LHCb Jet Substructure

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on behalf of LHCb
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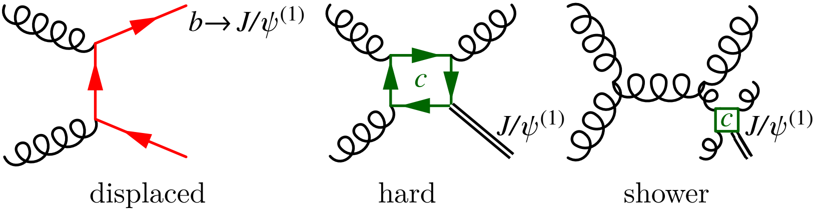
LHC-EW WG: Jets and EW bosons

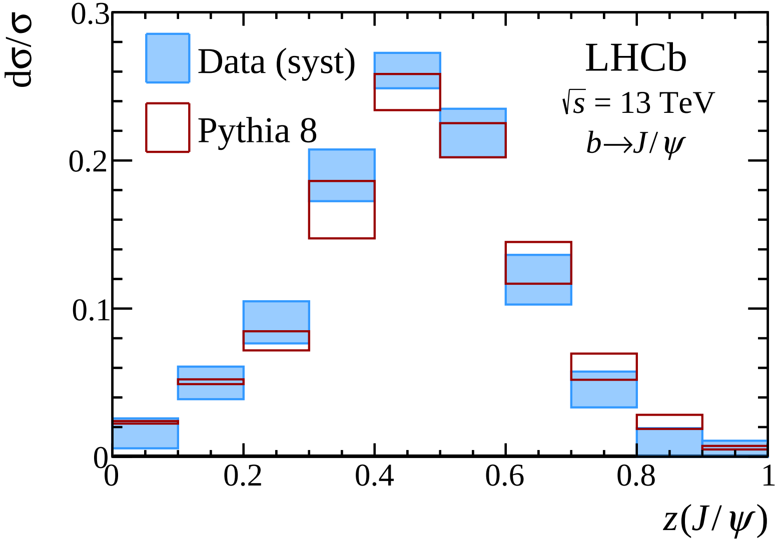
Why LHCb?

- LHCb has excellent secondary vertex tagging
- $\rightarrow$ substructure with flavor tags

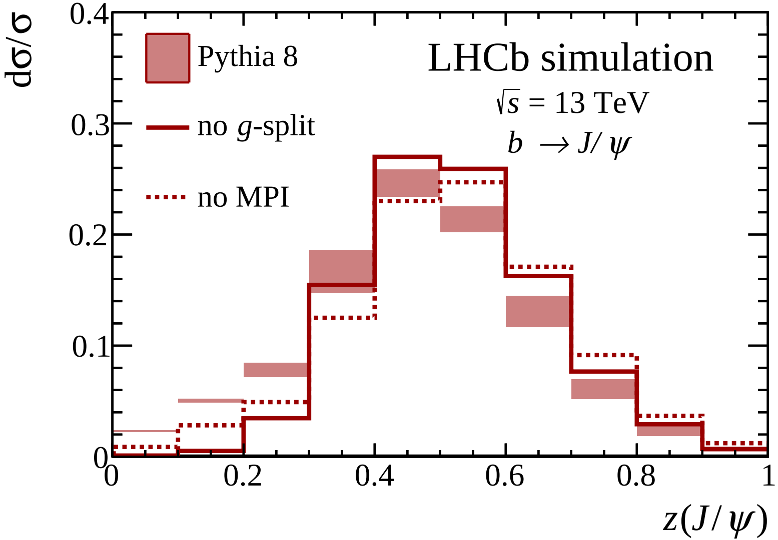


- J/ψ production in jets: LHCb, PRL 118 (2017)
- are J/ψ produced in isolation?
- measure $p_{\mathrm{T}}(J/\psi)/p_{\mathrm{T}}(\mathrm{jet})$

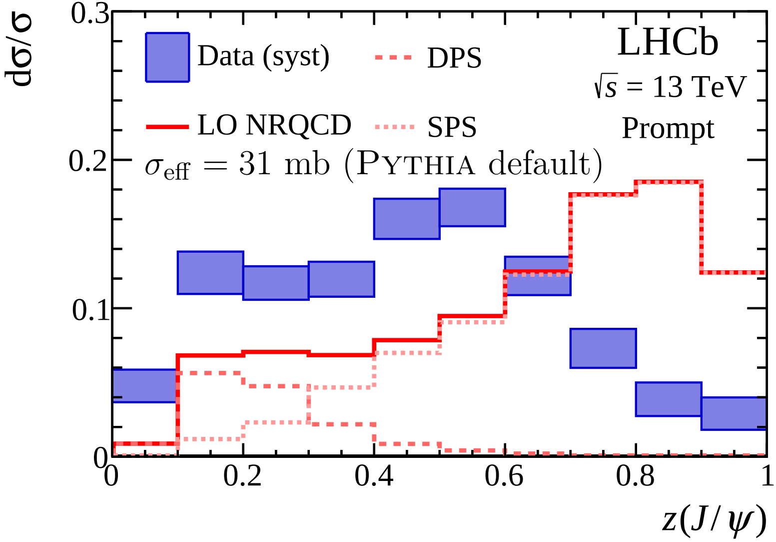
J/ψ Displaced Results



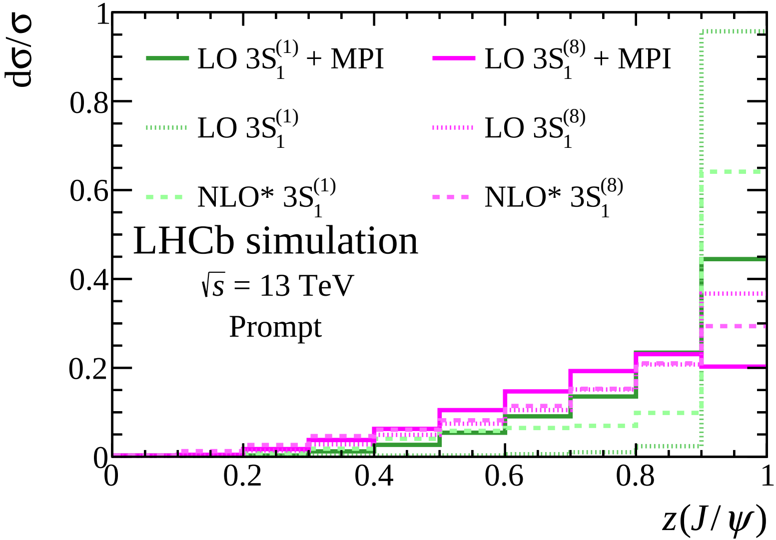
J/ψ Displaced Results



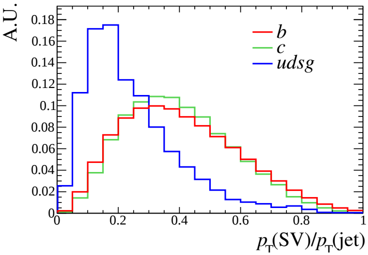
J/ψ Prompt Results

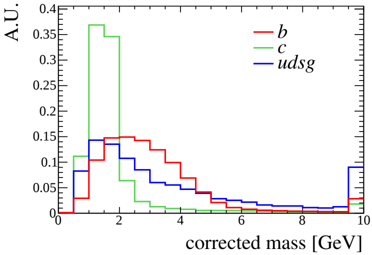


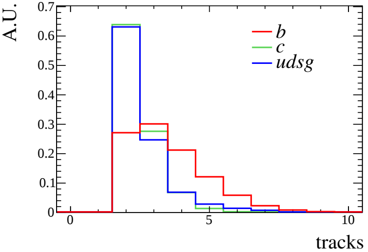
J/ψ Prompt Results



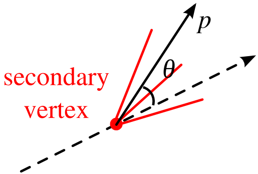
- use inclusive secondary vertex tags: LHCb, JINST 10 (2015)



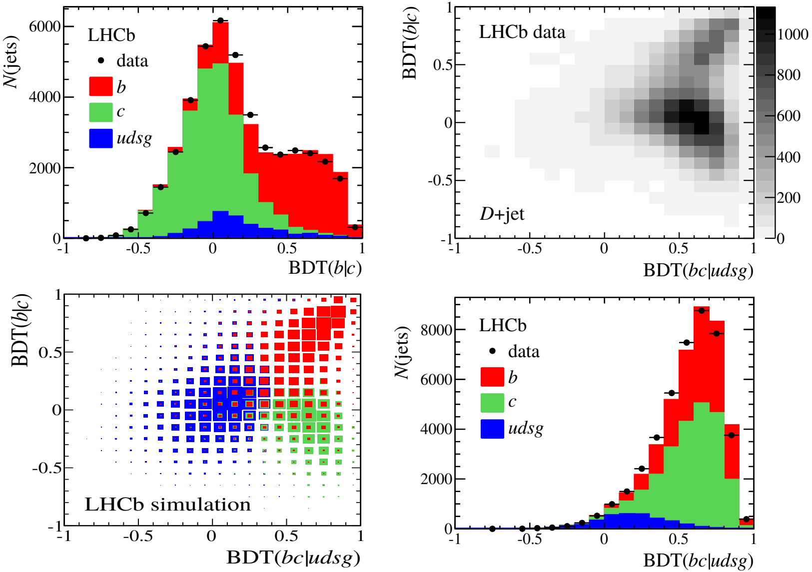


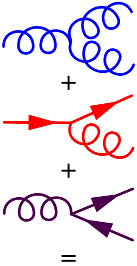


$$M_{\text{cor}} = \sqrt{M^2 + p^2 \sin^2\theta} + p\sin\theta$$



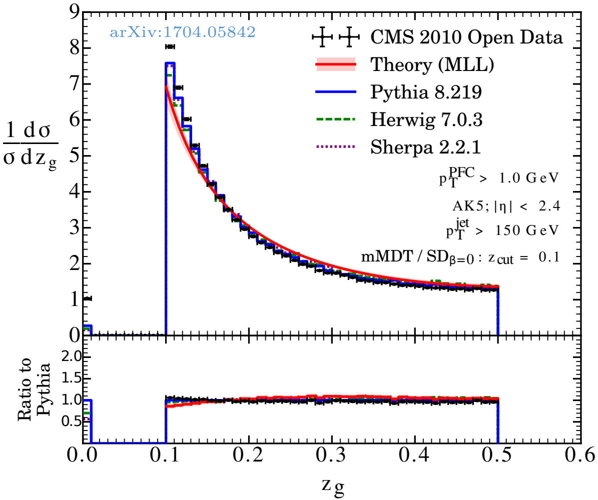
Extracting Flavor





$$\frac{1-z}{z} + \frac{z}{1-z} + \frac{1}{2}$$

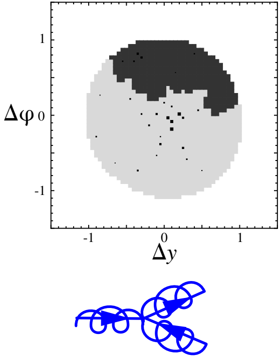
$$z_g \equiv \frac{p_{T1}}{p_{T1} + p_{T2}}$$



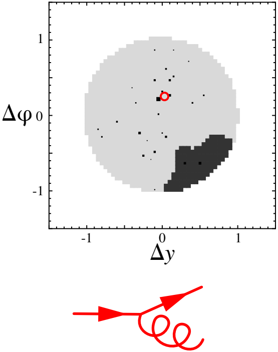
- use tags to understand $1 \to 2$ splittings
- Ilten, Rodd, Thaler and Williams, PRD 96 (2017)

Jet Anatomy

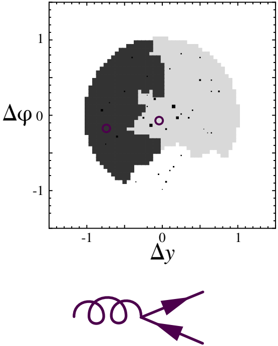
1. find all tags in event and treat as *ghosts*
2. build anti-k_t jets with $R = 1$, including tags
3. apply SoftDrop with $z_{\text{cut}} > 0.1$ and $\beta = 0$
4. consider sub-jet tagged if $p_{\mathrm{T}}^{\text{tag}}/(p_{\mathrm{T1}} + p_{\mathrm{T2}}) > 0.05$



$(0,0)_Q$



$(0,1)_Q$



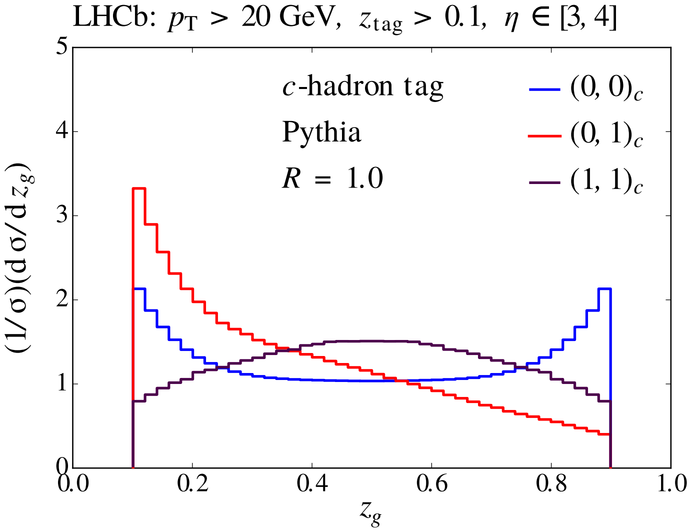
$(1,1)_Q$

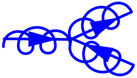
Some Numbers

	σ(Pythia) [μb]	σ(Herwig++) [μb]
$(0,0)_c$	9.96×10^2	5.28×10^2
$(0,1)_c$	7.56×10^1	2.64×10^1
$(1,1)_c$	6.87×10^0	2.87×10^0
$(0,2)_c$	1.00×10^1	5.64×10^0
other_c	8.86×10^{-1}	2.47×10^{-1}
$(0,0)_b$	1.07×10^3	5.52×10^2
$(0,1)_b$	1.34×10^1	9.58×10^0
$(1,1)_b$	8.40×10^{-1}	5.03×10^{-1}
$(0,2)_b$	9.50×10^{-1}	5.94×10^{-1}
other_b	1.13×10^{-2}	7.75×10^{-3}

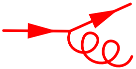
- missed tags migrate category up $\rightarrow$ minimal contamination
- efficiency of tagging well understood from data

Heavy Flavour Splittings





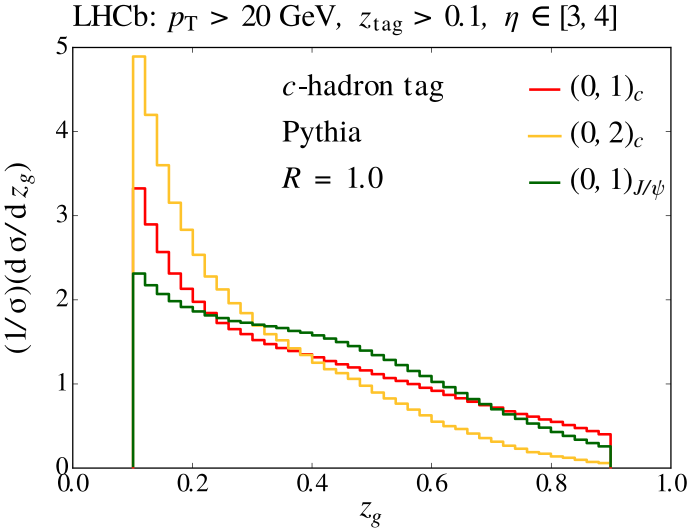
$(0, 0)_c$

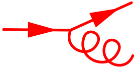


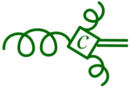
$(0, 1)_c$

$(1, 1)_c$

Quarkonia Splitting



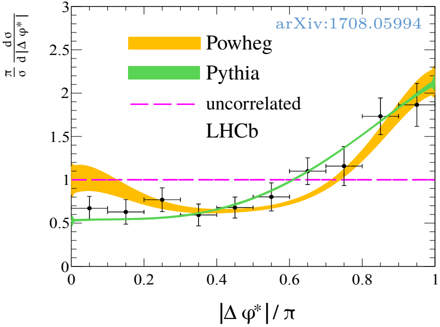


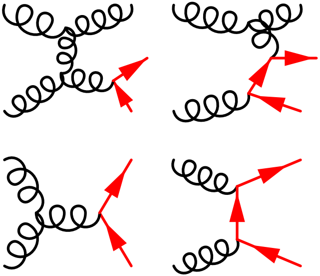


Heavy Flavour Production

- understanding heavy flavour production critical for many signals

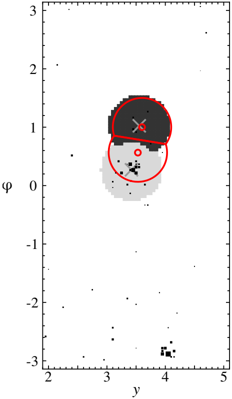
1. hadron-level: good angular properties, poor energy proxy
2. tagged jet-level: poor angular properties, good energy proxy

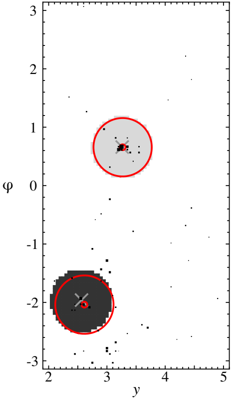




FlavorCone

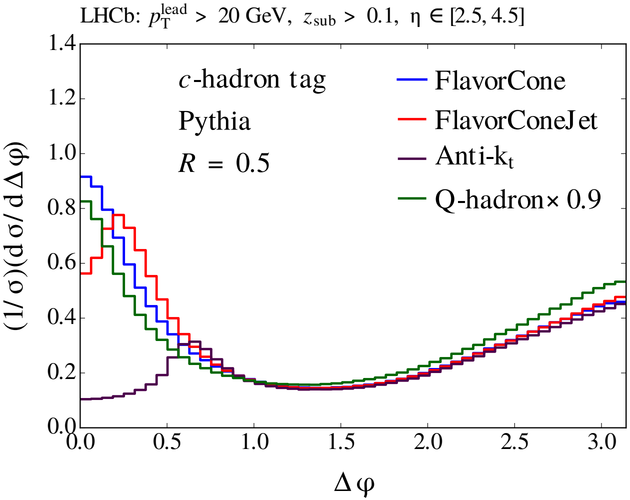
- good angular properties, good energy proxy
- collinear and infrared safe by jet-axis definition





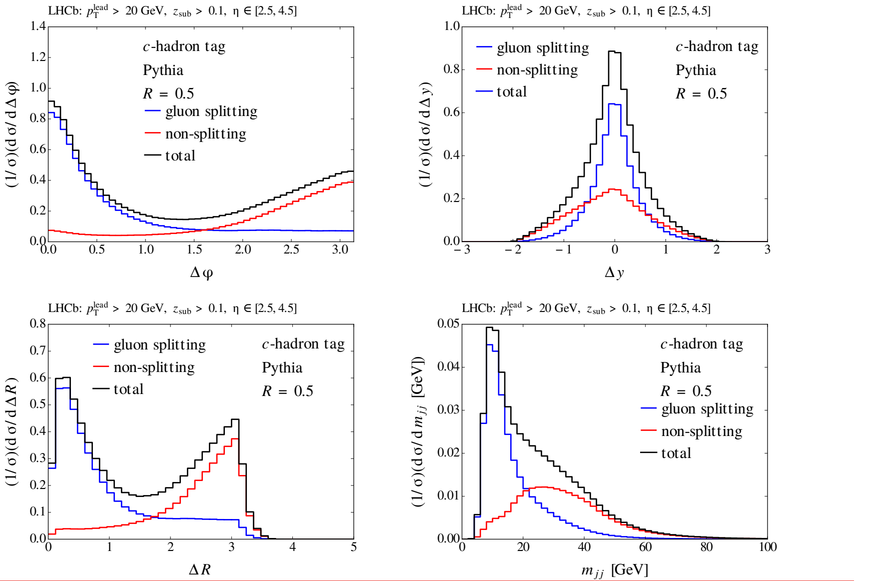
1. given n tags define n jet-axes
2. particles outside of R with an jet-axis is not clustered
3. remaining particles are clustered with nearest axis
4. jet momenta is sum of constituents

Comparison



LHCb: $p_T^{lead} > 20$ GeV, $z_{sub} > 0.1$, $\eta \in [2.5, 4.5]$
c-hadron tag
Pythia
$R = 0.5$
FlavorCone
FlavorConeJet
Anti-k_t
Q-hadron× 0.9
$(1/\sigma)(d\sigma/d\Delta\varphi)$
$\Delta\varphi$
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0.5
1.5
2.0
2.5
3.0

Variable Discrimination



Outlook

- LHCb has unique jet tagging capabilities
  - translates to interesting substructure
- J/ψ production is not isolated!
  - reconsider theory with parton shower framework
  - implications for J/ψ production in medium
  - more measurements are needed
- SoftDrop accesses fundamental $1 \to 2$ QCD splittings
  - paired with jet tagging, probe heavy flavour splitting
  - new technique to understand J/ψ production
- FlavorCone allows study of heavy flavour production

Thank you!