Incoherent photoproduction of π^0 and η from complex nuclei up to 12 GeV

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Outline:

- Physics motivation (chiral anomaly in QCD)
- Meson photoproduction from complex nuclei (the Primakoff approach)
- Calculation of the incoherent cross section: $\gamma + A \rightarrow \eta(\pi^0) + X$
- Results
  - Incoherent π^0 photoproduction in PrimEx
  - measured ratio $A_{eff} = \sigma_{\gamma A}/\sigma_{\gamma N}$ from Cornell
  - Incoherent π^0 and η photoproduction at 12 GeV
  - Incoherent η photoproduction in Cornell ($\eta \rightarrow \gamma\gamma$ decay width revisited)
- Conclusions and final remarks

➢Physics motivation (chiral anomaly in QCD)

Theoretical developments for the $\pi^0 \rightarrow \gamma\gamma$ decay amplitude

1. $\pi^0 \rightarrow \gamma\gamma$ decay proceeds primarily via the chiral anomaly in QCD:
(J. S. Bell and R. Jackiw, Nuovo Cimento 60A, 47 (1969); S. L. Adler, Phys. Rev. 177, 2426 (1969)

$$\Gamma_{\pi^0 \to \gamma\gamma} = \frac{\alpha^2 N_c^2 m_\pi^3}{576\pi^3 F_\pi^2} = 7.725 \pm 0.044\,\mathbf{eV}$$

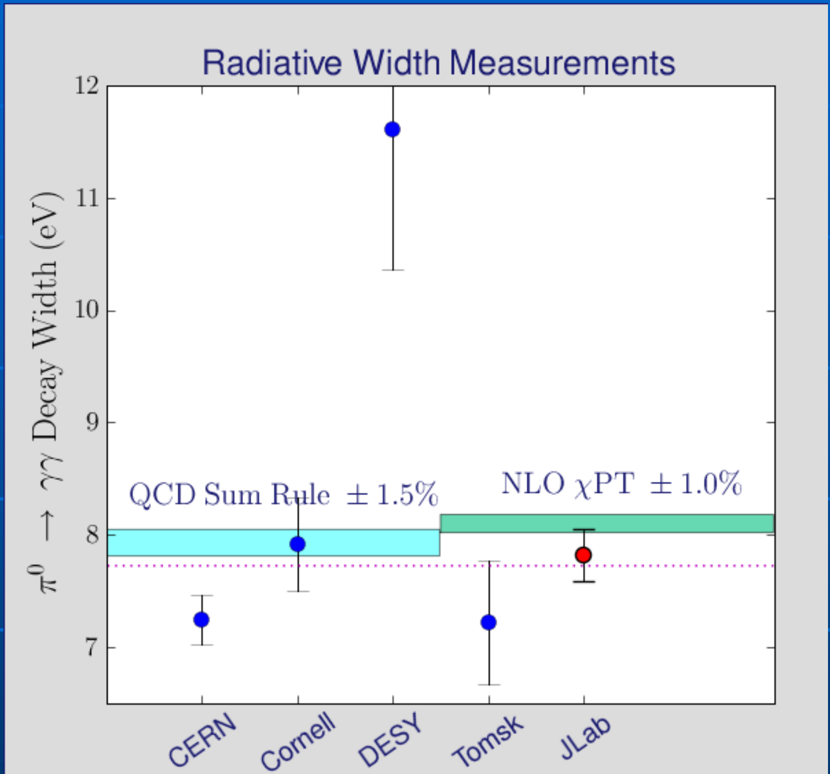
2. Recent calculations beyond the chiral anomaly

- ✓ NLO ChPT and $1/N_c$ expansion to $O(p^6)$
  $\Gamma_{\pi^0 \rightarrow \gamma\gamma} = 8.10\ \mathrm{eV} \pm 1.0\%$ [J. L. Goity *et al.*, Phys. Rev. D66, 076014 (2002)]
- ✓ NNLO two flavor ChPT
  $\Gamma_{\pi^0 \rightarrow \gamma\gamma} = 8.06\ \mathrm{eV} \pm 1.0\%$ [B. Ananthanarayan and B. Moussallam, JHEP 0205, 052 (2002)]
  $\Gamma_{\pi^0 \rightarrow \gamma\gamma} = 8.09\ \mathrm{eV} \pm 1.4\%$ [K. Kampf and B. Moussallam, Phys. Rev. D 79, 076005 (2009)]
- ✓ QCD sum rule (include π^0–η mixing)
  $\Gamma_{\pi^0 \rightarrow \gamma\gamma} = 7.93\ \mathrm{eV} \pm 1.5\%$ [B. L. Ioffe *et al.*, Phys. Lett. B647, 389 (2007)]

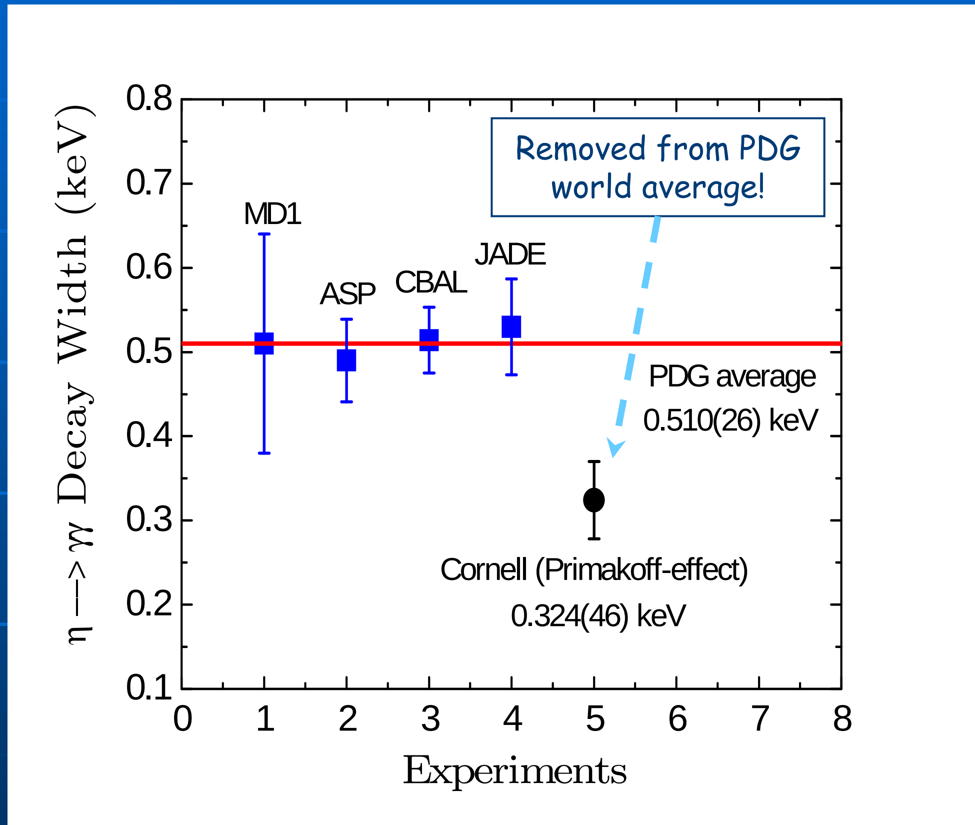
To obtain $\Gamma_{\pi^0 \rightarrow \gamma\gamma}$ beyond the chiral anomaly we need $\Gamma_{\eta \rightarrow \gamma\gamma}$

➢Physics motivation (chiral anomaly in QCD)

Experimental scenario for $\Gamma(\pi^0 \rightarrow \gamma\gamma)$ and $\Gamma(\eta \rightarrow \gamma\gamma)$



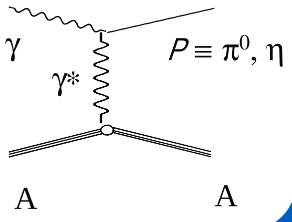
A. Gasparian, EINN 2009



Precision measurements of $\Gamma_{\pi^0 \rightarrow \gamma\gamma}$ and $\Gamma_{\eta \rightarrow \gamma\gamma}$ represent stringent tests of fundamental quantities in QCD

➢Meson photoproduction from complex nuclei (the Primakoff method)

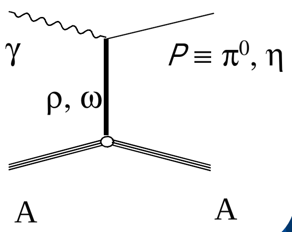
Primakoff



$$|T_P|^2 = \Gamma_{P\to\gamma\gamma} \frac{8\pi\alpha Z^2}{m_P^3} \frac{\beta^3 k^4}{Q^4} \left|\tilde{F}_{em}(Q)\right|^2 \sin^2\theta$$

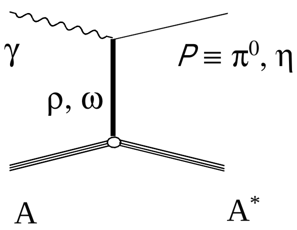
$$\frac{d\sigma}{d\Omega} = \left|T_P + e^{i\varphi} T_{NC}\right|^2 + \left|T_{NI}\right|^2$$

Nuclear Coherent



$$|T_{NC}|^2 = A^2 \left|\tilde{F}_N(Q)\right|^2 L^2 \sin^2\theta$$

Nuclear Incoherent



$$|T_{NI}|^2 = A_{eff}\, f(Q) |T_n|^2$$

➢ Calculation of the incoherent cross section: $\gamma + A \longrightarrow \eta(\pi^0) + X$

Main features included in the MCMC intranuclear cascade model:

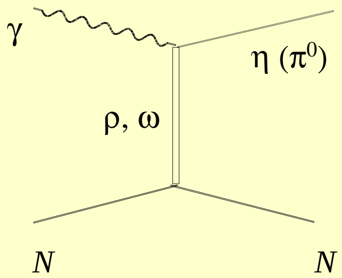
- ✓ Relativistic and time-dependent multicollisional algorithm [(1)–(6)];
- ✓ The elementary mechanism ($\gamma + N \longrightarrow \eta(\pi^0) + N$) in terms of a Regge model [(3),(4),(6)];
- ✓ Realistic MD for light nuclei [(*e,e´p*) knock-out reactions] [(6)];
- ✓ Non-stochastic Pauli-blocking in a multiple scattering scenario [(2)–(6)];
- ✓ Photon shadowing effects via a VMD model [(6)];
- ✓ Realistic angular distributions for the elastic scattering $\eta(\pi^0) + N \longrightarrow \eta(\pi^0) + N$ [(6)];
- ✓ Multiple meson production during secondary scatterings [(3),(4),(6)].

(1) M. G. Gonçalves *et al.*, Phys. Lett. B 406, 1 (1997).
(2) T. E. Rodrigues *et al.*, Phys. Rev. C 69, 064611 (2004).
(3) T. E. Rodrigues *et al.*, Phys. Rev. C 71, 051603(R) (2005).
(4) T. E. Rodrigues *et al.*, Braz. J. of Phys. 36, 1366 (2006).
(5) T. E. Rodrigues *et al.*, Phys. Rev. C 75, 014605 (2007).
(6) T. E. Rodrigues *et al.*, Phys. Rev. Lett. 101, 012301 (2008).

- Calculation of the incoherent cross section: $\gamma + A \to \eta(\pi^0) + X$

The elementary meson photoproduction: $\gamma + N \to \eta(\pi^0) + N$

The cascade "trigger"



$$\gamma(k) + N(p_1) \rightarrow P(p) + N(p_2)$$

$$s = (k + p_1)^2$$

$$t = (k - p)^2$$

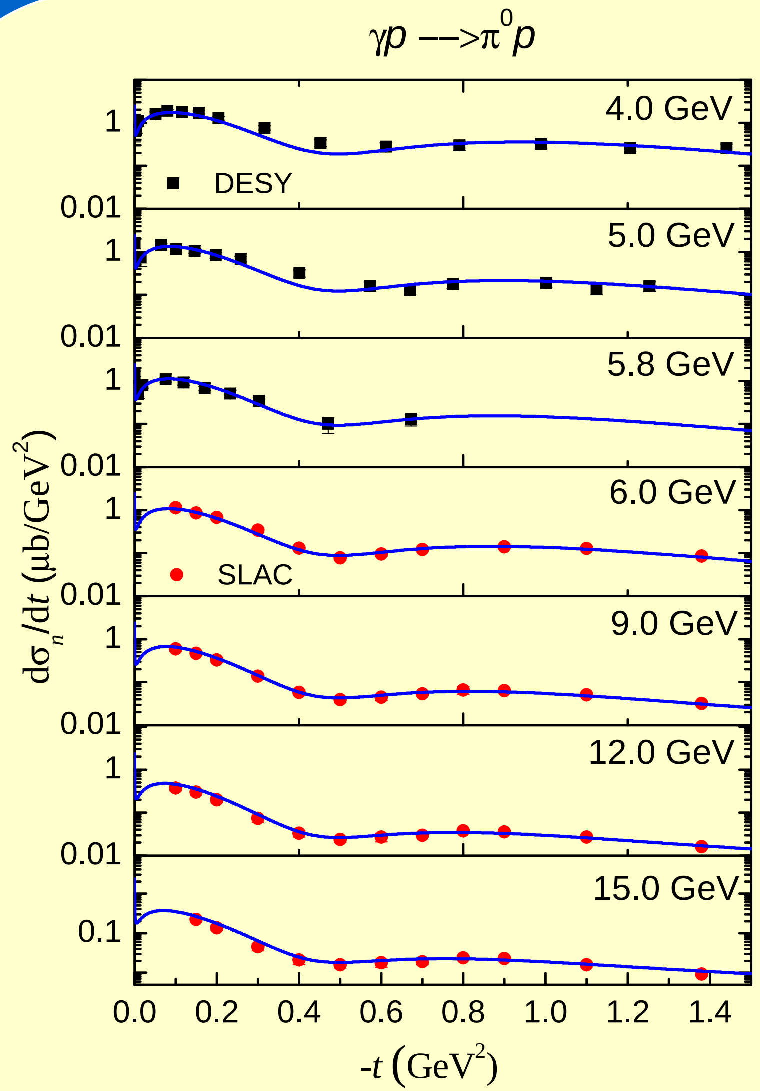
Cross section expanded in t-channel helicity amplitudes* (F_i)

$$\frac{d\sigma_N}{dt} \cong \frac{1}{32\pi}\left\{ F_2^2 + \frac{F_3^2}{4m_N^2} - \left[t + \left(\frac{\mu^2}{2k}\right)^2 \right]\left(F_4^2 + \frac{F_1^2}{4m_N^2} + \frac{F_3^2}{16m_N^4} + \frac{F_1 F_3}{2m_N p\sqrt{s}} \right) \right\}$$

$F_i \rightarrow$ Calculated using a Regge model (ρ and ω exhange) plus Reggeon cuts**

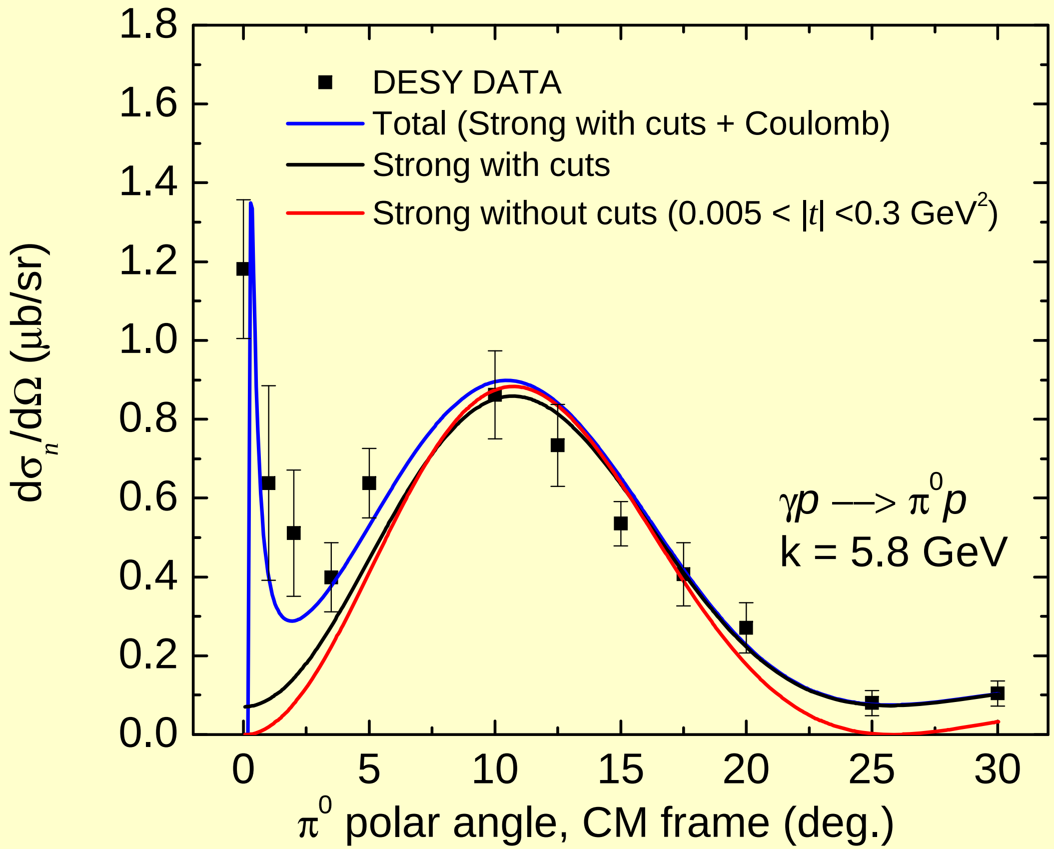
(*) A. Gasparian and S. Gevorkyan, *Theoretical part of PrimEx*, 2004.
(**) M. Braunschweig *et al.*, Nucl. Phys. B 20, 191 (1970).

➢The elementary mechanism: $\gamma + N \longrightarrow \pi^0 + N$

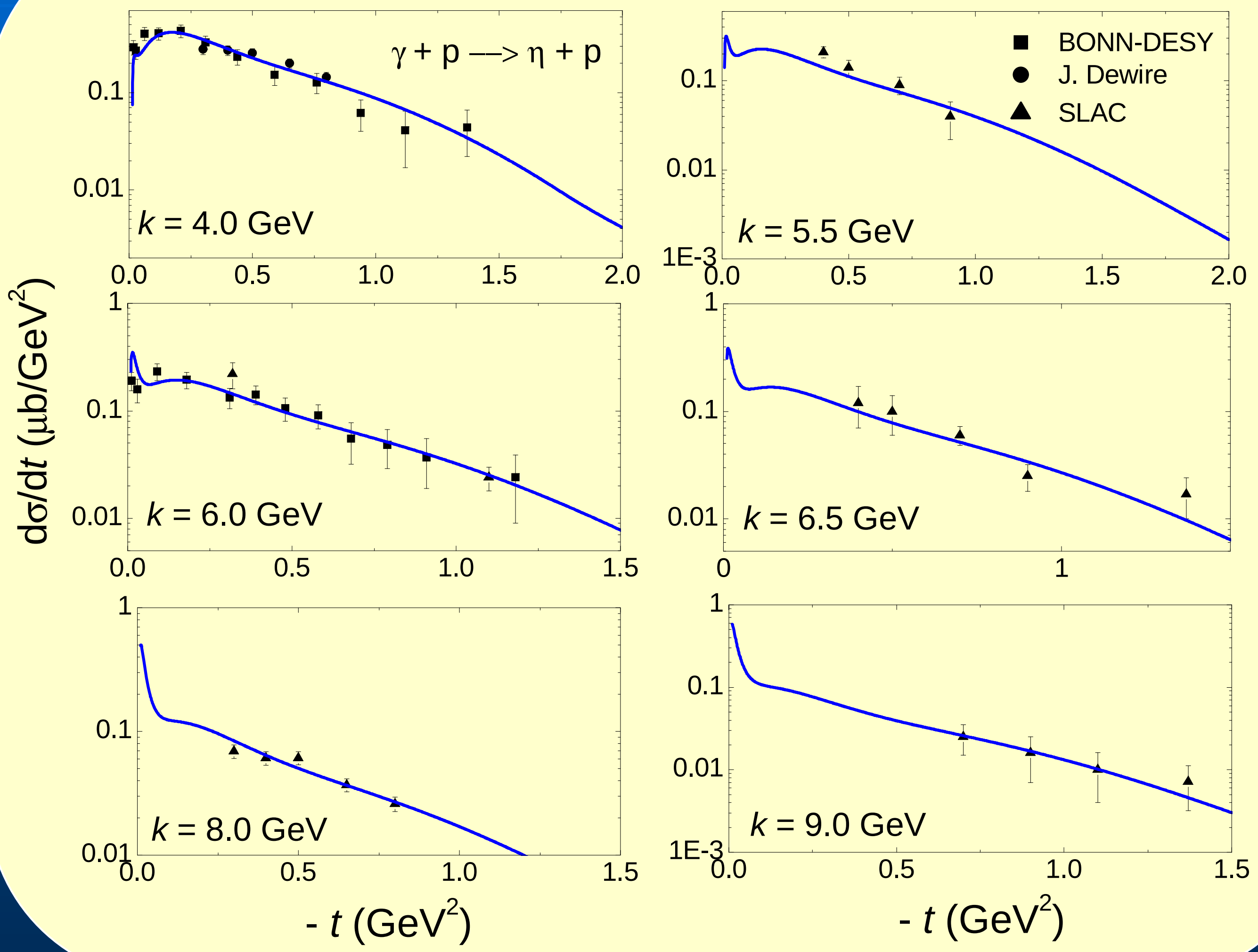


➢ The elementary mechanism: $\gamma + N \longrightarrow \pi^0 + N$

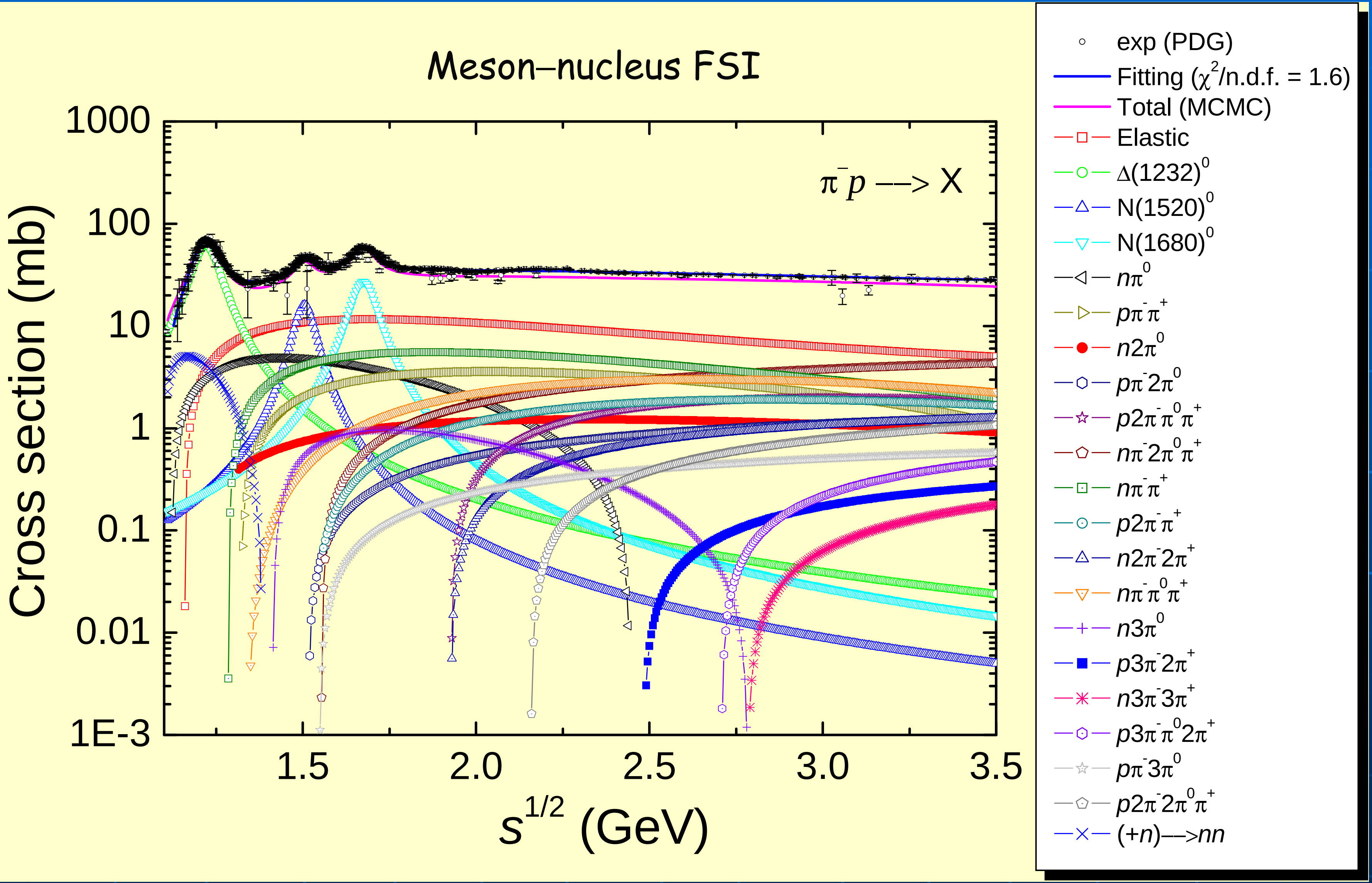
Contribution of the Reggeon cuts and the Coulomb amplitude



➢ The elementary mechanism: $\gamma + N \longrightarrow \eta + N$



➢ Calculation of the incoherent cross section: $\gamma + A \longrightarrow \eta(\pi^0) + X$



➢ Results: Incoherent π^0 photoproduction in PrimEx

Motivation:

To deliver a sophisticated calculation for incoherent π^0 photoproduction in PrimEx.

Kinematics and main features:

✓ Photon energy: 5.2 GeV
✓ pion elasticity: [0.92 – 1]
✓ angular range: [0 – 6] deg
✓ targets: C and Pb
✓ elementary photoproduction
✓ Pauli-blocking
✓ photon shadowing
✓ π^0 – nucleus FSI
✓ $\pi^0 N$ —> $\pi^0 N$ elastic channel
✓ single and double differential cross sections

The PrimEx Collaboration

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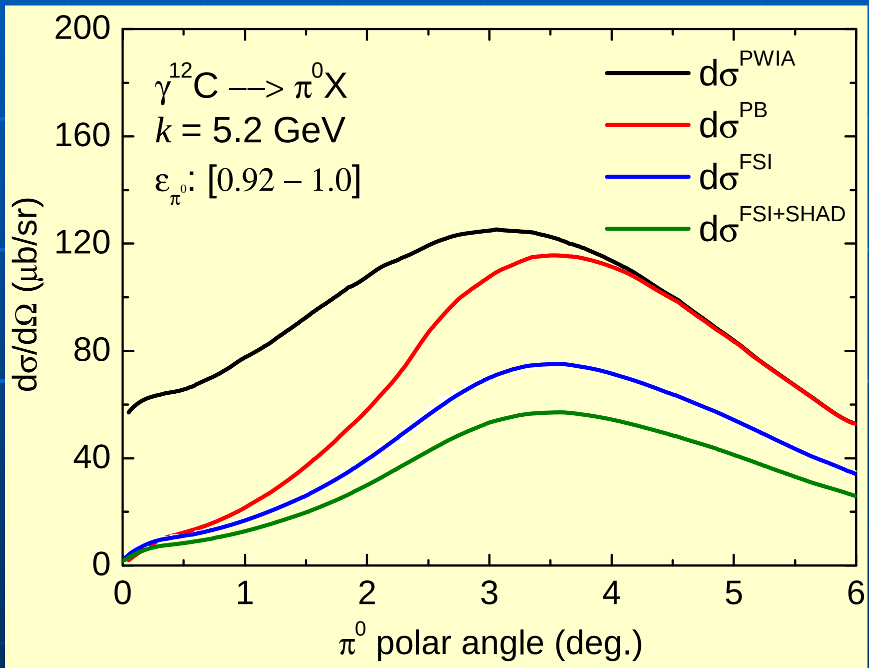
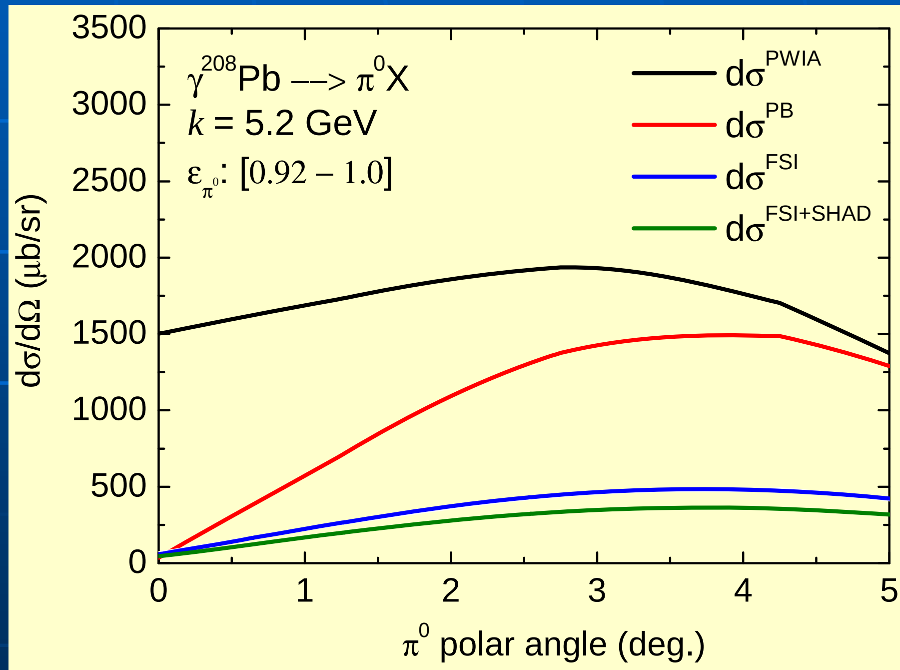
(a) Alikhanov Institute for Theoretical and Experimental Physics, (b) Arizona State University, (c) Catholic University of America, (d) Joint Institute for Nuclear Research, Dubna, (e) Hampton University, (f) Idaho State University, (g) Jefferson Lab, (h) University of Kentucky, (i) Kharkov Institute of Physics and Technology, (j) University of Massachusetts, (k) Massachusetts Institute of Technology, (l) Norfolk State University, (m) North Carolina A&T, (n) University of North Carolina, Wilmington, (o) Northwestern University, (p) Pacific Northwest National Laboratory, (q) Institute for High Energy Physics, Protvino, (r) University of São Paulo, (s) University of Virginia

➢ Results: Incoherent π^0 photoproduction in PrimEx

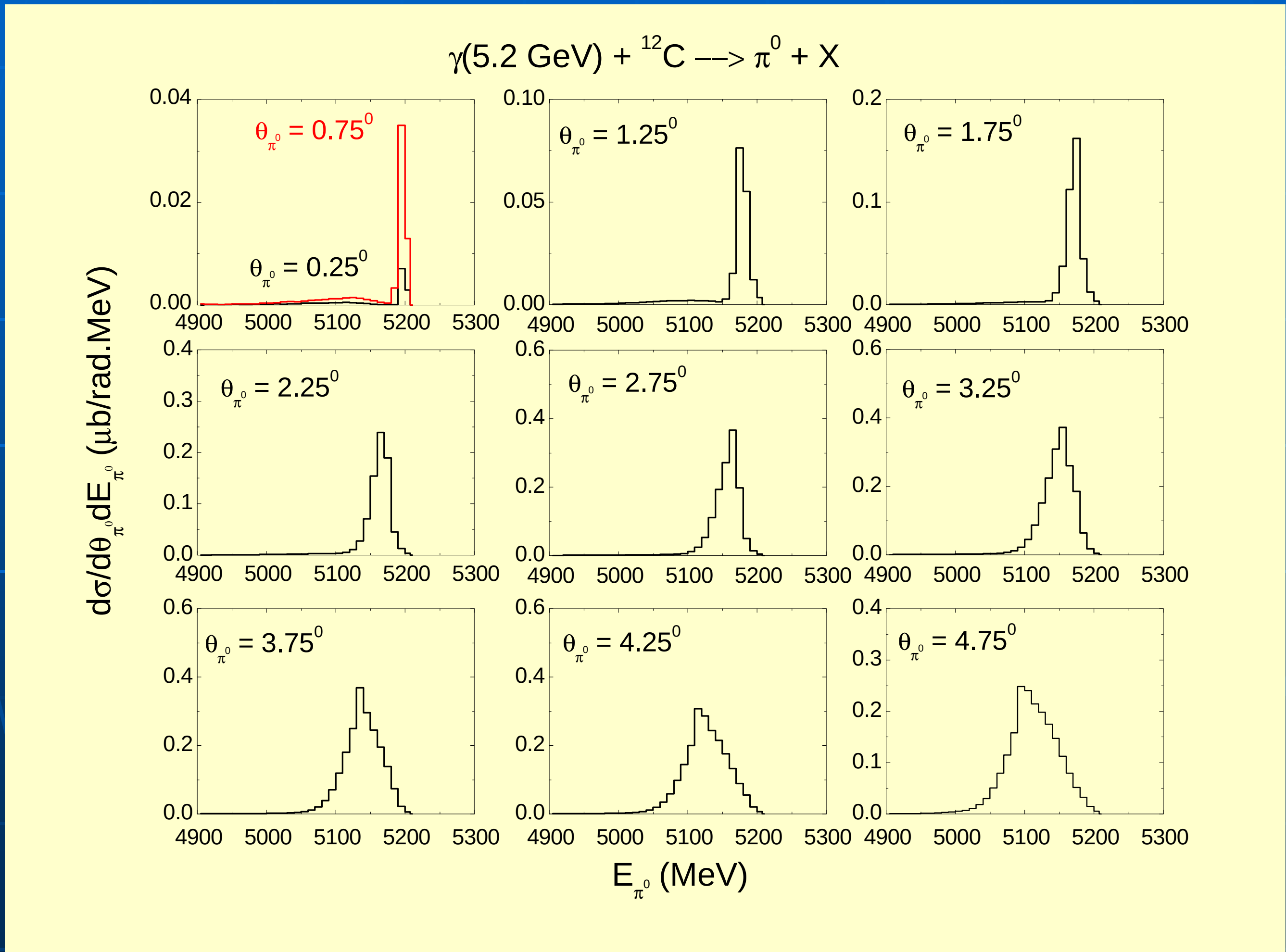
MCMC model calculations for the angular distribution of "quasi-elastic" π^0` s





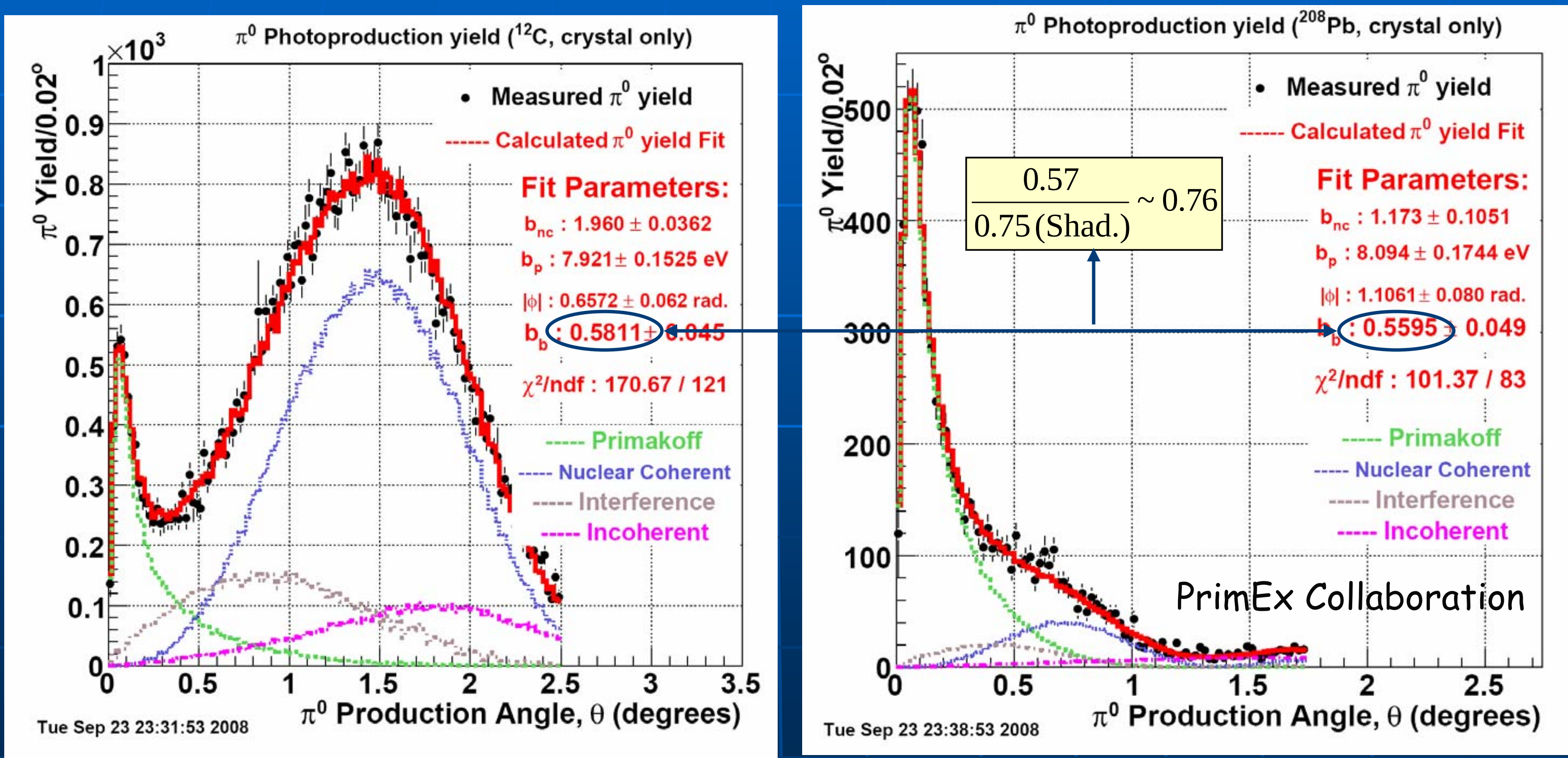
➢ Results: Incoherent π^0 photoproduction in PrimEx

MCMC model calculations for the double differential cross section



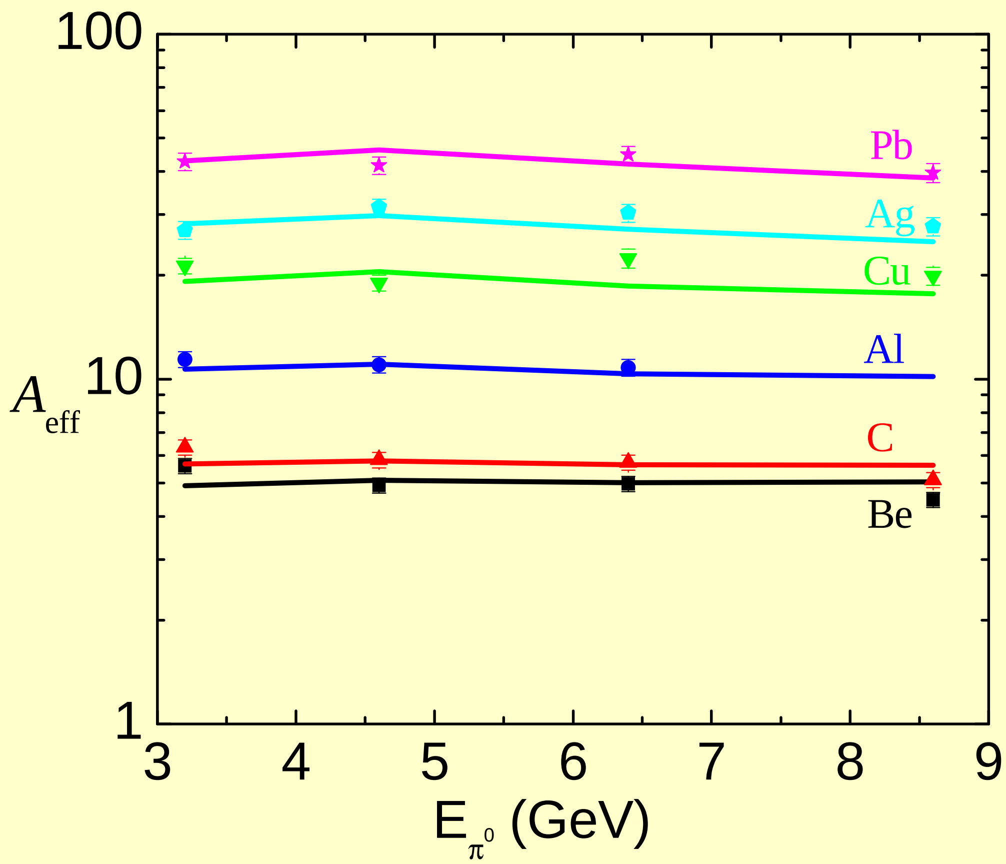
➢ Results: Incoherent π^0 photoproduction in PrimEx

Results from PrimEx experiment
(MIT/JLab analysis – plots from Dustin McNulty)



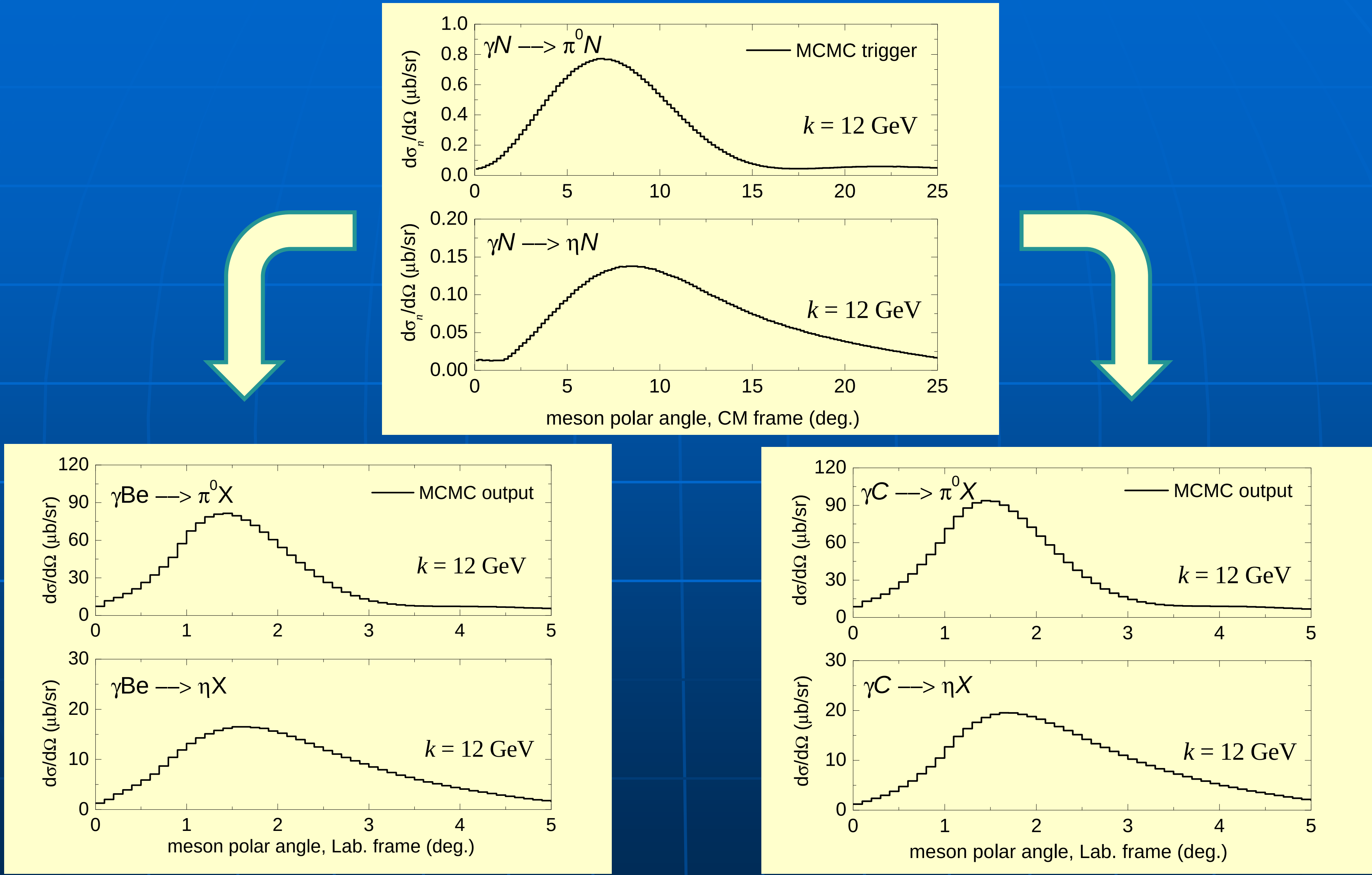
➢ Results: measured ratio $A_{eff} = \sigma_{\gamma A}/\sigma_{\gamma N}$ from Cornell

MCMC model calculations (solid lines) versus Cornell`s data*



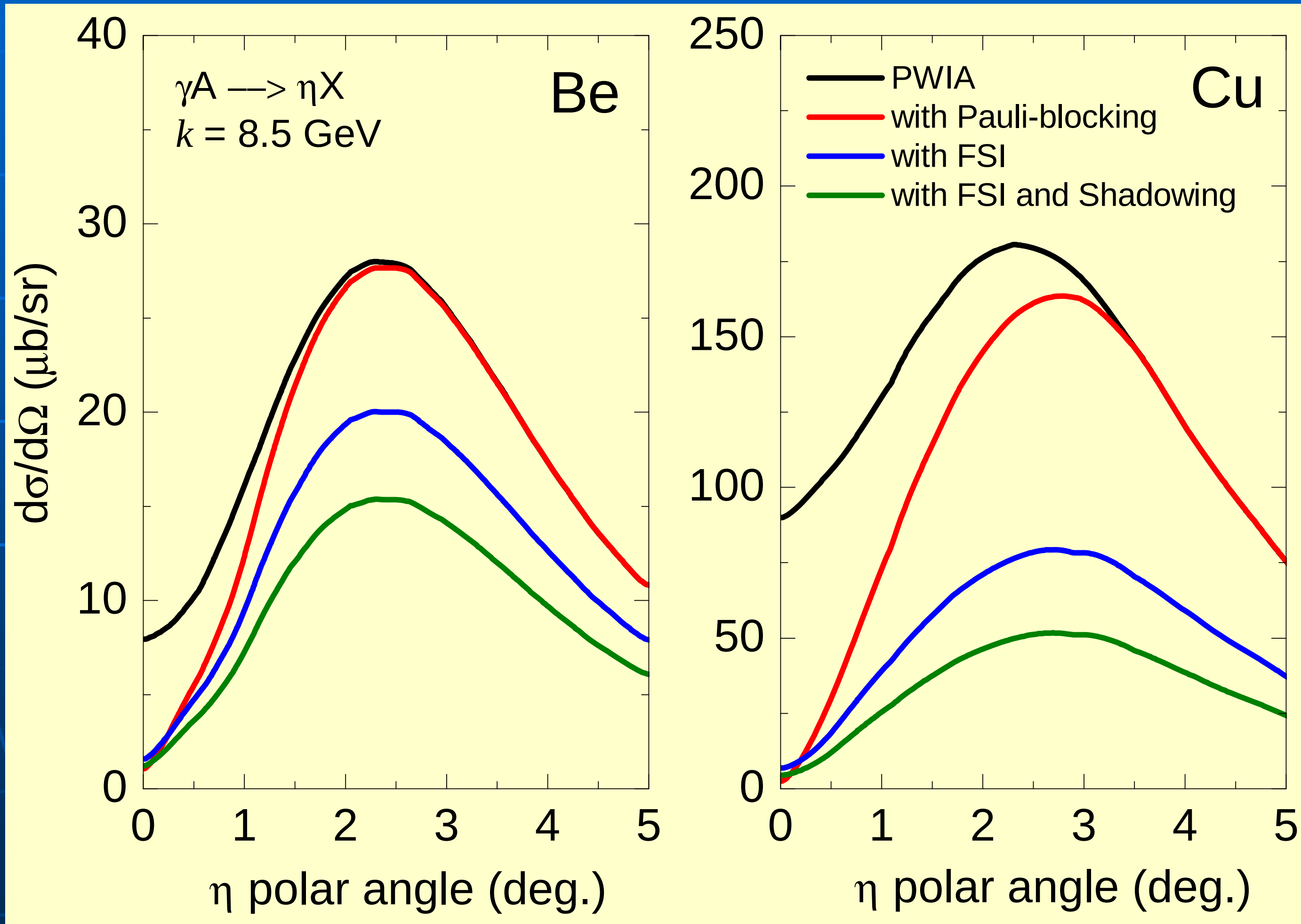
* W. T. Meyer et al., Phys. Rev. Lett. 28, 1344 (1972).

➢ Results: Incoherent π^0 and η photoproduction at 12 GeV



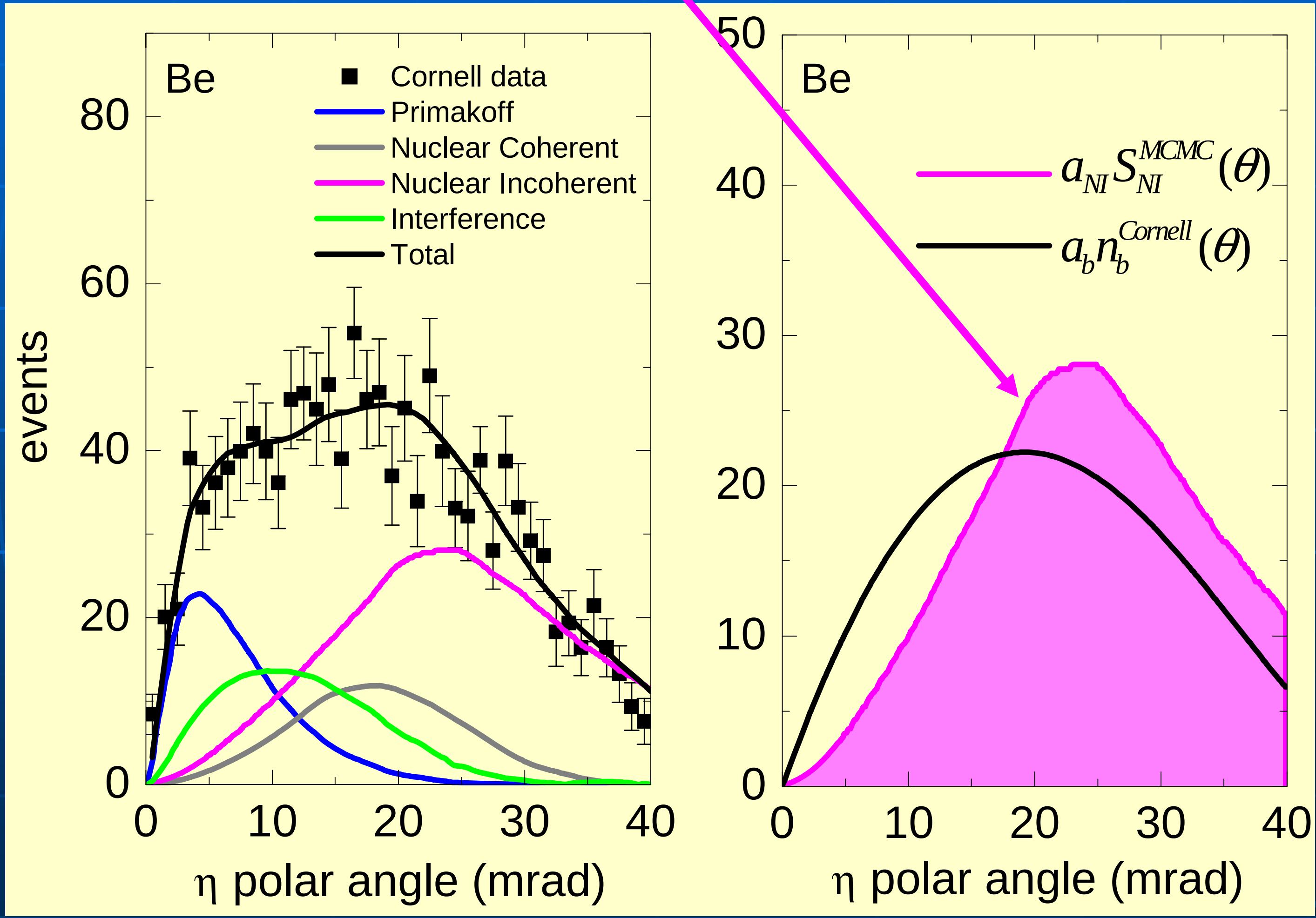
➢ Incoherent η photoproduction in Cornell
(η —> γγ decay width revisited)

MCMC model calculations for the angular distributions

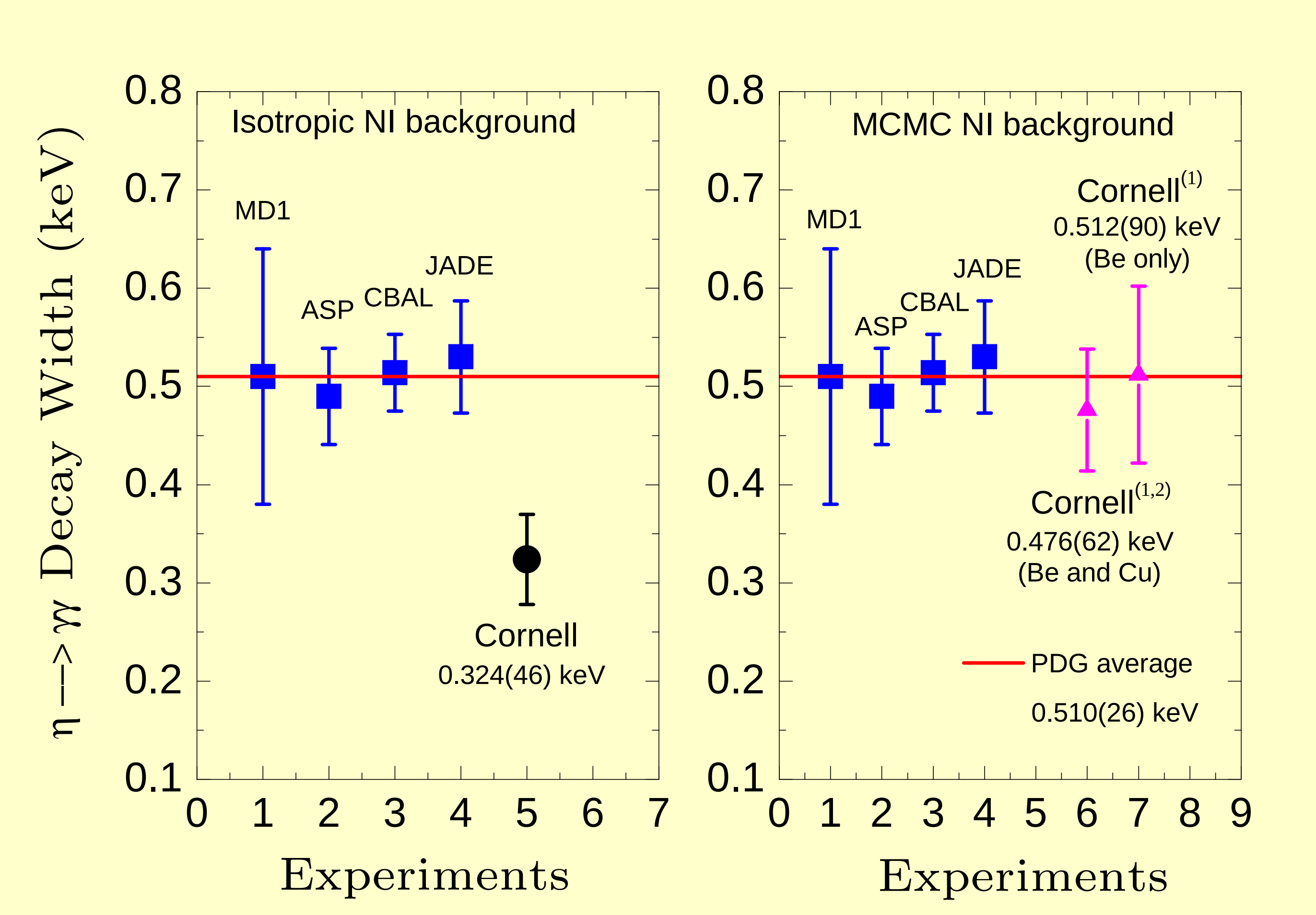


➢ Incoherent η photoproduction in Cornell (η ––> γγ decay width revisited)

$$n(\theta) = a_P S_P(\theta) + a_{NC} S_{NC}(\theta) + a_{NI} S_{NI}(\theta) + 2\sqrt{a_P a_{NC}}\,\mathbf{cos}(\phi)\sqrt{S_P(\theta) S_{NC}(\theta)}$$



➢ Incoherent η photoproduction in Cornell (η —> γγ decay width revisited)



(1) The error bars represent the statistical errors from the fits
(2) T. E. Rodrigues *et al.*, Phys. Rev. Lett. 101, 012301 (2008)

➢Conclusions and final remarks

✓ The MCMC model is a nice framework to address the nuclear matter effects within wide ranges of target masses and incident energies (4 to 12 GeV).

✓ The calculations for incoherent π^0 photoproduction fit the PrimEx data at larger angles both for Carbon (χ^2/n.d.f ~1.4) and Lead (χ^2/n.d.f ~1.2). The fitted parameters are mutually consistent and reasonably close to unit (~ 0.76).

✓ The calculations reproduced with good accuracy both the measured ratio A_{eff} and the inelastic background in Cornell's experiments of π^0 and η photoproduction from complex nuclei, respectively.

✓ The MCMC calculations for incoherent π^0 photoproduction show that the proton data (DESY/SLAC) and the complex nuclei data from Cornell (Be, C, Al, Cu, Ag and Pb) are mutually consistent.

➢Conclusions and final remarks

✓The result for the $\eta \longrightarrow \gamma\gamma$ decay width obtained [0.476(62) keV] is consistent with the PDG average [0.510(26) keV] and approximately 50% higher than the previous value from Cornell [0.324(46) keV]. On the other hand, the result is not supposed to supersede Cornell's result for the following reasons:

1. The uncertainty of the decay width does not include the systematic errors and represents a lower limit of the analysis;
2. We analyzed only a fraction of Cornell's data (Be and Cu at 9 GeV) not all the data.

✓The Monte Carlo method represents an important tool to delineate the NI cross section in future experiments to measure the radiative decay width of pseudo scalar mesons via the Primakoff effect.

✓A high precision Primakoff-type experiment to determine the $\eta \longrightarrow \gamma\gamma$ decay width and the proton amplitude with better accuracy is highly recommended with the 12 GeV upgrade at Jlab.

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Thank you!