Soft models and survival probability

Low x meeting, Ischia Island,Italy
September 8th – 13th 2009

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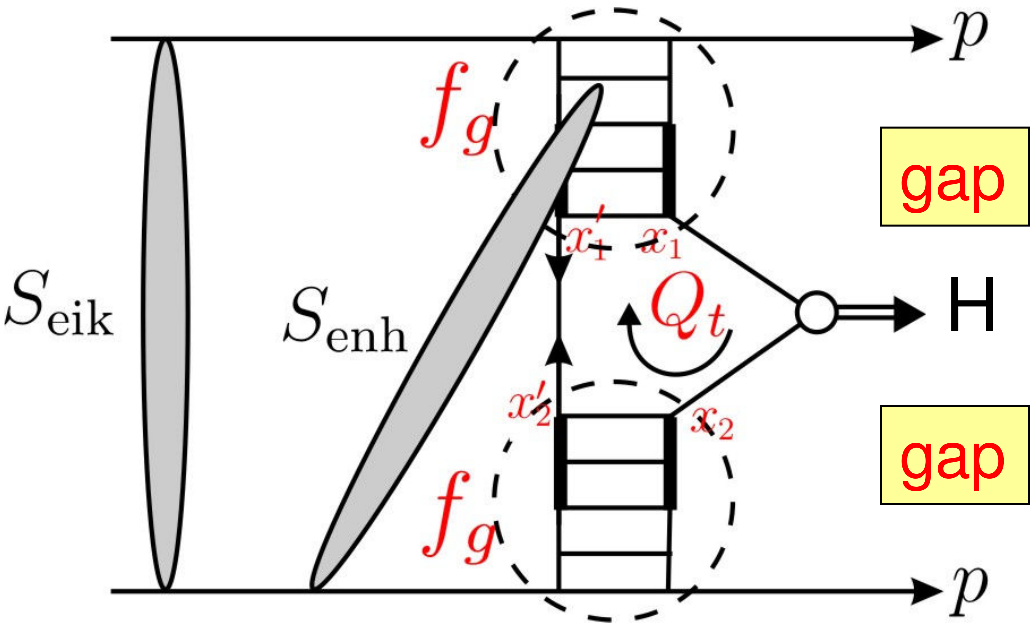
"soft" scatt. destroys gaps in exclusive prod.



e.g. pp → p+H+p

$$\sigma \sim S^2 \left| \int f_g \, \mathcal{M}_{gg\to H} \, f_g \, \frac{dQ^2}{Q^2} \right|^2$$

gap survival prob. S^2 to "soft"…

			soft-hard factoriz^n
eikonal rescatt:	between protons	←	conserved
enhanced rescatt:	involving intermediate partons	←	broken

Model for "soft" high-energy interactions

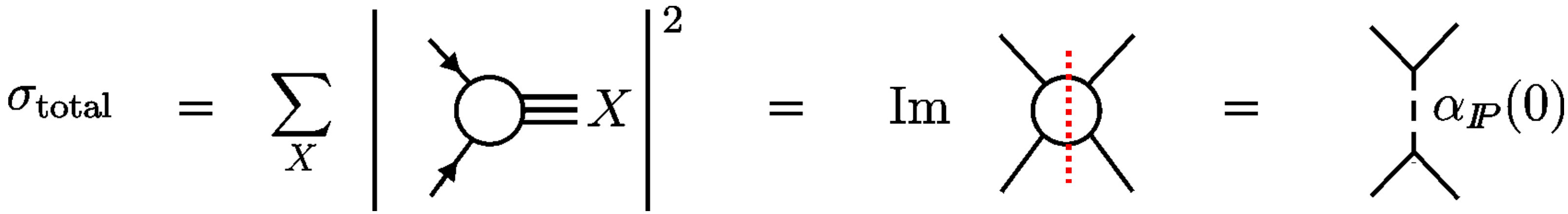
needed to ---- understand asymptotics, intrinsic interest
---- describe "underlying" events for LHC jet algor^{ms}
---- calc. rap.gap survival S^2 for exclusive prod^n

"Soft" model should:

1. be self-consistent theoretically --- satisfy unitarity
   → importance of absorptive corrections
   → importance of multi-Pomeron interactions
2. agree with available soft data CERN-ISR to Tevatron range $\sigma_{tot}, \frac{d\sigma_{el}}{dt}, \frac{d\sigma_{SD}}{dtdM^2}(pp \to pX)$
3. include Pomeron comp^{ts} of different size---to study effects of soft-hard fact^n breaking

Optical theorems

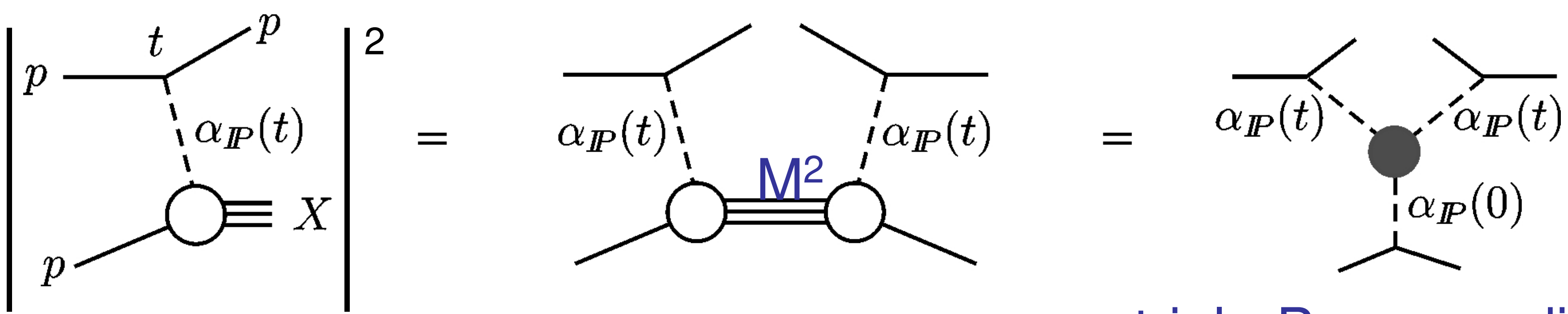
at high energy
use Regge



but screening important
so σ_{total} suppressed

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

High mass diffractive dissociation



triple-Pomeron diag

but screening important

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

$(g_{3P})_{\text{effective}} = S^2 (g_{3P})_{\text{bare}}$ so $(g_{3P})_{\text{bare}}$ increased

Must include unitarity

diagonal in b $\sim \ell/p$

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

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

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

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

e.g. black disc

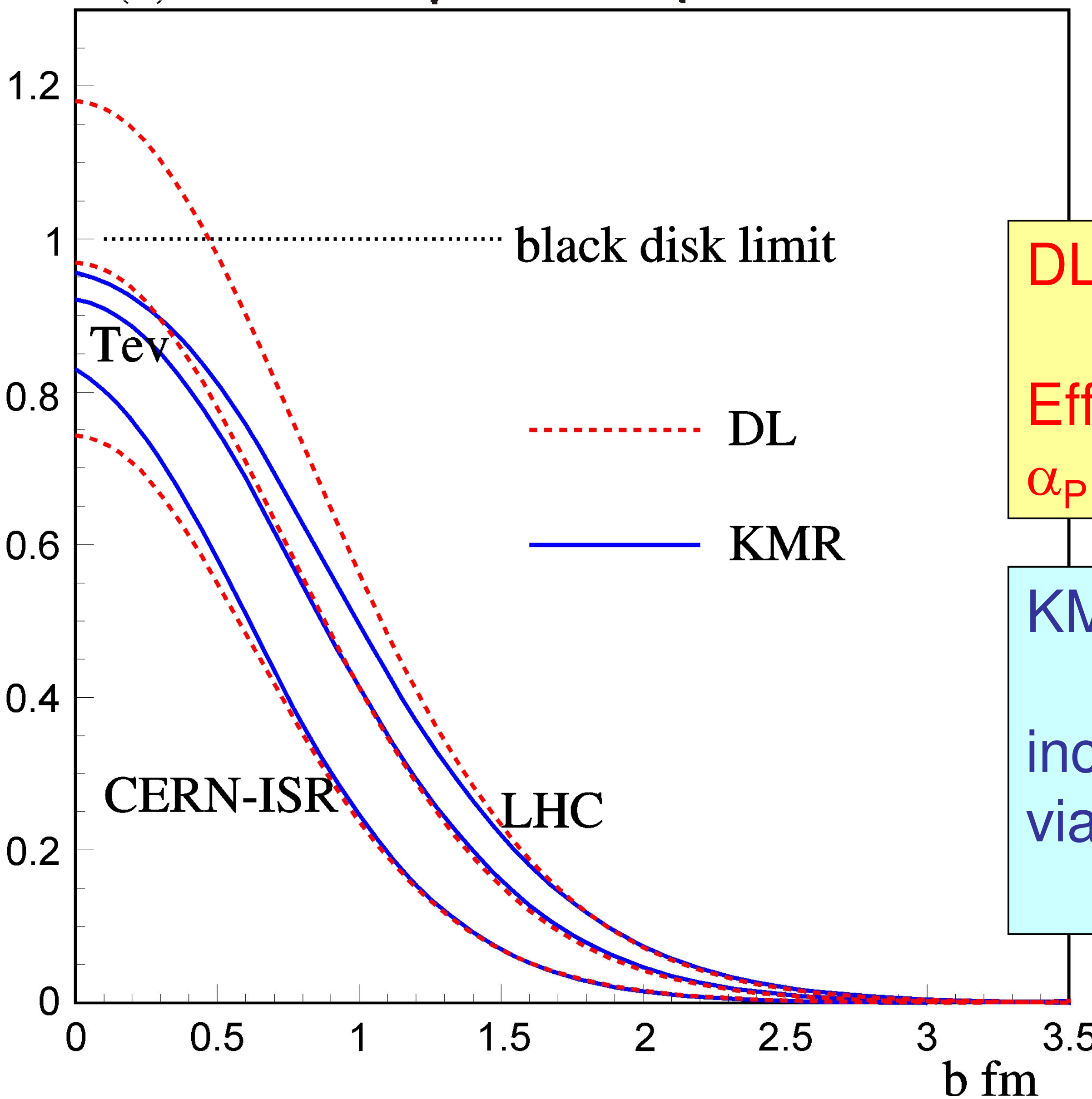
$\mathrm{Im}\,T_{el} = 1, \quad b < R$

$$\sigma_{tot} = 2\pi R^2$$

$$\sigma_{el} = \sigma_{inel} = \pi R^2$$

$e^{-\Omega}$ is the probability of no inelastic interaction

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



DL parametrization:

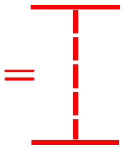
Effective Pomeron pole

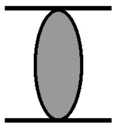
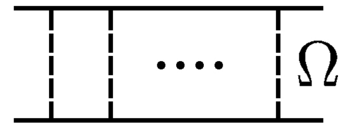
$\alpha_P(t) = 1.08+0.25t$

KMR parametrization

includes absorption via multi-Pomeron effects

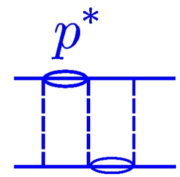
Elastic amp. $T_{el}(s,b)$

bare amp. $\Omega =$ 

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

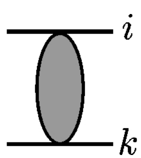
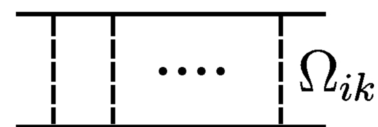
(-20%)

Low-mass diffractive dissociation



→multichannel eikonal

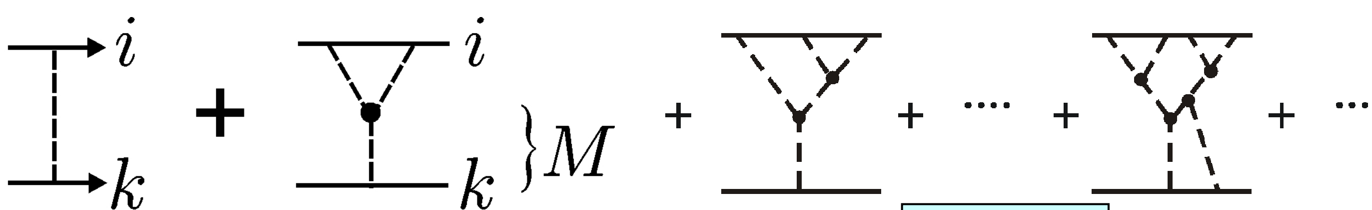
introduce diff^{ve} estates ϕ_i, ϕ_k (comb^{ns} of p,p*,..) which only undergo "elastic" scattering (Good-Walker)

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

(-40%)

include high-mass diffractive dissociation

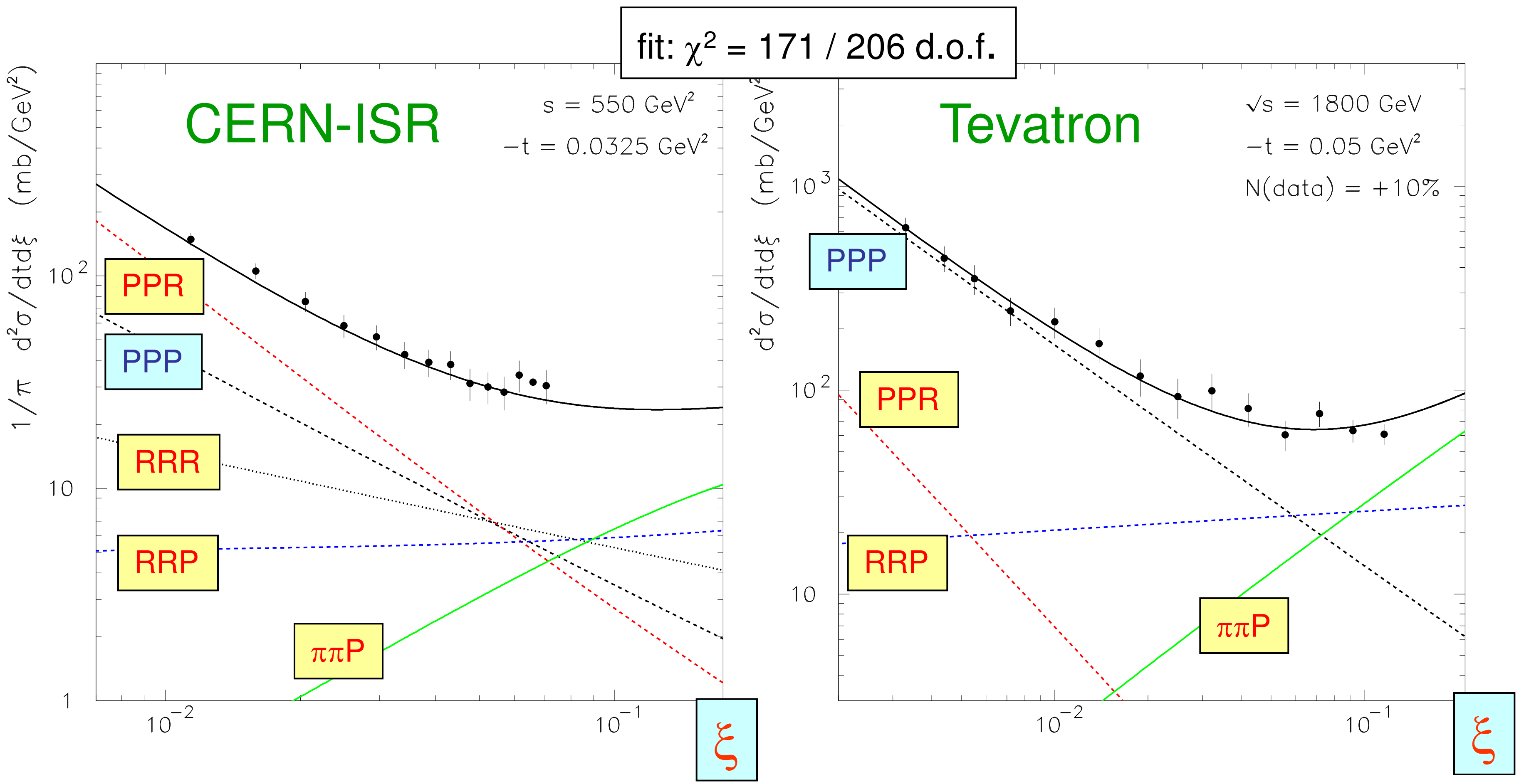
(SD -80%)

$\Omega_{ik} =$ 

g_{3P} ?

triple-Regge analysis of $d\sigma/dtd\xi$, including screening

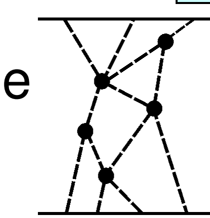
(includes compilation of SD data by Goulianos and Montanha)



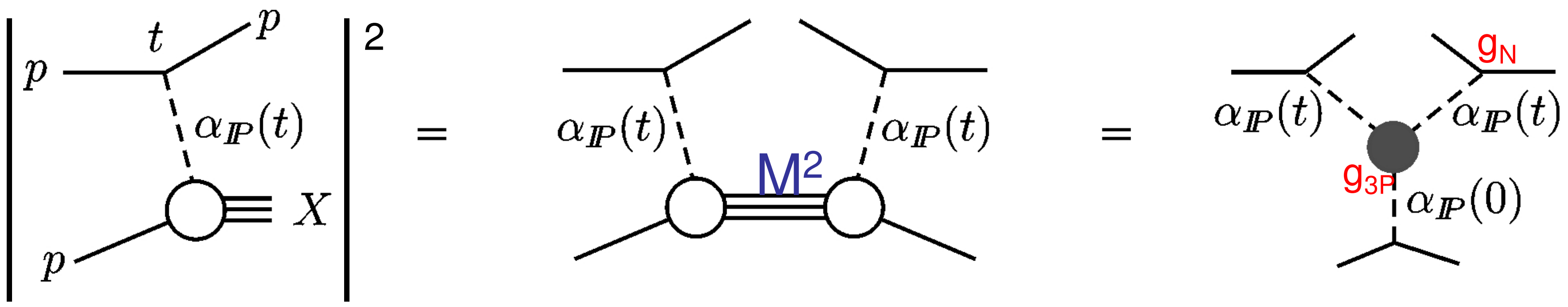
LKMR $g_{3P}=\lambda\ g_N \quad \lambda\sim 0.2$

see also Poghosan, Kaidalov,..

g_{3P} large, need to include multi-Pomeron effects



$g_{3P} = \lambda\ g_N \qquad \lambda \sim 0.2$ ← large ?



$M^2 d\sigma_{SD}/dM^2 \sim g_N^3\ g_{3P} \sim \lambda\sigma_{el}$

ln s

$$\sigma_{SD} = \int \frac{M^2 d\sigma_{SD}}{dM^2} \frac{dM^2}{M^2} \sim \underline{\lambda \ln s}\ \sigma_{el}$$

so at collider energies $\sigma_{SD} \sim \sigma_{el}$

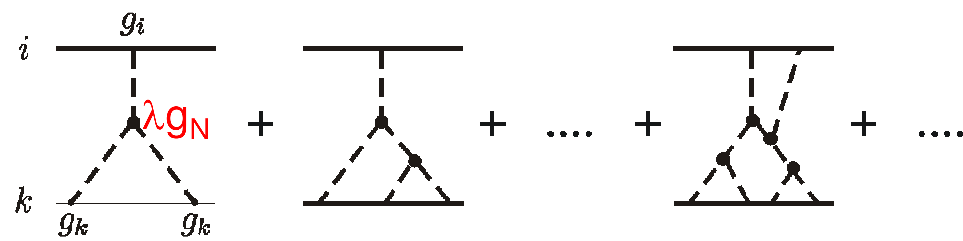
Multi-compt. s- and t-ch analysis of soft data

KMR 2008

$$\sigma_{\mathrm{tot}}, \quad \frac{d\sigma_{\mathrm{el}}}{dt}, \quad \sigma_{\mathrm{SD}}(\mathrm{low}\ M), \quad \frac{d\sigma_{\mathrm{SD}}}{dt\,dM^2}$$

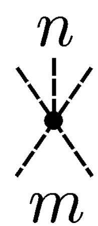
model:

- 3-channel eikonal,
  ϕ_i with i=1,3



- include multi-Pomeron diagrams

  ansatz →



$$g^n_m = \mathrm{nm}\,\lambda^{n+m-2} g_N / 2$$

- attempt to mimic BFKL diffusion in log q_t by including three components to approximate q_t distribution –
  possibility of seeing "soft → hard" Pomeron transition

Use four exchanges in the t channel

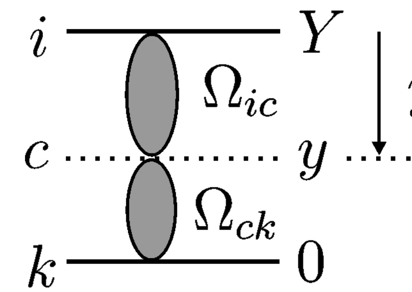
3 to mimic BFKL diffusion in $\ln q_t$

sec. Reggeon

$$a = P_{large}, \; P_{intermediate}, \; P_{small}, \; R$$

soft ⟶ pQCD

average q_{t1}~0.5, q_{t2}~1.5, q_{t3}~5 GeV



$V_{RP1} \sim g_{PPR}, g_{RRP}$

$V_{PiPj} \sim$ BFKL

evolve up from y=0 — bare pole — absorptive effects

$$\begin{cases} \dfrac{d\Omega^{a}_{ck}(y)}{dy} = \underbrace{(\Delta + \alpha' \nabla_b^2)\Omega^{a}_{ck}(y)}_{\text{bare pole}} \; \underbrace{e^{-\lambda\Omega_{ck}(y)/2} e^{-\lambda\Omega_{ic}(y')/2}}_{\text{absorptive effects}} + V_{aa'}\Omega^{a'}_{ic}(y) \\[2ex] \dfrac{d\Omega^{a}_{ic}(y')}{dy'} = (\Delta + \alpha' \nabla_b^2)\Omega^{a}_{ic}(y') \; e^{-\lambda\Omega_{ic}(y')/2} e^{-\lambda\Omega_{ck}(y)/2} + V_{aa'}\Omega^{a'}_{ck}(y') \end{cases}$$

evolve down
from y'=Y-y=0

solve for $\Omega^{a}_{ik}(y,b)$
by iteration

(arXiv:0812.2407)

Parameters

multi-Pomeron coupling λ from $\xi d\sigma_{SD}/d\xi dt$ data (ξ~0.01)

diffractive eigenstates from σ_{SD}(low M)=2mb at sqrt(s)=31 GeV,
-- equi-spread in R^2, and t dep. from $d\sigma_{el}/dt$

Results

All soft data well described

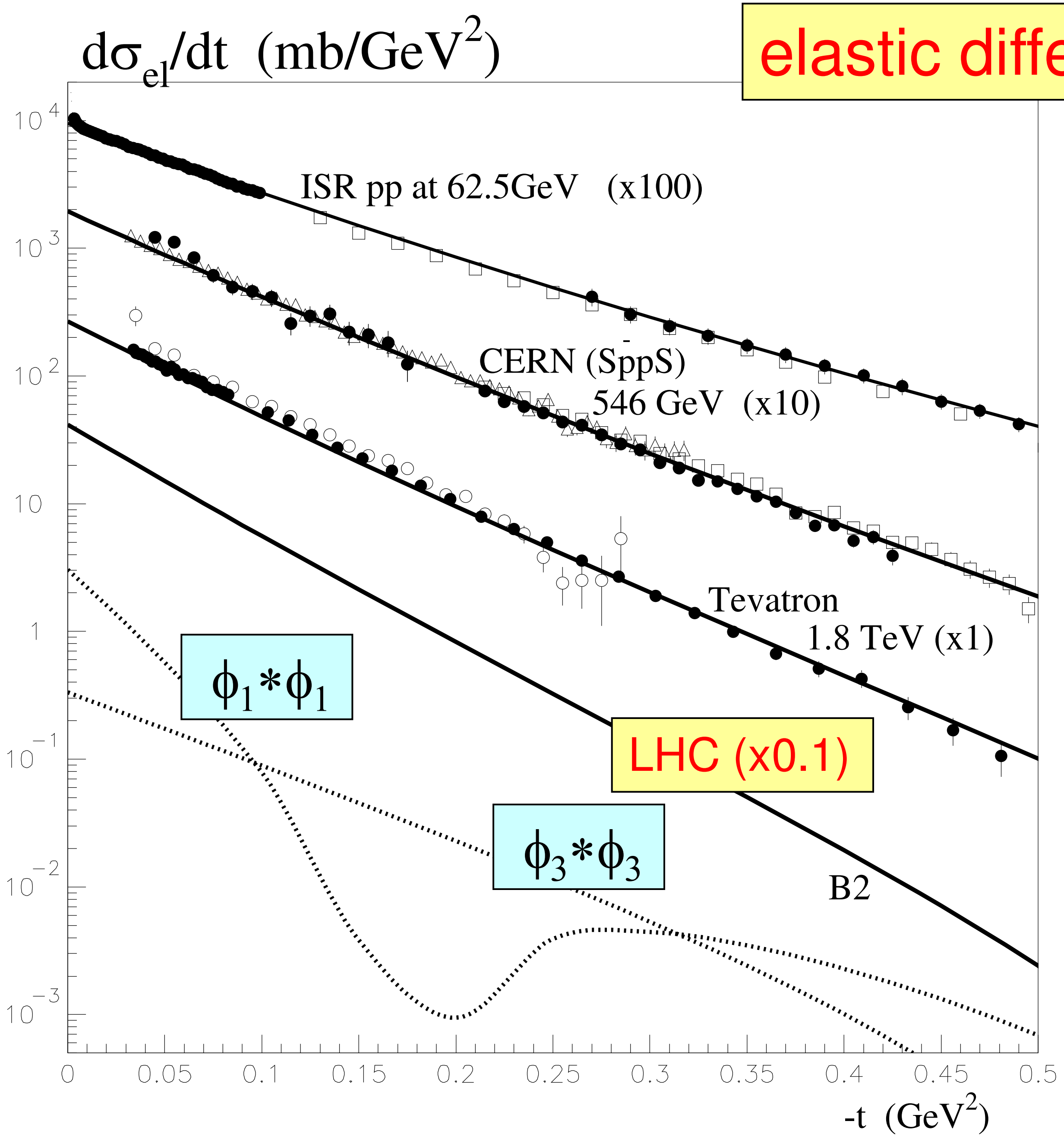
$g_{3P}=\lambda g_N$ with $\lambda=0.25$

$\Delta_{Pi} = 0.3$ (close to the BFKL NLL resummed value)
$\alpha'_{P1} = 0.05$ GeV^{-2}
These values of the bare Pomeron trajectory yield, after screening, the expected soft Pomeron behaviour ---
"soft-hard" matching (since P_1 heavily screened,….P_3~bare)

$\Delta_R = -0.4$ (as expected for secondary Reggeon)

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

elastic differential dσ/dt



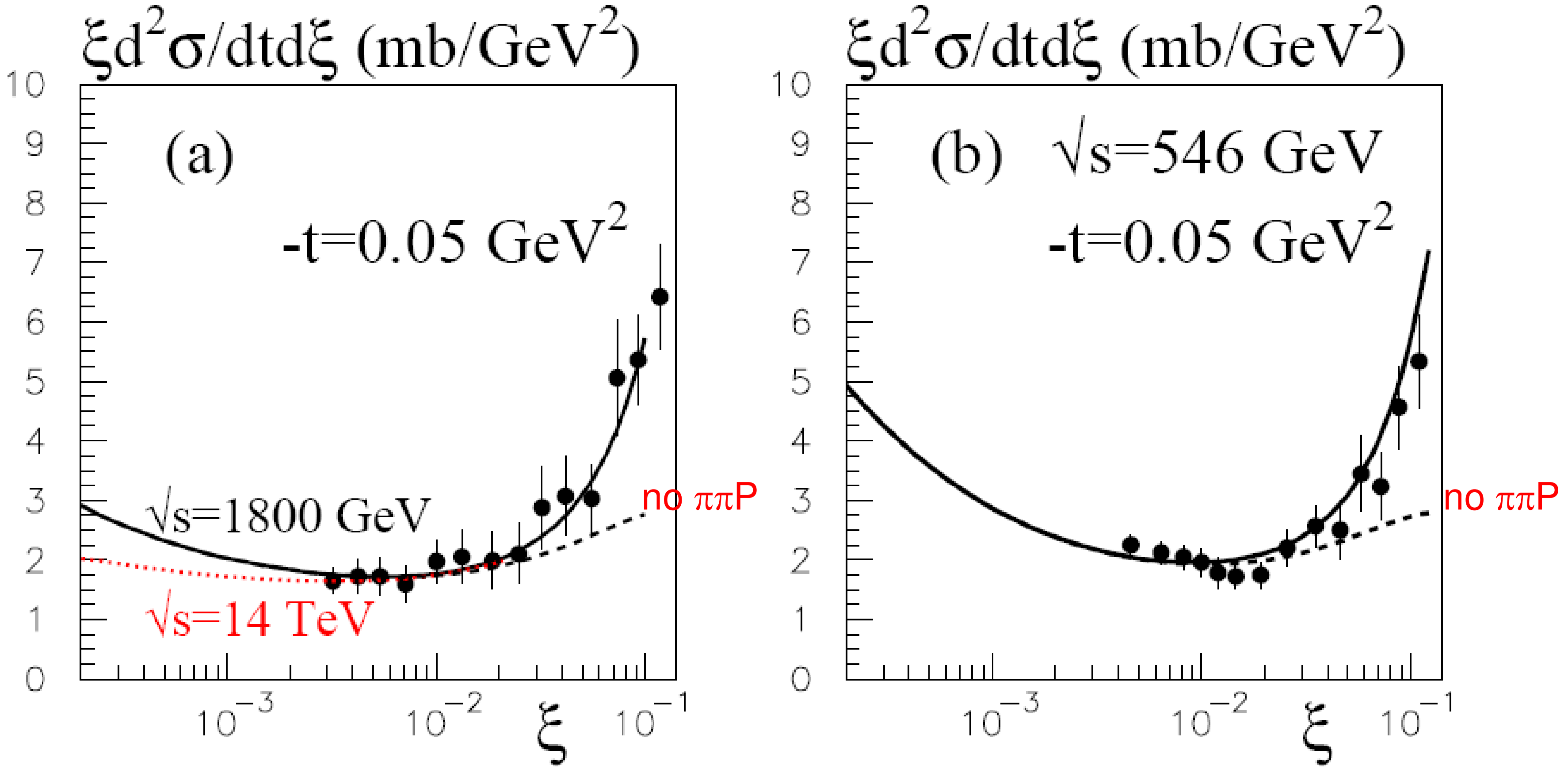
~ g, sea

ϕ_1: “large”

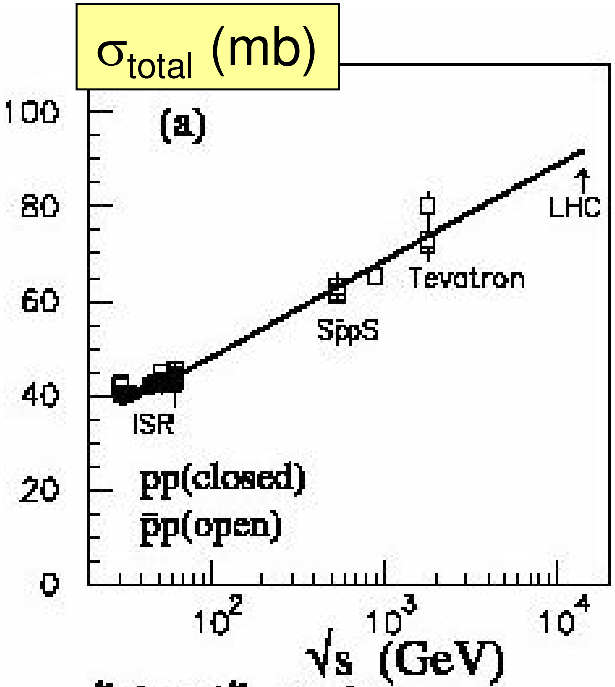
ϕ_3: “small”

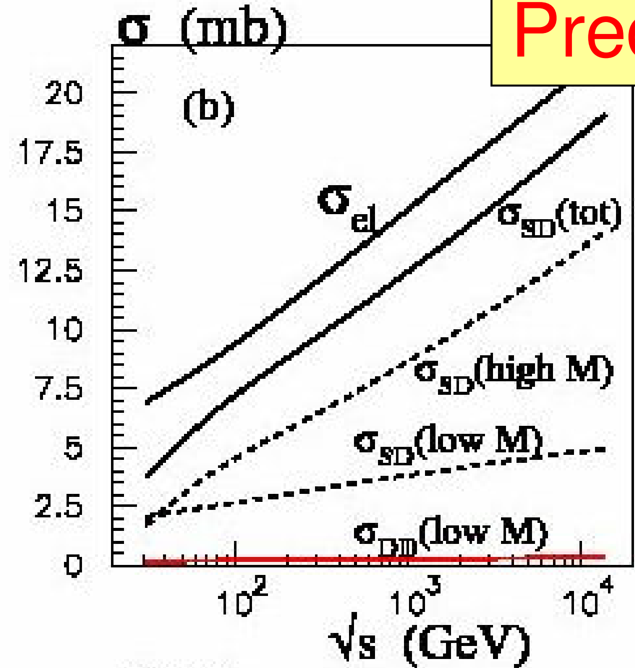
more valence

Description of CDF dissociation data



Predictions for LHC





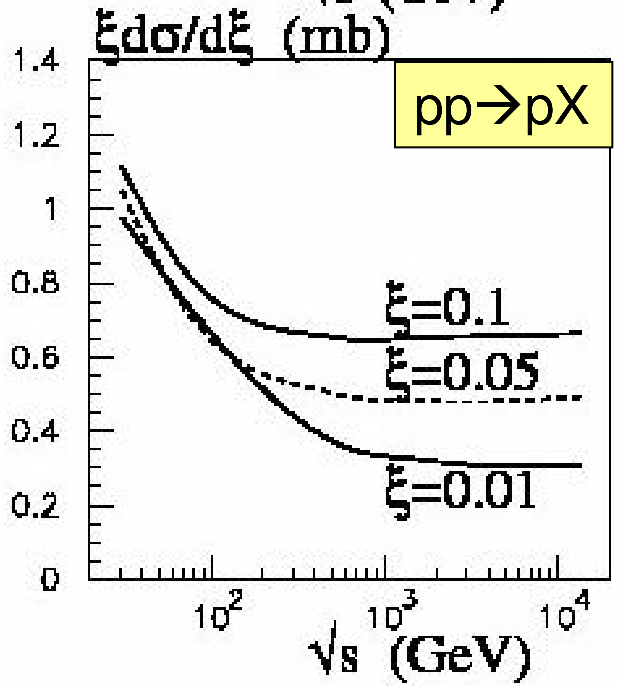
$\sigma_{total} = 91.7$ mb*

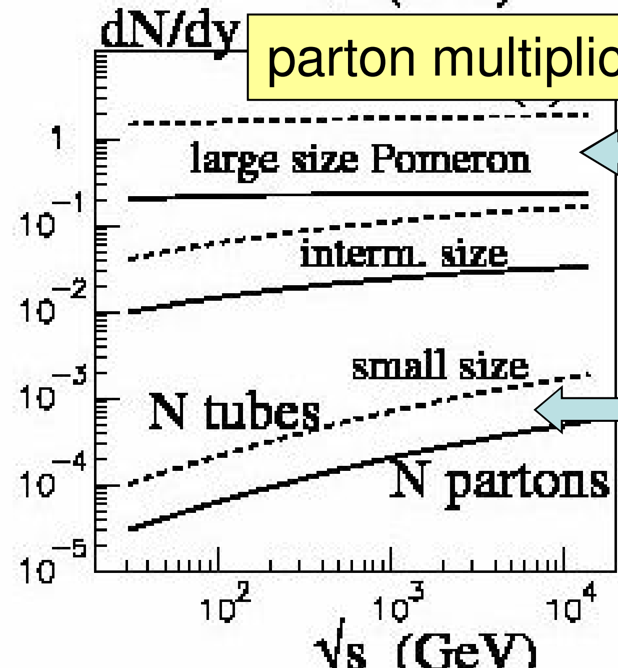
$\sigma_{el} = 21.5$ mb

$\sigma_{SD} = 19.0$ mb

*see also Sapeta, Golec-Biernat; Gotsman et al.

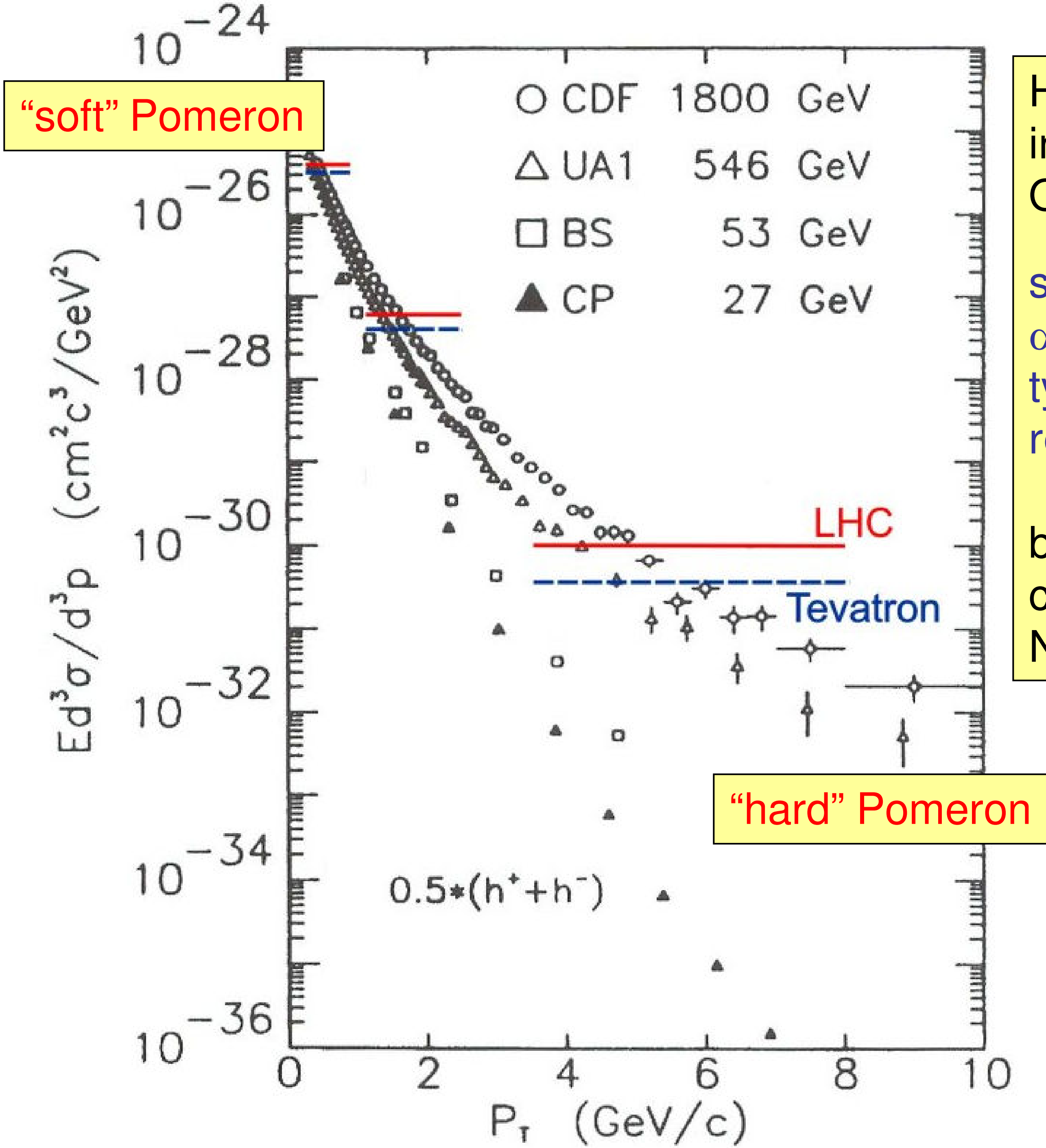
All Pom. compts have $\Delta_{bare}=0.3$





"soft", screened, little growth, partons saturated

"hard" ~ no screening much growth, $s^{0.3}$



HERA data smooth in transition region $Q^2 \sim 0.3 - 2\ \mathrm{GeV}^2$

slope of bare trajectory $\alpha' < 0.1\ \mathrm{GeV}^{-2}$, so typical k_t in Pom. amp relatively large ($\alpha' \sim 1/k_t^2$)

bare $\alpha_P(0) - 1 \sim 0.3$, close to BFKL, after NLL are resummed

Calculation of S^2_{eik} for pp → p + H +p

prob. of proton to be in diffractive estate i

over b

hard m.e. i k → H

survival factor w.r.t. soft i-k interaction

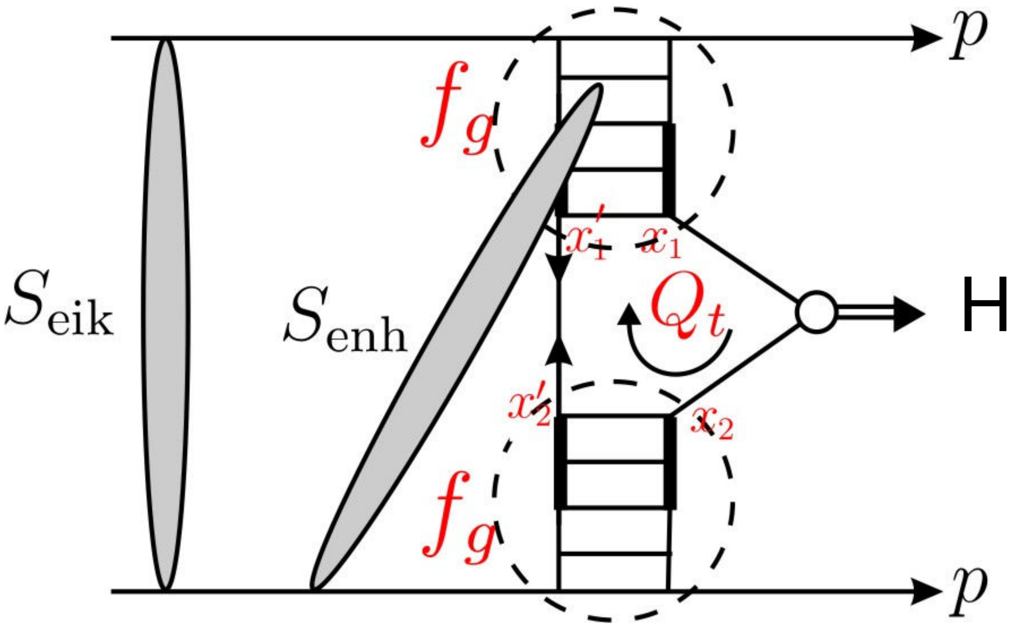
average over diff. estates i,k

$$\overline{S^2} = \frac{\sum_{i,k} \int d^2b\, |a_{pi}|^2\ |a_{p'k}|^2\ |\mathcal{M}_{ik}|^2\ \exp(-\Omega_{ik}(s,b))}{\sum_{i,k} \int d^2b\, |a_{pi}|^2\ |a_{p'k}|^2\ |\mathcal{M}_{ik}|^2}$$

$\overline{S^2}_{eik}$ ~ 0.02 for 120 GeV SM Higgs at the LHC

→ **σ ~ 2 - 3 fb at LHC**

Calculation of $S^2_{enhanced}$ for pp → p + H +p



gap

gap

Main enhanced rescatt. occurs at beginning of evolution.
Evolution of "beam" affected by enhanced int^n with "target".
S_{enh} changes (b, k_t) distrib^n of active partons: breaks fact^n
Inclusion of Pomeron q_t structure enables S^2_{enh} to be calculated

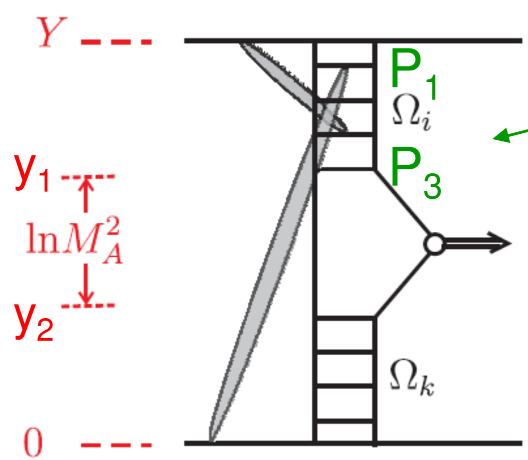
model has 4 t-ch. exchanges

3 to mimic BFKL diffusion in ln q_t

$a = P_{large}, P_{intermediate}, P_{small}, R$

soft ⟶ pQCD

average q_{t1}~0.5, q_{t2}~1.5, q_{t3}~5 GeV



enh. abs. changes P_3 distrib^n

V_{RP1} ~ g_{PPR}, g_{RRP}

V_{PiPj} ~ BFKL

evolve up to y_2

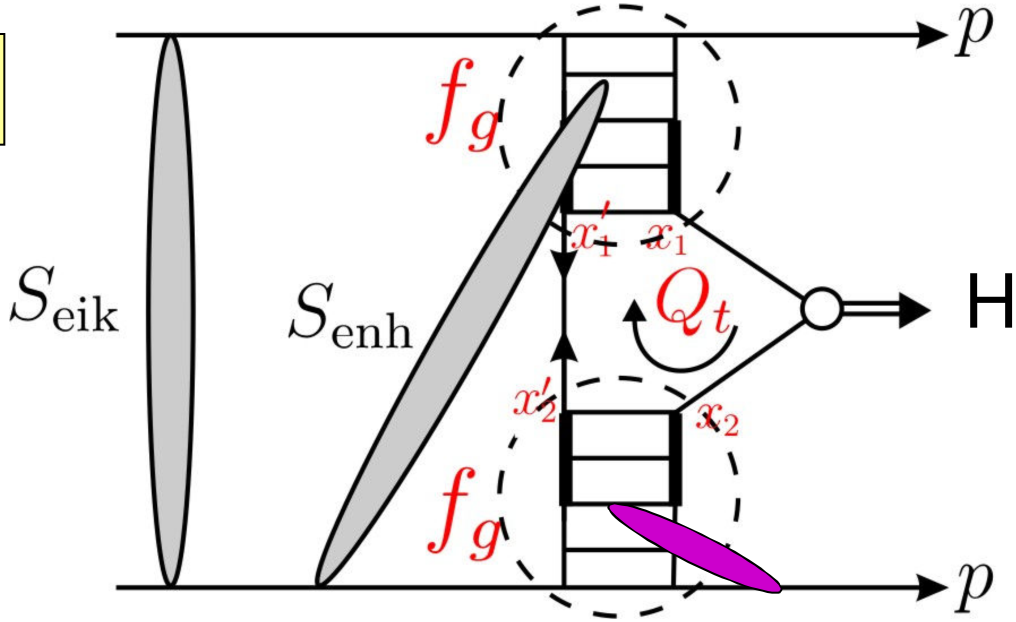
bare pole — absorptive effects

$$\begin{cases} \dfrac{d\Omega^a_{ck}(y)}{dy} = (\Delta + \alpha' \nabla_b^2)\Omega^a_{ck}(y)\; e^{-\lambda\Omega_{ck}(y)/2} e^{-\lambda\Omega_{ic}(y')/2} + V_{aa'}\Omega^{a'}_{ic}(y) \\ \dfrac{d\Omega^a_{ic}(y')}{dy'} = (\Delta + \alpha' \nabla_b^2)\Omega^a_{ic}(y')\; e^{-\lambda\Omega_{ic}(y')/2} e^{-\lambda\Omega_{ck}(y)/2} + V_{aa'}\Omega^{a'}_{ck}(y') \end{cases}$$

evolve down to y_1

~ solve with and without abs. effects

Two subtlities



gap

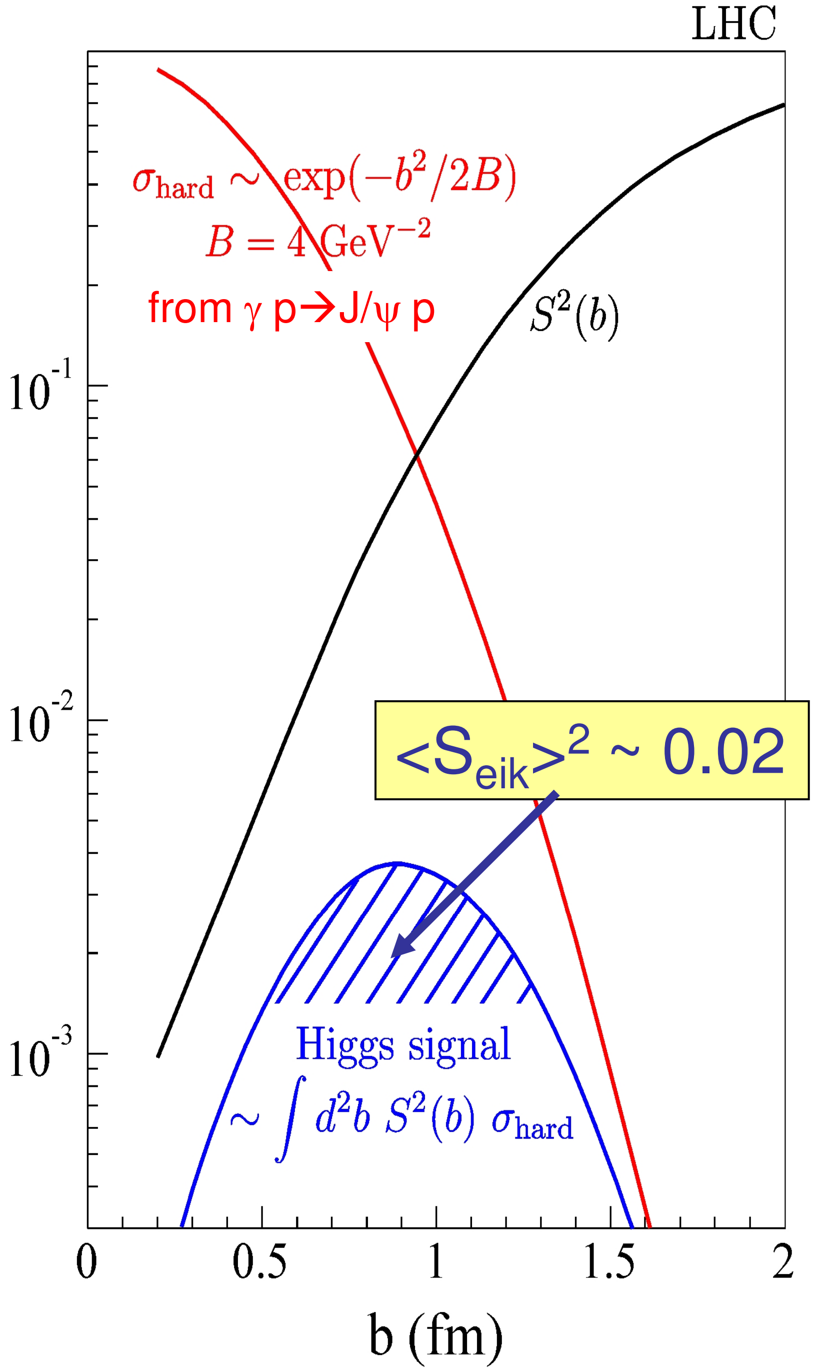
gap

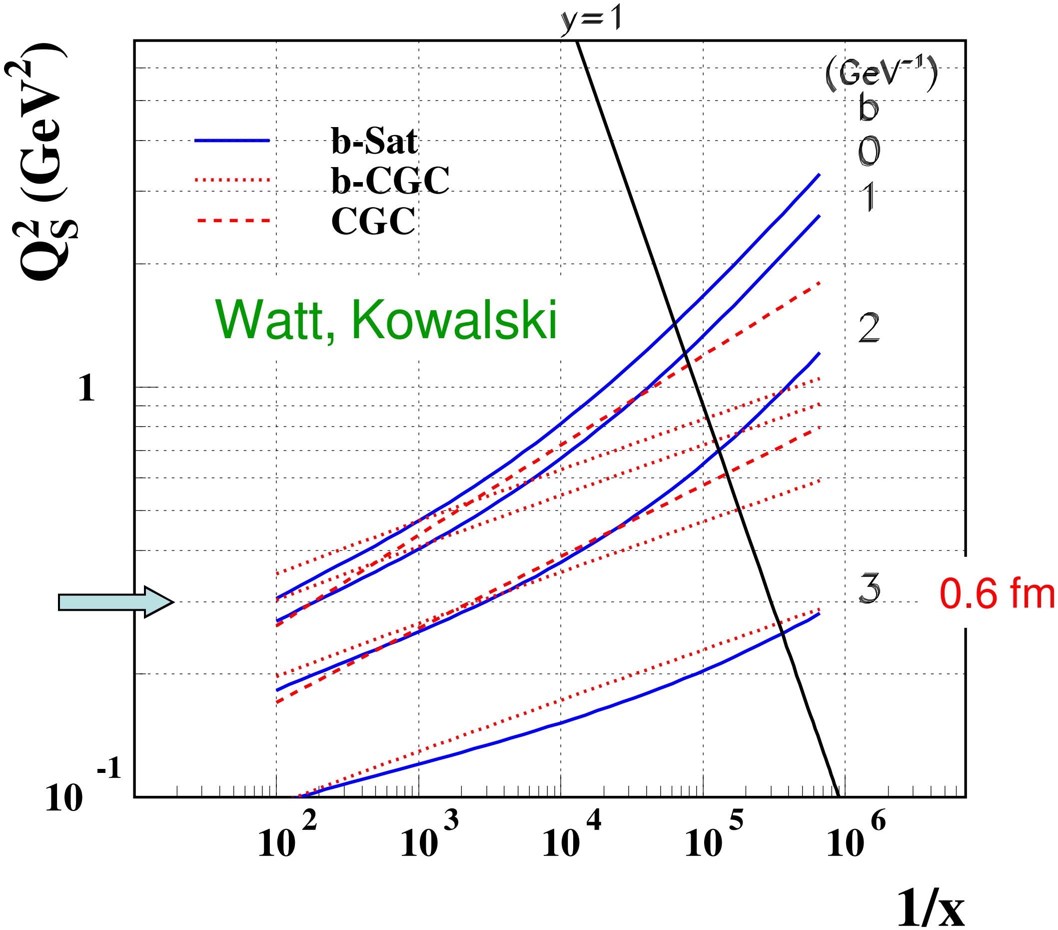
1. f_g's from HERA data already include rescatt. of intermediate partons with parent proton
2. Usually take p_t=0 and integrate with $\exp(-Bp_t^2)$. S^2/B^2 enters (where $1/B = \langle p_t^2 \rangle$). But enh. abs. changes p_t^2 behaviour from exp., so quote $S^2 \langle p_t^2 \rangle^2$

$\langle S^2_{tot} \rangle = \langle S^2_{eik} S^2_{enh} \rangle \sim 0.015$ (for B=4 GeV^{-2})

$\langle S^2_{tot} \rangle \langle p_t^2 \rangle^2 = 0.0015$ see arXiv:0812.2413

Sat^n scale $Q_s^2 < 0.3$ GeV^2 for $x \sim 10^{-6}$





parton only survives eik. rescatt. on periphery, where parton density is small and prob. of enh. abs. small

Comments on GLM(2008)

GLM include some 3P effects, but get $\langle S_{enh}^2 \rangle = 0.063$

$$\langle S_{tot}^2 \rangle = 0.0235 \times 0.063 = 0.0015$$

Calculation should be extended to obtain reliable S_{enh}

1. Need to calc. b, k_t dep., S_{enh} comes mainly from periphery (after S_{eik} suppression) where parton density is small. So S_{enh} (GLM) is much too small.
2. First 3P diagram is missing, so σ_{SD} much too small.
3. Four or more multi-Pomeron vertices neglected, so σ_{tot} asymptotically decreases (but GLM have σ_{tot} asym. const.). Model should specify energy interval where it is valid.
4. Need to consider threshold suppression.
5. Should compare predictions with observed CDF data.

Comments on Strikman et al.

also predict a v.small S_{enh} !

They use LO gluon with steep 1/x behaviour.

Obtain black disc regime at LHC energy, with low x gluon so large that only on the periphery of the proton will gap have chance to survive.

However, empricially the low x, low Q^2 gluon is flat – the steep 1/x LO behaviour is an artefact of the neglect of large NLO corrections.

Again should compare to CDF exclusive data.

Conclusions – soft processes at the LHC

-- screening/unitarity/absorptive corrections are **vital**

-- Triple-Regge analysis with screening → g_{3P} increased by ~3

→ **importance of multi-Pomeron diagrams**

(include, not just 3P vertices, but m→n vertices, otherwise σ_{total} decreases asymptotically)

-- Latest analysis of all available "soft" data:

multi-ch eikonal + multi-Regge + compts of Pom. to mimic BFKL

(showed some LHC predictions … σ_{total} **~ 90 mb,** σ_{SD}**~ 20 mb**)

-- **soft-hard Pomeron transition emerges**

"soft" compt. --- heavily screened --- little growth with s, $s^{0.08}$

"intermediate" compt. --- some screening

"hard" compt. --- little screening --- large growth (~pQCD), $s^{0.3}$

Conclusions – on gap survival probabilities

-- There is consensus for survival prob. of gaps to eik. rescatt.
e.g. S^2=0.02 for pp → p+H+p at LHC for 120 GeV SM Higgs

-- A reliable calc^n. of survival to enhanced rescatt. requires a soft model which includes the k_t dep. of Pomeron exchange (soft-hard factorization breaking). Calc^n has subtlities.
e.g. S^2 reduced by about 30% (conservative).

-- Largest unknown is low x, low Q^2 gluon

-- CDF exclusive data are encouraging. Exclusive dijet at LHC should be informative.