Soft QCD and Double Parton Scattering

with results from ALICE, ATLAS, CMS, LHCb, and TOTEM

Philip Ilten

UNIVERSITY OF BIRMINGHAM

April 25, 2019

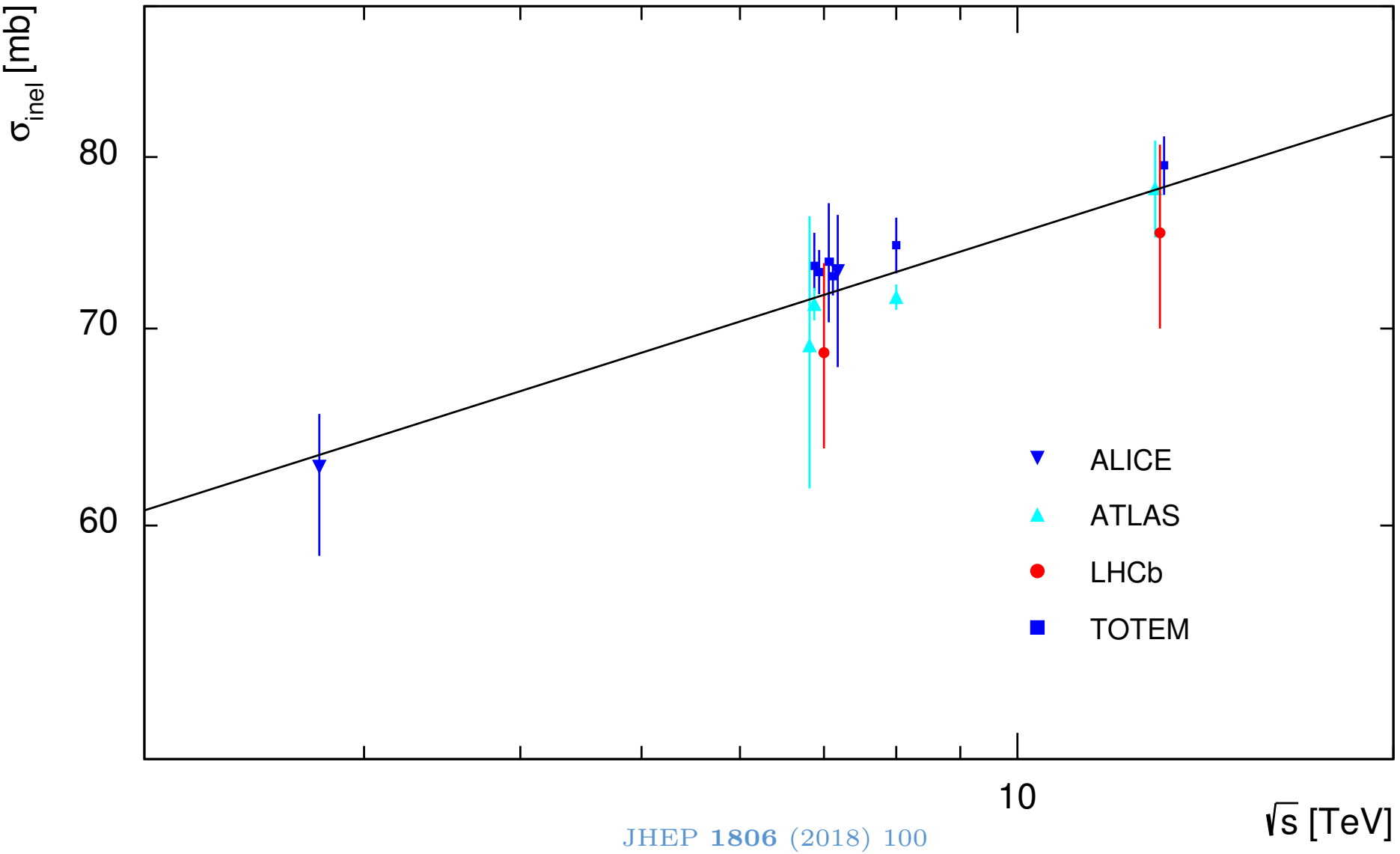
SM@LHC

Initial Thoughts

- this is *not* a summary talk!
- in principle, focus on forward results
- disclaimer, I am biased by LHCb and PYTHIA affiliation

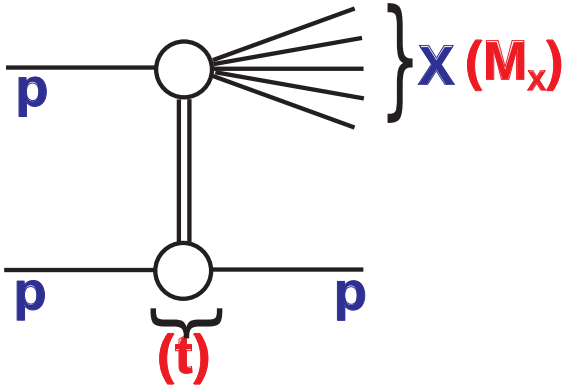
- some recent cross-sections
- understanding collective effects
- progress in double parton scattering

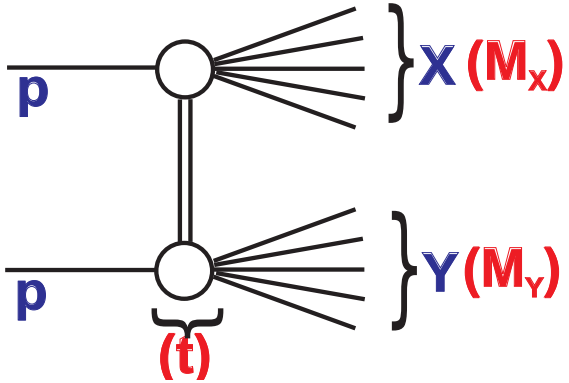
Inelastic Cross-Sections

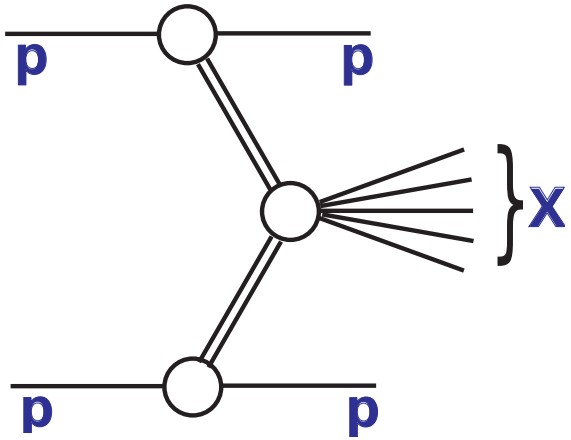


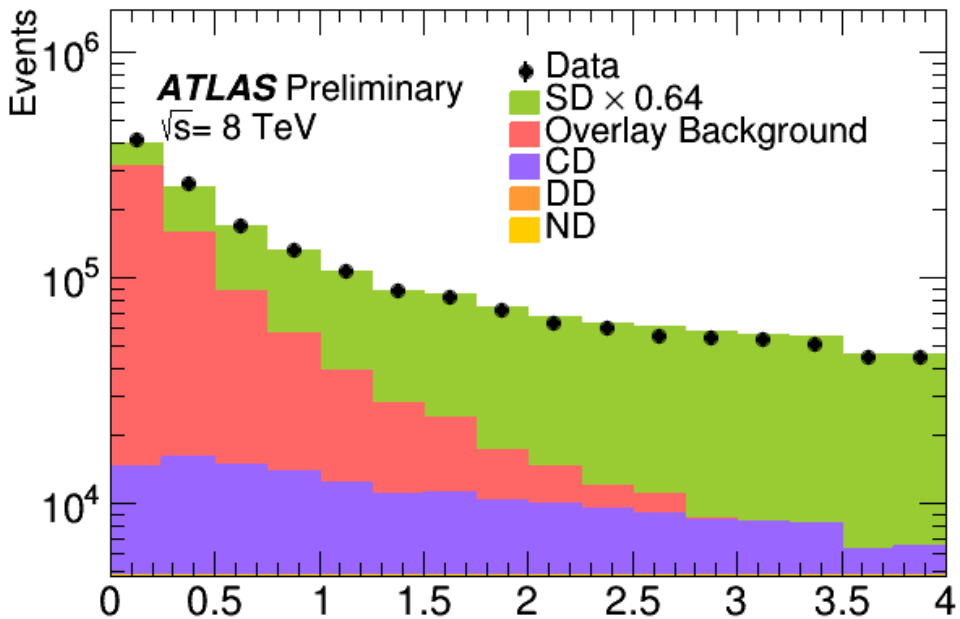
JHEP **1806** (2018) 100

Single Diffractive Cross-Section





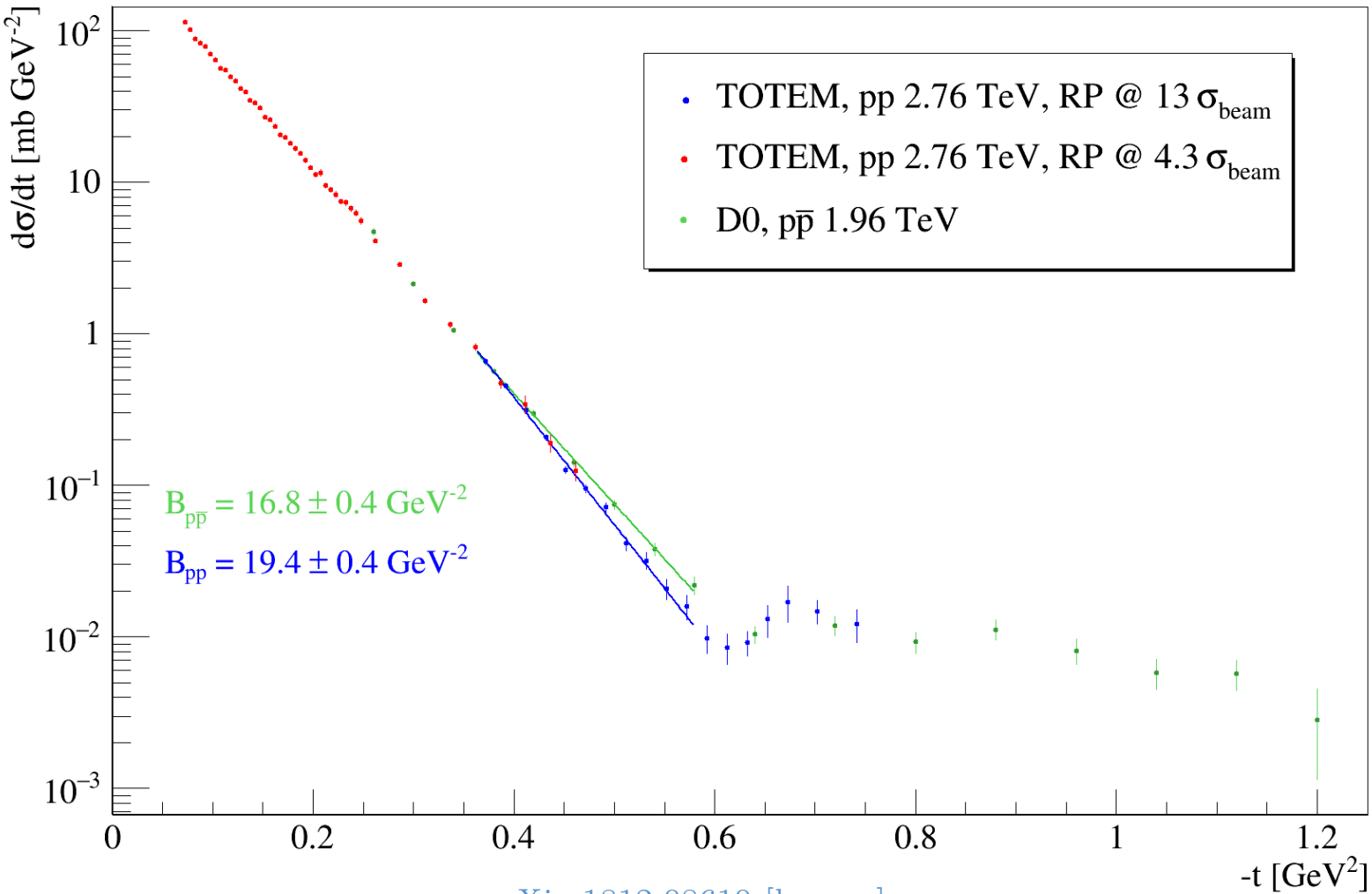




ATLAS-CONF-2019-012

Elastic Cross-Section

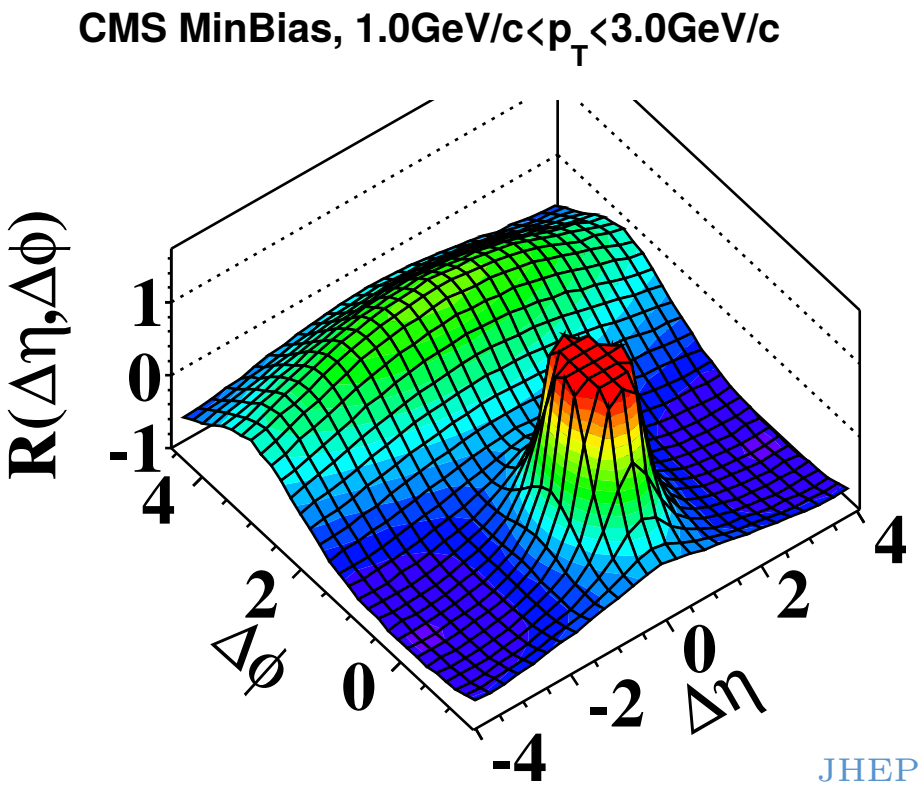
- difference between pp and $p\bar{p}$ slopes indicates three-gluon exchange

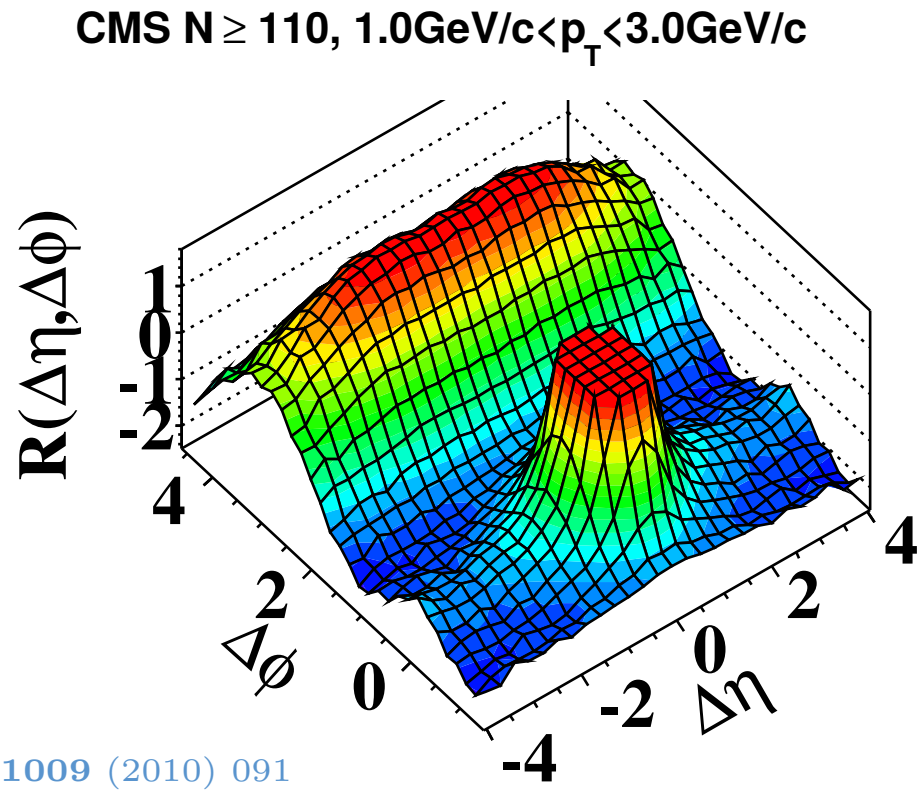


arXiv:1812.08610 [hep-ex]

The Ridge in the Room

- ridge first observed by STAR in Au Au collisions with QGP

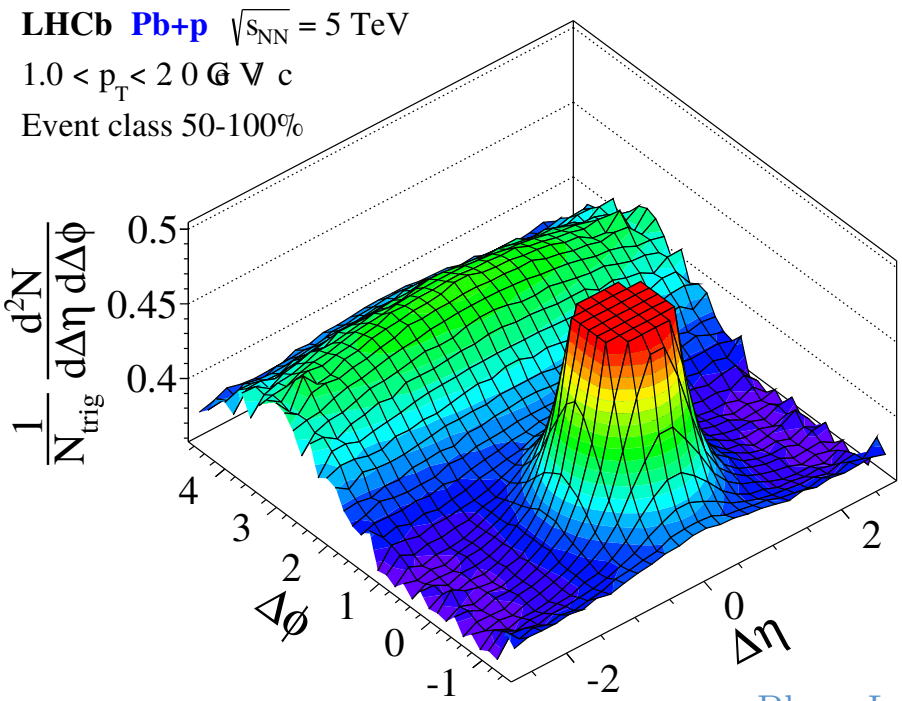


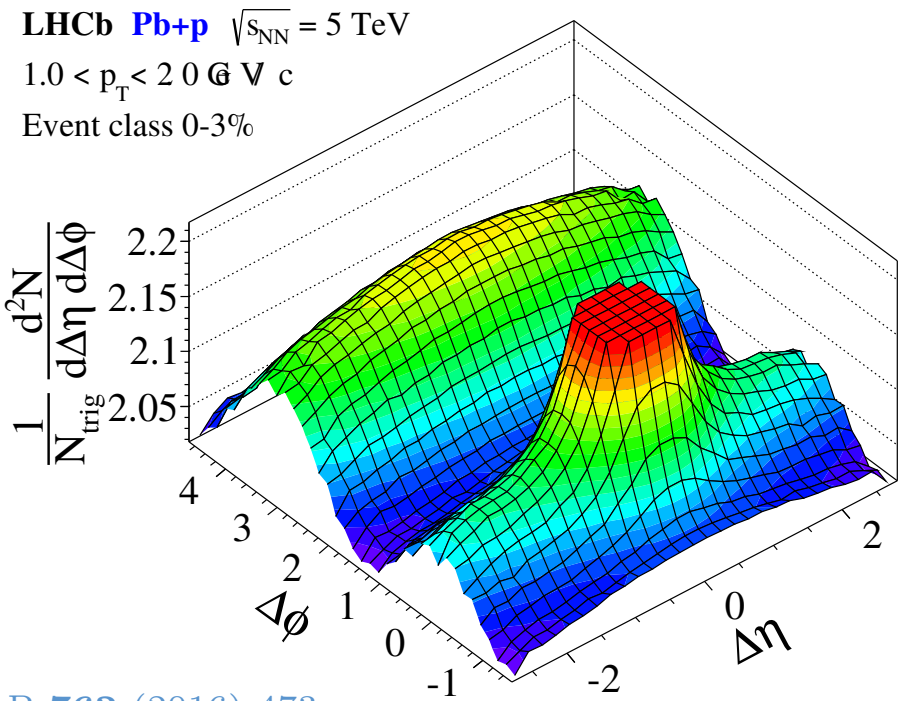


JHEP **1009** (2010) 091

A Forward Perspective

- ridge also observed in forward region, $-5.4 < y < -2.5$ in nucleon-nucleon system

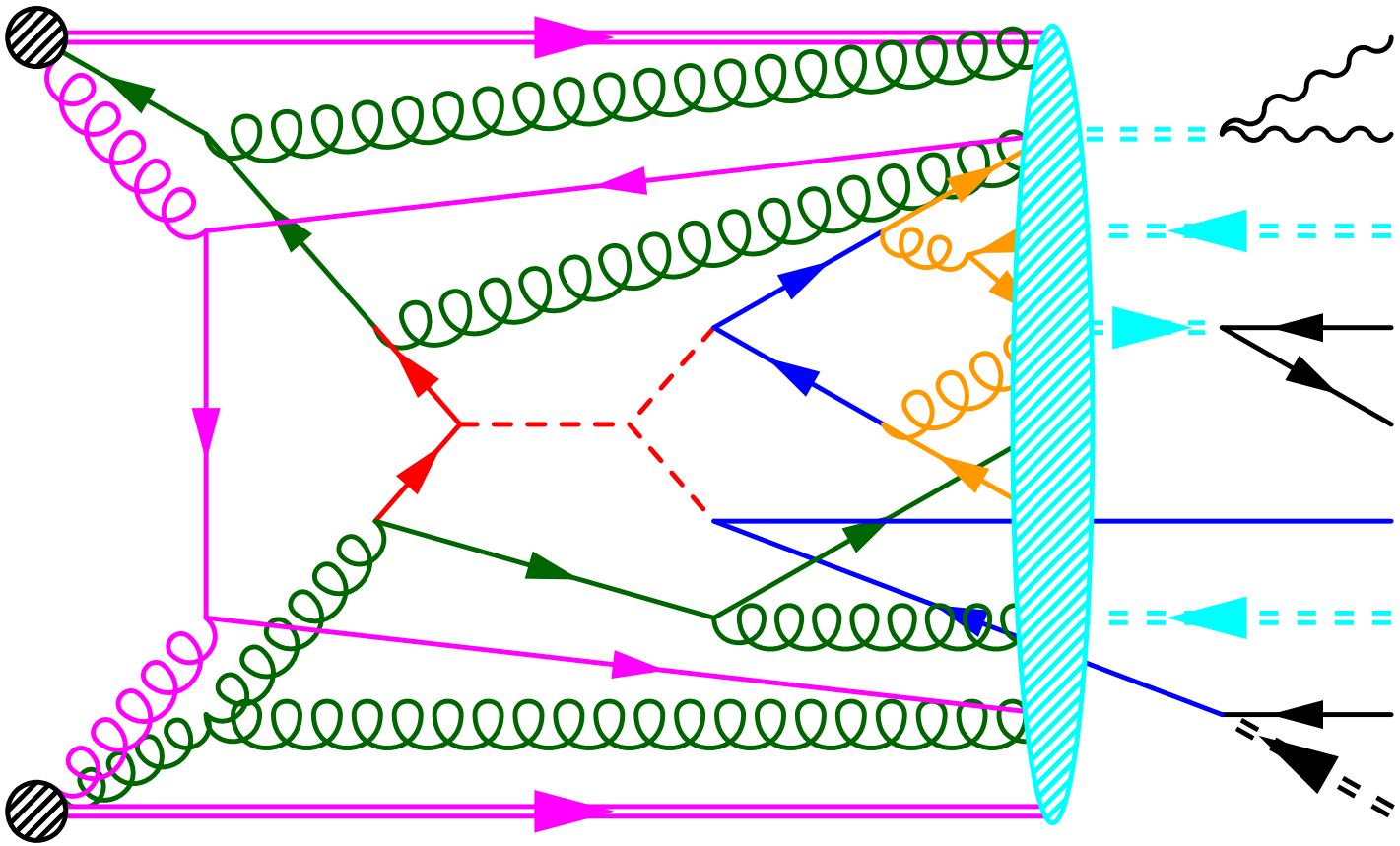




Phys. Lett. B **762** (2016) 473

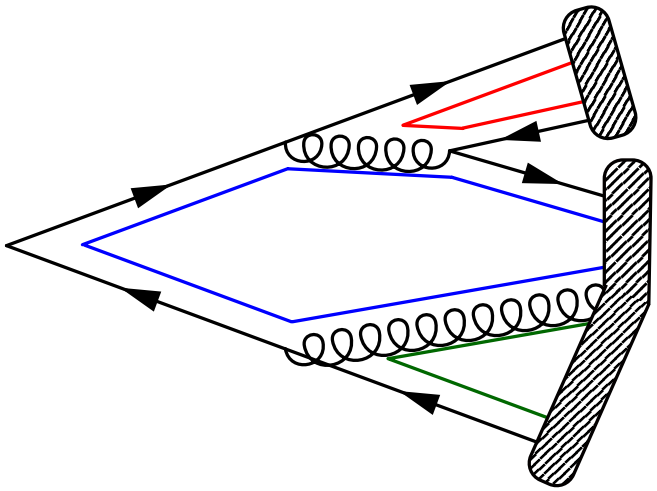
A Microscopic Model

- can consider *macroscopic* or *microscopic* models
- factorise event and overlay multiparton interactions



Strings or Clusters?

string model (PYTHIA)

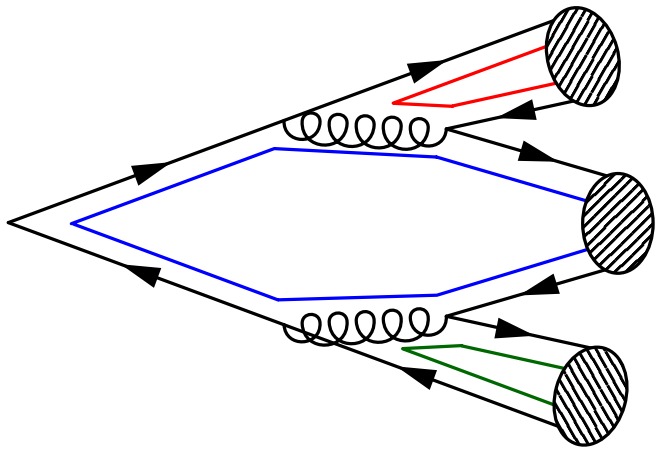


- linear confinement

$$V \approx \kappa r - \frac{4\alpha_s}{3r}$$

- split strings into hadrons

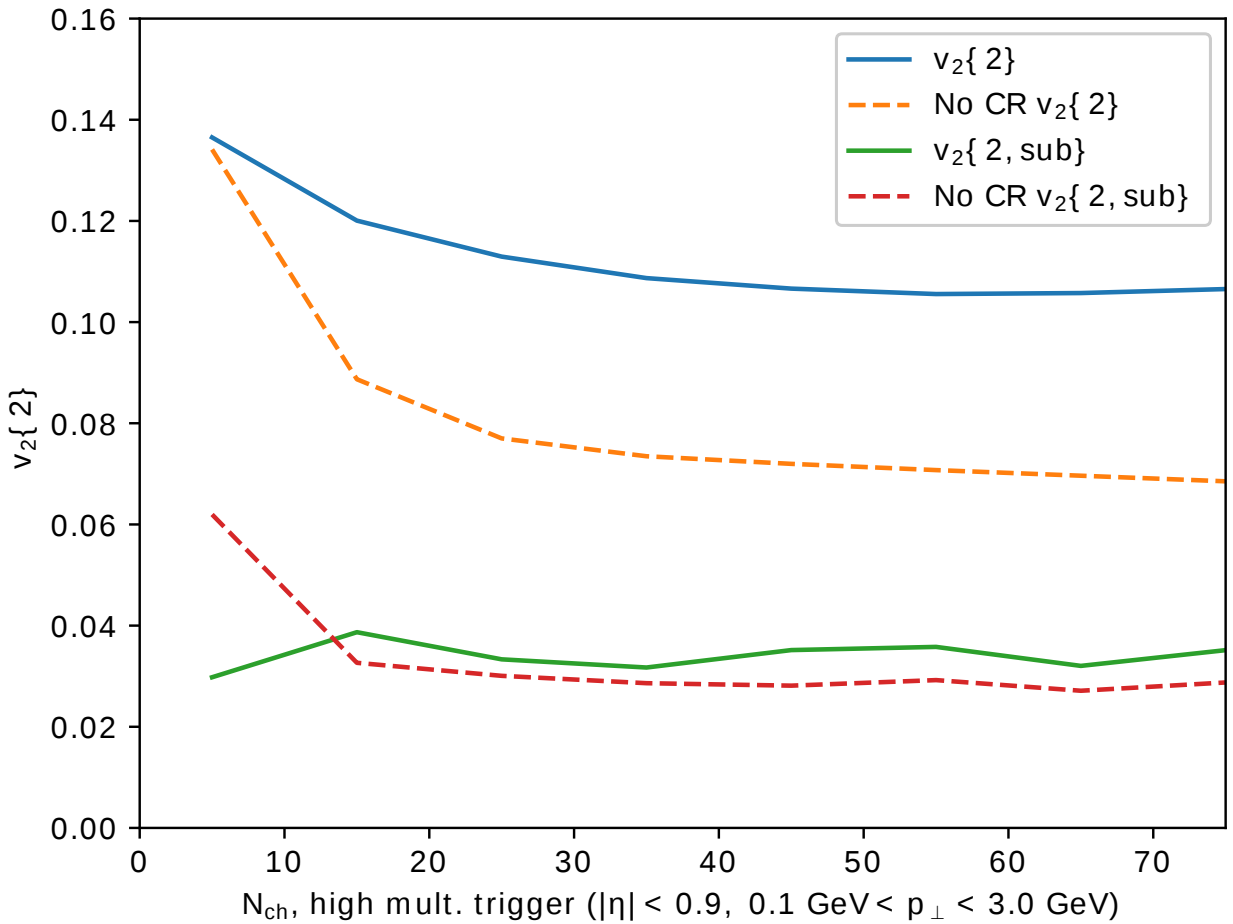
cluster model (HERWIG)



- pre-confinement
  - clusters independent of hard process scale
  - dependent on QCD and shower scale
- decay clusters into hadrons

Colour Reconnection

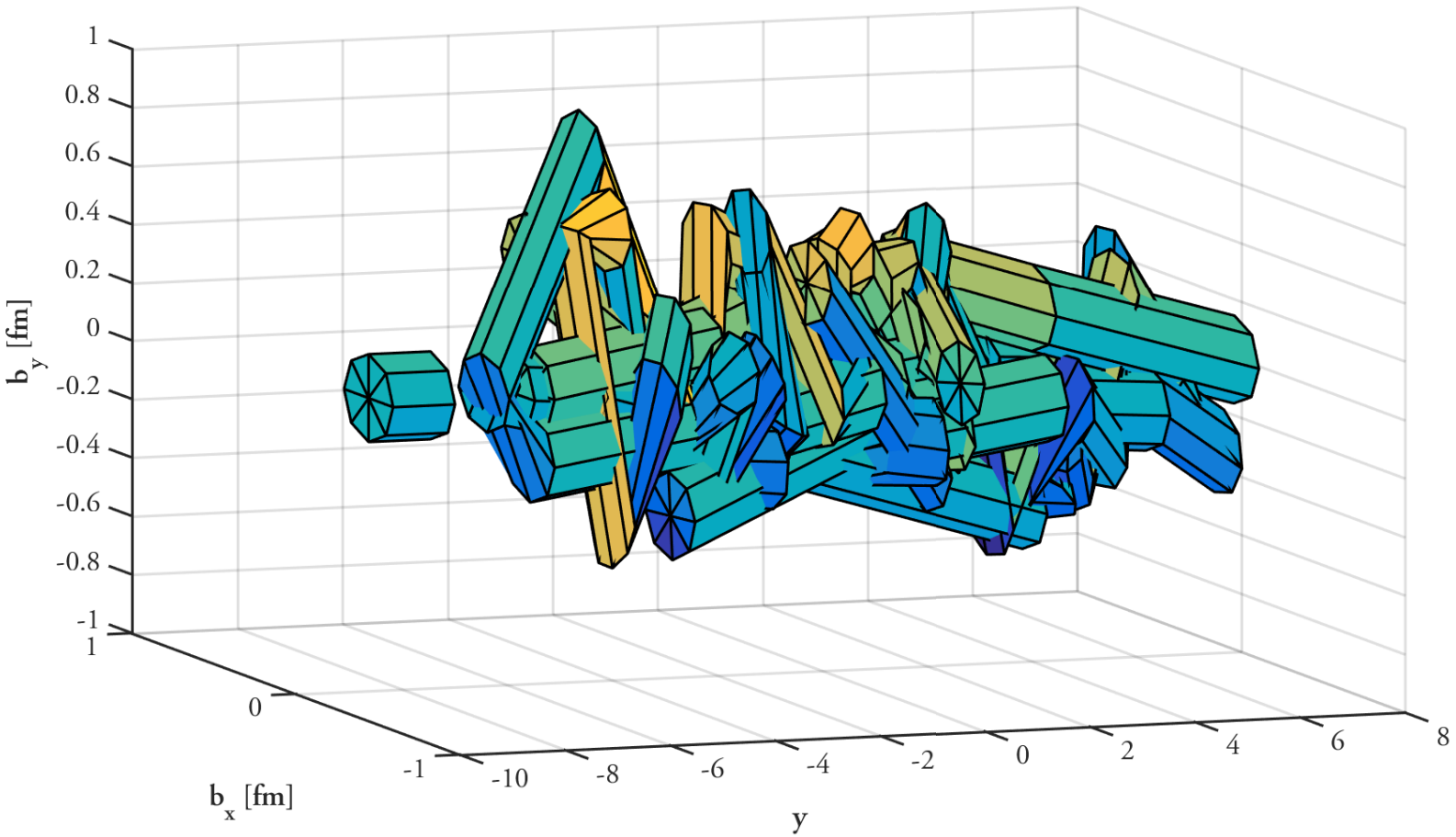
- use large colour limit, then minimise string lengths
- no long-range effect!



Nucl. Phys. A **982**, 499 (2019)

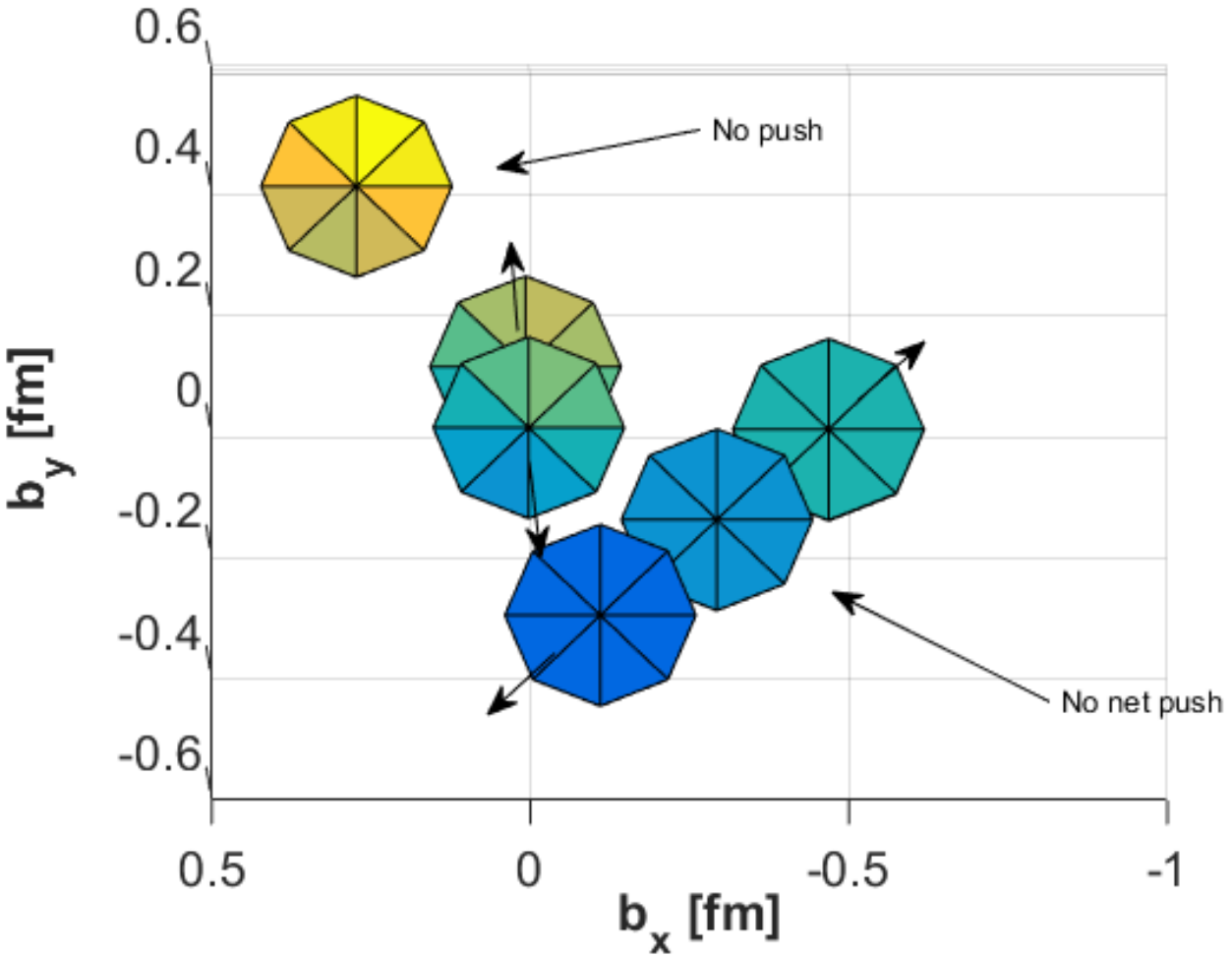
String Interactions

- overlap can be considerable (radius reduced by 10×)



arXiv:1702.01329

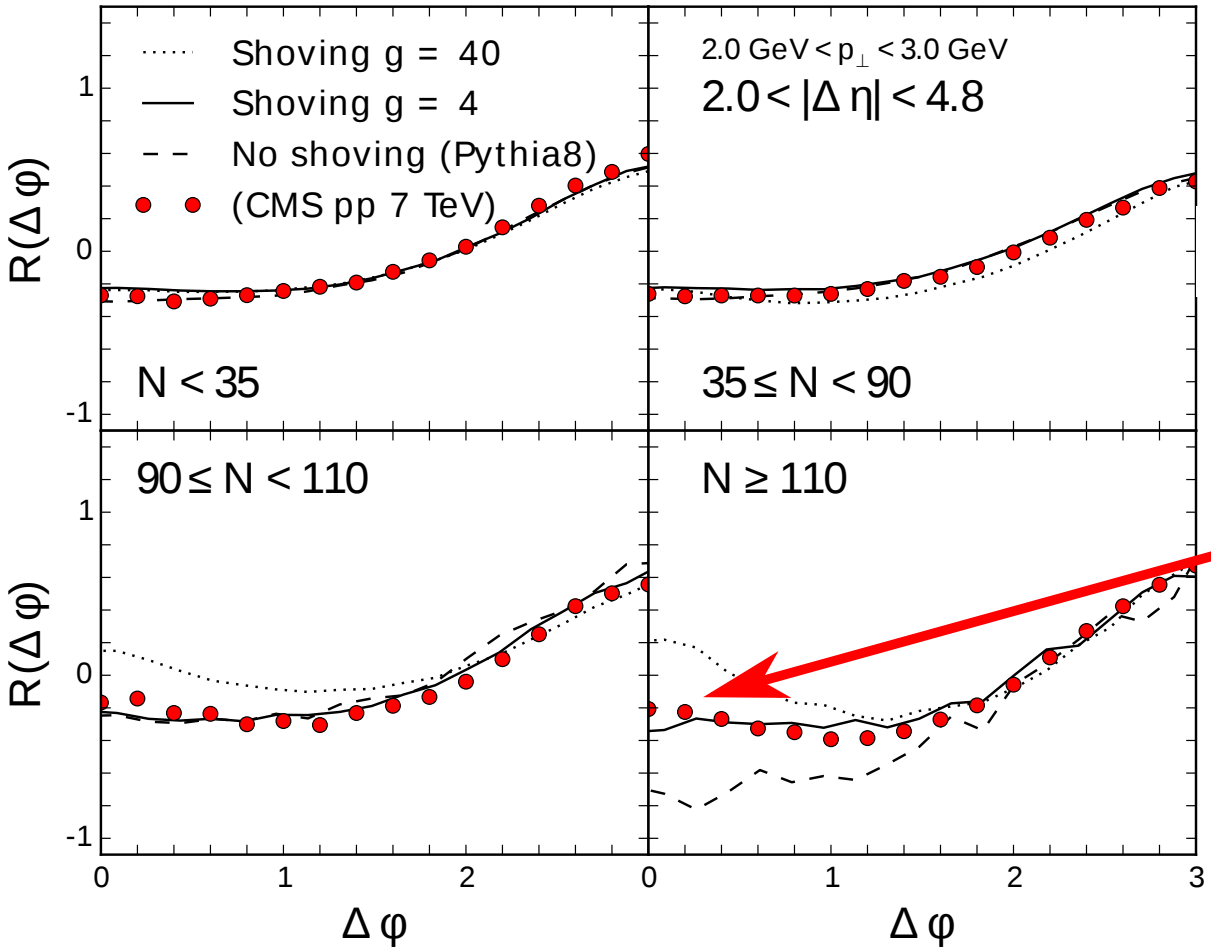
Ropes and Shoving

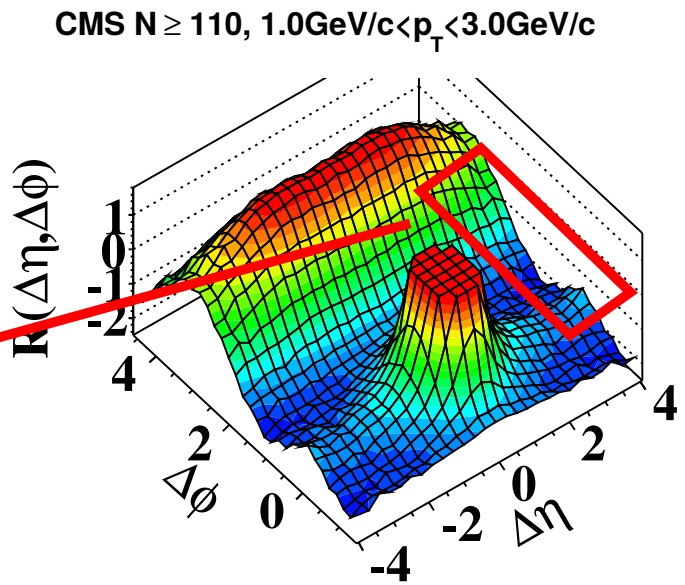


L. Lönnblad

- $0.0\,\mathrm{fm}/c$ no interactions
- $0.6\,\mathrm{fm}/c$ parton shower ends
- $1.0\,\mathrm{fm}/c$ shoving maximimal
- $2.0\,\mathrm{fm}/c$ hadro-nisation

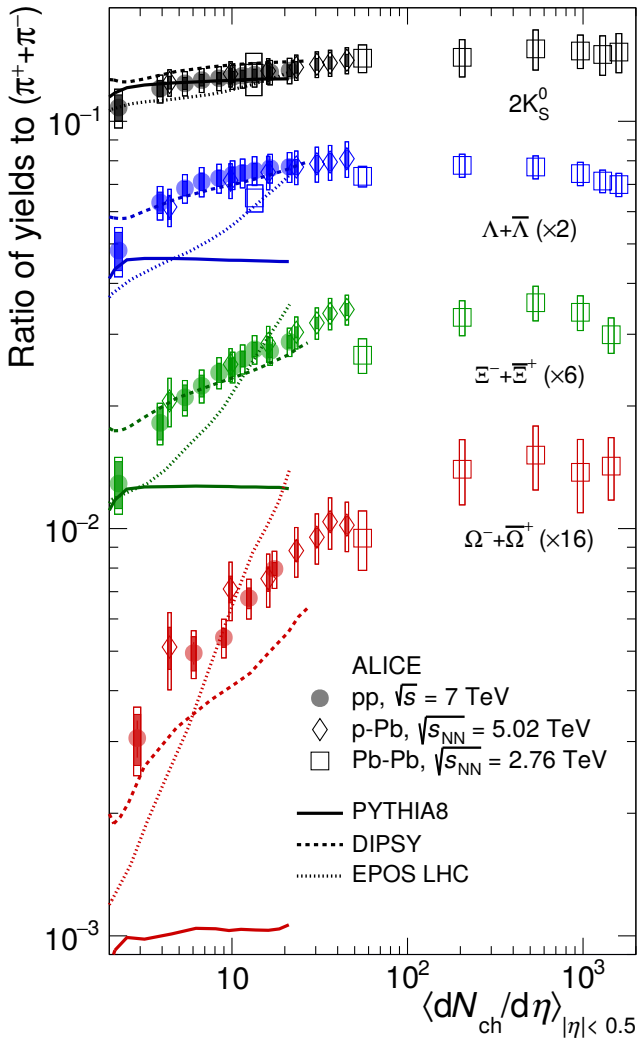
A Ridge Emerges!



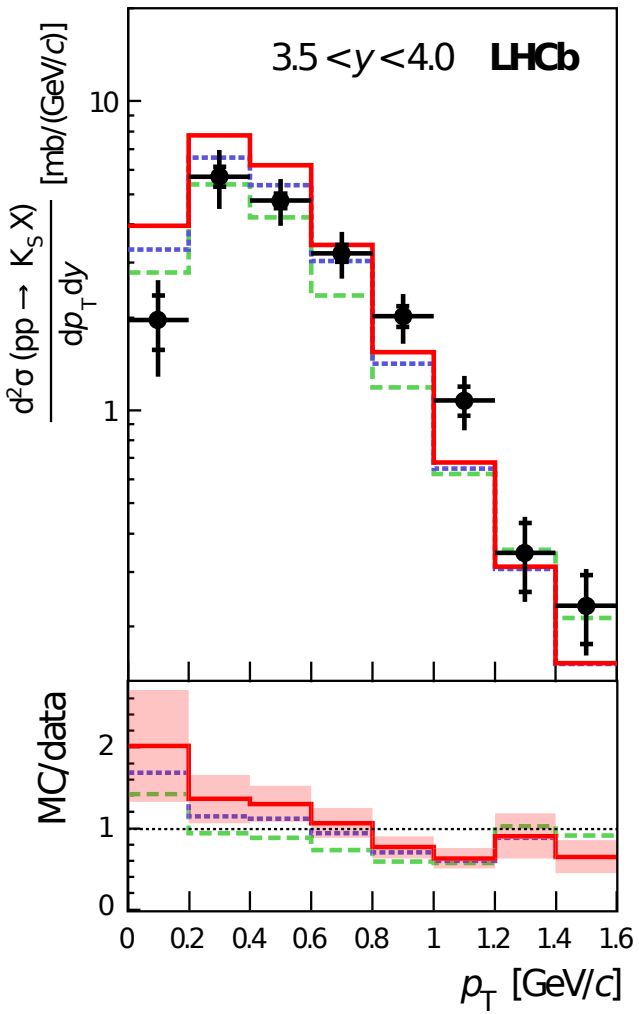


Phys. Lett. B **779** (2018) 58

Stranger Things



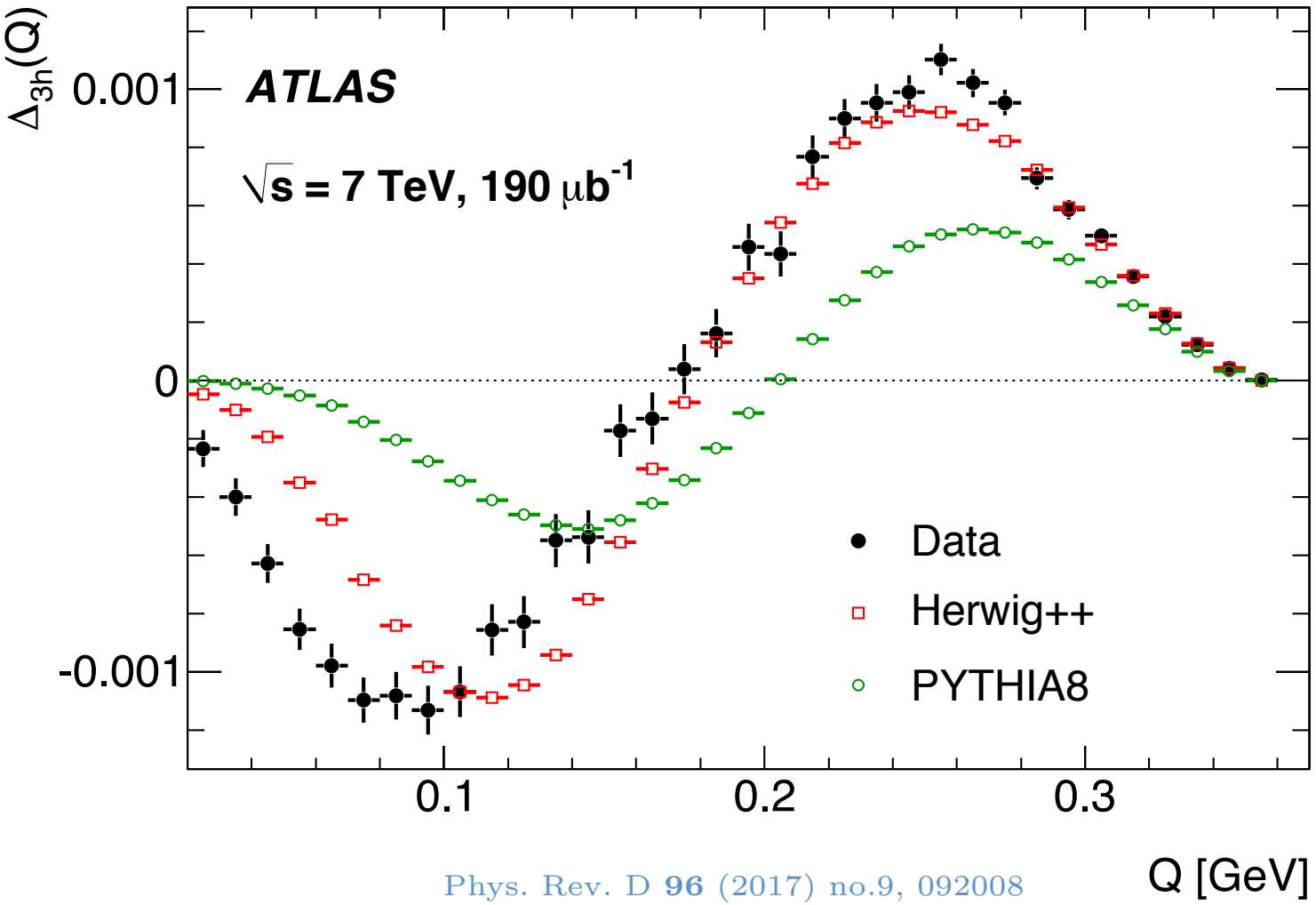
Nature Phys. **13** (2017) 535



Phys. Lett. B **693** (2010) 69

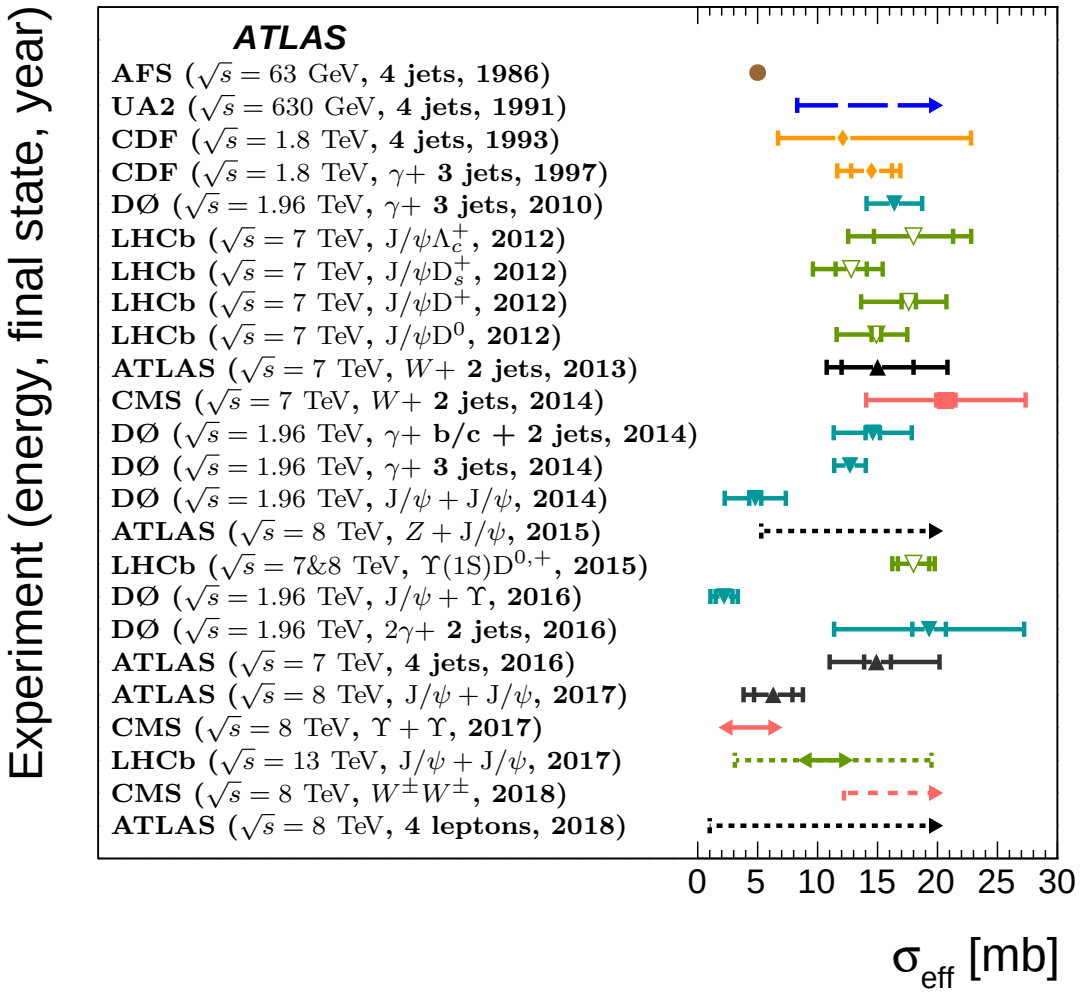
Adding a Twist

- what about strings with physical structure?



Phys. Rev. D **96** (2017) no.9, 092008

Double Parton Scattering



Phys. Lett. B **790** (2019) 595

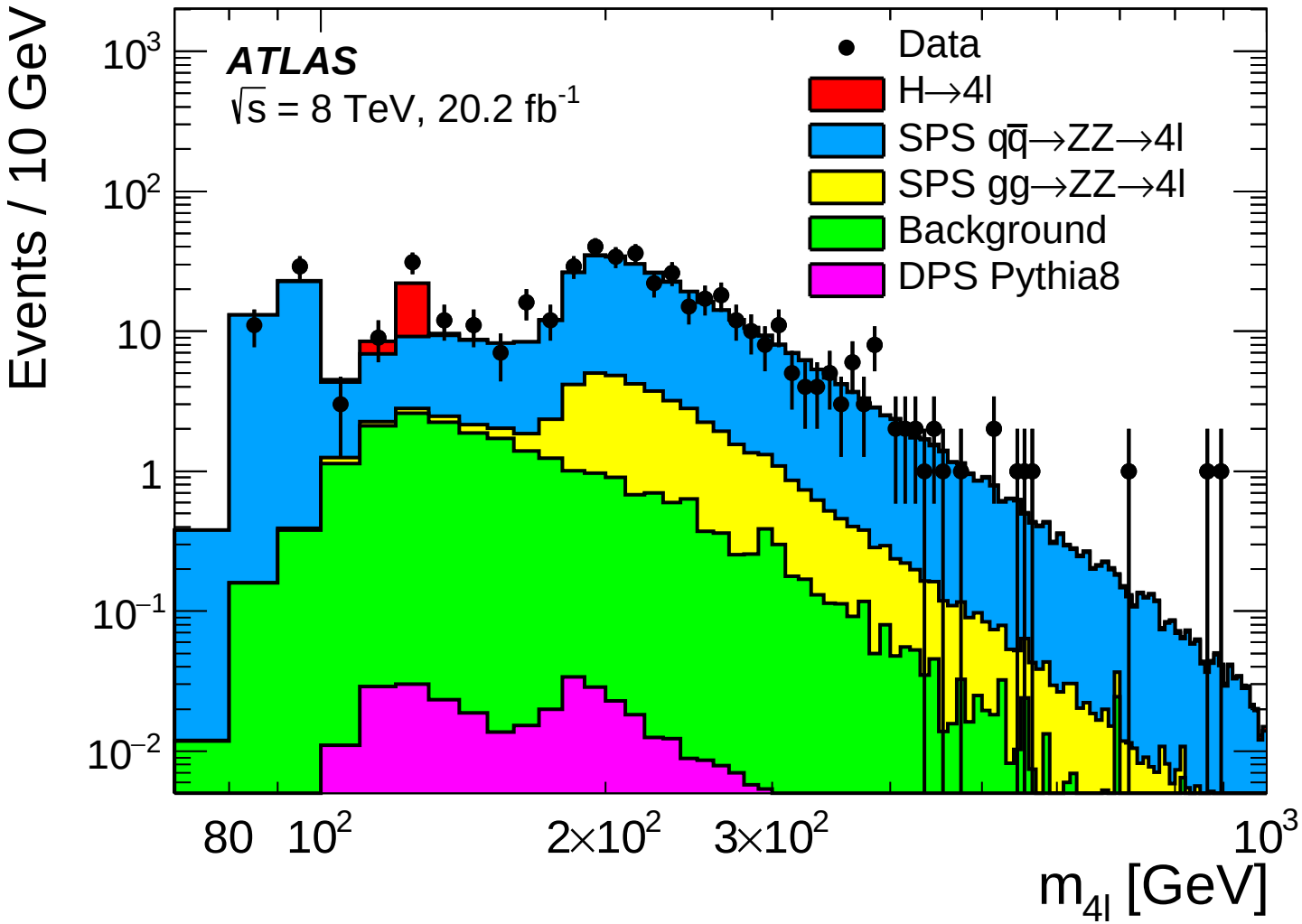
- double parton scattering directly related to multiparton interactions

$$\sigma_{12} = \frac{1}{1 + s_{12}} \frac{\sigma_1 \sigma_2}{\sigma_{\text{eff}}}$$

- σ_{eff} is *not* fixed, depends on energy and process scale

Why So Sensitive (or not)?

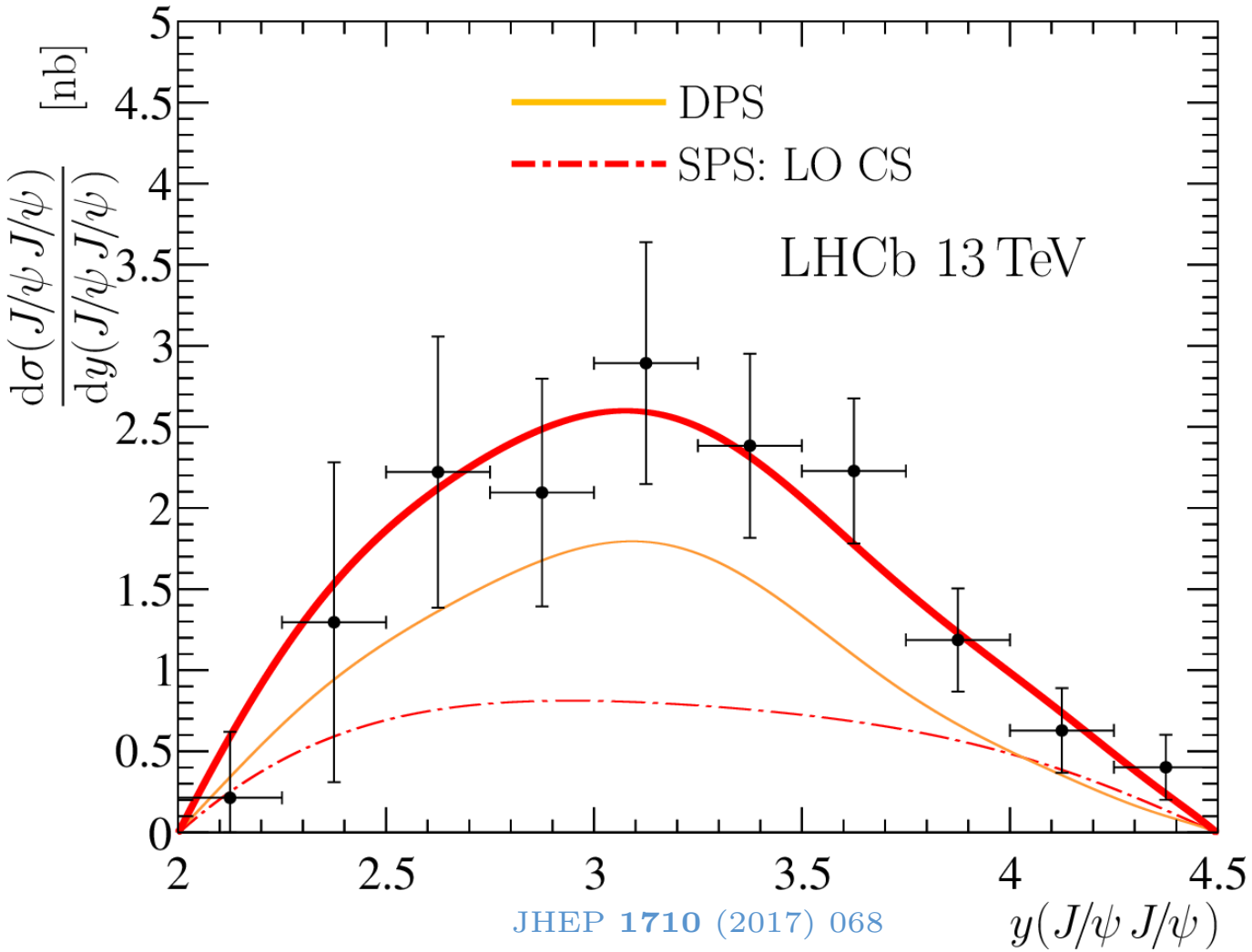
- swamped by $ZZ \to 4\ell$, p_{T} sum (vector/scalar) most sensitive



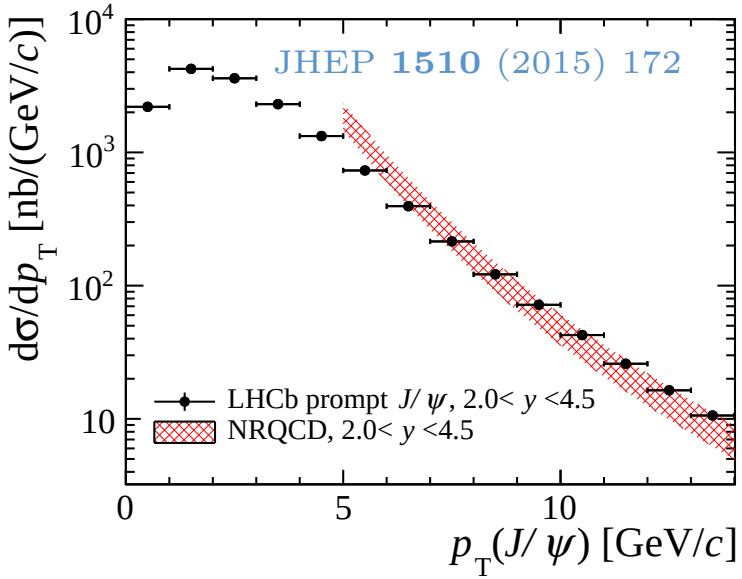
Phys. Lett. B **790** (2019) 595

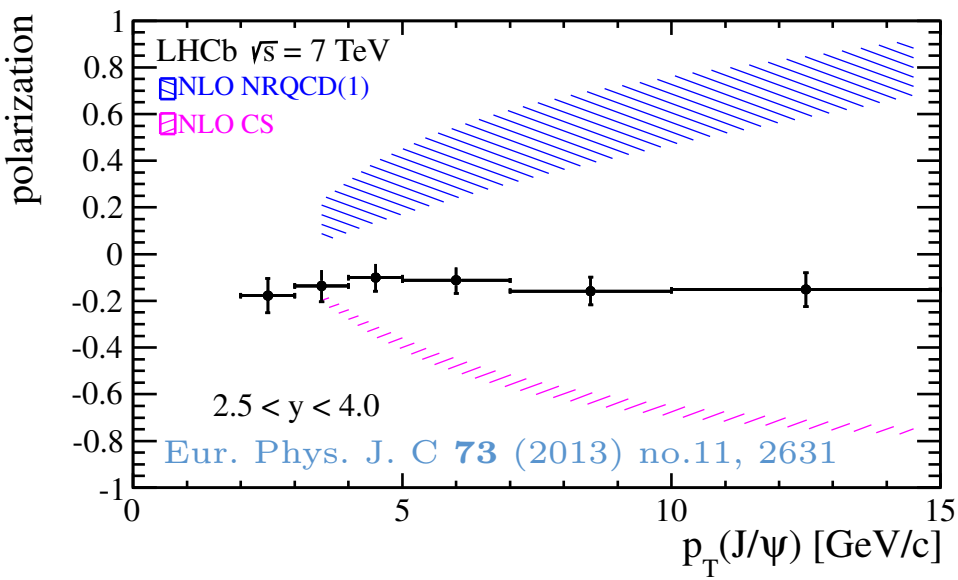
A Little Better

- $8.8\text{fb} < \sigma_{\text{eff}} < 12.5\,\text{fb}$, some model uncertainty

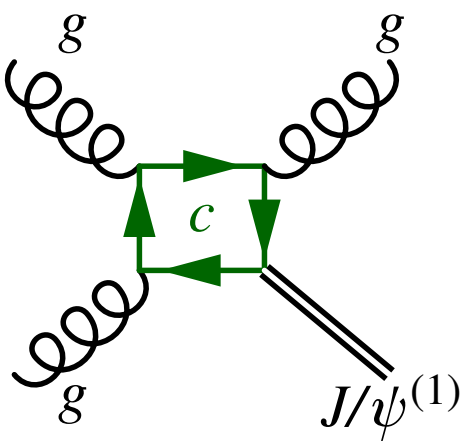


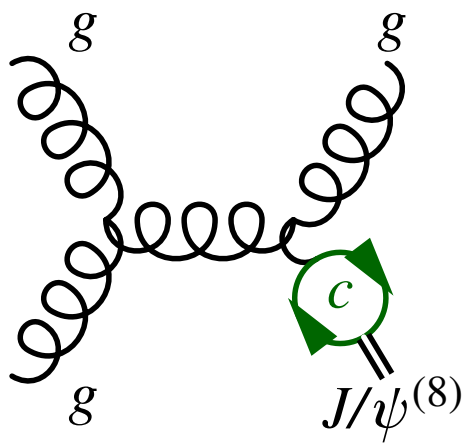
Troubles with Quarkonia





colour singlet
low p_T
longitudinal pol.

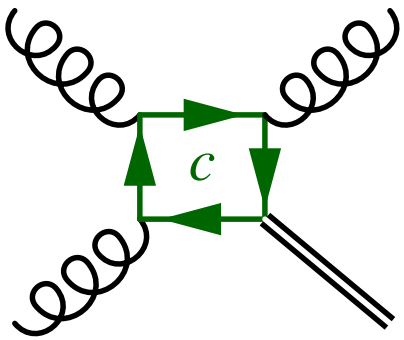




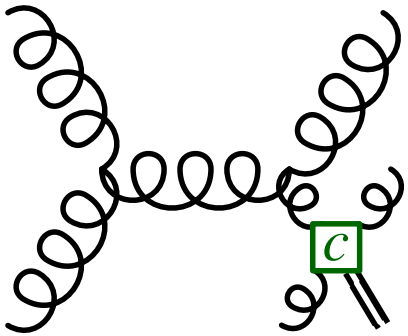
colour octet
high p_T
transverse pol.

A Tale of Two Pictures

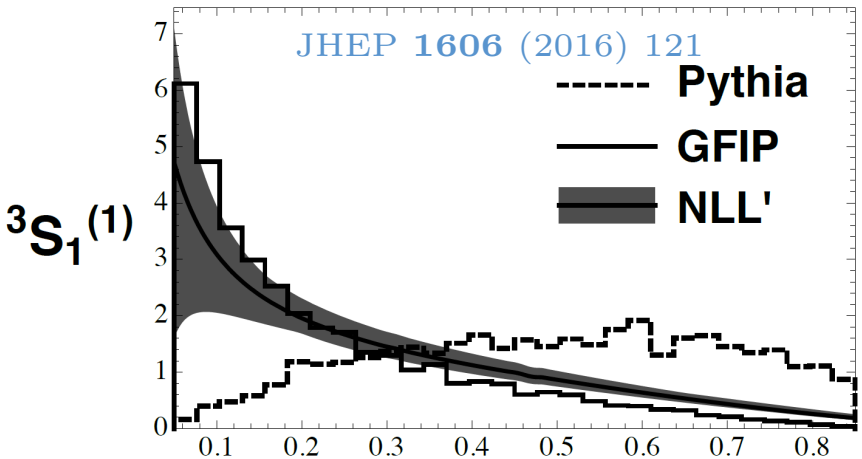
1. NRQCD hard process, octet states showered with QCD splittings
2. shower with NRQCD splittings, match with hard process

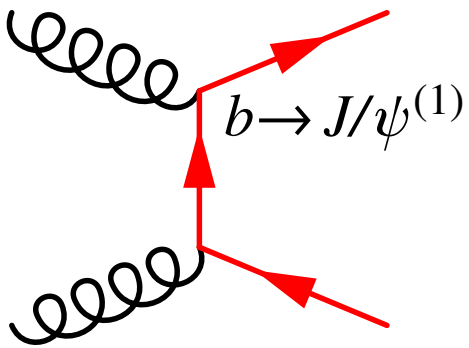


hard production

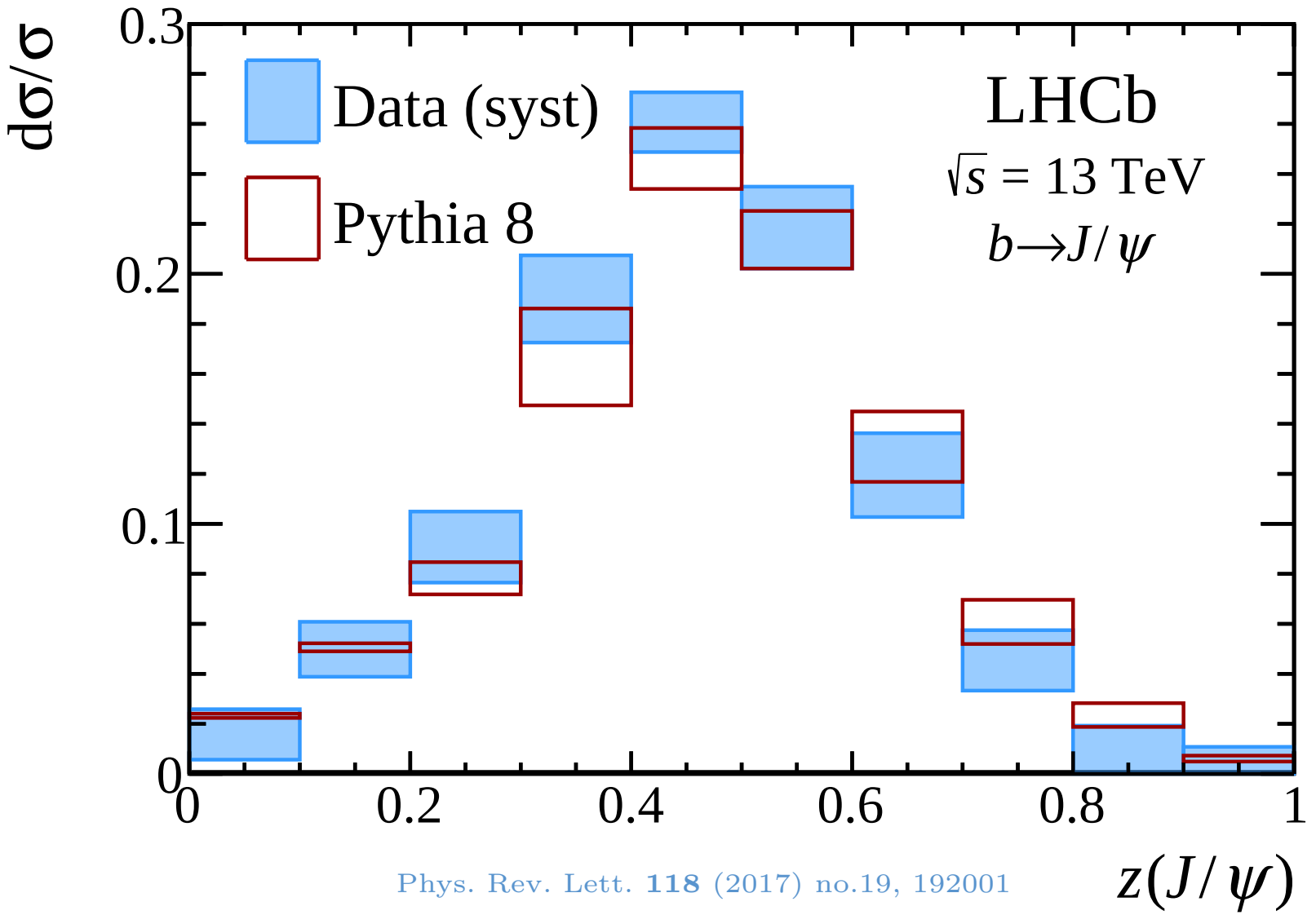


shower production



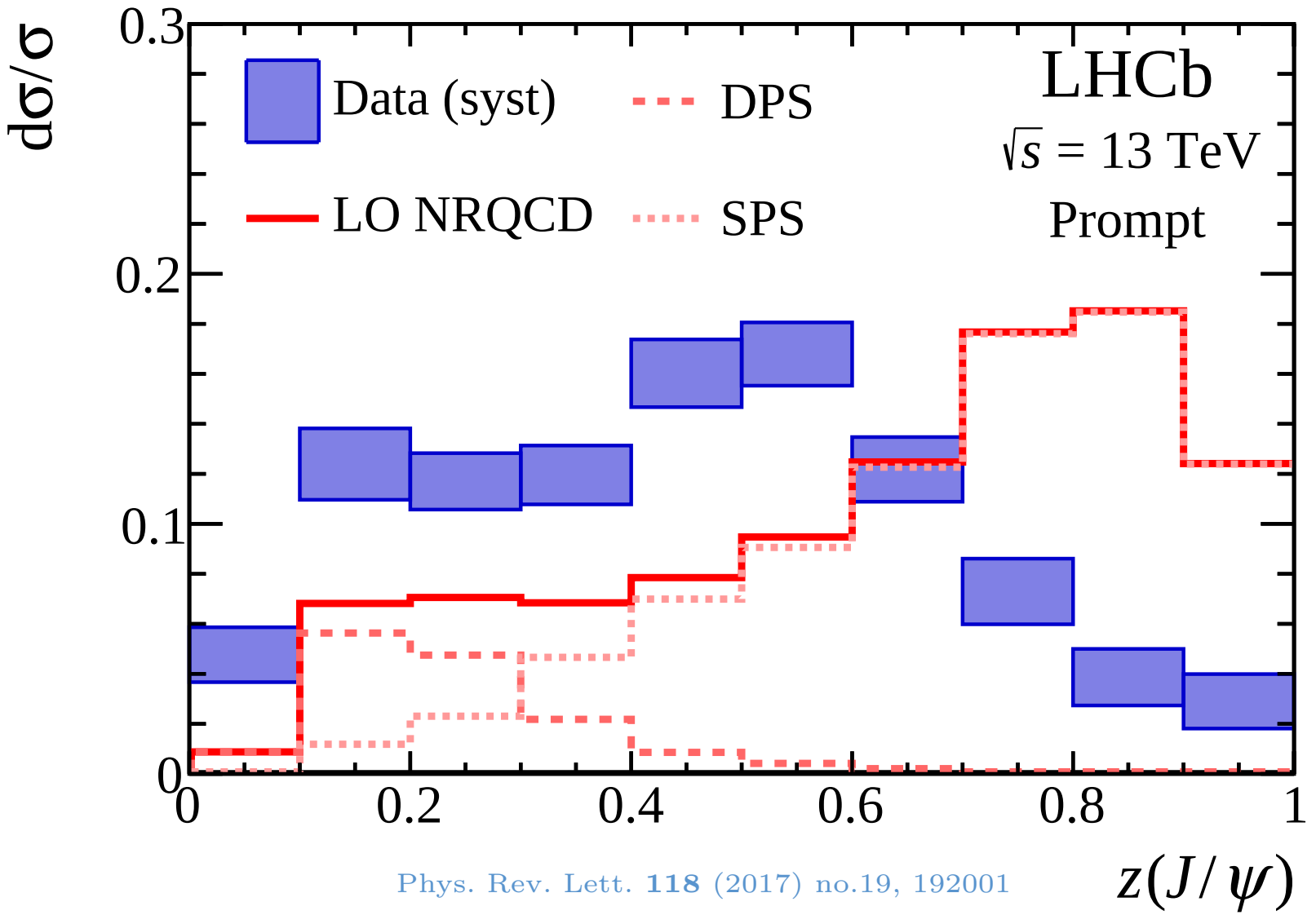


Displaced Results



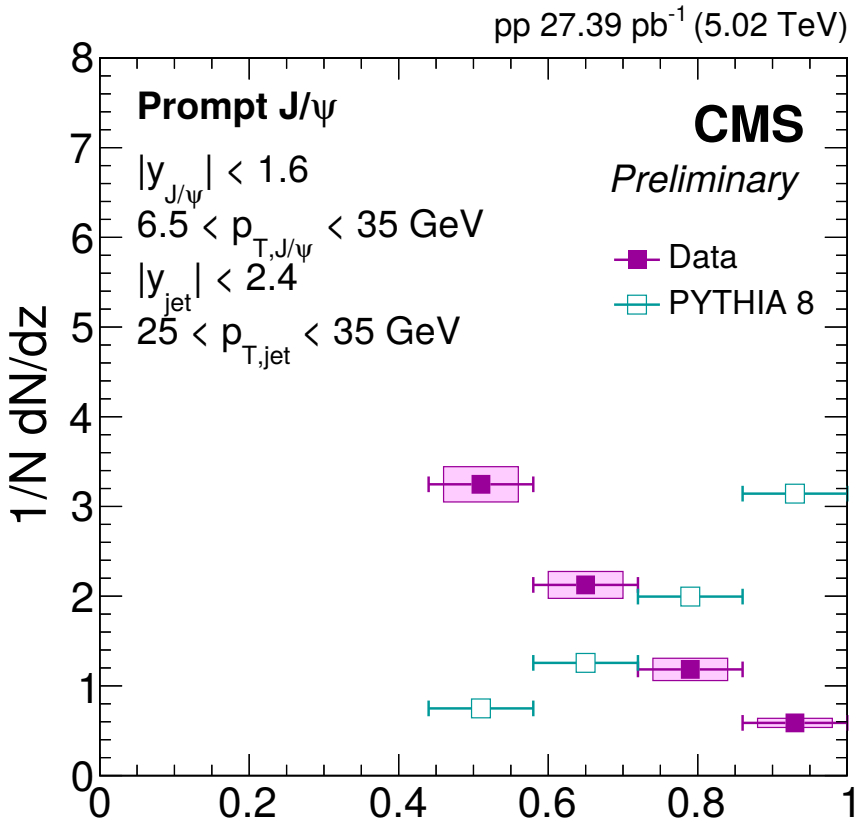
Phys. Rev. Lett. **118** (2017) no.19, 192001

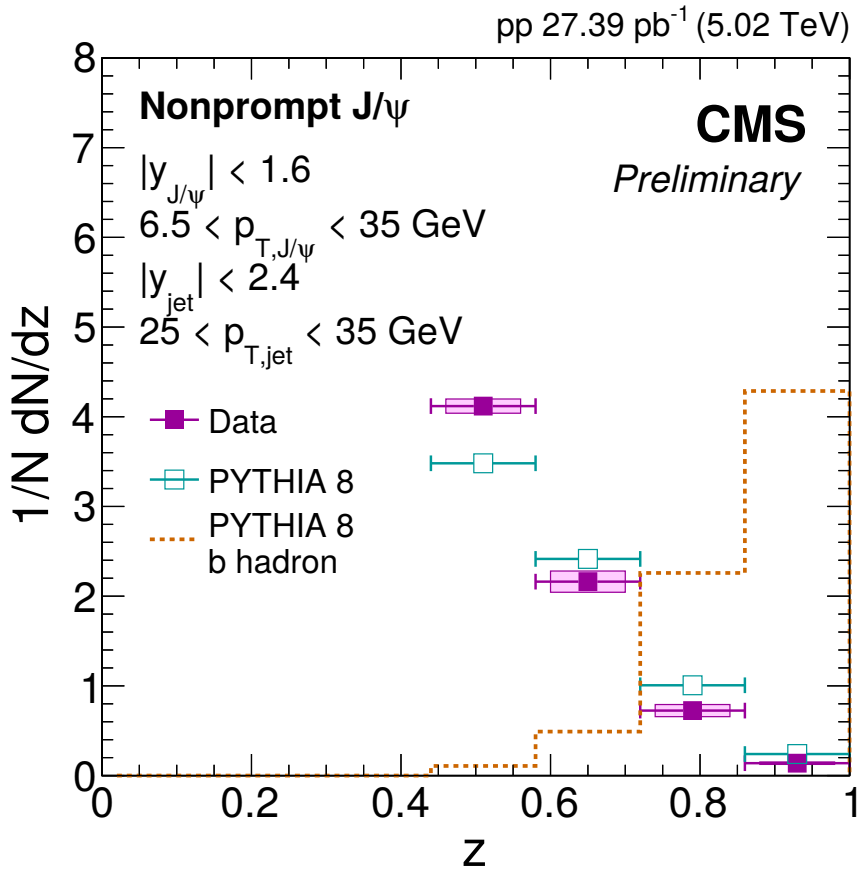
Prompt Results



Phys. Rev. Lett. **118** (2017) no.19, 192001

LHCb's Not Crazy





CMS-PAS-HIN-18-012

Outlook

- LHC measurements are critical for understanding soft QCD
- collective effects have helped unify heavy ions and high energy
- progress has been made in understand these effects, more work needed
- double parton scattering is an important tool for understanding multiparton interactions

Thank you!