Nuclear Physics Opportunities at Hall D: The Gluonic Content of Light Nuclei

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Motivation for high-statistics photonuclear data

- Currently ~1.5 months of nuclear data in Hall D (not including PrimeX)
- Sufficient to establish SRC breakup in high-statistics channels, but further data could be used
    - Study of $|t|$-dependence of SRC breakup data
    - Low-rate channels could be the most interesting

Target	Days of Beam	Luminosity (E_γ > 6 GeV)
Deuterium	4	18.0 nucleus · pb^{-1}
Helium-4	10	16.7 nucleus · pb^{-1}
Carbon-12	14	8.6 nucleus · pb^{-1}

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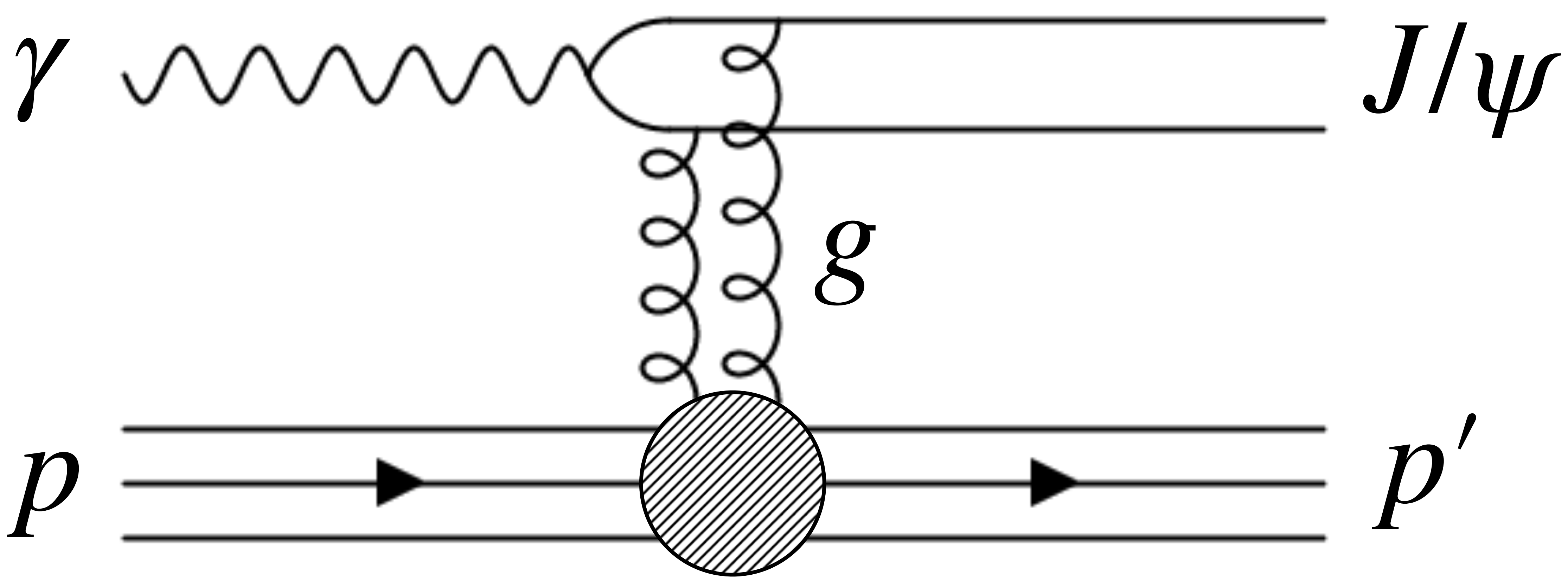
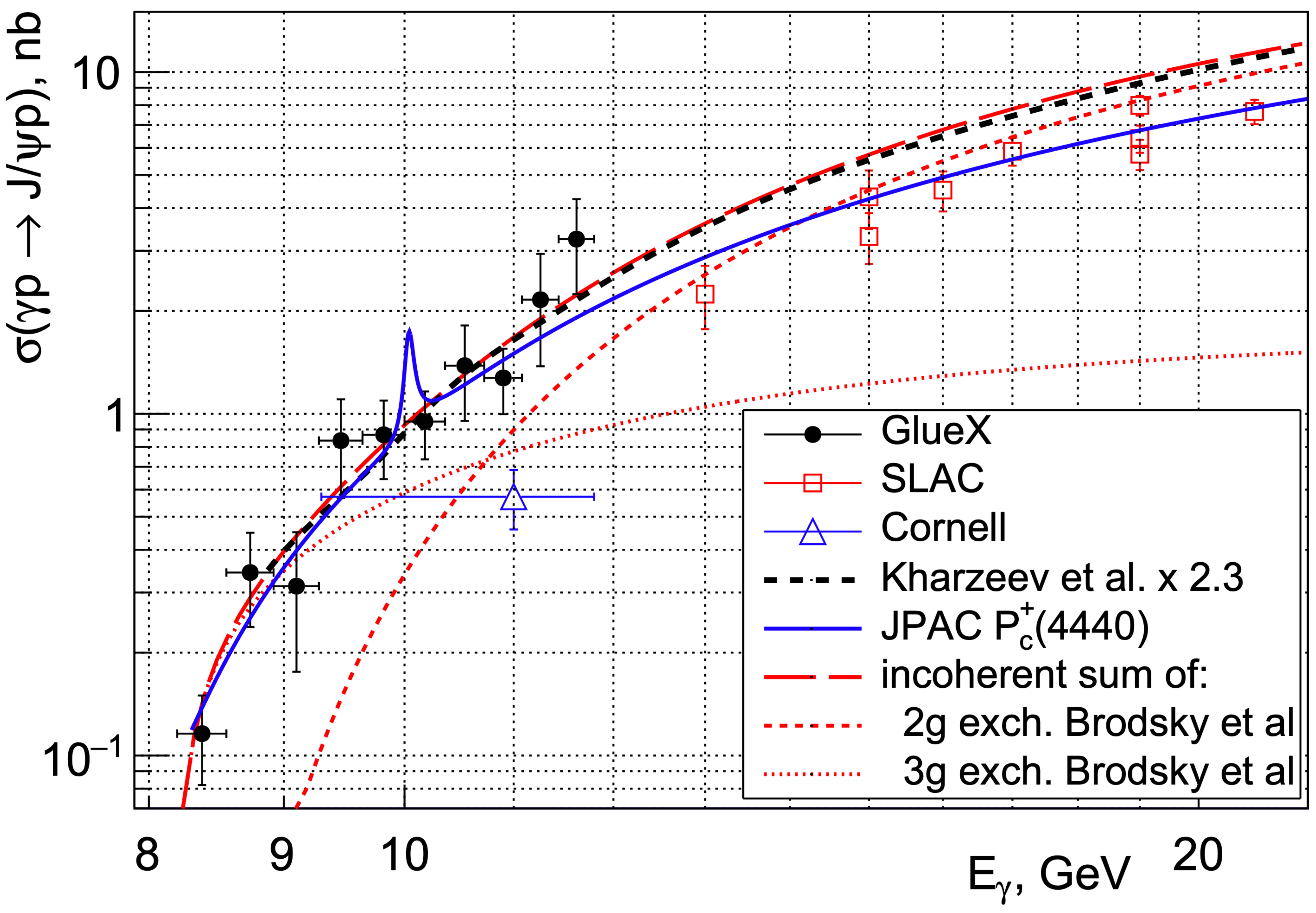
J/ψ photoproduction from the proton

- J/ψ is neutral 1^{--} meson → "vacuum" channel with no quantum numbers exchanged
- Lack of intrinsic charm in the nucleon → scattering is mediated by 2- or 3-gluon exchange
- Sensitive to gluon structure of the proton
- Leptonic $J/\psi \to e^+e^-$ decay relatively clean detection channel

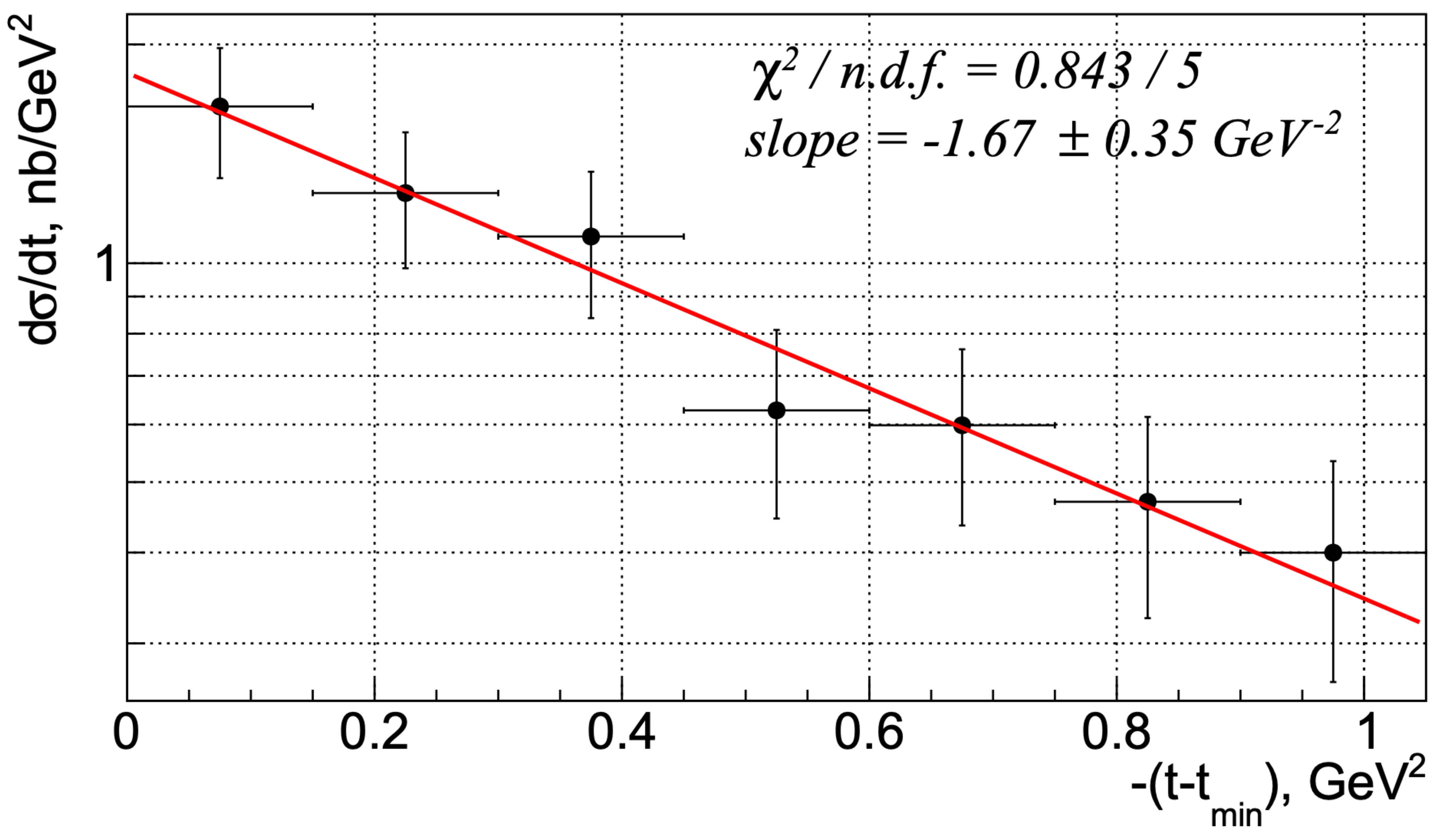


GlueX energies probe the threshold production region

Total Cross Sections



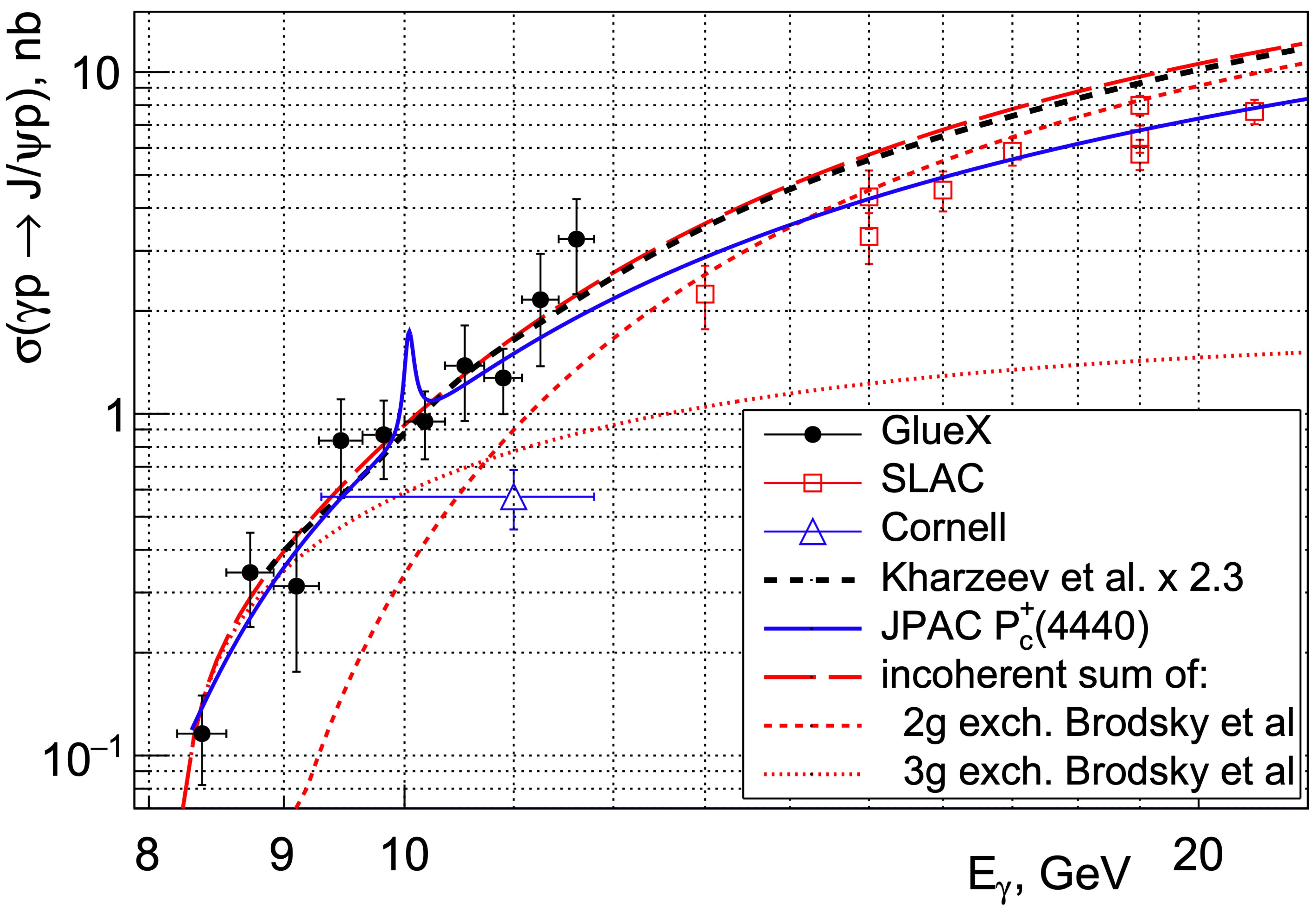
|t|-Dependence / Gluonic Form Factor



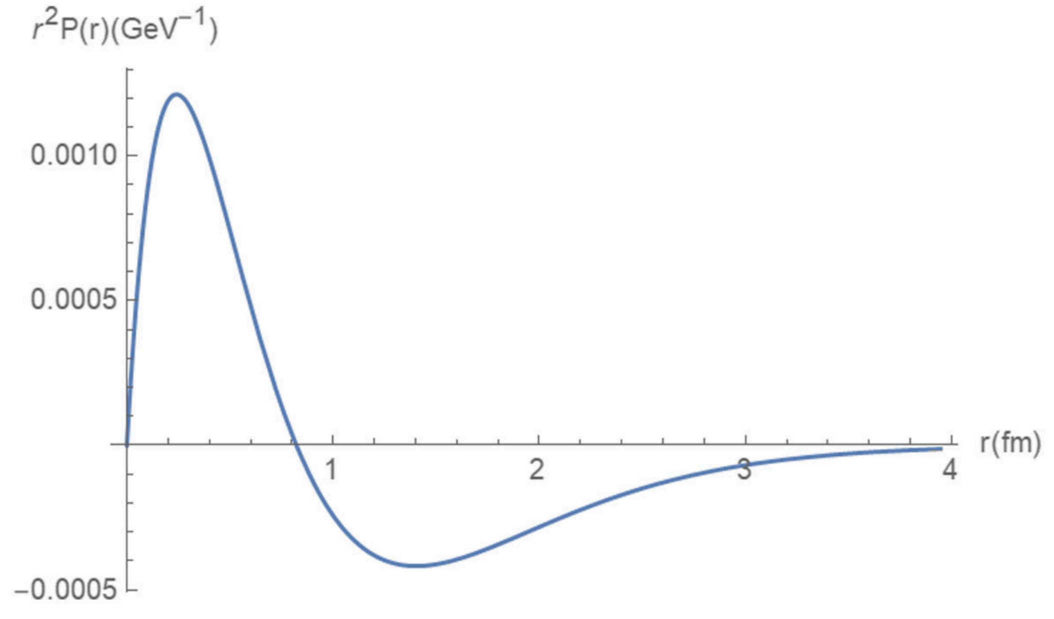
Ali et al. PRL (2019)

J/ψ photoproduction data has many applications

Ali et al. PRL (2019)

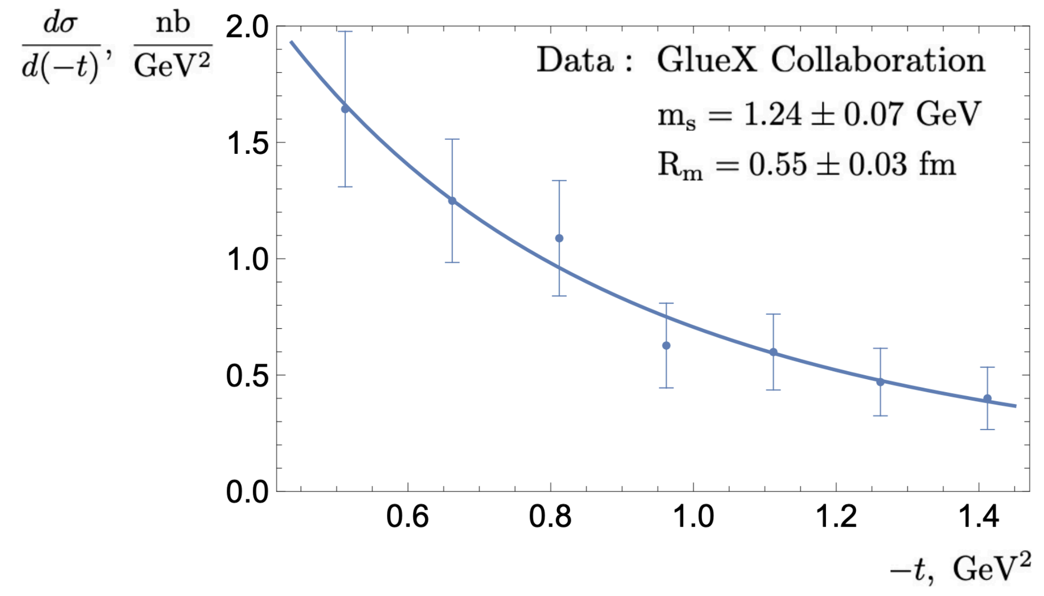


Gluonic GPDs



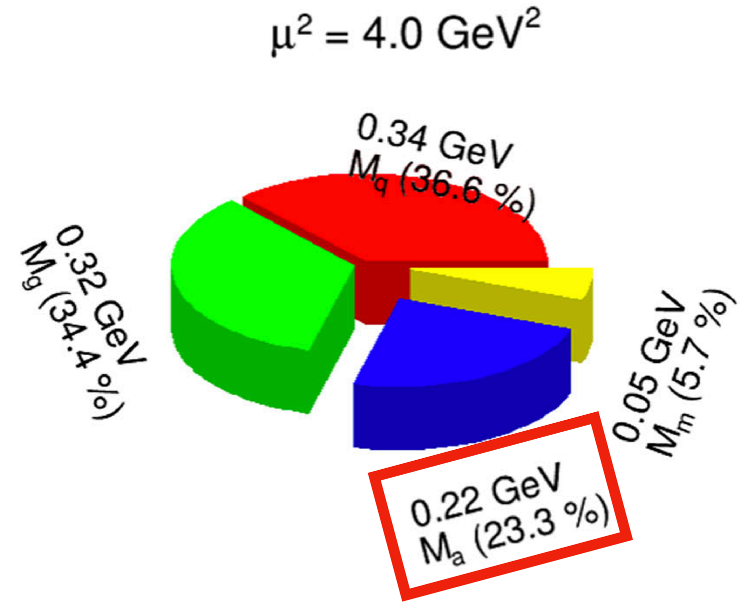
Guo, Ji, Liu, PRD (2021)

Mechanical/gluonic radius



Kharzeev, PRD (2021)

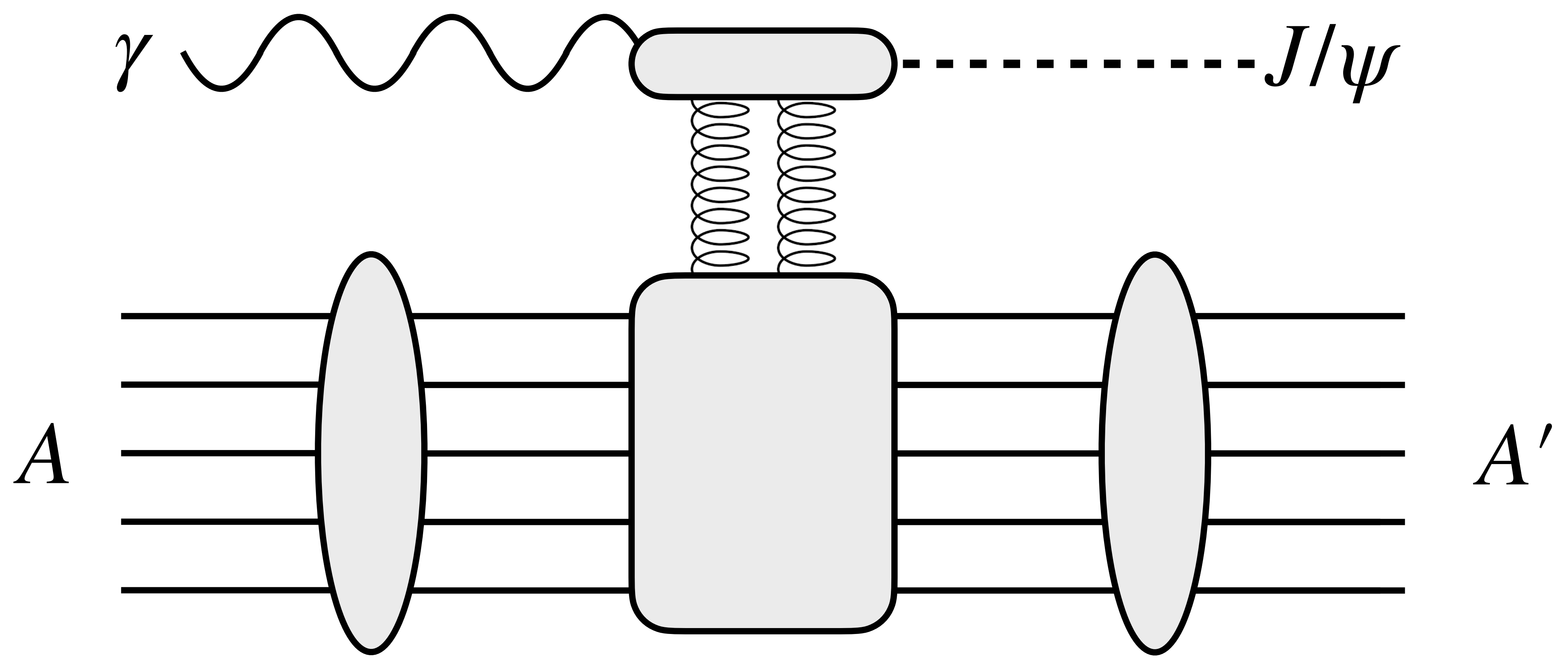
Trace Anomaly Mass Term



Wang, Chen, Evslin, EPJ C (2020)

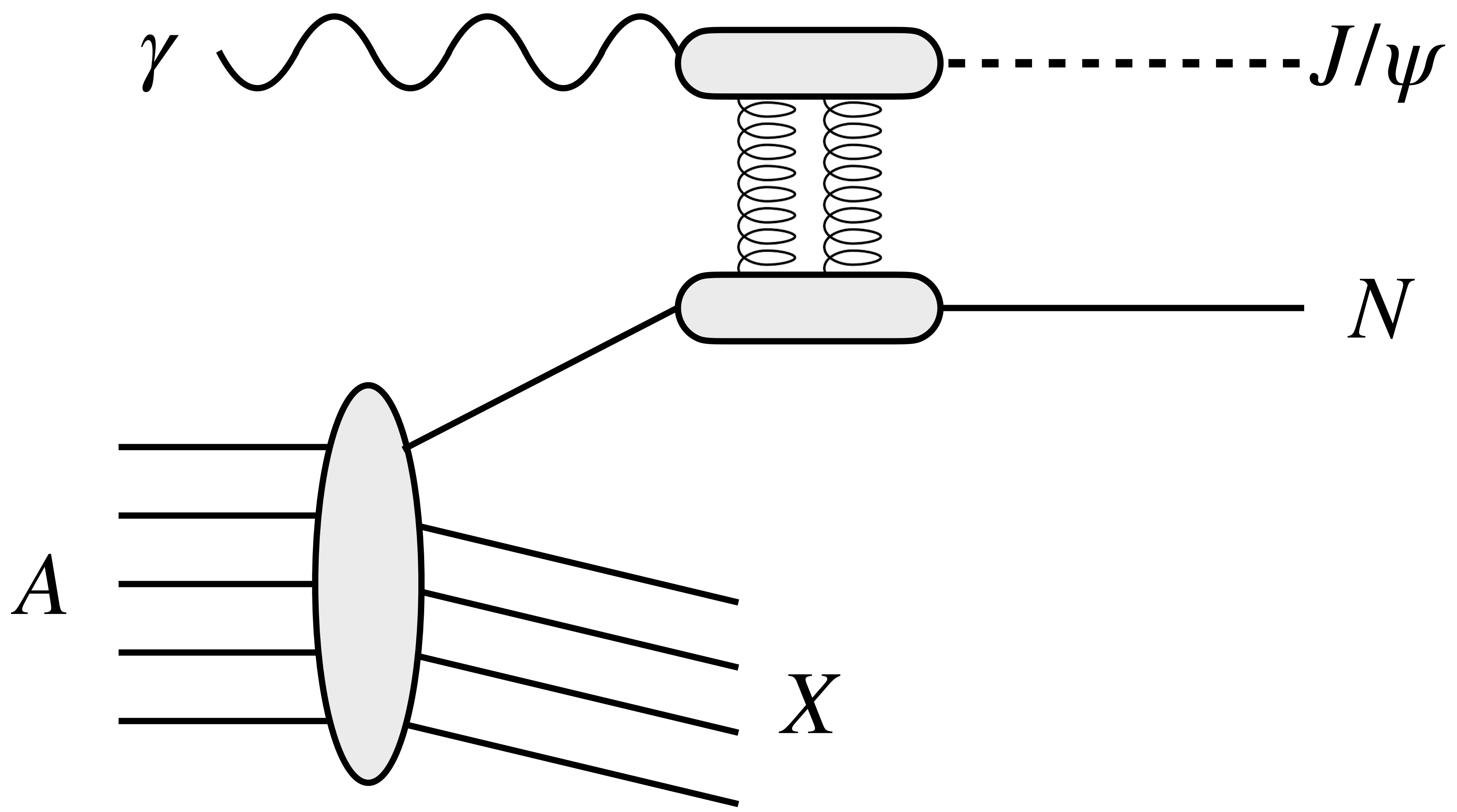
Photoproduction from the nucleus

Coherent Photoproduction



- Nucleus intact in the final-state
- Tells us about the ground-state of the nucleus
- Physics interpretations: Gluon radius of the nucleus, nuclear trace anomaly, nuclear gGPDs

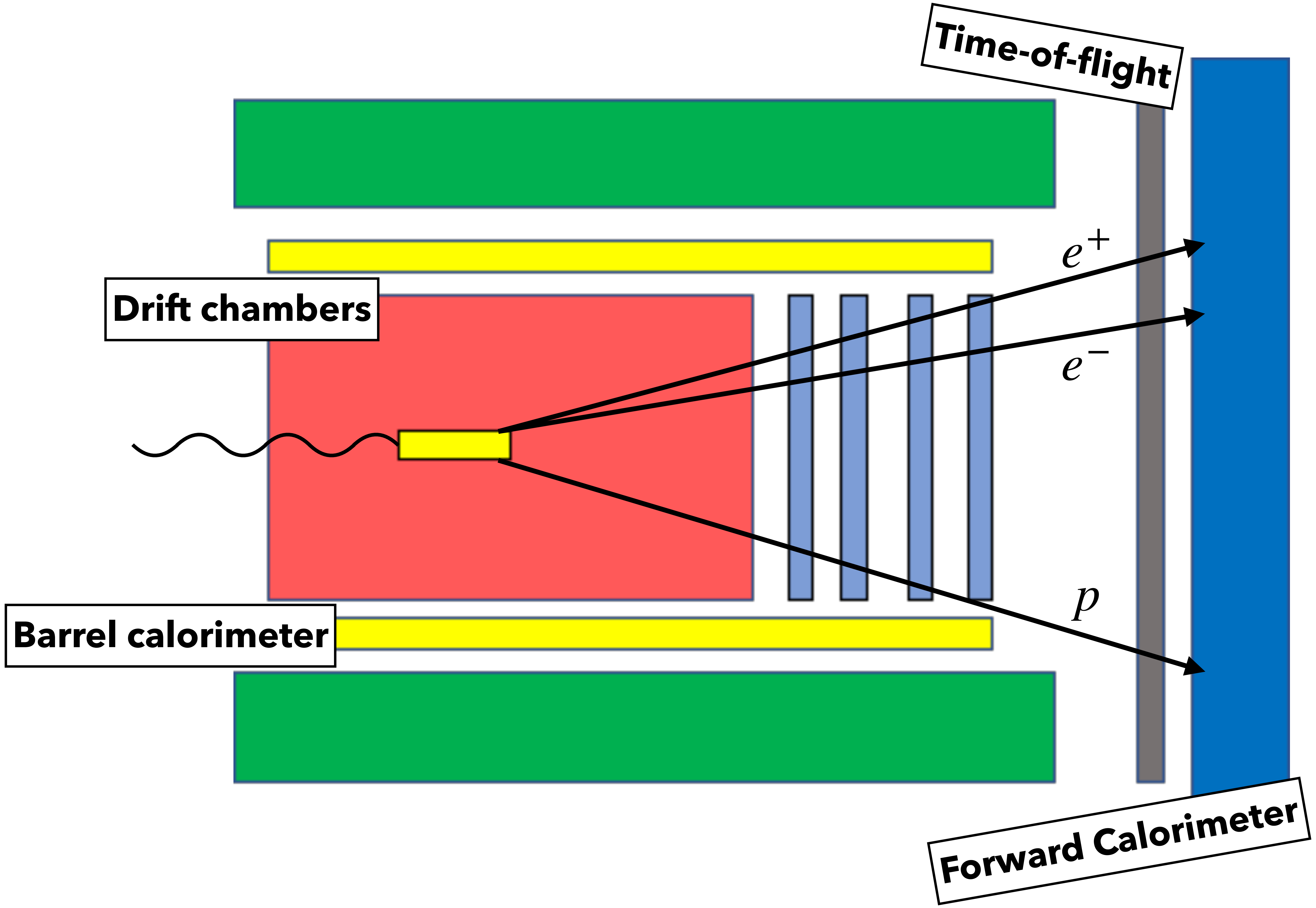
Incoherent Photoproduction



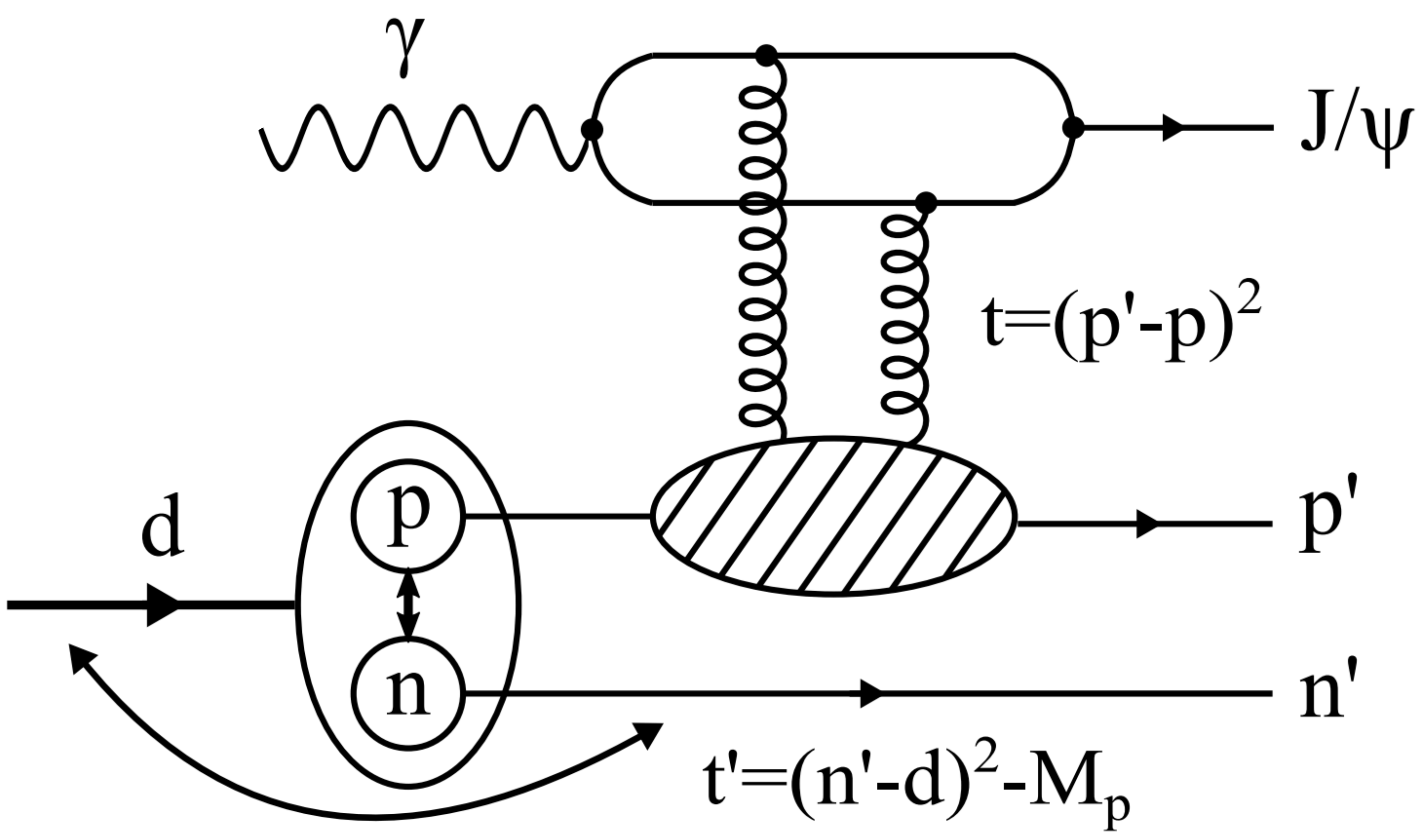
- Nucleus broken-up in the final state
- Tells us about fluctuations in the nucleus + bound nucleons within the nucleus
- Physics interpretations: Gluon content of the bound proton, neutron

Incoherent $A(\gamma, J/\psi\ p)X$

- $J/\psi \to e^+e^-$ decay detected in drift chambers
  - PID from calorimeter energy deposition
- Leading proton detected in drift chambers
  - PID from time-of-flight



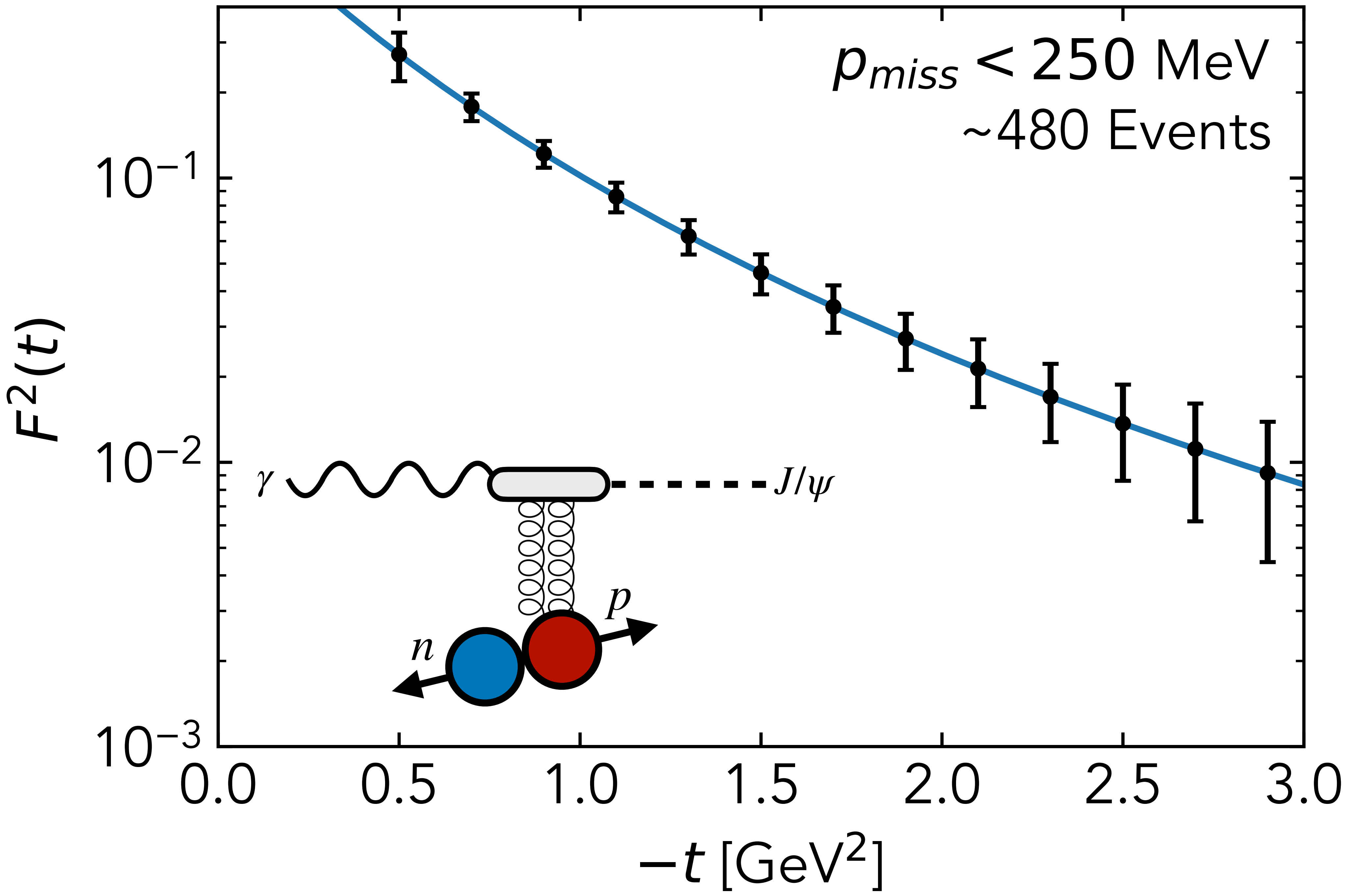
Binding effects in the gluonic content of the proton



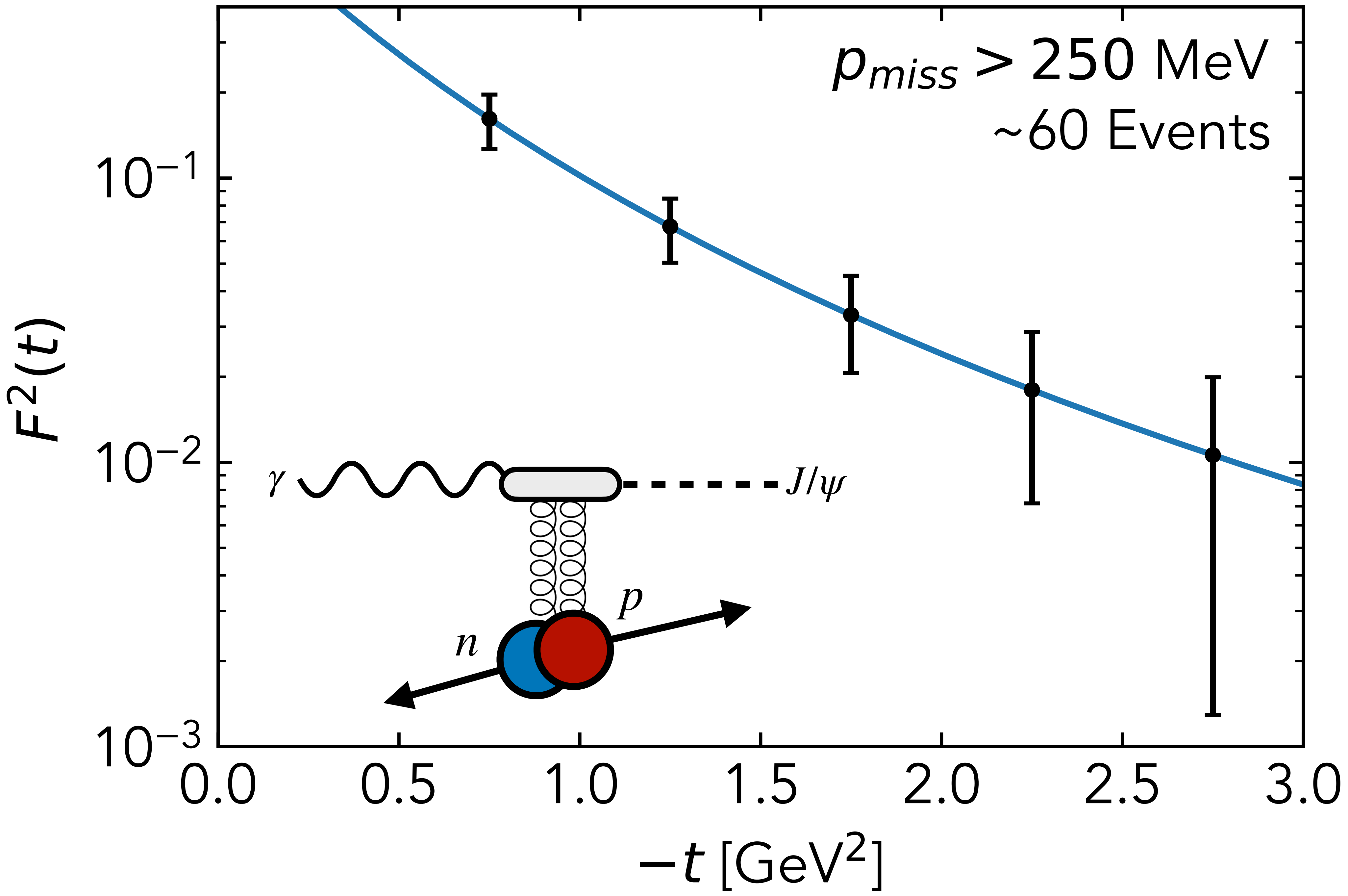
- Semi-exclusive measurements let us compare weakly- and strongly-bound protons
- Compare J/ψ photoproduction on low-momentum and high-momentum protons
- Deuteron preferred as exclusivity improves resolution

Comparing low- and high-momentum proton structure

Low-momentum / loosely bound



High-momentum / deeply bound

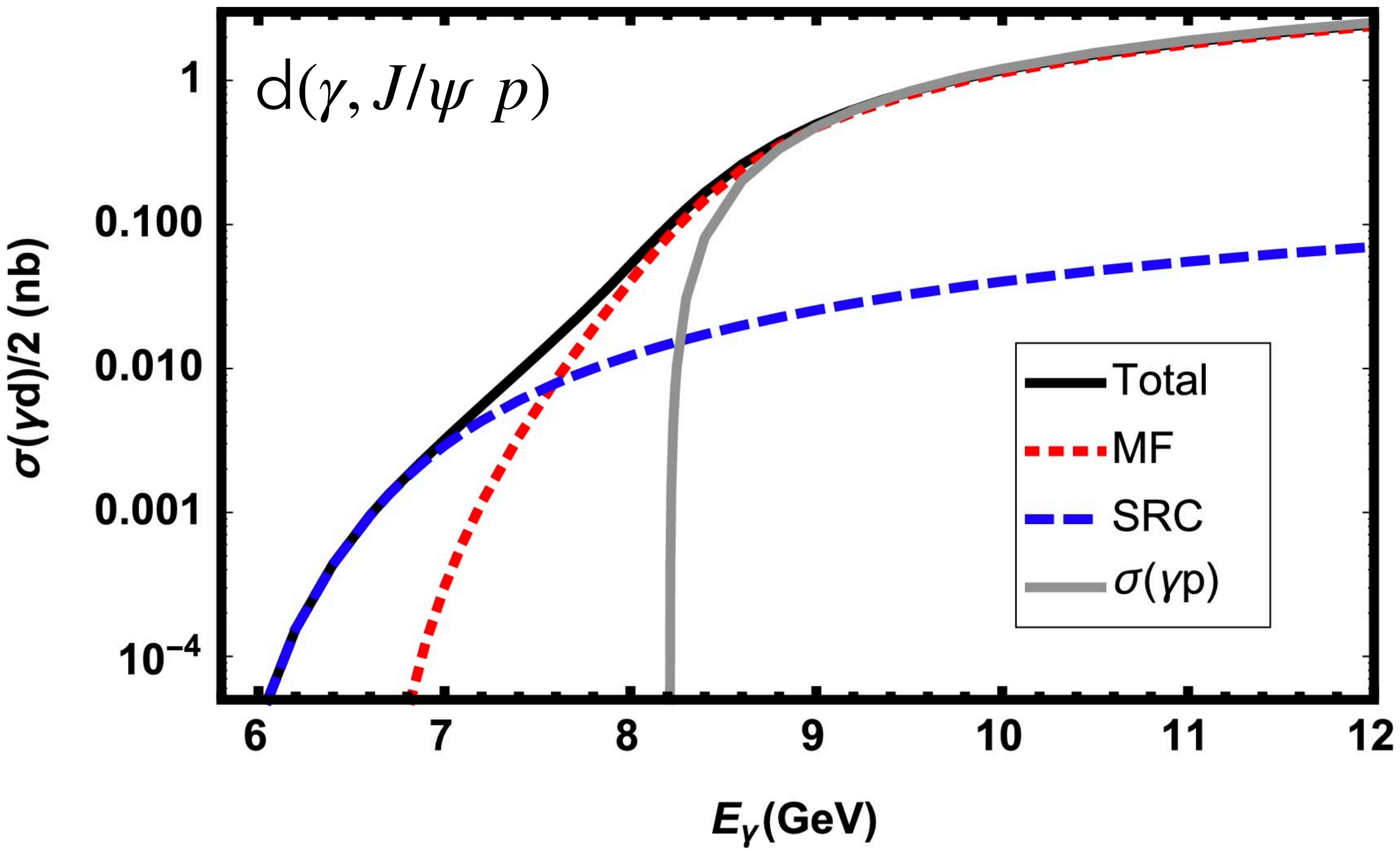


Statistical projection for 60 PAC days at 10.8 GeV energy

12 GeV would improve J/ψ rates, but background uncertainties need to be modeled

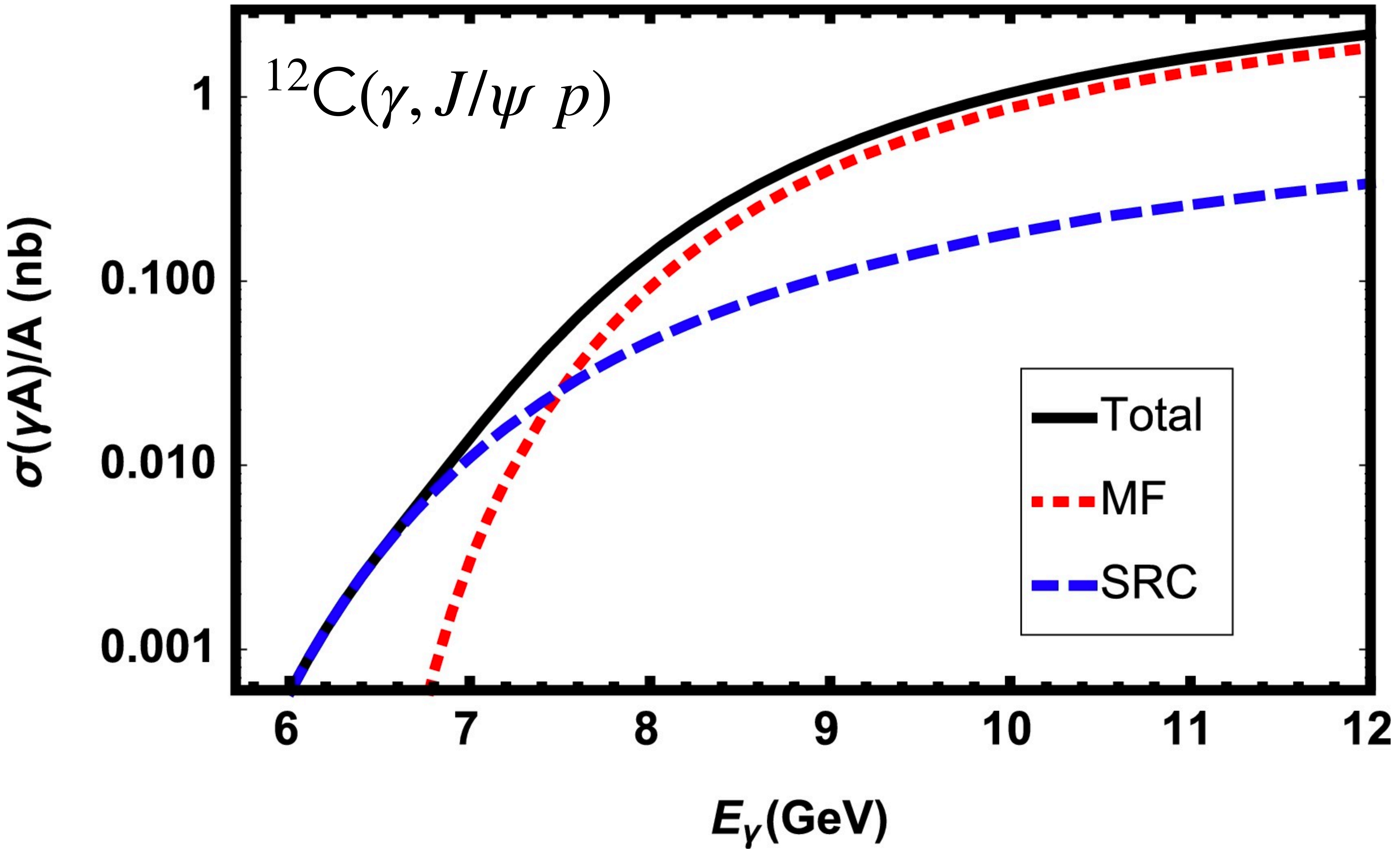
Sub-threshold production allows comparison of SRC abundances, but rates are limited

Deuterium



60 PAC days at 10.8 GeV → ~12 sub-threshold events from deuterium

Carbon

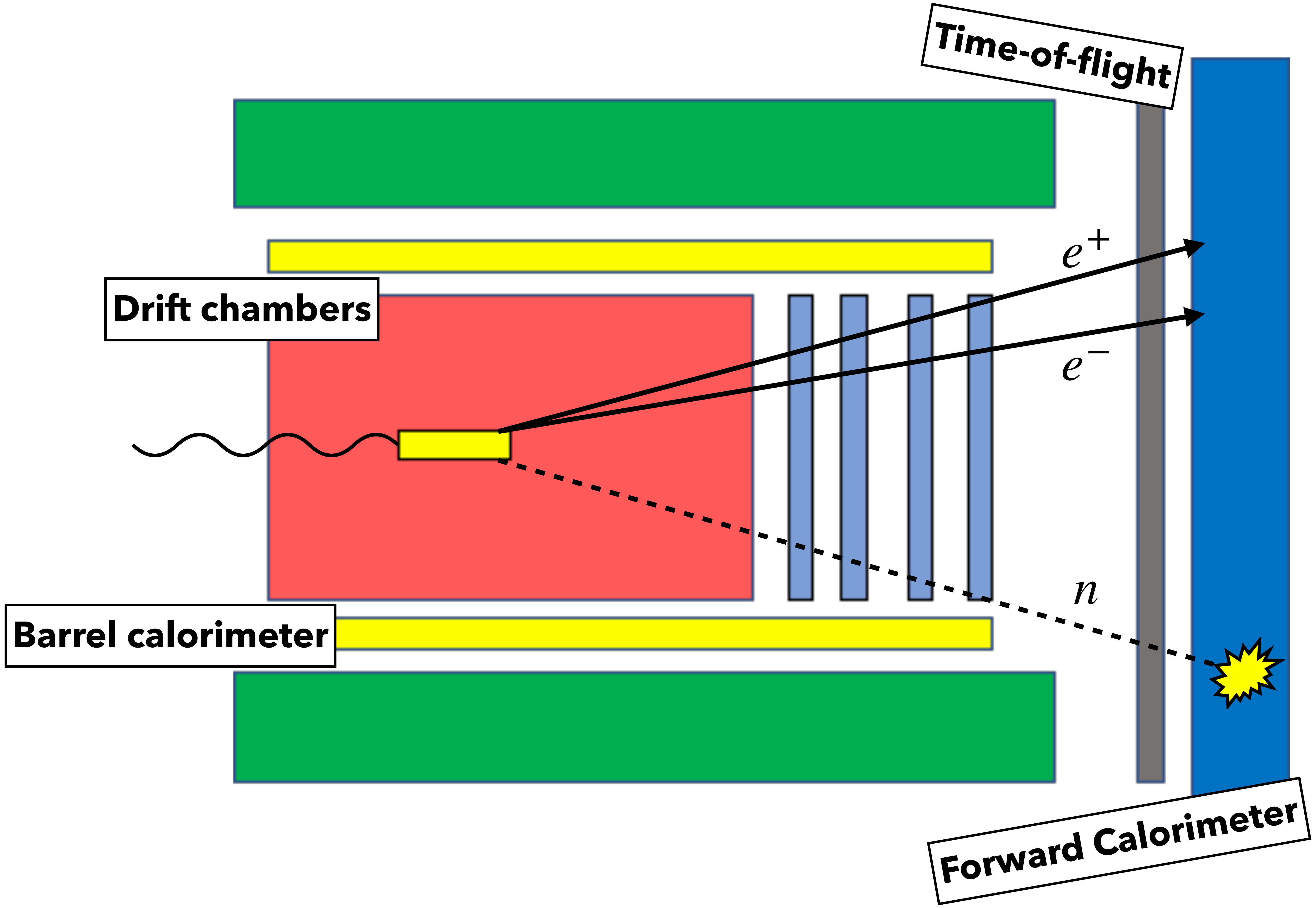


Carbon cross section higher by ~3-4

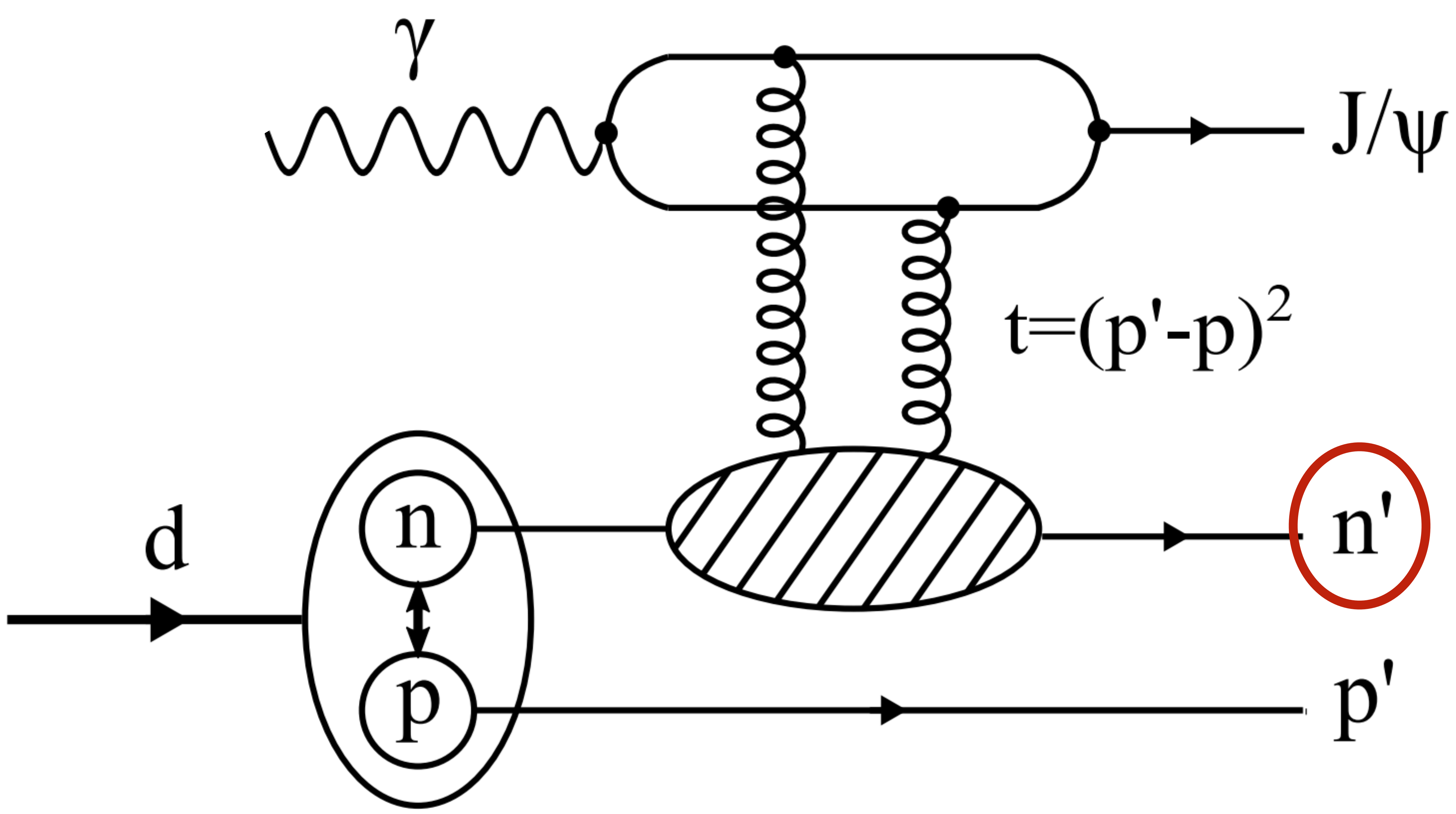
Hatta et al. PLB (2020)

Incoherent $A(\gamma, J/\psi\ n)X$

- Neutron detection possible by looking at hits in calorimeters
- More work required to determine neutron efficiency and momentum resolution in GlueX spectrometer



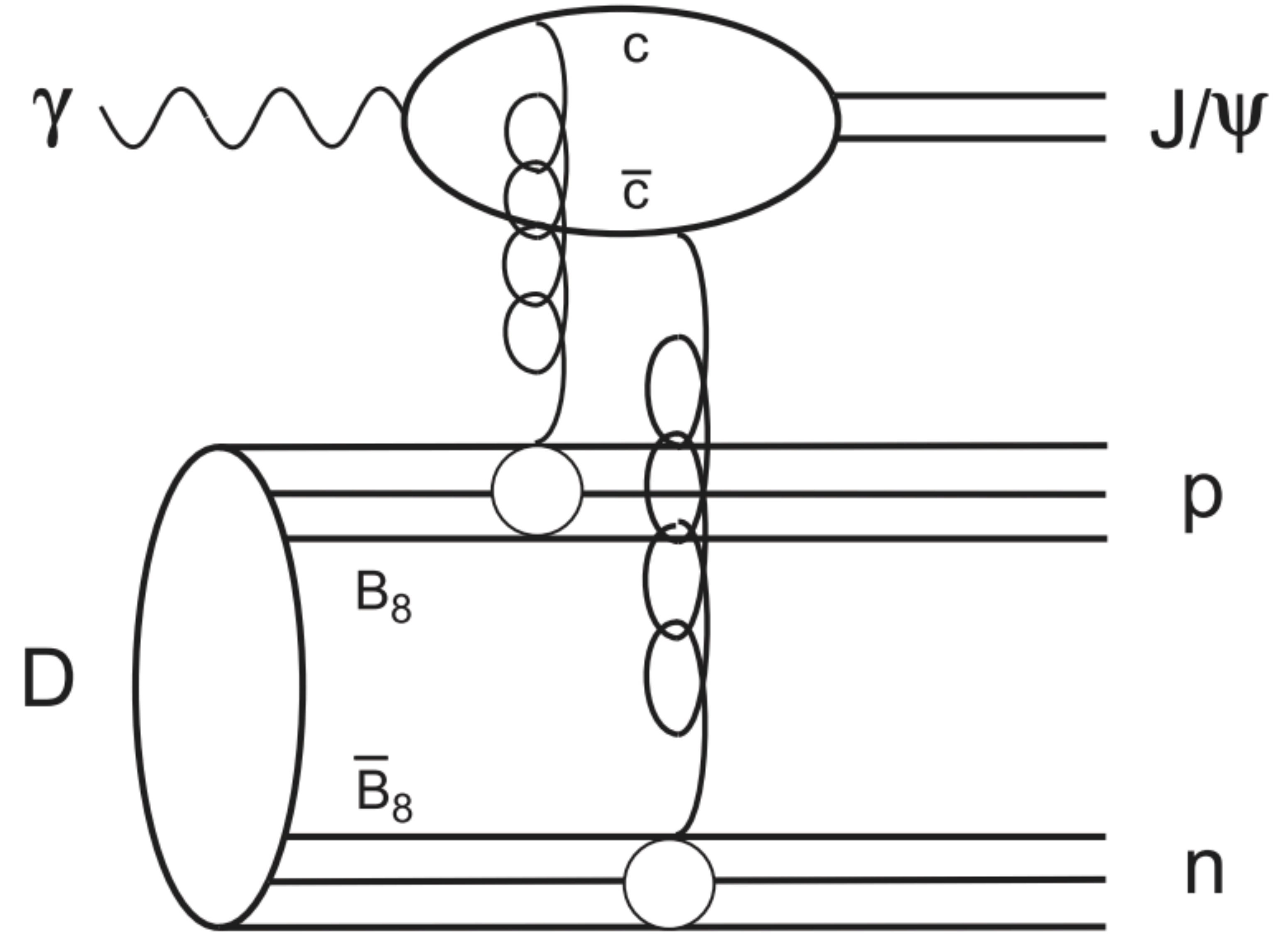
Gluonic measurements of the neutron

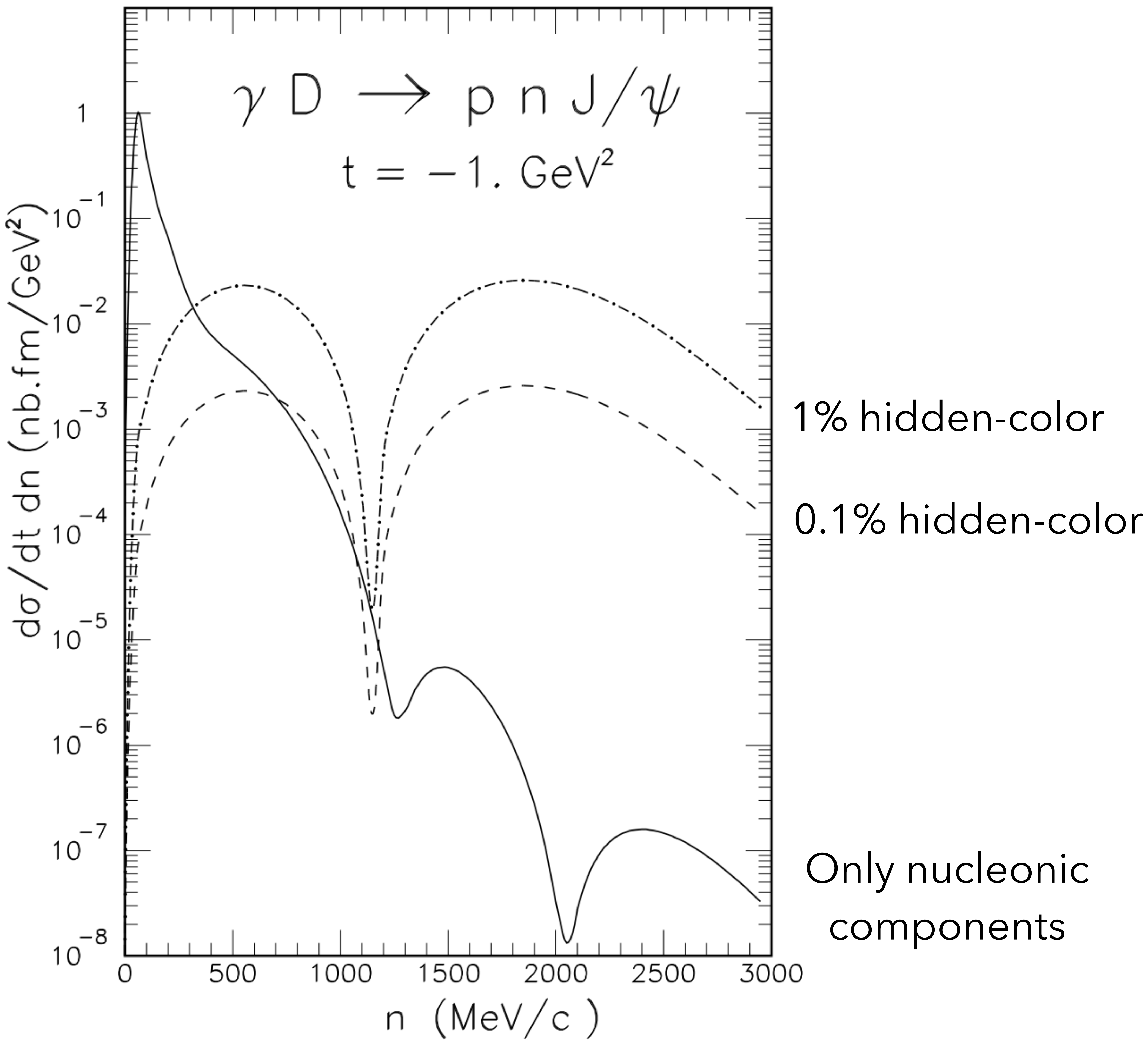


- Look for a **leading neutron** with high momentum transfer
- At low missing momentum, we can measure gluon content of the quasi-free neutron
- Major challenge is determining neutron detection in GlueX

Hidden-color sensitivity in incoherent production

- Color-octet states in the deuteron open up new production diagrams in J/ψ production
- Enhancement of production cross section at high momentum points to non-nucleonic components

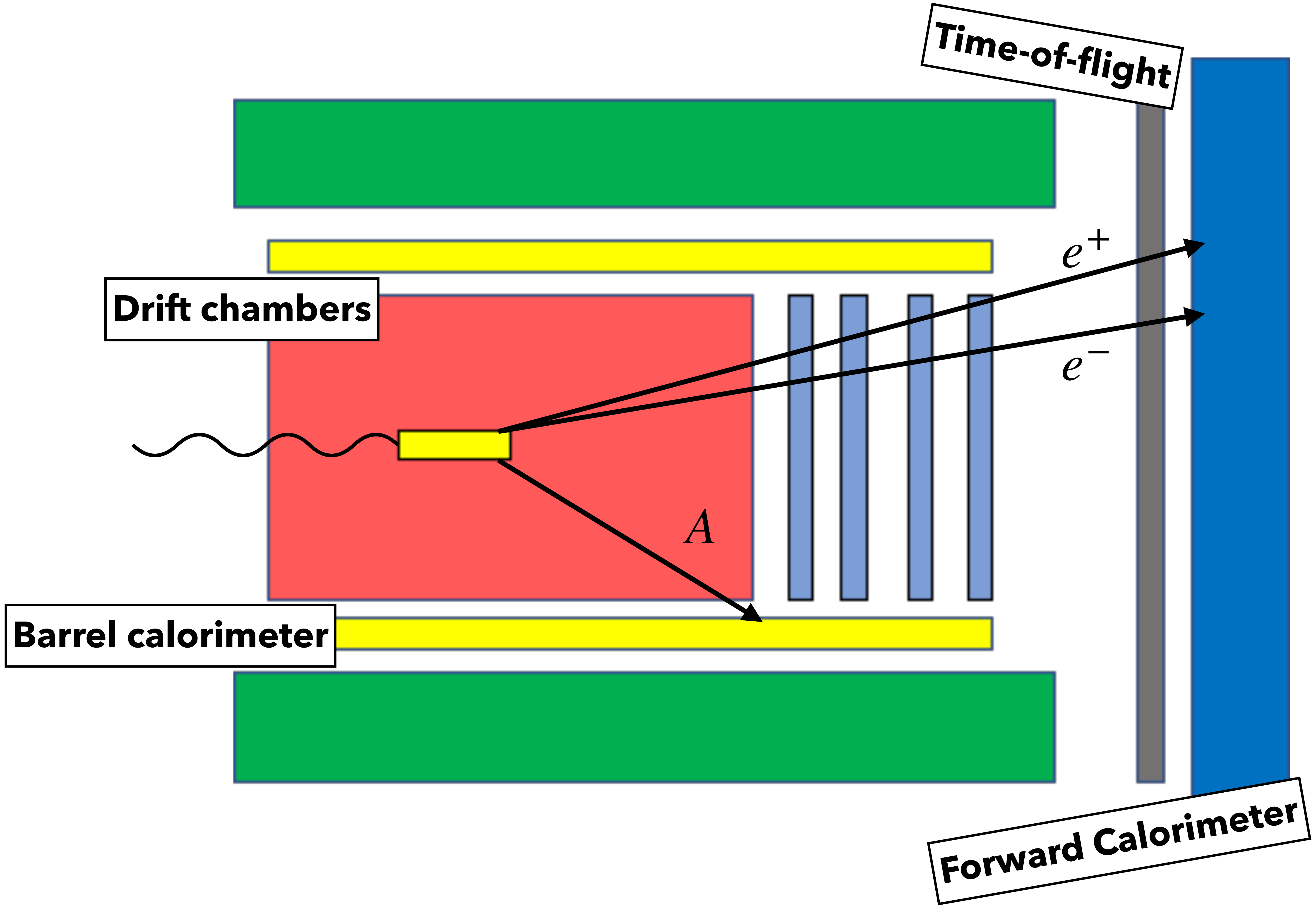




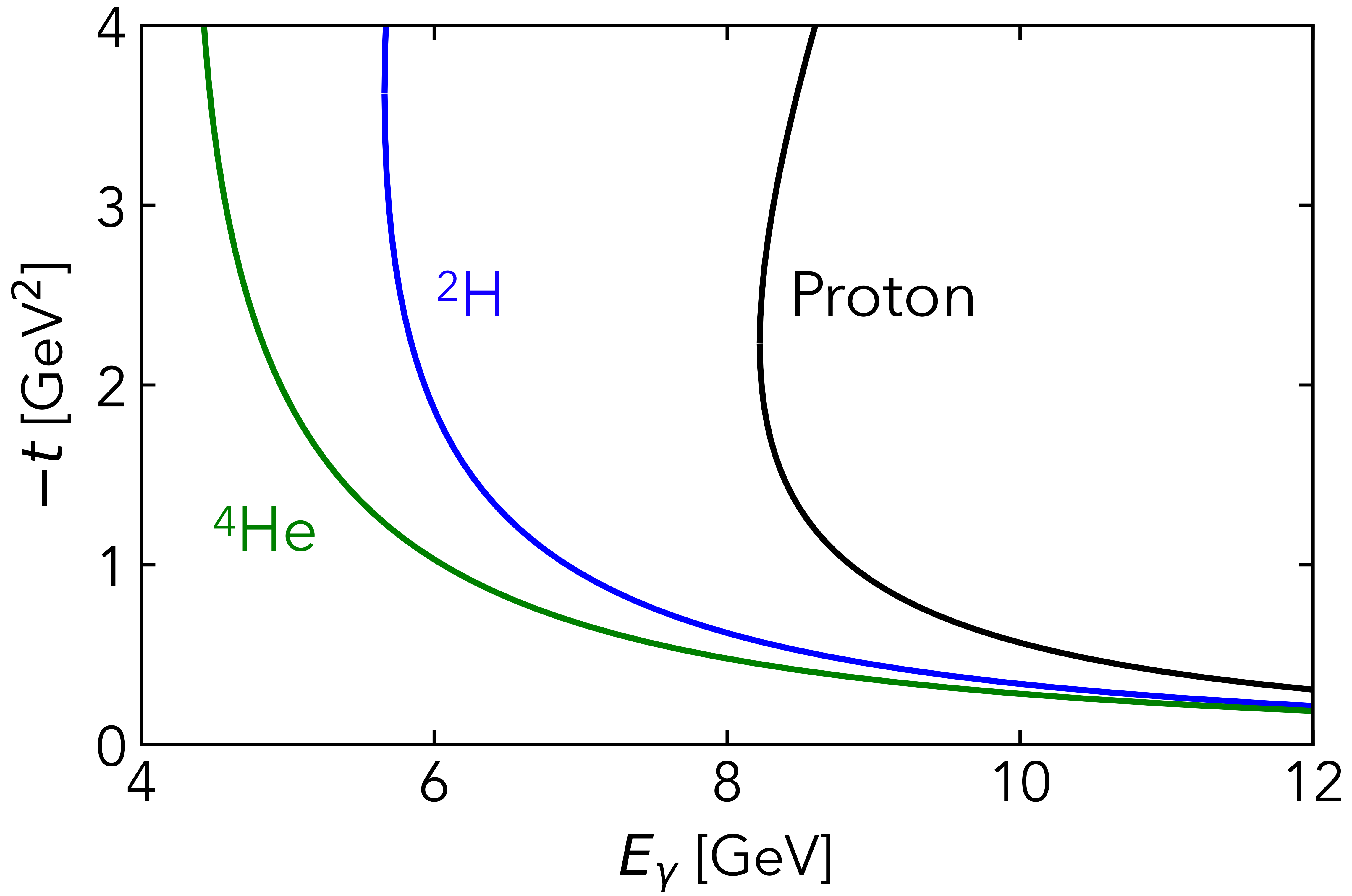
Brodsky et al. PLB (2001)

Coherent $A(\gamma, J/\psi\ A)$

- Large J/ψ mass results in substantial momentum transfer to target
- Light nucleus ^{2}H can be tagged to identify coherent production
  - dE/dx in drift chambers allows low-momentum PID
- Heavier nuclei need other options to remove incoherent background

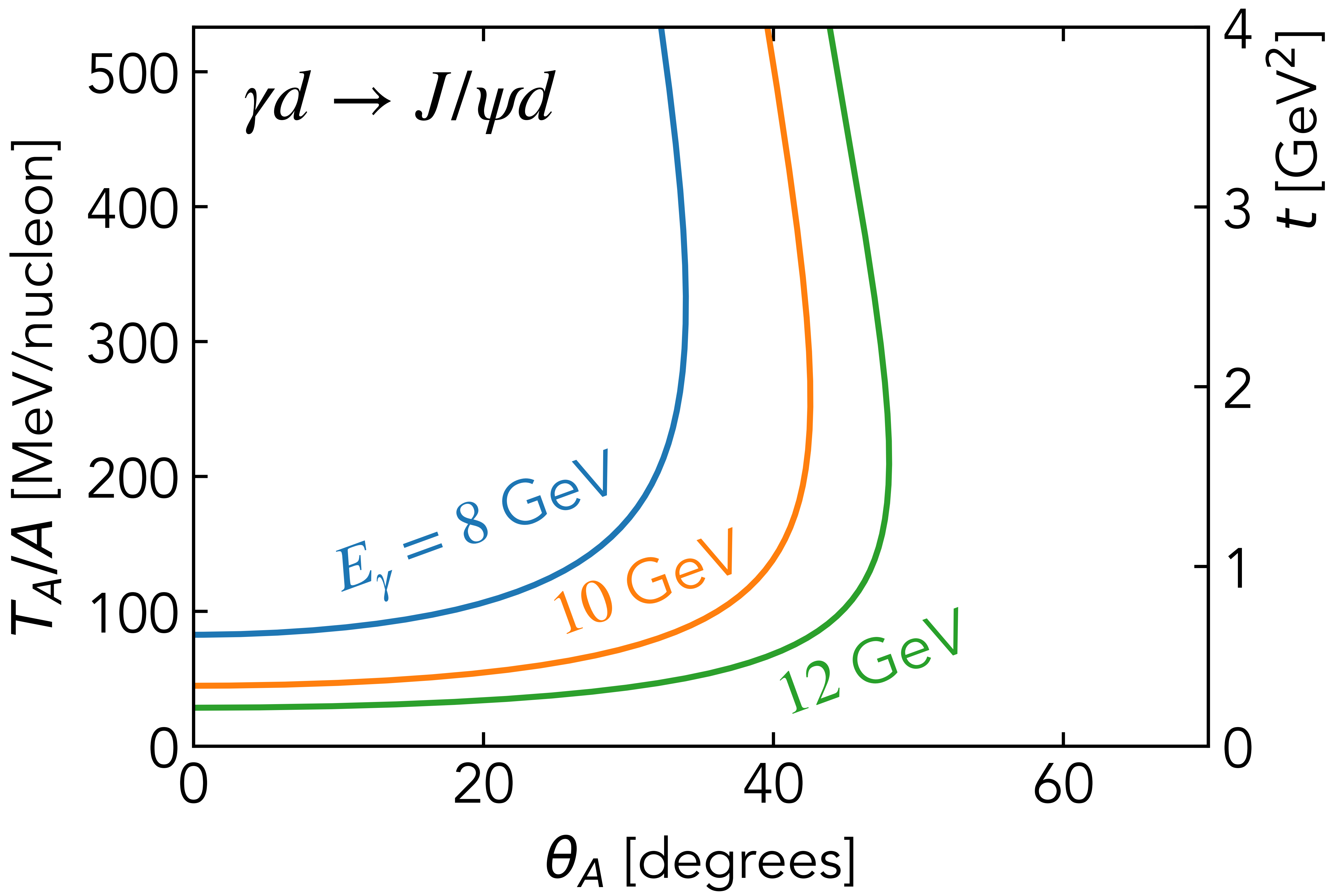


First question: do we have the phase space?



- High J/ψ mass requires high momentum transfer near threshold, but form factor slope increases rapidly with A
- Need to understand the $|t|$ -dependence of coherent production near threshold to determine if rates are sufficient

Second question: can we suppress backgrounds?



- GlueX resolution insufficient to separate coherent and incoherent production with missing mass
- High-$|t|$ coherent production from the deuteron could be tagged with high-momentum deuteron

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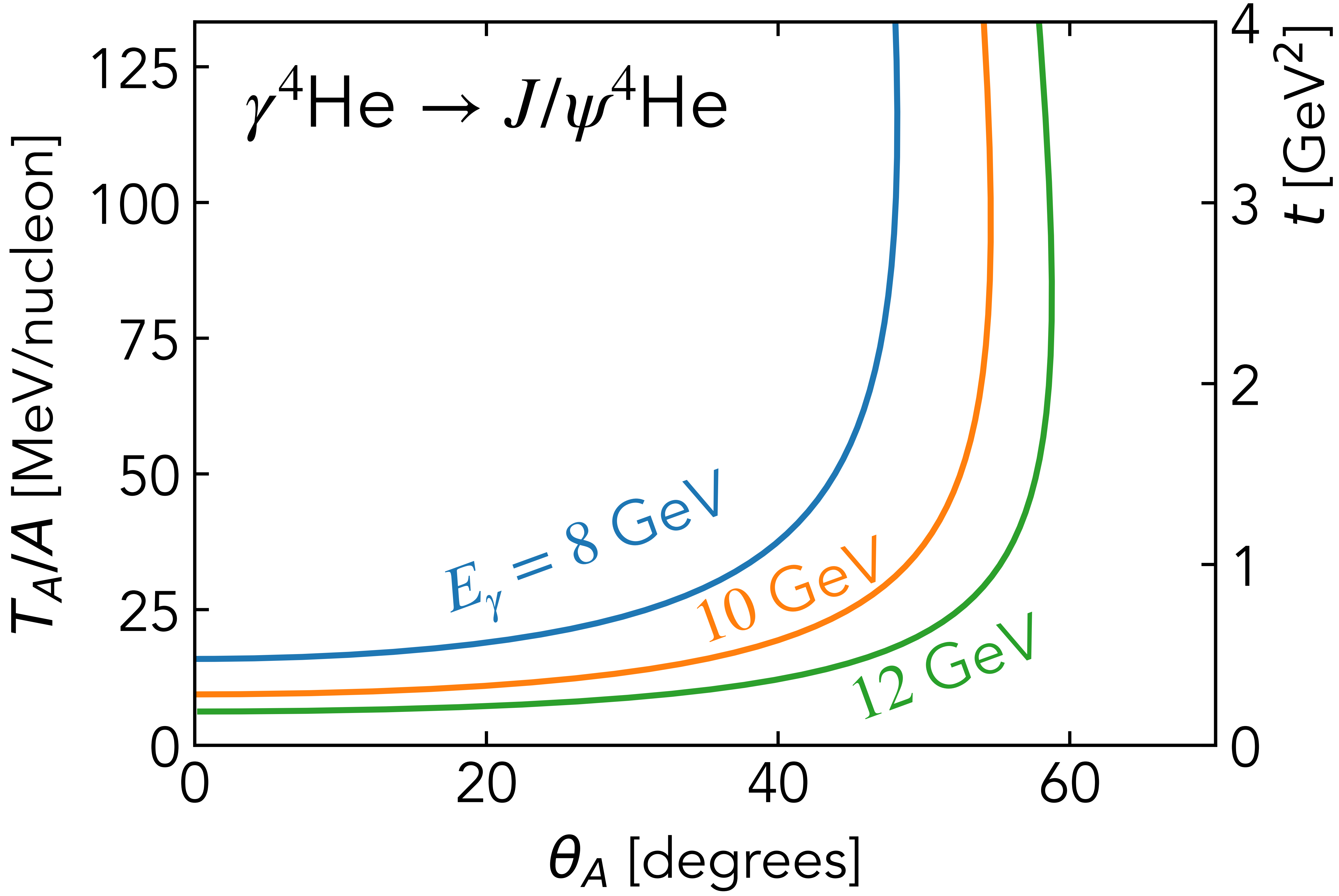

- Heavier nuclei such as ^{4}He move much slower and are unlikely to be reconstructed
- Possible to veto on detection of nuclear breakup productions in t_0 detector around target

Conclusions

- High-statistics photonuclear data could enable more detailed study of hard photonuclear reactions

- J/ψ production is especially interesting; can give insight into gluonic structure of the nucleus, including possible medium-modification effects

- Further work required to quantify achievable goals, desired luminosity and targets

- Input on possible photonuclear observables is welcome

Backup

Exclusive deuteron breakup significantly enhances J/ψ resolution