High-energy pp interactions from “hard” to “soft”

- “QCD” Pomeron ~ parton cascade ~ small transverse size
- It is natural object to extend into soft domain
- importance of eikonal & enhanced multi-Pomeron contrib^{ns}
- probes of this formalism for multiparticle prod. at LHC
  -- Bose-Einstein correlations
  -- minjets & correlations
  -- large rap gaps
- ridge effect

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Low x meeting, June 2011,
Santiago de Compostela, Spain

High-energy pp interactions

soft

hard

Reggeon Field Theory
with phenomenological
soft Pomeron

pQCD
partonic approach

smooth transition using
QCD / “BFKL” / hard Pomeron

There exists only one Pomeron, which makes
a smooth transition from the hard to the soft regime

see KMR “global” description of soft and semi-hard data and PDFs in terms of pQCD Pomeron EPJ **C71** (2011)
This is a partonic approach which includes the k_t dependence of the Pomeron in the ln(1/x) evolution/cascade, as well as eikonal & enhanced multi-Pomeron absorptive effects.

“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}, $d\sigma_{el}/dt$ data, described, in a limited energy range, by eff. pole $\alpha_P^{eff} = 1.08 + 0.25t$

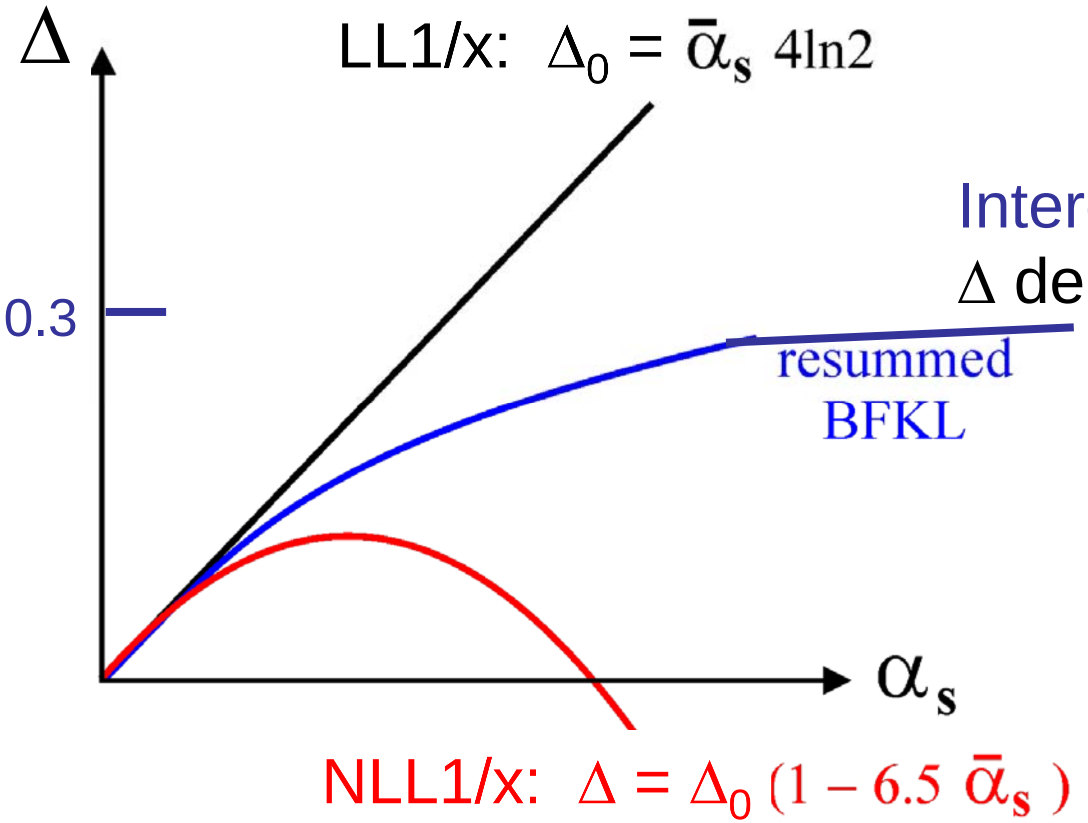
Sum of ladders of Reggeized gluons with, in LLx BFKL, a singularity which is a cut and not a pole. When HO are included the intercept of the BFKL/hard Pomeron is $\alpha_P^{bare}(0) \sim 1.3$

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

$\alpha_P^{eff} \sim 1.08 + 0.25\ t$ up to Tevatron energies $\leftarrow$ $\alpha_P^{bare} \sim 1.3 + 0\ t$ with absorptive (multi-Pomeron) effects

BFKL stabilized

Ciafaloni, Colferai and Salam

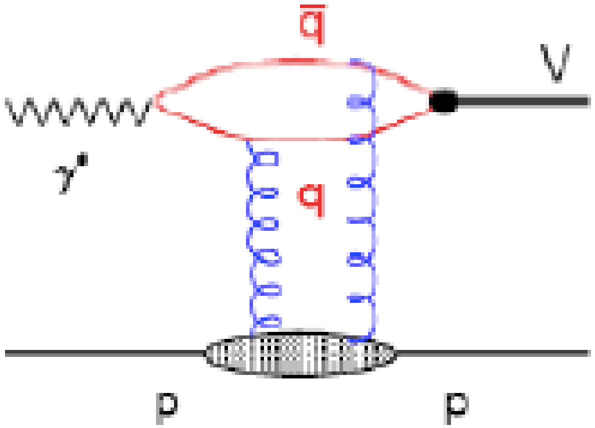


Intercept $\Delta = \alpha_P(0) - 1 \sim 0.3$

Δ depends weakly on k_t for low k_t

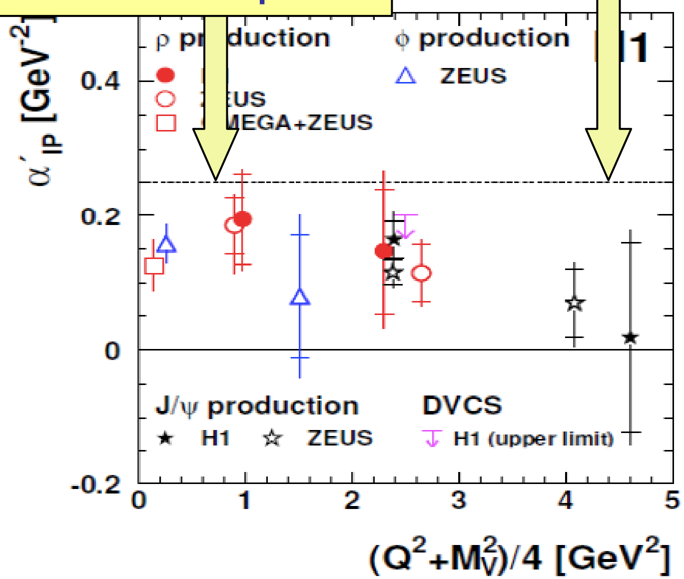
Small-size "BFKL" Pomeron is natural object to continue from "hard" to "soft" domain

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

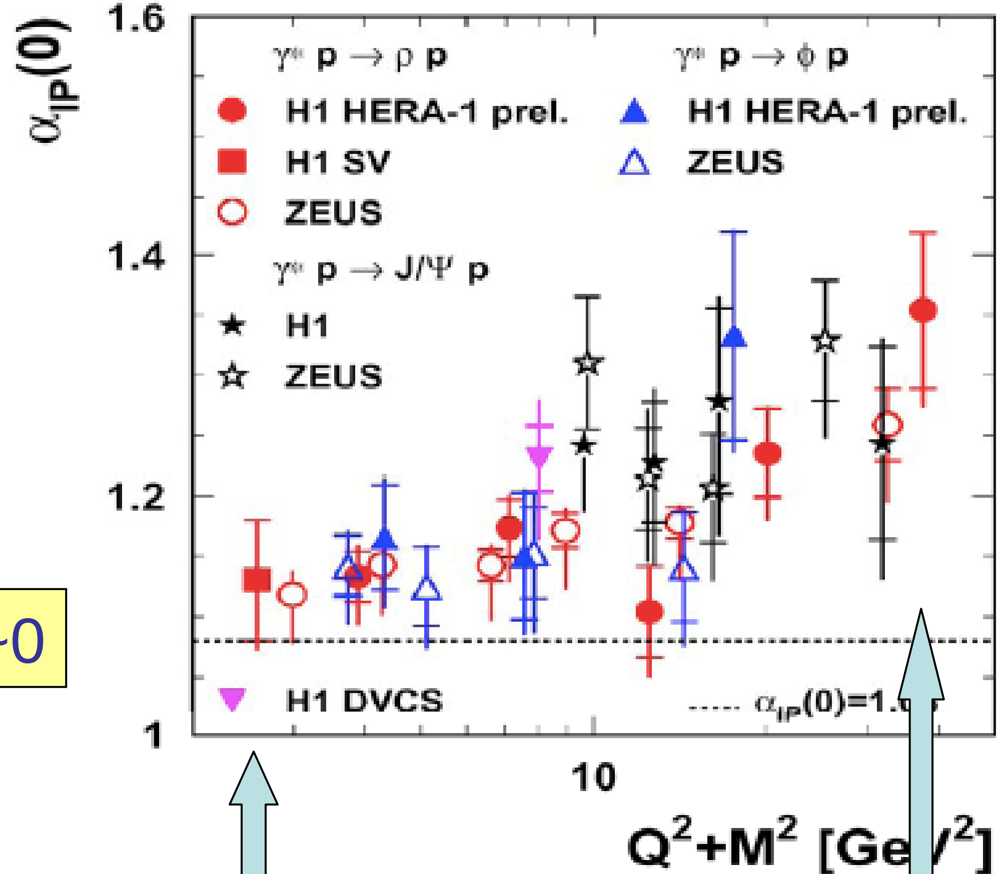


$\alpha'_P(0) \sim 0.25$
after absorption

$\alpha'^{bare}_P(0) \sim 0$



hard energy dependences

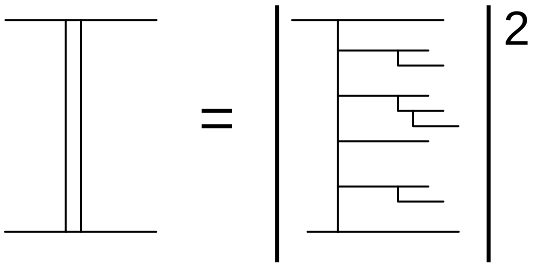


$\alpha_P(0) \sim 1.1$
after absorption

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

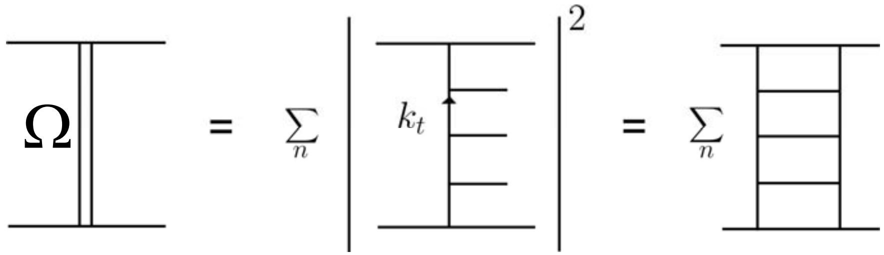
Phenomeno$^{\text{logical}}$ hints that $R_{\text{bare Pom}} \ll R_{\text{proton}}$

small slope $\alpha'_{\text{bare}} \sim 0$
success of Additive QM
small size of triple-Pomeron vertex
small size of BEC at low N_{ch}



Pomeron is a parton cascade which develops in ln(1/x) space, and which is not strongly ordered in k_t.
However, above evidence indicates the cascade is compact in b space and so the parton k_t's are not too low. We may regard the cascade as a hot spot inside the two colliding protons

bare QCD
Pomeron



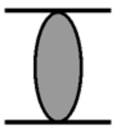
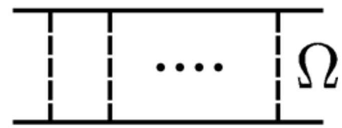
$s^{\Delta} \sim s^{0.3}$

growth of cascades with s → multi-Pomeron effects/absorption

Elastic & low-mass dissoc^{n}

eikonal

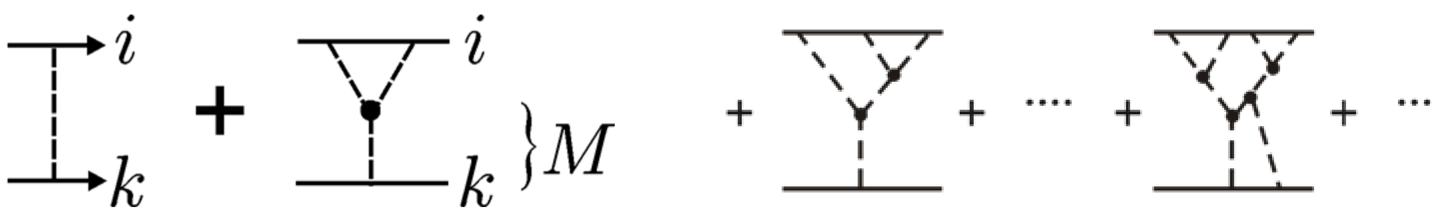
$\sigma_{tot} \sim s^{0.08}$
up toTevatron energies

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

(s-ch unitarity)

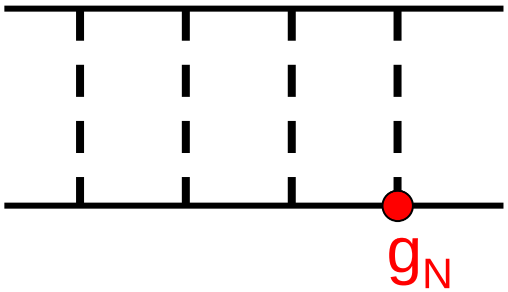
include high-mass diffractive dissoc^{n}

enhanced

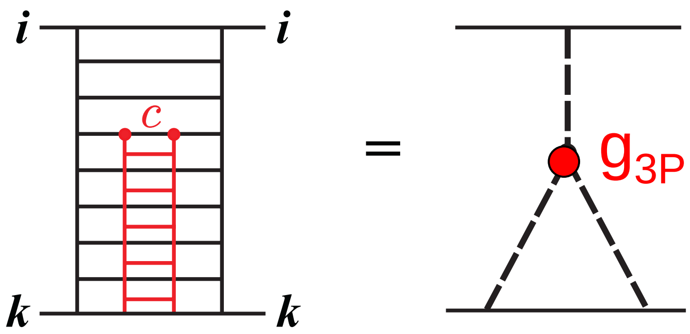
$\Omega_{ik} =$ 

Multi-Pomeron contributions

eikonal: Pomerons well separated in b-plane



enhanced: interactions with partons in an individual cascade



despite $g_{3P} \sim 0.2\ g_N$, enhanced by phase space, which grows with s

LHC

DGLAP ln k_t^2 evol^n interval << BFKL ln(1/x) evol^n interval

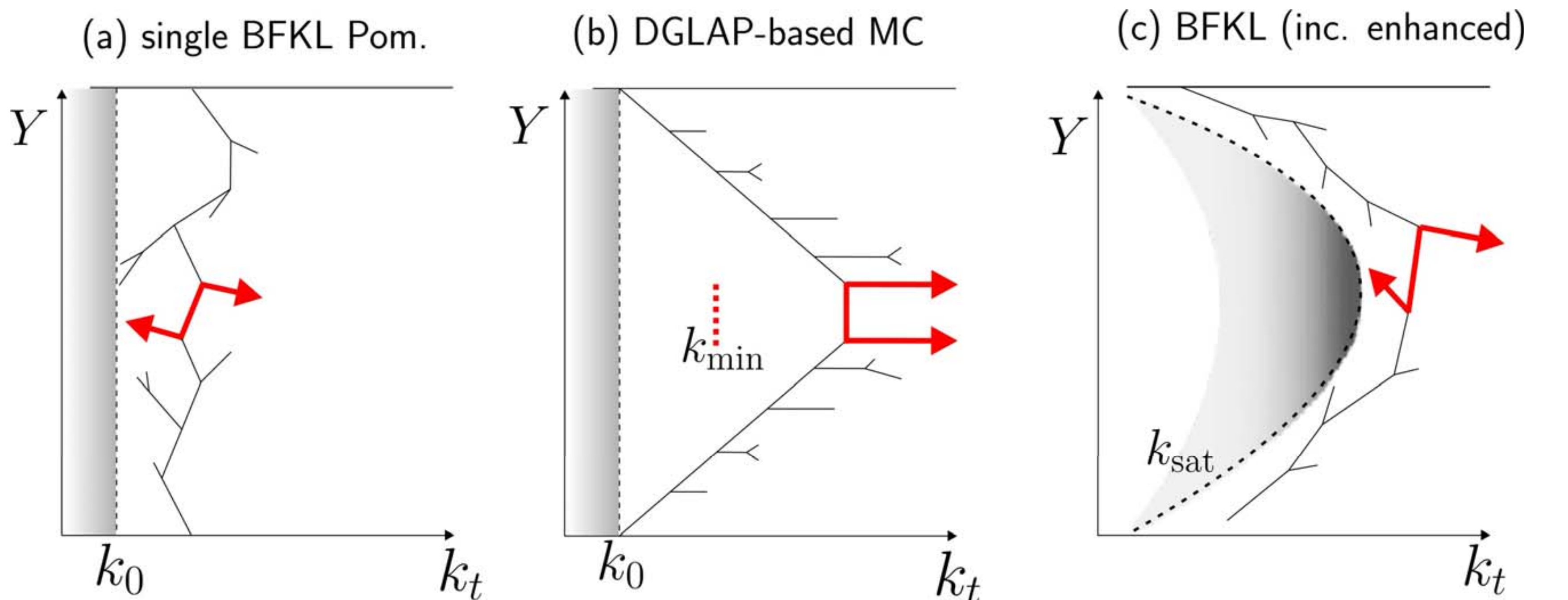
overestimates $<k_t>$

underestimates growth $dN/d\eta$

not strongly-ordered in k_t

$dN/d\eta = n_P \, (dN_{1\text{-}Pom}/d\eta)$

n_P=no. of Poms. grows



$d\sigma_{subp}/dk_t^2 \sim 1/k_t^4$

→tune cutoff to data

$k_{min} \sim s^a$, a=0.12

Enh: $\sigma_{abs} \sim 1/k_t^2$

→dyn.cutoff k_{sat}

→besides SD, DD

Main ingredients of formalism:

multi-Pomeron contributions arising from eikonal diagrams

that is the presence of hot spots

multi-Pomeron contributions arising from enhanced diagrams

which give absorption of low k_t partons and introduce an effective cutoff k_{sat}, which increases with energy

the presence of minijets

due to cutoff, $k_t > k_{sat}$, the main inelastic process is minijet production

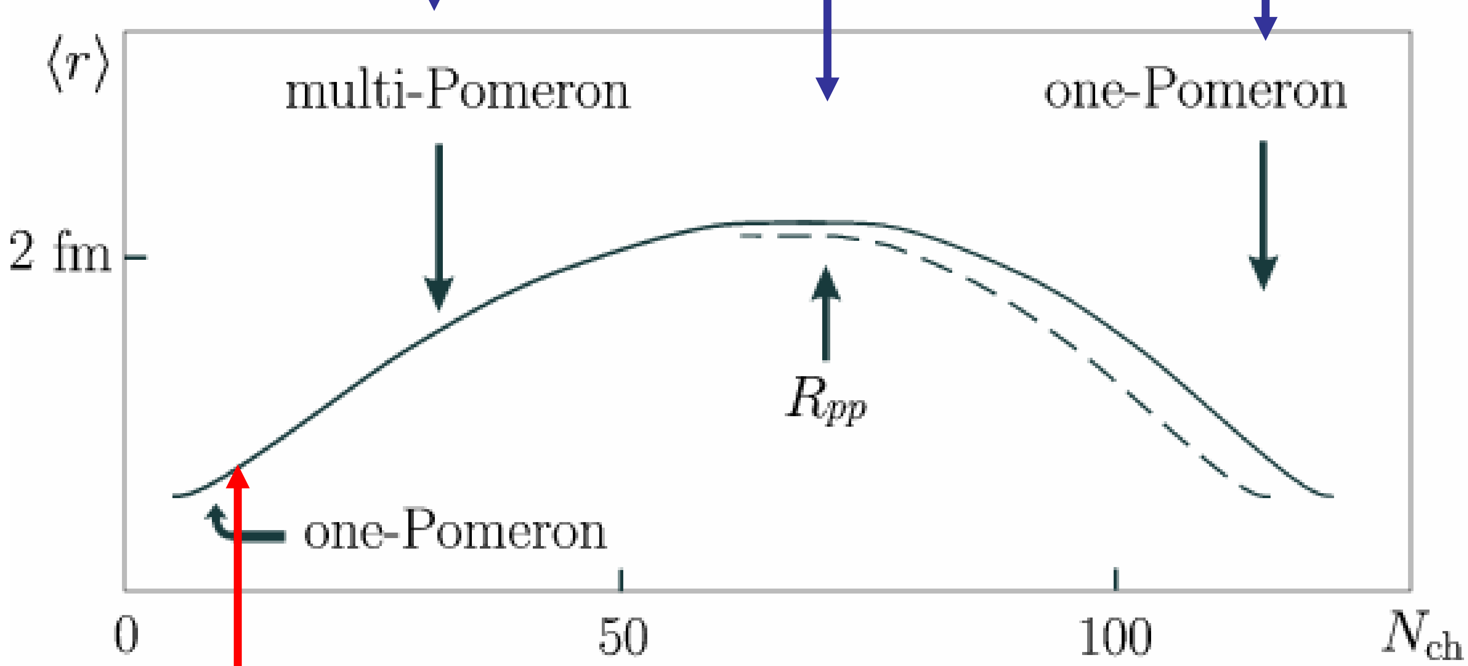
Probe of hot spots → Bose-Einstein correlations

identical pion correlations measure size of their emission region

dist. between Pomerons

saturates at $R_{pp} \sim B_{el}(s)^{1/2}$

large N_{ch} from high-E_T process from one ladder



size indep. of s—Pom. universal, but $r > R_{Pom}$ due to hadroniz^n

bkgd due to pions from resonances
-- reduced for pions of larger k_t

The LHC offers a wealth of opportunities to study of BEC with different kinematics:

Measure <r> for pions with $\eta>1$ for high N_{ch} with $\eta<-1$

<r> for events with a high E_T jet (or high p_t hadron)

<r> for events with large rapidity gap

<r> as a function of rapidity and/or p_t of pion pair

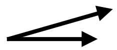
<r> for identical kaons (K_S^0)

Probe of enhanced diagrams via minijets and correlations

Minijets with $p_t > k_{sat}$ are main source of secondaries.
Difficult to see minijets at LHC, but can be revealed by two-particle correlations:

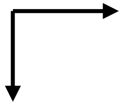
$$R_2(p_1, p_2) = \frac{d^2N/d^3p_1 d^3p_2}{(dN/d^3p_1)\ (dN/d^3p_2)} - 1$$

Correlations due minijet production



strong peak in $R_2 > 0$ of small width $\delta\eta = |\eta 1 - \eta 2| \sim 1$

weaker peak in $R_2 > 0$ of larger width $\delta\eta \sim 2\text{-}3$
from balancing minijets

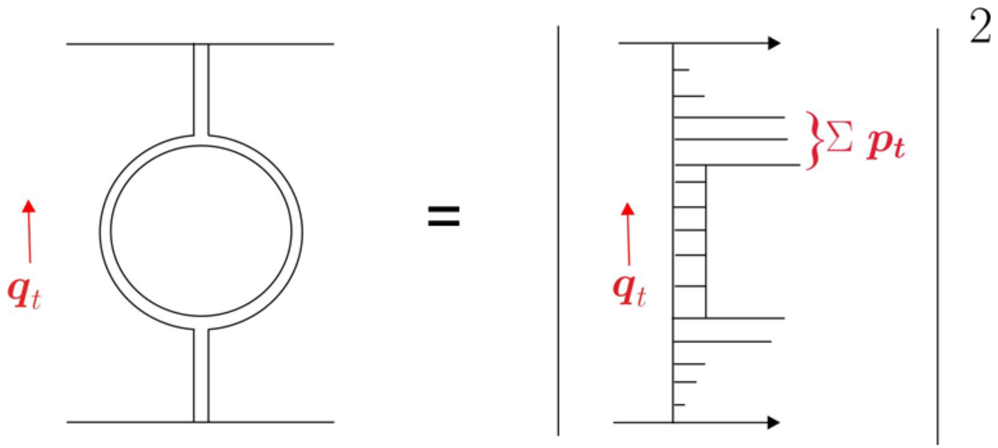


almost nothing

Resonance bkgd --- nothing in back-to-back
--- weaker at larger p_t

Probe of multi-Pomeron vertex via high-mass double-dissoc^n

size of triple-Pomeron vertex is small, get large <p_t> of secondaries near edge of LRG



Contrary to SD, where qt across gap limited by proton ff, for DD, q_t is controlled by small size of 3-P vertex and can be large. Large $\Sigma p_t \sim q_t$ would confirm small 3-P size

Ridge effect – "long-range near-side angular correlations"

CMS:

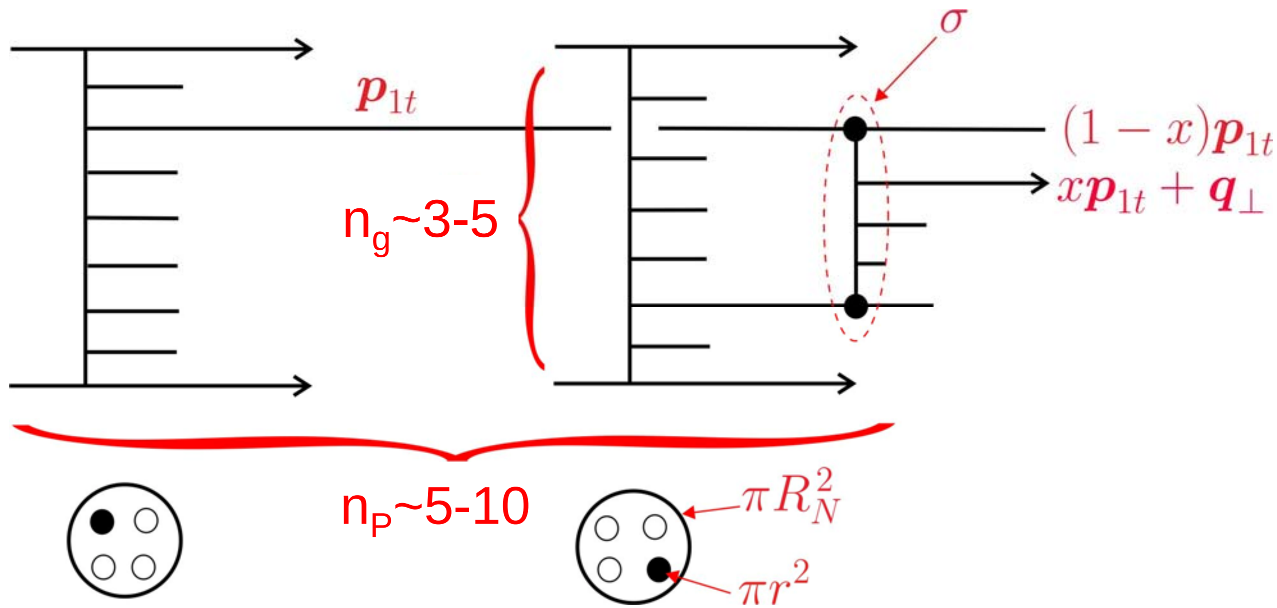
$$R = (\langle N_{\mathrm{ch}} \rangle - 1)\left(\frac{d^2 N^{\mathrm{signal}}/d^2p_1 d^2p_2}{d^2 N^{\mathrm{mixed}}/d^2p_1 d^2p_2} - 1 \right).$$

for N_{ch}>110 & p_t=1-3 GeV, R has peak at $\Delta\varphi$=0 of height ΔR~1-2 in a wide region of $\Delta\eta$

The relatively large p_t → comes from minijet
The large N_{ch} → large number, n_P, of Pomerons

Many studies – ridge due to additional interaction -- either formulated by hydrodynamic expansion or Pomeron ladders

Below we give a semi-quantitative estimate to show that the correlation, due to additional inter^n with relatively high-E_T minijet, is sufficient to give the observed ridge.



alignment x~exp(-$\Delta\eta$)~0.1-0.2

Prob. of secondary inter^n
$w = \sigma/\pi R_p^2 \sim 0.02 - 0.05$

$$R \sim (\langle N_{ch}\rangle - 1)\, x\, n_{parton}\, w$$

$n_{parton} = n_P n_g$ ~10-50

$\Delta R > 2$

AA collisions enhanced by $(A^{1/3})^2$ ~ 35 for Pb-Pb collisions

Conclusions

Soft and semihard high-energy pp interactions described by small-size QCD Pomeron (~parton cascade)

Multi-Pomeron contributions essential

(i) eikonal: needed to satisfy s-ch unitarity

(ii) enhanced: provides dynamical k_t cutoff in cascade, as well as describing high-mass SD, DD

Model, tuned to describe soft high-energy pp data, can

(i) predict rapidity gap survival probabilities

(ii) predict PDFs and diffractive PDFs at lowish scales

(iii) form basis of Monte Carlo for soft & hard interactions

Various probes of model at LHC were discussed