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Reproducing the DØ b -JES

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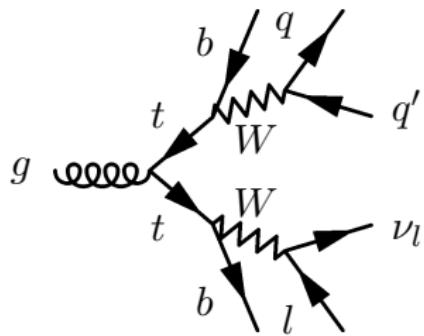
20.11.2018

Outline

- 1 Status of top mass
- 2 Single-particle response formalism
- 3 Jet flavour corrections
- 4 Jet responses and fitting simulation to data
- 5 Concluding remarks

Top mass measurements and b -Jet Energy Scale (b -JES)

- Consider for instance the $l+jets$ channel:



- The resulting top mass will depend on the reconstruction of a b -jet.
- Jets originating from different partons have different behaviour, requiring separate correction methods for gluon jets, b -jets and light quark jets.

Status of top mass

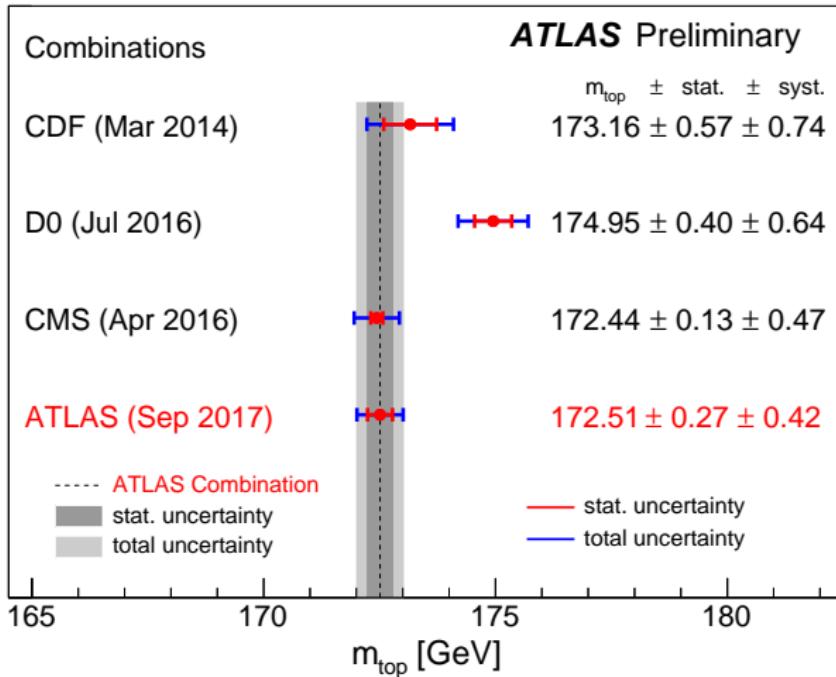
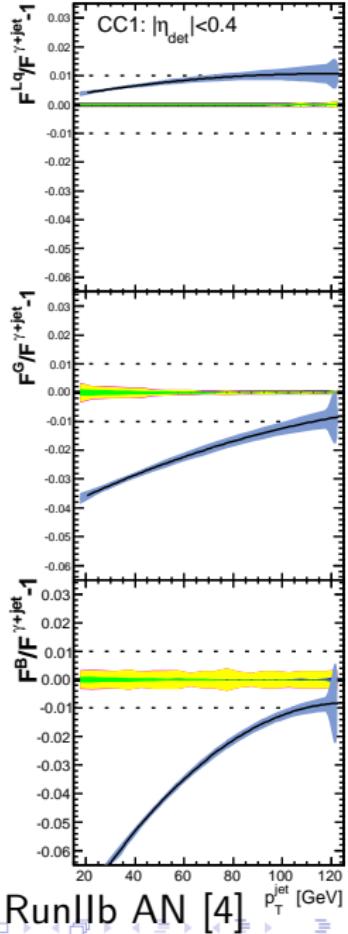
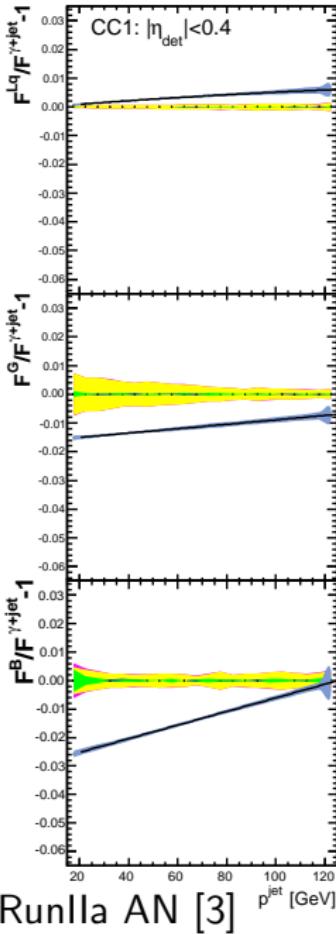


Figure from [1].

DØ result dominated by $l+jets$, based on precision of b JSF from [2, 3, 4].
Rule of thumb: -1% in b JSF $\implies +1$ GeV in m_t .

Jet flavour corrections at D \emptyset

- b -jets changed drastically between runs IIa and IIb.
- Less change in g -jets and (u, d, s, c)-jets.
- Integrated luminosities:
 $\mathcal{L}_{\text{IIa}} = 1.081 \text{ fb}^{-1}$,
 $\mathcal{L}_{\text{IIb}} = 8.655 \text{ fb}^{-1}$.
 $\Rightarrow m_t$ results dominated by IIb.



Single-particle response formalism

Before getting to jets, we reconstruct their constituents.

Single-particle responses (SPR)

- Response functions and parameters $p_\gamma^{(i)}, p_{e^\pm}^{(i)}, p_{\mu^\pm}^{(i)}, p_h^{(i)}$ with $h \in \{K^\pm, K_L, K_S, \Lambda, \mu^\pm, n, \pi^\pm, p\}$ determined from full GEANT detector simulation. Values for run IIa [3] and IIb [4] obtained from DØ analysis notes made public this spring.
- Runs IIa and IIb have different photon responses and we need a tag correction factor for the p_T -balance method

$$\frac{p_T^{\text{probe}}}{p_T^{\text{EM-tag}} \frac{R_\gamma^{\text{IIa}}}{R_\gamma^{\text{IIb}}} (E_{\text{tag}}, \eta_{\text{tag}})}$$

- Many thanks to Liu Huanzhao for delivering the relevant analysis notes. We also acknowledge invaluable discussions and e-mail exchange with Andreas Jung and Jan Stark in understanding the run IIa-IIb difference.

Single-particle responses (SPR)

E.g. hadron response

- Single-particle responses based on single-particle MC samples

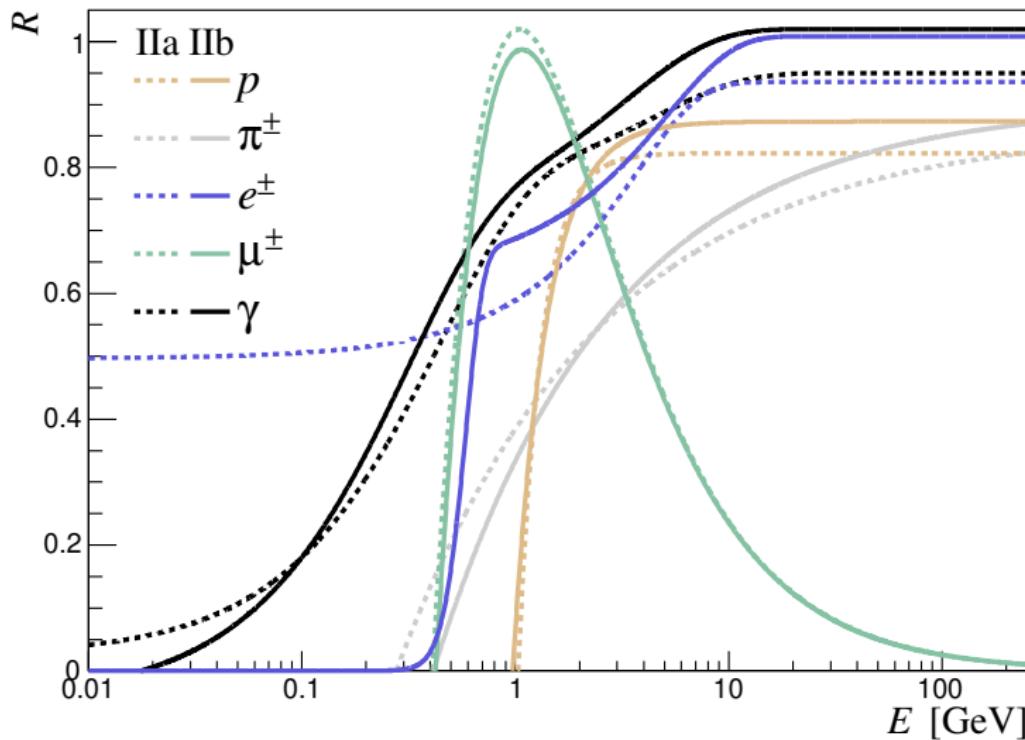
$$R_h^{\text{MC}} = \theta(|\vec{p}_T| - m_h) p_h^{(0)} \left(1 - p_h^{(1)} (4E/3)^{p_h^{(2)} - 1}\right).$$

- Fit MC response to match DØ data by introducing fit parameters A, B and C :

$$R_h^{\text{data}} = \theta(|\vec{p}_T| - m_h) C p_h^{(0)} \left(1 - A p_h^{(1)} (4E/3)^{p_h^{(2)} + B - 1}\right).$$

- Assume γ , e^\pm and μ^\pm responses are the same in data and MC.

Single-particle response summary



Finding jet flavour corrections

Flavour corrections at DØ

- Flavour dependent correction factors come from Jet Energy Scale (JES) determination:

$$F = \frac{\sum_{i \in \{\text{Particles in jet}\}} E_i R_i^{\text{data}}}{\sum_{j \in \{\text{Particles in jet}\}} E_j R_j^{\text{MC}}}.$$

- Normalization by the γ +jet sample avg.:

$$F_{\text{corr}} = \frac{F}{\langle F \rangle_{\gamma+\text{jet}}}.$$

- γ +jet events are studied since the leading photon can be reconstructed fairly accurately.
- Also EM+jet events studied in JES determination.

MC samples in JES determination

- Using FASTJET, DØ iterative midpoint algorithm.
- The hard processes included in PYTHIA 6 samples (tune A, PDF CTEQ6L1) for reproducing DØ JES determination results are listed here.

- Jet energy estimator

$$E' = |\vec{p}_T^{\text{tag}}| \cosh(\eta^{\text{probe}}).$$

- Jet 4-momentum reconstruction via single-particle responses:

$$(p_{\text{jet}}^{\text{reco}})^{\mu} = \sum_{i \in \{\text{Particles in jet}\}} R(E_i) (p_i^{\text{gen}})^{\mu}.$$

$\gamma + \text{jet}$

14 $f_i \bar{f}_i \rightarrow g \gamma$
29 $f_i g \rightarrow f_i \gamma$

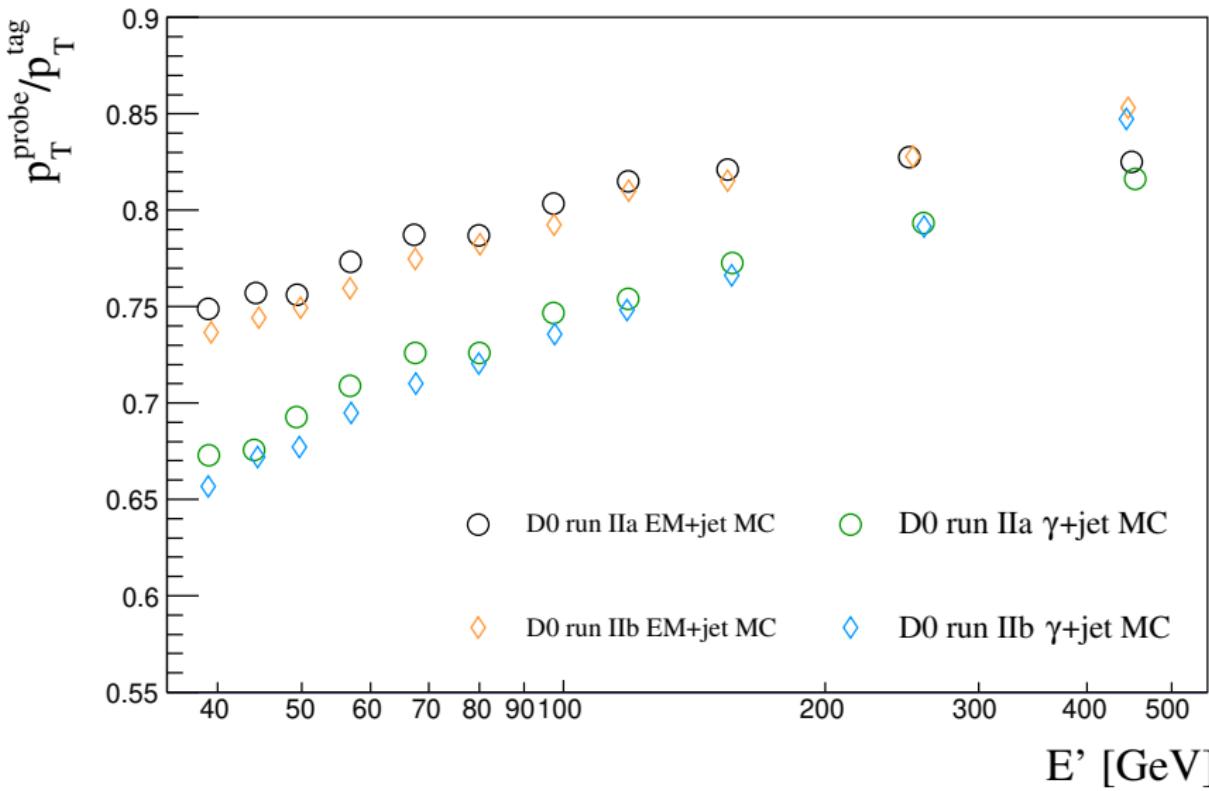
$\text{EM} + \text{jet}$

11 $f_i f_j \rightarrow f_i f_j$
12 $f_i \bar{f}_i \rightarrow f_k \bar{f}_k$
13 $f_i \bar{f}_i \rightarrow gg$
28 $f_i g \rightarrow f_i g$
53 $gg \rightarrow f_k \bar{f}_k$
68 $gg \rightarrow gg$

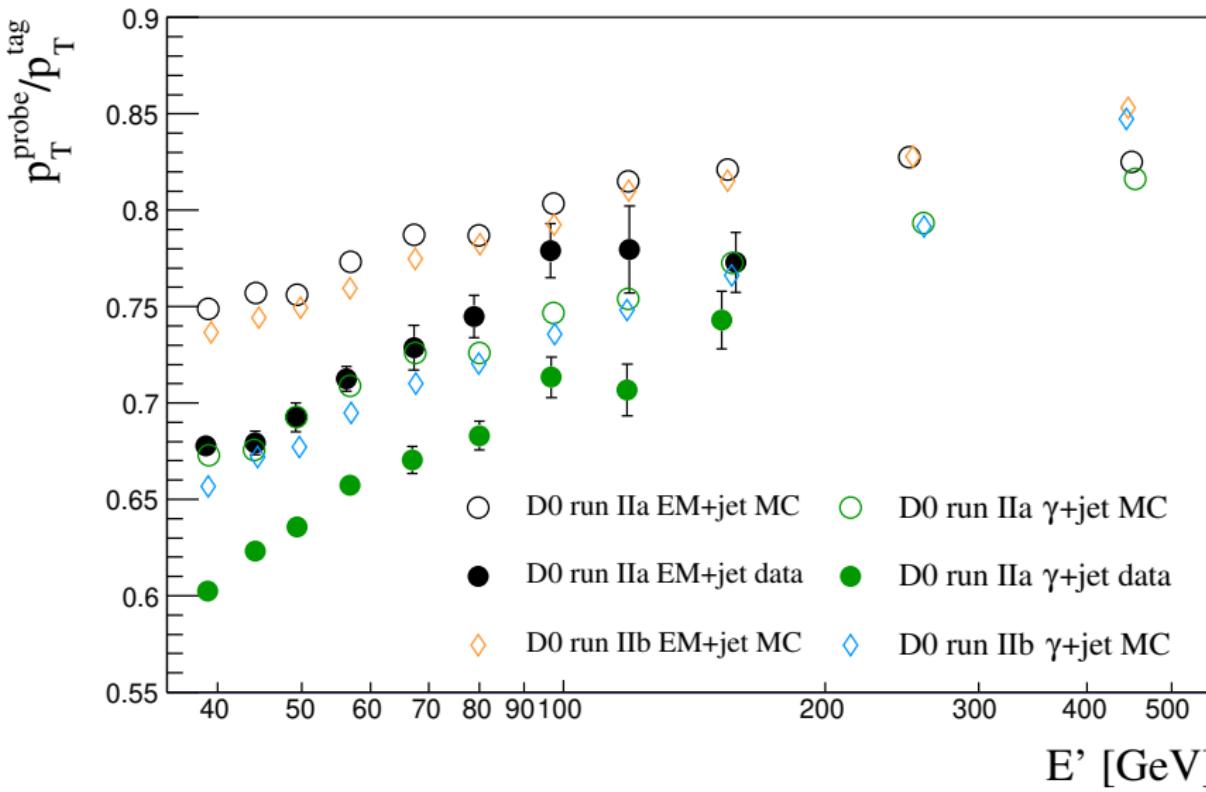
Jet response – from MC to data

DØ: tag (γ/EM) and probe (jet) $|\vec{p}_T|$ -balance method

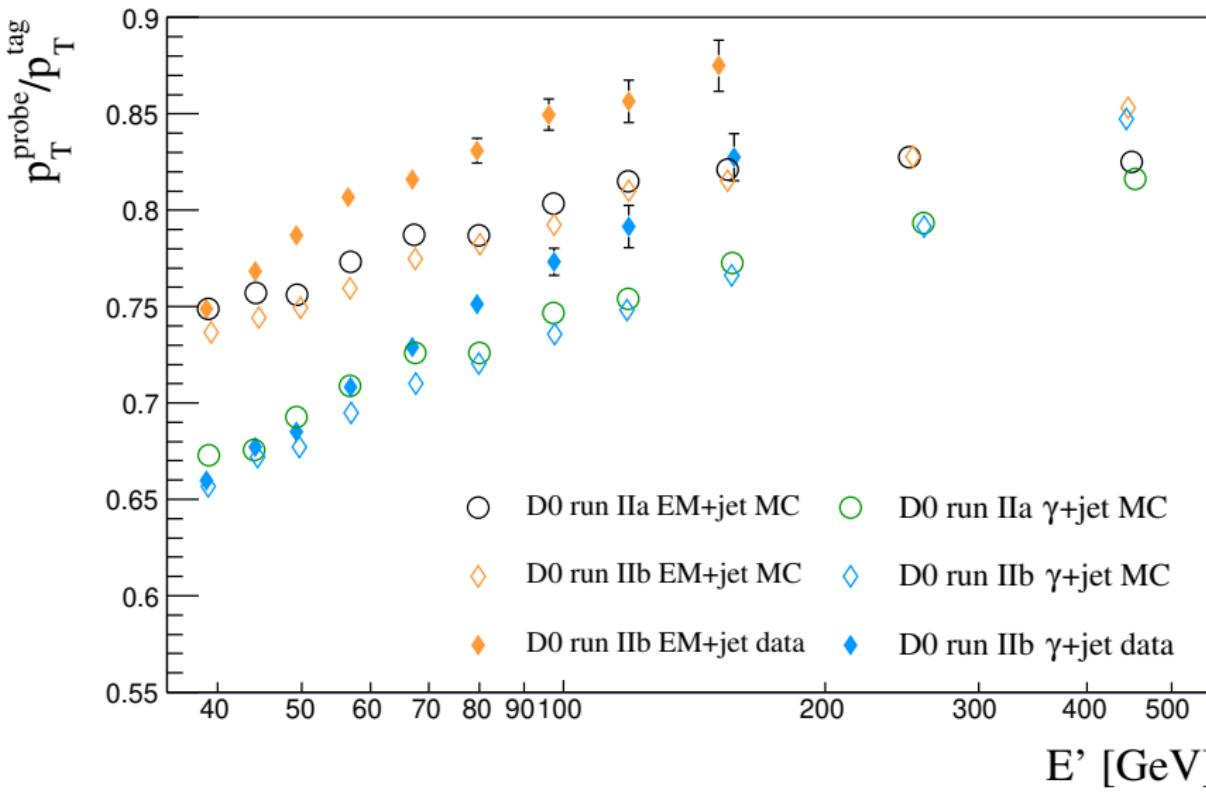
DØ MC – slight difference due to change in SPR



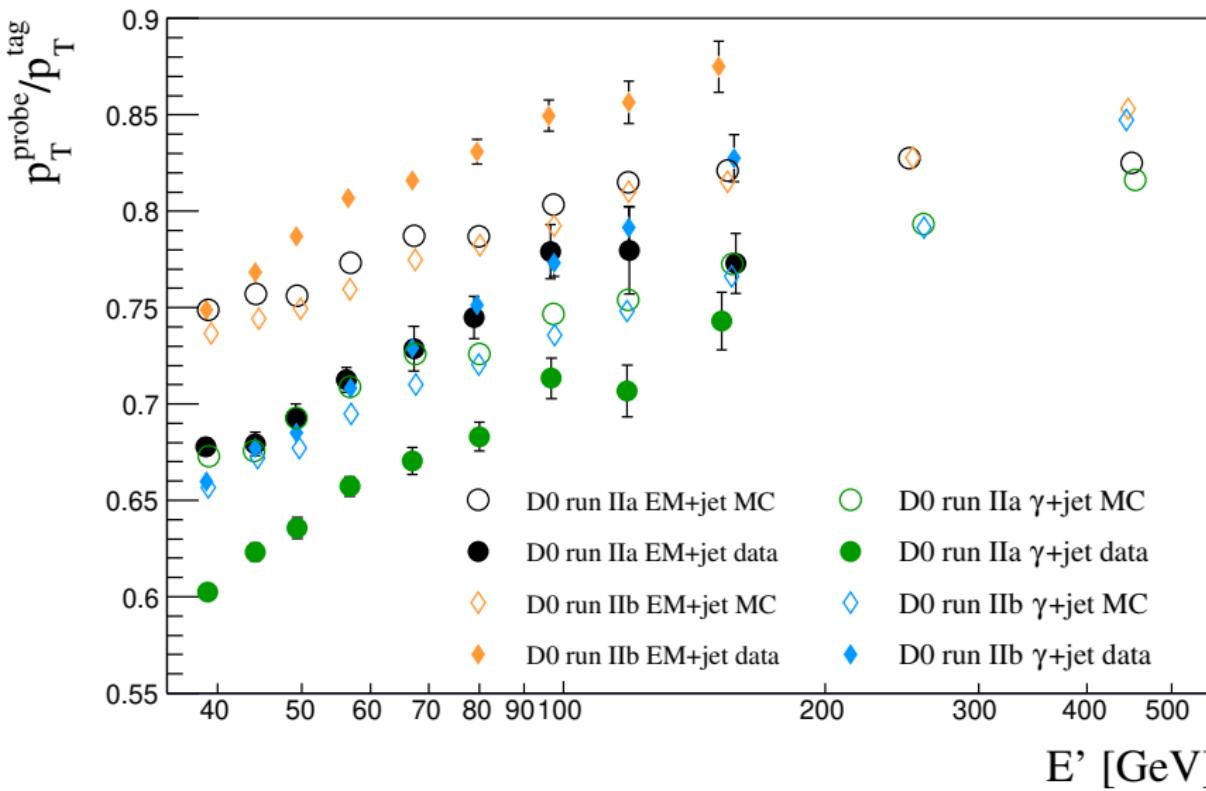
DØ MC and run IIa data



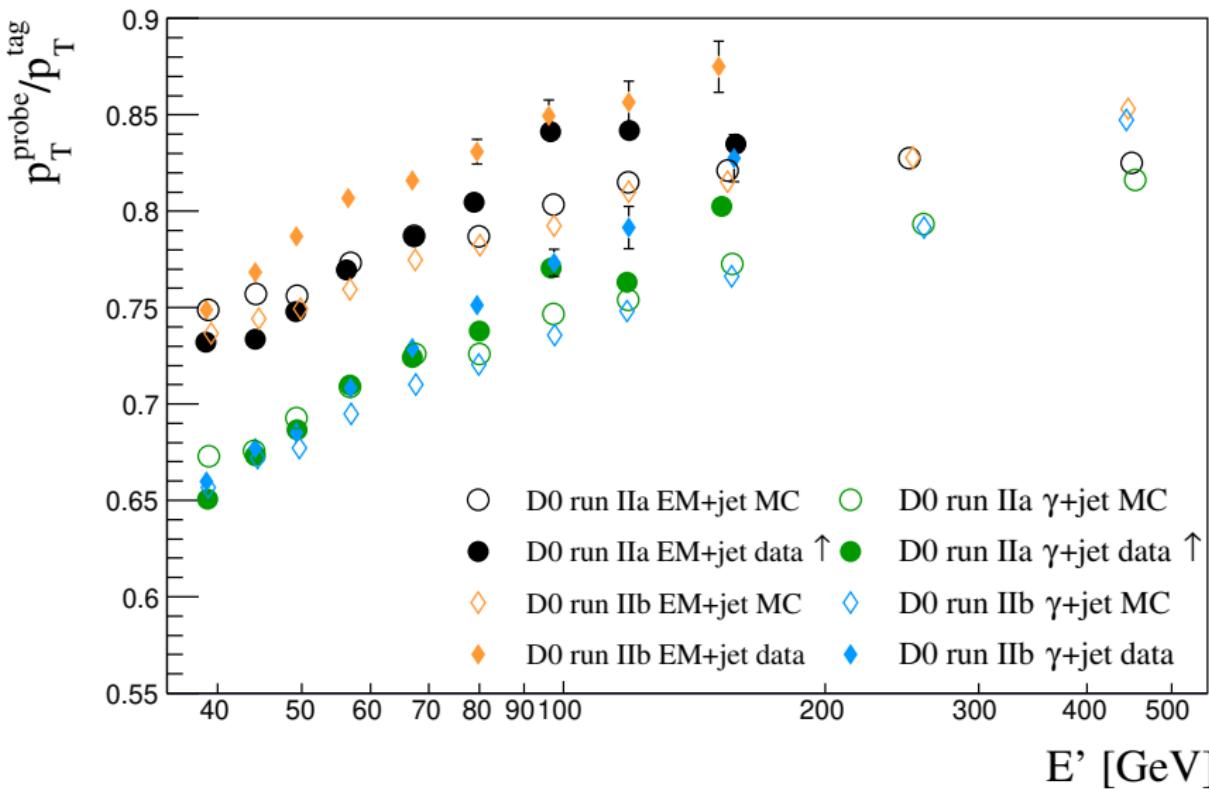
DØ MC and run IIb data



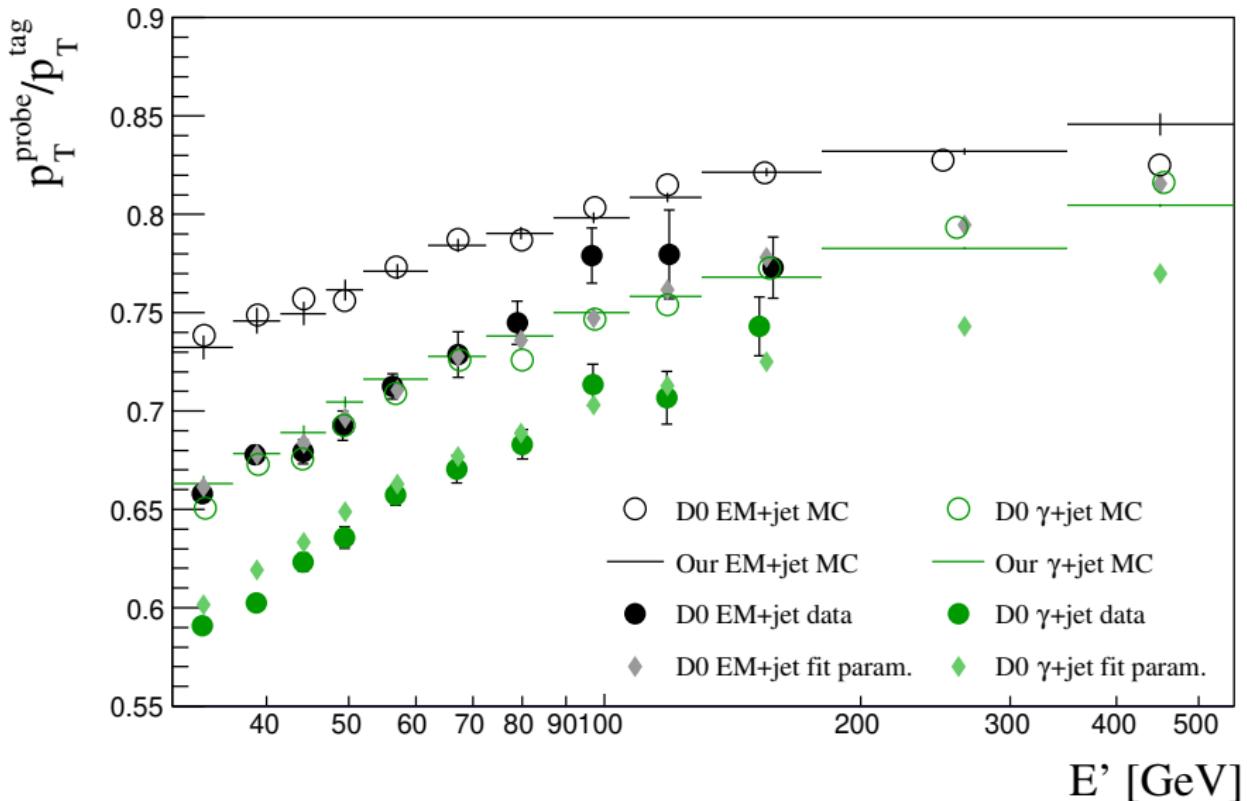
All DØ MC and data points



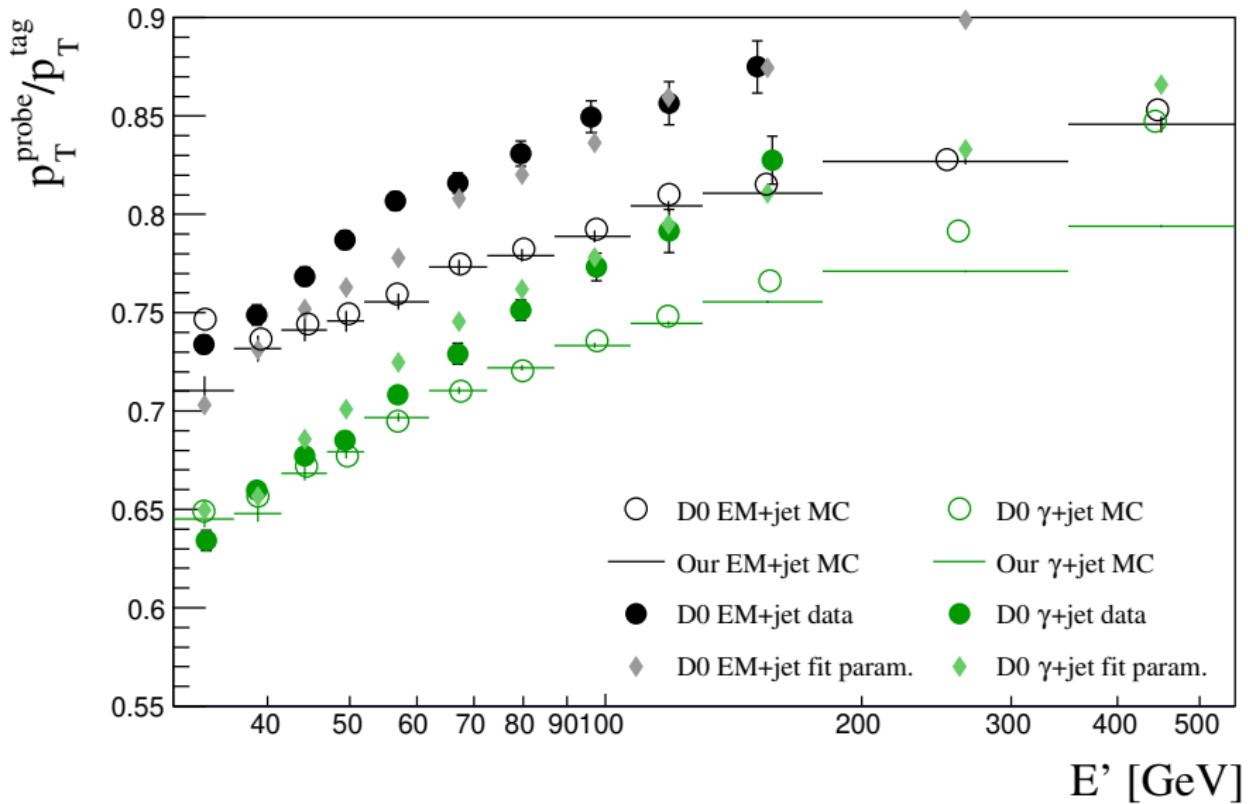
IIb tag correction corresponds to the shift in data:



Our MC & DØ fit param.s: IIa, $|\eta| < 0.4$



Our MC & DØ fit param.s: IIb, $|\eta| < 0.4$



Notes on fit formalisms

- Recall the hadron response

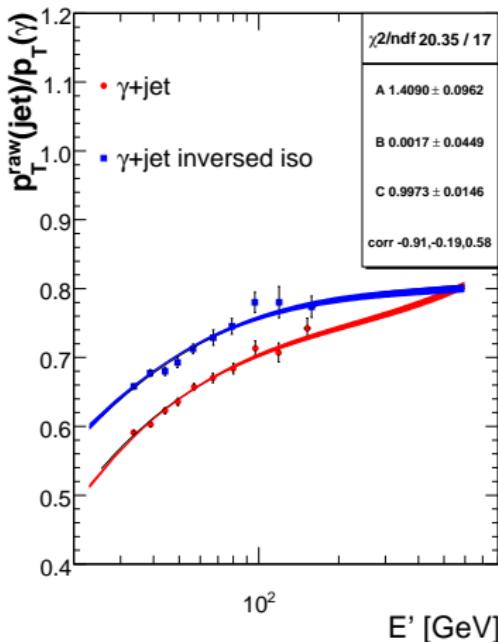
$$R_h^{\text{data}} = \theta(|\vec{p}_T| - m_h) C p_h^{(0)} \left(1 - A p_h^{(1)} (4E/3)^{p_h^{(2)} + B - 1}\right).$$

→ Constrain C close to 1.

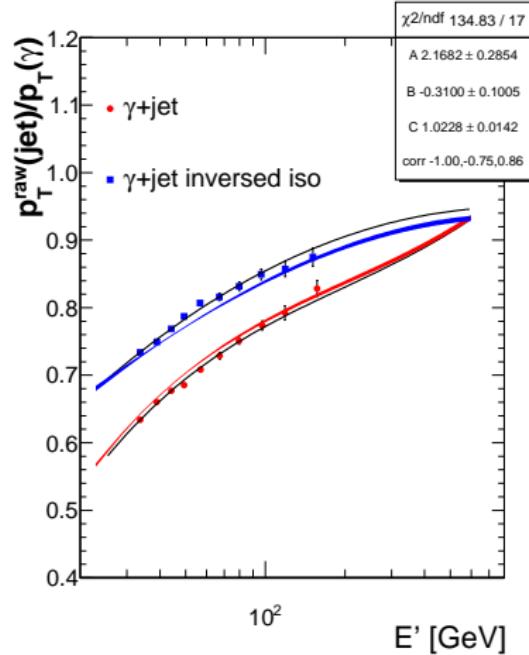
- DØ method scans through a grid of A, B, C values, computes a histogram using R_h^{data} (fit reco) at each point, fits a 3rd degree polynomial to it and computes χ^2 between the polynomial and data points.
- We implemented the Gauss-Newton method and calculate χ^2 directly from the difference of the fit-reco histogram and data points.

DØ fits

Run IIa [3]

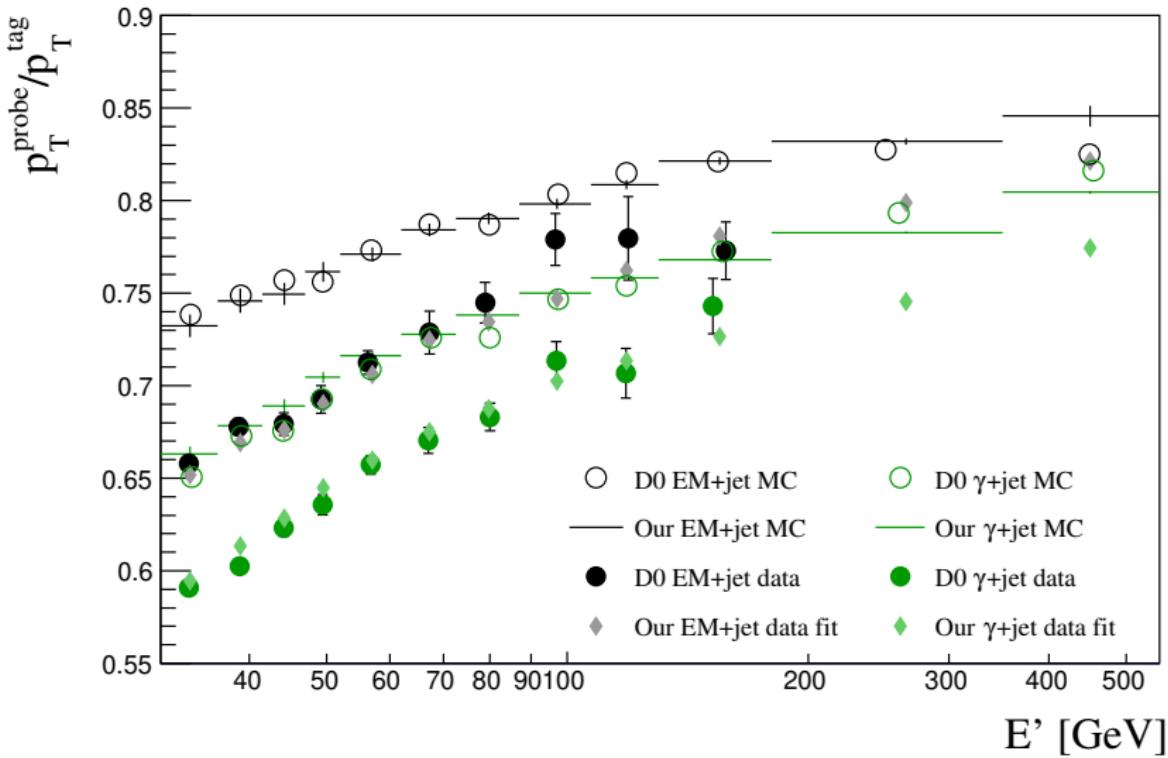


Run IIb [4]

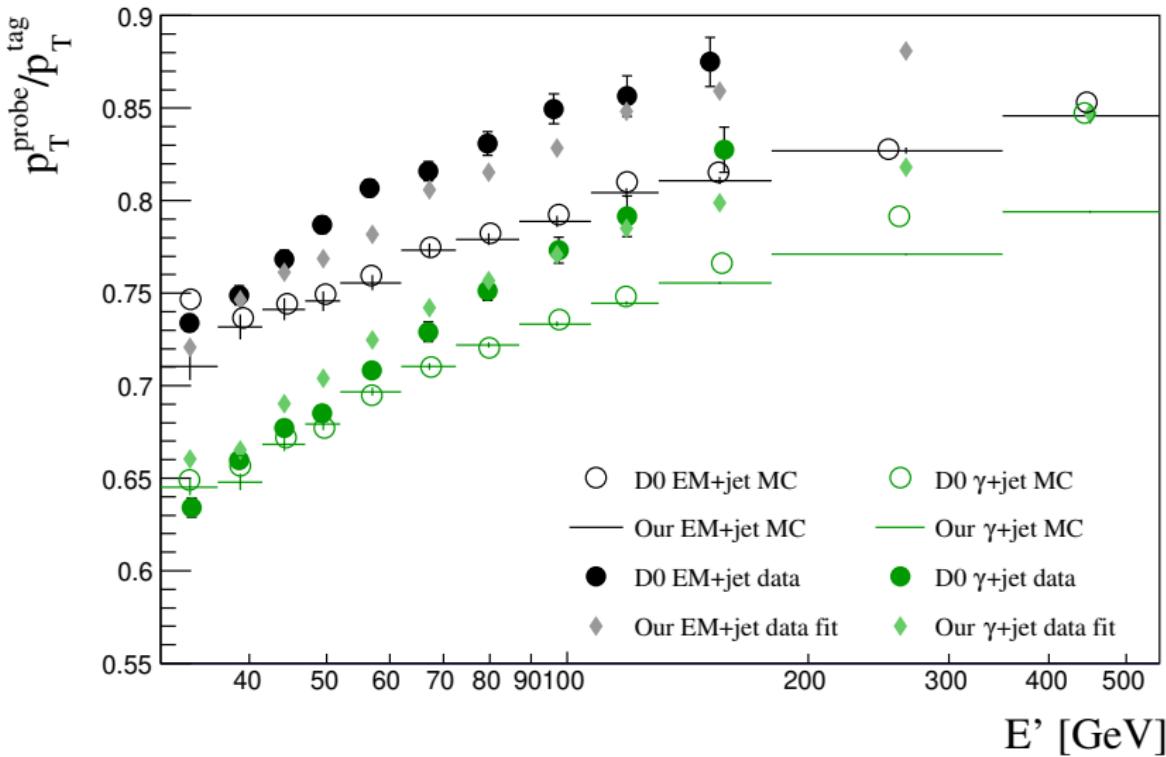


IIa fit has good χ^2/n_{dof} , closure and small residual A, B, C . IIb does not.

Our MC fitted to DØ data: IIa, $|\eta| < 0.4$

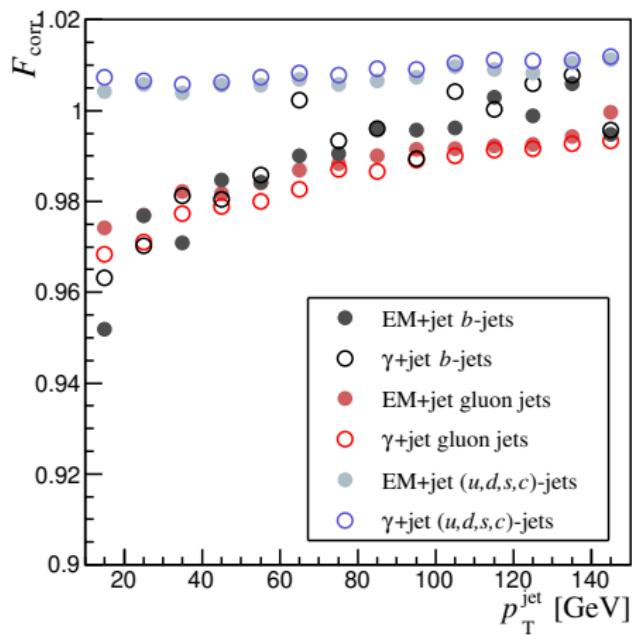


Our MC fitted to DØ data: IIb, $|\eta| < 0.4$

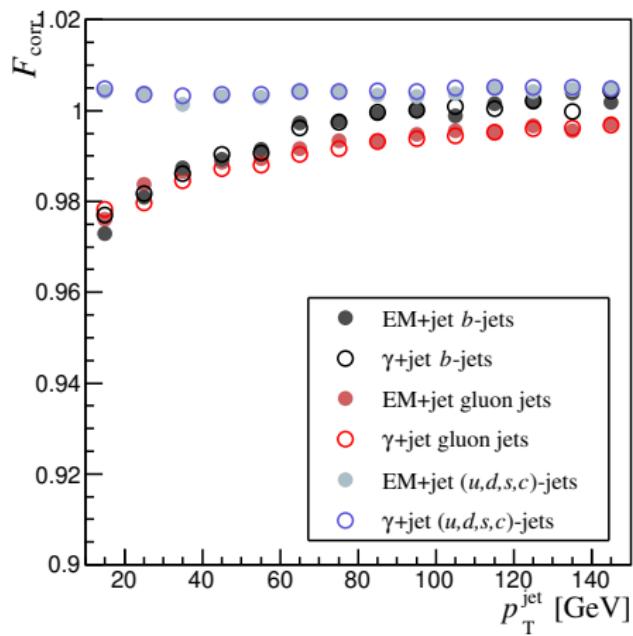


Our MC fitted to DØ data, $|\eta| < 0.4$

Run IIa

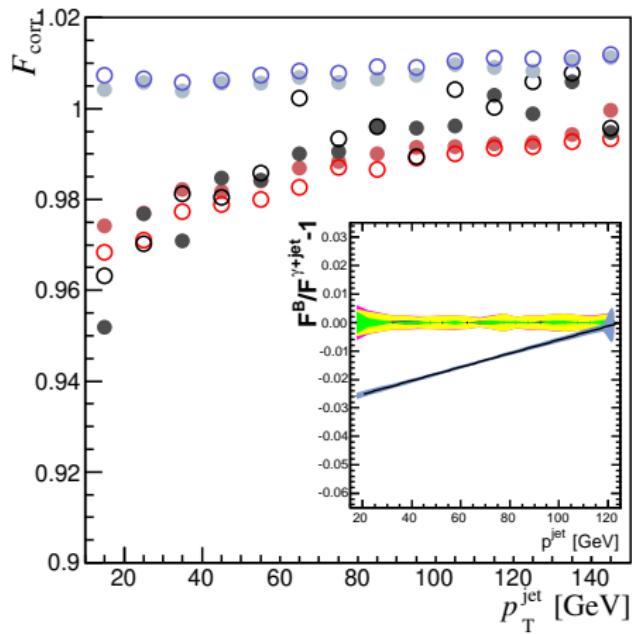


Run IIb

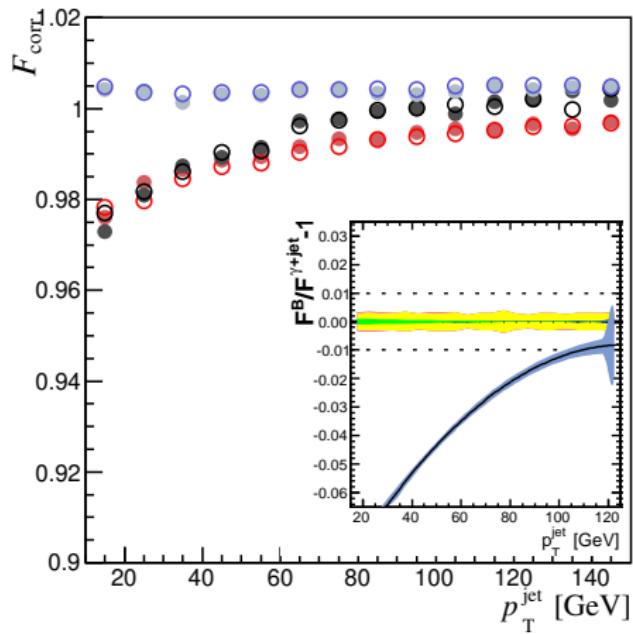


Our MC fitted to DØ data, $|\eta| < 0.4$

Run IIa



Run IIb



Concluding remarks

- We are able to reproduce DØ MC for IIa and IIb.
- Our fit to IIa data is in agreement with DØ.
- Reproducing the DØ IIb fit has turned out non-trivial.

Future plans

- Test FSR sensitivity with MPF method.
- Test hadronization sensitivity with HERWIG 7 and PYTHIA 8.

References

-  *Measurement of the top quark mass in the $t\bar{t} \rightarrow \text{lepton+jets}$ channel from $\sqrt{s}=8$ TeV ATLAS data.* Tech. rep. ATLAS-CONF-2017-071.
-  V.M. Abazov et al. "Jet energy scale determination in the DØ experiment". In: *Nucl. Instrum. Meth. A763* (2014). arXiv: 1312.6873 [hep-ex].
-  S. Atkins et al. "Correction For the MC-Data Difference in the Jet Response at DØ". In: *DØ note 6143* (2011).
-  K. Augsten and Z. Ye. "Correction For the MC-Data Difference in the Jet Response at DØ for Run IIB". In: *DØ note 6368* (2013).

Thanks for your attention!

Back-up

More details on SPR

Photon response

$$R_{\gamma}^{\text{MC}} = \frac{p_{\gamma}^{(0)}}{4} \left[1 + \text{Erf} \left(\frac{E + p_{\gamma}^{(1)}}{\sqrt{2}|p_{\gamma}^{(2)}|} \right) \right] \left[1 + \text{Erf} \left(\frac{E + p_{\gamma}^{(3)}}{\sqrt{2}|p_{\gamma}^{(4)}|} \right) \right] + p_{\gamma}^{(5)},$$

where

$$\text{Erf}(a) = \frac{2}{\sqrt{\pi}} \int_0^a e^{-x^2} dx.$$

Lepton response functions

Set $|\vec{p}_T^{\text{cut}}| = 0.3 \text{ GeV}$ for leptons.

$$R_{e^\pm}^{\text{MC}} = \theta(|\vec{p}_T| - |\vec{p}_T^{\text{cut}}|) \frac{p_{e^\pm}^{(0)}}{4} \left[1 + \text{Erf} \left(\frac{E + p_{e^\pm}^{(1)}}{\sqrt{2}|p_{e^\pm}^{(2)}|} \right) \right] \left[1 + \text{Erf} \left(\frac{E + p_{e^\pm}^{(3)}}{\sqrt{2}|p_{e^\pm}^{(4)}|} \right) \right],$$

$$R_{\mu^\pm}^{\text{MC}} = \theta(|\vec{p}_T| - |\vec{p}_T^{\text{cut}}|) \left(p_{\mu^\pm}^{(0)} + E \cdot p_{\mu^\pm}^{(1)} \right) \text{Landau} \left(E, p_{\mu^\pm}^{(2)}, p_{\mu^\pm}^{(3)} \right).$$

The probability density function of the Landau distribution is

$$\text{Landau}(x, \mu, \sigma) \equiv P_{\text{Landau}}((x - \mu)/\sigma) = \frac{1}{2\pi i} \int_{a-i\infty}^{a+i\infty} e^{s(x-\mu)/\sigma + \ln(s)} ds$$

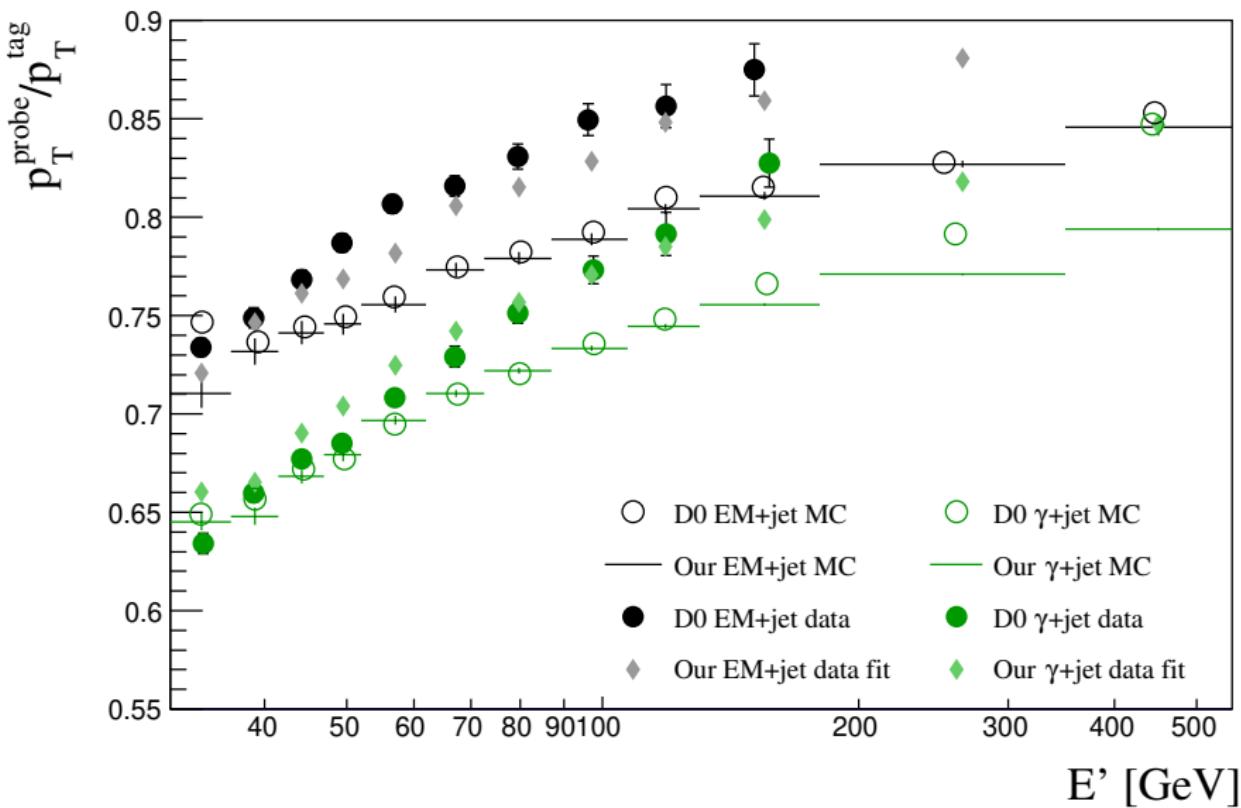
for any $a \in \mathbb{R}_+$.

Other particles

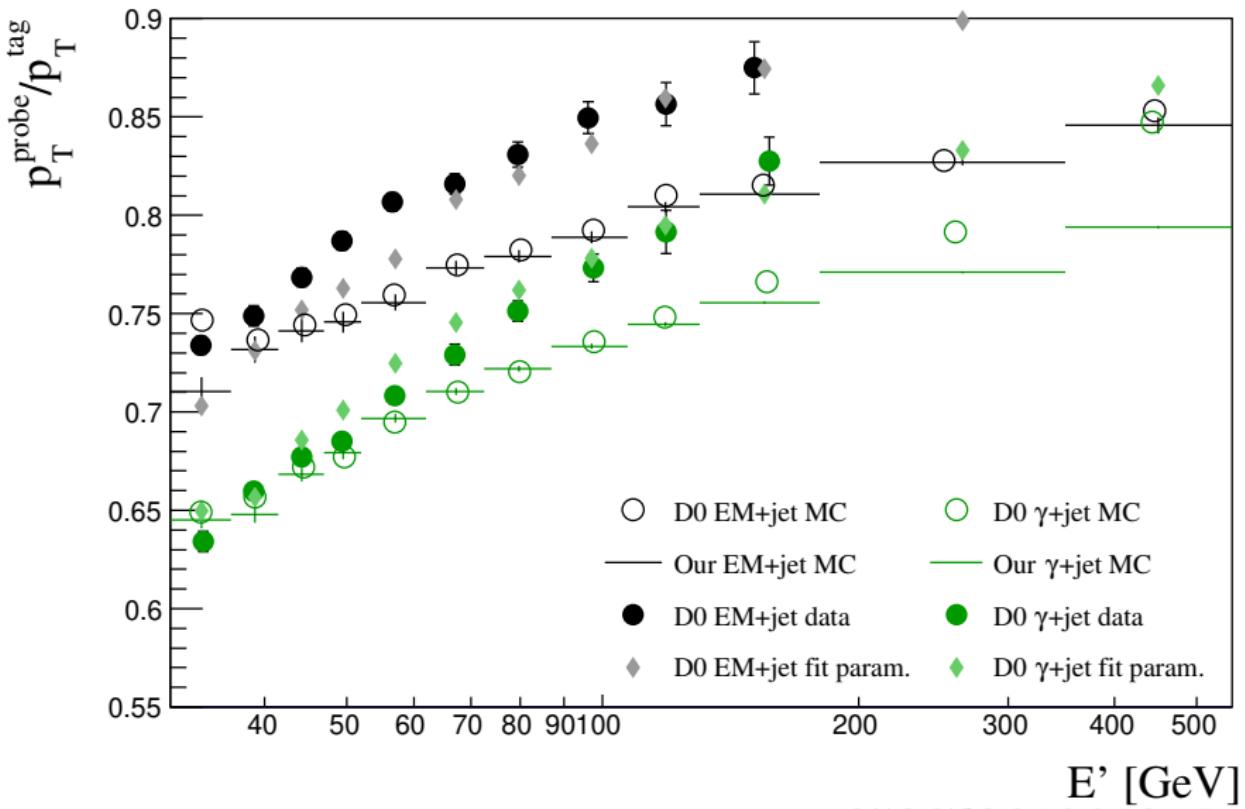
- $R_\nu^{\text{MC}} = R_\nu^{\text{data}} = 0$.
- At $c\tau = 10$ mm, PYTHIA 6 produces also Ξ , Σ and Ω .
- The DØ JES paper [2] mentions Ξ and Σ , but the analysis notes [3, 4, 2] do not present responses for them.
- Neglecting strange hadrons (sh) at $c\tau = 10$ mm doesn't reproduce DØ MC, so we need something.
 - An Ansatz based on π response, incorporate mass dependency by demanding $R^{\text{MC}}(E = m_{sh}) = 0$. This yields

$$p_{sh}^{(1)} = (4m_{sh}/3)^{1-p_\pi^{(2)}}.$$

Reminder: our MC fitted to DØ data: IIb, $|\eta| < 0.4$

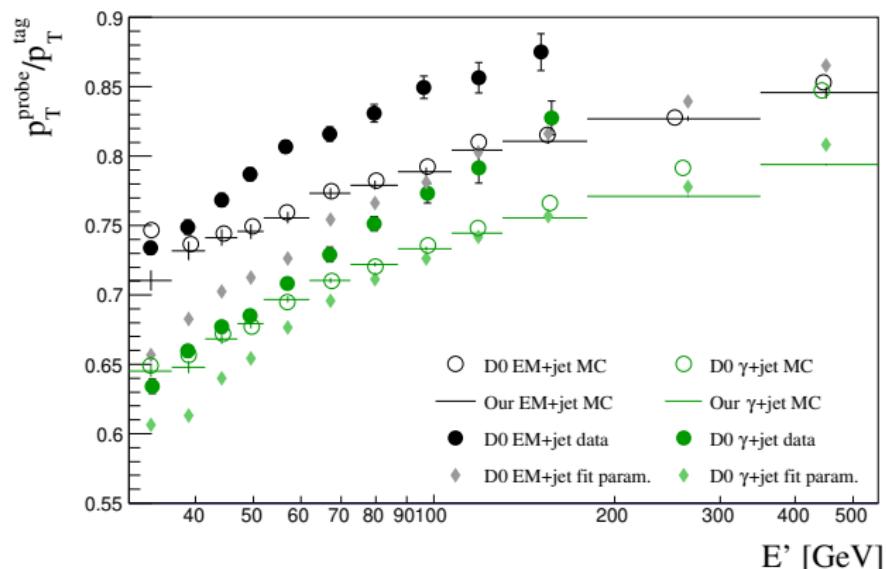


Reminder: our MC & DØ fit param.s: IIb, $|\eta| < 0.4$



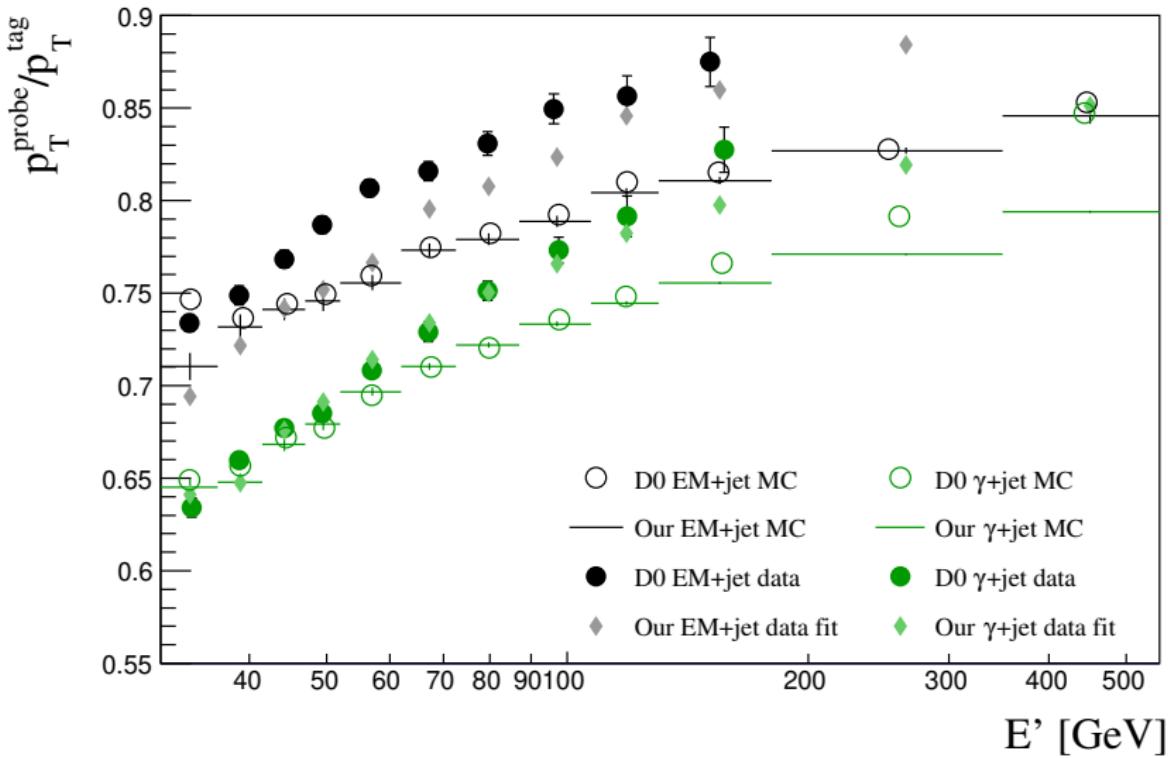
Necessity of run IIb tag correction

Example: Our MC (DØ run II cone) and DØ fit parameters, without correcting for the IIa-IIb R_γ difference:

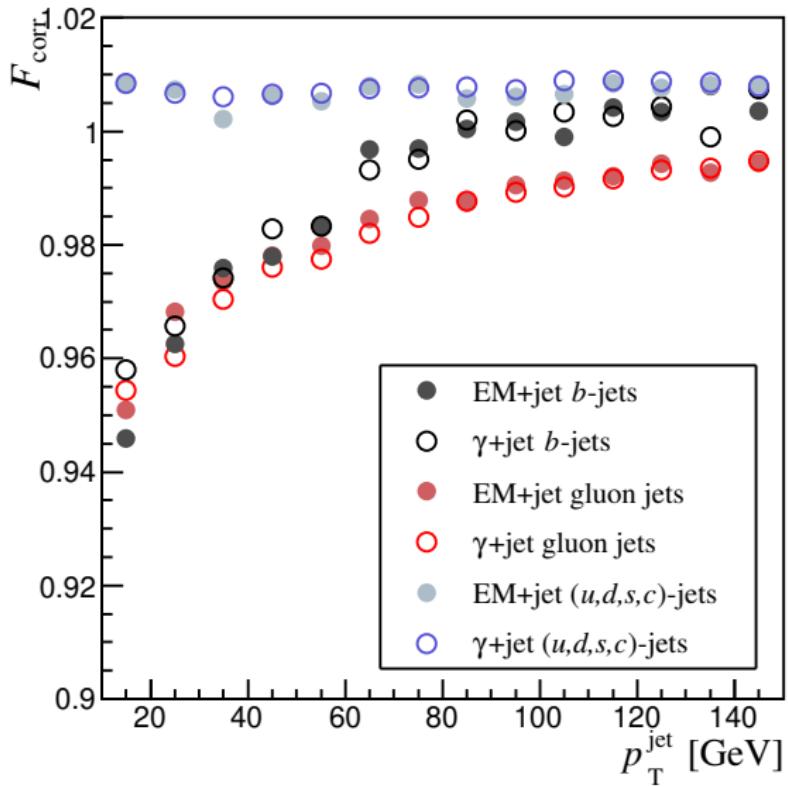


Fit histogram wont overlap data unless tag energy scale is shifted, despite MC similarity.

Our MC fitted to DØ γ +jet data only: IIb, $|\eta| < 0.4$



Our MC fitted to DØ γ +jet data only: IIb, $|\eta| < 0.4$



Work-in-progress: HERWIG 7

