Identification of Reconstructed b-jets in HI Collisions with CMS

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Selection of b-jet Results from CMS

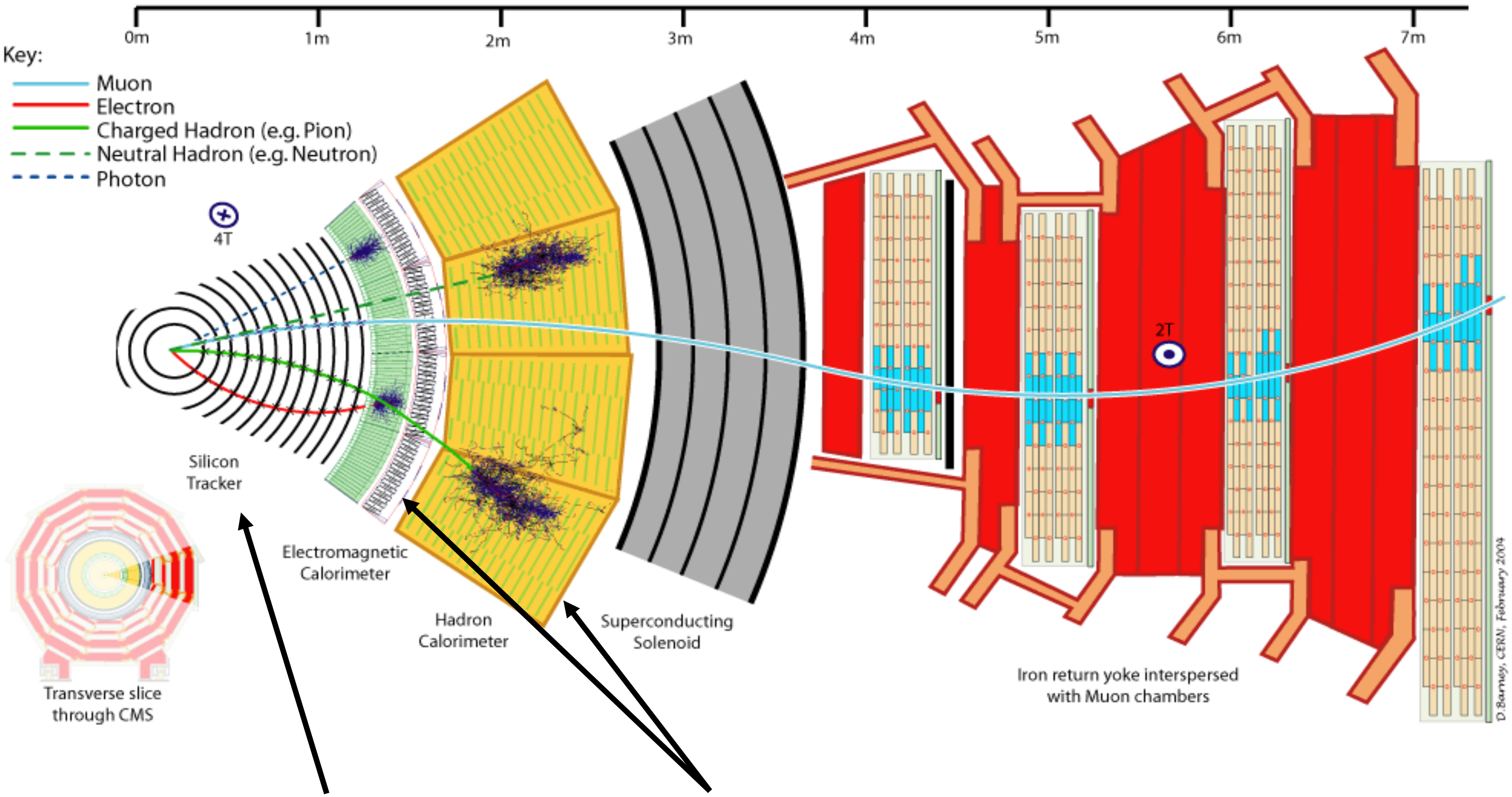
- Identification of b-quark jets with the CMS experiment
  Submitted to JINST last month, arXiv:1211.4462

- Inclusive b-jet production in pp collisions at $\sqrt{s}$ = 7 TeV
  JHEP 1204 (2012) 084, arXiv:1202.4617

- Measurement of $B\bar{B}$ Angular Correlations based on Secondary Vertex Reconstruction at $\sqrt{s}$ = 7 TeV
  JHEP 1103 (2011) 136, arXiv:1102.3194

- Measurement of the b-jet to inclusive jet ratio in PbPb and pp collisions at $\sqrt{s_{NN}}$ = 2.76 TeV with the CMS detector
  CMS Physics Analysis Summary HIN-12-003

The CMS Detector



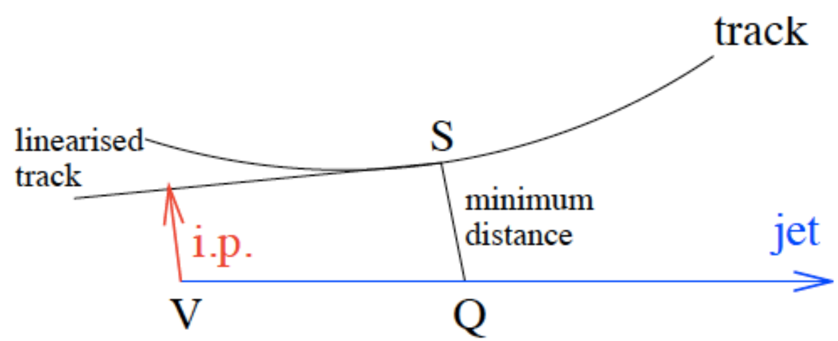
Silicon tracker used in jet reconstruction and for secondary vertices

EM and hadronic calorimeters used for jet reconstruction

b-jet Identification

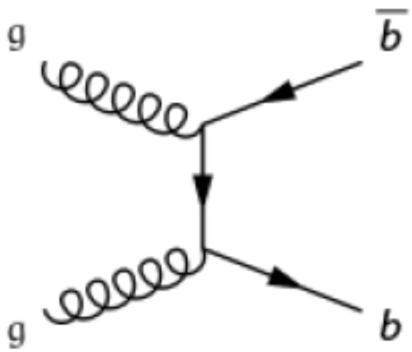
- Long lifetime of b (~1.5 ps) leads to measurable (mm or cm) displaced secondary vertices (SV)

- Subsequent charm decay may lead to a tertiary vertex
- Several classes of b-jet taggers using:
  - Reconstructed SV's, employing discriminating variables such as SV mass, flight distance, etc.
  - Impact parameter (IP) of tracks associated to the jet, w/o requiring a reco'd SV
  - Muons in jets, exploiting the large branching ratio (20%)

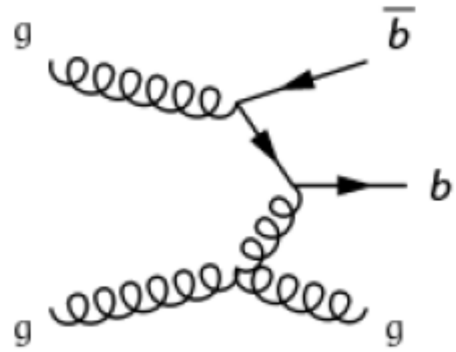


Bottom Production

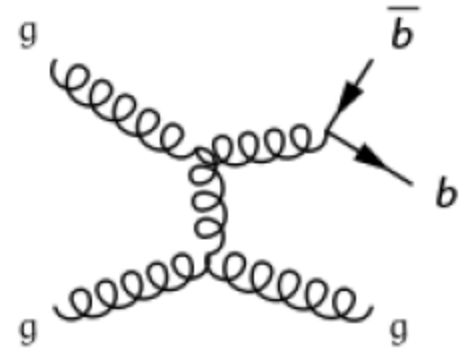
Flavor Creation (FCR)



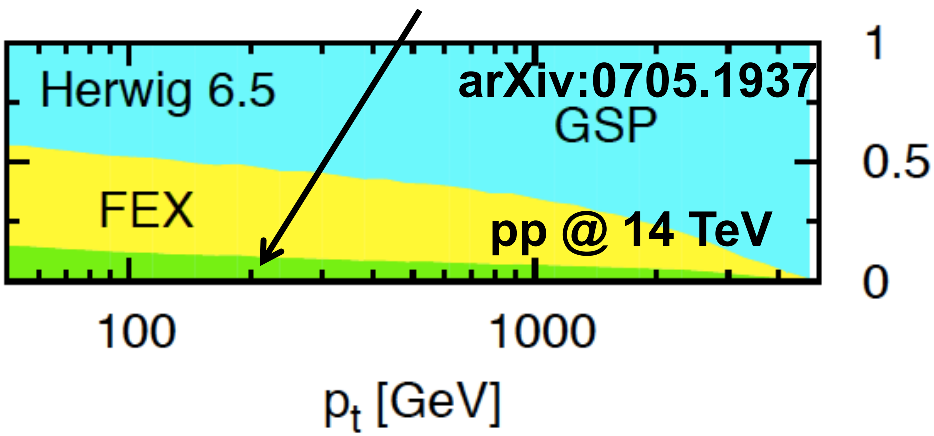
Flavor Excitation (FEX)



Gluon Splitting (GSP)

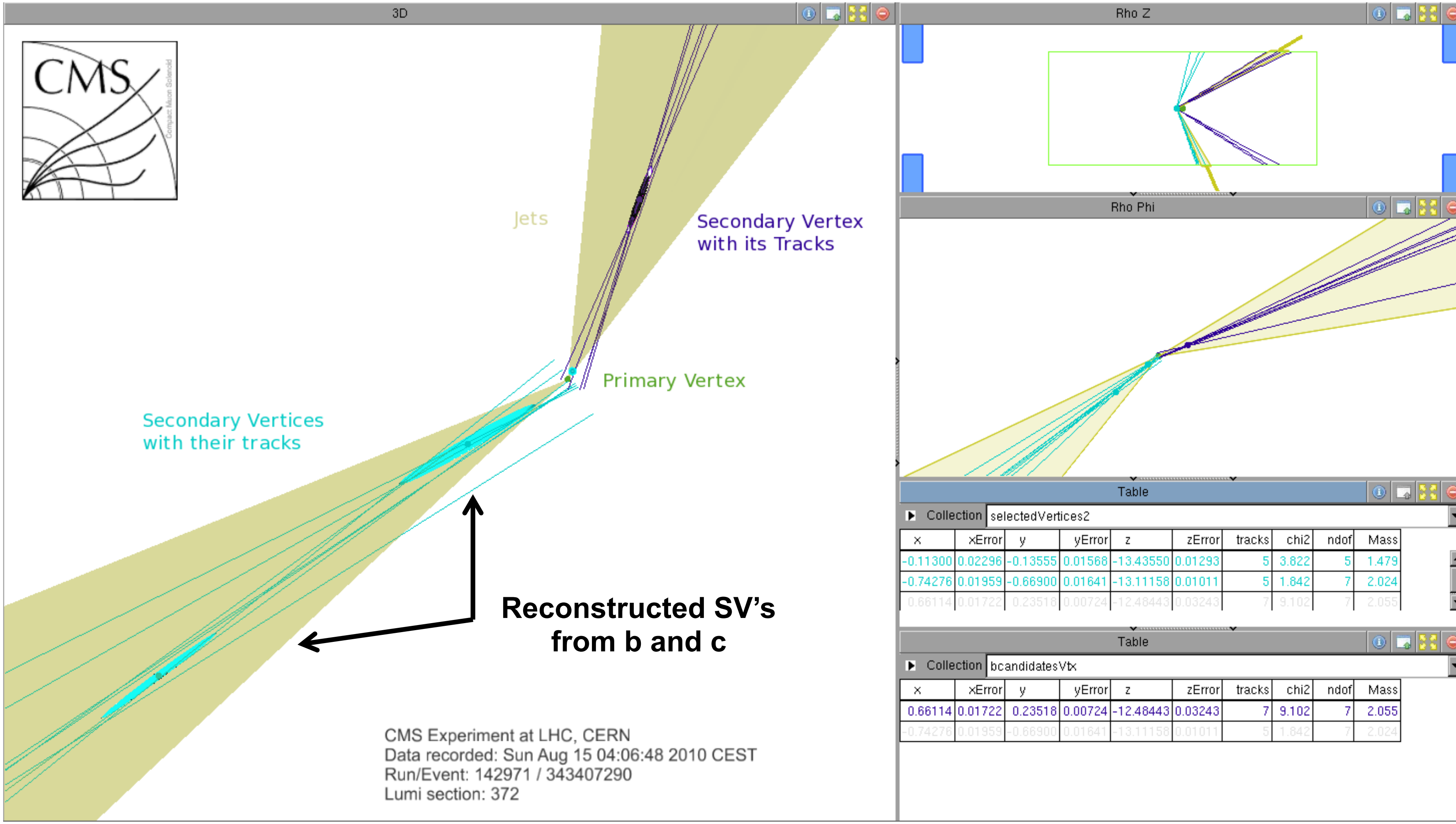


- LO b-$\bar{\text{b}}$ production (FCR) not dominant at the LHC



- At NLO
  - Excitation of sea quarks → b($\bar{\text{b}}$) + light dijet, w/ $\bar{\text{b}}$(b) at beam rapidity
  - Gluon splitting into b and $\bar{\text{b}}$ which can be reconstructed as a single jet

Flavor Creation Candidate (pp @ 7 TeV)



x	xError	y	yError	z	zError	tracks	chi2	ndof	Mass
-0.11300	0.02296	-0.13555	0.01568	-13.43550	0.01293	5	3.822	5	1.479
-0.74276	0.01959	-0.66900	0.01641	-13.11158	0.01011	5	1.842	7	2.024
0.66114	0.01722	0.23518	0.00724	-12.48443	0.03243	7	9.102	7	2.055

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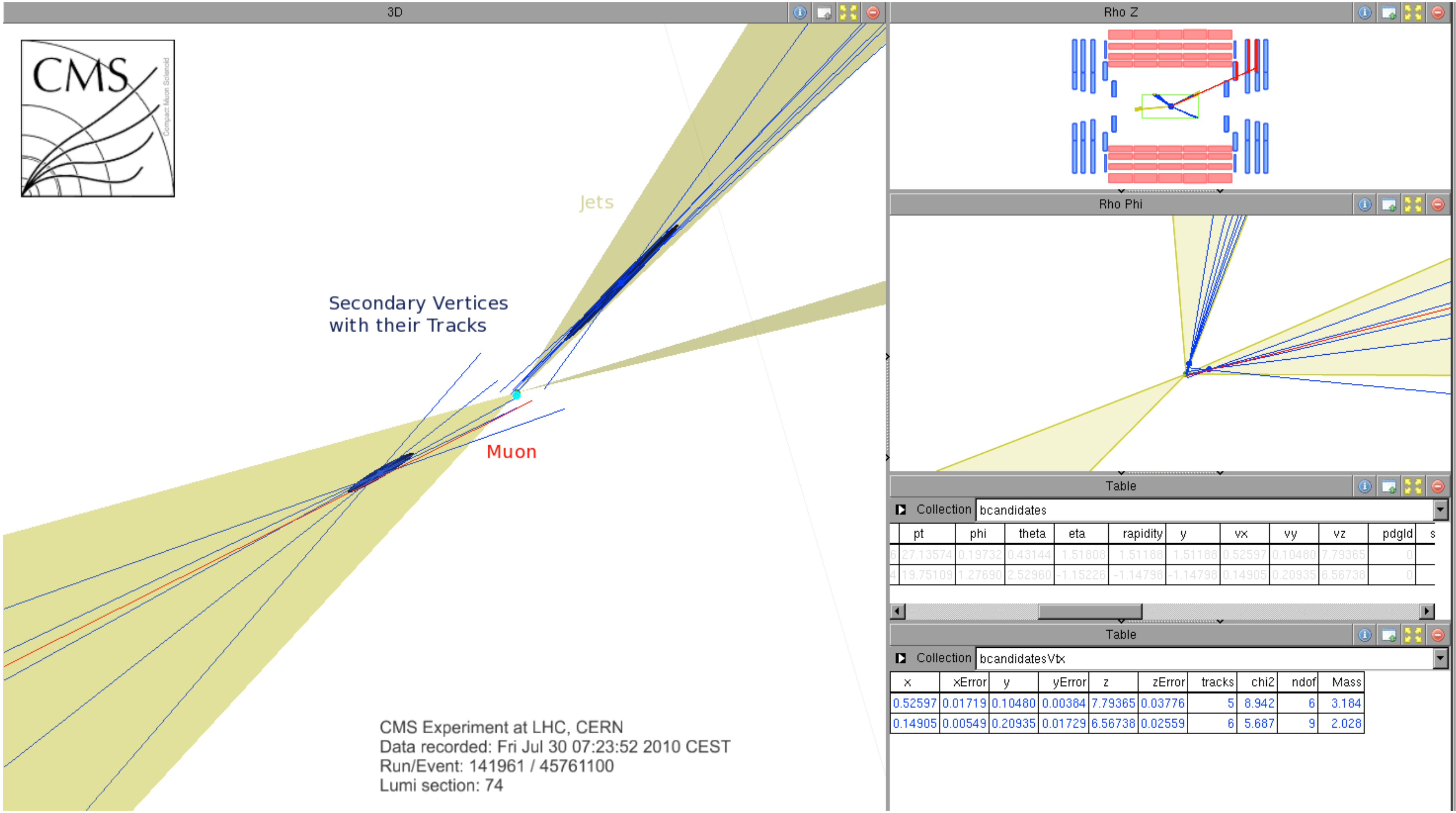
Gluon Splitting Candidate (pp @ 7 TeV)

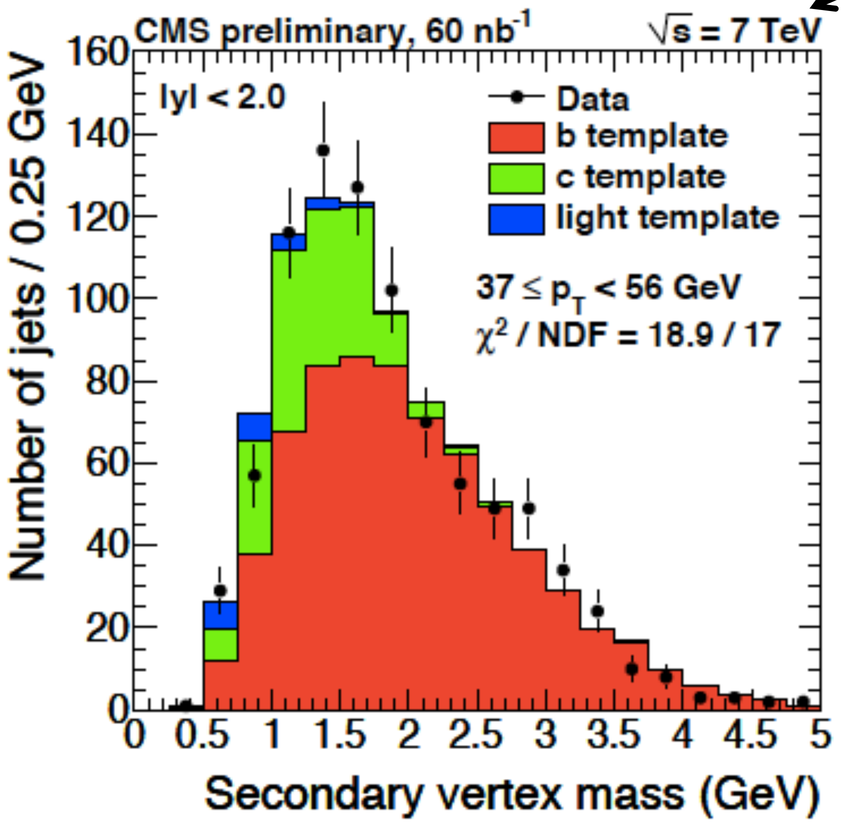


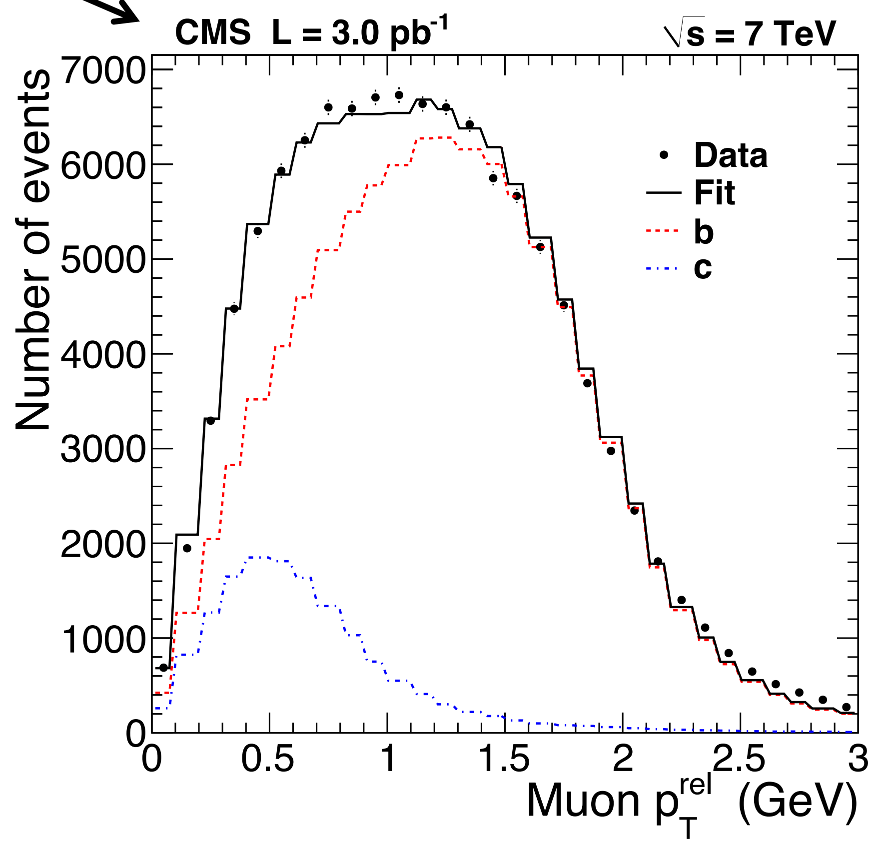
SV Reconstruction, Selection

- *Adaptive* vertex fitter, robust in the presence of outlying tracks
- Associated track selection
  - R < 0.5 w.r.t. jet axis
  - p_T > 1 GeV/c
  - # of hits > 8 (12) for pp (HI) collisions
- < 35% shared tracks with the primary vertex
- 3σ radial flight distance significance
- Rejection of long-lived particles and material interactions
  - < 2.5 cm radial distance from primary vertex
  - K^0 mass veto
  - Mass < 6.5 GeV/c^2
- *High Efficiency (Purity)* Selection >= 2 (3) tracks

Methods Used in pp @ 7 TeV

Starting point: good SV with a selection on the flight distance significance



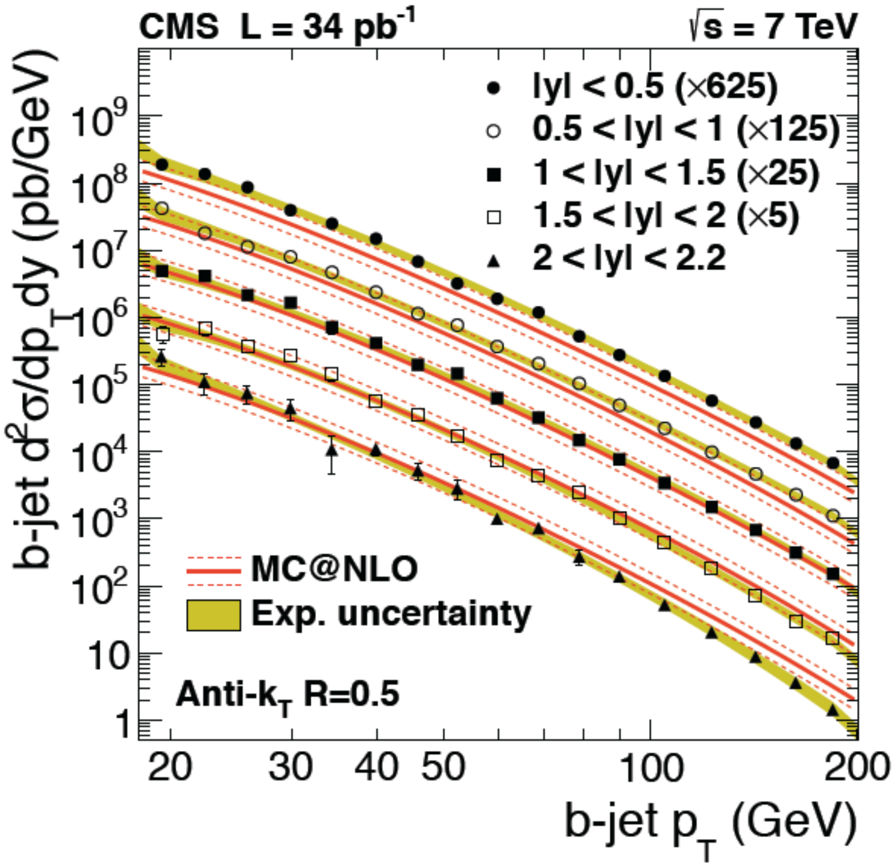


b-jet contribution determined by a template fit to the SV mass distribution

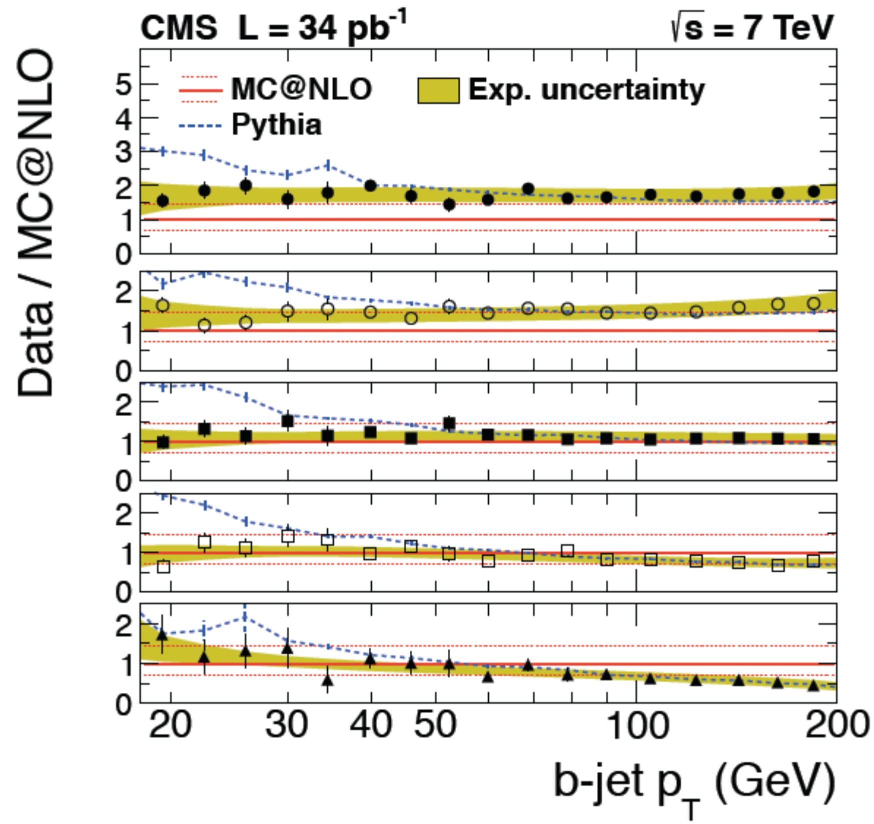
Alternate analysis uses muon-jets w/ $p_{T,rel}$ as a discriminating variable

b-jet Cross Section

Double differential x-section

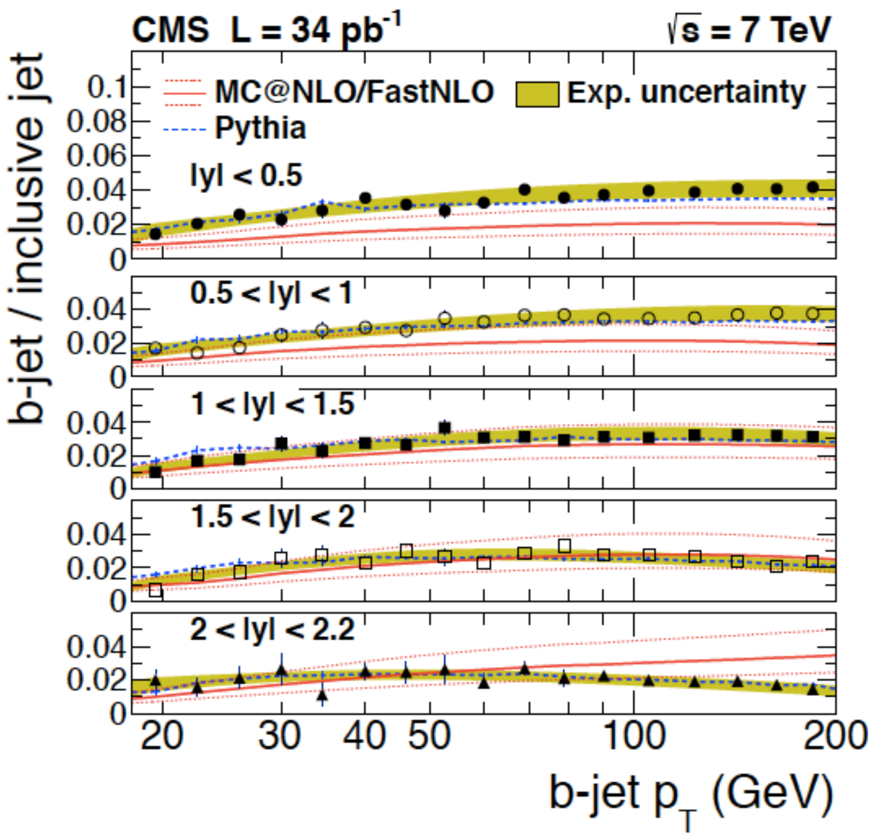


Ratio to MC@NLO



- MC@NLO agreement at the edge of uncertainties
- Pythia overshoots at low p_T, agrees well at high p_T

b-jet to Inclusive Jet Ratio

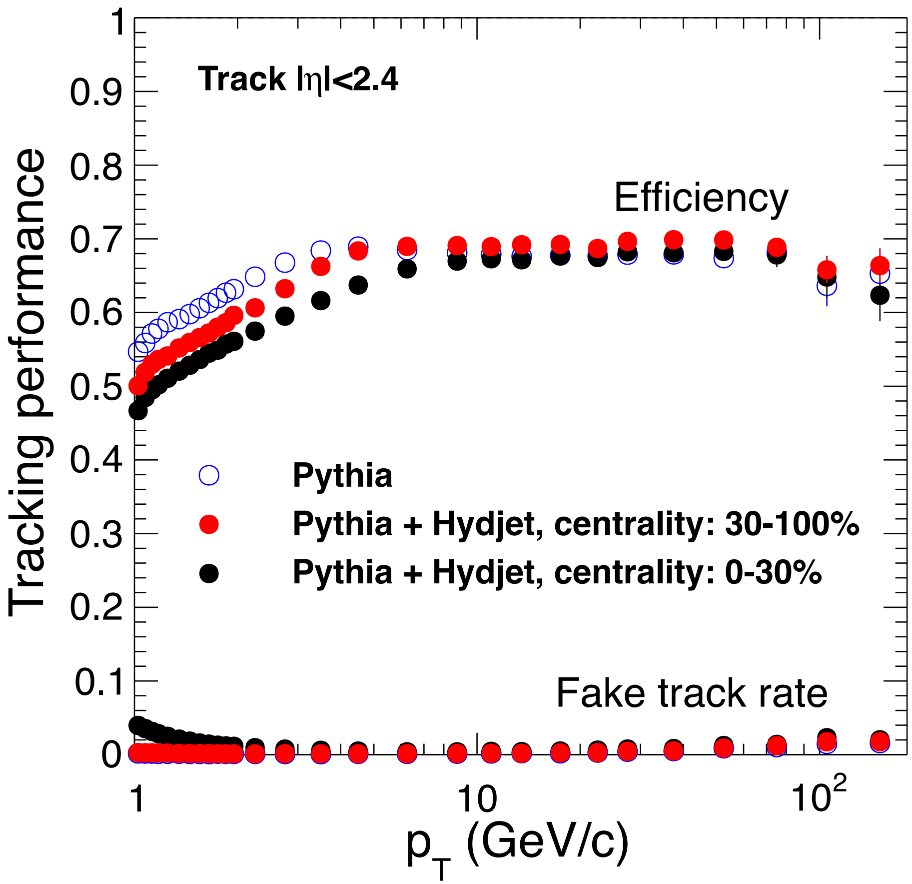


Despite relatively poor description of the cross section, Pythia gives a good description of the b-jet / inclusive jet ratio

Tracking in Heavy Ions

- Biggest challenge in PbPb is reconstructing displaced tracks in central events
- Standard HI track reco. and selection has a reasonable efficiency and low fake rate for primary tracks
- Reconstructing all displaced tracks is so far not possible due to huge number of hit combinations
- Solution is to run additional tracking locally inside jets to recover secondary tracks

“Standard” HI Tracking (2011)

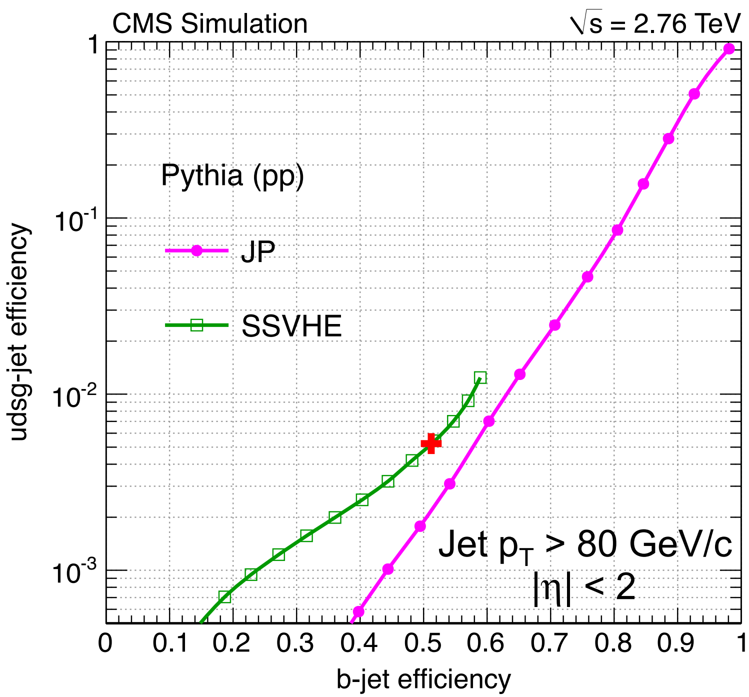


CMS-PAS-HIN-12-013

b-tagging Performance

Jets are tagged by cutting on discriminating variables

- *Simple Secondary Vertex High Efficiency* (SSVHE)
- *Jet Probability* (JP)



- Performance is benchmarked by comparing b-tagging efficiency to efficiency to mis-tag light jets
- *SSVHE* uses the SV flight distance
- JP uses large impact parameter tracks to estimate a likelihood that tracks come from the primary vertex

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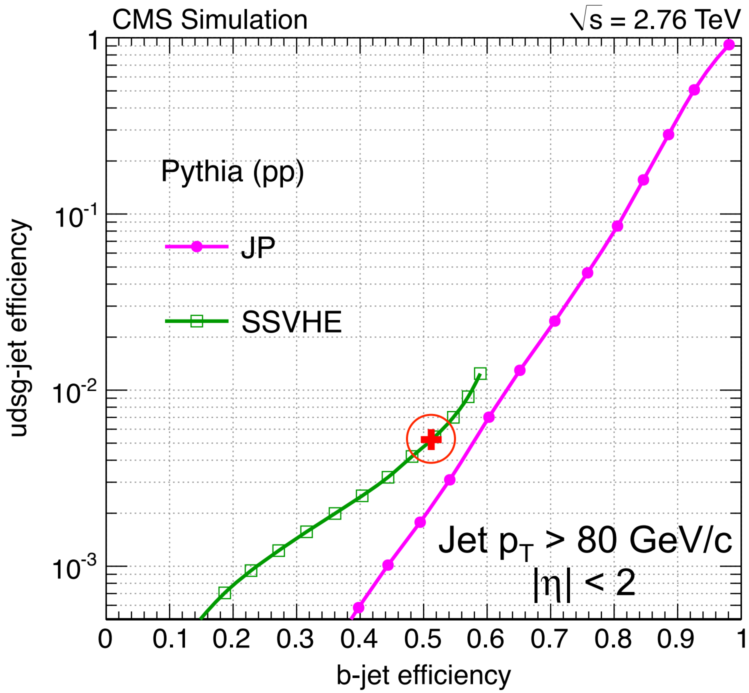


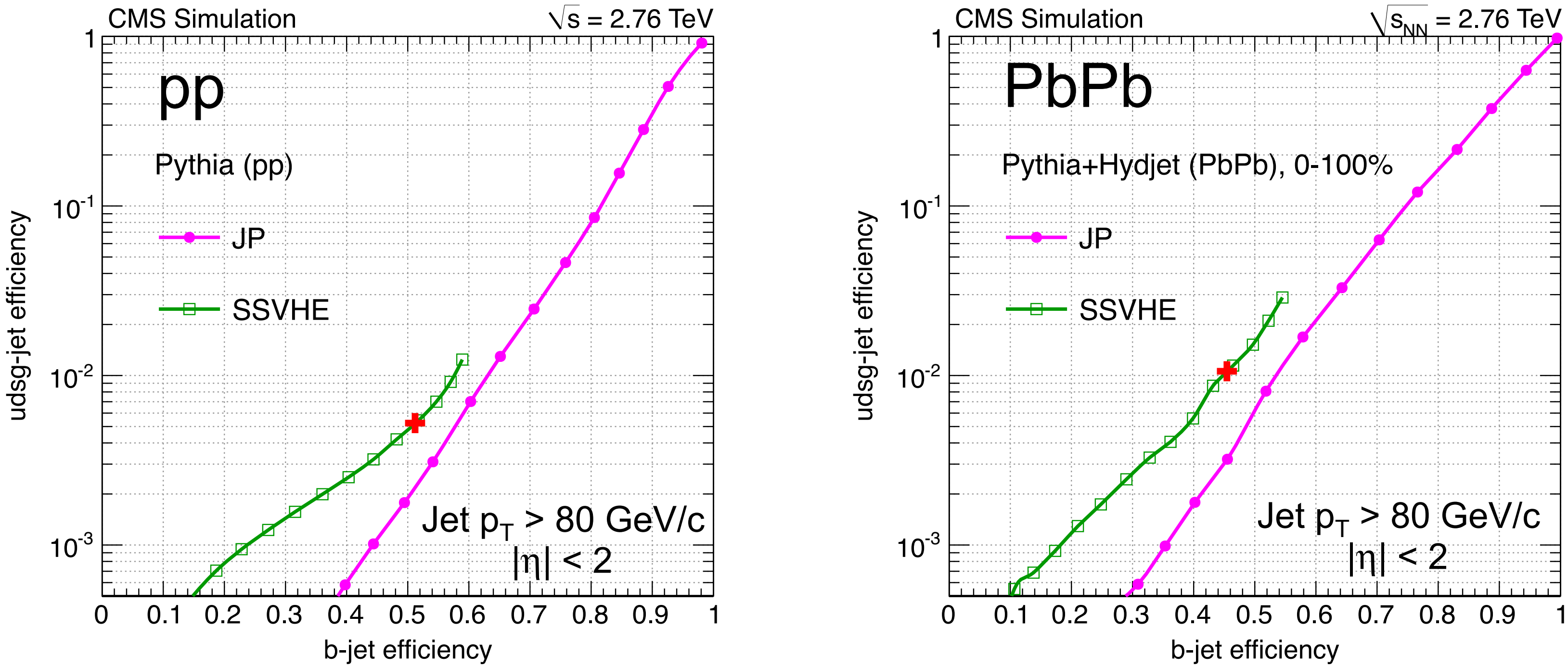
- *SSVHE* uses the SV flight distance
- JP uses large impact parameter tracks to estimate a likelihood that tracks come from the primary vertex
- Performance is benchmarked by comparing b-tagging efficiency to efficiency to mis-tag light jets

- We use an SSVHE working point which gives a factor of several hundred in light jet rejection for a b-jet efficiency of about 50%
- JP is used for data-driven studies of the SSVHE performance

Light Jet Discrimination

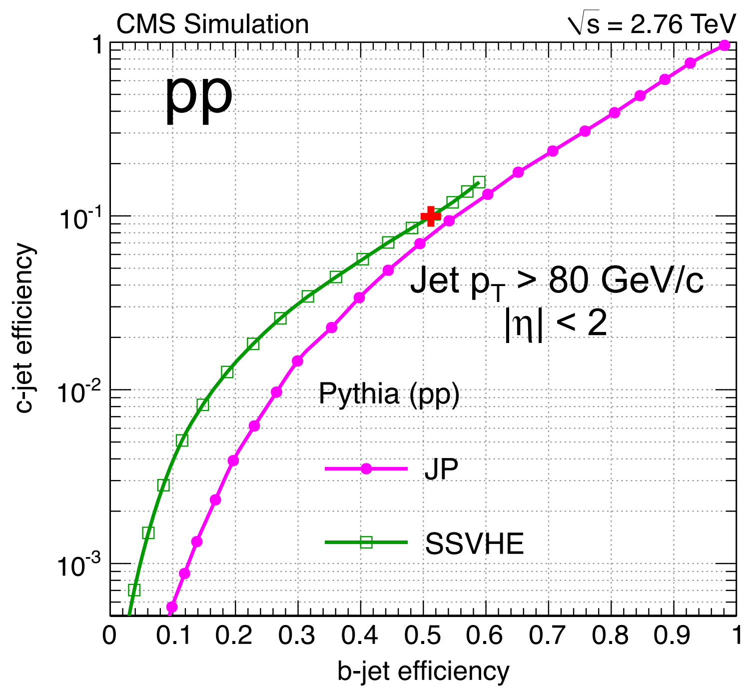
Jets are tagged by cutting on discriminating variables

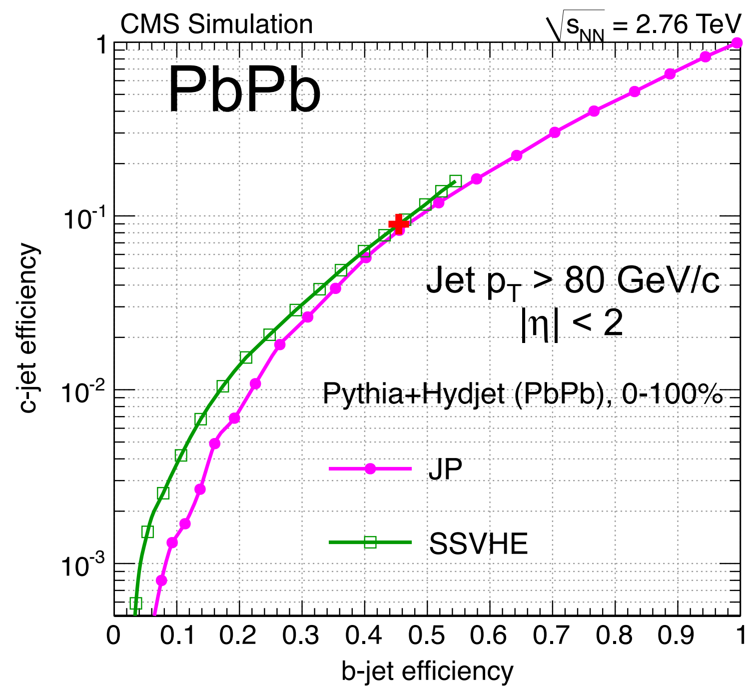
- *Simple Secondary Vertex High Efficiency* (SSVHE)
- *Jet Probability* (JP)



Some degradation of performance in PbPb compared to pp, but still a factor of ~100 light jet rejection for ~45% b-jet efficiency

Charm Jet Discrimination

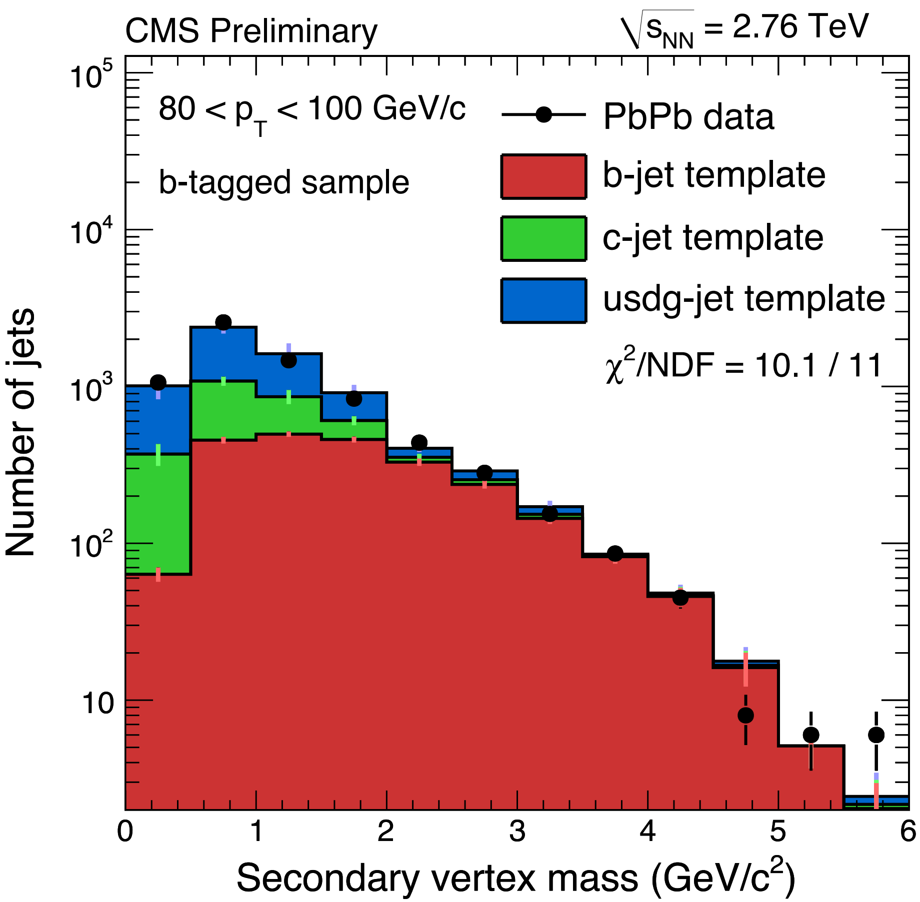




- Charm rejection is about a factor of 10 for the same working point
- Again, some degradation of performance for PbPb w.r.t. pp

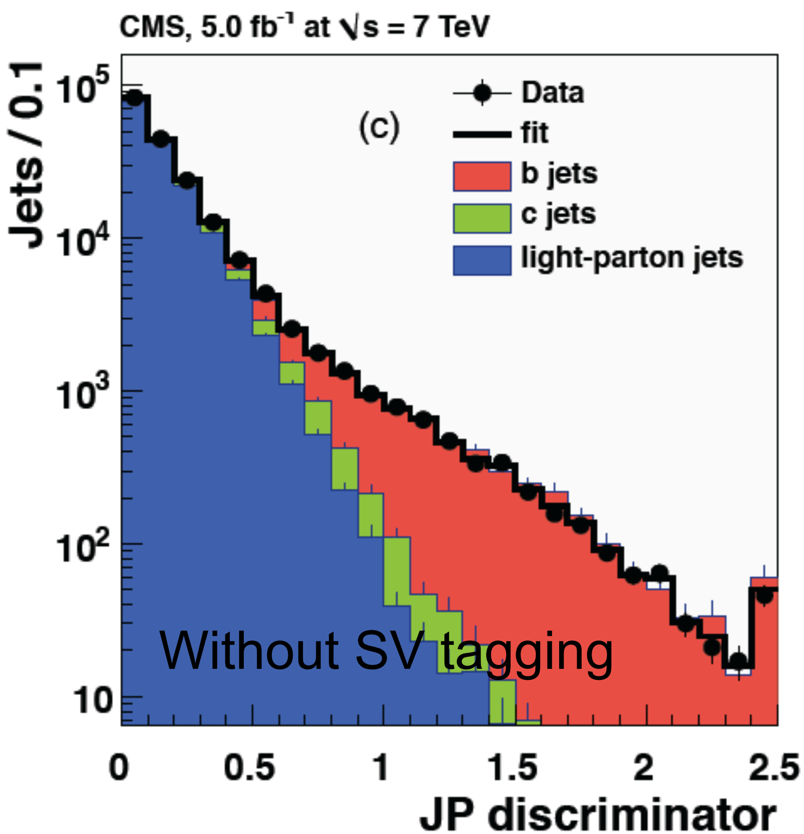
Secondary Vertex Mass Fits

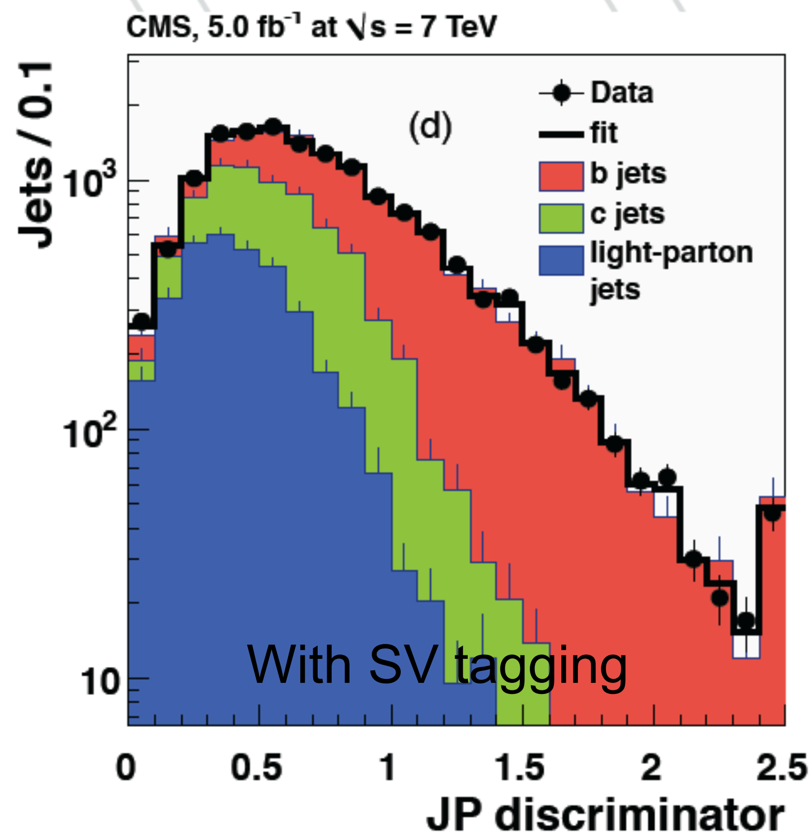
- After enriching sample in b-jets with the SSVHE tagger, the b-jet *purity* is derived from a fit to the SV mass distribution
- Shapes of b and non-b templates taken from MC, normalizations allowed to float
- The shapes of the non-b templates are cross-checked with data-driven templates
- The stability of the fits w.r.t. to the SSVHE working point and the shapes of the templates are the dominant sources of uncertainty on the b-jet purity



Reference Tagger Method

Idea: use a weakly correlated tagger to test SV tagging efficiency





$$\varepsilon_b(\text{data}) = \frac{C_b f_b^{tag} N_{data}^{tag}}{f_b^{notag} N_{data}^{notag}}$$

f_b = purity from template fit

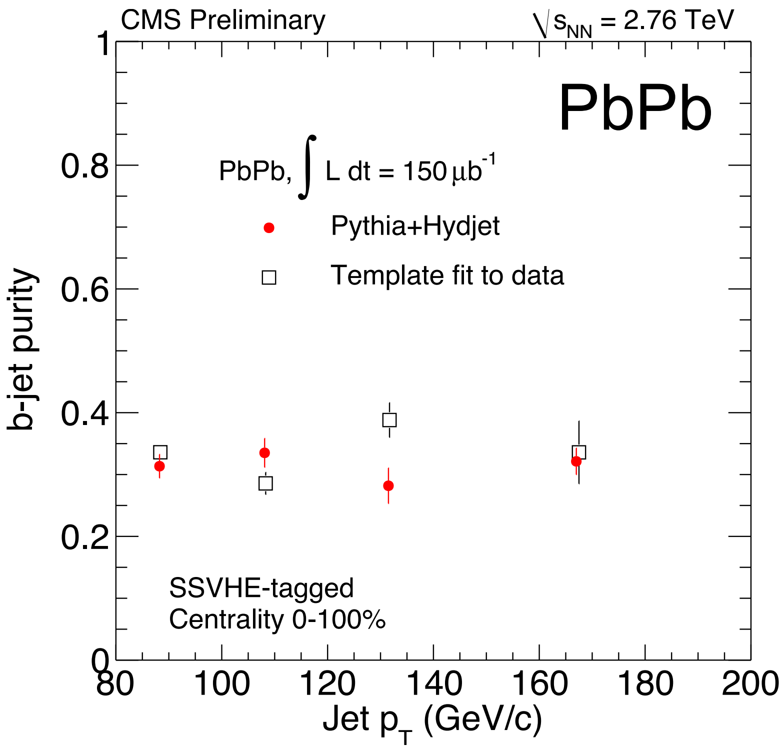
N_{data}^{tag} = # of tagged jets in data

N_{data}^{notag} = # of jets with JP information

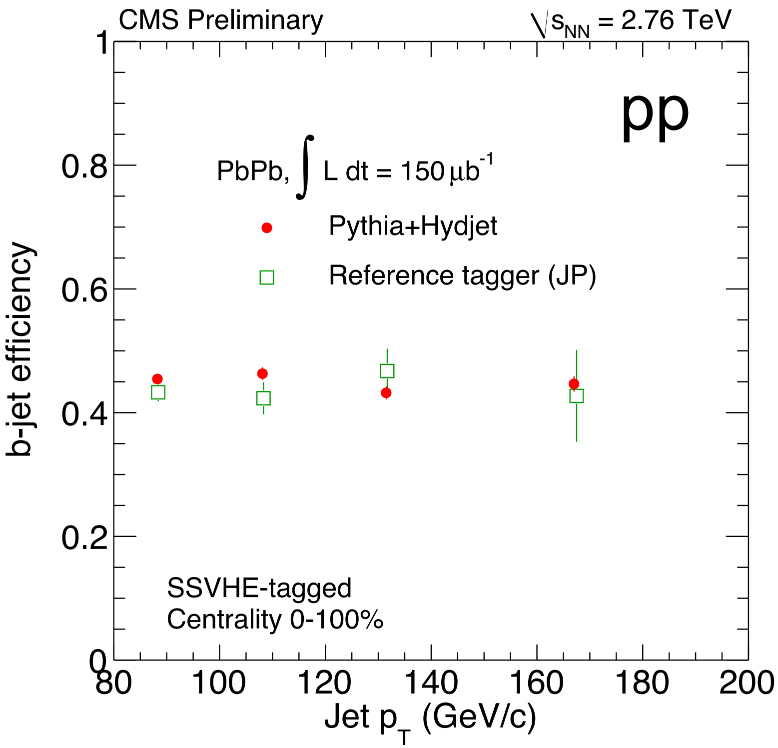
C_b = fraction of jets with JP information

b-Tagging Purity and Efficiency

Purity: b-jet fraction in SV tagged sample extracted from SV mass fit



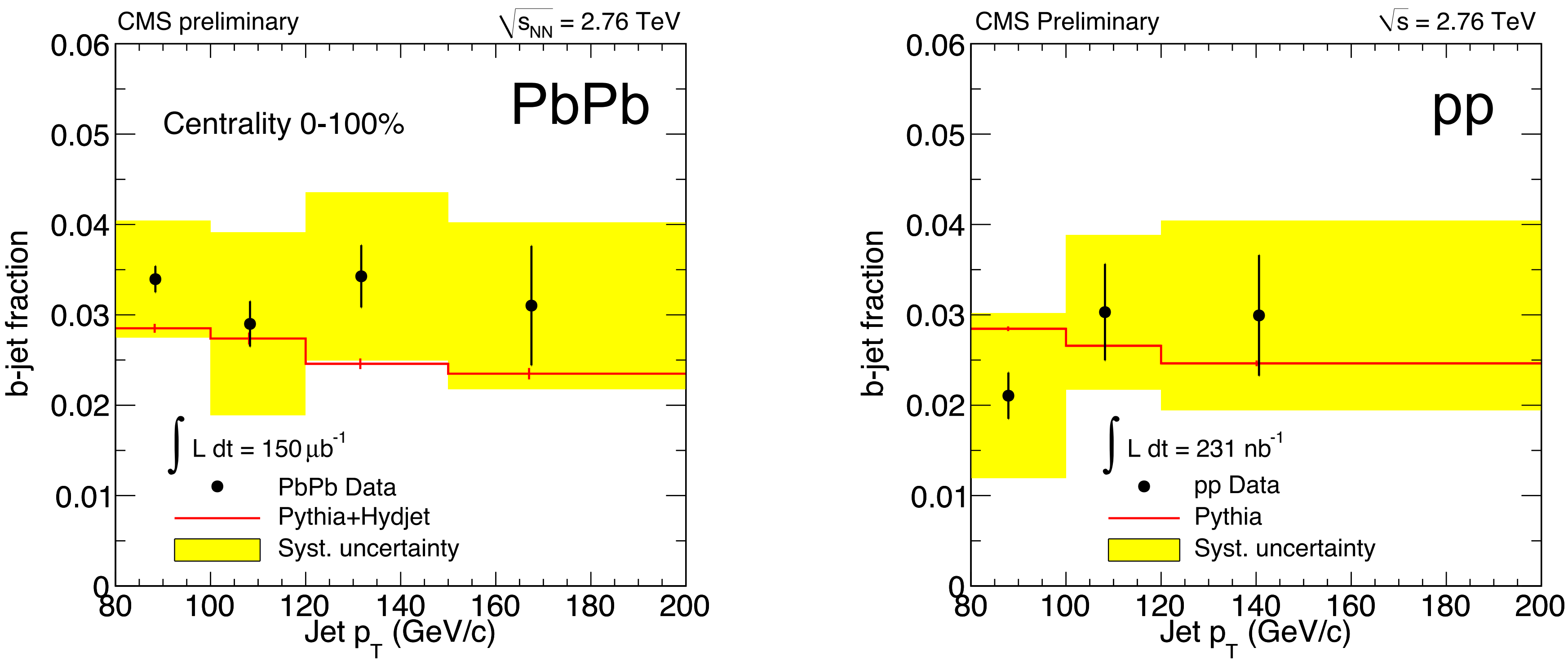
Efficiency: Fraction of b-jets which are tagged by their SV



- Efficiency is extracted from simulation and with a data-driven method using the JP tagger, i.e., w/o requiring a SV
- For both efficiency and purity, MC is fairly close to data "out of the box"

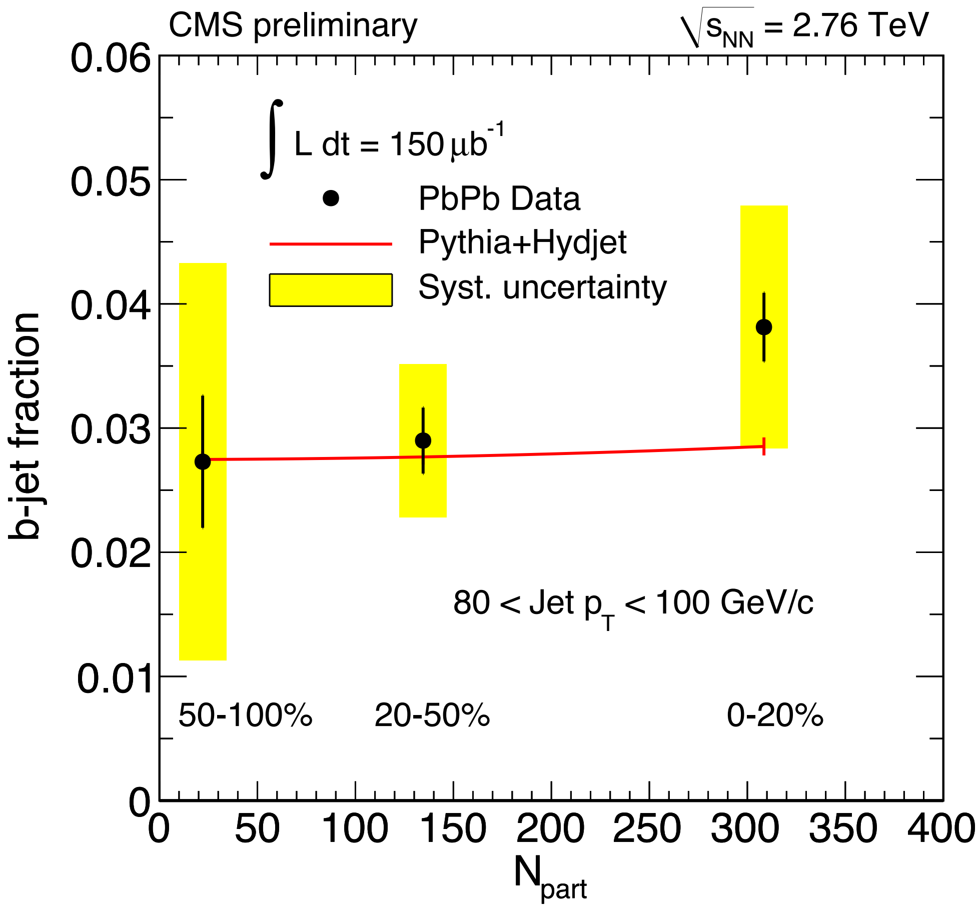
b-jet to Inclusive Jet Ratio

b-jet fraction = # of tagged jets * purity / efficiency



- b-jet fraction in PbPb larger than MC, but consistent within uncertainties
- pp data are also consistent with MC prediction

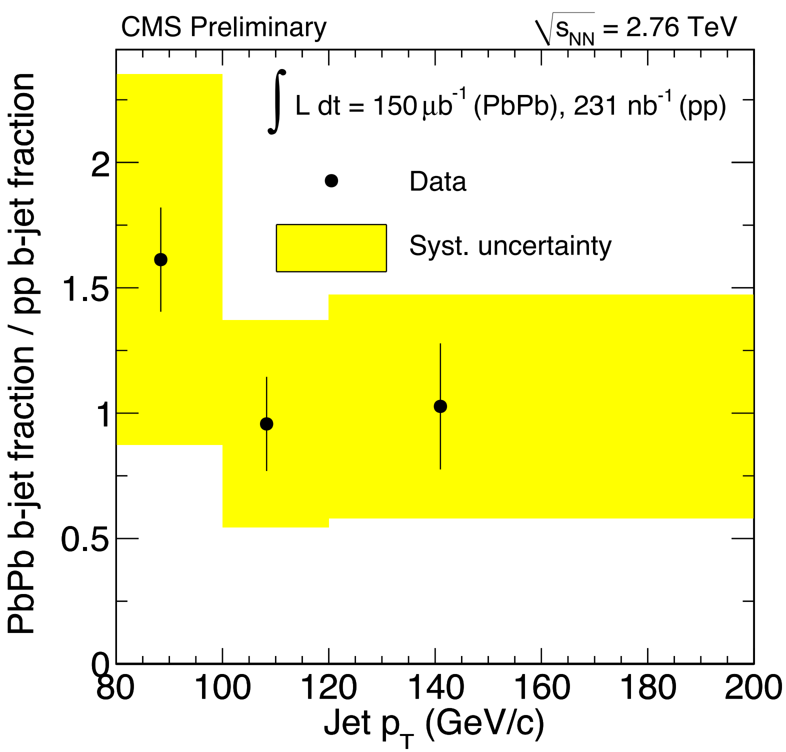
b-jet Fraction vs. Centrality



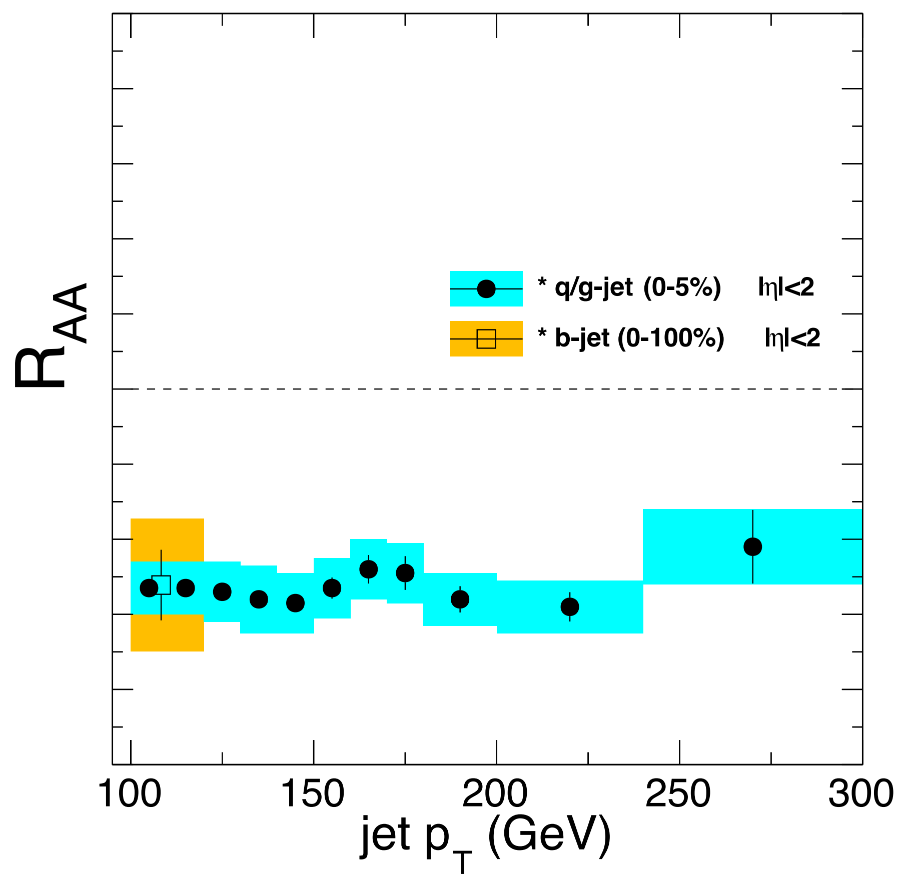
b-jet fraction does not show a strong centrality dependence

b-jet R_{AA}

b-jet fraction double ratio =
b-jet fraction $|_{PbPb}$ / b-jet fraction $|_{pp}$



b-jet R_{AA}
= inclusive jet R_{AA} * double ratio

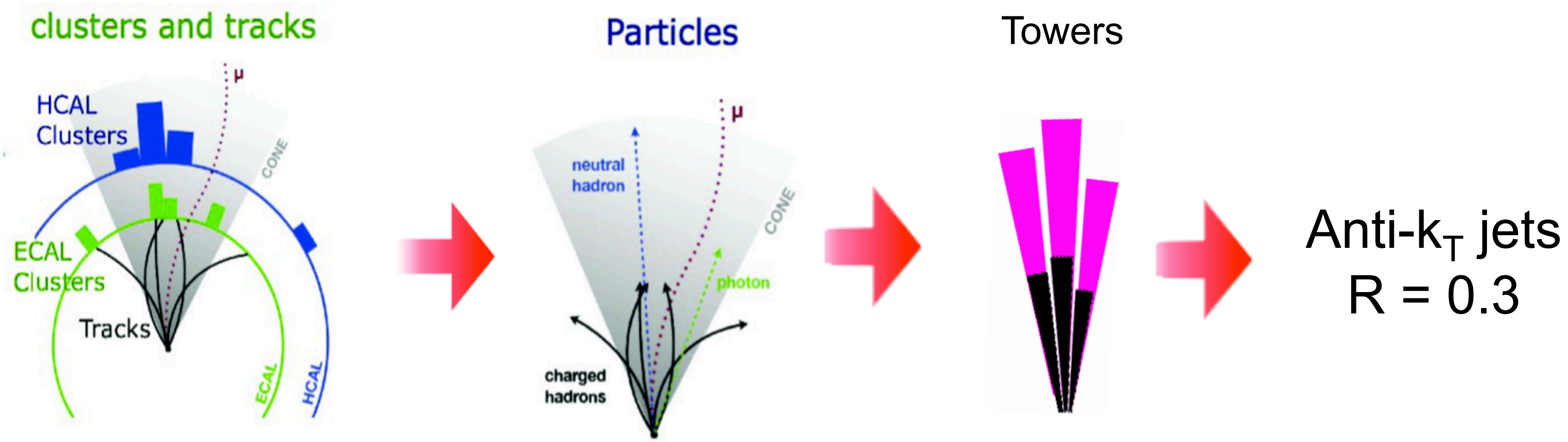


Conclusions, Outlook

- b-jet cross section measured in 7 TeV pp collisions
  - Using secondary vertices
  - Using muon jets
- Results agree with Pythia predictions
- Fully reconstructed b-jets have been identified in heavy-ion collisions for the first time
- b-jet fraction in PbPb is consistent with Pythia and pp data @ 2.76 TeV within fairly sizeable uncertainties
- Looking forward to
  - More pp @ 2.76 TeV which might be recorded in 2013
  - Further analysis pushing to lower p_T jets, muon-jets, double b-tagged dijets, etc.

Backup Slides

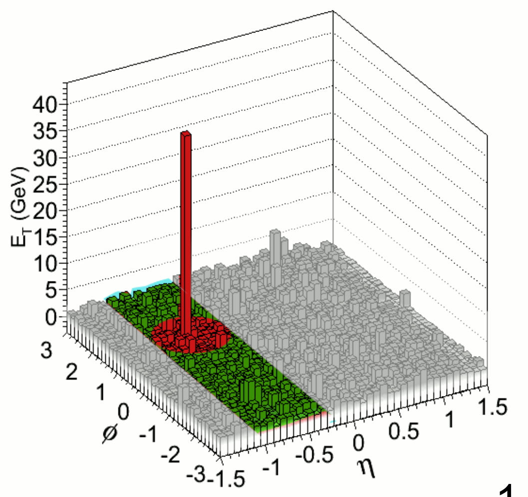
Jet Measurements in PbPb

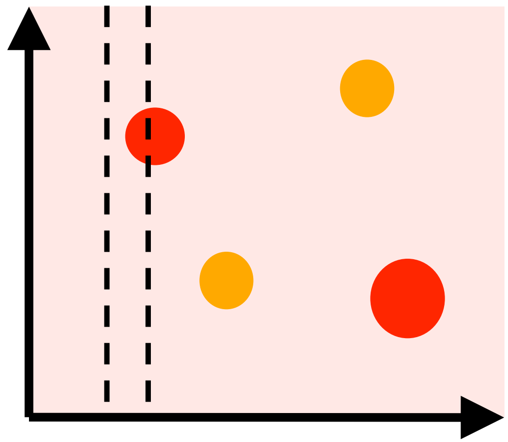


- Information from all sub-detectors are combined into particle candidates → "Particle flow" event reconstruction [1-2]
- Allows to exploit the excellent resolution of the tracker for the charged hadron component of the jet
- Also includes a fully consistent treatment of electron and muons inside jets
- Particle candidates combined into towers in order to subtract the heavy-ion background

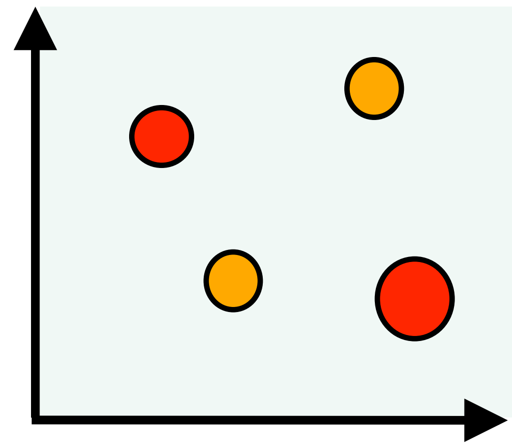
[1] arXiv:1107.0179
[2] CMS-PAS-PFT-09-001

Underlying Event Subtraction

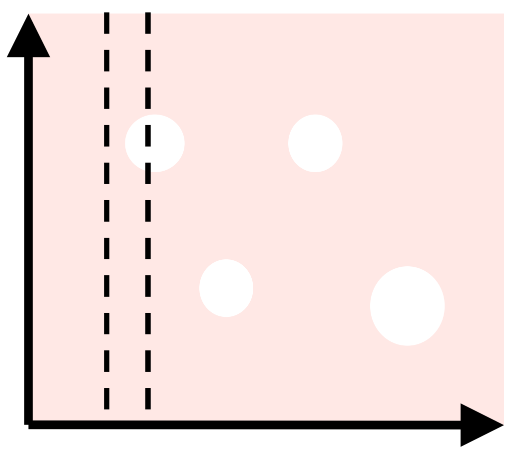




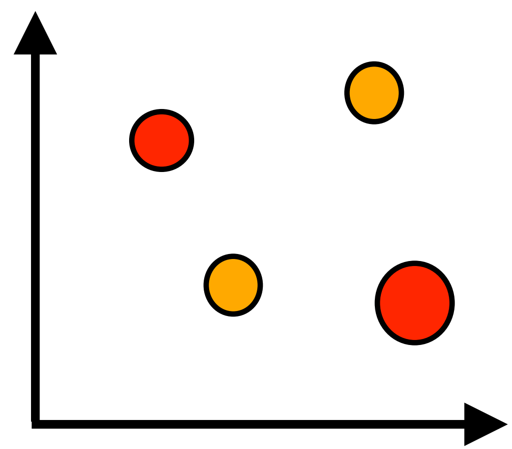
1. $\langle E_T \rangle$ calculated in strips of η.
Subtract $\langle E_T \rangle + \sigma$



2. Run anti-k_T algorithm on background-subtracted towers



3. Exclude reconstructed jets and re-estimate background



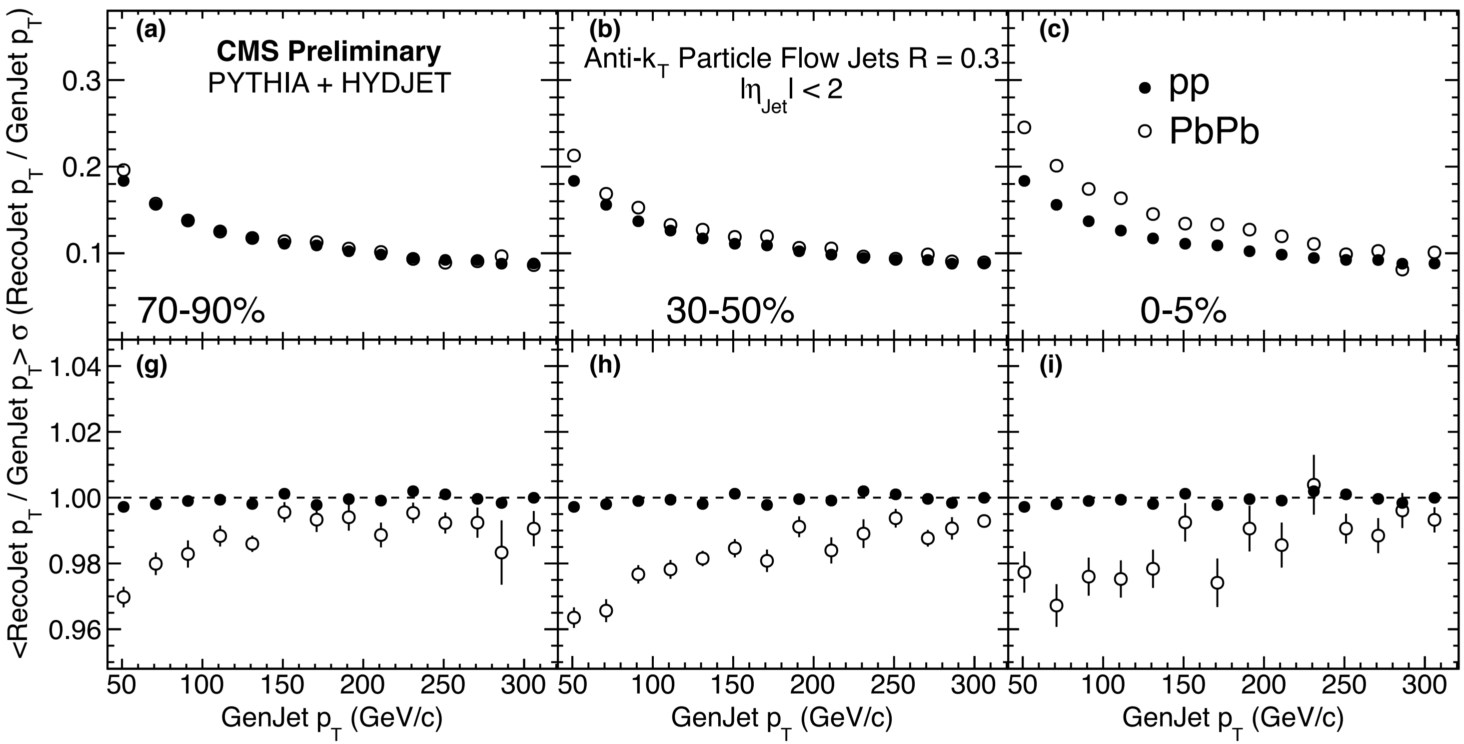
4. Re-run anti-k_T algorithm to get final jets

For details see:
- CMS, arXiv:1102.1957
- Kodolova et al., EPJC 50 (2007) 117

Jet Reconstruction Performance

Resolution

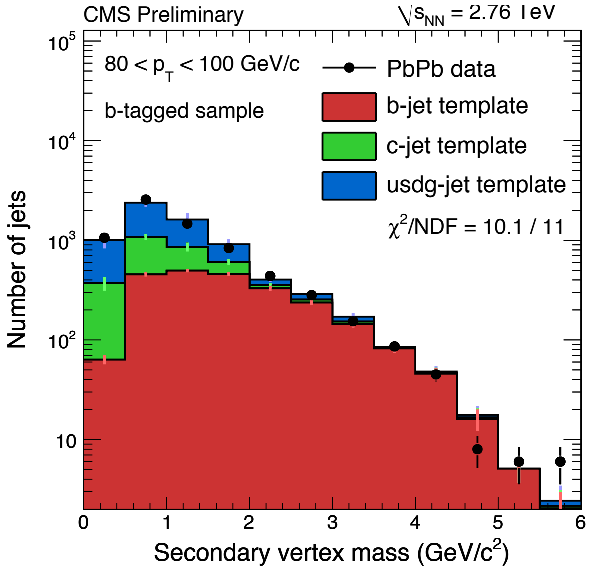
Response

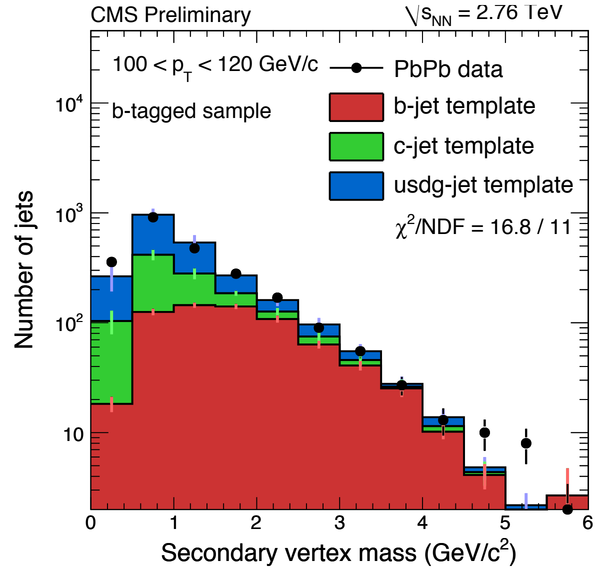


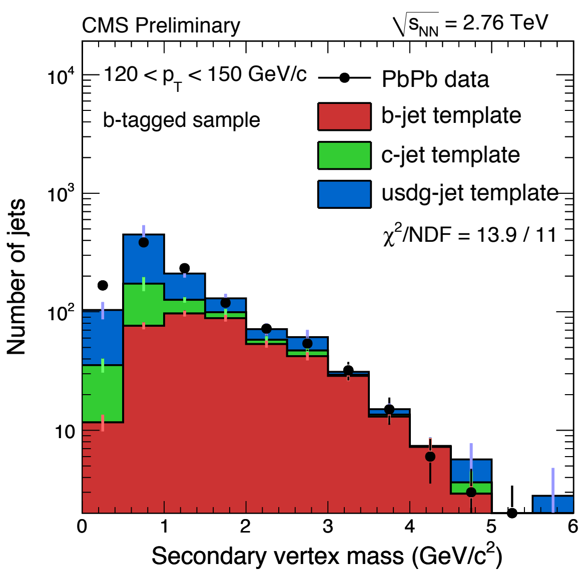
- Jet energy corrections based on PYTHIA simulations
- Corrected jet response close to unity even in central events
  → demonstrates reliability of HI background subtraction

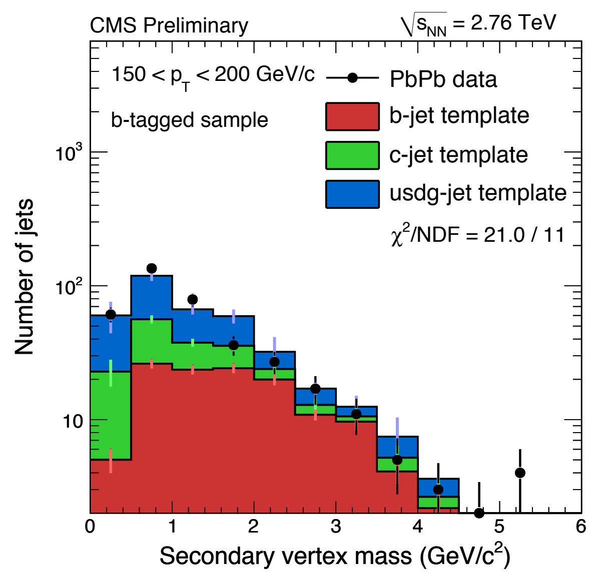
CMS-PAS-HIN-12-004

SV Mass Fits in All Jet p_T Bins

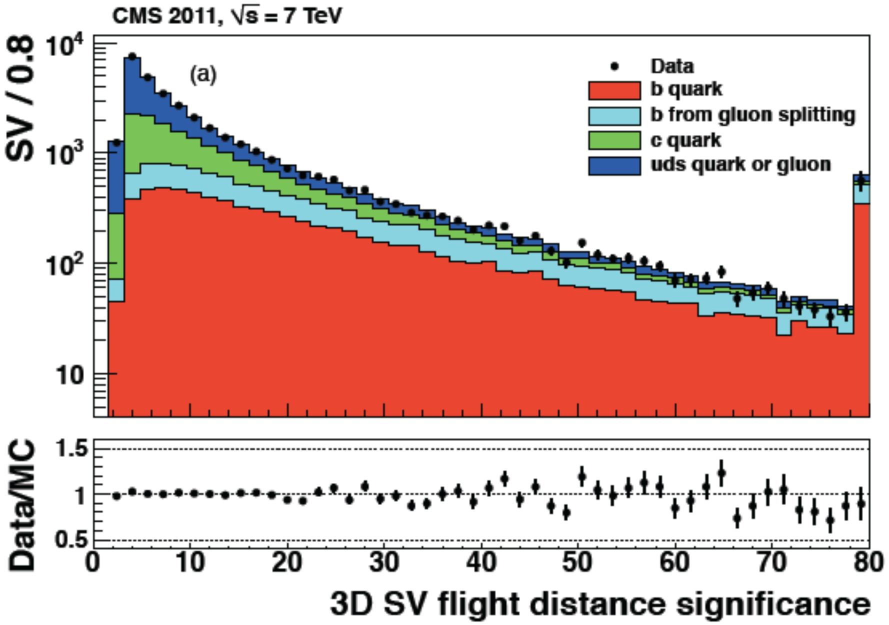


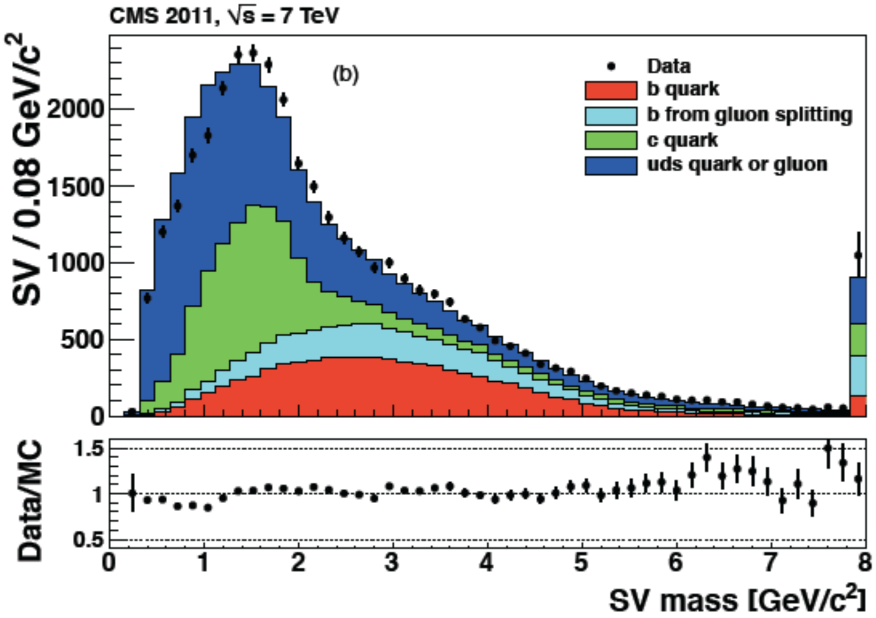


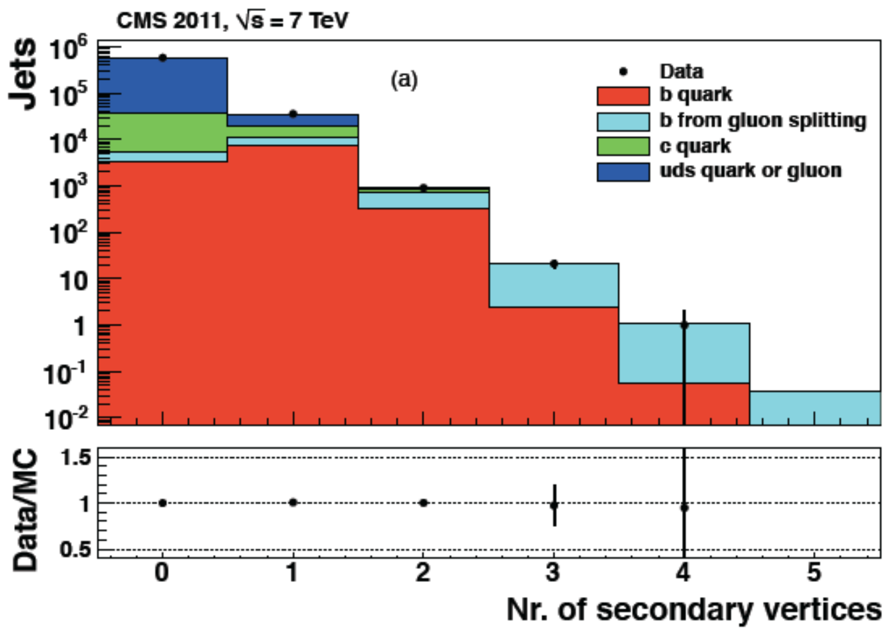




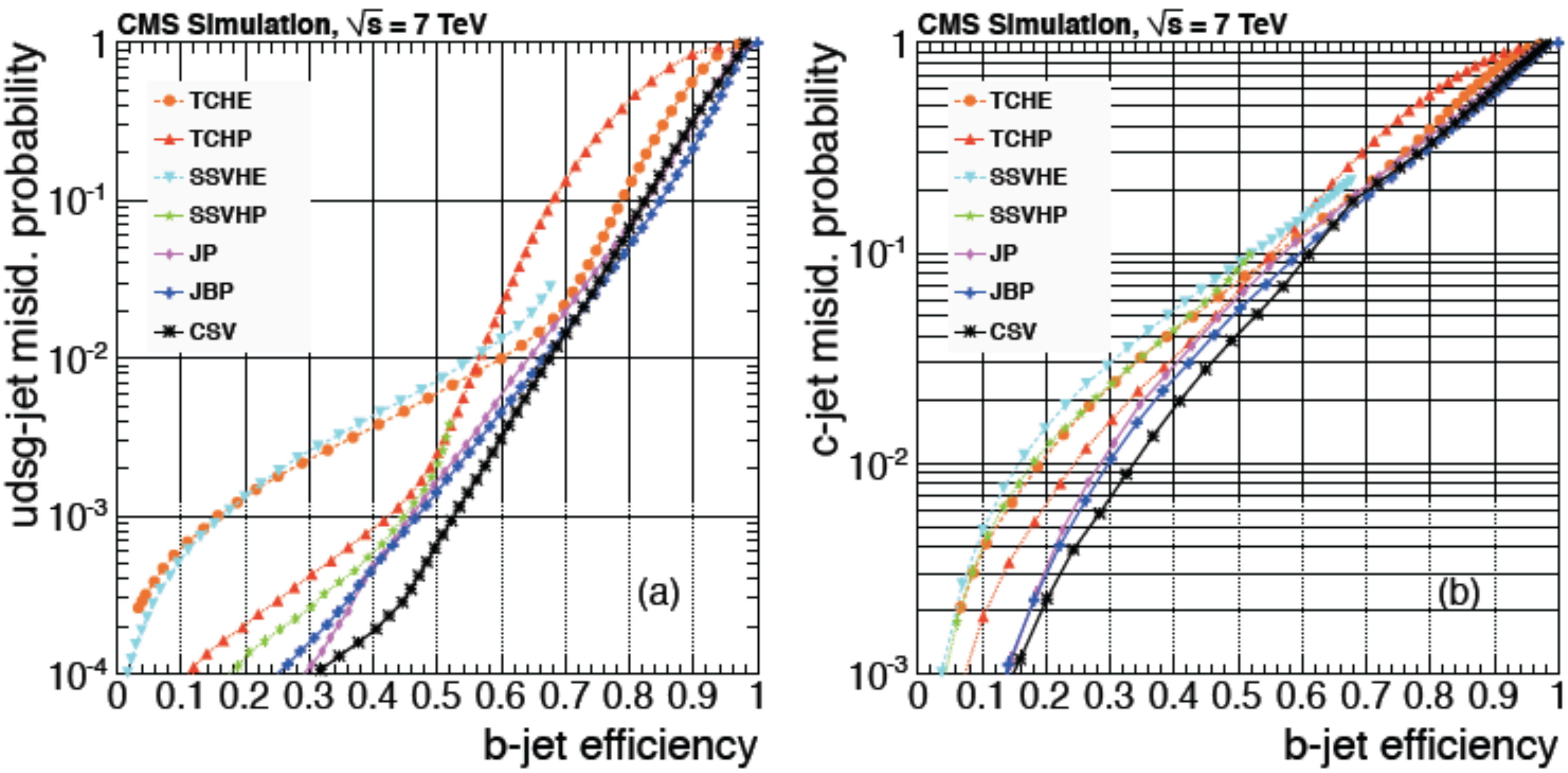
SV-related Quantities (pp @ 7 TeV)







Performance in pp @ 7 TeV

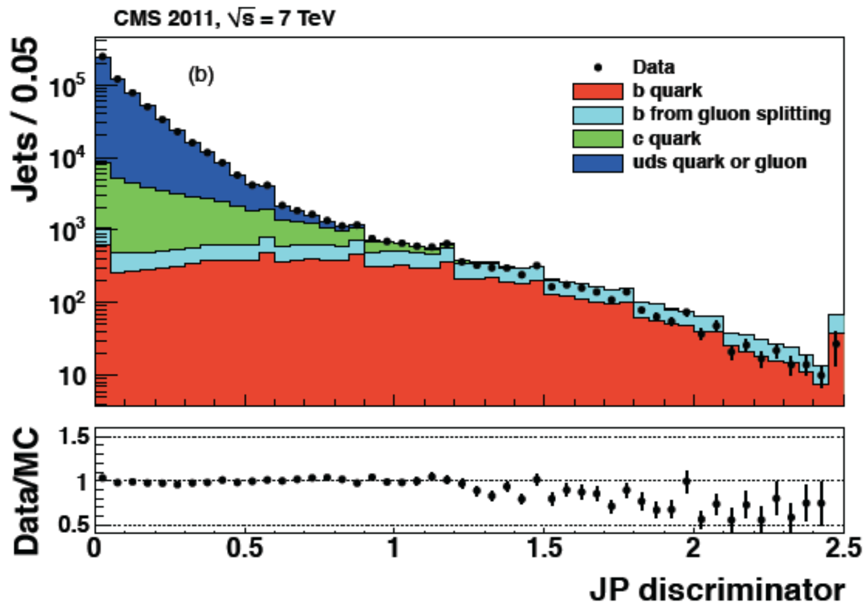


Jet Probability

- Tracks are ordered by IP significance
- Each track assigned a probability (*P*) that it's from the PV based on IP significance
- Likelihood that all tracks are compatible with the PV

$$P_{jet} = \Pi \cdot \sum_{i=0}^{N-1} \frac{(-\ln\Pi)^i}{i!} \quad \text{with} \quad \Pi = \prod_{i=1}^{N} \max(P_i, 0.005),$$

- 0.5% cutoff mitigates badly reco'd tracks
- P_i's are independently calibrated in data and MC using tracks with *negative* impact parameter



Sources of Systematic Uncertainty

1) Difference in efficiency between simulation and result obtained using the reference tagger (JP)
2) Relative contribution of charm and light jets
3) Uncertainty in non-b template shapes evaluated by comparing to data-driven templates obtained using an anti-b-tagging cut on the JP discriminator
4) Stability of template fits obtained by varying the discriminator working point
5) Difference between b-jet and inclusive jet energy scales
6) Contribution of gluon splitting varied by 50%