Backgrounds to Long-lived Particle Searches

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Executive summary

- Sources of background in LLP searches are less predictable than prompt analyses
- For each of five classes of backgrounds, we'll discuss:
    - Examples from LHC experiment analyses
- Future improvements (read: shameless plug for backgrounds WG)

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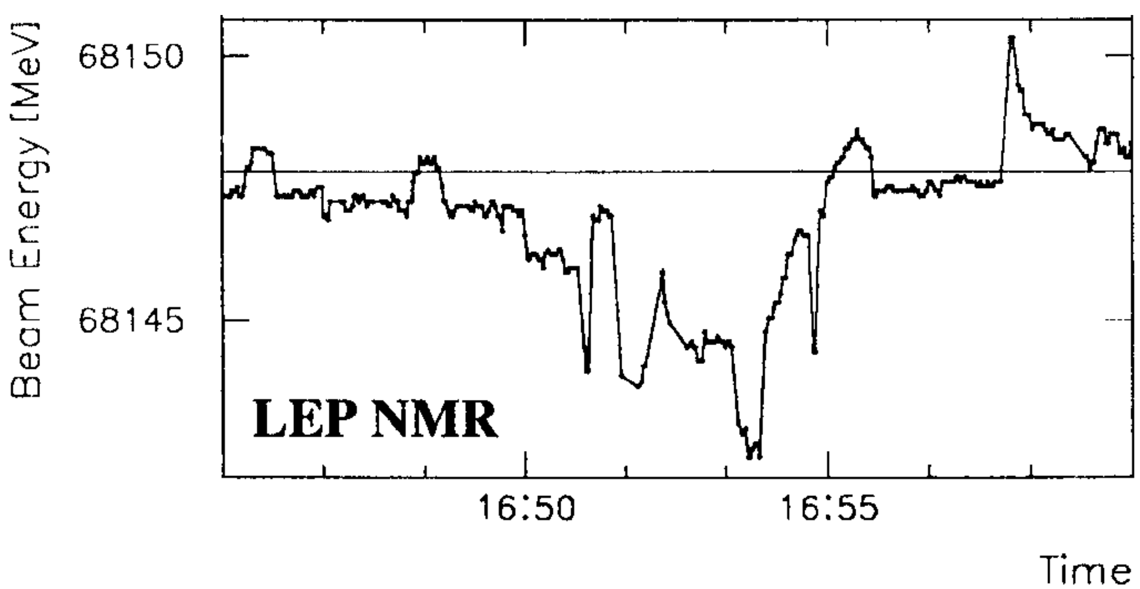
Week Monday 27 Novembre no 48/95 Semaine du lundi 27 novembre



the magnetic field inside one of LEP's dipole magnets, given in units of beam energy equivalent, MeV.

A strange disturbance was noticed in LEP in June 1995. A bizarre pattern in the bending magnetic field was detected for the first time thanks to new Nuclear Magnetic Resonance, NMR, probes recently installed in LEP. Small energy changes in the beam caused head scratching amongst the LEP energy team.

This disturbance always appeared at regular times, with peaks in the morning at 8 am, then from 11 am to 1pm, and later in the afternoon between 6 pm and 7 pm. Whereas between midnight and 4 in the morning things were completely calm. A bottle of champagne was offered to anyone who could solve the mystery.

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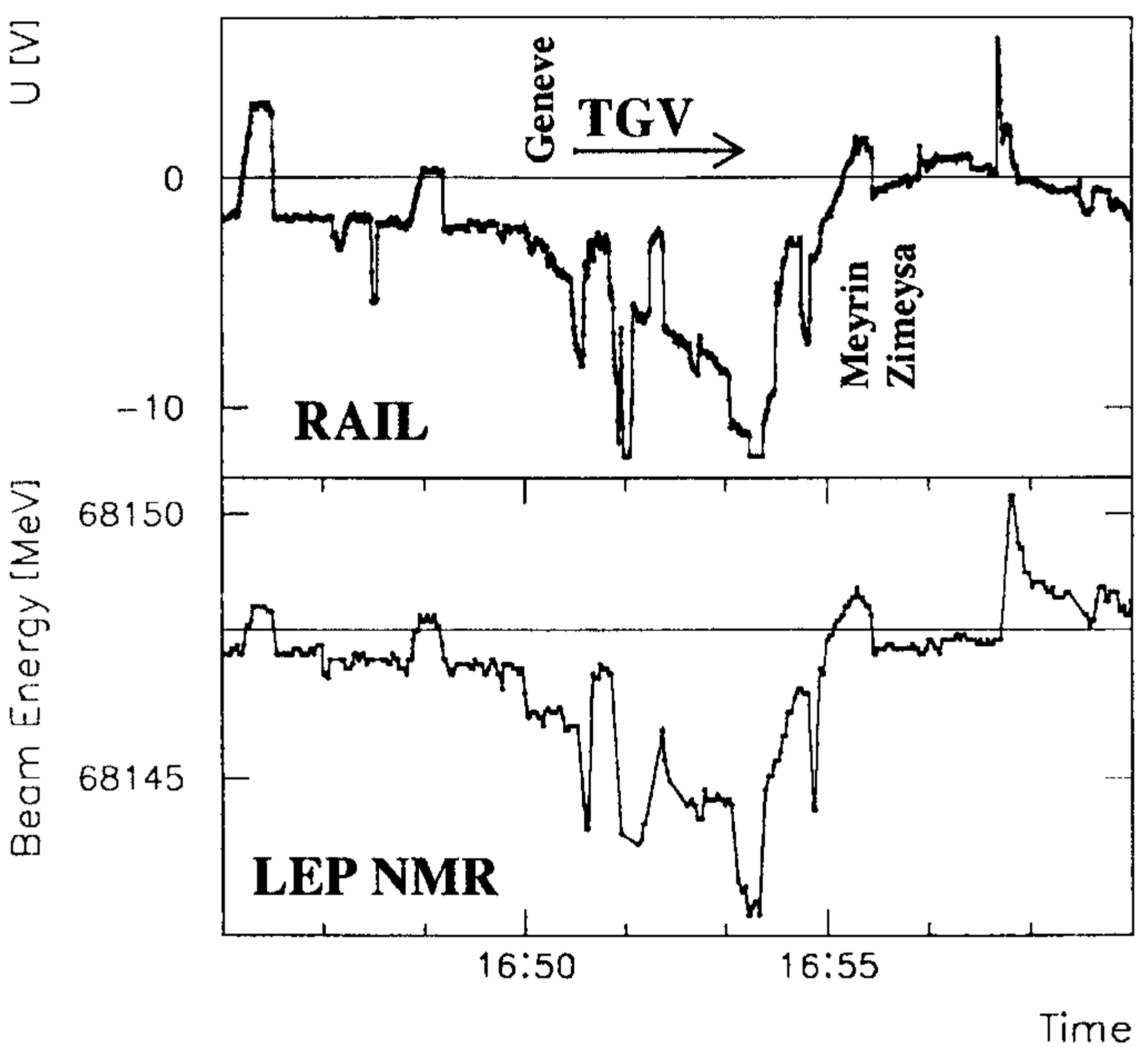

Recordings of the potential difference, U, between the rails and the Earth (top) compared with the magnetic field inside one of LEP's dipole magnets, given in units of beam energy equivalent, MeV.

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LEP, due to its large size, is a very sensitive machine, its beam energy can be affected by many parameters during running. Already, it has been shown that phenomena such as the moon's orbit and the water level in Lac Leman have to be taken into consideration to understand LEP's energy behaviour. This new disturbance, however, is smaller than either of these effects, at a level of under 5 MeV.

The change of magnetic field was found to be caused by small electrical currents flowing along the beam pipe. The energy calibration working group decided to consult the Swiss and French electricity companies, EOS and EDF. After some thinking, M. Fleury of EOS suggested that the disturbance could be due to known effects related to electrical trains, winning himself a bottle of champagne.

Two parallels with LLP searches

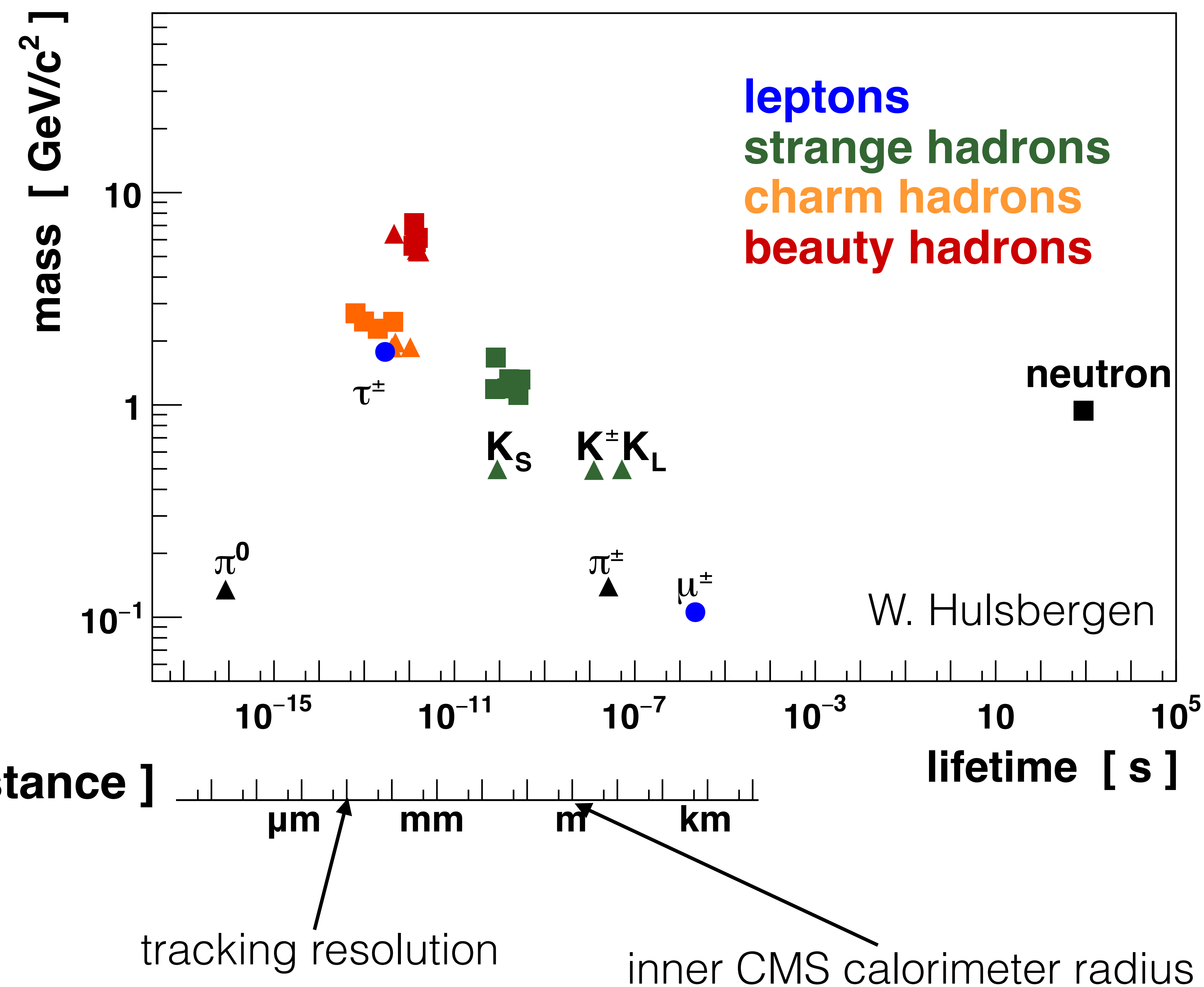
- **You don't know what your backgrounds will be**
  - Often very mis-modeled or not modeled at all
    - Hard to find out which case you're in
  - *Expect the unexpected!*
- **You may be the only one affected**
  - Effects relevant for LLP searches are often overlooked/ignored when developing the "standard" software algorithms

Five classes of backgrounds

Nature's fault	Our fault
particles created **at the detector center**	imperfect **hardware**
particles created **in the detector volume**	imperfect **software**
particles created **outside the detector**	

1. particles created at the detector center

aka long-lived particles in the SM



1. particles created at the detector center

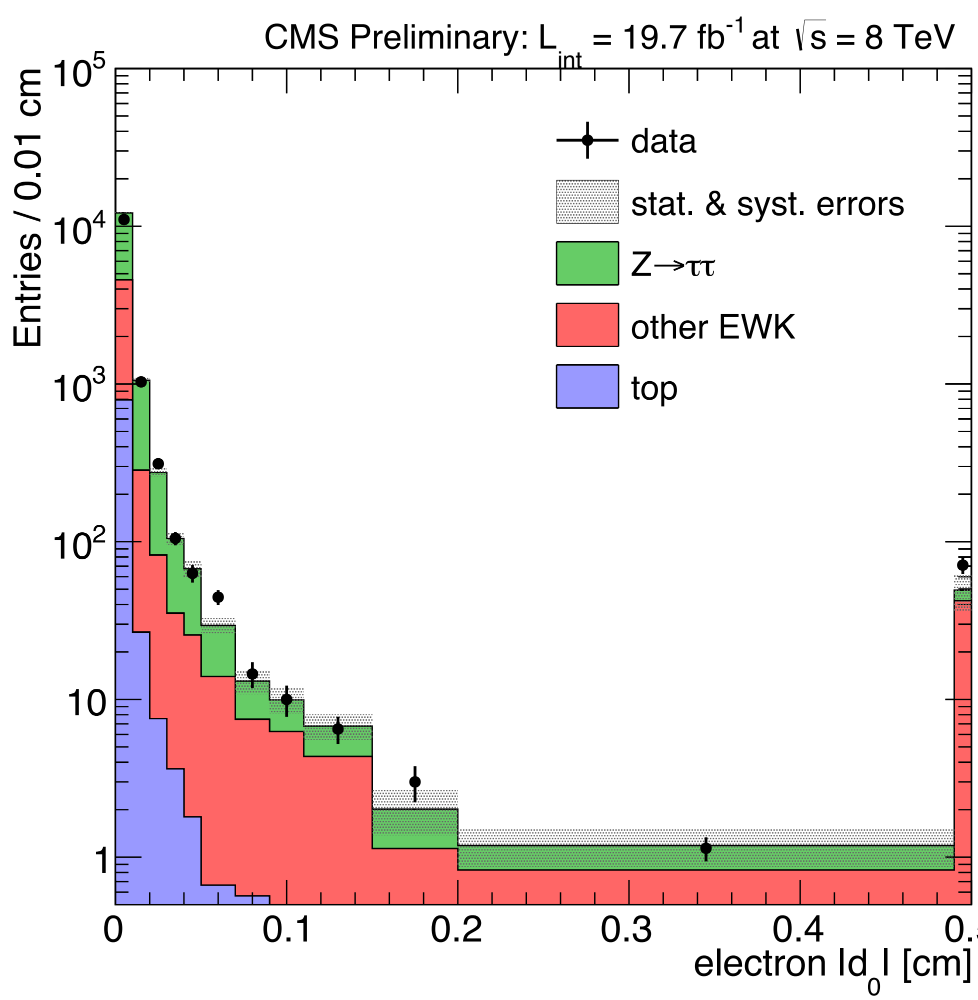
Example: Z→ττ in displaced e-μ search

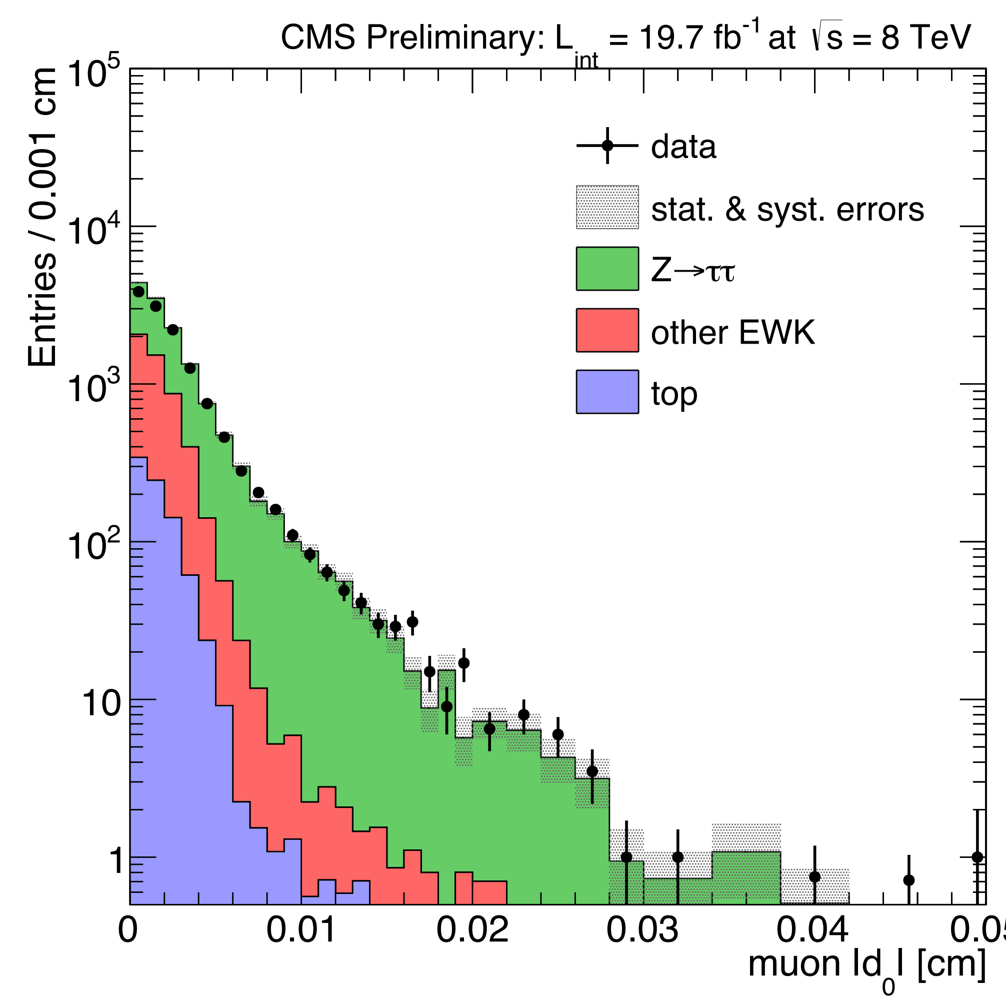
analysis preselection +

exactly one electron with $M_T < 50\,\mathrm{GeV}$
exactly one muon with $M_T < 50\,\mathrm{GeV}$
exactly one electron-muon pair with $\Delta\phi > 2.5$
$\sum p_{\mathrm{T}_{jet}} < 100\,\mathrm{GeV}$

control region used to validate MC

since Z→ττ has manageable cross section, MC used for signal region estimation

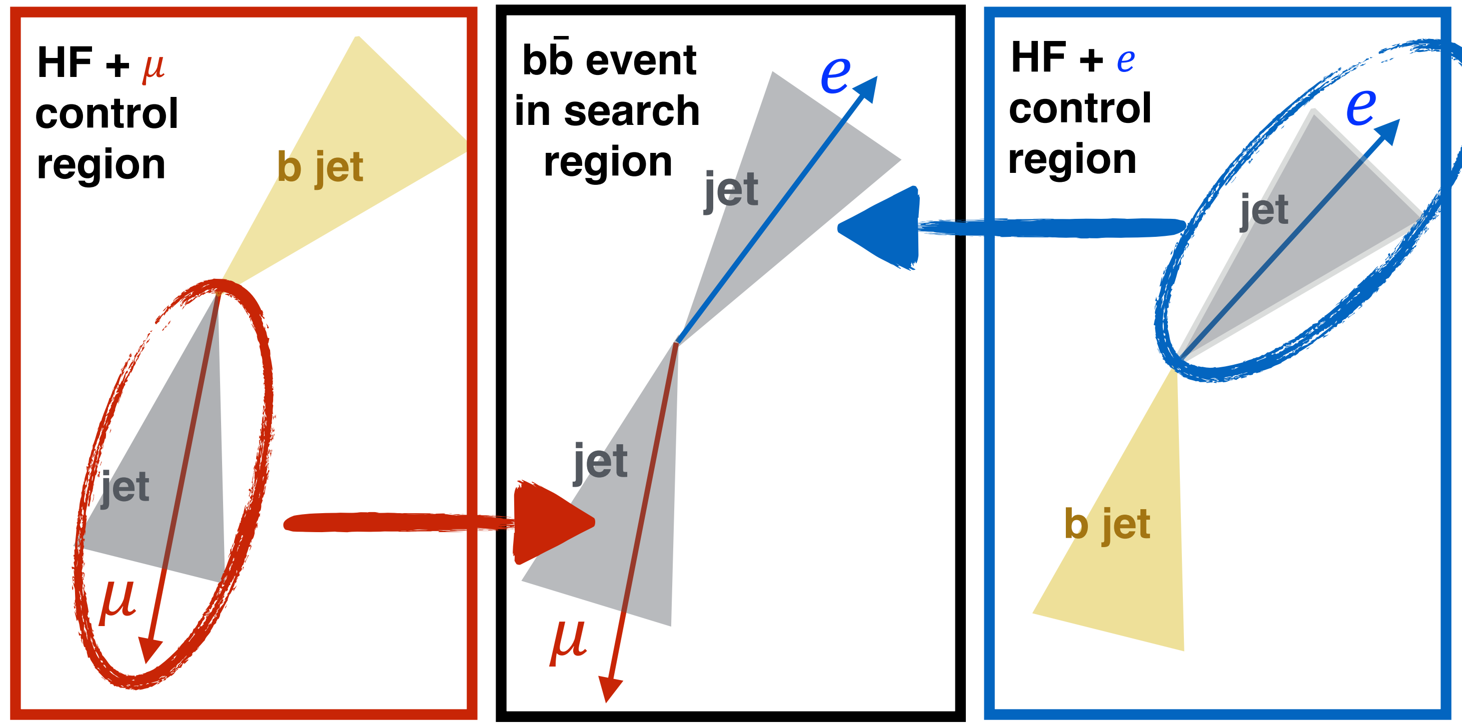




1. particles created at the detector center

Example: $b\bar{b} \rightarrow e\mu$ in displaced e-μ search

lepton isolation reduces rate, but still dominant background

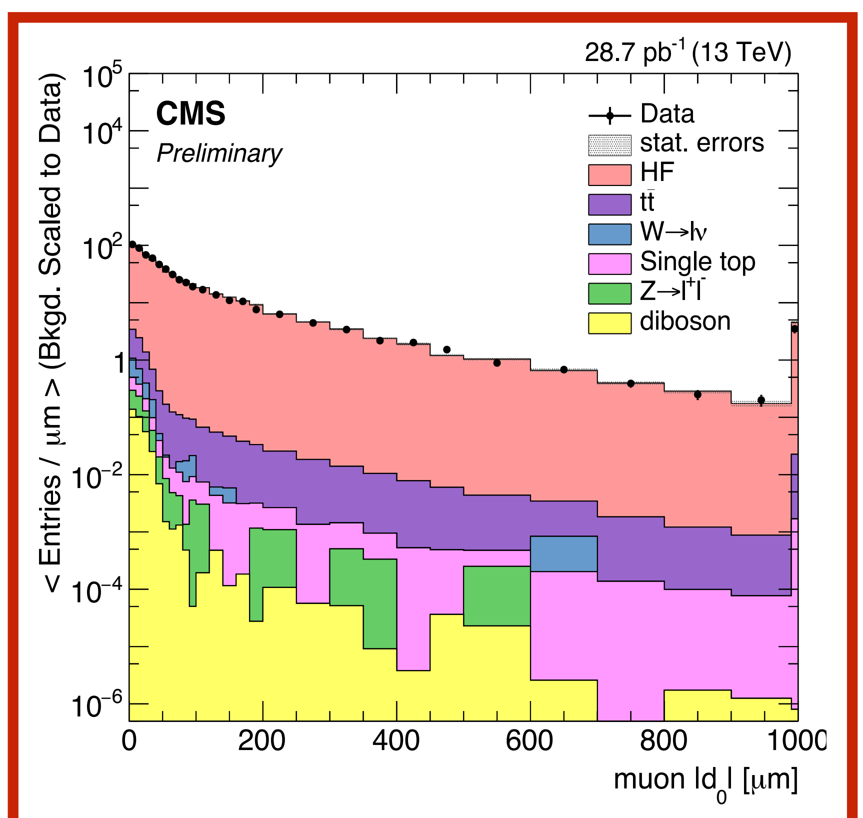


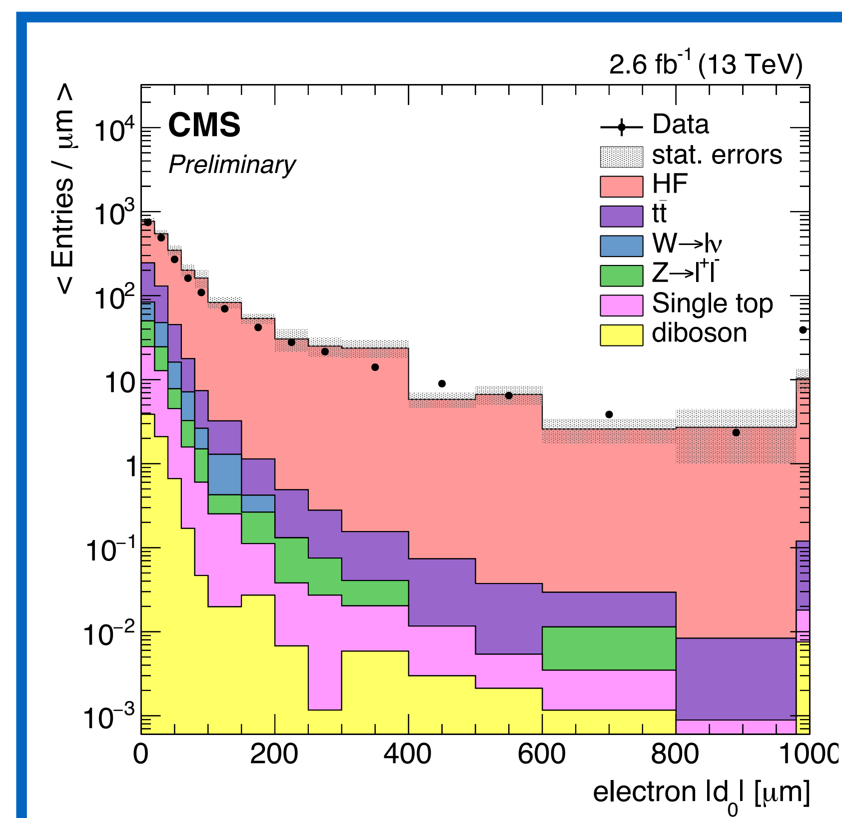
HF + μ/e control regions

- b-tagged jet
- back-to-back jet with nearby lepton

construct d_0 templates from the data in these control regions

calculate transfer factors from low d_0 sideband to high d_0 search regions

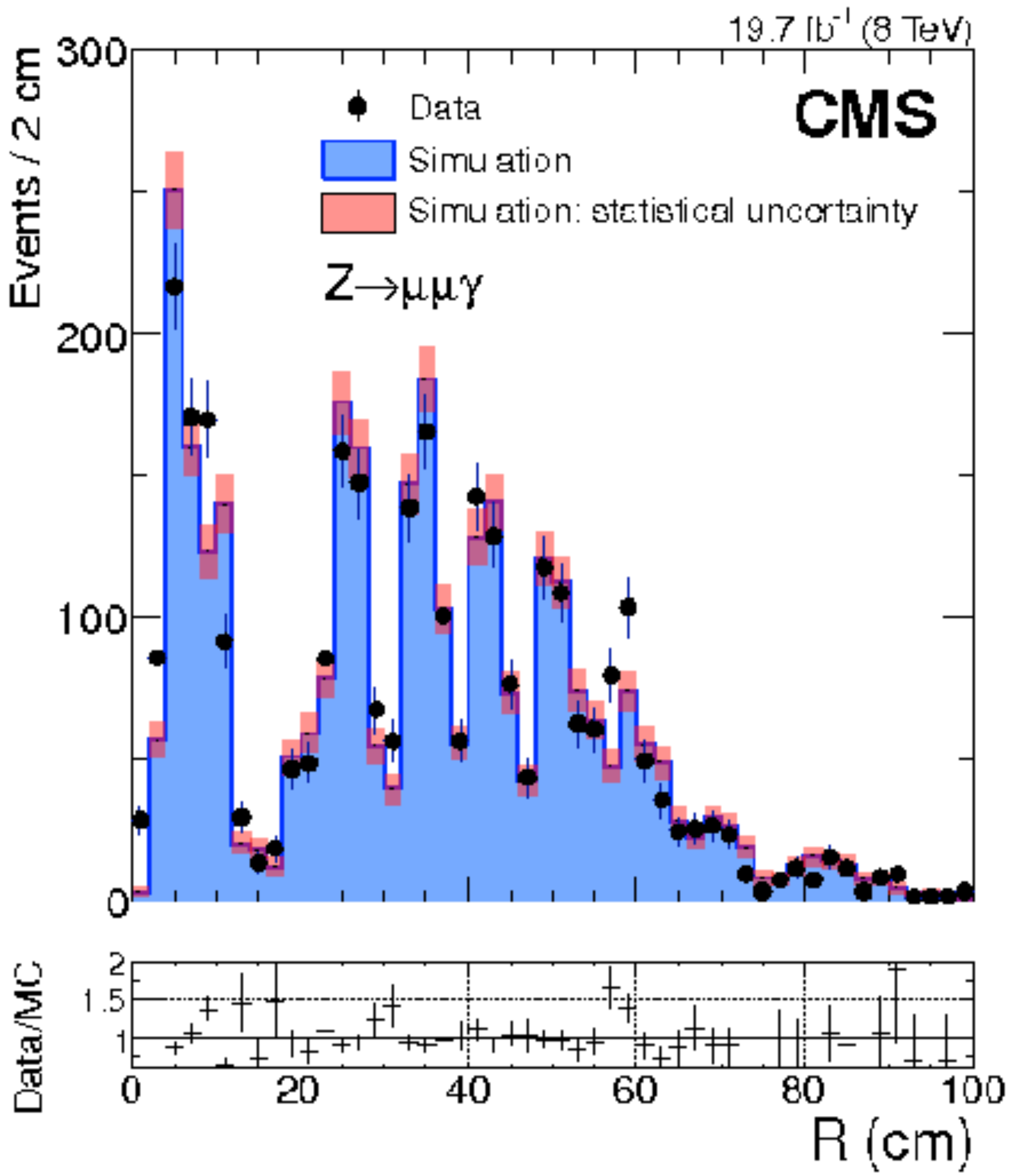




2. particles created in the detector volume

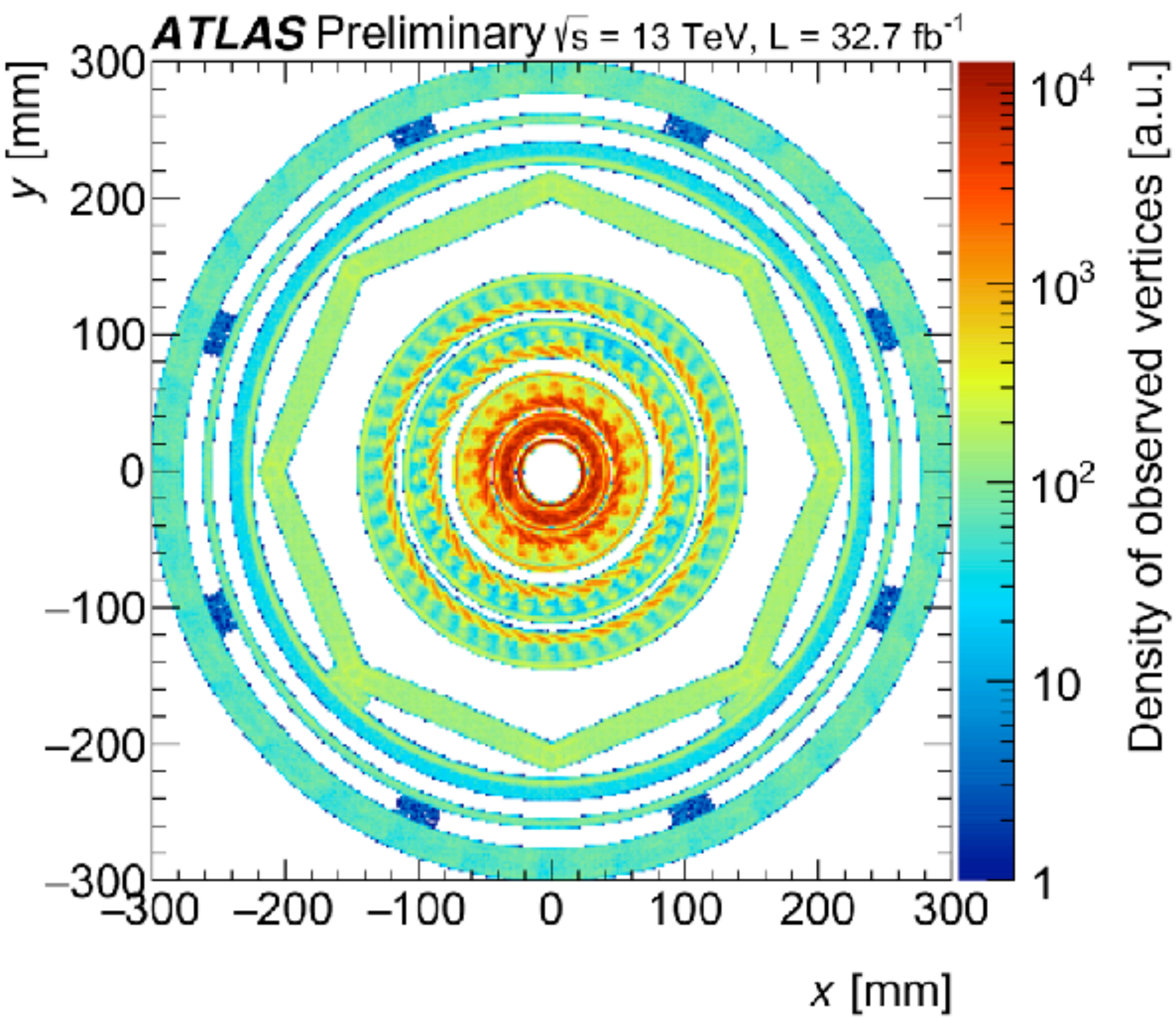
Example: photon conversions

- photon conversion = $\gamma \rightarrow e^+e^-$ in the presence of material
  - can create fake displaced electron signature
- since many people are doing photon physics (remember the 750?), there are robust conversion ID algorithms in place
  - finds two tracks with common vertex and zero mass



2. particles created in the detector volume

Example: nuclear interactions



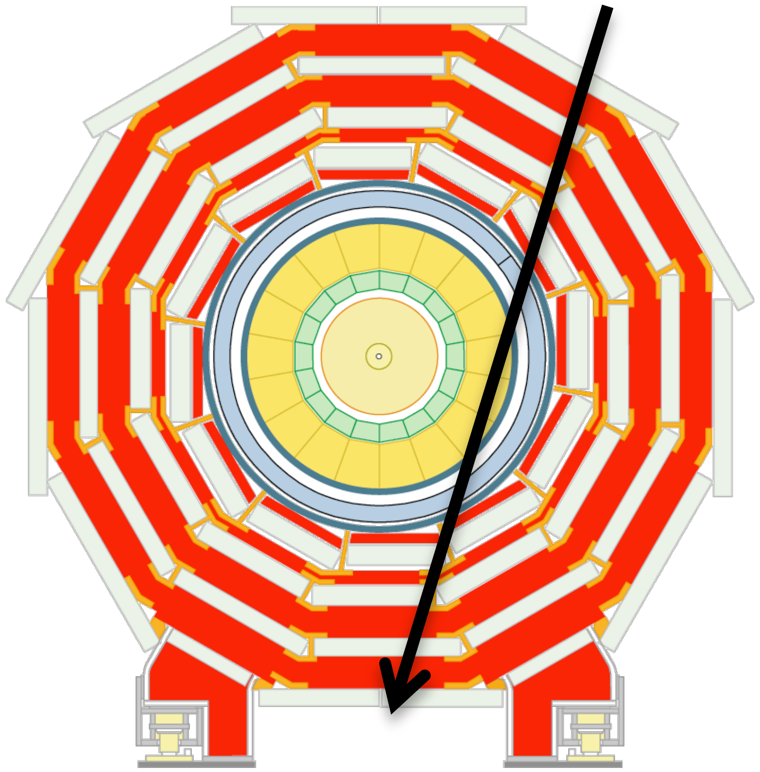
- interactions with detector material that generate displaced vertices
- can be rejected via vertex mass, track multiplicity cuts
- can also reject via fiducial cuts, removing all vertices near material (see ATLAS data-derived material map)

3. particles created outside the detector

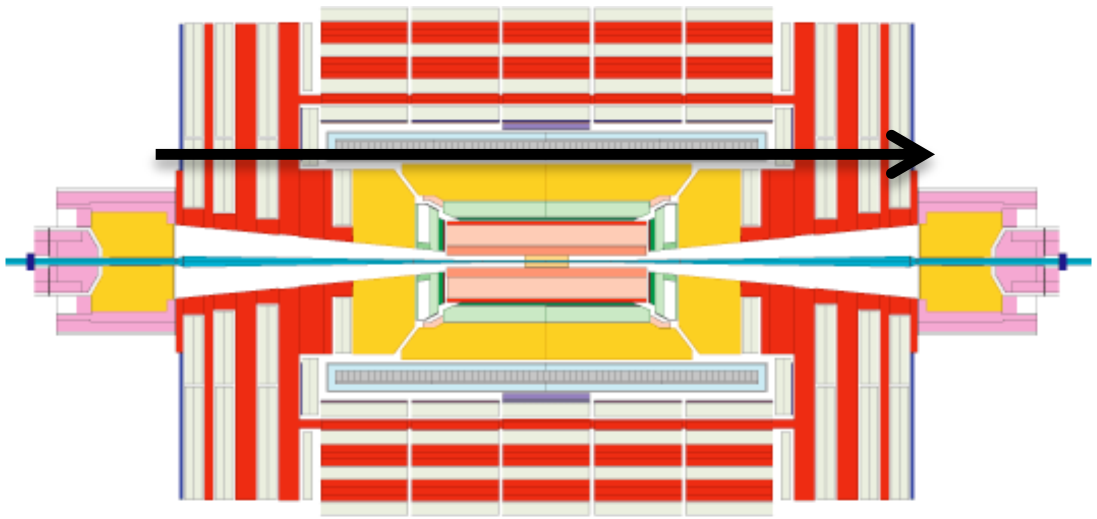
Example: cosmic and beam halo muons

- for track-based searches, can be easily vetoed by rejecting very back-to-back tracks
- for calo-based searches, muon bremsstrahlung can leave out-of-time deposits
  - can be rejected by looking for coincidence of muon chamber hits in line with call deposit

cosmic muons

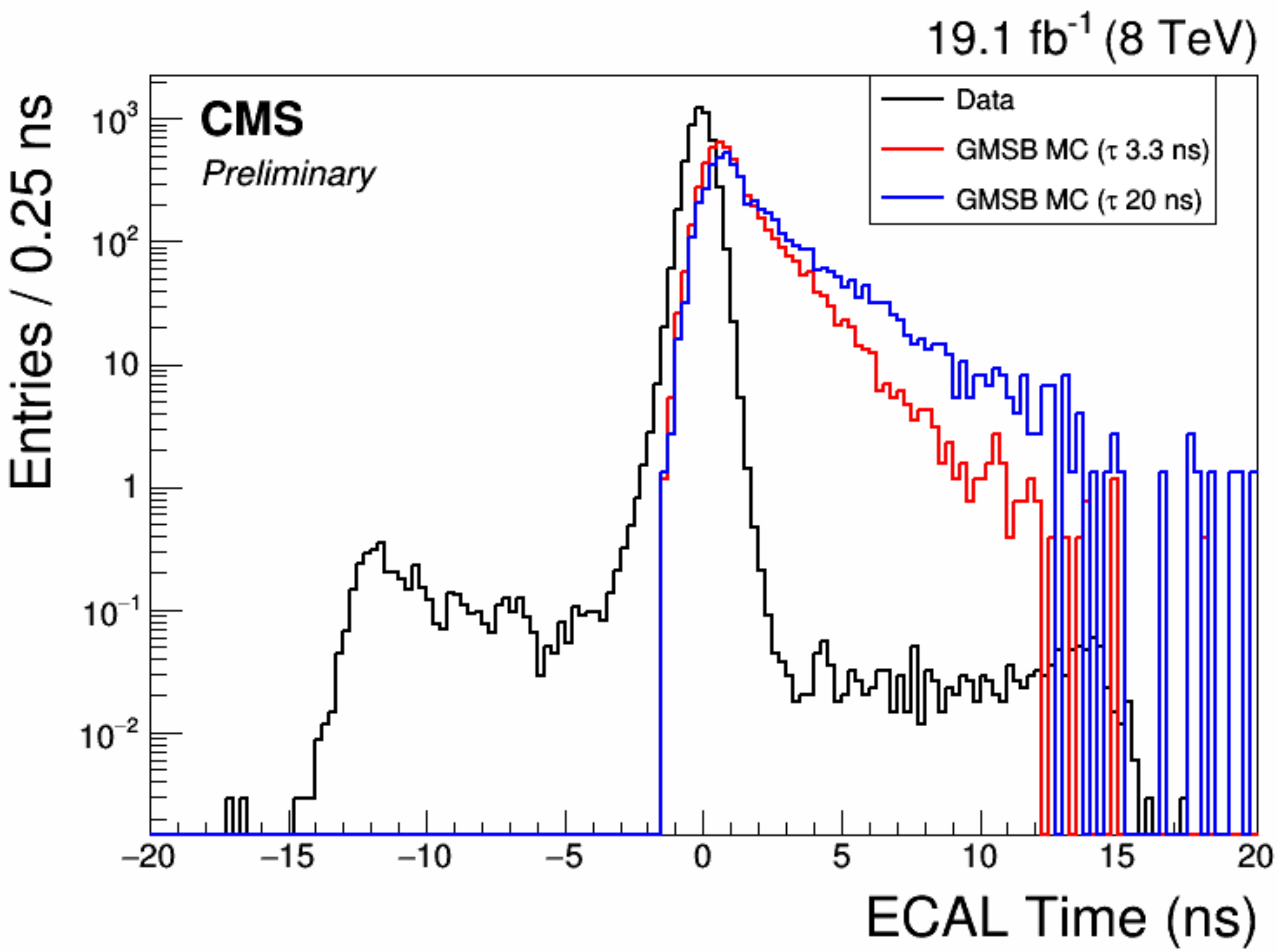


beam halo muons



4. imperfect hardware

Example: ECAL timing resolution

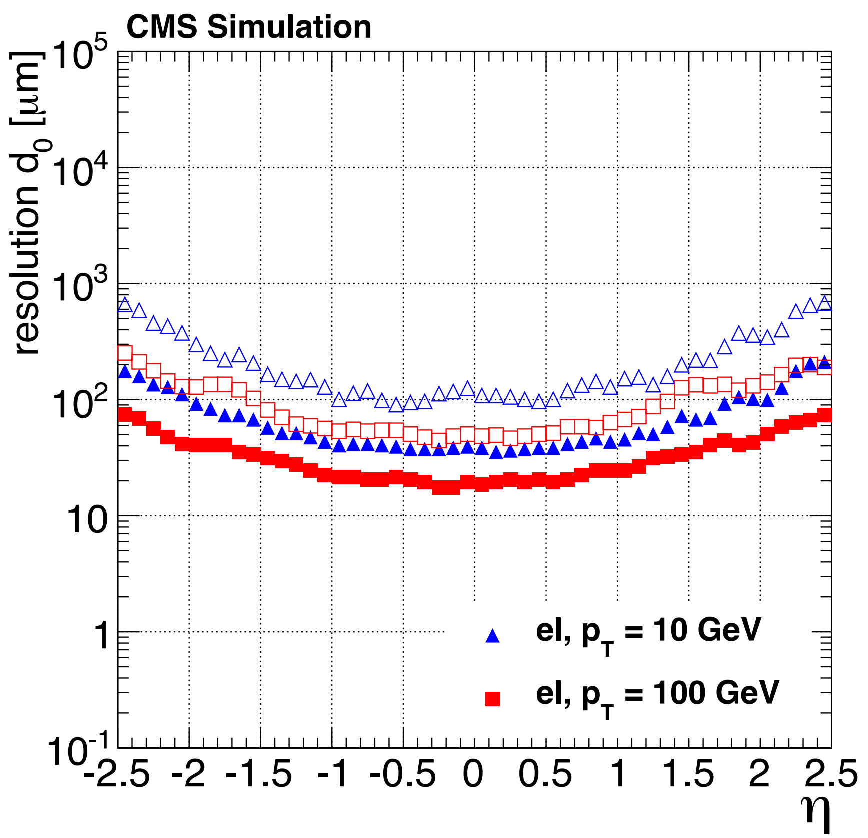


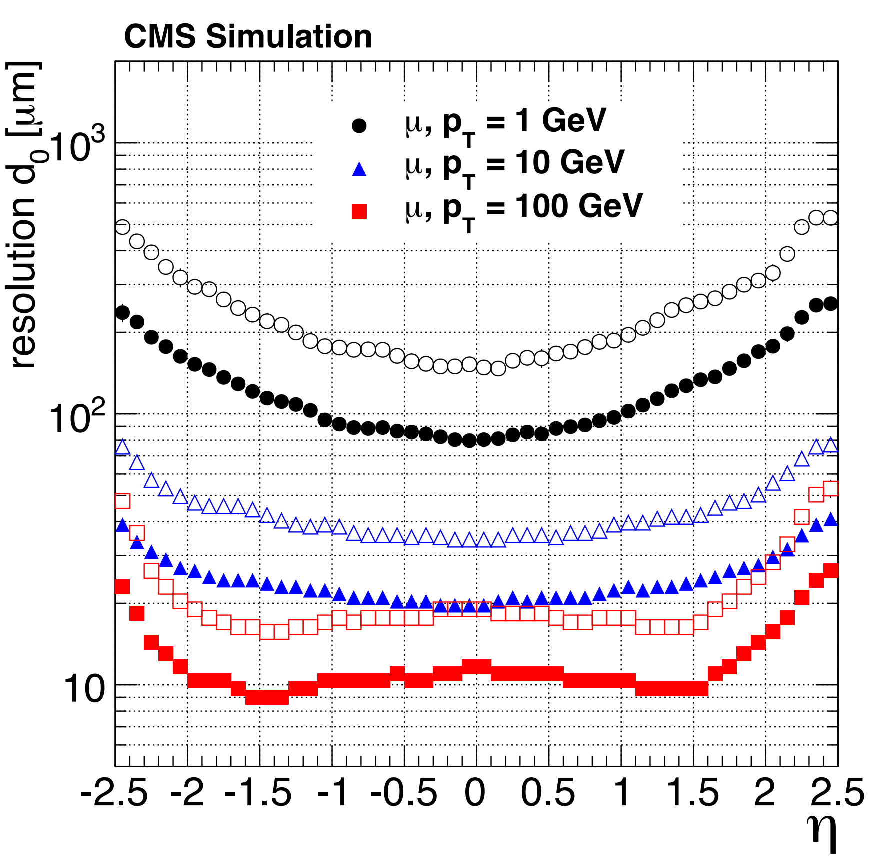
- O(ns) CMS ECAL intrinsic timing resolution limits lowest lifetime accessible to delayed photon searches
- We're keeping the same crystals for the life of the LHC, but there are proposals for dedicated precision timing detectors for the HL-LHC

4. imperfect hardware

Example: tracking resolutions

- O(10μm) tracking resolution limits lowest lifetimes accessible by displaced track searches
    - applies to displaced jets, displaced leptons, displaced vertices, etc.
- CMS/ATLAS recently installed pixel detector upgrade, lower lifetime regime should be revisited in coming data
- CMS/ATLAS are getting completely new trackers for the HL-LHC, pixels should be ~6x smaller



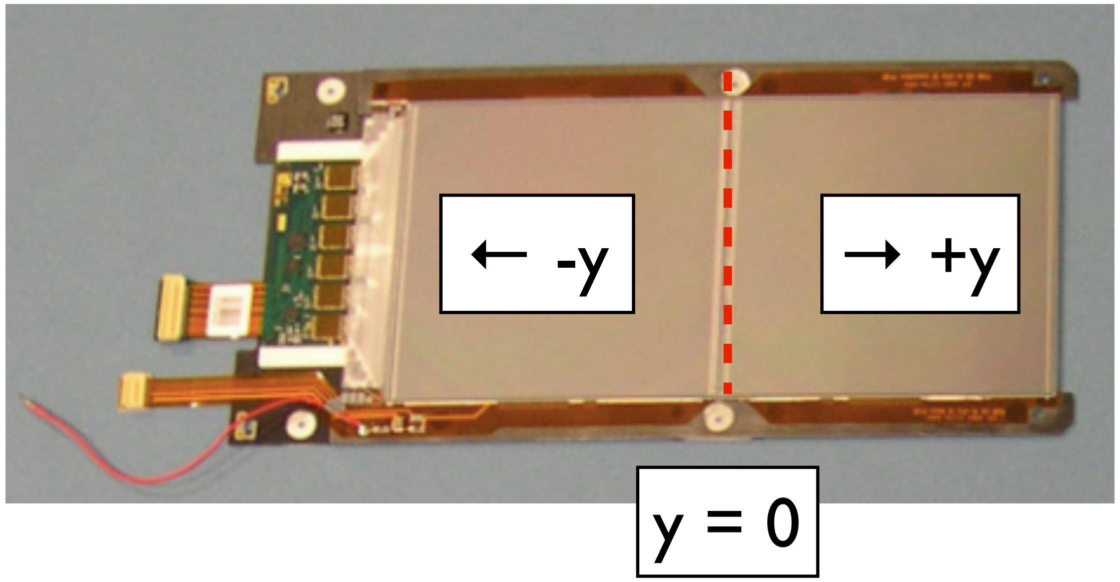


5. imperfect software

Example: artificial "missing hits"

- observed in CMS disappearing track search
- analysis requires several "**missing *outer* hits**" on a track
    - calculated by number of modules traversed by fitted track trajectory minus the number of recorded hits on the track
    - dead channels taken into account

CMS silicon strip module

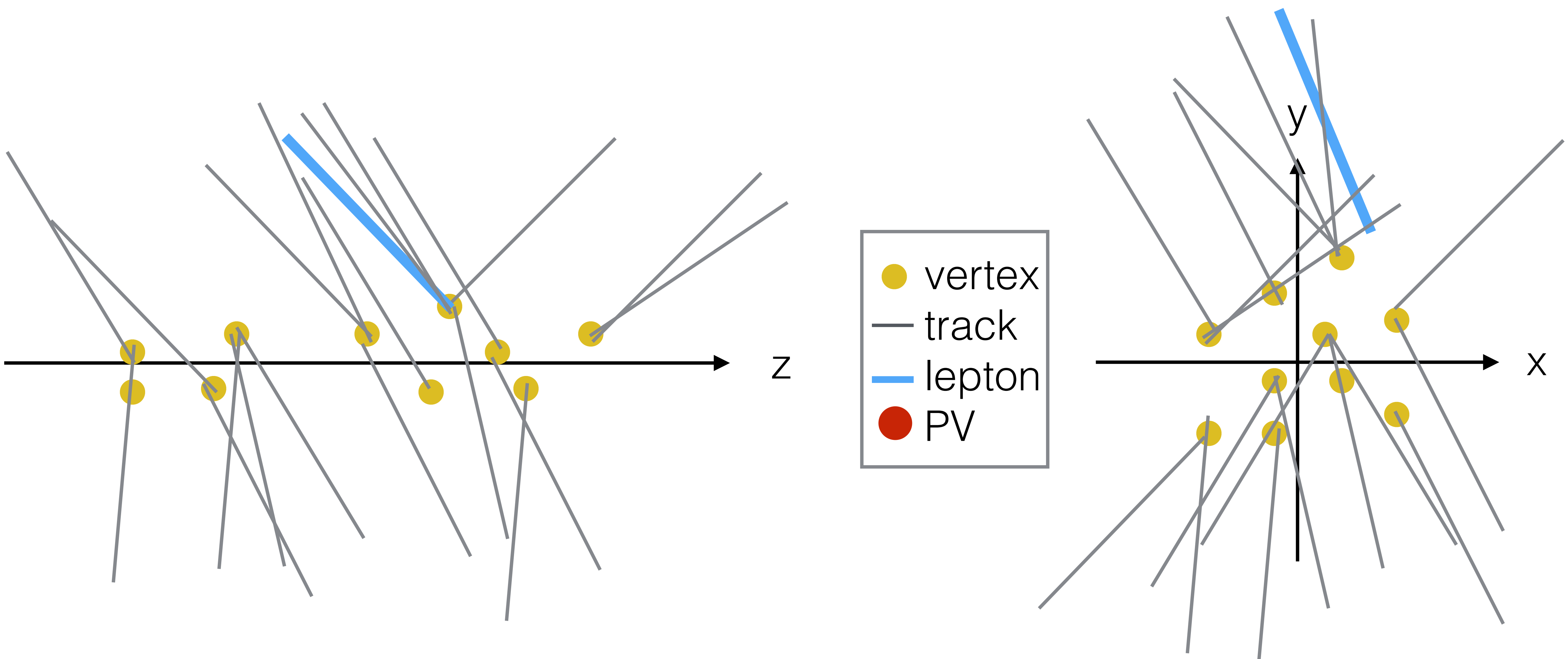


- discovered that large portion of missing hits had trajectories passing near to the center of the silicon detector module
- glue joint was causing lost hits, was in simulation code but not track reconstruction code

5. imperfect software

Example: artificially isolated leptons

- observed in CMS displaced lepton search
- selected lepton is from a B decay,
  surrounded by rest of B jet (not isolated)



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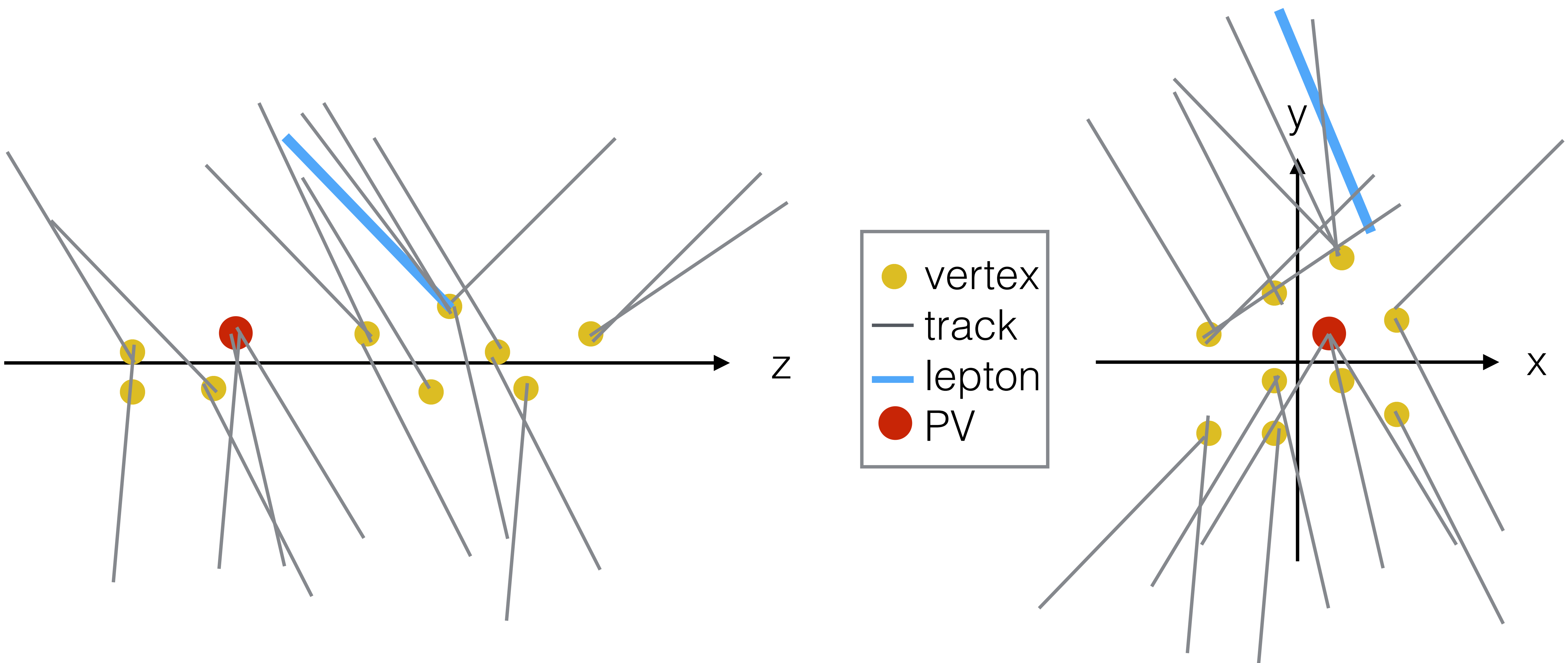
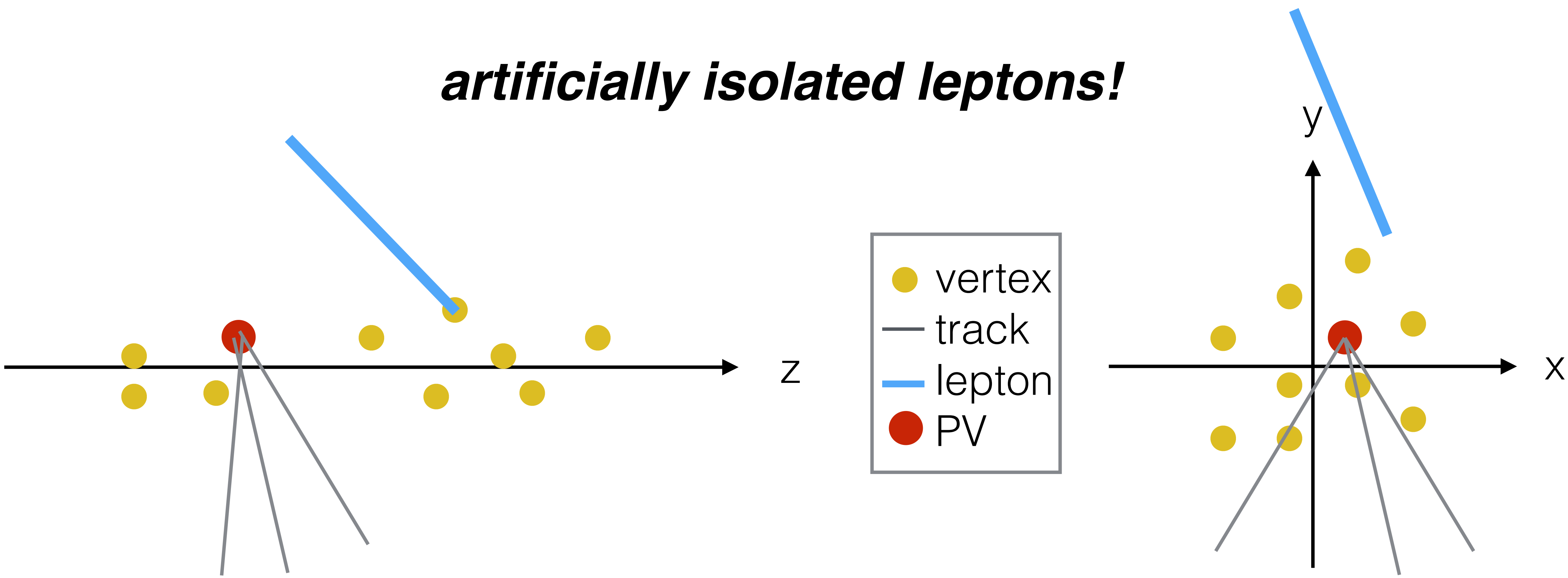


5. imperfect software

Example: artificially isolated leptons

- observed in CMS displaced lepton search
- selected lepton is from a B decay, surrounded by rest of B jet (not isolated)
- different vertex chosen as PV
- lepton isolation calculated wrt PV

artificially isolated leptons!



Future work

- Since the LHC startup, we've generally tried to design zero-background searches
  - makes sense to cast the broadest net possible at first
- It's (relatively) easy to search for very heavy, very displaced objects
- Moving forward, we'll start targeting more challenging regimes and holes in coverage
  - e.g. softer decays, lower lifetimes
- This will require deeper thinking about background rejection to balance sensitivity and generality
  - **much interesting work to be done!**

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