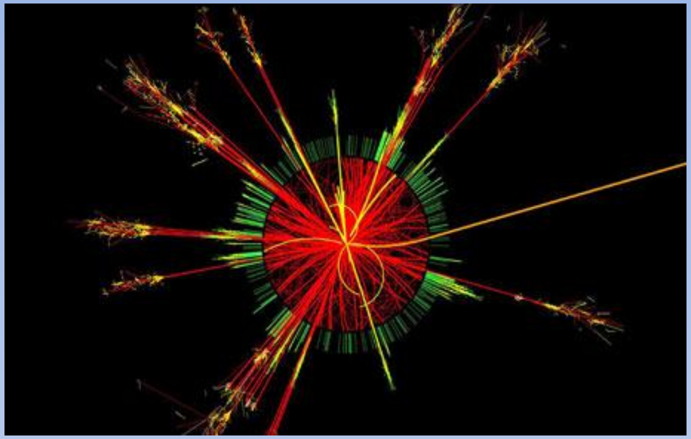


Diffractive W production

Roman Pasechnik

Lund University, THEP group

Based on:

Gunnar Ingelman, RP, Johan Rathsman and Dominik Werder
arXiv:1210.5976

EDS Blois 2013, Saariselkä
September 10th, 2013

In this talk I will touch upon...

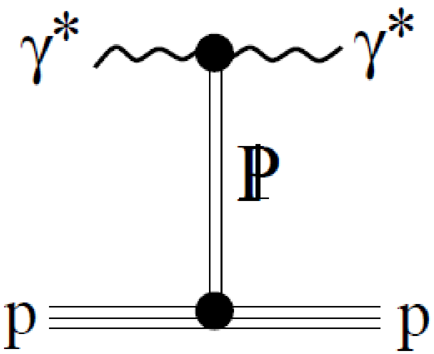
- Diffraction and soft QCD
- Perturbative vs soft color neutralization
- Soft Color Interactions model
- Generalized Area Law model
- Proton coherence in diffraction
- Diffractive W production in Color Reconnection models
- Single leading vs double leading protons
- W rapidity, pT and proton zP distributions at the LHC
- W charge asymmetry: diffractive vs inclusive
- Proton remnant treatment and hadronisation effects
- Discussion and conclusions

Diffraction and soft QCD

Soft processes are characterized by the soft hadronic scale: $R \sim 1\ \mathrm{fm}$

Hadronic diffraction ⟷ **predominantly soft phenomenon**

Regge theory approach

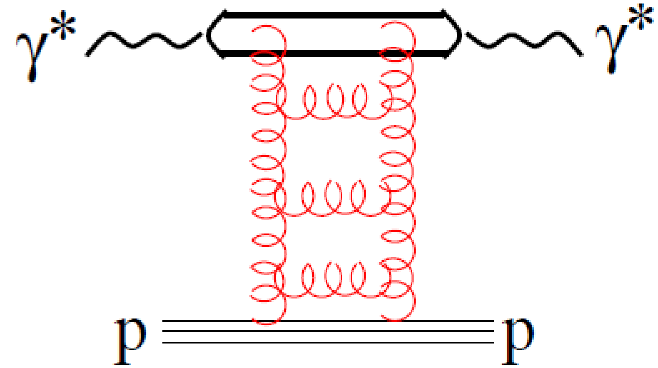


A. Donnachie, P.V. Landshoff, Nucl. Phys. **B231** (1984) 189.

Pomeron structure is still a mystery!

???

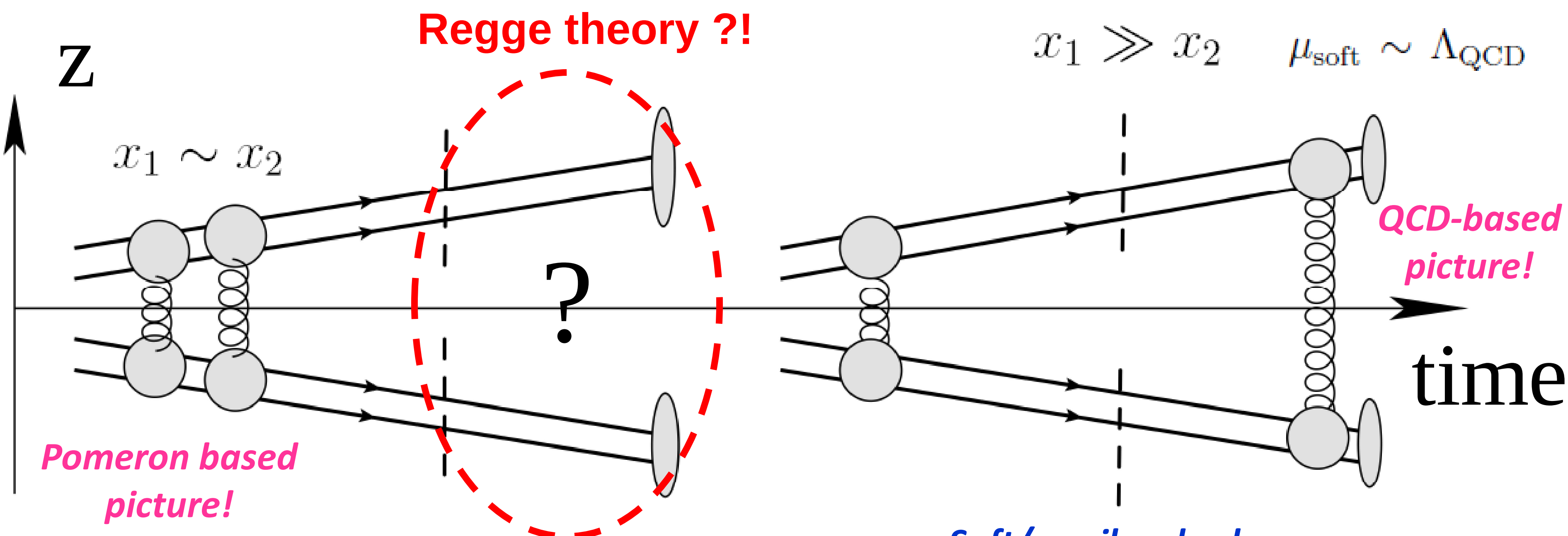
Perturbative QCD approach



pQCD motivated models:

- **Durham QCD mechanism**
- **Color Dipole Approach**
- **Color Reconnections**

Perturbative vs soft color neutralisation



Perturbative color neutralization

Soft/semihard color neutralization

Lack of absorptive effects!

- *Both include unitarity corrections and color neutralisation*
- *Both diffractive – nondiffractive processes*

Model I: Soft Color Interactions model

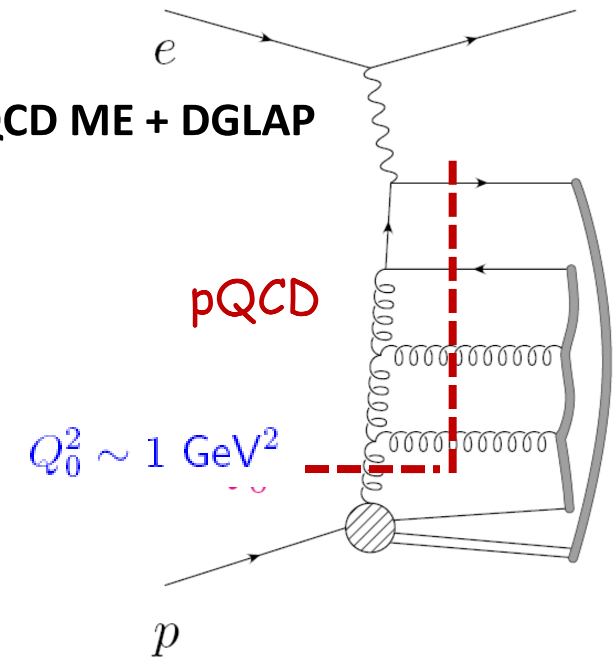
<u>*e.g. Ingelman'97*</u>

Constant color screening probability!

$P_{\text{SCI}} = 0.5$

diffractive ↔ nondiffractive

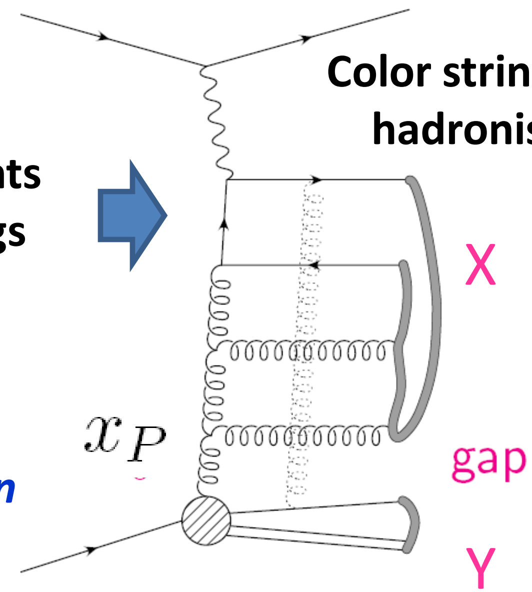
pQCD ME + DGLAP



Color rearrangements modify colour strings topology

Collinear factorisation picture!

Color string (Lund) hadronisation



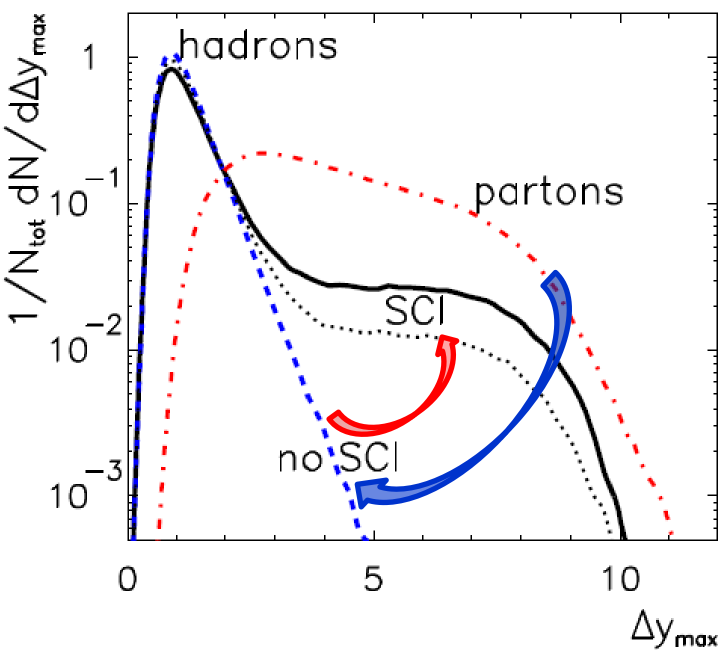
- *Soft interactions among the final state partons and proton remnants (=> proton color field) at small momentum transfers < 1 GeV*
- *Hard pQCD part (small distances) is not affected by soft interactions (large distances)*
- *Single parameter - probability for soft colour-anticolour (gluon) exchange*
- *Single model describing all final states: both diffractive and nondiffractive*

Soft Colour Interaction model (SCI)

Add-on to Lund Monte Carlo's LEPTO (ep) and PYTHIA ($p\bar{p}$)

ME + DGLAP PS $> Q_0^2$	$\rightarrow$	SCI model	$\rightarrow$	String hadronisation $\sim \Lambda$
colour ordered parton state		rearranged colour order		modified final state

Size Δy_{max} of largest gap in DIS events



SCI $\Rightarrow$ plateau in Δy_{max}
characteristic for diffraction

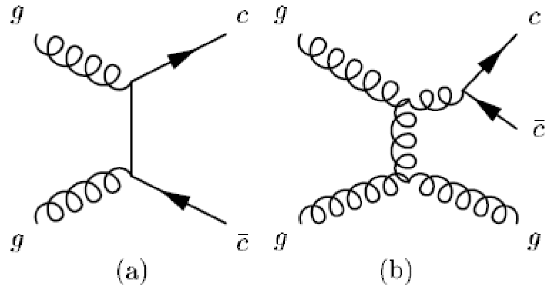
Small parameter sensitivity
— $P = 0.5$
$\cdots$ $P = 0.1$

Gap-size is infrared sensitive observable !

Large gaps at parton level
normally string across $\rightarrow$ hadrons fill up
SCI $\rightarrow$ new string topologies, some with gaps

Gap events not 'special', but
fluctuation in colour/hadronisation

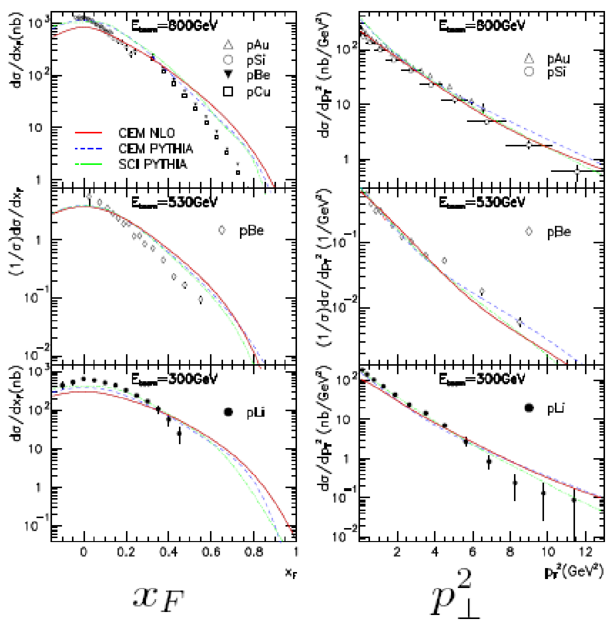
Soft Colour Interaction model → prompt charmonium



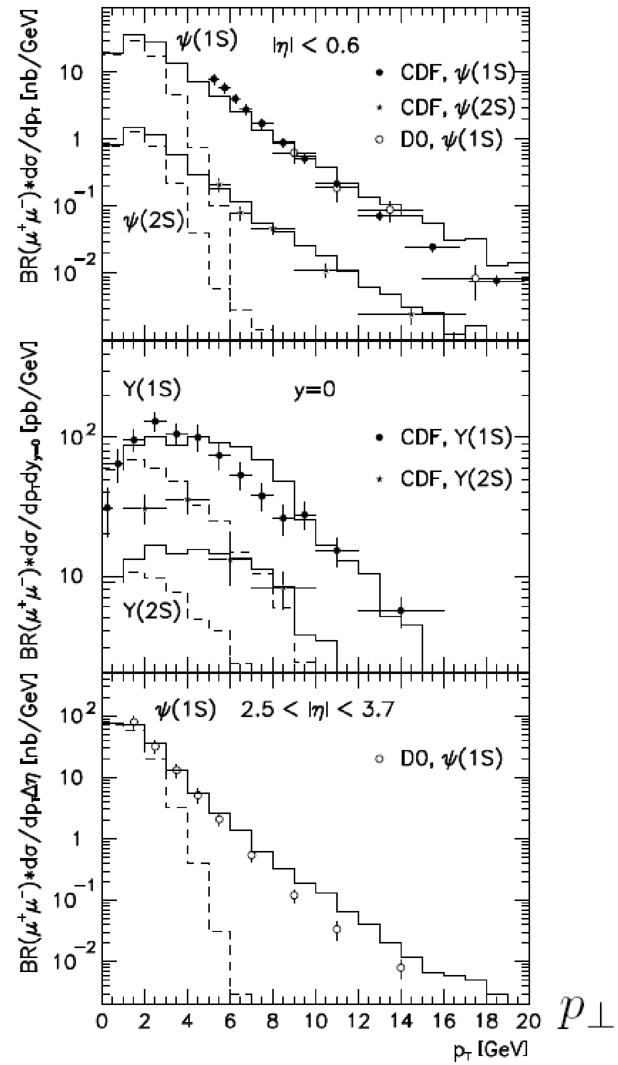
pert. QCD
↓
$c\bar{c}$ pair

Colour octet $c\bar{c}$ turned into singlet $c\bar{c}$

$m_{c\bar{c}} < 2m_D$ mapped on charmonium states
with spin statistics (+ soft smearing)



pA @
800 GeV
530 GeV
300 GeV



J/ψ, ψ' in fixed target πA, pA is OK   High-$p_\perp$ J/ψ, ψ', Υ at Tevatron is OK

A. Edin, G. Ingelman, J. Rathsman, Phys. Rev. **D56**, 7317-7320 (1997)

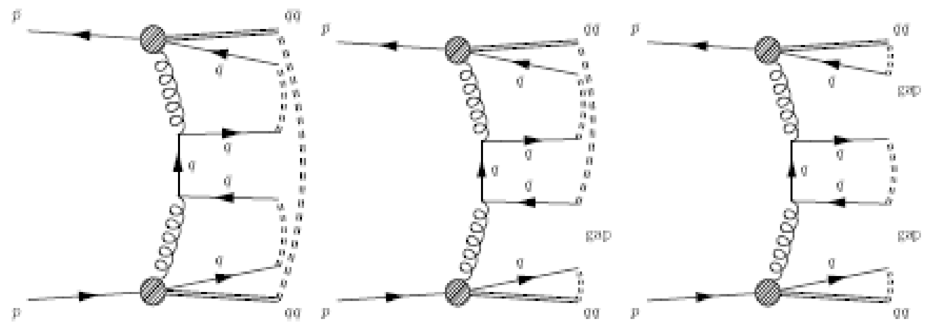
Jets, W, Z, $b\bar{b}$, J/ψ in diffractive gap events at the Tevatron

$$R_{\rm hard} = \frac{1}{\sigma^{\rm tot}_{\rm hard}} \int_{x_{F\min}}^{1} dx_F \, \frac{d\sigma_{\rm hard}}{dx_F}$$

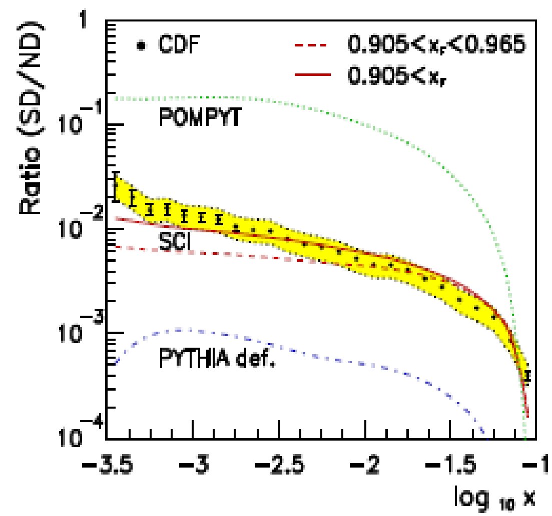
$R_{\rm hard}[\%]$	Exp.	observed	SCI
dijets	CDF	0.75 ± 0.10	0.7
W	CDF	1.15 ± 0.55	1.2
W	DØ	$1.08\,^{+0.21}_{-0.19}$	1.2
$b\bar{b}$	CDF	0.62 ± 0.25	0.7
Z	DØ	$1.44\,^{+0.62}_{-0.54}$	1.0
J/ψ	CDF	1.45 ± 0.25	1.4

↑ predictions

SCI → gap & $c\bar{c}$ colour octet → singlet → J/ψ



$R_{\rm dijets}$ vs x of parton in $\bar{p}$



SCI model OK, also for two-gap (DPE) events

Pomeron model too high, PYTHIA too low

SCI model phenomenologically successful — Why ?

Captures most essential QCD dynamics ⇒ theory emerging . . .

Model II: Generalized Area Law model

e.g. Rathsman'99

The first attempt to make string rearrangement probability dynamical!

Area spanned by a string in momentum space

$$A(p_i, p_j) = 2(p_i \cdot p_j - m_i \cdot m_j)$$

Area difference between two string configurations

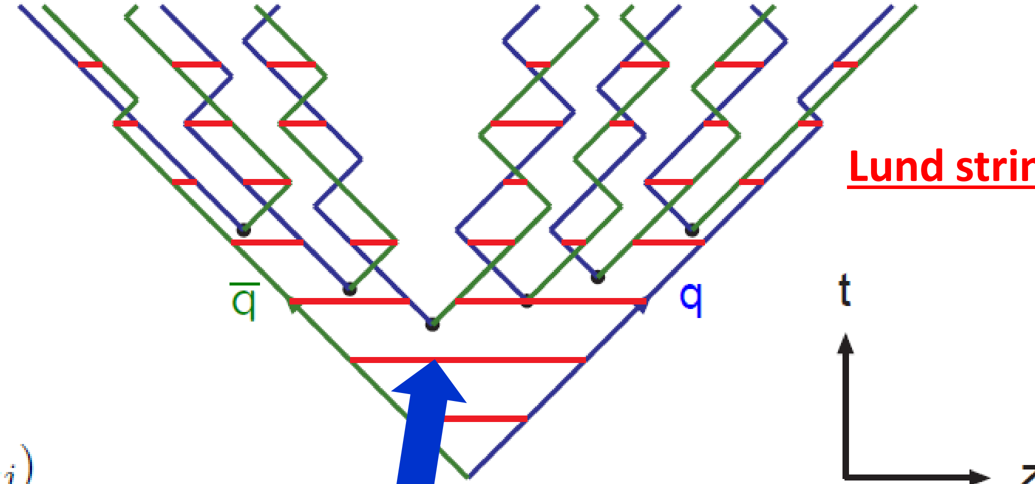
$$\Delta A = A^{\text{old}} - A^{\text{new}}$$

Reconnection probability

$$P_{\text{GAL}} = P_0 \left[1 - \exp(-b\Delta A)\right]$$

$$P_0 \sim 0.1$$

Motion of quarks and antiquarks in a $q\bar{q}$ system:



Lund string model

System prefers to turn to minimal area configuration!

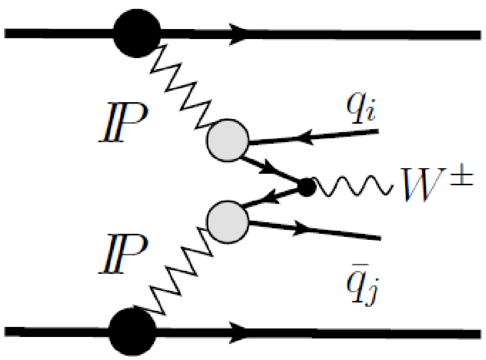
Both SCI and GAL have been adapted to Pythia v6.4

GAL has been successfully applied to inclusive and diffractive DIS

Diffractive W production in color reconnection models

Regge models

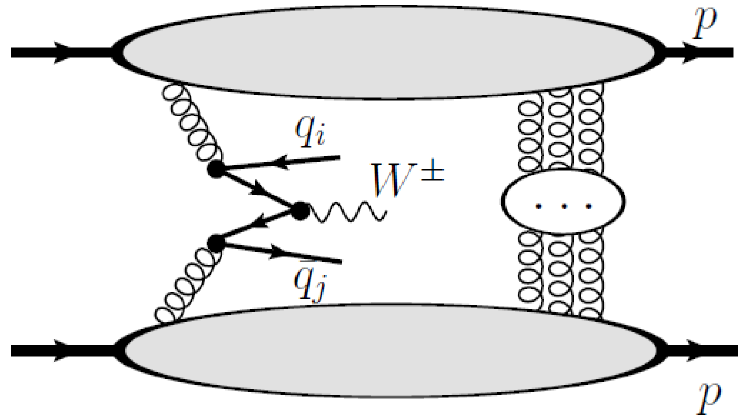
$\sqrt{|t|} \sim \Lambda_{QCD}$



Adv: (1) No issues with hadronisation
(2) Works in arbitrary soft kinematics

Disadv: (1) Unknown QCD origin
(2) Non-universal description of hard and soft asymptotics, energy dependence, inclusive and exclusive topologies

Color reconnection models (e.g. SCI)



Rather strong sensitivity to proton remnant treatment and soft QCD dynamics

Provides important tools for theoretical and experimental studies of soft QCD and the structure of Pomeron

Features:

- ✓ clean environment (color singlet)
- ✓ well-defined hard scale (tests of QCD factorisation)
- ✓ high sensitivity to the production mechanism
- ✓ large enough cross section to be experimentally observed and tested

Leading proton vs gap events

❖ **Leading proton requirement**

The case of CDF with Roman pots

Diffractive (small-x) component:
dominated by gluons!

$$gg \to W q\bar{q}$$

$$x_1 \sim x_2 \sim M_{\rm WX}/\sqrt{s} \ll 1$$

at central rapidities of W+X system!

Picking a quark from the proton state destroys its coherence: the signal in this case is very small and is dominated by remnant (e.g. diquark) fragmentation

Non-Diffractive (large-x) component:
quark-initiated!
most likely at forward rapidities/large W+X invariant masses!

No gap survivals, but strong remnant treatment sensitivity!

We stick to this case!

Theoretical challenge!

❖ **One or two gaps requirement**

The case of CMS

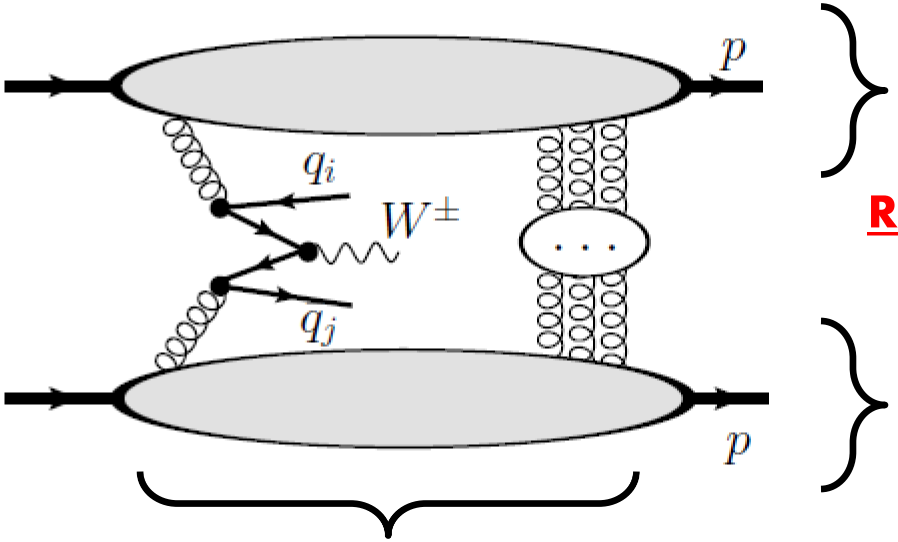
Remnant treatment/hadronisation is not an issue!
BUT! Gap survivals/gap acceptances are important!

❖ **Leading proton and gaps requirement**

Challenge for theory
Hard to measure/analyse

Proton state coherence in diffractive scattering

Consider leading proton case



Recombines back into a proton again

Soft colour exchange is possible before the coherent proton state is destroyed

True ONLY for gluon-initiated processes (no color screening for quark-initiated ones)

High sensitivity to remnant fragmentation

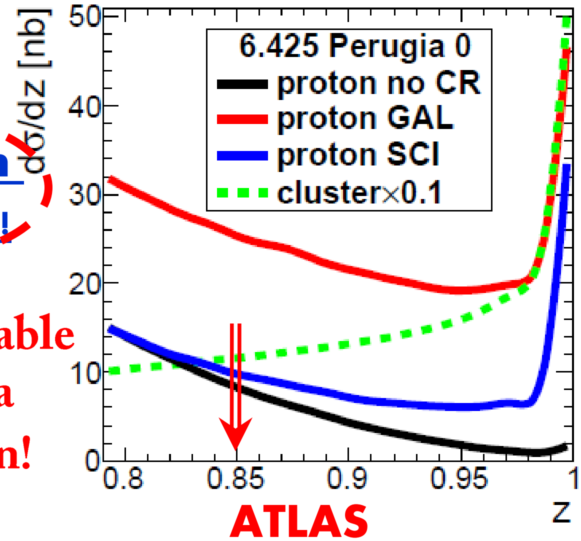
No W-charge asymmetry:
no charge transfer across the gap
(can only appear in quark-initiated processes)

An observation of W charge asymmetry is a probe for Reggeon exchange!

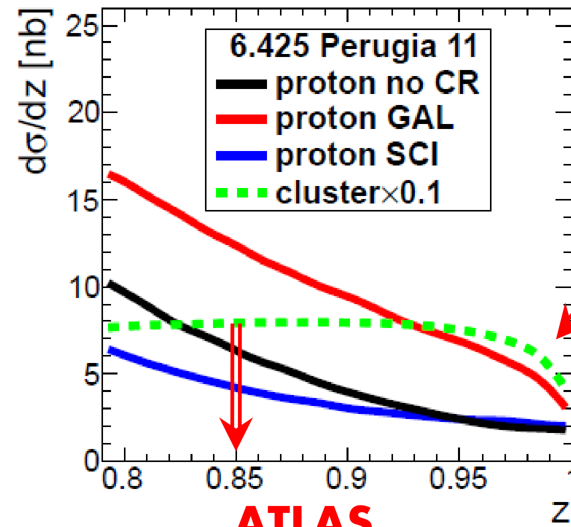
Single leading proton: pZ distributions

Our main scenario!

gives reasonable CDF data description!



ATLAS



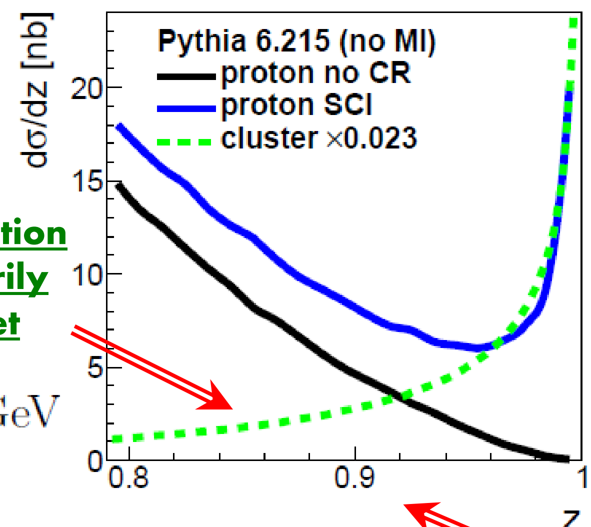
ATLAS

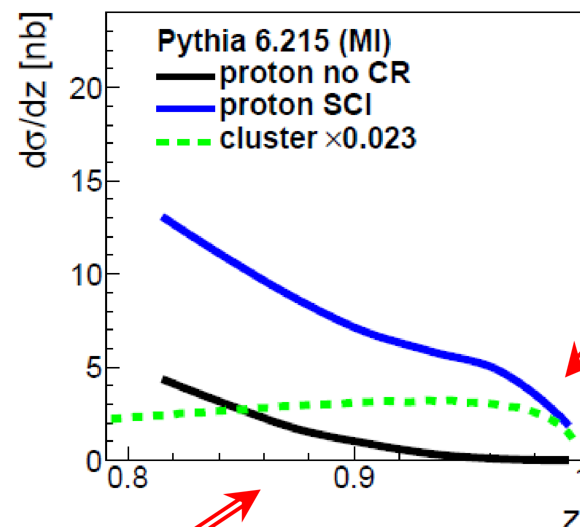
No diffractive peak in Perugia 11 tune

hard radiation from soft proton remnant!?

“Cluster”:
No hadronisation
Not necessarily color singlet

$m_{cl} \leq 1.5$ GeV





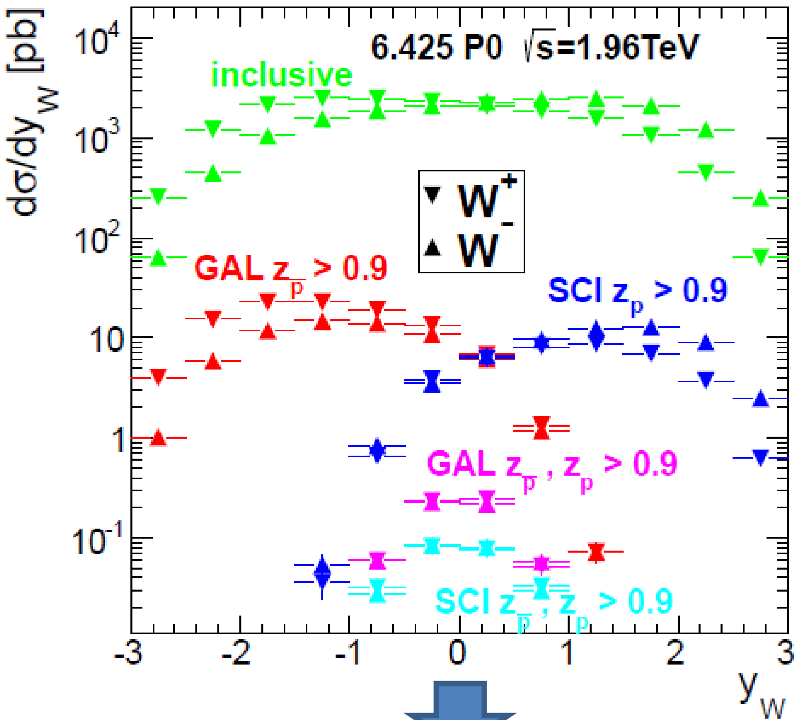
MI dump the diffractive peak

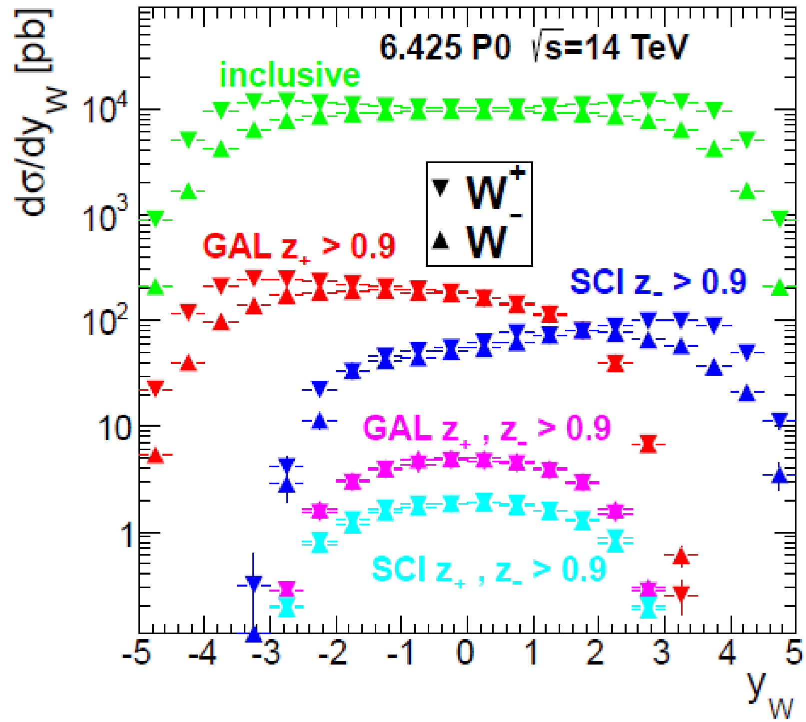
$$z = |p_z|/p_{\rm beam}$$

$$\sqrt{s} = 14 \text{ TeV}$$

Large diquark fragmentation contribution at smaller pZ equivalent to higher Reggeons contribution

Single leading (anti)proton: rates at Tevatron and LHC





Single leading antiprotons-to-inclusive ratio

1.0 % for GAL   0.5 % for SCI

CDF experiment

$(1.00 \pm 0.11)\%$

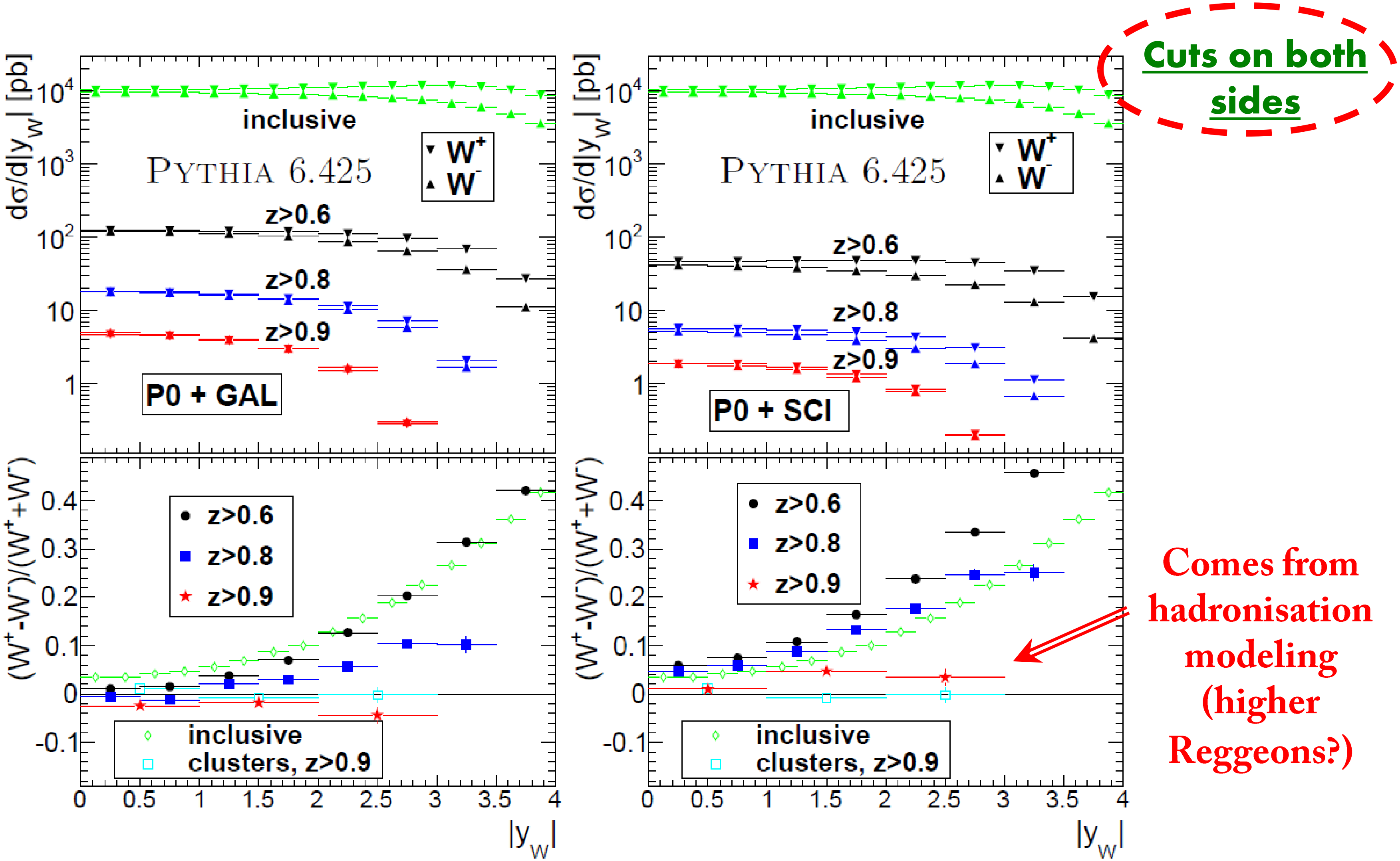
$0.90 < z < 0.97$

Double leading antiprotons-to-single leading ones ratio

0.3 % for GAL   0.2 % for SCI

Good agreement!

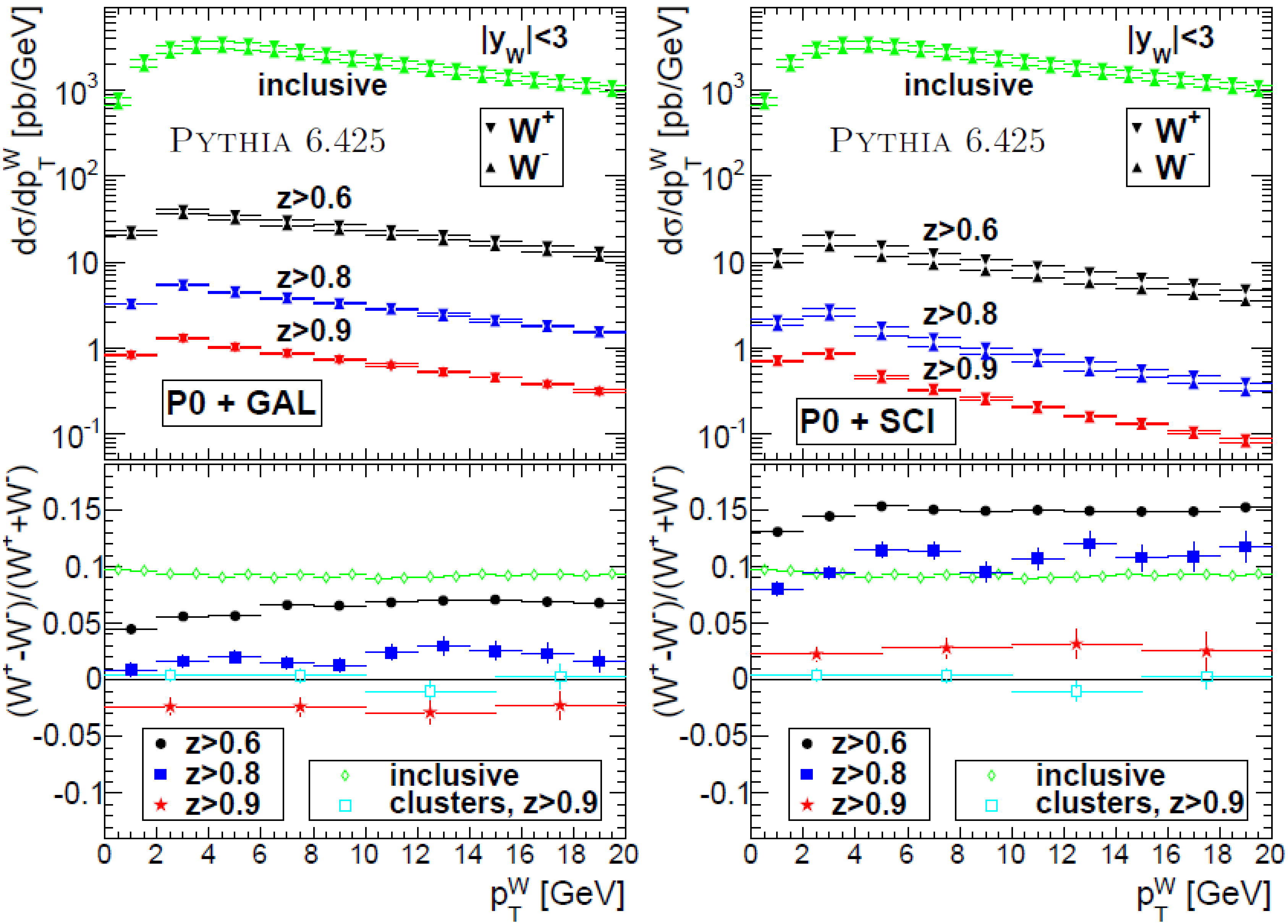
Double leading protons at the LHC: W rapidity dependence



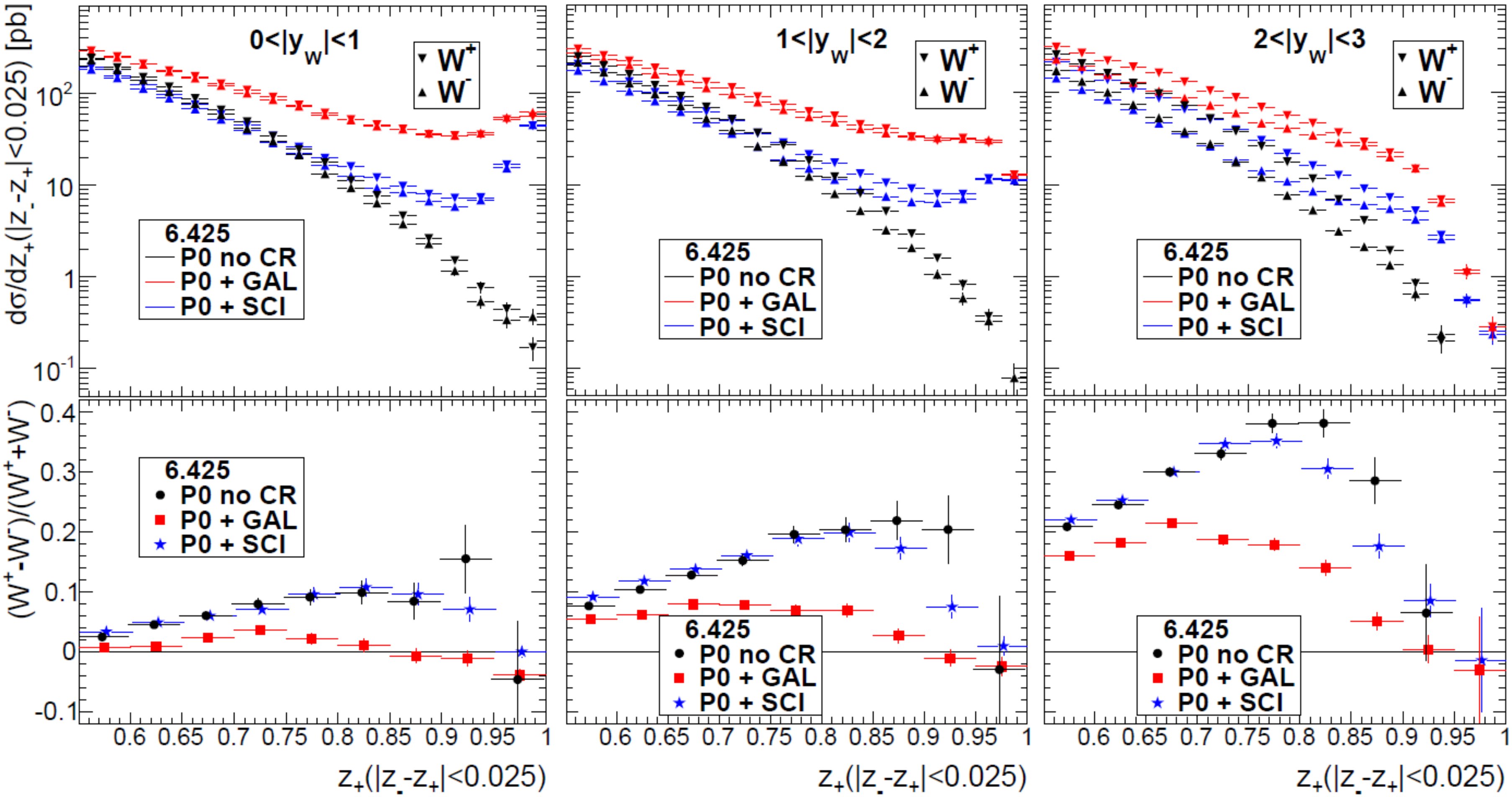
Inclusive asymmetry goes away when cutting on large Z

Mainly gluon-initiated!

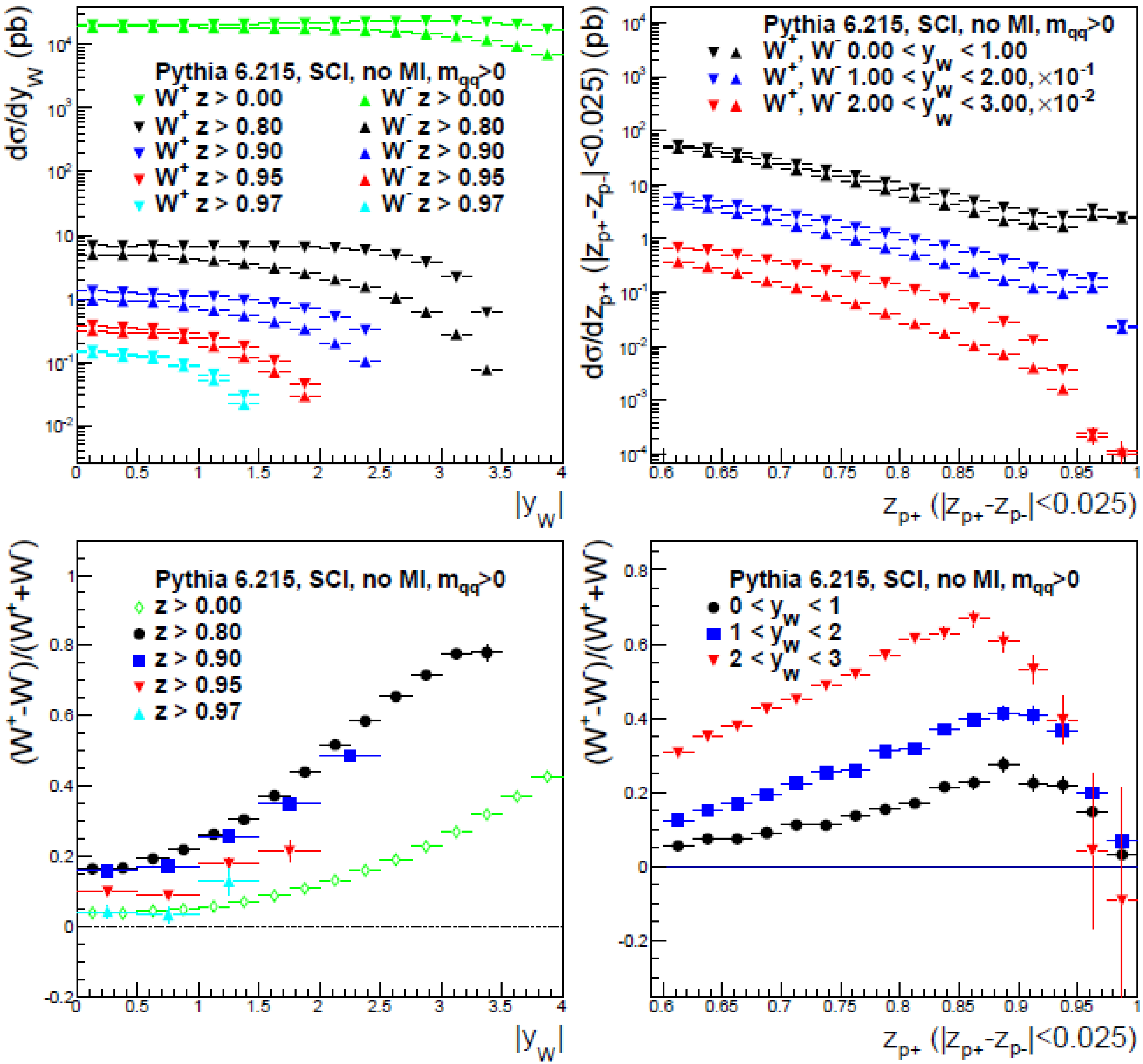
Double leading protons at the LHC: W pT dependence



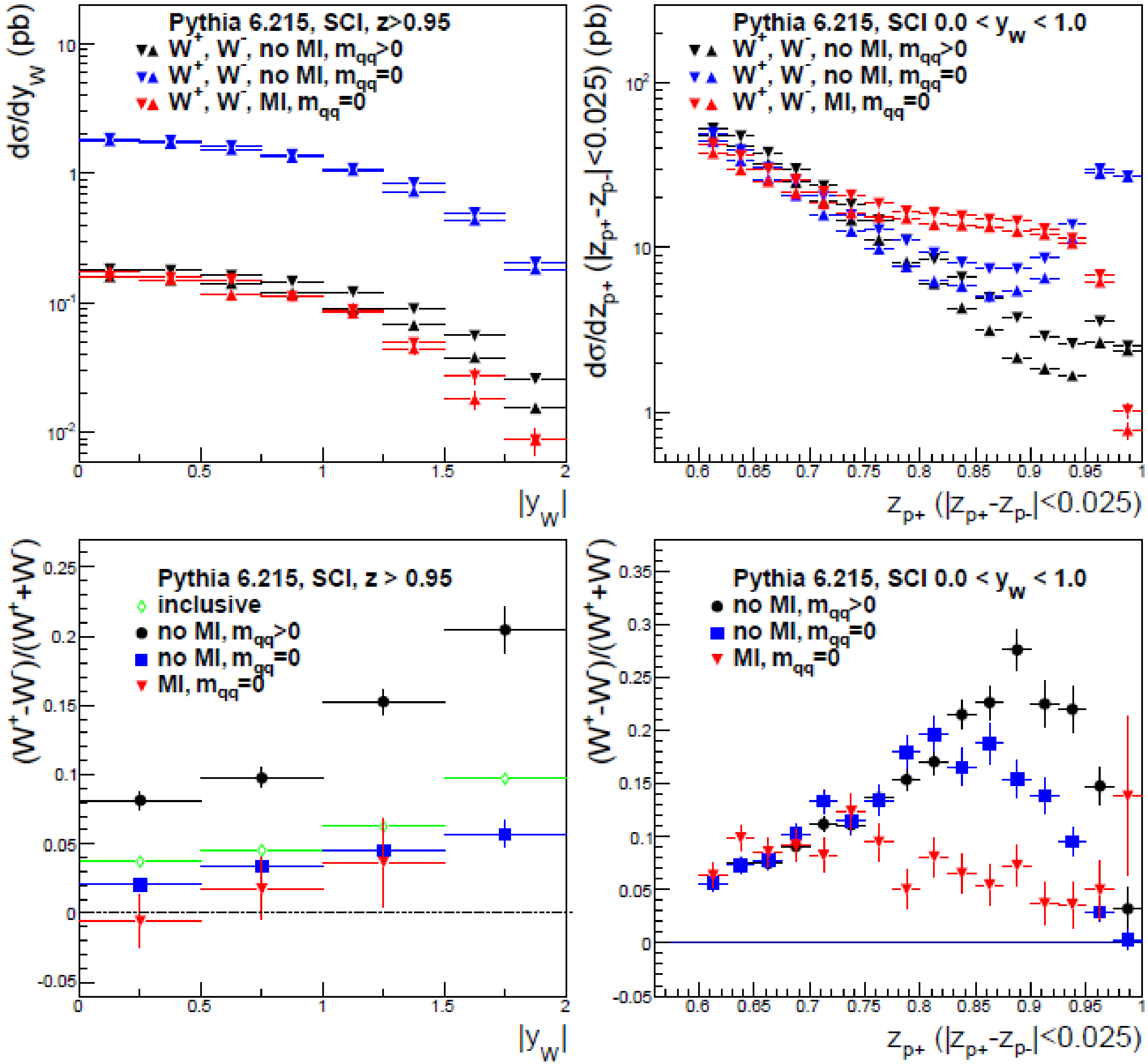
Double leading protons at the LHC: proton zP dependence



Double leading protons at the LHC: Pythia v6.215



Double leading protons at the LHC: Pythia v6.215



Conclusions

- *Basic color reconnection models (SCI and GAL) were applied to the diffractive W production at the Tevatron and LHC (with leading protons requirement)*
- *Monte Carlo (Pythia v6.425) analysis of basic observables is performed*
- *The role of proton remnant treatment and hadronisation effects was studied*
- *Results for Perugia 0, Pythia v6.425 are in agreement with CDF data*
- *Diffractive-like events dominate only at zP>0.95, otherwise the diquark fragmentation dominate the leading proton spectrum*
- *Inclusive charge asymmetry goes away when cutting on large zP, similar to Regge theory predictions*
- *Diffractive signatures are very sensitive to details of the Monte-Carlo modeling: parton showers, multiple interactions, quark/diquark masses*
- *Results for older Pythia v6.215 do not exhibit diffractive signatures (e.g. no forward proton peak) and the signal is dominated by remnant fragmentation due to large constituent quark masses*