EVIDENCE FOR NEW PHENOMENA AT THE LHC ?

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(work done with Genya Levin and Uri Maor)

Outline

- GLMM model for high energy soft interactions incorporating multi eikonal scattering plus multi-Pomeron vertices.
- Comparison with competing models
- Inclusive distributions - Model Predictions - Monte Carlo - Experimental Results
- Summary

Good-Walker Formalism

Diffractively produced hadrons at a given vertex are considered as a single hadronic state described by the wave function Ψ_D, which is orthonormal to the wave function Ψ_h of the incoming hadron (proton in the case of interest)

$$< \Psi_h | \Psi_D >= 0$$

We introduce two wave functions ψ_1 and ψ_2 that diagonalize the 2x2 interaction matrix $\mathbf{T}$

$$A_{i,k} =< \psi_i \, \psi_k | \mathbf{T} | \psi_{i'} \, \psi_{k'} >= A_{i,k} \, \delta_{i,i'} \, \delta_{k,k'}.$$

In this representation the observed states are written in the form

$$\psi_h = \alpha \, \psi_1 + \beta \, \psi_2 \, ,$$

$$\psi_D = -\beta \, \psi_1 + \alpha \, \psi_2$$

where, $\alpha^2 + \beta^2 = 1$

Good-Walker Formalism-2

Unitarity constraints:

$$Im\,A_{i,k}\,(s,b) = |A_{i,k}\,(s,b)\,|^2 + G^{in}_{i,k}(s,b),$$

$G^{in}_{i,k}$ is the contribution of all non diffractive inelastic processes i.e. it is the summed probability for these final states to be produced in the scattering of particle i off particle k.

A simple solution to the above equation is:

$$A_{i,k}(s,b) = i\left(1 - \exp\left(-\frac{\Omega_{i,k}(s,b)}{2}\right)\right),$$

$$G^{in}_{i,k}(s,b) = 1 - \exp\left(-\Omega_{i,k}(s,b)\right).$$

Good-Walker Formalism-3

Note

$$P^S_{i,k} = \exp\left(-\Omega_{i,k}(s,b)\right)$$

is the probability that the initial projectiles (i,k) reach the final state interaction unchanged, regardless of the initial state rescatterings, (i.e. no inelastic interactions).

Amplitudes in two channel formalism are:

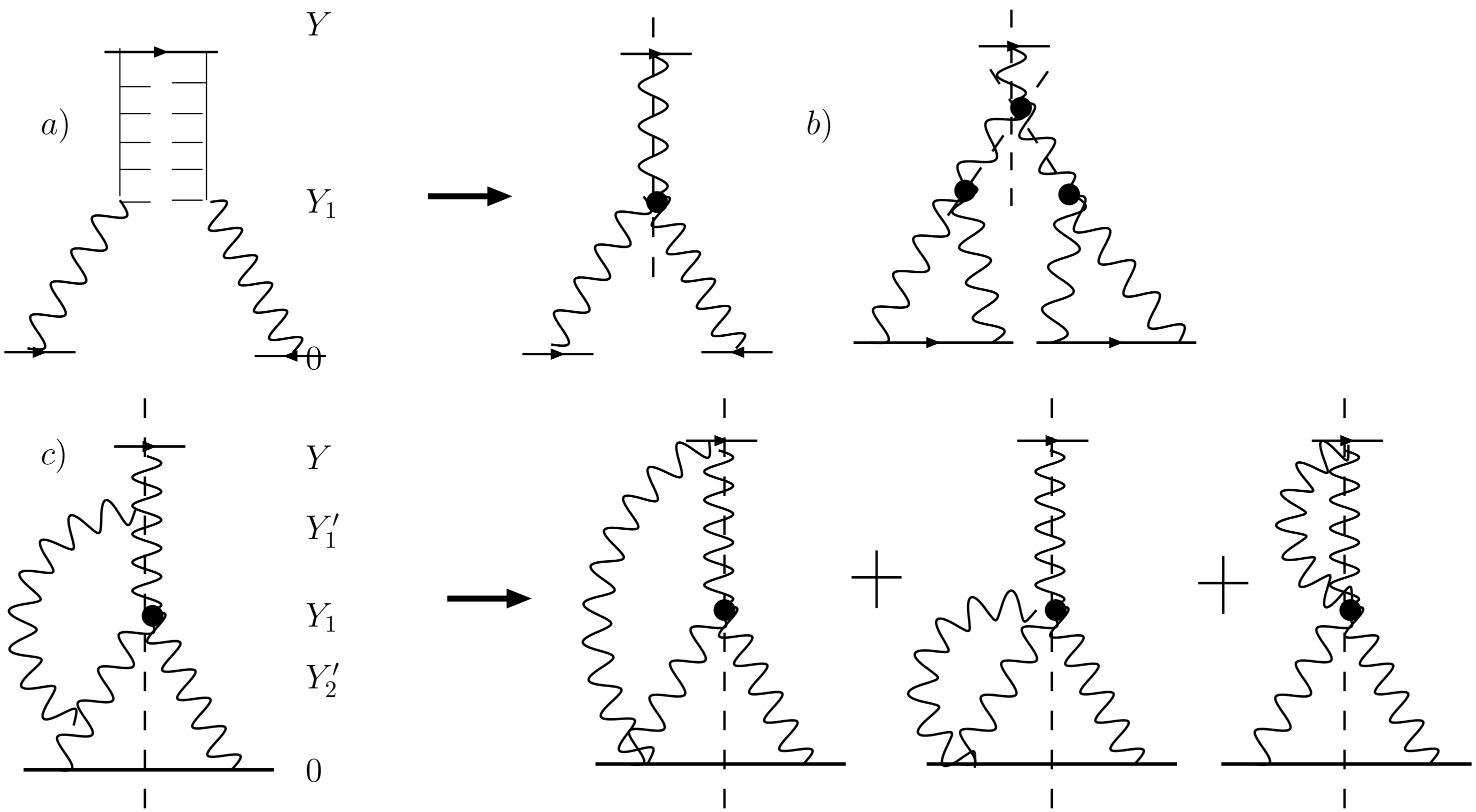
$$a_{el}(s,b) = i\{\alpha^4 A_{1,1} + 2\alpha^2\beta^2 A_{1,2} + \beta^4 A_{2,2}\},$$

$$a_{sd}(s,b) = i\alpha\beta\{-\alpha^2 A_{1,1} + (\alpha^2 - \beta^2)A_{1,2} + \beta^2 A_{2,2}\},$$
$$a_{dd}(s,b) = i\alpha^2\beta^2\{A_{1,1} - 2A_{1,2} + A_{2,2}\}.$$

With the G-W mechanism σ_{el} , σ_{sd} and σ_{dd} occur due to elastic scattering of ψ_1 and ψ_2, the correct degrees of freedom.

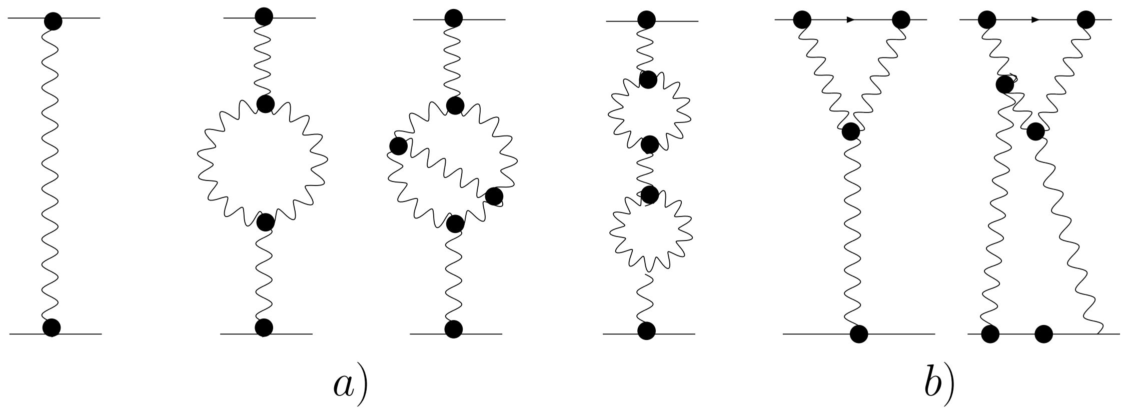
Examples of Pomeron diagrams

leading to diffraction NOT included in G-W mechanism



Examples of the Pomeron diagrams that lead to a different source of the diffractive dissociation that cannot be described in the framework of the G-W mechanism. (a) is the simplest diagram that describes the process of diffraction in the region of large mass $Y - Y_1 = \ln(M^2/s_0)$. (b) and (c) are examples of more complicated diagrams in the region of large mass. The dashed line shows the cut Pomeron, which describes the production of hadrons.

Example of enhanced and semi-enhanced diagram



Different contributions to the Pomeron Green's function
a) examples of enhanced diagrams (which are included); b) examples of semi-enhanced diagrams (which have not yet been included in most of our calculations)
Multi-Pomeron interactions are crucial for the production of LARGE MASS DIFFRACTION

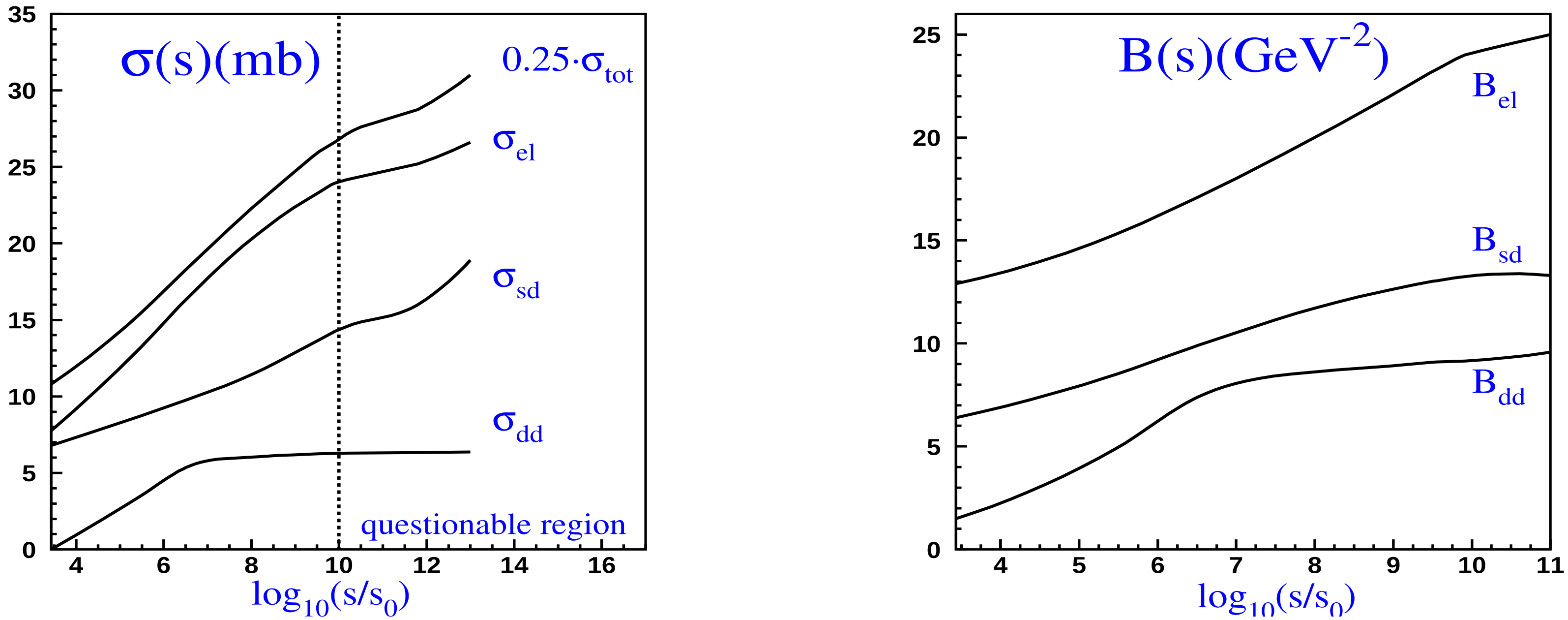
Parameters for our model fit includes G-W PLUS enhanced Pomeron diagrams

$\Delta_{I\!P}$	β	$\alpha'_{I\!P}$	g_1	g_2	m_2	m_1
0.335	0.339	0.012 GeV^{-2}	5.82 GeV^{-1}	239.6 GeV^{-1}	1.54 GeV	3.06 GeV
$\Delta_{I\!R}$	γ	$\alpha'_{I\!R}$	$g_1^{I\!R}$	$g_2^{I\!R}$	$R^2_{0,1}$	$\chi^2/d.o.f.$
- 0.60	0.0242	0.6 GeV^{-2}	13.22 GeV^{-1}	367.8 GeV^{-1}	4.0	1.0

For comparison parameters for the two channel model fit
(only G-W processes)

$\Delta_{I\!P}$	β	$\alpha'_{I\!P}$	g_1	g_2	m_1	m_2
0.120	0.46	0.012 GeV^{-2}	1.27 GeV^{-1}	3.33 GeV^{-1}	0.913 GeV	0.98 GeV
$\Delta_{I\!R}$	β	$\alpha'_{I\!R}$	$g_1^{I\!R}$	$g_2^{I\!R}$	$R^2_{0,1}$	$\chi^2/d.o.f.$
-0.438	0.46	0.60 GeV^{-2}	4.0 GeV^{-1}	118.4 GeV^{-1}	4.0 GeV^{-2}	0.87

Energy dependence of cross sections



Note that σ_{el} and σ_{sd} have different energy behaviour.

Consequences of the GLM (and KMR) Model

- Have only ONE Pomeron
  No requirement for "soft" and "hard" Pomeron.
  In accord with the Hera data which is smooth throughout the transition region.

- GLM find from their fit that the slope of the Pomeron $\alpha'_{I\!P} \approx 0.01$ (KMR assume $\alpha'_{I\!P} = 0$).
  Small values for $\alpha'_{I\!P}$ obtained by Zeus and H1 in their fits to DIS data.

- This is consistent with what one expects in pQCD
  since for a BFKL $I\!P$ $\alpha'_{I\!P} \propto 1/Q_s^2 \rightarrow 0$ as $s \rightarrow \infty$.

- GLM and KMR analyses (including enhanced absorptive effects) have for the bare $I\!P$ intercept
  $\Delta_{I\!P} = \alpha_{I\!P}(0) - 1 \approx 0.3$
  close to the value of the BFKL $I\!P$ (after NLL corrections are resummed).

Having $\alpha'_{I\!P} \rightarrow 0$ provides a necessary condition that links strong (soft) interactions with the hard interactions described by pQCD.

Kaidalov and Poghosyan

"Description of soft diffraction in the framework of Reggeon calculus. Predictions for LHC" (arXiv:0909.5156)

Attempt to describe data on soft diffraction taking into account all possible non-enhanced absorptive corrections to 3 Reggeon vertices and loop diagrams.

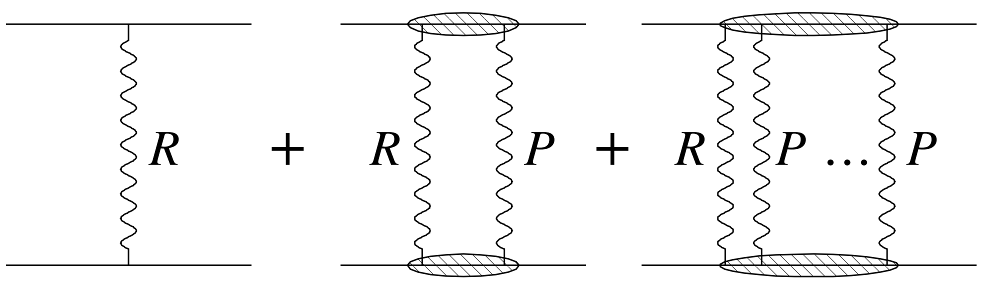
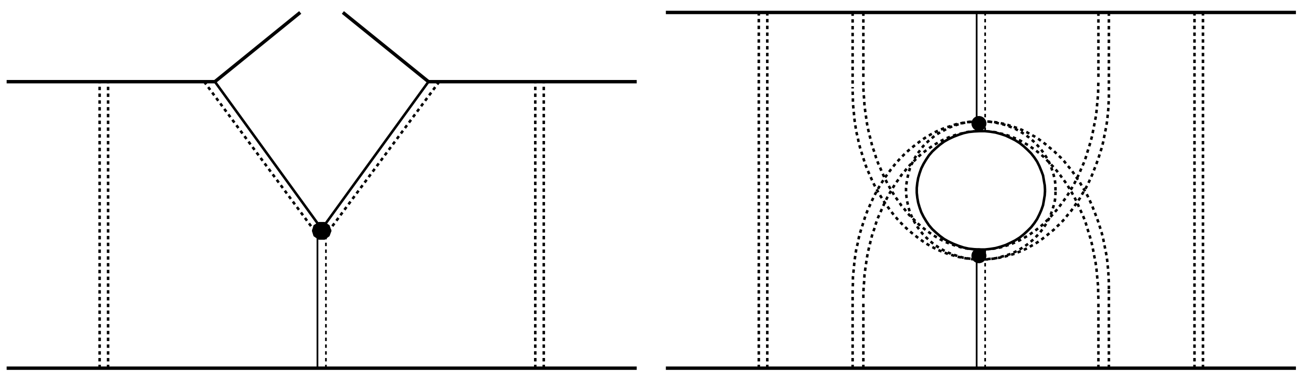


Figure 1: Single pole and RP^n cut contribution in the elastic scattering amplitude. R stands for secondary Reggeon and for Pomeron.

They apply AGK rules for calculating the discontinuity of the matrix element, and the generation of the optical theorem for the case of multi Pomeron exchange.

Kaidalov and Poghosyan 2

The K-P model is based on eikonalised 3 R and loop diagrams which are proposed to describe σ_{sd} and σ_{dd} processes respectively.



In the above Figure, the solid line accompanied by a dashed line corresponds to one Regggeon (P or R)exchange together with any number of Pomeron exchanges. Double dashed lines represent eikonal screening.

Kaidalov and Poghosyan 3

Following Kaidalov, Pononomrev and Ter-Martirosyan and assuming π meson exchange dominance of muti-Pomeron interaction they have for n $\longrightarrow$ m Pomerons

$$\lambda^{(n,m)} = r_{3P} g_{\pi}^{n+m-3} \exp\left(-R_{\pi}^2 \sum_{i=1}^{n+m} q_i^2 \right).$$

For $pp \rightarrow pp$ and $p\bar{p} \rightarrow p\bar{p}$ they use the f trajectory in place of the π.

The linear trajectories are taken as: $\alpha_f \ = \ 0.7 + 0.8t$; $\alpha_\omega \ = \ 0.4 + 0.9t$;

While $\alpha_P \ = \ 1.17 + 0.252t$, and the required residues are determined from a fit to data.

Comparison of results obtained in GLMM, Ostapchenko and KMR models

Ostapchenko (arXiv:1003.0196) has made a comprehensive calculation in the framework of Reggeon Field Theory based on the resummation of both enhanced and semi-enhanced Pomeron diagrams.

To fit the total and diffractive cross sections he assumes TWO POMERONS:

"SOFT POMERON" $\alpha^{Soft} = 1.14 + 0.14t$

"HARD POMERON" $\alpha^{Hard} = 1.31 + 0.085t$

The above are the values for Set (C) of his fit including the E710 value of $\sigma_{tot} = 72.8 \pm 2.24$ mb at the Tevatron.

	Tevatron				LHC (14 TeV)			
	GLMM	KMR(07)	KMR(08)	OS(C)	GLMM	KMR(07)	KMR(08)	OS(C)
σ_{tot}(mb)	73.3	74.0	73.7	73.0	92.1	88.0	91.7	114.0
σ_{el}(mb)	16.3	16.3	16.4	16.8	20.9	20.1	21.5	33.0
σ_{sd}(mb)	9.8	10.9	13.8	9.6	11.8	13.3	19.0	11.0
σ_{dd}(mb)	5.4	7.2		3.93	6.1	13.4		4.83
$\frac{\sigma_{el}+\sigma_{diff}}{\sigma_{tot}}$	0.43	0.46		0.42	0.42	0.53		0.43

Comparison of results obtained in Models and Monte Carlos

	0.9 TeV		7 TeV		10 TeV		14 TeV			
	GLMM	KP	GLMM	KP	GLMM	KP	GLMM	KP	Pythia6.214	Phojet1.12
σ_{tot}(mb)	66.6		86.0		89.2		92.1		101.5	119.1
σ_{el}(mb)	14.5		19.5		20.3		20.9		22.5	34.5
σ_{sd}(mb)	8.83	8.2	10.7	11.6	11.1	12.0	11.8	13.0	13.3	10.8
σ_{dd}(mb)	4.71	5.7	5.9	6.1	6.0	6.2	6.1	6.4		

Newer version of the Durham model (EPJC60,265(2009)) includes 3 components of the POMERON, with different transverse momenta of the partons in each component, to mimic BFKL diffusion in k_t.

	Tevatron			LHC (14 TeV)			W$=10^5$ GeV		
	GLMM	KMR(07)	KMR(08)	GLMM	KMR(07)	KMR(08)	GLMM	KMR(07)	KMR(08)
σ_{tot}(mb)	73.3	74.0	73.7	92.1	88.0	91.7	108.0	98.0	108.0
σ_{el}(mb)	16.3	16.3	16.4	20.9	20.1	21.5	24.0	22.9	26.2
σ_{sd}(mb)	9.8	10.9	13.8	11.8	13.3	19.0	14.4	15.7	24.2
σ_{dd}(mb)	5.4	7.2		6.1	13.4		6.3	17.3	
$\frac{\sigma_{el}+\sigma_{diff}}{\sigma_{tot}}$	0.43	0.46		0.42	0.53		0.41	0.57	

Single inclusive cross section 1

We expand our approach to soft hadron interactions to describe rapidity distributions at high energies e.g. the single inclusive cross section.

Assumptions

- $\alpha'_{I\!P} = 0$.
- Only the triple Pomeron vertex is included to describe the interaction of the soft Pomerons.
- The single inclusive cross section in the framework of the Pomeron calculus can be calculated using Mueller diagrams shown in the following figure.

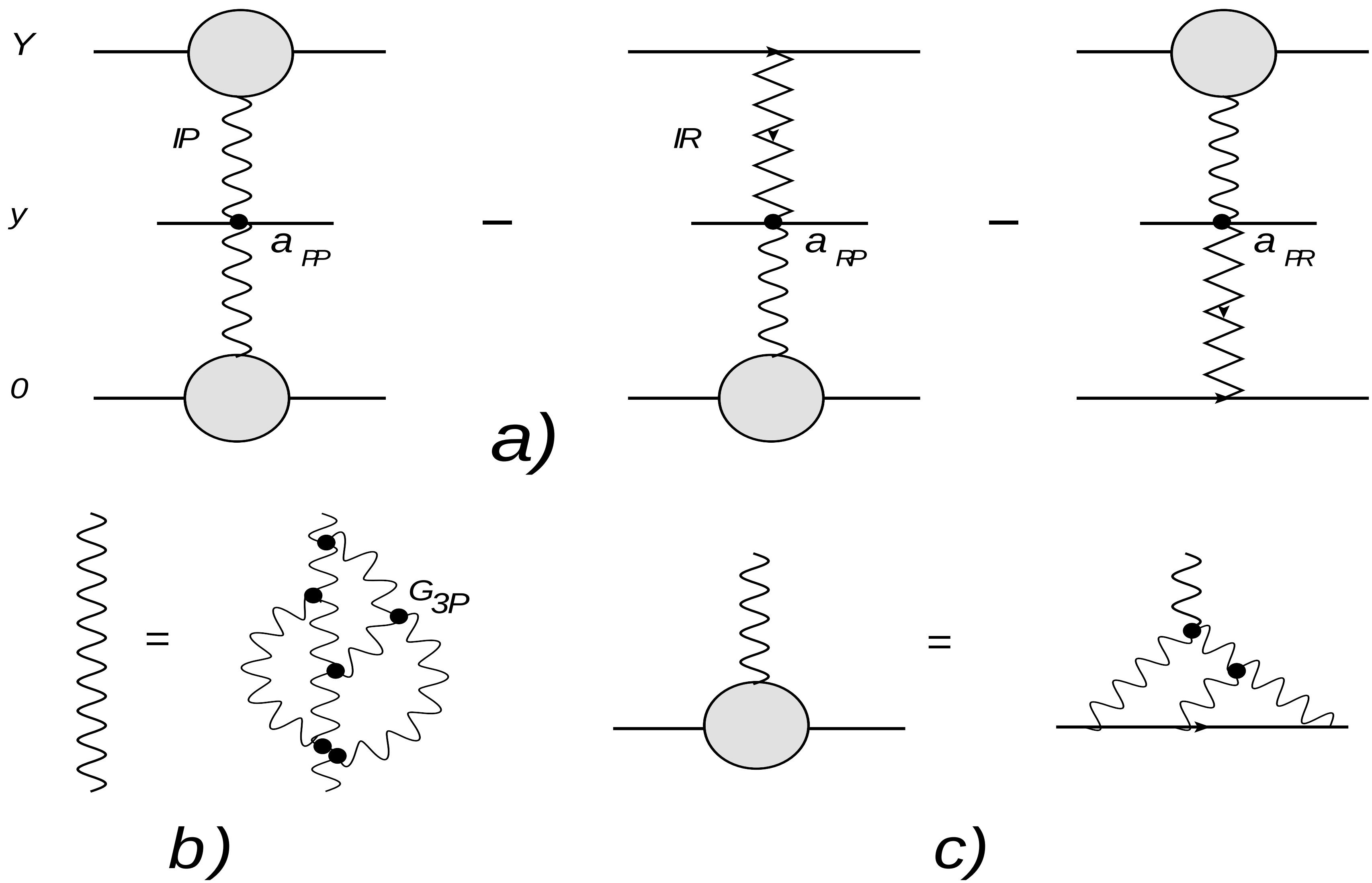


Figure 2: The Mueller diagrams for single inclusive cross section. The wavy bold line denotes the exact Pomeron Green function which is the sum of the enhanced diagrams. The zig-zag line stands for the exchange of the Reggeon

Single Inclusive cross section 3

They lead to the following expression for the single inclusive cross section

$$\frac{1}{\sigma_{in}}\frac{d\sigma}{dy} = \frac{1}{\sigma_{in}(Y)}\Big\{a_{PP}\left(\alpha^2 g_1 + \beta^2 g_2\right)^2 G\left(T\left(Y/2 - y\right)\right) \times G\left(T\left(Y/2 + y\right)\right)$$

$$- \quad a_{RP}\left(\alpha^2 g_1^R + \beta^2 g_2^R\right)\left(\alpha^2 g_1 + \beta^2 g_2\right)$$

$$\left[e^{(\Delta_R(Y/2-y)} \times G\left(T\left(Y/2+y\right)\right) \; + \; e^{(\Delta_R(Y/2-y)} \times G\left(T\left(Y/2+y\right)\right)\right]\Big\}$$

with

$$G_{enh}(Y) \; = \; 1 \; - \; \exp\left(\frac{1}{T(Y)}\right)\frac{1}{T(Y)}\Gamma\left(0, \frac{1}{T(Y)}\right)$$

where $T(Y) = \gamma \exp(\Delta_{I\!P} Y)$.

Single Inclusive cross section 4

- $\alpha'_{I\!P} = 0$.
- We take into account the sum of enhanced diagrams considering them as the first approximation for the exact Green function of the Pomeron (as was suggested by Gribov.)
- This gives the explicit form of the Green's function in the case of $\alpha'_{I\!P} = 0$.
- We also include the contribution of the secondary Reggeons, and introduced two new phenomenological parameters: $a_{I\!P I\!P}$ and $a_{I\!R I\!P}$ to describe the emission of hadrons from the Pomeron and the Reggeon.
- As well as a dimensional parameter Q, which has the meaning of the average transverse momentum of produced minijet.

Single Inclusive cross section 5

In the GLMM parametrization the value of the Pomeron-particle vertices $\tilde{g}_i$ is large.

So it is reasonable to sum diagrams of semi-enhanced type that contribute to the exact vertex of Pomeron - particle interaction.

Then the Pomeron-particle vertex can be replaced by

$$G_{enh}\,(y)\,g_i\,(b) \;\rightarrow\; \quad \Gamma\,(b;y)\;G_{enh}\,(y) \;=\; g_1\,G_{enh}(y)\,S_i(b)/(1+g_i G_{enh}(y)\,S_i(b))$$

where

$$S_i(b) = \frac{m_i^2}{4\pi}\,b\,m_i\,K_1(m_i\,b)$$

Single Inclusive cross section 6

Introducing a more compact notation:

$$V(y) \;=\; \int d^2b\tilde{V}(b,y) \;=\; \int d^2b(\alpha^2\, g_1(b, Y/2-y) + \beta^2 g_2(b, Y/2-y))$$

we then have

$$\frac{1}{\sigma_{in}}\frac{d\sigma}{dy} \;=\; \frac{1}{\sigma_{in}(Y)}\,\{a_{PP}V(y/2-y)V(Y/2+y)$$

$$-\,a_{RP}\,(\alpha^2\,g_1^R + \beta^2 g_2^R)\,(V(Y/2-y)\,e^{(\Delta_R\,(Y/2+y)} + V(Y/2+y)\,e^{(\Delta_R\,(Y/2-y))}\Big\}$$

Experimental Results

The three experimental groups ALICE, CMS and ATLAS have slight differences in the presentation of their results for for psuedo-rapidity distributions at the LHC.

$$\sigma_{tot} \ = \ \sigma_{ND} + \sigma_{el} + \sigma_{SD} + \sigma_{DD} = \sigma_{el} + \sigma_{inel}$$

ATLAS give results for σ_{ND}

CMS display

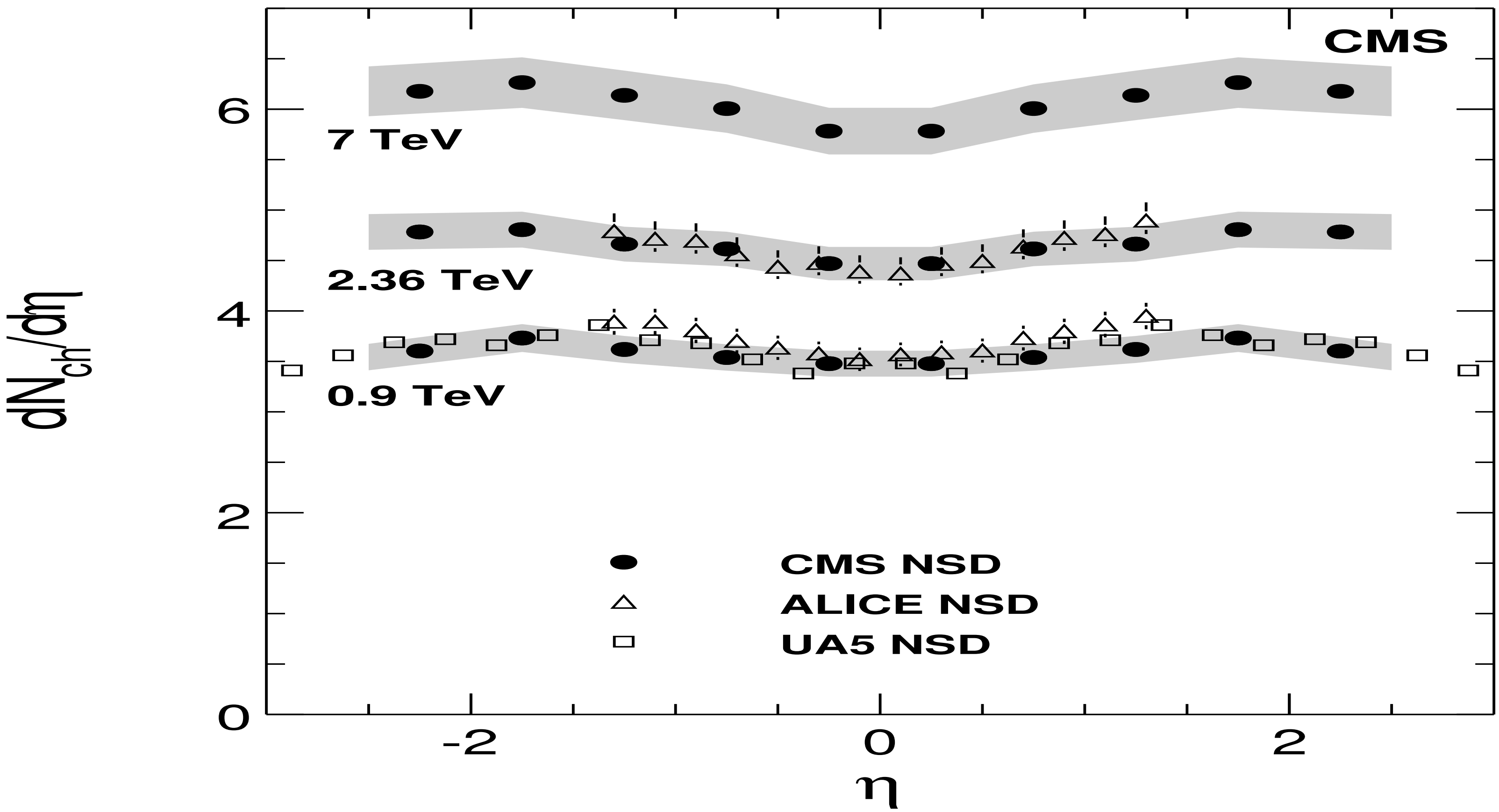
$$\sigma_{NSD} \ = \ \sigma_{ND} + \sigma_{DD} = \sigma_{tot} - \sigma_{el} - \sigma_{SD}$$

$$\sigma_{inel} = \sigma_{ND} + \sigma_{SD} + \sigma_{DD}$$

ALICE also present σ_{NSD} for W $=$0.9 and 2.36 TeV, however, for W $=$ 7 TeV they impose an additional constraint requiring at least one charged particle in the interval $\mid \eta \mid < 1$ $(inel > 0_{|\eta|<1})$.

RESULTS 2 CMS 1

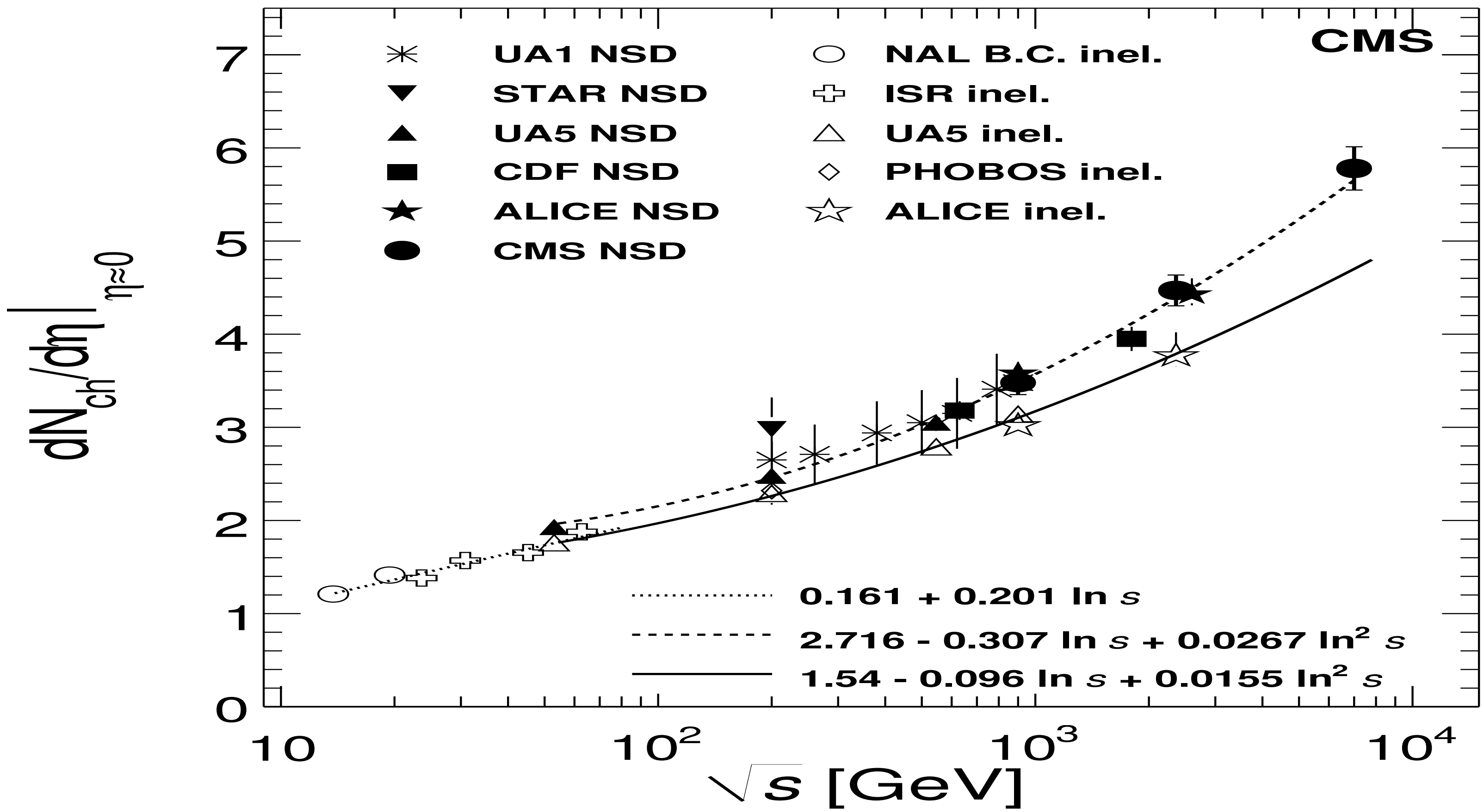
CMS Collaboration arXiv:1008.3299



Charged particle η distributions in region $|\eta| < 2.4$ for $dN_{ch}/d\eta$. Comparison of UA5 , ALICE and CMS results for NSD events.

RESULTS 3 CMS 2

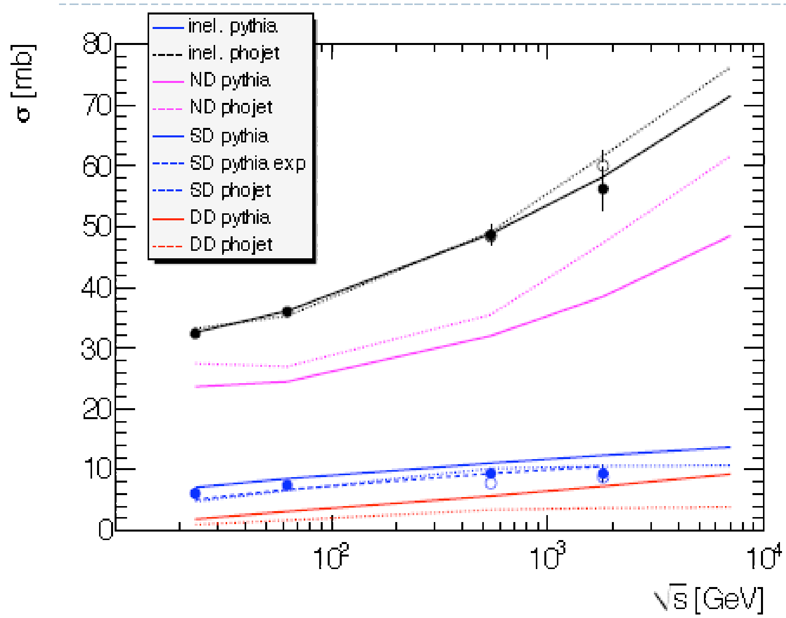
CMS Collaboration arXiv:1008.3299



Average value of $dN_{ch}/d\eta$ in the central η region as a function of the c.m. energies in pp and $\bar{p}$p collisions

MONTE CARLO RESULTS 4 ATLAS 1

Cross Section versus Energy

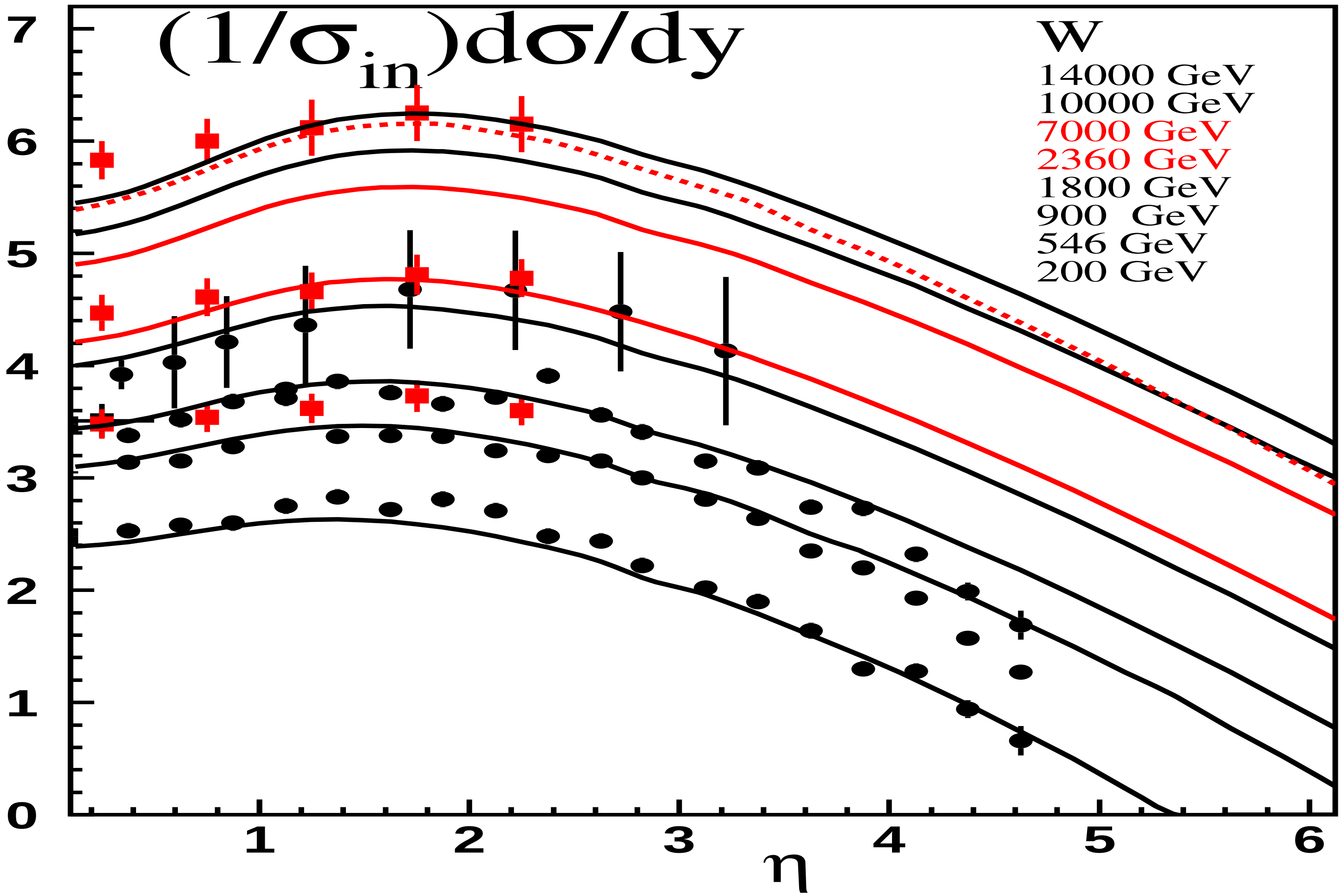


√s (TeV)		Pythia6 MC09	Phojet
0.9	ND	34.4 mb	40.0 mb
	SD	11.7 mb	10.5 mb
	DD	6.4 mb	3.5 mb
7.0	ND	48.5 mb	61.6 mb
	SD	13.7 mb	10.7 mb
	DD	9.3 mb	3.9 mb

- Measured cross sections agree with data for both
  - ND component differ due to different contribution of DD process
  - Diffractive components rise stronger in Pythia than Phojet
- see talk by P. Skands for explanation

Comparison of cross sections obtained in GLMM, Phythia6(MC09) and Phojet

$\sqrt{s}$ TeV		Pythia6 (MC09)	Phojet	GLMM
0.9	ND	34.4 mb	40.0 mb	38.5 mb
0.9	SD	11.7 mb	10.5 mb	8.8 mb
0.9	DD	6.4 mb	3.5 mb	4.7 mb
7.0	ND	48.5 mb	61.6 mb	49.8 mb
7.0	SD	13.7 mb	10.7 mb	10.7 mb
7.0	DD	9.3 mb	3.9 mb	5.9 mb



Single inclusive density versus energy. The dotted data were taken from PDG. The square data points correspond to the experimental data from LHC by Alice Collaboration at W = 900 GeV and the CMS collaboration at W = 900, 2360 and 7000 GeV.

Summary

- We present a model for soft interactions having two components:
  (i) G-W mechanism for elastic and low mass diffractive scattering
  (ii) Pomeron enhanced contributions for high mass diffractive production.
- Key Hypothesis:
  Soft processes are not "soft", but orginate from short distances.
- Enhanced $I\!\!P$ diagrams, make important contributions to both σ_{sd} and σ_{dd}.
- GLLM is in agreement with Inclusive rapidity distribution (σ_{NSD}) data
  up to energies of $\sqrt{s} = 2.36$ TeV.
  At $\sqrt{s} = 7$ TeV underestimates data (rise not as fast as seen experimentally).
- Until Monte Carlos are successfully "tuned", it is difficult to determine
  the diffractive components, and hence correct normalization.
- This is essential before one can conclude whether the inclusive data measured
  at 7 TeV indicates the appearance of novel phenomena.

Comparison of experimental results of ALICE and CMS with the GLMM model

Pythia	Phojet	Alice	Alice*
0.9 to 2.3 TeV	0.9 to 2.3 TeV	0.9 to 2.3 TeV	0.9 to 7.0 TeV
18.5%	14.5%	28.4 $\pm$ 1.4 $\pm$2.6 %	57.6 $\pm$ 0.4 $^{3.6}_{1.8}$ %
CMS	CMS	GLM	GLM
0.9 to 2.3 TeV	0.9 to 7.0 TeV	0.9 to 2.3 TeV	0.9 to 7.0 TeV
28.4 $\pm$ 0.04 $\pm$0.16 %	66.1 $\pm$ 1.0 $\pm$4.2 %	23.6 %	44.8 %

Comparison of experimental results of ALICE and CMS with Monte Carlos

Relative increase of the NSD pseudorapidity density:

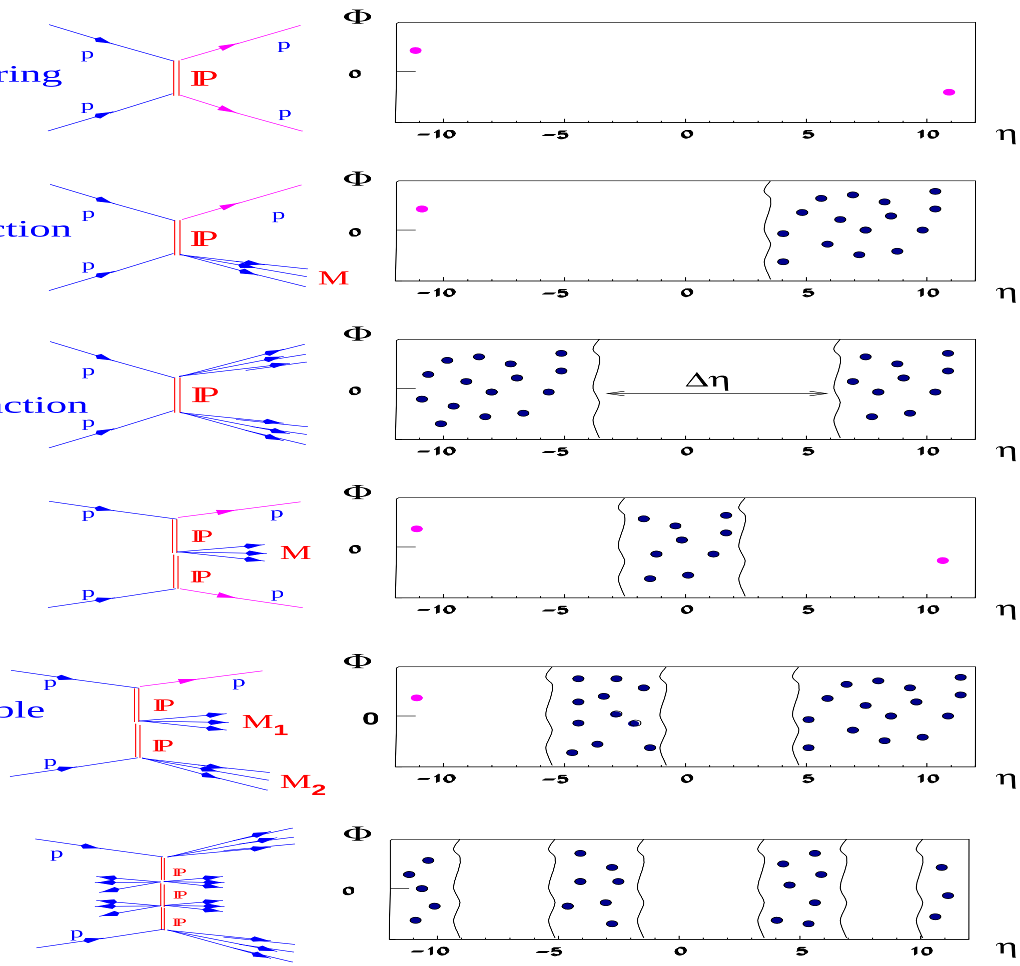
CMS for $\mid \eta \mid < 2.4$, for W $=$ 0.9, 2.36 and 7.0 TeV:
ALICE for $\mid \eta \mid < 0.5$, for W $=$ 0.9 and 2.3 TeV
while at W $=$ 7 TeV ALICE measure $dN_{ch}/d\eta$ requiring at least one charged particle in region $\mid \eta \mid < 1$.

Pythia		Phojet		Alice	
0.9 to 2.3	0.9 to 7	0.9 to 2.3	0.9 to 7	0.9 to 2.3	0.9 to 7*
18.5%	43.3%	14.5%	33.4%	28.4 $\pm$ 1.4 $\pm$2.6 %	57.6 $\pm$ 0.4 $^{+3.6}_{-1.8}$ %

CMS	
0.9 to 2.3	0.9 to 7
28.4 $\pm$ 0.04 $\pm$0.16 %	66.1 $\pm$ 1.0 $\pm$4.2 %

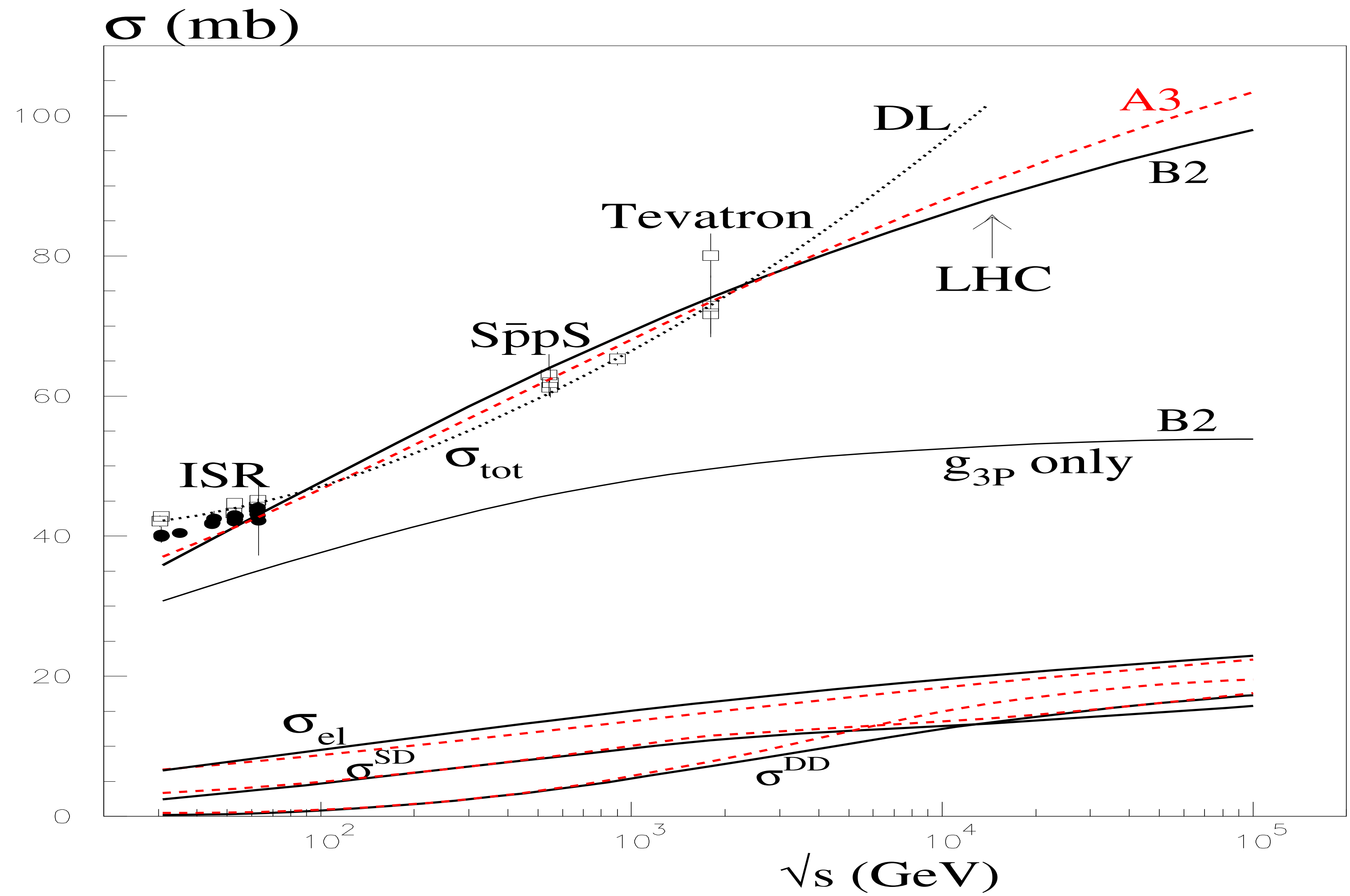
DIffractive Processes

Results from Deile et al (arXiv:hep-ex/0602021) based on PYTHIA 6



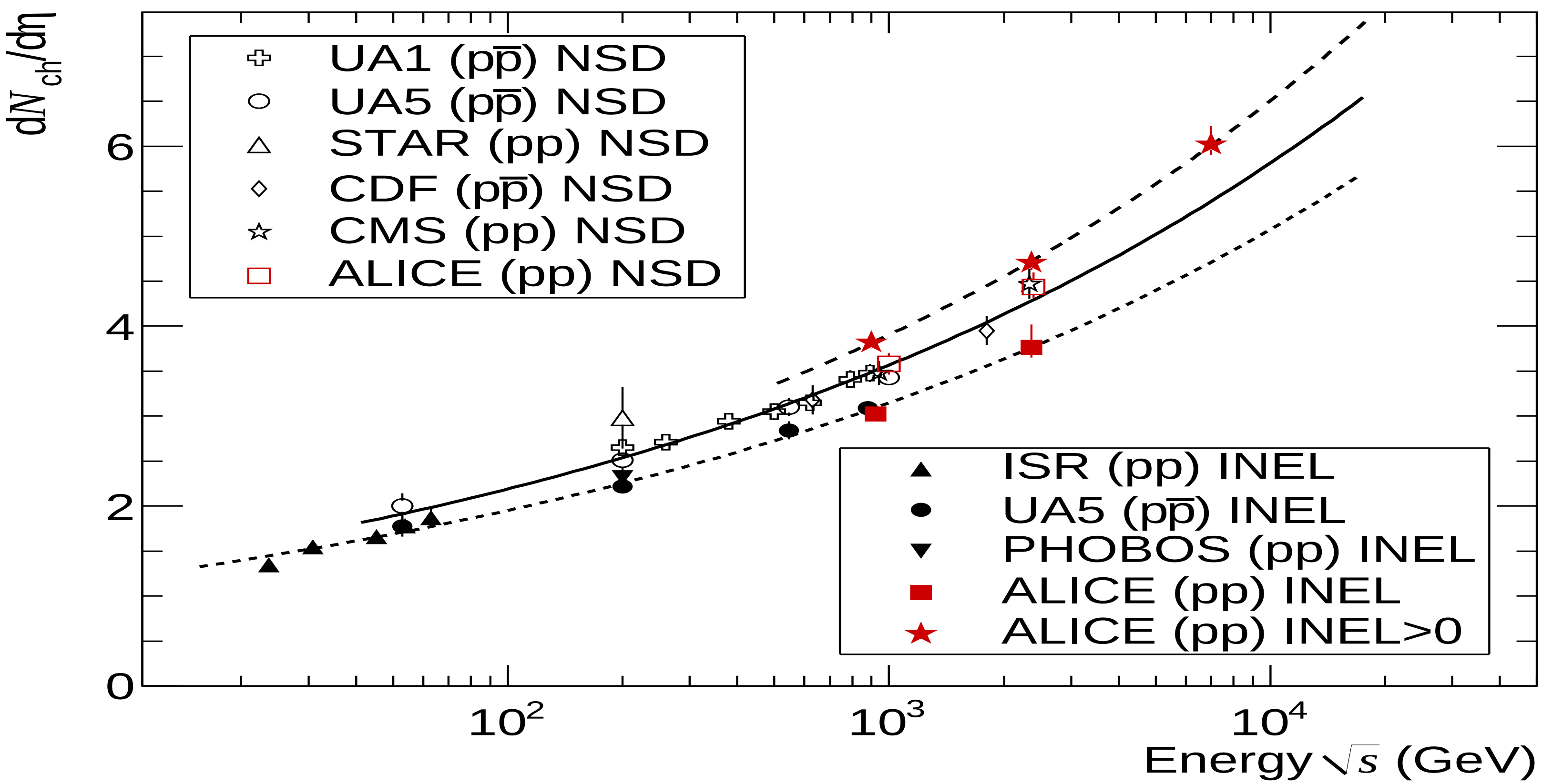
Process	σ (1.8 TeV)	σ (14 TeV)
Elastic Scattering	18 mb	~30 mb
Single Diffraction (SD)	9.4 mb	~10 mb
Double Diffraction (DD)	6.3 mb (for $\Delta\eta > 3$)	~7 mb
Double Pomeron Exchange (DPE)	?	~1 mb
Single + Double Diffraction (SDD)	1.5 mb (for $\Delta\eta > 3$)	?
Multi Pomeron Exchange	?	?

KMR Cross Sections (EPJ,C54,199(2008))



RESULTS 1 ALICE 1

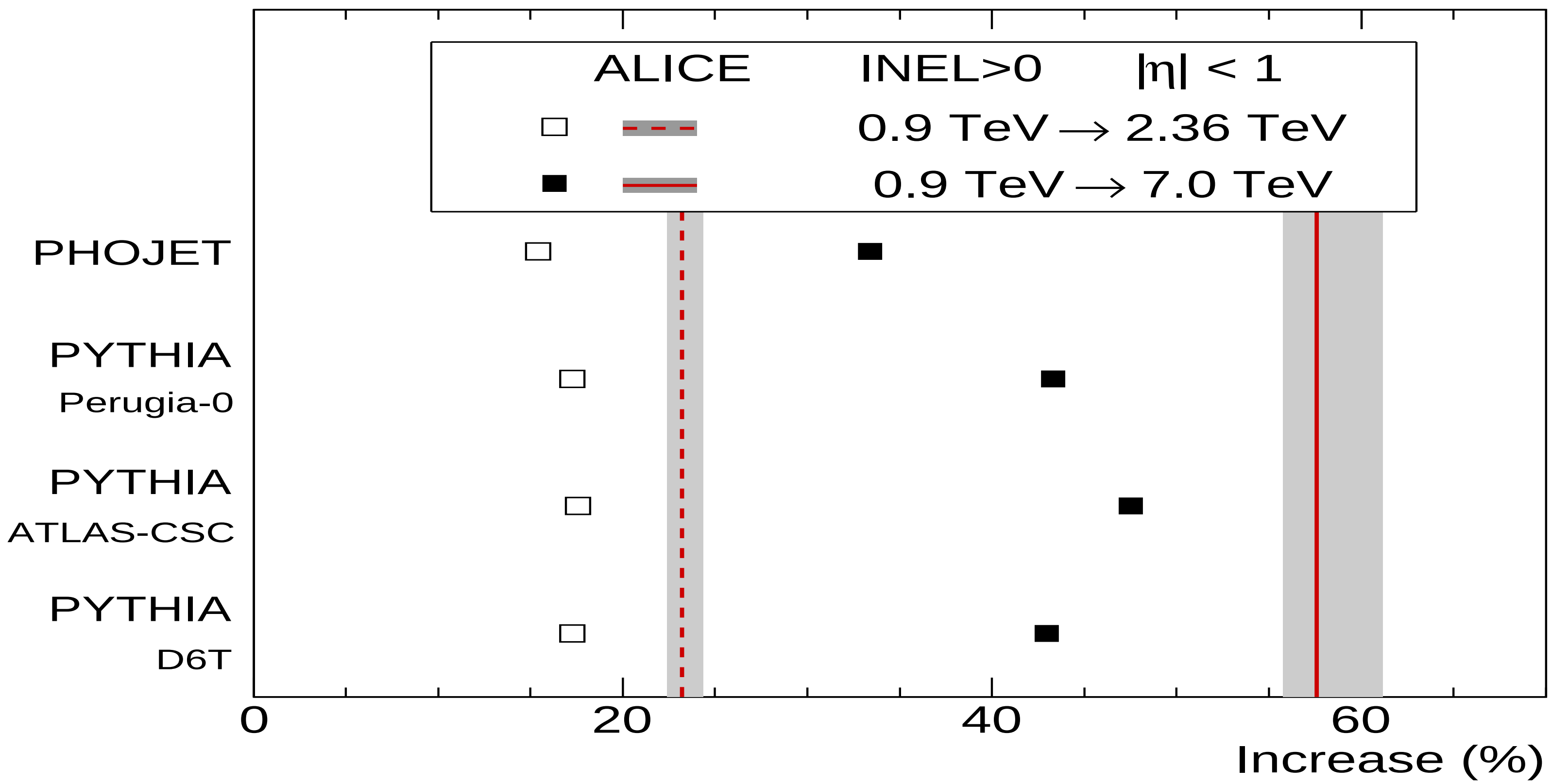
K. Aamodt et al arXiv:1004.3514



Charged particle η density in region $|\eta| < 0.5$ for $\sigma_{inel,NSD}$, and in $|\eta| < 1$ for σ_{inel} with at least one charged particle in that region. The lines indicate the fit using a power-law dependence on energy.

COMPARISON OF MONTE CARLO AND ALICE RESULTS

K. Aamodt et al arXiv:1004.3514



Relative increase of charged particle η density having at least one charged particle in $|\eta| < 1$, between $\sqrt{s} = 0.9$ TeV and 2.36 Tev (open squares) and between between $\sqrt{s} = 0.9$ and 7 TeV (full squares). ALICE measurements are shown by dashed and full lines.

Results of Kaidalov and Poghosyan

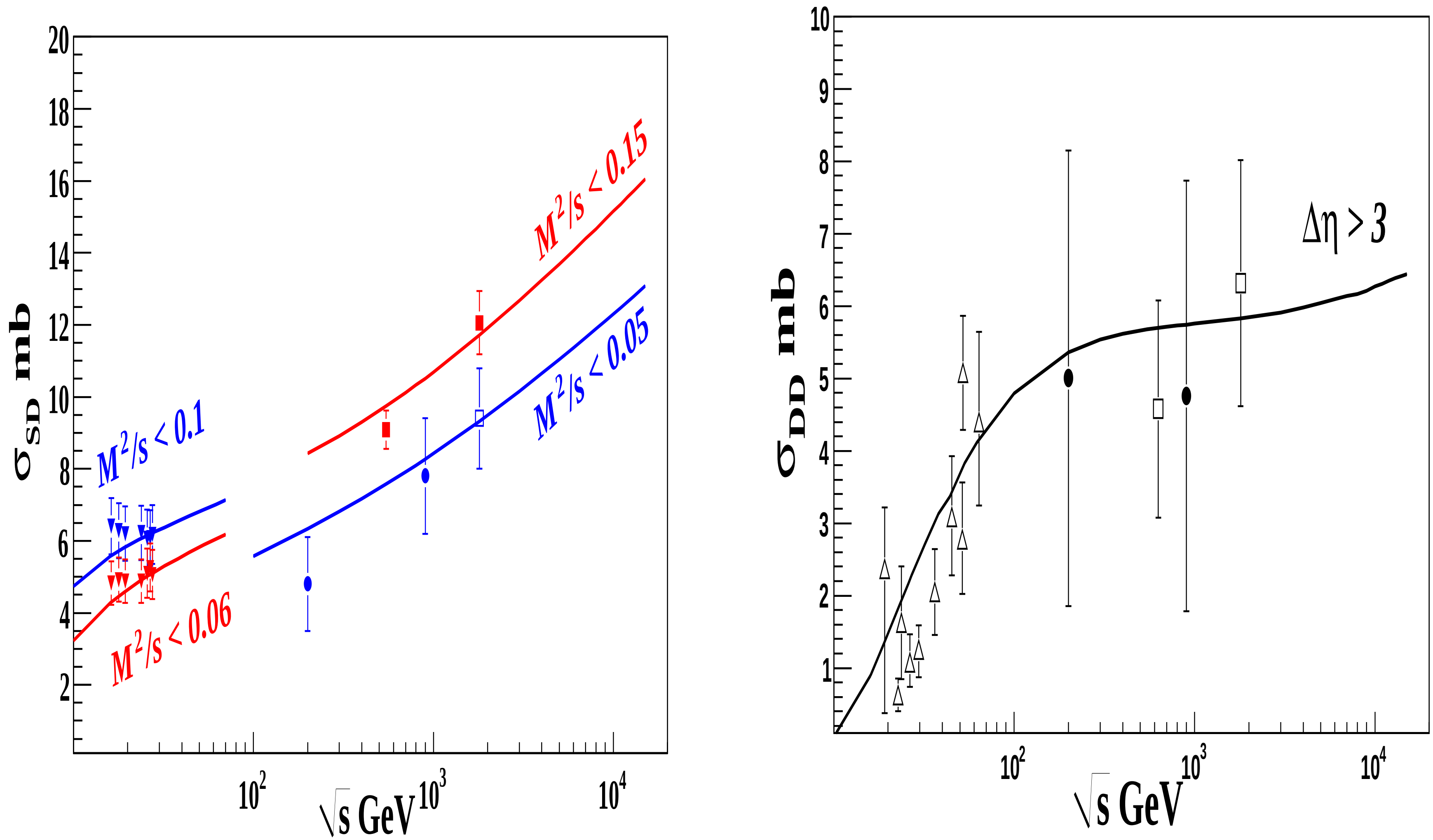
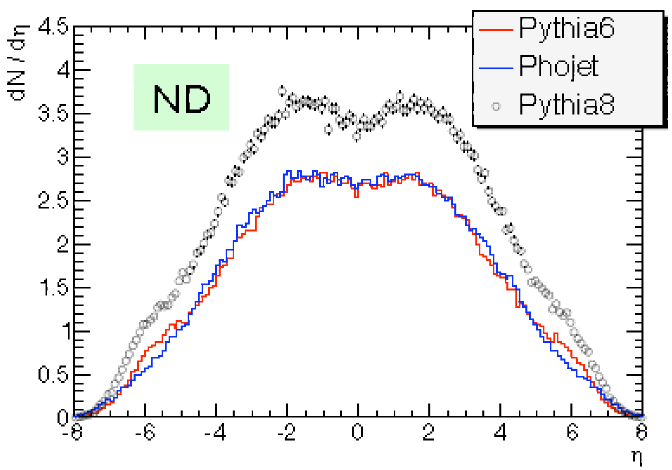
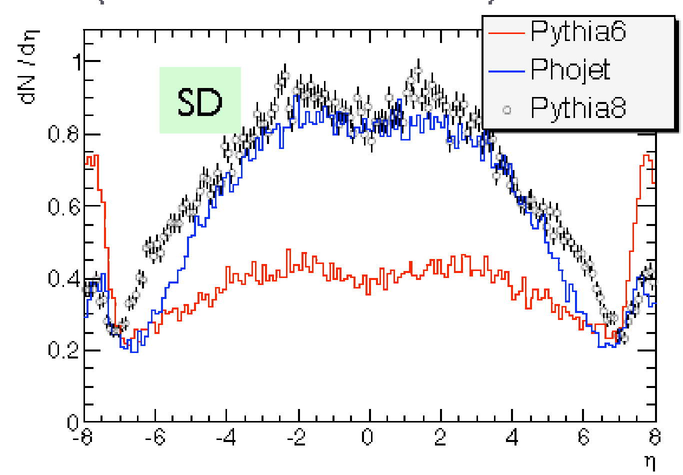


Figure 3: Integrated single and double diffractive cross-sections as a function of $\sqrt{s}$

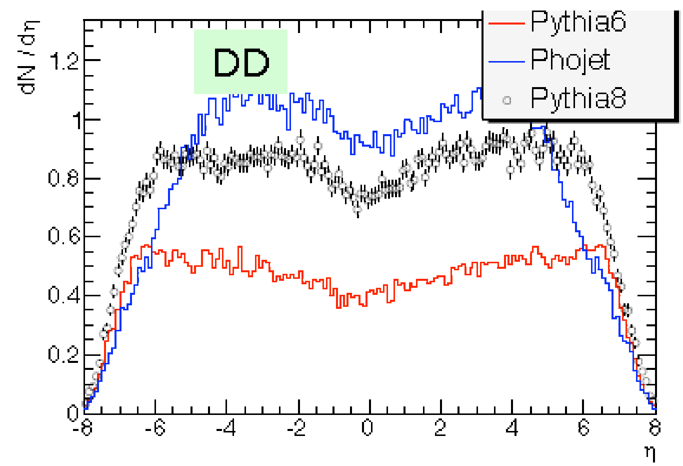
MONTE CARLO RESULTS 4 ATLAS 2

dN/dη Distributions ($\sqrt{s}$=0.9 TeV)





- p_T>0.25 GeV
- Rather large differences in both shape and normalization
- Cross-check between different fwd detectors very useful



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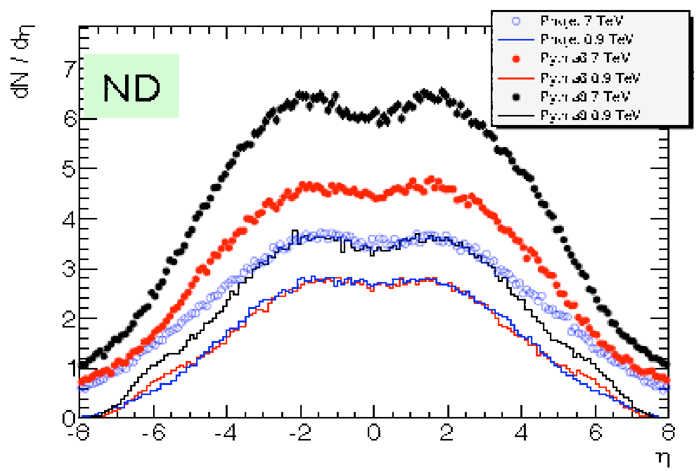
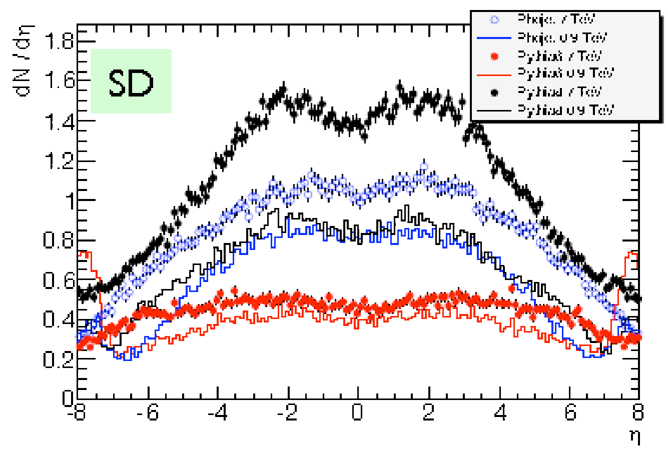
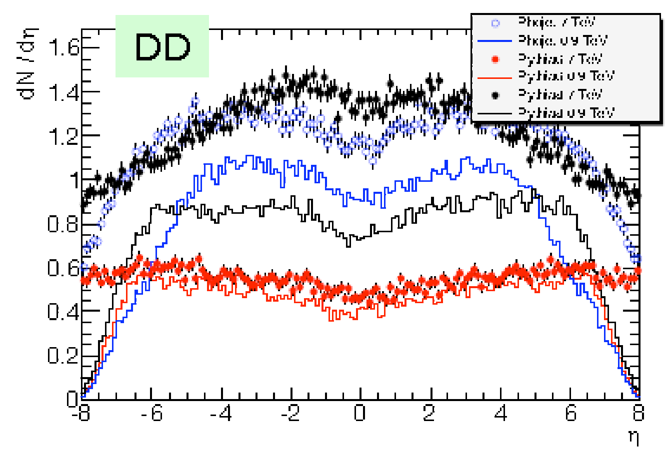
MONTE CARLO RESULTS 4 ATLAS 3

dN/dη Distributions for p_T>0.25 GeV $\sqrt{s}$=7 TeV





- **Pythia6** lacks energy-dependence for diffractive processes
  - See previous slide
- Large differences also between **Pythia8** and **Phojet**



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