Overview of ZDC Requirements for the EIC

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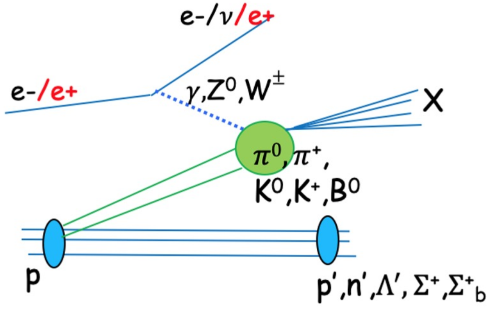
Basic “Requirements”

- ZDC requirements were put together prior to the Yellow Report, and before any comprehensive study of the physics was really put together.
  - Hadronic energy resolution: $\frac{\sigma_E}{E} \leq \frac{50\%}{\sqrt{E}} \oplus 5\%$
  - EM energy resolution: $\frac{\sigma_E}{E} \leq \frac{25\%}{\sqrt{E}} \oplus 2\%$
  - Soft photon sensitivity for $E \sim 100$ MeV
  - Sufficient dynamic range for energy deposits from breakup of heavy nuclei (several neutrons with $E \sim 110$ GeV)
  - Sufficient granularity to provide angular resolution for pT reconstruction: $\frac{\sigma_\theta}{\theta} \leq \frac{3\,mrad}{\sqrt{E}}$
- ZDC acceptance: θ < 5mrad (not ϕ-symmetric) – driven by aperture, not detector.

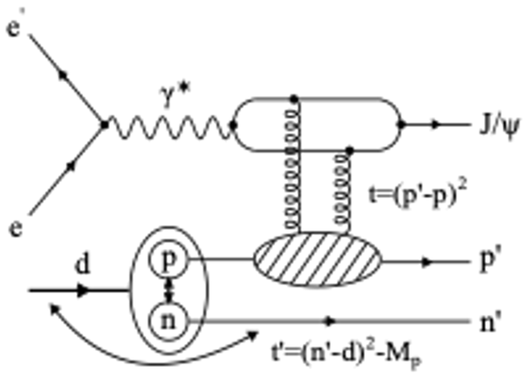
<u>General NB:</u> Previous and current studies and extracted resolutions all assume “perfect” ZDC performance, except for transverse and longitudinal leakage. They do not include effects of backgrounds, electronics, light collection, etc.

(some) Physics channels relying on ZDC

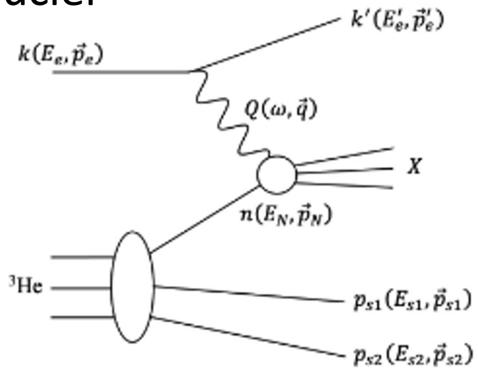
Sullivan process



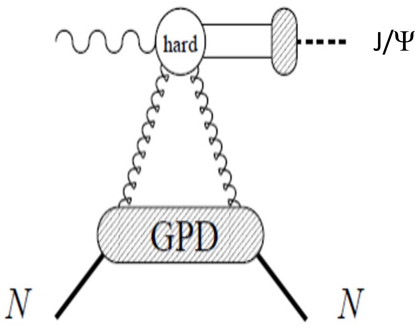
e+d exclusive J/Psi with p/n tagging



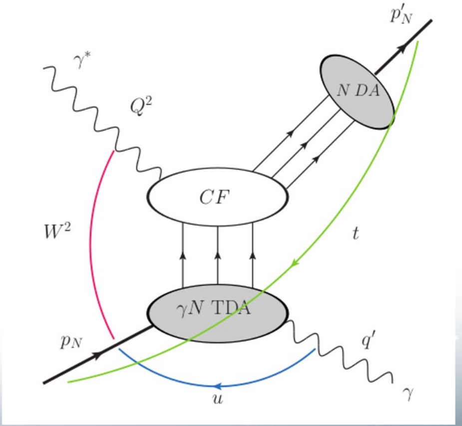
spectator tagging in light nuclei



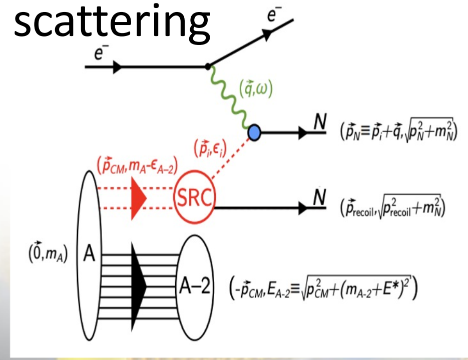
coherent/incoherent J/ψ production in e+A



u-channel backward exclusive electroproduction

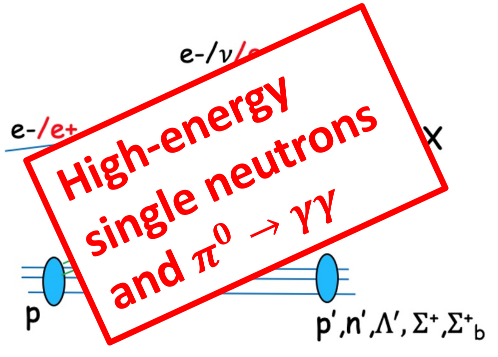


Quasi-elastic electron scattering

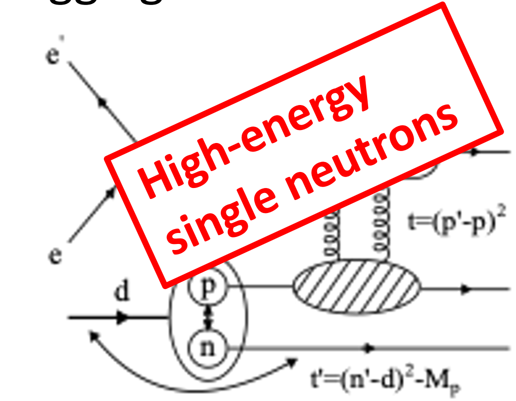


(some) Physics channels relying on ZDC

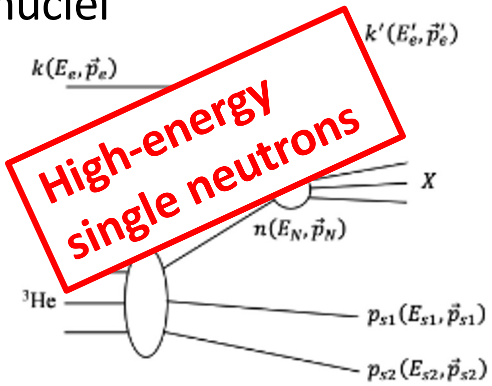
Sullivan process



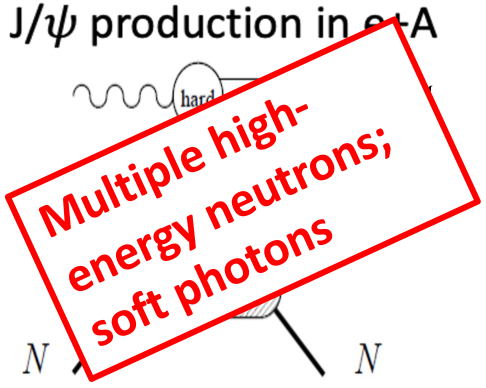
e+d exclusive J/Psi with p/n tagging



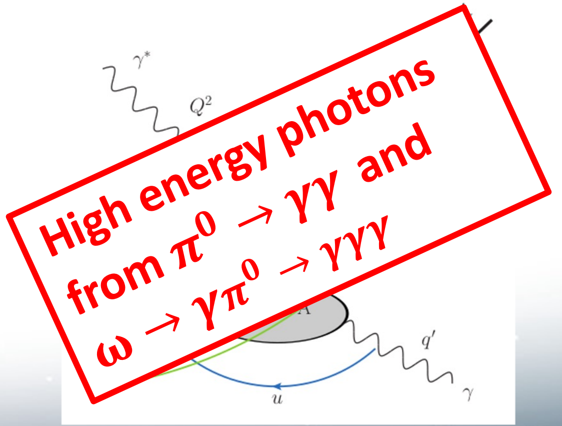
spectator tagging in light nuclei



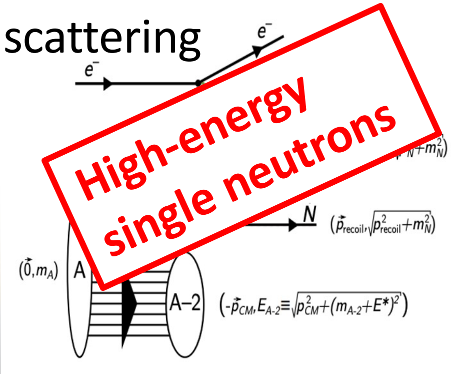
coherent/incoherent J/ψ production in e+A



u-channel backward exclusive electroproduction



Quasi-elastic electron scattering



- In every case, we will only have *one* of the possible final state options (e.g. either neutrons or photons, not both).

Top-level Summary of Requirements

Physics process	Final State particles (for ZDC)	Required HCAL E resolution	Required HCAL angular resolution	Required EMCAL E resolution	Required EMCAL spatial resolution	Notes
Spectator tagged e+d breakup	Neutrons	$\frac{\sigma_E}{E} \leq \frac{50\%}{\sqrt{E}} \oplus 5\%$	$\frac{\sigma_\theta}{\theta} \leq \frac{2\ mrad}{\sqrt{E}}$	N/A	N/A	https://arxiv.org/pdf/2005.14706.pdf https://arxiv.org/abs/2108.08314
Exclusive π^+ production	Neutrons			N/A	N/A	
Incoherent vetoing of e+A events	Neutrons/photons	$\frac{\sigma_E}{E} \leq \frac{100\%}{\sqrt{E}}$	N/A	100 MeV photon sensitivity	N/A	https://arxiv.org/abs/2108.01694
u-channel backward VCS	Photons	N/A	N/A	$\frac{\sigma_E}{E} \leq \frac{20\%}{\sqrt{E}} \oplus 3\%$	< 1-2cm	https://arxiv.org/pdf/2308.10478.pdf https://indico.bnl.gov/event/21074/contributions/82988/attachments/50847/86922/23_11_07%20ZDC%20Update.pdf
Kaon structure functions	$\Lambda^0 \longrightarrow n + \pi^0$	$\frac{\sigma_E}{E} \sim \frac{35-50\%}{\sqrt{E}} \oplus 3-5\%$	$\frac{\sigma_\theta}{\theta} \leq \frac{2\ mrad}{\sqrt{E}}$	$\frac{\sigma_E}{E} \leq \frac{(2-5)\%}{\sqrt{E}} \oplus (1-3)\%$	< 1-2cm	https://arxiv.org/pdf/2102.11788.pdf

Photons

- Soft photon tagging important for vetoing of incoherent e+A events (about 3.25% of events produce *only* soft photon).

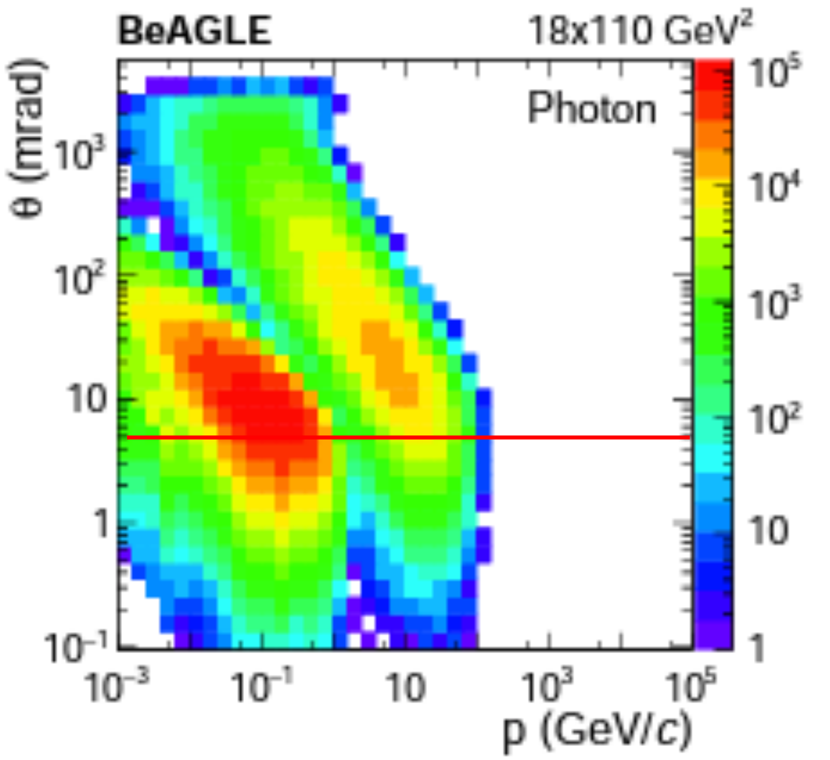
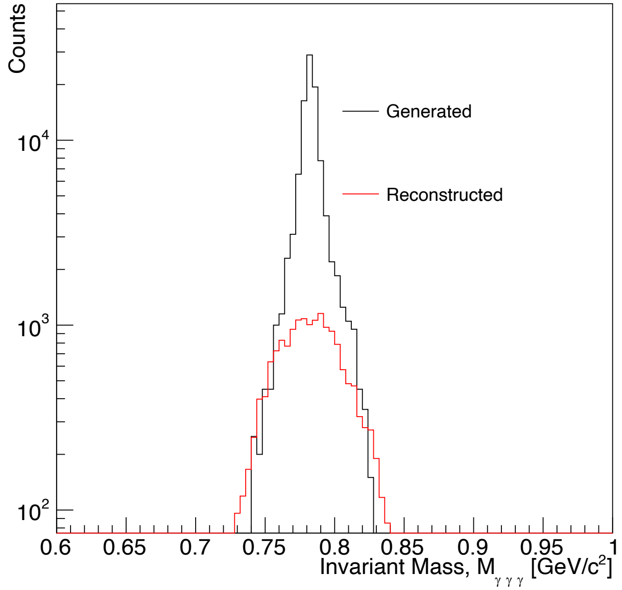
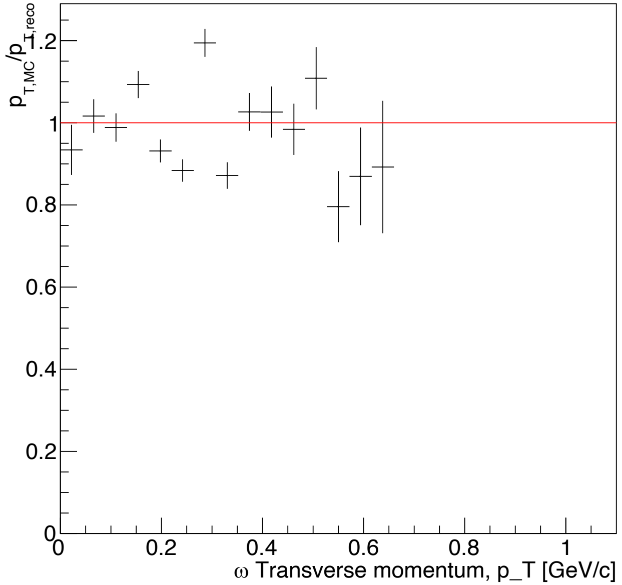


Figure from: W. Chang, E.C. Aschenauer, M. D. Baker, A. Jentsch, J.H. Lee, Z. Tu, Z. Yin, and L.Zheng, Phys. Rev. D **104**, 114030 (2021)

- Backward u-channel ω production.





- Study performed with STARLIGHT events using EICROOT.
- Final state: $\omega \rightarrow \gamma\pi^0 \rightarrow \gamma\gamma\gamma$ (ZDC acceptance ~ 16%)
- Study assumed $\frac{\sigma_E}{E} \leq \frac{10\%}{\sqrt{E}} \oplus 3\%$ and $\frac{\sigma_\theta}{\theta} \leq \frac{1\ mrad}{\sqrt{E}}$

Photons

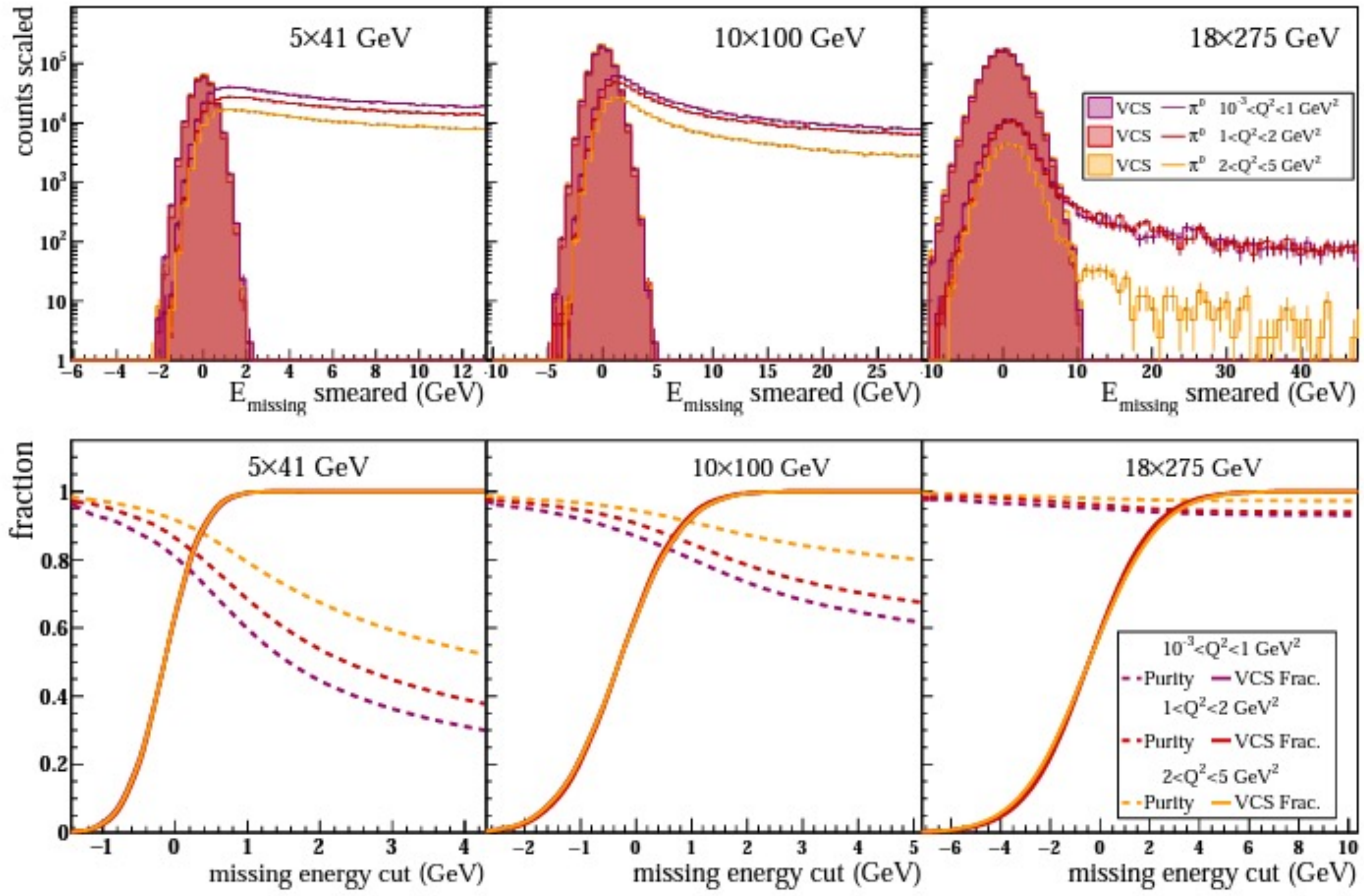


FIG. 9. (top) Missing energy distribution of single photons within ZDC acceptance. The π^0 distributions are scaled to the Compton distributions by the ratio of their cross sections as shown in Tab. II. (bottom) Purity fraction and fraction of signal collected for a given missing energy cut.

- Calculation of missing energy requires precise knowledge of the photon energy from the $\pi^0 \to \gamma\gamma$ decay.
- Reference for the study implies need for **1-2cm spatial resolution** to resolve decay photons and separate $\pi^0 \to \gamma\gamma$ from desired Compton photon, and implies need for $\frac{\sigma_E}{E} \leq \frac{(20)\%}{\sqrt{E}} \oplus 3\%.$
  - https://arxiv.org/pdf/2308.10478.pdf

Photons

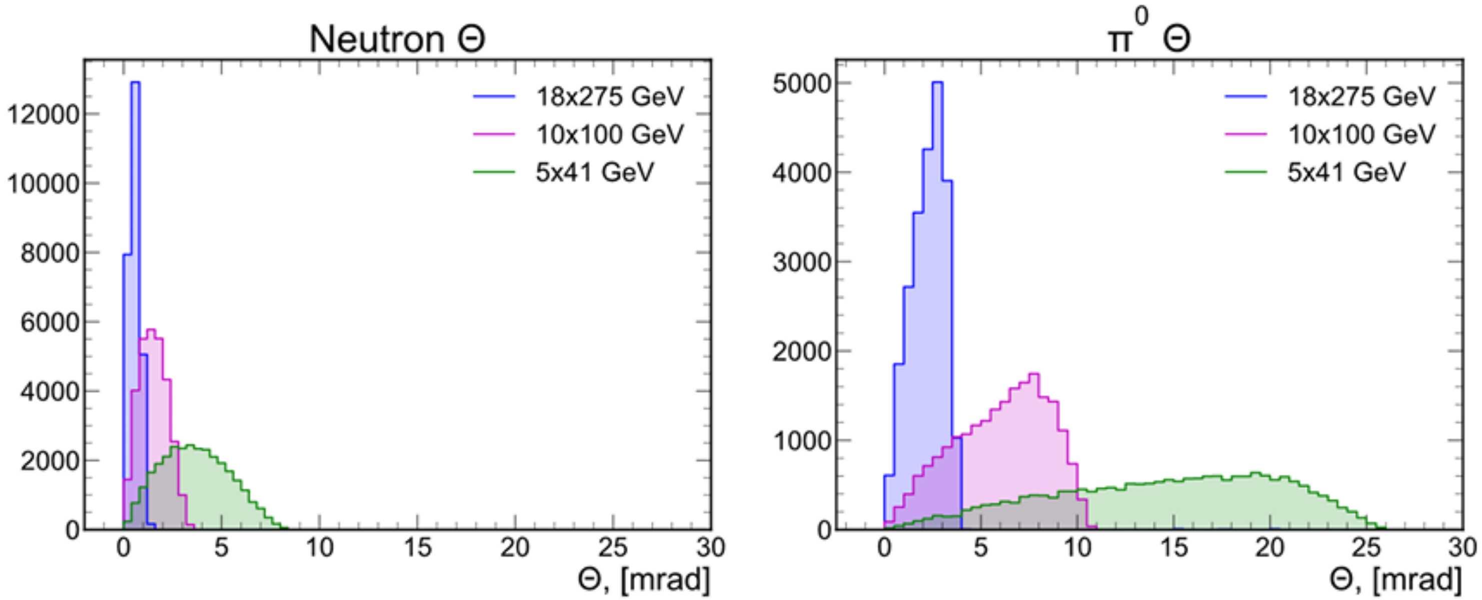


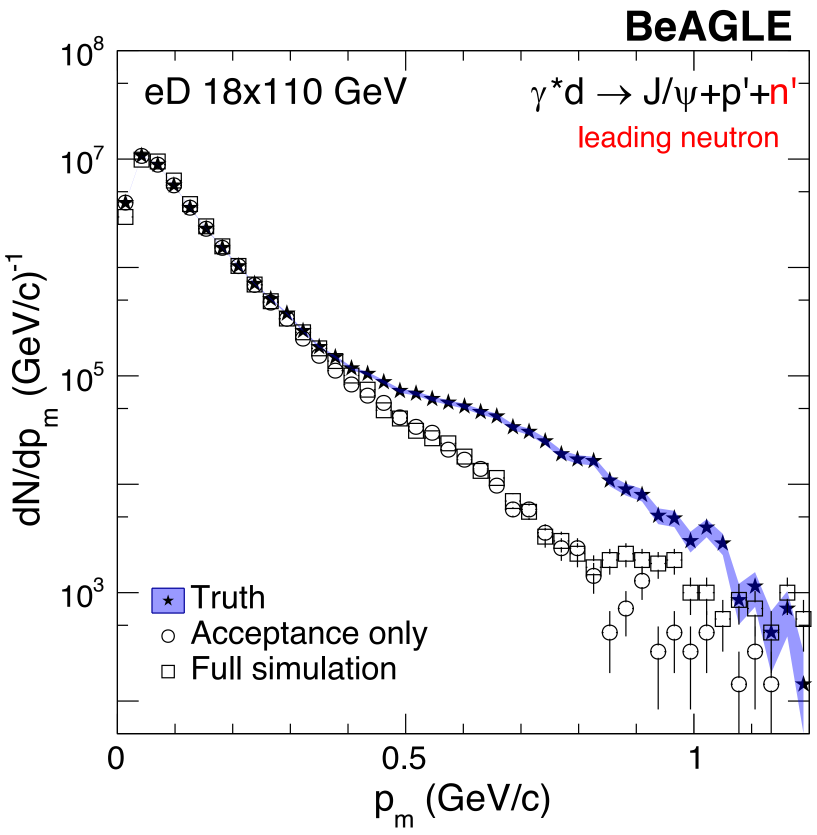
Figure 20: Angular distributions for detected decay products of $\Lambda \rightarrow n + \pi^0$: (a) neutrons; and (b) π^0. Beam energy settings: 18×275, 10×100, and 5×41.

- Requires precise knowledge of the photon energy from the $\boldsymbol{\pi^0} \rightarrow \boldsymbol{\gamma\gamma}$ decay.
- **1-2cm spatial resolution required** for separation of neutron and gamma from $\Lambda^0 \longrightarrow n + \pi^0$.
  - Depends on the decay vertex for the Λ^0 along the beamline!
- Reference for the study implies need for $\frac{\sigma_E}{E} \leq \frac{(2-5)\%}{\sqrt{E}} \oplus (1-3)\%$.
  - ➢ https://arxiv.org/pdf/2102.11788.pdf

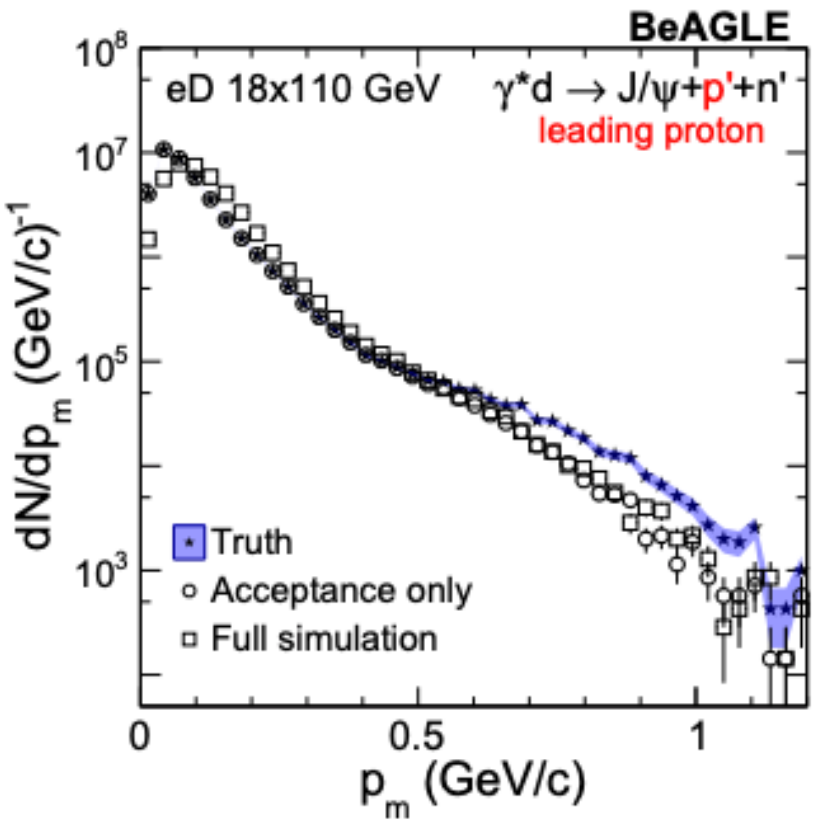
From: Z. Tu, A. Jentsch *et al.*, Phys. Lett. B, 811 (2020)

Single Neutrons

- e+d spectator tagging to study short-range correlations.



Proton spectator from OMD.



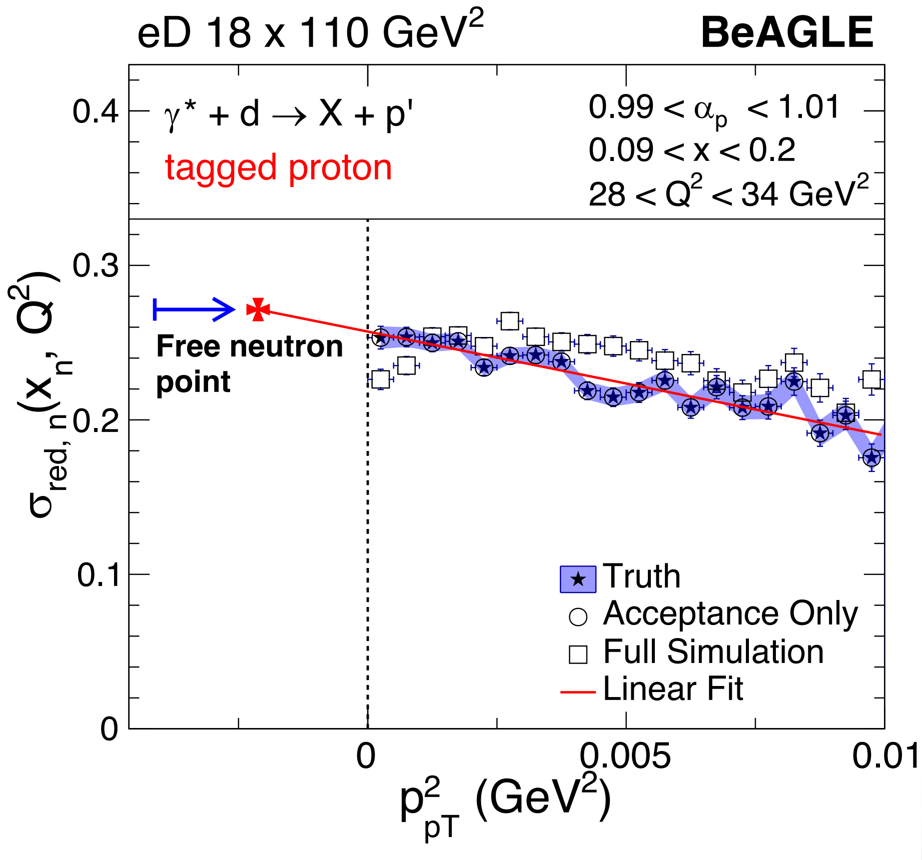
Neutron spectator from ZDC.

Assuming $\frac{\sigma_E}{E} \leq \frac{50\%}{\sqrt{E}} \oplus 5\%$ and $\frac{\sigma_\theta}{\theta} \leq \frac{3\ mrad}{\sqrt{E}}$

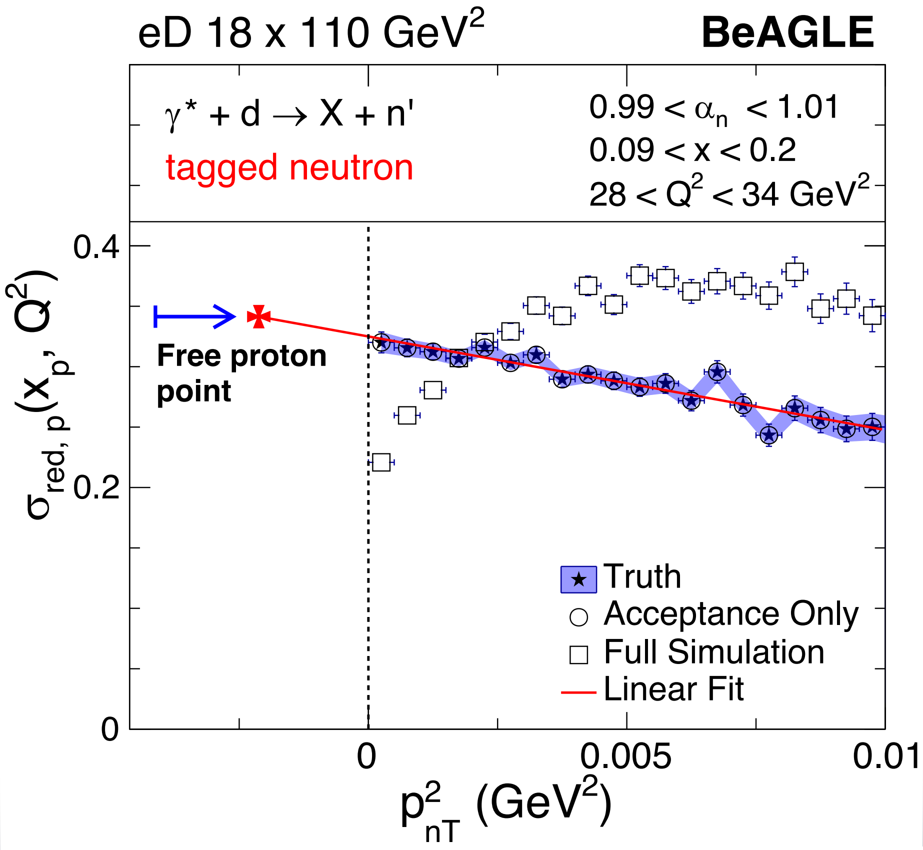
Single Neutrons

From: A. Jentsch, Z. Tu, and C. Weiss, Phys. Rev. C 104, 065205, (2021)

- e+d spectator tagging to study neutron structure functions → focus on very small angle neutrons near $\theta \sim 0\ mrad$.



Proton spectator from OMD.

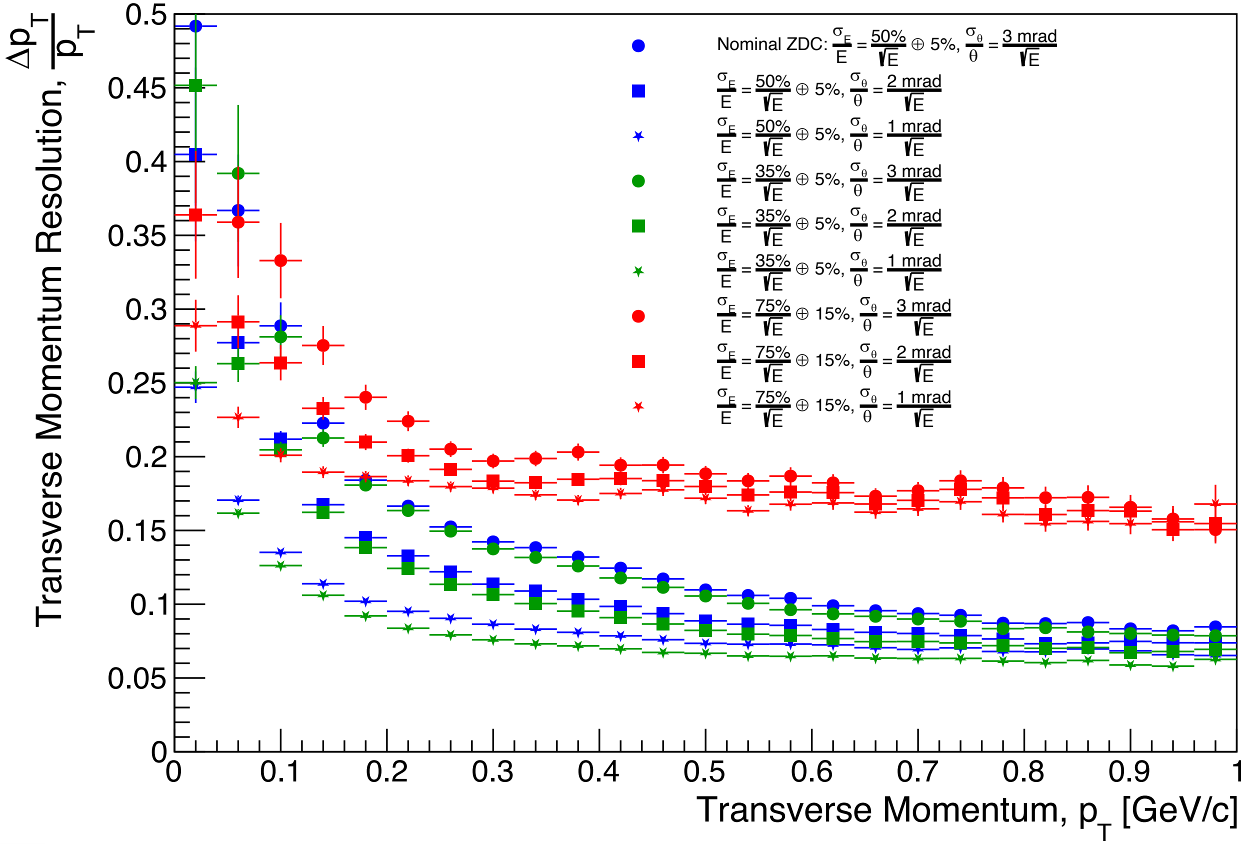


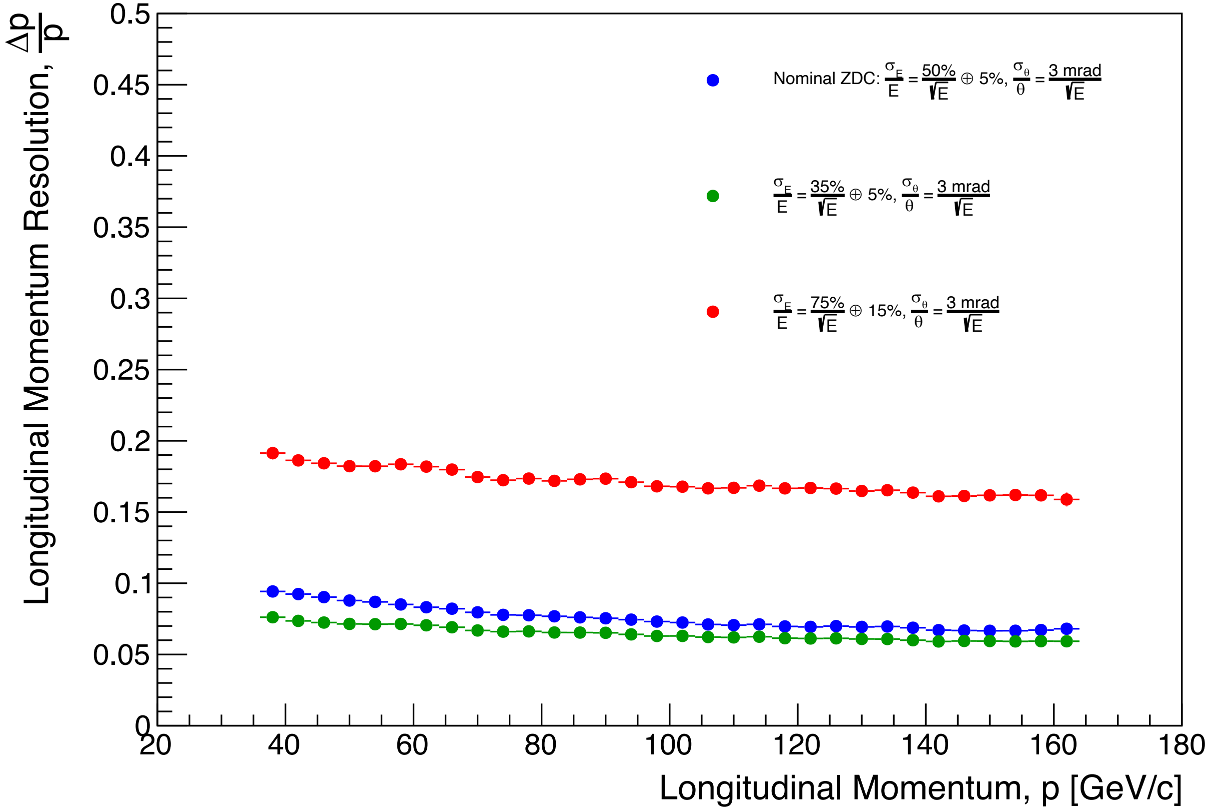
Neutron spectator from ZDC.

Assuming $\frac{\sigma_E}{E} \leq \frac{50\%}{\sqrt{E}} \oplus 5\%$ and $\frac{\sigma_\theta}{\theta} \leq \frac{3\ mrad}{\sqrt{E}}$

Baseline ZDC assumption is problematic here – would benefit from improved neutron energy and angular resolution.

Single Neutrons



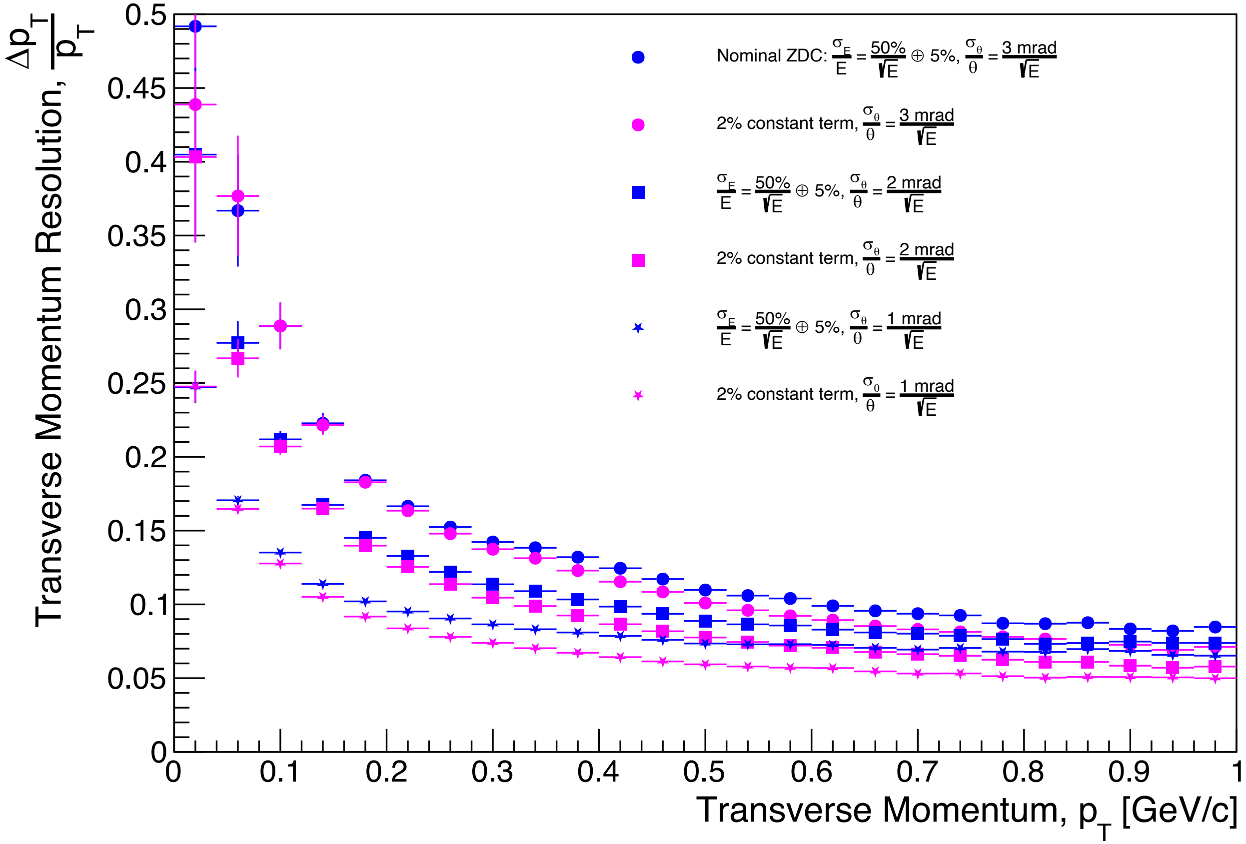


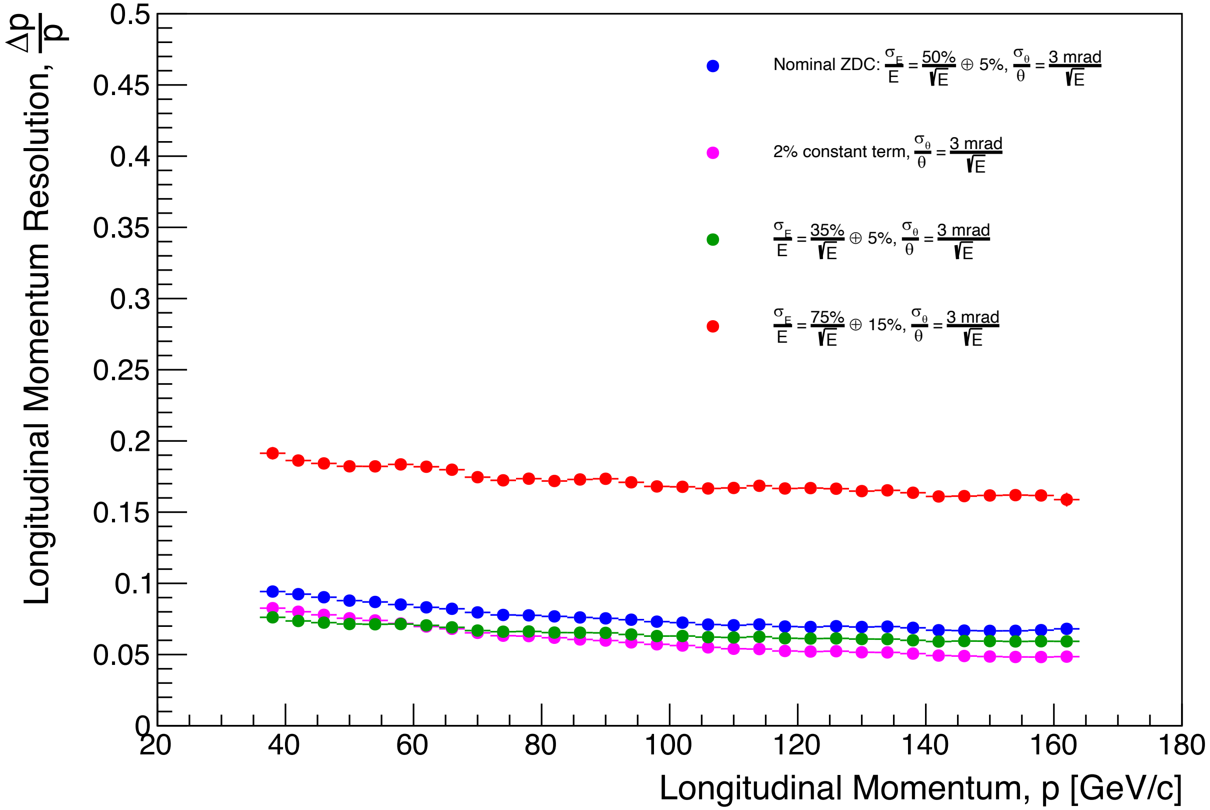
- If energy resolution is too poor, better spatial/angular resolution does very little to improve pT-resolution.
  - ➢ **Need minimum $\frac{\sigma_E}{E} \leq \frac{50\%}{\sqrt{E}} \oplus 5\%$**

To get pT resolution competitive with the tagged-proton case would require $\frac{\sigma_\theta}{\theta} \leq \frac{2\ mrad}{\sqrt{E}}$

Very little difference between $\frac{\sigma_E}{E} \leq \frac{50\%}{\sqrt{E}} \oplus 5\%$ and $\frac{\sigma_E}{E} \leq \frac{35\%}{\sqrt{E}} \oplus 5\%$ → Improved constant term has small effect.

Single Neutrons (better constant term)





- If energy resolution is too poor, better spatial/angular resolution does very little to improve pT-resolution.
  - ➢ **Need minimum $\frac{\sigma_E}{E} \leq \frac{50\%}{\sqrt{E}} \oplus 5\%$**

To get pT resolution competitive with the tagged-proton case would require $\frac{\sigma_\theta}{\theta} \leq \frac{2\ mrad}{\sqrt{E}}$

Very little difference between $\frac{\sigma_E}{E} \leq \frac{50\%}{\sqrt{E}} \oplus 5\%$ and $\frac{\sigma_E}{E} \leq \frac{35\%}{\sqrt{E}} \oplus 5\%$ → Improved constant term has small effect.