Dark showers: experimental searches and challenges

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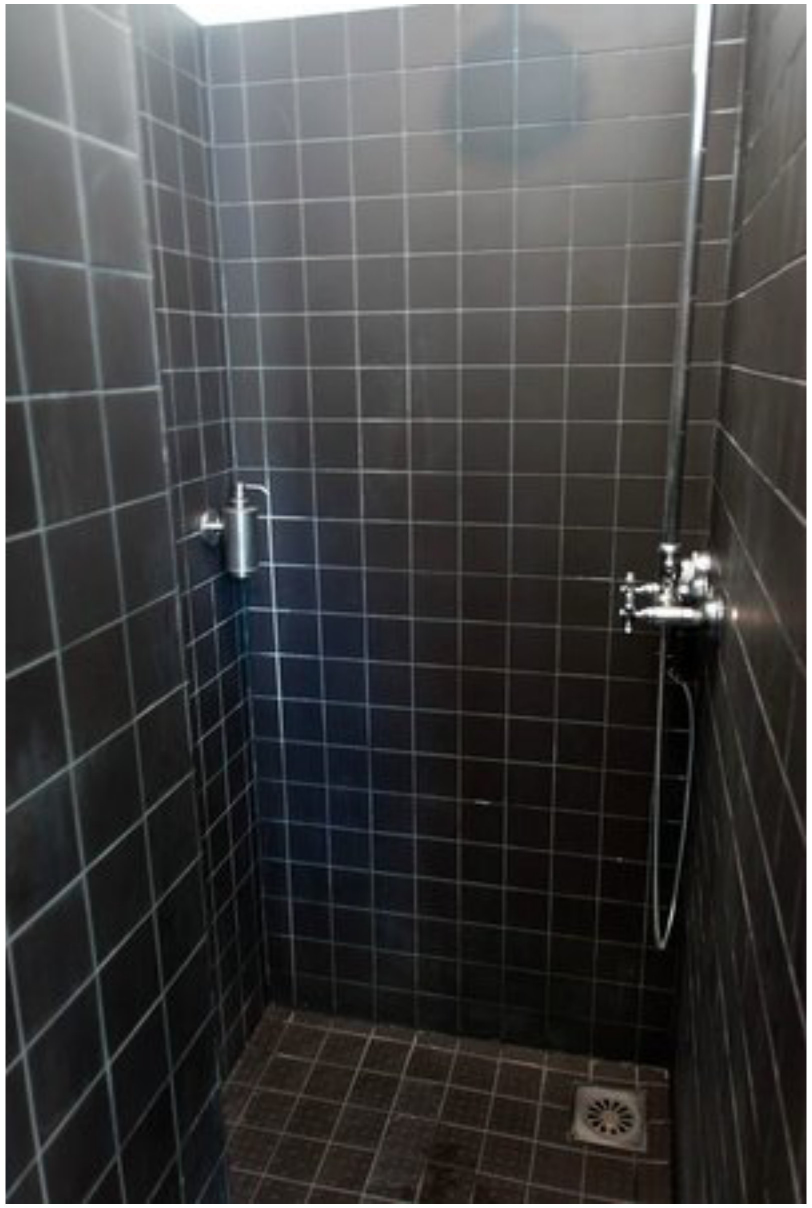
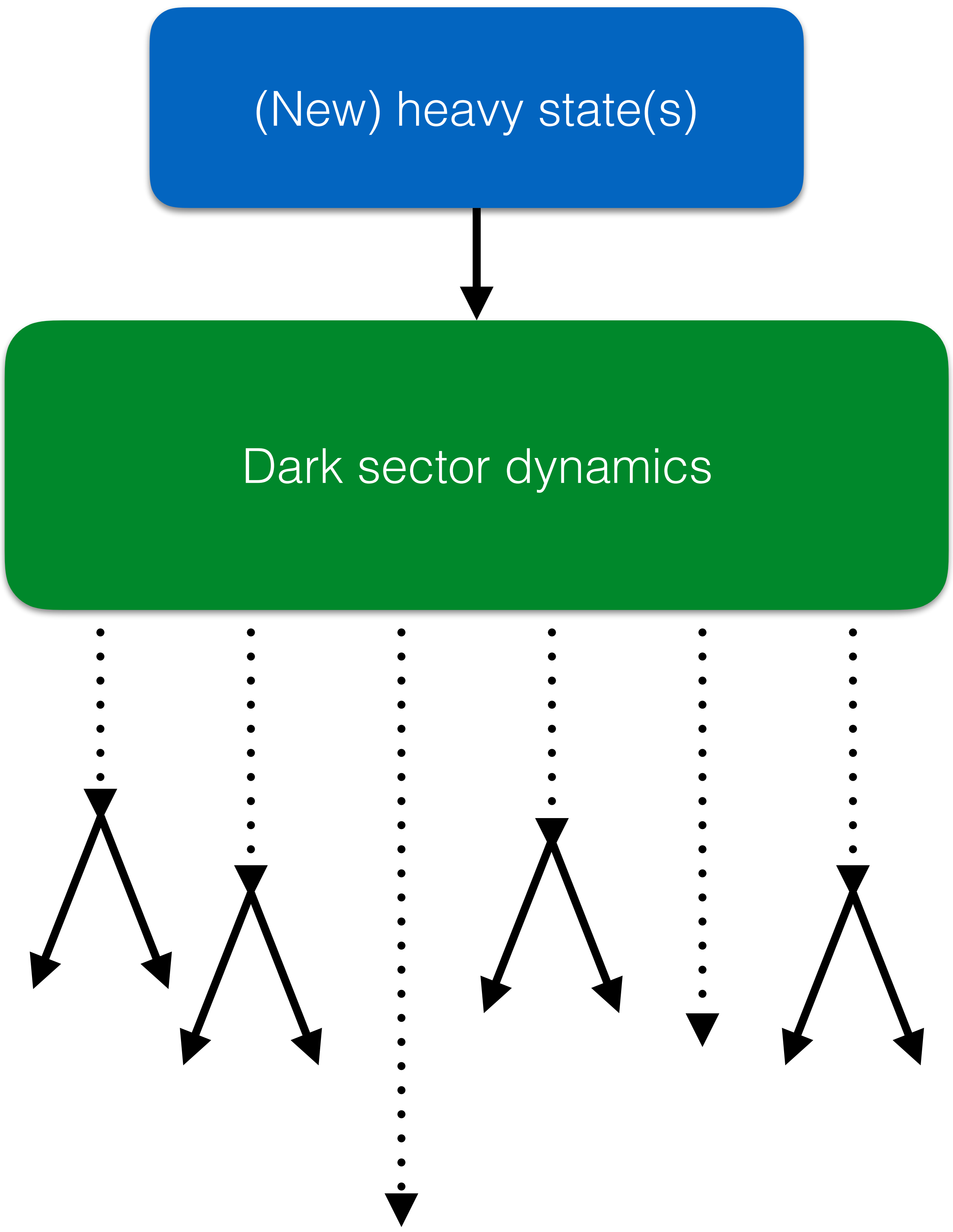
Overview

- Characteristics of dark shower models
- Triggering strategies
- Reconstruction challenges
- Background estimation

Bias to CMS/ATLAS in this discussion; LHCb can attack the same models with somewhat different strategies (see talk by M. Borsato)



Dark shower models

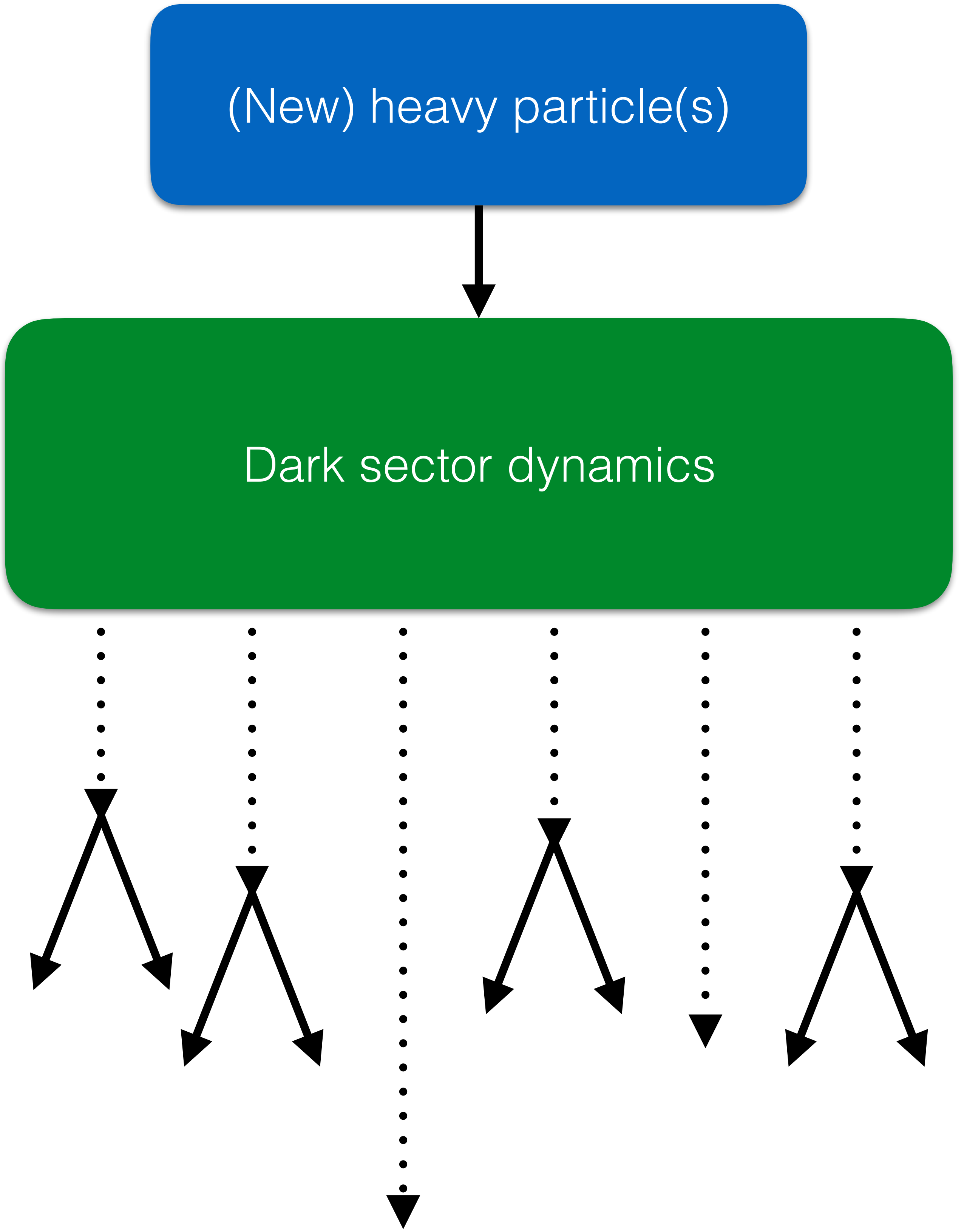


Dark shower models

Extremely rich phenomenology of dark shower models.

- Hadronic/leptons/photons/...
- High/low multiplicity
- Boosted/not boosted
- Clustered/unclustered
- Displacement large/small

As an experimenter, this means it is difficult to cover them comprehensively.



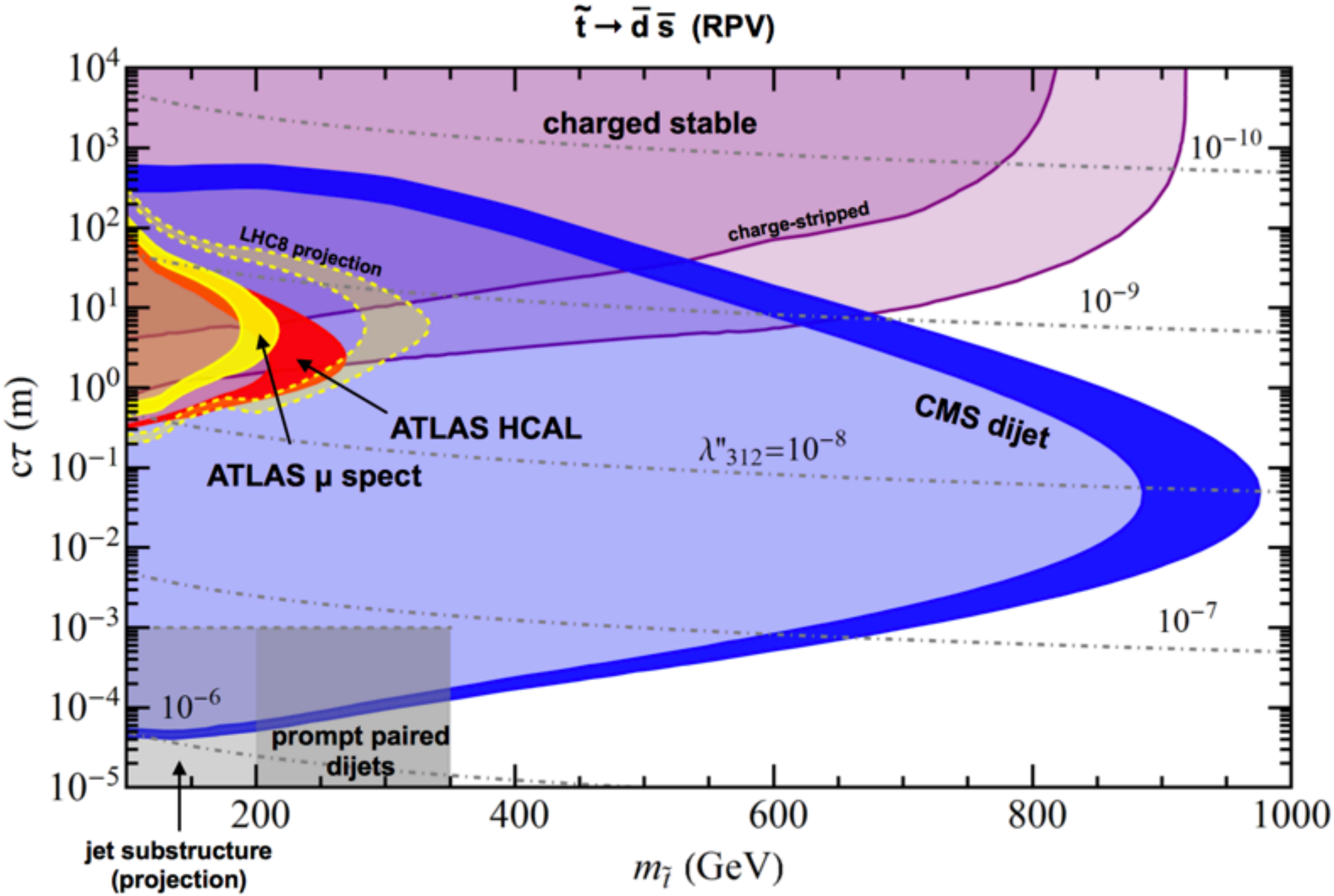
What's not excluded?

The range of lifetimes for which the displacement is actually relevant for the detector is rather small compared to the possibilities…

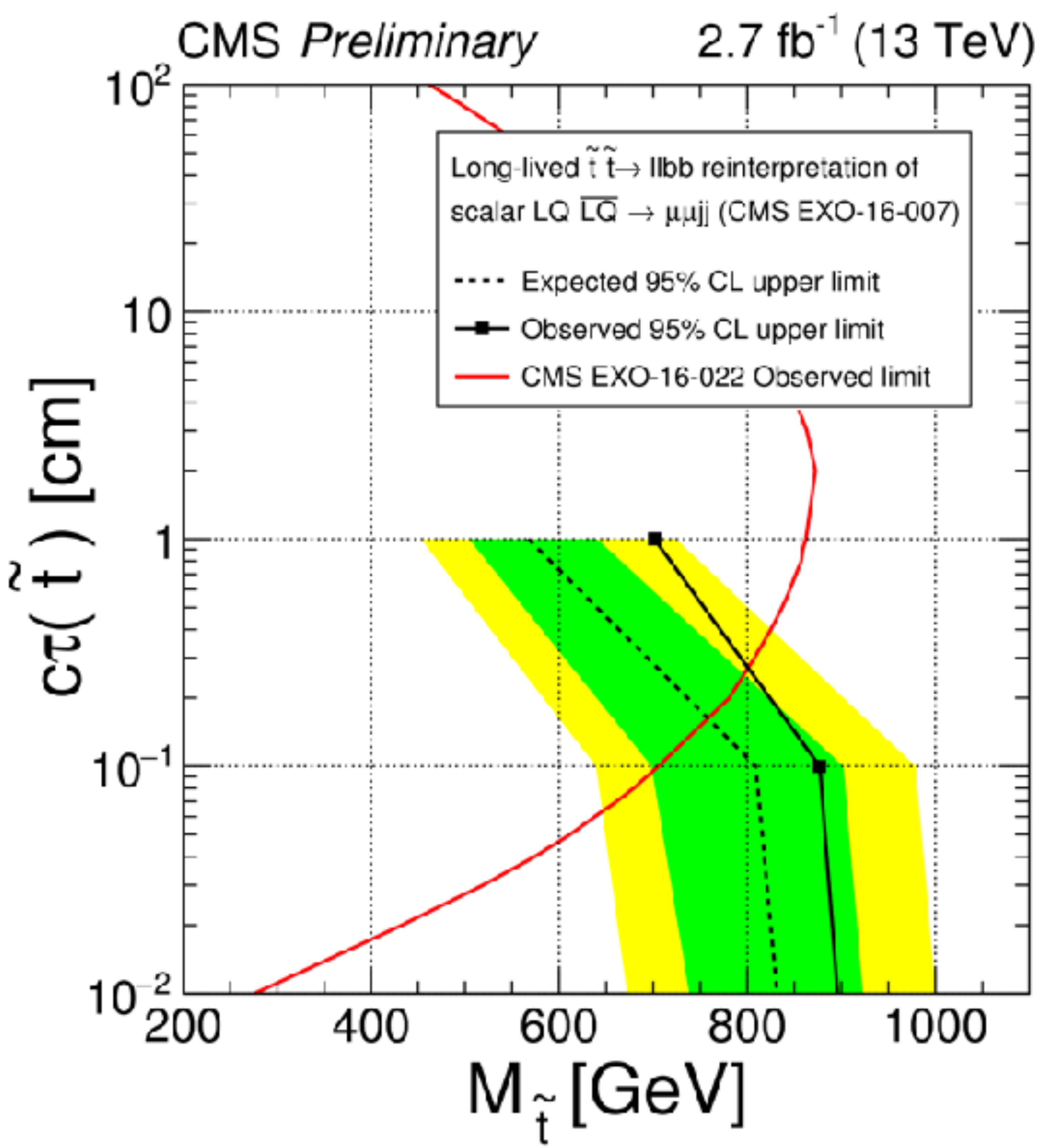
- At low lifetimes, hadronic exotic searches (resonant and non-resonant) are the way to go
- At high lifetimes, prompt SUSY and DM-style analyses will be sensitive

Some standard SMS of dark showers and displaced jets will help to quantify what we are really talking about.

A theorist's attempt



More realistic example

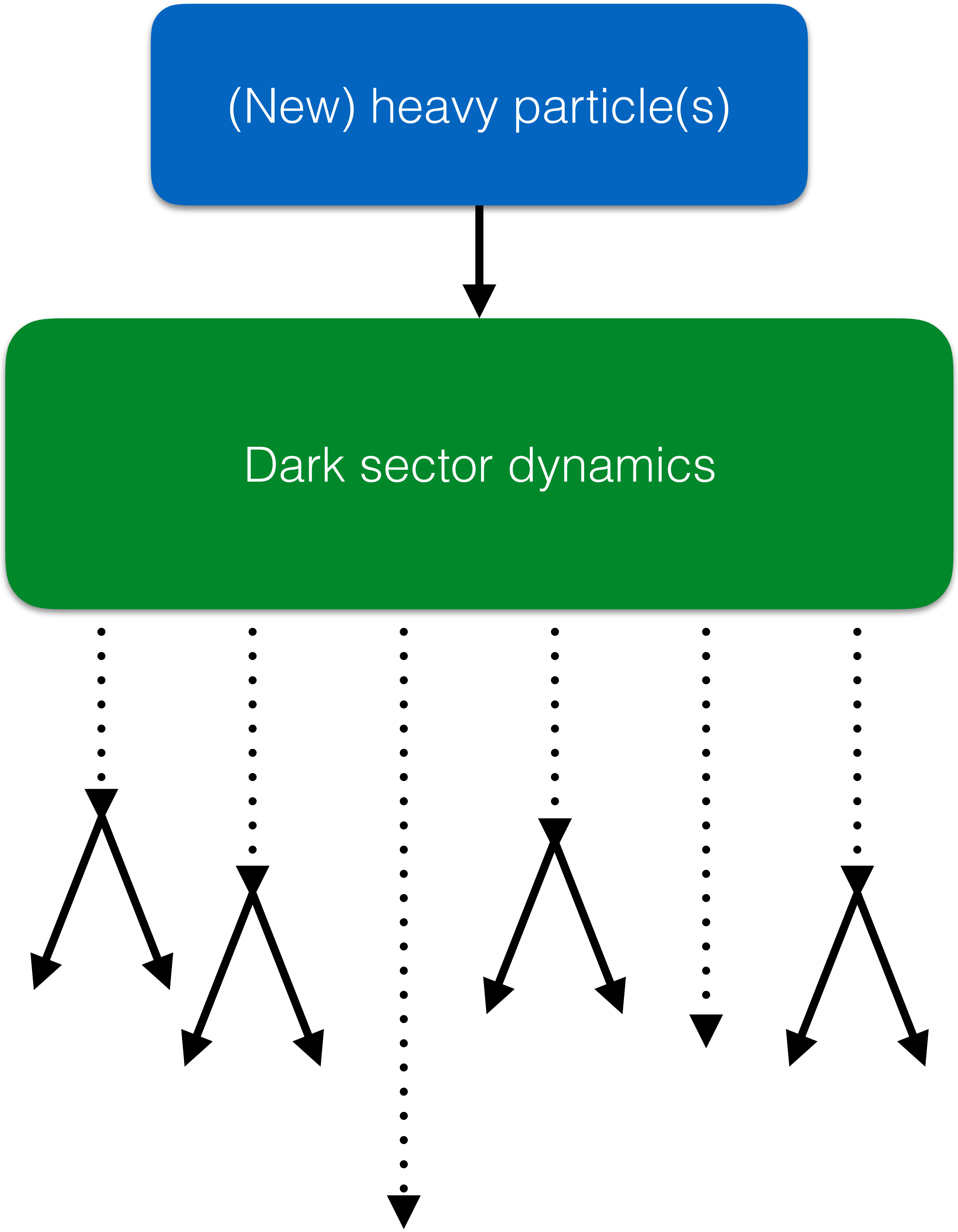


Triggering

Broadly two triggering strategies:

- Trigger on the (new) heavy particle(s) (e.g. HT) or its production process (e.g. ISR)
- Trigger on the decays back to SM particles: e.g. displaced jet, displaced vertex

(Can also be combined in cross-triggers.)



Triggering: examples

ATLAS ‘inclusive’ displaced vertex search (https://arxiv.org/pdf/1504.05162.pdf)

- High-pT μ
- High-pT γ (actually displaced electron)
- High-MET
- High jet multiplicity

Triggering: examples

CMS 'inclusive' displaced jet search: http://cds.cern.ch/record/2256654?ln=en

- Plain HT
- HT + 2 jets w/ prompt track veto

Reconstruction challenges

In general we want to fully reconstruct the ‘jet’ resulting from the dark shower, but…

- Jet will fail usual jet ID due to strange distribution of energy within calorimeters or due to anomalous charged track characteristics, so tend towards loosening these criteria
    - Increases vulnerability to e.g. calorimeter noise or badly reconstructed QCD jets
- Vertices may be low multiplicity
    - Few tracks at large displacement makes vertexing nearly impossible
- Vertices are most likely not isolated

CMS inclusive displaced jet

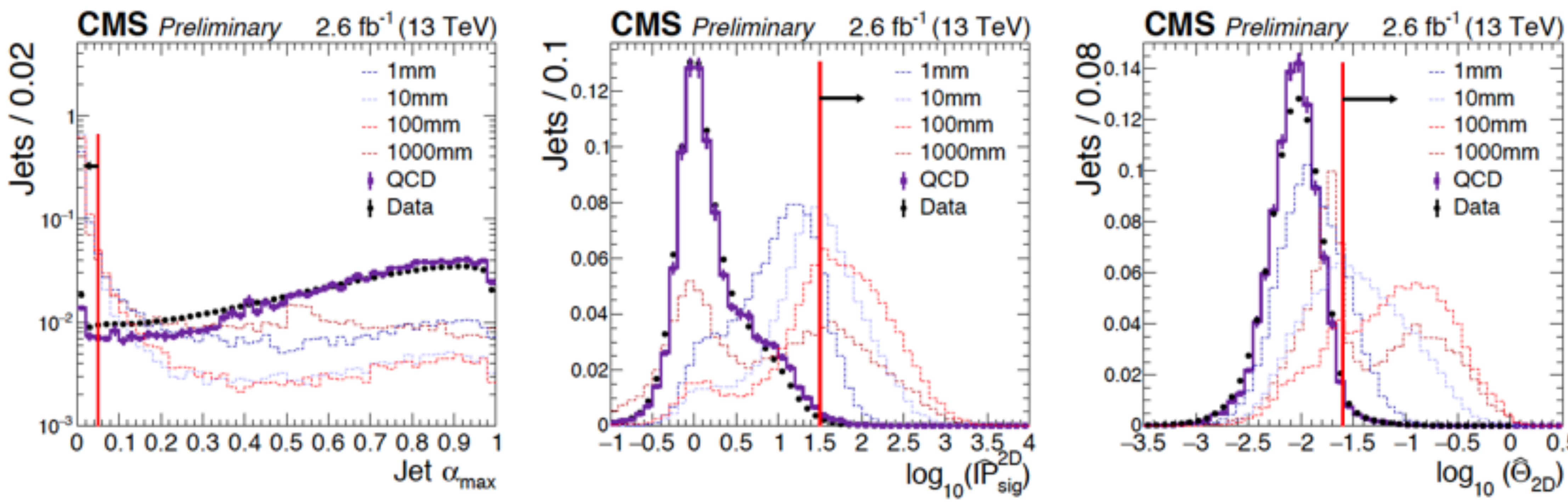


Figure 1: Comparison of MC and data distributions for the displaced-jet tagging variables $\alpha_{\max}$ (left), $\widehat{IP}^{2D}_{sig}$ (center), and $\widehat{\Theta}_{2D}$ (right). The data distributions (circles) are compared to the expected background distributions from multijet events (squares) and several Jet-Jet benchmark models (dotted histograms) of pair-produced long-lived neutral scalar particles with $m_X = 700\,\mathrm{GeV}$ and different values of $c\tau_0$. The vertical lines designate the value of requirement for the nominal displaced-jet tag. The direction of the arrow indicates the values included in the requirement. All distributions have unit normalization.

Background estimation

Backgrounds depend a lot on how I define my reconstruction strategy:

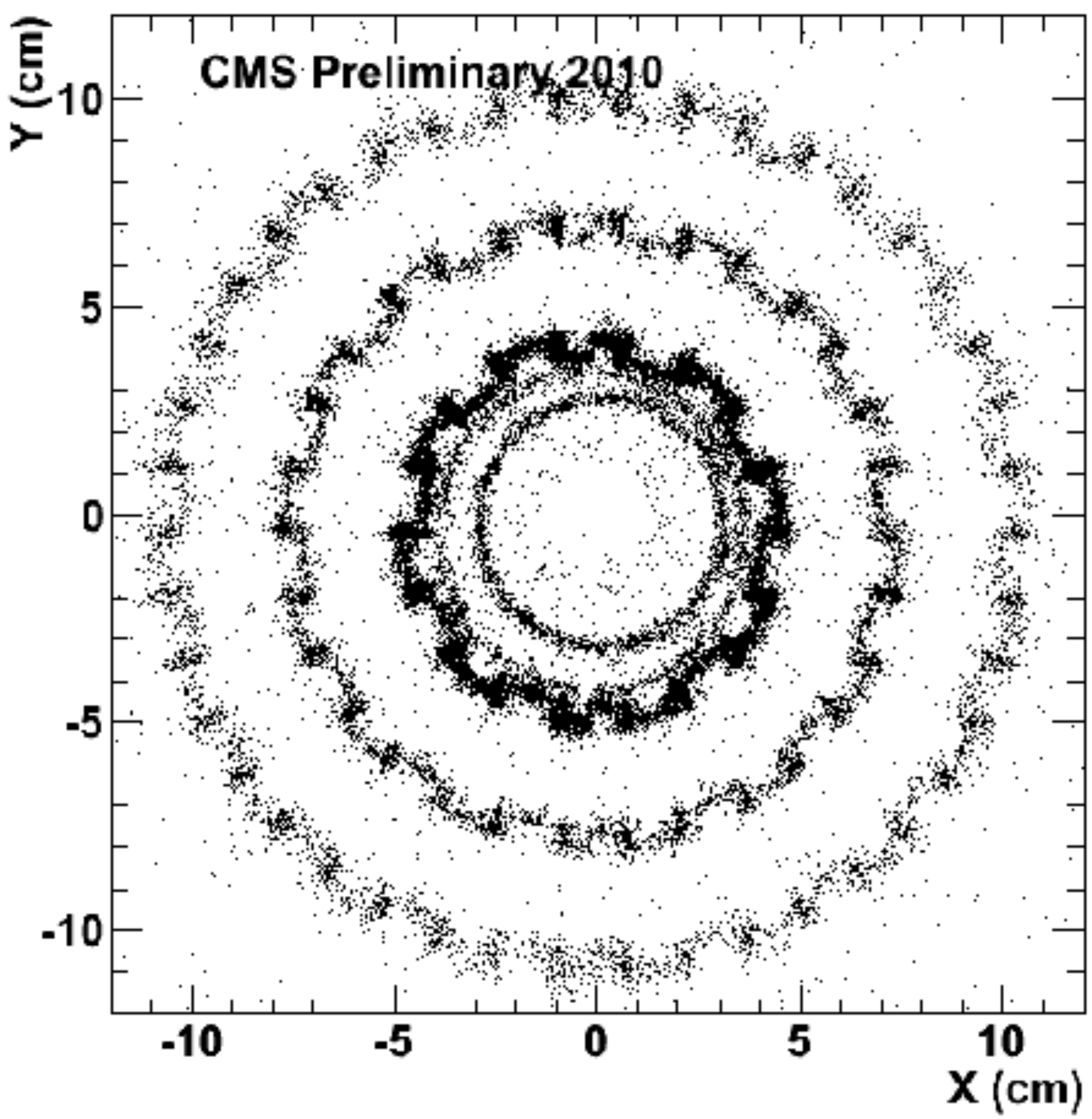
- At low lifetime limit — HF jets (wether reducible or not depends on object definition)
- Atypical hadronization of QCD jet
- SM particles with finite decay length
- Material interactions (photon conversions and nuclear interactions)
- Trackless jets from calo noise, OOT PU, ...

Background estimation

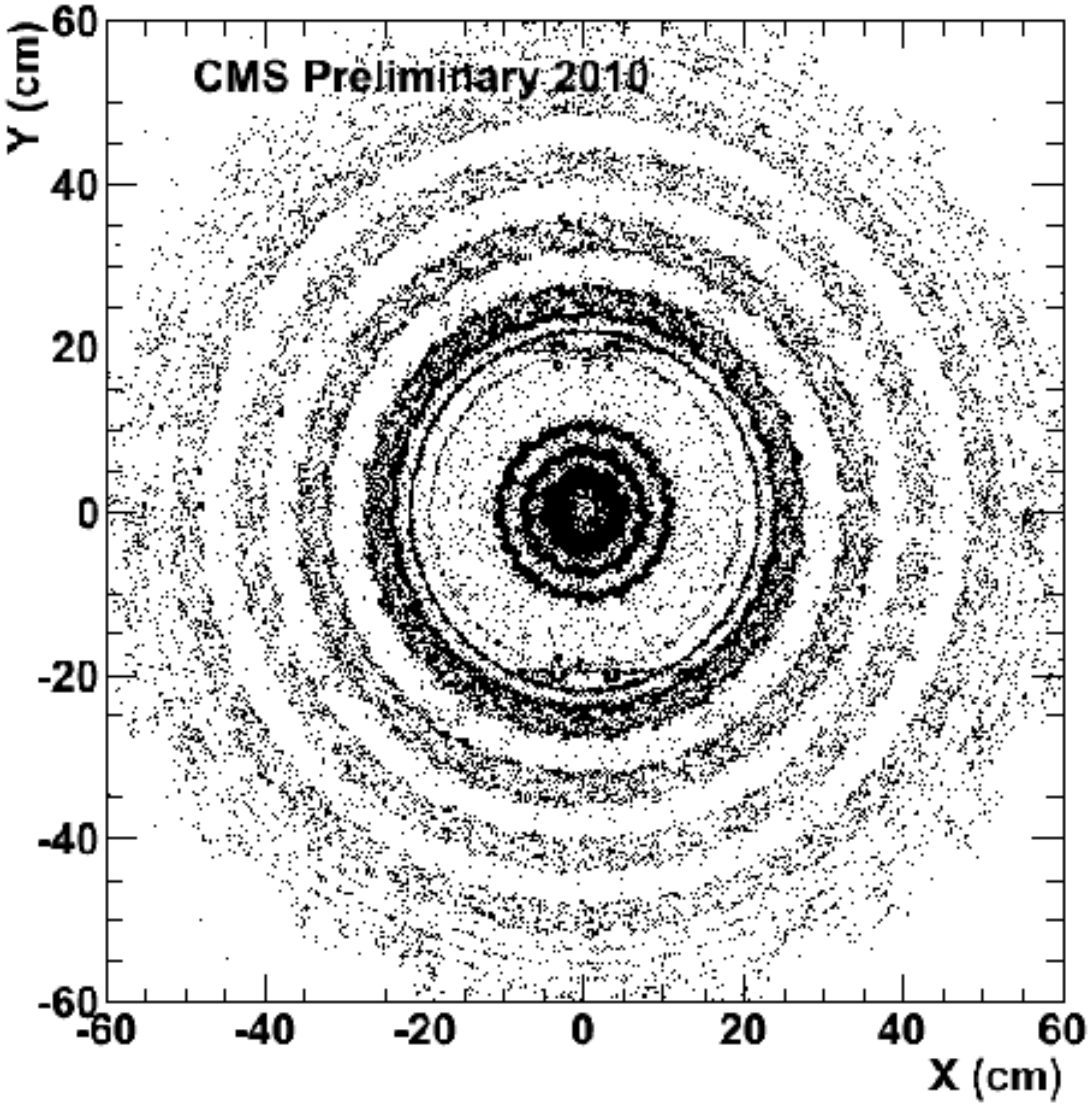
All the factors on the previous slide tend to push me towards a data-driven background estimation, but…

- Hard to find a ‘pure QCD’ background region
- Can use probes like photon, W/Z to select jets without signal contamination
- Can play spatial games to understand material effects

Displaced vertices in data

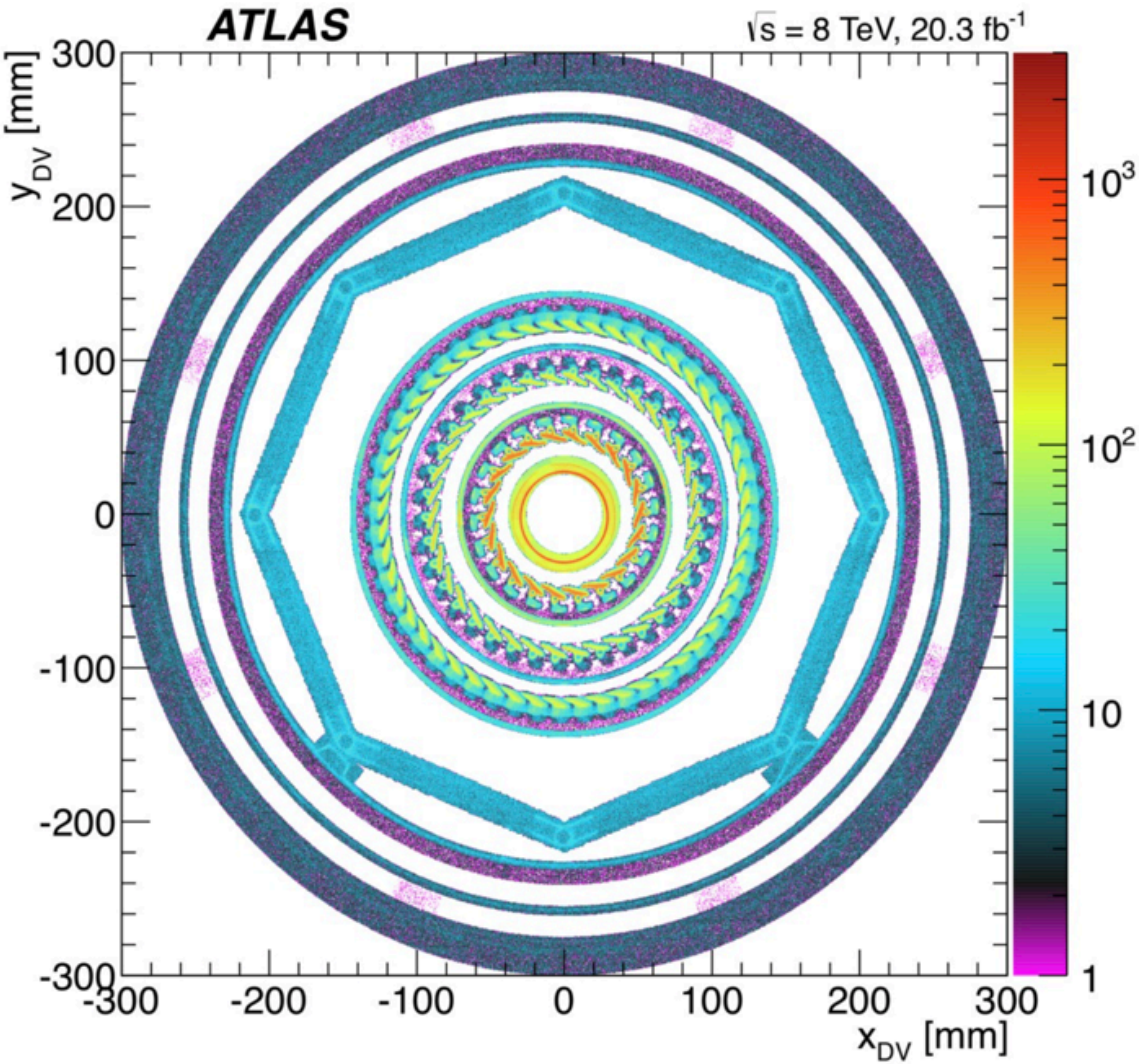


conv.



N.I.

Displaced vertices in data



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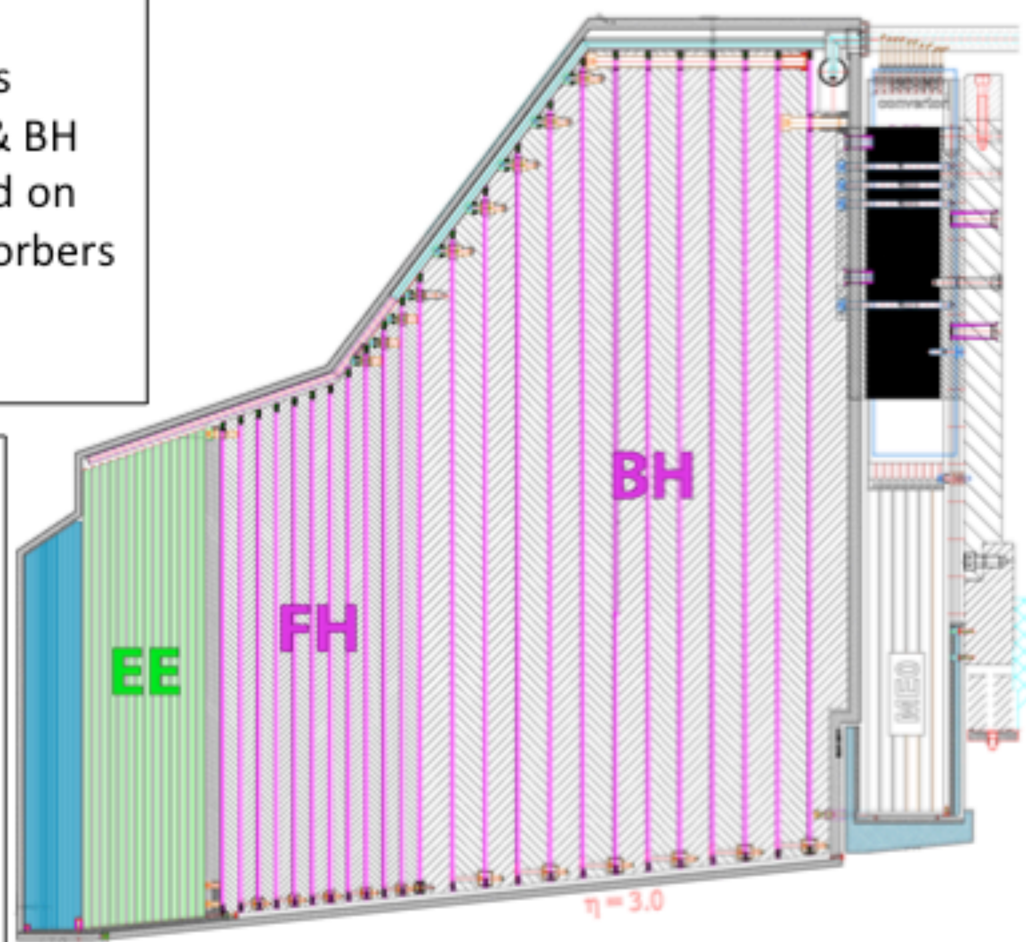
Phase 2 upgrade

Active Elements:

- Hexagonal modules based on Si sensors in EE and high-radiation regions of FH & BH
- "Cassettes": multiple modules mounted on cooling plates with electronics and absorbers
- Scintillating tiles with SiPM readout in low-radiation regions of FH & BH

Key Parameters:

- HGCAL covers $1.5 < \eta < 3.0$
- Full system maintained at -30°C
- ~600m^2 of silicon sensors
- ~500m^2 of scintillators
- 6M si channels, 0.5 or 1 cm^2 cell size
- ~22000 si modules
- Power at end of HL-LHC: ~60 kW per endcap



Endcap Electromagnetic calorimeter (**EE**): Si, Cu & CuW & Pb absorbers, 28 layers, 25 X_0 & ~1.3λ
Front Hadronic calorimeter (FH): Si & scintillator, steel absorbers, 12 layers, ~3.5λ
Backing Hadronic calorimeter (BH): Si & scintillator, steel absorbers, 12 layers, ~5λ

Summary

- Dark showers are interesting to search for
- A lot of overlap with existing analyses and dedicated analyses are on the way
- Challenges in triggering, reconstruction, background estimation
- Stay tuned