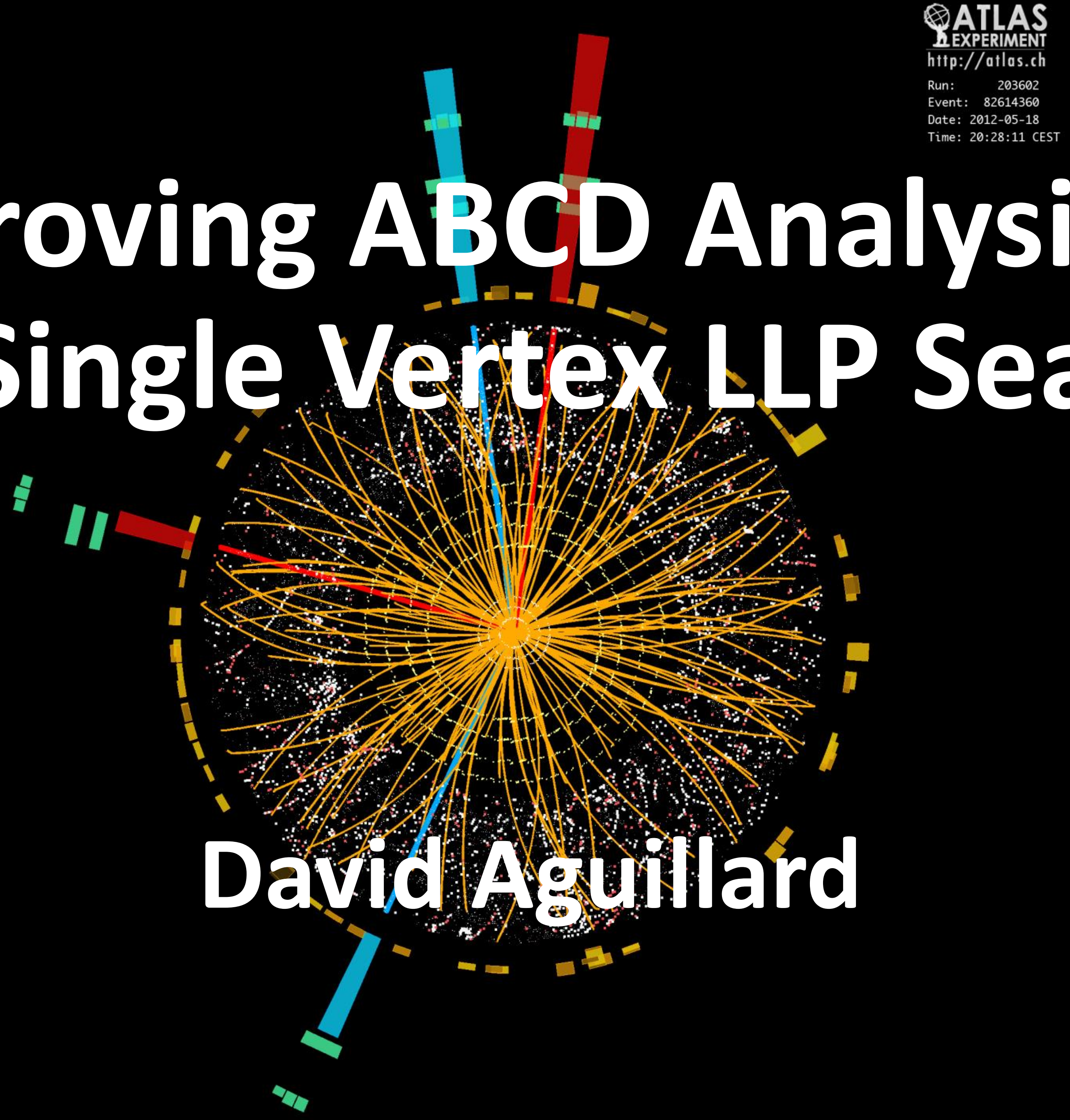
Improving ABCD Analysis in the Single Vertex LLP Search



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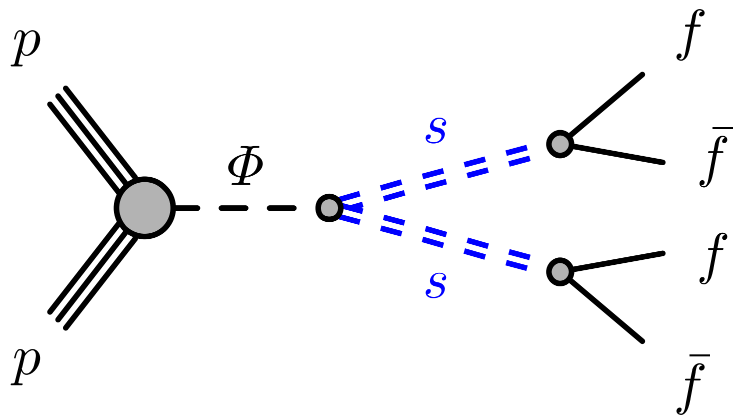
ATLAS Long Lived Particle (LLP) Search

<u>Idea:</u> Higgs decays into "new" undetectable particle which escapes HCal

- "New" particle decays into SM particles which are detected by the MS



Boson (Higgs) to long-lived scalars

- Easy - Just look for a decay without a track in the ID, ECal, or Hcal

ATLAS LLP Analysis strategy

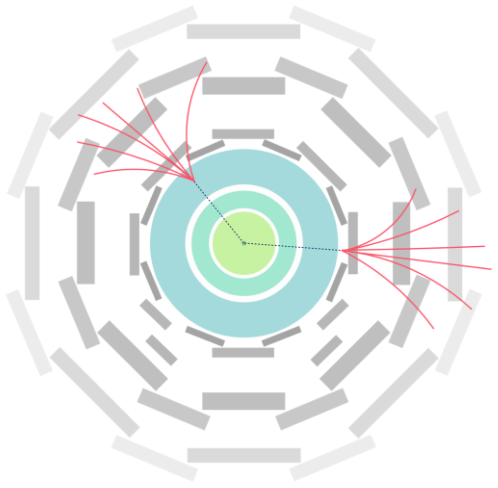
Two possible strategies:

1. Two-vertex analysis

- Looking for **two displaced vertices** in the MS

  Pro: Negligible background

  Con: Little sensitivity to longer lifetimes

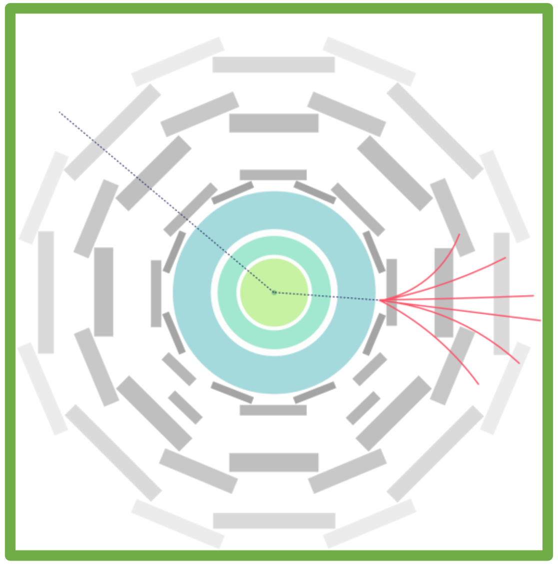


2. One-vertex analysis

- Looking for **one displaced vertices** in the MS

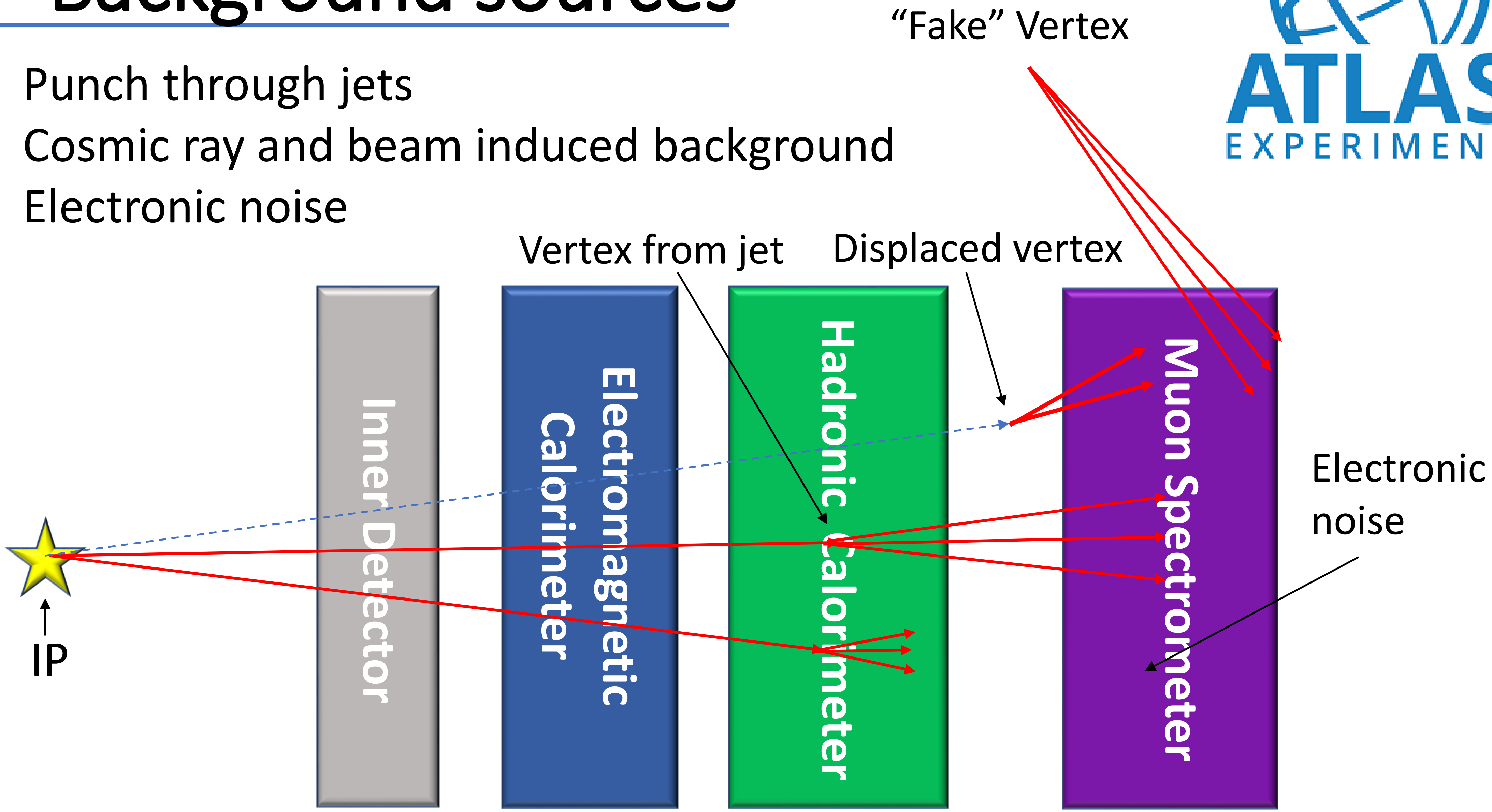
  Pro: Better sensitivity to longer lifetimes

  Con: Much higher background → need a strategy to estimate it!



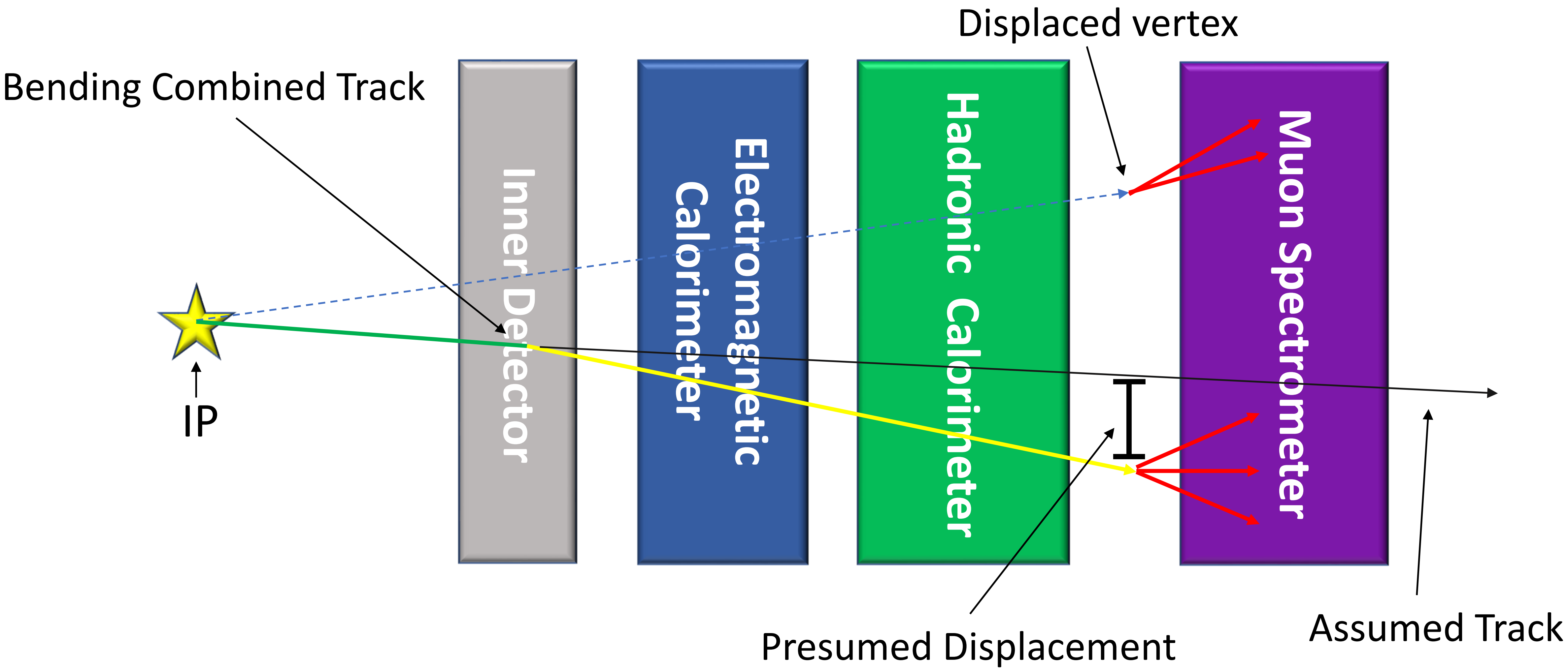
LLP Background sources

- Punch through jets
- Cosmic ray and beam induced background
- Electronic noise



Possible new source – Discovered in my work

- Limitations in only considering inner detector tracks



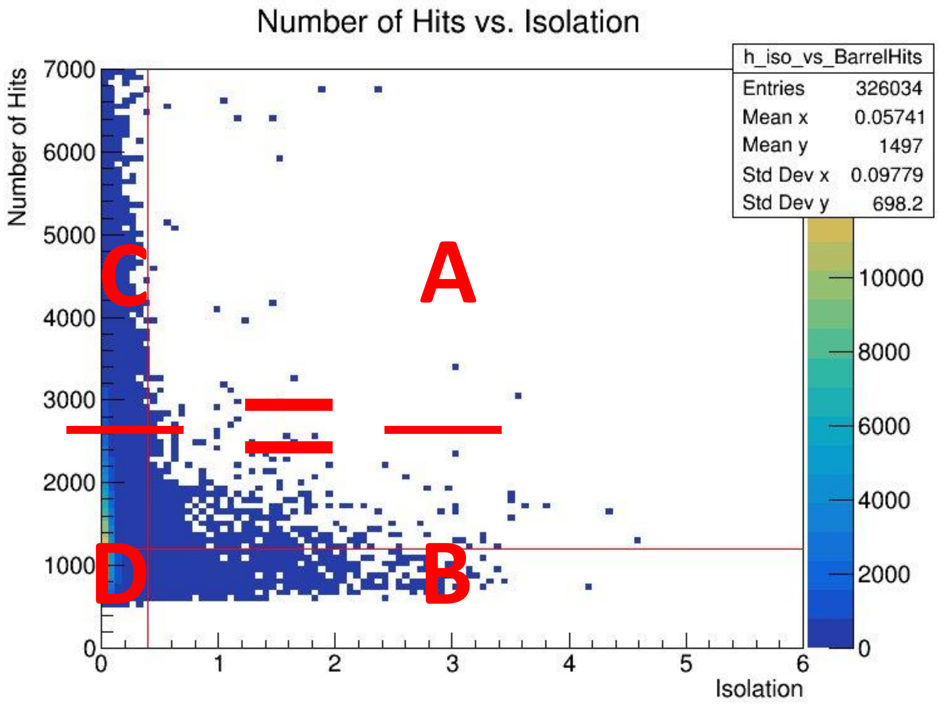
Questions my group seeks to answer

1. What are the sources of LLP background in MS for single vertex search?
2. How can we control for them?

Method: ABCD Analysis

Principle: Given a plot of two uncorrelated variables divided into quadrants:

$$\frac{Events_{regionA}}{Events_{regionB}} = \frac{Events_{regionC}}{Events_{regionD}}$$



Use this to our advantage: Axis choice of the ABCD plane

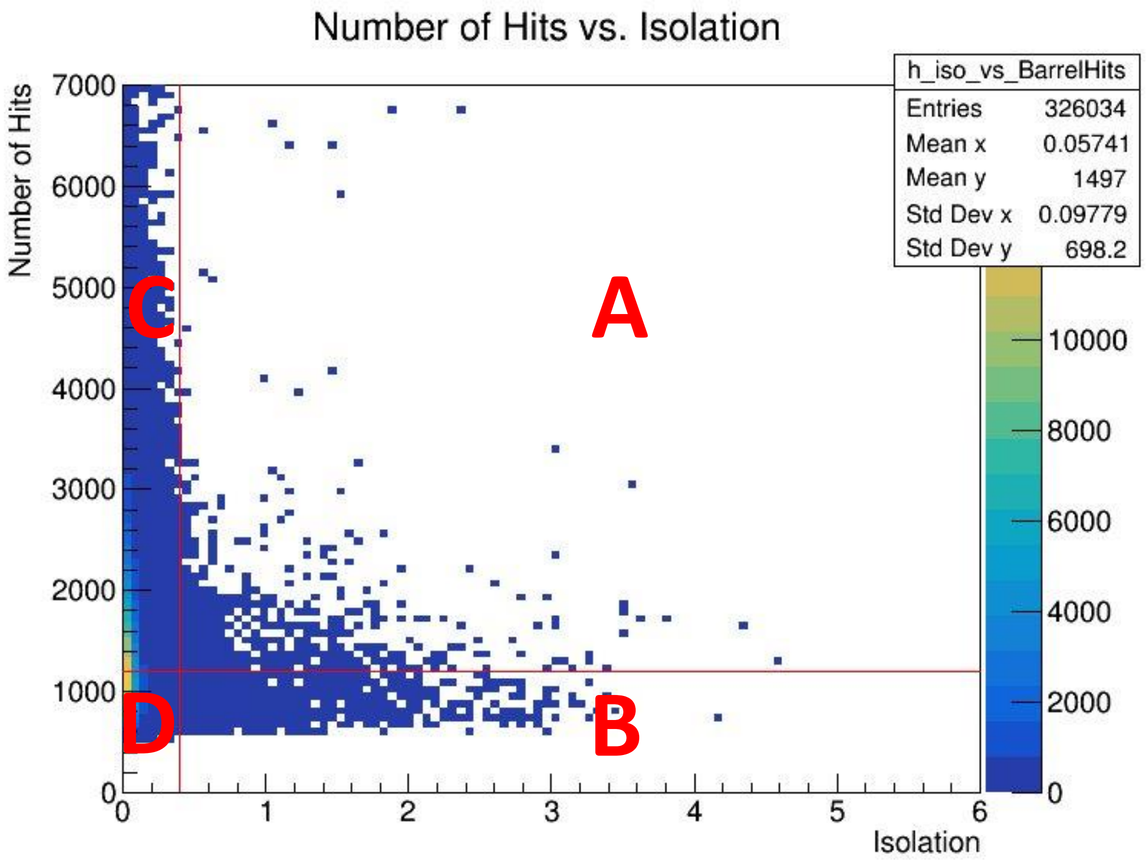
<u>Choose:</u> Uncorrelated variables which separate signal from background

Y – axis: Number of hits

- LLP's are predicted to decay into fermions – signature is high number of hits

X – axis: Isolation

- LLP's do not have an inner detector track or jet which points in their direction



But why don't we just say that events with high isolation and hit numbers are signal?

The single vertex search is incredibly prone to background, and we cannot get rid of it

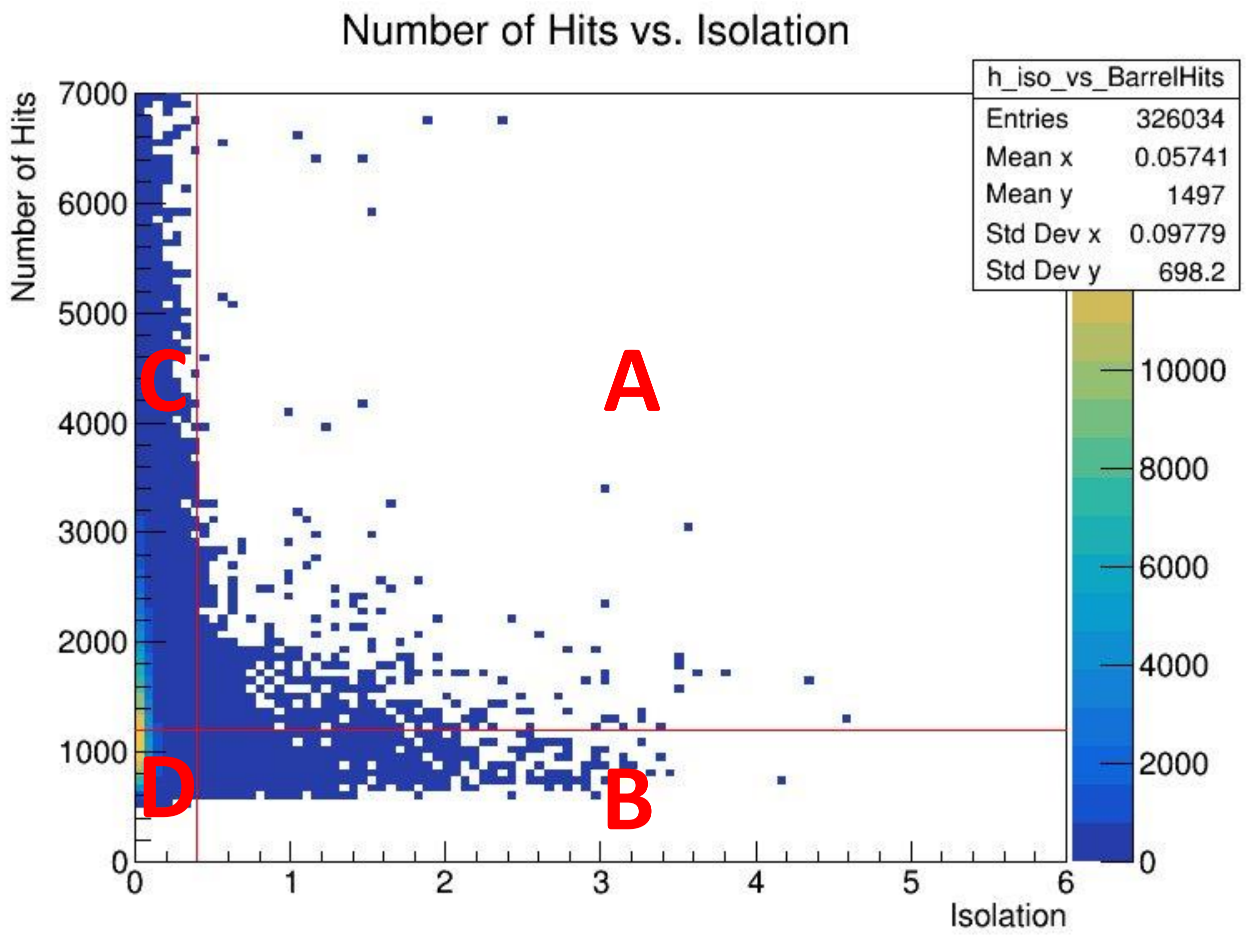
But we can determine its rate!

Use ABCD to estimate background in signal region

1. If ABCD plane working properly: Can predict rate of background MS vertices in certain region (A) using:

$$\frac{CB}{D} = A$$

2. If this equality holds, any excess in region A is signal



My Role: Look for background populating specific region

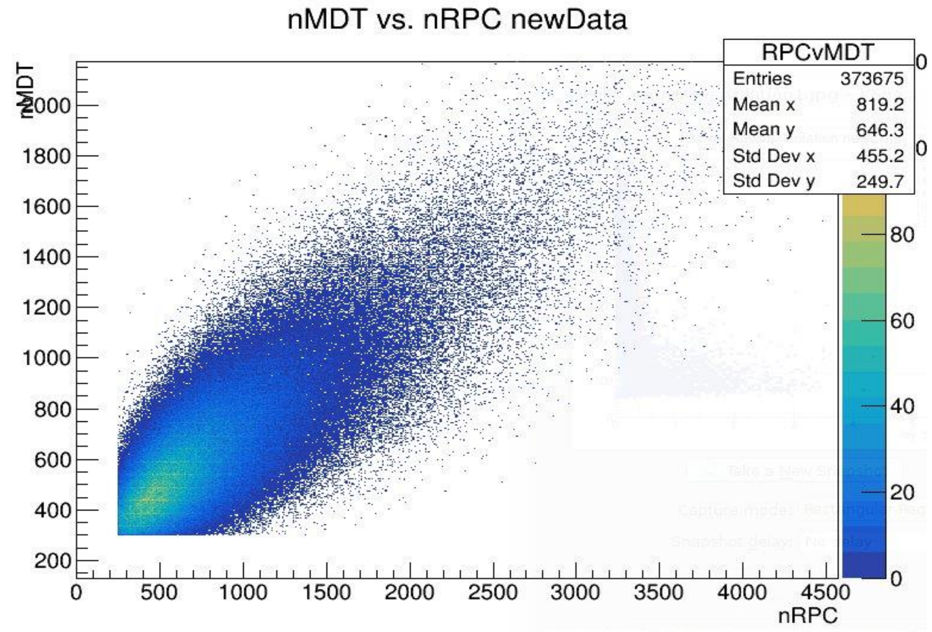
- When searching for Higgs to scalar models, this method did not work for these variables (before unblinding):

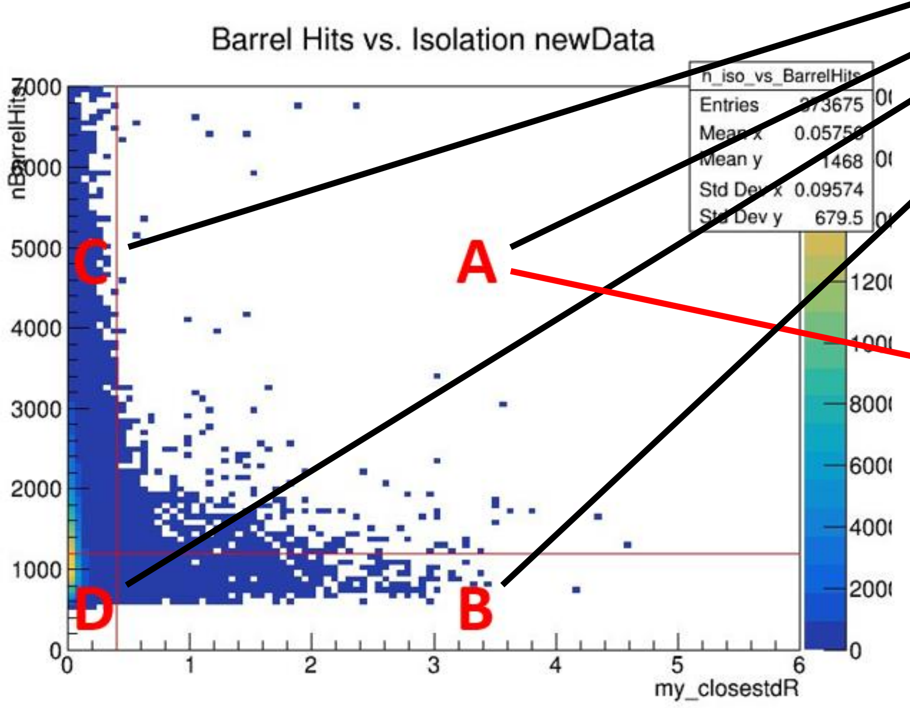
$$A \neq \frac{CB}{D}$$

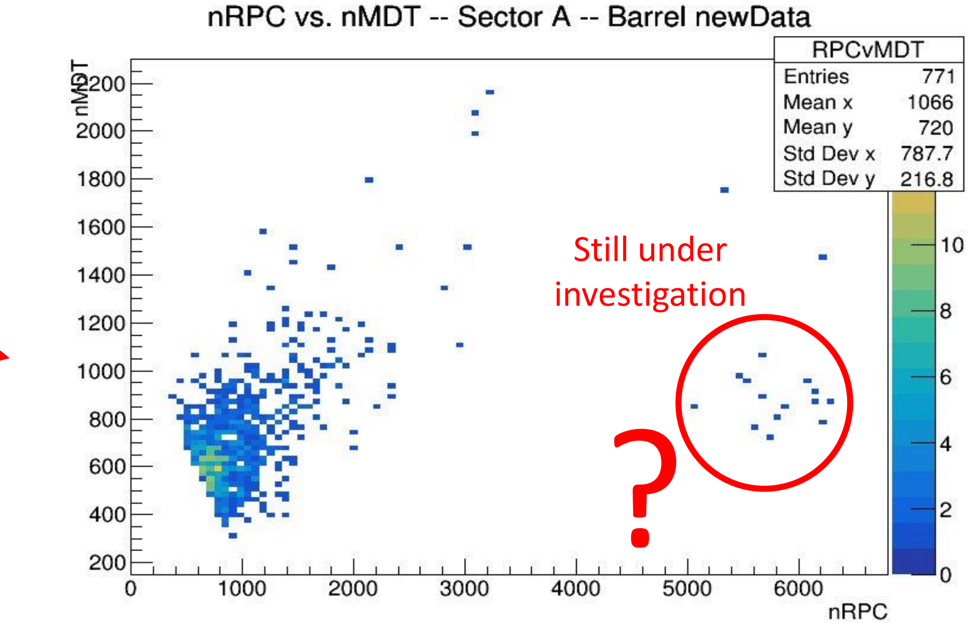
- ABCD analysis requires no specific background populates a specific region
  - My role – search for background populating a specific region

Execution of my role

- I Created skimmed version of Ntuple to perform analysis
- Wrote code which pulls MS vertices from A, B, C, D
- Compared behavior of key MS variables in different regions of ABCD plane –
  - looked for anomalies that could explain the failure of the ABCD plane







Execution: Look for new places to cut background

Step 1: Plotted variables alongside Monte Carlos

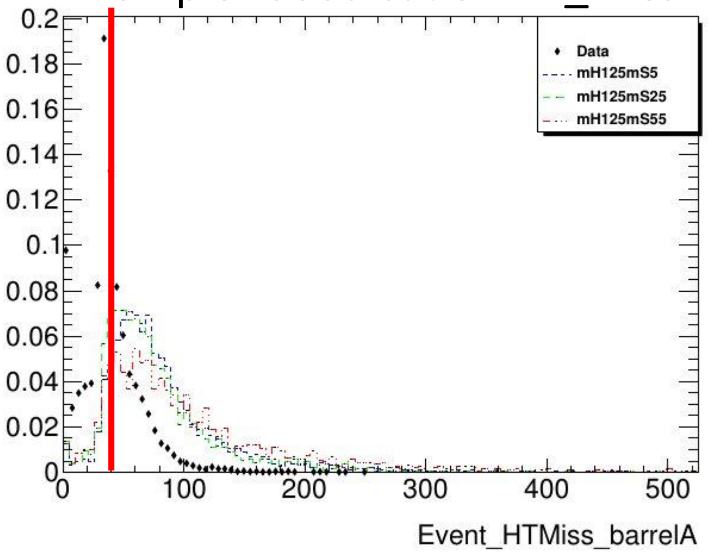
Step 2: Compared data in each region

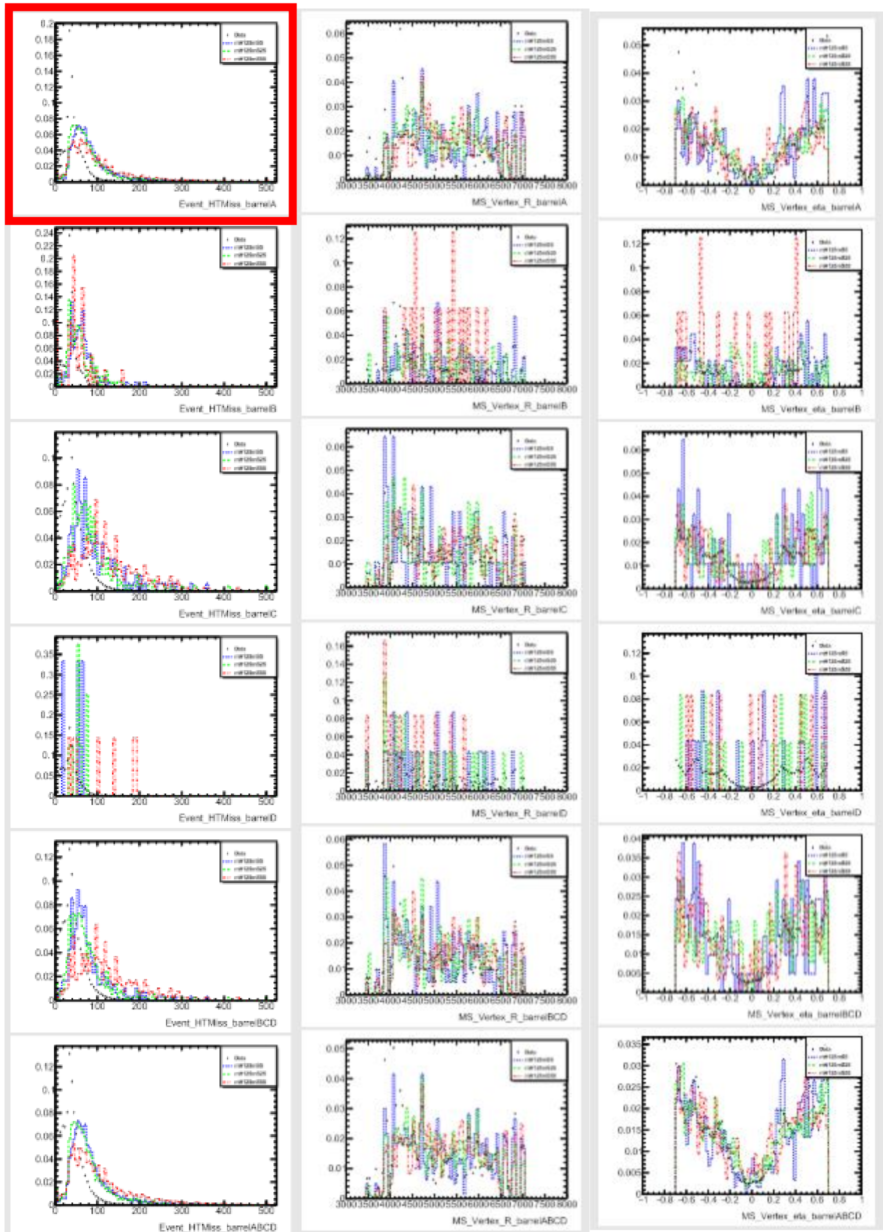
- If data distribution differs between regions, can explain why the ABCD does not work

Alternative: Look for areas with lots of data and small predicted signal

- good background cuts; may or may not improve ABCD
- Candidates for new ABCD axis

Example: Good cut on HT_Miss





x30

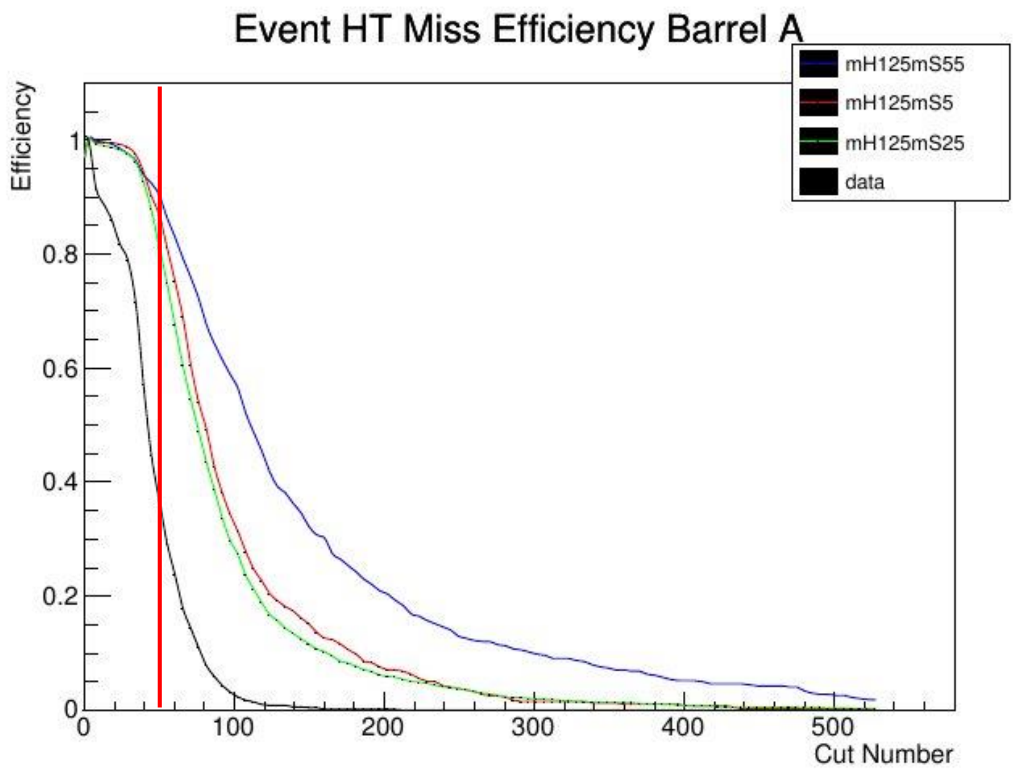
Execution: Ensuring efficiency of the cut

Example: Good cut I made

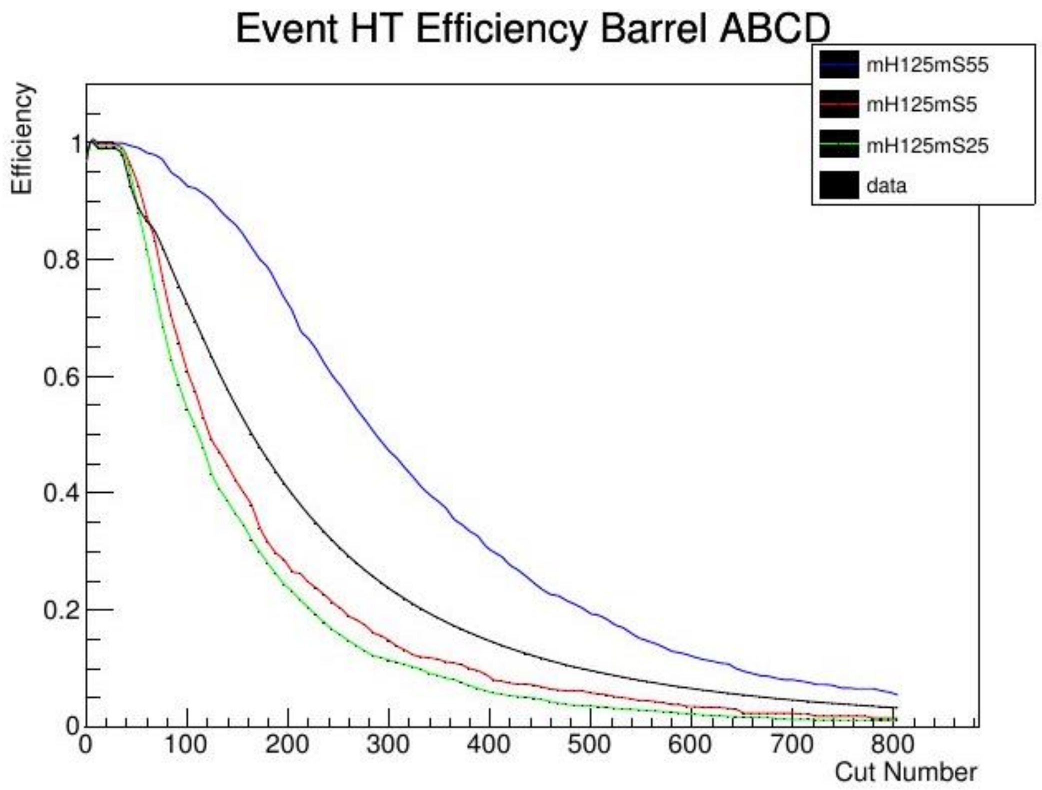
Efficiency of signal remains high while data efficiency drops means the cut is almost purely background

Example: Bad cut I did not make

Signal efficiency and data efficiency do not diverge



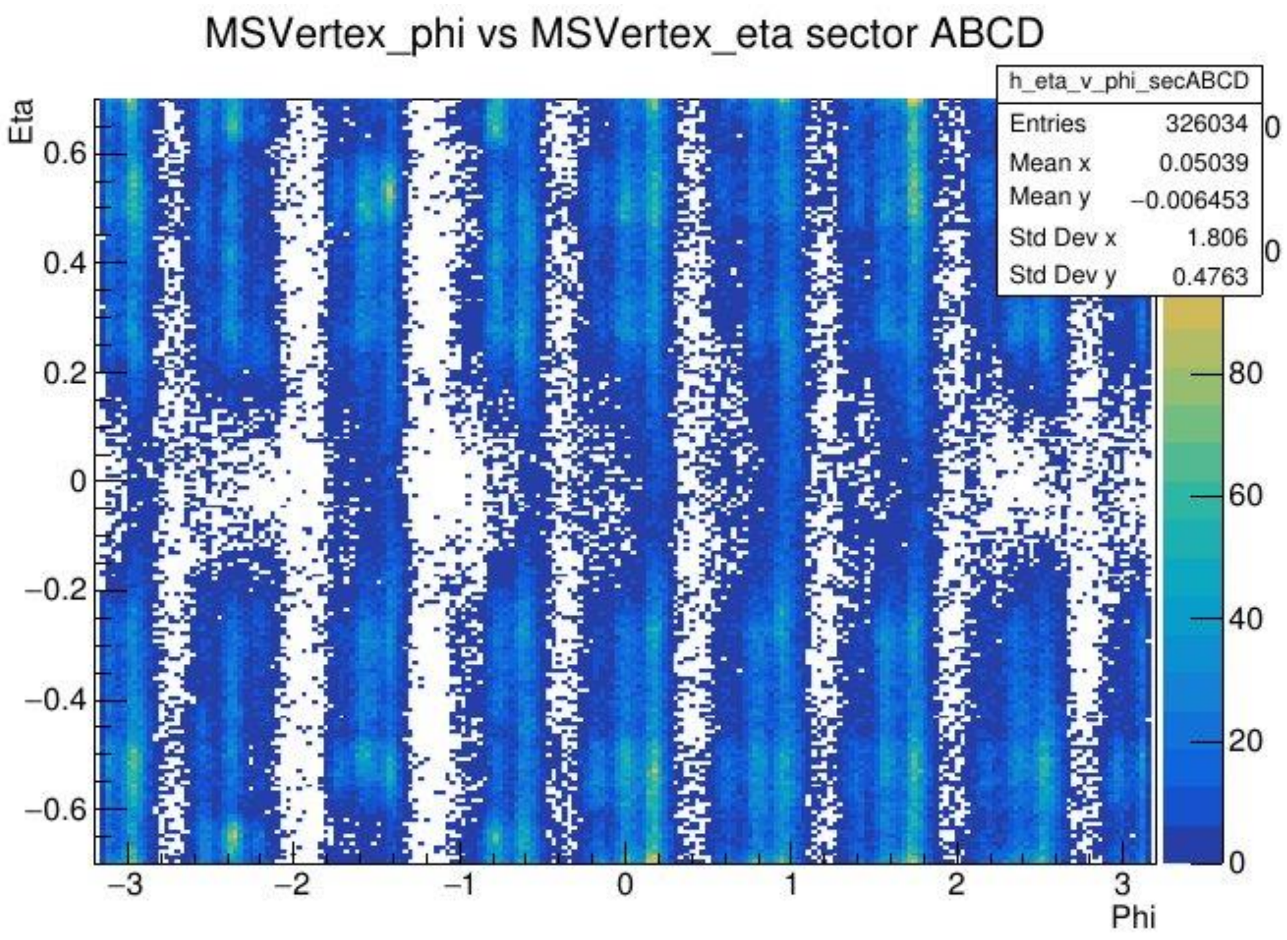
HT_Miss = Missing transverse momentum of event

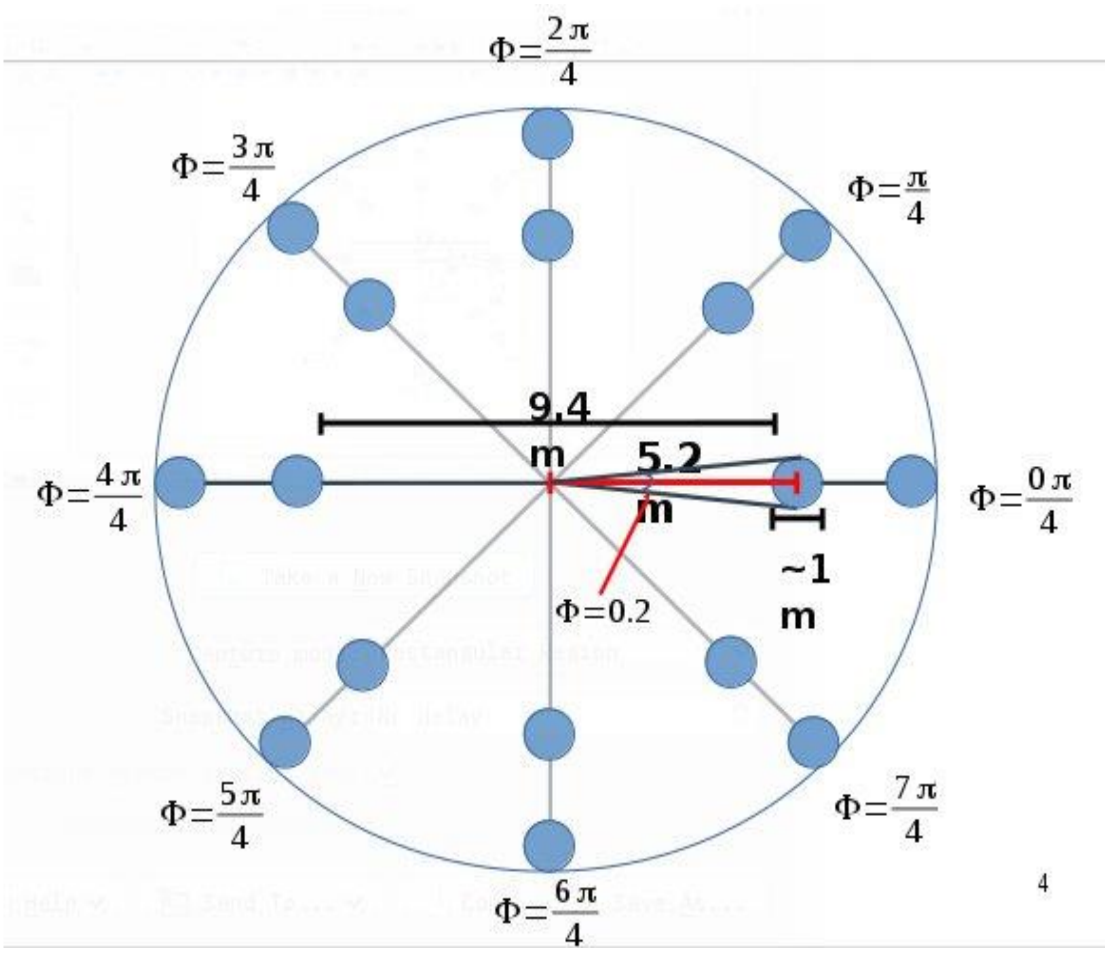


HT = Total transverse momentum of event

Material Veto: Toroids

- Attempted cut: areas of high activity due to dense toroids
- Not efficient, but still a possible cut due to high amounts of muon showering/deflecting

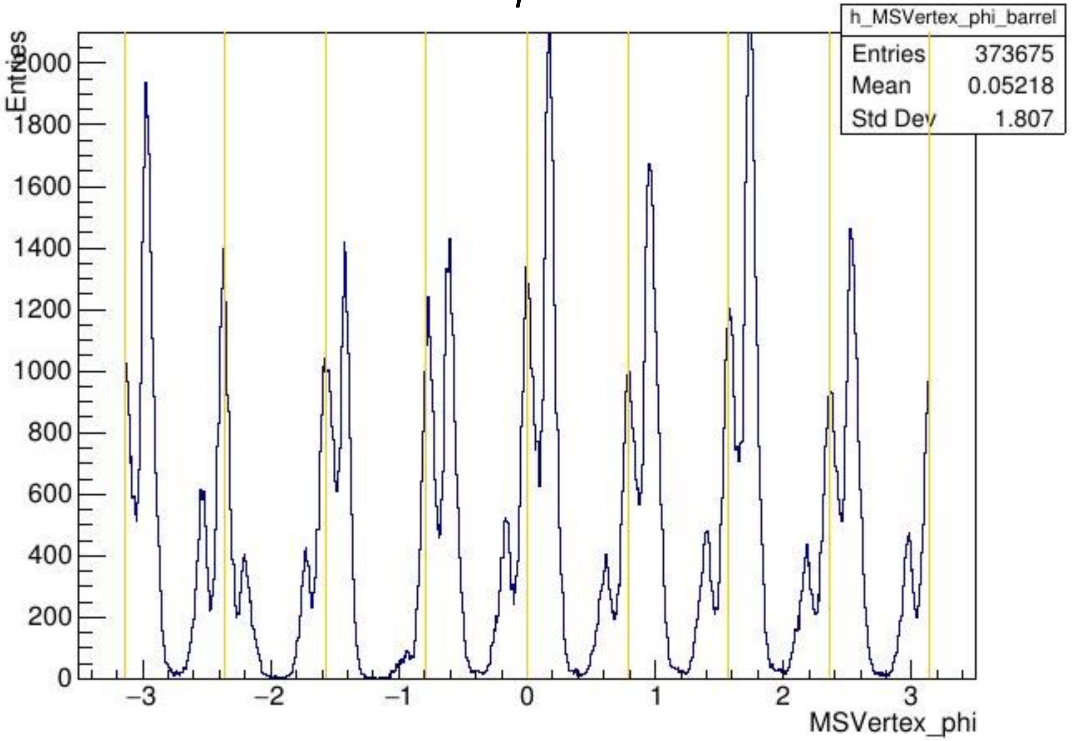




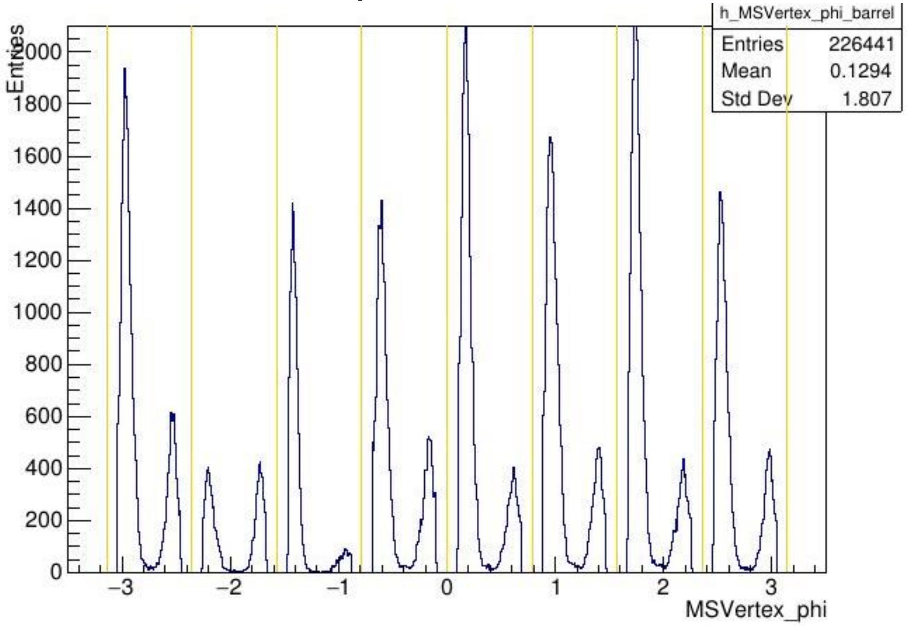
Material Veto: Toroids

Results from cut:

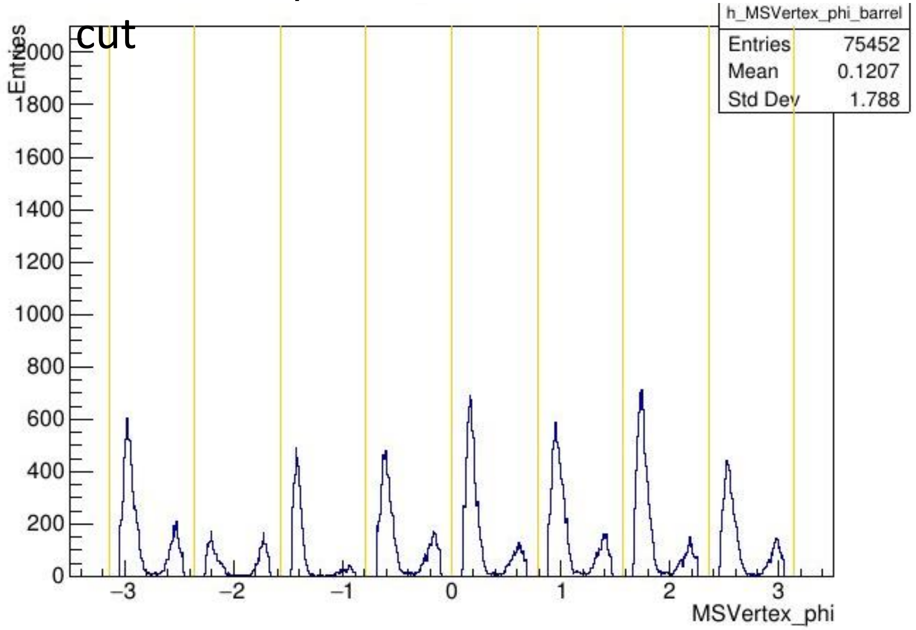
MS Vertex ϕ Position



MS Vertex ϕ Position; Toroid Cut



- MS Vertex ϕ Position; Toroid and HT Miss cut



Results from new cuts (only those preserving efficiency):

Calculation to test ABCD:

Standard error between A and $\frac{BC}{D}$:

$$A = \frac{BC}{D}$$

$$\Delta = \left|A - \frac{BC}{D}\right|$$

$$\Delta_E = \sqrt{\sqrt{(A)^2} + \sqrt{(B)^2}}$$

$$\sigma = \frac{\Delta}{\Delta_E}$$

Before new cuts:

Standard error between A and $\frac{BC}{D}$:

$$A = 1001$$

$$\frac{BC}{D} = 2023$$

$$\Delta = 1022$$

$$\Delta_E = 54.9$$

$$\sigma = 18.6$$

After new cuts:

Standard error between A and $\frac{BC}{D}$:

$$A = 298$$

$$\frac{BC}{D} = 580$$

$$\Delta = 282$$

$$\Delta_E = 29.6$$

$$\sigma = 9.5$$

Results from all cuts:

Before new cuts:

Standard error between A and $\frac{BC}{D}$:

$$A = 1001$$

$$\frac{BC}{D} = 2023$$

$$\Delta = 1022$$

$$\Delta_E = 54.9$$

$$\sigma = 18.6$$

After new HT Miss and Toroid cuts:

Standard error between A and $\frac{BC}{D}$:

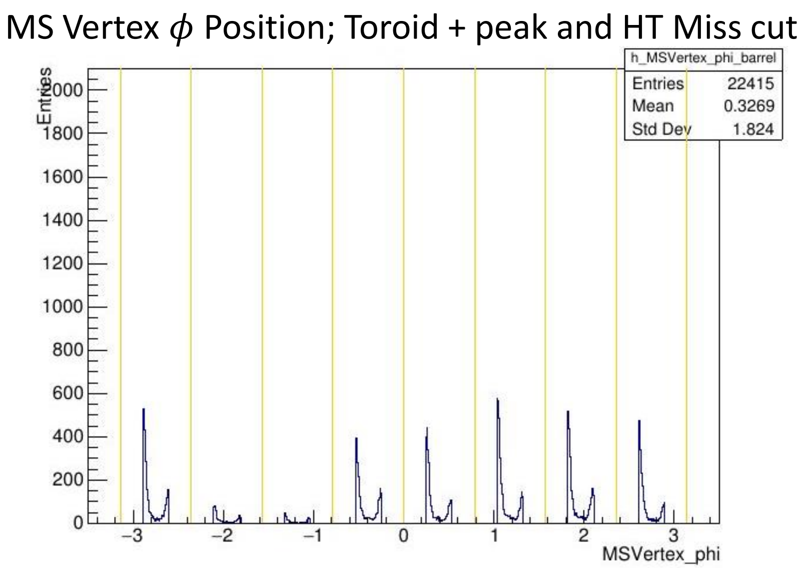
$$A = 186$$

$$\frac{BC}{D} = 345$$

$$\Delta = 159$$

$$\Delta_E = 29.6$$

$$\sigma = 6.9$$



Extending cut to all material around toroid:

$$A = 33$$

$$\frac{BC}{D} = 33.37$$

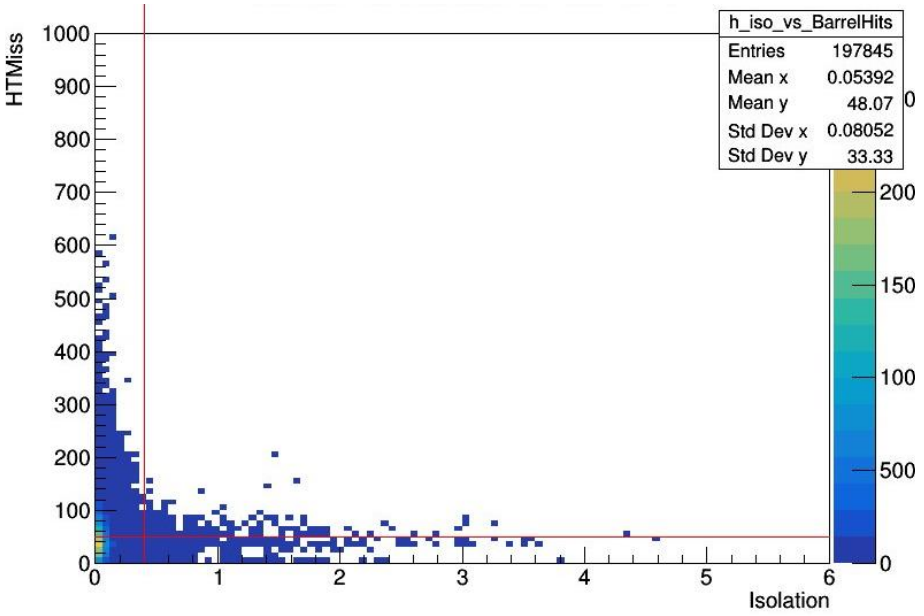
$$\Delta = 0.37$$

$$\Delta_E = 8.12$$

$\sigma = 0.045$ – horrible efficiency

Replacing number of hits with HT Miss:

New ABCD Plane: HT Miss vs. Isolation



Performance of Hits v. Isolation:

Standard error between A and $\frac{BC}{D}$:

$$A = 1001$$

$$\frac{BC}{D} = 2023$$

$$\Delta = 1022$$

$$\Delta_E = 54.9$$

$$\sigma = 18.6$$

Performance of HT Miss v. Isolation:

Standard error between A and $\frac{BC}{D}$:

$$A = 259$$

$$\frac{BC}{D} = 379$$

$$\Delta = 120$$

$$\Delta_E = 25.25$$

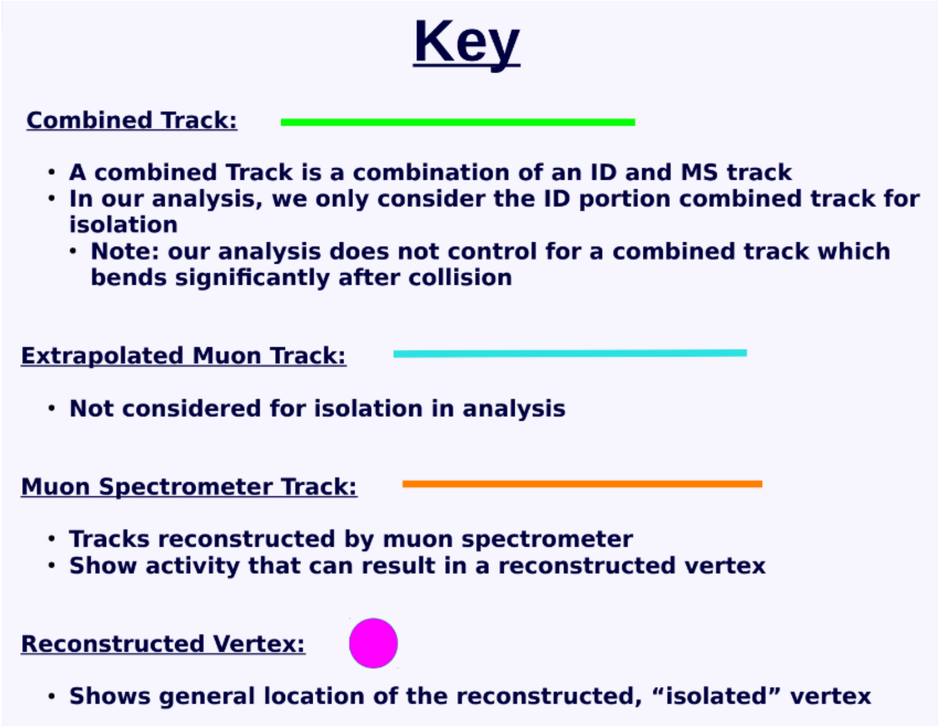
$$\sigma = 4.8$$

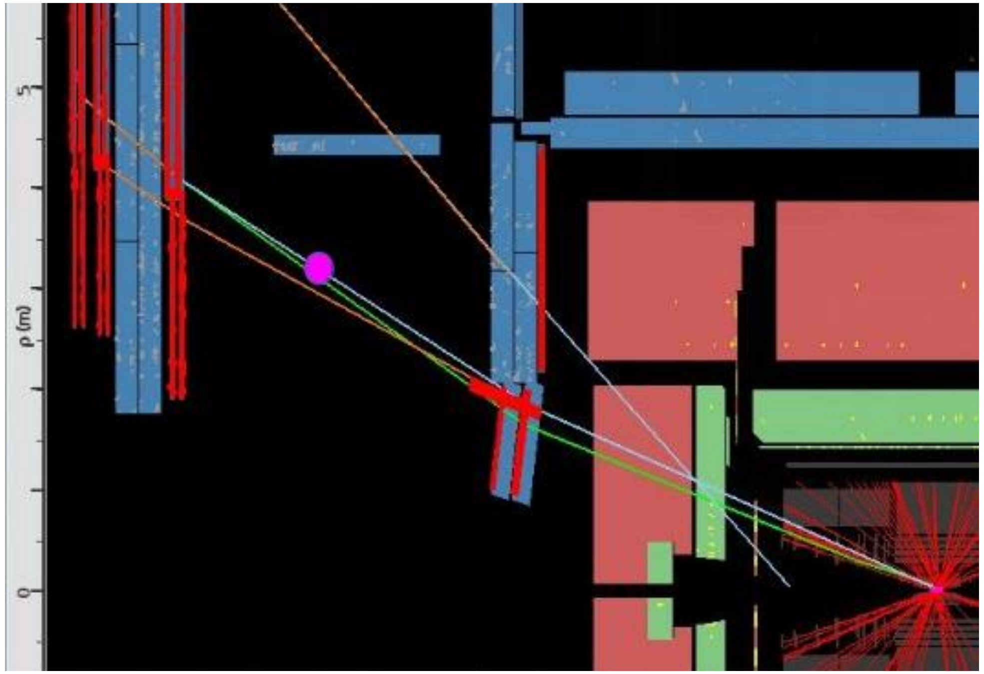
Event display: New Source of background

<u>New Source:</u> Combined Tracks

- I found region A event display showed bending combined tracks
  - Combination of MS and ID tracks
  - Current analysis does not control for this
  - Found in all events I observed

- Depending on the rate these occur, could be main source of background
  - Unfortunately, this information is not in our containers – will require a few months wait





Future

- May run tests on data associated with combined tracks, once available
  - Gives me an opportunity to stay connected in future

Lessons

- Using computer as main tool in a working environment
- Creative problem solving
- Communicating across language barriers

Thank You:

National Science Foundation

University of Michigan

CERN


Il vostro caffè.