Ab Initio Approaches in Many-Body QCD
Confront Heavy-Ion Experiments
Heidelberg
December 2012

Targeting Moments in Measurements of Jet Fragmentation Functions

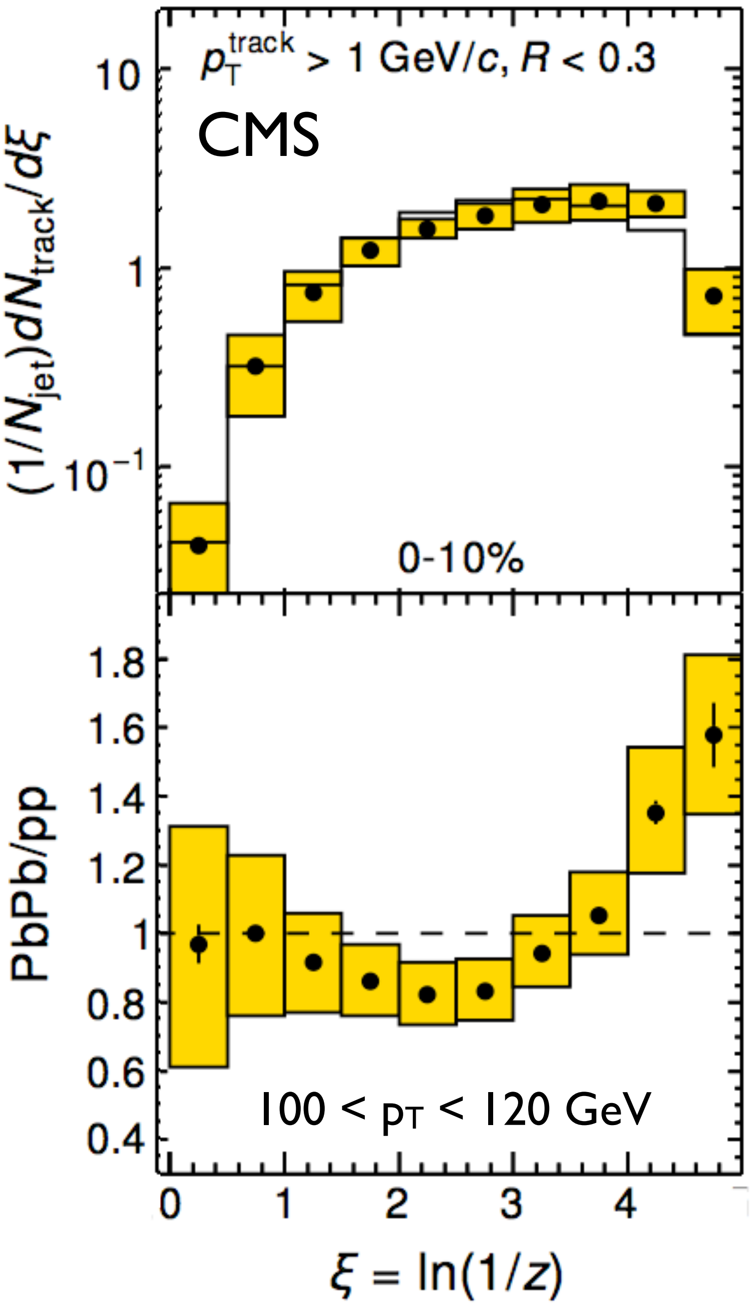
Matteo Cacciari

LPTHE - Paris 6,7 and CNRS

MC, Quiroga, Salam, Soyez, 1209.6086

Charged jet fragmentation in PbPb

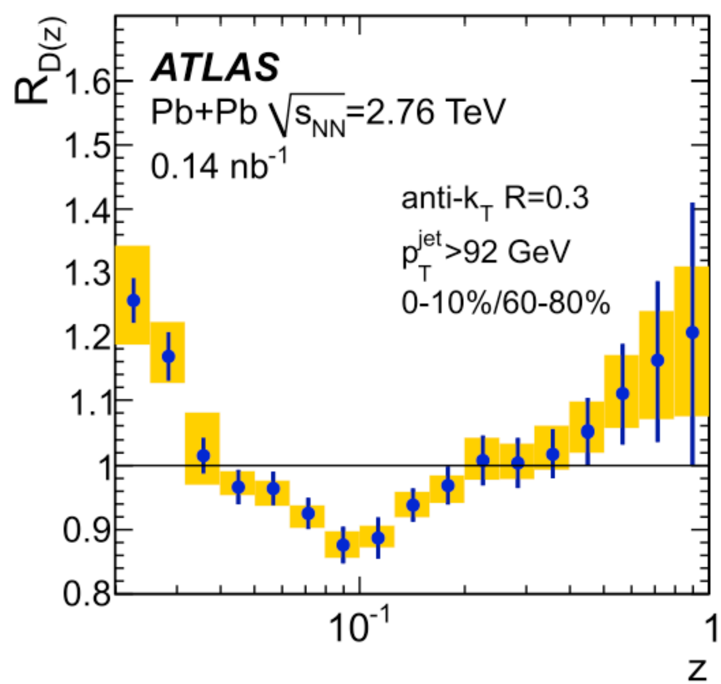
CMS 1406.0932, ATLAS 1406.2979



$$D(z) \equiv \frac{1}{N_{jet}} \frac{dN_{ch}}{d\xi} \qquad D(z) \equiv \frac{1}{N_{jet}} \frac{dN_{ch}}{dz}$$

$$z \equiv p_{\parallel}^{track} / p^{jet} \qquad z \equiv \mathbf{p}_T^{ch} \cdot \mathbf{p}_T^{jet} / |\mathbf{p}_T^{jet}|^2$$

Charged tracks within a radius R from jet



ATLAS and CMS, by all means please DO use different observables, variables, plot scales to represent the same measurements.
We theorists do love puzzles.

Also, please DO NOT put your data on HEPDATA.
We love scraping numbers from plots.

/rant

Background effects

The HI underlying event (= background) affects the fragmentation functions in two ways:

- It increases the momentum of the reference jet
- It adds many soft particles to the jet

These effects are corrected for in experimental analyses, usually by correcting the jet p_T and by subtracting from the FF a distribution measured elsewhere in the detector

Background effects

Even after subtracting the background, its **fluctuations** can still have large effects and induce biases:

- A steeply falling p_T spectrum means that when selecting jets above a given threshold upward fluctuations are preferred
- This means that, even after background subtraction, residual effects that increase the reference jet momentum and add soft particles remain (and tend to be correlated)
- The net effect is to shift the FF to lower values of z and to increase it at small values of z

These effects are also corrected for in measurements, typically via iterative numerical deconvolutions

Proposal

MC, Quiroga, Salam, Soyez, 1209.6086

- Represent the jet FFs in moment space

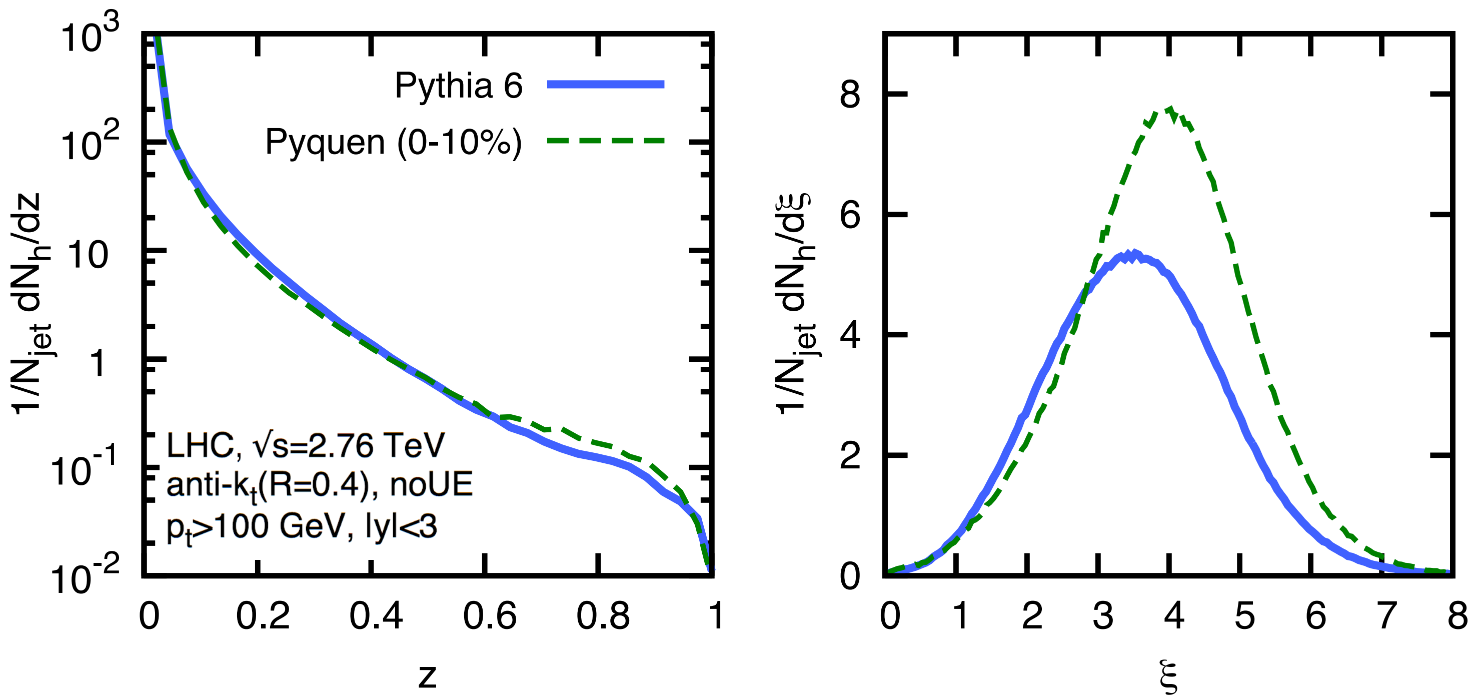
- Subtract background with the jet area-median method

- Correct for fluctuations analytically, using exclusively experimentally measured parameters (and some approximations)

Yet another jet FF definition...

$$z \equiv \frac{p_T^h}{p_T^{jet}}$$

h = all hadrons in jet

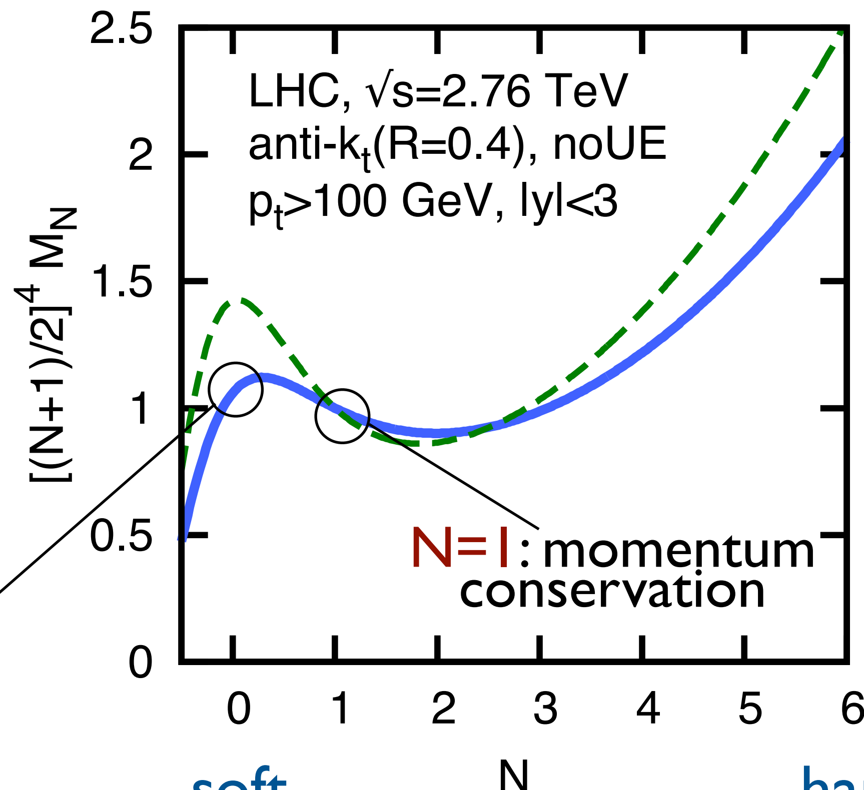


PYQUEN curve illustrative of possible quenching effects (softening of the FF)

Jet FF in moments space

From z distributions to moments

$$M_N = \frac{1}{N_{jet}} \int_0^1 z^N \frac{dN_h}{dz} dz = \frac{1}{N_{jet}} \int_0^\infty e^{-N\xi} \frac{dN_h}{d\xi} d\xi$$



N=0: multiplicity

soft region

hard region

In practice,

$$M_N^{jet} = \frac{\sum_{i \in jet} p_{t,i}^N}{p_t^N}$$

and $M_N = \langle M_N^{jet} \rangle_{jets}$

Jet FF moments and R_{AA}

$$\frac{d\sigma^{jet}}{dp_T} \sim \frac{1}{p_T^n}$$

(in practice, n ~ 5-6)

$$\Downarrow$$

$$\frac{M_{n-1}^{\mathrm{AA}}}{M_{n-1}^{\mathrm{pp}}} = \frac{R_{\mathrm{AA}}^{\mathrm{h}}}{R_{\mathrm{AA}}^{\mathrm{jet}}}$$

Background momentum density

$$\rho = \underset{\text{patches}}{\text{median}} \left\{ \frac{p_{t,\text{patch}}}{A_{\text{patch}}} \right\}$$

Transverse momentum correction

$$p_{T,jet}^{sub} = p_{T,jet} - \rho A_{jet}$$

Subtraction for jet FF moments

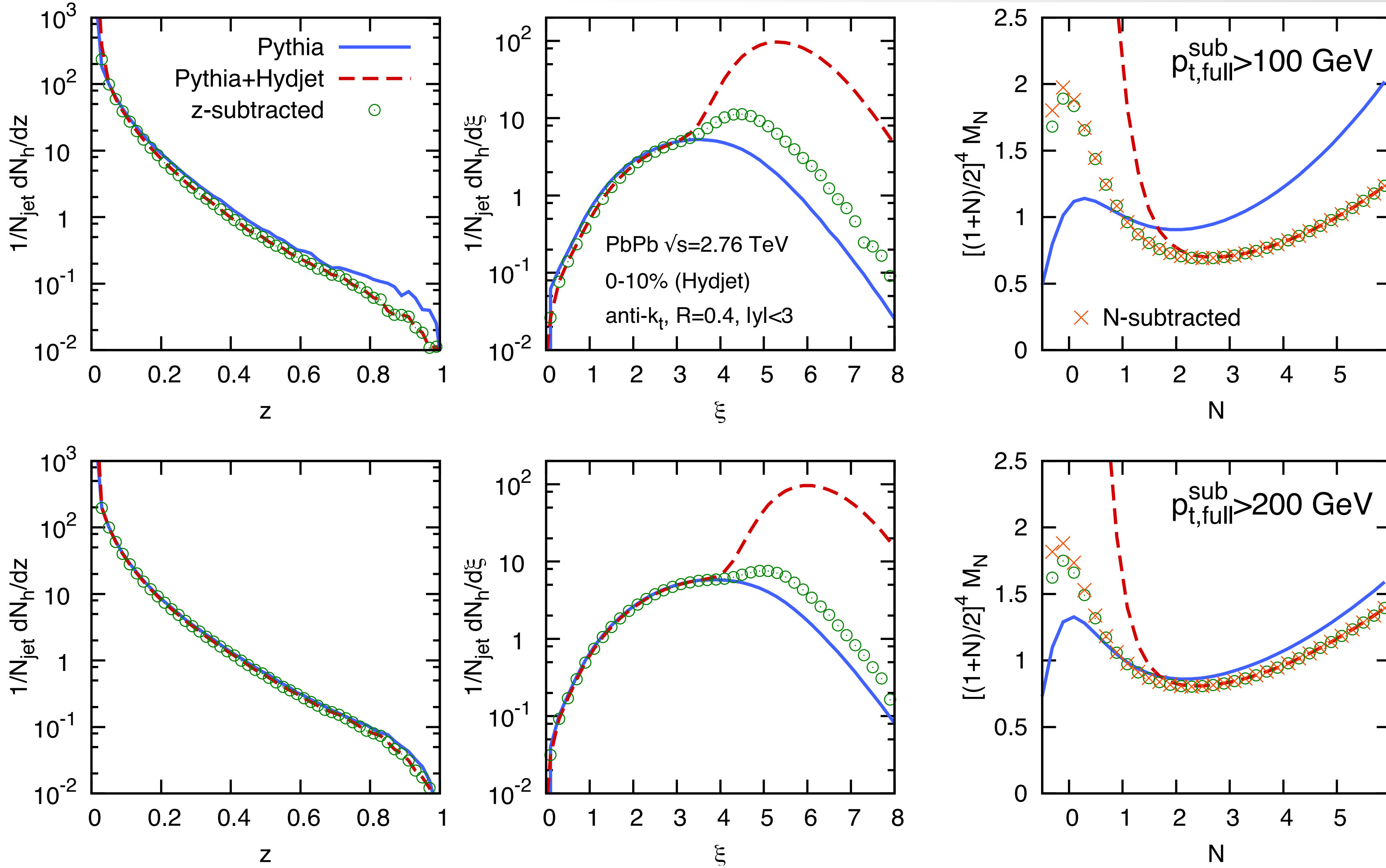
Alongside the usual ρ, extract from the background the quantities

$$\rho_N = \underset{\text{patches}}{\text{median}} \left\{ \frac{\sum_{i\in \text{patch}} p_{t,i}^N}{A_{\text{patch}}} \right\}$$

and subtract the moments according to

$$M_N^{sub} = \frac{\sum_i p_{t,i}^N - \rho_N A}{(p_t - \rho A)^N} \equiv \frac{S_N}{S_1^N}$$

Jet fragmentation functions in HI



- Subtraction of moments (orange crosses) is no worse but also no better than the 'standard' z-space subtraction (green circles)
- Quality of reconstruction of pp-equivalent result ('Pythia', blue line) not great at p_t = 100 GeV, starts getting better at p_t = 200 GeV

Residual discrepancies between "subtracted" and "pp reference" are due to incorrect background subtraction because of its fluctuations

$$Q_N = \left(\sum_{i \in \mathrm{jet\,(bkgd)}} k_{t,i}^N \right) - \rho_N A$$

Actual background contamination (unmeasurable)

Background subtraction

By definition, $Q_1 = q_t$ = transverse momentum mis-subtraction

Fluctuations

Given a fluctuation q_t, we need to improve the subtracted moment $M_N = S_N/S_1{}^N$ by deconvoluting the fluctuations:

$$M_N^{sub} = \frac{S_N}{S_1^N} \rightarrow M_N^{sub,imp} \sim \left.\frac{S_N - Q_N}{(S_1 - q_t)^N}\right|_{\text{Averaged over fluctuations}}$$

Where do we get q_t and Q_N and their distributions from?

Fluctuations treatment: I

Model transverse momentum fluctuations as gaussian

$$B(q_t) \equiv \frac{dP}{dq_t} = \frac{1}{\sqrt{2\pi A\sigma}} \exp\left(-\frac{q_t^2}{2\sigma^2 A}\right)$$

$\sigma^2 A$ are the background fluctuations in patches of area A
Can be measured from data, i.e. using area-median

Fluctuations treatment: 2

Consider effect of fluctuations at subtracted momentum S_1

$$\left.\frac{dP}{dq_t}\right|_{S_1} = \frac{H(S_1 - q_t)B(q_t)}{\int dq'_t H(S_1 - q'_t)B(q'_t)}$$

Parametrising the hard (= pp) transverse momentum spectrum $H(p_t)$ as

$$H(p_t) \equiv \frac{d\sigma}{dp_t} = \frac{\sigma_0}{\mu}\exp(-p_t/\mu)$$

one finds

$$\langle q_t \rangle = \frac{\sigma^2 A}{\mu}$$

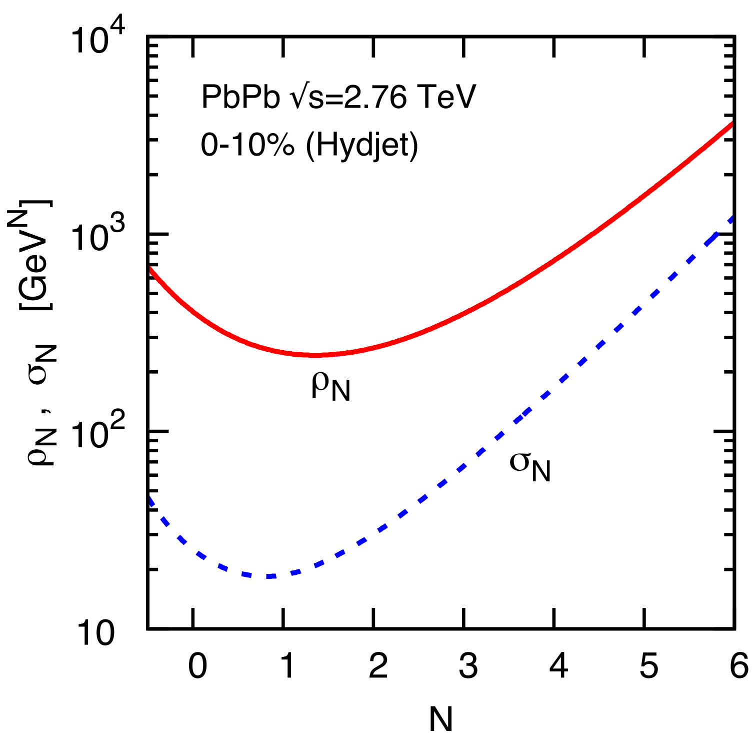
Fluctuations treatment: 3

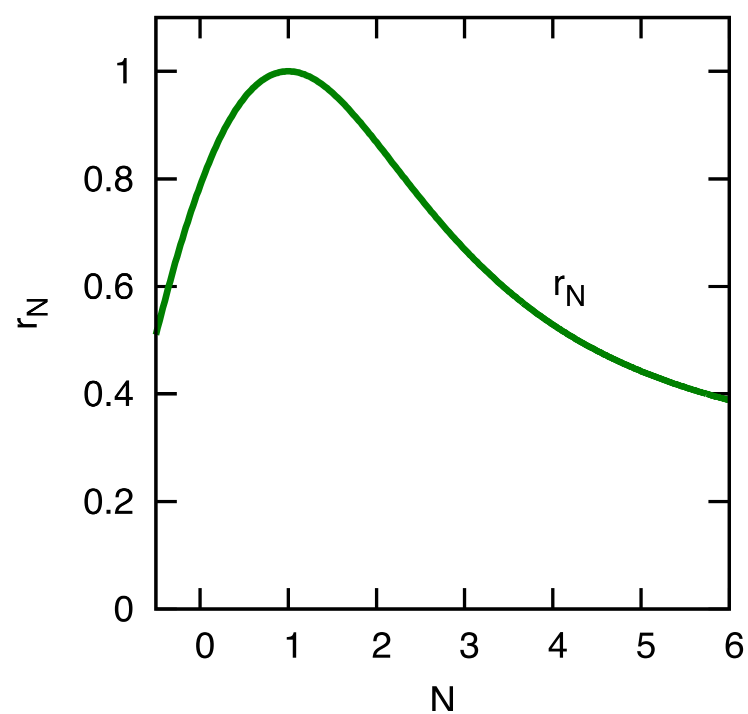
Exploit correlation between Q_N and q_t

$$\langle Q_N \rangle (q_t) = \frac{\mathrm{Cov}(q_t, Q_N)}{\mathrm{Var}(q_t)} q_t = r_N \frac{\sigma_N}{\sigma} q_t$$

$$r_N = \frac{\mathrm{Cov}(q_t, Q_N)}{\sqrt{\mathrm{Var}(q_t)\mathrm{Var}(Q_N)}}$$

correlation coefficient





Fluctuations treatment: 4

Put things together.

Given a fluctuation q_t, the correction to the subtracted moment $M_N = S_N/S_1^N$ will be

$$M_N^{sub,imp} = \frac{S_N - \langle Q_N \rangle (q_t)}{(S_1 - q_t)^N} = \frac{S_N - r_N \frac{\sigma_N}{\sigma} q_t}{(S_1 - q_t)^N}$$

$$= \frac{S_N}{S_1^N} + N \frac{S_N q_t}{S_1^{N+1}} - r_N \frac{\sigma_N q_t}{\sigma S_1^N} + \mathcal{O}\left(q_t^2\right)$$

One then averages over all possible q_t.

Fluctuations: final result

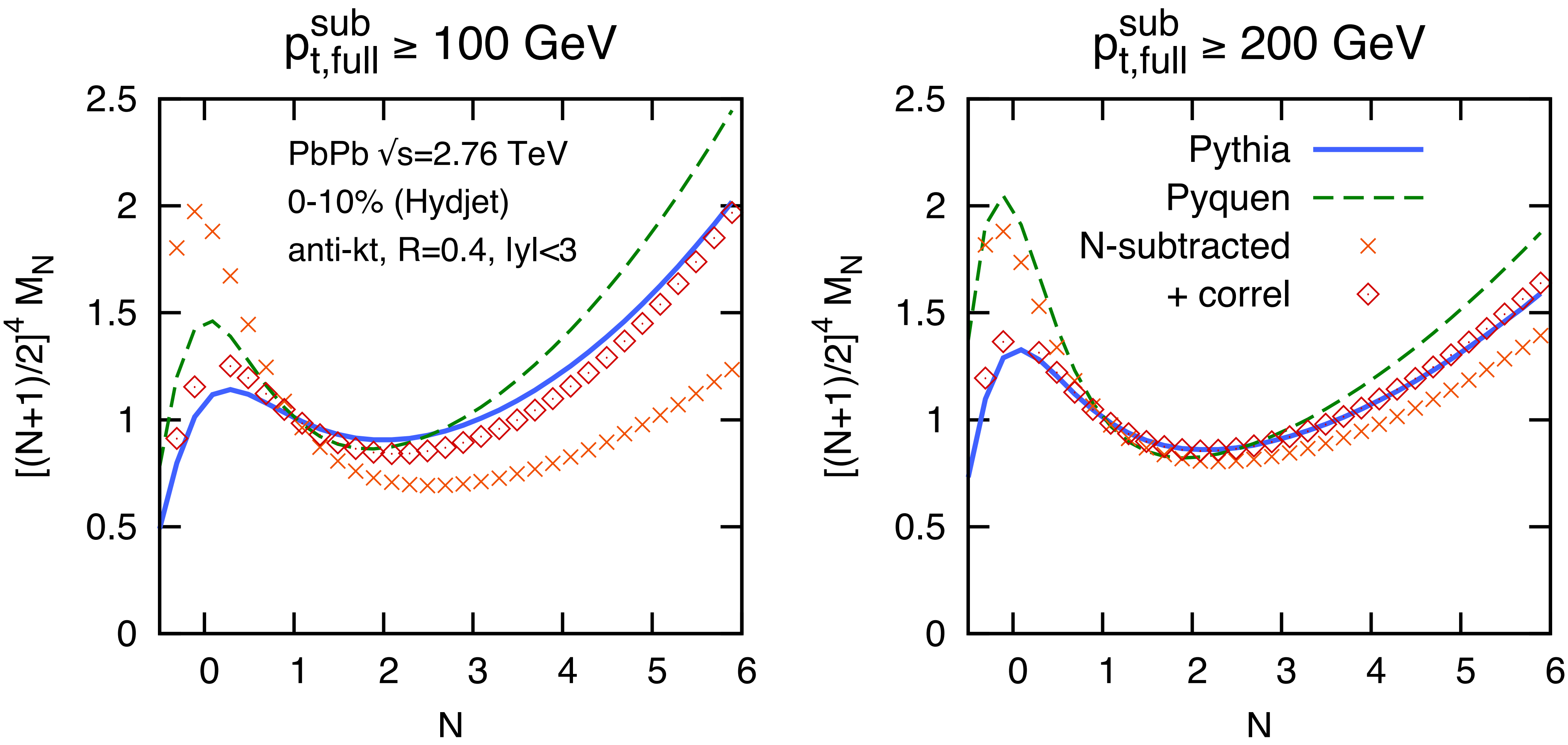
$$M_N^{\text{sub,imp}} = M_N^{\text{sub}} \times \left(1 + N\frac{\sigma^2 A}{S_1 \mu}\right) - r_N \frac{\sigma \sigma_N A}{\mu S_1^N}$$

Corrects for upward fluctuations of jet momentum that lead to underestimate z. Relevant at **large N**

Corrects for the correlation between background fluctuations contribution to jet p_t and to moments. Relevant at **small N**

All the ingredients are experimentally measurable, μ can be measured in pp collisions

Fluctuations: final result



Improvement: from the orange crosses to the red diamonds

Precision now better than potential quenching effects

Tools to do this is available at http://fastjet.hepforge.org/contrib

Final remarks

- Subtraction and deconvolution of background from moments of jet fragmentation functions seems to be a nice theoretical playground
  - Same technique (jet area/median) used for inclusive jets and jet shapes
  - Possibility to perform the deconvolution analytically
  - Only uses directly measured quantities
- Can it concretely work experimentally?

Extra material

z/ξ contributions to N moments