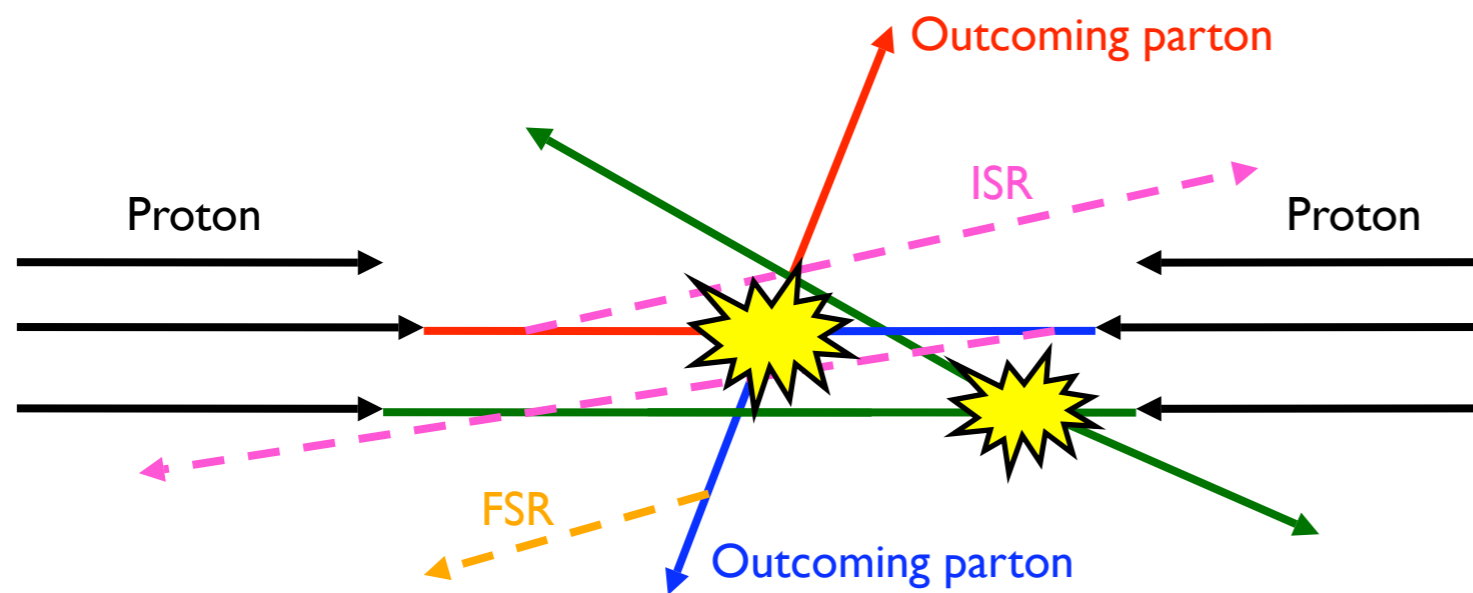


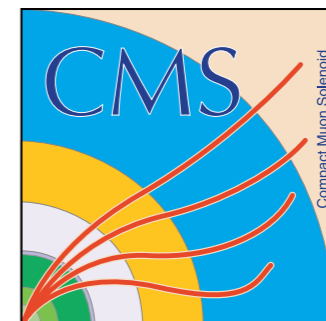
# Minimum bias and underlying event studies with CMS

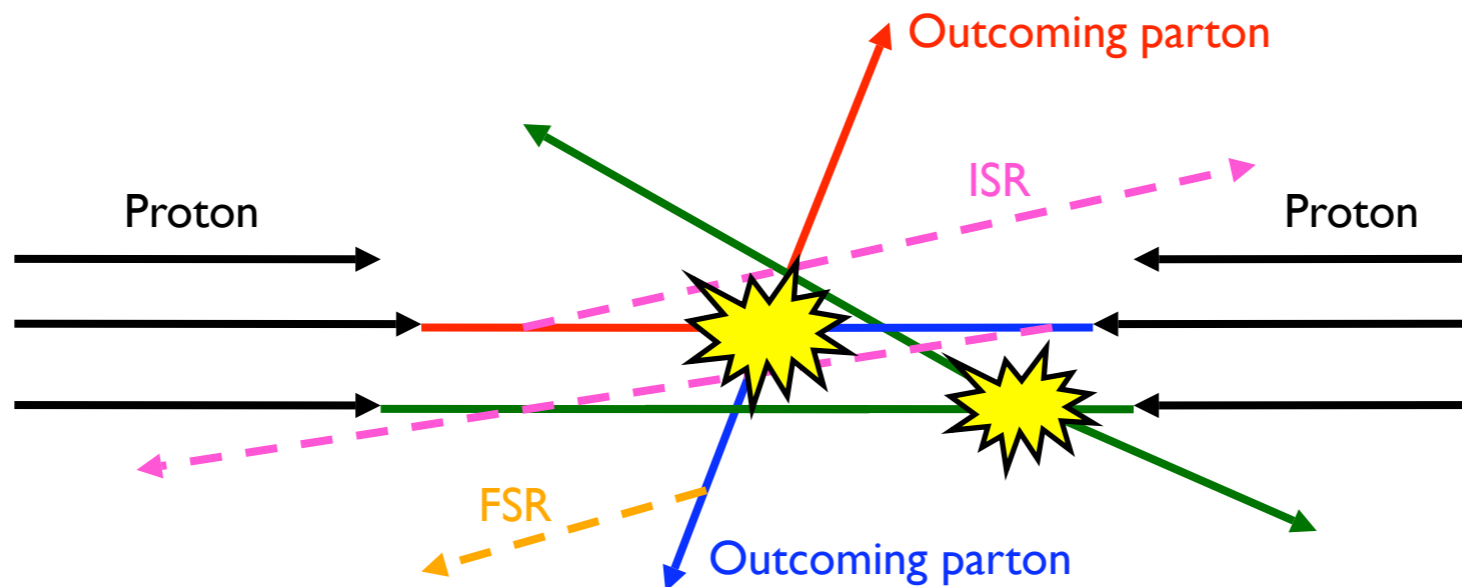
Florian Bechtel (Hamburg / Lund) on behalf of the CMS collaboration  
*XVI Int. Workshop on Deep-Inelastic Scattering and Related Subjects*  
7 - 11 April 2008, University College London



*Thanks to:*

DIS Workshop Organizers  
CMS **QCD** & HI groups



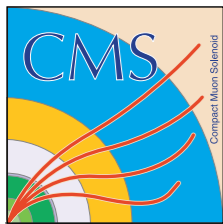


## ▶ **Minimum-bias**

- Trigger
- Expected particle yields, energy dependence

## ▶ **Underlying event**

- Multiple parton-parton interactions (MPI)
- Phenomenological models and their extrapolation to the LHC
- CMS strategy to measure MPI
- Charged-jet topologies



# Soft pp-scatters at 14 TeV



## ▶ **Need to establish QCD at $\sqrt{s} = 14 \text{ TeV}$**

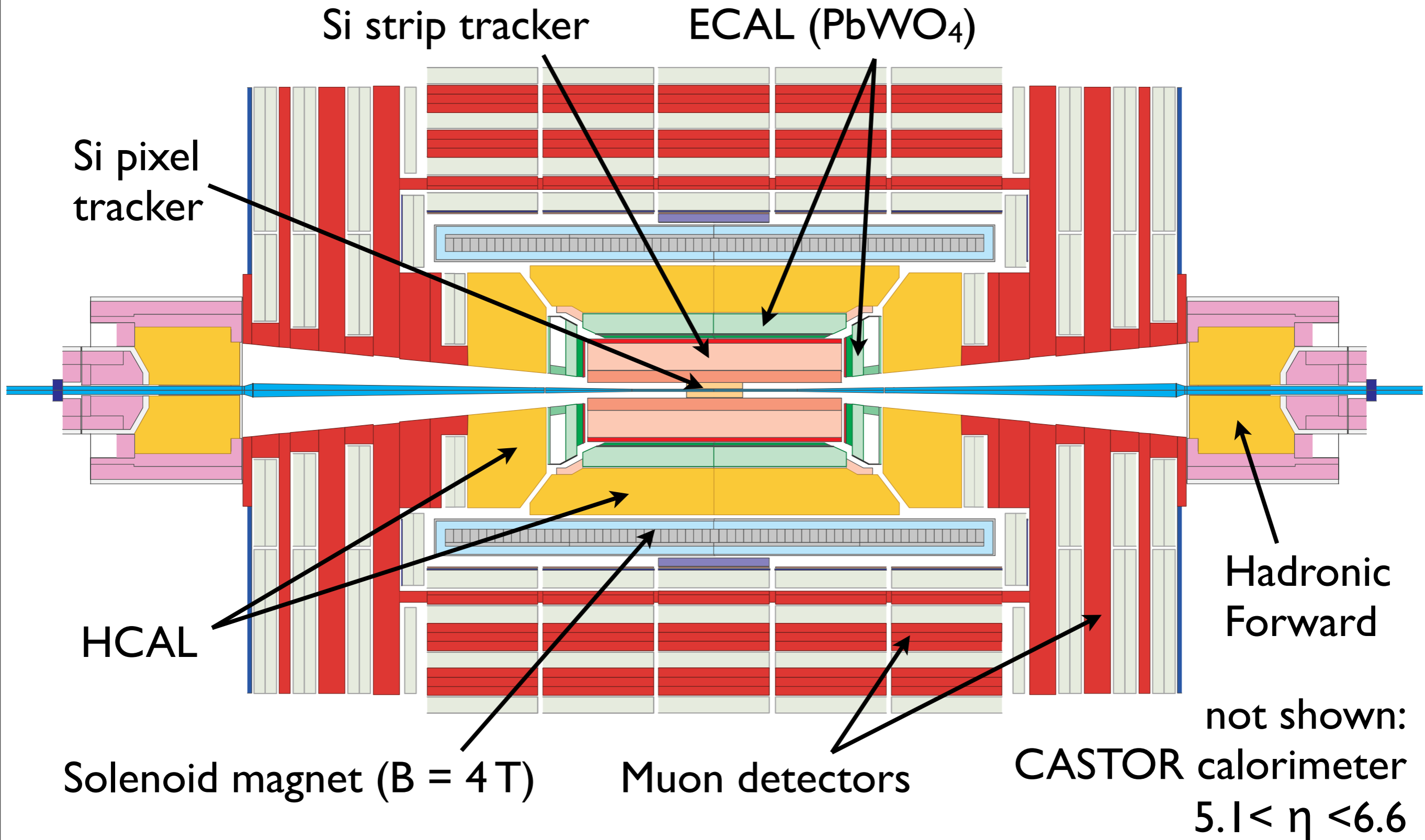
- LHC collisions in different region of phase-space than collisions at Tevatron → naïve rescaling of cross-sections will not work

## ▶ **Triggering soft physics**

- Need strategy to trigger soft events
- Study of soft physics in pile-up possible?

## ▶ **Physics modelling**

- Tuning of event generators: non-trivial interplay of perturbative (multiple interactions) and non-perturbative (beam remnants, ISR, FSR) aspects
- Understand and model jet structure in minimum-bias events



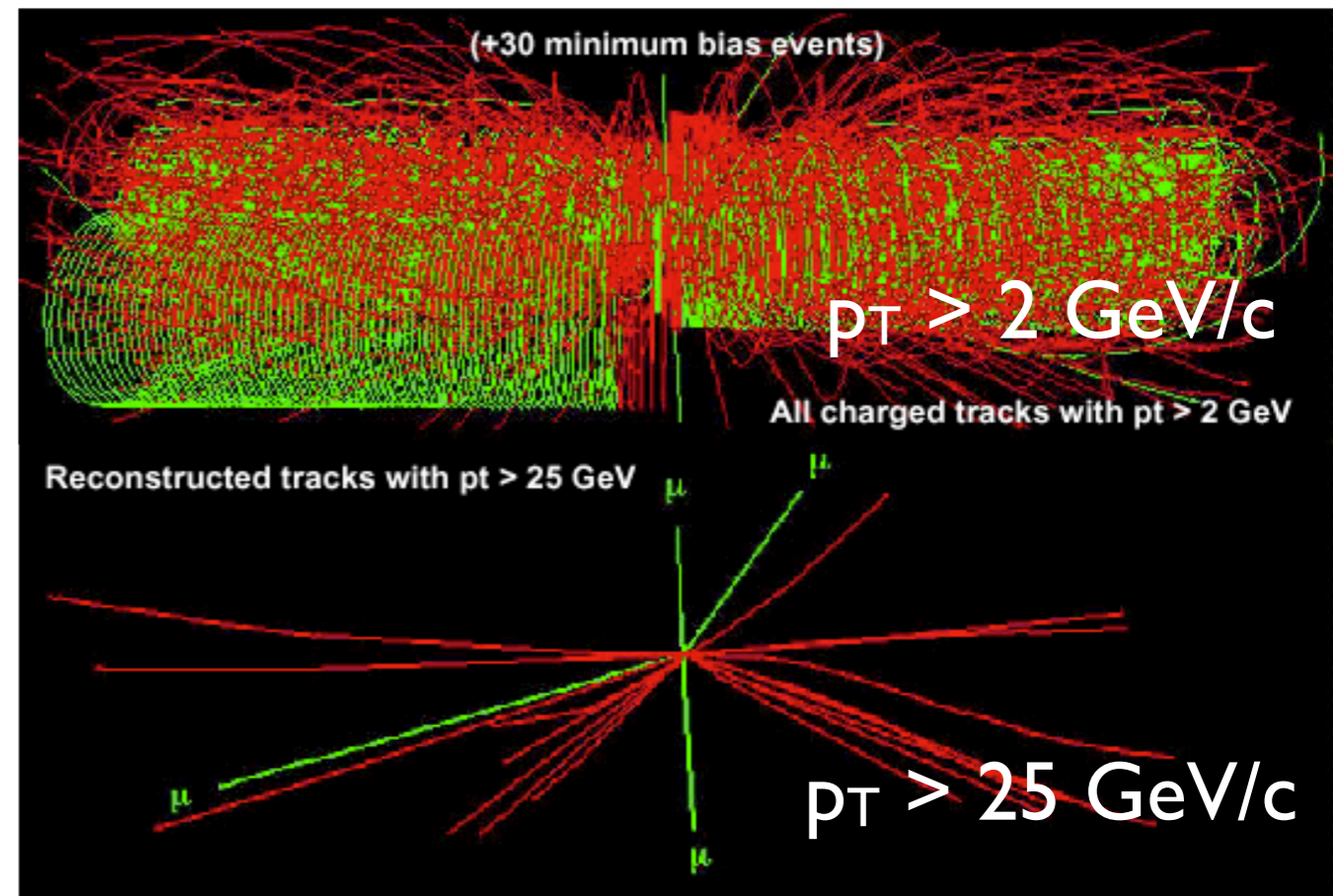
- ▶ **Minimum-bias**  $\leftrightarrow$  **totally inclusive trigger**
  - corresponds to single generic proton-proton interaction
  - may be elastic or diffractive
  - $\sigma(\text{el. and inel.})(\text{LHC}) \approx 100 \text{ mb}$

▶ **Average properties**

- low  $p_T$  particles
- low multiplicity

- ▶ **LHC: many ( $\sim 35$  for  $L = 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ ) minimum-bias events per bunch-crossing**

- $\langle N_{\text{int}} \rangle = L_{\text{inst}} * \sigma / f$
- constitute **pile-up** accompanying the triggered event

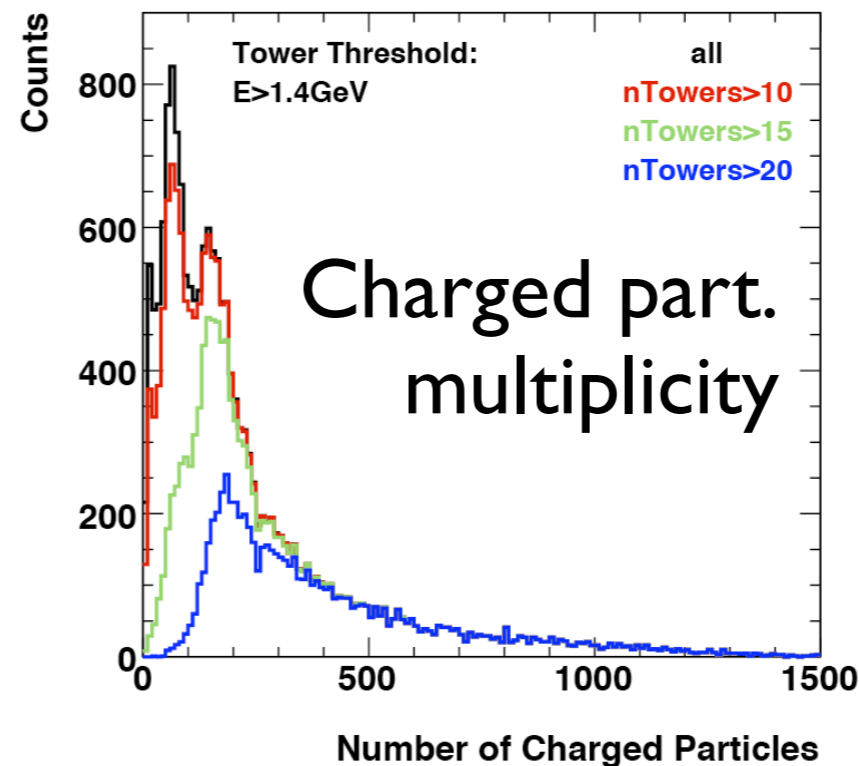
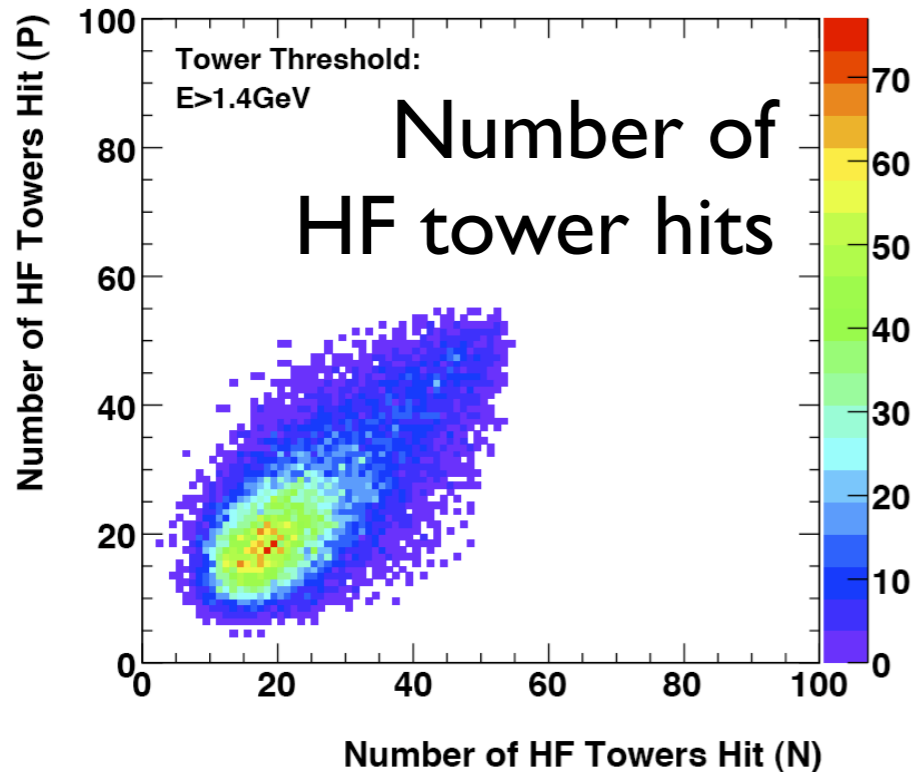
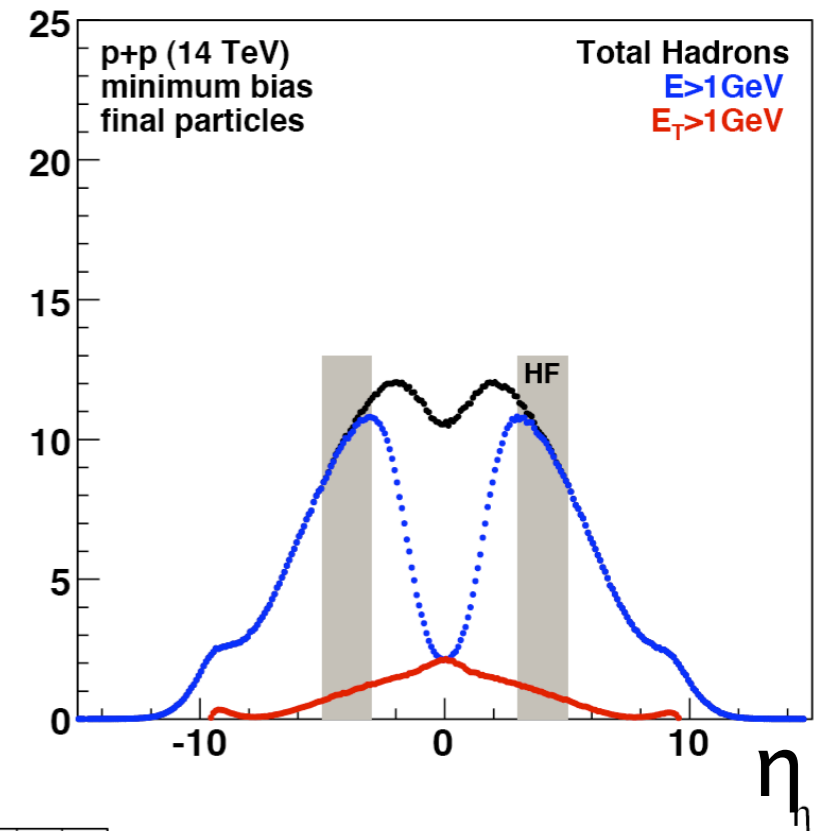


► **use Hadron Forward (HF) calorimeter**

- Geometrical coverage:  $3 < |\eta| < 5$
- 18 wedges per side
- $0.175 \times 0.175$  towers

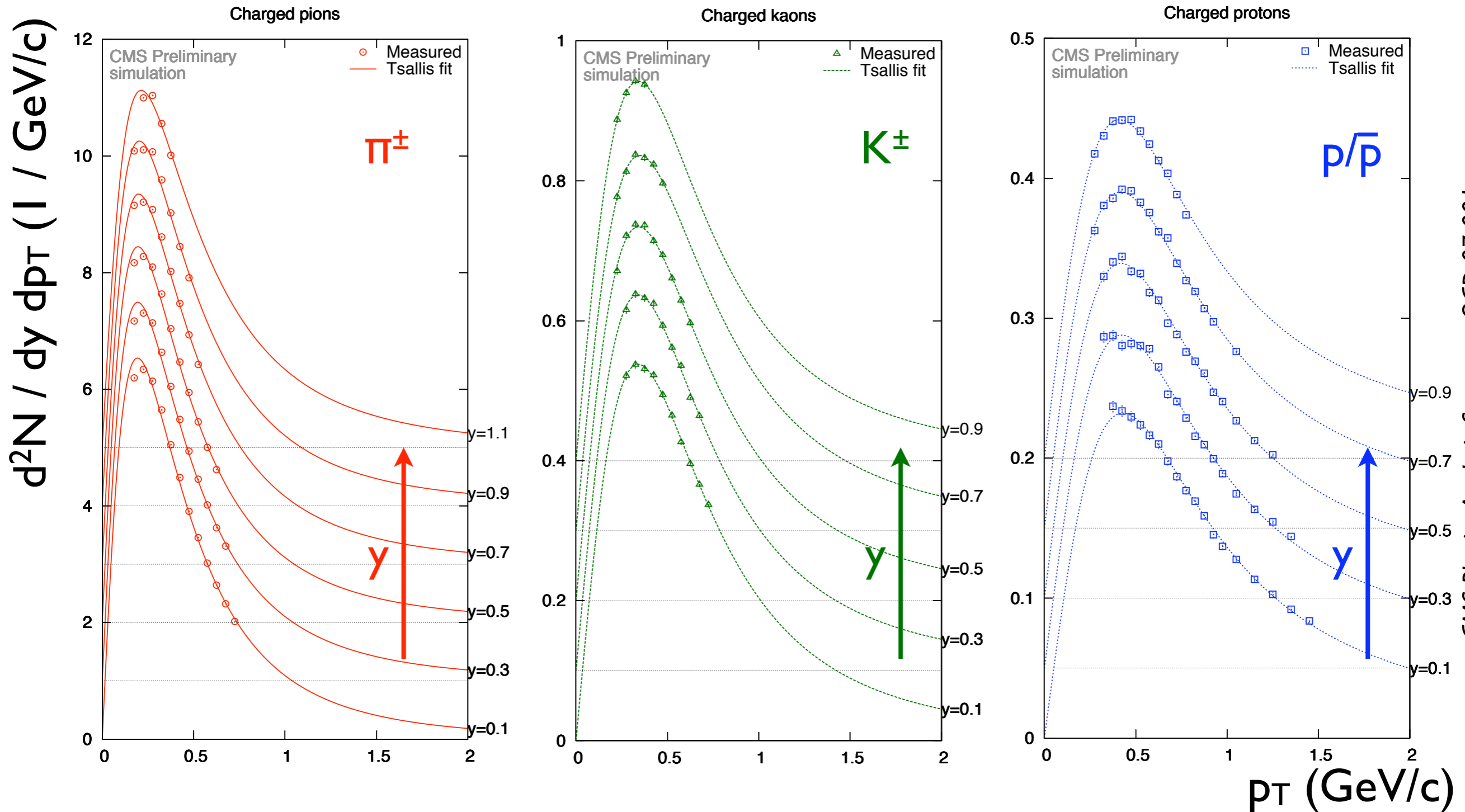
► **HF min-bias trigger:**

- use towers or single cells
- e.g.  $N(\text{calo towers}) > 10 \rightarrow 90\%$  efficiency



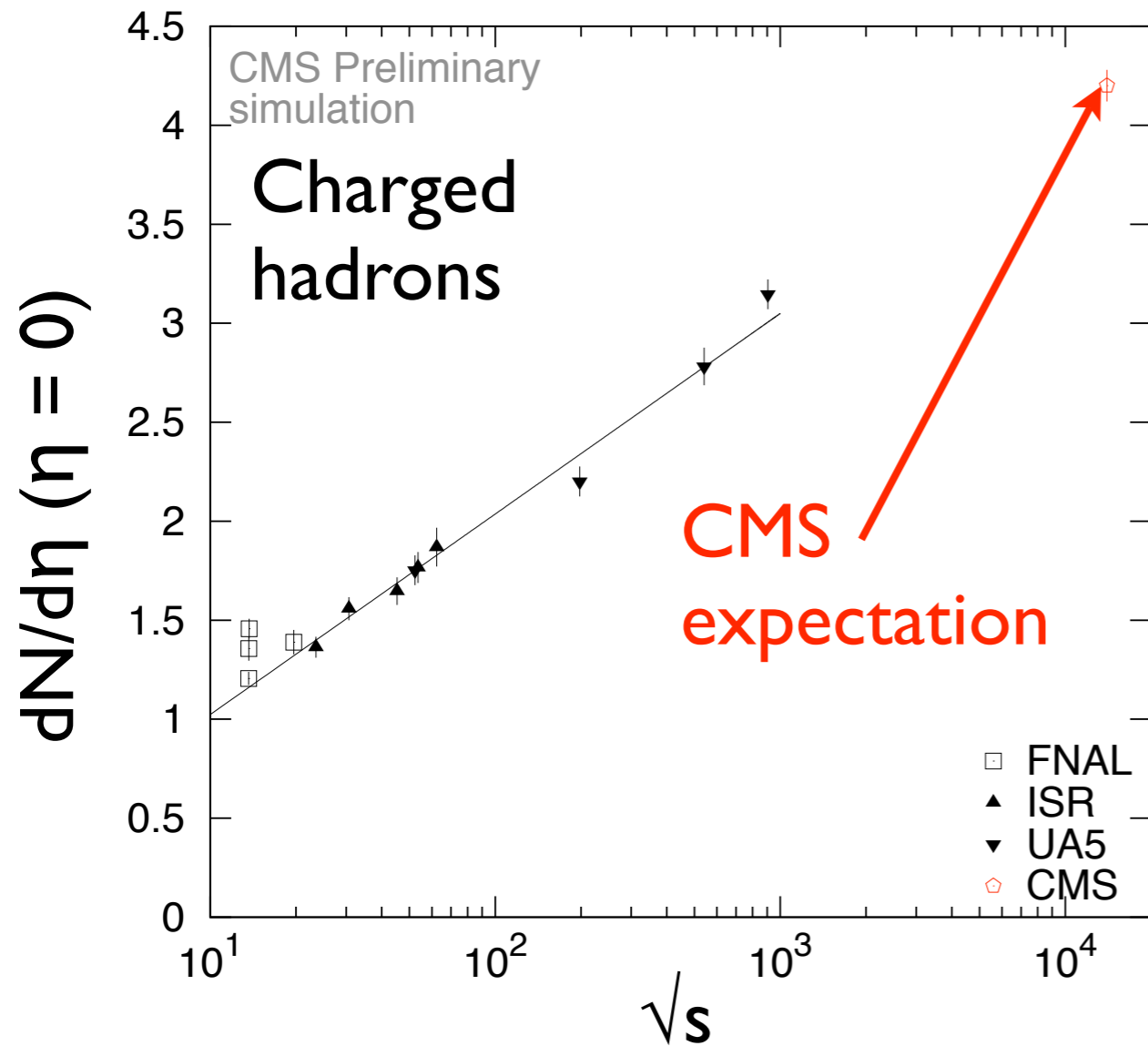
*J. Phys. G: Nucl. Part. Phys. 34 (2007) 2307-2455*

(no pile-up included)

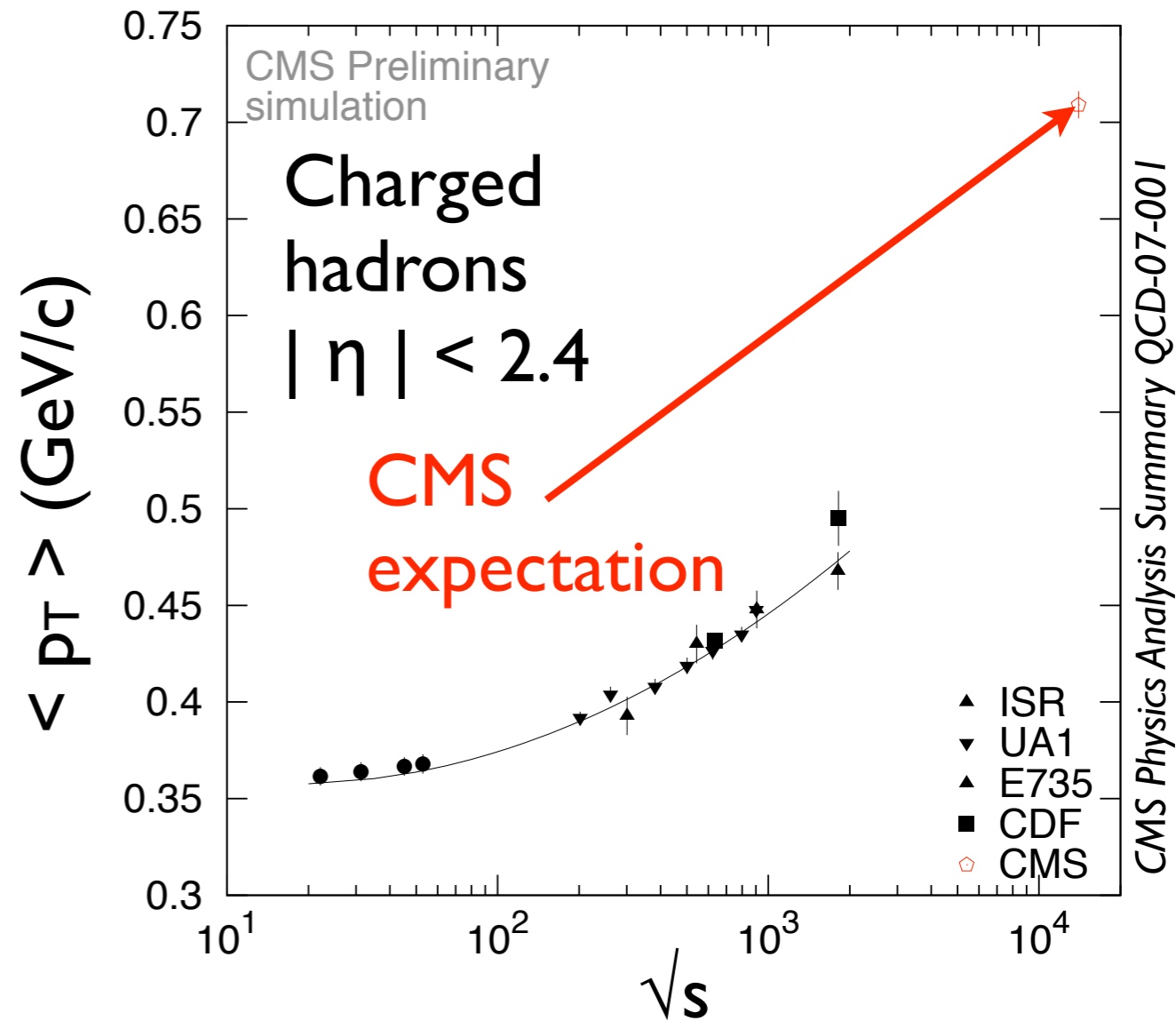


Diff. yields of identified  $\pi^\pm$ ,  $K^\pm$ ,  $p/\bar{p}$  together with *Tsallis*-function fits  
 (inverse slope  $T = 0.2 \text{ GeV}/c$ , high  $p_T$  exponent  $n = 7.2$ )

## Multiplicity in central region :



## Average $p_T$ :



- **on average 4.2 charged hadrons in the central region**
- **average  $p_T$  of charged hadrons  $\approx 0.7$  GeV/c**



▶ **All particles from a single proton-proton interaction except the hard scatter**

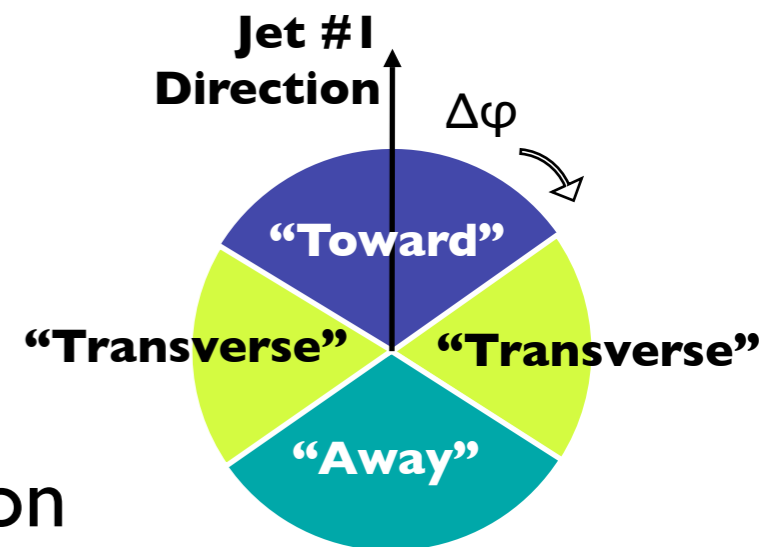
- → What happens to the beam remnants after the hard scatter?
- UE: **NOT** a minimum-bias event on top of hard process
- correlations (in angle, energy, ...) are significant → **colour-flow**

▶ **tied to the process of interest**

- same production vertex
- “pedestal effect” → UE activity grows with process’ energy scale

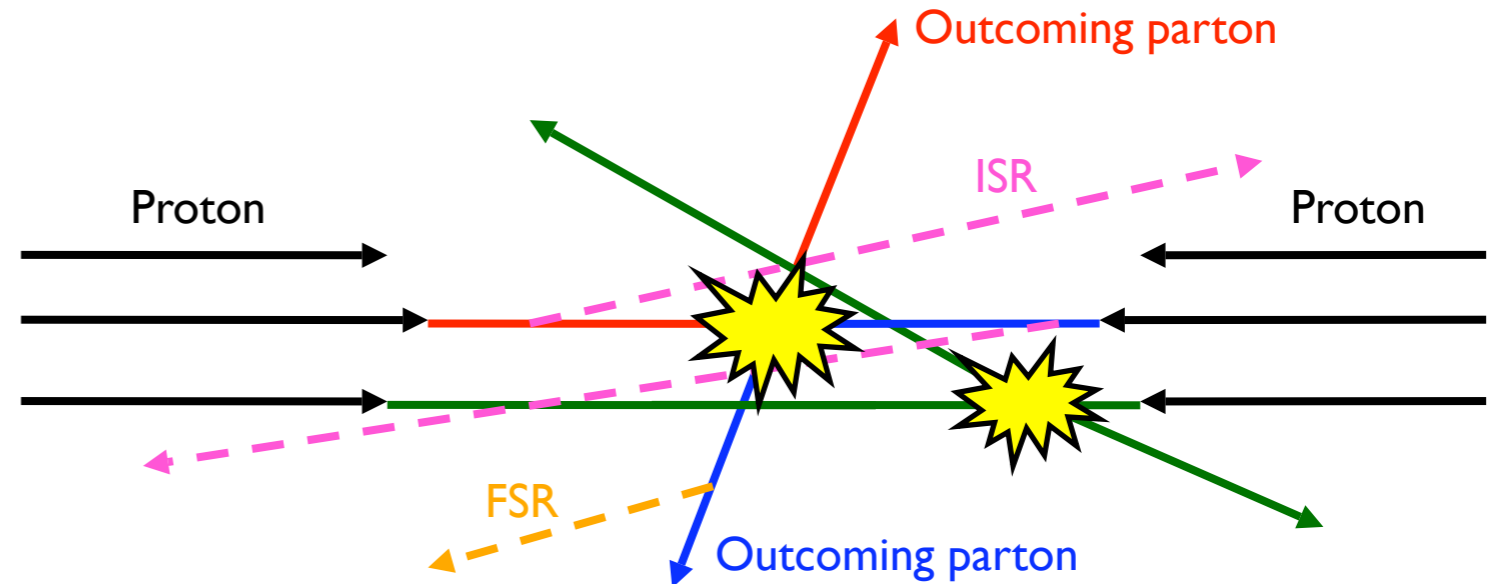
▶ **UE phenomenology (→ CDF)**

- “charged jet” from iterative cone algorithm on massless tracks
- energy scale:  $p_T$ (charged jet)
- study multiplicity and  $p_T$  density in transverse region



## ► Underlying event:

- ISR, FSR, beam remnants
- **+ multiple parton-parton interactions**



## ► Perturbative models:

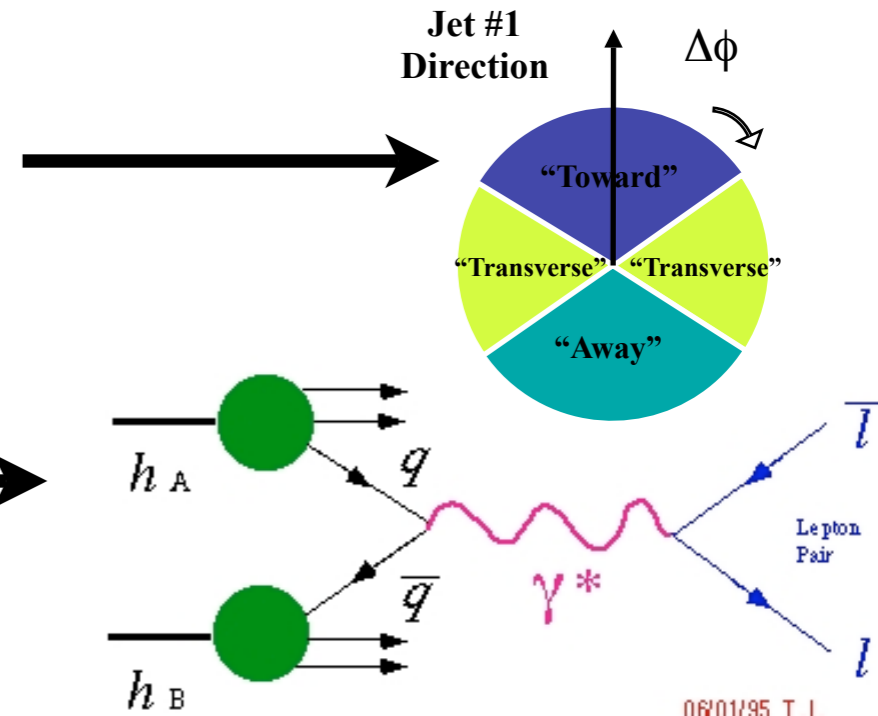
- allow **more than one parton-parton scatter** per pp-scatter (MPI)
- regularize QCD  $2 \rightarrow 2$  cross section for  $p_T \rightarrow 0$  (cut-off  $p_{T0}$ )
  - tunes to Tevatron data: e.g. Pythia DW, DWT (different energy dependence of  $p_{T0}$ )
  - Variable impact parameter models
  - Colour reconnection models (e.g. Pythia  $S_0$ )

## ► Extrapolation to LHC energies unclear

- **exponential** (favoured by CDF, UA5) versus **constant** (favoured by color glass condensate theory) evolution of  $p_{T0}$

## ▶ Charged-particle-jet topologies

- transverse region sensitive to UE ( $\rightarrow$  CDF)



## ▶ Drell-Yan $Z \rightarrow \mu \mu$ topologies

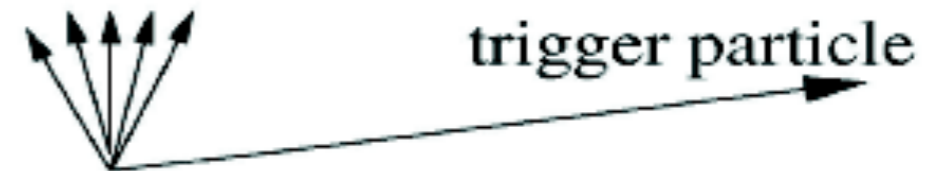
- entire event minus  $\mu$  pair = UE
- *J. Phys. G: Nucl. Part. Phys.* 34 995-1579

## ▶ Rapidity gap survival probability in hard diffraction

$\rightarrow$  talk by A.Vilela-Pereira in session on *Diffraction and Vector Mesons*

## ▶ Long-range correlations ( $\rightarrow$ CASTOR)

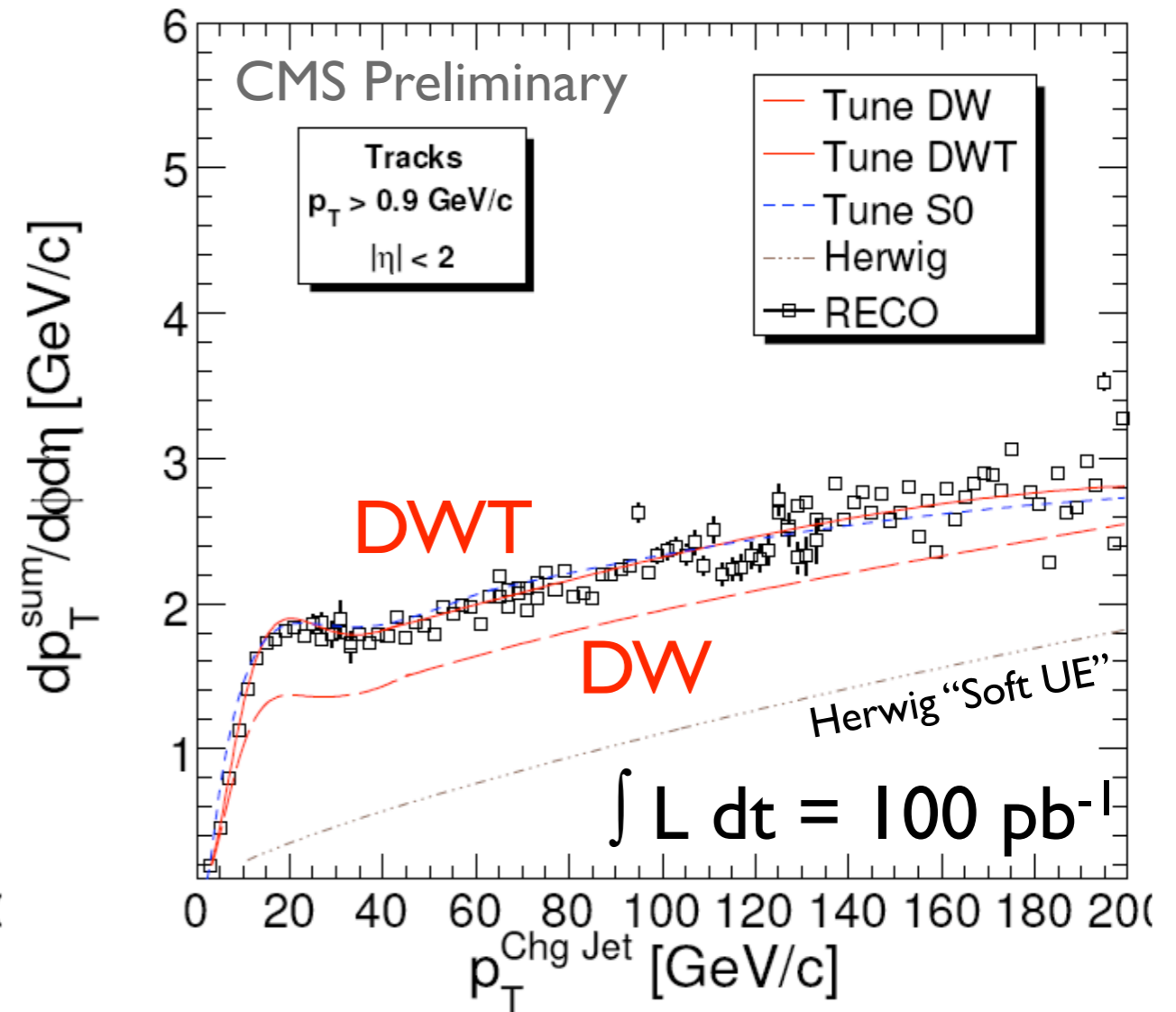
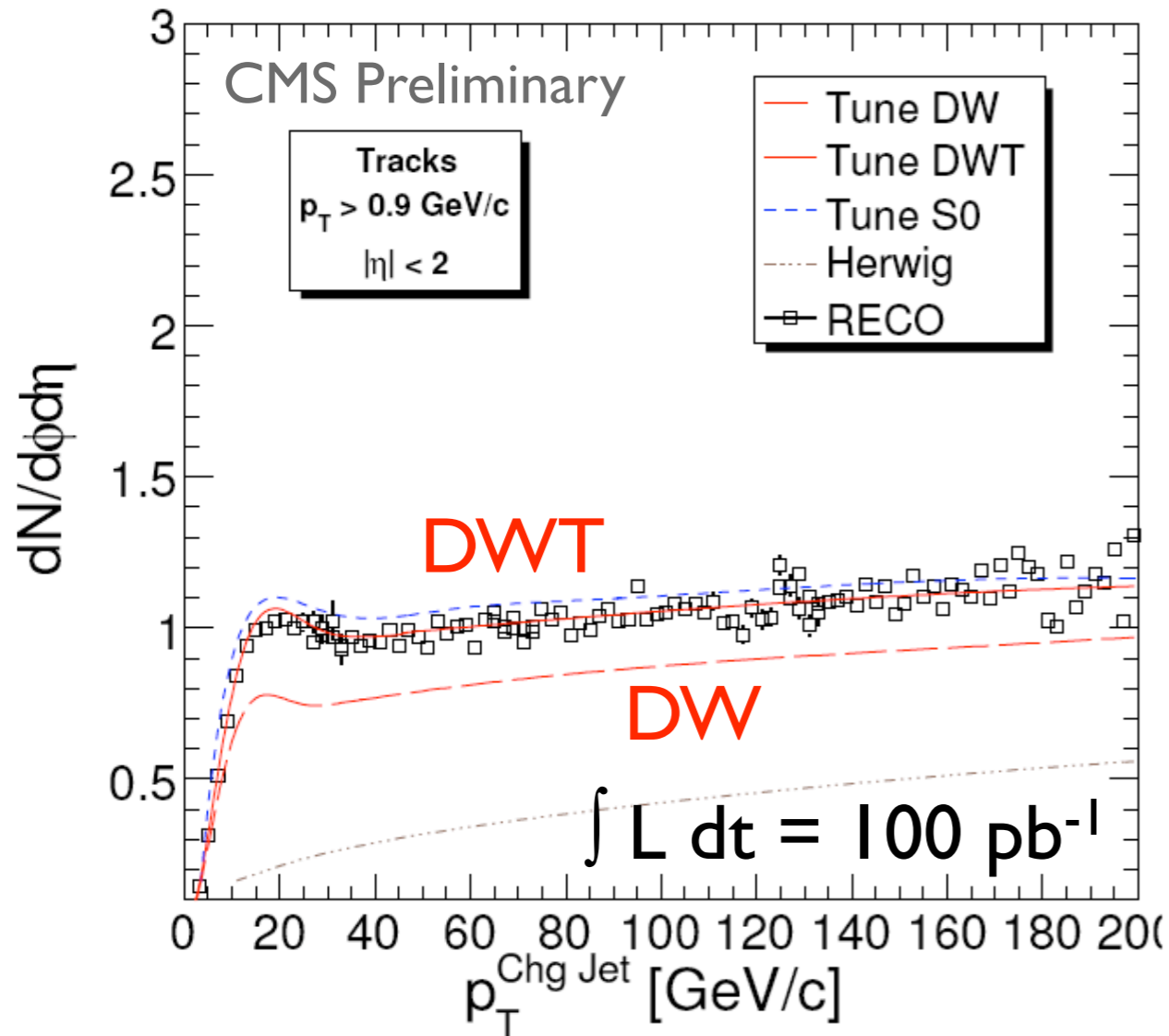
- charged particle multiplicity in forward vs central region:



## ▶ Double-parton-scattering

- four-jet production ( $\rightarrow$  AFS, UA2, CDF)
- like-sign  $W$  production
- $\gamma$  + 3-jet production ( $\rightarrow$  CDF)

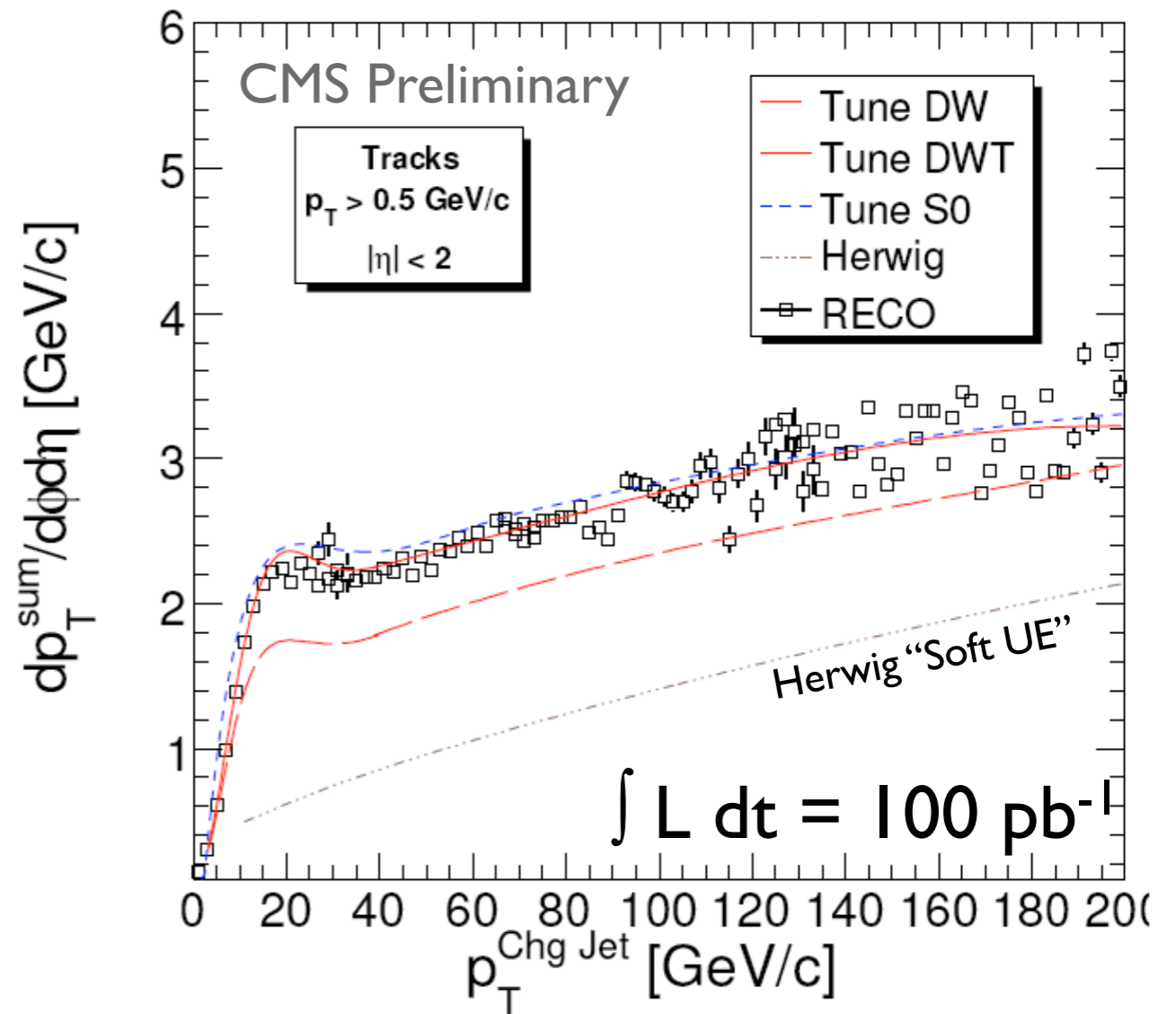
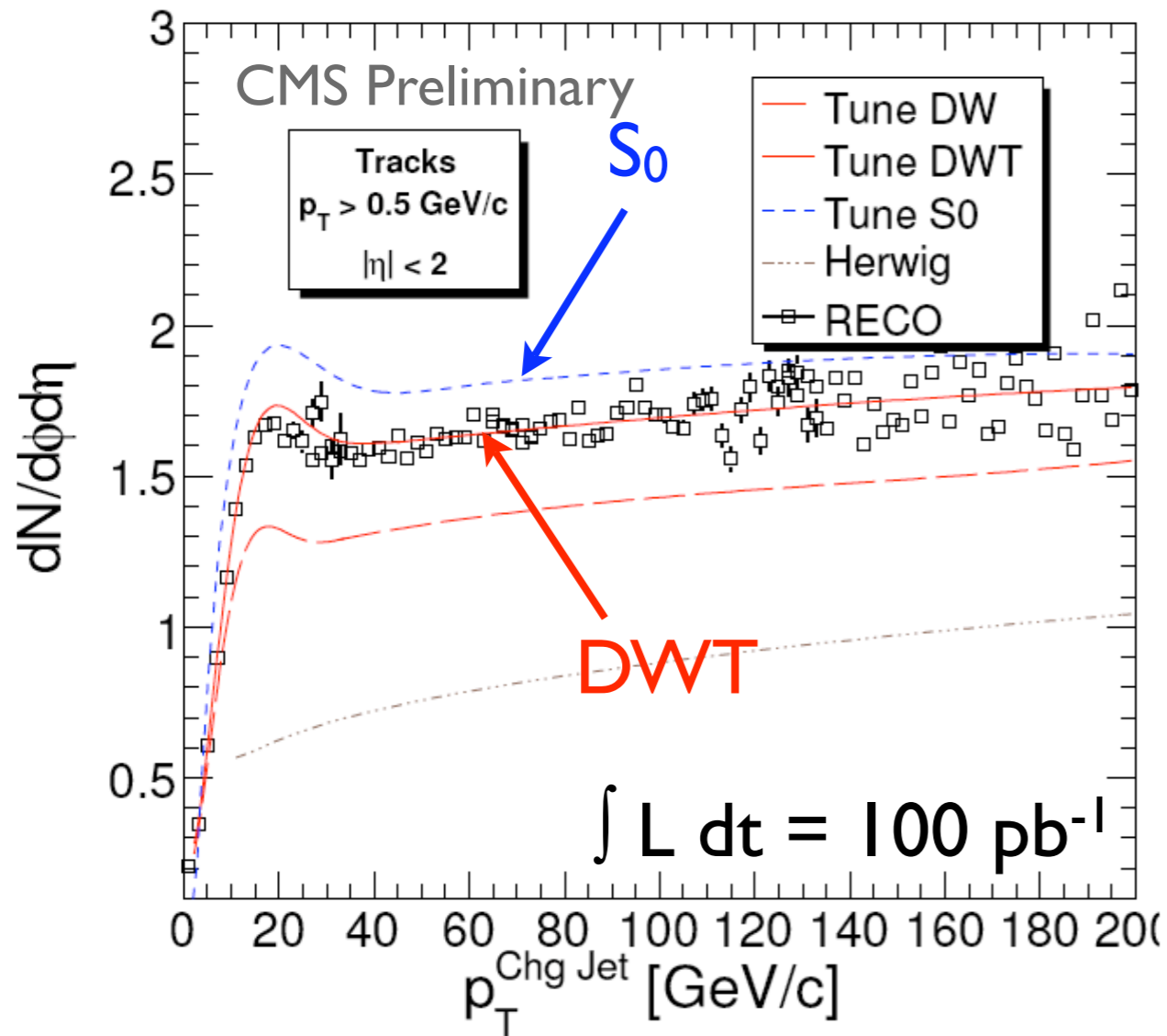
Select charged tracks in  $|\eta| < 2$  with  $p_T > 0.9$  GeV/c



→ discriminate DW against DWT

(no pile-up included)

Select charged tracks in  $|\eta| < 2$  with  $p_T > 0.5$  GeV/c



→ discriminate DWT against  $S_0$

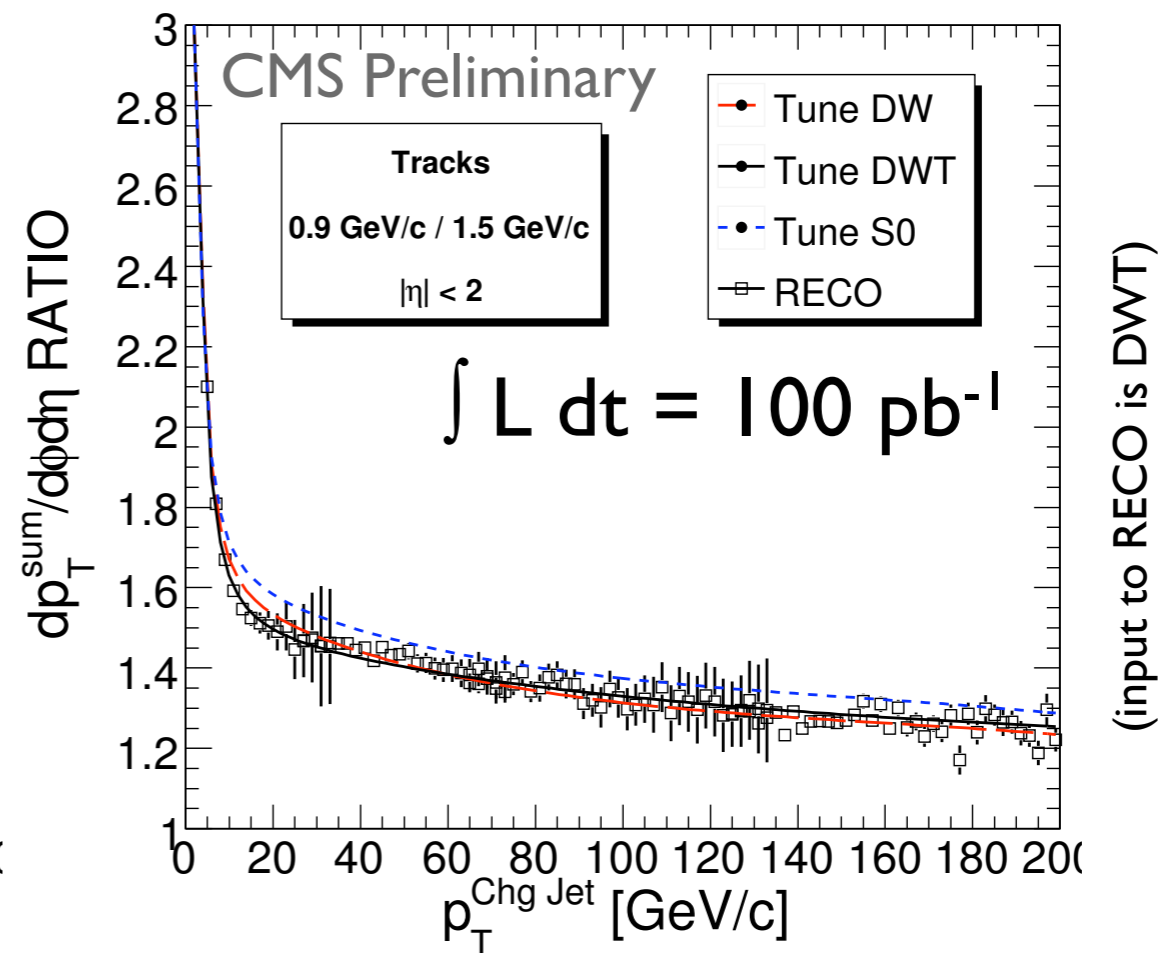
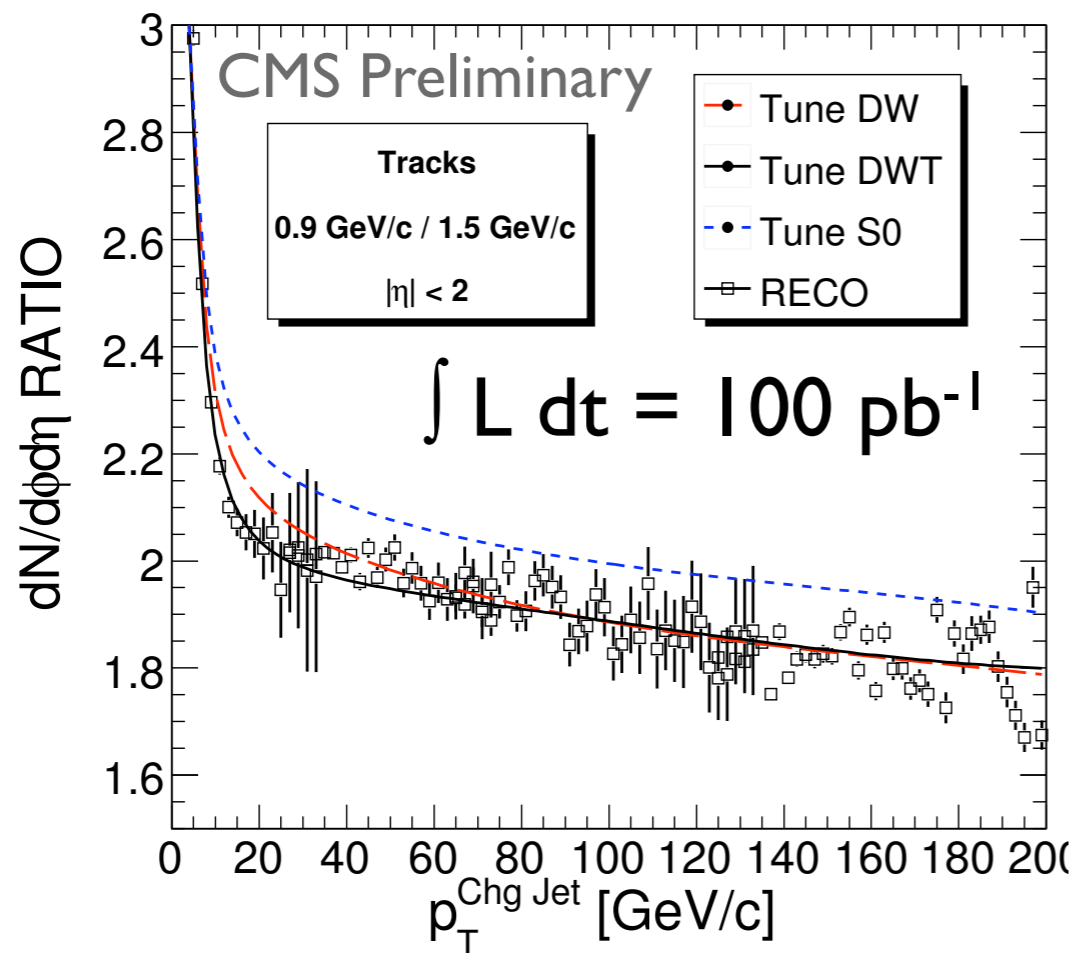
(no pile-up included)

► **Ratios between uncorrected UE-observables:**

- UE-density( $p_T(\text{track}) > 0.9 \text{ GeV}/c$ ) / UE-density( $p_T(\text{track}) > 1.5 \text{ GeV}/c$ )

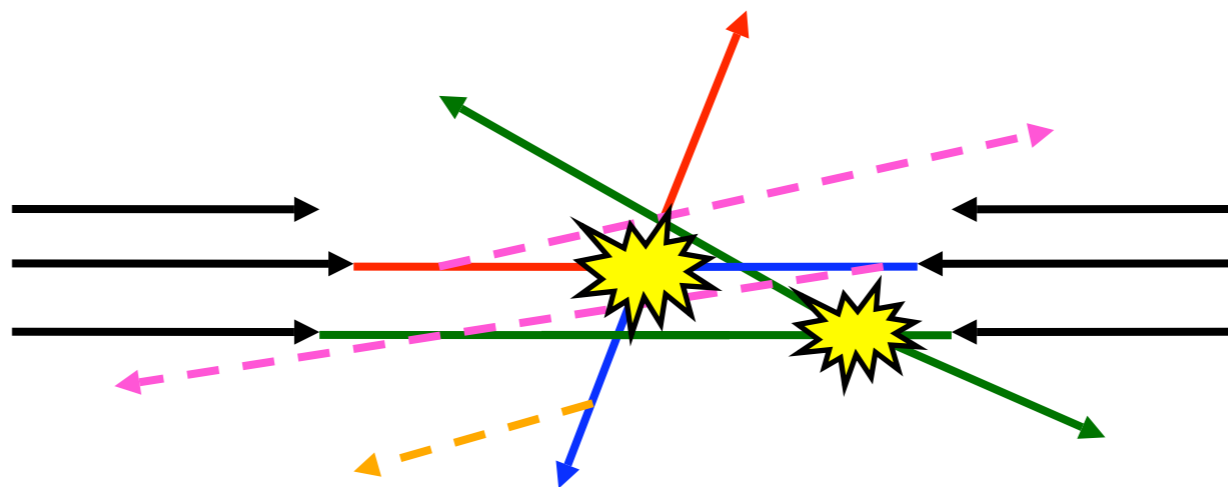
► **No additional track reconstruction corrections needed!**

- track reconstruction performance uniform in  $p_T$  for  $p_T > 0.9 \text{ GeV}/c$

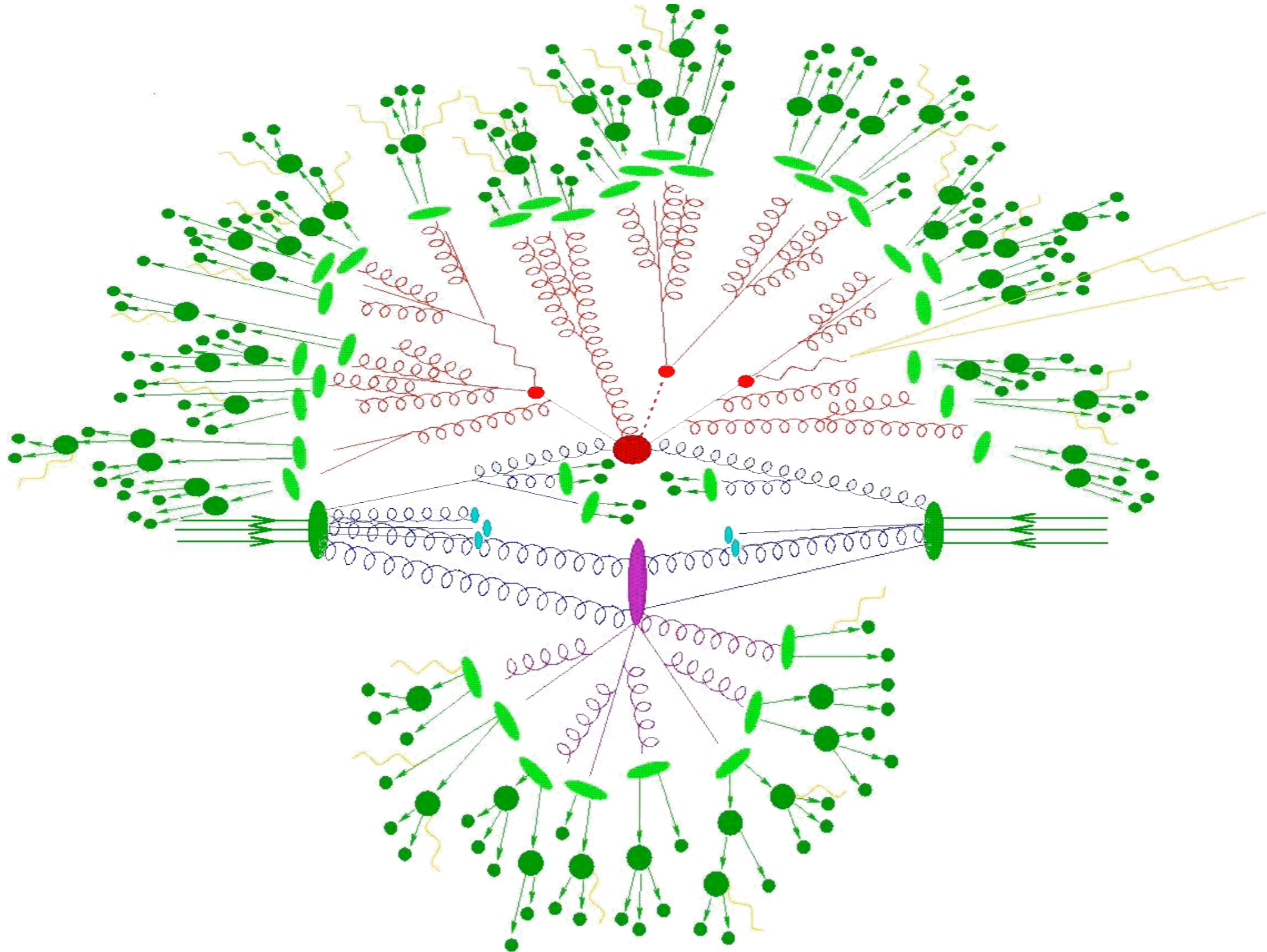


→ **discriminate DW/DWT against S<sub>0</sub>**

- Minimum-bias events: *pile-up* on triggered events
- Underlying event: everything except the hard scatter
- Underlying event models: *multiple* parton-parton interactions, *extrapolation* to the LHC unclear
- Minimum-bias trigger: Use *hadronic forward* calorimeter
- Expect: 4.2 charged hadrons in central region, 0.7 GeV/c average  $p_T$
- Measure the underlying event in *charged-jet topologies*
- Discriminate between underlying event tunes (DW, DW,  $S_0$ ) with the help of *soft tracks* ( $p_T > 0.5$  GeV/c) or ratios ( $\int L dt = 100$  pb<sup>-1</sup>)
- Absorb systematic uncertainties in ratio observables



# BACKUP





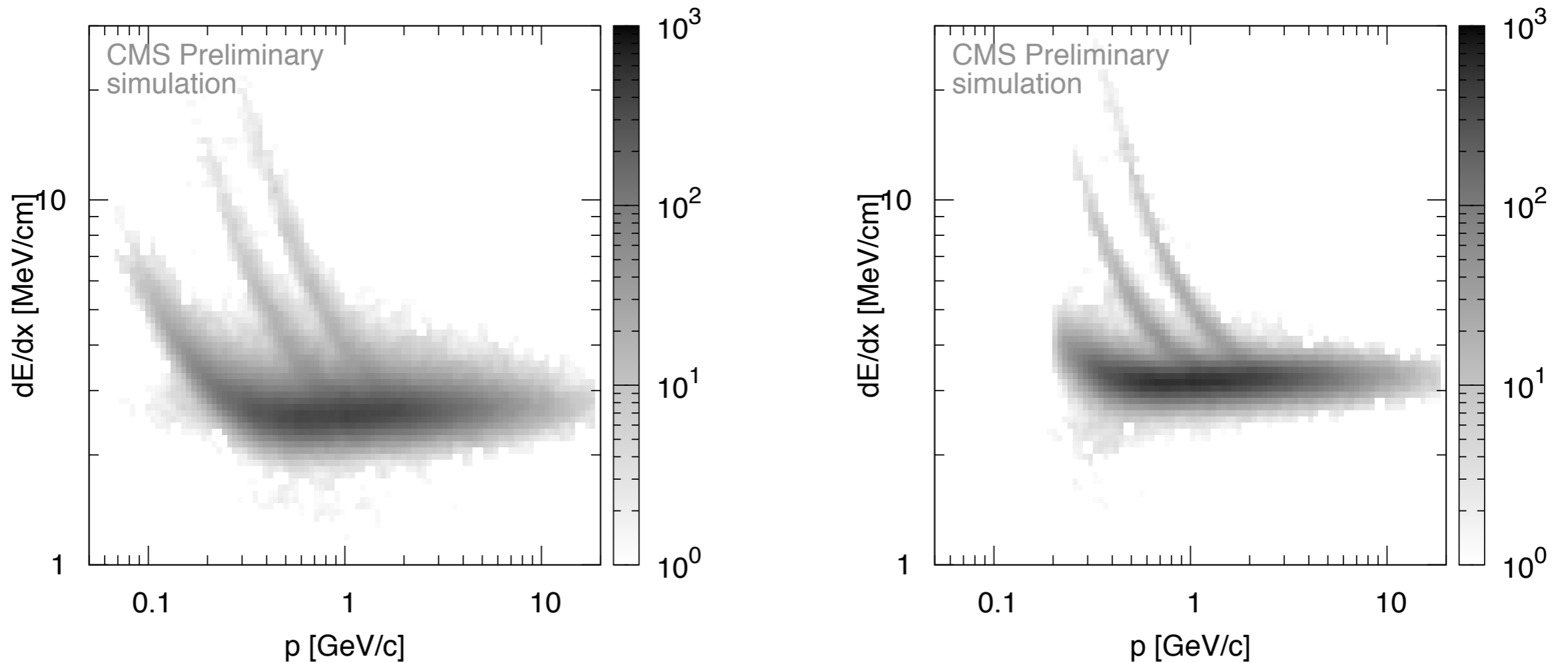
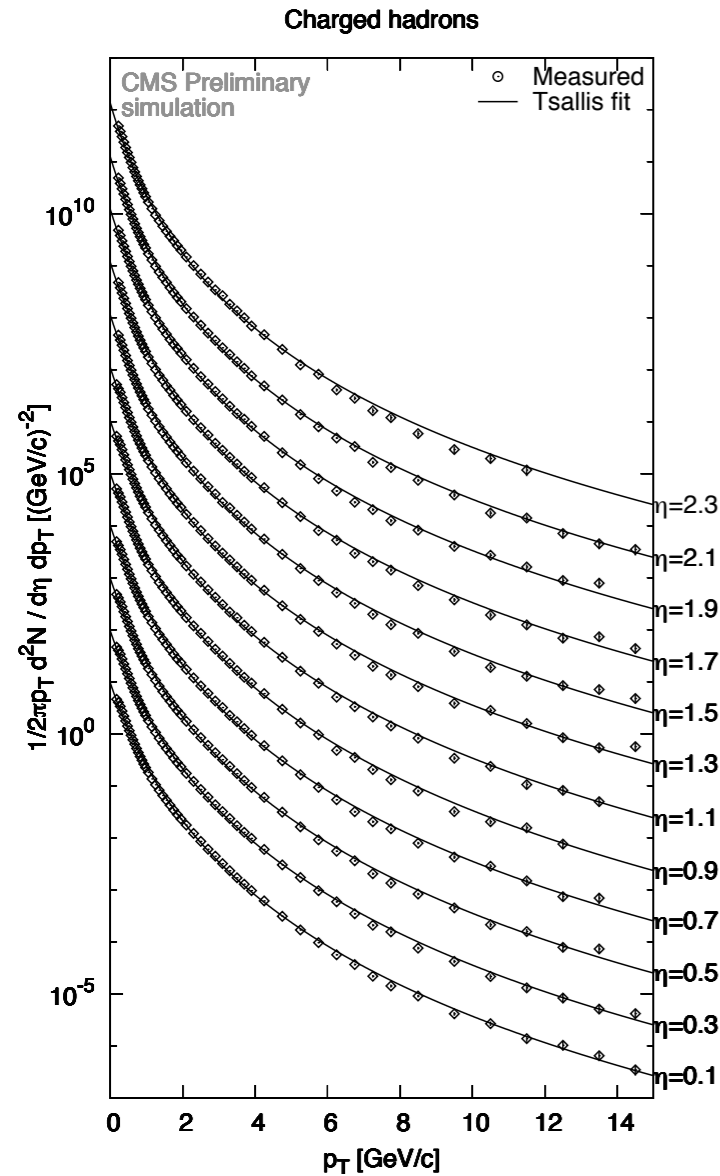


Figure 5: Distribution of the truncated mean estimator  $dE/dx$  as a function of momentum  $p$  for pixel hits (left) and strip hits (right).



The invariant yields were fitted by the Tsallis function [7], a function that successfully combines and describes both the low  $p_T$  exponential and the high  $p_T$  power-law behaviors [8]:

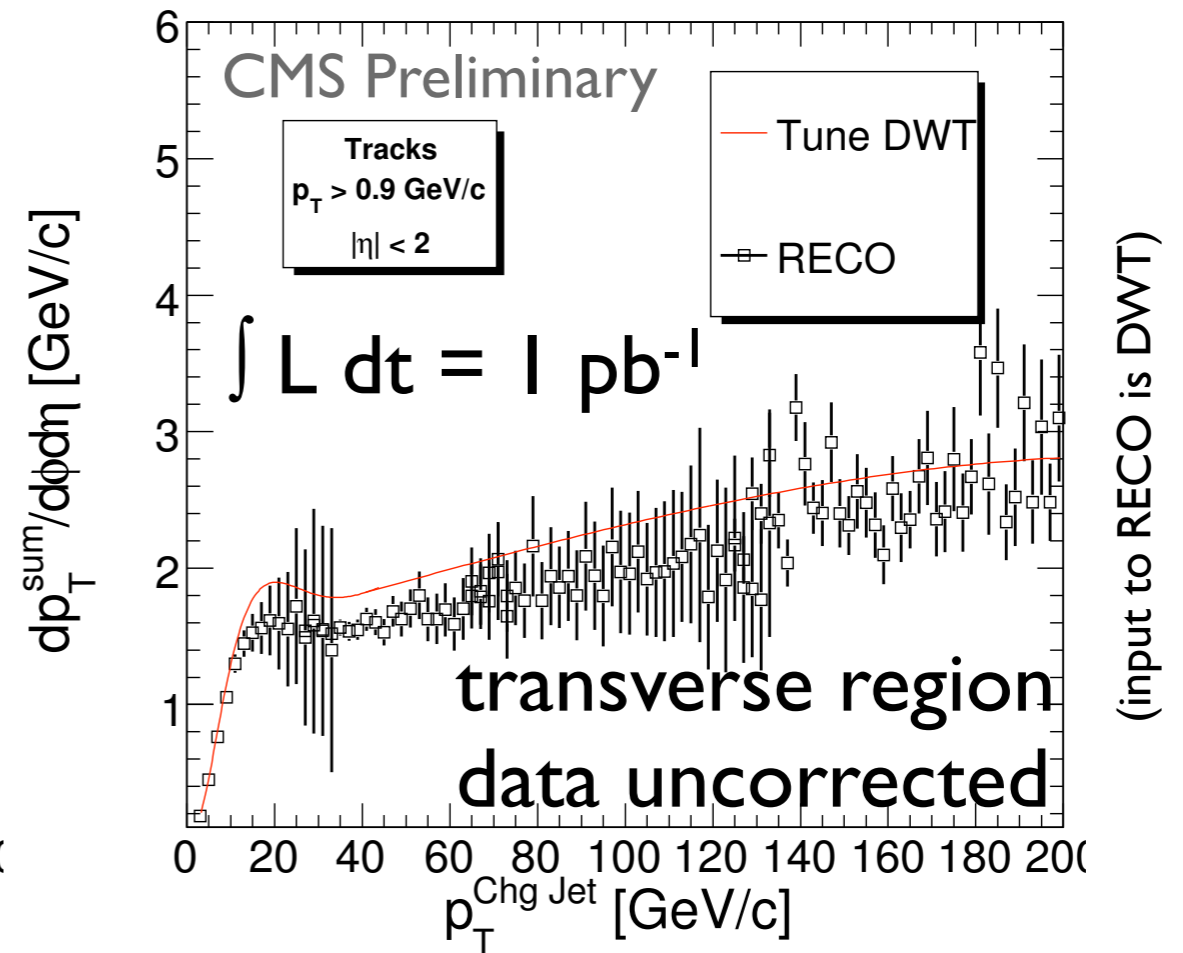
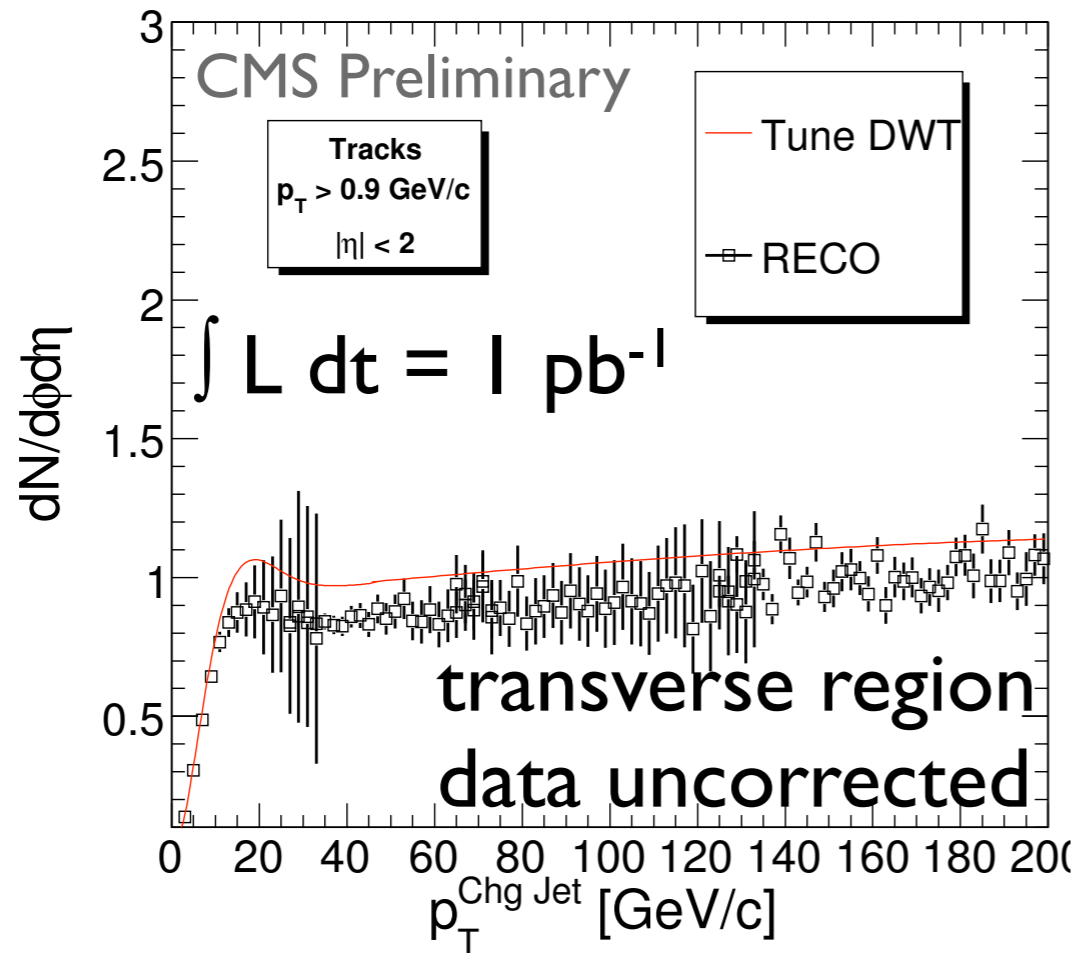
$$E \frac{d^3N}{dp^3} = \frac{dN}{dy} \frac{(n-1)(n-2)}{2\pi nT [nT + (n-2)m]} \left[ 1 + \frac{E_T(p_T)}{nT} \right]^{-n}, \quad (1)$$

where  $E_T(p_T) = \sqrt{m^2 + p_T^2} - m$ . This form provides both the inverse slope parameter  $T$ , characteristic for low  $p_T$ , and the exponent  $n$ , of the high  $p_T$  power-law tail. The average transverse momentum is  $\langle p_T \rangle = 2n / (n-3) \cdot T$ .

Figure 7: Selection of particle spectra. Left: Measured invariant yields of charged hadrons in the range  $0 < |\eta| < 2.4$  with a series of 0.2 unit wide bins. Measured values (black diamonds) and empirical fit functions (Eq. 1) are plotted using linear  $p_T$  scale. Values are successively multiplied by 10. Right: Measured differential yields of identified charged pions in the range  $0 < |y| < 1.2$  with a series of 0.2 unit wide bins. Measured values (red circles) and empirical fit functions (Eq. 1), with  $n$  fixed from unidentified spectra, are plotted. Values are successively shifted upwards by one unit for clarity. Only those rapidity bins are used where there are at least four measured points.

## ► Study mis-alignment effects at startup

- modify track selection: increase spatial window to find trajectory-compatible hits → ok in transverse region (low track density)



→ recover nominal tracking performance

CMS Preliminary

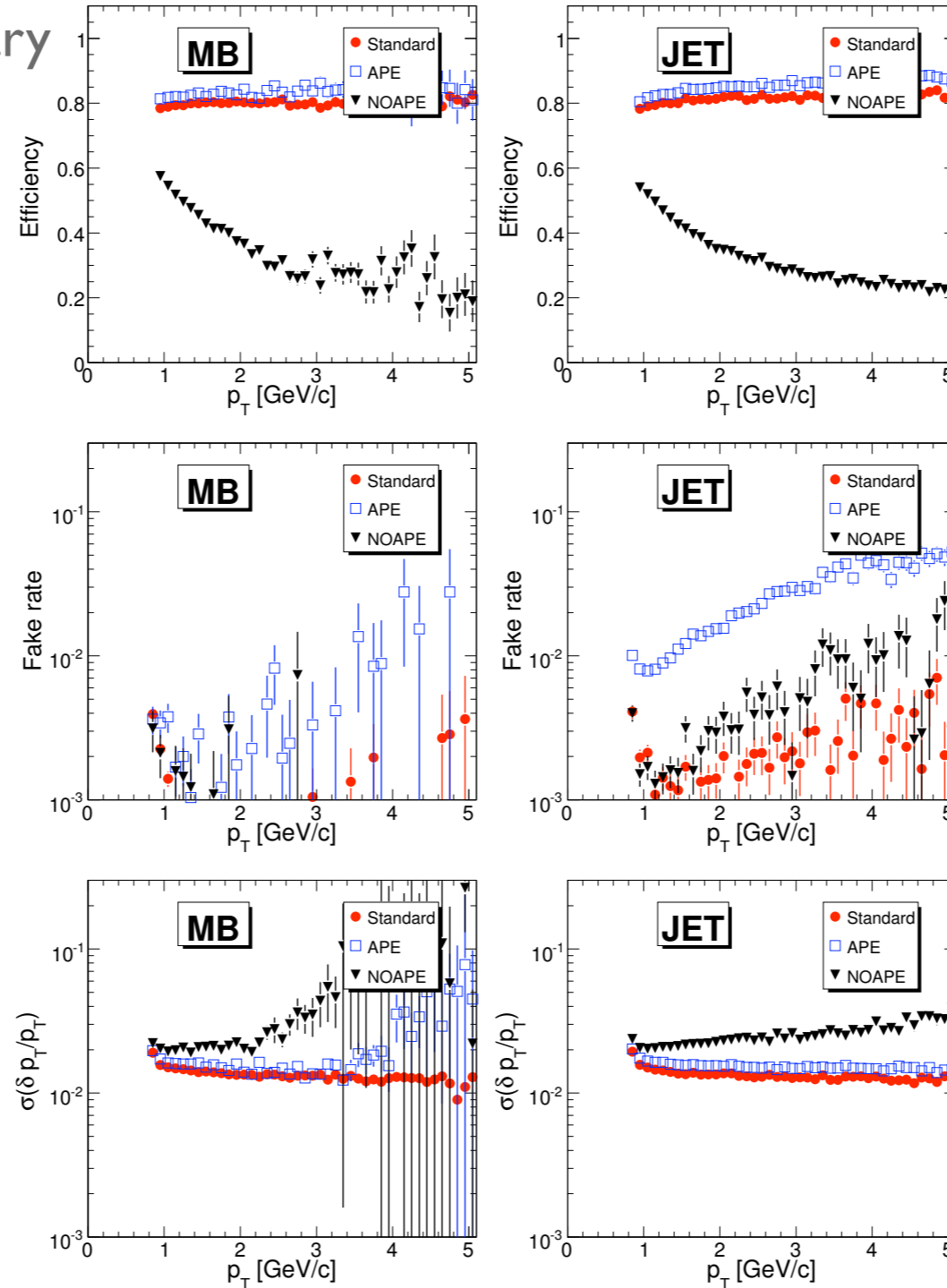


Figure 9: Tracking performance for an ideal tracker (circles), for a misaligned tracker as expected at start-up (triangles) and for a misaligned tracker with use of the APE tool (squares), for charged particles with  $p_T > 0.9$  GeV/c from the MB (left) and JET (right) samples: track reconstruction efficiency, fake track rate and relative  $p_T$  resolution, as a function of the leading charged jet  $P_T$ .

# DIS 2008



XVI International Workshop on Deep-Inelastic Scattering and Related Subjects

7-11 April 2008, University College London

## Topics

- Structure Functions and Low-x
- Diffraction and Vector Mesons
- Electroweak Measurements and Beyond the Standard Model
- Hadronic Final States and QCD
- Heavy Flavours
- Spin Physics
- Future Colliders

<http://www.hep.ucl.ac.uk/dis2008>



## International Advisory Committee

Aharon Levy, Tel Aviv (chair)	Lev Lipatov, St. Petersburg
Giulio 'Agostini, Roma	Pierre Marage, Brussels
Giulio Alariol, CERN	Rosario Nisida, Bologna
Vibitta Britson, Orsay	José Raposo, Argonne
Dušan Bruncko, Slovak Acad.	Wesley Smith, Wisconsin
Allen Caldwell, Munich	Fank Schill, Columbia
John Dalsgaard, Liverpool	James Stirling, Durham
Andraž Esteve, Koper	Katsuo Takahashi, KEK
Joël Falesse, Saclay	Albrecht Wagner, DESY
Robert Klanner, DESY	Günter Wolf, DESY
Max Kuhn, Liverpool	

## Local Organising Committee

<b>UCL</b>	<b>Oxford</b>
Matthew Wing (co-chair)	Ralph Devenish (co-chair)
Jon Butterworth	Amanda Cooper-Saunders
Clive Gwenlan	James Forshaw
Christine Johnston	Brian Foster
Mark Lancaster	
John Laflamme	
Robert Thom	
Gaëme Wall	

Sponsors:

