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

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') (Slides)	Rick Field
09:25	Underlying event studies with Castor calorimeter in CMS experiment (15') (Slides)	Zuzana Rurikova
09:45	Modeling the underlying event: MC tunes for the LHC (20') (Slides)	Arthur Moraes
10:05	COFFEE (25')	
10:30	The underlying event in Herwig++ (20') (Slides)	Manuel Baehr
10:55	Double parton scattering studies with Pythia 8 and Herwig++ (20') (Slides)	Florian Bechtel (*Hamburg / Lund*)
11:20	A new framework for estimating multi-jet final states (20') (Slides)	Chris White
11:45	Multiple Interactions in photoproduction at H1 (20') (Slides)	Lluis Marti
12:10	Prerequisites for the Validation of Experiment and Theory (10') (Slides)	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') (Paper)	Pierre-Antoine Delsart
14:20	Performance of Jet Reconstruction at CMS (20') (Slides)	Christian Sander
14:40	b-jets at LHCb (20') (Slides)	Victor Coco
15:00	Forward jets with the calorimeter CASTOR in the CMS experiment (20') (Slides)	Albert Hans Knutsson
15:20	COFFEE (20')	
15:40	Update on the SISCone and Anti-kT algorithms (20') (Slides)	Gregory Soyez
16:00	Jet areas and subtraction (20') (Slides)	Matteo Cacciari
16:20	Performance of jet algorithms at the LHC (20') (Slides)	Juan Rojo-Chacon
16:40	Non-perturbative effects for QCD jets at hadron colliders (20') (Slides)	Lorenzo Magnea
17:00	Azimuthal de-correlations in QCD jets (20') (Slides)	Mrinal Dasgupta
17:20	Discussion - ALL (30')	

Jet physics

Challenges at the LHC

- (LHC) Environment related:

  pile-up – ~23 interactions / bunch crossing

- Physics related:

  the underlying event

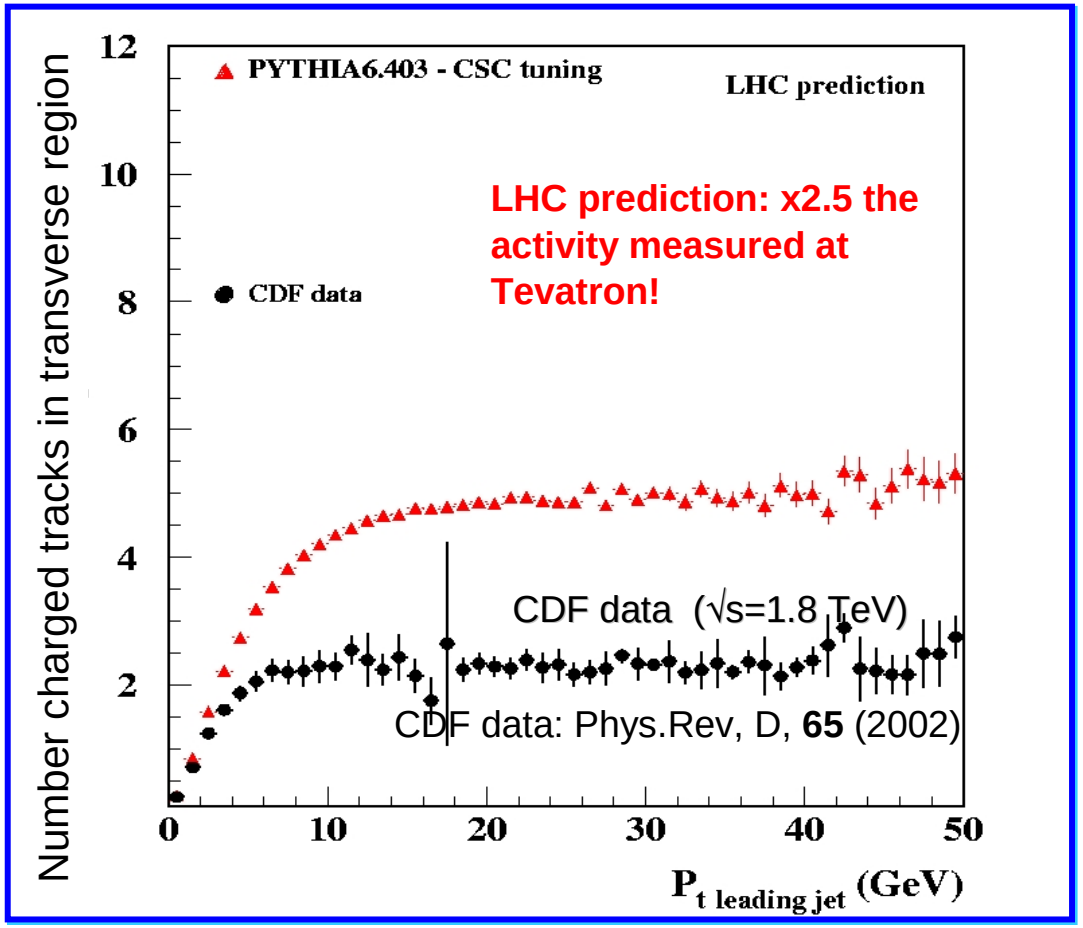
  and multi-parton interactions

- Detector related:

  calorimeters resolutions,

  noise, and “slow” response

Arthur Moraes



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:

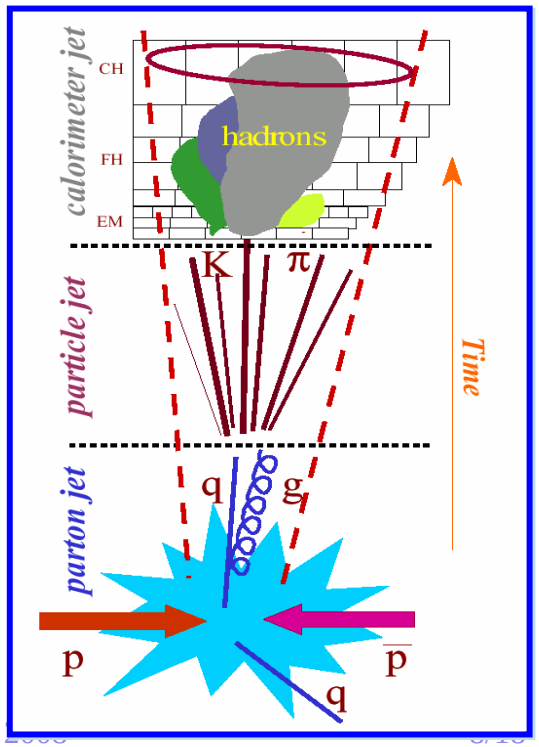
- Jet reconstruction crucial to ATLAS and CMS physics programs
- Analysis demand excellent jet resolution and small energy scale uncertainties

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

calibration

jet energy scale



- Develop several calibration methods

  data will "dictate" best strategy to adopt in the future …

Jet studies in ATLAS (1/2)

Pierre-Antoine Delsart

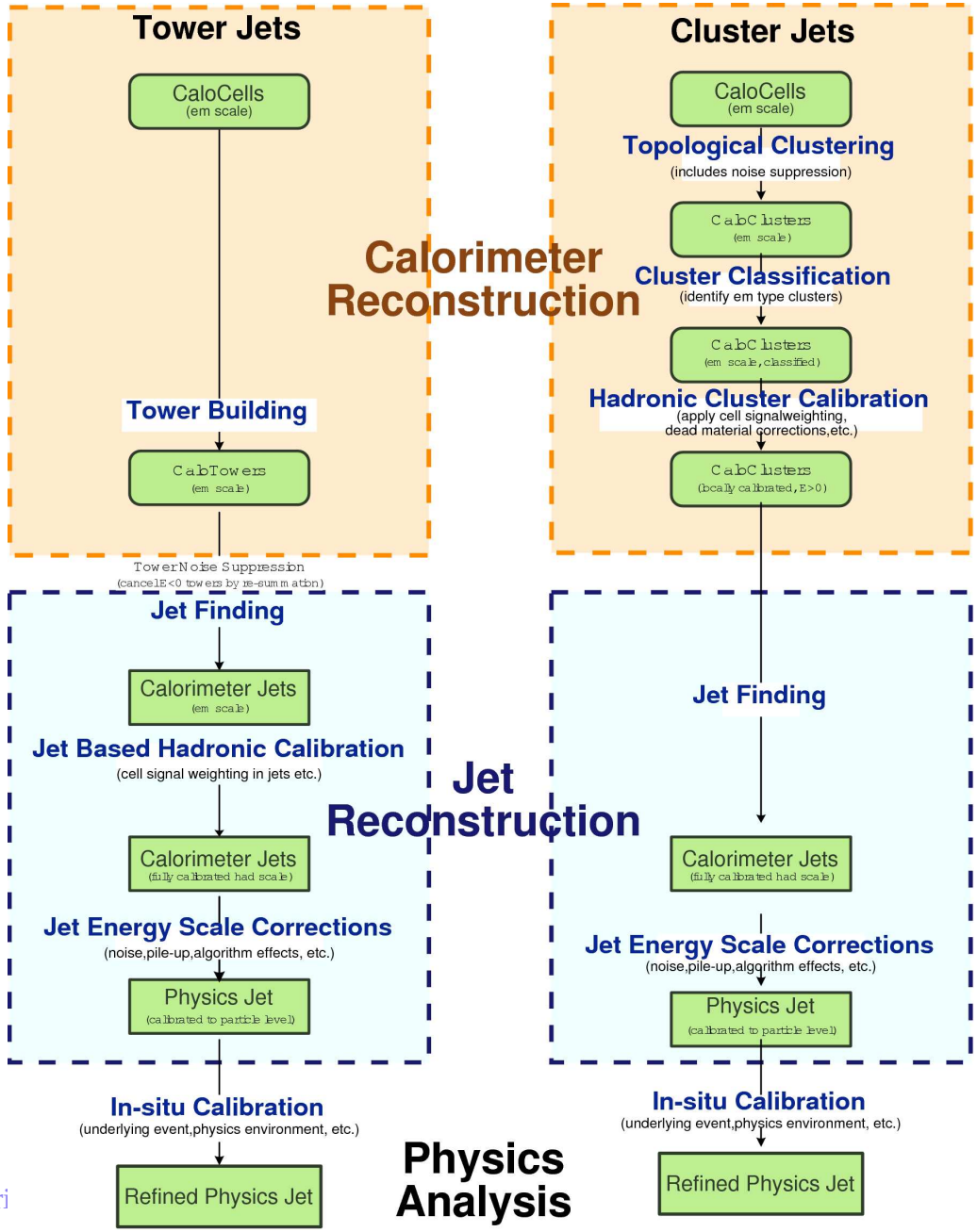
2 strategies for reconstruction of calibrated jets

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.)



Jet studies in ATLAS (2/2)

Pierre-Antoine Delsart

Calibration efforts:

- Challenge: ATLAS possesses a non-compensation calorimeter (e/h ~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:

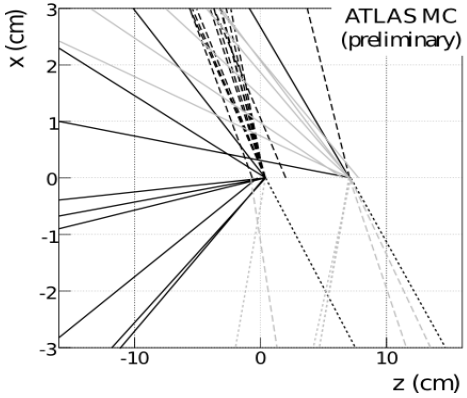
- Challenge: aim at ~1% JES uncertainty!

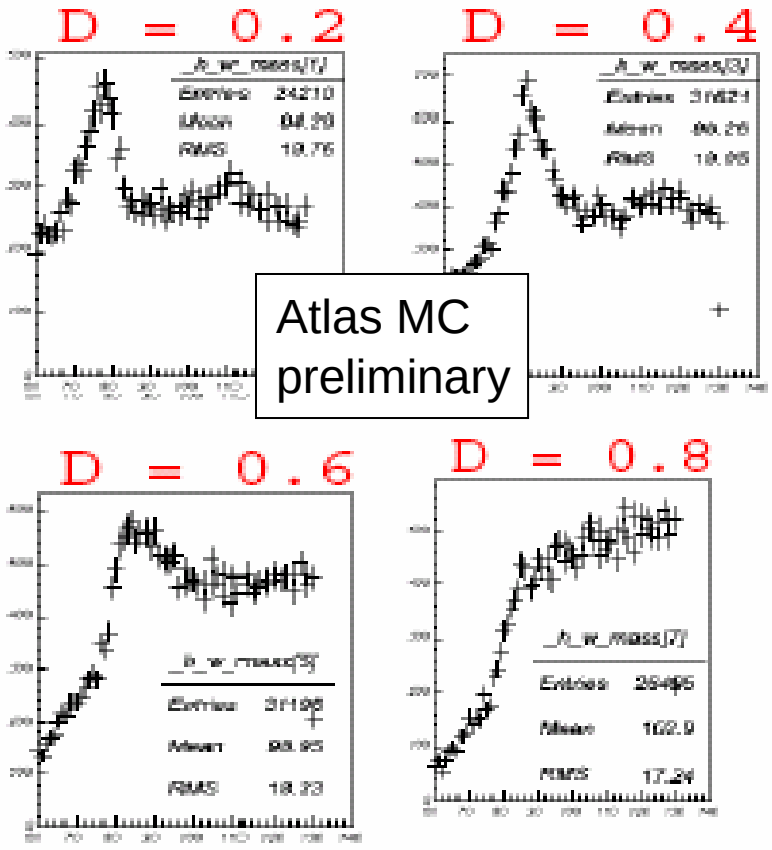
Jet finding efforts:

- 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

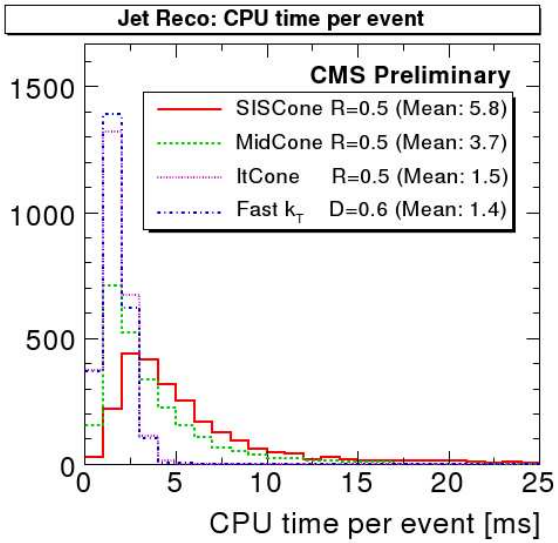
Jet algorithms considered:

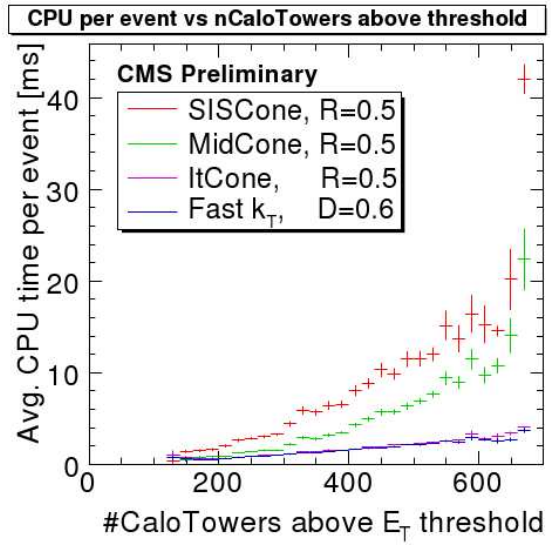
- Cone-based algorithms:

  iterative cone, MidPoint cone, SISCone

- Clustering algorithms:

  k_T with fast-kt implementation





Studies:

- Comparison of algorithms

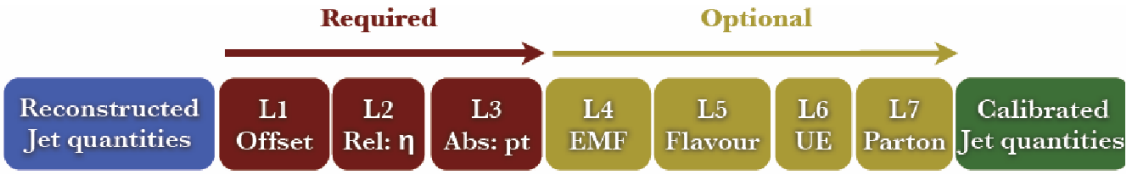
  - similar computing time for all algorithms

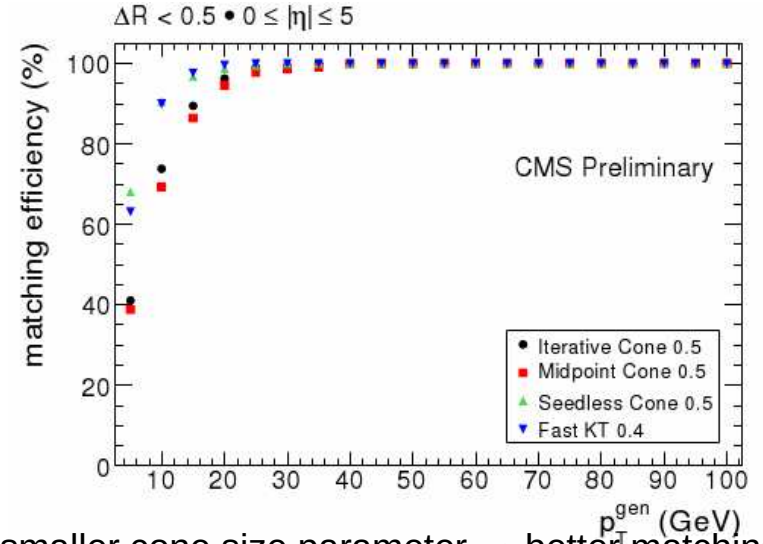
  - SISCone and k_T tend to have better performance

- Calorimeter jet calibration:

  both MC-truth-based and data-driven methods

- Performance on t-tbar events

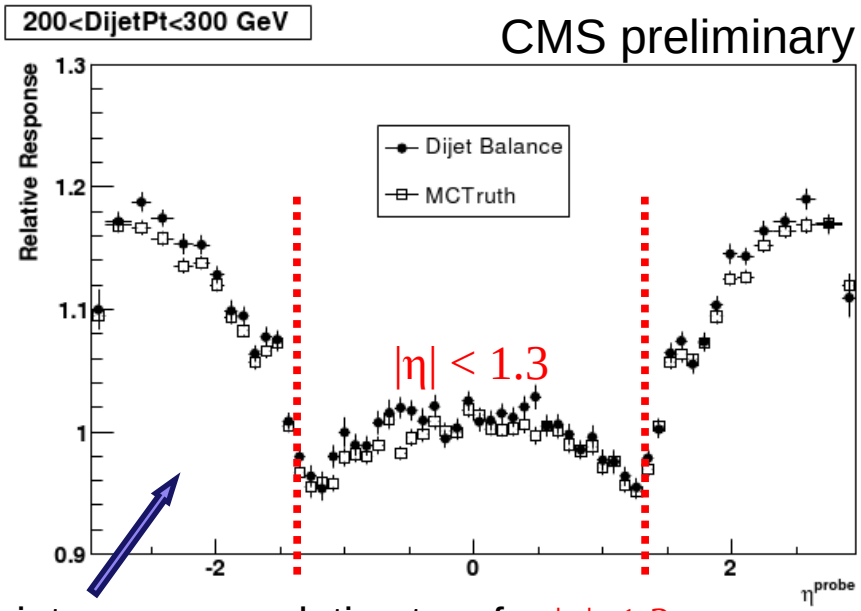




(smaller cone size parameter → better matching eff.)

Jet studies in CMS (2/2)

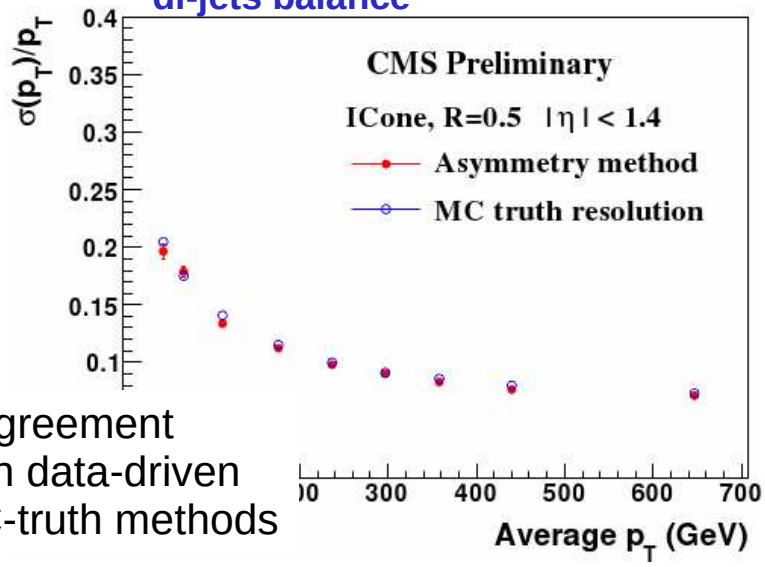
Christian Sander



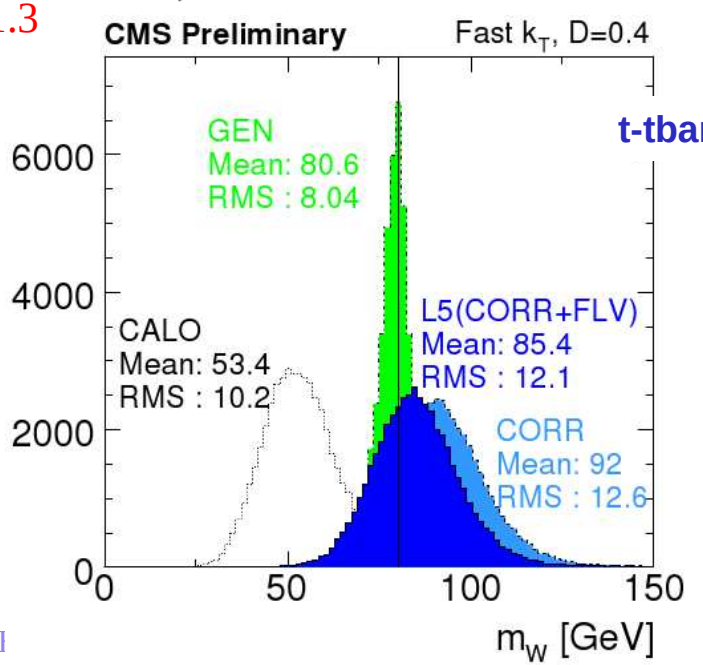
jet response relative to η for |η|<1.3
Good agreement for data-driven dijet-balance and MC-truth

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

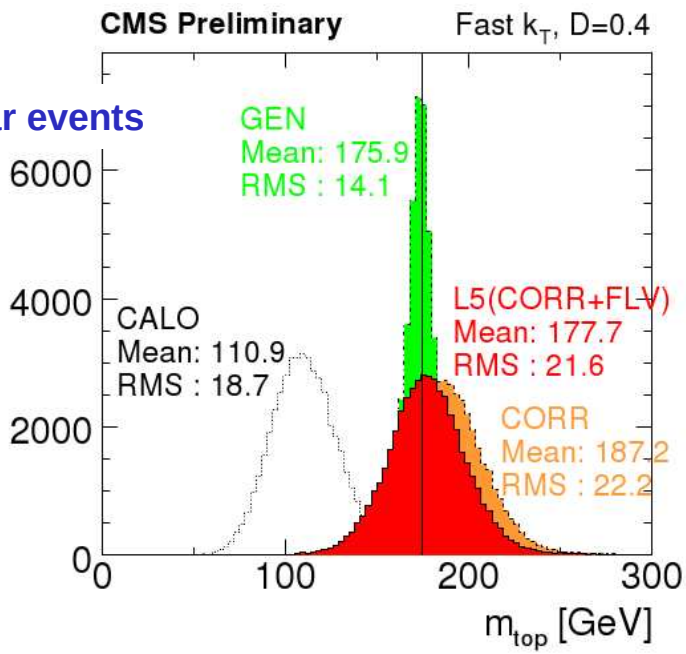
di-jets balance



Good agreement between data-driven and MC-truth methods



t-tbar events

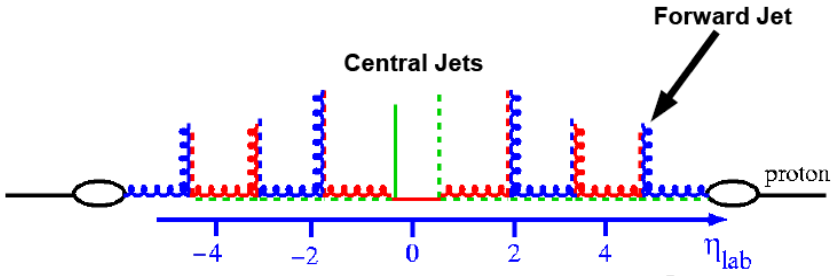


Forward jet studies with CASTOR & CMS

Albert Knutsson

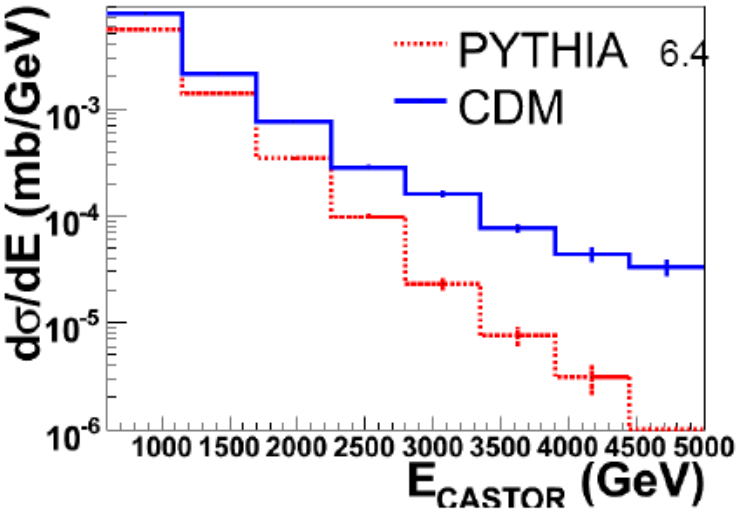
Detector:

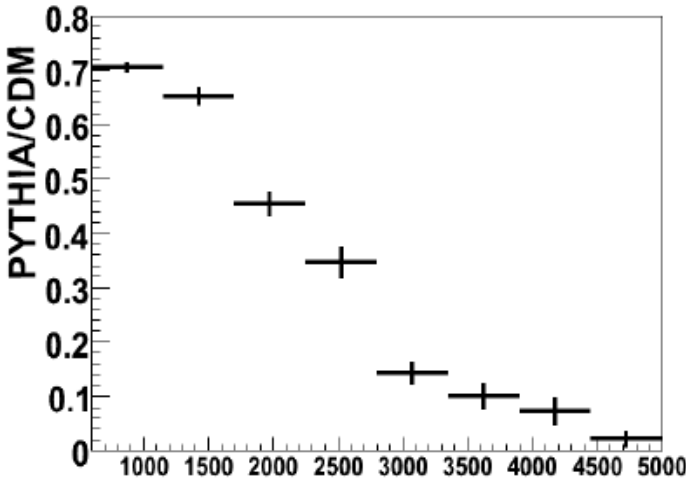
- CMS “add-on” Cherenkov radiation calorimeter
- Very forward: $5.2 < \eta < 6.6$



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: $2 \bullet 10^{32}\ cm^{-2}\ s^{-1}$

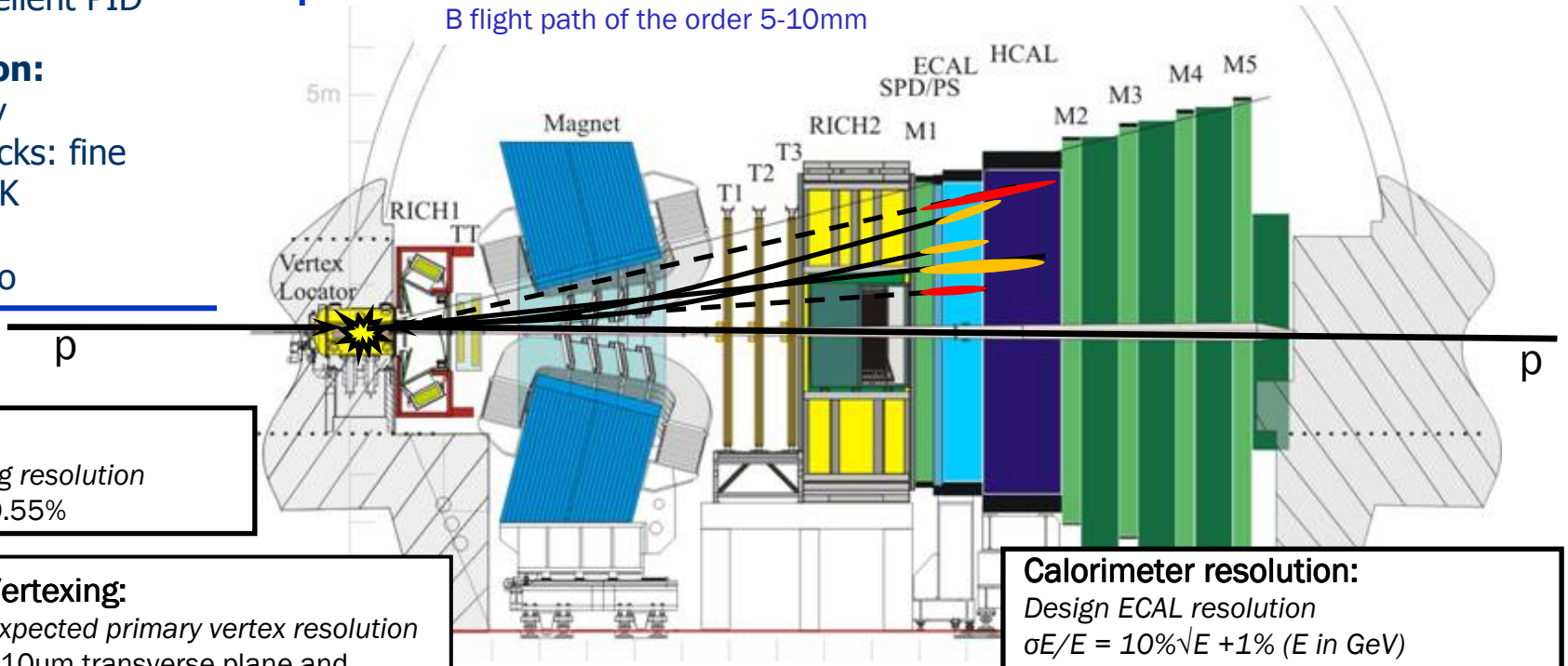
Nr of B's / year: 10^{12}

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



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

Vertexing:
Expected primary vertex resolution
~10μm transverse plane and
~60μm in the longitudinal one
Expected Impact parameter resolution $\sigma_{IP} = 14\mu m + 35\mu m/p_T$

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)

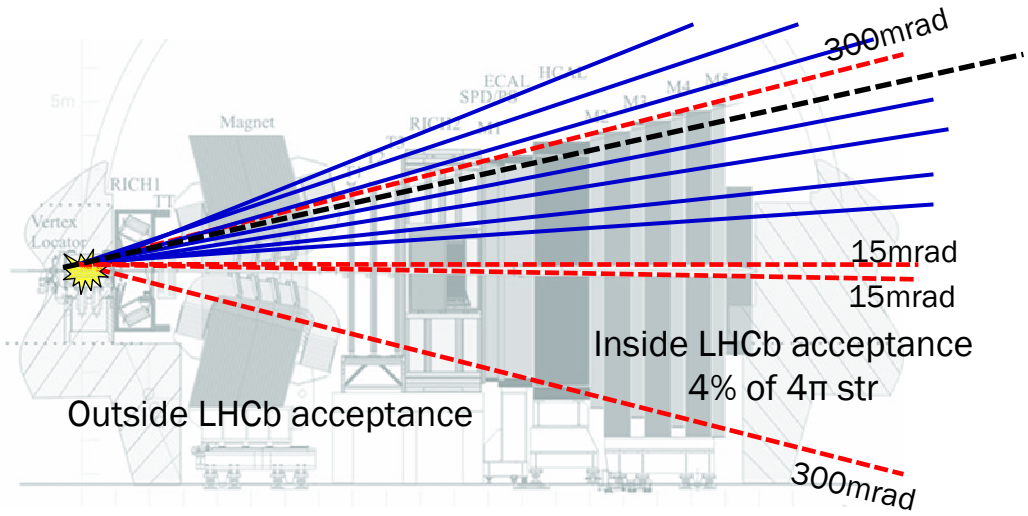
Victor Coco

Jet reconstruction issues:

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

Jet reconstruction strategy:

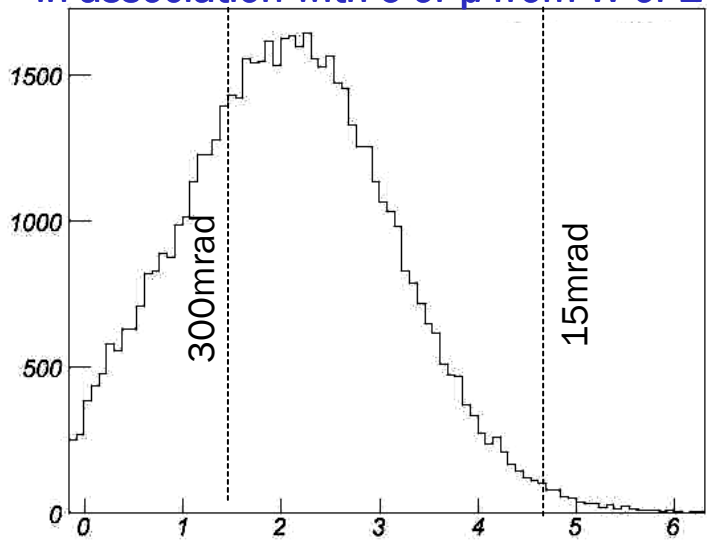
- k_T algorithm
- Use calorimeter information
- Use tracks information for charged particles
- Energy corrections
- B-jet tagging



Dijet mass resolution is affected

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

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



Pseudorapidity of b-quarks coming from H(120GeV) (high pt lepton in the acceptance)

Multi-parton interactions and underlying event

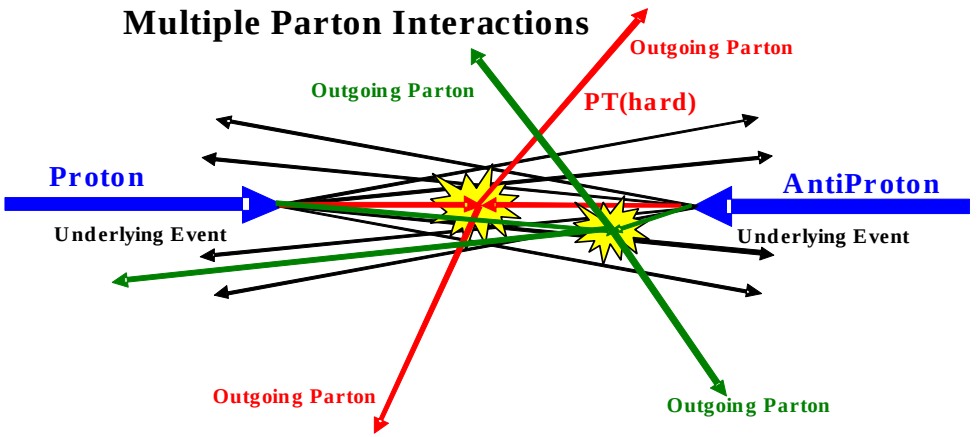
- typically presented in joint sessions with MC Tools WG
- Present status in Paolo Bartalini's summary
- Focus here on experimental aspects and tools rather than MC tunings

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:

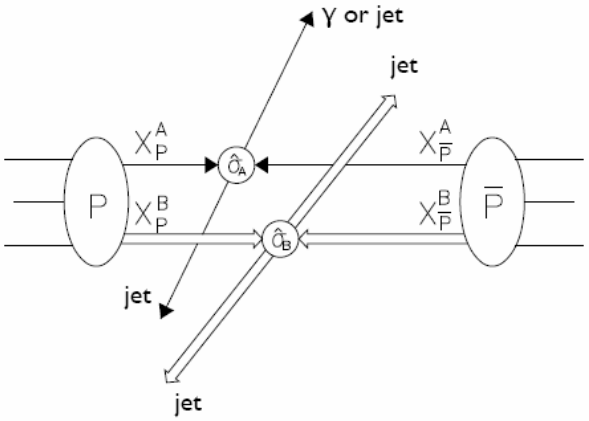
- Many studies of the UE at TeVatron
- New models implemented in new MCs
  (e.g. Herwig++)
- Testing of new models on (TeVatron) data

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 γ + 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:

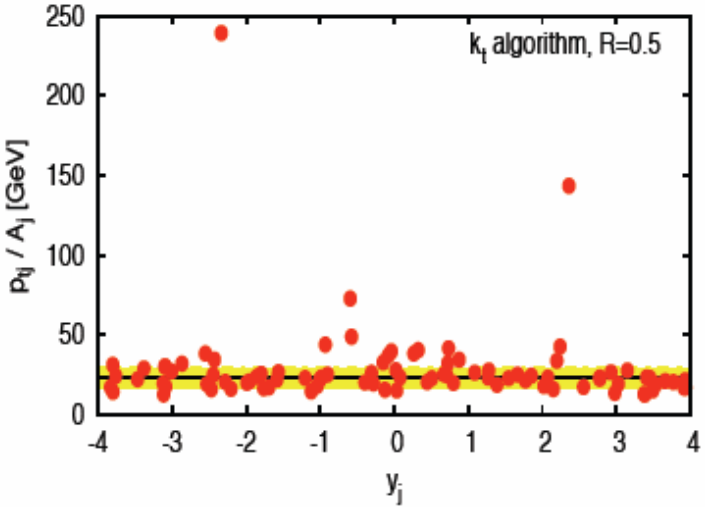
- To be measured from jet events & Drell-Yan μ-pair production
- CASTOR can also extend the TeVatron results to the very forward region (jet profiles help determining UE component)

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 …!