Transverse proton structure and rapidity–gap processes

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Penn State, 28–30 Apr 08

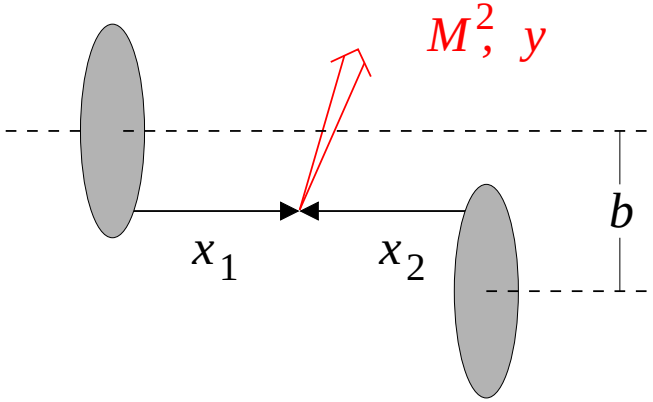
Interplay of hard and soft interactions in two–scale picture of transverse structure

$$\text{Area}\,(x > 10^{-2}) \;\ll\; \text{Area}\,(\text{soft})$$

- inclusive $pp \to H + X$
  event structure $\leftrightarrow$ hard process
  black–disk regime
- diffractive $pp \to p + H + p$
  rapidity gap survival
  p_{T1}, p_{T2} dependence
  color fluctuations

[Frankfurt, Strikman, CW, Phys.Rev.D69:114010,2004
Frankfurt, Hyde, Strikman, CW, Phys.Rev.D75:054009,2007]

Two–scale picture: Basic idea

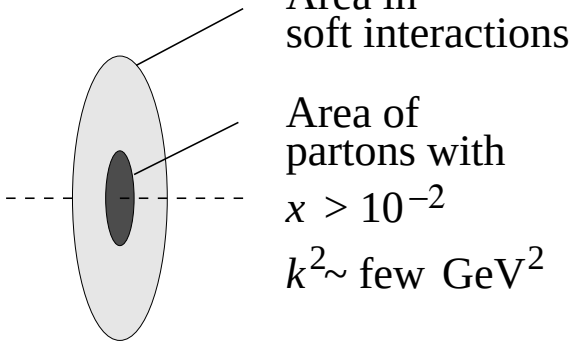


- High energies: b conserved
- Hard process: $x_{1,2} = \frac{M}{\sqrt{s}}\ e^{\pm y}$
- Two–scale picture

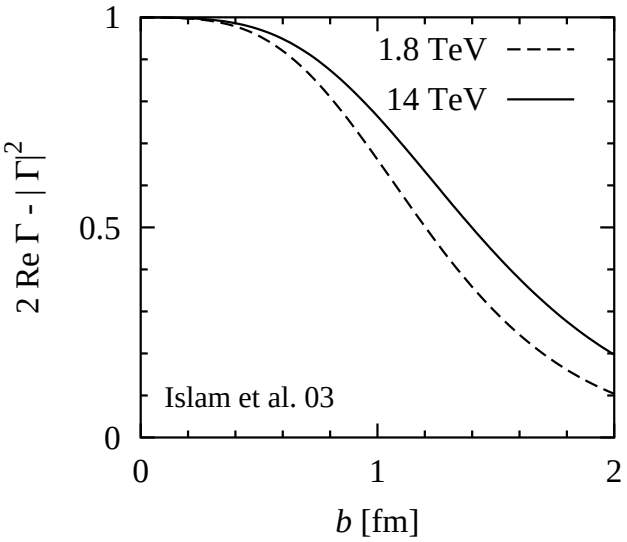
  $R^2(\text{partons } x > 10^{-2}) \ll R^2(\text{soft})$

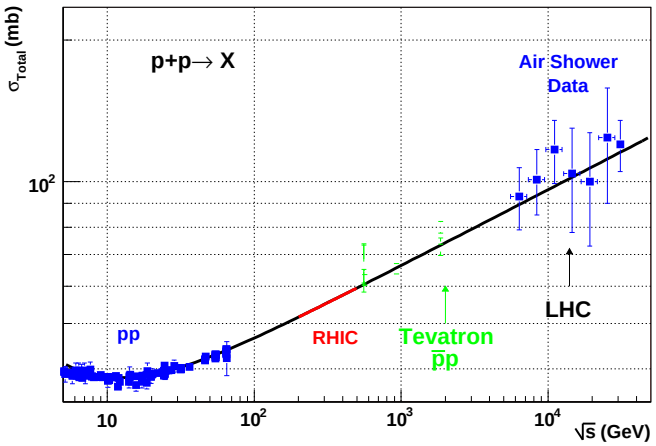
  – Ratio grows with s for fixed M

  – Ordering principle (small parameter), numerous implications



Two–scale picture: Soft interactions





- Elastic pp amplitude

$$T_{\rm el}(s,t) \;=\; \frac{is}{4\pi}\int d^2b\;\; e^{-i\vec{\Delta}_\perp\cdot\vec{b}}\;\; \Gamma(s,b)$$

  - pp total cross section
  - pp elastic scattering t–dep.

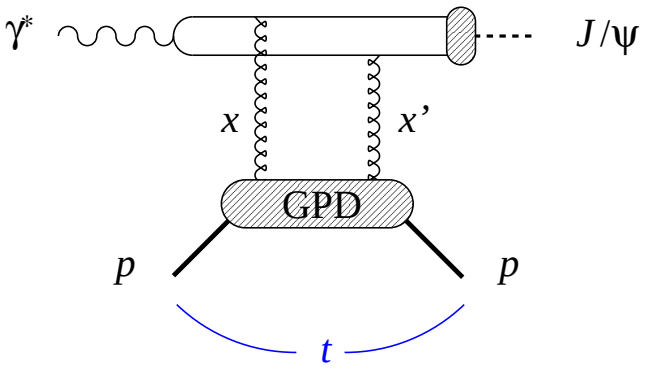
- Black–disk limit: $\Gamma \sim 1$ at $b < b_0$ for $s > 2\,\text{TeV}$

- Transverse area

$$R^2(\text{soft}) \;=\; B(s) \;> 20\,\text{GeV}^{-2} \;\; (t\text{–slope})$$

  - increases with $\alpha' = 0.25\,\text{GeV}^{-2}$

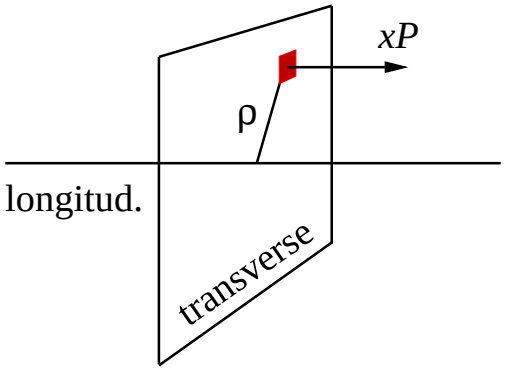
Two–scale picture: Partons with $x > 10^{-2}$



- Exclusive processes $\gamma^* p \to J/\psi + p$ etc. probe generalized parton distributions

$$G(x,t) \;=\; \int d^2\rho \;\; e^{-i\vec{\Delta}_T\cdot\vec{\rho}} \;\; G(x,\rho)$$

  - transverse spatial distribution of gluons with longitudinal momentum fraction x



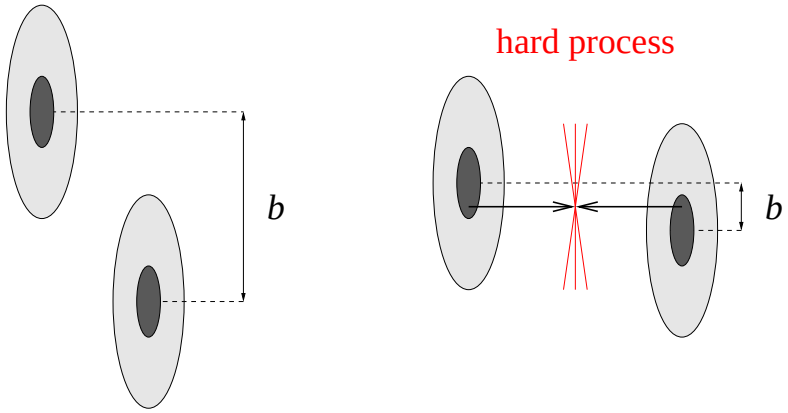
- Transverse area

$$R^2(x \sim 10^{-2}) \;=\; 2\,B_g \;\approx 7\,\text{GeV}^{-2}$$

  - increases with $\alpha_g \ll \alpha'$
  - decreases with increas. Q^2 (DGLAP)

[FNAL E401/E458 (1981);
see also HERA H1, ZEUS]

Inclusive $pp \to H + X$: Centrality trigger



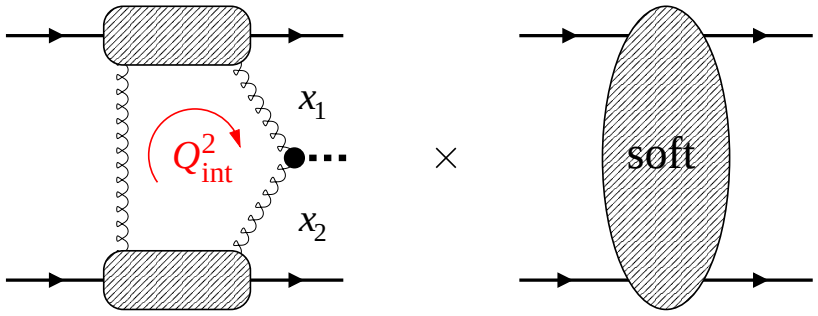
	$\sqrt{s}$ [TeV]	$\langle b^2 \rangle$ [fm^2] min.bias	hard*
LHC	14	2.7	0.67
Tevatn	1.8	1.8	0.63
RHIC	0.5	1.43	0.59

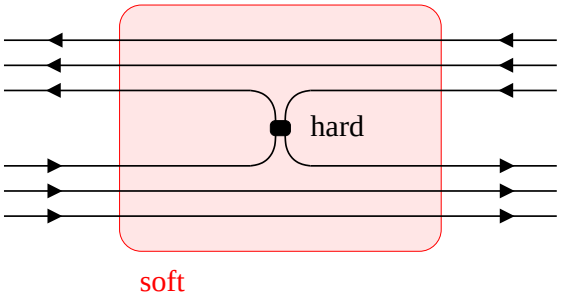
*dijet $q_T = 100$ GeV

- Events with hard processes are much more central than min. bias: "Centrality trigger"
- Different global event characteristics
  - Interactions of large–x spectators deep in black–disk regime (LHC)
  - High p_T of forward hadrons, low multiplicity
  - High activity at central rapidities

Essential tool for exploring black-disk/saturation regime

Diffraction: Hard–soft interplay in $pp \to p + H + p$





Different time/distance scales!

- H produced in hard process with two–gluon exchange

  $\mu^2_{\rm soft} \ll Q^2_{\rm int} \ll M^2$ [Khoze et al. 97]

  $x_{1,2} \sim \frac{M}{\sqrt{s}} \sim 10^{-2}$ Higgs at LHC

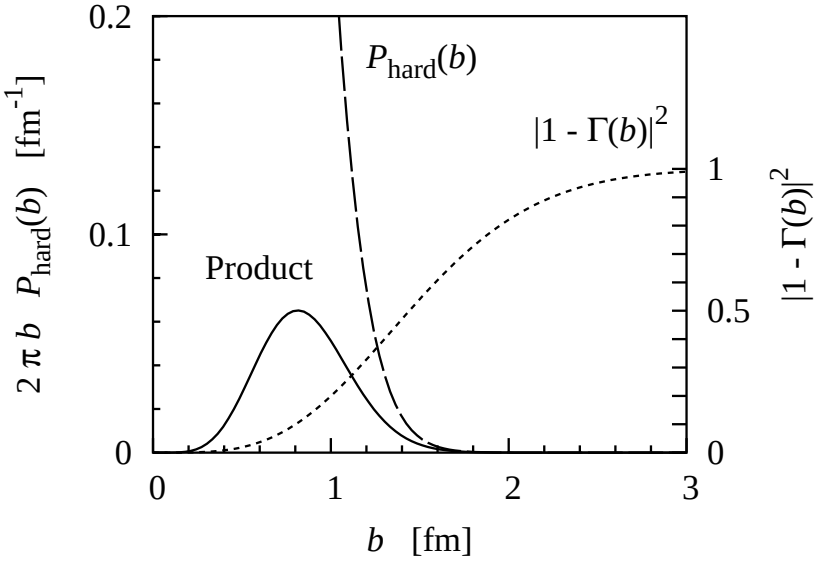
- Soft interactions must not produce particles

  $$S^2 \equiv \frac{\sigma_{\rm diff}(\text{full})}{\sigma_{\rm diff}(\text{no soft})}$$

  Gap survival probability

- Mean–field approximation: Amplitude calculable in terms of
  - Gluon GPD
  - pp elastic S–matrix

Diffraction: Rapidity gap survival



$$P_{\text{hard}}(b)$$
$$\propto \int d^2\rho_1\, d^2\rho_2\, \delta(\boldsymbol{b} - \boldsymbol{\rho}_1 + \boldsymbol{\rho}_2)$$
$$\times\ G^2(x_1, \rho_1)\, G^2(x_2, \rho_2)$$

Overlap of squared gluon densities

- Gap survival probability

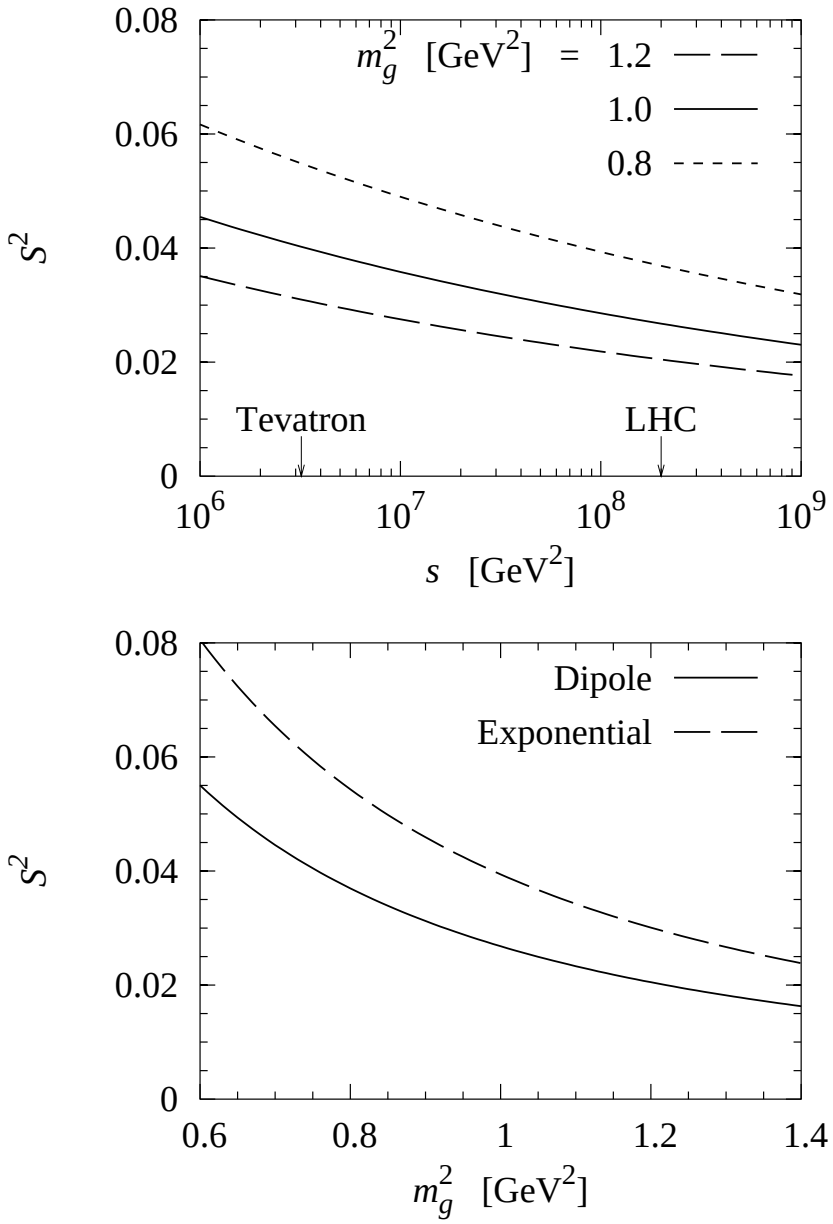
$$S^2 = \int d^2b \quad P_{\text{hard}}(b) \quad |1 - \Gamma(b)|^2$$

Probability for two–gluon collision	Probability for "no inelast. interaction"
favors small $b \sim \sqrt{B_g}$	favors large $b \sim \sqrt{B}$

- "Blackness" $\Gamma \sim 1$ suppresses diffraction at small impact parameters

Two–scale picture explains "physics" of gap survival

Diffraction: Numerical results



- Dominant effect: "Blackness" of pp amplitude suppresses small b

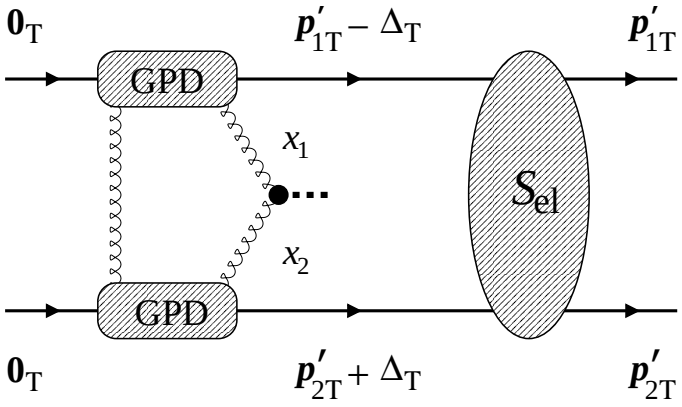
  . . . model–independent!

- Sensitive to functional form of t–dependence of gluon GPD

- Agreement with Khoze et al. partly accidental (different parameters)

[Details: FHSW, PRD **75**, 054009 (2007)]

Diffraction: p_T dependence



$$T_{\mathrm{diff}}(\boldsymbol{p}_{1\mathrm{T}}, \boldsymbol{p}_{2\mathrm{T}}) \propto \int d^2\Delta_\mathrm{T} \times G(x_1, \boldsymbol{p}_{1\mathrm{T}} - \boldsymbol{\Delta}_\mathrm{T}) \times G(x_2, \boldsymbol{p}_{2\mathrm{T}} + \boldsymbol{\Delta}_\mathrm{T}) \times \underbrace{S_\mathrm{el}(\boldsymbol{\Delta}_\mathrm{T})}_{1 + iT_\mathrm{el}}$$

- Amplitude computed in terms of

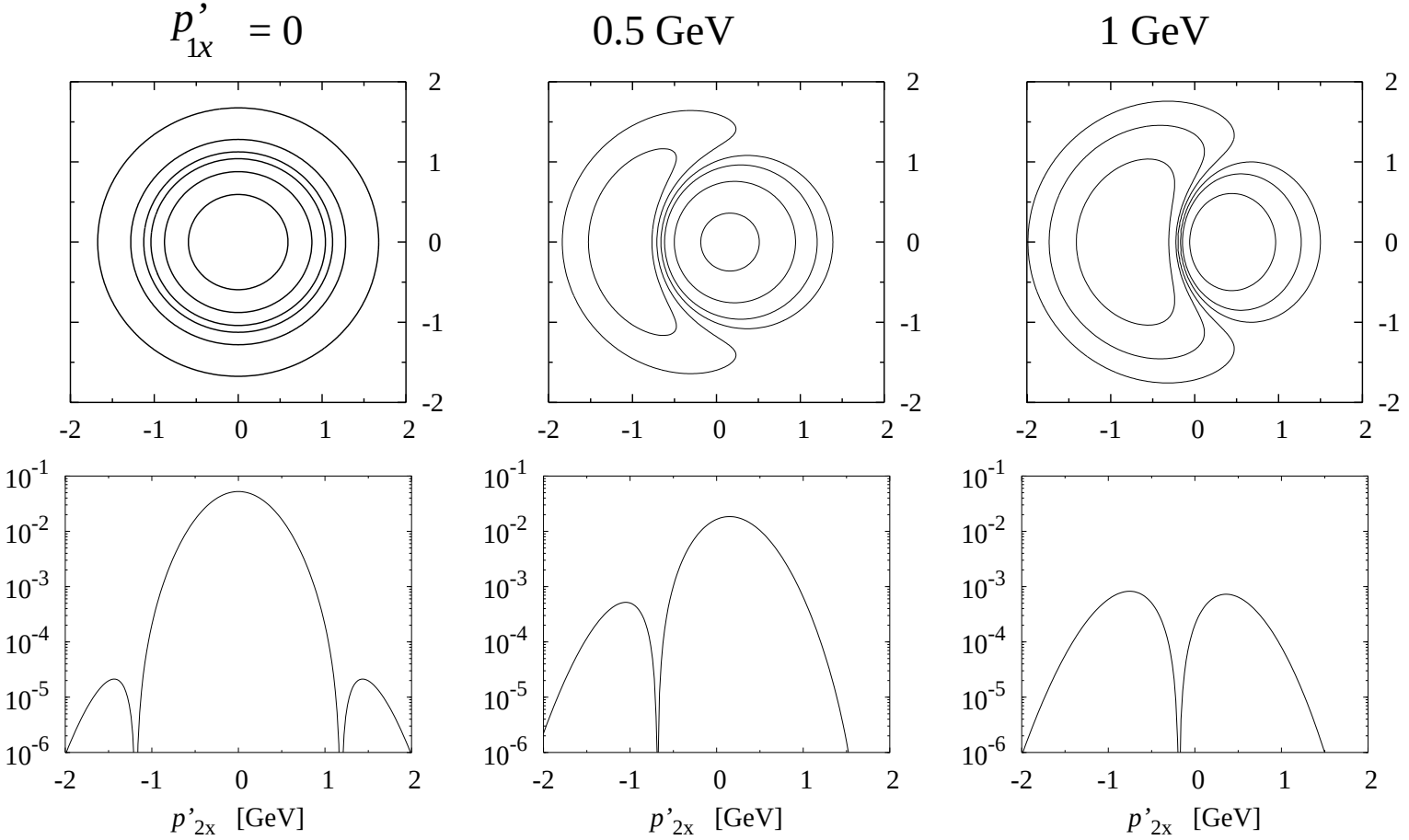
  Gluon GPD t–dep. $\sim B_g$
  pp elastic S–matrix t–dep. $\sim B$

- Diffractive minimum

  "elementary" amp. 1
  "absorbed" amp. T_el
  } destructive interference

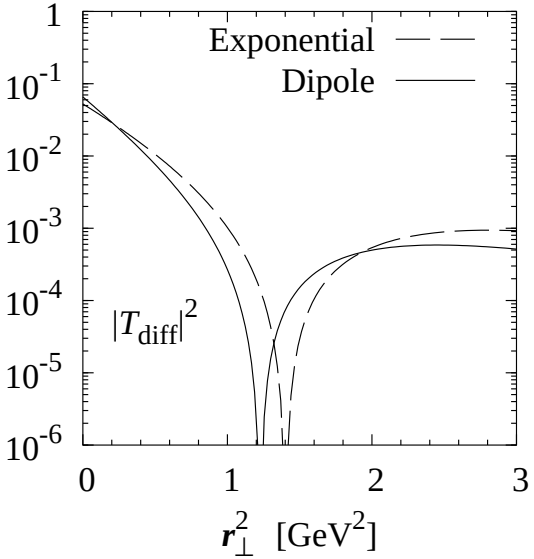
- Coordinate representation:
  Diffraction of wave packet
  from "hole" $1 - \Gamma(b)$

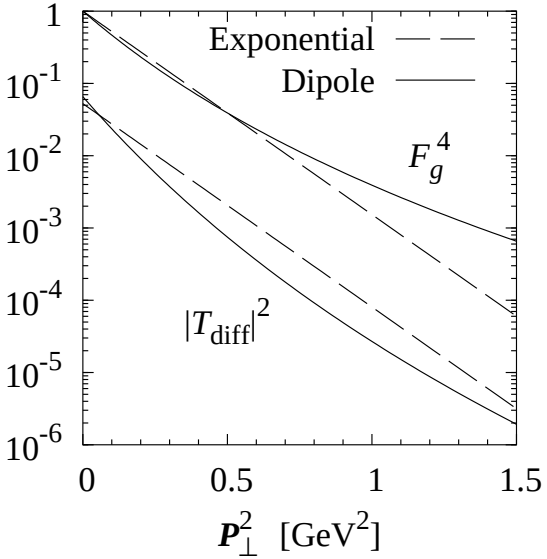
Diffraction: p_T dependence



- Pattern determined by two scales $B_g \ll B$
- Entangled dependence on $\boldsymbol{p}_{1\mathrm{T}}$ and $\boldsymbol{p}_{2\mathrm{T}}$

Diffraction: Disentangling $p_{\rm T}$





- Define CM and relative momentum

$$\boldsymbol{P}_{\rm T} = (\boldsymbol{p}_{1\rm T} + \boldsymbol{p}_{2\rm T})/2$$
$$\boldsymbol{r}_{\rm T} = \boldsymbol{p}_{1\rm T} - \boldsymbol{p}_{2\rm T}$$

- $\boldsymbol{r}_{\rm T}$ dependence has diffractive minimum (B and B_g)

- $\boldsymbol{P}_{\rm T}$ dependence sensitive to t–dependence of gluon GPD (B_g only)

Test reaction mechanism and two–scale picture

Diffraction: Beyond the mean–field approximation

- Mean–field approximation:

  Parton density $G(x, \boldsymbol{\rho})$ and Spectator interactions $\Gamma(s, \boldsymbol{b})$ } independent, determined by "average" configurations

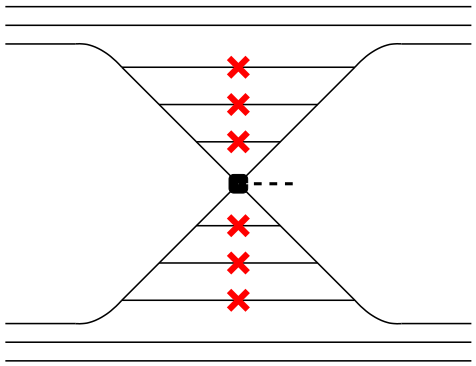
- Several effects lead to correlations between parton density and spectator interactions

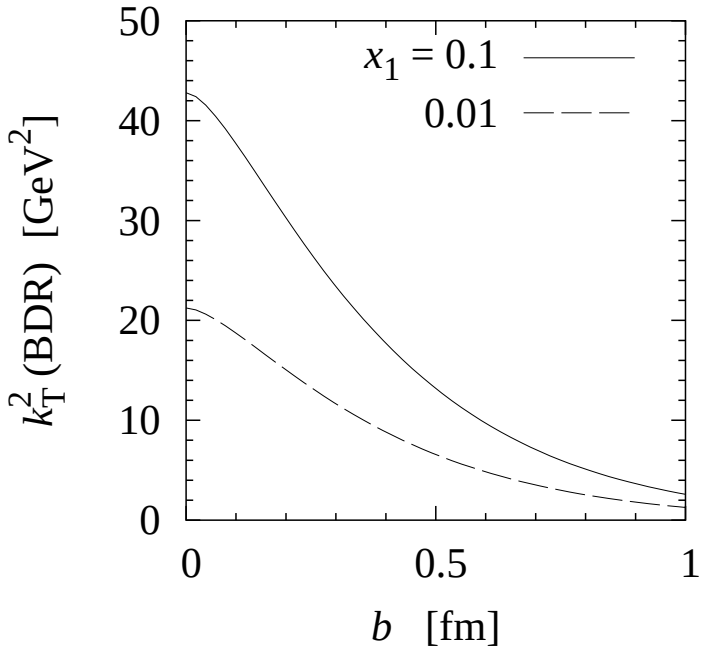
  $\rightarrow$ lower RGS probability S^2

  $\rightarrow$ steeper $\boldsymbol{p}_{1\mathrm{T}}, \boldsymbol{p}_{2\mathrm{T}}$ dependence

  [FHSW, arXiv:0710.2942 arXiv:0708.3106; in progress]

Diffraction: Hard spectator interactions





- Parent partons ($k^2 \sim$ few GeV^2) experience absorptive interactions with small–x gluons in other proton

  "Black–Disk Regime"

- Use estimate of "critical" k_{T}^2 from dipole model

- Effect reduces RGS probability at LHC by at least factor 2
  . . . much weaker effect at Tevatron

- Larger impact parameters
  $\rightarrow$ steeper $p_{1\mathrm{T}}, p_{2\mathrm{T}}$ dependence!

Summary

- Two–scale picture essential tool for modeling interplay of hard and soft interactions in pp

- Rapidity gap survival in $pp \to p + H + p$: Suppression of small b by "blackness" of pp scattering

- $\boldsymbol{p}_{1\mathrm{T}}, \boldsymbol{p}_{2\mathrm{T}}$ reflects interplay of two scales B and B_g
  - Exp. tests of reaction mechanism
  - Proton structure (GPDs)

- Beyond the mean–field approximation: $\boldsymbol{p}_{1\mathrm{T}}, \boldsymbol{p}_{2\mathrm{T}}$ dependence steeper than originally estimated [in progress]
  - Absorption of spectator partons
  - Correlated fluctuations gluon density $\leftrightarrow$ soft interactions