Survival factors in CEP; and the elusive Odderon

See the Review KMR: 1710.11505

Alan Martin (IPPP, Durham)

EMMI Workshop on Central Exclusive Production (CEP) at the LHC
Heidelberg, February 6th, 2019

The two topics seem disconnected, but not so

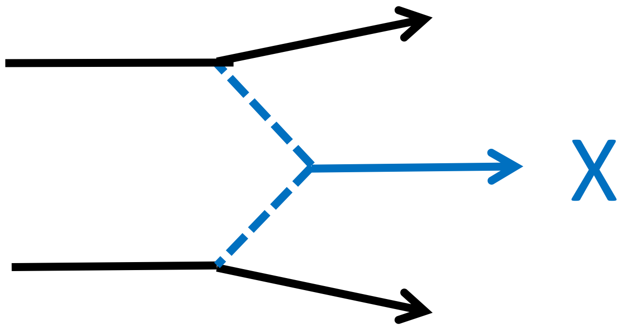
CEP must take care of gap survival factor S^2

Odderon searching must take care of absorptive corr^{ns}

$\Omega = \Omega_{even} + \Omega_{odd}$, and of background processes

Advantages of CEP

For example: pp → p + X + p



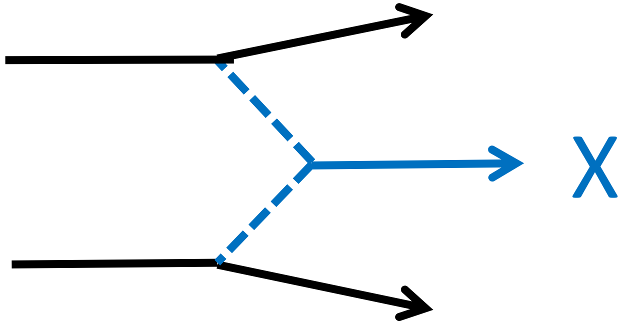
- Very clean experimental environment to explore the system X

- Mass of system X can be measured two ways
  1. From its decay products (using the central detector)
  2. From dedicated forward proton detectors about 200m either side of interaction point---measuring intact protons with fractional energy loss $0.015 < \xi < 0.15$ corresponding to $0.2 < M_X < 2$ TeV

but there is a price to pay

CEP of X $\quad pp \rightarrow p + X + p$

X may result from gg, $\gamma\gamma$ or (WW if p*) fusion



Survival of LRGs Gaps may be populated by:

Soft multiple inter^{ns} (MI) of spectator partons: mean no. <n>

exclusive event---no MI----survival prob. $S^2 = P_0 \sim \exp(-\langle n \rangle)$

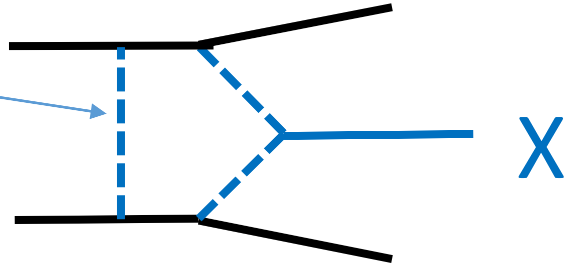
(eikonal suppression)

Hard QCD bremsstrahlung: X accompanied by QCD minijets

exclusive event----survival prob. $T^2 = P_0 \sim \exp(-\langle n_{jets} \rangle)$

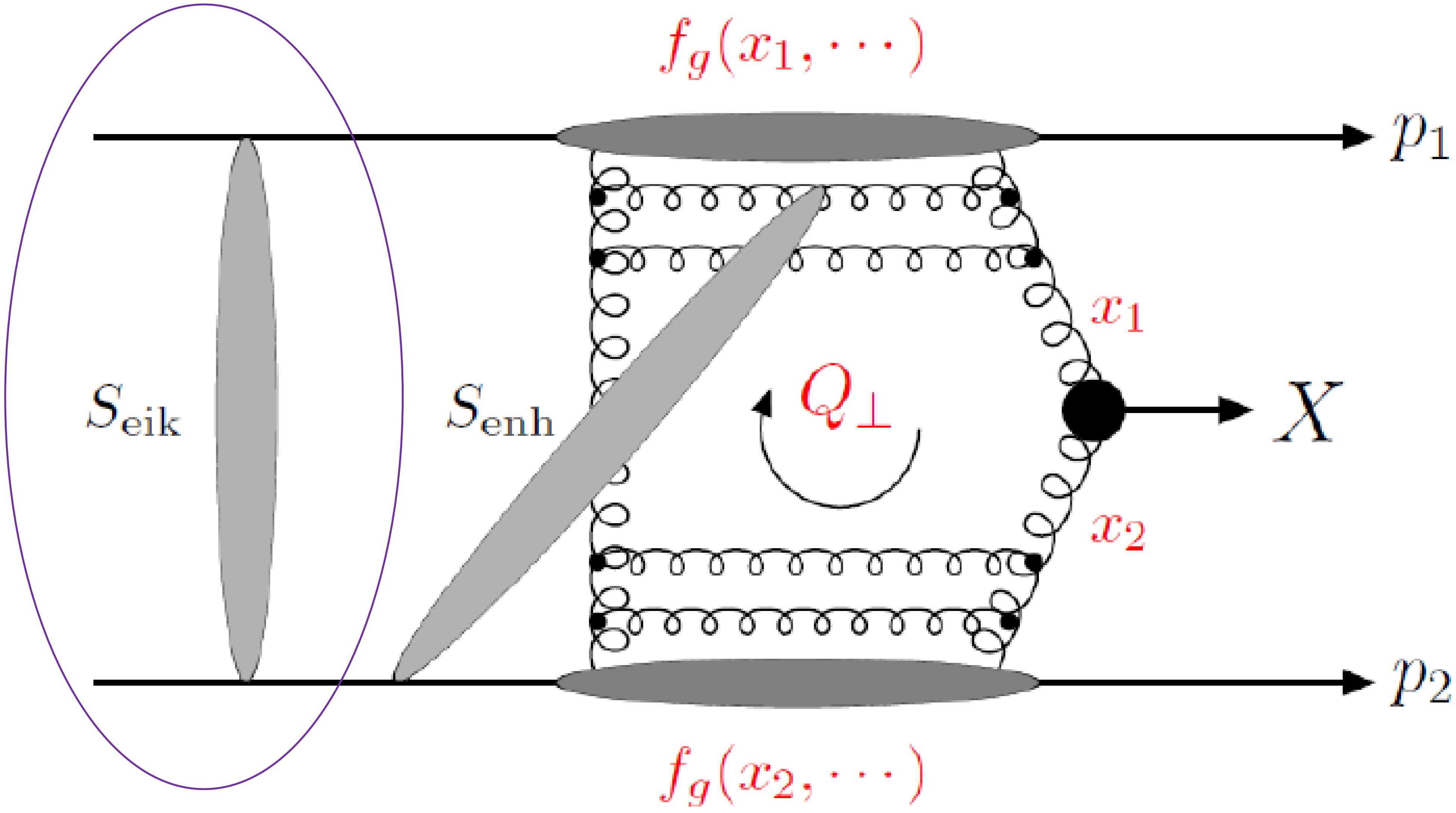
(Sudakov suppression)

Gluon needed to neutralize colour for gg fusion



Exclusive price = $S^2 T^2$

Possibilities to populate the rapidity gaps in pp → p + X + p

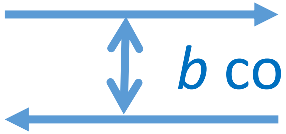


Survival factor S_{eik}^2 from eikonal parametrization

s-ch unitarity $\quad SS^\dagger = I \quad (\text{let } \; S = I + iA) \quad \rightarrow \quad \underline{i(A^\dagger - A) = A^\dagger A}$

$< i | \ldots\ldots\ldots\ldots | i >$

Work in b space



b conserved at HE

Unitarity equation

$$\underline{2\,\mathrm{Im}A_{\rm el}(b)} = \sum_n |A_{i\to n}(b)|^2 = \underline{|A_{\rm el}(b)|^2 + G_{\rm inel}(b)}$$

$$\text{where} \quad G_{\rm inel}(b) = \sum_{n\neq i} |A_{i\to n}(b)|^2 < 1 = \text{probability of inelastic scatt.}$$

Solution of unitarity eq.

$$A(b) \equiv \underline{A_{\rm el}(b) = i(1 - e^{-\Omega(b)/2})} \quad \text{with} \quad \mathrm{Re}\Omega(b) \geq 0$$

In terms of partial waves $l = b\sqrt{s}/2$: $\exp(2i\delta_l)$

Probability of no inelastic inter^n at *b*

$$\sigma_{\rm inel}(b) = \sigma_{\rm tot}(b) - \sigma_{\rm el}(b) = \mathrm{Im}A(b) - |A(b)|^2 = 1 - e^{-\Omega}$$

It is really exp(-ReΩ), but for Pom it is ~ real

At HE the inelastic contribution, $G_{\rm inel}$, dominates; $\Omega(s,b) \gg 1$.
In this so-called "black disk" limit $\quad {\rm Im}T_{\rm el}(s,b) = 1$

Example: black disc of radius R

Note
$T_{el} = A_{el}$

$$\left.\begin{array}{l} \text{for } b<R,\ \Omega=\infty \\ \quad (T_{el}=i) \\ \text{for } b>R,\ \Omega=0 \\ \quad (T_{el}=0) \end{array}\right\}$$

$$\sigma_{inel} = 2\pi\int_0^R (1-e^{-\Omega})\, b\, db = \pi R^2$$

total absorption

$\sigma_{el} = \pi R^2$ $\Big\{$ shadow due to absorption leads to elastic scattering

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

Since $\quad \dfrac{d\sigma_{\rm el}}{dt} = |{\rm Im}T_{\rm el}(s,t)|^2\,(1+\rho^2)$

data directly determines ${\rm Im}T_{\rm el}(s,b)$

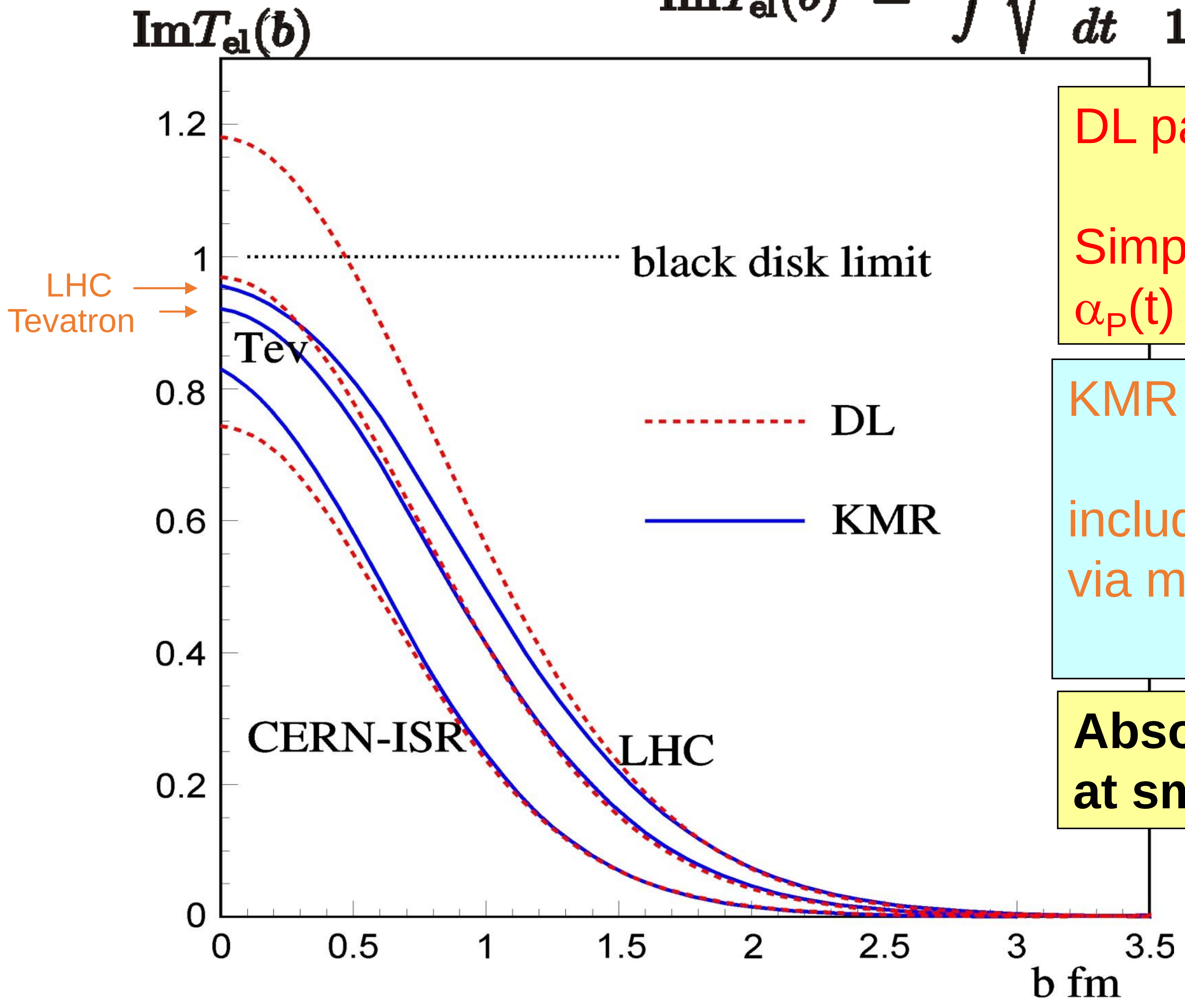
Fourier transform
to b-space:

$(-t = q_T^2)$

$\vec{b} \longleftrightarrow \vec{q}_T$

wide narrow

$$\mathrm{Im}T_{\mathrm{el}}(b) = \int \sqrt{\frac{d\sigma_{\mathrm{el}}}{dt}\,\frac{16\pi}{1+\rho^2}}\; J_0(q_T b)\,\frac{q_T\,dq_T}{4\pi}$$



DL parametrization:

Simple Pom. pole
$\alpha_P(t) = 1.08+0.25t$

KMR **eikonal** param^n

includes absorption via multi-Pomeron effects

Absorption crucial at small b

Survival factor S_{eik}^2 from eikonal parametrization

s-ch unitarity $\quad \mathbf{S}\mathbf{S}^\dagger = \mathbf{I} \quad (\text{let } \mathbf{S} = \mathbf{I} + i\mathbf{A}) \quad \rightarrow \quad \underline{i(\mathbf{A}^\dagger - \mathbf{A}) = \mathbf{A}^\dagger \mathbf{A}}$

$< i | \ldots\ldots\ldots\ldots | i >$

Work in b space $\qquad$ *b* conserved at HE

Unitarity equation
$$\underline{2\,\mathrm{Im}A_{\mathrm{el}}(b)} = \sum_n |A_{i\to n}(b)|^2 = \underline{|A_{\mathrm{el}}(b)|^2 + G_{\mathrm{inel}}(b)}$$

$$\text{where } \; G_{\mathrm{inel}}(b) = \sum_{n\neq i} |A_{i\to n}(b)|^2 < 1 \; = \text{probability of inelastic scatt.}$$

Solution of unitarity eq.
$$A(b) \equiv \underline{A_{\mathrm{el}}(b) = i(1 - e^{-\Omega(b)/2})} \quad \text{with } \; \mathrm{Re}\Omega(b) \geq 0$$

In terms of partial waves $l = b\sqrt{s}/2$: $\exp(2i\delta_l)$

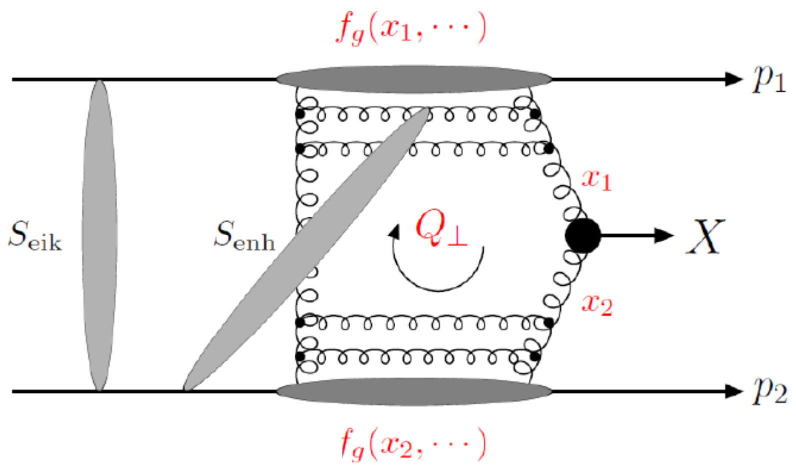
Probability of no inelastic inter[n] at *b*

$$\sigma_{\mathrm{inel}}(b) = \sigma_{\mathrm{tot}}(b) - \sigma_{\mathrm{el}}(b) = \mathrm{Im}A(b) - |A(b)|^2 = 1 - e^{-\Omega}$$

It is really exp(-ReΩ), but for Pom it is ~ real

First Approx: one-channel eikonal; take average value of S_{eik}^2

$$\langle S^2_{\text{eik}} \rangle = \frac{\int d^2b_1\, d^2b_2\, |T(s, b_1, b_2)|^2 \exp(-\Omega(s,b))}{\int d^2\, b_1 d^2 b_{2t}\, |T(s, b_1, b_2)|^2}$$



where $b = b_1 + b_2$

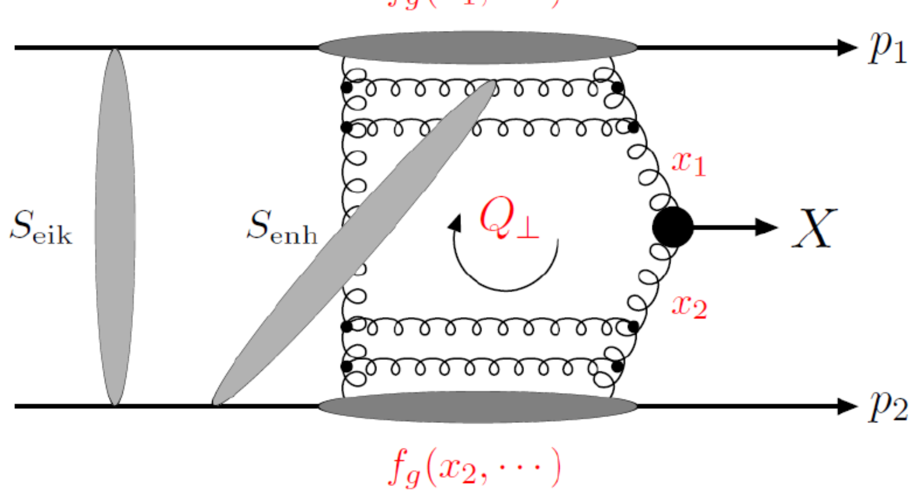
$$T(s, p_{1_\perp}, p_{2_\perp}) = \int d^2b_1\, d^2b_2\, e^{ip_{1_\perp}\cdot b_1} e^{-ip_{2_\perp}\cdot b_2} T(s, b_1, b_2)$$

is the CEP amplitude given by pQCD for high M_X

$\Omega(s,b)$ is the opacity determined from soft HE *pp* scattering data

Need to allow for low-mass proton excitations *N** , that is $p \rightarrow N^* \rightarrow p$,
in determining $\Omega(s,b)$ from *pp* scattering data

Two-channel eikonal (p,N^*) determination of S_{eik}^2



GW formalism:

$$|p\rangle \;=\; \sum_i a_i|\phi_i\rangle\;, \qquad |N^*\rangle \;=\; \sum_k c_k|\phi_k\rangle$$

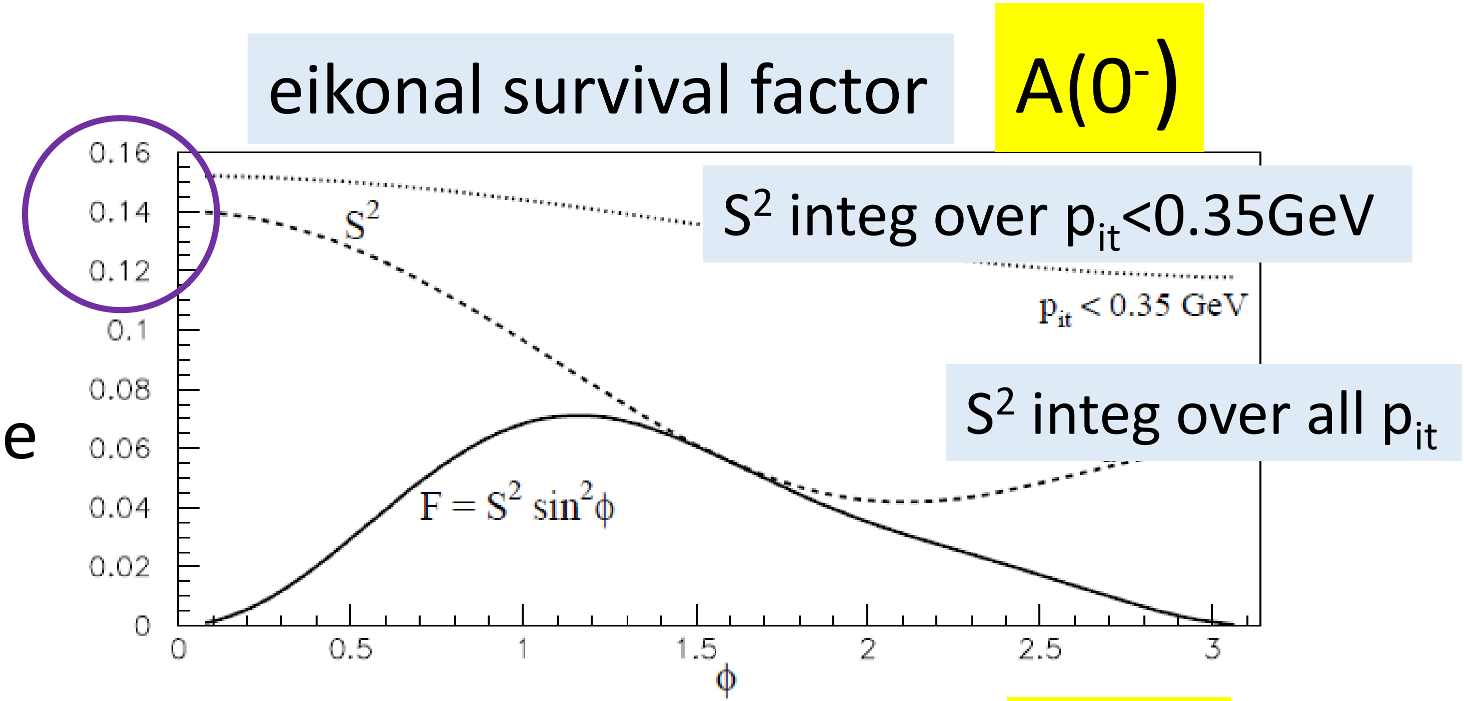
states $|\phi_1\rangle$, $|\phi_2\rangle$ only undergo 'elastic scattering' $\langle\phi_i|A|\phi_k\rangle = 0$ for $i \neq k$

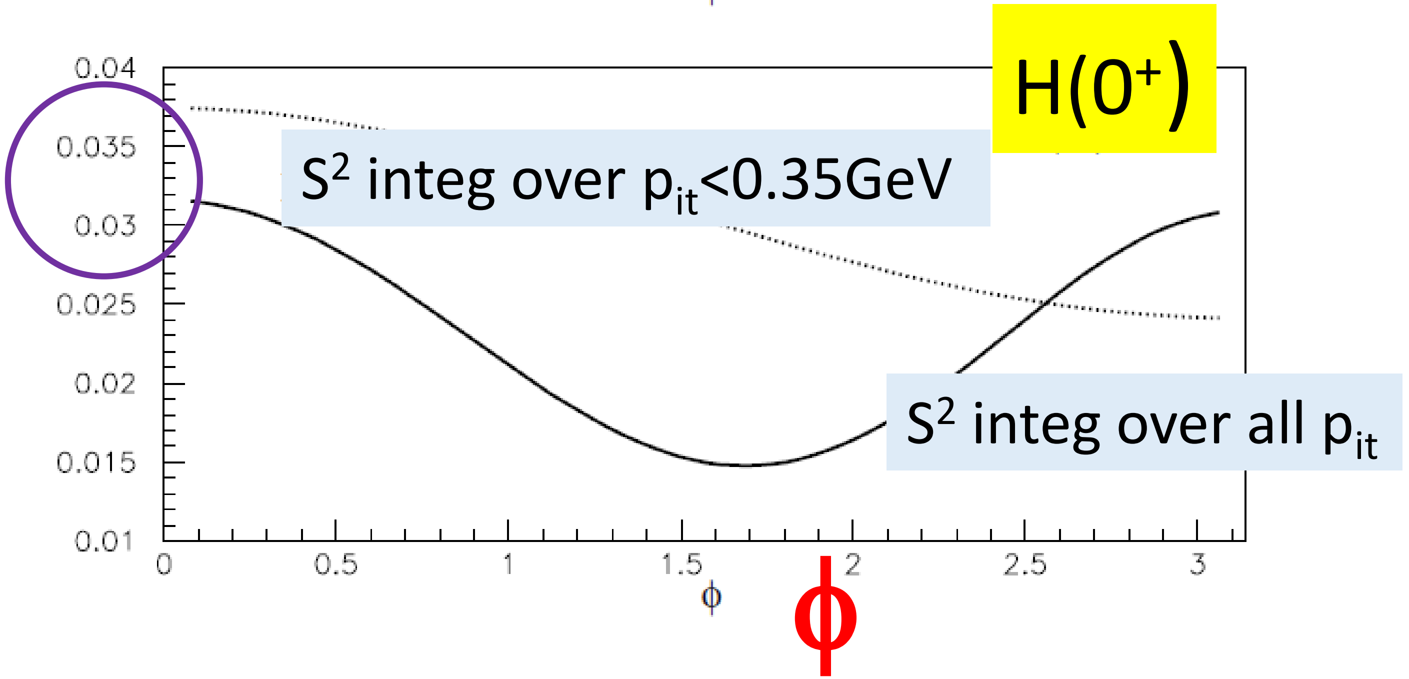
$$\boxed{S^2_{\rm eik}({\rm b}) \;=\; \frac{\left|\sum_{i,k}|a_i|^2\;|a_k|^2\;\mathcal{M}_{ik}({\rm b})\;\exp(-\Omega_{ik}(s,{\rm b})/2)\right|^2}{\left|\sum_{i,k}|a_i|^2\;|a_k|^2\;\mathcal{M}_{ik}({\rm b})\right|^2}}$$

Need hypothesis to distribute global PDFs between components of $|\phi_i >$

Need to do 2-ch eikonal fit to HE *pp* scatt. data for $d\sigma(el)/dt$, σ_{lowM}^{diff}, $\sigma(tot)$, …

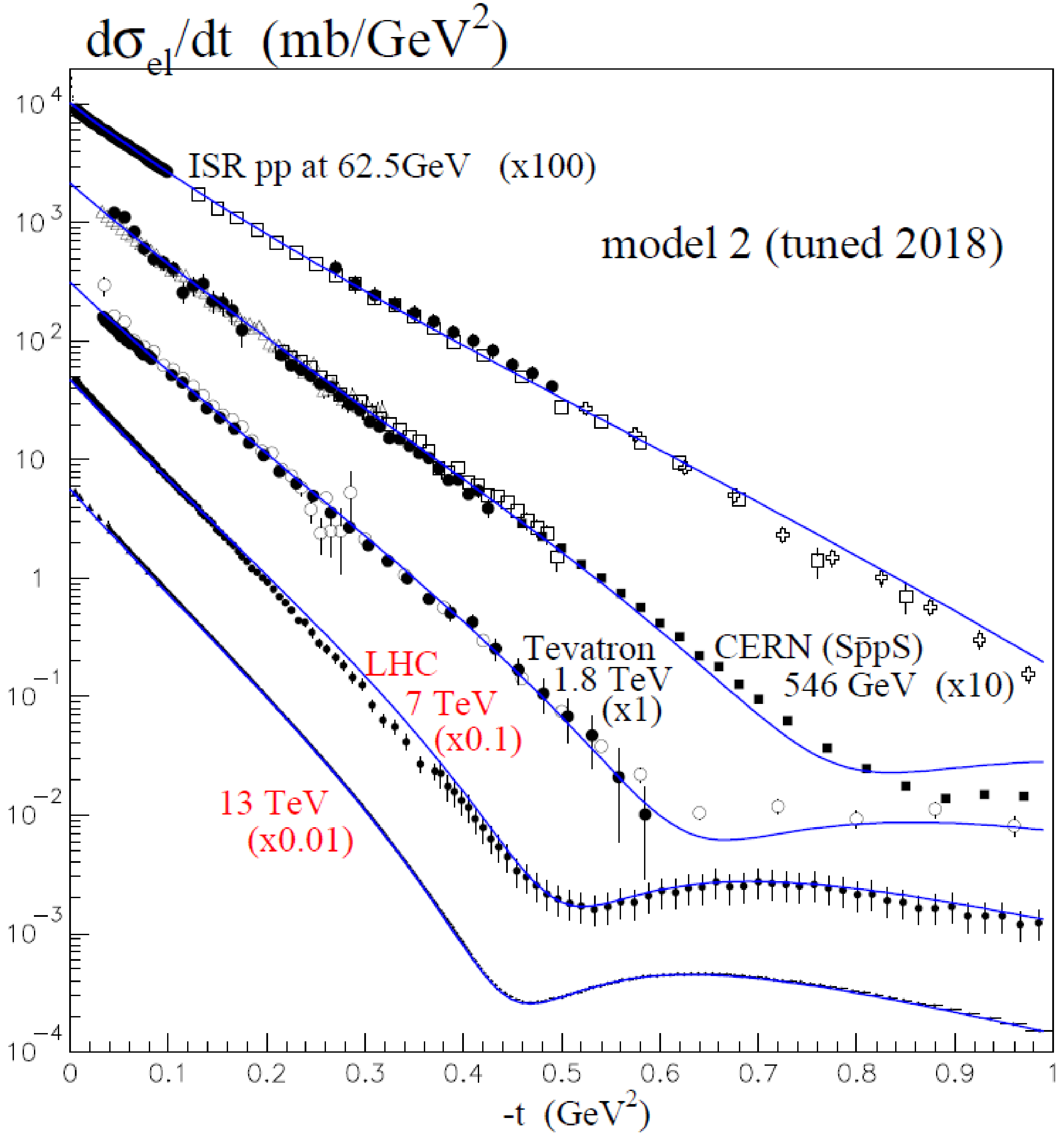
$S_{eik}{}^2$ suppression depends on matrix element of CEP hard process and on transverse momentum of the outgoing protons. Plots are for **azimuthal angle ϕ between proton transverse momenta**





pp → p + (A or H) + p

Part of 2-ch eikonal fit which determines $\Omega(b,s)$ --- which is needed to calculate S_{eik}^2



HE behaviour dominated by leading (highest) Regge-exch. trajectory

σ_{tot}(hadron-hadron) $\rightarrow$ const. (actually slightly rising as $s \rightarrow$ infinity)

that is $T(s, t=0) \sim s$ (actually $s^{1.08}$)

Implies Regge-pole exchange with $\alpha(0) = 1$ (1.08 ?)

called the Pomeron

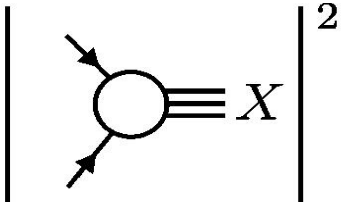
We shall see later that the Pomeron is represented by gluon exchange – we need two gluons to form colourless exchange. But, for the moment, let us consider the Pomeron as a simple (effective) Regge pole

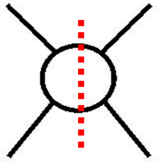
three?

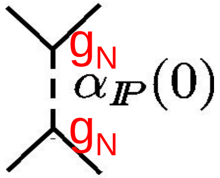
Optical theorem

at high energy
use Regge

$$\sigma_{\rm total} = \sum_X \left| \quad \right|^2 = {\rm Im} \quad = \quad g_N \; \alpha_{I\!P}(0) \; g_N$$

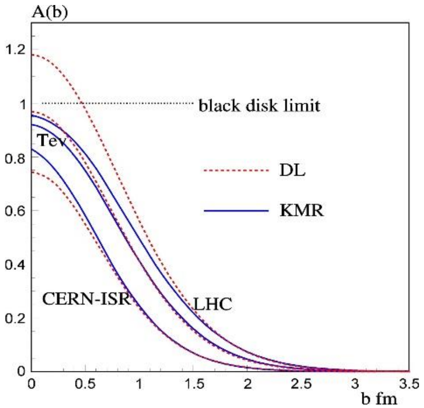






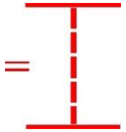
but screening/s-ch unitarity important so $\sigma_{\rm total}$ suppressed

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

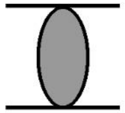


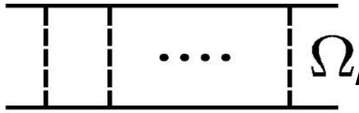
Elastic amp. $T_{el}(s,b)$

bare amp. $\Omega/2$ =



$${\rm Im}\; A_{\rm el} = \quad = 1 - e^{-\Omega/2} = \sum_{n=1}^{\infty} \quad \Omega/2$$

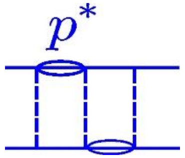




(s-ch unitarity)

(-20%)

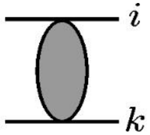
Low-mass diffractive dissociation

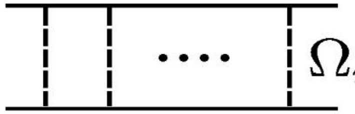


→multichannel eikonal

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

$${\rm Im}\; A_{ik} = \quad = 1 - e^{-\Omega_{ik}/2} = \sum \quad \Omega_{ik}/2$$

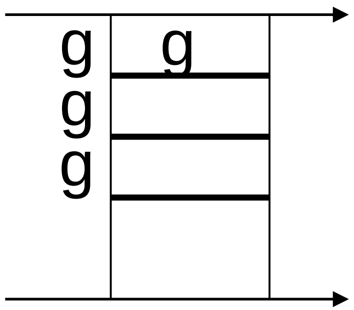




(-40%)

Ladder structure of the Pomeron after QCD

Shortly after the discovery of QCD it was proposed that (colourless) two-gluon exch. had properties of Pomeron exch:
vacuum quantum no's, singularity close to j=1



--Later, using the BFKL formalism, in which the t-ch gluons (rather than hadrons) become Reggeized, it was found possible (for sufficiently large k_T) to describe HE (low x) interactions in pQCD.

--BFKL sum up the leading $(\alpha_s \log 1/x)^n$ contributions and build up the hard/pQCD/BFKL Pomeron.

--The Pomeron, is not a pole, but a branch cut in the complex angular momentum plane, plus more complicated cuts at HO

"Soft" and "Hard" Pomerons

A vacuum-exchange object drives soft HE interactions. Not a simple pole, but an enigmatic non-local object. Rising σ_{tot} means multi-Pom diags (with Regge cuts) are necessary to restore unitarity. σ_{tot}, $d\sigma_{el}/dt$, σ_{lowM}^{diff}, described, by an effective pole

$\alpha_P^{eff} = 1.13 + 0.05t$

Sum of ladders of Reggeized gluons with, in LLx BFKL, a singularity which is a cut and not a pole. When HO are included the intercept of the BFKL/hard Pomeron is $\alpha_P^{bare}(0) \sim 1.3$

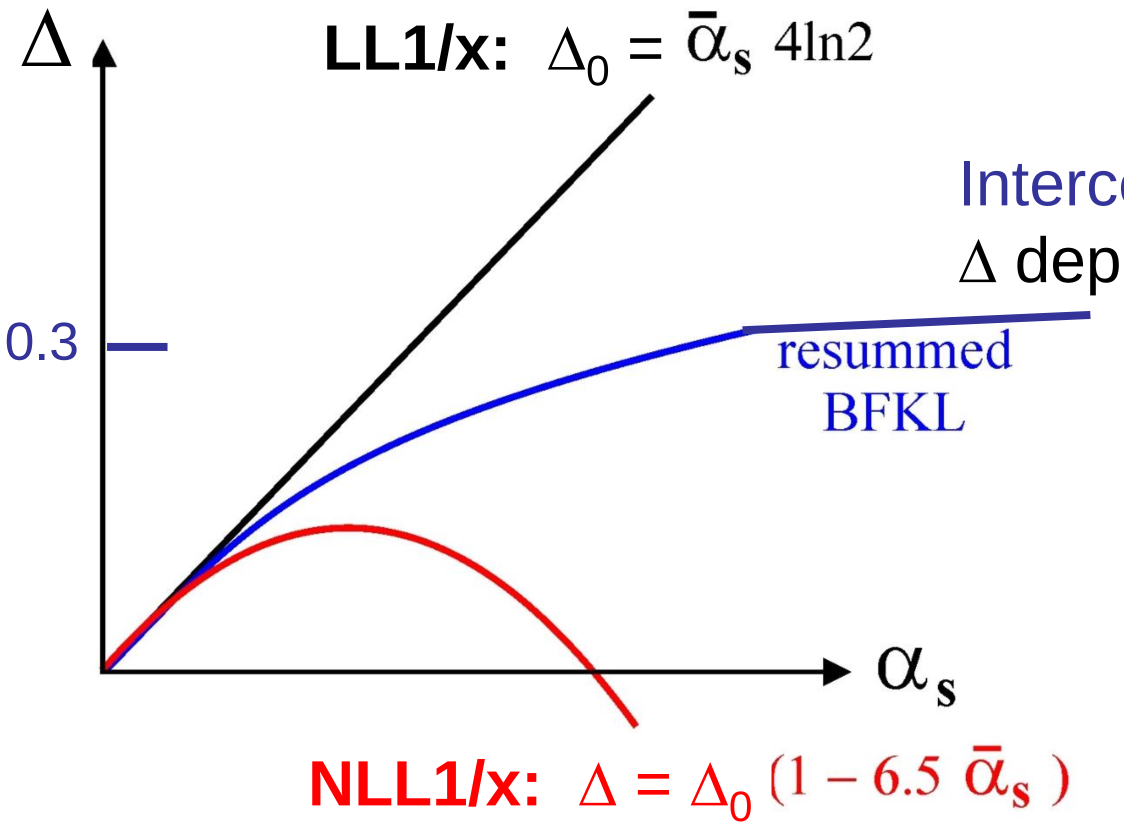
$\boldsymbol{\Delta = \alpha_P(0) - 1 \sim 0.3}$

$\alpha_P^{eff} \sim 1.13 + 0.05\ t$ ← $\alpha_P^{bare} \sim 1.3 + 0\ t$

Accounting for absorptive (multi-Pomeron) effects

BFKL stabilized

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



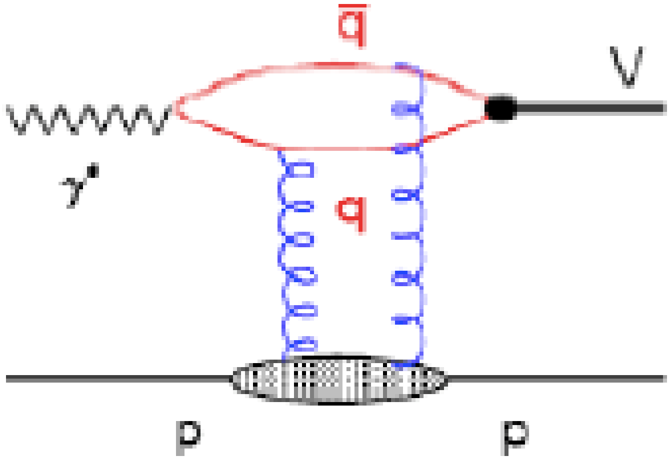
Intercept $\Delta = \alpha_P(0) - 1 \sim 0.3$

Δ depends weakly on k_t for low k_t

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

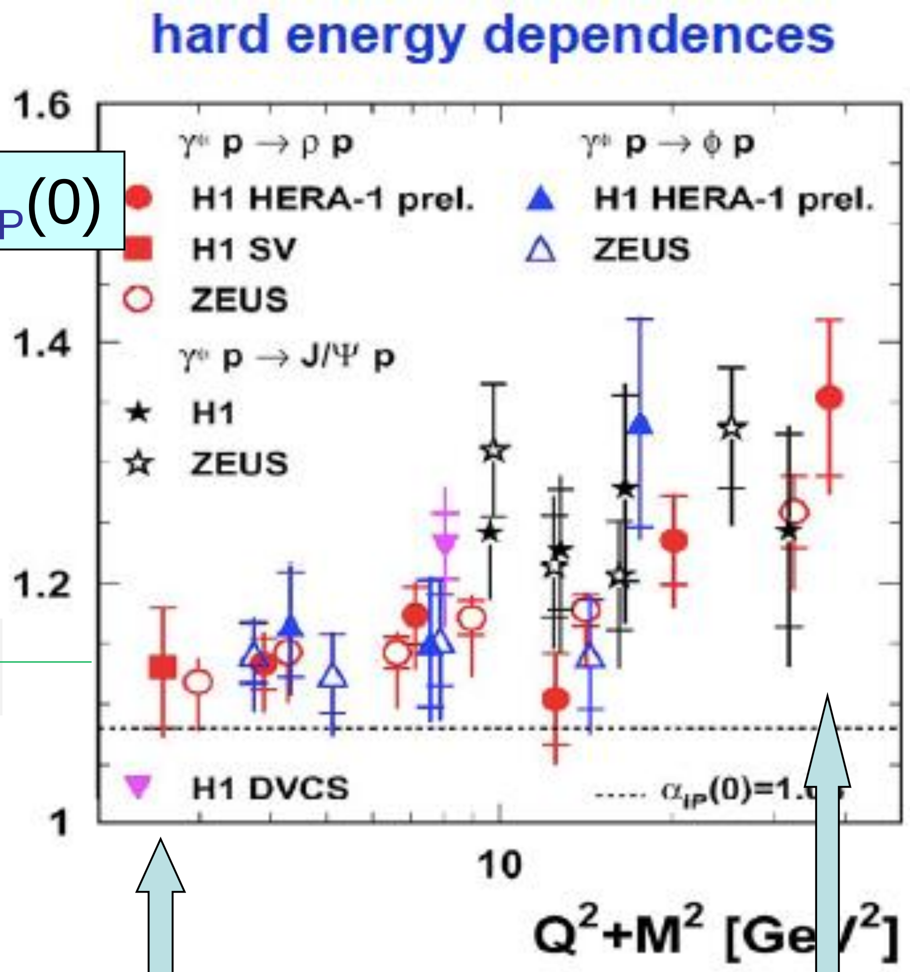
Vector meson prod^n at HERA
~ bare QCD Pom. at high Q^2
~ no absorption

Q^2



$\alpha_P(0)$

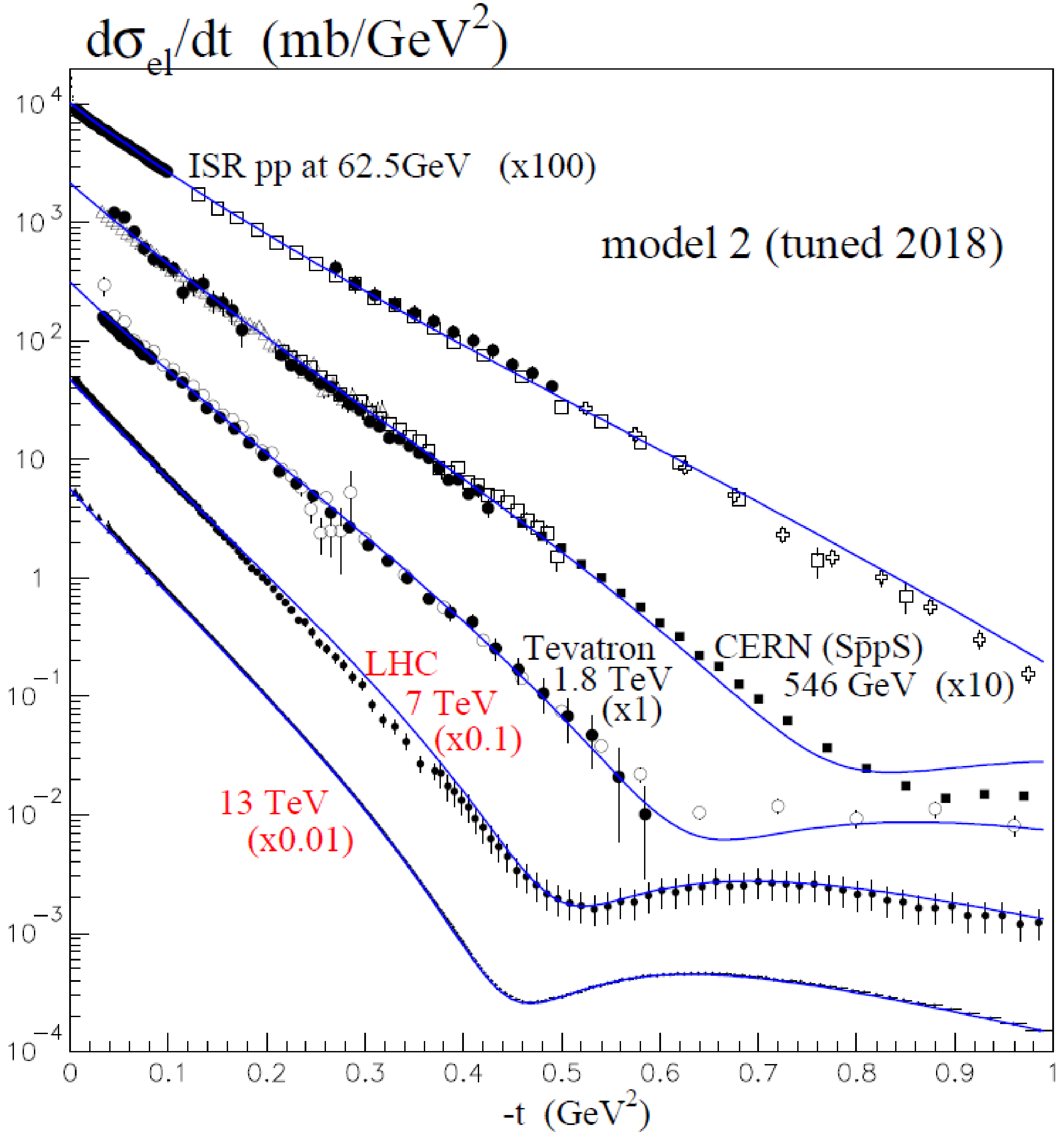
1.13



$\alpha_P(0) \sim 1.1$
after absorption

$\alpha_P^{bare}(0) \sim 1.3$

Part of 2-ch eikonal fit which determines $\Omega(b,s)$ --- which is needed to calculate S_{eik}^2



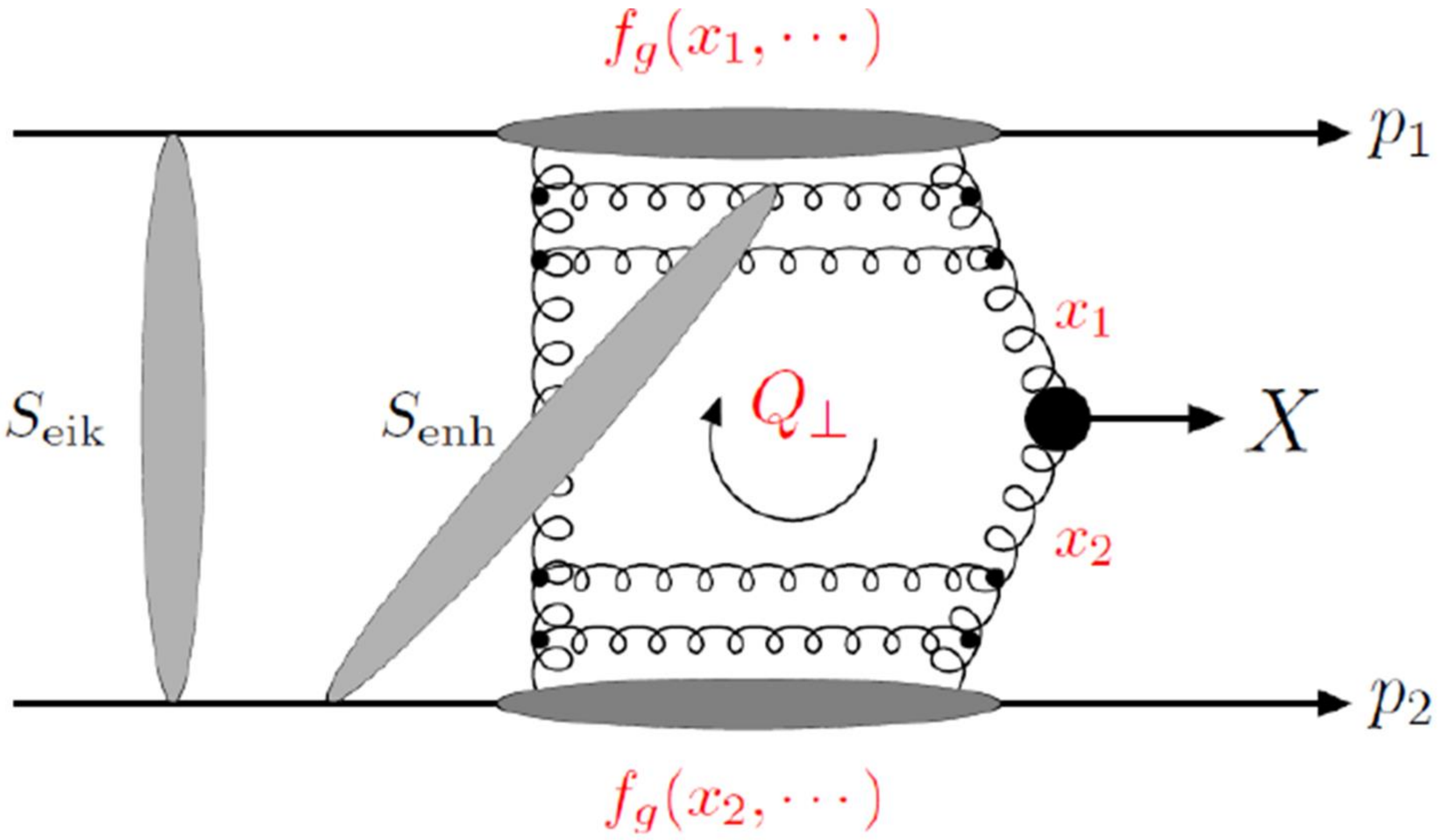
11 parameters in total to describe all high-energy $d\sigma_{el}/dt$, σ_{tot}, σ_{lowM}^{diff} pp data

4 for Pom: σ_0, $\alpha_P(0)$, α'_P, γ
7 for two GW eigenstates

$\alpha_P(0)=1.13$

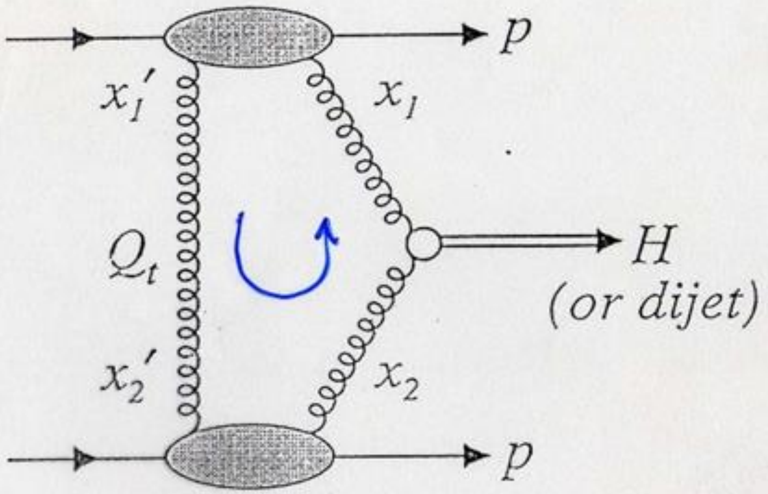
Large number of intermediate partons

In general "enhanced" screening is small for large M_X due to strong k_t ordering of intermediate partons



QCD bremmstrahlung --- Sudakov suppression

$f(x_1, x_1', Q_t, M_H)$



$pp \to p + H + p$

Survival prob. of rap. gaps

$W = S^2 \, T^2$

price for $\boxed{\text{no soft rescatt.}}$ $\boxed{\text{no } g \text{ rad}^n \text{ in } gg \to H}$

Not a simple multiplication. Need to embed the Sudakov factor in the pQCD integral over Q_t to ensure infrared convergence

$\Lambda^2_{QCD} \ll Q_t^2 \ll M_H^2 \quad \to$ pQCD

$\left(x' \sim \frac{Q_t}{\sqrt{s}}\right) \ll \left(x \sim \frac{M_H}{\sqrt{s}}\right) \ll 1$

need uninteg. skewed gluons

$f(x_i, x_i', \ldots)$

Sudakov factor $T(Q_t,\mu) \sim \exp(-\alpha_s \ln^2(Q_t^2/M_H^2))$ ensures no gluon emission from the fusing gluon as it evolves from Q_t to hard scale μ. It ensures infrared convergence of Q_t integral

$$\left(x' \sim \frac{Q_t}{\sqrt{s}}\right) \ll \left(x \sim \frac{M_H}{\sqrt{s}}\right) \ll 1$$

need uninteg. skewed gluons

$$\mathcal{M} = \underline{\frac{A}{M_H^2} \int \vec{Q}_{1t} \cdot \vec{Q}_{2t} \, \frac{d^2 Q_t}{Q_t^6}} \; f\left(x_1, x_1', Q_t^2, \frac{M_H^2}{4}\right) f\left(x_2, x_2', Q_t^2, \frac{M_H^2}{4}\right)$$

where $f(x, x', Q_t^2, \mu^2) \approx R \dfrac{\partial}{\partial \ln Q_t^2} \left[\sqrt{T(Q_t, \mu)} \, x g(x, Q_t^2) \right]$

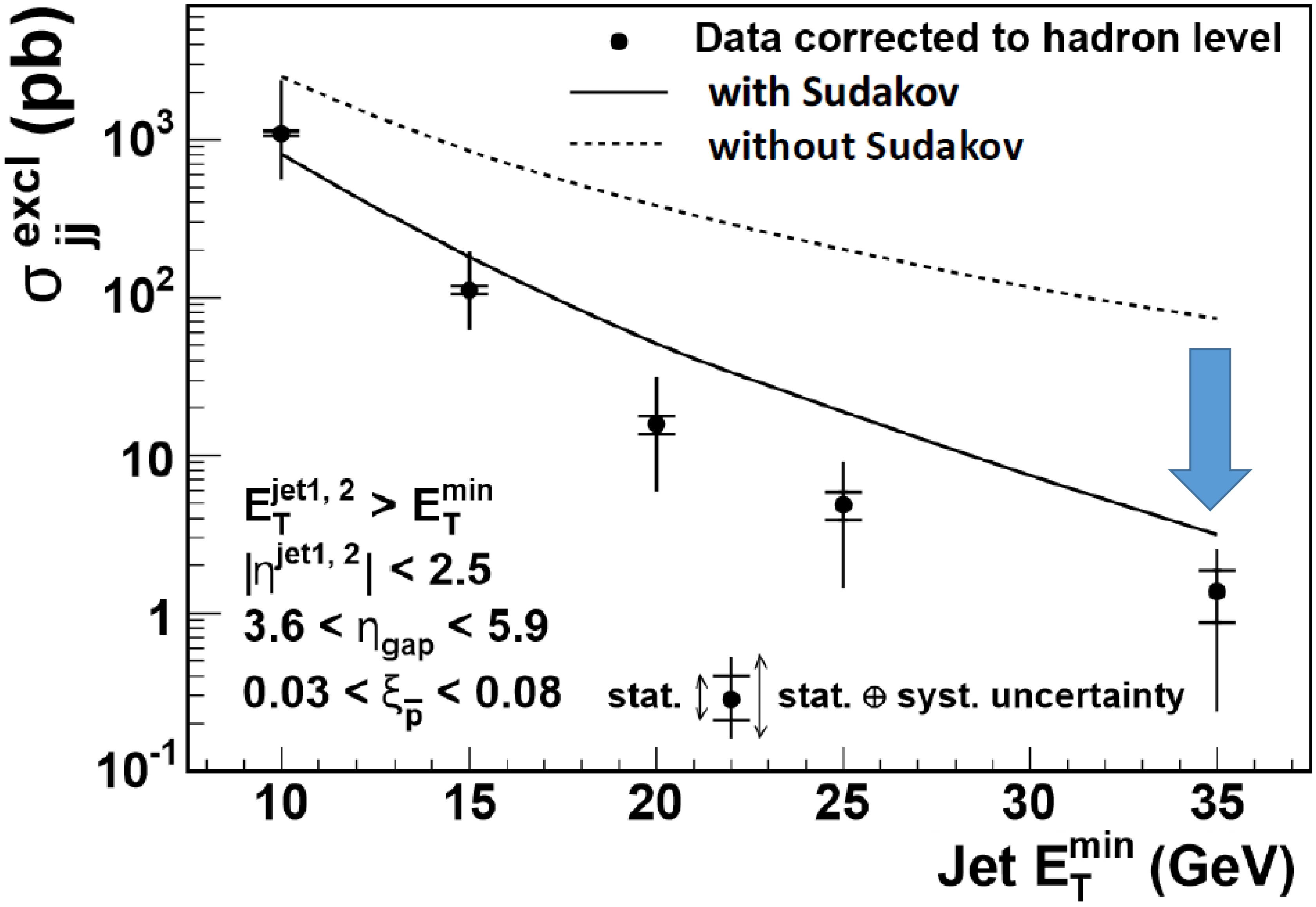
R is calculable skewed effect (R=1.2 at LHC)

$$\boxed{T(Q_t, \mu) = \exp\left(- \int_{Q_t^2}^{\mu^2} \frac{dk_t^2}{k_t^2} \frac{\alpha_s}{2\pi} \int_0^{1-k_t/\mu} dz \, z P_{gg} \ldots \right)}$$

strongly suppresses Q_t infrared region

no emission when $(\lambda \sim 1/k_t) > (d \sim 1/Q_t)$
i.e. only emission with $k_t > Q_t$

Exclusive dijet production



Factor 25 Sudakov suppression

Even better descrip^{n} data→higher E_T

Odderon

Very nice review by Carlo Ewerz

The Odderon in QCD

hep-ph/0306137 (2003)

Properties of odd-signature high-energy amp studied in early 70's

Odderon first promoted in 1973 (Lukaszuk, Nicolescu) by Regge exchange for high-energy cross sections; for example pp and p$\bar{\text{p}}$

$$\boxed{A_\pm \;=\; A(pp) \;\pm\; A(p\bar{p})}$$

simple poles $\alpha_{P,O}(0) \sim 1$

$$A_+(pp) \;=\; A_+(p\bar{p}) \qquad C = +1$$

$$A_-(pp) \;=\; A_-(p\bar{p}) \qquad C = -1$$

Pomeron --- dominately imag

Odderon --- dominately real

Maximal Odderon (MO)

allowed by asymptotic theorems

$$\boxed{\begin{array}{l} \mathrm{Im} A_+ \le c\, \ln^2 s \quad (\text{Froissart}) \\ \mathrm{Re} A_- \le c'\, \ln^2 s \ (\text{MO analogy}) \end{array}}$$

1. Pomeranchuk theorem $\quad \Delta\sigma \;\equiv\; \sigma(\bar{p}p) - \sigma(pp) \;\sim\; \mathrm{Im} A_- \;\to\; 0 \qquad \text{as} \quad s \to \infty$

2. Generalized Pomeranchuk th: $\quad \dfrac{\sigma(\bar{p}p)}{\sigma(pp)} \;\to\; 1 \qquad \text{as} \quad s \to \infty$

1. Pomeranchuk theorem $\Delta\sigma \equiv \sigma(\bar{p}p) - \sigma(pp) \sim \mathrm{Im}A_- \to 0 \quad \text{as} \quad s \to \infty$

2. Generalized Pomeranchuk th: $\dfrac{\sigma(\bar{p}p)}{\sigma(pp)} \to 1 \quad \text{as} \quad s \to \infty$

$$\left.\begin{aligned} &\boxed{\text{1 and 2 are not equivalent}} \\ \sigma(\bar{p}p) &= A \ln^2 s + B \ln s + C \\ \sigma(pp) &= A \ln^2 s + B' \ln s + C' \end{aligned}\right\}$$

if $B \neq B'$ then satisfy 2, but not 1

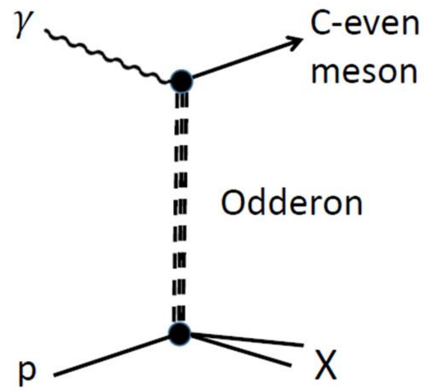
In general $\Delta\sigma \leq c \ln s$

Little evidence of Odderon from $d\Delta\sigma/dt$ in dip region at 53 GeV

Then in 1980 the Odderon is found to be a firm prediction of QCD

But no evidence of Odderon exchange from HERA data for exclusive photoprod. of C-even mesons $\gamma p \to \pi^0 p, \eta p, f_2 p$... (Nachtmann et al

Discuss evidence from LHC later.



First, explain why Maximal Odderon violates unitarity →

Why the Maximal Odderon violates unitarity

Khoze, Martin, Ryskin
arXiv: 1801.07065

1. Unitarity

$$\mathbf{SS}^\dagger = \mathrm{I} \quad (\text{let} \quad \mathbf{S} = \mathrm{I} + \mathrm{i}\mathbf{A}) \quad \to \quad \mathrm{i}(\mathbf{A}^\dagger - \mathbf{A}) \; = \; \mathbf{A}^\dagger\mathbf{A}$$

Unitarity equation

$$2\,\mathrm{Im}A_{\rm el}(b) \;=\; \sum_n |A_{i\to n}(b)|^2 \;=\; |A_{\rm el}(b)|^2 \;+\; G_{\rm inel}(b)$$

$$\text{where} \quad G_{\rm inel}(b) \;=\; \sum_{n\neq i} |A_{i\to n}(b)|^2 \;<1 \quad = \; \text{probability of inelastic scatt.}$$

Solution of unitarity eq.

$$A(b) \;\equiv\; A_{\rm el}(b) \;=\; i(1-e^{-\Omega(b)/2}) \quad \text{with} \quad \mathrm{Re}\Omega(b) \geq \; 0$$

No solution of unitarity eq. if $G_{\rm inel}(b) > 1.$

Let us calculate $G_{\rm inel}(b)$

exp(2iδ_l) in terms of partial waves l = b√s/2

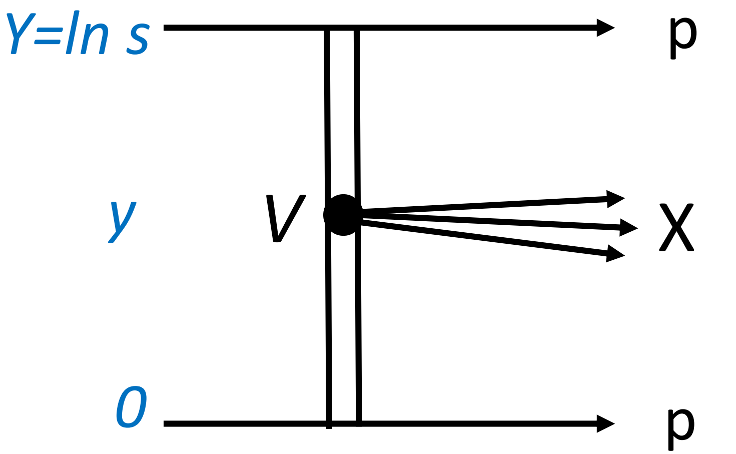
2. Finkelstein-Kajantie problem: $\sigma(\text{diff}^{ve}) > \sigma(\text{total})$ due to $\int_0^{\ln s} dy\ldots \sim \ln s$

Simple example: Central Exclusive Prod. pp → p+X+p

In the Froissart limit $\sigma_{\text{CEP}} \sim ln^5 s$

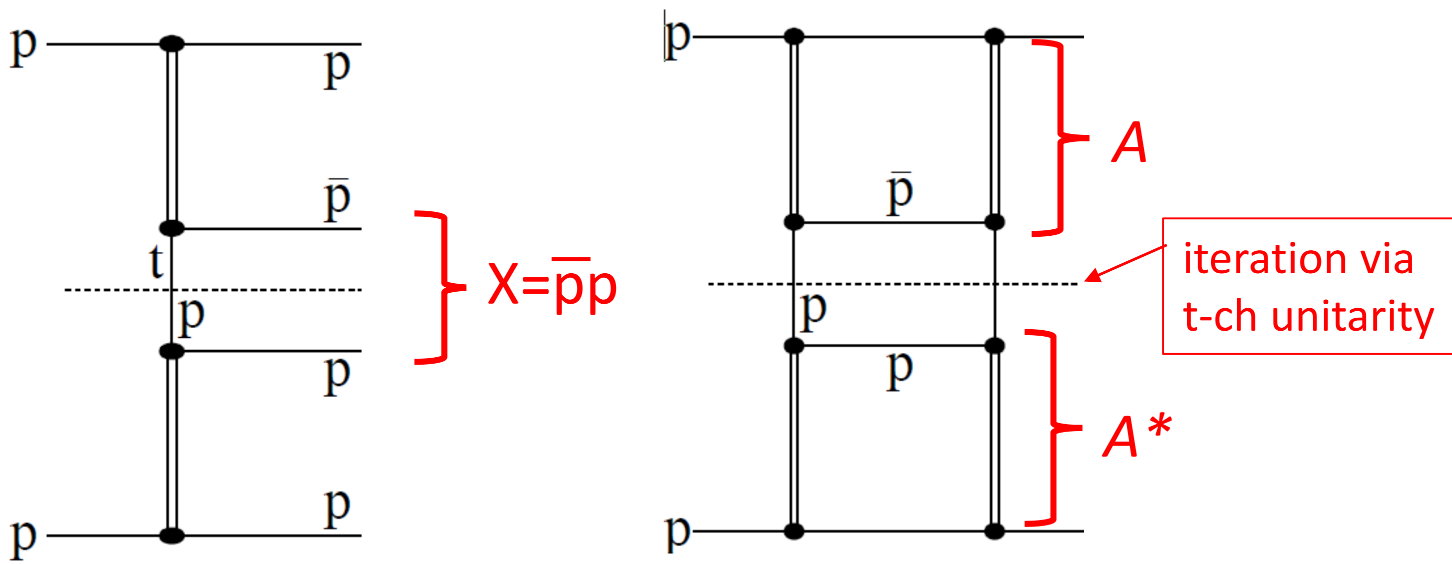
so $\sigma_{\text{CEP}} > \sigma_{\text{tot}} \sim ln^2 s$

Could the explanation be that vertex $V = 0$? **No**



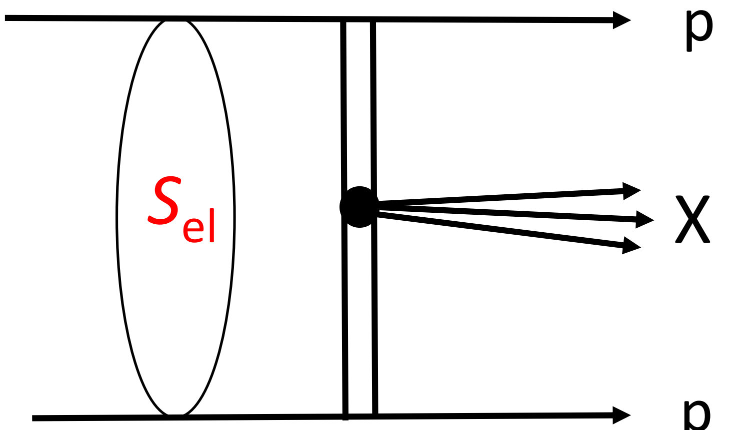
Can show, for example, that the $p\bar{p}$ component of X generated by t-channel unitarity has $V \neq 0$, and cannot be compensated due to the singularity/pole at $t=m_p^2$.

So starting from A_{el} we see t-ch unitarity gives a component of $G_{inel}(b)$ increasing faster than $\int_0^{\ln s} dy.. \sim \ln s$



Figs: amplitude (left) and cross section (right) of $\bar{p}p$ Central Exclusive Prod. generated by t-ch unitarity

3. Solution to the Finkelstein-Kajantie problem



Complete CEP must include rescattering S_{el} (that is the survival probability $S^2 = |S_{el}|^2$ of the rapidity gaps)

$$A_{CEP}(b) = S_{el}(b)\, A_{bare}(b)$$

$$\text{where} \quad |S_{\rm el}(b)|^2 \;=\; |1+iA_{\rm el}(b)|^2 \;=\; e^{-{\rm Re}\Omega(b)}$$

Black disc asymptotics: $\quad {\rm Re}\Omega \to \infty, \;\; A_{\rm el}(b) \to i, \quad \boldsymbol{S^2(b) \to 0 \text{ for } b < R}$

If $\sigma_{\rm tot}$ increases, Black disc is the only known solution to the FK problem

To repeat, if at least one component of $G_{\rm inel}(b)$ increases (due to $\int dy \sim \ln s$) then unitarity is violated as $s \to \infty$. The only way to restore unitarity is to have $S(b) \to 0$

4. Maximal Odderon contradicts unitarity as s →∞

Maximal Odderon

Asymptotially MO means $\mathbf{Re}A/\mathbf{Im}A \to$ constant $\neq 0$

In this case $\quad S^2(b) \;=\; |1+iA(b)|^2 \;\geq\; |{\rm Re}A(b)|^2 \;\neq 0$

so there is no possibility to compensate the growth of $\sigma_{\rm CEP}$.

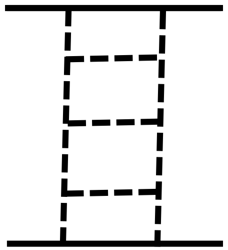
The Odderon exists in QCD

Need the existence of symmetric tensor d_{abc} of non-Abelian $SU(3)_{col}$ to form colourless ggg exchange with C=-1

Pomeron (gg)

Odderon (ggg)

BFKL eq.

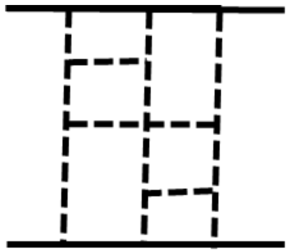


resum

$\alpha_P(0) > 1$

BKP eq.

Bartels; Kwiecinski, Praszalowicz 1980



resum

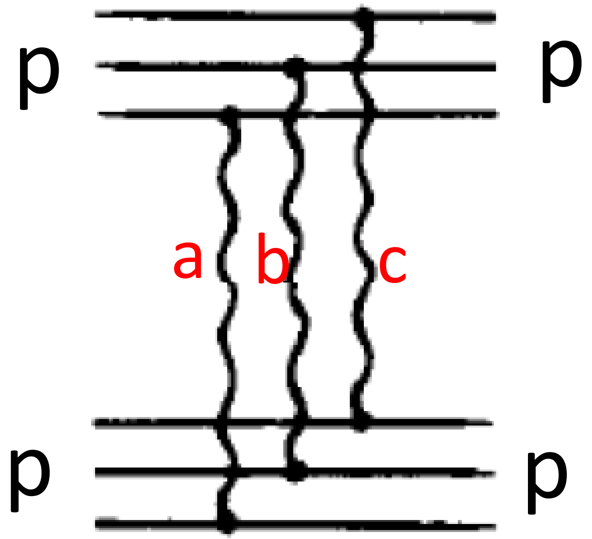
$\alpha_O(0) \approx 1$

Janik-Wosiek solution

Bartels-Lipatov-Vacca solution, 2000

Estimate of Odderon contrib^n

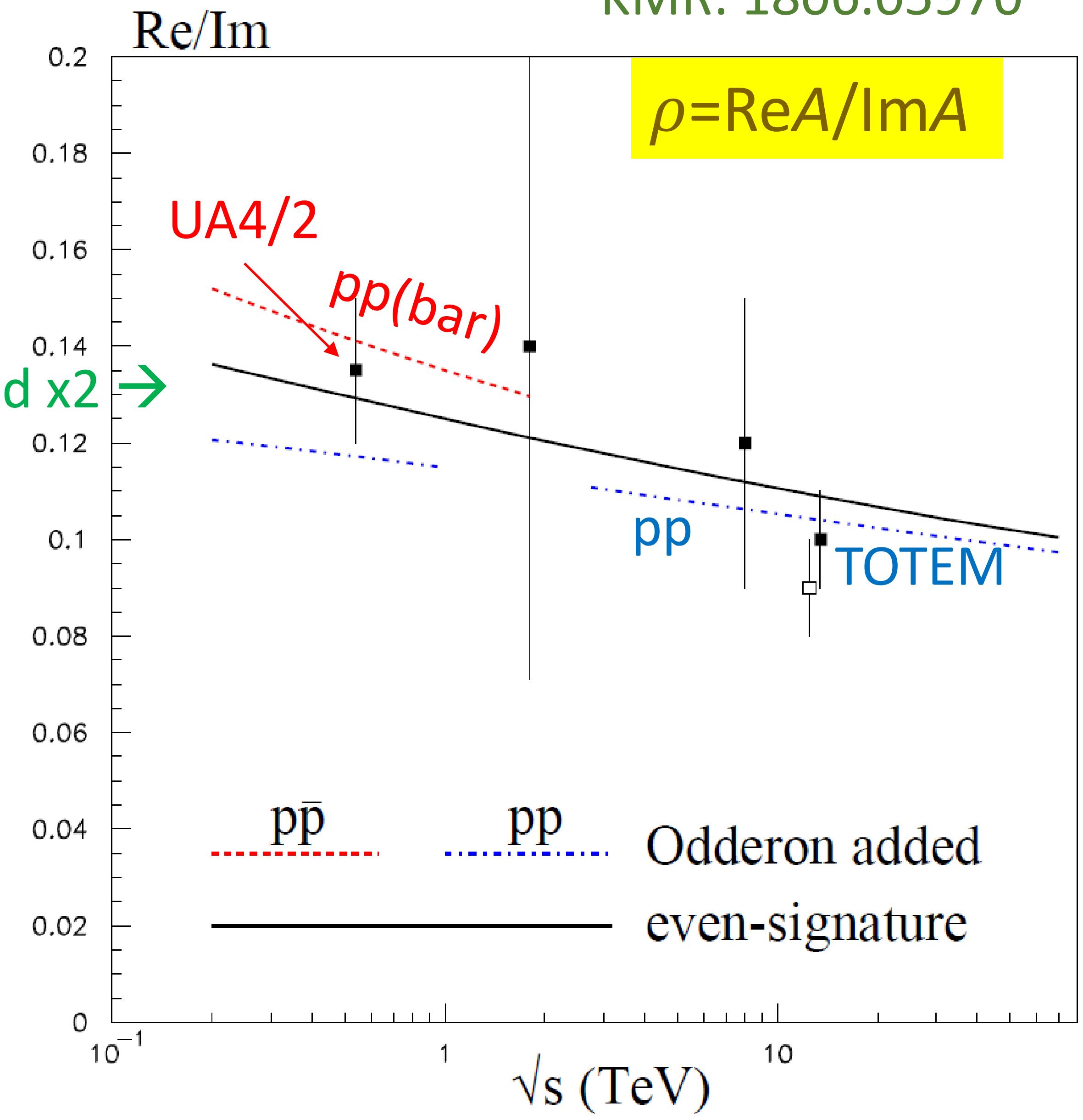
QCD lowest α_s order Ryskin '87
(Fukugita, Kwiecinski '79;
Kwiecinski,Motyka..'96 (η_c at HERA))



x d_{abc}

KMR: 1806.05970

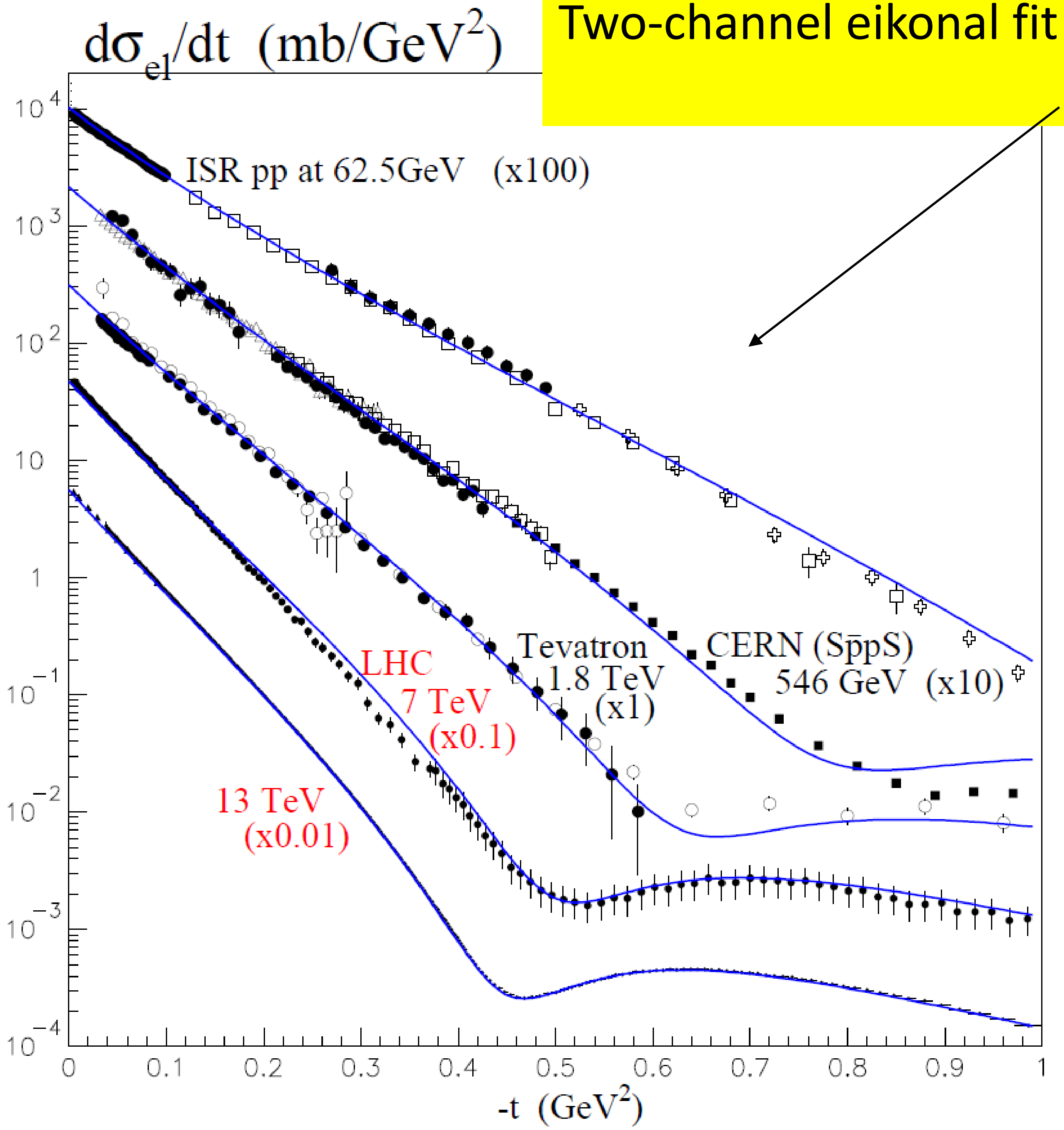
enhanced x2 →



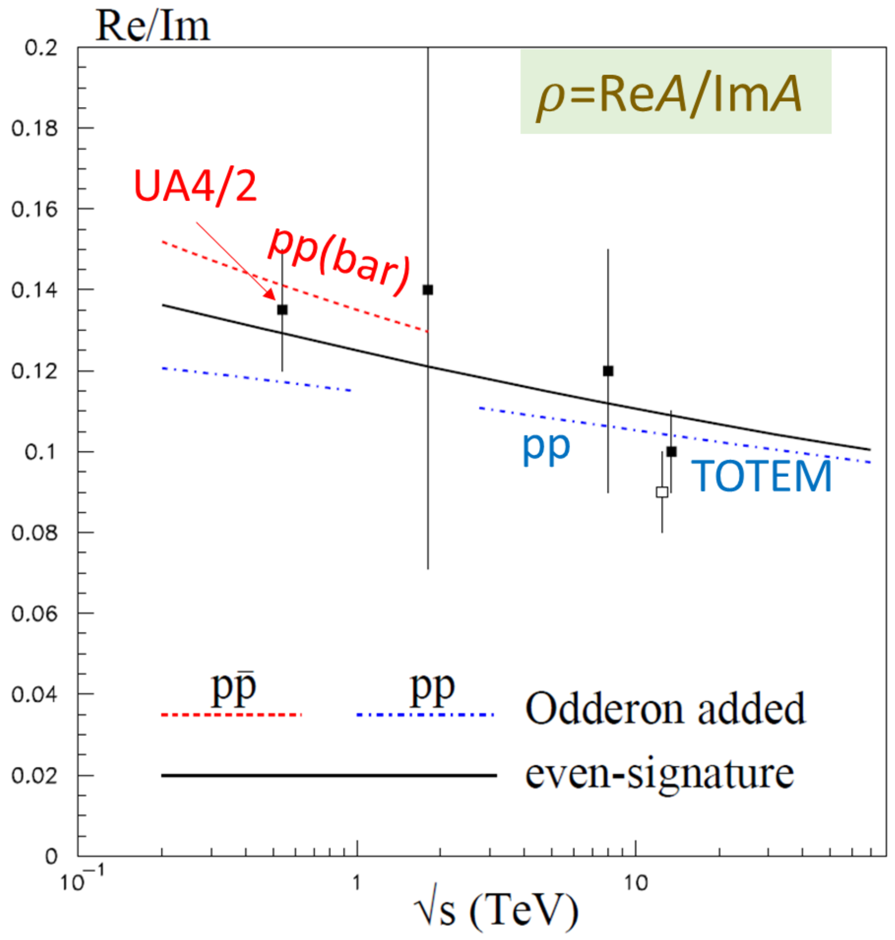
Two-channel eikonal fit to high-energy pp scatt. data

$d\sigma_{el}/dt$, σ_{tot}, $\sigma_{\text{low mass Diffraction}}$

crucial data



Gives acceptable fit to ReA/ImA without an Odderon



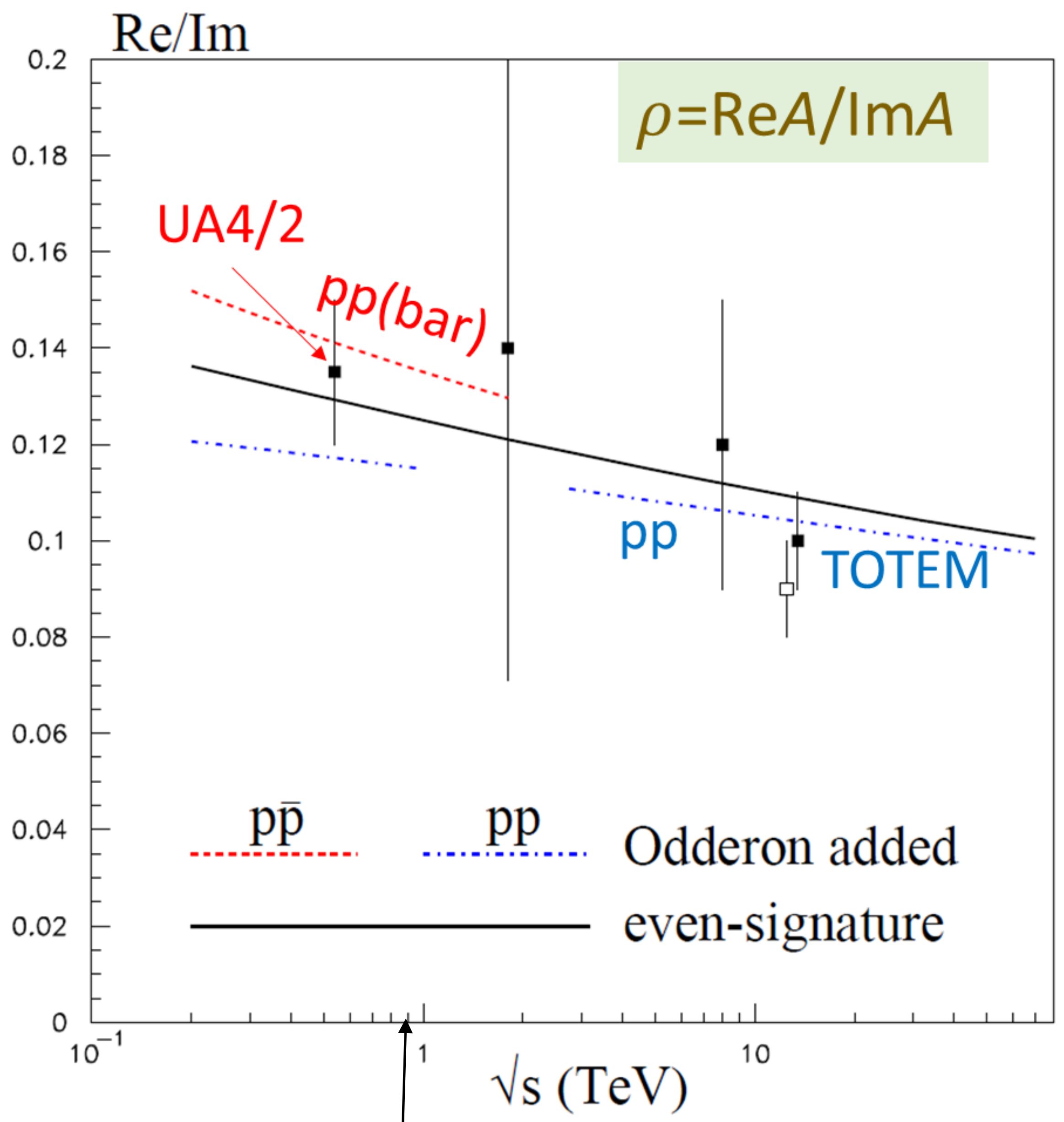
Including the Odderon gives only a marginal improvement

Must include full Ω in amplitude

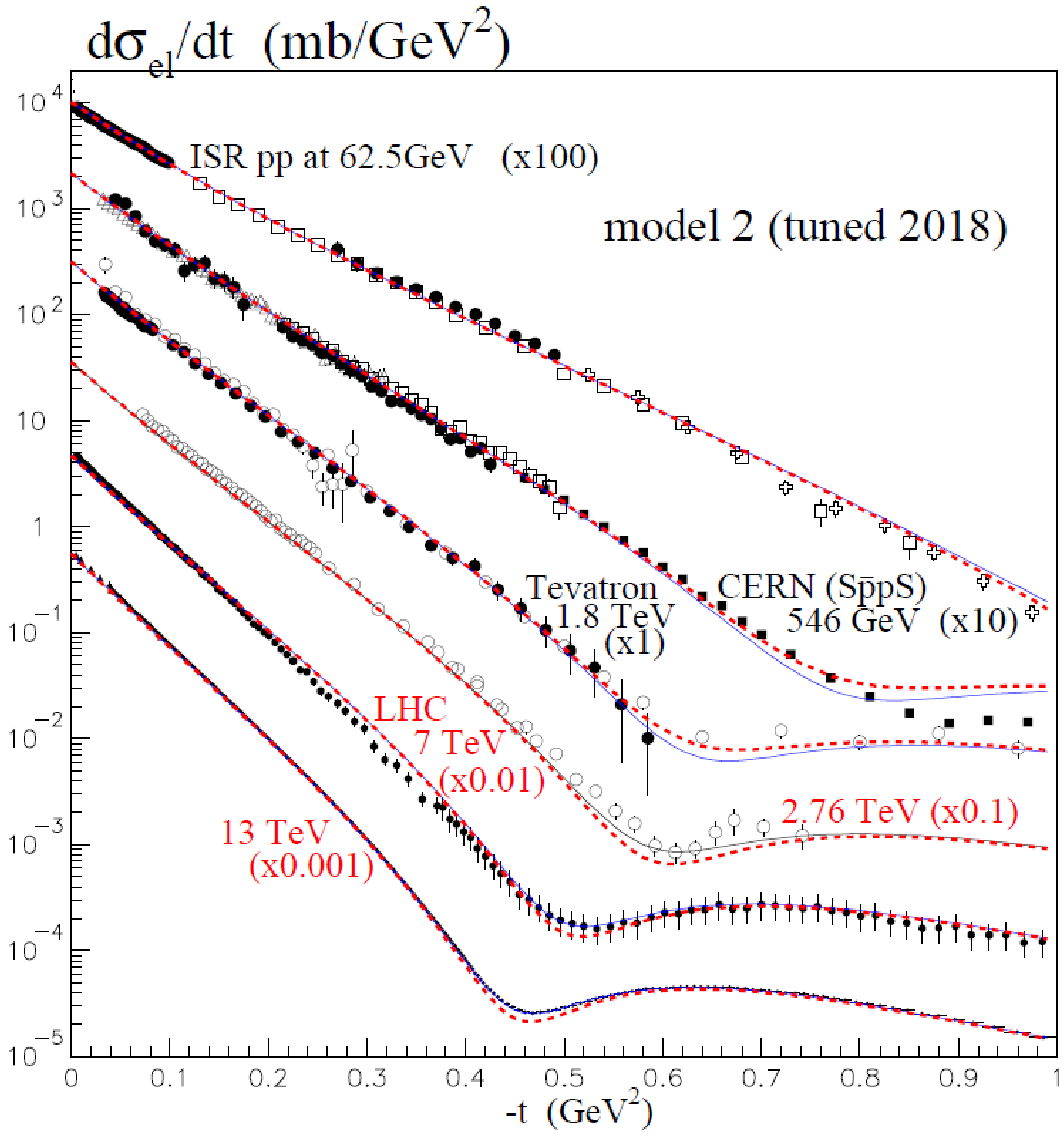
$$A(b) \;=\; i\left(1 - e^{-\Omega(b)/2}\right)$$

with $\quad \Omega \;=\; \Omega_{\rm even} + \Omega_{\rm odd}$

Automatically accounts for absorptive effect caused by elastic rescattering



TOTEM measurement 0.9 TeV could be informative?



Previous fit, but now red-dotted curves show the effect of the Odderon fixed to agree with ρ=Re*A*/Im*A*

Note Odderon increases pp(bar)

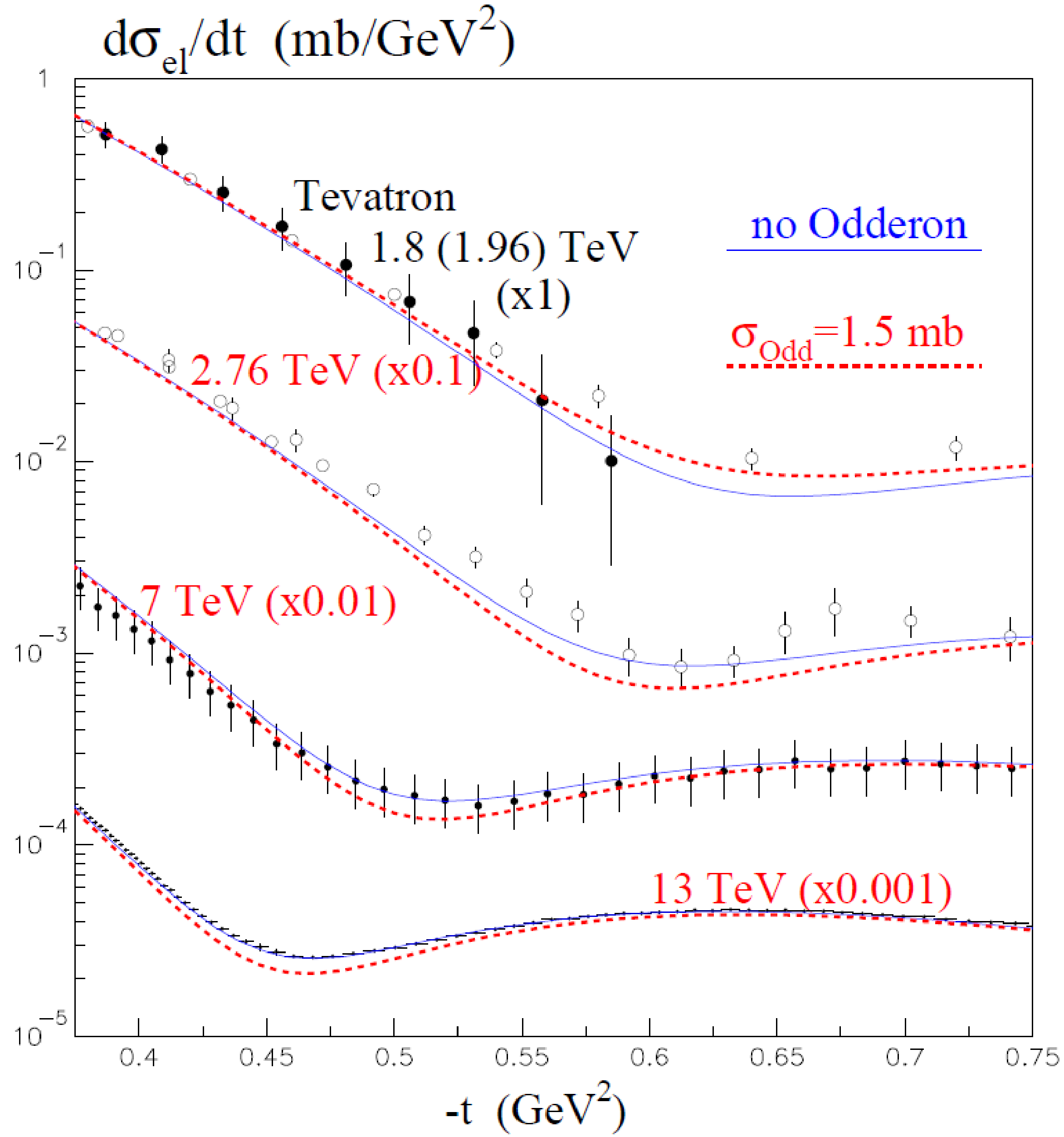
decreases pp

Main effect in dip region

New TOTEM data at 2.76 TeV

Dip region

No conclusive evidence for a larger Odderon



pp(bar)

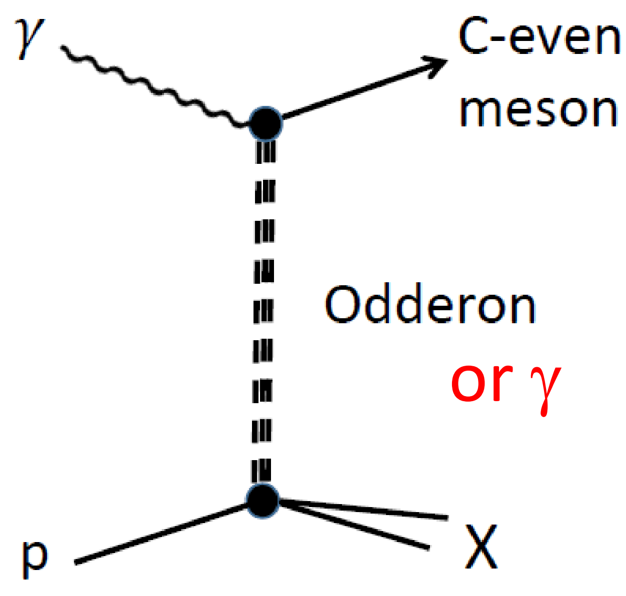
pp

pp

pp

Odderon signals

- pp scatt Odderon exch. is a small correction to even-signature term $(g_{pO})^2$
- photoproduction of C even mesons π^0, f_2, η ...



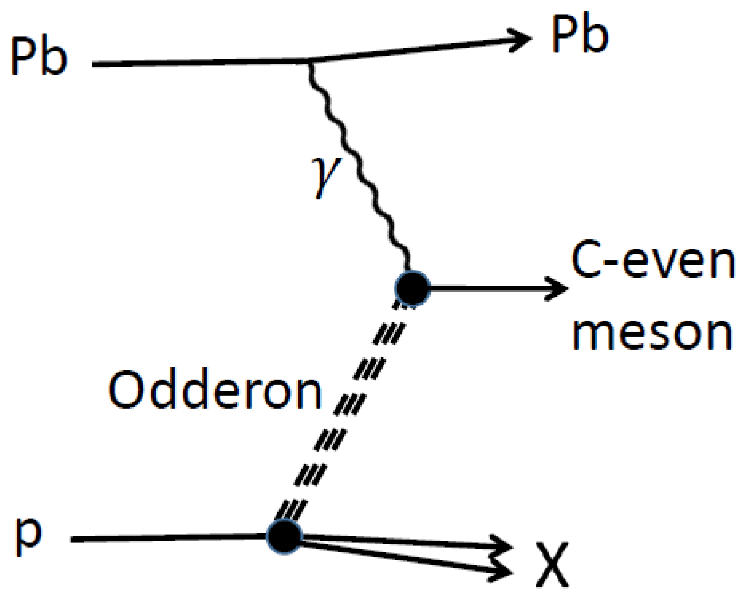
No evidence in HERA data

upper limits $\sigma(\pi^0)$=39nb, $\sigma(f_2)$=16nb

Need to suppress back^{gd} due to γ exchange

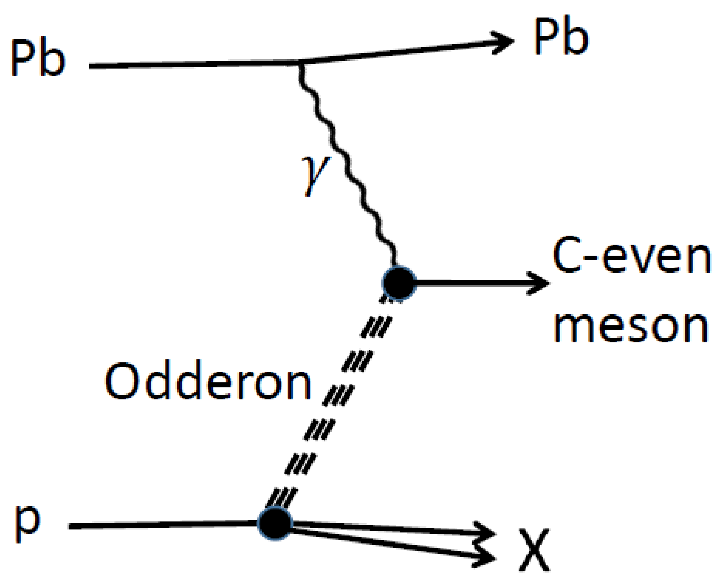
- ultraperipheral production in p-Pb collisions

Z^2 in photon flux



Odderon signal in p-Pb collisions?

$d\sigma/dy_M\|_{y_M=0}$	Expected upper limits [μb]
π^0	7.4
η	3.4
$f_2(1270)$	3.0

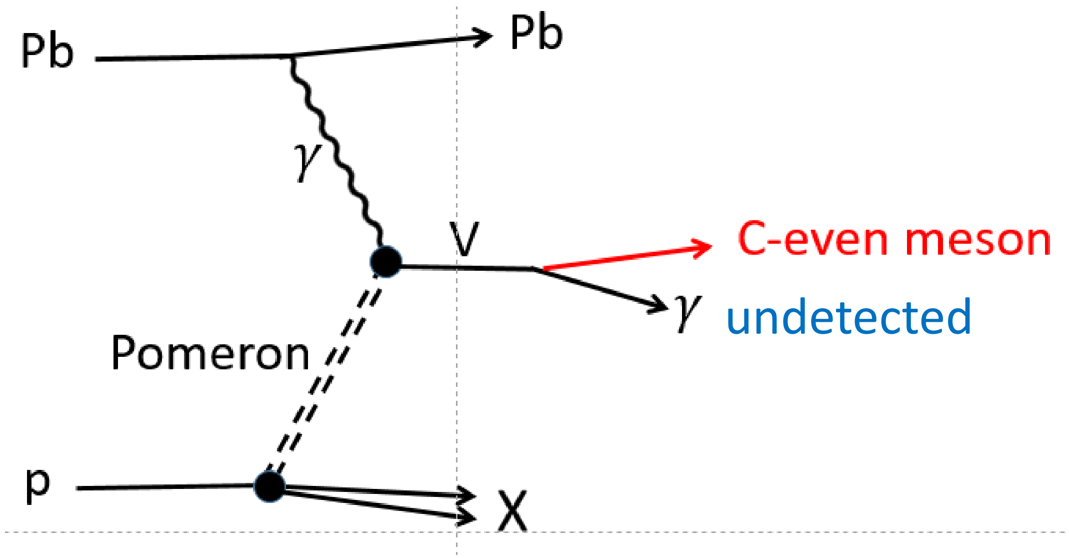


Healthy signal,
but backgrounds
are due to

production of C-even meson by

1. $\gamma\gamma$ fusion
2. Pomeron-Pomeron fusion
3. Via vector meson

   V → C-even meson + undetected γ

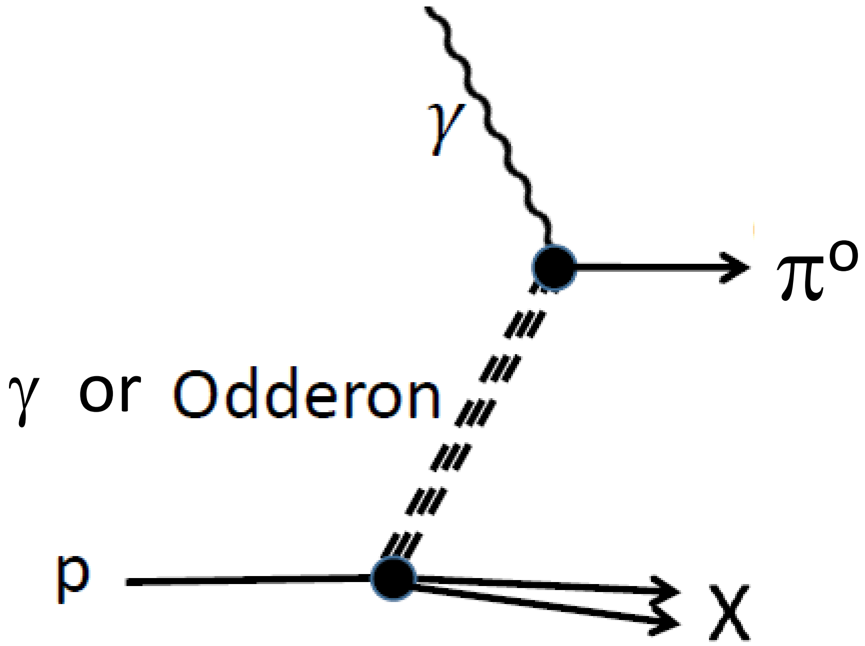


π^0

$\sigma(\pi^0)$ from $\gamma\gamma$ fusion is well known.
Estimwating the cross section due to Odderon exchange, allowing for the colour factors etc. and integrating over $0.04<|t|<1\ \mathrm{GeV}^2$ we find

$$\sigma_{Odd}(\gamma p \rightarrow \pi^0+X) \sim 5(1)\ \mathrm{nb}$$

for the cutoff $\mu = 0.3(0.5)$ GeV.
The t cut adequately suppresses the $\gamma\gamma$ fusion background.

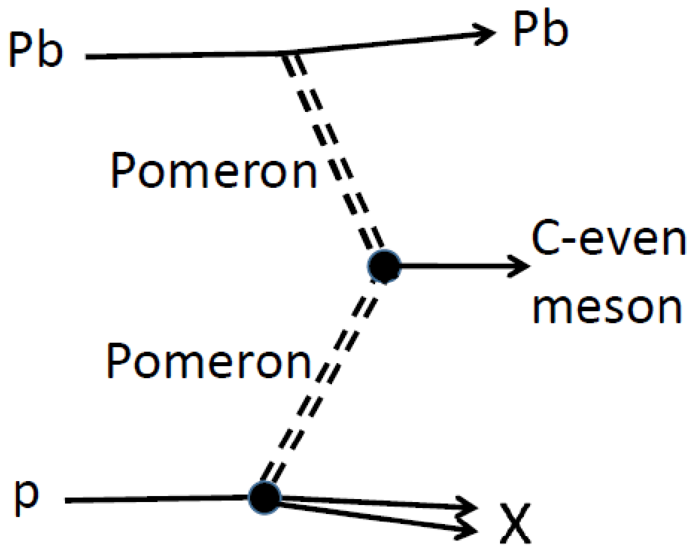


Pomeron-Pomeron background entirely absent by SU(3) flavour

However the reducible background from radiative ω decay is very large

$\omega \rightarrow \pi^0 + \gamma$ (undetected)

f_2



There is a very low backround due to radiative V decay. However the problem here is the v.large Pomeron-Pomeron background. The signal-to-bkgd may be suppressed by observing central (semi)exclusive production (CEP*) of C-even mesons in which the proton may break up but the Pb-ion remains intact. For such events we expect a larger possibility of break-up for Odderon exchange --- exptally challenging.

In any nucleon-proton interaction creating the C-even meson there is a large probability of inelastic nucleon-proton interactions which will populate the rapidity gaps. Only in very peripheral ion-proton collisions is there a chance to observe a CEP* event.

Can show the A dependence of CEP* events scales as $A^{1/3}$. Recall the photoprod^n cross section (the signal) scales as Z^2, so the expected $A^{1/3}$ backg^{d} scaling is much milder.

η

Pom-Pom background is small as η has small SU(3) singlet compt. However again the reducible backgrounds coming from $\phi \rightarrow \eta\gamma$ and $\eta' \rightarrow \eta\pi^0\pi^0$ are rather large

η_c

In principle, viable channel but has a much smaller production rate.

C-even meson (M)	Odderon Signal		Backgrounds		
	Upper Limit	QCD Prediction	$\gamma\gamma$	Pomeron-Pomeron	$V \to M + \gamma$
π^0	7.4	0.1 - 1	0.044	–	30
$f_2(1270)$	3	0.05 - 0.5	0.020	3 - 4.5	0.02
$\eta(548)$	3.4	0.05 - 0.5	0.042	negligible	3 $\phi \rightarrow \eta\gamma$
η_c	–	$(0.1 - 0.5) \cdot 10^{-3}$	0.0025	$\sim 10^{-5}$	0.012

0.05 included

signal and background for dσ(Pb p → Pb + *M* +X)/dY at Y=0

$d\sigma/dY_M$ at $Y_M = 0$ in μb

C-even meson (M)	Odderon Signal		Backgrounds		
	Upper Limit	QCD Prediction	$\gamma\gamma$	Pomeron-Pomeron	$V \to M + \gamma$
π^0	7.4	0.1 - 1	0.044	–	30 ($\omega \to \pi^0\gamma$)
$f_2(1270)$	3	0.05 - 0.5	0.020	3 - 4.5	0.02 ($J/\psi \to f_2\gamma$)
$\eta(548)$	3.4	0.05 - 0.5	0.042	negligible	3 ($\phi \to \eta\gamma$)
η_c	–	$(0.1 - 0.5) \cdot 10^{-3}$	0.0025	$\sim 10^{-5}$	0.012 ($J/\psi \to \eta_c\gamma$)

γ unobserved

η_c x 0.05 for observable BR included

p p → p + *M* + X Pom – Pom background overwhelming
Pb Pb → Pb + *M* + Pb γγ background overwhelming

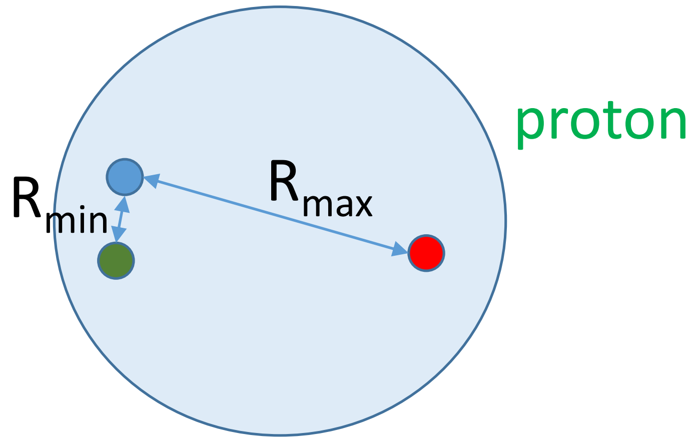
Ronan McNulty: Pb-Pb data could check model for Pom-Pom bkgd for f_2; BR($f_2 \to \gamma\gamma$)~10^{-5}

Conclusions

CEP survival factors calculable but depend on kinematics

Theoretically the Odderon exists (pQCD), but the amplitude is small in comparison with the Pomeron

$$A_{Odd} \sim \alpha_s^3 R_{min}^2$$
$$A_{Pom} \sim \alpha_s^2 R_{max}^2$$



Experimentally the Odderon is elusive, but with experimental ingenuity and precision it stands a good chance of being cornered

Use HERA data to predict diffractive dijet production at Tevatron

$$\sigma = \mathrm{PDF}_{\mathrm{proton}}(x_1) \otimes |M|^2 \otimes \mathrm{PDF}_{\mathrm{pomeron}}(x_2)$$

factor ~ 10 too big