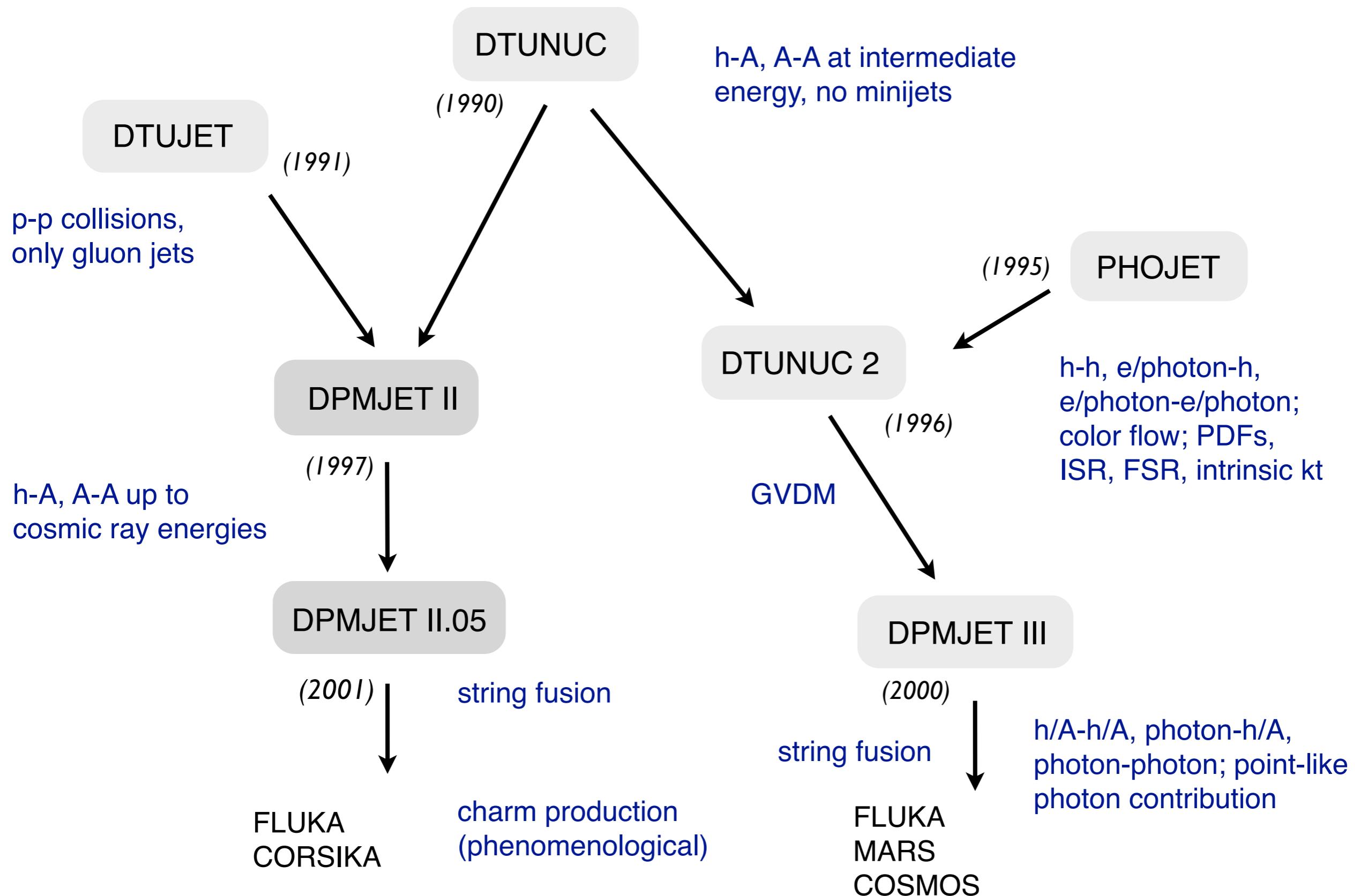


# **PHOJET & DPMJET III**

**Ralph Engel,  
Anatoli Fedynitch,  
Stefan Roesler**



# History of DPMJET



# PHOJET

## Photoproduction within the two-component Dual Parton Model: amplitudes and cross sections

R. Engel

Fachbereich Physik, Universität Leipzig, D-04109 Leipzig, Germany, and Fachbereich Physik,  
Universität Siegen, D-57068 Siegen, Germany

## Hadronic photon-photon interactions at high energies

R. Engel

*Institut für Theoretische Physik, Universität Leipzig, D-04109 Leipzig, Germany  
and Universität Siegen, Fachbereich Physik, D-57068 Siegen, Germany*

J. Ranft\*

*Laboratoire de Physique des Particules, Institut National de Physique Nucléaire et de Physique des Particules, Boîte Postale 110,  
F-74941 Annecy-le-Vieux, France*

## Diffraction dissociation, an important background to photon-photon collisions via heavy ion beams at LHC

R. Engel<sup>1,2</sup>, M.A. Braun<sup>3\*</sup>, C. Pajares<sup>3</sup>, J. Ranft<sup>3</sup>

<sup>1</sup>Institut für Theoretische Physik, Universität Leipzig, D-04109 Leipzig, Germany

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<sup>3</sup>Departamento de Física de Partículas, Universidad de Santiago de Compostela, E-15702 Santiago de Compostela, Spain

## Hard diffraction in hadron-hadron interactions and in photoproduction

R. Engel

*Universität Leipzig, Fachbereich Physik, D-04109 Leipzig, Germany  
and Universität Siegen, Fachbereich Physik, D-57068 Siegen, Germany*

J. Ranft

*CERN, CH-1211 Genève 23, Switzerland*

S. Roesler

*Universität Siegen, Fachbereich Physik, D-57068 Siegen, Germany  
(Received 21 February 1995)*

# PHOJET

## Photoproduction within the two-component Dual Parton Model: amplitudes and cross sections

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Universität Siegen, D-57068 Siegen, Germany

**409 citations**

**360 citations**

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<sup>3</sup>Departamento de Física de Partículas, Universidad de Santiago de Compostela, E-15

**108 citations**

## Hard diffraction in hadron-hadron interactions and in photoproduction

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and Universität Siegen, Fachbereich Physik, D-57068 Siegen, Germany*

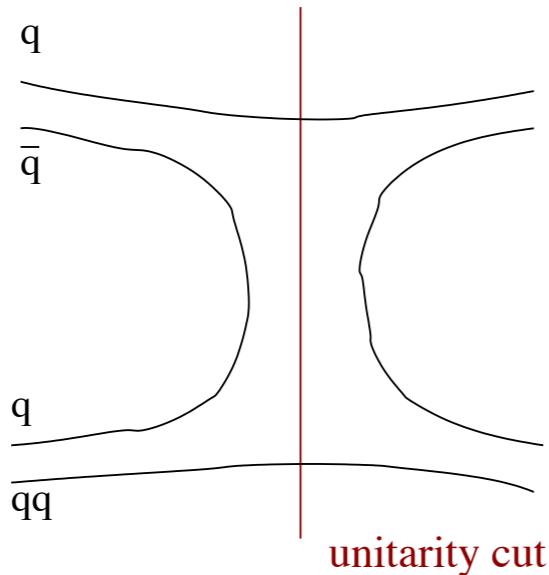
J. Ranft

*CERN, CH-1211 Genève 23, Switzerland*

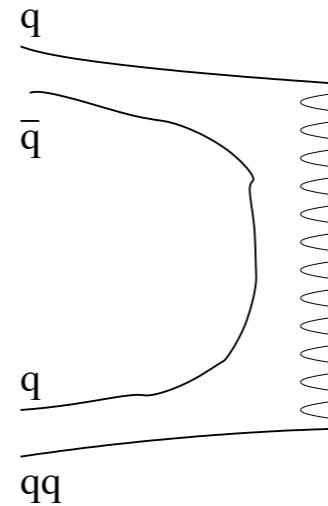
S. Roesler

*Universität Siegen, Fachbereich Physik, D-57068 Siegen, Germany  
(Received 21 February 1995)*

# Unitarity cuts (optical theorem)

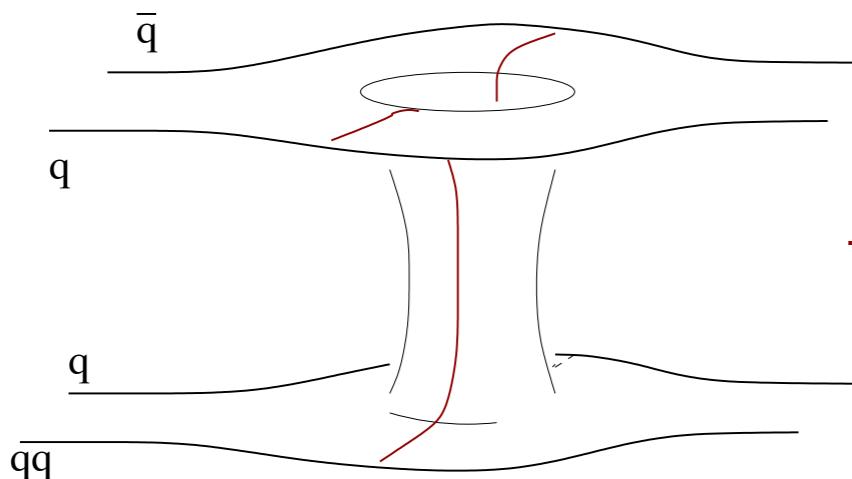


→

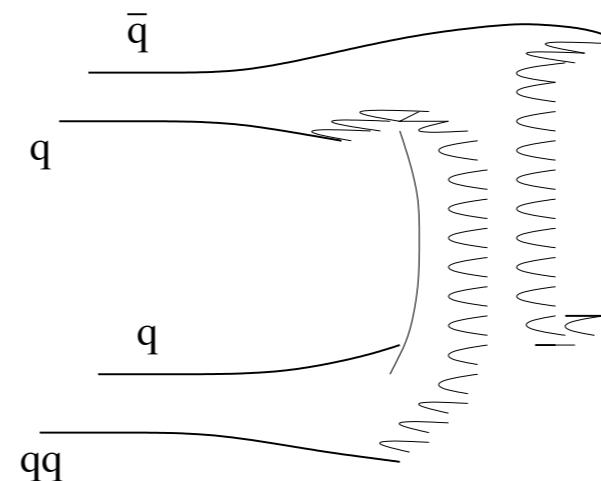


('t Hooft, Veneziano, Witten, ... 1974)

Unitarity cut of Reggeon exchange: chain of hadrons



→



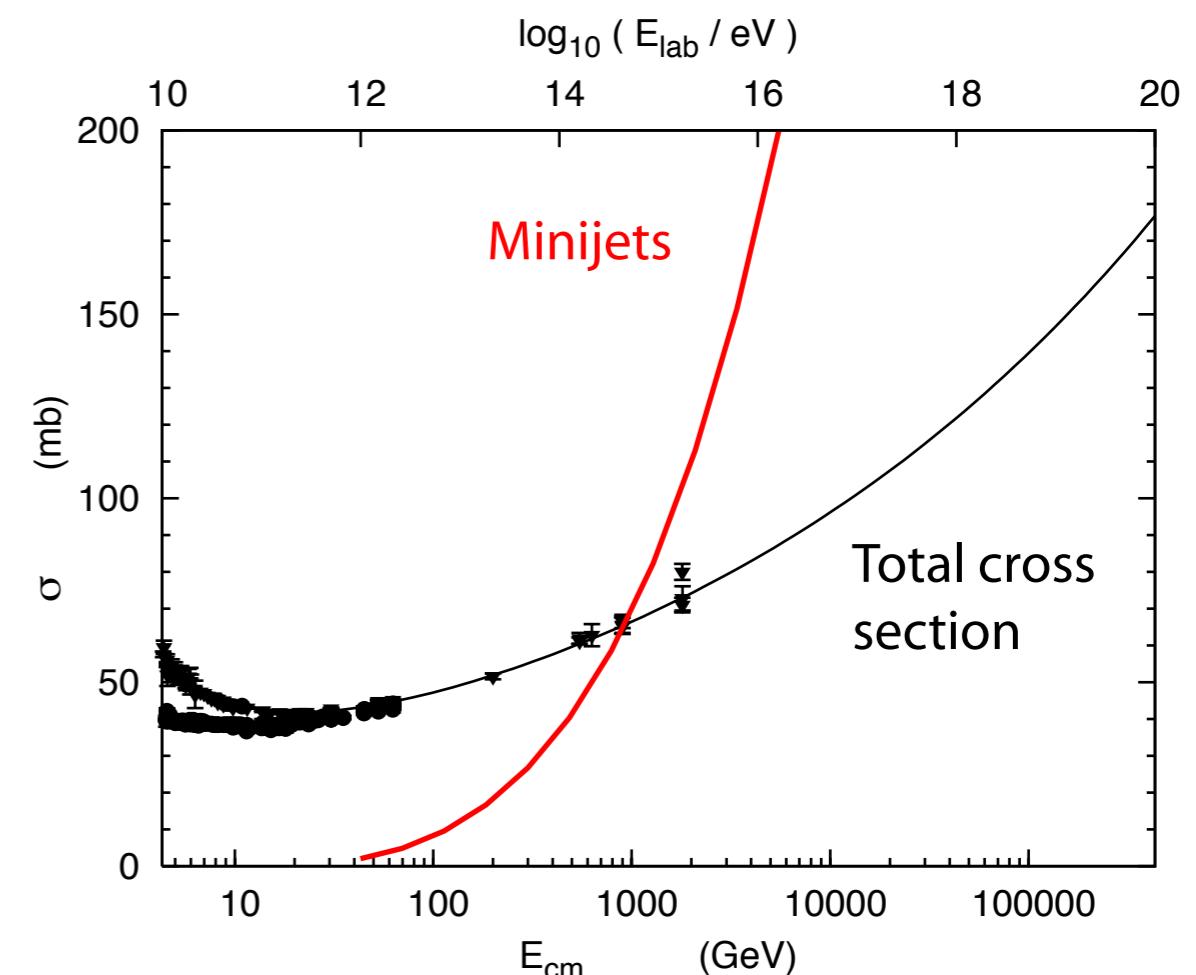
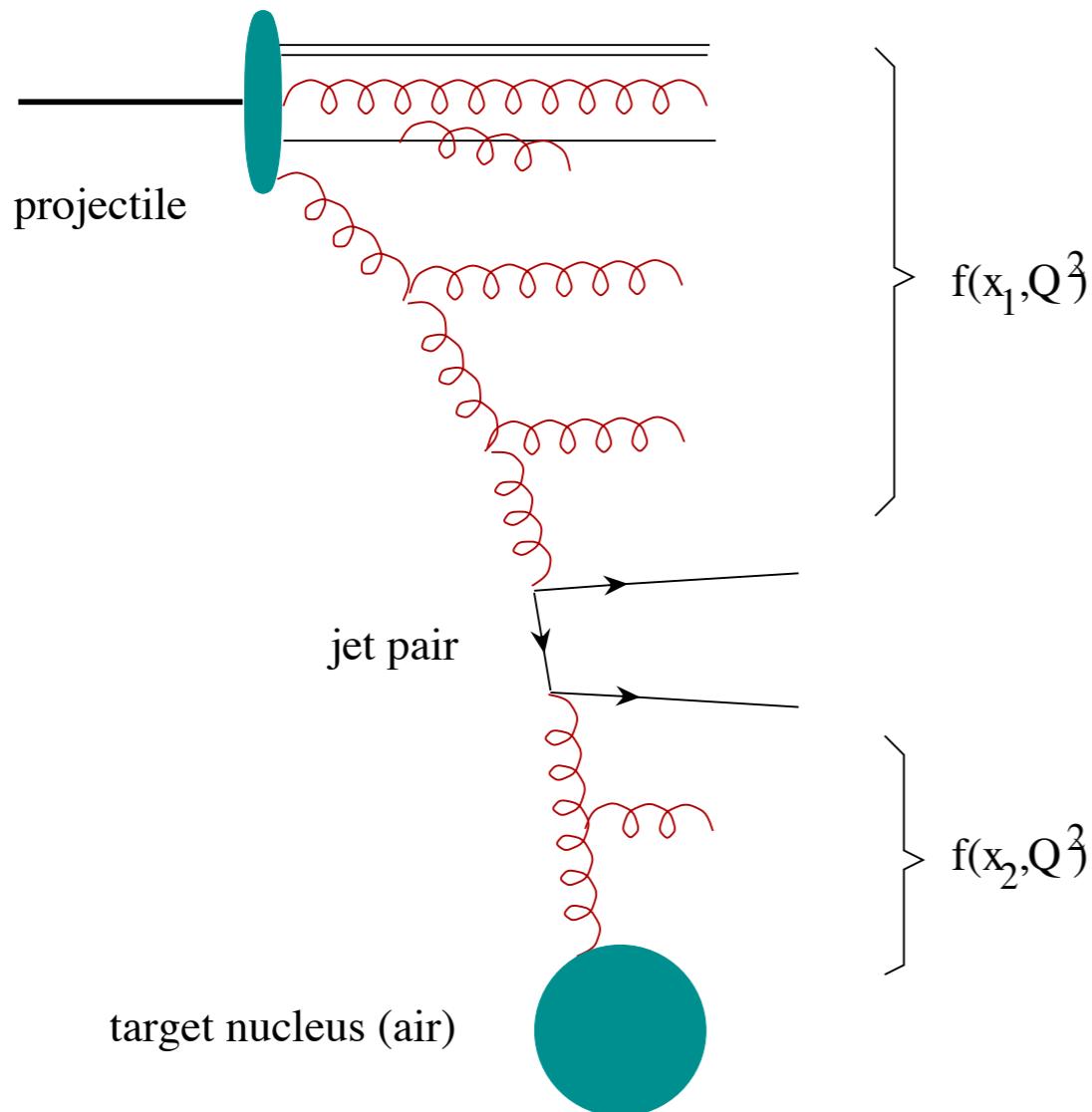
Pomeron exchange: two strings of hadrons

Splitting functions  
(Regge asymptotics)

$$f_{\text{nuc}}^{\text{DPM}}(x) \sim x_q^{-1/2} (1-x_q)^{3/2}$$

$$f_{\text{mes}}^{\text{DPM}}(x) \sim x_q^{-1/2} (1-x_q)^{1/2}$$

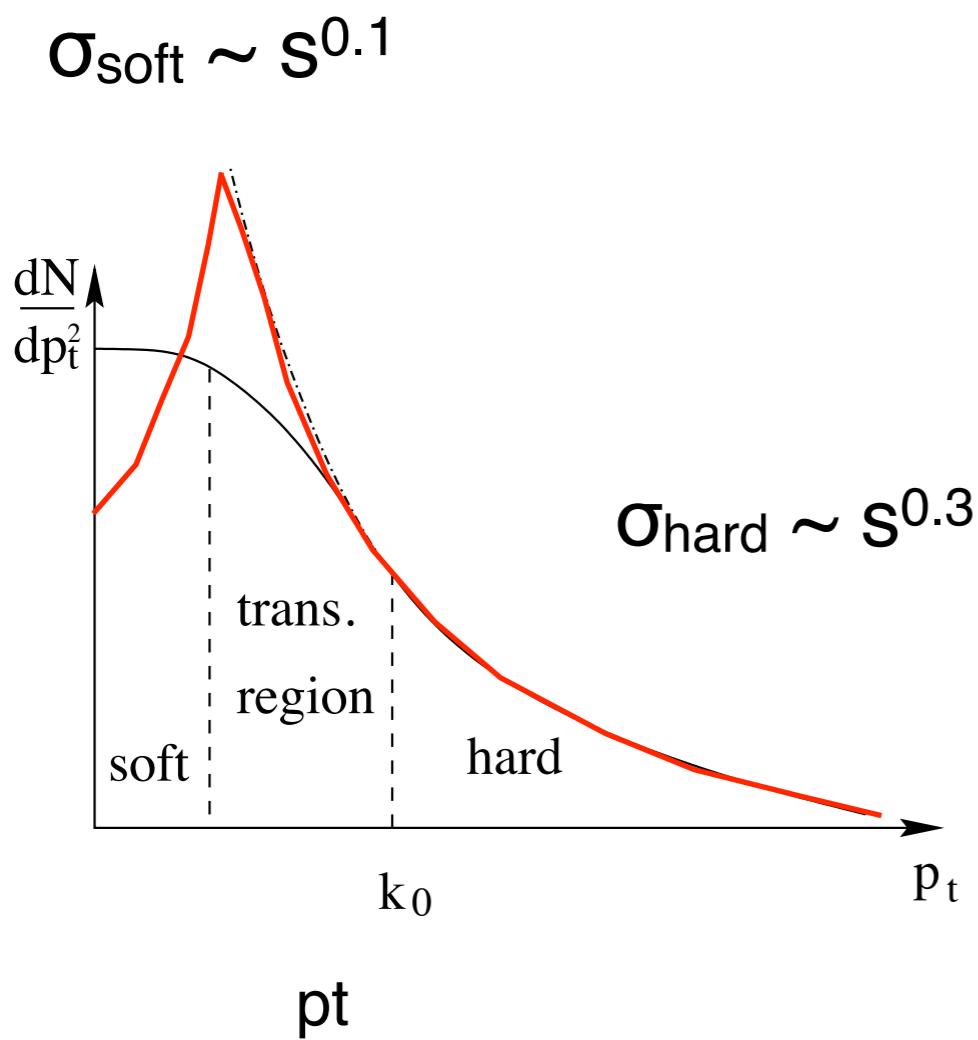
# QCD parton model: minijets



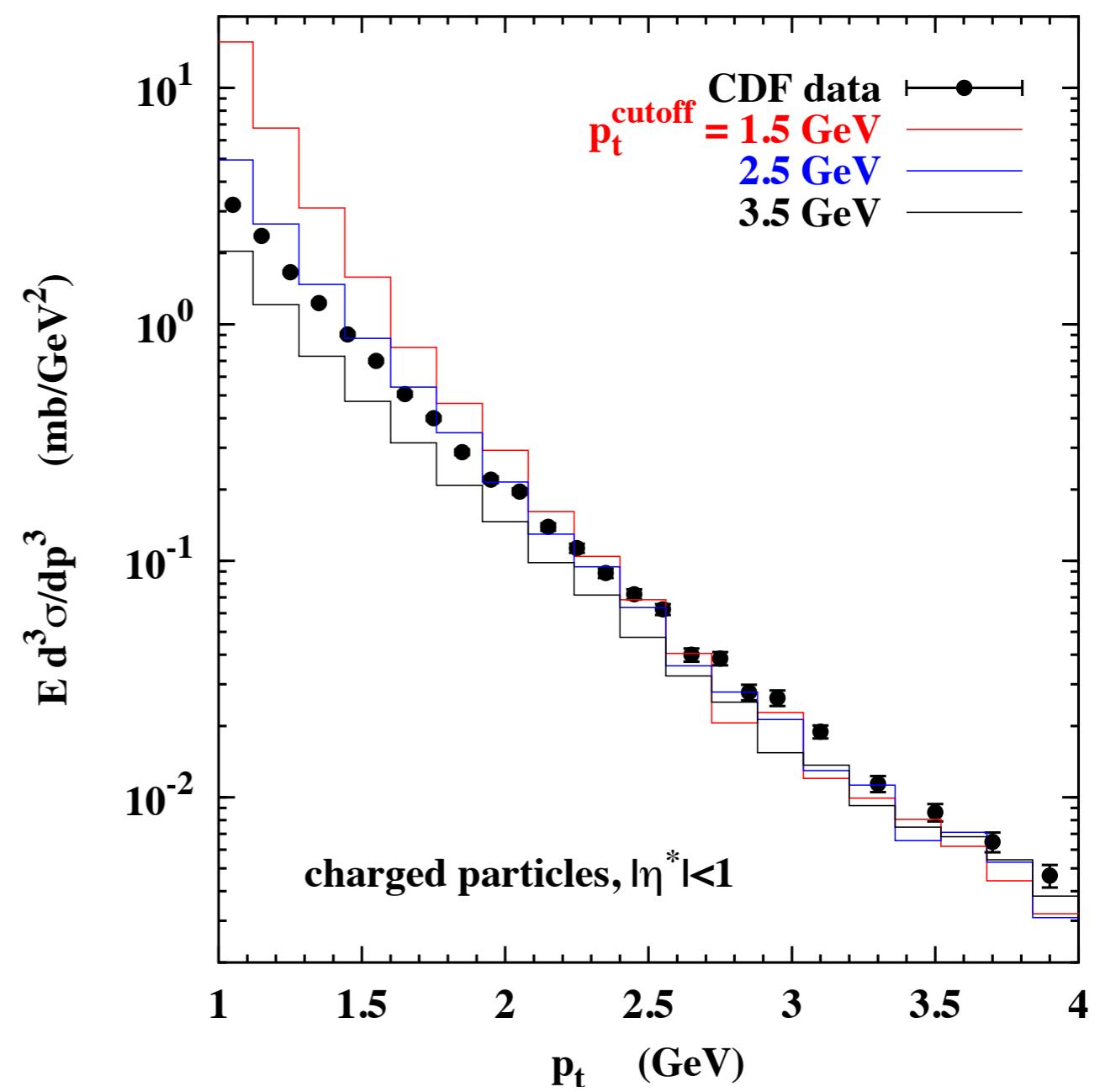
$$\sigma_{QCD} = \sum_{i,j,k,l} \frac{1}{1 + \delta_{kl}} \int dx_1 dx_2 \int_{p_\perp^{\text{cutoff}}} dp_\perp^2 f_i(x_1, Q^2) f_j(x_2, Q^2) \frac{d\sigma_{i,j \rightarrow k,l}}{dp_\perp}$$

# Conceptual problem: matching soft/hard

$p_t$  distribution of partons  
due to one cut pomeron

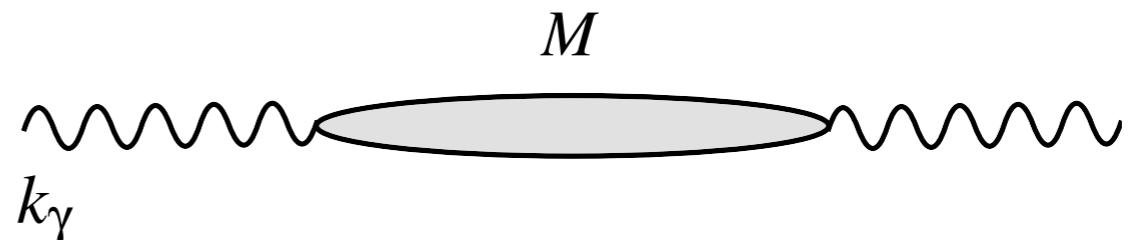


CDF inclusive charged  
particle distribution



# Vector meson dominance model

Lifetime of hadronic  
fluctuation of real photon



$$t_{\text{fluc}} \sim 1/\Delta E \sim \frac{2k_\gamma}{M^2 + Q^2}$$

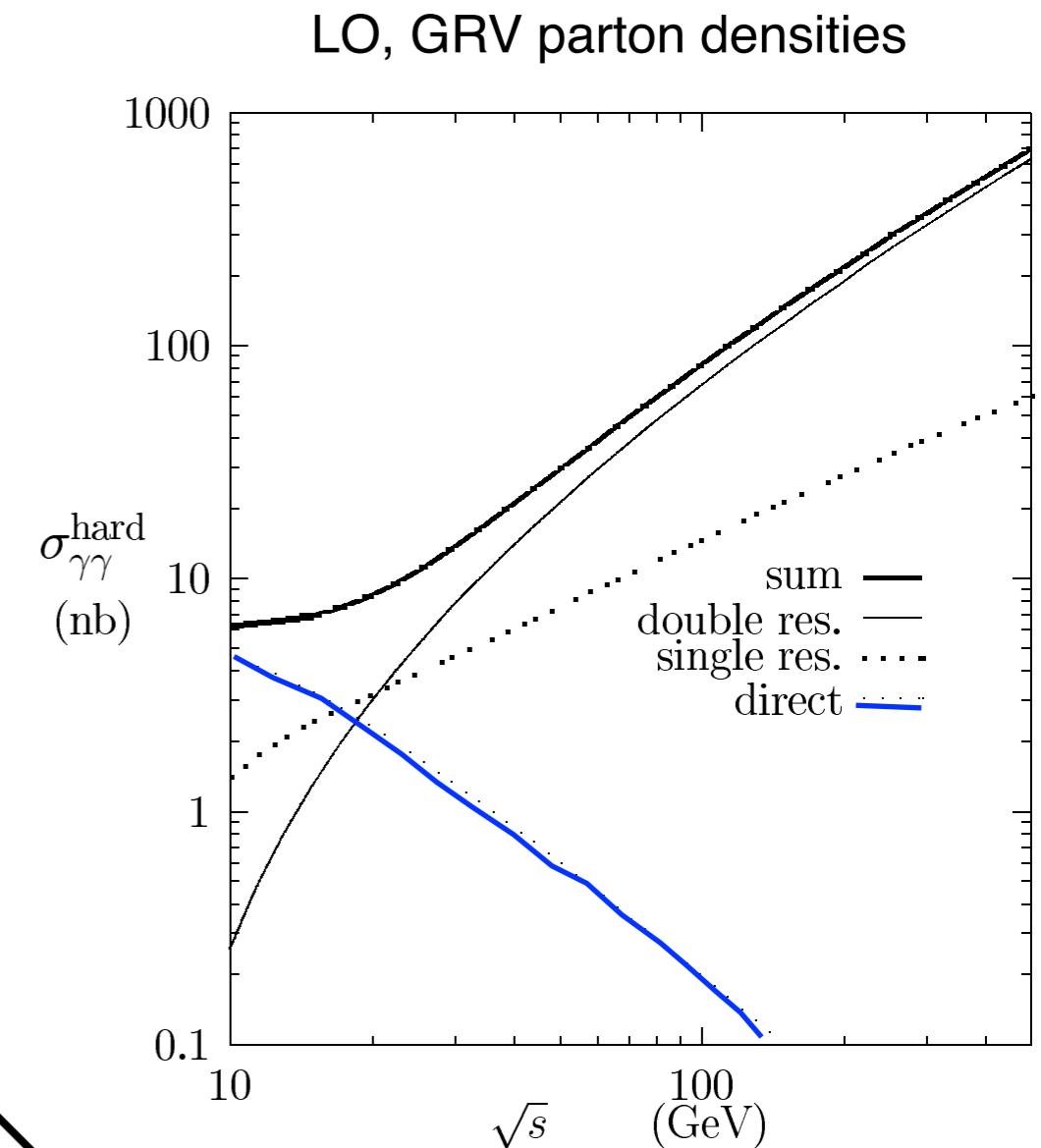
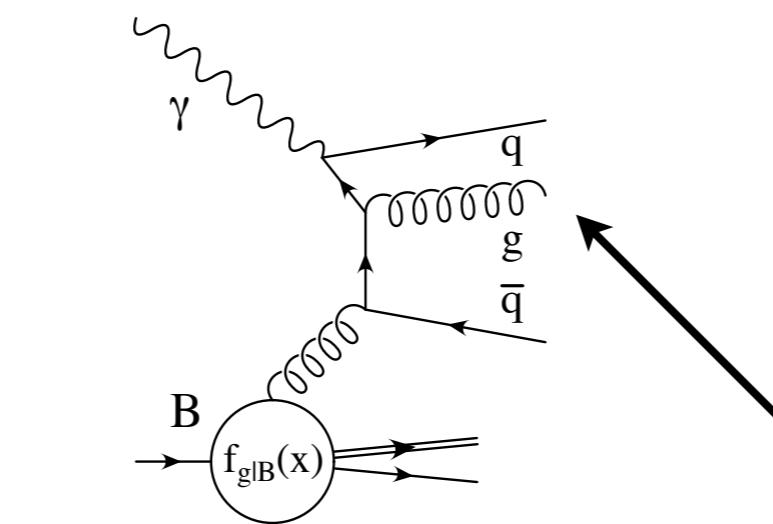
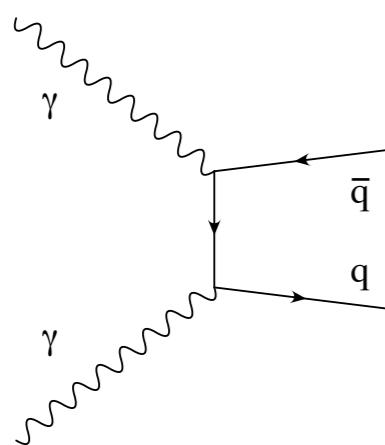
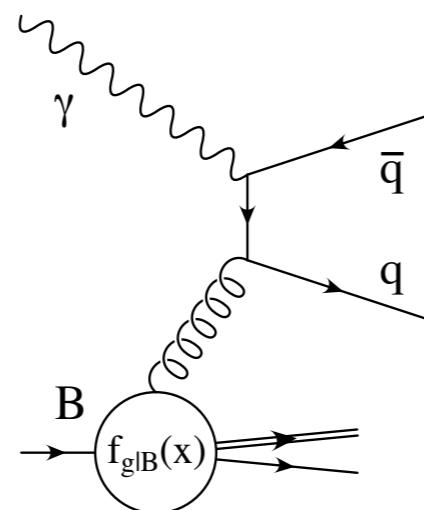
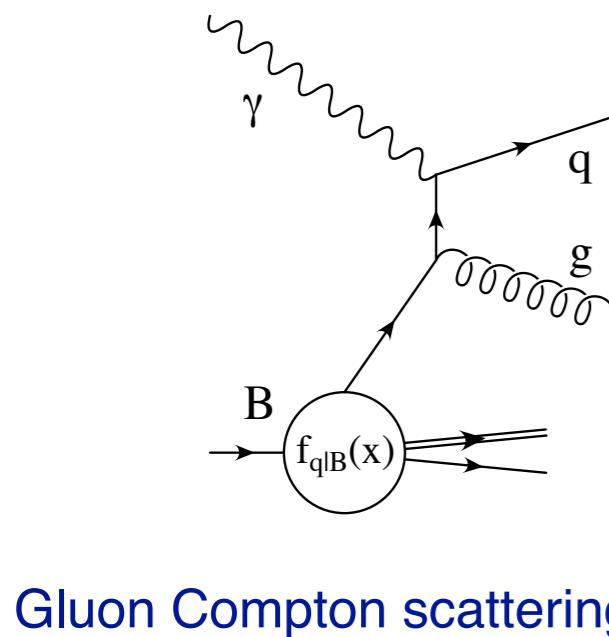
Approximation (low energy):

$$\begin{aligned} A_{\gamma h \rightarrow X}^{(T)}(s, t, q^2, \dots) &= \sum_{V=\rho, \omega, \phi} \left( \frac{e}{f_V} \right) \frac{m_V^2}{m_V^2 - q^2 - i\Gamma_V m_V} A_{V h \rightarrow X}^{(T)}(s, t, \dots) \\ A_{\gamma h \rightarrow X}^{(L)}(s, t, q^2, \dots) &= \sum_{V=\rho, \omega, \phi} \left( \frac{e}{f_V} \right) \left( \frac{-q^2 \xi_V}{m_V^2} \right)^{\frac{1}{2}} \frac{m_V^2}{m_V^2 - q^2 - i\Gamma_V m_V} A_{V h \rightarrow X}^{(T)}(s, t, \dots) \end{aligned}$$

$$\frac{e^2}{f_\rho^2} \approx 0.0036, \quad \frac{e^2}{f_\omega^2} \approx 0.00031, \quad \frac{e^2}{f_\phi^2} \approx 0.00055$$

**Very successful at low  $Q^2$**

# PHOJET: direct interactions of photons



ISR parton shower does not always end at soft scale

# DPMJET III

## Single diffractive hadron–nucleus interactions within the dual parton model

J. Ranft<sup>1</sup>, S. Roesler<sup>2,\*</sup>

<sup>1</sup> INFN, Sezione di Milano, Via Celoria 16, I-20133 Milano, Italy

<sup>2</sup> CERN/TIS-RP, CH-1211 Genève 23, Switzerland

## The single diffractive component in hadron-hadron collisions within the two-component Dual Parton Model

S. Roesler, R. Engel, J. Ranft

Fachbereich Physik, Universität Leipzig, Augustusplatz 10-12, D-7010 Leipzig, Germany

## Photoproduction off nuclei and pointlike photon interactions. I. Cross sections and nuclear shadowing

R. Engel

Universität Leipzig, Fachbereich Physik, D-04109 Leipzig, Germany  
and Universität Siegen, Fachbereich Physik, D-57068 Siegen, Germany

J. Ranft\*

Departamento de Física de Partículas, Universidad de Santiago de Compostela, E-15706 Santiago de Compostela, Spain

## Photoproduction off nuclei: Particle and jet production

S. Roesler\*

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Universität Leipzig, Fachbereich Physik, D-04109 Leipzig, Germany  
and Universität Siegen, Fachbereich Physik, D-57068 Siegen, Germany

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(Received 20 November 1996; revised manuscript received 17 September 1997; published

S. Roesler

bereich Physik, D-57068 Siegen, Germany  
(Received 9 October 1996)

## Antiparticle to particle production ratios in hadron-hadron and d-Au collisions in the DPMJET-III Monte Carlo model

F. W. Bopp\* and J. Ranft†

Fachbereich Physik, Universität Siegen, D-57068 Siegen, Germany

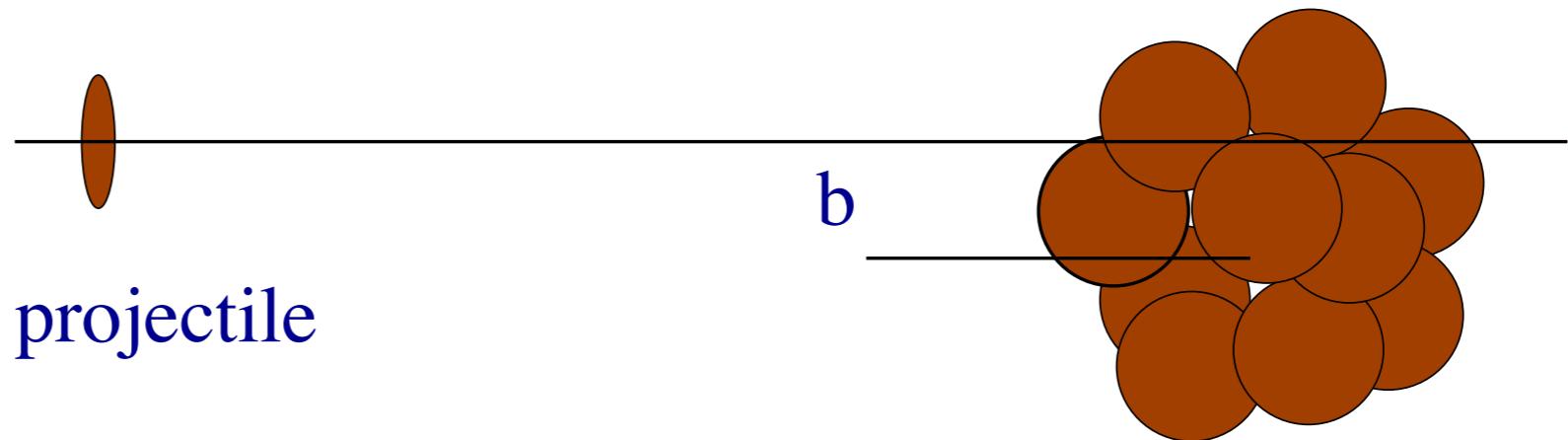
R. Engel‡

Forschungszentrum Karlsruhe, Institut für Kernphysik, Postfach 3640, D-76021 Karlsruhe, Germany

S. Roesler§

CERN, Geneva, Switzerland

# DPMJET: Glauber model of nuclear collisions



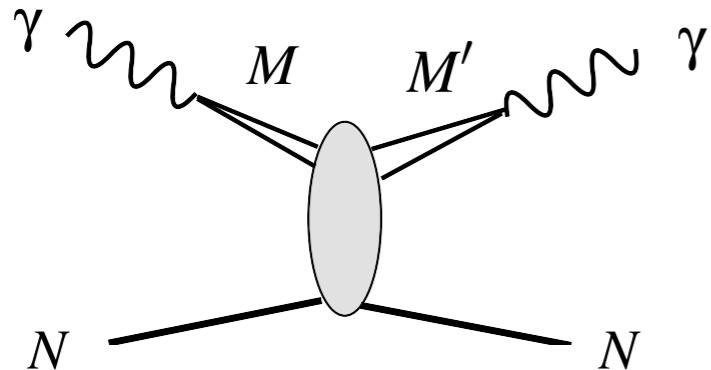
Standard Glauber approximation:

$$\sigma_{\text{inel}} = \int d^2\vec{b} \left[ 1 - \prod_{k=1}^A \left( 1 - \sigma_{\text{tot}}^{NN} T_N(\vec{b} - \vec{s}_k) \right) \right] \approx \int d^2\vec{b} \left[ 1 - \exp \left\{ -\sigma_{\text{tot}}^{NN} T_A(\vec{b}) \right\} \right]$$

$$\sigma_{\text{prod}} \approx \int d^2\vec{b} \left[ 1 - \exp \left\{ -\sigma_{\text{ine}}^{NN} T_A(\vec{b}) \right\} \right]$$

- Diffraction dissociation
- Pauli blocking
- intranuclear cascade with formation zone
- Remnant nucleus treatment

# Generalized vector dominance model (GVDM)



- Sum over all hadronic states
- Non-diagonal terms
- Many parameters (assumptions needed)

Neglecting off-diagonal transitions:

$$D(M^2) = \frac{R_{e^+ e^-}(M^2)}{12\pi^2 M^2}$$

$$\sigma_{\gamma^\star N}(s, Q^2) = 4\pi\alpha_{\text{em}} \int_{M_0^2}^{M_1^2} dM^2 D(M^2) \left( \frac{M^2}{M^2 + Q^2} \right)^2 \left( 1 + \epsilon \frac{Q^2}{M^2} \right) \sigma_{VN}(s, Q^2, M^2)$$



$$\sigma_{VN}(s, Q^2, M^2) = \frac{\tilde{\sigma}_{VN}(s, Q^2)}{M^2 + Q^2 + C^2}$$

# GVDM and Glauber model

Detailed implementation of diagonal of GVDM in DPMJET III

$$\sigma_{\gamma^* A}(s, Q^2) = 4 \pi \alpha_{\text{em}} \int_{M_0^2}^{M_1^2} dM^2 D(M^2) \left( \frac{M^2}{M^2 + Q^2} \right)^2 \left( 1 + \epsilon \frac{Q^2}{M^2} \right) \sigma_{VA}(s, Q^2, M^2)$$

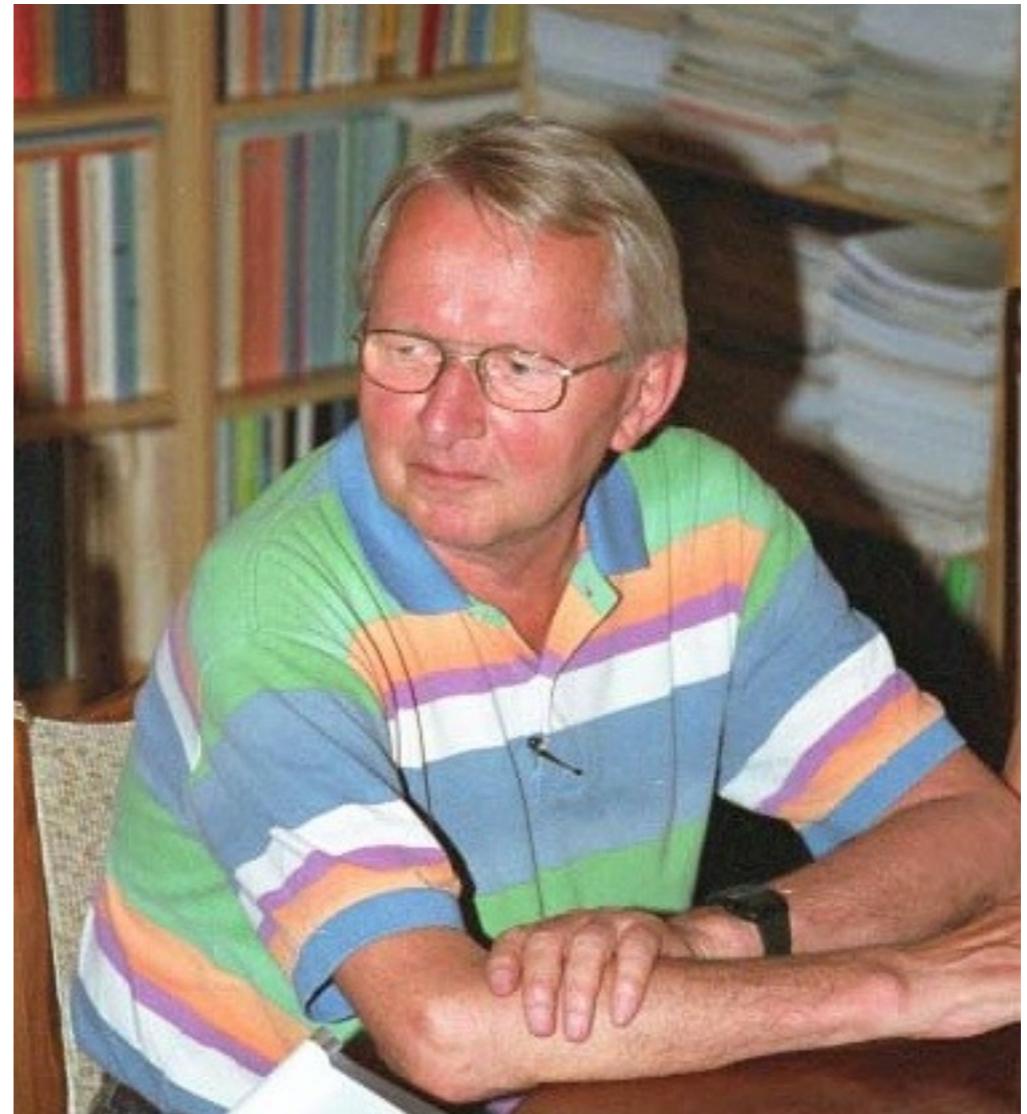
$$\Gamma(s, Q^2, M^2, \vec{b}) = \frac{\sigma_{VN}(s, Q^2, M^2)}{4 \pi B(s, Q^2, M^2)} \left( 1 - i \frac{\text{Re}f(0)}{\text{Im}f(0)} \right) \exp \left( \frac{-\vec{b}^2}{2B(s, Q^2, M^2)} \right)$$

$$B(s, Q^2, M^2) = 2 \left[ B_0^2 + \alpha'_P \ln \left( \frac{s}{M^2 + Q^2} \right) \right],$$

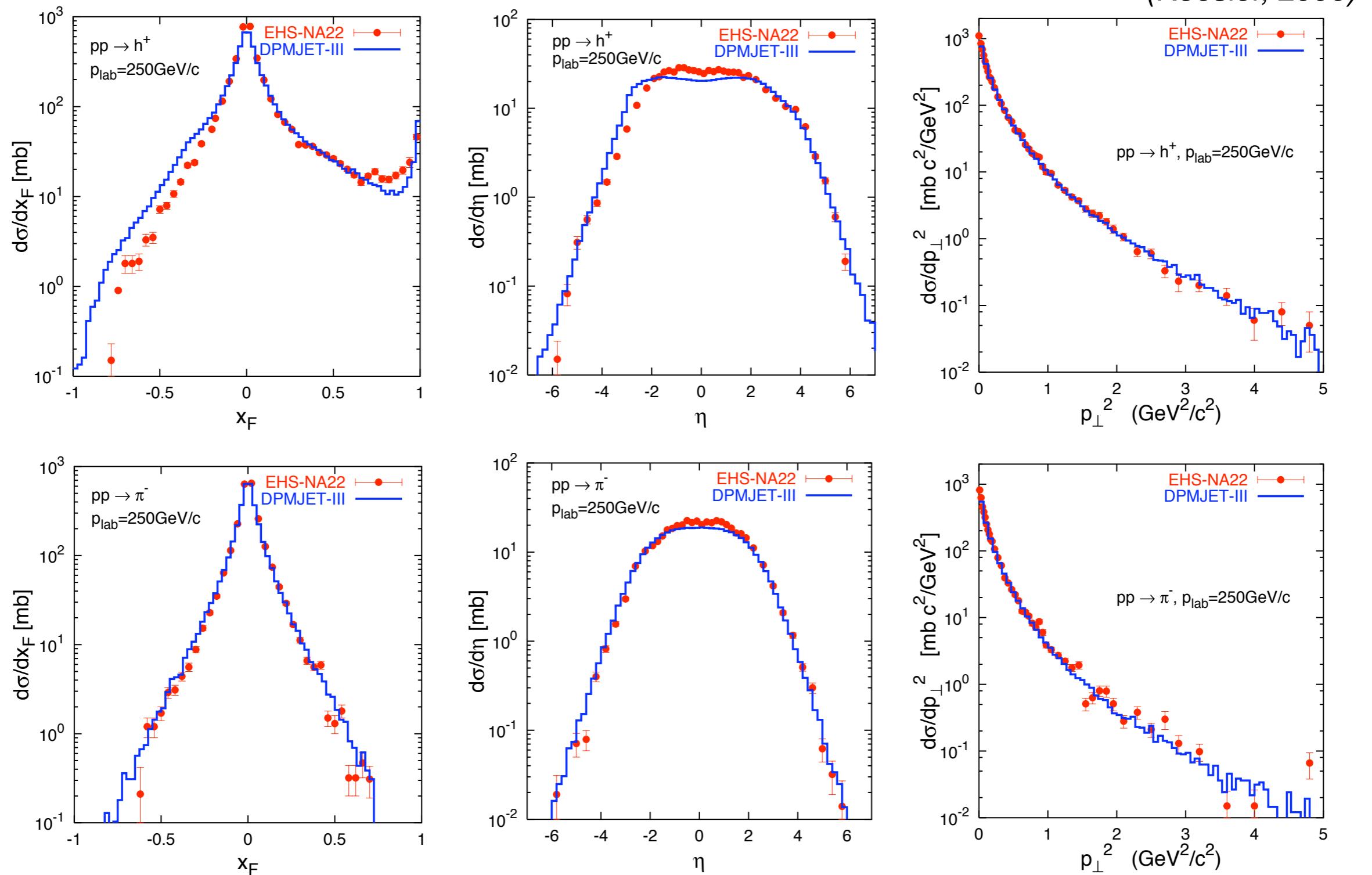
$$B_0^2 = \left( 2 + \frac{m_\rho^2}{M^2 + Q^2} \right) \text{GeV}^{-2}, \quad \alpha'_P = 0.25 \text{GeV}^{-2}$$

$$\sigma_{VA}^{\text{inel}}(s, Q^2, M^2) = \int d^2 b \int \prod_{j=1}^A d^3 r_j \rho_A(\vec{r}_j) \left( 1 - \left| \prod_{i=1}^A [1 - \Gamma(s, Q^2, M^2, \vec{b}_i)] \right|^2 \right)$$

# **Pre-LHC model comparions with data**



# NA22 European Hybrid Spectrometer data



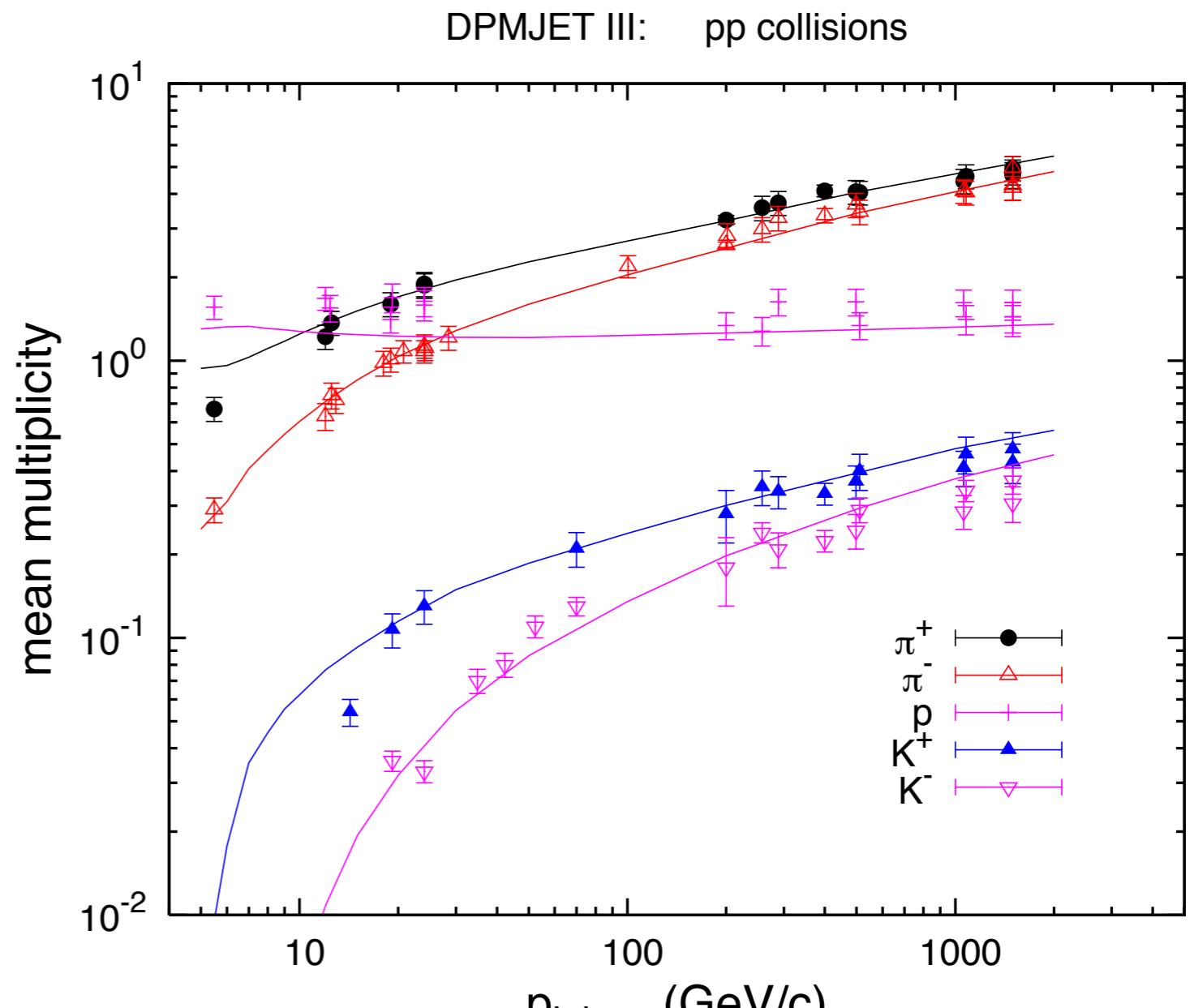
(Roesler, 2006)

# Multiplicity at low energy

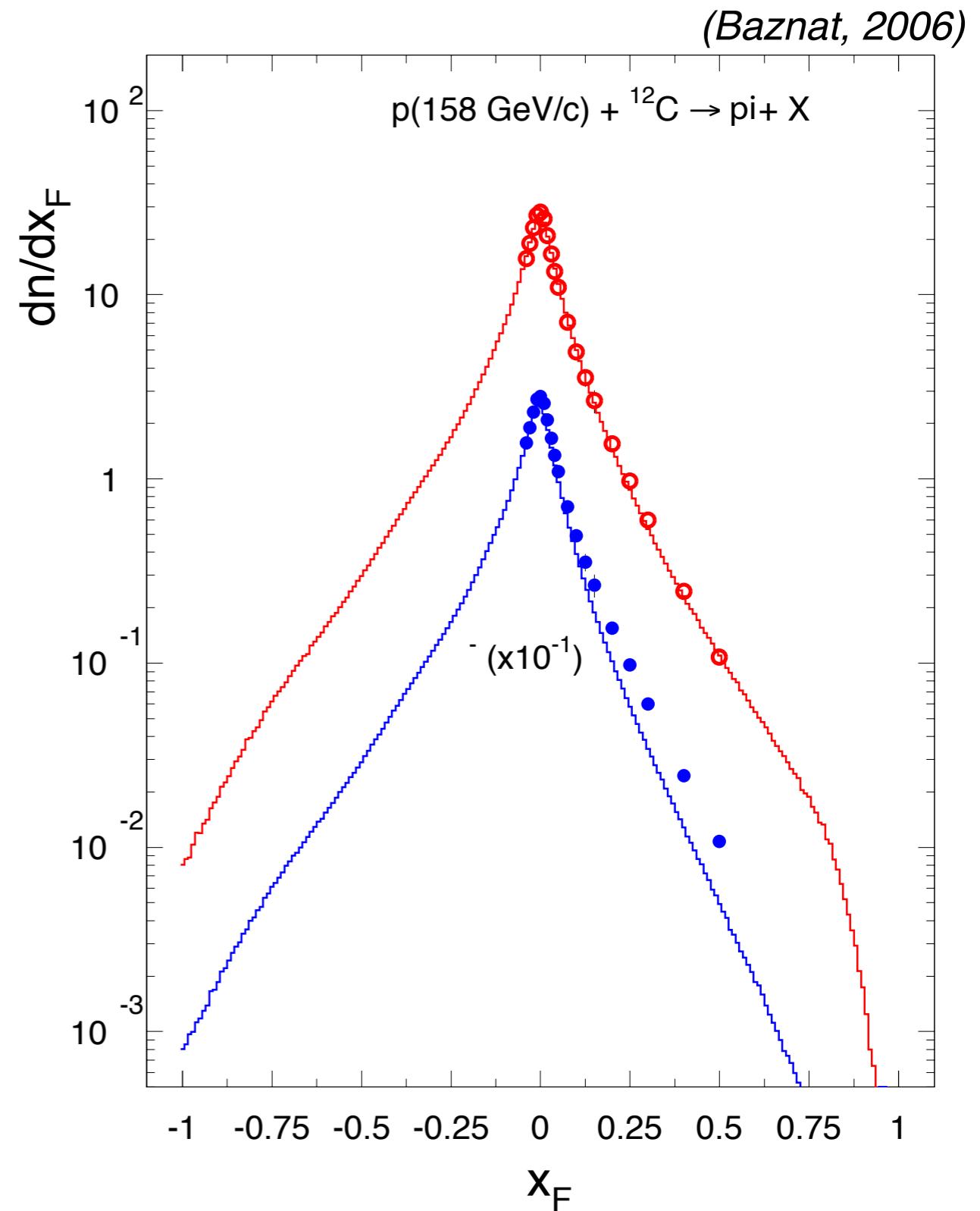
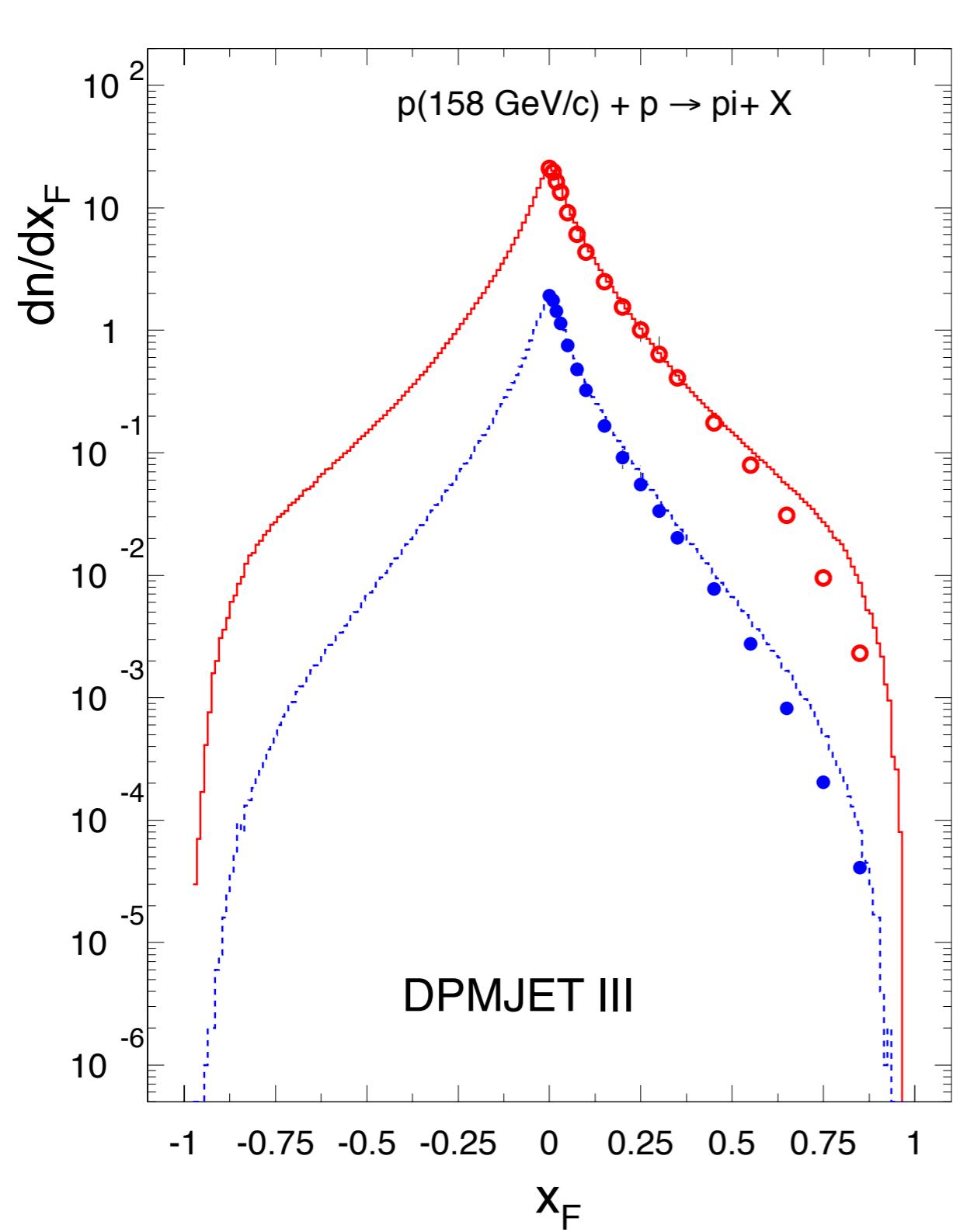
DPMJET in p-p mode:  
simulation of particle  
production from  
energy threshold on

proton - proton,  $E_{\text{lab}} = 200 \text{ GeV}$

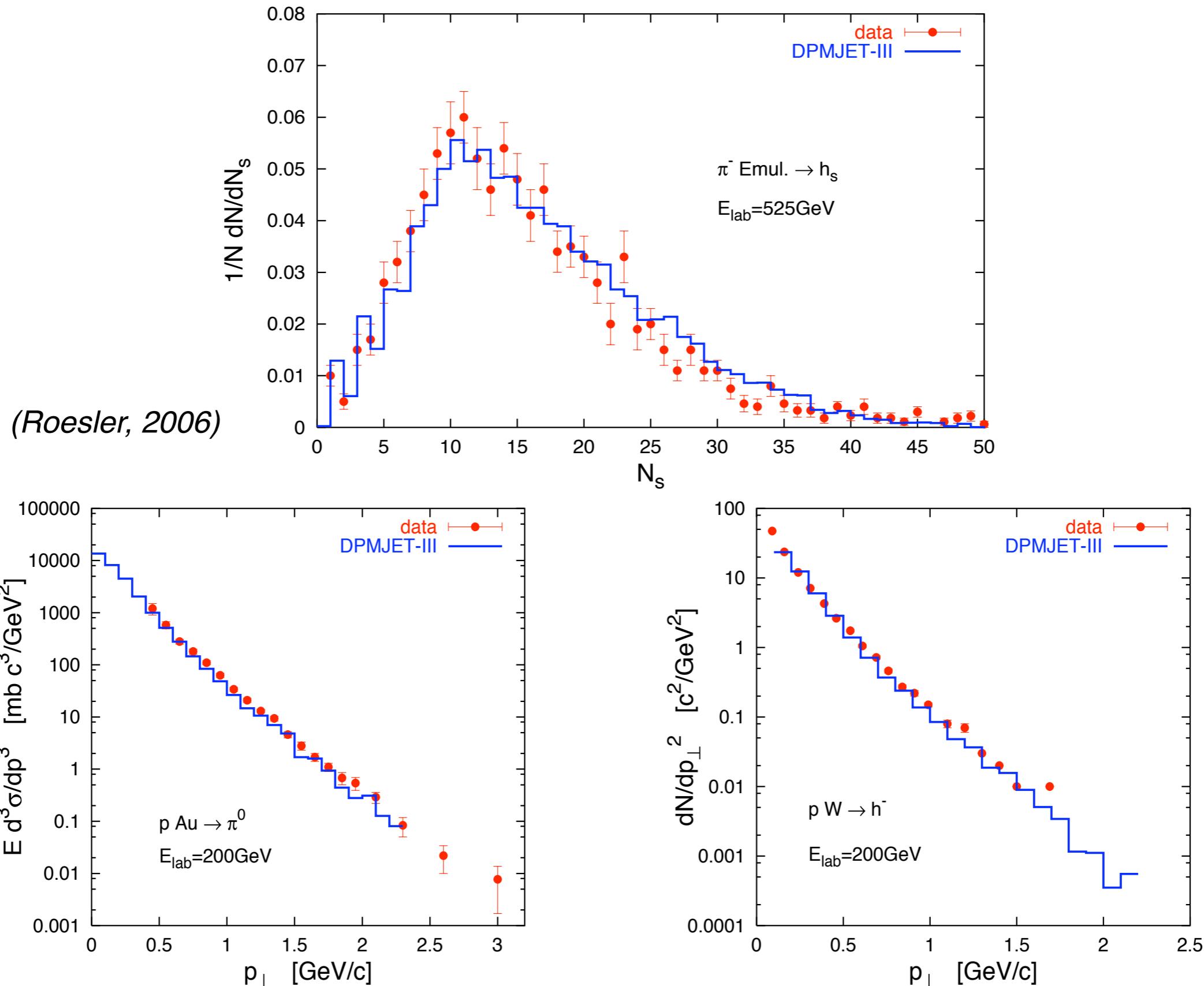
	Exp.	DPMJET-III
charged	$7.69 \pm 0.06$	7.64
neg.	$2.85 \pm 0.03$	2.82
p	$1.34 \pm 0.15$	1.26
n	$0.61 \pm 0.30$	0.66
$\pi^+$	$3.22 \pm 0.12$	3.20
$\pi^-$	$2.62 \pm 0.06$	2.55
$K^+$	$0.28 \pm 0.06$	0.30
$K^-$	$0.18 \pm 0.05$	0.20
$\Lambda$	$0.096 \pm 0.01$	0.10
$\bar{\Lambda}$	$0.0136 \pm 0.004$	0.0105



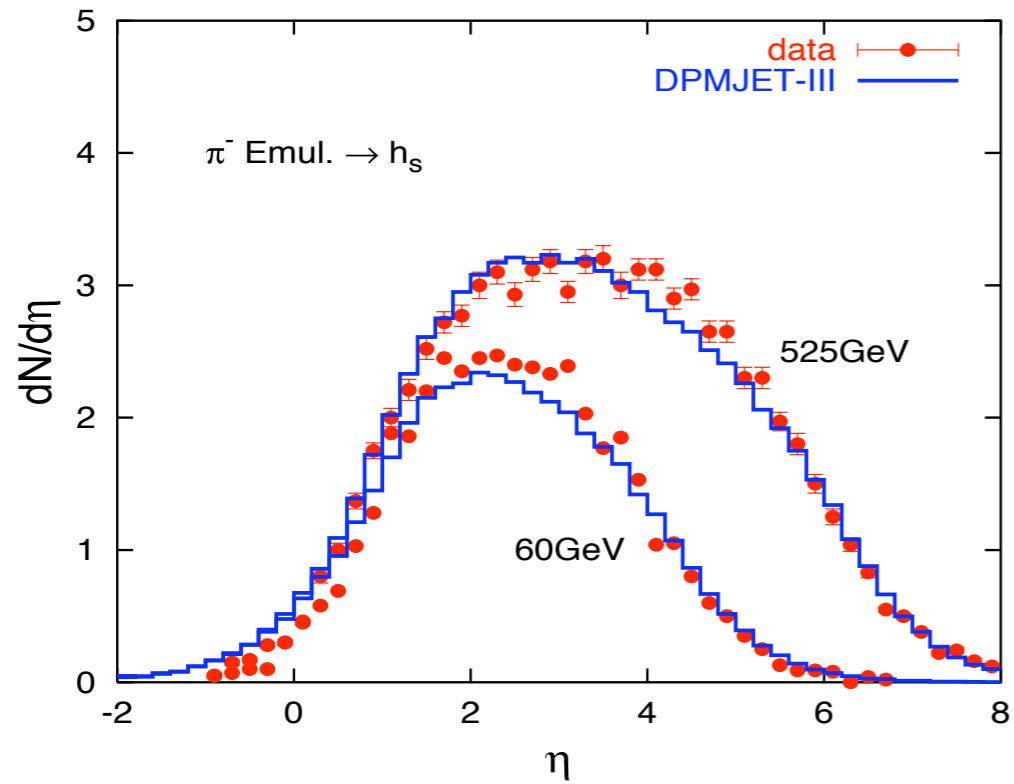
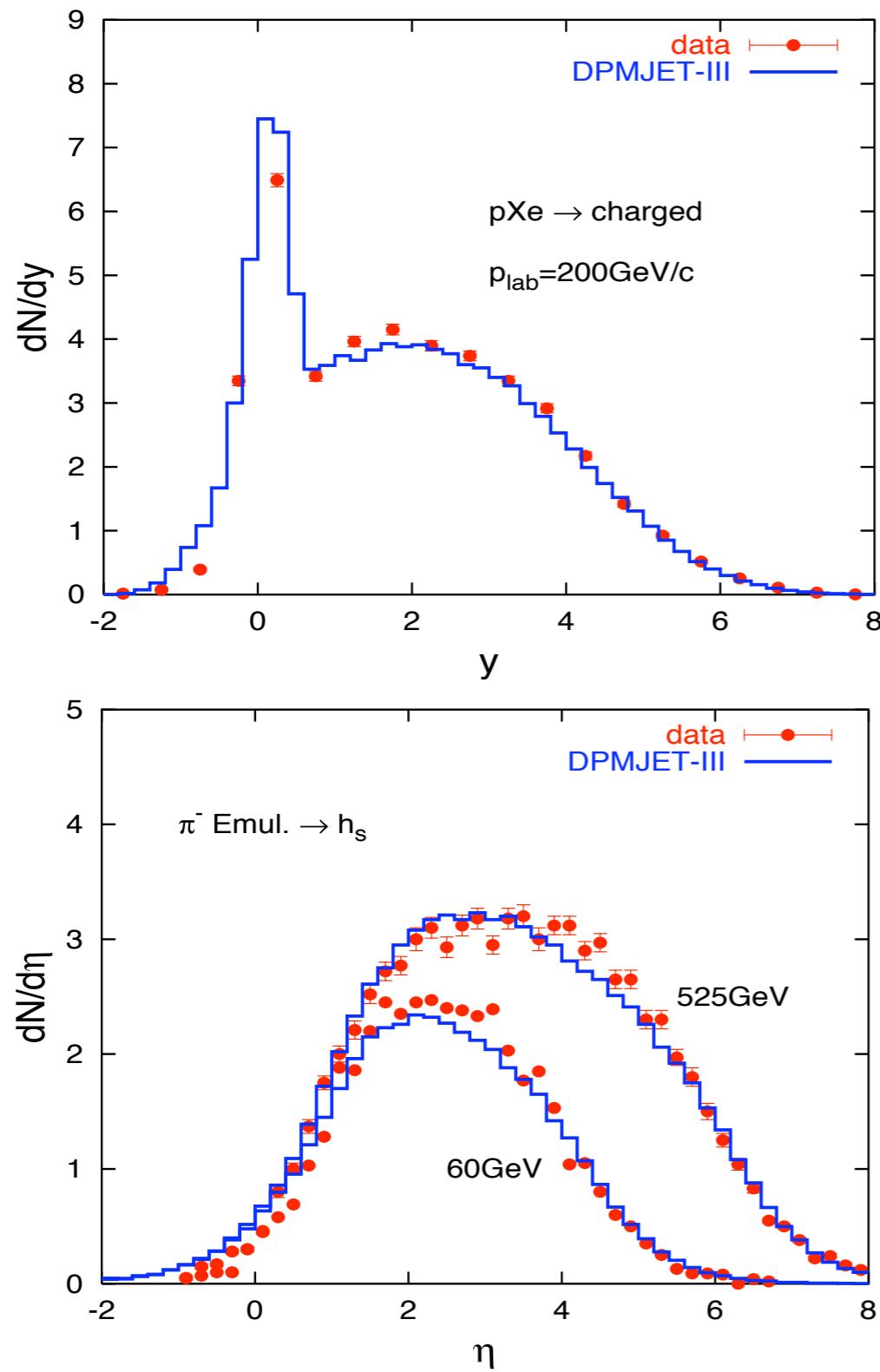
# NA49 data (p-p and p-C, 158 GeV)



# Fixed-target hadron-nucleus data (i)

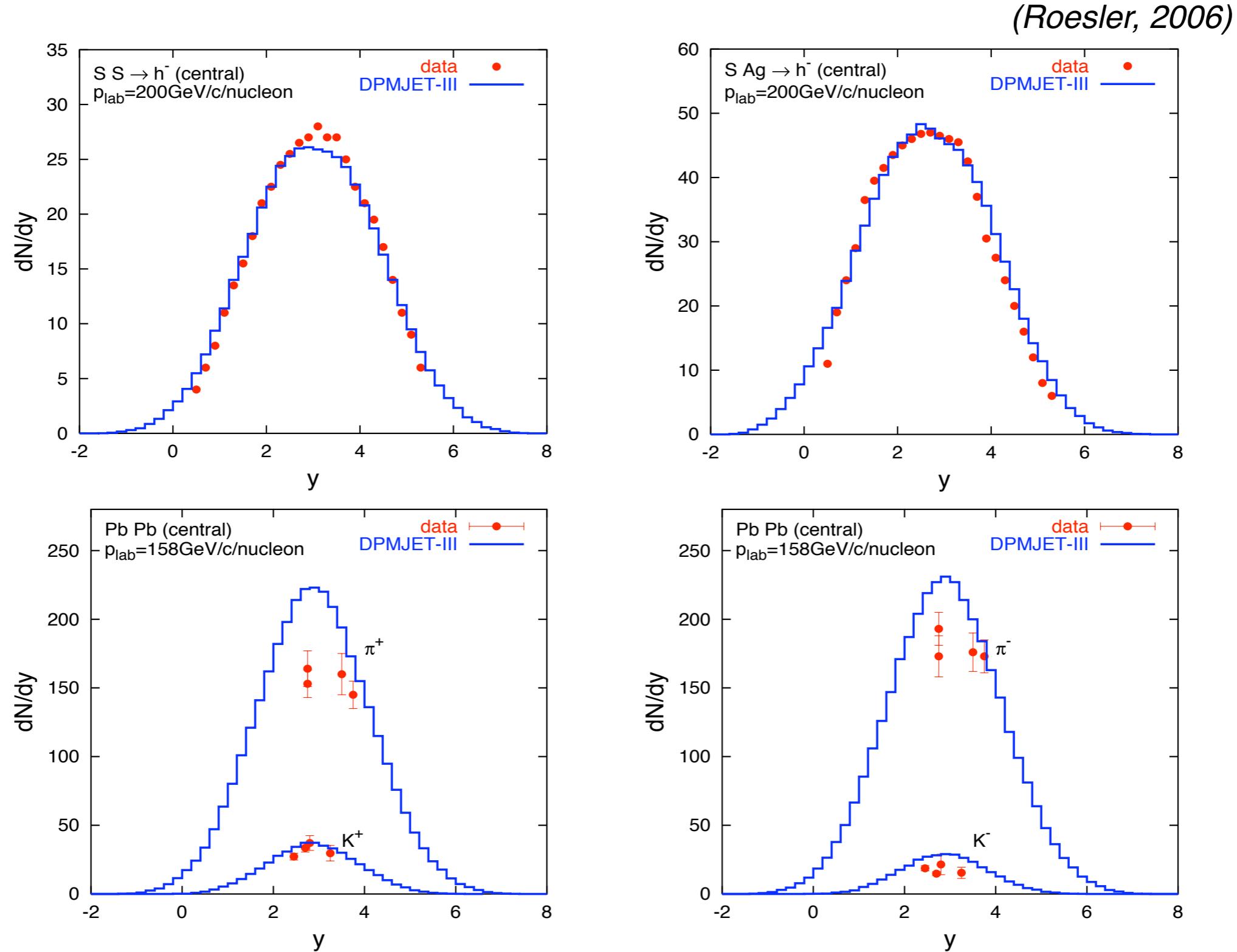


# Fixed-target hadron-nucleus data (ii)



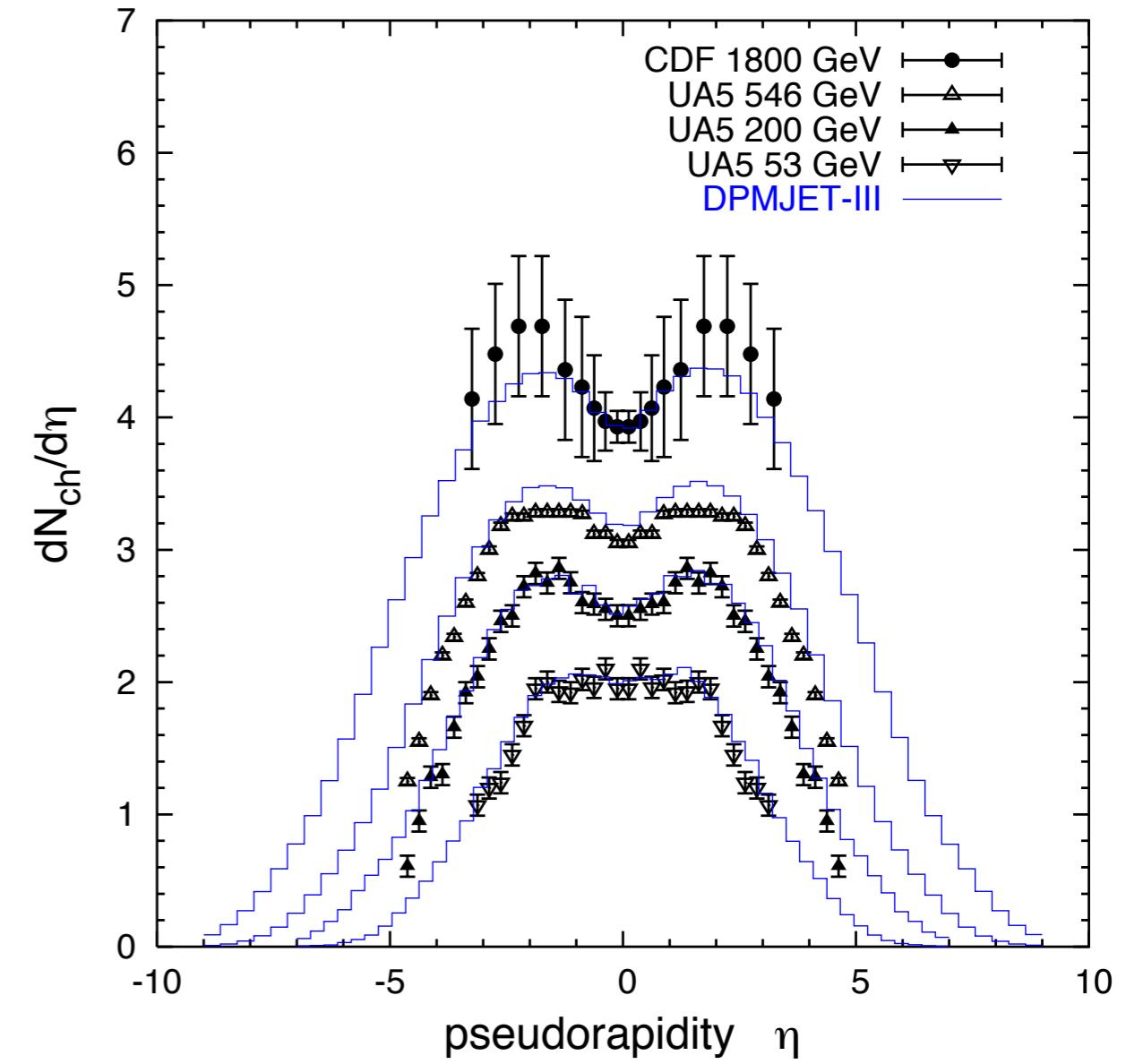
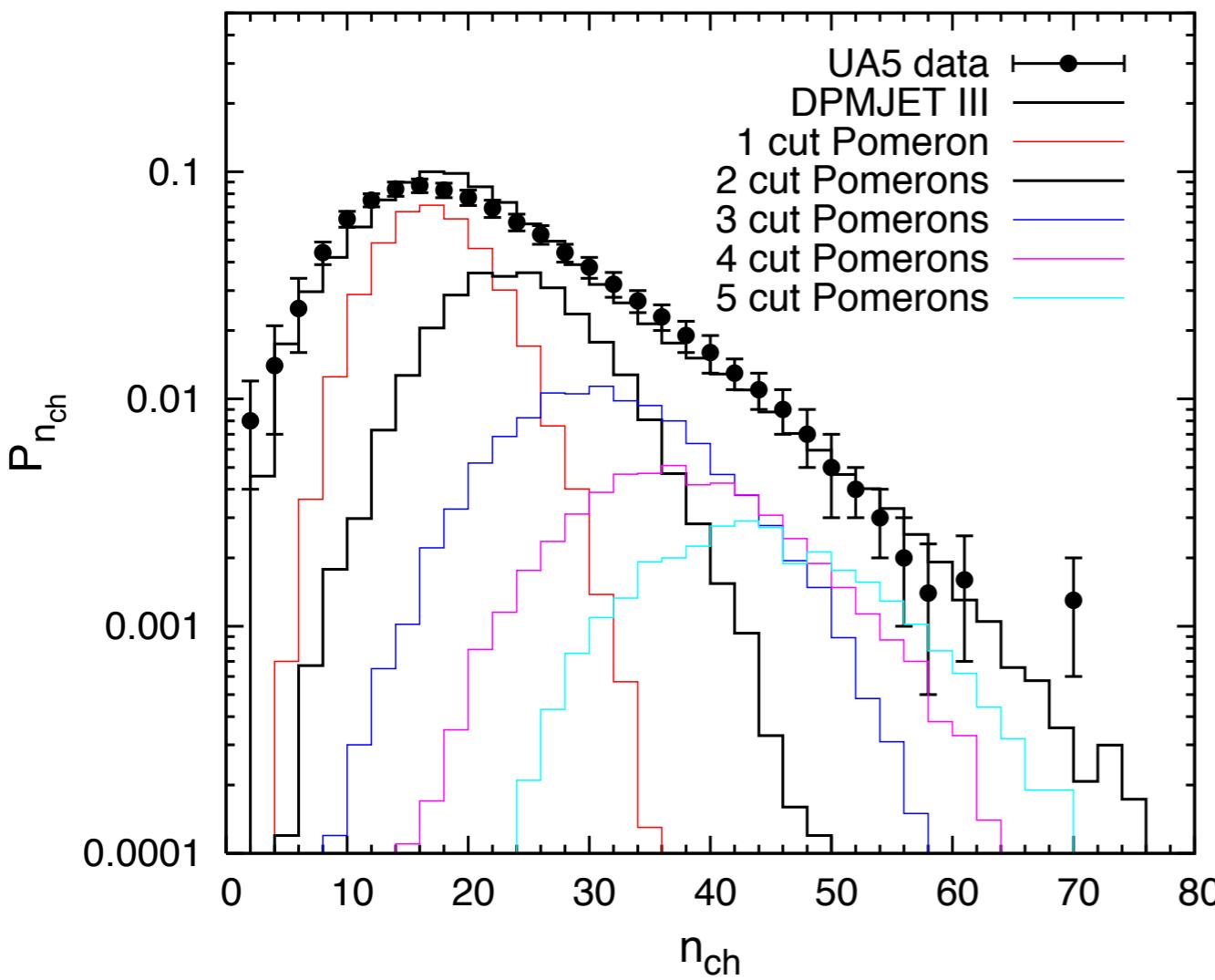
(Roesler, 2006)	Exp.	DPMJET-III
14.6 GeV	$1.57 \pm 0.23$	1.52
	$2.15 \pm 0.33$	1.92
200 GeV	$5.0 \pm 0.2$	4.98
	$6.84 \pm 0.13$	6.67
360 GeV	$6.8 \pm 0.6$	5.87
	$8.9 \pm 0.4$	8.77

# Fixed-target nucleus-nucleus data



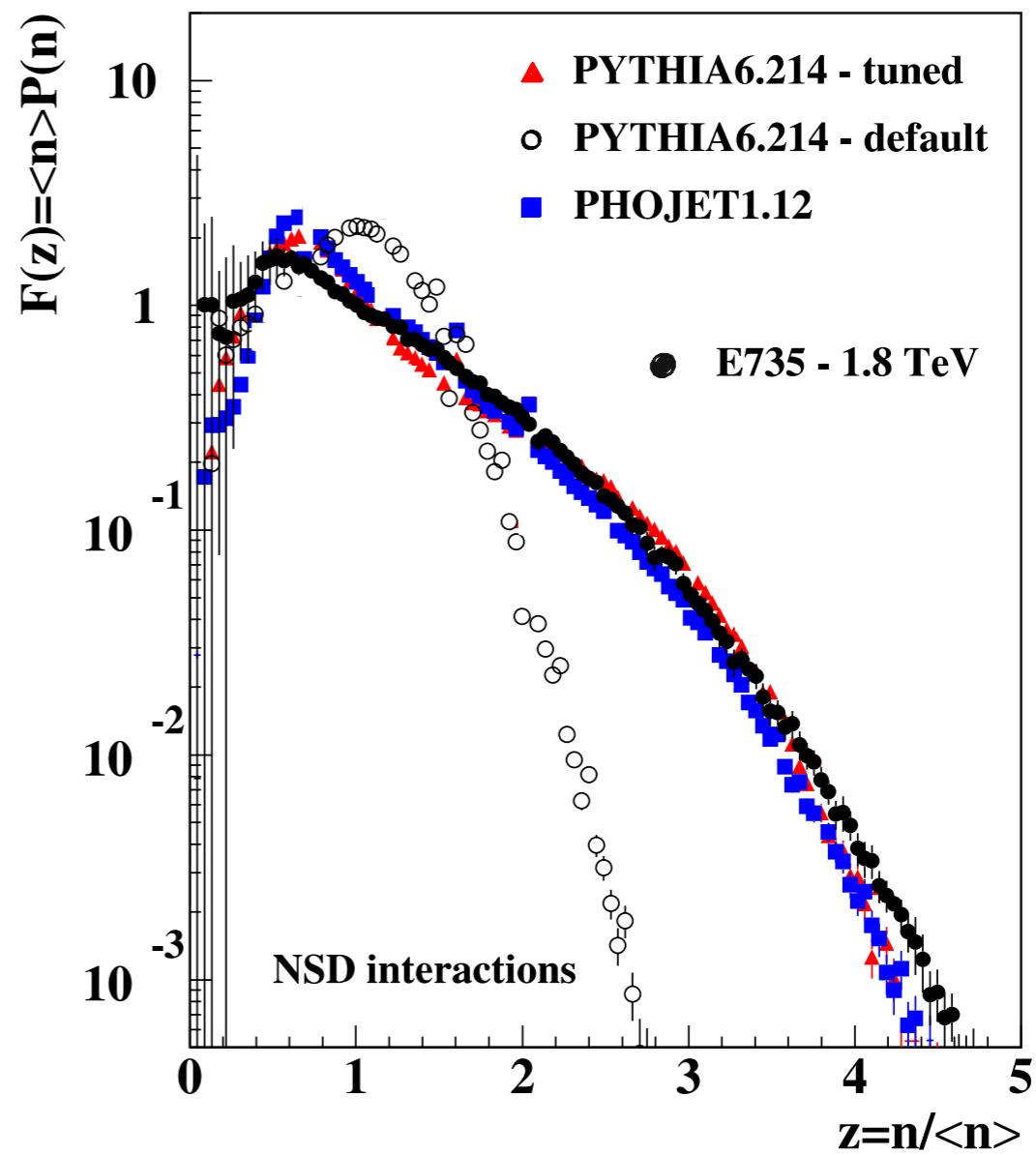
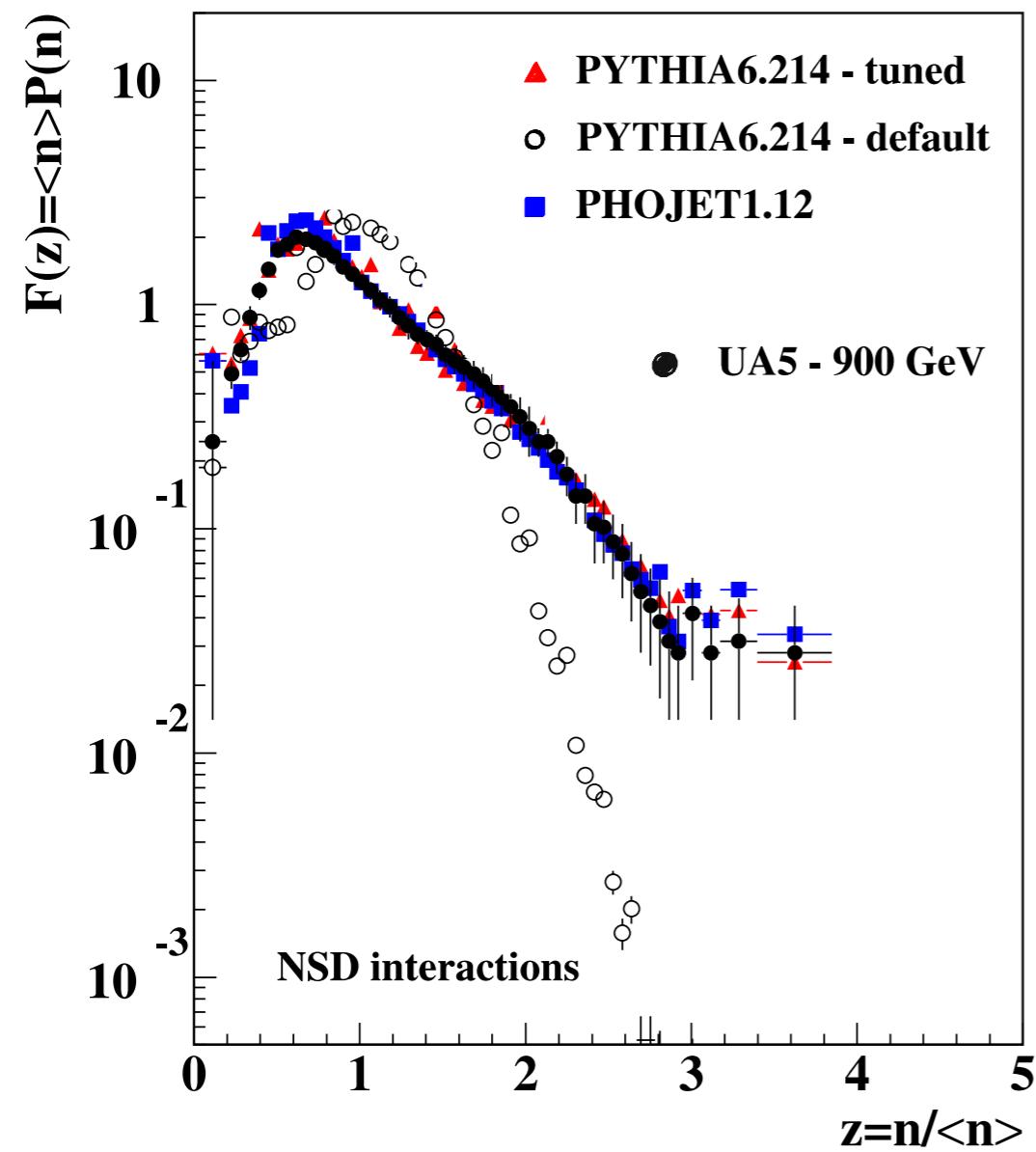
# Comparison with collider measurements

Charged particle multiplicity distribution at 200 GeV cms.

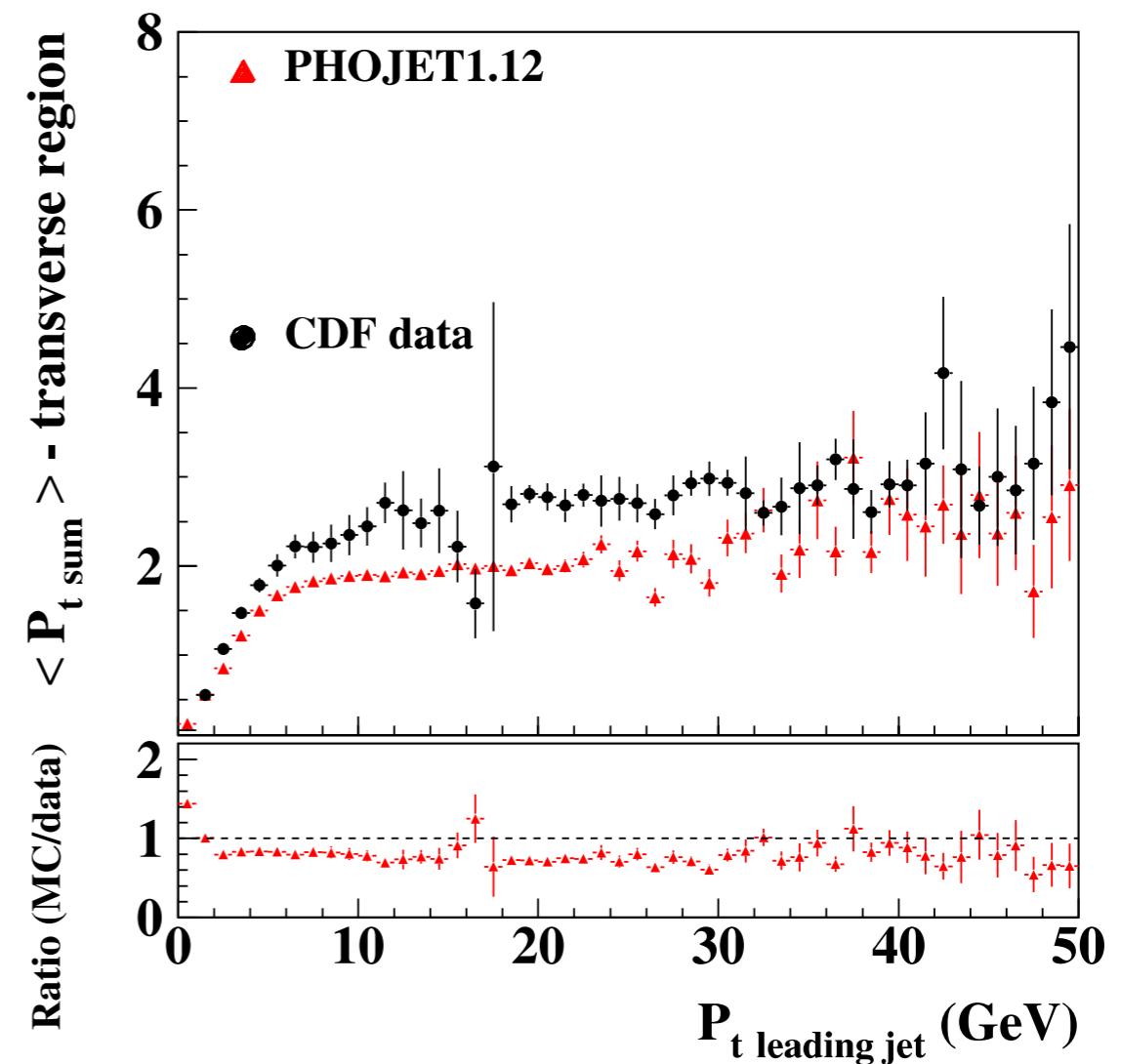
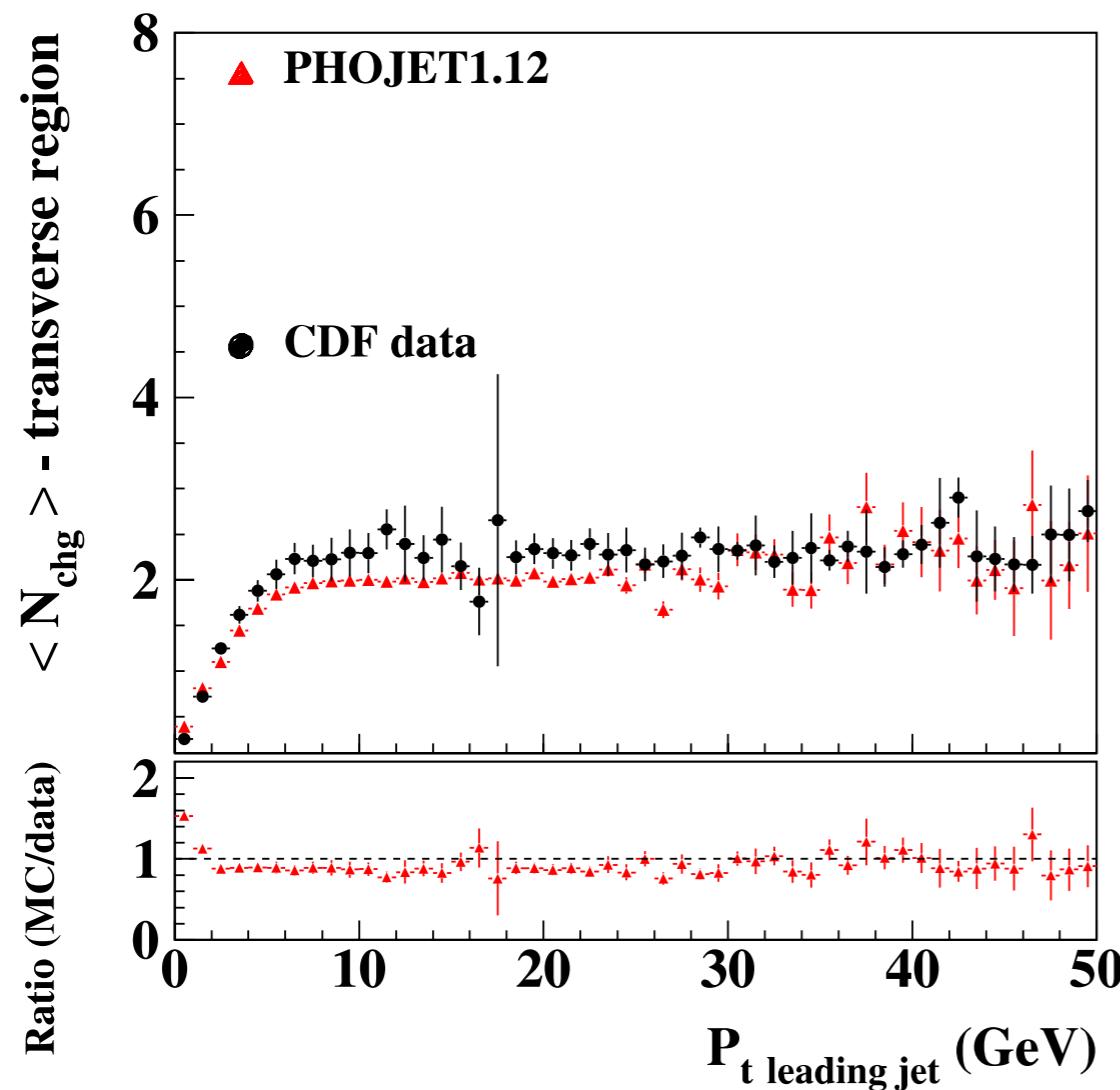


Charged particle  
pseudorapidity distributions

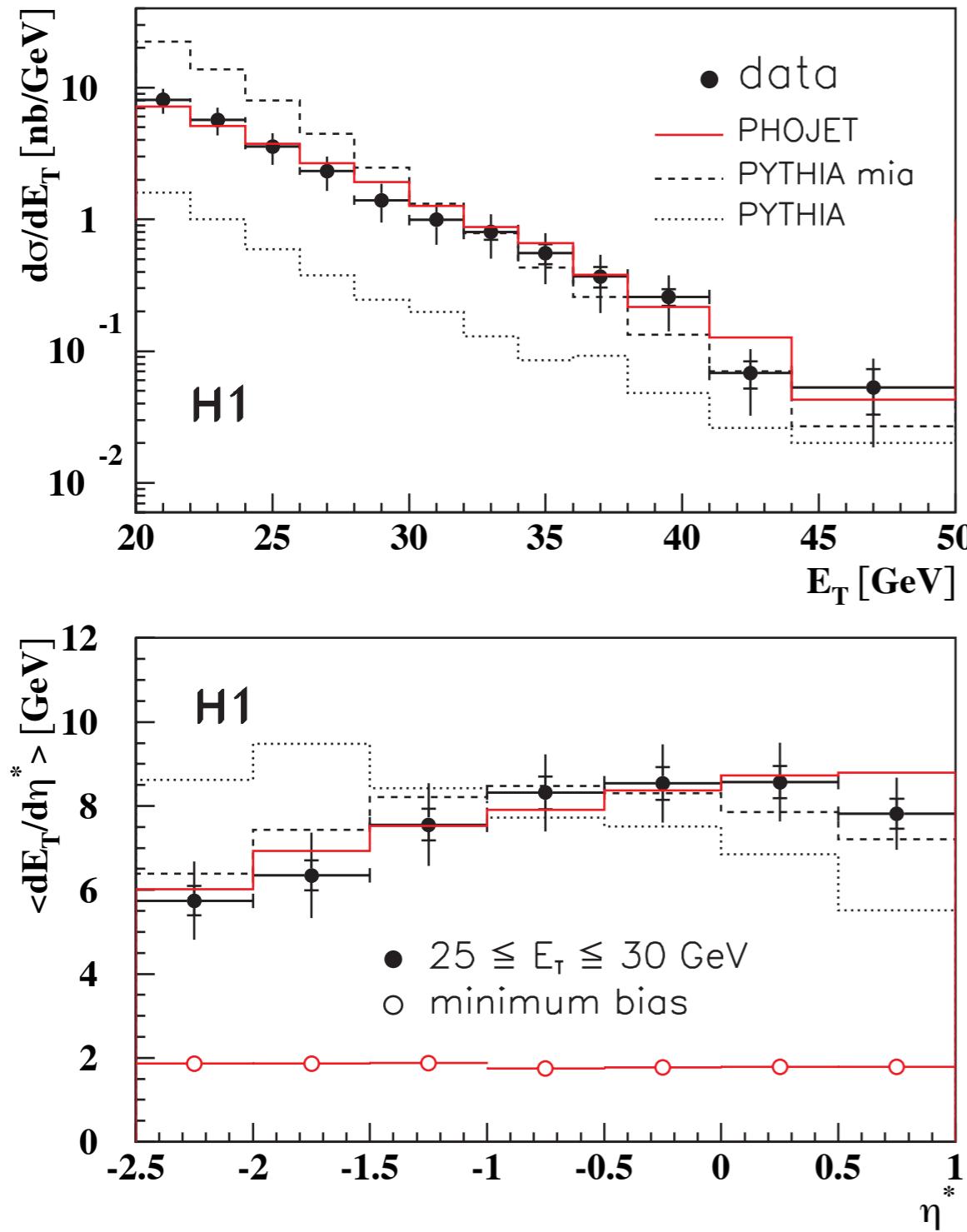
# Comparison with collider measurements



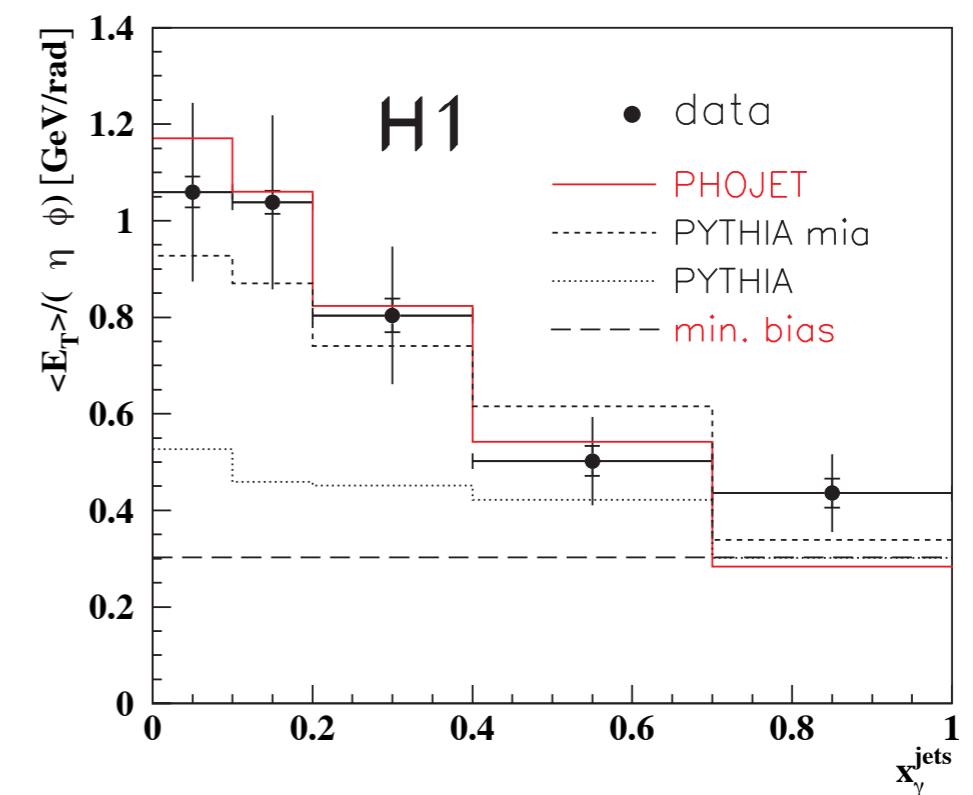
# Comparison with collider measurements



# Photoproduction at HERA



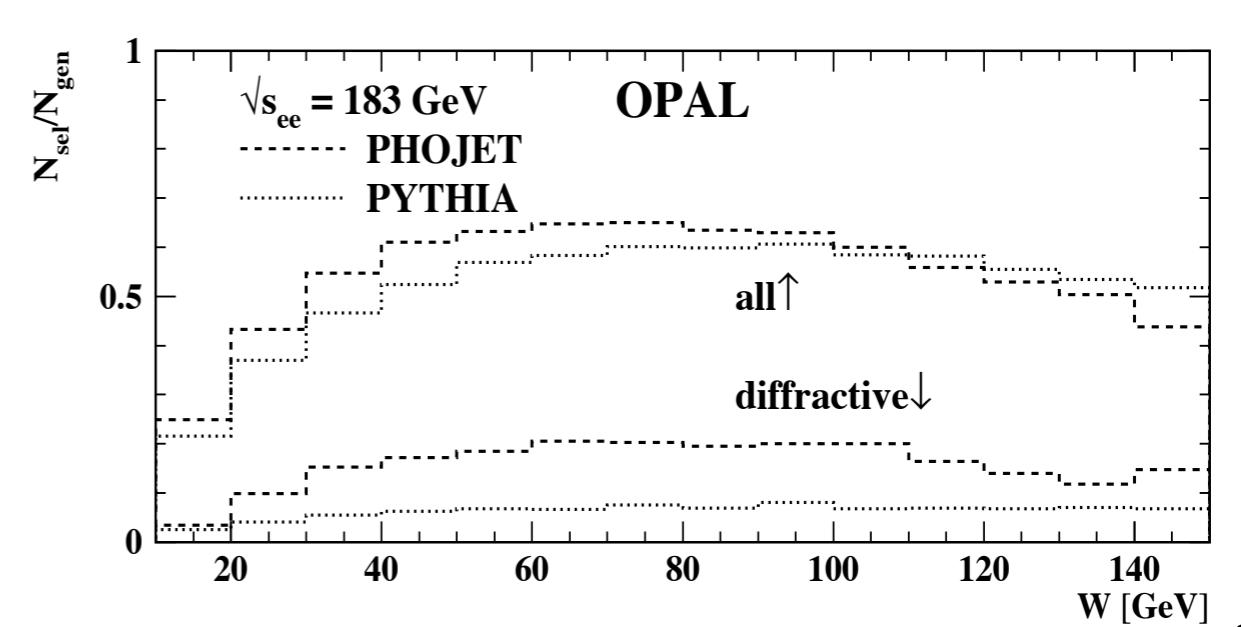
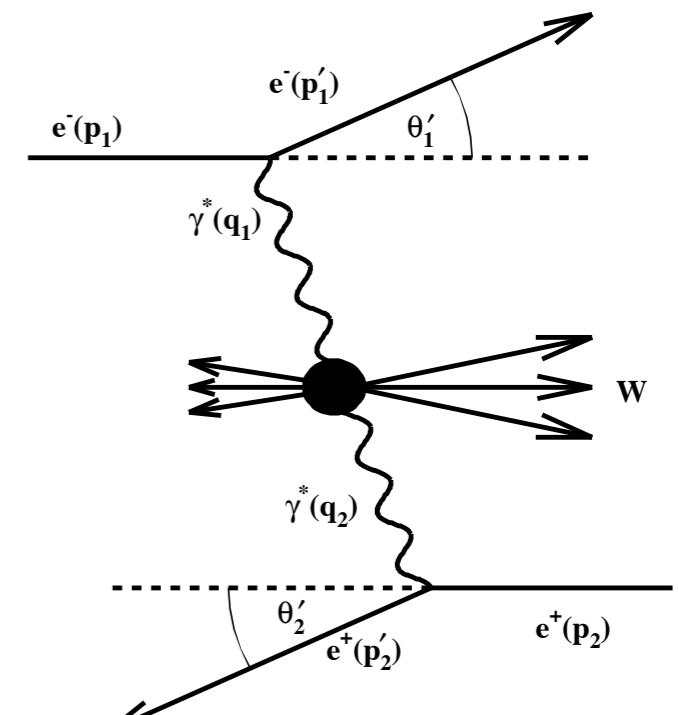
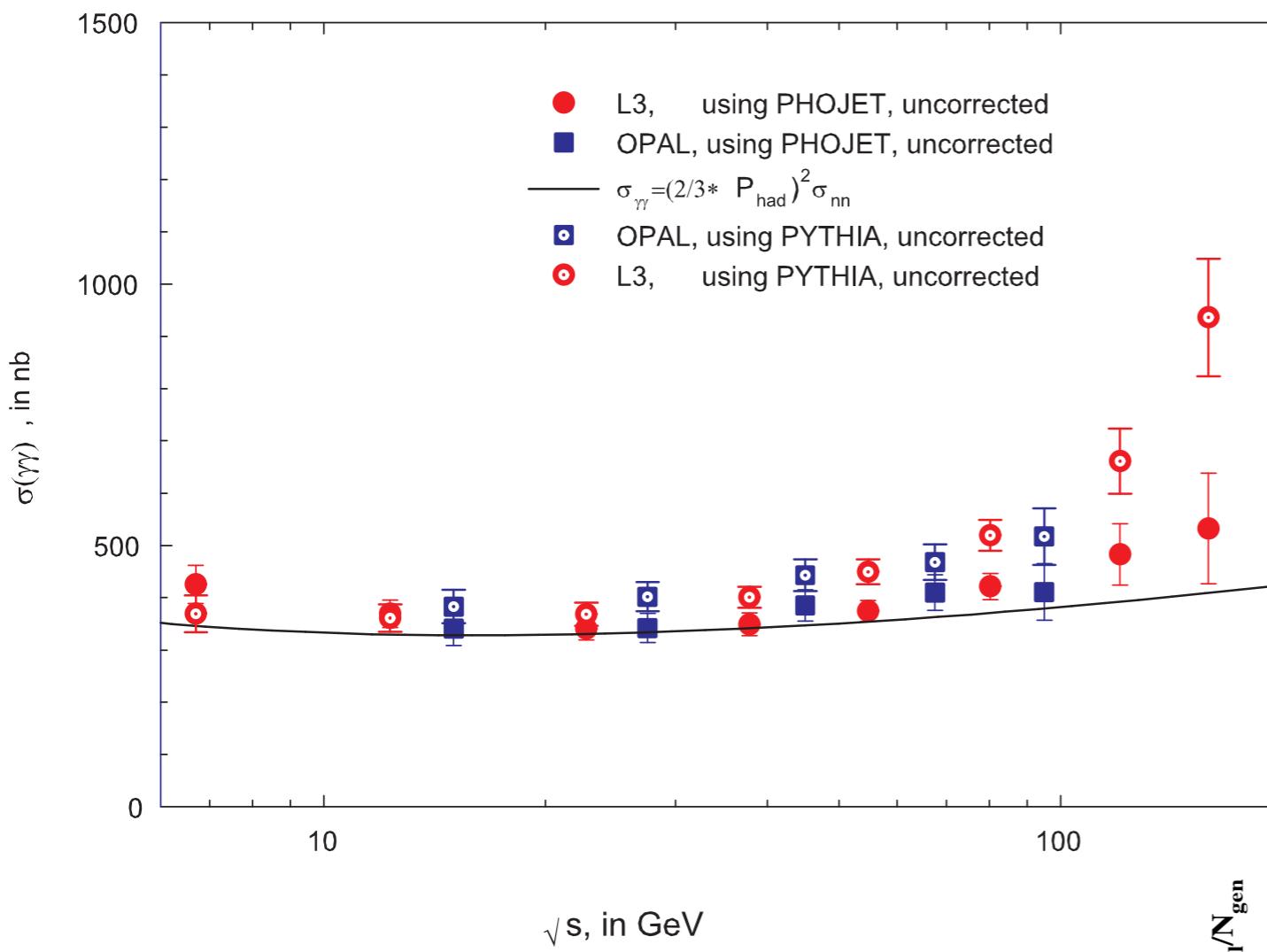
Jet and multiple interaction study by H1



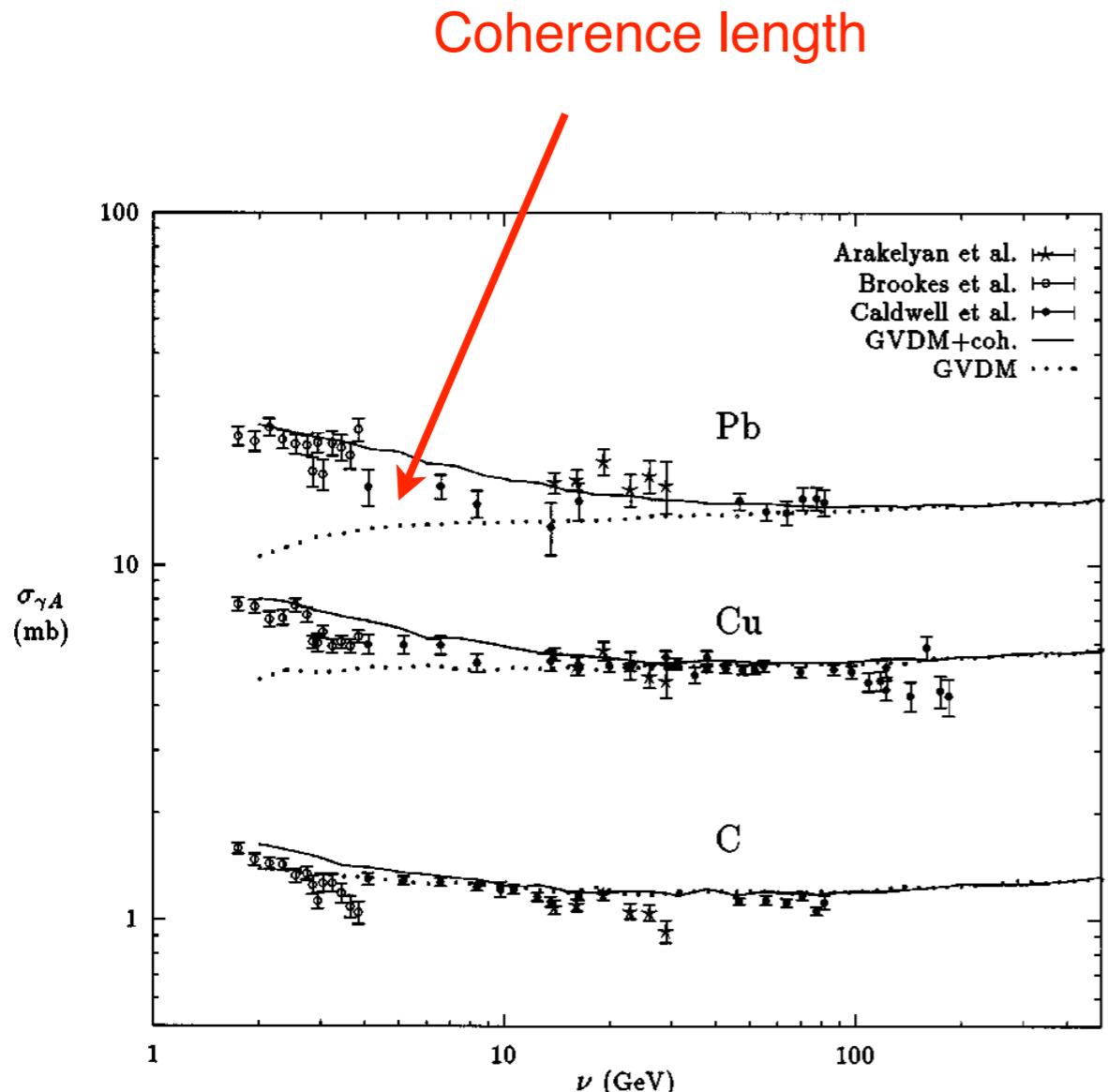
Energy density outside of jet cone,  
averaged over  $-1 \leq \eta^* \leq 1$

# Photon-photon interactions at LEP

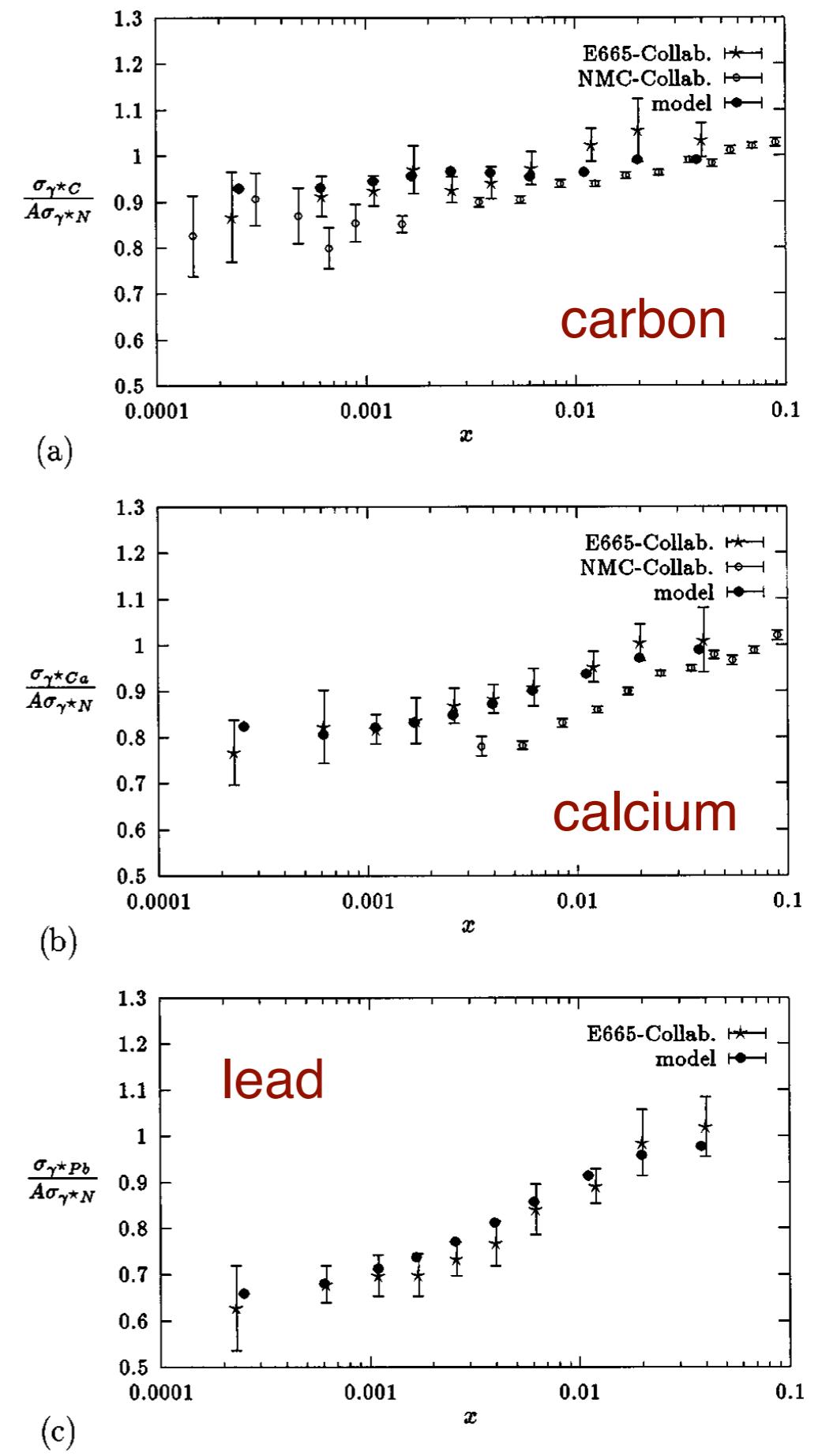
(Block & Kang, Int.J.Mod.Phys.A20, 2005)



# DPMJET: photon-nucleus cross sections

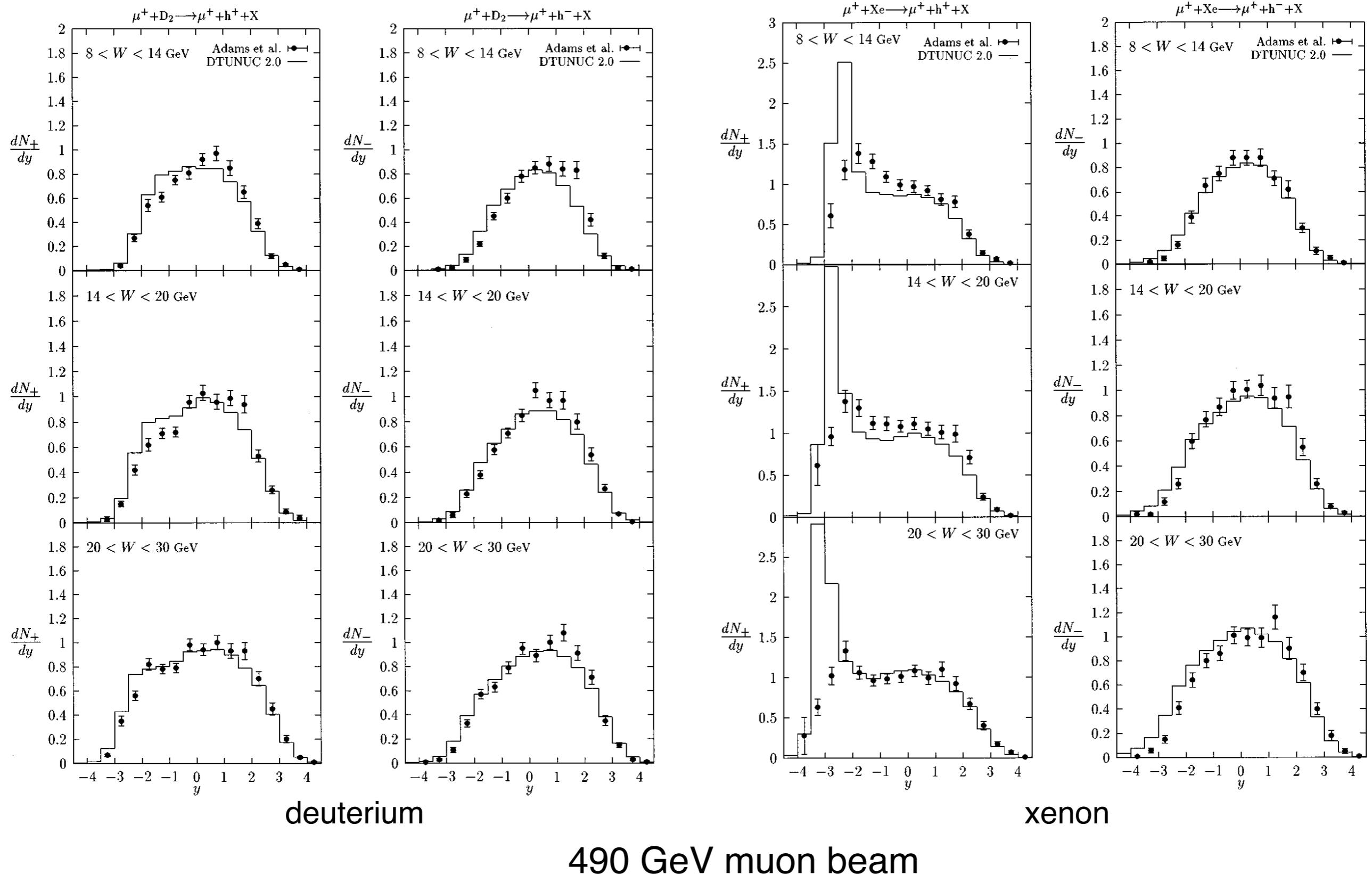


Photoproduction cross section

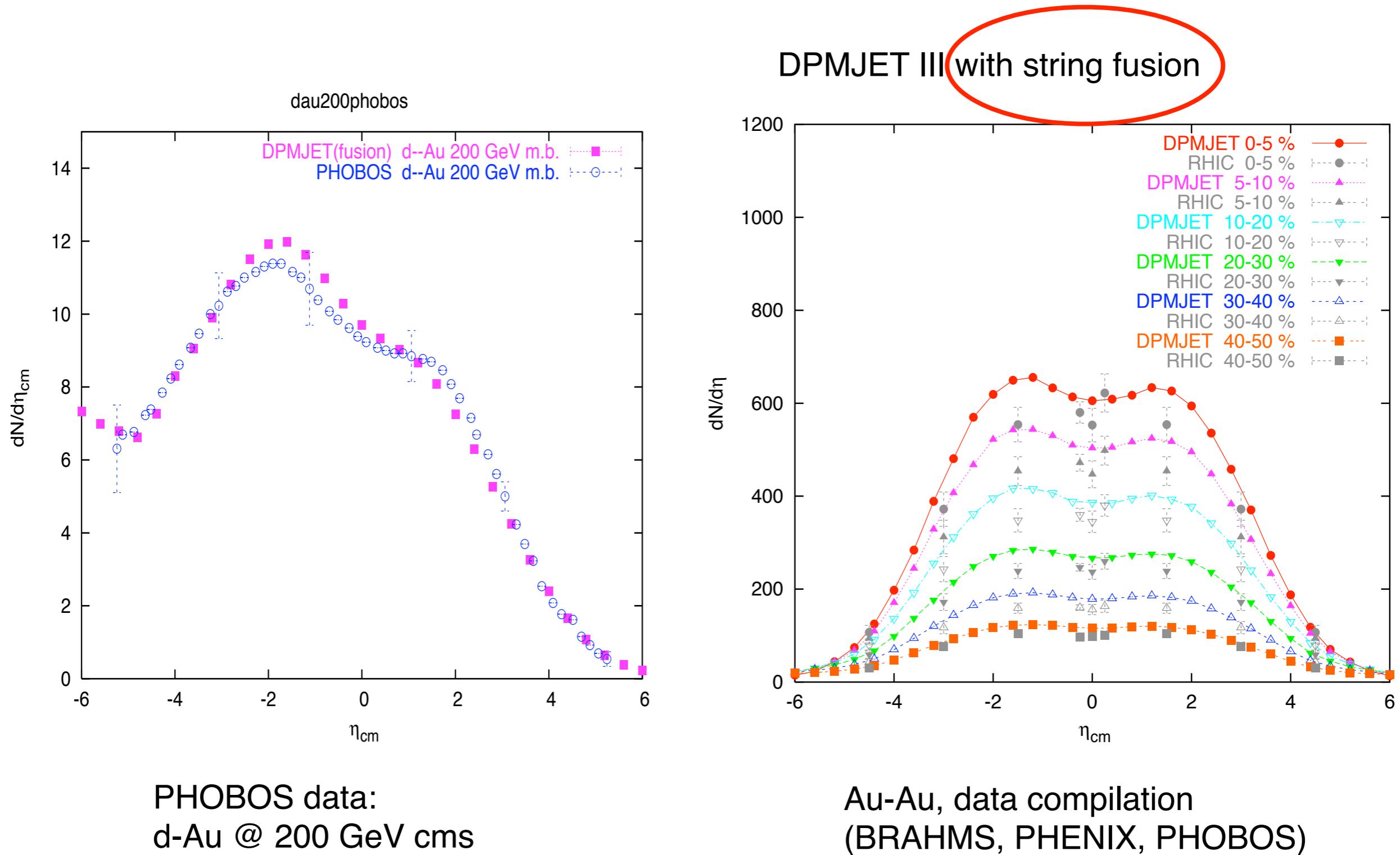


$0.15 \leq Q^2 \leq 8 \text{ GeV}^2$

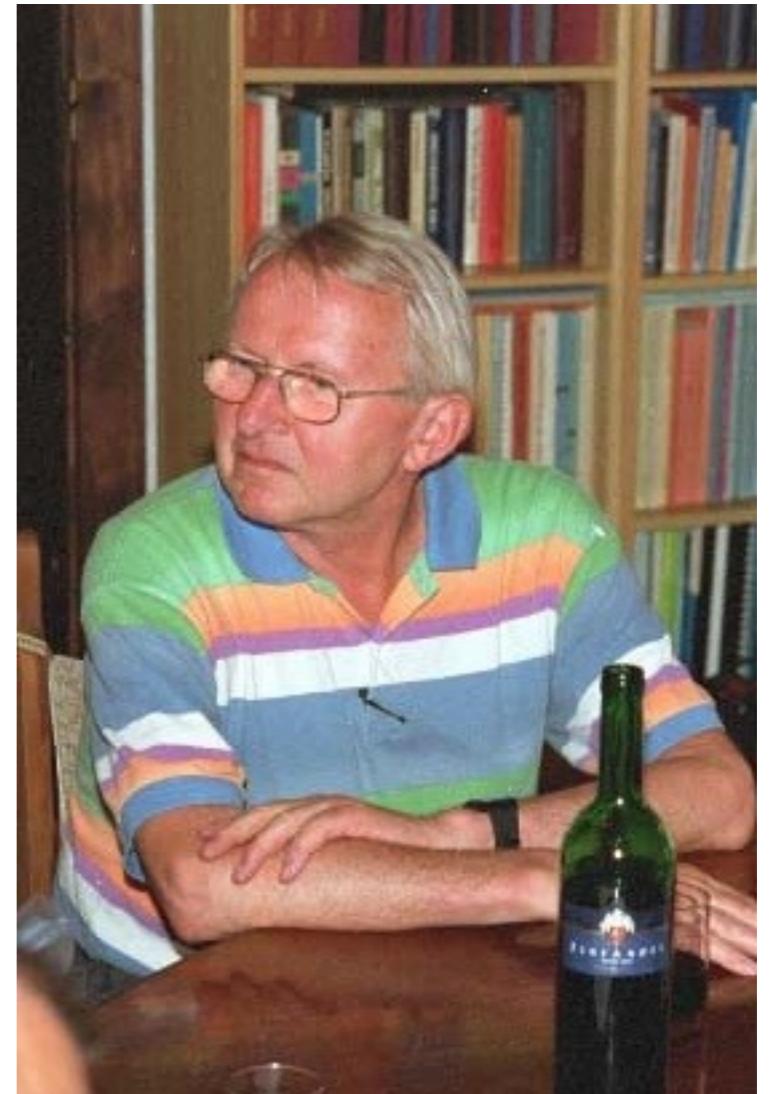
# Inclusive photoproduction on nuclei



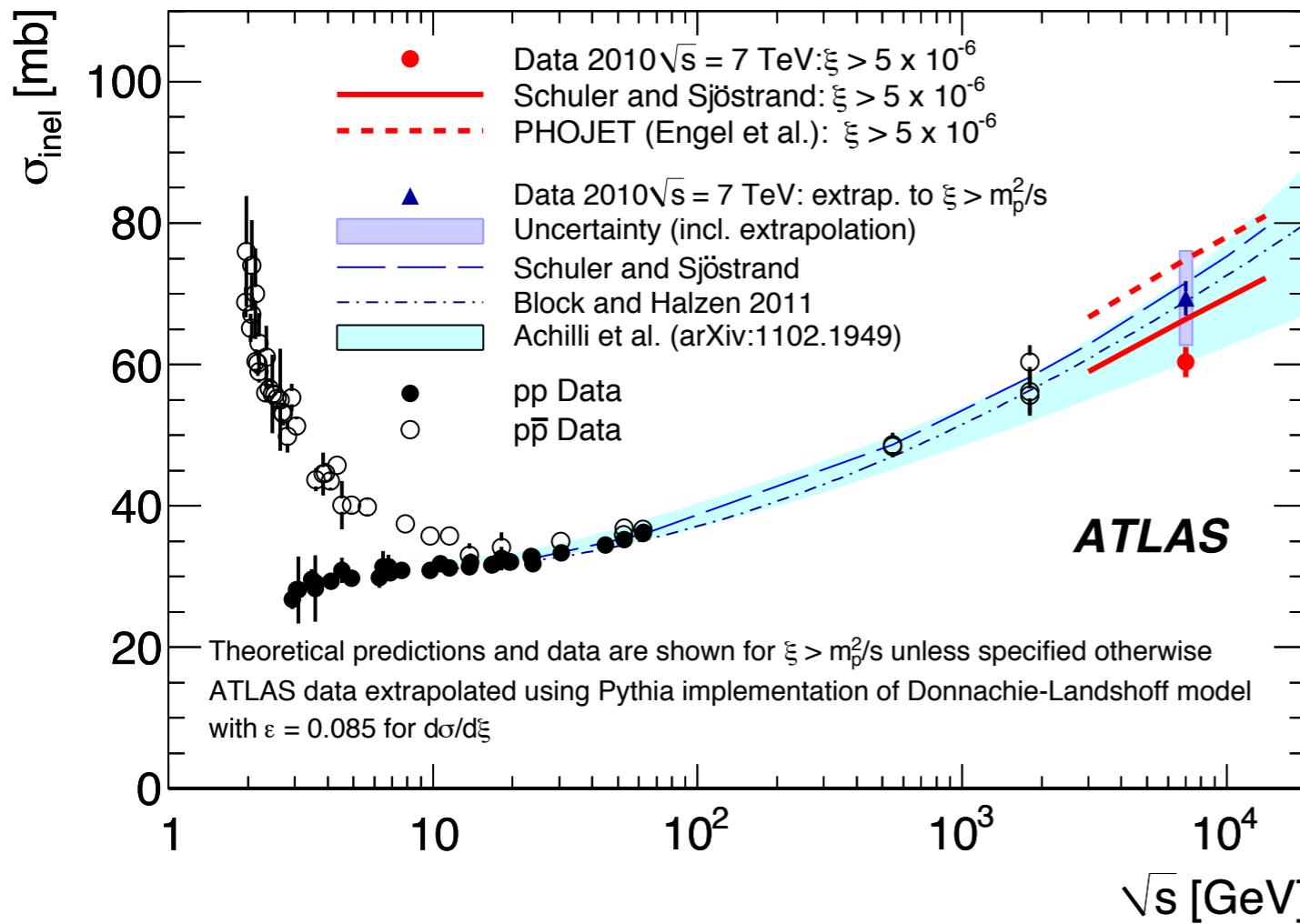
# RHIC: nucleus-nucleus data



## Comparison with LHC data

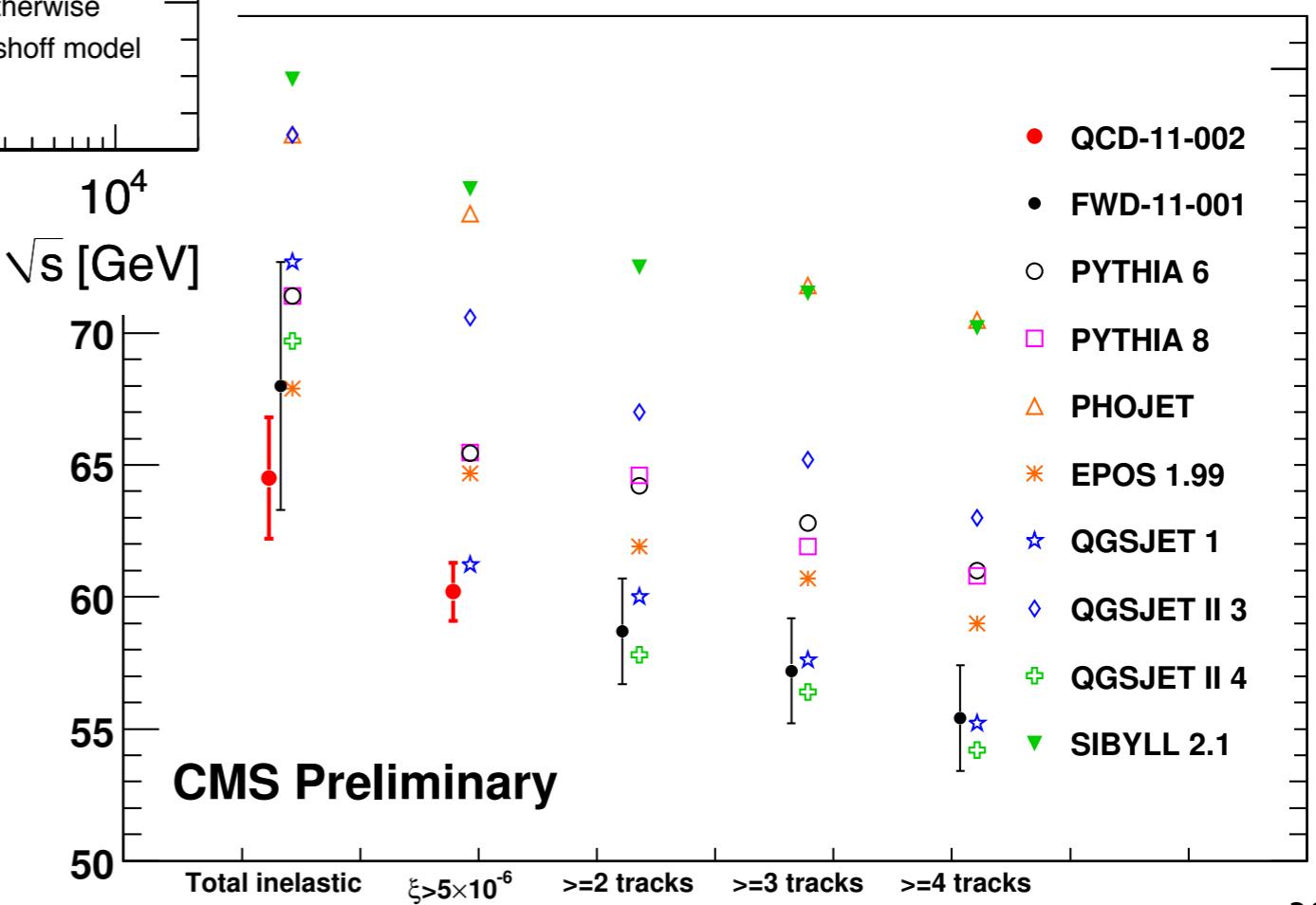


# LHC cross section measurements

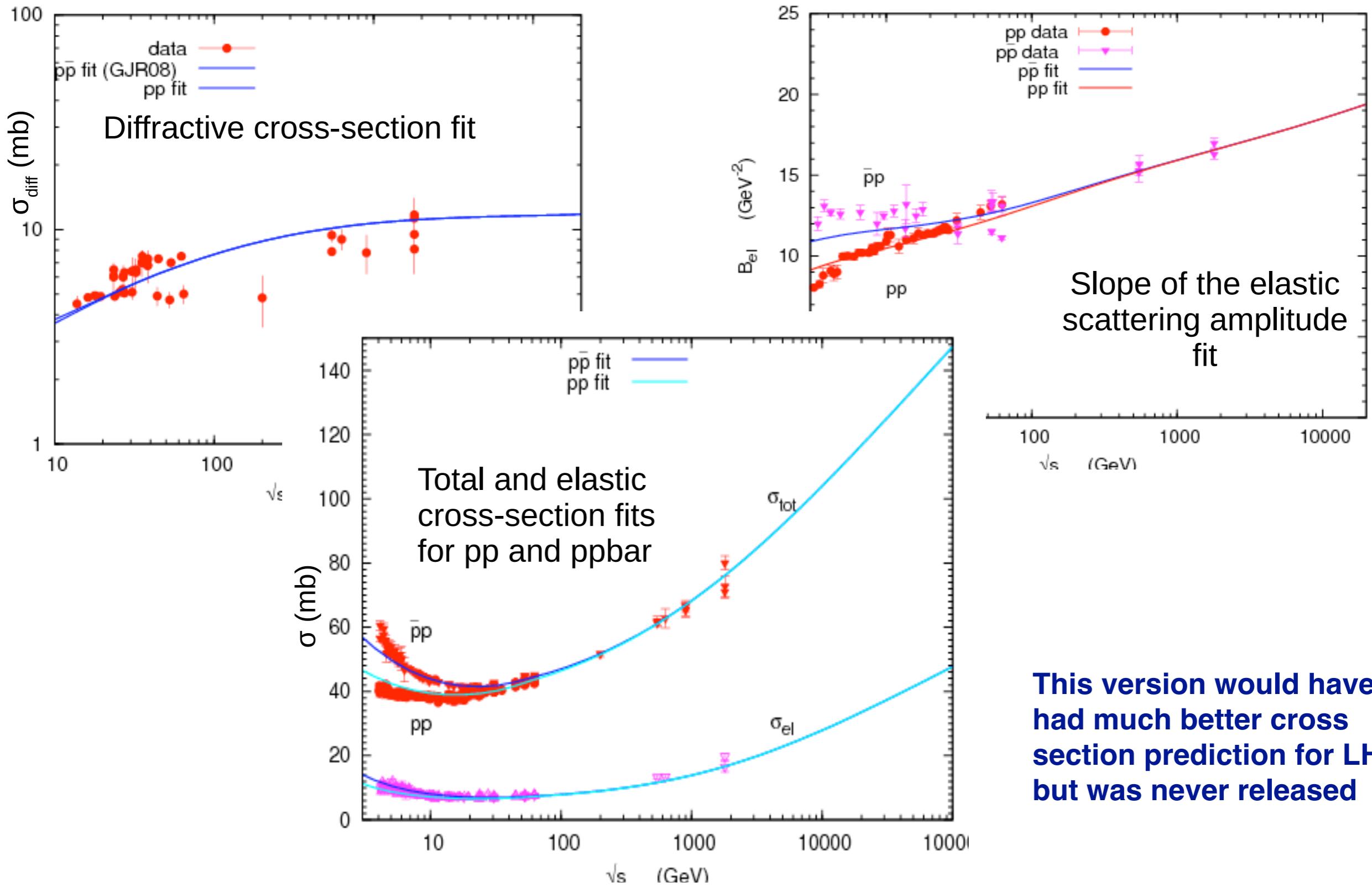


Last fit to cross section data  
made in 1997 using GRV94

Cross section too high at 7 TeV

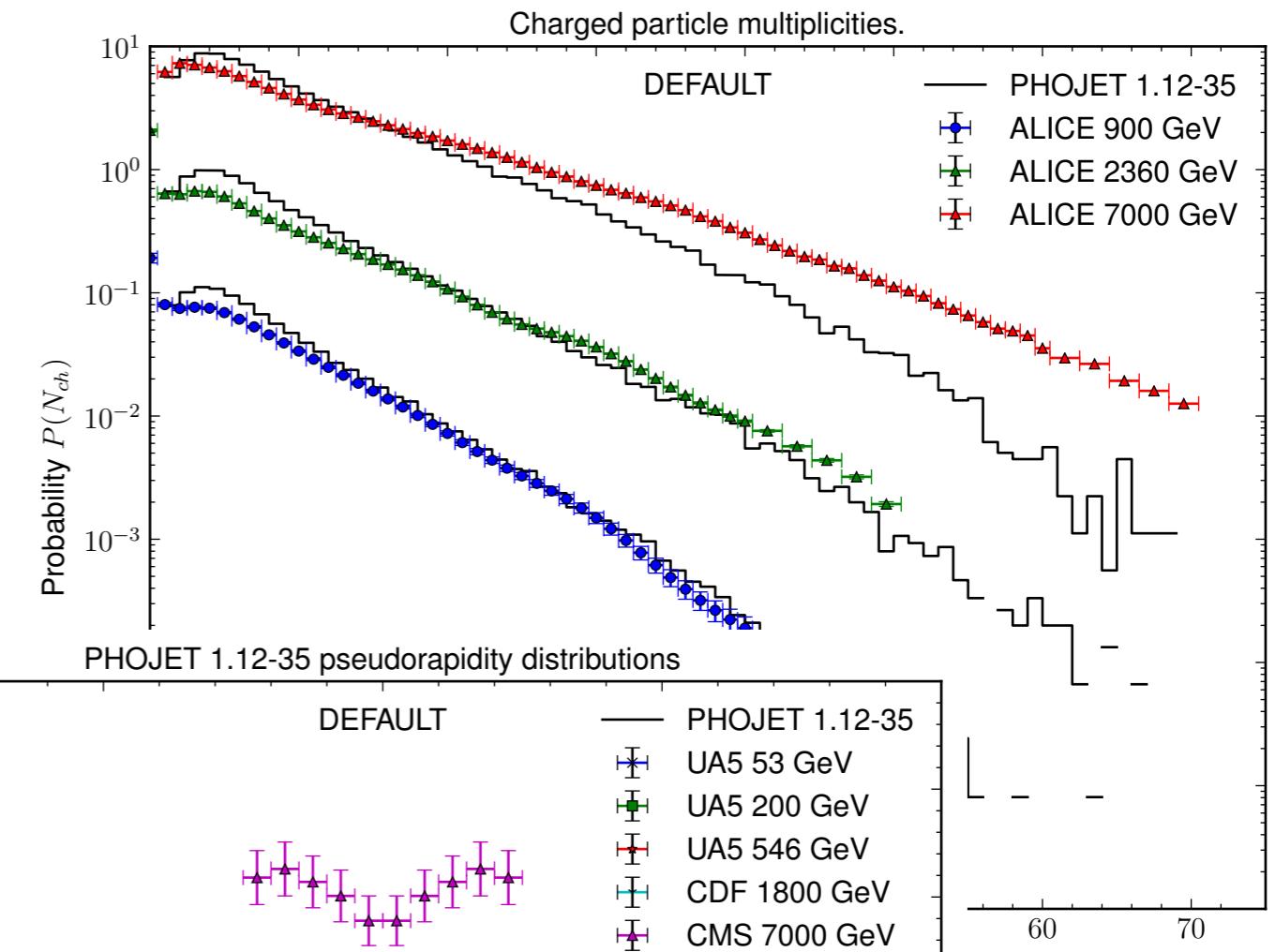
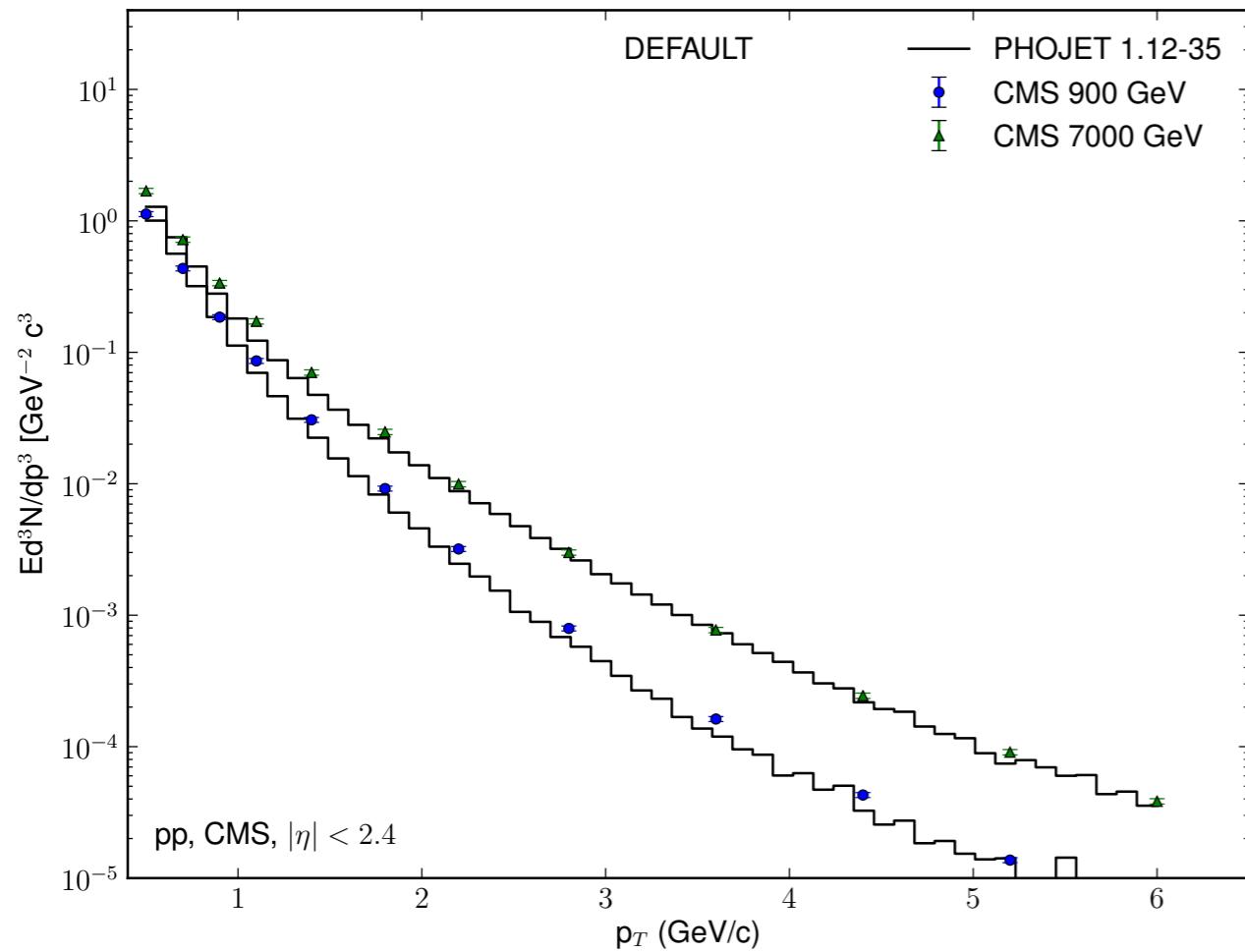


# Cross section fits (GJR08 parton densities)



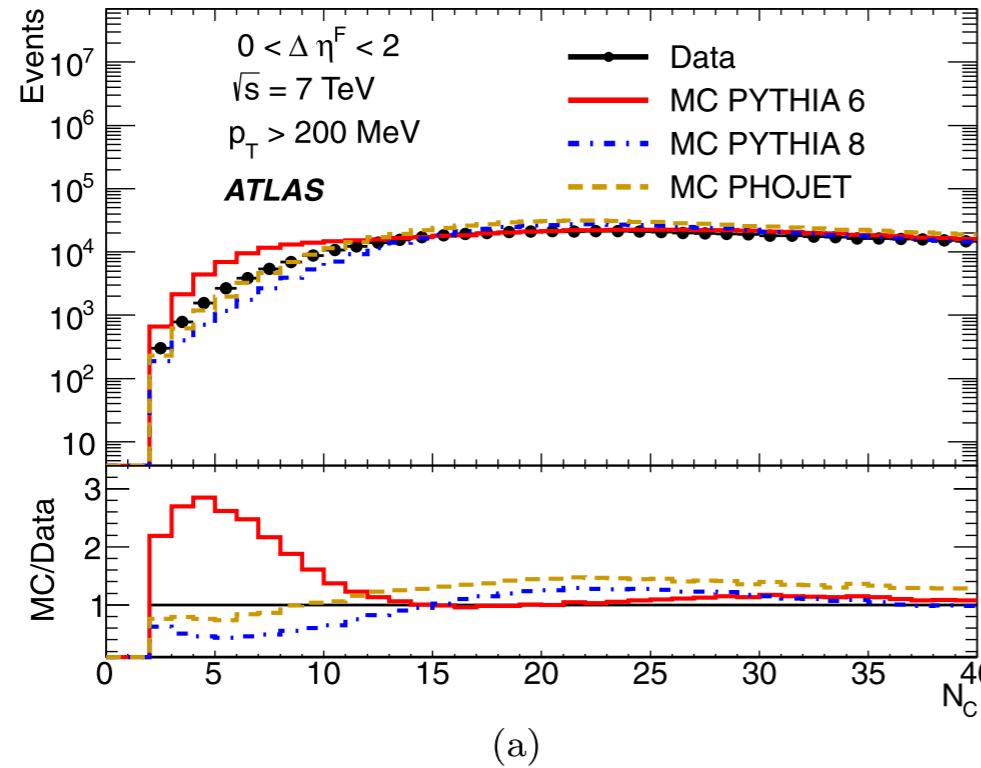
# LHC minimum bias data: proton-proton

PHOJET 1.12-35  $p_T$  spectra vs. CMS 2011 JHEP, 2011(8) (linear scale).

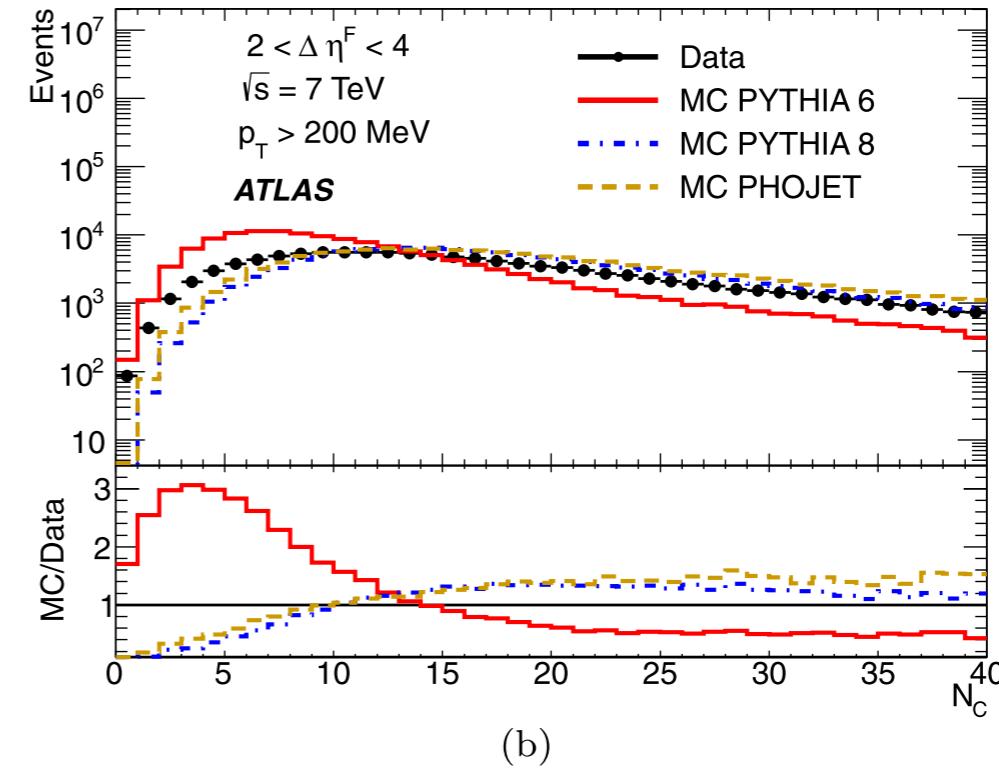


Multiplicity does not rise fast enough with energy

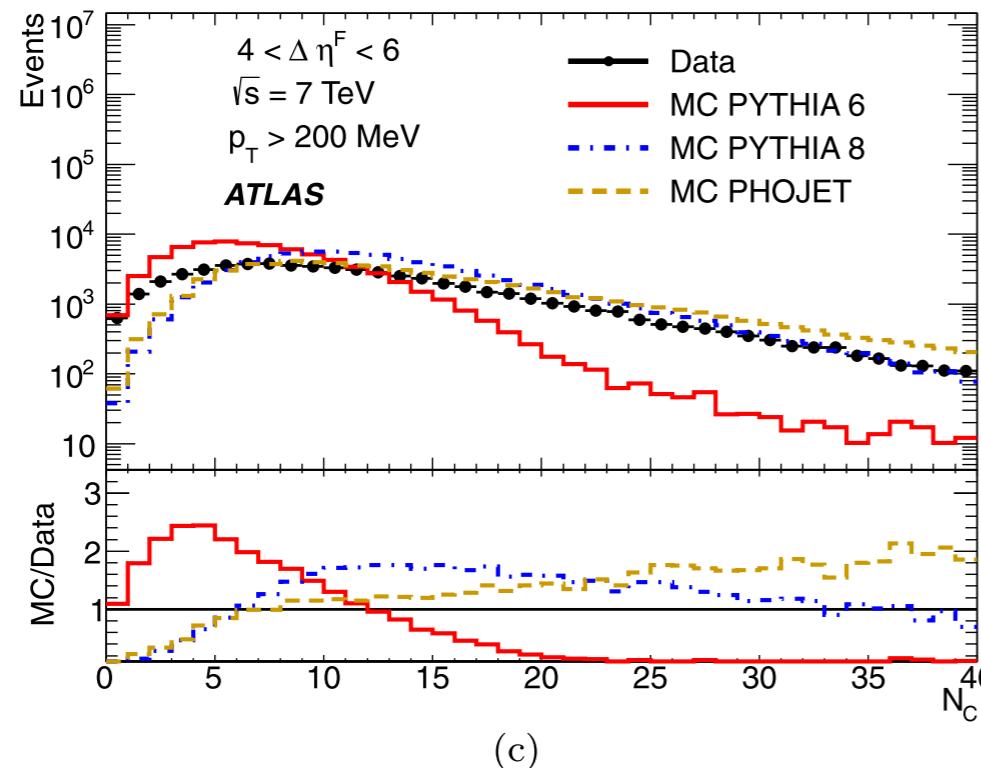
# Distributions in diffraction dissociation



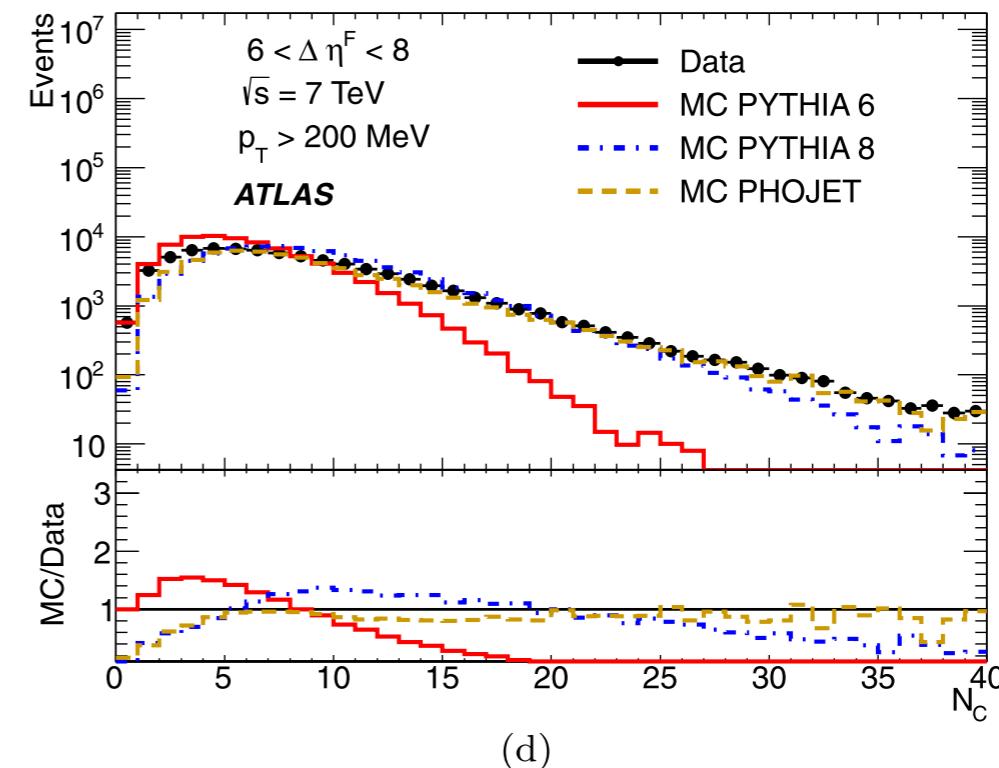
(a)



(b)



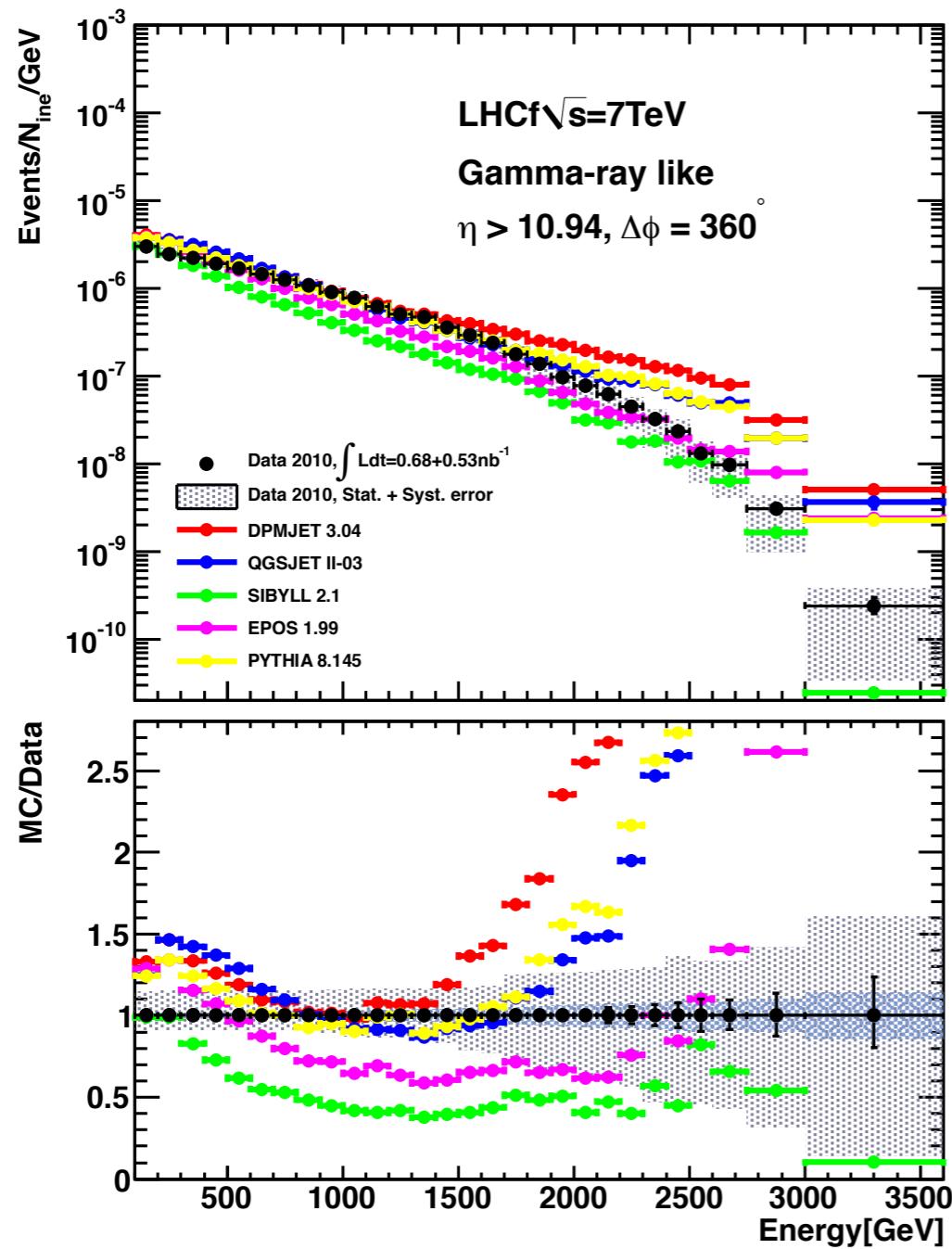
(c)



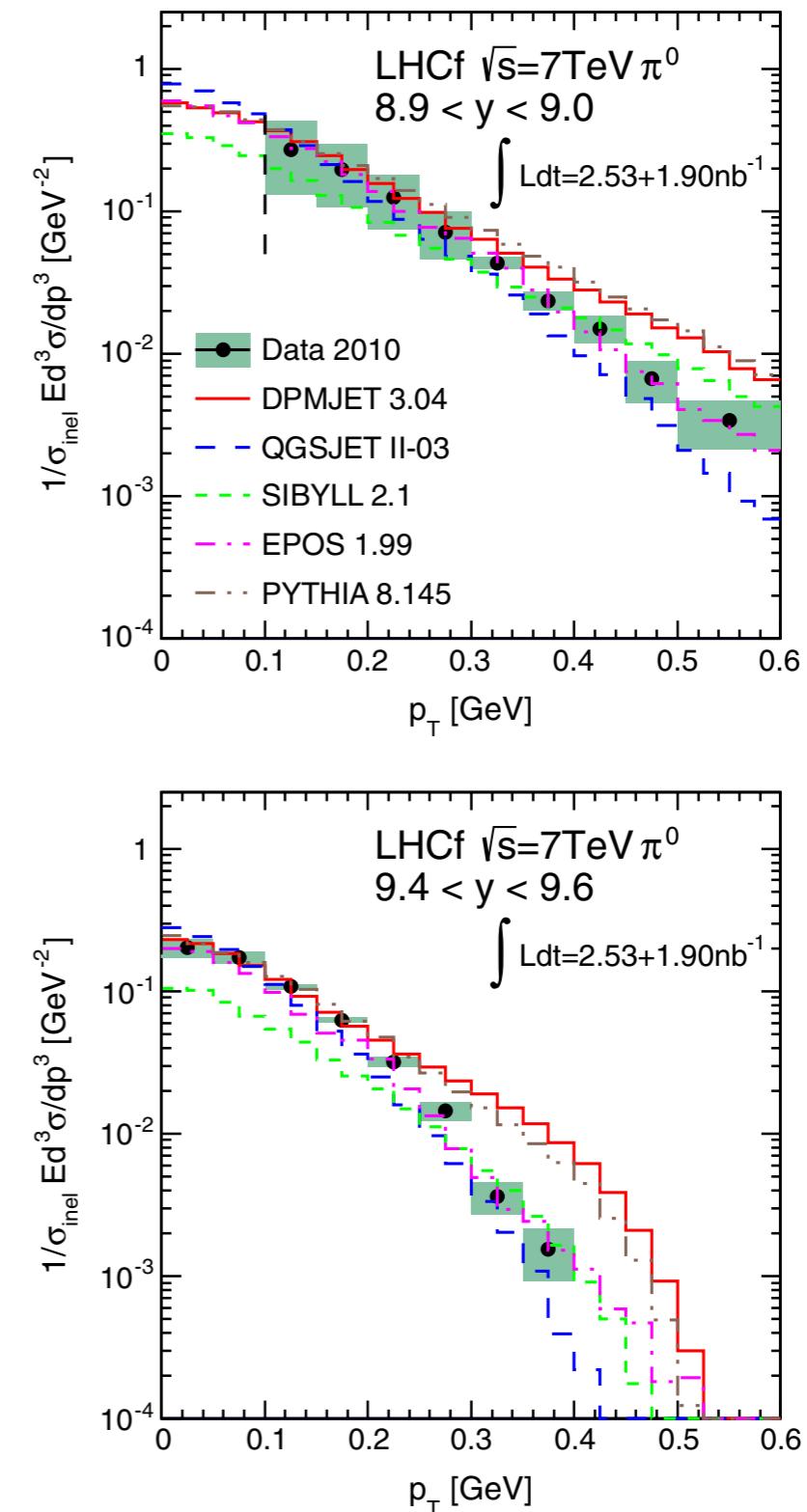
(d)

# Very forward pi0 production in p-p

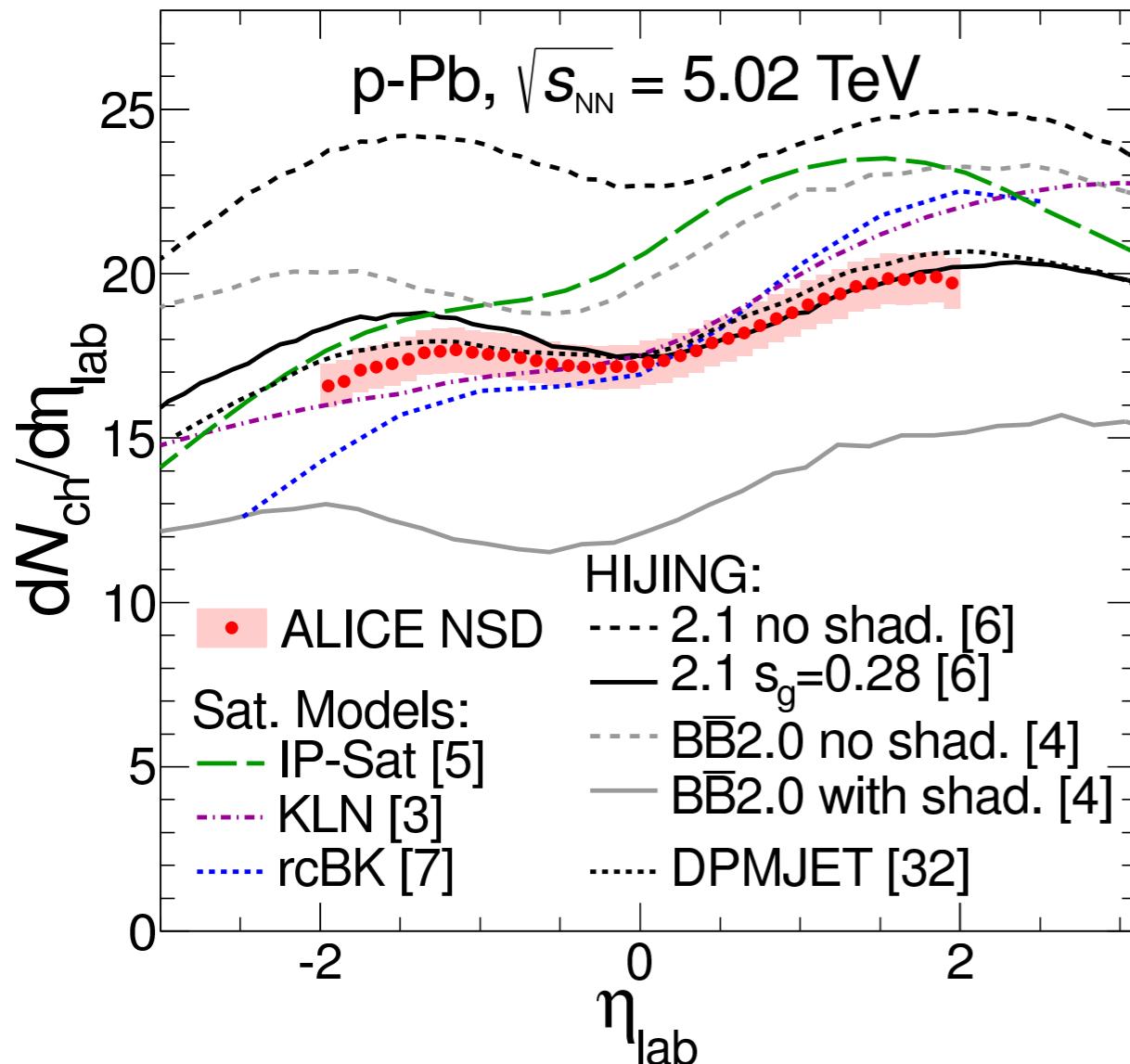
Energy distribution



Transverse momentum

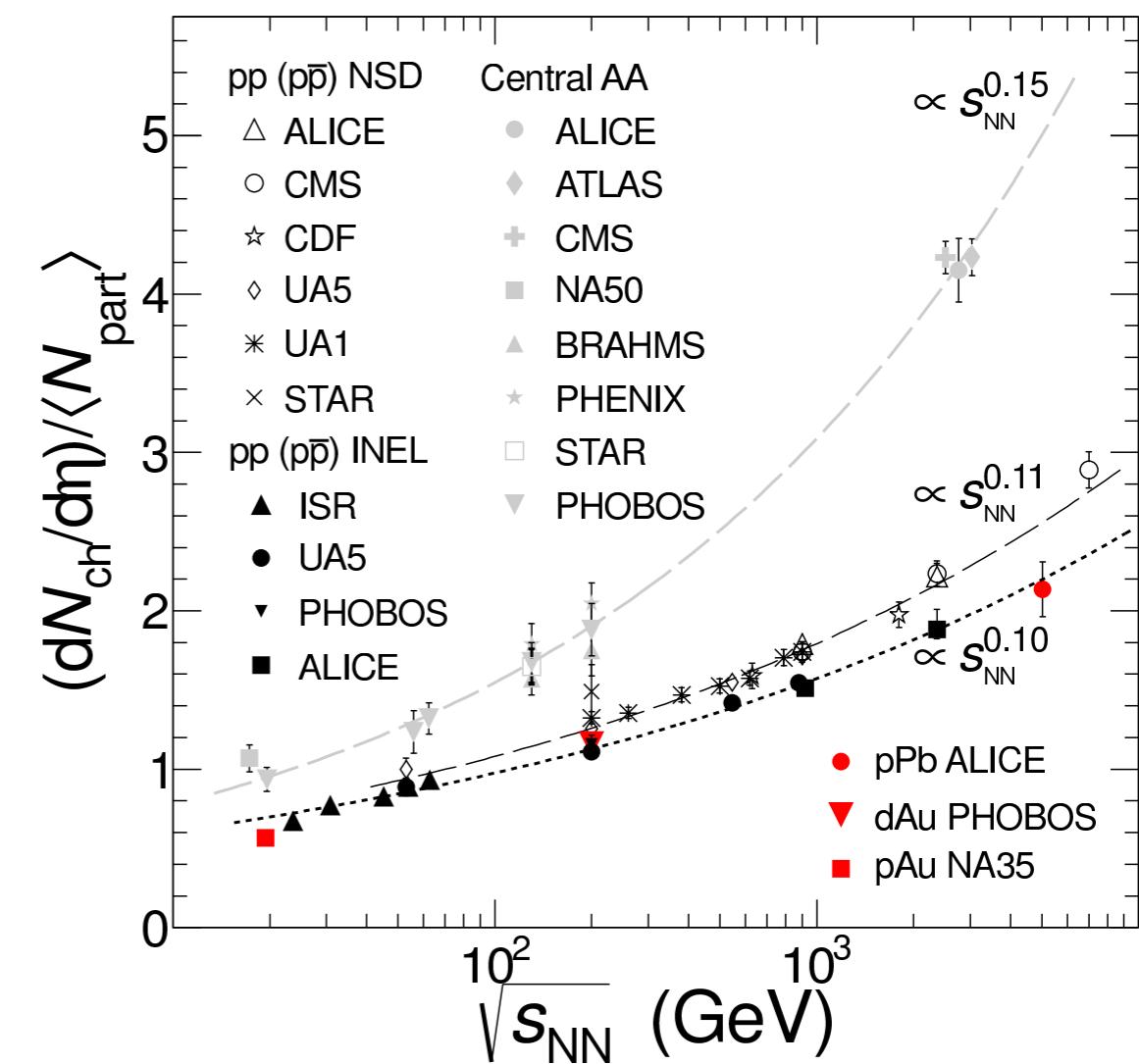


# LHC minum bias data: proton-lead multiplicity

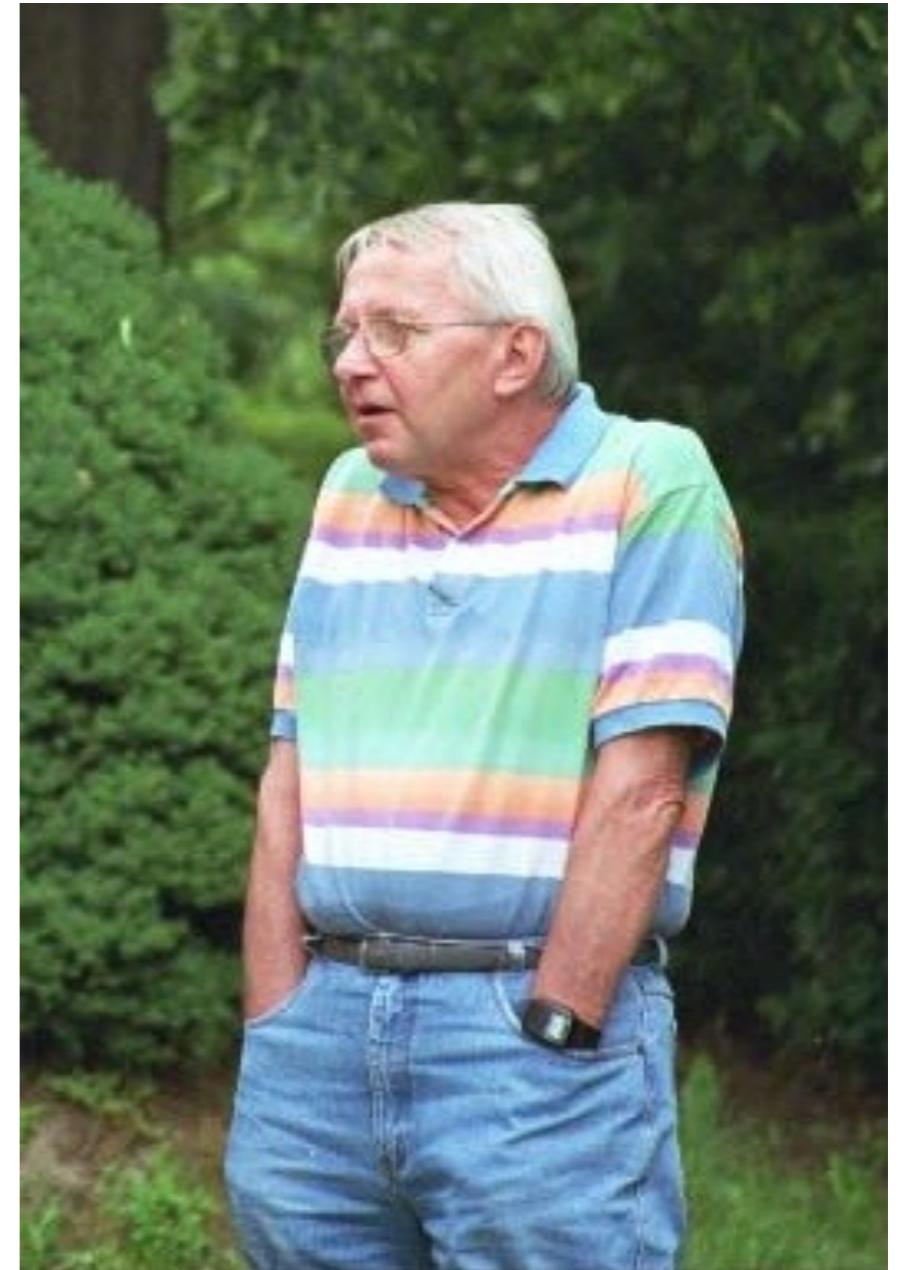


String fusion key feature of model to reproduce data

Important test still to be done:  
centrality dependence



**Towards new versions  
of PHOJET/DPMJET !**



# Pragmatic solution to allow extrapolation

PHYSICAL REVIEW D

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## New parton structure functions and minijets in the two-component dual parton model

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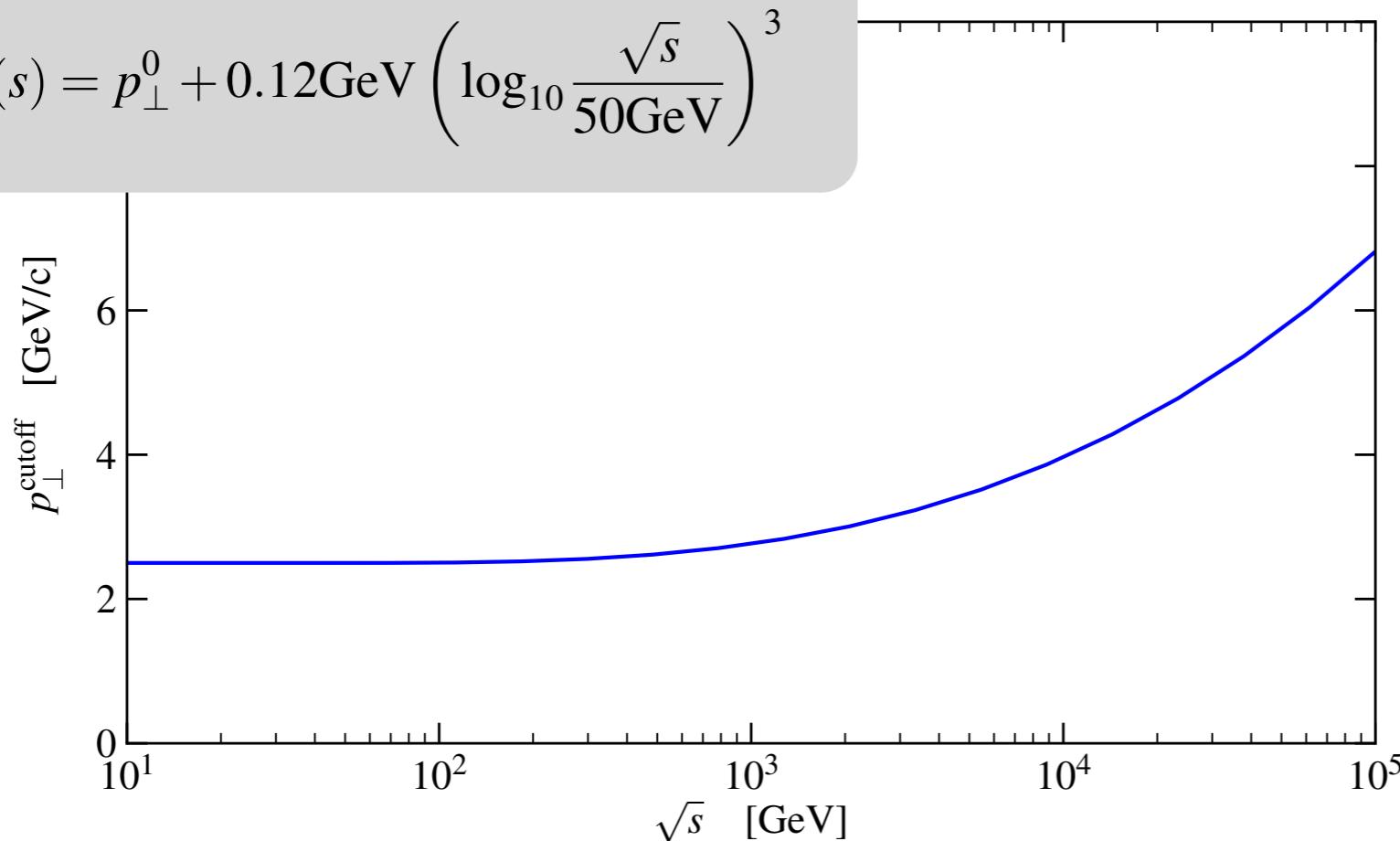
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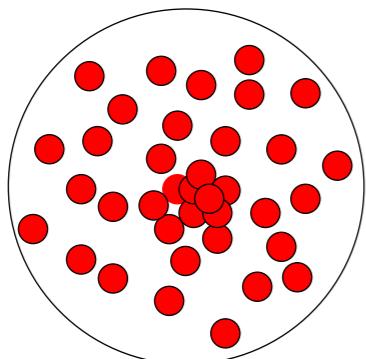
(Received 22 December 1993)

$$p_\perp(s) = p_\perp^0 + 0.12 \text{GeV} \left( \log_{10} \frac{\sqrt{s}}{50 \text{GeV}} \right)^3$$

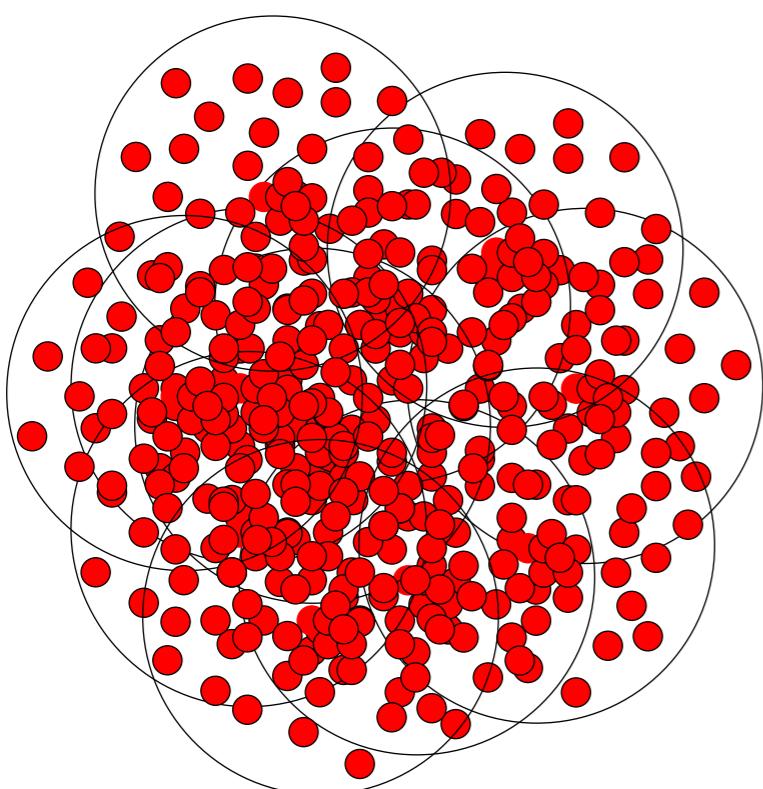


- Initially only developed for p-p interaction
- Now also used in p-A and A-A, but applicability unclear

# Microscopic model for saturation scale



nucleon



nucleus

*String fusion vs. parton saturation*

## Saturation:

- parton wave functions overlap
- number of partons does not increase anymore at low  $x$
- extrapolation to very high energy unclear

## Simple geometric criterion

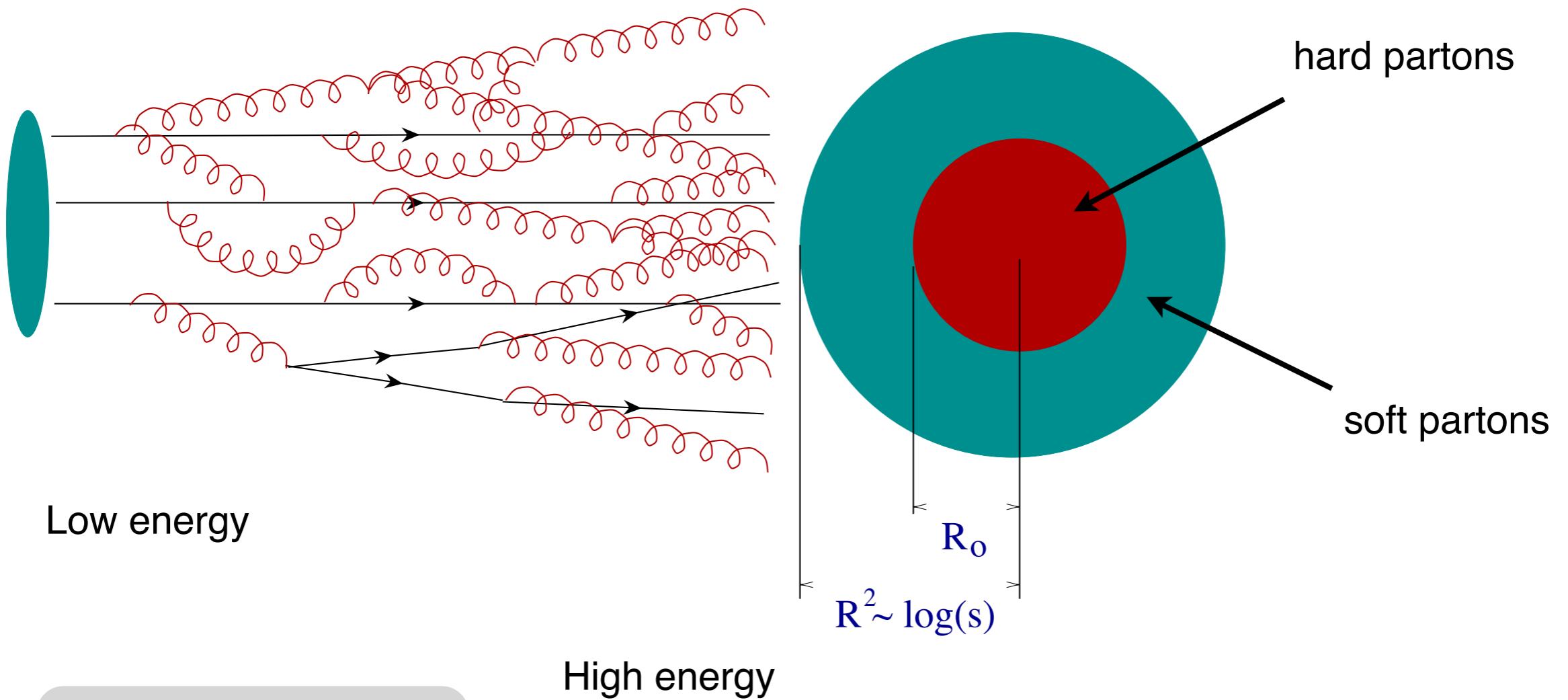
$$\pi R_0^2 \simeq \frac{\alpha_s(Q_s^2)}{Q_s^2} \cdot x g(x, Q_s^2)$$

size of proton

Size of  
one gluon

number of  
gluons

# Smooth transition of soft/hard interactions



$$\Delta \vec{b} \cdot \Delta \vec{p}_\perp \sim 1$$

$$A_{\text{soft}}(s, \vec{b}) = \frac{1}{4\pi R^2(s)} \exp \left\{ -\frac{\vec{b}^2}{4R^2(s)} \right\}$$

$$R^2(s) = R_0^2 + \alpha' \ln s$$