Performance of the b-jet tagging algorithm in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV at ALICE

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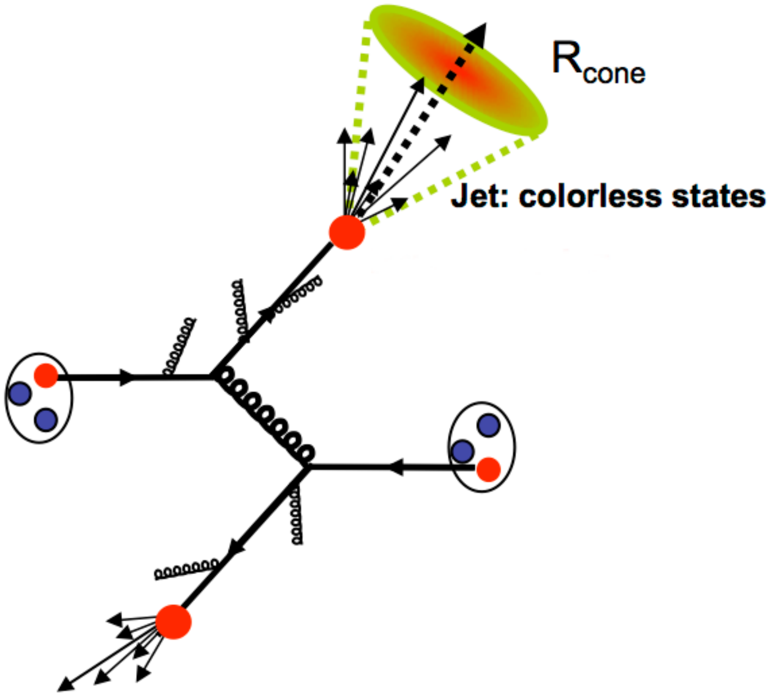
Introduction: Jets

Jet – a collimated spray of hadrons, created during hadronization of quark or gluon after hard scattering, defined via algorithm



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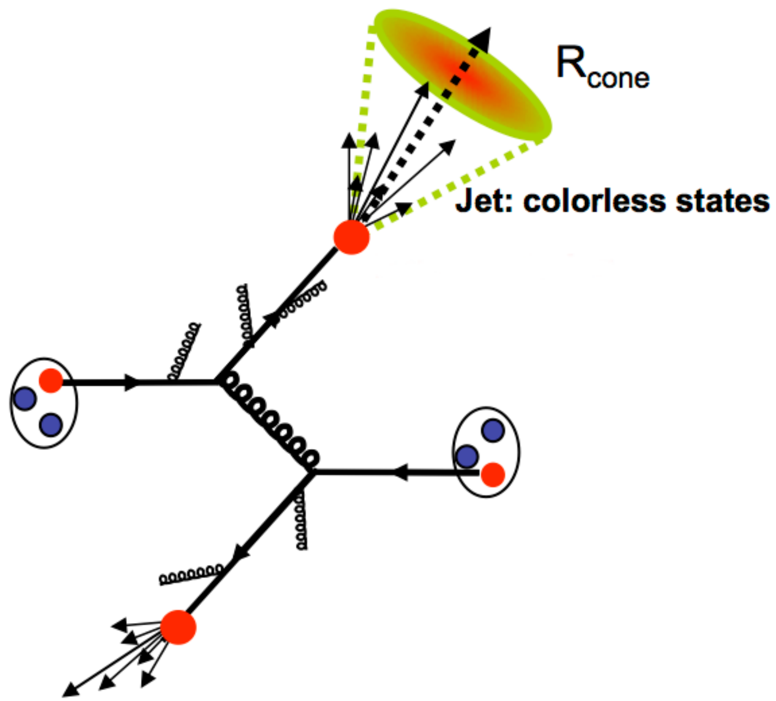
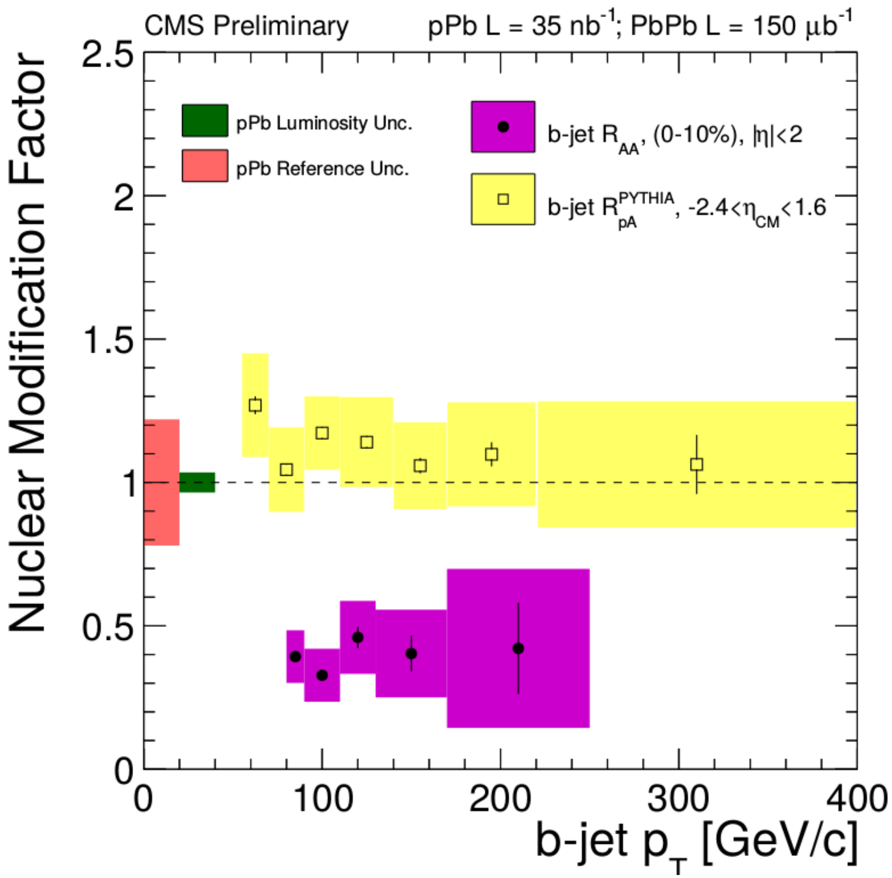


Properties of b-quark:

- 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

Nuclear Modification Factor

CMS Results
(pPb, 5.02 TeV, 2014)



Nuclear modification factor comparison for b-jet R_{AA} and R_{pA}

$$R_{AA} = \frac{dN_{AA}/dp_T}{<N_{coll}>\cdot dN_{pp}/dp_T}$$

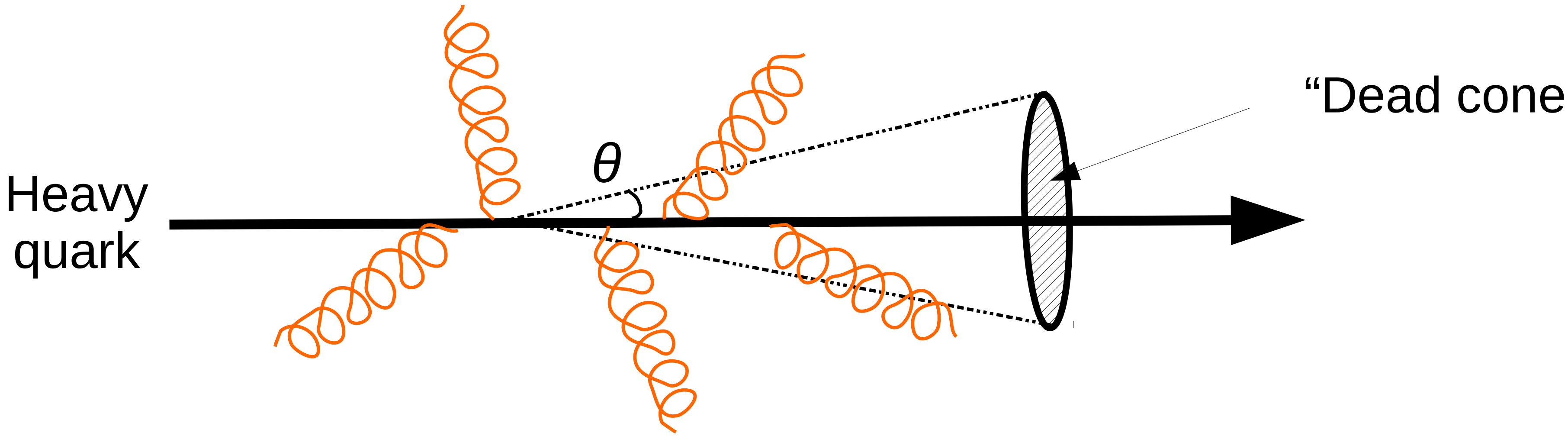
Nuclear modification factor describes influence of the Jet Quenching effect

CMS measures were published for $50 < p_{T,\,jet} < 400$ GeV/c → might be too high to see the “dead cone” effect.

[Kurt Jung- “Measurements of b-jet Nuclear Modification Factors in pPb and PbPb Collisions with CMS”, arXiv:1410.2576]

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

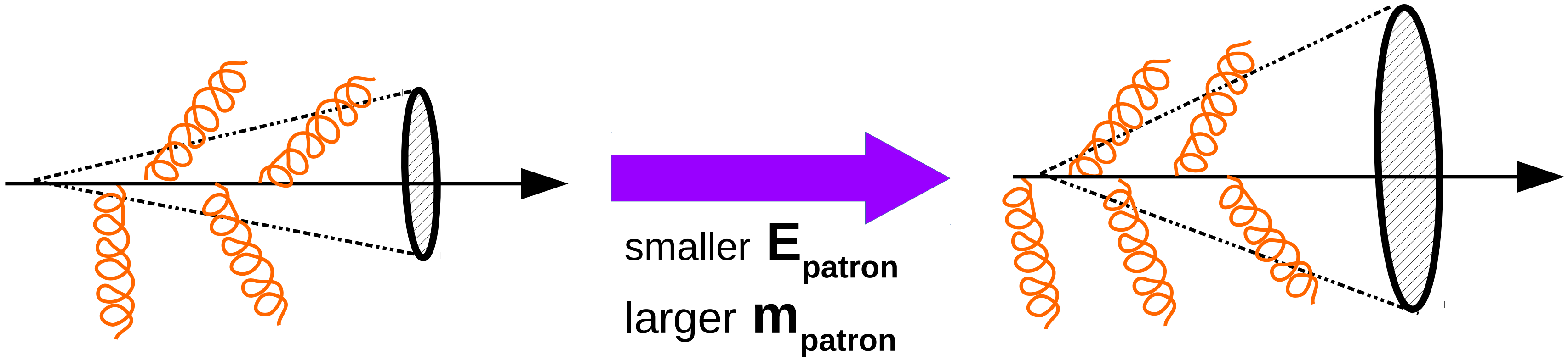
Gluonsstrahlung probability

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

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

Dead cone effect

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



- Dead cone effect is better observed for heavy quarks
- CMS range might be too high to observe effect

"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

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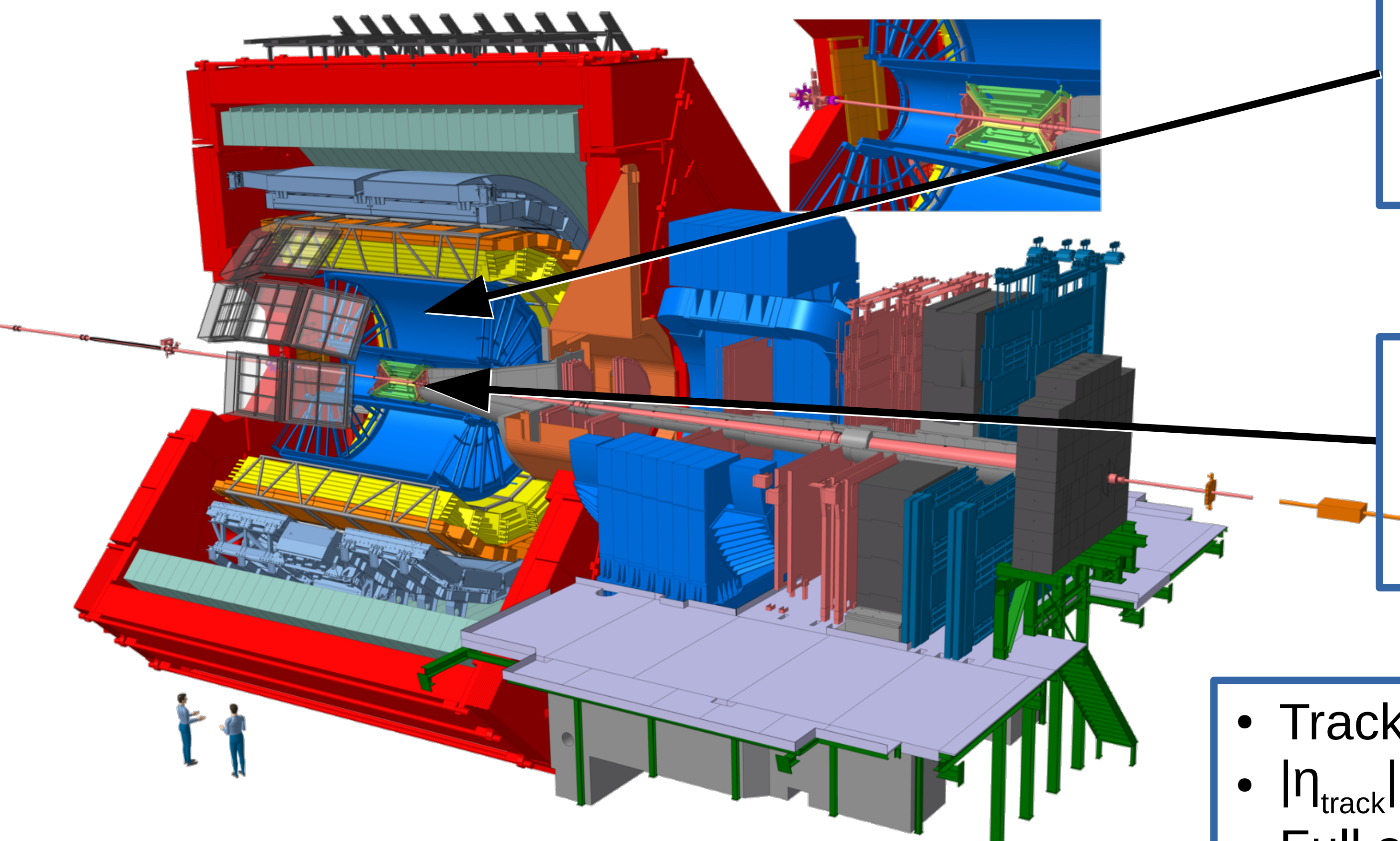
ALICE experiment



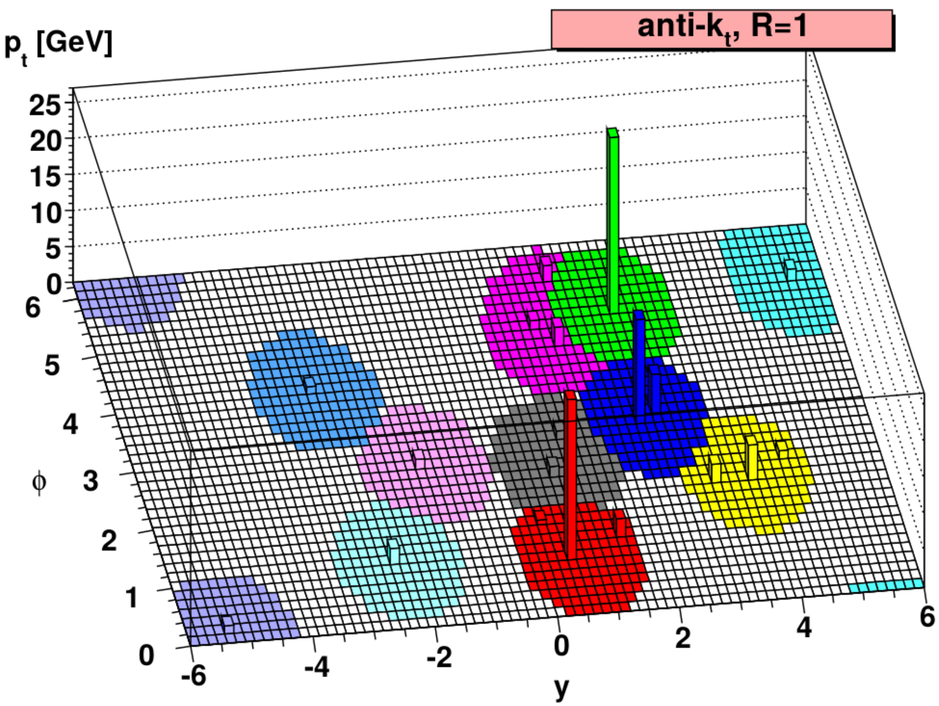
Time Projection Chamber
- Track reconstruction
- Particle identification via specific energy loss

Inner Tracking System
- Track reconstruction
- Primary and secondary vertex reconstruction

- Track impact param. < 75 μm
- $|\eta_{track}| < 0.9$
- Full azimuth
- 0.5 T solenoid
- $p_{T,\,track} > 0.15$ GeV/*c*

V0
Scintillator array for triggering

Jet reconstruction



[M. Cacciari, G. P. Salam and G. Soyez, “The anti-k_t jet clustering algorithm,” JHEP, arXiv:0802.1189]

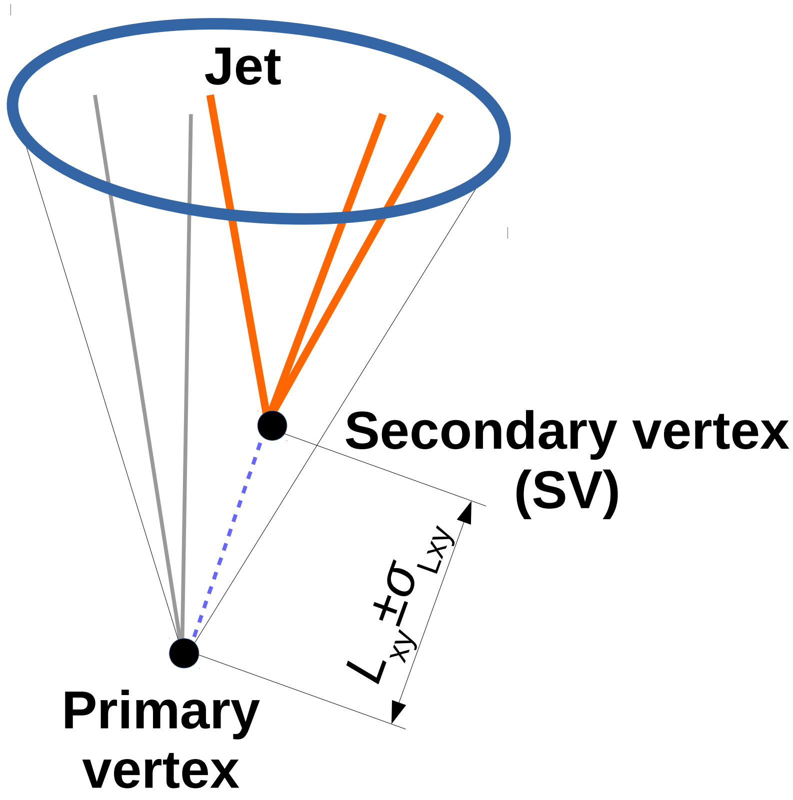
- Jets were reconstructed with the anti-k_T algorithm:

$$\begin{cases} d_{ij} = min(p_{Ti}^{-2}, p_{Tj}^{-2}) \dfrac{\Delta R_{ij}^2}{R^2} \\ \Delta R_{ij}^2 = (y_i - y_j)^2 + (\varphi_i - \varphi_j)^2 \\ d_{iB} = p_{Ti}^2 \end{cases}$$

- Resolution parameter R = 0.4
- $|\eta_{jet}| < 0.9 - R$
- Charged tracks with $p_T > 0.15$ GeV/c
- Jet momentum is corrected for the mean underlying event density

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

B-jet selection



b-jet candidate selection:

- Significance of the distance between primary and secondary vertices L_{XY}/σ_{Lxy}
- Choice of the most displaced SV
- 3 prong SV
- Dispersion of the SV σ_{SV}:

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

d_i – distance of the closest approach of *i*-th prong to SV

Contribution of the work

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

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

P_b − purity of the b-jet candidates

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

RAW spectra correction

- We need to optimize the cuts such, that they will significantly suppress the number of c and light-quark admixture (<1%) and keep the number b-jets as high as possible
- Efficiency of b-jet tagging:

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

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

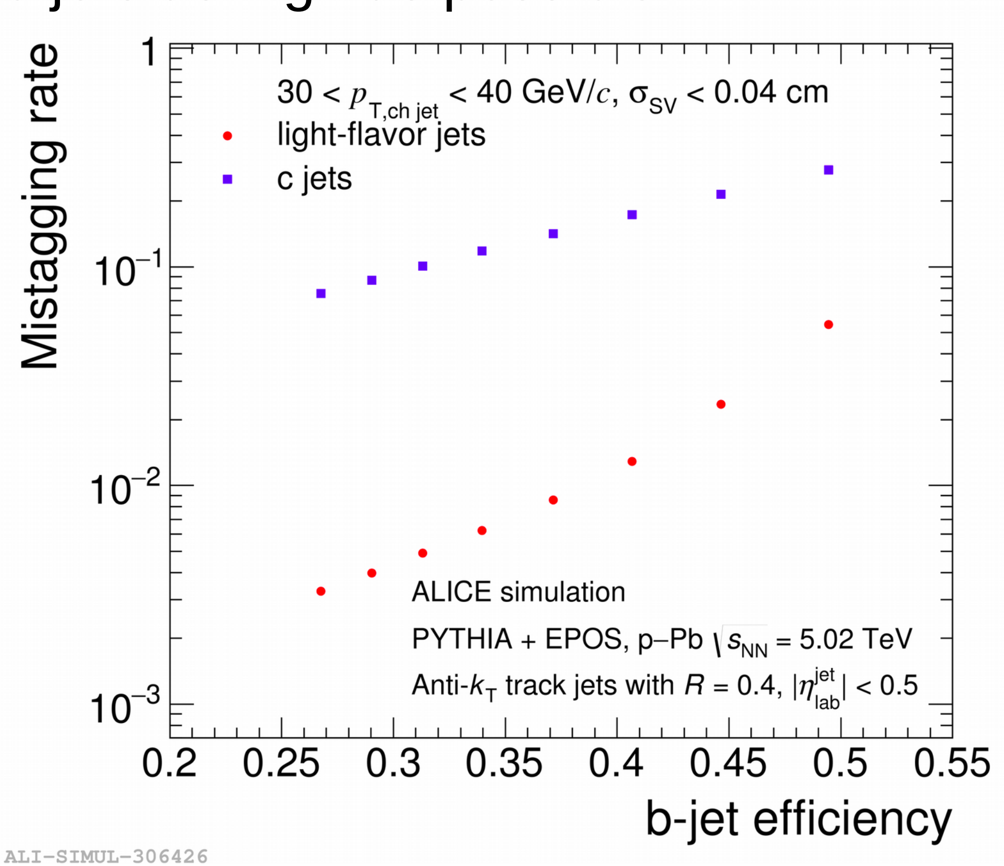
$N_{b-jets}^{selected}$ − the number of b-jets that were reconstructed when applying cuts on b-jets candidates

- Efficiency estimate is based on MC data (PYTHIA + EPOS)

["PYTHIA 6.4 Physics and Manual" - arXiv:hep-ph/0603175]

Cut optimization

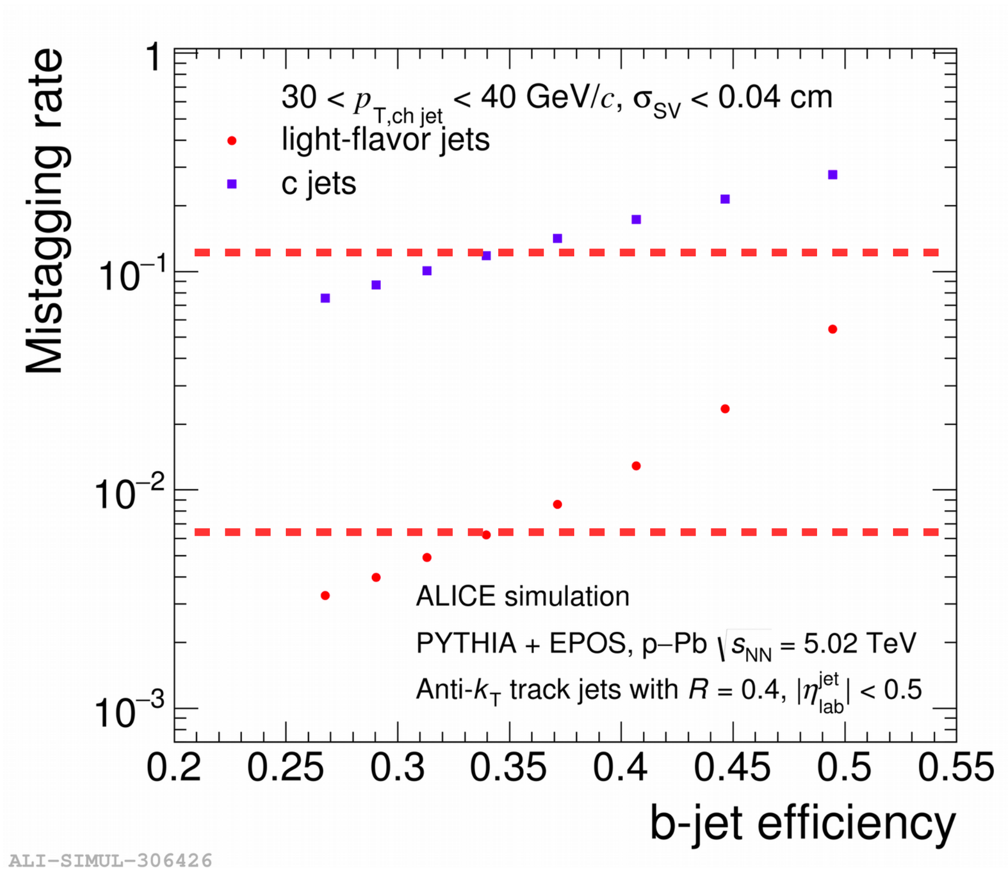
- We need to optimize the cuts such, that they will significantly suppress the number of c and light-quark admixture (<1%) and keep the number b-jets as high as possible



- $L_{xy}/\ \sigma_{Lxy}$ was varied form 3 to 10 while keeping σ_{SV} fixed

Cut optimization

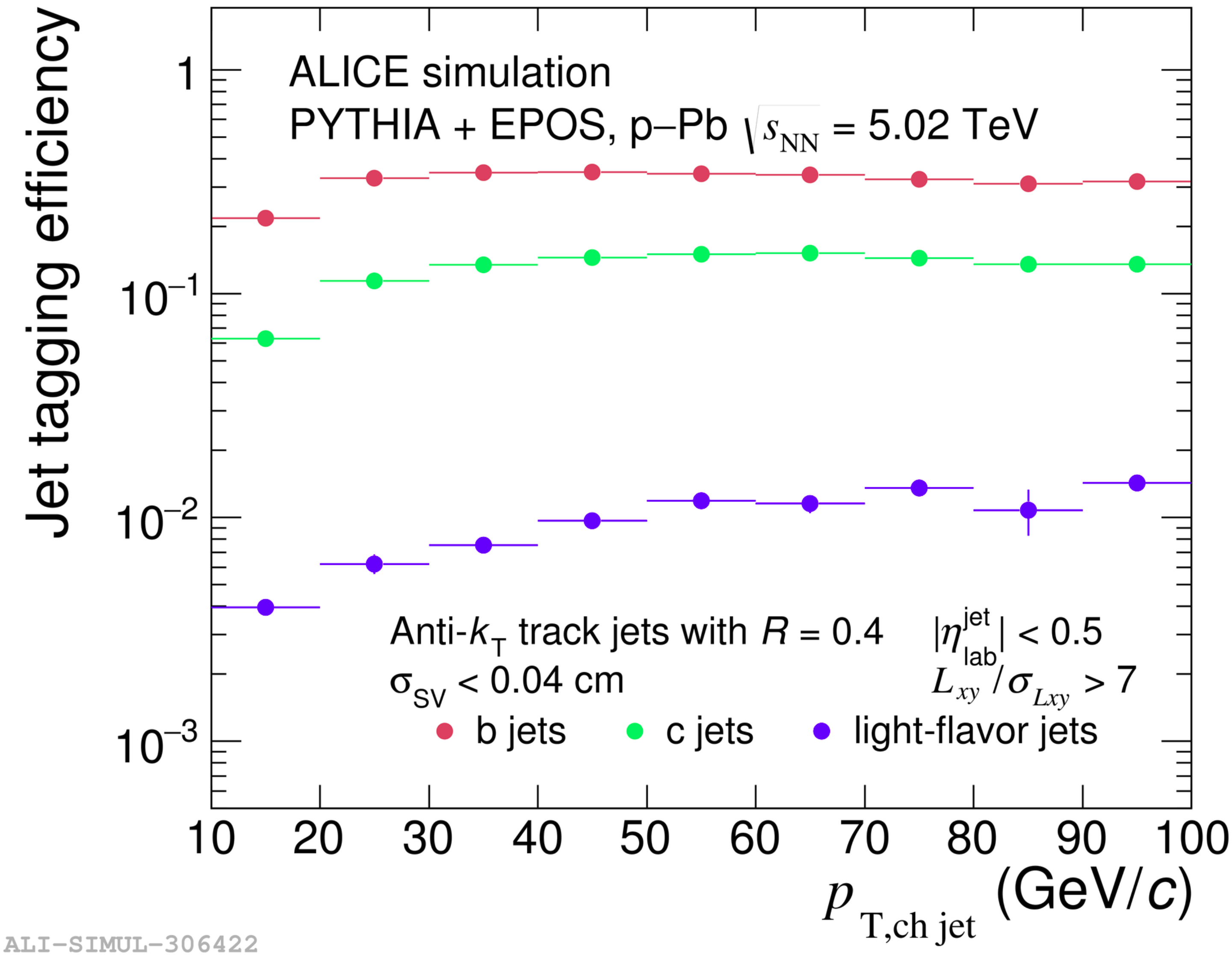
- Cuts are optimized such, that they significantly suppress c and light-quark admixture (<1%) and keep the number b-jets as high as possible



- $L_{xy}/\ \sigma_{Lxy}$ was varied from 3 to 10 while keeping σ_{SV} fixed
- **Optimal $L_{xy}/\ \sigma_{Lxy} > 6$**

Efficiency of jet tagging

Jet tagging efficiency for jets with different flavors as a function of $p_{T,\,jet\,ch}$



$\varepsilon_b \approx 35\ \%$

$\varepsilon_c \approx 11\ \%$

$\varepsilon_{LF} \approx 1\ \%$

Purity of b-jets

- Purity gives a fraction of real b-jets in spectra of b-jet candidates
- Purity of b-jets is defined as:

$$P_b = \frac{N^{true}_{b\text{-}jets,cut}}{N^{candidates}_{b\text{-}jets,cut}}$$

$N^{true}_{b\text{-}jets,cut}$ – the true number of b-jets after cuts

$N^{candidates}_{b\text{-}jets,cut}$ – the total number of jets in reconstructed spectra

- Purity estimate is based on MC data (PYTHIA + EPOS)

Purity via data driven method

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

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

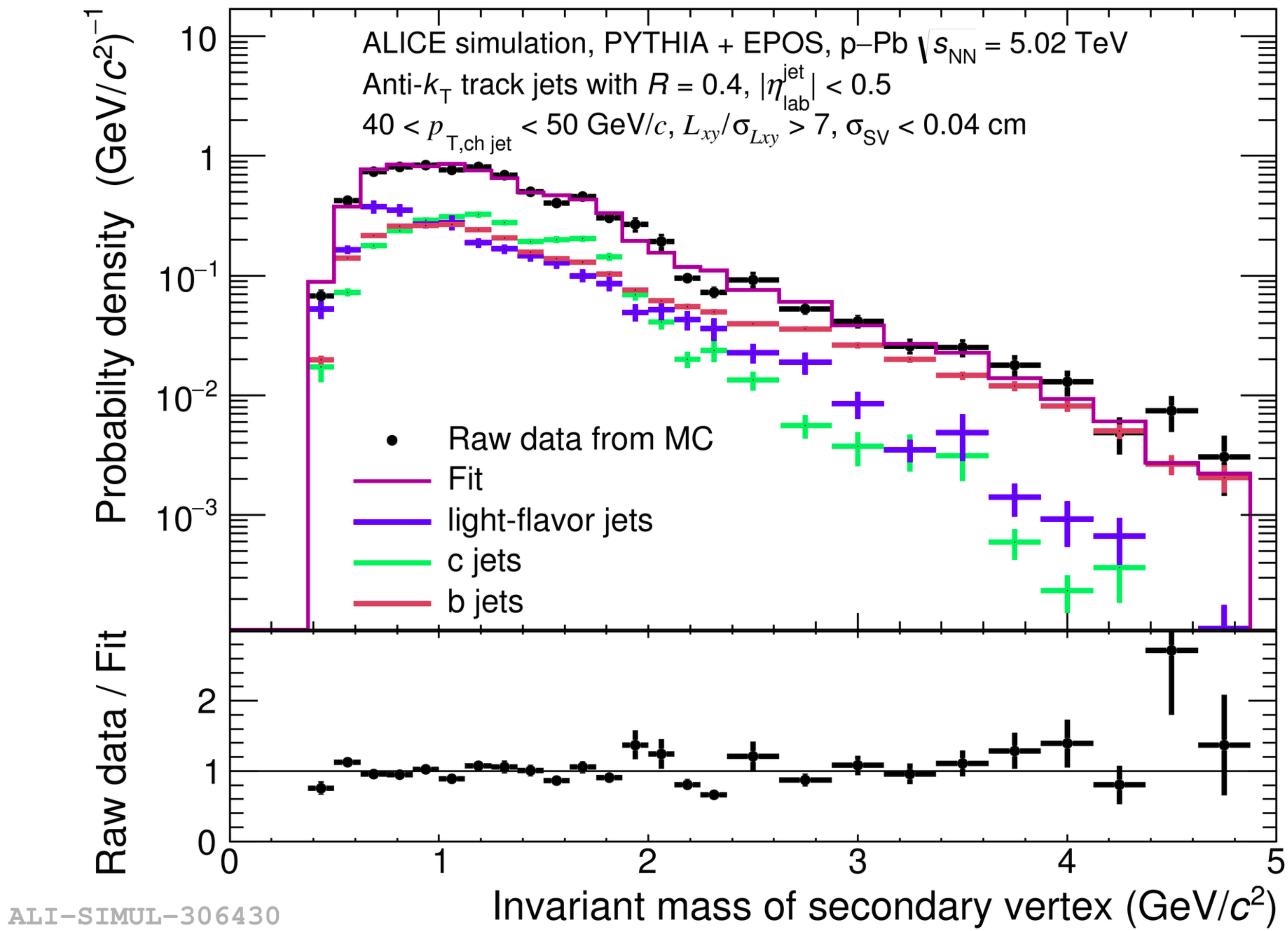
n_{SV} − reconstructed SV invariant mass distribution in given jet-p_T bin

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

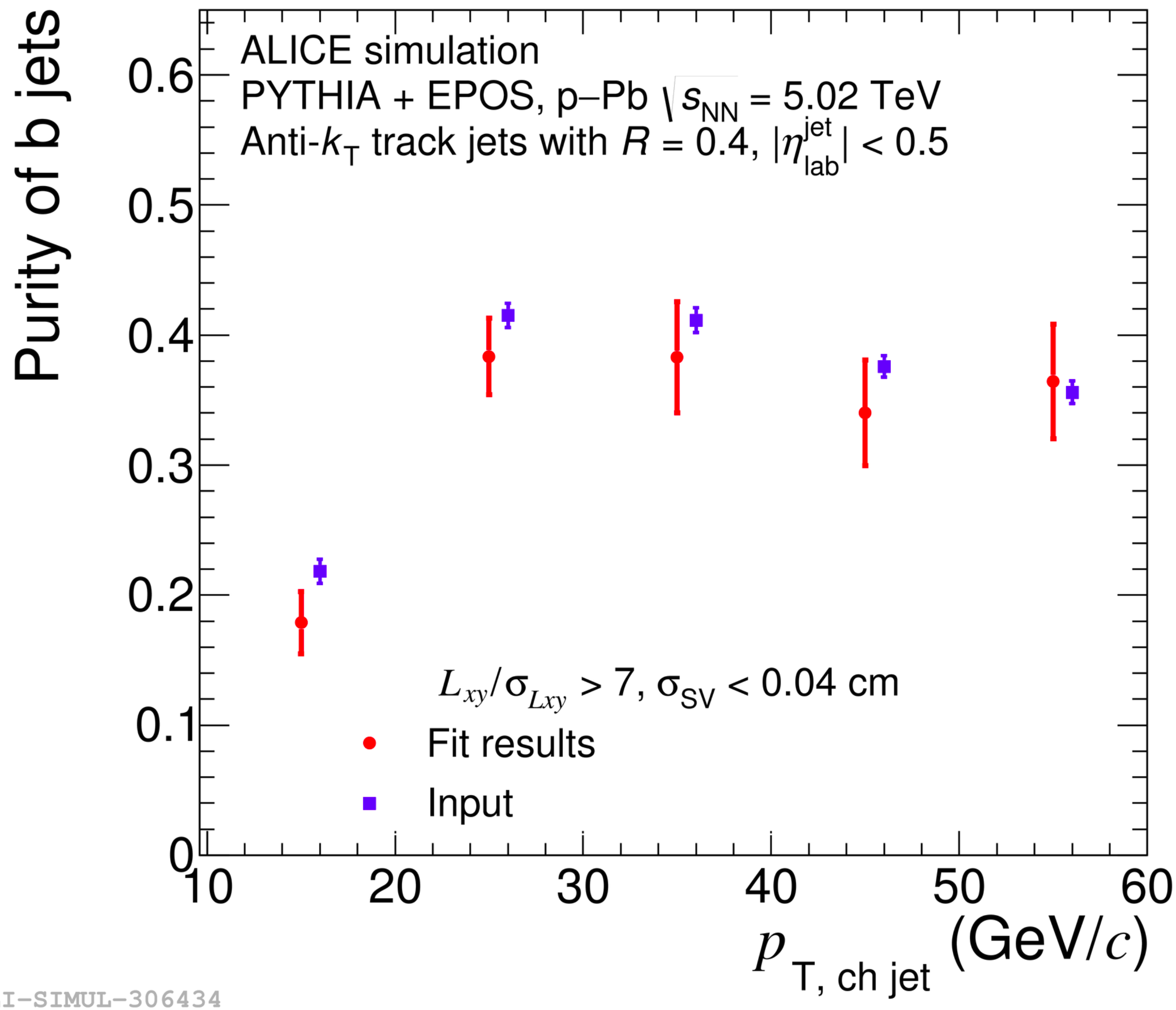
P_b, P_c, P_{LF} − purity for each jet flavor

- Purity is evaluated in following $p_{T,\text{ jet ch}}$ bins = {10, 20, 30, 40, 50, 60} GeV/*c*
- TMinuit library was used to fit MC templates to reconstructed distribution
- Template-fit method was tested on MC simulation (PYTHIA + EPOS)

Results of fitting



Closure test



Summary

- Performance of b-jet tagging algorithm was studied for different $L_{xy}/\ \sigma_{Lx}$ and σ_{SV} choices
- For $L_{xy}/\ \sigma_{Lx} > 7$ and $\sigma_{SV} < 0.04$ cm, the expected b jet efficiency will be 35% and purity ~40%
- Closure test of data-driven algorithm for calculation of purity of b-jets was done

Further steps:

- Apply the data driven template fit method to real data to assess purity
- Compare results of purity calculation with POWHEG simulation

Backup

Fitting procedure

To perform fitting and calculate purity we used **TMinuit** library

This package allows to minimize a multi-parameter user function

In this work we used function:

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

Where

$n_{SV,i}$ – invariant mass distribution of SV, **non-enhanced** MC

$T_{b,i}$, $T_{c,i}$, $T_{LF,i}$ – invariant mass distribution of SV **for each flavor** MC

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

σ_{nsv}, σ_{Tb}, σ_{Tc}, σ_{TLF} – statistical error for each jet flavor

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:

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

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

Where

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

dP_0 - Probability to radiate gluon