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Elastic and diffractive cross sections: a theoretical perspective, in the light of LHC data

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(based on works with Alan Martin and Misha Ryskin)

Focus on the implications of the LHC Run I (above the knee) data on the phenomenological models of hadron-hadron interactions.

Disclaimer

Topic/data selection/interpretation –a bit of personal flavour.

Recent detailed reviews:

I. Dremin, Elastic scattering of hadrons, Usp.Fiz.Nauk 183 **(2013) 3-32.**

E.Gotsman, E.Levin, U.Maor, A comprehensive model of soft interactions in the LHC era, arXiv:1403.4531.

.

V.A. Khoze, A.D. Martin, M.G. Ryskin, Elastic scattering and Diffractive dissociation in the light of LHC data, arXiv:1402.2778.

S. Ostapchenko, LHC data on inelastic diffraction and uncertainties in the predictions for longitudinal EAS development, arXiv: 1402.5084;

D. d'Enterria et al, Constraints from the first LHC data on hadronic event generators for UHECR physics, Astropart. Phys. 35 (2011) 98.

OUTLINE

- Introduction.
- Theoretical background.
- Surprises in the LHC Run I data.
- Implications of the LHC Run I data.
- Much needed Run II measurements. (possible regime change) 
- Conclusion and outlook.

INTRODUCTION

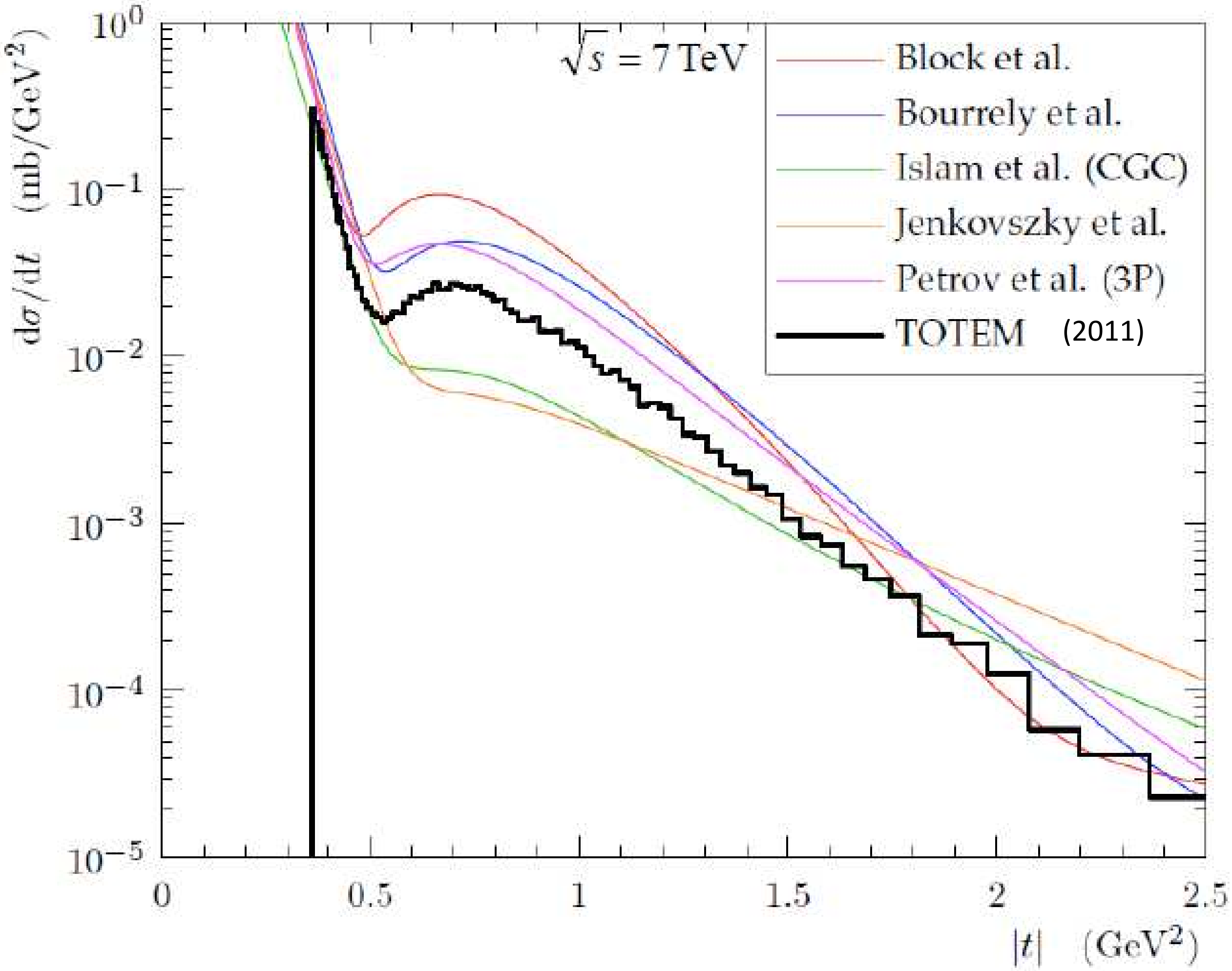
- The determination of the primary energy and mass composition of UHECR strongly relies on the detailed modelling of the HE pp scattering. Diffractive interactions are especially important for understanding air-showers.

- The LHC Run I data (equivalent to the CR proton energy above the knee region) have already provided important constraints on the QCD-inspired models (and MCs) used in CR physics.

- The Run II data will drastically improve our theoretical knowledge and will be extremely useful in refining the models used in HE air shower physics, in particular reducing the number of extrapolating factors in evaluation of $\sigma_{p-\mathrm{air}}^{\mathrm{inel}}$.

- Previously successful theoretical models of the pre-LHC era did not perform well under the trial by TOTEM fire.

(pre-LHC) Model Comparisons



No theoretical / phenomenological model describes the TOTEM data completely.

- $\sigma_{\rm tot}$, $\sigma_{\rm inel}$ … could not be calculated from the first principles based on QCD- intimately related to the confinement of quarks and gluons
 (some attempts within N=4 SYM , GLM).

- Basic fundamental model-independent relations: unitarity, crossing, analyticity, dispersion relations. The Froissart-Martin **bound**:

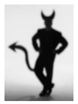
$$\sigma_{tot} \leq \text{Const} \ \ln^2 s.$$

most models asympt. ~ $\ln^2 s.$

but not a Must

- Important testable constraints on the cross sections.

- Phenomenological models- fit the data in the wide energy range and extrapolate to the higher energies. Next step- MC implementations.

- Well developed approaches based on Reggeon Field Theory with multi-Pomeron exchanges+ Good –Walker formalism to treat low mass diffractive dissociation: KMR-Durham, GLM- Tel-Aviv, Kaidalov-Poghosyan, Ostapchenko. Differences/**Devil**  – in details

$$d\sigma/dt = |T(t)|^2/16\pi s^2 \propto \exp(B_{el}t)$$

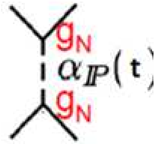
optical theorem: $\mathrm{Im}\,T(s,t=0) = s\sigma_{tot}$

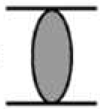
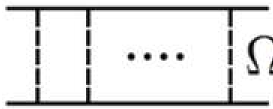
THEORETICAL BACKGROUND

Pomeron (Gribov-1961)

Elastic amp. $T_{el}(s,b)$

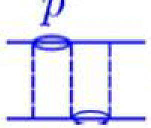
One Pomeron bare amp. $\Omega/2$ =



$\text{Im}\ T_{el} =$  $= 1 - e^{-\Omega/2} = \sum_{n=1}^{\infty}$  $\Omega/2$

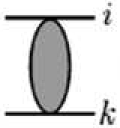
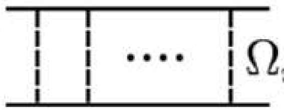
(s-ch unitarity)

Low-mass diffractive dissociation

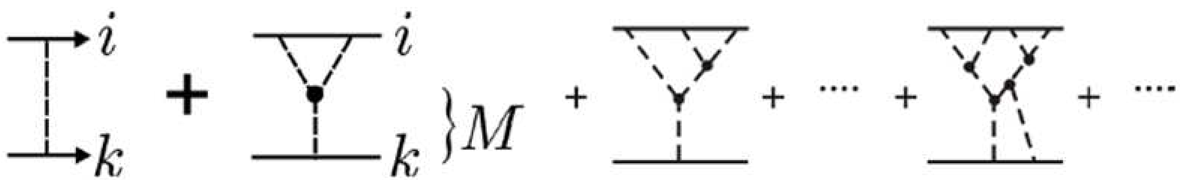


→multichannel eikonal

introduce diff^{ve} estates ϕ_i, ϕ_k (comb^{ns} of p,p*,..) which only undergo "elastic" scattering (Good-Walker)

$\text{Im}\ T_{ik} =$  $= 1 - e^{-\Omega_{ik}/2} = \sum$  $\Omega_{ik}/2$

include high-mass diffractive dissociation

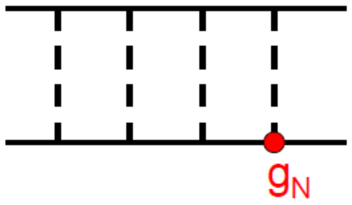
$\Omega_{ik} =$ 

(non-linear **PP** interactions)

Multi-Pomeron contributions

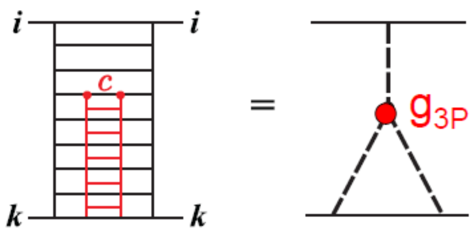
Absorptive Effects.

eikonal: Pomerons well separated in b-plane

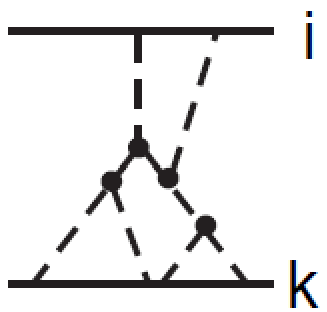


(Igor's talk)

enhanced: interactions with partons in an individual cascade

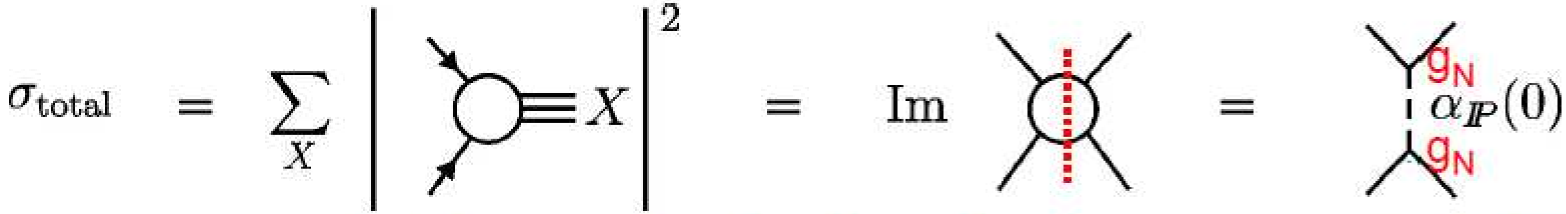


Rescattering of the intermediate partons in the 'parton ladder'



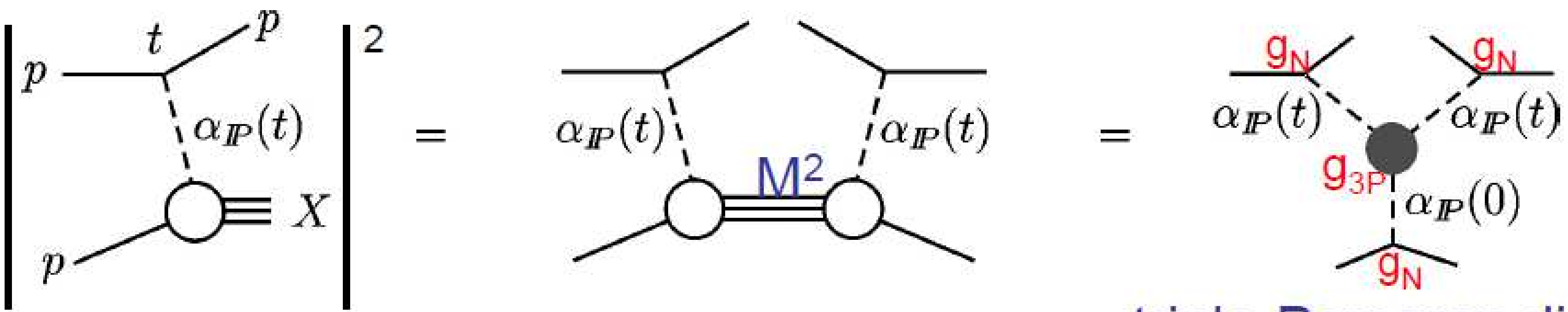
Optical theorems

at high energy
use Regge



but screening/s-ch unitarity
important so $\sigma_{\rm total}$ suppressed $g_N^{\;2}\left(\frac{s}{s_0}\right)^{\alpha_{I\!P}(0)-1}$

High-mass diffractive dissociation



triple-Pomeron diag

$$g_N^{\;3} g_{3P} \left(\frac{M^2}{s_0}\right)^{\alpha_{I\!P}(0)-1} \left(\frac{s}{M^2}\right)^{2\alpha_{I\!P}(t)-2}$$

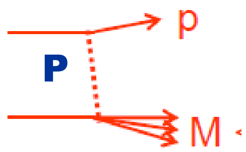
but screening even more important

- **Diffractive Dissociation –of special importance for CR physics**
  - absorptive effects in pp and pA interactions (deviat. from Glauber-Gribov formalism).
  - model predictions for inelasticity $K^{\rm inel}_{p-\rm air}$.
- -Higher diffraction – slower EAS development (deeper shower maximum).
  - Difference between MC models (e.g. QGSJET-II and PITHYA) mostly due to LM Diff.

SO

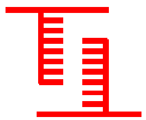
- Unfortunately at the moment the exp. information on LM SD is still **very** limited

No unique definition of diffraction



1. Diffraction is elastic (or quasi-elastic) scattering caused, via s-channel unitarity, by the absorption of components of the wave functions of the incoming particles
   e.g. pp→pp,
   pp→pX (single proton dissociation, SD),
   pp→XX (both protons dissociate, DD)

Good for quasi-elastic proc.
– but not high-mass dissoc^n



MIND THE GAP

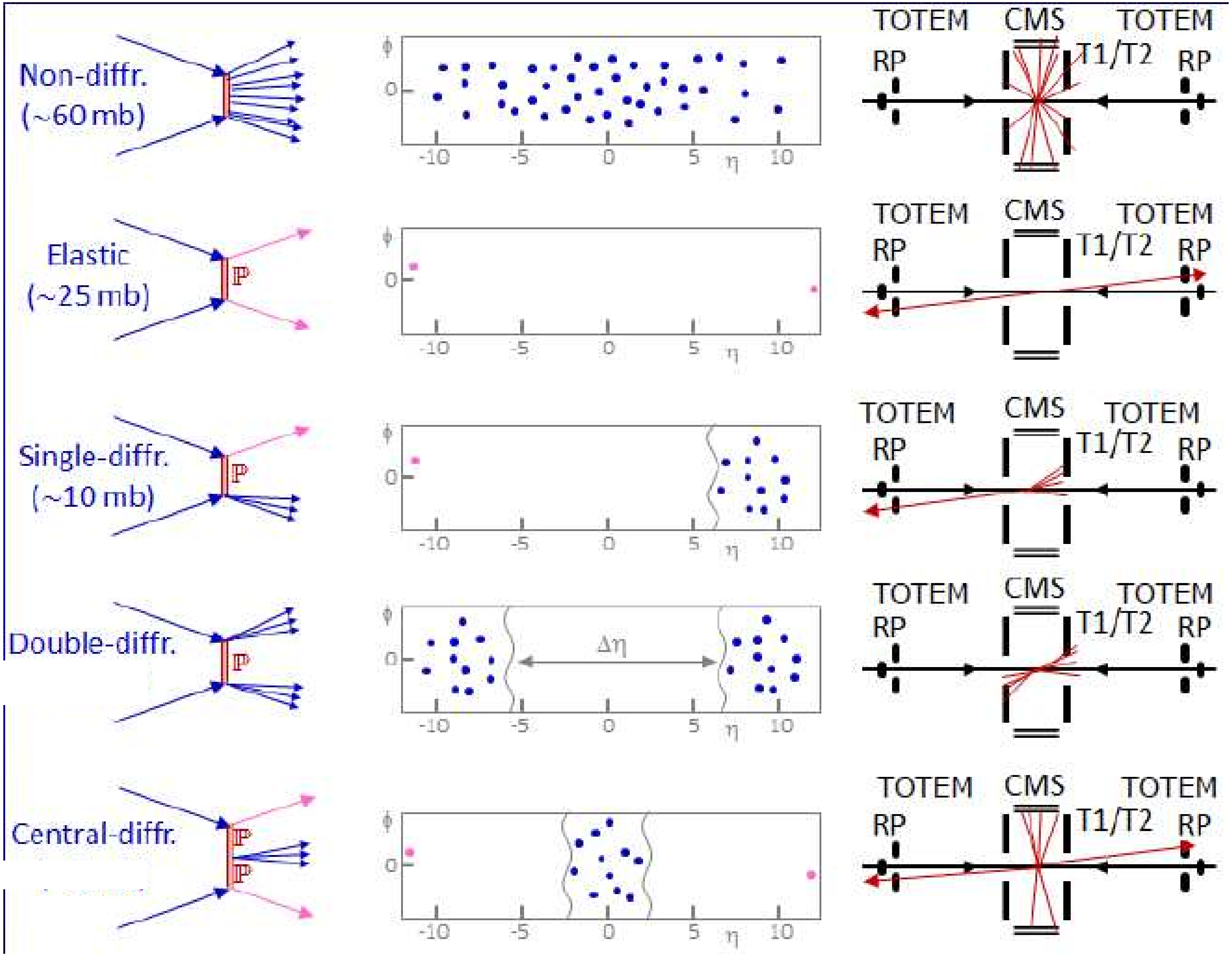
2. A diffractive process is characterized by a large rapidity gap (LRG), which is caused by t-channel “Pomeron” exch.

(Igor’s talk)

Only good for very LRG events – otherwise
Reggeon/fluctuation contaminations

TOTEM –CMS

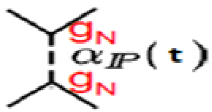
(Igor's talk)



Surprises in the LHC Run I data

(Emilio's talk)

Lesson 1.



In the pre-LHC era all data successfully reproduced by DL (1992) fits:

$$\sigma = \sigma_0 \cdot \left(\frac{s}{s_0}\right)^{\alpha_P(0)-1} + \sigma_R \cdot \left(\frac{s}{s_0}\right)^{\alpha_R(0)-1}$$

$$A_{el}(t) = \sigma_0 \cdot F_P(t) \cdot \left(\frac{s}{s_0}\right)^{\alpha_P(t)} + \sigma_R \cdot F_R(t)) \cdot \left(\frac{s}{s_0}\right)^{\alpha_R(t)}$$

$$\alpha_P(t) = 1 + \Delta + \alpha'_P t \;,$$

with $\Delta = 0.08$ and $\alpha'_P = 0.25\ \mathrm{GeV}^{-2}$

In the Tevatron-LHC energy interval $\sigma_{\rm tot}$ starts to grow faster and the slope of effective P- trajectory α'_P increases.

At 7 TeV

$\sigma_{DL} = 90.7$ mb — Totem - $\sigma = 98.6 \;\pm 2.2 mb$

ALFA: $95.4 \pm 1.4\ mb$

(faster than predictions of pre-LHC KMR and GLM models)

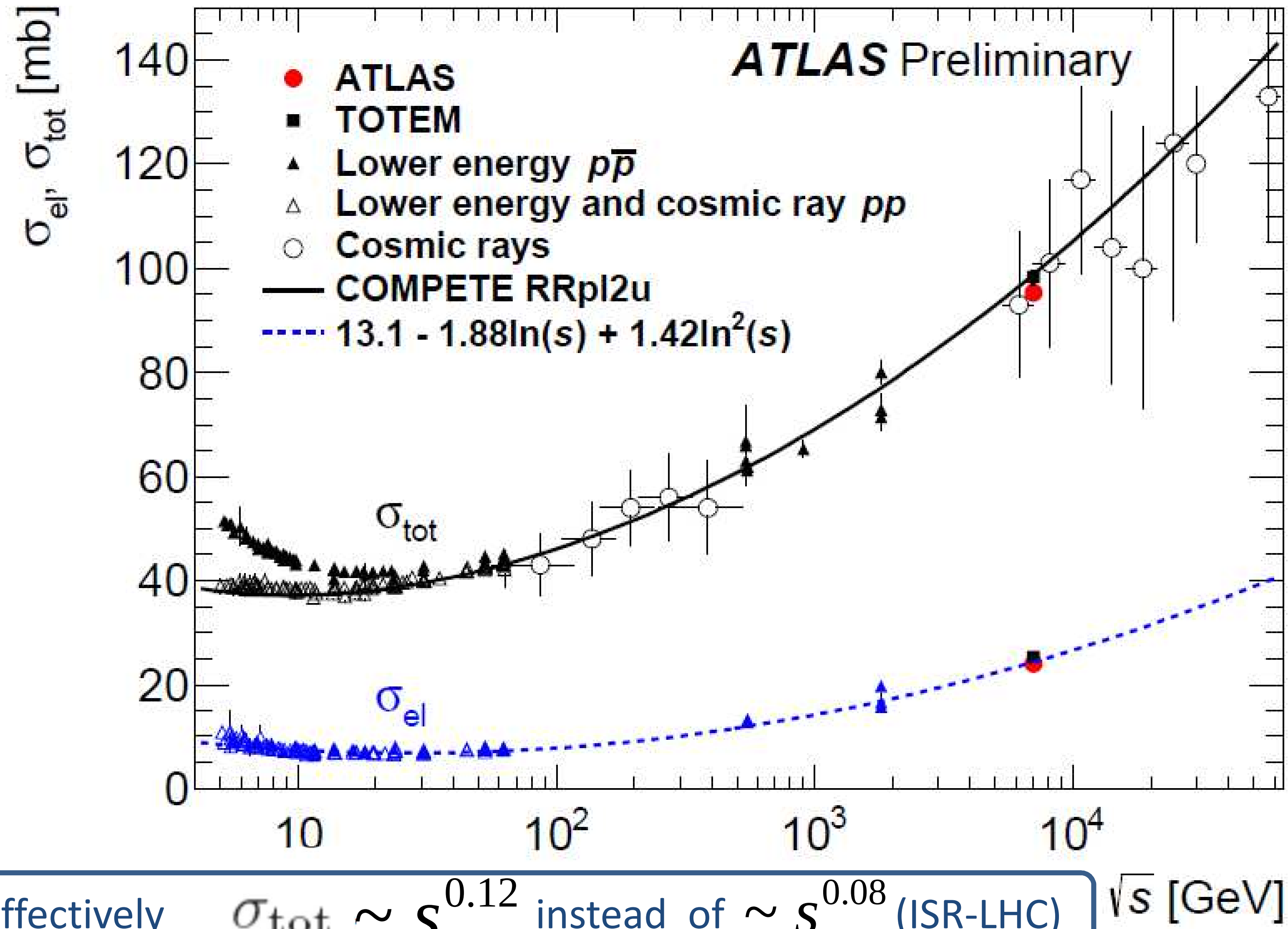
NEW!

t-slope: with $\alpha'_P = 0.25\ \mathrm{GeV}^{-2}$

$B_{DL} \;\leq\; 18.3\ \mathrm{GeV}^{-2}$

$B_{LHC} = 19.9 \pm 0.3\ \mathrm{GeV}^{-2}$ (TOTEM) ; 19.73 ± 0.24 GeV^{-2} (ALFA)

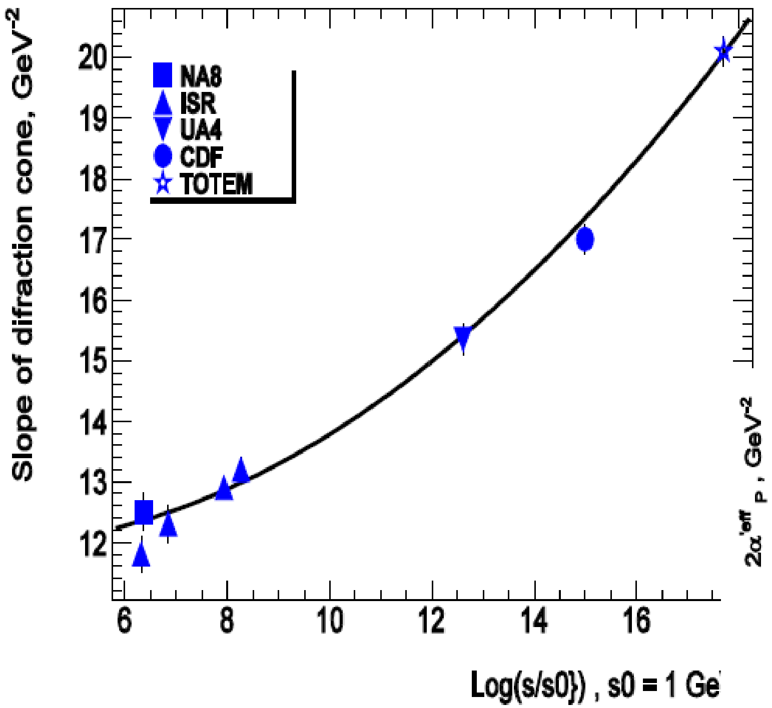
(Emilio's talk)



Effectively $\sigma_{tot} \sim s^{0.12}$ instead of $\sim s^{0.08}$ (ISR-LHC)

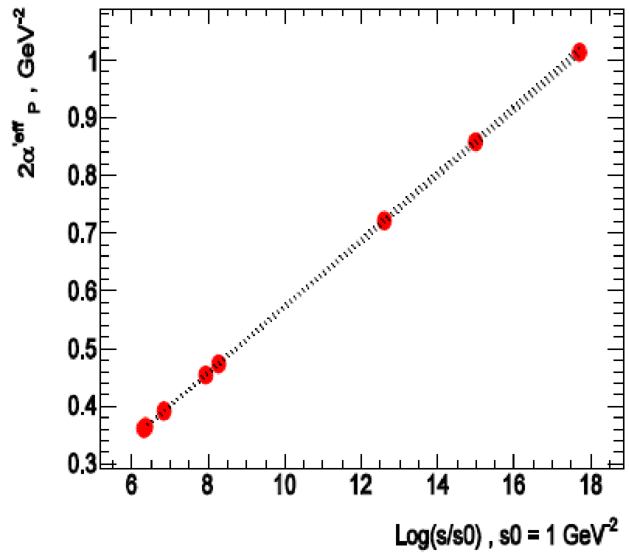
Figure 19: Comparison of total and elastic cross-section measurements presented here with other published measurements [11, 29, 55–58] and model predictions as function of the centre-of-mass energy.

B_{el} - an effective transverse size of the interaction; proton is 'looking larger'



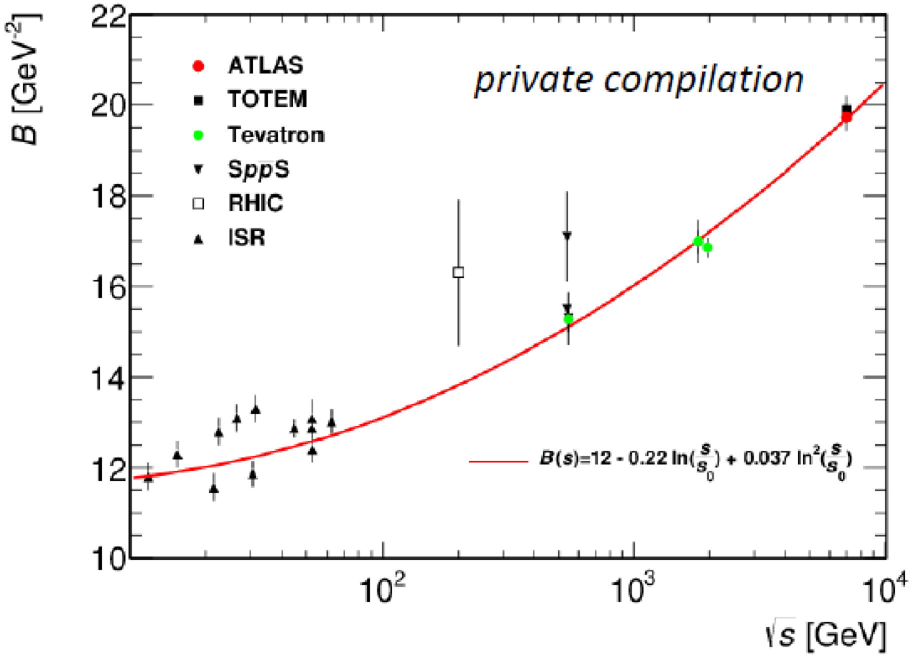
V.A. Schegelsky, Ryskin
Phys.Rev. D85 (2012) 09402

$$2\alpha_P^{'eff} = dB_{el}/d(ln(s/s_0))$$



Increasing role of multi-Pomeron interactions .
Run II data are much needed.

Energy evolution of B



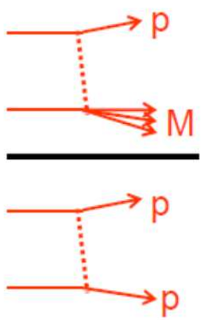
Increase of B compatible with a 2nd order polynomial in ln(s).

Parameters from: V.A.Schegelsky and M:G: Ryskin , Phys.Rev.D 85 (2012) 0940243

Lesson 3.

Decrease of $\frac{\sigma_{\text{low M}}}{\sigma_{\text{elastic}}}$ with energy increasing.

(Igor's talk)



	CERN-ISR 62.5 GeV		TOTEM 7 TeV	(M<3.4 GeV)	(UA4, M<4 GeV)
$\frac{\sigma_{\text{low M}}}{\sigma_{\text{elastic}}} =$	$\frac{2\text{-}3\ \text{mb}}{7\ \text{mb}}$	$\stackrel{?}{=}$	$\frac{2.6\ \text{mb}}{25.4\ \text{mb}}$		

(the end of a simple quasi-eikonal ?)

Unexpectedly small

Before TOTEM, models predicted $\sigma_{\text{low M}} \sim 6\text{-}10$ mb

TOTEM

$\sigma_{tot} = 98.6 \pm 2.2$ mb

$\sigma_{el} = 25.4 \pm 1.1$ mb

$\sigma_{inel} = 73.1 \pm 1.3$ mb

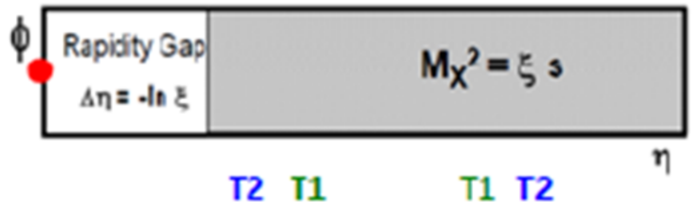
$\sigma_{inel(|\eta|<6.5)} = 70.5 \pm 2.9$ mb

$\sigma_{\text{low M dissn.}} = 2.6 \pm 2.2$ mb

(Emilio, Sahal, Yoshitaka, Igor)

Lesson 4.

TOTEM PRELIMINARY RESULTS ON SD



	M_X [GeV]	$\xi = \Delta p/p$
①	3.4 – **8**	**2x** $10^{-7} - 10^{-6}$
②	**8** – 350	10^{-6} – 0.0025
③	350 – 1100	0.0025 – 0.025
④	1100 – ...	0.025 – ...

⚠ CAUTION

- -only in the conference talks
- -errors $\pm 20\%$
- -'tensions' between HM SD data (TOTEM vs CDF, ATLAS, CMS)

(mb)

Mass interval (GeV)	(3.4, 8)	(8, 350)	(350, 1100)
Prelim. TOTEM data	1.8	3.3	1.4

Taking the preliminary TOTEM SD data at face value:

- $d\sigma^D/d\ln M_X^2$ depends on $\xi = M_X^2/s$ non-flat/plateau distrib. In $\Delta\eta$

more than twice smaller in the centre (second M- interval) than in the fragmentation (first interval)

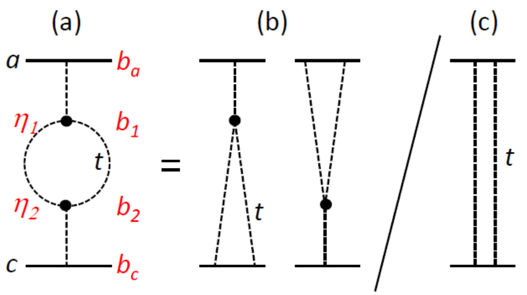
Lesson 5.

Strong violation of 'naïve factorization ' between the observed elastic, SD and DD cross sections.

In the first rapidity/mass interval from the TOTEM 7 TeV results it follows:

$$\frac{\sigma_{\rm DD}\ \sigma_{\rm el}}{(\sigma_{\rm SD})^2} \simeq 3.6,$$

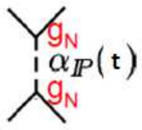
$\sigma_{\rm DD} = 0.116$ mb (TOTEM, arXiv:1308.6722)



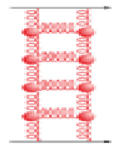
$$\frac{d\sigma_{\rm DD}}{dt d\eta_1 d\eta_2} = \frac{d\sigma_{\rm SD}}{dt d\eta_1}\frac{d\sigma_{\rm SD}}{dt d\eta_2} \Big/ \frac{d\sigma_{\rm el}}{dt}.$$

IMPLICATIONS OF THE LHC RUN I DATA
(exemplified in terms of Durham model)

(KMR, 2011-2014)



(Gribov-1961)



(BFKL-1975-78)

Yes, it is possible to describe all "soft" HE data

σ_{tot}, $d\sigma_{el}/dt$, $\sigma_{low\ M}$, (+ $\sigma_{high\ M}$)

from CERN-ISR → Tevatron → LHC

in terms of a single "effective" pomeron

Energy dep. of σ_{el}, σ_{tot} controlled by intercept and slope of "effective" pomeron trajectory

Diffractive dip and $\sigma_{low\ M}$ controlled by properties of GW eigenstates

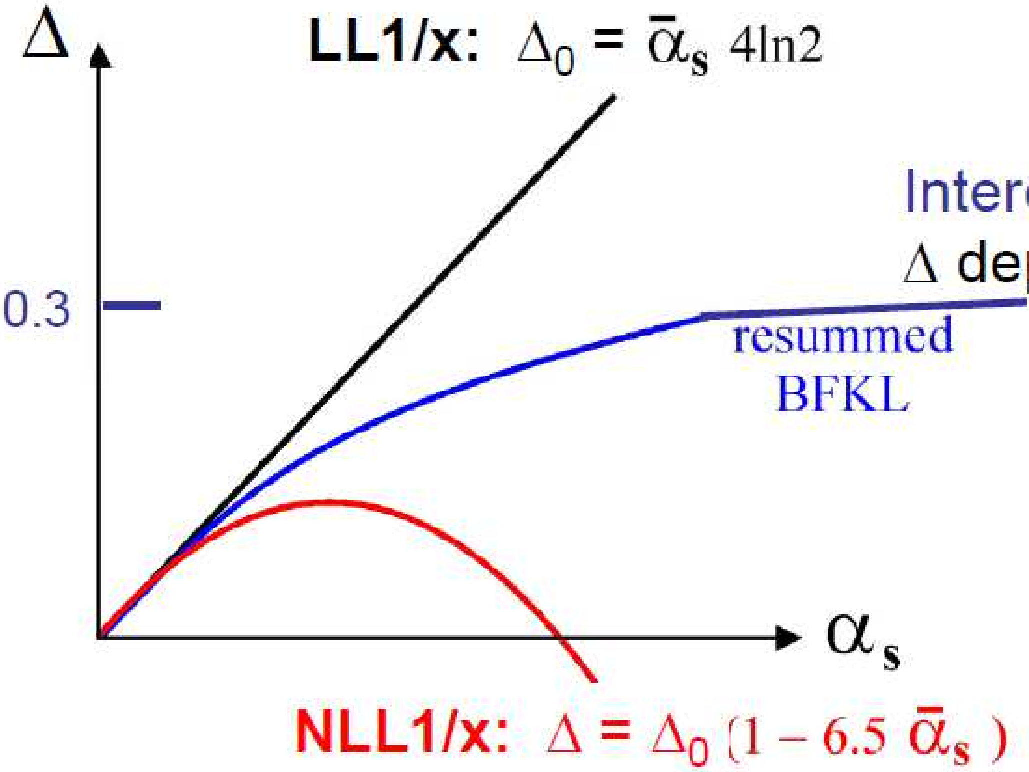
High-mass diss^n driven by multi-pomeron effects

BFKL Pomeron naturally allows to continue from the 'hard' domain to the 'soft' region: after resummation of the main HO effects- the intercept weakly depends on the scale,

$$\Delta \equiv \alpha_P(0) - 1 \sim 0.3$$

BFKL stabilized

$\Delta = \alpha_P(0) - 1$



Intercept $\Delta = \alpha_P(0) - 1 \sim 0.3$

Δ depends weakly on k_t for low k_t

DGLAP: $\alpha_s \ln Q^2$

BFKL: $\alpha_s \ln 1/x$

Small-size “BFKL” Pomeron is natural object to continue from “hard” to “soft” domain

- Low-mass dissociation is a consequence of the internal structure of proton. A constituent can scatter & destroy coherence of $|p\rangle$

Good-Walker: $|p\rangle = \sum a_i |\varphi_i\rangle$ (1960)

where φ_i diagonalize T -- have only "elastic-type" scatt

- Usually GW eigenstates assumed independent of t & s
  KMR (2013) parametrize form factor $F_i(t)$ for each $\varphi_{i=1,2}$

  - Allows for $B_{el} \sim 10$ GeV^{-2} at CERN-ISR
    $B_{el} \sim 20$ GeV^{-2} at LHC (7 TeV)
    as well as diff^{ve} dip

- abs. corr^{ns} between intermediate parton-parton inter^{ns}
  $\sigma_{abs} \sim 1/k_t^2$, suppress low k_t → mean k_t increases with s

$$k_{min}^2 \sim s^{0.28}$$

(enhanced multi-pom effects introduce dynamical infrared cutoff)

✶ Conventional RFT assumed all k_t limited and small.

KMR MODEL

$$g_i = \gamma_i \sqrt{\sigma_0} F_i(t)$$

Two-channel eikonal
effective (renormalized) Pomeron $\alpha(0) = 0.12$
slope of trajectory $\alpha'_P = 0.05$ GeV^2

Each Good-Walker eigenstate has formfactor
$F_i(t) \simeq \exp(-b_i\sqrt{t})$ (*Orear-like*)

and the coupling

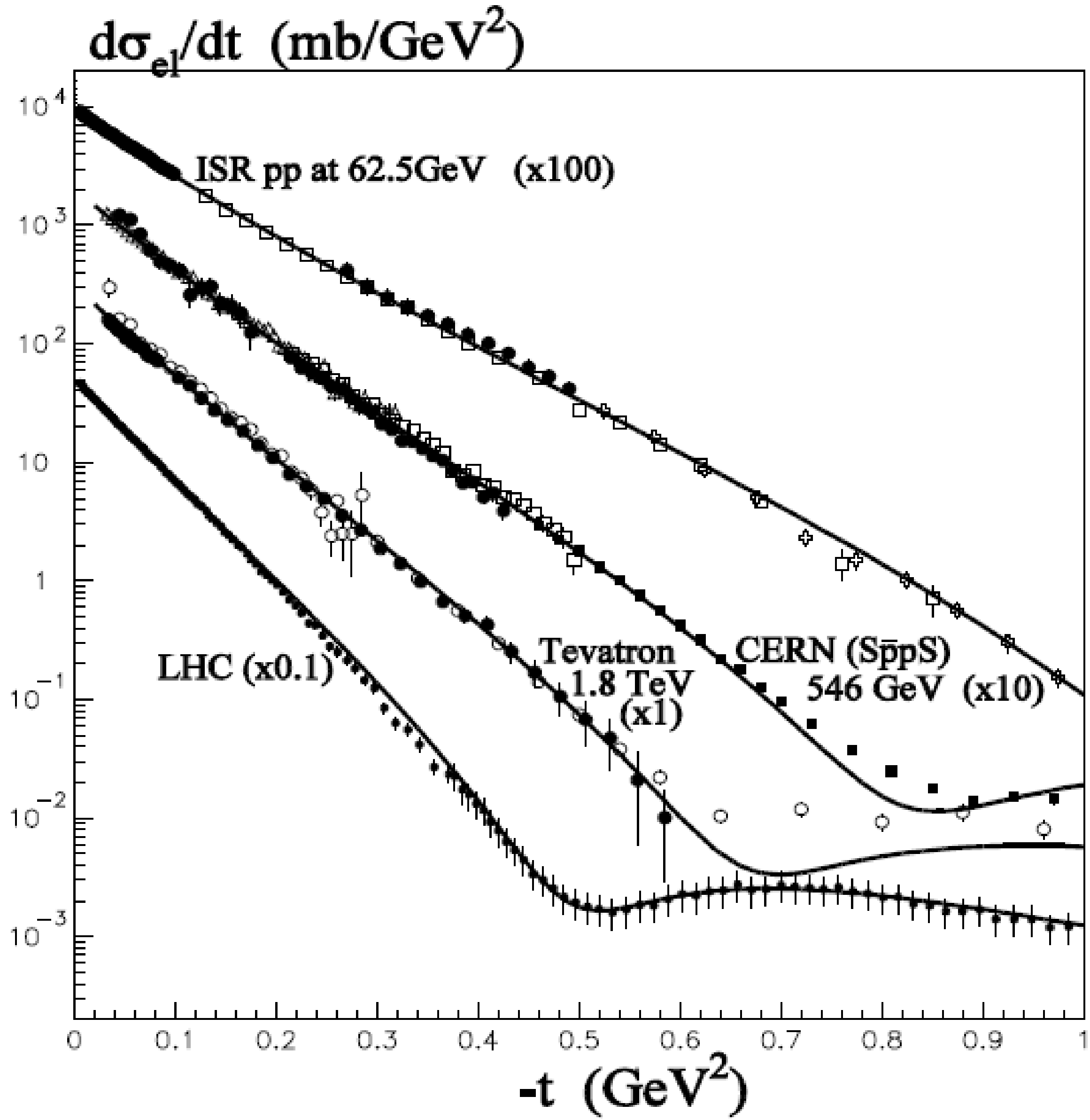
$$\gamma_i \propto N_i * k_P^2/(k_P^2 + k_i^2)$$

$k_P^2 = k_0^2 \cdot s^{0.28}$ $(\sigma \sim \alpha_s^2 \cdot r^2 \sim 1/k^2)$
(at $\sqrt{s} = 1800$ GeV we
have $k_P/k_1 = 0.35$ and $k_P/k_2 = 0.17$)

Triple pomeron coupling $g_{3P} = \lambda g_N$, $\lambda \propto \frac{1}{k_t^2}$.

Introduction of the theoretically motivated energy dependence of k_t within the 2-channel eikonal model allows to describe the existing HE data on the elastic $d\sigma/dt$ and SD $d\sigma/dM^2$ cross sections, including σ^{SD}_{lowM} .

KMR-13



dσ$_{el}$/dt (mb/GeV^2)
ISR pp at 62.5GeV (x100)
CERN (Sp̄pS)
546 GeV (x10)
Tevatron
1.8 TeV
(x1)
LHC (x0.1)
-t (GeV^2)

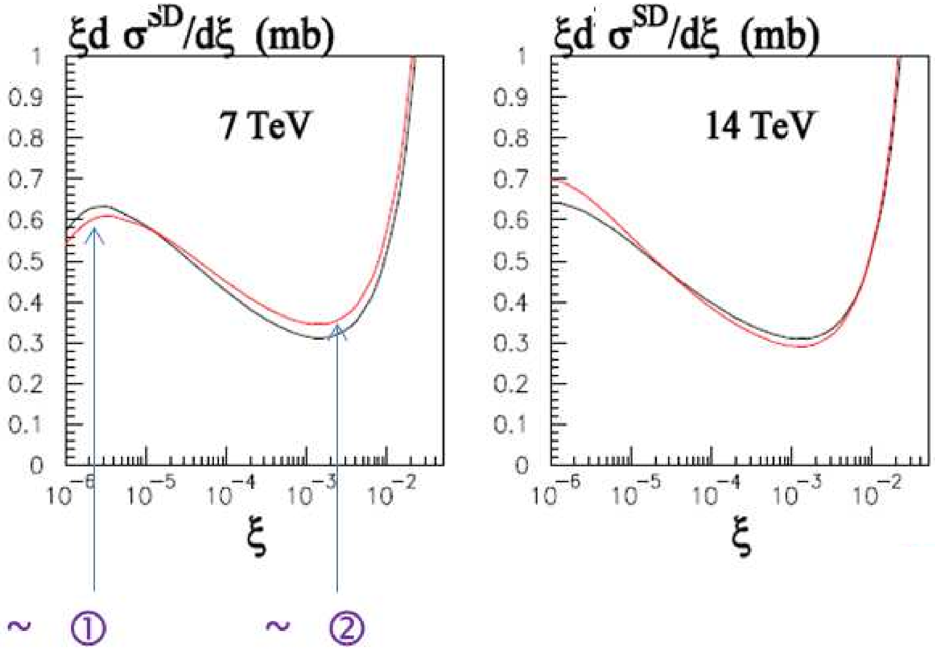
Mass interval (GeV)	(3.4, 8)	(8, 350)	(350, 1100)
Prelim. TOTEM data	1.8	3.3	1.4
CMS data (LRG)		4.3	
Present model KMR	2.3	4.0	1.4

$\sqrt{s}$	$\sigma_{\rm tot}$	$\sigma_{\rm el}$	$B_{\rm el}(0)$	$\sigma_{\rm SD}^{{\rm low}\,M}$	$\sigma_{\rm DD}^{{\rm low}\,M}$	$\sigma_{\rm SD}^{\Delta\eta_1}$	$\sigma_{\rm SD}^{\Delta\eta_2}$	$\sigma_{\rm SD}^{\Delta\eta_3}$	$\sigma_{\rm DD}^{\Delta\eta}$
(TeV)	(mb)	(mb)	(GeV^{-2})	(mb)	(mb)	(mb)	(mb)	(mb)	(μb)
1.8	77.0	17.4	16.8	3.4	0.2				
7.0	98.7	24.9	19.7	3.6	0.2	2.3	4.0	1.4	145
8.0	101.3	25.8	20.1	3.6	0.2	2.2	3.95	1.4	139
13.0	111.1	29.5	21.4	3.5	0.2	2.1	3.8	1.3	118
14.0	112.7	30.1	21.6	3.5	0.2	2.1	3.8	1.3	115
100.0	166.3	51.5	29.4	2.7	0.1				

The predictions of the present model for some diffractive observables for high energy pp collisions at $\sqrt{s}$ c.m. energy. $B_{\rm el}(0)$ is the slope of the elastic cross section at $t=0$. Here $\sigma_{\rm SD}$ is the sum of the single dissociative cross section of both protons. The last four columns are the model predictions for the cross sections for high-mass dissociation in the rapidity intervals used by TOTEM at $\sqrt{s}$=7 TeV: that is, $\sigma_{\rm SD}$ for the intervals $\Delta\eta_1 = (-6.5, -4.7)$, $\Delta\eta_2 = (-4.7,\ 4.7)$, $\Delta\eta_3 = (4.7,\ 6.5)$, and $\sigma_{\rm DD}^{\Delta\eta}$ is the double dissociation cross section where the secondaries from the proton dissociations are detected in the rapidity intervals $\Delta\eta_1 = (-6.5, -4.7)$ and $\Delta\eta_3 = (4.7,\ 6.5)$, At $\sqrt{s}$=7 TeV, the three 'SD' rapidity intervals correspond, respectively, to single proton dissociation in the mass intervals $\Delta M_1 = (3.4, 8)$ GeV, $\Delta M_2 = (8, 350)$ GeV, $\Delta M_3 = (0.35, 1.1)$ TeV, s

Concave –up behaviour of $d\sigma^D/d\ln M_X^2$

KMR-2011



Absorptive corrections appreciably modify the diffractive xsections

KMR

Strong absorption at low k_T and small b_t pushes the partons to a larger mean $< k_T >$ and a larger b_t; that is the interaction radius (and B_{el}) increases.

This leads to a larger α'_P and a smaller triple-Pomeron vertex $g_{3P} \sim 1/k_T^2$.

S. Ostapchenko (arXiv:1402.5084)

option SD_ of QGSJET-II-04 (fit more closely to TOTEM preliminary SD results)

M_X range	< 3.4 GeV	$3.4 - 1100$ GeV	$3.4 - 7$ GeV	$7 - 350$ GeV	$350 - 1100$ GeV
TOTEM [13, 24]	2.62 ± 2.17	6.5 ± 1.3	$\simeq 1.8$	$\simeq 3.3$	$\simeq 1.4$
QGSJET-II-04	3.9	7.2	1.9	3.9	1.5
option SD+	3.2	8.2	1.8	4.7	1.7
option SD-	2.6	7.2	1.6	3.9	1.7

Table 1: σ_{pp}^{SD} (mb) at $\sqrt{s} = 7$ TeV for different ranges of mass M_X of diffractive states produced.

- Faster rise of $\sigma_{\rm tot}$ and $\sigma_{\rm inel}$, low SD (Low Mass). .

Impact on the EAS characteristics : consistency of the current data with almost pure proton composition in the energy range $E_0 = 10^{18} - 10^{20}$ eV

➔ possible long-ranging consequences for astrophysical interpretation of UHECR.

MUCH NEEDED RUN II MEASUREMENTS

- Measurements of σ_{tot} and elastic slope B at 13 TeV (in particular a confirmation of the rise of effective α'_P).

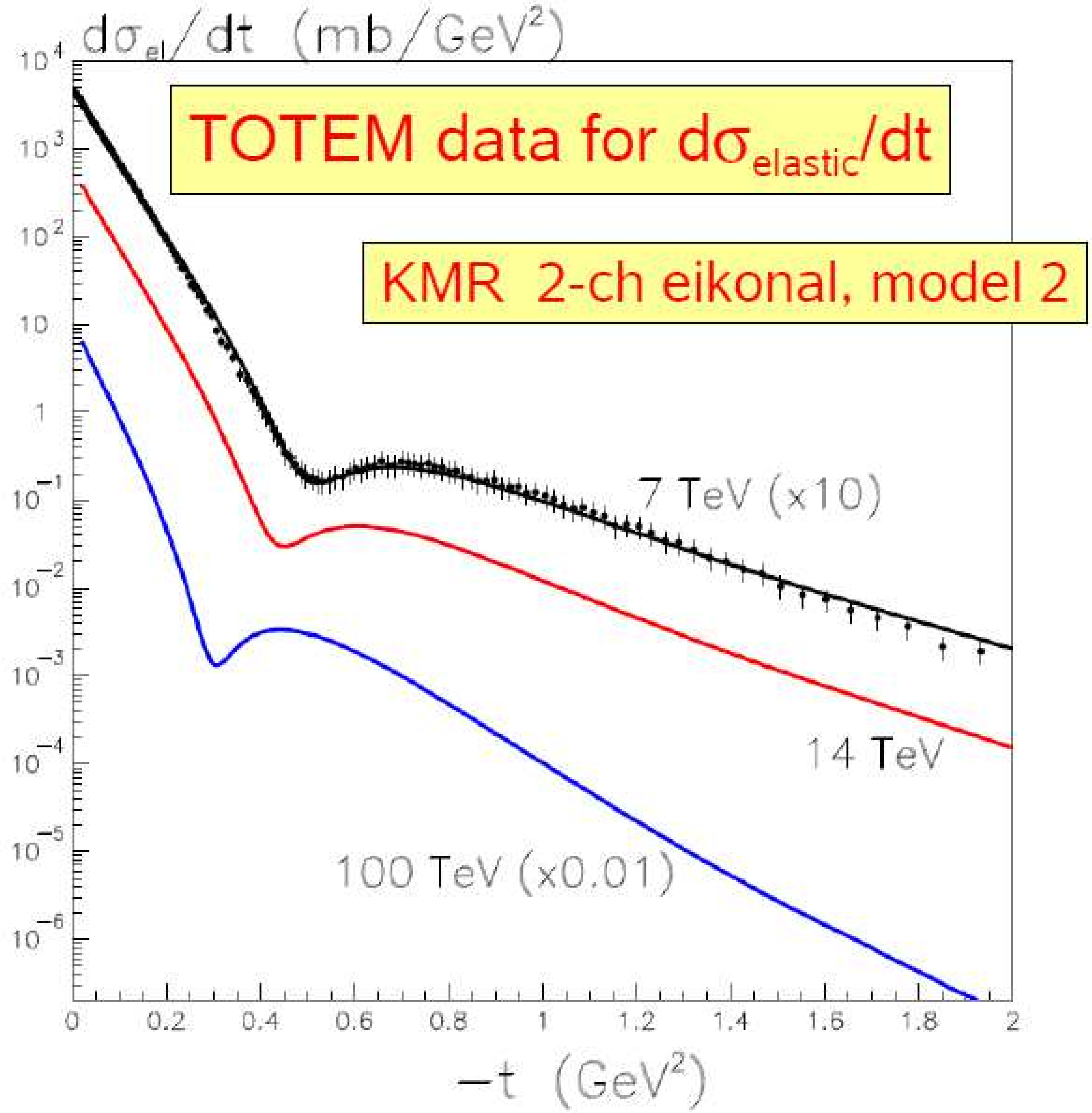
- Accurate determination of σ_{LM}^{SD}, σ_{SD}, σ_{DD} in different mass intervals
TOTEM-CMS (with FSC), ALFA+ ATLAS.
Prospects at the LHCb with FSC counters (HERSHEL -currently being installed).

- Detailed comparison of $d\sigma_{el}/dt$, in the wide t-interval with the theory predictions.

- Comparison of particle distributions in the **PP**, **P**p events with those in the pp collisions (TOTEM-CMS, ALFA+ ATLAS).
- CEP- interferometry : proton correlations in $pp \to p + \pi^+\pi^-(dijets) + p$.

- p_t-spectra of D- mesons- close to parton k_t- distributions. $d\,\sigma^D/d\,p_t dy(s,y)$
(Rise of k_t of secondaries with s- already seen at the LHC).

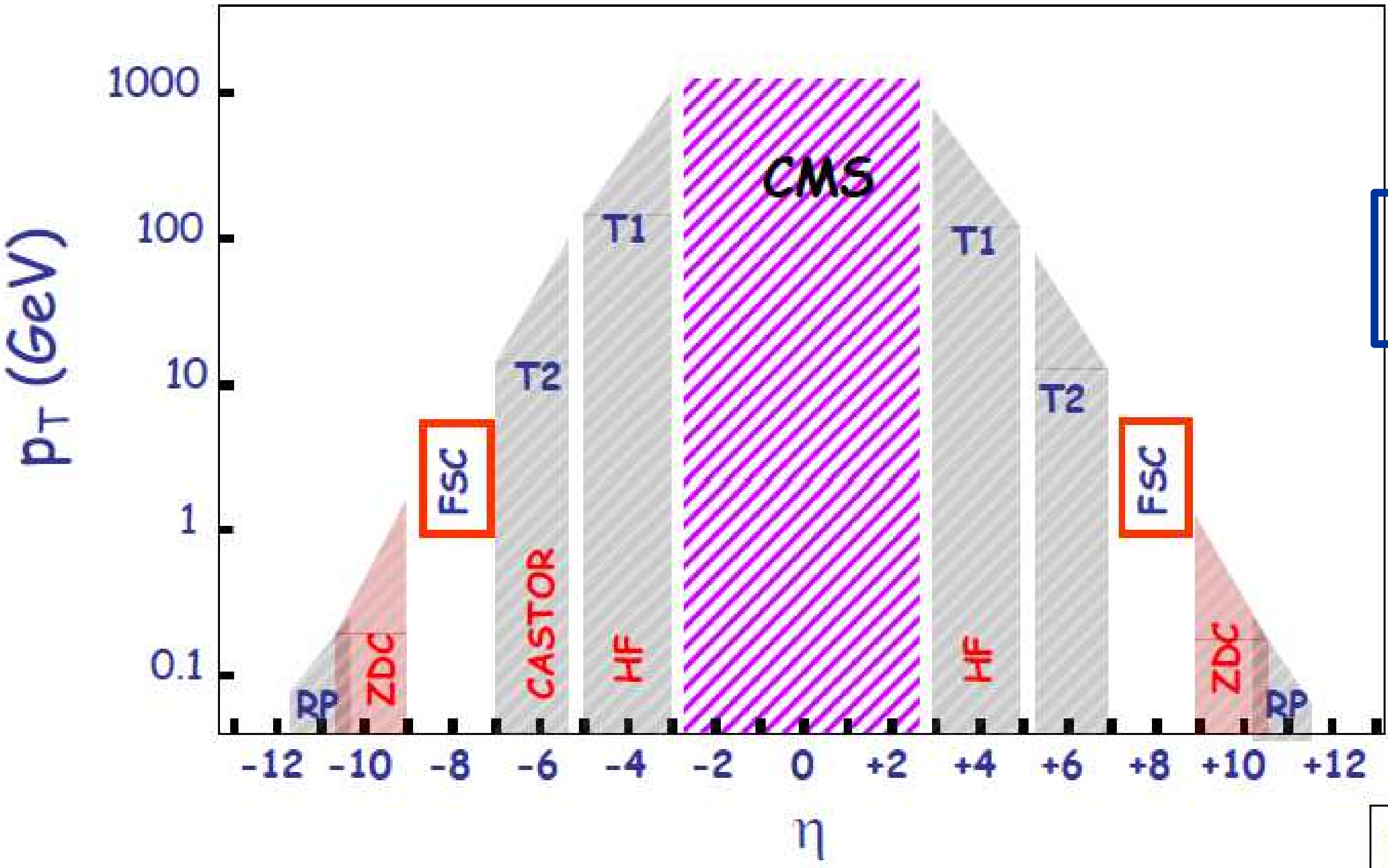
! Special LHC runs with low lumi/ large β^* are badly needed.



TOTEM data for dσelastic/dt
KMR 2-ch eikonal, model 2
dσel/dt (mb/GeV²)
7 TeV (x10)
14 TeV
100 TeV (x0.01)
−t (GeV²)
10⁴
10³
10²
10
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

Towards Full Acceptance

FAD (bj-1992)



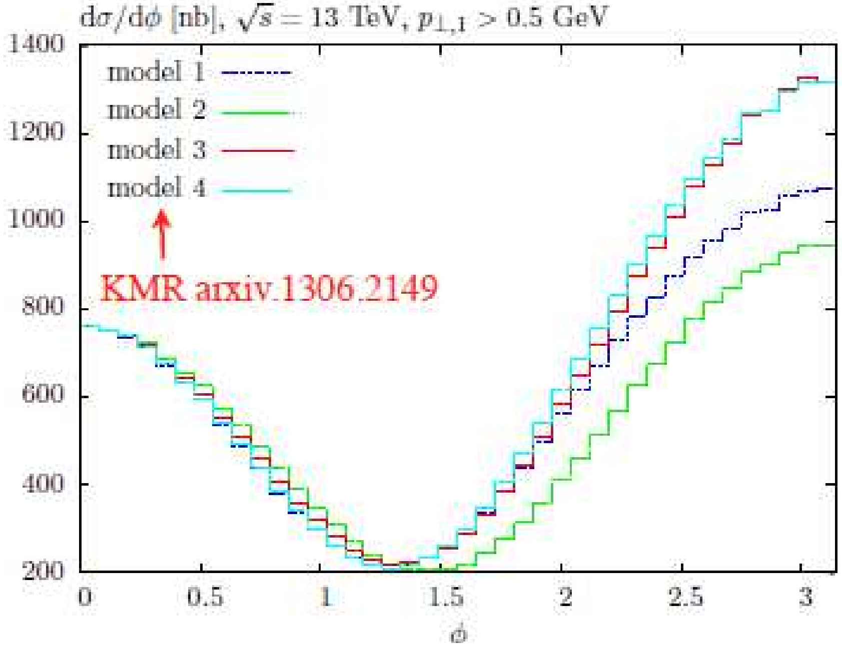
FSCs-M.Albrow et al
2009
Installed-2011

figure adapted from
Risto Orava
(Diffraction 2006)

FSC covers a gap in η between the forward calorimeters (HF, CASTOR) and the very forward (ZDC, TOTEM RP)

$$pp \to p + \pi^+\pi^- + p.$$

S^2 on



KHARYS, arXiv:1312.4553

- Distribution in angle ϕ between outgoing protons strongly effected, in model dependent way.
- In particular true when larger values of proton $p_\perp$ are selected. Cancellation between screened and unscreened amplitudes leads to characteristic 'diffractive dip' structure

Plots for $\pi^+\pi^-$ but similar effect seen in dijet production

CONCLUSION AND OUTLOOK

- The Run I LHC data have already led to important implications for the theoretical models of soft hadron interactions. Allowed to distinguish between previously successful theory scenarios.

- The post-Run I comprehensive models based on RFT+GW allow a fairly good description of the whole range of the HE soft diffractive data.

- The experimental studies in the soft diffraction domain in Run II with forward detectors would provide the critical tests of the current theoretical approaches and could be of upmost importance for the Cosmic Ray field.

- Measurements with special (high β^*) optics and full acceptance coverage in Run II are much needed.


THANK
YOU


QUESTIONS?

BACKUP

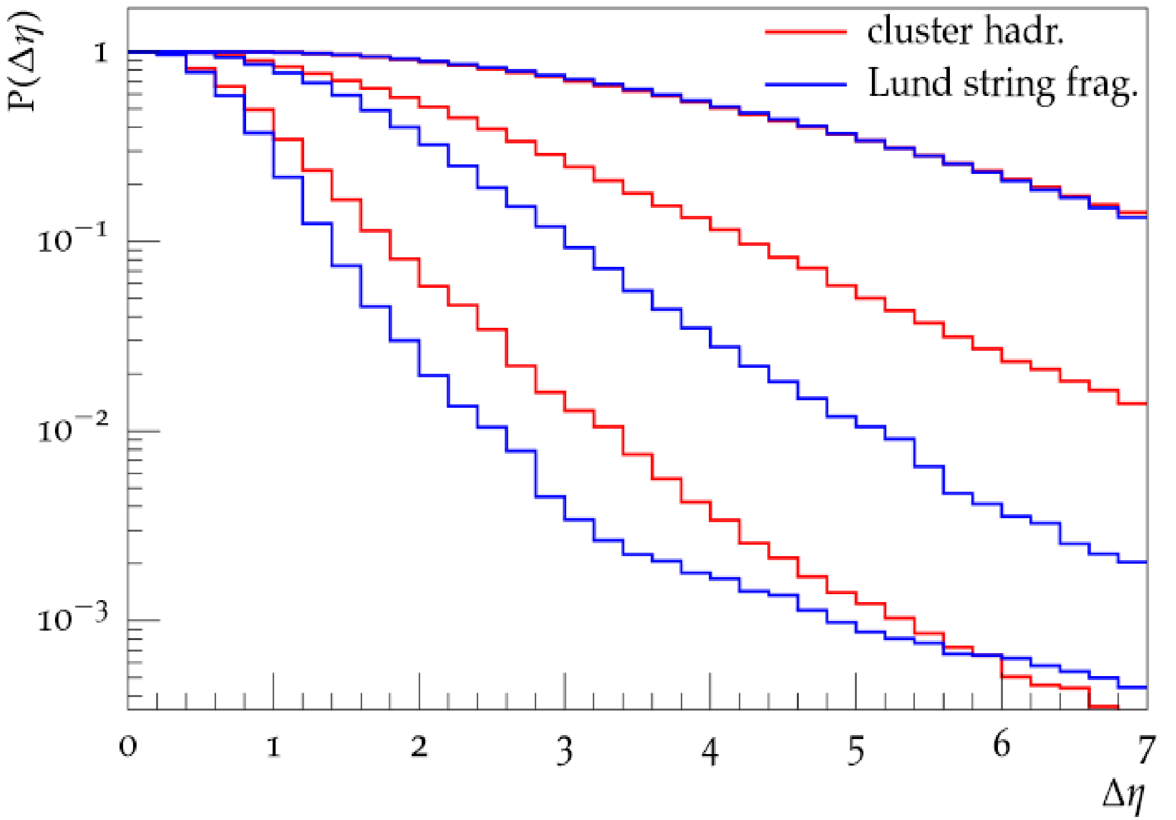


Fig. 4. Probability for finding a rapidity gap (definition 'all') larger than $\Delta\eta$ in an inclusive QCD event for different threshold $p_\perp$. From top to bottom the thresholds are $p_{\perp,\,\mathrm{cut}} = 1.0\,,\ 0.5\,,\ 0.1\,\mathrm{GeV}$. Note that the lines for cluster and string hadronisation lie on top of each other for $p_{\perp,\,\mathrm{cut}} = 1.0\,\mathrm{GeV}$. No trigger condition was required, $\sqrt{s} = 7\,\mathrm{TeV}$.

Aside: absorption needed at LHC

$ds_{el}/dt \sim |\,\mathrm{Im}T_{el}(s,t)\,|^2$ $(r=|Re/Im|<<1)$

so can get impact parameter profile $\mathrm{Im}T_{el}(s,b)$, via a Fourier transform q → b space ($t=q^2$), “direct” from data for elastic diff. x-sect:

$$\mathrm{Im}T_{\mathrm{el}}(b) \;=\; \int \sqrt{\frac{d\sigma_{\mathrm{el}}}{dt}\,\frac{16\pi}{1+\rho^2}}\; J_0(qb)\,\frac{qdq}{2\pi}$$

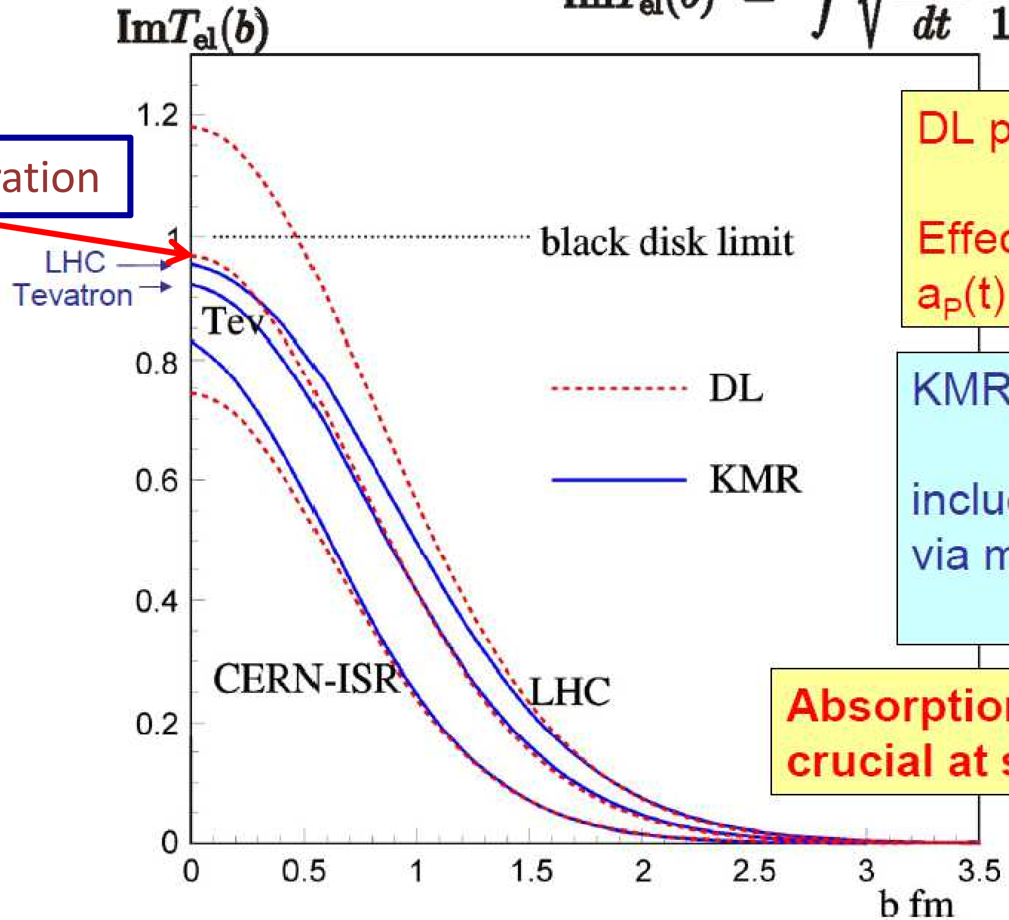
↑ data

$d\sigma_{el}/dt \sim |\,\mathrm{Im}T_{el}(s,t)\,|^2$

impact parameter profile $\mathrm{Im}T_{el}(s,b)$

$$\mathrm{Im}T_{el}(b) = \int \sqrt{\frac{d\sigma_{el}}{dt}\,\frac{16\pi}{1+\rho^2}}\; J_0(qb)\,\frac{q\,dq}{2\pi}$$

close to total saturation



DL parametrization:

Effective Pom. pole
$a_P(t) = 1.08+0.25t$

KMR parametrization

includes absorption via multi-Pomeron effects

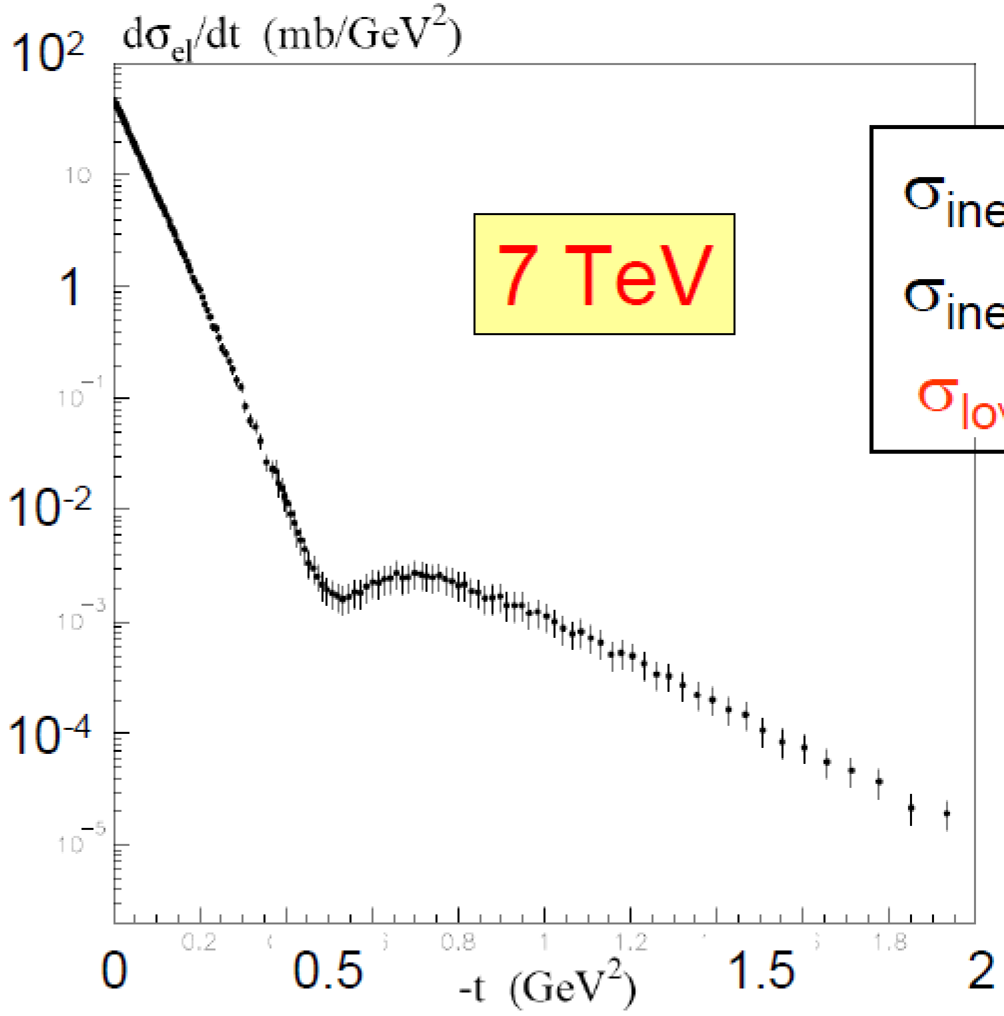
Absorption/ s-ch unitarity crucial at small b at LHC

(similarly, GLM, KP, Ostapchenko)

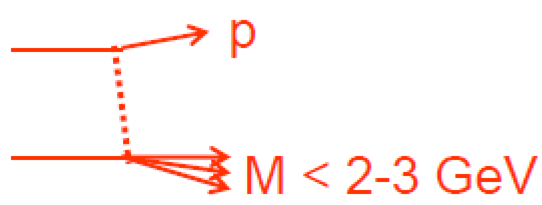
TOTEM data

σ_{tot} = 98.6 +/- 2.2 mb

σ_{el} = 25.4 +/- 1.1 mb



σ_{inel}	= 73.1 +/- 1.3 mb
$\sigma_{inel(\|\eta\|<6.5)}$	= 70.5 +/- 2.9 mb
$\sigma_{low\ M\ dissn.}$	= 2.6 +/- 2.2 mb



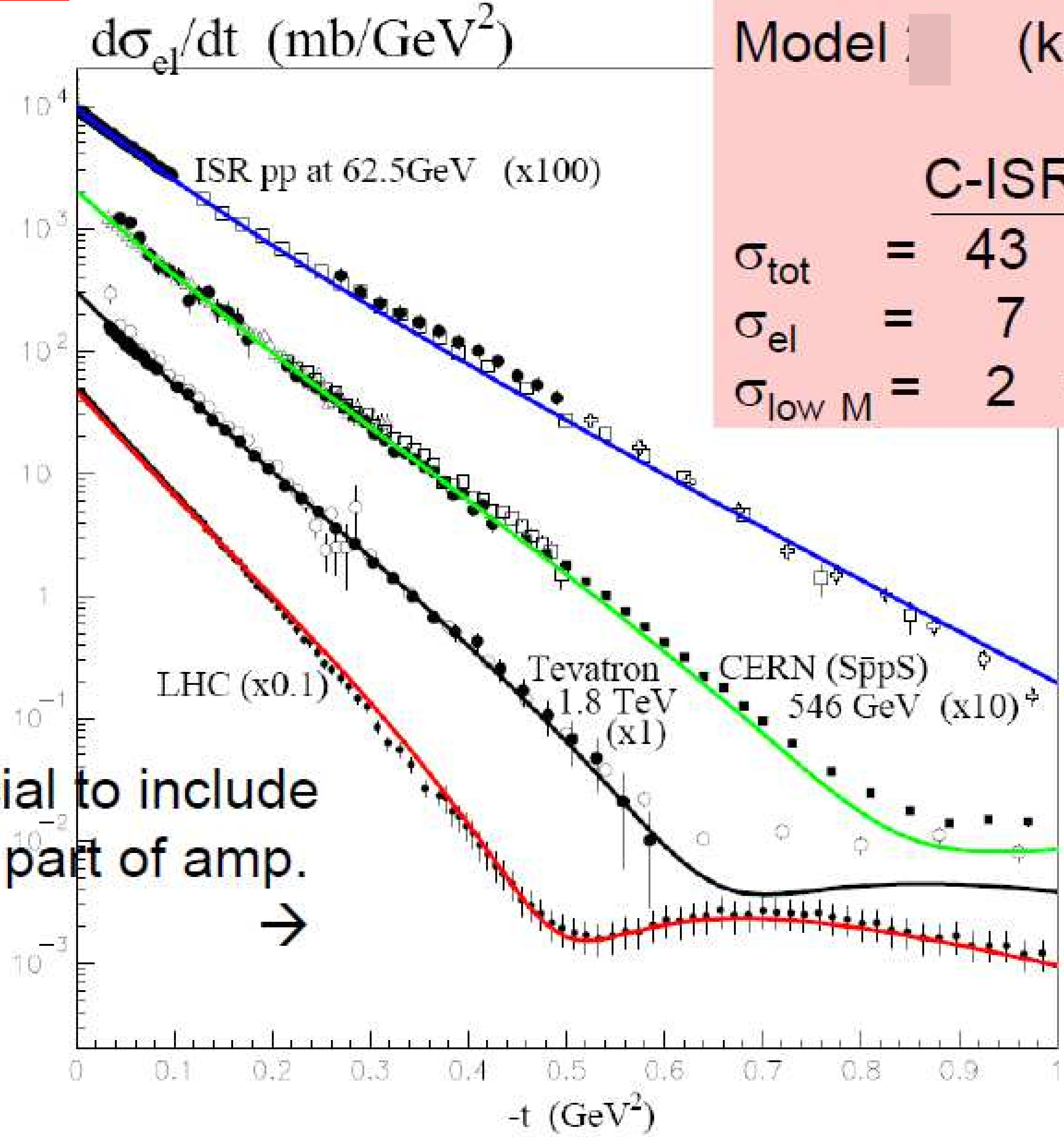
NEW

ALFA (2014) data

σ_{tot} = 95.4 +/-1.3 mb

σ_{el} = 24 .0 0 +/- 06 mb

KMR-13



Model $(k_{min} \sim s^{0.12})$

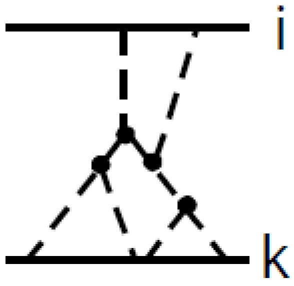
		C-ISR → LHC
σ_{tot}	=	43 → 96.4 mb
σ_{el}	=	7 → 24 mb
$\sigma_{low\ M}$	=	2 → 3.2 mb

closer to ALFA

crucial to include real part of amp. →

high-mass dissociation →

How are Multi-Pomeron contrib[ns] included?



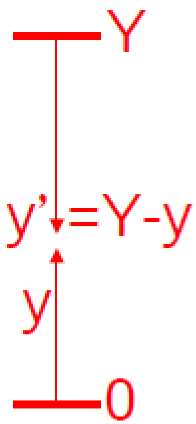
Now include rescatt of intermediate partons with the "beam" i and "target" k (KMR)

evolve up from y=0

$$\frac{\partial \Omega_k(y)}{\partial y} = \bar{\alpha}_s \int d^2k'_t \, \exp(-\lambda(\Omega_k(y) + \Omega_i(y'))/2) \; K(k_t, k'_t) \; \Omega_k(y)$$

evolve down from y'=Y-y=0

$$\frac{\partial \Omega_i(y')}{\partial y'} = \bar{\alpha}_s \int d^2k'_t \, \exp(-\lambda(\Omega_i(y') + \Omega_k(y))/2) \; K(k_t, k'_t) \; \Omega_i(y')$$



where $\lambda\Omega_{i,k}$ reflects the different opacity of protons felt by intermediate parton, rather the proton-proton opacity $\Omega_{i,k}$ $\lambda \sim 0.2$

solve iteratively for $\Omega_{ik}(y,k_t,b)$ **inclusion of k_t crucial**

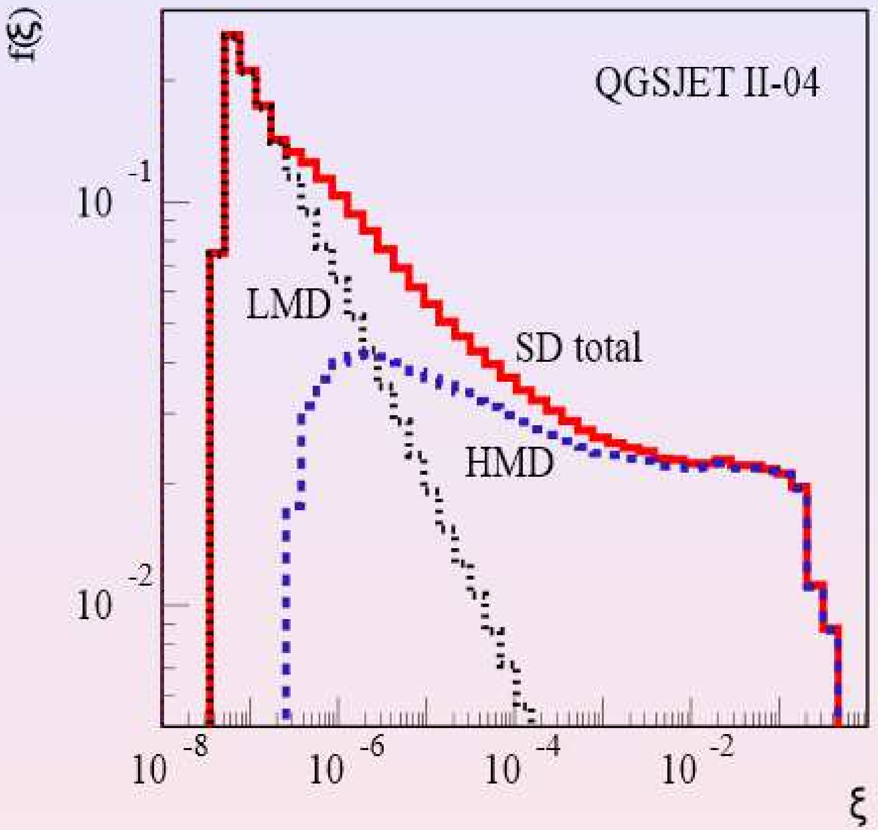
Comparison of results of various models

W = 1.8 TeV	GLM	KMR14	KMR2C	Ostap(C)	MBR*	KP
$\sigma_{\rm tot}(mb)$	79.2	77.0	77.2	73.0	81.03	75.0
$\sigma_{\rm el}(mb)$	18.5	17.4	17.4	16.8	19.97	16.5
$\sigma_{SD}(mb)$	11.27	3.4(LM)	2.82(LM)	9.2	10.22	10.1
$\sigma_{DD}(mb)$	5.51	0.2(LM)	0.14(LM)	5.2	7.67	5.8
$B_{el}(GeV^{-2})$	17.4	16.8	17.5	17.8		

W = 7 TeV	GLM	KMR14	KMR2C	Ostap(C)	MBR	KP
$\sigma_{\rm tot}(mb)$	98.6	98.7	96.4	93.3	98.3	96.4
$\sigma_{\rm el}(mb)$	24.6	24.9	24.0	23.6	27.2	24.8
$\sigma_{SD}(mb)$	14.88	3.6(LM)	3.05(LM)	10.3	10.91	12.9
$\sigma_{DD}(mb)$	7.45	0.2(LM)	0.14(LM)	6.5	8.82	6.1
$B_{el}(GeV^{-2})$	20.2	19.7	19.8	19.0		19.0

W = 14 TeV	GLM	KMR14	KMR2C	Ostap(C)	MBR	KP
$\sigma_{\rm tot}(mb)$	109.0	112.7	108.	105.	109.5	108.
$\sigma_{\rm el}(mb)$	27.9	30.1	27.9	28.2	32.1	29.5
$\sigma_{SD}(mb)$	17.41	3.5(LM)	3.15(LM)	11.0	11.26	14.3
$\sigma_{DD}(mb)$	8.38	0.2(LM)	0.14(LM)	7.1	9.47	6.4
$B_{el}(GeV^{-2})$	21.6	21.6	21.1	21.4		20.5

S. Ostapchenko (ISVHECRI 2012)



- drastic effect due to LMD
- nontrivial shape for HMD: due to absorptive effects

Re/Im=0.104 +/- 0.027 +/- 0.010 (at 546 GeV Re/Im=0.13 but pp_bar)