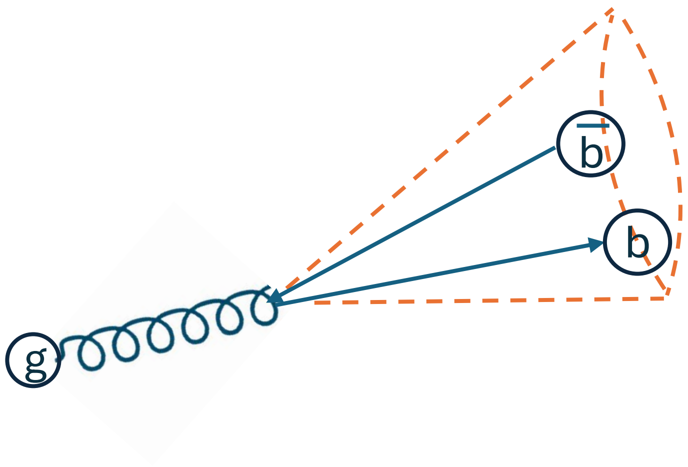
Jet Substructure of Unresolved Gluon to b-$\bar{b}$ Jets



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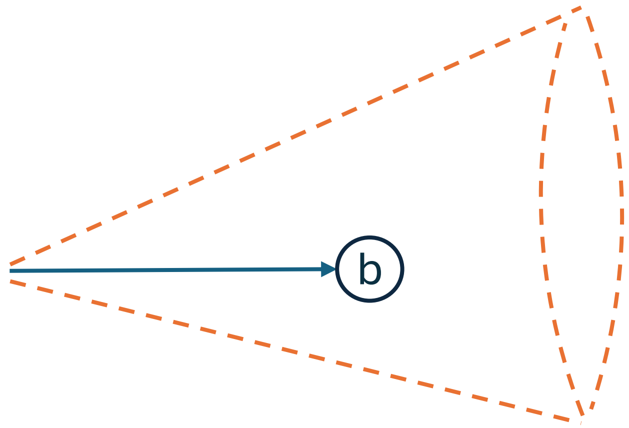
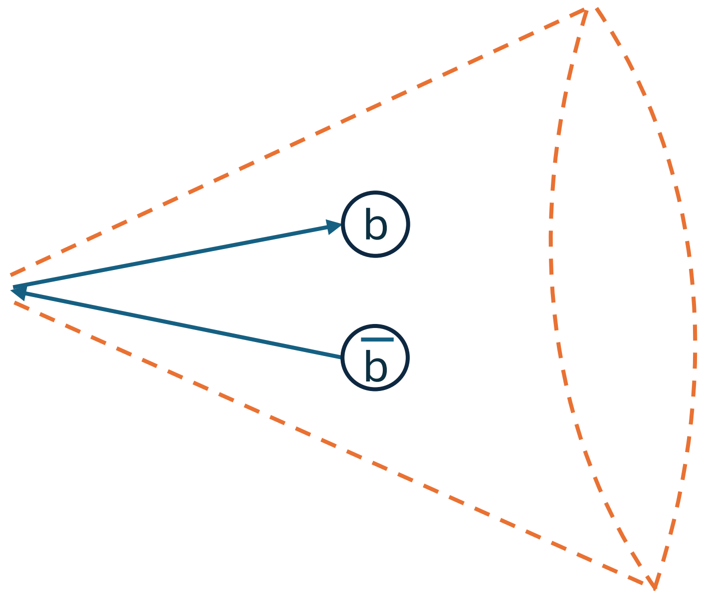
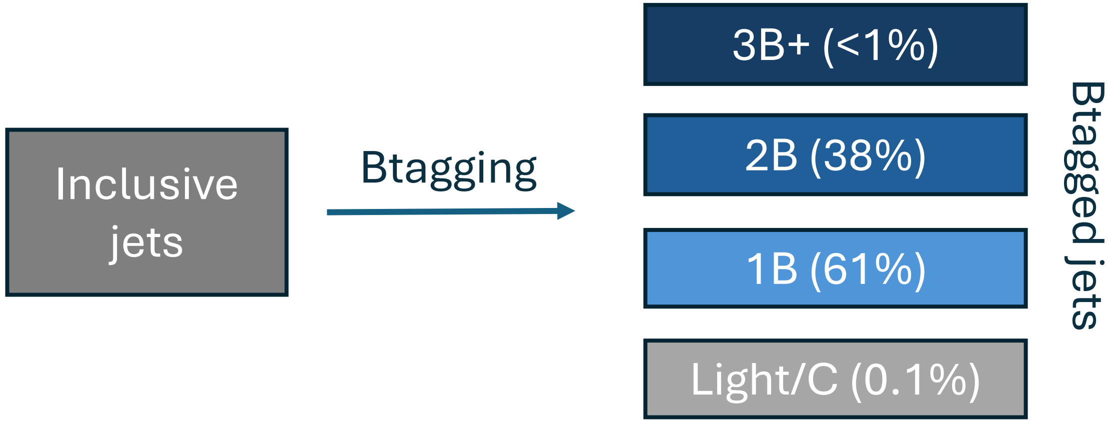
Unresolved Gluon to B-Bbar Jets

- B-tagged jets
  - Btag identifies 68% of B jets, which includes single and double Bs
- **Unresolved**: the B hadron pair ends up in the **same jet**

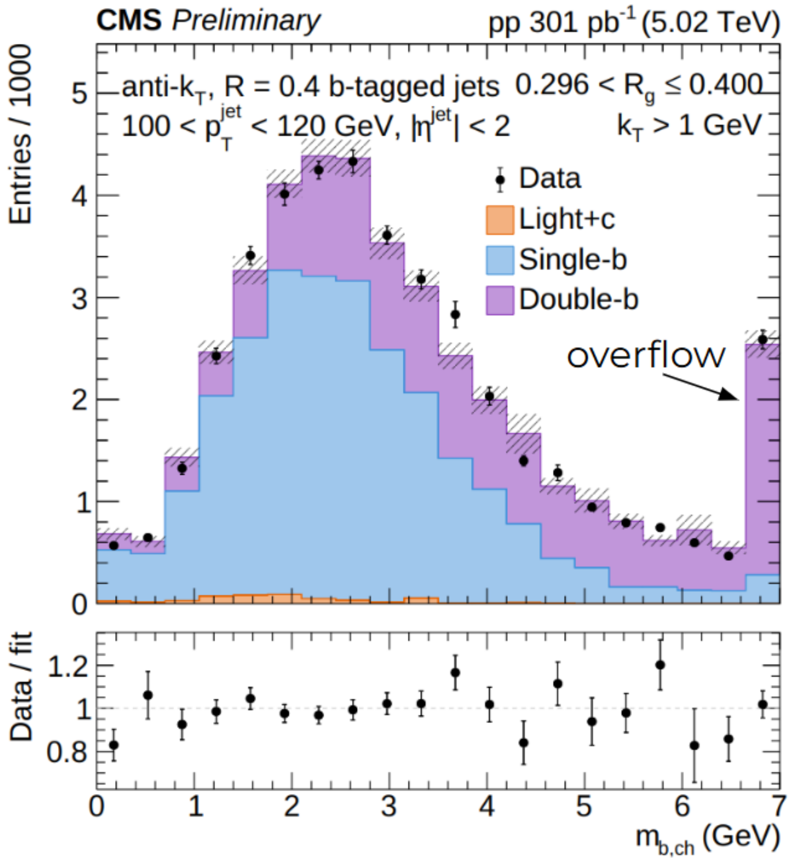






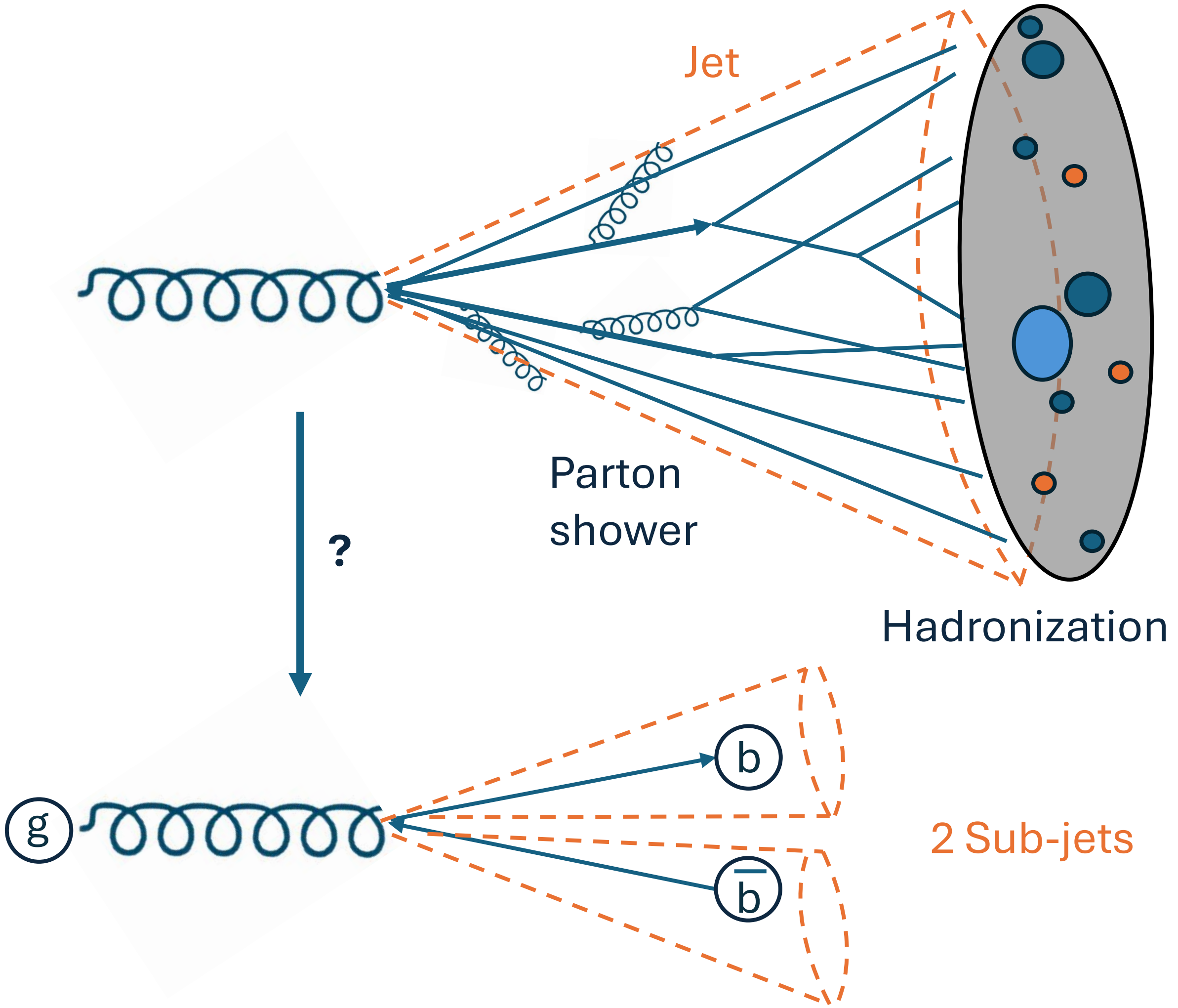
Motivation

- Main background in previous single B analysis
- Previous analysis of BB jets structure
- Can we measure the properties of these double B jets?
- Can we make this measurement in heavy ion collisions to study **quark-gluon plasma**?



B Hadron Decays

- **Objective:** recreate the **dual prong structure,** where each B is in a subjet
- **Problem 1:** **Reconstructing** Bs: B hadrons decay in a wide variety of decay modes (into π^+, μ^-, e^-, neutral particles...)
- **Problem 2:** **Differentiating** these double B from single B jets

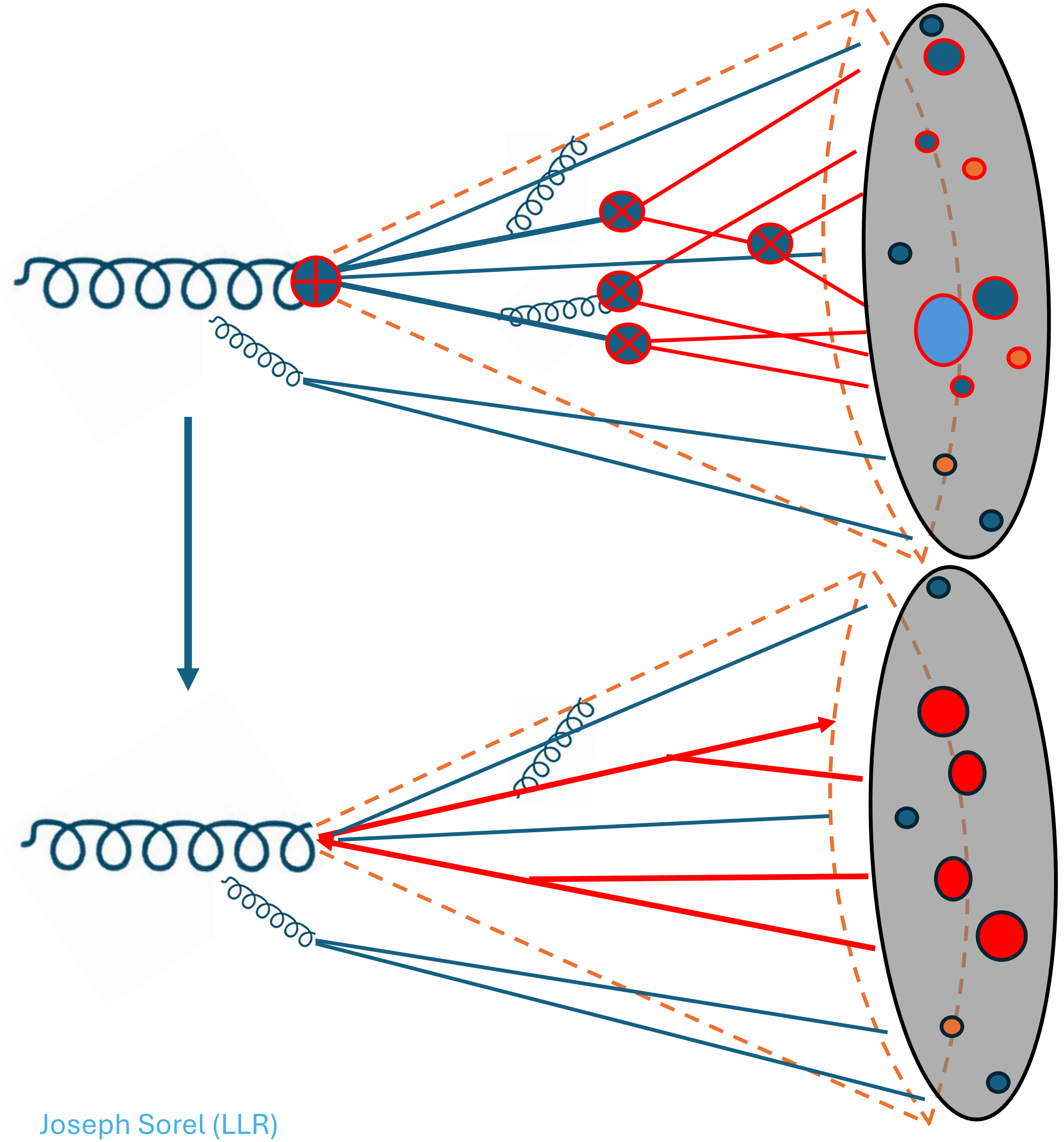


Problem 1: Reconstructing Bs

- B hadrons decay at a certain **flight distance** away from the primary vertex ⊕
- Group displaced tracks from same **secondary vertices** ⊗

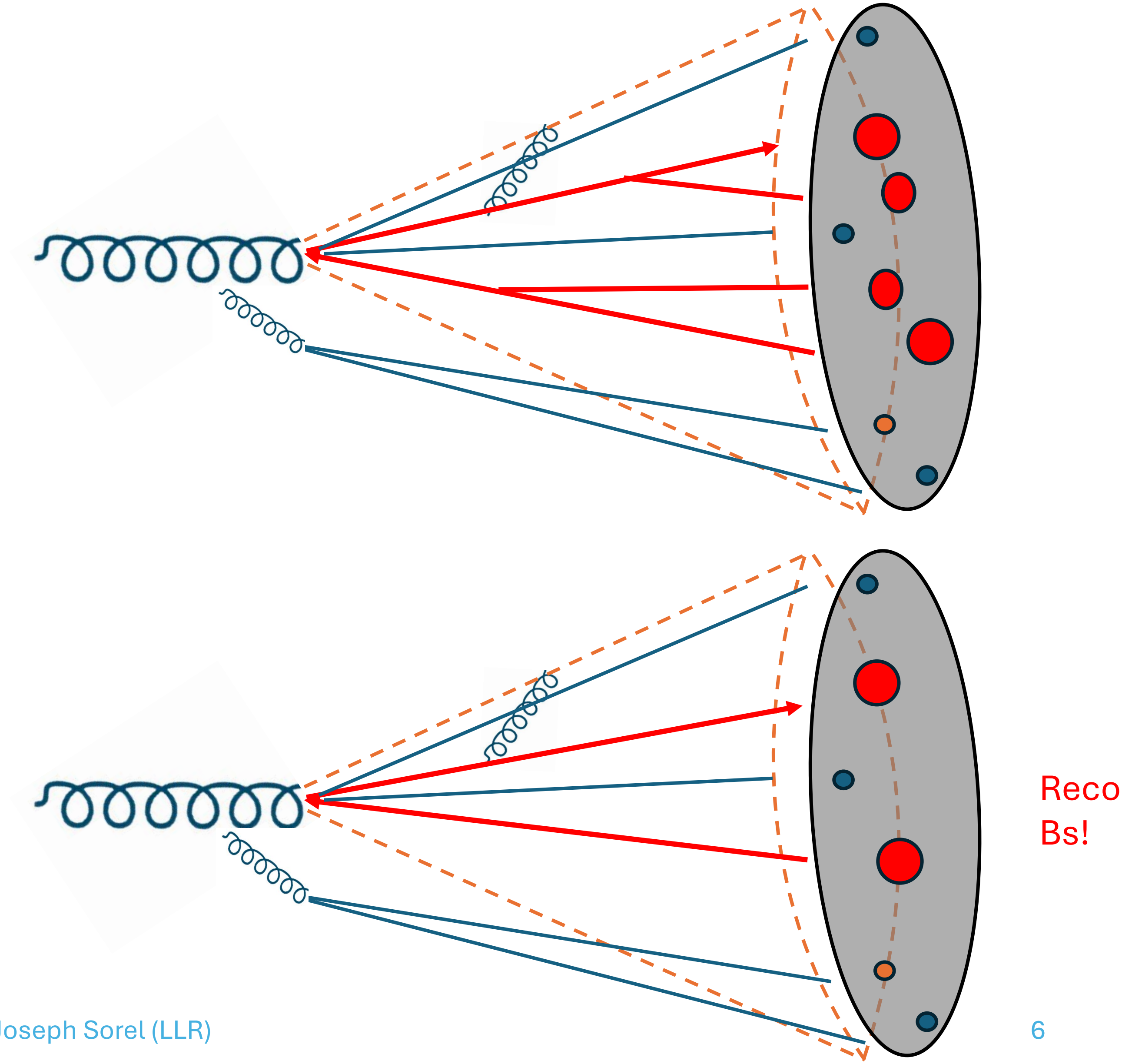
Only charged particles

Tracks >1 GeV



Problem 1: Reconstructing Bs

- And if there are **more than 2** secondary vertices? Merge them!
- We have effectively reconstructed our two Bs but they're **still in the same jet.**



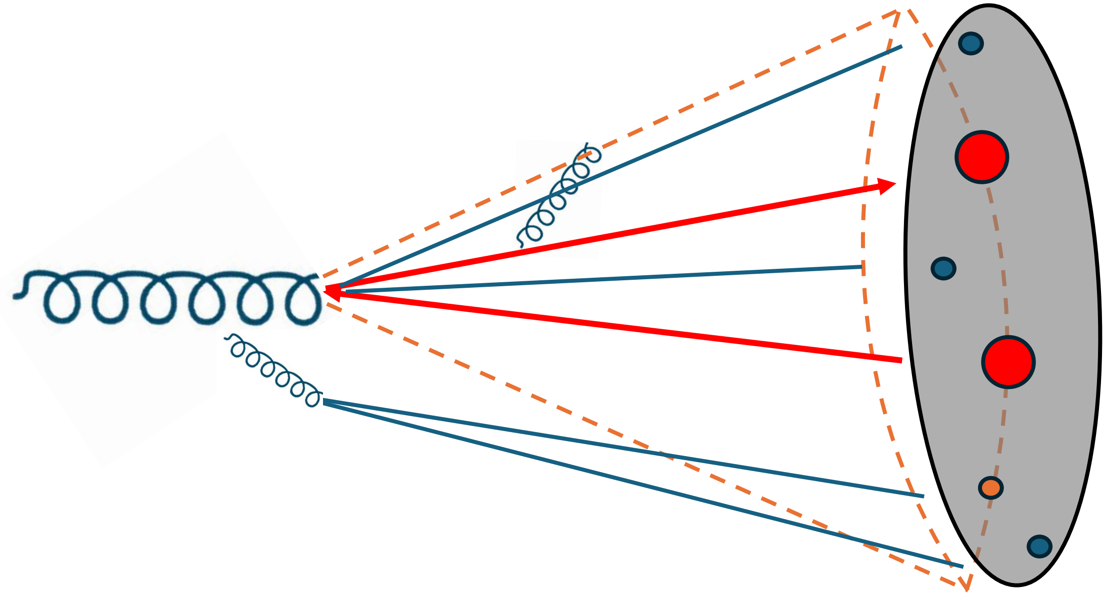
Forming Sub-jets

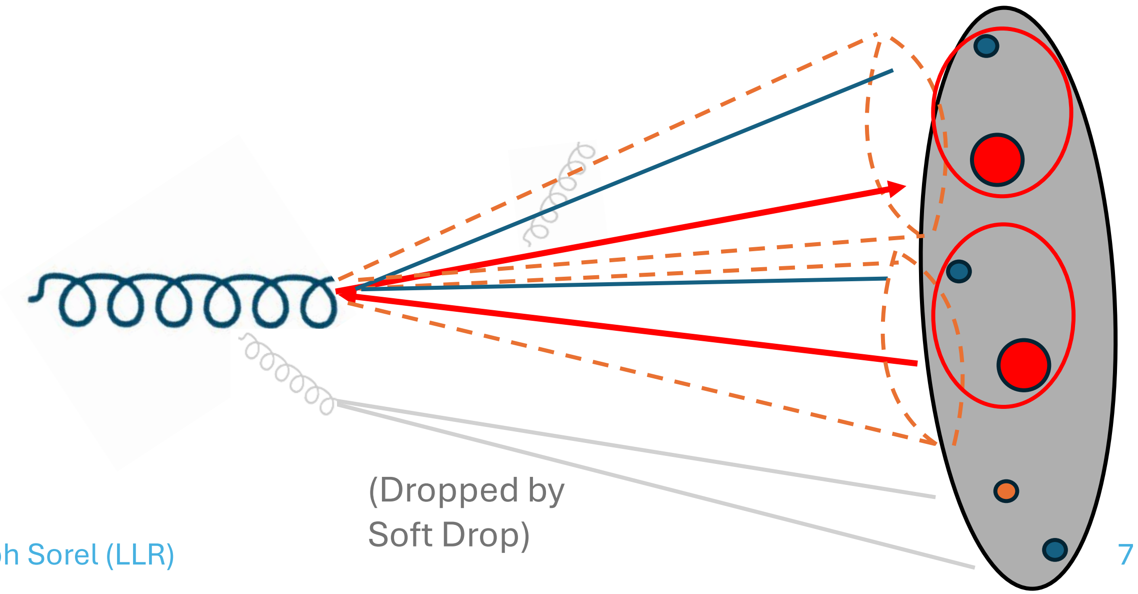
1 jet → **Cambridge Aachen Algorithm** (merge closest tracks until 2 remain) → 2 sub-jet candidates → Do they pass Soft Drop condition?

$$\frac{p_{T_1}}{p_{T_1}+p_{T_2}} > 0.1$$

No, keep leading sub-jet only → 1 jet

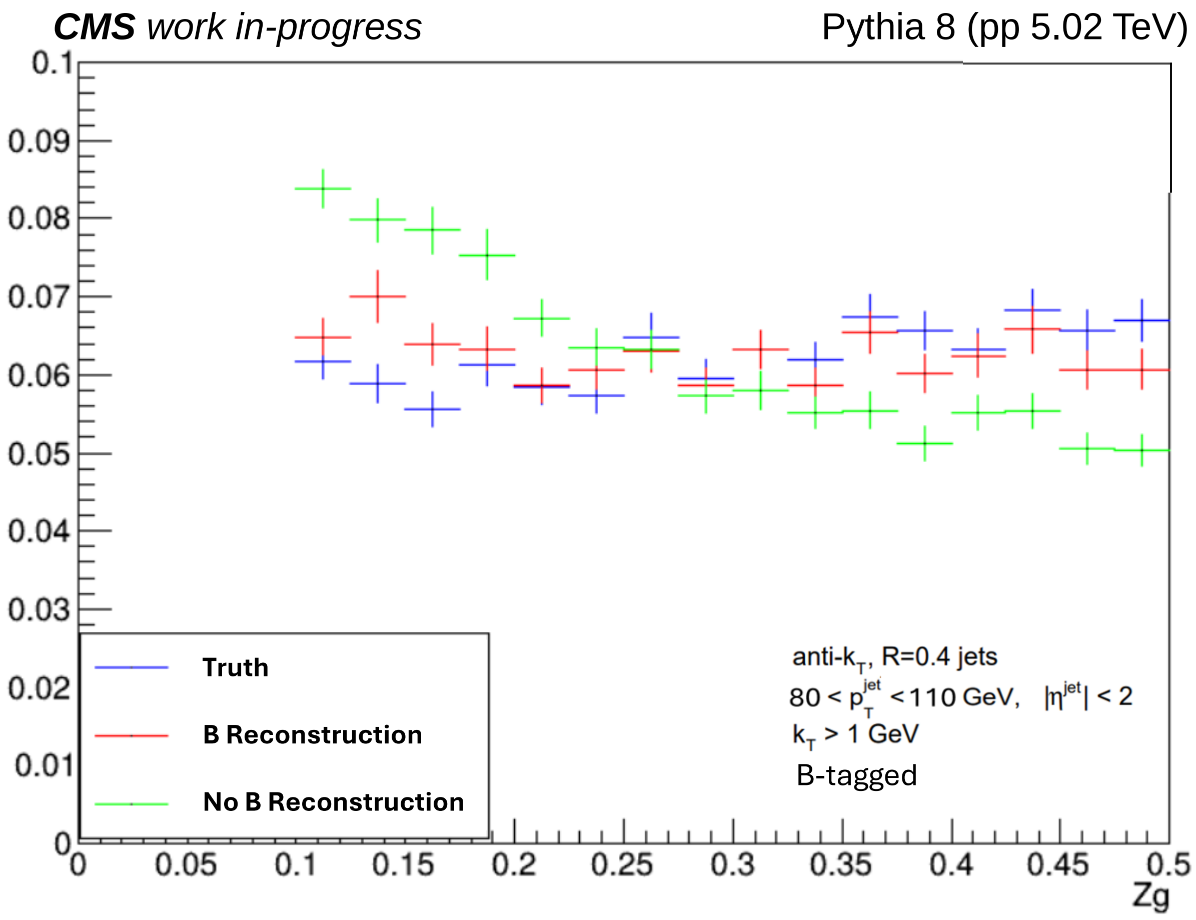
Yes! → 2 sub-jets passing Soft Drop





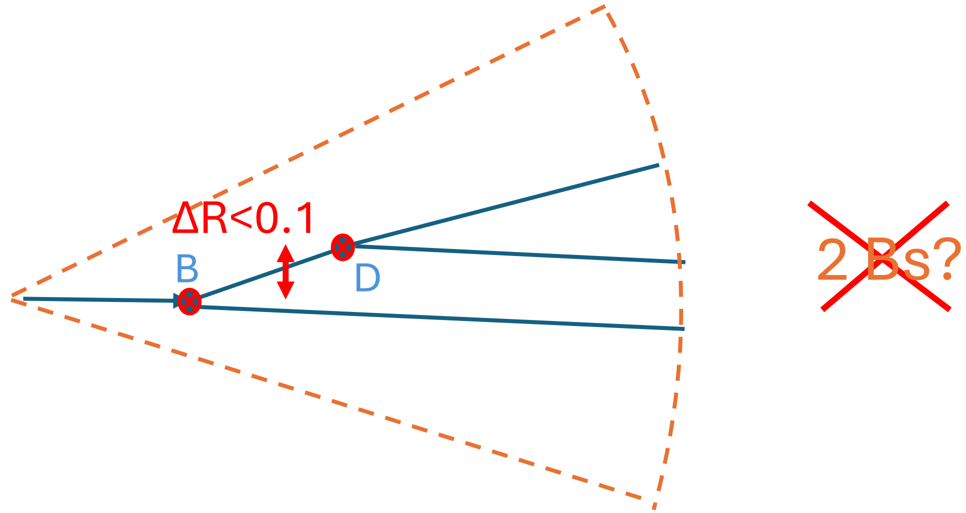
BB Reconstruction Outcome

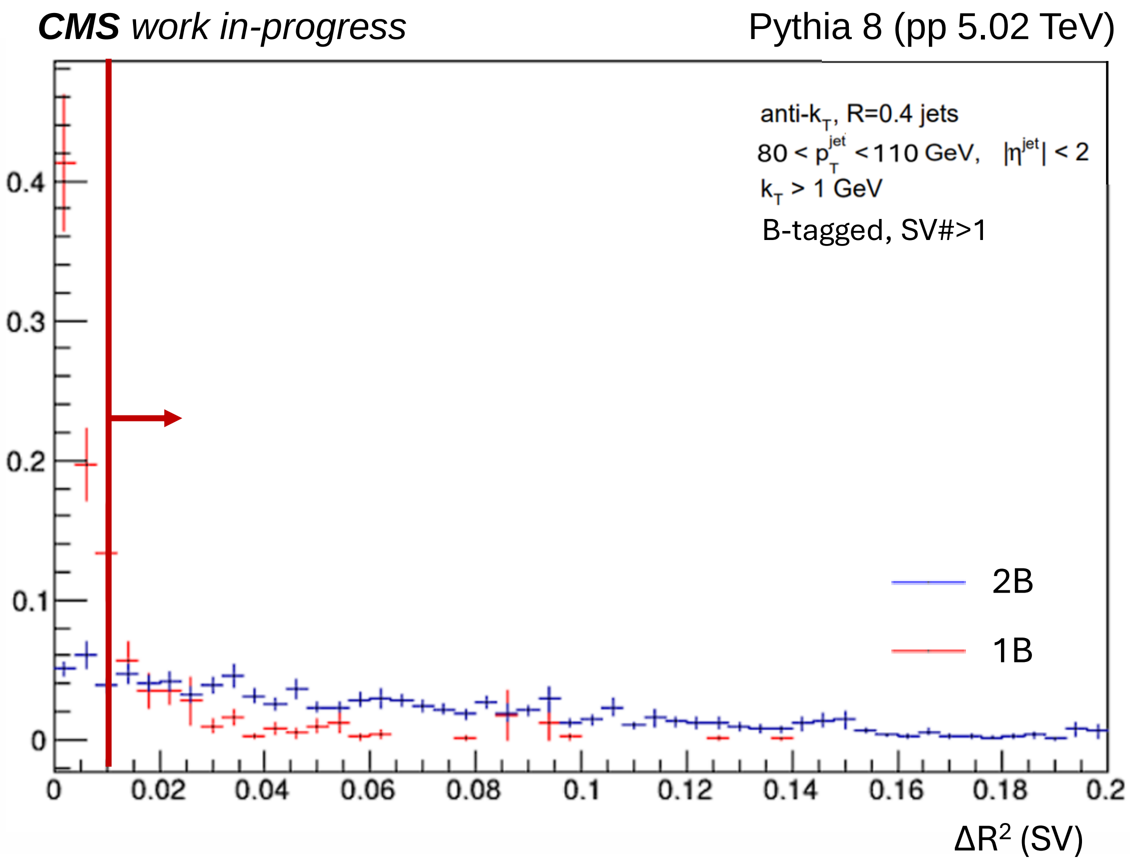
- Significant improvement from no reconstruction: using secondary vertices is effective
- Momentum balance between sub-jets distribution shown (Z_G), similar improvement across substructure variables



Problem 2: Isolating Double B Jets

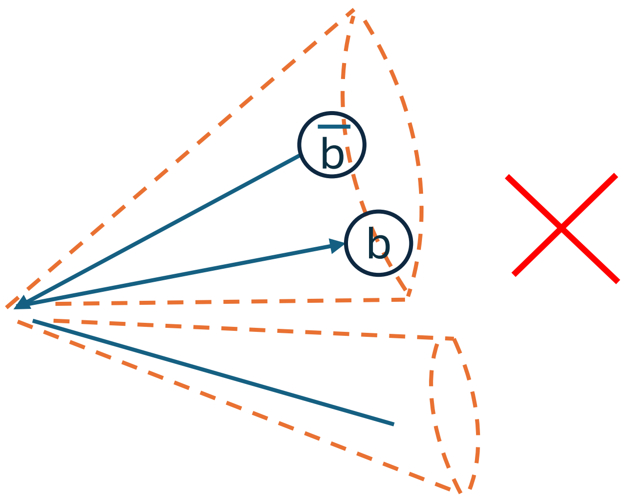
- Select jets with **at least two secondary vertices**
- Merge **very close secondary vertices** ($\Delta R<0.1$)

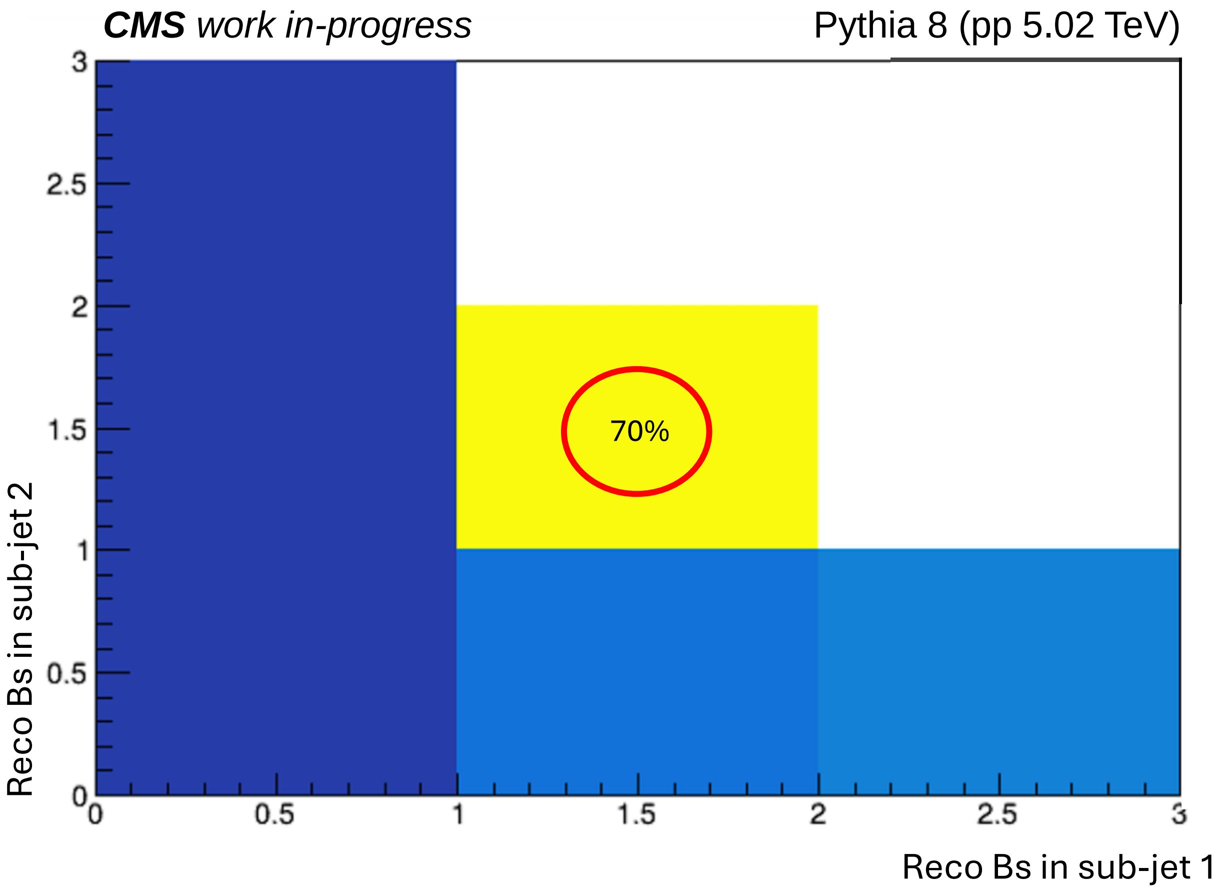




Problem 2: Isolating Double B Jets

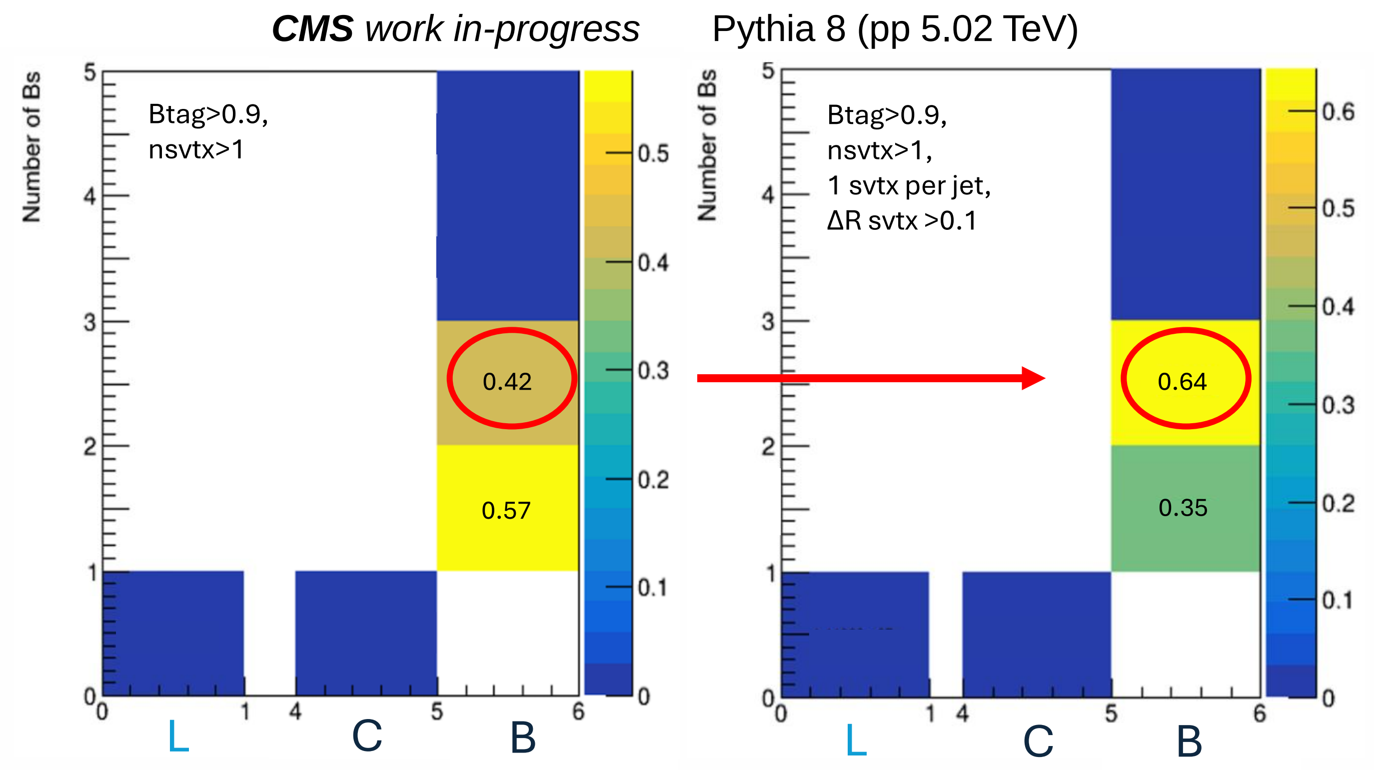
- Require one reconstructed B in each subjet





Cut Results

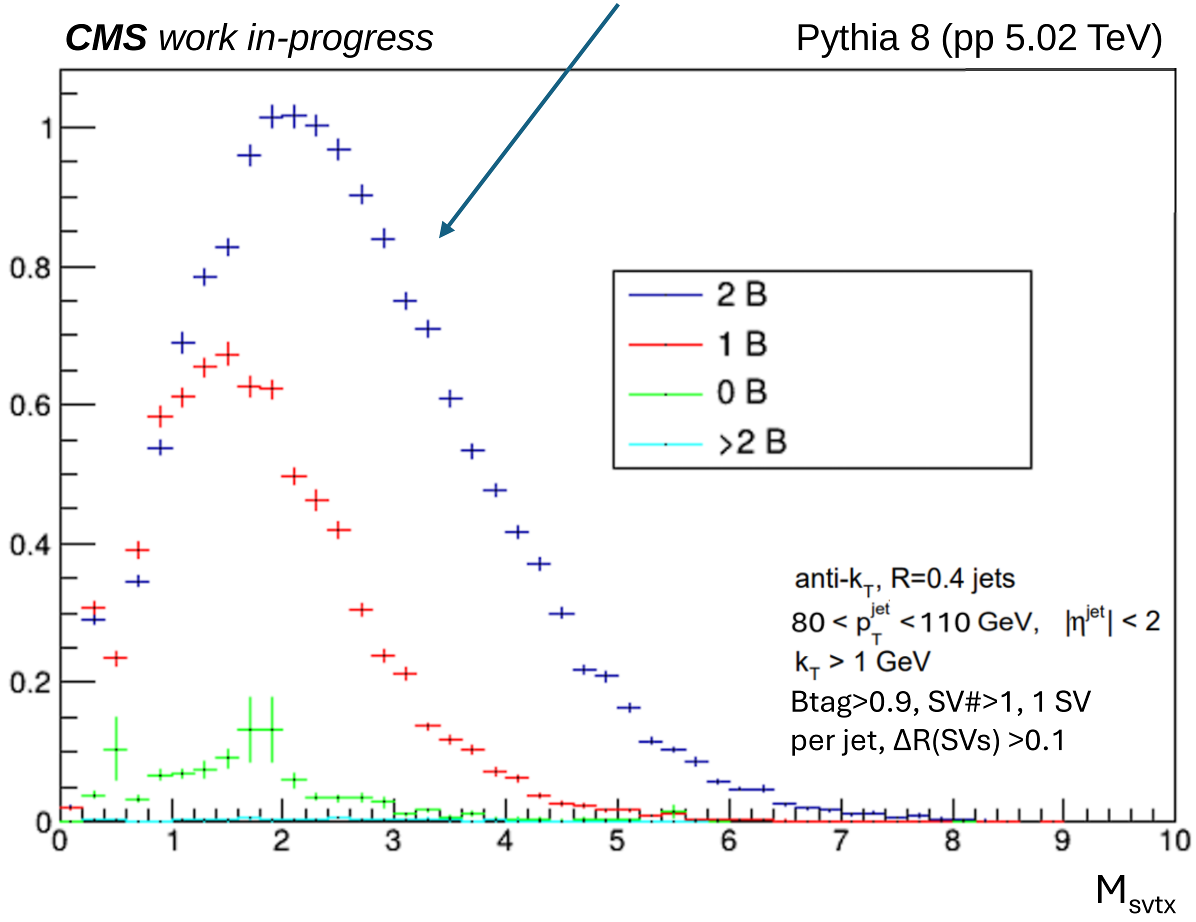
- 2B signal purity: 42%->64%
- Single B background: 57%->35%



Problem 2: Isolating Double B Jets

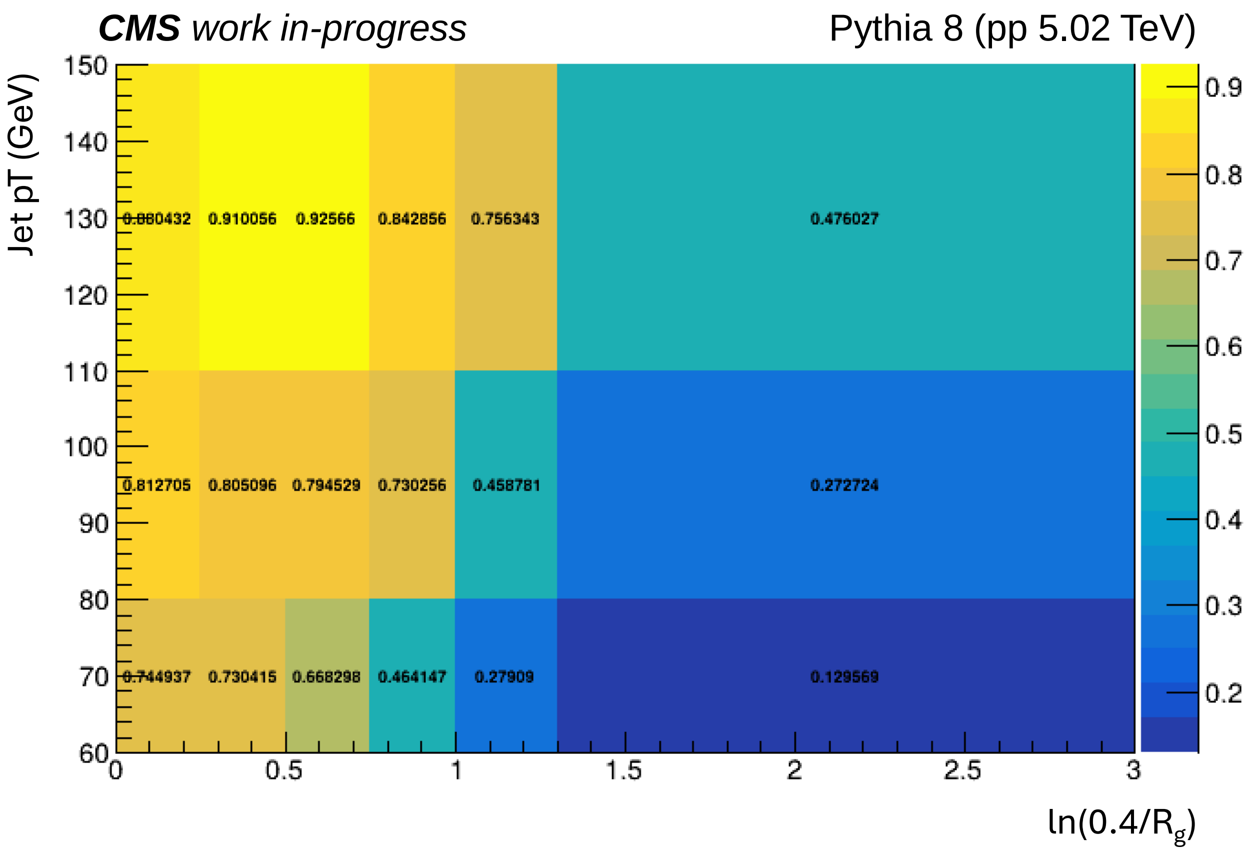
- After all this, there is still background! -> **template fit**
- Using discriminating svtx mass variable (naturally bigger for 2 B masses instead of 1), we can **extract double B signal** from majority single B background

We only want the blue!

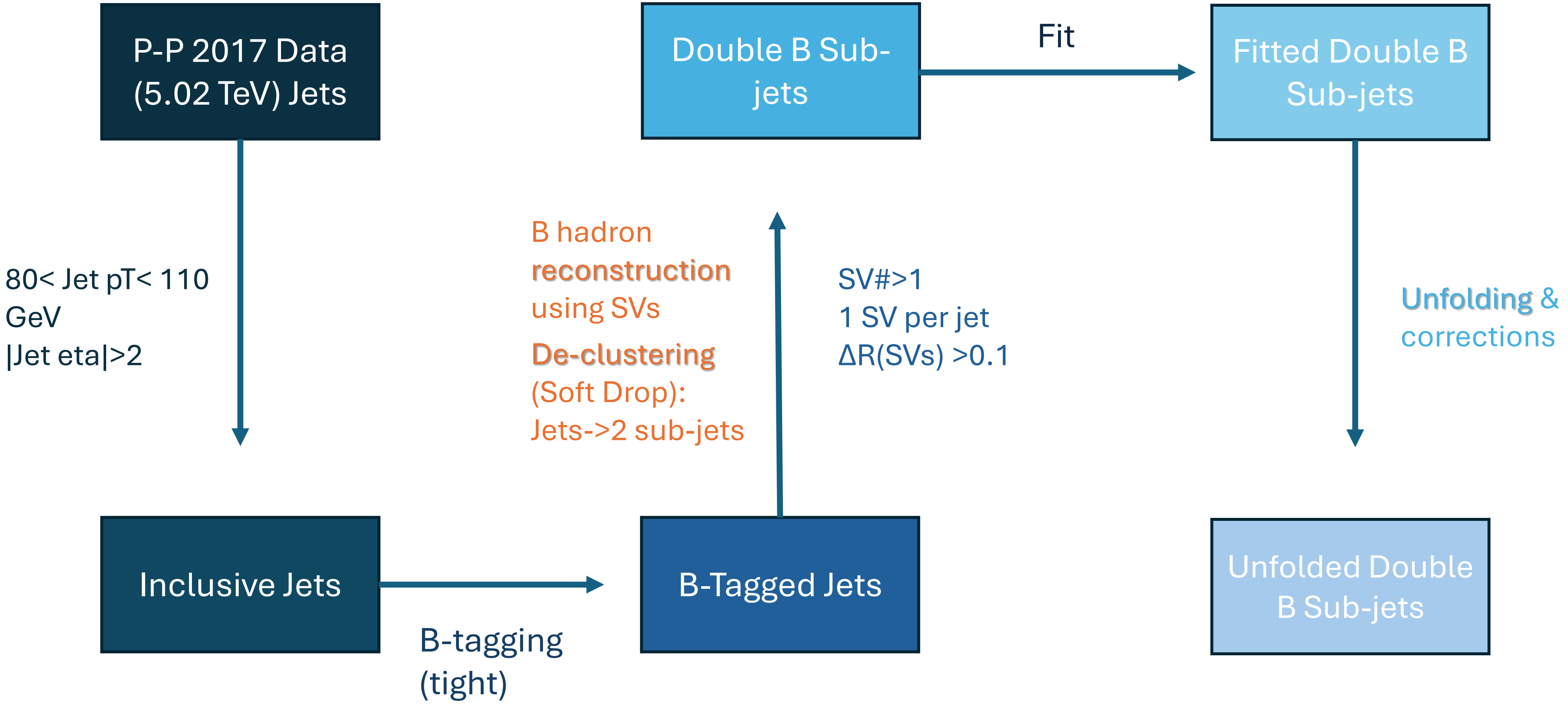


Problem 2: Isolating Double B Jets

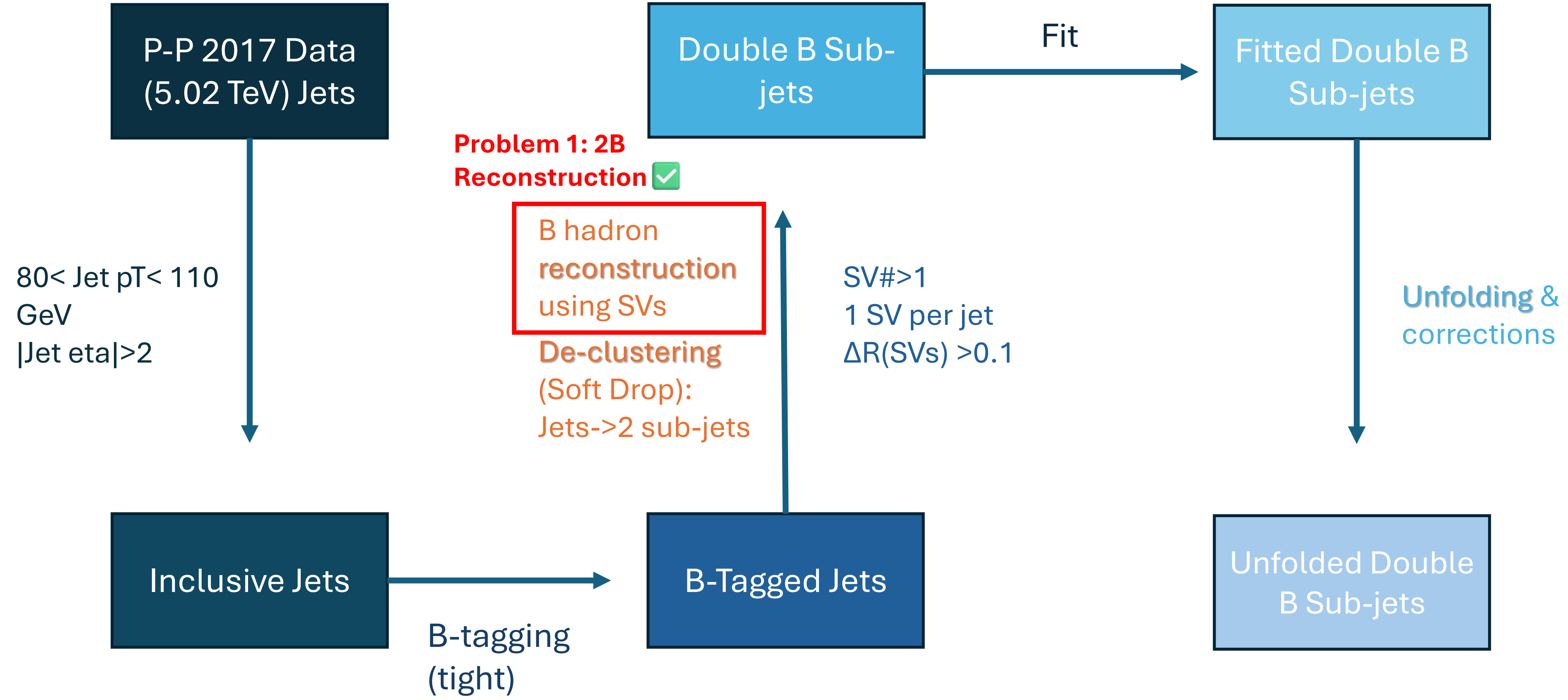
- Fit done in every substructure variable and jet pT bin
- Fit performance: we obtain a **signal fraction** (avg 60-70%) in each bin



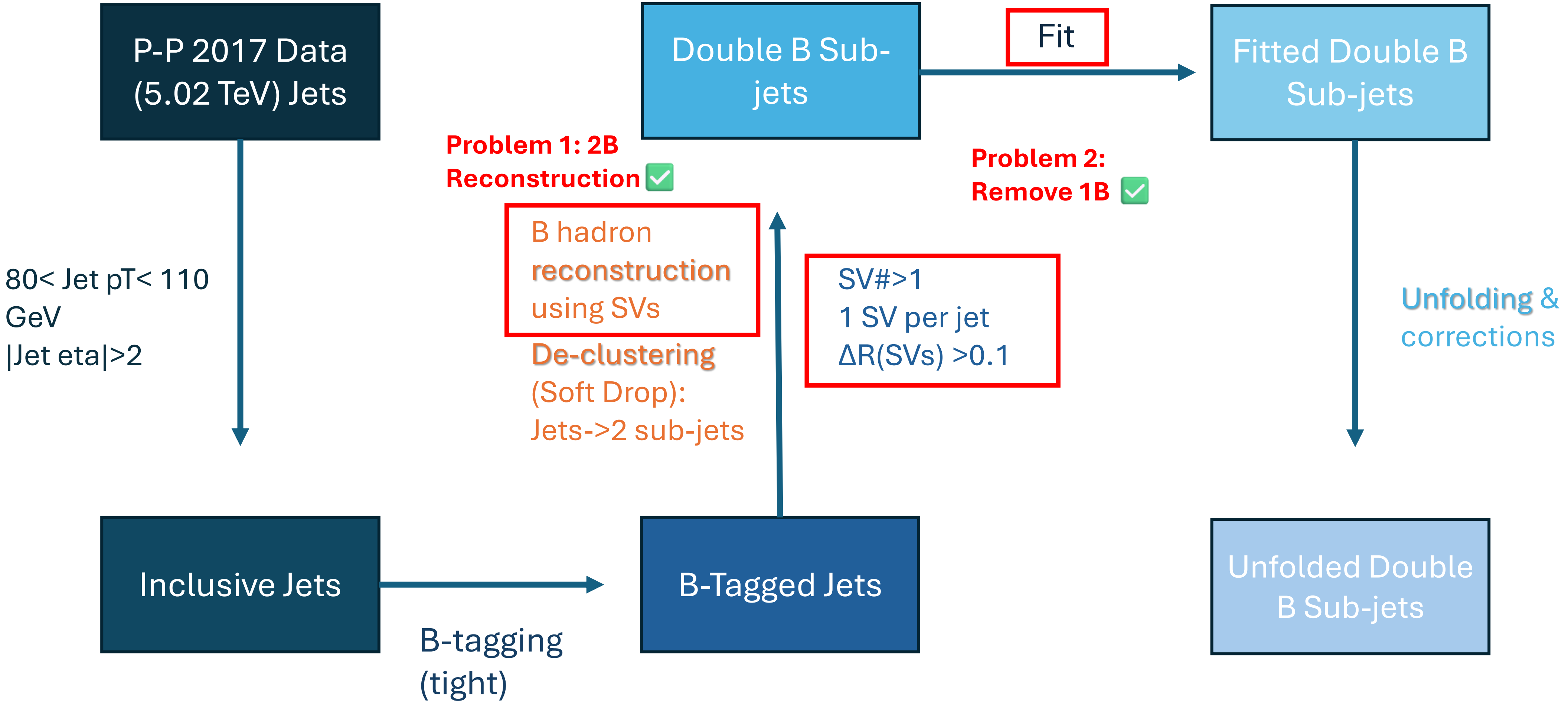
Event Selection Summary



Event Selection Summary

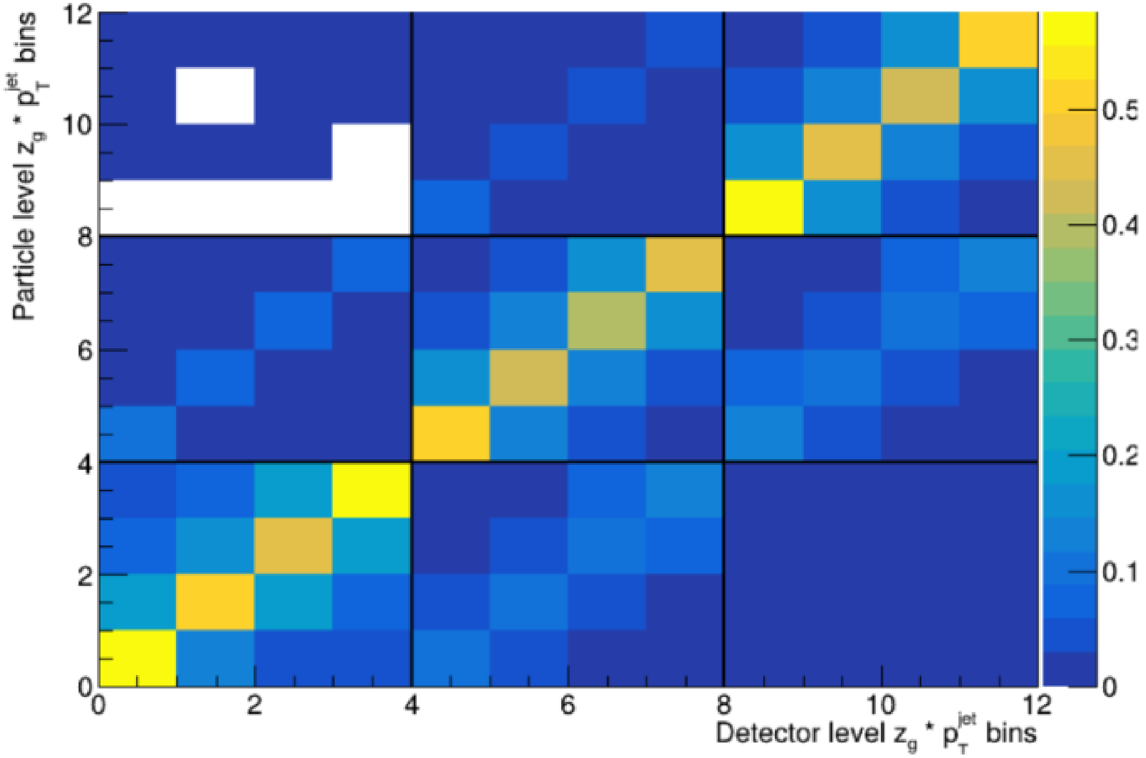


Event Selection Summary



Unfolding & Corrections

- Throughout reconstruction, track differences and their imperfect manipulation can cause "migrations" between **substructure variable** and **jet pt bins**
- Matrix inversion used by **2D unfolding** to compensate for the migration effects
- Efficiency and purity corrections also applied



Substructure Observables

- Momentum balance (Z_G)

$$Z_G = \frac{p_{T2}}{p_{T1} + p_{T2}}$$

- Groomed jet radius (R_G or ΔR)

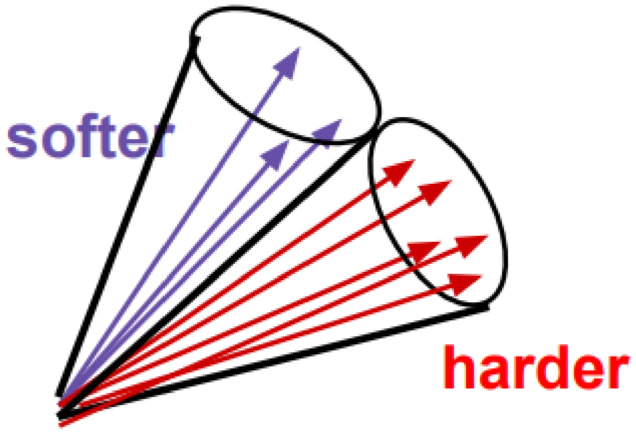
$$R_G = \sqrt{(\Phi_1 - \Phi_2)^2 + (\eta_1 - \eta_2)^2}$$

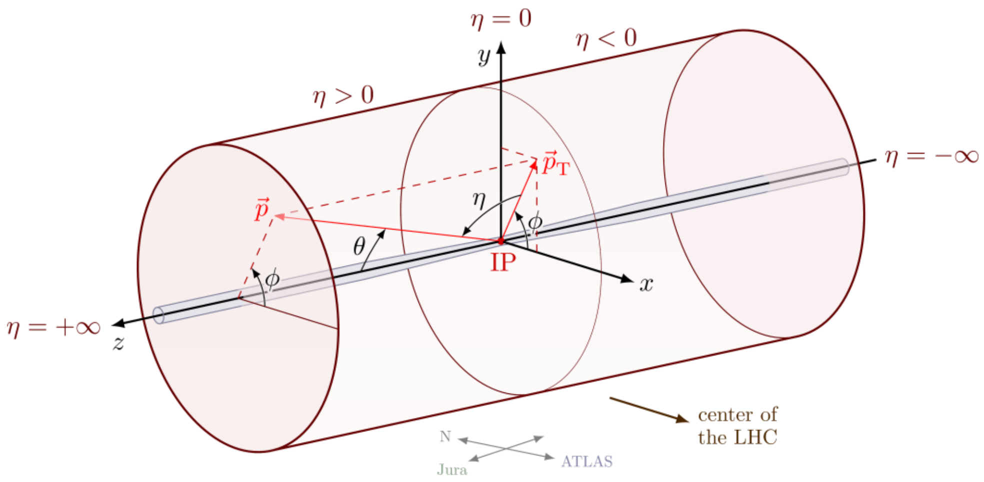
Often plotted as $ln(\frac{0.4_{(jetradius)}}{\Delta R(sj_1, sj_2)}) = ln(\frac{0.4_{(jetradius)}}{R_G})$

- Relative transverse momentum (K_T)

$$K_T = p_{T2}(\Delta R(sj_1, sj_2))$$

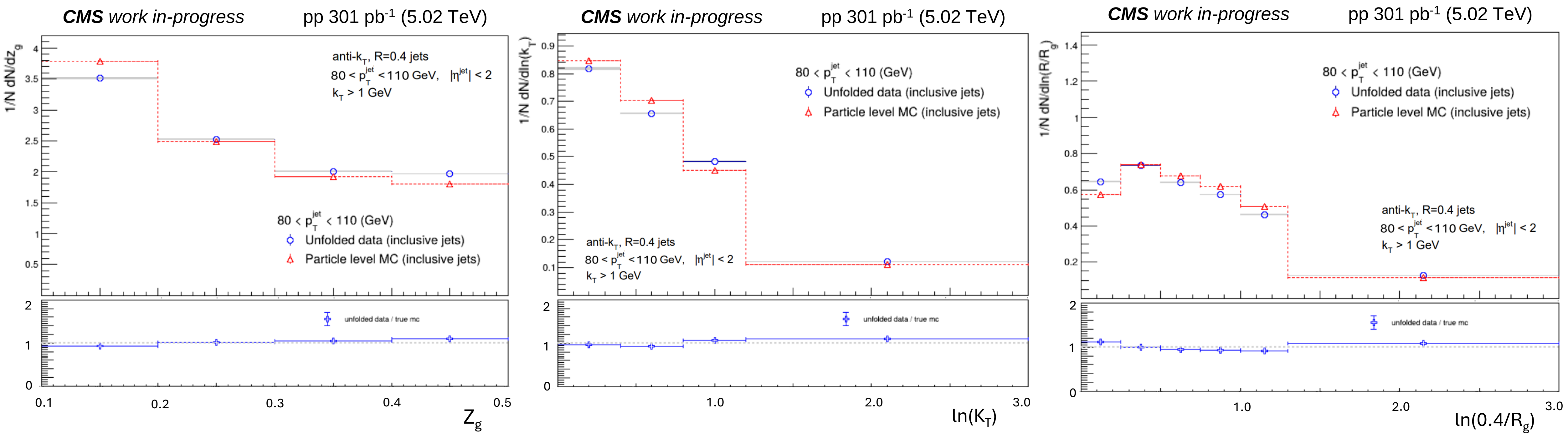
Often plotted as $ln(K_T)$





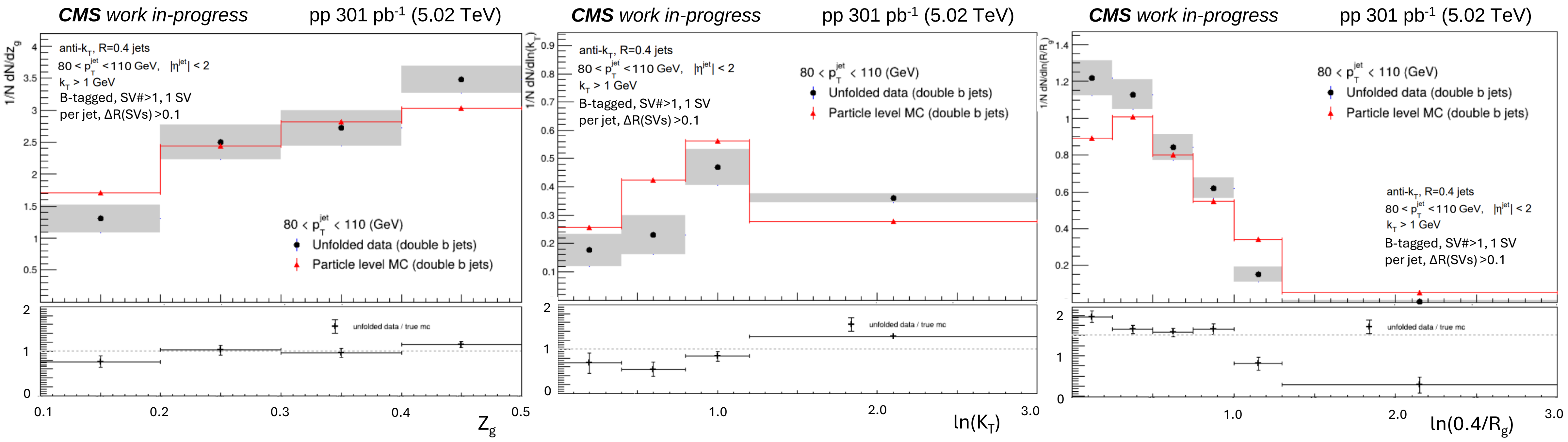
Results: Inclusive **Data** & MC

- Inclusive data and Monte Carlo simulation show good agreement, meaning we can reliably use them for signal comparison
- Consideration: systematic uncertainties not shown!



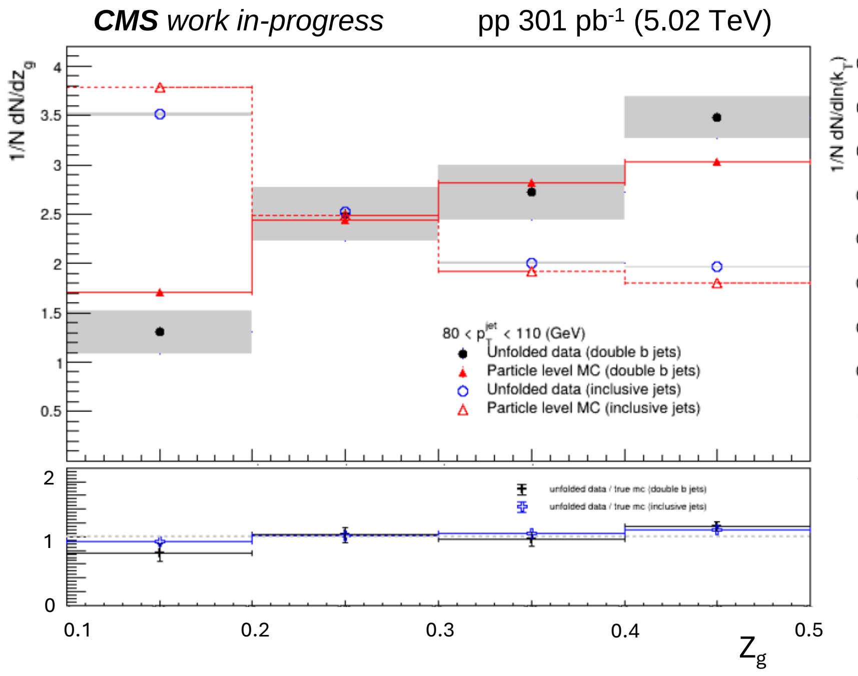
Results: Double B **Data** & **MC**

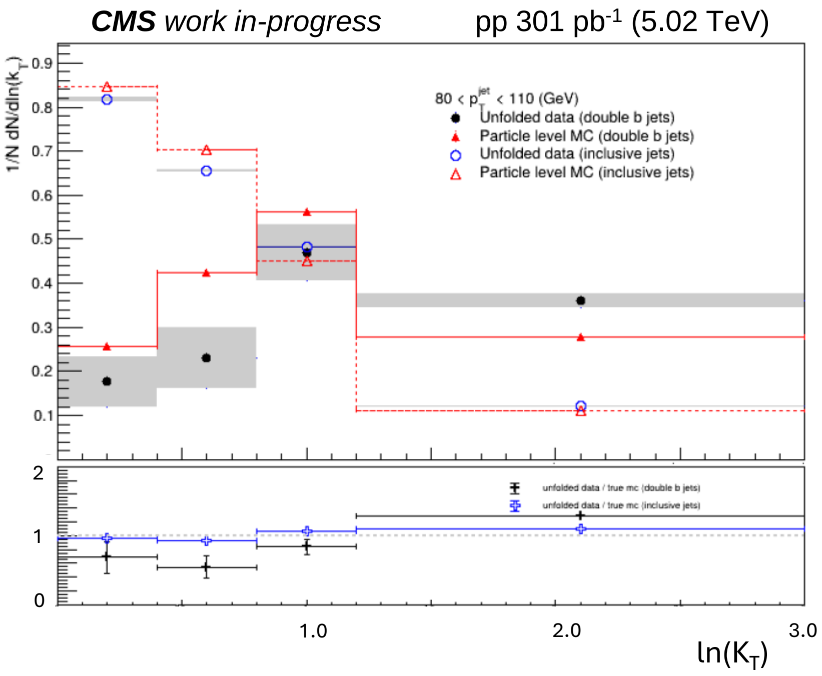
- Again, decent MC/data agreement, differences will likely disappear with systematic uncertainties

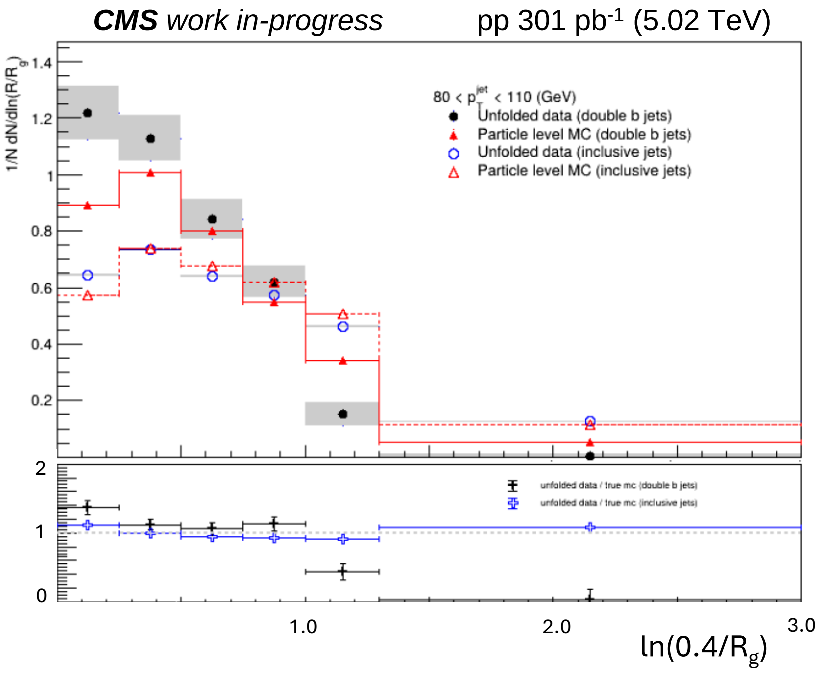


Results: **2B Data** & **Inclusive Data** & **MC**

- Double B jets exhibit **more balanced momentum** sharing between subjets, consistent with gluon to heavy quark splitting vs generic soft emissions with asymmetric splittings
- Larger kT in double B is consistent with the **transverse recoil** from gluon splitting to heavy quarks
- Systematically larger jet radii in double B jets implies **more angularly separated** subjets

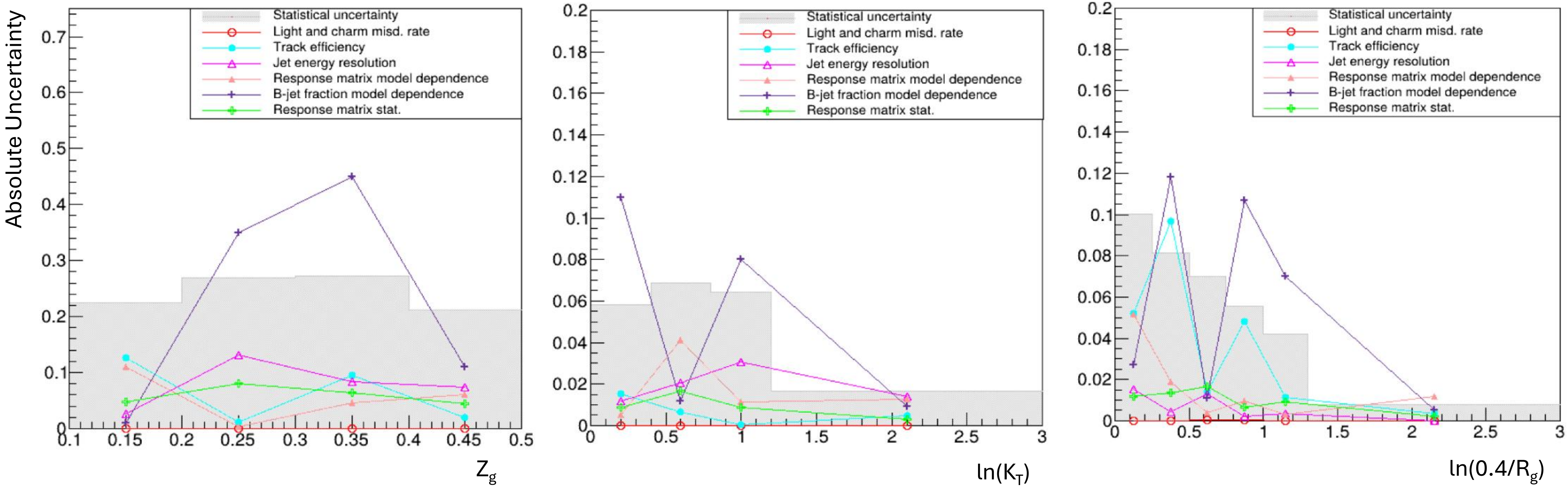






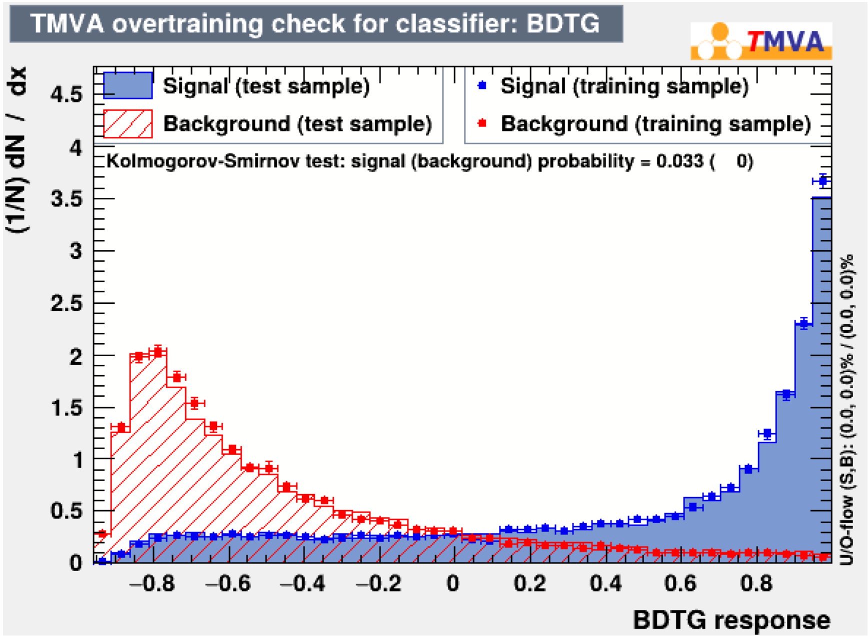
A Peek at Systematic Uncertainties

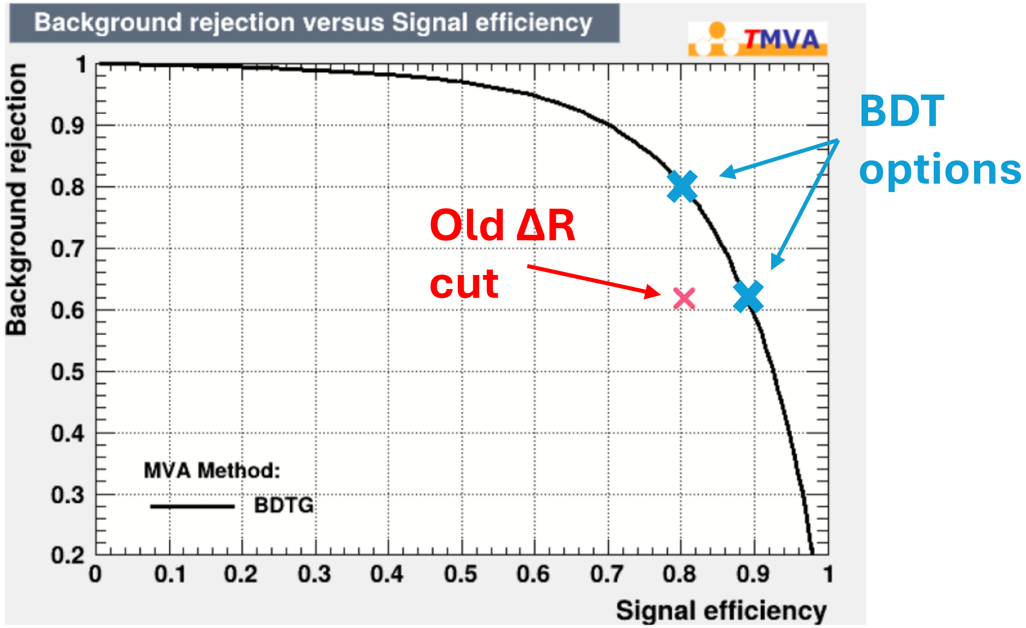
- Systematic uncertainties are considered related to the **hadronization model**, the **jet and track reconstruction**, the **b tagging efficiency** and the **signal extraction**
- Very preliminary!



BDT Study

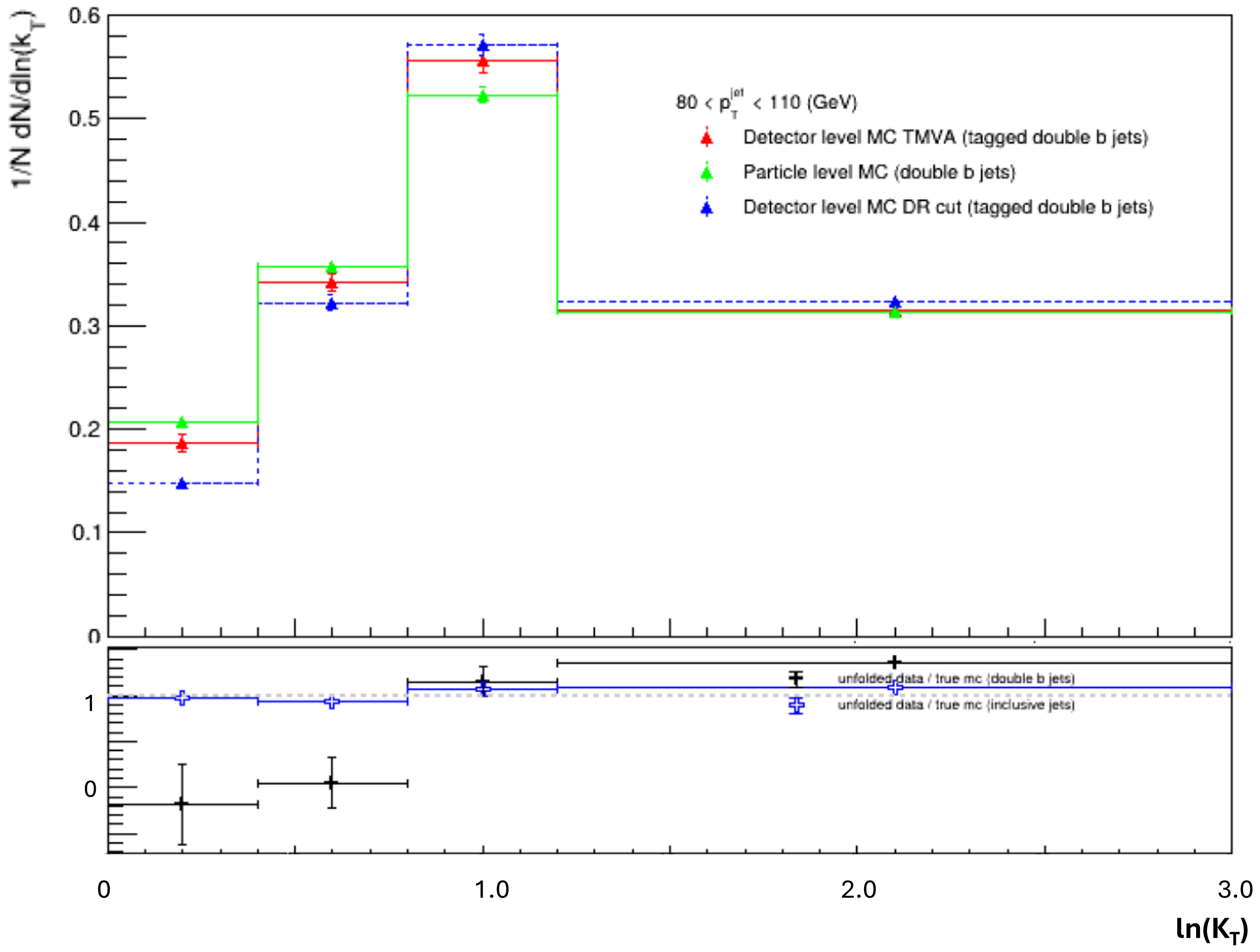
- **Boosted Decision Trees** are used to distinguish pairs of secondary vertices coming from a single or double B jet (instead of simply merging close ones)
- Discriminating variables: **mass, pT, ntracks** (for SV1 and SV2), **distance** ΔR(SVs)





BDT Outcome

- We choose to **save signal**: +10% signal with same background rejection (~60%)
- When applying this **BDT cut (>-0.5)** we obtain improved (closer to the truth MC) distributions



Summary

- Successful B hadron **reconstruction**, jet **de-clustering** and signal **isolation**
- Logical **results**, new **systematics** and **BDT cut**
- Will be interesting to **compare** with Pb-Pb

Check out our lab office parody video!