

# Lo Studio dei processi di Interazione Multipla a LHC

(Minimum Bias, Mini Jets, Underlying Event, Double Scattering etc.)

Vedere anche  
Contributi  
Precedenti  
MCWS  
LH *w/s*  
HERA/LHC *w/s*

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(NTU)

MCWS, Frascati 18-20 Gennaio 2008



# Lo studio delle Interazioni Multiple all'LHC

## Programma di ricerca



- 1) Underlying Event (UE) in Jet and Drell-Yan Events at the LHC
- 2) Extension of (1) to Diffractive Topologies
- 3) Minimum Bias (MB) & Mini-jets
- 4) Double Parton Scattering (DPS) at the LHC
- 5) Tuning & Validation of Monte Carlo Models based on (1)-(4)

### MCWS - 2006:

- ✓ Principalmente MB, UE
- ✓ Esperienza / Eredita' di Tevatron
- ✓ Studi a livello generatore in ATLAS, CMS

### MCWS - Oggi:

- ✓ UE in Jet: fattibilita' in CMS
- ✓ Struttura Mini-jets del MB (livello generatore)
- ✓ DPS in 3jet +  $\gamma$  & Validazione di Pythia 8



National Taiwan University (Taiwan)  
Universities of Perugia & Trieste (Italy)  
University of Florida (USA)  
University of Hamburg (Germany)  
Chokurova University (Turkey)

## MB & UE: Stato e Definizioni



### Minimum Bias

La generica interazione particella-particella

### Underlying Event (UE)

Cio' che accompagna la componente hard scattering dell'interazione  
(definizione necessariamente approssimata, stante le correlazioni)

UE  $\neq$  MB ma alcuni aspetti e concetti sono simili:

Studio fenomenologico della molteplicita' e dello spettro in  $P_T$  delle tracce cariche

-> I sistemi di tracciatura consentono di studiare bene le tracce a basso  $P_T$

-> Associazione non ambigua coi vertici di interazione

### Fenomenologia

-MB: CDF, UA5. Molteplicita' cariche e distribuzioni in  $PT$

-UE: CDF. Densita' di carica e di momento lontane dall'area dei jet

### pQCD Models

**MPI (multiple parton interactions)**

Estendono la descrizione perturbativa fino a  $PT \sim 1$  GeV,

Particolarmente adeguati a descrivere sia MB che UE

# Modelli pQCD



ISR, FSR, SPECTATORS...

Non sufficienti per dare conto delle alte molteplicità osservate ai collider adronici



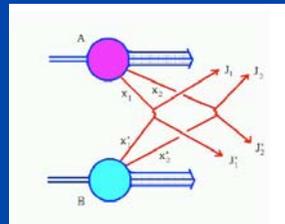
Soluzione Pythia

[T. Sjöstrand et al. PRD 36 (1987) 2019]

Multiple Parton Interactions (MPI)

(ora disponibile in altri general purpose MCs: Herwig/Jimmy, Sherpa, etc.)

Ispirata dall'osservazione di double high  $P_T$  scatterings



Main Parameter:  $P_T$  cut-off  $P_{T0}$

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

(il dampening descrive anche le x-sections quarkonia)

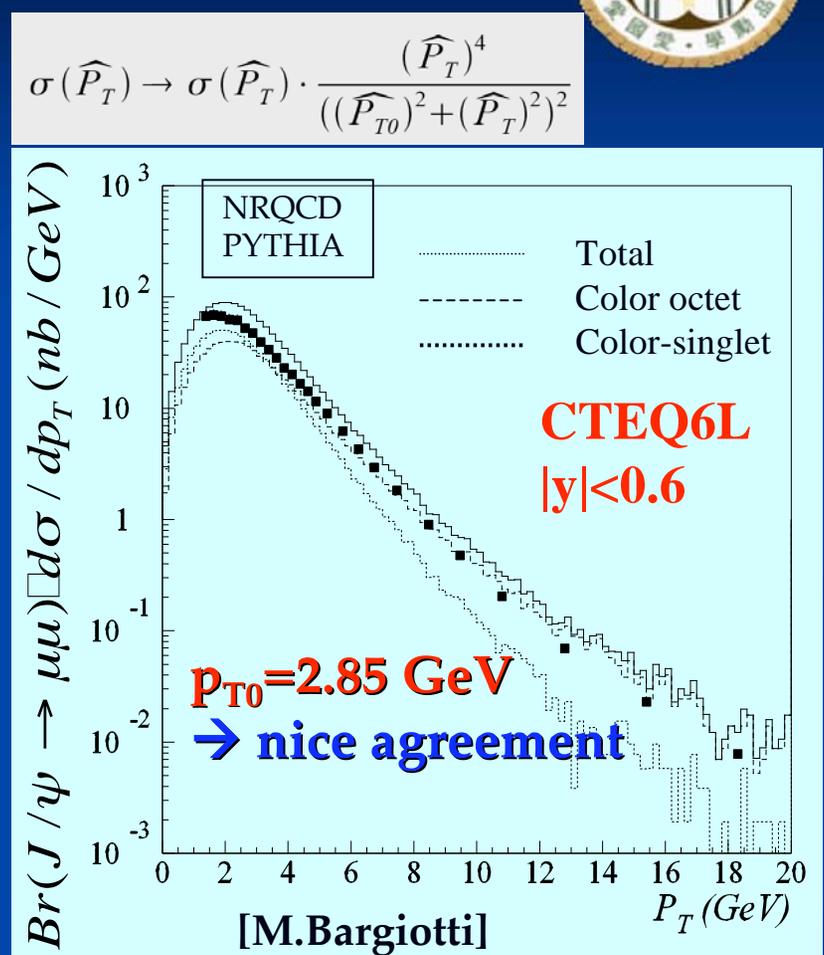
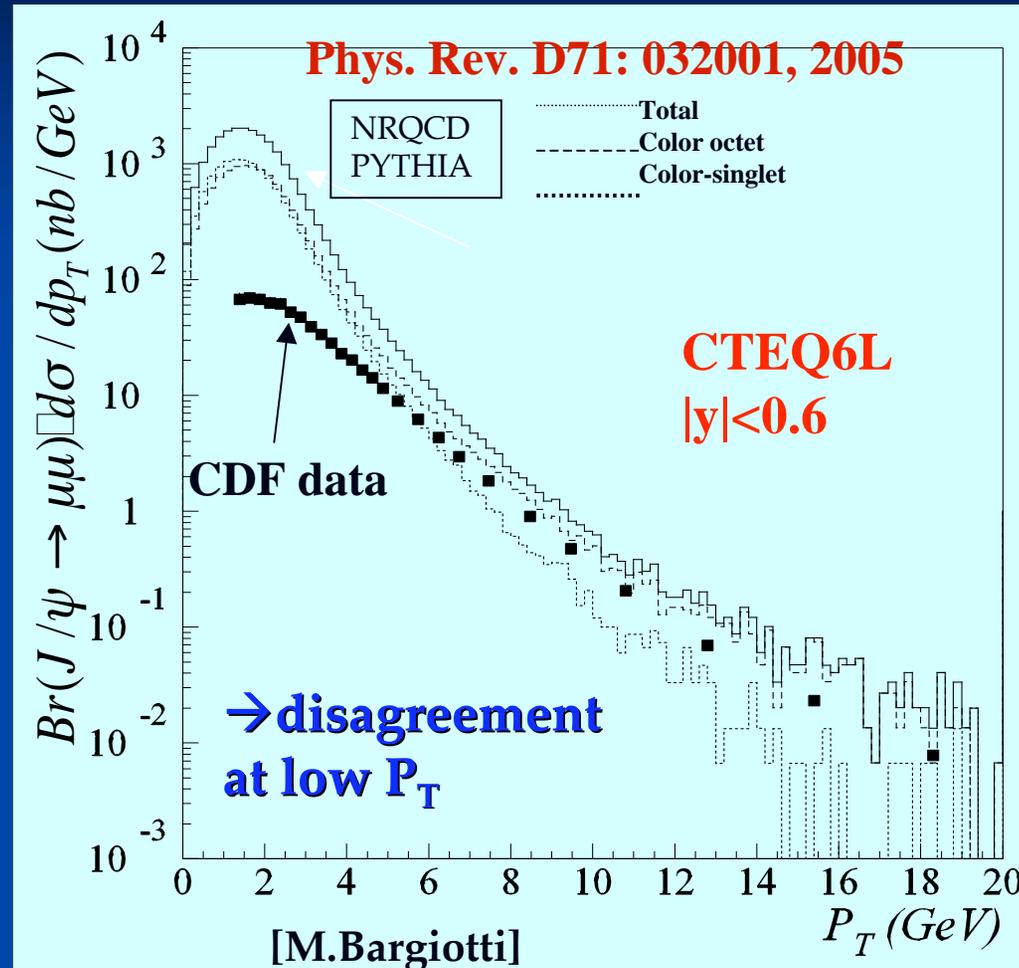
- ✓ Regularizzazione sezione d'urto per  $P_T \rightarrow 0$
- ✓  $P_{T0}$  può essere interpretato come l'inverso di una lunghezza di screening
- ✓ **Controlla il numero di interazioni, quindi la Molteplicità':**  $\langle N_{int} \rangle = \sigma_{parton-parton} / \sigma_{proton-proton}$

Enfasi sulla dipendenza in energia dei parametri

- ✓ La fenomenologia CDF, UA5 MB favorisce una dipendenza esponenziale di  $P_{T0}$
- ✓ Le teorie CGC favoriscono indipendenza [G.Gustafson & G.Miu]

Modelli con parametro di impatto variabile descrivono meglio momenti delle distribuzioni

# Anche le sezioni d'urto Quarkonia preferiscono il dampening ?



Processo simile. Scambio di gluone nel canale t:  $d\sigma/dP_T^2 \sim 1/dP_T^4$

Indicazione di universalita': stesso  $P_{T0}$  delle MPI. Stessa dipendenza da  $s$  ?

# MC Tunes

- + Pythia Tune DW ( $\epsilon=.125$ )
- OLD MPI, IP CORRELATIONS, ~ TUNE A
- + Pythia Tune DWT ( $\epsilon=0.08$ )
- DW with default PT-cut-off evolution
- + Pythia Tune S0 ( $\epsilon=0.08$ )
- P.Skands, New MPI, more correlations

Tutti questi tunes di Pythia descrivono MB & UE al Tevatron.

	$\sigma_{\text{parton-parton}}$ at 1.96 TeV	$\sigma_{\text{parton-parton}}$ at 14 TeV
Tune DW	351.7 mb	549.2 mb
Tune DWT	351.7 mb	829.1 mb
Tune S0	lower	lower

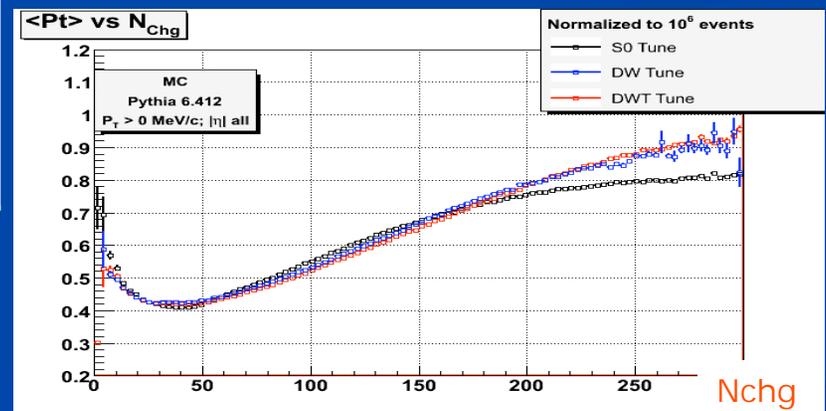
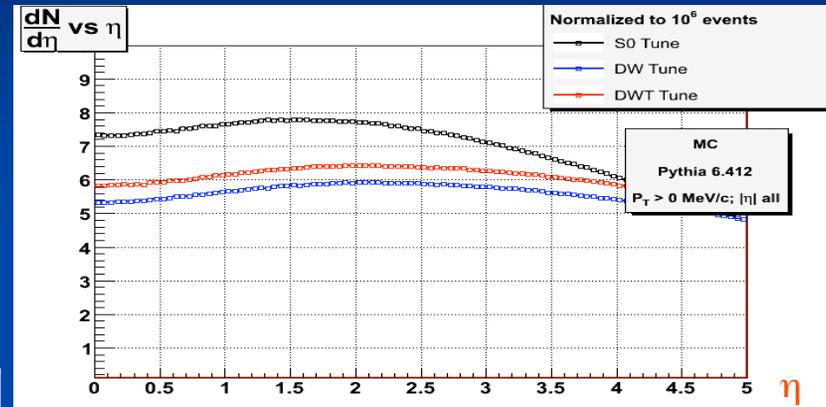
$$P_{T0} = P_{T0}^{TUN} \left( \frac{\sqrt{s}}{E_{TUN}} \right)^{2\epsilon}$$

**MB: Differenze sensibili all'LHC.**

ma e' necessario tenere ampio lo spettro delle osservabili ed estendere all'UE



## Osservabili MB



# UE: Programma di ricerca in CMS

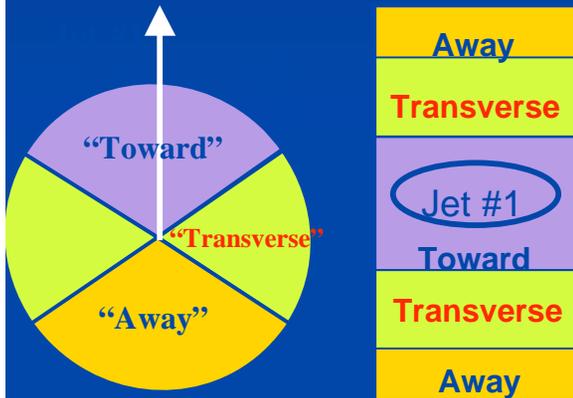
- PAS di prossima pubblicazione
- CMS Note 2006/067
- CMS PTDR vol. 2 (SM\_QCD section)



## Eventi Jet inclusivi (usando triggers MB e Jets)

### Studio topologico delle tracce cariche

### Definizione Jet Carico -> ICA con tracce massless come input



Il leading Jet definisce una direzione sul piano  $\phi$

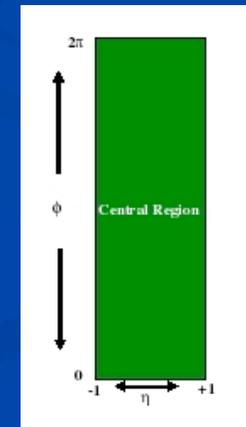
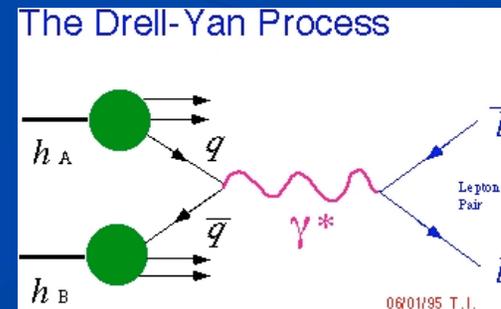
La regione trasversa e' particolarmente sensibile all'UE

### Osservabili principali:

- +  $dN/d\eta d\phi$ , densita' carica
- +  $d(PT_{sum})/d\eta d\phi$ , densita' in PT

## Eventi D-Y di-muone (usando triggers muonici)

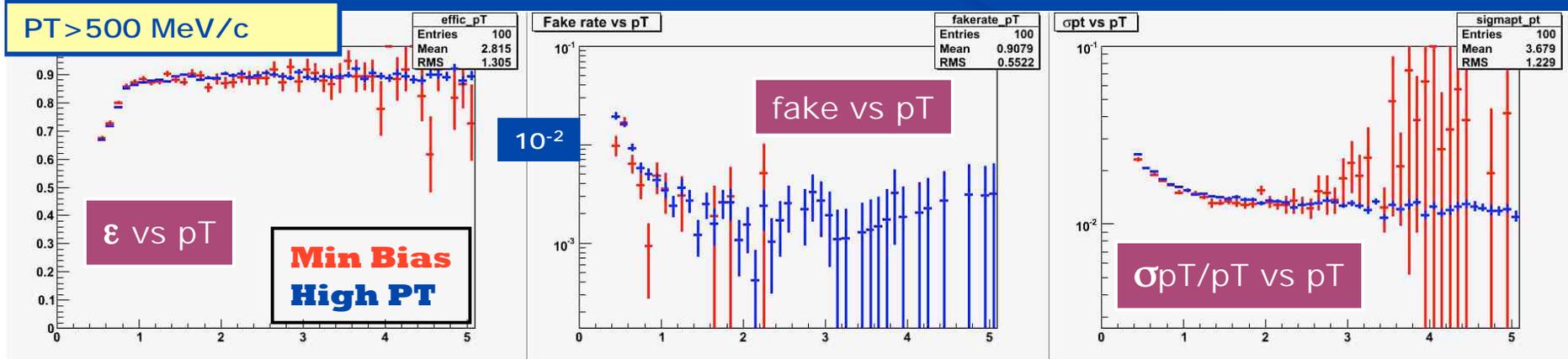
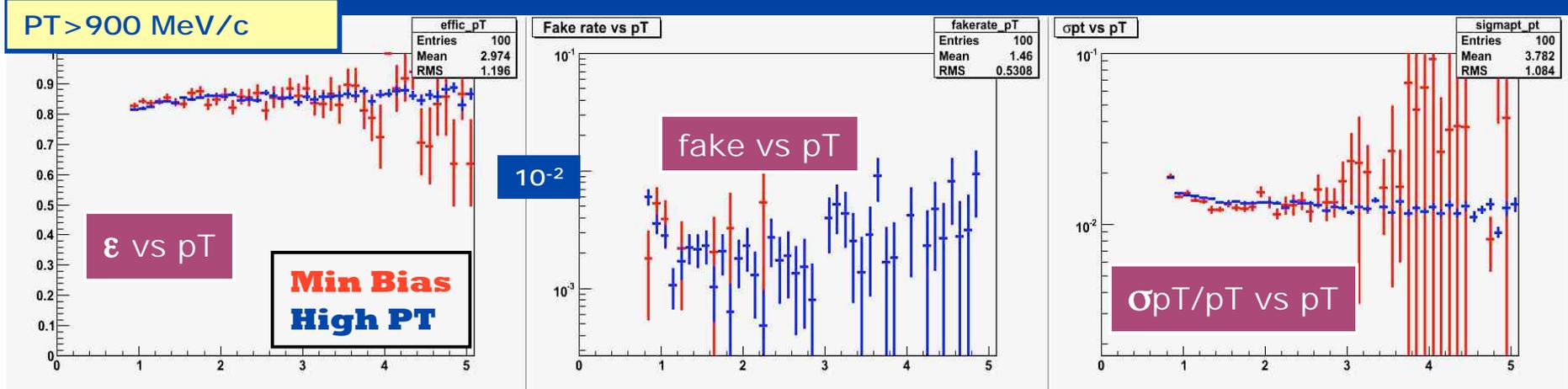
### Stesse osservabili definite in tutto il piano $\phi$



# Performances di Soft Tracking



- + CMS adotta 900 MeV come minimo (standard) per la ricostruzione di tracce cariche, ma la tracciatura a partire da 500 MeV risulta comunque possibile
- > Buona risoluzione in PT (~ 2%), sufficiente efficienza (da 70% a 90%) e fakes sotto controllo (~2%)
- + La tracciatura a partire da 500 MeV e' utilizzata per migliorare il potere discriminante delle osservabili UE nella regione trasversa



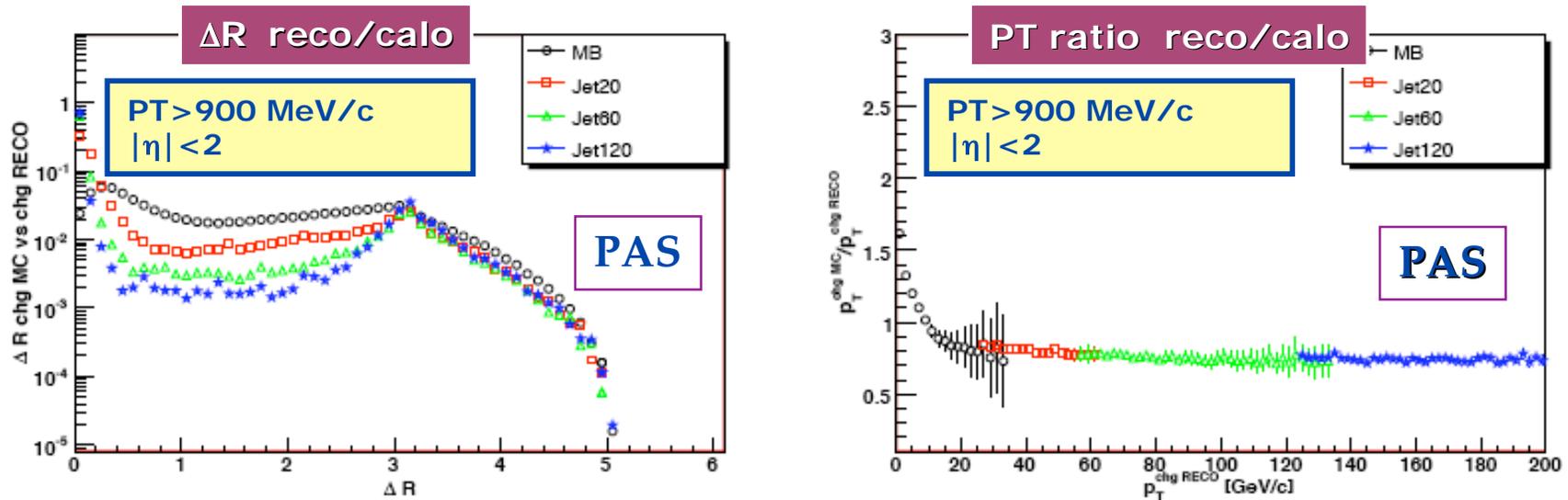


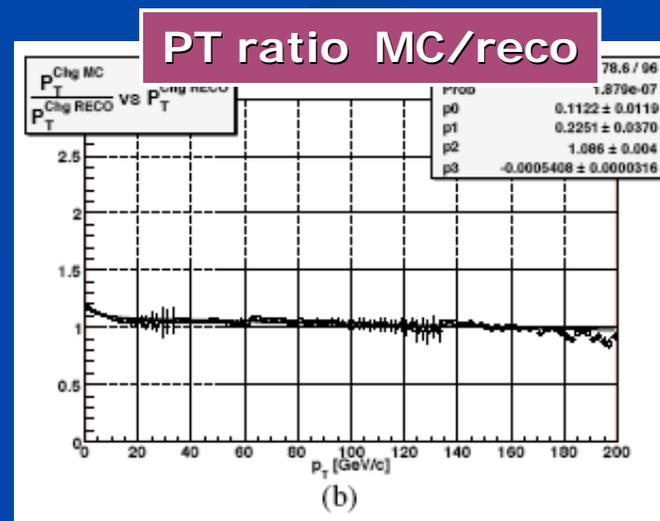
Figure 1: Charged Jet performances. *Left*:  $\Delta R$  ( $= \sqrt{\Delta\phi + \Delta\eta}$ ) between the charged and the calorimetric leading jets. *Right*: charged jet response function ( $P_T^{charged} / P_T^{calorimetric}$ ).

Jet carico anzichè jet calorimetrico

+ accesso alla componente low PT

+ Intrinsecamente indipendente dalle condizioni di pile-up

+ miglior controllo degli effetti sistemati allo start-up di LHC

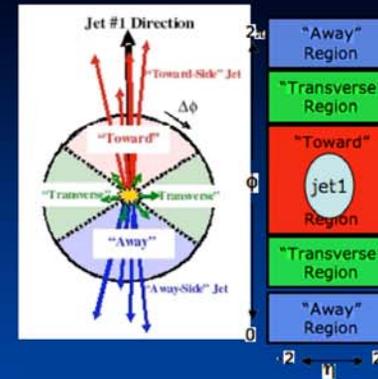


Calibrazione MC/RECO del leading jet

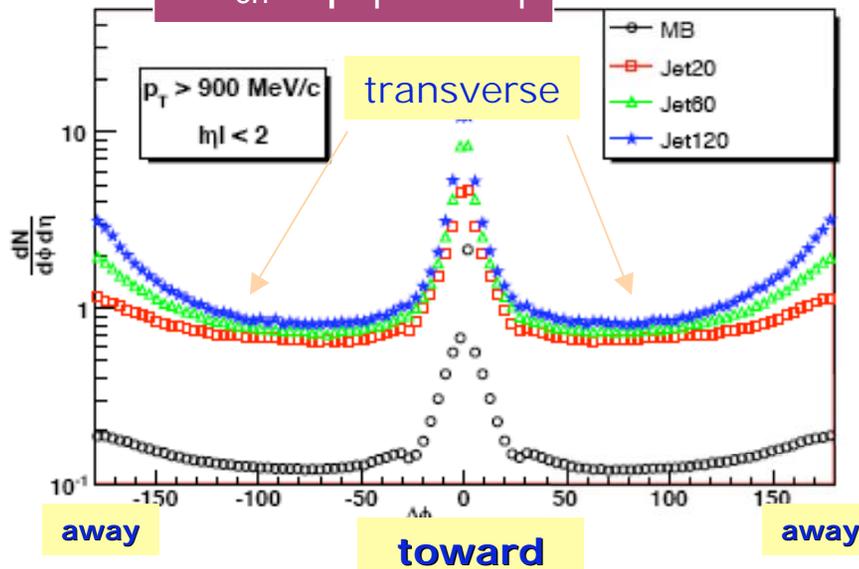
# Densita' in Azimuth per differenti triggers

$p_T > 900 \text{ MeV}/c$   
 $|\eta| < 2$

Osservabili vs  $\Delta\phi$  (Jet Carico Principale - Track)  
Distribuzioni non corrette per  $10\text{pb}^{-1}$



$dN_{ch}/d\eta d\phi$  VS  $\Delta\phi$



$d\langle p_T \rangle / d\eta d\phi$  VS  $\Delta\phi$

PAS

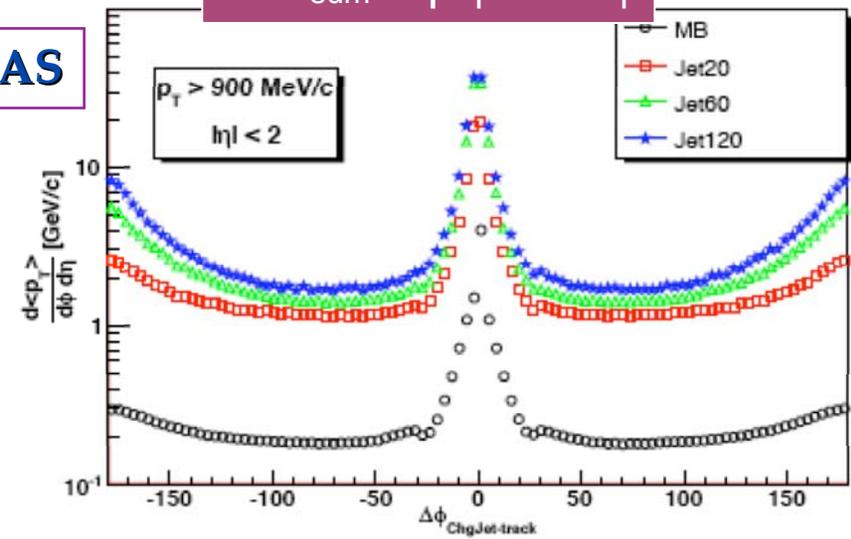


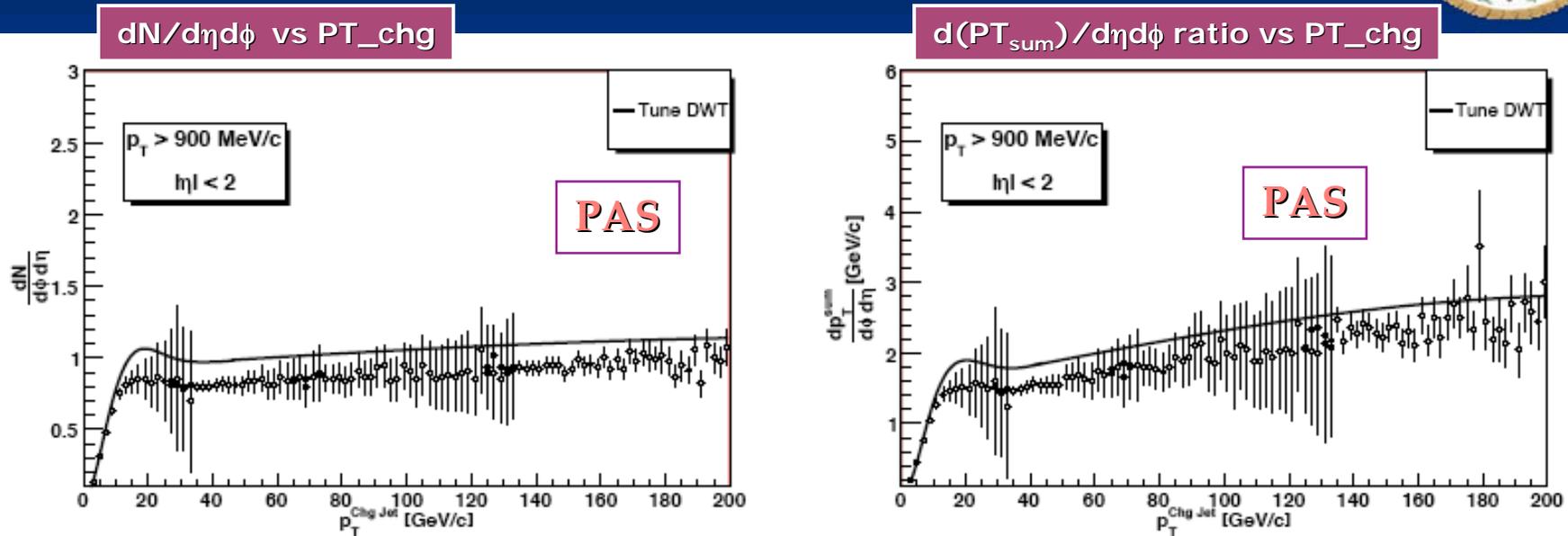
Figure 2: Density of charged particles,  $dN/d\eta d\phi$  (left), and average charged  $\sum p_t$  density (right) versus the azimuthal distance between charged tracks and leading charged jet. Reconstructed data from different triggers are superimposed.

-> Chiara indicazione di Pedestal Effect

# Fattibilita' UE in CMS. Scenario start-up: 1 pb<sup>-1</sup>



Osservabili VS PT Jet Carico Principale  
Distribuzioni non corrette per 1pb<sup>-1</sup>



(realistic errors, big event weights due to the limited MC statistics)

Figure 11: Transverse region. Uncorrected distribution at startup using APE. Density of charged particles  $dN/d\eta d\phi$  (left) and the average charged  $dp_T/d\eta d\phi$  density (right) versus the transverse momentum of the leading charged jet.

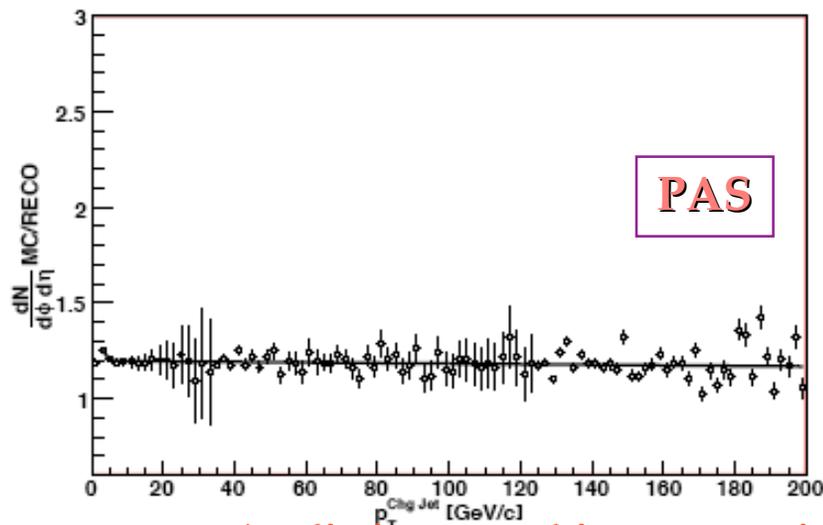
I profili simulati e ricostruiti hanno la medesima forma, le differenze sono compatibili con le calibrazioni, con le inefficienze e con I rates di fakes  
-> Funzioni di correzione, Primo tuning dei modelli

La tracciatura allo start-up dell'LHC risente della ridotta conoscenza del rivelatore, in particolare per quanto riguarda l'allineamento  
-> vedi slides di back-up

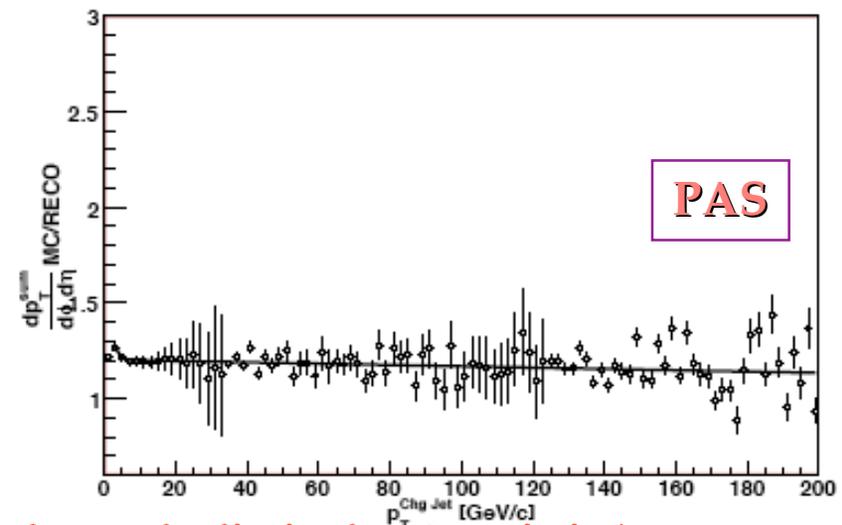
# Fattibilita' UE in CMS. Funzioni di correzione per $10 \text{ pb}^{-1}$



$dN/d\eta d\phi$  (MC/RECO) vs  $PT\_chg$



$d(P_{T\_sum})/d\eta d\phi$  (MC/RECO) vs  $PT\_chg$



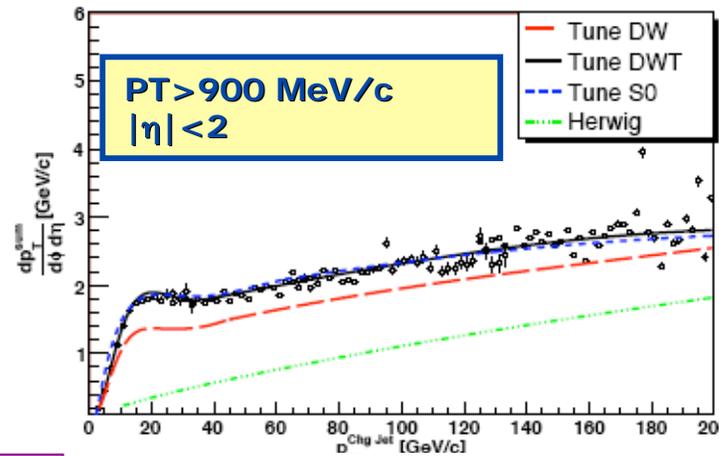
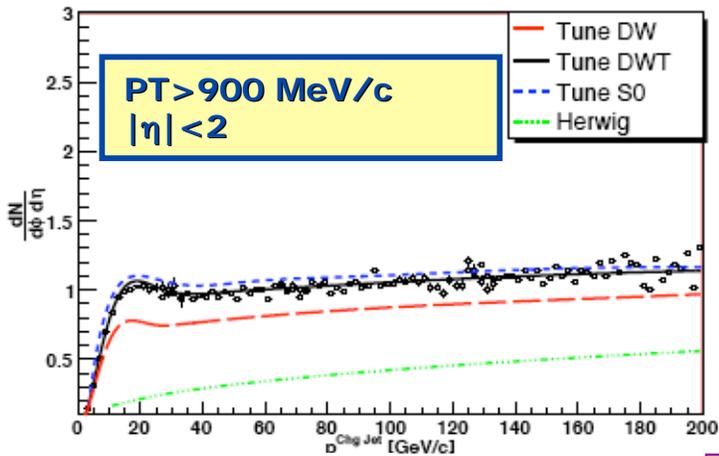
(realistic errors, big event weights due to the limited MC statistics)

Figure 5: Ratio between generator level DWT expectations and reconstructed data for  $dN/d\eta d\phi$  (left) and average charged  $\sum p_t$  density (right). The corrections as a function of the charged jet transverse momentum are then obtained from the fit.

Procedura di correzione/calibrazione a la CDF [PRD 65 (2003) 092002]:  
+ Funzioni di risposta vs  $PT\_jet$  applicate evento per evento

-> In CDF fornisce le medesime performances della correzione particle level

# Osservabili UE: Distribuzioni corrette per 100pb<sup>-1</sup>

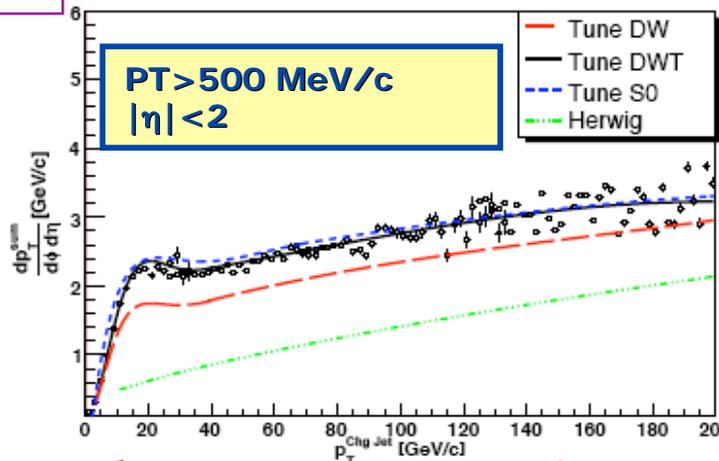
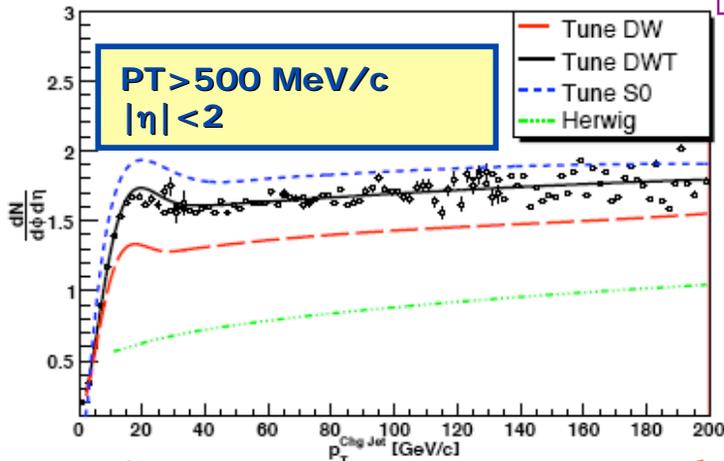


pT > 900 MeV/c  
(fig.6)

dN/dηdφ vs PT\_chg

PAS

d(PT<sub>sum</sub>)/dηdφ vs PT\_chg



pT > 500 MeV/c  
(fig.8)

(realistic errors, big event weights due to the limited MC statistics)

Effetto delle correzioni

-> ri-ottenere il tune DWT

Buon potere di discriminazione

-> DW/DWT (con PT minimo 900 MeV)

Separazione S0/DWT usando la tracciatura da 500 MeV

# Fattibilita' UE in CMS. Sistematiche principali



- $\sigma_\epsilon = \sigma_{fake} = 1\% (2\%)$
- $\sigma_{Pt} = 2\% (4\%)$

Le incertezze si riferiscono allo stato del tracker dopo  $100 \text{ pb}^{-1}$  [dal CMS PTDR] (x2) -> "safety" factor

$$\sigma_{dN} = \sigma_\epsilon$$

$$\sigma_{dPT}^2 = dN^2 * \sigma_{Pt}^2 + dPT^2 * \sigma_\epsilon^2$$

$$\sigma_{dN_{corr}}^2 = dN^2 * (\sigma_\epsilon^2 + \sigma_{fake}^2) + (1 - \epsilon + fake)^2 * \sigma_{dN}^2$$

$$\sigma_{dPT_{corr}}^2 = dN_{corr}^2 * \sigma_{Pt}^2 + dPT_{corr}^2 * (\sigma_{dN_{corr}} / dN_{corr})^2$$

Ad esempio, per PT del jet carico  $100 \text{ GeV}/c$  e con lumi integrata di  $100 \text{ pb}^{-1}$

$pT > 900 \text{ MeV}/c$

$$dN/d\eta d\phi = 1.07 \pm 0.02 \text{ (statistical)} \pm 0.02 \text{ (systematic)}$$

$$PT_{sum} = 2.25 \pm 0.06 \text{ (statistical)} \pm 0.07 \text{ (systematic)}$$

$pT > 500 \text{ MeV}/c$

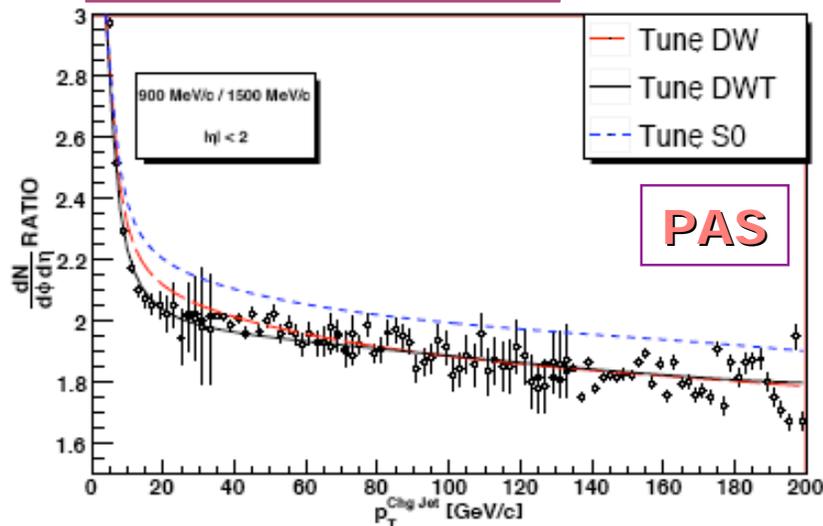
$$dN/d\eta d\phi = 1.75 \pm 0.03 \text{ (statistical)} \pm 0.07 \text{ (systematic)}$$

$$PT_{sum} = 2.85 \pm 0.08 \text{ (statistical)} \pm 0.15 \text{ (systematic)}$$

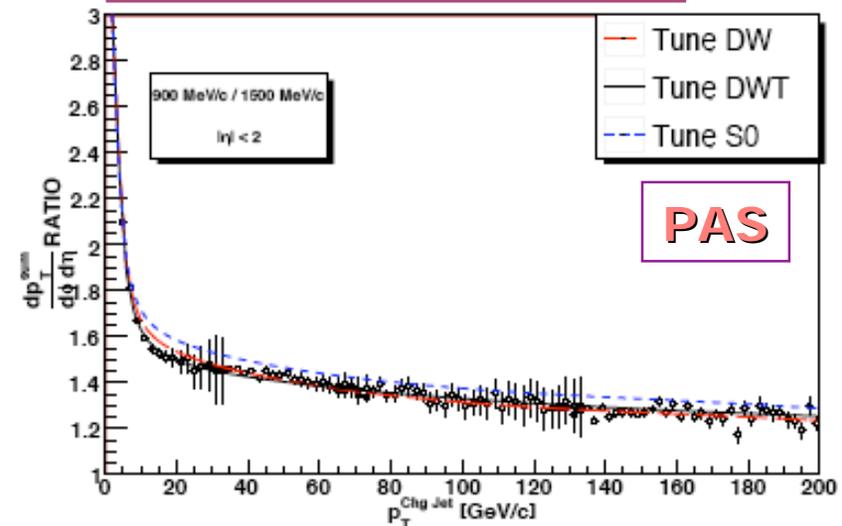
# Fattibilita' UE a LHC. Rapporti tra osservabili per 100 pb<sup>-1</sup>



dN/dηdφ ratio vs PT\_chg



d(PT<sub>sum</sub>)/dηdφ ratio vs PT\_chg



(realistic errors, big event weights due to the limited MC statistics)

Figure 9: Ratio plots using track with  $p_T > 1.5 \text{ GeV}/c$  and  $p_T > 0.9 \text{ GeV}/c$  for density of charged particles  $dN/d\eta d\phi$  (left) and average charged  $\sum p_t$  density (right) versus the transverse momentum of the leading charged jet.

Dati non corretti

Rapporti tra osservabili dello stesso tipo definiti per due diverse soglie in PT minimo delle tracce (900 MeV/c e 1.5 GeV/c)

+ Notevole vantaggio sperimentale: le correzioni si assorbono nel rapporto!

+ Ulteriore potere discriminante tra i vari tunes



## UE in topologie jet ad LHC: Bottom Line

Lo studio dell'Underlying Event in topologie con jet sara' una delle prime misure delle collaborazioni CMS ed ATLAS, rilevante di per se' al fine di comprendere alcuni aspetti generali delle interazioni p-p all'LHC, essenziale per ottenere I primi tuning degli shower MC (con MPI) sui dati veri di LHC ed importante per testare e calibrare tool di analisi di base connessi con la ricostruzione delle tracce.

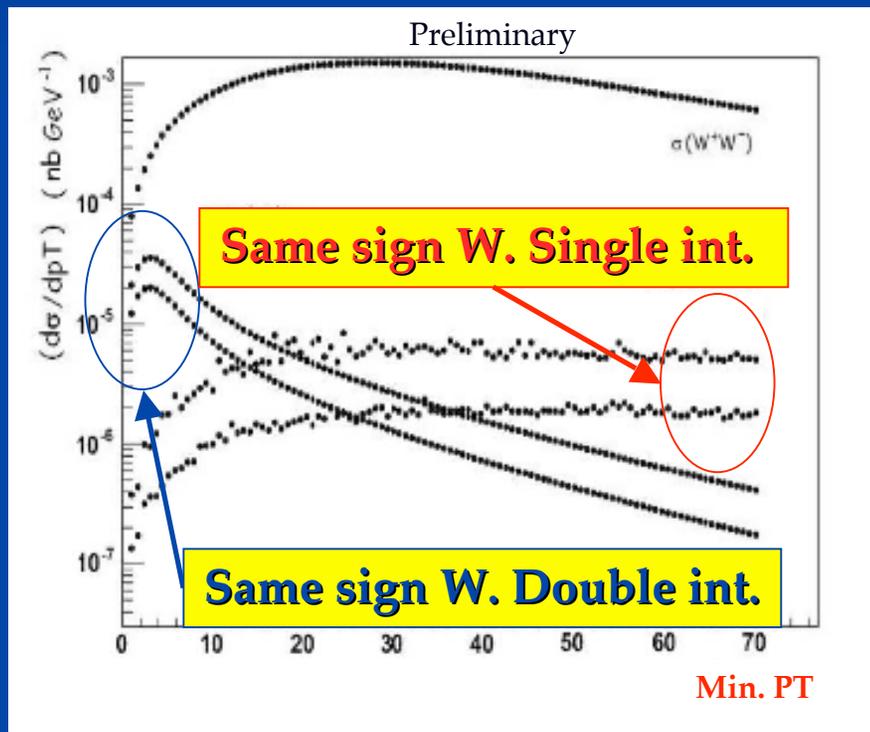
❖ **Tune dei modelli MC, Early Tracking, Calibrazione degli osservabili di isolamento, Test del modello di analisi ai centri regionali, of analysis, etc.**

Lo studio di fattibilita' con il piano propedeutico di misure fino a  $100\text{pb}^{-1}$  e' stato recentemente approvato dalla collaborazione CMS. Da sottolineare alcuni aspetti originali come l'utilizzo di rapporti tra osservabili omogenei ottenuti con diverse soglie minime in PT sulla ricostruzione delle tracce (**ratios**)

# La sfida delle MPI all'LHC



LO SCOPO ULTIMO E' IL RAGGIUNGIMENTO DI UNA DESCRIZIONE UNIFORME DEI FENOMENI MPI AD ALTO  $P_T$  E BASSO  $P_T$



Come ?

- Misure Standard MB & UE (secondo l'esperienza di CDF)
- Conteggio delle coppie di mini-jet carichi in eventi di Minimum Bias
- **3j +  $\gamma$**  (ancora una volta, si puo' beneficiare dell'esperienza di CDF)
- Conteggio di coppie di bosoni

NEW

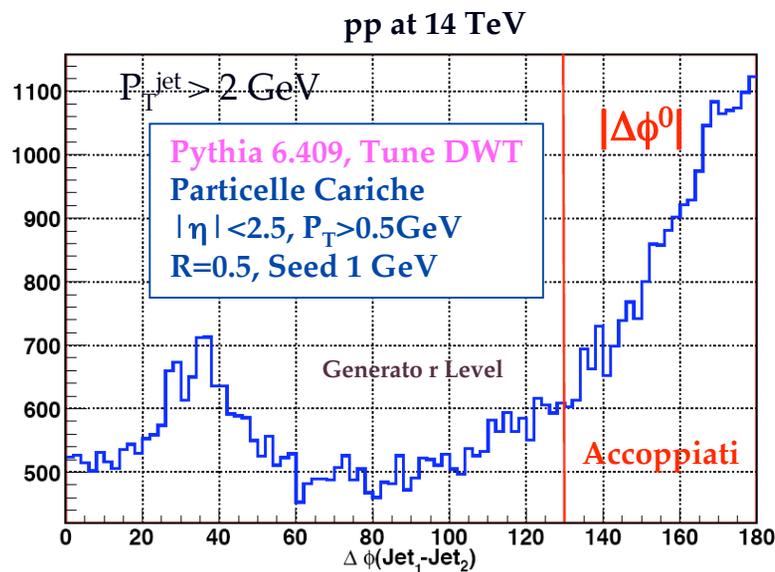
NEW

Vedi contributi di D.Treleani ad HERA/LHC

# Conteggio delle MPIs tramite coppie di Mini-Jets back-to-back

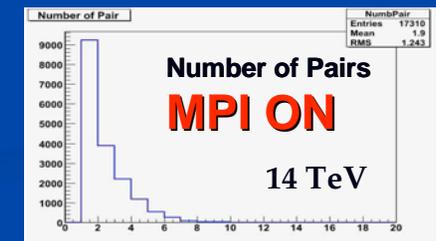
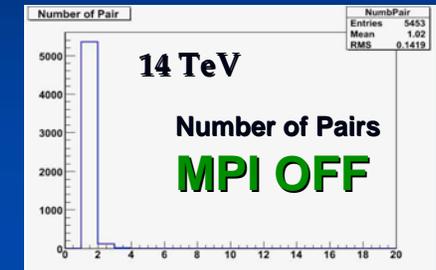


Distribuzione  $\Delta\phi$  tra i due mini-jet carichi piu' energetici dell'evento



## Algoritmo di Accoppiamento

- MiniJets ordinati in  $P_T$  decrescente
- Iniziare dal primo
- Accoppiato = jet con il  $P_T$  piu' vicino che soddisfa la condizione  $|\Delta\phi^0| < |\Delta\phi|$



L'idea della misura e' quella di studiare il rate di coppie di mini-jet ( $N$ ) al di sopra di una soglia in  $P_T$  -> **Quantita' Infrared Safe**

$$\langle N \rangle \sigma_H = \sigma_S \quad \text{and} \quad \frac{1}{2} \langle N(N-1) \rangle \sigma_H = \sigma_D \quad \langle N(N-1) \rangle = \langle N \rangle^2 \frac{\sigma_H}{\sigma_{\text{eff}}}$$

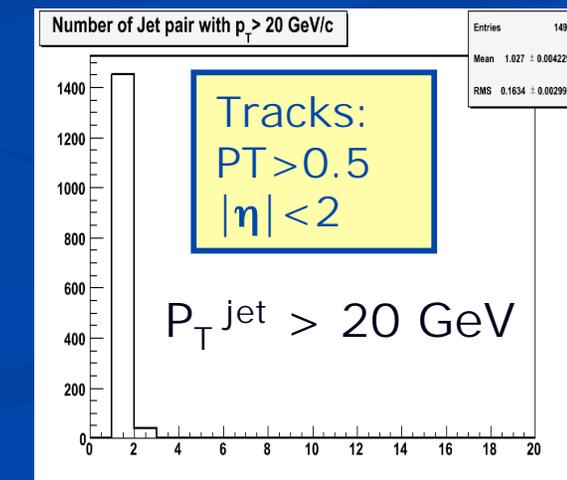
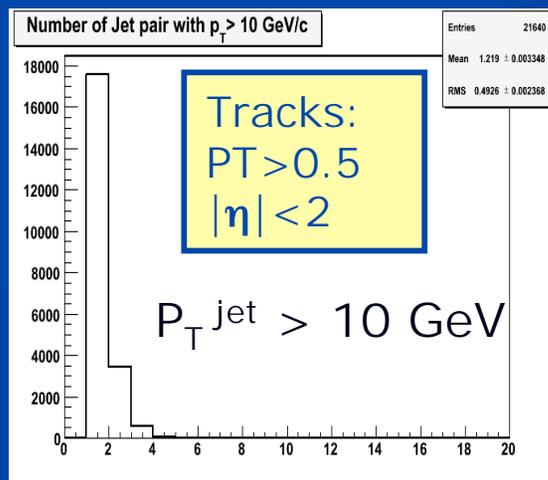
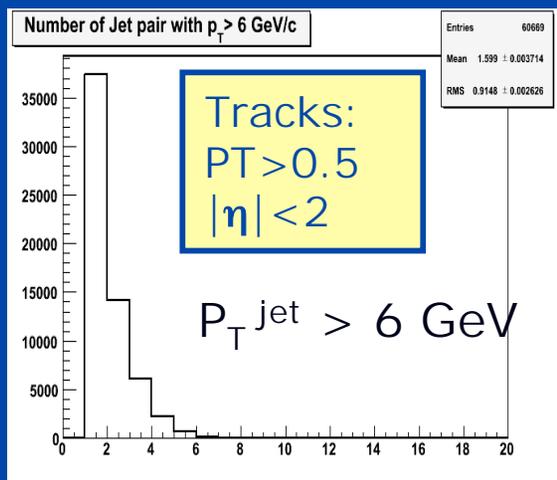
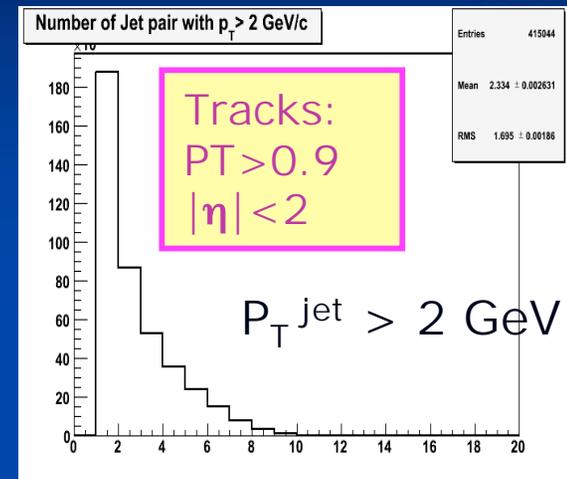
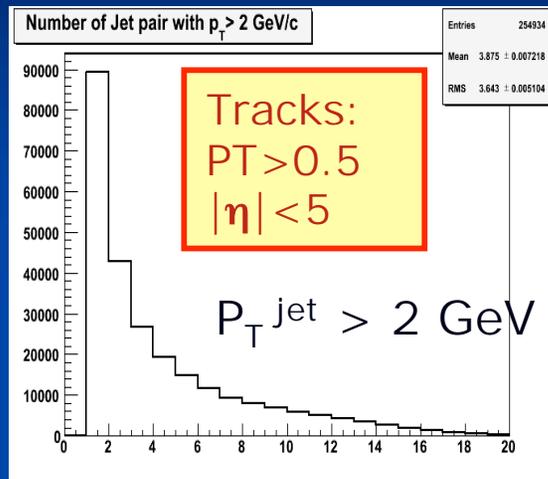
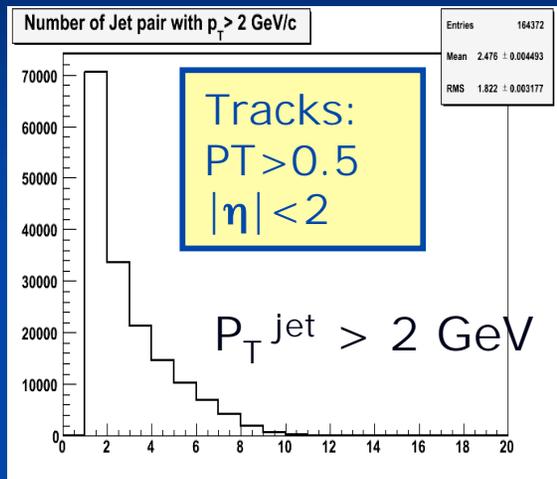
Dove  $\sigma_{\text{inel}} = \sigma_{\text{soft}} + \sigma_H$

"S" = Interazioni Singola, "D" = Interazioni doppie, "H" = Hard  
 $\sigma_{\text{eff}}(P_T)$  contiene l'informazione spaziale dei partoni (principalmente gluoni!)

# Conteggio delle MPIs tramite coppie di Mini-Jets back-to-back



$N$  = Numero di coppie di jet in vari ranges di  $\eta$ ,  $P_{T,track}$ ,  $P_{T,jet}$

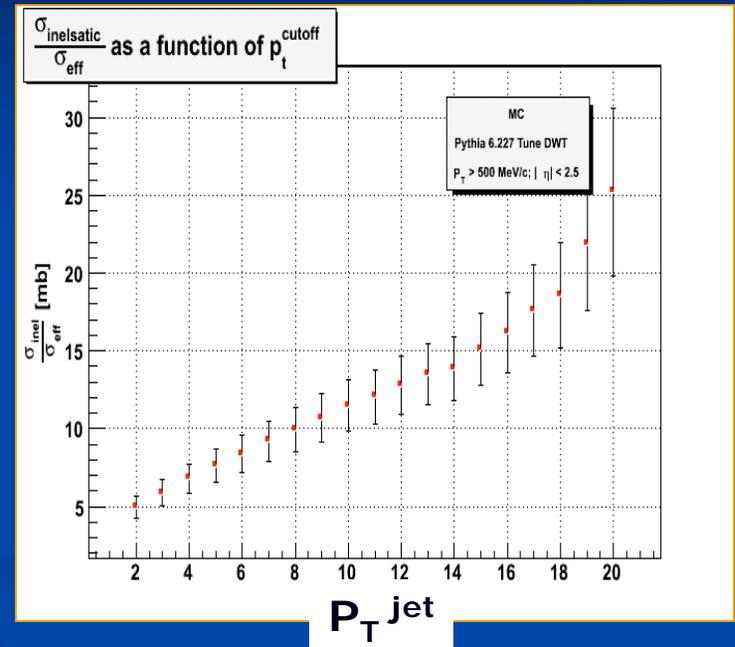
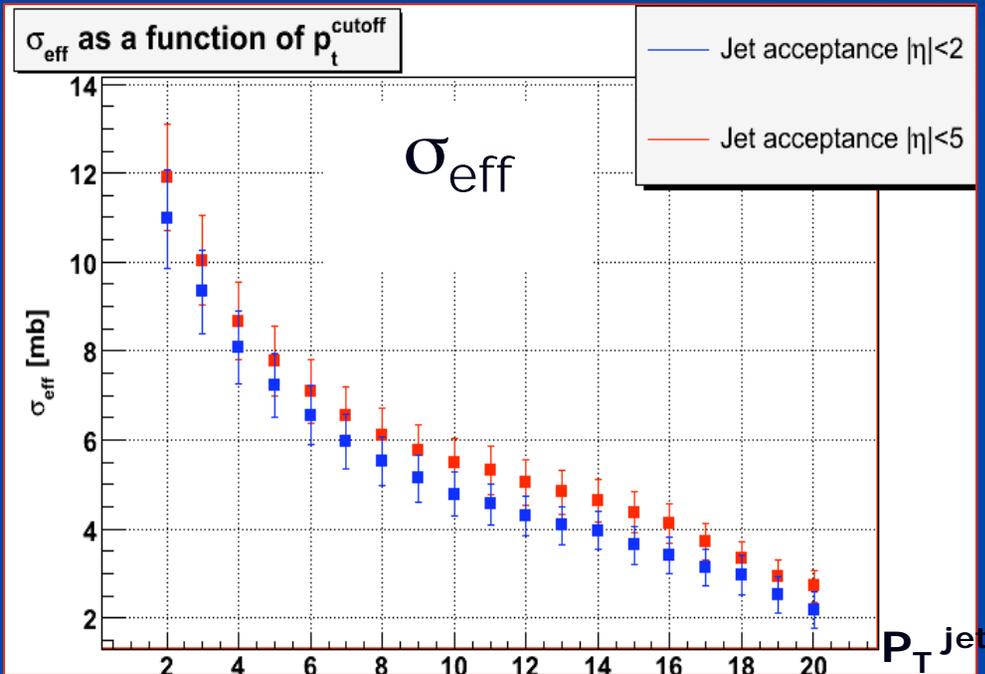


$N$  dipende in modo marcato da efficienze e accettanze

# Conteggio delle MPIs tramite coppie di Mini-Jets back-to-back



$$\langle N \rangle \sigma_H = \sigma_S \quad \text{and} \quad \frac{1}{2} \langle N(N-1) \rangle \sigma_H = \sigma_D \quad \langle N(N-1) \rangle = \langle N \rangle^2 \frac{\sigma_H}{\sigma_{eff}}$$



**Incremento nella probabilita' di MPI addizionali**

$\sigma_{eff}$  non dipende da accettazione e efficienza (come atteso dalla teoria)

# Conteggio delle MPIs tramite coppie di Mini-Jets back-to-back: Bottom Line



**Dati I progressi sulla ricostruzione di tracce soffici, la linea di ricerca e' molto promettente.**

**Studi di fattibilita' in corso**

**Da provare**

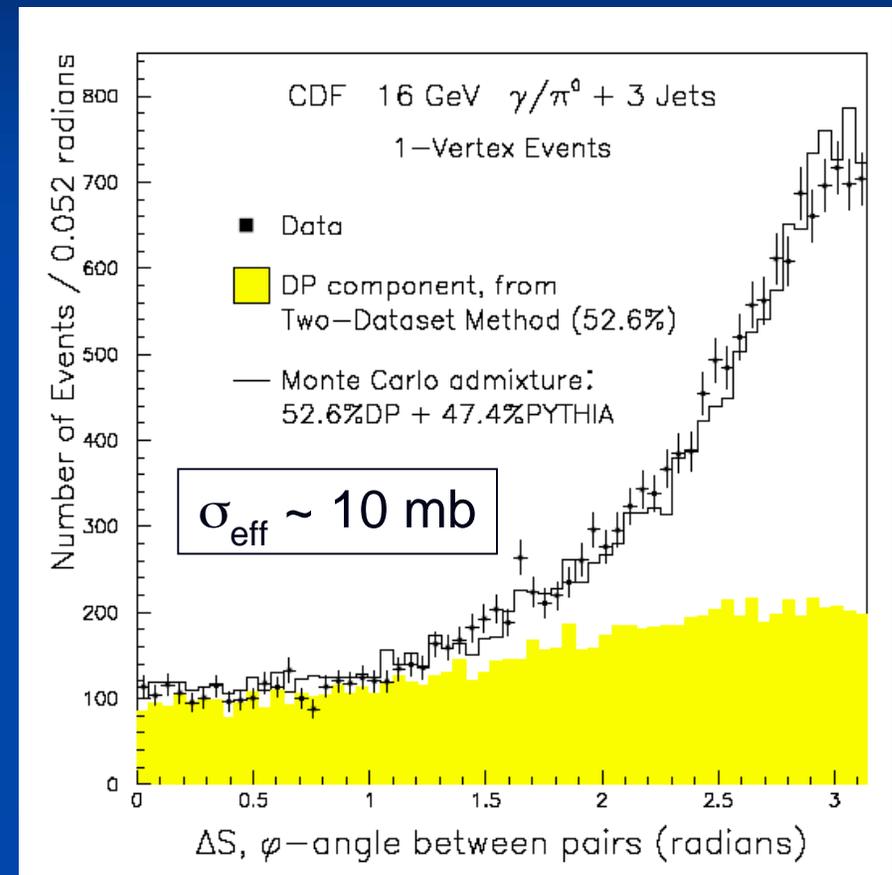
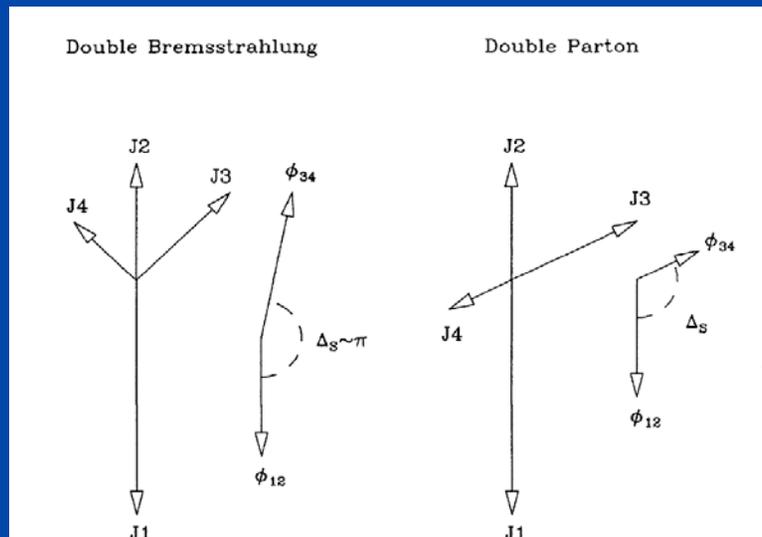
- Uteriori modelli e tunes (Herwig+Jimmy, S0)
- Altri algoritmi di Clustering (fast KT etc.)

# $\gamma + 3 \text{ jets @ CDF}$



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

CDF e' stato il primo esperimento a ricercare il doppio scattering di partoni in topologie  $\gamma jjj$ , studiando l'angolo azimuthale tra I vettori PT delle coppie  $\gamma-j$  e  $j-j$



**Need DP component to describe the data!**

# $\gamma$ +jet: confronto tra modelli QCD



- **Pythia 6.413**  $p^T > 20 \text{ GeV}/c$ 
  - DWT (CMS default)
  - S0 (colour reconnection)
- **Pythia 8.1**  $p^T > 20 \text{ GeV}/c$ 
  - Default settings (underlying physics ~ Pythia 6 S0)
  - MPI switched off
  - **Generate two jets on top of photon + jet (DPS)**
- **Herwig 6.510**  $p^T > 20 \text{ GeV}/c$ 
  - “Soft underlying event” (no MPI)
  - Jimmy 4.2

**arXiv:0710.3820**

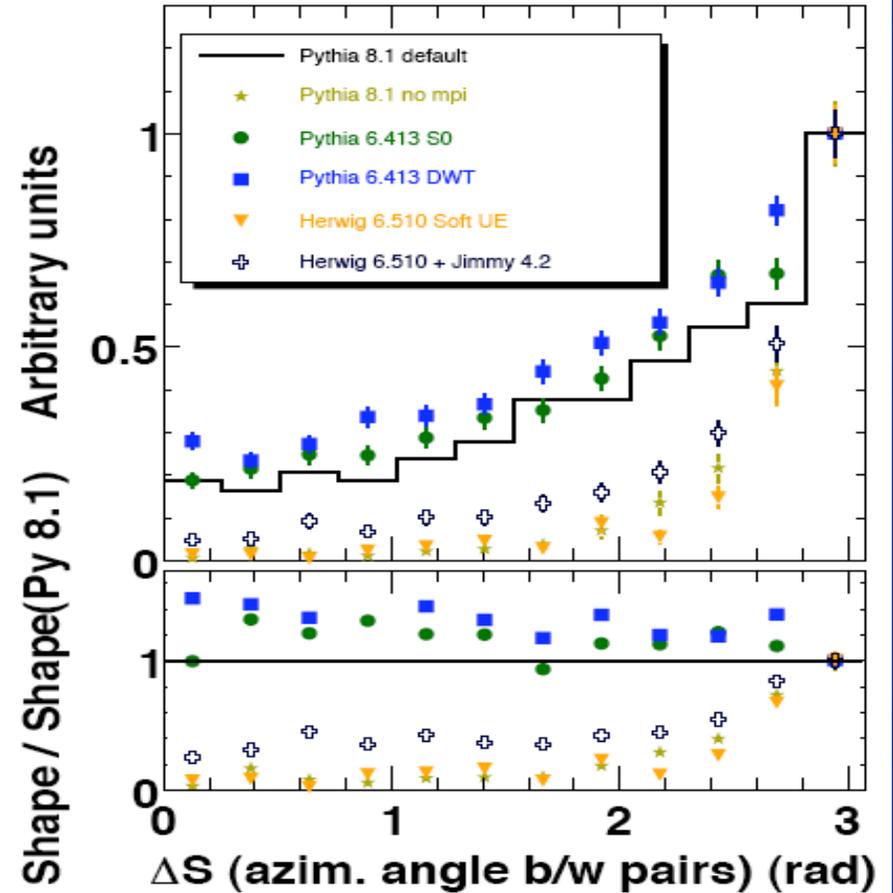
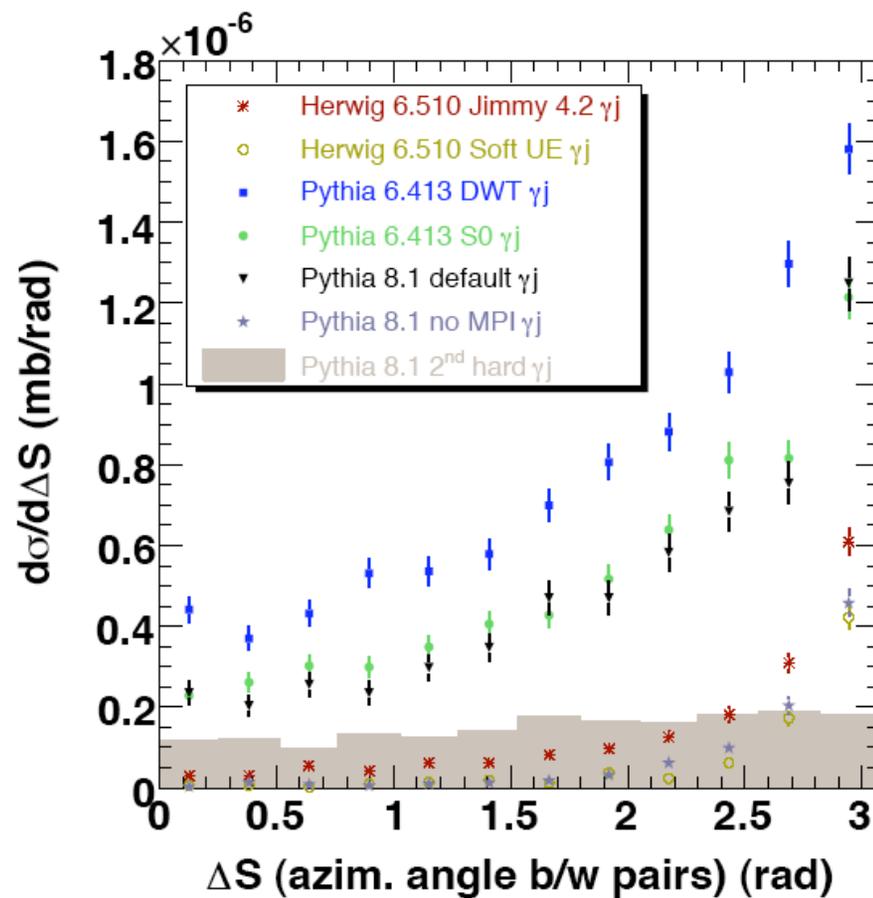
**First operational release of complete C++ rewrite**

**→ Can set two hard interactions in the same event (= double high- $p^T$  interactions, double parton scattering)**

# $d\sigma/d\Delta S$

## • Selezione

- ICA,  $R=0.7$
- $p T(\gamma) > 30 \text{ GeV}/c$
- $p T(\text{jet}) > 30 \text{ GeV}/c$
- $dR_{ij} > 0.8$

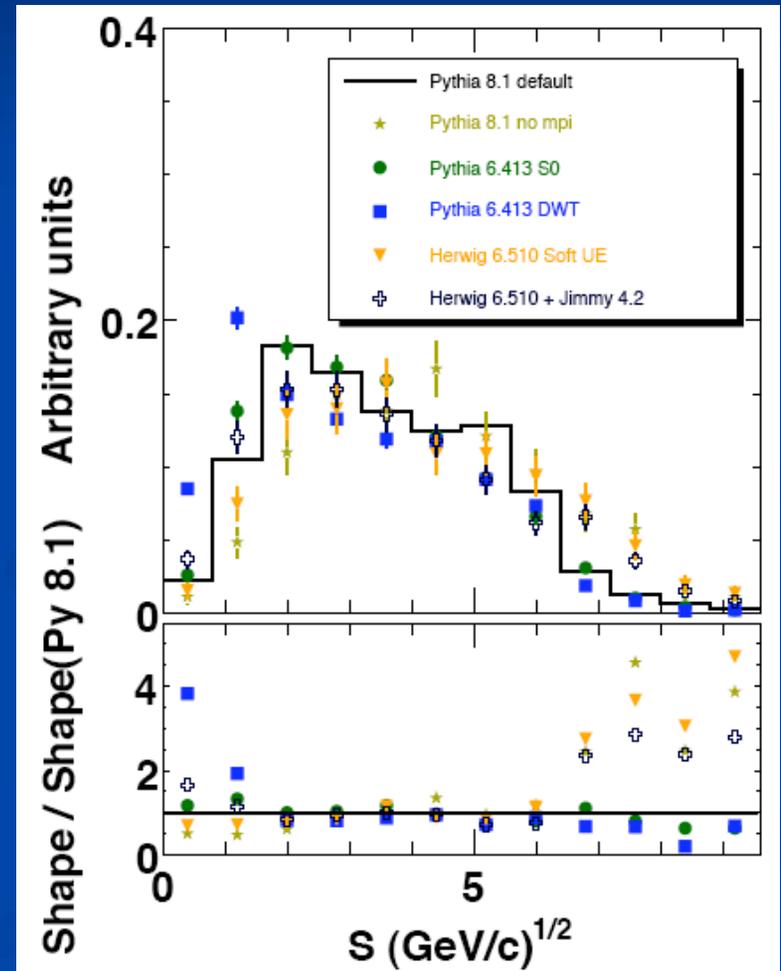


# S shapes



$$S = \frac{1}{\sqrt{2}} \sqrt{\left(\frac{\vec{p}_T(\gamma, i)}{\delta p_T(\gamma, i)}\right)^2 + \left(\frac{\vec{p}_T(j, k)}{\delta p_T(j, k)}\right)^2}$$

$$\delta p_T(i, j) = \sqrt{p_{Ti} + p_{Tj}}$$



# $\gamma + 3 \text{ jets @ LHC}$ Bottom Line



- CMS propone il confronto tra diversi modelli MPI in Pythia e in Herwig per il processo  $\gamma + 3\text{jet}$ , uno studio motivato anche dalla necessita' di validare il nuovo MC Pythia 8.1
    - Come previsto, le predizioni di Pythia 8.1 sono molto simili a quelle di Pythia 6.4 con il medesimo Tune (S0)
    - Vi sono grandi differenze (in forma e normalizzazione delle distribuzioni) tra diversi tune di Pythia e tra diversi Shower MC con MP, ad esempio Herwig/Jimmy vs Pythia
- La risposta finale spetta ai dati!

# MPI e Diffrazione dura all'LHC



## Un'introduzione euristica

- Una topologia diffrattiva viene influenzata dalla presenza di ulteriori interazioni partoniche
  - Probabilità di sopravvivenza di protoni e Large Rapidity Gaps (LRGs)  $\sim e^{-\langle N_{int} \rangle}$

$$\text{Dove } \langle N_{int} \rangle = \sigma_{parton-parton} / \sigma_{inel\ proton-proton}$$

[R.Field]	$\sigma_{parton-parton}$ at 1.96 TeV	$\sigma_{parton-parton}$ at 14 TeV
Tune A	309.7 mb	484.0 mb
Tune DW	351.7 mb	549.2 mb
Tune DWT	351.7 mb	829.1 mb

~ 80 mb

Si puo' dare un significato meno legato al modello per  $\sigma_{parton-parton}(P_T)$ , ad esempio attraverso l'analisi delle coppie di mini-jet

- Misura alternativa dei fattori di soppressione (direttamente dalla fisica diffrattiva)
  - Estrapolare le dPDFs misurate ad HERA e a Tevatron e confrontare le predizioni per le sezioni d'urto all'LHC
  - Misurare  $F_2^D$ , ad esempio in eventi dijet per SD e DPE, quindi comparare



## MPI@LHC - Conclusioni

Le Interazioni Partoniche Multiple (MPI) svolgono un ruolo chiave nel determinare le caratteristiche generali degli eventi p-p ad LHC  
-> **Molteplicita', Spettro in PT, etc.**

La comprensione delle MPI e' un passaggio decisivo per tenere sotto controllo le sistematiche nelle ricerche  
-> **Isolamenti, Occupanze, Calibrazione in Energia, Veti su Jet, Ricostruzione dei Vertici di interazione**

Lo studio delle MPI beneficia di un ricco quadro fenomenologico di processi ad alto e basso PT che fin'ora sono stati interpretati in contesti eterogenei  
-> **Underlying Event in varie topologie, Struttura Mini-jet del Minimum Bias, Double parton scattering (double boson, 3jet+gamma etc.), Large Rapidity Gap Suppression, etc.**

# Crediti



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Torbjorn Sjostrand,  
Aneta Iordanova,  
Richard Hollis,  
Craig Buttar  
etc...

# MPI@LHC'08

FIRST INTERNATIONAL WORKSHOP ON MULTIPLE PARTONIC INTERACTIONS AT THE LHC

Perugia, Italy,  
27- 31 October, 2008



Home	Programme	Registration	Registered Participants	Organizing Committee
Accommodation	Guidelines & Travelling	Contacts	Bulletin & Poster	Instructions for Authors



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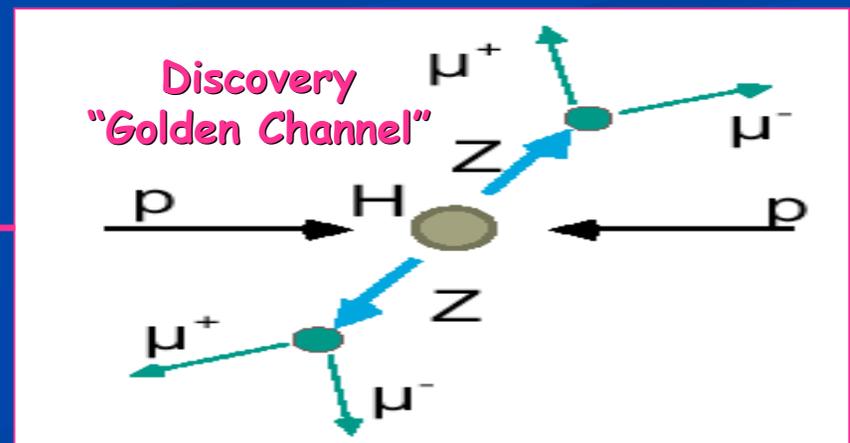
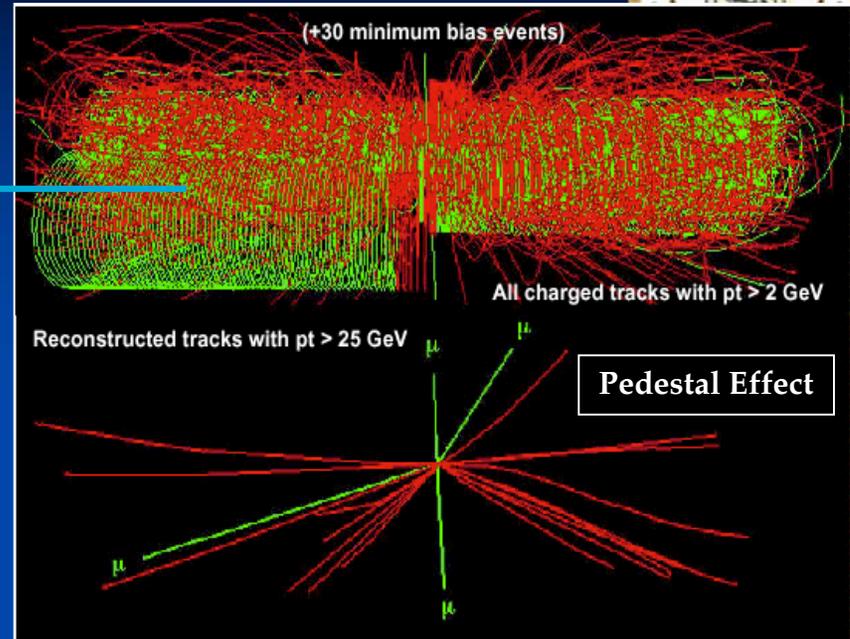
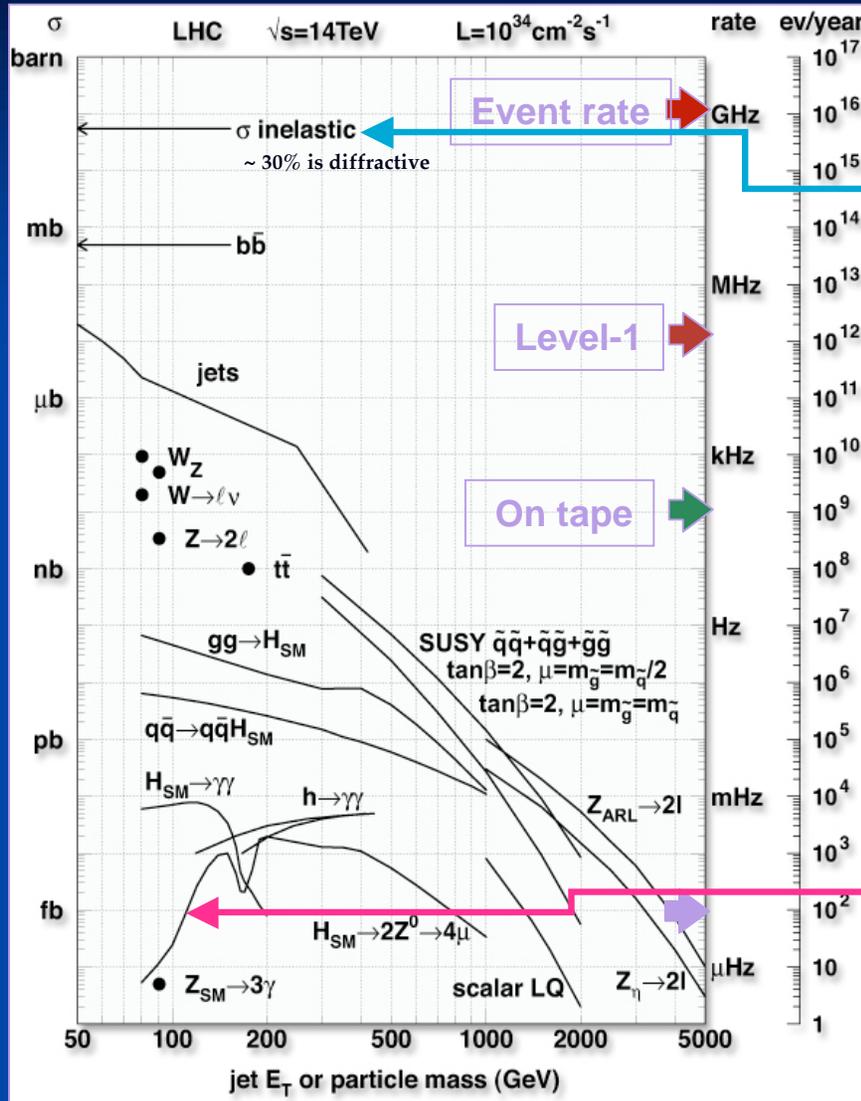
F. Ambroglini, L. Fano', A. Santocchia, G. Chiozzi  
(Istituto Nazionale di Fisica Nucleare, Perugia, IT)

<http://www.pg.infn.it/mpi08>

# *BACKUP*



# Stati finali ad LHC



# Definitions & Terminology



## ■ Minimum Bias (MB)

- The generic single particle-particle interactions.
  - Elastic + Inelastic (including Diffractive).  $\sim 100 \text{ mb @ LHC}$ .
    - Soft. Low  $P_T$ , low Multiplicity..
  - What we would observe with a fully inclusive detector/trigger.
  - At the LHC, several MB interactions can take place in a single beam crossing.  $\langle N_{\text{int}} \rangle = L_{\text{inst}} * \sigma$ .
    - MB seen if “interesting” Triggered interaction also produced.
    - Pile-up effect.
- Tracking detectors help to separate the different primary vertices.  
Possible overlap of clusters in calorimeters. Need energy flow.

## ■ Underlying Event (UE)

- All the activity from a single particle-particle interaction on top of the “interesting” process.
  - Initial State Radiation (ISR).
  - Final State Radiation (FSR).
  - Spectators.
  - ... Not enough! What else ??? (Will see in a moment...).
- The UE is correlated to its “interesting” process.
  - Share the same primary vertex.
  - Events with high  $P_T$  jets or heavy particles have more underlying activity → Pedestal effect.
    - Sometimes useful! Ex. Vertex reconstruction in  $H \rightarrow \gamma\gamma$ .
- UE  $\neq$  MB but some aspects & concepts are similar.
  - Phenomenological study of Multiplicity &  $P_T$  of charged tracks.

# Motivations



- Study of “soft” QCD
  - Exploring Fundamental aspects of hadron-hadron collisions
    - Structure of Hadrons, Factorization of interactions
    - Energy dependence of cross sections and charged multiplicities

$$\text{Regge: } s^{\alpha_p(s) - 1}$$

$$\text{Froissard bound: } (\ln s)^2$$

$$\alpha_p(s) - 1 = 0.12 \text{ [Kaidalov '91]}$$

## → Tuning of Monte Carlo Models

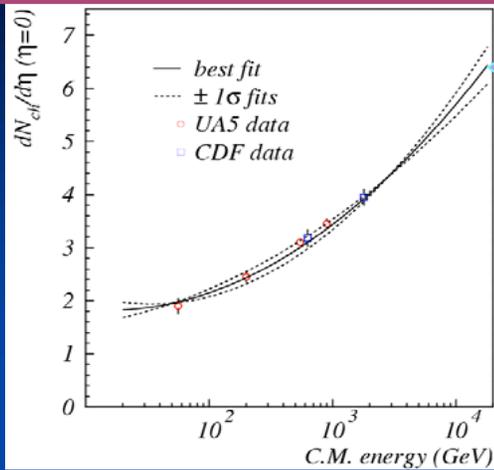
## → Understanding the detector

- Occupancies, Backgrounds, etc.

## → Calibration of major physics tools

- Jet Energy, Missing Energy, Jet Vetoes, Vertex Reconstruction, Photon/Lepton Isolation

# MB: Average Charged Multiplicity at $\eta=0$



Extrapolation to the LHC Energy

- UA5 at  $\sqrt{s} = 53, 200, 546, 900$  GeV  
[Z. Phys. C 33 (1986) 1]
- CDF at  $\sqrt{s} = 630, 1800$  GeV  
[PRD 41 (1989) 2330]

[CERN 2000-004, pgg 293-300]

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

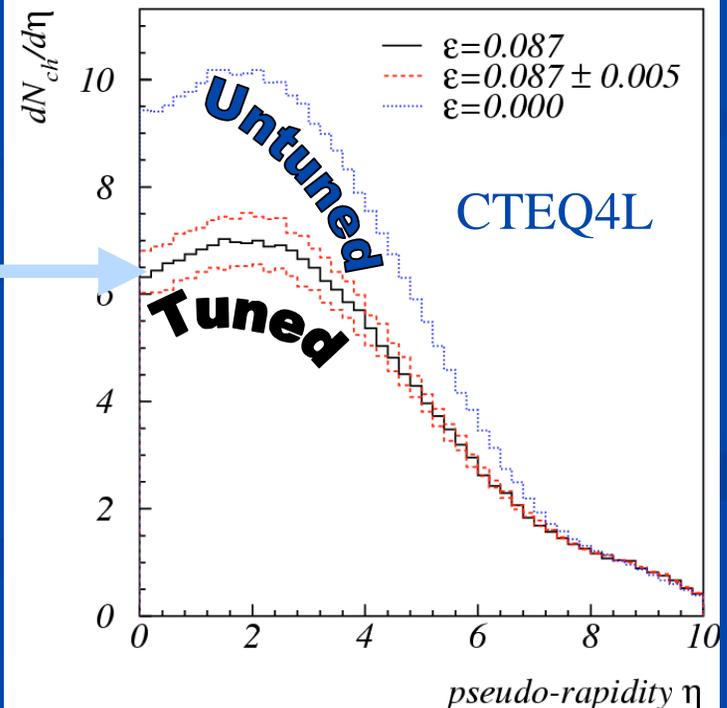
$$x g(x, Q^2) \rightarrow x^{-\epsilon} \text{ for } x \rightarrow 0$$

- $P_T$  cut-off adjusted to reproduce the measured multiplicity for each PDF
- $P_T$  cut-off fitted with exponential function

$$P_{T0} = P_{T0}^{LHC} \left( \frac{\sqrt{s}}{14 \text{ TeV}} \right)^{2\epsilon}$$

Agreement With Phenomenological Fit

[CERN 2000-004, pgg 293-300]



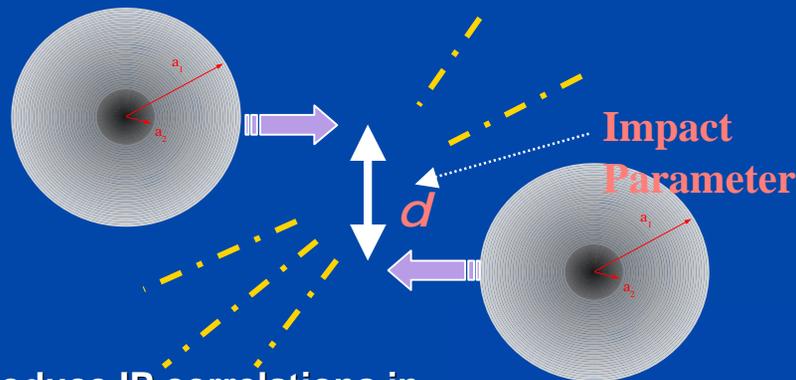
# MB: Charged Multiplicity Distribution



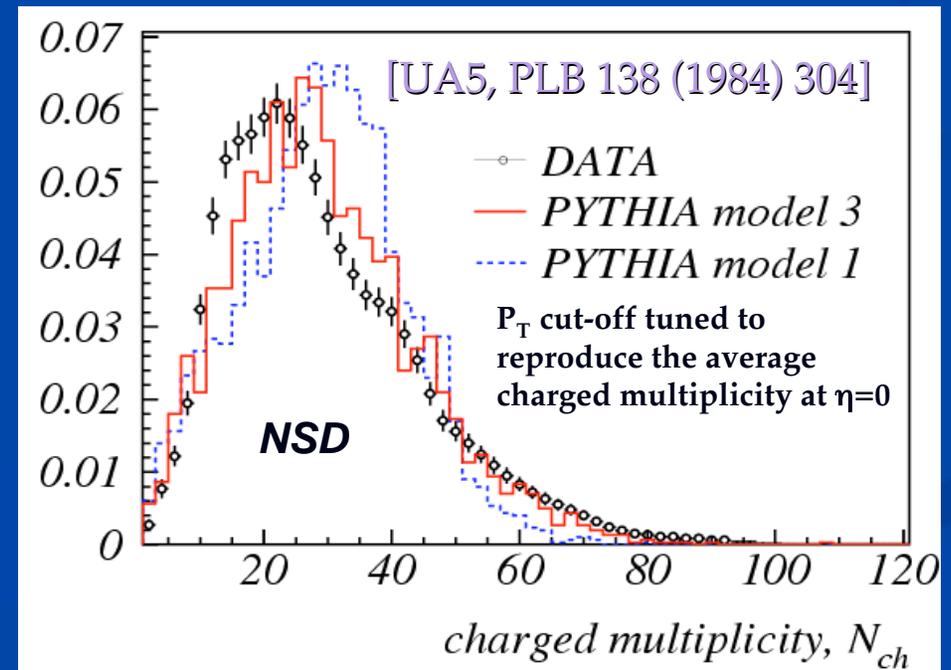
## Choice of the multiple interaction model:

- All hadron collisions equivalent (MSTP(82)=1)
  - Abrupt turn off of the cross section at  $P_T$  cut-off
  - All the partonic interactions equivalent
- Varying impact parameter between the colliding hadrons.
  - Continuous turn off of the cross section at  $P_T$  cut-off
  - Correlated partonic interactions.
  - Hadronic matter described by one (MSTP(82)=3) or two (MSTP(82)=4) Gaussian(s)

Model with Varying impact parameter between the colliding hadrons; hadronic matter is described by Gaussians



Introduce IP correlations in Multiple Parton Interactions → Pedestal Effect



# *Side Note on the energy dependency of the $P_T$ cut-off*



**G.Gustafson & G.Miu**

rather suggest energy independency of the  $P_T$  cut-off.

Minijets and transverse energy flow in high-energy collisions.  
[Phys.Rev.D63:034004,2001]

Hadronic collisions in the linked dipole chain model.  
[Phys.Rev.D67:034020,2003]

# Pythia CTEQ5L Tunes



Parameter (PYTHIA v.6412+)	A	ATLAS	DW	DWT	S0
UE model MSTP(81)	1	1	1	1	21
UE infrared regularisation scale PARP(82)	2.0	1.8	1.9	1.9409	1.85
UE scaling power with $\sqrt{s}$ PARP(90)	0.25	0.16	0.25	0.16	0.16
UE hadron transverse mass distribution MSTP(82)	4	4	4	4	5
UE parameter 1 PARP(83)	0.5	0.5	0.5	0.5	1.6
UE parameter 2 PARP(84)	0.4	0.5	0.4	0.4	n/a
UE total gg fraction PARP(86)	0.95	0.66	1.0	1.0	n/a
ISR infrared cutoff PARP(62)	1.0	1.0	1.25	1.25	( = PARP(82) )
ISR renormalisation scale prefactor PARP(64)	1.0	1.0	0.2	0.2	1.0
ISR $Q_{\max}^2$ factor PARP(67)	4.0	1.0	2.5	2.5	n/a
ISR infrared regularisation scheme MSTP(70)	n/a	n/a	n/a	n/a	2
ISR FSR off ISR scheme MSTP(72)	n/a	n/a	n/a	n/a	0
FSR model MSTJ(41)	2	2	2	2	( $p_T$ - ordered)
FSR $\Lambda_{QCD}$ PARJ(81)	0.29	0.29	0.29	0.29	0.14
BR colour scheme MSTP(89)	n/a	n/a	n/a	n/a	1
BR composite $x$ enhancement factor PARP(79)	n/a	n/a	n/a	n/a	2
BR primordial $k_T$ width $\langle  k_T  \rangle$ PARP(91)	1.0	1.0	2.1	2.1	n/a
BR primordial $k_T$ UV cutoff PARP(93)	5.0	5.0	15.0	15.0	5.0
CR model MSTP(95)	n/a	n/a	n/a	n/a	6
CR strength $\xi_R$ PARP(78)	n/a	n/a	n/a	n/a	0.2
CR gg fraction (old model) PARP(85)	0.9	0.33	1.0	1.0	n/a

Table 3.1: PYTHIA parameters, divided into main categories: UE (underlying event), ISR (initial state radiation), FSR (final state radiation), BR (beam remnants), and CR (colour reconnections). The UE reference energy for all models is PARP(89)=1800GeV, and all dimensionful parameters are given in units of GeV.

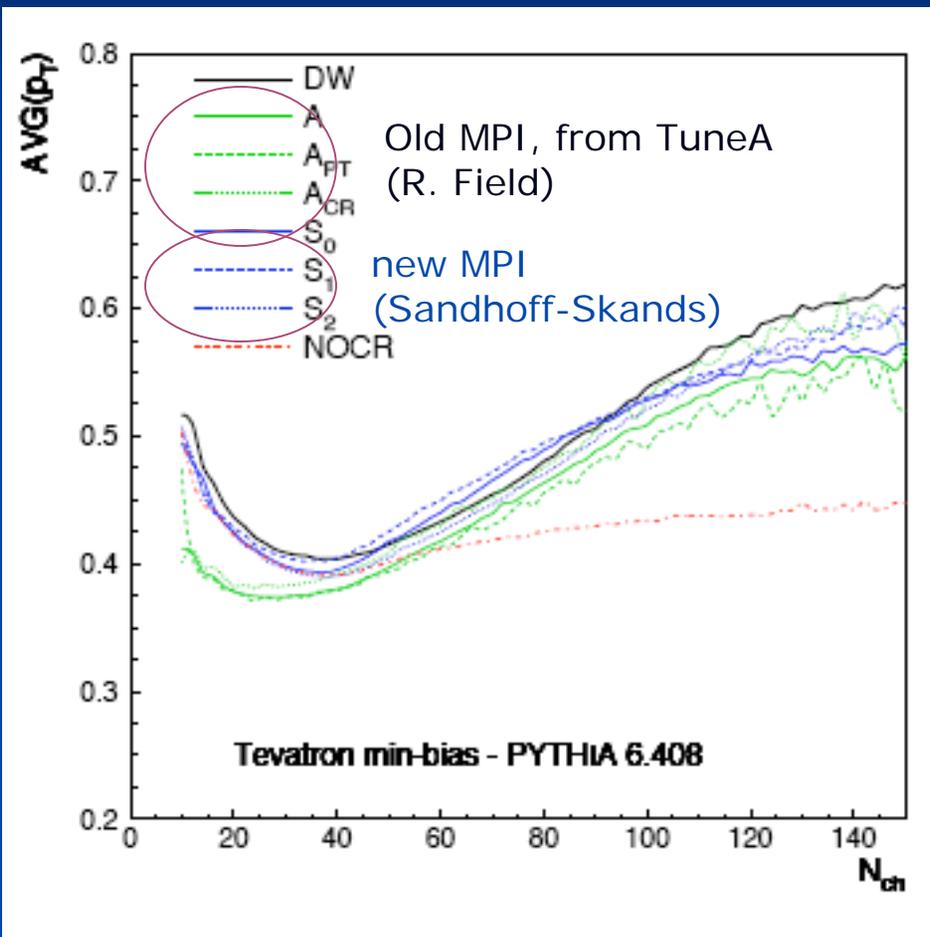


# MB: Further observables sensitive to the differences between the models:

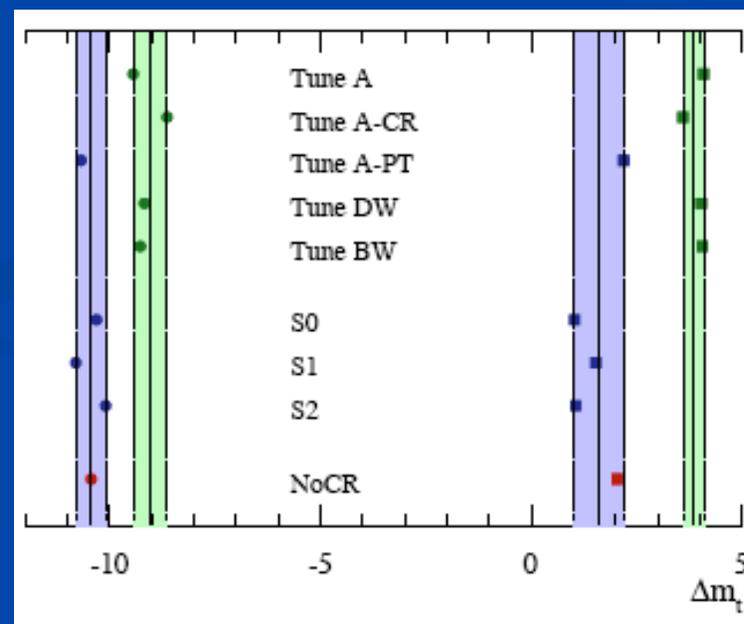
## $\langle P_T \rangle$ vs Multiplicity



[P.Skands, D.Wielke, hep/ph 0703081]



Effect on the top mass for different models (new/old Pythia MPI) and reconnections scenarios



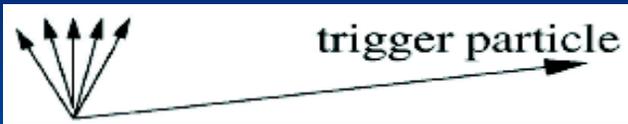
Further information on tunings in back-up slides

# MPI: Forward-Central Correlations



Long range correlations

central forward



no correlation



long range correlation

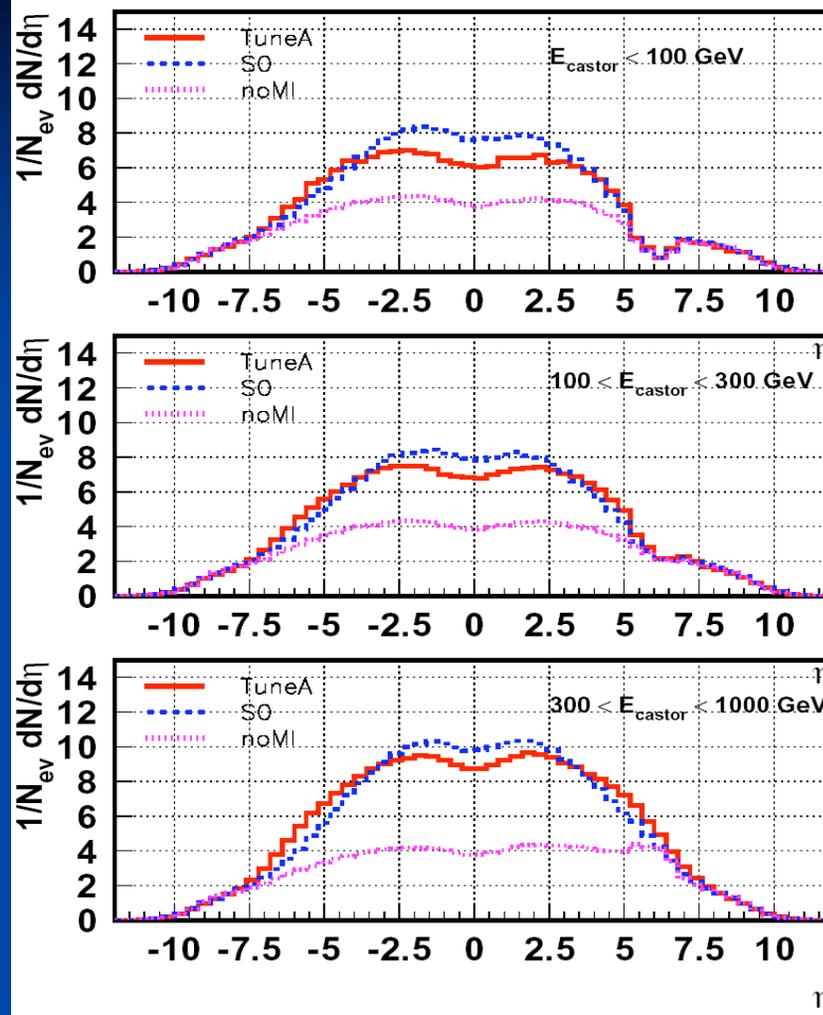


Pythia without MI:

no correlation

Pythia with MI:

Long range correlations, trigger enhancing differences in the central region



[K.Borras]

Generator Level Studies with Pythia 6.4x

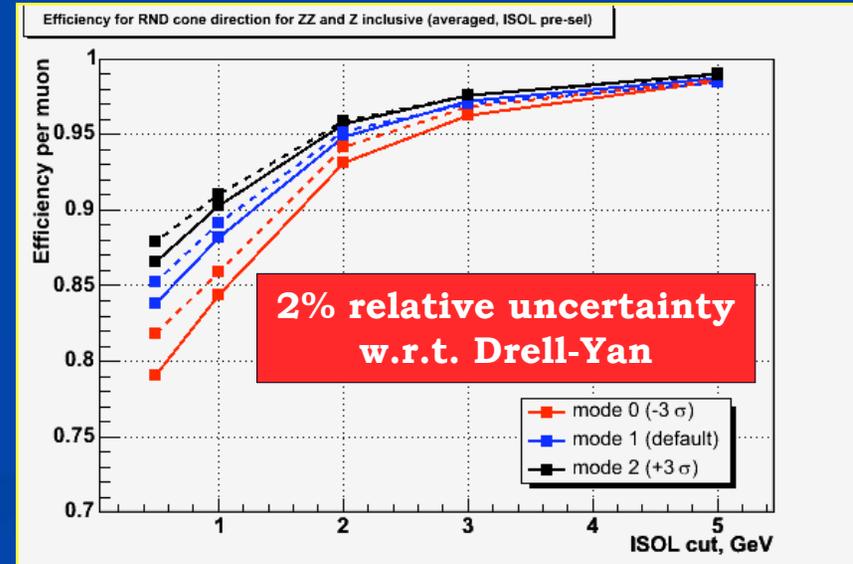
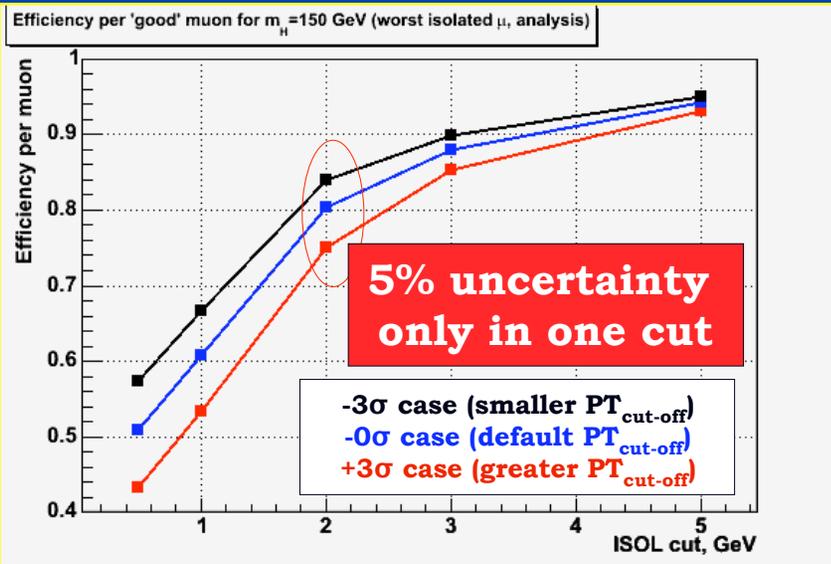
# UE: Application to muon isolation in $H \rightarrow 4\mu$ search (suppression of $t\bar{t}$ and $Zb\bar{b}$ backgrounds)



1. How well can we predict the isolation cut efficiency using the current Monte Carlo generators?
2. Can we calibrate the isolation cut efficiency using the experimental data themselves and, if yes, would the associated experimental systematic errors be smaller than the Monte Carlo based theoretical uncertainties?

Isolation parameter is a sum of  $P_T$  of tracks inside a cone  $dR(\eta, \varphi) = 0.3$   
( $P_T$  of considered tracks  $> 0.8$  GeV)

Random cone direction: all the calculations for isolation observable done for uniformly distributed random directions in event instead of directions for 'real' muons.



## CMS: MB & Jet Trigger



### MB Trigger definition:

10+10 cells with  $E > 1 \text{ GeV}$   
in the Hadron Forward

### Triggers

**MB:** Bandwidth 1 Hz

**Jet20:** Bandwidth 2.5 Hz

**Jet60:** Bandwidth 2.8 Hz

**Jet120:** Bandwidth 2.4 Hz

# CMS MB Trigger

## Based on Hadron Forward Calo



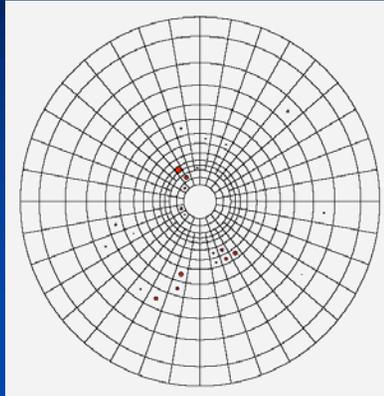
1 pp interaction:

[HI addendum to CMS PTDR]

$$3 < |\eta| < 5$$

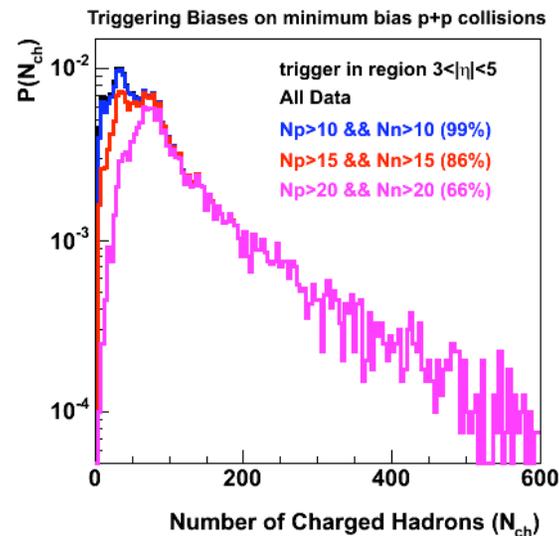
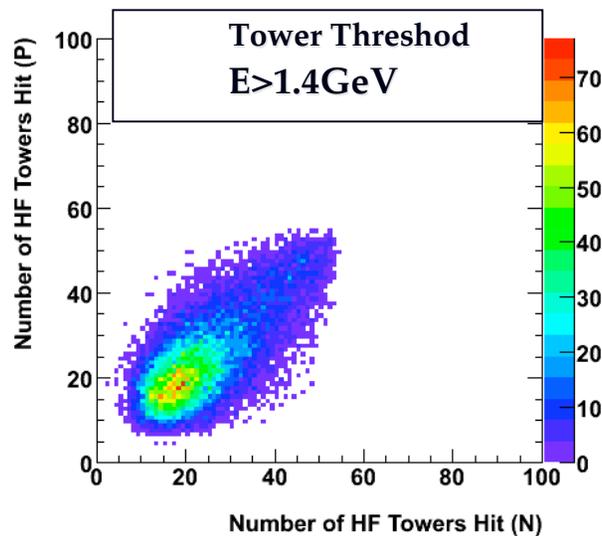
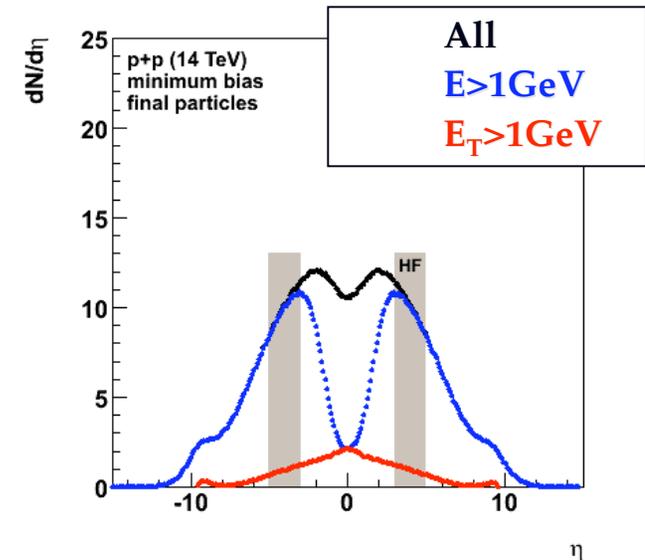
18 wedges/side

0.175x0.175  
towers



Noise per  
Tower  $\ll 1$  GeV:  
HF is a good  
particle counter!

Using towers or single cells fired



Cut on the number  
of calorimeter cells

$> 10$  cells hit

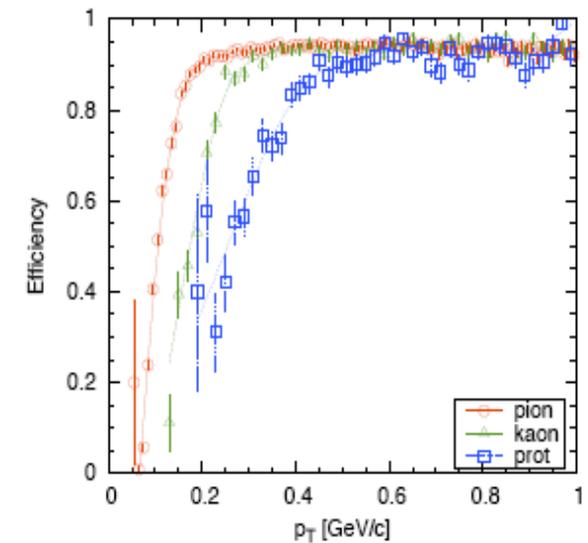
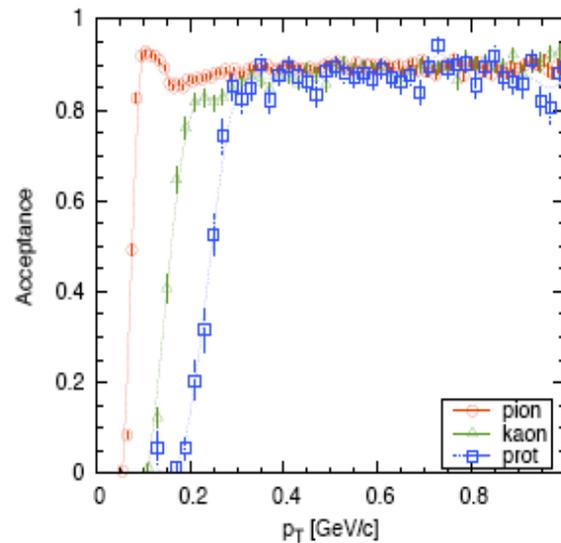
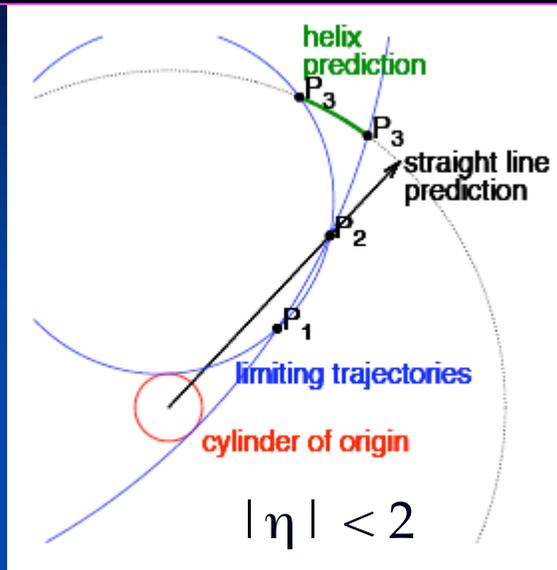
99% efficient

$> 10$  forward cells and  
 $> 10$  backward cells

$> 15 \rightarrow 86\%$

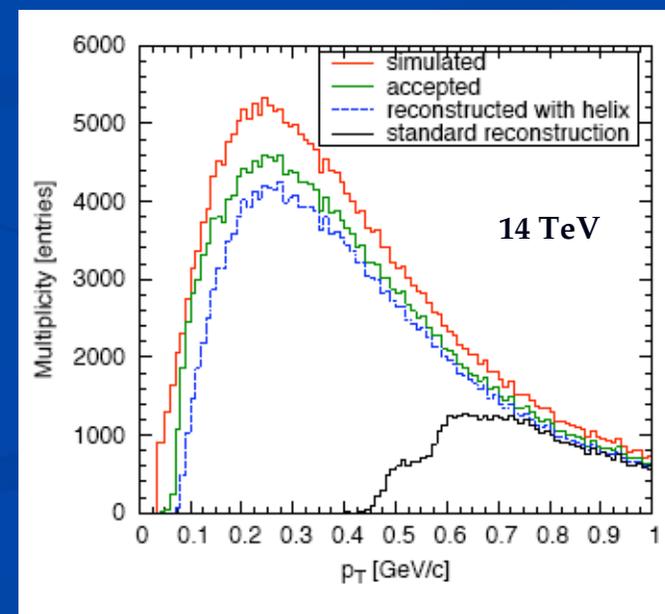
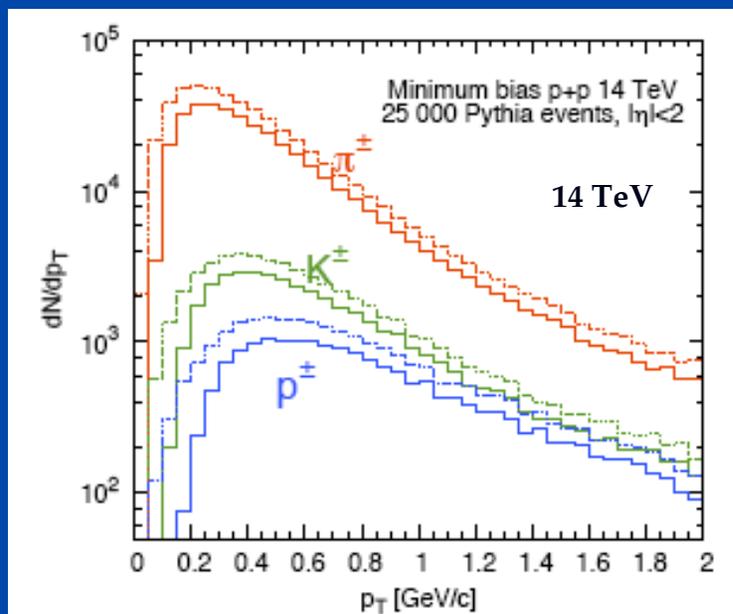
$> 20 \rightarrow 66\%$

# MB (&UE) activity - very soft tracking



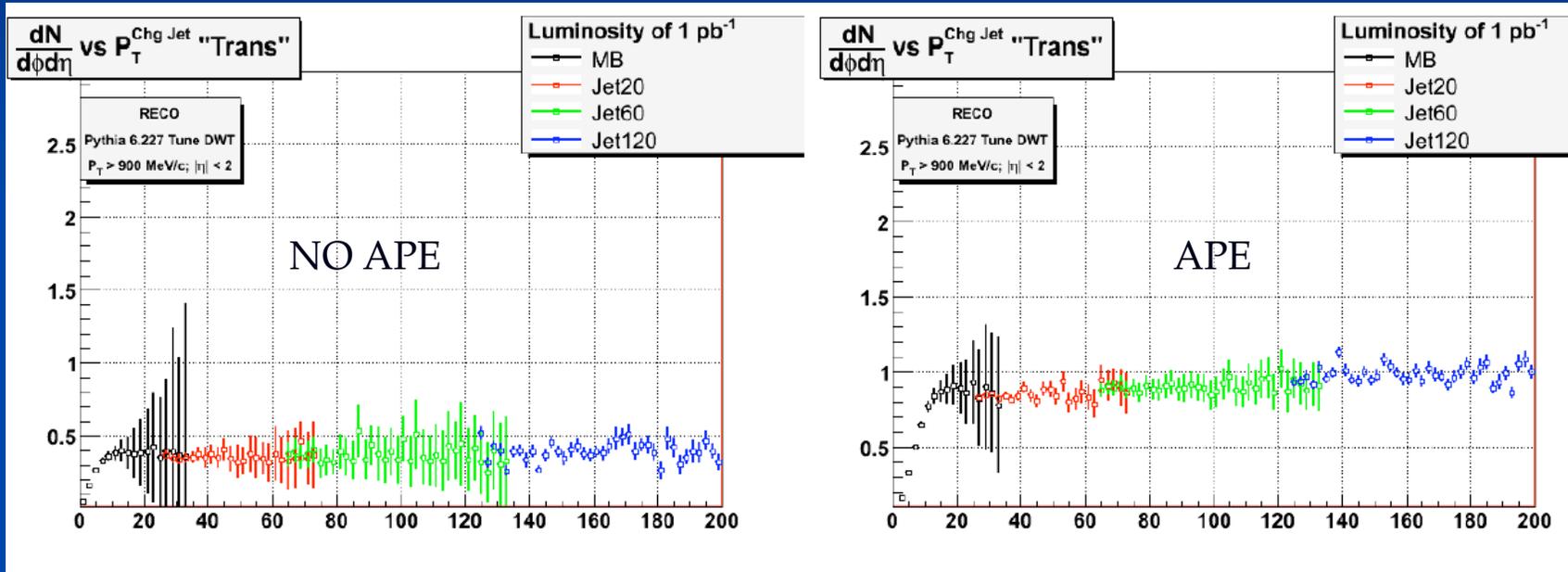
Tracklets:  
 Only pixel triplets:  
 down to 150 MeV !

[F.Sikler et al.  
 hep-ph/0702193]  
 & HI addendum to  
 CMS PTDR





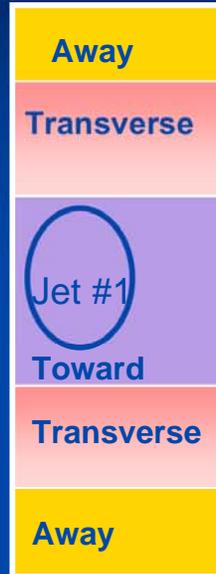
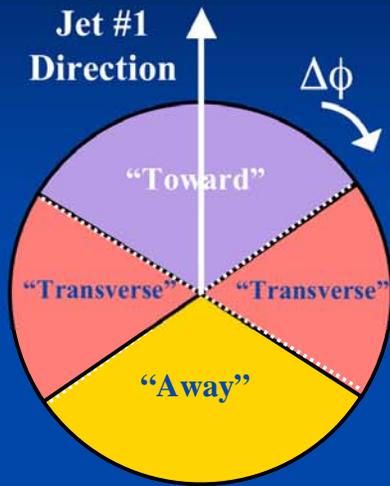
Effect of the alignment in the Start-up scenario  $1\text{pb}^{-1}$



$dN_{ch}/d\eta d\phi$  vs  $PT$

# CDF: Basic Underlying Event Observables

[R.Field et al., PRD 65 (2003) 092002]



- "Charged jet" definition with  $R=0.7$
- Assign all charged particles ( $P_T > 0.5$  GeV/c) and  $|\eta| < 1$  to a jet

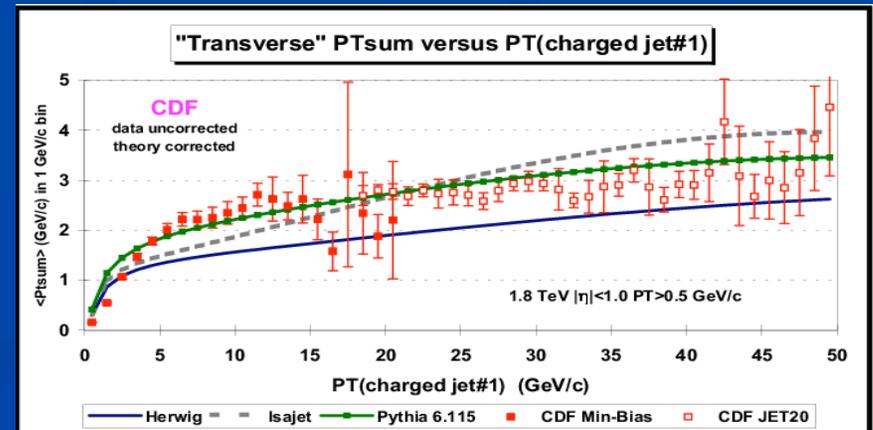
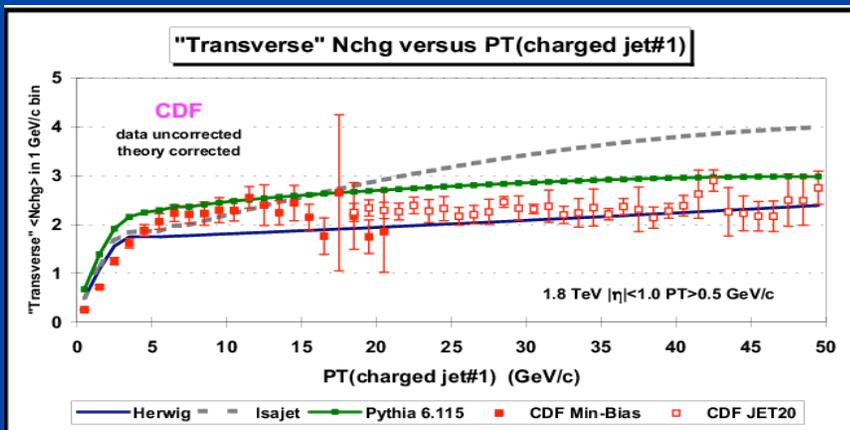
In the three different zones define:

- Charged Multiplicity
- $\Sigma P_T$  (charged tracks)

Transverse regions are expected to be sensitive to the Underlying Event

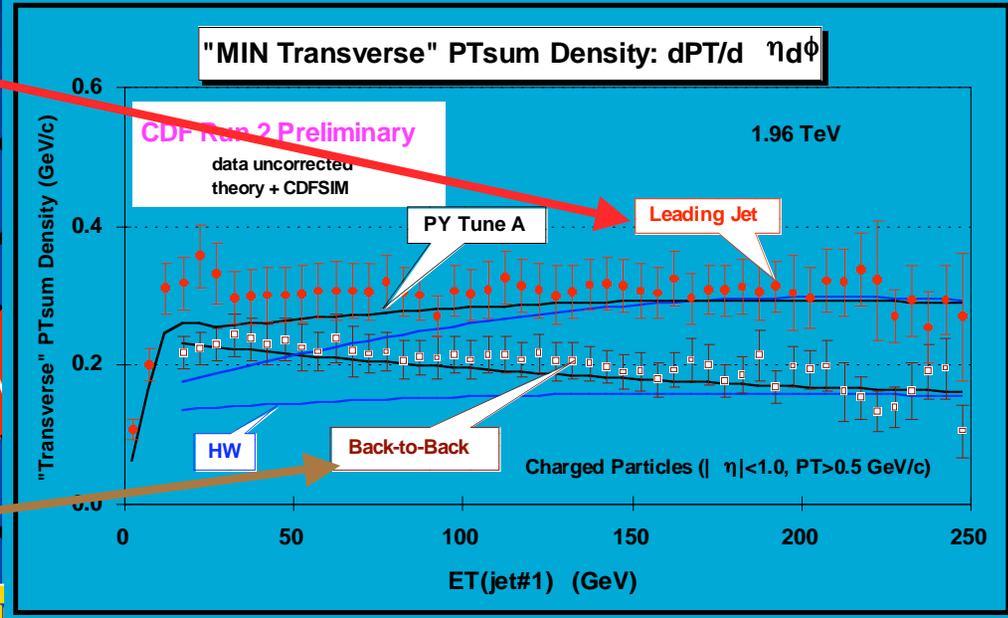
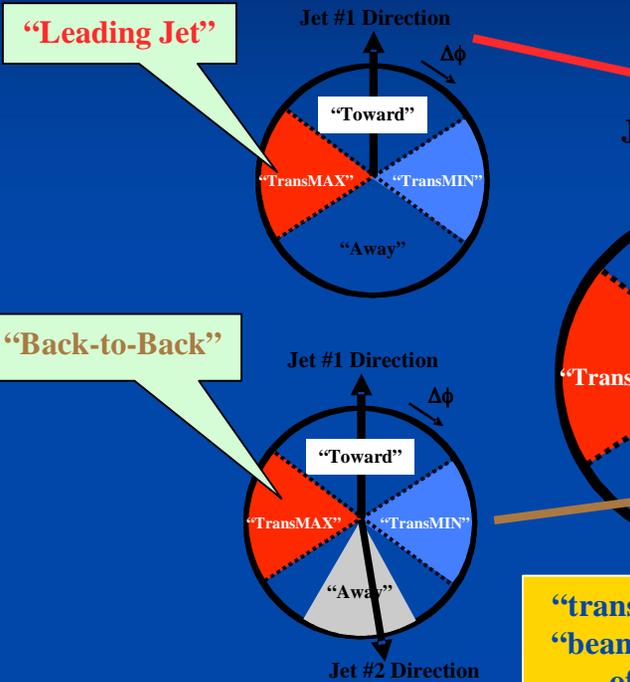
Rapid growth and then constant plateau for  $PT(jet\#1) > 5$  GeV/c

Smooth connection between Minimum bias and jet events





# "TransMIN" PTsum Density versus $E_T(\text{jet}\#1)$ in CDF



"transMIN"  
"beam-beam remnant" component  
of the "underlying event"!

- Use the leading jet to define the MAX and MIN "transverse" regions on an event-by-event basis with MAX (MIN) having the largest (smallest) charged particle density.
- Shows the "transMIN" PTsum density,  $dPT_{\text{sum}}/d\eta d\phi$ , for  $p_T > 0.5 \text{ GeV}/c$ ,  $|\eta| < 1$  versus  $E_T(\text{jet}\#1)$  for "Leading Jet" and "Back-to-Back" events.

[R.Field]