Neutron angular distribution and dose in ZDC

ePIC TIC meeting

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Yuji Yamazaki (Kobe University)

Introduction: neutron rate and dose: order estimation possible?

- Neutron dose: about 20 kJ/yr total
  - Assuming 100 GeV dose / event ~ 1.6×10^{-8} Joule / event
  - ep event rate $600\ \mathrm{kHz}$ @ $10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ → 0.01 J/s, 20% of events with neutron ⇒ 2×10^{-3} J/s, or 20kJ/yr for the entire ZDC (assuming total absorption, ignoring direct π^0s)
    - The event rate (photoproduction) may be as higher as 2 MHz
- We need to estimate the weight to be absorbed
  - LHCf number: 1/3 of dose per kg (shower concentrated in 3kg material !!) i.e. almost 10kGy/yr
    - This corresponds to 10^{14} neutrons/cm^2 using ILC number I had somewhere
  - It should be quite a bit more dilute at the EIC … but question is how much
- Angular distribution of the incident particles is important
  - Naively: the dose (energy per weight) $\propto E_{beam}^3$ (if shower size ≪ primary neutron spread)
    - linearly with energy, the neutron cone size $\propto 1/E_{beam}^2$
    - Most of the dose at 275 GeV

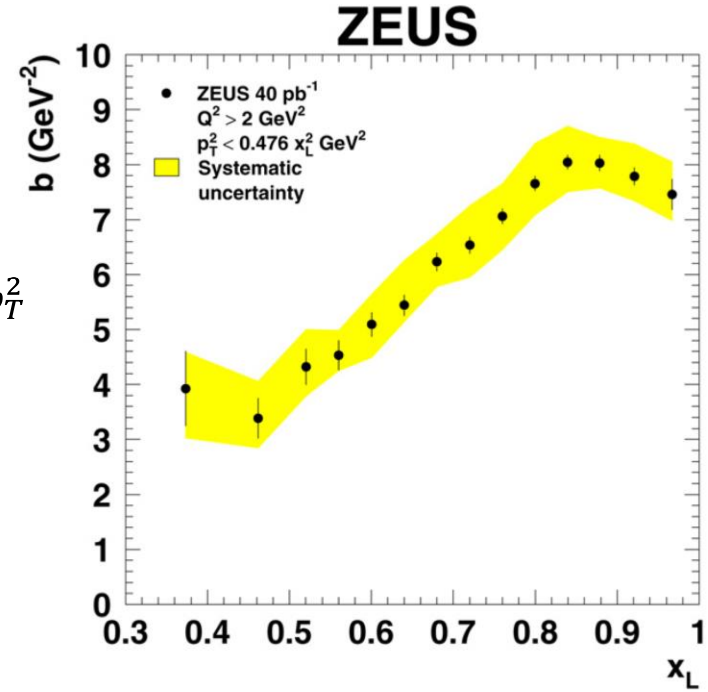
	40 GeV	100 GeV	275 GeV
Luminosity per unit of time	0.61	1.0	0.154
$(E_{pbeam}/100\ \mathrm{GeV})^3$	0.03	1.0	3.2

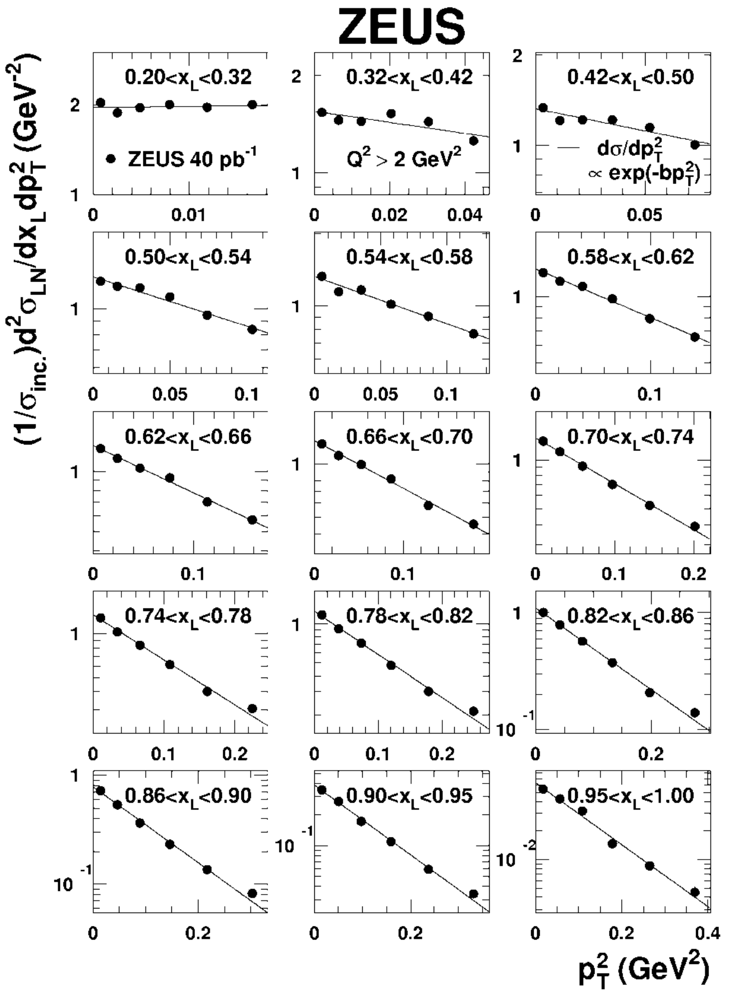
Estimating faction of events with a neutron at the ZDC (1)
p_T measurement at HERA to estimate the fraction in the aperture

- 27.5 x 820 GeV data (year 2000)
- Using scintillator hodoscope embedded in the ZDC (1cm wide)
- Slope is steeper for high-momentum neutrons: $x_L \equiv \xi = p_n/p_{pbeam}$

NPB 776(2007) 1-37

$$\frac{d\sigma}{dp_T^2} \propto e^{-bp_T^2}$$





Fraction of DIS events with a high-momentum neutron

- The observed fraction with a neutron in ep collisions at HERA/ZEUS
  - given in an earlier ZEUS publication:
    NPB 637 (2002) 3-56
  - We expect and assume that the leading neutron spectrums are the same for ep, pp and beam-gas pA
    since the ZDC is on the proton-beam direction
- The result is basically flat in (x, Q^2)
  - only a strong function of $\xi = x_L$
  - Suggesting that the assumption above is correct
- This number is visible fraction for < 0.75mrad
  - to be extrapolated using the p_T slope

ZEUS Collaboration / Nuclear Physics B 637 (2002) 3–56 33

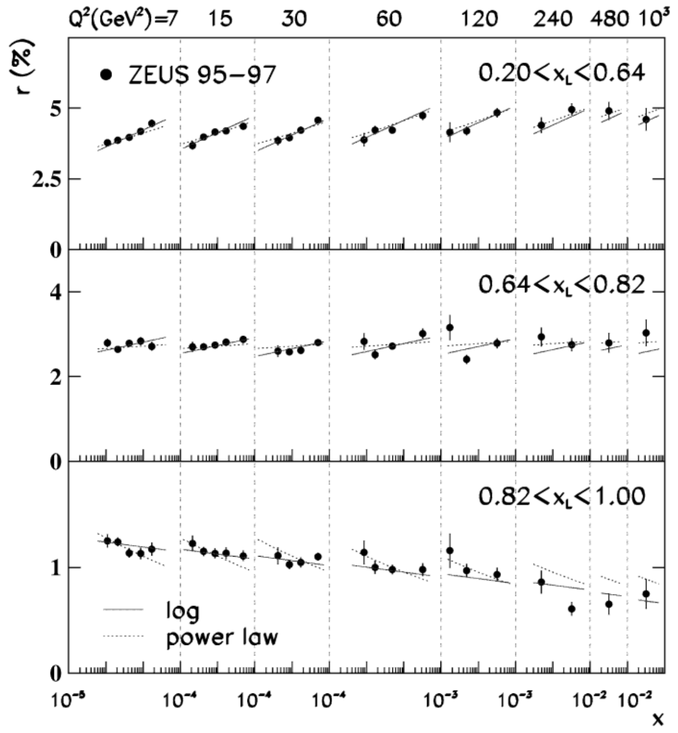
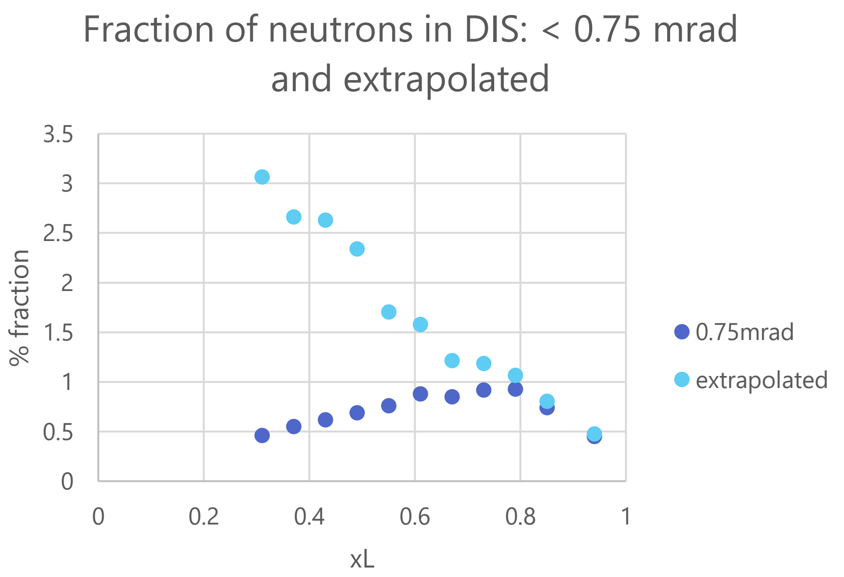


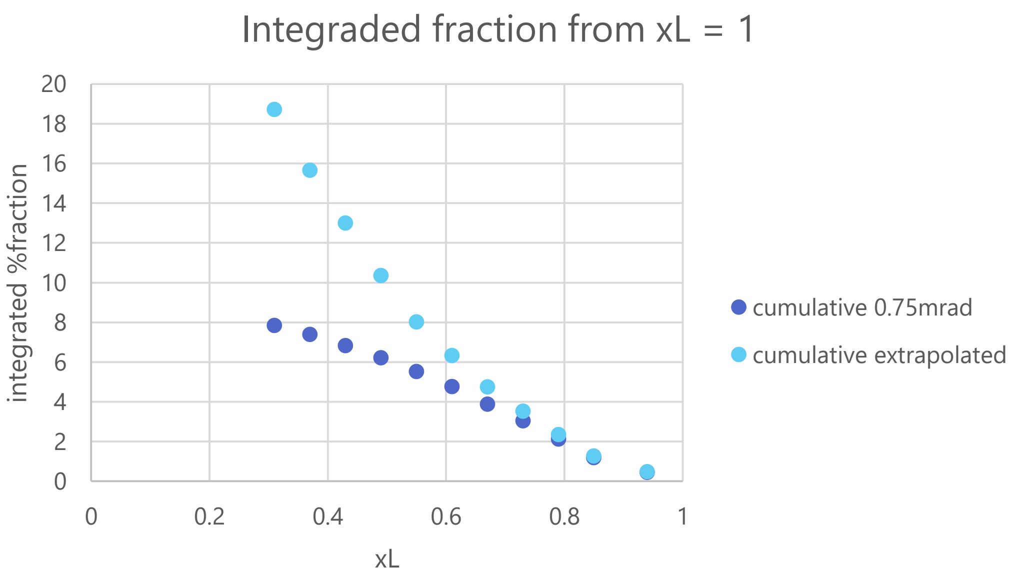
Fig. 13. Neutron production ($\theta_n \leqslant 0.8$ mrad) for the DIS region, $Q^2 > 4$ GeV^2, as a fraction of the inclusive cross section and as a function of x for the low ($0.2 < x_L < 0.64$), medium ($0.64 < x_L < 0.82$), and high ($0.82 < x_L < 1$) x_L ranges, in the indicated bins of Q^2. The dotted lines show the result of fitting a power law in x to the ratio. The solid lines show the result of a fit to the ratio linear in both $\ln x$ and $\ln Q^2$, as discussed in the text. Not shown are the correlated systematic uncertainties given in Table 1.

Extrapolated differential and integrated %fraction

- ZEUS aperture was 0.75mrad
- The fraction was extrapolated to infinity assuming the exponential behavior (slide #3)
  - In practice we should have tail, though: this is a lower limit number
- Most are within < 0.75mrad at HERA for high ξ, while many are outside for low ξ
  - EIC aperture is 4mrad: most of the neutrons (> 20% of events) reaches to ePIC ZDC angular-wise
    Average energy: ~ 100 GeV for 275 GeV run (need data for low ξ)
  - Only 20% of events with fast neutron?? This was a mystery at HERA, eager to see ePIC result

% fraction
of total events
in that bin



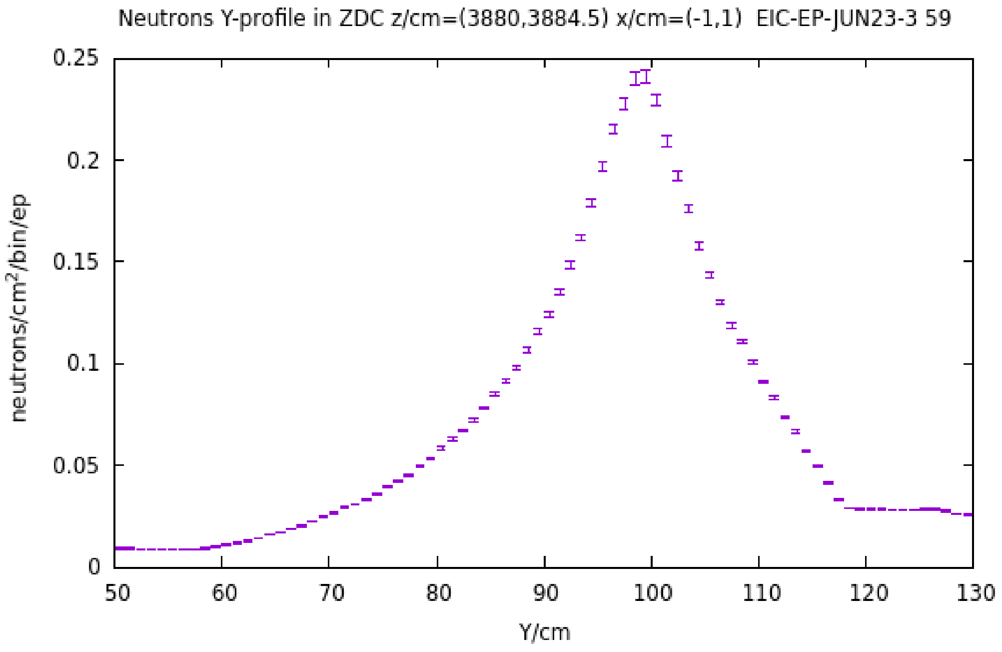


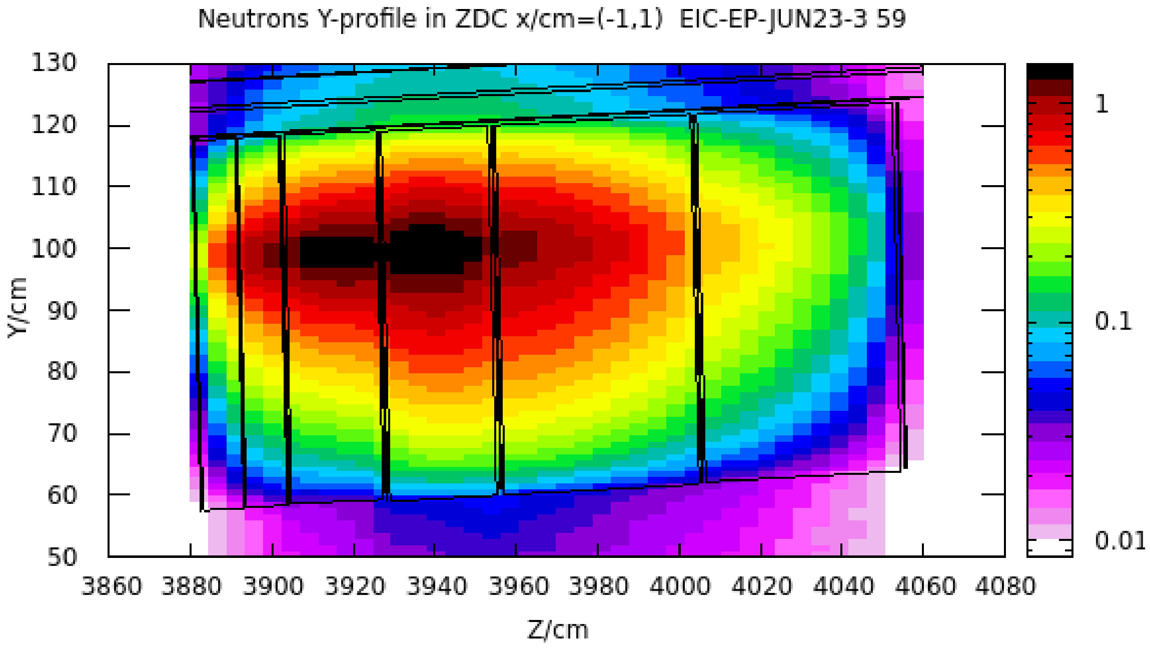
Neutron spot size

- $b \sim 8\ \mathrm{GeV}^{-2}$ at high ξ , as measured at HERA
  - Average $p_T^2 \sim 0.12\ \mathrm{GeV}^2$ or $p_T \sim 0.3 - 0.4$ GeV
    0.3 GeV / 200 GeV = 1.5mrad
  - Smaller than the EIC aperture size (12 cm aperture radius @ 35m: ~ 4mrad)
- This means the neutrons are $\ll 1/e$ at the edge of the aperture
  - most of the neutrons go into the aperture
  - dose center is about 1/10 of the aperture area or 1/3 of the aperture size
- Therefore, the maximum dose at neutron spot center would be significantly higher than the average dose
  - the hadronic shower size (~ 10cm) is indeed wider than the spot size:
    this broadening should help reduce dose from slow neutrons
  - but not for ionization dose (EM shower size $\ll$ spot size)

Vitali's study in 2021

- Using Fluka for shower simulation
  - not clear what was used for the *ep* collision simulation
- estimating 10^{14} neutrons for 4 years, or 2.5×10^{13} per year
- The distribution of neutrons is peaked at the center width ~ 2mrad: seems ~ OK
  - The fraction of events with a neutron is unknown in this simulation





Summary

- Neutron dose simulation has large uncertainty on:
  - **the incident angular distribution** of the neutrons for the ZDC case
- We see about an order of magnitude difference between Vitaly 2021 and the ePIC study https://wiki.bnl.gov/EPIC/index.php?title=Radiation_Doses
  - The ePIC study shows $< 10^{12}$ per year
  - Vitaly: 2.5×10^{13} : this number agrees with my order estimation
- This difference is not too striking (LHC central detector dose uncertainty in 2008: factor 5)
- But we should understand the origin
  1. Hadronic shower package (factor a few between Geant4 and Fluka?)
  2. **Angular distribution and yield of neutrons**
  3. **Geometry of the detector and upstream (beam pipe thickness, material ...)**
  - For the item 2, HERA data should help
  - For the item 3, see Michael Pitt's talk