QCD and Electroweak Physics at the LHC

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Today's Menu

- Tevatron Appetizer
- QCD for a Starter
- EWK Boson Platter
- Dibosonic Dessert
- Outlook

From a WW Workshop in 2001

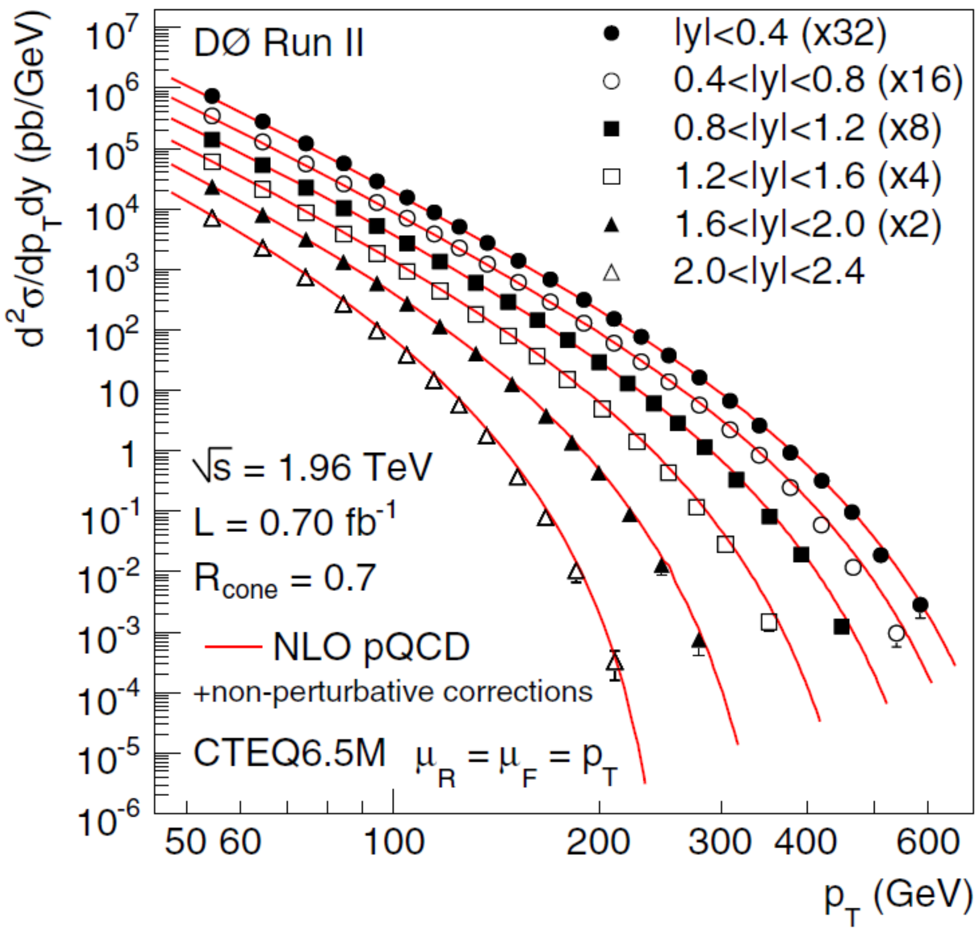
Concentrated on a selection of recent results for LHC start-up, apologies for unavoidable omissions. Complete references can be found here:

ATLAS public results web page:
https://twiki.cern.ch/twiki/bin/view/Atlas/AtlasResults

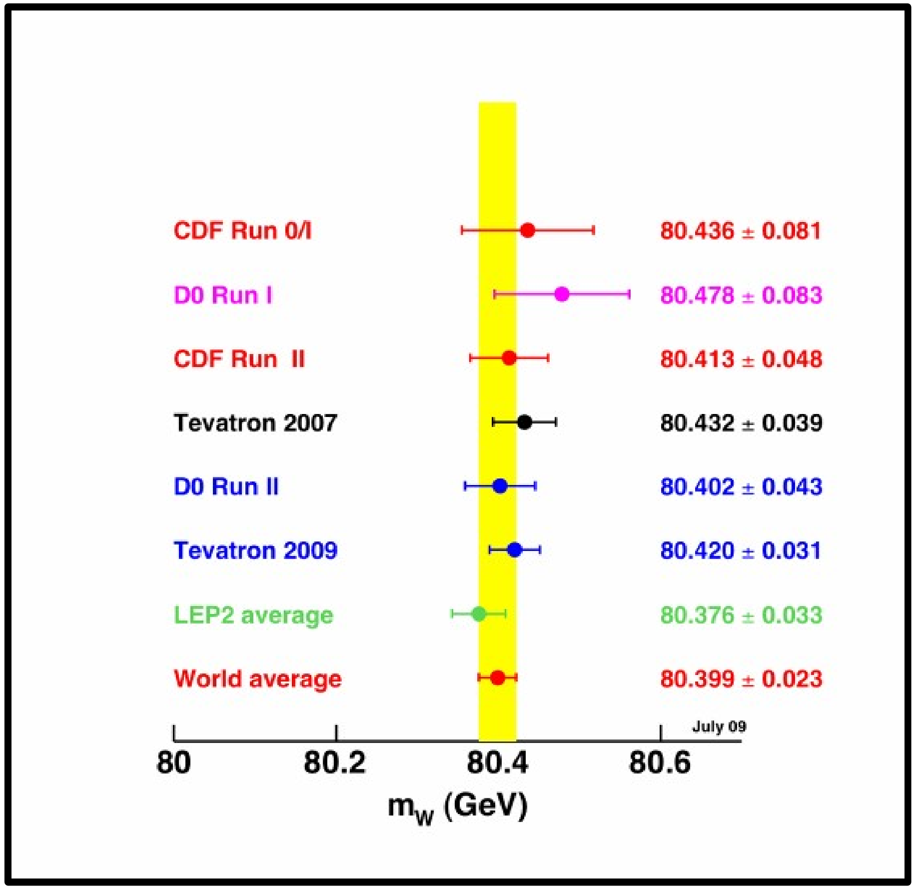
CMS public results web page:
https://twiki.cern.ch/twiki/bin/view/CMS/PhysicsResults

Tevatron Appetizer

Inclusive Jet Cross Sections



W Mass



Precision Measurements that take a lot of work to accomplish!

JES uncertainty: 2-3% D0, 3-4% CDF

See yesterdays talk by Rainer Wallny!

The ATLAS Detector

Inner Detector (ID) tracker:

- Si pixel and strip + transition rad. tracker
- $\sigma(d_0)$ = 15µm@20GeV
- $\sigma/p_T \approx 0.05\% p_T \oplus 1\%$

Calorimeter

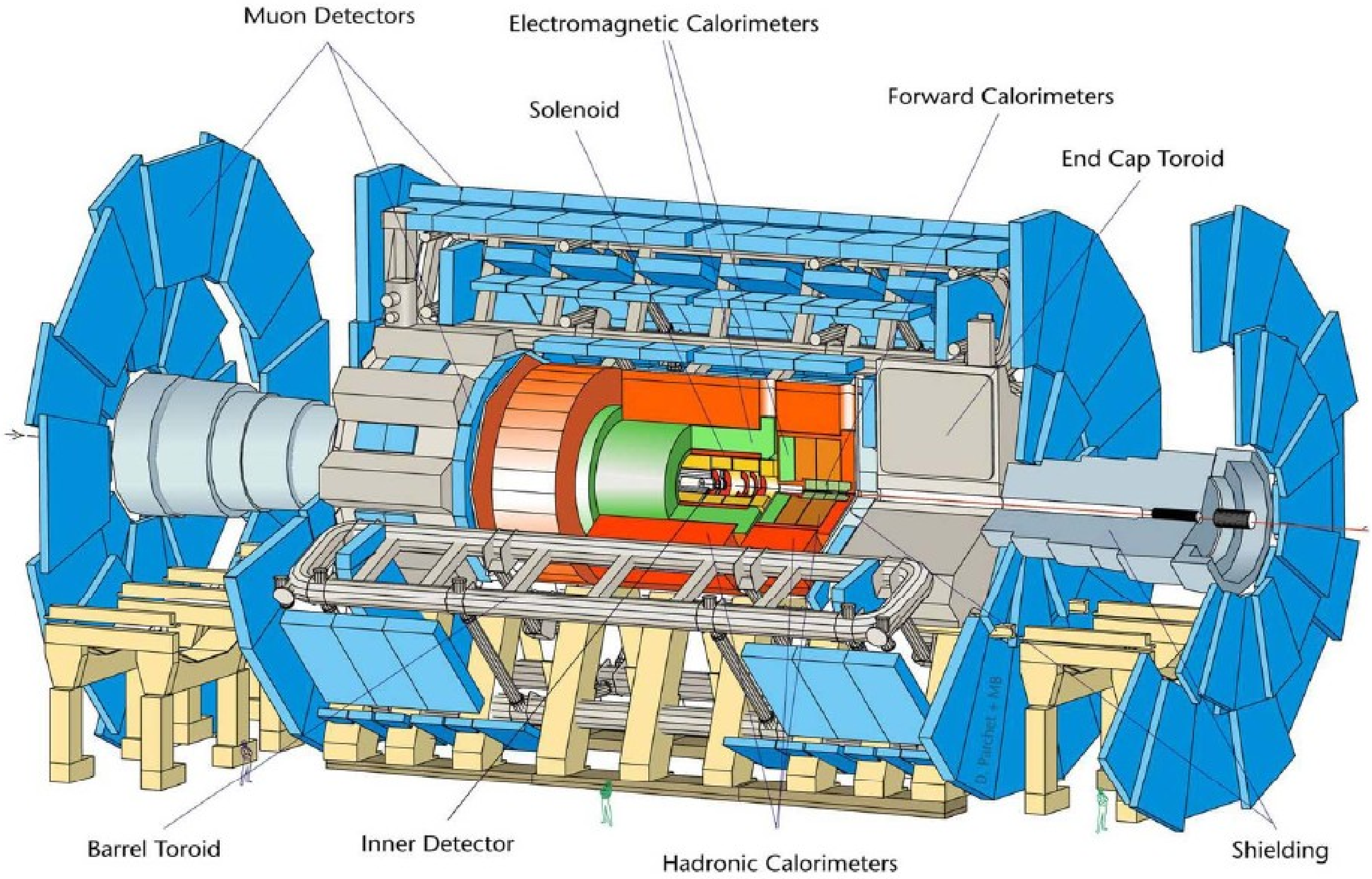
- Liquid Ar EM Cal, Tile Had.Cal
- EM: $\sigma_E/E = 10\%/\sqrt{E} \oplus 0.7\%$
- Had: $\sigma_E/E = 50\%/\sqrt{E} \oplus 3\%$

Muon spectrometer

- Drift tubes, cathode strips: precision tracking +
- RPC, TGC: triggering
- $\sigma/p_T \approx$ 2-7%

Magnets

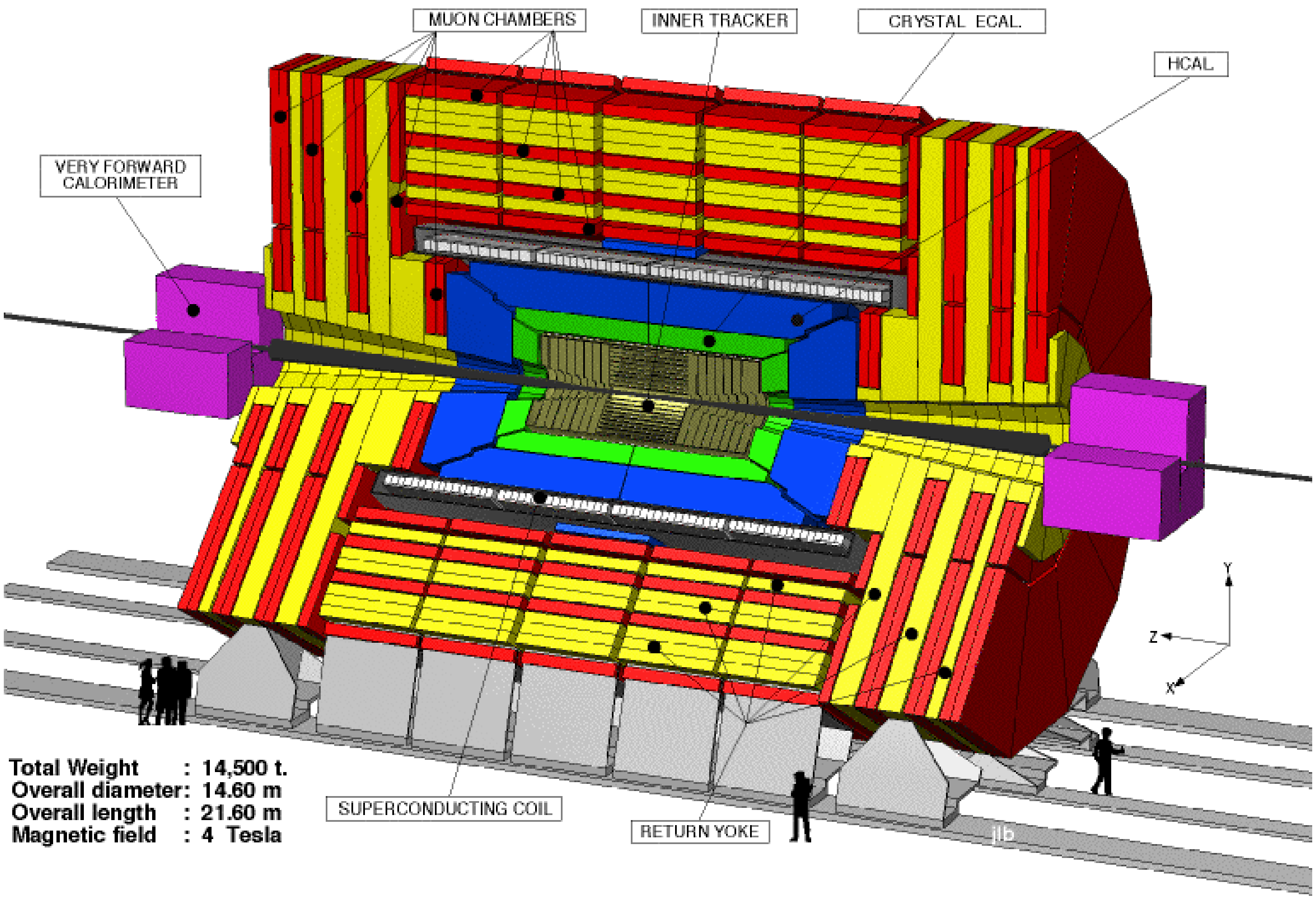
- Solenoid (ID) → 2T
- Air toroids (muon) → up to 4T



Full coverage for $|\eta|<2.5$, calorimeter up to $|\eta|<5$

See also JINST 3 2008 S08003

The CMS Detector



Inner detector (tracker):

- Si pixel & strip tracker
- $\sigma/p_T \approx$ 1-2% (μ at 100 GeV)

Calorimeter:

- PbWO4 crystal ECAL, brass/scintillator HCAL
- ELM: $\sigma_E/E = 2.8\%/\sqrt{E} + 0.3\%$
- HAD: $\sigma_E/E = 100\%/\sqrt{E} + 5\%$

Muon system:

- Drift tubes, cathode strips, resistive plate chambers
- $\sigma/p \approx$ 10 – 50% (muon alone)
- $\approx$ 0.7 – 20% (with tracker)

Magnet:

- Solenoid → 3.8T

See also:
PTDR I LHCC-2006-001,
JINST 3 2008 S08003

QCD/EWK at LHC Start-up

7 TeV, but still high enough rates left ...

Assuming $L = 10^{32} cm^{-2}s^{-1}$

- **Startup with SM Reactions:**
  - Not much statistically limited
  - First measurements at multi TeV energy scale
  - Re-establishment of Standard Model, i.e. test extrapolations from Tevatron energies
  - Background to be understood for almost everything
  - Physics commissioning of CMS
  - Be prepared for surprises ...

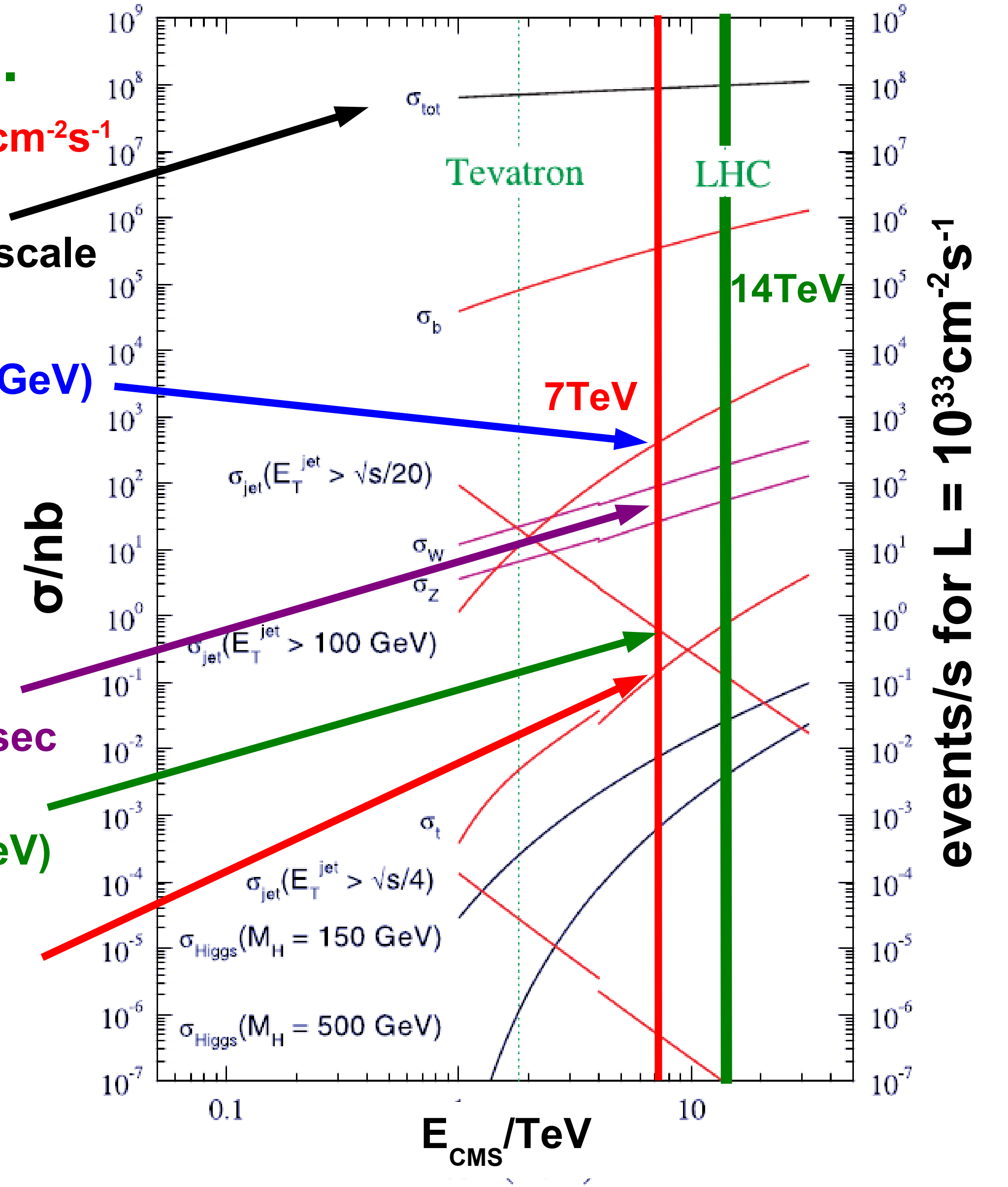
MinBias
· 1/trigger prescale

$\sigma_{jet}(E_T^{jet} > 100GeV)$
40/sec

σ_W, σ_Z
10/sec, 3/sec

$\sigma_{jet}(E_T^{jet} > 350GeV)$
3/min

σ_{tt}
36/h

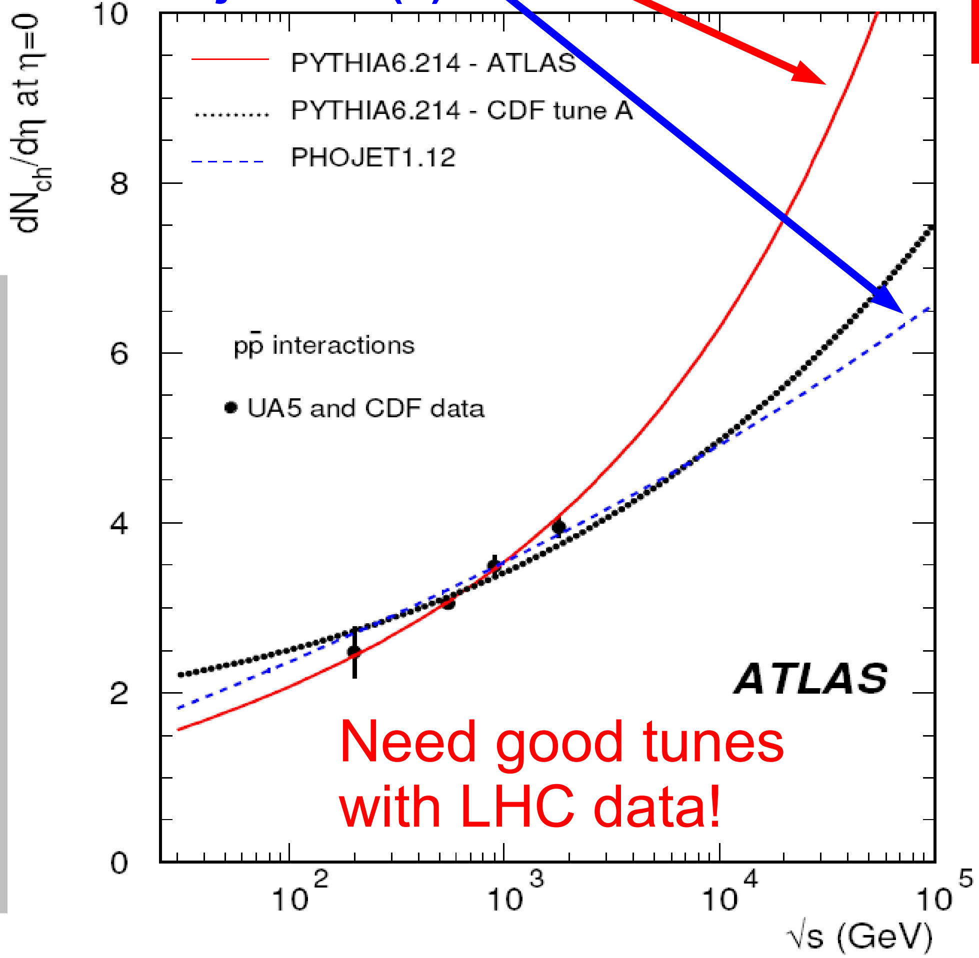


Check MC with MinBias

ATLAS, CERN-OPEN-2008-020

Model expectations for charged particles at |η| = 0 vs. √s:

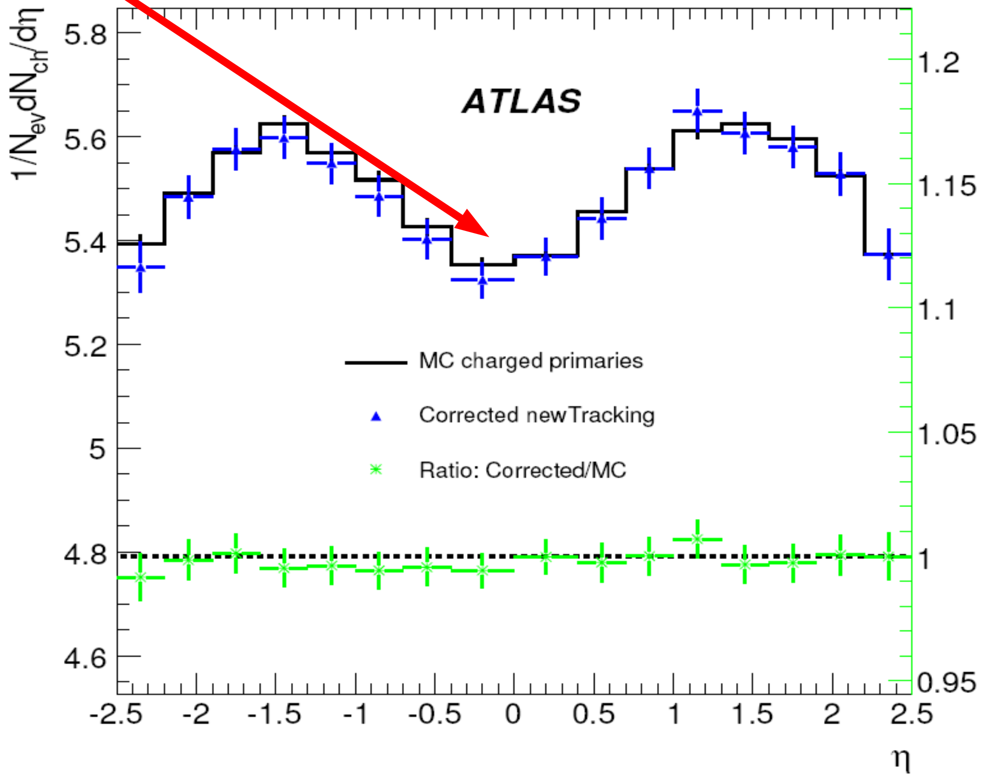
- Pythia: ~ $\ln^2(s)$
- Phojet: ~ $\ln(s)$



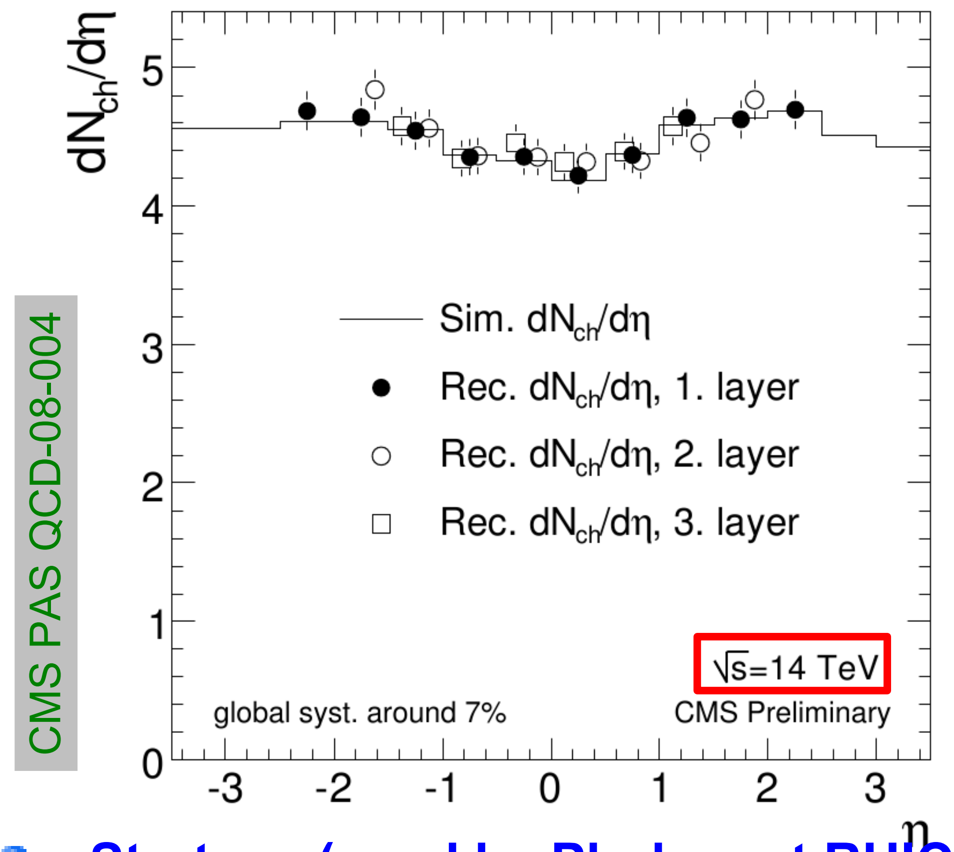
Need good tunes with LHC data!

Data?

Process	Cross-section (mb) PHOJET	PYTHIA
non-diff.	69	55
single diff.	11	14
double diff.	4	10
central diff.	1	-
total inelastic	85	79
elastic	35	23
total	120	102

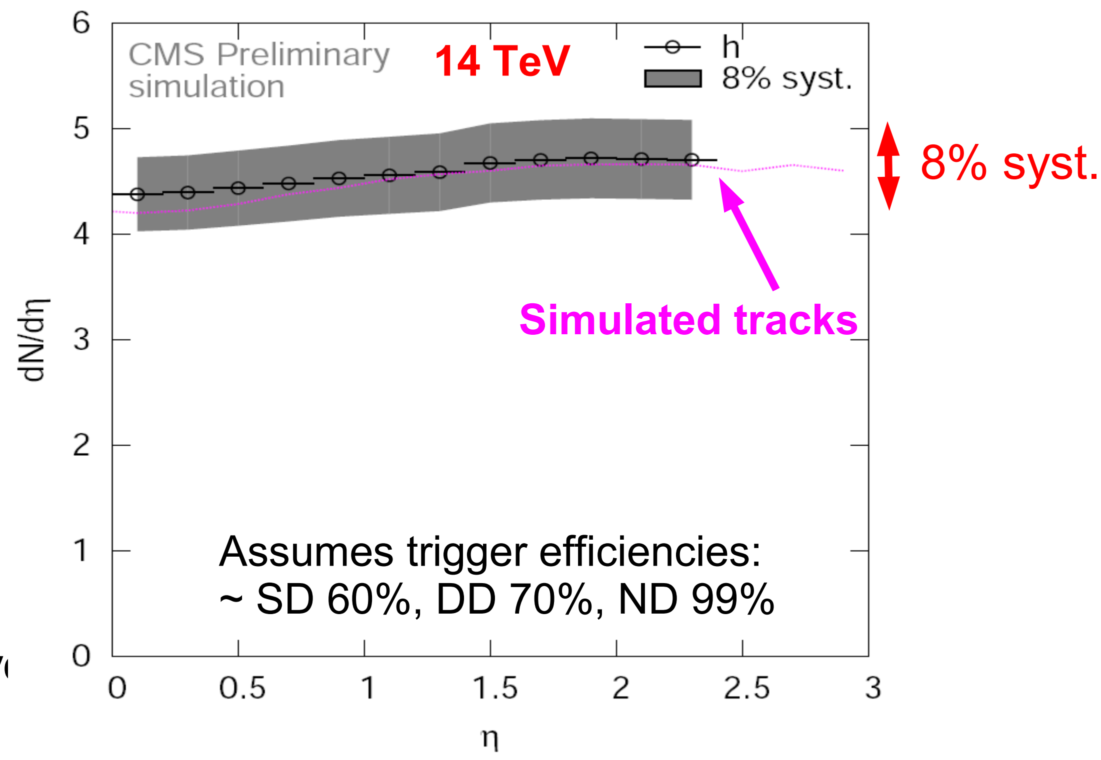


Charged Particle Rapidity Density with CMS



Simulation result from CMS:

- **Charged particle pseudo-rapidity distribution**
- **Pythia tune DWT**



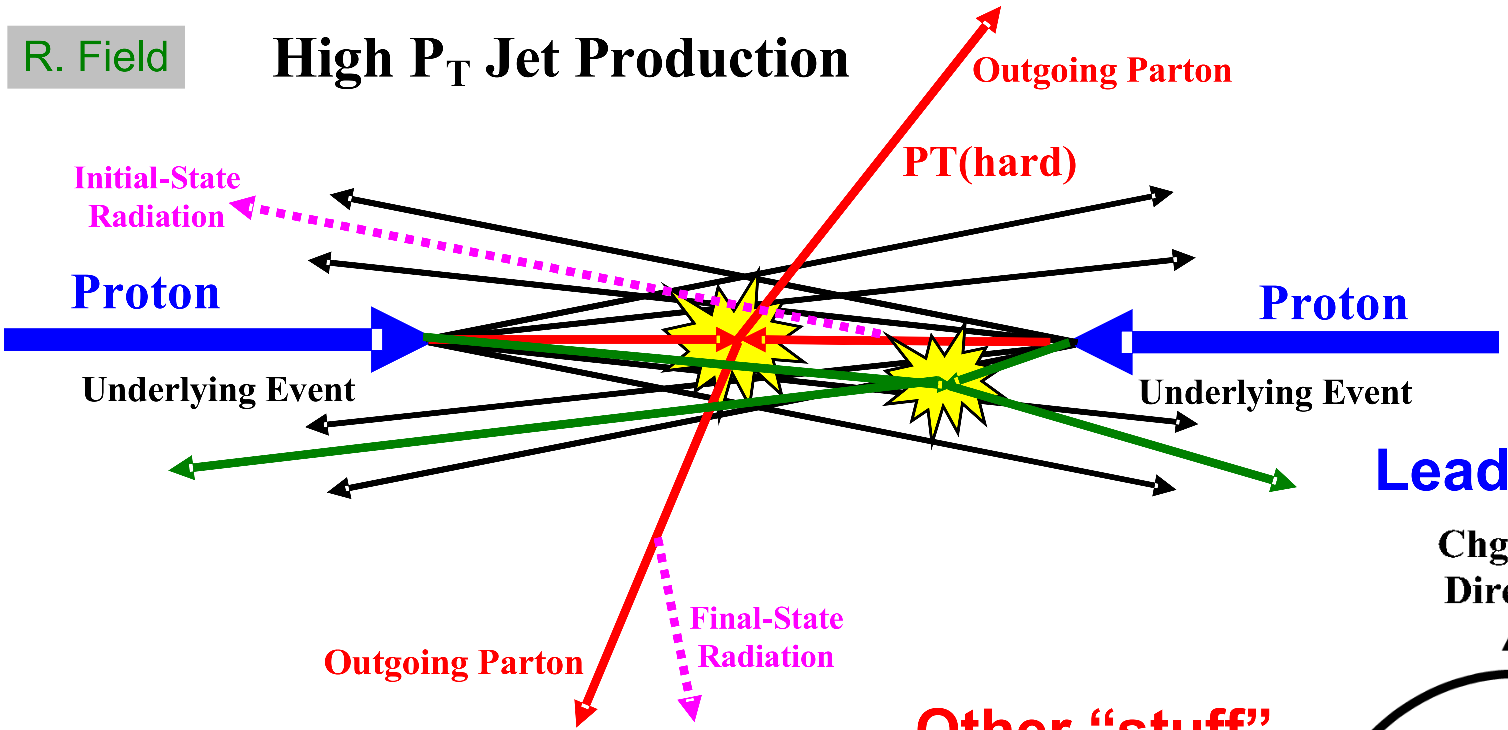
- **Strategy (used by Phobos at RHIC):**
  - **No tracking**, just hit counting in the pixel lay
  - Cluster size to estimate z vertex
  - Systematic uncertainty expected below 10%

CMS PAS QCD-07-001

The Underlying Event

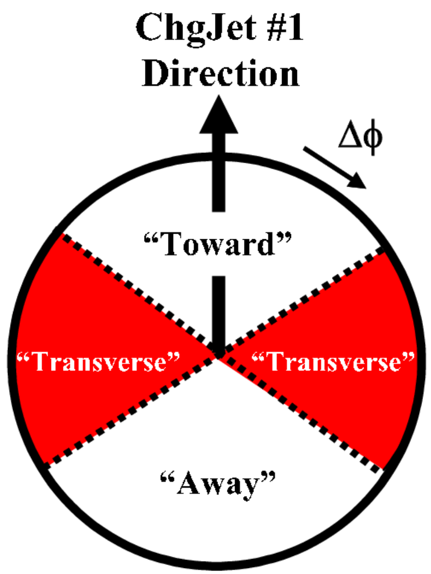
R. Field

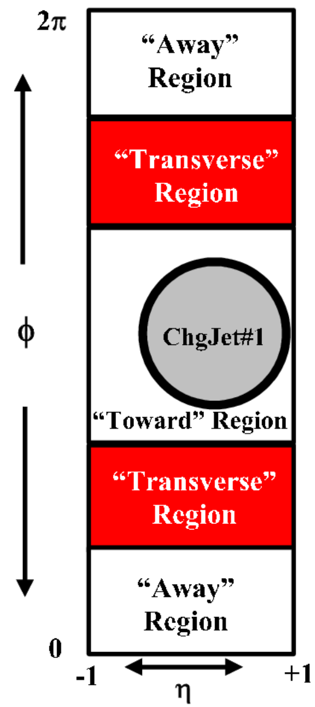
High P_T Jet Production



The Underlying Event is everything but the hard scatter.

Leading jet





Balancing jet

Other "stuff" but the hard scatter

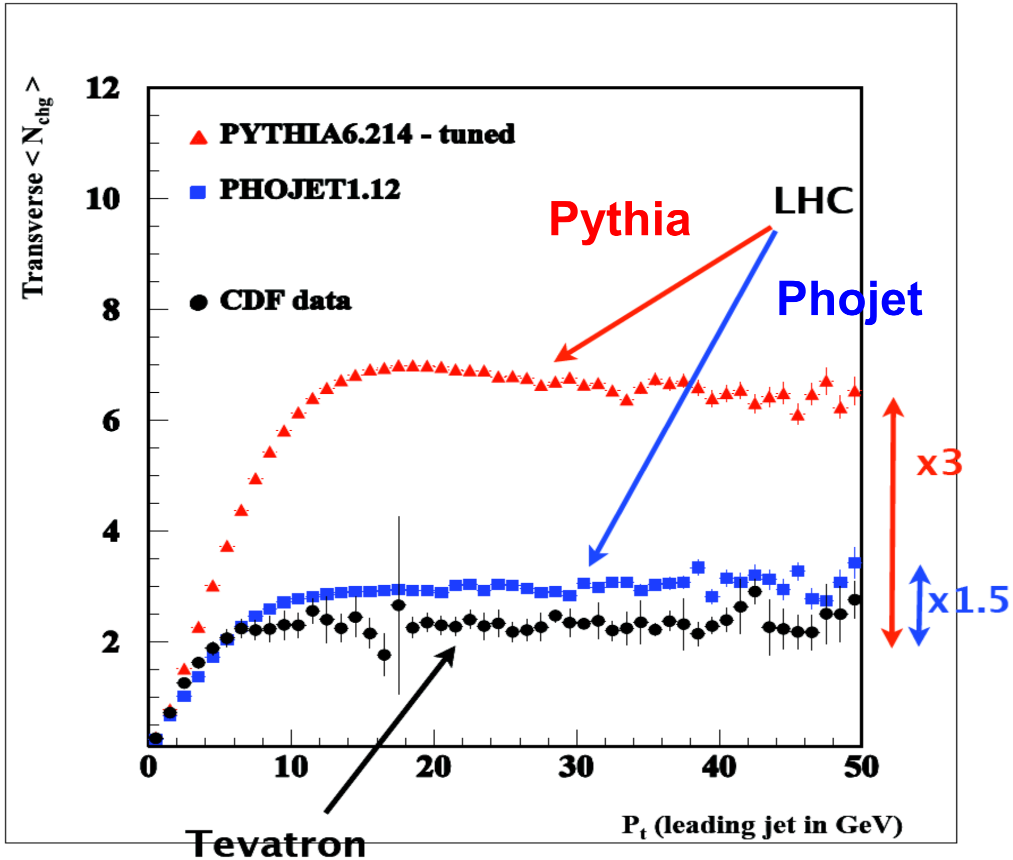
Measurement possibility:

- Charged particle and p_T sum densities in transverse region of leading jet of charged particles

The Underlying Event

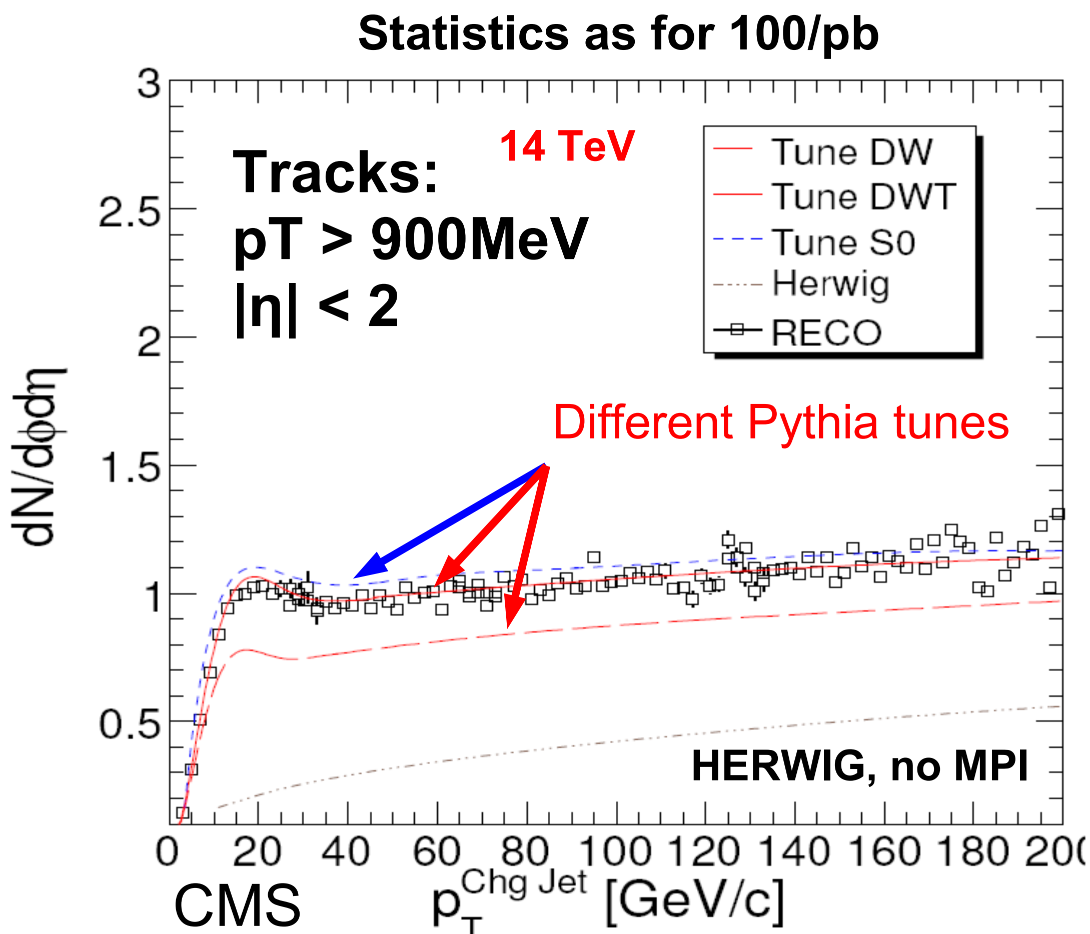
Charged particle density in transverse plane vs. leading charged jet p_T

Extrapolation to LHC from CDF data



ATLAS

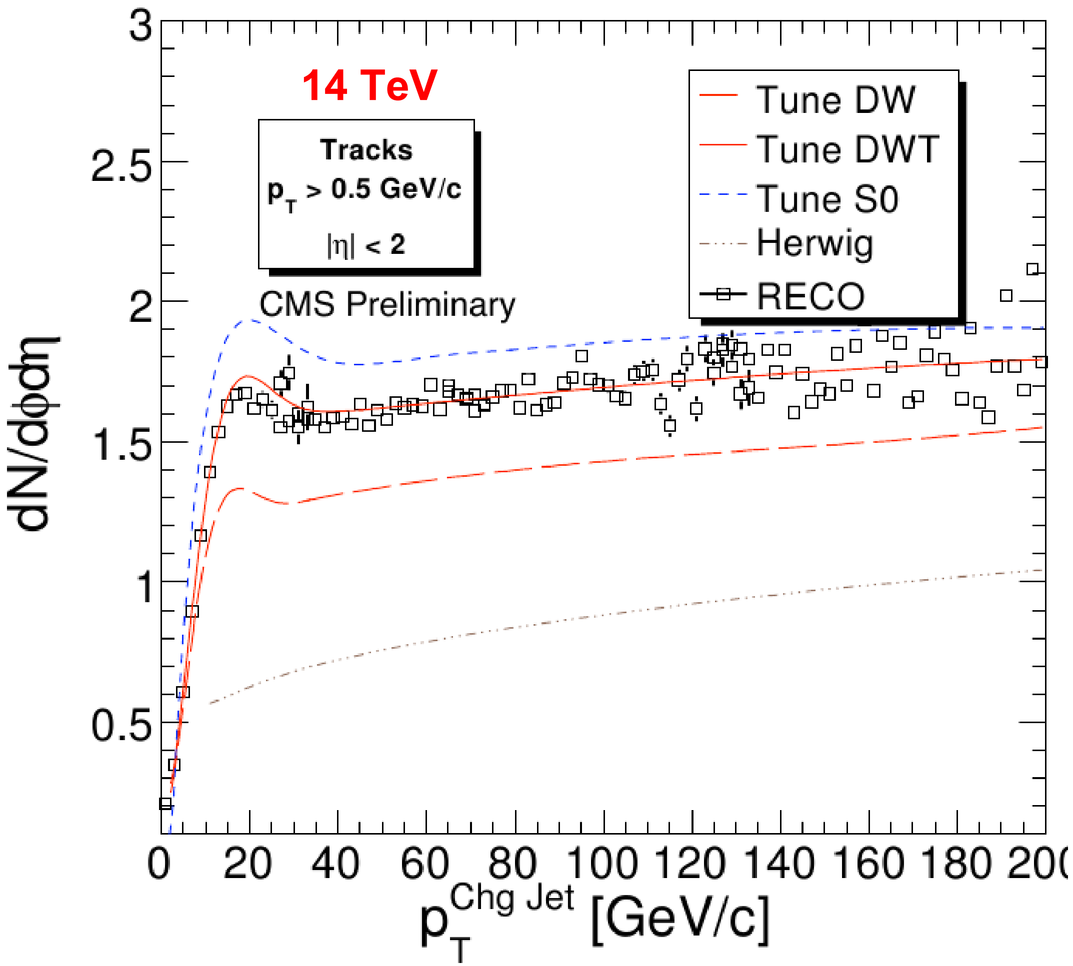
Comparison of different Pythia tunes



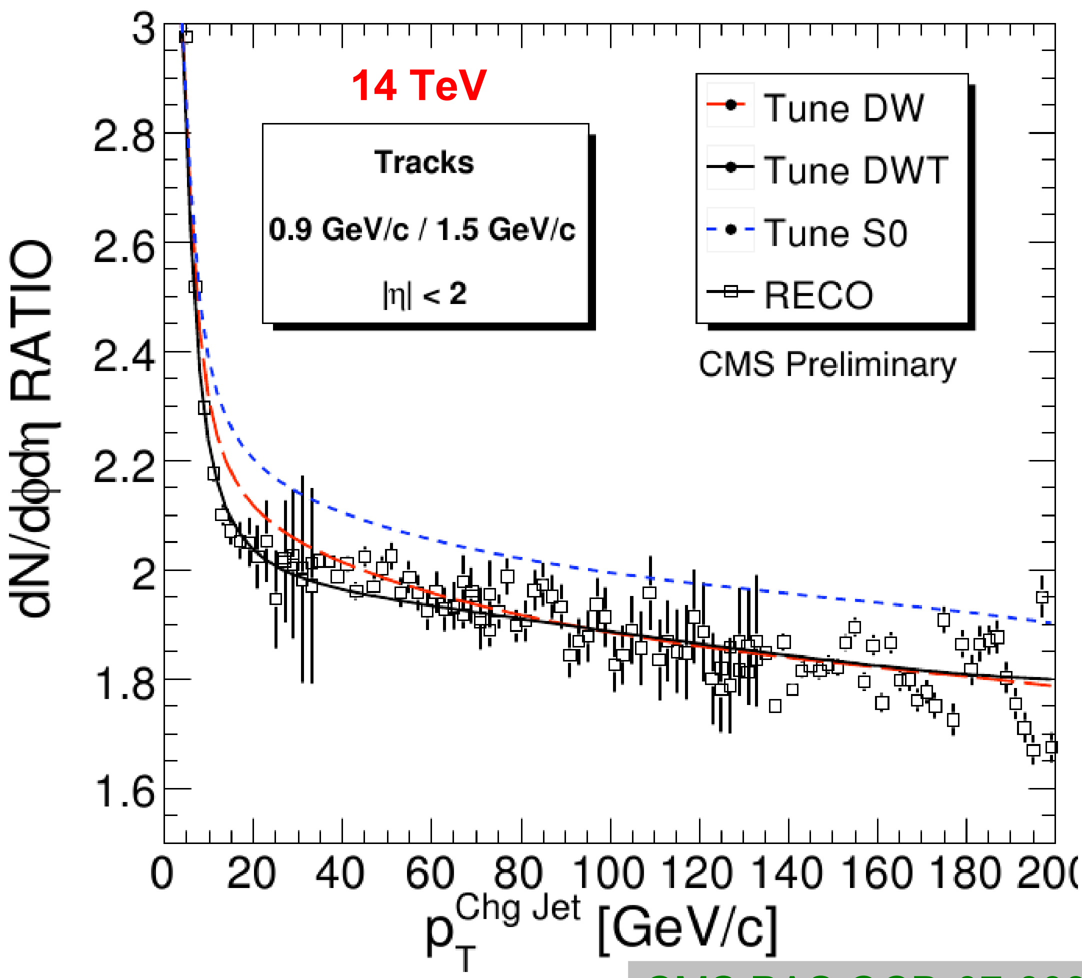
CMS PAS QCD-07-003

The Underlying Event

Increase sensitivity with tracks from p_T > 0.5 GeV instead of > 0.9 GeV



Decrease systematic effects with ratio, but with similar systematic → 0.9 / 1.5

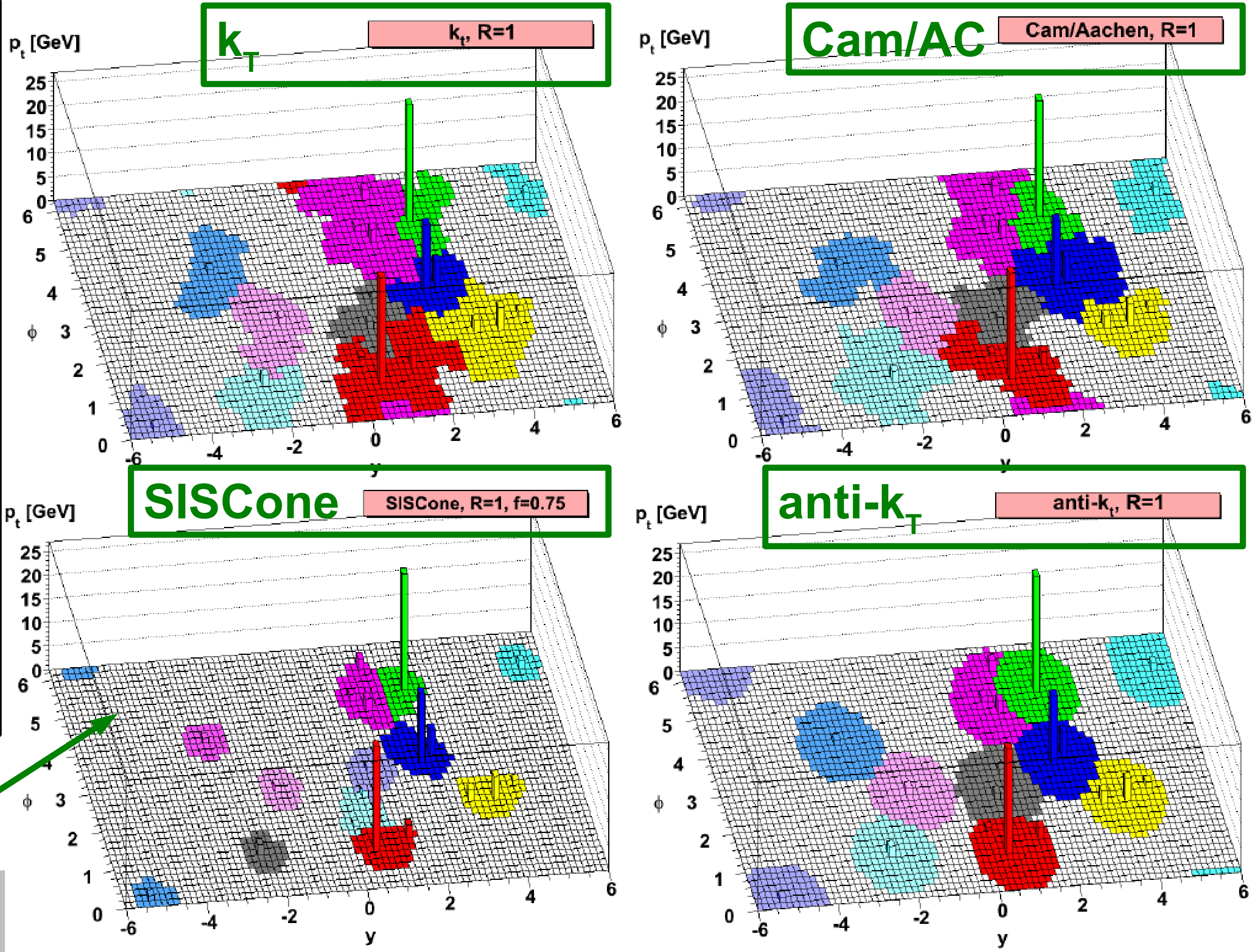


CMS PAS QCD-07-003

Jet Algorithms at LHC

In use lately:

- ICone-PR: R = 0.5 (CL unsafe, CMS)
- ICone-SM: R = 0.4, 0.7 (IR unsafe, ATLAS)
- k_T: R = 0.4, 0.6 (ATLAS & CMS)
- SISCone: R = 0.5, 0.7 (CMS)
- Anti-k_T: R = 0.5, ? (recently adopted by both, ATLAS & CMS)
- Cambridge/Aachen used in jet substructure, for example in boosted top



General interest to work with all these 4

Fast kT, Cacciari/Salam, PLB641, 2006
SISCone, Salam/Soyez, JHEP05, 2007
anti-kT, Cacciari et al., JHEP04, 2008

Jet Measurements

All jets in the event satisfying the selection criteria

$$\frac{d^2\sigma}{dp_T dy} = \frac{N_{jets}}{\epsilon \cdot L \cdot \Delta p_T \cdot \Delta y} \times C_{unsm}$$

Master Equation

- ➡ Jet Efficiency
- ➡ Event Efficiency

Bins of **corrected** Jet Pt and Jet rapidity

Unsmearing correction (due to the finite detector Pt resolution)

The JES dominates the total uncertainty of the measurement

K. Kousouris

Jet Analysis Uncertainties

- **Theoretical Uncertainties (~ in order of importance):**
  - PDF Uncertainty
  - pQCD (Scale) Uncertainty
  - Non-perturbative Corrections
  - PDF Parameterization
  - Electroweak Corrections
  - Knowledge of $\alpha_s(M_Z)$
  - • • •

- **Experimental Uncertainties (~ in order of importance):**
  - Jet Energy Scale (JES)
    - Noise Treatment
    - Pile-Up Treatment
  - Luminosity
  - Jet Energy Resolution (JER)
  - Trigger Efficiencies
  - Resolution in Rapidity
  - Resolution in Azimuth
  - Non-Collision Background
  - • • •

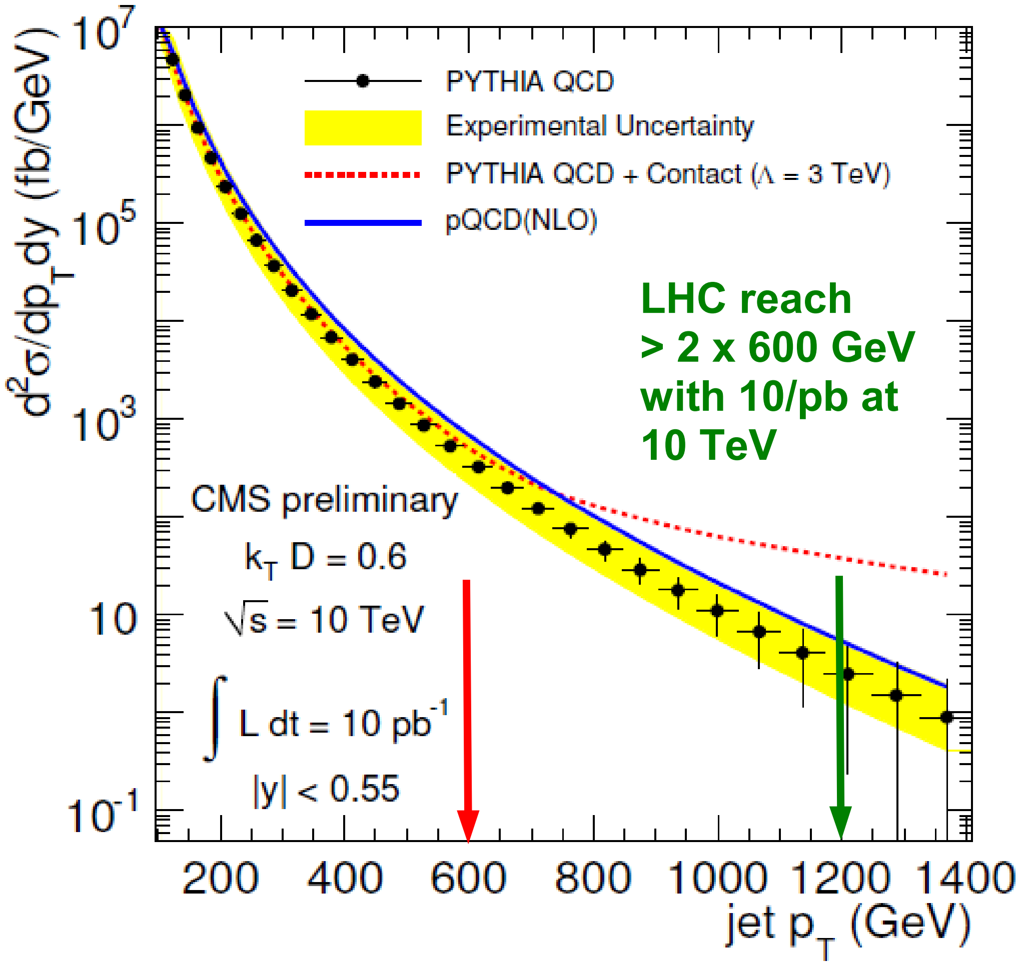
Jet Analysis Examples

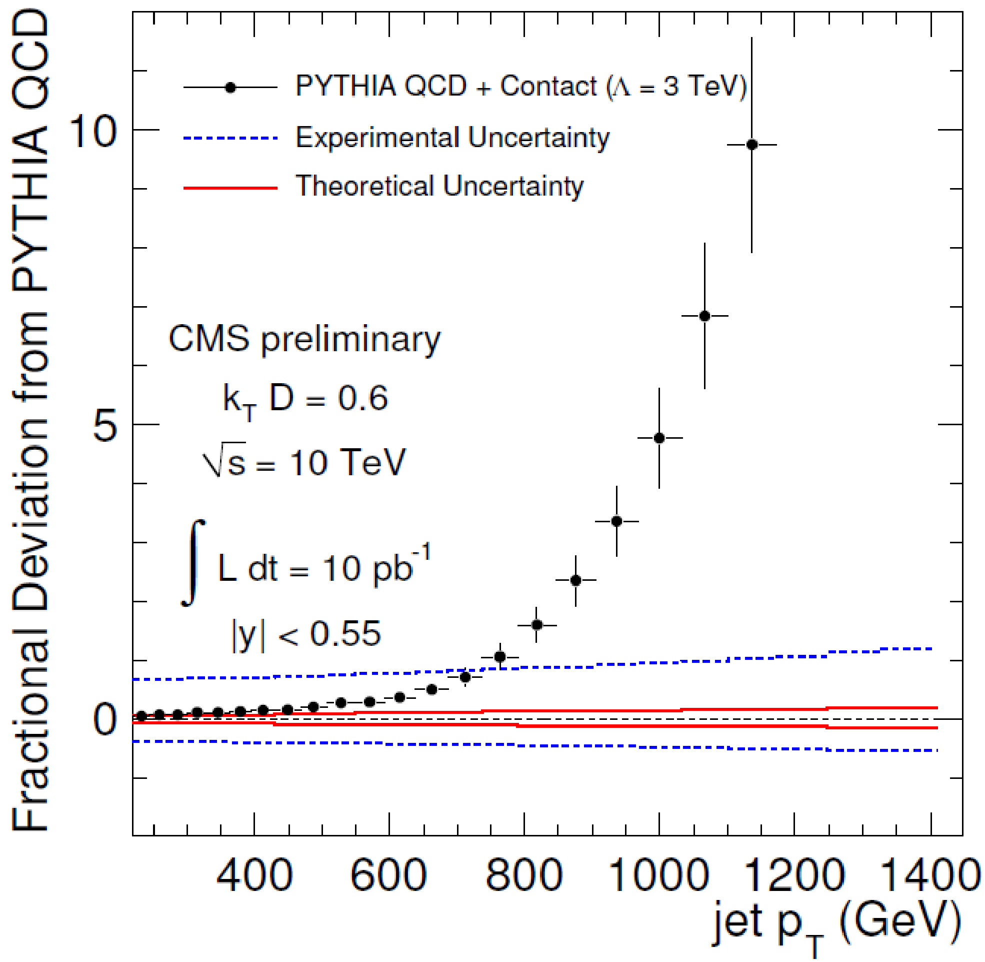
- Important especially at start-up:
  - Underlying Event
- Examples for jet analyses at high transverse momenta:
  - Inclusive jet p_T or dijet mass cross sections
    - Most complicated, require all uncertainties to be under control!
  - Incl. jet or 3-jet cross section ratios, dijet mass cross section ratios in rapidity
    - Reduced sensitivity to JES, not dependent on luminosity
  - Dijet azimuthal decorrelation, normalized dijet $\chi = \exp(|y_1-y_2|)$ distr.
    - Less sensitive to JES, not dependent on luminosity
  - Event shapes
  - Jet shapes

Inclusive Jets at the LHC

k_T, D=0.6, 10 TeV

Comparison with Contact Interactions





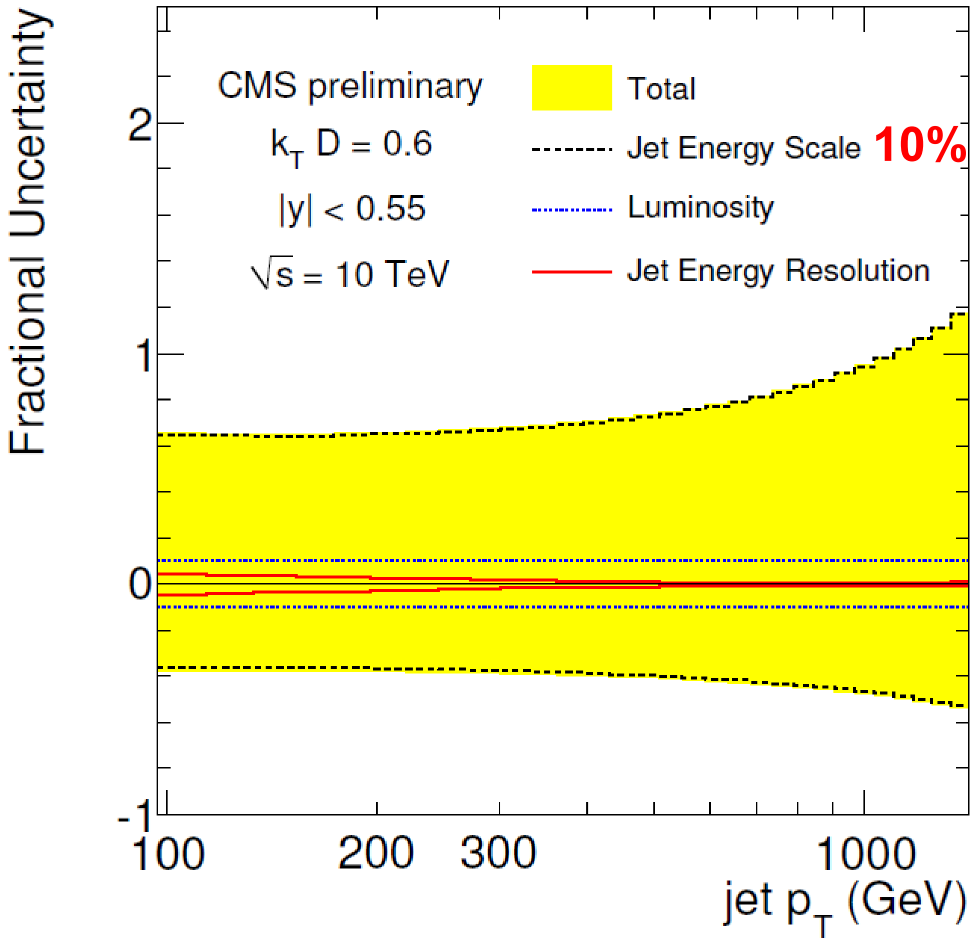
Tevatron limit ~600 GeV

CMS PAS QCD-08-001

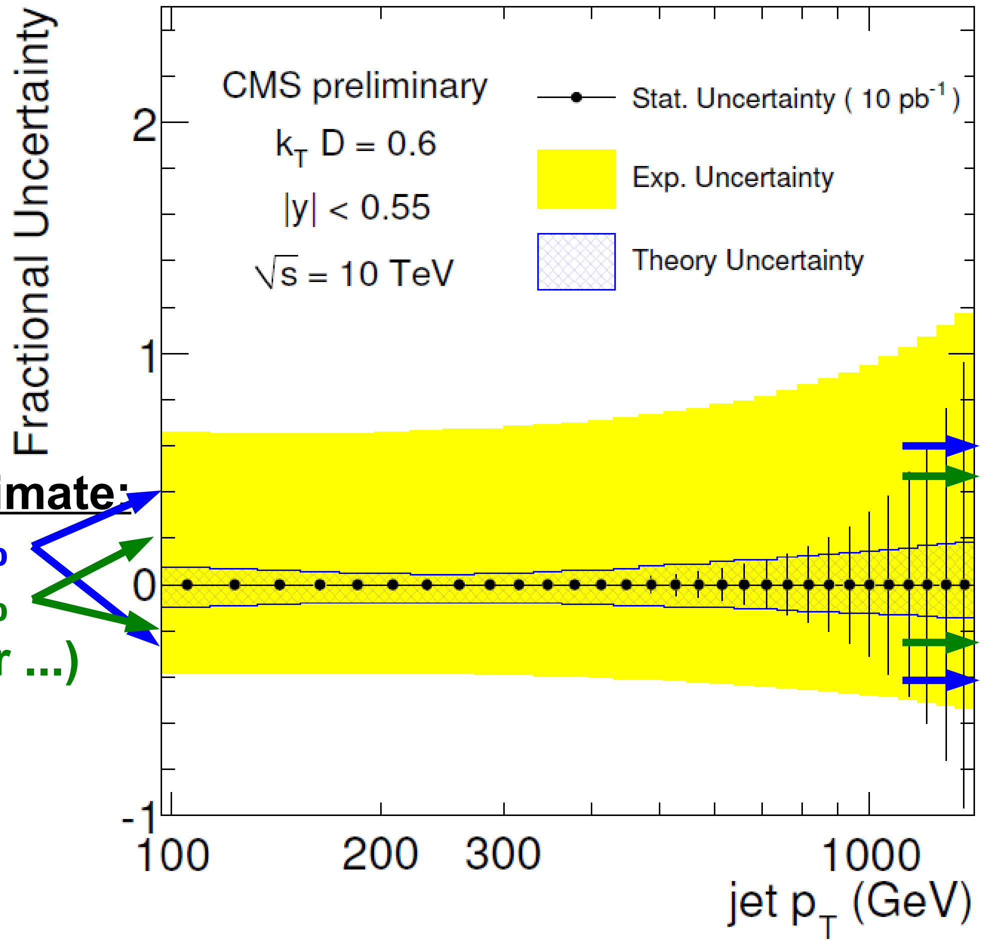
Uncertainties at Start-up

k_T, D=0.6, 10 TeV

Experimental Uncertainties



Comparison Exp. - Theory



Rough estimate:
JES 6%
JES 3%
(years later ...)

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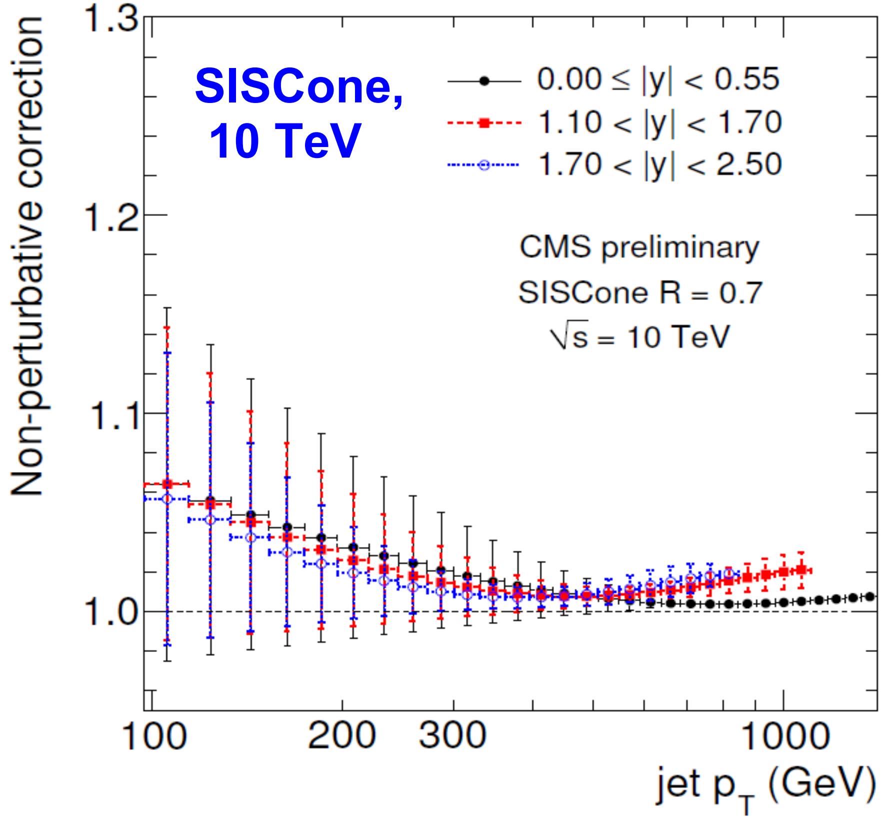
Non-perturbative Corrections

To compare with data correct NLO for:

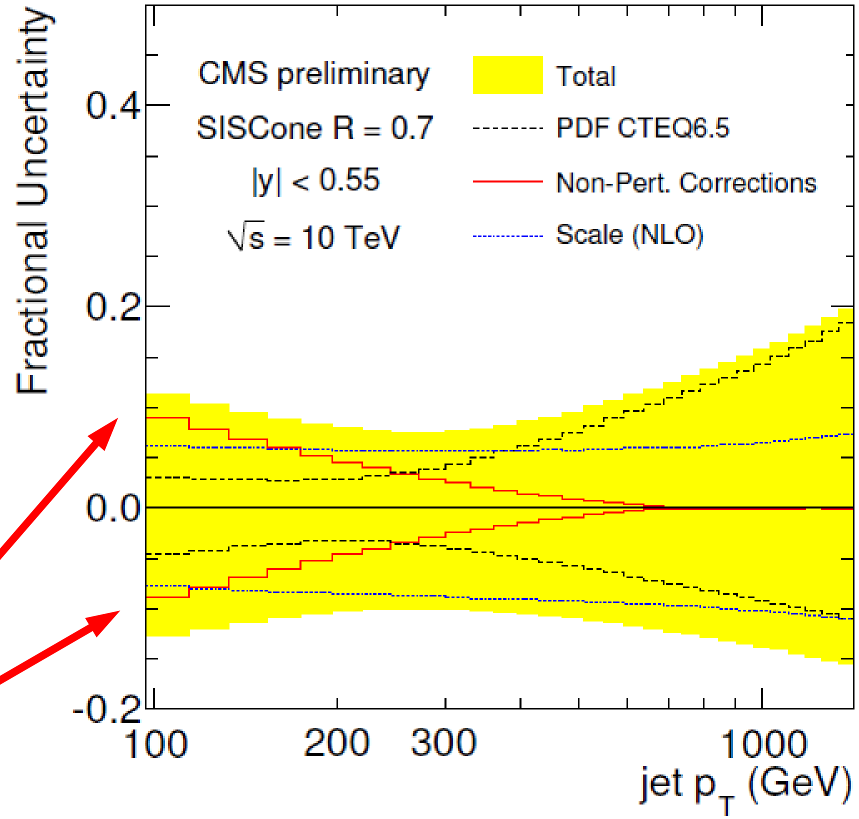
- **Multiple Parton Interactions (MPI)**
- **Hadronization & Decays (Lund, Cluster)**



Compared different tuned MC:

- **Pythia Tune D6T**
- **Herwig++**

Theoretical Uncertainties



Take correction as average and half the spread as uncertainty.

Possible improvements: 1) Better MC Tunes with LHC data!
2) Full NLO event generator for QCD jets

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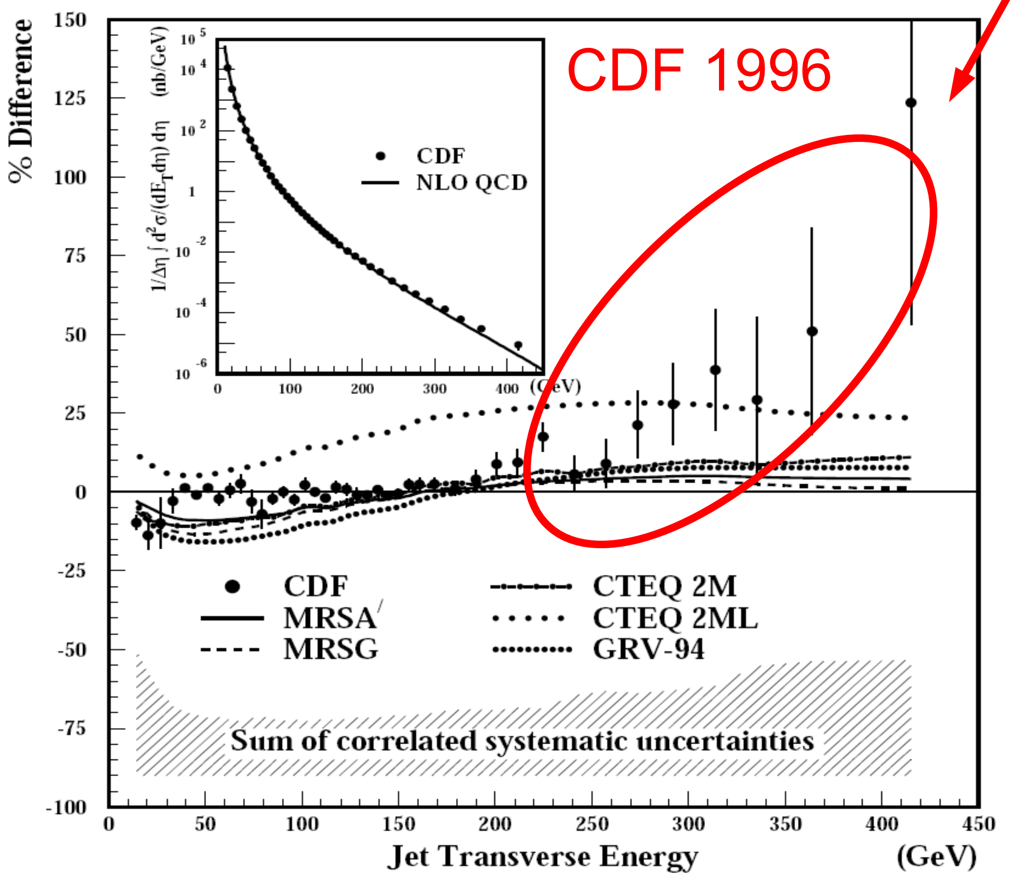
Parton Density Experience

"The data are compared with QCD predictions for various sets of parton distribution functions.
The cross section for jets with E_T>200 GeV is significantly higher than current predictions based on $O(\alpha_s^3)$ perturbative QCD calculations. ..."

Phys.Rev.Lett. 77 (1996)

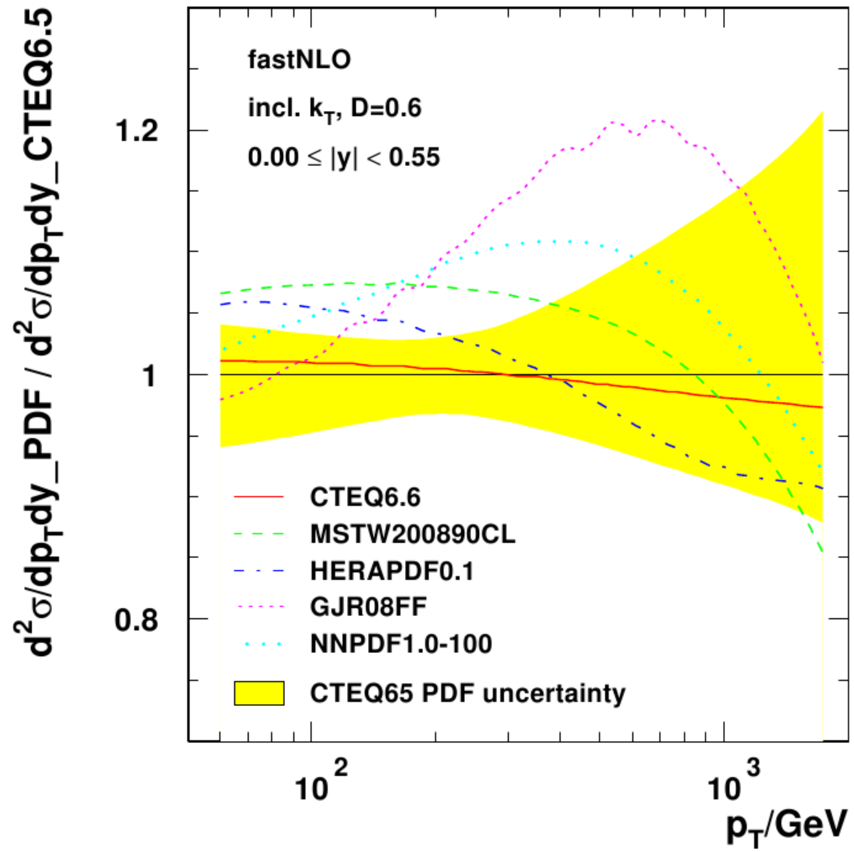


Explained by change in gluon density which then can be constrained by jets!

<u>Today</u>:

Much better estimates of PDF uncertainties

But beware ...



Dijet Azimuthal Decorrelation

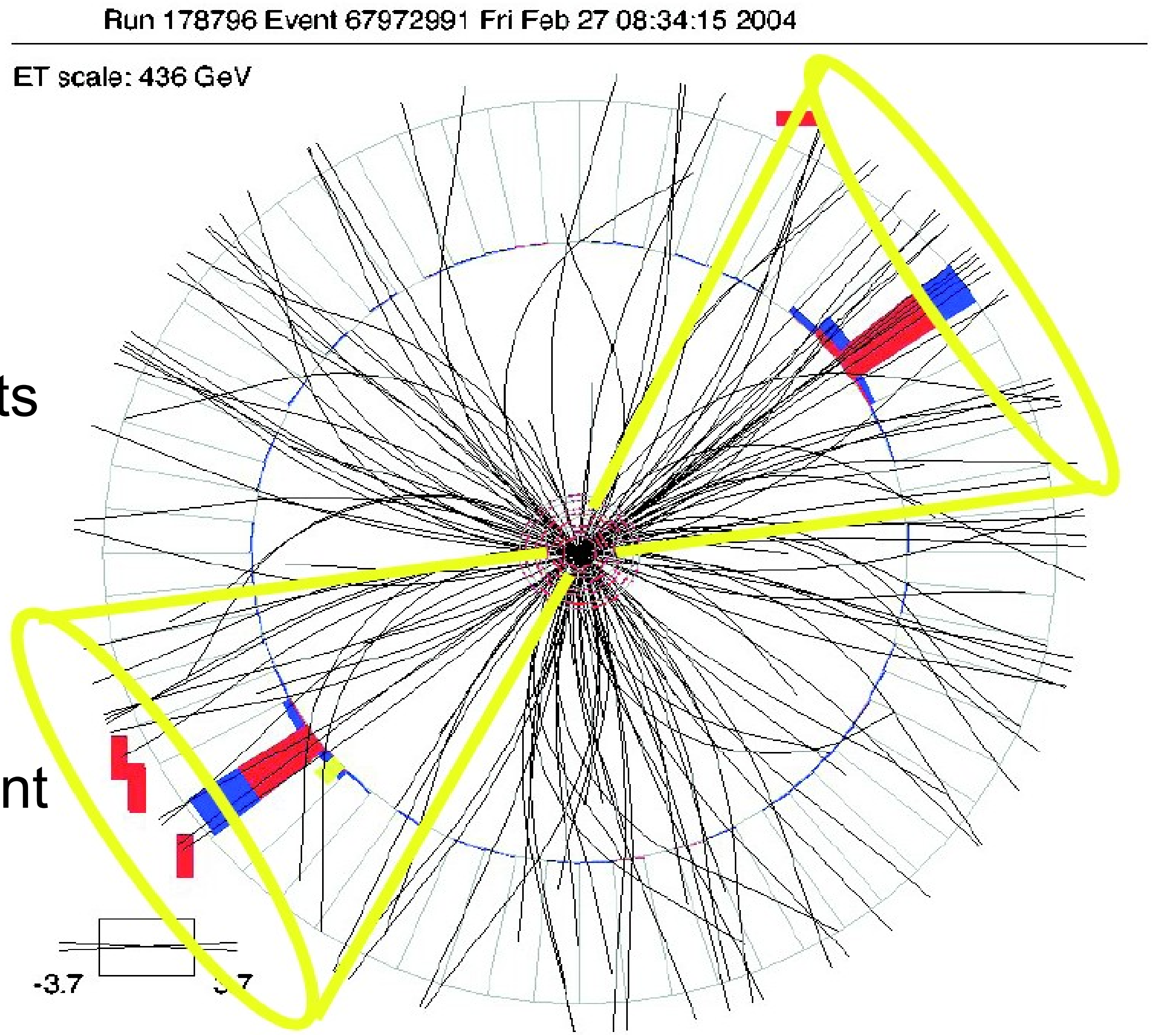
Dijets in pp collisions:

Δφ dijet = π →
Exactly two jets, no further radiation

Δφ dijet small deviations from π →
Additional soft radiation outside the jets

Δφ dijet as small as 2π/3 →
One additional high-pT jet

Δφ dijet small – no limit →
Multiple additional hard jets in the event



hep-ex/0409040
PRL 94, 221801 (2005)

Dijet Azimuthal Decorrelation

Dijets in pp collisions:

Angular measurement →
  Reduced sensitivity to jet energy scale

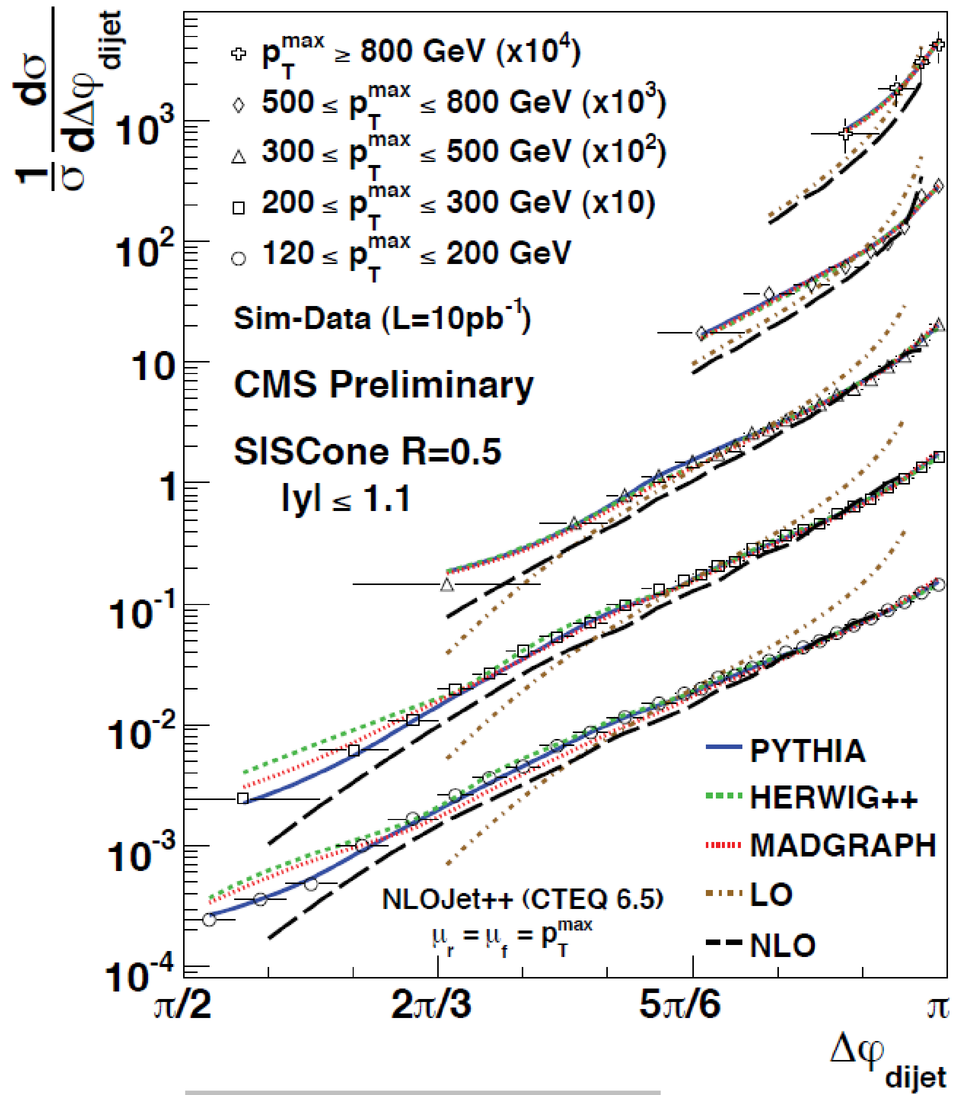
Normalized →
  No dependence on luminosity uncertainty

Also look into:

$$\chi = \exp(|\eta_1 - \eta_2|) = \frac{1+|\cos(\hat{\theta})|}{1-|\cos(\hat{\theta})|}$$

Allows to look for deviations from QCD like scattering due to new physics (extra dimensions, ...)

Evaluation of systematics in progress ...



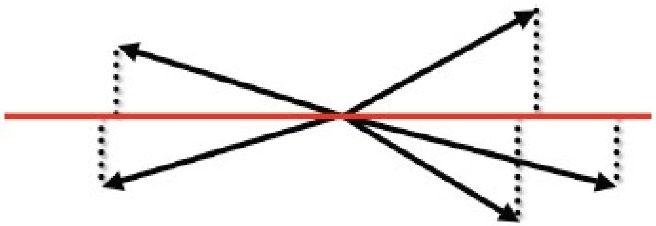
CMS PAS QCD-09-003

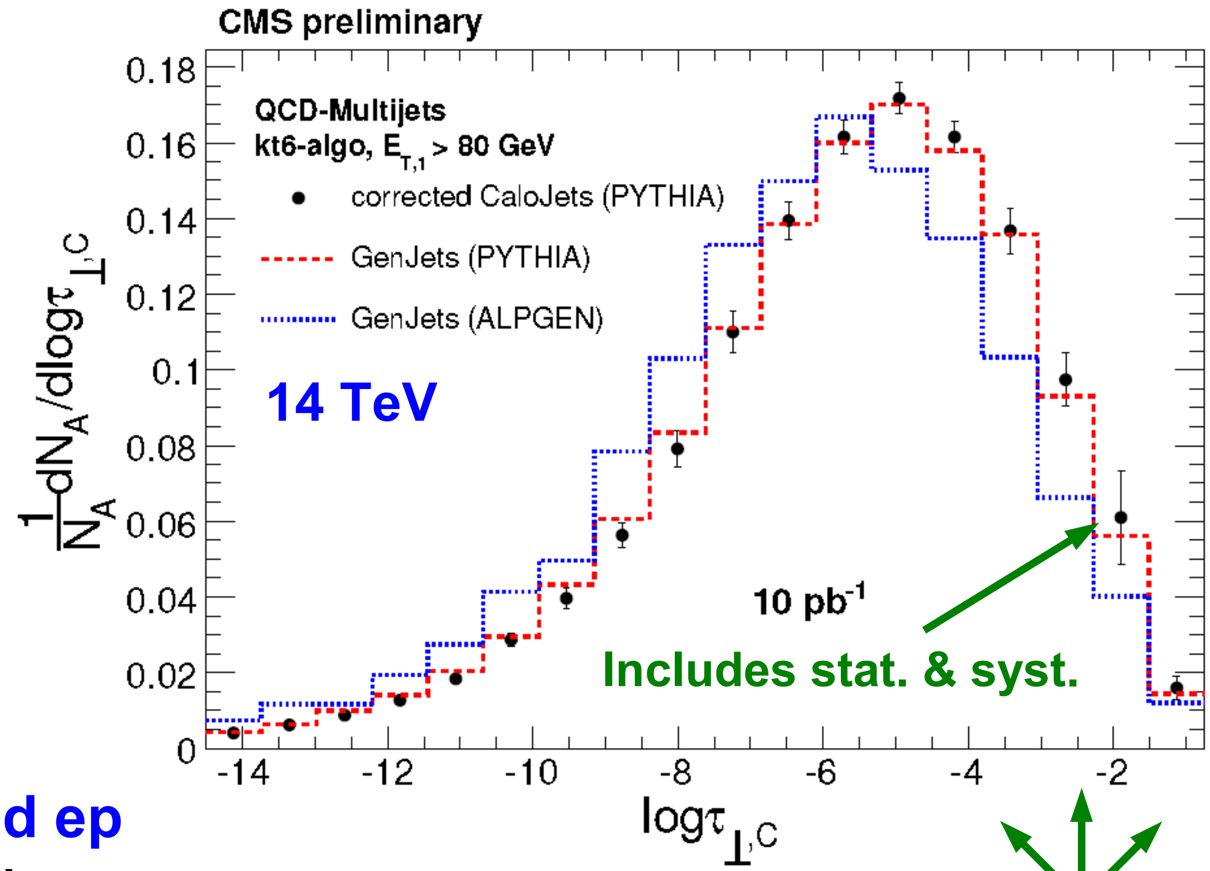
Event Shapes

Definition:

Transverse global Thrust
(k_T jets, $E_{T,1}$ > 80 GeV, $E_{T,all}$ > 60 GeV)

$$T_{\perp,g} \equiv \max_{\vec{n}_T} \frac{\sum_i |\vec{p}_{\perp,i} \cdot \vec{n}_T|}{\sum_i p_{\perp,i}}$$





Similar as Event Shapes in e^+e^- and ep

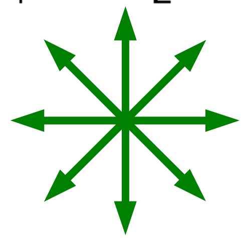
- **In praxis, need to restrict rapidity range:**
|η| < 1.3 → Transverse central Thrust
- **Less sensitive to JES & JER uncertainty**
- **No luminosity uncertainty**
- **Useful for MC tuning**

CMS PAS QCD-08-003

linear

linear

$$\tau_{\perp,g} \equiv 1 - T_{\perp,g}$$



spherical

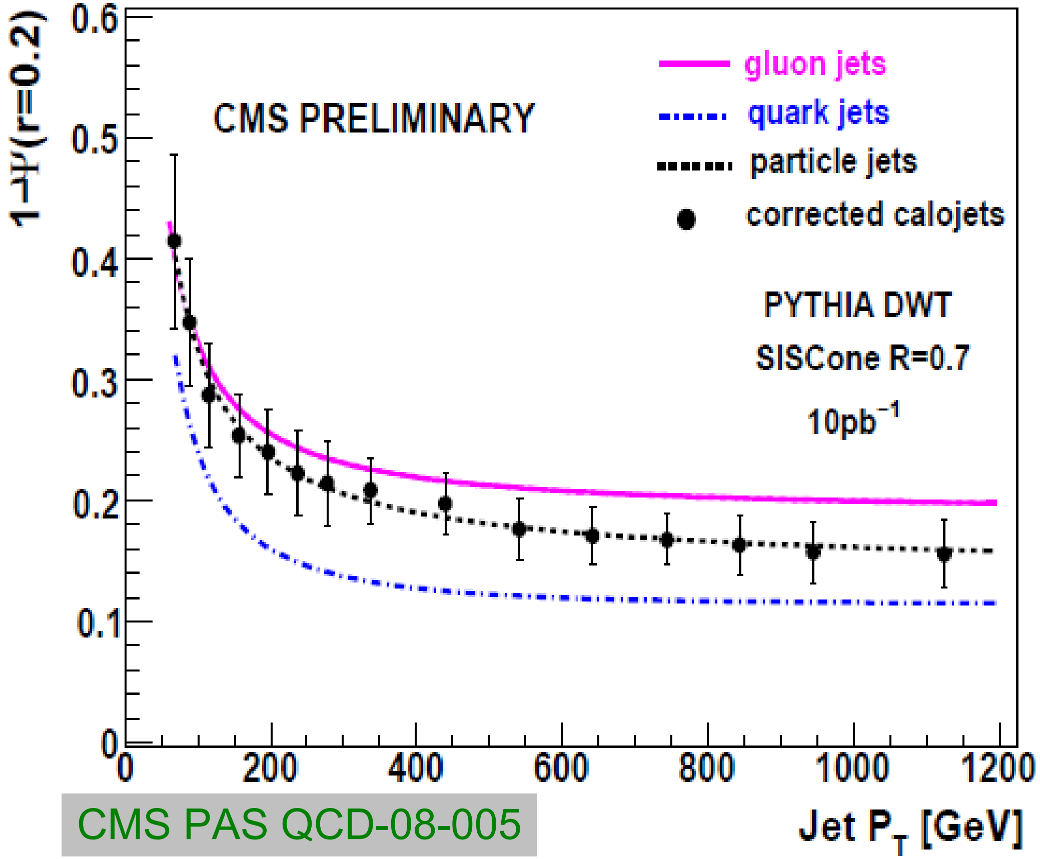
Jet Substructure

CDF like: Integrated jet shape

New: 2nd radial moment of jet profile

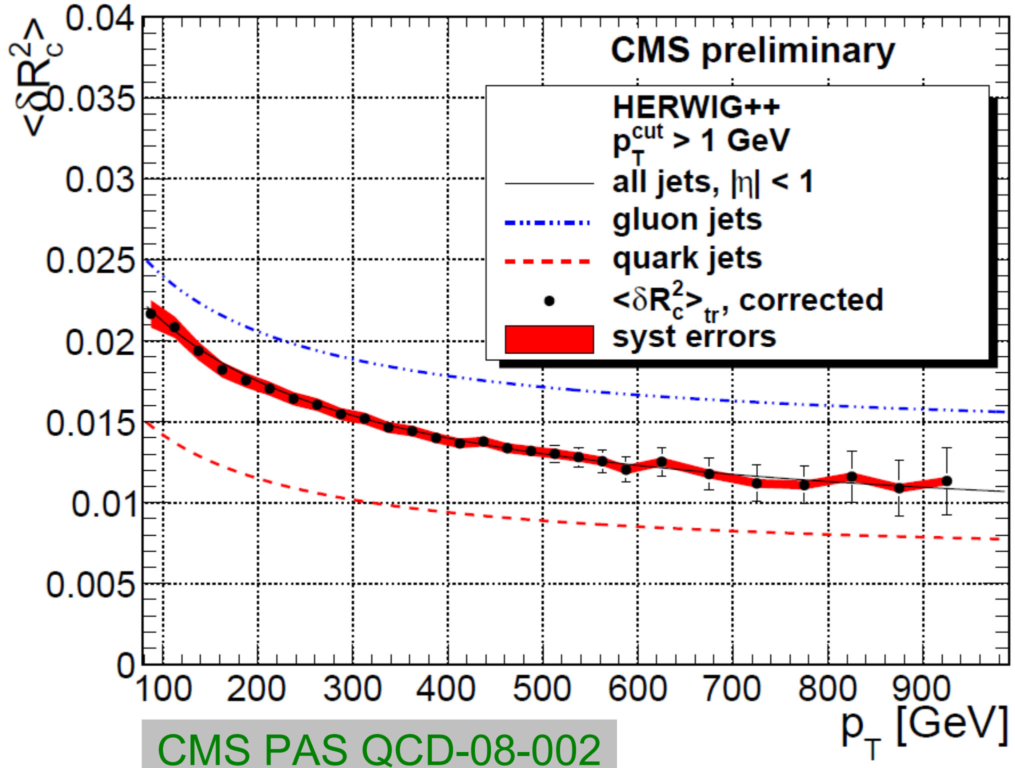
$$\left\langle \delta R^2_{jet} \right\rangle (p_T) = \frac{\sum_{i \in jet} \Delta R^2(i, jet) \cdot p^i_T}{\sum_{i \in jet} p^i_T}$$

Calorimeter jets, √s = 14 TeV



CMS PAS QCD-08-005

Track jets, √s = 10 TeV



CMS PAS QCD-08-002

W/Z Measurements

Signal

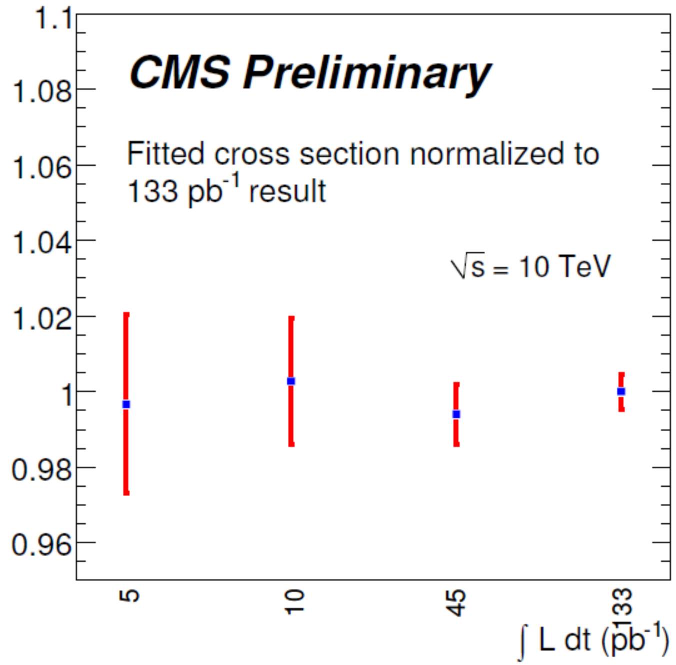
Background

$$\sigma = \frac{N - B}{\mathcal{L}\, A\, \varepsilon}$$

Luminosity

Efficiency

Acceptance



- **Uncertainties:**
  - **ΔN: Purely statistics; improves with integrated luminosity**

CMS PAS EWK-09-001

  - **ΔB, ΔA, Δε: Exp. & theor.; improves over time with better understanding**
    - **Background, acceptance & efficiency estimations, i.a. using MC detector simulations**
  - **ΔL: Luminosity uncertainty; improves with better understanding of LHC beam parameters and luminosity monitors**

W/Z Event Selections

ATLAS

Electron channels:

$W \to e\nu$: $E_{T,e} > 25$ GeV
$|\eta_e| < 2.4$
MET > 25 GeV
$M_T > 40$ GeV
Veto 2nd e from Z

$Z \to ee$: $E_{T,e} > 15$ GeV
$|\eta_e| < 2.4$

Muon channels:

$W \to \mu\nu$: $p_{T,\mu} > 25$ GeV
$|\eta_\mu| < 2.5$
MET > 25 GeV
$M_T > 40$ GeV
Veto 2nd μ from Z

$Z \to \mu\mu$: $p_{T,\mu} > 15$ GeV
$|\eta_\mu| < 2.5$
$|M_{\mu\mu} - M_Z| < 20$ GeV

CMS

Electron channels:

$W \to e\nu$: $E_{T,e} > 30$ GeV
$|\eta_e| < 2.5$
MET > 30 GeV
$M_T > 40$ GeV
Veto 2nd e from Z

$Z \to ee$: $E_{T,e} > 20$ GeV
$|\eta_e| < 2.5$

Muon channels:

$W \to \mu\nu$: $p_{T,\mu} > 25$ GeV
$|\eta_\mu| < 2.0$
$M_T > 50$ GeV
Veto 2nd μ from Z

$Z \to \mu\mu$: $p_{T,\mu} > 20$ GeV
$|\eta_\mu| < 2.0$
$60 < M_{\mu\mu} < 120$ GeV

Lepton isolation: Radii in (η,Φ) of 0.3 to 0.5 are imposed
Lepton ID: Criteria might be looser for μ compared to e and for $Z \to ll$ compared to $W \to l\nu$
Lepton Pairs: Opposite charges required

Inclusive W/Z Measurements

E_{cms} = 14 TeV — ATLAS, CERN-OPEN-2008-020

$$\sigma = \frac{N - B}{\mathscr{L} A \varepsilon}$$

Without Luminosity uncertainty!

L_{int} = 50/pb — **Signal** — **Background** — **Acc. & Eff.**

Process	$N(\times 10^4)$	$B(\times 10^4)$	$A \times \varepsilon$	$\delta A/A$	$\delta\varepsilon/\varepsilon$	σ (pb)
$W \to e\nu$	22.67 ± 0.04	0.61 ± 0.92	0.215	0.023	0.02	$20520 \pm 40 \pm 1060$
$W \to \mu\nu$	30.04 ± 0.05	2.01 ± 0.12	0.273	0.023	0.02	$20530 \pm 40 \pm 630$
$Z \to ee$	2.71 ± 0.02	0.23 ± 0.04	0.246	0.023	0.03	$2016 \pm 16 \pm 83$
$Z \to \mu\mu$	2.57 ± 0.02	0.010 ± 0.002	0.254	0.023	0.03	$2016 \pm 16 \pm 76$

W: ~5% Precision

Z: ~3% Precision

L_{int} = 1/fb

Process	$N(\times 10^5)$	$B(\times 10^5)$	$A \times \varepsilon$	$\delta A/A$	$\delta\varepsilon/\varepsilon$	σ (pb)
$W \to e\nu$	45.34 ± 0.02	1.22 ± 0.41	0.215	0.023	0.004	$20520 \pm 9 \pm 516$
$W \to \mu\nu$	60.08 ± 0.02	4.02 ± 0.05	0.273	0.023	0.004	$20535 \pm 7 \pm 480$
$Z \to ee$	5.42 ± 0.01	0.46 ± 0.02	0.246	0.023	0.007	$2016 \pm 4 \pm 49$
$Z \to \mu\mu$	5.14 ± 0.01	0.02 ± 0.001	0.254	0.023	0.007	$2016 \pm 4 \pm 49$

W/Z: 1-2%with 1/fb

Example from CMS, 10 TeV, 10/pb:

W→ev: <2% stat., 4%syst.

Z→ee: <2% stat., 2.4% syst.

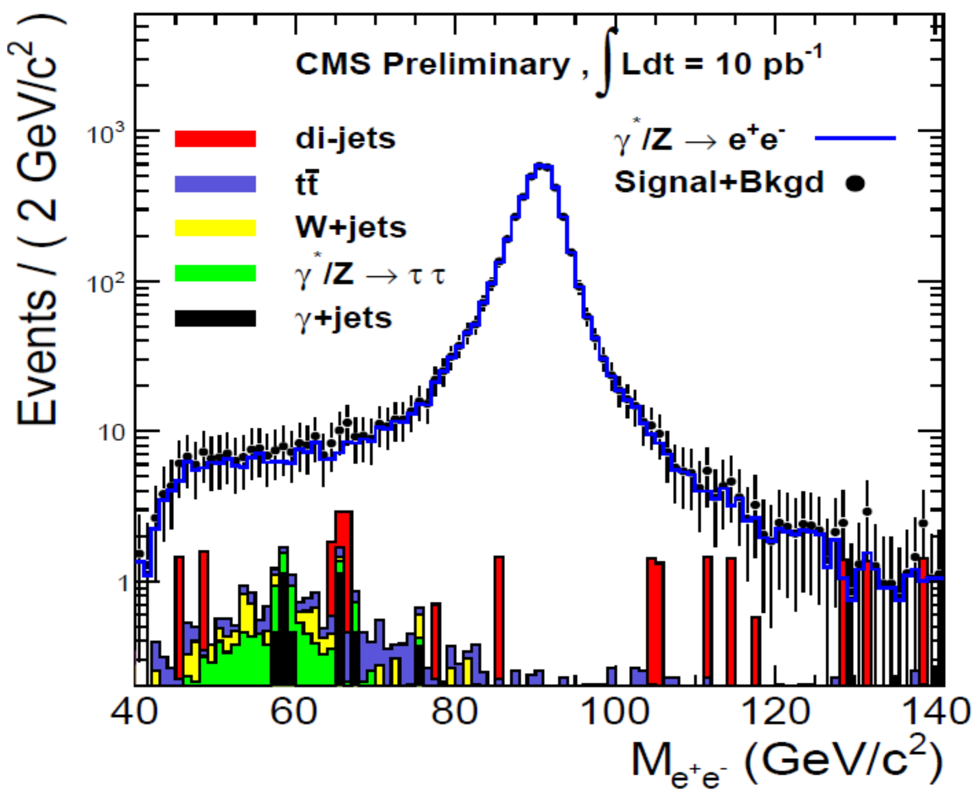
CMS PAS EWK-09-004

Theory: < 1%

W/Z Mass Distributions

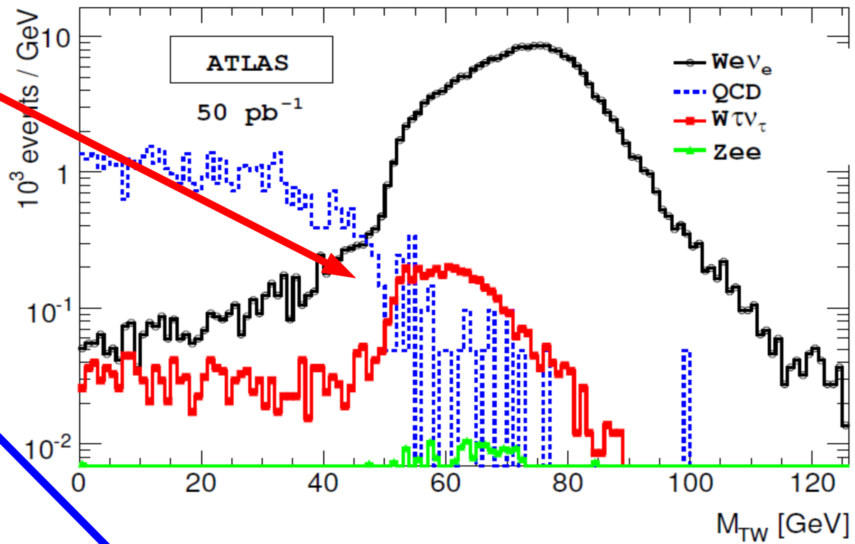
Dominant background to W→eν: W→τν
Dominant background to W→μν: Z→μμ & W→τν
Very clean process: Z→ee

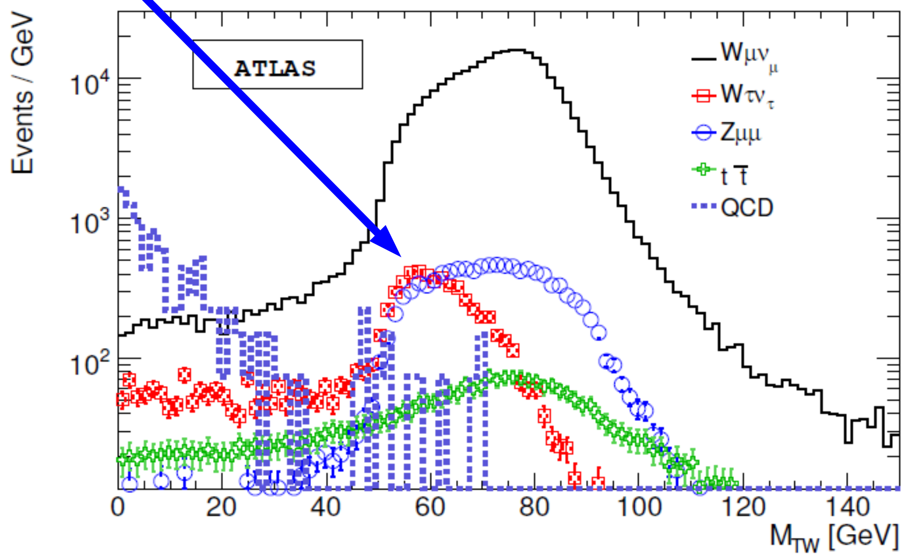
Z→ee mass, 10 TeV, 10/pb



CMS PAS EWK-09-004

W→eν, W→μν transverse mass, 14 TeV, 50/pb

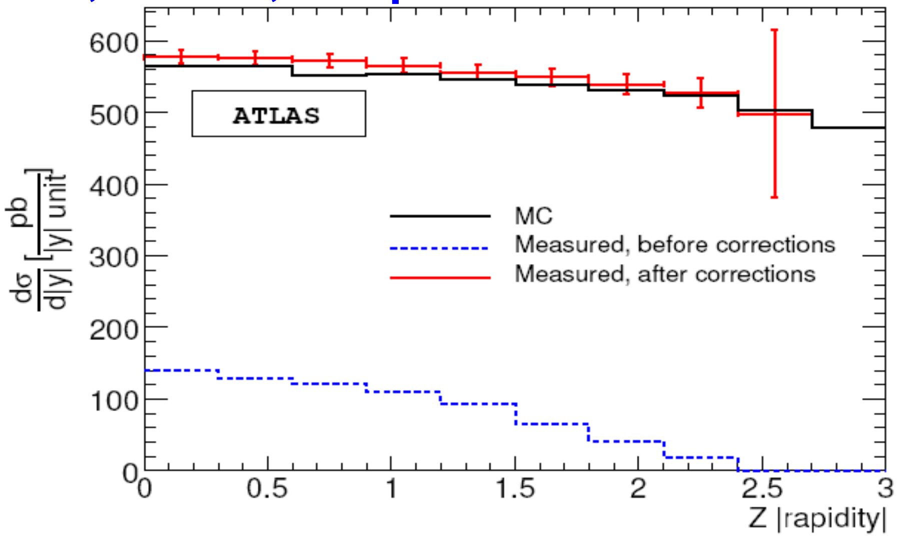


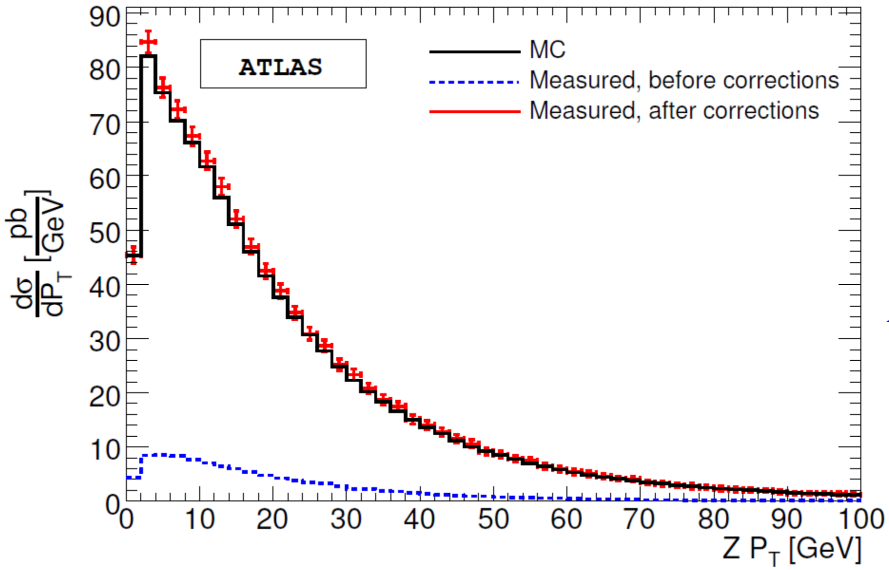


ATLAS, CERN-OPEN-2008-020

Z Differential Distributions

Z→ee, 14 TeV, 200/pb

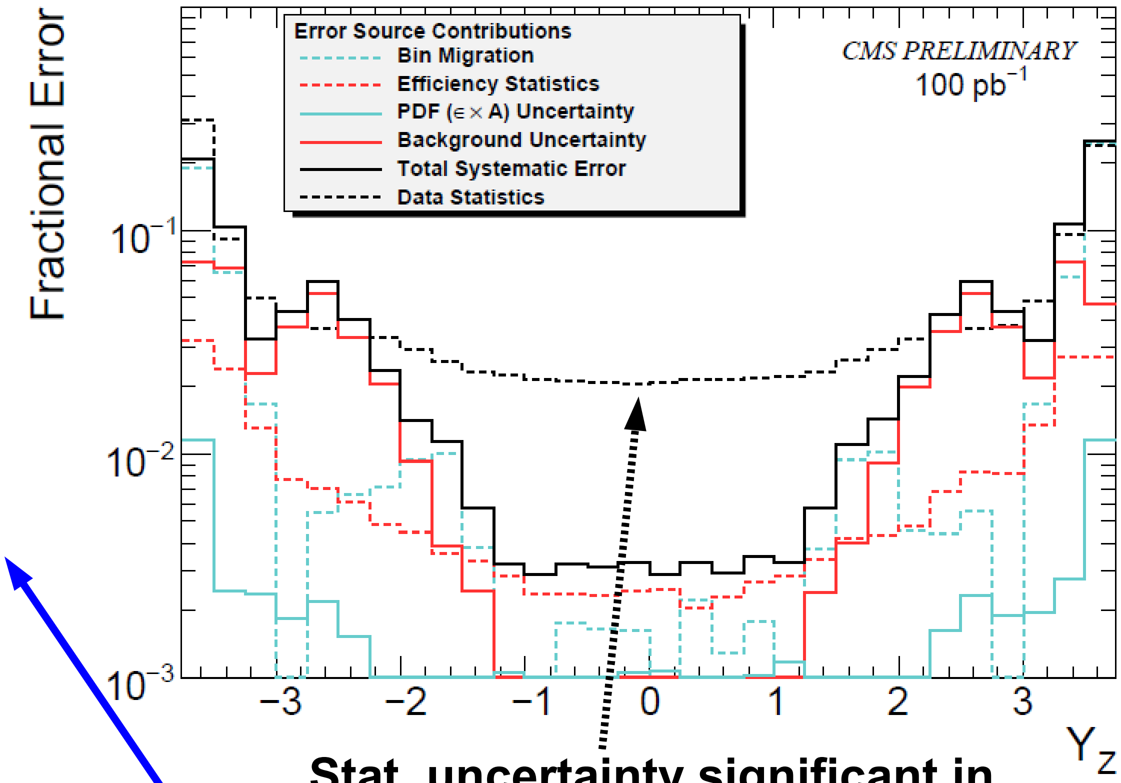




ATLAS, CERN-OPEN-2008-020

Z→ee Channel

Z→ee, 10 TeV, 100/pb



CMS PAS EWK-09-005

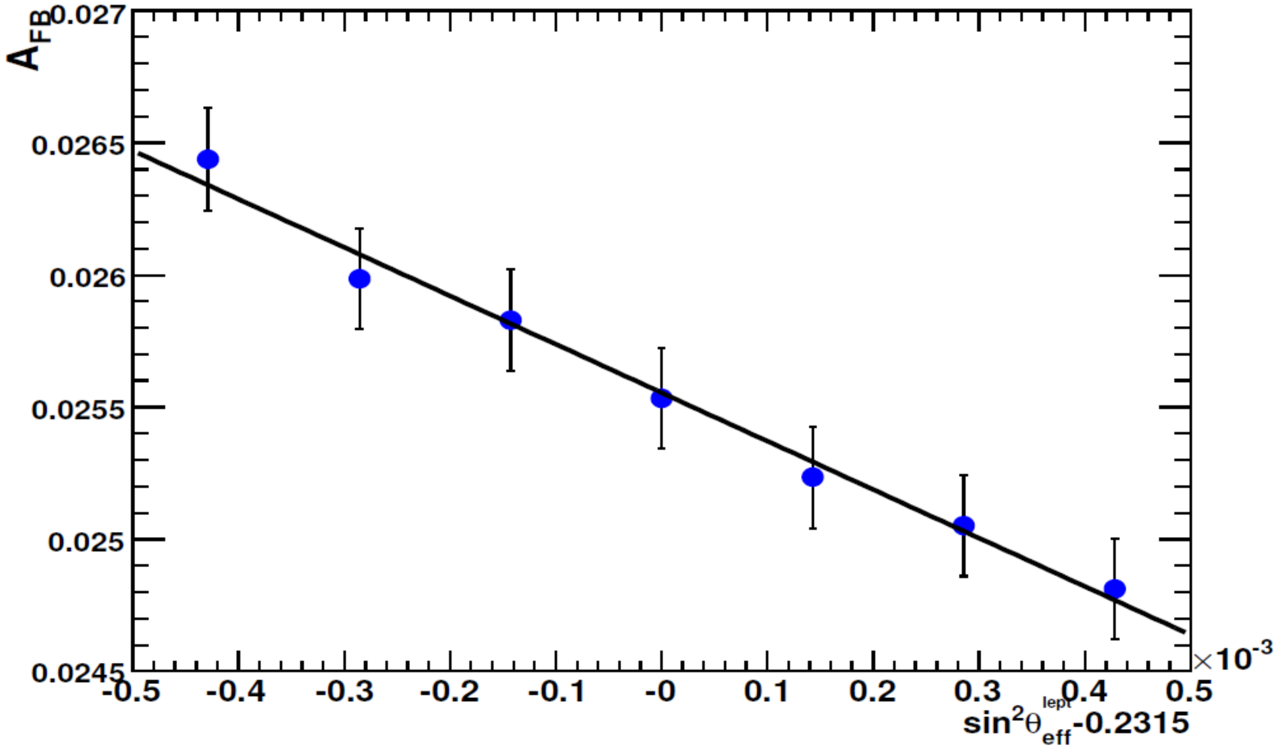
Stat. uncertainty significant in Distributions with only 100/pb @ 10 TeV

Example from ATLAS for Z rap. and p_T distributions;

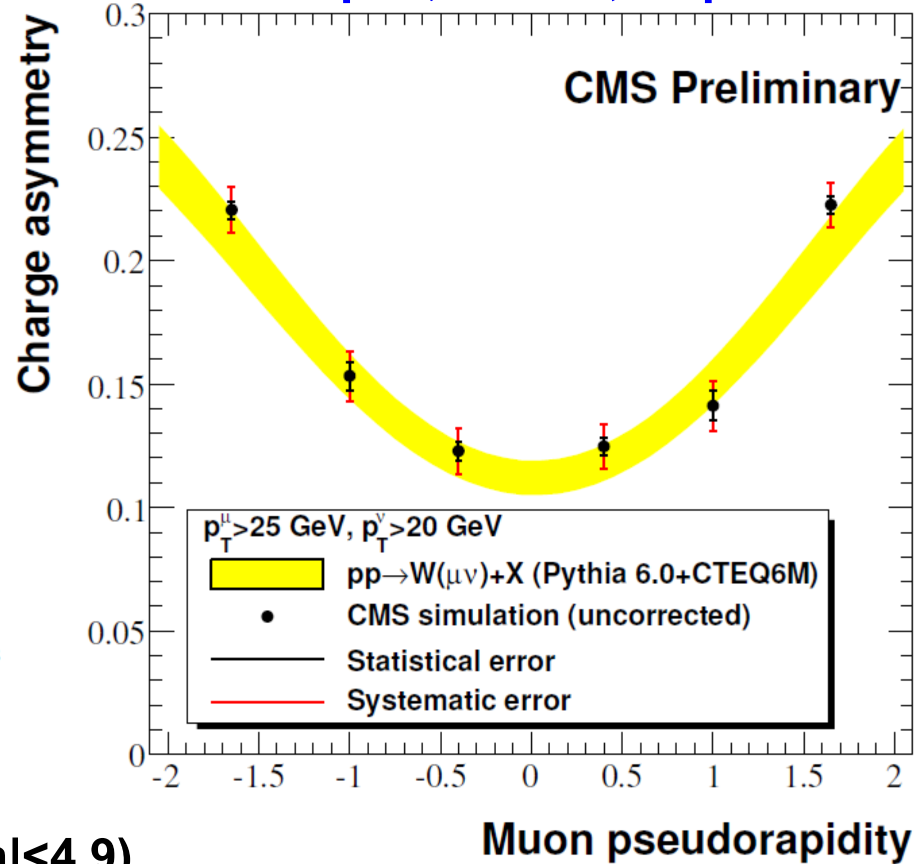
- statistical precision shown
- improve MC tuning & PDF knowledge
- reduce acceptance uncertainties in inclusive W/Z

W/Z Asymmetries

FB-Asymmetry $Z/\gamma^* \rightarrow eeX$, 14 TeV, 100/fb



W Charge Asymmetry
$W \rightarrow \mu\nu X$, 10 TeV, 10/pb



ATLAS projection for the weak mixing angle:

Exploits electron measurement in forward calos ($2.5<|\eta|<4.9$)

Needs 100/fb!

$$\Delta\sin^2\theta_{eff} = (1.5\ (\text{stat.}) \pm 0.3\ (\text{exp.}) \pm 2.4\ (\text{PDF})) \cdot 10^{-4}$$

ATLAS, CERN-OPEN-2008-020

CMS: Can constrain PDFs starting with only 50/pb

CMS PAS EWK-09-003

A Word on the W Mass

ATLAS, CERN-OPEN-2008-020

W→eν, W→μν transverse mass & lepton p_T, 14 TeV, 15/pb

Method	$p_T(e)$ [MeV]	$p_T(\mu)$ [MeV]	$M_T(e)$ [MeV]	$M_T(\mu)$ [MeV]
δm_W (stat)	120	106	61	57
δm_W (α_E)	110	110	110	110
δm_W (σ_E)	5	5	5	5
δm_W (tails)	28	< 28	28	< 28
δm_W (ε)	14	–	14	–
δm_W (recoil)	–	–	200	200
δm_W (bkg)	3	3	3	3
δm_W (exp)	114	114	230	230
δm_W (PDF)	25	25	25	25
Total	167	158	239	238

Start-up scenario!

Current uncertainties on M_W: LEP combined: 30 MeV

Summer2009, see R. Wallny yesterday

PDG Review 2009

Tevatron combined: ~~40 MeV~~ → 31 MeV

World: ~~25 MeV~~ → 23 MeV

Long term: 14 TeV, 10/fb: ΔM_W= O(<10 MeV) per channel & exp. SN-ATLAS-2008-070

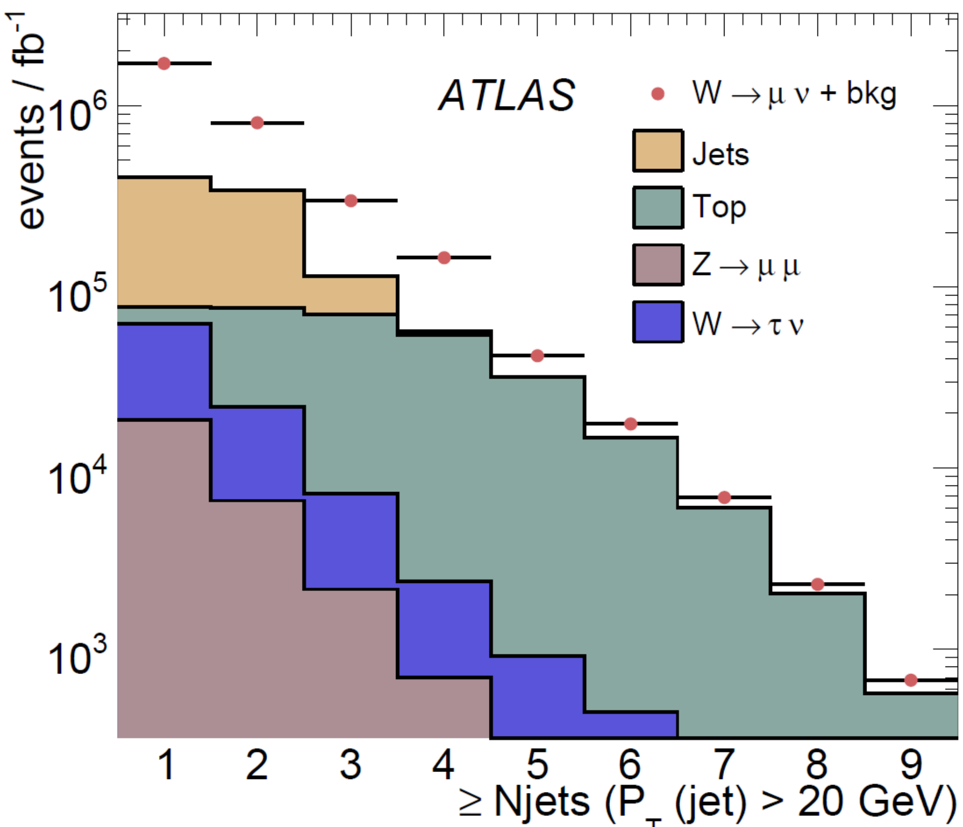
Assumes i.a. radiative corrections to be under control.

See also A. Vicini yesterday

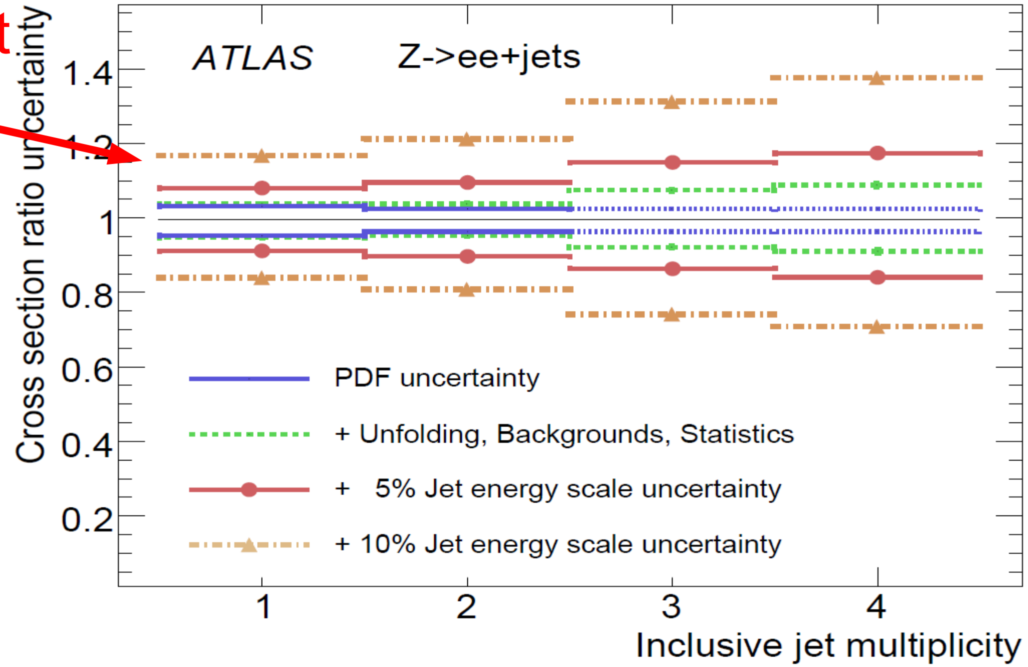
W/Z plus Jets

Uncertainties for Z→ee+jets, JES dominant

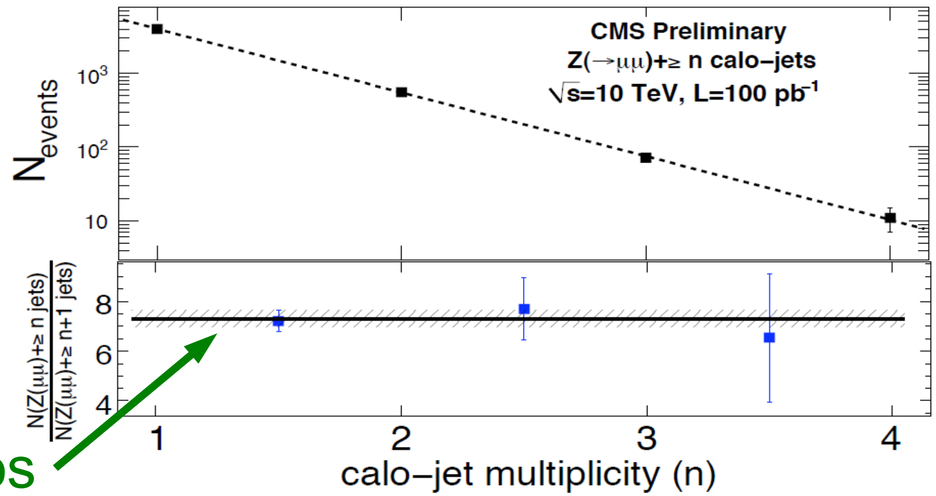
W→μν + Njets distribution, 14 TeV



ATLAS public results page



ATLAS public results page

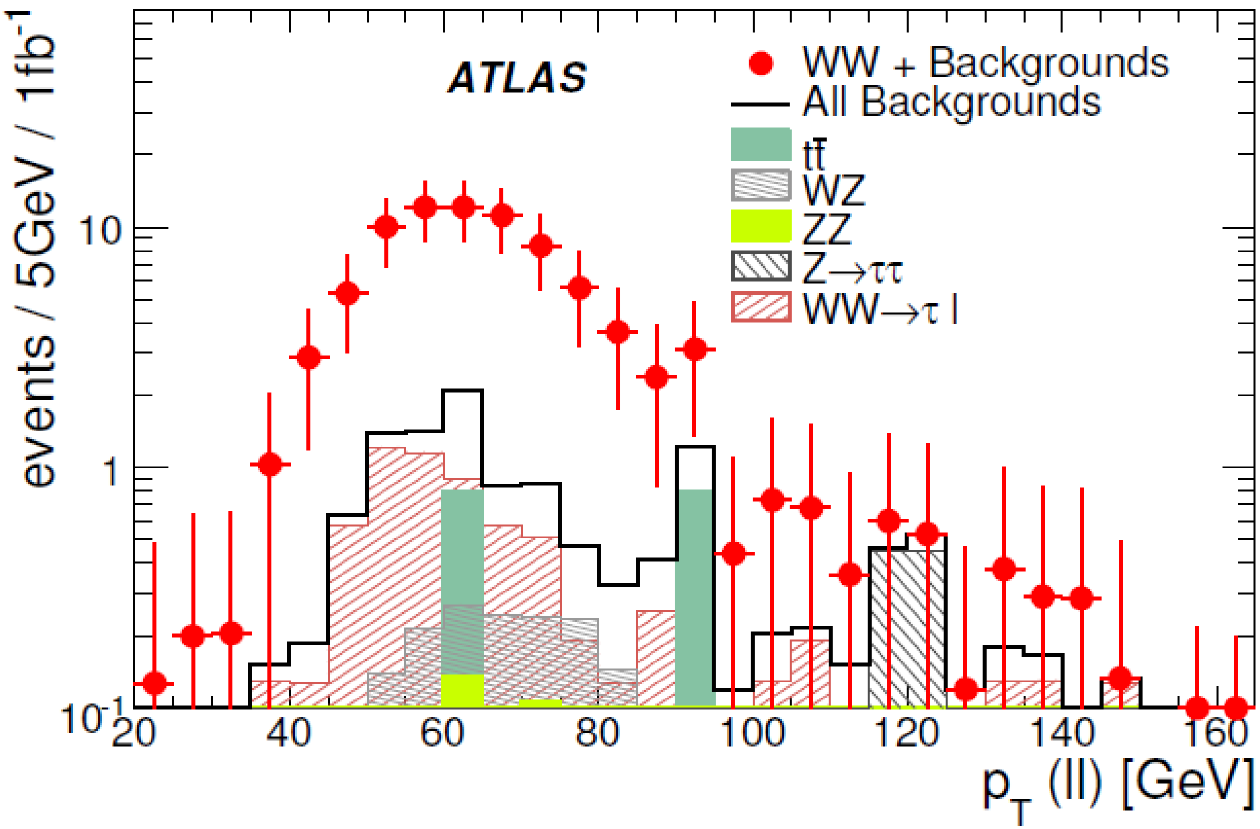


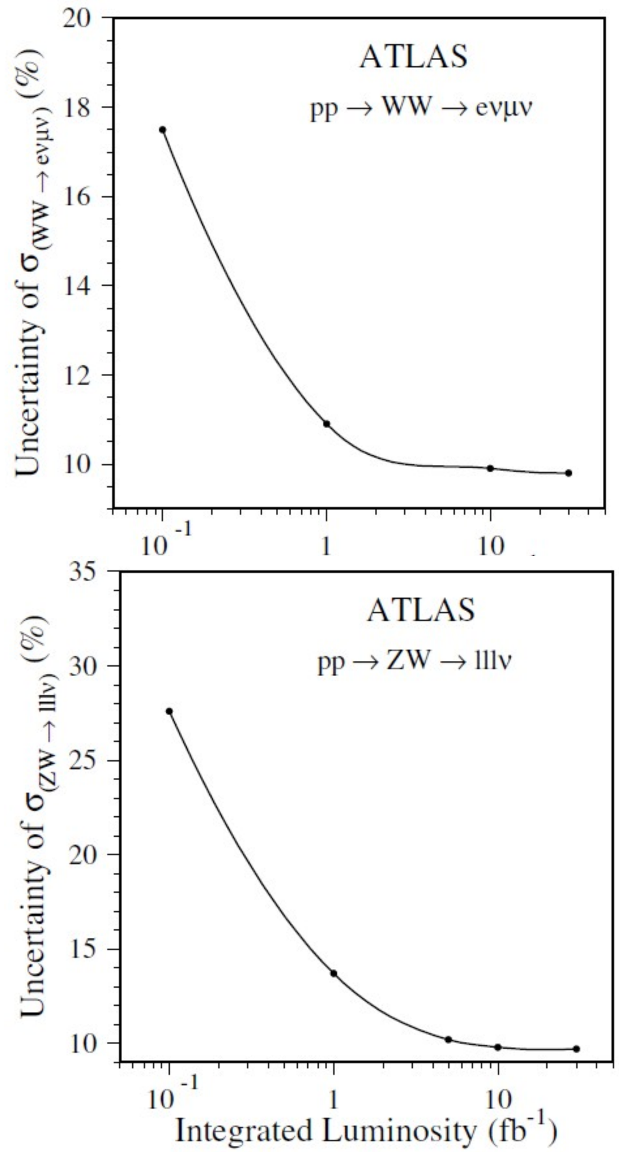
CMS PAS EWK-08-006

Reduced uncertainties N jets/ (N+1) jets ratios

Diboson Production

p_T of lepton pairs in WW production, 14 TeV





Establish SM diboson signals with significance > 5σ:

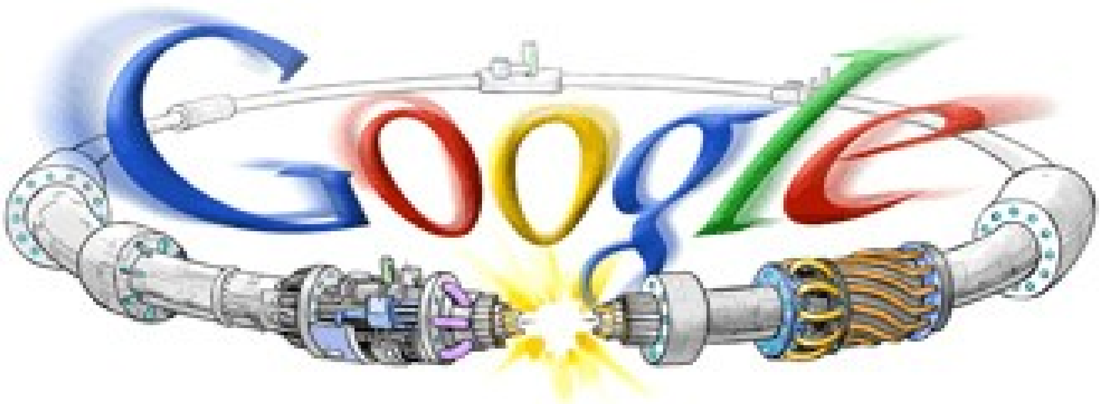
WW, WZ, Wγ & Zγ: 100/pb

ZZ: 1/fb

Correction to yesterday :-)

Rainer

KR



Outlook

- At the LHC we will go beyond Tevatron limits to explore unknown territory in the Standard Model and hopefully find some new physics
- LHC is a superb laboratory to investigate weak boson and jet production
- Some tough experimental systematics to deal with (JES, Luminosity)
  - First LHC data will enable us to write the detector user manuals
  - Together with YOU we will get better tuned MC generators & better PDFs
  - More data not only reduces statistical uncertainties but also allows to:
    - improve the understanding of the detectors (efficiencies, …) and LHC (lumi)
    - combine different detector parts to beat down on systematics
- Of course we always hope for new theory tools and more precise calculations
- New measurements are just ahead!

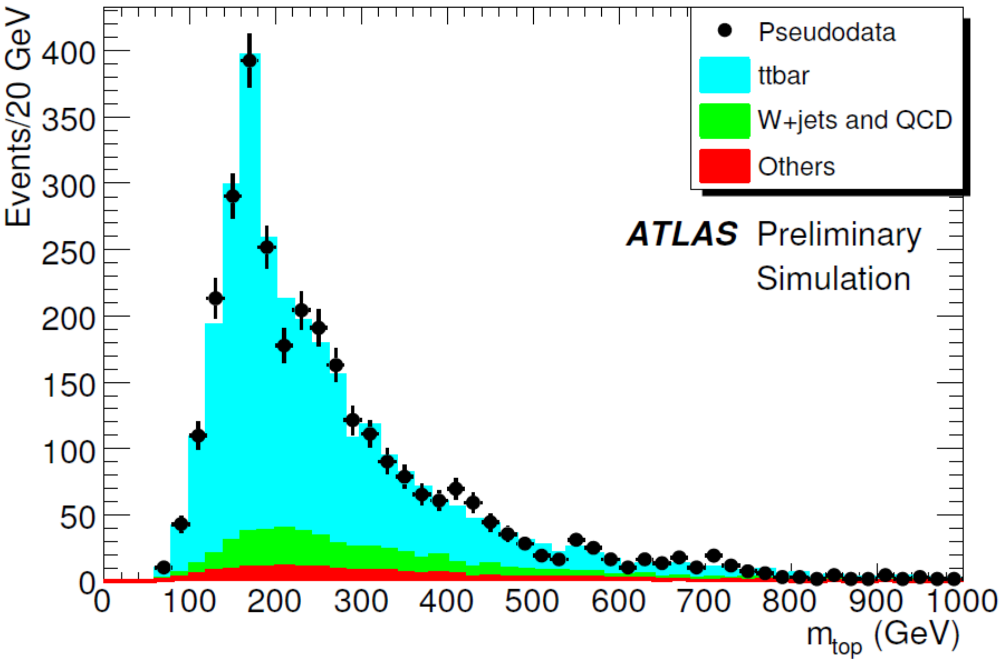
Thanks to the organizers for inviting me to this workshop
in Ascona as one experimentalist of the week.

Backups

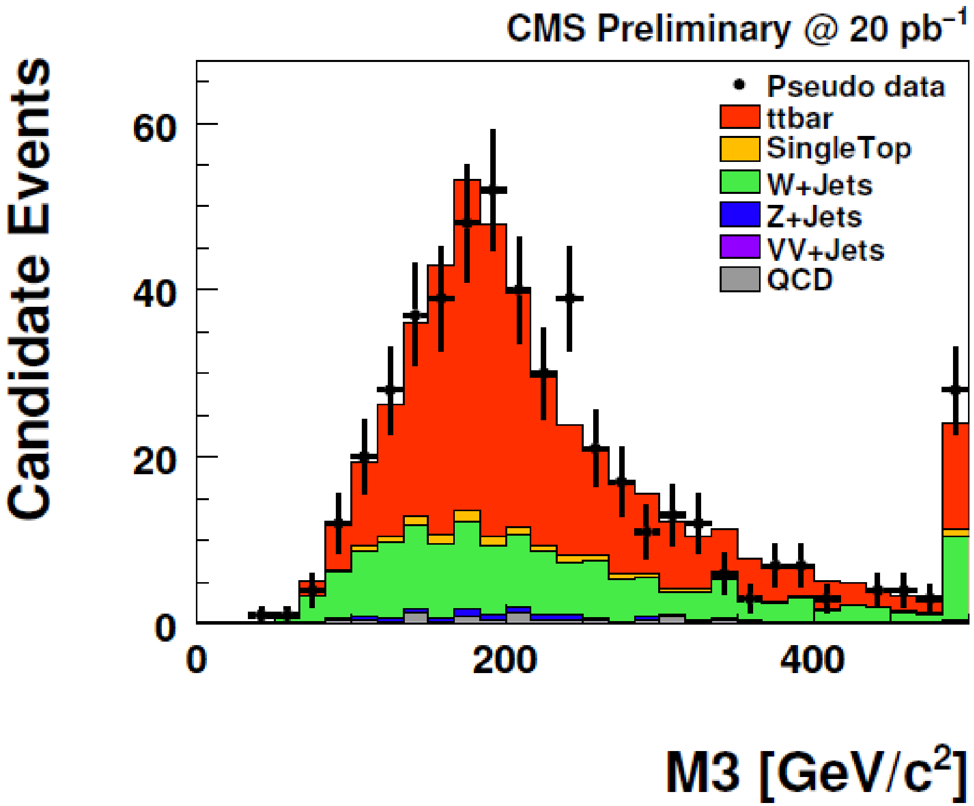
Some Topping

μ+jets, 10 TeV, 200/pb
M_{top} distribution

ATL-PHYS-PUB-2009-087



μ+jets, 10 TeV, 20/pb
M_{inv} of 3 jets w. highest vec-p_T sum



CMS PAS TOP-09-003

Both experiments try for start-up:

- to avoid b-tagging and missing E_T selections
- use data driven methods for background estimation wherever possible (W+jets …)
- uncertainty estimates on ttbar cross section of O(20%) syst., dom.by JES

Further Top Reading

From ATLAS Report:
See also: ATLAS public results page

- Top Quark Physics at ATLAS (introduction)
- Triggering top quark events in ATLAS
- Jets from light quarks in ttbar events (including jet calibration)
- Determination of the top quark pair production cross-section
- Prospects for single top quark cross-section measurements
- Top quark mass measurements
- Top quark properties (top charge, spin, polarisation, rare decays and reconstruction of ttbar resonances)

Recent ATLAS Notes:

- Prospects for measuring top pair production in the dilepton channel with early ATLAS data at sqrt(s)=10 TeV (ATL-PHYS-PUB-2009-086).
- Prospects for the top pair pair production cross-section at sqrt(s)=10 TeV in the single lepton channel in ATLAS (ATL-PHYS-PUB-2009-087).
- Prospects for associated single top quark production cross-section measurements in the dilepton decay mode with ATLAS (ATL-PHYS-PUB-2009-001).
- Reconstruction of High Mass ttbar Resonances in the Lepton+Jets Channel (ATL-PHYS-PUB-2009-081).

From CMS Physics Analysis Summaries:
See: CMS public results page

- TOP-09-009: Study of the top-pair invariant mass distribution in the semileptonic muon channel at 10 TeV (July 2009) NEW
- TOP-09-001: Probing the heavy flavor content of the t-tbar dilepton channel at 10 TeV (July 2009) NEW
- TOP-09-010: Expectation for a measurement of the t-tbar production cross section in the muon+jets final state using a multivariate technique (July 2009) NEW
- TOP-09-002: Expectations for observation of top quark pair production in the dilepton final state with early data at 10 TeV (Jun 2009) NEW *This analysis supersedes the following two older results*:
  - TOP-08-001: Di-lepton ttbar cross section with 10 pb^-1
  - TOP-08-002: Di-lepton ttbar cross section with 100 pb^-1
- TOP-09-003: Plans for an early measurement of the t-tbar cross section in the muon+jets channel at 10 TeV (Jul 2009) NEW *This analysis supersedes the following older result*:
  - TOP-08-005: Semi-leptonic (muon) ttbar cross section with 10 pb^-1
- TOP-09-004: Plans for an early measurement of the t-tbar cross section in the electron+jets channel at 10 TeV (Jul 2009) NEW
- TOP-09-005: Prospects for the measurement of the single-top t-channel cross section in the muon channel with 200 pb−1 at 10 TeV (Jul 2009) NEW
- TOP-09-007: Plan for a B(t->Wb)/B(t->Wq) measurement in t-tbar semi-leptonic decays at 10 TeV (Jul 2009) NEW
- TOP-08-004: Di-lepton ttbar tau channels (en route to)
- TOP-07-004: Jet Energy Scale from top events

Recent Higgses

From ATLAS Report: ATLAS, CERN-OPEN-2008-020
See also: ATLAS public results page

Topic
Introduction on Higgs boson searches
Prospects for the Discovery of the SM Higgs Boson using the H->γγ decay
Searches for the Standardmodel H->ZZ*->4l
Searches for the SM Higgs Boson via VBF production processes in the di-τ channel
Higgs Boson searches in gluon fusion and VBF using the H->WW decay mode
Searches for ttH (H->bb)
Study of signal and background conditions in ttH, H->WW* and WH, H->WW*
Discovery potential of h/H/A->ττ->ll 4ν
Search for the neutral MSSM Higgs bosons in the decay channel A/H/h -> $\mu^+\mu^-$
Sensitivity to an invisibly decaying Higgs boson
Charged Higgs boson searches
Statistical combination of several important Standard Model Higgs boson searches

From CMS Physics Analysis Summaries:
See: CMS public results page

- HIG-08-003: Search for Higgs to ZZ* NEW (January 2009).
- HIG-08-006: Search for Higgs to WW* NEW (January 2009).
- HIG-08-008: Higgs to tau-tau NEW (October 2008)
- HIG-08-001: qqH production, with H-->tau-tau

Add some Flavour

From ATLAS Report: ATLAS, CERN-OPEN-2008-020
See also: ATLAS public results page

Introduction to B-Physics
Performance Study of the Level-1 Di-Muon Trigger
Triggering on Low-p_T Muons and Di-Muons for B-Physics
Heavy Quarkonium Physics with Early Data
Production Cross-Section Measurements and Study of the Properties of the Exclusive $B^+ \to J/\psi K^+$ Channel
Physics and Detector Performance Measurements for $B_d^0 \to J/\psi K^{0*}$ and $B_s^0 \to J/\psi\phi$ with Early Data
Plans for the Study of the Spin Properties of the Λ_b Baryon Using the Decay Channel $\Lambda_b \to J/\psi(\mu^+\mu^-)\Lambda(p\pi^-)$
Study of the Rare Decay $B_s^0 \to \mu^+\mu^-$
Trigger and Analysis Strategies for B_s^0 Oscillation Measurements in Hadronic Decay Channels

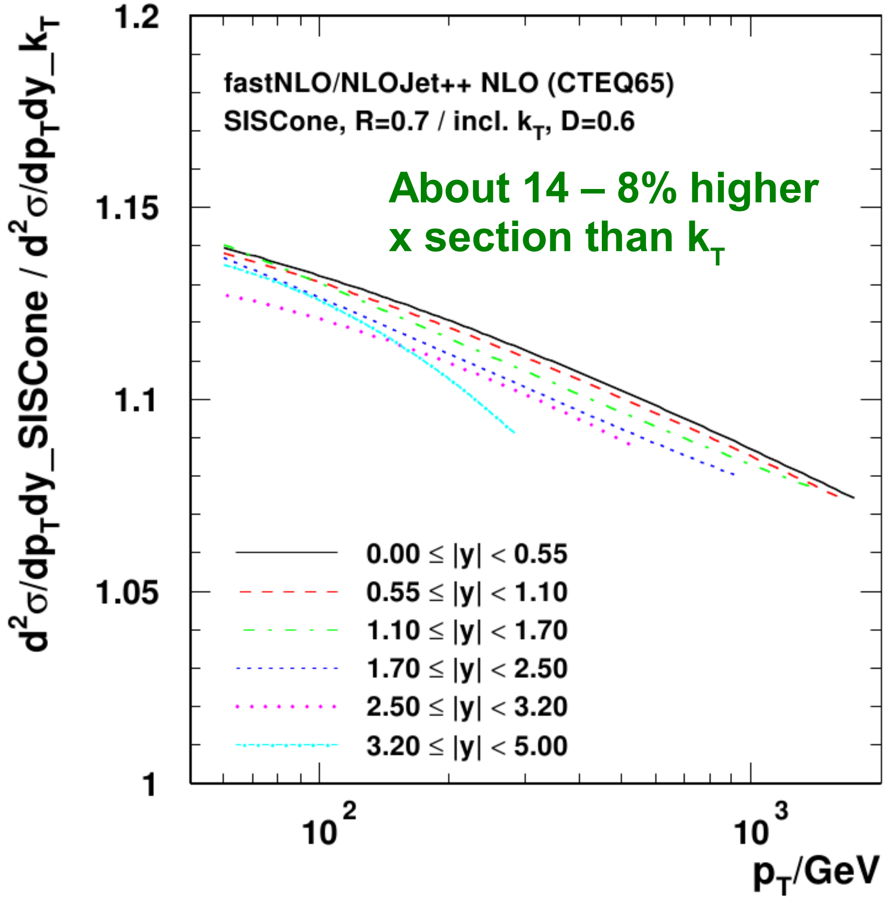
From CMS Physics Analysis Summaries:
See: CMS public results page

- BPH-07-001: Study of B_s -> μ+μ− NEW (Jul 2009)
- BPH-09-001: Measurement of Differential Production Cross Sections and Lifetime Ratio for Exclusive Decays of B+ and B0 Mesons in pp Collisions at 10 TeV NEW (Jun 2009)
- BPH-08-004: Study of b-bbar correlations using J/psi + muon events NEW (Mar 2009)
- BPH-07-002: Feasibility study of a J/psi cross section measurement with early CMS data (July 2008)

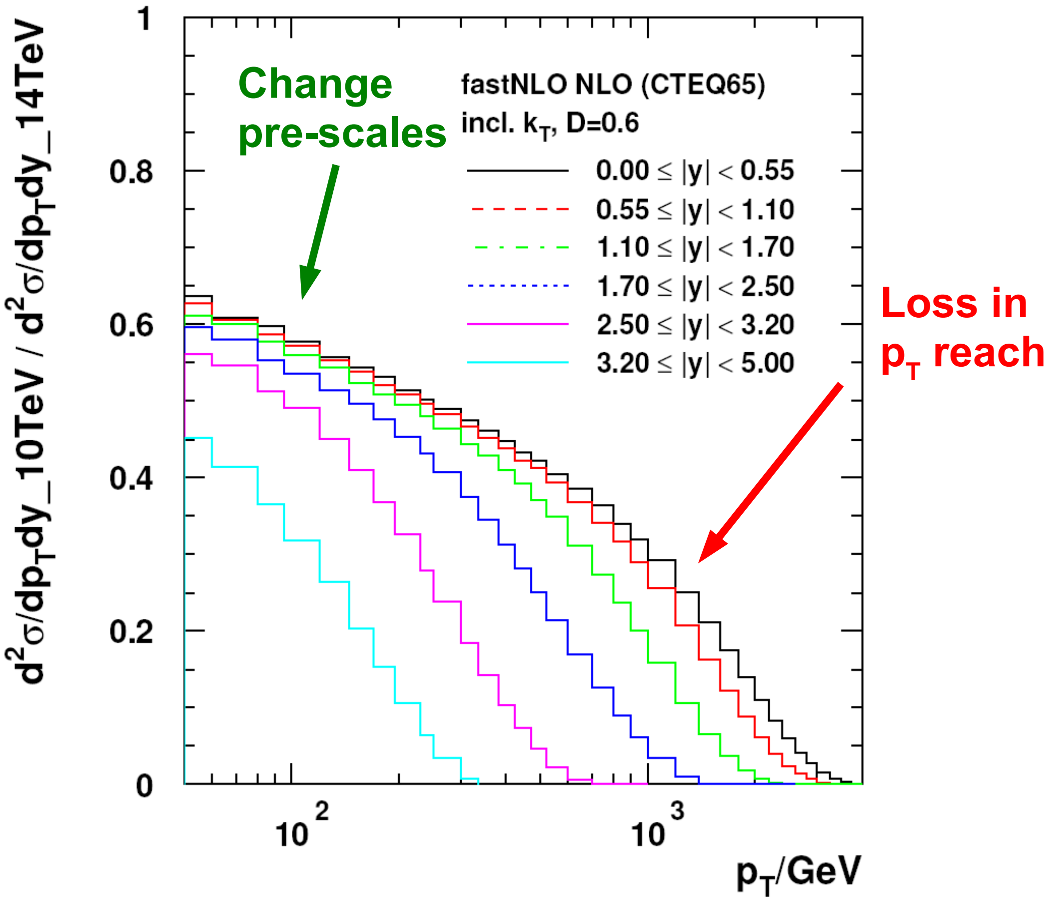
Cross Section Ratios

Cross section ratios in 6 bins in rapidity y

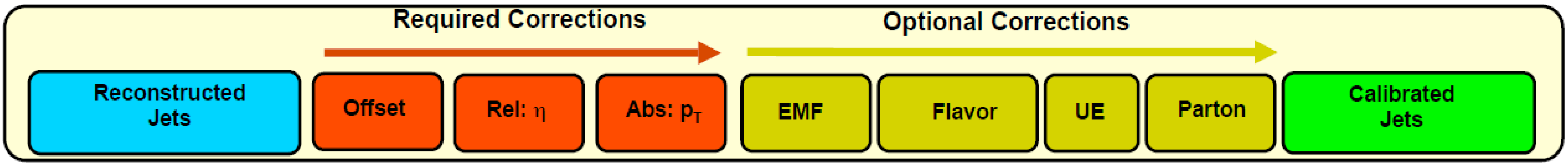
SISCone 0.7 / k_T 0.6 @ 10 TeV



k_T 0.6 10 TeV / 14 TeV



Jet Energy Calibration



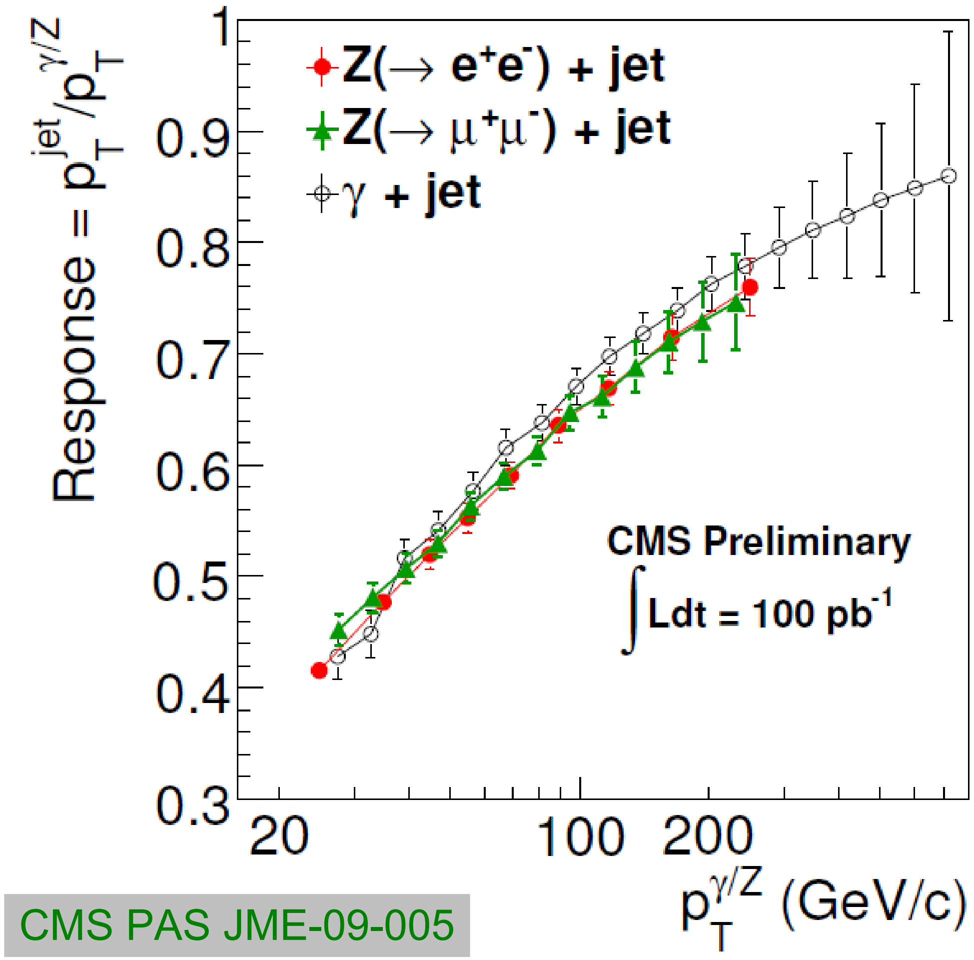
- **Offset:** **Correct for detector noise and pile-up (use random triggers = zero bias, special read-out for noise)**
- **Relative (η):** **Equalize jet response in η w.r.t. control region (barrel) (dijet balancing; or MC)**
- **Absolute (p_T):** **Correct measured jet p_T to particle jet p_T (photon + 1jet, Z + 1jet events)**
- **Optional analysis dependent corrections:** **Electromagnetic fraction, flavour, … will not discuss here**
- **Initial assumption on JEC uncertainty: 10%**

CMS PAS JME-07-002

Absolute Correction

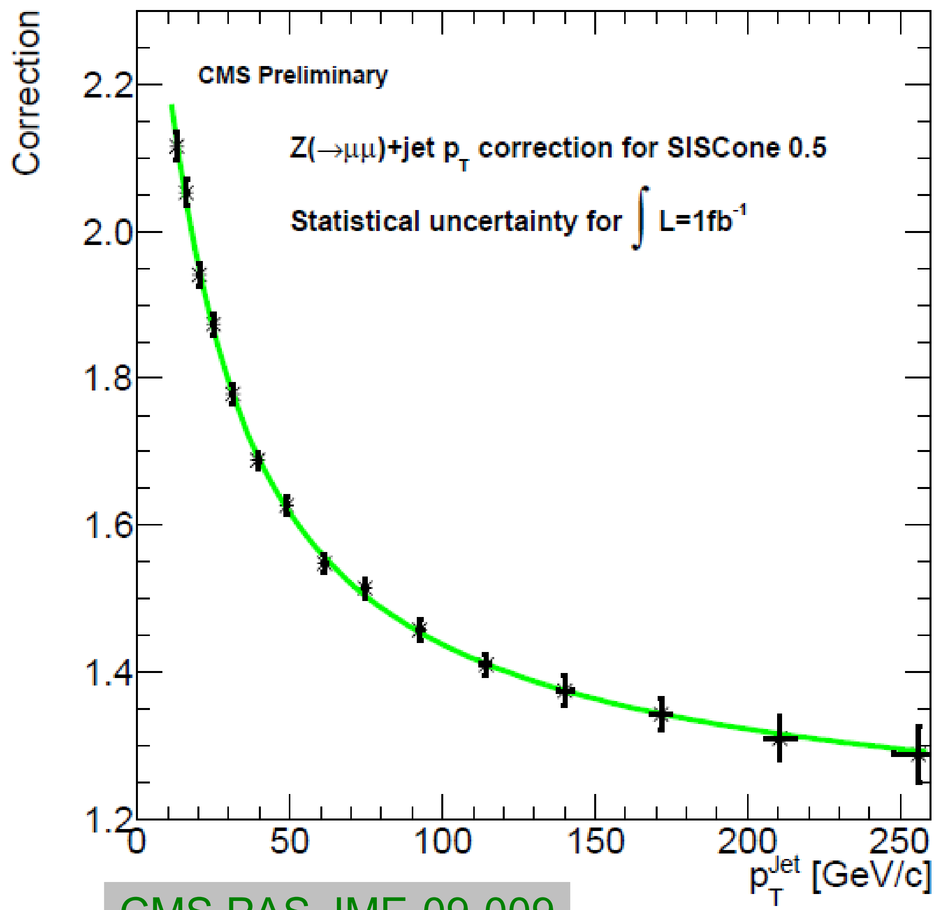
CMS detector simulation, calorimeter towers, E_{CMS} = 10 TeV

Comparison of jet responses



CMS PAS JME-09-005

Derived correction at the example of Z(→μμ) + 1jet



CMS PAS JME-09-009

Jet Energy Resolution

CMS detector simulation, calorimeter towers, E_{CMS} = 10 TeV

Jet energy resolution (JER):

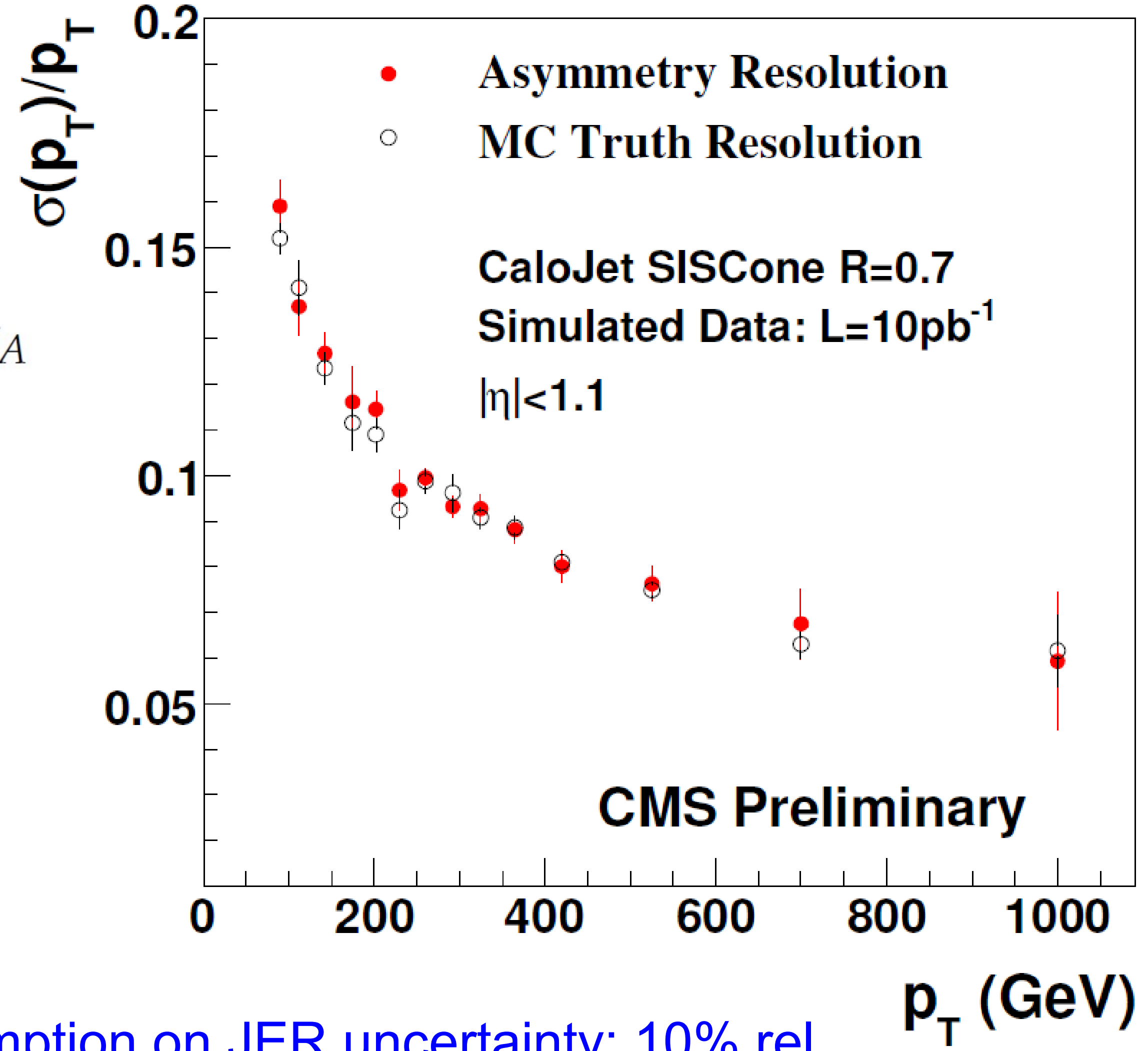
- Can be measured from data using Asymmetry Method used:
  For dijet events:

$$A = \frac{(p_T^{jet1} - p_T^{jet2})}{(p_T^{jet1} + p_T^{jet2})} \Rightarrow \left(\frac{\sigma_{p_T}}{p_T}\right) = \sqrt{2}\sigma_A$$

  Used at Tevatron.
- Comparison using MC information (matched jets) gives consistent results

Jet reconstruction efficiency:

- From tag-and-probe with Z+1jet events, > 95% for pT_Z >≈ 25 GeV
  ≈ 100% for pT > 30 GeV



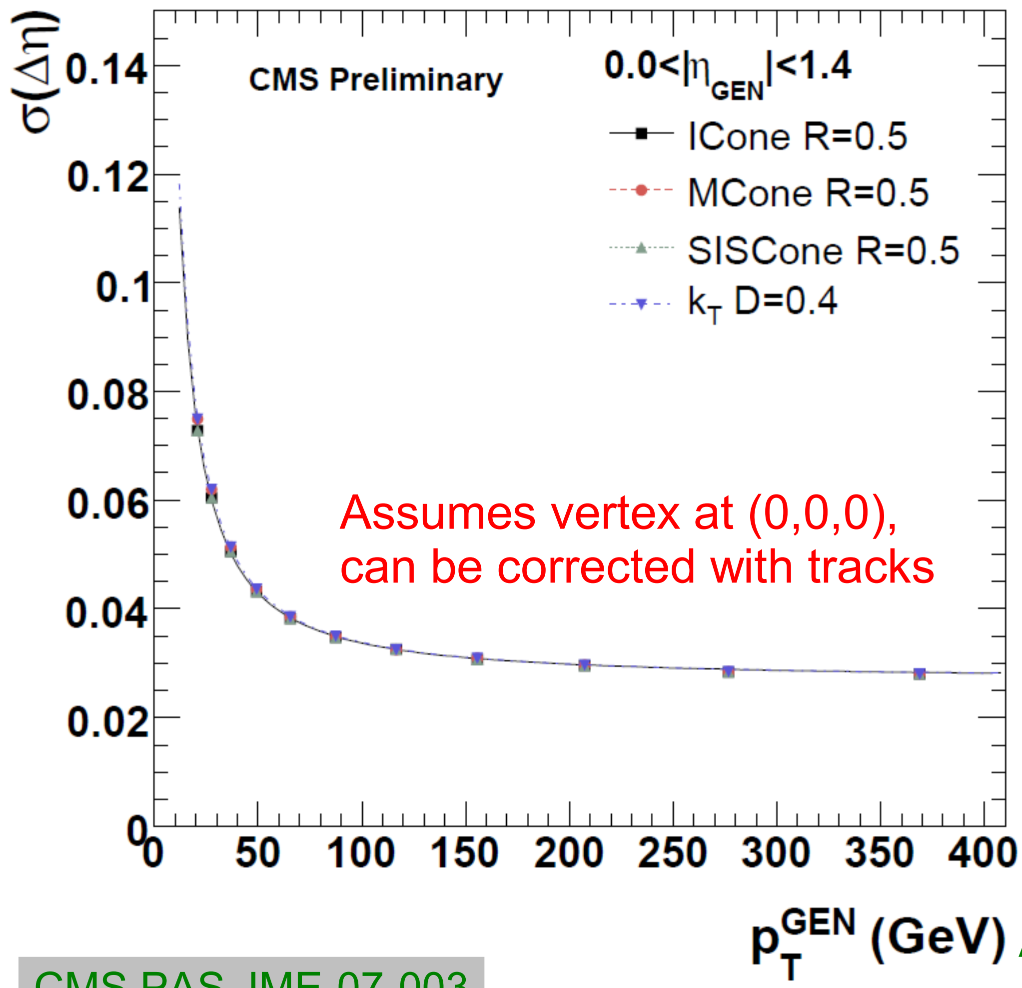
CMS PAS JME-09-007

Initial assumption on JER uncertainty: 10% rel.

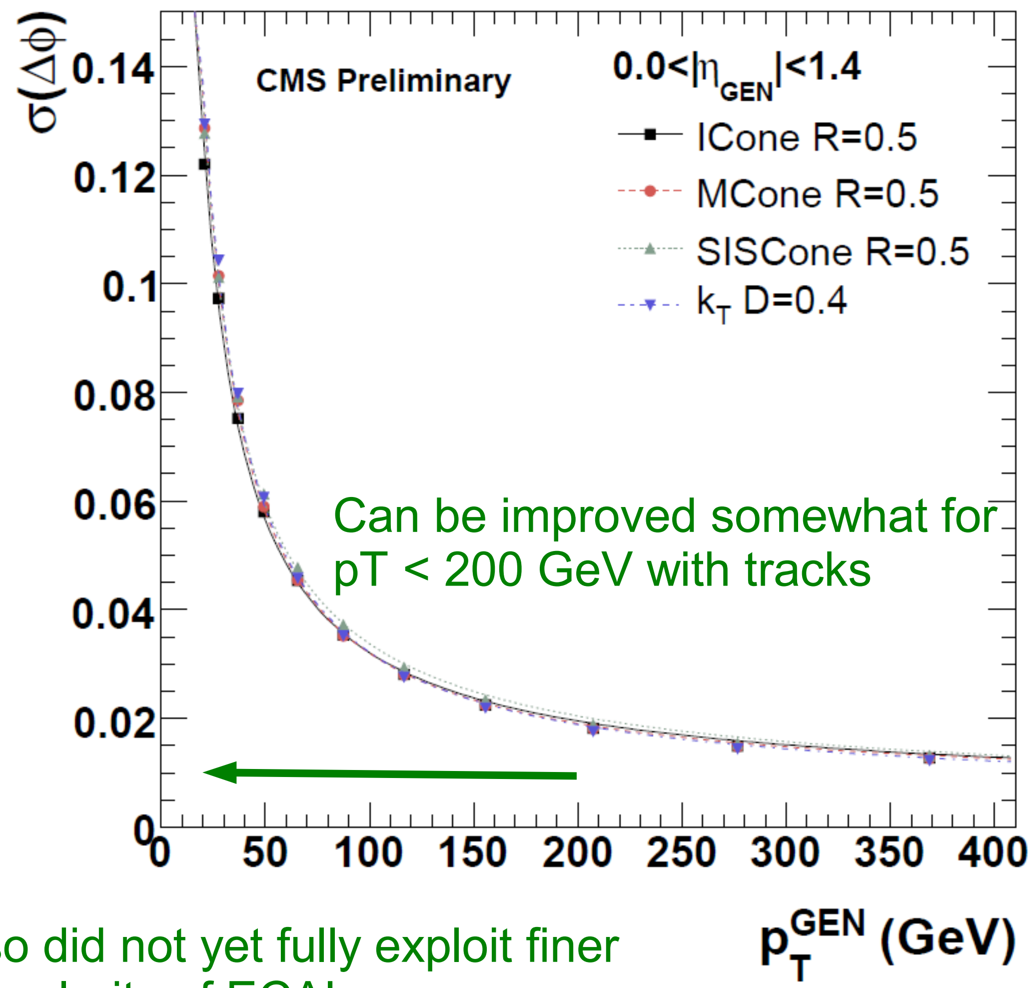
Jet Angular Resolutions

CMS detector simulation, calorimeter towers, E_{CMS} = 14 TeV

Resolution in jet rapidity



Resolution in jet azimuth



Also did not yet fully exploit finer granularity of ECAL

CMS PAS JME-07-003

Signal & Backgrounds W/Z

Elektron channels

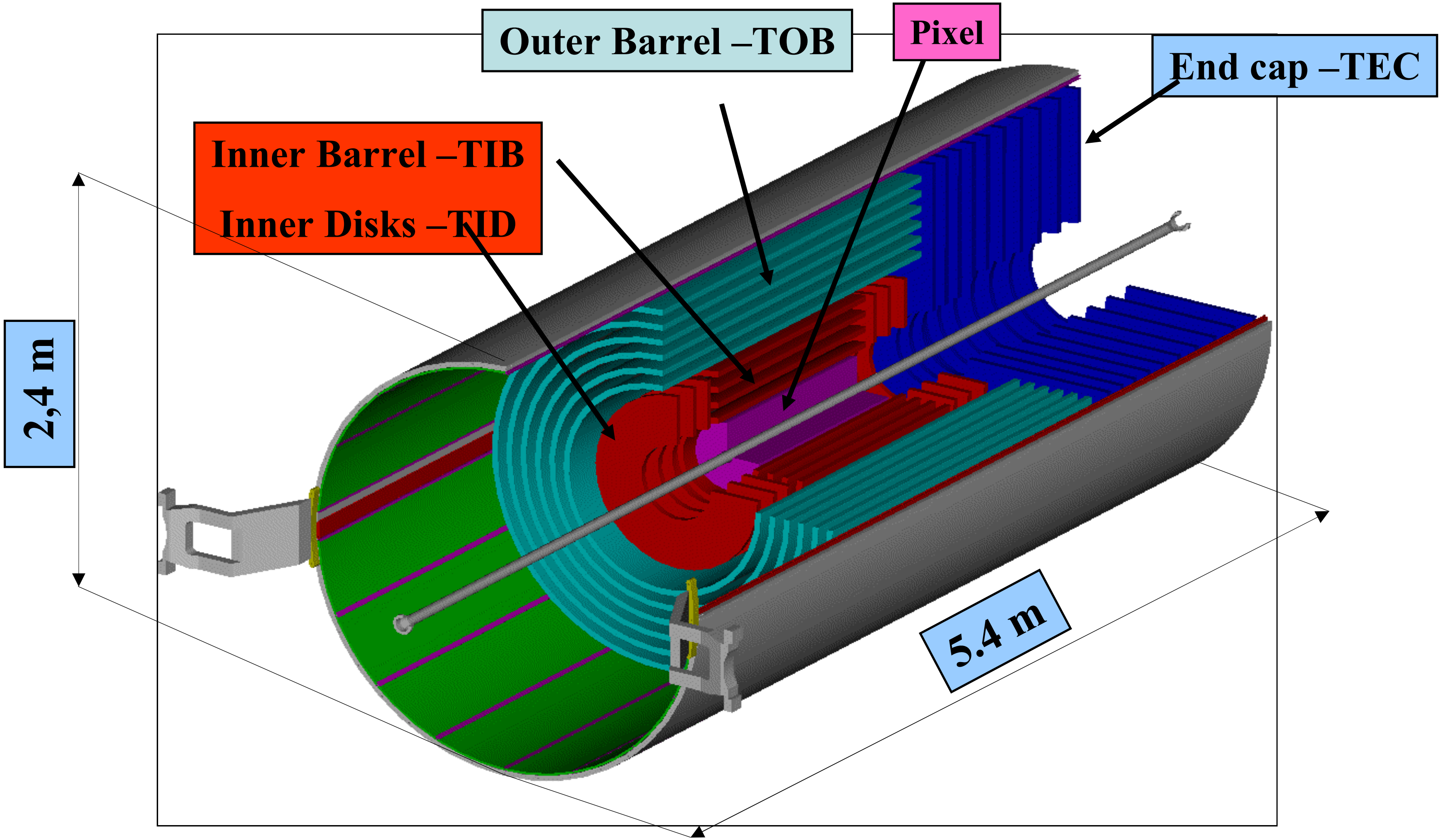
Channel	$\sigma(\times B_r)$	ε_{filter}	N_{evt} $(\times 10^3)$	$\mathscr{L}$ (pb^{-1})
$W \to e\nu$	20510 pb	0.63	140	11
$\gamma/Z \to ee, \sqrt{\hat{s}} > 60$ GeV	2015 pb	0.86	399	230
$\gamma/Z \to ee, \sqrt{\hat{s}} < 60$ GeV	9220 pb	0.022	197	969
$W \to \tau\nu_\tau$	20510 pb	0.20	32	8
$Z \to \tau\tau$	2015 pb	0.05	13	129
$t\bar{t}$	833 pb	0.54	382	850
Inclusive jets (p_T >6 GeV)	70 mb	0.058	2480	0.0006
Inclusive jets (p_T >17 GeV)	2333 μb	0.09	3725	0.02
WW$\to (e\nu)(e\nu)$	1.275 pb	1.	20	15608
ZZ	14.8 pb	1.	43	2922
WZ	29.4 pb	1.	50	1699

ATLAS, CERN-OPEN-2008-020

Channel	$\sigma(\times B_r)$	ε_{filter}	N_{evt} $(\times 10^3)$	$\mathscr{L}$ (pb^{-1})
$W \to \mu\nu$	20510 pb	0.69	190	13
$\gamma/Z \to \mu\mu, \sqrt{\hat{s}} > 60$ GeV	2015 pb	0.89	446	249
$W \to \tau\nu_\tau$	20510 pb	0.20	32	8
$Z \to \tau\tau$	2015 pb	0.05	13	129
$t\bar{t}$	833 pb	0.54	382	850
$b\bar{b} \to \mu + X$	766 μb	2.1×10^{-4}	110	0.67
$b\bar{b} \to \mu\mu + X$	25 μb	1.6×10^{-4}	140	35

Muon channels

Silicon Tracker



Pixel:
1 m² area
66 M pixels

Strips:
200 m² area
10 M strips

Momentum resolution (μ, 100 GeV):
1 – 2% (up to |η| ≈ 1.6)

Reconstruction efficiency:
μ: ≈99%, π: ≈90% (up to |η| ≈ 1.6)

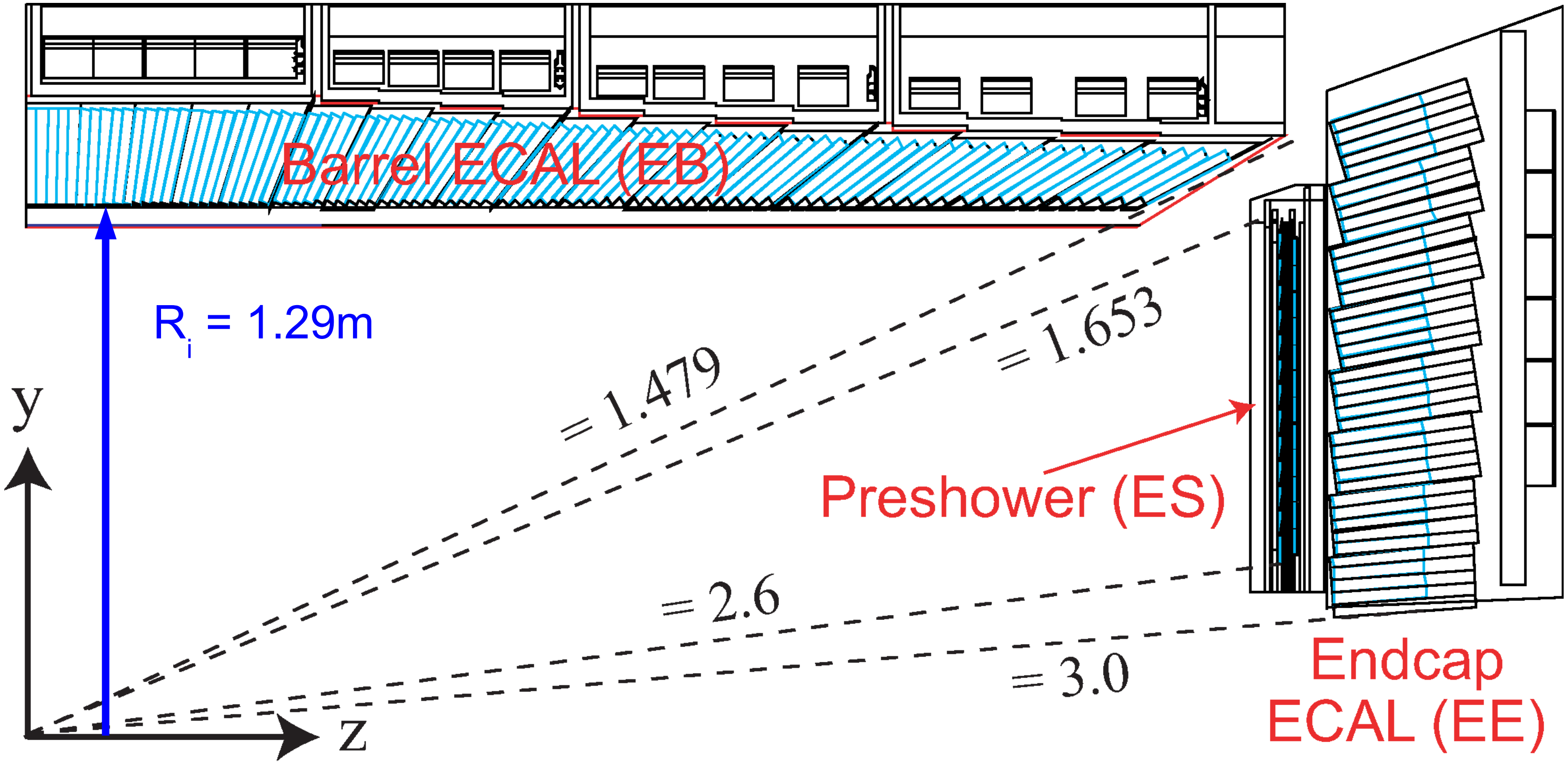
Electromagnetic Calorimeter

Barrel (EB):
- η segments: 2x85
- φ segments: 360

→ 61200 crystals ($PbWO_4$, 26 X_0)

→ Δη x Δφ ≈ 0.0174 x 0.0174

Segmentation



Segmentation

Endcaps (EE):
- (x,y) grid on two halfs
- front face 28 x 28 mm^2

→ 2 x 2 x 3662 crystals = 14648 ($PbWO_4$, 25 X_0)

Energy resolution from test beam:

S = 2.8%, N = 120 MeV, C = 0.30%

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{S}{\sqrt{E}}\right)^2 + \left(\frac{N}{E}\right)^2 + C^2$$

Hadronic Calorimeter

<u>HCAL (tower structure)</u>:

- Barrel (HB): $|\eta| < 1.4$, 2592 towers
- Endcaps (HE): $1.3 < |\eta| < 3.0$, 2592 "
- Outside coil (HO): $|\eta| < 1.26$, 2160 "

→ Depth (Brass abs. & plast. scint., ≈ 6 - 10 λ_N)

→ $\Delta\eta \times \Delta\varphi \approx 0.087 \times 0.087 \rightarrow 0.350 \times 0.175$

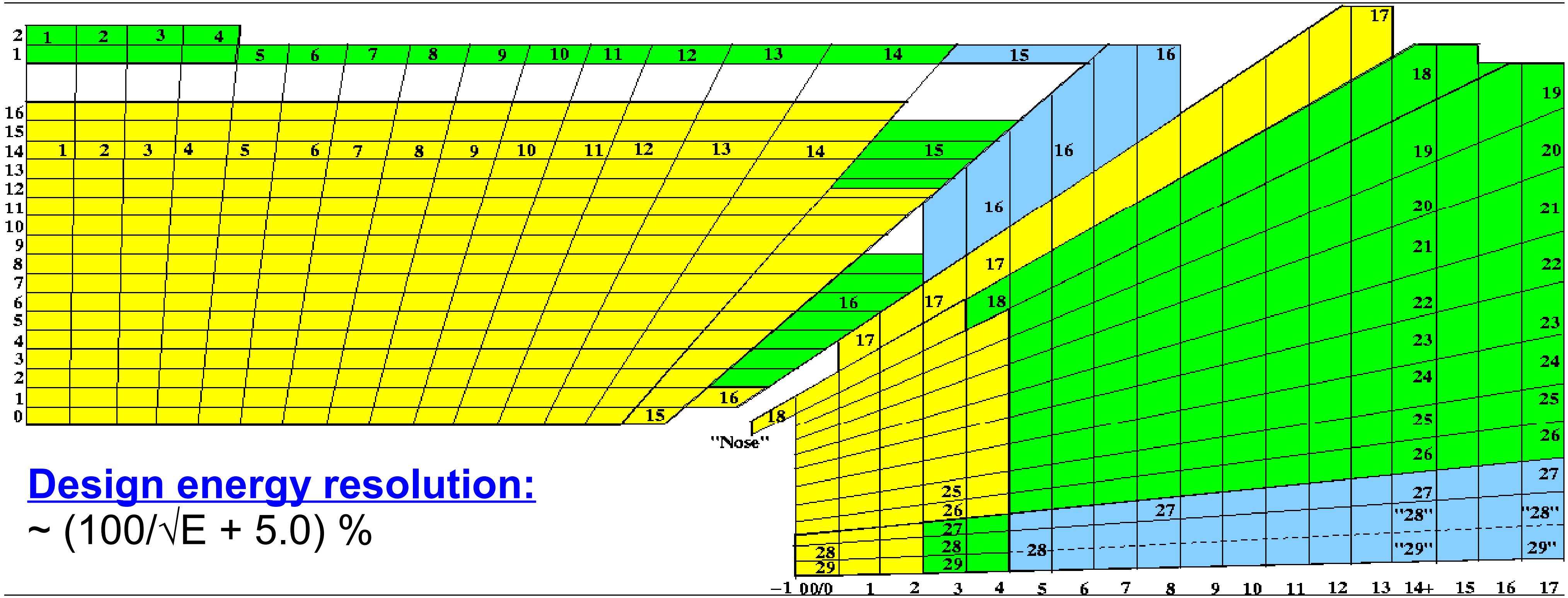
- Forward (HF): $2.9 < |\eta| < 5.0$ (not shown)

→ 2 x 864 towers (Brass,quartz fibers, ≈ 10 λ_N)

→ $\Delta\eta \times \Delta\varphi \approx 0.111 \times 0.175 \rightarrow 0.302 \times 0.350$

<u>CASTOR calorimeter</u> (not shown):

- $5.1 < |\eta| < 6.5$, ≈ 22 X_0, ≈ 10 λ_N



<u>Design energy resolution:</u>

~ $(100/\sqrt{E} + 5.0)$ %