Calibration of the absolute jet energy scale with Z(→μμ)+jet events at CMS

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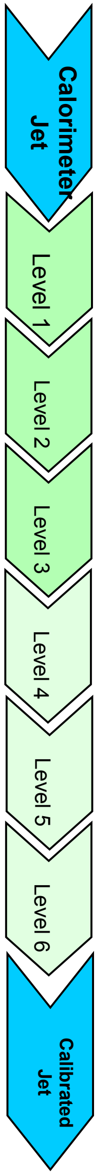
Outline

- Jet Energy Corrections in CMS
- Z(→μμ)+ 1 jet events selection: cuts, signal and backgrounds.
- Estimator of the balancing quality: the jet response
- Evaluation of the method
- 7 to 10 TeV centre of mass energy reduction effects
- Absolute jet energy scale calibration with Z(→μμ)+ 1 jet events
- Dependence on flavour composition and comparison with MC Di-jets calibration

Jet energy corrections in CMS



Must

Optional

Levels of jet energy correction

Level 1: Jets corrected for offsets from pile-up and electronic noise.

Level 2: Relative jets corrections (η response)

QCD dijet events (currently derived from MC truth information)

Level 3: Absolute correction of the jet energy scale (absolute P_T)

QCD dijet jet events (derived from MC truth information)

Z plus jets, photon plus jets, top events, qcd three jet events …

- important level of correction for analysis.

Level 4: Flavour jets corrected to the particle level.

→ Specialized jets at particle level for top and Higgs measurements.

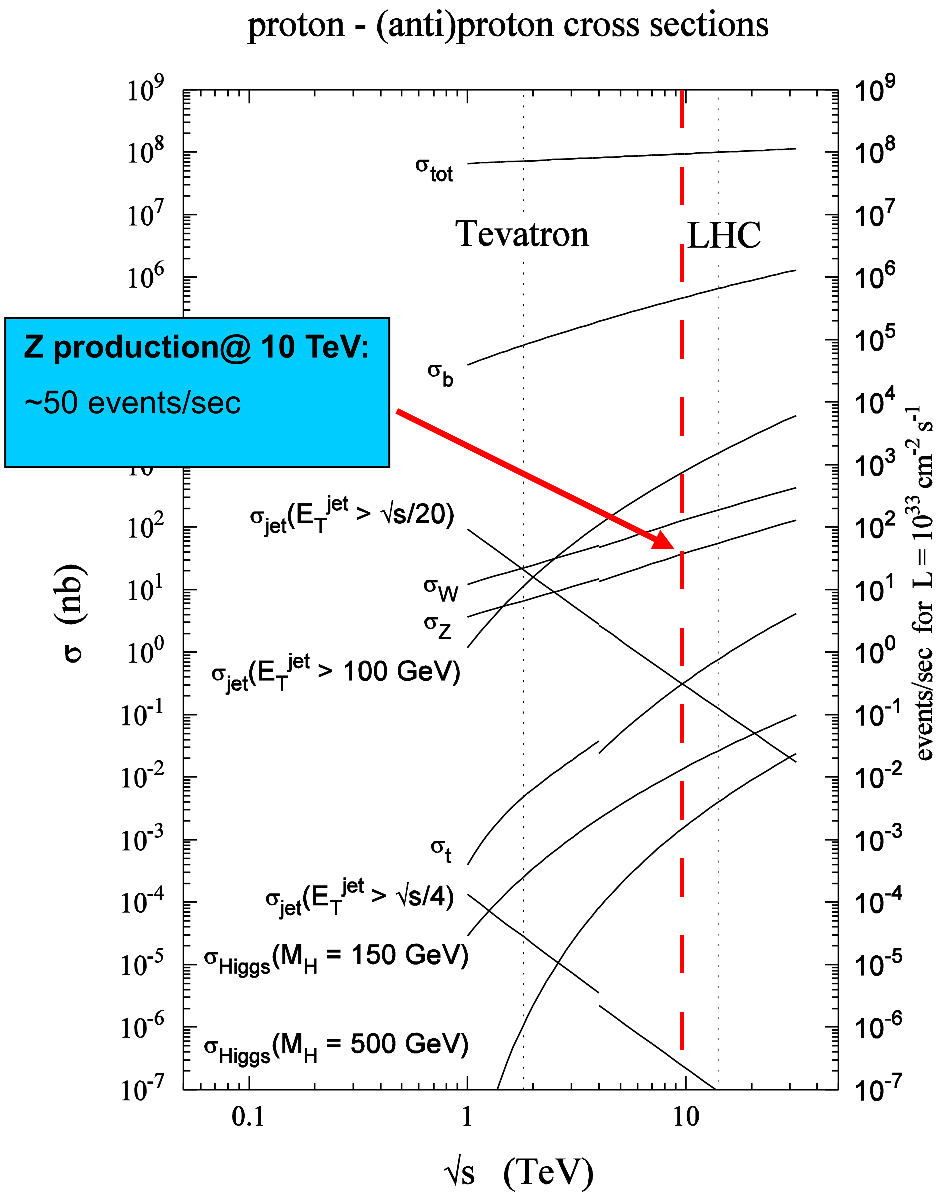
Level 5: Jets corrected to particle level with underlying event removed.

→ Comparisons with perturbative QCD (N)NLO calculations.

Level 6: Jets corrected to the parton level.

→ Model dependent searches for new physics, top and Higgs mass measurements, etc.

CMS uses factorised approach for jet calibration



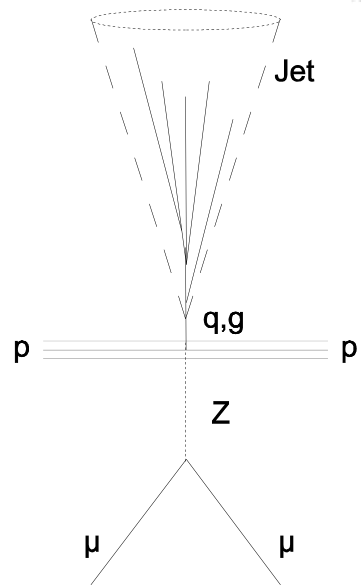
arXiv:hep-ph/0005025v1

- Large number of Z boson events available
- Can be used for:
  - Commissioning of the tracker
  - Luminosity measurement
  - Calibration of the calorimeters and jets

Analyses based on Z boson events are well suited for early phase of LHC

Jet calibration with Z+1jet events:

- Z momentum balanced by one parton of the hard sub-process
- Determination of balanced jet momentum through comparison with Z momentum
- Cross section smaller but kinematics of the Z boson can be reconstructed very precisely
- Only tracker (μμ) or ECAL (ee) calibration



Event selection for:

Cuts on muons:

- P_T > 15 GeV and |η| < 2.3 (Trigger and detector constraints)
- Isolated muons: Sum transverse momenta of all tracks in a cone of ΔR<0.3 smaller than 3 GeV
- Trigger: Require at least one muon in the event being identified by the HLT

Reconstruction of Z boson:

- Match muons with opposite charge and invariant mass closest to Z mass
- Accept only events with reconstructed mass of Z boson with $|M - M_Z| < 20$ GeV

Jet selection:

- Leading jet: $|\eta|_{jet} < 1.3$ due to CMS detector geometry, is JEC control region
- No cut on leading jet transverse momentum to not bias the analysis

To ensure a clean Z+1 Jet sample, the following cuts are applied:

- Transverse momentum 2nd leading jet in P_T small compared to Z momentum $P_T(\mathrm{Jet2}) / P_T(Z) < 0.2$ **(F2J cut)**
- Z boson and leading jet have to be balanced in Phi with $|\Delta\Phi(Z,\mathrm{Jet}) - \pi| < 0.2$

Investigated background processes for Z+1jets:

- QCD sample enriched with b and c quark decays into muons
- W boson decaying into a muon and a neutrino
- Z boson decaying into two taus

CMS Preliminary

process	events available	after selection	weight ($1\,\mathrm{fb}^{-1}$)	events ($1\,\mathrm{fb}^{-1}$)
QCD $b,c \to \mu$	$11.294 \cdot 10^6$	0	10.7734	<32.3 (95%CL)
$W \to \mu\nu_\mu$	$1.09642 \cdot 10^6$	0	7.46827	<22.4 (95%CL)
$Z \to \tau\tau$	$1.01364 \cdot 10^6$	9	1.91785	17.3

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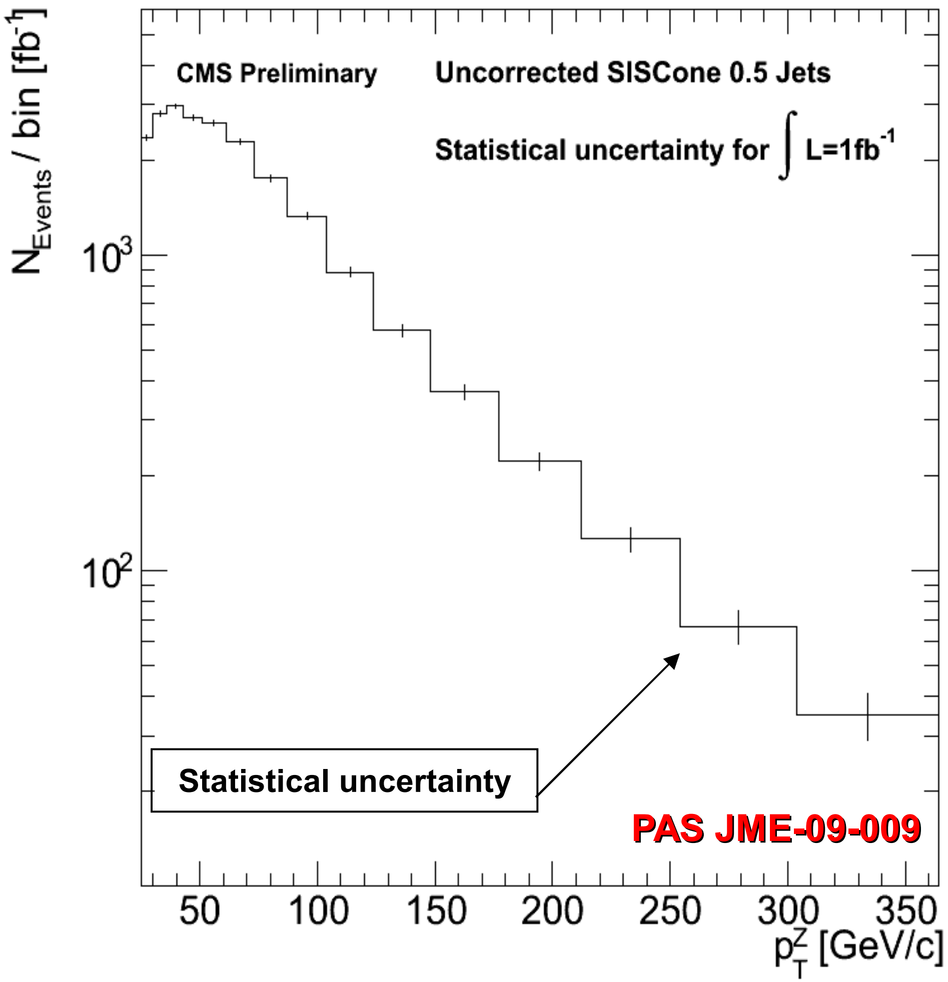
- No event of QCD and W sample passed the selection criteria
  - Upper limit (95% CL assuming Poissonian statistics): less than 55 events from both processes for $1\mathrm{fb}^{-1}$
- Only 9 events from the Z → tau tau sample selected
  - Corresponds to ~17 events for $1\mathrm{fb}^{-1}$
- CMS EWK-07-002 has studied the background to $Z \to \mu\mu$. Bkg also for their selection negligible

Almost no background expected

Expected number of Z+1 jet events for an integrated luminosity of $1fb^{-1}$



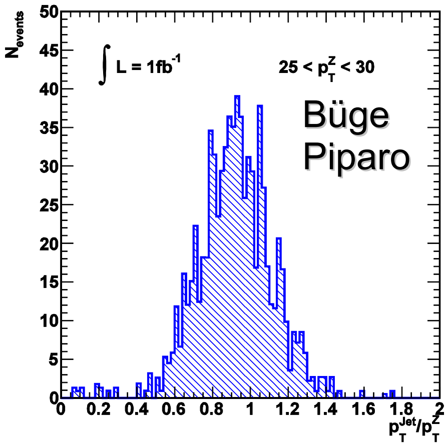
After event selection:

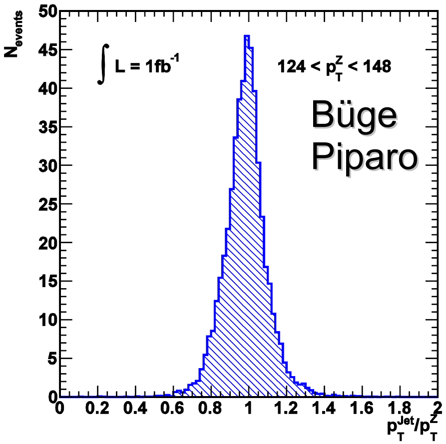
- Negligible uncertainty related to number of generated MC events
- Background negligible
- Most promising candidate for Jet calibration for small jet transverse momentum where photon + jet is affected by large QCD background

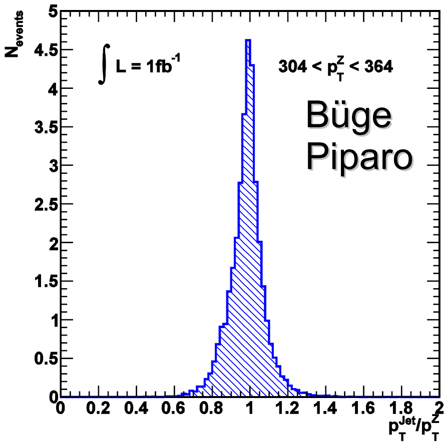
Large number of Z+1jet events available

Estimator Of The Balancing Quality

- Jet response R used as measure for the quality of the balancing: $R = P_T^{Jet} / P_T^{Z}$
- Evaluated in bins of P_T^Z to suppress fluctuations
- Variable bin size to reflect the steeply falling P_T^Z spectrum
  - Upper bound: 20% incremental of value of lower edge, rounded to integer
- Only bins with > 20 events are considered







Very low P_T^{Z}:

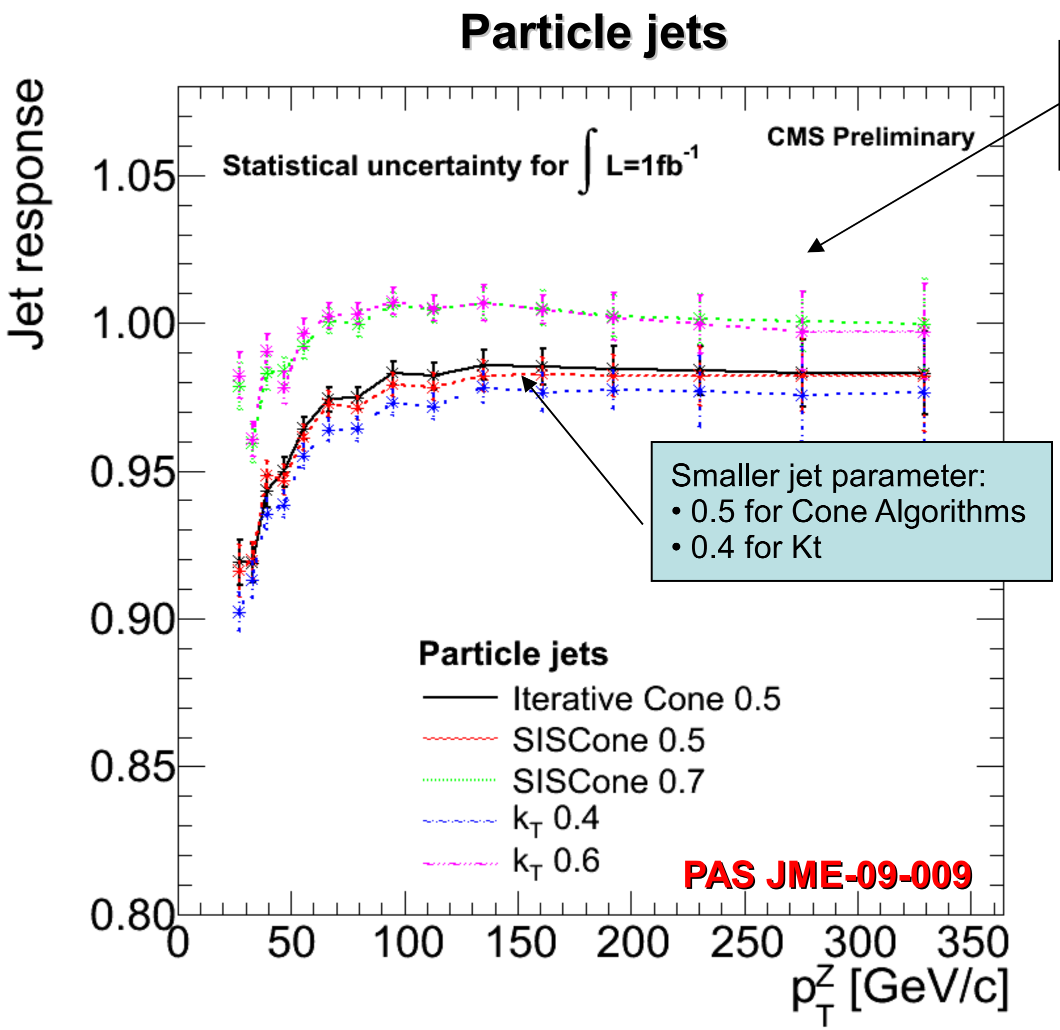
- slight asymmetry and tails

→ Mean slightly shifted to smaller value

Medium and high P_T^Z: symmetric and no tails

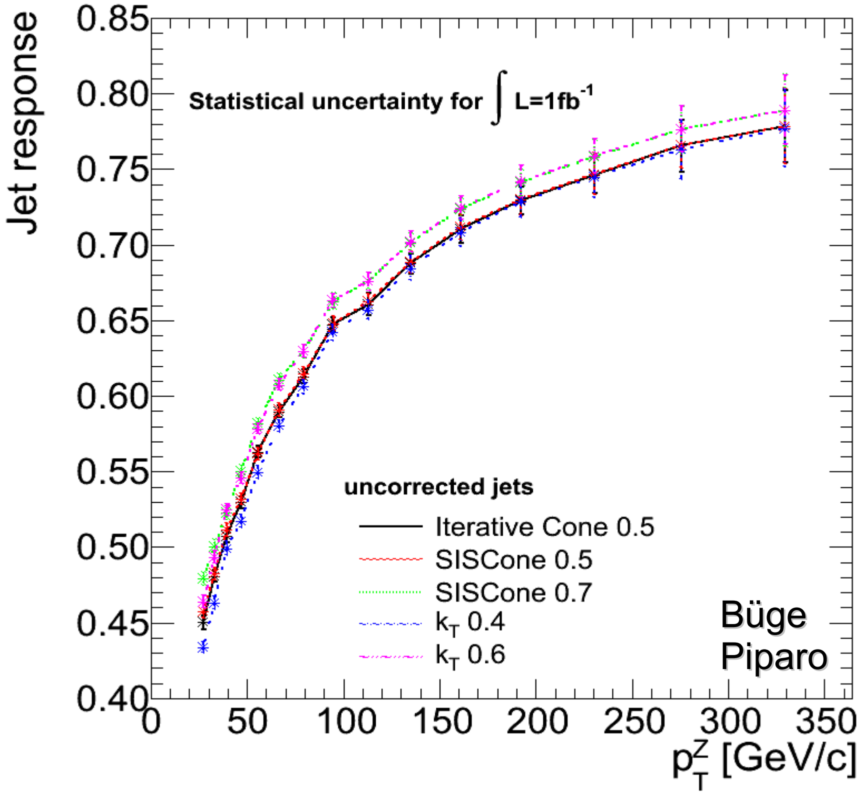
→ Mean good estimator for R and robust against fluctuations, especially for the low statistics bins

- Jet Response mean for every P_T^Z bin considered



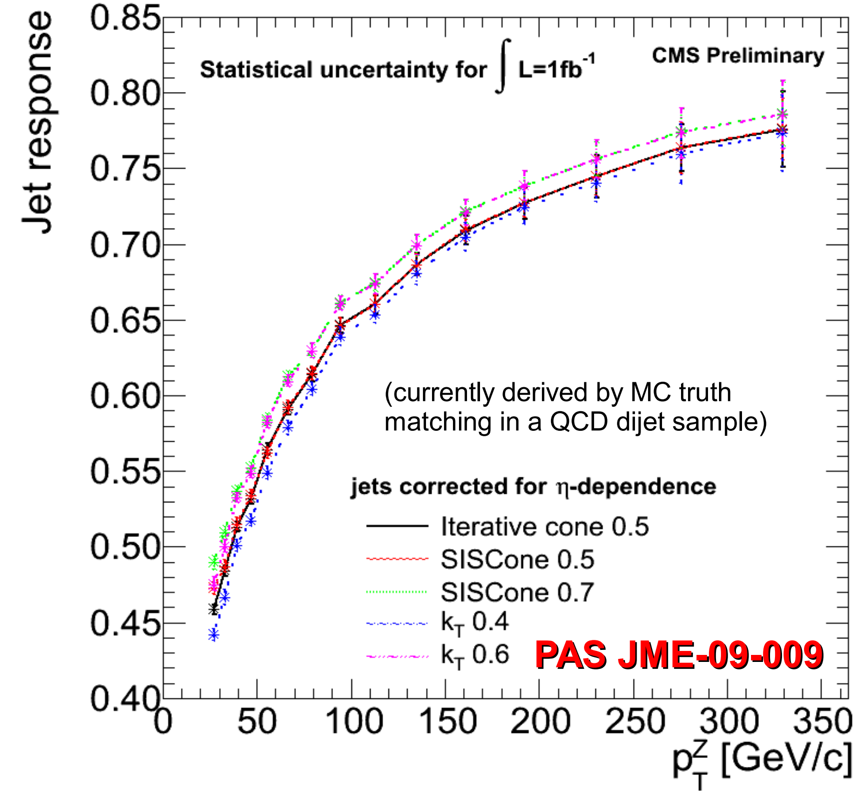
- The mean of the response is plotted versus the mean of the corresponding P_T^Z distribution.
- Statistical uncertainty on the response determined by toy MC experiments for an integrated luminosity of $1fb^{-1}$.
- Smaller jet parameters slightly under-, larger slightly overbalance the momentum of the Z boson

Z and Jet P_T are in good agreement on generator level



Shows expected underestimation of P_T for uncalibrated calorimeter jets

- 45% of Z P_T for small P_T^Z bins
- 80% of Z P_T for large P_T^Z bins



Relative η corrections (L2) do not affect the P_T ratio in control region

→ *Provide a pt absolute calibration using Z+1 jet events*

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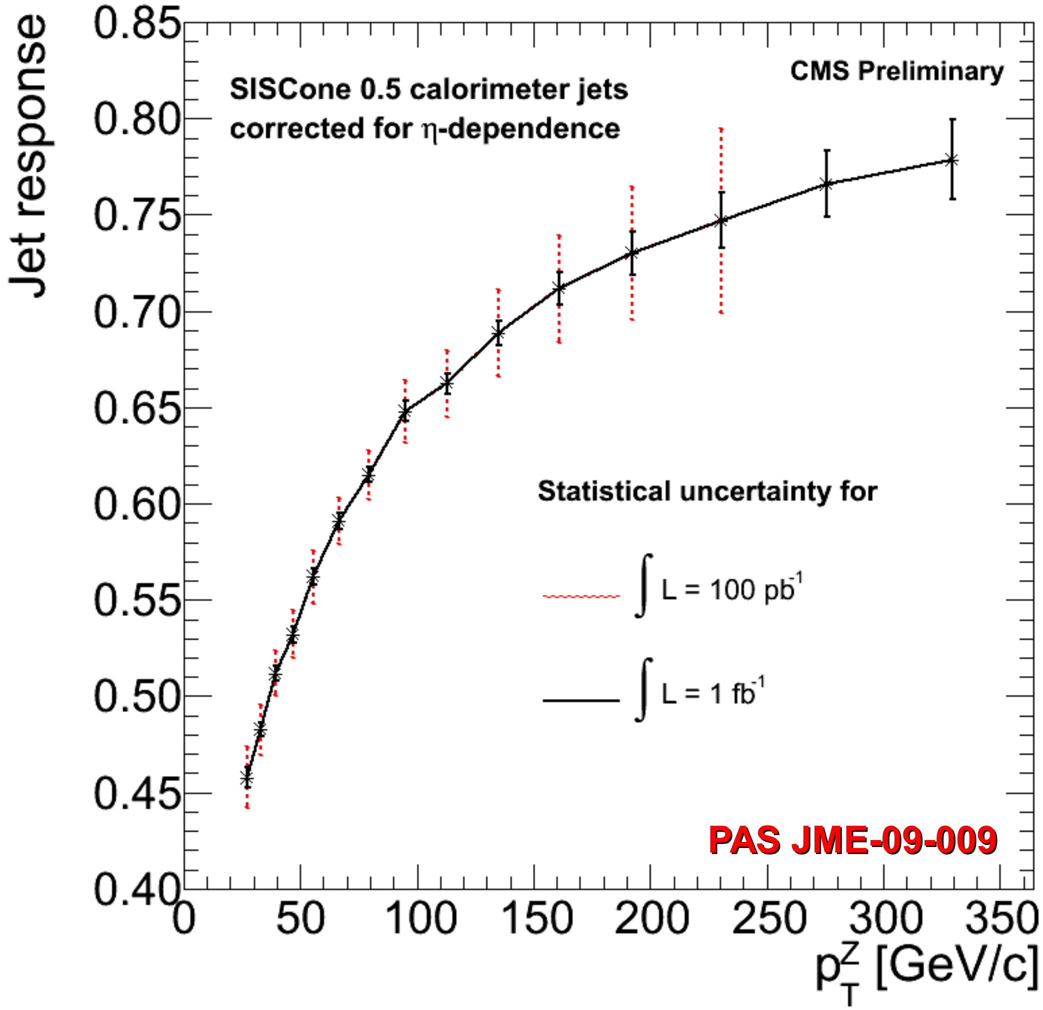
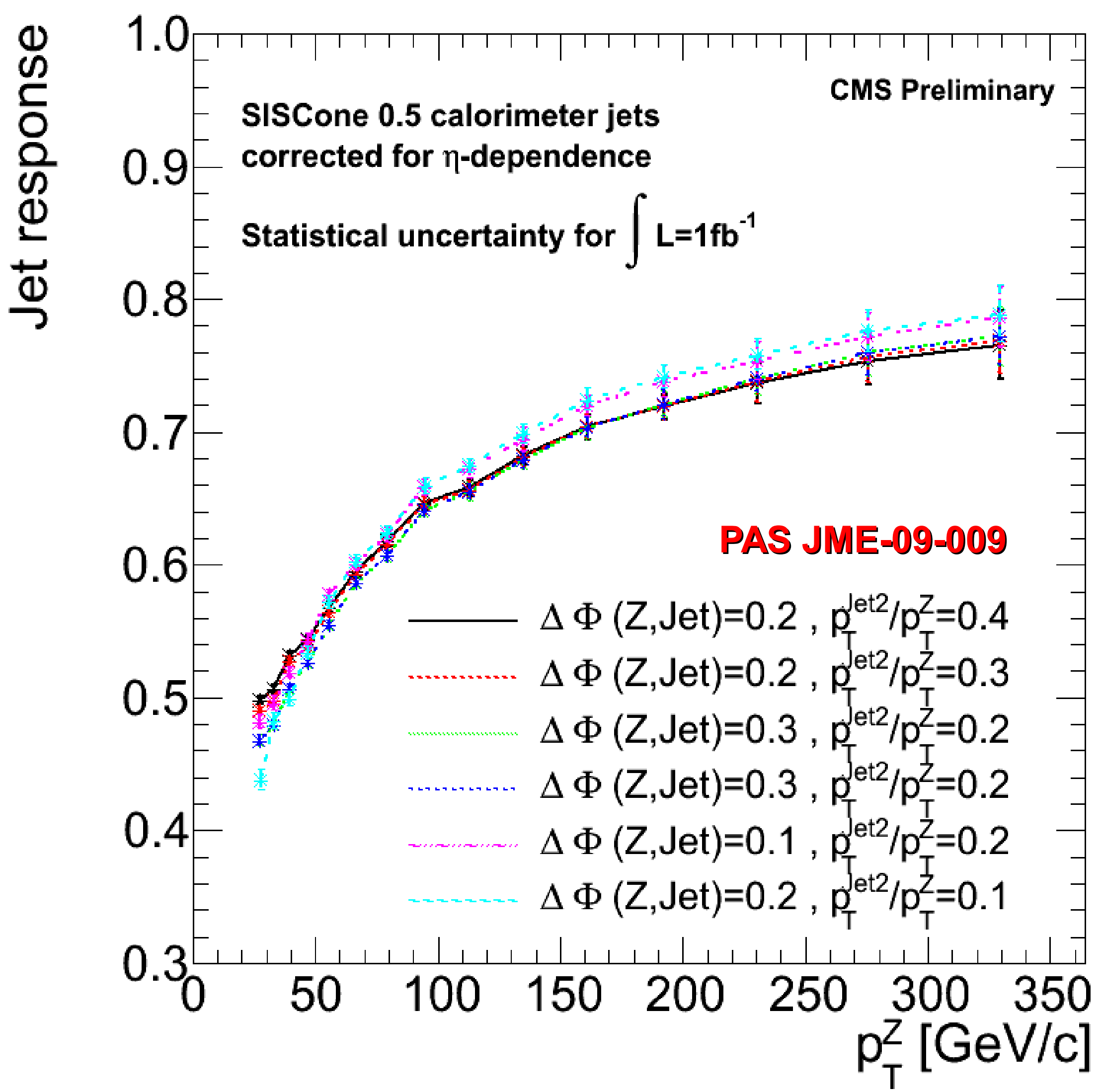
- Statistical uncertainty on the response as expected for two luminosities:
- L= 1 fb^{-1}:
  - Sufficient events for calibration up to a transverse momentum of the Z boson of ~350 GeV
  - Statistical uncertainty on the response < 5%
- L= 100 pb^{-1} :
  - Calibration possible up to P_T^Z of 250 GeV with a statistical uncertainty < 6%



Z+1jet calibration can provide Calibration factors for P_T^Z < 250 GeV for 100 pb^{-1}

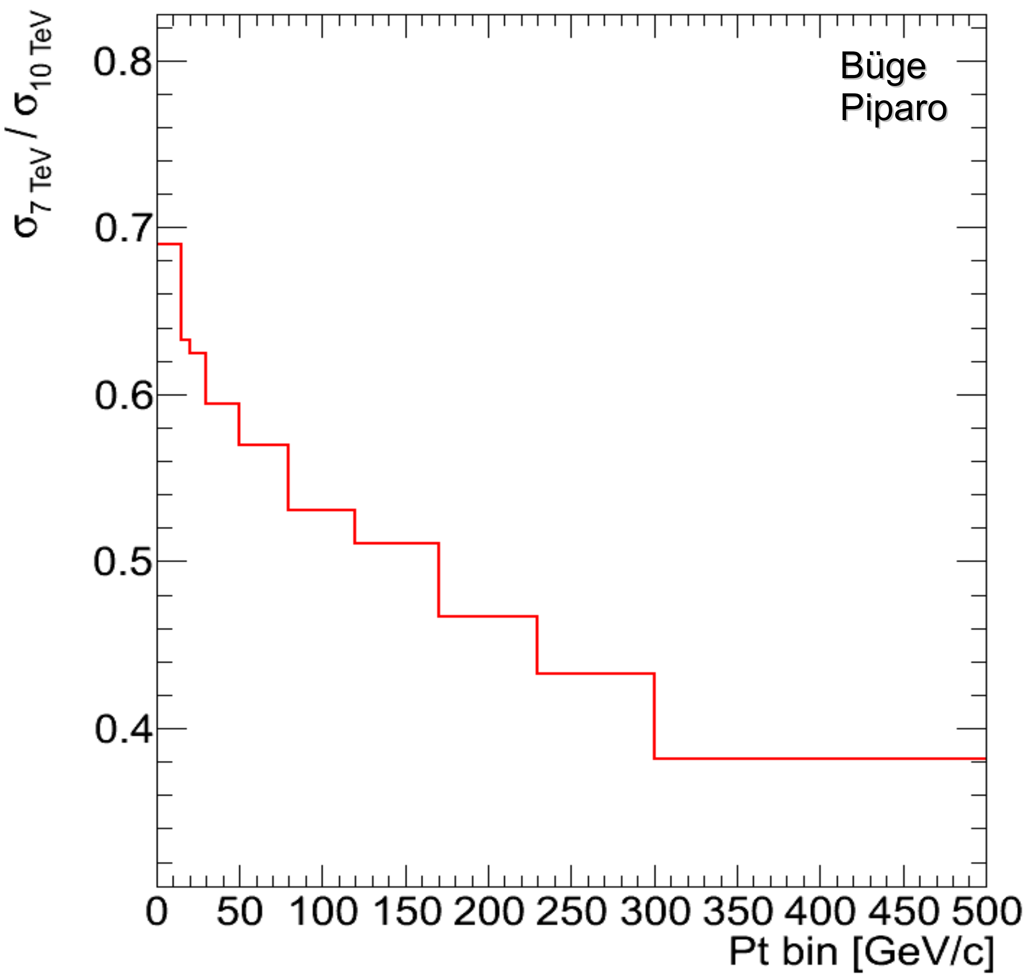


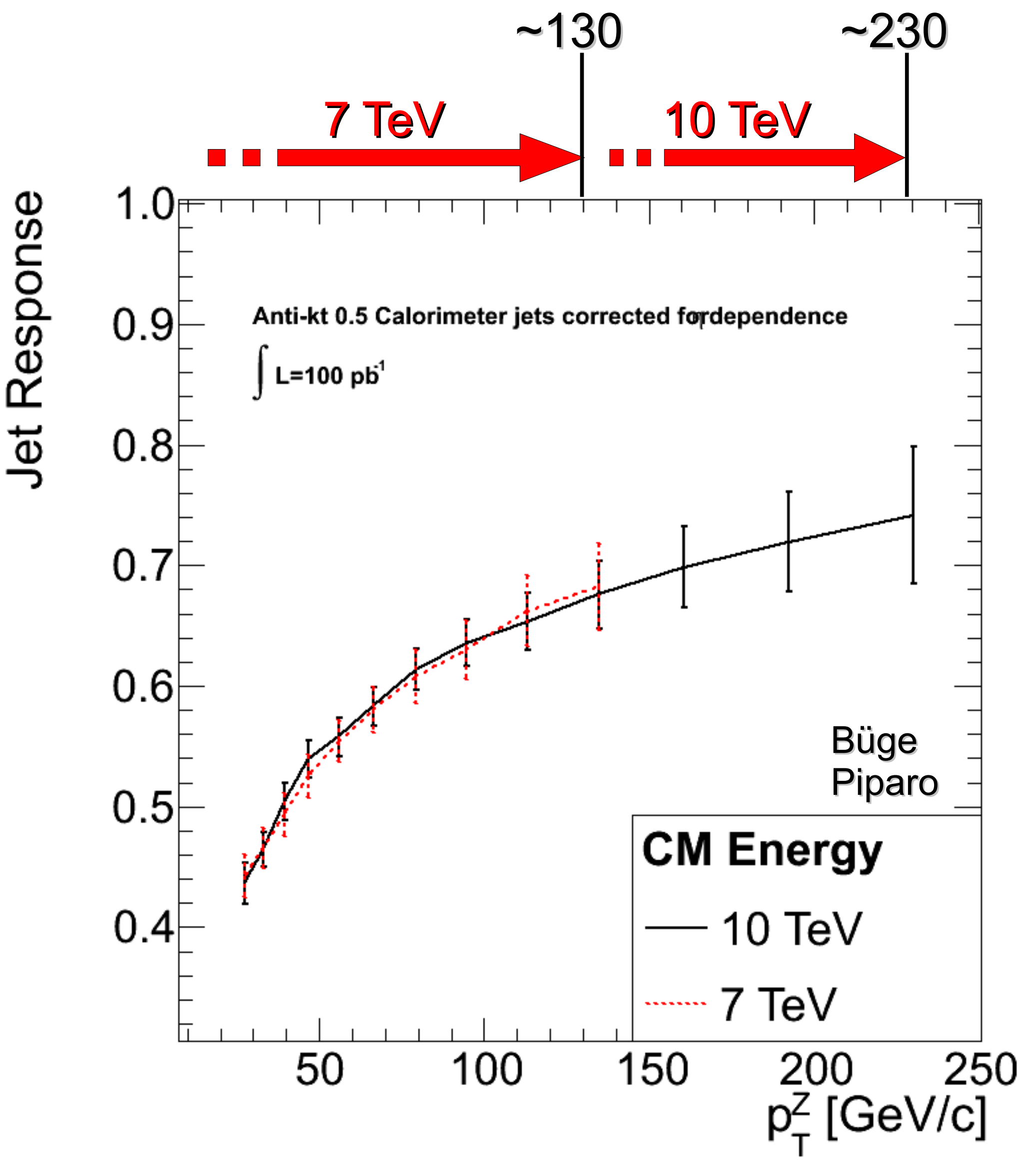
- Variation of Z+1 jet selection cuts
- All other cuts are set to their default value
- Both, the shape and the offset of the response are only slightly affected by the variation

Only small systematic uncertainty due to Z+1 jet selection

The Z (→ μμ)+jet cross sections at 10 and 7 TeV

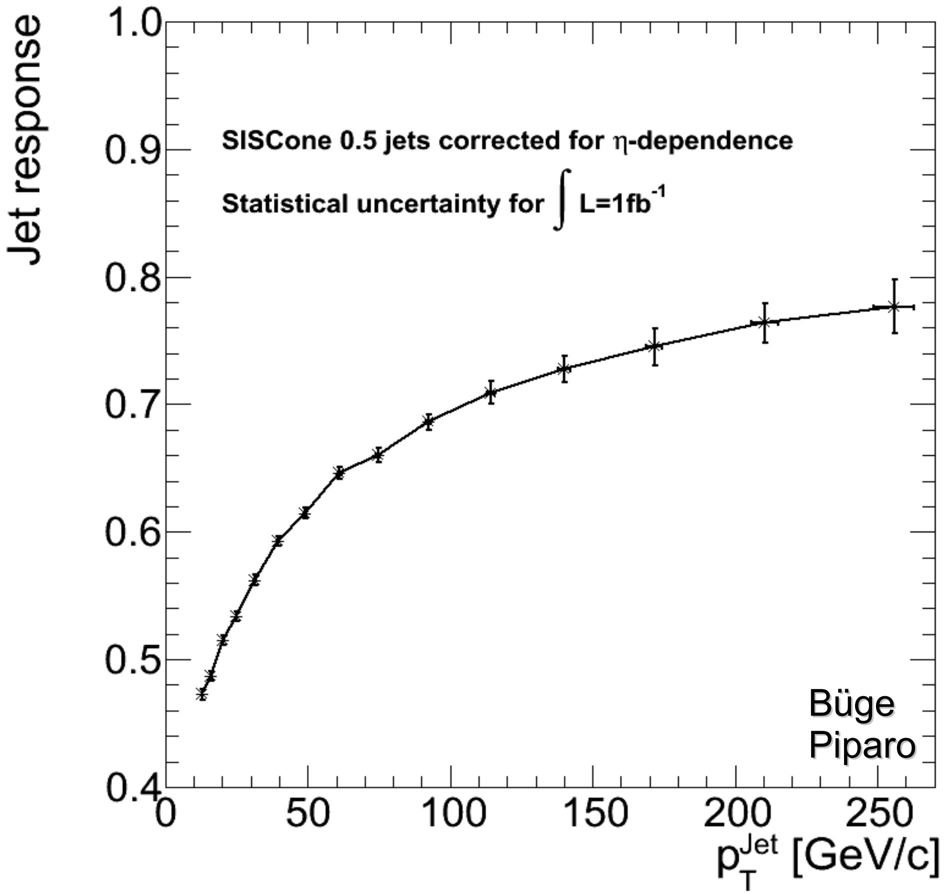
- Important reduction of the cross section
- 40% less at low pt, 60% less around 250 GeV
- Impact on the calibrated Pt range seizable





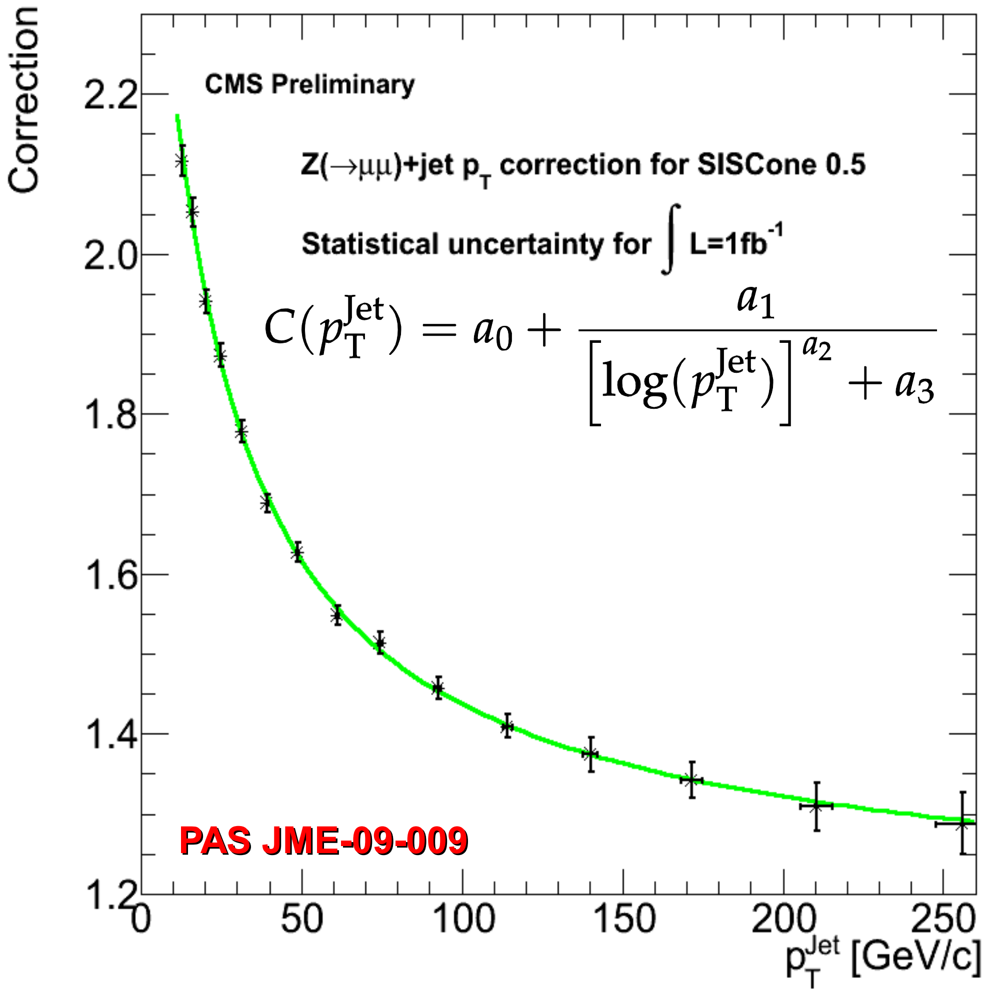
Response as a function of the transverse momentum of the jet

- For the evaluation of the method, the response was evaluated in versus P_T^Z
- Now shown versus the mean of the transverse momentum of the leading jet in the P_T^Z bin
- RMS of P_T^{Jet} stated as uncertainty on this value



Determination of calibration factors possible for 10 GeV < P_T^{Jet} < 250 GeV for 1fb^{-1}

Calibration with Z (→ μμ)+ 1 jet Events 2/4

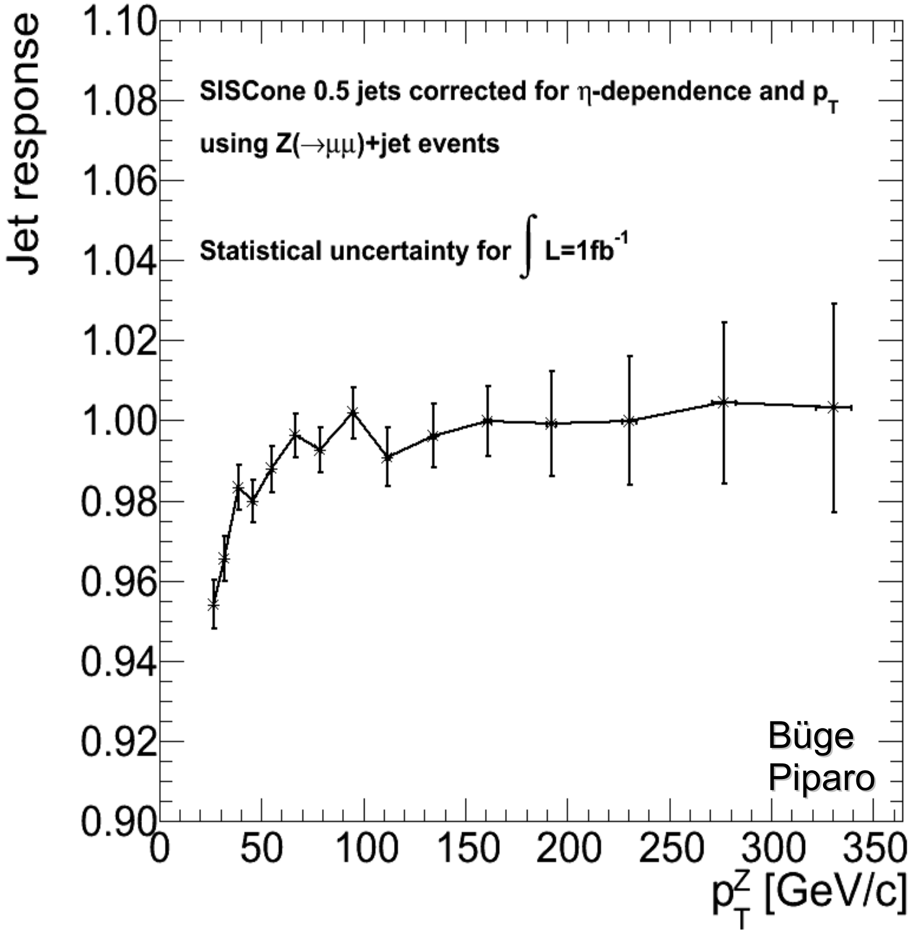


- Correction factor C(Jet):
  C(Jet) = 1/R(Jet)
- Uncertainty: ΔC = ΔR / R^2
  with ΔR uncertainty on the response
- Correction factors from fit

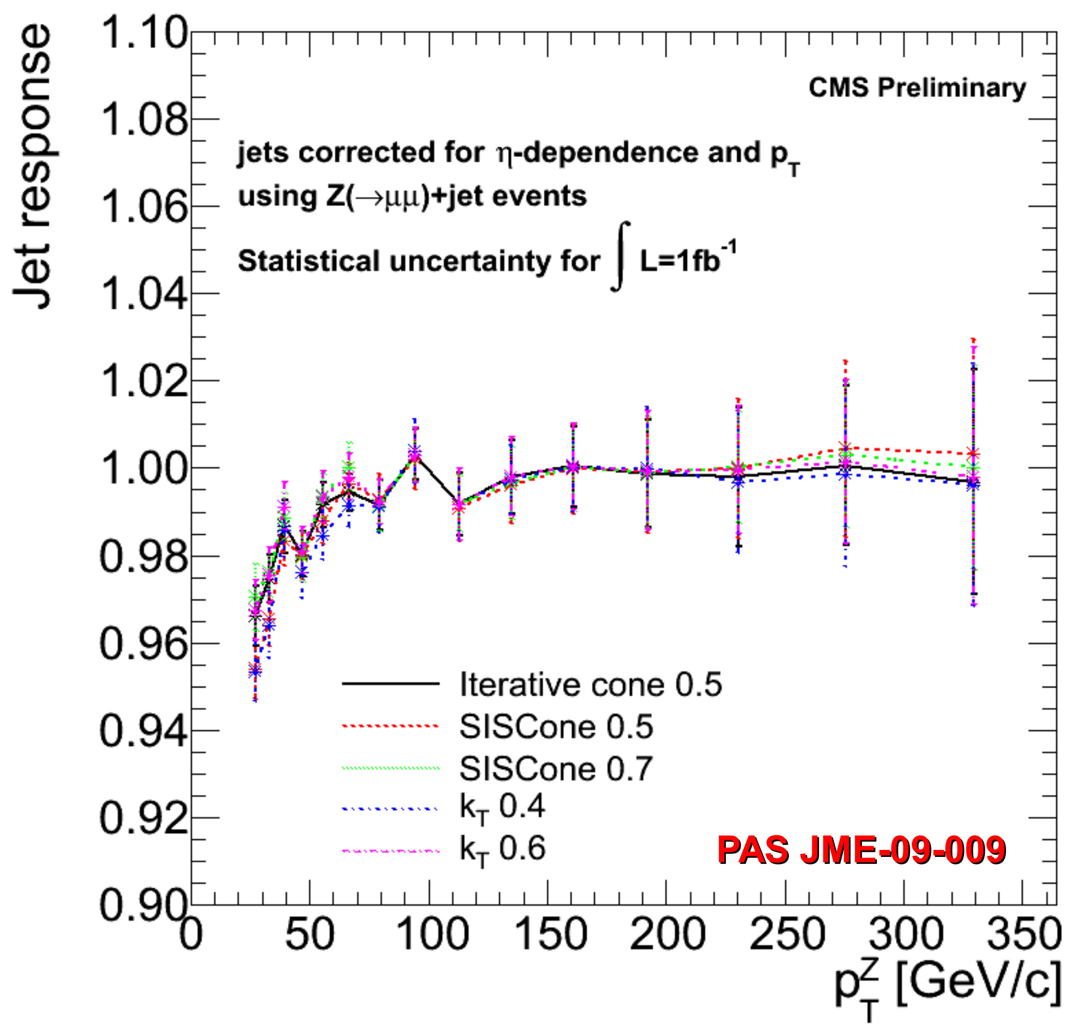
Calibration factors for SISCone 0.5 jets for 10 GeV < P_T^{Jet} < 250 GeV (for 1fb^{-1})

Test of self consistency of the derived calibration factors – *Closure test*:

- Closure: First test of self-consistency of the derived calibration factors for the SISCone 0.5 jet algorithm performed on the same dataset
- Deviation from unity smaller than 1% for transverse momentum of the Z boson larger than 50 GeV



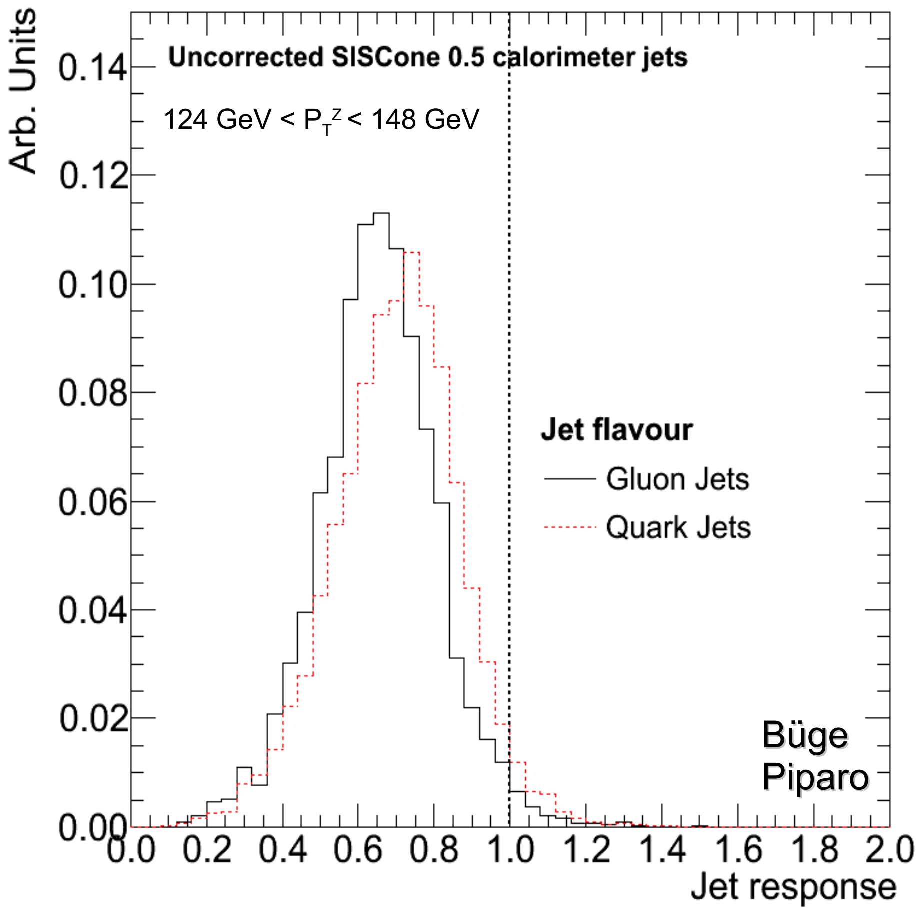
Closure test of calibration factors for SISCone 0.5 jets successful



- Calibration factors and closure test of the derived calibration for all algorithms (same dataset)
- Deviation from unity smaller than 1% for transverse momentum of the Z boson larger than 65 GeV

Closure test of the L3$^{Z\to\mu\mu}$ calibration factors successful

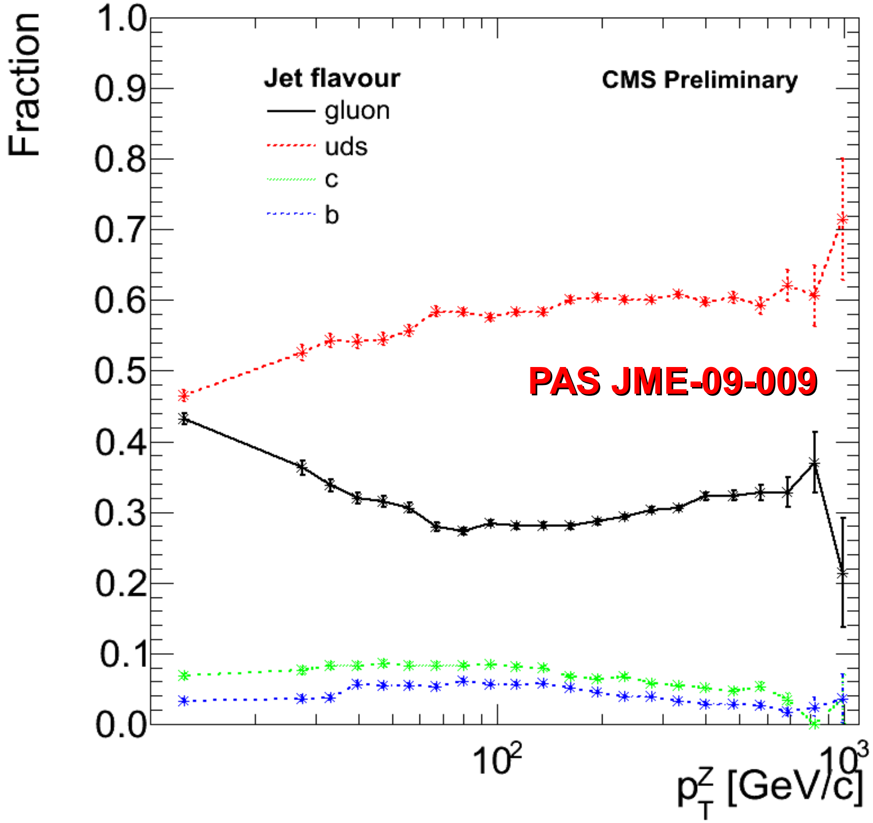
Dependence on flavour composition



Fraction of quark and gluon jets balancing the Z boson:

Z+jet sample: Quark dominated

For example: QCD dijet samples mainly dominated by gluon jets for low hard transverse momentum scales.



Difference of Z and jet transverse momentum is larger for gluon jets compared to quark jets

→ Jet energy in Z+jet samples is overestimated as mainly quark jets are balancing the Z boson!

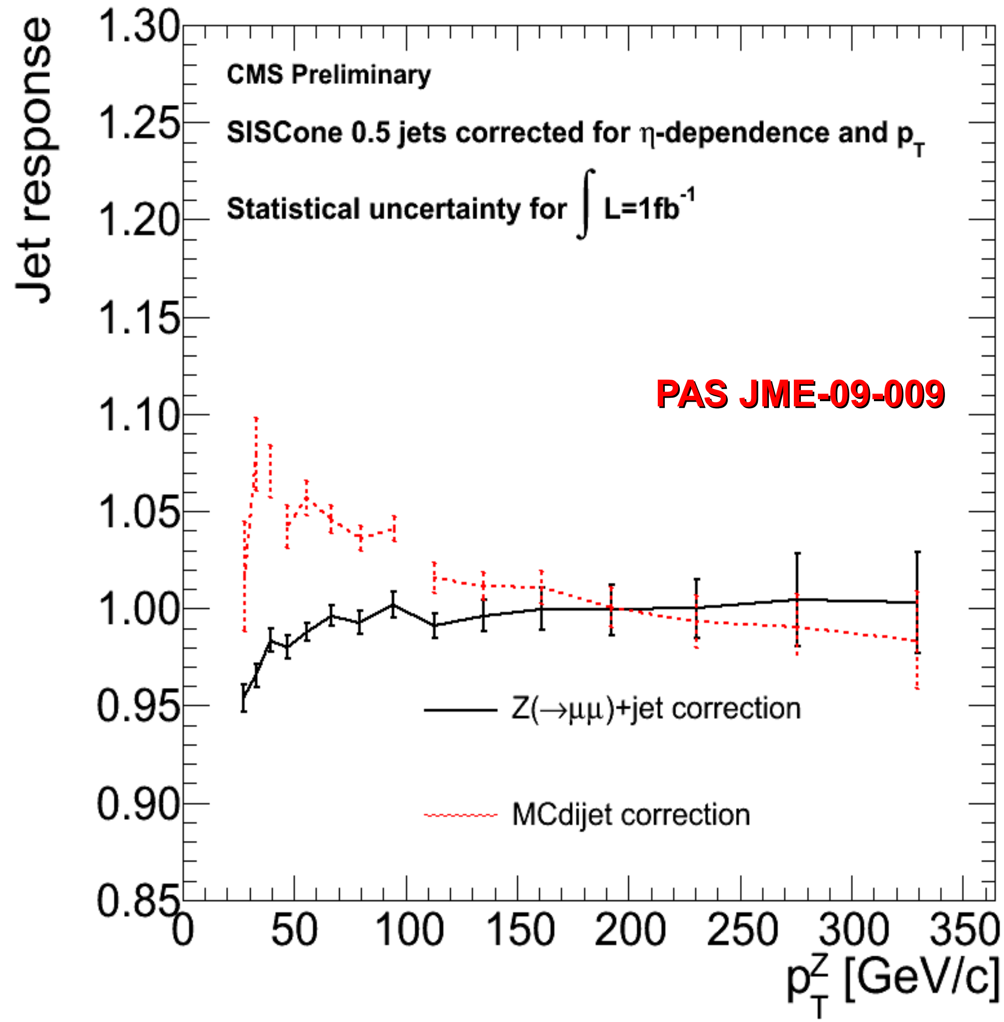
Need jet calibration which can handle different fractions of quark and gluon jets

- QCD dijet sample mainly dominated by gluon initiated jets in the low P_T region
- Z+jet samples has only 30% of gluon initiated jets
- Response for gluon jets is smaller compared to quark jets

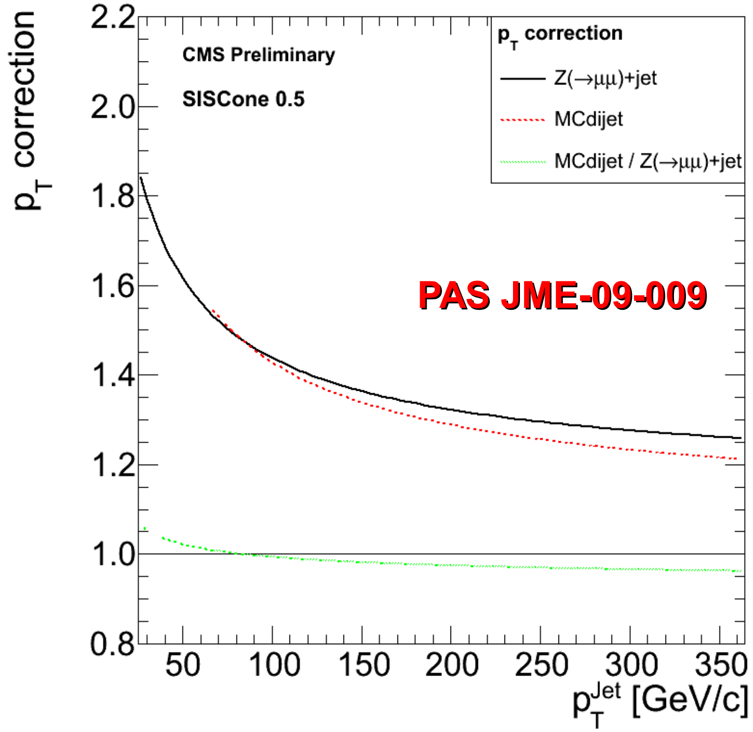
→ Overcalibration of Z+Jet Response with MC dijet absolute pt corrections

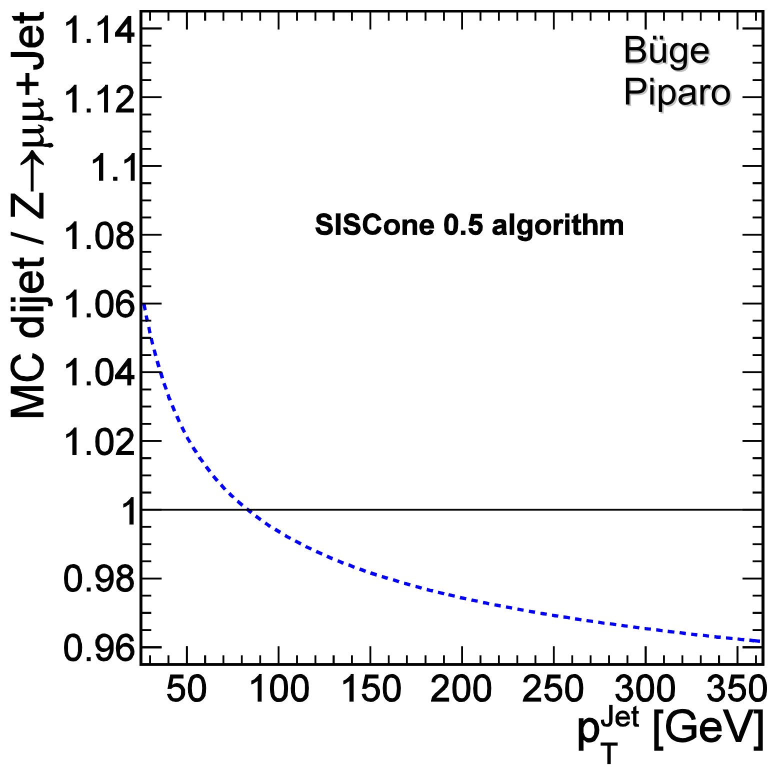
→ Changes to slight under-calibration for higher P_T (related to changed flavour fraction in the QCD dijet sample

- Indicates the need for a flavour dependent correction to combine different calibrations or to apply $Z \rightarrow \mu\mu$ absolute pt calibration factors on QCD Dijet events



Ratio of QCD Dijet and $Z \rightarrow \mu\mu$+jet calibration shows expected behaviour





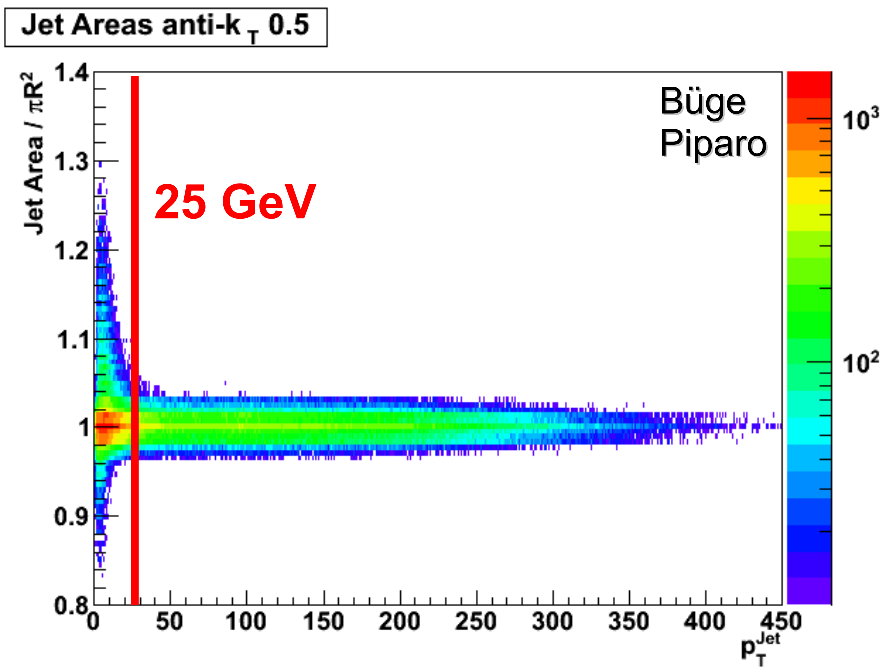
$Z \rightarrow \mu\mu$+jet calibration factors slightly smaller in the low P_T region and become larger for higher transverse momenta

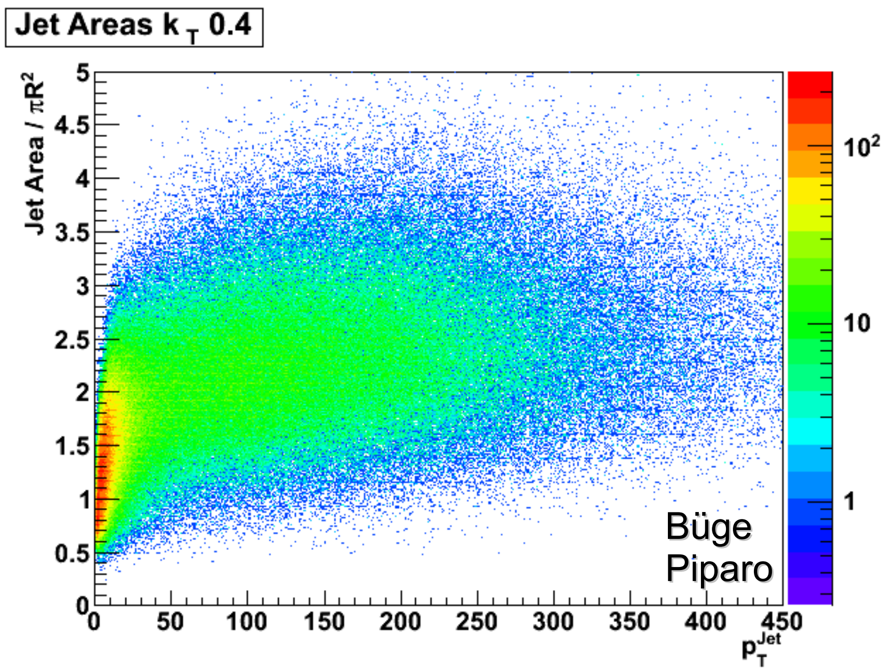
Use ratio of calibrations derived from MC simulation to correct for flavour dependence?

Using Anti-kt as an official algorithm

- CMS adopted Anti-kt as an official jet algorithm
- Jet Area: measure of jet's susceptibility to soft radiation (depends on algorithms clustering dynmics)
- Exploit Z(→μμ)+jet topology to study jet areas
- Compare Anti-kt 0.5 and kt 0.4 calorimeter jets
- Normalise jet area to area of disc with radius = R parameter

See: G. Salam's - Towards Jetography arXiv0906.1833v1





Antikt:
→ Almost circular areas after 25 GeV
→ Easy PU/UE subtraction
→ All good features of kt algorithms

Thanks to M. Heinrich for technical help and fruitful discussions

Conclusions

- Large number of Z plus one jet events will be available at the LHC.
- Mean of the response is a good and robust estimate of the response to be determined in bins of the transverse momentum of the Z boson.
- Determination of calibration factors from Z boson balancing possible for transverse momenta of uncalibrated jets between 10 GeV < P_T^{Jet} < 250 GeV for an integrated luminosity of 1fb^{-1} @ 10 TeV
- Anti-kt algorithm will ease the PU/UE subtraction for the Z(→μμ)+jet

Available on the CERN CDS information server CMS PAS JME-09-009

CMS Physics Analysis Summary

Contact: cms-pog-conveners-jetmet@cern.ch 2009/05/20

Calibration of the absolute jet energy scale with $Z(\rightarrow \mu^+\mu^-)$+ jet events at CMS

The CMS Collaboration

Abstract

We present a plan for the absolute calibration of the jet energy scale using events with a Z boson recoiling in the transverse plane against a jet with about 100 to 1000 pb^{-1} of data from proton-proton collisions at $\sqrt{s}$ = 10 TeV. Especially events in which the Z boson decays into two muons are well suited, as the kinematics of the boson can be reconstructed very precisely and without relying on calorimetric information. At the Large Hadron Collider (LHC), a large number of these events will be available and the calibration of the absolute jet energy scale using Z plus jet events becomes feasible for the first time. The improved knowledge of the jet energy correction directly translates into more precise measurements in all analyses where the jet energy scale is the dominant systematical uncertainty.

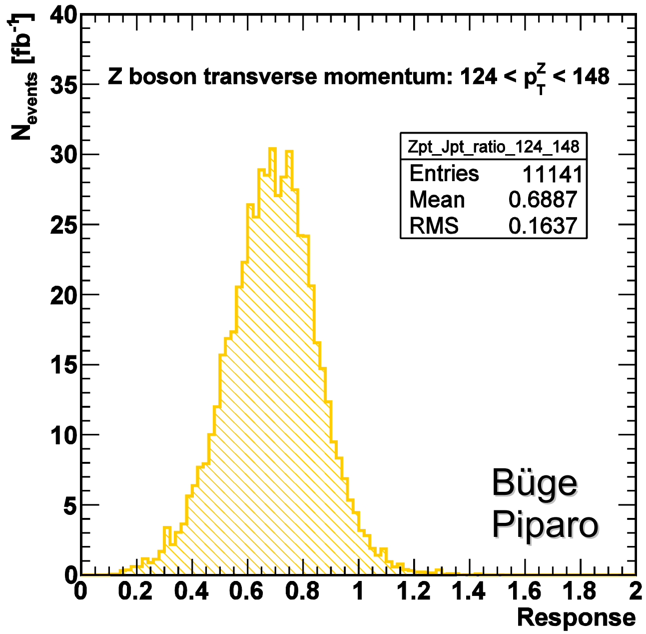
More details in CMS PAS JME-09-009

- Approved by the CMS collaboration on May the 20th 2009
- Publicly available here

Backup

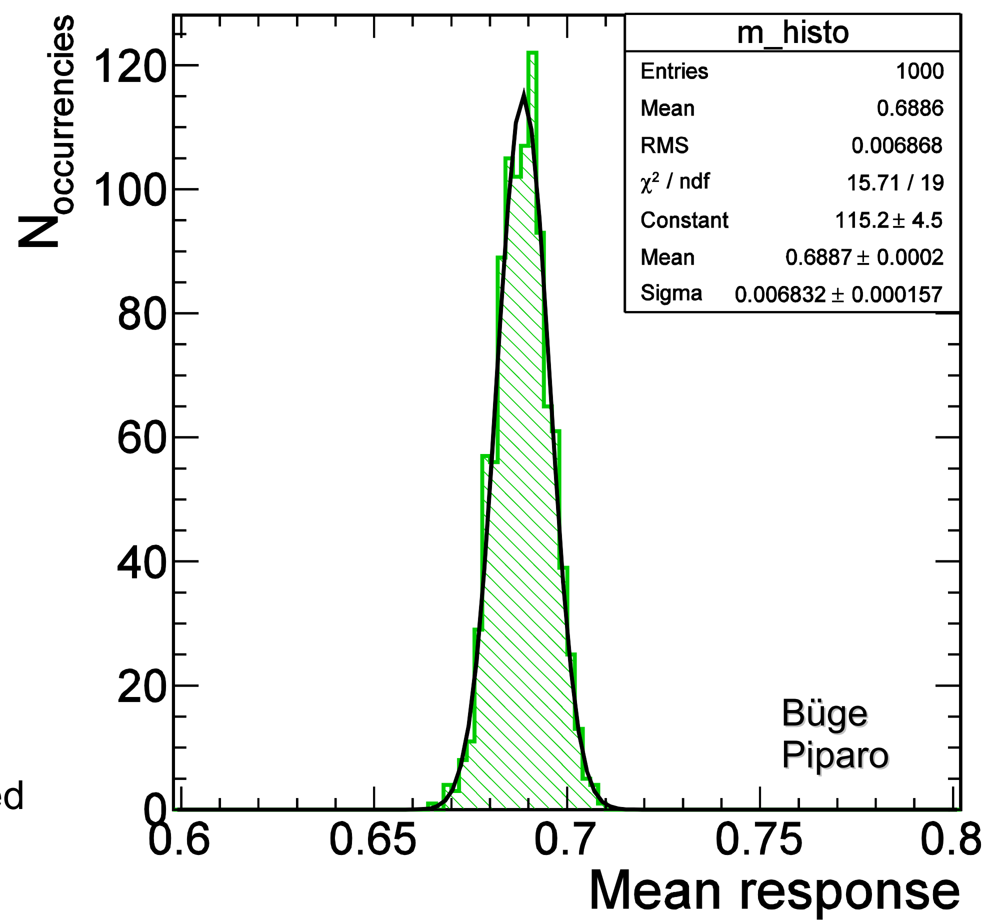
Measure for the Quality of the Balancing II

Response of one P_T^Z bin



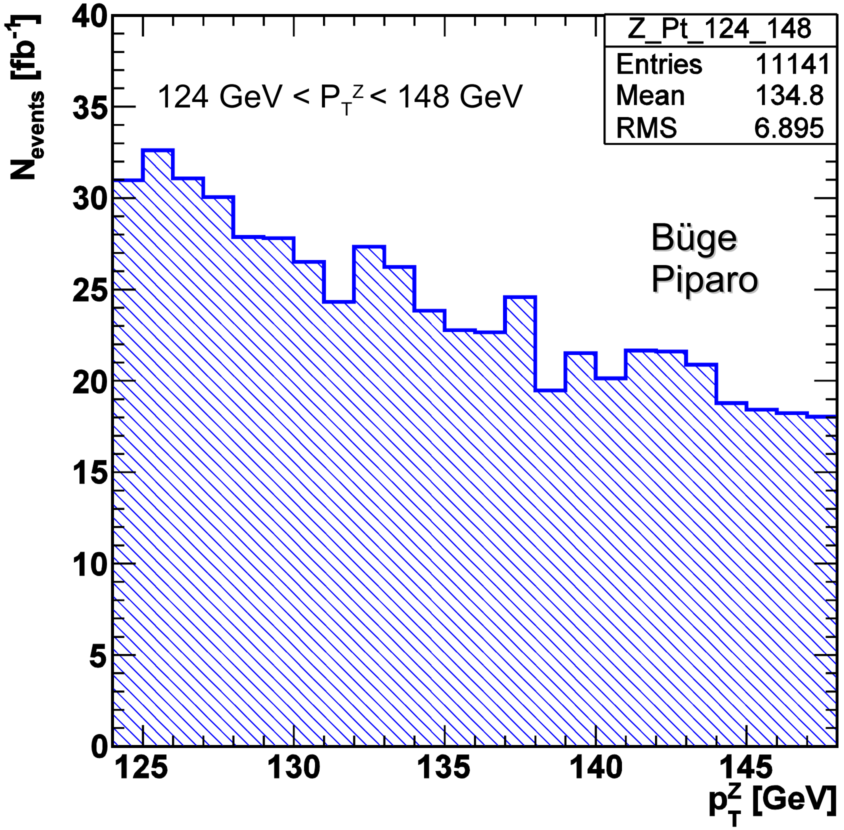
- Content of each bin of the histogram is fluctuated assuming Poissonian statistics
- Mean of the fluctuated histogram is calculated
- Repeated 1000 times
- Width of the corresponding Gaussian (left) is stated as statistical uncertainty

Uncertainty on the response is determined using toy Monte-Carlo experiments

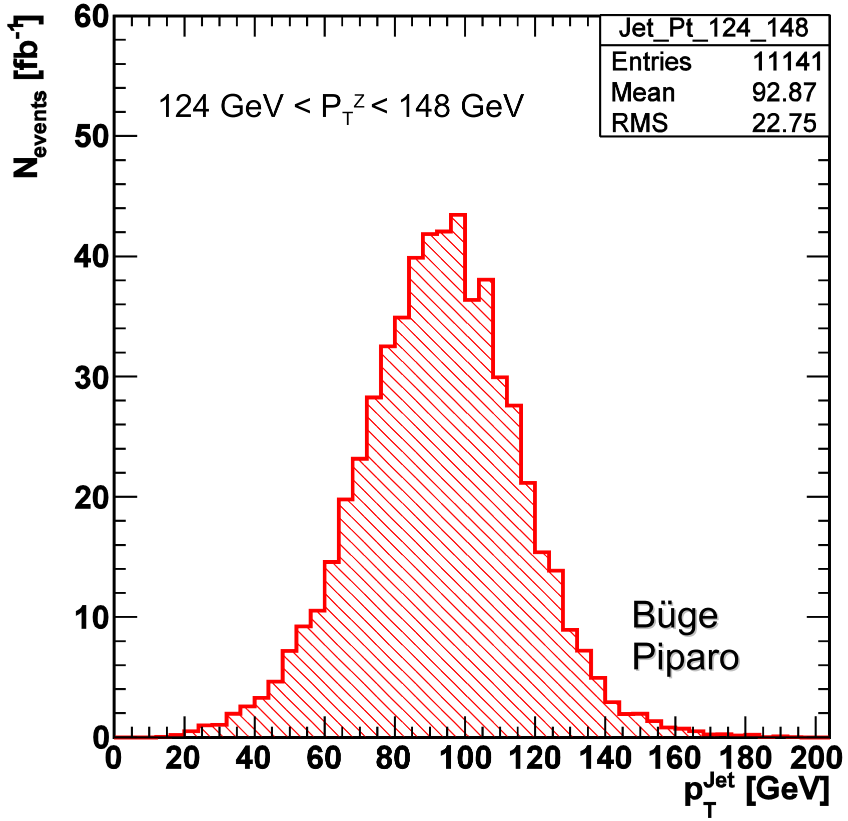


Measure for the Quality of the Balancing III

Mean of the response is shown versus …



… the mean of P_T^Z in the corresponding bin.



… the mean of the transverse momentum of the leading jet P_T^{Jet} in the corresponding bin. The RMS of the distribution is states as the uncertainty.

Influence of the Selection Cuts I

Influence of the Z+1 jet selection cuts on the response

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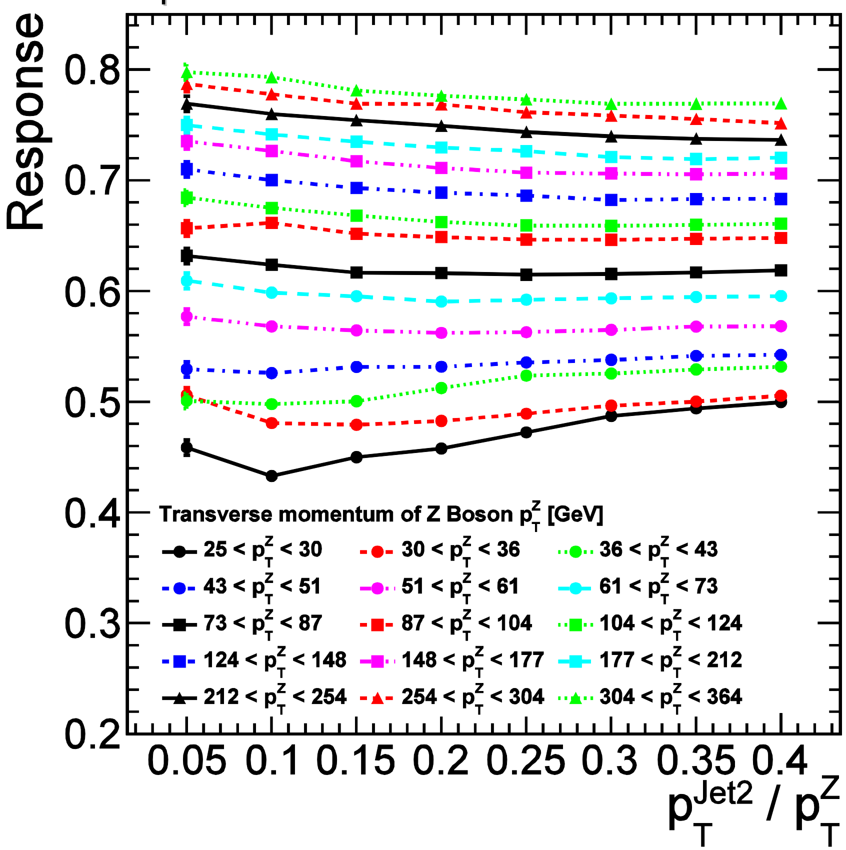
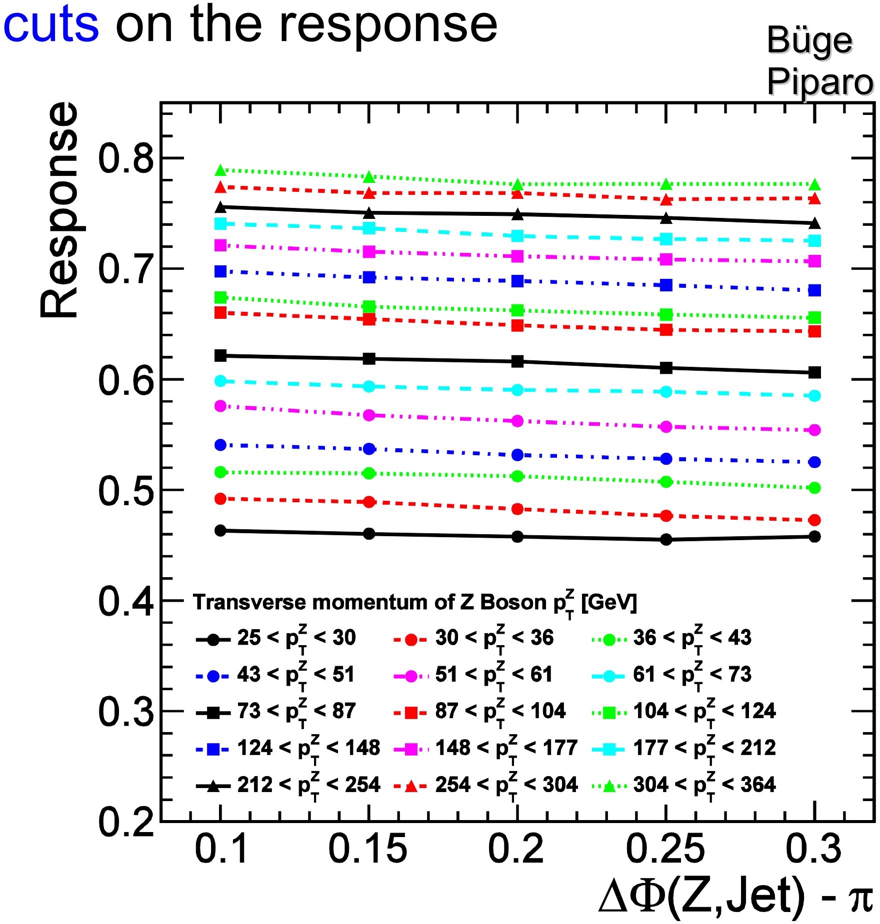
Piparo

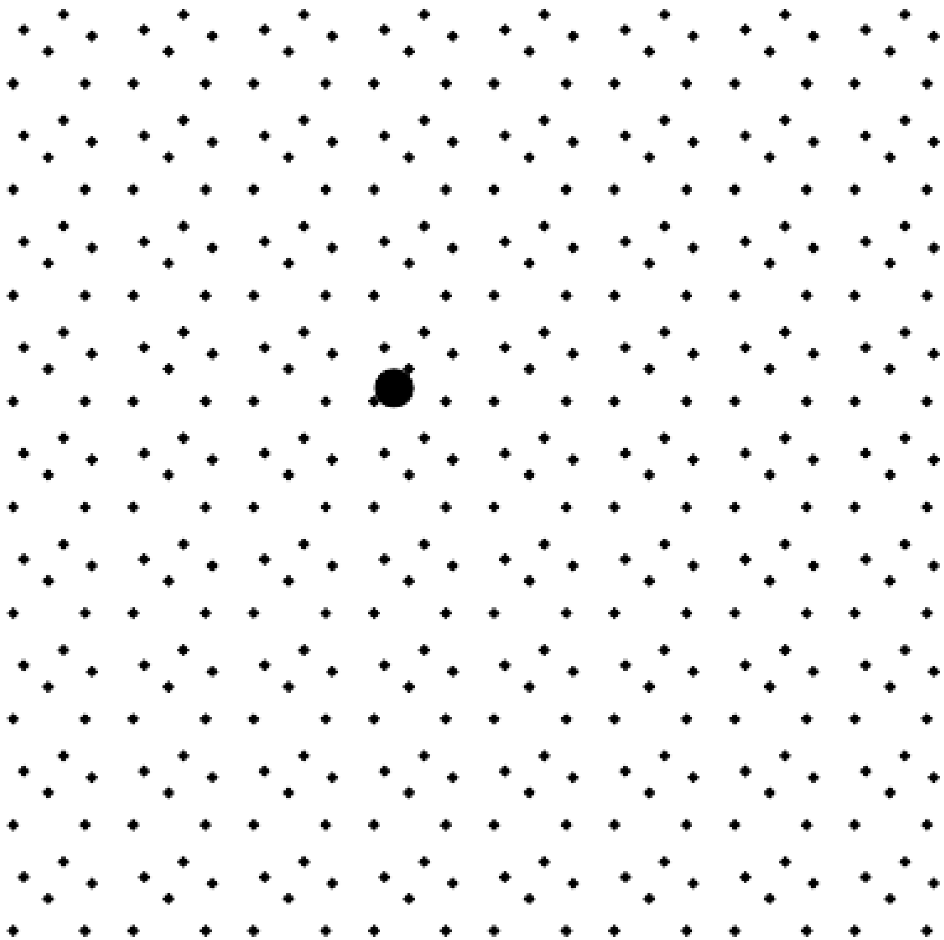




- Variation of $P_T(Jet2) / P_T(Z)$ (left) and $|\Delta\Phi(Z,Jet) - \pi|$ (right)
- In each case, all other cuts are fixed to their default values
- Only a small dependence of the response on the cuts observable

E.g. SISCone jet area

1. One hard particle, many soft



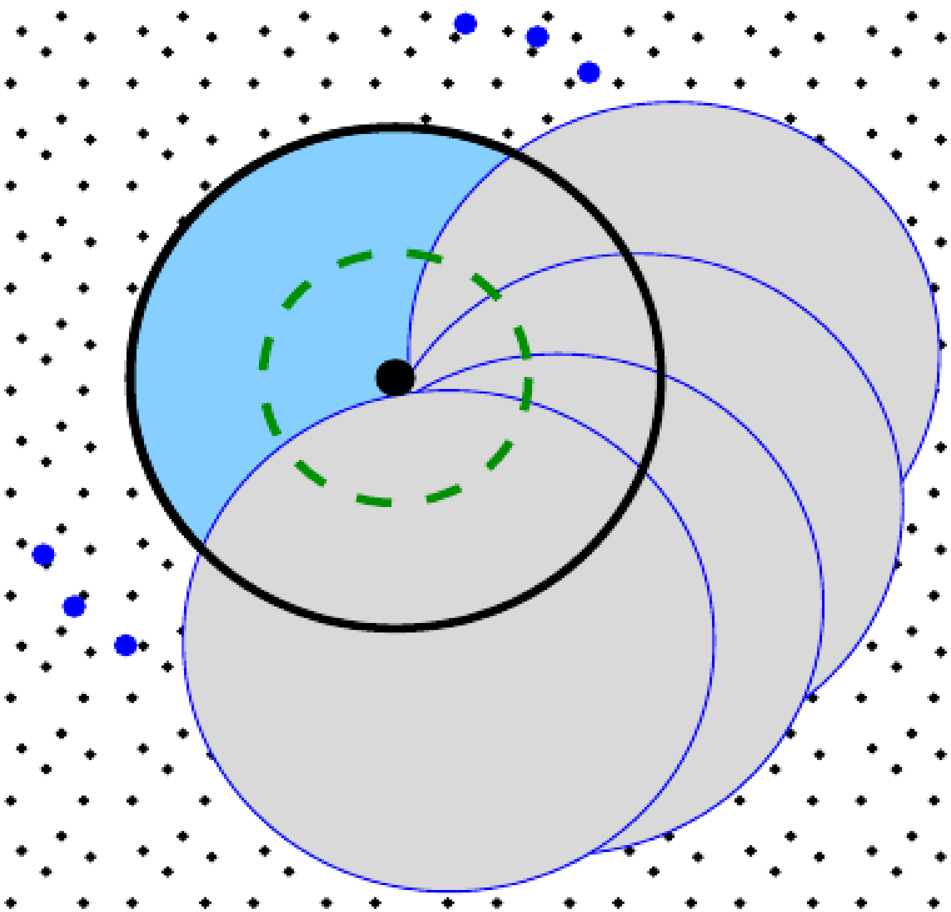
SISCone, any R, $f \gtrsim 0.391$

Jet area =
Measure of jet's susceptibility to uniform soft radiation

Depends on details of an algorithm's clustering dynamics.

E.g. SISCone jet area

4. "Split" the overlapping parts



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