Update on the Jet Cross Section Ratio: $\sigma(pp \rightarrow n\ njets+X\ n \geq 3) / \sigma(pp \rightarrow n\ njets+X\ n \geq 2)$

P.Kokkas, **I.Papadopoulos**, **C.Fountas**, **I.Evangelou**,
N.Manthos

University of Ioannina, Greece

QCD meeting 29/9/2009

Outline

- Measurement of the Jet Cross Section Ratio:

$$R_{32} = \frac{\sigma_3}{\sigma_2} = \frac{\sigma(pp \to n \ \text{jets} + X;\ n \geq 3)}{\sigma(pp \to n \ \text{jets} + X;\ n \geq 2)}$$

  - Motivation
  - Analysis plan
- Previous work:
  - Definition of the measured cross section at hadron level $\sigma(\ p_T \geq 50$ GeV; $|\eta| \leq 2.5)$
  - R_{32} at $10pb^{-1}$
  - Trigger study (Single Jet Triggers combination: HLT Jet50, Jet80, Jet110)
- Study the dominant systematic from JES uncertainty
  - Perform studies by varying JES by 10%
    - Evaluate uncertainty of the 2 jet, 3 jet cross sections and R_{32}
    - Demonstrate the level off cancellation of these errors on the measured R_{32}
- Summary & plans

Motivation

D0 PRL 86, p1955 (2001)

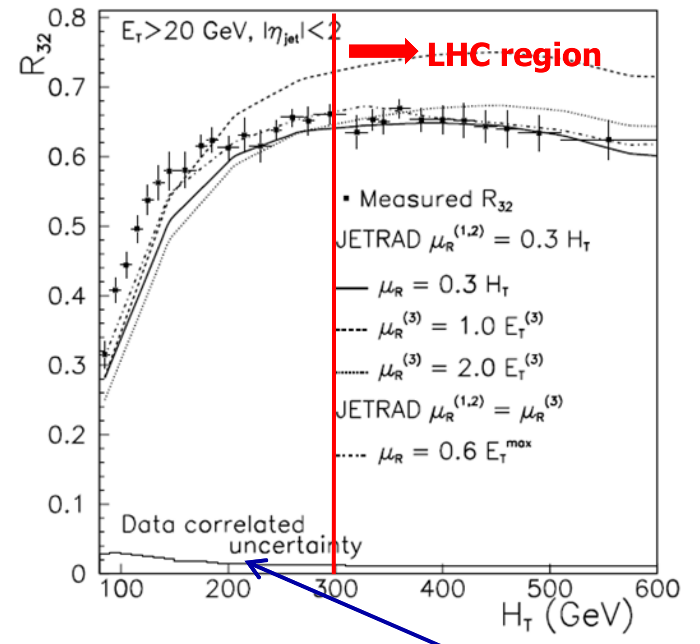


FIG. 2. The ratio R_{32} as a function of H_T, requiring jet $E_T >$ 20 GeV and $|\eta_{\rm jet}| < 2$. Error bars indicate statistical and uncorrelated systematic uncertainties, while the histogram at the bottom shows the correlated systematic uncertainty. The four smoothed distributions show the JETRAD prediction for the renormalization scales indicated in the legend.

Jet finder radius 0.7
We should be able to extend this
up to an H_T~ 1.5 TeV
(σ(2J) = 1 pb @ Pt-hat = 700 GeV)

- Motivation: Measure the ratio R_{32} vs H_T and compare with pQCD predictions with goals:
  - Extend the phase space of the measurement in a regime that goes above the Tevatron.
  - Comparisons of the measured ratio at hadron level with the predictions of pQCD (parton level), after accounting for renormalisation scale and hadronization uncertainty will measure the QCD coupling constant α_s at a scale never measured before.
- We measure the ratio because we expect that it will be less sensitive than absolute cross section measurements to a number of experimental systematics such as
  - the JES uncertainty
  - the uncertainty in the luminosity measurement.

Analysis Plan

- Definition of the measured cross section at hadron level $\sigma(p_T \geq X; |\eta| \leq Y)$
  - Pseudorapidity studies
  - p_T resolution studies

  Define the 2 Jet and 3 Jet kinematic cuts.

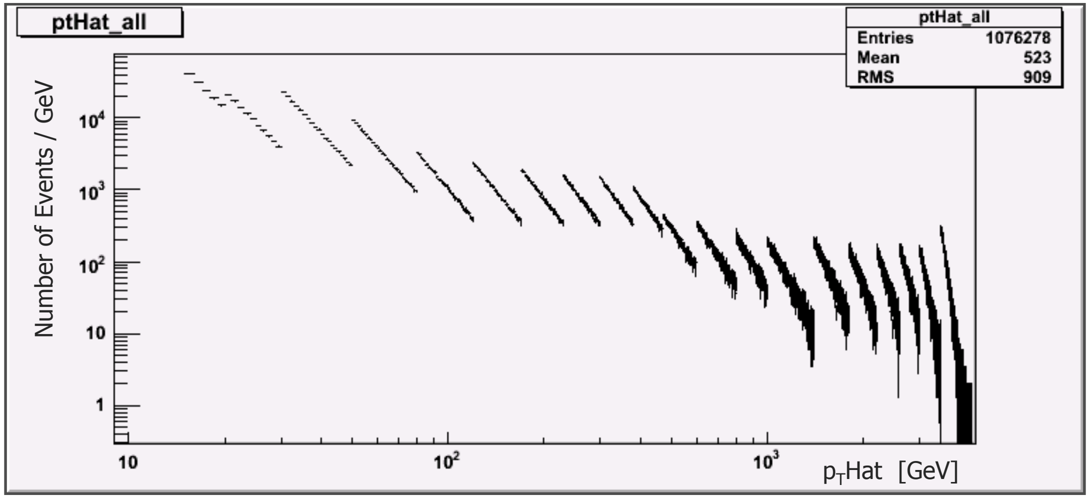
  - Jet finder studies sisCone7, sisCone5.
- Trigger studies of available HLT's, to select the right scheme
  - Compute trigger efficiencies.
  - Combine triggers to have R_{32}.
- Estimate the dominant systematics (Jet energy scale…)
  - Use the known resolutions and information on systematic shifts in p_T to estimate:
    - The Systematics of the 2 jet and 3 jet cross sections.
    - Demonstrate the level off cancellation of these errors on the measured R_{32}
- Estimate the magnitude of hadronisation correction
  - Need to use several hadronisation models.
- Compute the theoretical rate with NLO programs and estimate the uncertainty due to μ_R, μ_F

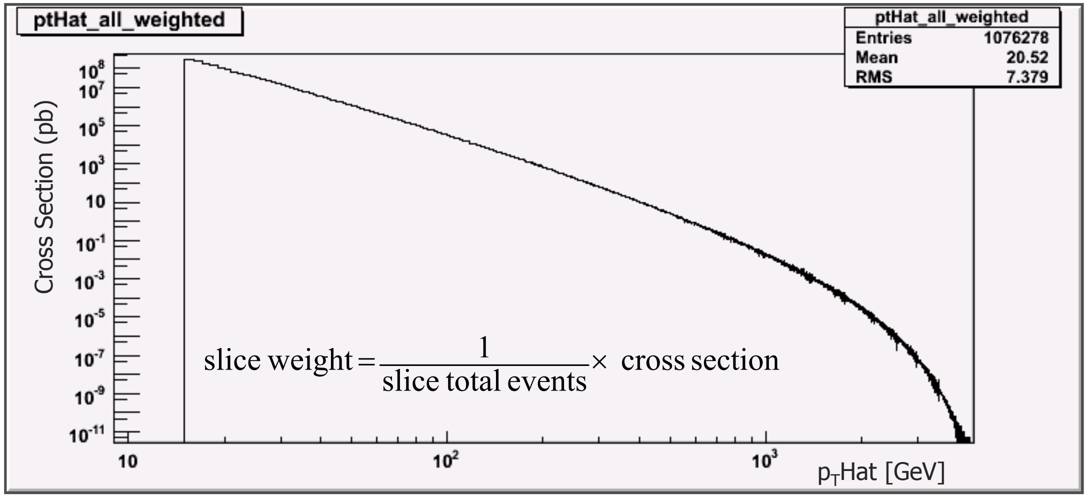
Tools and MC Samples used

Analysis done using version CMSSW_2_2_6

- QCD DiJet Summer 08
- Jet Algorithm: sisCone7
- Jet Energy Corrections: L2L3
- Bin p_THat:0-15 GeV not used

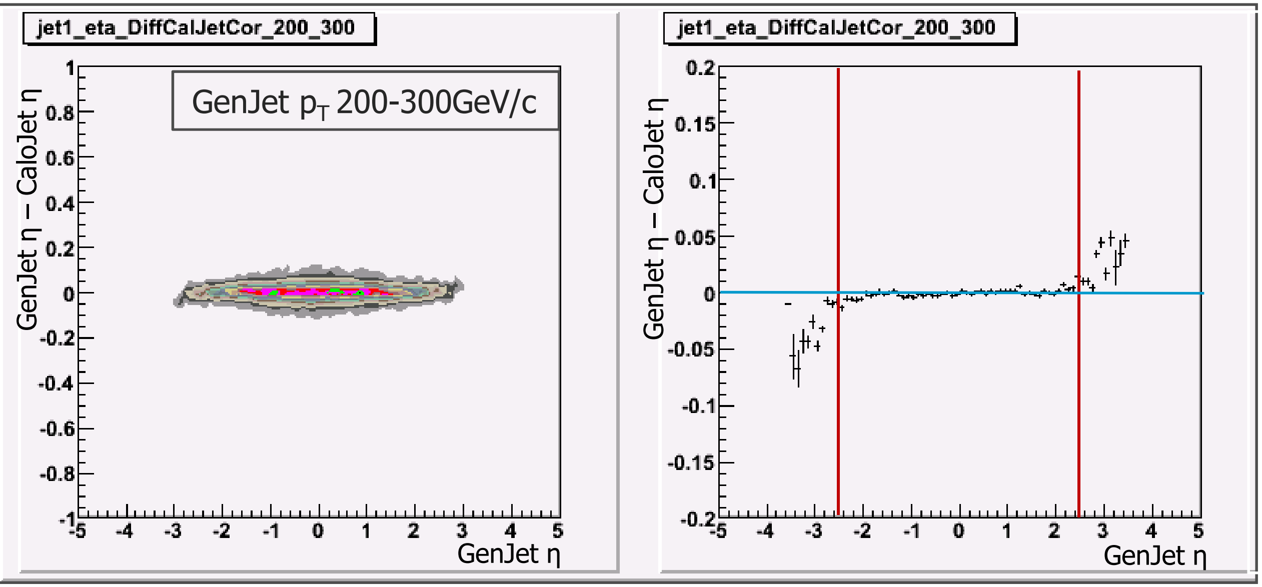
	P_THat bin [GeV]	Number of events	Cross section [pb]	Equivalent Luminosity [pb^{-1}]
1	0-15	103860	51562800000	2.01E-06
2	15-20	129600	949441000	1.37E-04
3	20-30	101880	400982000	2.54E-04
4	30-50	169200	94702500	1.79E-03
5	50-80	103545	12195900	8.49E-03
6	80-120	51300	1617240	3.17E-02
7	120-170	50085	255987	0.19
8	170-230	51840	48325	1.07
9	230-300	54000	10623.2	5.08
10	300-380	60048	2634.94	22.79
11	380-470	51840	722.099	71.79
12	470-600	27648	240.983	114.73
13	600-800	28620	62.4923	457.98
14	800-1000	20880	9.42062	2.22E03
15	1000-1400	24640	2.34357	1.05E04
16	1400-1800	27744	0.156855	1.77E05
17	1800-2200	22848	0.013811	1.65E06
18	2200-2600	22560	0.00129608	1.74E07
19	2600-3000	22800	0.00011404	2.00E08
20	3000-3500	20880	0.0000084318	2.48E09
21	3500-inf	34320	0.00000018146	1.89E11





$$\text{slice weight} = \frac{1}{\text{slice total events}} \times \text{ cross section}$$

Definition of measured cross section at hadron level $\sigma(p_T \geq 50\ \mathrm{GeV};\ |\eta| \leq 2.5)$



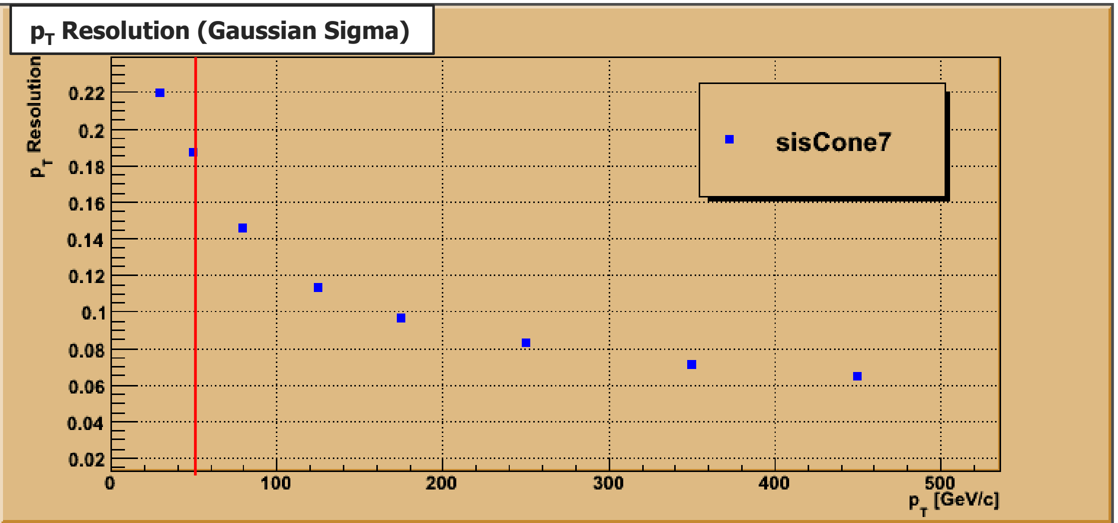
Scatter Plot

Profile

Plot the difference:

$$(\eta_{\mathrm{Gen}} - \eta_{\mathrm{Calo}})\ \mathrm{vs}\ \eta_{\mathrm{Gen}}$$

- For various bins of GenJet p_T
- Jet Algorithm sisCone7
- Distributions flat for $|\eta| \leq 2.5$ (Barrel + EndCap regions)
- Reasonable cut: $|\eta| \leq 2.5$



For our analysis we apply a cut on Jet $p_T \geq 50$ GeV/c

With this cut we can compare our results with Tevatron for a region of H_T between 300-600 GeV

Around 50 Gev/c p_T resolution ~18%

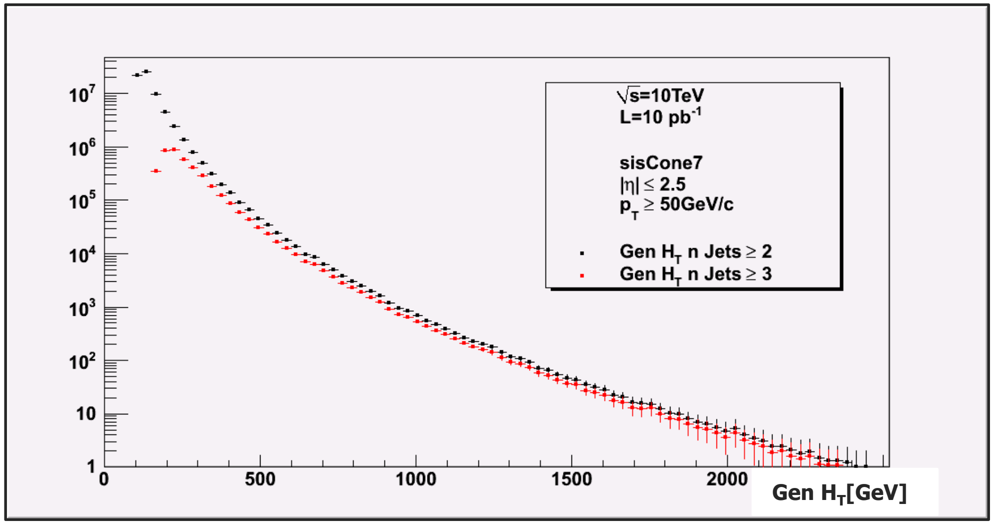
Gen Jet Ratio R_{32}

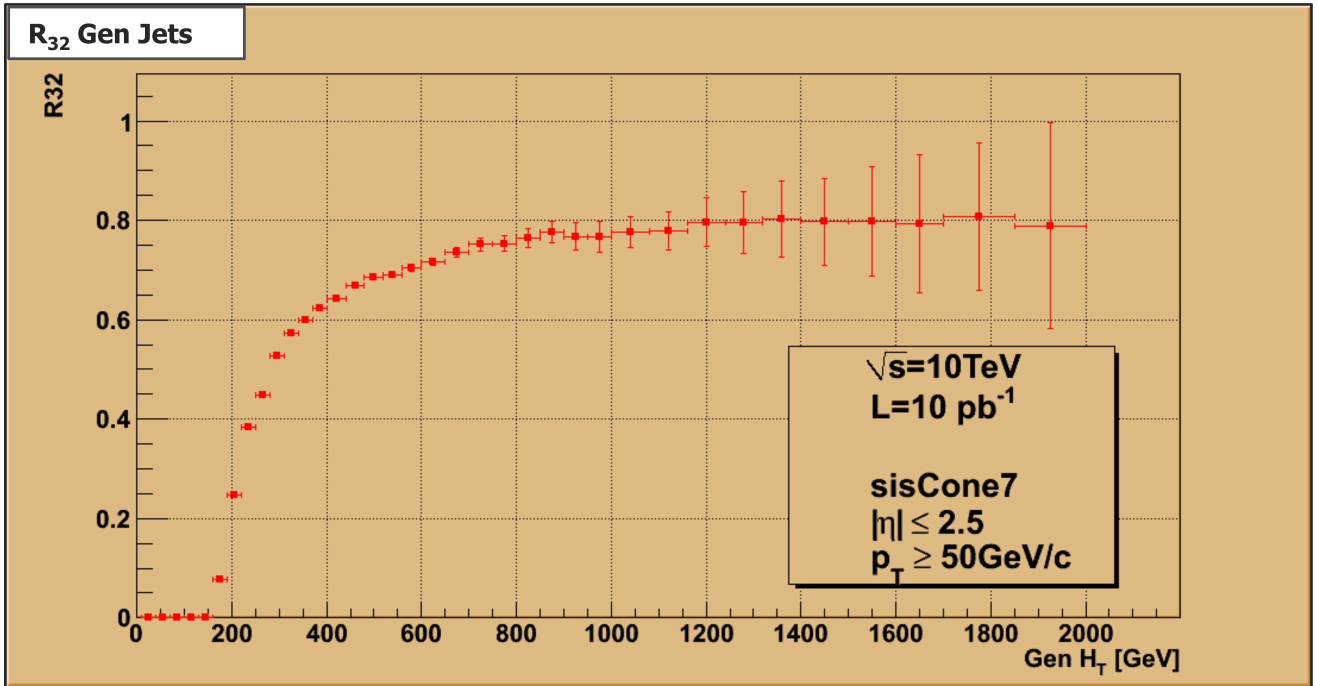
Evaluation of 3Jet/2Jet Ratio vs H_T.

$$R_{32} = \frac{\sigma_3}{\sigma_2} = \frac{\sigma(pp \rightarrow n \ \text{jets} \ + X;\ n \geq 3)}{\sigma(pp \rightarrow n \ \text{jets} \ + X;\ n \geq 2)}$$

Event Selection cuts:

$|\eta|<2.5$ and Jet $p_T \geq 50$ GeV/c



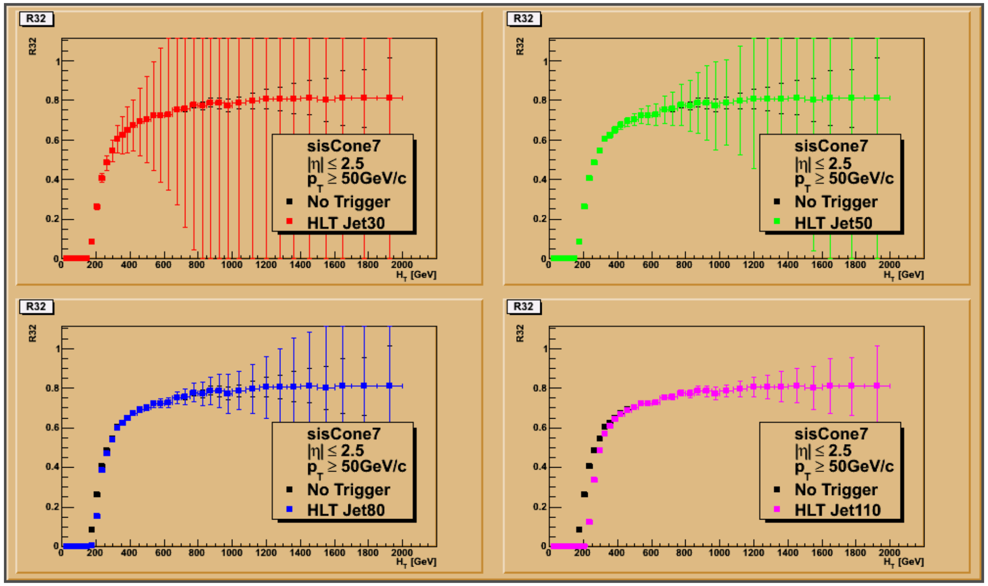


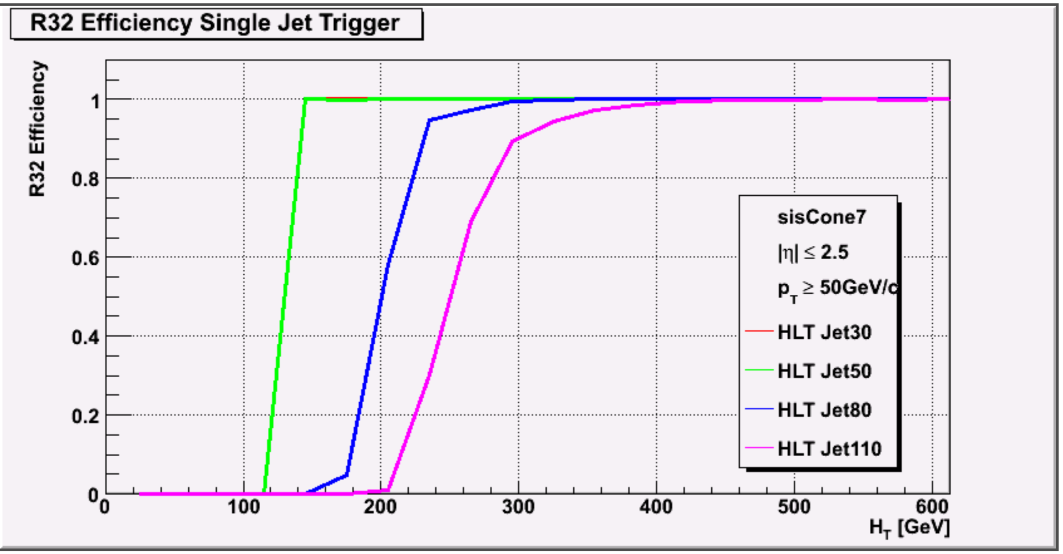
Trigger study: Single Jet Triggers

Study of Single Jet HLTs.

- Plot R_{32} after applying the HLTs
- Evaluate trigger efficiency for ratio R_{32}

Path name	L1 Trigger	Prescale (L1xHLT)
HLT Jet30	L1_SingleJet15	500x5
HLT Jet50	L1_SingleJet30	50x1
HLT Jet80	L1_SingleJet50	5x2
HLT Jet110	L1_SingleJet70	1

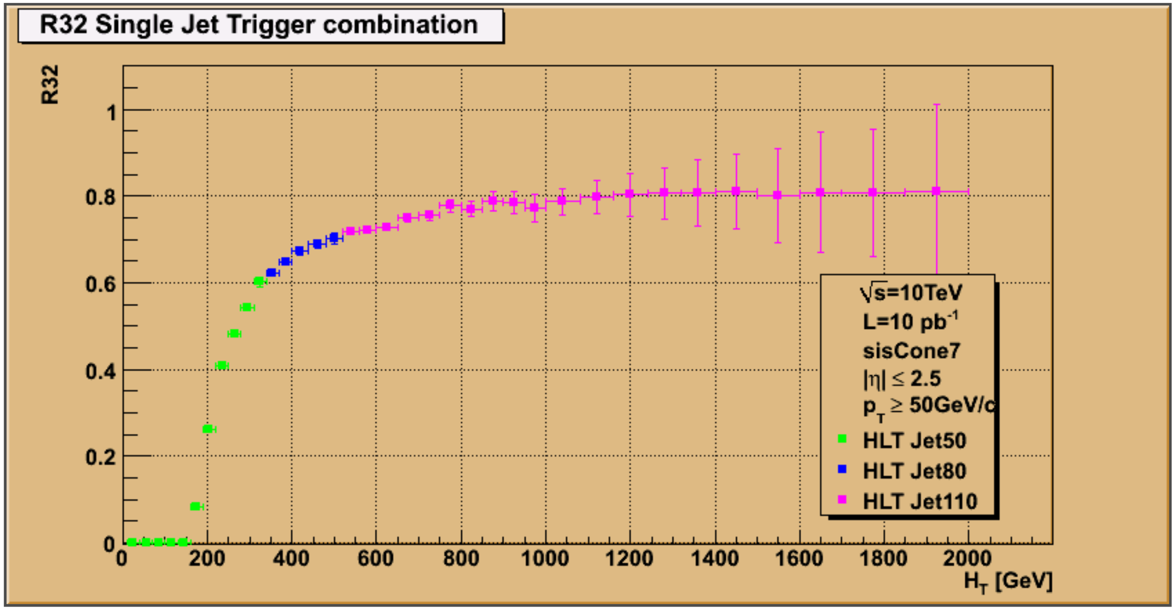




Trigger Path name	Threshold (100% efficient)
HLT Jet30	150
HLT Jet50	150
HLT Jet80	350
HLT Jet110	500

HLT Jet30 & HLT Jet50
Fully efficient from 150 GeV

Trigger study: Single Jet Triggers



Combine Single Jet HLTs for data collection :

- HLT Jet50 (prescale 50x1)
- HLT Jet80 (prescale 5x2)
- HLT Jet110 (prescale 1)

Trigger scheme fully efficient from ≥150 GeV

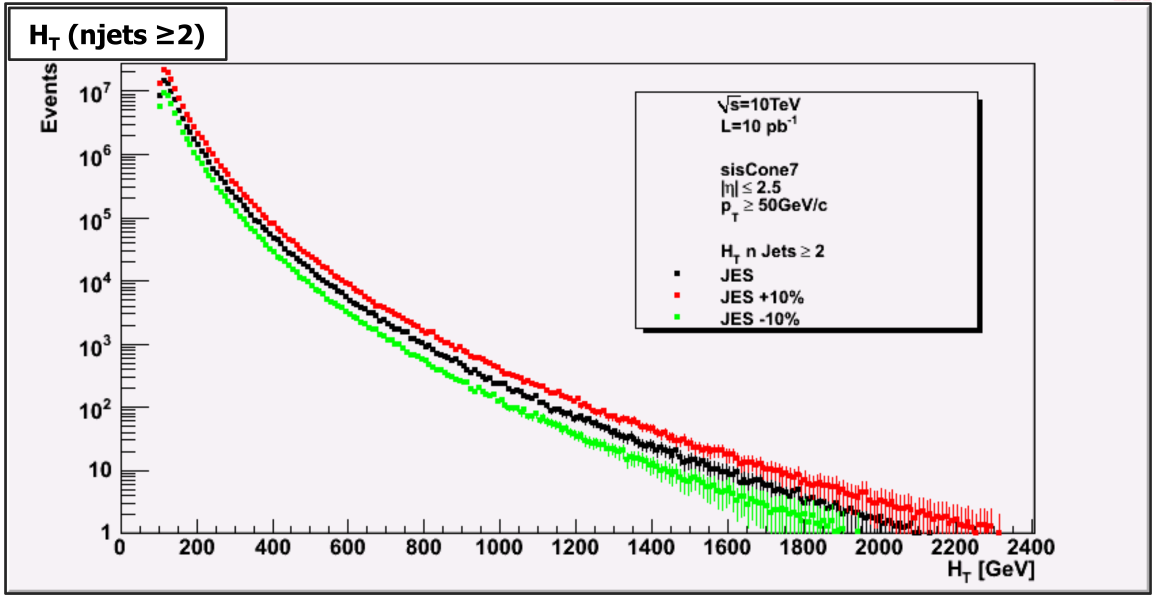
Trigger HLT Jet50 can be tested using trigger HLT Jet30

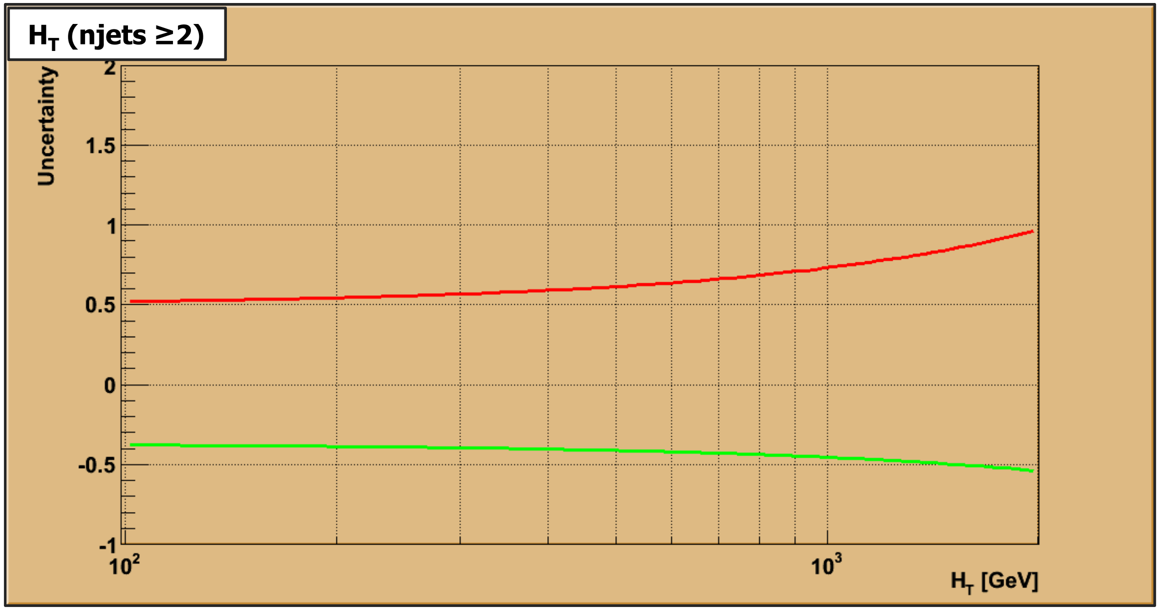
H_T (nJets≥2)

- The dominant systematics come from JES uncertainty.
- CMS JetMET group : suggests a flat 10% JES uncertainty.
- Changing all jets p_T by ±10%

First step: Simple study to see if measurement is not very sensitive to JES uncertainty.

Uncertainty 50% to 100%
Consistent with other studies

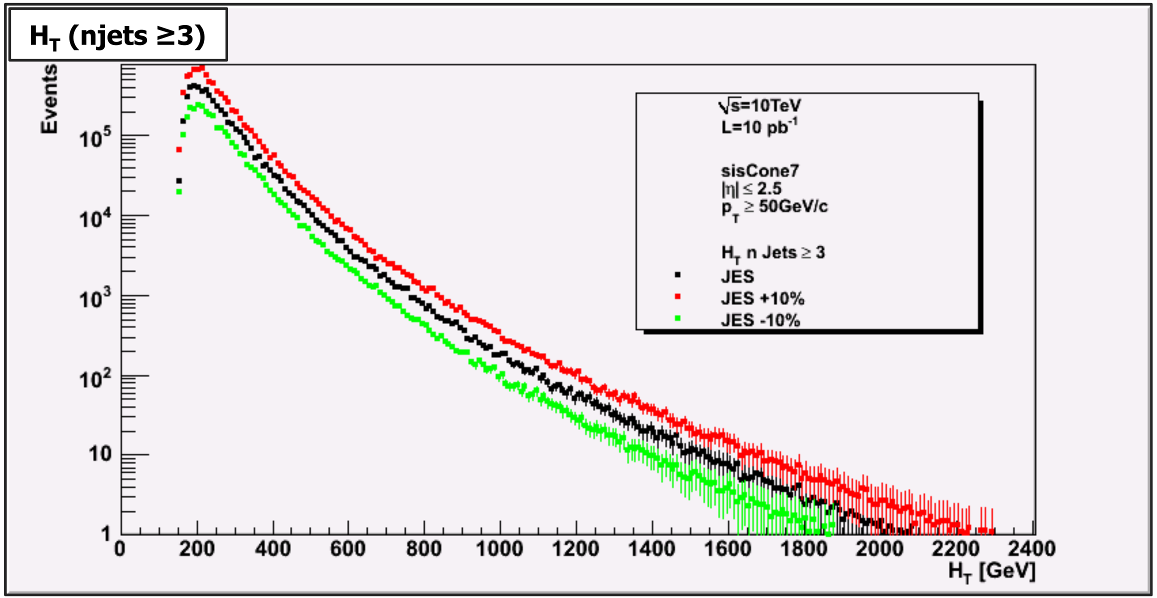


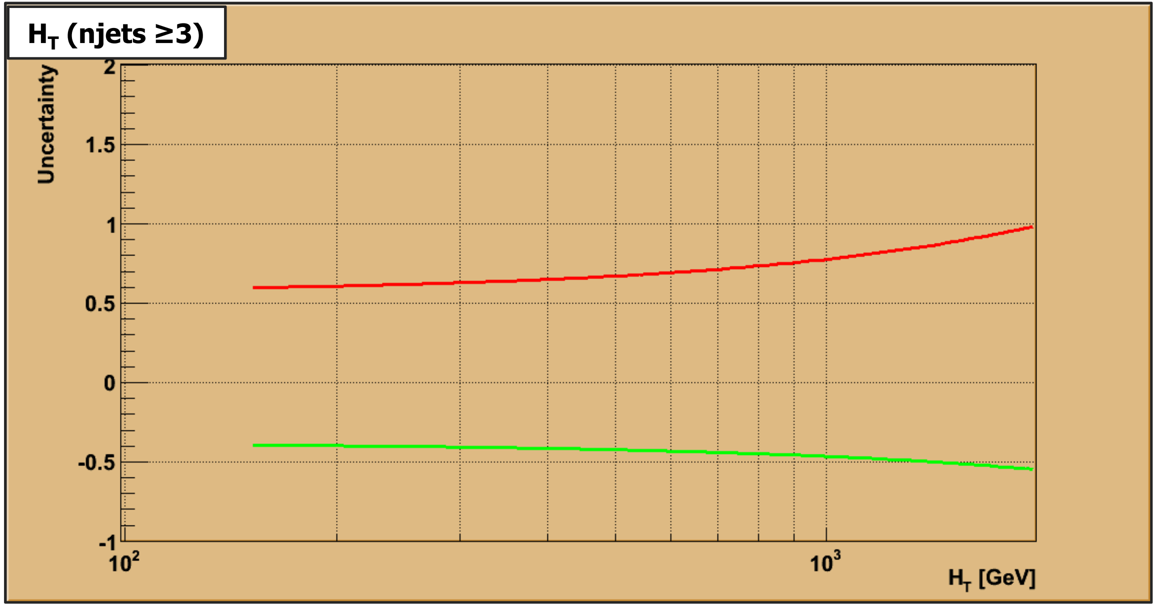


H_T (nJets≥3)

Changing all jets p_T by±10%

Uncertainty 50% to 100%
Consistent with other studies

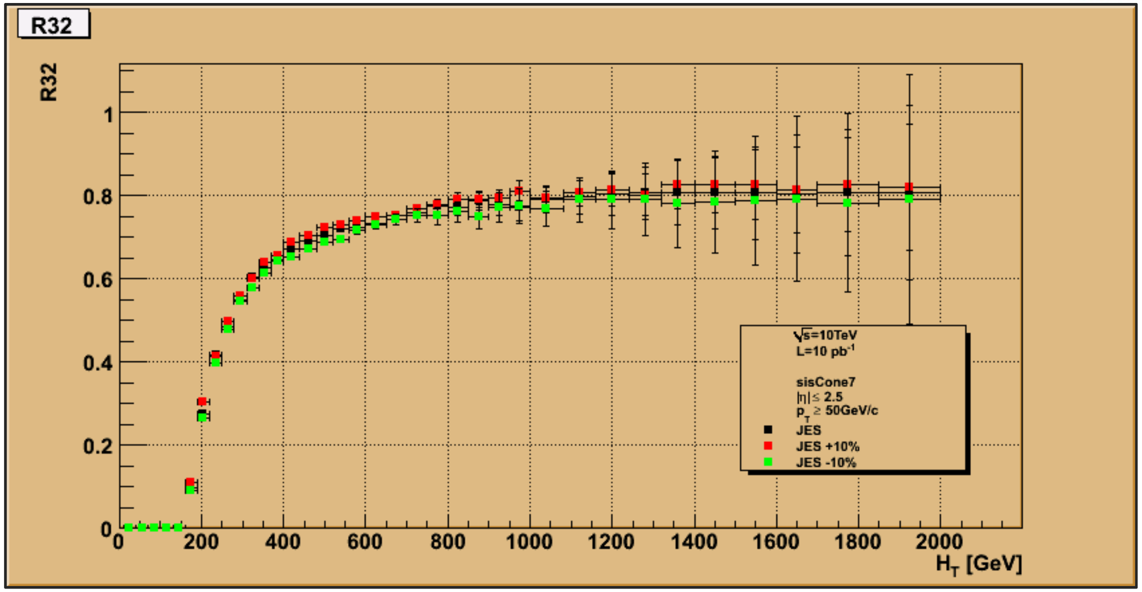




Ratio R_{32}

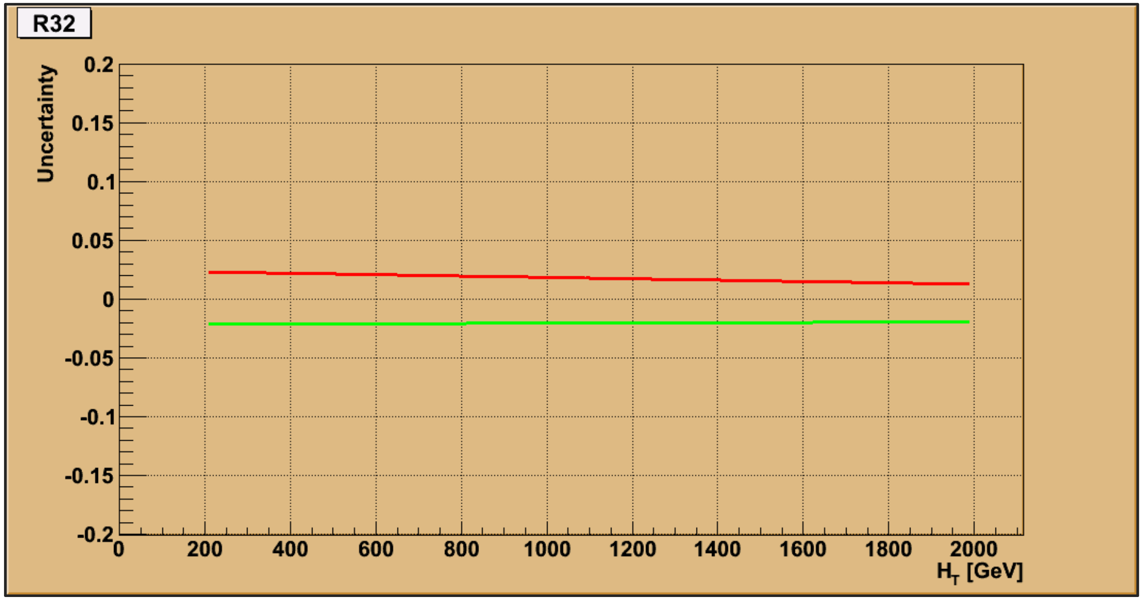
Changing all jets p_T by ±10%

Ratio R_{32}



Strong uncertainty cancellation

Looks very promising



Ratio R_{32}

Inclusive jet cross section

$$\frac{d^2\sigma}{dH_T d\eta} = \frac{C_{Smear}}{L \cdot \varepsilon} \cdot \frac{N^{Calo}(jets)}{\Delta H_T \cdot \Delta\eta}$$

C_{Smear} : smearing correction

$$C_{Smear} = \frac{\text{Number of reconstructed Calo events from Gen events at bin i}}{\text{Number of reconstructed Calo events in bin i}}$$

L : the integrated luminocity

ε : the efficiency for events survived cuts

$$\varepsilon = \frac{\text{Number of reconstructed Calo events from Gen events at bin i}}{\text{Number of Gen events in bin i}}$$

$N^{Calo}(jets)$: number of events counted in a bin

ΔH_T and $\Delta\eta$: are the H_T and pseudorapidity bin sizes respectively

Ratio R_{32}

Ratio R_{32}

$$R_{32}=\frac{\dfrac{d^2\sigma_3}{dH_T d\eta}}{\dfrac{d^2\sigma_2}{dH_T d\eta}}=\frac{\dfrac{C_{Smear3}}{\cancel{L}\cdot\varepsilon_3}\cdot\dfrac{N^{Calo}(n\ Jets\geq 3)}{\Delta H_T\cdot\Delta\eta}}{\dfrac{C_{Smear2}}{\cancel{L}\cdot\varepsilon_2}\cdot\dfrac{N^{Calo}(n\ Jets\geq 2)}{\Delta H_T\cdot\Delta\eta}}=\boxed{\frac{\dfrac{N^{Calo}(n\ Jets\geq 3)}{\Delta H_T\cdot\Delta\eta}}{\dfrac{N^{Calo}(n\ Jets\geq 2)}{\Delta H_T\cdot\Delta\eta}}}\cdot\boxed{\frac{C_{Smear3}}{\varepsilon_3}}\cdot\boxed{\frac{\varepsilon_2}{C_{Smear2}}}$$

measurement ⬍ **A** ⬍ **B**

$$A=\frac{N^{Gen}(n\ \ jets\geq 3)}{N^{CaloPass}(n\ \ jets\geq 3)}\times\frac{N^{CaloPass}(n\ \ jets\geq 3)}{N^{Calo}(n\ \ jets\geq 3)}$$

$$B=\frac{N^{Calo}(n\ \ jets\geq 2)}{N^{CaloPass}(n\ \ jets\geq 2)}\times\frac{N^{CaloPass}(n\ \ jets\geq 2)}{N^{Gen}(n\ \ jets\geq 2)}$$

$1/\varepsilon_3$ (1/efficiency)
nJets≥3

C_{Smear3}
Smearing correction
nJets≥3

$1/C_{Smear2}$
Smearing correction
nJets≥2

ε_2 (efficiency)
nJets≥2

With

$N^{Gen}(n\ \ jets\geq 2{,}3)$: Number of Gen events in bin i of H_T

$N^{Calo}(n\ \ jets\geq 2{,}3)$: Number of reconstructed Calo events in bin i of H_T

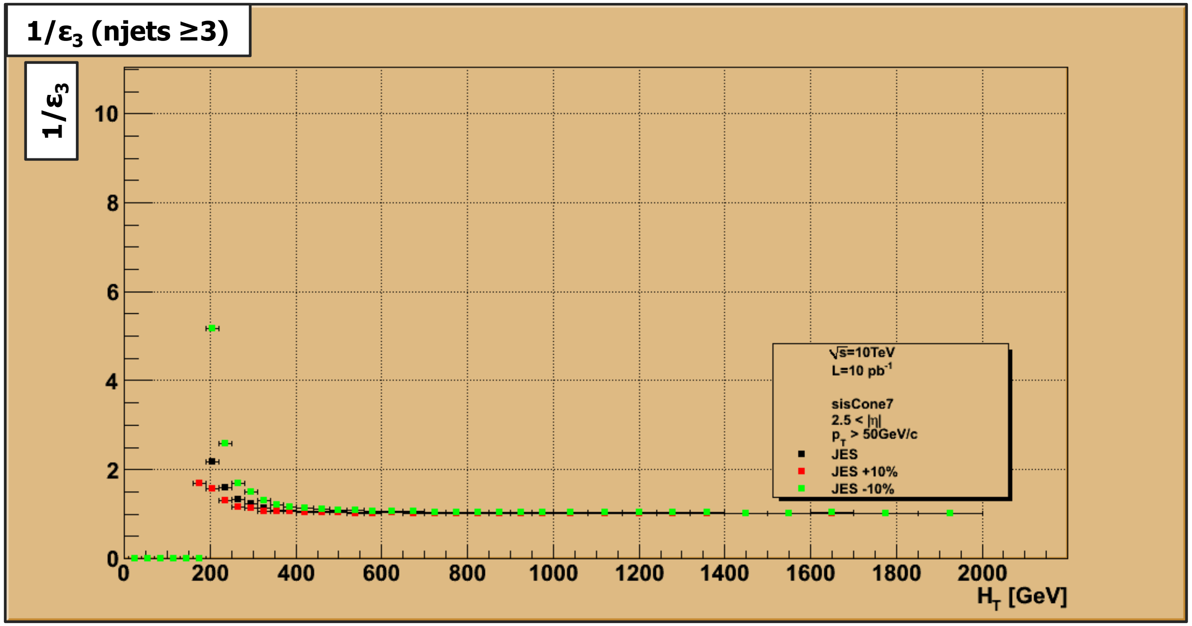
$N^{CaloPass}(n\ \ jets\geq 2{,}3)$: For Gen events of bin i of H_T all reconstructed Calo events survived cuts and appear to any bin

nJets≥3 : $1/\varepsilon_3$, C_{res3}

$1/\varepsilon_3$ (1/efficiency)
nJets≥3

$$\frac{N^{Gen}(n\ \ jets \geq 3)}{N^{CaloPass}(n\ \ jets \geq 3)}$$

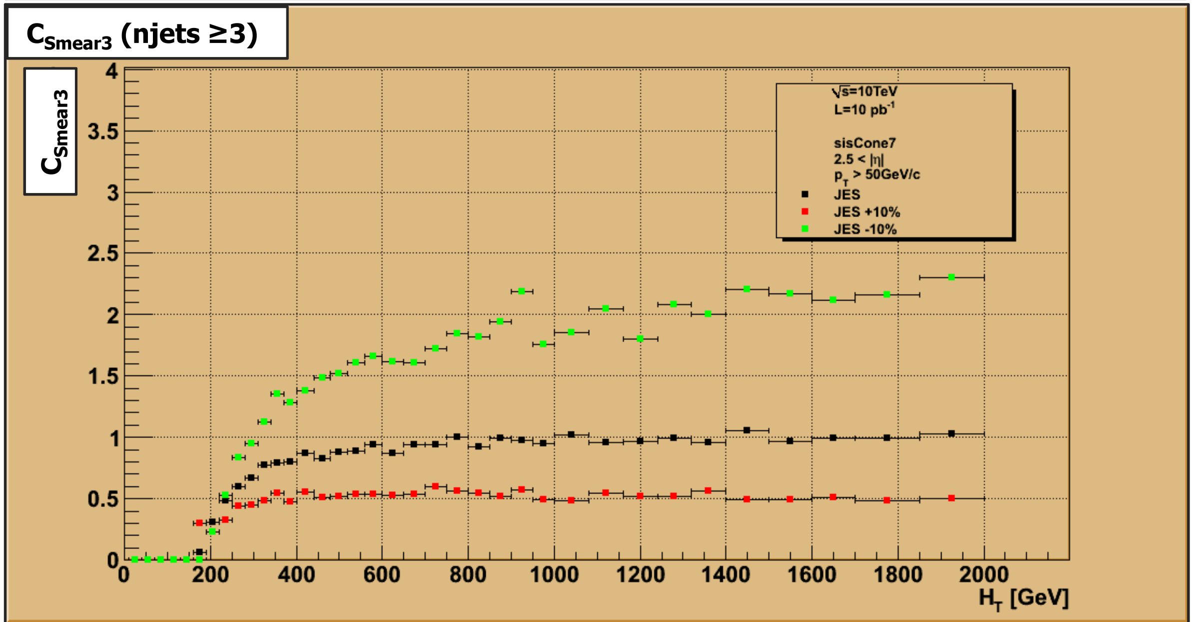
The $p_T \geq 50$ GeV/c cut modulates the efficiency at low H_T


$1/\varepsilon_3$ (njets ≥3)

C_{Smear3}
Smearing correction
nJets≥3

$$\frac{N^{CaloPass}(n\ \ jets \geq 3)}{N^{Calo}(n\ \ jets \geq 3)}$$

Above 400 GeV we observe a rather flat distribution shifted by
50% for JES + 10%
80% for JES – 10%

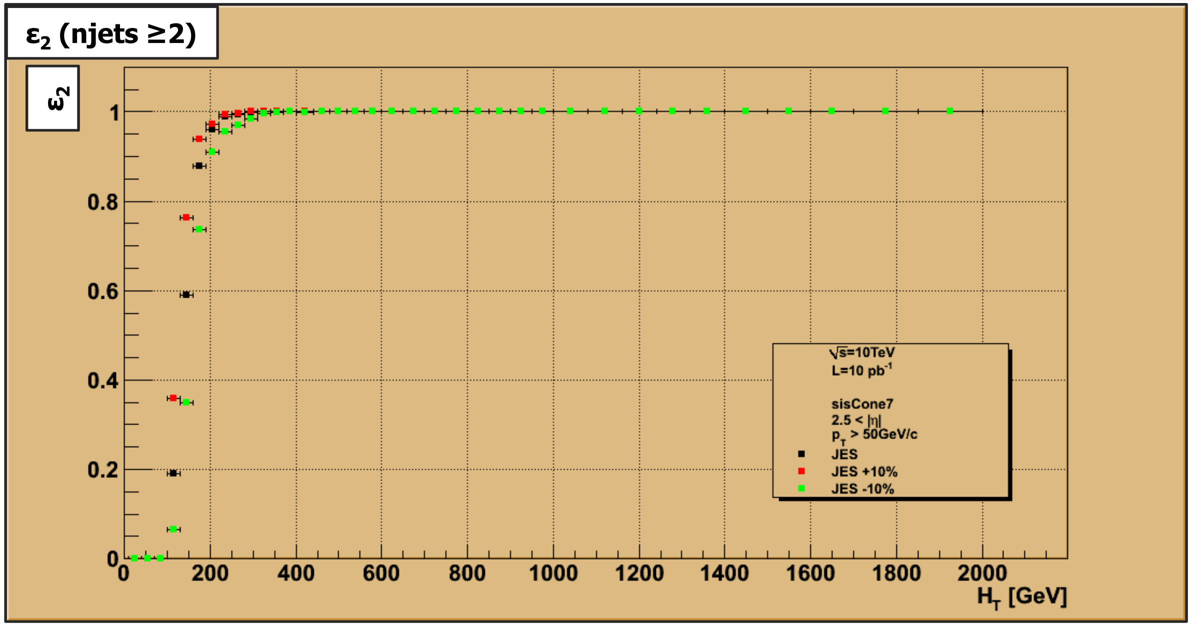

C_{Smear3} (njets ≥3)

nJets≥2 : ε_2 , $1/C_{res2}$

ε_2 (efficiency)
nJets≥2

$$\frac{N^{CaloPass}(n\ \ jets \geq 2)}{N^{Gen}(n\ \ jets \geq 2)}$$

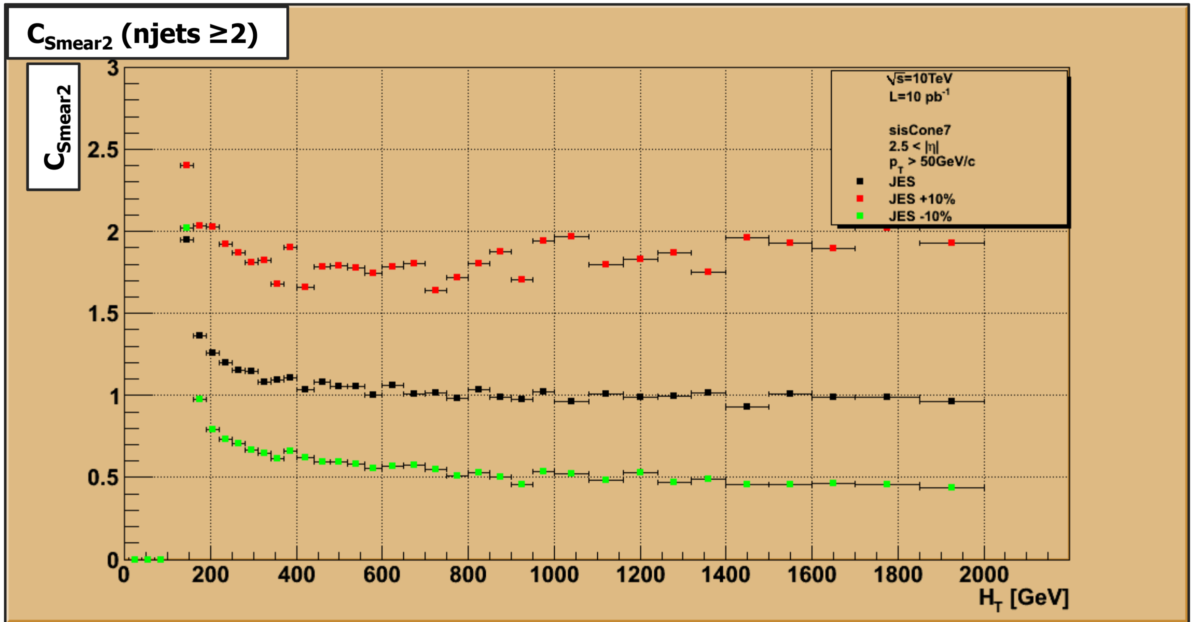
The $p_T \geq 50$ GeV/c cut modulates the efficiency at low H_T



$1/C_{Smear2}$
Smearing correction
nJets≥2

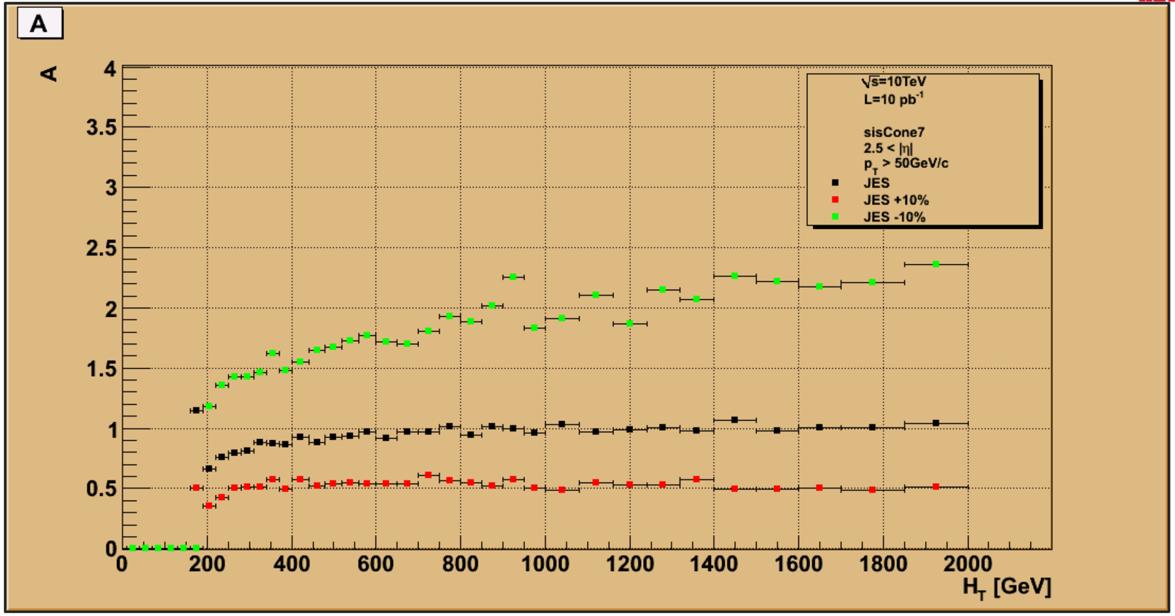
$$\frac{N^{Calo}(n\ \ jets \geq 2)}{N^{CaloPass}(n\ \ jets \geq 2)}$$

Above 400 GeV we observe a rather flat distribution shifted by
50% for JES - 10%
80% for JES + 10%



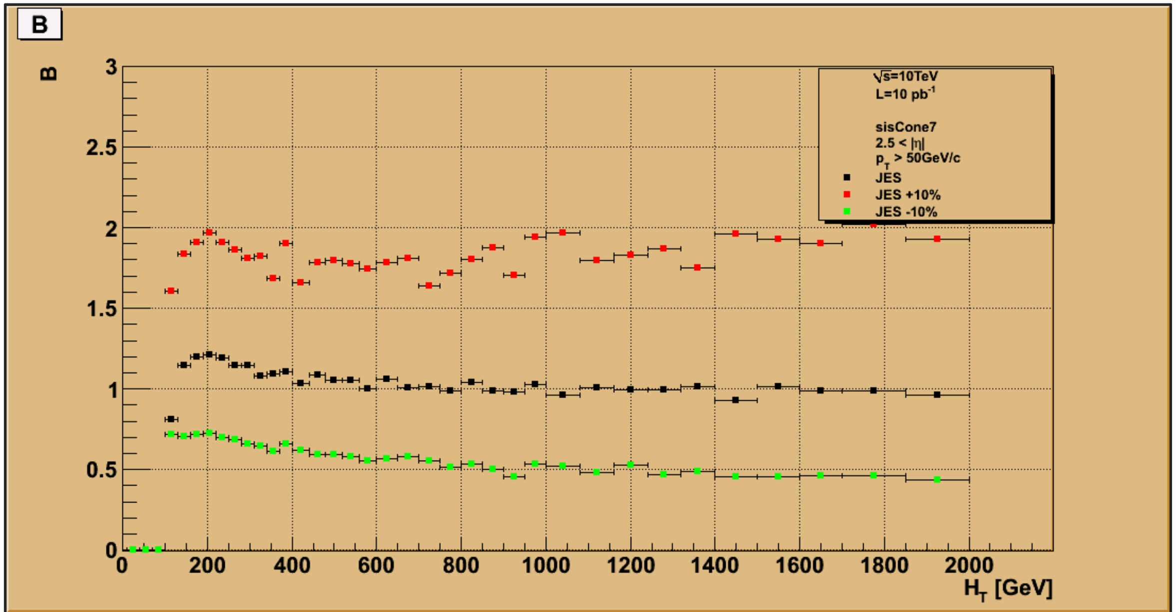
A and B

$$A = \frac{N^{Gen}(n\ \ jets \geq 3)}{N^{CaloPass}(n\ \ jets \geq 3)} \times \frac{N^{CaloPass}(n\ \ jets \geq 3)}{N^{Calo}(n\ \ jets \geq 3)}$$



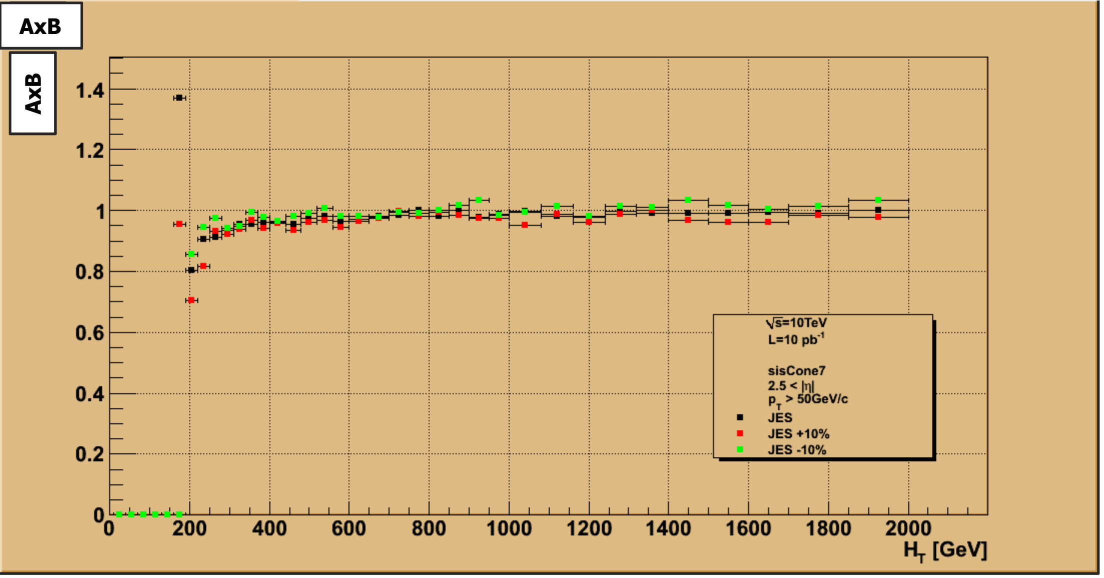
Smearing effects dominate

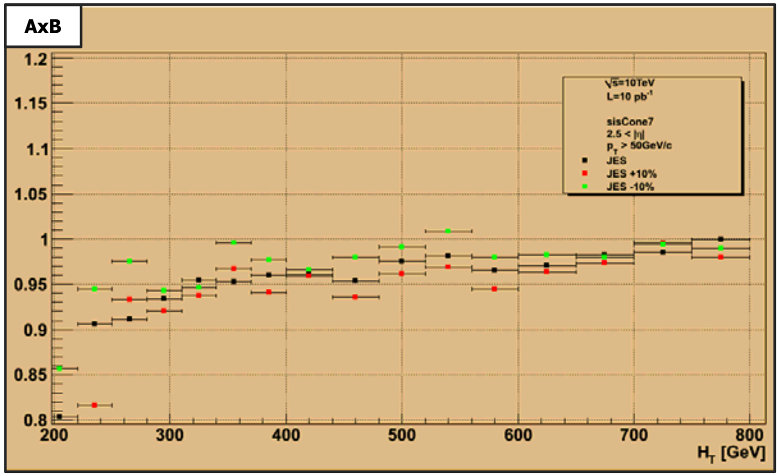
$$B = \frac{N^{Calo}(n\ \ jets \geq 2)}{N^{CaloPass}(n\ \ jets \geq 2)} \times \frac{N^{CaloPass}(n\ \ jets \geq 2)}{N^{Gen}(n\ \ jets \geq 2)}$$

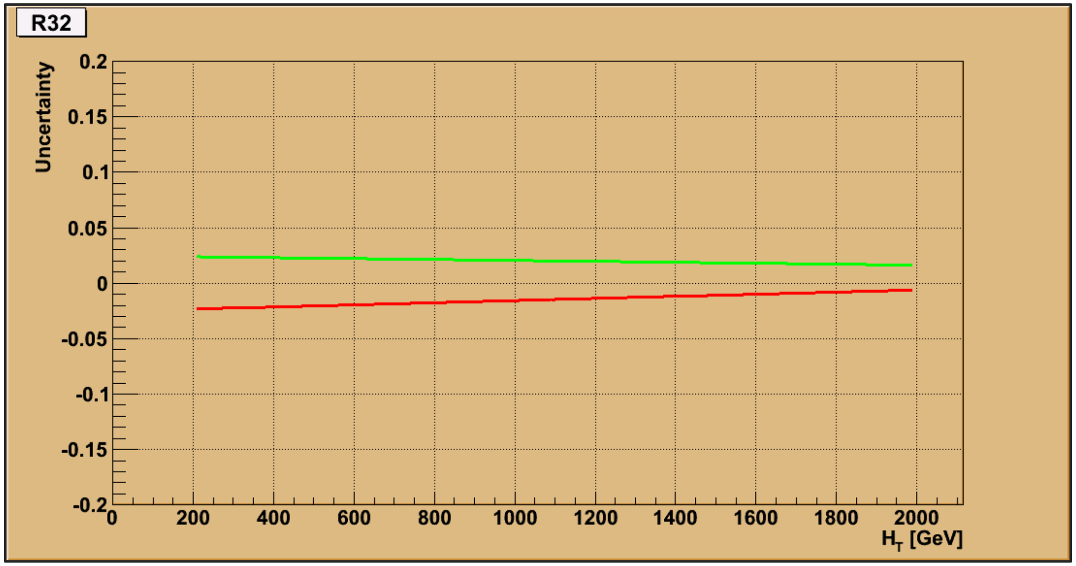


AxB

$$\left(A=\frac{N^{Gen}(n\ \ jets\geq 3)}{N^{CaloPass}(n\ \ jets\geq 3)}\times\frac{N^{CaloPass}(n\ \ jets\geq 3)}{N^{Calo}(n\ \ jets\geq 3)}\right)\times\left(B=\frac{N^{Calo}(n\ \ jets\geq 2)}{N^{CaloPass}(n\ \ jets\geq 2)}\times\frac{N^{CaloPass}(n\ \ jets\geq 2)}{N^{Gen}(n\ \ jets\geq 2)}\right)$$







We observe a strong uncertainty cancellation (uncertainty less than 5%)

Summary & Plans

- We performed studies to evaluate systematic uncertainties of 2 jet, 3jet cross sections and of measured R_{32} by varying JES by 10%
  - Uncertainties of 2 jet, 3 jet consisted with other studies ~50-100%
  - Our study shows strong uncertainty cancellation for R_{32} (uncertainty of R_{32} is less than 5%)

- We have started to write a note with details of our analysis.

- Still to be done:
  - Closure test (use the correction factor to reproduce the hadron level)
  - Estimate the magnitude of hadronisation uncertainty
  - Compute the theoretical rate with NLO programs and estimate the uncertainty due to μ_R, μ_F
  - Plan to move to 7 TeV MC samples
  - Studies with Madgraph to follow shortly in the next High P_T meetings