Meet a USCMS Postdoc

USCMS Summer Undergraduate
Research Internship Program 2022

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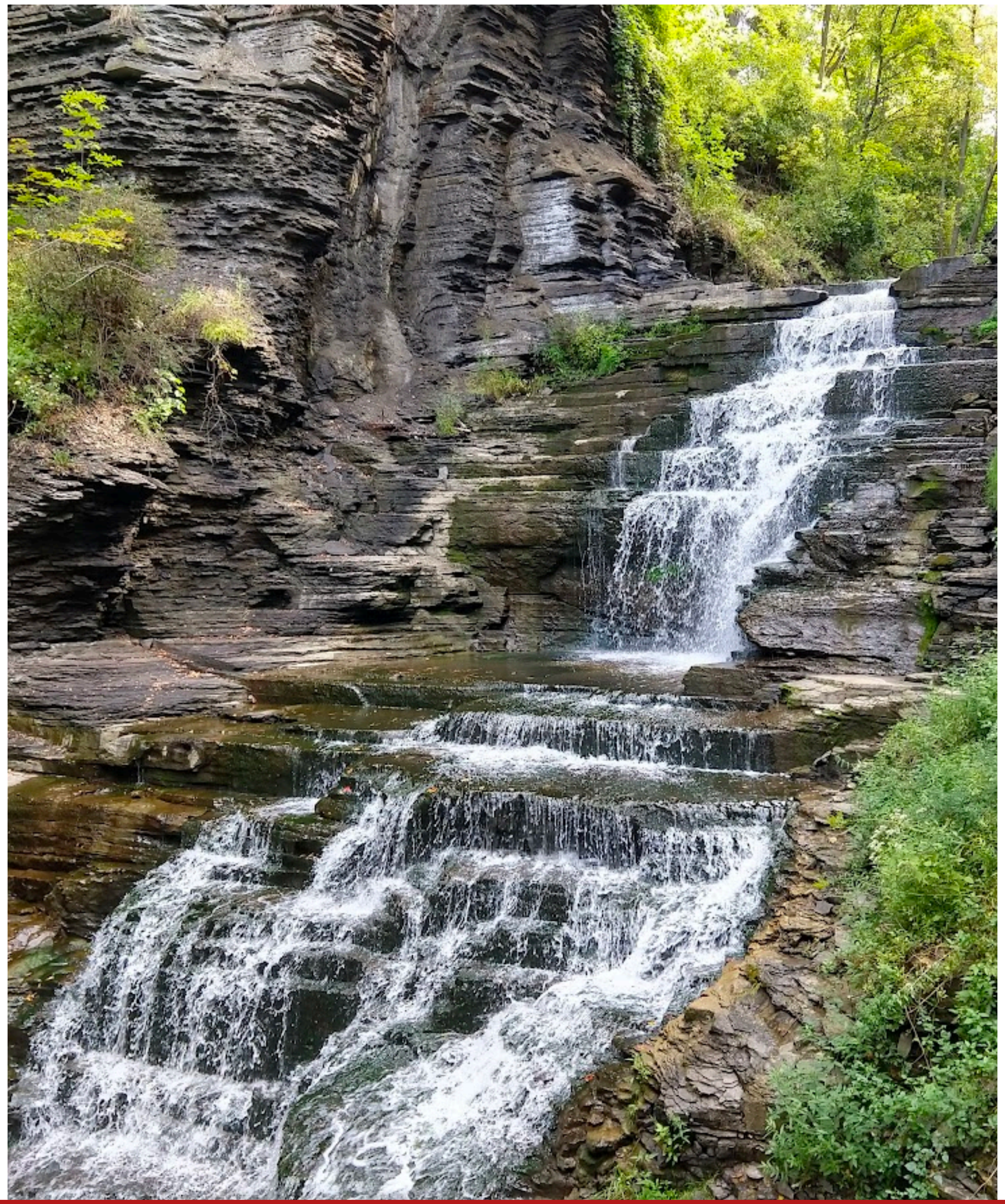
Introduction

Hi! I’m a postdoc at Cornell University.

Please feel free to interrupt and ask questions during the talk! I only have a few slides, and we can think of this as a Q&A / discussion.



My Background

1) Undergrad at Rutgers; research on CMS and HPS (small fixed-target experiment at Jefferson Lab in Virginia)

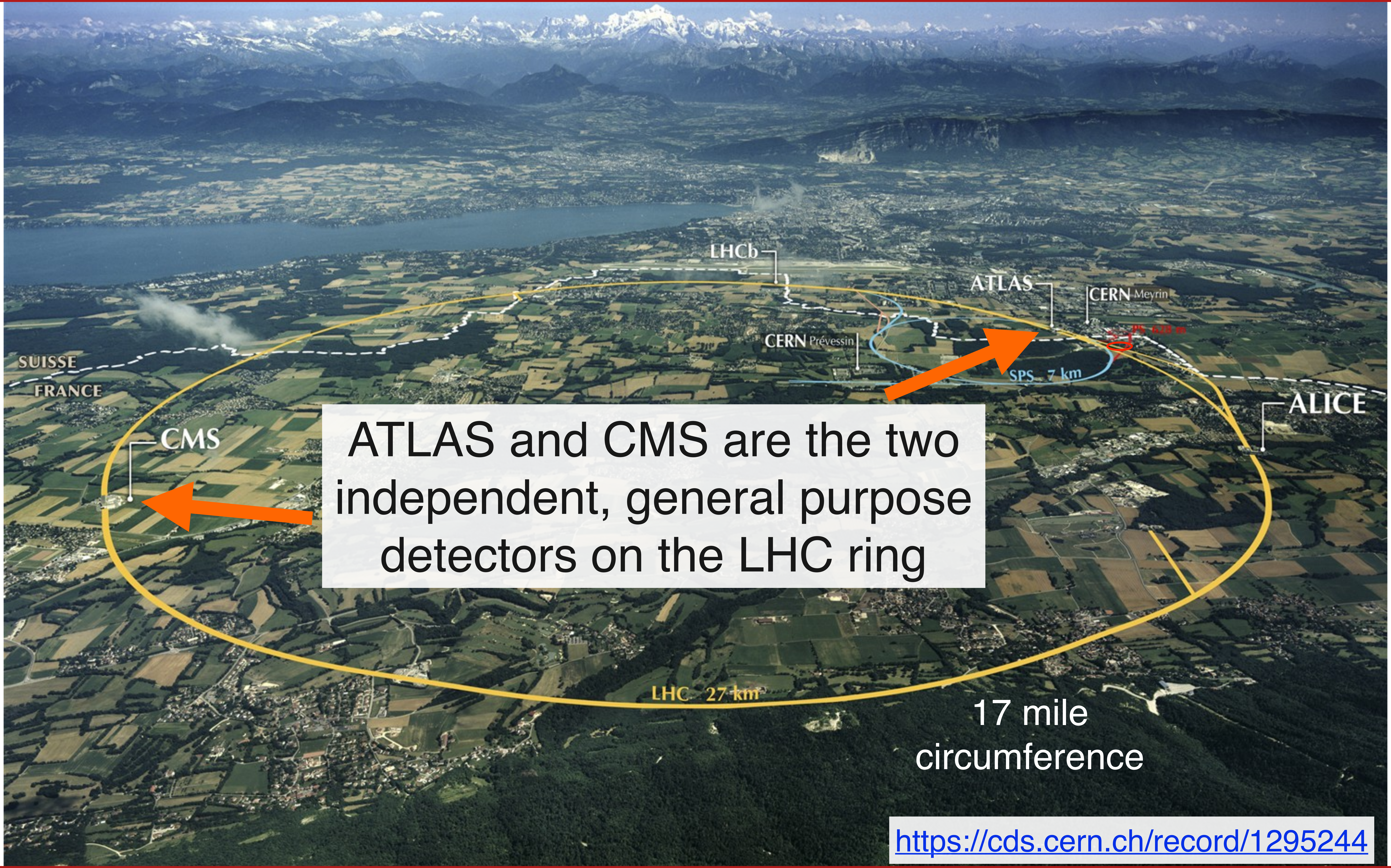
2) PhD at UPenn; research on the ATLAS experiment

3) Postdoc at Cornell; research on CMS

"Big Picture" Research Interests

- Searches for new physics
  - with long-lived particles, or
  - with leptons
- Using our detector to reconstruct and identify particles of interest, while discriminating against background sources.
- Detector upgrades—to ensure high detector performance even in the harsh conditions expected at the HL-LHC!

Research on ATLAS as a grad student (in brief)

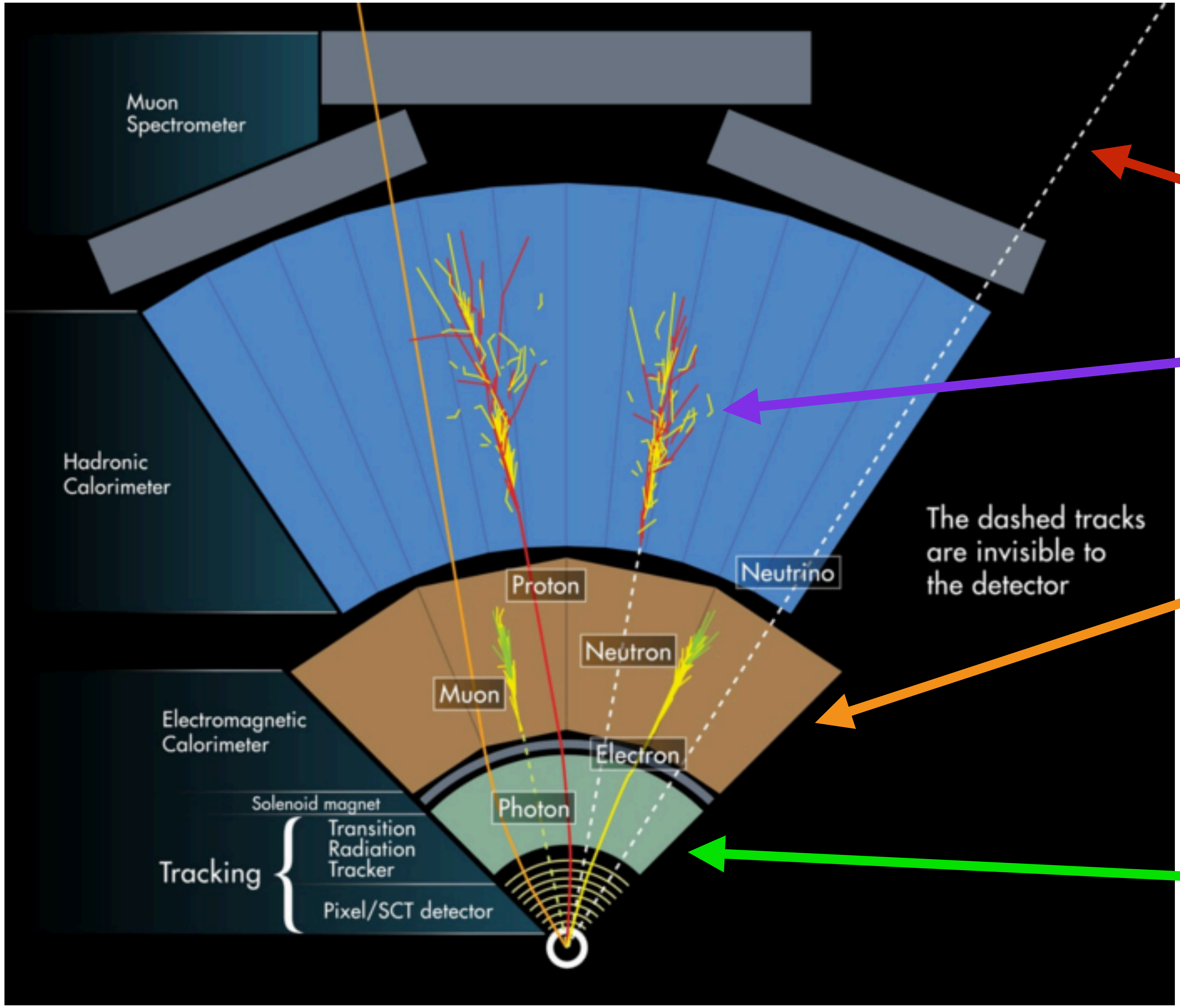


ATLAS and CMS are the two independent, general purpose detectors on the LHC ring

17 mile circumference

https://cds.cern.ch/record/1295244

Research on ATLAS as a grad student (in brief)



"MET" = $-\Sigma p_{T,vis}$

Hadronic "jets"

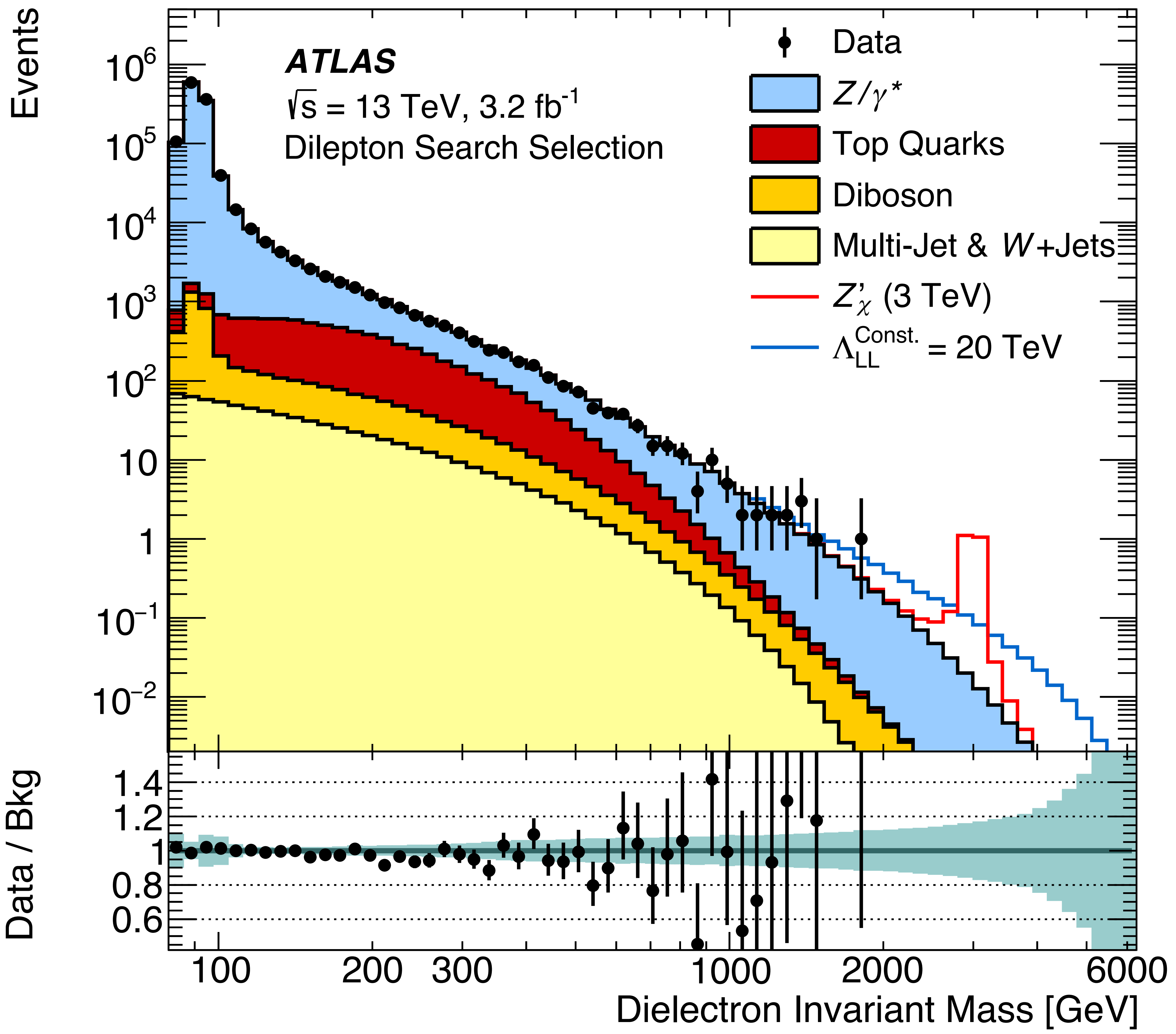
LAr accordion EM calorimeter

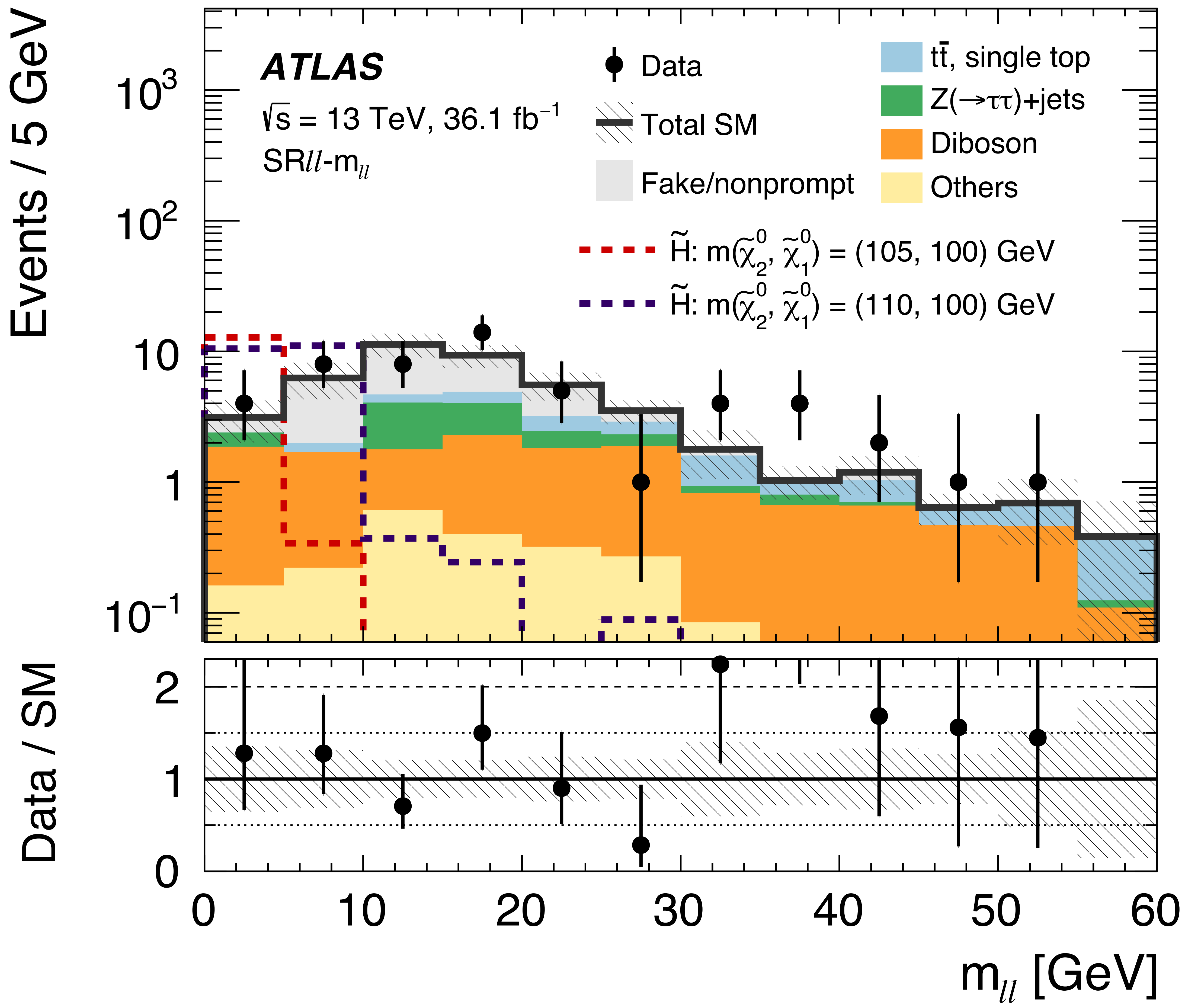
TRT provides tracking and $e^{\pm}$ ID

I was responsible for defining the electron identification for ATLAS during Run 2.

Worked on extending the algorithm used to both low and high p_T, as well as its use at the software-based trigger.

Research on ATLAS as a grad student (in brief)





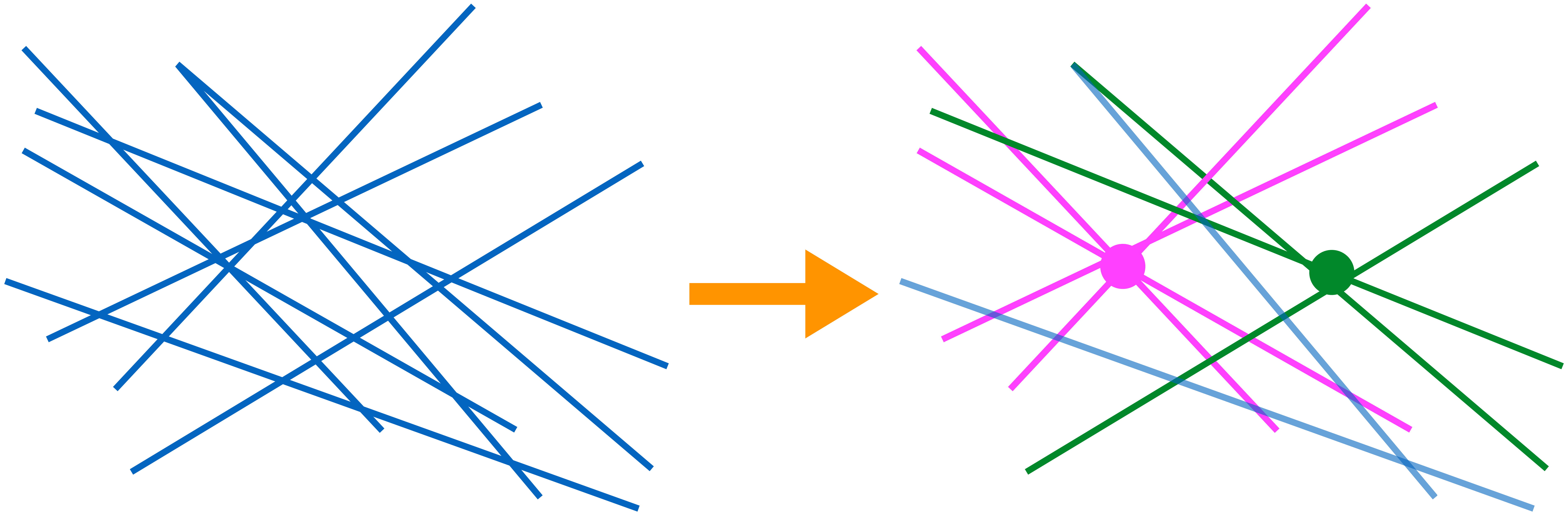
Searches for new physics at both high mass and low mass relied on a well-performing electron identification!

Research on CMS as a postdoc (in brief)

Building on my experience as a grad student, as a postdoc I've worked on:

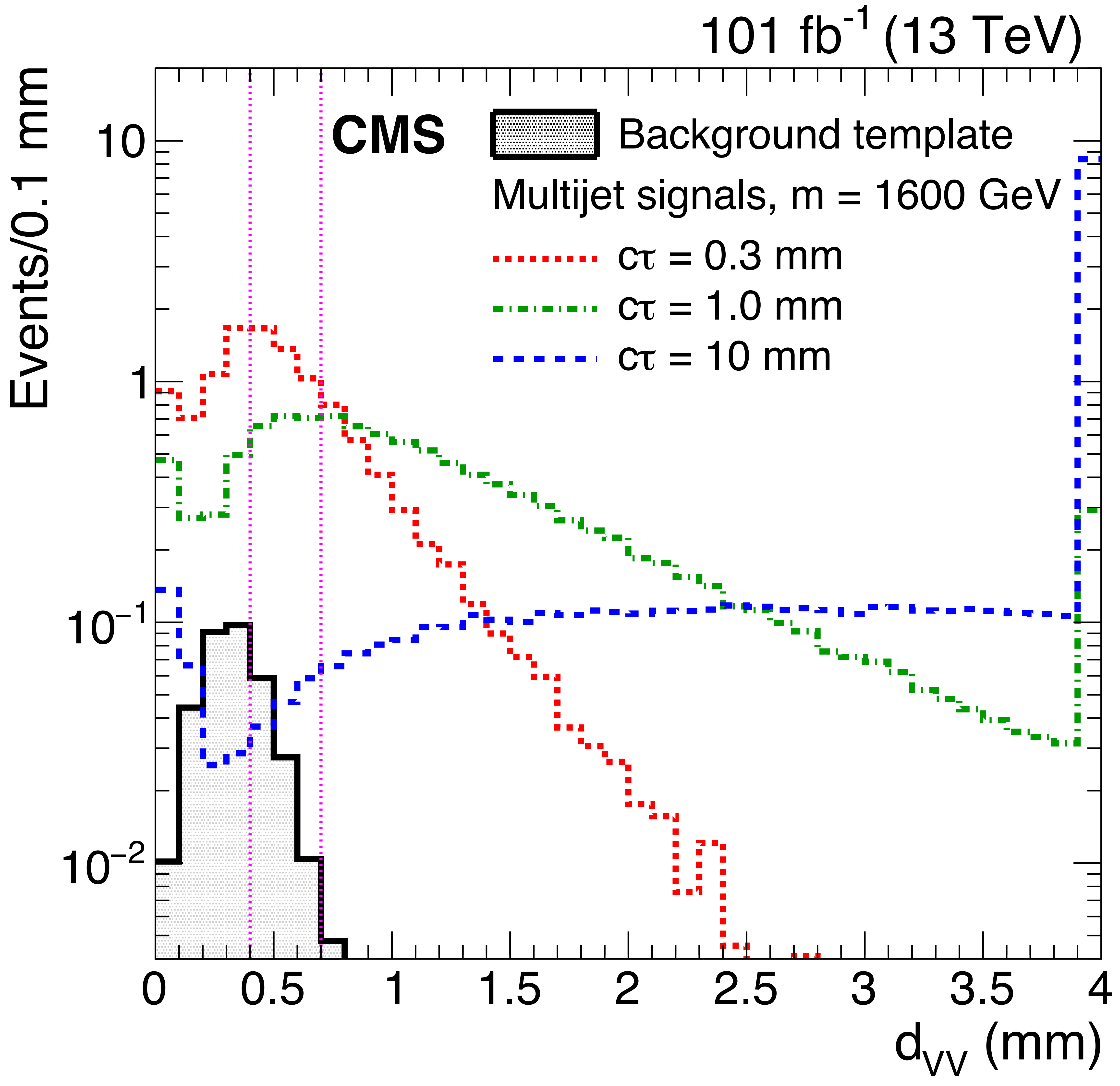
- Searches for long-lived particles decaying to jets w/ displaced decay points
    - Requires custom reconstruction algorithm, data-driven background estimation, and other fun + novel techniques.
- Co-leading the group searching for "exotic" new physics in final states with leptons and photons
- Upgrades for the Inner Tracker
    - Including beam tests of pixel sensors to evaluate their performance, as well as work towards setting up a quality control center here at Cornell

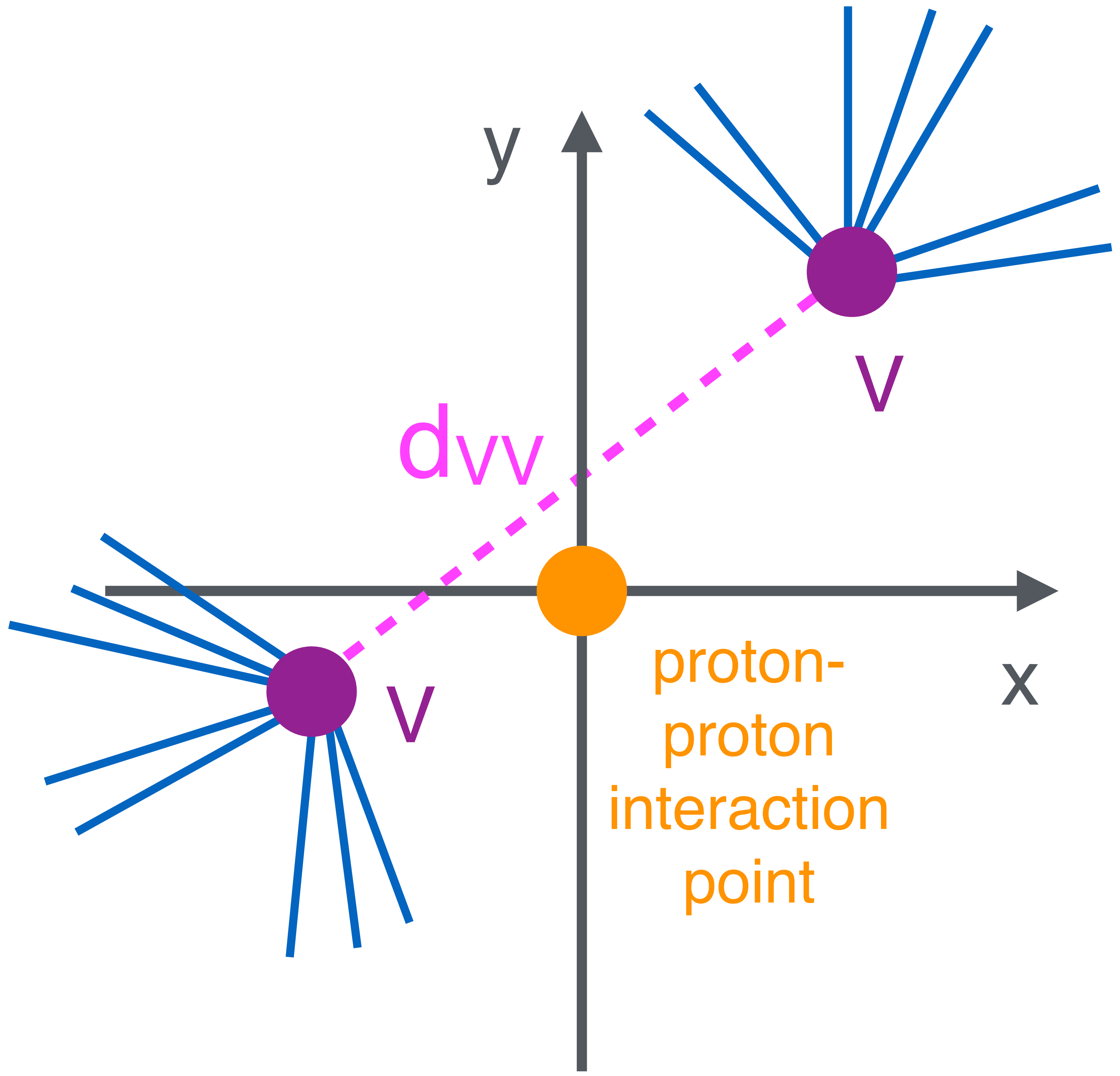
Search for displaced vertices



Custom vertex reconstruction: iteratively merge tracks into vertices, and apply various quality criteria to distinguish against backgrounds (e.g. many tracks per vertex, which is typical of signals!)

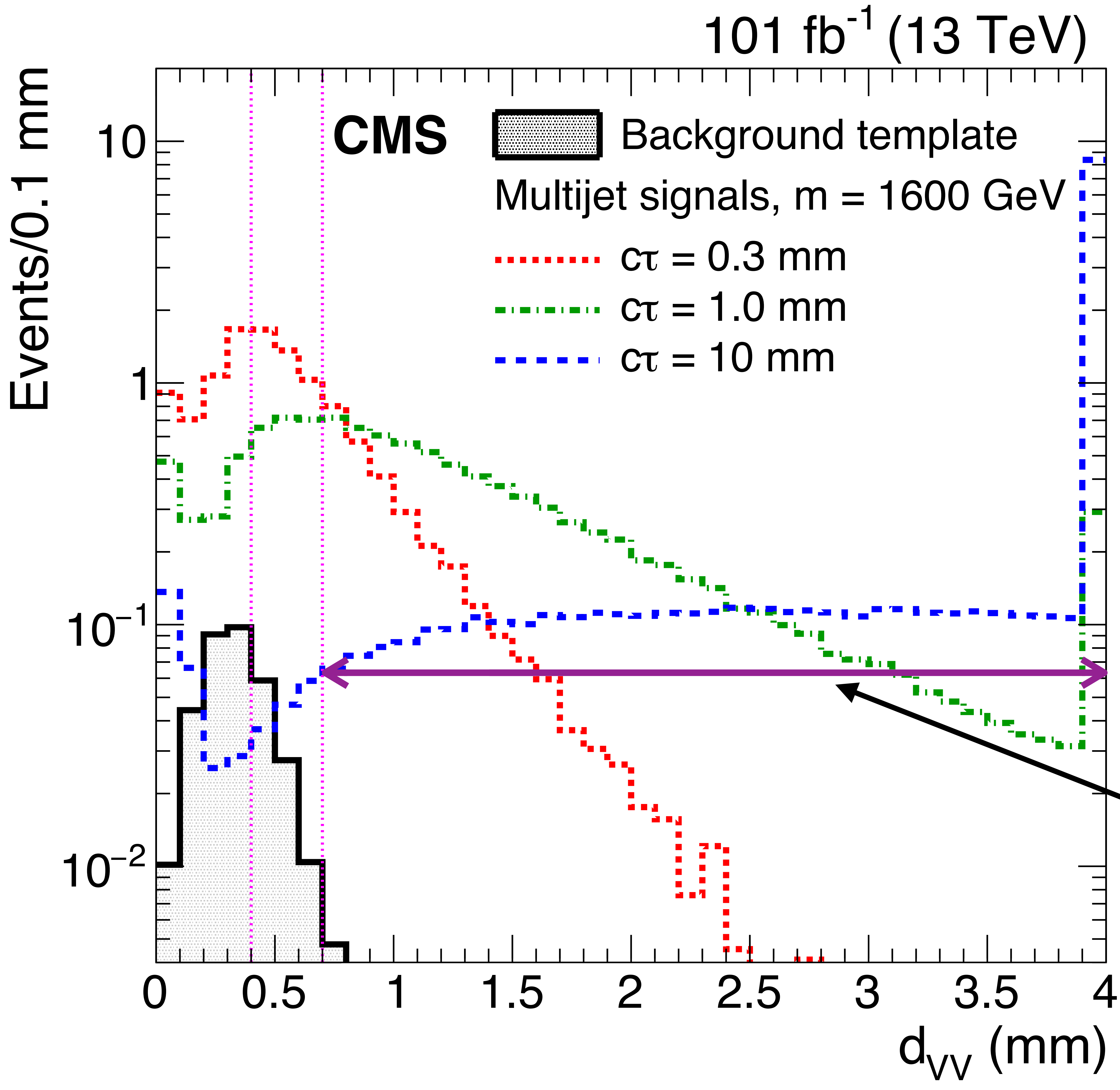
Search strategy

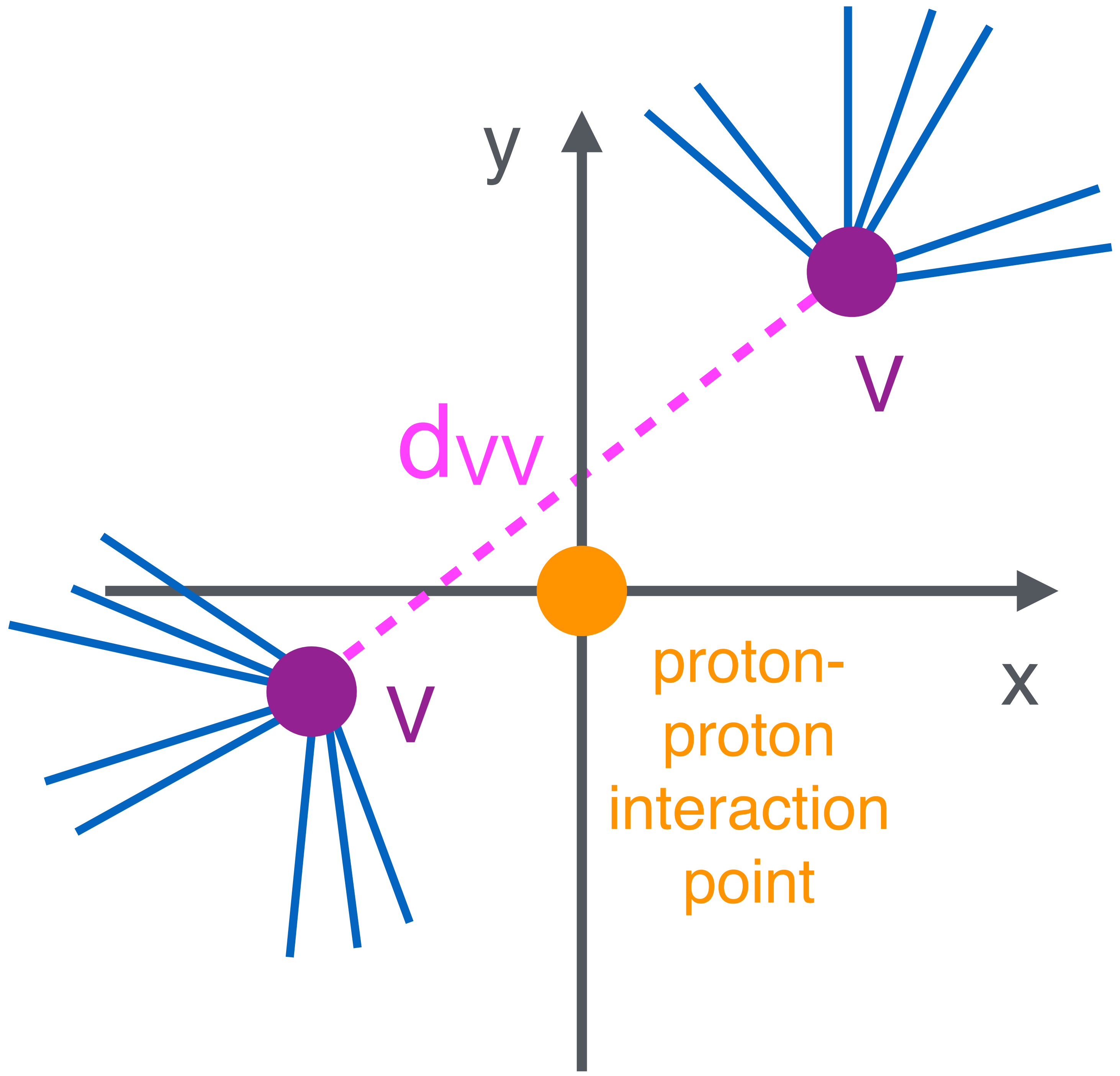




d_{VV} is the primary discriminating variable, and three search bins are used.

Search strategy





Expect many signal events in this bin alone, but observed **zero** in the data! Use this to set limits on potential signal models.

Inner Tracker / Pixel Sensor Upgrades

To study rare processes, we need large datasets

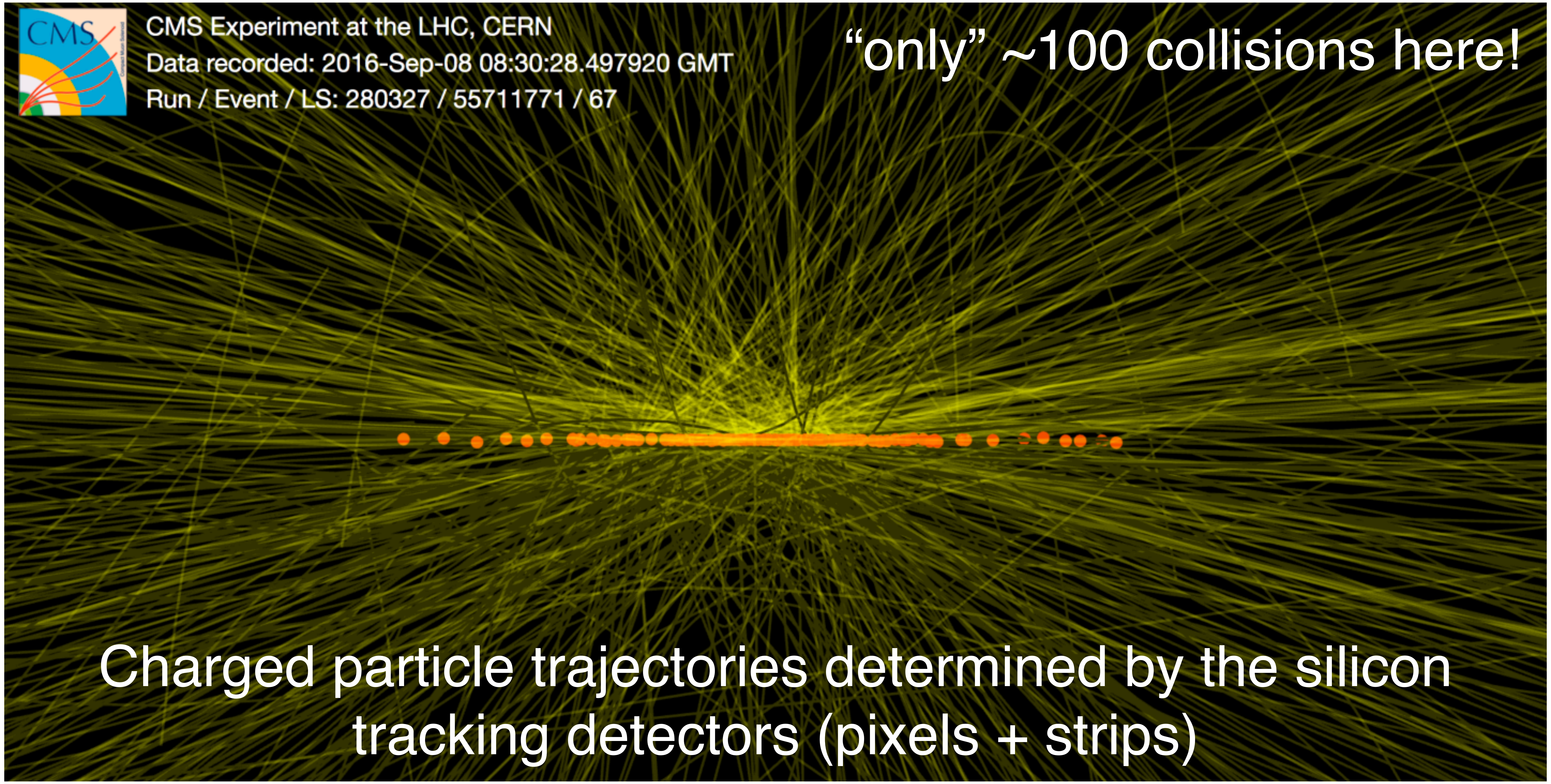
- HL-LHC targets ~3000-4000 fb^{-1} of pp collisions
  - ~45-60x more than CMS collected in 2018

How to reach that target?

- Option 1: run at same conditions for 45-60 more years!
  - Pros: job security (?), no innovation needed
  - Cons: not very cost effective, would get boring, wouldn't get answers to fundamental questions for a very long time!

Inner Tracker / Pixel Sensor Upgrades

Option 2: use of large pileup—up to 200 pp interactions per bunch crossing at HL-LHC!



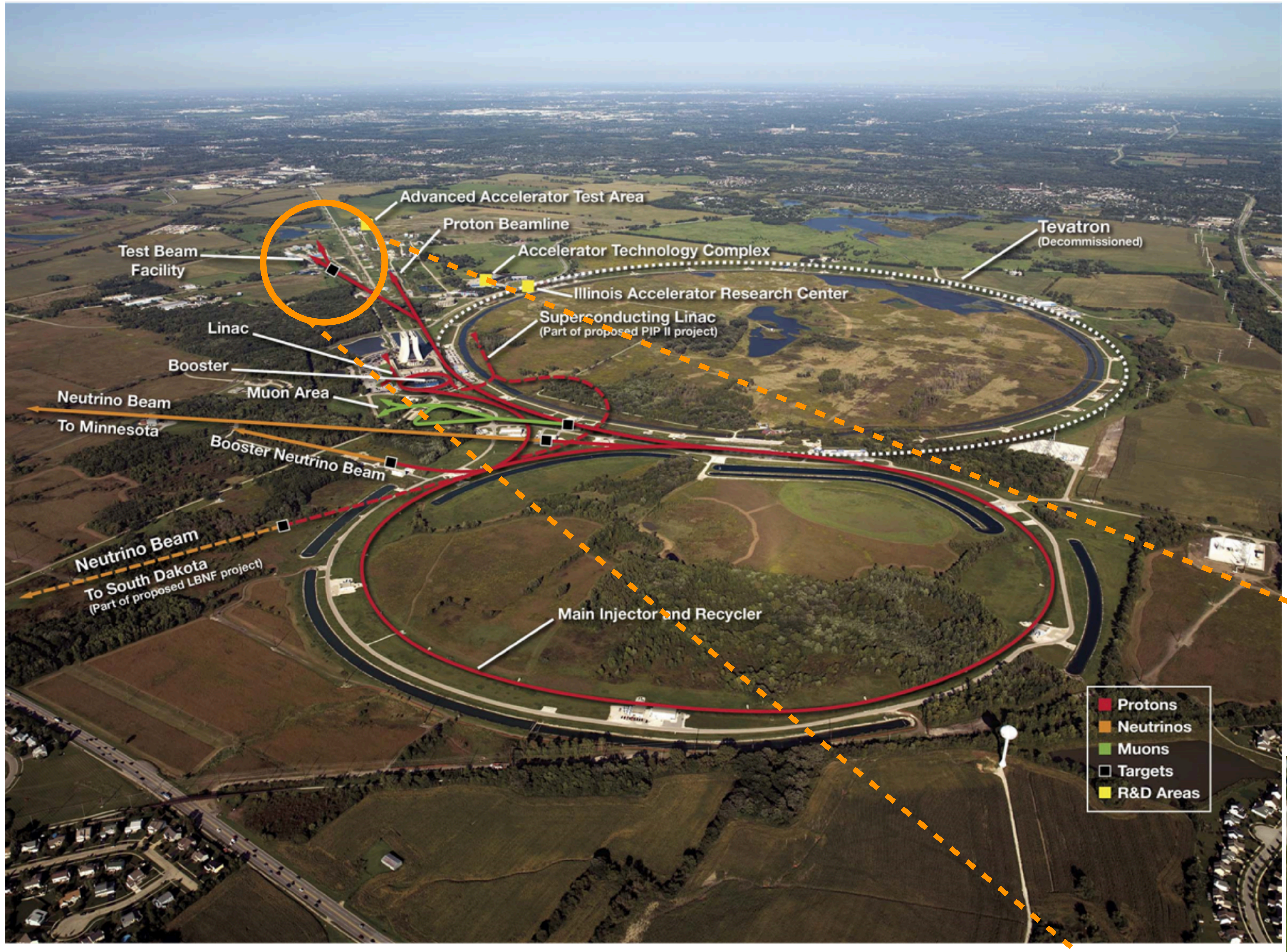
Inner Tracker Upgrades: Challenges

Challenges that the upgraded pixel detector must solve:

- *Many* charged particles traveling through the detector.
  - Up to 3 billion hits per cm^2, per second!
  - How to distinguish interesting collisions from uninteresting ones (“vertexing”)?
- How to survive huge radiation fluences? Up to 10x more radiation than current pixel detector designed for.

Solutions include smaller pixels (finer granularity by 6x), thinner pixels, new technologies (“3D” sensors), etc. But we have to test that our prototypes work!

Fermilab Accelerator Complex and Test Beam Facility



Facilities at FNAL are used to:

- irradiate our sensors to emulate their expected rad damage at HL-LHC
- and to test their performance (e.g. hit detection efficiency, position resolution, etc.)

Test Beam Telescope

We place prototype sensors in the middle of a tracking “telescope” made of silicon detectors

- The telescope measures charged particle tracks from the 120 GeV proton beam, and we use these tracks to evaluate the pixel sensor performance

strip telescope (two 30μm pitch sensors, for x and y measurements, at each position)

prototype sensor in cold box

strip telescope

pixel telescope (100x150 μm² pitch; primarily for hit confirmation)

Test Beams

pixel sensor

For our CMS pixel sensor prototypes, we've performed >10 test beams in the past few years, each lasting several weeks.

- Tested dozens of devices, which typically performed as we hoped!
  - Always *some* surprises, and our test beam time is often quite hectic.
- We then irradiated many of these sensors, and started to see how well we should expect them to perform during later stages of the HL-LHC run
  - Here there were *more* surprises—some which we were able to resolve, and others that are a work-in-progress
  - But many of the surprises were unrelated to the sensor performance, and typically we've found high performance even at large radiation fluences

Summary

In my completely biased opinion, I think experimental particle physics is a really fun field to be involved in, and we're in very exciting times.

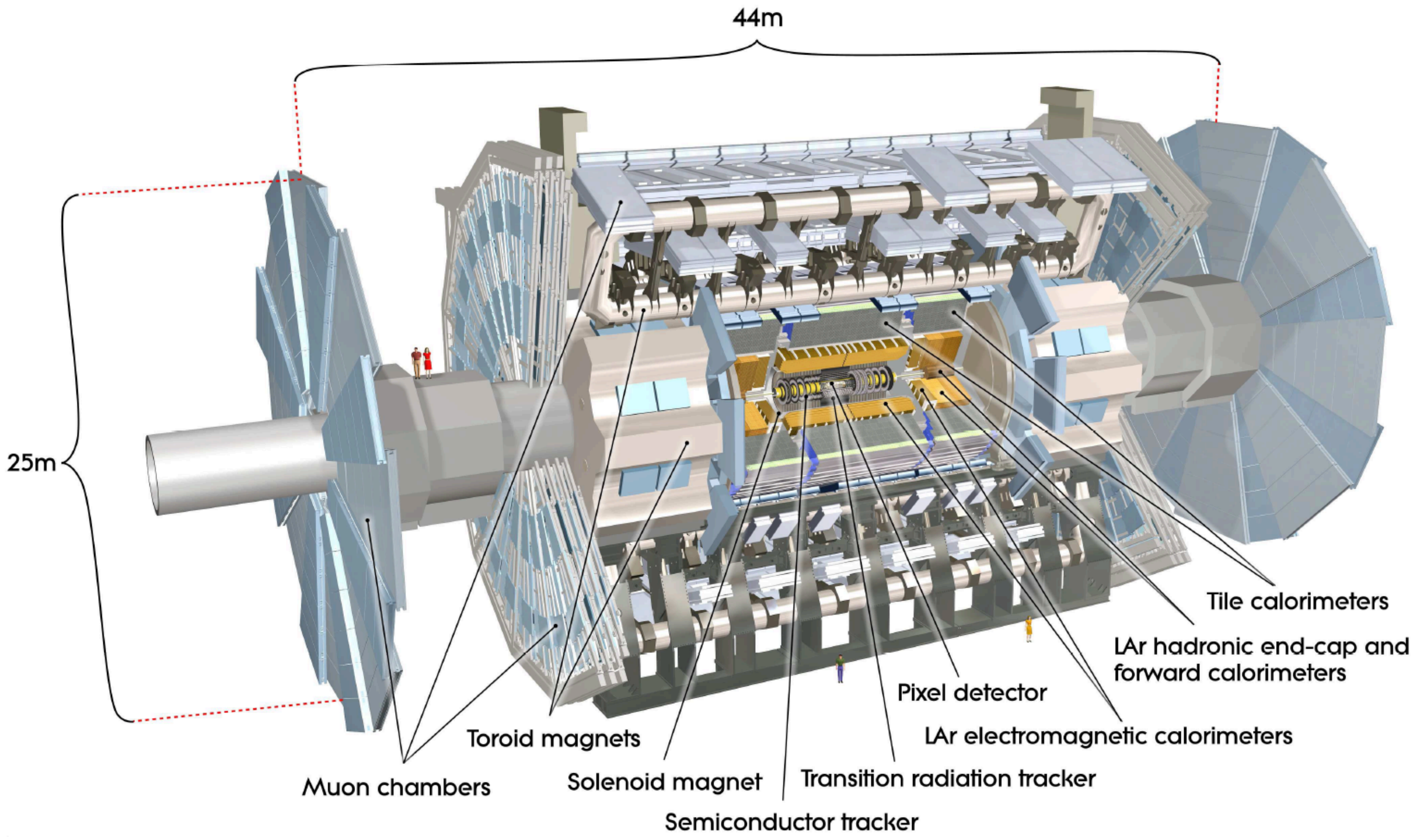
- Huge collaborations like CMS can seem overwhelming at times, but they give opportunities to work with many people on *very* interesting problems.
  - Personally, I've never felt that any project I've ever worked on was unimportant or uninteresting.
  - We're trying to find answers to really challenging but fun questions: whether it is where new physics lies, how to make our software efficient, or how to build detectors that can withstand huge amounts radiation.

Enjoy the rest of the summer internship!

In addition to any questions now, feel free to email me with any follow-ups.

Backup

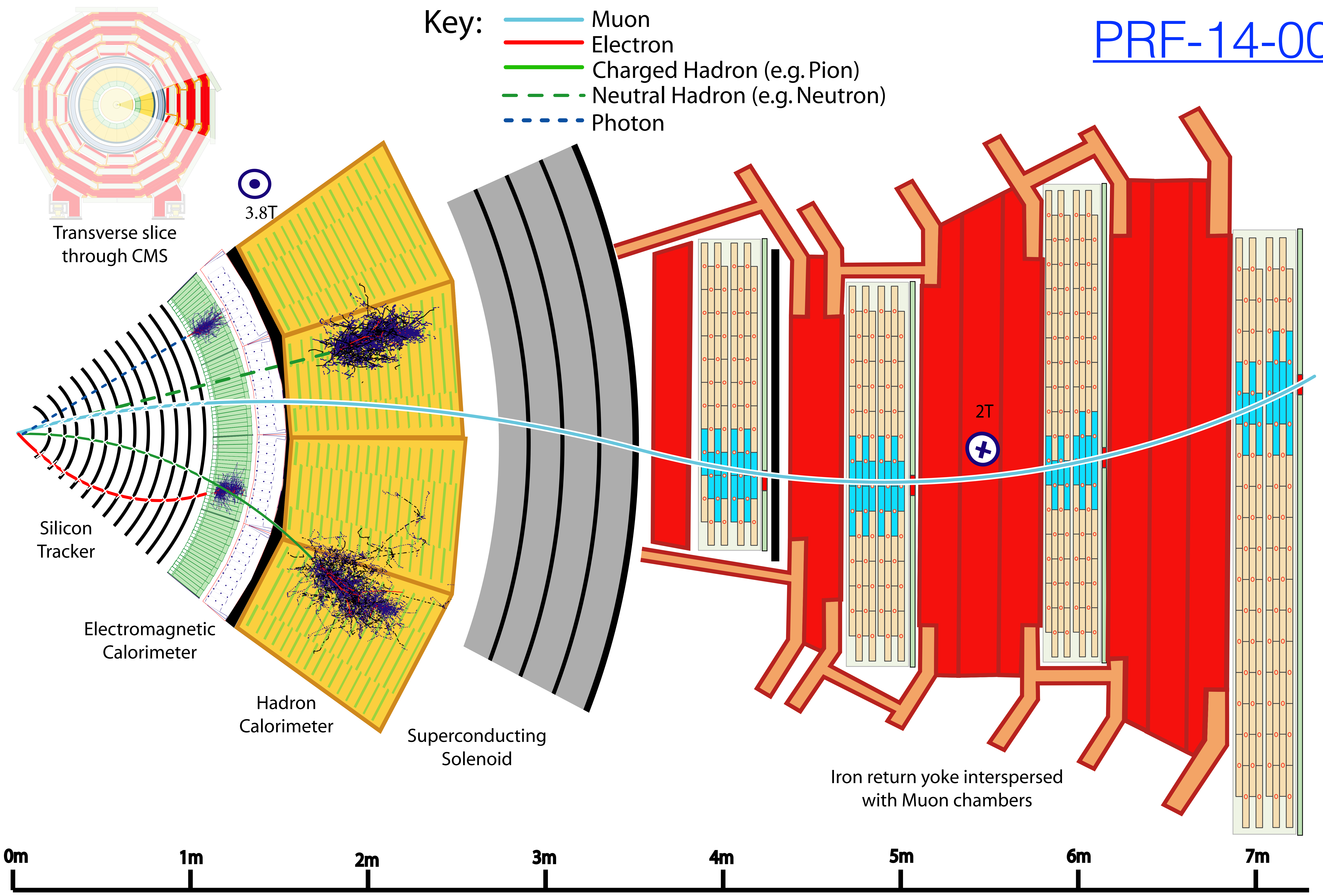
The ATLAS Detector



ATLAS is a 7000 ton machine designed to look for particle signatures resulting from pp collisions

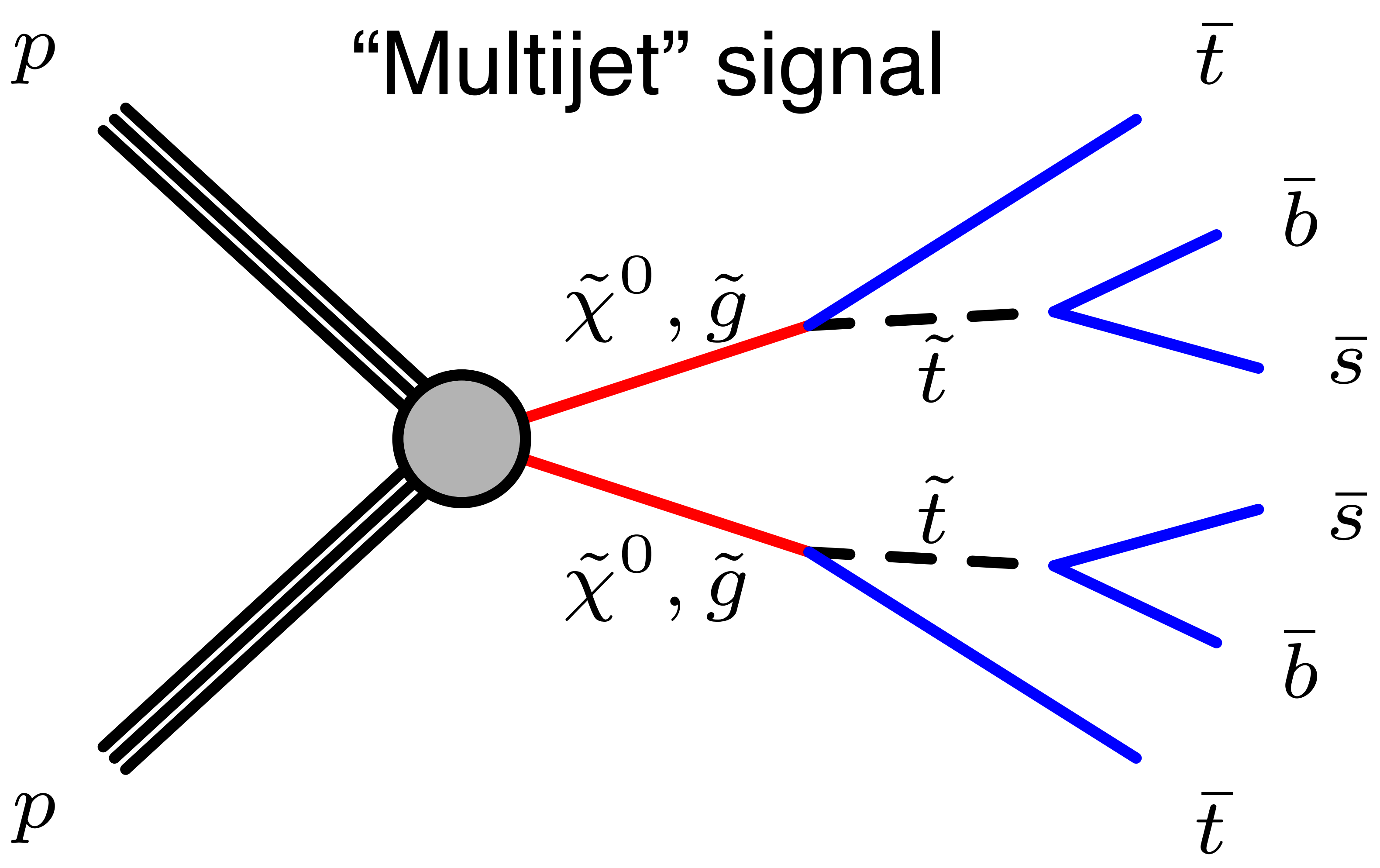
The CMS Detector

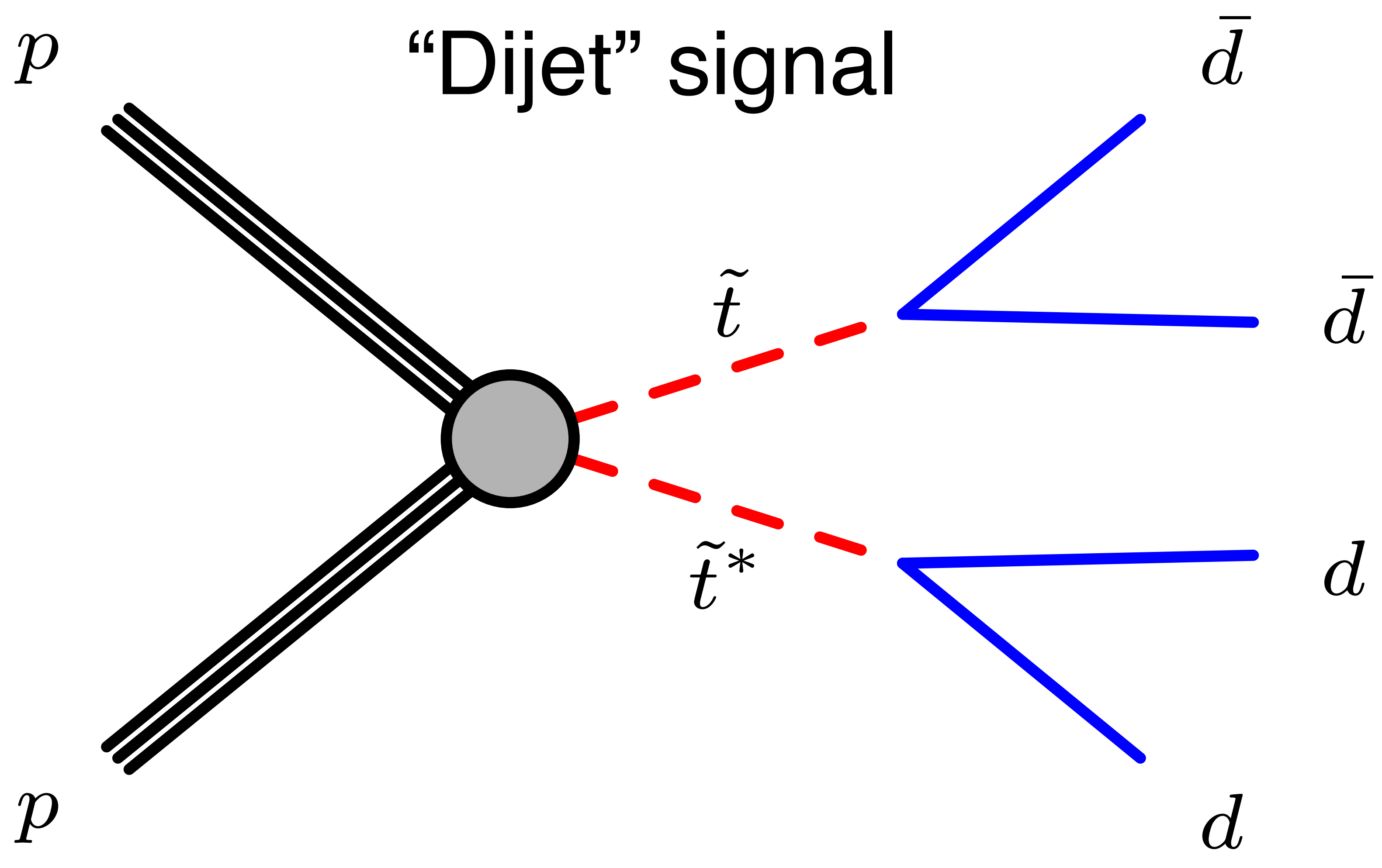
[PRF-14-001]



Search for displaced vertices

Many models predict final states w/ hadronically decaying pairs of LLPs

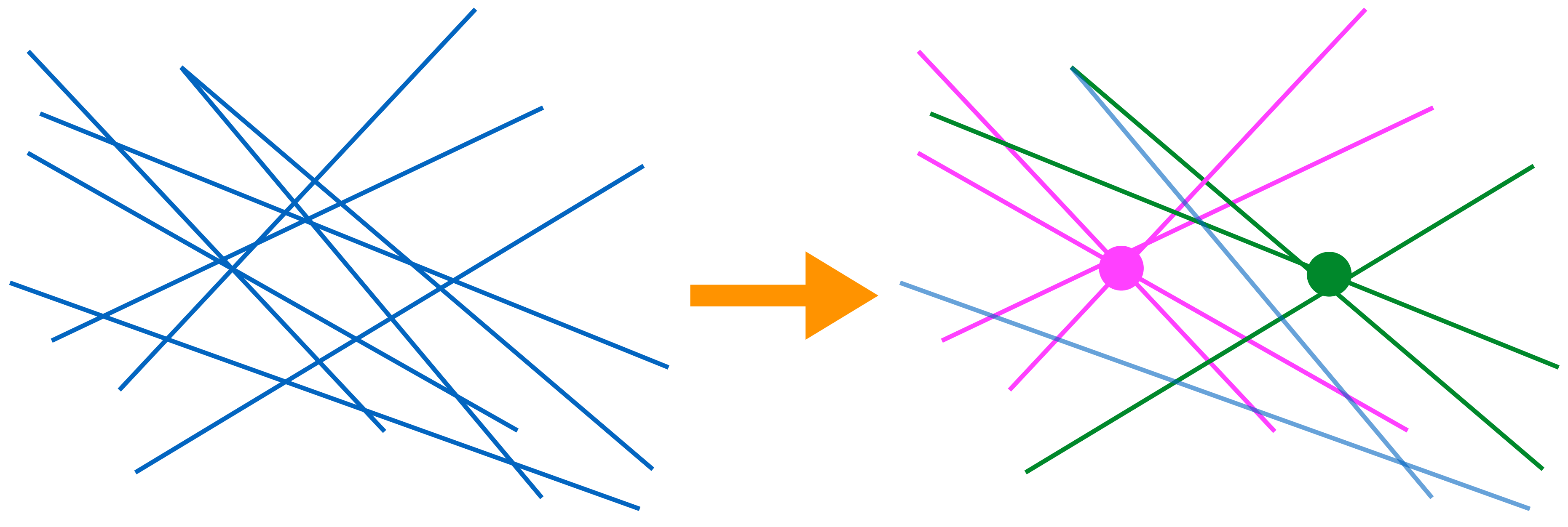




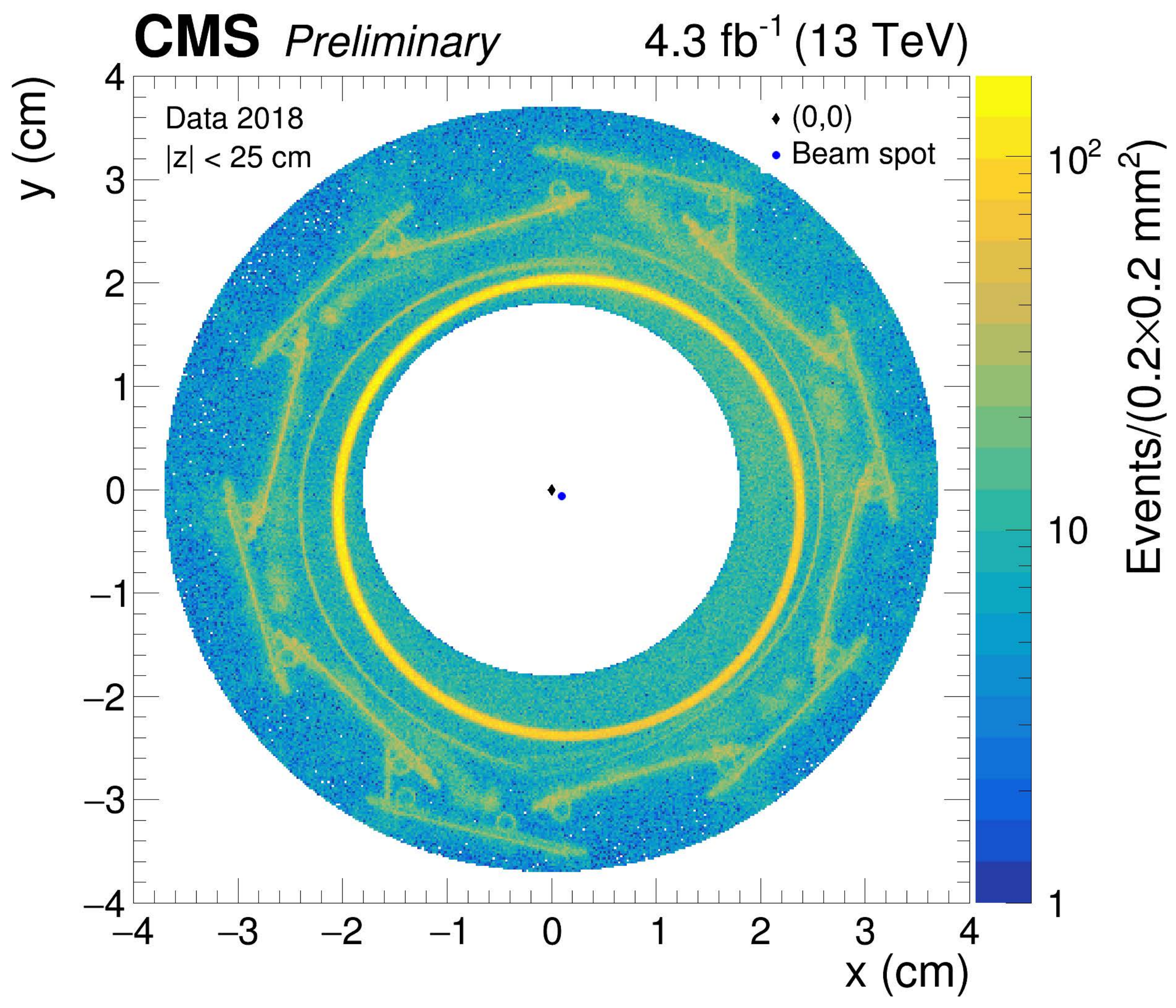
RPV SUSY models w/ small couplings prevent e.g. proton decay, while allowing the LSP to be long-lived before decaying.

We use these as our benchmark models, but the search is fairly model-independent!

Search for displaced vertices

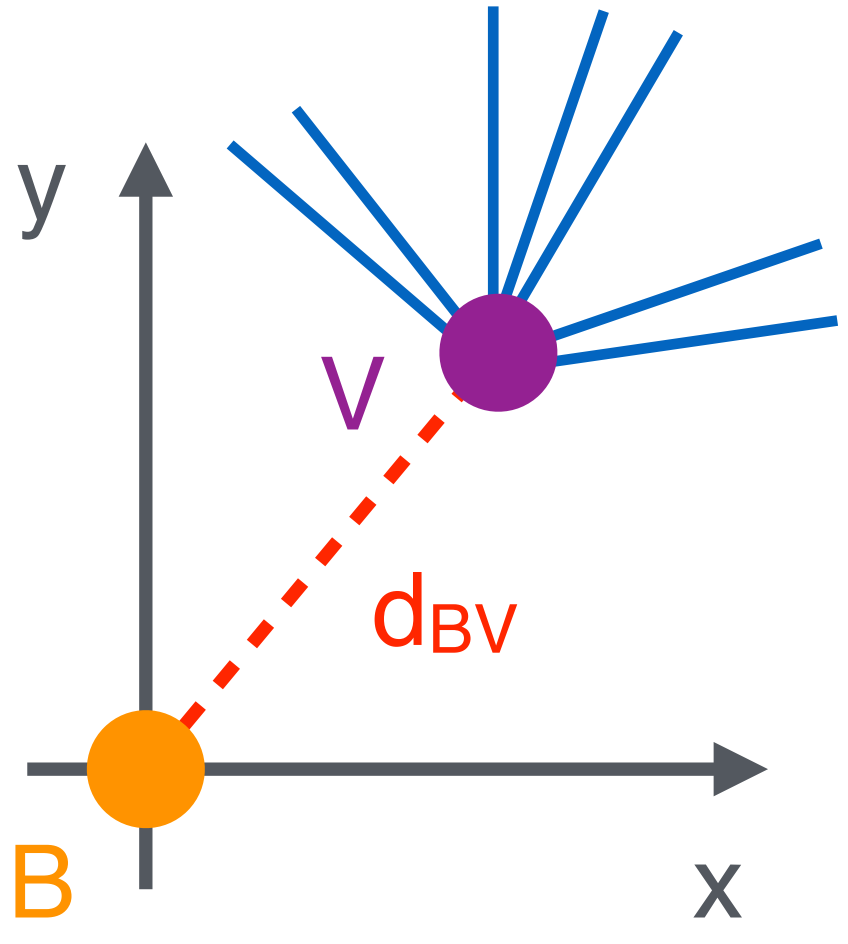


Custom vertex reconstruction: iteratively merge tracks into vertices.



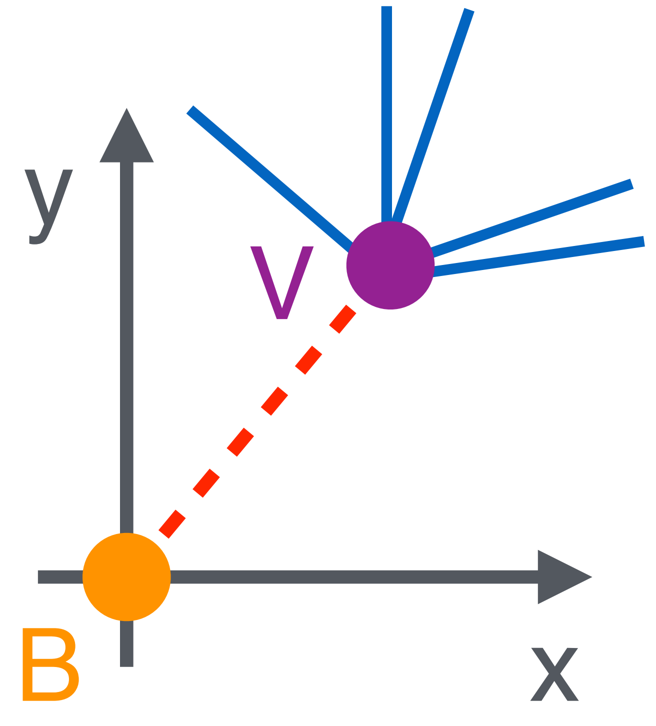
Only accept DVs within beam pipe

TrackerMaterial Position2018

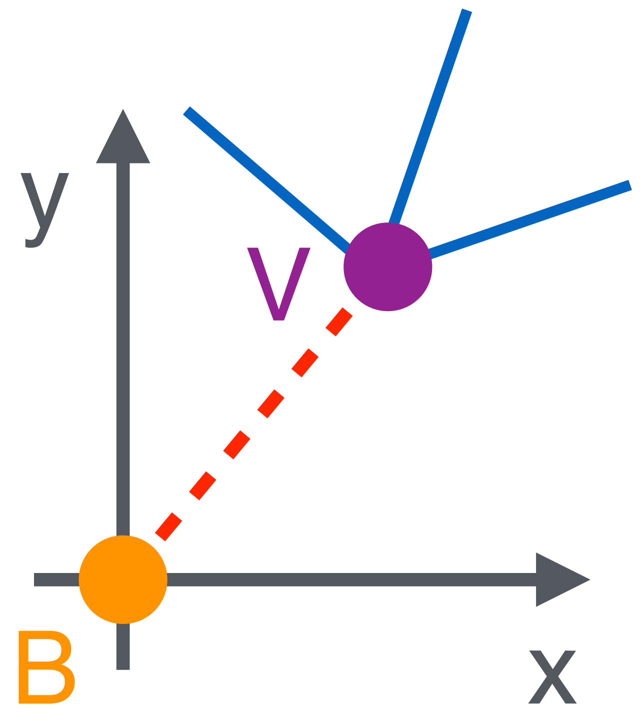


Require $d_{BV} > 100\ \mu m$ (avoid displaced PVs)

$\sigma(d_{BV}) < 25\ \mu m$ allows us to suppress b-jet vertices (collimated)



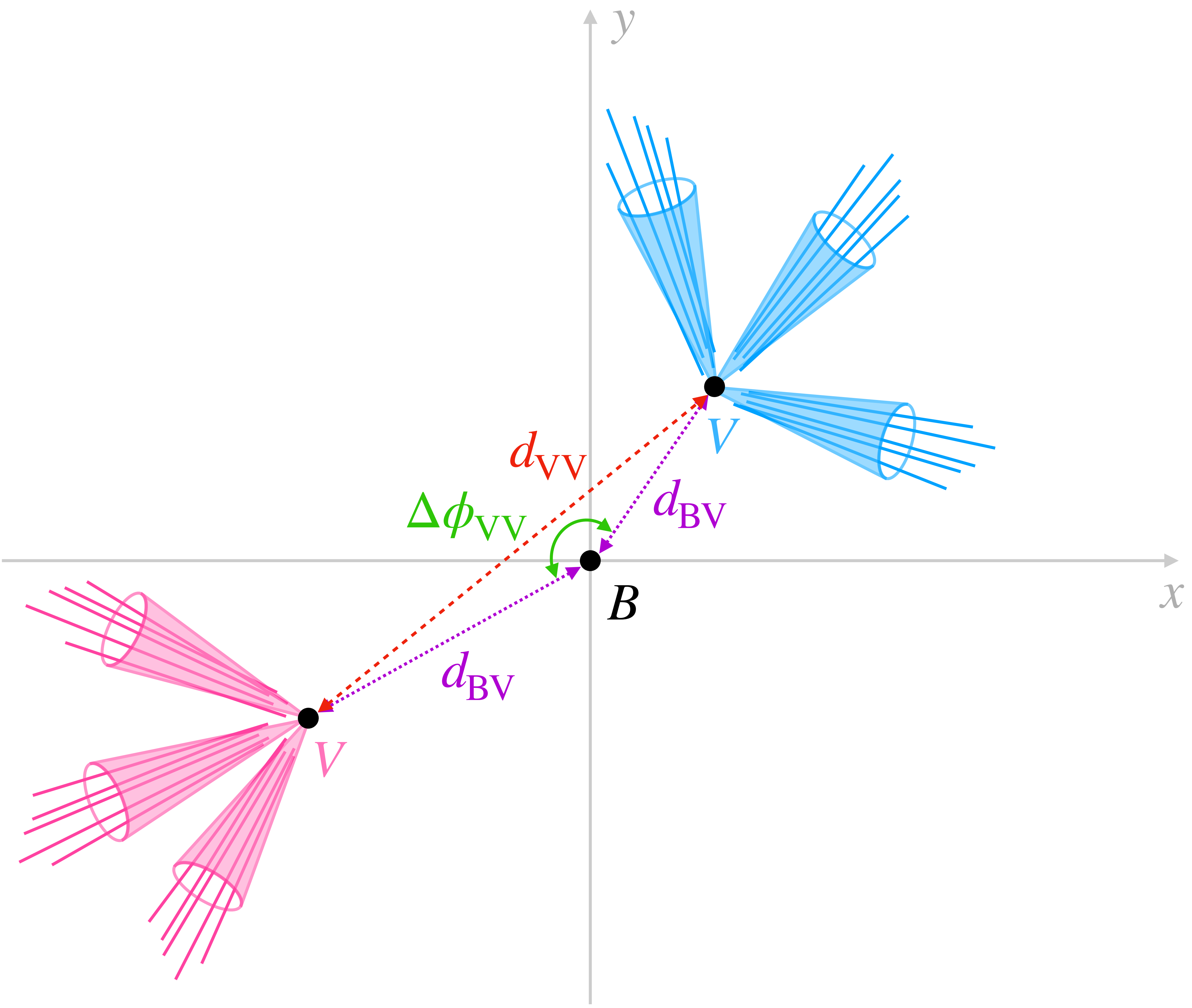
Signal vertices: $n_{track} \geq 5$



Control sample: $n_{track} = 3$ or 4

Data-Driven Background Estimation

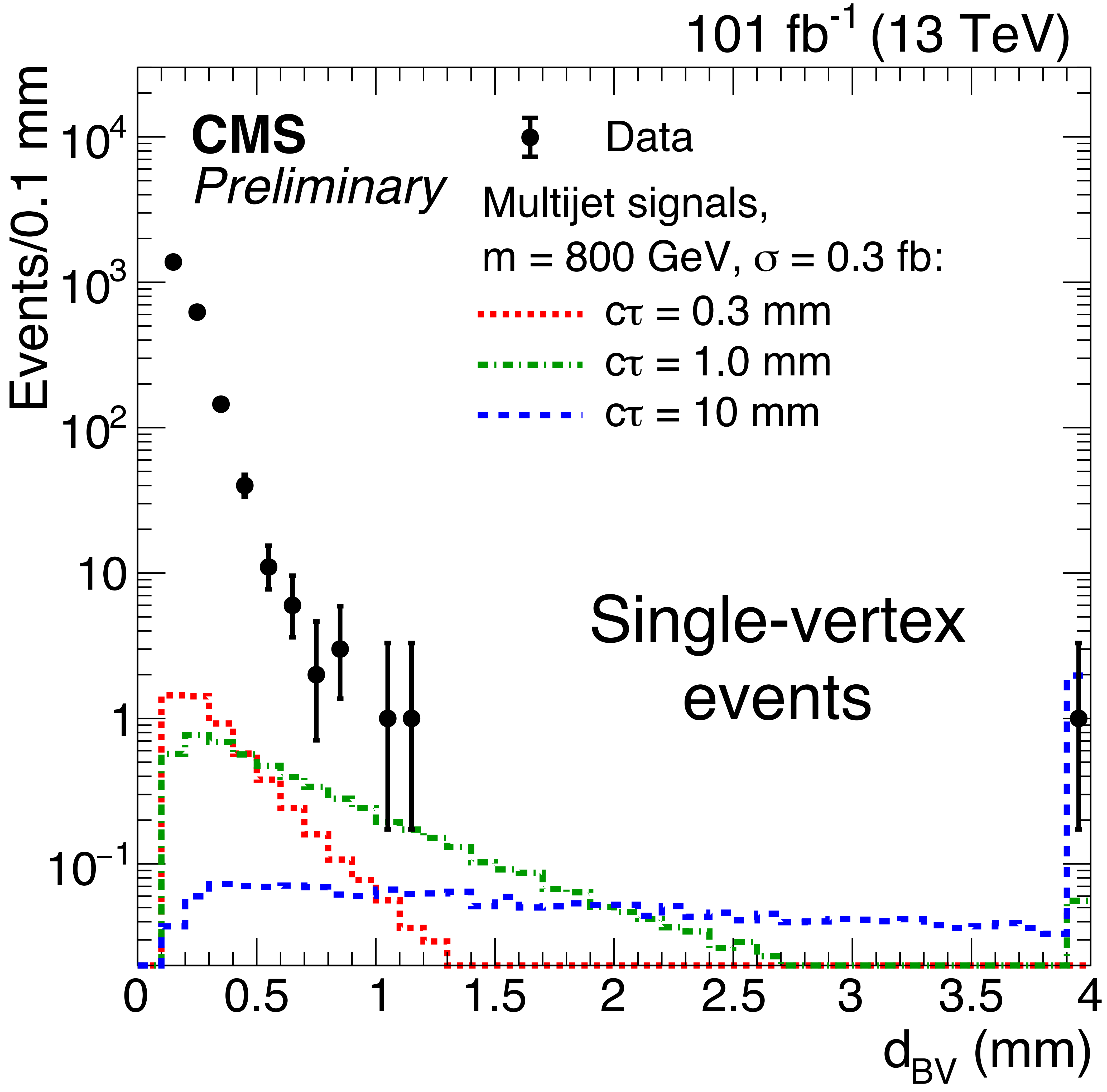
Background vertices arise from misreconstructed tracks—no guarantee that simulation can faithfully reproduce such effects!



Instead:

- Look at characteristics of a two-vertex event
- *Emulate* d_{VV} in data using (bkg-dominated) single-vertex events

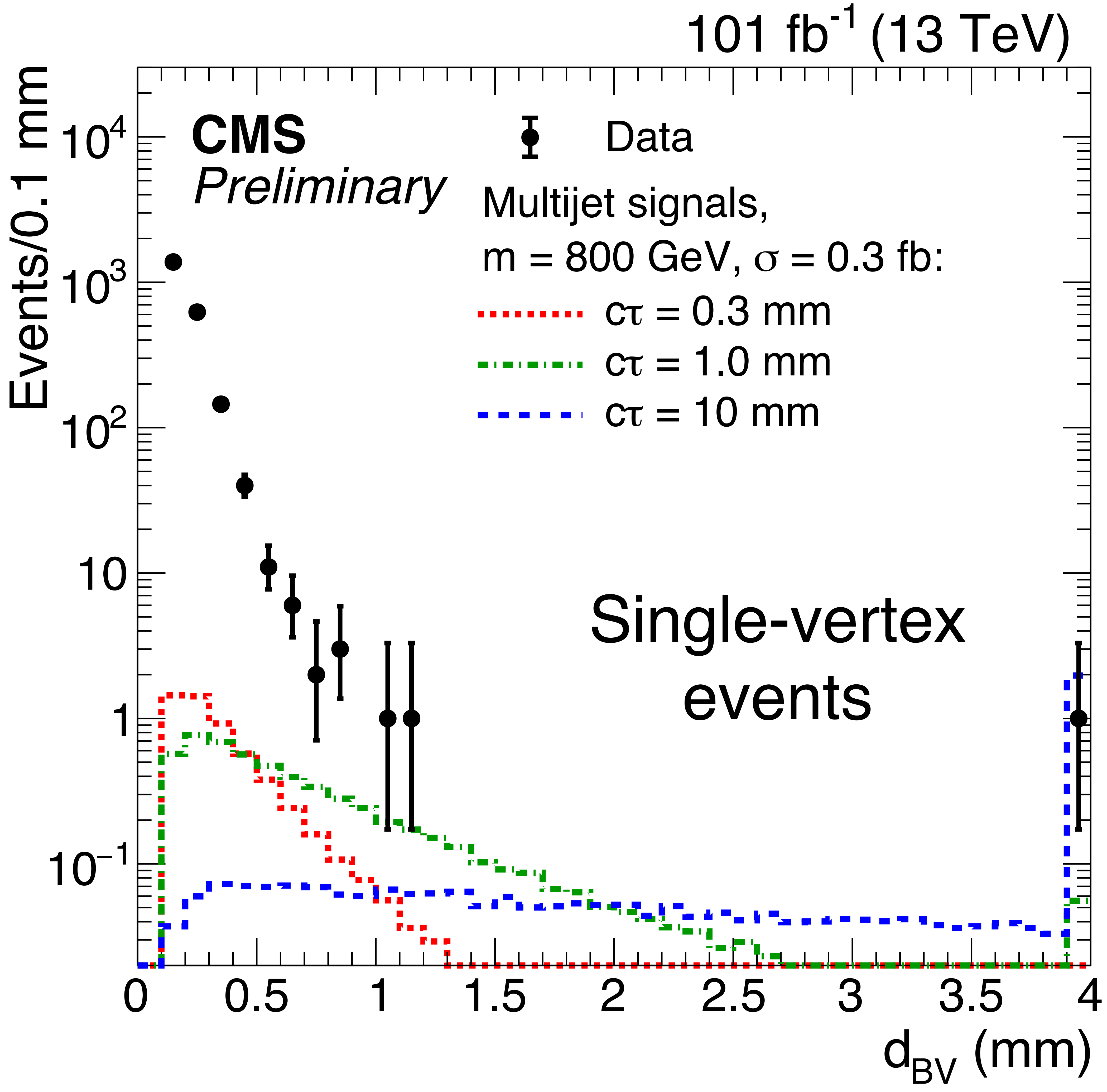
Data-Driven Background Estimation



Construct a background d_{VV} template from single-vertex data using:

- Two random d_{BV} values
- Randomly chosen $\Delta\phi_{VV}$, estimated via jet angles

Data-Driven Background Estimation



Construct a background d_{VV} template from single-vertex data using:

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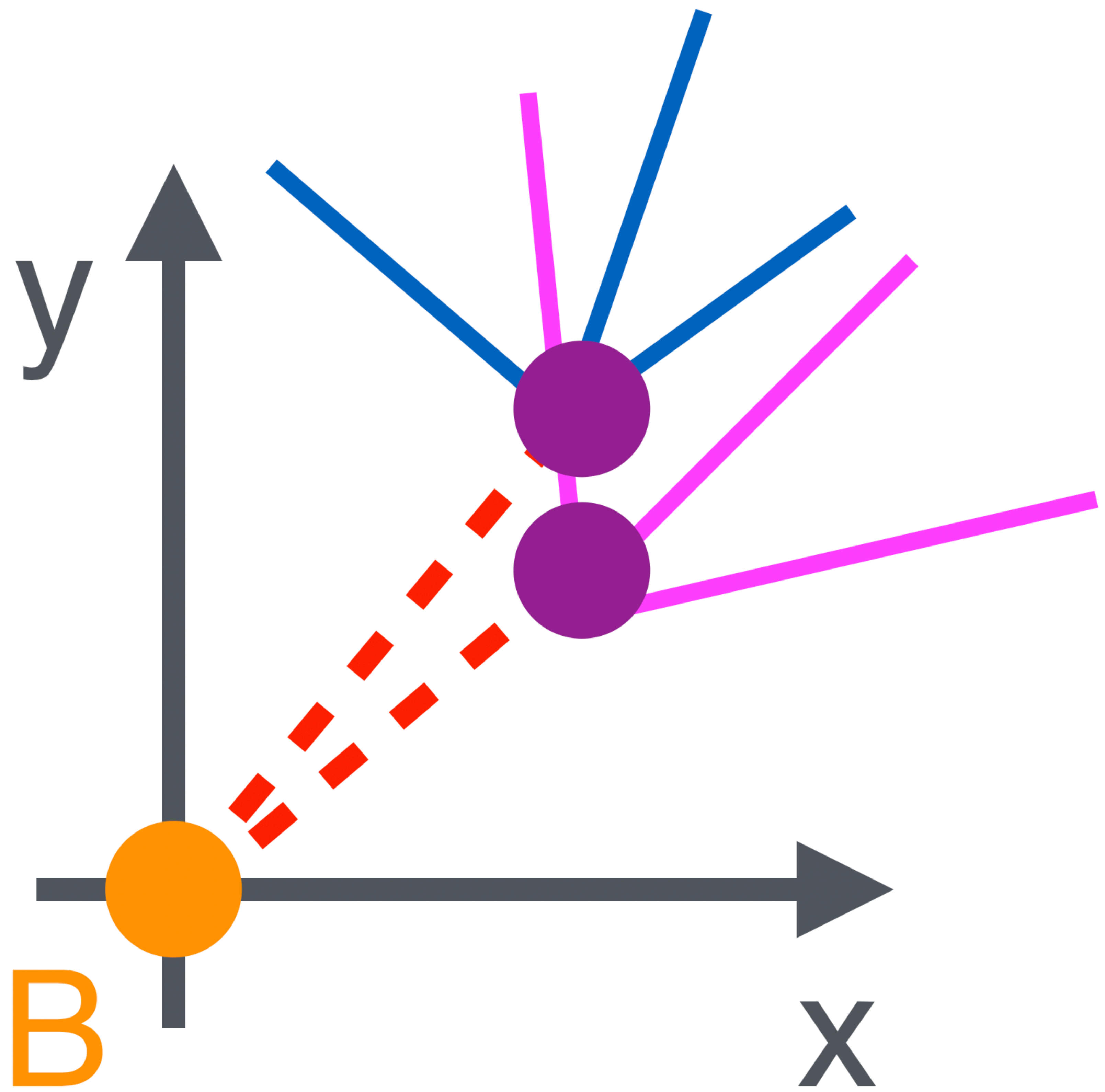
- Corrections for b-quarks (larger displacements)

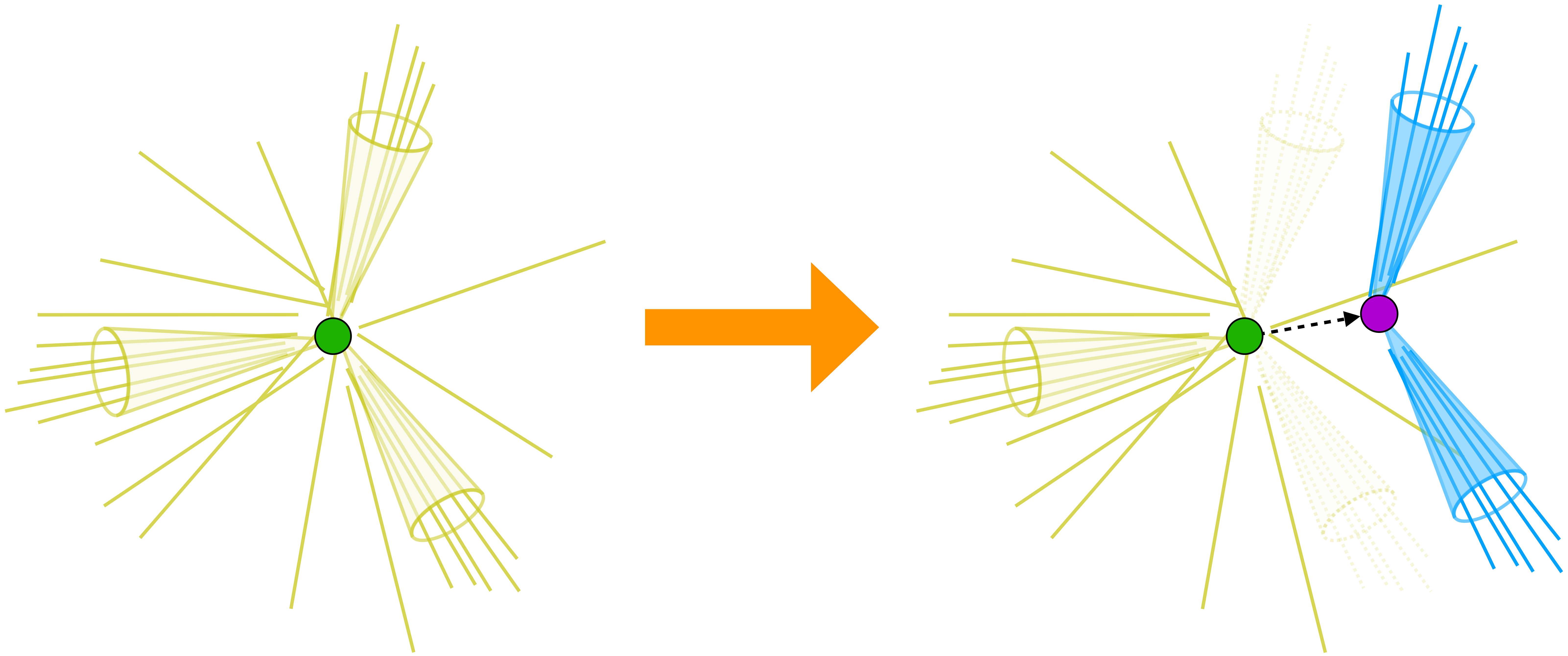
Data-Driven Background Estimation



Construct a background d_{VV} template from single-vertex data using:

- Two random d_{BV} values
- Randomly chosen $\Delta\phi_{VV}$, estimated via jet angles
- Corrections for b-quarks (larger displacements) and overlapping vertices

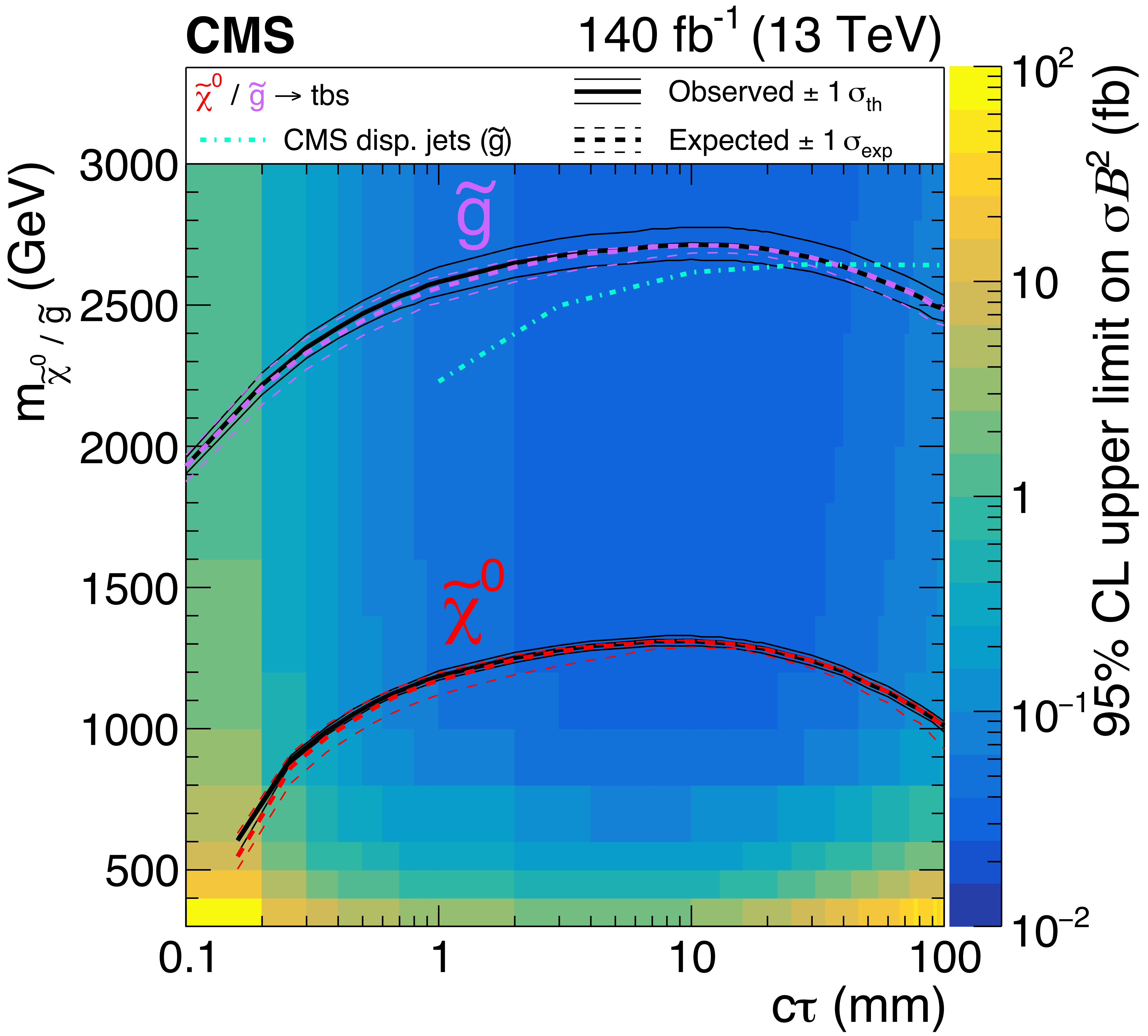
Signal Efficiency and Systematics

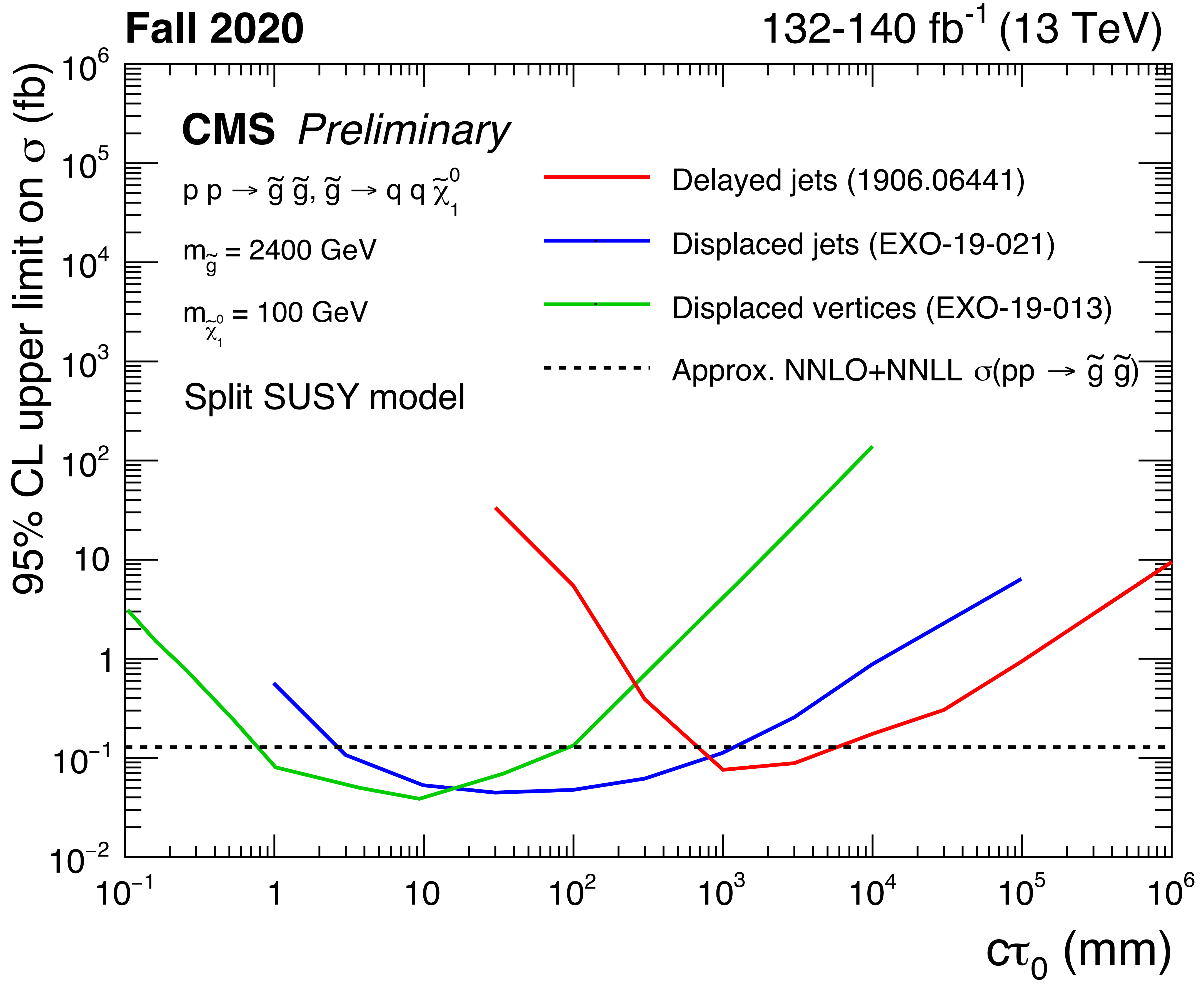


Manually displace tracks from SM jets in data and MC to create artificial displaced vertices.

Measure vertexing ε to determine ε corrections and systematic uncertainties to apply to signal MC.

Results





Excluded certain long-lived SUSY scenarios with cτ ∈ [100μm, 100mm] for masses up to 2.7 TeV! Search is complementary with other long-lived searches.

Extensions to the displaced vertices search

Now that we performed the search, we want to extend it to other scenarios:

- Higgs decays to long-lived particles inaccessible in our current high-mass search; working to use other triggers (such as lepton triggers) to cover this
- In the Standard Model, b-quarks have $c\tau \approx 500\mu m$. We can use b-jet triggers that CMS has already put into place!
- Some supersymmetry scenarios predict long-lived particles produced in association with missing energy—use missing energy triggers too!

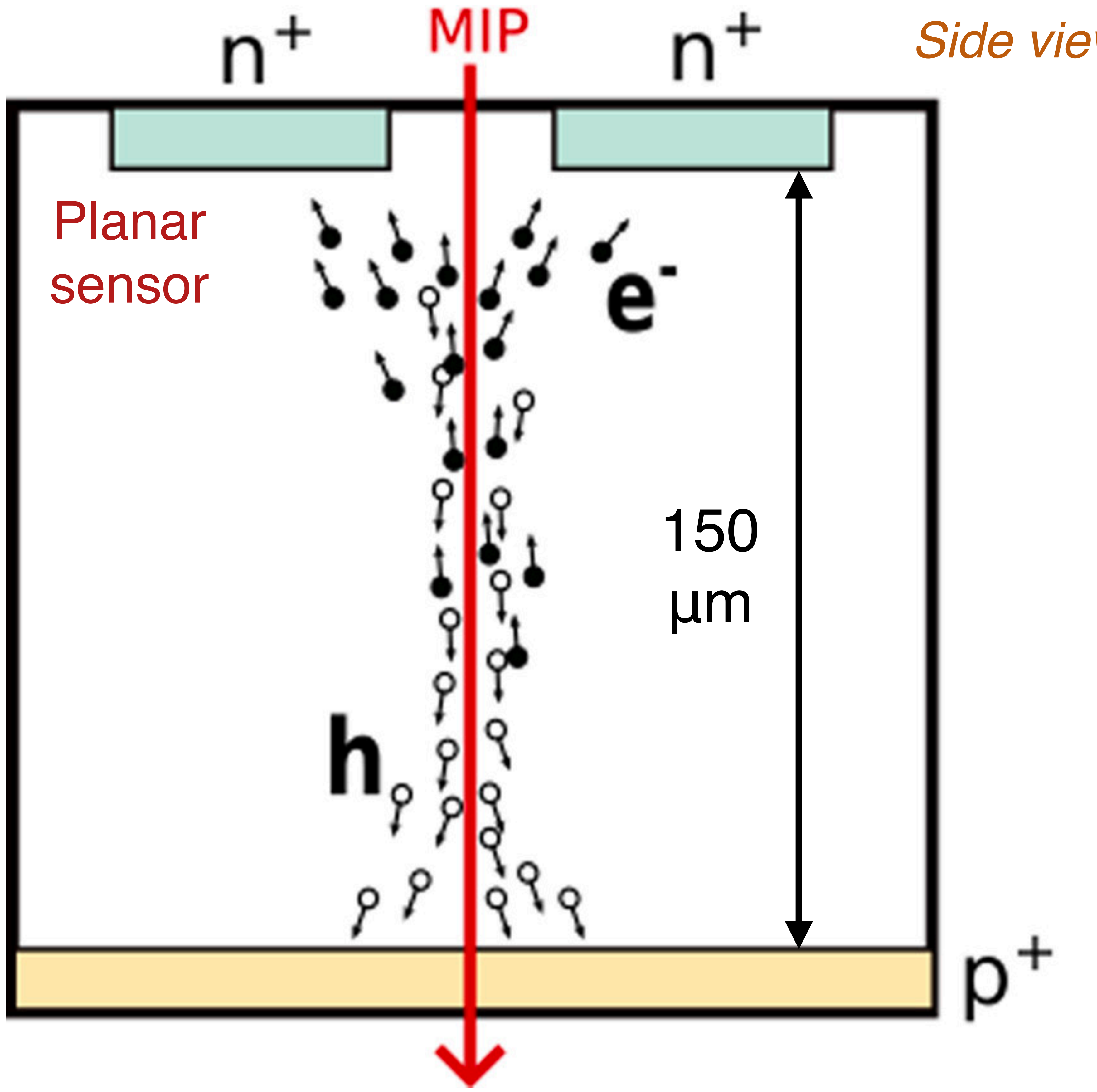
In addition: we are improving our vertexing algorithm, and so far can reduce backgrounds by 2x with small impact on the signal efficiency.

Phase-1 vs. Phase-2 Pixel Sensor Sizes

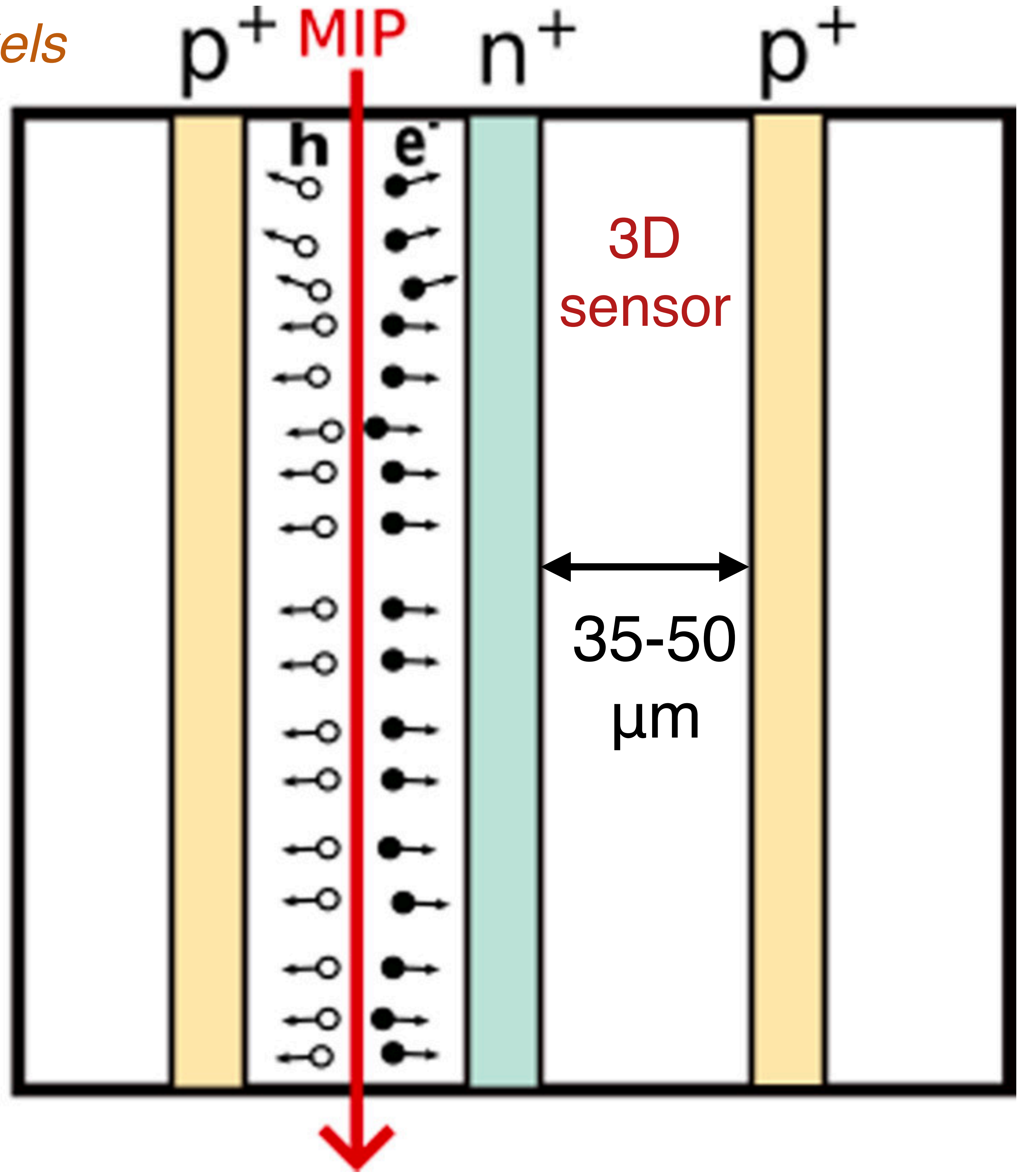
	Phase-1 (current detector)	Phase-2 (for HL-LHC)
pitch	150 μm × 100 μm	50 μm × 50 μm or 100 μm × 25 μm 6x smaller area!
thickness	~300 μm	~150 μm Thinner sensor ⟹ better radiation tolerance

Planar vs. 3D sensor technology

Side view of pixels



More conventional, and currently used by CMS



More radiation tolerant, but more complex + expensive

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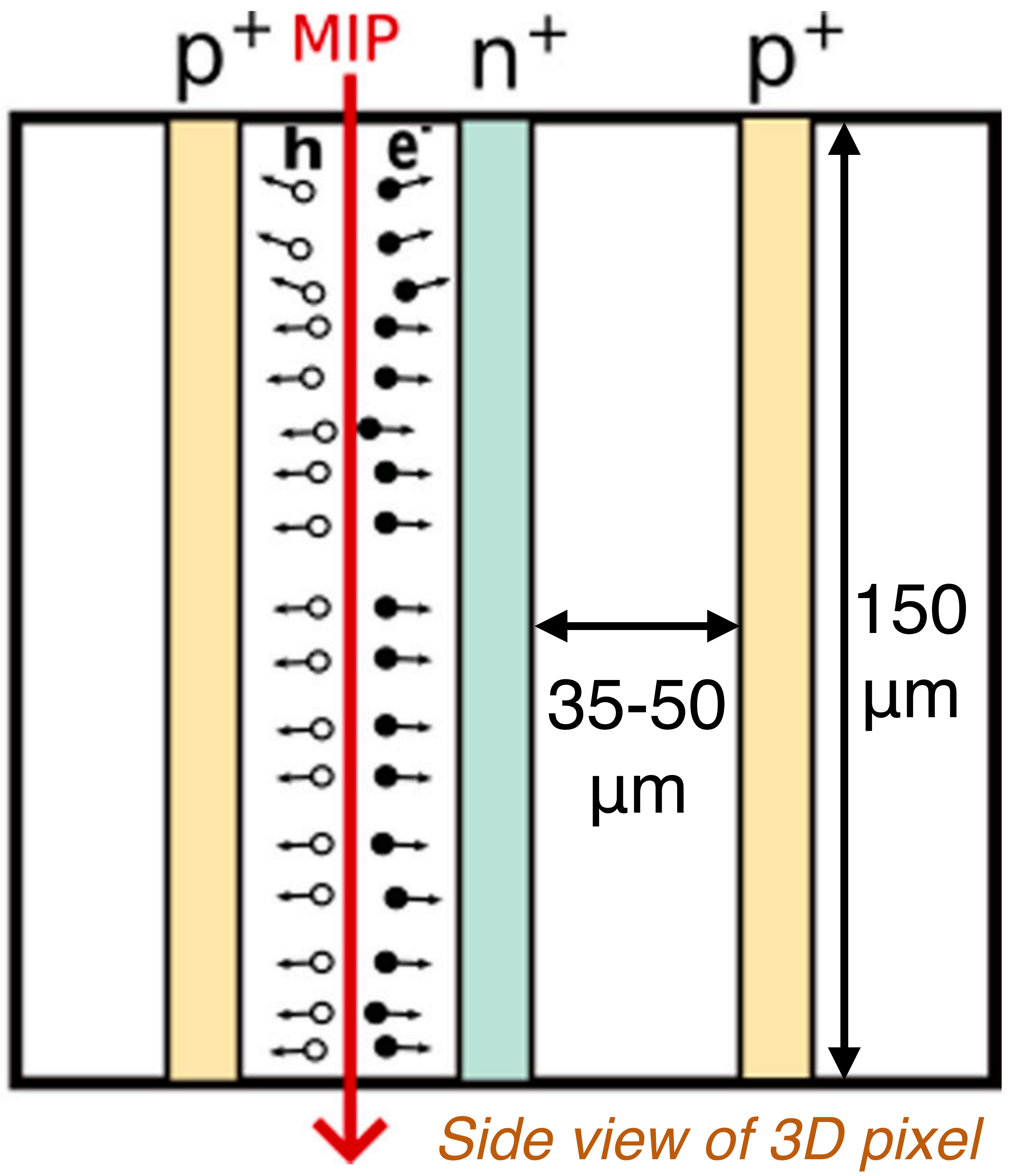
Radiation damage and 3D sensors



Side view of 3D pixel

Damage to Si lattice results in trapping of charge carriers (smaller signal)

- e^-/h^+ travel smaller distance in 3D sensors than planar, i.e. less trapping, faster charge collection, etc.
- Smaller voltage needed to deplete 3D sensor than planar

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