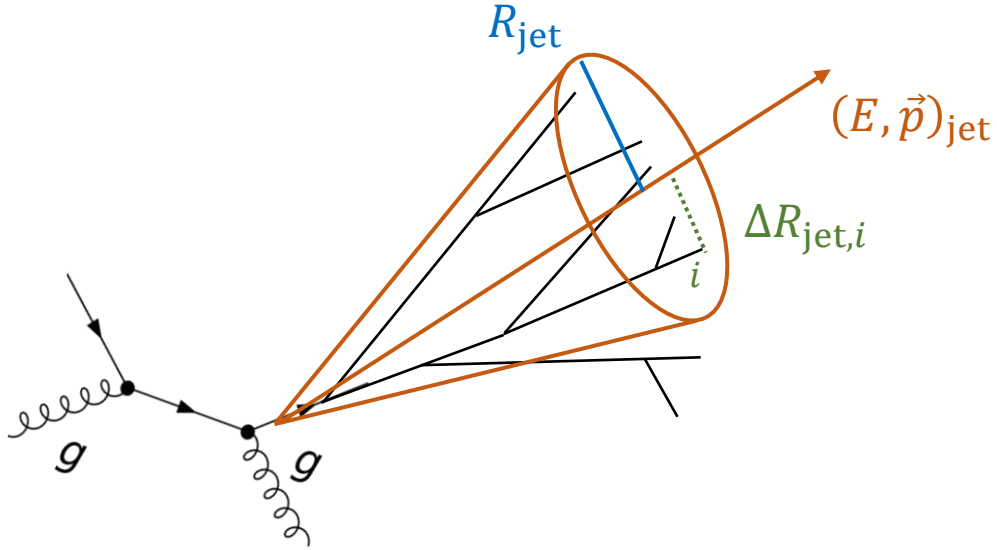
Flavored jets on LHCb

Ezra D. Lesser (CERN)
on behalf of the LHCb Collaboration
11 June 2024

Flavored jets at the LHC // Durham, England, UK

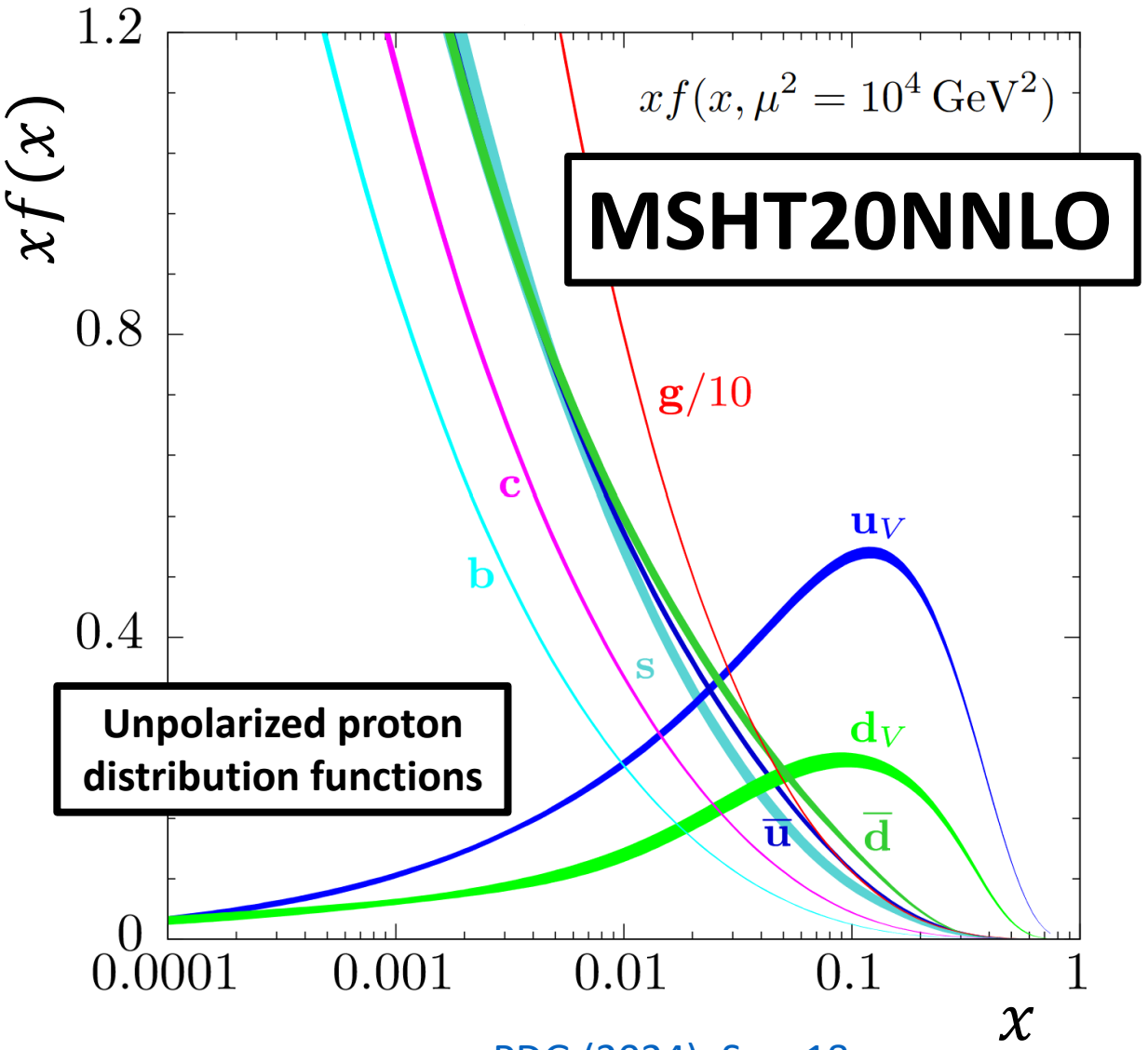


b-quark production at the LHC

- No inherent b-quark component in the proton wavefunction

→ Prominent LO production is:

$$gg \to b\bar{b}, \qquad q\bar{q} \to b\bar{b}$$



PDG (2024), Sec. 18

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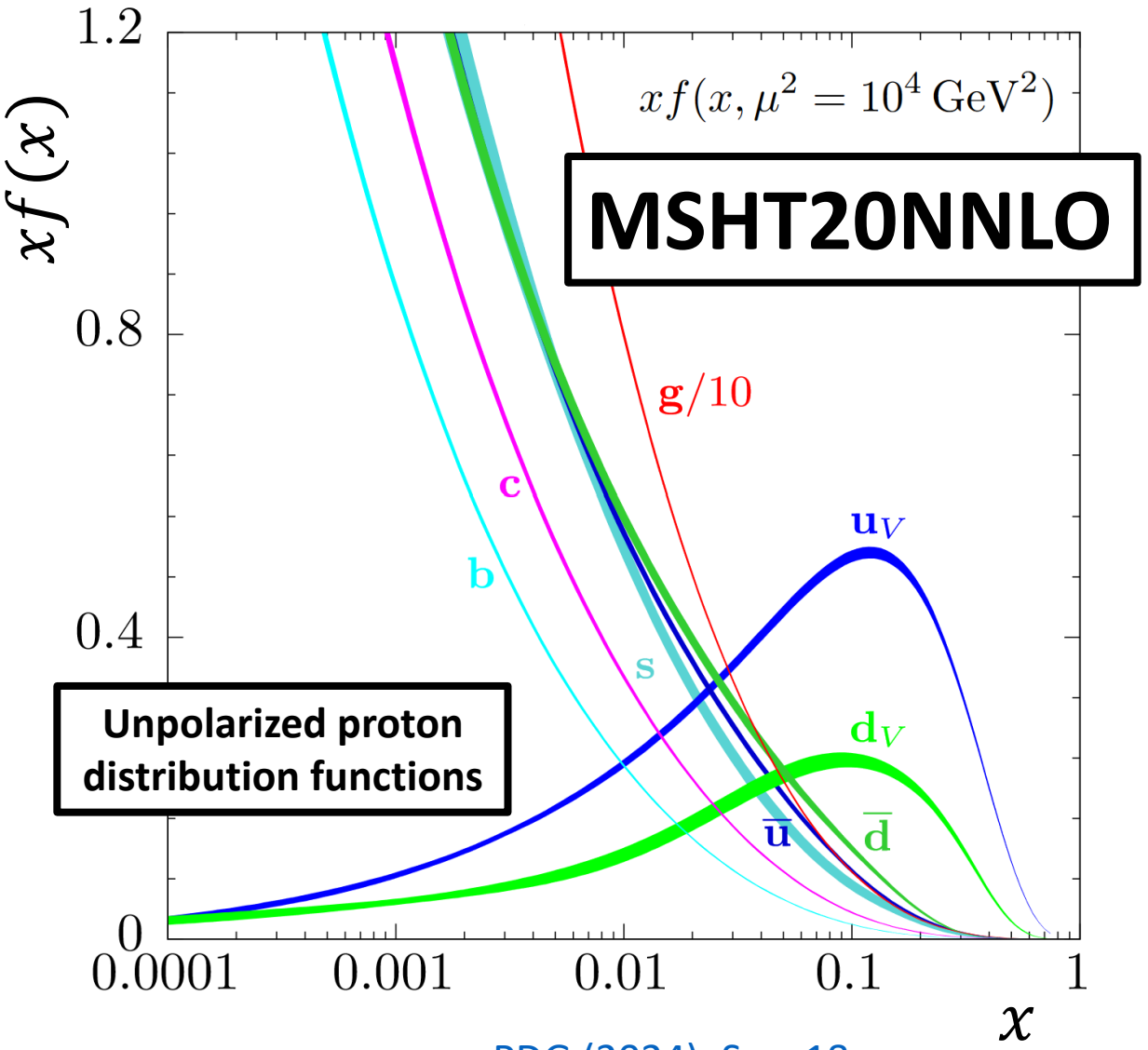

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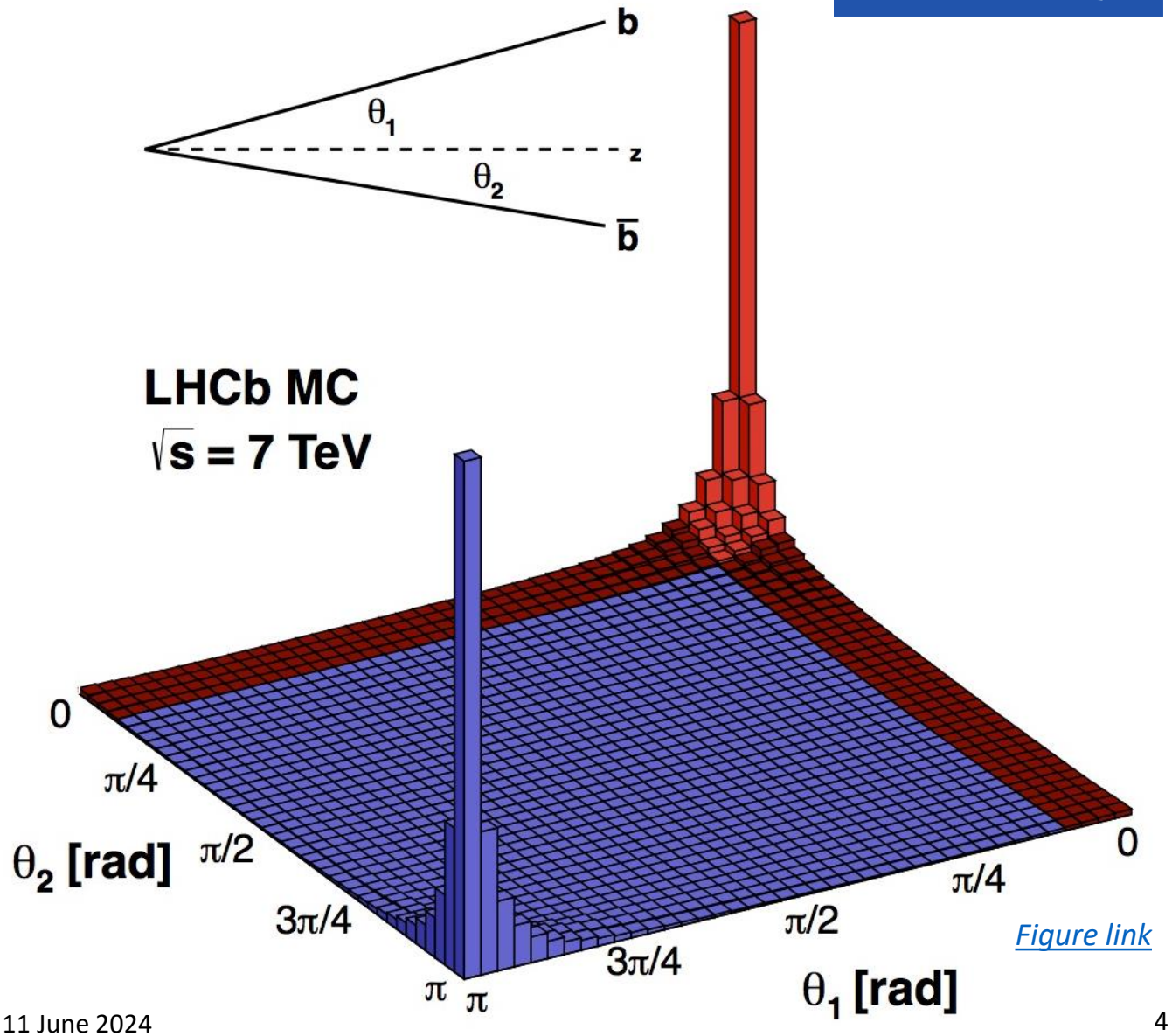
- **$b\bar{b}$ pairs are predominantly produced at small angles from the beam direction**



A different kind of jet detector…

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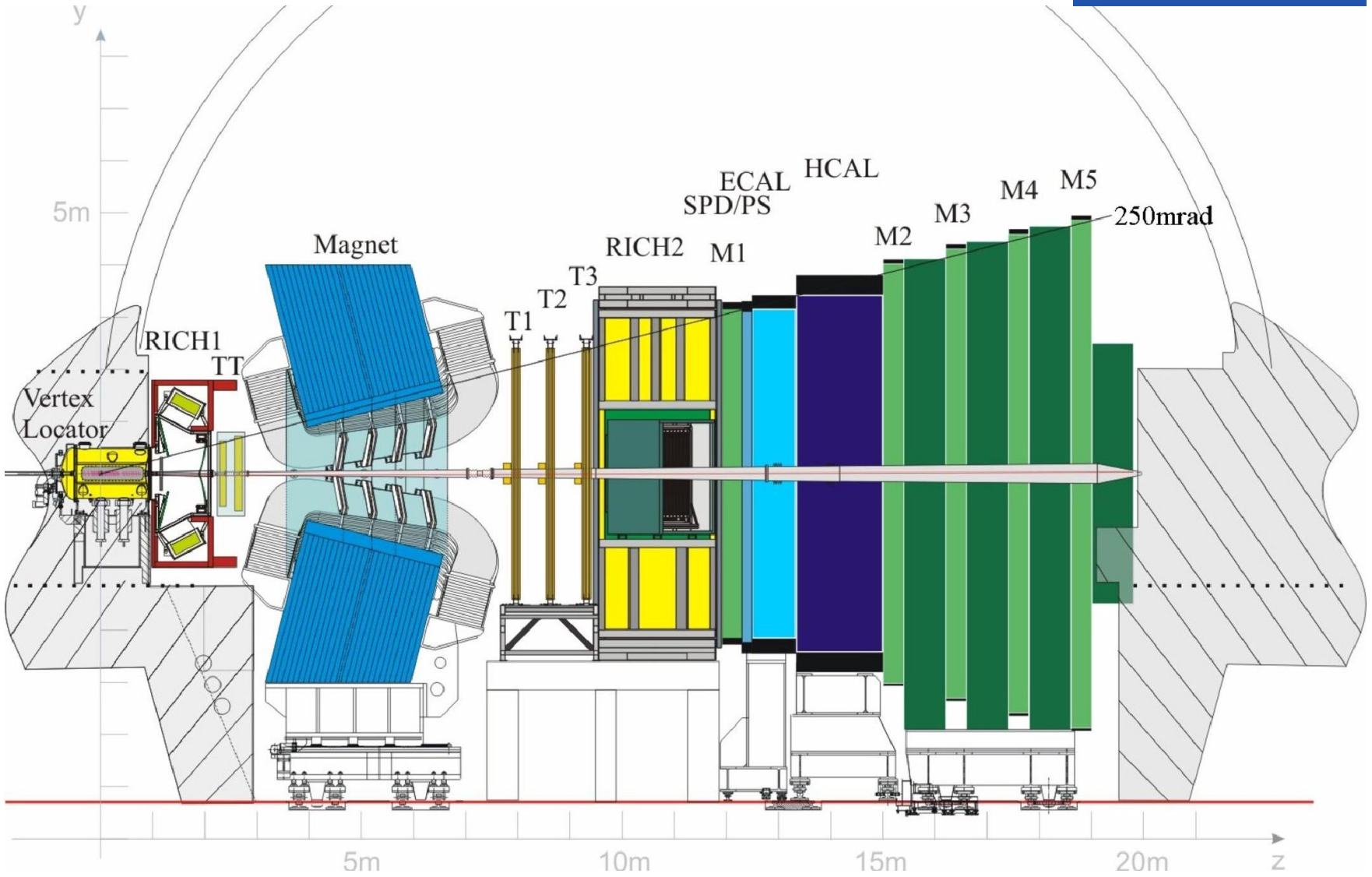
- LHCb is a completely forward detector ($2 < \eta < 5$)



https://cds.cern.ch/record/1978280

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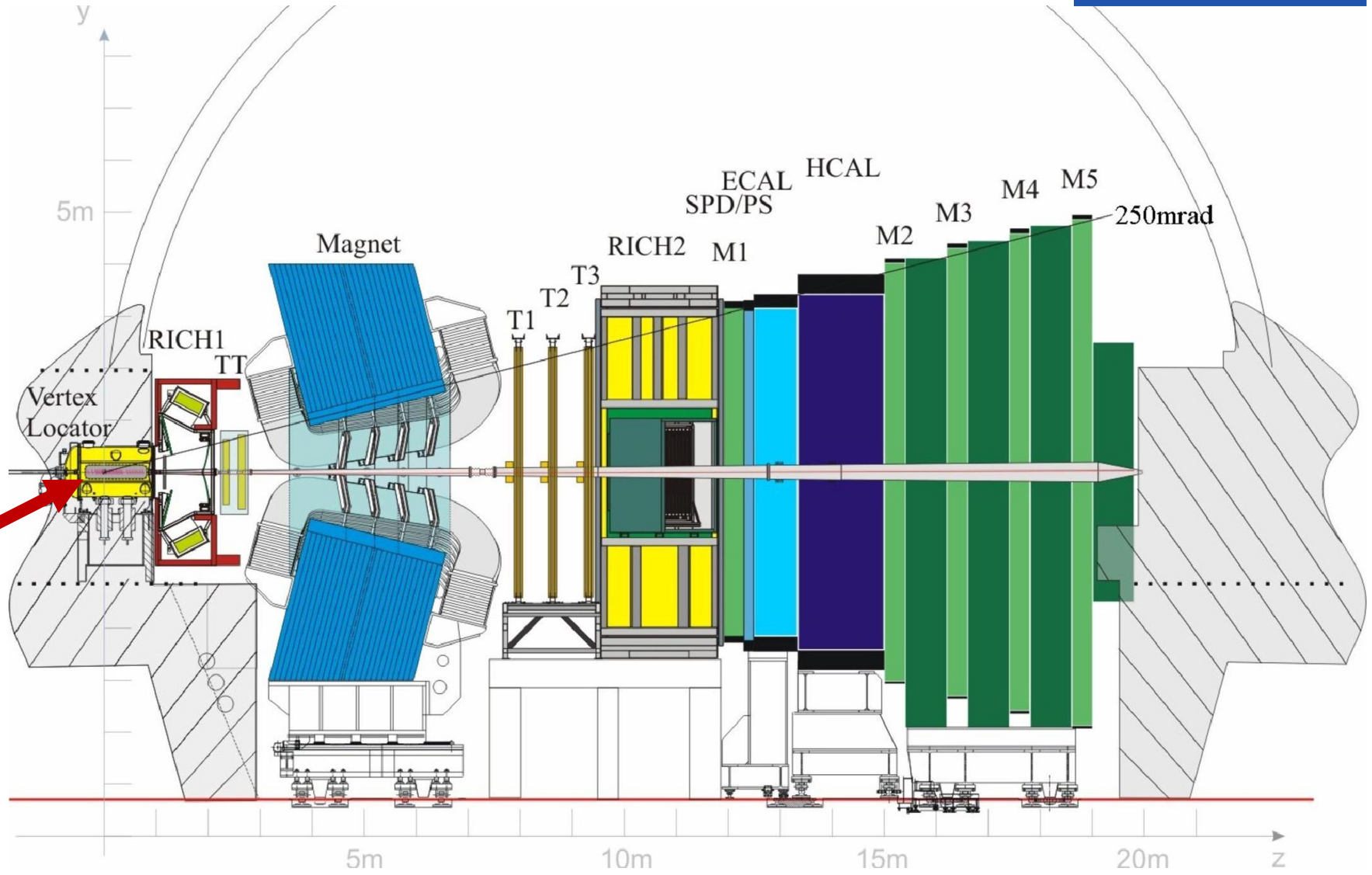
Interaction Point (IP)



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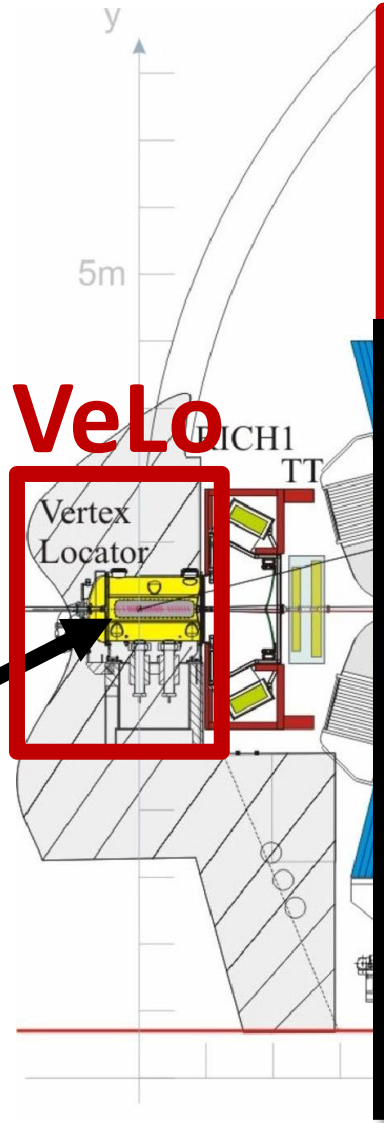
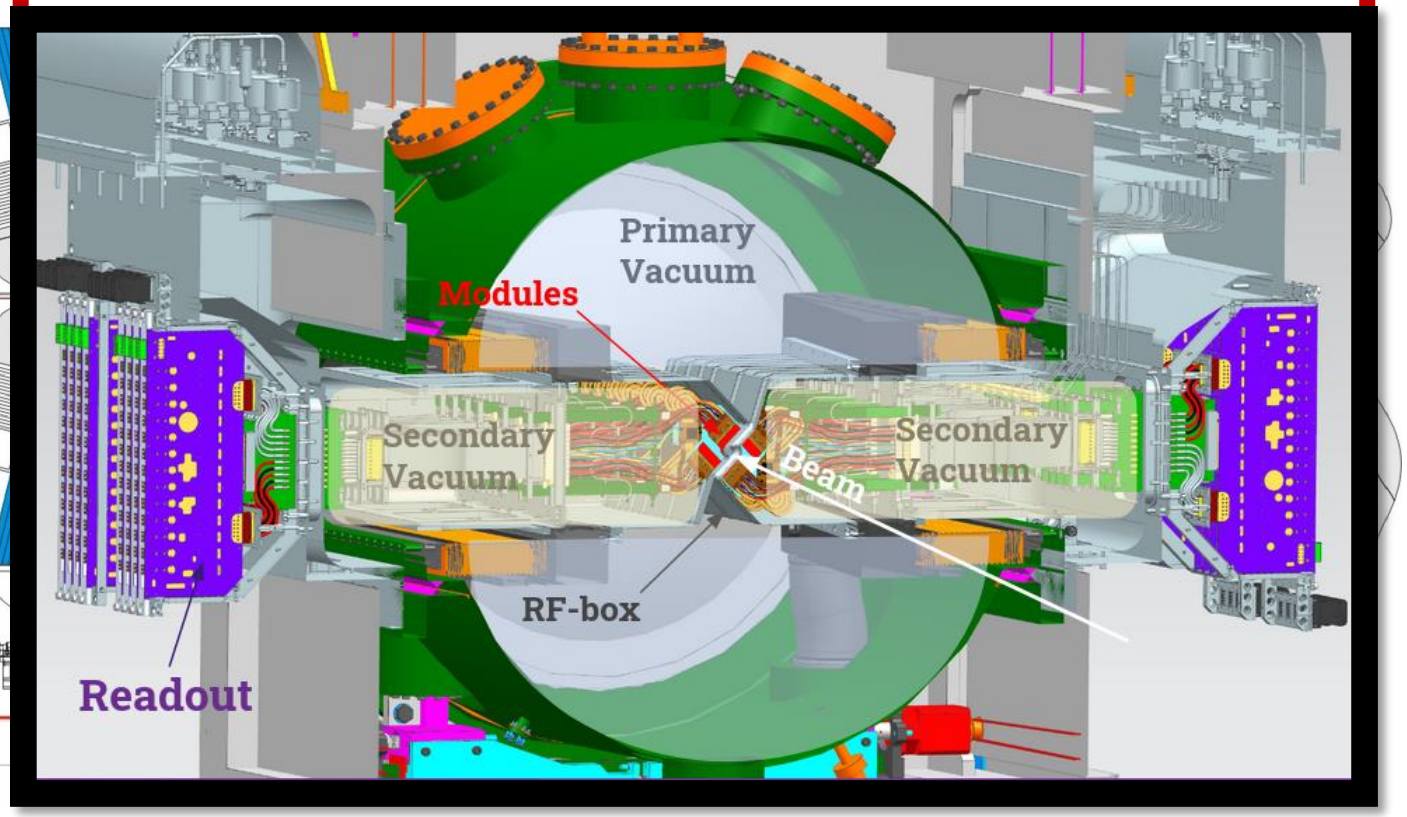


- LHC beampipe opened(!) for silicon tracking detectors to be placed closer to the beam
- Excellent primary vertex resolution of ~10 (transverse directions x, y) / ~40 (z) μm



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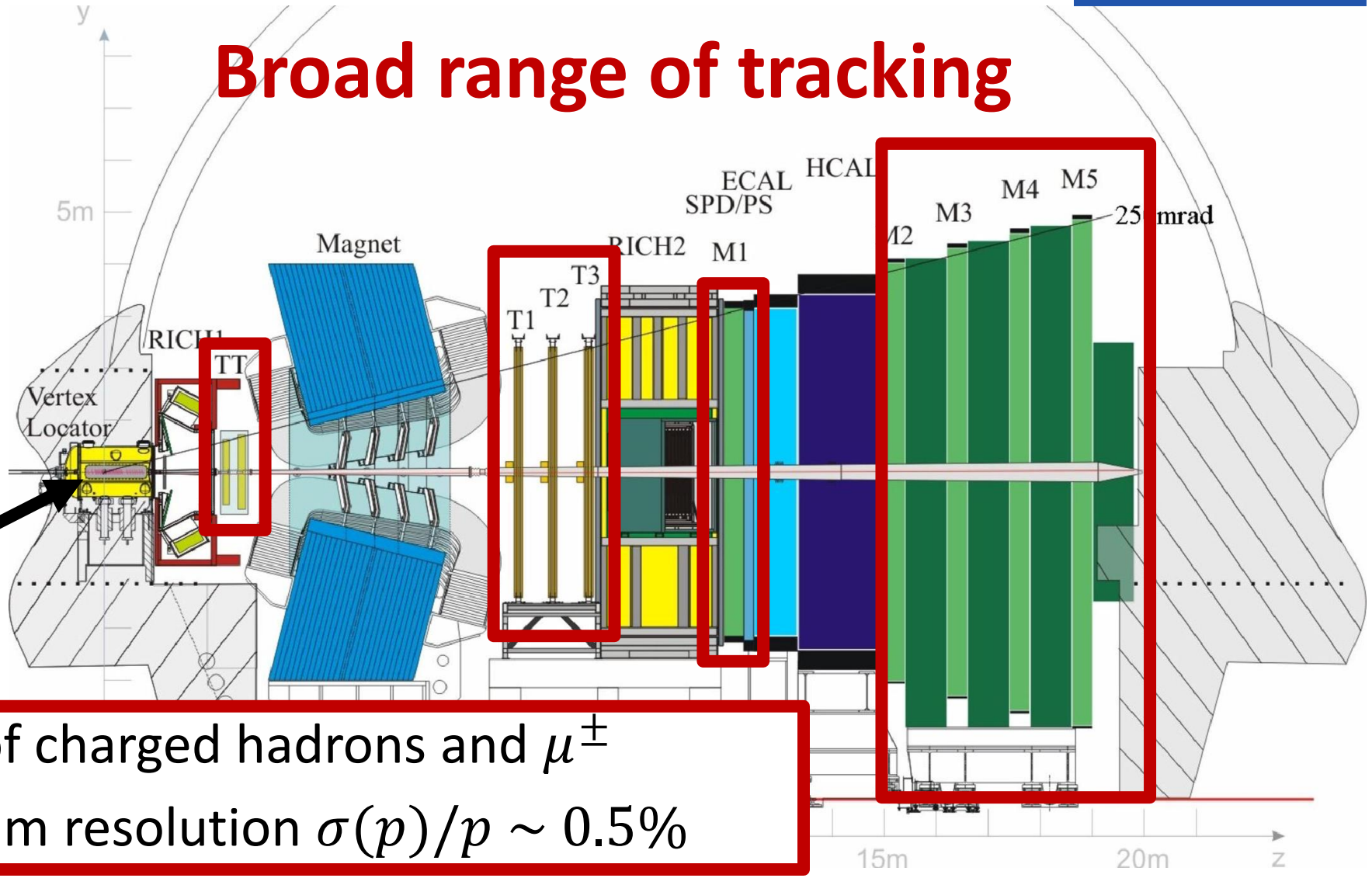
Broad range of tracking



Interaction Point (IP)

- Measurement of charged hadrons and $\mu^{\pm}$
- Great momentum resolution $\sigma(p)/p \sim 0.5\%$

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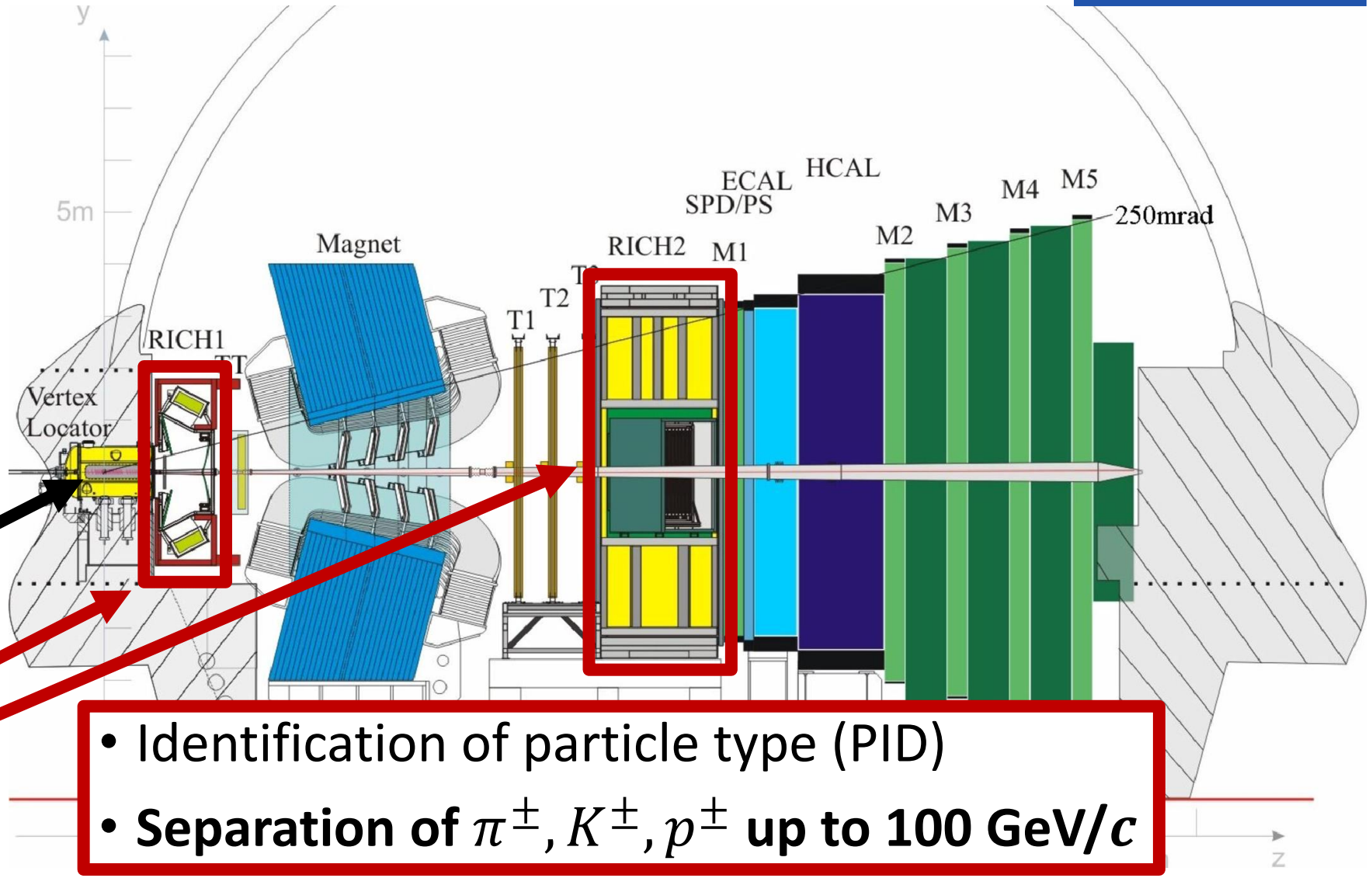

Interaction Point (IP)

Cherenkov detectors

- Identification of particle type (PID)
- **Separation of $\pi^{\pm}, K^{\pm}, p^{\pm}$ up to 100 GeV/c**

A different kind of jet detector…

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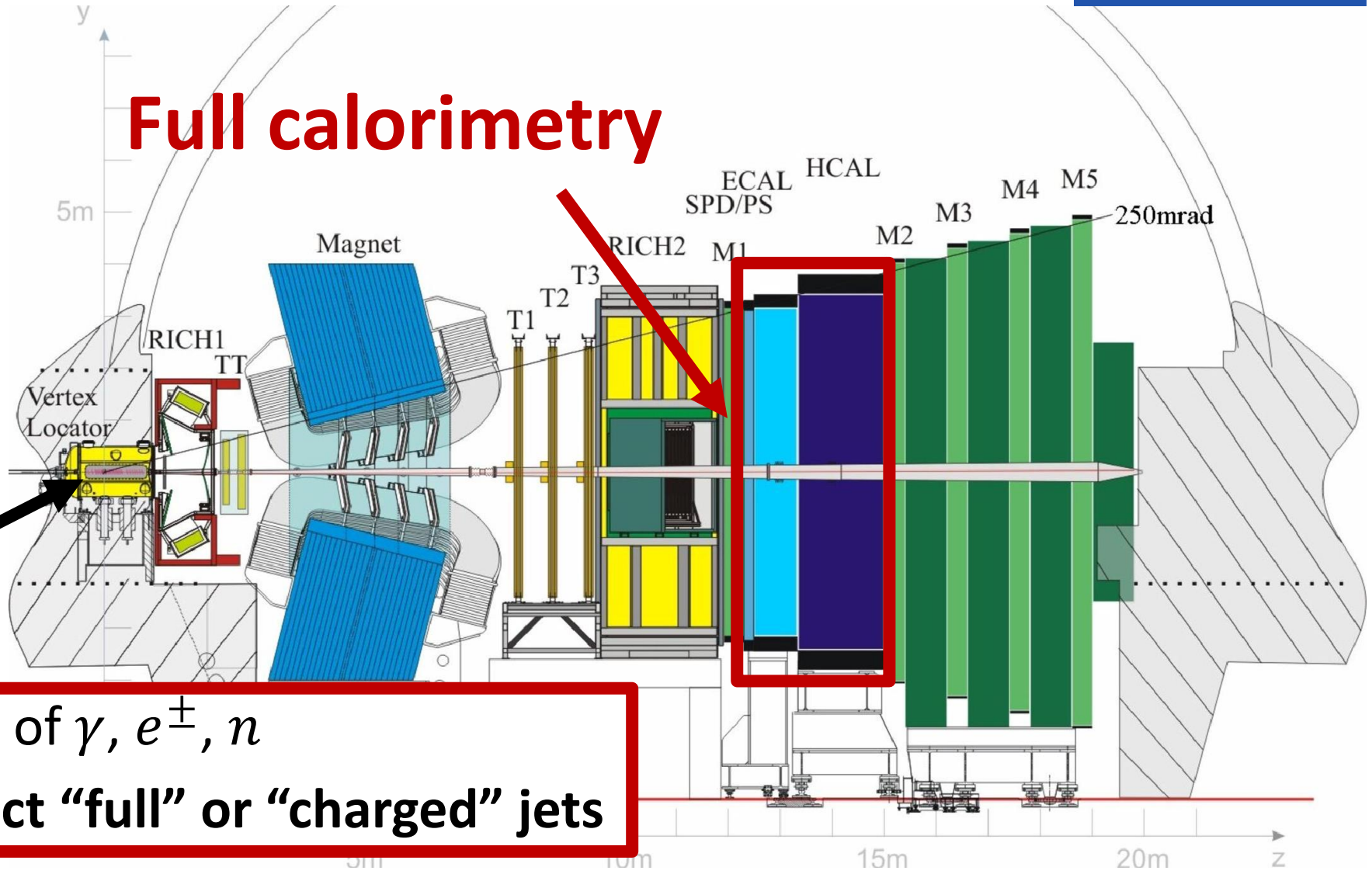
Full calorimetry



Interaction Point (IP)

- Measurement of γ, $e^{\pm}$, n
- **Can reconstruct "full" or "charged" jets**

A different kind of jet detector…

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Int

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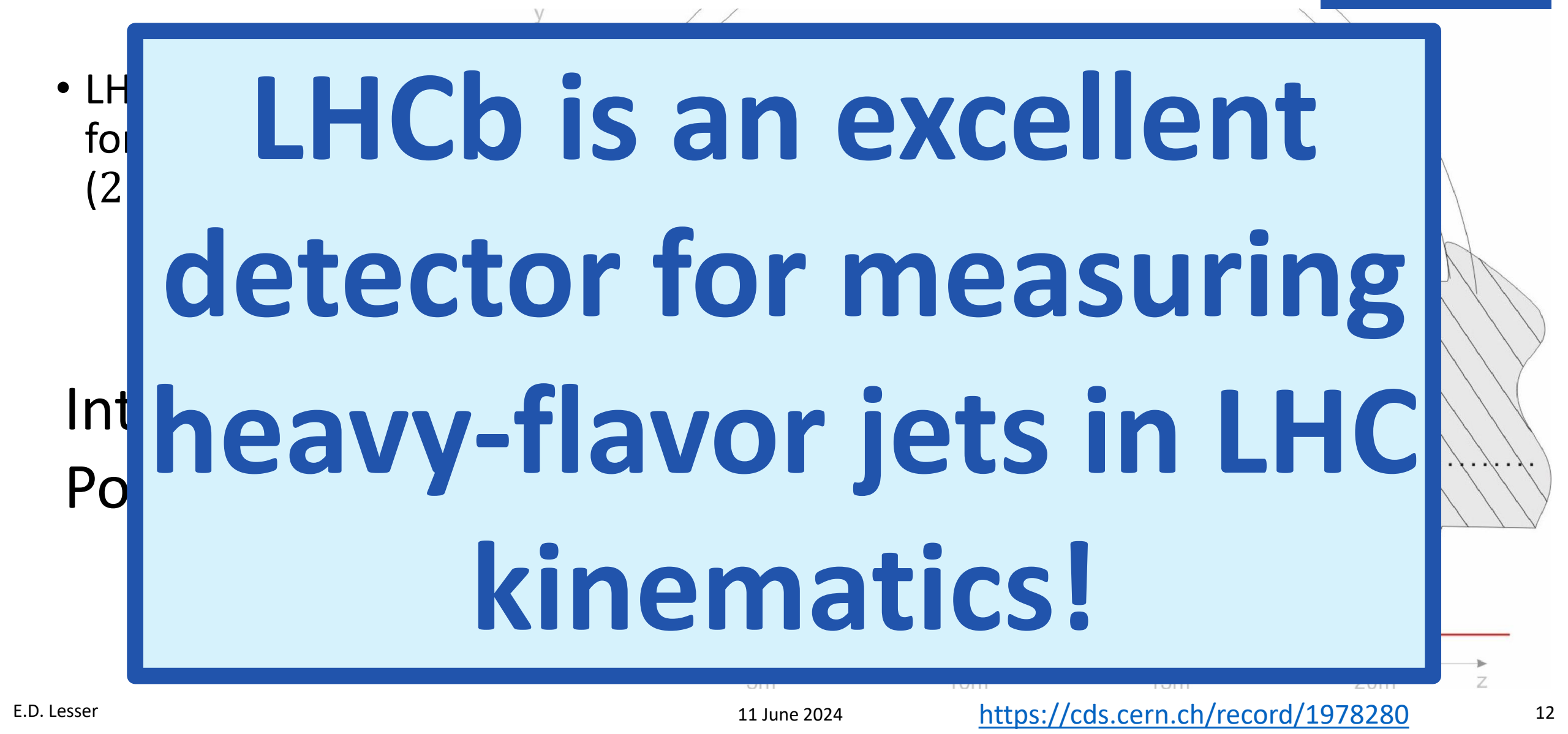
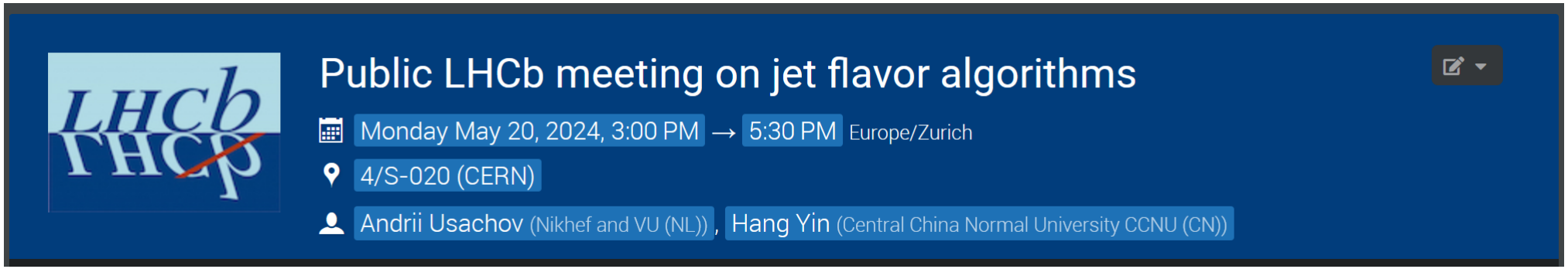
LHCb is an excellent detector for measuring heavy-flavor jets in LHC kinematics!



Public meeting on flavor algorithms

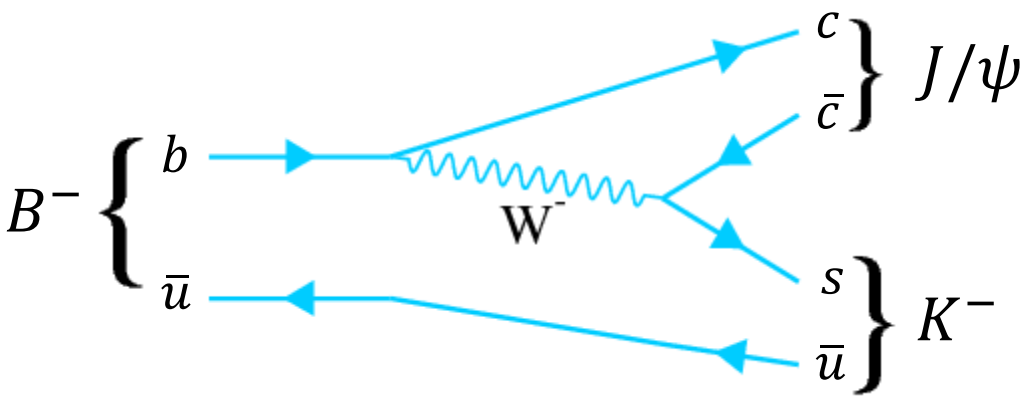
- Many thanks to **Rene Poncelet**, **Daniel Reichelt**, **Andrew Larkoski**, **Giovanni Stagnitto**, and **Ludo Scyboz** for the excellent presentations!



- Indico link: https://indico.cern.ch/event/LHCb-jet-flavor
  - Recording of the event is available

Two paths to heavy flavor

1) Reconstructing **individual decay channels**
   - e.g., $B^{\pm} \to (J/\psi \to \mu^+\mu^-)\, K^{\pm}$
   - Minimal bias on the reconstructed HF-hadron candidates



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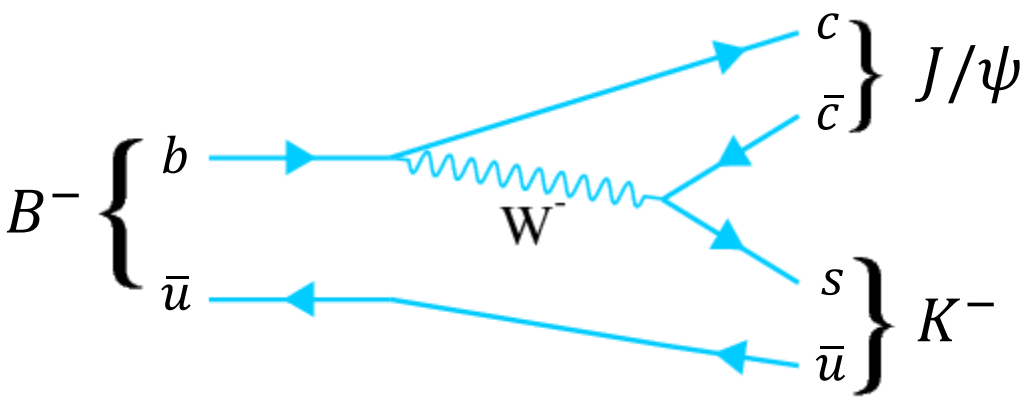
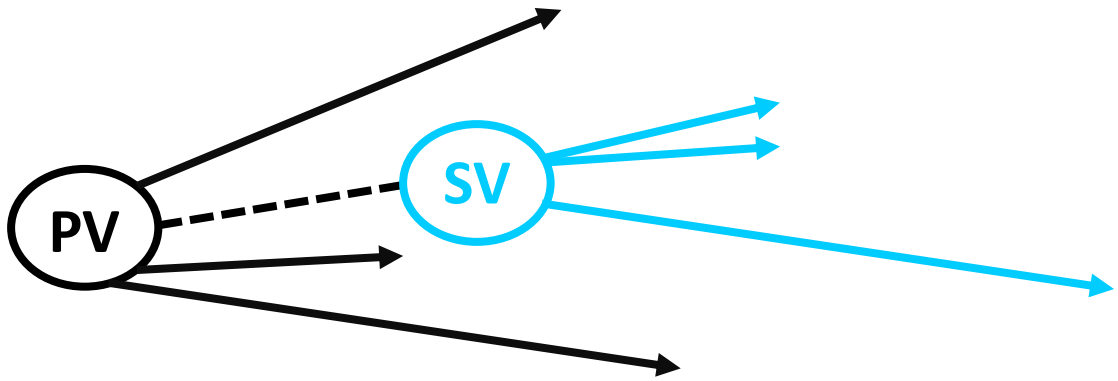
   - Build SV from tracks which are displaced from the primary vertex (PV)





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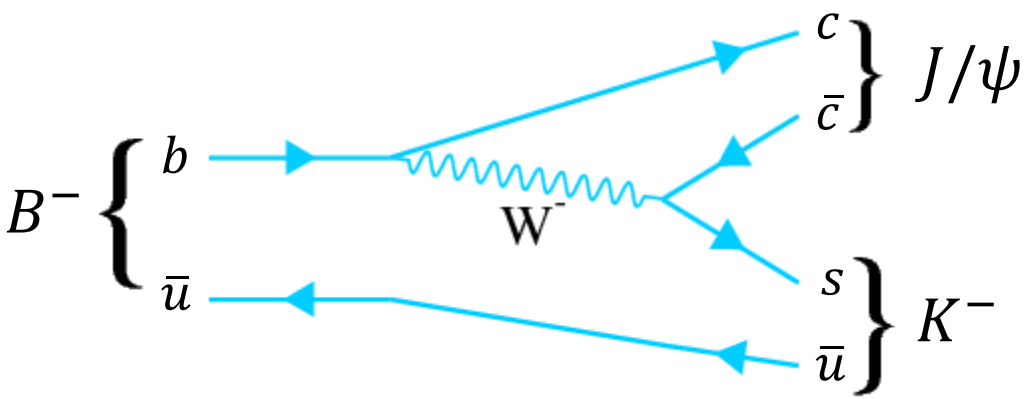

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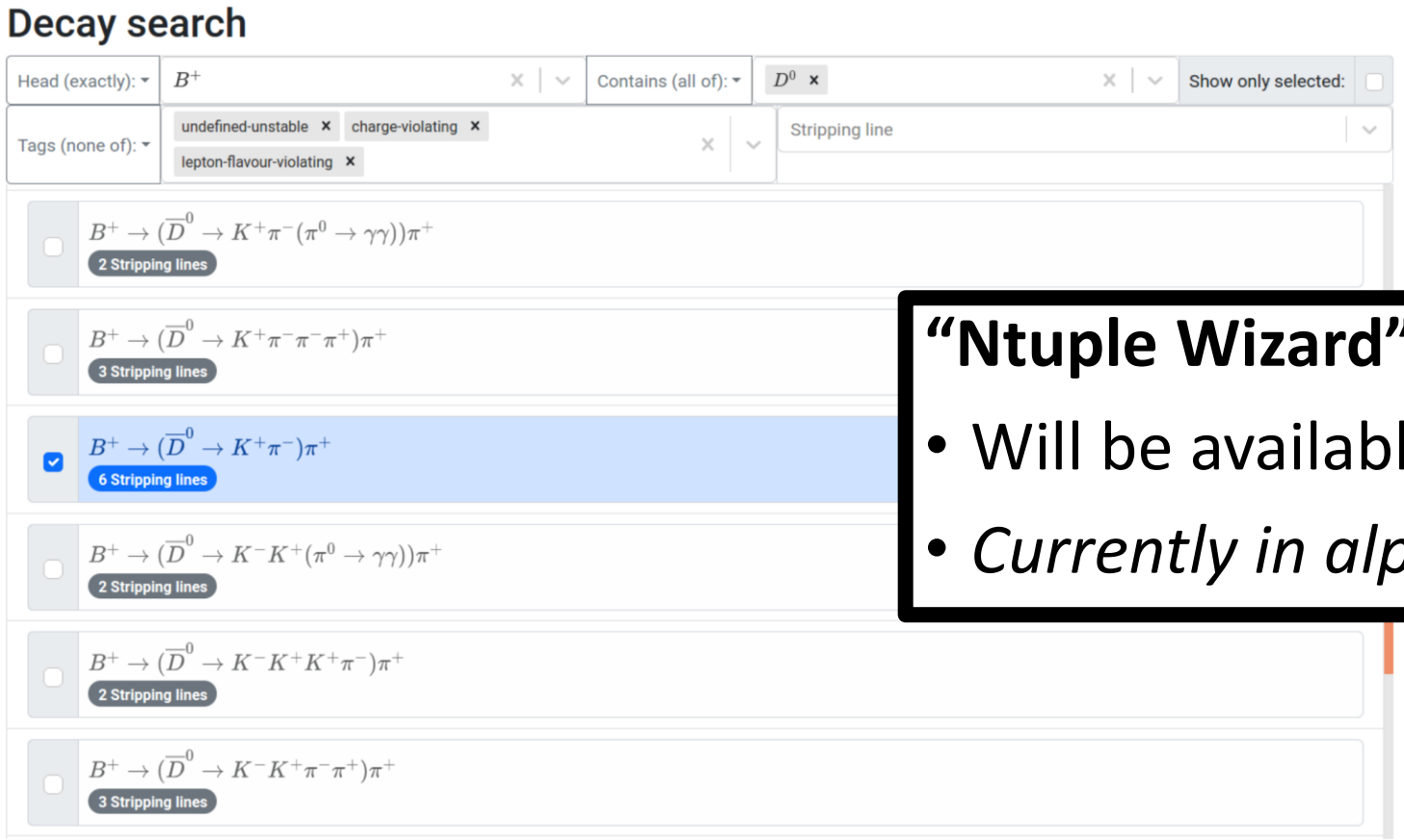

"Ntuple Wizard" for selecting decay(s)

- Will be available for **LHCb open data**
- *Currently in alpha testing (internal)*

Comput. Softw. Big Sci. 7 (2023), no. 6

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  - E.g., $B^{\pm} \to (J/\psi \to \mu^{+}\mu^{-})\, K^{\pm}$ plus $B^{\pm} \to (D^{0} \to K^{\pm}\pi^{\mp})\, \pi^{\pm}$
- Very difficult to reconstruct all HF hadrons through all decay channels
  - Correcting for gluon splitting jets in the **new algorithms will require large purity corrections**, estimated from MC models

Using the new tagging algorithms

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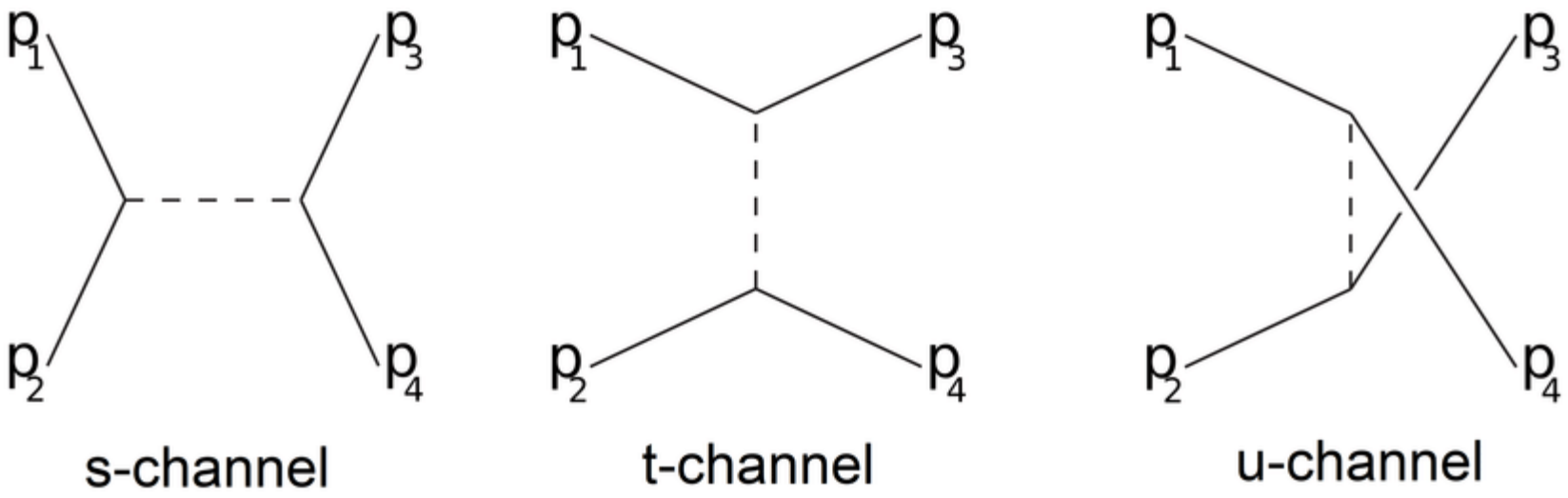
- Use Pythia 8 with **`HardQCD:all=on`** (enabling all 2 → 2 matrix elements)



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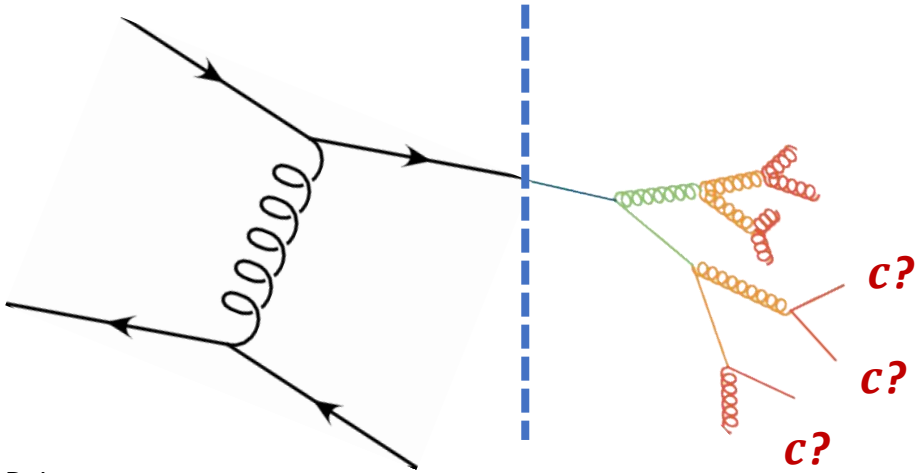

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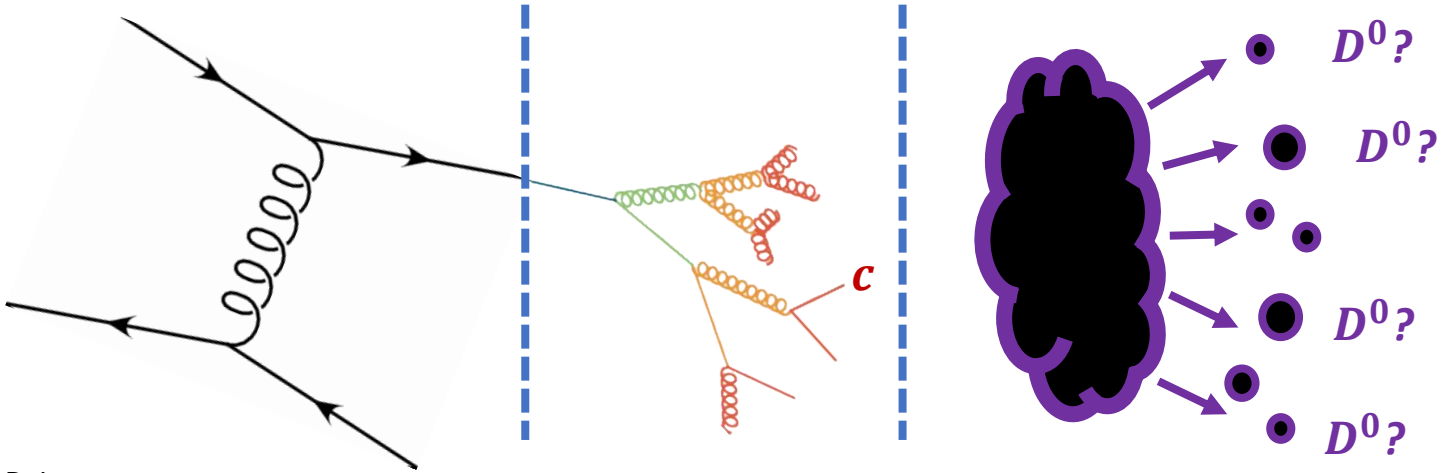

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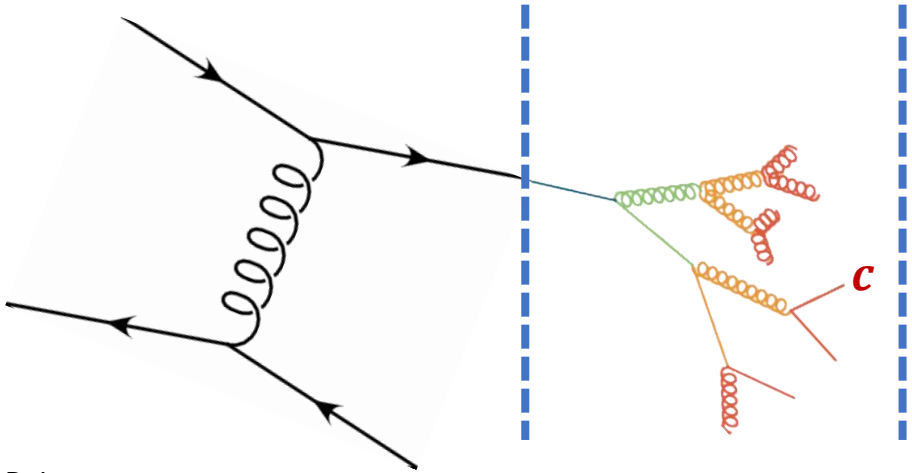

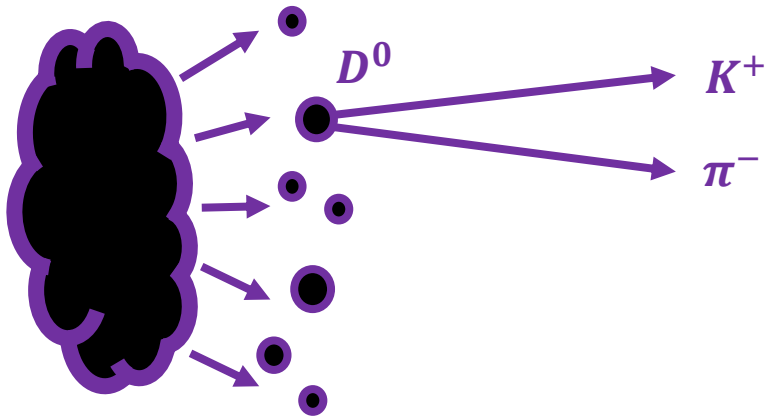

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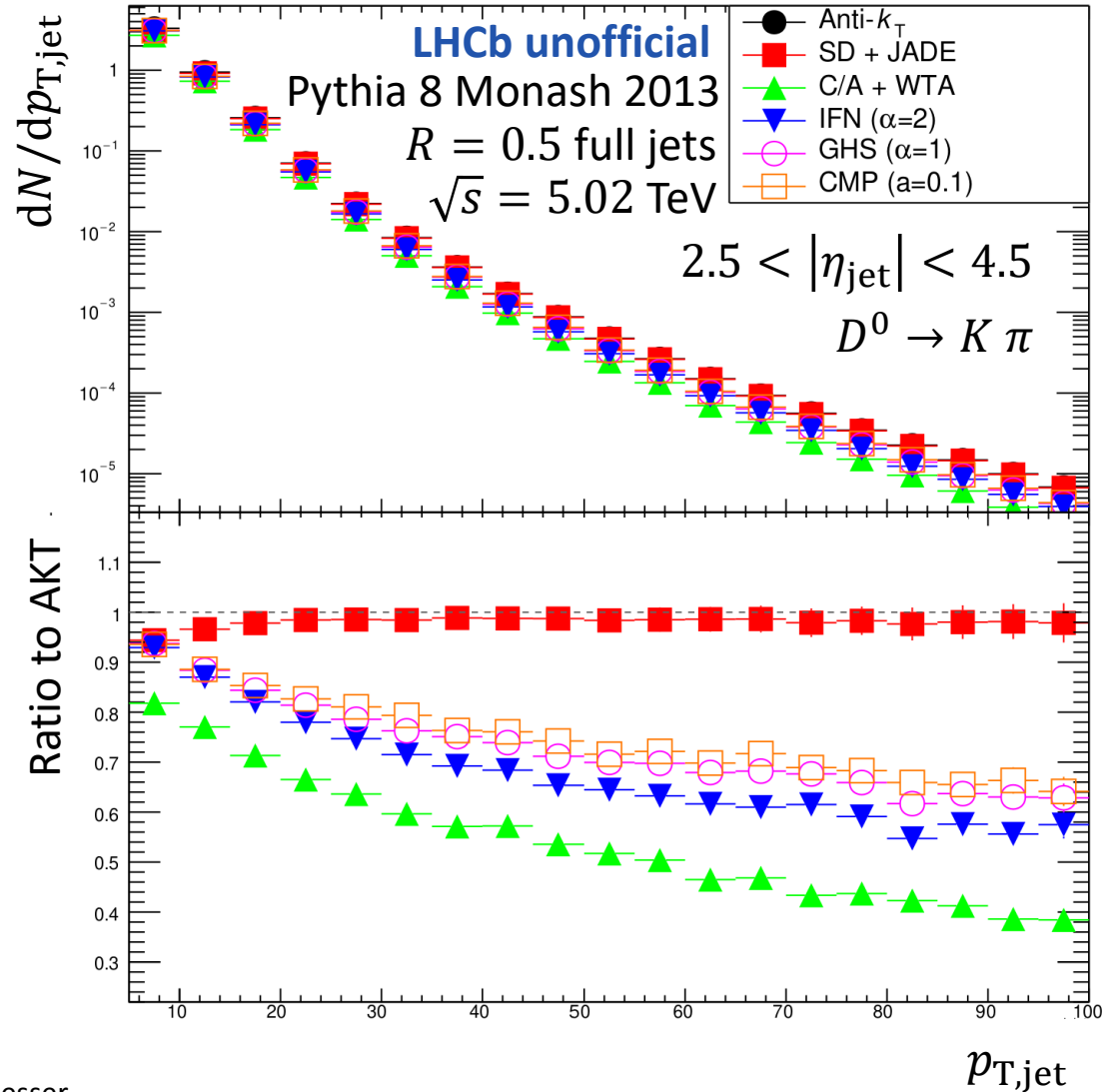
- 11 p_{T}hat bins, 1M events each: **`(9, 12, 16, 21, 28, 36, 45, 57, 70, 85, 100, ∞)`**
  - Scale histograms by **`pythia.info.sigmaGen() / N_events`**

Using the new tagging algorithms



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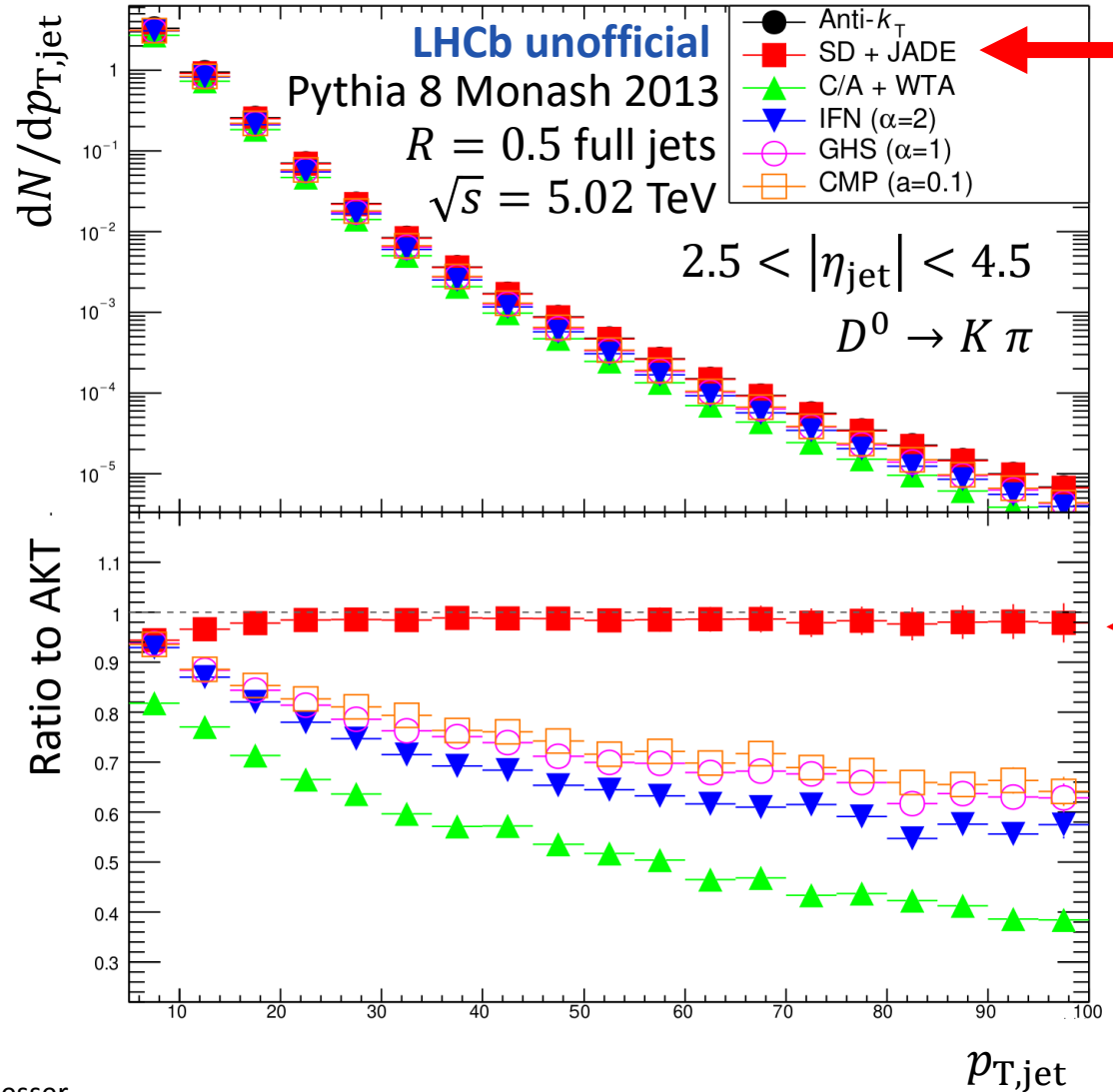

Old, local implementation of SDF

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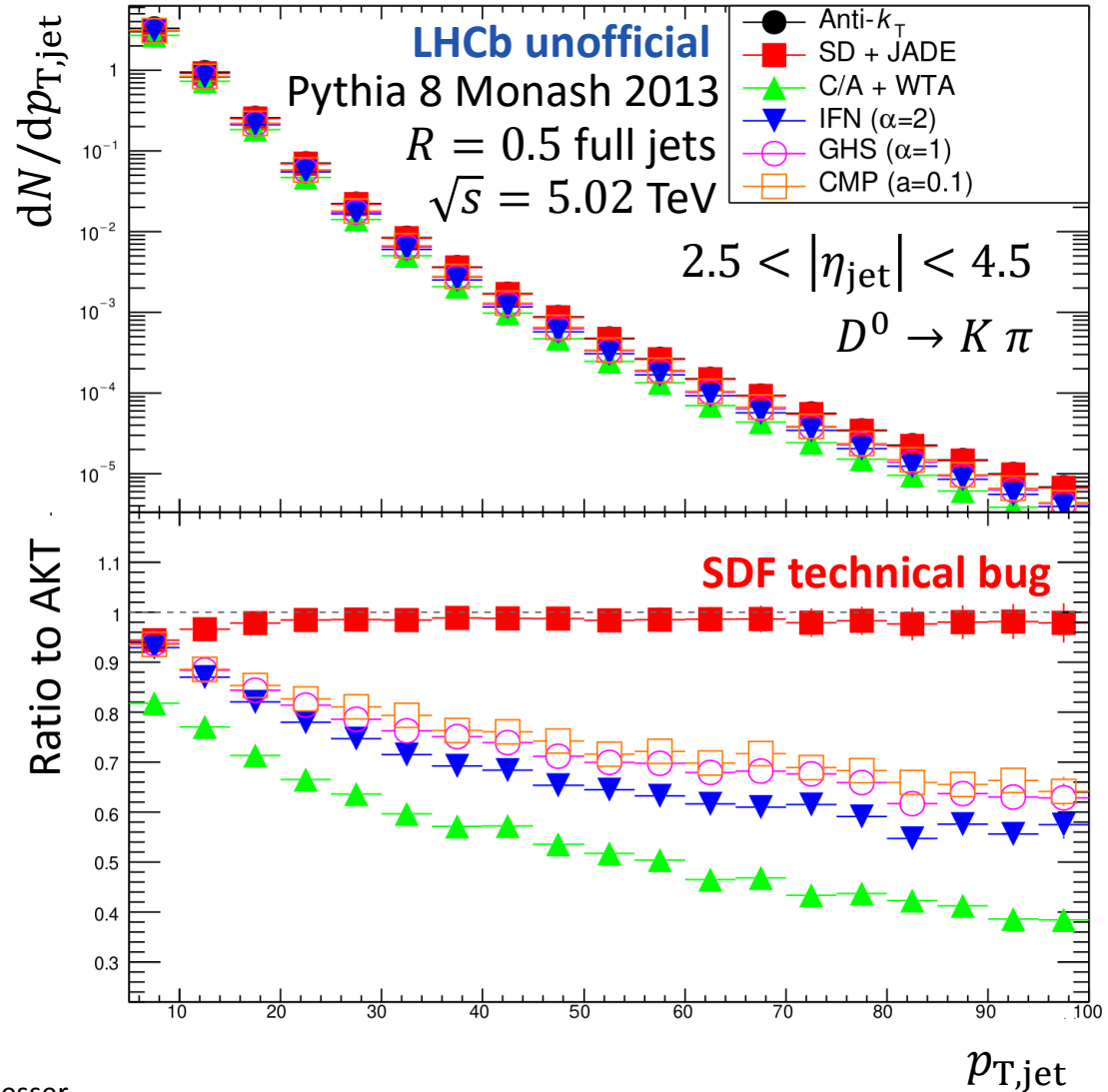
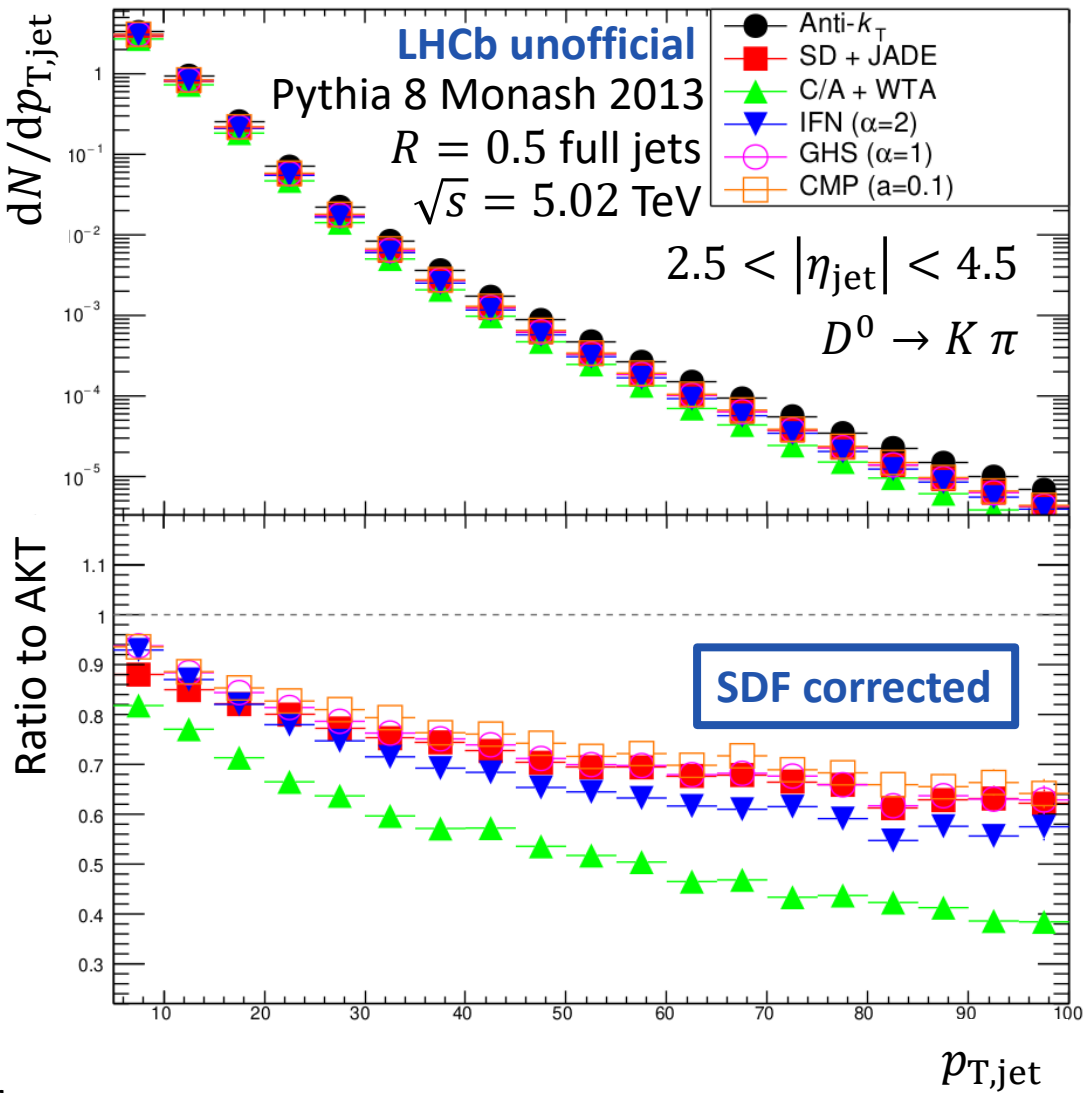
- Ratio designates the "tagging fraction", e.g. the statistics retained in new tagging algorithms

Not removing jets with a second charm hadron ($D^{\pm}$, Λ_c, D^*, …)

→ **This was a technical bug in the local implementation**

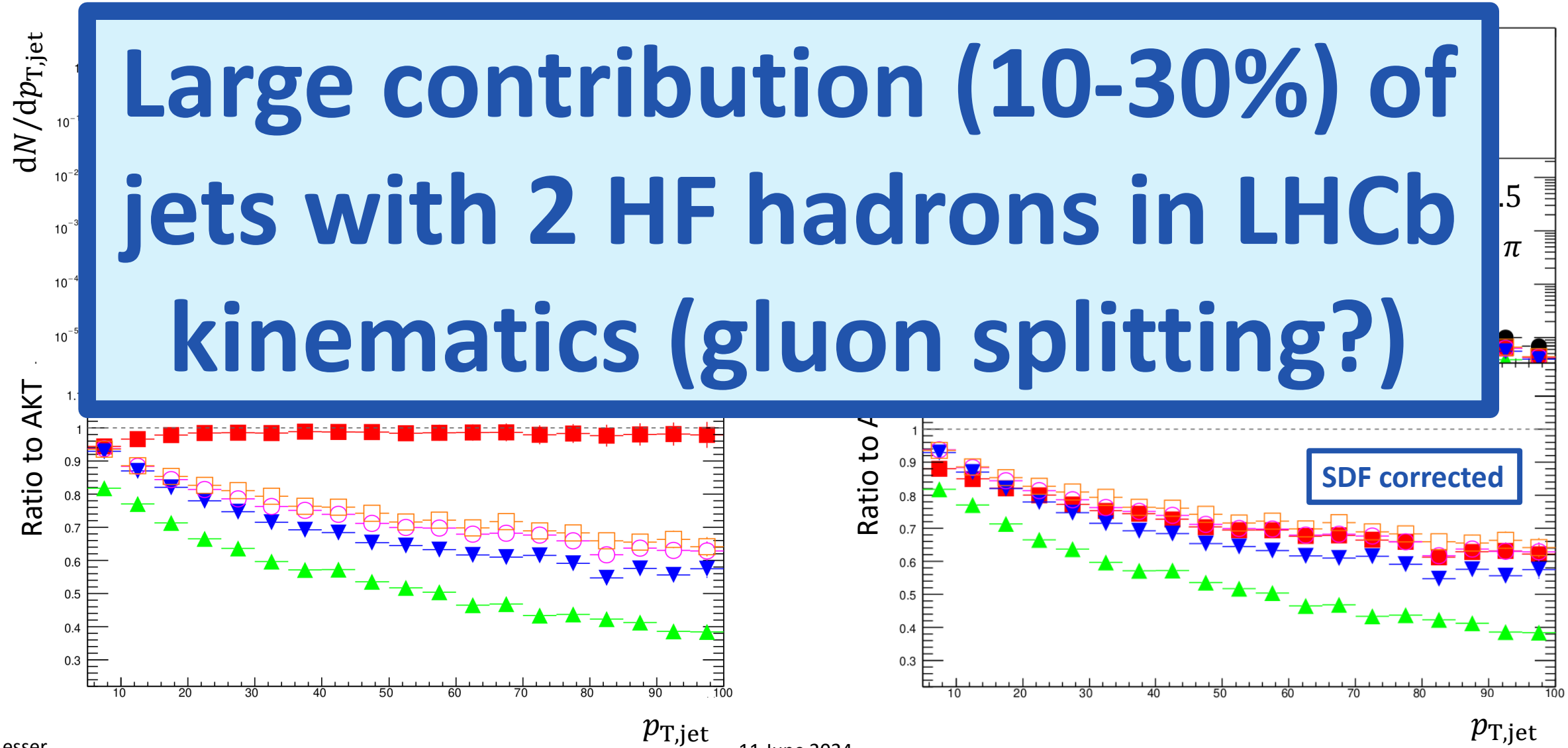
Using the new tagging algorithms





Using the new tagging algorithms

Large contribution (10-30%) of jets with 2 HF hadrons in LHCb kinematics (gluon splitting?)



Comparing 2→2 QCD with Z+jet

- Z+jet naturally enhances the production of quark-jets at LO

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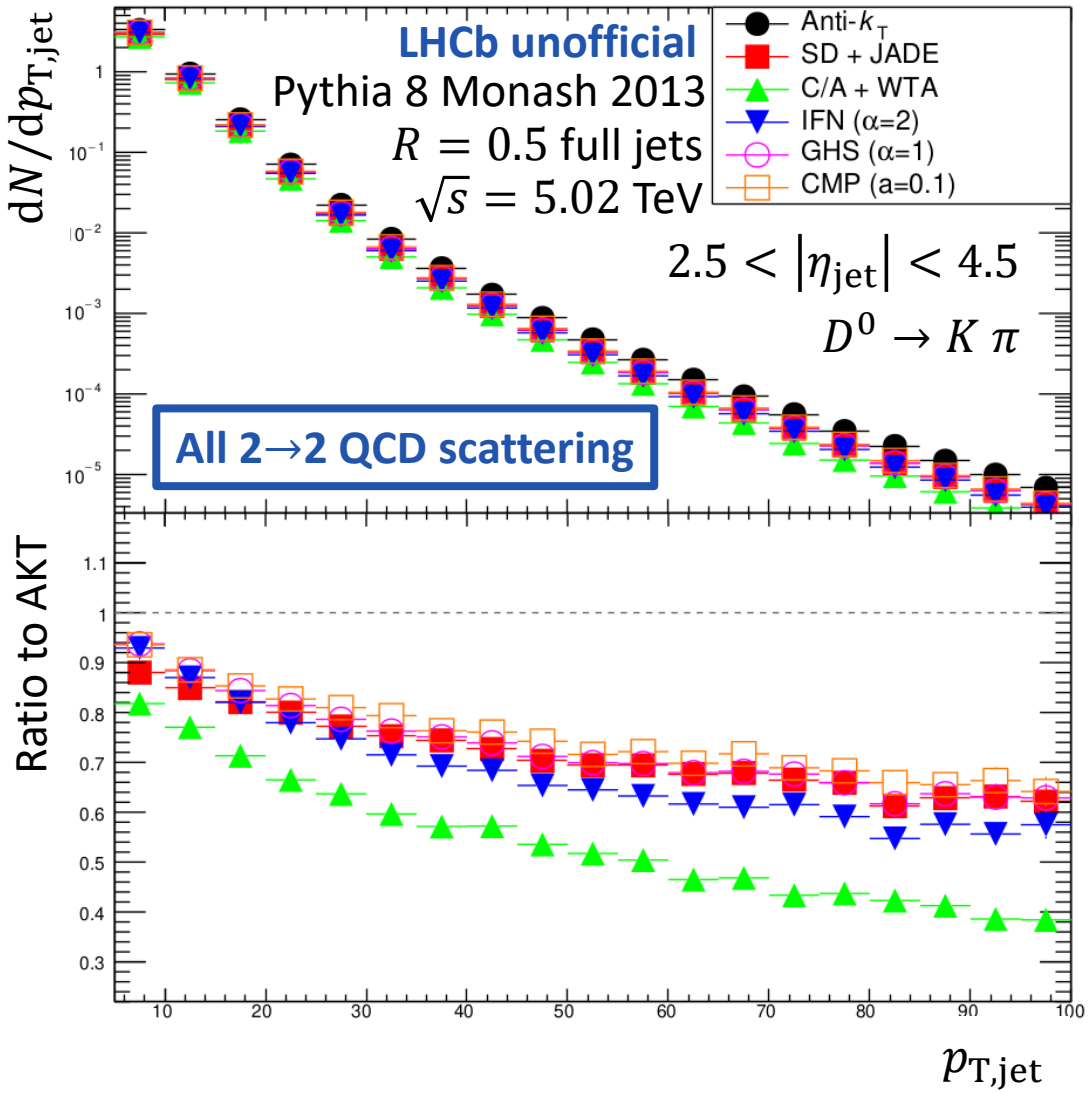
- Replace **`HardQCD:all=on`** with **`off`** and:
  - **`WeakBosonAndParton:qqbar2gmZg=on`** $(q\bar{q} \to \gamma^*/Z^0\ g)$
  - **`WeakBosonAndParton:qg2gmZq=on`** $(qg \to \gamma^*/Z^0\ g)$

Comparing 2→2 QCD with Z+jet



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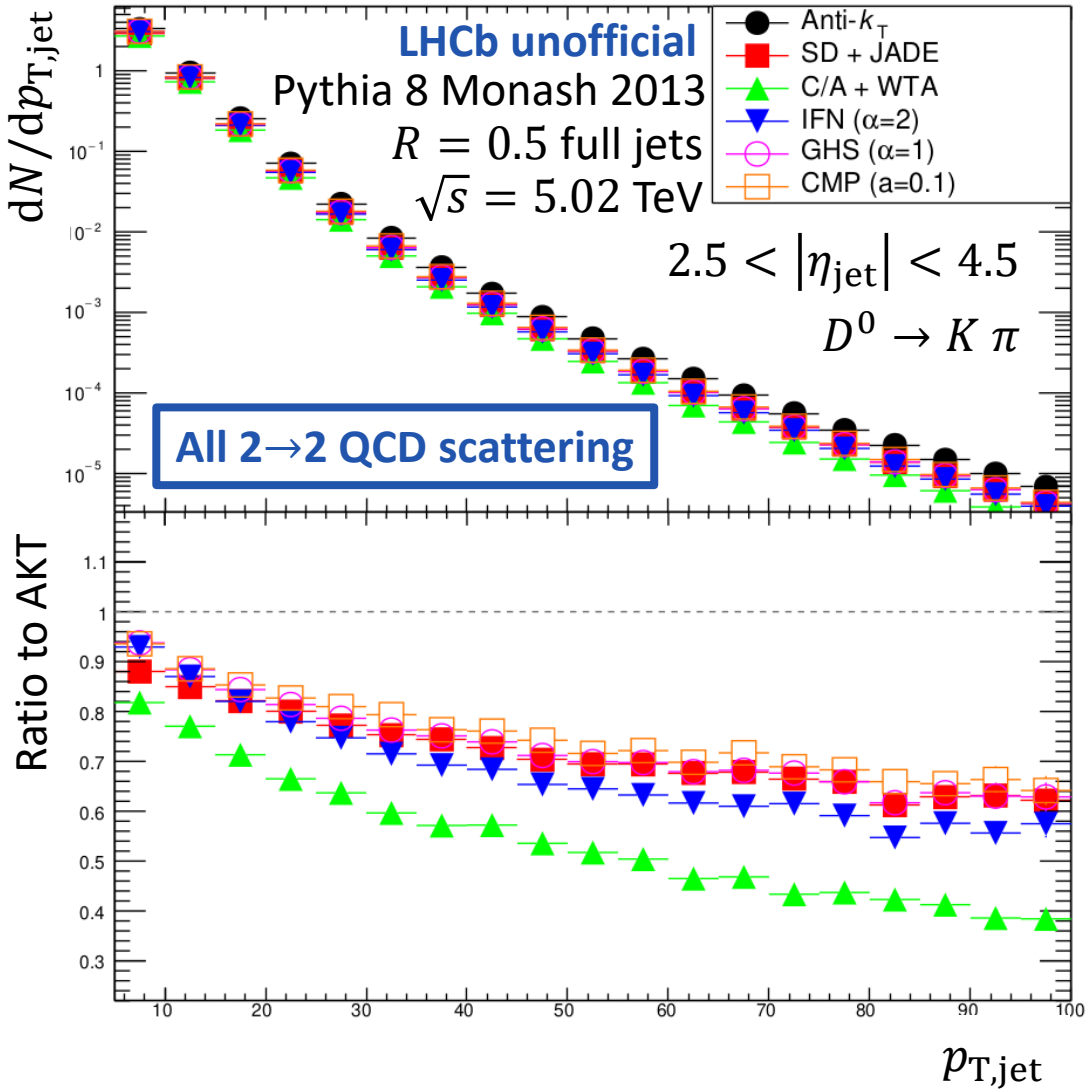

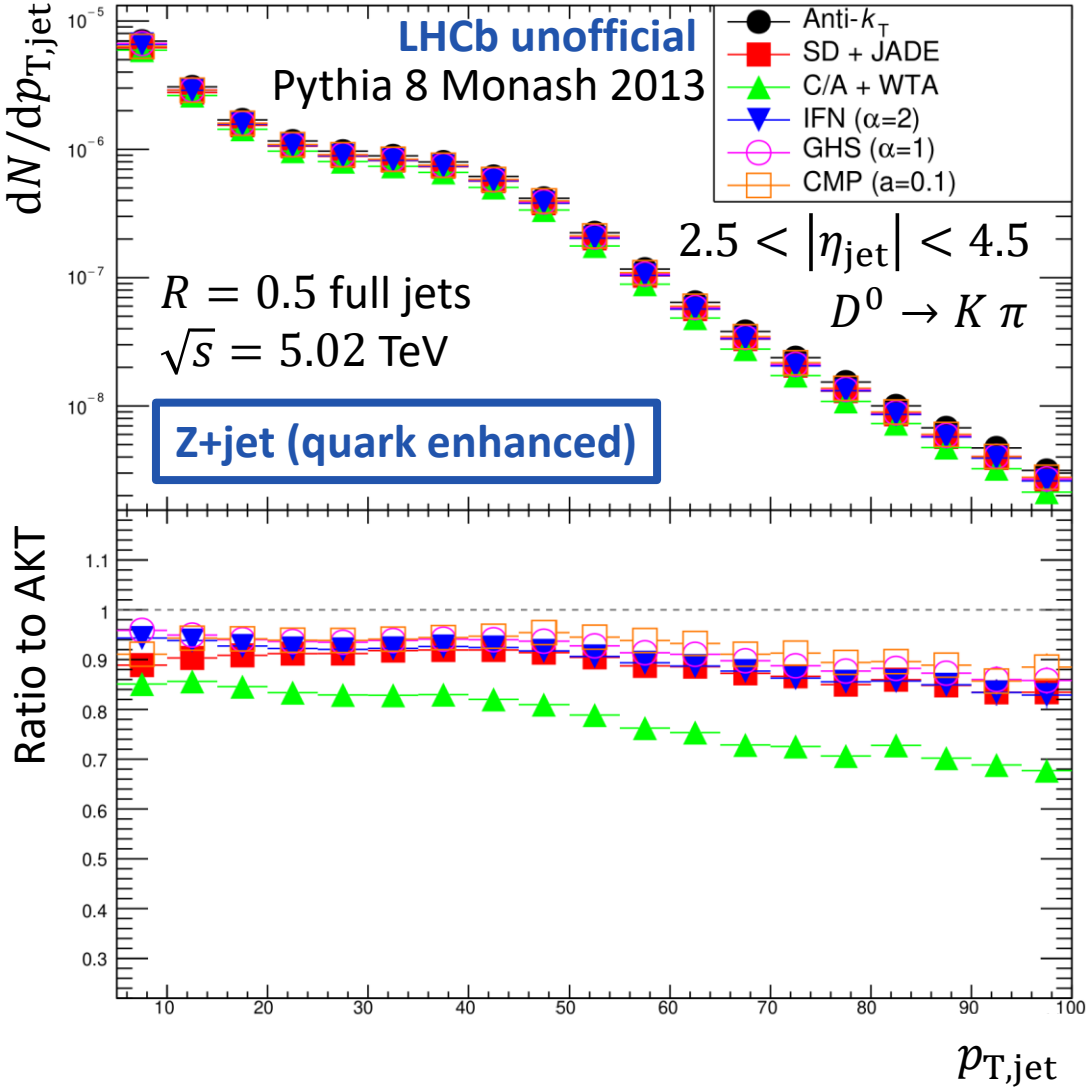

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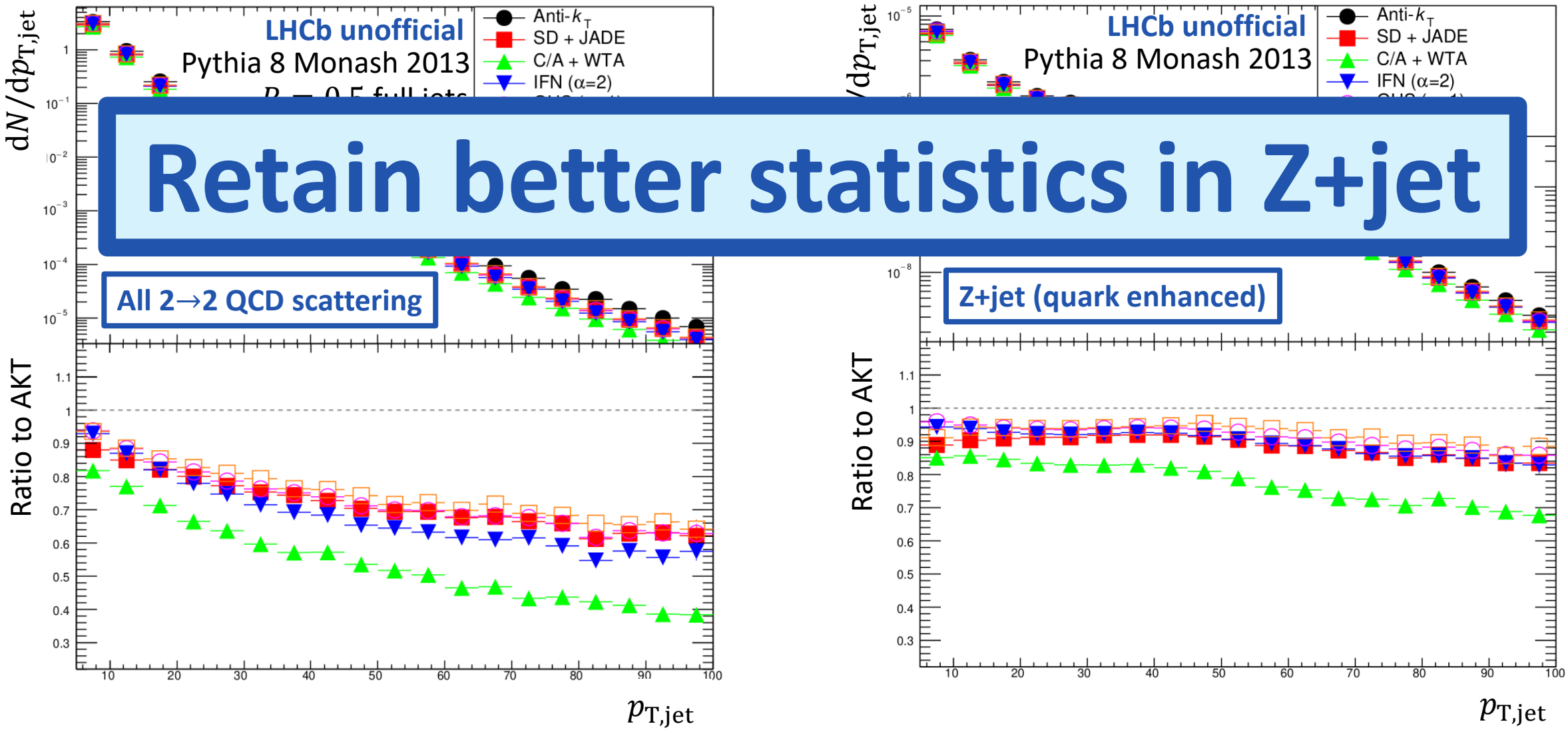
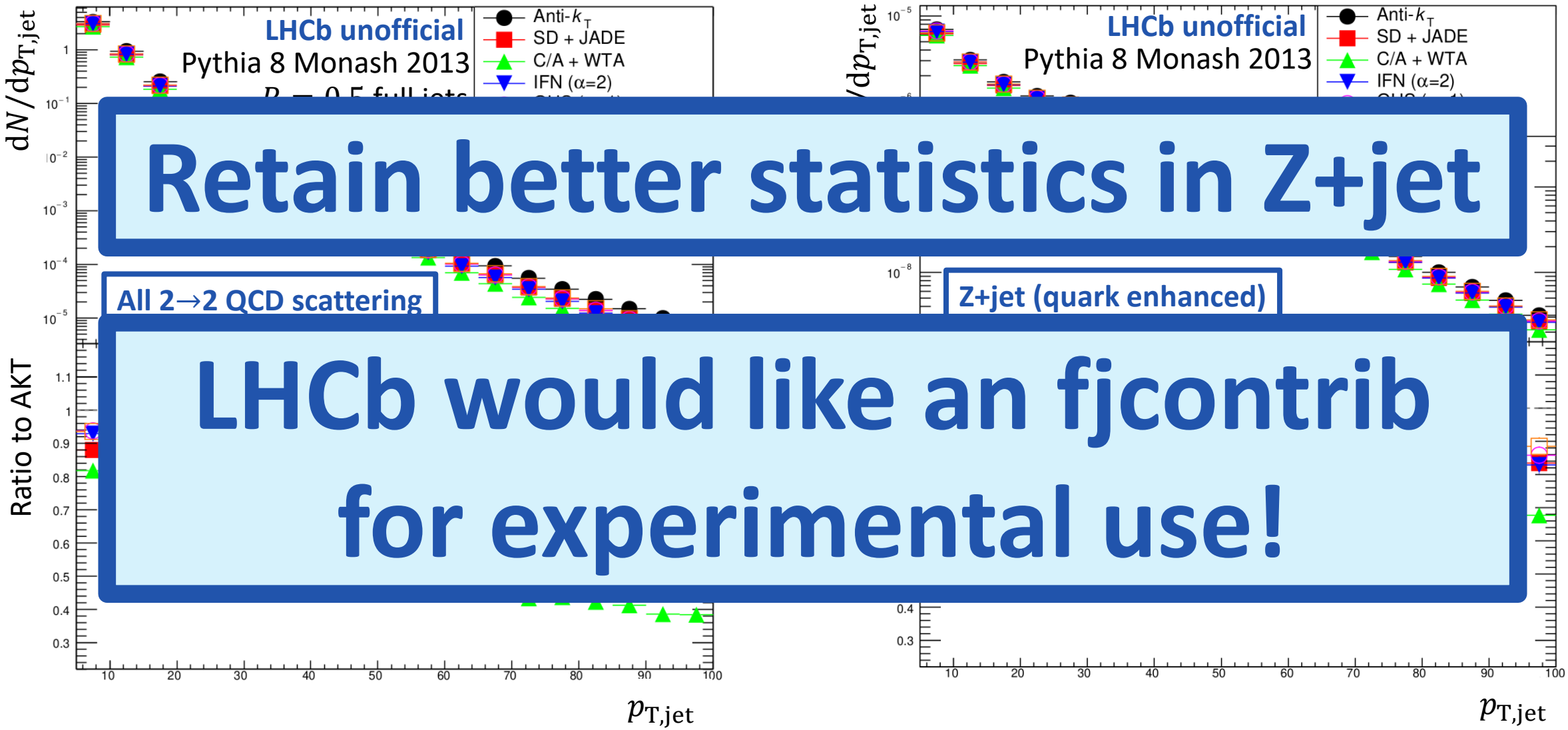


Retain better statistics in Z+jet

Comparing 2→2 QCD with Z+jet



Retain better statistics in Z+jet

LHCb would like an fjcontrib for experimental use!

Heavy quarkonium in-jet?

- How to think about “heavy-flavor” jets with heavy $q\bar{q}$ pairs (e.g. J/ψ)?

Phys. Rev. Lett. 118, 192001 (2017)

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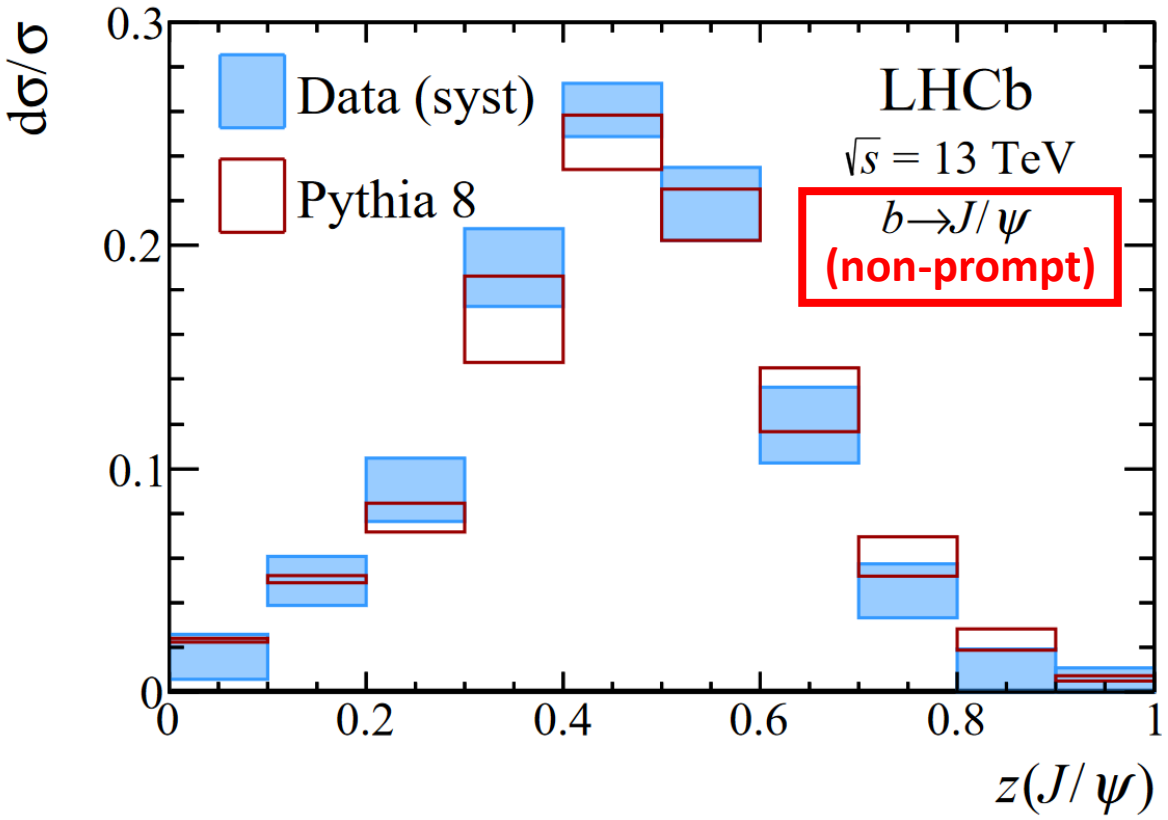

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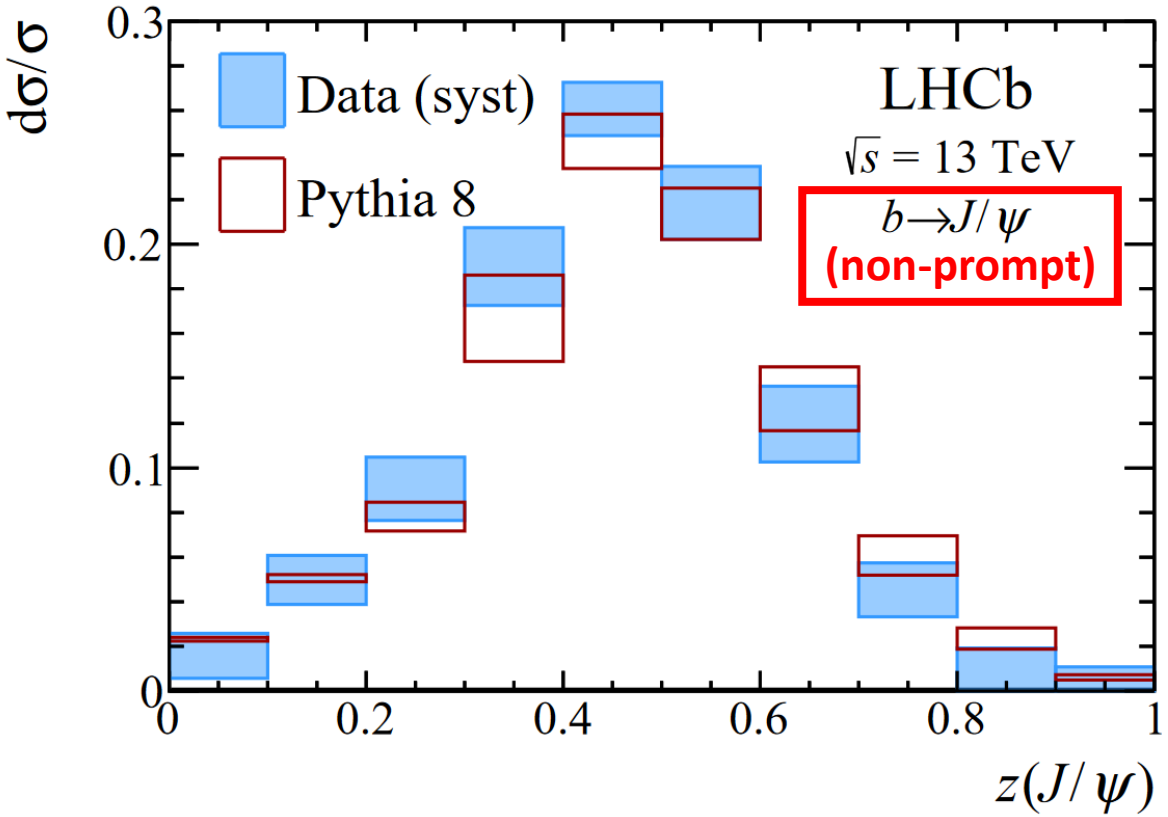

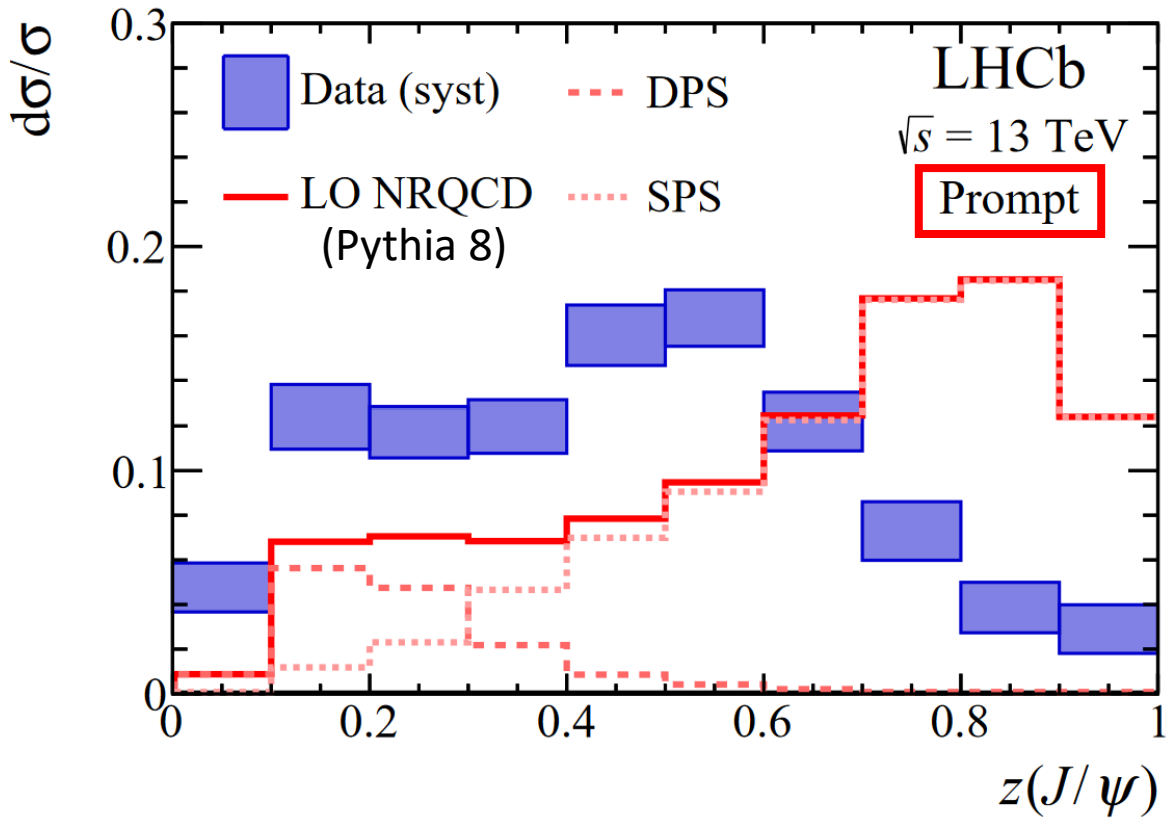

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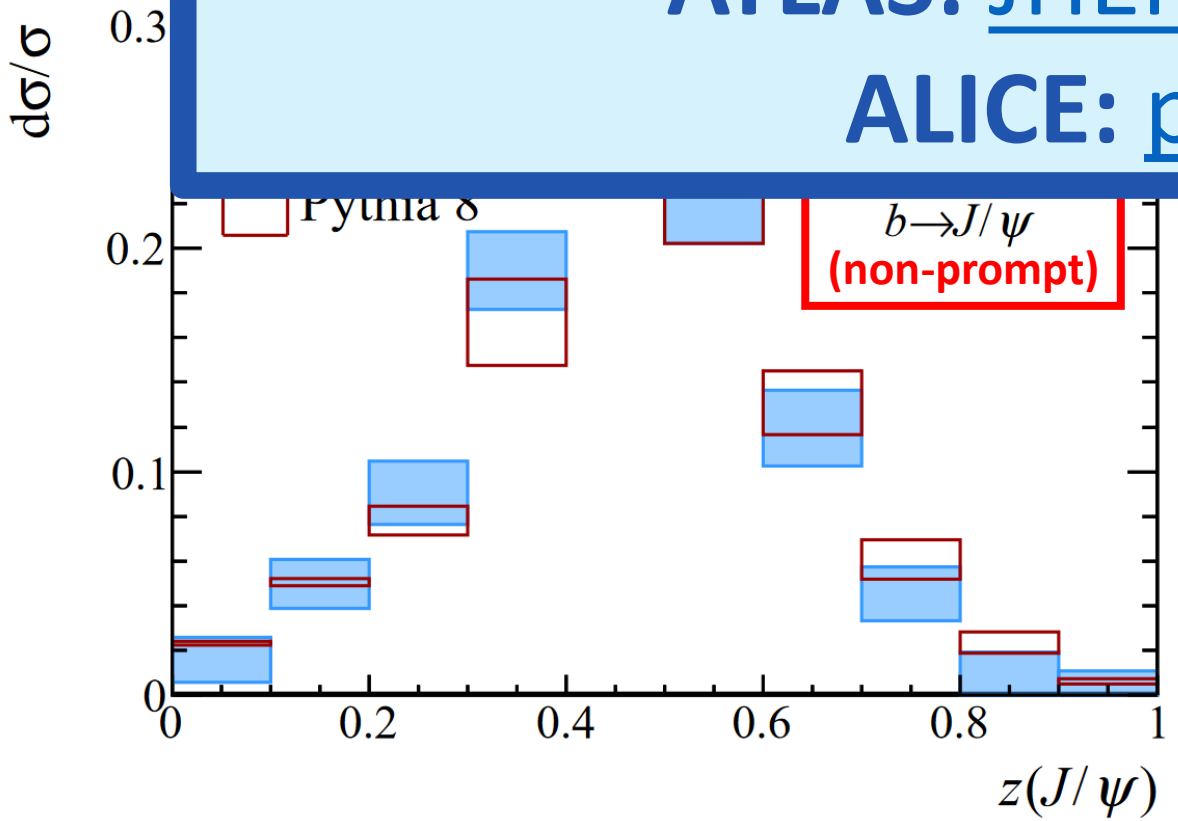
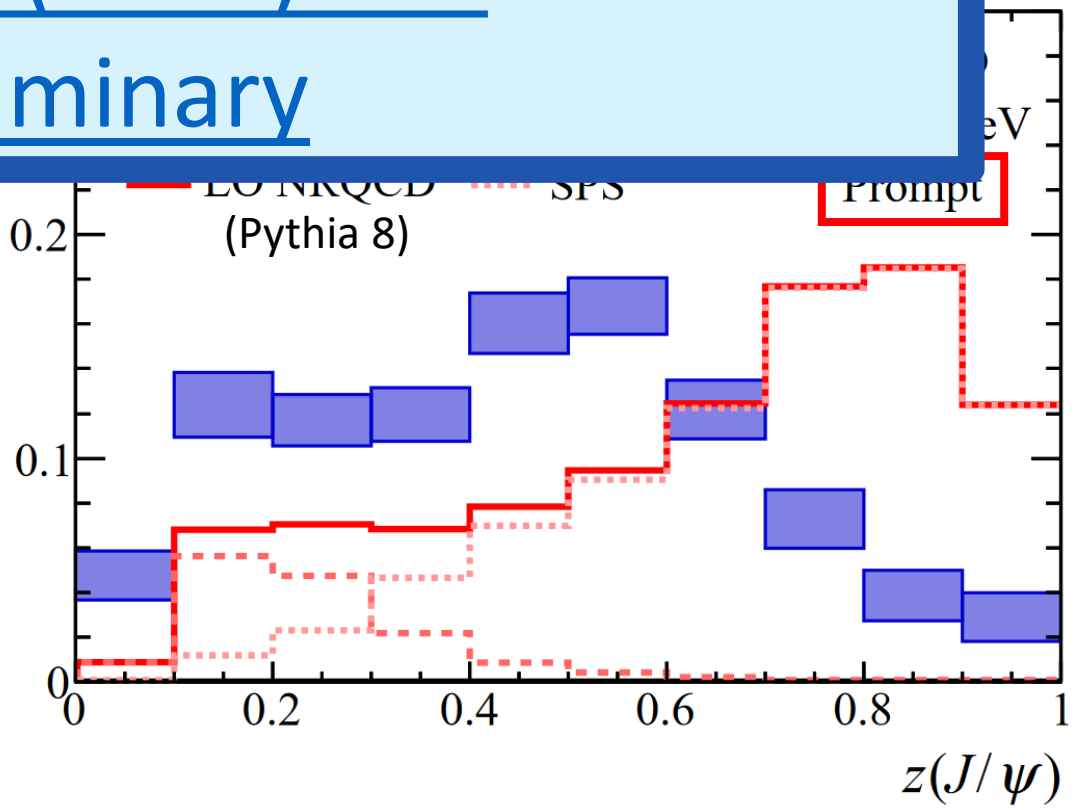
This *exact observable* also measured by:

CMS: PLB 825 (2021) 136842

ATLAS: JHEP 12 (2021) 131

ALICE: preliminary





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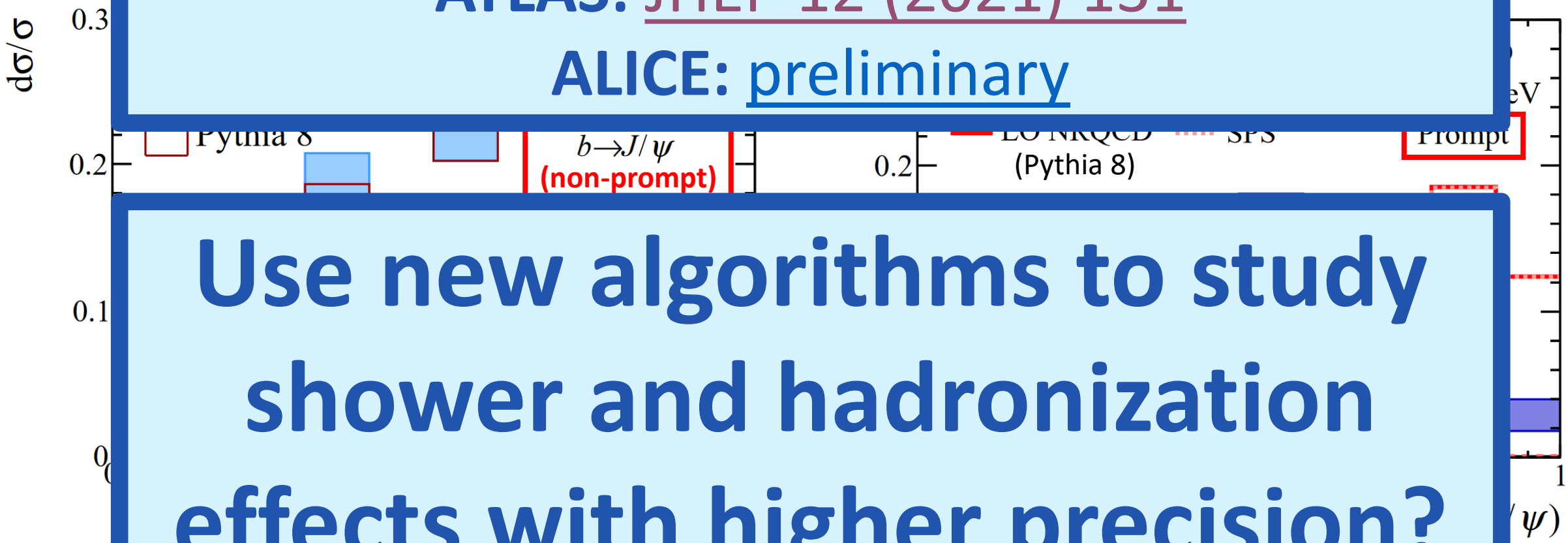

Use new algorithms to study shower and hadronization effects with higher precision?

Phys. Rev. Lett. 118, 192001 (2017)

Two paths to heavy flavor

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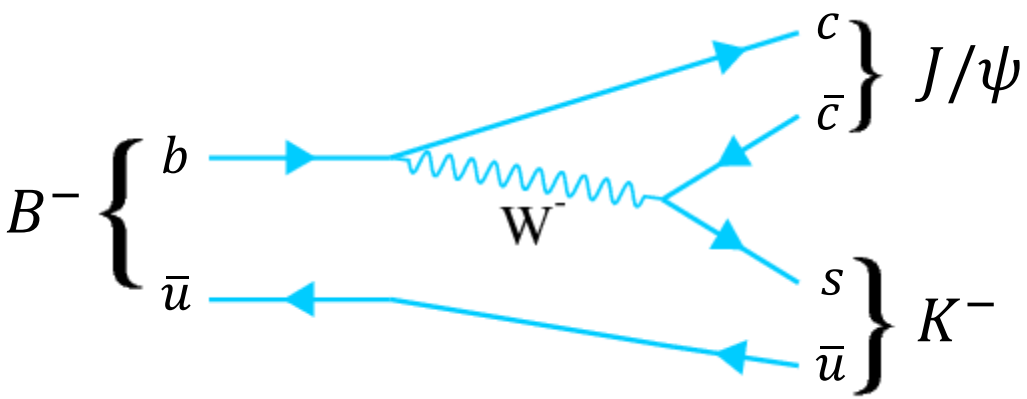
   - e.g., $B^{\pm} \to (J/\psi \to \mu^+\mu^-)\, K^{\pm}$
   - Minimal bias on the reconstructed HF-hadron candidates

2) Reconstructing **secondary vertices (SVs)**
   - Build SV from tracks which are displaced from the primary vertex (PV)



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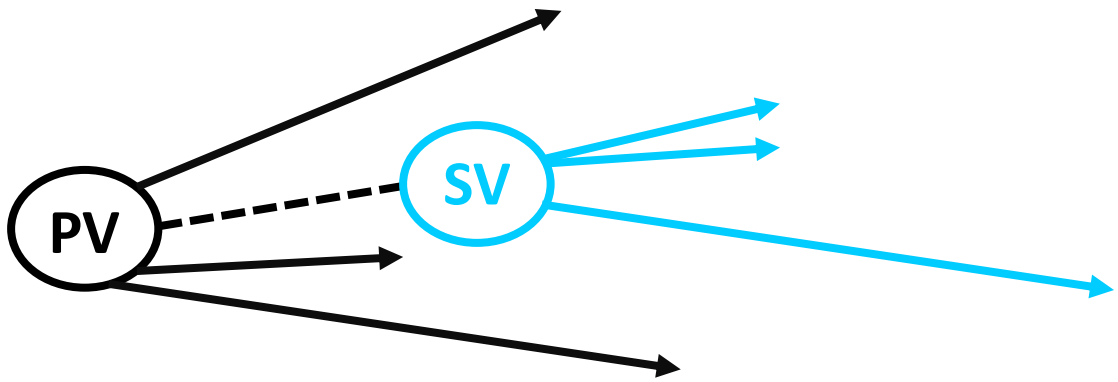
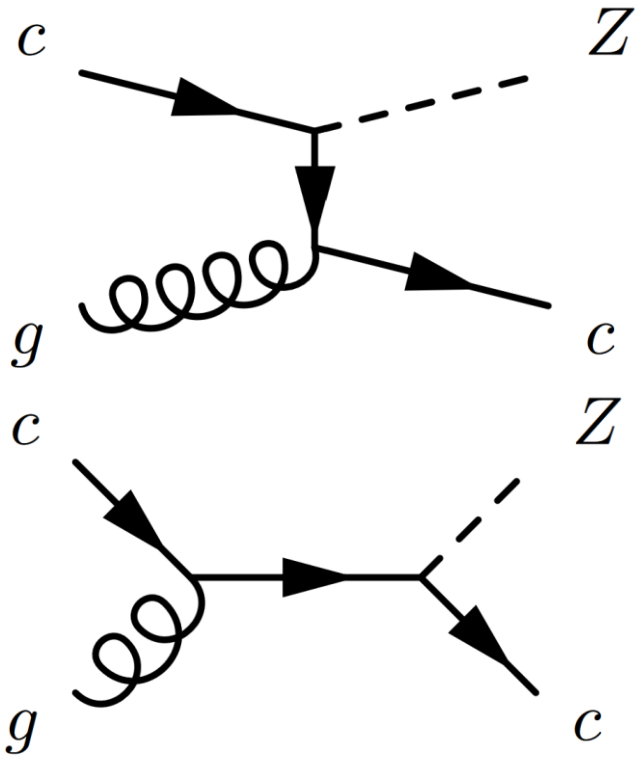
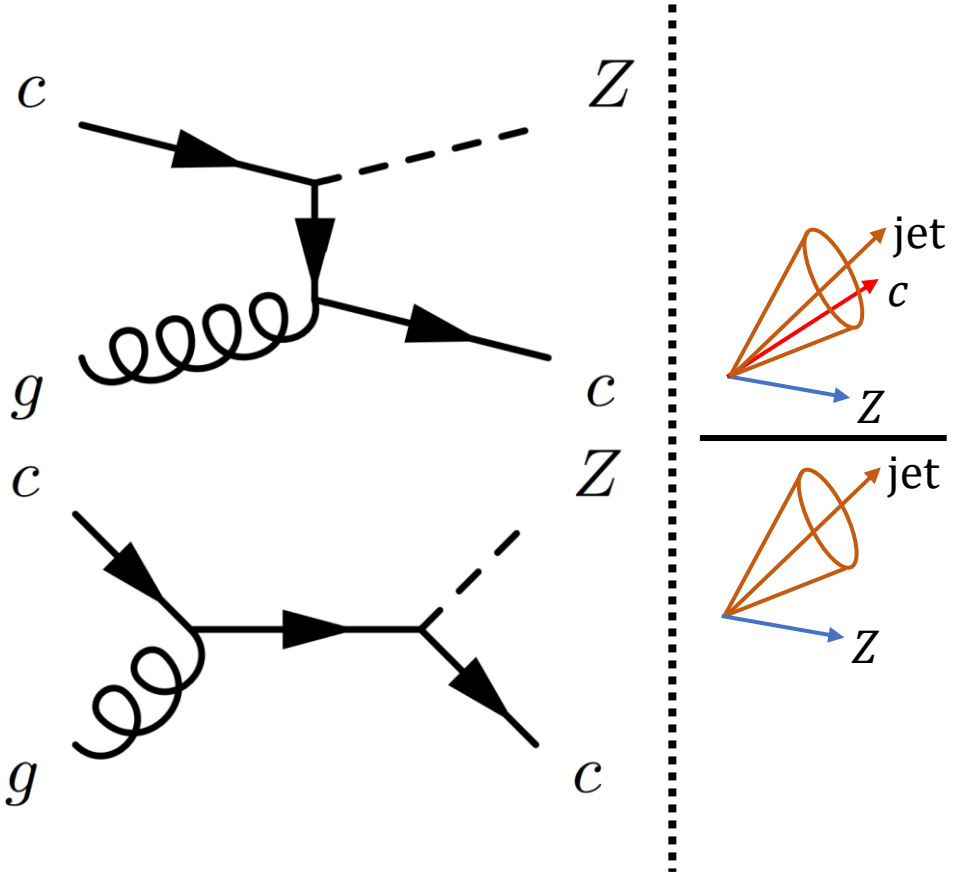


EW-tagged heavy flavor production



- Search for intrinsic charm

EW-tagged heavy flavor production



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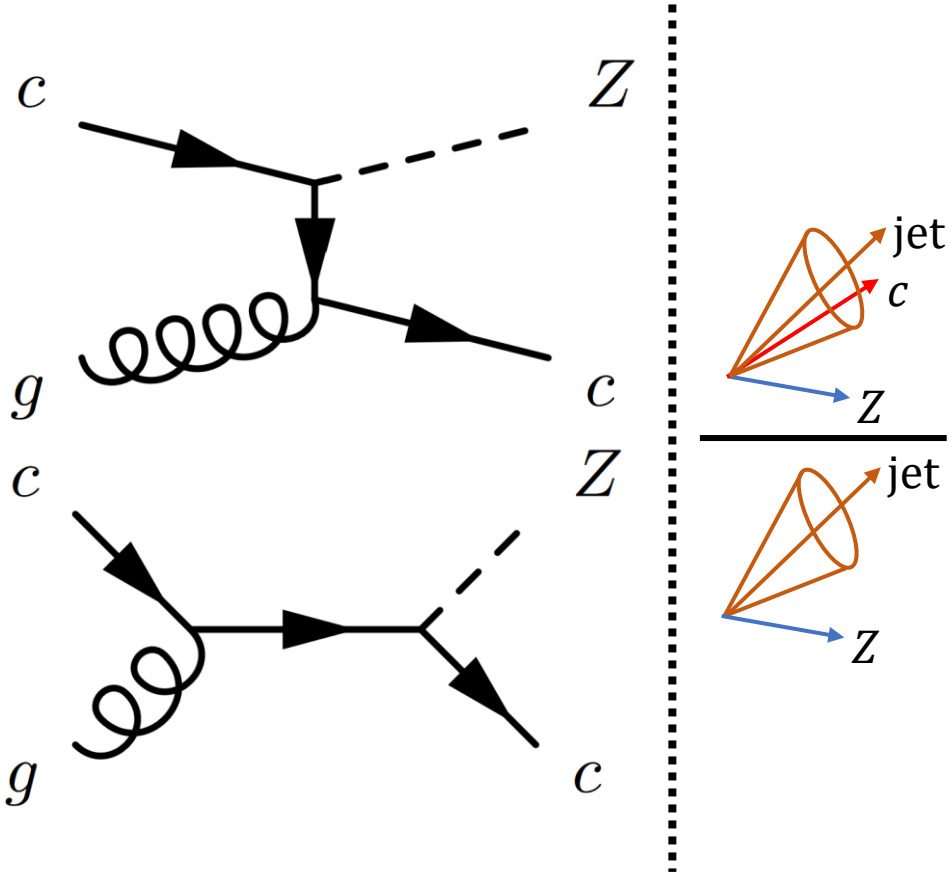

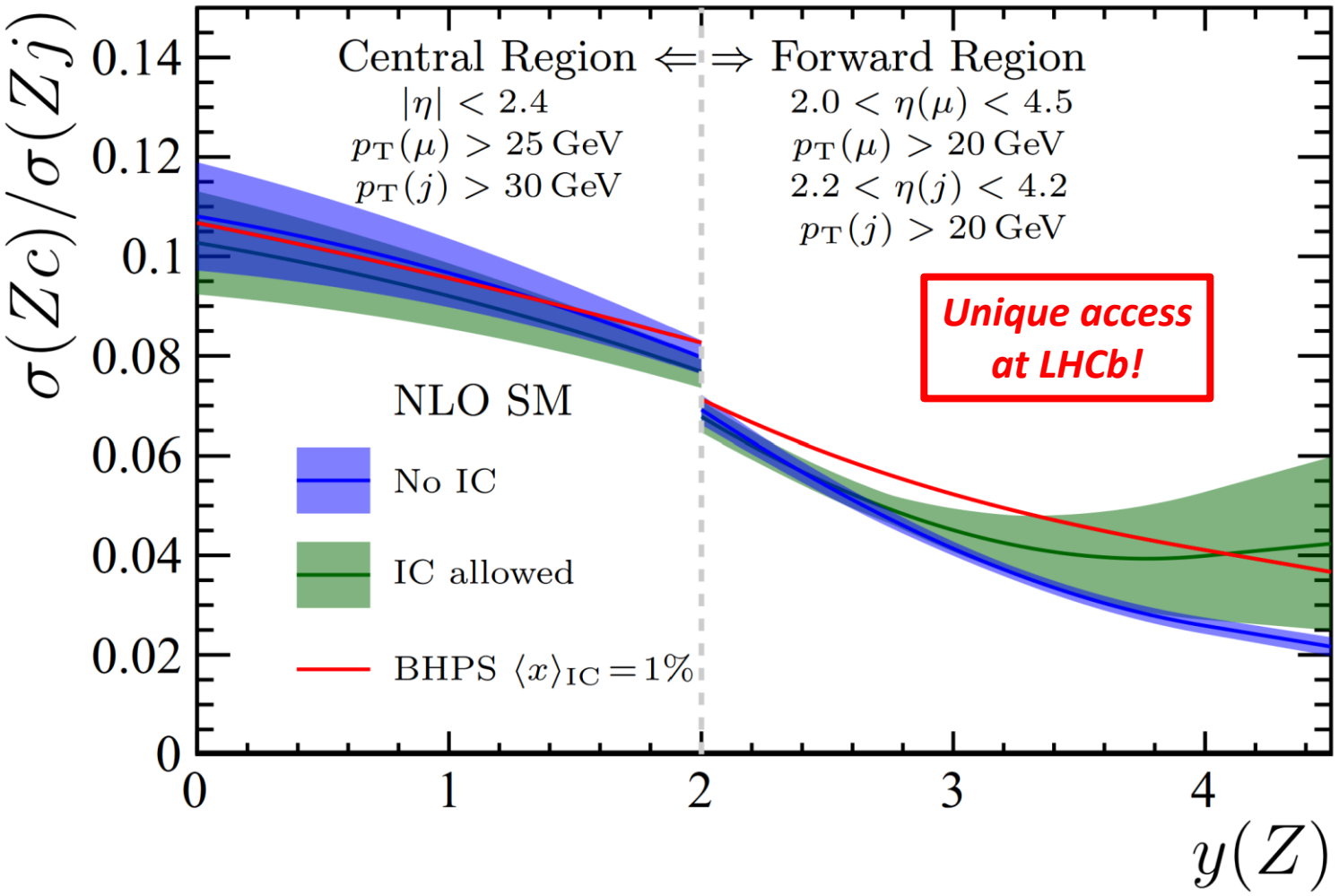

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Phys. Rev. Lett. 128 (2022) 082001

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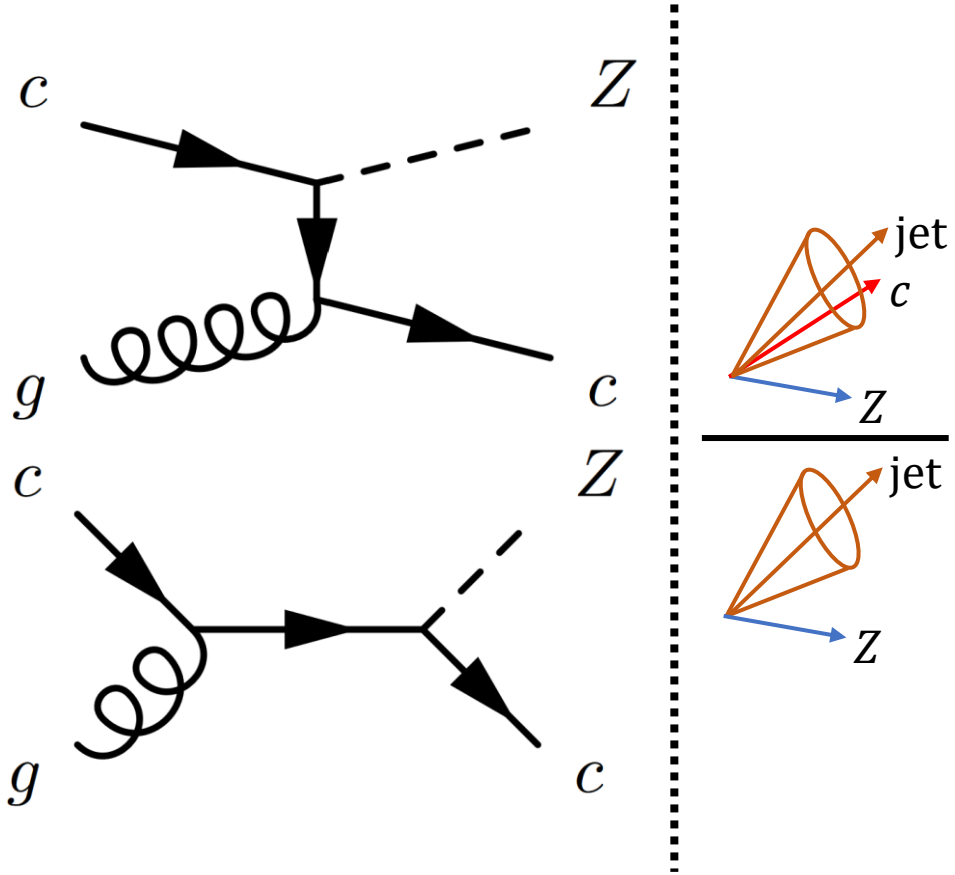

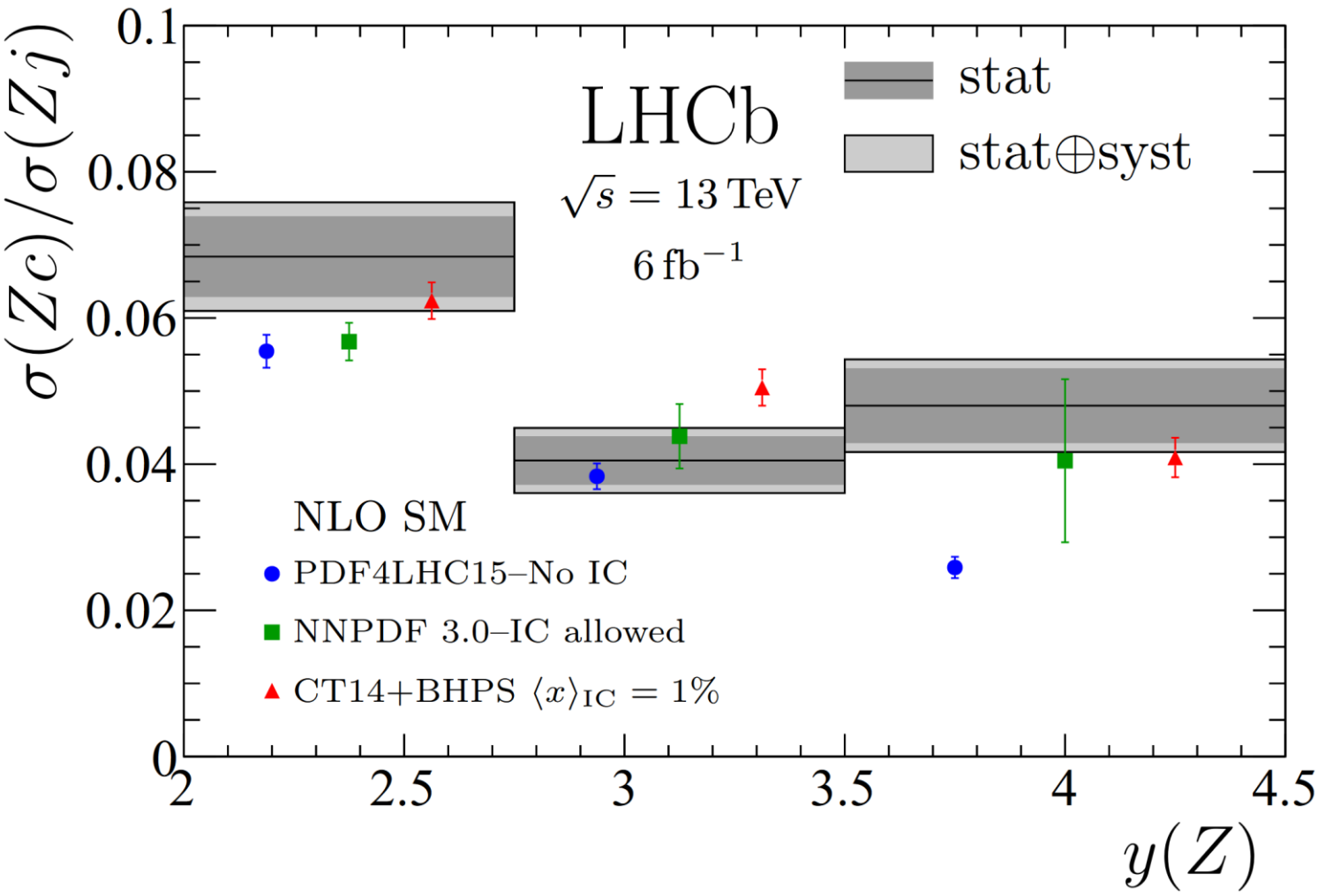

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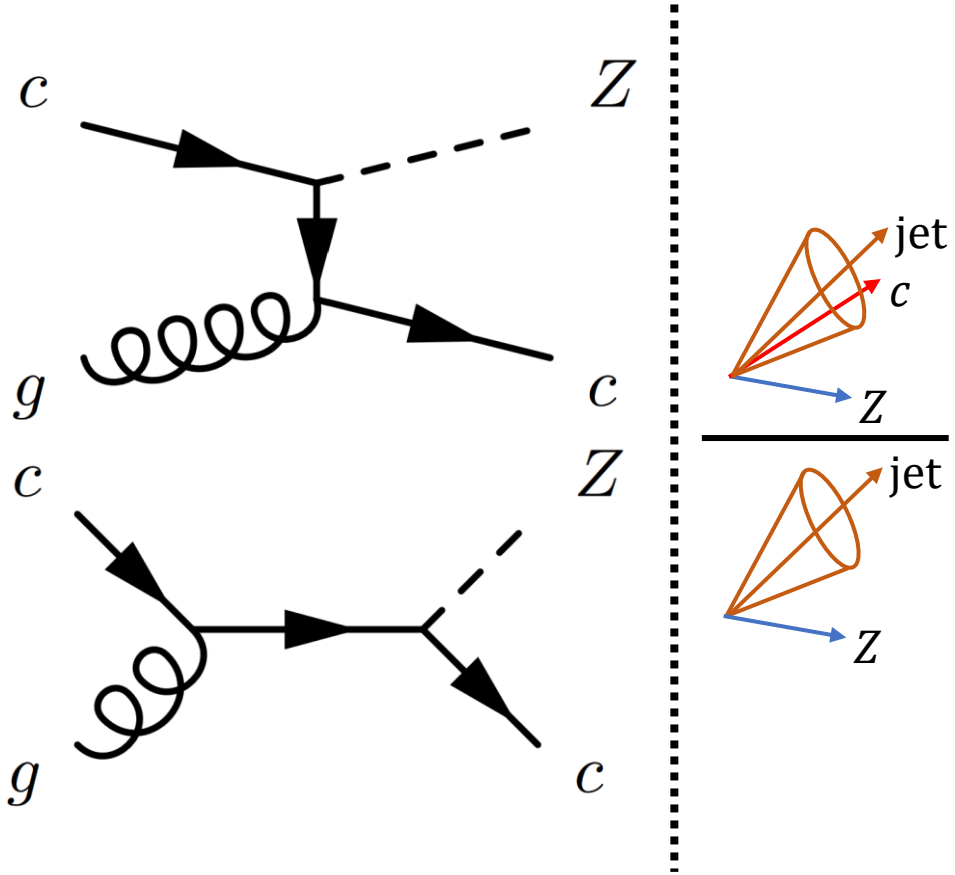

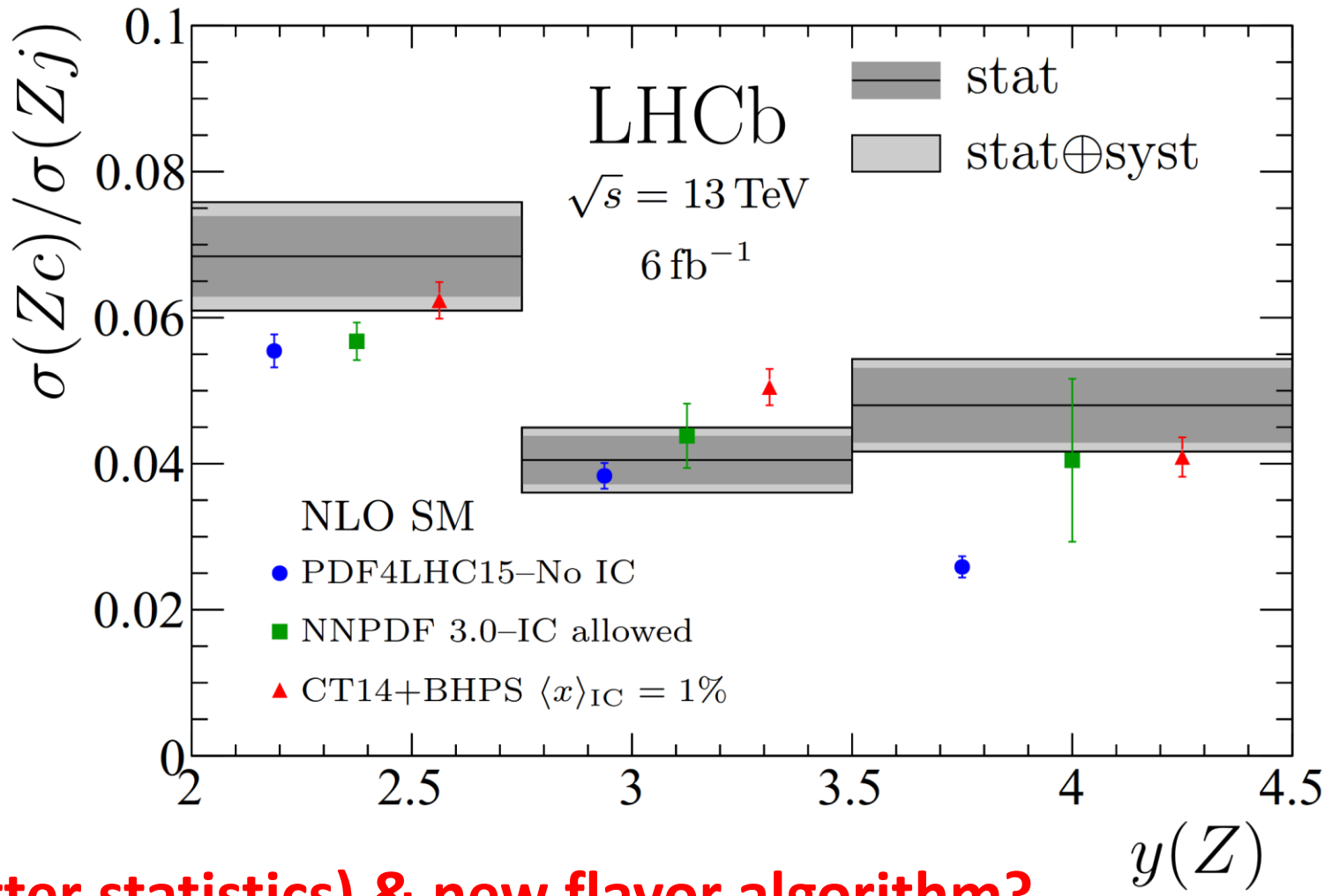

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- **Repeat with Run 3 data (better statistics) & new flavor algorithm?**

Phys. Rev. Lett. 128 (2022) 082001

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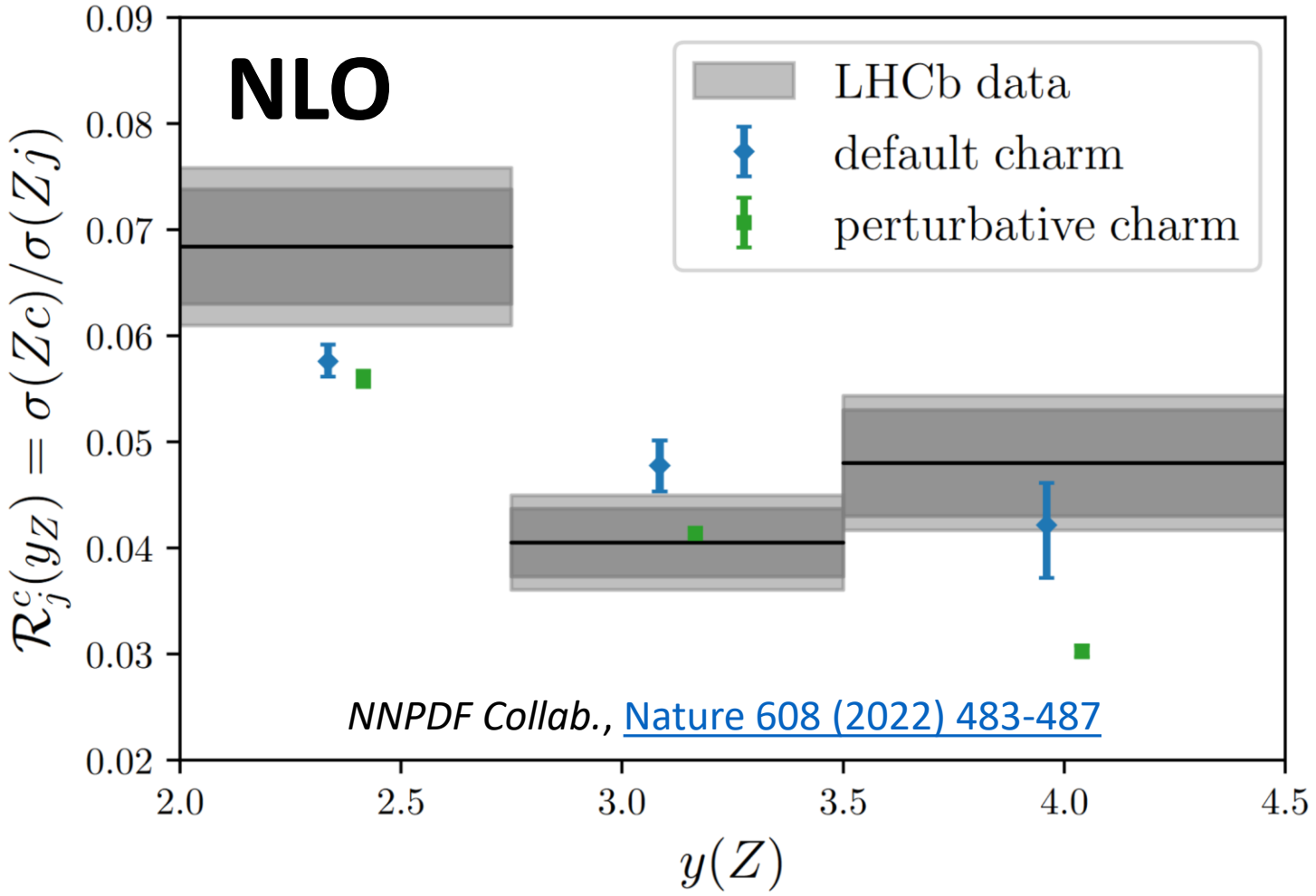

NNPDF Collab., Nature 608 (2022) 483-487

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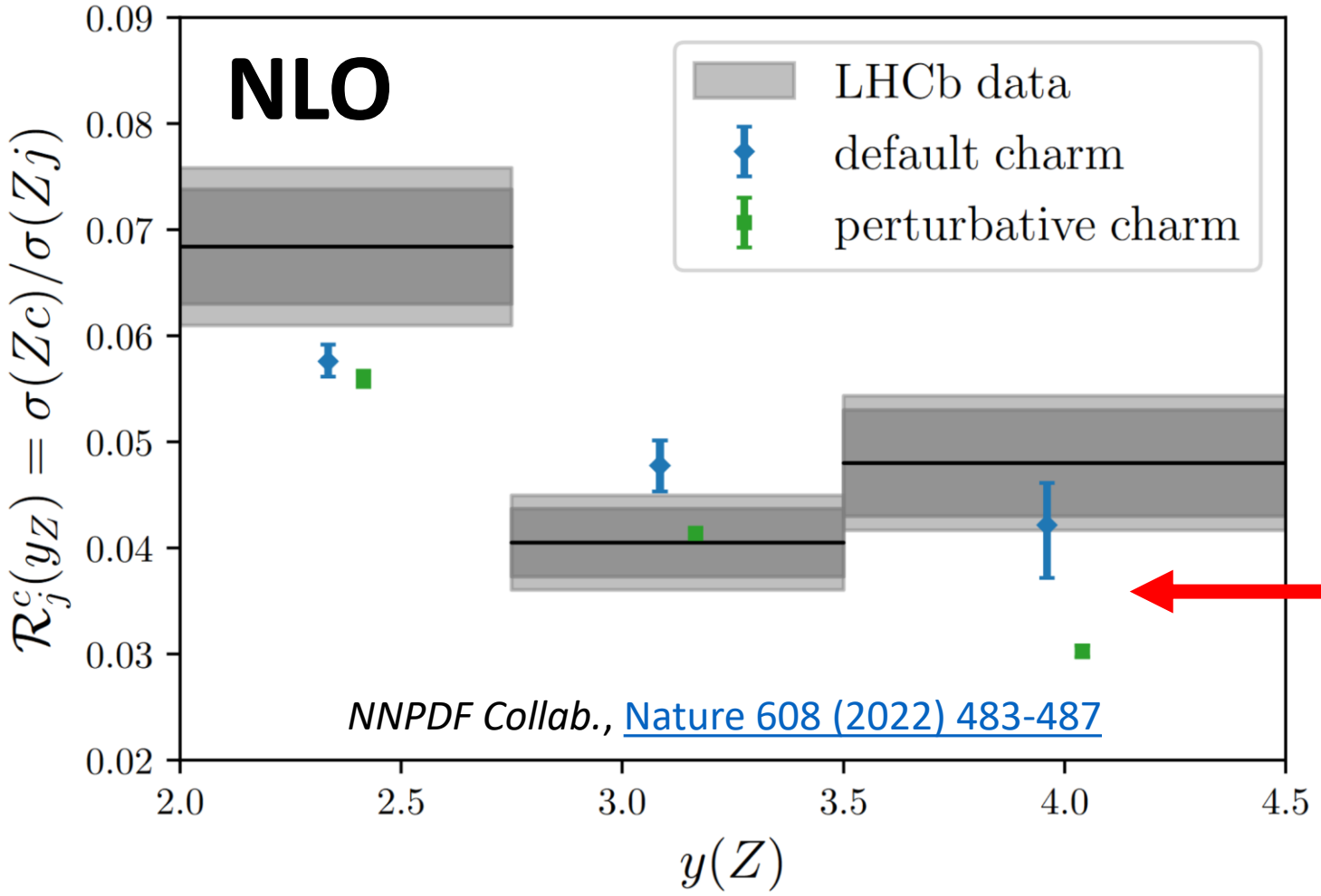

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"We establish the existence of intrinsic charm at the 3σ level"

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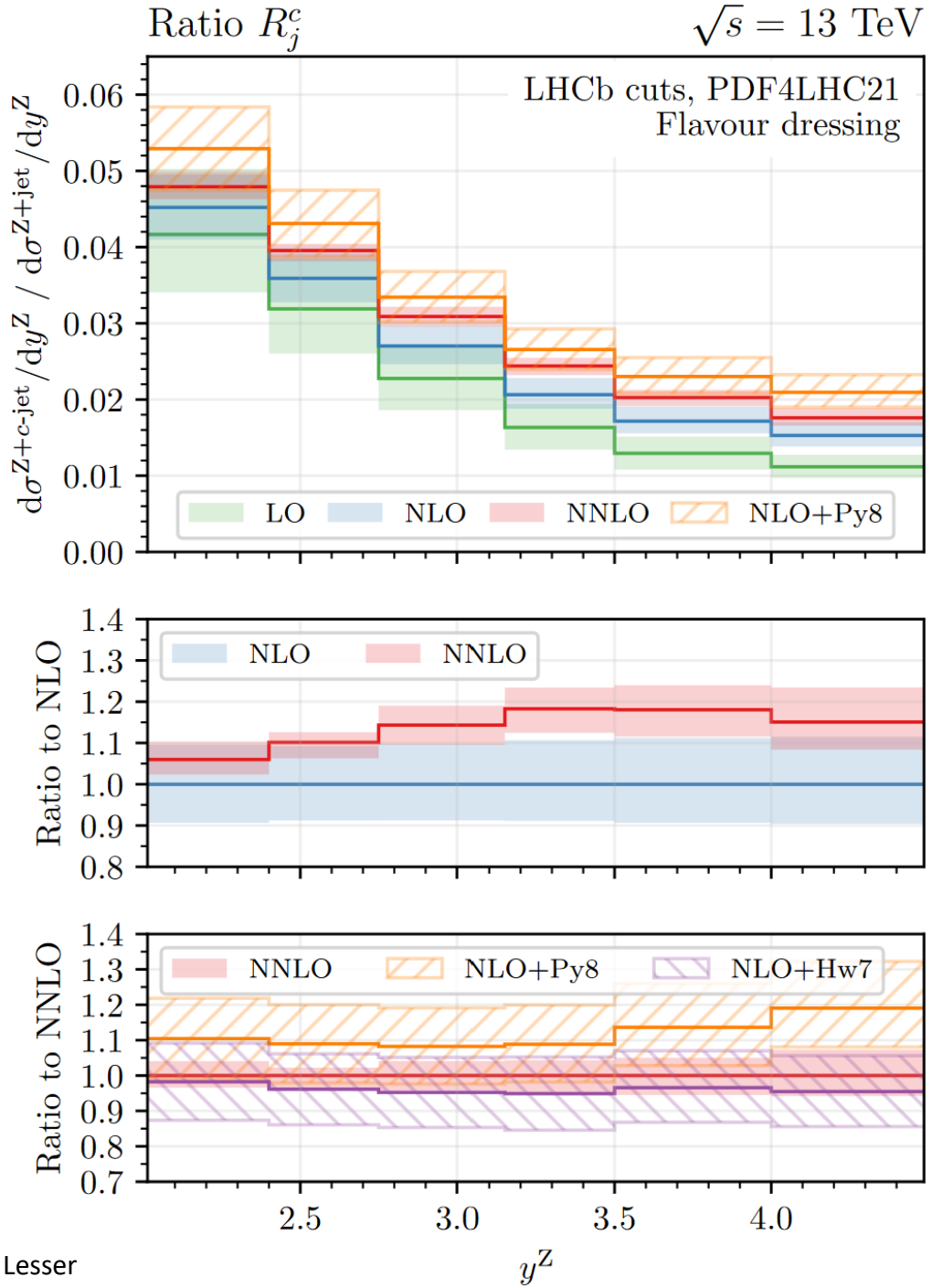

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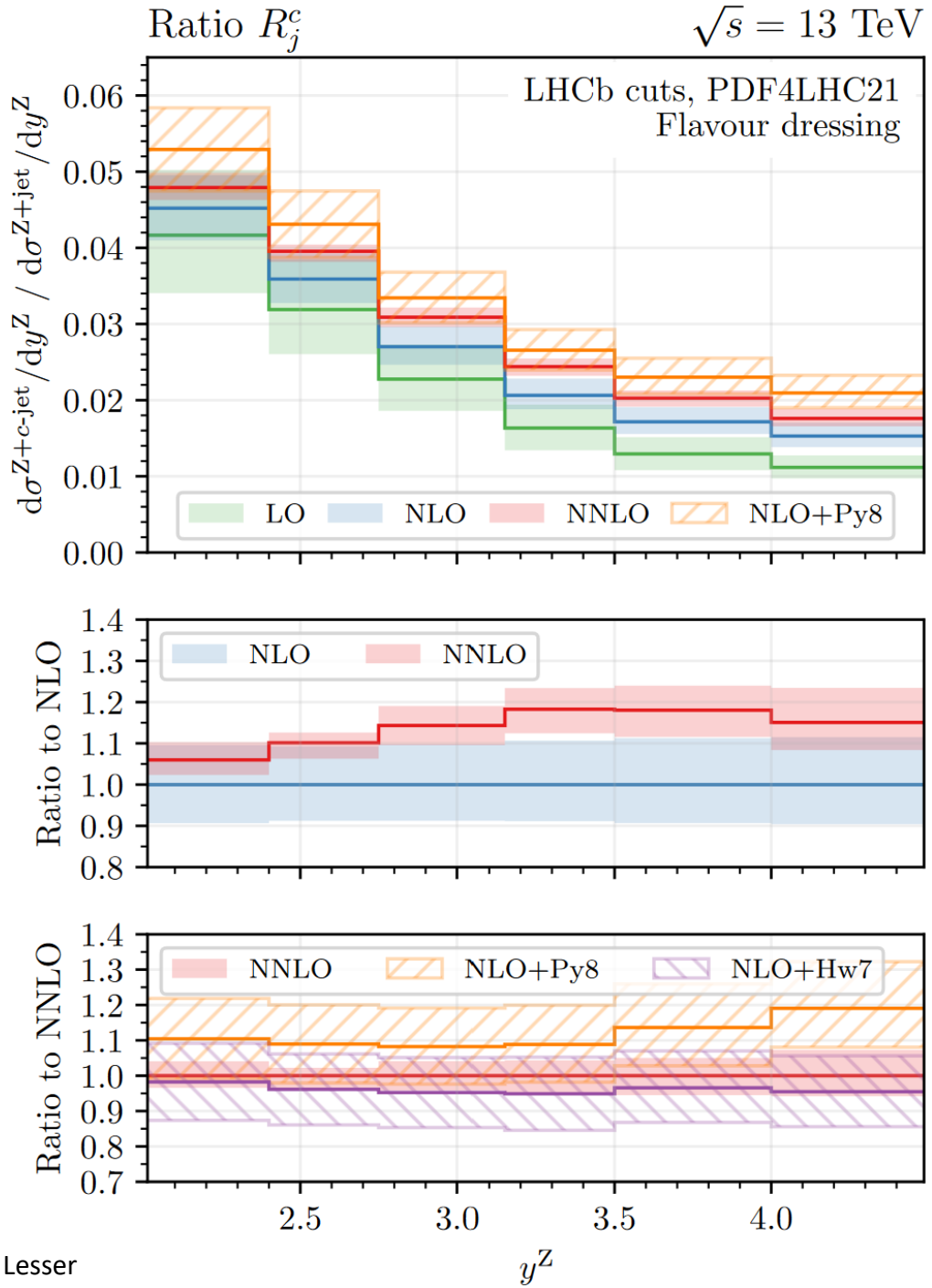
Eur. Phys. J. C 83 (2023) 4, 336



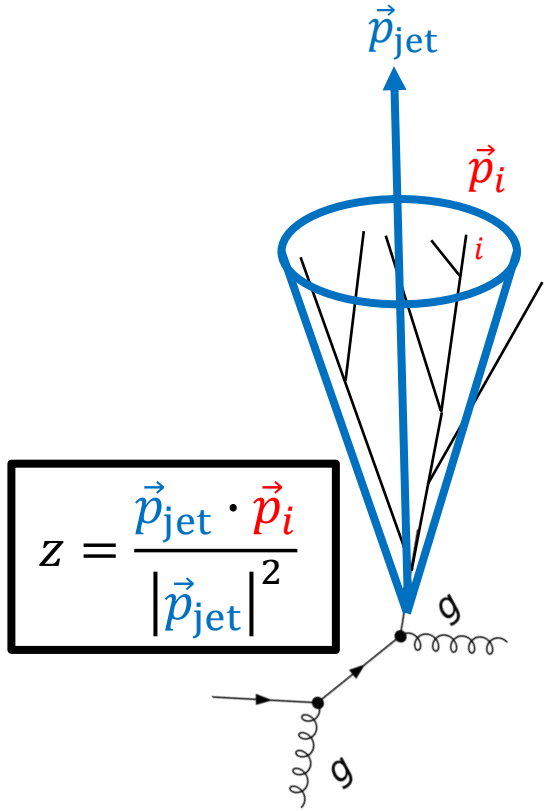
Repeat with Run 3 data (better statistics) & new flavor algorithm?

- NNLO predictions now available
  - Requires use of IRC-safe flavor tagging algorithm

- Possibility to **resolve the 3σ discrepancy** with a new Run 3 measurement, using **higher-precision experimental & theoretical methods**

Eur. Phys. J. C 83 (2023) 4, 336

Jet fragmentation functions

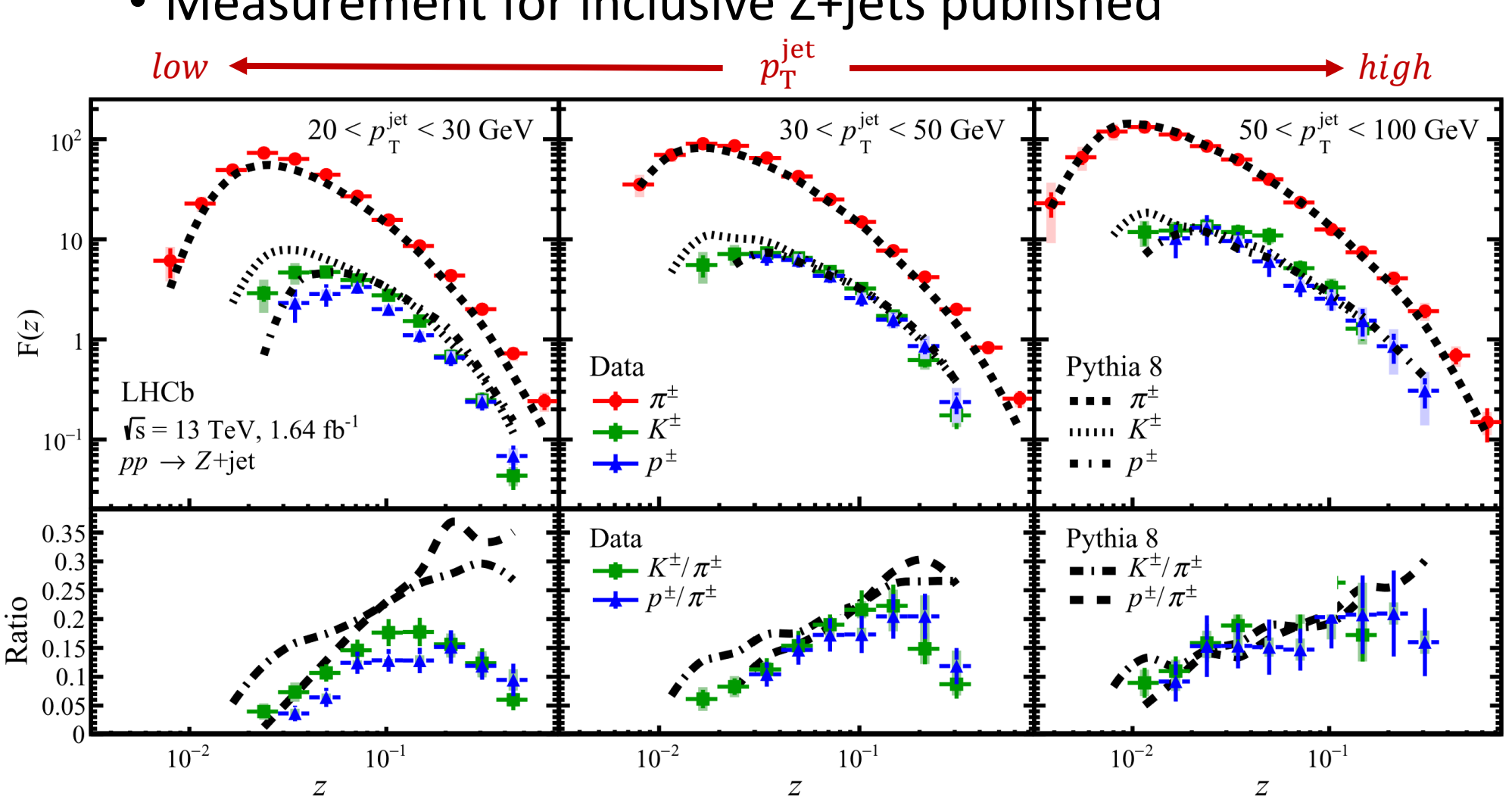


$$z = \frac{\vec{p}_{\text{jet}} \cdot \vec{p}_i}{\left|\vec{p}_{\text{jet}}\right|^2}$$

Phys. Rev. D 108 (2023) L031103

Jet fragmentation functions

- Measurement for inclusive Z+jets published



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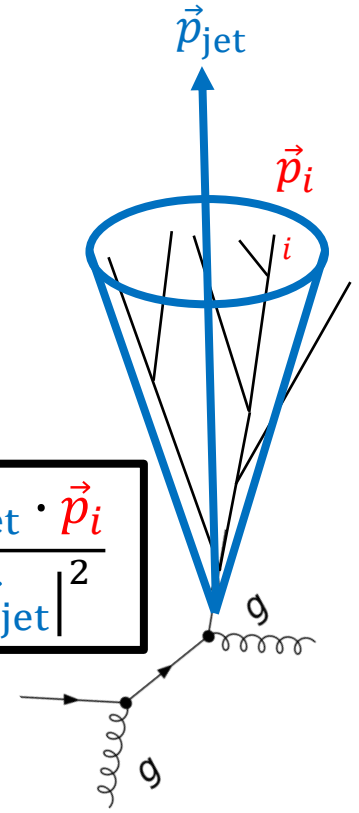

Phys. Rev. D 108 (2023) L031103

Jet fragmentation functions

- Measurement for inclusive Z+jets published

Ongoing measurement of jet fragmentation functions for HF jets using SV tagging approach (more soon!)

Phys. Rev. D 108 (2023) L031103

Machine Learning approach

- Train a **Boosted Decision Tree (BDT)** to identify HF jet candidates

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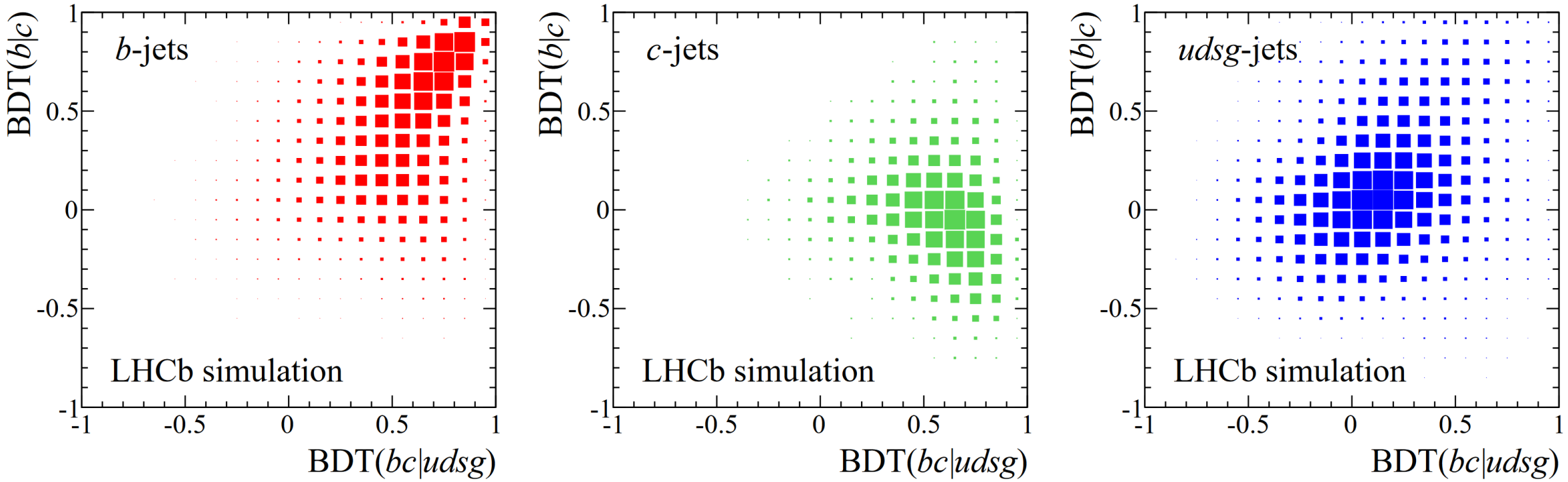

JINST 10 (2015) P06013

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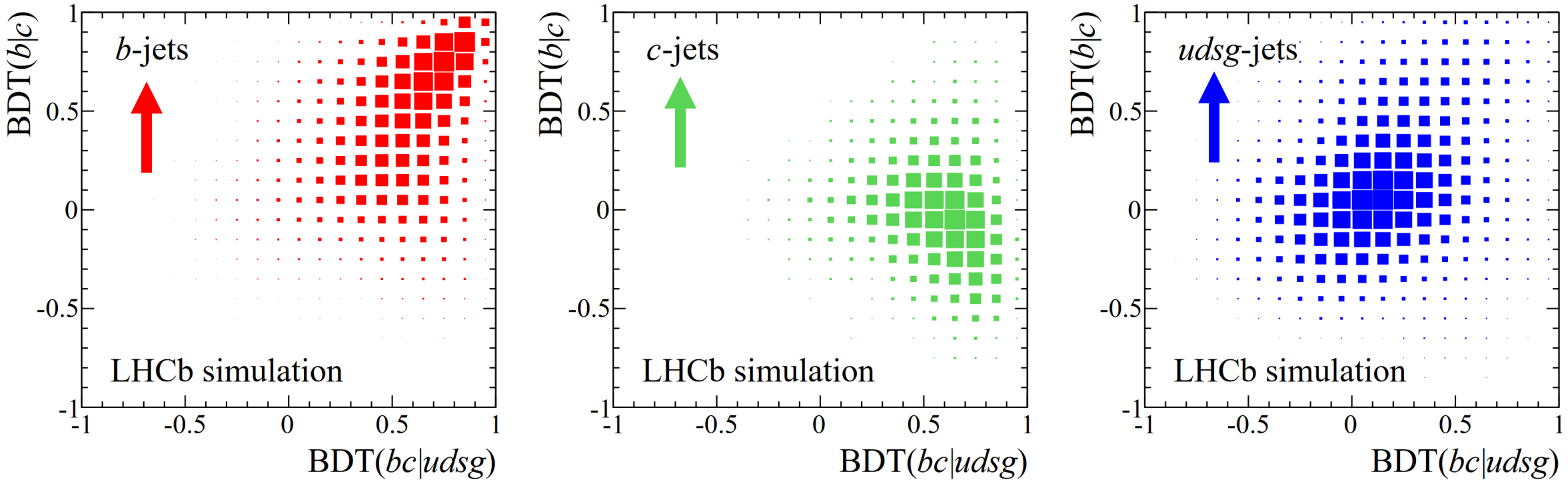

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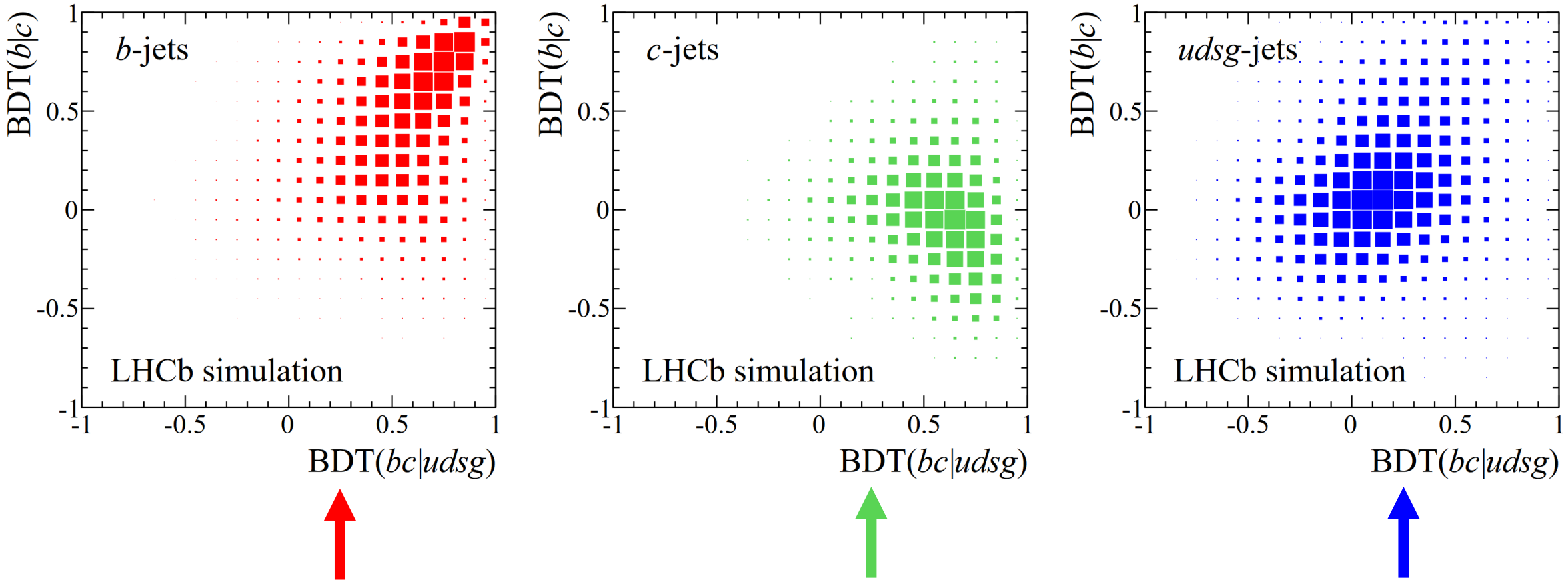

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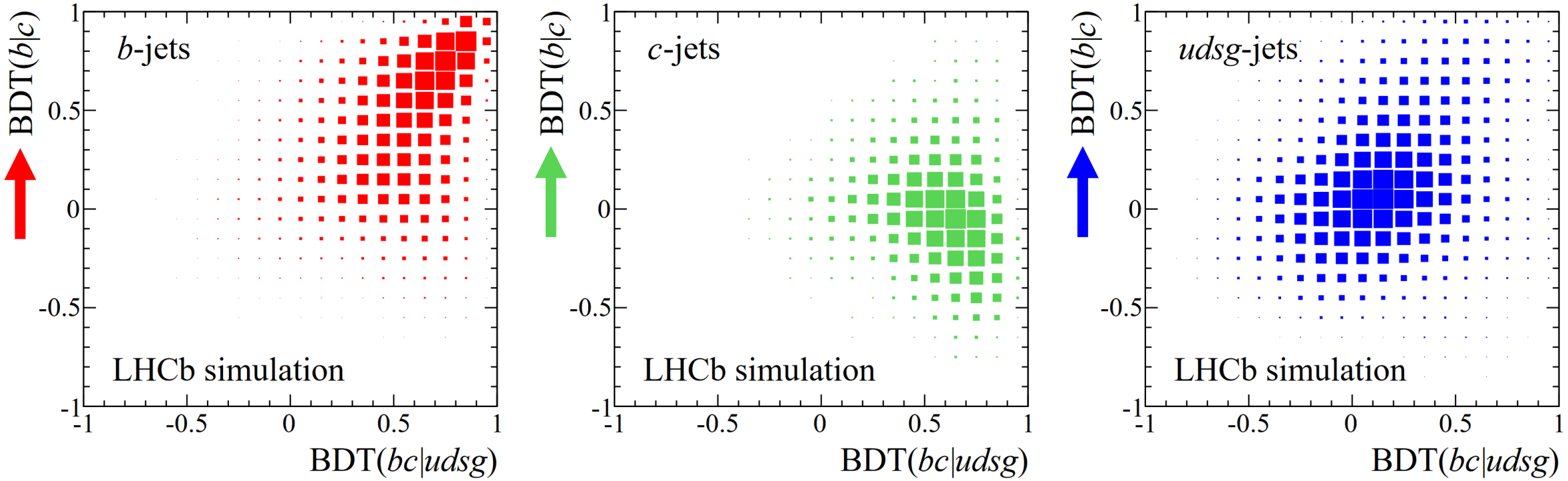

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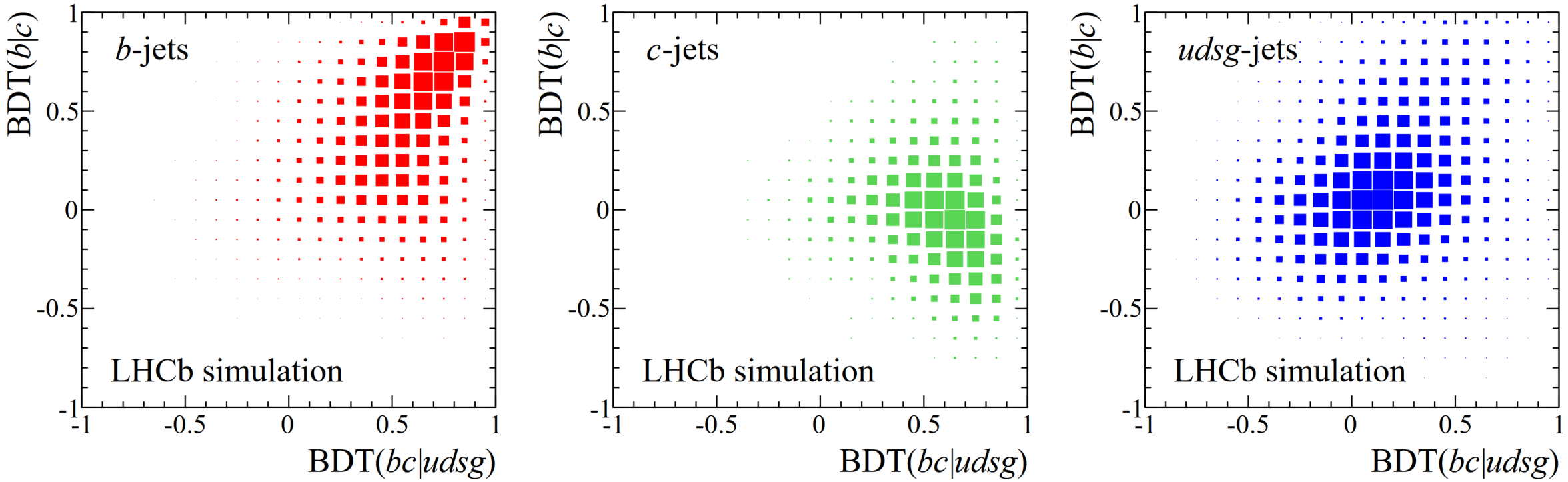

- **Could be (re)trained to study $B^{\pm}$-jets of theoretical interest?**

… More very soon from 

!

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… More very soon from LHCb!

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- Feel free to contact us for collaboration ☺