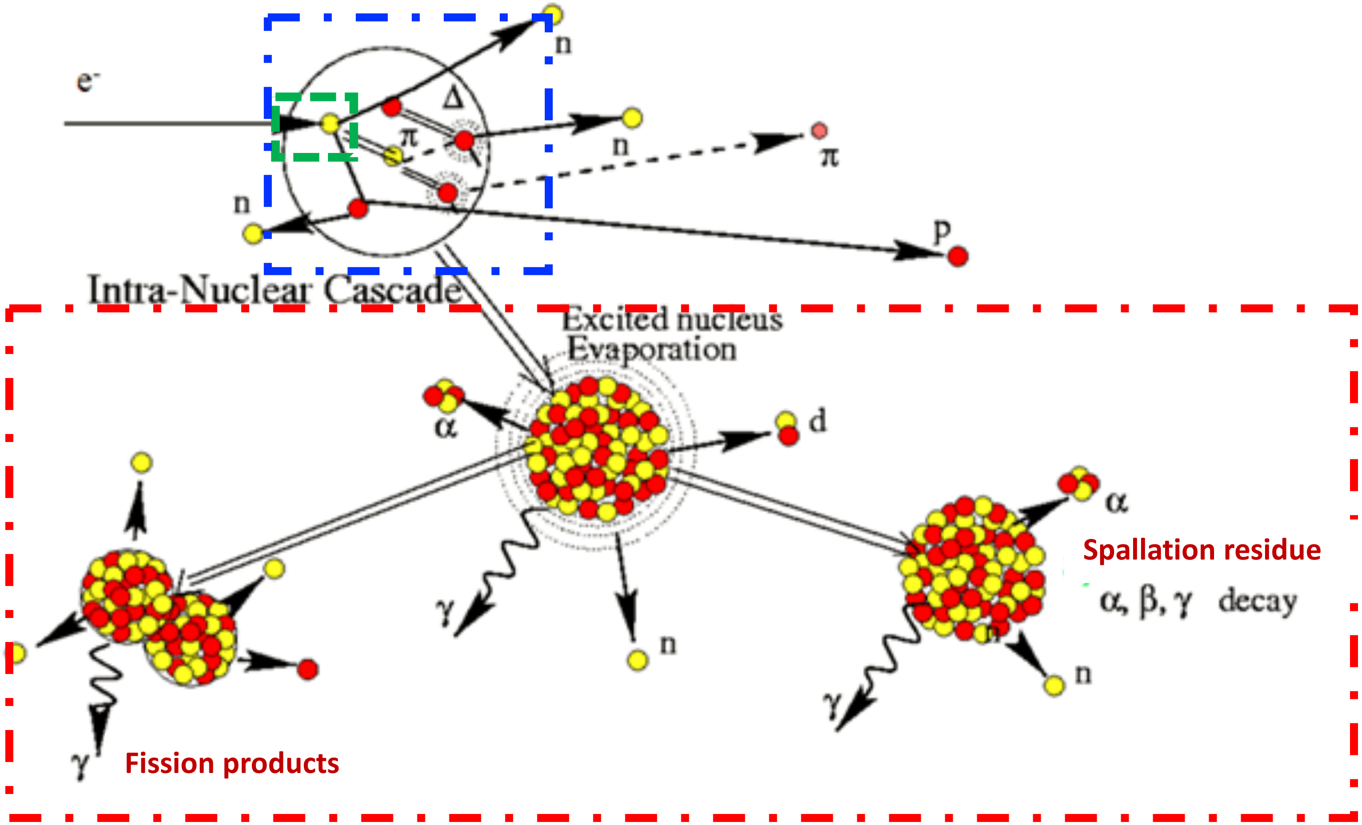
eA collisions



1. Deep inelastic scattering off a nucleon: primary interaction
2. Intra-nuclear cascade process: secondary interactions
3. Nuclear remnant breaks up depending on the excitation: evaporation

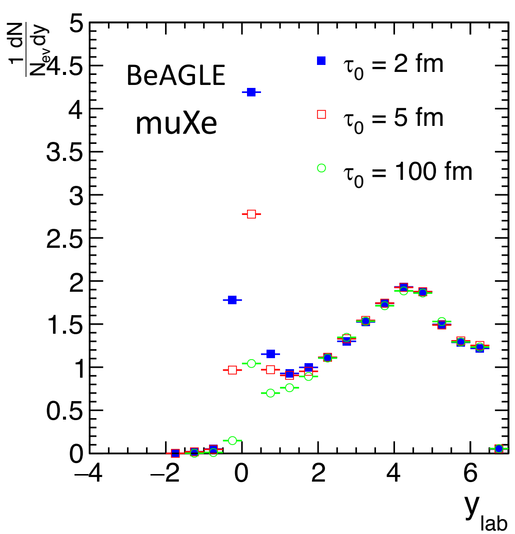
BeAGLE muXe/muP vs. SPS pXe/pp

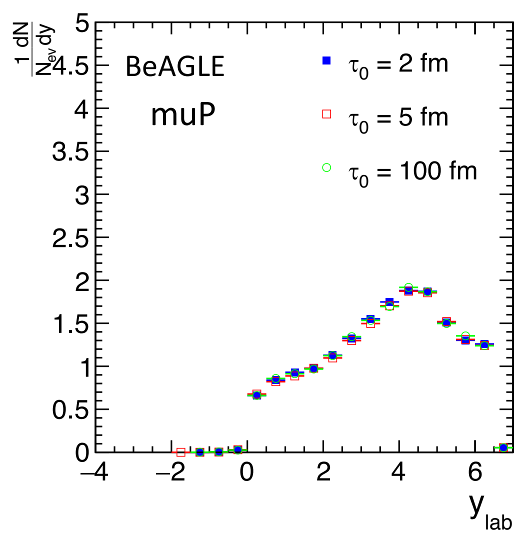
BeAGLE: muXe muP
mu beam is 490 GeV
17<W<23 GeV

vs.

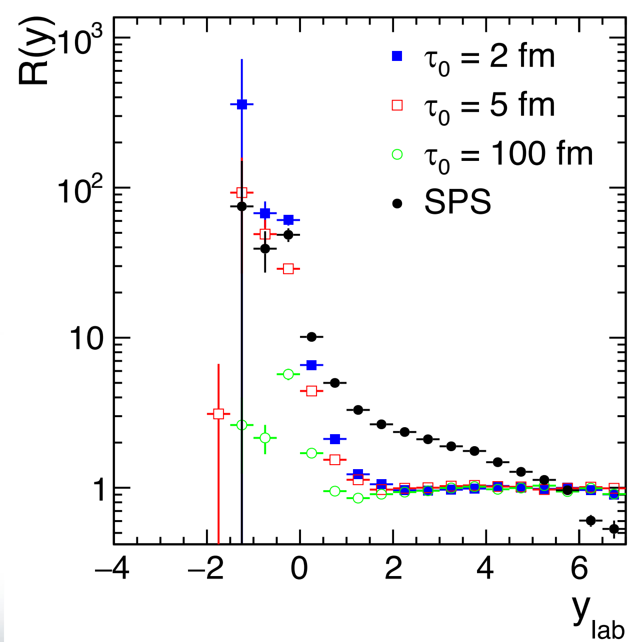
SPS: pXe/pp
proton momentum is 200GeV/c
(√sNN=19.4 GeV)

$$\rho(y) = \frac{1}{N_{ev}}\frac{dN}{dy} \qquad R(y) = \rho_{Xe}(y)/\rho_p(y)$$





BeAGLE recalculate E vs. SPS



These results of BeAGLE are with recalculate E.

C. De Marzo et al., Phys. Rev. D 26, 1019 (1982)