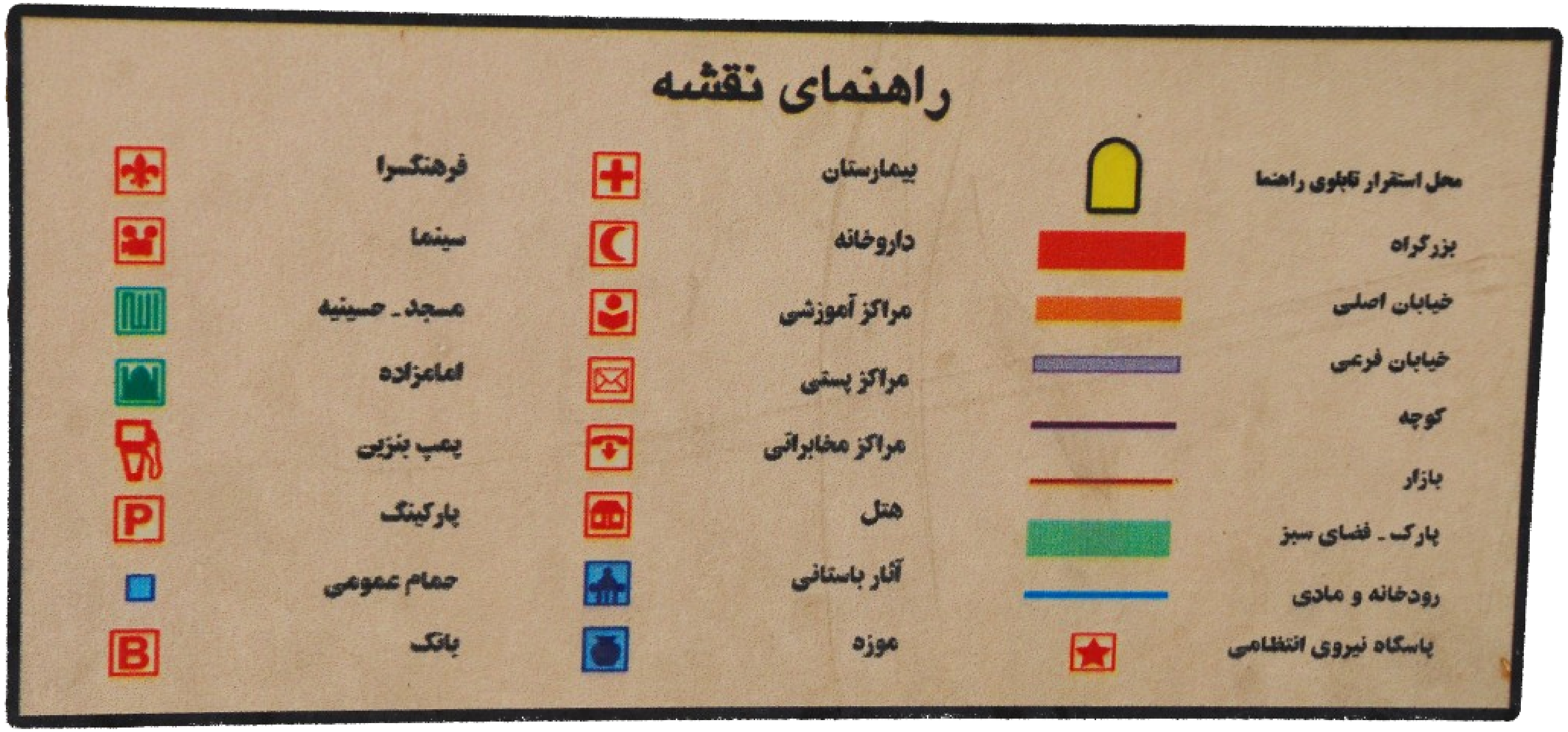
QCD Physics
Potential of CMS

On behalf of the CMS Collaboration
Klaus Rabbertz
University of Karlsruhe

Outline



- What is QCD?
- Tracks and Hadrons
- Jets
- Photons
- Summary

What is QCD?

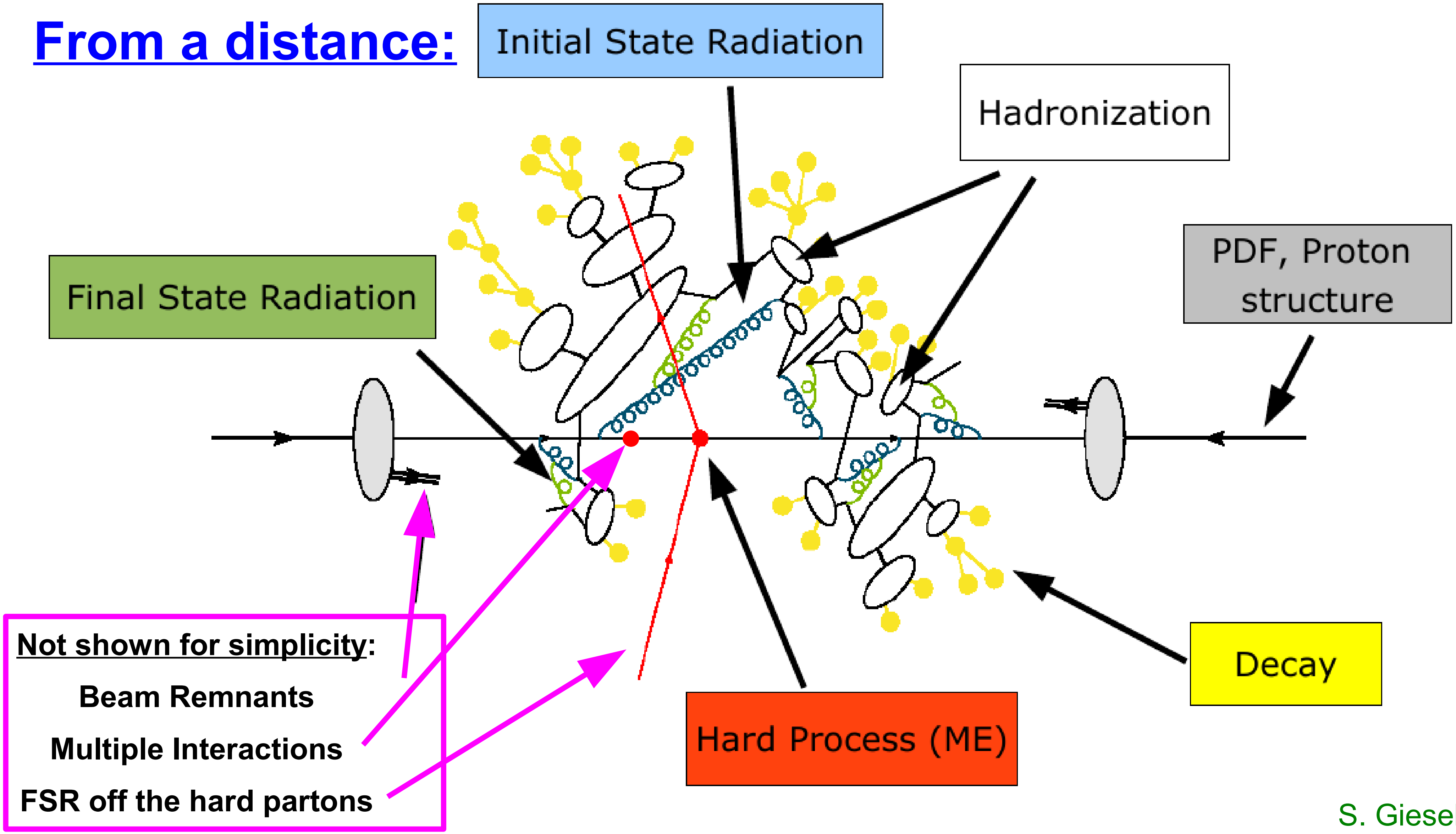
What is QCD?

First of all … it is 98% of us (our mass)
as we have heard yesterday from Raphael!
So we should better know it.

- **In Formulae:**
  - $$\mathcal{L} = -\frac{1}{4} F^{A}_{\alpha\beta} F^{\alpha\beta}_{A} + \sum_{\text{flavours}} \bar{q}_a (i\not{D} - m)_{ab} q_b + \mathcal{L}_{\text{gauge-fixing}}$$
- **In Words:**
  - QCD is the theory of the strong interaction, one of the four fundamental forces of nature, describing especially
    - the hard interactions between the coloured quarks and gluons
    - but also how they bind together to form hadrons.

What is QCD?

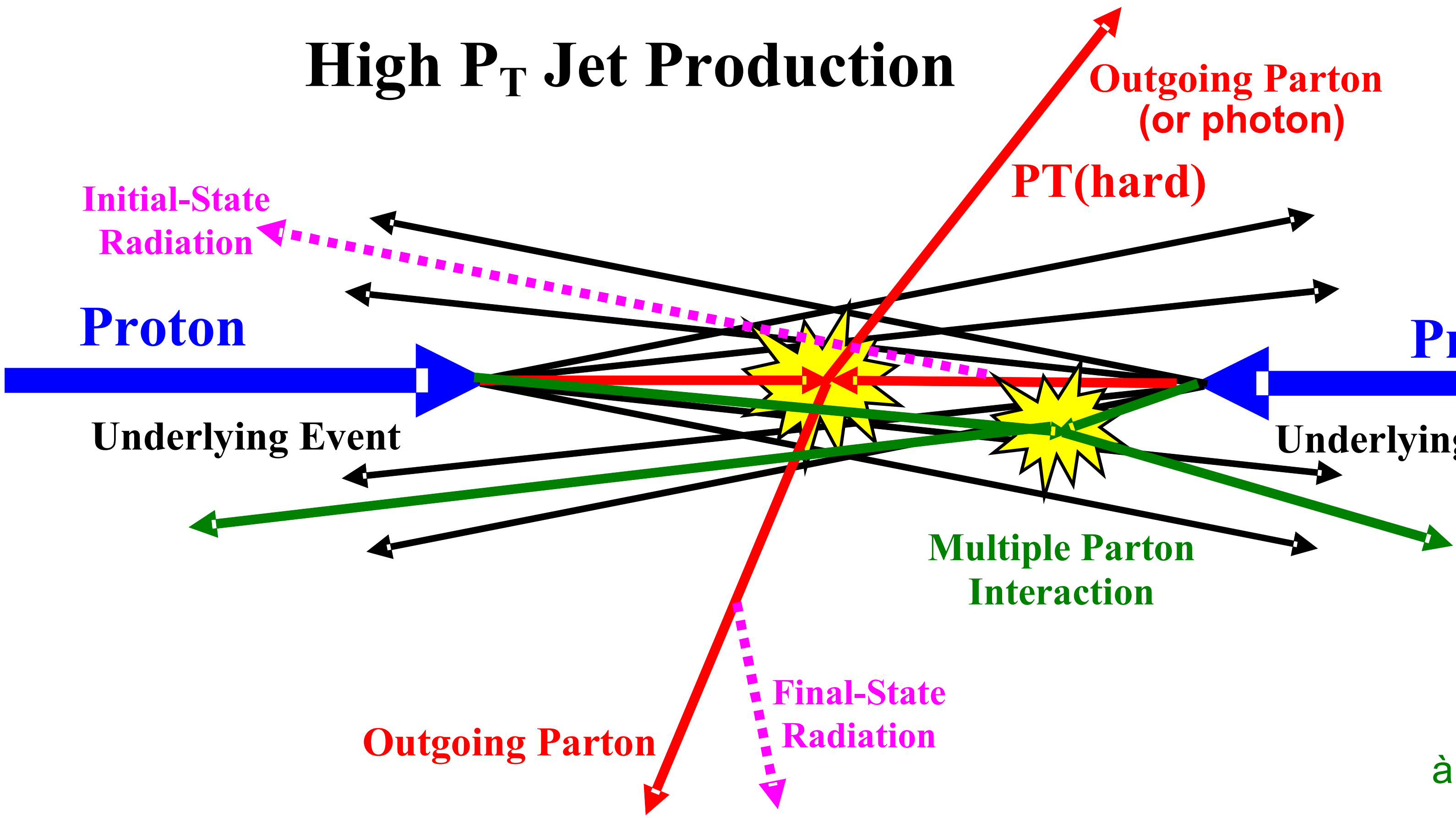
- **From a distance:**



S. Gieseke

What is QCD?

- **Zoomed in:**



à la R. Field

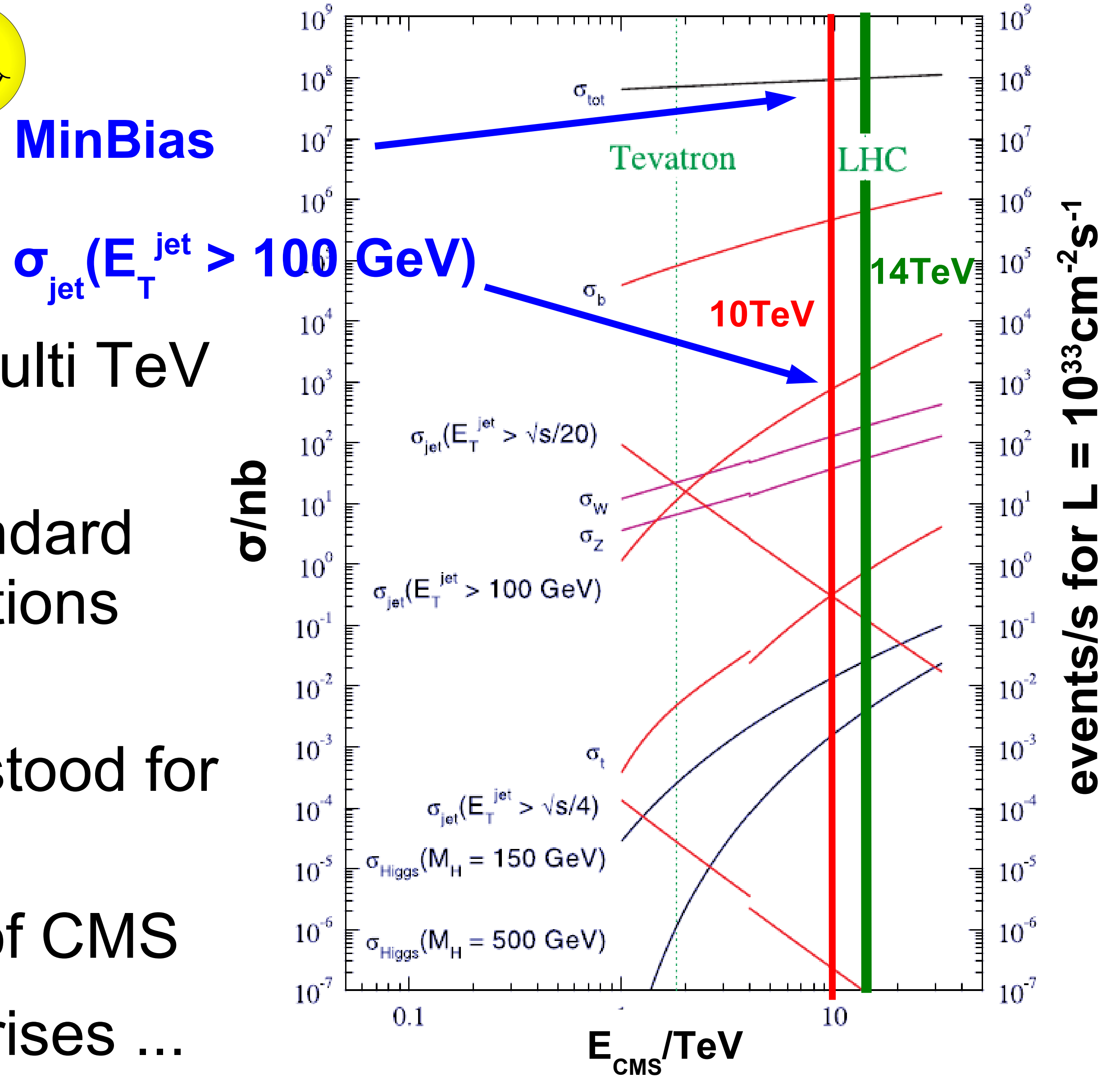
QCD in CMS

- **CMS QCD Group:**
  - **Everything** … not excluded:
    - New particles, exotics, SUSY (Higgs, Exotica, SUSY) — Mostly Background
    - Weak bosons (EWK) — PDFs, Multijets
    - Heaviest quarks (Top, B Physics) — Multijets, Hadrons
    - Very forward topology (Forward Physics) — Jets, PDFs, Evolution
    - Colliding hadrons other than protons (Heavy Ions) — Baseline
  - **Three subdivisions:**
    - Low p_T measurements (tracker, hadrons)
    - High p_T measurements (calorimeter, jets)
    - Measurements with photons (ECAL, photons)
  - **Plus common efforts (PDFs, ...)**

QCD at Startup

Still enough events/sec left

- **Startup with QCD:**
  - Not 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
  - But be prepared for surprises ...



Tracks and Hadrons

First Observations

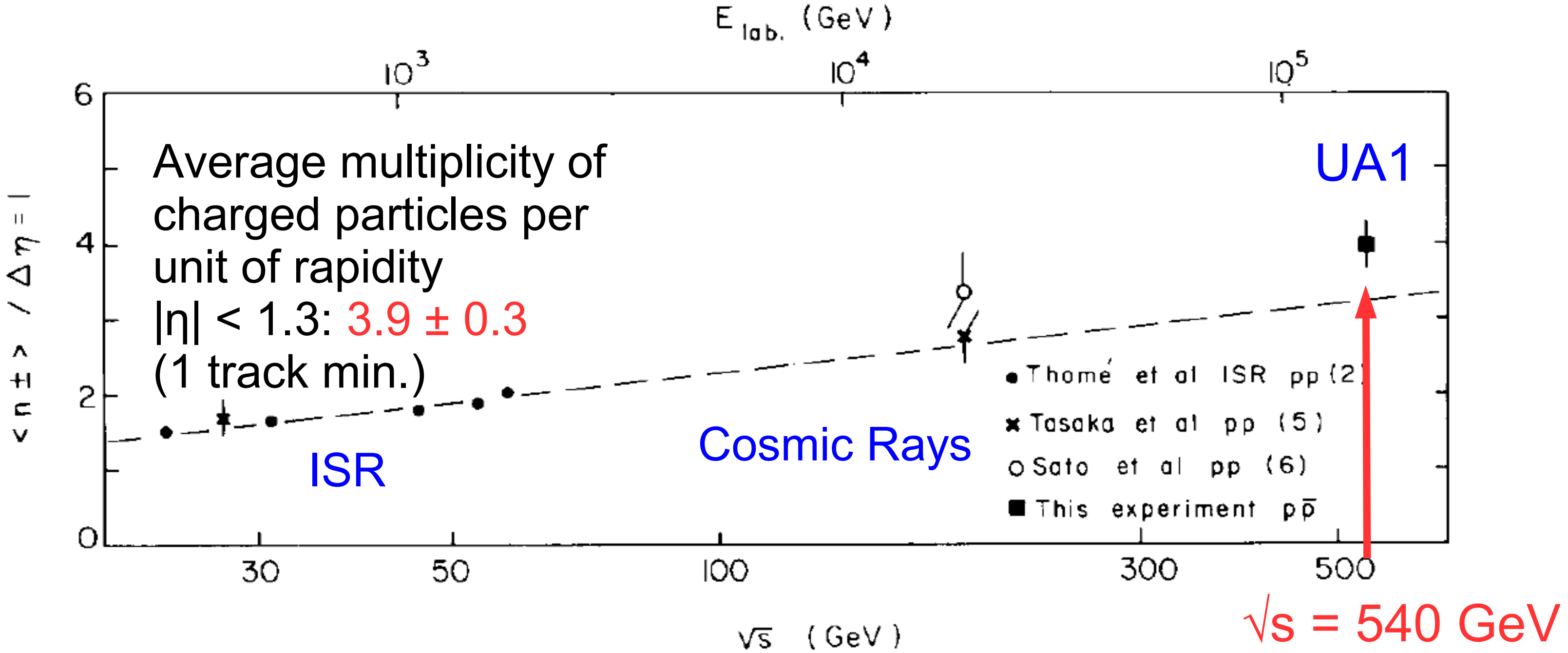
… just a bunch of hadrons!

- **Track based analyses:**
  - Charged particle rapidity density
  - Charged hadron spectra
  - Underlying event from transverse region

Also at 900 GeV

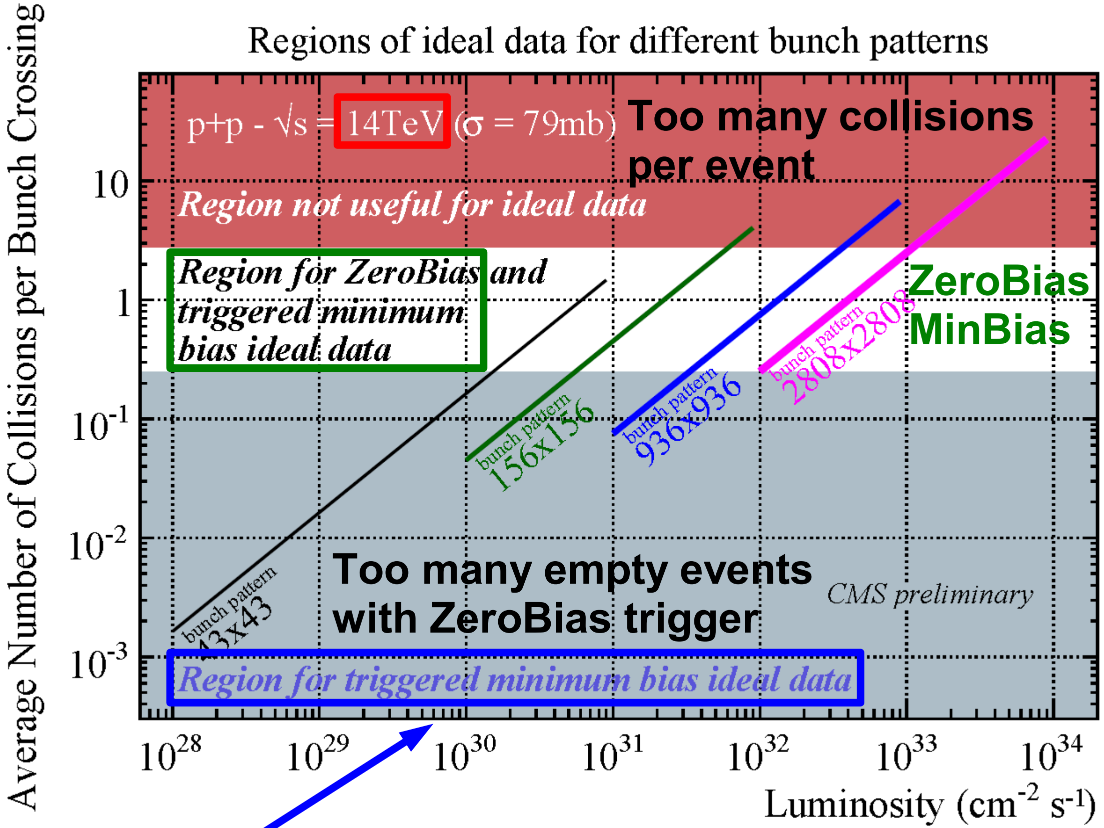
Phys.Lett.Vol.107B, no. 4 First UA1 Publication QCD 17. December 1981

Recall: SOME OBSERVATIONS ON THE FIRST EVENTS SEEN AT THE CERN PROTON–ANTIPROTON COLLIDER

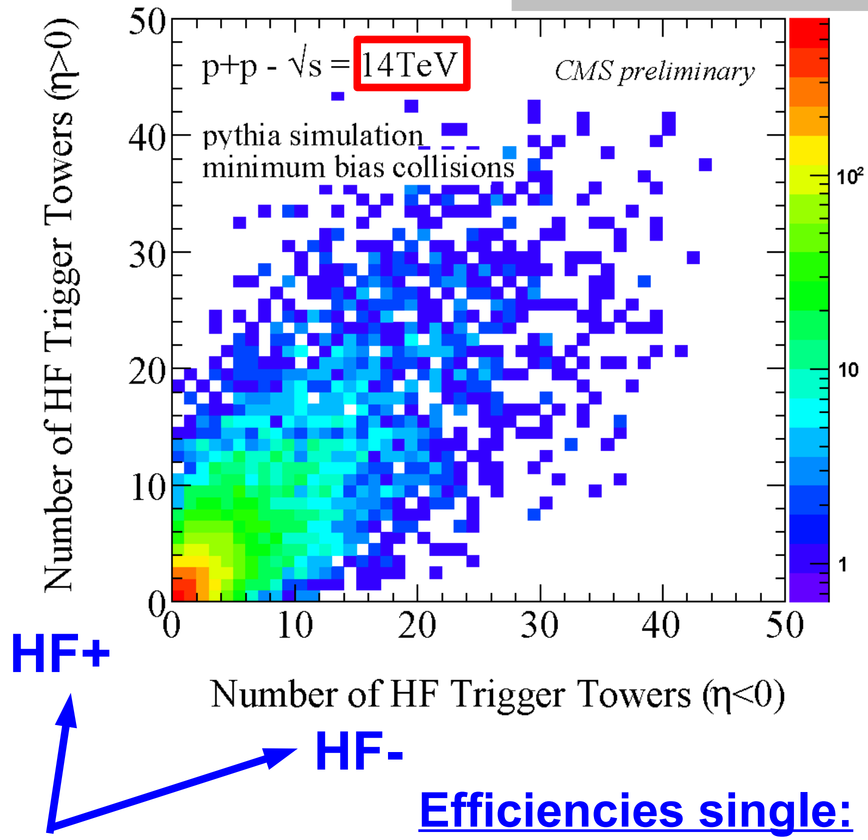


Hadron Trigger at Startup

At low luminosity want to collect "ideal" data meaning exactly one collision per bunch crossing



CMS PAS QCD-07-002



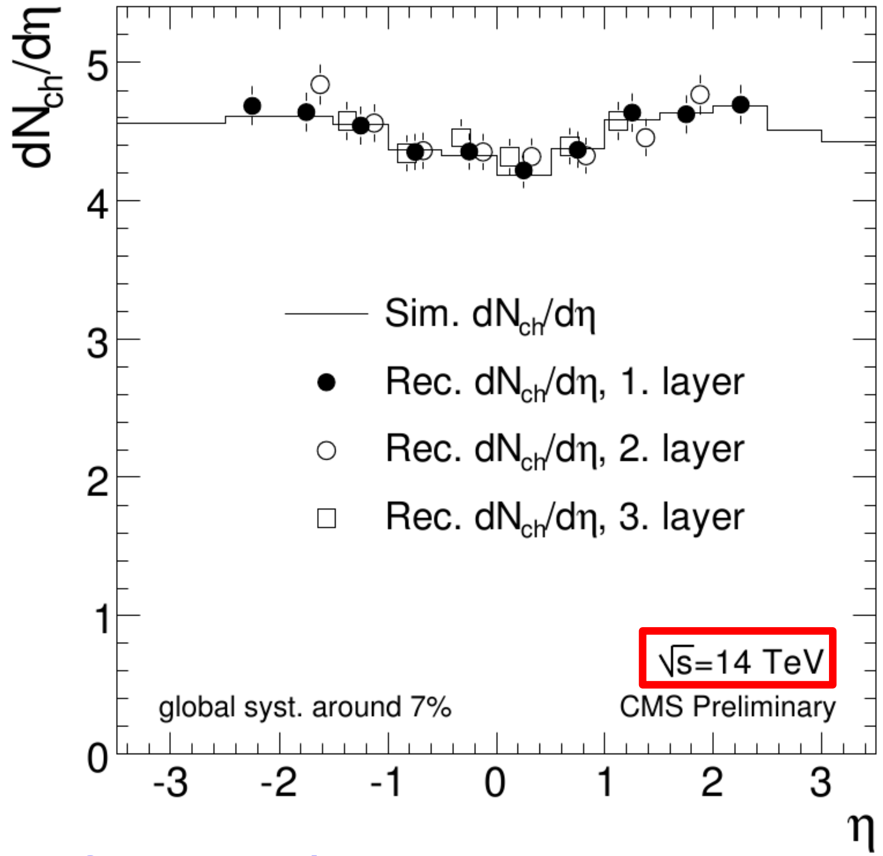
Need trigger (Pythia):
- 69% non-diffractive
- 18% single-diffractive
- 13% double-diffractive

Possibilities:
- single or double-sided HF Trigger Tower #
- others like PixelTracks under examination

Efficiencies single:
- 81% non-diffractive
- 15% single-diffractive
- 15% double-diffractive

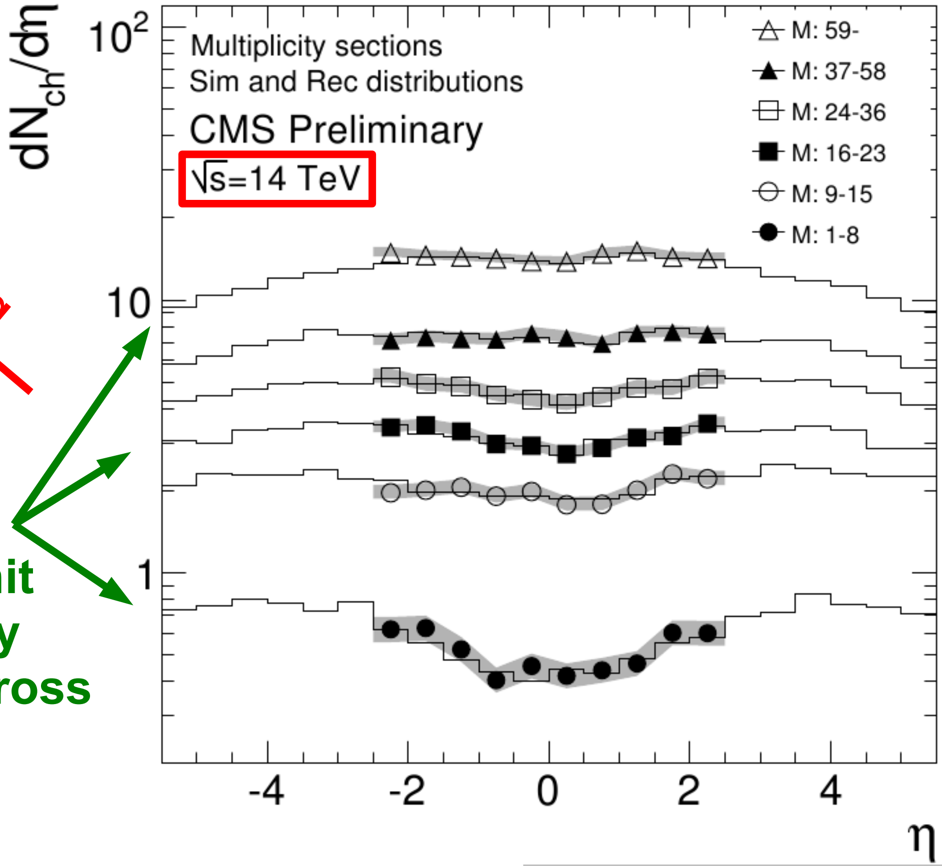
Double kills diffr. events!

Charged Particle Rapidity Density from Hits



Averaging

6 bins in hit multiplicity of equal cross sections

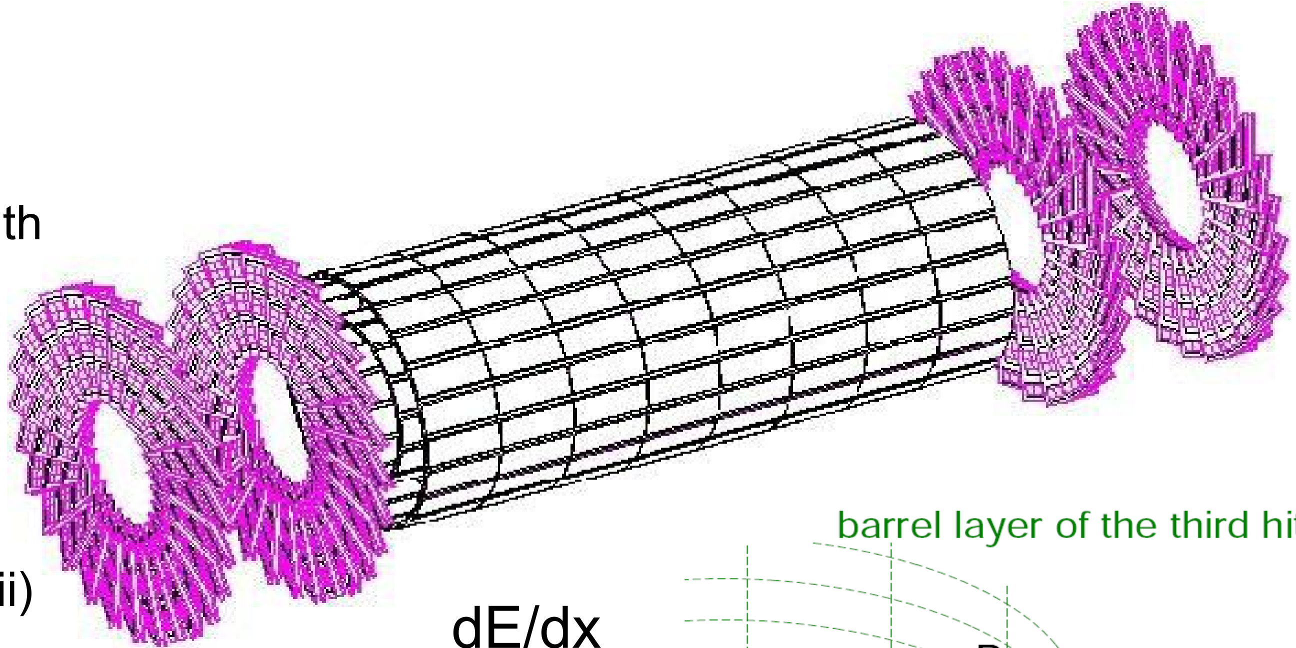


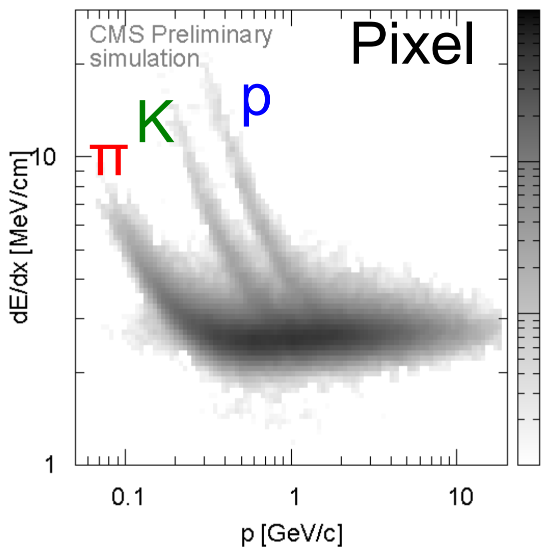
CMS PAS QCD-08-004

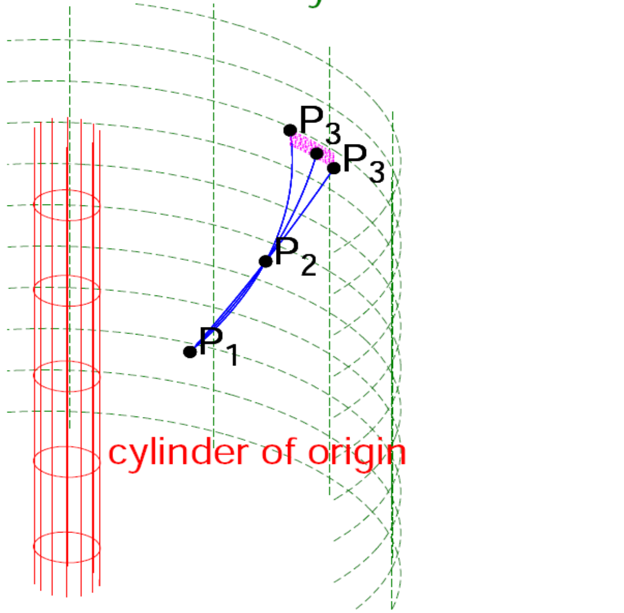
- **Strategy (used by Phobos at RHIC):**
  - **No tracking**, just count clusters in the pixel barrel layers (4, 7 and 10 cm radii)
  - Use cluster size to estimate z vertex and to remove hits at high η from non-primary sources
  - Correction for loopers, secondaries; systematic uncertainty expected below 10%

CMS Pixel Triplets

- **Expect:**
  - **~ 2 million events** assuming one month with 1 Hz allocated bandwidth
- **Strategy:**
  - **Still “no” tracking**, Pixel Triplets
- **CMS pixel detector:**
  - 3 barrel layers (4, 7 and 10 cm radii) and 2 end caps on each side
  - 100 × 150 μm^2 pixels
- **Hit triplets:**
  - Use pixel hit triplets instead of pairs, loss of acceptance but lower fake rate
  - Reconstructing down to p_T = 0.075 GeV



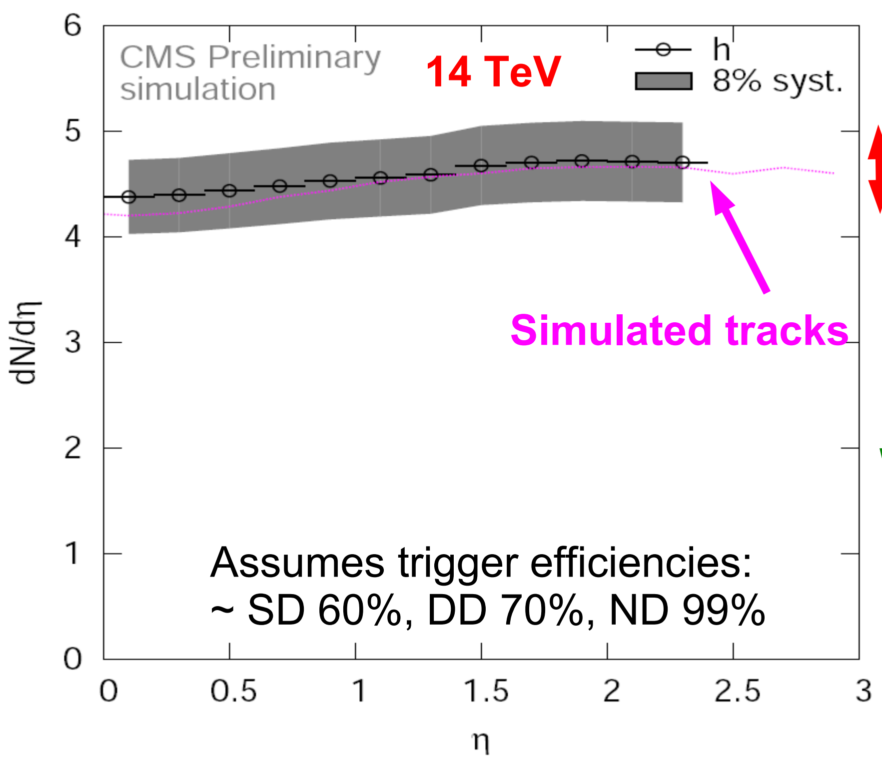




Charged Particle Rapidity Density from Triplets

Simulation result from CMS:

- Charged particle pseudo-rapidity distribution
- Pythia tune DWT

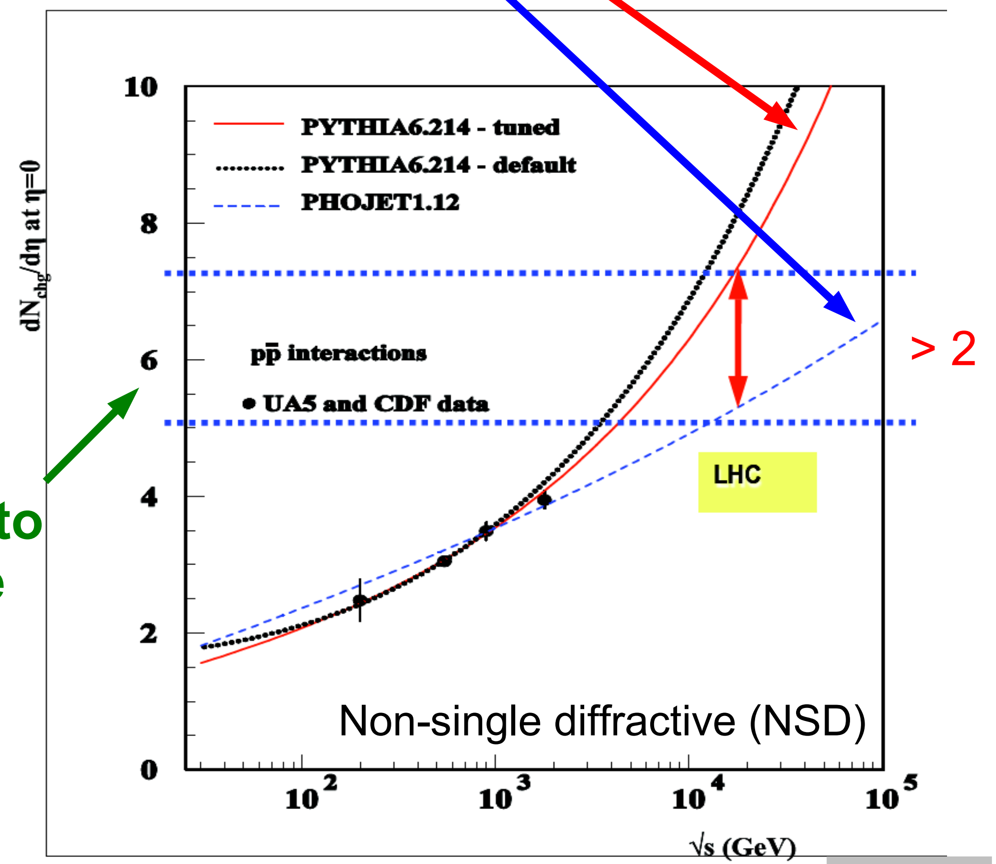


CMS PAS QCD-07-001

Will be able to differentiate

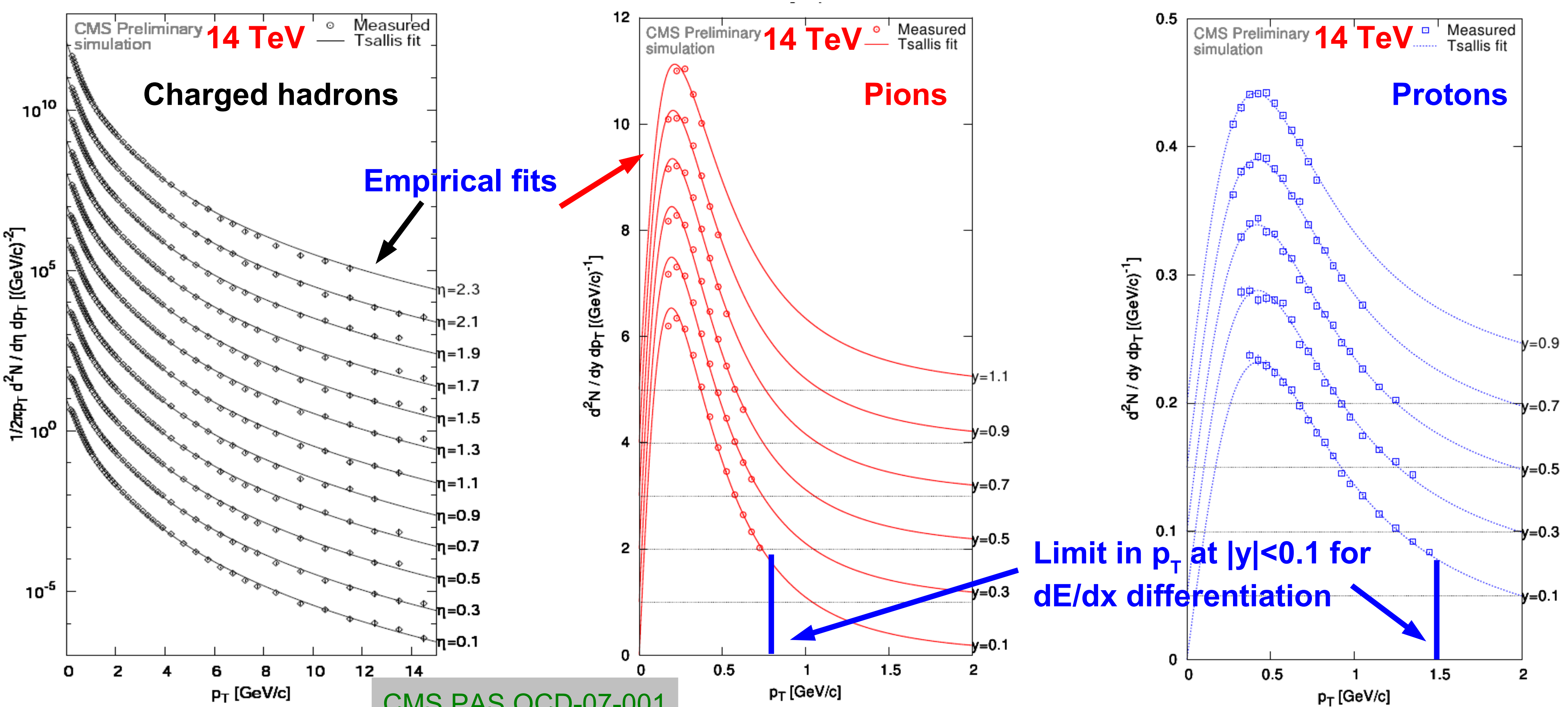
Model expectations for charged particles at |η| = 0 vs. √s:

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



ATLAS

Charged Hadron Spectra



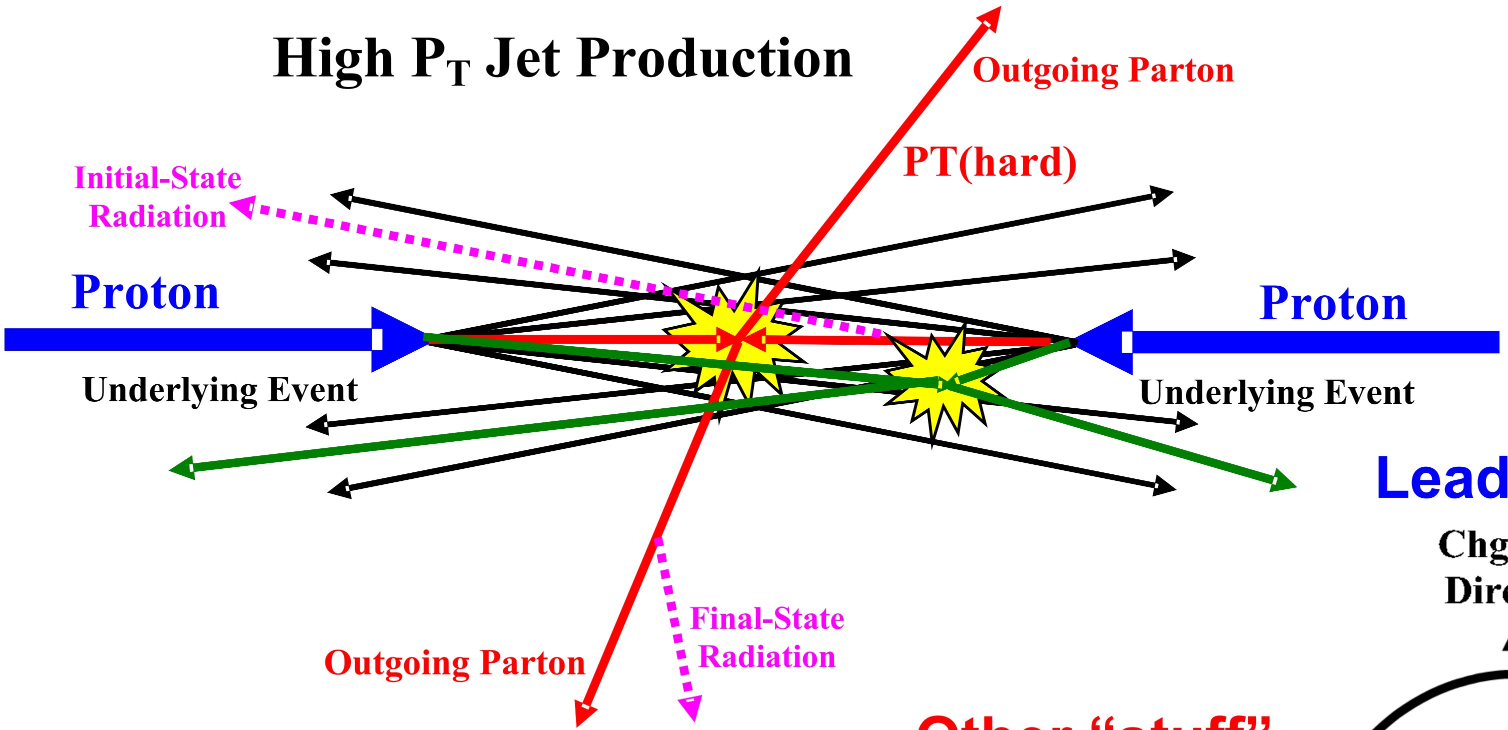
CMS PAS QCD-07-001

Technique:
Tracks from pixel triplet seeding
→ Tracking down to p_T of 75 MeV

Systematic:
Trigger, feed-down, geom. acceptance, alg. efficiency

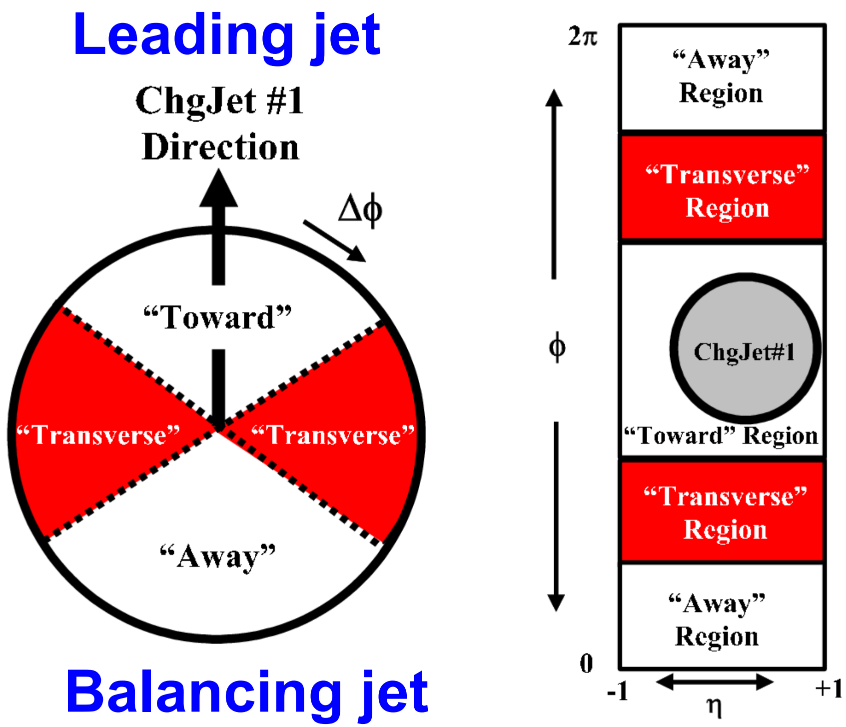
Events: ~ 2M
One month with 1 Hz allocated bandwidth

The Underlying Event



The Underlying Event is everything but the hard scatter.

Other "stuff" but the hard scatter

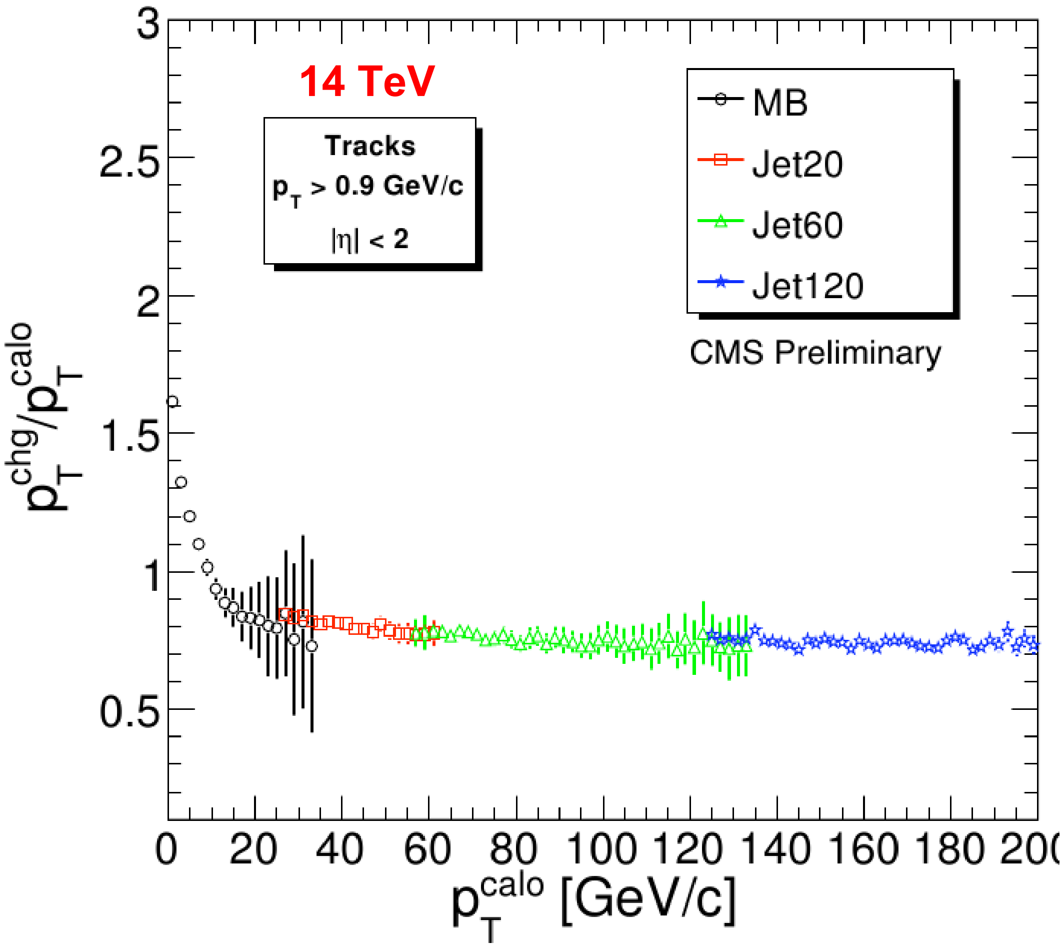


Measurement possibility:

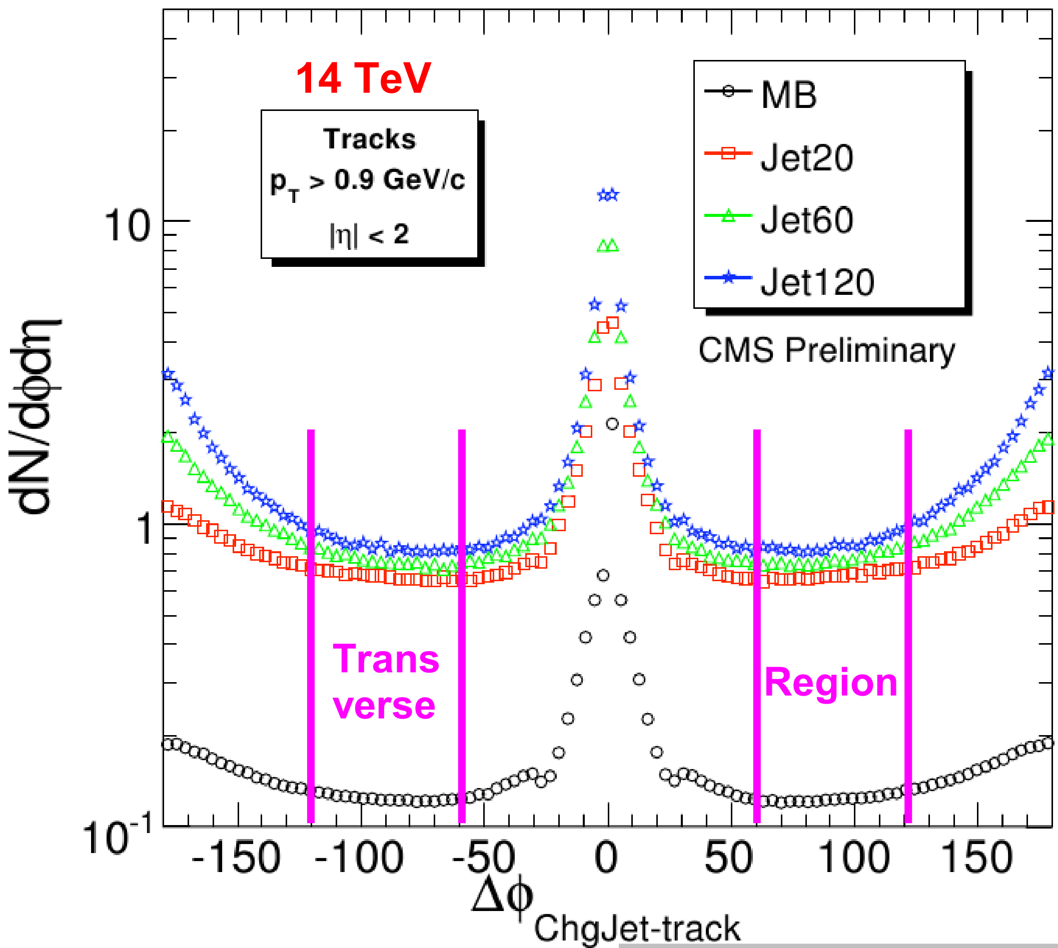
- Charged particle and p_T sum densities in transverse region of leading jet of charged particles

The Underlying Event

Mix of contributing MinBias and calorimetric jet triggers



Decomposition of trigger contributions to charged particle density in ΔΦ plane

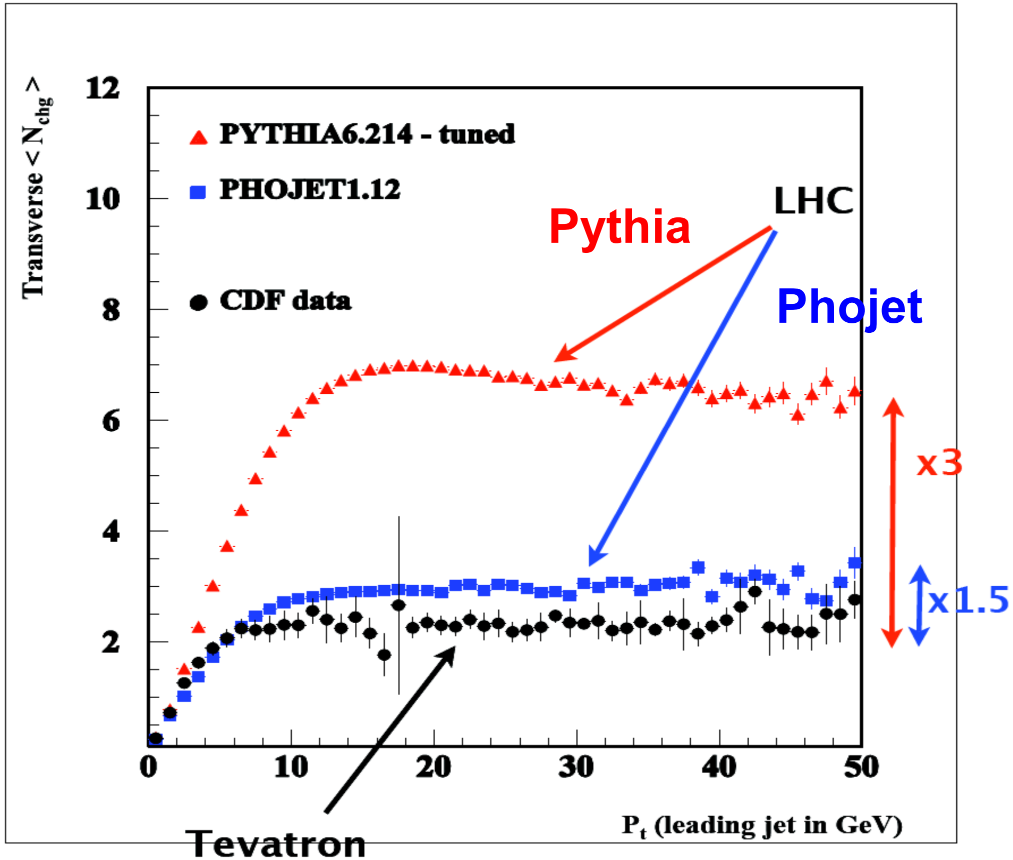


CMS PAS QCD-07-003

The Underlying Event

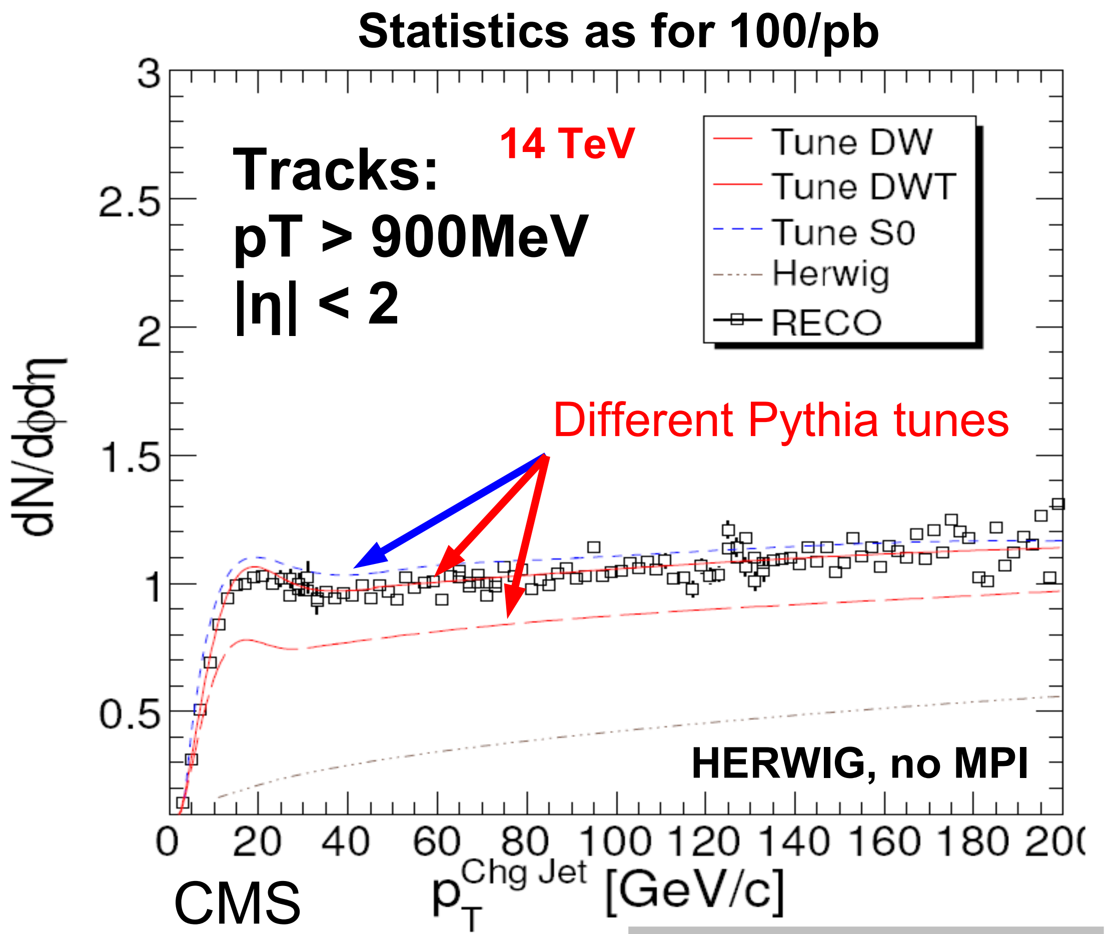
Charged particle density in transverse plane vs. leading charged jet p_T

Extrapolation to LHC from CDF data



ATLAS

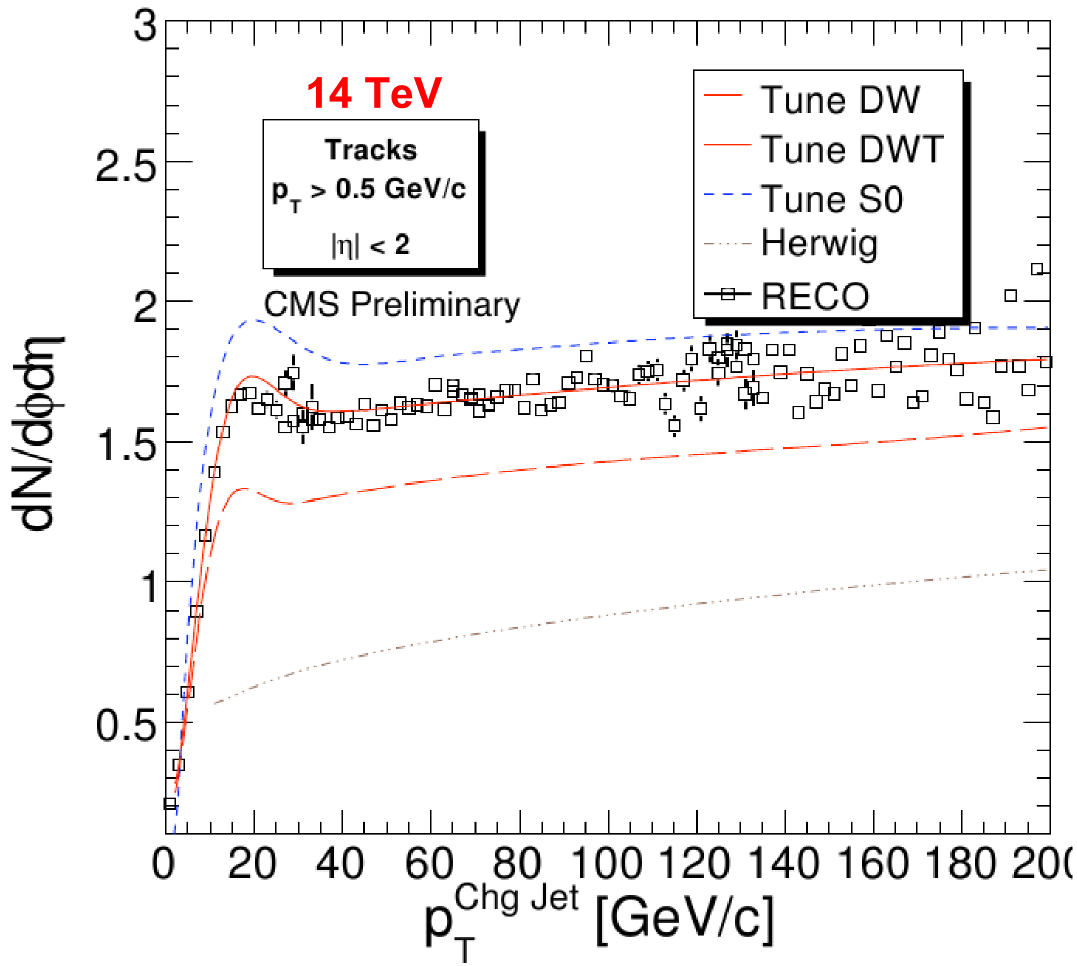
Comparison of different Pythia tunes



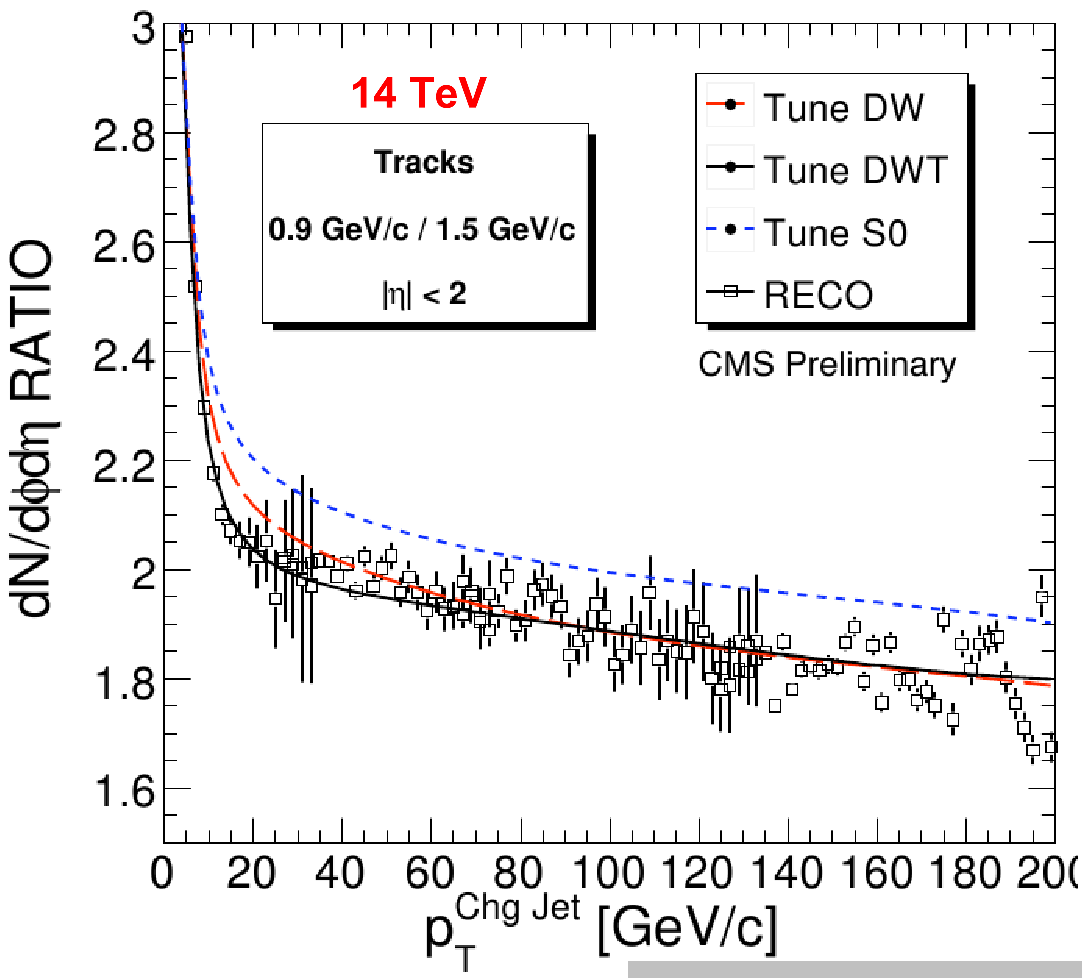
CMS PAS QCD-07-003

The Underlying Event

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



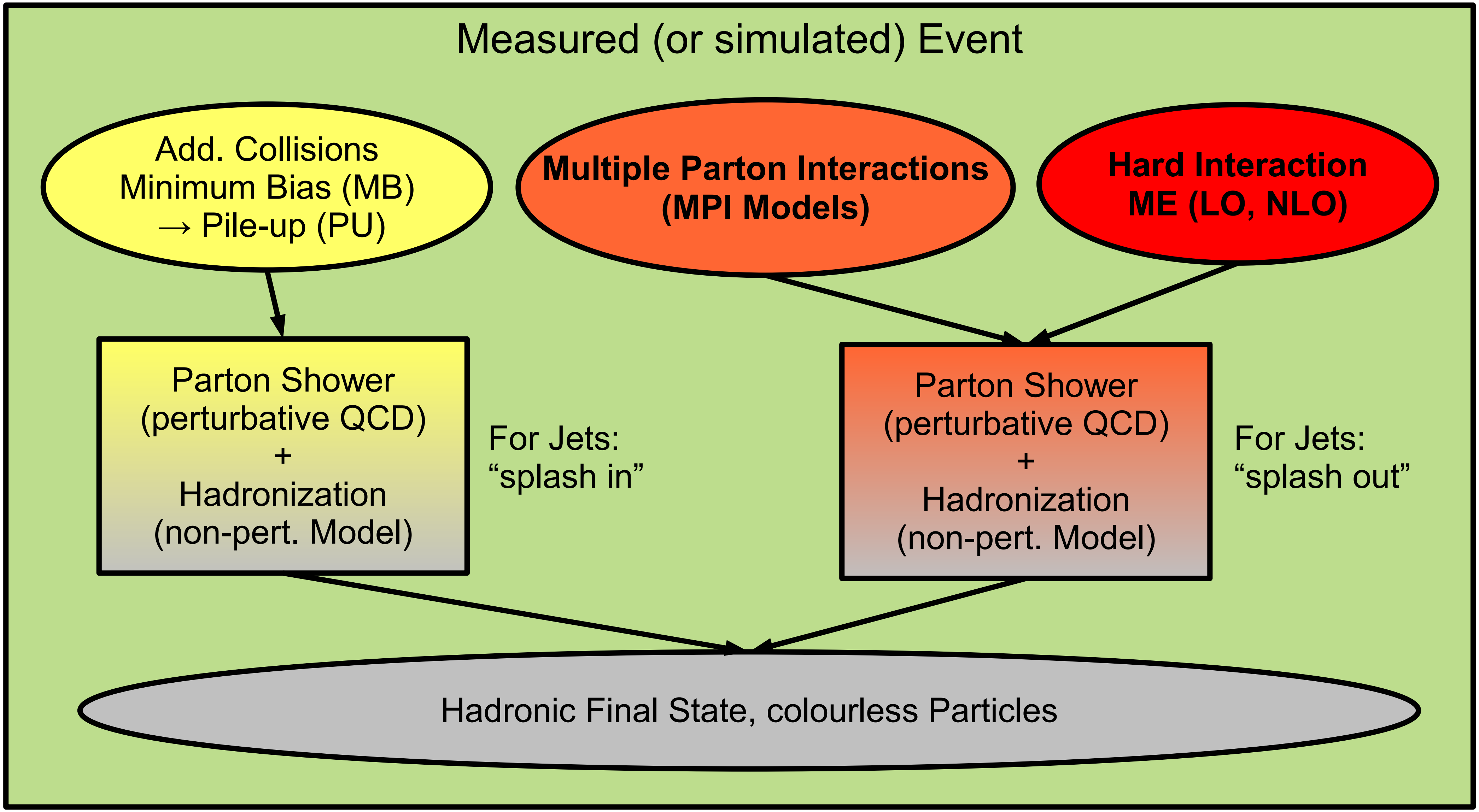
Decrease systematic effects with ratio, but with similar systematic → 0.9 / 1.5



CMS PAS QCD-07-003

Jets

Theory Picture



Experimental Picture

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)

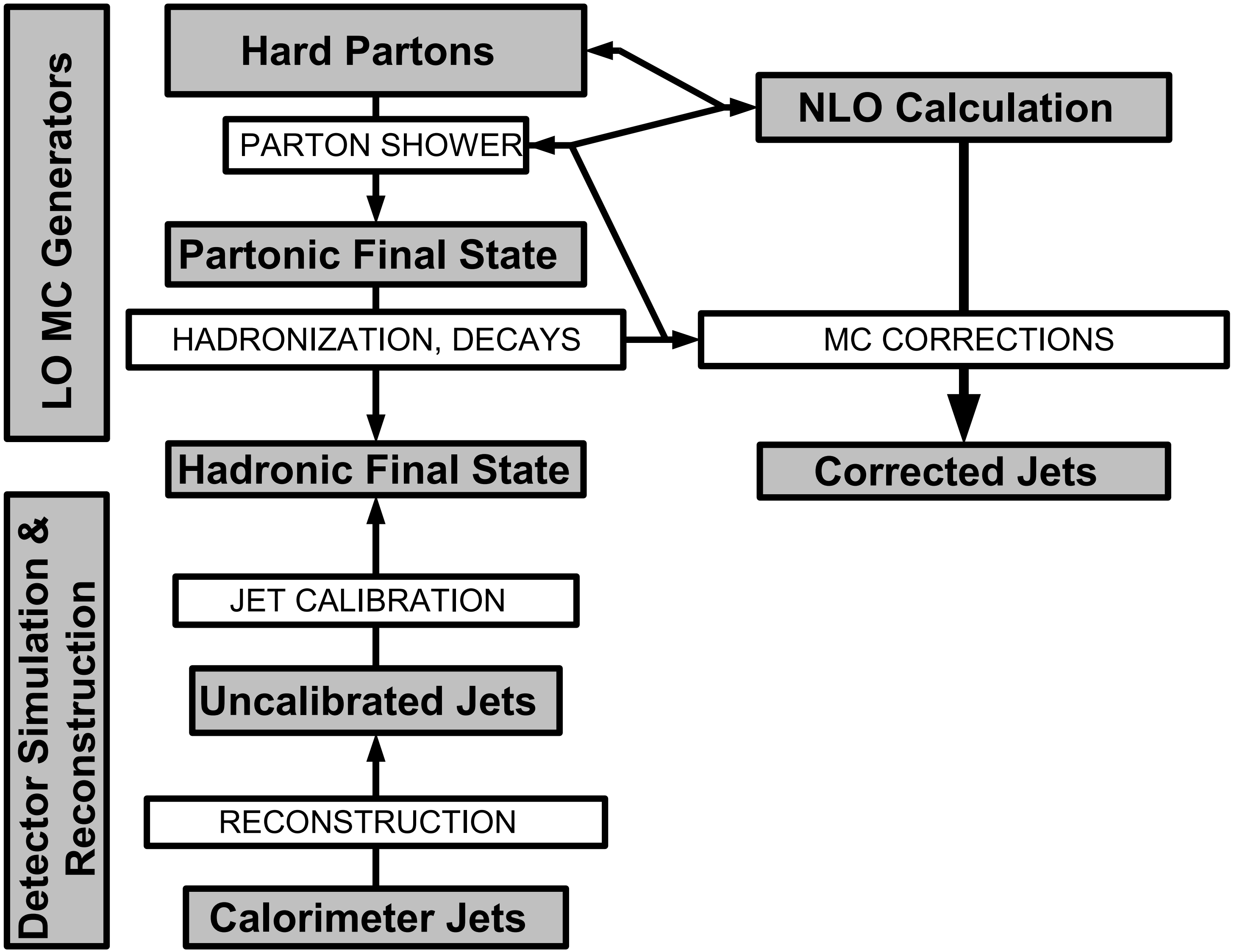
The JES dominates the total uncertainty of the measurement

K. Kousouris

Generic Jet Analysis

- Requires:
  - PDFs
  - LO & NLO MC
  - Det. simulation
  - Jet energy scale and resolution
  - Calorimeter calibration
  - Jet triggers
  - Luminosity
  - and ...

  Data, of course!



Jet Analysis Uncertainties

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

Recall: Jet Algorithms used by CMS:
- Iterative Cone R = 0.5
- SISCone R = 0.5, 0.7
- k_T D = 0.4, 0.6

- **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
  - • • •

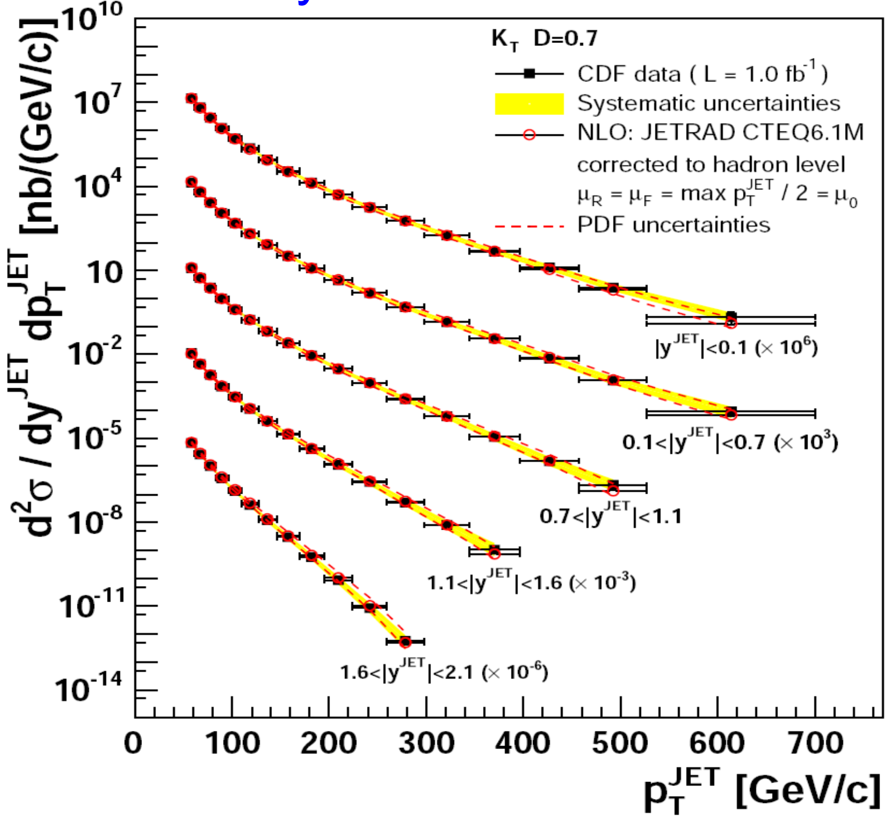
QCD Jet Analyses

- **Jet analyses at high transverse momenta:**
  - **Dijet azimuthal decorrelation**
    - **Less sensitive to JES, not dependent on luminosity**
  - **Event shapes**
    - **Reduced sensitivity to JES & JER, not dependent on luminosity**
  - **Dijet production ratios & angles**
    - **Reduced sensitivity to JES, not dependent on luminosity**
  - **Jet cross section ratios (3-jet / all, R=0.7 / R=0.5, SISCone / kT)**
    - **Reduced sensitivity to JES, not dependent on luminosity**
  - **Jet shapes**
  - **Multi-jet studies**
  - **Inclusive jet cross section**
    - **Most complicated, requires all uncertainties to be under control!**

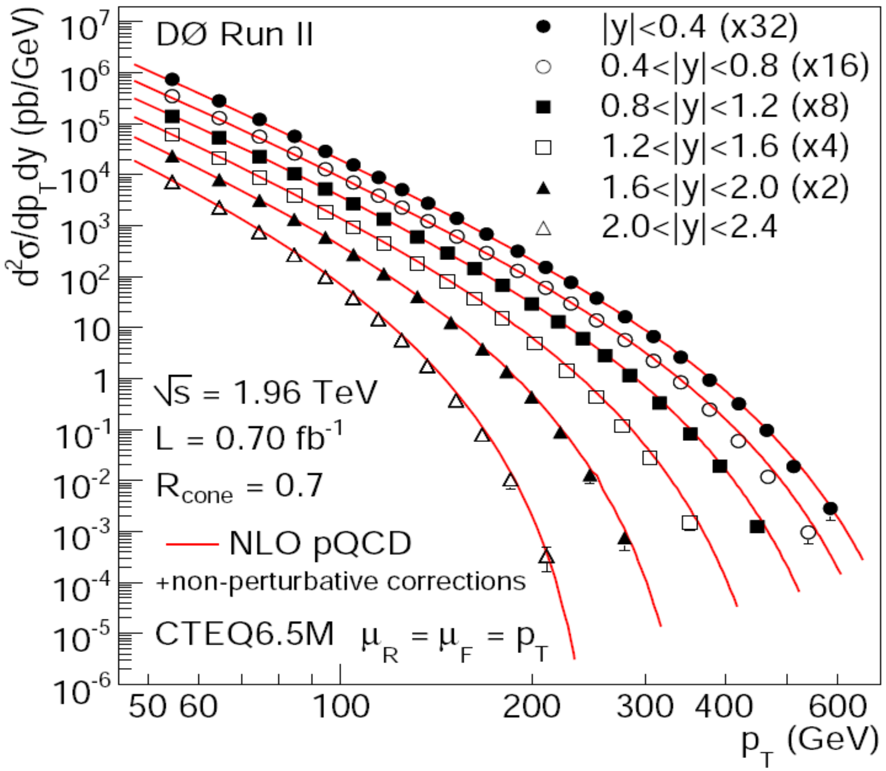
Inclusive Jets at the Tevatron

CDF Incl. k_T jets, D=0.7
Theory: NLO with CTEQ6.1M

Phys.Rev.D75:092006,2007



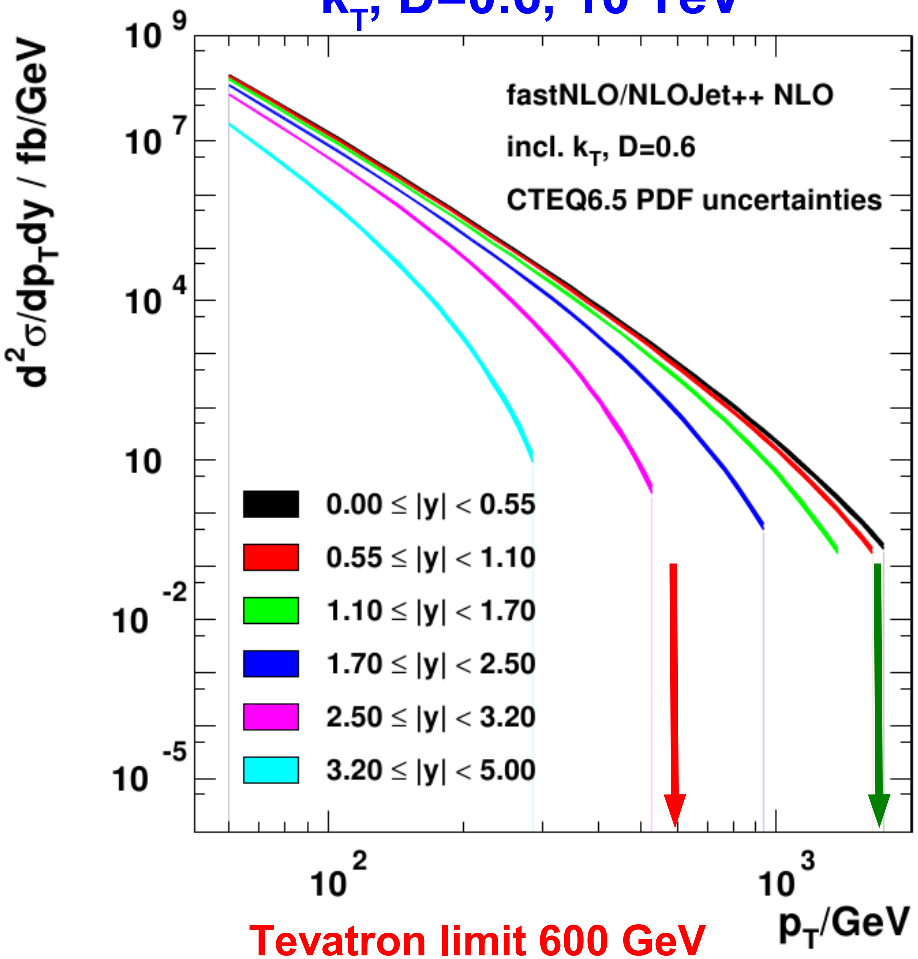
D0 Incl. MidPoint cone jets, R=0.7
Theory: NLO with CTEQ6.5M



arXiv:0802.2400 [hep-ex]

Inclusive Jets at the LHC

k_T, D=0.6, 10 TeV

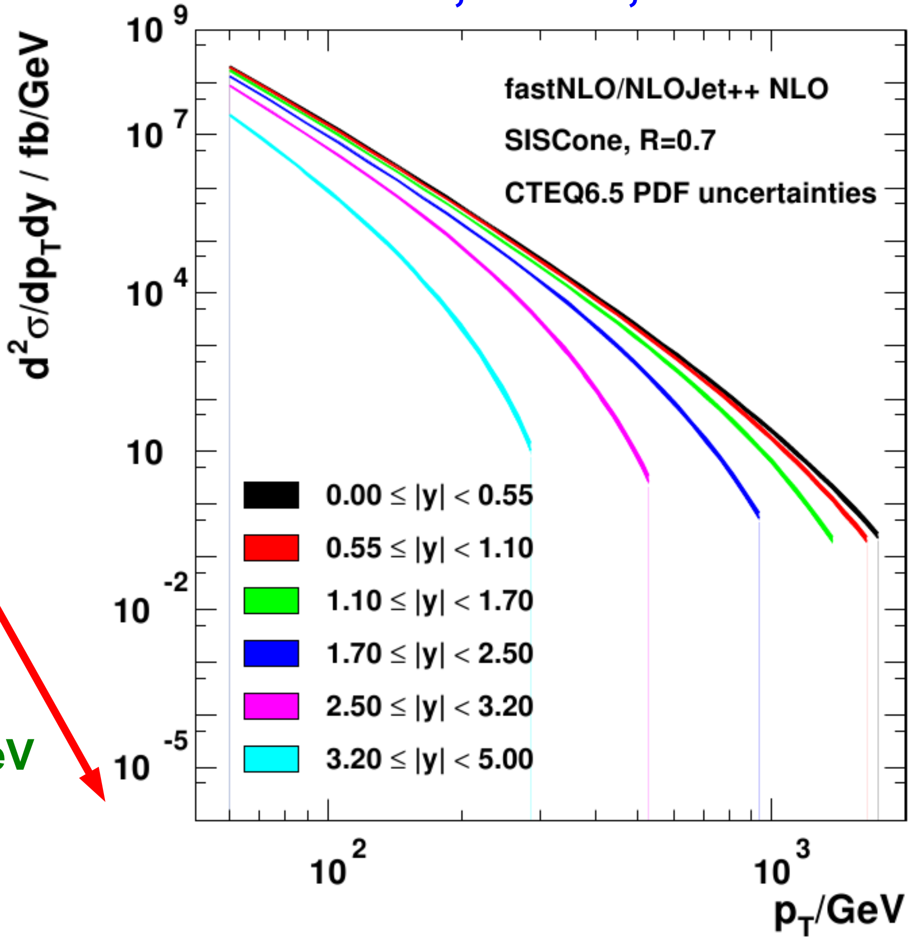


Tevatron limit 600 GeV

Log Scale

LHC reach
> 2 x 600 GeV
with 10/pb

SISCone, R=0.7, 10 TeV



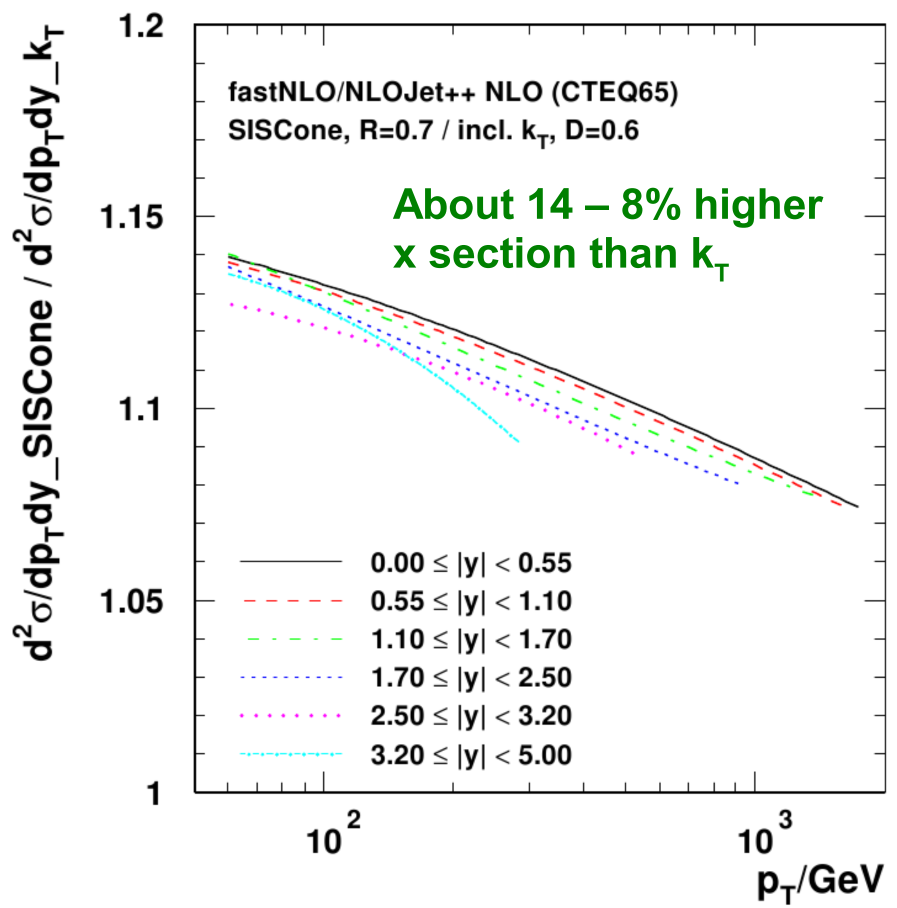
Bands are PDF uncertainties from CTEQ6.5

NLOJET++, PRL 88 122003 (2002),PR D68 094002 (2003)
fastNLO, hep-ph/0609285
fastjet: PLB641 (2006) [hep-ph/0512210],
SISCone: JHEP 05 (2007) 086 [arXiv:0704.0292 (hep-ph)]

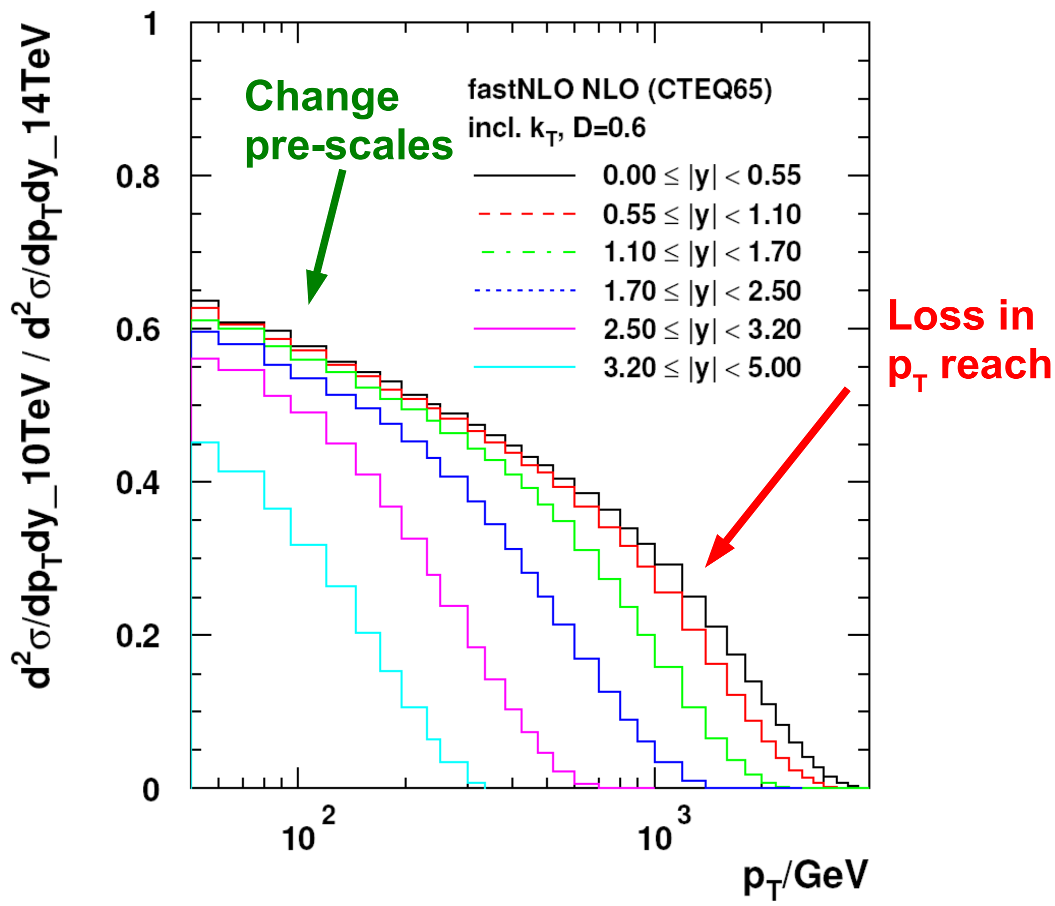
Cross Section Ratios

Cross section ratios in 6 bins in rapidity y

SISCone 0.7 / k_T 0.6 @ 10 TeV



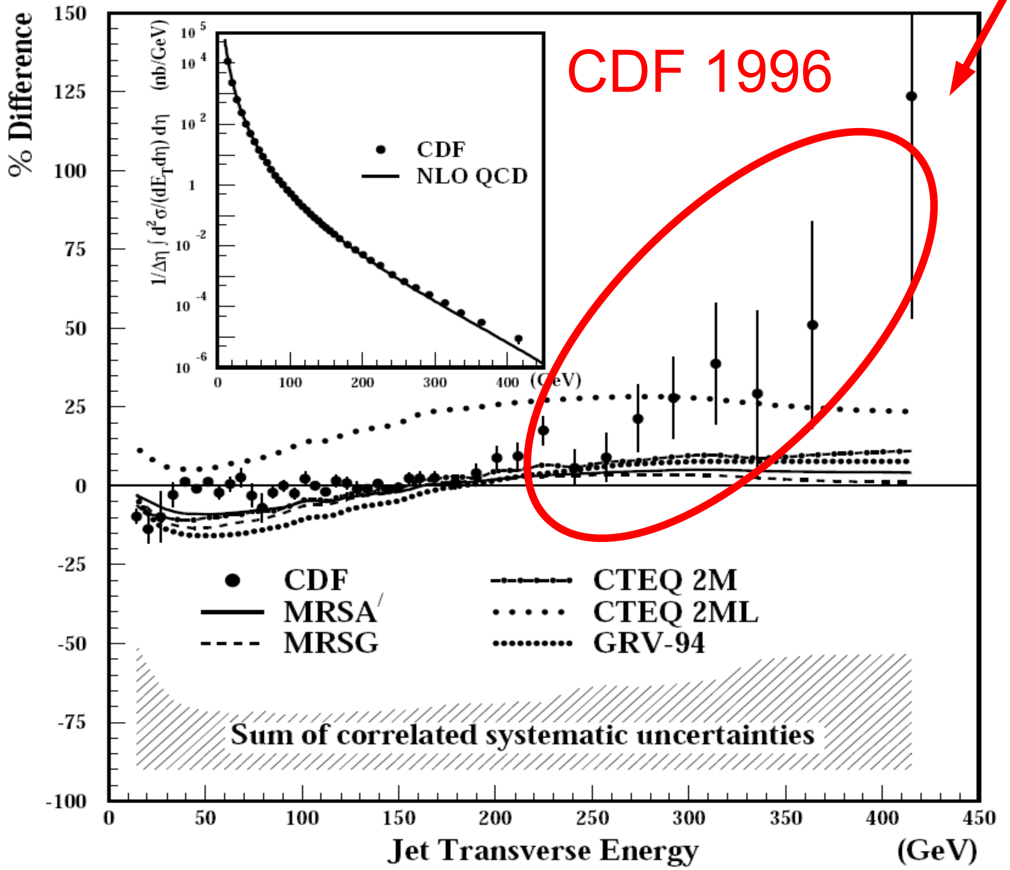
k_T 0.6 10 TeV / 14 TeV



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)

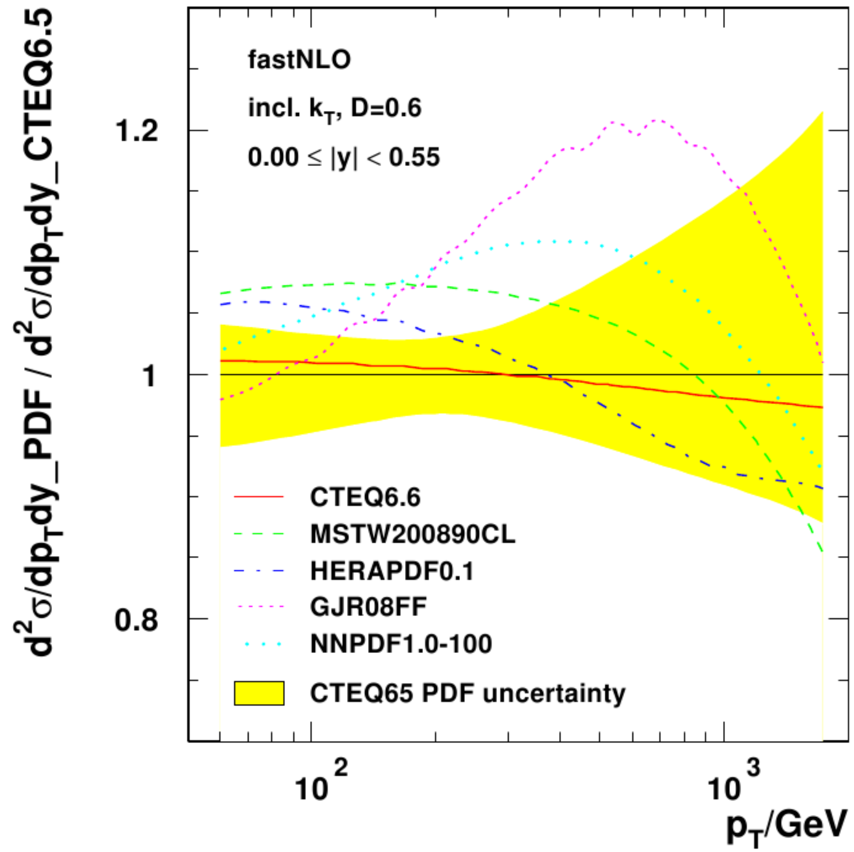


Explained by change in gluon density which then can be constrained by jets!

Today:

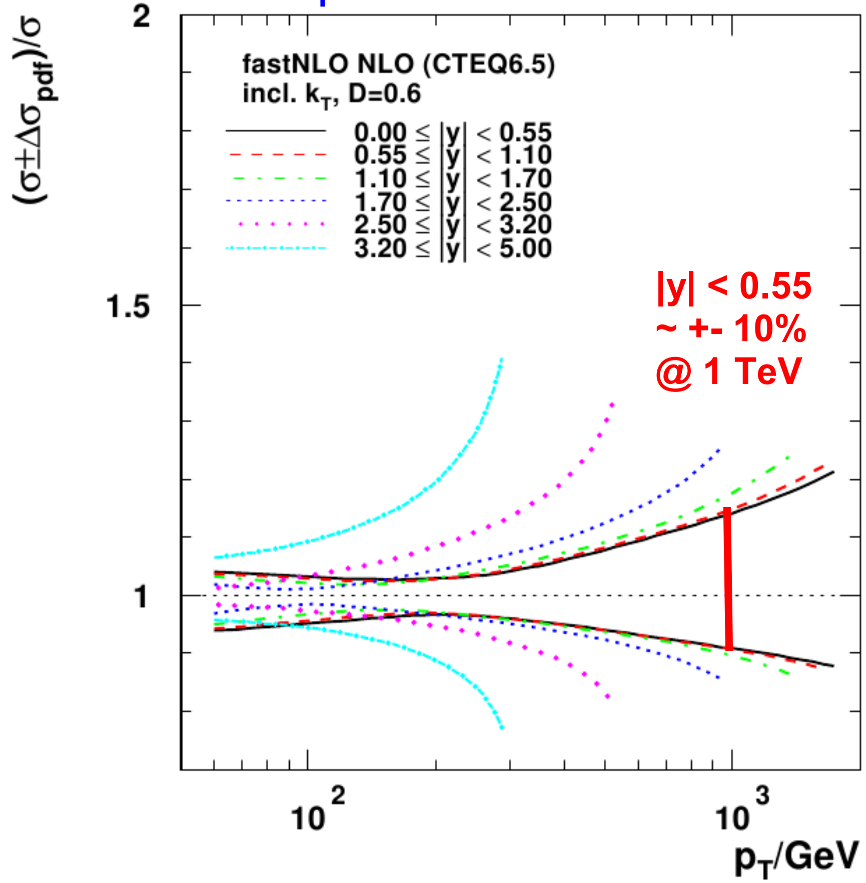
Much better estimates of PDF uncertainties

But beware ...



PDF and Scale Uncertainties

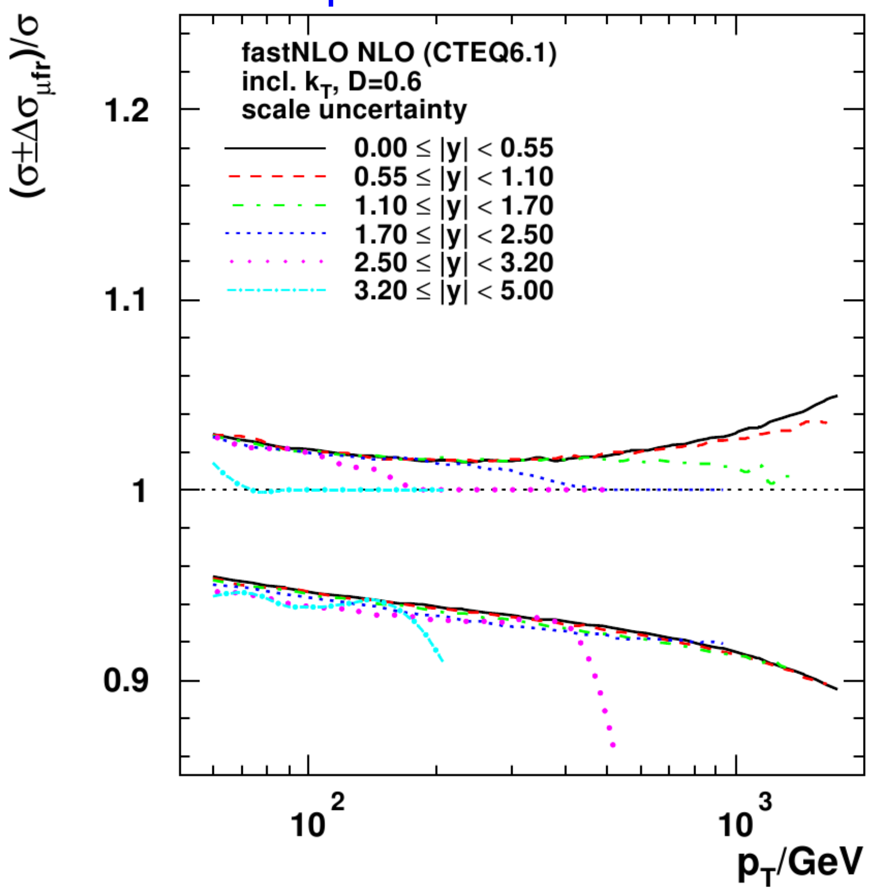
k_T, D=0.6, 10 TeV



SISCone: Similar result

PDF uncertainties from CTEQ 6.5
At 4 TeV in p_T about -20% to +35%

k_T, D=0.6, 10 TeV

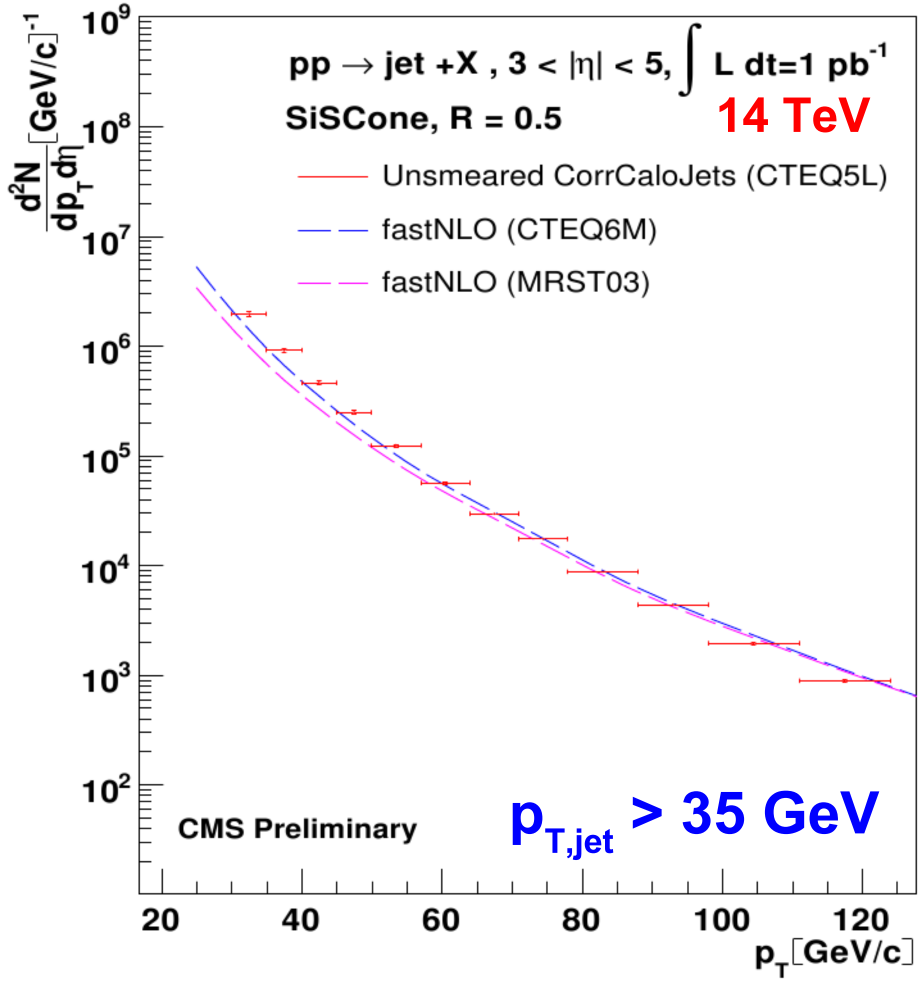


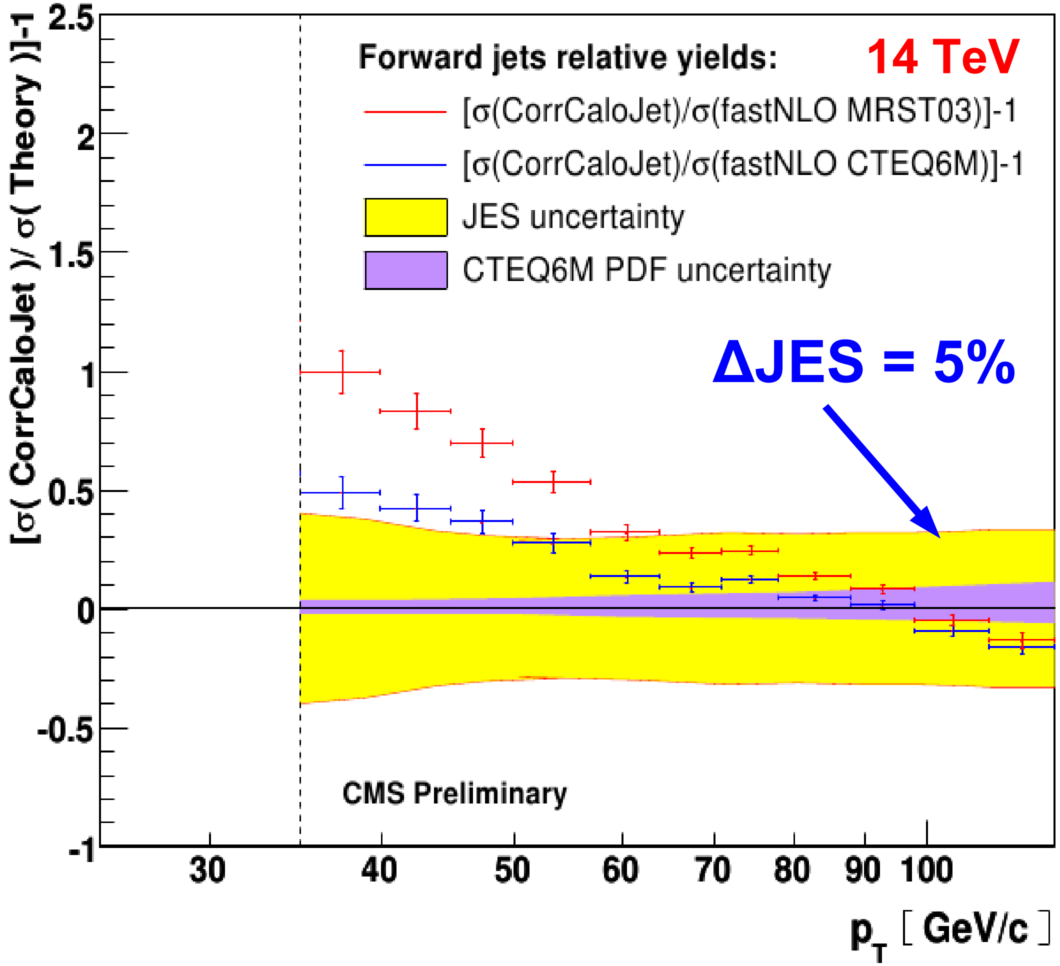
SISCone: Up to twice as large!

Scale variation of $p_{T,jet}$ to
0.5 * $p_{T,jet}$ and 2 * $p_{T,jet}$

Forward Jets and PDFs

Possible constraint on PDFs, but need to know JES!





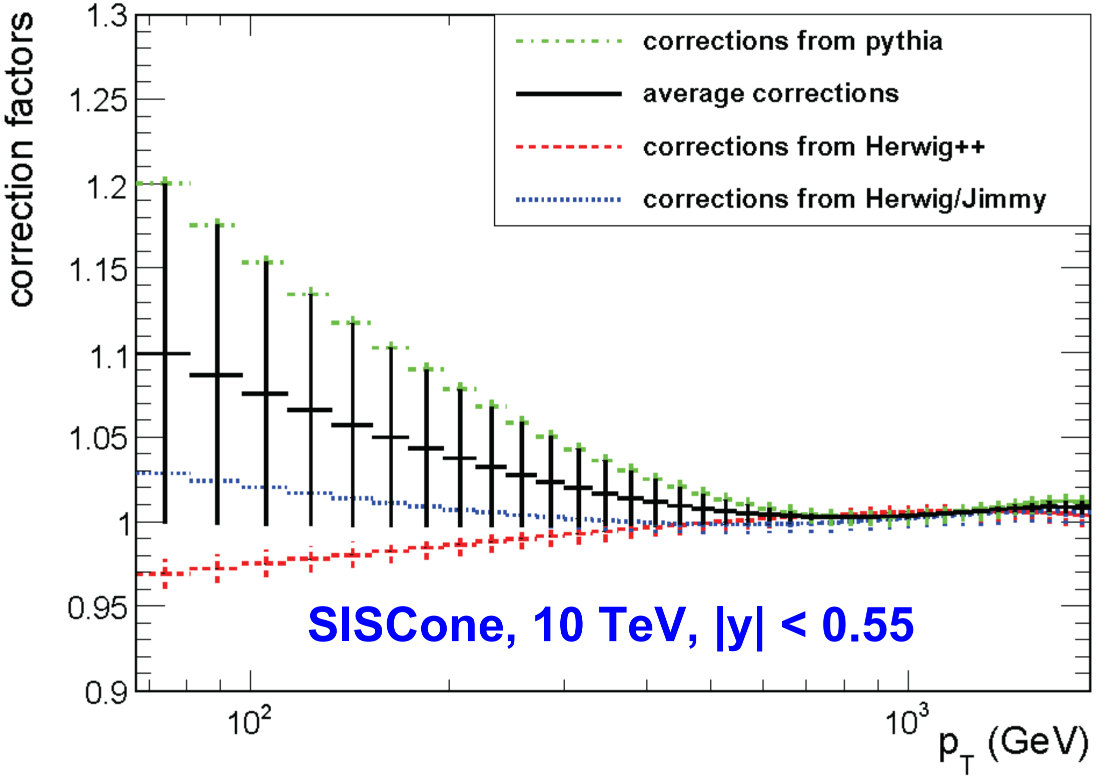
CMS PAS FWD-08-001

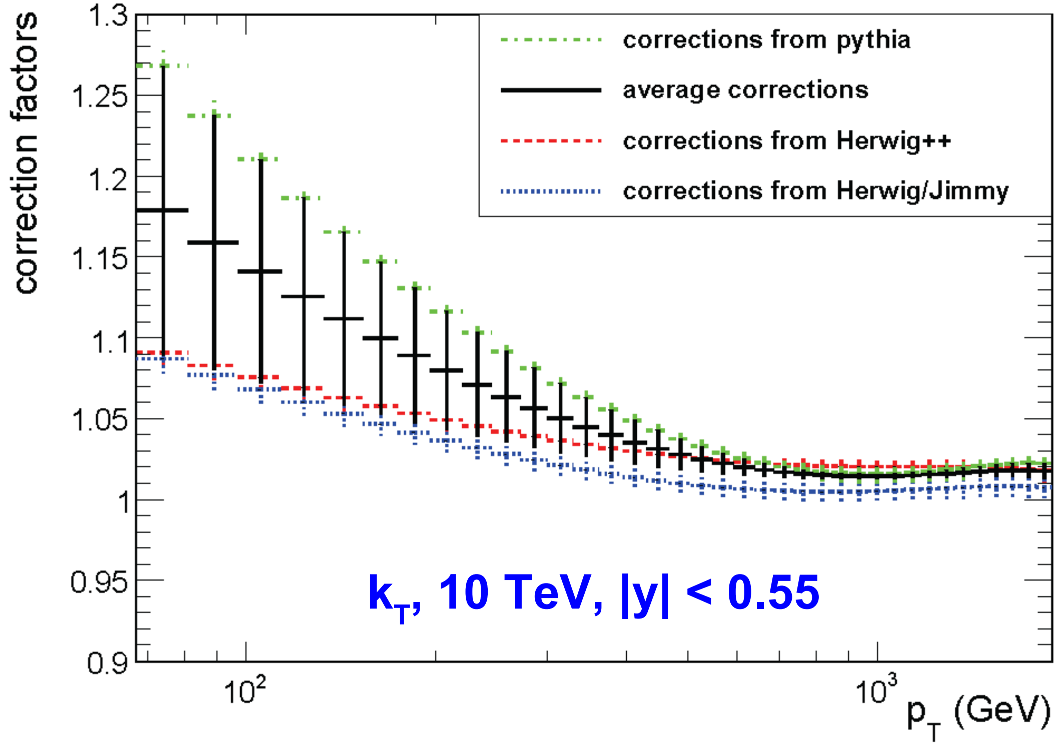
Non-perturbative Corrections

To compare with data correct NLO for:

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

Less compensation of these effects for k_T than for SISCone, not negligible in both cases.
Need MC tunes for UE with first LHC data!



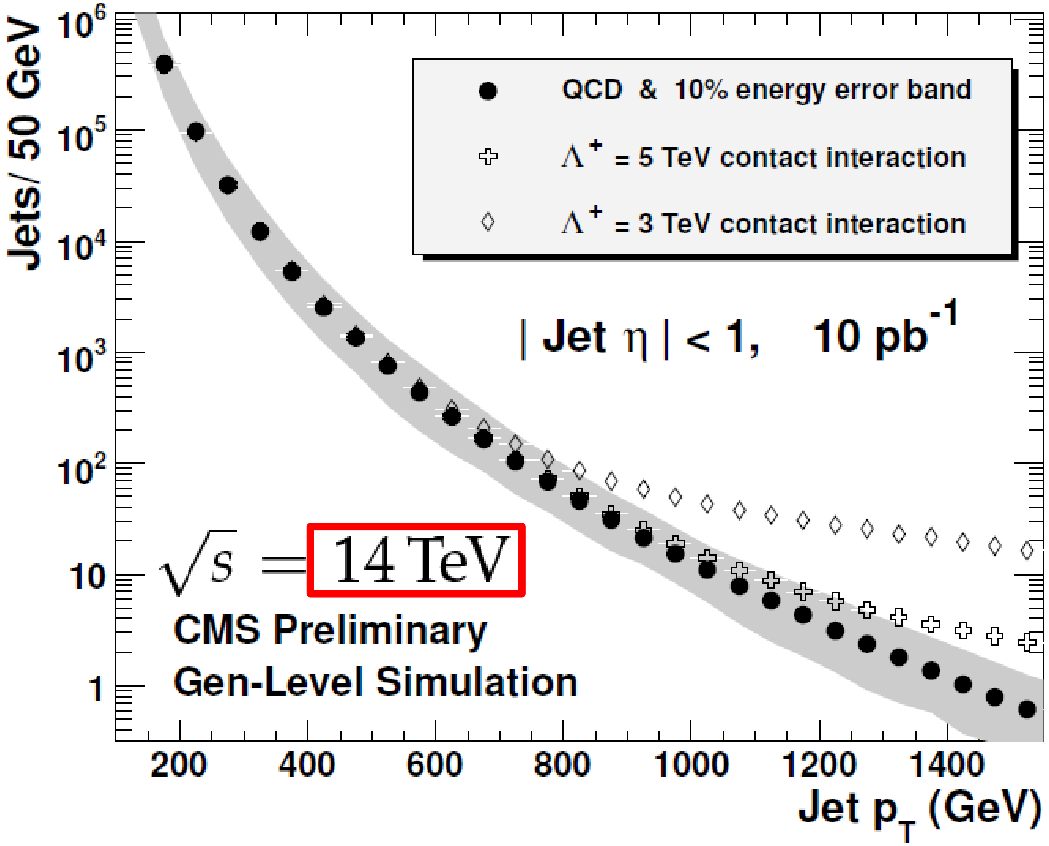


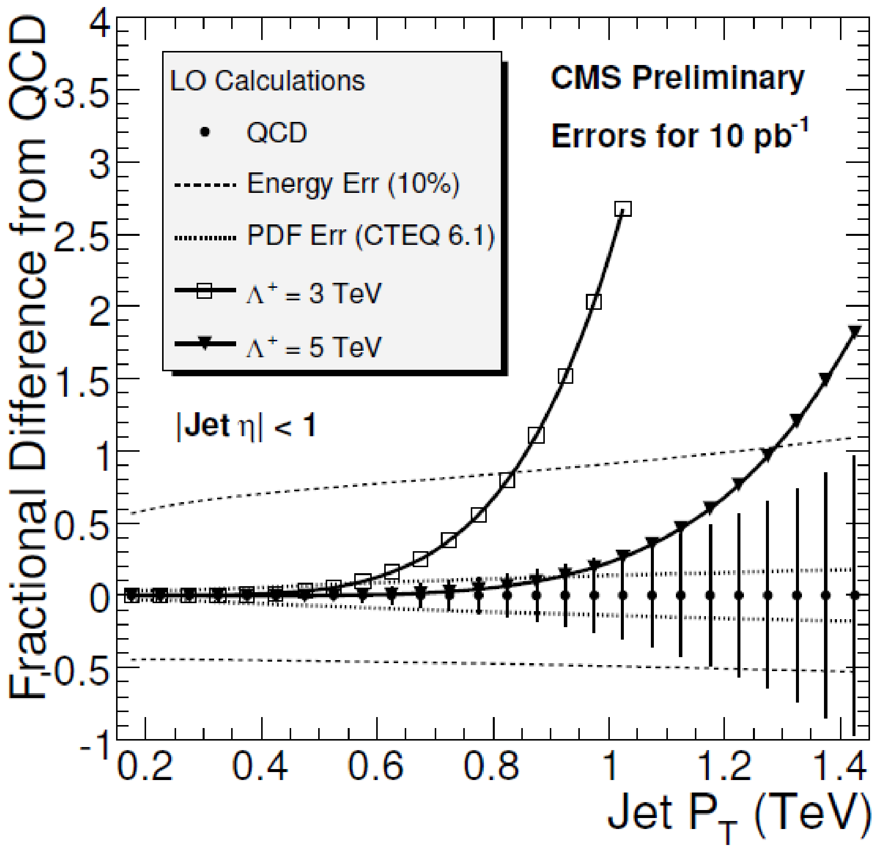
Compared 3 different tuned MC:

- **Pythia Tune D6T**
- **Herwig++**
- **Herwig/Jimmy with settings from ATLAS**

Take e.g. correction as average of Pythia and half of each, Herwig++ and Herwig/Jimmy, as uncertainty

JES and New Physics





- Dominating experimental uncertainty: JES (assumed ± 10% at startup)
- More data and improved JES knowledge needed to start constraining PDFs
- Sensitive to Contact Interactions beyond Tevatron reach (2.7 TeV) with 10 pb^{-1}

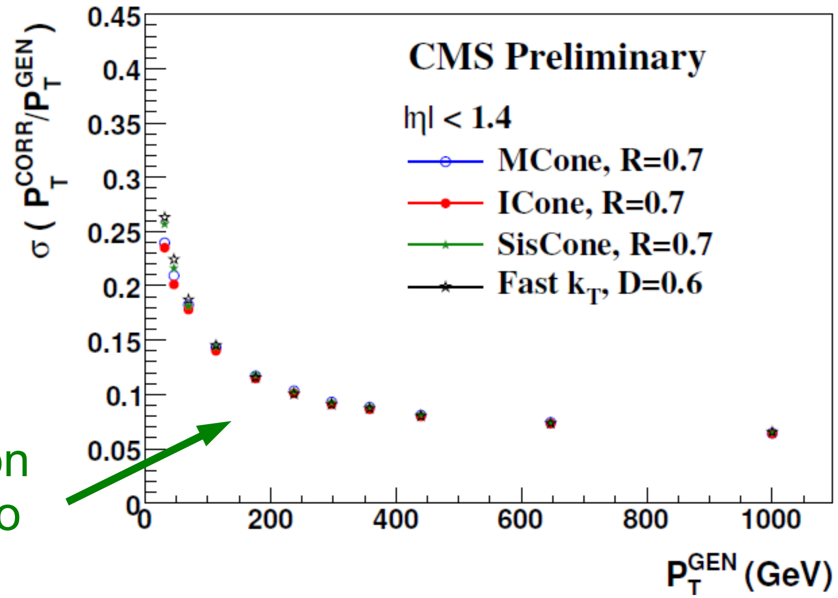
CMS PAS SBM-07-001

Jet Energy Resolution

- Jet energy resolution from CMS performance study
- JER usually parameterized by:

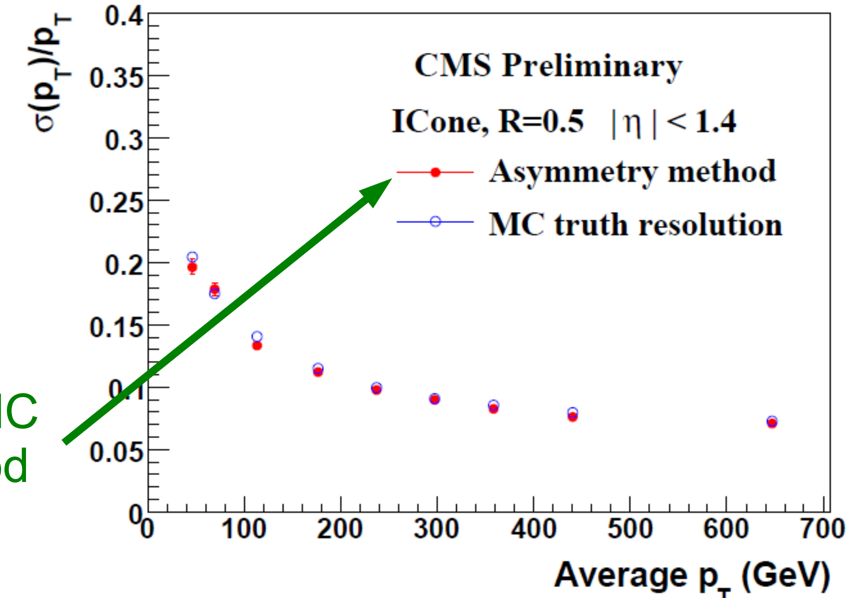
$$\sigma(p_T) = p_T \cdot \sqrt{C^2 + \frac{S^2}{p_T} + \frac{N^2}{p_T^2}}$$

Derived from MC comparison
Fairly independent of jet algo



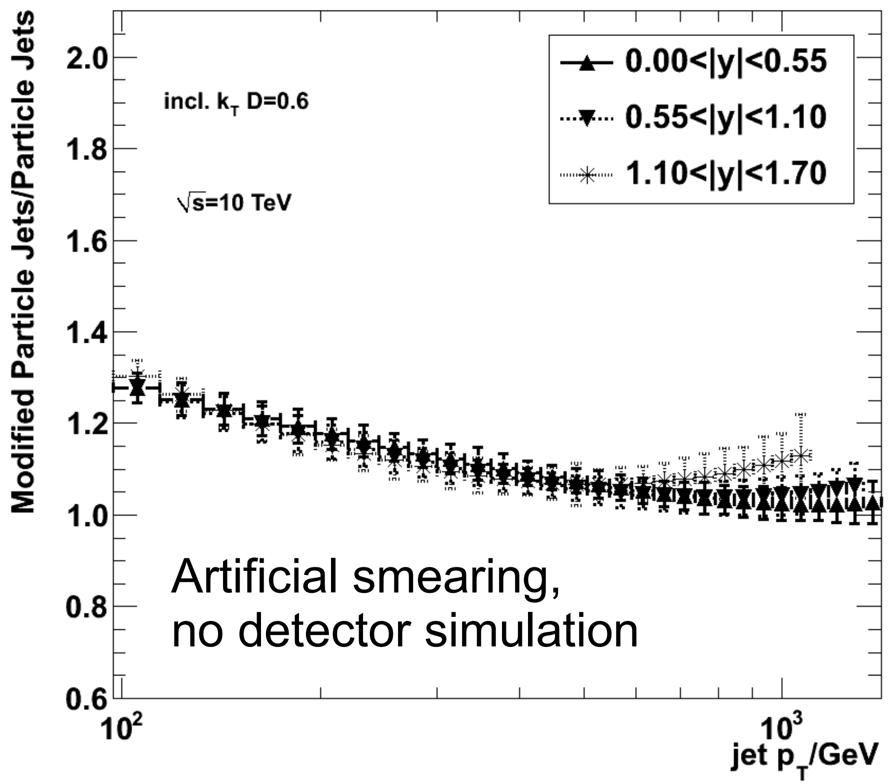
Finite detector resolution on a steeply falling jet p_T spectrum leads to strongly asymmetric bin migrations!

Can be derived from dataMC
with dijet asymmetry method

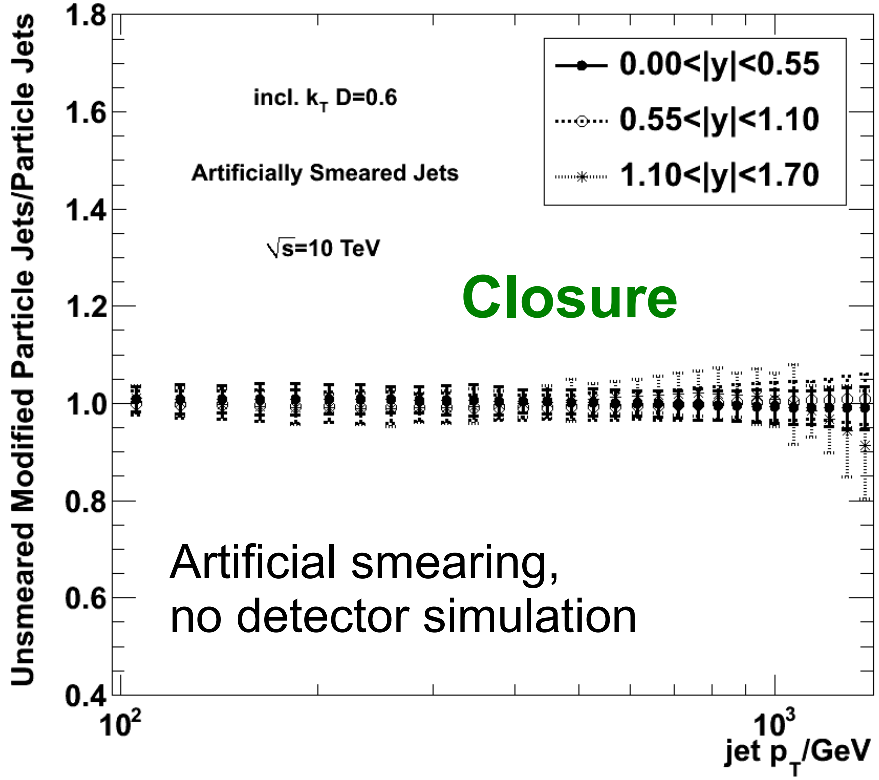


CMS PAS JME-07-003

Unsmearing Applied



Unsmearing by "Ansatz Method"

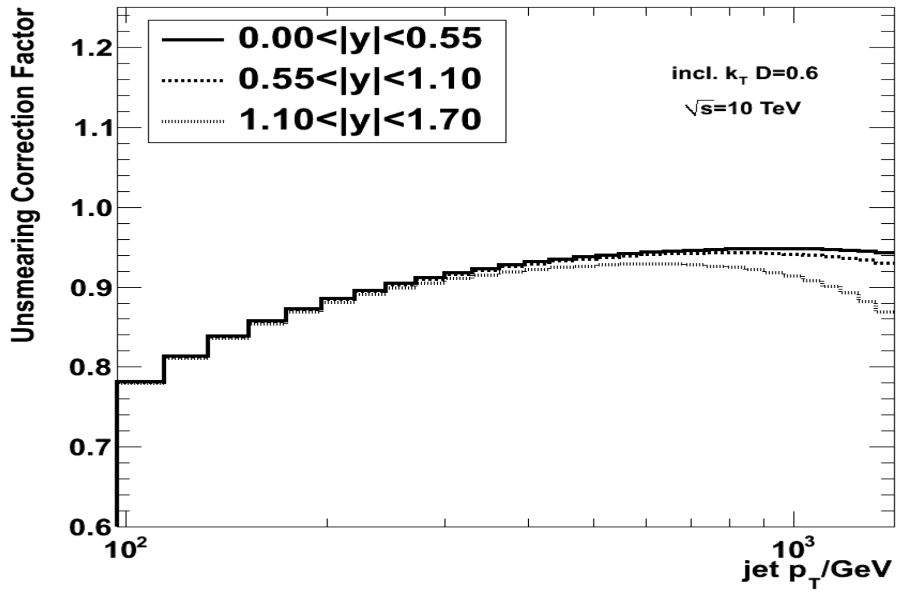


- Artificially smear jets by Gaussian with an arbitrary but reasonable p_T dependent width.
- Apply ansatz method
- Method corrects p_T smearing effects on steeply falling spectrum

Unsmearing Steps

Motivation

The **observed** cross section is **higher** than the true one due to the falling shape of the spectrum and the finite p_T resolution. More events migrate into a bin of measured p_T than out of it.



Unsmearing steps:

Analytical expression of the p_T resolution ➡

$$R(p'_T, p_T) = \frac{1}{\sqrt{2\pi}\sigma(p'_T)} \exp\left[-\frac{(p'_T - p_T)^2}{2\sigma^2(p'_T)}\right]$$

Ansatz function with free parameters to be determined by the data ➡

$$f(p_T) = N \cdot p_T^{-a} \cdot \left(1 - \frac{2\cosh(y_{min})p_T}{\sqrt{s}}\right)^b \exp(-\gamma p_T)$$

Fitting the data with the Ansatz function smeared with p_T resolution. ➡

$$F(p_T) = \int_0^\infty f(p'_T) R(p'_T, p_T) dp'_T$$

Unsmearing correction calculated bin by bin. ➡

$$C_{bin} = \frac{\int_{bin} f(p_T) dp_T}{\int_{bin} F(p_T) dp_T}$$

JER Uncertainty

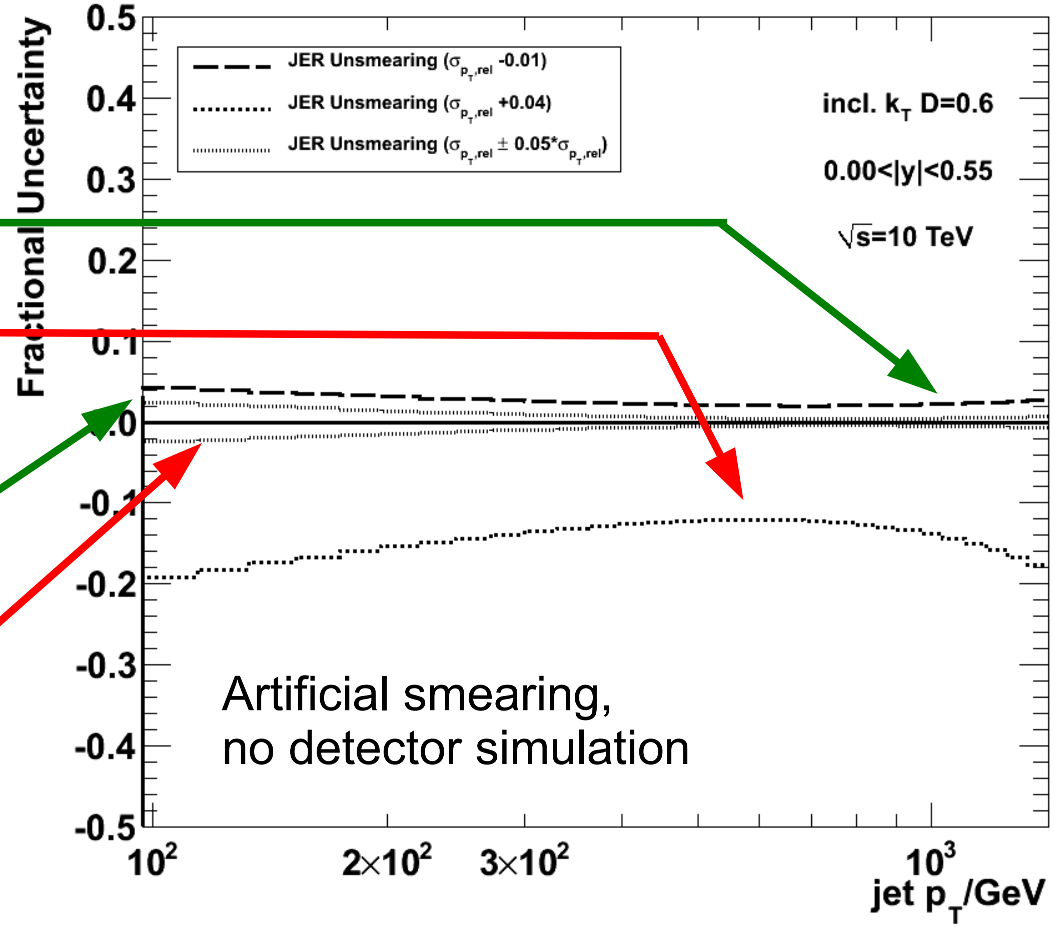
Good knowledge of the resolution required!
A wrong assumption can shift the final spectrum easily by some percent ...

Two scenarios studied:

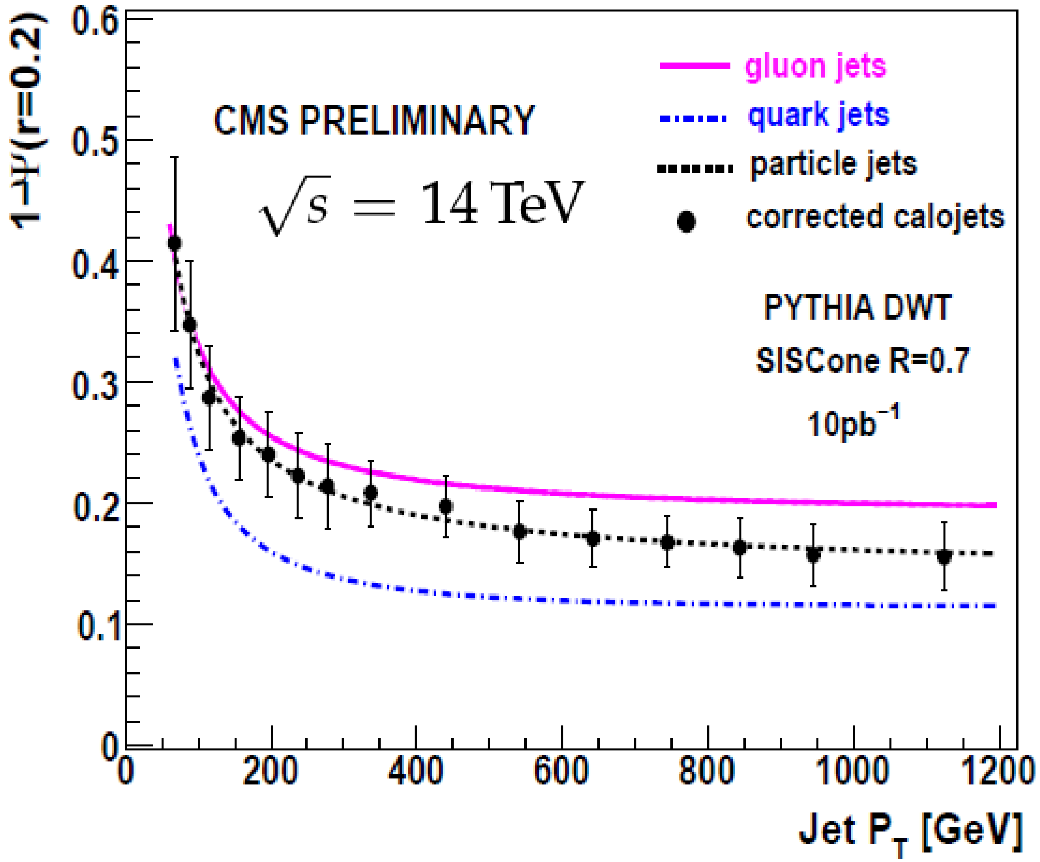
- **Very pessimistic:**
  - Resolution in unsmearing is "real" resolution (in %) - 1 %: 1% better (-)
  - Resolution in unsmearing is "real" resolution (in %) + 4%: 4% worse (+)

Optimistic:

- Resolution in unsmearing is 0.95 times "real" resolution (in %): 5 % better (*)
- Resolution in unsmearing is 1.05 times "real" resolution (in %): 5 % worse (*)



Jet Shapes

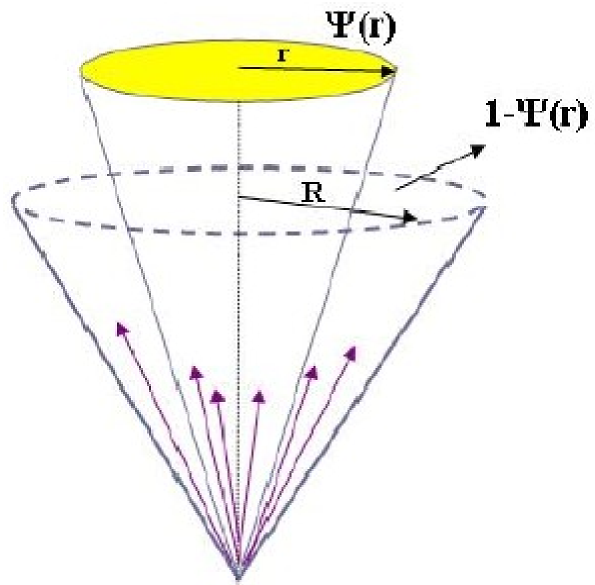


Measurement of the average integrated (differential) energy flow inside jets.

Jet shape measurements can be used to test the showering models in the MC generators.

Jet shape measurements can be used to discriminate between different underlying event models.

Can be used to distinguish gluon originated jets from quark jets.



Integrated jet shape
Ψ(r)

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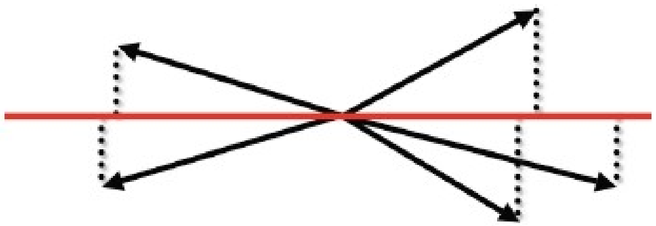
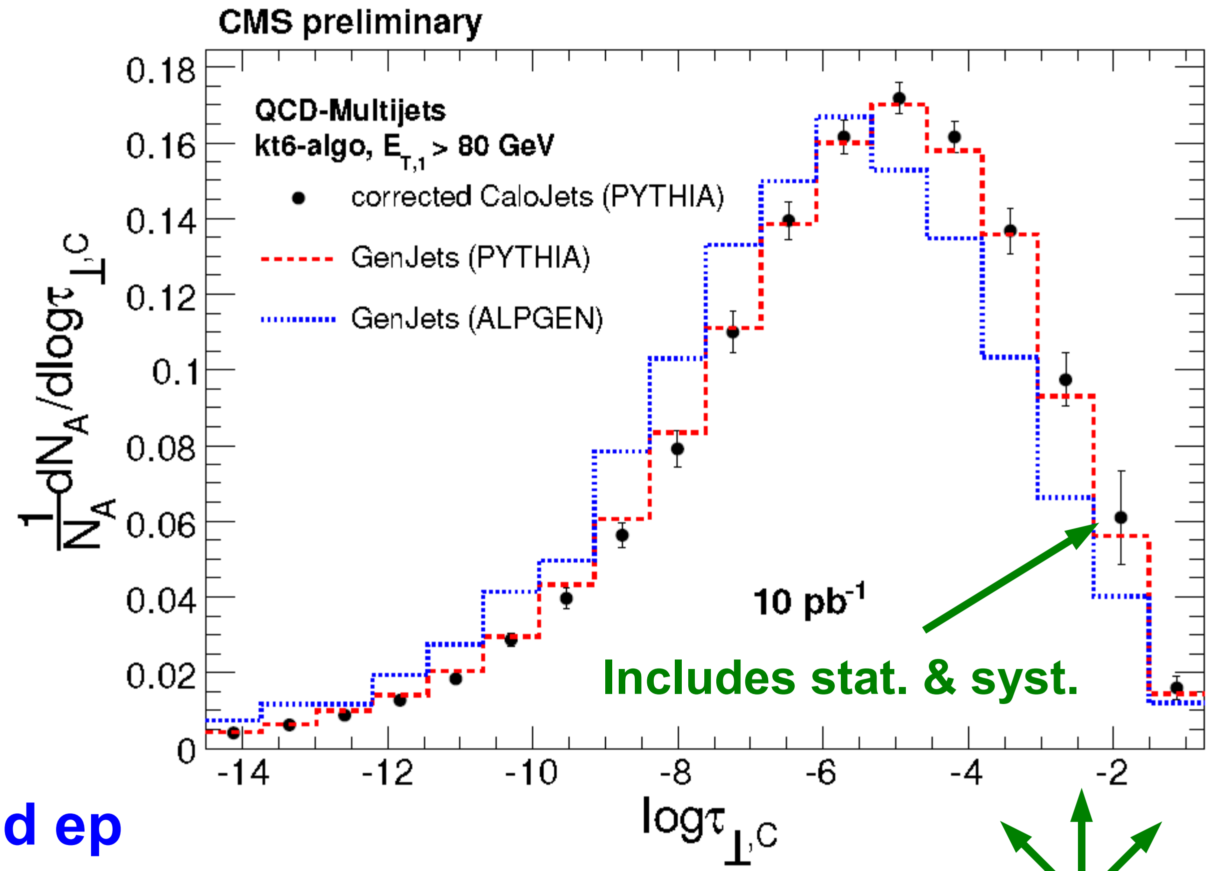
Event Shapes

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**

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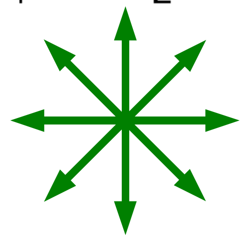
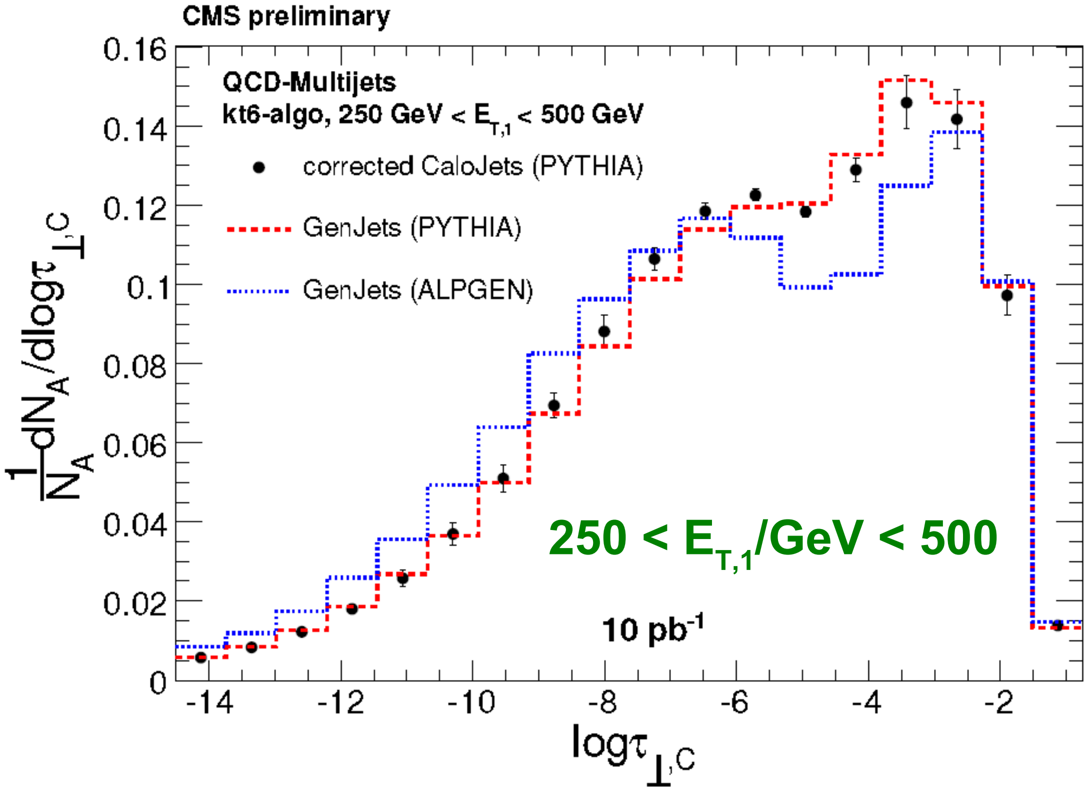
linear

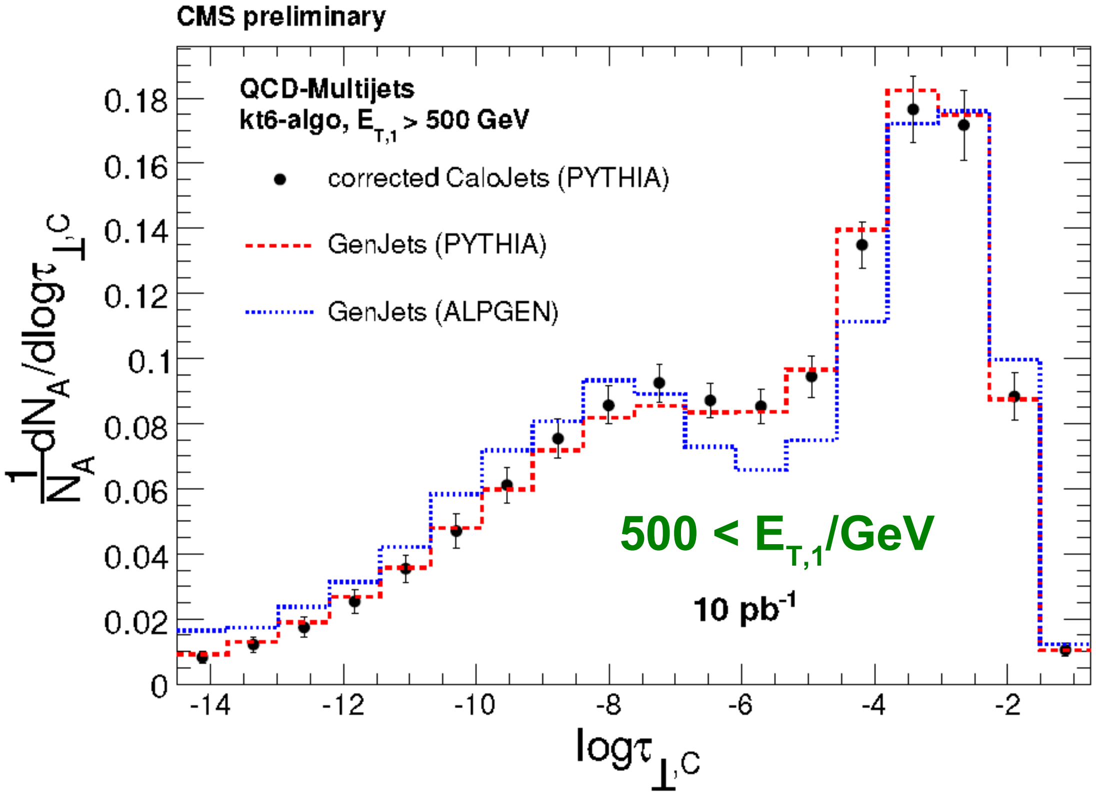


linear $\quad \tau_{\perp,g} \equiv 1 - T_{\perp,g} \quad$ spherical

Event Shapes

- Distributions get more peaked at higher E_T
- Corrected pseudo-data follow behaviour of original Pythia MC
- Alpgen makes different predictions





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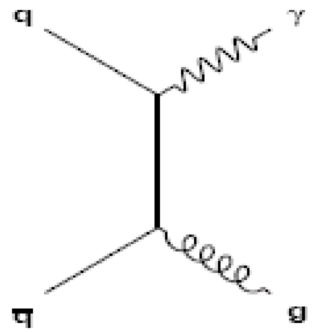
Some Photons (and Jets)

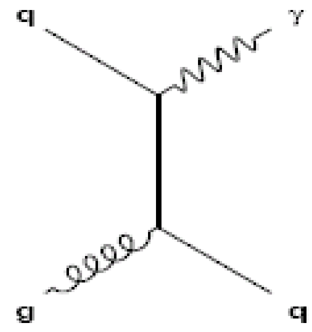
Photons

- <u>Photon processes:</u>
  - Direct photon production
  - Di-photons
  - Photon + n jets

< 20% LO Dominant: > 80%



Annihilation Process



Compton Process

# bunches	β^* (m)	I_b	L ($\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	Pileup	Photons/hour ($p_T > 20\,\mathrm{GeV}$)
1x1	18	10^{10}	10^{27}	low	$3.2 \cdot 10^{-1}$
43x43	18	$3 \cdot 10^{10}$	$3.8 \cdot 10^{29}$	0.05	$1.2 \cdot 10^{2}$
43x43	4	$3 \cdot 10^{10}$	$1.7 \cdot 10^{30}$	0.21	$5.4 \cdot 10^{2}$
43x43	2	$4 \cdot 10^{10}$	$6.1 \cdot 10^{30}$	0.76	$2.0 \cdot 10^{3}$
156x156	4	$4 \cdot 10^{10}$	$1.1 \cdot 10^{31}$	0.38	$3.6 \cdot 10^{3}$
156x156	4	$9 \cdot 10^{10}$	$5.1 \cdot 10^{31}$	1.9	$1.6 \cdot 10^{4}$
156x156	2	$9 \cdot 10^{10}$	$1.1 \cdot 10^{32}$	3.9	$3.6 \cdot 10^{5}$

Not taken into account → (Pileup)

Photon rate estimations:

- Photon p_T > 20GeV
- Photon $|\eta|$ < 2.5

S. Ganjour

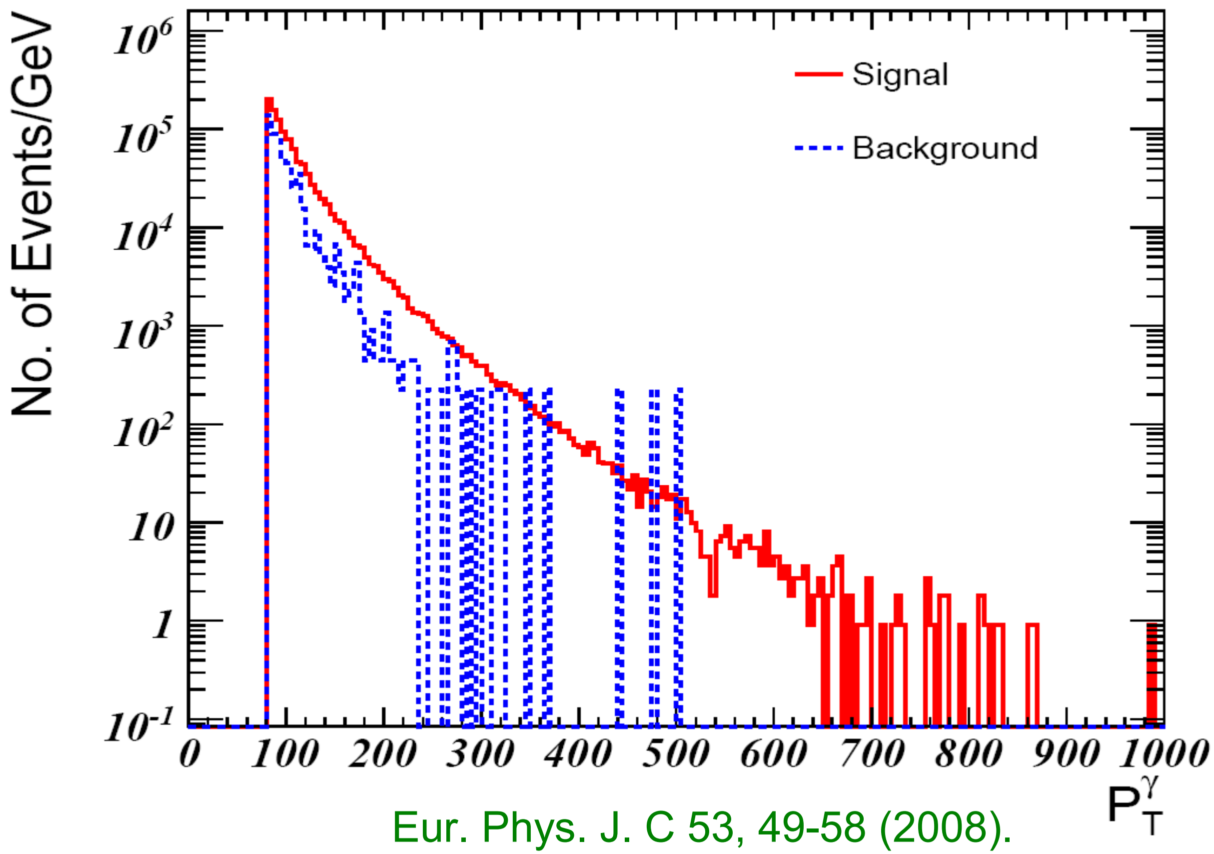
Photon Isolation

Gauge boson production gives important additional information:

- Luminosity measurement
- Detector calibration
- PDFs
- Background for new physics :-(

CMS photon study:

- Photon p_T spectrum for 1/fb
- Background QCD jets in blue
- After photon isolation cuts
- Improves S/B > 2 orders of magnitude



Eur. Phys. J. C 53, 49-58 (2008).

Important steps:

- Good efficiency including photon conversions
- Proper photon isolation to suppress background

Outlook

- **CMS is preparing (again) for first LHC data in autumn**
- **At the LHC we will go beyond Tevatron limits and explore unknown territory in QCD and new physics immediately**
- **First measurements, even at 900 GeV, will be QCD**
- **Some tough experimental systematics to deal with, but combining detector parts may help in certain phase space regions (jets+tracks, particle flow)**
- **Measurements of jets and photons are important tests of QCD and help to**
  - **calibrate the calorimeters**
  - **better understand the dominant background to many new physics channels**
  - **constrain the PDFs**
- **New measurements are just ahead!**

Thanks to all colleagues helping in preparing this presentation!

Be prepared for

at the LHC in autumn!

Thank you for your attention!

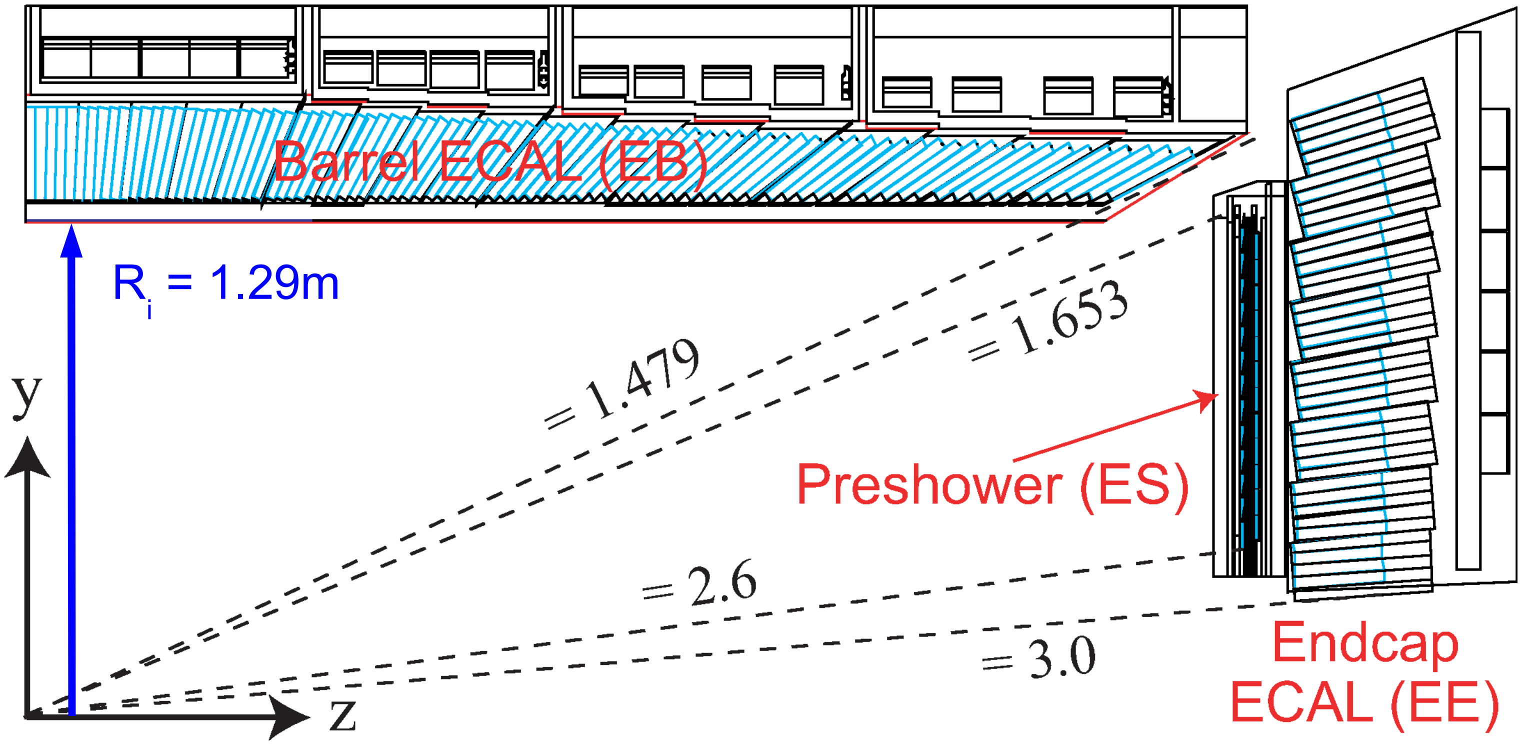
Backups

CMS 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



Energy resolution from test beam:
S = 3.63%, N = 124 MeV, C = 0.26%

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

End caps (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)

CMS Hadronic Calorimeter

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

- Barrel (HB): $|\eta| < 1.4$, 2304 towers
- End caps (HE): $1.3 < |\eta| < 3.0$, „ towers
- Outside coil (HO): $|\eta| < 1.26$ (tail catcher)

→ 4608 towers (Plastic scintillator tiles, ≈ 10 λ_N)

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

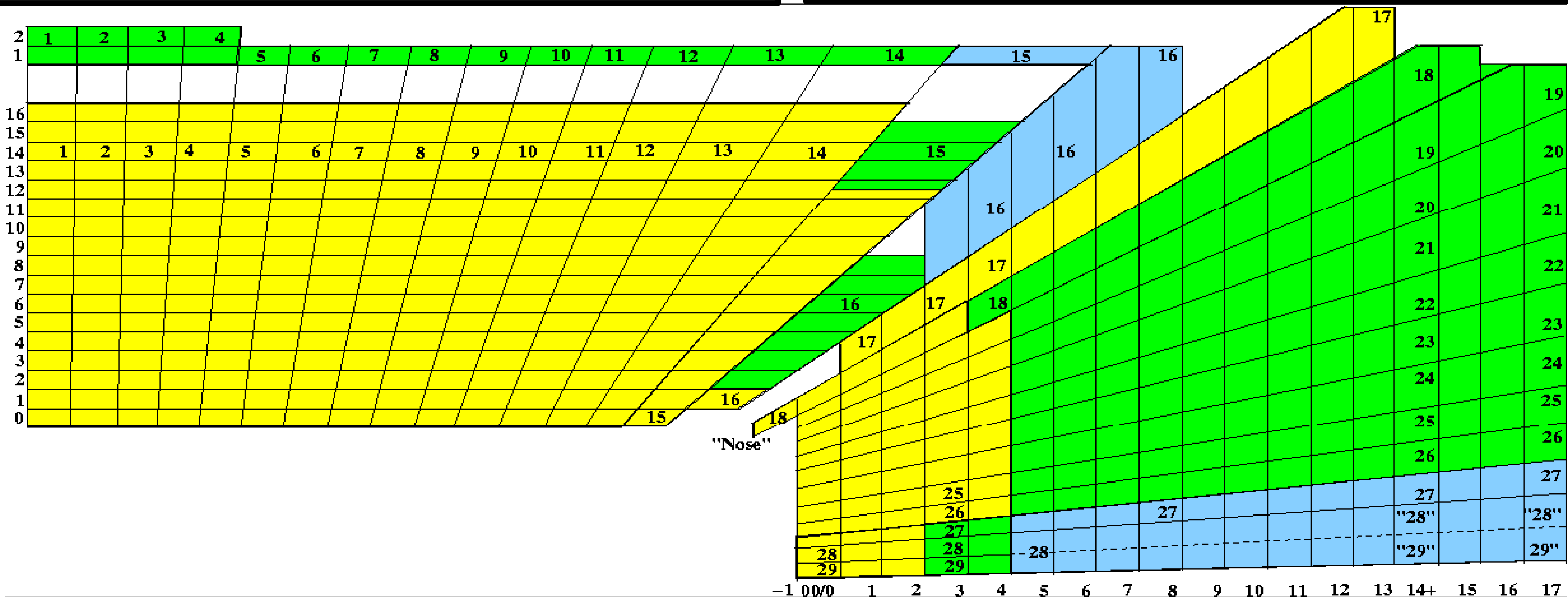
- Forward (HF): $2.9 < |\eta| < 5.0$ (not shown)

→ 2 x 900 towers (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



Hadron Spectra Systematics

CMS Pixel triplets

$$\Delta N_{\text{corrected}} = \frac{(1 - \text{fakeRate}) \cdot (1 - \text{feedDown})}{\text{geomAccep} \cdot \text{algoEffic} \cdot (1 - \text{multiCount})} \cdot \Delta N_{\text{measured}}$$

Correction	Dependence on kine	part	mult	Corr. [%]	Syst. [%]
Trigger	no	no	yes	15	5
Geometrical acceptance	yes	yes	no	10-20	2
Algorithmic efficiency	yes	yes	no	10-20	2
Multiple track counting	yes	no	no	small	small
Fake track rate	yes	no	yes	small	small
Feed-down	yes	yes	no	2-15	1-2
η, p_T resolution	no	no	no	1-5	1-5
Total	yes	yes	yes		7-9

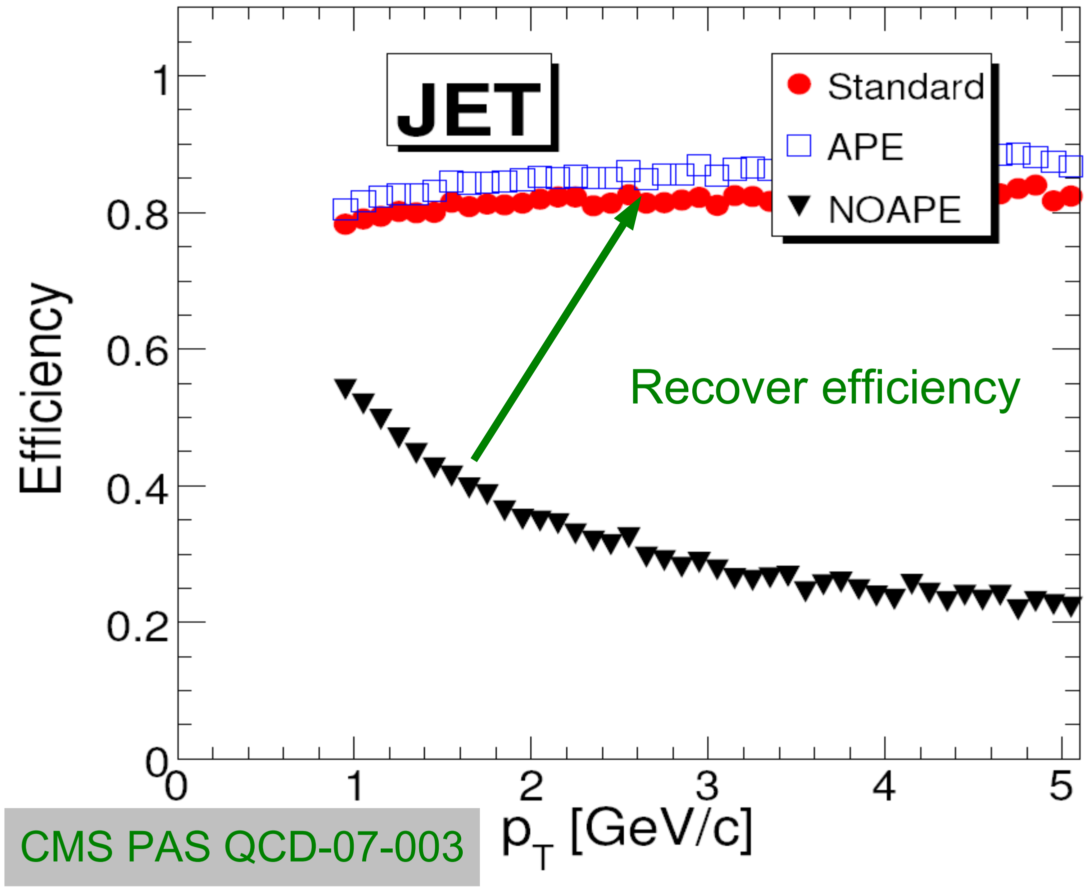
CMS PAS QCD-07-001

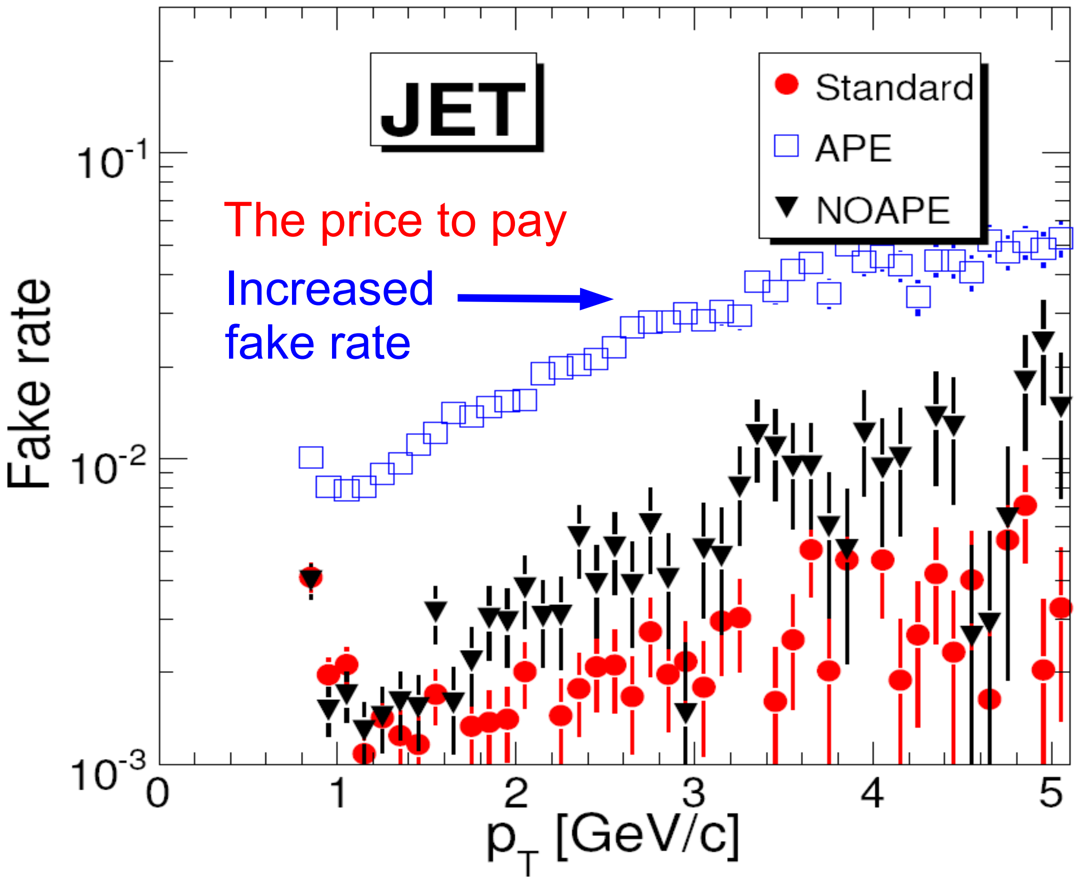
Tracking Performance

Comparison of tracking performance for:

- Ideal conditions
- Start-up (misaligned)
- Alignment Position Error application

Track reconstruction efficiency | **Fake rate**





CMS PAS QCD-07-003

Dijet Azimuthal Decorrelation

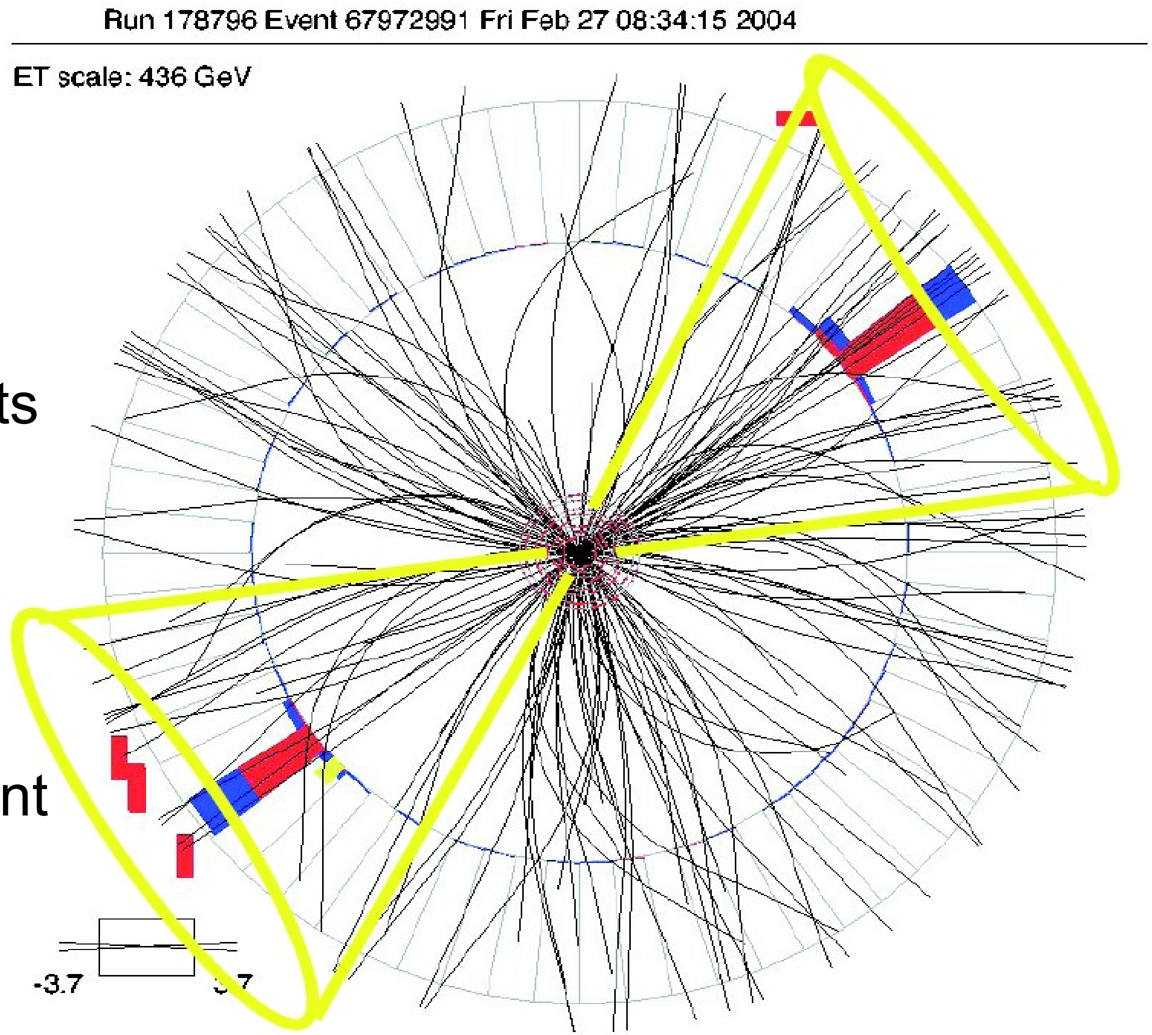
Dijets in pp collisions:

$\Delta\varphi$ dijet = π →
Exactly two jets, no further radiation

$\Delta\varphi$ dijet small deviations from π →
Additional soft radiation outside the jets

$\Delta\varphi$ dijet as small as $2\pi/3$ →
One additional high-pT jet

$\Delta\varphi$ dijet small – no limit →
Multiple additional hard jets in the event



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

Partonic Subprocesses

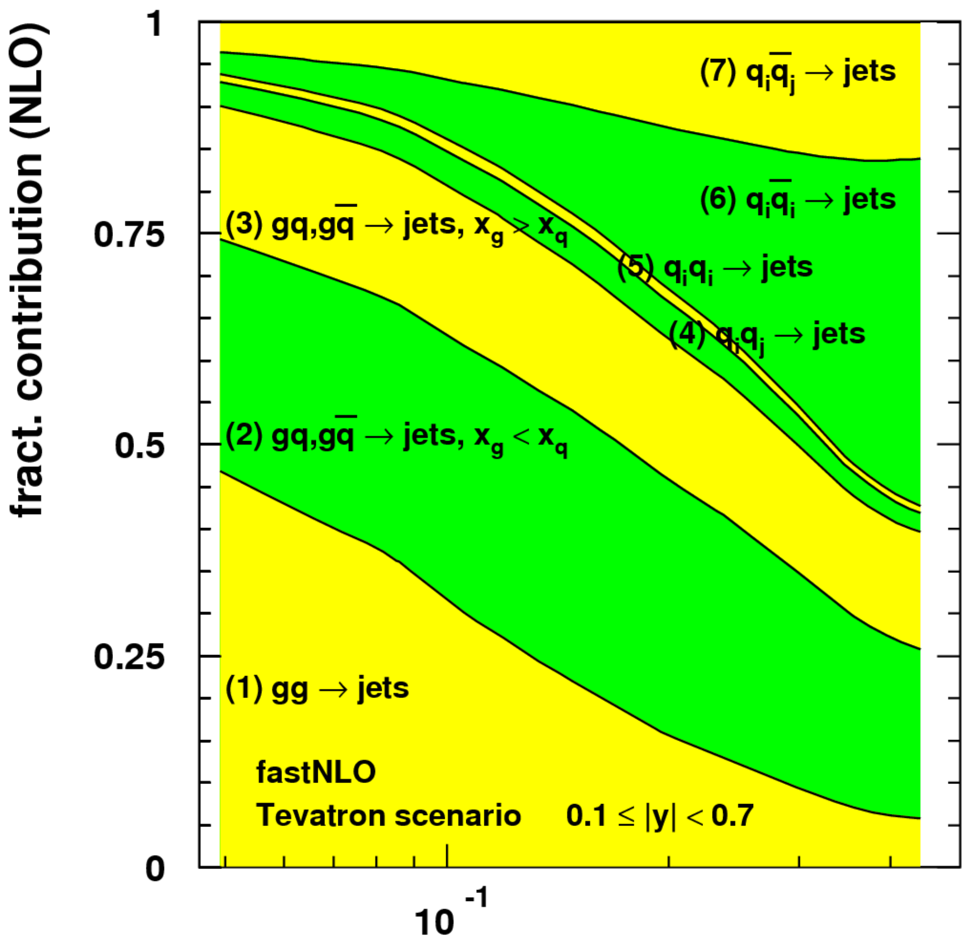
- For hh → jets there are **seven** relevant partonic subprocesses:

$$
\begin{array}{lrcll}
1) & gg & \Rightarrow & \text{jets} & \propto H_1(x_1, x_2) \\
2) & qg, \bar{q}g & \Rightarrow & \text{jets} & \propto H_2(x_1, x_2) \\
3) & gq, g\bar{q} & \Rightarrow & \text{jets} & \propto H_3(x_1, x_2) \\
4) & q_i q_j, \bar{q}_i \bar{q}_j & \Rightarrow & \text{jets} & \propto H_4(x_1, x_2) \\
5) & q_i q_i, \bar{q}_i \bar{q}_i & \Rightarrow & \text{jets} & \propto H_5(x_1, x_2) \\
6) & q_i \bar{q}_i, \bar{q}_i q_i & \Rightarrow & \text{jets} & \propto H_6(x_1, x_2) \\
7) & q_i \bar{q}_j, \bar{q}_i q_j & \Rightarrow & \text{jets} & \propto H_7(x_1, x_2)
\end{array}
$$

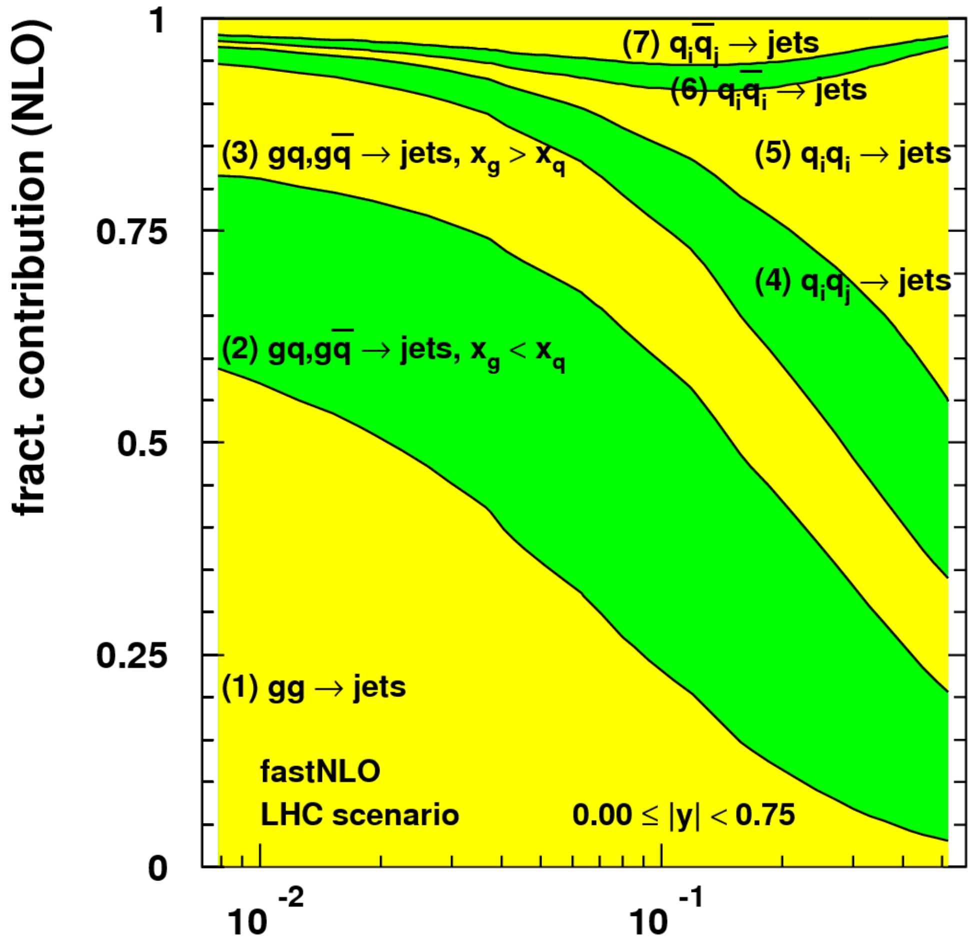
- Seven linear combinations H_i of PDFs

Subprocess Decomposition

Decomposition of the total ppbar, pp → jets cross section (NLO) into subprocesses
At central rapiditySubprozesse against the scaling variable $x_T = 2p_T/\sqrt{s}$



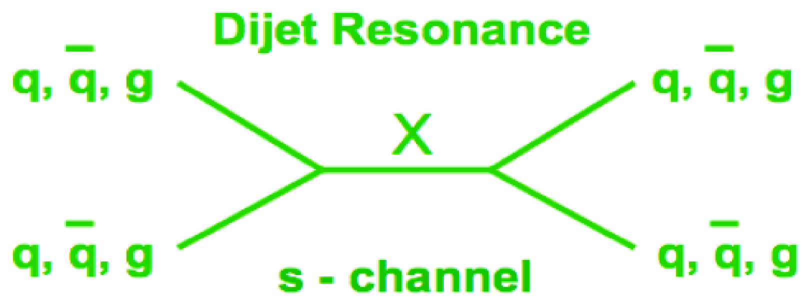
Tevatron x_T



LHC, 14 TeV x_T

New Physics from Dijets

- **New Physics with Jets:**
  - Contact interactions
    - **Resonances**
      - ★ W' & Z' (Grand Unified Theory)
      - ★ E_6 diquarks (D) (Superstrings & GUT)
      - ★ Excited quarks (q*) (Compositeness)
      - ★ RS Gravitons (G) (Extra Dimensions)
      - ★ Colorons (C) & Axigluons (A) (Extra Color)
  - Di-jet mass distribution

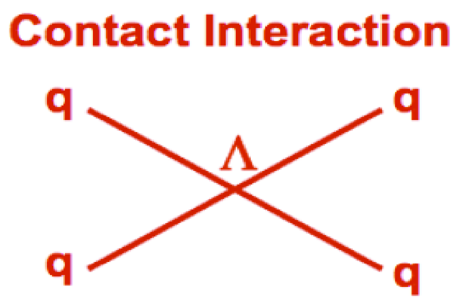


Need E_{CMS} > M

Model	J	Color	Cross Section (pb) M=0.7 TeV $\|\eta\| < 1$	M=0.7 TeV $\|\eta\| < 1.3$	M=2.0 TeV $\|\eta\| < 1$	M=2.0 TeV $\|\eta\| < 1.3$	M=5.0 TeV $\|\eta\| < 1$	M=5.0 TeV $\|\eta\| < 1.3$
q*	1/2	Triplet	7.95×10^2	1.27×10^3	9.01	1.36×10^1	1.82×10^{-2}	2.30×10^{-2}
A,C	1	Octet	3.22×10^2	5.21×10^2	5.79	8.82	1.55×10^{-2}	2.04×10^{-2}
D	0	Triplet	8.11×10^1	1.26×10^2	4.20	5.97	4.65×10^{-2}	5.75×10^{-2}
G	2	Singlet	3.57×10^1	5.47×10^1	1.83×10^{-1}	2.60×10^{-1}	2.64×10^{-4}	3.19×10^{-4}
W'	1	Singlet	1.46×10^1	2.37×10^1	3.49×10^{-1}	5.31×10^{-1}	8.72×10^{-4}	1.17×10^{-3}
Z'	1	Singlet	8.86	1.44×10^1	1.81×10^{-1}	2.77×10^{-1}	5.50×10^{-4}	7.26×10^{-4}

- **Contact Interactions**
  - ★ Sensitive to Scale $\Lambda >> \sqrt{s}$!

$$L_{qq} = \frac{Ag^2}{2\Lambda^2}(\bar{q}_L\gamma^\mu q_L)(\bar{q}_L\gamma_\mu q_L)$$



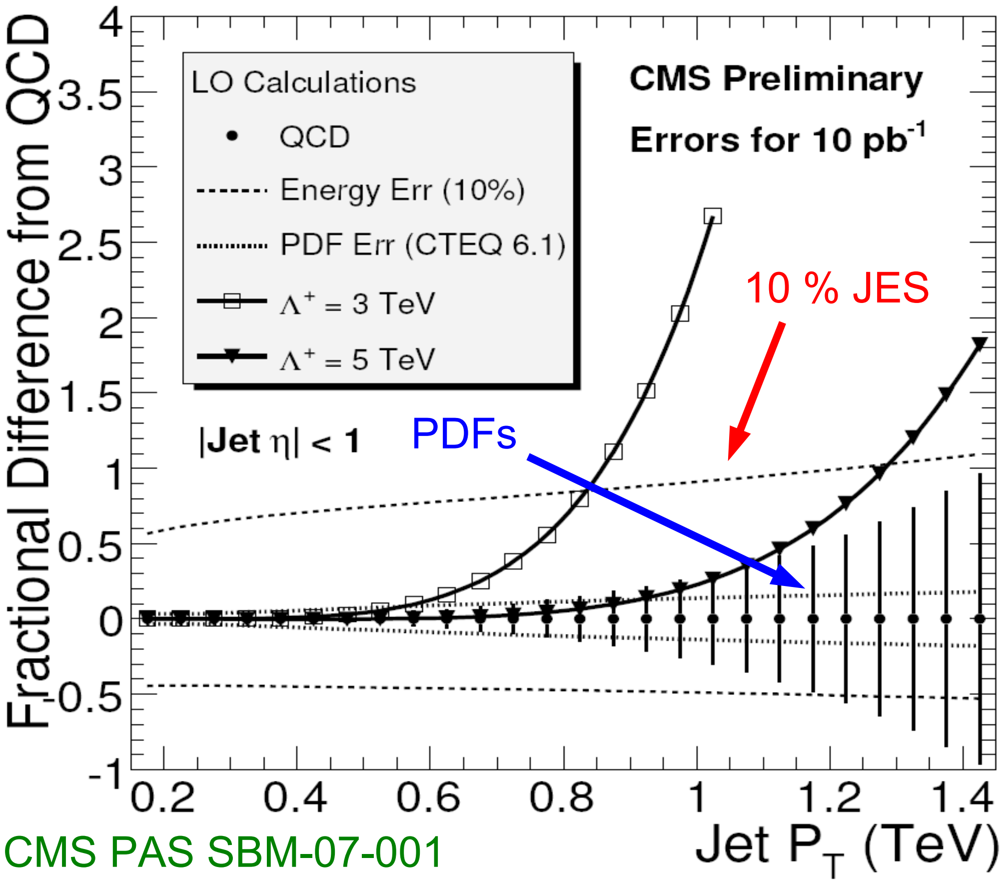
CMS

New Physics from Dijets

Search for deviation from expected event rate:

- QCD from PYTHIA (here) or NLO
- Contact interaction: PYTHIA or LO

Cross section ratios



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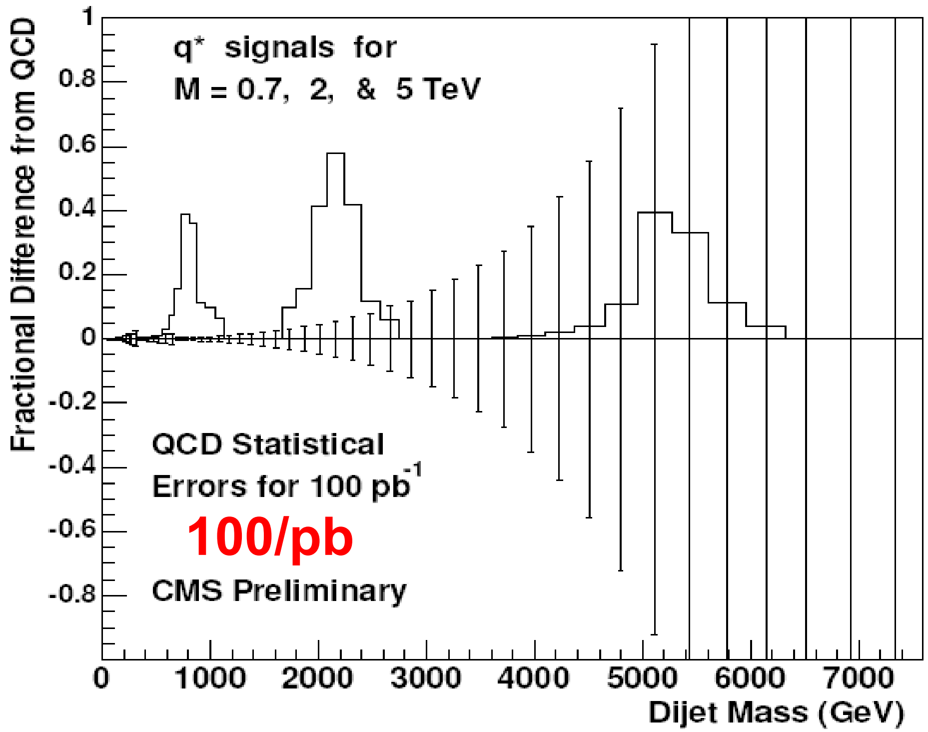
Search for resonances

Possible signals of q* relative to QCD prediction, visible for < 2 TeV
(statistical uncertainty only!)



One means to avoid systematics is by looking into cross section ratios in η

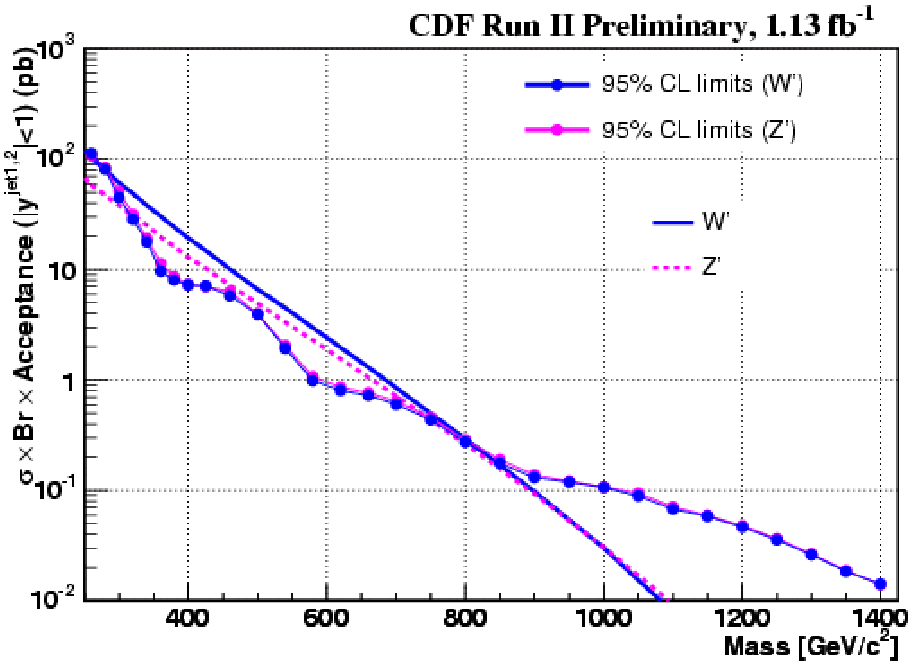
Recent Limits

Tevatron limit on contact interaction scale (qqqq): > 2.4 - 2.7 TeV

Dijet resonance search

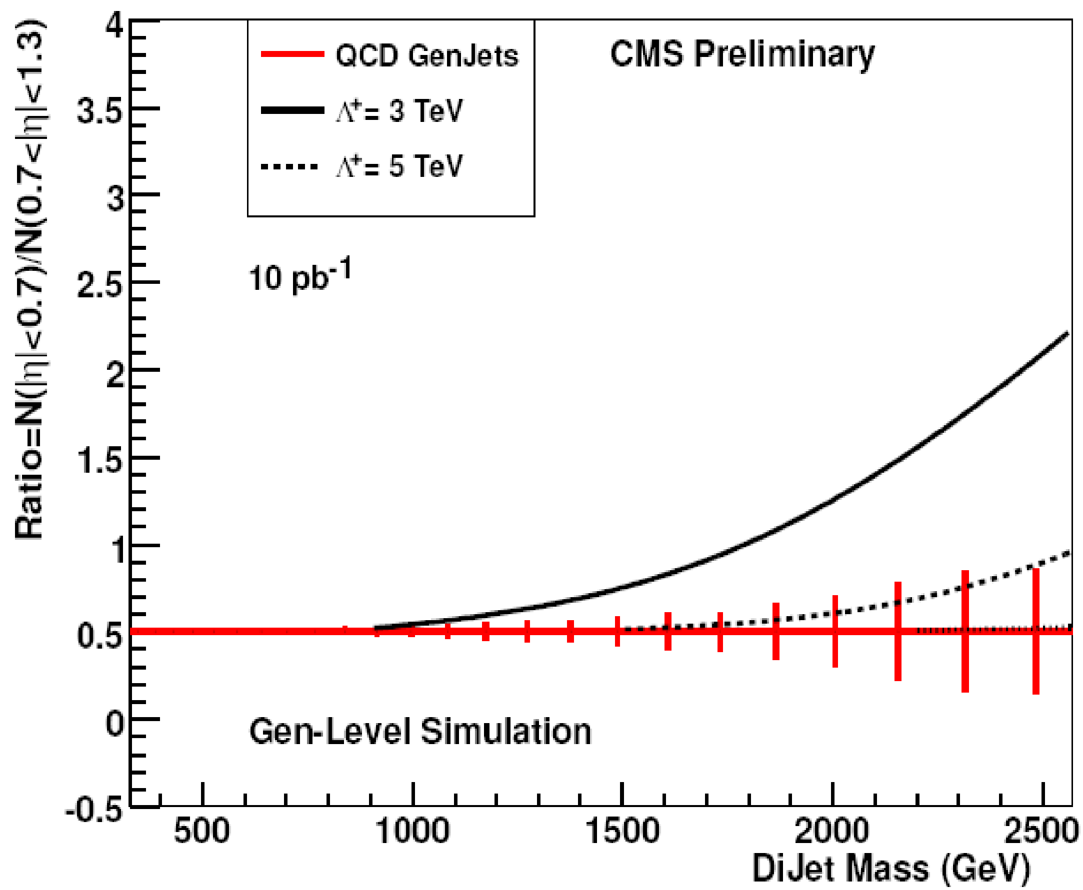
Resonance	Excluded (GeV)	Resonance	Excluded (GeV)
A or C	260 - 1250	D	290 - 630
ρ_{T8}	260 - 1110	W '	280 - 840
q *	260 - 870	Z '	320 - 740

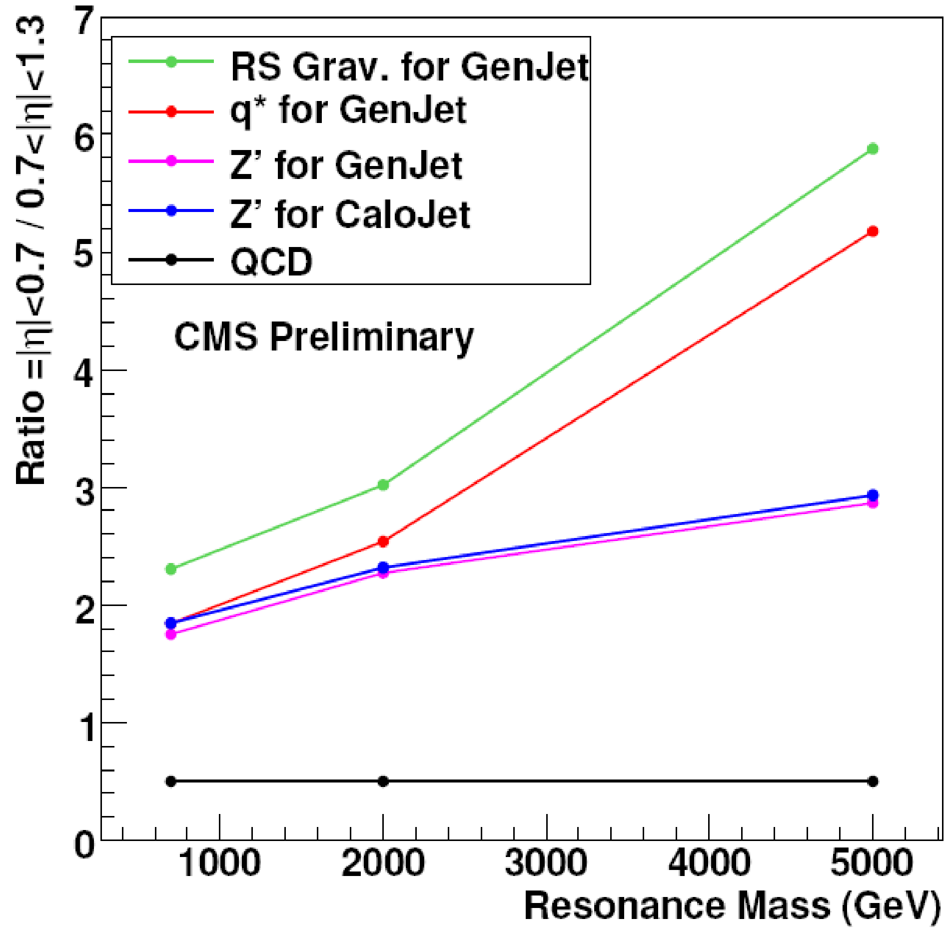
CDF Preliminary 03/2008



Exclusion limits for W' and Z'

Dijet Ratios





- Sensitivity to new physics from dijet x section ratios in pseudo-rapidity
- Reduced sensitivity to jet energy scale

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Jet Shapes

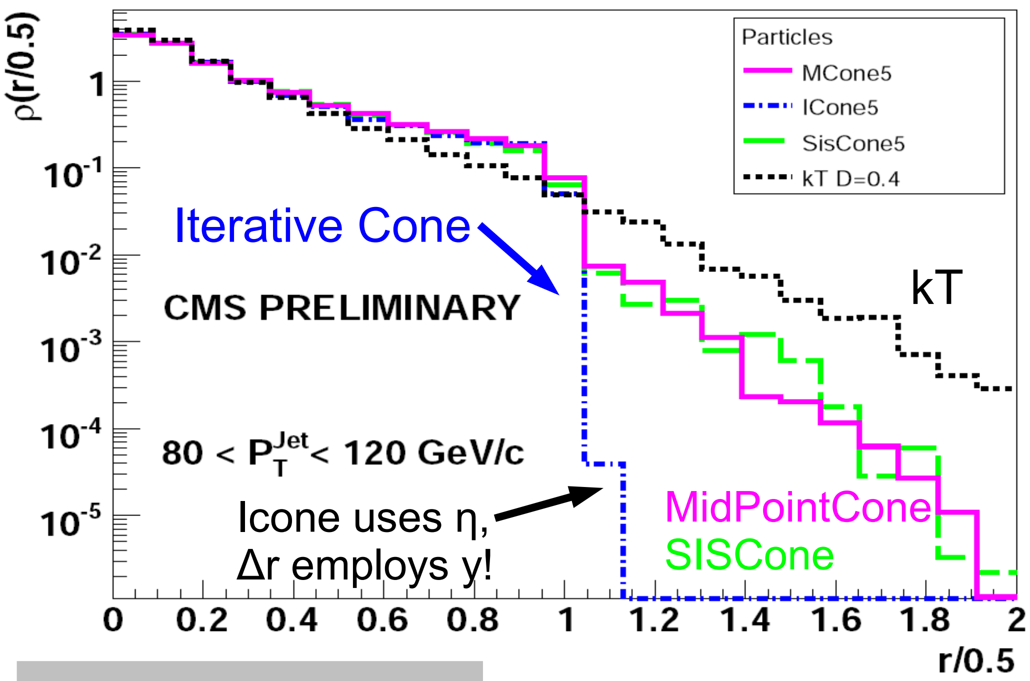
A possibility to look into details of QCD and jet structure!

Norm. transverse energy distribution:

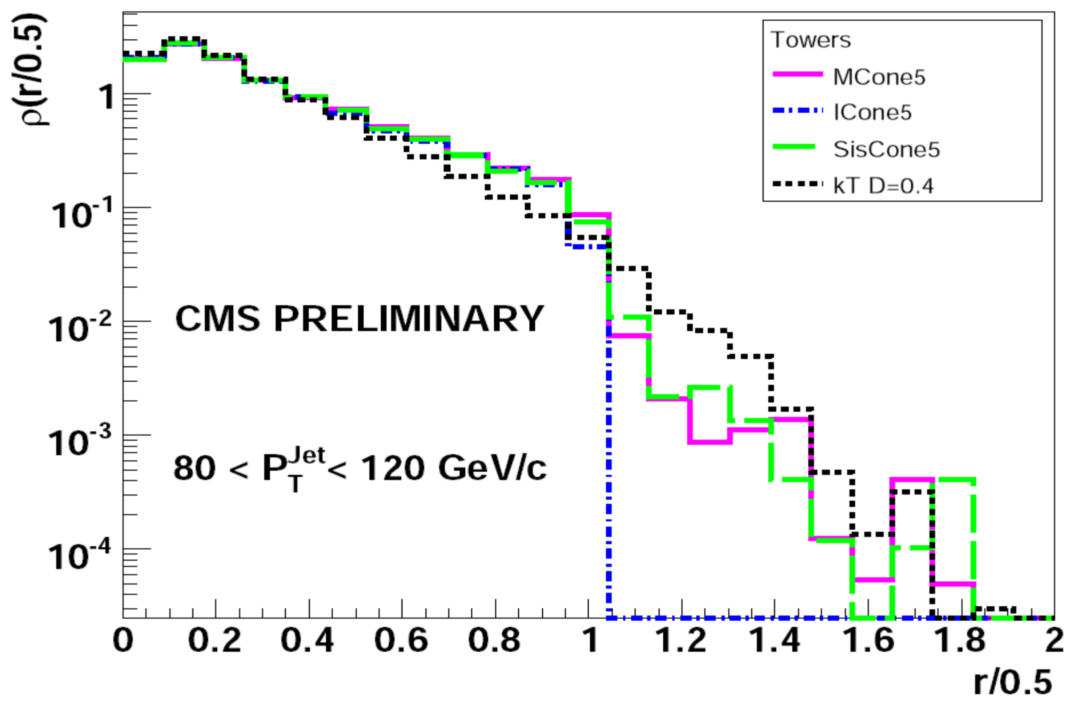
$$\rho(r) = \frac{\sum p_T(r-\Delta r/2, r+\Delta r/2)}{\Delta r \sum p_T^{Jet}}$$

Good reproduction of general properties (central region |η| < 1, matched jets)

Jets from generator particles



Jets from calorimeter towers



CMS PAS JME-07-003

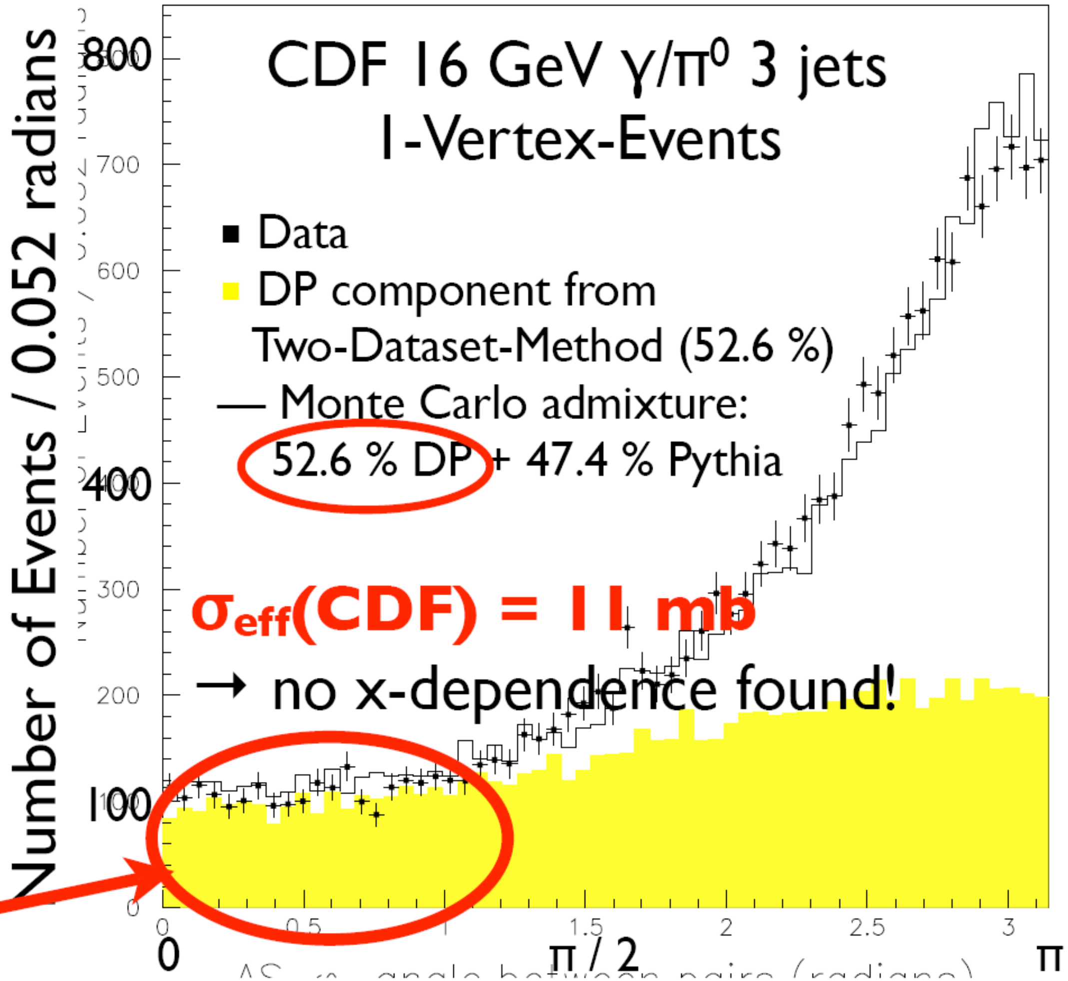
Multiple Parton Interactions

Phase space:

As low as possible in pT:
- photon pT > 10 GeV
- jet pT > 20 GeV for calojets
=> could consider jets from tracks

- **Double-parton-scattering**
  - four-jet production (→ AFS, UA2, CDF)
  - like-sign W production
  - **γ + 3-jet production (→ CDF)**

- **Need double-parton component to describe the data**



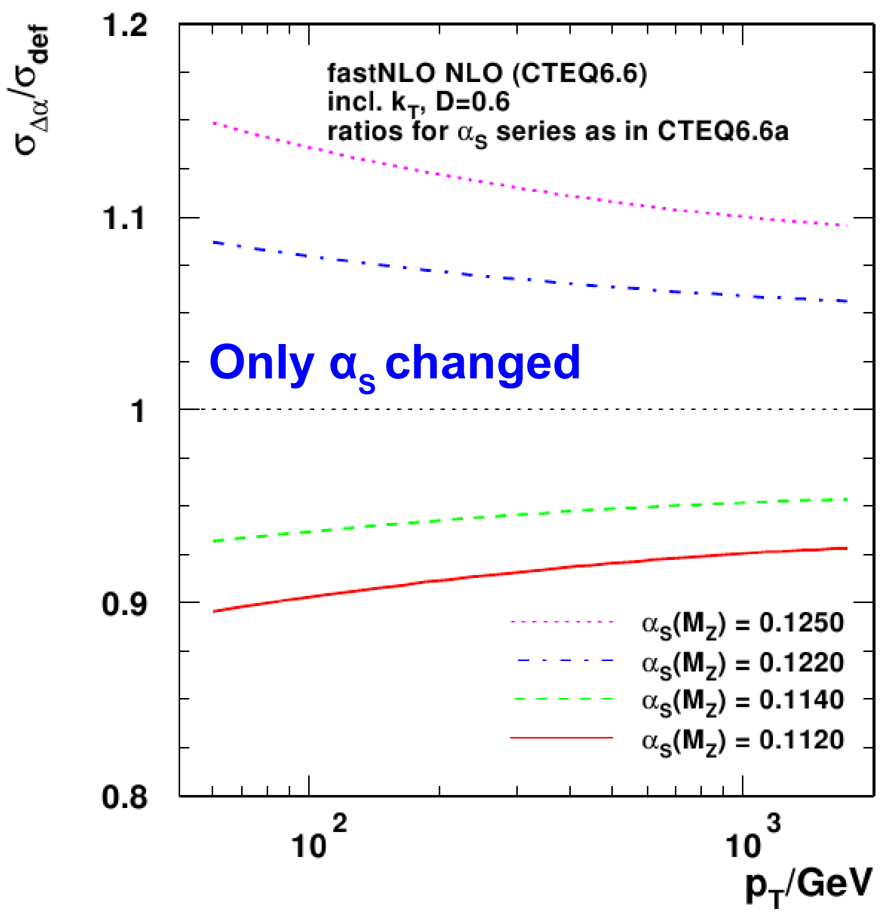
ΔS, φ-angle b/w P_T's of pairs (rad)

Influence of $\alpha_s(M_Z)$

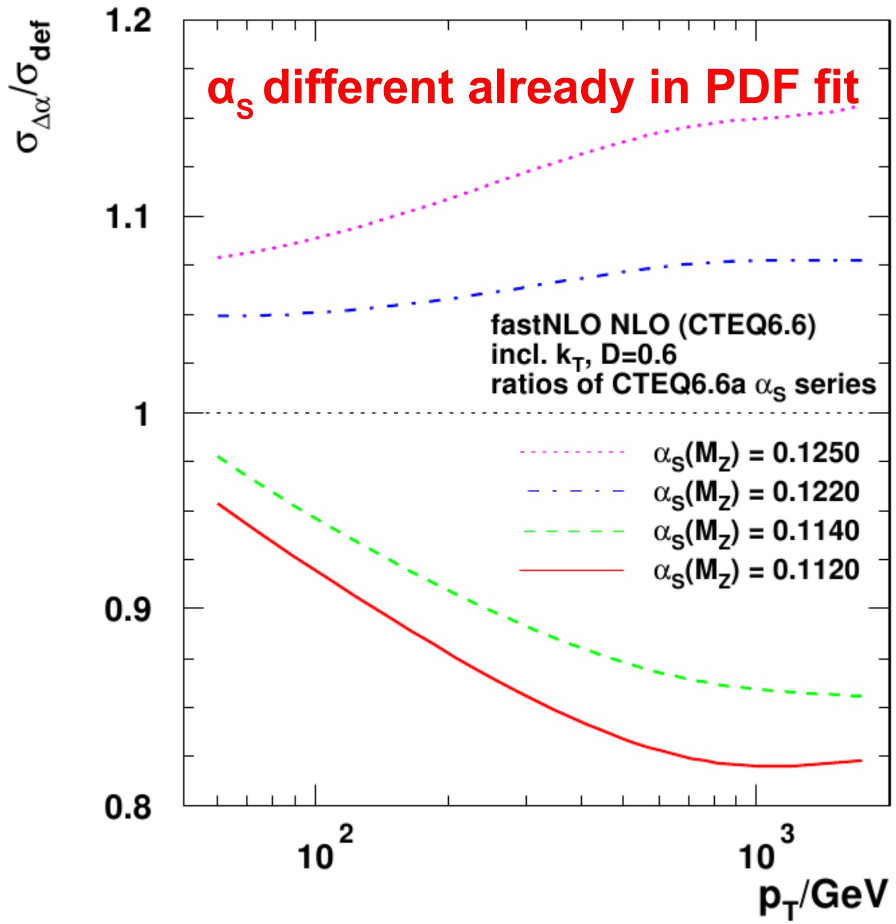
Cross section ratios at central rapidity
$\alpha_s(M_Z)$ varies from 0.112 to 0.125

PDG Value $\alpha_s(M_Z) = 0.1176 \pm 0.0020$
Would lead to 2 to 4% variation

With CTEQ6.6 central PDF



With CTEQ6.6A α_s PDF series



Some UA1 Quotations

- **Quotations from Phys. Lett. Vol. 107B, no. 4:**
  - ... dipole magnet which produces a field of **0.7 T** over a volume of 7m x 3.5m x 3.5m ...
  - ... yields space points at **centimetre** intervals on the detected tracks
  - ... two short accelerator development periods in October and November 1981 ...
  - The events were **scanned by physicists** on a Megatek display.
  - ... was examined independently by all physicists who participated in the scanning. The combined effect of the **scanner variations** ...