Inclusive p_T spectrum of b-jets in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

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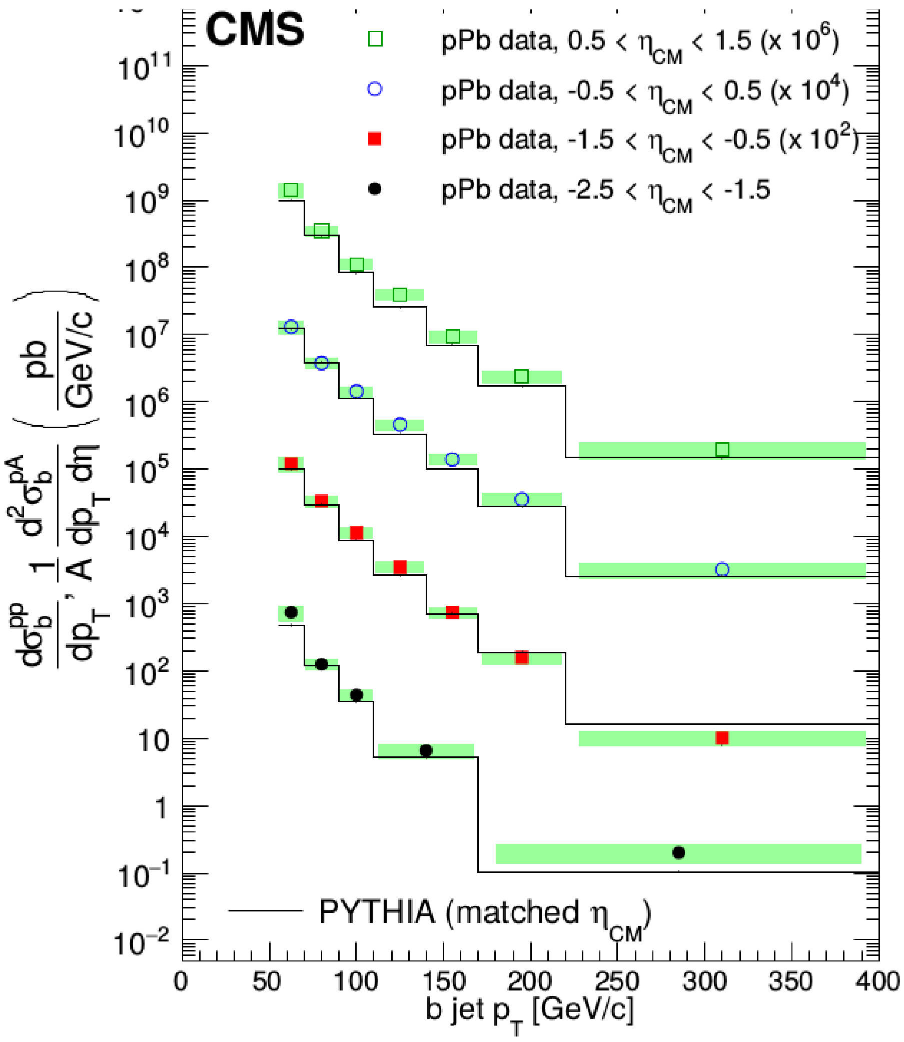
Motivation

CMS Results (pPb, 5.02 TeV, full jets 2018)



Properties of b-quark:

- large mass (4.62 GeV/c^2) → it can be created only in initial hard scatterings. Its production rate can be calculated from pQCD
- long lifetime → it survives through the whole evolution of QGP

ALICE wants to study b-jets at lower momenta

[The CMS Collaboration - “Transverse momentum spectra of inclusive b jets in pPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV”, CERN-PH-EP/2013-037, 2018/10/09]

Analysis settings

Event selection

- Minimum bias trigger (V0 scintillator arrays)
- $|z_{vtx}| < 10$ cm
- Pileup rejection

After event selection we have $6 \cdot 10^8$ minimum bias events

Track selection

- Hybrid tracks
- $|\eta_{track}| < 0.9$

Jet selection:

- Charged anti-k_T, R=0.4
- $p_{T,\text{ constituent}} > 0.15$ GeV/c
- p_T recombination scheme
- $|\eta_{jet}| < 0.9 - R < 0.5$

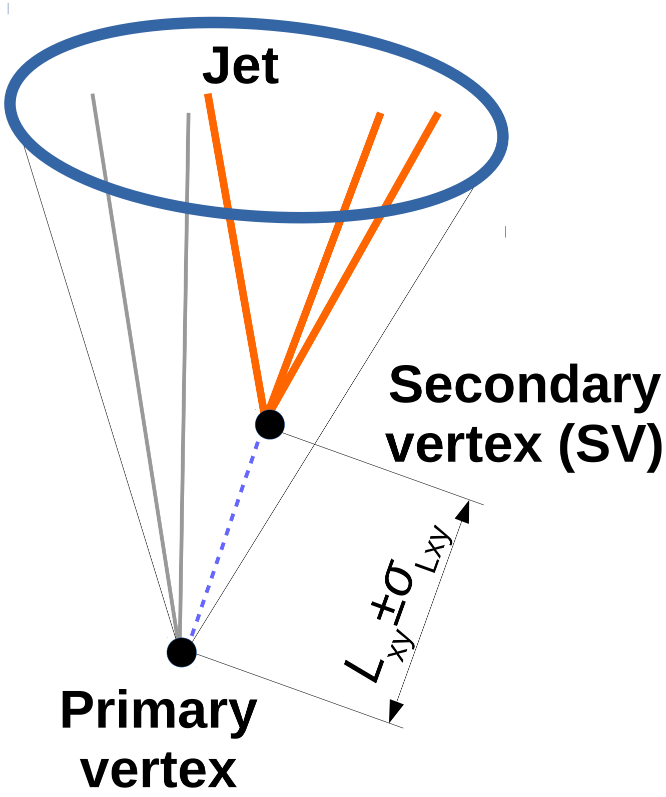
Background density correction:

Two leading k_T jets are excluded

$$p_{T,charged\ jet}^{corrected} = p_{T,charged\ jet}^{RAW} - \rho \cdot A_{jet}$$

$$\rho = \frac{A_{physical\ jets}}{A_{all\ jets}} \times median_{k_{T\ physical\ jet}} \left\{ \frac{p_{T,jet}^{ch,raw}}{A_{jet}} \right\}$$

B-jet tagging via SV reconstruction



b-jet candidate selection:

- 3 prong SV is made out of jet constituents
- In each event we consider the most displaced SV

Discrimination variables:

1) Significance of the distance between primary and secondary vertices

$$\mathbf{SLxy = L_{XY}/\sigma_{Lxy} > 5\ to\ 9}$$

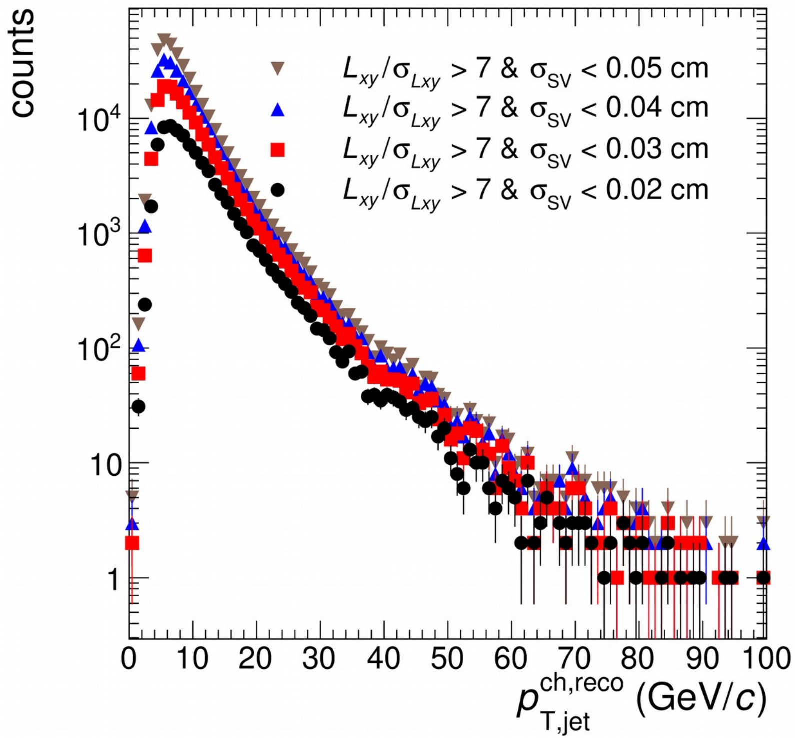
2) Dispersion of the SV $\boldsymbol{\sigma_{SV} < 0.02\ to\ 0.05\ cm}$

$$\sigma_{SV} = \sqrt{\sum_{i=1}^{3} d_i^2}$$

d_i – distance of the closest approach (DCA) of i-th prong to SV

3) Invariant mass in SV *(reserved for purity estimation)*

Raw p_T spectrum of b-jets



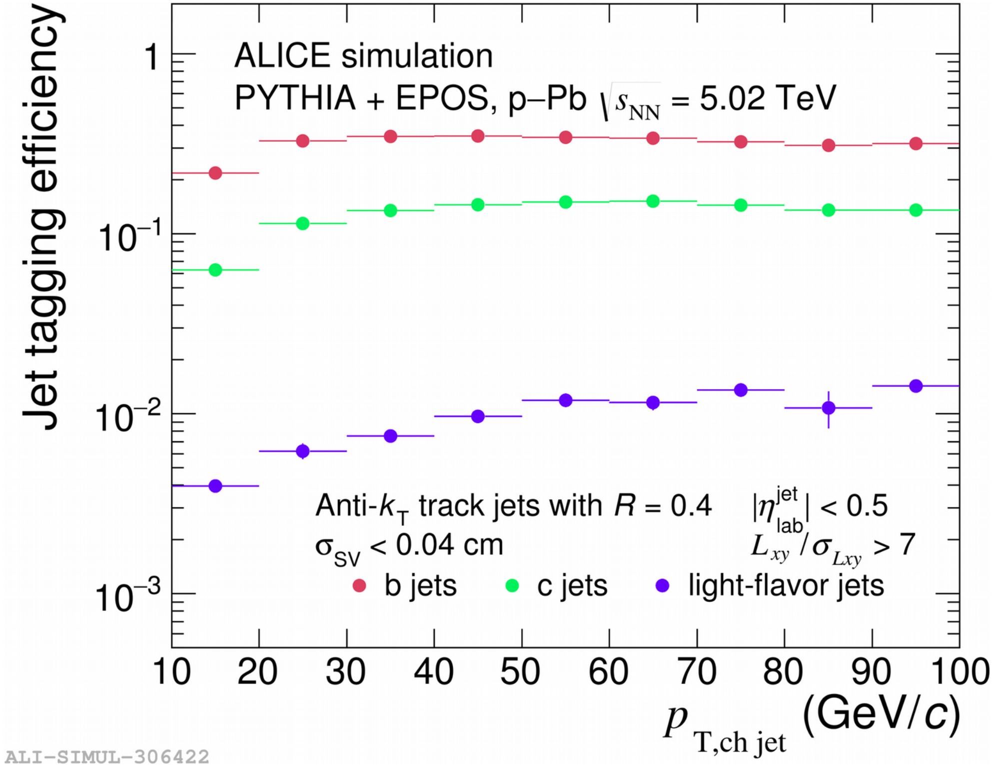
- Selected sample of b-jet candidates contains b, c and LF-jets.
- To get RAW transverse momentum spectra of b-jets, the spectrum of b-jets candidates needs to be corrected:

$$\frac{dN_{b\text{-}jet}^{primary}}{dp_{T,\,jet\,ch}} = \frac{dN_{b\text{-}jet\,candidates}^{raw}}{dp_{T,\,jet\,ch}} \times \frac{P_b}{\varepsilon_b}$$

P_b − purity of the b-jet candidates

ε_b − efficiency of the b-jet selection after applying cuts

Efficiency of SV tagging



$$\varepsilon_b \approx 35\ \%,\ \varepsilon_c \approx 11\ \%,\ \varepsilon_{LF} \approx 1\ \%$$

b-jet tagging efficiency is estimated from EPOS+PYTHIA detector-level simulation:

$$\varepsilon_b = \frac{N_{b-jets}^{selected}}{N_{b-jets}^{all}}$$

N_{b-jets}^{all} – the number of b-jets without any constraint on presence and parameters of SV

$N_{b-jets}^{selected}$ – the number of b-jets that were reconstructed when applying cuts on b-jets candidates

b-jet purity from data driven template fit method

- The datca driven method is based on representation of the measured distribution of invariant mass of SV as a linear combination of MC templates:

$$\begin{cases} n_{SV} = P_b \cdot T_b + P_c \cdot T_c + P_{LF} \cdot T_{LF} \\ 1 = P_b + P_c + P_{LF} \end{cases}$$

n_{SV} – measured SV invariant mass distribution in given jet-p_T bin

T_b, T_c, T_{LF} – MC template spectra for each jet flavor

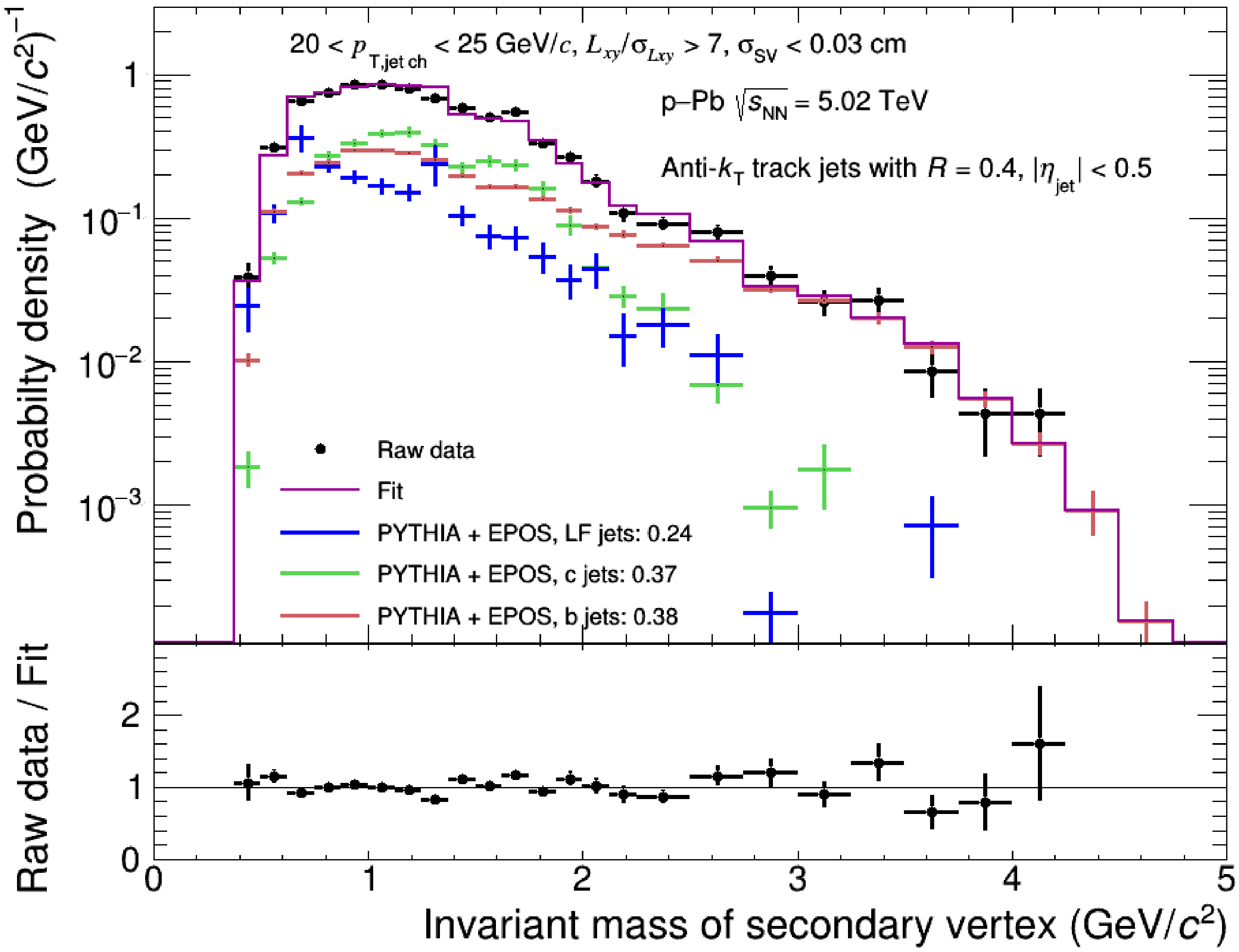
P_b, P_c, P_{LF} – purity for each jet flavor

- Purity is evaluated in 5 GeV/*c* wide $p_{T,\text{ jet ch}}$ bins
- TMinuit library was used to fit MC templates to measured distribution

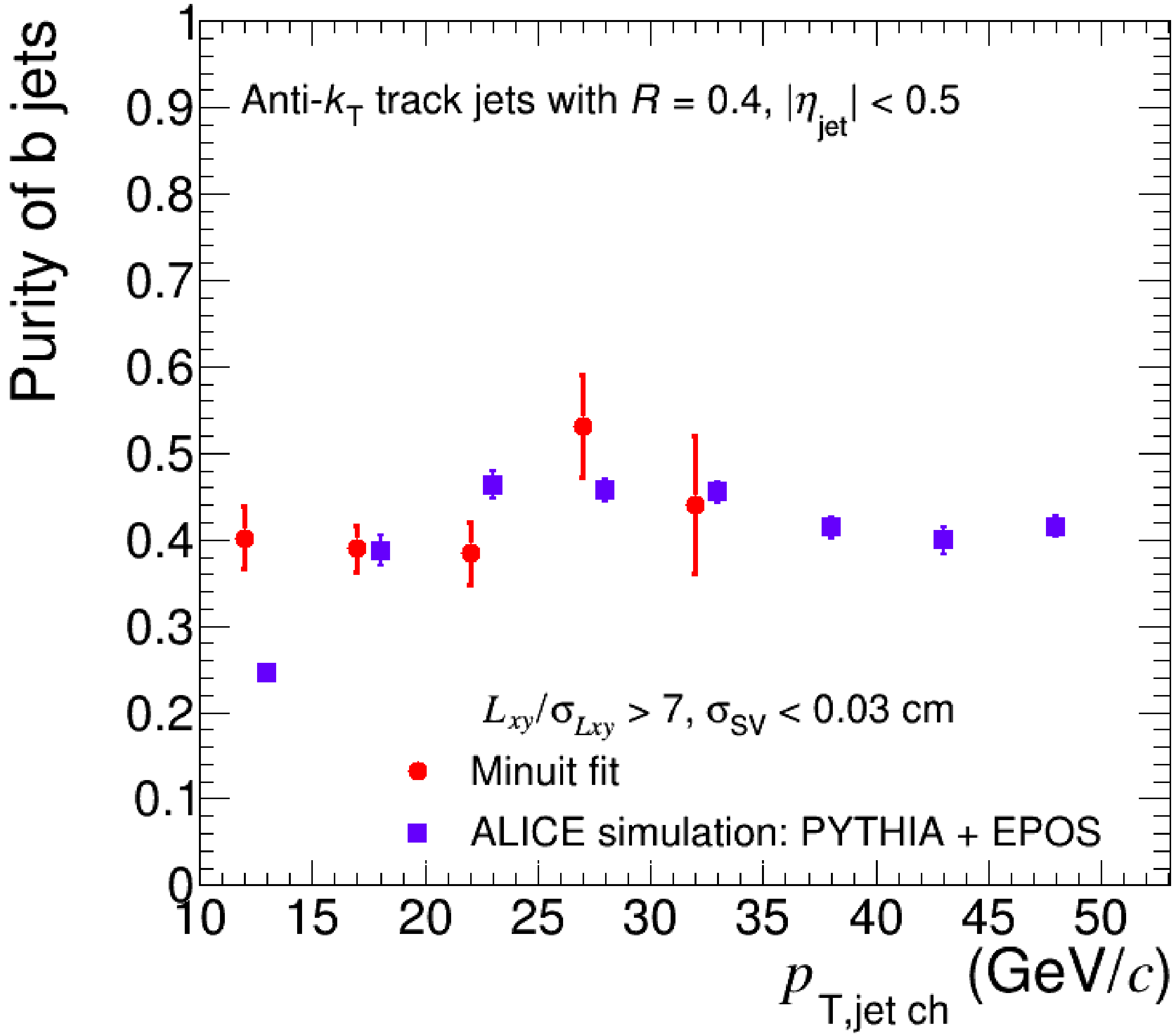
$$\chi^2 = \sum_{i=1}^{nbis} \frac{\left(n_{SV,i} - P_b \cdot T_{b,i} - P_c \cdot T_{c,i} - P_{LF} \cdot T_{LF,i}\right)^2}{\sigma^2_{n_{SV,i}} + \left(\sigma_{T_{b,i}} \cdot P_b\right)^2 + \left(\sigma_{T_{c,i}} \cdot P_c\right)^2 + \left(\sigma_{T_{LF,i}} \cdot P_{LF}\right)^2}$$

$\sigma_{nsv}, \sigma_{\mathrm{Tb}}, \sigma_{\mathrm{Tc}}, \sigma_{\mathrm{TLF}}$ – statistical error for each jet flavor

Results of TMinuit fitting



Data-driven method results



- Bad convergence for $p_{T,jet\ ch}$ > 35 GeV/c → larger statistics for MC and Real Data is required

POWbc method to assess purity of SV

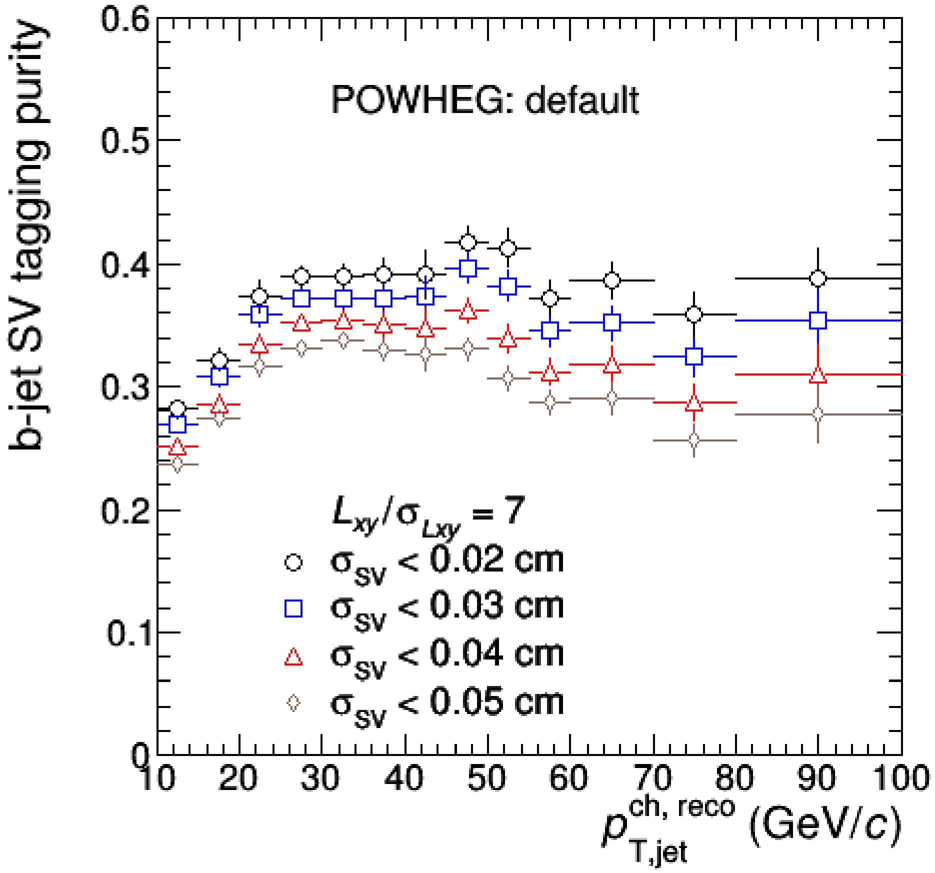
POWbc method - based on *b* and *c-jets* spectra calculated by Next-to-Leading Order (NLO) POWHEG generator:

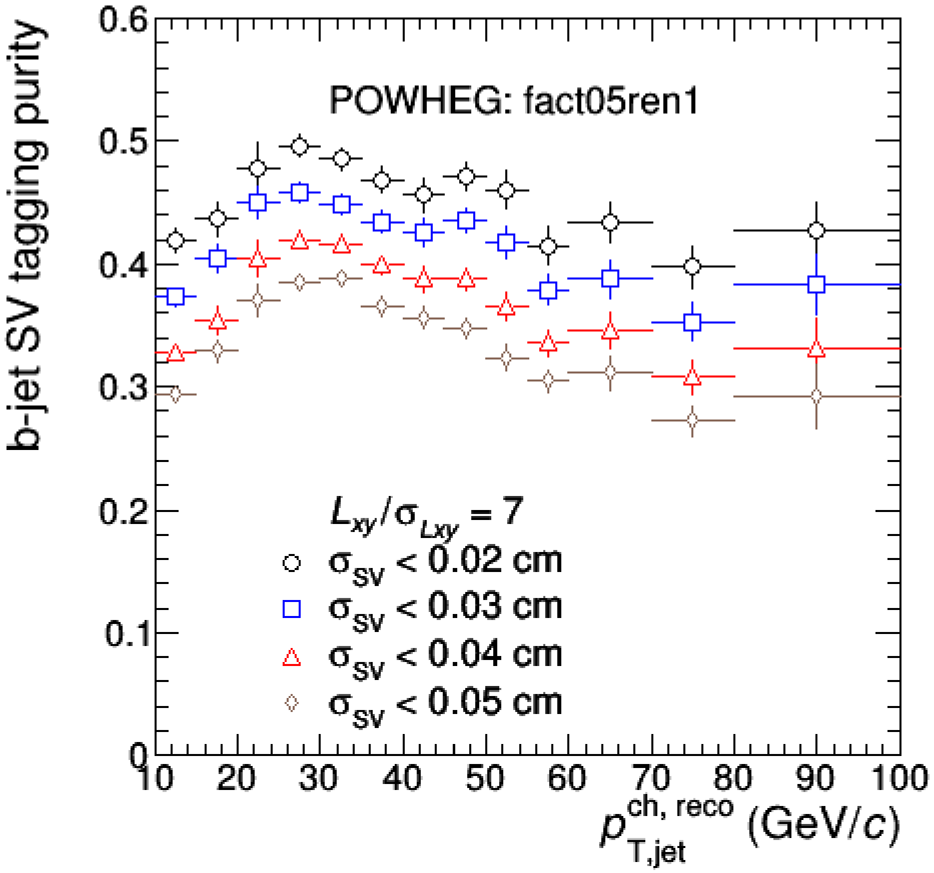
1) Fold generated *b* and *c* jet spectra (particle level) with jet response matrix which accounts for momentum smearing due to local background fluctuations and instrumental effects
2) Purity estimate:

$$P_b = \frac{N_b \varepsilon_b}{N_b \varepsilon_b + N_c \varepsilon_c + N_{LF} \varepsilon_{LF}}$$

N_b, N_c − folded POWHEG p_T spectrum of *b* and *c*-jets
N_{LF} = *RAW p_T spectrum of inclusive jets* − $N_b \varepsilon_b - N_c \varepsilon_c$
$\varepsilon_b, \varepsilon_c, \varepsilon_{LF}$ − *efficiency* of SV tagging for *b*, *c* and *LF*-jets for corresponding SL_{xy} and σ_{SV}

POWbc method results

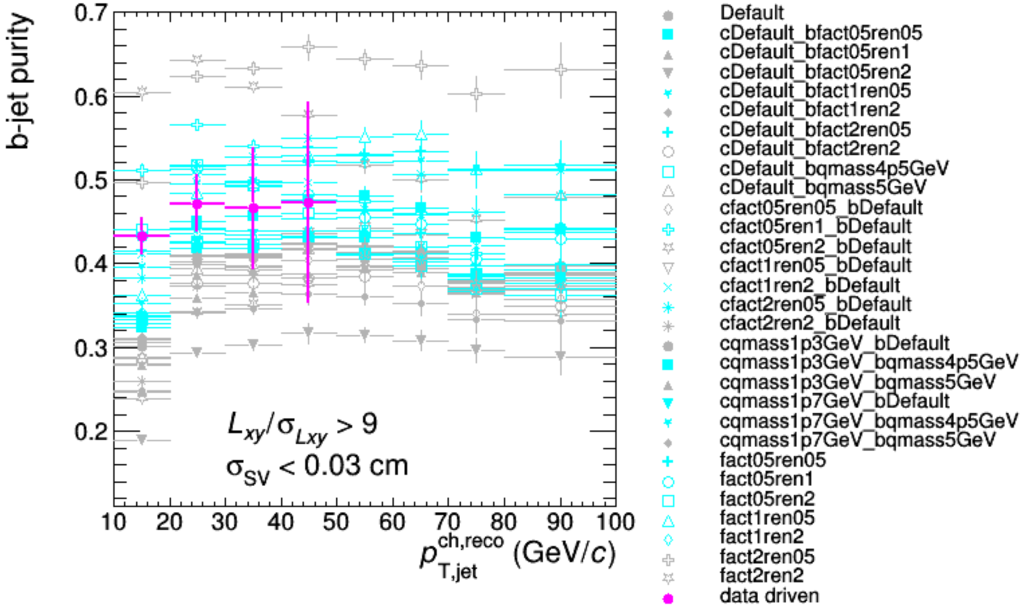


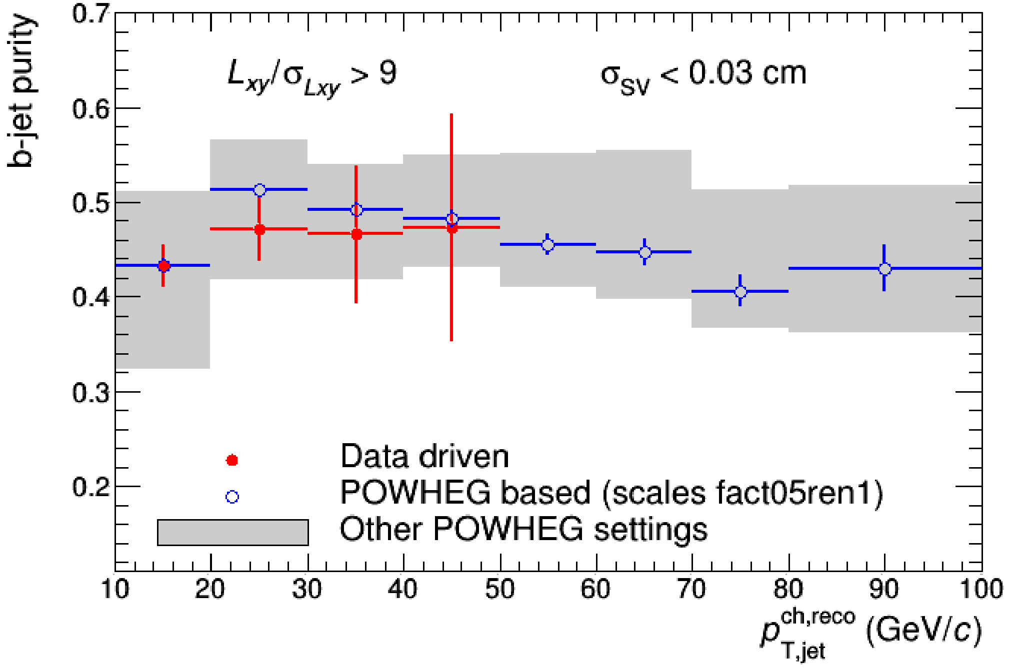


- Problem with a significant scale uncertainty from POWHEG
- Results strongly depends on POWHEG settings → need to choose the optimal one

Hybrid method for purity estimation

Hybrid method: different POWHEG settings were tested against the template fit results to find plausible POWHEG settings (regularization and renormalization scale)



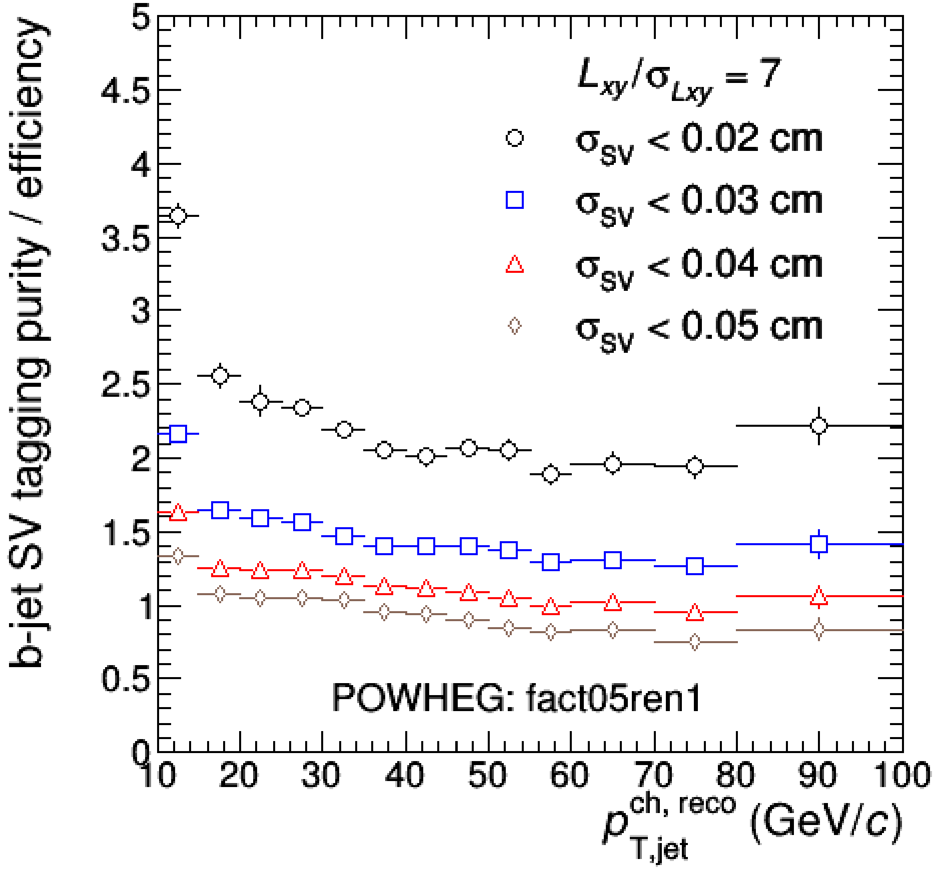


χ^2 compatibility of POWHEG with data was

$$\chi^2=\sum_{bins}\frac{\left(f_b^{POWbc}-f_b^{data-driven}\right)^2}{\sigma^2_{POWbc}+\sigma^2_{data-driven}}$$

- χ^2 was computed for all tagging settings (SL_{xy} and σ_{SV})
- Only settings for which χ^2 / n.d.f. < 10 were used

Purity to efficiency correction



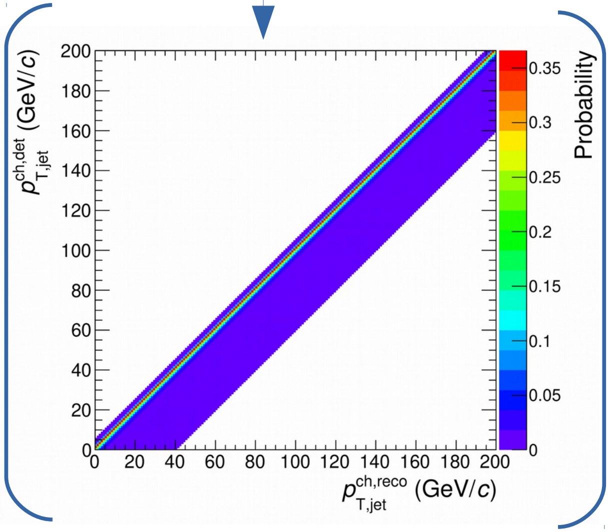
Unfolding procedure

δpT matrix represents smearing of p_T spectrum due to local fluctuations in background density

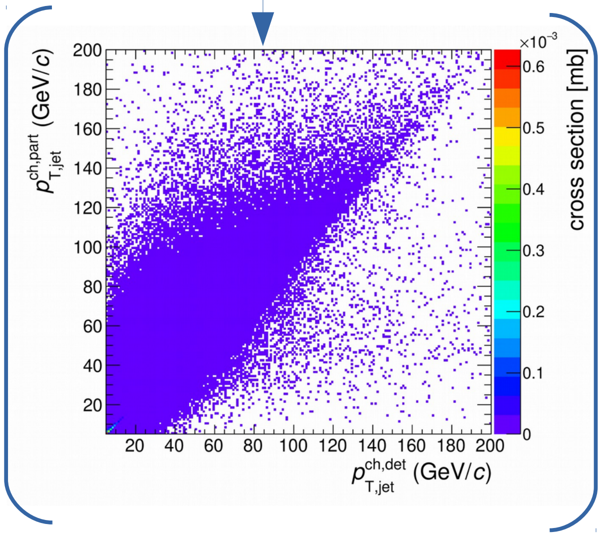
Instrumental matrix represents detector effects

b-jets p_T spectrum on a particle level this is our goal

Measured b-jet p_T spectrum corrected for SV efficiency and purity



X



$$\times \left[N^{ch,\, particle\, level}_{T,\, jet} \right] = \left[N^{ch,\, detector\, level}_{T,\, jet\, corrected} \right]$$

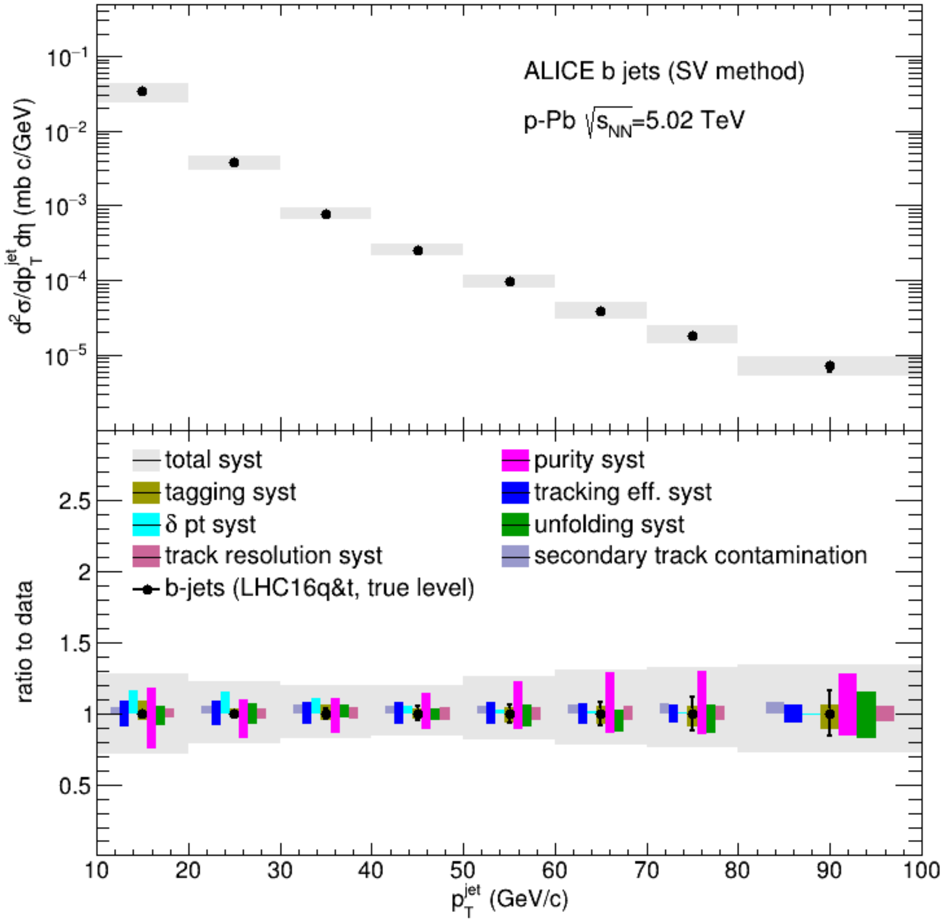
The problem of searching of b-jet p_T spectrum on a particle level can be solved with unfolding technics

Systematic uncertainties

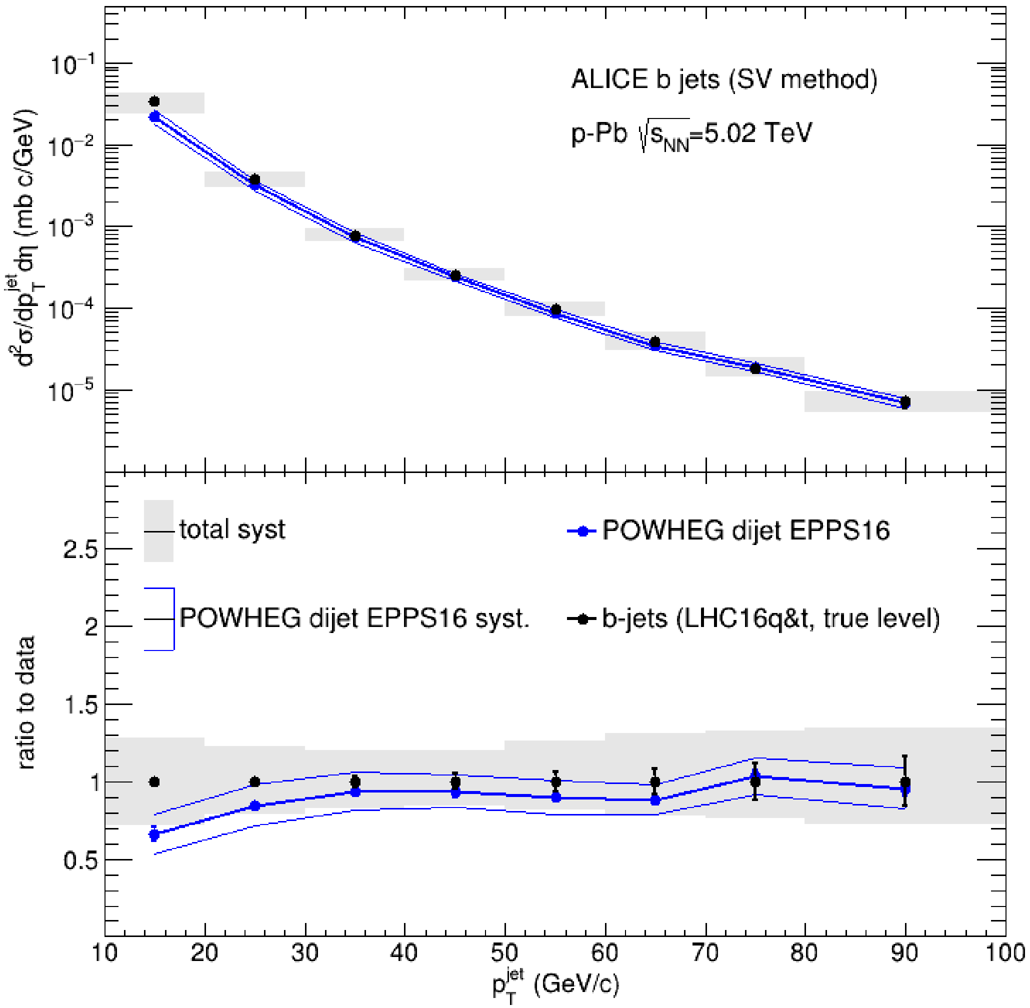
Total systematics calculated with the formula:

$$\Delta_{sys}^{tot} = \sqrt{\sum_i \left(\Delta_{sys}^{i}\right)^2}$$

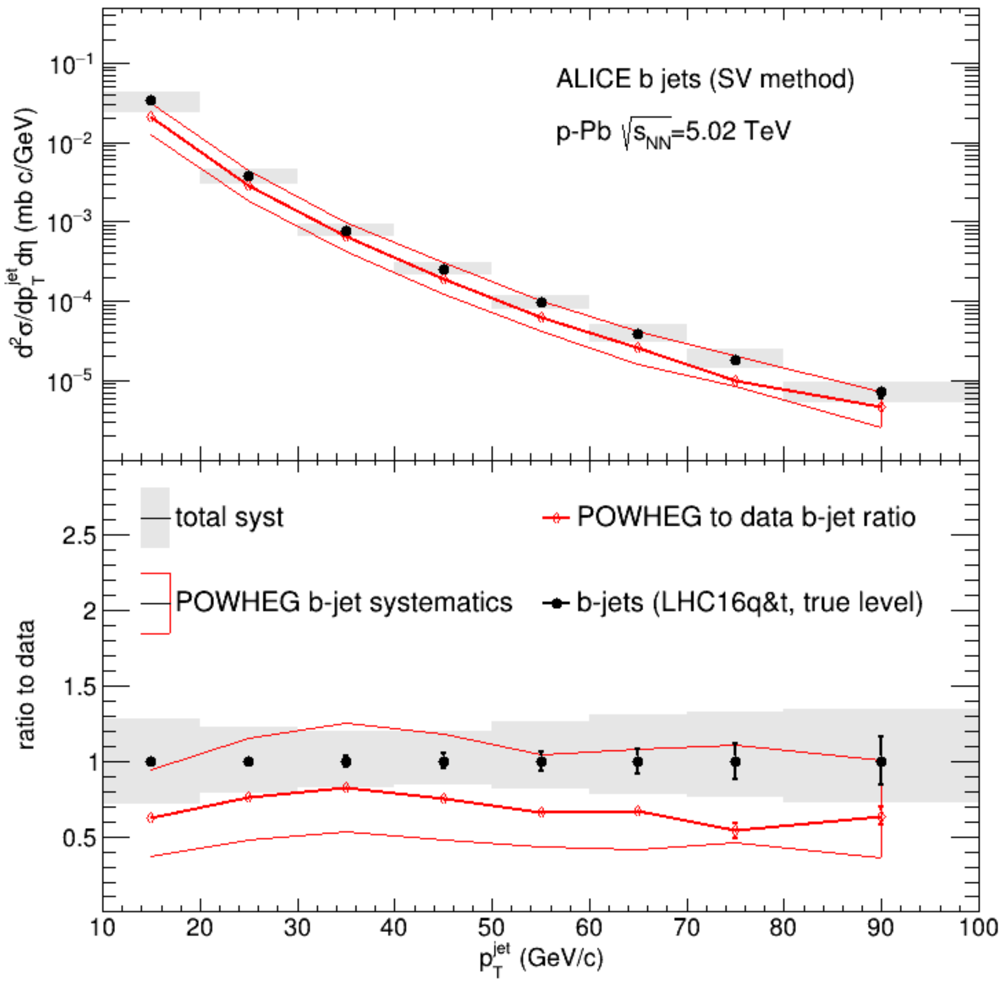
Source of syst. uncert.	$10 < p_{T,\text{ch jet}} < 20$ GeV/c	$40 < p_{T,\text{ch jet}} < 50$ GeV/c	$80 < p_{T,\text{ch jet}} < 100$ GeV/c
Purity (%)	-24.7 / +18.2	-11.0 / +14.8	-15.7 / +28.5
SV Tagging (%)	-4.7 / +9.1	-4.3 / +3.1	-11.2 / +5.9
Unfolding (%)	-8.5 / +5.6	-4.4 / +3.6	-17.8 / +14.9
Tracking eff. (%)	-9.2 / +9.2	-7.9 / +7.9	-6.5 / +6.5
$p_{T,\text{track}}$ smearing (%)	-3.3 / +3.3	-4.5 / +4.5	-5.3 / +5.3
Secondaries (%)	-0 / +4.1	-0 / 5.4	-0 / +7.8
δp_T	-0 / +16.0	-0 / +5.4	-0 / +0.2
Total (%)	-28.2 / +28.5	-15.5 / +19.6	-27.5 / +34.7



Comparison SV results to POWHEG simulations

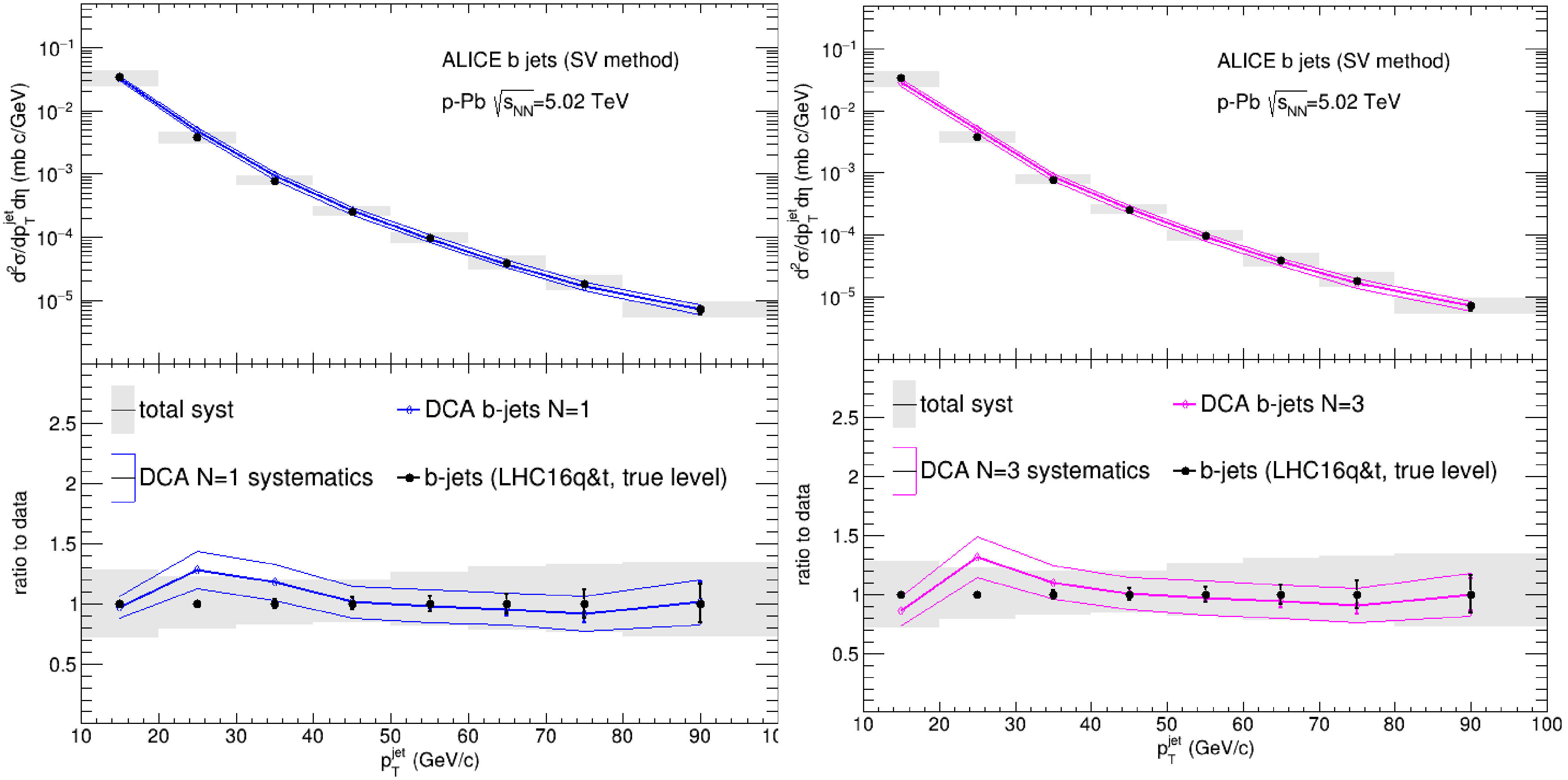


HVQ EPPS16 PYTHIA8



HVQ EPPS09NLO PYTHIA6

Comparison SV results to DCA analysis



DCA analysis was done by Hadi Hassan in parallel [?]

Summary

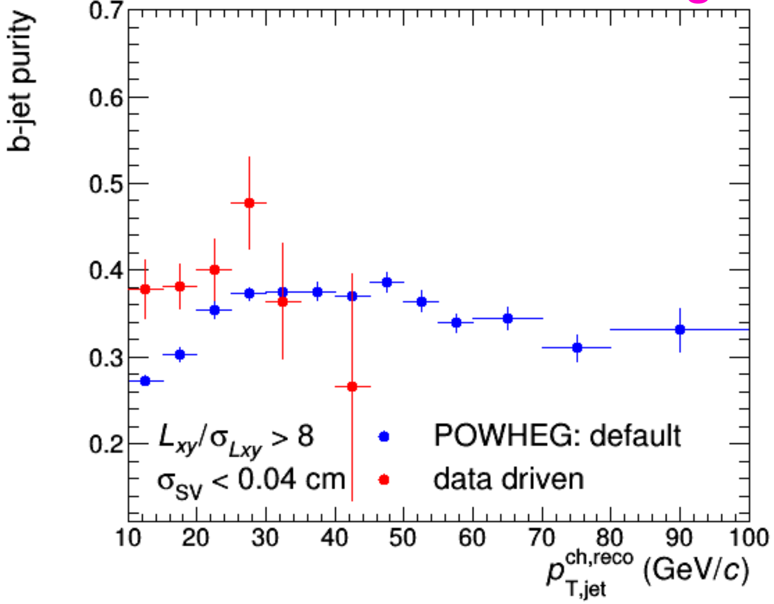
- SV method was applied to measure b-jet spectra in p-Pb collisions at $\sqrt{s_{NN}}$= 5.02 TeV
- Correction on efficiency / purity of SV tagging was done with hybrid method (data-driven + POWbc)
- Results successfully are compatible with different POWHEG simulations and an independent analysis based on the DCA

Further steps:

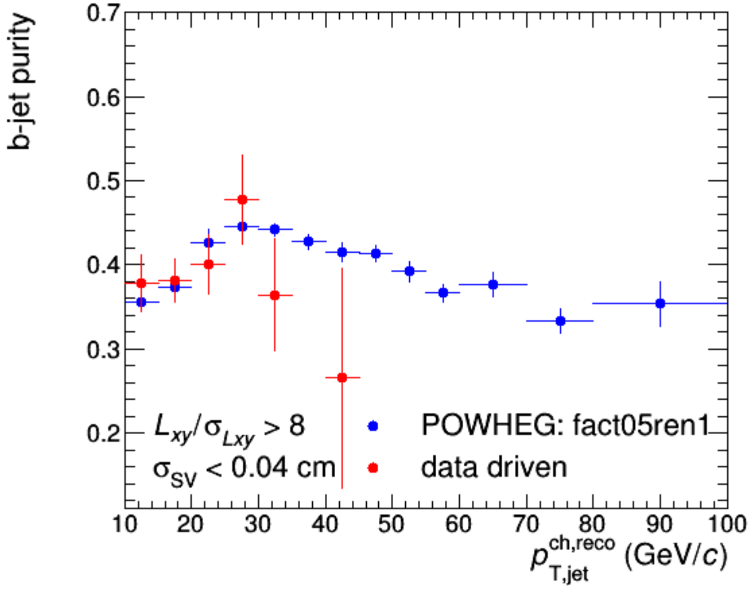
- Calculate R_{pB} for b-jets
- Apply MVA methods to estimate SV purity to efficiency correction and decrease systematic uncertainties

Backup

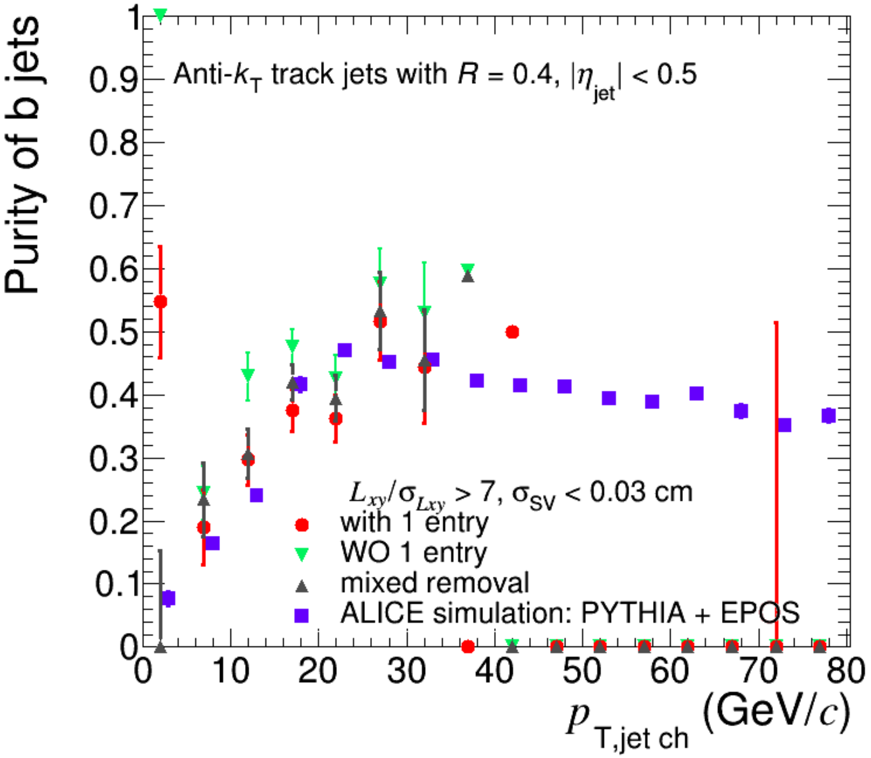
Default POWHEG settings



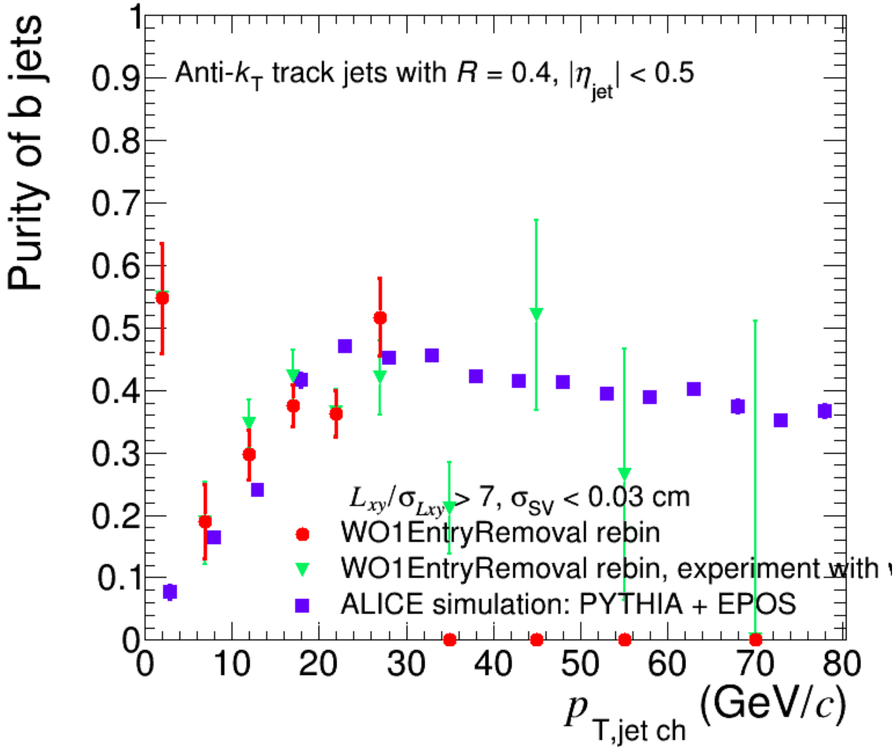
POWHEG fact05ren1



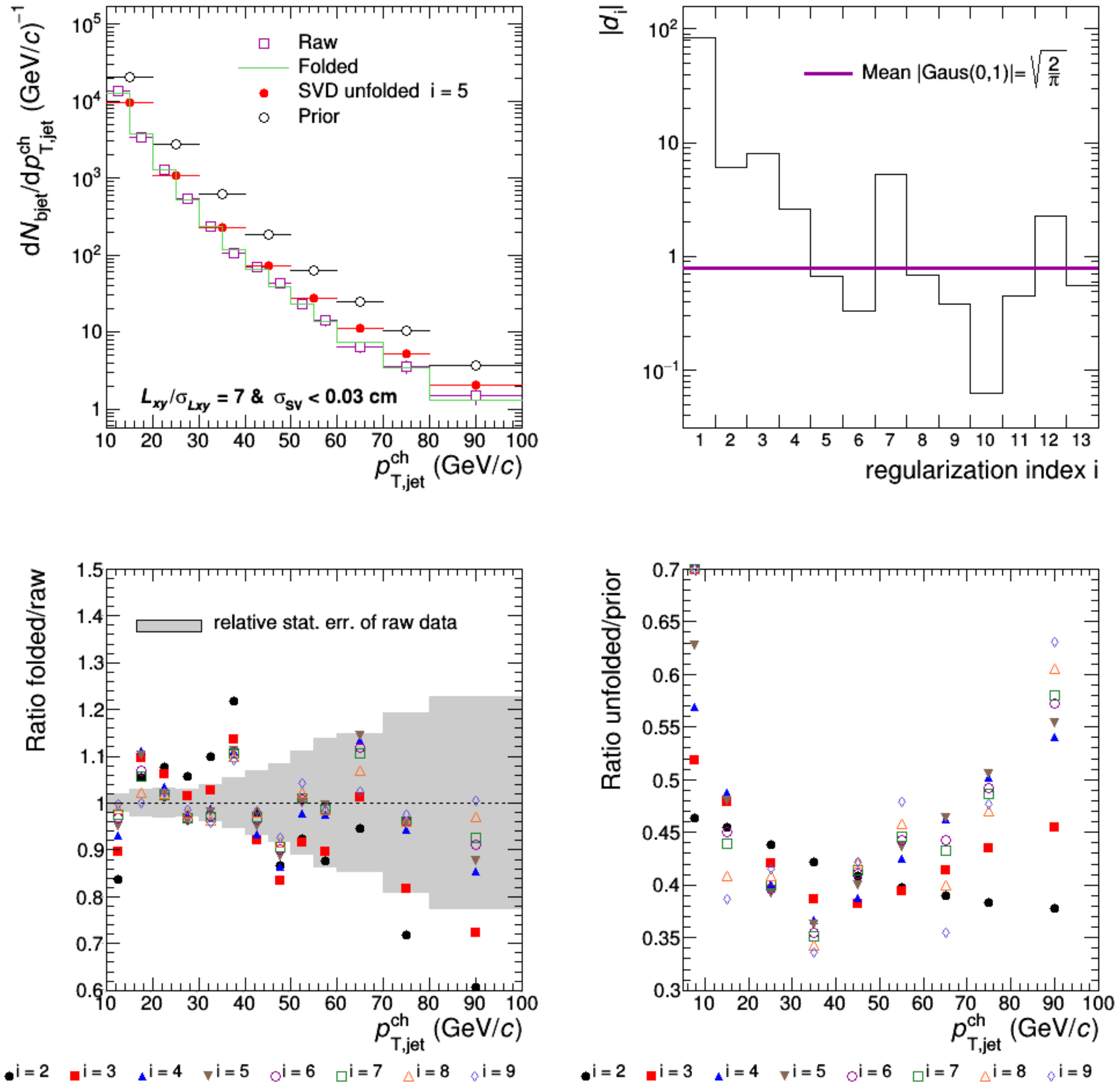
Effect of removal of 1-entry bin



Different binning



Unfolding of raw b-jet spectrum



Analysis settings:

- SL_{xy}>7, σ_{SV} <0.03 cm

- SVD unfolding with k=5

- Pur/Eff correction from hybrid method

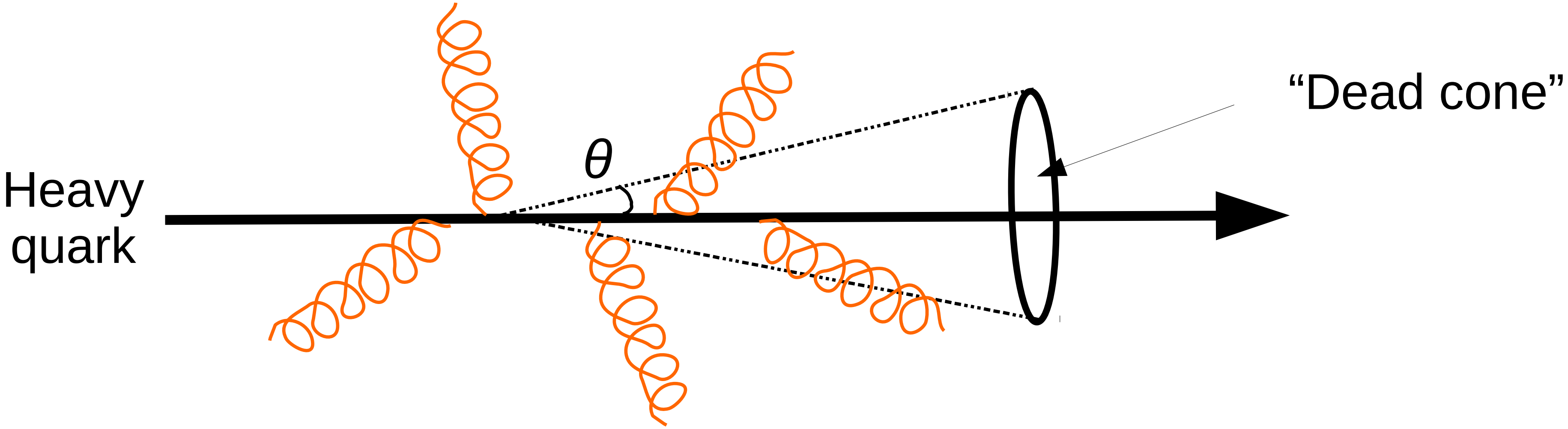
- prior POWHEG+PYTHIA6 b-jet spectrum

- δp_T matrix from real data events with SV

- instrumental matrix from PYTHIA

Dead cone effect

“Gluonsstrahlung” - process of gluon radiation by quarks (or gluons)



“Dead cone” effect – gluon radiation from massive quarks is suppressed at angles $\theta < m/E$ → Less E loss inside the medium for heavy quarks expected

Gluonsstrahlung probability

$$\sim \frac{\theta^2}{[\theta^2+(m/E)^2]^2}$$

[Yu.L. Dokshitzer, D.E. Kharzeev - “Heavy Quark Colorimetry of QCD Matter”, arXiv:hep-ph/0106202]

Probability of gluon emission

For light quarks:

$$dP_0 \simeq \frac{\alpha_s C_F}{\pi} \frac{d\omega}{\omega} \frac{dk_T^2}{k_T^2} = \frac{\alpha_s C_F}{\pi} \frac{d\omega}{\omega} \frac{d\theta^2}{\theta^2}$$

For heavy quarks:

$$dP_{HQ} = \frac{\alpha_s C_F}{\pi} \frac{d\omega}{\omega} \frac{k_T^2 dk_T^2}{(k_T^2 + \omega^2 \theta_0^2)^2} = \frac{\alpha_s C_F}{\pi} \frac{d\omega}{\omega} \frac{\theta^2 d\theta^2}{(\theta^2 + \theta_0^2)^2}$$

$$\theta_0 = \frac{M}{E}$$

Where

ω - Energy, C_F - “color charge”, k_T - transverse momenta

dP_0 - Probability to radiate gluon

Probability of gluon emission

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