origin of di-jet asymmetry

1512.08107 [hep-ph]

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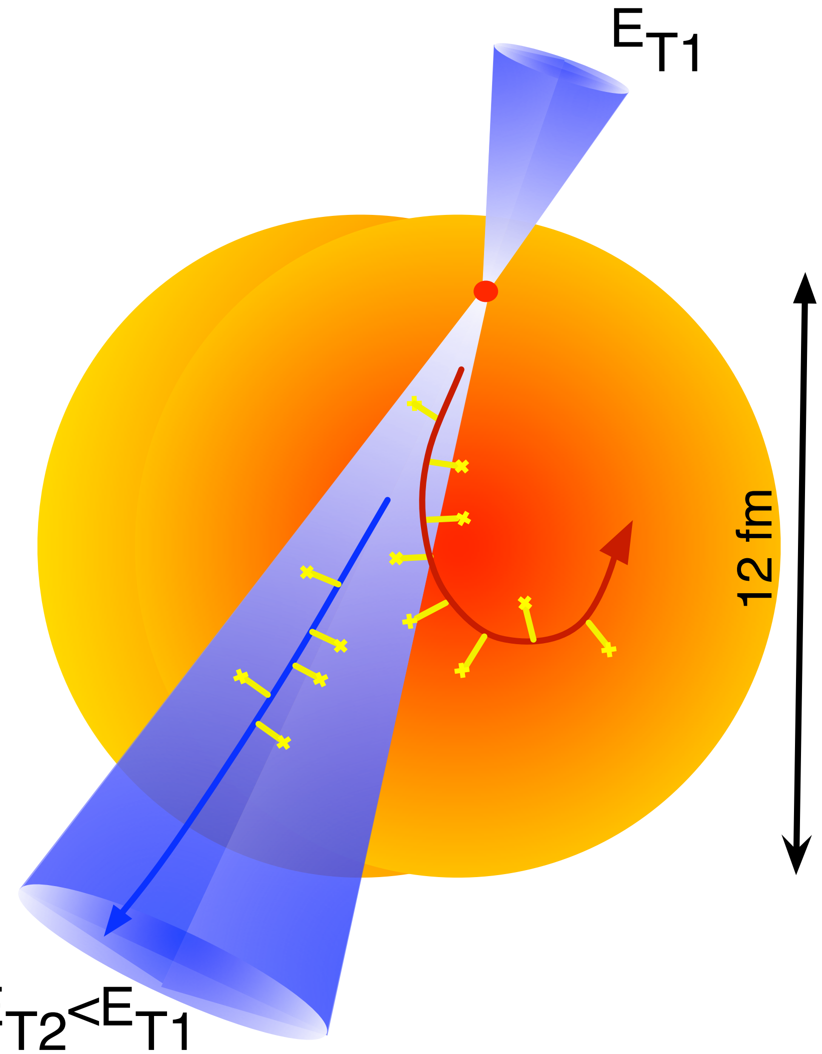
2010

Casalderrey, Milhano, Wiedemann ::1012.0745 [hep-ph]



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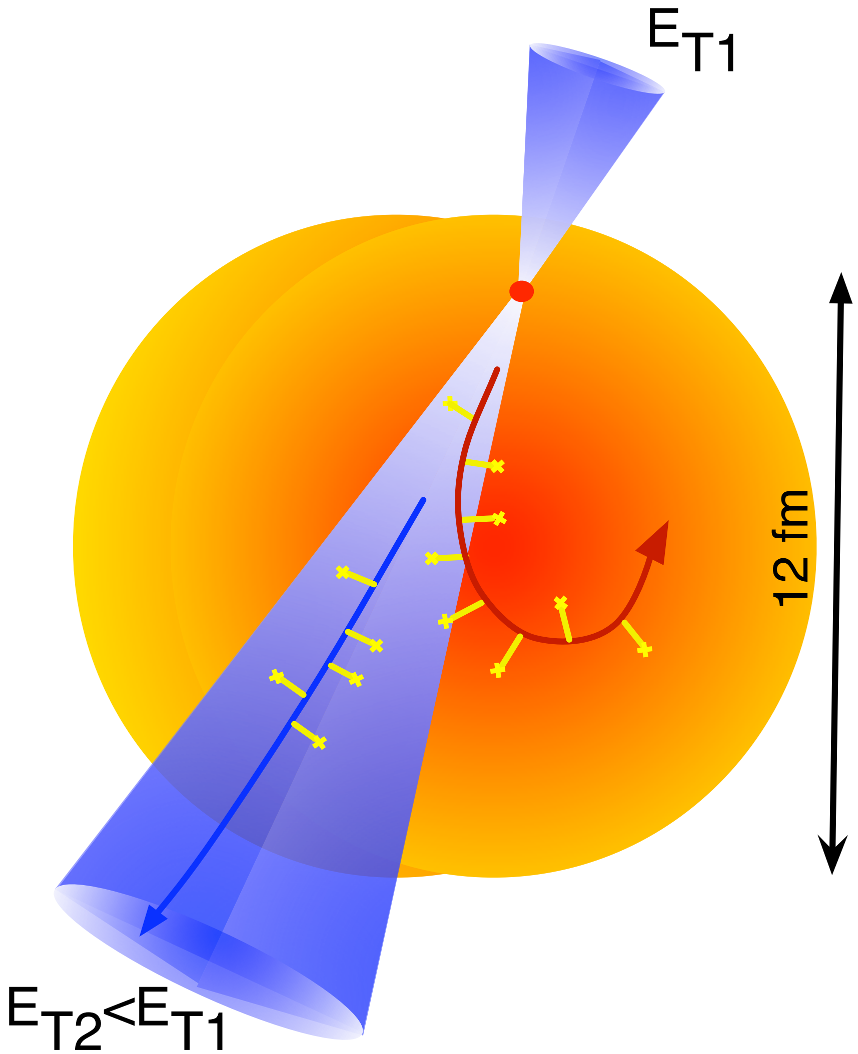

- observed increase in di-jet asymmetry in AA collisions due to peeling-off of soft radiation [both vacuum-like and medium-induced]

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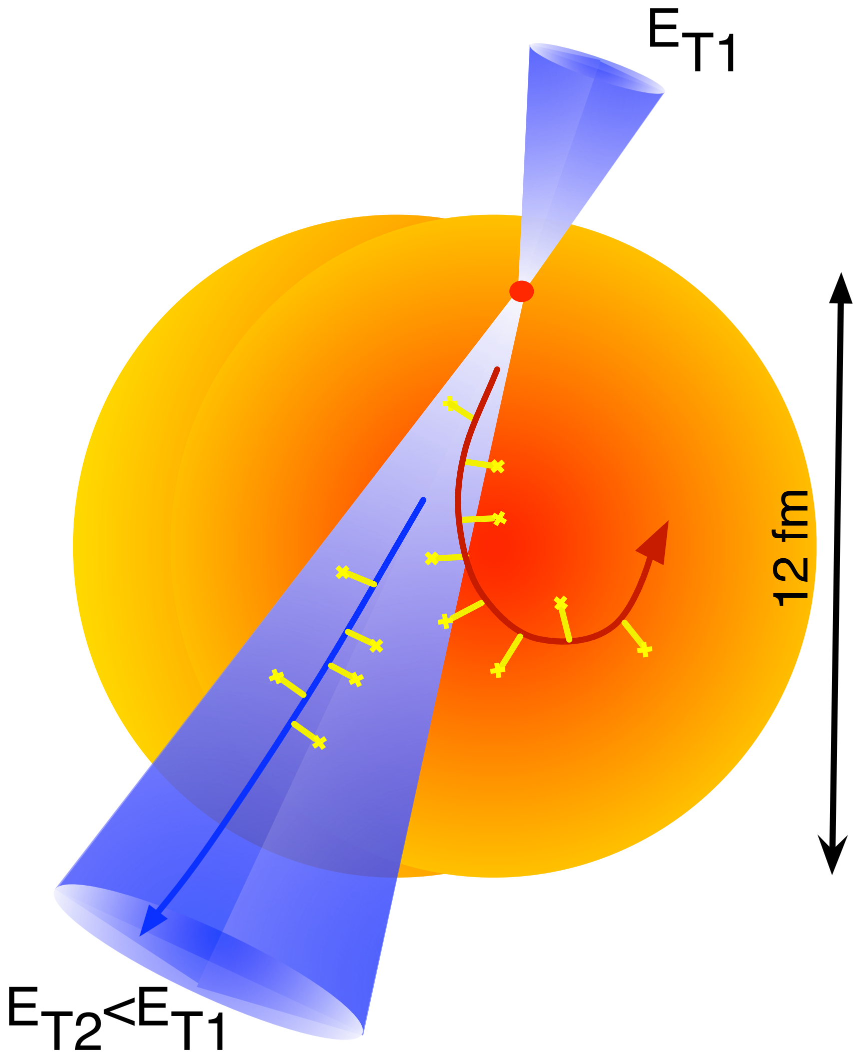

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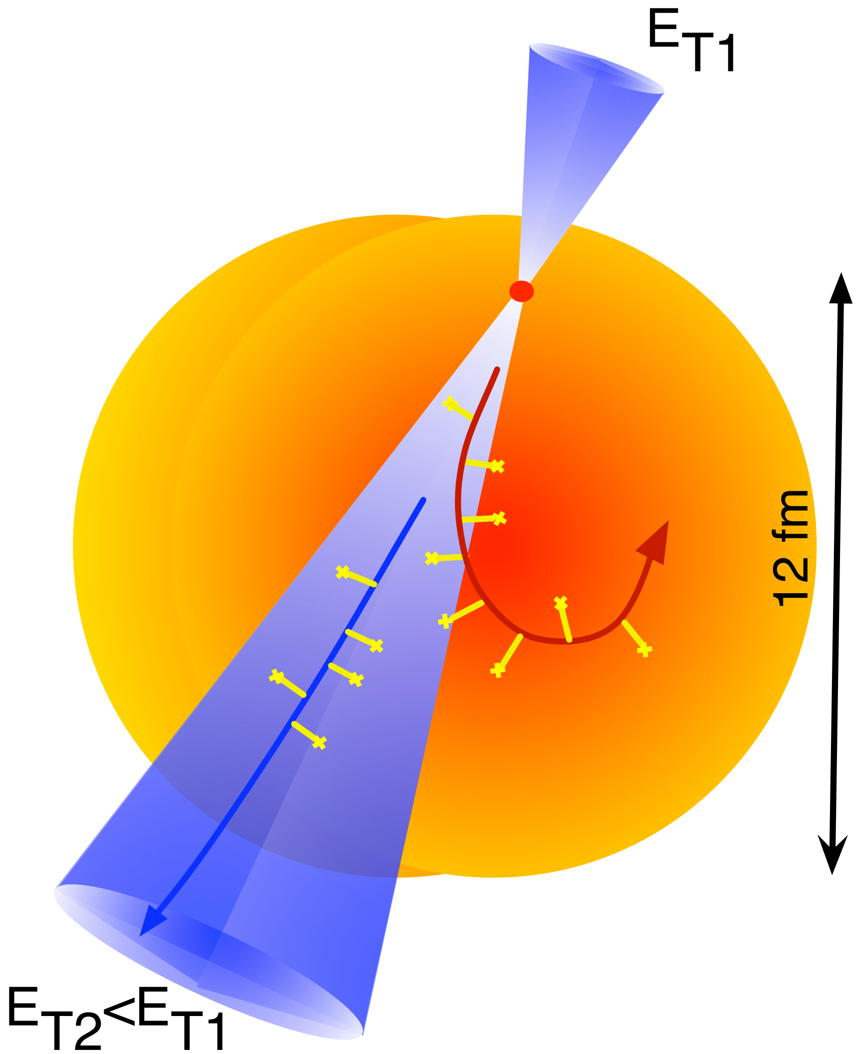

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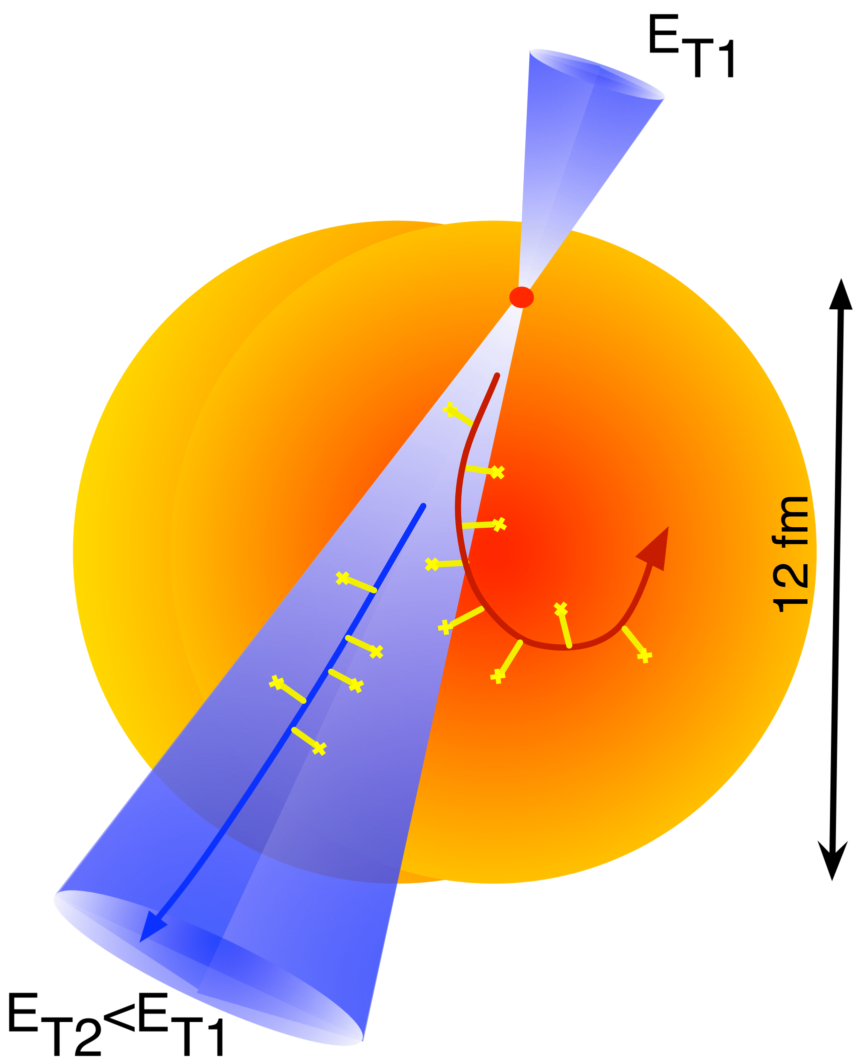

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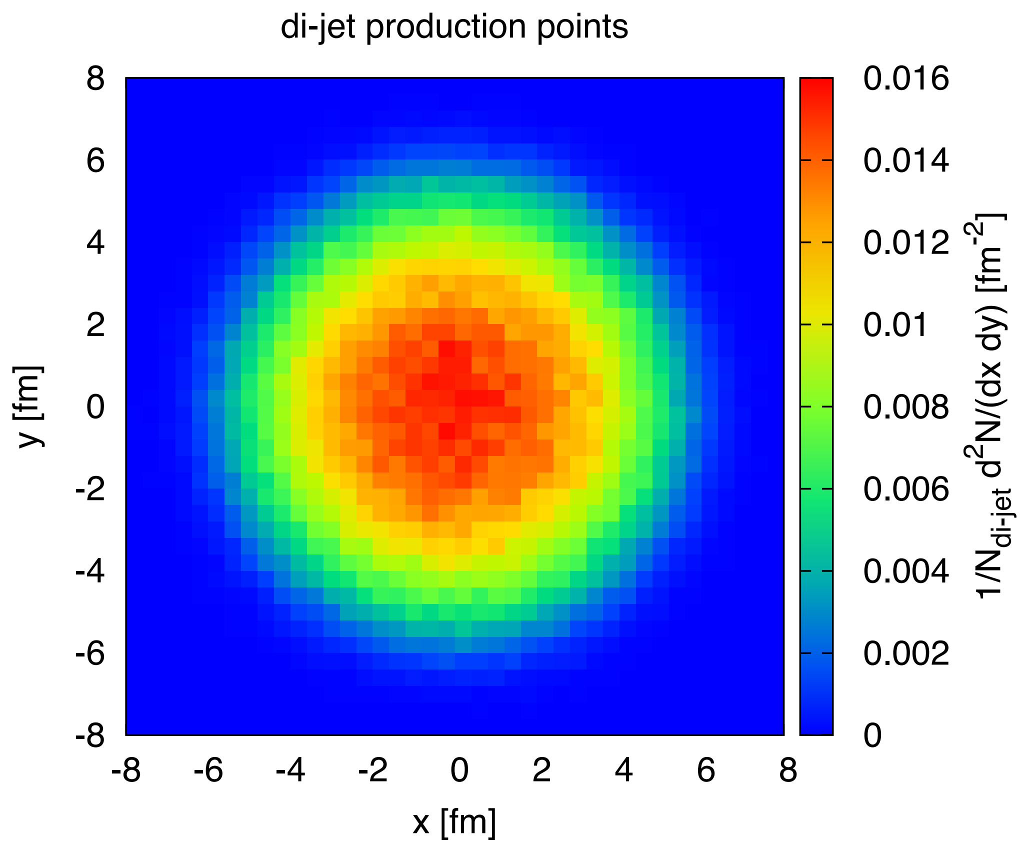
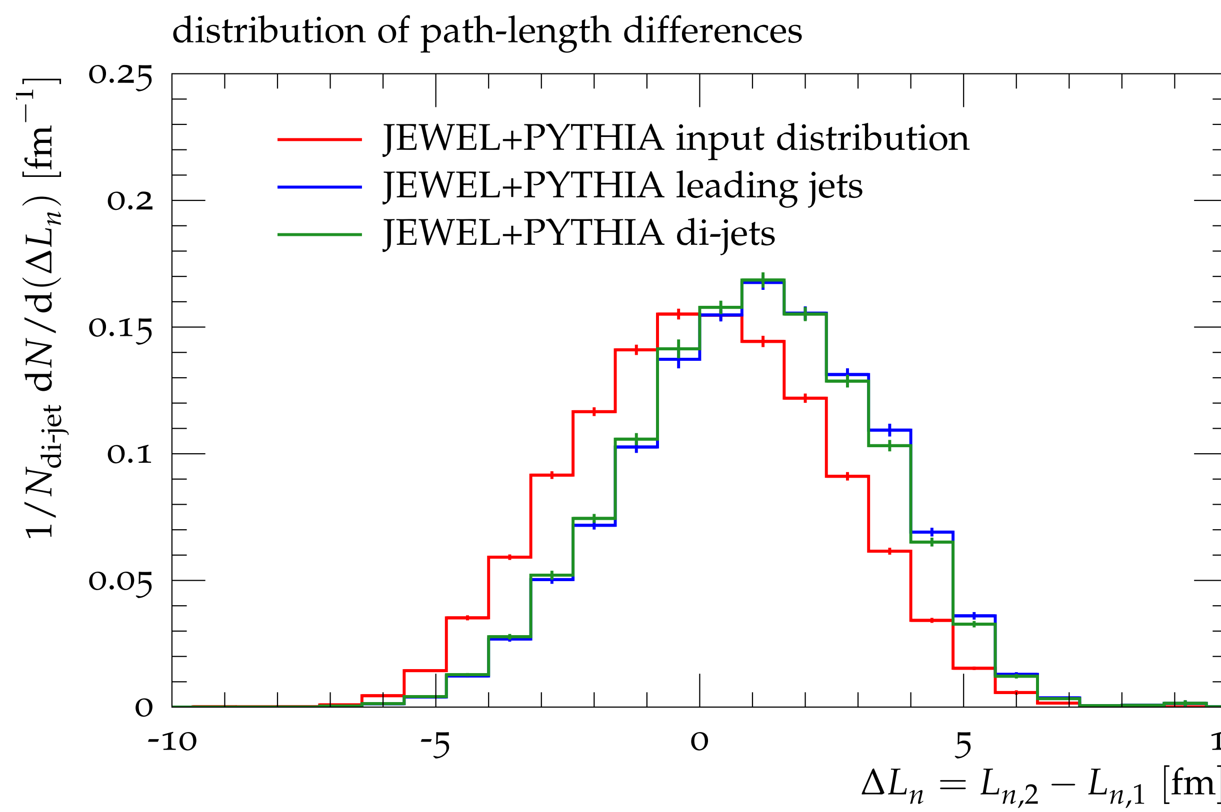
- NOT compatible with jet energy loss via induced radiation of few hardish gluons
- original works assumed [at least implicitly] considerable path-length difference between the two jets
  - thus, that path-length difference was assumed important for the increase of asymmetry

DOES THE LEADING JET TRAVERSE LESS QGP?





density weighted path-length
[accounts for medium expansion, rapidity independent for boost invariant medium]

$$L_n = 2\frac{\int \mathrm{d}\tau\, \tau n(\mathbf{r}(\tau),\tau)}{\int \mathrm{d}\tau\, n(\mathbf{r}(\tau),\tau)}$$

- small bias towards smaller path-length for leading jets
  - however, significant fraction [34%] of events have longer path-length for leading jet
  - consequence of fast medium expansion

CAN A_J BE GENERATED FOR EQUAL PATH LENGTHS ?

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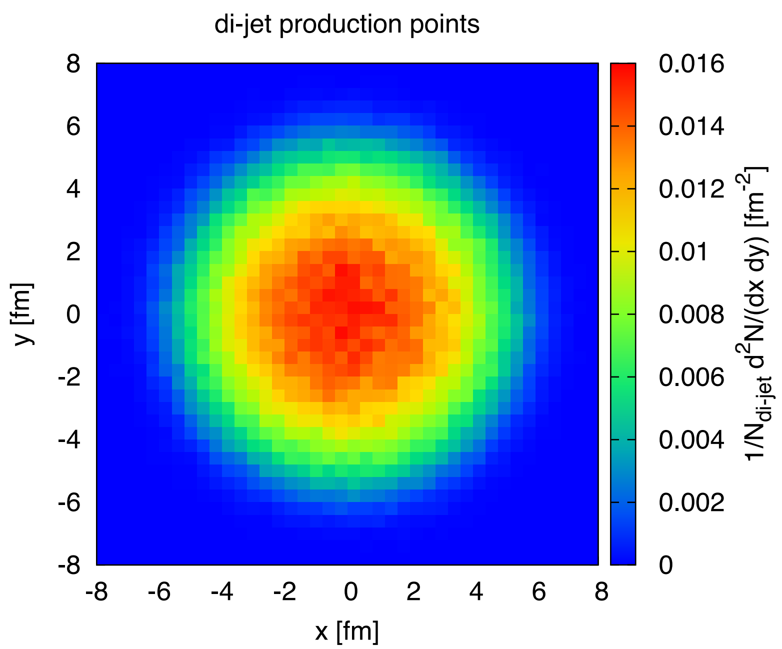

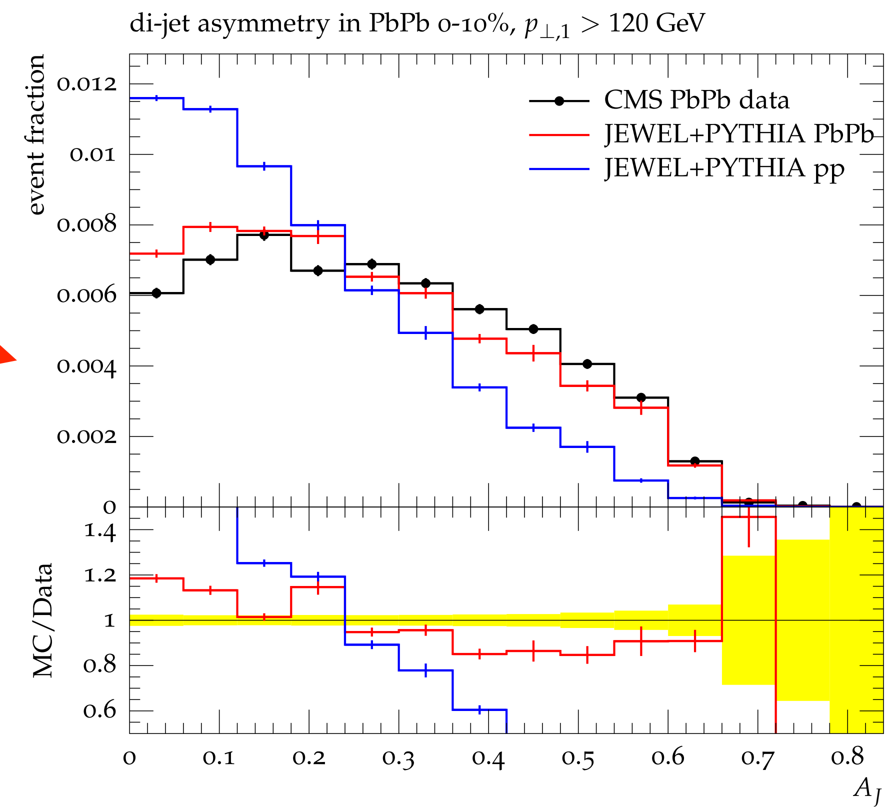

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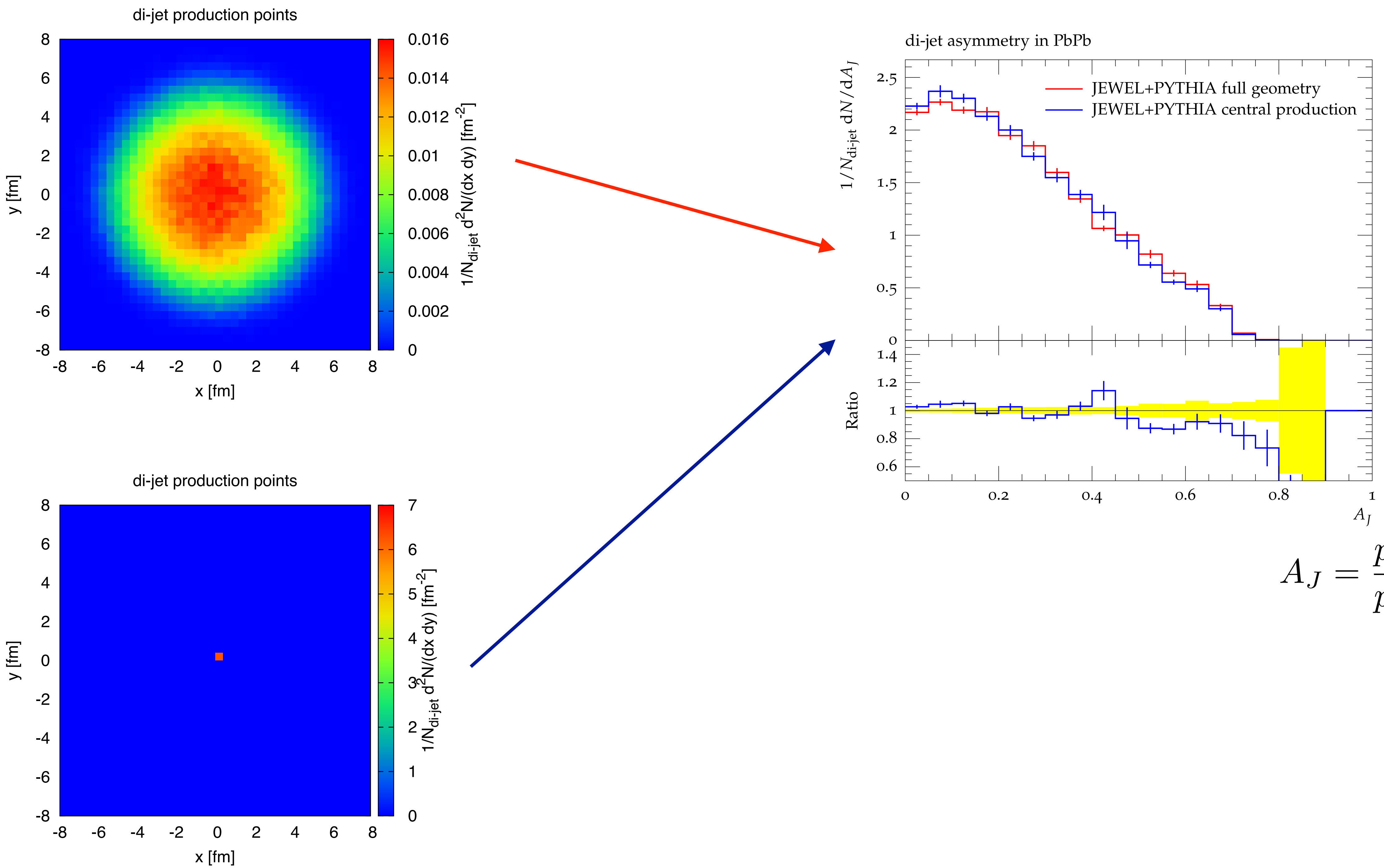

$$A_J = \frac{p_{\perp,1} - p_{\perp,2}}{p_{\perp,1} + p_{\perp,2}}$$

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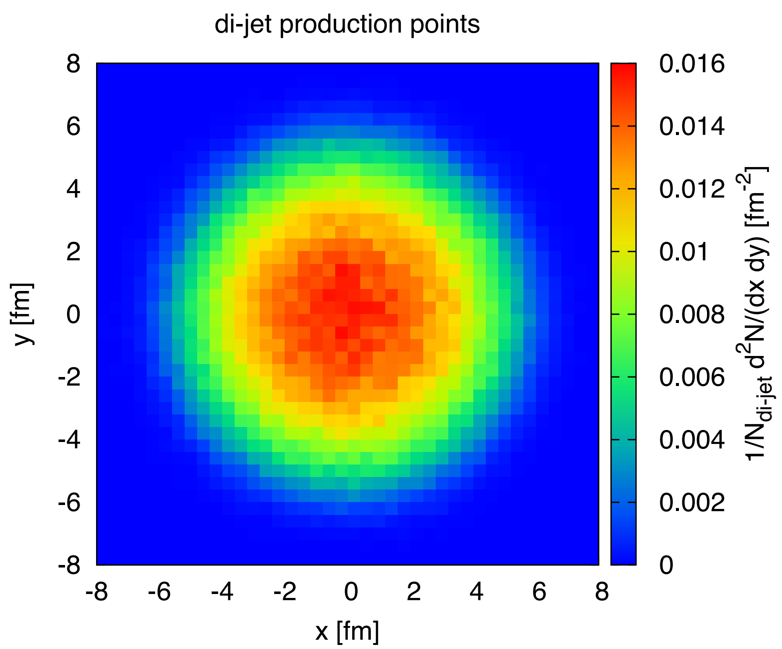
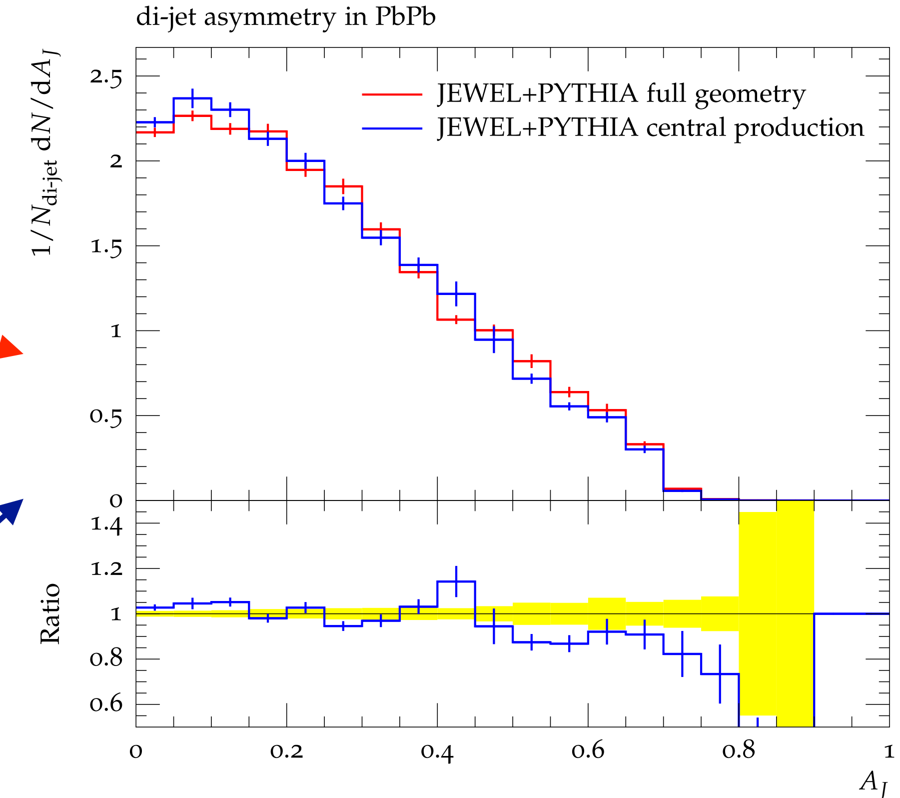
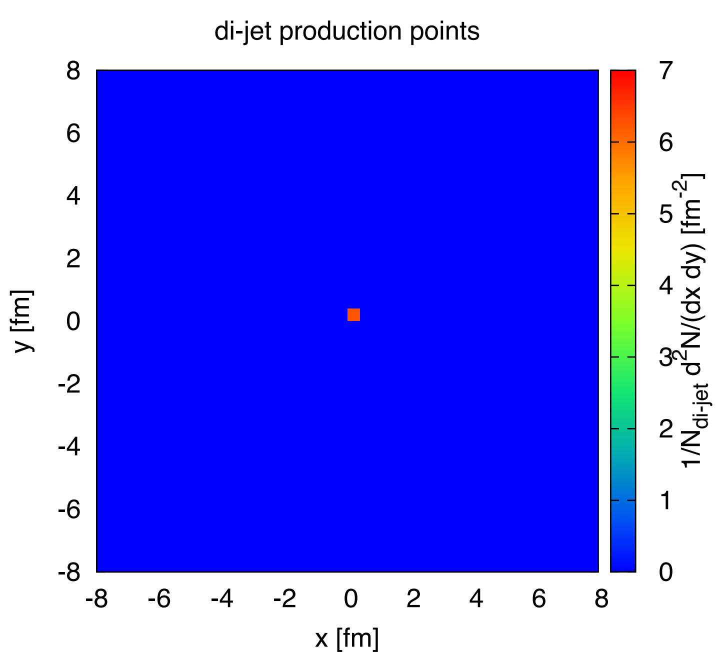


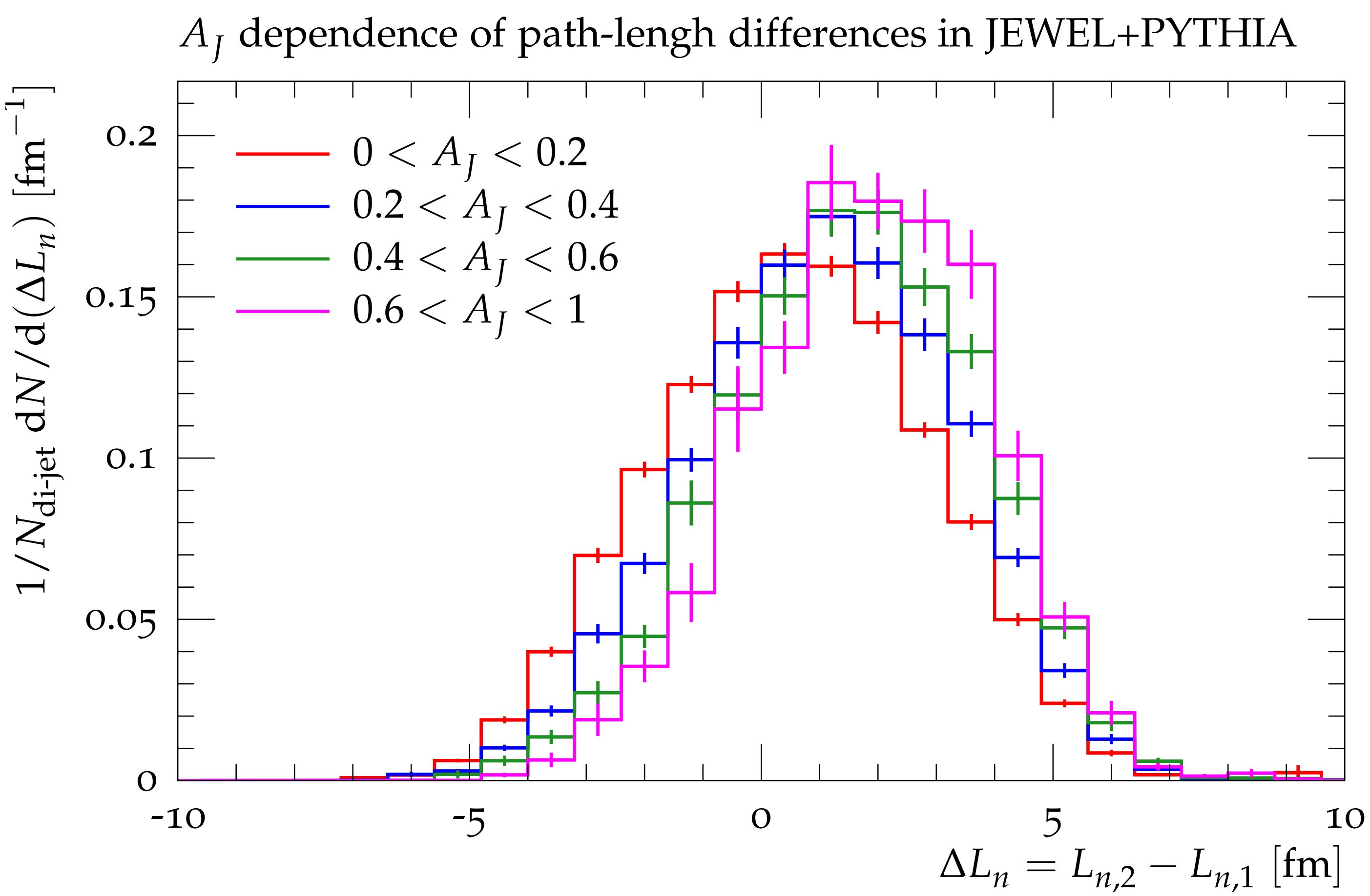




$$A_J = \frac{p_{\perp,1} - p_{\perp,2}}{p_{\perp,1} + p_{\perp,2}}$$

- di-jet event sample with no difference in path-length have A_J distribution compatible with realistic [full-geometry] sample
  - ‘typical’ event has rather similar path-lengths
  - difference in path-length DOES NOT play a significant role in the observed modification of A_J distribution

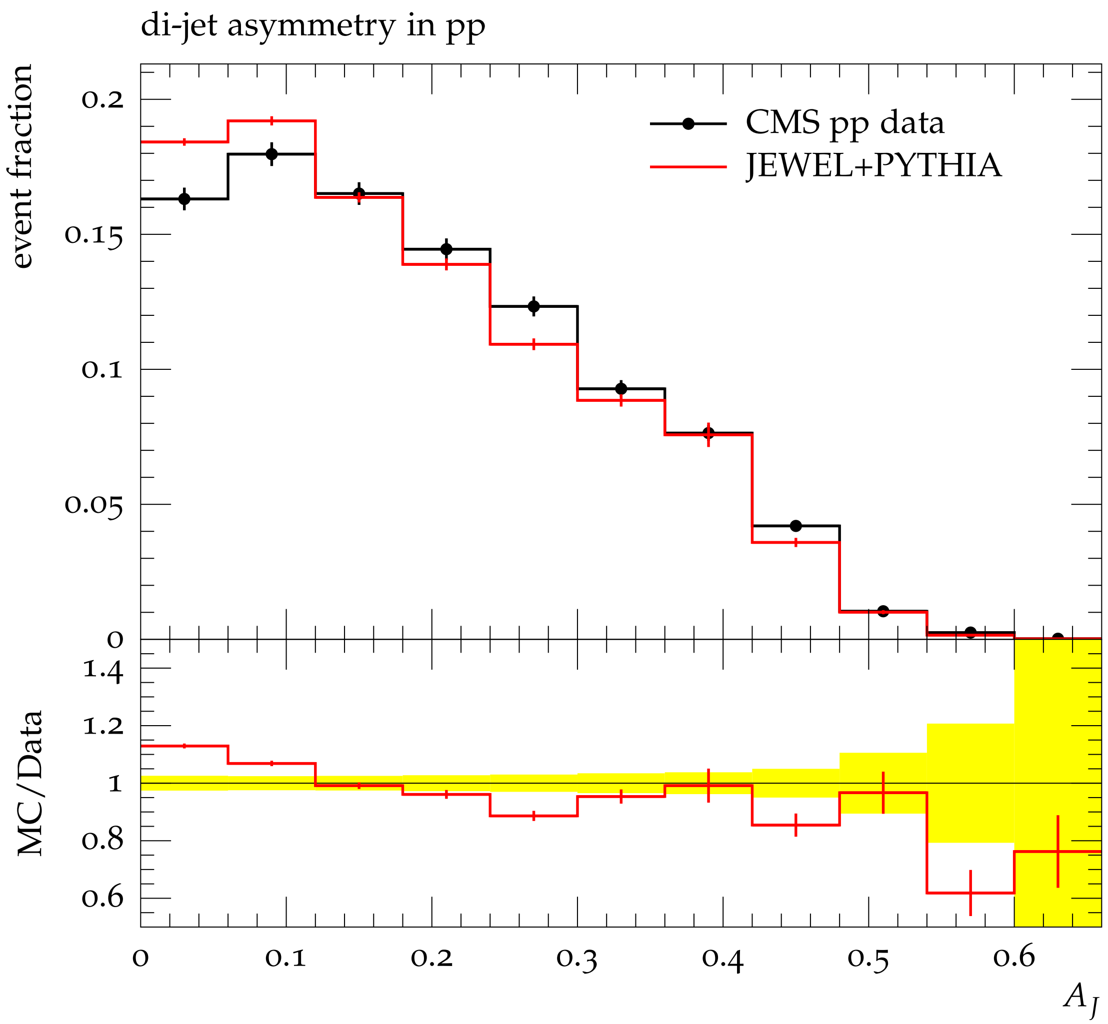
CORRELATION OF PATH-LENGTH DIFFERENCE WITH A_J



- mild correlation between path-length difference and A_J
  - [more asymmetric events arise from larger average path-length differences]
  - however, shift of distribution from lowest to highest A_J much smaller than width of distributions

- effect of average path-length clearly seen in centrality dependence of A_J distribution [not for this talk]
- effect of difference in path-length clearly seen from azimuthal angle dependence [not for this talk]

JEWEL [AND BASELINE]



- a lot of discussion in this meeting on ability to describe accurately pp baselines
  - not an issue here: JEWEL provides reasonable description of A_J in both pp and AA
- all in this talk is JEWEL with NO recoils
- the whole analysis is RIVET[ized] :: recall Lisbon Accord

EVENT SAMPLES

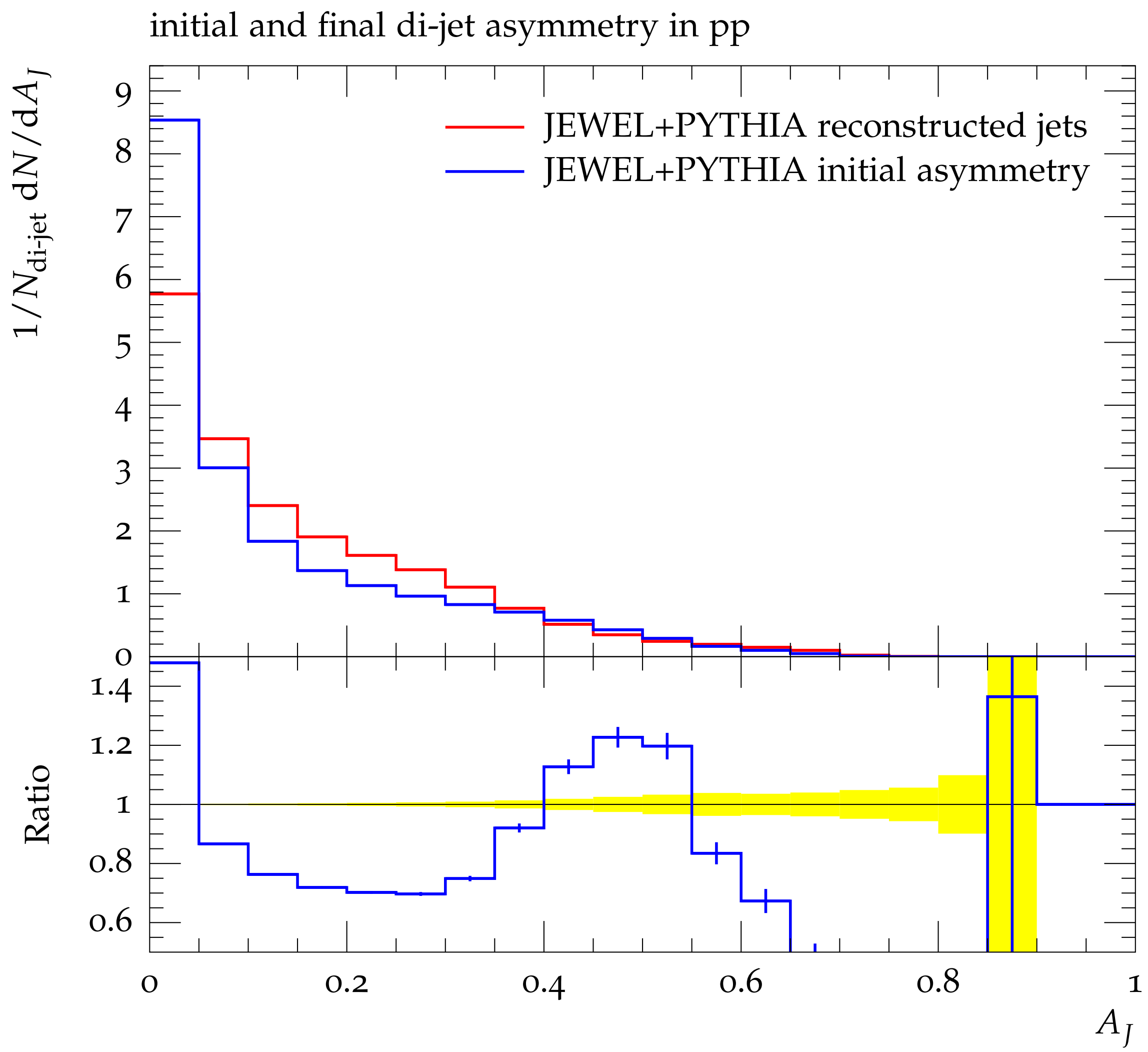
- $\sqrt{s}$ = 2.76 TeV
- simple parametrized background [few tests with full hydro showed no sizeable difference]
- τ_i =0.6 fm; T_i =485 MeV; T_c =170 MeV
- fully central events only [b=0] :: this is not a data comparison exercise
- matching baseline samples for pp

- di-jet sample [JEWEL 2.0.2]
  - anti-k_t R=0.4 jets within $|\eta|<2$
  - $p_{T,1}>100$ GeV; $p_{T,2}>20$ GeV; $\Delta\varphi_{12}>\pi/2$

- γ-jet sample [unreleased extension of JEWEL 2.0.2 :: Rajhav's talk]
  - $p_T<5$ GeV photons removed before jet reconstruction
  - anti-k_t R=0.4 jet within $|\eta|<5$ with $p_T>20$ GeV
  - initial parton within $|\eta|<2.5$ with $p_T>20$ GeV [to avoid cases where no jet is reconstructed because there is no initial parton in relevant phase space]
  - LO matrix element [only one initial parton in the event]

A_J IN pp COLLISIONS

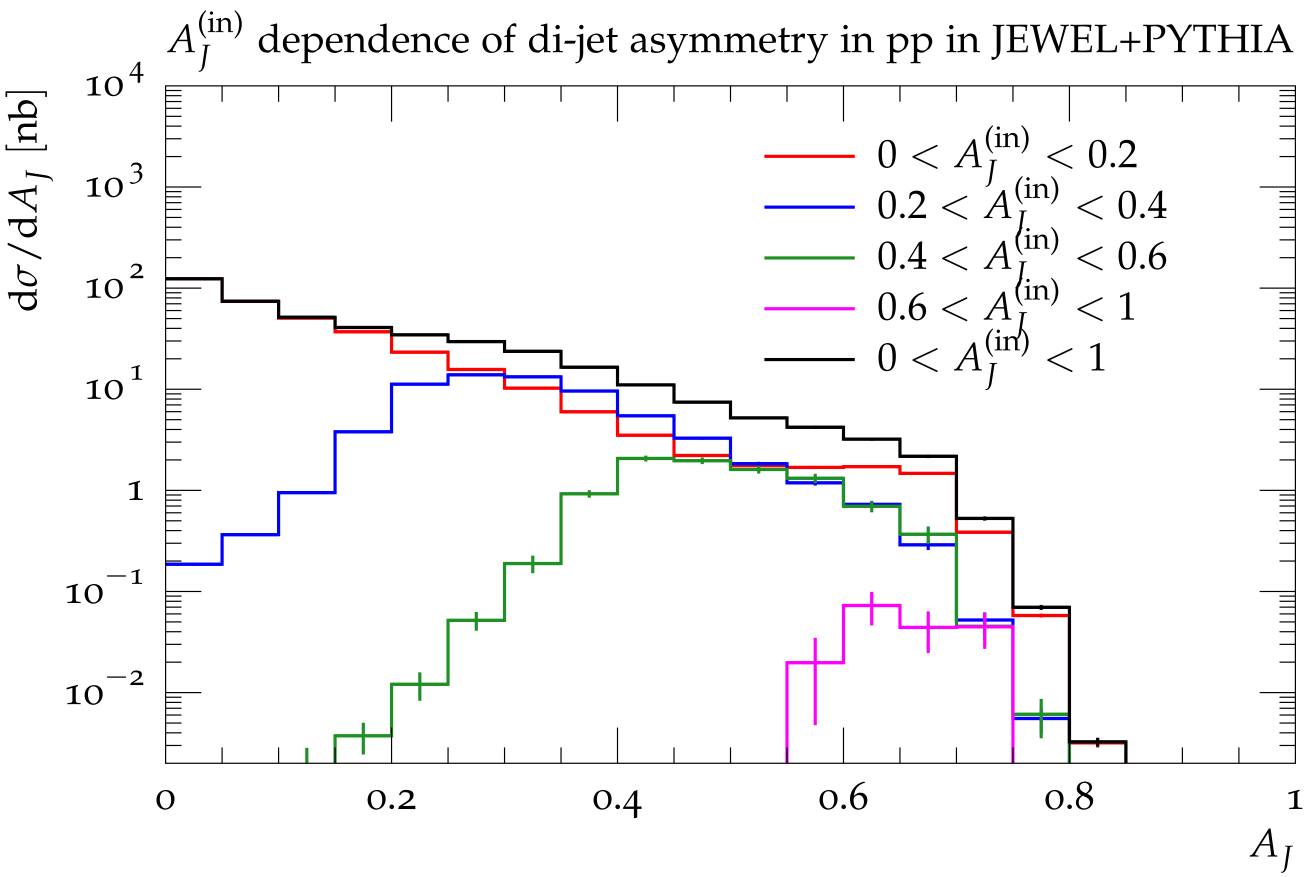
- in pp collisions di-jet asymmetry can only arise from fluctuations in the splitting pattern of the jets
  - radiation out of reconstruction cone [multiple jet events, fatter jets]
  - initial pair of hard partons cannot have an asymmetry [this statement is also true beyond LO]
  - define initial asymmetry as including all recoil effects from ISR [taken by final state partons] and first FSR [taken by the other final state parton]



reconstructed jets asymmetry mostly accounted for by asymmetry of 'initial' parton configuration

effect of recoil against first FSR is small [not shown]

EbE INITIAL-FINAL ASYMMETRY CORRELATION



- showering slightly increases average asymmetry

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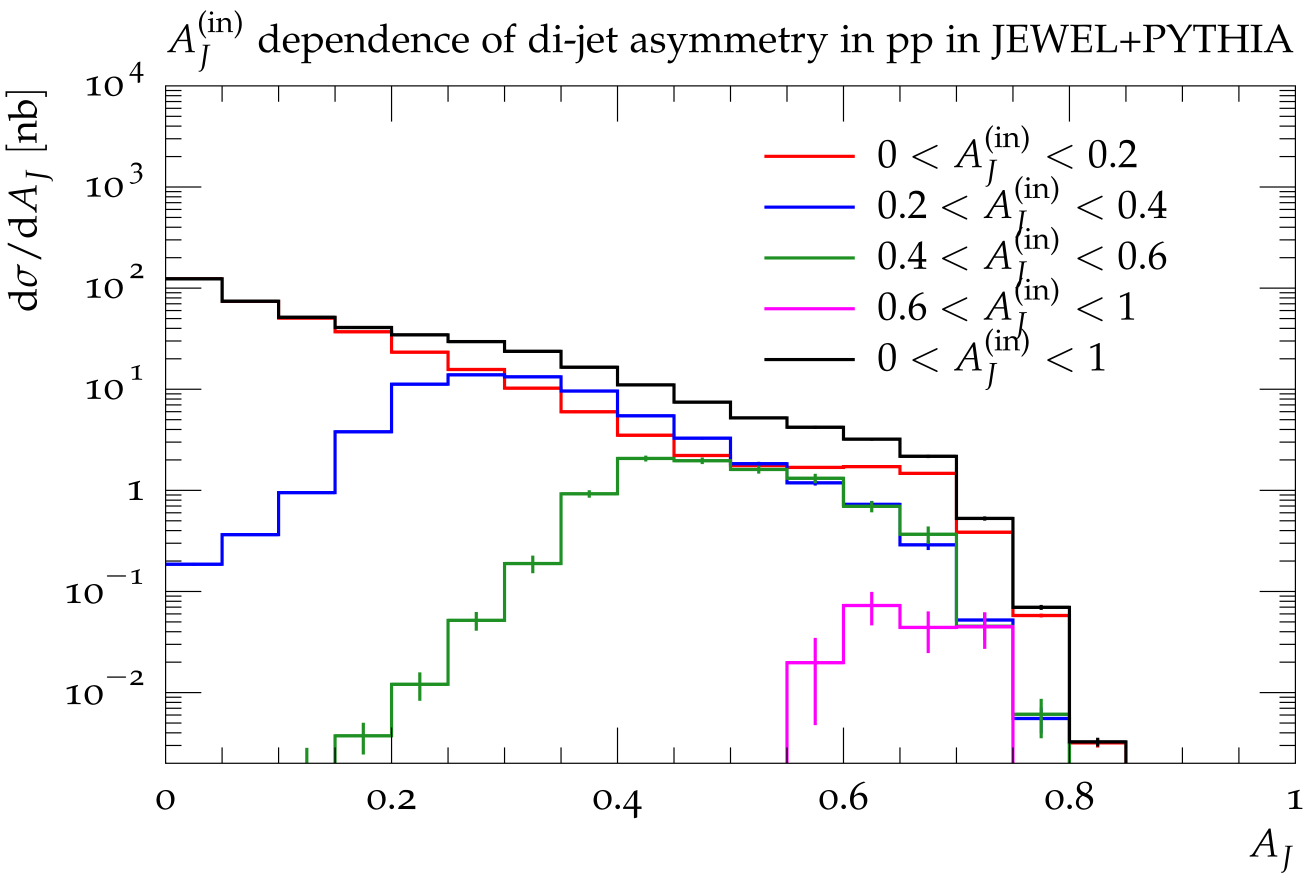

- showering slightly increases average asymmetry
    - larger energy loss for sub-leading jet

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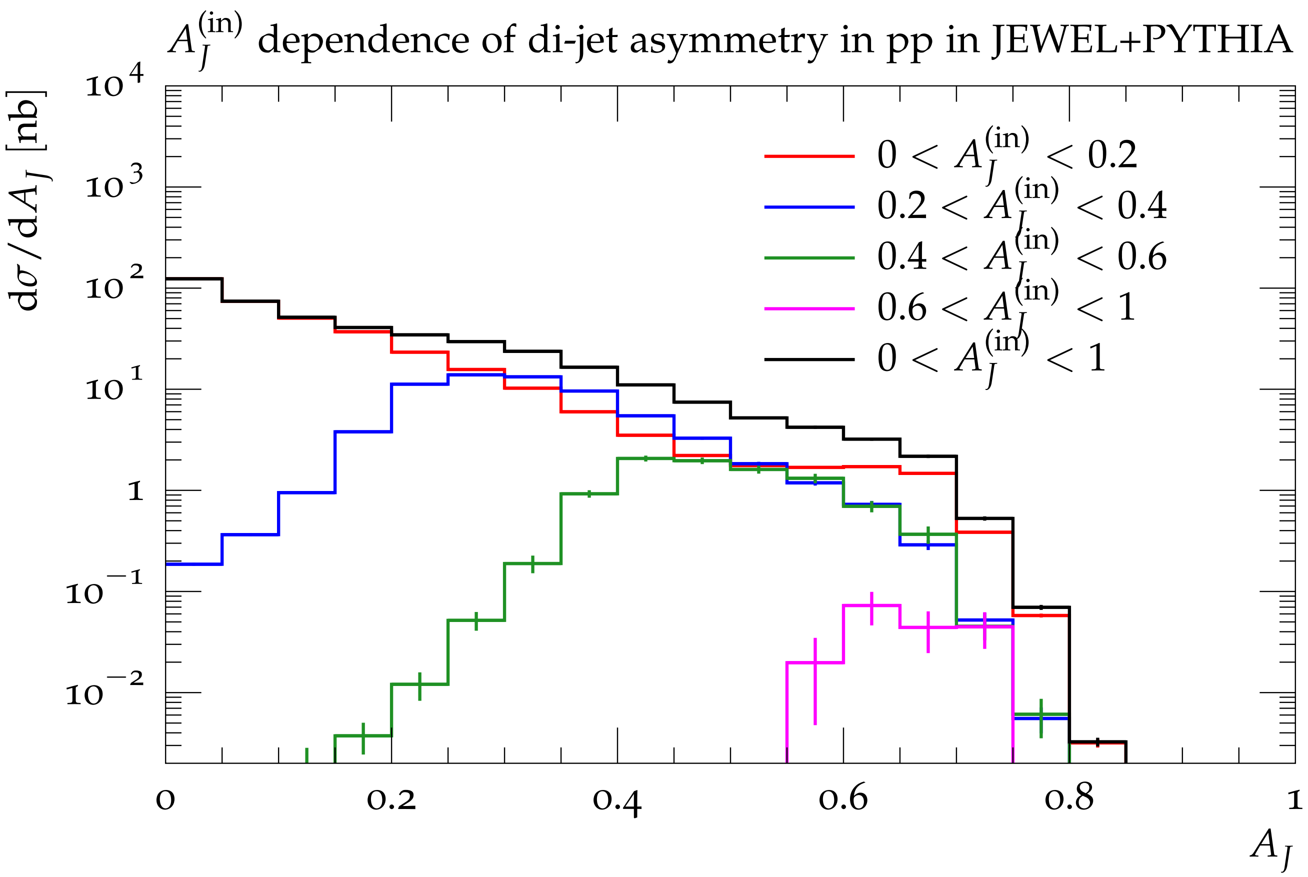
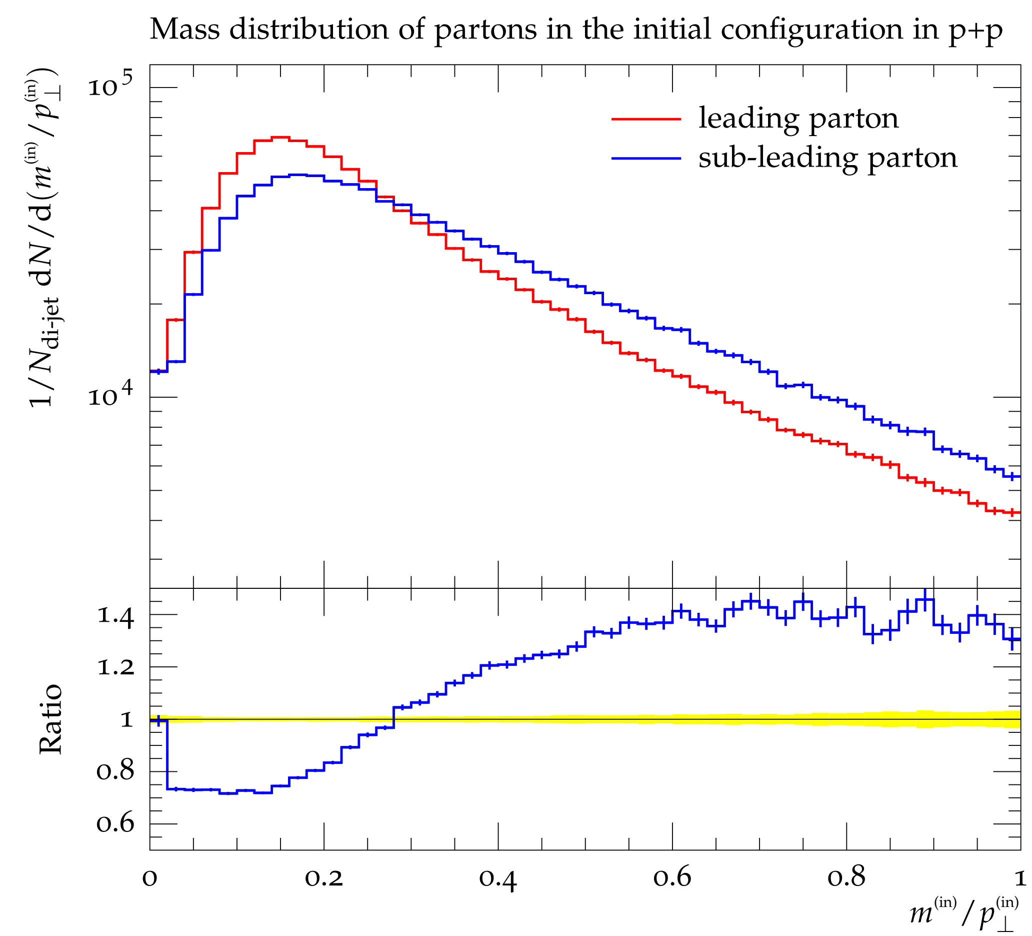
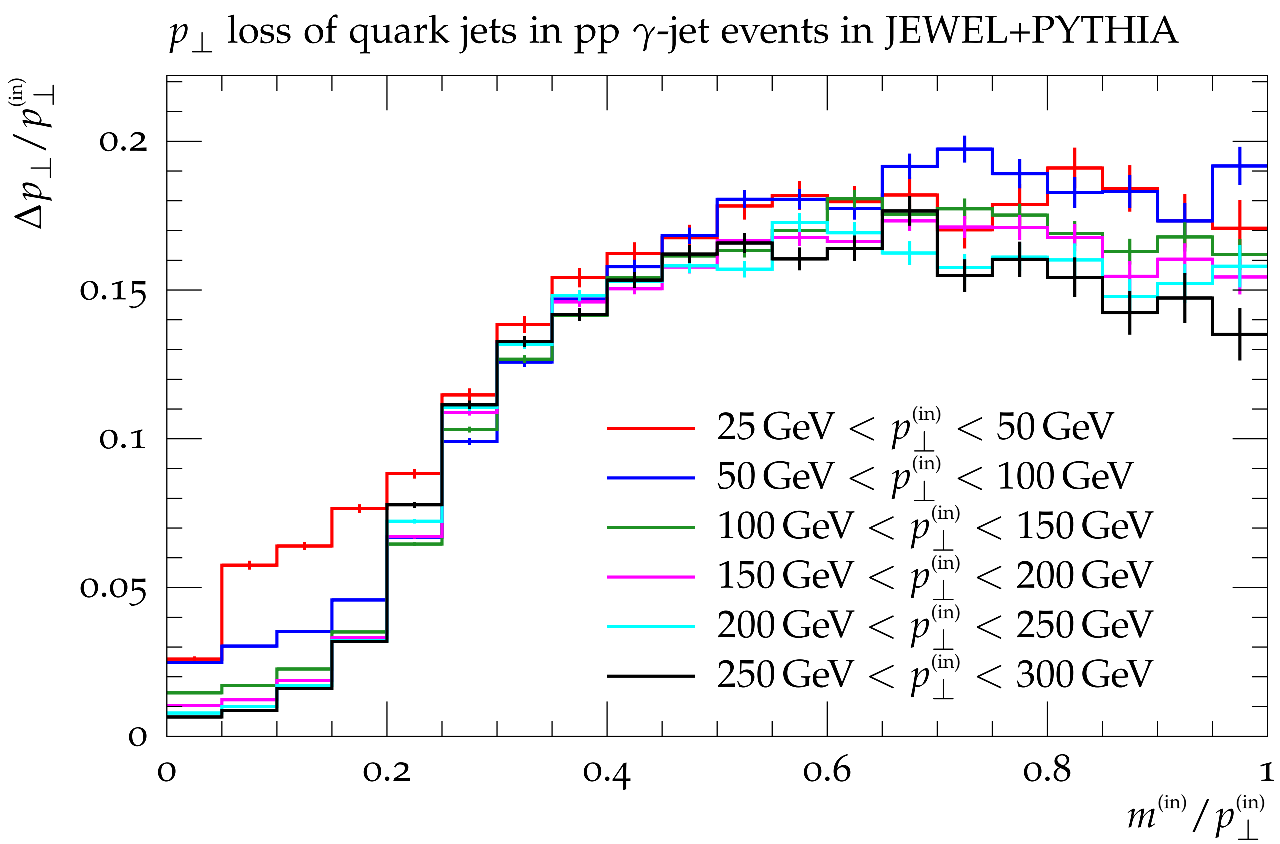




- showering slightly increases average asymmetry
  - larger energy loss for sub-leading jet
  - sub-leading jets originate from initial partons with higher mass to p_t ratio [those with a softer fragmentation pattern]

GAMMA-JET INTERMEZZO [still pp]

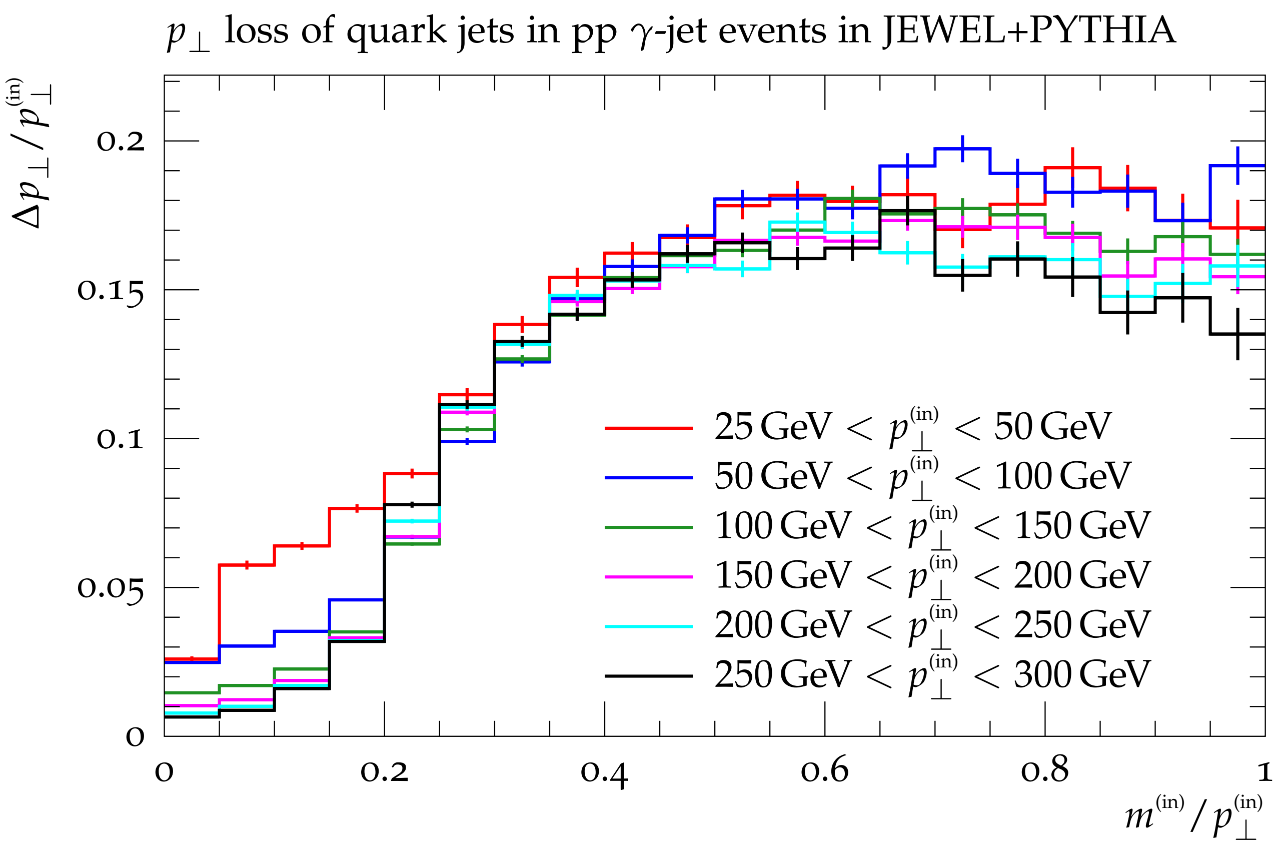
- transverse momentum loss when going from parton to reconstructed jet in di-jet events requires ill-defined parton-jet matching procedure
    - straightforward in γ-jet events without ISR
        - no ISR jets
        - only one initial parton from which all reconstructed jets must originate
        - associate hardest reconstructed jet to initial parton

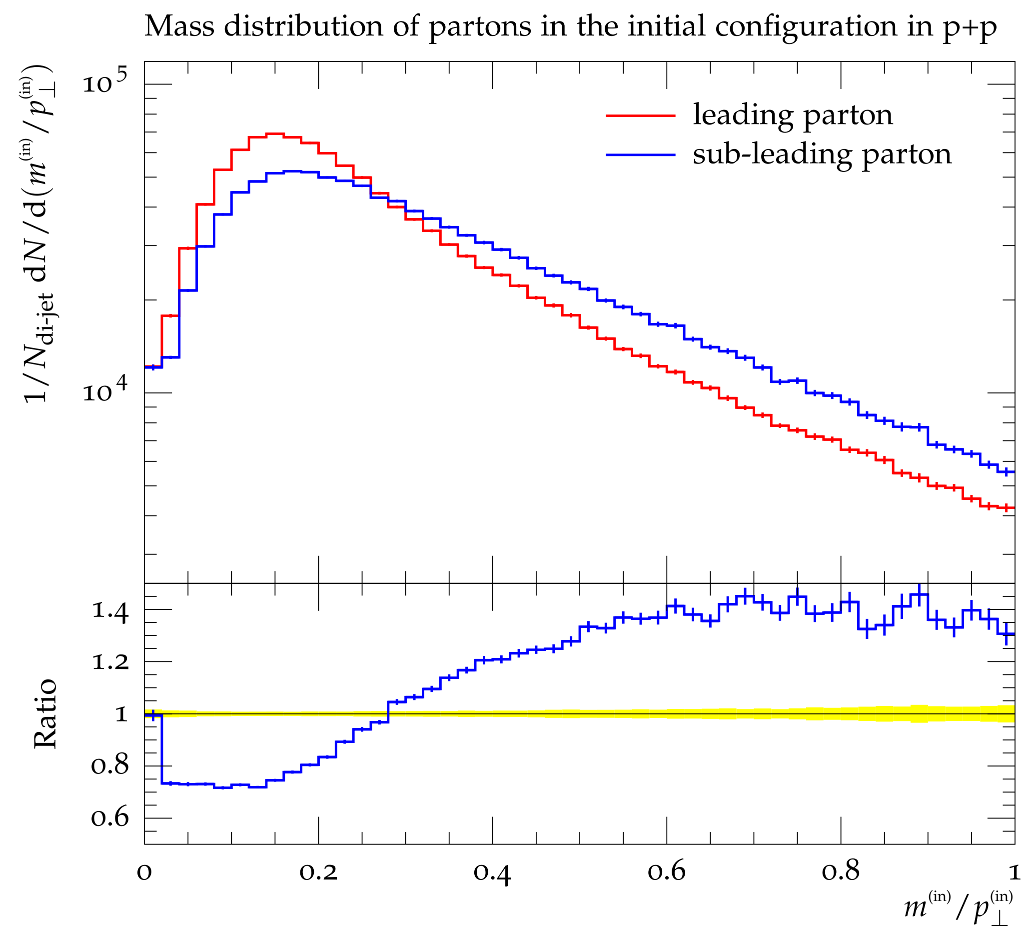


$$\Delta p_\perp = p_\perp^{(\mathrm{in})} - p_\perp^{(\mathrm{jet})}$$

transverse momentum loss largely determined by mass-to-p_t ratio

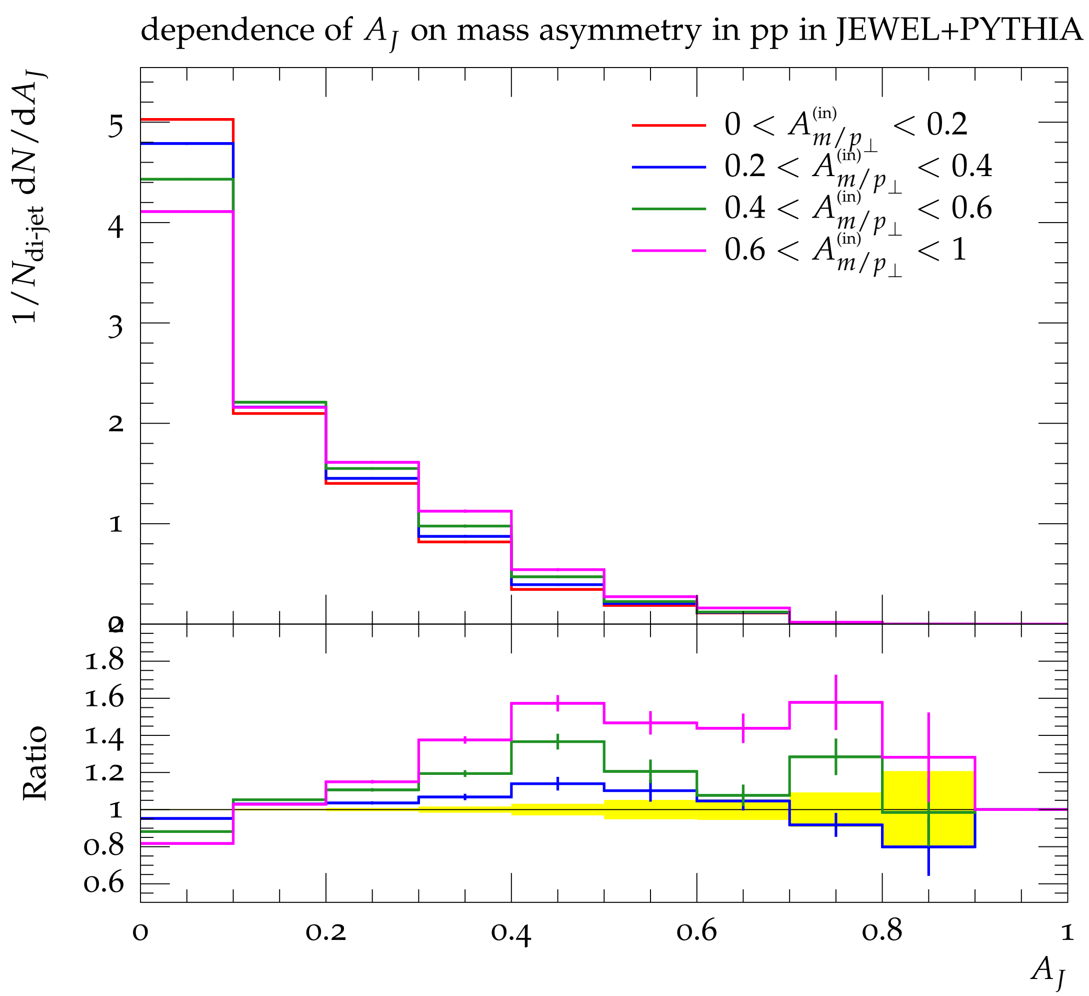
GAMMA-JET INTERMEZZO [still pp]

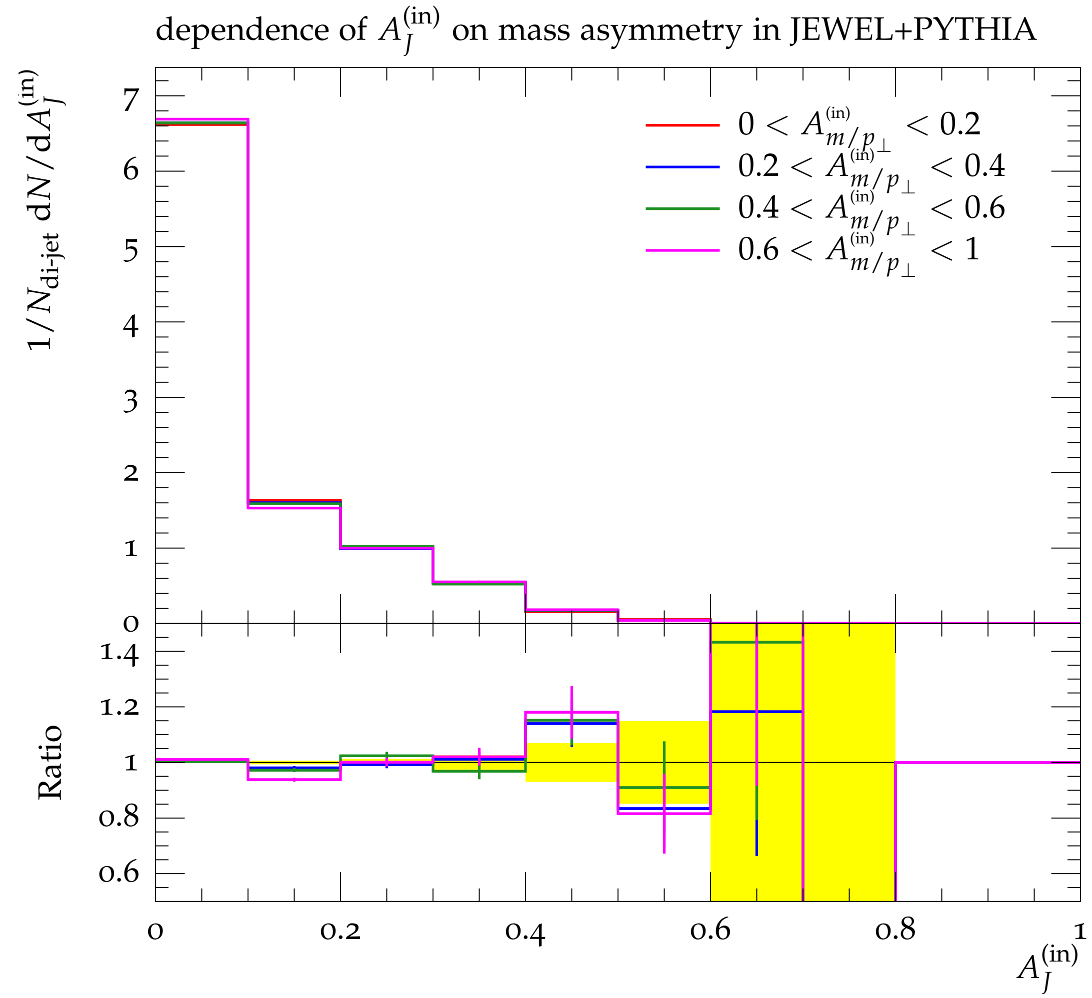




- transverse momentum loss largely determined by mass-to-p_t ratio
  - strong dependence for bulk of distribution
  - saturation at high ratio result from reconstruction cone radius [large angle structure beyond R] :: will shift to higher values for higher R

INITIAL MASS ASYMMETRY [still pp]





reconstructed jet AJ strongly correlated with initial mass asymmetry

reconstructed jet AJ independent of initial mass asymmetry

$$A^{(\text{in})}_{m/p_\perp} = \frac{\left| m_1^{(\text{in})}/p_{\perp,1}^{(\text{in})} - m_2^{(\text{in})}/p_{\perp,2}^{(\text{in})} \right|}{m_1^{(\text{in})}/p_{\perp,1}^{(\text{in})} + m_2^{(\text{in})}/p_{\perp,2}^{(\text{in})}}$$

increase of asymmetry from parton to jet driven by initial mass

[finally] A_J IN AA COLLISIONS

- what drives the increase of asymmetry in heavy ion collisions?
  - NOT path-length difference
  - nPDF effects are very small in the relevant kinematics
  - first FSR, typically hard, occurs on very short time-scale [~0.01 fm] and is unaffected by medium
    - 'initial' [partonic] asymmetry is the same as in pp

the increase in asymmetry in AA collisions must originate from fluctuations in vacuum like fragmentation pattern and/or fluctuations of jet-medium interactions

VACUUM-LIKE OR MEDIUM INDUCED

- distinction obviously not meaningful
  - a gluon is a gluon is a gluon is a gluon
- however, emissions at scales well above medium scales cannot be attributed to jet-medium interaction :: we refer to these as the vacuum-like part of the fragmentation pattern
  - which does NOT mean they are irrelevant for energy loss
    - [in fact quite the contrary]

ROLE OF VACUUM-LIKE FRAGMENTATION IN ENERGY LOSS

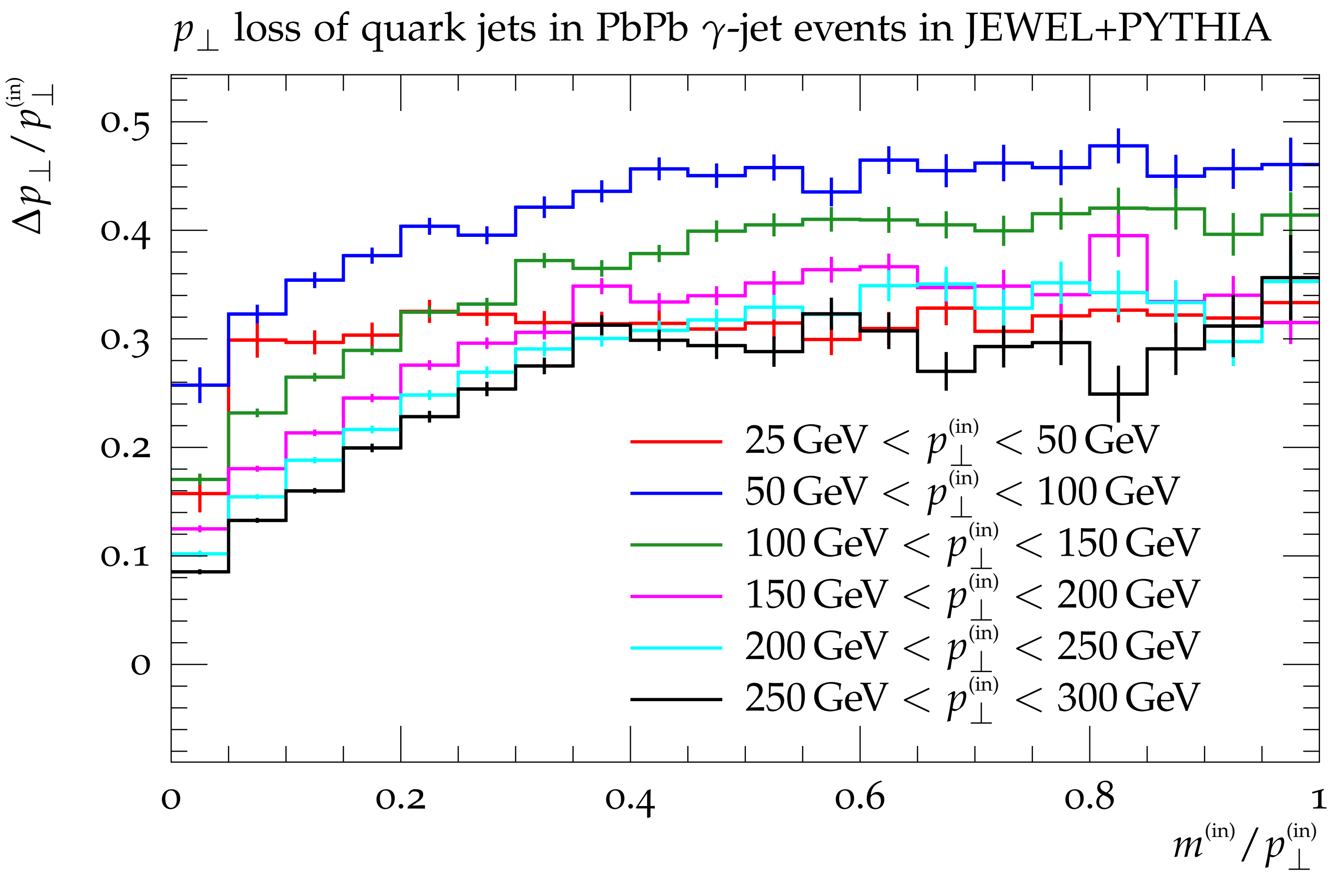
- jets with softer fragmentation pattern [softer and in larger number constituents] lose more energy
  - each resolved jet constituent is candidate for energy loss

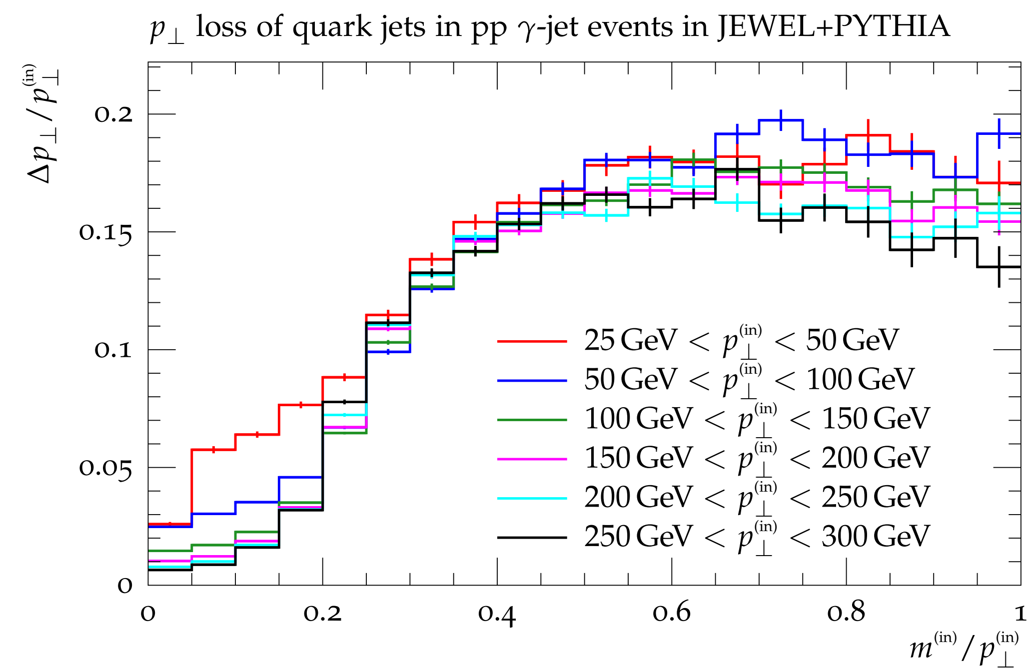
    Casalderrey, Mehtar-Tani Salgado, Tywoniuk ::1210.7765 [hep-ph]
    - the more constituents the larger the energy loss
  - soft components more likely to be transported away from reconstruction radius

    Casalderrey, Milhano, Wiedemann ::1012.0745 [hep-ph]
  - both mechanisms present in JEWEL

jet-medium interactions leading to energy loss amplified in jets with softer fragmentation [higher initial mass to p_t ratio]

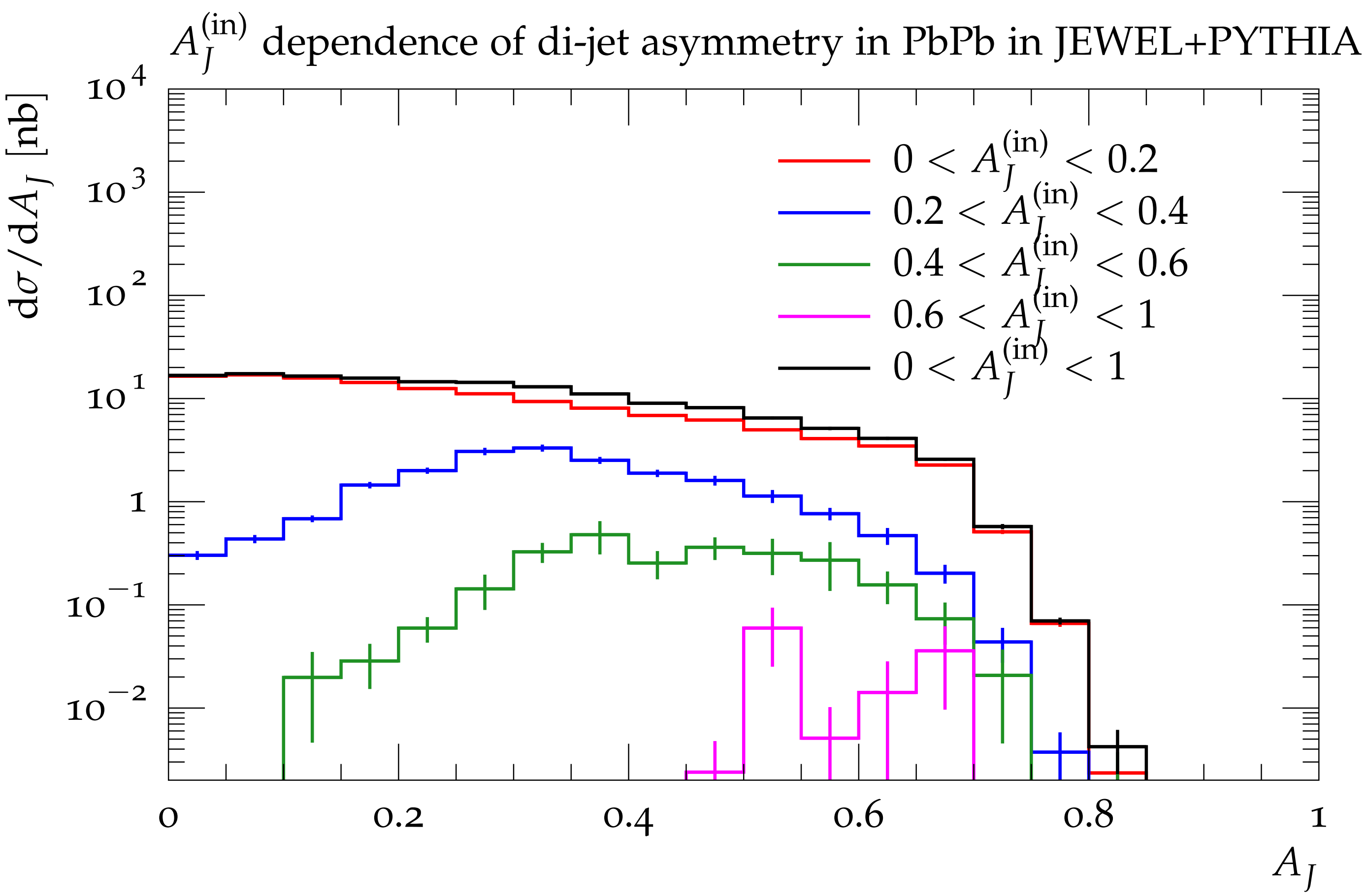
ROLE OF VACUUM-LIKE FRAGMENTATION IN ENERGY LOSS

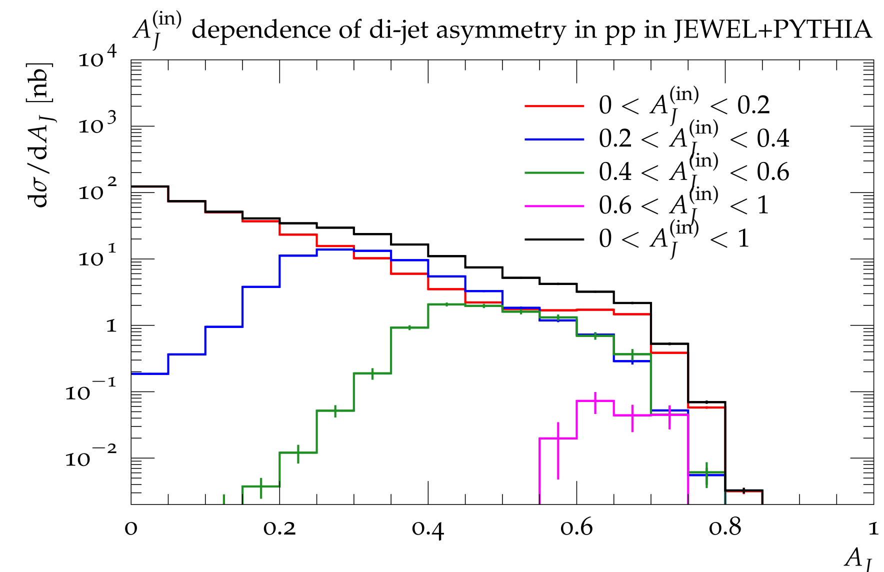




- same qualitative behaviour for momentum loss as in pp
    - importance of vacuum-like fluctuations of fragmentation pattern
    - p_t loss larger [by a factor of 2] than in pp
    - near independence of mass to p_t ratio for lower energy jets shows importance of fluctuations of medium induced energy loss

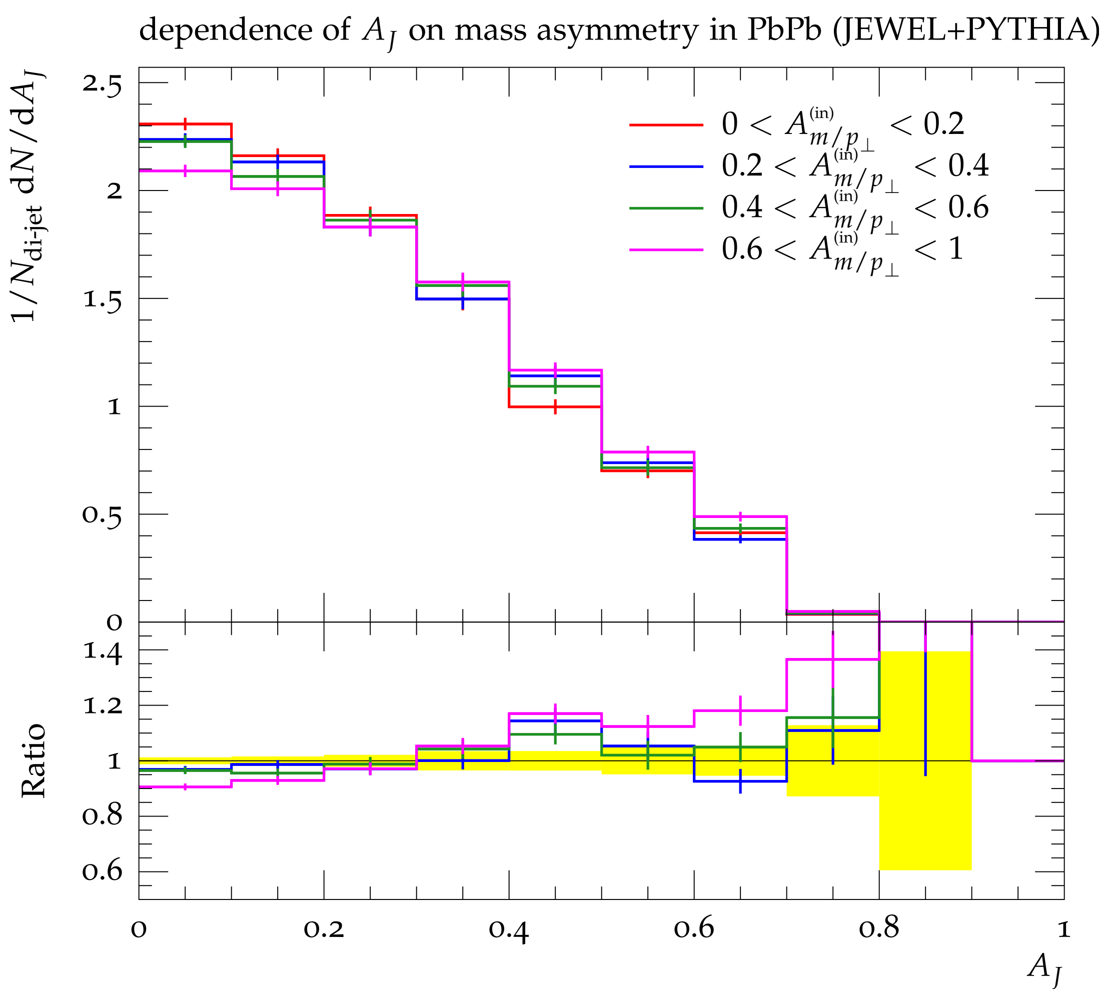
INTERPLAY OF VACUUM AND MEDIUM-INDUCED FLUCTUATIONS





- broader distributions in AA
    - large initial asymmetries are reduced [events are lost]

INTERPLAY OF VACUUM AND MEDIUM-INDUCED FLUCTUATIONS



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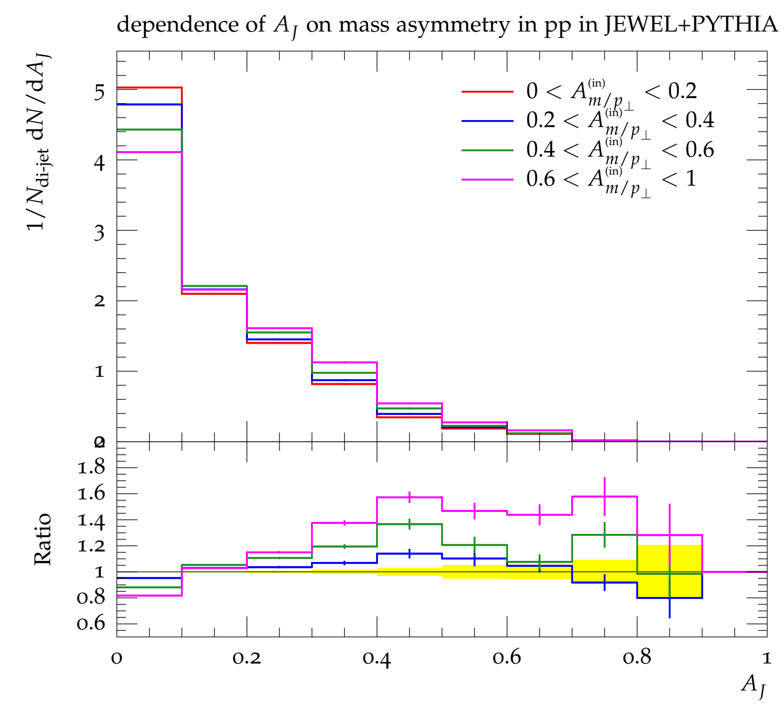

- ➤ same trend as in pp [importance of vacuum-like fluctuations], albeit weaker [importance of jet-medium interaction fluctuations]

WHAT WE LEARNT

- the path-length difference between the leading and sub-leading jets in a di-jet pair does not play a significant role in generating momentum imbalance

- the increase in di-jet asymmetry in AA collisions is the result of the compound effect of fluctuations in the vacuum-like fragmentation pattern [parton shower features also present in the absence of a medium] and medium related fluctuations

- to a large extent, the amount of energy lost from a jet is determined by the mass to transverse momentum ratio of the parton from which it originates

OTHERS

- amplification of energy loss for jets with larger number of constituents clearly identified earlier

  Casalderrey, Mehtar-Tani Salgado, Tywoniuk ::1210.7765 [hep-ph]

  - here confirmed in a realistic MC

- analogous result from strongly coupled calculation [mass to p_t ratio ~ jet width]

  Rajagopal, Sadofyev, van der Schee ::1602.04187 [hep-ph]

  - [does that make it more robust?]

NEXT

- initial mass to p_t ratio obviously not measurable
  - find proxy [which is not easy]
  - proxy should be jet property that is insensitive to medium effects [an unquenchable]
    - proxy would be ideal ‘binning variable’ to study quenching

- the *observable post-mortem* protocol outlined here could/should be replicated for any observable of interest
  - essential to understand what each observable is sensitive to

SOME SPECULATION ON MARTA´S OBSERVABLE

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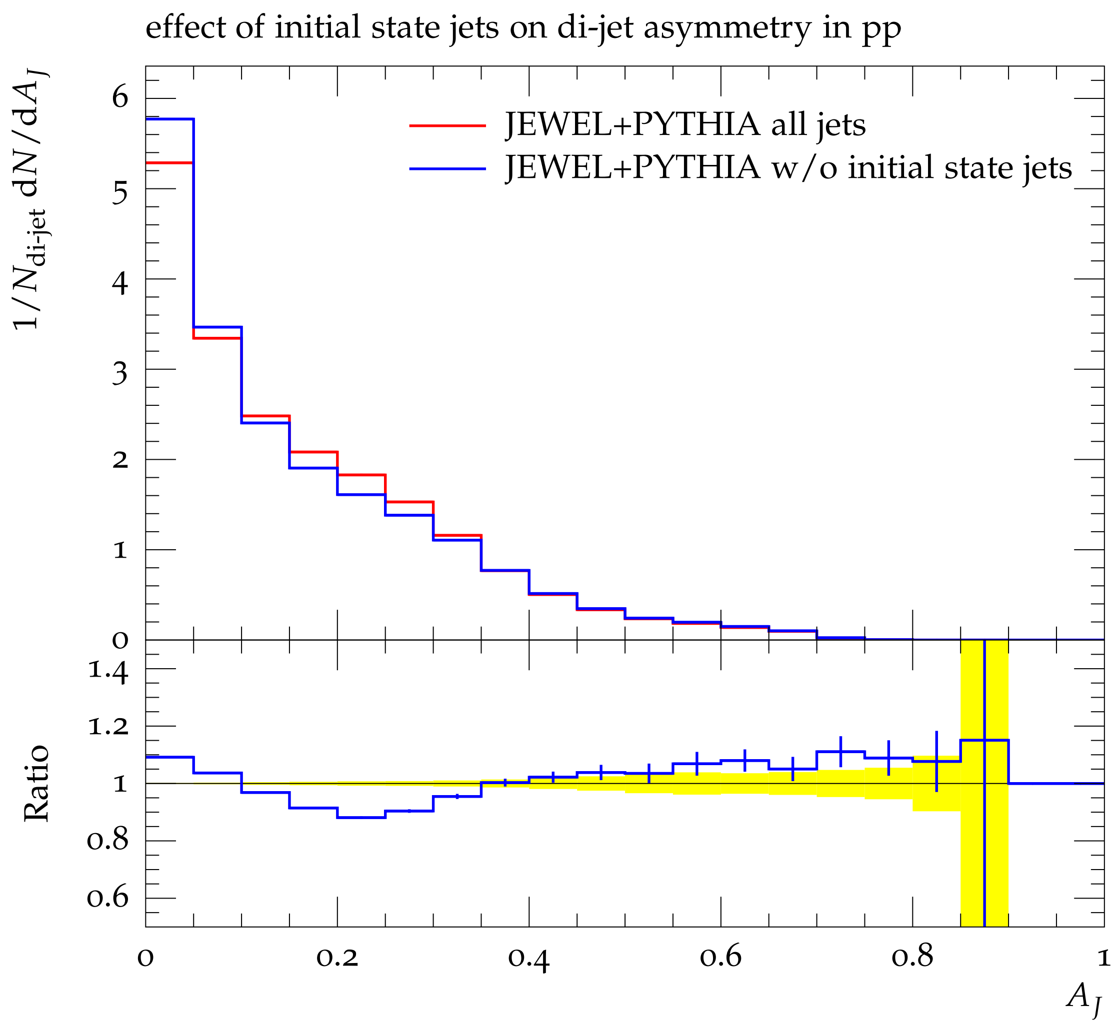
which shall remain off-the-record

backups

CONTAMINATION FROM ISR



- ➤ minor contamination from ISR jets
- ➤ ISR jets removed by parton-jet matching
  - ➤ this is the only plot for which [ill-defined] parton-jet matching is invoked
- ➤ ISR jets will not change the conclusions of the study

LOST JETS

$A_J^{(\mathrm{in})}$ bin	$(\sigma_{\mathrm{pp}} - \sigma_{\mathrm{PbPb}})/\sigma_{\mathrm{pp}}$
$0.0 < A_J^{(\mathrm{in})} < 0.2$	0.623 ± 0.002
$0.2 < A_J^{(\mathrm{in})} < 0.4$	0.699 ± 0.009
$0.4 < A_J^{(\mathrm{in})} < 0.6$	0.729 ± 0.034
$0.6 < A_J^{(\mathrm{in})} < 1.0$	0.354 ± 0.291
$0.0 < A_J^{(\mathrm{in})} < 1.0$	0.637 ± 0.002