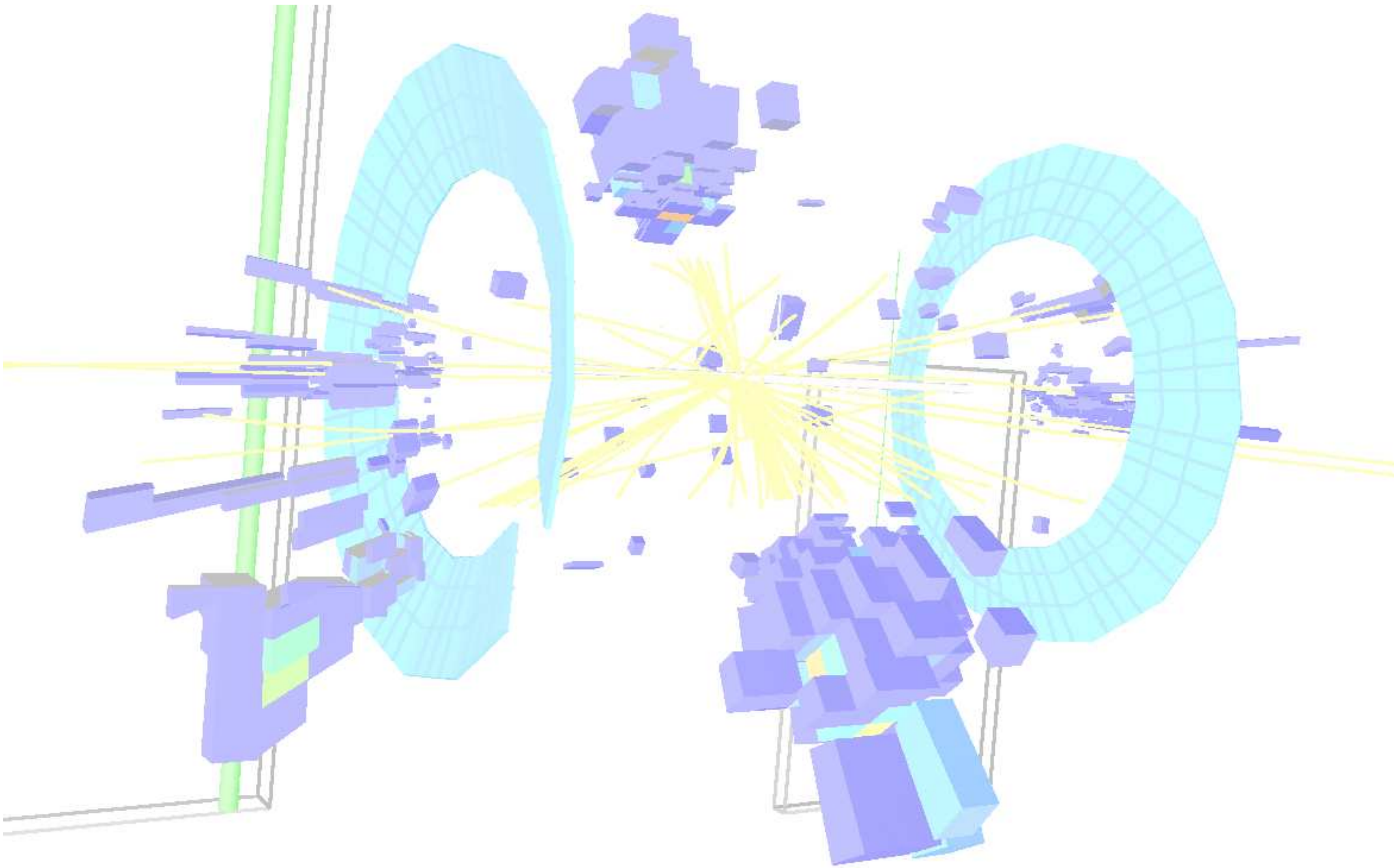
Jet energy scale at DØ

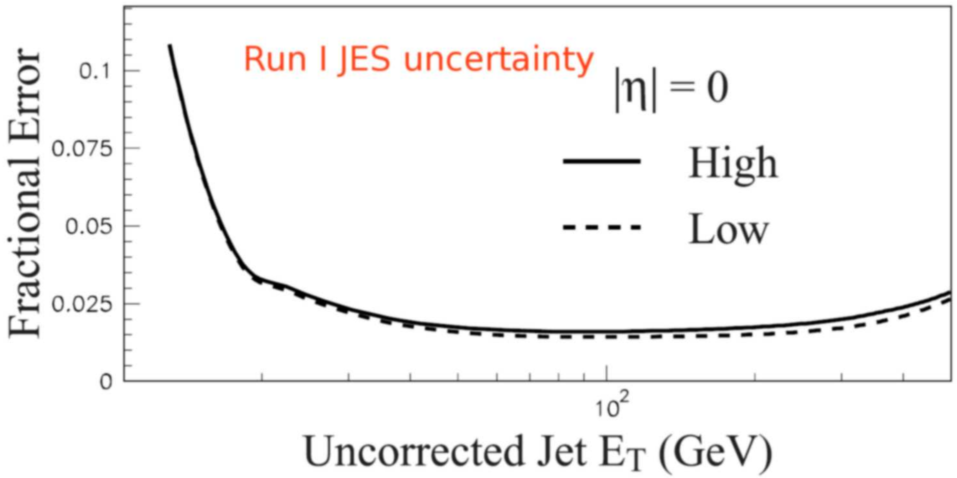
24th October, 2008

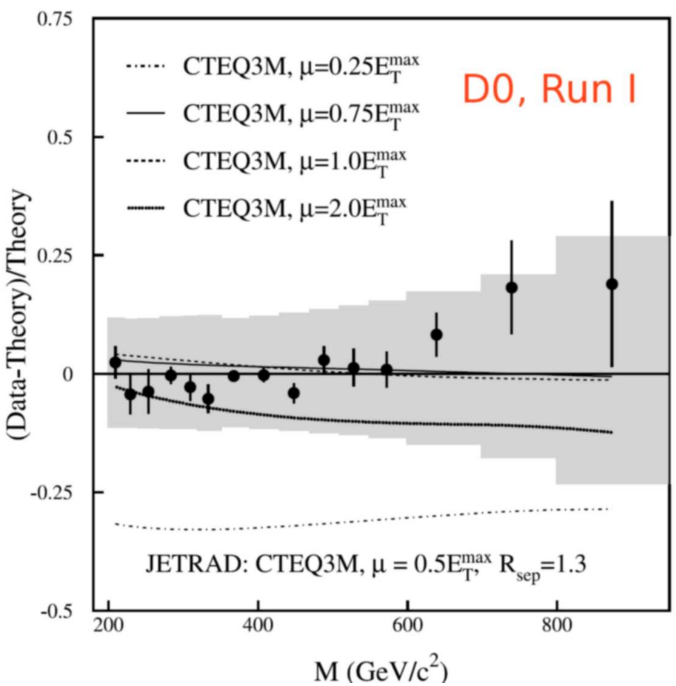
Alexander Kupčo



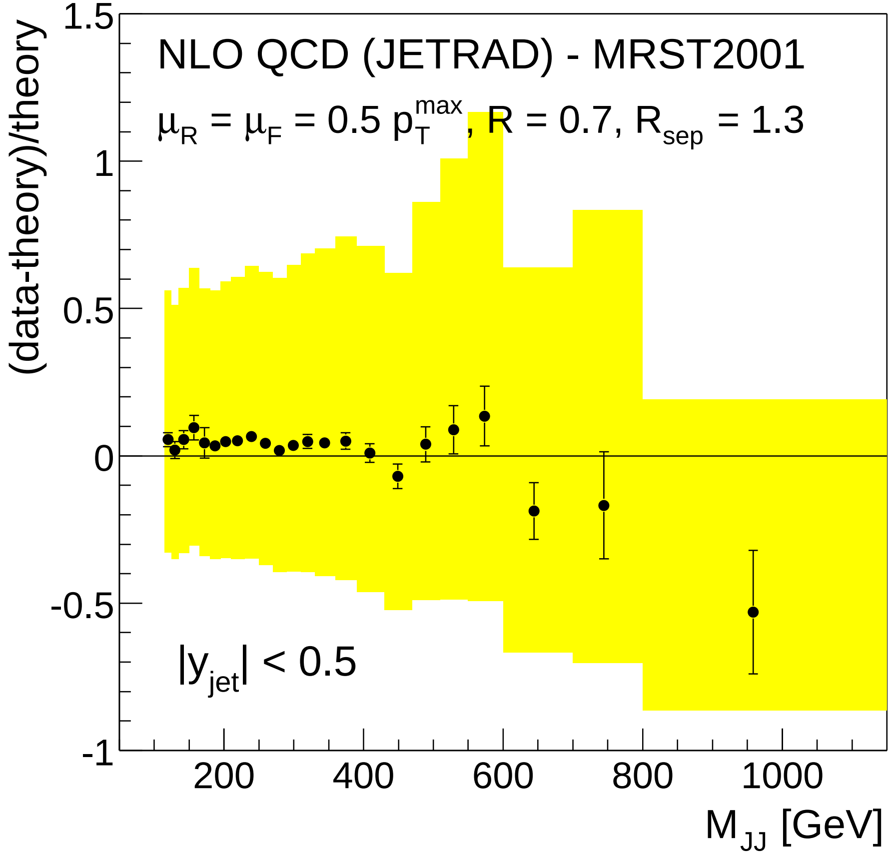
Motivation

- Uncertainty in jet energy calibration dominant systematics for most of hadron collider analyzes with jets in the final state

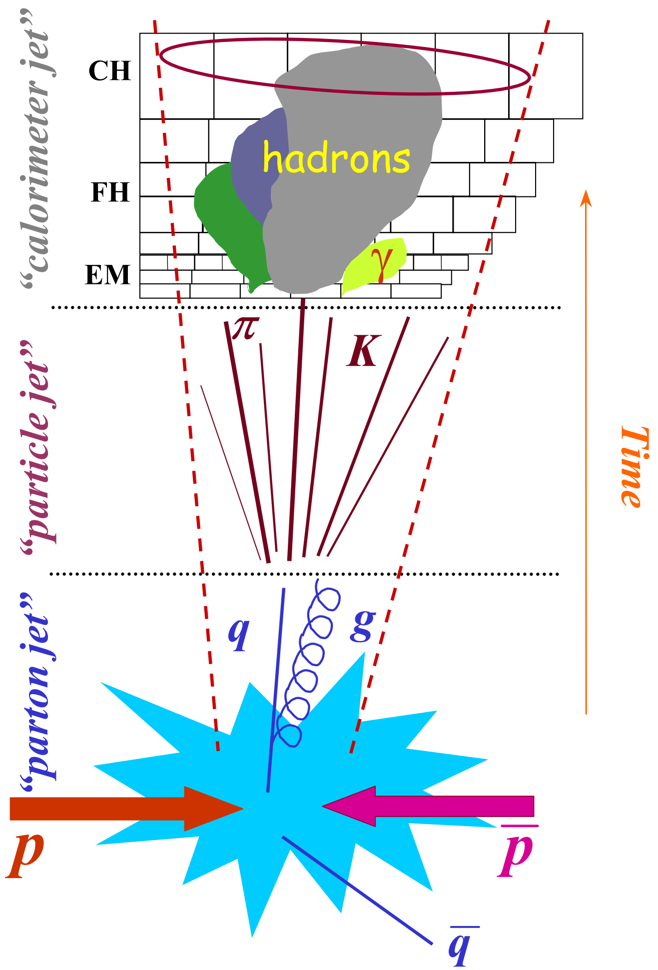




Early RunII data
(my thesis)



Jets



- ▷ calorimeter jet
  - jet is a collection of calorimeter towers
  - correct for detector effects (calibration, resolution, ...)
- ▷ particle jet
  - no theory from the first principles of QCD
  - predictions are model dependent
- ▷ parton jet
  - hard parton jets (fixed order calculations) or after development of parton showers (resummation)
- ▷ Jet Cone Algorithm in Run II
  - geometrical definition: $\Delta R = \sqrt{\Delta^2\phi + \Delta^2 y}$
  - E-scheme recombination: $P_{jet} = \sum P_{towers}$
  - add midpoints between jets as an additional starting seed

Run II cone jets - midpoint algorithm

- as in RunI **iterative** algorithm
- draw cone $R = \sqrt{\phi^2 + y^2}$ around calorimeter towers with $E_T > 1$ GeV
- calculate "protojet" 4-momentum using E-**scheme**

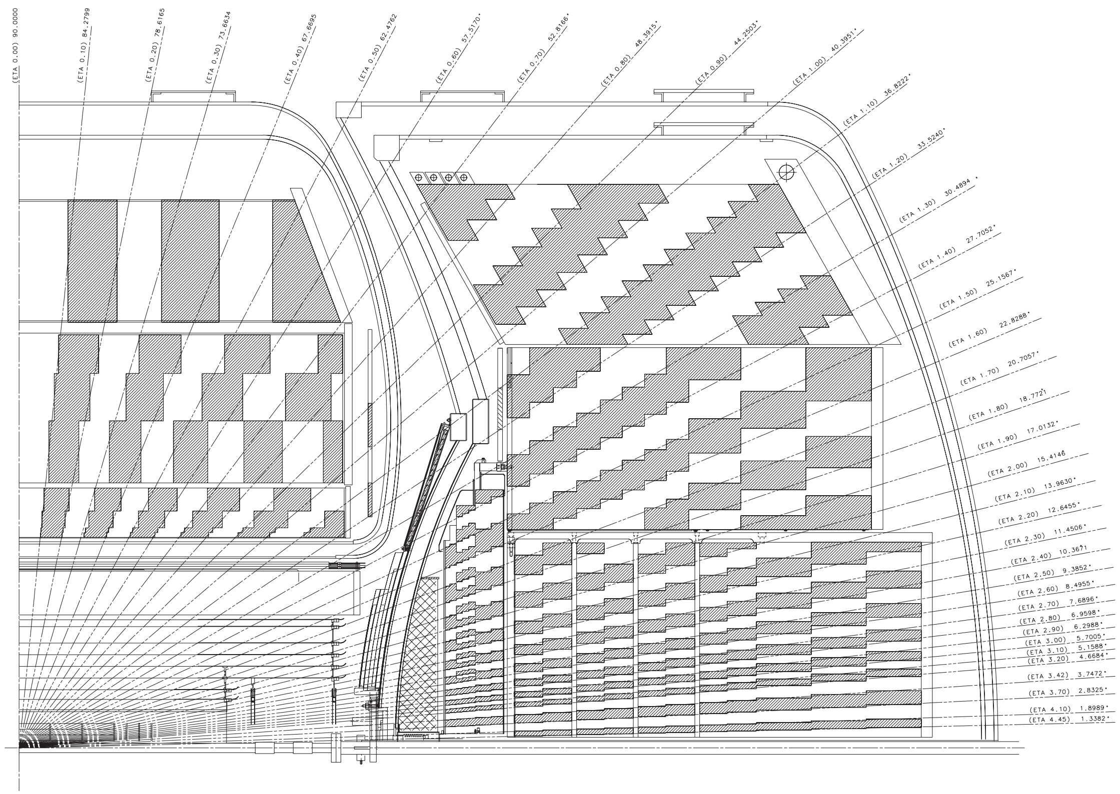
$$E = \sum_{\Delta R < R}^{towers} E_{tower} \,, \qquad \vec{p} = \sum_{\Delta R < R}^{towers} \vec{p}_{tower}$$

- draw new cone around new "protojet" 4-momentum and iterate until stable direction is found
- use **midpoints** between close proto-jets ($\Delta R < 2R$) as additional seeds
- merge/split proto-jets

Midpoint algorithm cures some remedies of RunI algorithm

- the infrared/collinear sensitivity of $2 \to 2$ NNL0 QCD or $2 \to 3$ NLO QCD calculations

Calorimeter



- uniform and hermetic
  - coverage up to $|\eta| < 4.2$
- nearly compensating
  - $e/\pi < 1.05$ for $E > 30$ GeV
- fine segmentation
  - $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$

    (3rd EM layer: 0.05×0.05)
- particle energy resolution

  e : $\frac{\sigma}{E} = \frac{15\%}{\sqrt{E}} \oplus 0.3\%$

  π : $\frac{\sigma}{E} = \frac{45\%}{\sqrt{E}} \oplus 4\%$

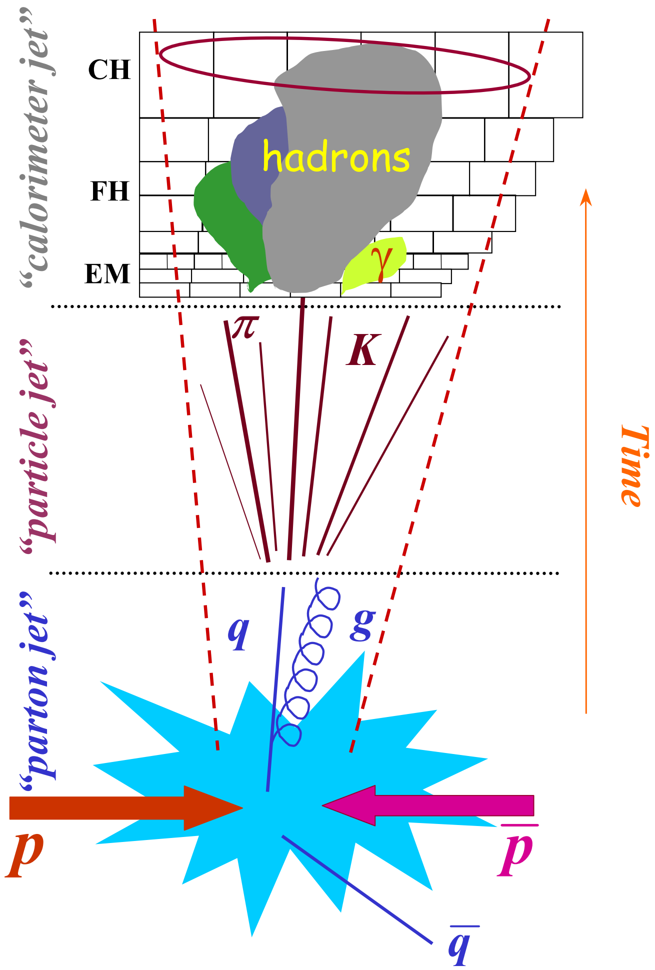
Run II upgrade

- shorter time between bunch crossings (396 ns) $\Rightarrow$ faster trigger and readout electronics
- more material in front of calorimeter (magnet, new tracker) $\Rightarrow$ new preshower detector
- non-linear electronics $\Rightarrow$ all this call for new calorimeter calibration

Jet energy scale

- correction of the jet energy measured on the detector level to the jet energy on the particle level

$$E^{jet}_{ptcl} = \frac{E^{jet}_{det} - \mathcal{O}}{R_{jet}\, S\, k_{MPF} k_{ZS}}$$



Offset ($\mathcal{O}$) - energy not associated with the hard interaction (U noise, pile-up from previous crossings, additional $p\bar{p}$ interactions)

Response ($R_{jet} = R_{CC} \cdot F(\eta)$)

- calorimeter response to the jet
- EM part calibrated on $Z \to ee$ mass peak
- measured from E_T balance in γ+jet events
- relative scale for forward jets is determined using both $\gamma +$ jet and dijet events

Showering (S) - losses due to showering the energy in the calorimeter in and out of the jet cone

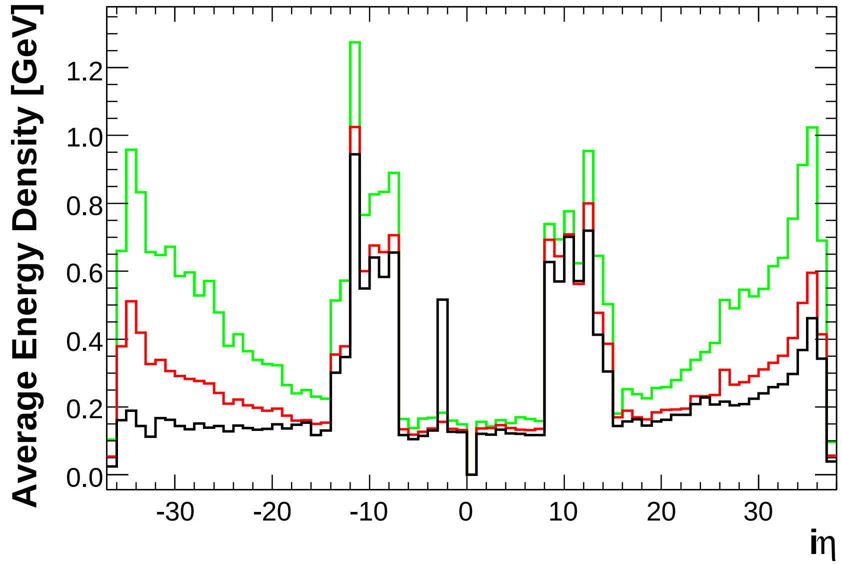
Offset

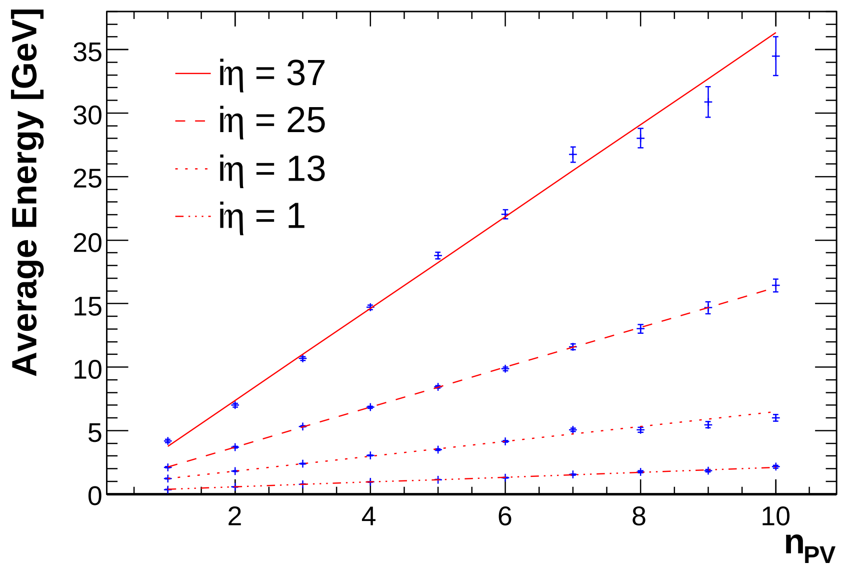
Z. Hubáček

- noise and pile-up from ZB
- multiple $p\bar{p}$ interactions from MB

$$\mathcal{O}(\mathcal{L}, n_{PV}) = \mathcal{O}_{ZB}(\mathcal{L}) + \mathcal{O}_{MB}(\mathcal{L}, n_{PV}) - \mathcal{O}_{MB}(\mathcal{L}, n_{PV} = 1)$$

- not corrected for soft underlying event



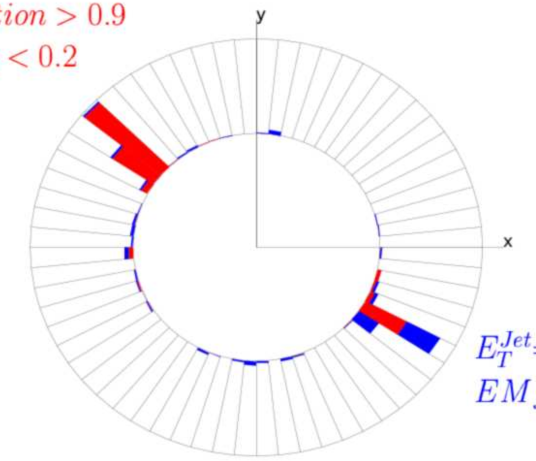


Jet response - absolute scale

- measured hadron energy is different from its original energy
  - calorimeter is not perfectly compensated : $\frac{e}{\pi} \sim 1.05$ for $E > 30$ GeV
  - dead material, module-to-module fluctuations, ...

Missing E_T projection method

- jet response determined from the p_T imbalance in γ+jet events



$$\vec{E}_{T\gamma} + \vec{E}_{Trecoil} = 0 \qquad \text{(ideal)}$$

$$R_\gamma \vec{E}_{T\gamma} + R_{recoil} \vec{E}_{Trecoil} = -\vec{\not{E}}_T \qquad \text{(real)}$$

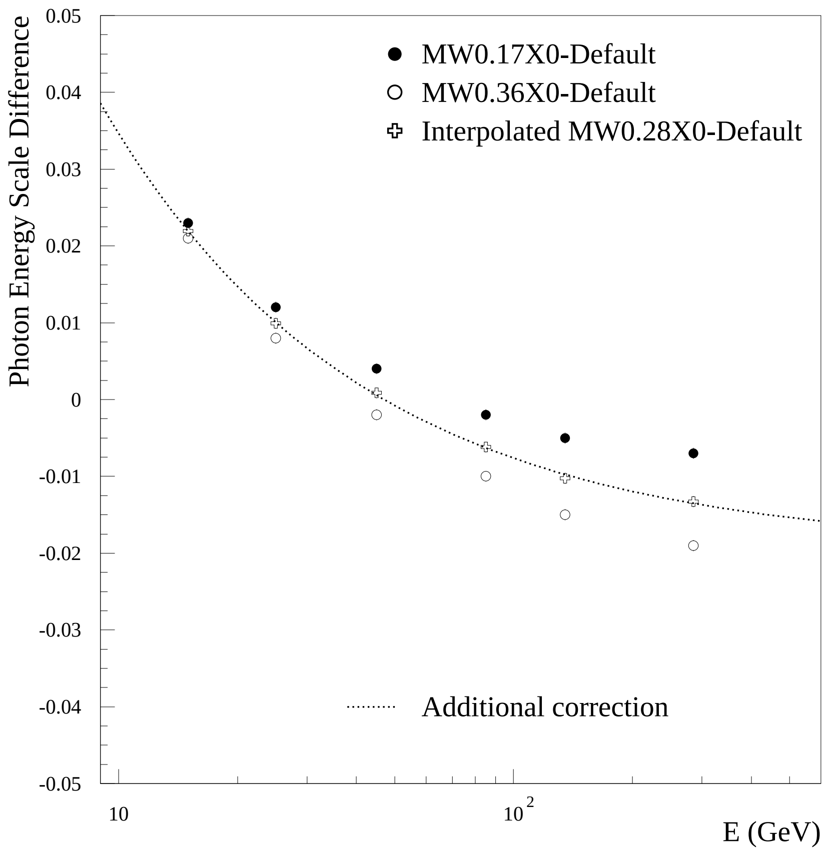
- after EM energy calibration from the $Z \to ee$ mass peak ($R_\gamma = 1$)

$$R_{recoil} = 1 + \frac{\vec{n}_{T\gamma} \cdot \vec{\not{E}}_T}{E_{T\gamma}}$$

- select back-to-back γ+jet events

$$R_{jet} = R_{recoil}$$

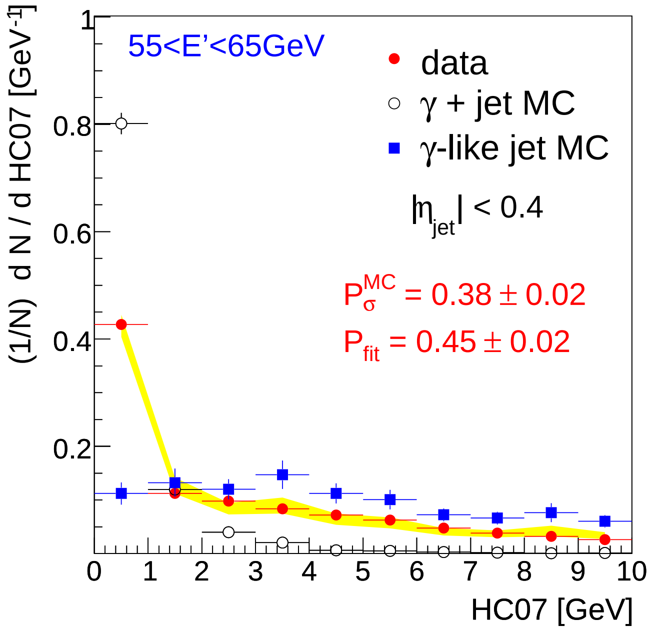
Troubles with photons - energy scale



- electron energy scale from $Z \rightarrow ee$ mass peak
- photon scale different from electron one
- need to be derived from MC
- standart DØ MC simulation is not good enough
- new `d0gstar` (Geant) simulations with improved electromagnetic shower description developed by W Mass Group (60x slower)

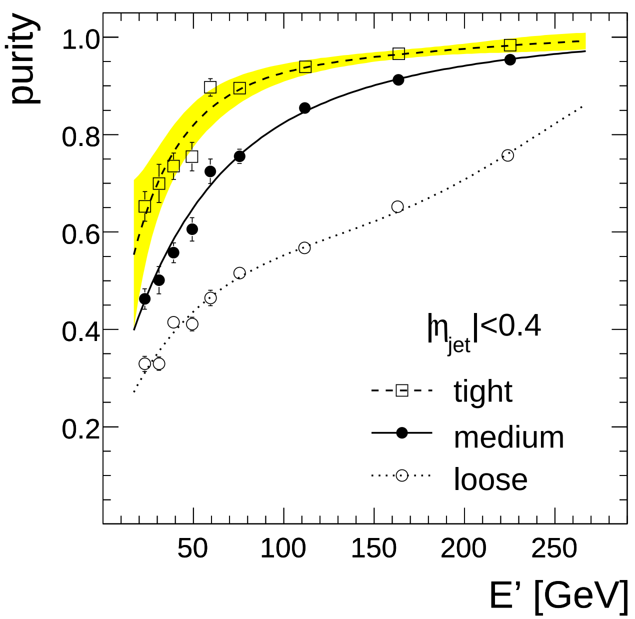
- significant change with respect to the photon scale determined from the DØ standard MC production

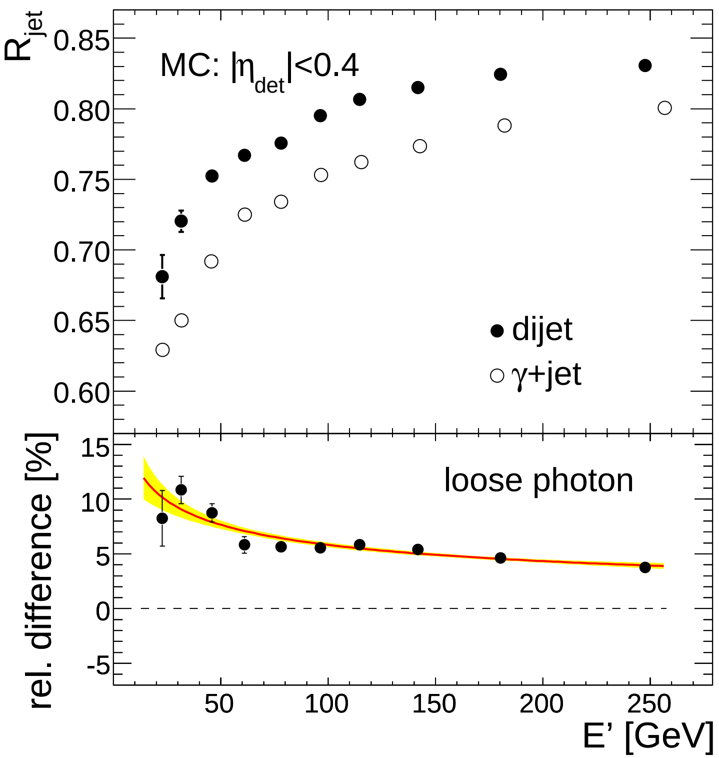
Troubles with photons - purity



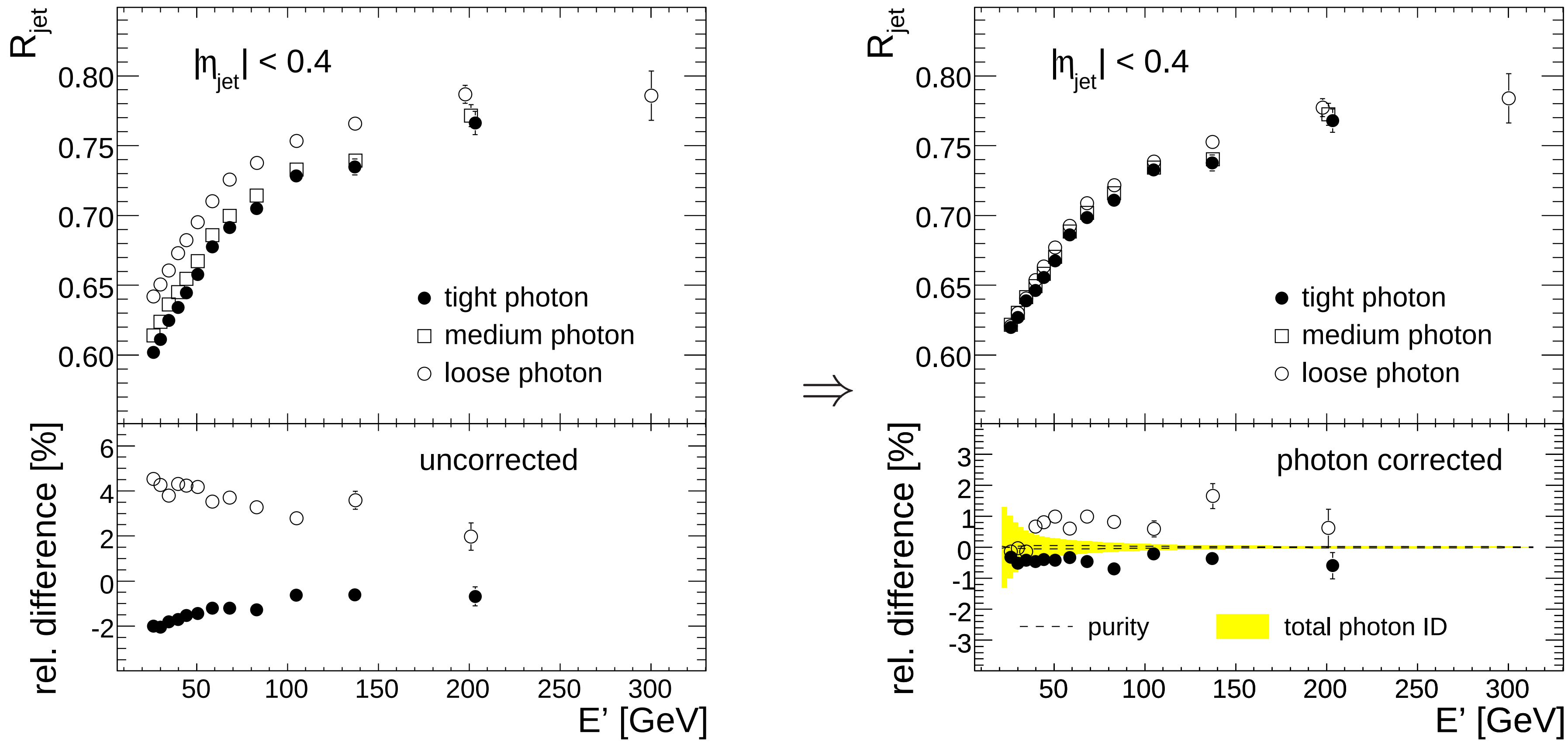
- photon ID
  - $EMF > 0.96$, $ISO < 0.07$, $EM3W < 14\,\text{cm}^2$
  - $P_{track} < 0.1\%$, $HC07 < 1\,\text{GeV}$, CPS cuts
- loose, medium, and tight photons

$$R_{data} = PR_{\gamma+jet} + (1-P)R_{dijet}$$



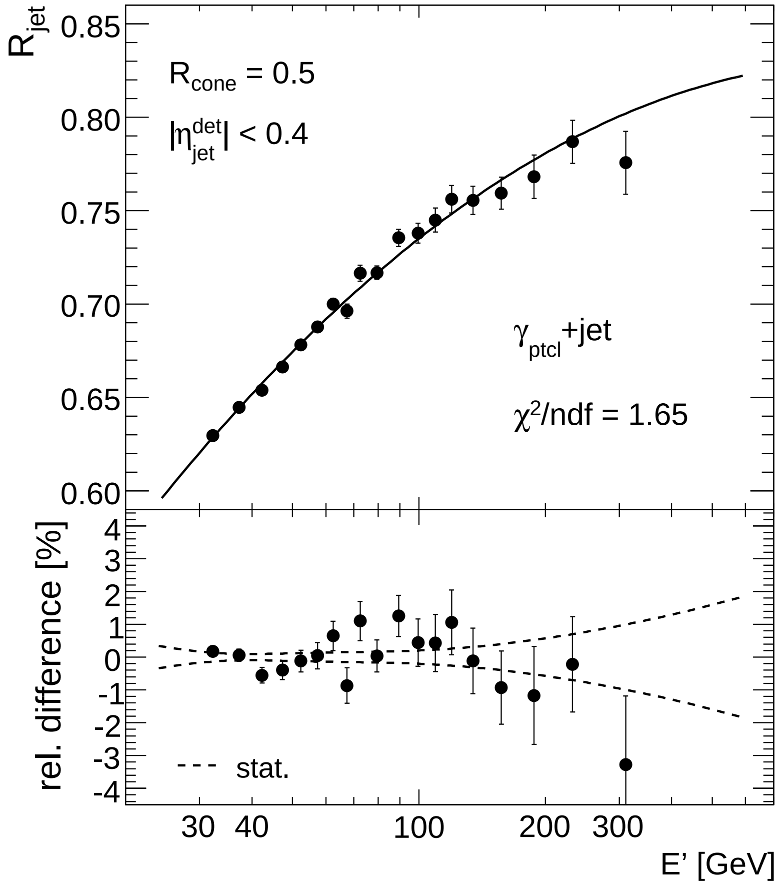


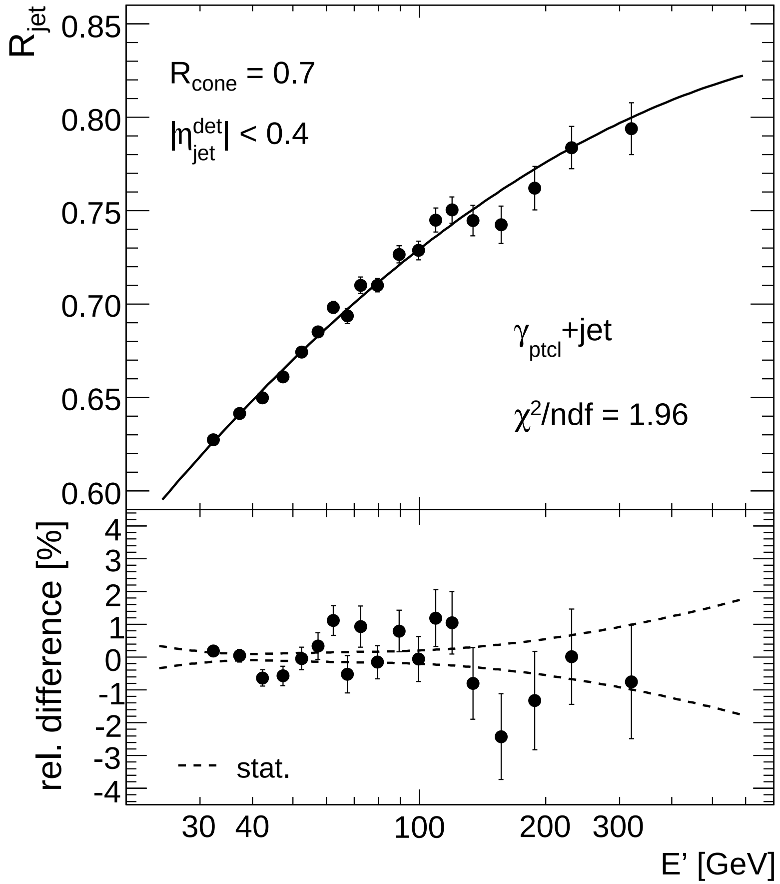
Troubles with photons - purity



- test the background correction (based on MC) on data
- finally, tight photon definition used (smallest correction implies smaller systematics), loose photons ID only at highest energy bin

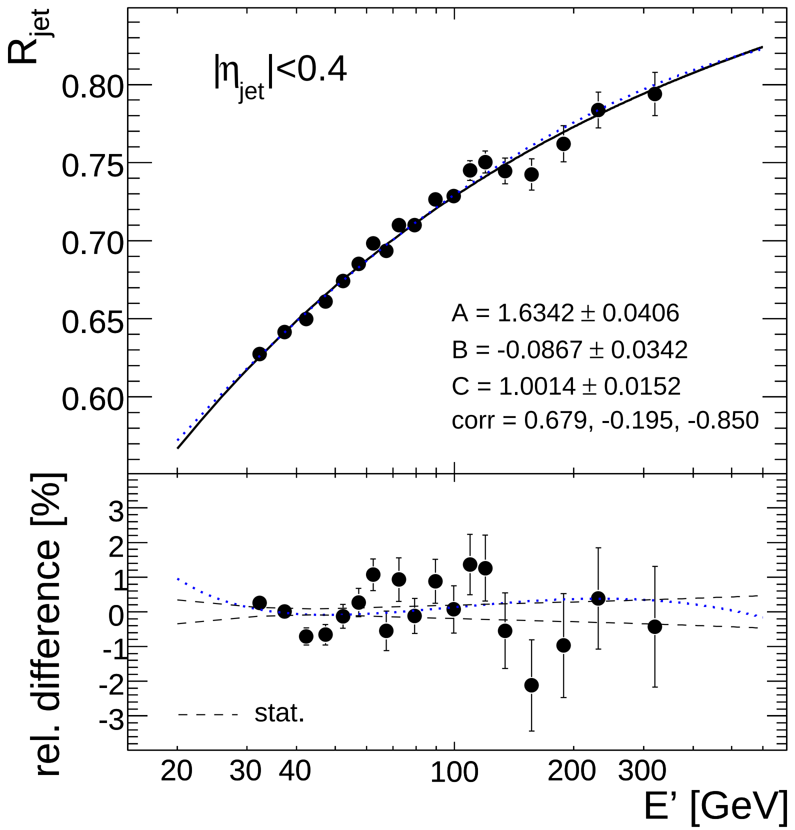
Central jet response





- quadratic-log fit
- about 2% extrapolation error for jet energies around 600 GeV

High energy extrapolation (cone 0.7 jets)

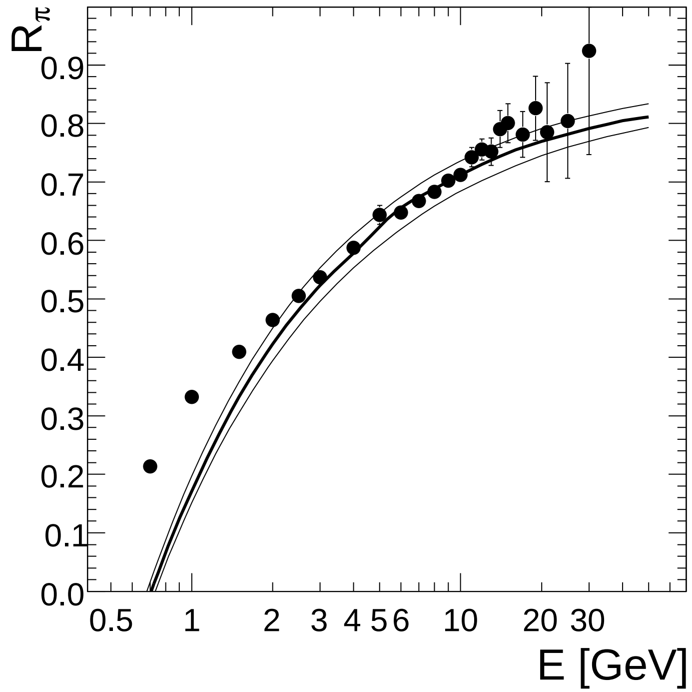


- fit of A, B, C parameters instead of quad-log ones
- stat. error: 0.5% at 600 GeV
- syst.: 0.9% (fragmentation)

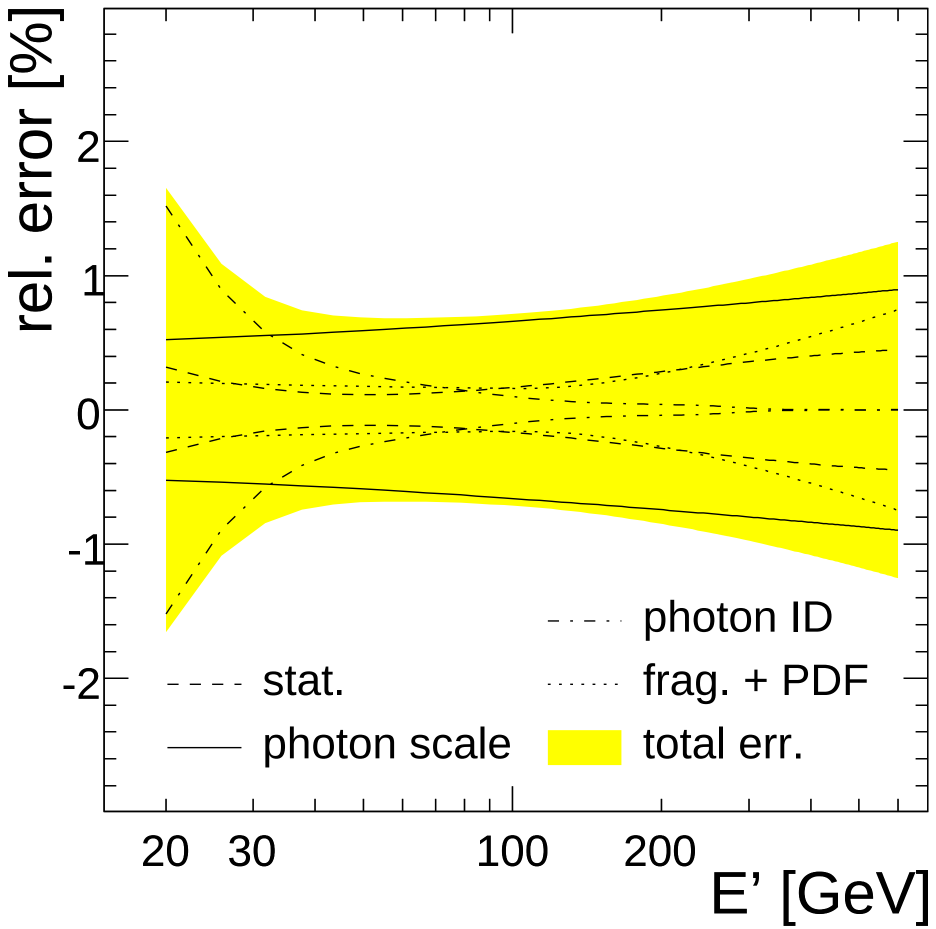
- from CC jets only, no use of EC
- quad-log fit: 1.8% error at 600 GeV
- parametrized single pion response:

$$R_\pi(E) = cC[1 - aA(E/E_0)^{m+B-1}]$$

Also compared to preliminary direct measurement of R_π



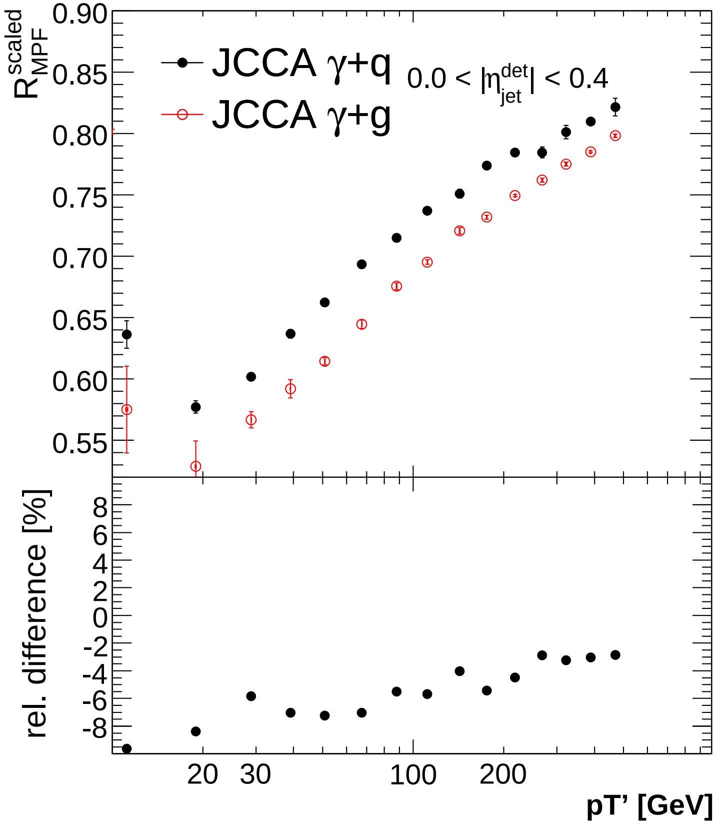
Absolute normalization uncertainties

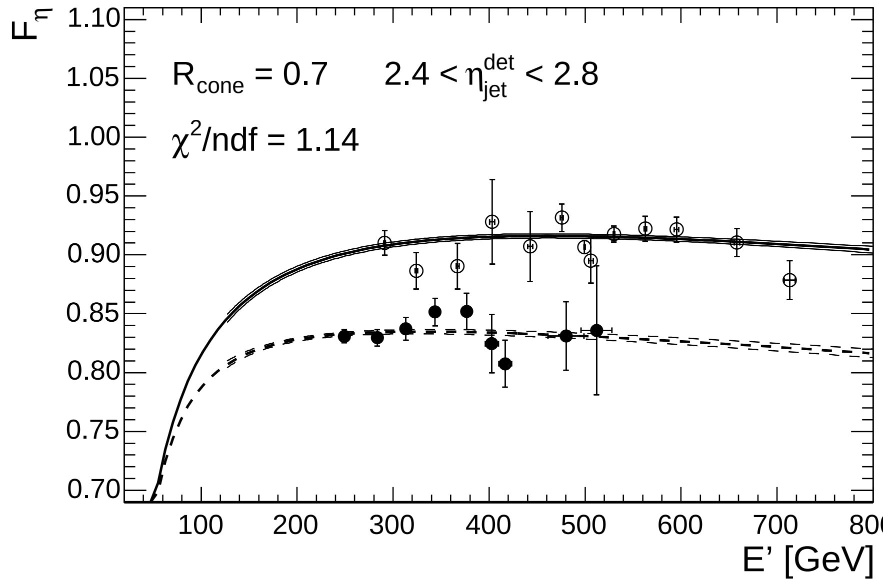


- photon scale dominant uncertainty in most of the kinematic domain
- background important for energies below 30 GeV
- jet fragmentation contributes also at high energies

Relative response correction

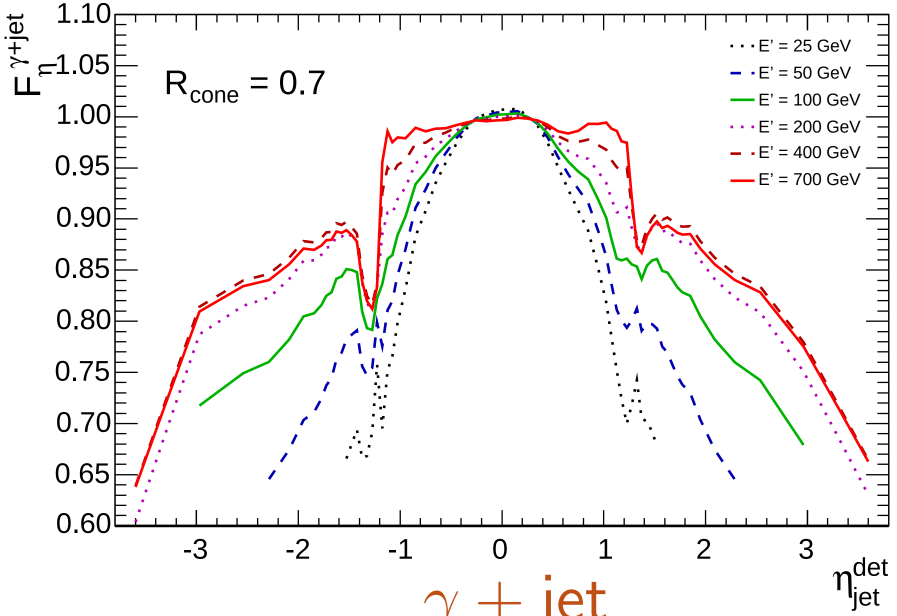
- increased statistics of dijet events allows to determine F_η in very fine bins of η_{det}
- $\gamma +$ jet sample extends the measurement towards the low energies



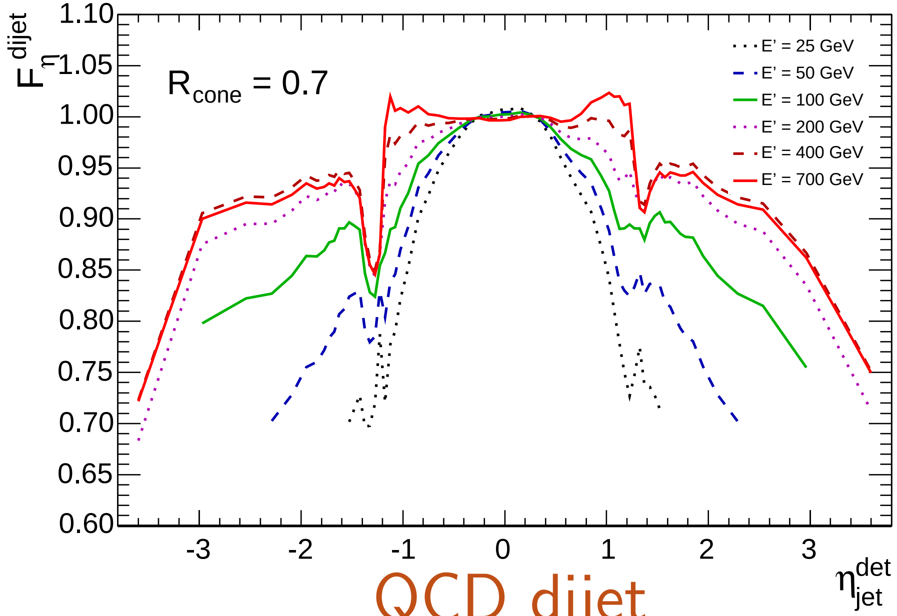


- differencies mostly due to different jet flavour (increased sensitivity due to more material in front of calorimeter which is causing much smaller response for low energetic hadrons)

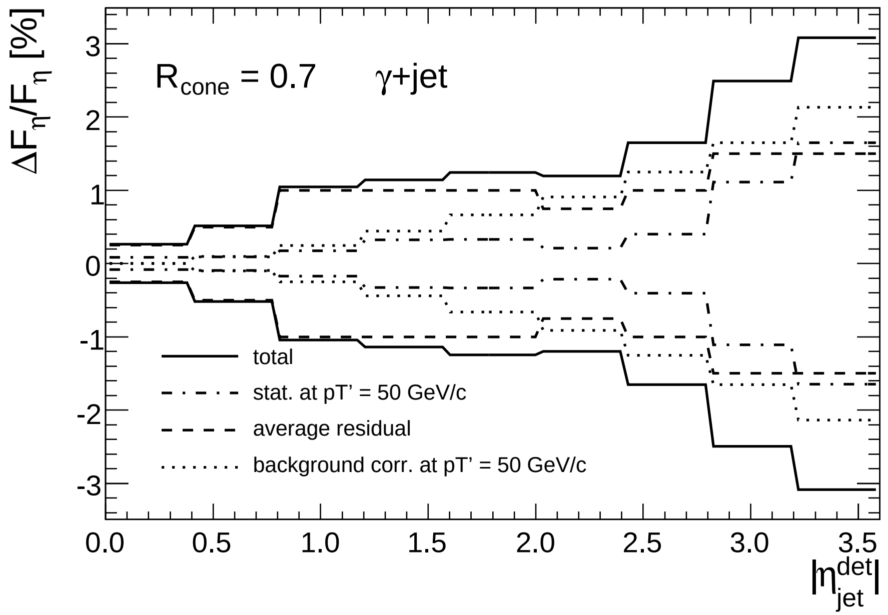
Relative response vs. eta

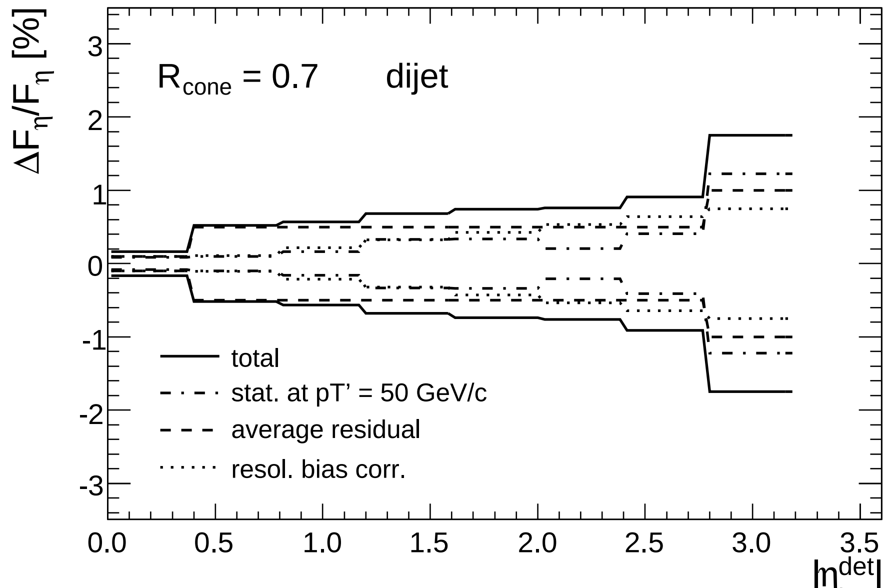


γ + jet



QCD dijet

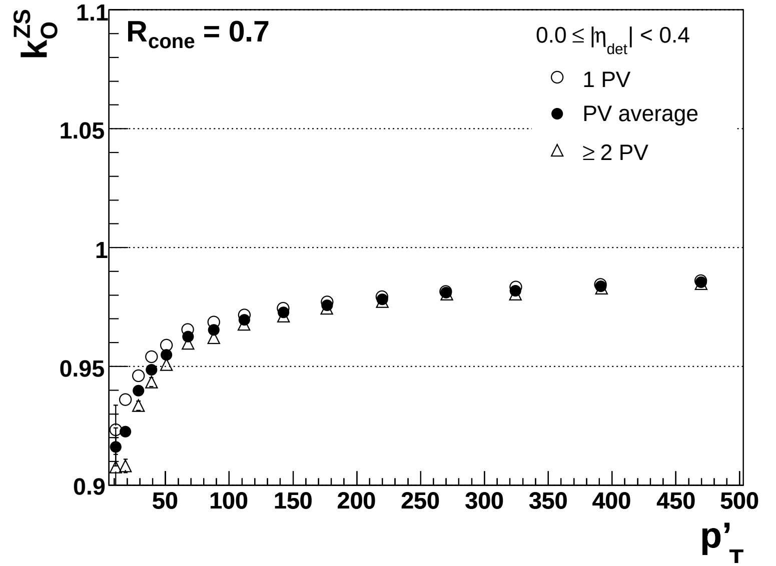


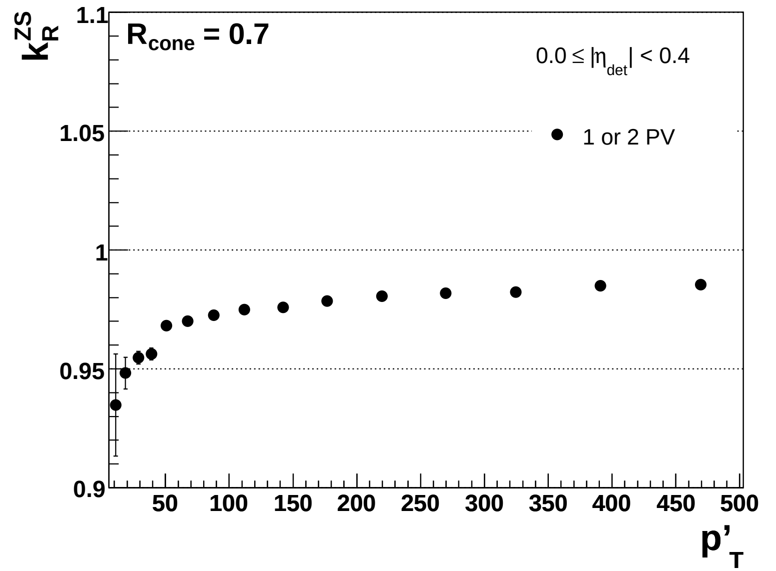


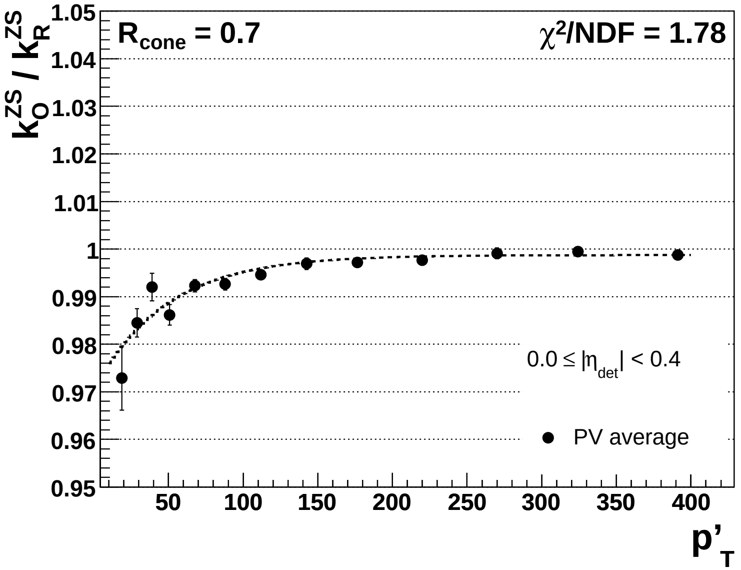
Zero suppression effects

J. Kvita

- due to ZS, energy density deposited in calorimeter in MB events is different to the energy in jet environment
- affects both offset and response
- to the first order, the two effects compensate each other (assumption used in preliminary JES)
- in this JES, explicitly corrects for this ZS effects

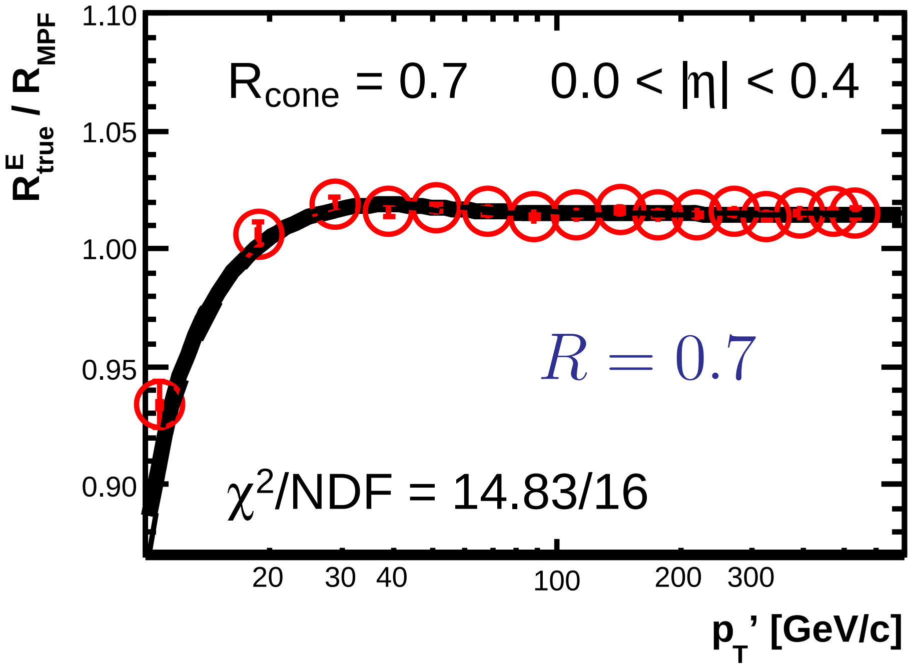


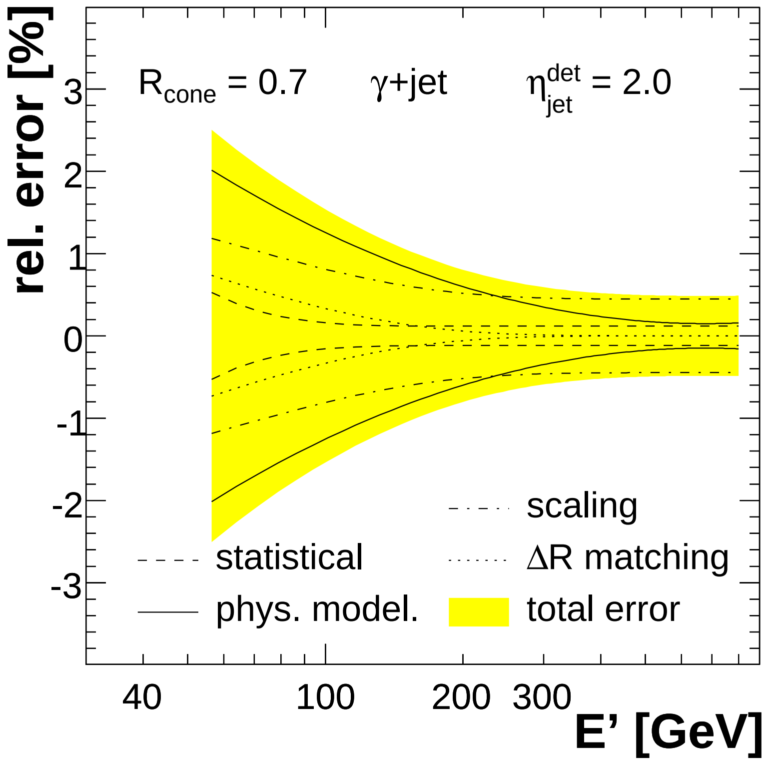




MPF bias

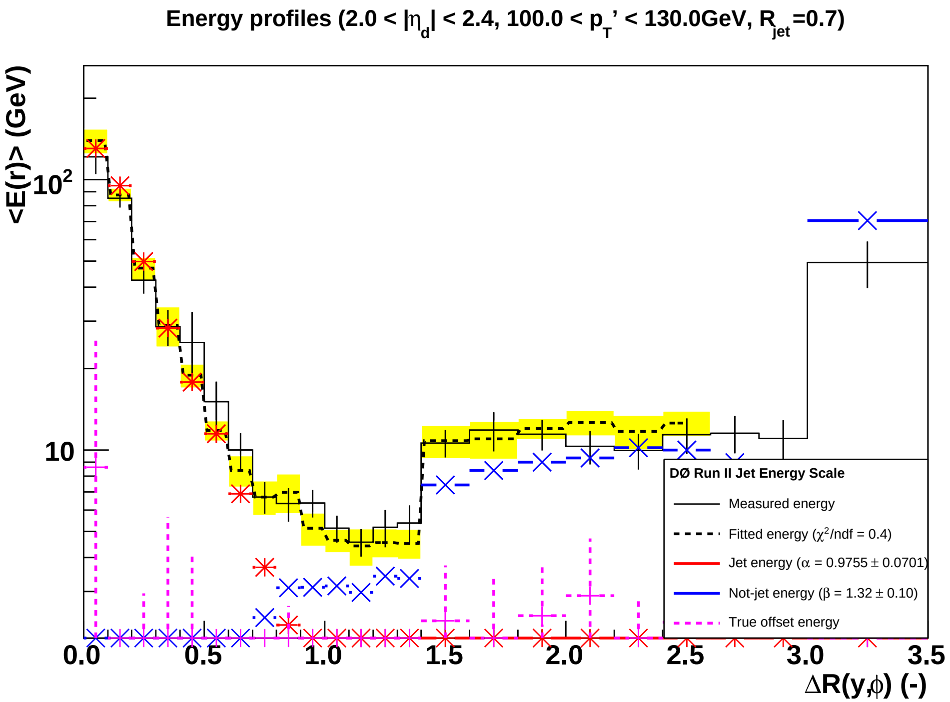
- bias of MPF method due to kinematic cuts ($N_{jet} = 1$, $\Delta\Phi > 3.0$), jet mass effects, etc
- derived by comparing "true" response obtained in MC by tracking individual energy depositions in cal. cells with MPF response



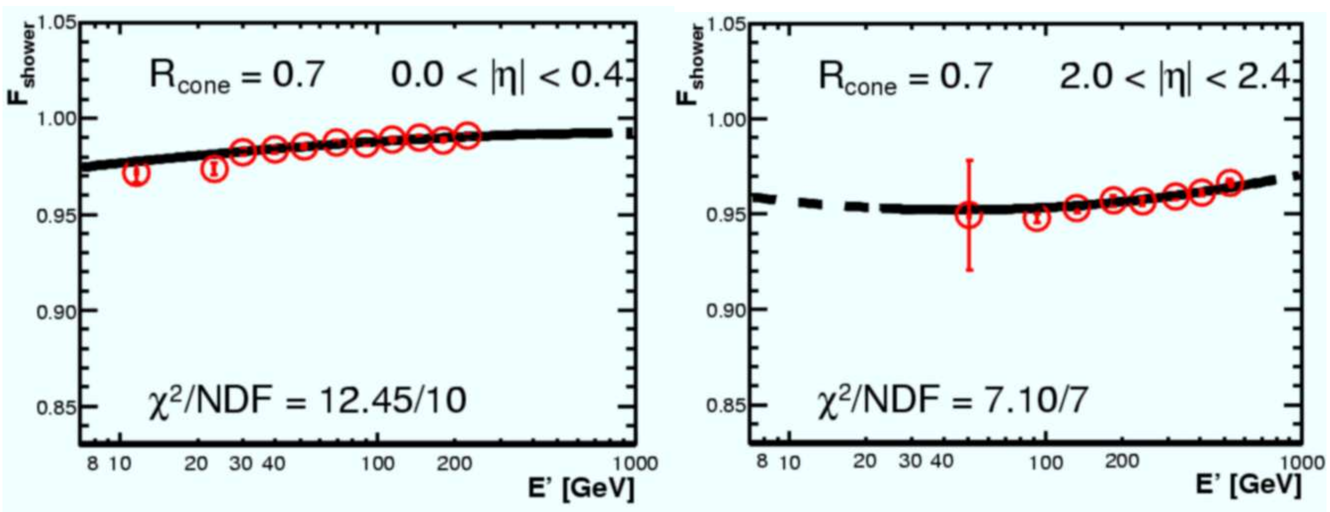


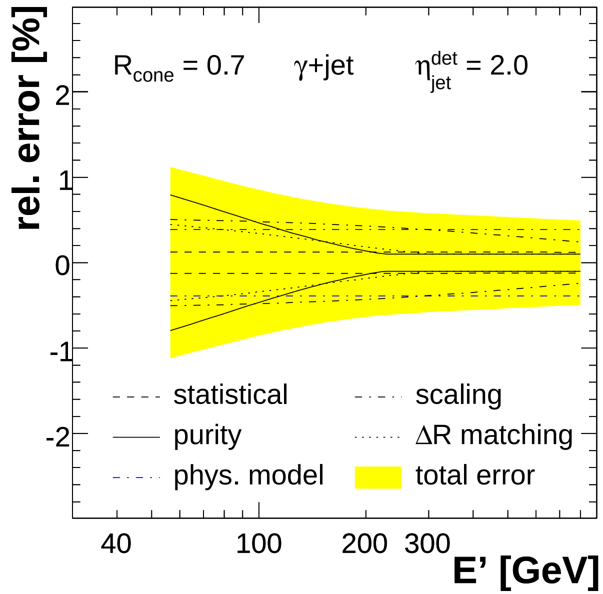
- bias would be tiny for CC jets if we would be calibrating jet p_T, MPF bias on jet energy is large mostly because of jet mass
- in forward region, it is rather a difference between actual jet and recoil

Showering



- two methods
  - "true" showering in MC derived by tracking individual energy depositions in calorimeter cells of all particles in the event
  - template fit of jet profiles
- both methods give compatible results



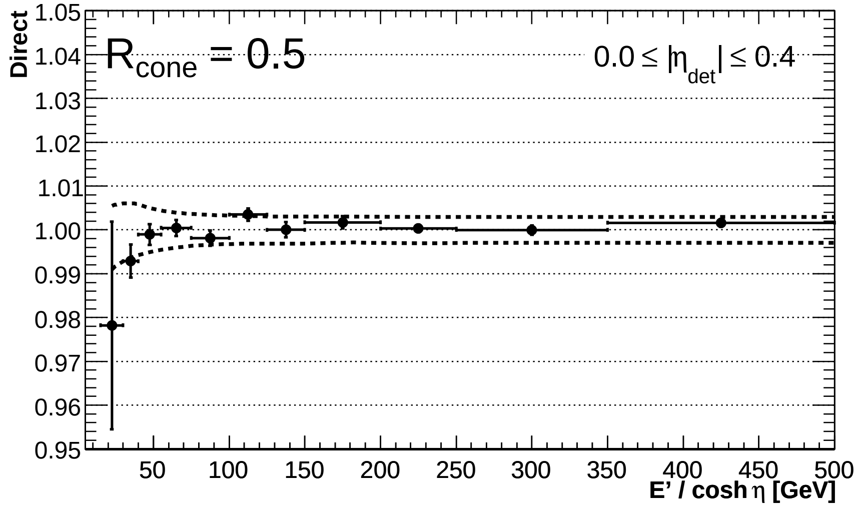


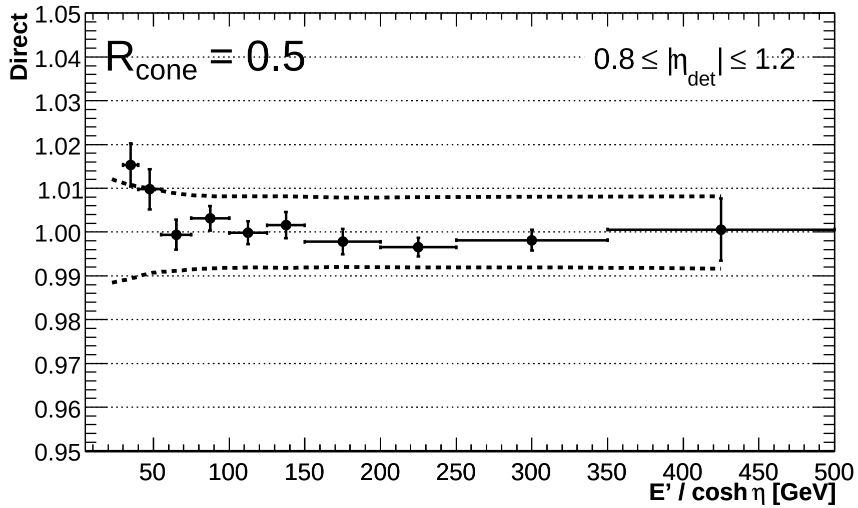
Closure tests

J. Kvita

- Direct closure in MC
  - compare corrected jets directly with the matched particle level jets
- Closure in data
  - hemisphere method
  - $\Delta S = p_{Tjet}/p_{T\gamma} - 1$
  - physics analyses on their own
  - need to understand the biases at the same 1% level as for MPF method

Direct closure in MC



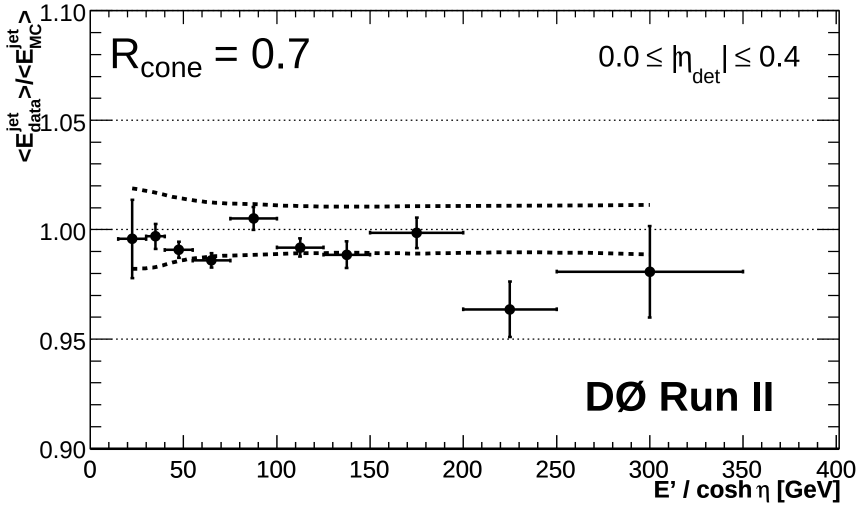


Closure tests

J. Kvita

Closure in data

- Direct closure in MC
  - compare corrected jets directly with the matched particle level jets



- Closure in data
  - hemisphere method
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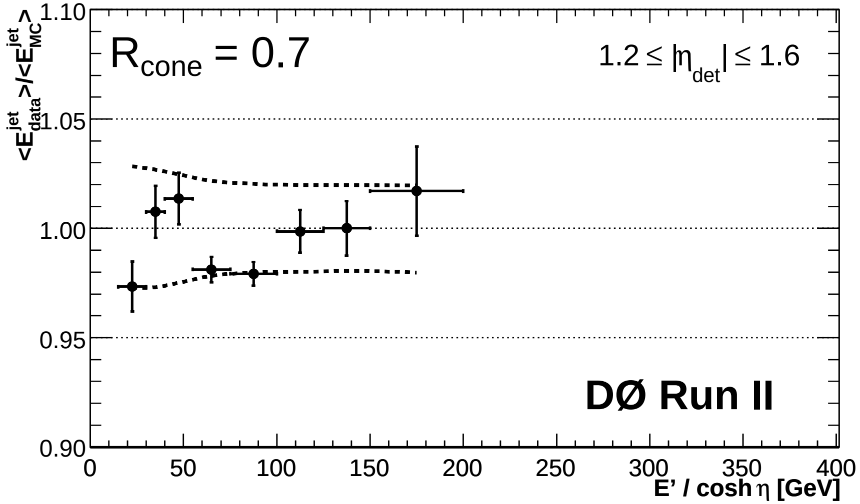
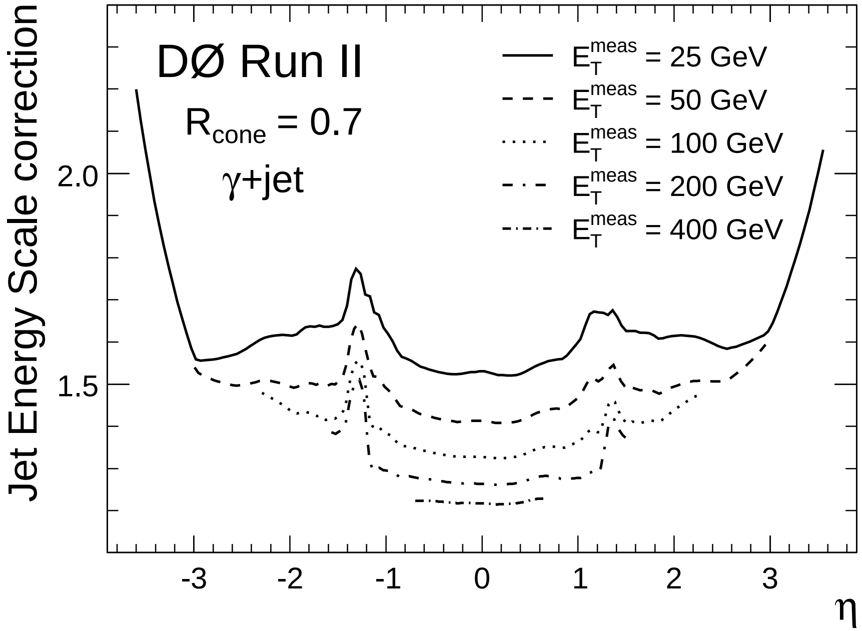
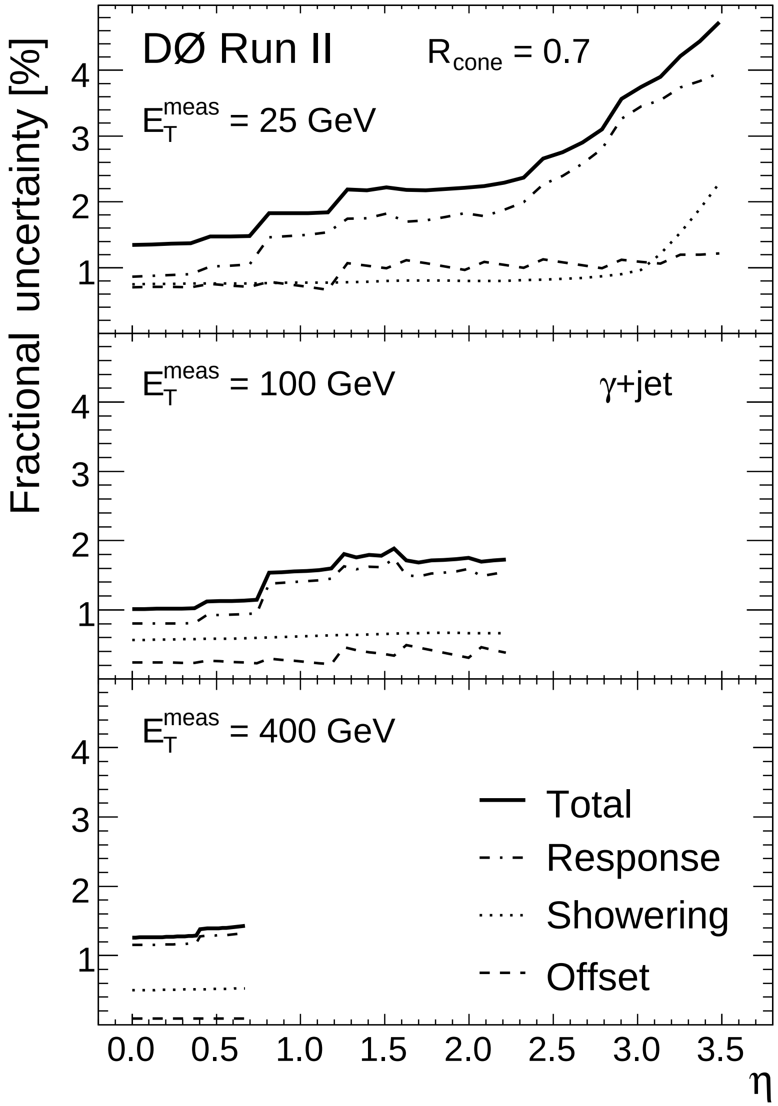


Overall performance





- $1 - 2\%$ uncertainty in wide kinematic region
- to maintain this precision, sample specific correction must be derived

Correlations

E_1 [GeV] \ E_2	25	50	100	200	500
25	1	0.932	0.816	0.681	0.512
50	0.932	1	0.957	0.843	0.651
100	0.816	0.957	1	0.951	0.79
200	0.681	0.843	0.951	1	0.932
500	0.512	0.651	0.79	0.932	1

$\eta_1 = \eta_2 = 0$

E_1 [GeV] \ E_2	25	50	100	200	500
25	0.731	0.749	0.671	0.563	0.427
50	0.574	0.682	0.685	0.624	0.507
100	0.429	0.568	0.628	0.639	0.586
200	0.319	0.452	0.548	0.627	0.666
500	0.221	0.326	0.433	0.559	0.687

$\eta_1 = 0,\ \eta_2 = 1.4$

E_1 [GeV] \ E_2	50	100	200	500
25	0.76	0.745	0.67	0.494
50	0.62	0.691	0.69	0.558
100	0.471	0.585	0.659	0.617
200	0.354	0.487	0.62	0.683
500	0.245	0.379	0.54	0.692

$\eta_1 = 0,\ \eta_2 = 1.9$

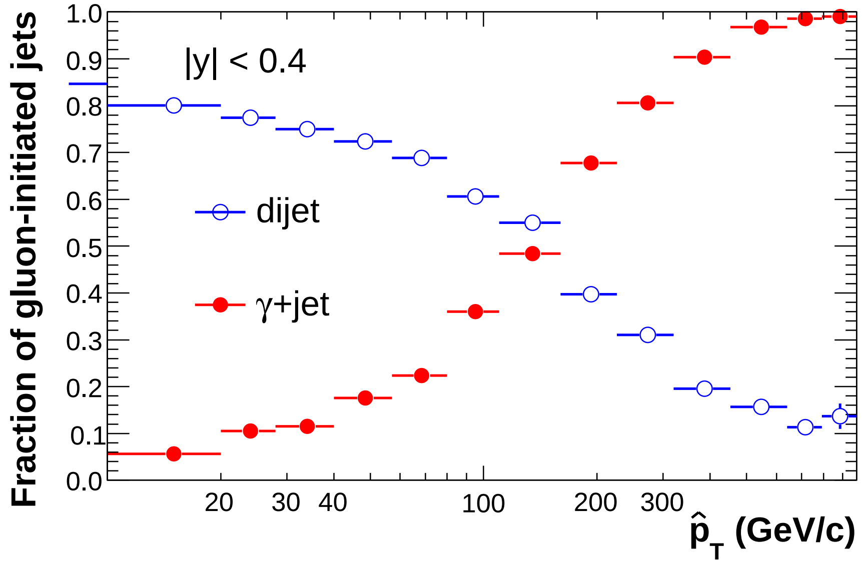
E_1 [GeV] \ E_2	50	100	200	500
25	0.663	0.714	0.701	0.582
50	0.483	0.603	0.666	0.612
100	0.328	0.47	0.581	0.626
200	0.228	0.371	0.514	0.655
500	0.148	0.276	0.432	0.645

$\eta_1 = 0,\ \eta_2 = 2.4$

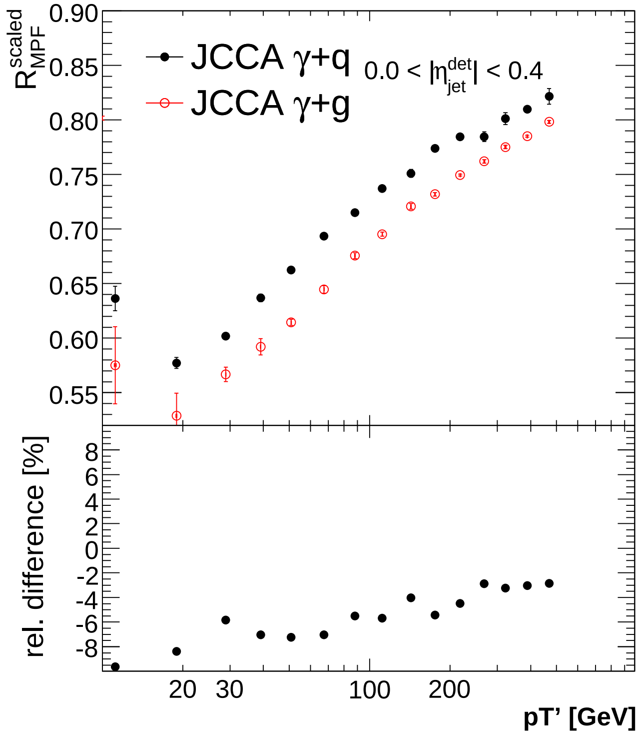
E_1 [GeV] \ E_2	100	200	500
25	0.565	0.53	0.459
50	0.406	0.446	0.439
100	0.273	0.35	0.408
200	0.194	0.291	0.402
500	0.135	0.233	0.38

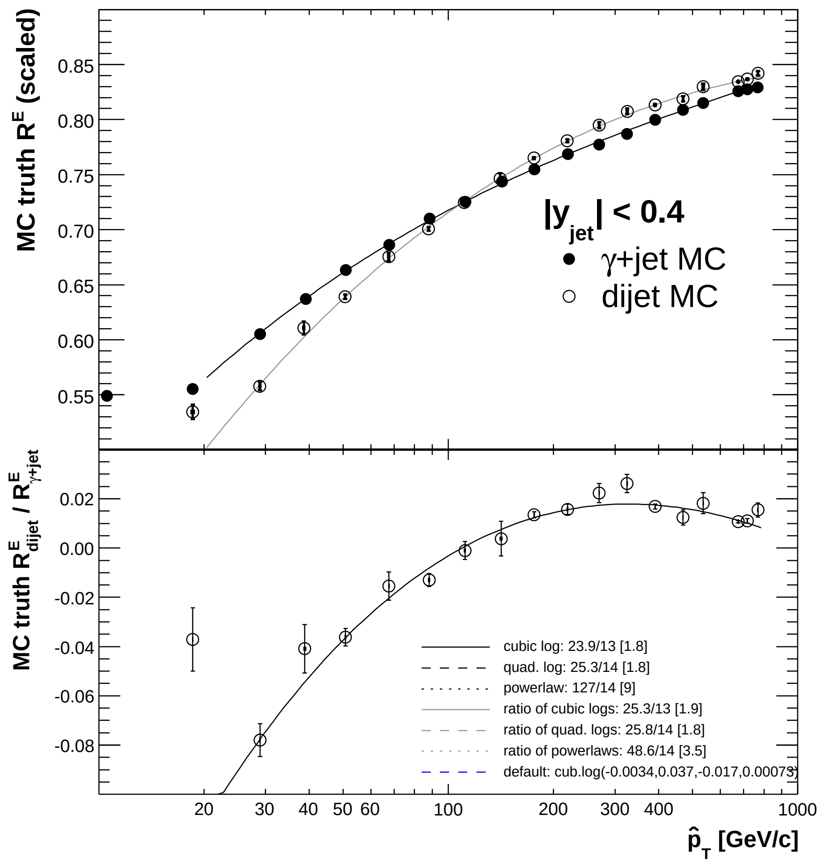
$\eta_1 = 0,\ \eta_2 = 3.2$

QCD sample specific JES



- need to fix absolute scale for central jets from dijet sample
- from MC with tuned single pion response





RunIIa JES Team

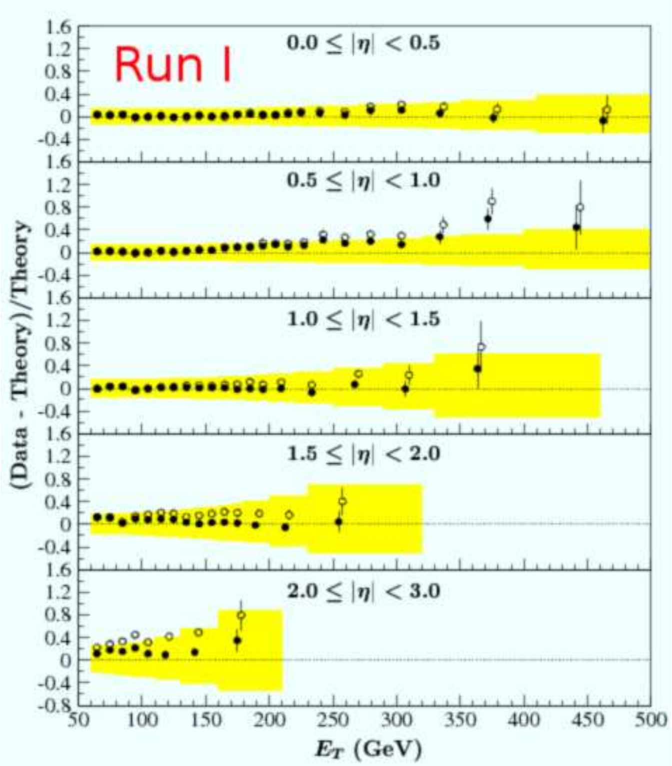
Dmitry Bandurin, Jochen Cammin, Subhendu Chakrabarti, Dag Gillberg, Jeroen Hegeman, Jean-Francois Grivaz

Zdenek Hubacek, Aurelio Juste, Alexander Kupco, Jiri Kvita, David Lam, Christophe Ochando

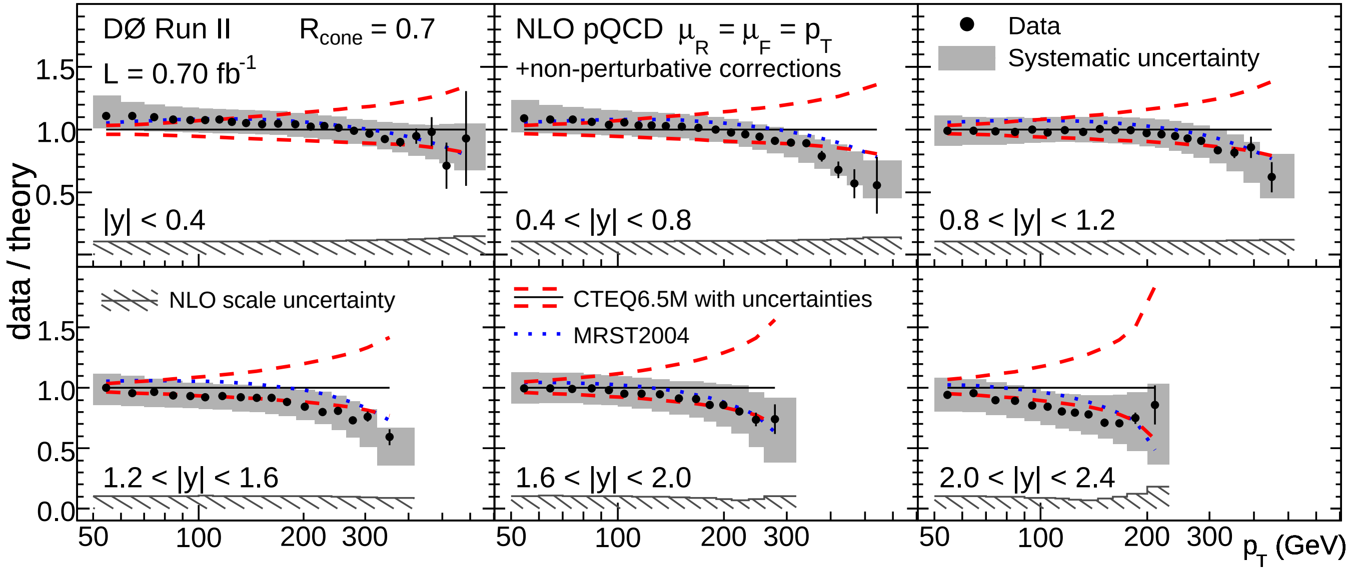
Jeremie Lellouch, Zhiyi Liu, Christophe Royon, Andres Tanasijczuk, Mikko Voutilainen

- possible only due to dedicated work of $\mathcal{O}(10)$ people in last 2 years
- now, we are trying to do the work for RunIIb with 5 people

Jet p_T spectra



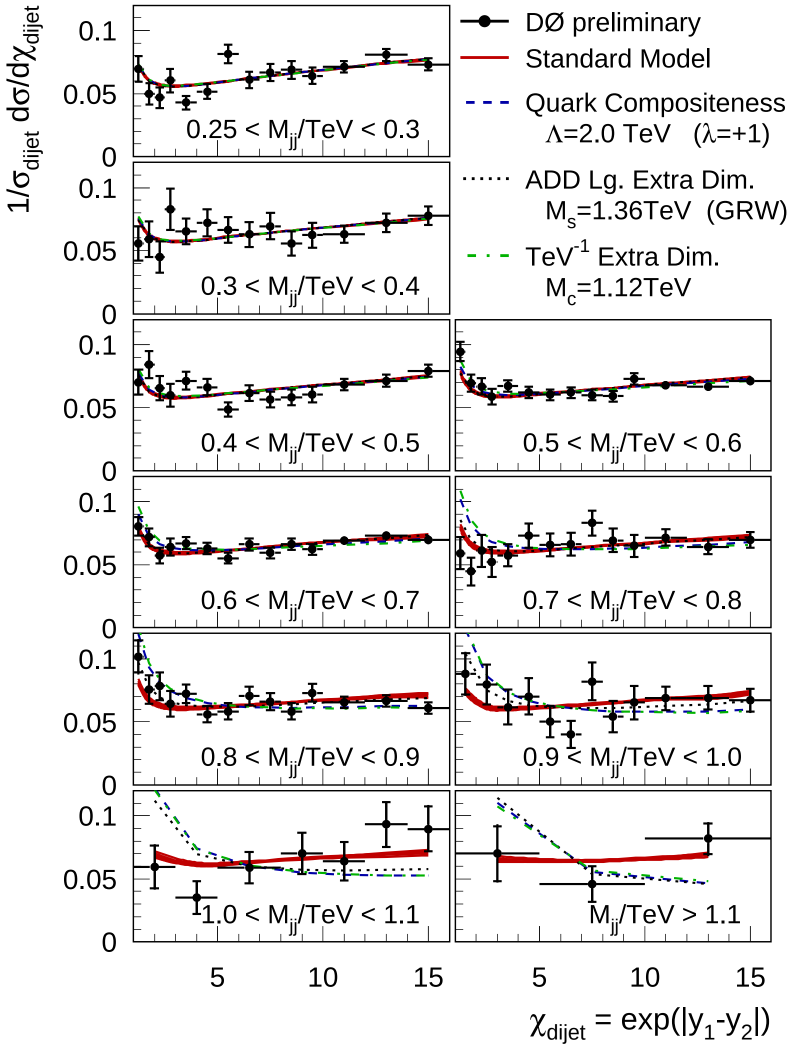
Run II

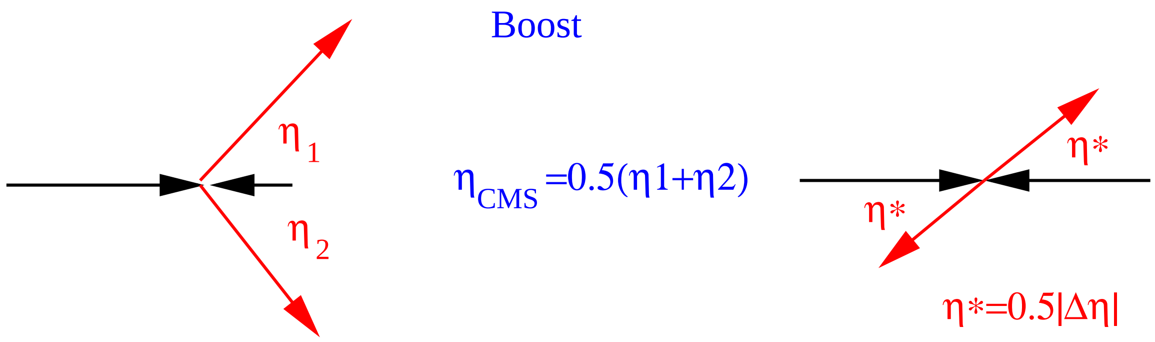


- more precise than Run I and CDF Run II results in wide kinematic range

- at high energy, the errors are smaller than current CTEQ6.5 uncertainties $\Rightarrow$ data are carrying new information about gluon content in proton at large x

Dijet angular distribution and quark compositeness

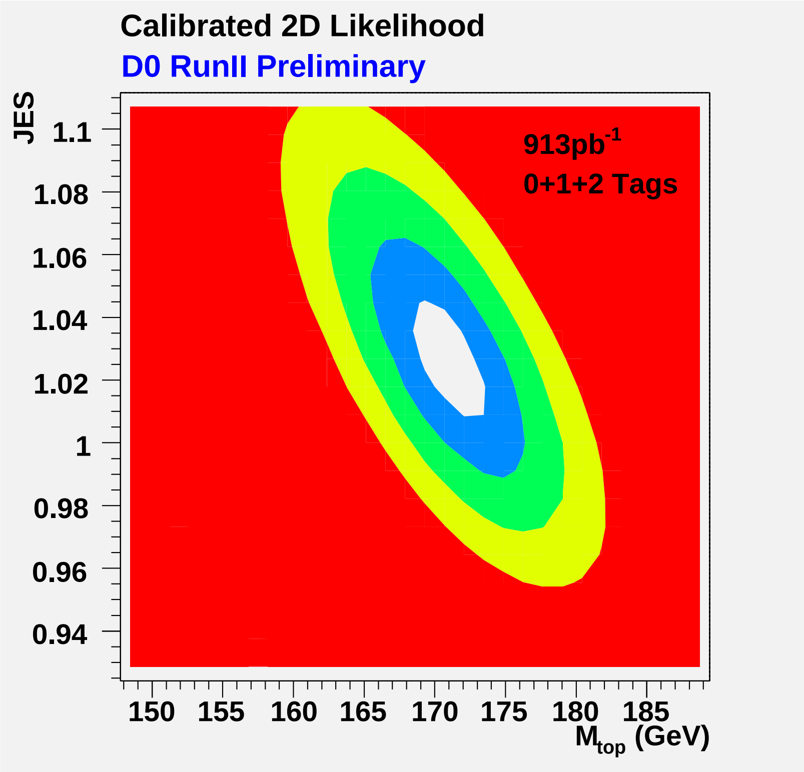




$$\chi = \exp(|\eta_1 - \eta_2|)$$

- distribution normilized to 1
- reduction of many systematic and theoretical unceratinties
- still understanding JES, namely, the correlations between different parts of the detector is important for estimation on new physics searches

Top mass



- RunIIa ($1\,\mathrm{fb}^{-1}$) from lepton+jet

$$m_{top} = 170.5 \pm 2.5\,(stat{+}JES) \pm 1.4\,(syst)\ \mathrm{GeV}$$

- absolute scale is floating with JES prior (fixed by W mass)

$$JES = 1.039 \pm 0.024$$

- up-to-date results even more precise
- DØ as a single experiment measures top mass with precision better than 1%