Boosted objects in heavy-ion physics: a powerful probe of QGP

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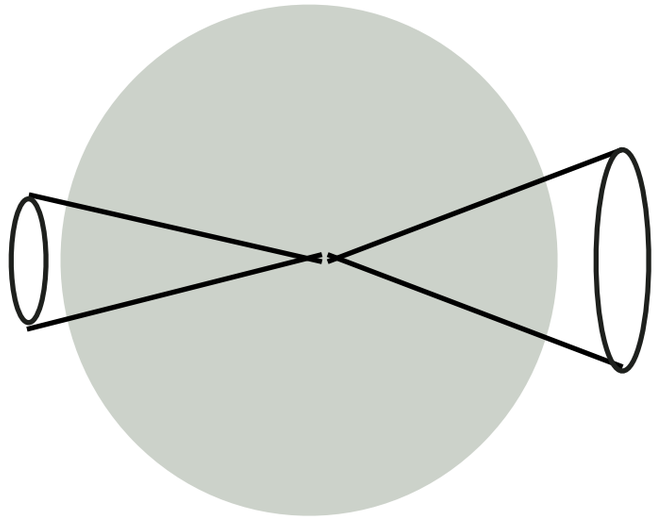
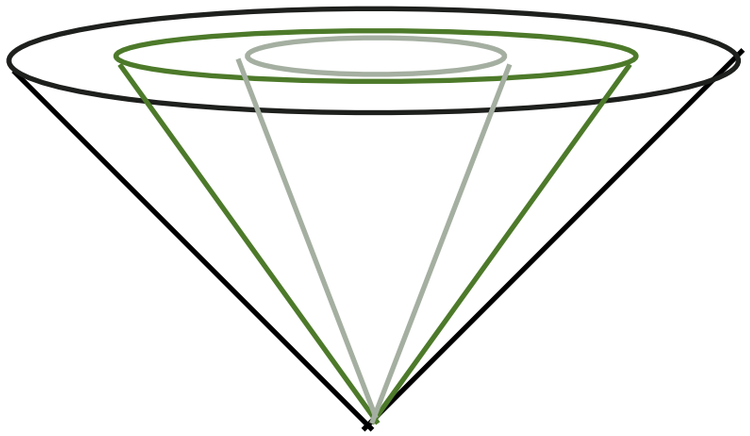
HIC Probes: Road so far…

- What we measured so far? What properties can we assess?
  - Jet R_{AA}, Jet energy loss (dijets, Z/Jet, photon/Jet), Missing p_T, …
    - Average behaviours of in-medium showering, possible path-length dependence, amount of back-reaction (?)…
- Intra-Jet observables (Jet Shapes, Splitting Functions - Marta's Talk, …)
  - Intrinsic properties of QCD in the presence of hot and dense medium (Yacine's Talk)





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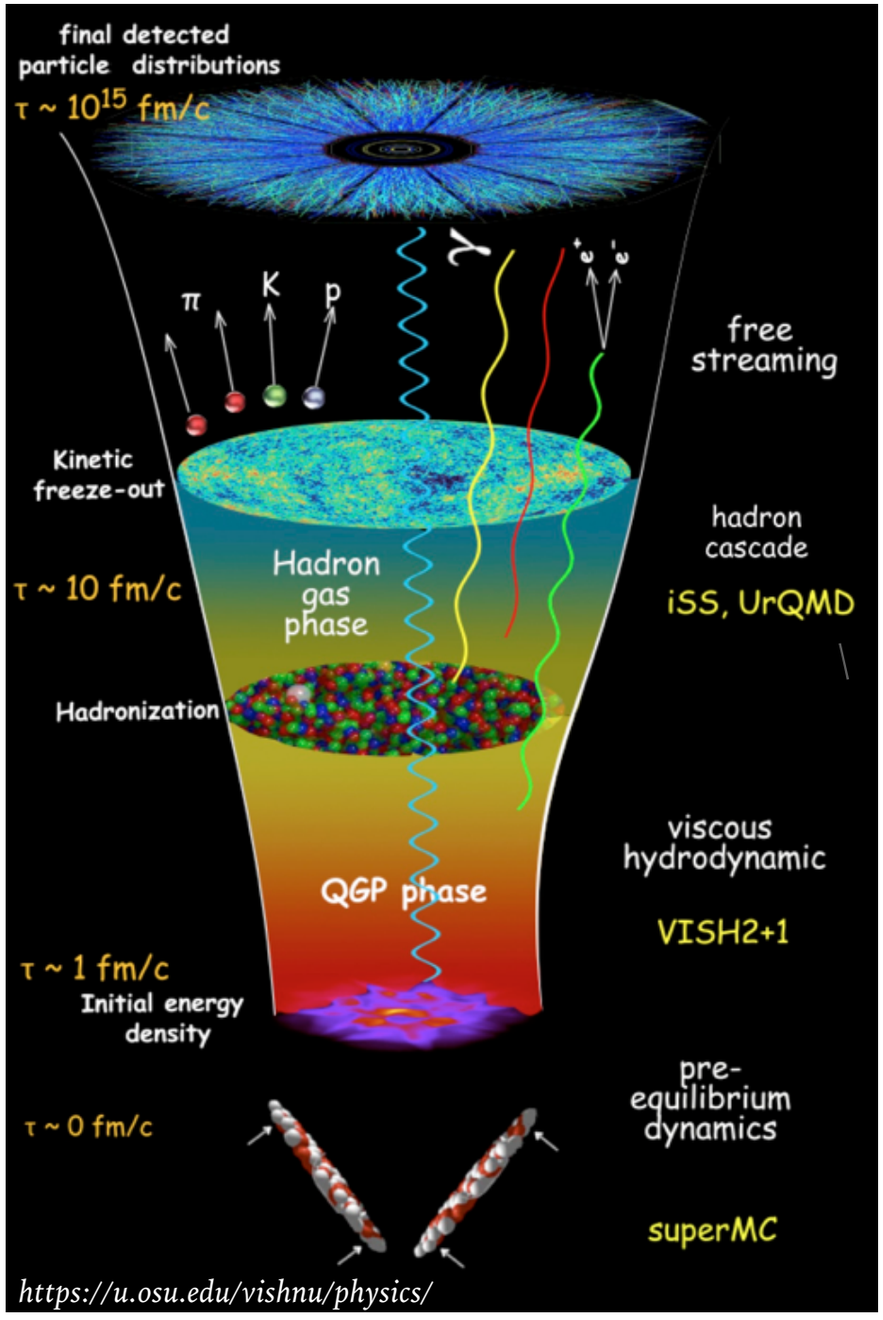
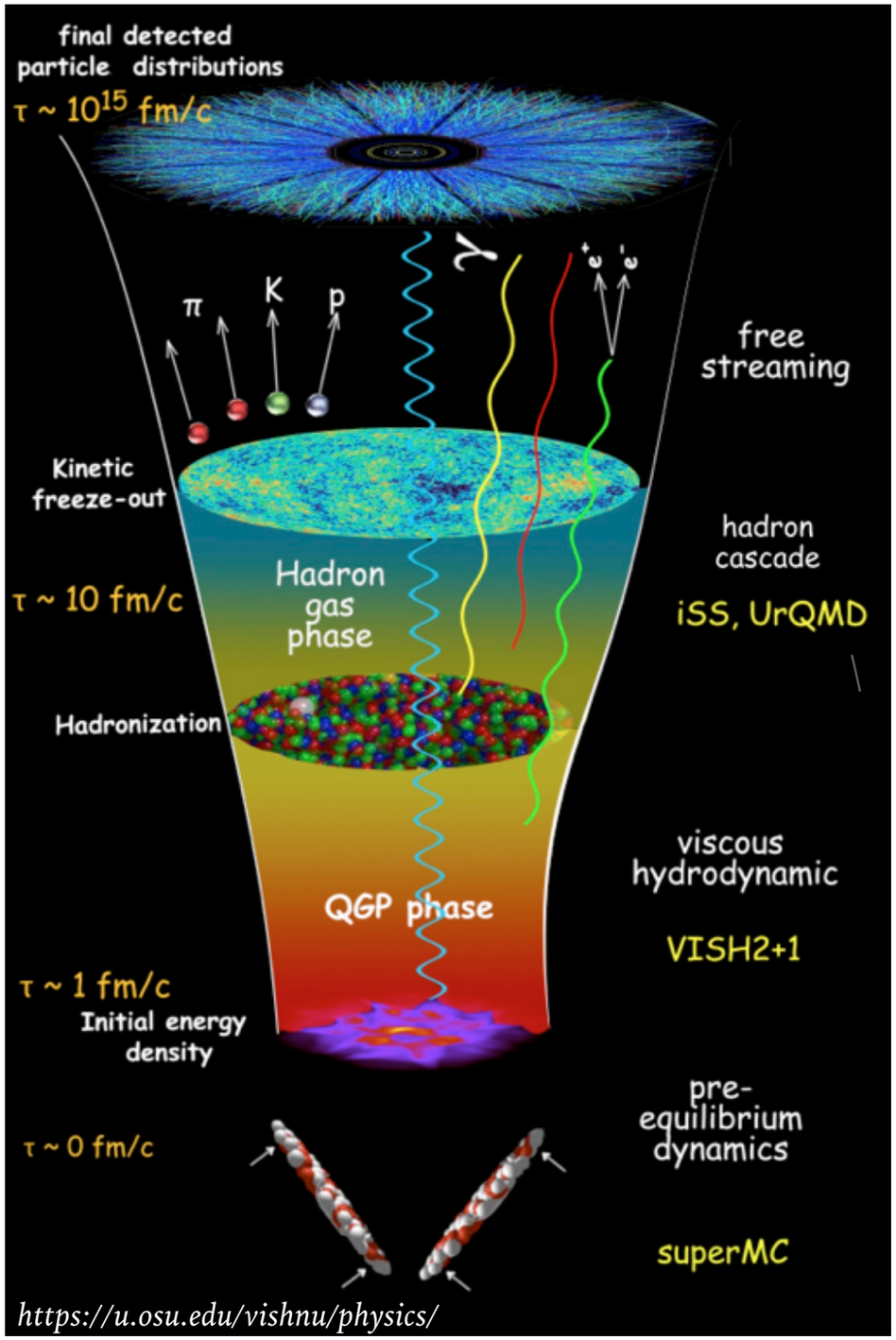


All of them are the integrated result over the whole medium evolution…

QGP Time Evolution

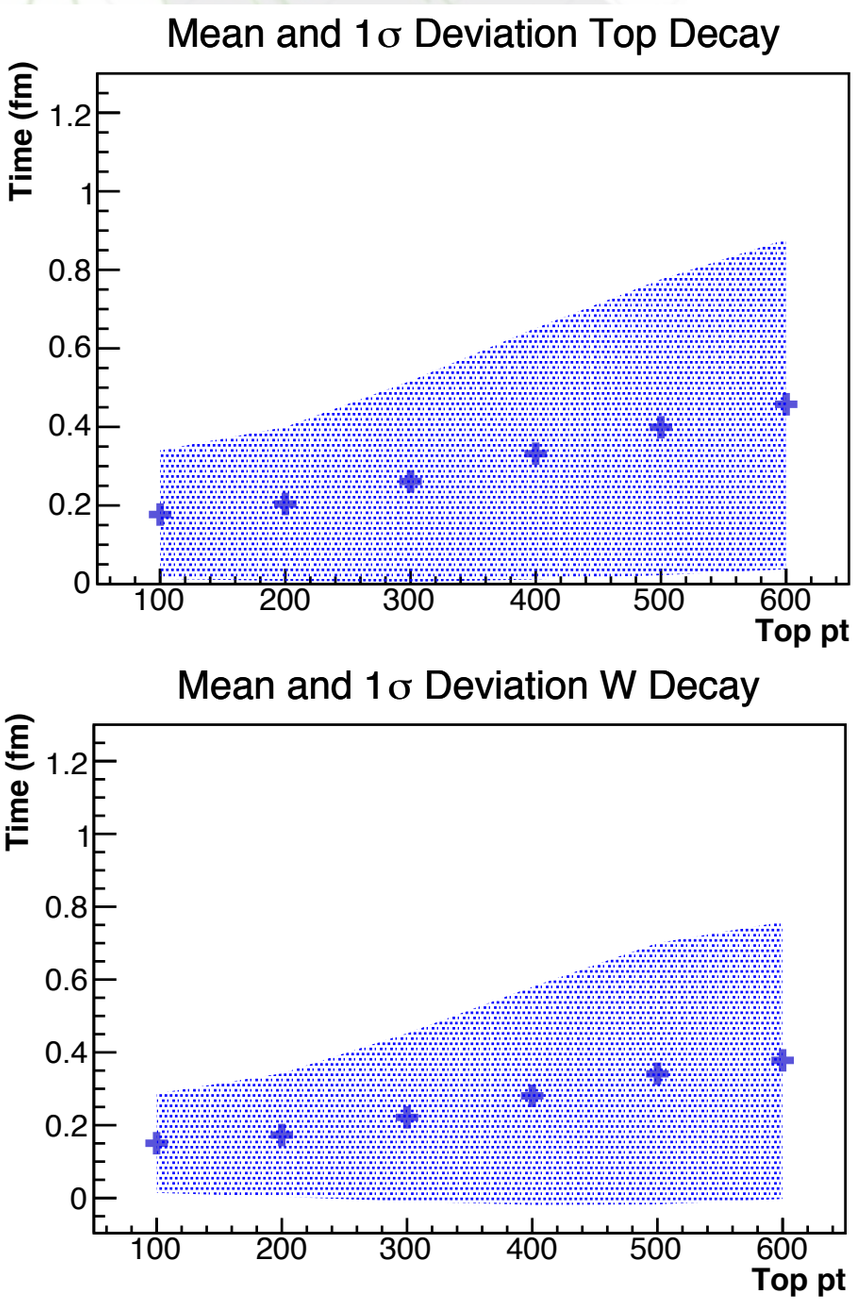
- Is it possible to assess different time intervals of the medium evolution?
  - Using sources of QCD particles that are delayed in time:
    - $t + \bar{t} \rightarrow b + \bar{b} + W^+ + W^- \rightarrow q + \bar{q} + \nu + \mu$
      - Hadronic W boson: probe of the medium
      - Leptonic W boson: tagging
- Top lifetime at rest: ~0.15 fm/c
- W boson lifetime at rest: ~0.10 fm/c



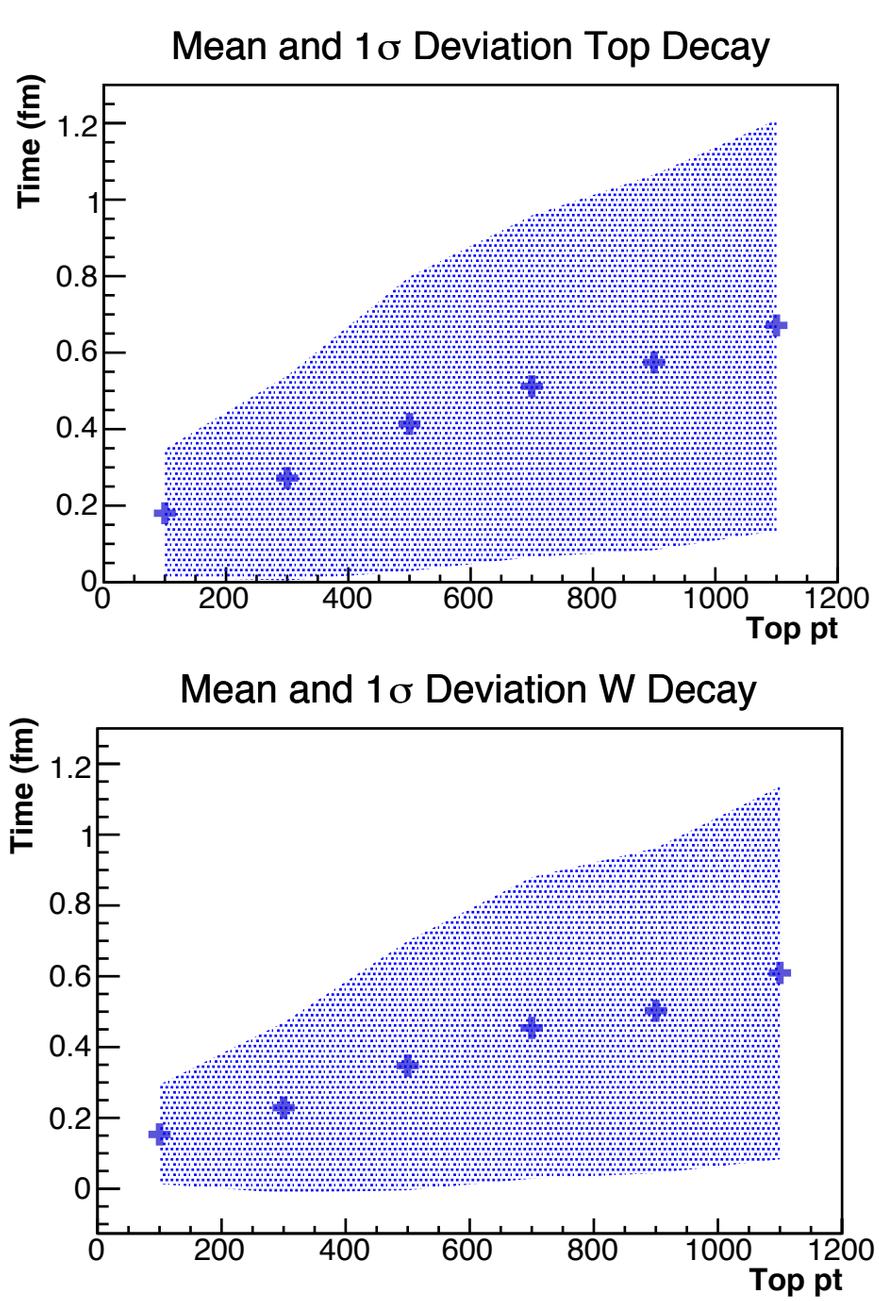
QGP Time Evolution

- LHC (5.5 TeV) and FCC (39 TeV) centre-of-mass energies large enough to probe different timescales as a function of the probe p_T:

LHC

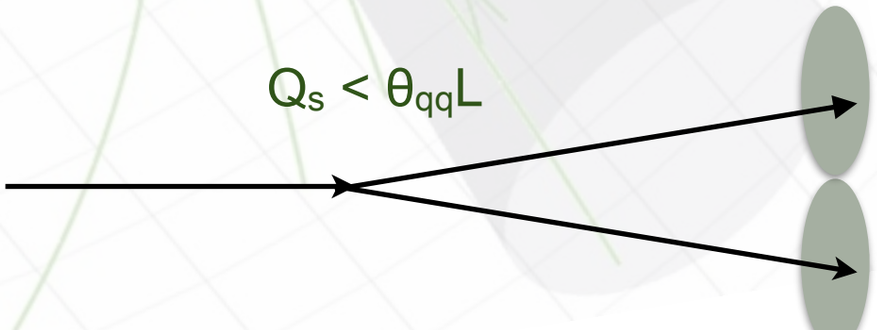


FCC

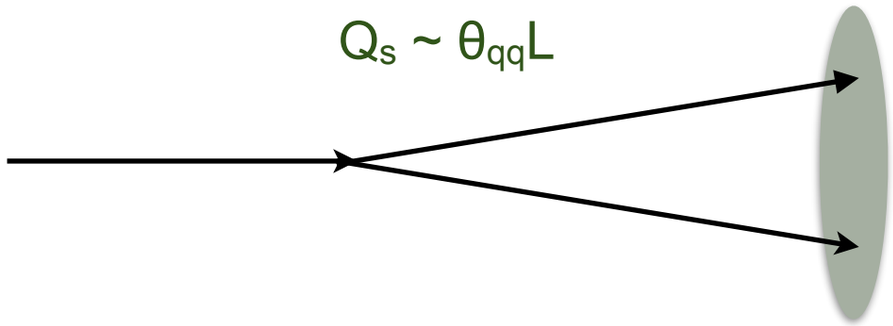


Jet Quenching

- Moreover, W boson hadronic decay is the natural setup to study coherence effects:



Medium able to “see” both particles
Color correlation is broken
Both particle emit independently



Medium “sees” both particles as one single emitter
Particles emit coherently

Saturation scale:

$$Q_s^2 = \hat{q}\, L$$

Transport coefficient: $\hat{q}$
Medium length: L

Mehtar-Tani, Salgado, Tywoniuk (2010-2011)
Casalderrey-Solana, Iancu (2011)

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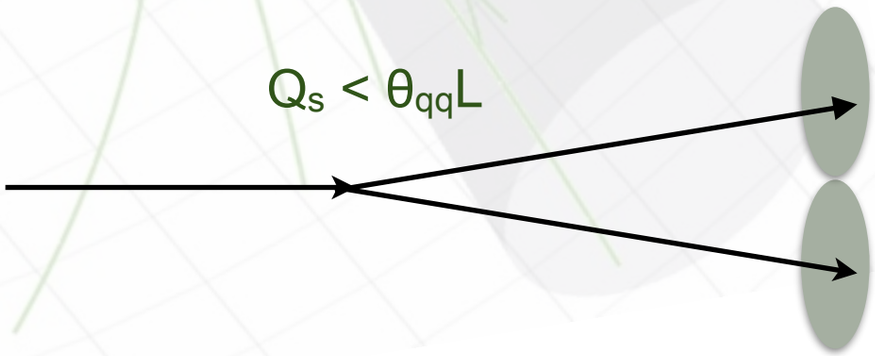

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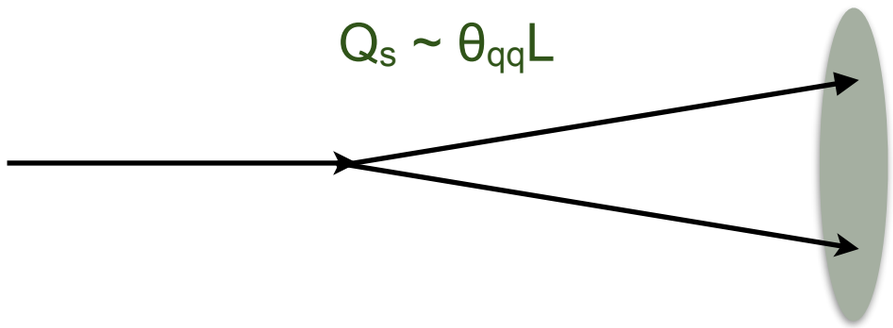

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Saturation scale:

$$Q_s^2 = \hat{q}\, L$$

Transport coefficient: $\hat{q}$
Medium length: L

- Increase even more the time delay allowing to have a complete mapping of the QGP evolution:
  - Stay in colourless singlet state during: $t_d = \left(\frac{3}{\hat{q}\theta_{q\bar{q}}^2} \right)^{1/3}$

Mehtar-Tani, Salgado, Tywoniuk (2010-2011)
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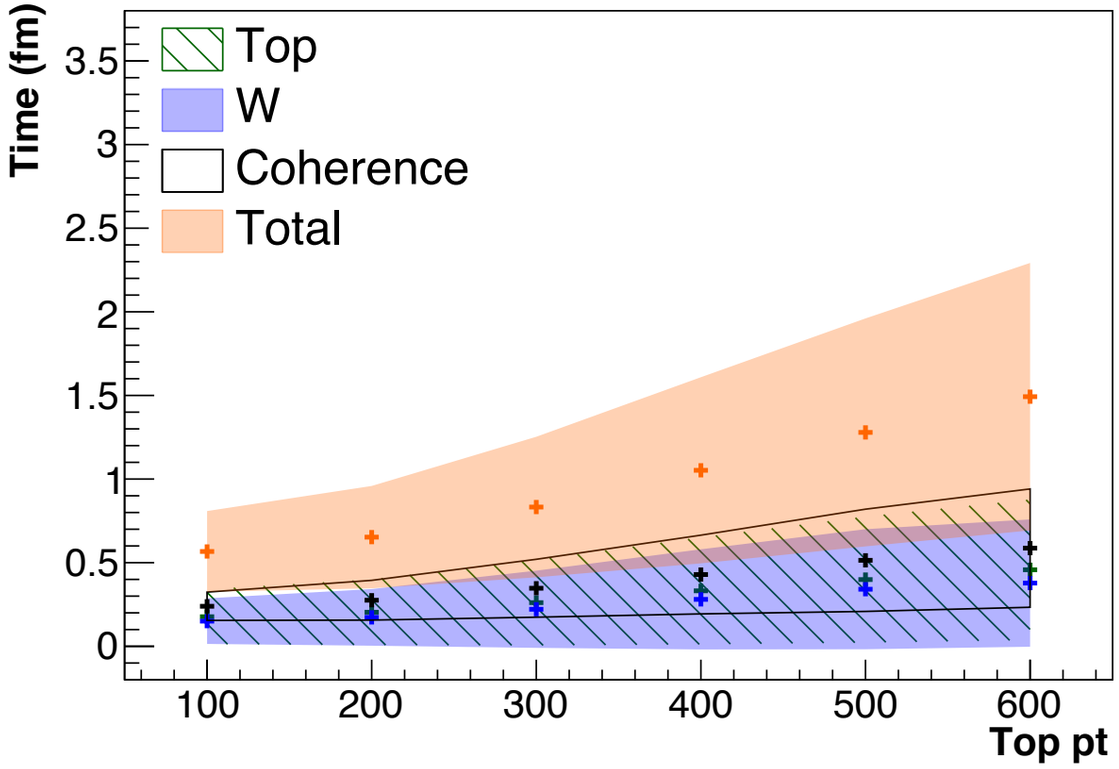
Available Time Scales

- Total delay time:
  - Boosted top lifetime + Boosted W lifetime + Decoherence Time

LHC

Decay Times



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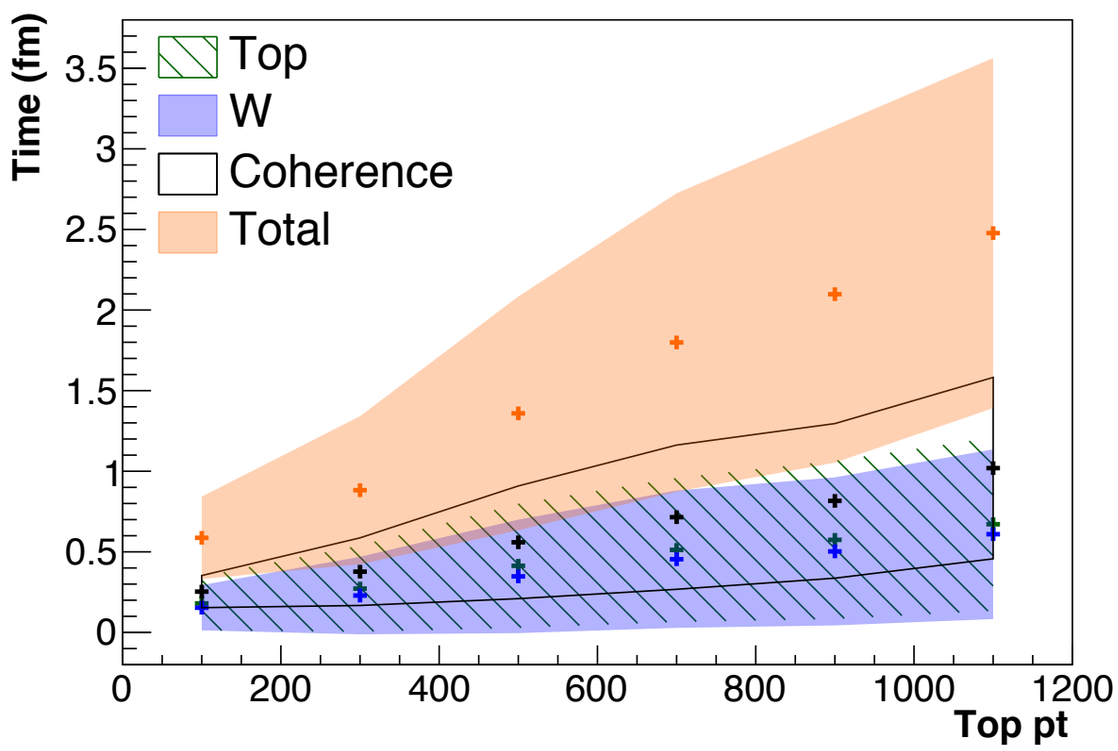

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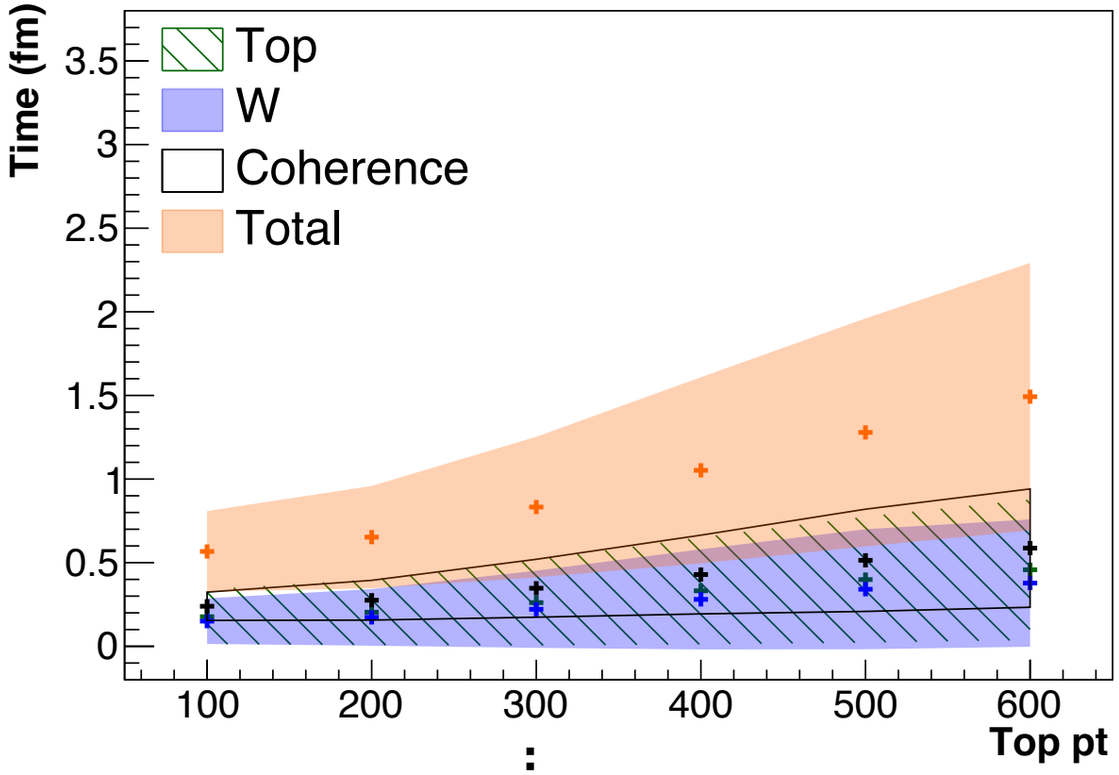
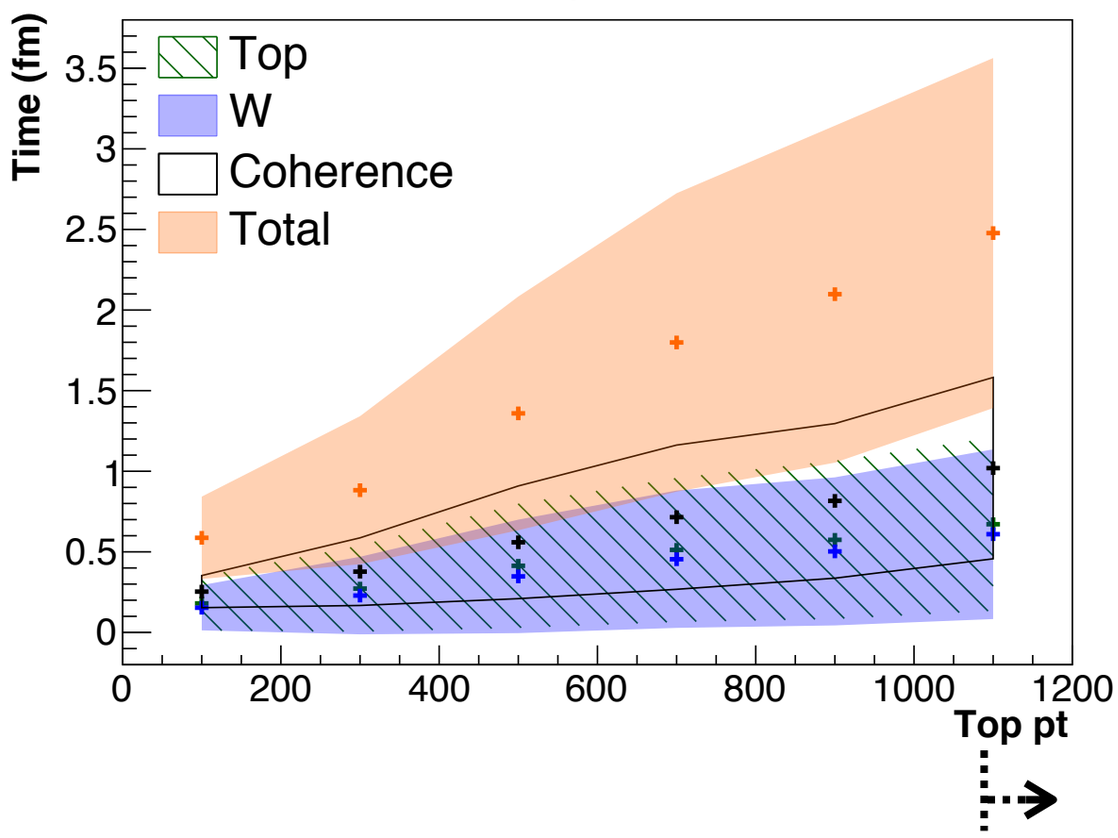


Not enough statistics…

Probe ~ [0.4; 1.2] fm

FCC

Decay Times



Probe ~ [0.5; 3.5] fm

Simple analysis to make a proof of principle

Simulation Parameters

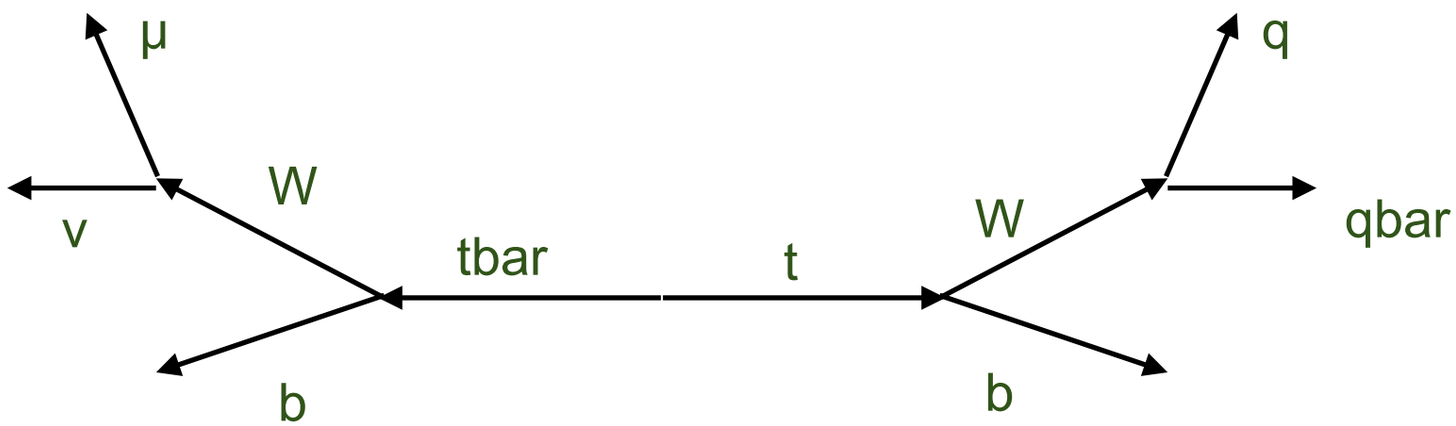
- POWHEG (hard event) + PYTHIA 8 (parton shower)

LHC - HL	FCC
5.5 TeV/nucleon	39 TeV/nucleon
L_{int} = 10 nb^{-1}	L_{int} = 30 nb^{-1}
A = 208 (Pb)	A = 208 (Pb)
0-10% centrality class (~42% of ttbar events)	0-10% centrality class (~42% of ttbar events)

No HI background.
No detector effects.

Jet Reconstruction

- Event with at least:
  - 1 (isolated) muon, p_T > 25 GeV, |η| < 2.5.
  - 2 b jets (assumed 70% efficiency)
  - >= 2 non-b jets



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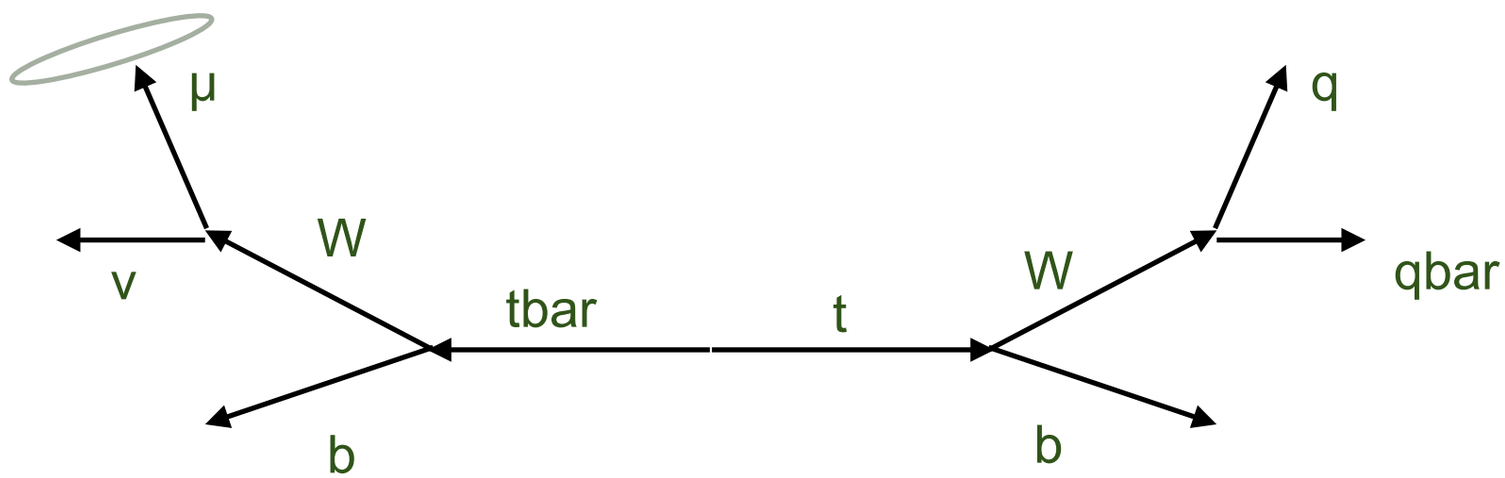

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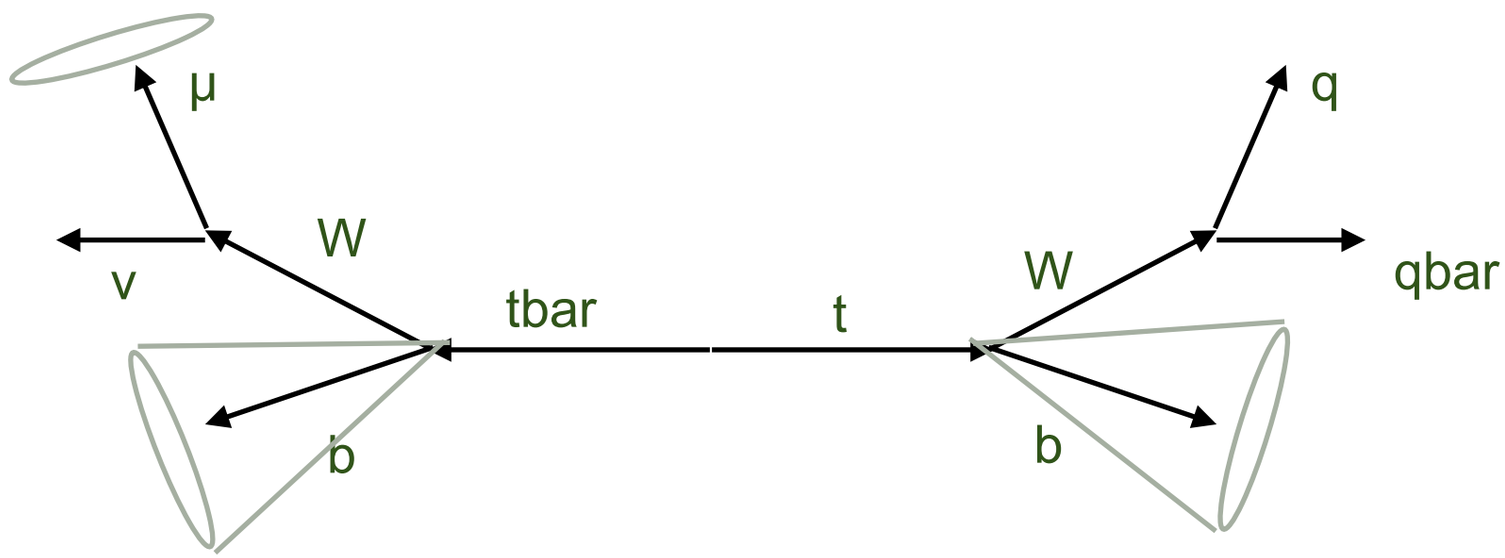

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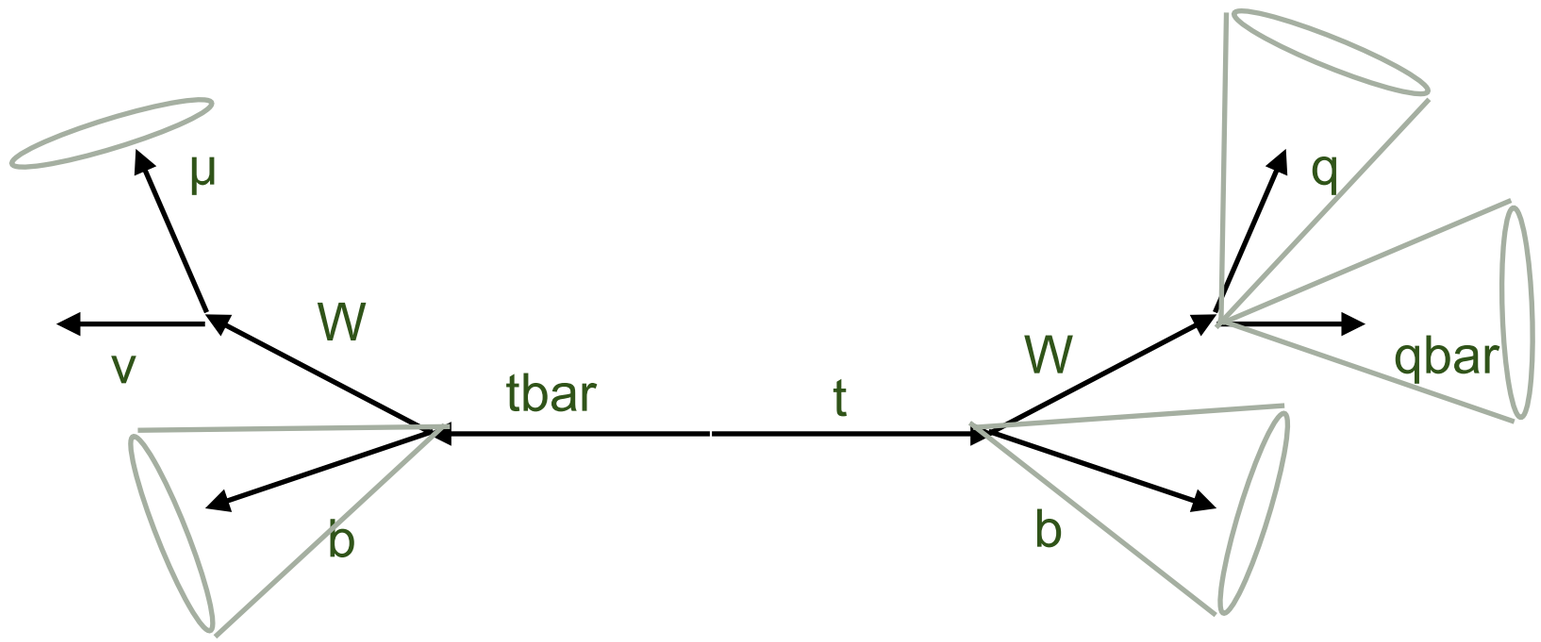

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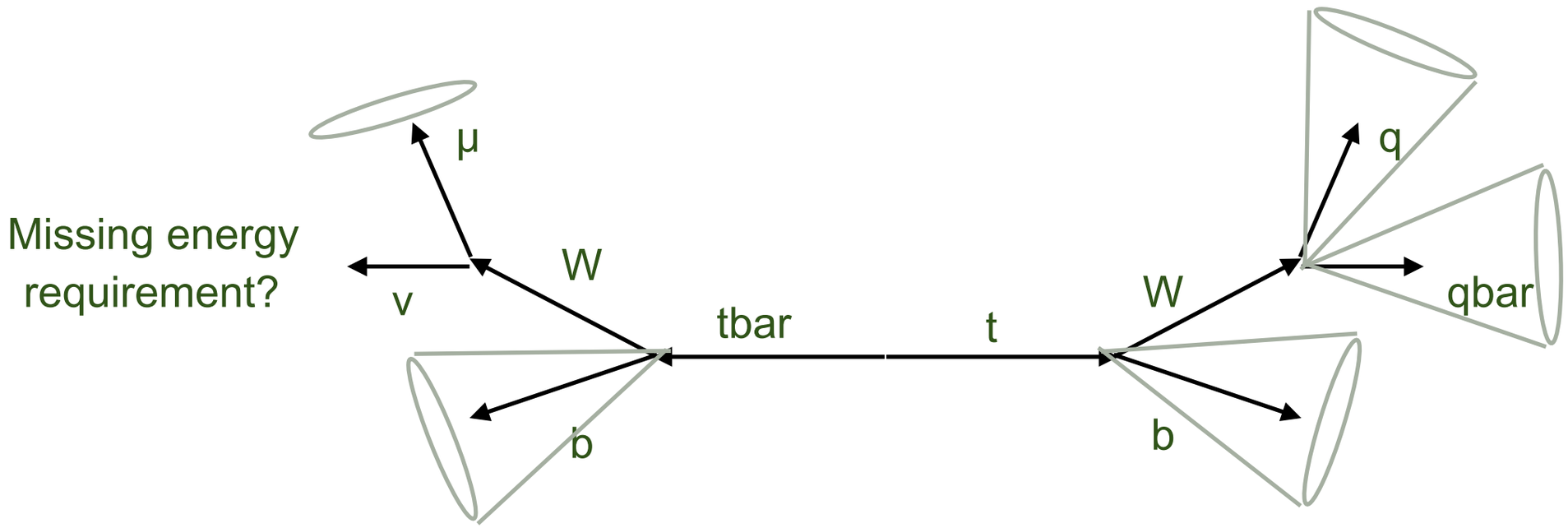
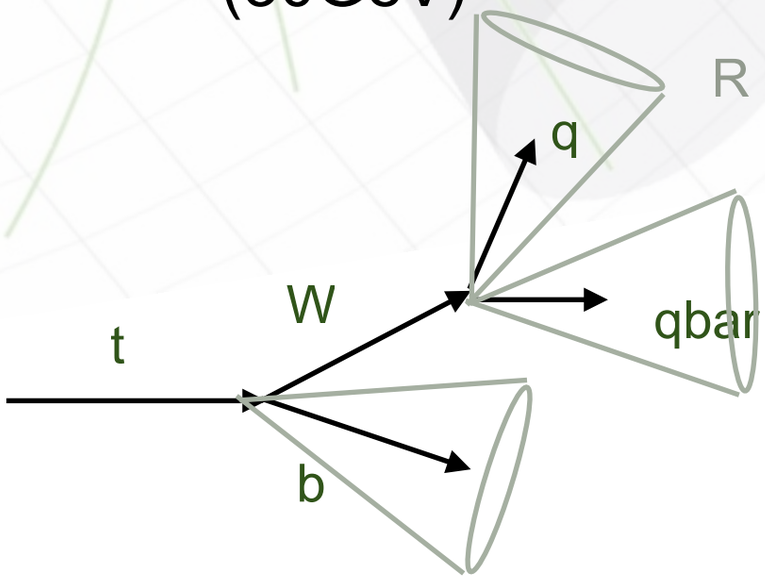


Jet Reconstruction

- Anti-k_T jets with R = 0.3, p_T > 30 GeV, |η| < 2.5.
  - Recluster with k_T algorithm, R = 1.0 and decluster with dcut = $(30GeV)^2$



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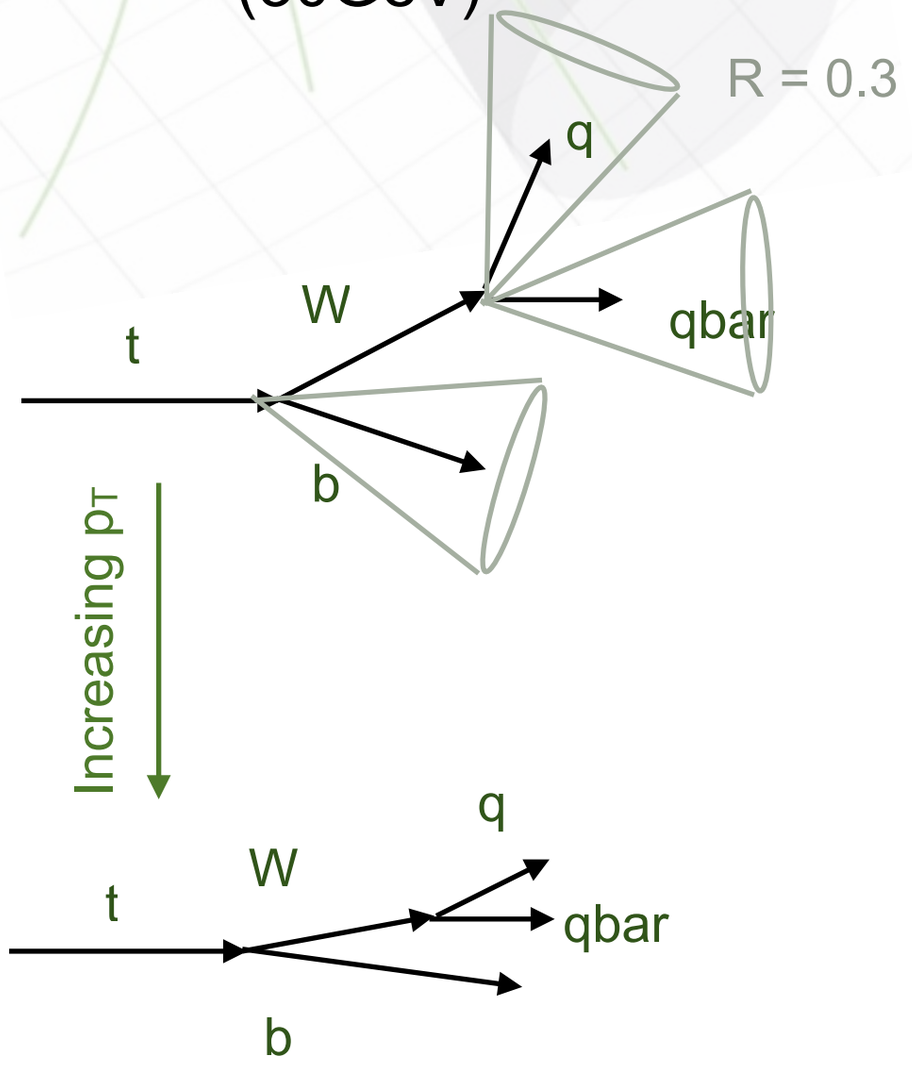

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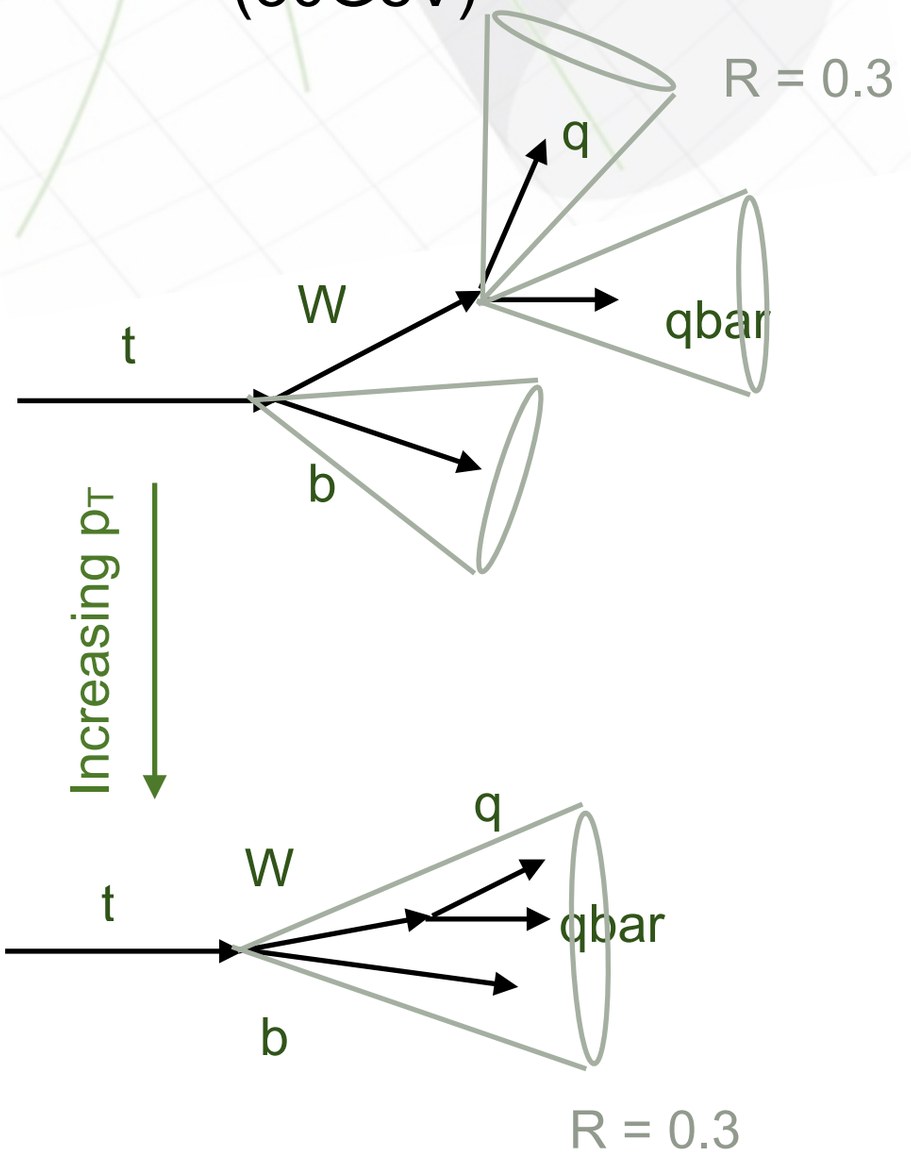

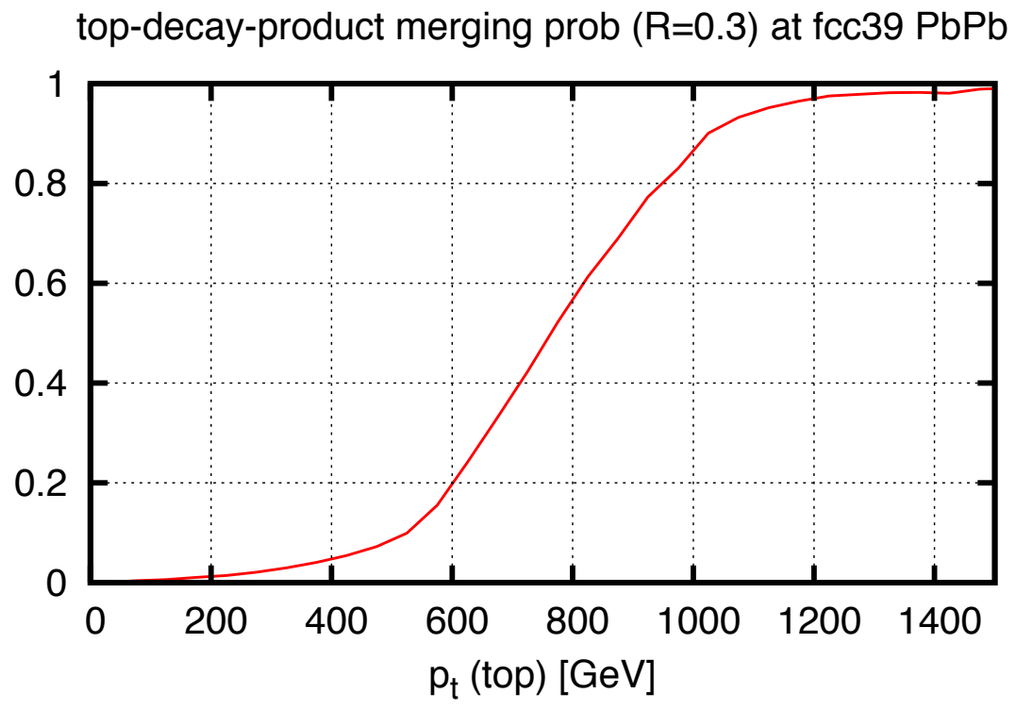

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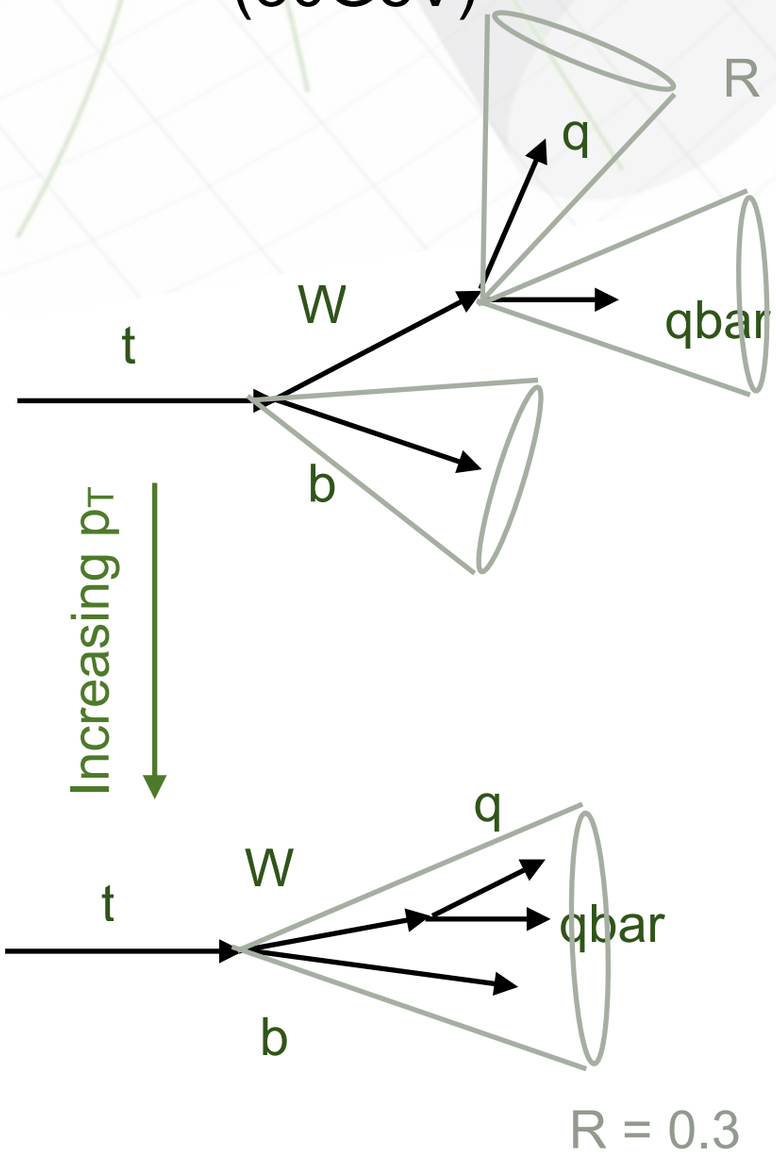

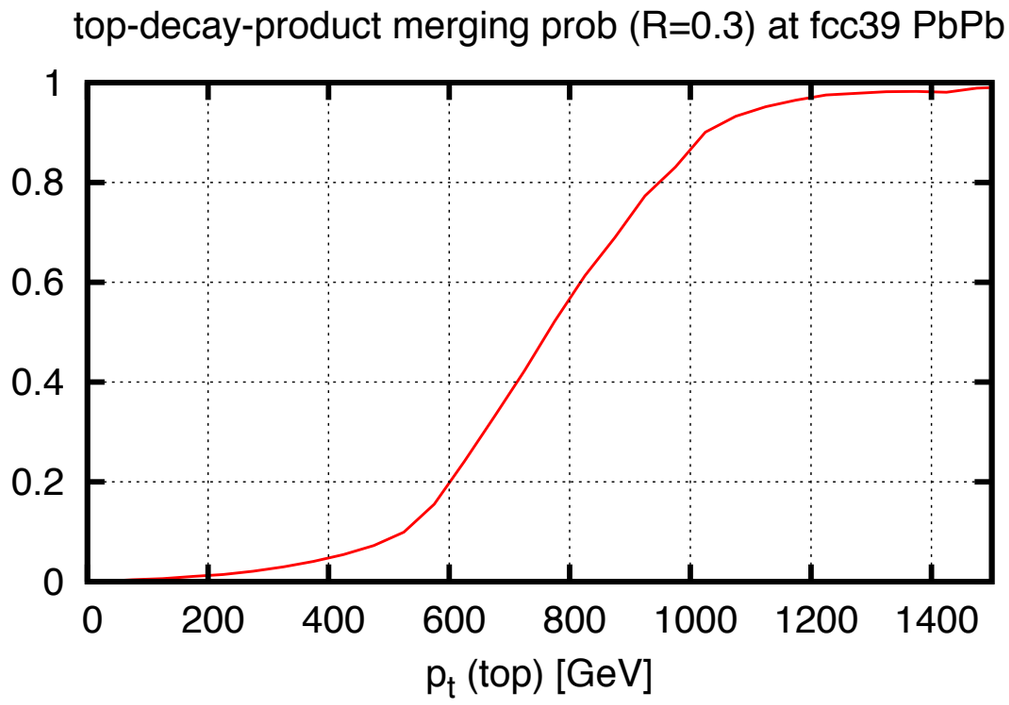

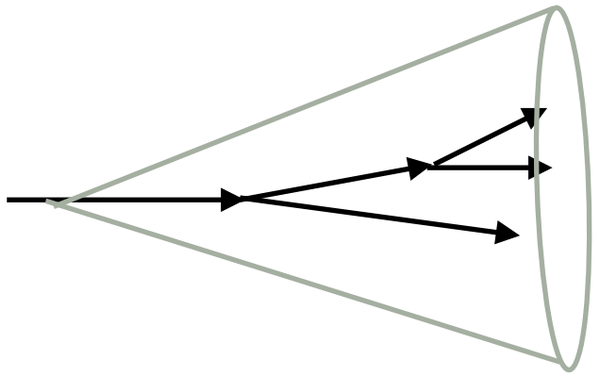

Reclusters with larger R and find sub-jets with $p_{T,rel}$ > $\sqrt{(d_{cut})}$

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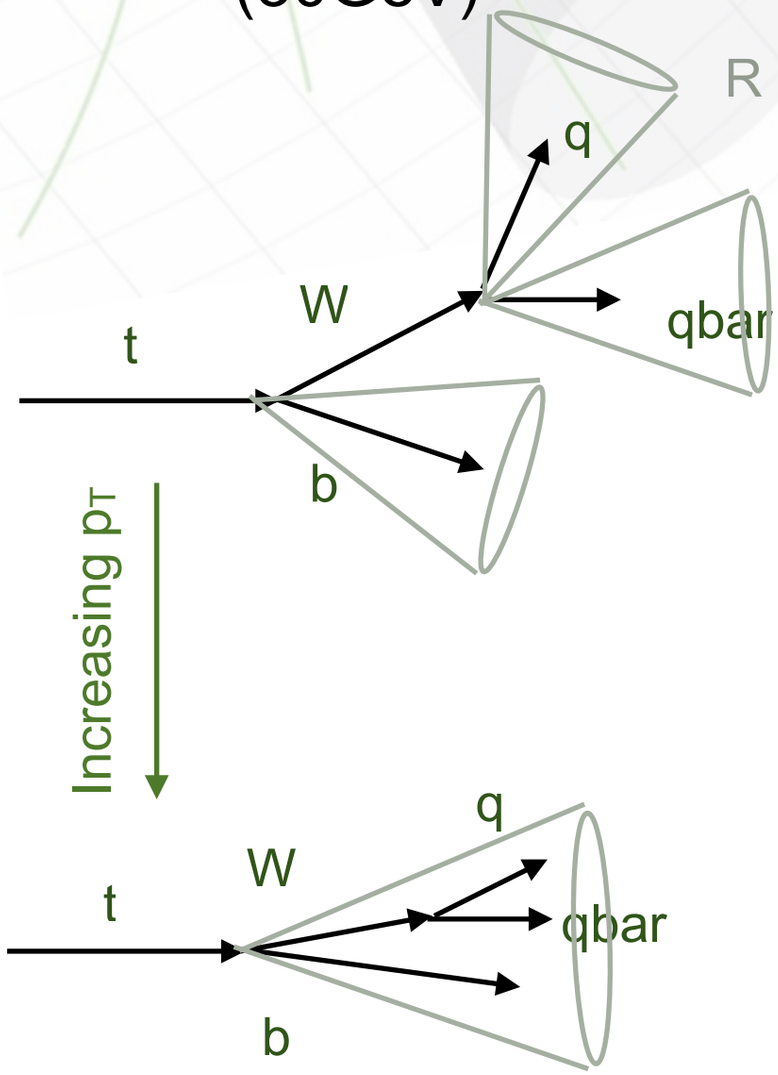
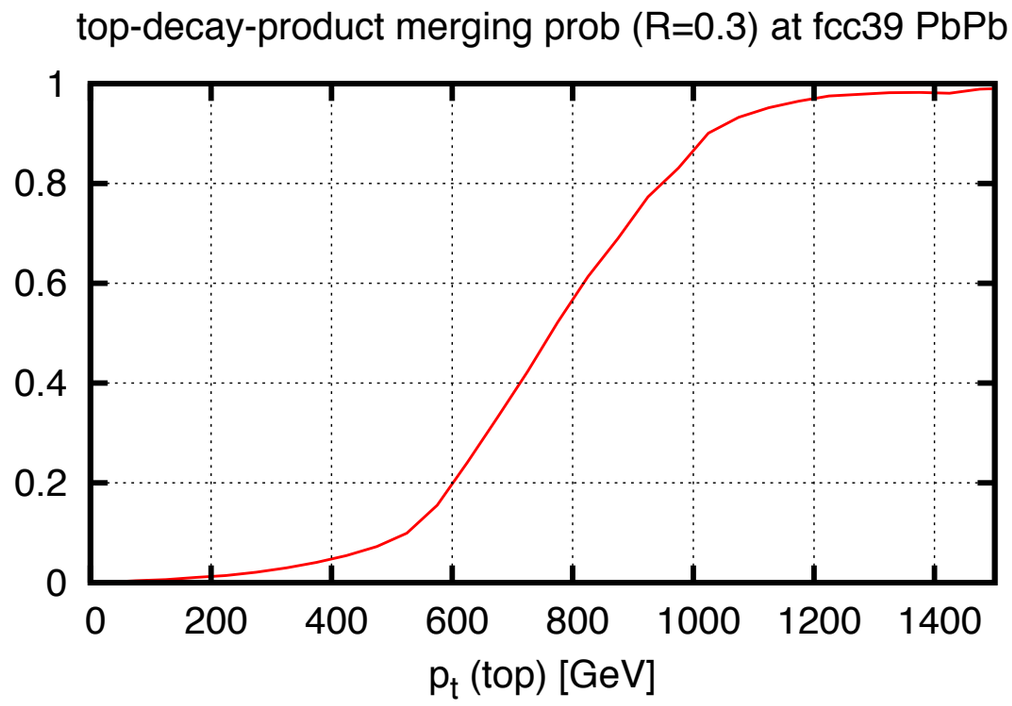
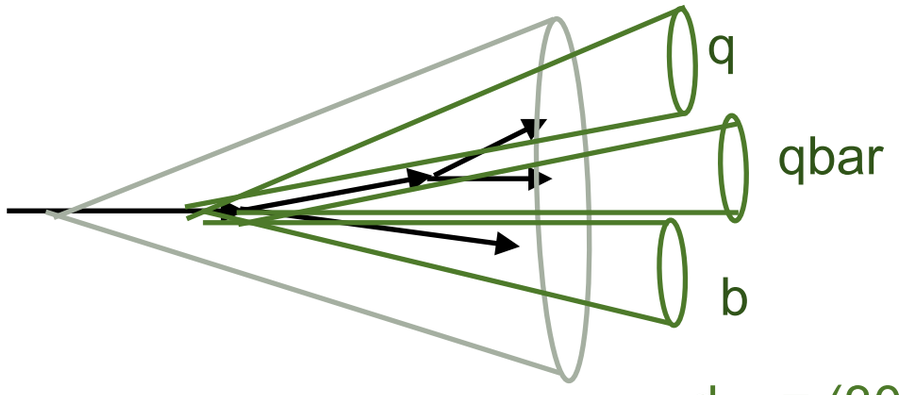




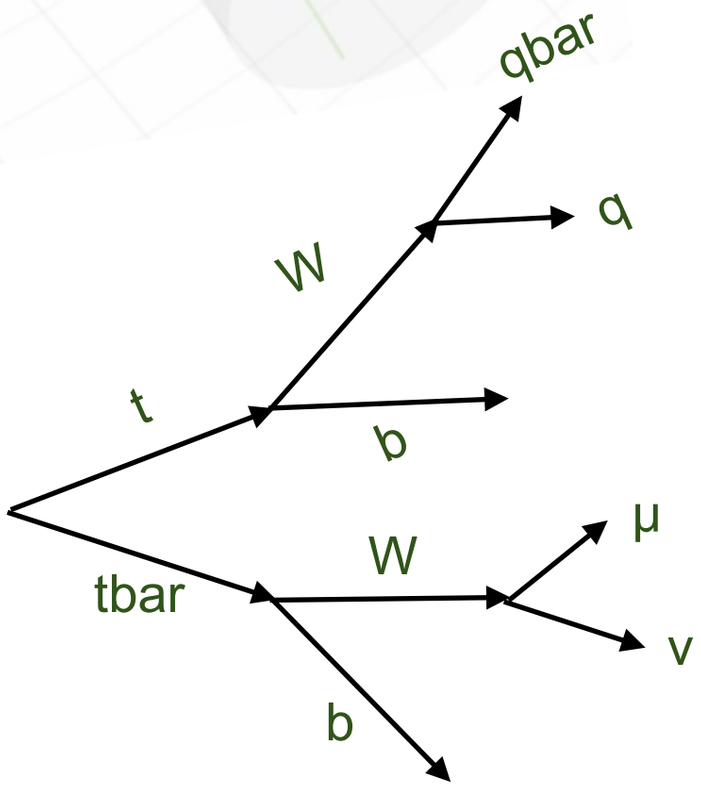


$d_{cut} = (30GeV)^2$

Reclusters with larger R and find sub-jets with $p_{T,rel} > \sqrt{(d_{cut})}$

Jet Reconstruction

- W jets are taken to be the 2 highest-p_T non-b jets.
- “Muonic” top is reconstructed assuming b-jet closest to muon (ATLAS 1502.05923).



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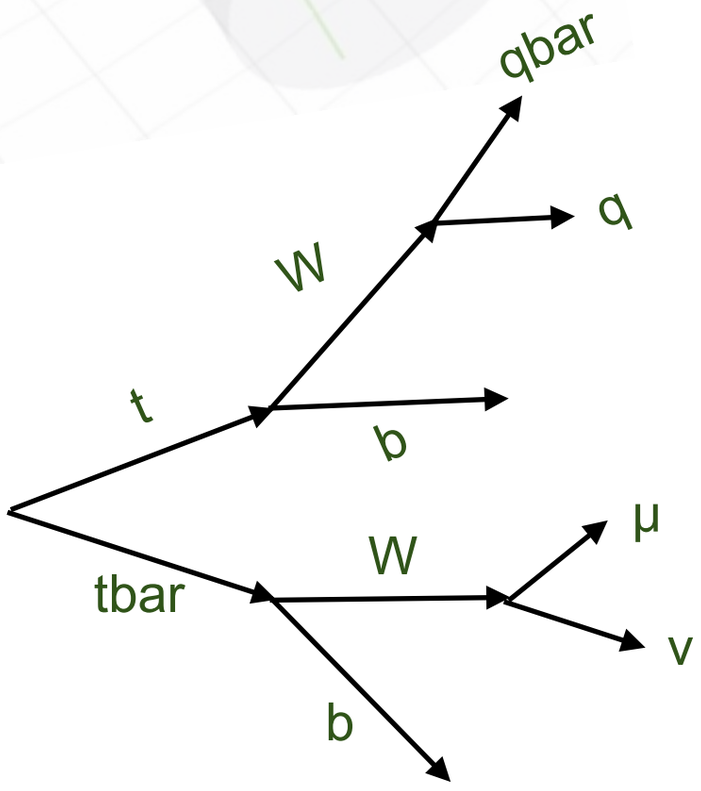

Top reconstructed with the wrong b-jet

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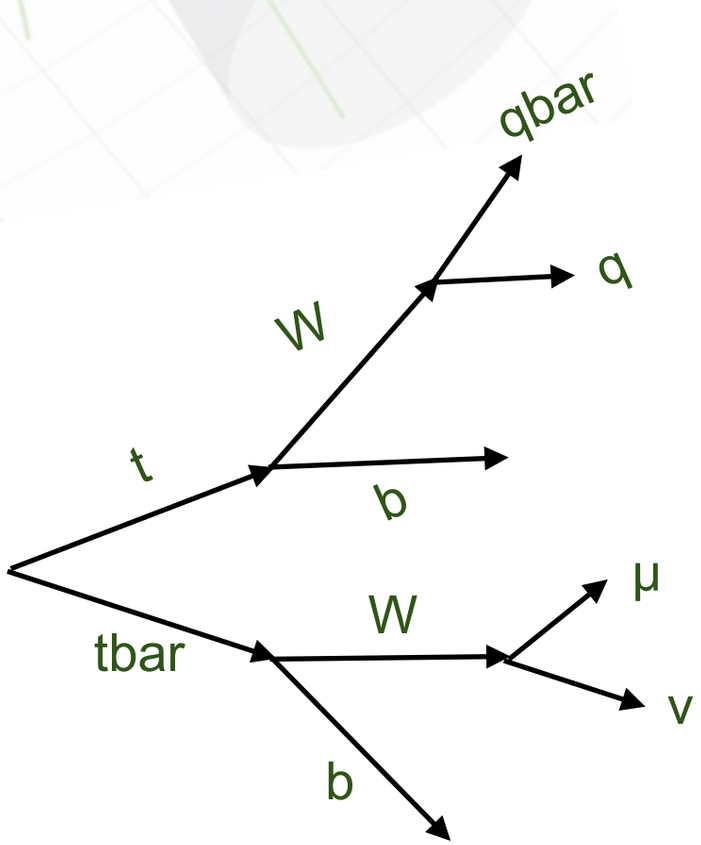
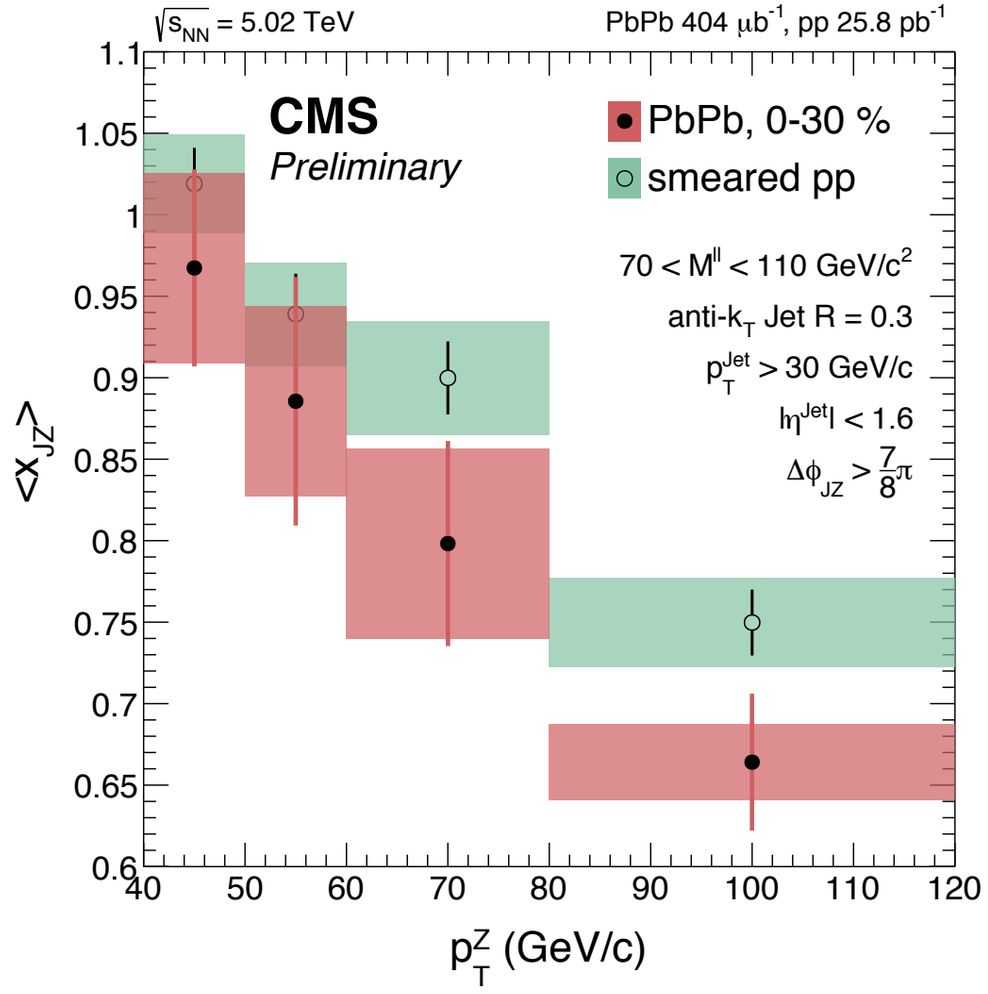


Top reconstructed with the right b-jet

Jet Quenching Model

- Very simplistic picture of jet quenching:
  - Z + Jet: Delta p_T in [5-10%] (low p_T) to [10-15%] (high p_T)
  - Our attempt: 10% of energy loss to all colourful partons

CMS-PAS-HIN-15-013
(Average momentum imbalance Z + Jet)

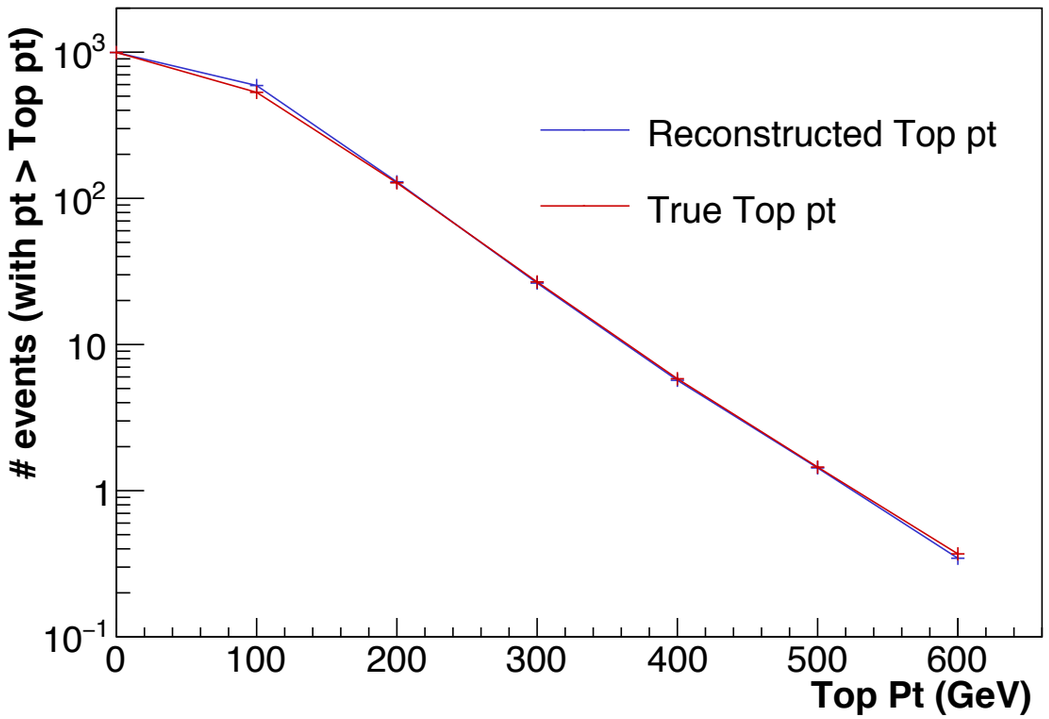


Cross-section

- Total cross-sections compatible with NLO CT14 calculations:
  - $\sigma_{ttbar \rightarrow qqbar + \mu\nu}$ ~ 10 pb (LHC) and 1 nb (FCC)

LHC - HL

Expected number of Reconstructed Top Events



Can go up to p_T ~ 300 GeV

Limited probe: [0.4; 2.4] fm → [0.4; 1.2] fm

FCC

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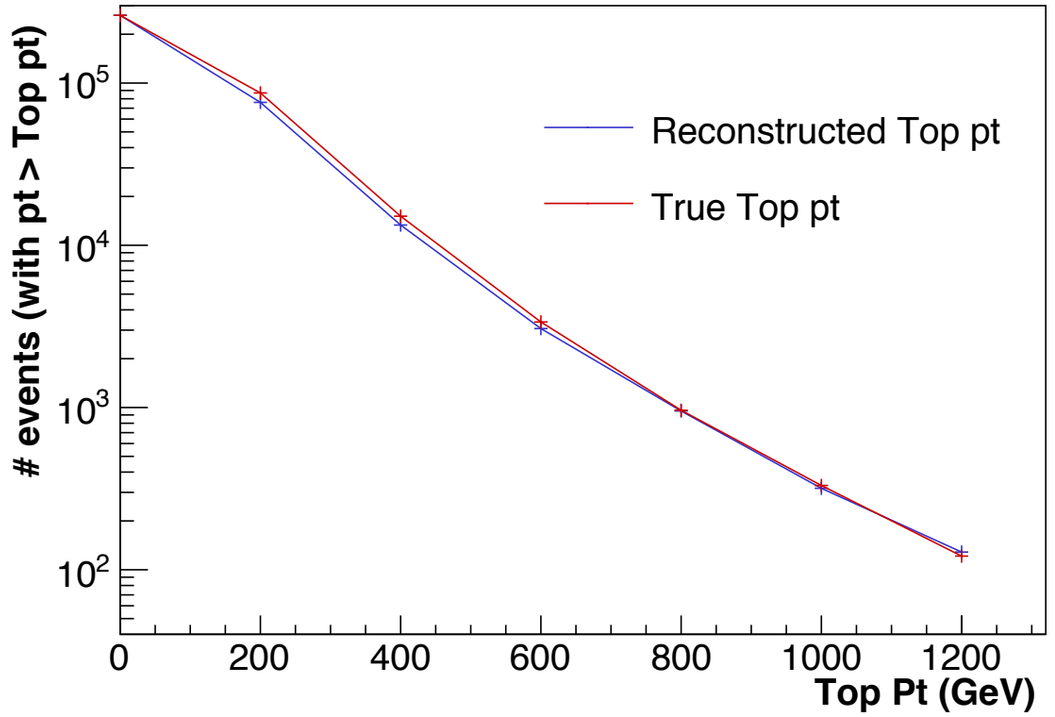

Can go up to p_T ~ 1000 GeV

Probe: [0.5; 3.5] fm

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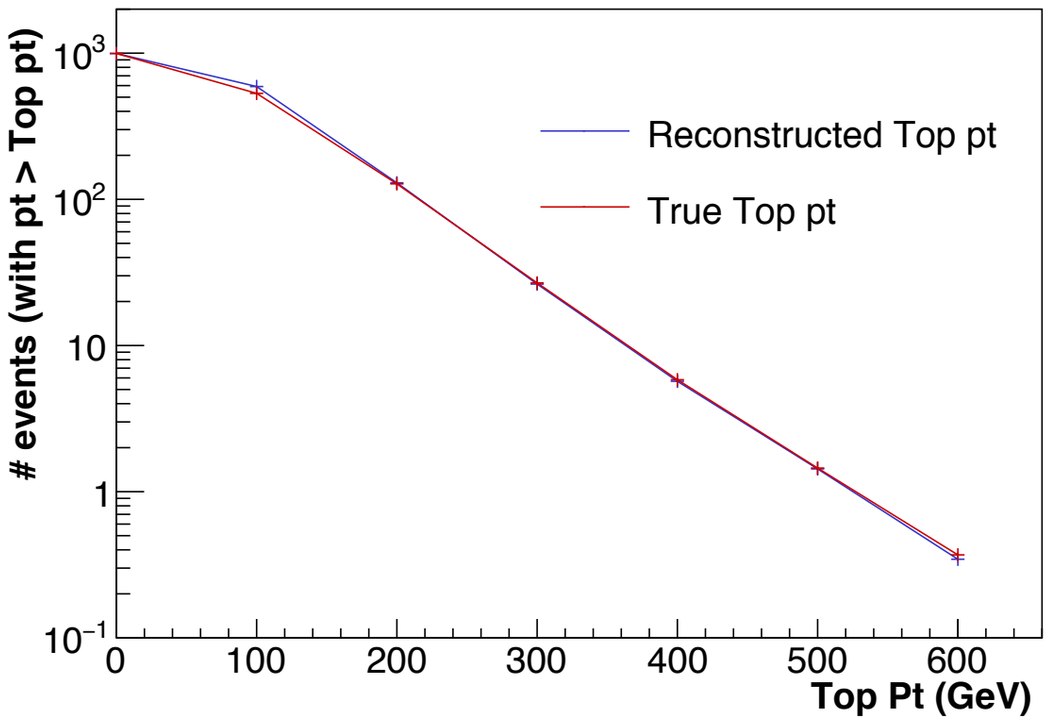

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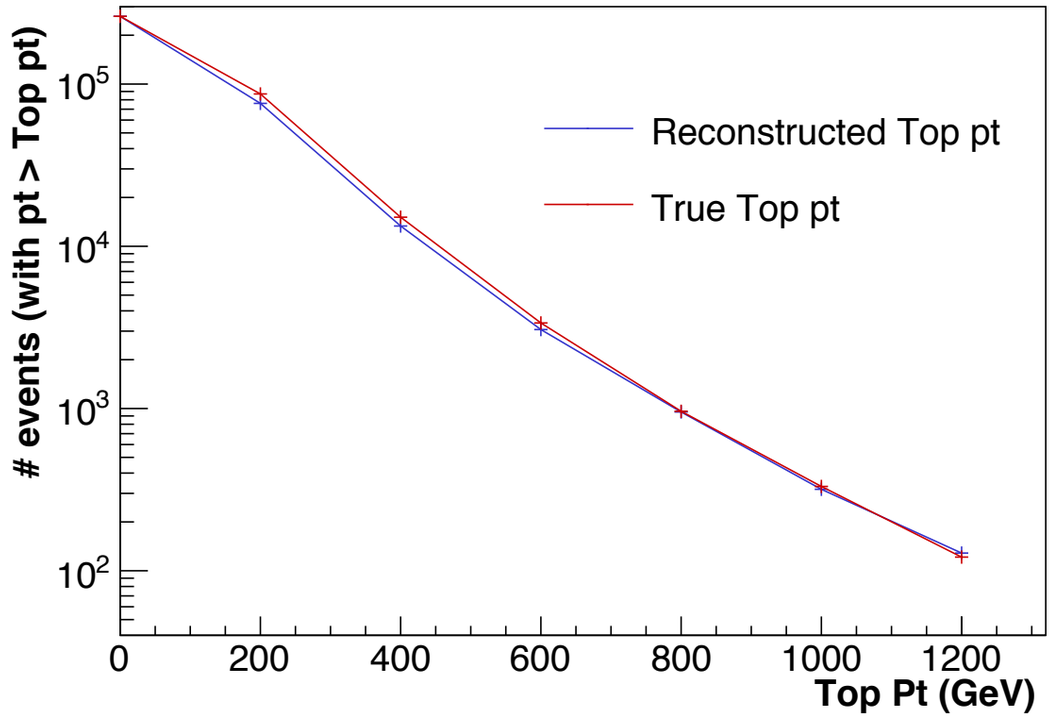
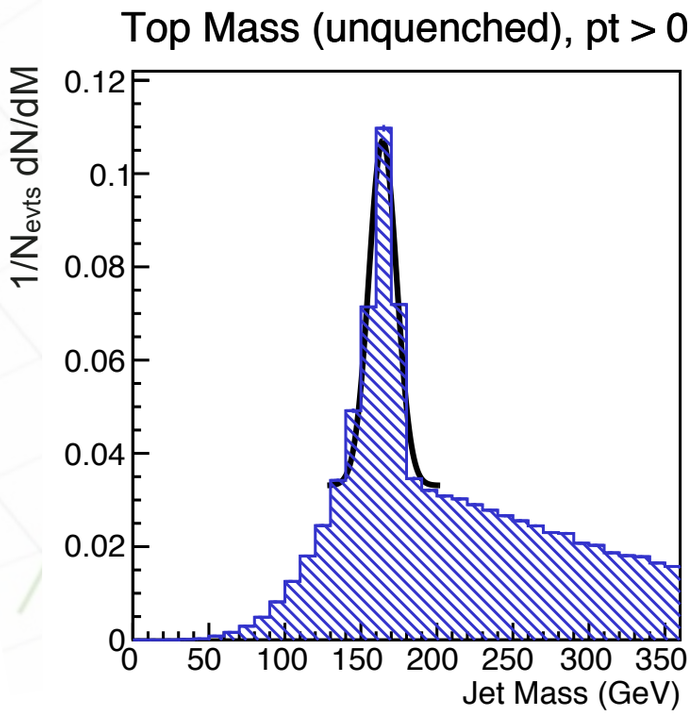
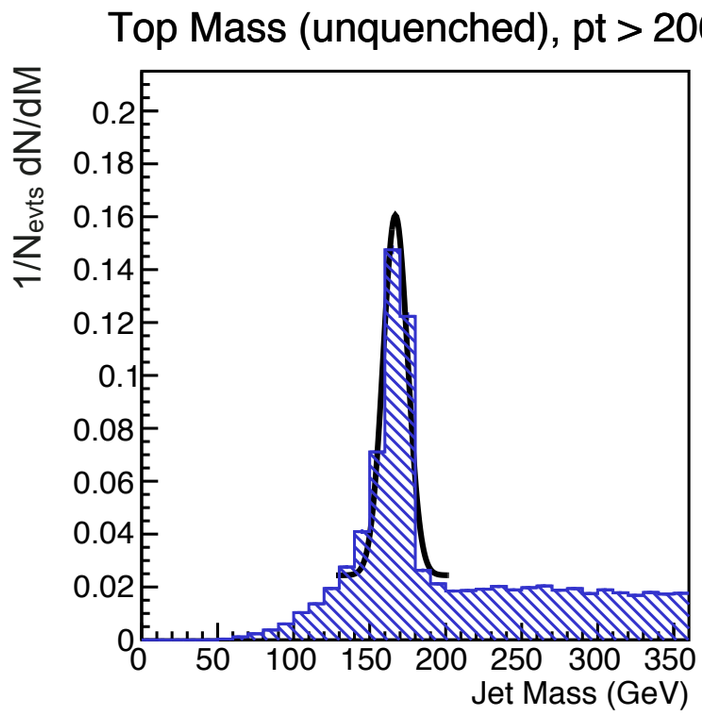


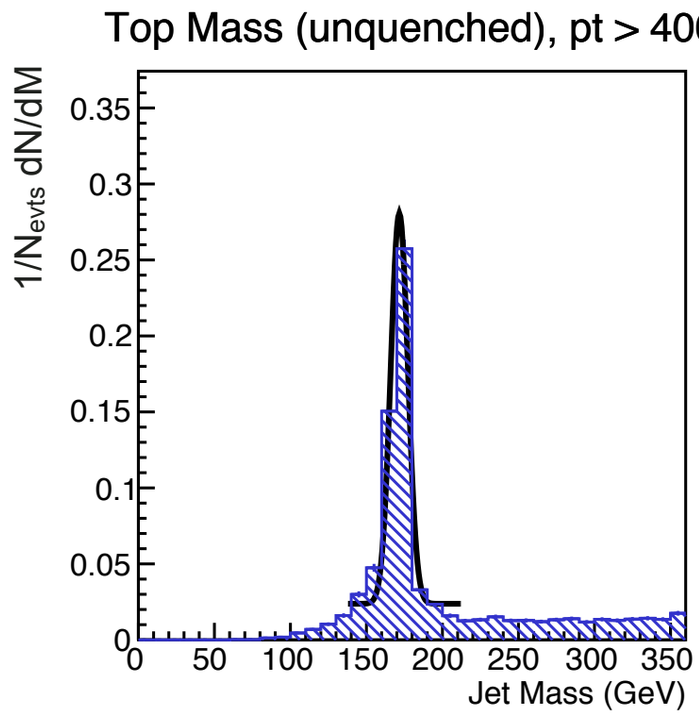
Can go up to p_T ~ 1000 GeV

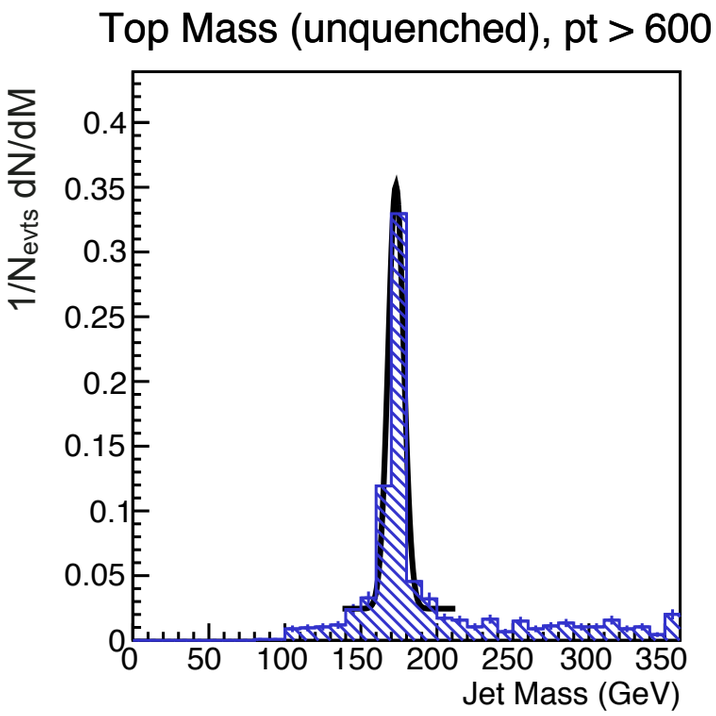
Probe: [0.5; 3.5] fm

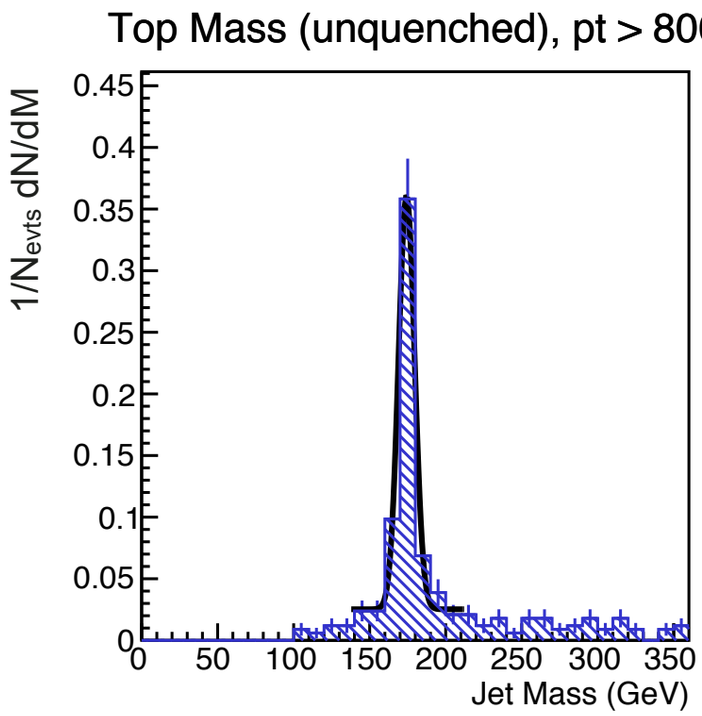
Reconstructed Top Mass

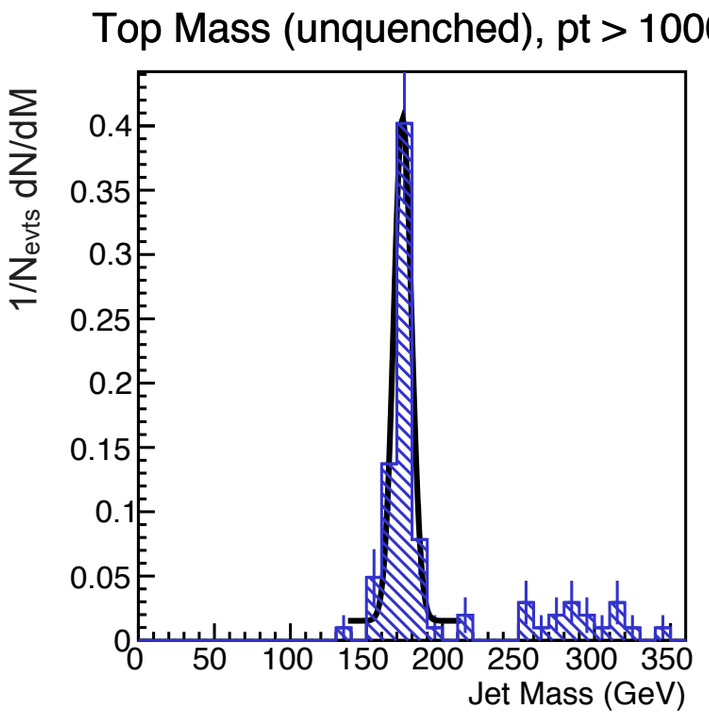






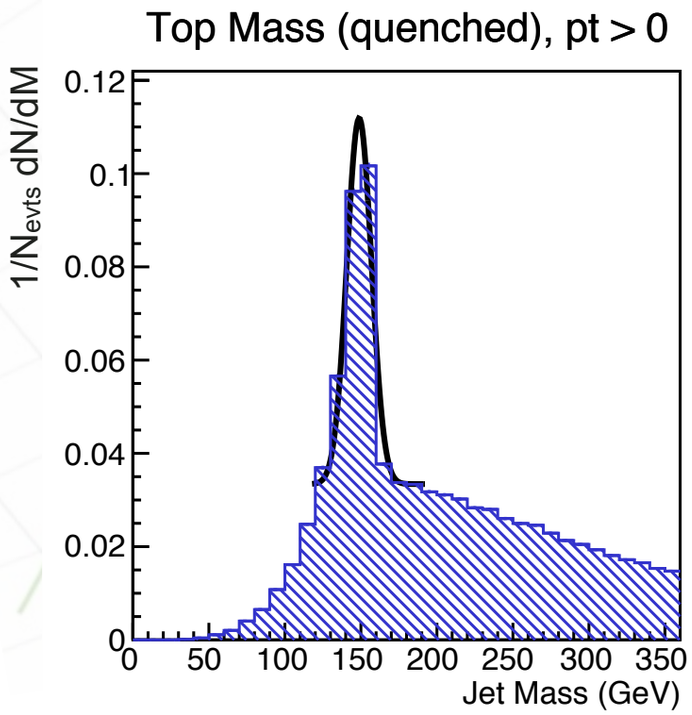


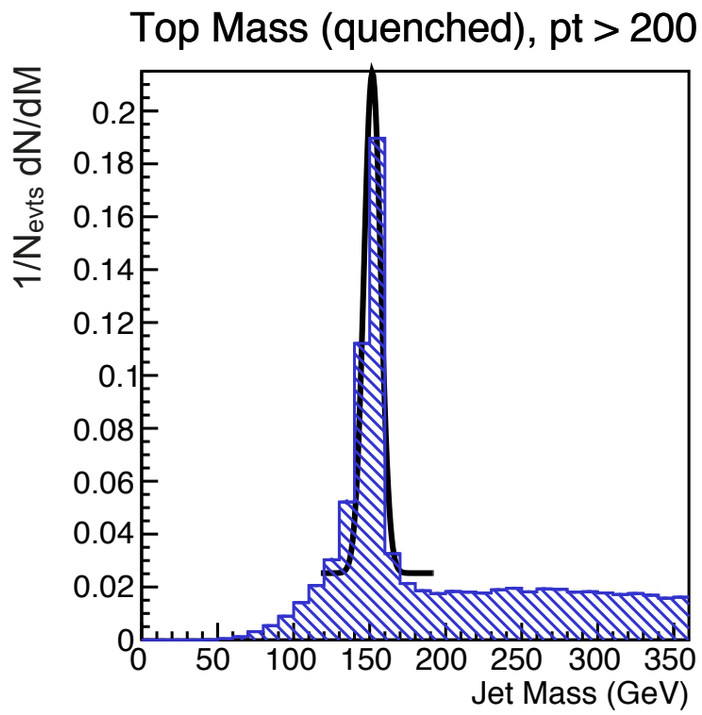


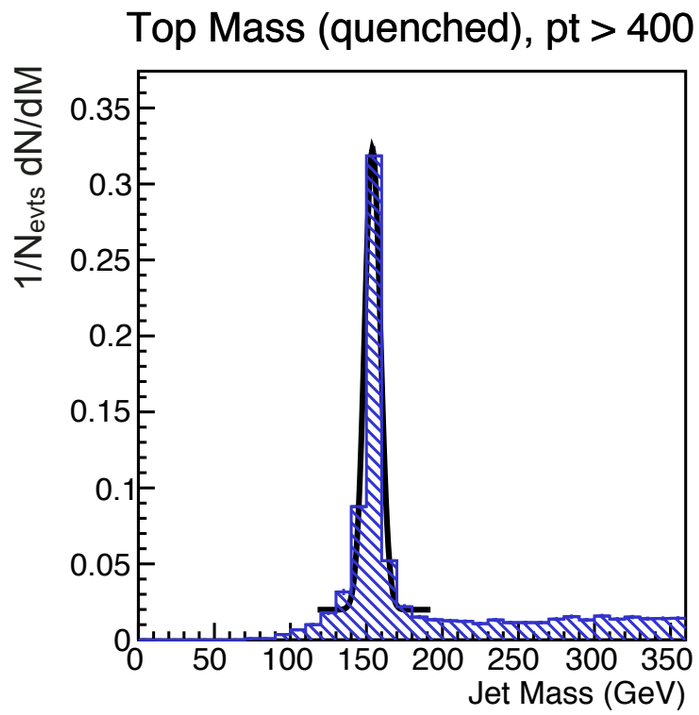


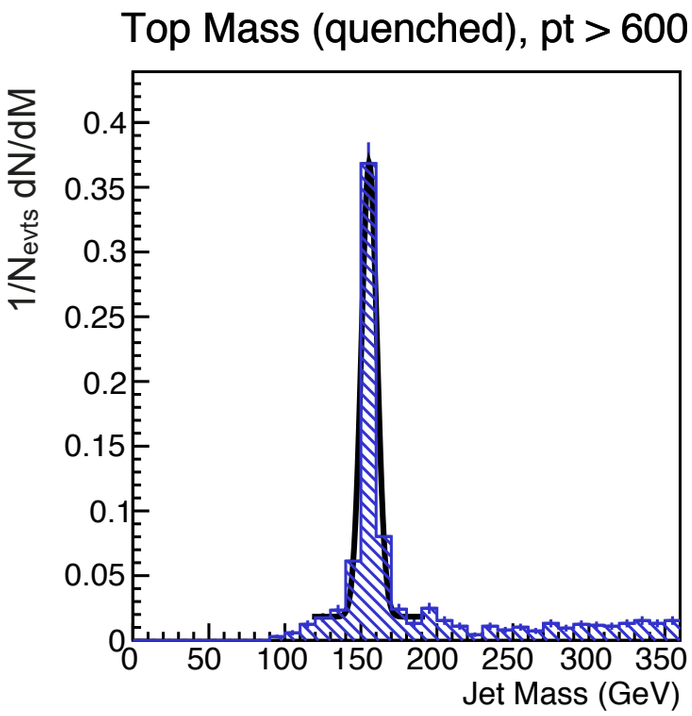
"True-Size MC sample"

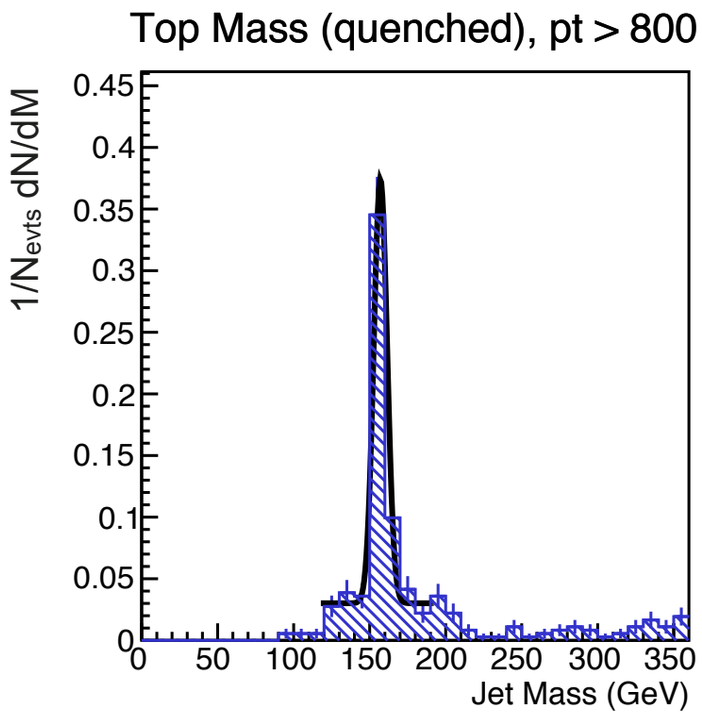
Reconstructed Top Mass

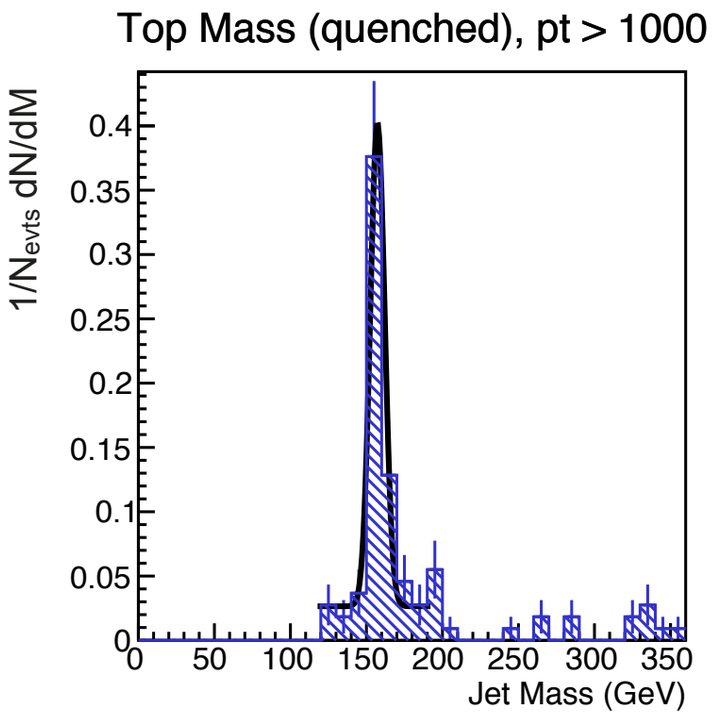






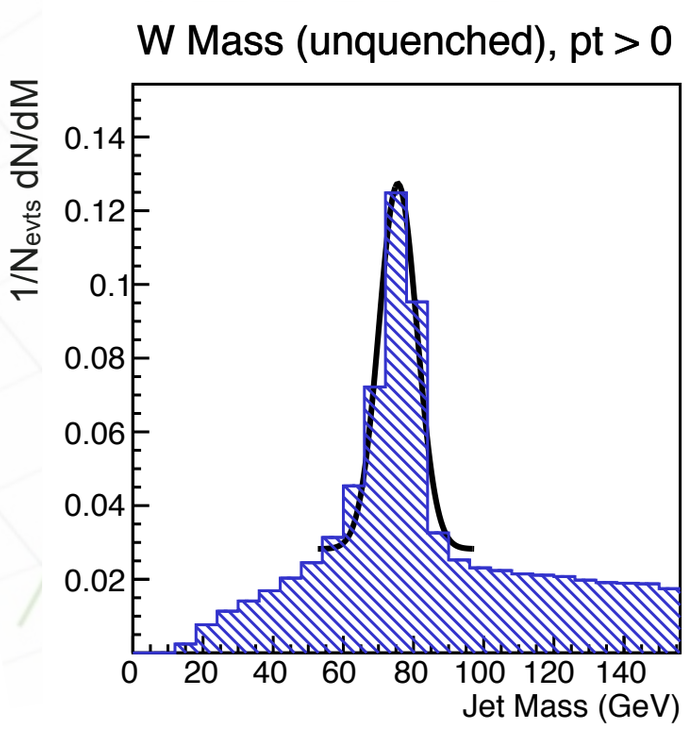


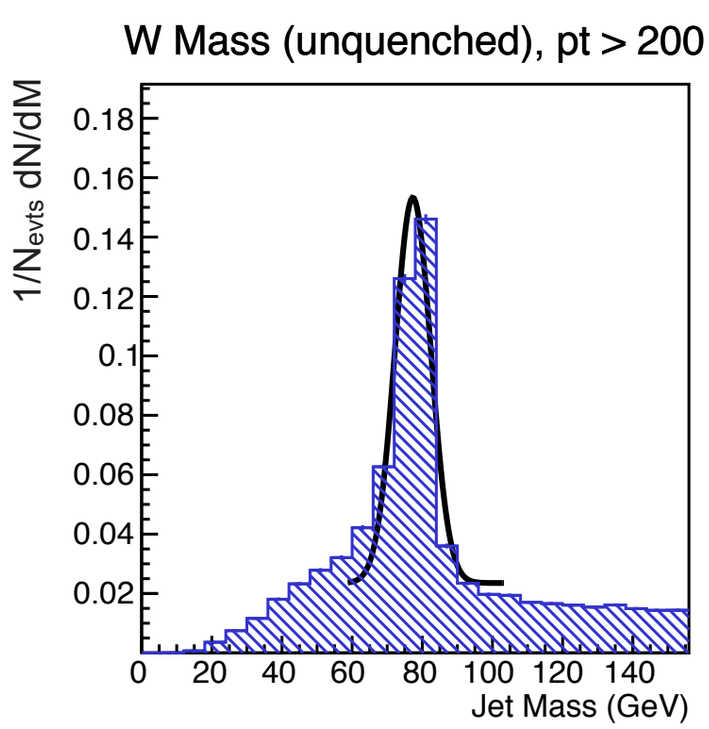


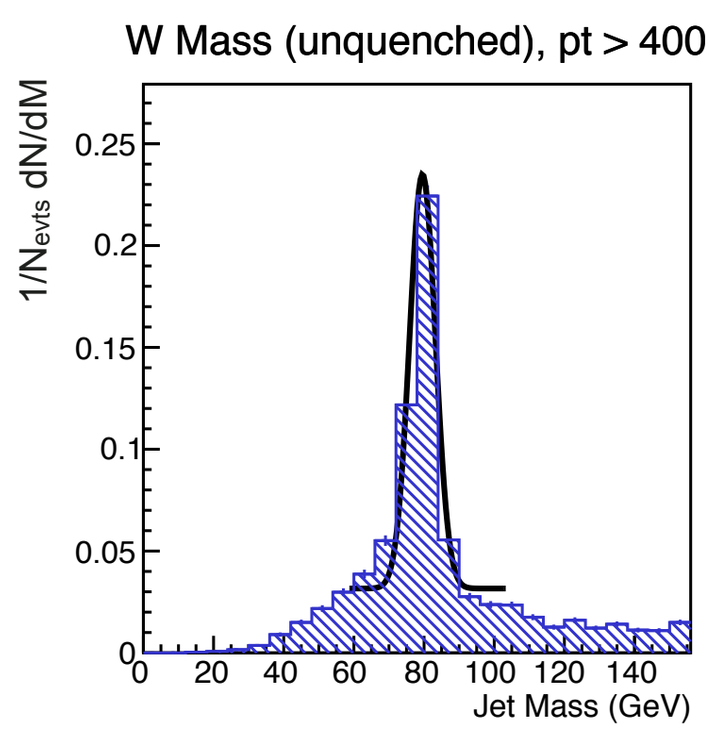


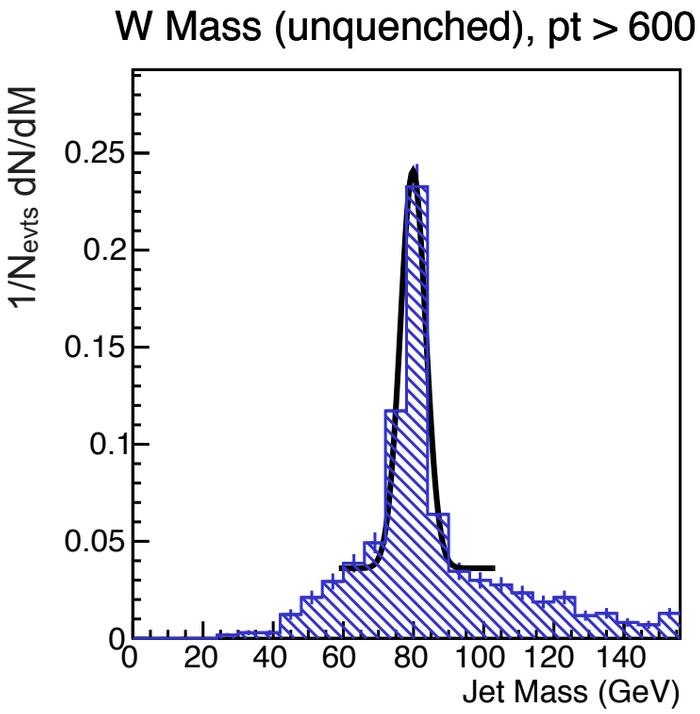
"True-Size MC sample"

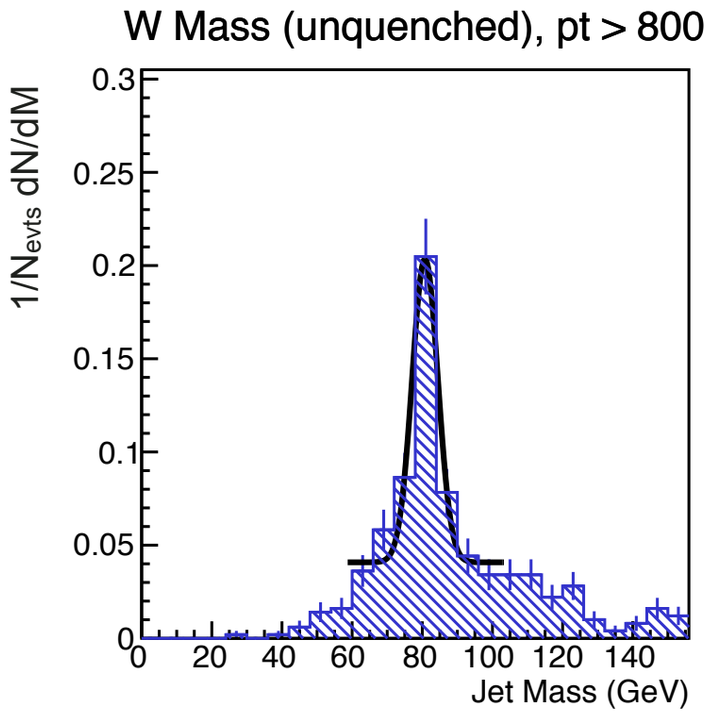
Reconstructed W Mass

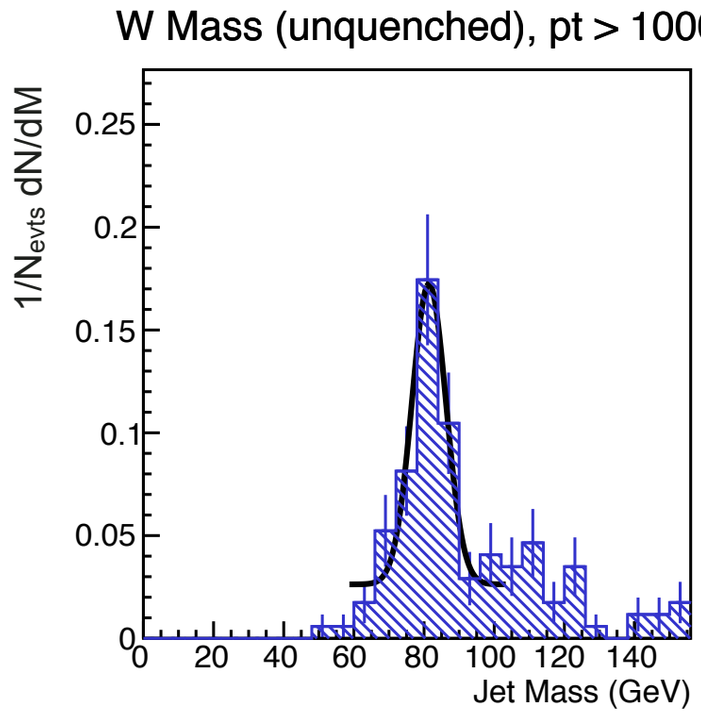












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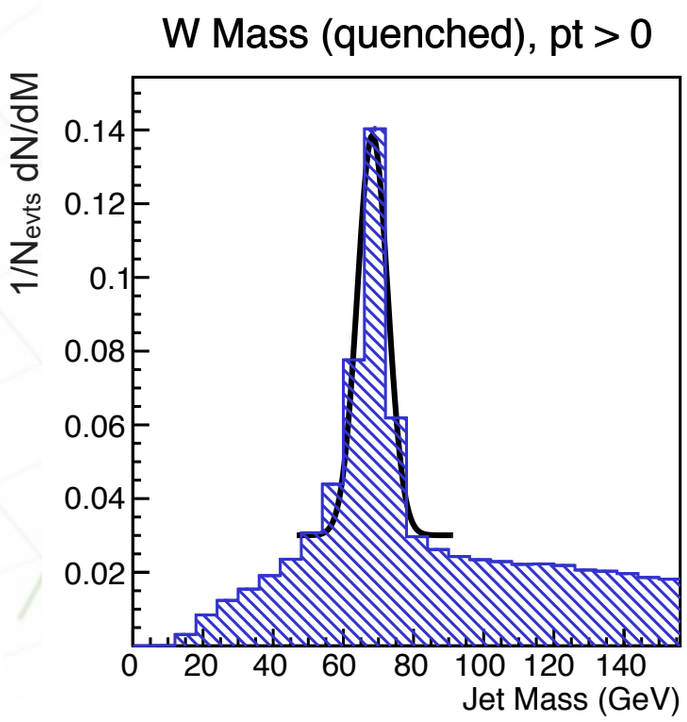
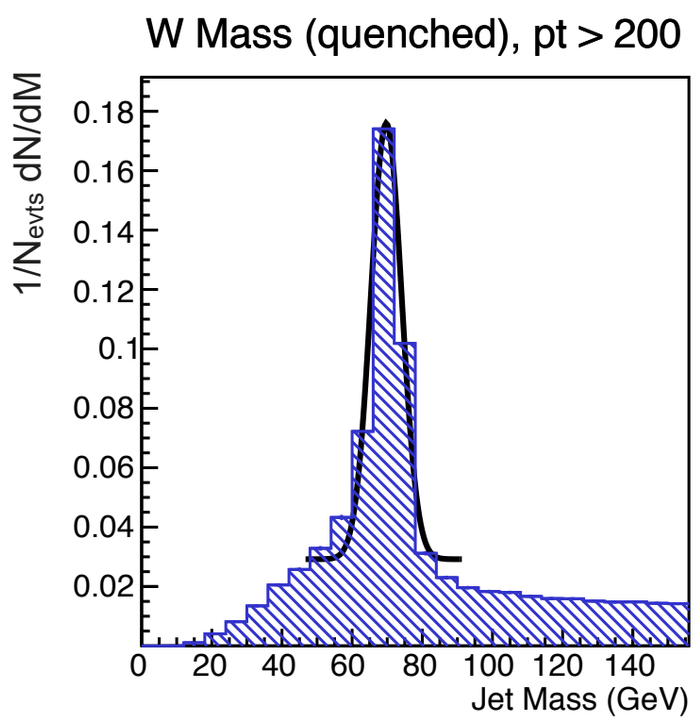
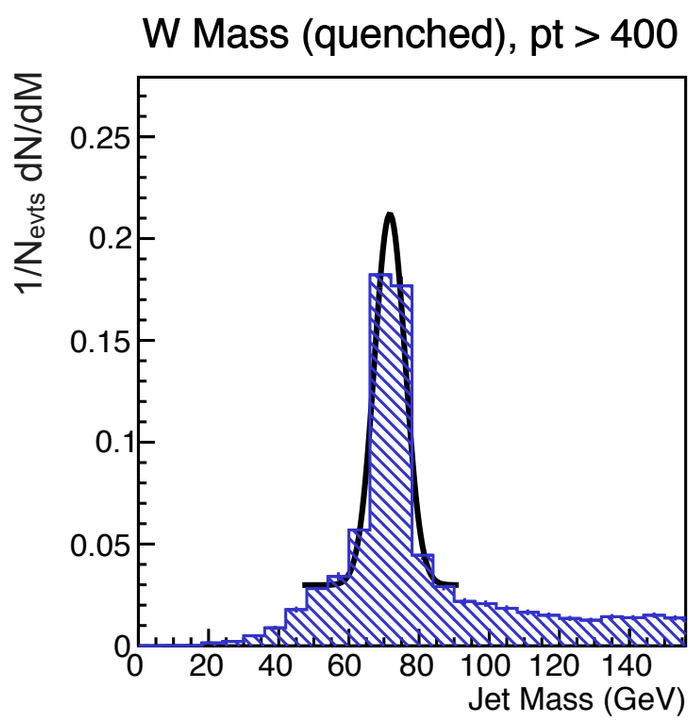
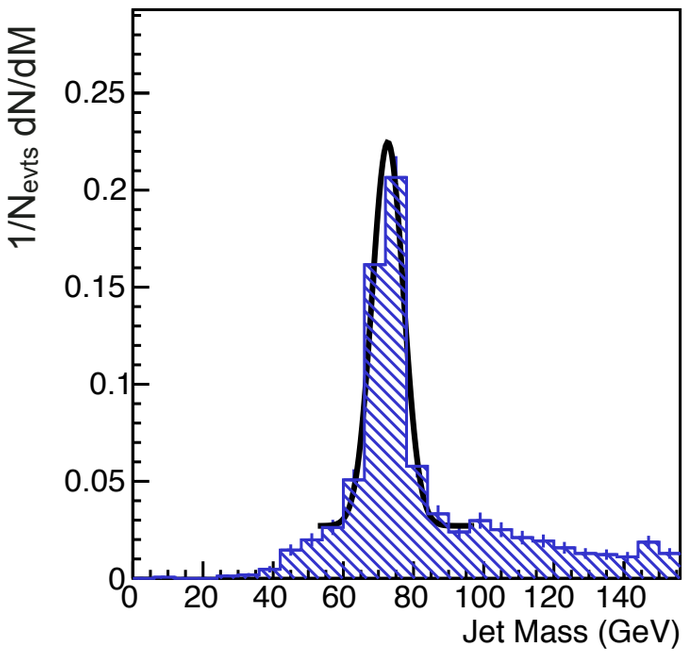
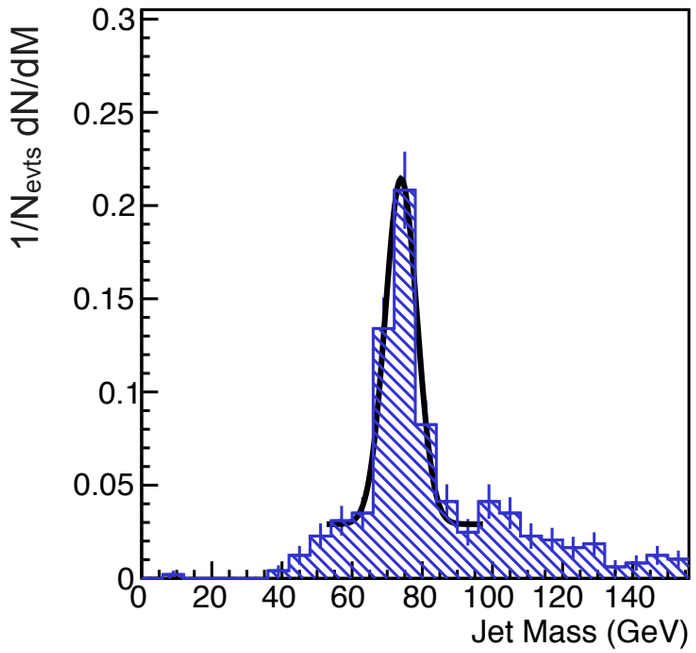
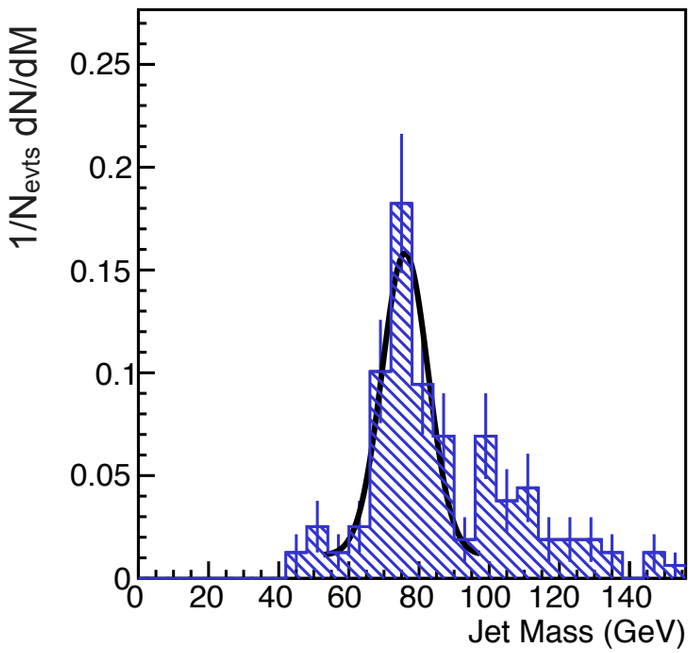








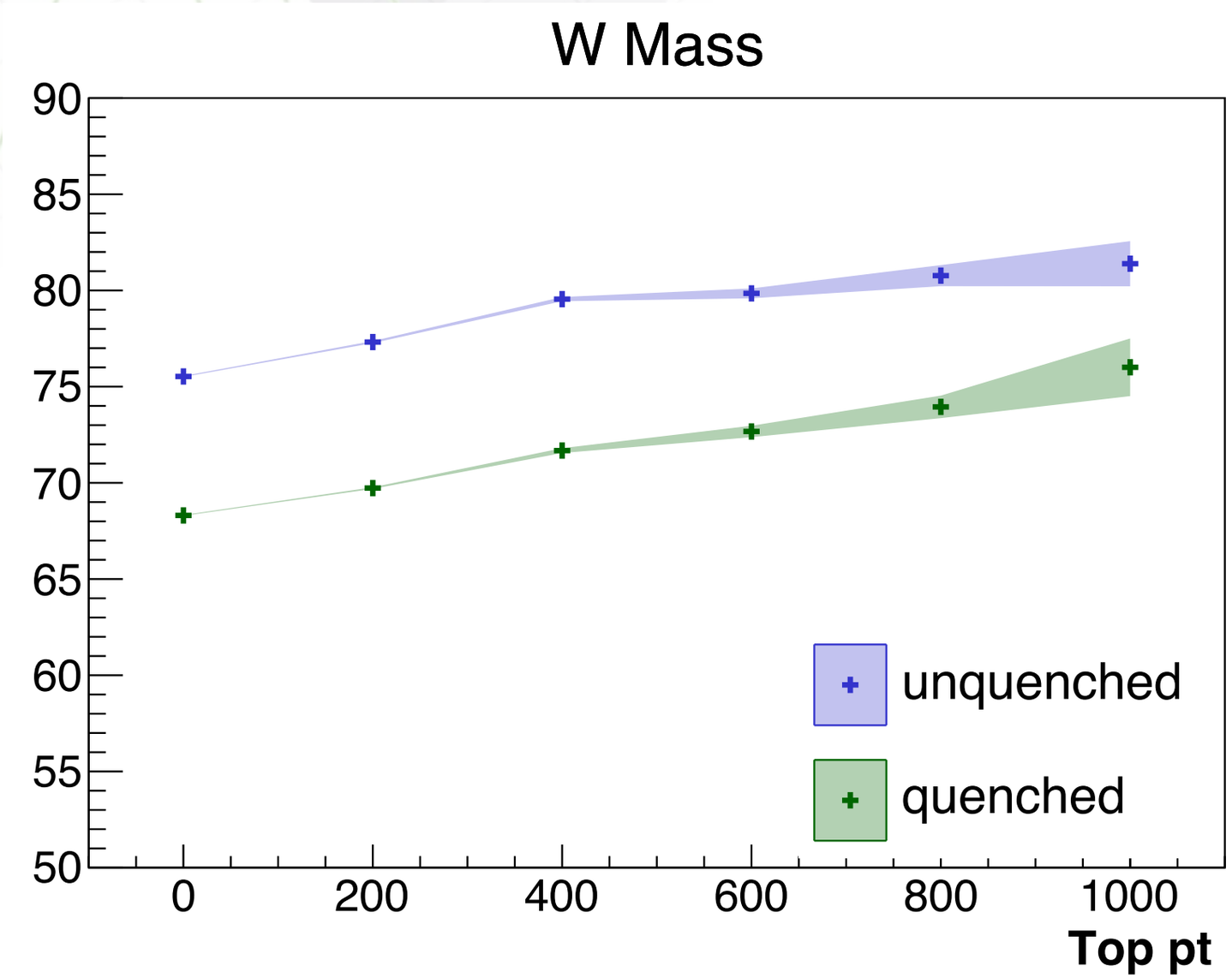


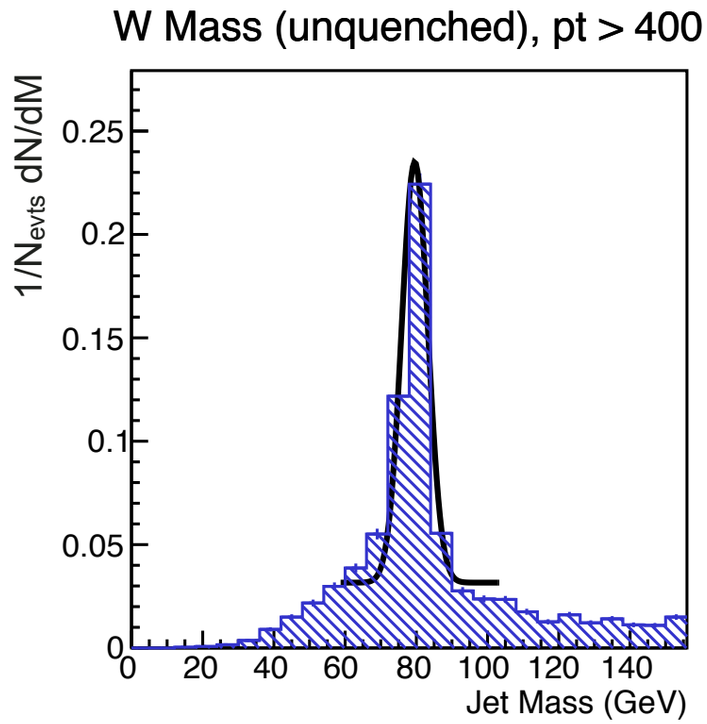


"True-Size MC sample"

Jet Mass with p_T

- Statistical significance from a fit using a Gaussian + offset
  - $\sigma/\sqrt{N}$, with $N = N_{evts}$ under the gaussian





Possible to distinguish quenched from unquenched jet masses

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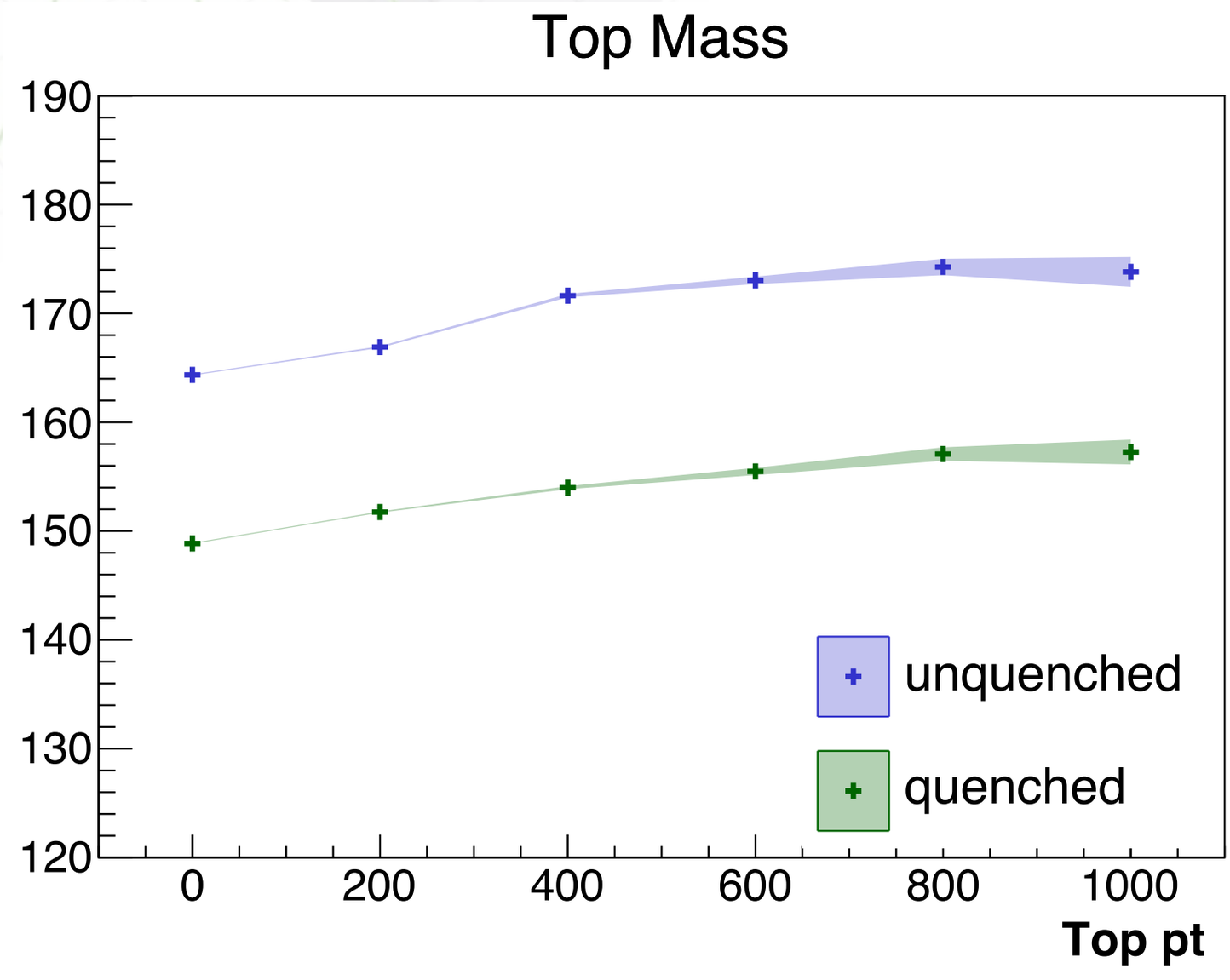
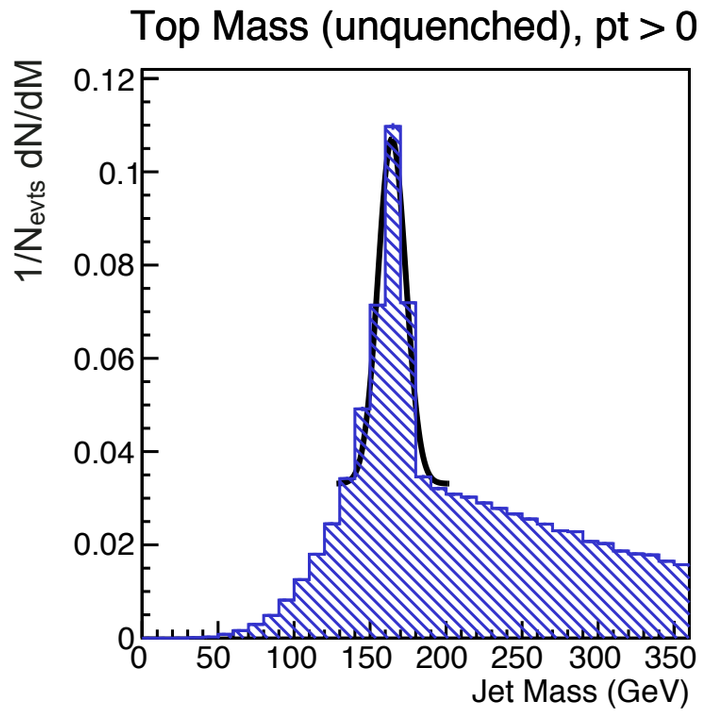
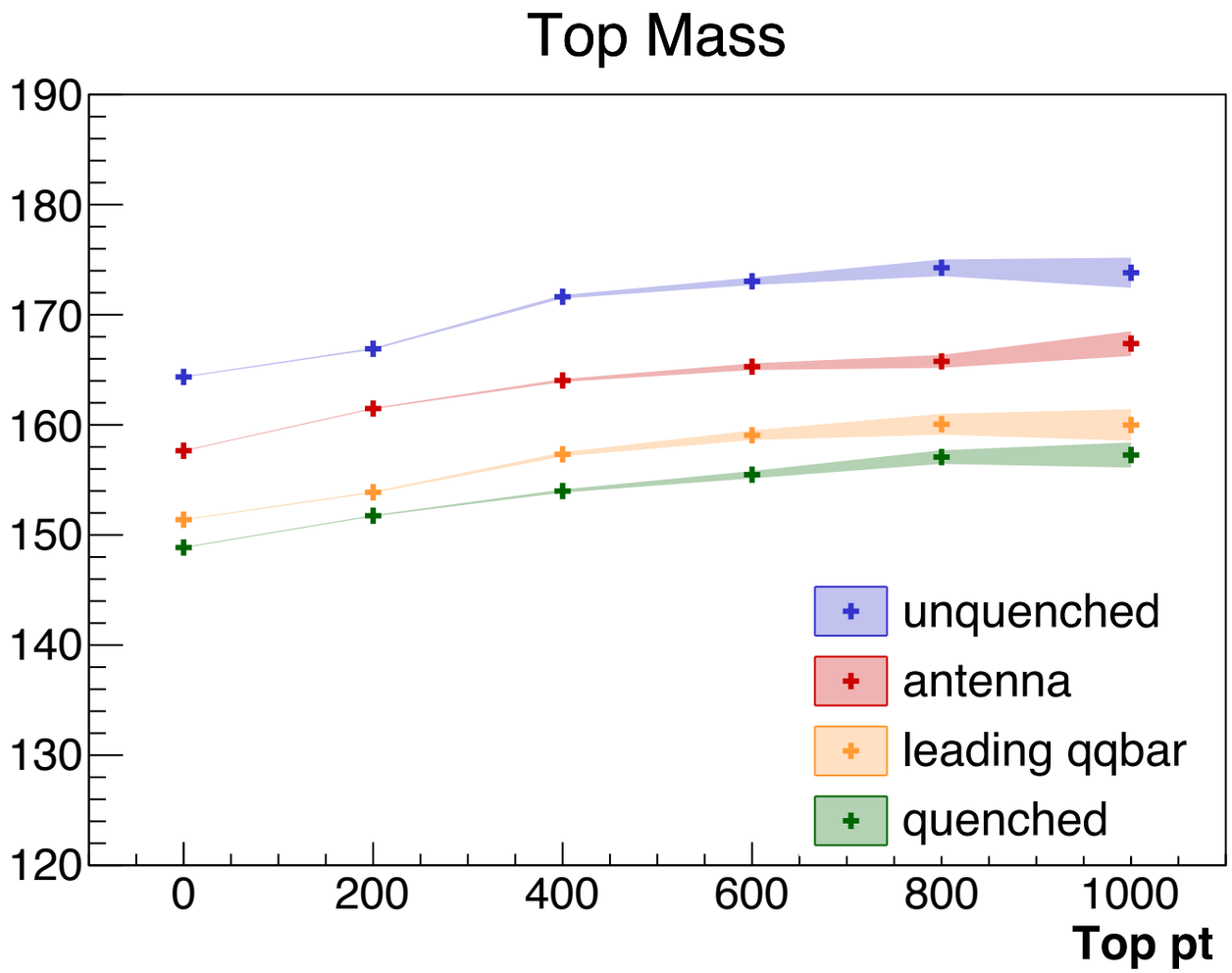




Possible to distinguish quenched from unquenched jet masses

Jet coherence

- To study jet coherence we applied 2 simple models:
  - “antenna”: energy loss applied to all colourful partons except the decay products of the hadronic W boson
  - “leading qqbar”: energy loss applied to all colourful partons except the leading qqbar from the decay of the hadronic W boson



Absolute value of jet mass can give information on the “degree” of coherence of the system

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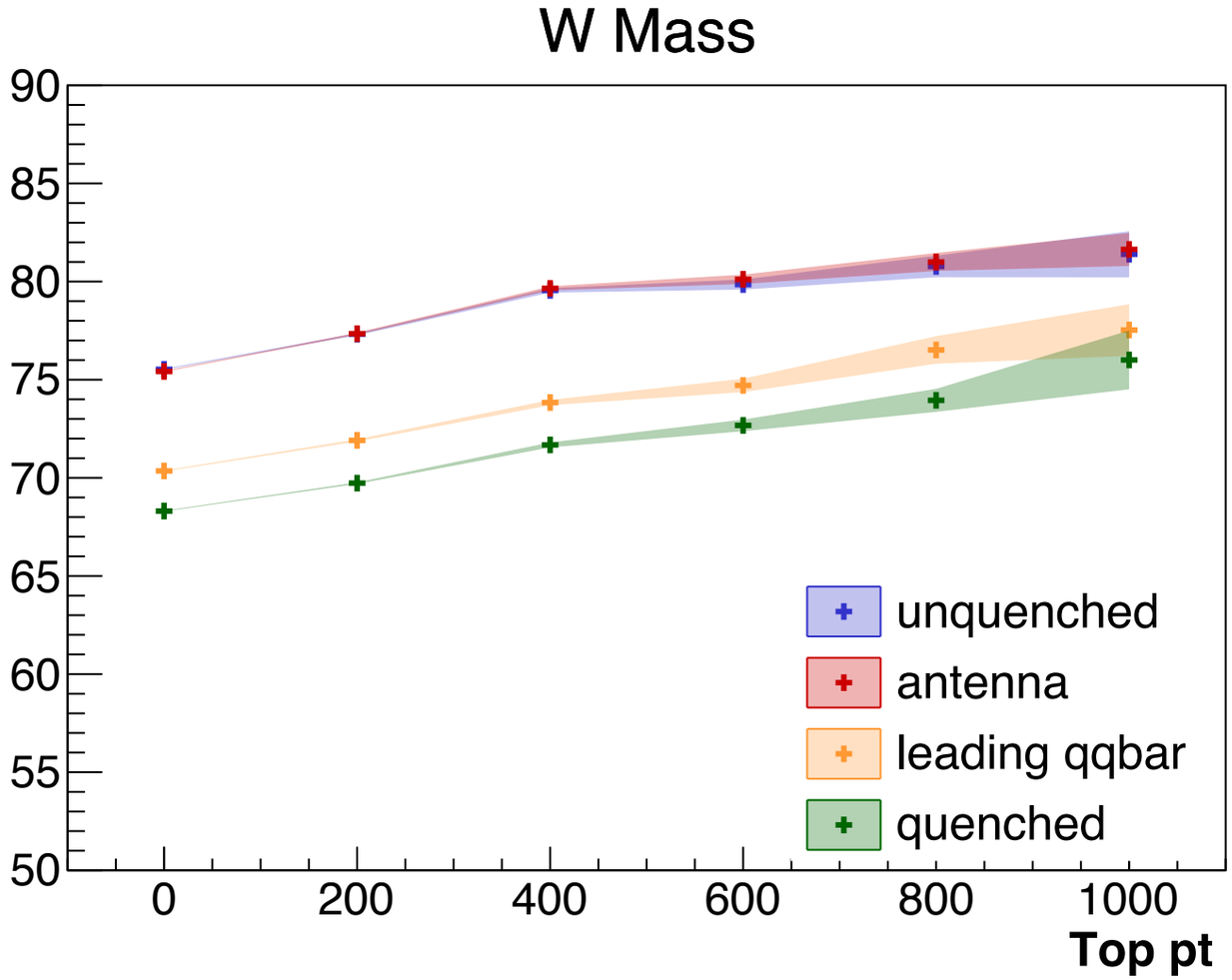

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  - Jet coherence/decoherence scenarios

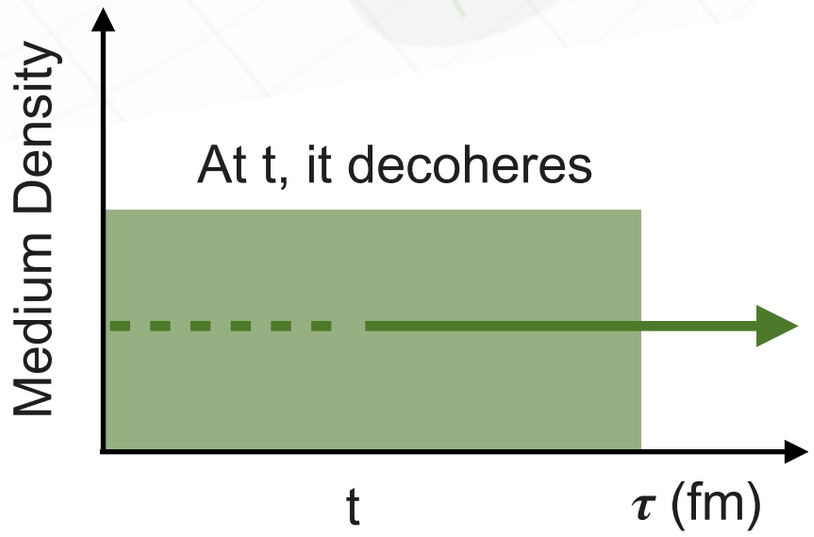
- Can we go further?
  - In theory, one can probe select timescales of the medium by using $p_T > p_{T,Cut}$

Time Dependent Energy Loss

- Very simple model: W decay products lose energy as
  - $\Delta E/E = (\tau - t)/\tau * 0.1$

τ = Total medium lifetime

t = “total” delay time



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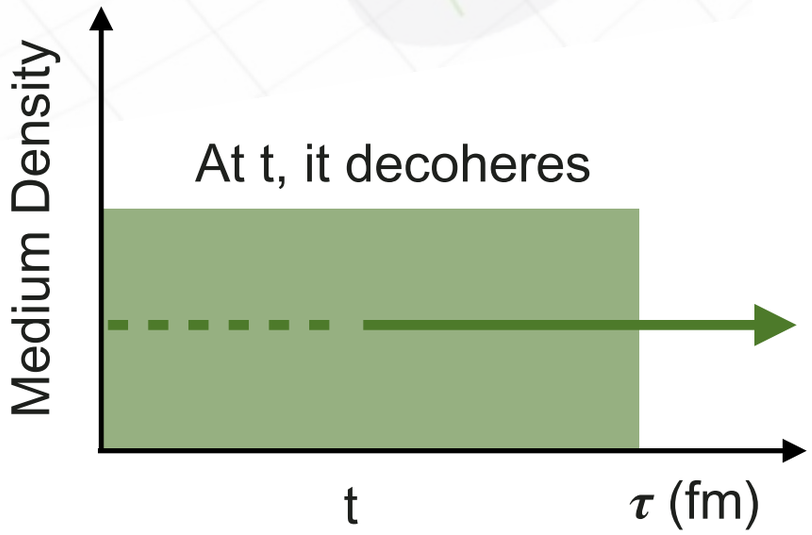

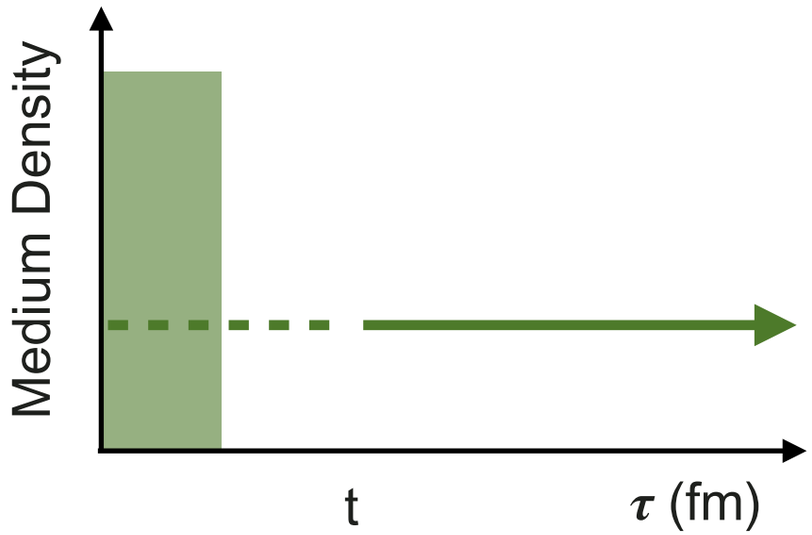

Remaining hadronic particles lose always 10% of energy after τ.

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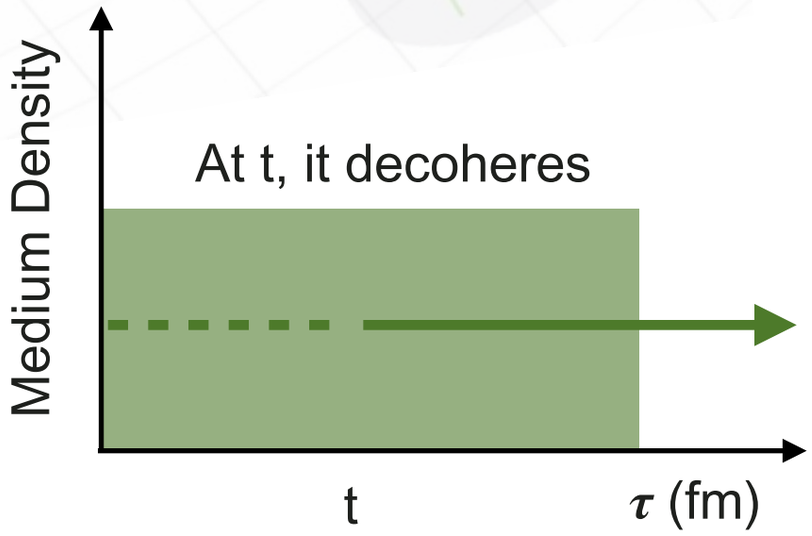

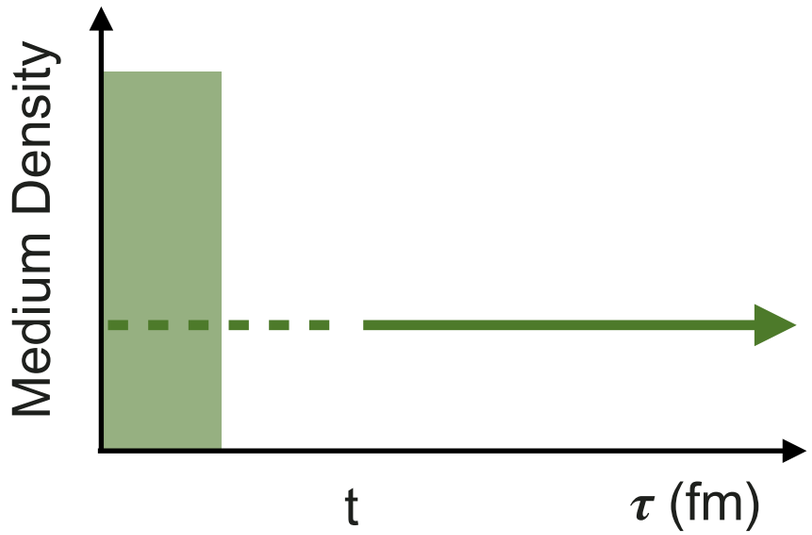

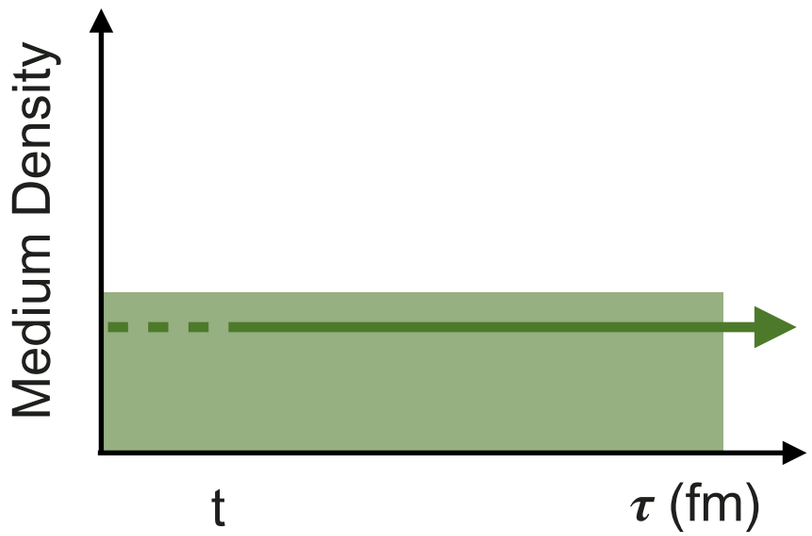

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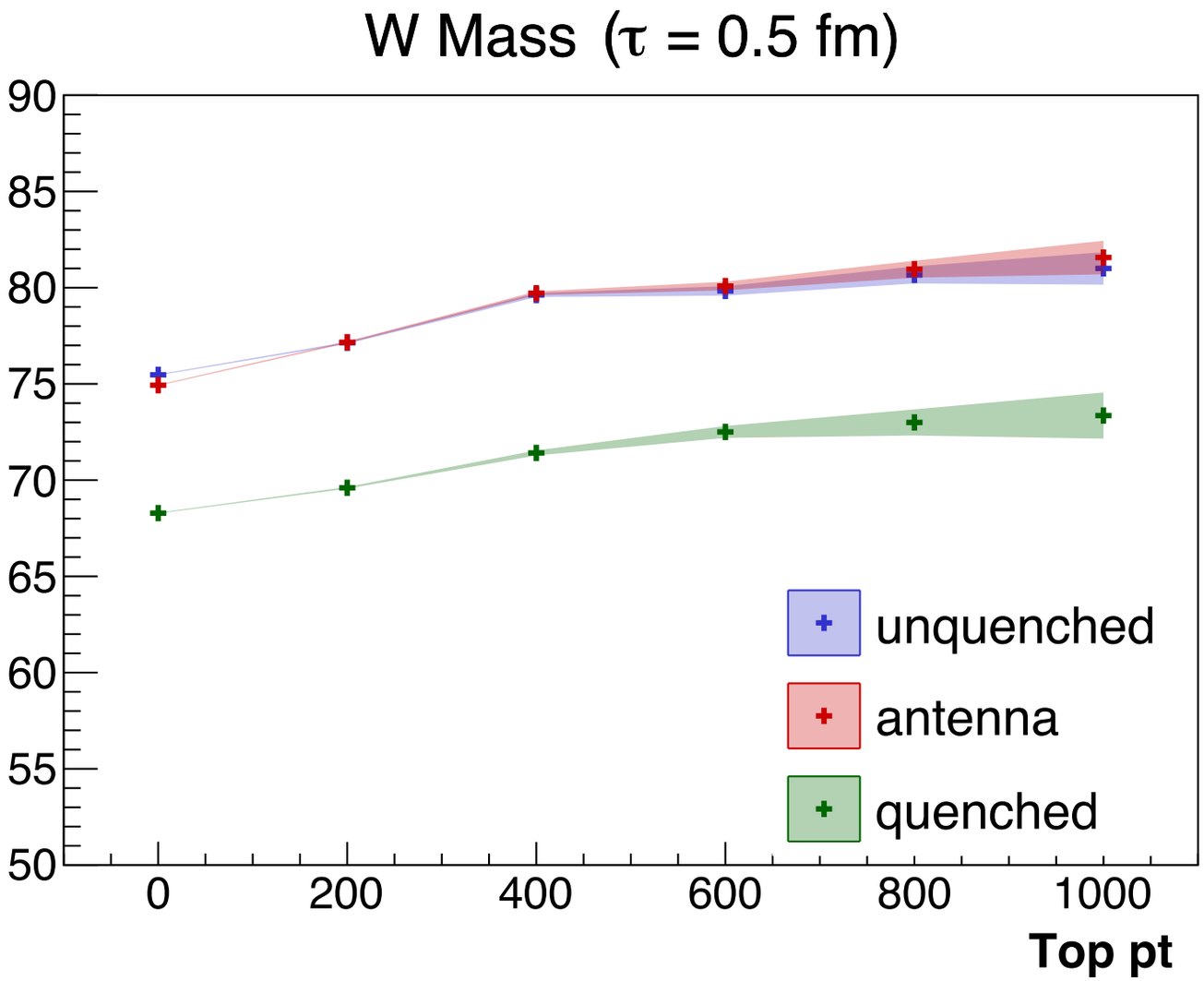
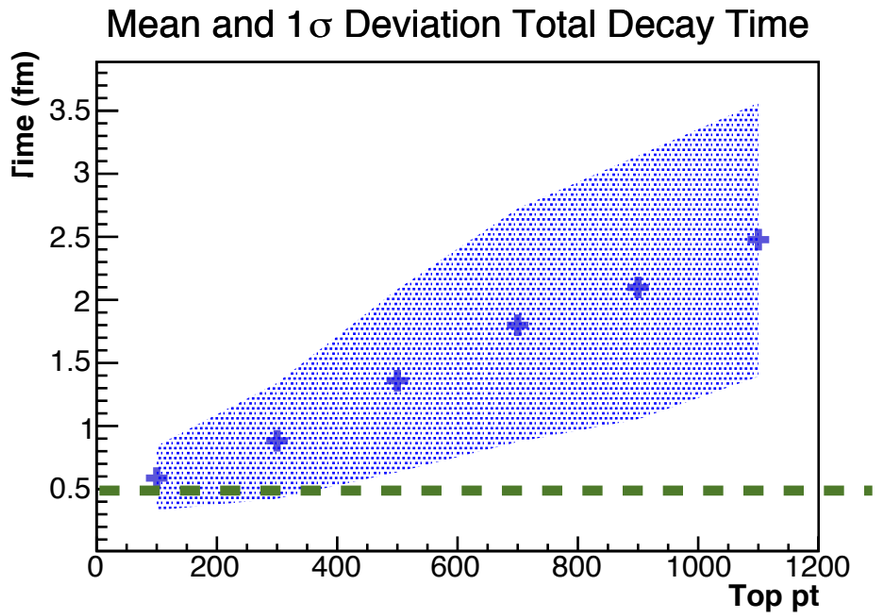
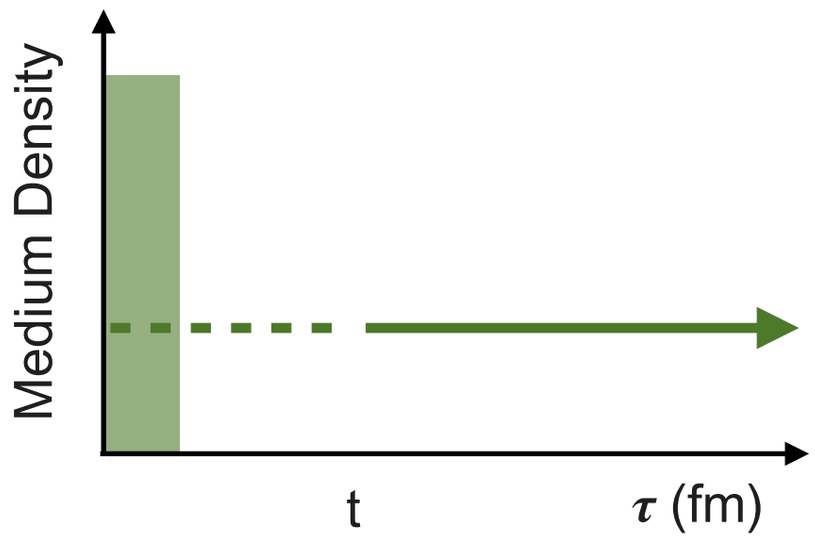
Time Dependent Energy Loss

- Reconstructed W Jet Mass:







Antenna decoheres outside the medium

Time Dependent Energy Loss

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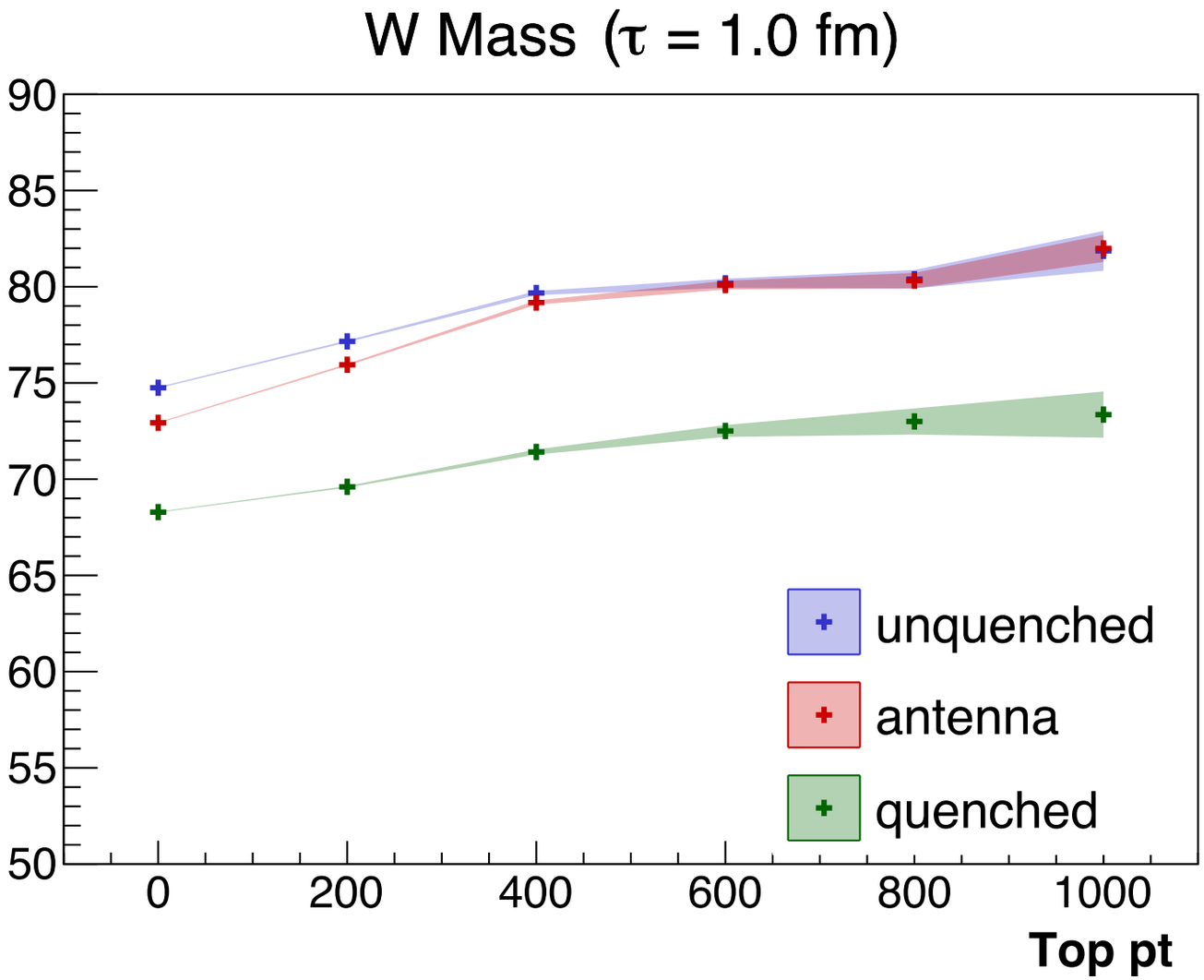
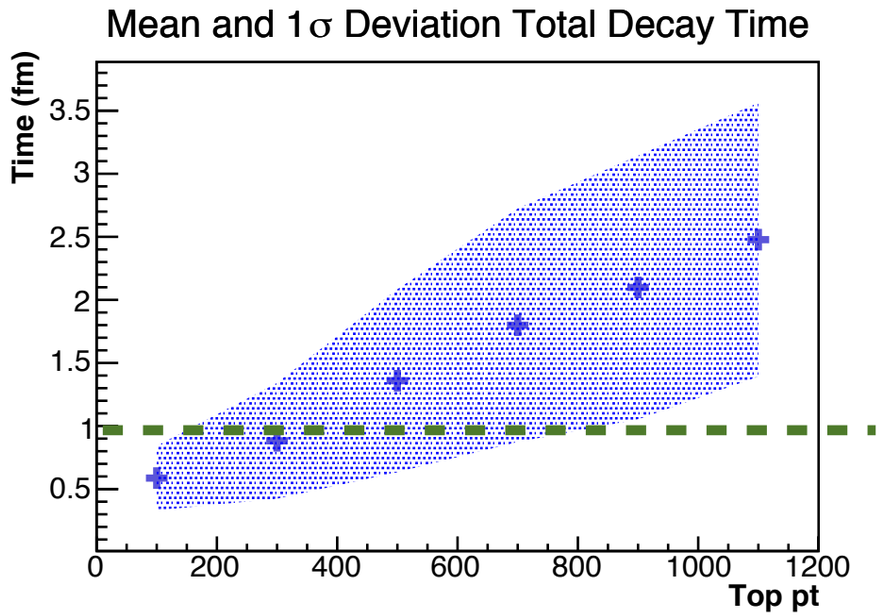
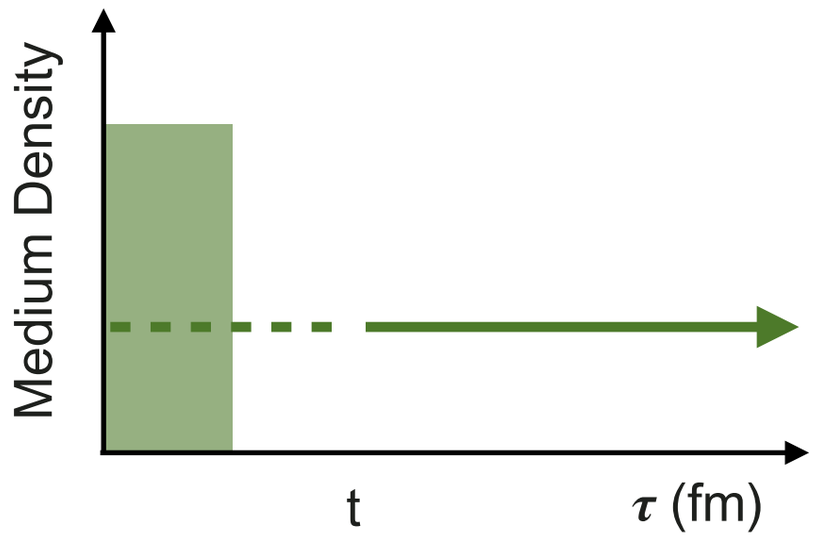
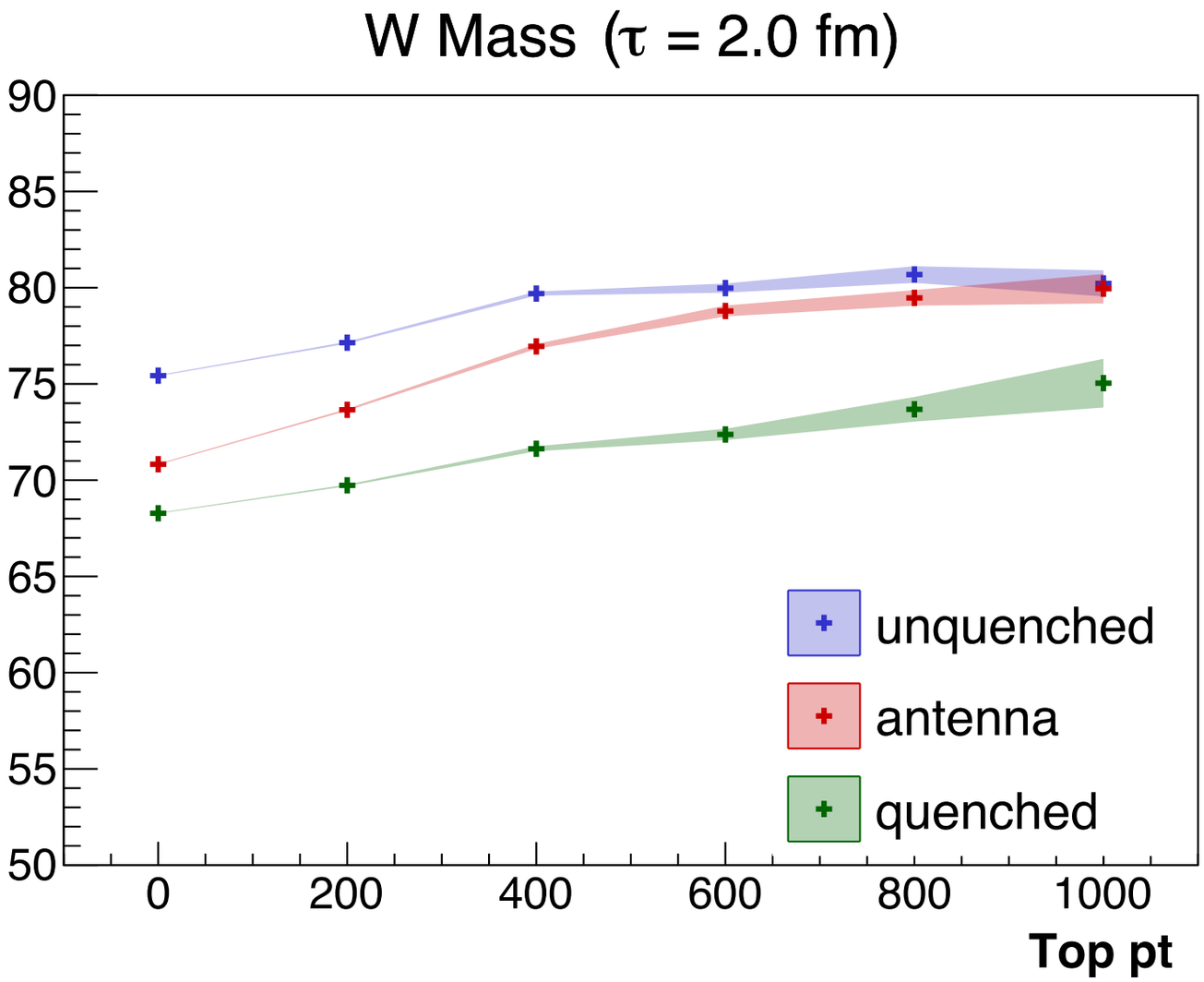


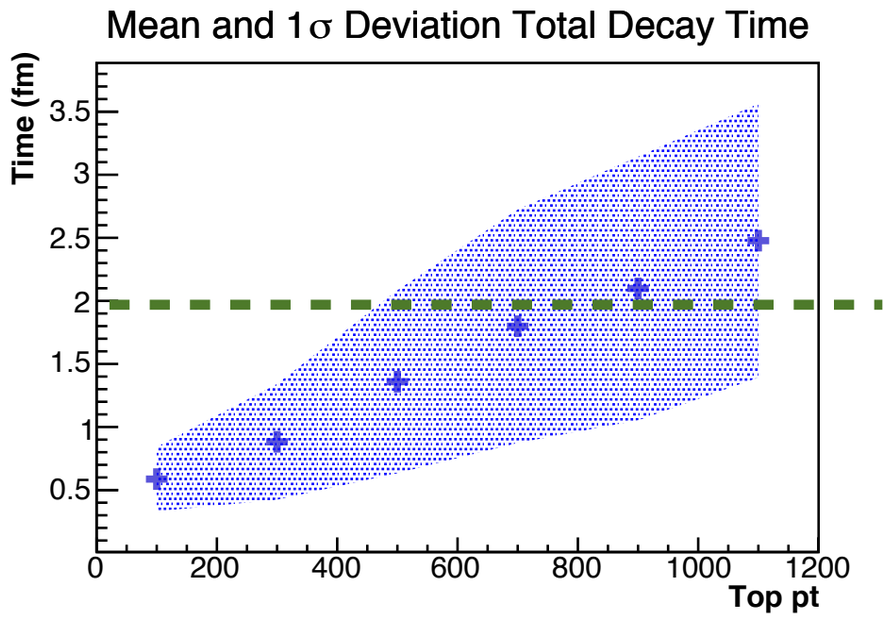


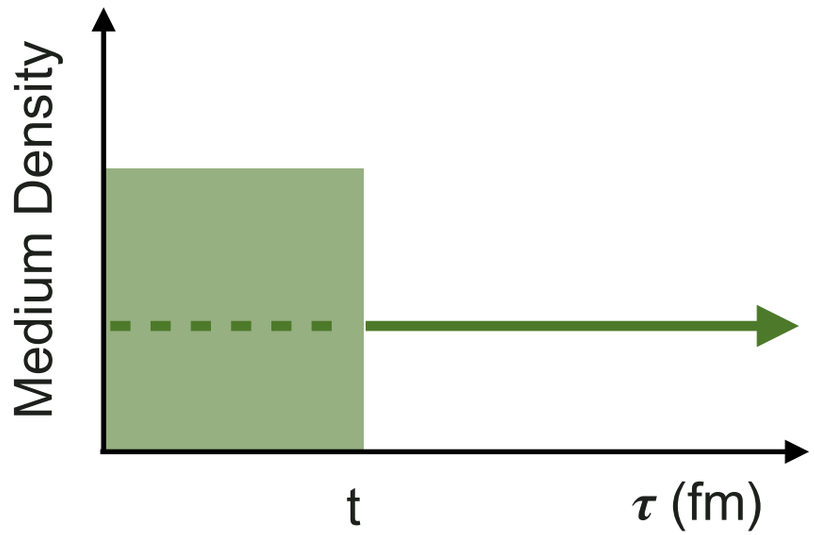


Time Dependent Energy Loss

- Reconstructed W Jet Mass:







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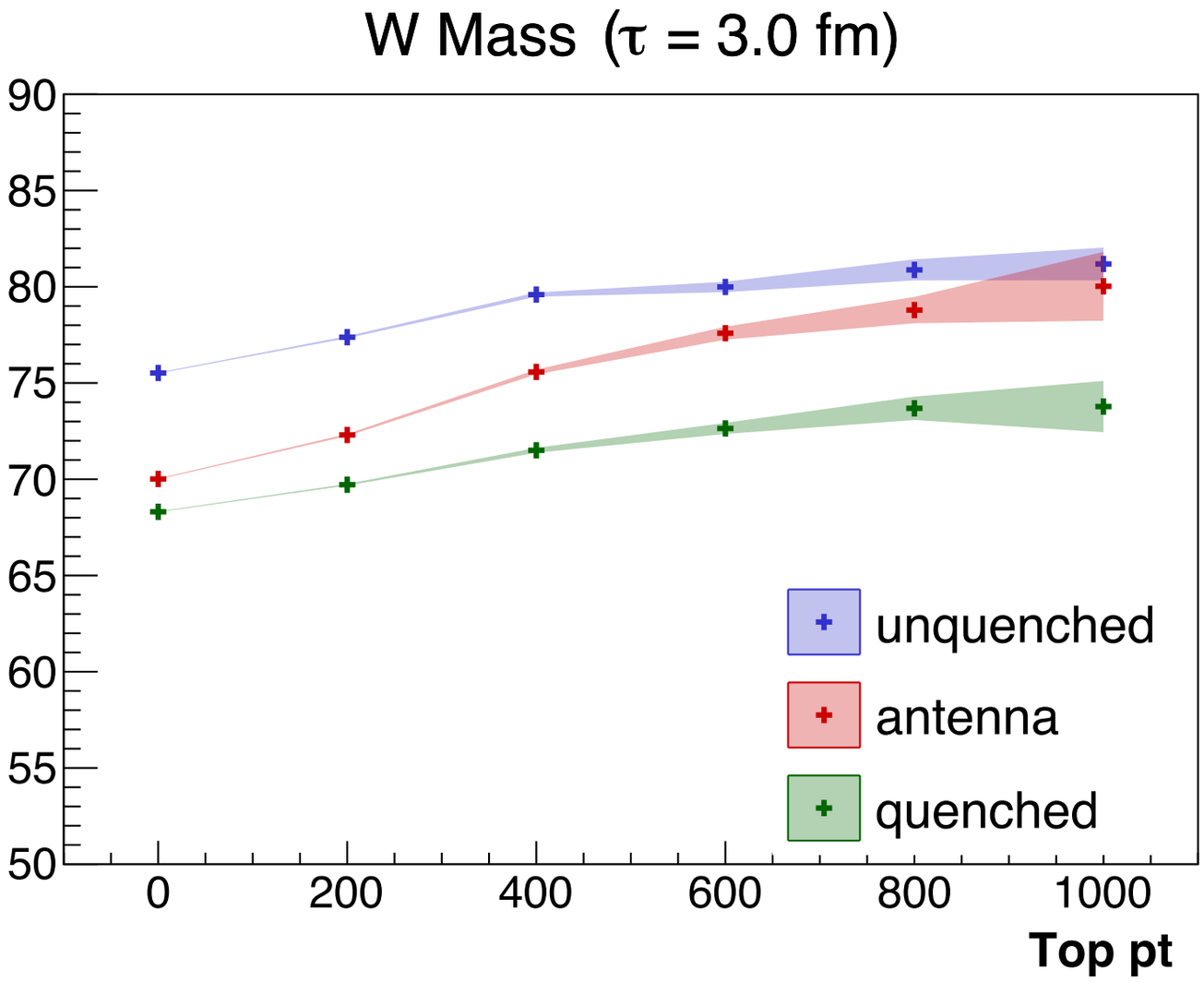

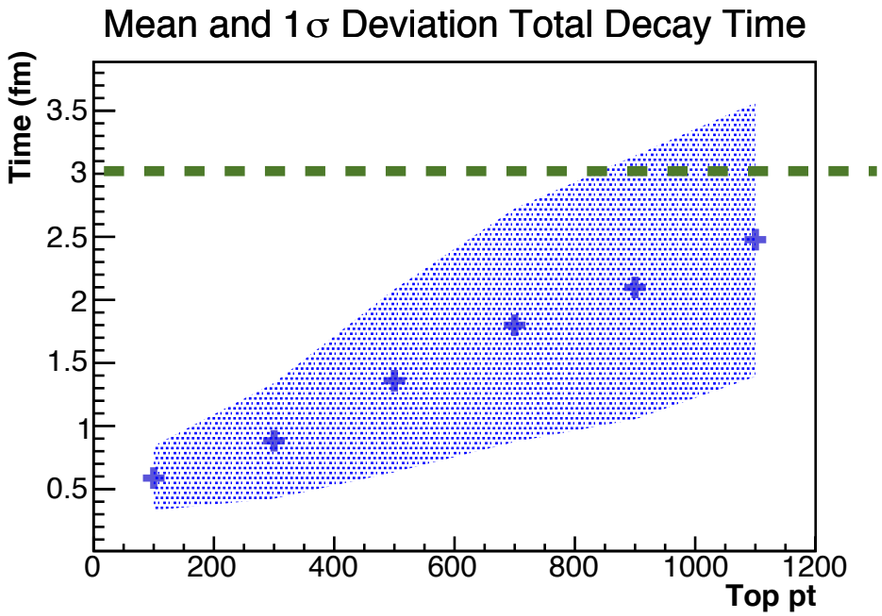

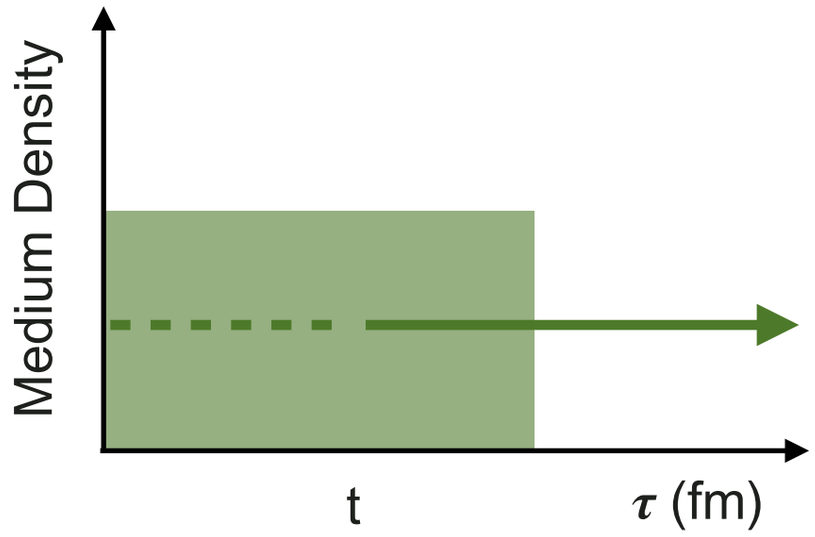

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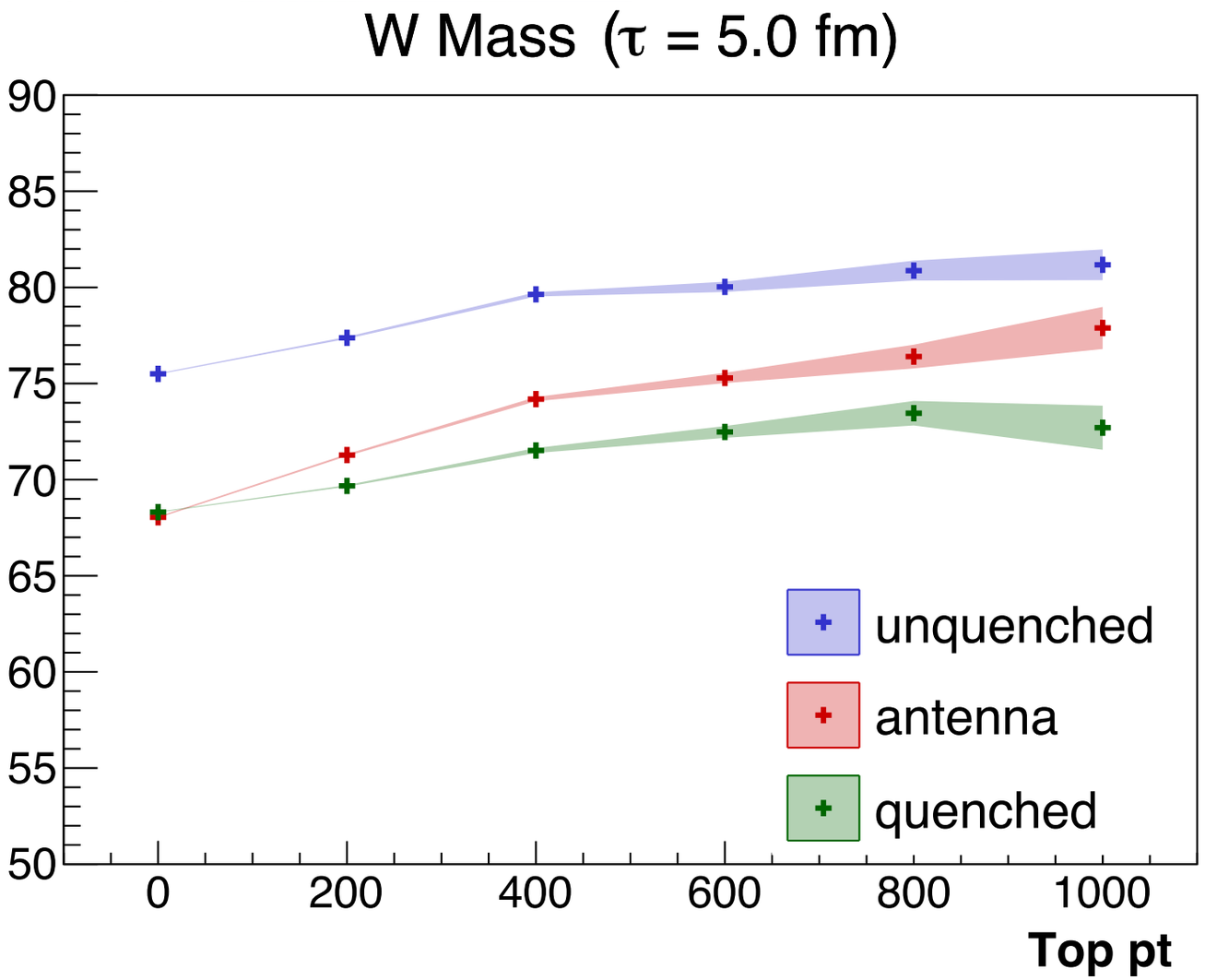
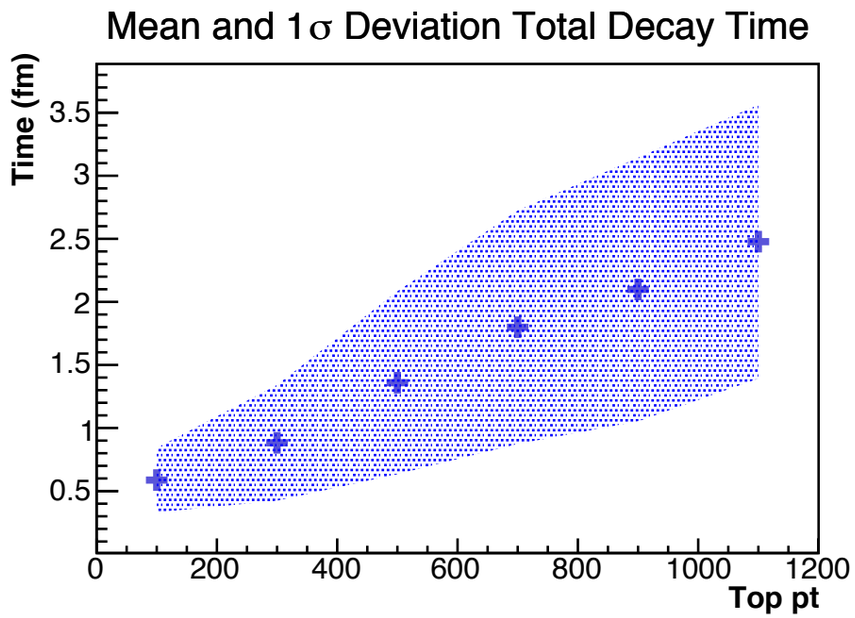
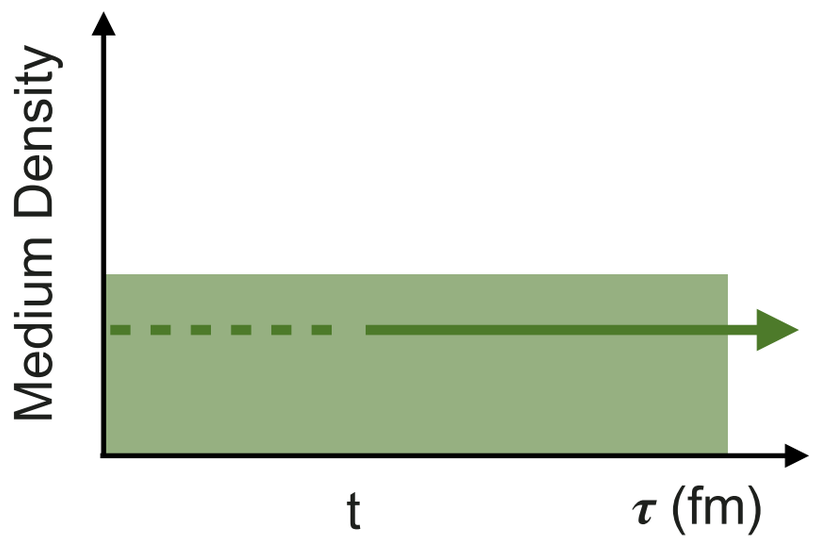


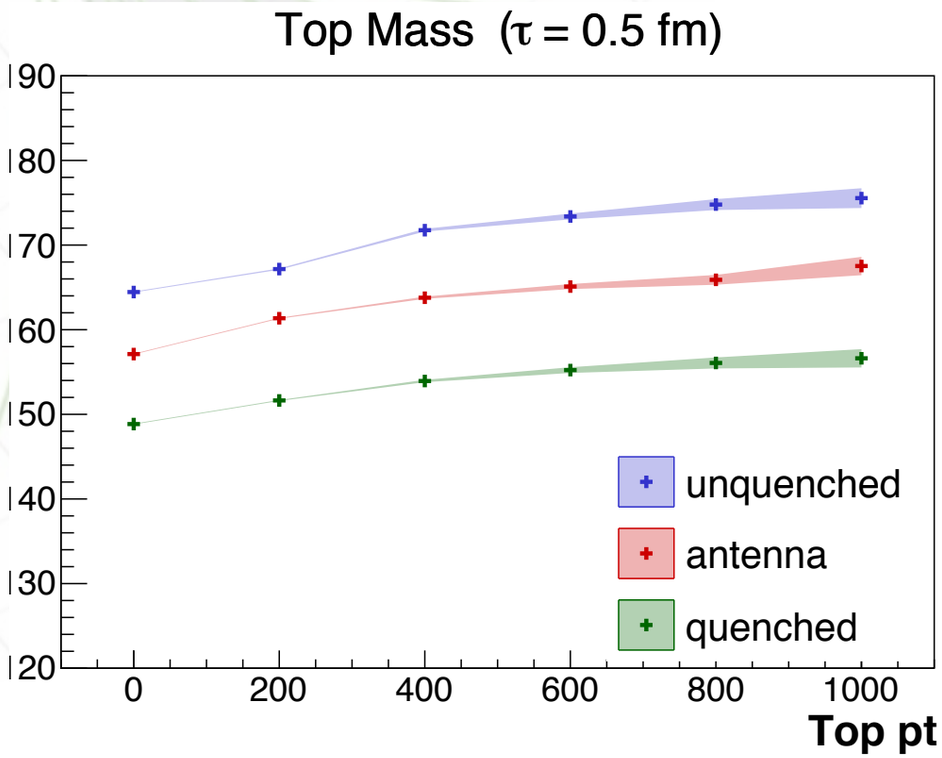


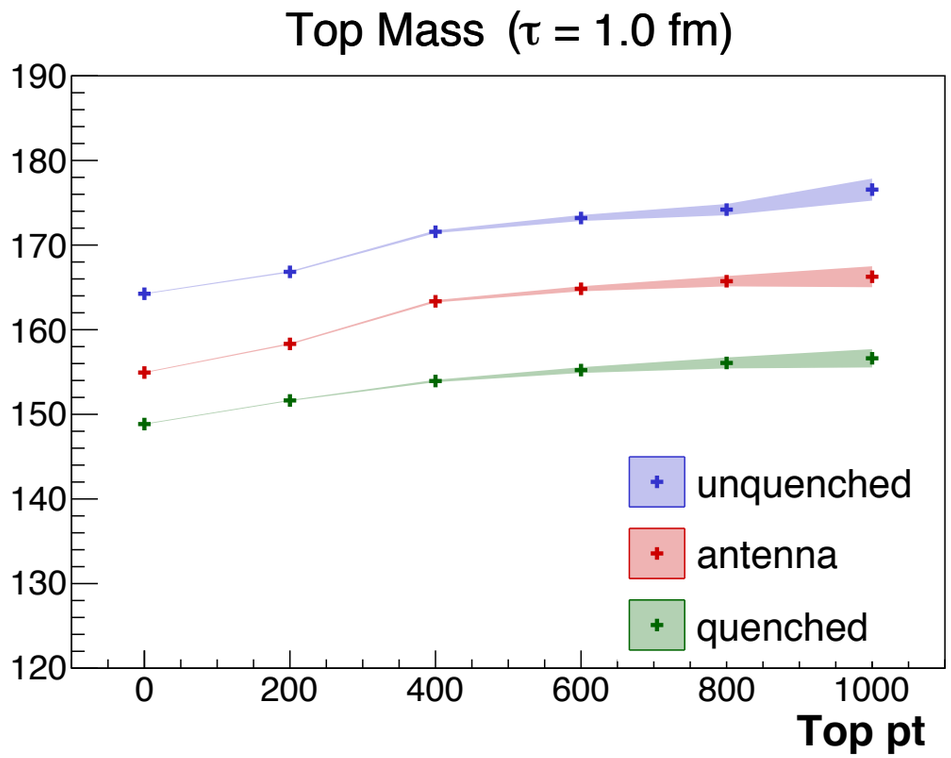


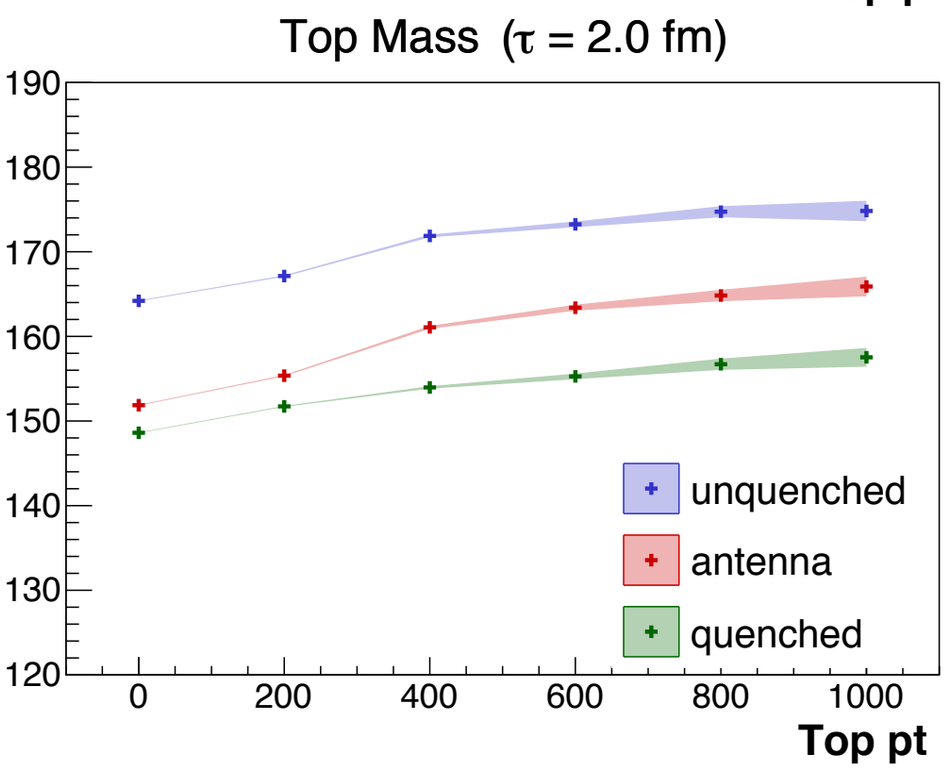
Depending on the chosen p_T, the antenna may still lose some energy.

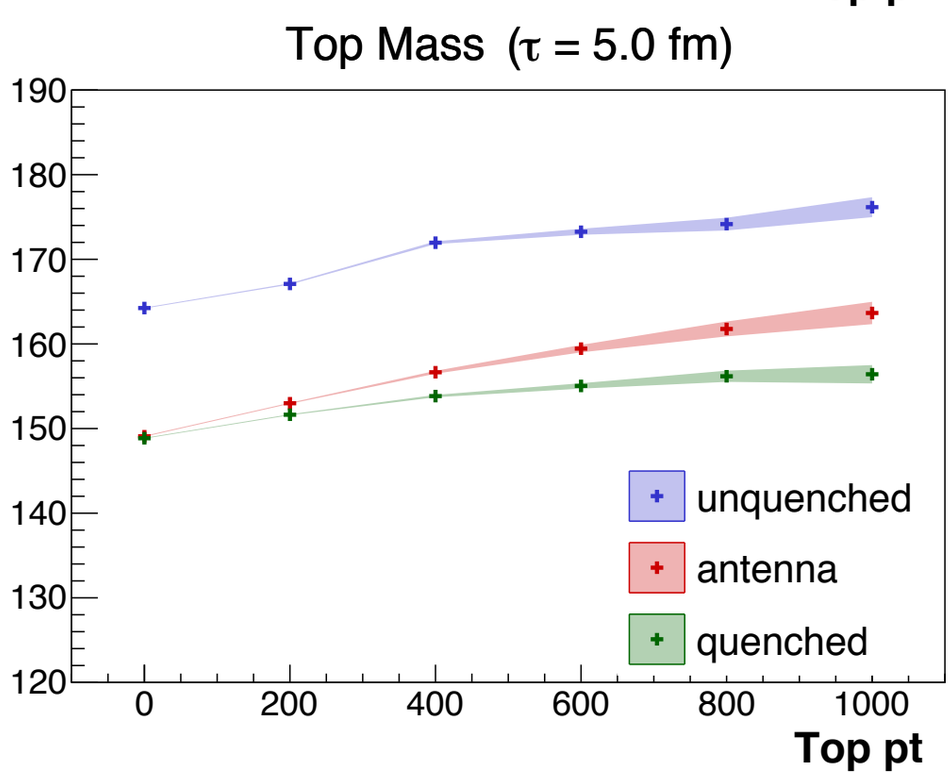
Knowing the energy loss, it is possible to build the density evolution profile of the medium!

Top Mass For Different T's



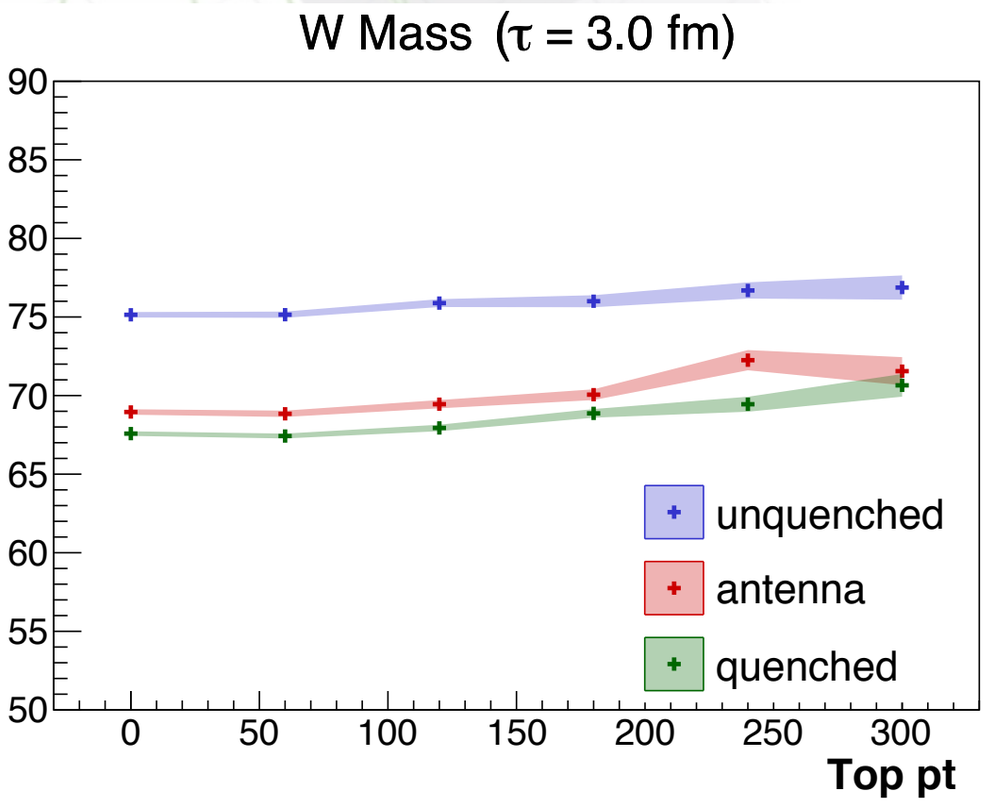


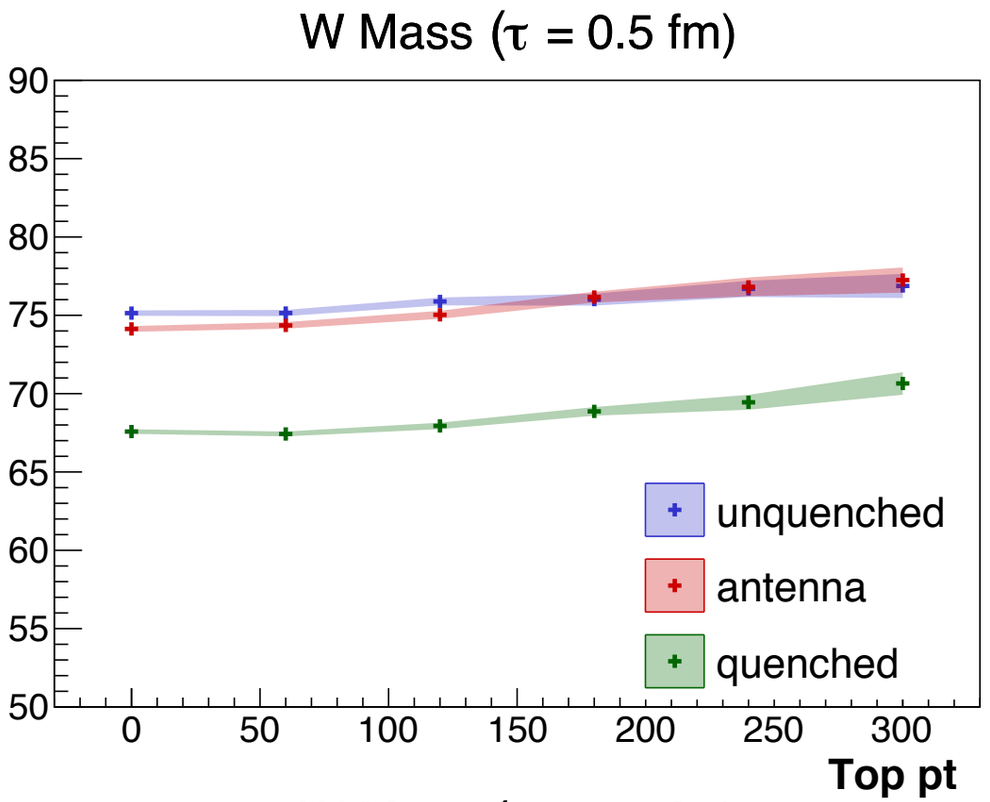


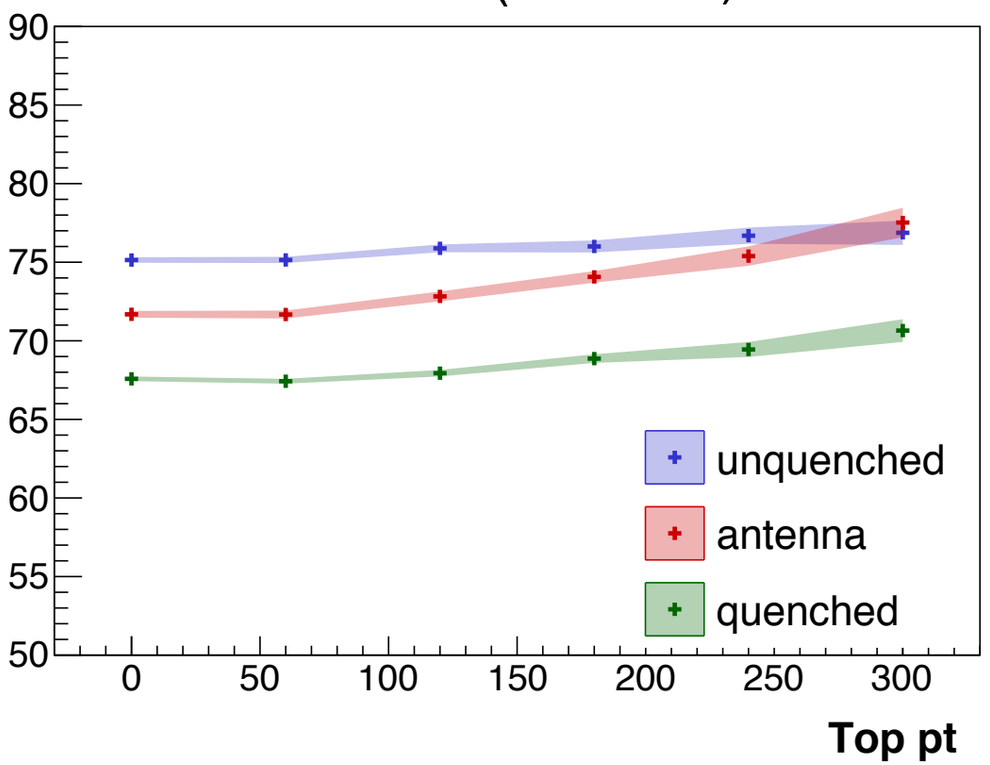


@ HL-LHC

- Because of statistics, we can only go up to t ~ 1 fm:







It is still possible to study jet coherence/ decoherence and different medium timescales (although more limited than FCC)

Conclusions

- Boosted probes (Top, W) might allow us to:
  - Assess more precisely the amount of quenching;
  - Test further the physics of jet coherence/decoherence;
  - Build up a picture of the density evolution:
    - [0.5 - 3.5] fm @ FCC (and further for higher luminosities)
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“A Yoctosecond Chronometer.”

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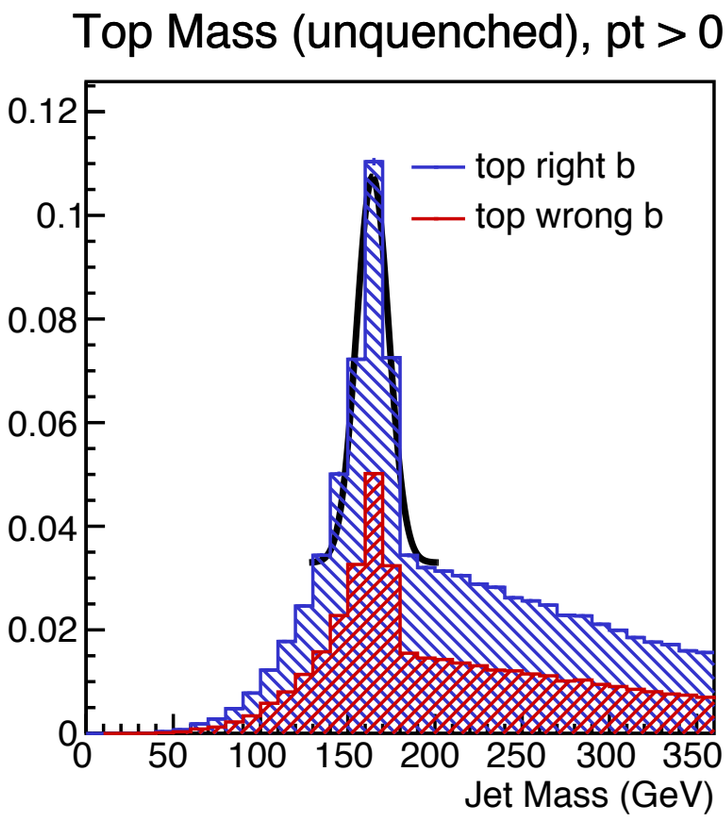
“A Yoctosecond Chronometer.”

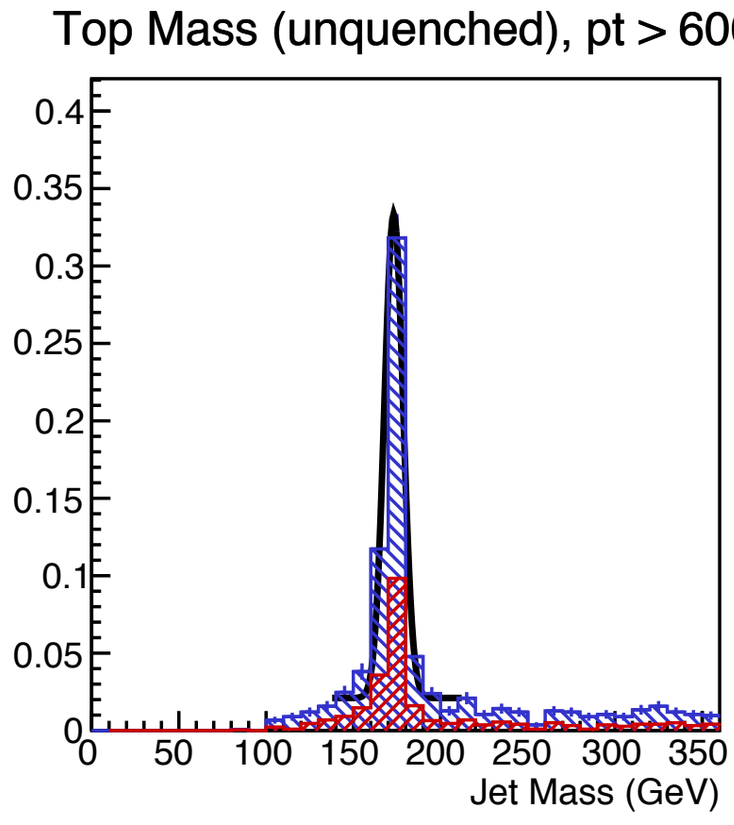
Thank you!

Backup Slides

Top with Right vs Wrong b-jet

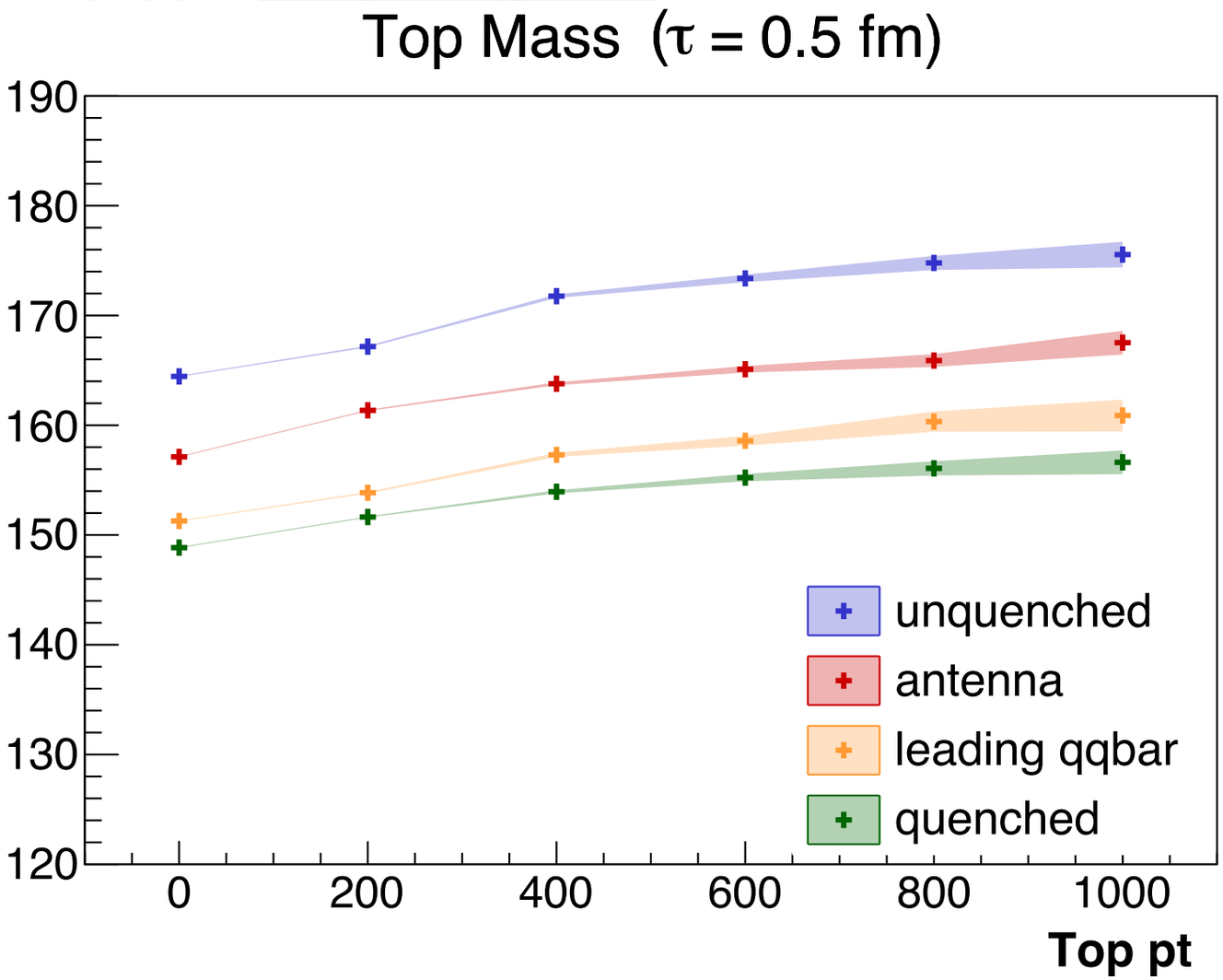
- Top Mass @ FCC:

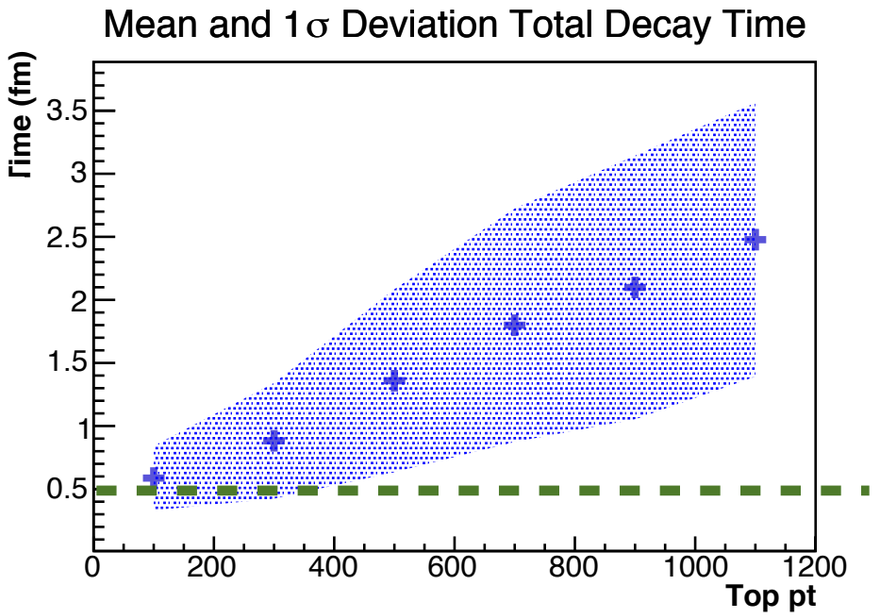


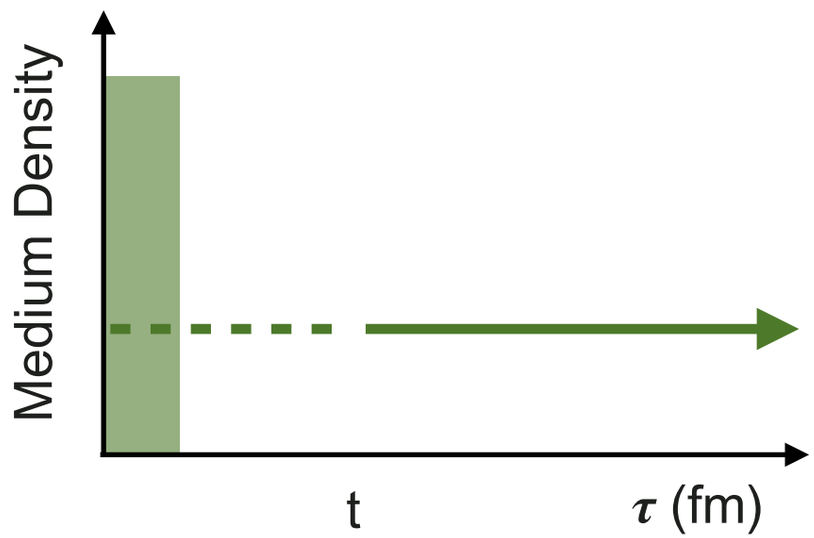


Time Dependent Energy Loss

- Reconstructed Top Jet Mass:



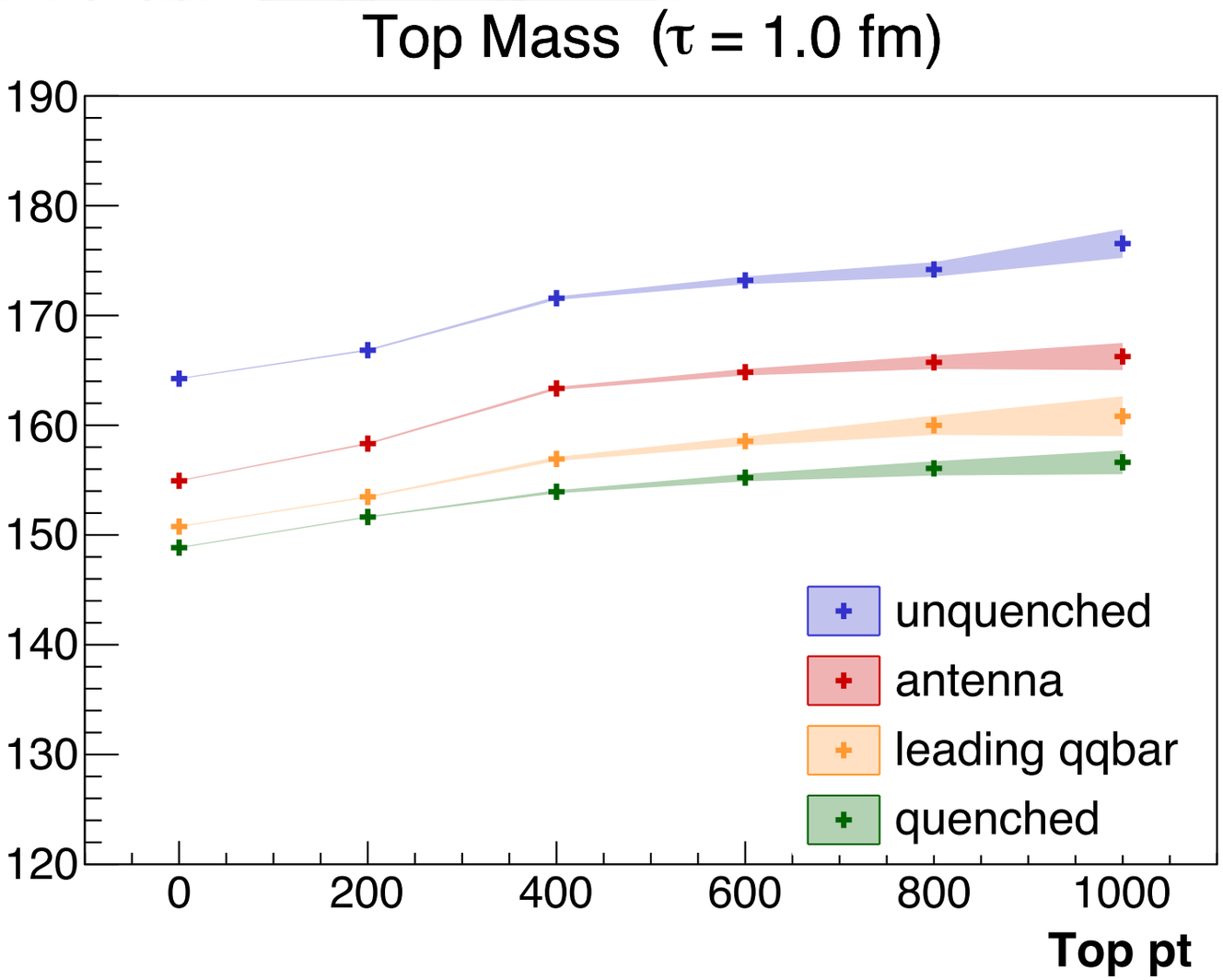


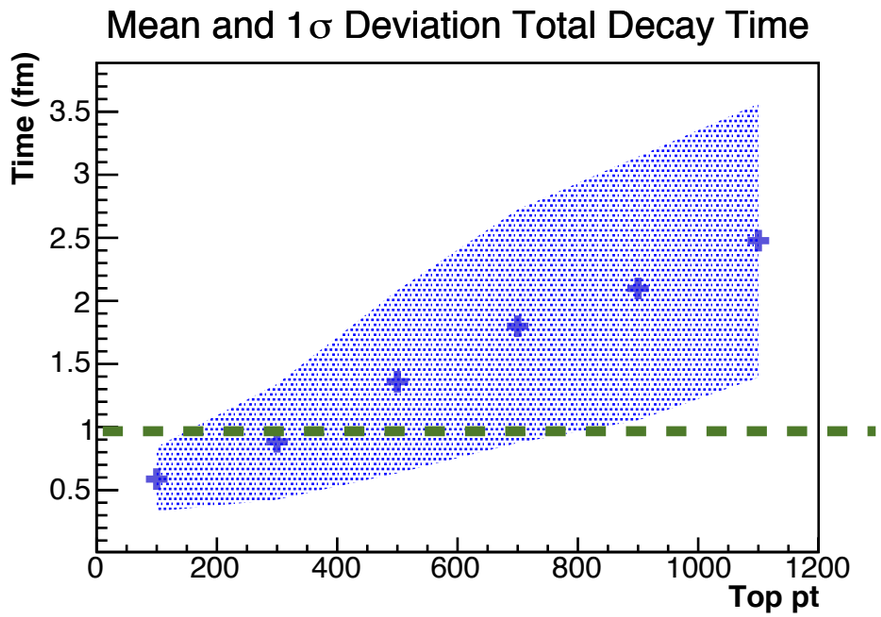


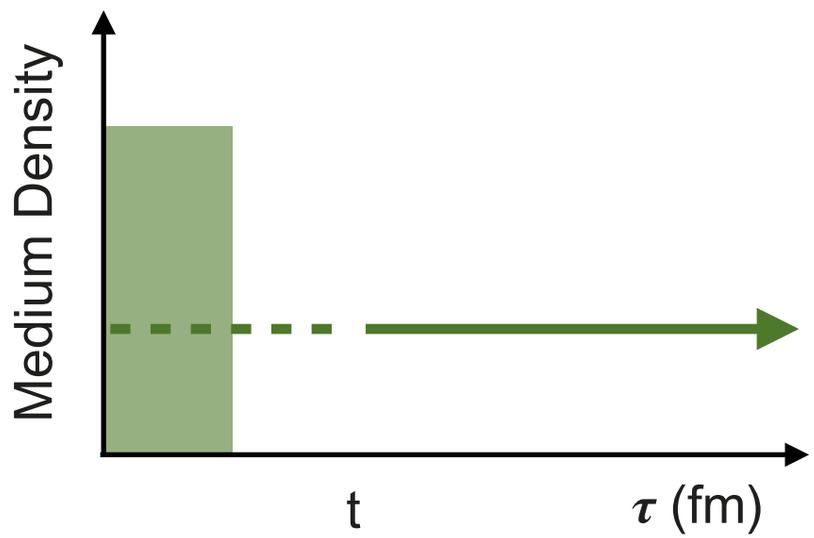
All particles lose energy but the antenna

Time Dependent Energy Loss

- Reconstructed Top Jet Mass:

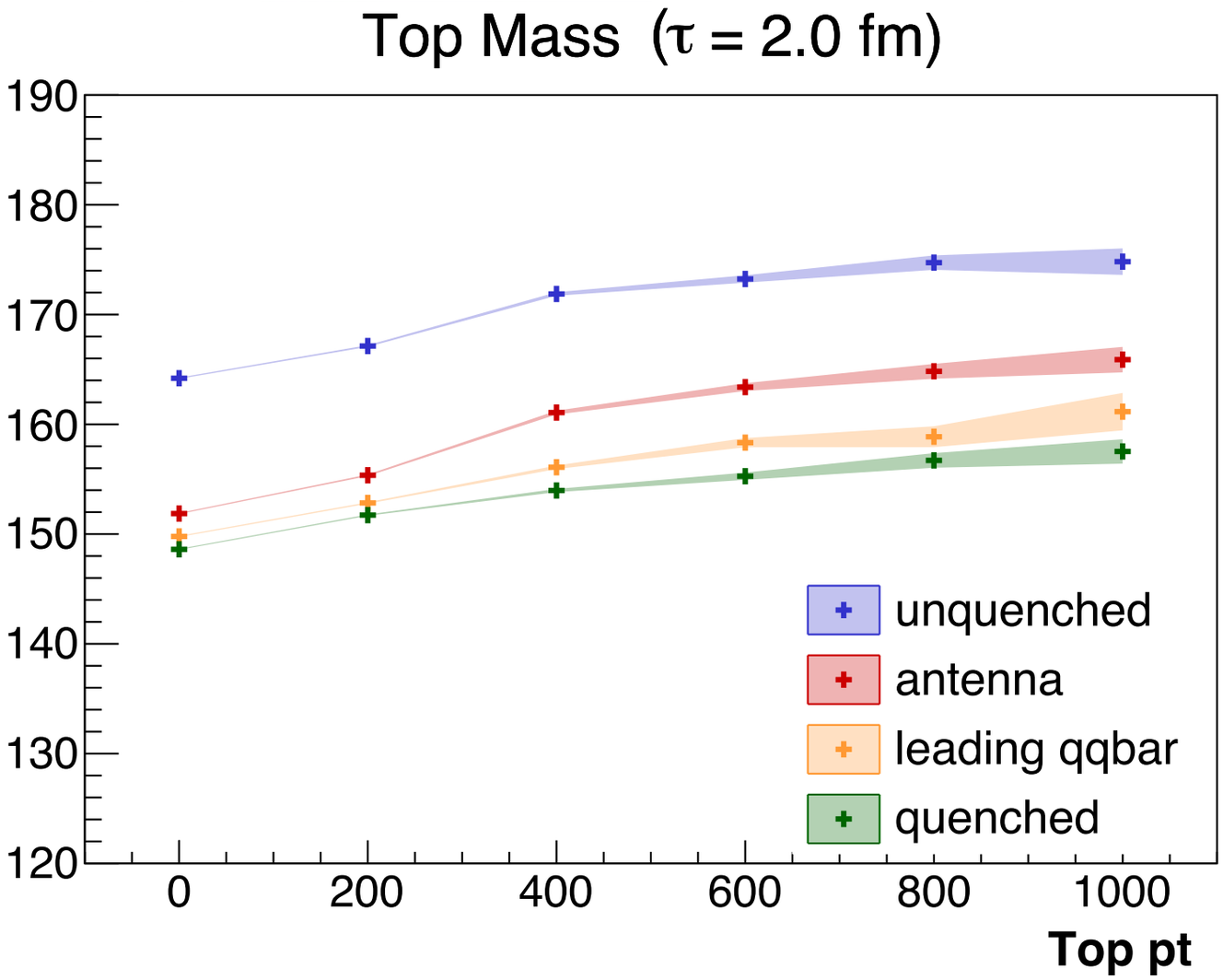


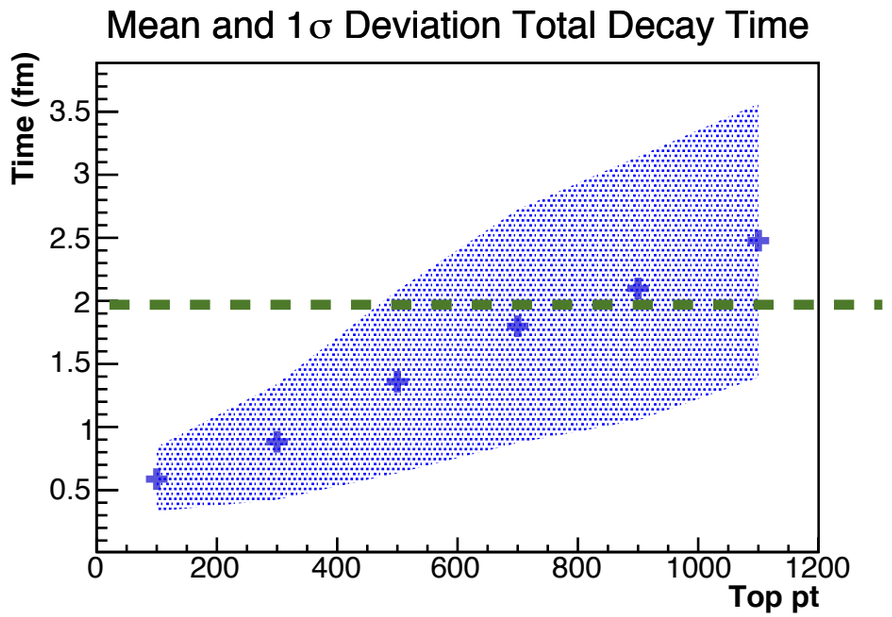


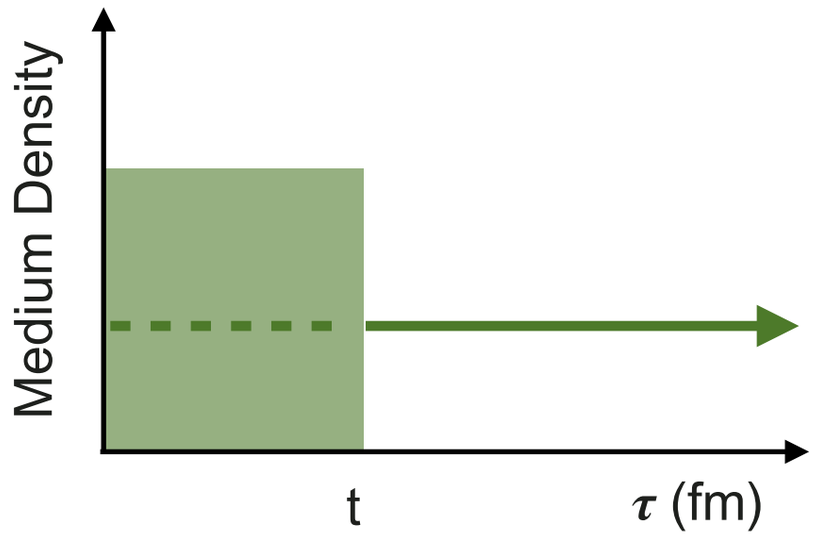


Time Dependent Energy Loss

- Reconstructed Top Jet Mass:

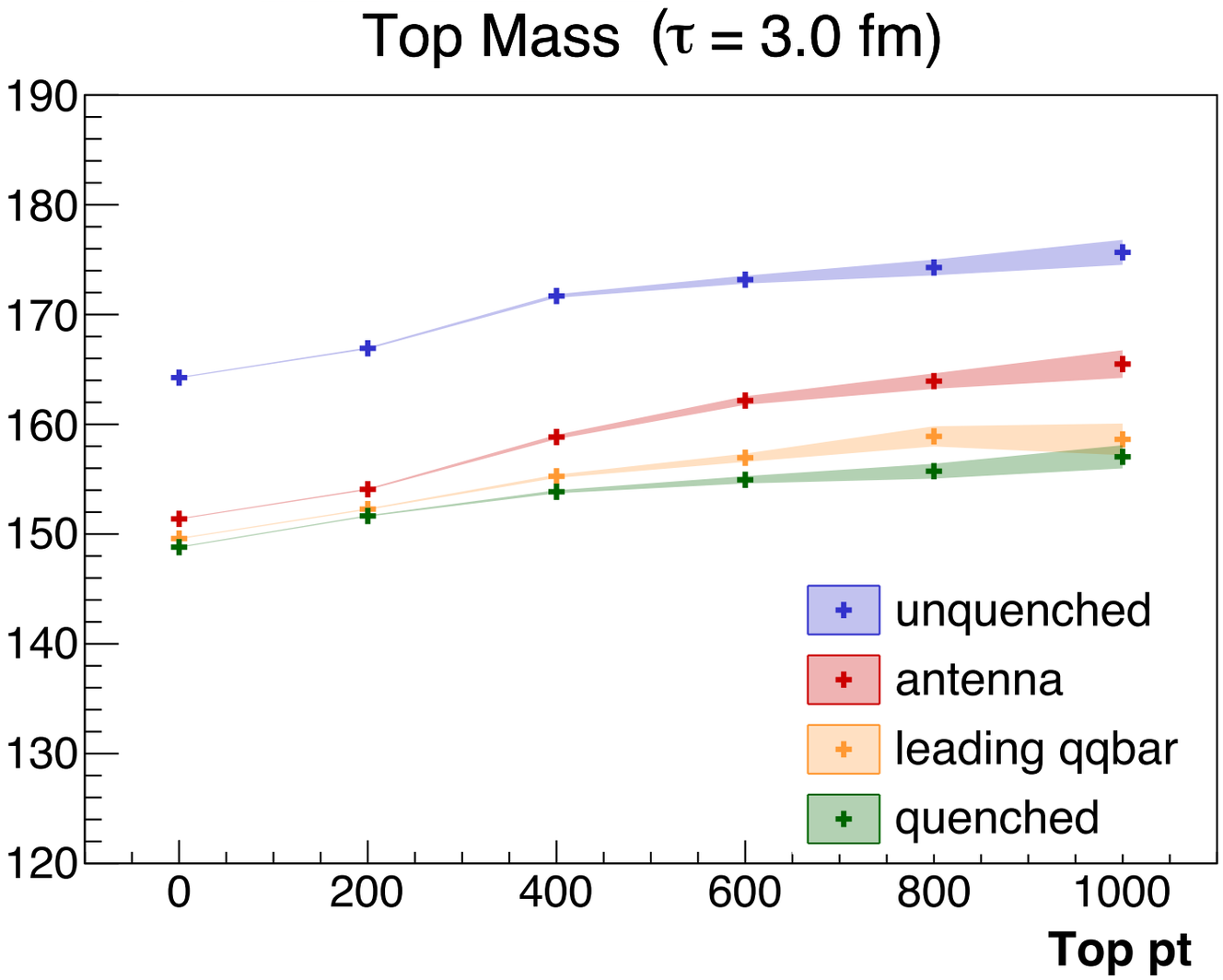


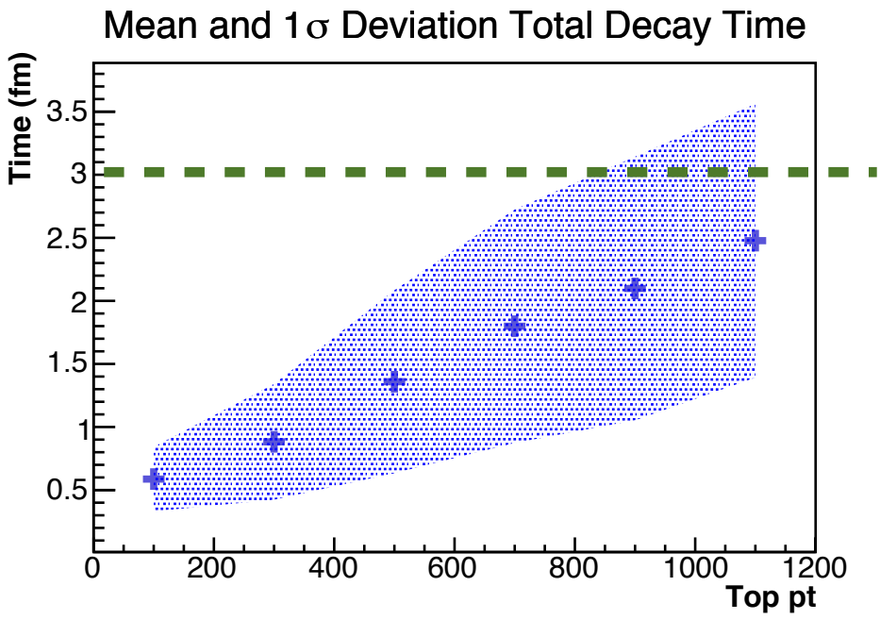


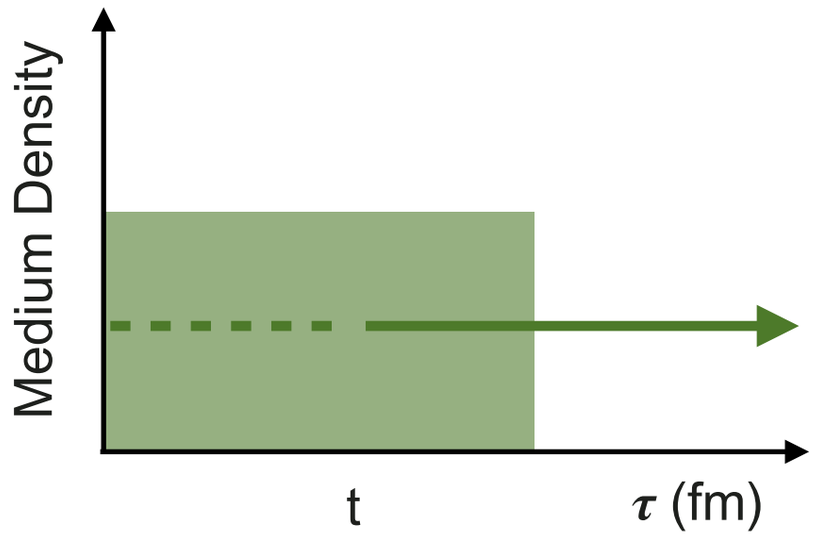


Time Dependent Energy Loss

- Reconstructed Top Jet Mass:



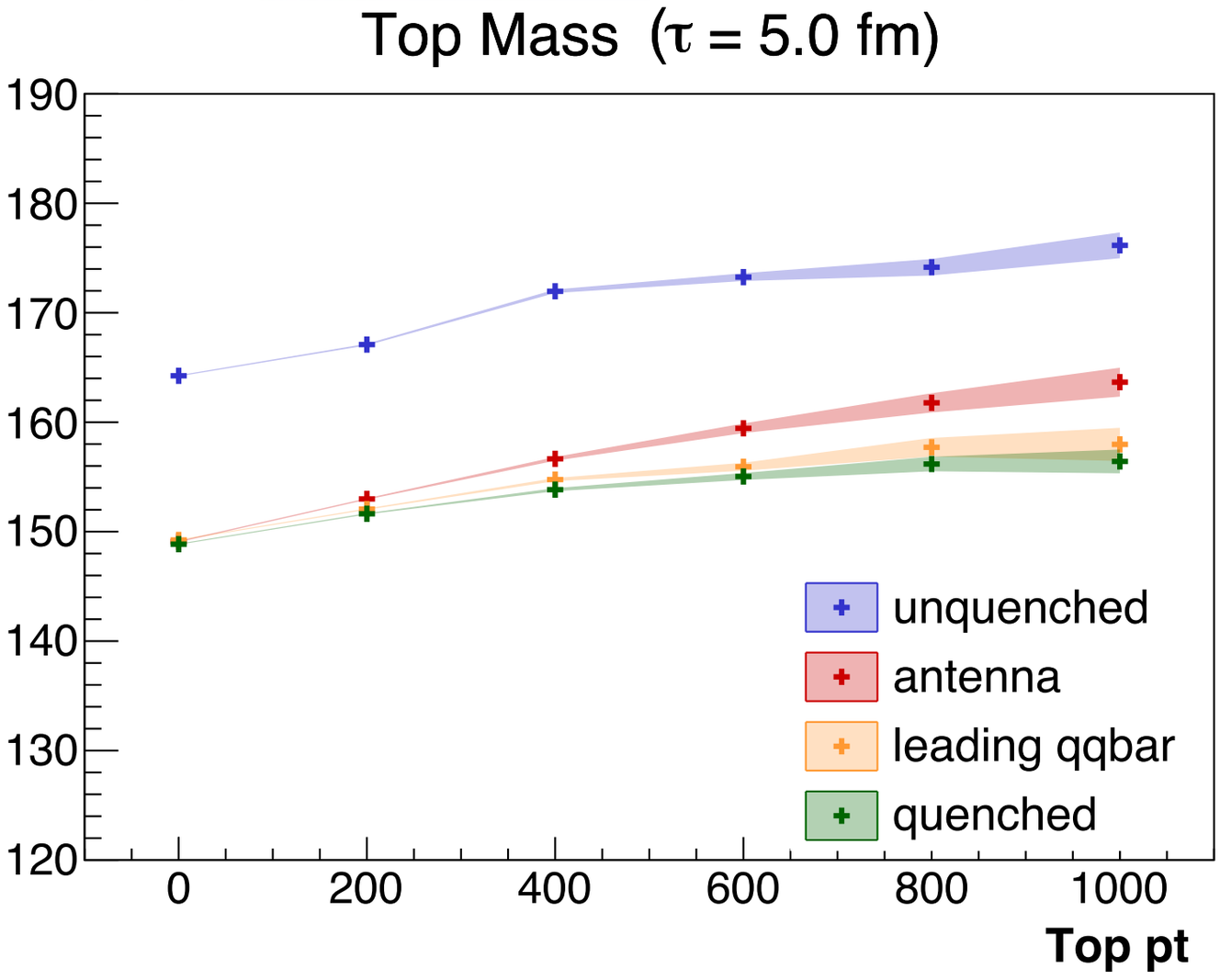


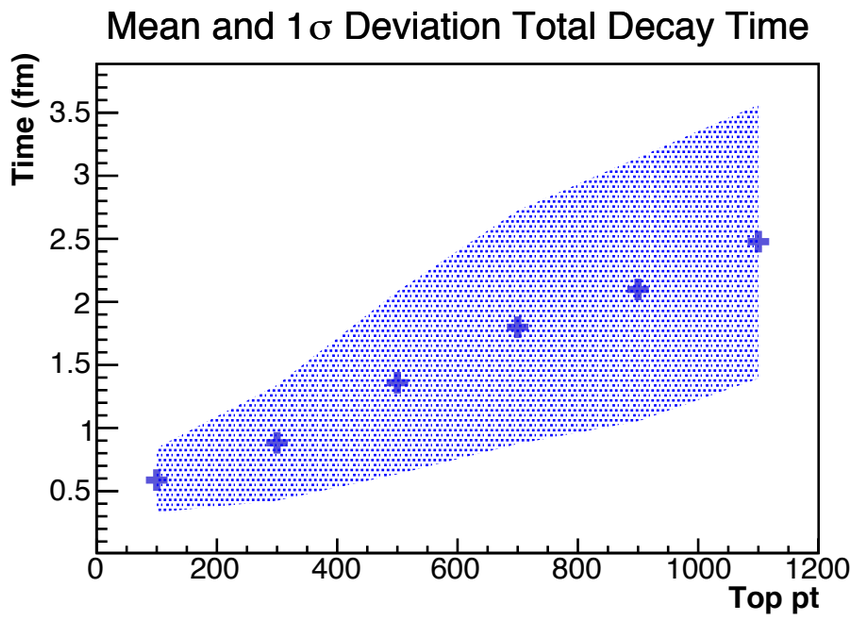


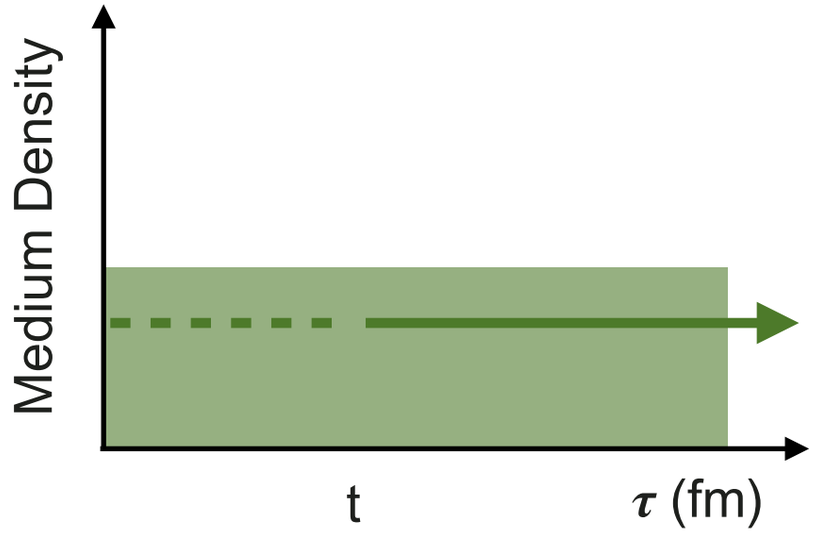
All particles lose energy but the antenna

Time Dependent Energy Loss

- Reconstructed Top Jet Mass:



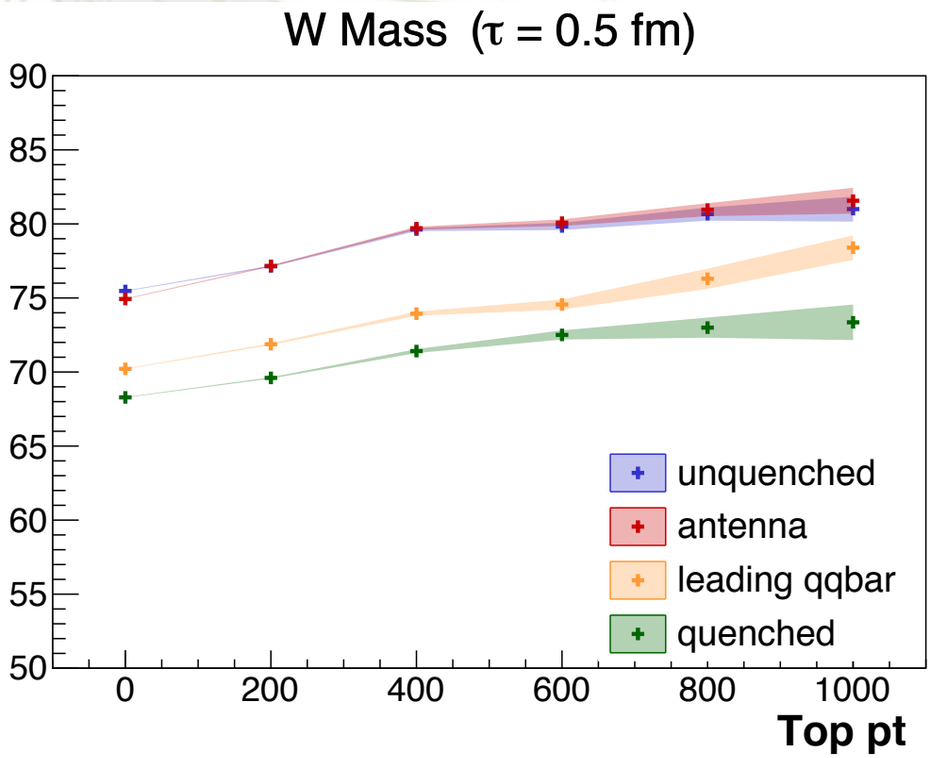


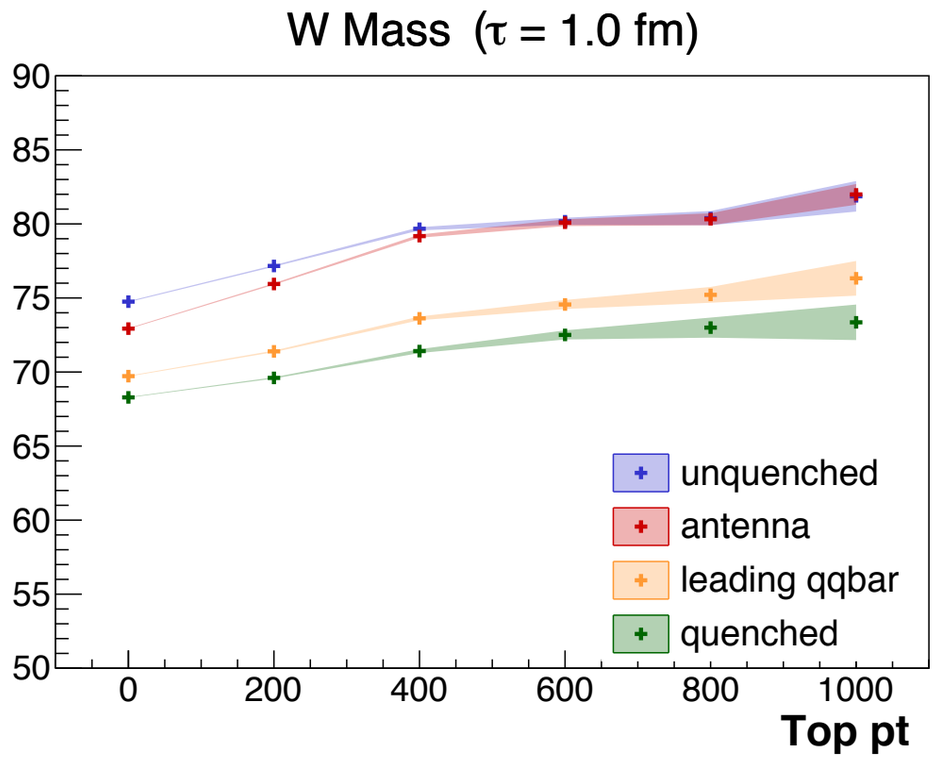


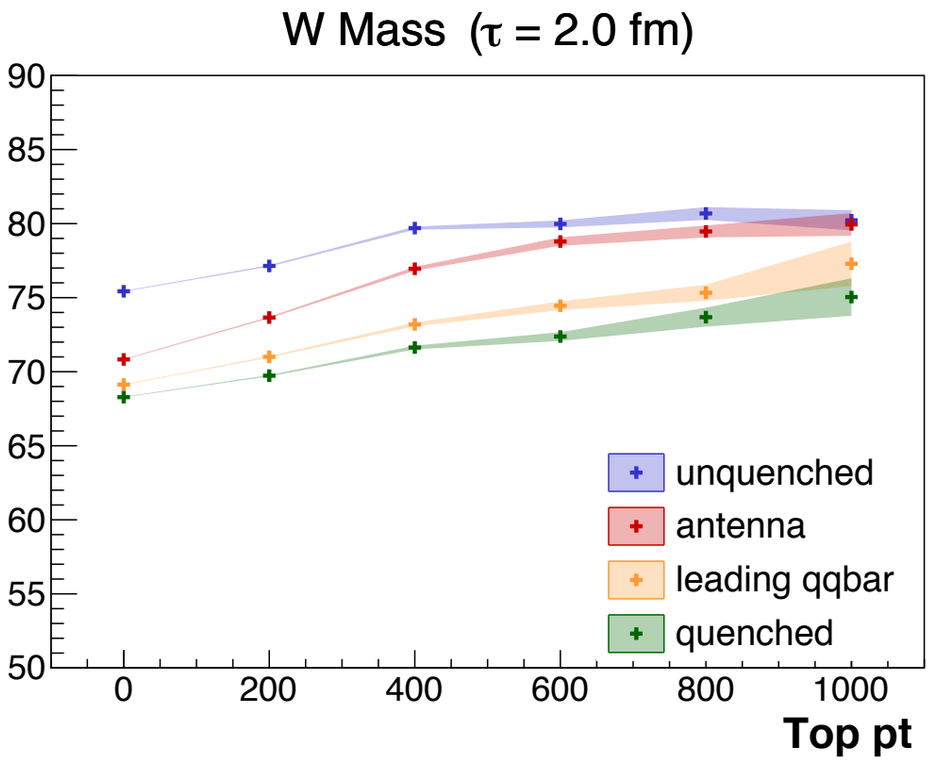
Depending on the chosen p_T, the antenna may still lose some energy.

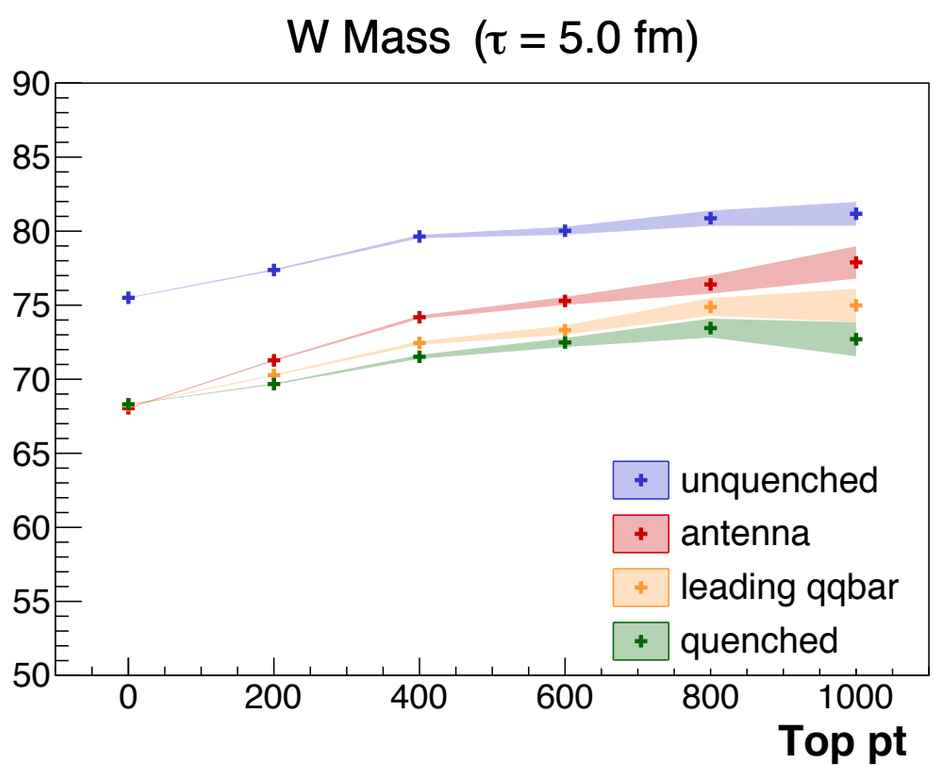
Knowing the energy loss, it is possible to build the density evolution profile of the medium!

W Mass For Different T's



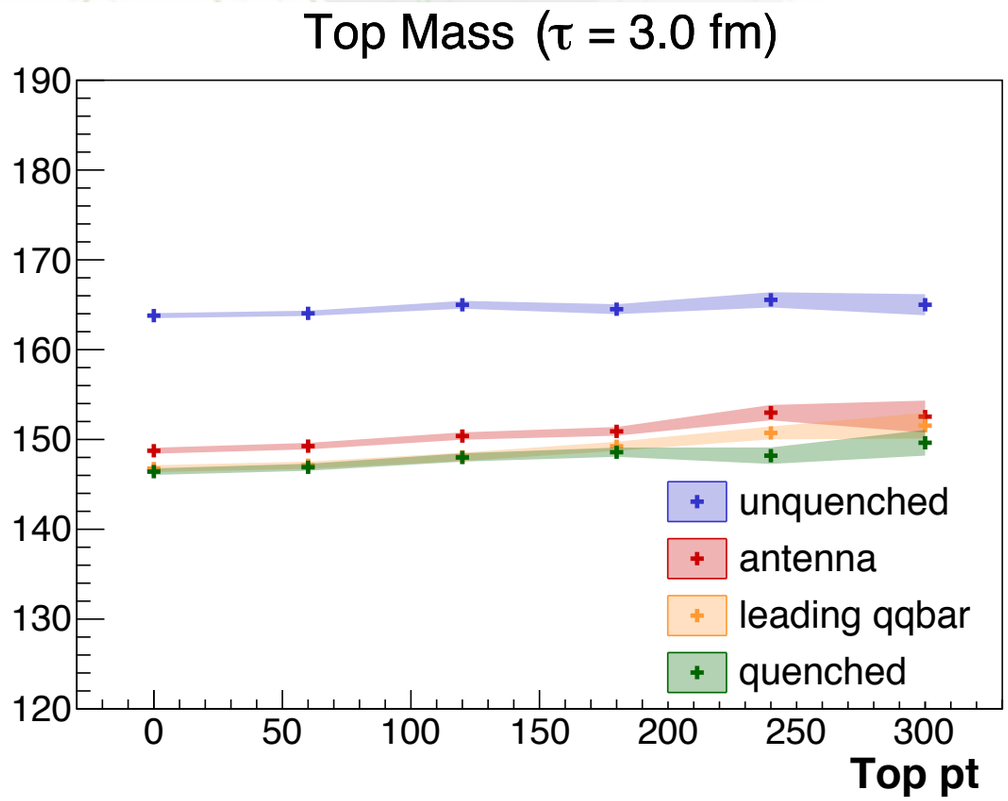


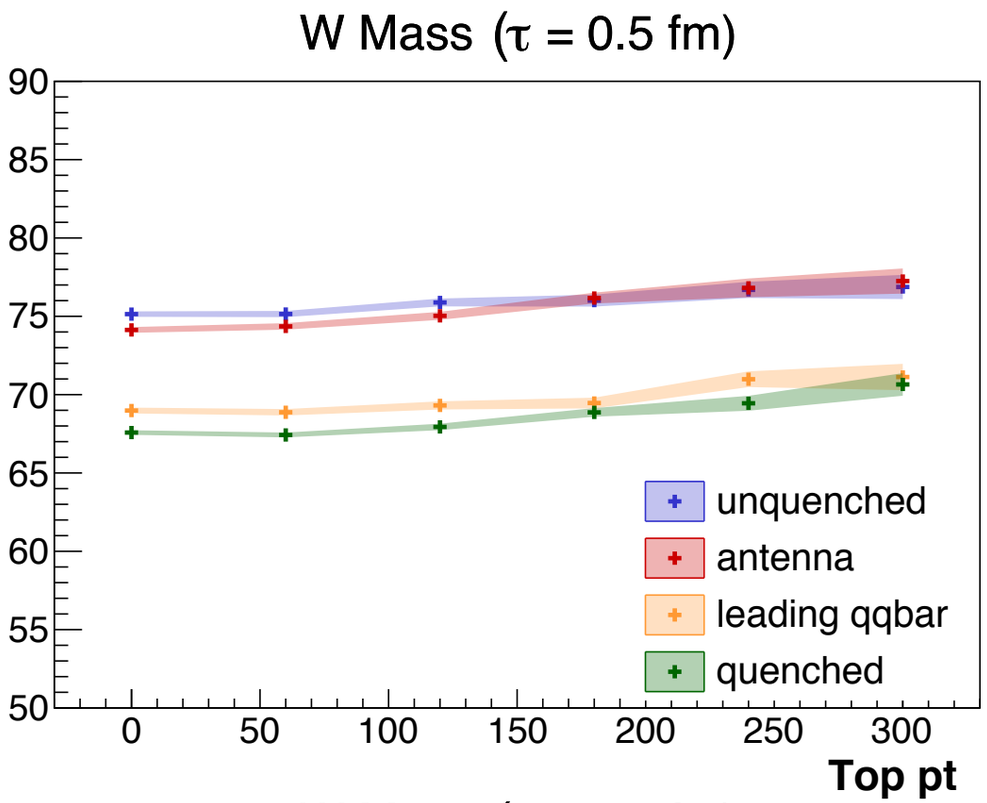


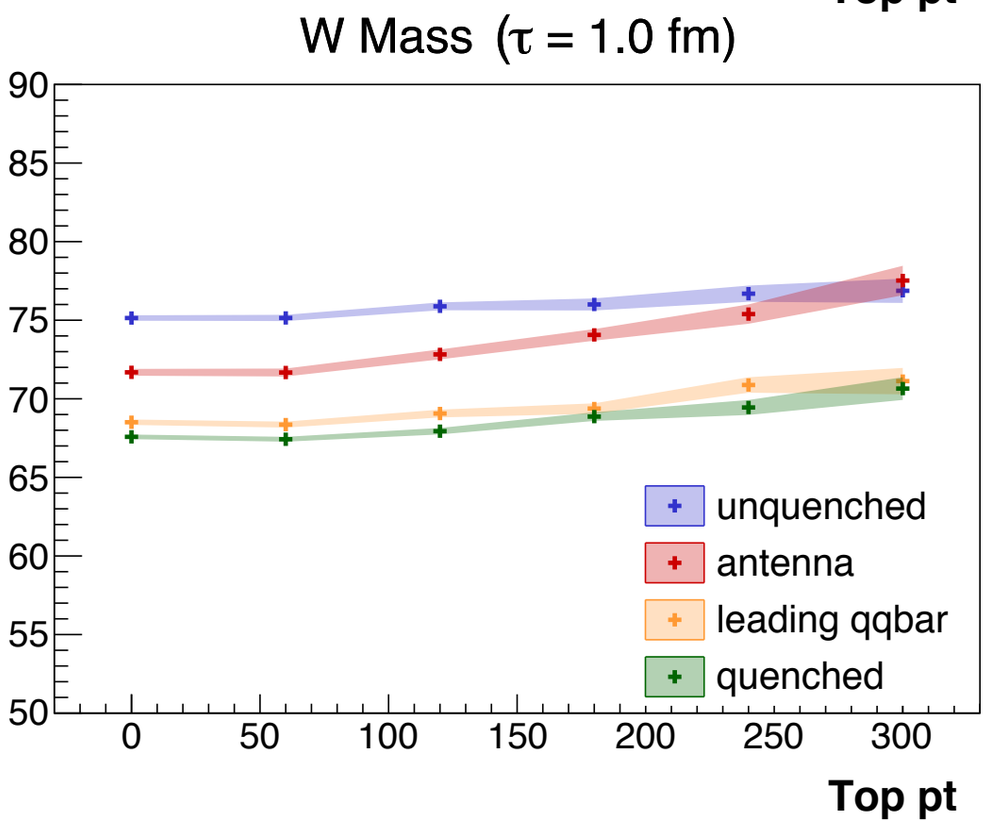


@ HL-LHC

- Because of statistics, we can only go up to t ~ 1 fm:







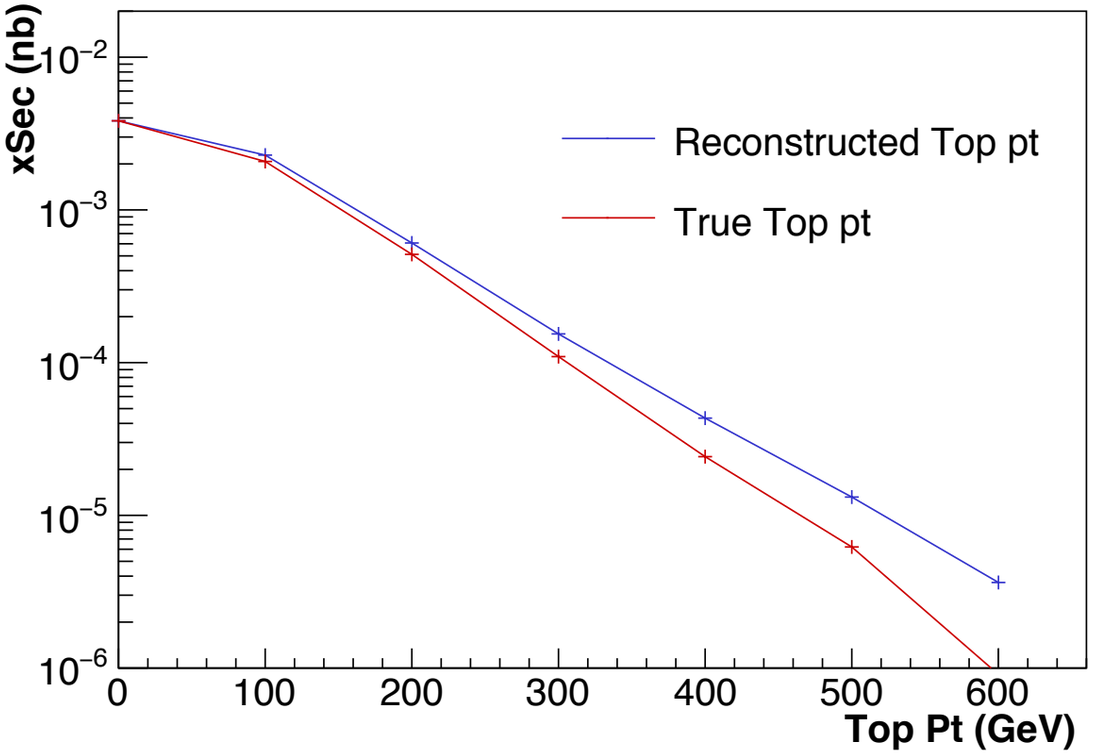
It is still possible to study jet coherence/ decoherence and different medium timescales (although more limited than FCC)

Pythia8 Cross Section

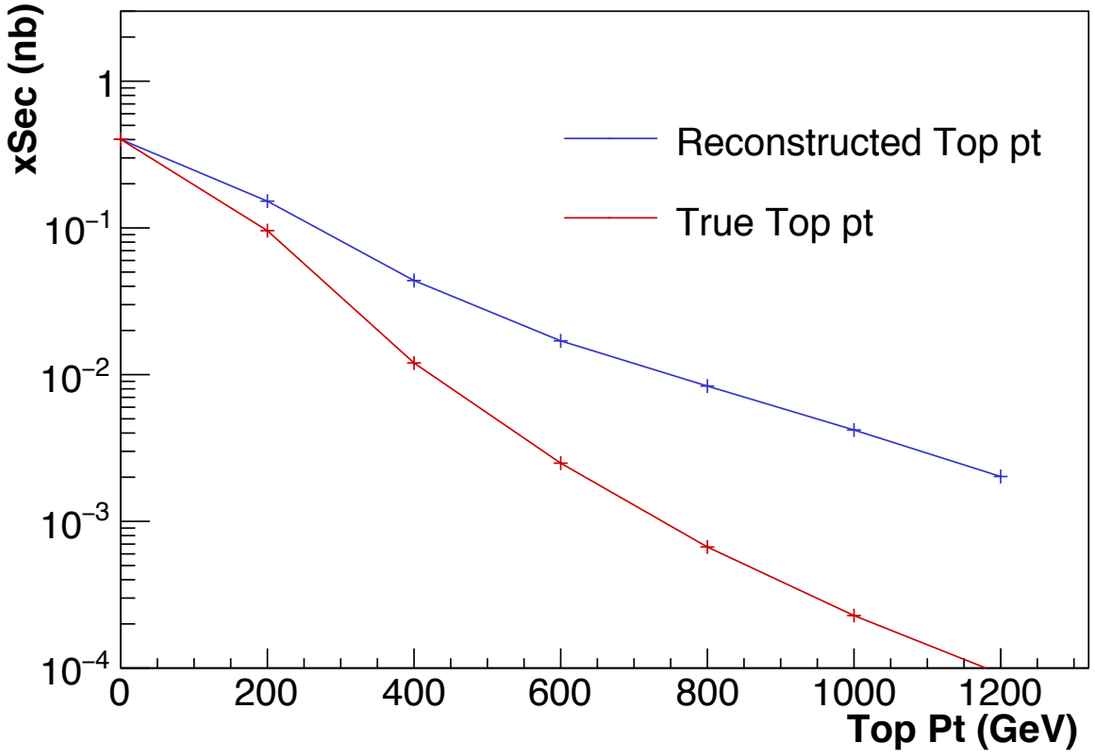
- Compatible with NLO CT14 but ISR contamination not entirely understood…

LHC - HL	FCC

Reconstructed Top cross-section



Reconstructed Top cross-section



Pythia8: Top and W Mass vs P_T

- Statistical significance calculated using a bootstrap technique: