

Measurement of coherent ϕ meson photoproduction from the deuteron at 6-11 GeV

Bo Yu

Duke University

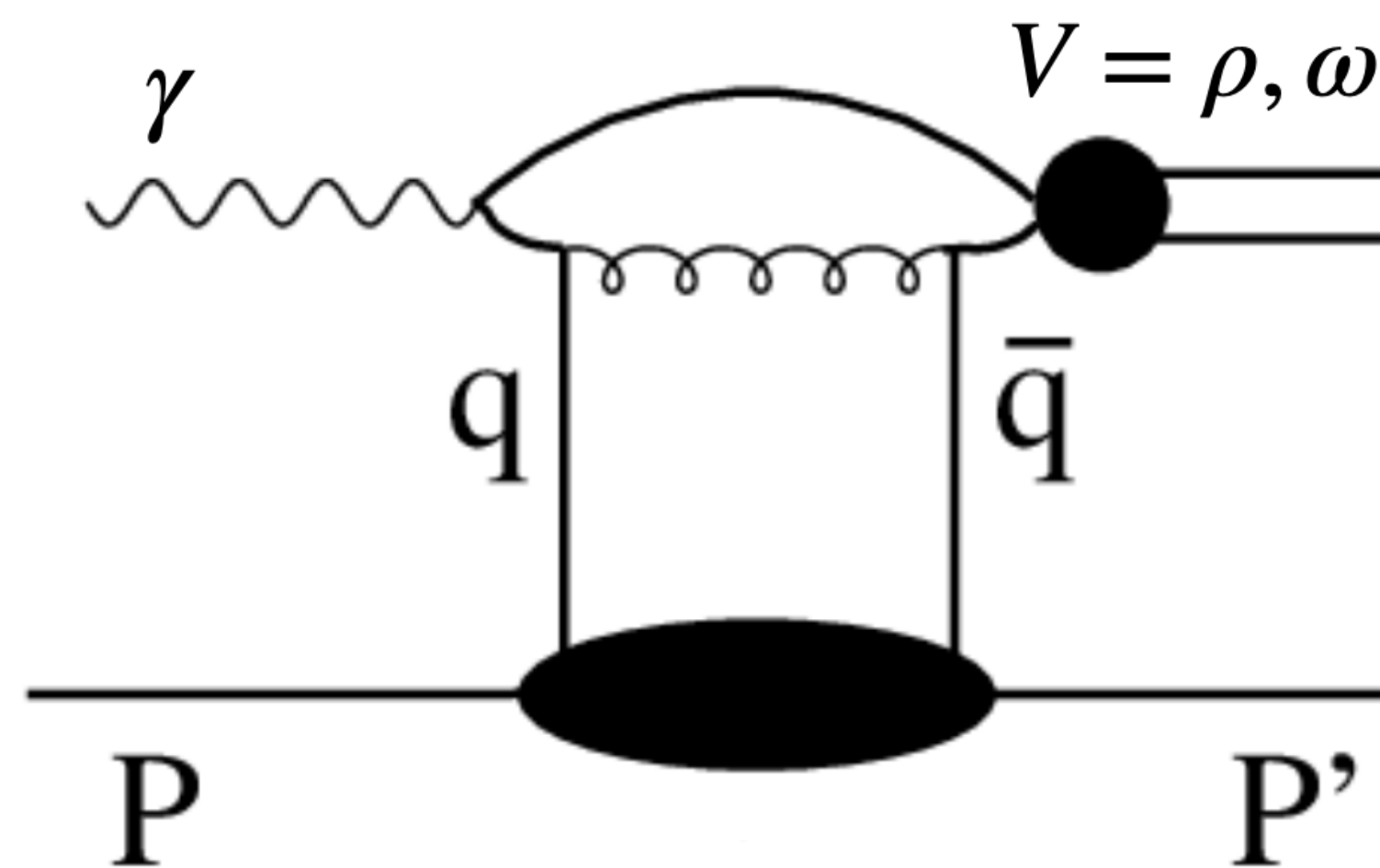
APS DNP 2025

Oct 18, 2025, Chicago, IL



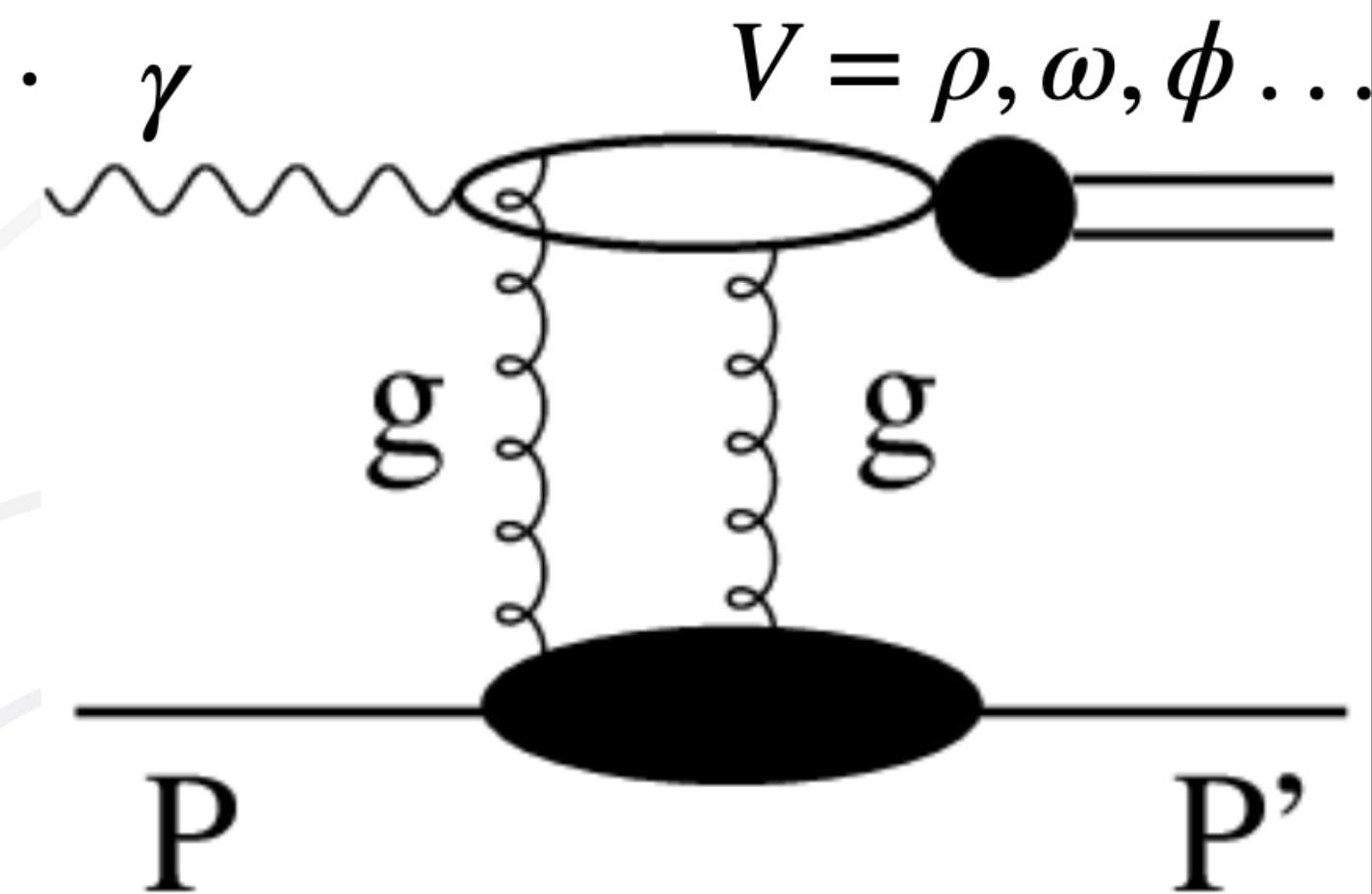
Uniqueness of ϕ meson

- $\phi(1020) \approx s\bar{s}$
- Unique to study gluon exchange at low energies!
- $\sigma_{\phi N}$ is a quantity that characterizes $\phi - N$ interactions
- It provides essential information for QCD inspired models



Quark exchange

Suppressed in $\phi - N$ interaction
due to no common valence quark

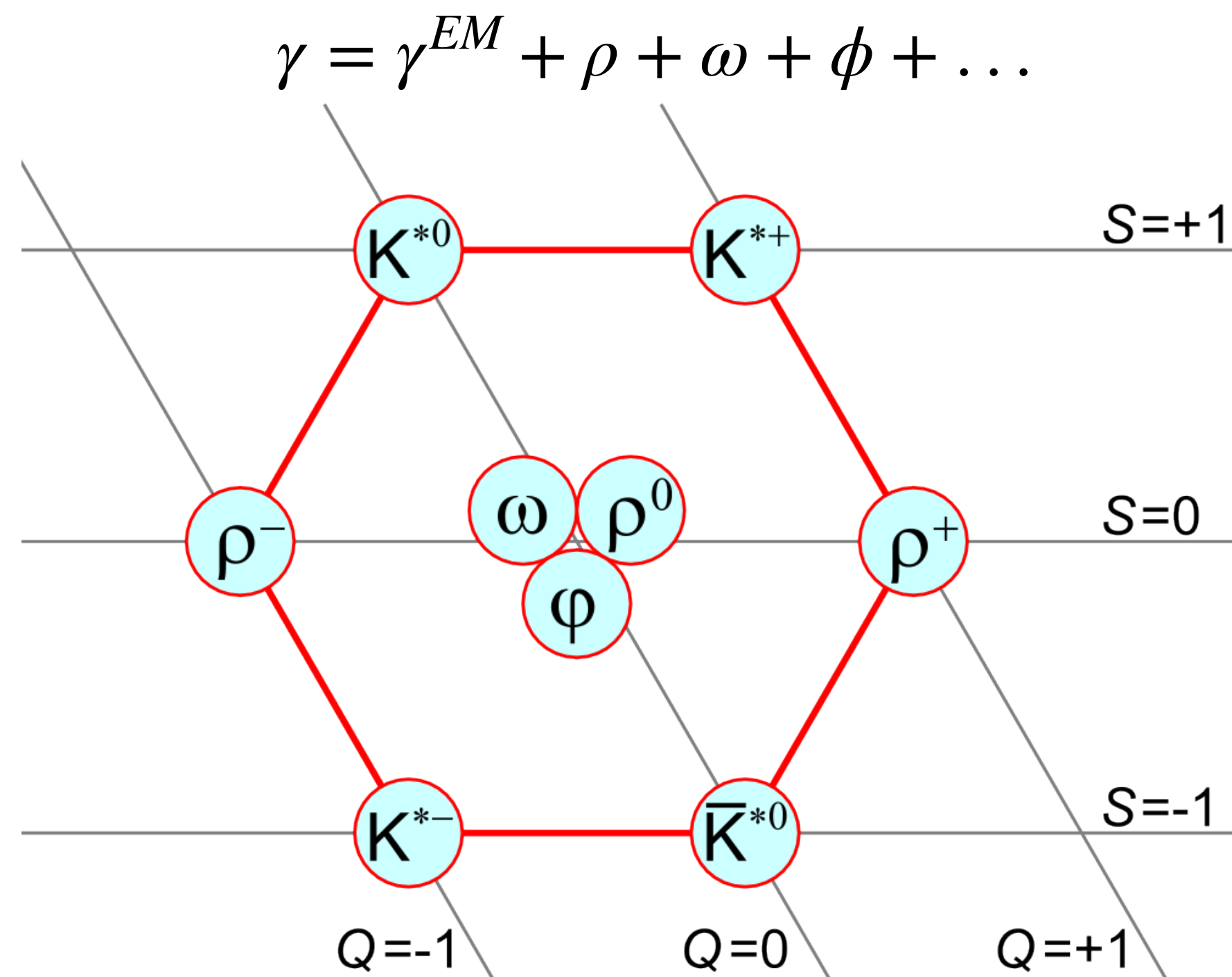


Gluon exchange

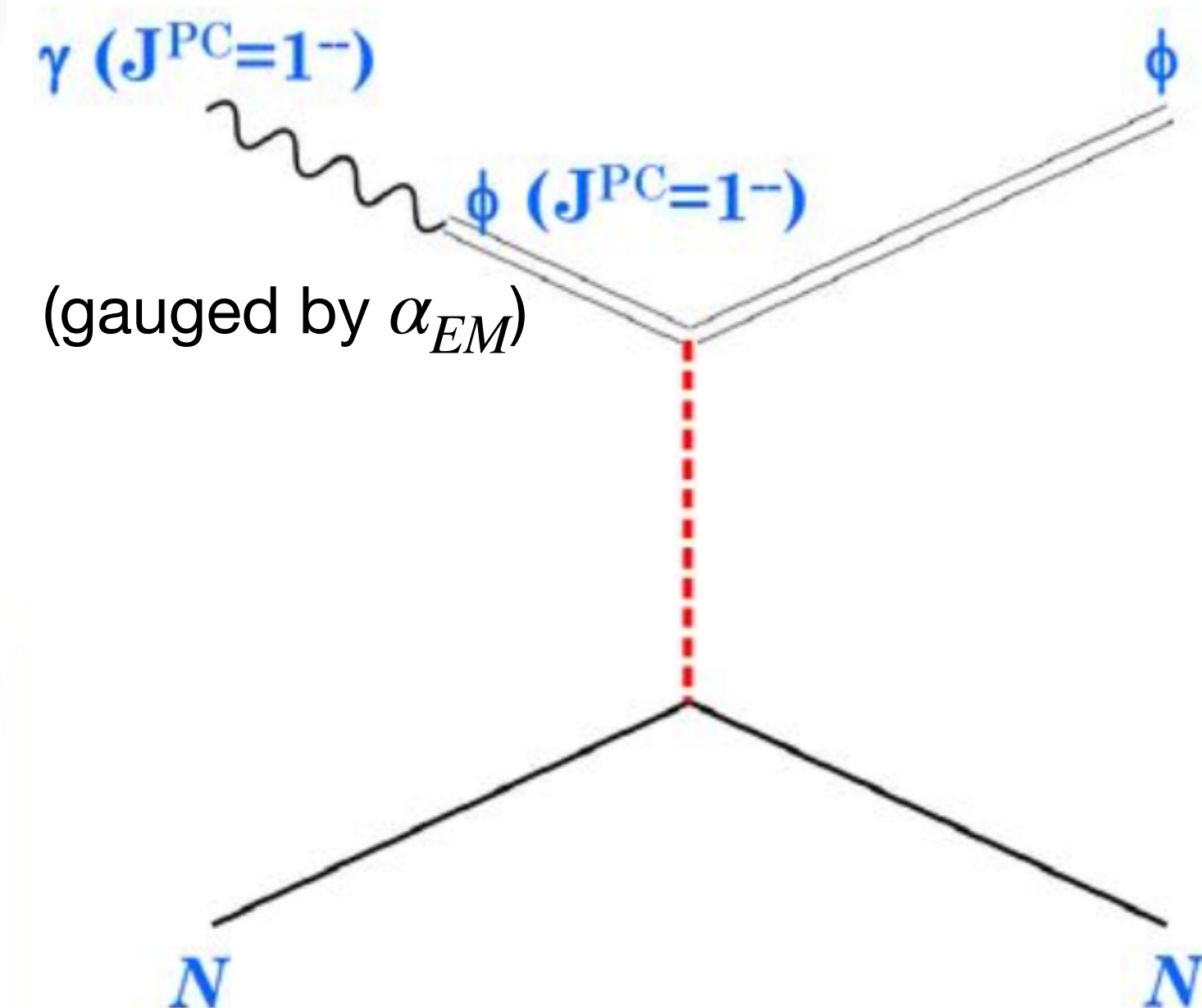
Dominant in $\phi - N$ interaction
universal in hadron interactions

Extract $\sigma_{\phi N}$ from ϕ photoproduction

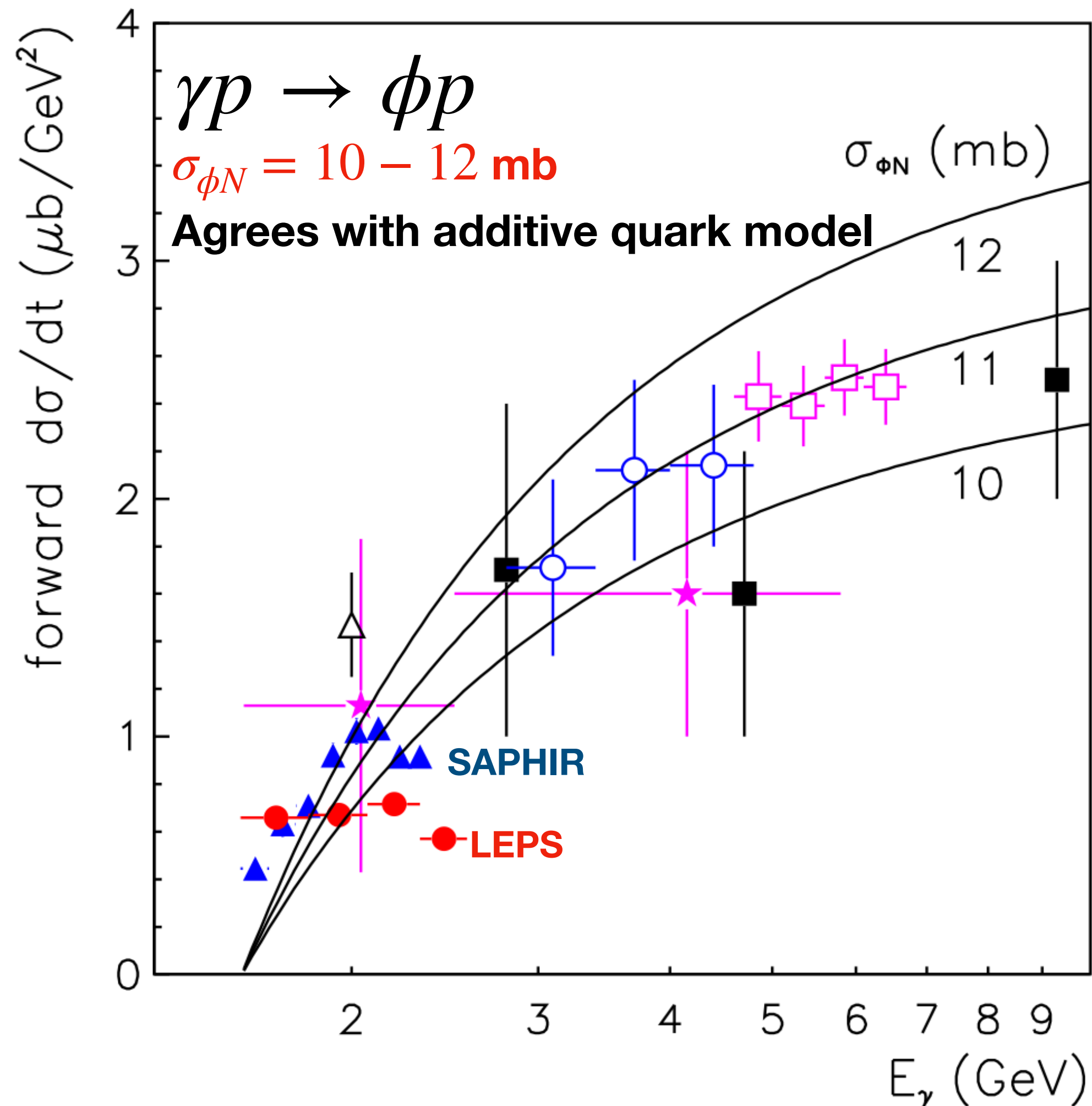
- Use photons as hadronic probe
- Vector meson dominance (VMD) model describes photon-hadron interactions very well at high energies



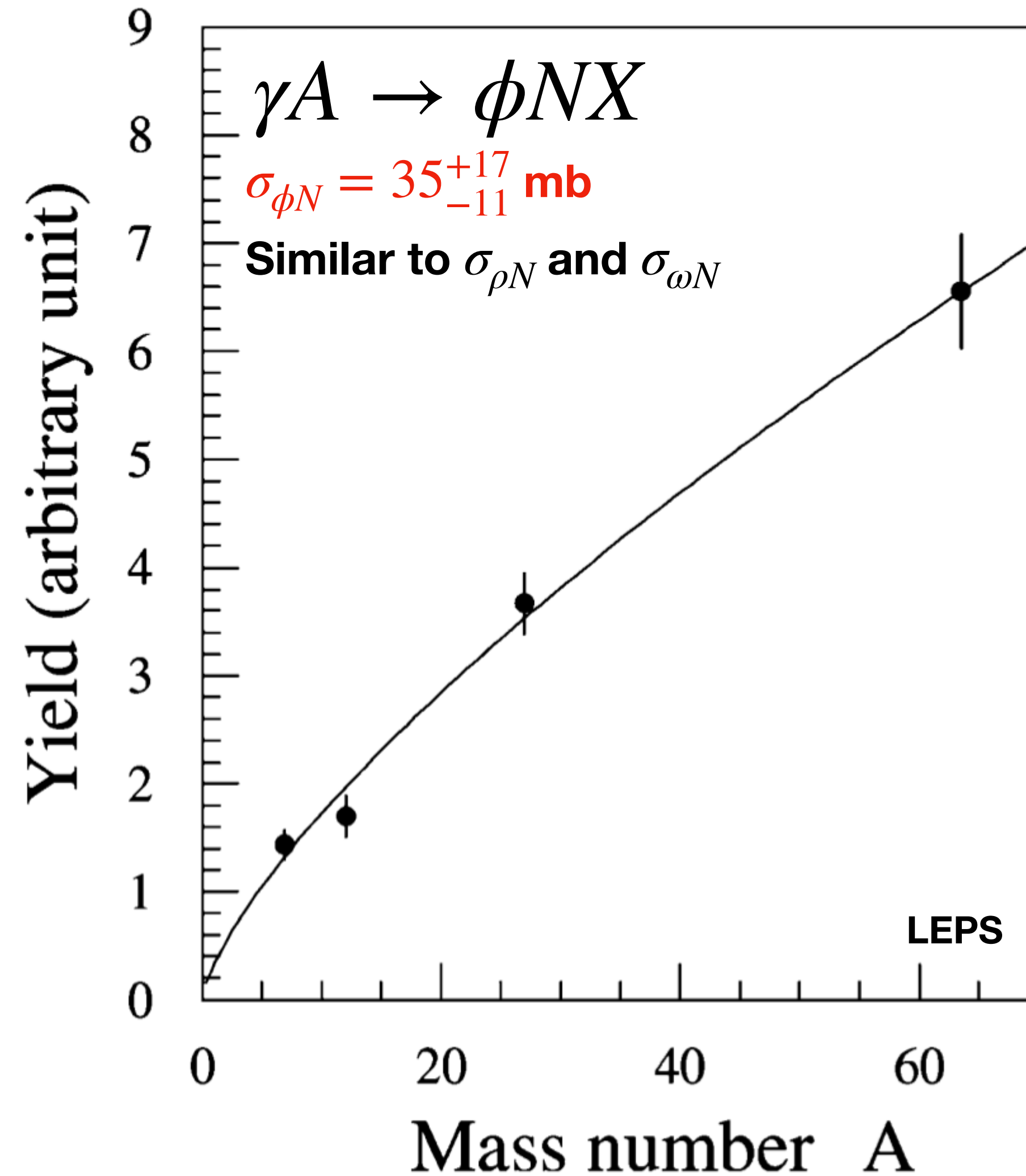
Connects ϕN interactions with γN interactions



Discrepancies on $\sigma_{\phi N}$ extractions



Sibirtsev *et al.* EPJA 29, 209–220 (2006)



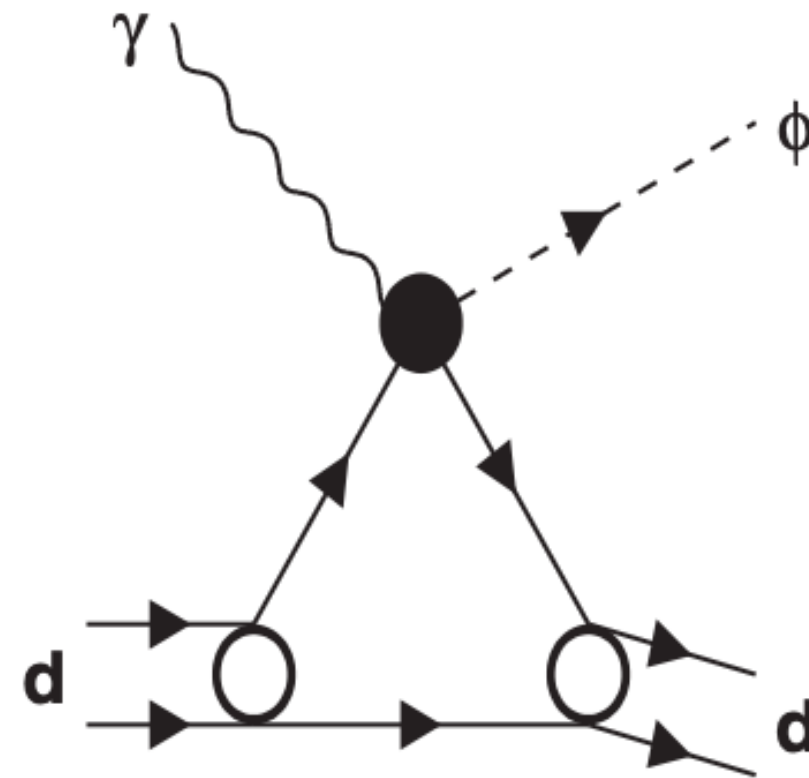
Ishikawa *et al.* PLB 608 (2005) 215–222

Coherent photoproduction on deuteron

Single scattering

One nucleon receives all the momentum transfer

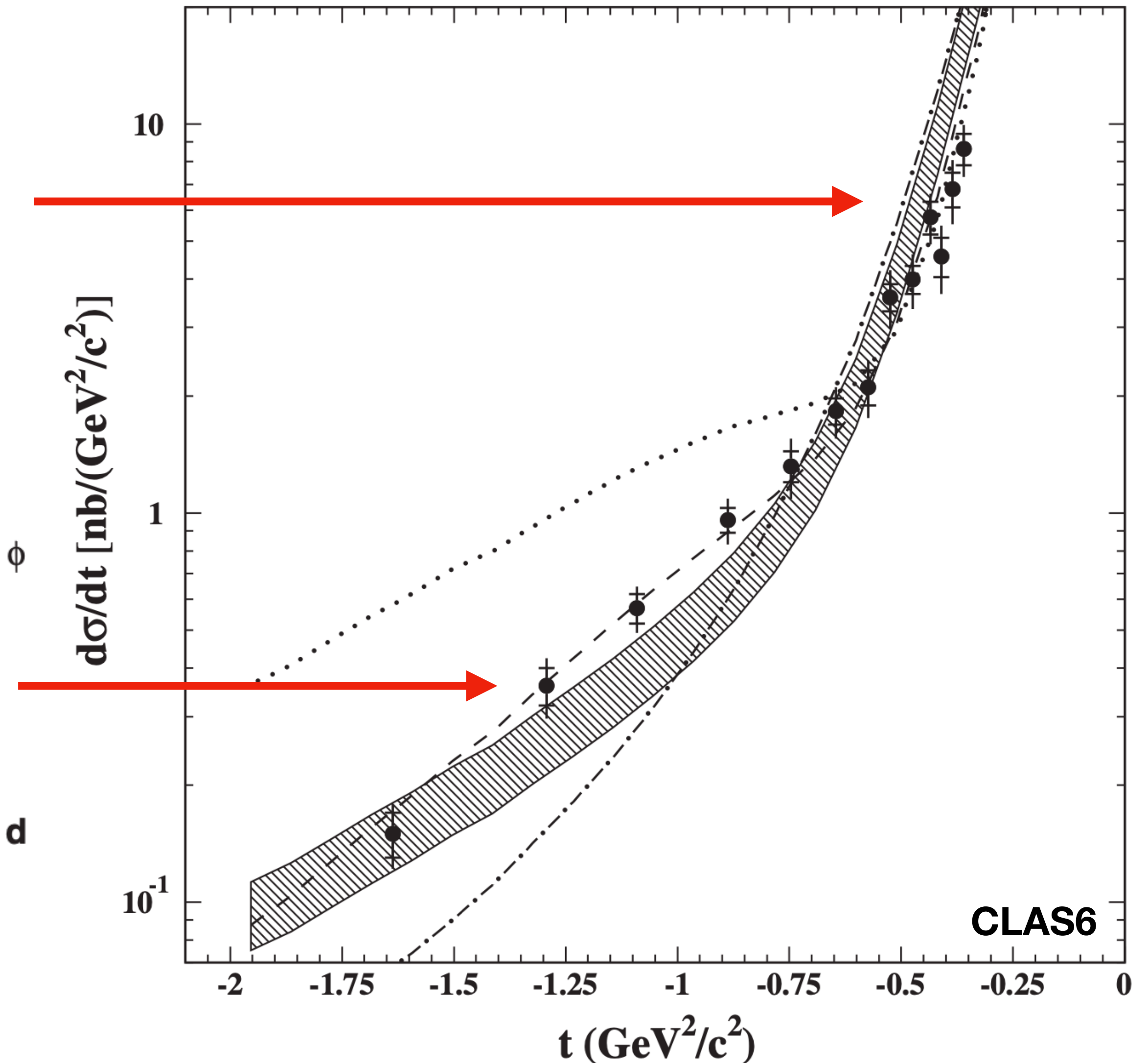
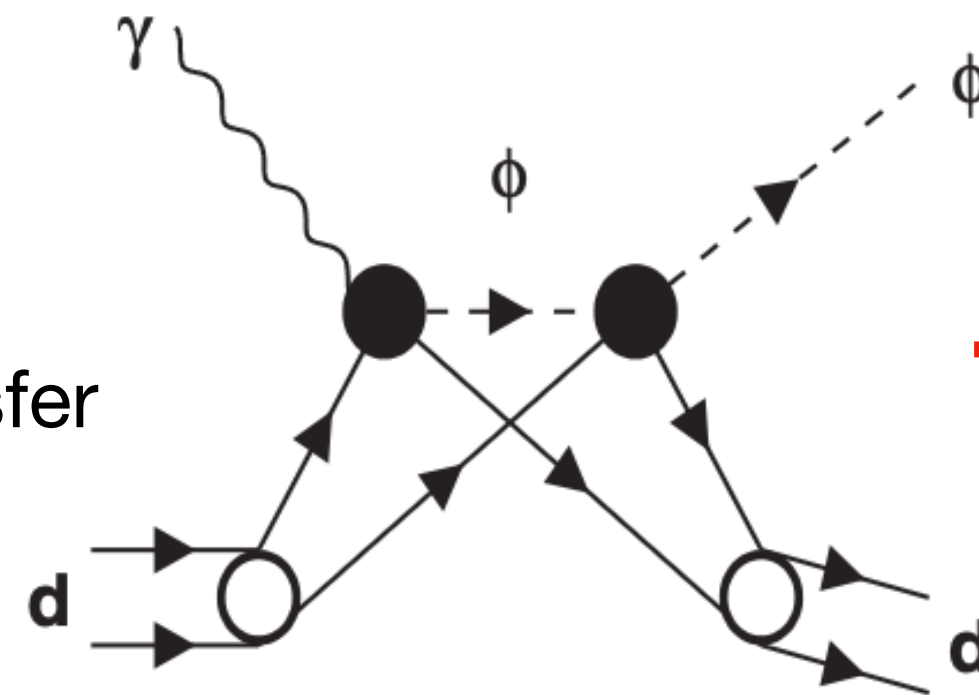
Dominates at low $|t|$



Double scattering

Each nucleon receives half the momentum transfer

Dominates at high $|t|$



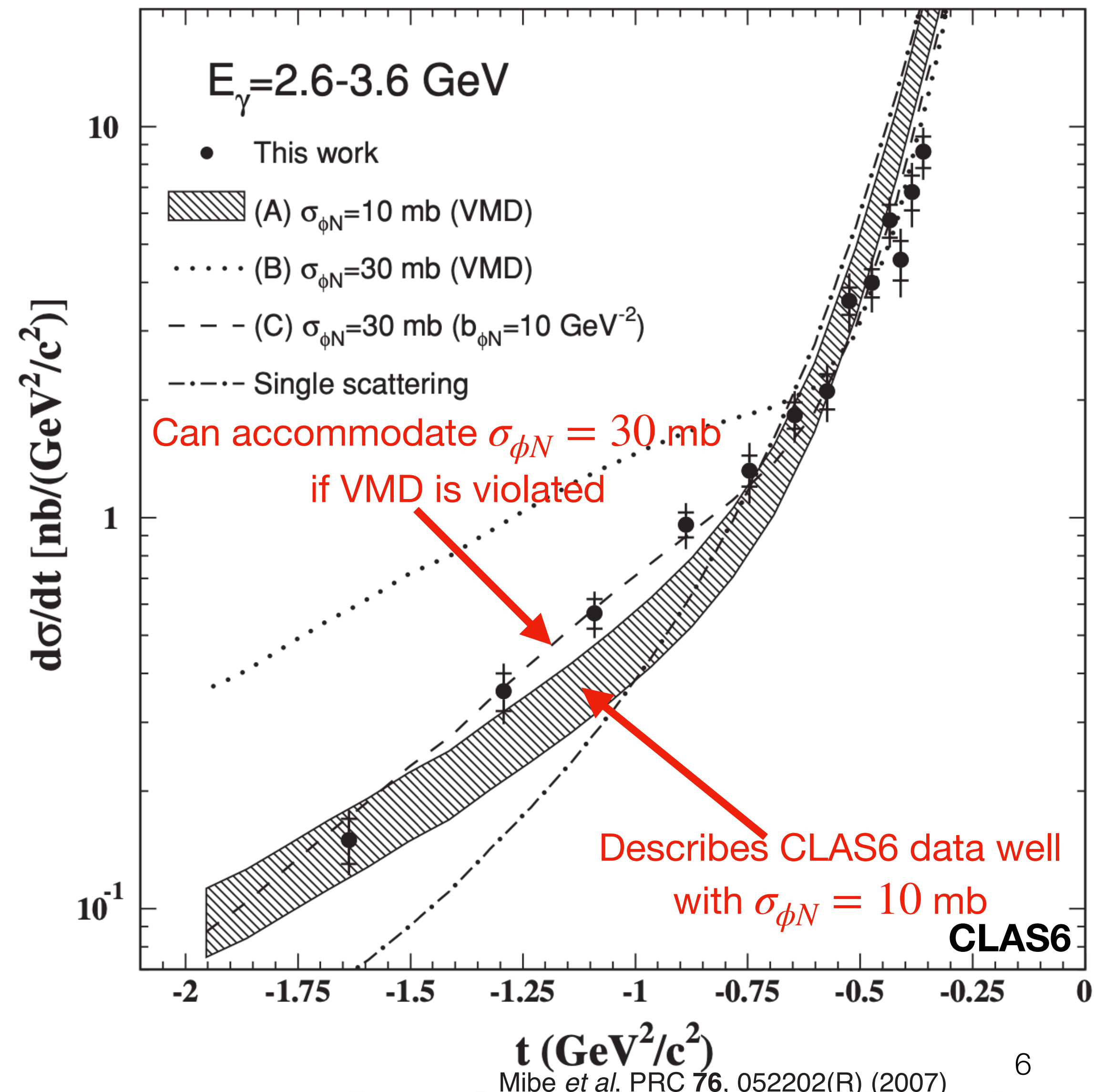
Model of coherent ϕ photoproduction

- Standard ingredients in the model
 - Vector meson dominance
 - Paris potential for deuteron wave function
 - Glauber scattering theory
 - Longitudinal interaction length of the photon

- $f_{\phi N} \propto \sigma_{\phi N}(1 + \alpha_{\phi}i)e^{-b_{\phi N}t}$

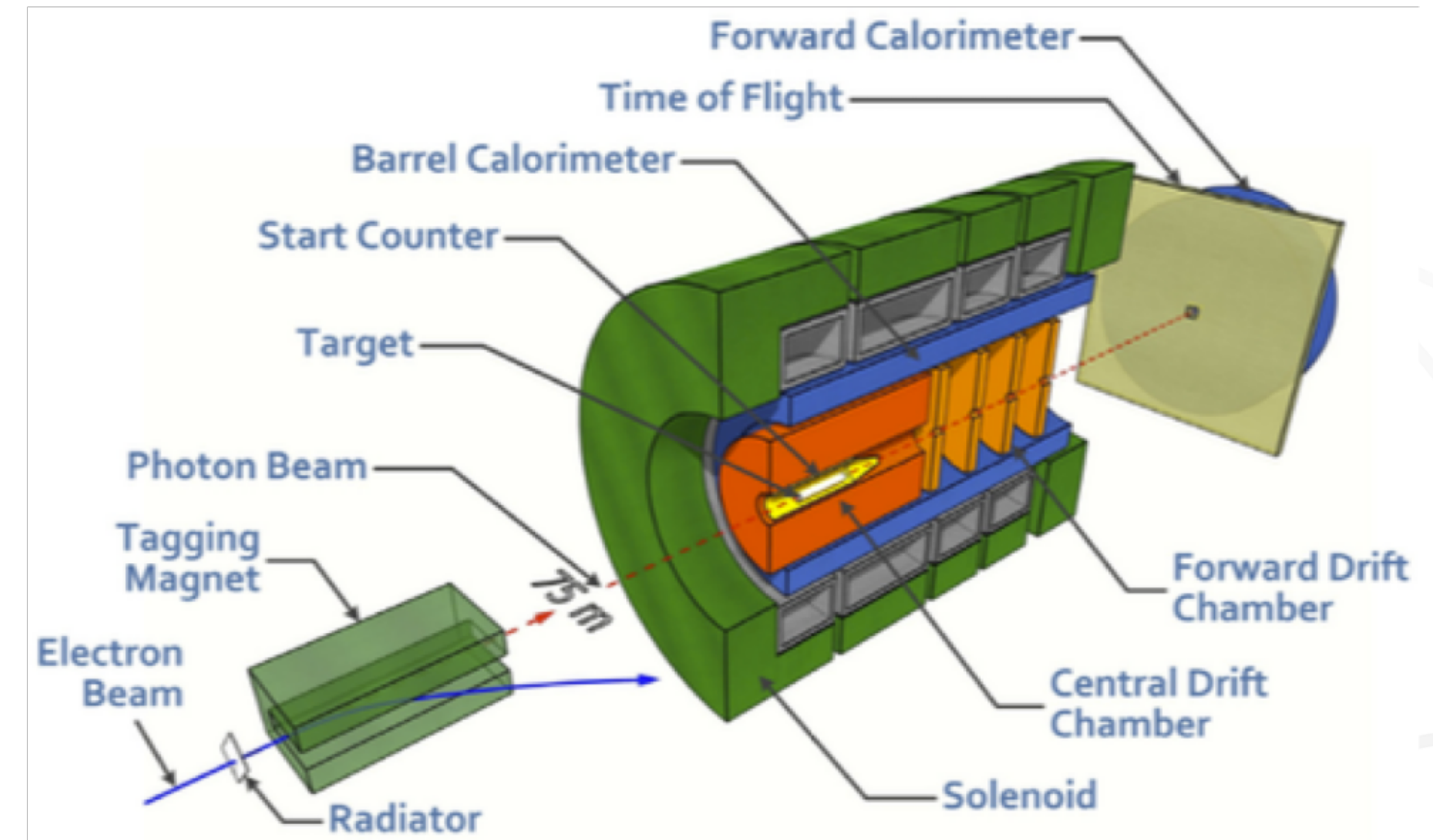
α_{ϕ} set to be $-\frac{1}{2}$

- VMD assumes $\sigma_{\phi N} = \sigma_{\gamma N}$, $b_{\phi N} = b_{\gamma N}$



The SRC-CT experiment

- Short range correlation (SRC), color transparency (CT) and bound nucleon structure
- Fall 2021 at JLab Hall D with GlueX detector
- Tagged linearly polarized photon beam from 10.8 GeV electron beam
- 40 days running of ^2H , ^4He , ^{12}C



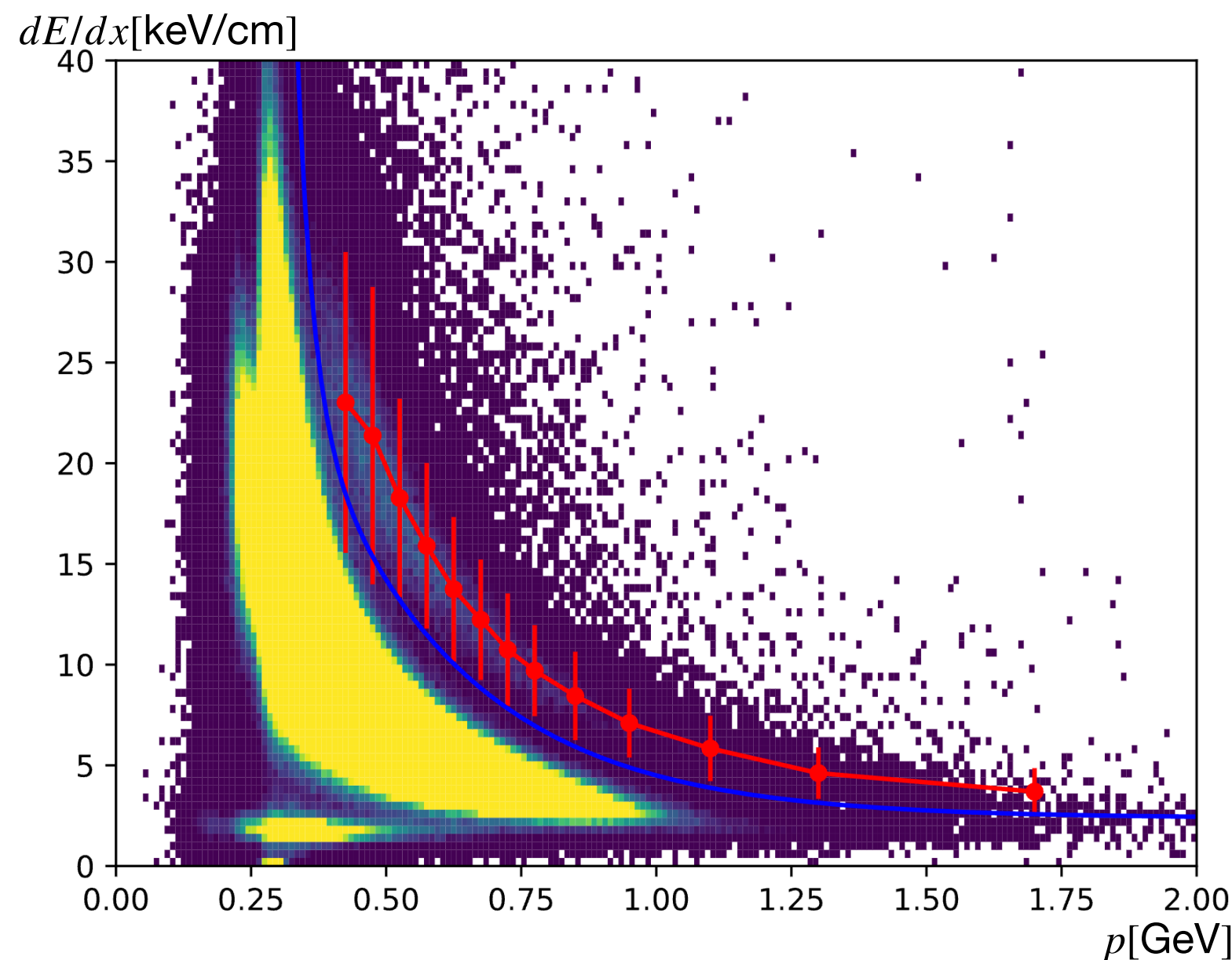
Adhikari *et al.* NIM A 987, 164807



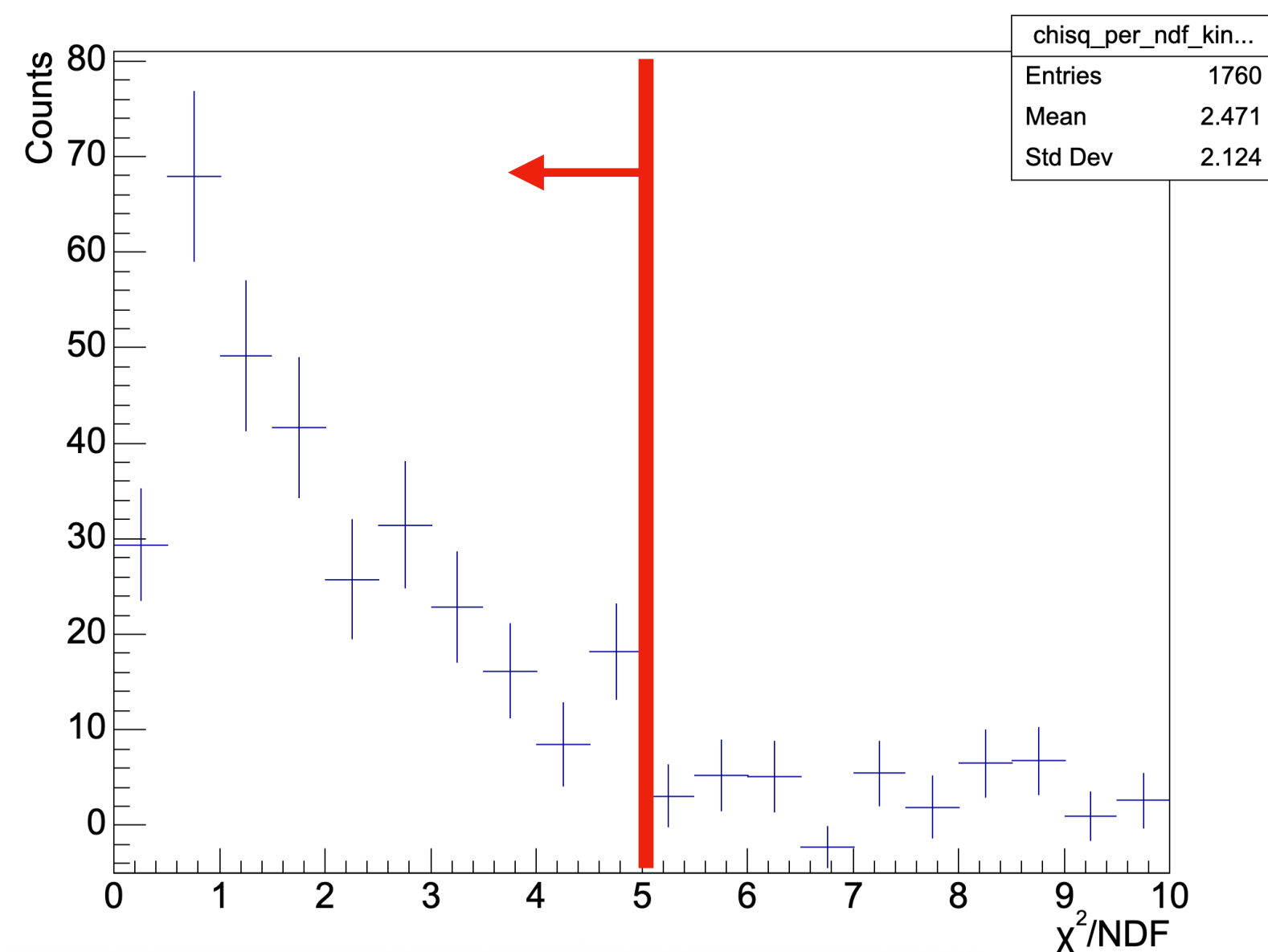
Event selection

- $\phi \rightarrow K^+ K^-$ decay channel with 48.9% branching ratio
- Kaon TOF cuts, photon energy cuts, fiducial cuts...
- Bin centering corrections applied

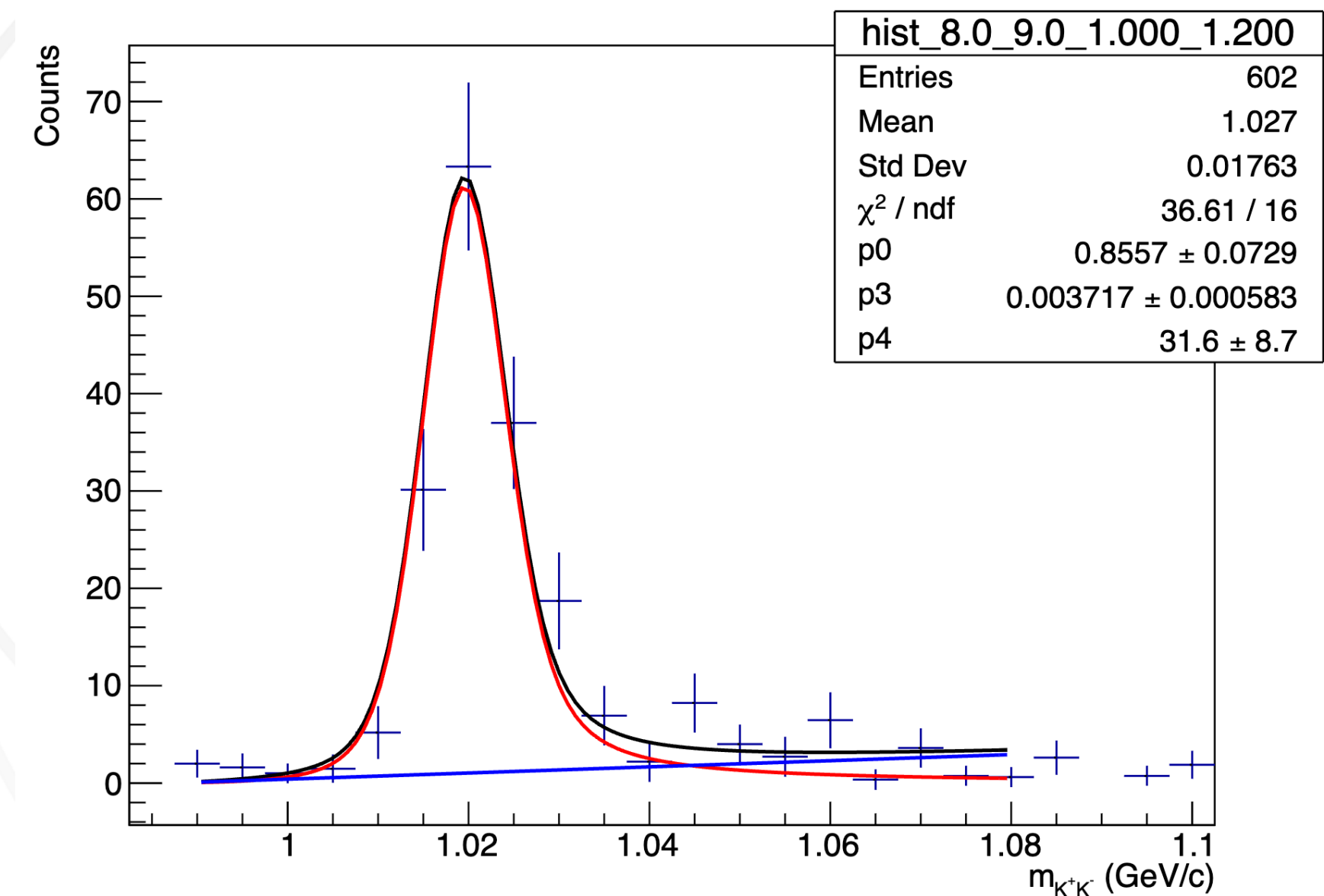
Deuteron energy loss in drift chamber



Kinematic fitting χ^2/NDF

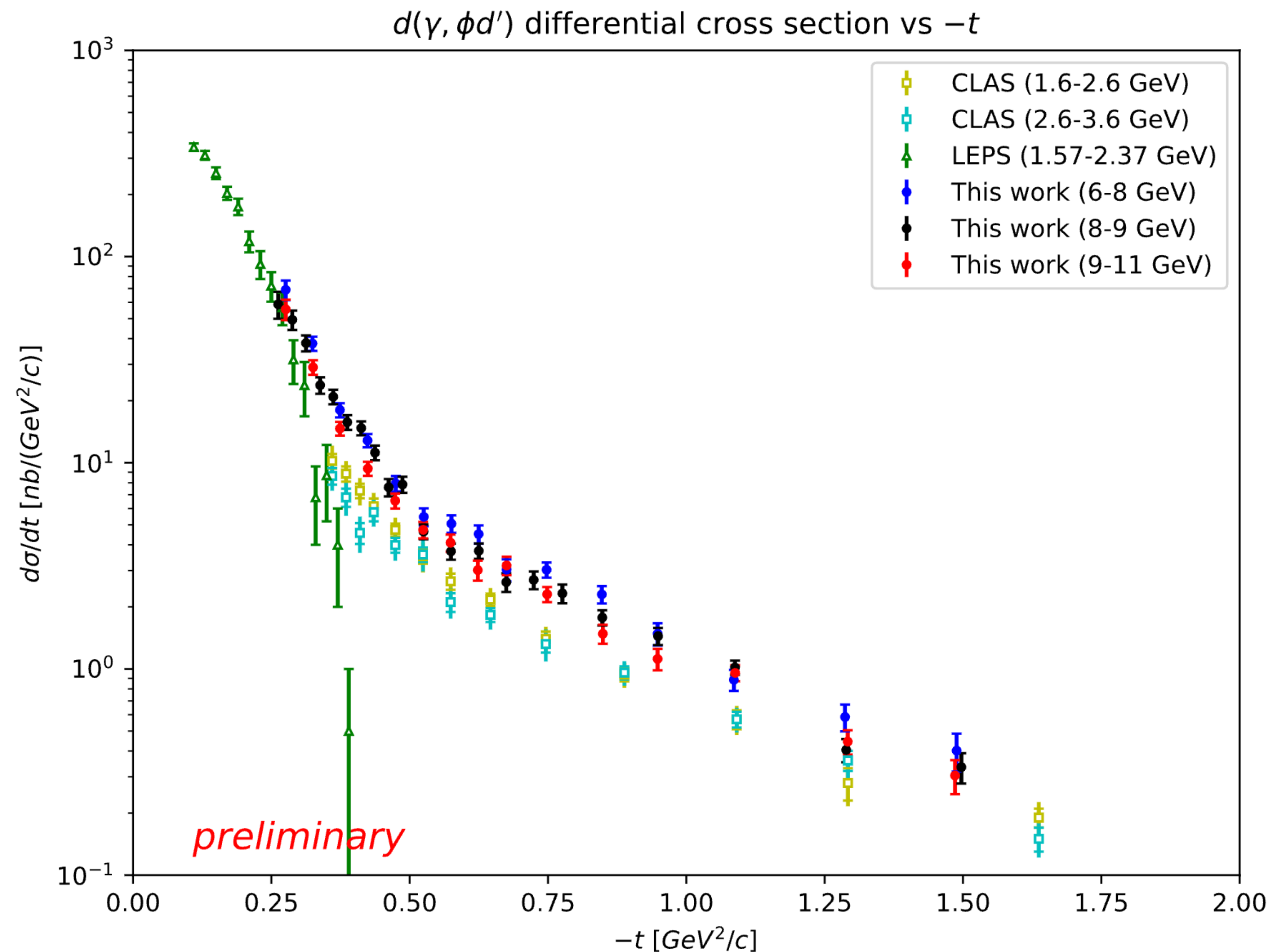


Yield extraction



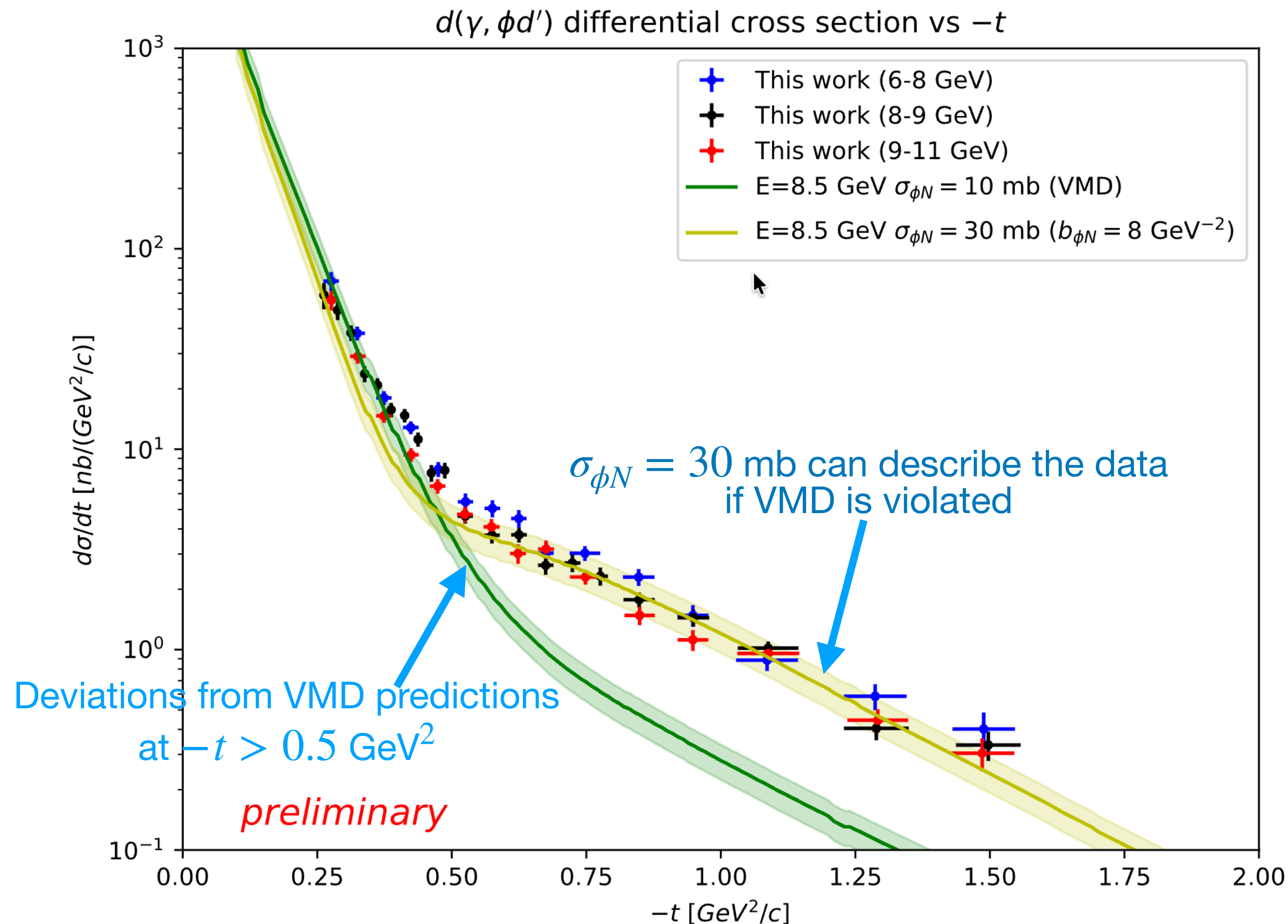
Differential cross sections

- Compare with world data (stats uncertainties only)



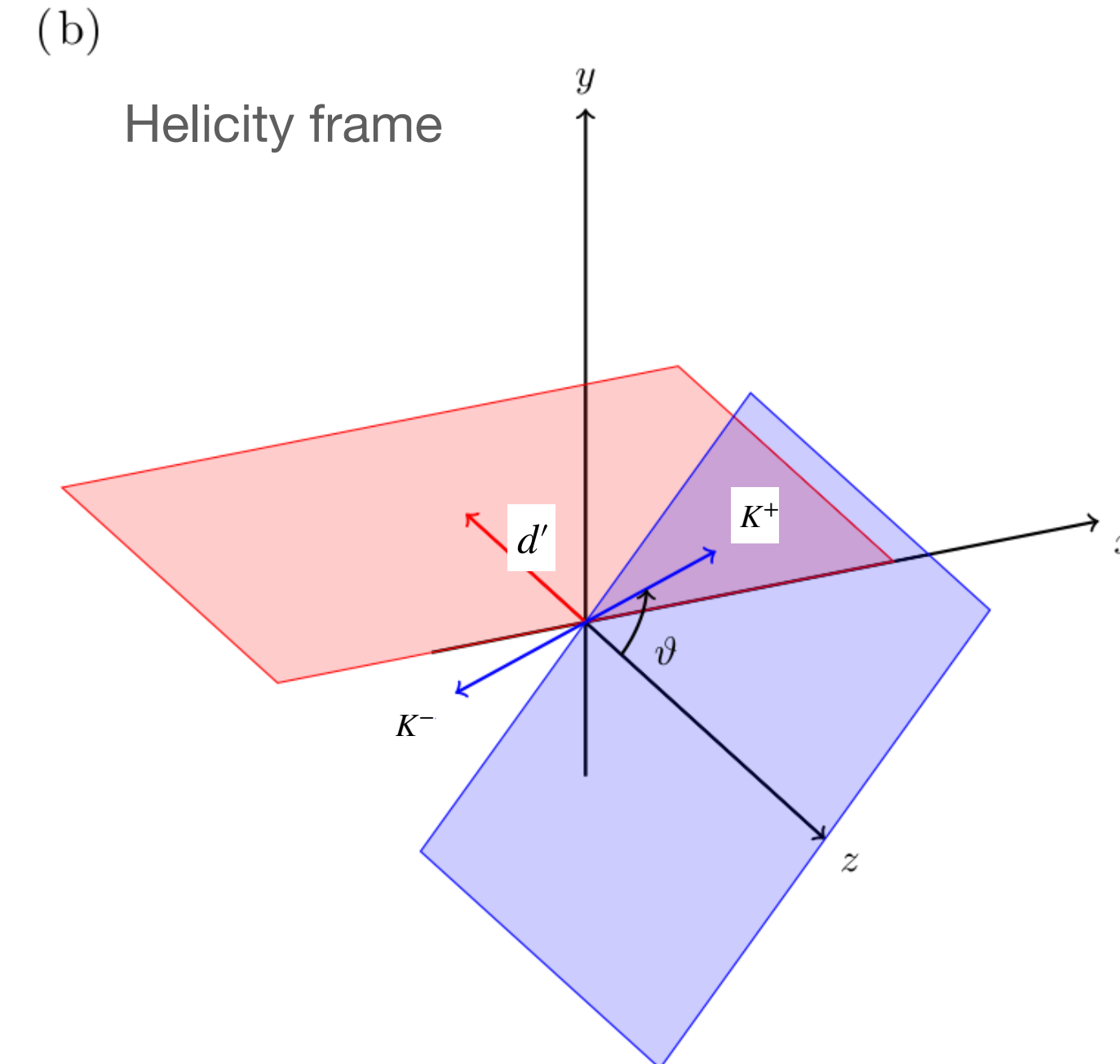
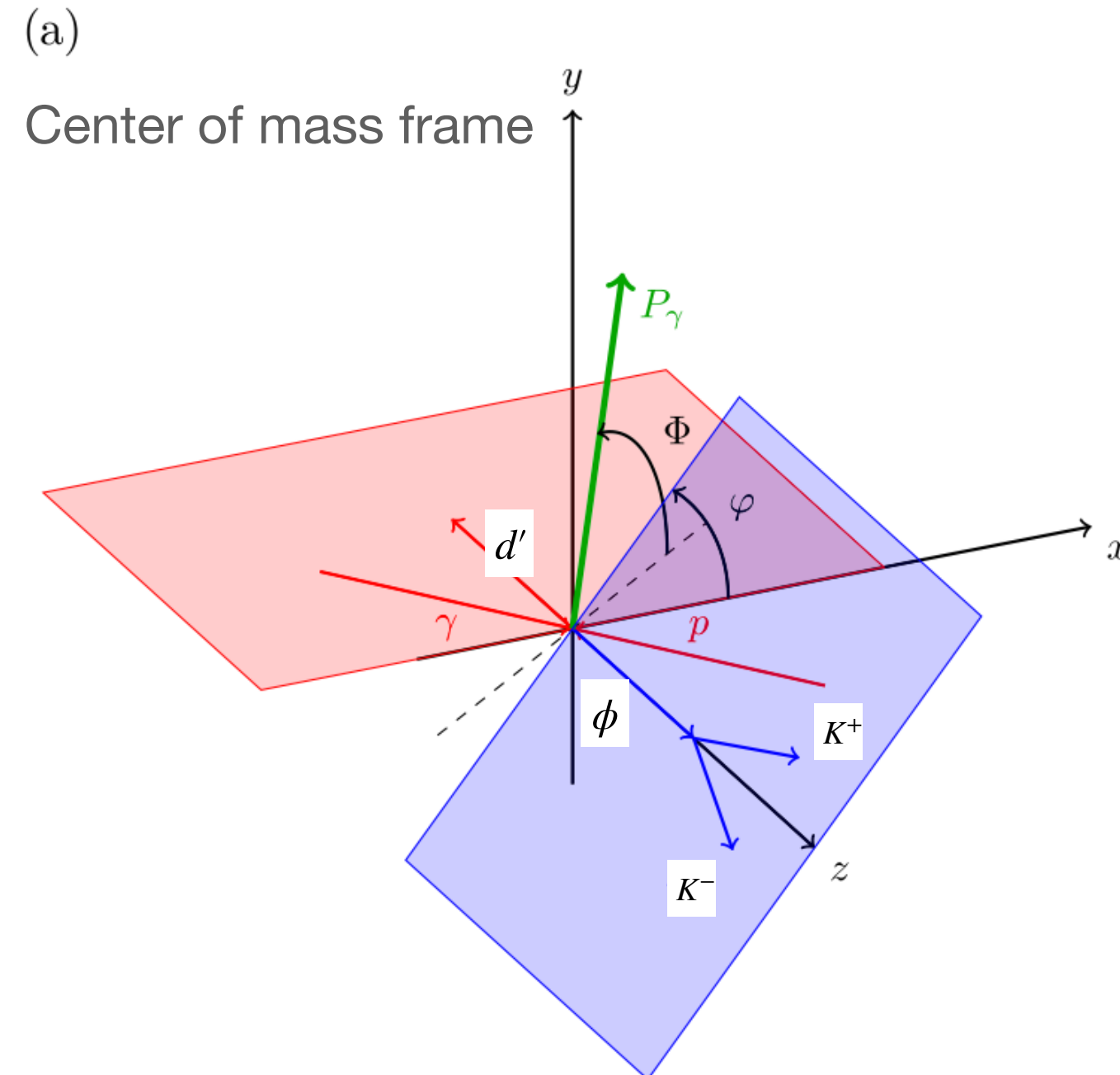
Differential cross sections

- Compare with calculations from theoretical models



Decay angular distributions

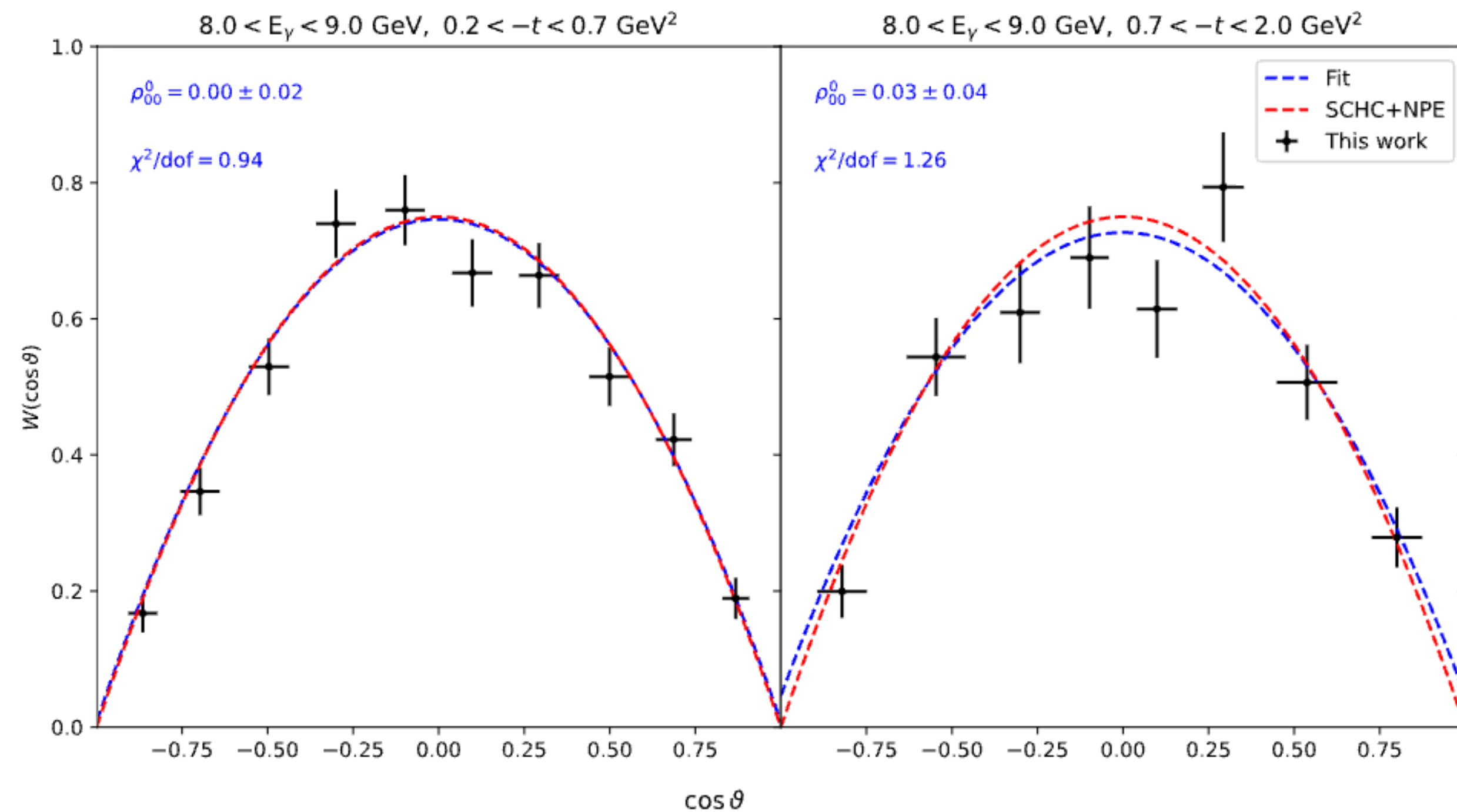
- Angular distributions of the K^+ , K^- in the helicity frame, $W(\cos \vartheta, \varphi, \Phi)$
- Parameterized by spin density matrix elements (SDME) ρ_{ij}^k
- s-channel helicity conservation (SCHC) predicts: $h_\phi = h_\gamma \rightarrow \rho_{11}^0 = \rho_{1-1}^1 = |\text{Im}\rho_{1-1}^2| = \frac{1}{2}$



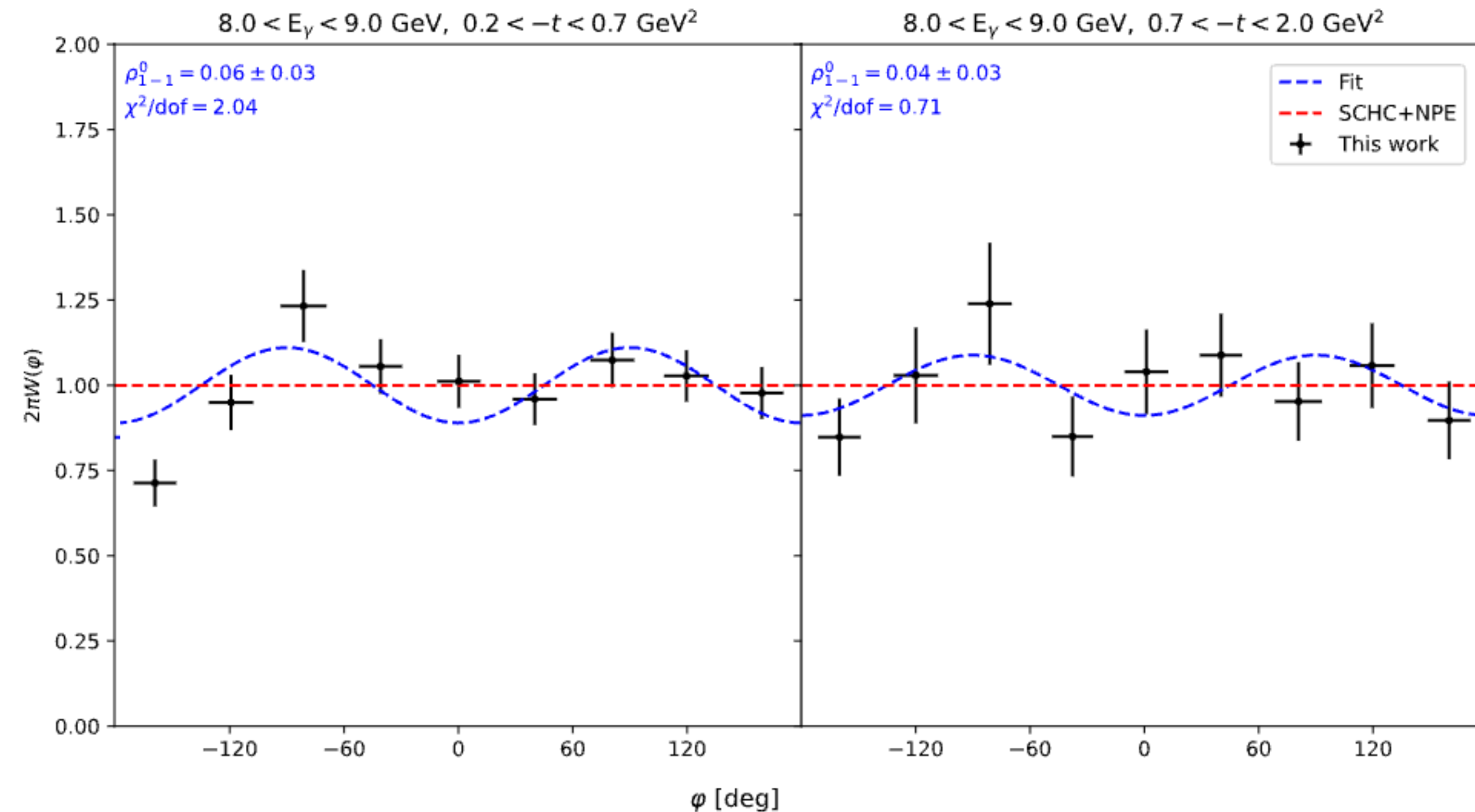
Decay angular distributions

- High degree of helicity conservation is observed for different E_γ and t

$$W(\cos \vartheta) = \frac{3}{4}[(3\rho_{00}^0 - 1)\cos^2 \vartheta + (1 - \rho_{00}^0)] \stackrel{\text{SCHC}}{=} \frac{3}{4}(1 - \cos^2 \vartheta)$$



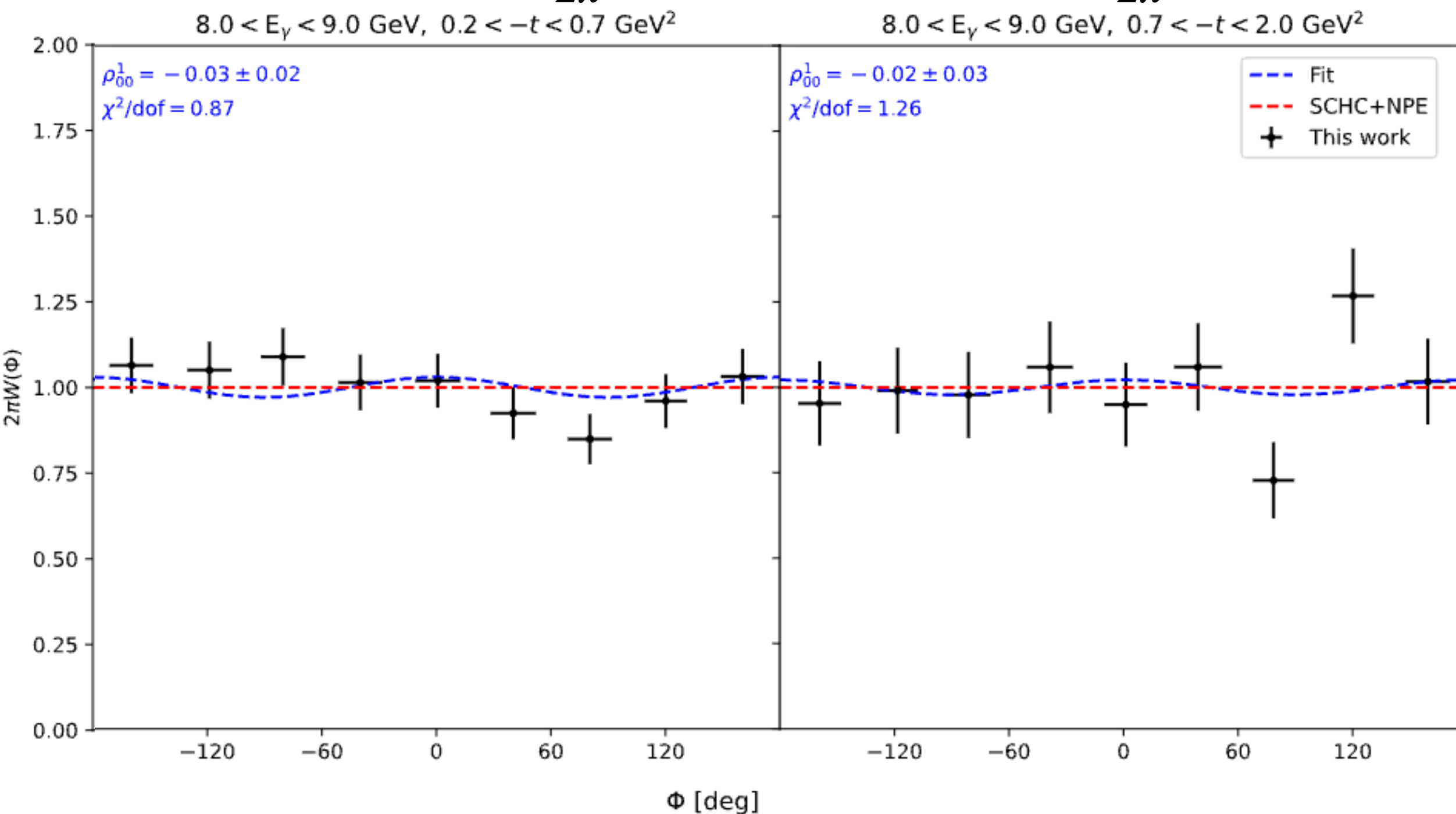
$$W(\varphi) = \frac{1}{2\pi}(1 - 2\rho_{1-1}^0 \cos 2\varphi) \stackrel{\text{SCHC}}{=} \frac{1}{2\pi}$$



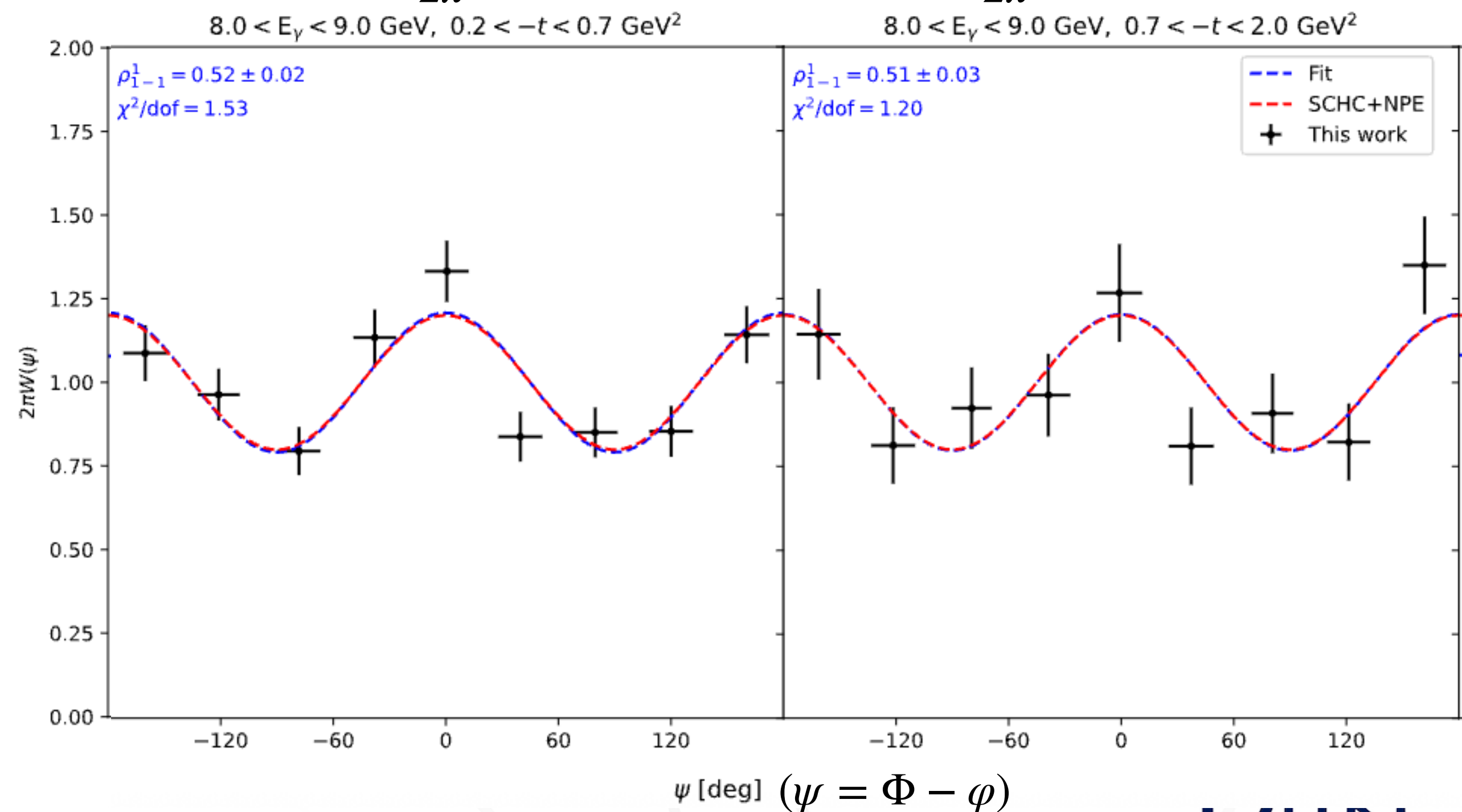
Decay angular distributions

- High degree of helicity conservation is observed for different E_γ and t

$$W(\Phi) = \frac{1}{2\pi}(1 - 3P_\gamma\rho_{00}^1 \cos 2\Phi) \stackrel{\text{SCHC}}{=} \frac{1}{2\pi}$$



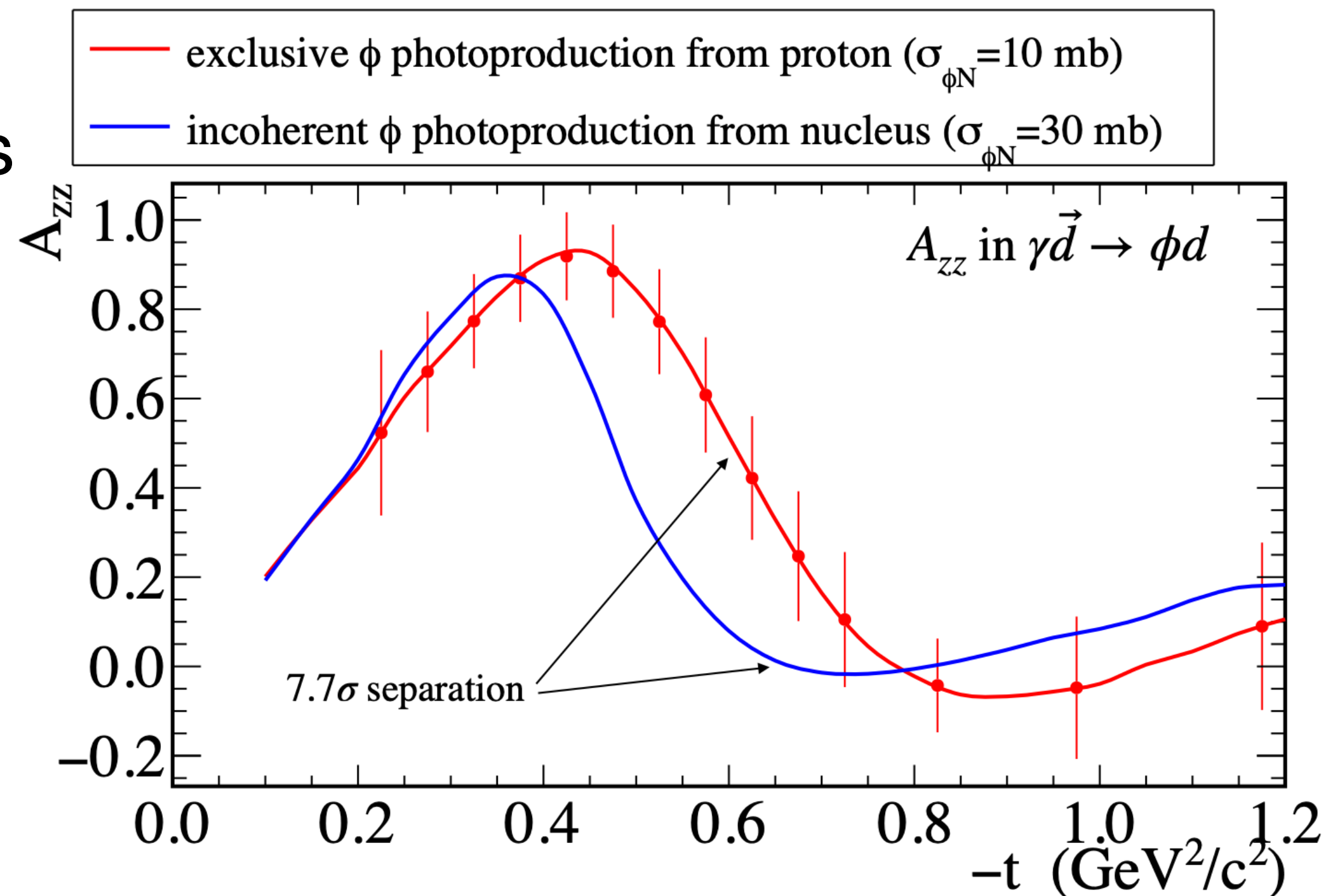
$$W(\psi) = \frac{1}{2\pi}(1 + 2P_\gamma\rho_{1-1}^1 \cos 2\psi) \stackrel{\text{SCHC}}{=} \frac{1}{2\pi}(1 + P_\gamma \cos 2\psi)$$



Latest development

- New GlueX proposal of $\gamma d \rightarrow \phi d$ with a tensor polarized deuterium target
- High precision extractions of $\sigma_{\phi N}$ with the additional target spin degree of freedom
- Approved to run 65 PAC days

$$A_{zz} = \frac{\sigma_1 + \sigma_{-1} - 2\sigma_0}{\sigma_1 + \sigma_{-1} + \sigma_0}$$



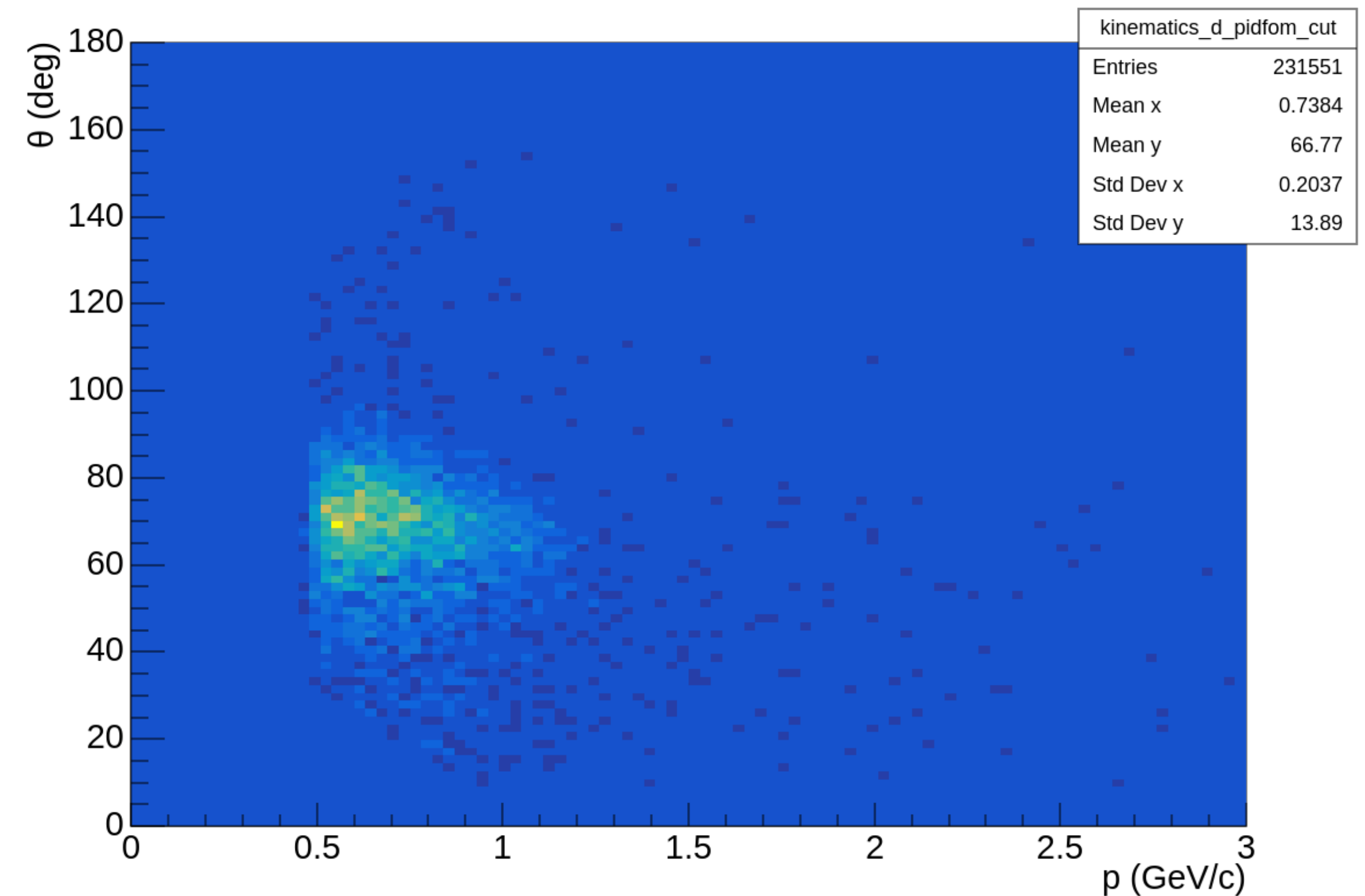
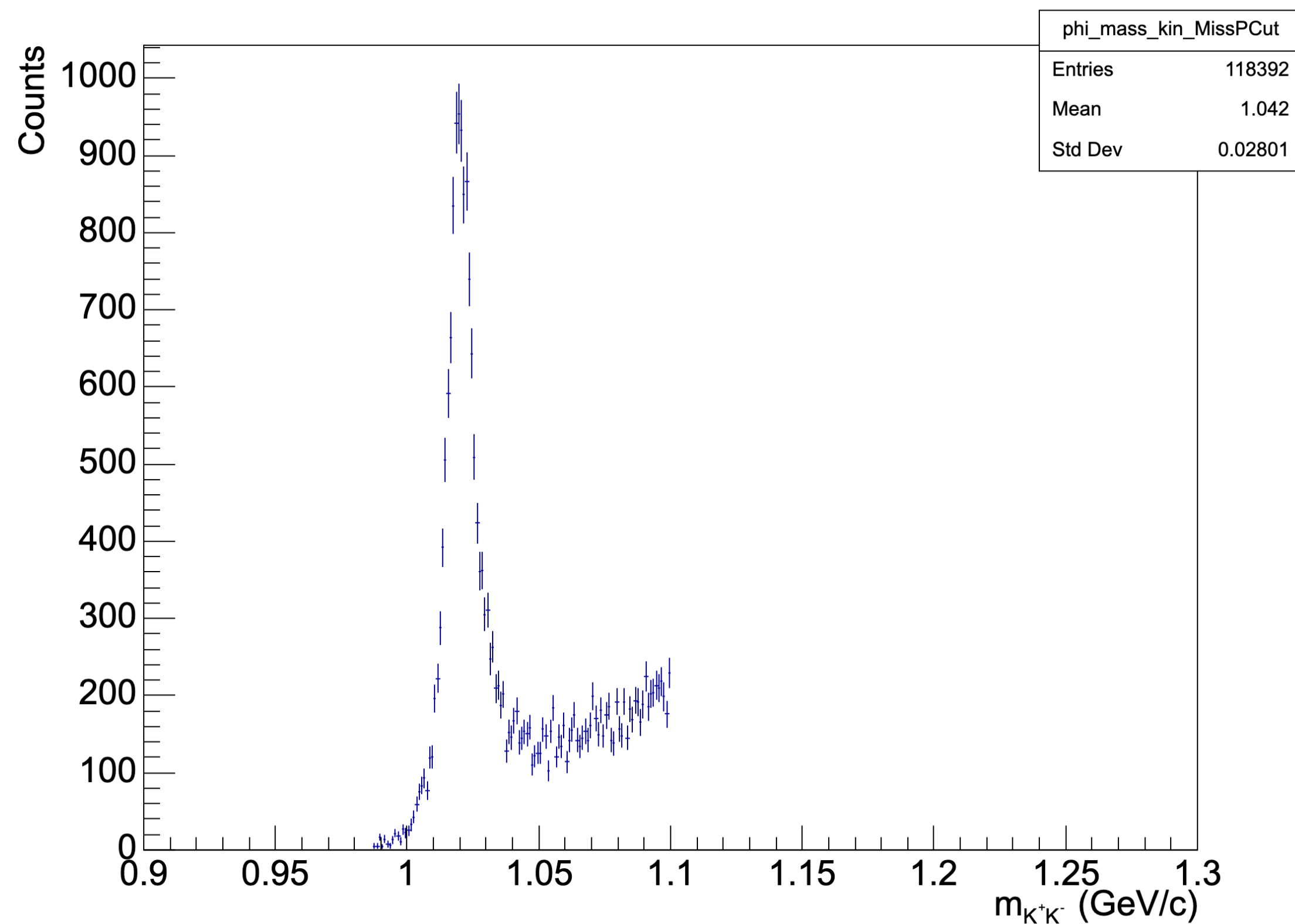
Summary

- ϕ meson is unique to study the gluon exchange at low energies and $\sigma_{\phi N}$ is an essential component for QCD inspired models
- $\sigma_{\phi N}$ can be extracted from ϕ photoproduction based on VMD, however, discrepancies are observed and not well understood
- Coherent ϕ photoproduction on deuterons offers great opportunities to study the $\phi - N$ interactions and the limits of VMD
- We presented new $\gamma d \rightarrow \phi d$ measurement with GlueX detector that opens new window to extract $\sigma_{\phi N}$
- Upcoming experiment with a tensor polarized deuterium target will measure $\sigma_{\phi N}$ with high precision

Backups

Outlook

- Deuteron knockout from helium and carbon target
- $\gamma A \rightarrow \phi d X$



Latest development

- D-wave of the deuteron can be isolated with tensor polarization
- Important tool to study SRC and CT
- Coherent ρ photoproduction offers the easiest measurement opportunity

