Soft physics at the LHC

- A brief survey of diffraction
- New model for high energy proton-proton interactions, based on a full set of multi-Pomeron interactions, as well as including multichannel eikonal scattering
- The model description of the total, elastic and (low and high mass) diffractive cross sections; and the predictions for the LHC

Ryskin, Martin, Khoze
arXiv: 0710.2494

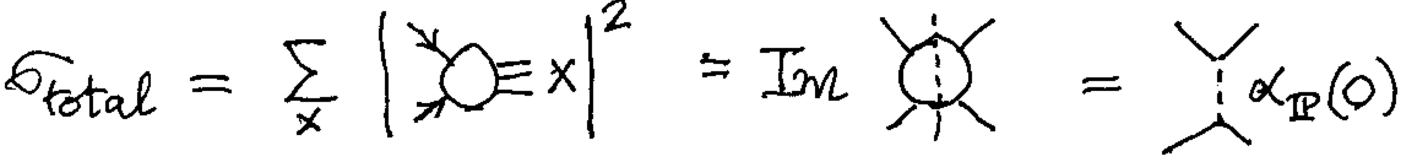
Alan Martin (Durham)
October 2007

Example of diffraction: p-nuclear scatt.

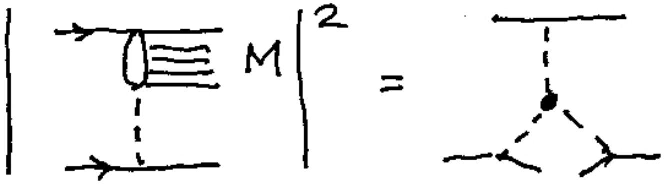
Like light scatt from black disc.

Wave nature → QM description.

Soft interactions



High mass M diffractive dissociation }

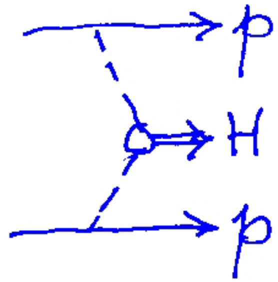


triple-Pomeron

Hard diffraction

diffractive prod of jets, W, Z, Higgs, $Q\bar{Q}$, SUSY...

interplay of 'soft' and 'hard' physics



$$SS^\dagger = I \quad \text{with} \quad S = I + iT \quad \rightarrow \quad T - T^\dagger = i T^\dagger T$$

elastic unitarity →

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

$$\left\{ \begin{array}{l} \dfrac{d^2\sigma_{tot}}{d^2b} = 2\,\mathrm{Im}\,T_{el} = 2\left(1 - e^{-\Omega/2}\right) \\[2ex] \dfrac{d\sigma_{el}}{d^2b} = |T_{el}|^2 = \left(1 - e^{-\Omega/2}\right)^2 \\[2ex] \dfrac{d\sigma_{inel}}{d^2b} = 2\,\mathrm{Im}\,T_{el} - |T_{el}|^2 = 1 - e^{-\Omega} \end{array} \right.$$

Opacity / Eikonal $\Omega(s,b) \geq 0$

e.g. black disc, $\mathrm{Im}\,T_{el} = 1, \quad b < R$

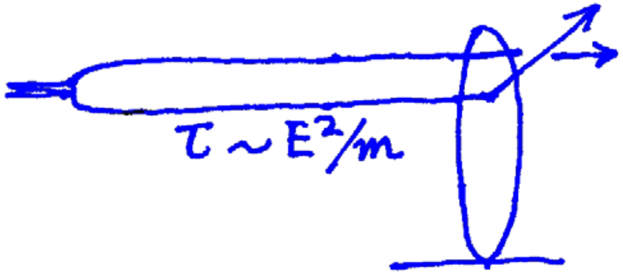
$$\left.\begin{array}{l} \sigma_{tot} = 2\pi R^2 \\ \sigma_{el} = \sigma_{inel} = \pi R^2 \end{array}\right.$$

absorption → diffraction

Inelastic diffraction

consequence of internal structure

H.E.



coherence destroyed

→ inelastic diffⁿ.

Good-Walker:

Introduce diffractive eigenstates ϕ_k

which only undergo "elastic scattⁿ": $\langle \phi_j | T | \phi_k \rangle = 0 \quad j \neq k$

$$\mathrm{Im}\, T\, |\phi_k\rangle = F_k\, |\phi_k\rangle$$

↑

prob. amp. of process via eigenstate ϕ_k

→ multichannel eikonal

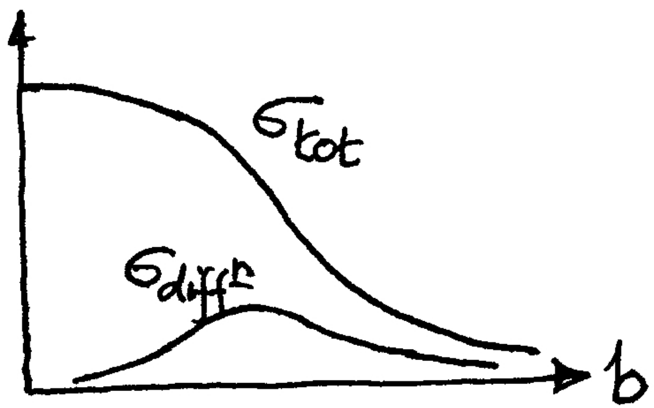
Incoming state $|j\rangle = \sum_k a_{jk} |\phi_k\rangle$

$$\frac{d\sigma_{tot}}{d^2b} = 2\,\mathrm{Im}\langle j|T|j\rangle = 2\sum_k |a_{jk}|^2 F_k = 2\langle F\rangle$$

$$\frac{d\sigma_{el}}{d^2b} = |\langle j|T|j\rangle|^2 = \left(\sum_k |a_{jk}|^2 F_k\right)^2 = \langle F\rangle^2$$

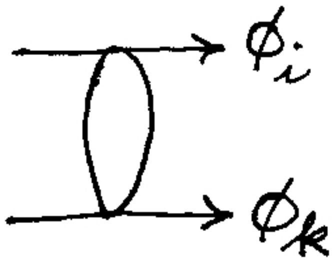
$$\frac{d\sigma_{el+diff^n}}{d^2b} = \sum_k |\langle \phi_k|T|j\rangle|^2 = \sum_k |a_{jk}|^2 F_k^2 = \langle F^2\rangle$$

so
$$\boxed{\frac{d\sigma_{diff^n}}{d^2b} = \langle F^2\rangle - \langle F\rangle^2}$$
dispersion



If all ϕ_k absorbed equally $\sigma_{diff^n} = 0$

At H.E. black disc limit
for small $b \rightarrow F_k = 1 \quad \sigma_{dif} = 0$
Diffraction is peripheral

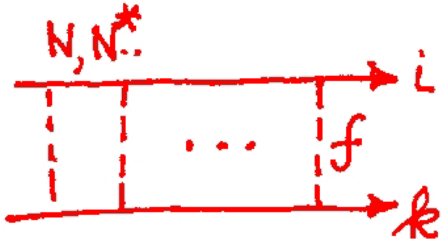


multichannel eikonal

"elastic" scatt. amps

$$F_{ik} = 1 - e^{-\Omega_{ik}/2}$$

$F_{ik} = \sum_{n=1}^{\infty}$



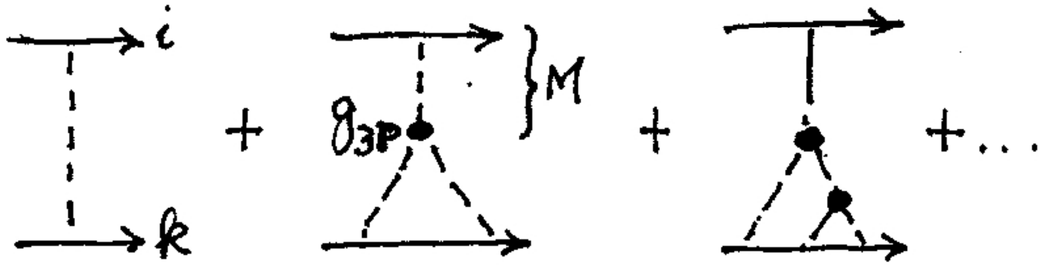
includes low M dissociation

$$f_{ik} = \Omega_{ik}$$

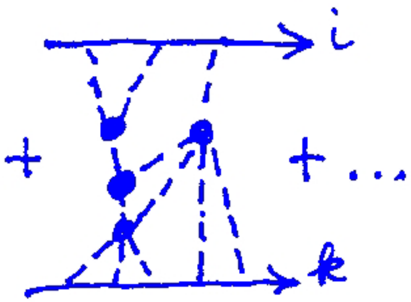
High M dissociation

multi-$\mathbb{P}$ diagrams

$f =$



... +



+ ...

$g_{3\mathbb{P}} \simeq \frac{g_N}{3}$ (not small)

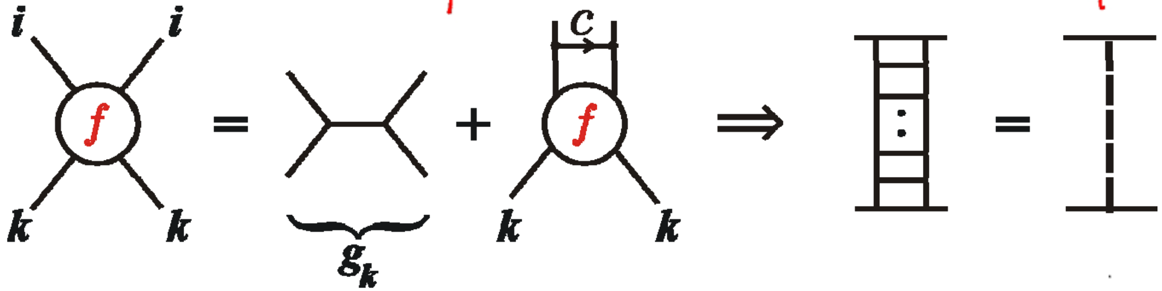
sum $3\mathbb{P}$ fan diagrams

$$g_m^n = g_N \lambda^{n+m-2}$$

Evolution of elastic bare Pomeron amplitude

$$\frac{df}{dy} = \Delta f \quad \rightarrow \quad f = g_k e^{\Delta y} \sim g_k \left(\frac{s}{s_0}\right)^{\Delta}$$

$f = \Omega$; $\quad \Delta = \alpha_{\mathbb{P}}(0) - 1$ is prob. to emit c in rap. int. dy



Multi-Pomeron contrib^n

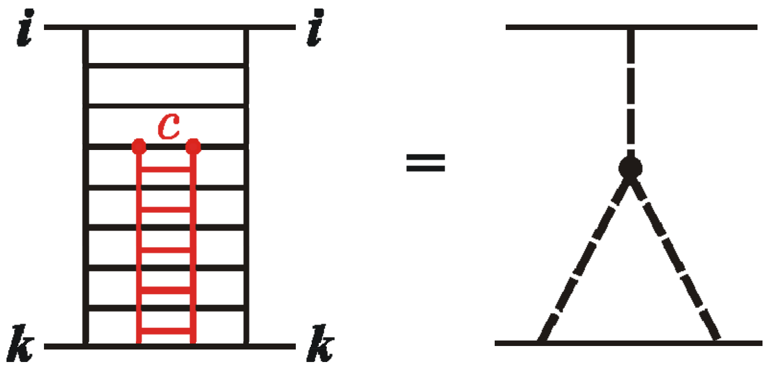
(corresponds to absorption of c during evol^n)

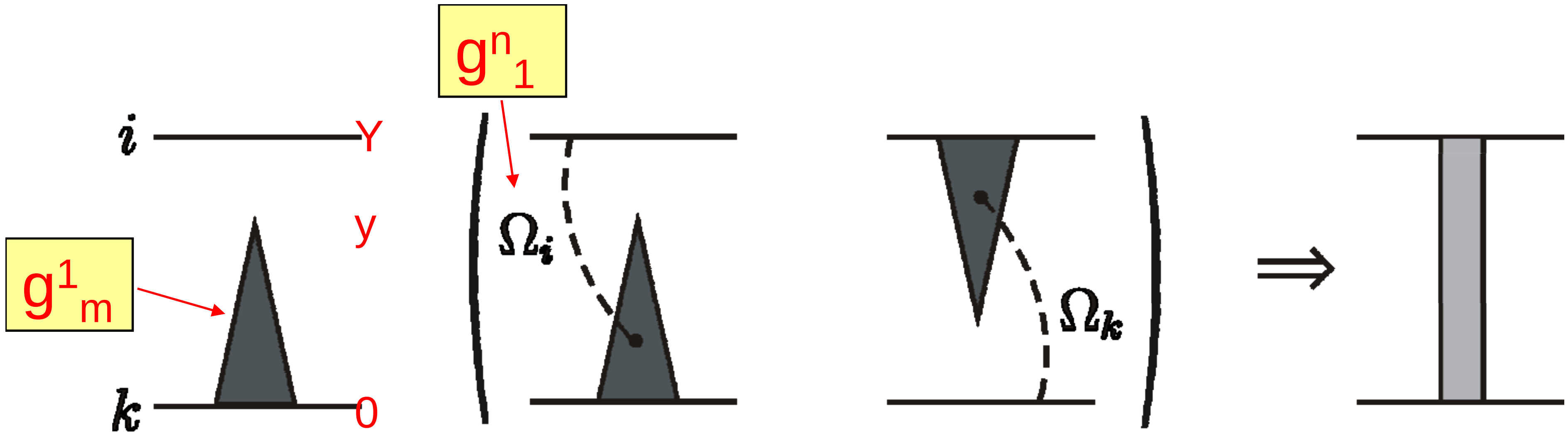
$$\frac{df}{dy} = \Delta f \, e^{-\Omega/2}$$

assuming eikonal form of multi-$\mathbb{P}$ – proton vertex

$\Omega = \lambda f$ is opacity of c on target k

↑ introduce λ as ck ≠ ik scatt.





$$\frac{df}{dy} = f \Delta e^{-\Omega_k(y)/2}$$

$$\frac{df(y)}{dy} = f(y)\, \Delta\, e^{-(\Omega_k(y)+\Omega_i(y'))/2}$$

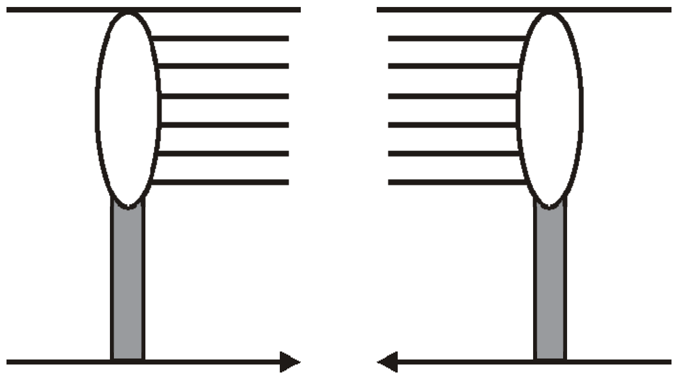
$$\frac{df(y')}{dy'} = f(y')\, \Delta\, e^{-(\Omega_i(y')+\Omega_k(y))/2}.$$

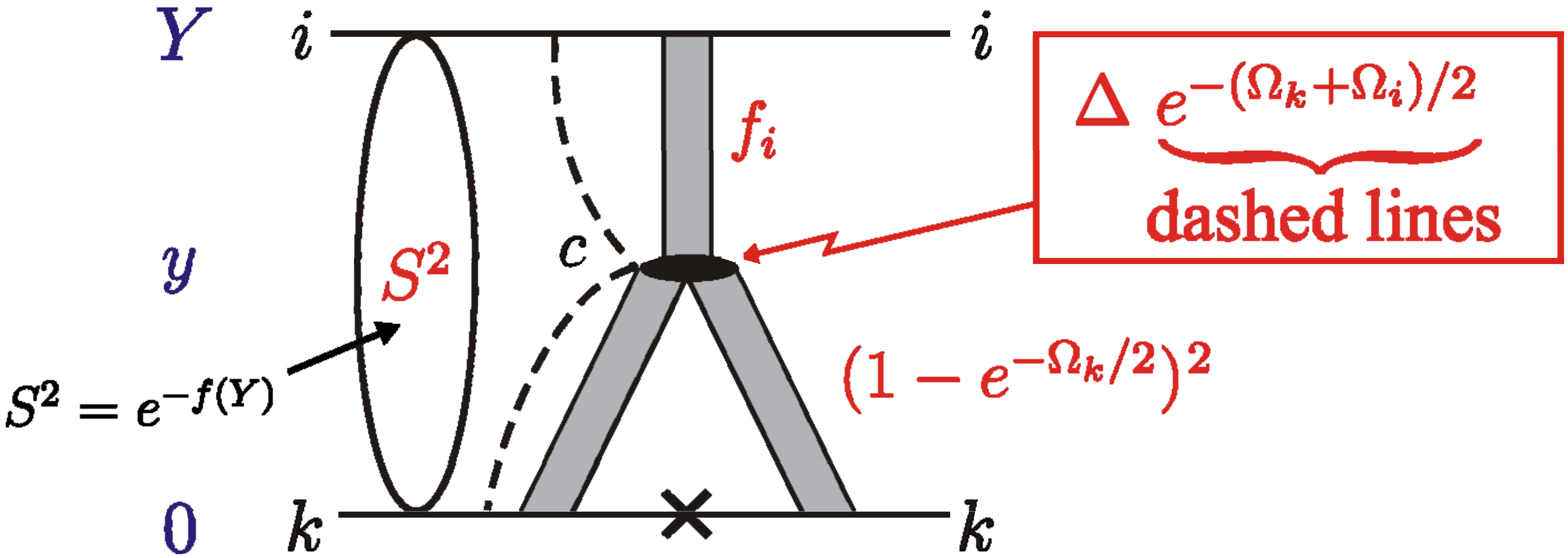
$y' = Y - y$

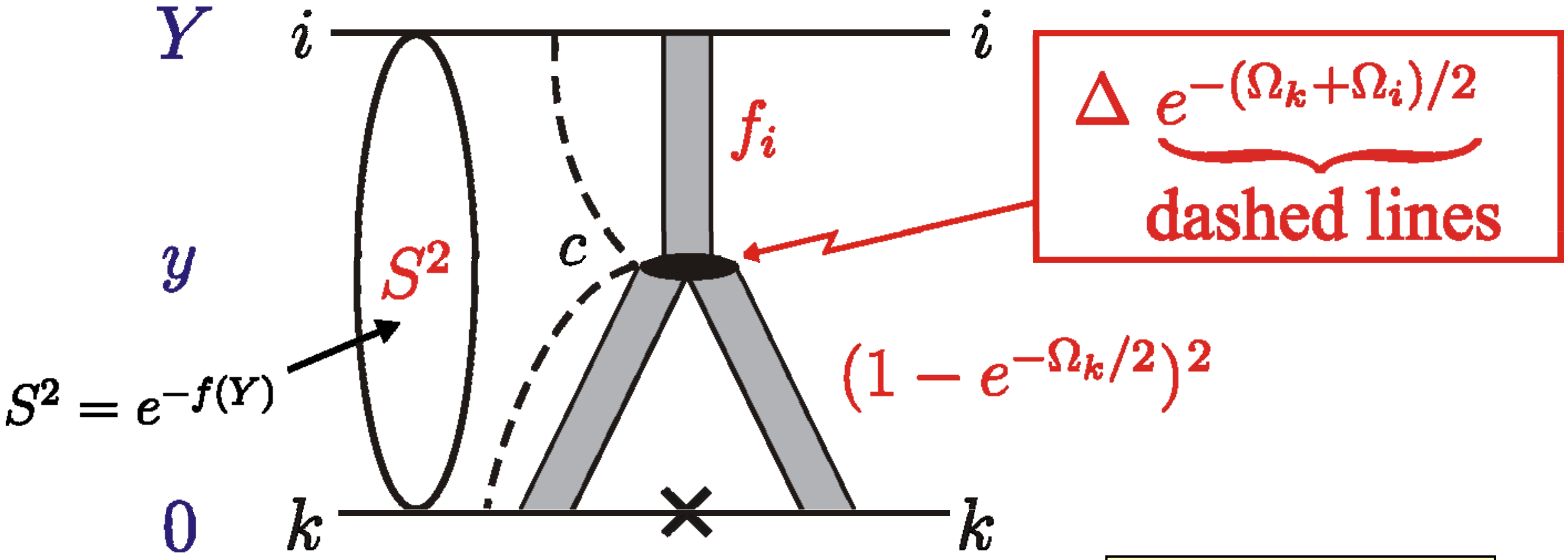
amplitude containing full sum of multi-P diagrams g^n_m

Single dissociation

σ_{SD}







amp. of c-i int^n

$$\frac{d\sigma_{\rm SD}}{dy'} = (1 - e^{-\Omega_k/2})^2 \; \Delta \; e^{-(\Omega_k + \Omega_i)/2} \; f_i(y') \; S^2$$

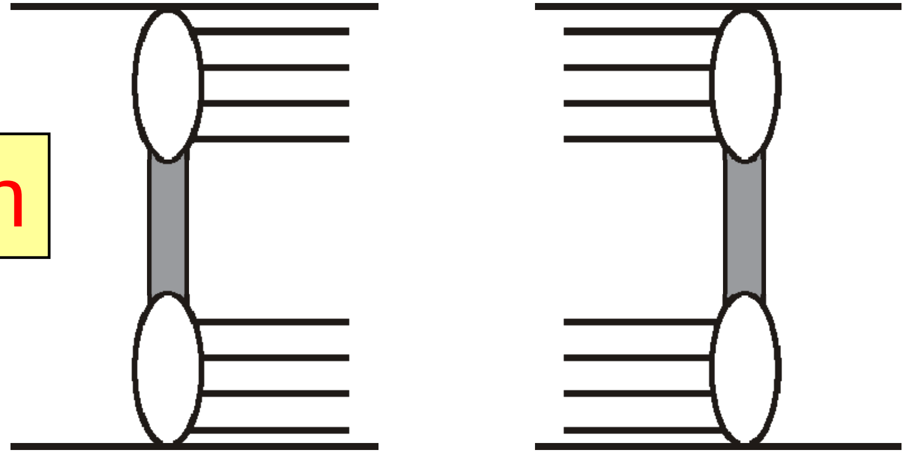
elastic σ(c-k)

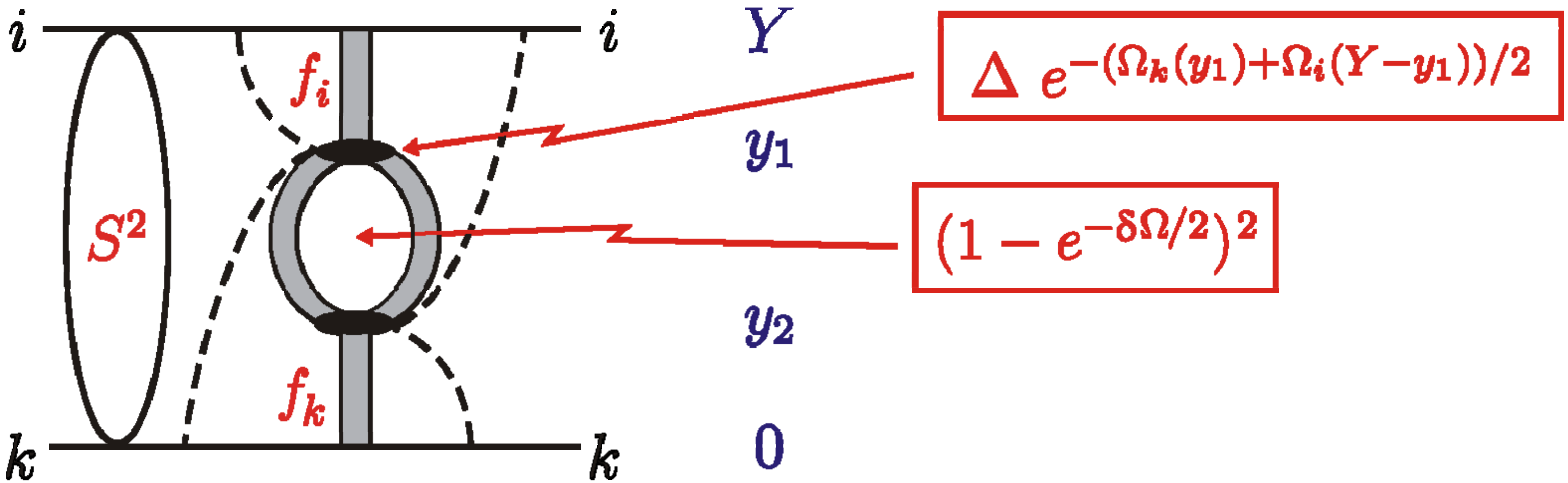
prob. of c in dy'

no additional i-k scatt

Double dissociation

σ_{DD}





Model fit to existing soft pp data

low M dissoc. given eikonal --- y_0=2.3 for y evol^n (M>2.5GeV)

use 3-channel eikonal (results similar for 2-ch.)

ϕ_i-Pomeron vertex: $\beta_i \dfrac{e^{at}}{(1-t/a_1)^2}.$

(A) each compt. β_i same trans. size / differs in parton density

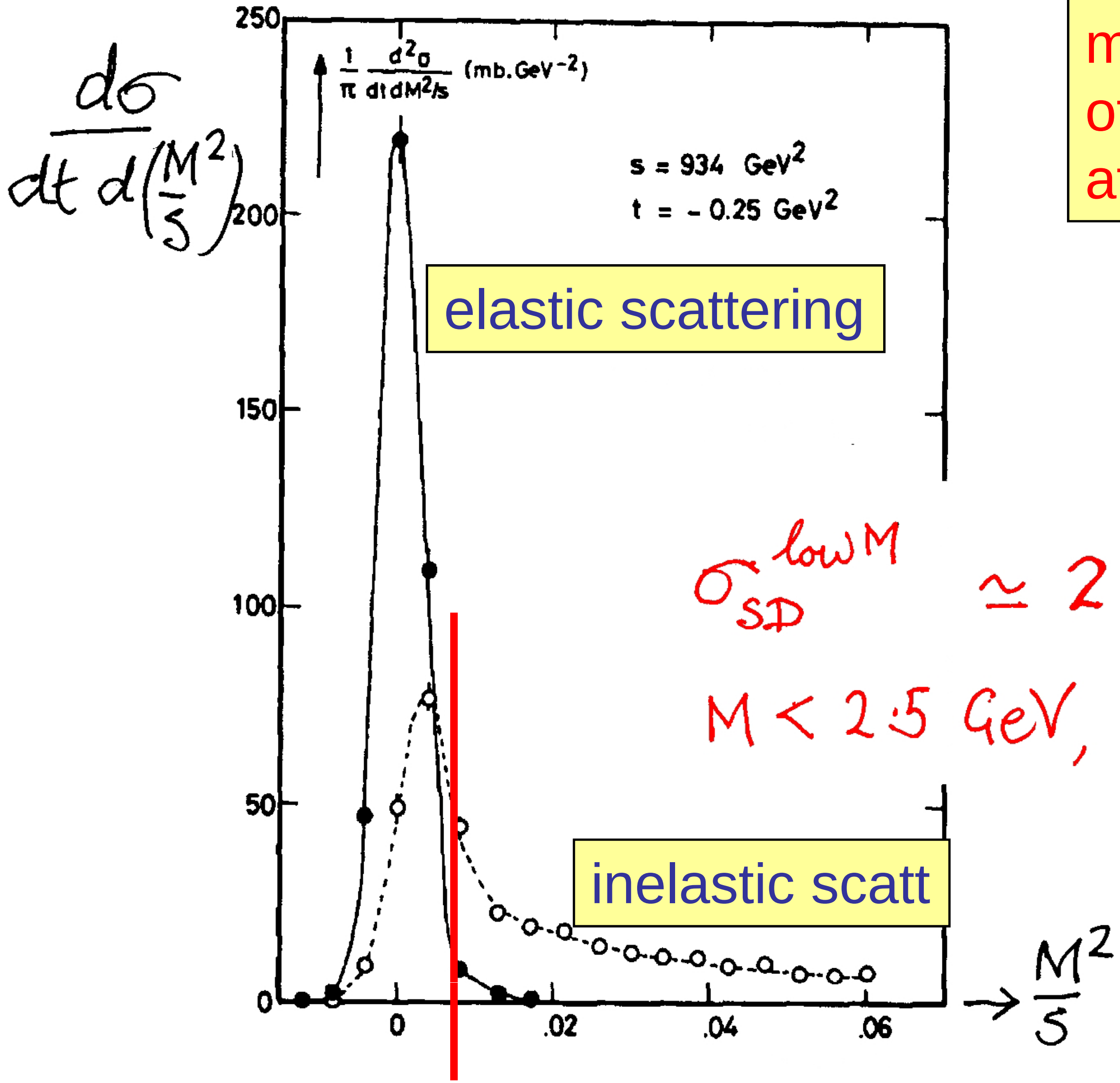
(B) compts. differ in trans. size / max. density same

CERN-ISR expts: $\sigma_{\rm SD}^{{\rm low}M} \simeq$ 2 – 3 mb

λ fixed by CDF $d\sigma_{SD}/dx_L dt$ data

$\sigma_0 = (\overline{\beta_i})^2$

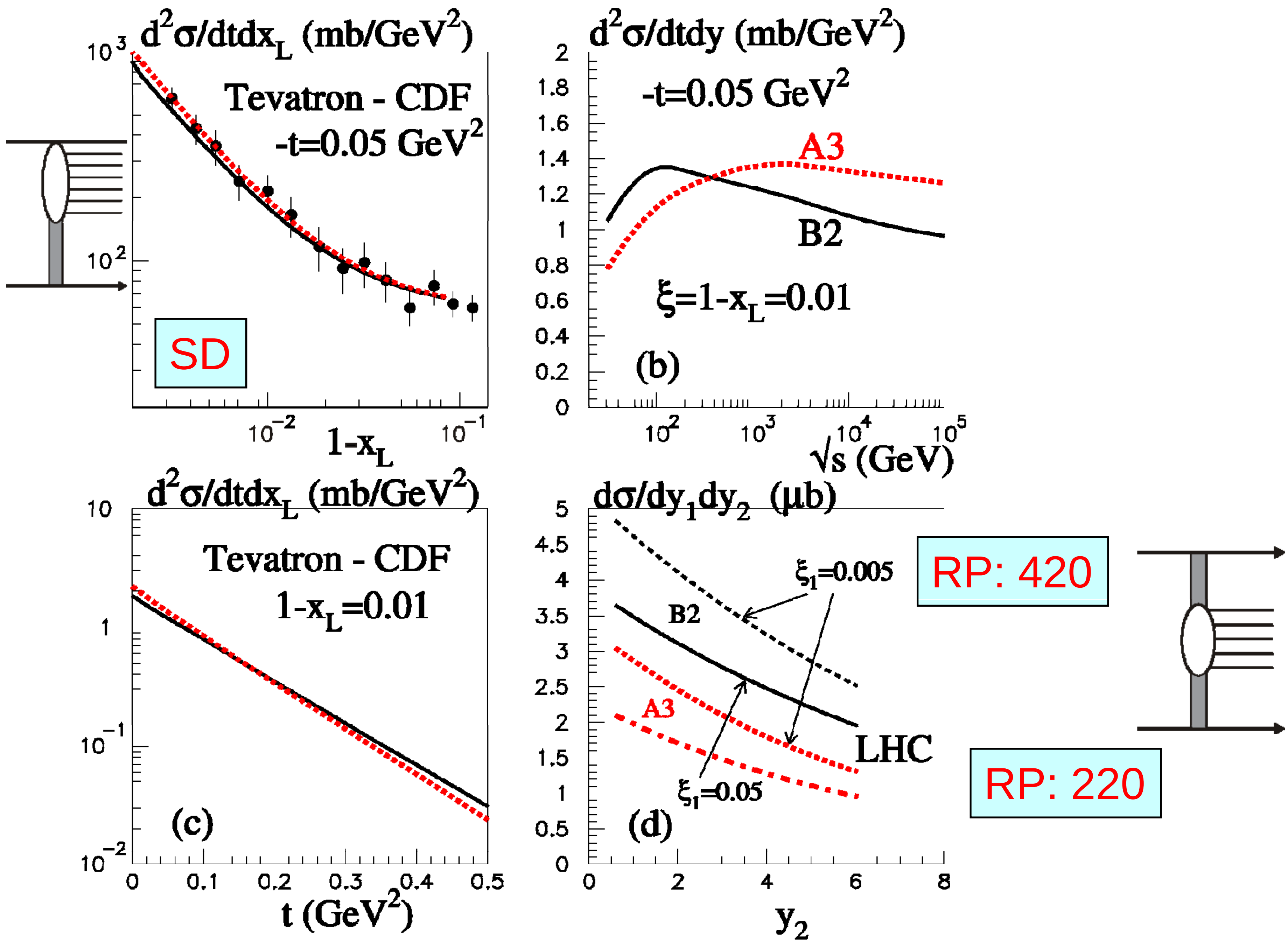
model	Δ	λ	a_1	γ^2	σ_0 mb
(A3)	0.53	0.22		0.9	85
(A2)	0.40	0.30		0.42	47
(B3)	0.65	0.30	1.80	0.48	38
(B2)	0.55	0.33	1.55	0.275	33



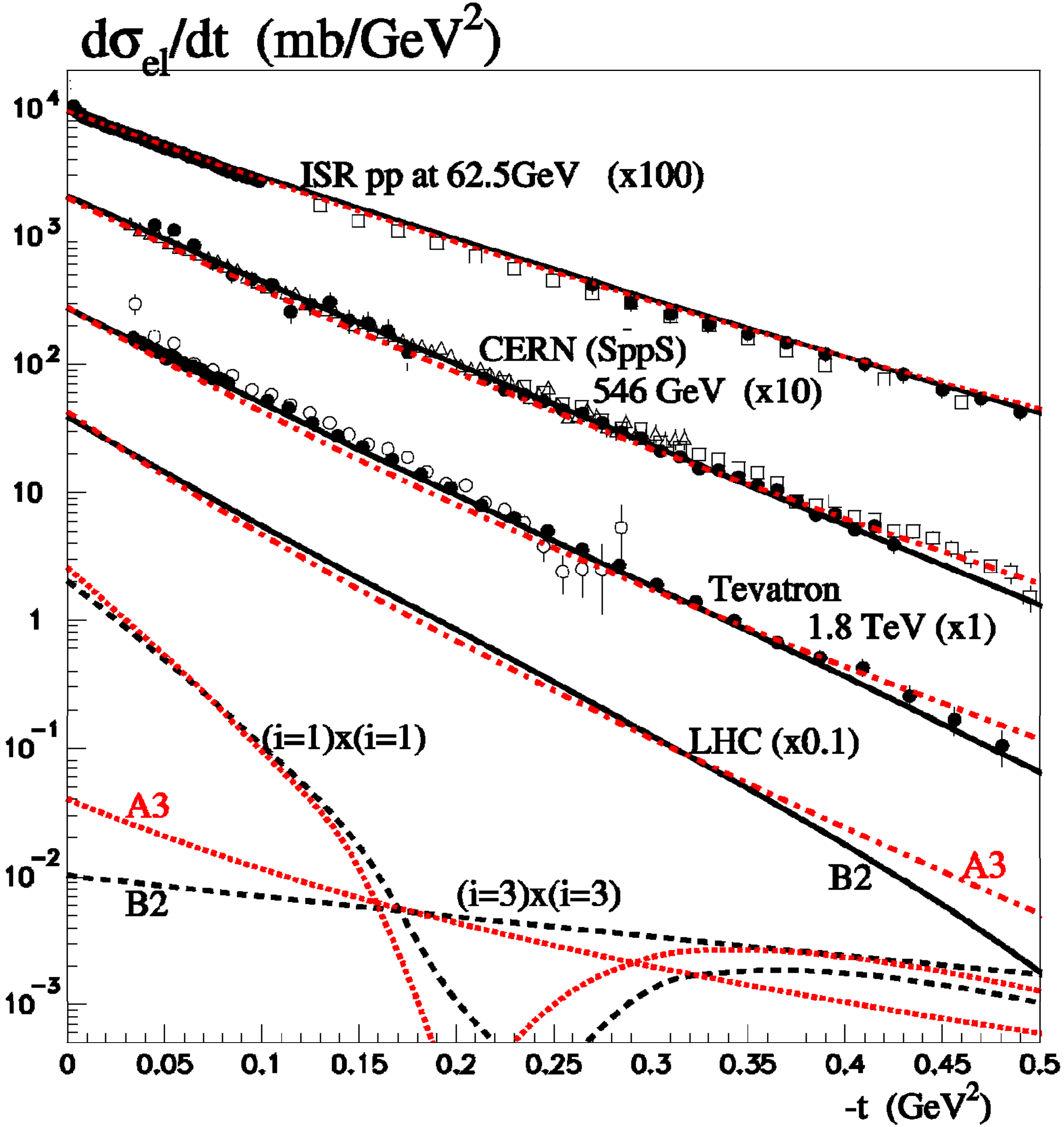
CERN-ISR measurements of single dissoc^n at low mass

$\sigma_{SD}^{low\,M} \simeq 2\,mb - 3\,mb$

$M < 2.5$ GeV, $\sqrt{s} \simeq 31$ GeV

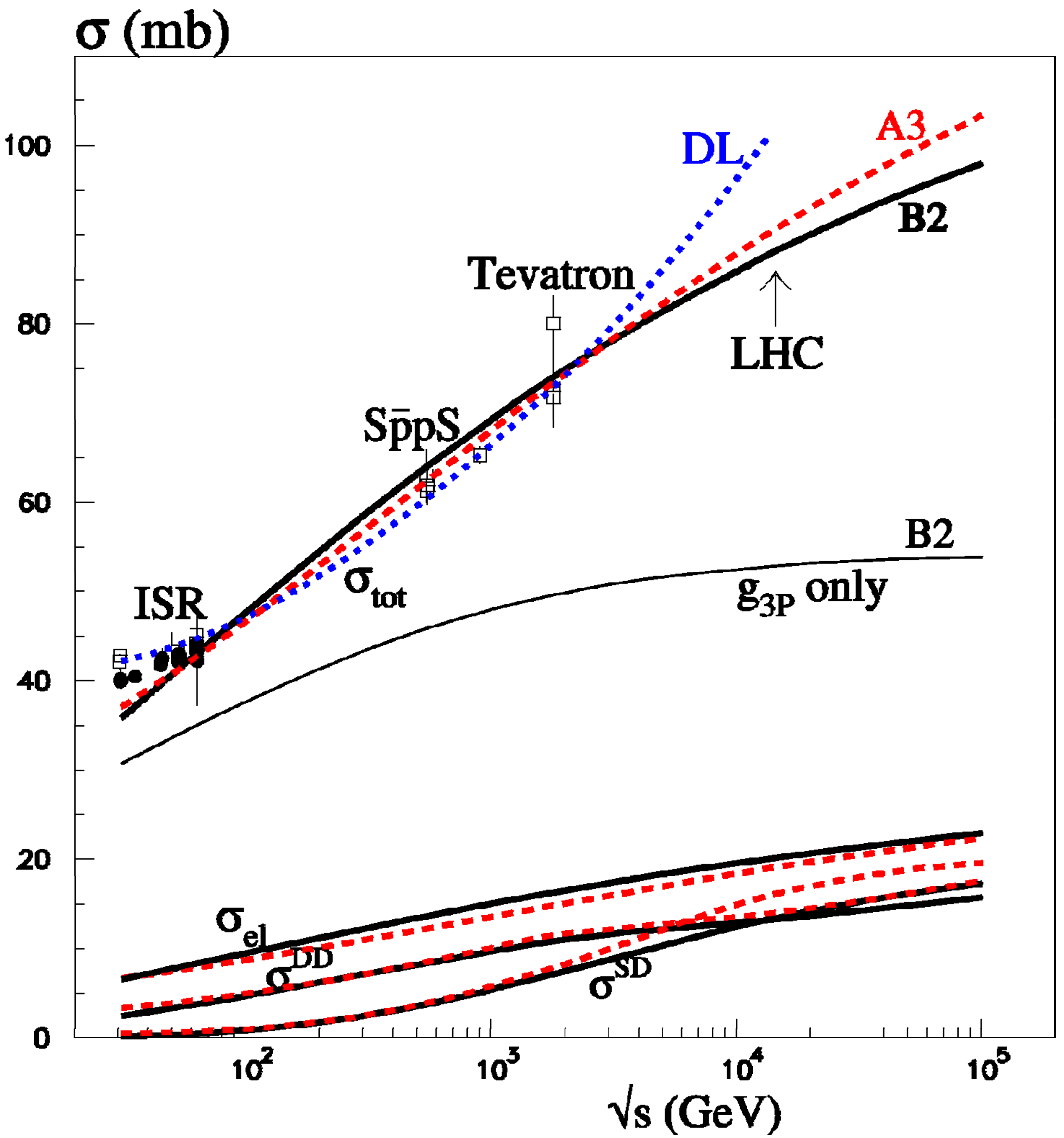


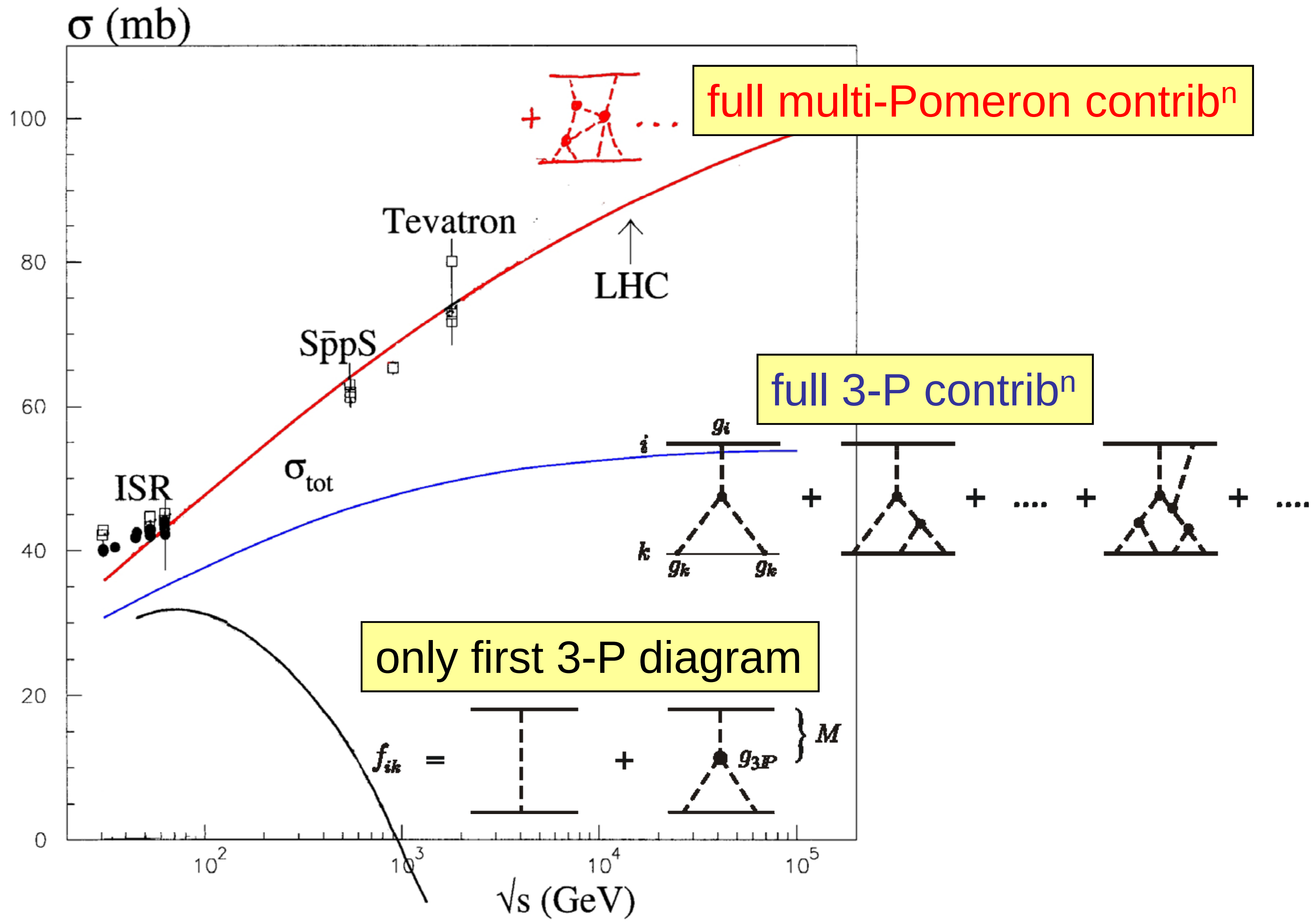
d²σ/dtdx_L (mb/GeV²)
Tevatron - CDF
-t=0.05 GeV²
SD
1-x_L
d²σ/dtdy (mb/GeV²)
-t=0.05 GeV²
A3
B2
ξ=1-x_L=0.01
(b)
√s (GeV)
d²σ/dtdx_L (mb/GeV²)
Tevatron - CDF
1-x_L=0.01
(c)
t (GeV²)
dσ/dy₁dy₂ (μb)
ξ₁=0.005
B2
A3
LHC
ξ₁=0.05
(d)
y₂
RP: 420
RP: 220



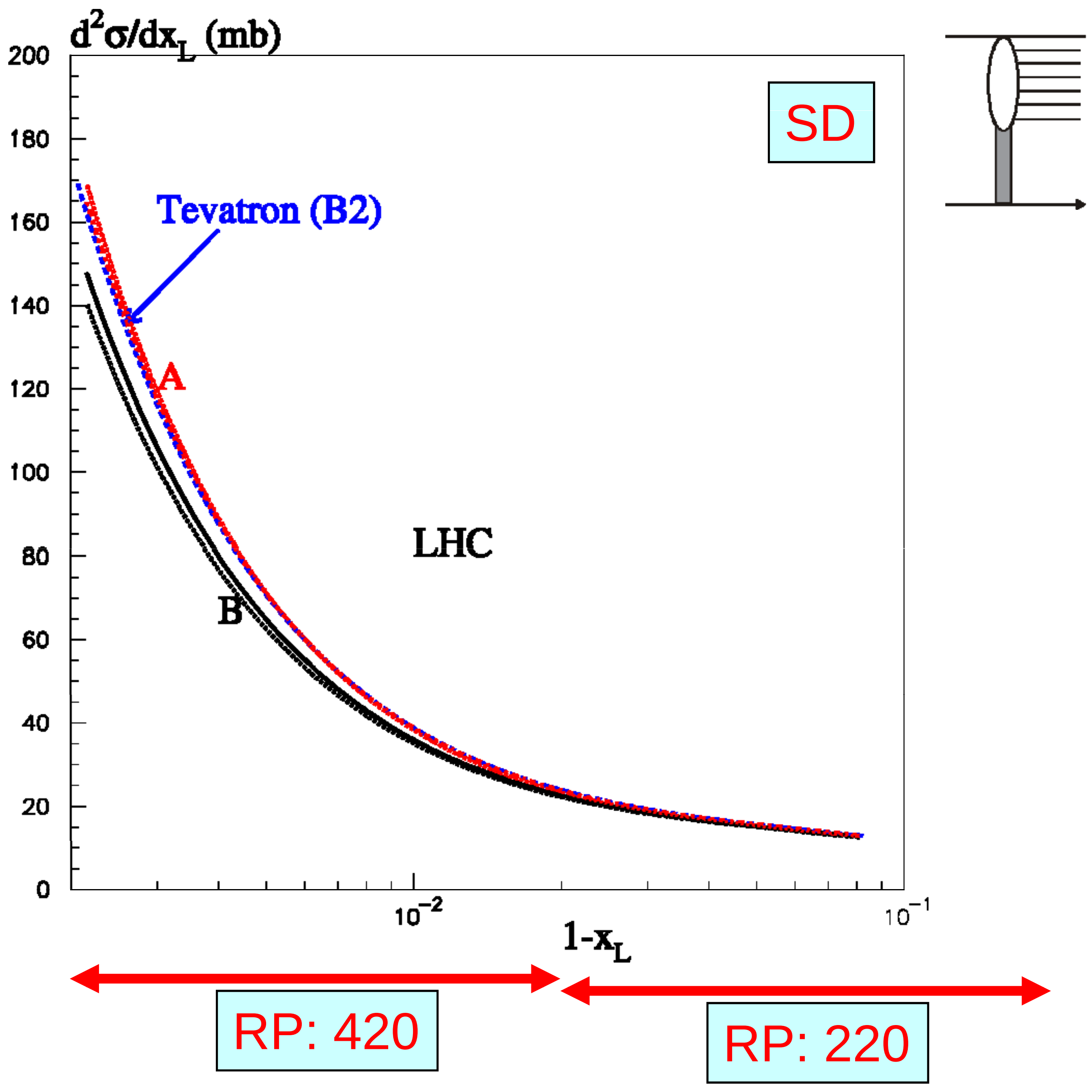
ϕ_1: "large"

ϕ_3: "small"


σ (mb)
100
80
60
40
20
0
DL
A3
B2
Tevatron
LHC
Sp̄pS
B2
g3P only
σtot
ISR
σel
σDD
σSD
10^2
10^3
10^4
10^5
√s (GeV)

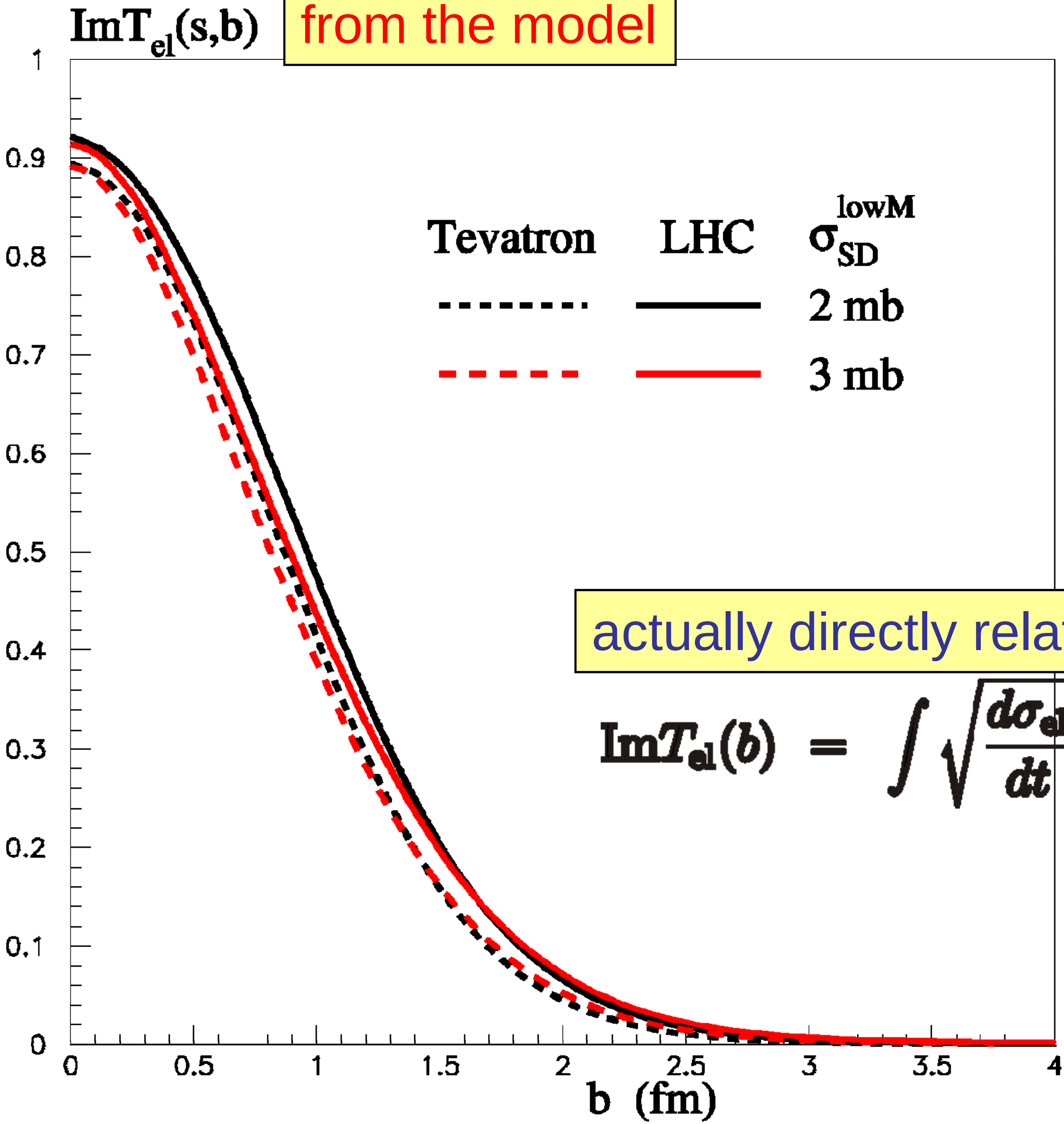

σ (mb)
full multi-Pomeron contribn
full 3-P contribn
only first 3-P diagram
Tevatron
LHC
Sp̄pS
ISR
σtot
100
80
60
40
20
0
10^2
10^3
10^4
10^5
√s (GeV)
gi
i
k
gk
gk
fik
=
+
g3P
M
+
+
....
+
+
....

	Tevatron	LHC	$\sqrt{s} = 10^5$ GeV
$\sigma_{\rm tot}$	74.0 (73.9)	88.0 (86.3)	98.0 (94.3)
$\sigma_{\rm el}$	16.3 (15.1)	20.1 (18.1)	22.9 (20.0)
$\sigma_{\rm SD}$	10.9 (12.7)	13.3 (16.1)	15.7 (17.7)
$\sigma_{\rm SD}^{{\rm low}M}$	4.3 (6.0)	5.1 (7.0)	5.7 (7.9)
$\sigma_{\rm SD}^{{\rm high}M}$	6.5 (6.7)	8.1 (9.1)	10.0 (9.8)
$\sigma_{\rm DD}$	7.2 (8.7)	13.4 (12.9)	17.3 (21.1)
$\sigma_{\rm DD}^{{\rm low}M}$	0.2 (0.5)	0.2 (0.5)	0.2 (0.6)
$\sigma_{\rm DD}^{{\rm high}M}$	4.5 (4.0)	9.3 (5.9)	11.7 (12.9)
$\sigma_{\rm DD}^{({\rm high}M*{\rm low}M)}$	2.1 (3.6)	2.9 (5.2)	3.8 (6.0)
$\sigma_{\rm DD}^{({\rm SD}*{\rm SD})}$	0.4 (0.7)	1.0 (1.3)	1.6 (1.6)
$\overline{S^2}$ $(B=4)$	0.027 (0.018)	0.017 (0.012)	0.013 (0.009)
$\overline{S^2}$ $(B=5.5)$	0.048 (0.032)	0.032 (0.023)	0.025 (0.018)



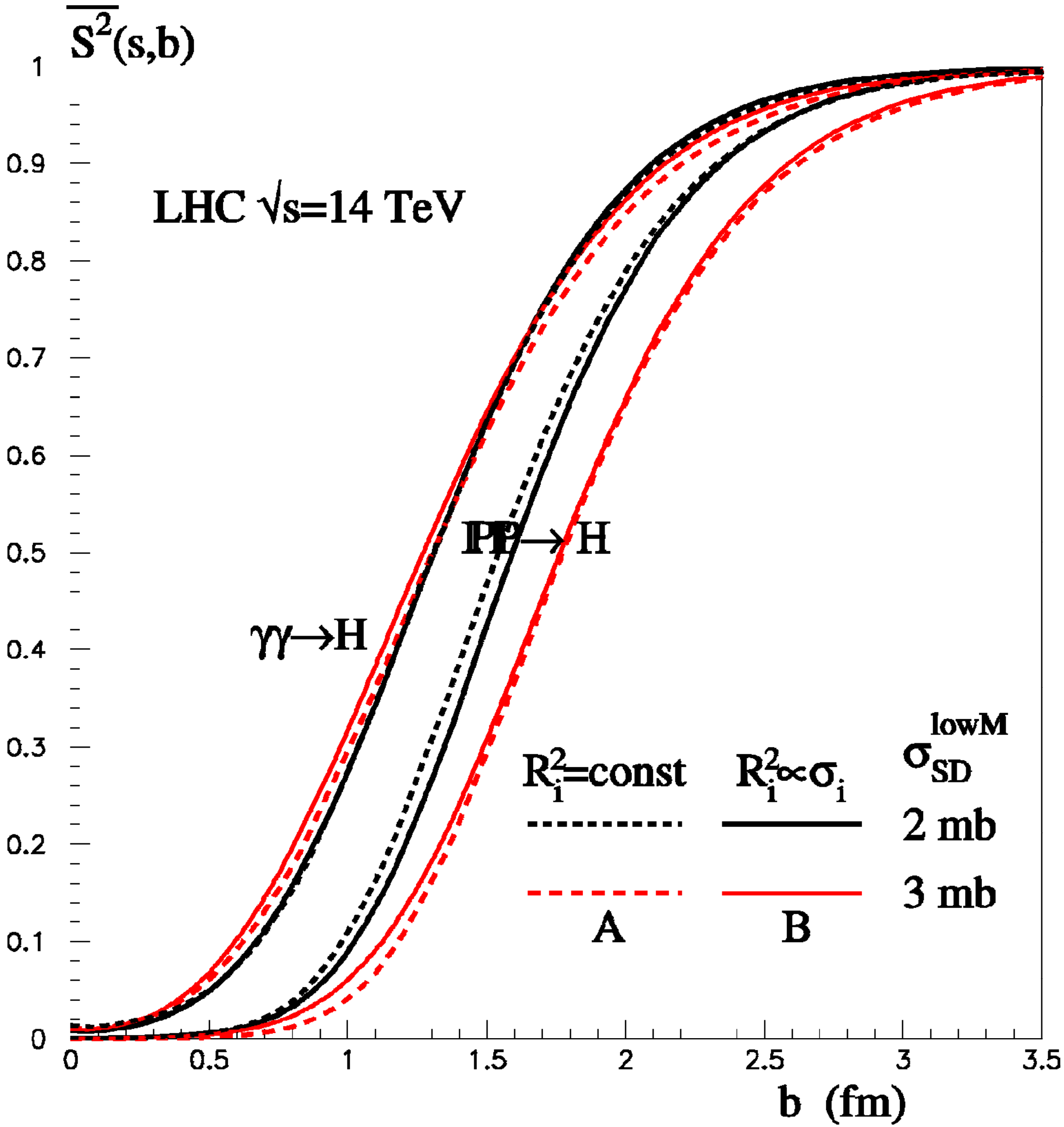
d²σ/dx_L (mb)
200
180
160
140
120
100
80
60
40
20
0
SD
Tevatron (B2)
A
B
LHC
10⁻²
10⁻¹
1-x_L
RP: 420
RP: 220

from the model



actually directly related to elastic data

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



$\overline{S^2}(s,b)$
LHC √s=14 TeV
γγ→H
IPIP→H
R_i^2=const
$R_i^2 \propto \sigma_i$
σ_{SD}^{lowM}
2 mb
3 mb
A
B
b (fm)

Suppression factor / survival prob. of rap. gap

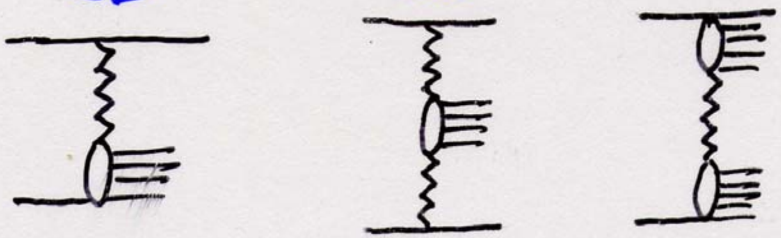
prob. of p to be in diff. estate ϕ_n

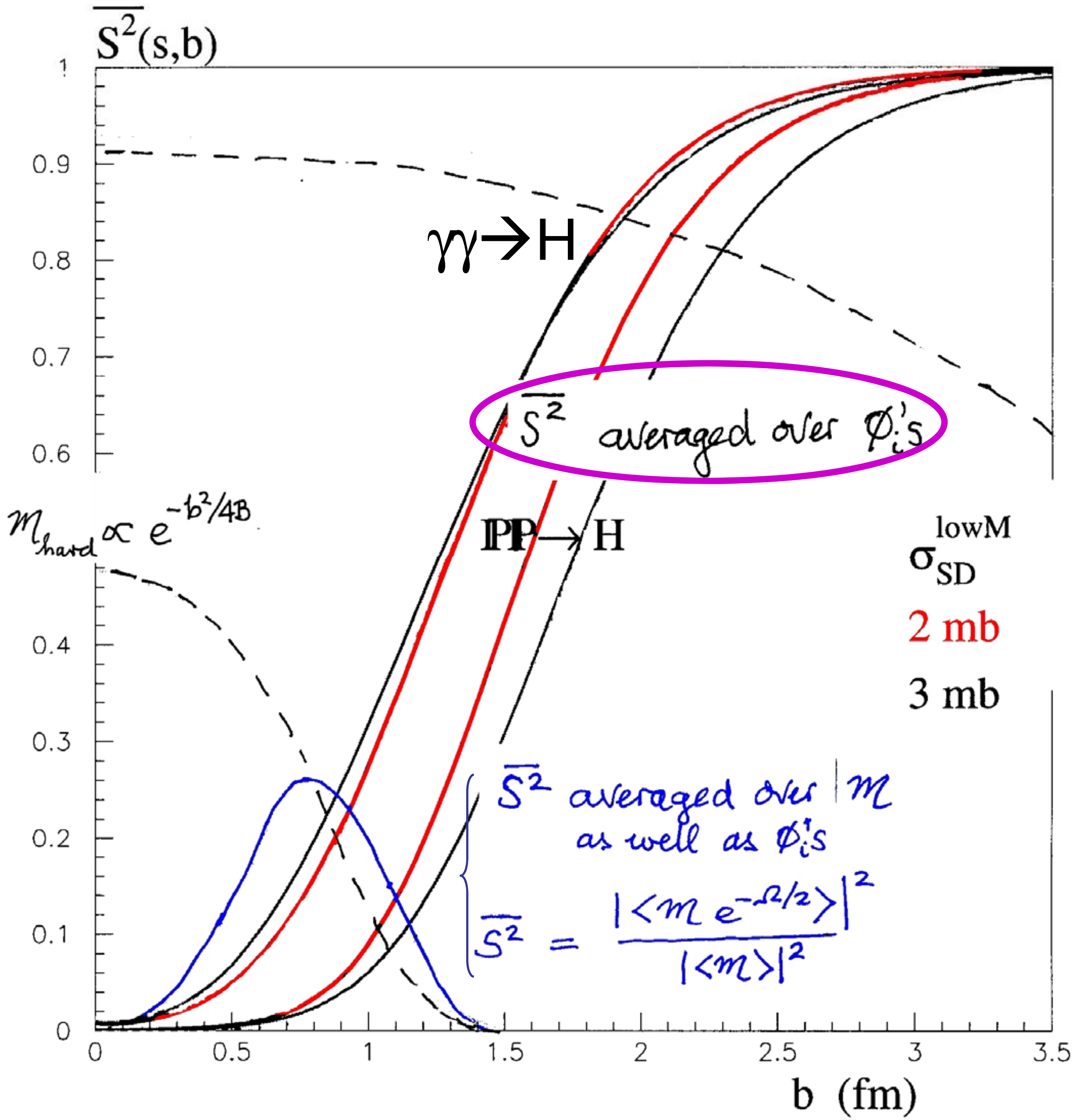
prob. of producing heavy system from ϕ_n

prob. to have no inel. reaction

$$S^2 = \frac{\sum_n \int d^2b \, |a_{pn}|^2 \, |\mathcal{M}_n|^2 \, e^{-\Omega_n}}{\sum_n \int d^2b \, |a_{pn}|^2 \, |\mathcal{M}_n|^2}$$

Values of S^2	SD	CD	DD
Tevatron	0·10	0·05	0·15
LHC	0·06	0·02	0·10





$\overline{S^2}(s,b)$
γγ→H
$\overline{S^2}$ averaged over ϕ_i's
$\mathcal{M}_{hard} \propto e^{-b^2/4B}$
PP→H
σ_{SD}^{lowM}
2 mb
3 mb
$\overline{S^2}$ averaged over $\mathcal{M}$ as well as ϕ_i's
$\overline{S^2} = \frac{|\langle \mathcal{M} e^{-\Omega/2} \rangle|^2}{|\langle \mathcal{M} \rangle|^2}$
b (fm)

Conclusions

$g^n_m =$ 

$= g_N \lambda^{n+m-2}.$

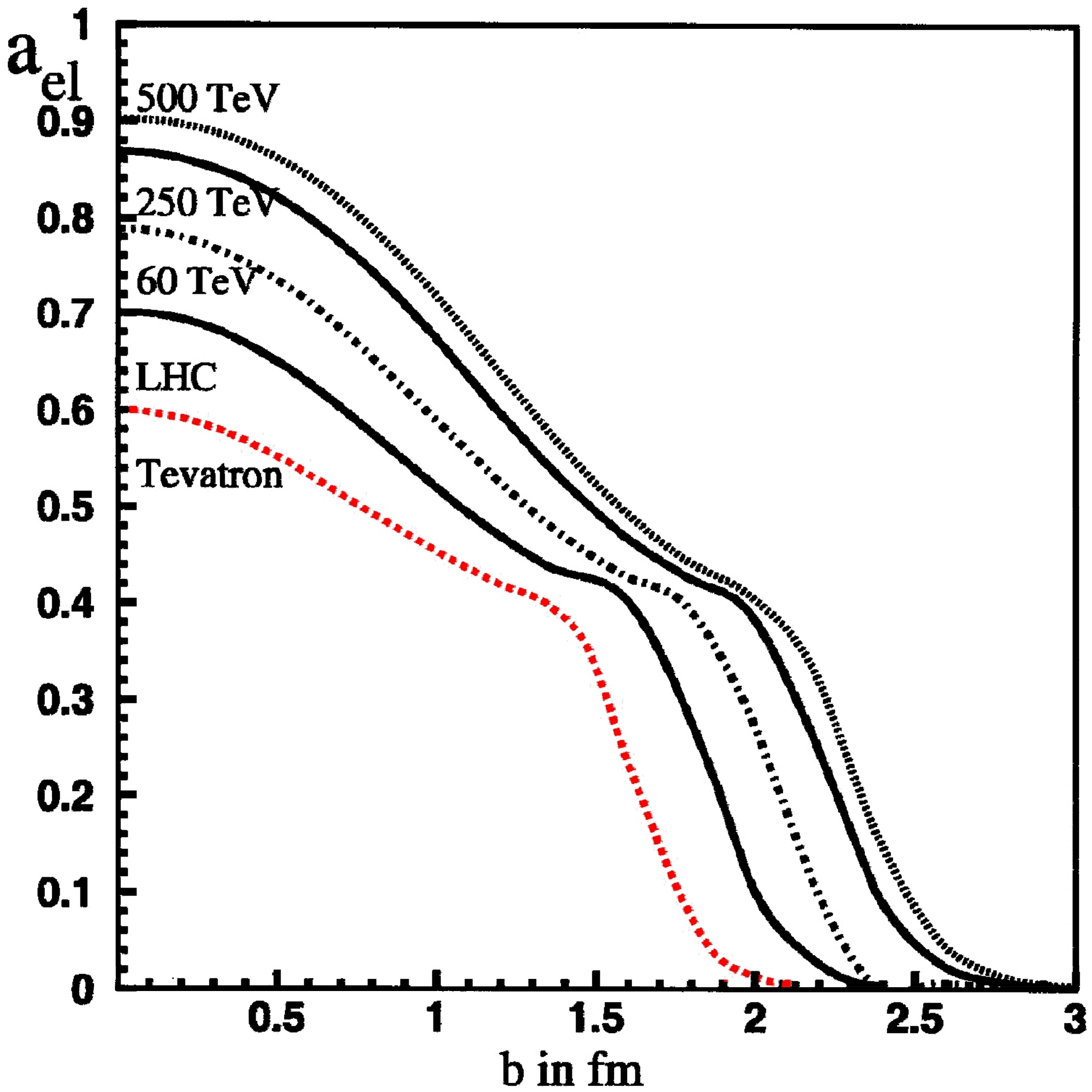
First, self-consistent multi-Pomeron, multi-ch eikonal of soft pp interactions

All multi-P interactions collected in $e^{-(\Omega_k + \Omega_i)/2}$ factors which describe absorption of intermediate partons during the evolution of the parton cascade

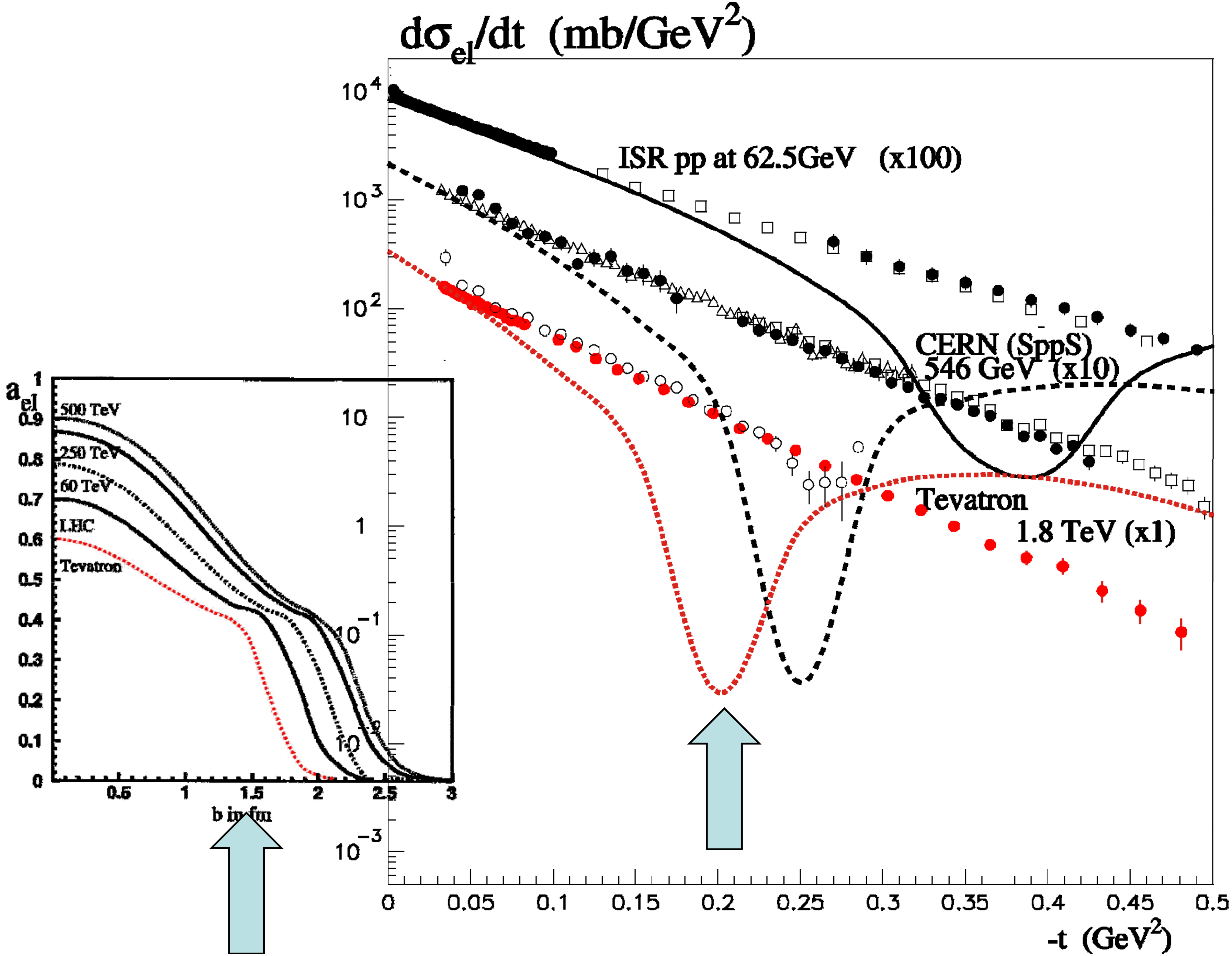
Even with minimum no. of parameters, get satisfactory description of all available soft data --- model (B) favoured

Inescapable consequence of absorption by low M in eikonal rescatt. and high M in multi-P int^n: σ(total) ~ 90 mb at LHC

In principle, can predict all diffractive processes at LHC but important to measure low M SD etc. to constrain model



a_el
500 TeV
250 TeV
60 TeV
LHC
Tevatron
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.5
1
1.5
2
2.5
3
b in fm



dσel/dt (mb/GeV2)
ISR pp at 62.5GeV (x100)
CERN (SppS)
546 GeV (x10)
Tevatron
1.8 TeV (x1)
-t (GeV2)
ael
500 TeV
250 TeV
60 TeV
LHC
Tevatron
b in fm