

WG2 experimental summary multi-jet final states and energy flows

Eduardo Rodrigues
University of Glasgow

4th HERA-LHC Workshop, CERN, 26-30 May 2008

~~Last but~~ First and not least

Thanks!

to all the speakers for their valuable contributions



HERA AND THE LHC
4th workshop on the implications of HERA for LHC physics

26-30 May 2008
CERN

Parton density functions
Multijet final states and energy flow
Heavy quarks
Diffraction
Monte Carlo tools

Organizing Committee:
G. Abbiendi (CERN), J. Blumlein (DESY),
M. Buge (NIKHEF), J. Butterworth (UCL),
A. De Roeck (CERN) (chair), K. Eggert (CERN),
T. Haru (DESY), M. Jona (DESY) (chair),
M. Klein (DESY), M. Mangano (CERN),
A. Moyal (CERN), G. Politis (INFN),
O. Schneider (RPPL), C. Vallee (CPPM)

Advisory Committee:
J. Barfete (Hamburg), M. Della Negra (CERN),
J. Eise (CERN), J. Engelen (CERN),
G. Gustafson (Lund), G. Ingelman (Glasgow),
P. Jonck (CERN), M. Kramer (DESY),
L. McLerran (BNL), T. Nakata (CERN),
D. Schilder (CERN), F. Schwenn (DESY),
J. Sjöstrand (CERN), J. Stirling (Durham),
M.A. Trott (Michigan State), A. Weiler (DESY),
H. Yokoyama (LANL)

www.desy.de/~heralhc heralhc.workshop@cern.ch

Disclaimer(s)

- **This was the last workshop before LHC start-up**
- **Talk will mention the achievements since after the 2005 workshop proceedings**
- **Not all contributions individually summarised**

Workshop sessions since 2005 proceedings

29 Oct. – 2 Nov. 2007, DESY:

- Working group week
- WG2 + MC Tools joint session: mostly theoretical contributions

12-16 March 2007, DESY:

















- 3rd workshop
- Good mix of WG2 talks from HERA and LHC communities
- First presentations of new developments on jet algorithms (e.g. SISCone and jet areas)
- WG2 + MC Tools joint session: focus on multiple interactions

6-9 June 2006:

- 2nd workshop
- WG2 + MC Tools joint session: focus on underlying event
- Good mix of WG2 talks from HERA and LHC communities







This week's WG2 sessions with an experimental flavour

Multi-jet final states and energy flows (joint session with MCTools) (09:00 ->12:35) Location: [40-S2-D01](#)

09:00	New Results from CDF on the Underlying Event and Extrapolations to the LHC (20') ( )	Rick Field
09:25	Underlying event studies with Castor calorimeter in CMS experiment (15') ( )	Zuzana Rurikova
09:45	Modeling the underlying event: MC tunes for the LHC (20') ( )	Arthur Moraes
10:05	COFFEE (25')	
10:30	The underlying event in Herwig++ (20') ( )	Manuel Baehr
10:55	Double parton scattering studies with Pythia 8 and Herwig++ (20') ( )	Florian Bechtel (Hamburg / Lund)
11:20	A new framework for estimating multi-jet final states (20') ( )	Chris White
11:45	Multiple Interactions in photoproduction at H1 (20') ( )	Lluís Martí
12:10	Prerequisites for the Validation of Experiment and Theory (10') ( )	Lars Sonnenschein

Summarised in
MC Tools report

Multi-jet final states and energy flows: Jets and jet algorithms (14:00 ->18:00) Location: [40-5-A01](#)

14:00	Jet finding strategies in ATLAS (20') ()	Pierre-Antoine Delsart
14:20	Performance of Jet Reconstruction at CMS (20') ( )	Christian Sander
14:40	b-jets at LHCb (20') ( )	Victor Coco
15:00	Forward jets with the calorimeter CASTOR in the CMS experiment (20') ( )	Albert Hans Knutsson
15:20	COFFEE (20')	
15:40	Update on the SISCone and Anti-kT algorithms (20') ( )	Gregory Soyez
16:00	Jet areas and subtraction (20') ( )	Matteo Cacciari
16:20	Performance of jet algorithms at the LHC (20') ( )	Juan Rojo-Chacon
16:40	Non-perturbative effects for QCD jets at hadron colliders (20') ( )	Lorenzo Magnea
17:00	Azimuthal de-correlations in QCD jets (20') ( )	Mrinal Dasgupta
17:20	Discussion - ALL (30')	

Jet physics

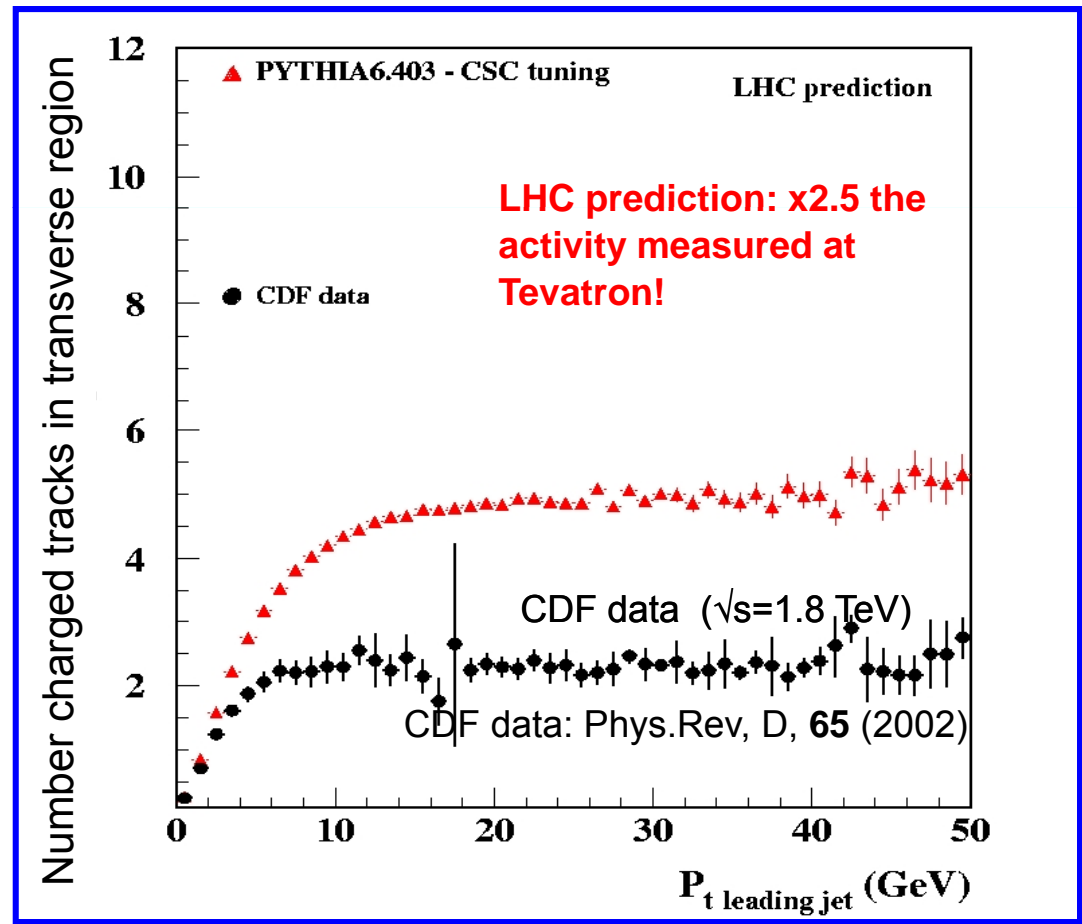
Challenges at the LHC

- (LHC) Environment related:
pile-up – ~23 interactions / bunch crossing

Arthur Moraes

- Physics related:
the underlying event
and multi-parton interactions

- Detector related:
calorimeters resolutions,
noise, and “slow” response



Analysis of jets – connection to theory

Many developments in the past 2 years!

Jet algorithms:

- ❑ New algorithms on the market:
 - Infrared-safe cone algorithm: SIScone
 - Recombination algorithms: anti- k_T
- ❑ Fast implementations available in the fast-kt package

Technical details in
Giulia's summary

Jet reconstruction performance:

- ❑ New variables exist for a quantitative assessment of the jet quality

Dealing with pile-up and underlying event:

- ❑ Exploitation of the concept of jet area

M. Cacciari, J. Rojo, G. Salam, G. Soyez

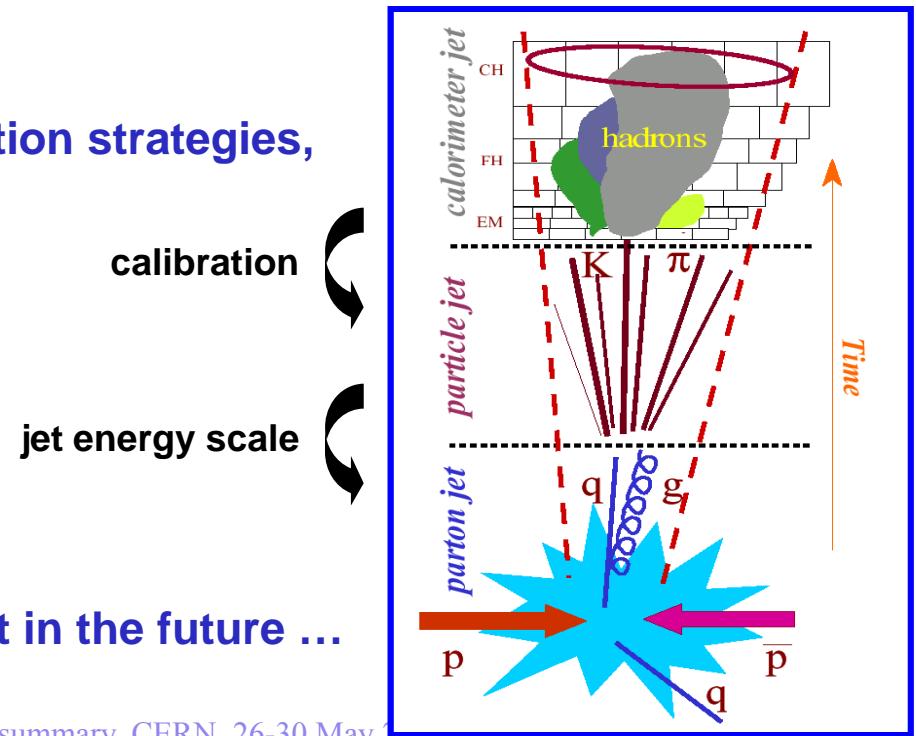
Jet reconstruction strategies

LHC preparations:

- ❑ Jet reconstruction crucial to ATLAS and CMS physics programs
- ❑ Analysis demand excellent jet resolution and small energy scale uncertainties

General ATLAS and CMS strategies – “the power of flexibility”:

- ❑ Use/exploit/study different jet algorithms and tools
- ❑ Develop several jet energy scale correction strategies, both MC-based and data-driven
- ❑ Develop several calibration methods
data will “dictate” best strategy to adopt in the future ...



Jet studies in ATLAS (1/2)

Pierre-Antoine Delsart

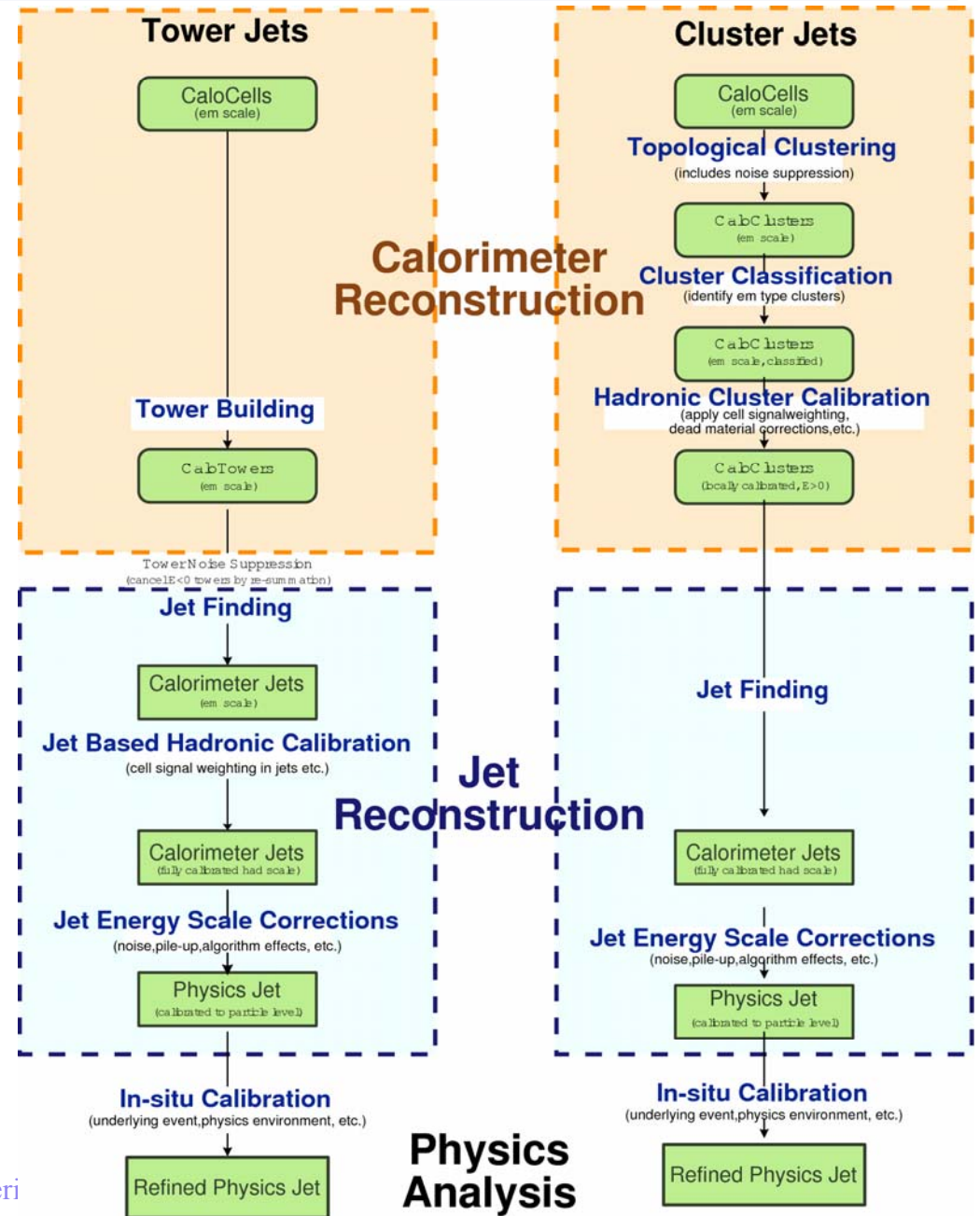
2 strategies for reconstruction of calibrated jets

Jet algorithms considered:

- ATLAS allows choice among several:
 - Cone-based algorithms:
 - seeded cone, MidPoint cone, SIScone
 - Clustering algorithms:
 - k_T with fast-kt implementation

Studies:

- Comparison of algorithms
- Methods of jet calibration
- Methods of jet energy scale determination (di-jets balance, Z+jets, etc.)



Calibration efforts:

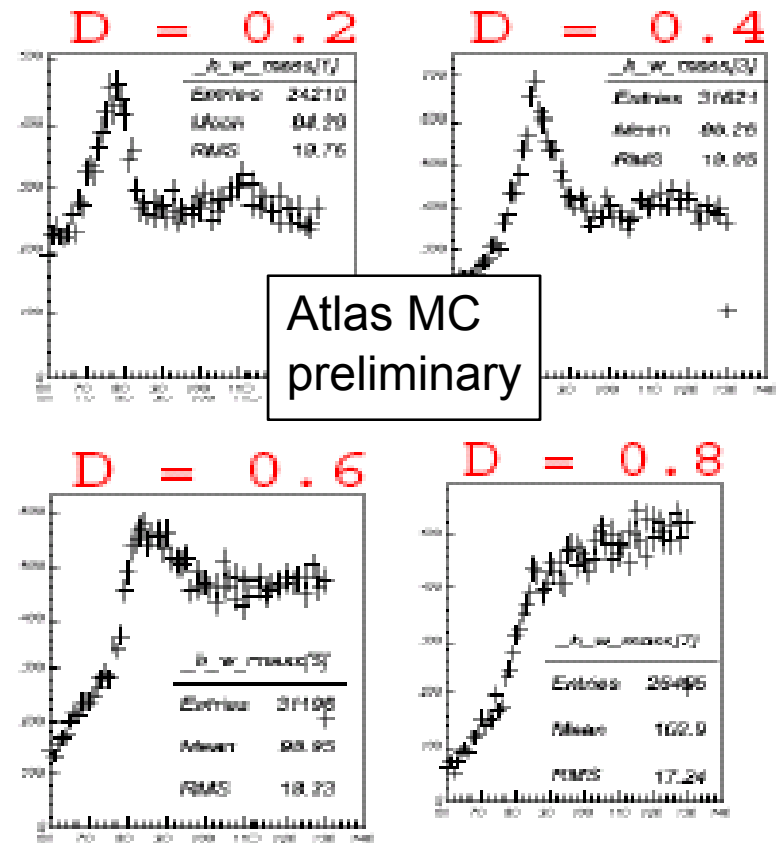
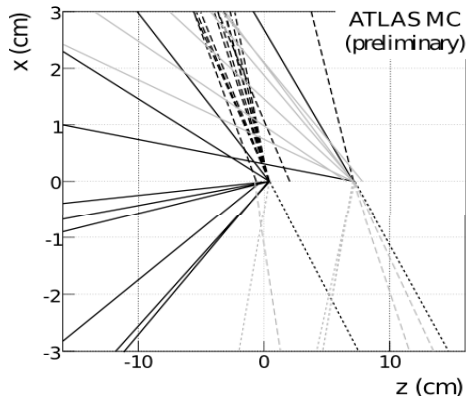
- Challenge: ATLAS possesses a non-compensation calorimeter ($e/h \sim 1.3-1.6$)
 \Rightarrow electromagnetic component of jets is important and shape of corrections non-trivial vs. jet η , E , E_T

Jet energy scale efforts:

- Challenge: aim at $\sim 1\%$ JES uncertainty!

Jet finding efforts:

- Choice of algorithm can impact significantly on analysis
- Need to “tune” algorithm (e.g. R size parameter)
- “Tracks jets” also available:
 - used to correct energy scale
 - track jet vertex helps rejecting pile-up jets



top quark mass distribution for different values of the D parameter of k_T algorithm

Jet studies in CMS (1/2)

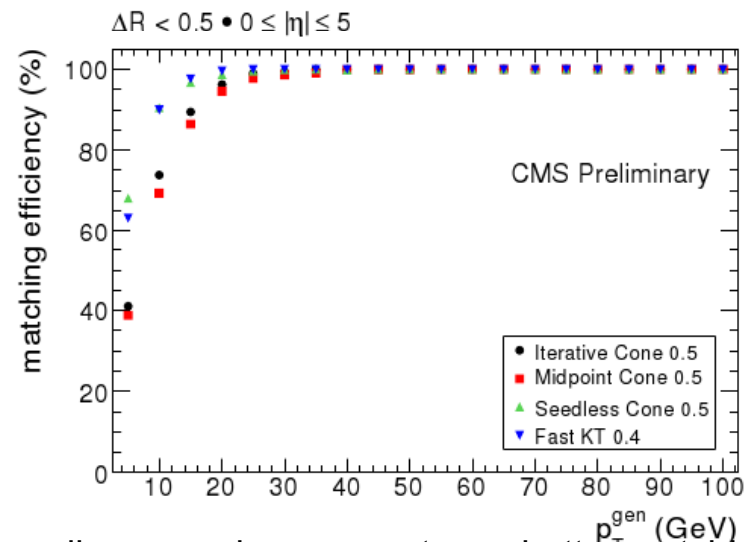
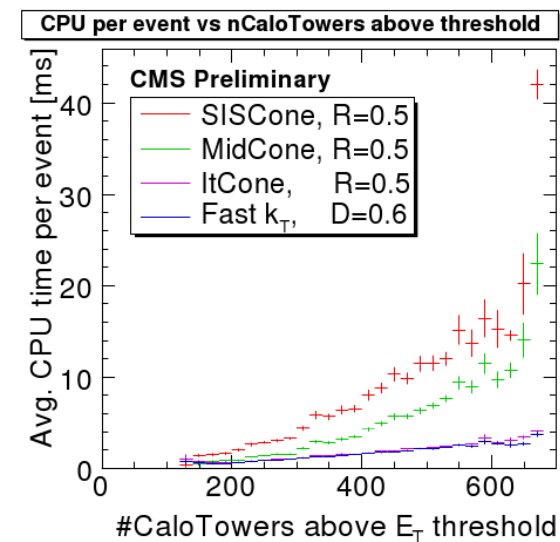
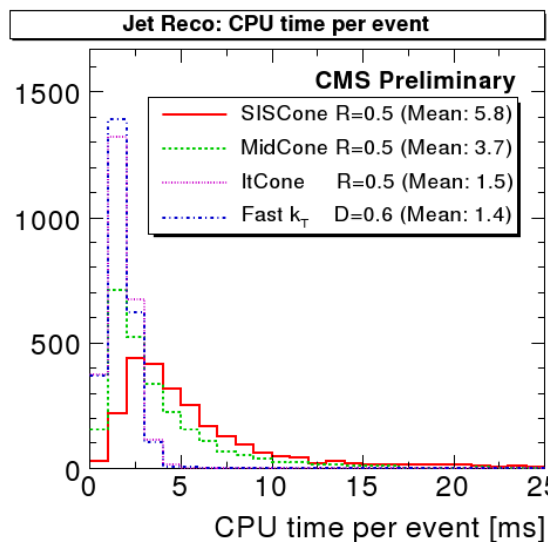
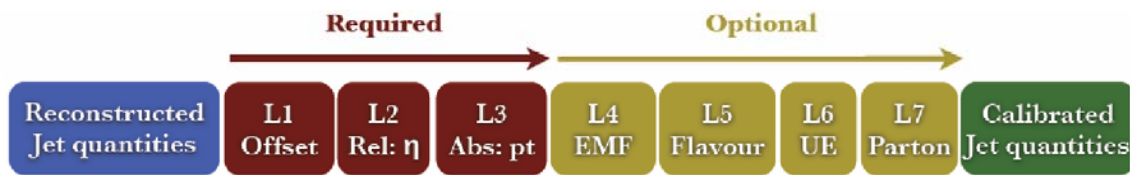
Christian Sander

Jet algorithms considered:

- ❑ Cone-based algorithms:
 - iterative cone, MidPoint cone, SISCone
- ❑ Clustering algorithms:
 - k_T with fast-kt implementation

Studies:

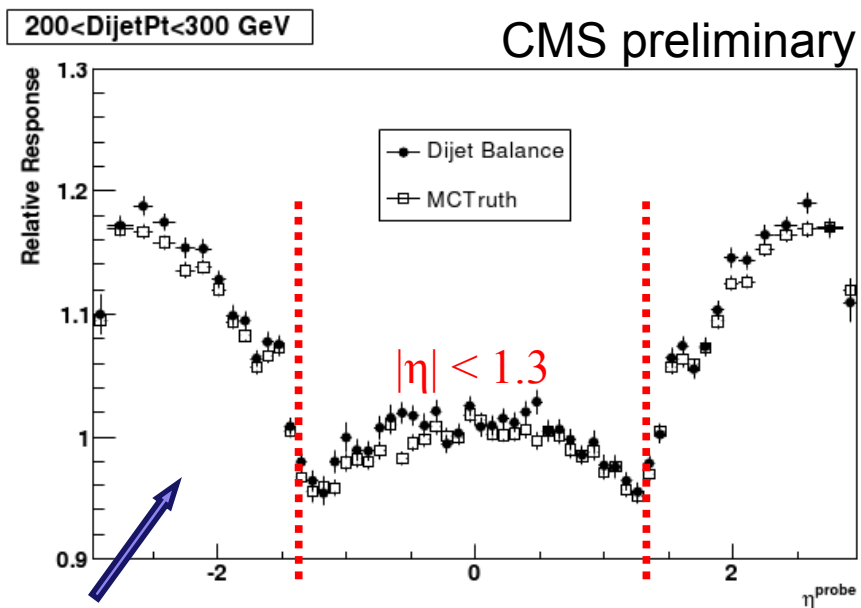
- ❑ Comparison of algorithms
 - similar computing time for all algorithms
 - SISCone and k_T tend to have better performance
- ❑ Calorimeter jet calibration:
 - both MC-truth-based and data-driven methods
- ❑ Performance on t-tbar events



(smaller cone size parameter → better matching eff.)

Jet studies in CMS (2/2)

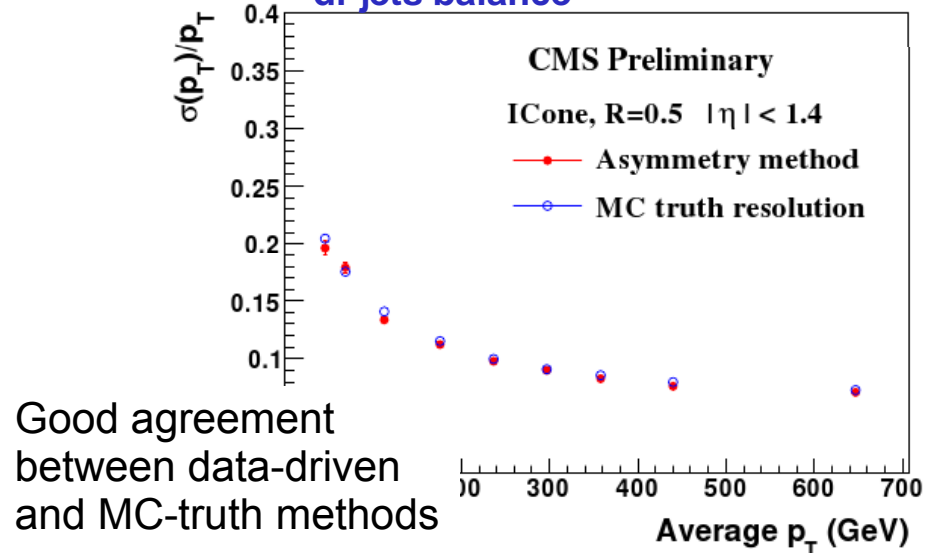
Christian Sander



jet response relative to η for $|\eta| < 1.3$
 Good agreement for data-driven dijet-balance and MC-truth

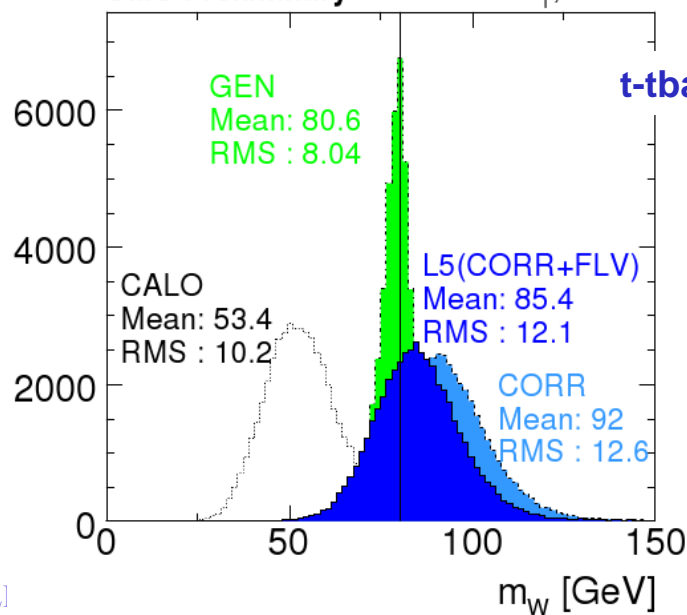
$$\text{Response} = \frac{\text{Calorimeter jet } p_T}{\text{Particle jet } p_T}$$

di-jets balance



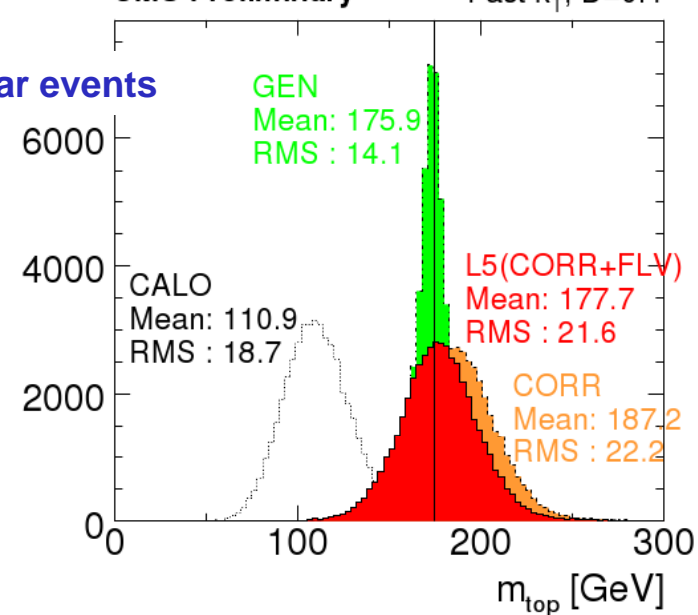
CMS Preliminary

Fast k_T, D=0.4



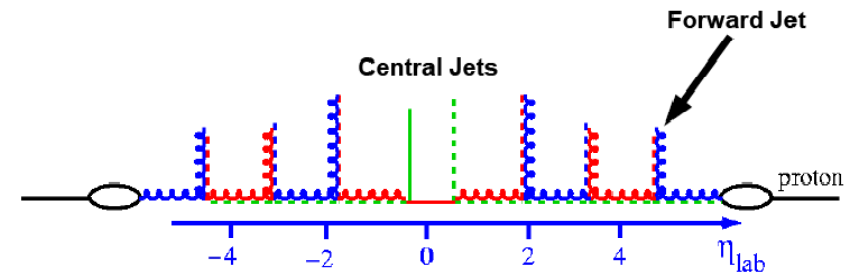
CMS Preliminary

Fast k_T, D=0.4



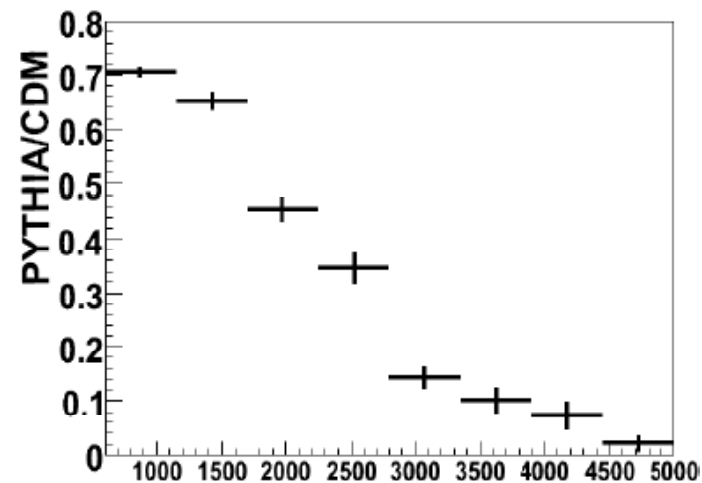
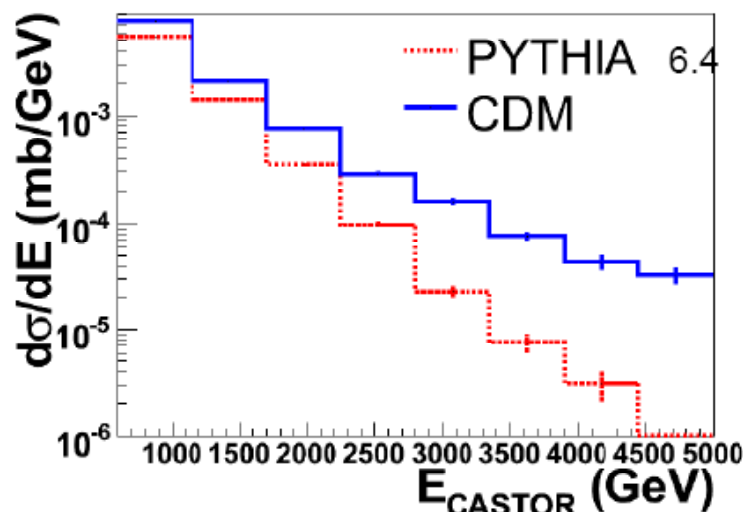
Detector:

- ❑ CMS “add-on” Cherenkov radiation calorimeter
- ❑ Very forward: $5.2 < \eta < 6.6$



Purpose:

- ❑ At HERA DGLAP describes well inclusive measurements but fails for more exclusive final states, ex. forward jet production
- ❑ Study of QCD dynamics, try to distinguish between different parton evolution models (DGLAP vs. BFKL)



Jet studies in LHCb (1/2)

Victor Coco

Forward spectrometer

Acceptance: $1.8 < \eta < 4.9$

Luminosity: $2 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$

Nr of B's / year: 10^{12}

Detector: excellent tracking
excellent PID

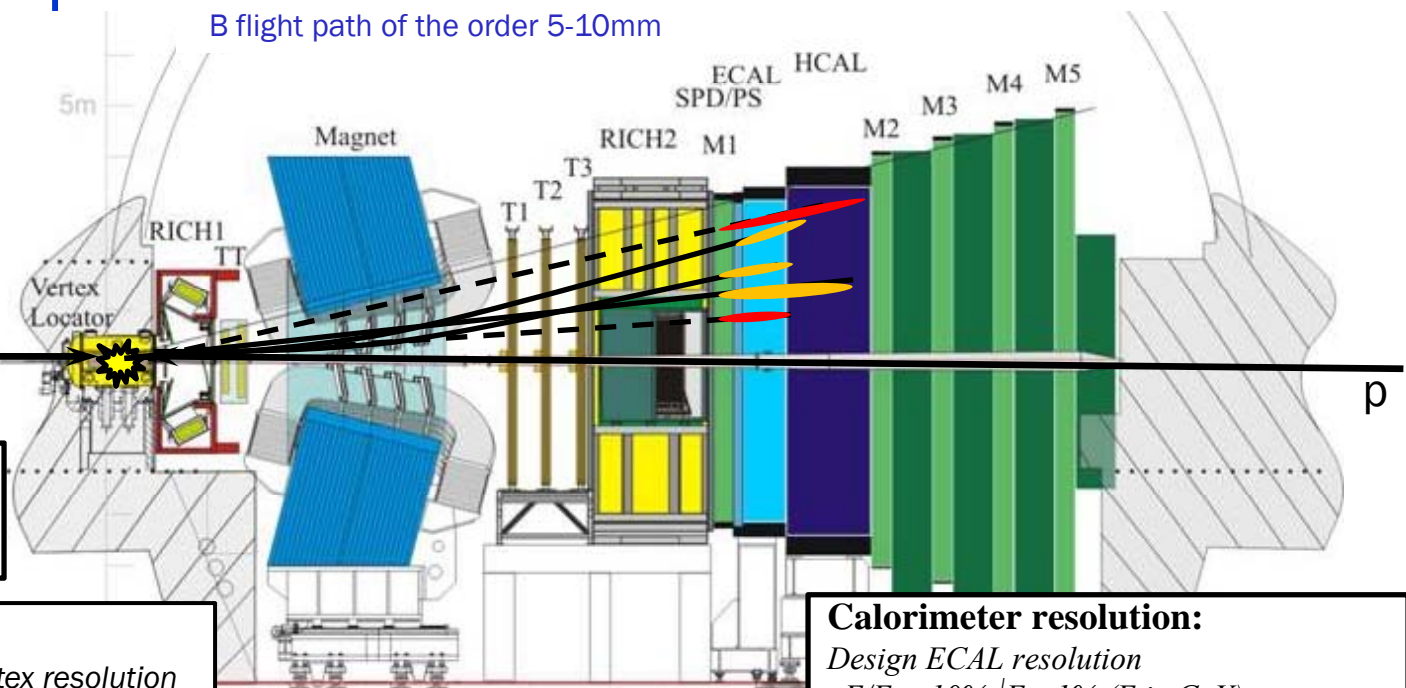
Reconstruction:

- muons: easy
- hadronic tracks: fine
- electrons: OK
- π^0 's: tricky
- neutrinos: no

Mission statement

- Search for new physics probing the flavour structure of the SM
- Study CP violation and rare decays in the B-meson sector

B flight path of the order 5-10mm



Tracking:

Expected tracking resolution
 $\delta p/p = 0.35\%$ to 0.55%

Vertexing:

Expected primary vertex resolution
 $\sim 10\mu\text{m}$ transverse plane and
 $\sim 60\mu\text{m}$ in the longitudinal one
Expected Impact parameter
resolution $\sigma_{iP} = 14\mu\text{m} + 35\mu\text{m}/p_T$

Calorimeter resolution:

Design ECAL resolution
 $\sigma E/E = 10\%\sqrt{E} + 1\%$ (E in GeV)
HCAL resolution from test-beam data
 $\sigma E/E = (69 \pm 5)\%\sqrt{E} + (9 \pm 2)\%$ (E in GeV)

Jet studies in LHCb (2/2)

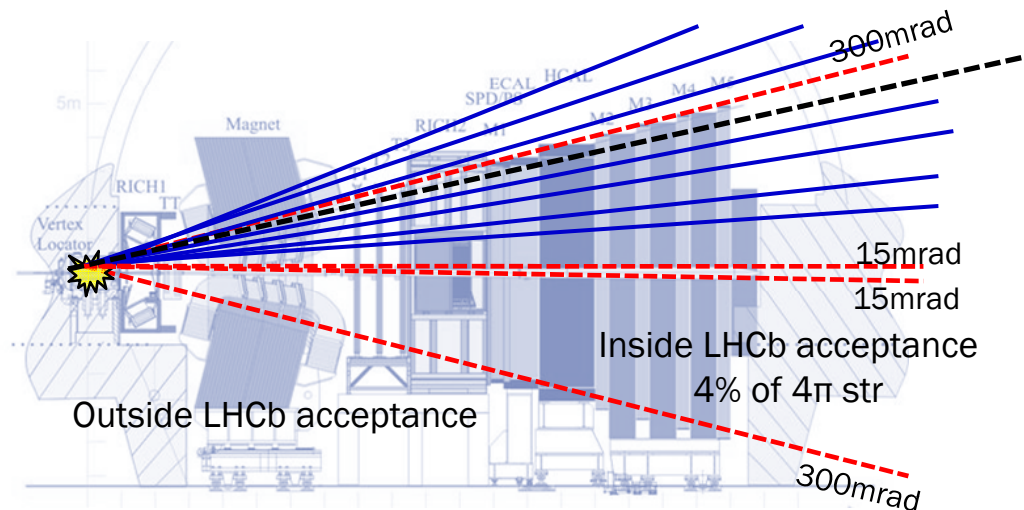
Victor Coco

Jet reconstruction issues:

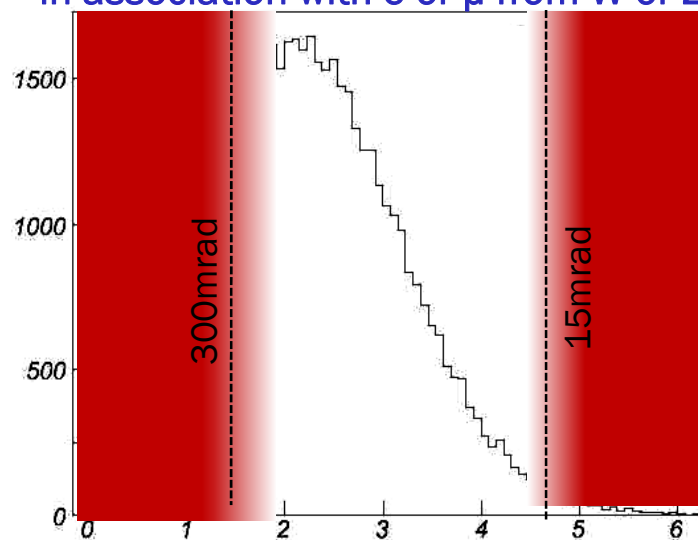
- ❑ Rather restricted detector angular coverage
- ❑ Calorimeter optimised for B-physics, not jet physics

Jet reconstruction strategy:

- ❑ k_T algorithm
- ❑ Use calorimeter information
- ❑ Use tracks information for charged particles
- ❑ Energy corrections
- ❑ B-jet tagging



SM Higgs decaying to $b\bar{b}$ with $m_H=120\text{GeV}$
in association with e or μ from W or Z



Pseudorapidity of b-quarks coming from $H(120\text{GeV})$
(high pt lepton in the acceptance)

Dijet mass resolution is affected



LHCb allow reconstruction of b-jets in the range $2 < \eta < 4$

Multi-parton interactions and underlying event

- typically presented in joint sessions with MC Tools WG
- Present status in Paolo Bartalini's summary
- Focus here on experimental aspects and tools rather than MC tunings

P. Bartalini, L. Fano, R. Field, A. Moraes et al., D. Treleani, etc.

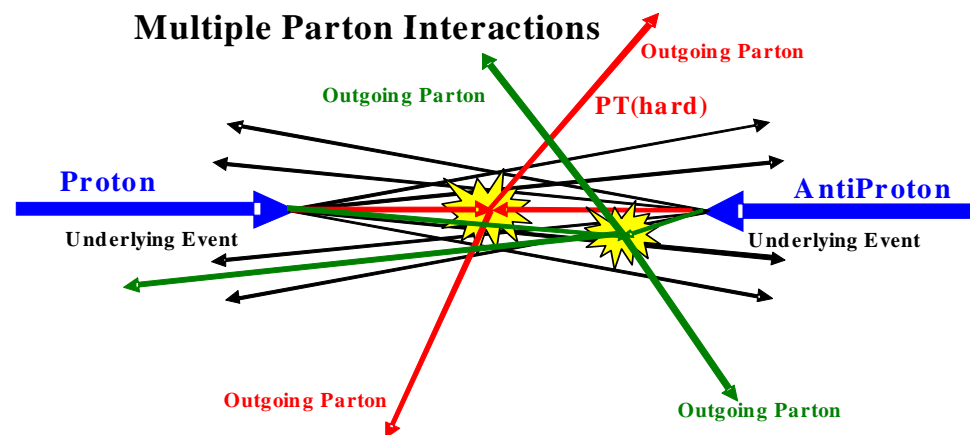
Multi-parton interactions & underlying event (1/2)

Multi-parton interactions:

- ❑ Great deal understood with HERA data (see e.g. Magro's talk)
- ❑ HERA and TeVatron data used to tune MCs

UE before the LHC:

- ❑ Many studies of the UE at TeVatron
- ❑ New models implemented in new MCs (e.g. Herwig++)
- ❑ Testing of new models on (TeVatron) data

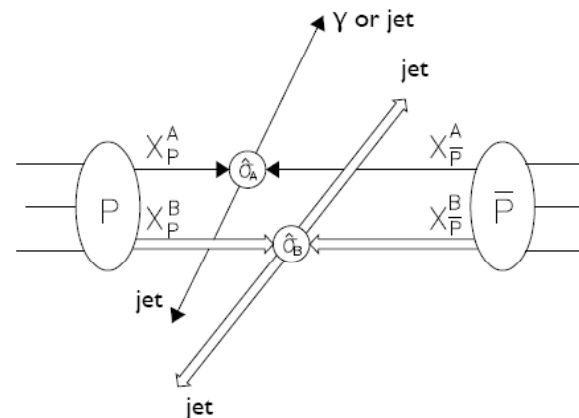


Status report given at joint session with MC tools WG. See Paolo Bartalini's summary

Double-parton scattering:

Florian Bechtel

- ❑ Identified in final states with $\gamma + 3$ jets
- ❑ Direct evidence for multi-parton interactions
- ❑ MPI models agree with TeVatron data
- ❑ Studies ongoing for similar analyses at the LHC, where MI expected to contribute significantly



Multi-parton interactions & underlying event (2/2)

Underlying event at the LHC:

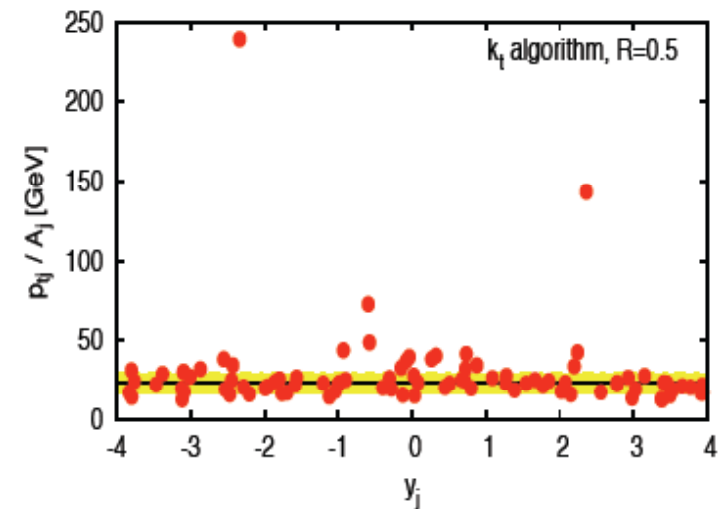
- ❑ To be measured from jet events & Drell-Yan μ -pair production
- ❑ CASTOR can also extend the TeVatron results to the very forward region (jet profiles help determining UE component)

Zuzana Rurikova

How to deal with the UE and pile-up?

Matteo Cacciari et al.

- ❑ Concept of jet area used to determine and subtract these contributions on an event-by-event basis
- ❑ Key observation: jet E_T / jet area ~ constant except for hard jets
- ❑ LHC experiments urged to explore the idea ...
... it fits well now that both ATLAS and CMS need to study jet reconstruction in the presence of pile-up ...



Outlook

- Workshop has seen the birth of many new ideas
- There has been a constant flow of ideas/tools/etc. from HERA to LHC community
- Looking forward to seeing all these developments “in action” using LHC data ...!