Investigation of the underlying event (and multi parton scattering) in pp collisions at the LHC with CMS

QCD@Work

Lecce 18-22 Giugno 2012

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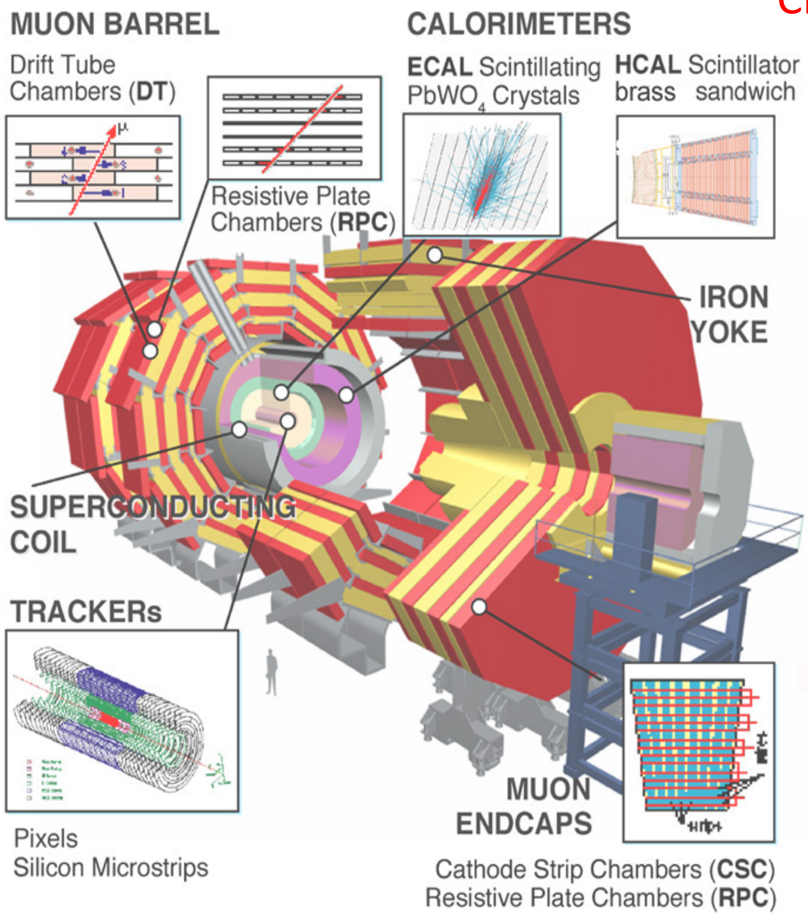
(NTU)

CMS Design features

Detectors



Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

CMS design choice: optimize performance for muon / track momentum resolution (and electromagnetic energy resolution)

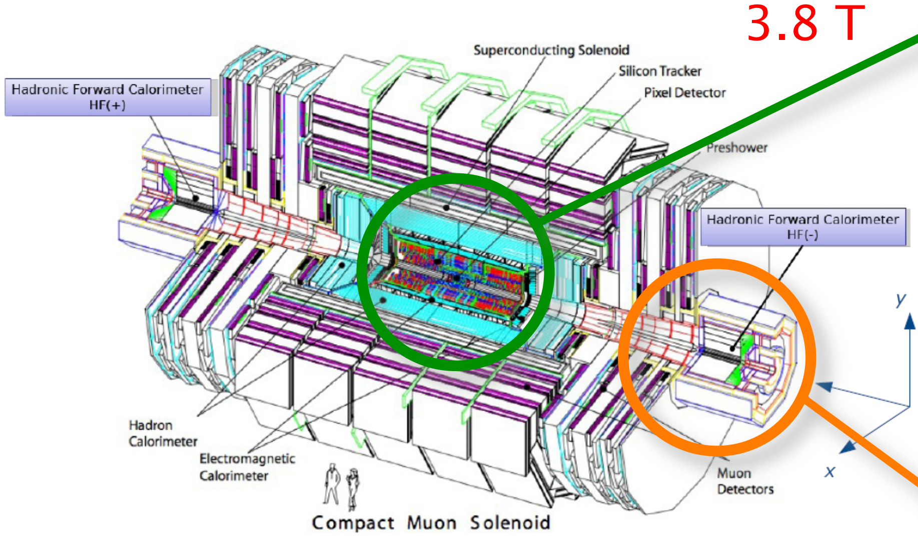
Long 4 Tesla Solenoid containing Tracker, ECAL and HCAL
Tracking up to η ~ 2.4
μ system in return iron
First μ chamber just after Solenoid (max. sagitta)
Big lever arm for P_T measurement

Event Rates:	$\sim 10^9$ Hz
Event size:	~1 MByte
Level-1 Output	~100kHz
Mass storage	$\sim 10^2$Hz
Event Selection:	$\sim 1/10^{13}$

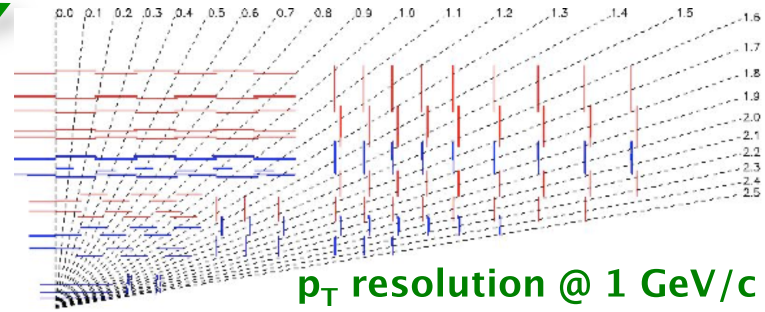
Measuring tracks in CMS

CMS Detector

3.8 T



CMS Tracker



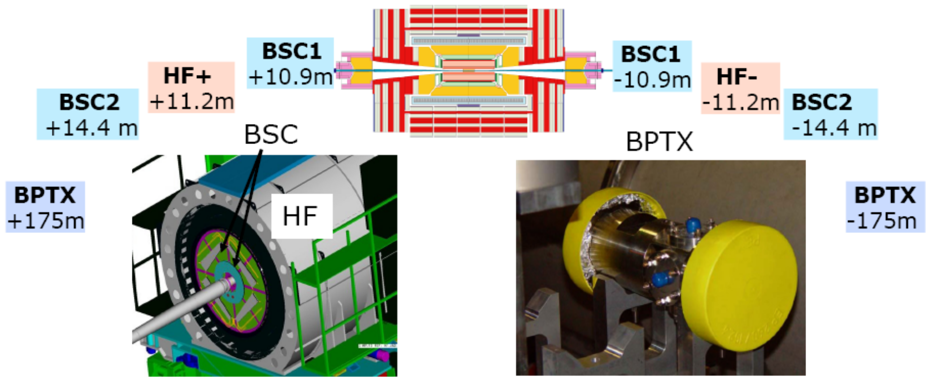
p_T resolution @ 1 GeV/c is:
0.7% at η = 0 and
2% at $|\eta|$ = 2.5

"CMS Tracking Performance Results from early LHC Operation", [Eur. Phys. J. C70 (2010) 1165-1192]

Beam Scintillator Counters (BSC) → 96.3% efficiency for MIPs and time resolution of 3 ns.

Beam Pick-up Timing for eXperiments (BPTX) time resolution better than 0.2 ns.

Trigger System



Hadron Forward:

- @11.2m from interaction point
- rapidity coverage: $3 < |\eta| < 5$
- Steel absorbers/ quartz fibers (Long +short fibers)
- 0.175x0.175 η/φ segmentation

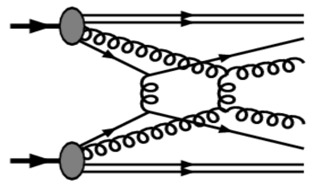
pQCD Models

RADIATION, SPECTATORS…
not enough to account for
the observed multiplicities
& p_T spectra

→

The Pythia solution:
[T. Sjöstrand et al. PRD 36 (1987) 2019]
Multiple Parton Interactions (MPI)
(now available in other general purpose MCs:
Herwig/Jimmy, Sherpa, etc.)

Inspired by observations of double high P_T scatterings



Main Parameter: P_T cut-off P_{T0}

$$\sigma(\widehat{P}_T) \rightarrow \sigma(\widehat{P}_T)\cdot\frac{(\widehat{P}_T)^4}{((\widehat{P}_{T0})^2+(\widehat{P}_T)^2)^2}$$

(dampening)

✓ Cross Section Regularization for $P_T \rightarrow 0$.

✓ P_{T0} can be interpreted as inverse of effective colour screening length.

✓ Controls the number of interactions hence the Multiplicity: $<N_{int}> = \sigma_{parton\text{-}parton} / \sigma_{proton\text{-}proton}$

Tuning for the LHC: Emphasis on the Energy-dependence of the parameters.

- "post Hera" PDFs have increased color screening at low x ?

  $x\,g(x,Q^2) \rightarrow x^{-\varepsilon/2}$ *for* $x \rightarrow 0$

$$P_{T0}^{s'} = P_{T0}^{s}\,(\sqrt{s'}/\sqrt{s})^{\varepsilon}$$

Pythia Tunes in CMS

- Pythia 6 Virtuality ordered showers, old MPIs
  - **CTEQ5L** pre-LHC Tune **DW(T)**
  - **CTEQ6LL** pre-LHC Tune **D6(T)**

  [arXiv:1003.4220]
  - Describe UE and other very important observables at Tevatron like p_T(heavy bosons) and Jet azimuthal decorrelation

PRE-LHC

- Pythia 6 new MPIs with interleaved p_T-ordered showers **(MORE RADIATION, LESS MPIs)**
  - **CTEQ5L** LHC Tune **Z1** uses Professor AMBT1 LEP fragm. & ATLAS Min Bias: **Updated Color Rec.**
  - **CTEQ6LL** LHC Tune **Z2 inherits MPI parameters from Z1 → retuned in Z2***

  [arXiv:1012.5104, **arXiv:1010.3558v1]**

POST-LHC

- Pythia 8, brand new MPI model, inteleaved p_T-ordered showers
  - **CTEQ6LL** Tevatron **Tune 2C** describes the relevant Tevatron phenomenology
  - **CTEQ6LL** LHC **Tune 4C** describes ATLAS MB & UE (leading track)

  [arXiv:1011.1759]

$p_{T0}^{LHC} = p_{T0}^{Tevatron} (\sqrt{s}^{LHC} / \sqrt{s}^{Tevatron})^{\varepsilon}$ **Where ε = PARP(90) or MultipleInteractions:EcmPow**

DW, Z1, Z2 **→ large ε ≈ 0.24 - 0.30 (CTEQ5L, CTEQ6LL** for Z2)

T versions (for example D6T) 2C, 4C, Z2* → small ε ≈ 0.16 - 0.21 (CTEQ6LL)

Still no coherent description of Tevatron and LHC

Underlying Event measurements @ CMS

QCD-10-001: "First Measurement of the Underlying Event Activity at the LHC with √s = 0.9 TeV". Eur. Phys. J. C 70 (2010) 555-572.

QCD-10-010: "Measurement of the Underlying Event Activity at the LHC with √s = 7 TeV and Comparison with √s = 0.9 TeV". JHEP 1109, 109 (2011).

QCD-10-021: "Measurement of the Underlying Event Activity with the Jet Area/Median Approach at 7 TeV and comparison to 0.9 TeV". CERN-PH-EP-2012-152, submitted to JHEP.

QCD-11-012: "Measurement of the Underlying Event Activity in the Drell-Yan process in proton-proton collisions at √s = 7 TeV". CERN-PH-EP-2012-085, arXiv:1204.1411v1, submitted to Eur. Phys. J. C.

FWD-10-008: "Forward Energy Flow, Central Charged-Particle Multiplicities, and Pseudorapidity Gaps in W and Z Boson Events from pp Collisions at 7 TeV. ". Eur.Phys.J. C72 (2012) 1839.

FWD-10-011: "Measurement of energy flow at large pseudorapidities in pp collisions at √s = 0.9 and 7 TeV". JHEP 1111 (2011) 148, Erratum-ibid. 1202 (2012) 055.

FWD-11-003: "Study of the Underlying Event at Forward Rapidity in Proton-Proton Collisions at the LHC". CDS Record: 1434458.

"There would not be a vertex in H → $\gamma\gamma$ events without the Underlying Event…"

…

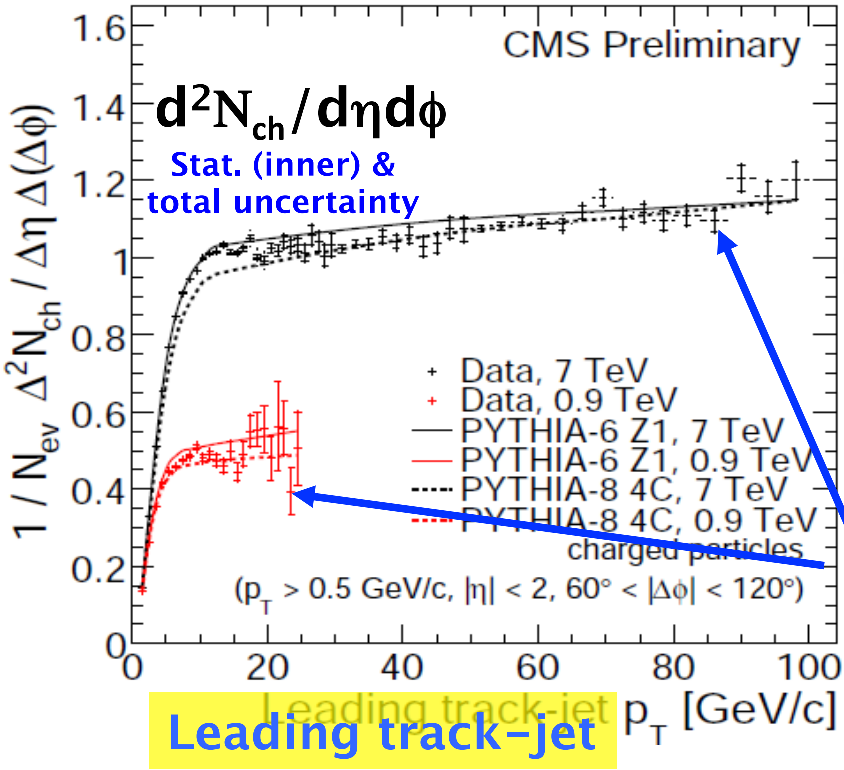
Actually UE is interesting per se! Handle on soft MPI.

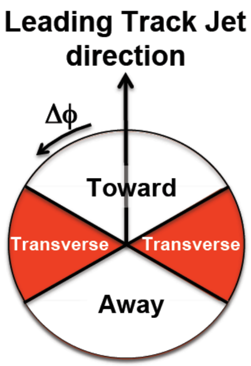
QCD- (or FWD-) XX-YYY: ….

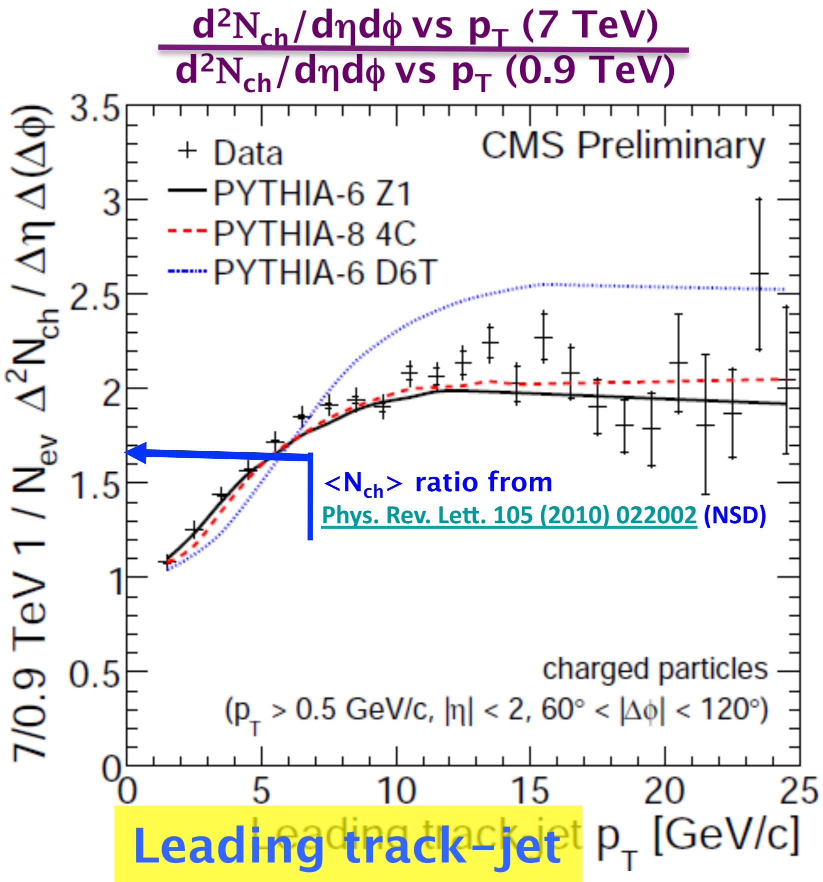
[FWD-XX-YYY]

UE in Jets: Densities in the Transverse Region

7 TeV and 0.9 TeV results for the reference charged multiplicity density profiles including Z1 (solid) and 4C (dashed) MC predictions.







Fast rise for p_T < 8 GeV/c (4 GeV/c), attributed mainly to the **increase of MPI activity**, followed by a **Plateau-like region** with ≈ constant average number of selected particles in a **saturation regime**.

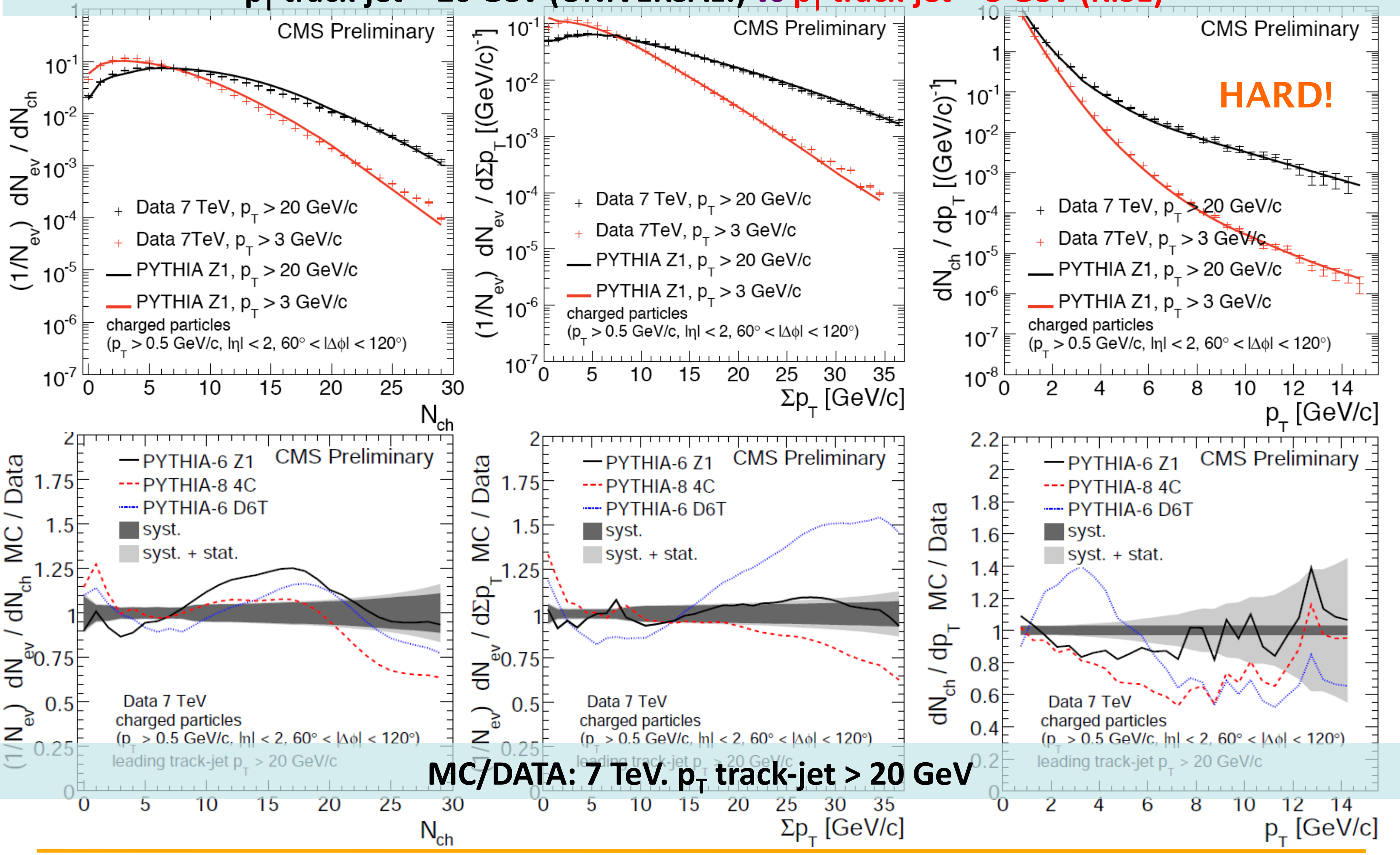
A factor 2 UE increase going from 0.9 TeV to 7 TeV to be compared with 1.66 for MB.

Nota bene: corrected distributions!

See interpretation of M.Strikman et al. Phys. Rev. **D83 (2011) 054012**
more details in back-up slides

UE in Jets: $\sqrt{s}$ = 7 TeV. N_{ch}, $\Sigma(p_T)$ and p_T in Transverse Region

p_T track-jet > 20 GeV (UNIVERSAL!) vs p_T track-jet > 3 GeV (RISE)



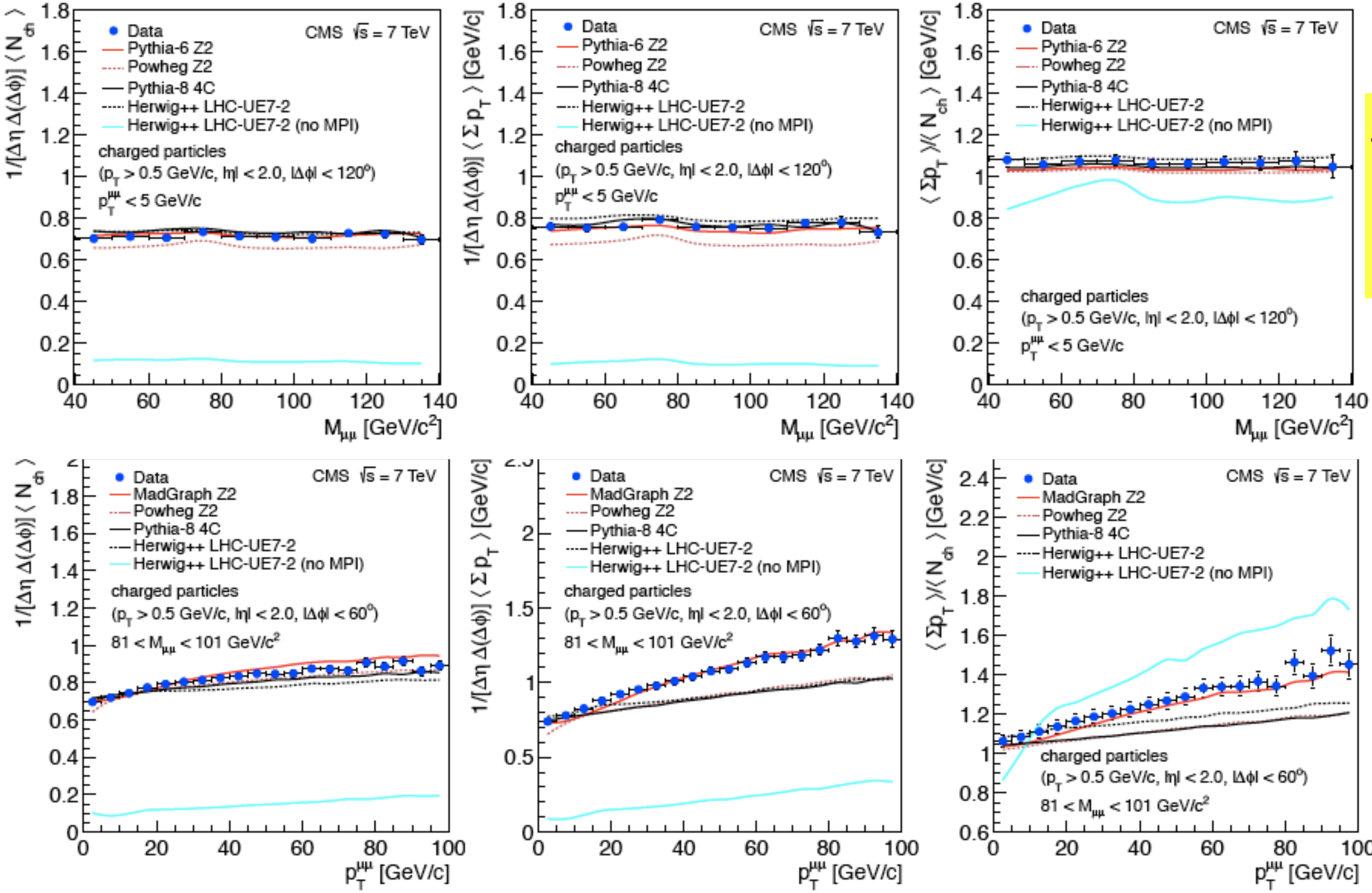
MC/DATA: 7 TeV. p_T track-jet > 20 GeV

[QCD-10-001, QCD-10-010]

UE activity in Drell-Yan events (μμ)

81 GeV < Mμμ < 101 GeV

particle density | energy density | ratio of energy and particle densities



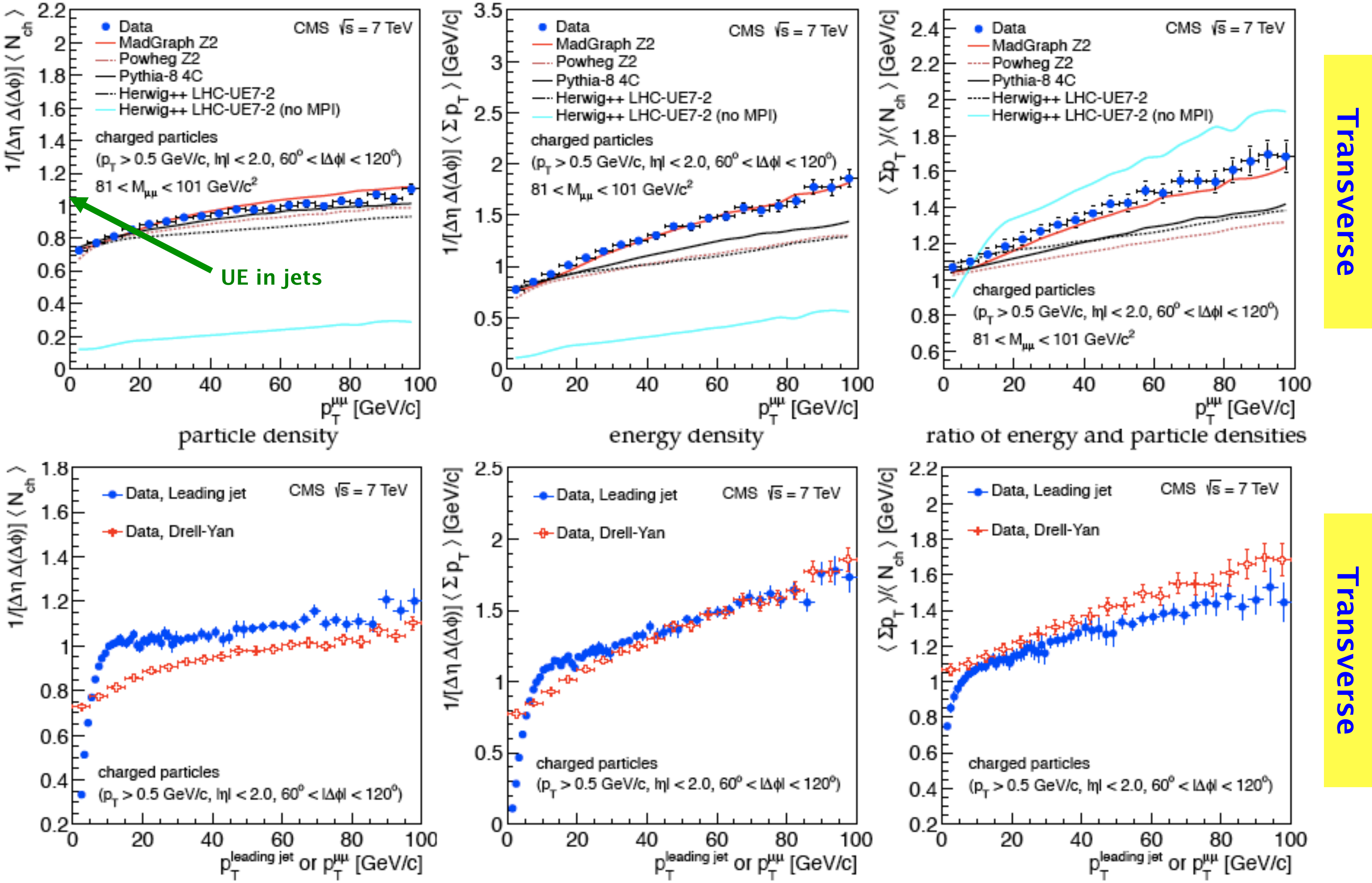
Toward & Transverse $p_T^{\mu\mu} < 5$ GeV

Toward

[QCD-11-012]

UE activity in Drell-Yan events (μμ)

81 GeV < Mμμ < 101 GeV



[QCD-11-012]

MPI vs Generalized Parton Distributions

"Transverse nucleon structure and diagnostics of hard parton-parton processes at LHC".

[M.Strikman @ Northwest Terascale w/s and **Phys. Rev. D83 (2011) 054012**]

Gluon transverse size decreases with increase of x

$<\rho^2>_g$ from analysis of GPDs from J/ψ photo production

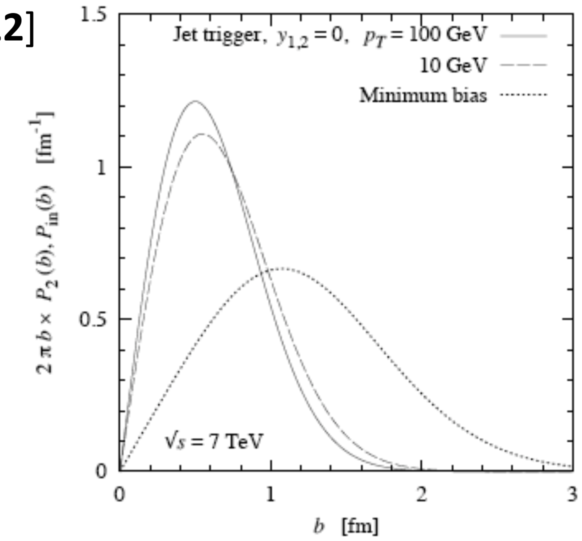
Transverse size of large x partons is much smaller than the transverse range of soft strong interactions

$$\langle \rho^2 \rangle_g = \frac{\partial}{\partial t} \frac{G(x.t)}{G(x,0)}$$

$$\langle \rho^2 (x > 10^{-2} \rangle \ll R^2_{soft}$$

$\Downarrow$

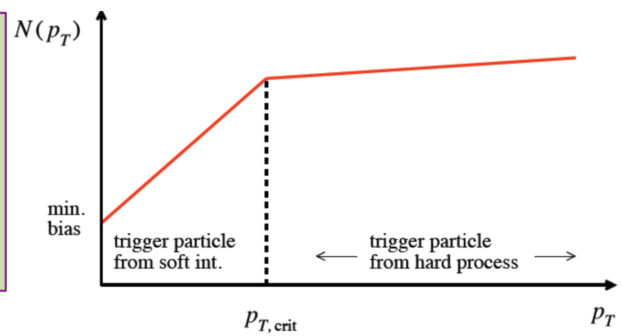
Two scale picture



Impact parameter distributions of inelastic pp collisions at $\sqrt{s}$ = 7TeV. Solid (dashed) line: Distribution of events with a dijet trigger at zero rapidity, $y_{1,2}$ = 0, c, for p_T = 100 (10) GeV . Dotted line: Distribution of minimum–bias inelastic events (which includes diffraction).

Also explains general features of UE @ hadron colliders

$<\rho^2>_g$ < $<\rho^2>_q$ explains UE in DY < UE in Jets



A new approach to UE: Jet Area/Median

Based on the paper: "On the characterization of the underlying event"; JHEP04(2010)065; M. Cacciari, G. Salam, S. Sapeta.

The underlying event activity is given by ρ=median{p_T/A}. (less sensitive to outliers!)

To estimate the jet area η-ϕ cells are filled by ghost deposits of O(10^{-100} GeV).

FastJet [arXiv:hep-ph/0512210] essential to speed up the calculation.

0.9 TeV: ghost jets dominate the median!!!

→CMS Adjusted observable for low occupancy:

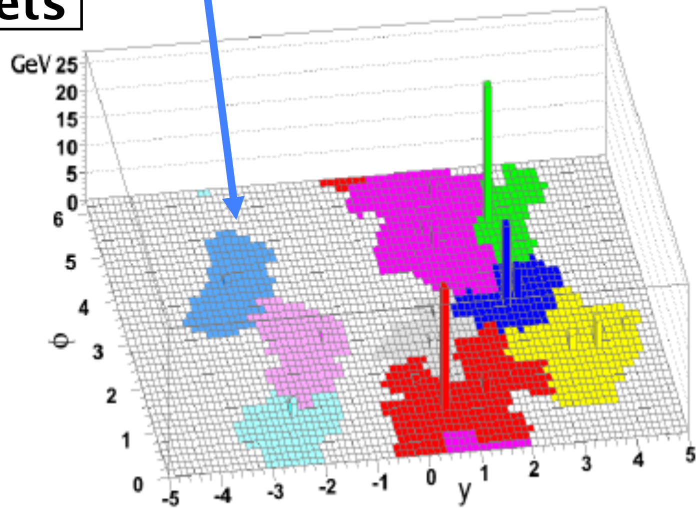
$$\rho' = \underset{j \in physical\ jets}{median}\left[\left\{\frac{p_{T,j}}{A_j}\right\}\right] * C$$

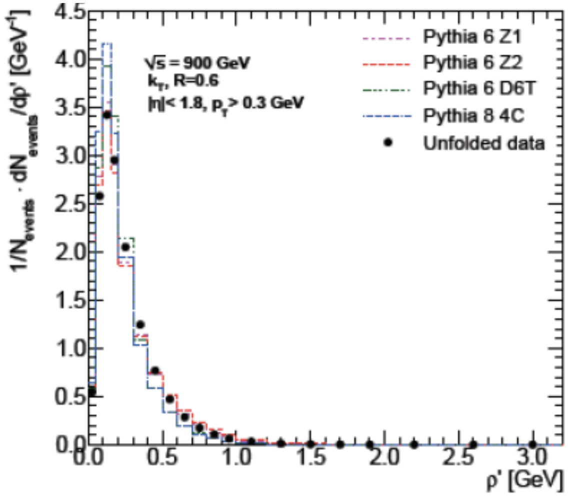
$$C = \frac{\Sigma_j A_j}{A_{tot}}$$

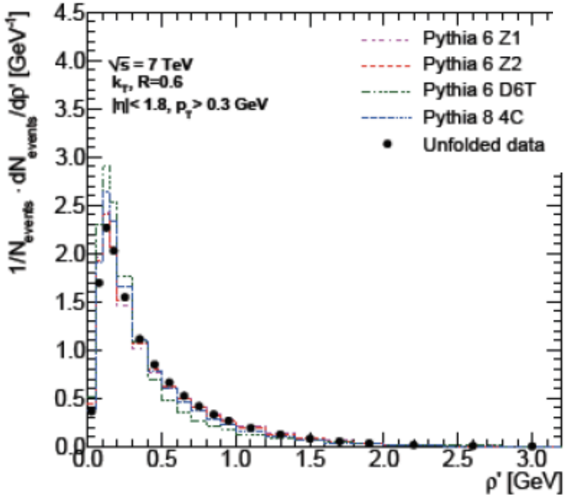
Tracks: p_T > 0.3 GeV

|η| < 2.3

k_T jets





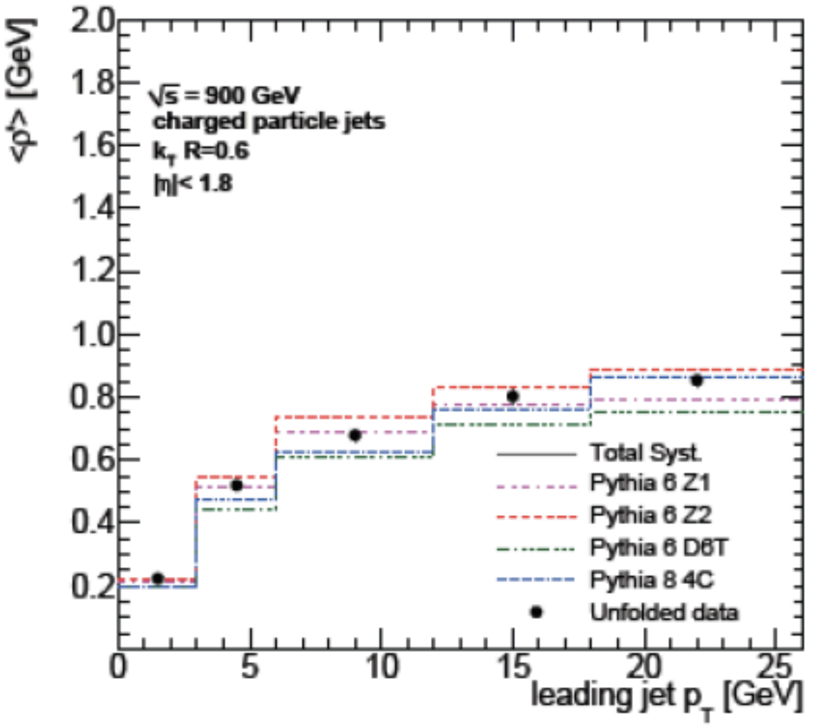


Clear sensitivity to the differences between the Models / Tunes

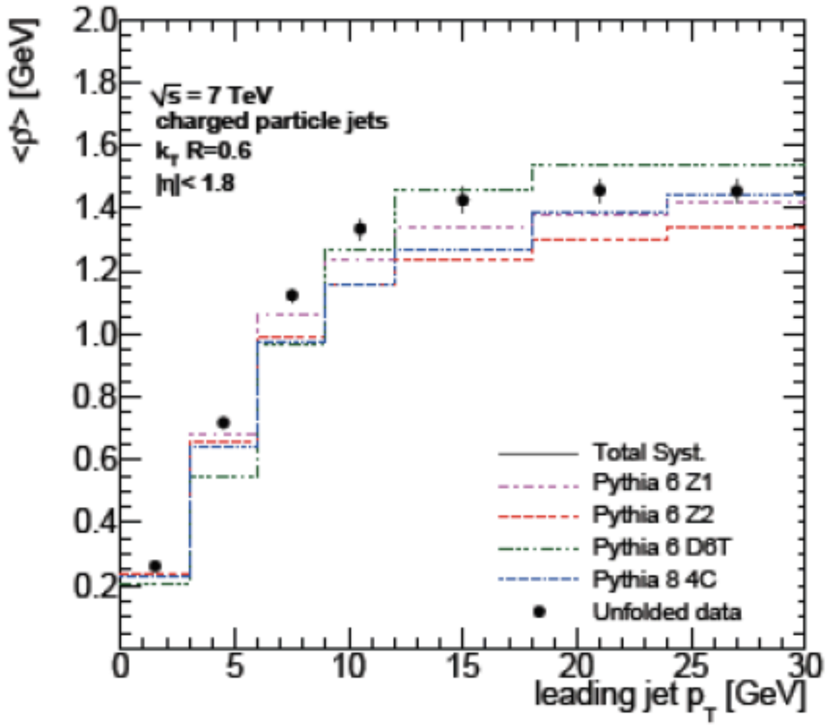
A new approach to UE: Jet Area/Median

The energy evolution of the new Underlying Event observables shows similar qualitative features with respect to the traditional approaches used to quote the UE activity (i.e. charged multiplicity and charged transverse momentum densities).

√s = 0.9 TeV



√s = 7 TeV



Energy flow in the forward region

- Measurement relies on the energy flow in the Hadron Forward Calorimeter ($3.15 < \eta < 4.9$) in the presence of events "triggered" by a more central activity (Minimum Bias, di-Jets)

→Test of central-forward correlations

- Corrected data

  - Distributions studied:

$$E_{FLOW}(dijet) = \frac{1}{N_{dijet}} \frac{\Delta E}{\Delta \eta}(dijet)$$

$$E_{FLOW}(minbias) = \frac{1}{N_{minbias}} \frac{\Delta E}{\Delta \eta}(minbias)$$

- Two different √s included: 0.9 and 7 TeV

Definition of di-Jet samples: $|\eta| < 2.5, |\Delta\phi_{jet1,jet2} - \pi| < 1$

  - p_T Calo Jet > 8 GeV at 0.9 TeV
  - p_T Calo Jet >20 GeV at 7 TeV

MB event selection: At least one charged particle in both the forward and the backward regions. (Single Diffractives events suppressed)

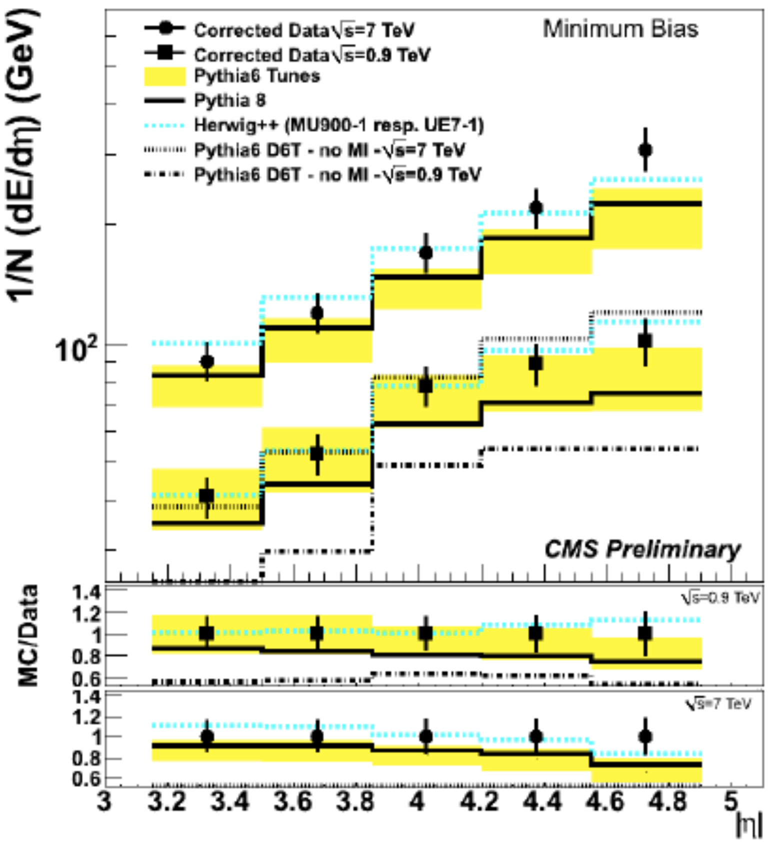
Energy flow in the forward region

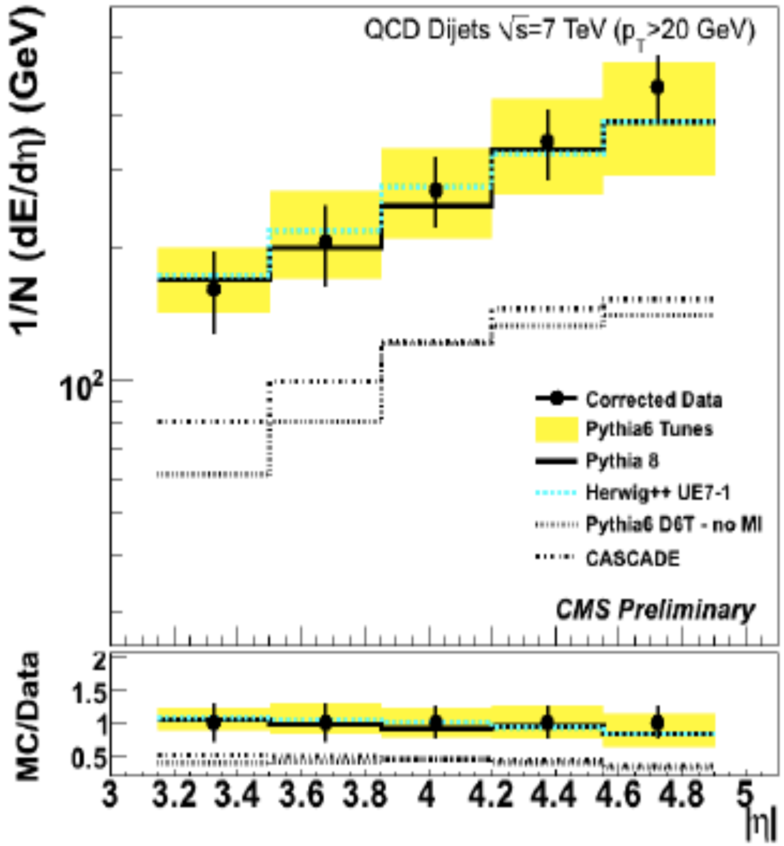
Energy flow increases with the scale (MB vs di-jet) & √s:

→ Effect attributed mainly to MPI.

Pattern very similar with respect to the traditional UE measurement from both a quantitative and a qualitative point of view.

Energy flow also increases with η (close to beam remnant)



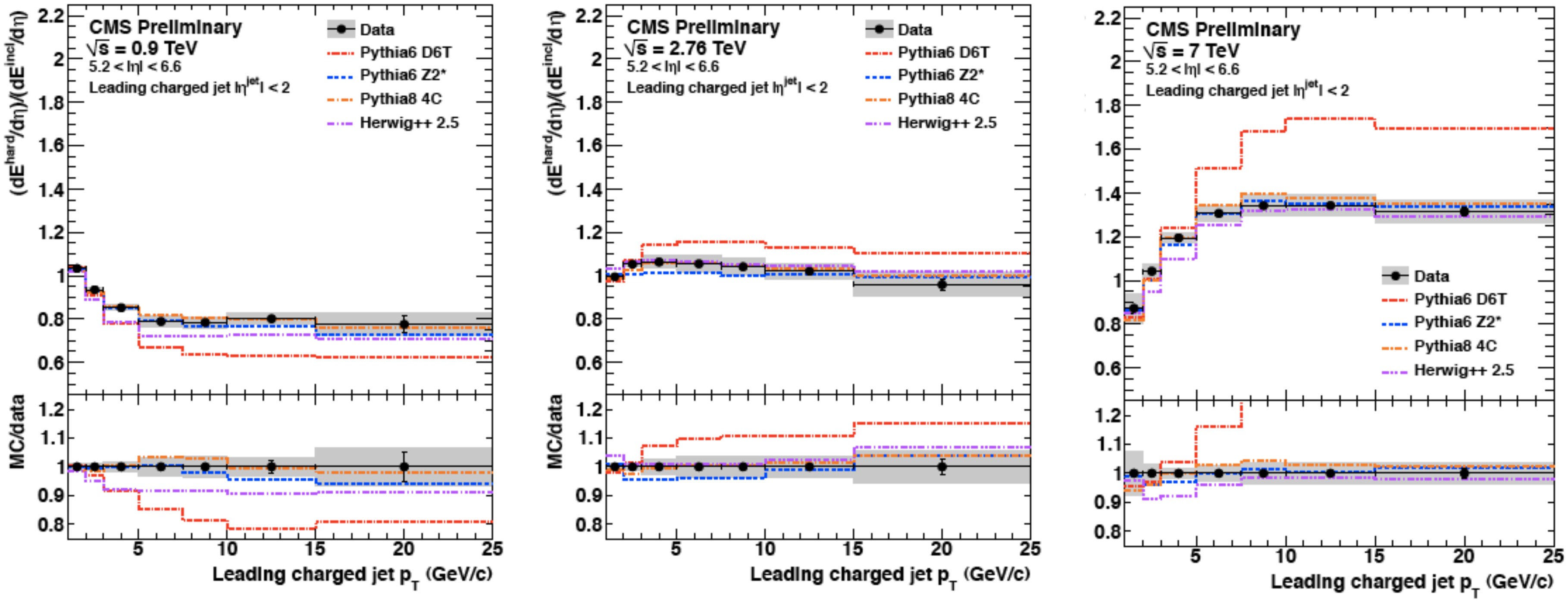


Cascade K_t-factorization based MC, no MPI.

Compared to the traditional UE measurements, we draw slightly different conclusions for what concerns the agreement of the MC models & tunes

Energy flow in the VERY forward region

$\sqrt{s}$ = 0.9 TeV **$\sqrt{s}$ = 2.76 TeV** **$\sqrt{s}$ = 7 TeV**



Energy deposited in CASTOR (5.2 < $|\eta|$ *< 6.6) for events* with a charged particle jet in the central pseudorapidity region $|\eta_{jet}|$ *< 2, as a* function of charged particle jet transverse momentum p_T *(normalized to the average energy in inclusive events)*

→ p_T evolution of observable changes trend with √s (decreasing at low √s, increasing at high √s)
→ Post LHC models adopting pT-ordered showers are favored by data (agreement within 5-10%)
→ Good agreement also for ***EPOS 1.99, QGSJET01, QGSJETII-03, SIBYLL 2.1*** (within 20%)

Underlying Event measurements @ CMS

- Jets: Traditional UE study in the central pseudorapidity region relying on tracks
  - Increase of the activities with the scale of the interactions and with $\sqrt{s}$ corroborates MPIs, which saturate at a modest energy scale.
    - UE in di-jet events is ≈ universal.
- Jets: First measurement of the UE with Jet Area/Median approach.
  - Original methodology developed to handle events with low particle multiplicity.
- MB/Jets: energy flow studies on the forward and very forward regions relying on the Hadron Forward and on the CASTOR calorimeters.
  - Enhanced sensitiveness to the beam remnant component of the UE.
  - Challenging test of pp general purpose and cosmic rays MC models. Good performances of p_T-ordered showers.
- Drell-Yan: first measurement of the Underlying Event at the LHC with $\sqrt{s}$ = 7 TeV.
  - MPI saturated. Radiative increases of UE activity with p_T di-lepton. Constant vs $M_{di\text{-}lepton}$. Min activity around 80% with respect to the plateau in jet events.
- UE in Drell-Yan w.r.t. Jet → Interpretation in the context of the GPDF.

[QCD-10-001, QCD-10-010, QCD-10-005, etc.]

- BACKUP

Focusing on the forthcoming Multiple Parton Interactions measurements at high p_T
i.e. on the Double Parton Scattering

(Soft) Multiple Parton Intractions highlights @ LHC

- Charged multiplicity measurements:
  - CMS confirms large multiplicity tails and KNO violation more pronounced at high energies.
  - → On the other hand MPI models have been invented to describe large multiplicity tails and KNO violation at SPS.

- UE Measurements in Jets:
  - Steep rise followed by plateau. Indication of two different regimes (two scale picture). MPI rise dominates at low p_T, radiation rise dominates at higher p_T.
  - → UE in di-jet events is ≈ universal.

- UE Measurements in Drell-Yan:
  - MPI saturated. Radiative increases of UE activity with p_T di-lepton.
  - Constant vs $M_{\text{di-lepton}}$.
  - → Min activity around 70% with respect to the plateau in jet events.

- Evidence of MPI effects provided also in terms of Forward-Central correlations.

- MPI play a major role in the “ridge” effect at the LHC.

MPI: from "soft" to "hard"

- $\sigma(A+B) = m * \sigma(A) * \sigma(B) / \sigma_{eff}$ (m = ½ for identical interactions, m = 1 otherwise)
  - $\sigma_{eff} \approx$ (process,) scale and $\sqrt{s}$ independent

    [D.Treleani et al. rich bibliography]

$P(B|A) = P(B) * (\sigma_{inel}/\sigma_{eff})$

- For A = B, σ_{eff} related to the momenta of the "hard" collisions' multiplicity:

$$\langle \mathbf{N(N-1)} \rangle = \langle \mathbf{N} \rangle^{\mathbf{2}} \frac{\sigma_{\mathbf{hard}}}{\sigma_{\mathbf{eff}}}$$

- σ_{eff} (Tevatron) ≈ 11 mb [Treleani et al., PRD76:076006,2007] from CDF 3jet+γ.

- Pythia: $\sigma_{eff} = \sigma_{Non\text{-}Diffractive} / \langle f_{impact} \rangle$
  - where f_{impact} is tune dependent → σ_{eff} (Tevatron) ≈ 20÷30 mb

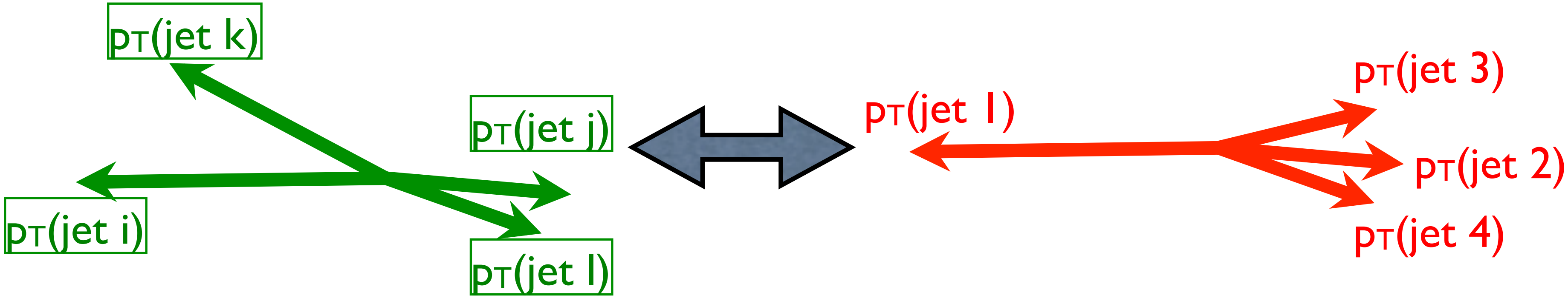
- **DPS Strongly underestimated in the models? Can DPS be measured at the LHC ?**
- **What are the relationships beween "soft" and "hard" MPI measurements?**
- **Which are the impacts on LHC searches? Particularly relevant for the multi fb^{-1} analyses**

DPS / MPI studies in CMS: **Target 4th MPI w/s (fall 2012)**

- ✓ DPS in 3 jet + γ events at 7 TeV.
- ✓ DPS in 2-b-jets + 2-jets.
- ✓ DPS in Z + di-jet events.
- ✓ DPS in W + di-jet events.
- ✓ Same sign W production.
- ✓ Double J/Ψ production.
- ✓ Double Υ.
- ✓ Rapidity gap suppression…

Double Parton Scattering in 4 "objects" topologies

Disentangle double-parton-scattering from bremsstrahlung



- No correlation (DPS) vs Strong correlation (SPS)

Define different correlation angles between jet pairs:

AFS solution:

- Study $\Delta\varphi$ between p_{T1} - p_{T2} and p_{T3} - p_{T4}

CDF solution:

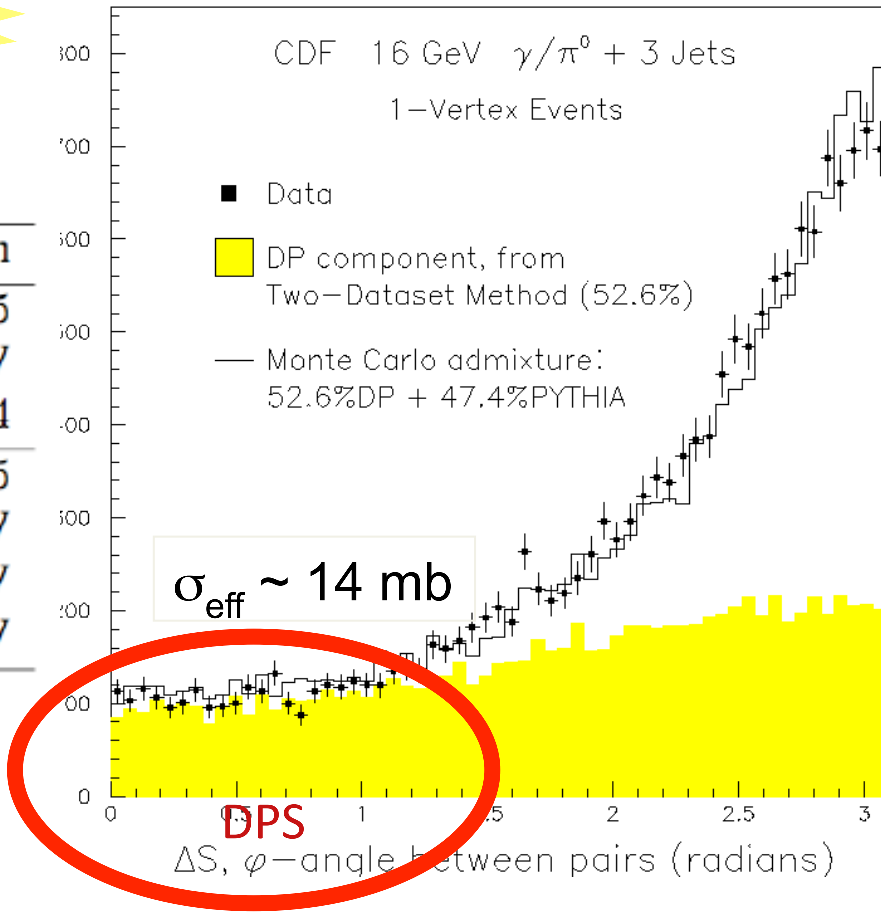
- Study $\Delta\varphi$ between p_{T1} + p_{T2} and p_{T3} + p_{T4} (CDF nomenclature: ΔS)

Measurement of DPS @ Tevatron (3jet + γ)

Double high P_T interactions observed by AFS, UA2, CDF, D0!!!

	CDF	LHC extrapolation
Photon	$\|\eta\| \leq 1.1$	$\|\eta\| \leq 2.5$
	$E_T \geq 16$ GeV	$E_T \geq 50$ GeV
	Cone $R = 0.7$	$k_\perp$ $D = 0.4$
	$\|\eta\| \leq 4.2$	$\|\eta\| \leq 5$
Jets	$E_T \geq 5$ GeV	$E_T \geq 20$ GeV
	$E_{T4} < 5$ GeV	$E_{T4} < 10$ GeV
	$E_{T2}, E_{T3} < 7$ GeV	$E_{T2}, E_{T3} < 30$ GeV

[CDF Collab, Phys. Rev. Lett. 79, 584 (1997)]



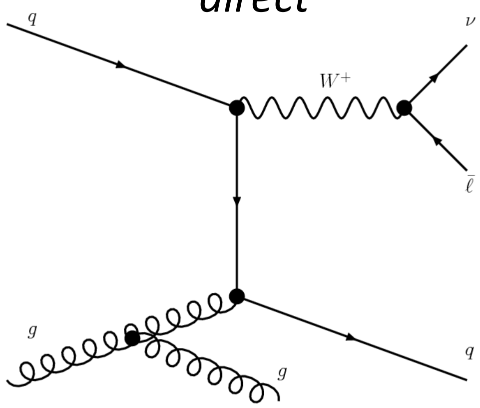
σ_{eff} ~ 16 mb [D0 collaboration Phys.Rev. D81 (2010) 052012]

W → lν + 2 jets

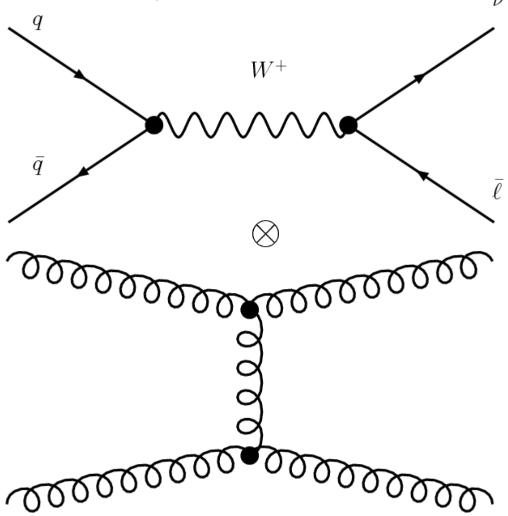
Slide from
[T. Hreus, EDS Blois Workshop, Vietnam,
15-21 Dec 2011]

ATLAS-CONF-2011-160

direct



double parton interaction



$$d\sigma^{(tot)}_{W+2j}(s) = d\sigma^{(dir)}_{W+2j}(s) + d\sigma^{(DPI)}_{W+2j}(s)$$

$$\boxed{f^{\mathrm{R}}_{\mathrm{DP}} = \frac{N_{W_0+2\mathrm{j}_{\mathrm{DPI}}}}{N_{W+2j}}}$$

$$\boxed{\sigma_{eff} = \frac{1}{f^{R}_{DP}} \cdot \frac{N_{W_0} N_{2j}}{N_{W+2j}} \cdot \frac{1}{\varepsilon_{2j} L_{2j}}}$$

- measure fraction of $W_0 + 2j_{DPI}$ in the *W+2jet* sample (f^{R}_{DP})
  - use difference in kinematics (p_T, …)
- σ_{eff}

W selection
Single lepton trigger
1 lepton (e, μ) $p_T > 20$ GeV, $\eta < 2.5$
MET > 25 GeV, $m_T > 40$ GeV
2 jets, $p_T > 20$ GeV, $|y| < 2.8$

Jet selection
(Minimum bias trigger used to measure di-jet x-section alone)
2 jets, $p_T > 20$ GeV, $|y| < 2.8$

W → lν + 2 jets : DPS Rate

Slide from
[T. Hreus, EDS Blois Workshop, Vietnam,
15-21 Dec 2011]

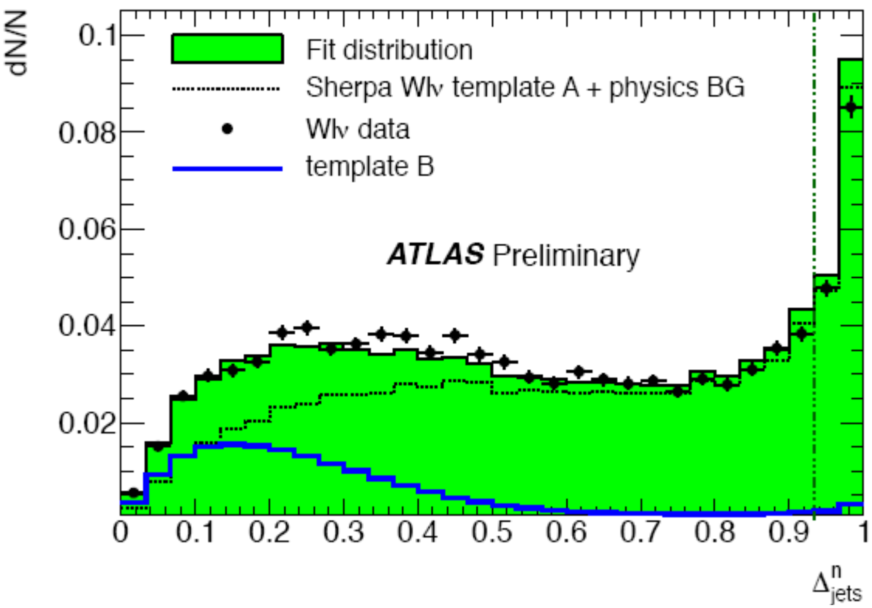
ATLAS-CONF-2011-160

- Extraction of f^{R}_{DP} using fit to data with two templates
- Template A (non DPS sample): both jets originate from the primary scatter
- Template B (a DPS sample) : both jets originate from the DPS scatter

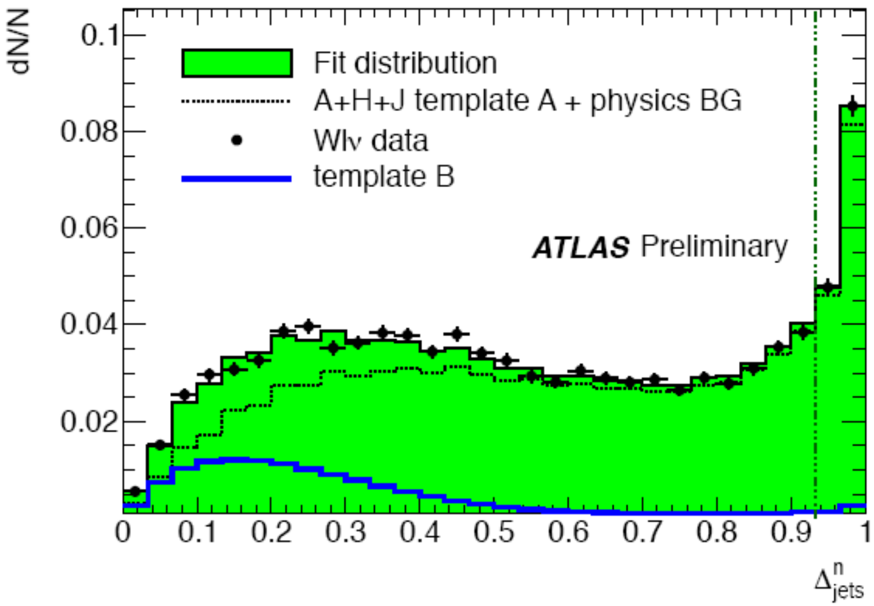
$$\Delta^{n}_{jets} = \frac{\left|\vec{p}_T^{\,J1} + \vec{p}_T^{\,J2}\right|}{\left|\vec{p}_T^{\,J1}\right| + \left|\vec{p}_T^{\,J2}\right|}$$

$$(1 - f^{R}_{DP}) \cdot A + f^{R}_{DP} \cdot B$$

X^2/N_{dof} 1.4, $f^{R}_{DP} = 0.18$



X^2/N_{dof}=0.9, $f^{R}_{DP} = 0.14$

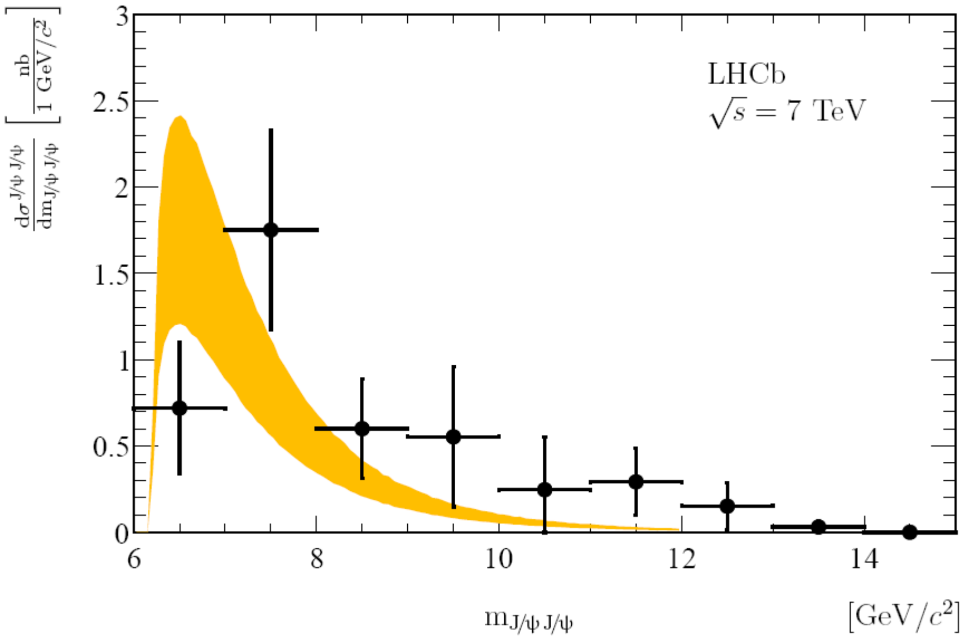


$$f^{R}_{DP} = 0.16 \pm 0.01\ (\text{stat.}) \pm 0.03\ (\text{sys.})$$

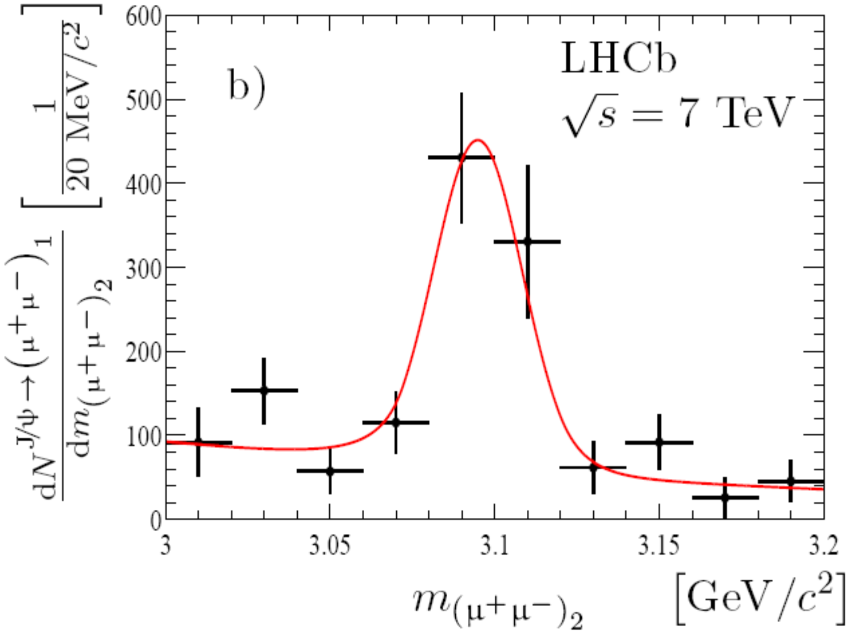
Double J/ψ Production

Slide from
[T. Hreus, EDS Blois Workshop, Vietnam, 15-21 Dec 2011]

[arXiv 1109.0963 [hep-ex]]



Corrected event yield: N = 672 ± 129



Prediction of $\sigma^{J/\psi J/\psi}$ includes direct production and freed down from ψ(2S), but no DPS

J/ψ candidates ordered with increasing p_T.
Fit: *double-sided Crystal Ball function*

Measured cross-section (6σ excess):

$\sigma^{J/\psi J/\psi}$ = 5.1 +- 1.0 (stat) +- 1.1 (syst) nb

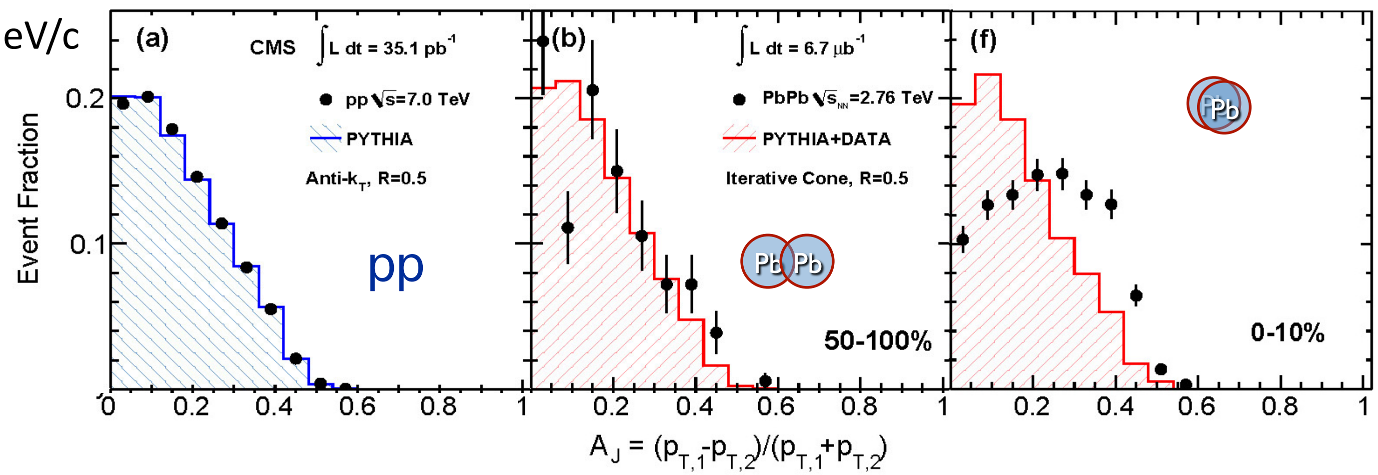
reasonable agreement between data and theory (within uncertainties)

→ *contribution from DPS?*

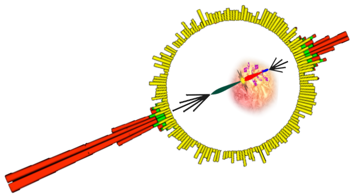
HI: Jet quenching via large dijet energy imbalance & DPS!

- Dijets, calorimeters only
  - Leading p_T>120 GeV/c
  - Sub-leading p_T>50 GeV/c

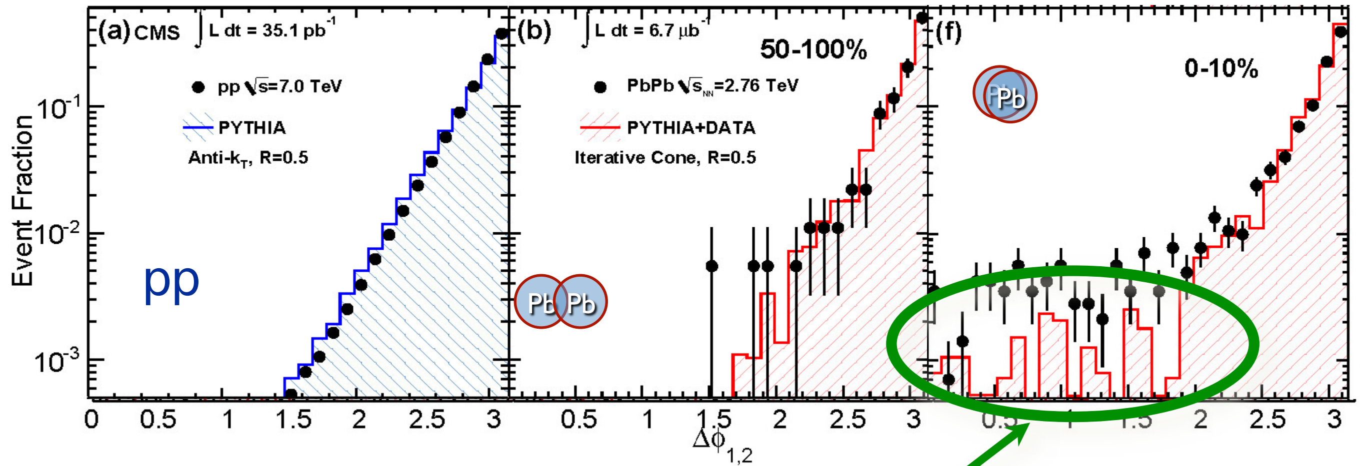
pp PbPb, 50 - 100% PbPb 0 - 10%



p_T imbalance, increasing with centrality



Back-to-back $\Delta\phi \sim \pi$ for all centralities



arXiv:1102.1957

Double Parton Scattering!

Relevant literature (2011)

Keyword MULTIPLE PARTON INTERACTIONS (MPI)

1) Disentangling correlations in Multiple Parton Interactions
By Giorgio Calucci, Daniele Treleani.
arXiv:1009.5881 [hep-ph].
Phys.Rev. D83 (2011) 016012.

TH

2) Multiple parton interactions and forward double pion production in pp and dA scattering
By Mark Strikman, Werner Vogelsang.
arXiv:1009.6123 [hep-ph].
Phys.Rev. D83 (2011) 034029.

HI vs pp

3) Multiple Parton Interactions in Z+ jets production at the LHC. A comparison of factorized and non-factorized double parton distribution functions
By Ezio Maina.
arXiv:1010.5674 [hep-ph].
JHEP 1101 (2011) 061.

4) Multiple Parton Interactions Studies at CMS
By Paolo Bartalini, Livio Fano'.
arXiv:1103.6201 [hep-ex].

LHC hard/soft

5) Azimuthal decorrelations and multiple parton interactions in photon+2 jet and photon+3 jet events in $p\bar{p}$ collisions at $\sqrt{s}=1.96$ TeV
By D0 Collaboration (Victor Mukhamedovich Abazov et al.).
arXiv:1101.1509 [hep-ex].
Phys.Rev. D83 (2011) 052008.

Tevatron hard/soft

6) Soft multiple parton interactions as seen in multiplicity distributions at Tevatron and LHC
By I.M. Dremin, V.A. Nechitailo.
arXiv:1106.4959 [hep-ph].
Phys.Rev. D84 (2011) 034026.

Relevant literature (2011) continued

Keyword DOUBLE PARTON SCATTERING (DPS)

1) Double Parton Splitting Diagrams and Interference and Correlation Effects in Double Parton Scattering
By Jonathan R. Gaunt.
arXiv:1110.1536 [hep-ph].

2) Double Parton Scattering Singularity in One-Loop Integrals
By Jonathan R. Gaunt, W.James Stirling.
arXiv:1103.1888 [hep-ph].
JHEP 1106 (2011) 048.

TH

3) Probing double parton scattering with leptonic final states at the LHC
By Jonathan R. Gaunt, C.H. Kom, A. Kulesza, W.J. Stirling.
arXiv:1110.1174 [hep-ph].

DPS@LHC
In final states with leptons

4) A Fresh look at double parton scattering
By M.G. Ryskin, A.M. Snigirev.
arXiv:1103.3495 [hep-ph].
Phys.Rev. D83 (2011) 114047.

2 Jets + 2 b-Jets

5) Investigations of Double Parton Scattering: Example of $pp \rightarrow b \bar{b} \rm{jet~jet} X$
By Edmond L. Berger.
arXiv:1106.0078 [hep-ph].

Relevant literature (2011) continued

Keyword DOUBLE PARTON SCATTERING (DPS)

6) Prospects for observation of double parton scattering with four-muon final states at LHCb
By C.H. Kom, A. Kulesza, W.J. Stirling.
arXiv:1109.0309 [hep-ph].

7) Pair production of J/psi as a probe of double parton scattering at LHCb
By C.H. Kom, A. Kulesza, W.J. Stirling.
arXiv:1105.4186 [hep-ph].
Phys.Rev.Lett. 107 (2011) 082002.

8) Double parton scattering as a source of quarkonia pairs in LHCb
By Alexey Novoselov.
arXiv:1106.2184 [hep-ph].

9) Double heavy meson production through double parton scattering in hadronic collisions
By S.P. Baranov, A.M. Snigirev, N.P. Zotov.
arXiv:1105.6276 [hep-ph].

10) Calculation of W b bbar Production via Double Parton Scattering at the LHC
By Edmond L. Berger, C.B. Jackson, Seth Quackenbush, Gabe Shaughnessy.
arXiv:1107.3150 [hep-ph].

11) LHC Sensitivity to Wbb Production via Double Parton Scattering
By Seth Quackenbush, Edmond L. Berger, C.B. Jackson, Gabe Shaughnessy.
arXiv:1109.6271 [hep-ph].

LHCb

QUARKONIA

W + 2b-jets

Relevant literature (2012) preliminary

Keyword DOUBLE PARTON SCATTERING (DPS)

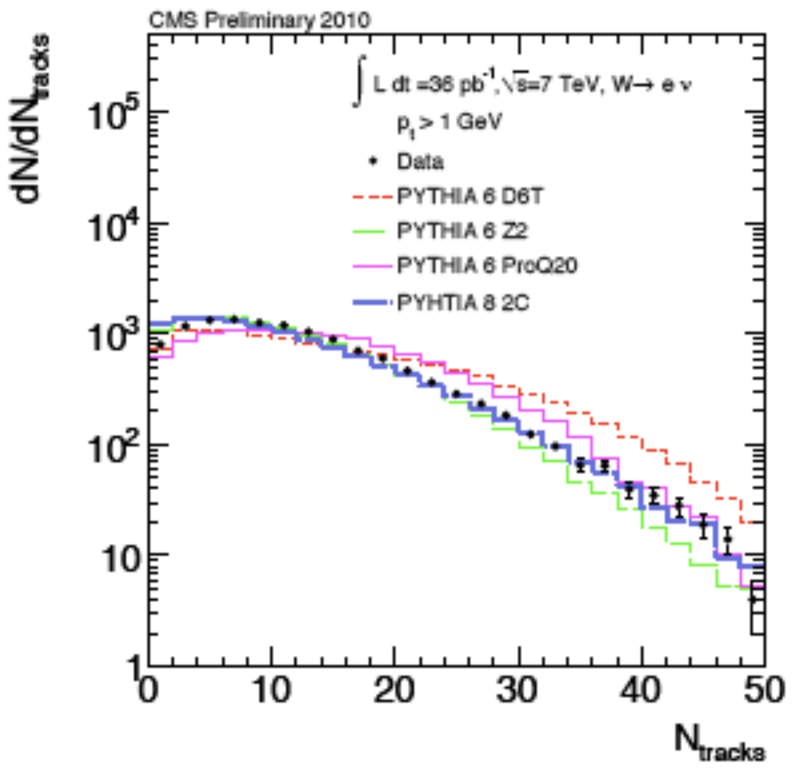
Double parton scattering in double logarithm approximation of perturbative QCD
M.G. Ryskin (St. Petersburg, INP), A.M. Snigirev (SINP, Moscow). Mar 2012. 7 pp.
e-Print: **arXiv:1203.2330**

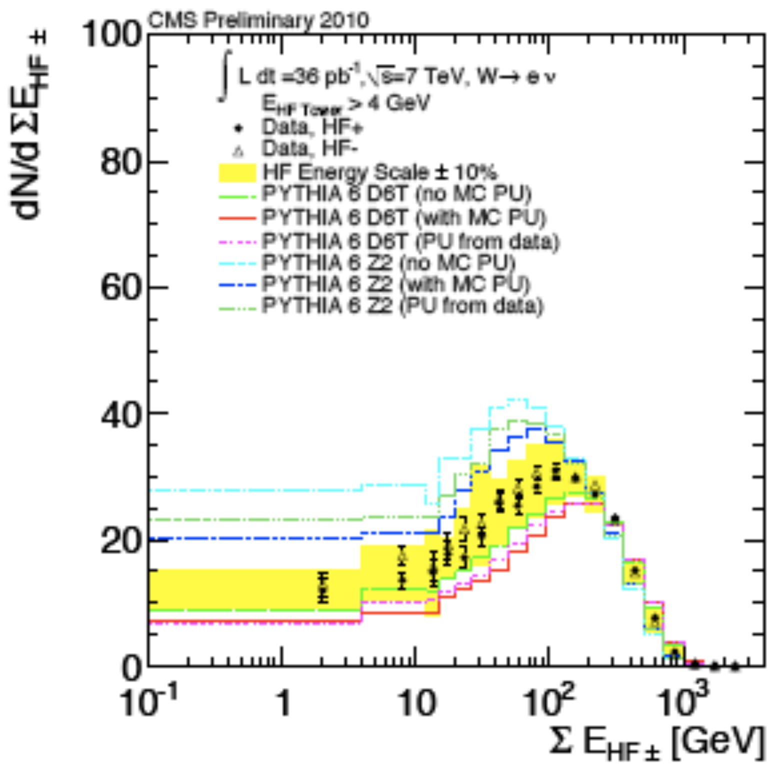
What is Double Parton Scattering?
Aneesh V. Manohar, Wouter J. Waalewijn, . Feb 2012. 5pp. Temporary entry
e-Print: **arXiv:1202.5034**

A QCD Analysis of Double Parton Scattering: Color Correlations, Interference Effects and Evolution.
Aneesh V. Manohar, Wouter J. Waalewijn, . Feb 2012. 24pp. Temporary entry
e-Print: **arXiv:1202.3794**

- FWD / BACKUP

Energy flow in W (and Z) events





W selected requiring leptonic decays:

p_T(l) > 25 GeV, Missing Energy E_T> 30 GeV, M_{inv}(l,E_T) > 60 GeV.

Investigating both central tracks and forward energy.

Conclusions similar for Z events.

Further studies selecting events with Large Rapidity Gaps (not shown here)