# Large Rapidity Gap (LRG) in proton-nucleus interactions

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Advantage of the LRG events
– the background from underlying/MPI events
is practically absent.

LRG events are attractive for:
i) searching the new/BSM physics
ii) studying the Pomeron-Pomeron (multi-Pomeron) interactions.

## 1. Kinematics

## 2. LRG in pp-collisions

a) SD, DD

b) multi-Pomeron exchange/vertices

## 3. LRG in proton-lead collisions

a) incohernt

gap survival factor

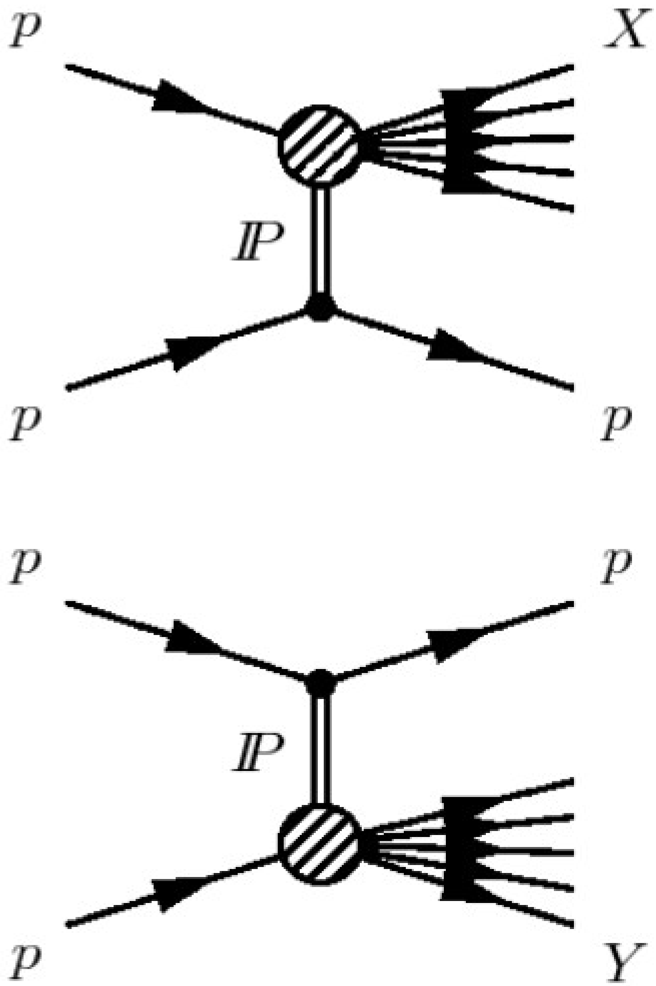
peripheral interaction

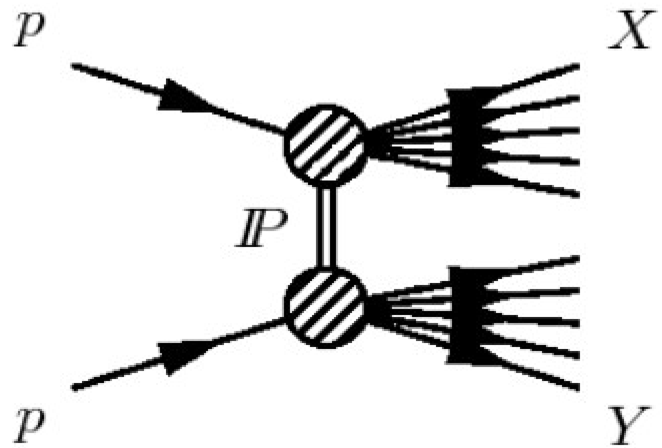
role of the LRG pp-amplitude size

b) coherent Pomeron emission

c) photon exchange

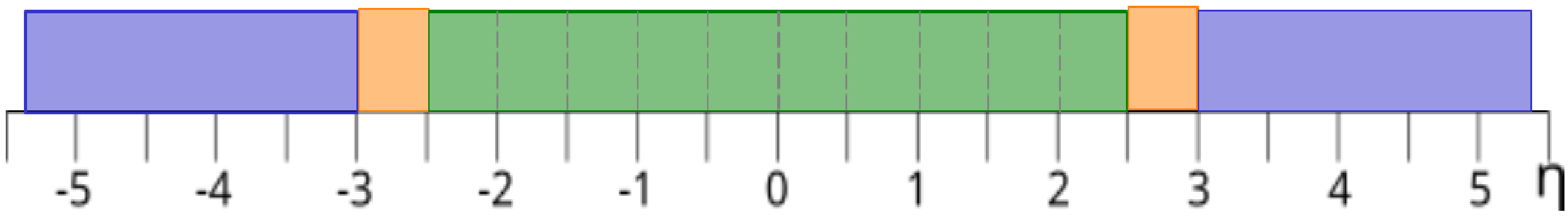
## 4. comparison with the CMS 2301.07630 results.




(c)

# Pb-p diffraction [arXiv:2301.07630]: Used thresholds

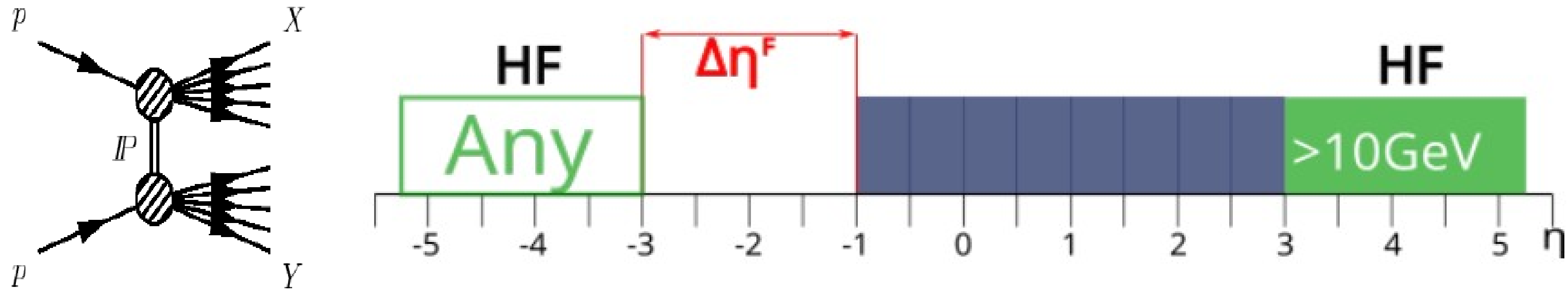


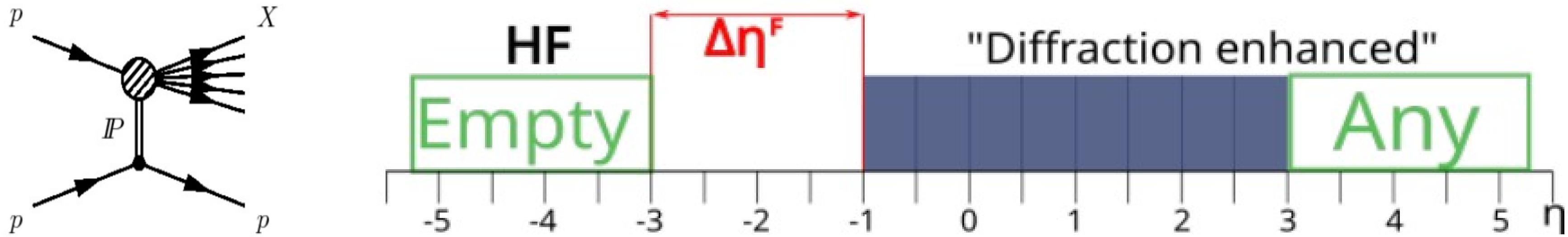

Central part with tracking ($\eta \in [-2.5; 2.5]$) η bin is empty:

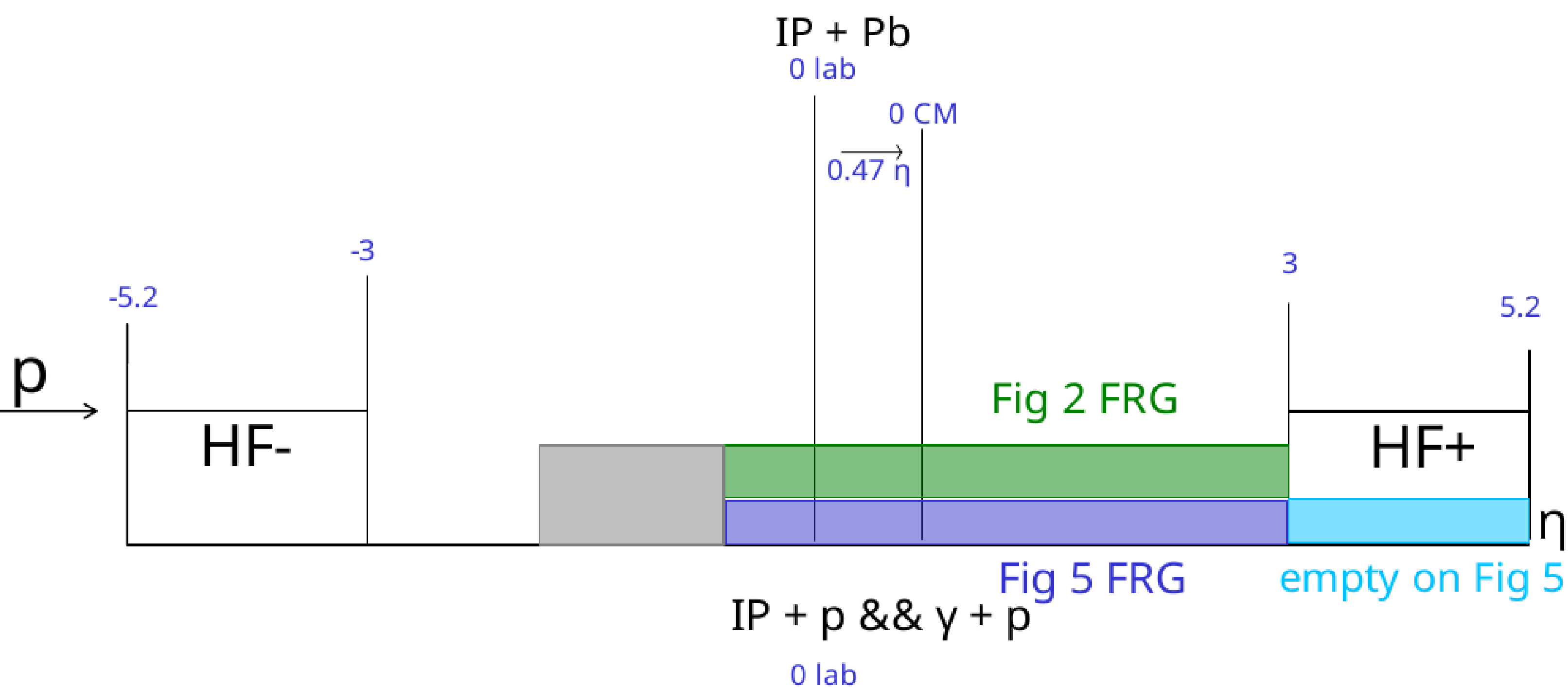
no tracks with pT > 200 MeV and $\sum_{bin} E_{pf} < 6\ GeV$

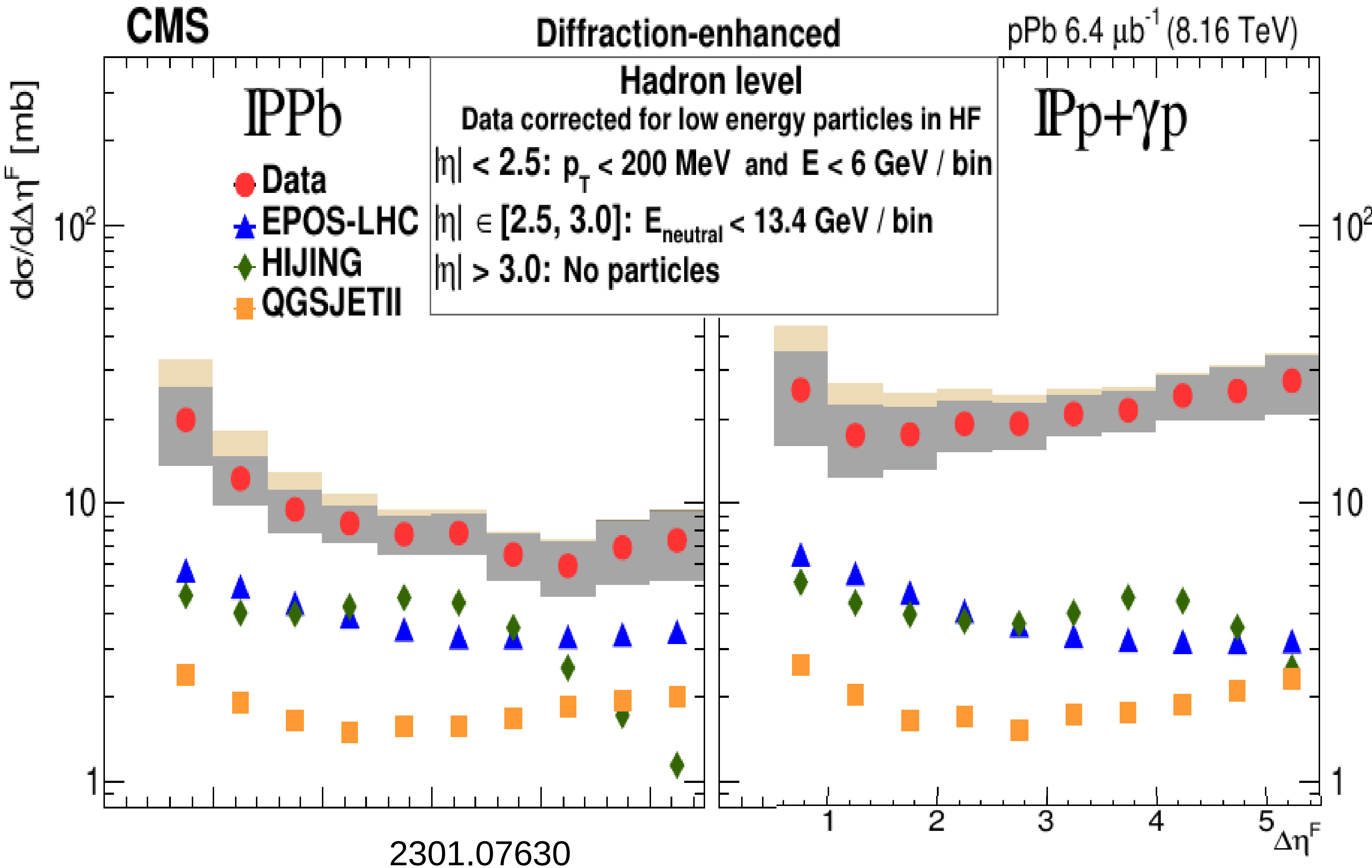
Central part without tracking ($|\eta| \in [2.5; 3.0]$) η bin is empty: $\sum_{bin} E_{pf}^{neutral} < 13.4\ GeV$

HF ($|\eta| \in [3.0; 5.2]$) on the side with RG:

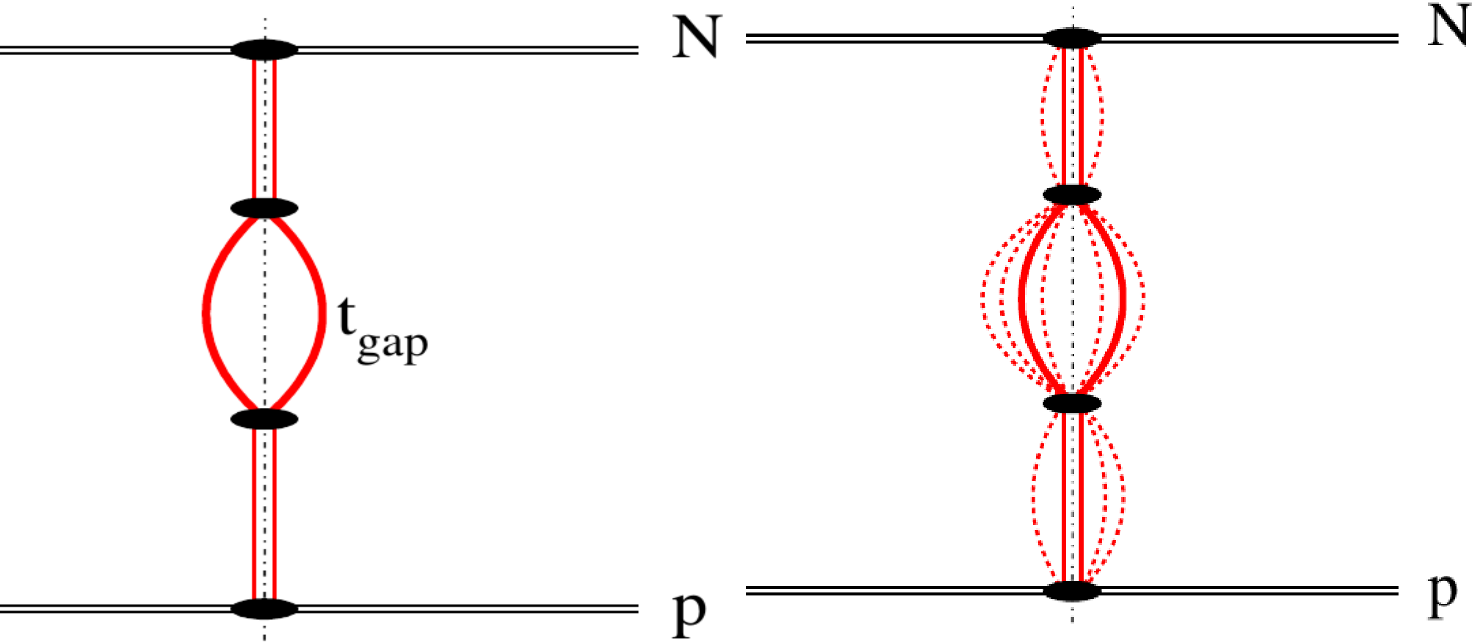

p
X
IP
p
Y
HF
Δη^F
HF
Any
>10GeV
-5 -4 -3 -2 -1 0 1 2 3 4 5 η


p
X
IP
p
p
HF
Δη^F
"Diffraction enhanced"
Empty
Any
-5 -4 -3 -2 -1 0 1 2 3 4 5 η


IP + Pb
0 lab
0 CM
0.47 η
-3
-5.2
3
5.2
p
Pb
Fig 2 FRG
HF-
HF+
η
Fig 5 FRG
empty on Fig 5
IP + p && γ + p
0 lab


CMS
Diffraction-enhanced
pPb 6.4 μb-1 (8.16 TeV)
Hadron level
Data corrected for low energy particles in HF
|η| < 2.5: pT < 200 MeV and E < 6 GeV / bin
|η| ∈ [2.5, 3.0]: Eneutral < 13.4 GeV / bin
|η| > 3.0: No particles
IPPb
IPp+γp
Data
EPOS-LHC
HIJING
QGSJETII
dσ/dΔηF [mb]
ΔηF

2301.07630




Pomeron==> $\Omega(b,s)$=opacity

$$\Omega(b,s) = \frac{g_N^2}{2\pi B}\left(\frac{s}{s_0}\right)^{\alpha_P(0)-1} e^{-b^2/2B}$$

$$2\mathrm{Im}A_{el}(b) = |A_{el}(b)|^2 + G_{inel}(b)$$

$$A_{el} = i(1 - e^{-\Omega(b)/2}) \qquad G_{inel} = 1 - e^{-\Omega(b)}$$

probability Not to have inelastic interaction is $S^2(b) = e^{-\Omega(b)}$

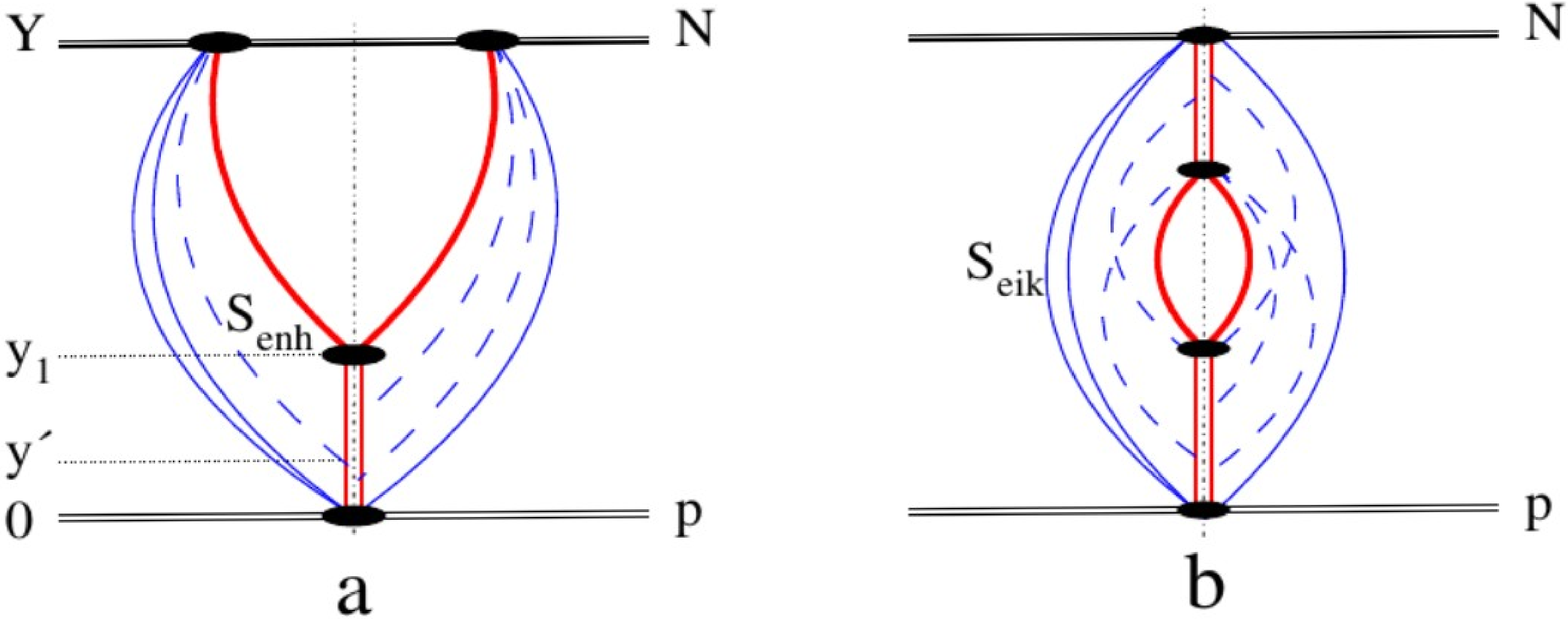



Figure 3: Diagrams for the single (a) and double (b) diffractive dissociation. Heavy red lines denote the elastic amplitude $1 - e^{-\Omega(\Delta b)/2}$ originated by the Pomeron(s) exchange across the LRG; double red lines cut by the dot-dashed line denote the inelastic Pomeron-induced amplitudes $1 - e^{-\Omega(b)}$. In both cases, $\Omega(b)$ is the corresponding opacity caused by one Pomeron exchange in the $b$ representation. Dashed lines describe the semi-enhanced gap survival factor. Here we account for the whole inelastic interactions. That is, the dashed lines correspond to $(1-e^{-\Omega})$ and integration over the interactions with any intermediate Parton in central pomeron (from $y' = 0$ to $y' = y_1$ in the case of the left figure and analogous for the upper part of the right figure) is included. The continuous thin blue lines indicate the non-enhanced Pomeron exchange. Its sum forms the eikonal survival factor $S^2_{eik} = \exp(-\Omega(b))$.

$$S^2_{enh}(\delta b) = \exp\left(-\lambda_1 \int_0^{y_1} dy'(1 - e^{\Omega_{parton}(\delta b)})\right)$$

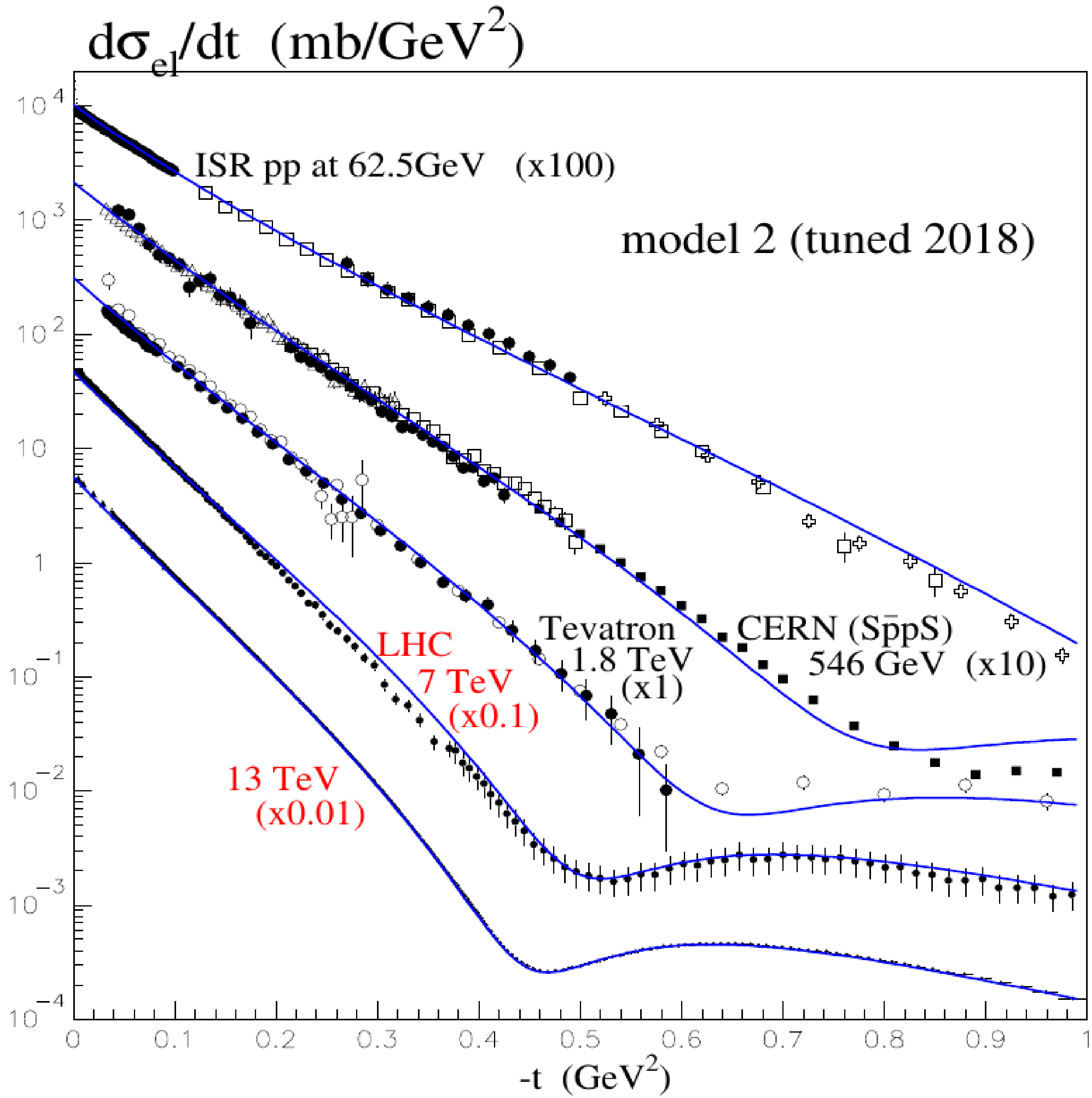
$$g_n^m(k_i^2, k_j^2) = \lambda_1(\lambda_2 g_N)^{m+n-2}\Pi_{i=1}^m e^{-b_{3P}k_i^2}\Pi_{j=1}^n e^{-b_{3P}k_j^2} , \tag{9}$$

where $g_N$ is the Pomeron nucleon coupling taking from [11], $k_i^2$, $k_j^2 > 0$ are the transverse momenta squared transferred through the corresponding Pomeron, and we put the slope $b_{3P} = 0.5$ GeV$^{-2}$. $\lambda_1 = 0.4$ and $\lambda_2 = 0.5$, that is $g_{3P} = \lambda_1\lambda_2 g_N = 0.2 g_N$.

The constant $\lambda_1 = dn/dy$ is the density of the intermediate partons, $dn/dy$, in the rapidity space while $\lambda_2$ is the ratio $g_{parton}/g_N = \lambda_2$ of the Pomeron coupling to the parton at the edge of LRG, $g_{parton}$, to the Pomeron-nucleon coupling, $g_N$.

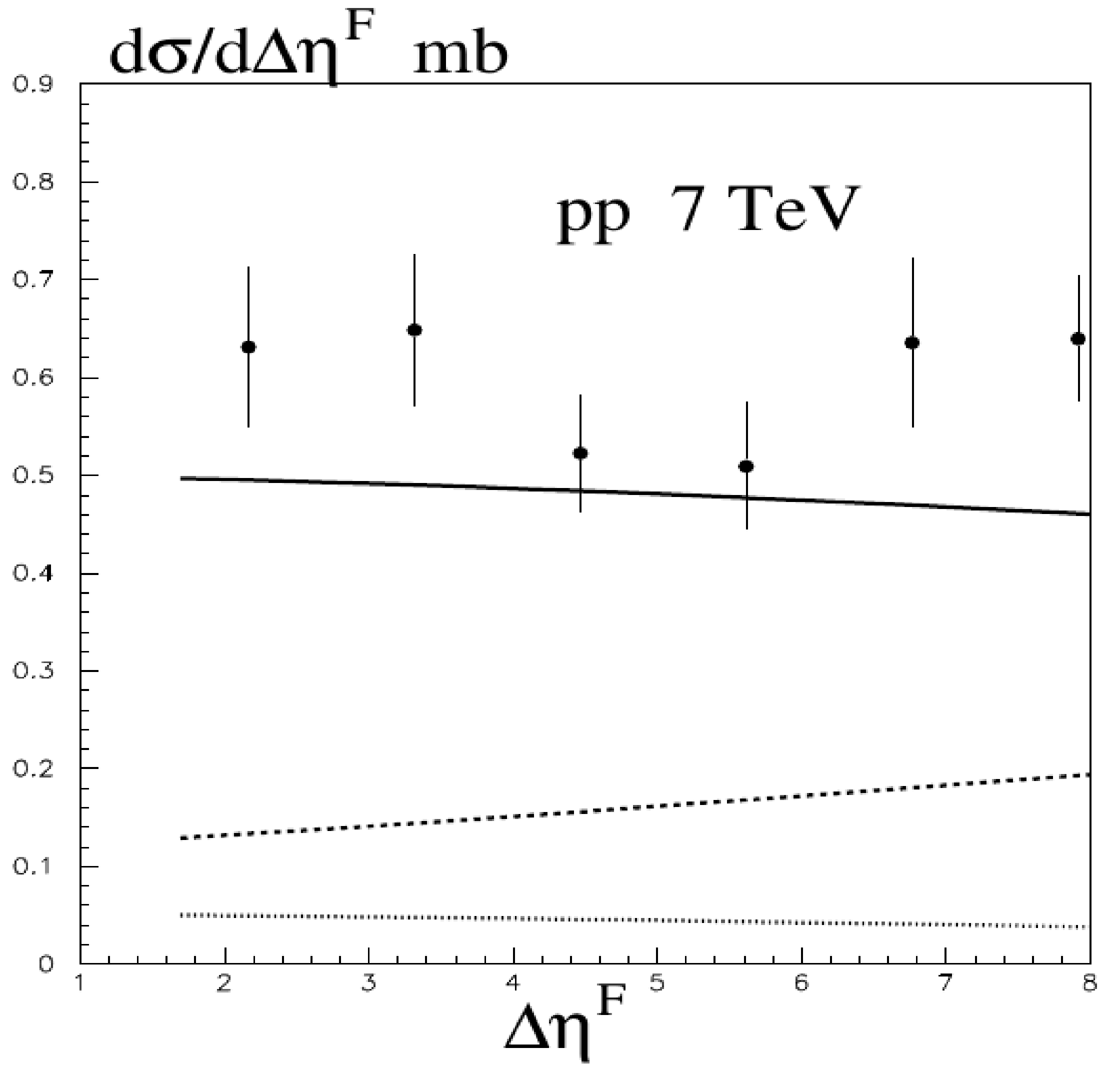
Pomeron parameters are from two (Good-Walker) channel KMR model 1806.05970 $\alpha_P(0) = 1.13$

$\alpha'_P = 0.052$ GeV$^{-2}$ $g_N^2 = 23$ mb

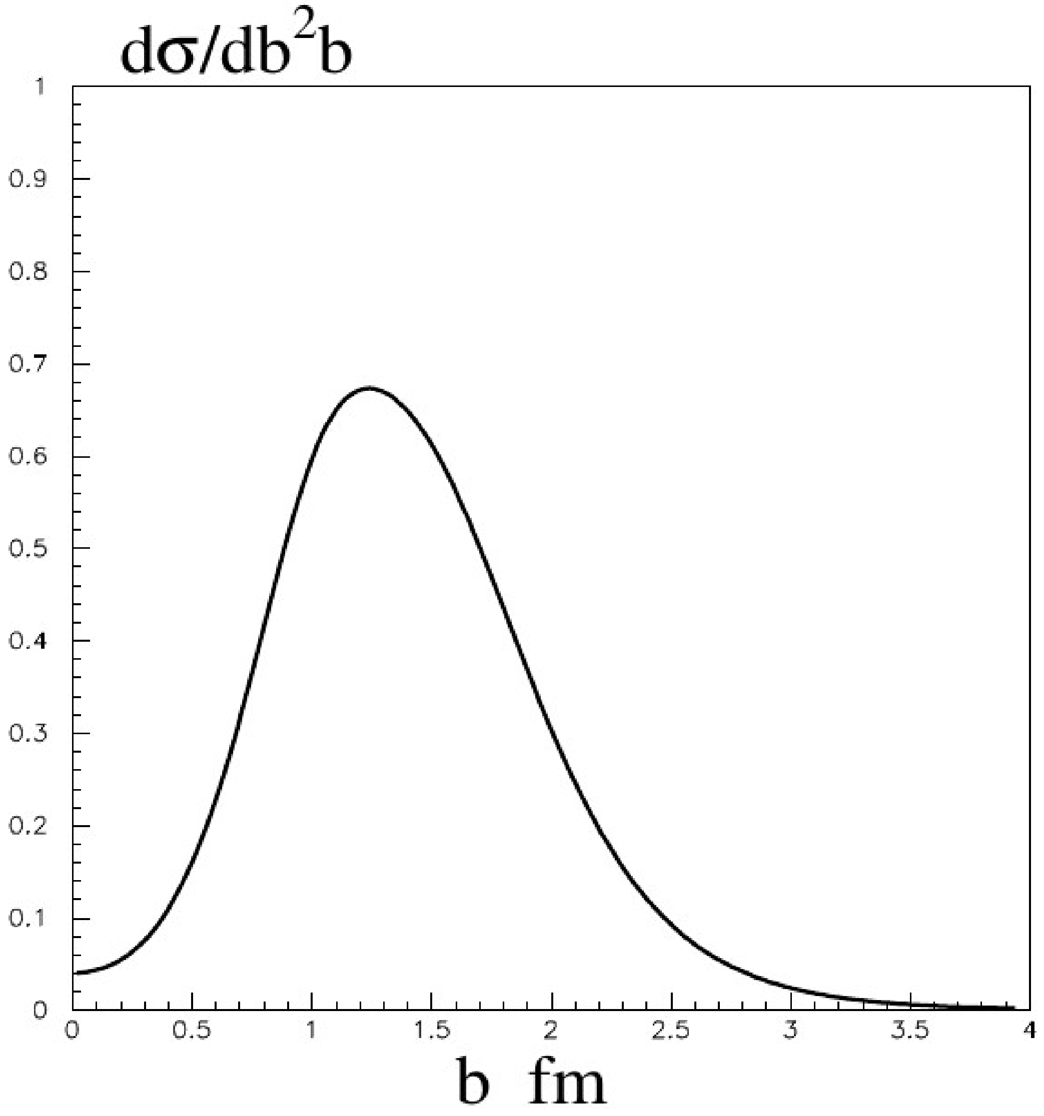


dσel/dt (mb/GeV2)
ISR pp at 62.5GeV (x100)
model 2 (tuned 2018)
Tevatron
1.8 TeV
(x1)
CERN (Spp̄S)
546 GeV (x10)
LHC
7 TeV
(x0.1)
13 TeV
(x0.01)
-t (GeV2)

Data - CMS 1503.08689




The model underestimates CMS LRG cross sections But overestimates the ATLAS-ALFA SD




Due to small gap survival

$$S^2(b) = e^{-\Omega(b)}$$

at small b the LRG amplitude

becomes peripheral with

Maximum at b ~ 1.2 -1.3 fm.

# LRG in proton-lead collisions

## a) incoherent

$$\sigma_{\rm incoh} = \int d^2b T_e(b)|A|^2 S^2(b)$$

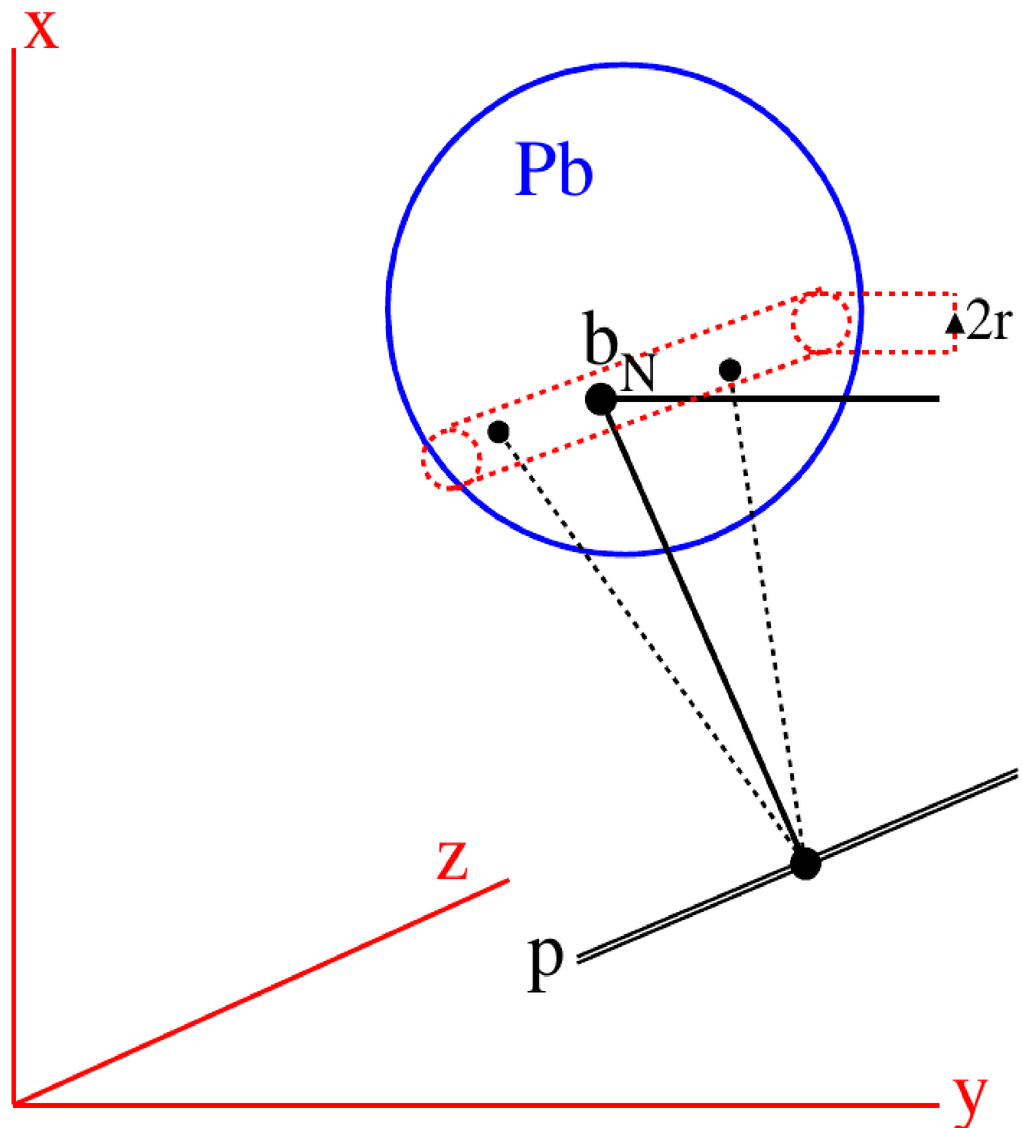
$$S^2(b) = \exp\left(- < \nu(b) >\right)$$

$$< \nu(b) >= T_s(b)\sigma(pN) - 1$$

$$T_e(b) = \frac{\int d^2b' \; T(b')|A(\vec{b} - \vec{b}')|^2}{\int d^2b'|A(b')|^2}$$

$$\sigma(pN) = \sigma_{tot} - \sigma_{el} - \sigma_{LRG}$$

$$\sigma(pN) = 65 \text{ mb}$$



$$T(b) = \int_{-\infty}^{+\infty} dz(\rho_p(r) + \rho_n(r)) \tag{11}$$

with $r = \sqrt{z^2 + r_t^2}$ and $r_t = b$. For the nucleon density in the lead $\rho(r)$ we use the Wood-Saxon form [12]

$$\rho_N(r) = \frac{\rho_0}{1 + \exp\left((r - R)/d\right)} \;, \tag{12}$$

where the parameters $d$ and $R$ respectively characterise the skin thickness and the radius of the nucleon density in the heavy ion; $r = (z, r_t)$. For $^{208}$Pb we take the recent results of [13, 14]

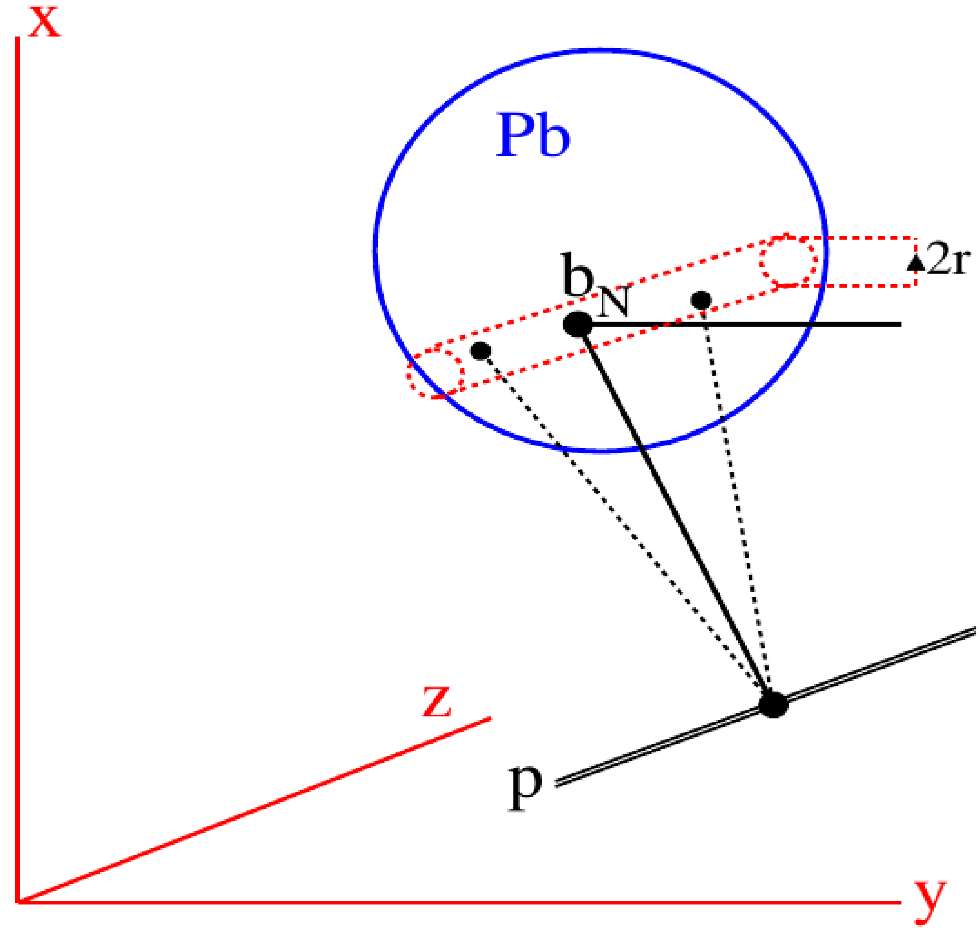
$$\begin{aligned} R_p &= 6.680\,\text{fm} \;, & d_p &= 0.447\,\text{fm} \;, \\ R_n &= (6.67 \pm 0.03)\,\text{fm} \;, & d_n &= (0.55 \pm 0.01)\,\text{fm} \;. \end{aligned} \tag{13}$$

$$T_e(b) = \frac{\int d^2b' \; T(b')|A(\vec{b} - \vec{b}')|^2}{\int d^2b'|A(b')|^2}$$

## b) coherent

$$\sigma_{\rm coh} = 4\pi B_{sd} F^2_{\rm Pb}(t_{\rm min}) \int d^2b T_e^2(b)|A|^2 S^2(b) \ ,$$

$$B_{sd} = 1/ < k_T^2 >,$$



# Photon exchange

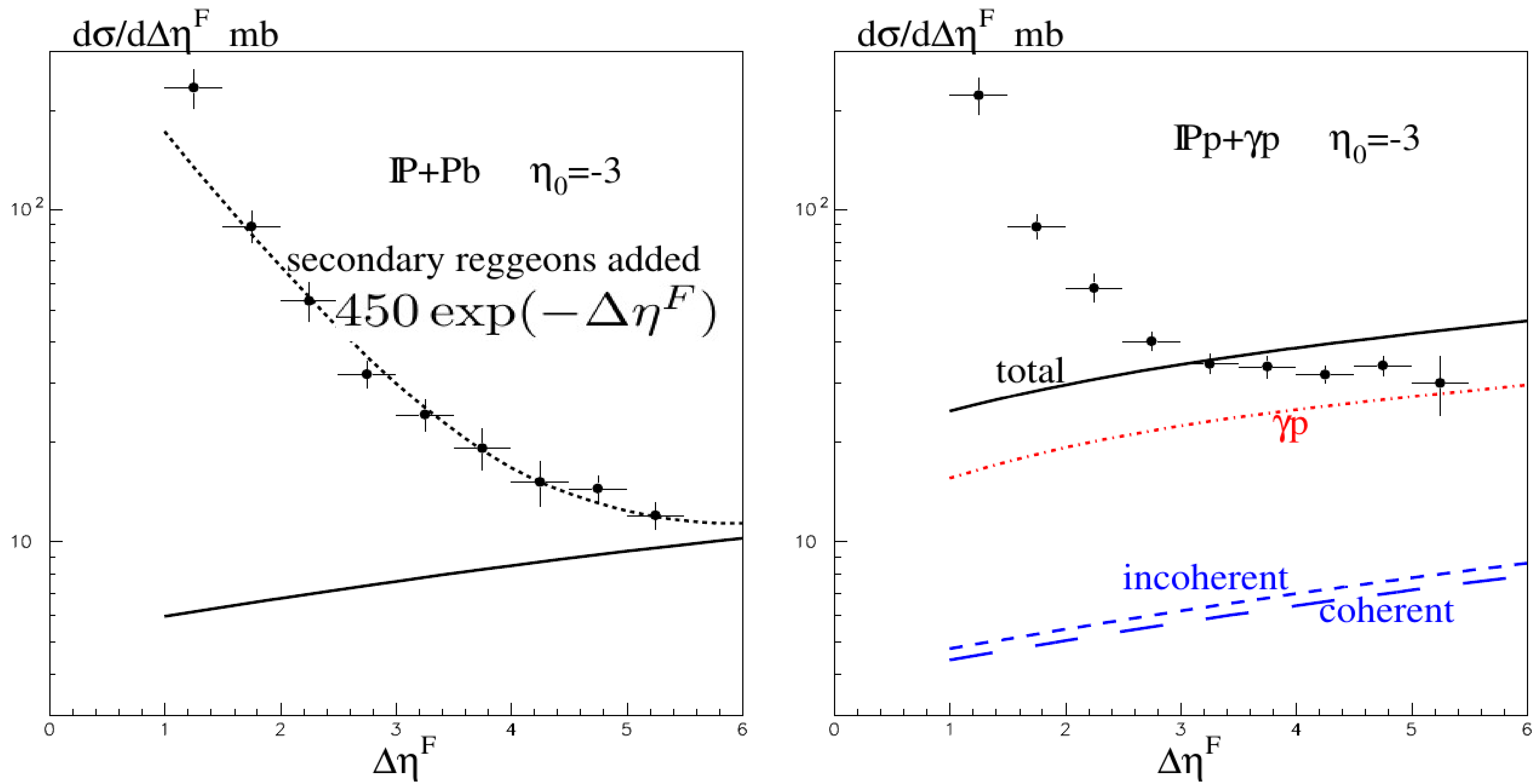
$$\frac{x\sigma(Pb \to \gamma + p)}{dx} = \sigma(\gamma + p) \int d^2b \frac{xd^3 n_\gamma(x,b)}{dxd^2b} \cdot S^2(b)$$

$$\frac{d^3 n_\gamma}{dx d^2 b_\gamma} = \frac{Z^2 \alpha^{\text{QED}}}{x \pi^2 b_\gamma^2} (x m_N b_\gamma)^2 \; K_1^2(x m_N b_\gamma)$$

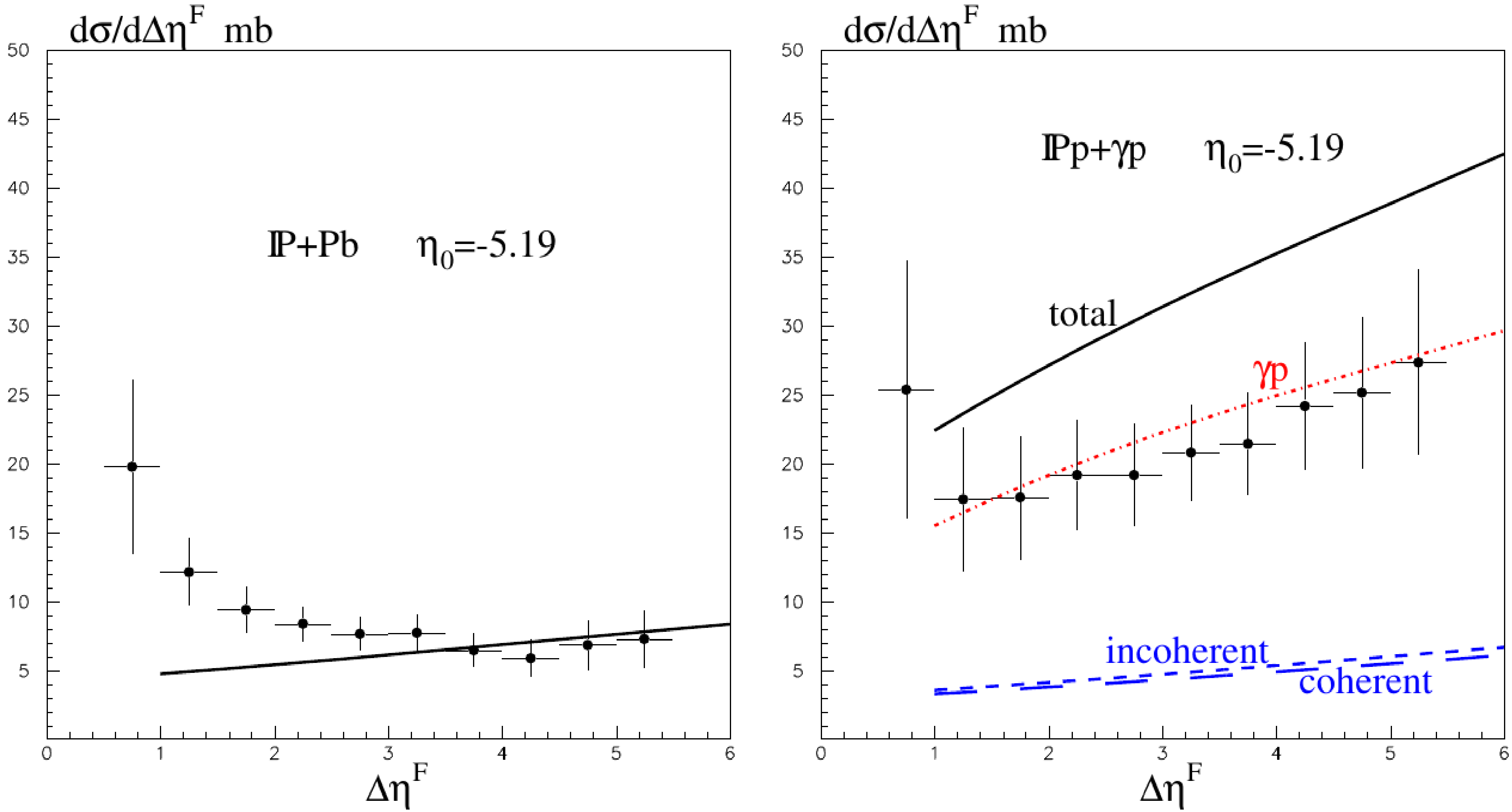
$$Z^2 = 82^2 = 6724$$

$$\sigma(\gamma + p) = 0.0677mb \cdot s_{\gamma p}^{0.0808} + 0.129mb \cdot s_{\gamma p}^{-0.4525}$$

A. Donnachie, P.V. Landshoff, Phys.Lett. B **296** (1992) 227.


dσ/dΔη^F mb
IP+Pb η0=-3
secondary reggeons added
450 exp(−Δη^F)
Δη^F
dσ/dΔη^F mb
IPp+γp η0=-3
total
γp
incoherent
coherent
Δη^F

No HF veto




Note that neglecting the transverse size of the elementary amplitudes both for the LRG amplitude and the absorptive cross-section we get almost twice the smaller cross-section – 4.6 mb instead of the 8.4 mb.

the result depends on the value of absorptive cross-section $\sigma(pN)$
replacing $\sigma(pN) = 65$ mb by 70 mb
changes the total value of $d\sigma/d\eta^F$ at $\Delta\eta^F = 6$
from 42.5 mb to 41.2 mb (right)
and from 8.4 mb to 7.8 mb (left)

If no additional experimental cuts were imposed to select the $I\!Pp + \gamma p$ conguration,

then we face the problem – why is the Pomeron-induced coherent plus incoherent contribution, which is expected to be about 13 mb, is not seen in the data?

# THANK YOU