

Disappearing tracks

2

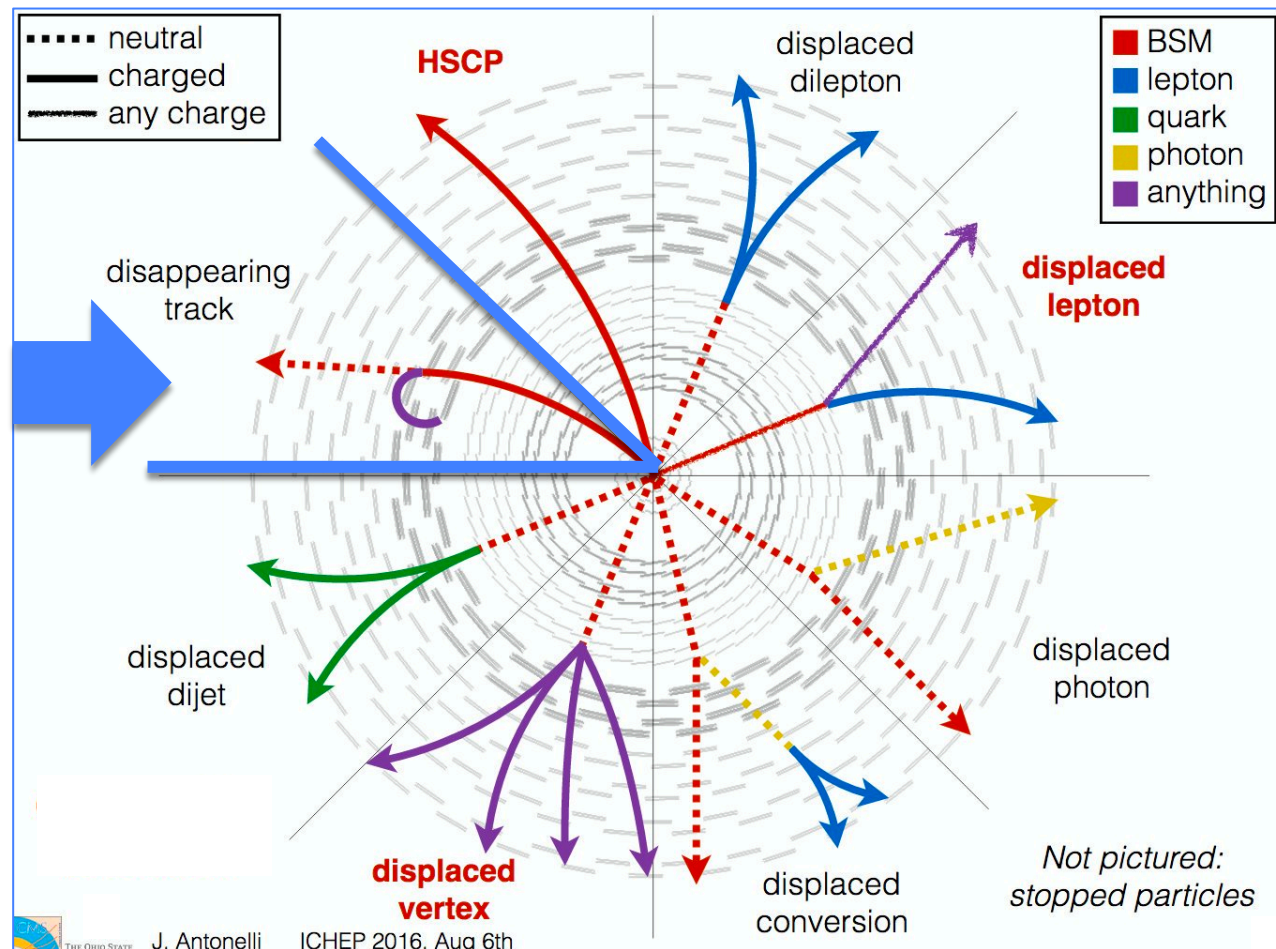
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- From **charged long-lived particles** decaying to **invisible** products in the **inner tracker**, therefore may be identified by:

→ Missing hits in outer silicon tracker

→ No energy deposit in calorimeter

→ No muon hits



Inputs

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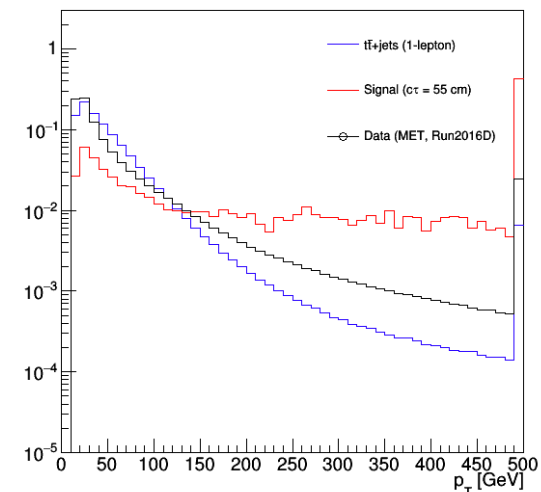
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- Look at **clean** track collection in data, SM MC, and signal MC
 - MET PD, full Run2016D (Golden JSON)
 - $t\bar{t}$ +jets, semi-leptonic
 - pMSSM with $c\tau = 55$ cm
- **NOTE:** for signal, only tracks **matched** to a GEN chargino are selected
- Matching criterion: $dR < 0.01$
- **CAVEAT:** for data, no specific trigger path is required

→ Apply **basic track selection:**

- $p_T > 15$ GeV & $|\eta| < 2.4$
- $dx_{xy} < 0.02$ cm
- $dz < 0.1$ cm

→ Look at **PF isolation** after basic track selection

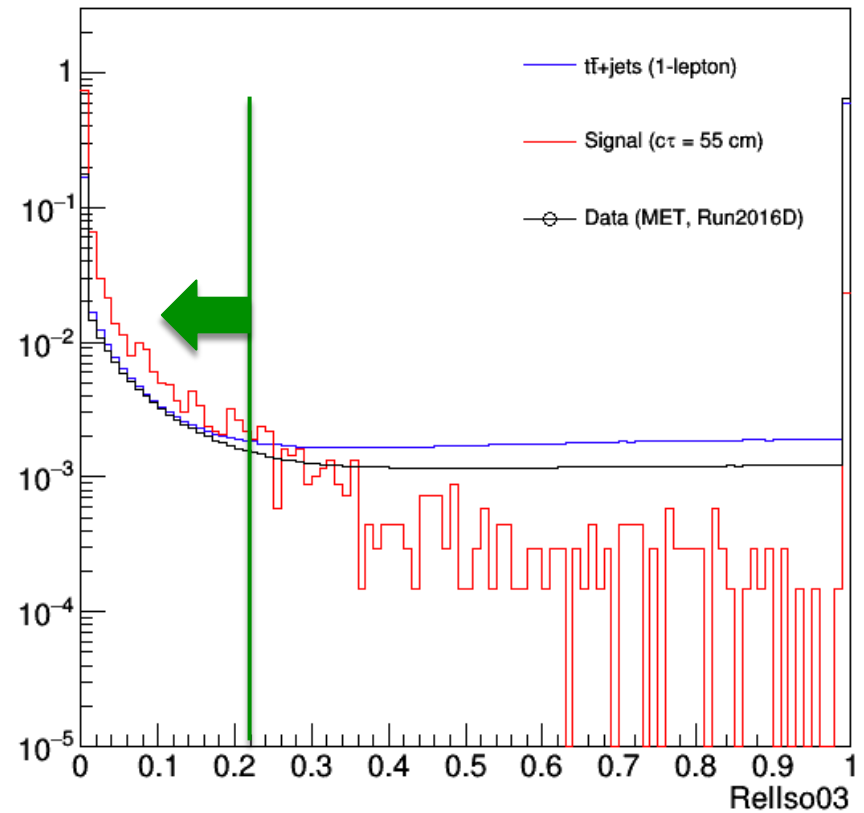
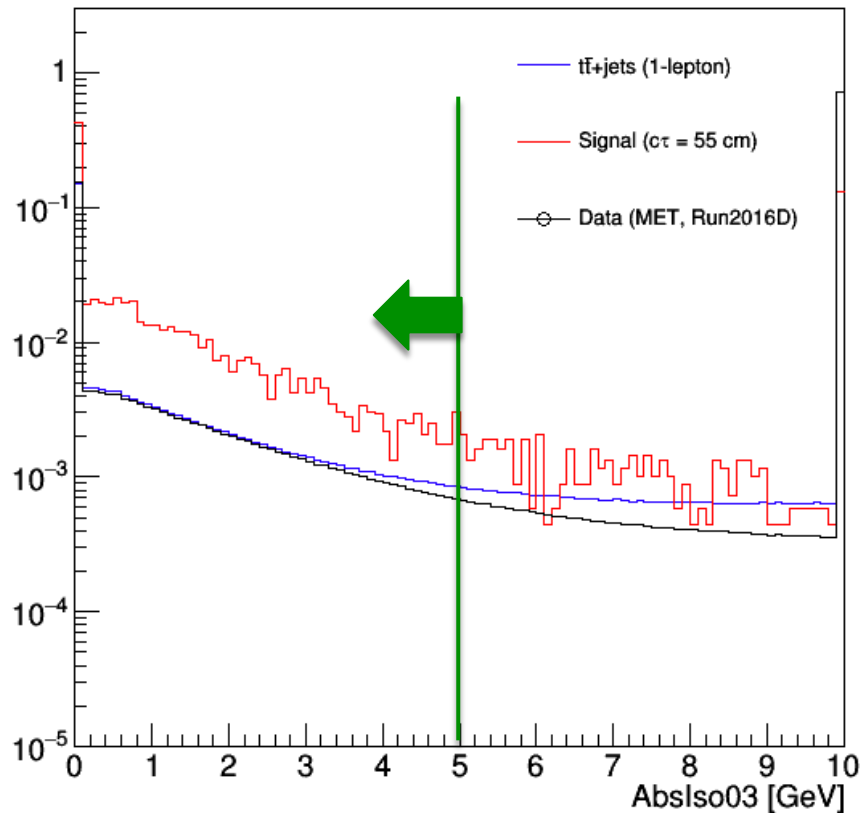


Isolation requirements

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- Look at clean track collection, in data, SM MC and signal MC



→ Apply (loose) isolation requirements: **PFRelIso03 < 0.2 & PFAbsIso03 < 5 GeV**

What's next?

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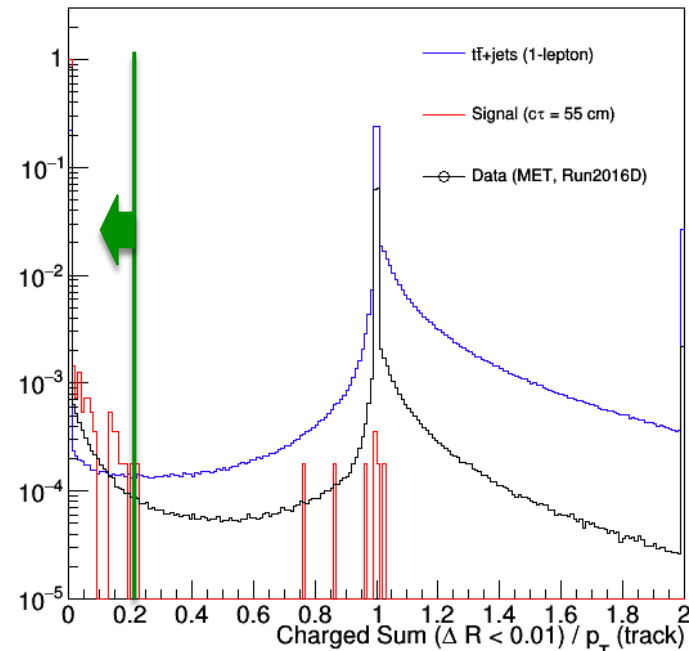
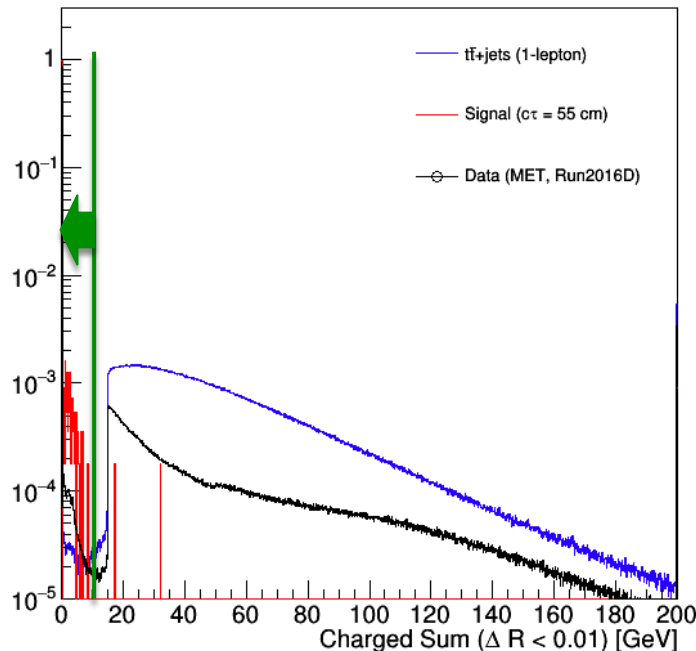
1. Apply basic selection & isolation requirements on tracks
 - $p_T > 15 \text{ GeV}$ & $|\eta| < 2.4$
 - $d_{xy} < 0.02 \text{ cm}$
 - $d_z < 0.1 \text{ cm}$
 - $\text{PFAbsIso03} < 5 \text{ GeV}$
 - $\text{PFRellIso03} < 0.2$
2. Look at track-related variables
3. Identify (possible) disappearing track selection
4. Evaluate SM rejection + signal efficiency

Sum of charged candidates

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- Sum of charged PF candidates (non-PU) within $dR < 0.01$ from track



- For signal, do not charged expect PF candidates from isolated track
 - Isolated (disappearing) tracks do not make it to PF collection (in 80X)
 - Why peak at 0 for data? Under investigation: may be 'dirty' tracks.

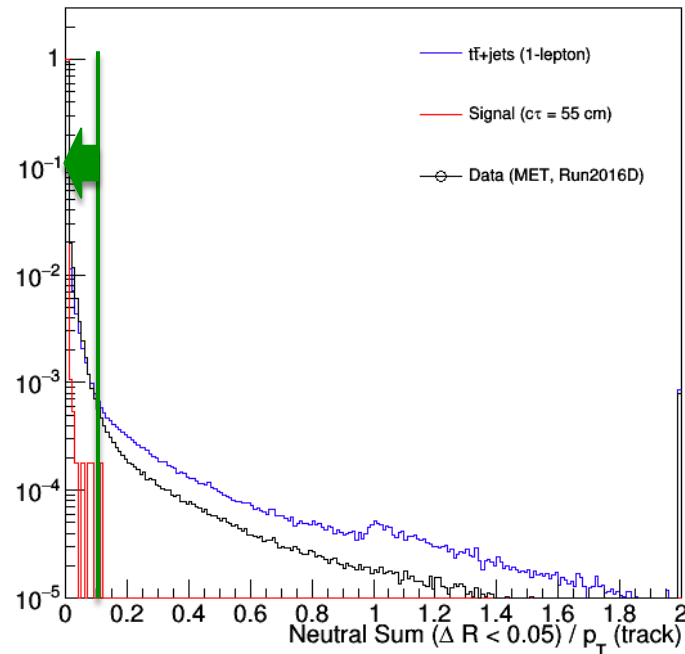
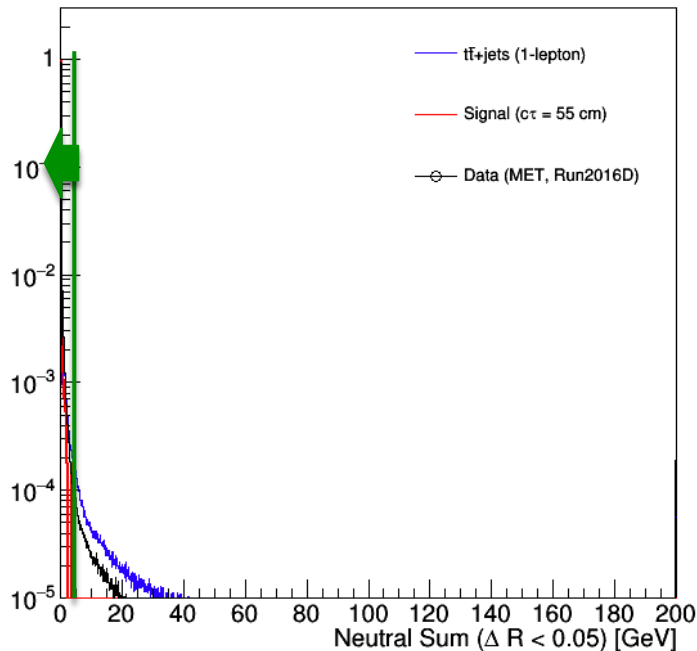
→ Select tracks with **charged sum ($dR < 0.01$) < 10 GeV** & **charged sum ($dR < 0.01$)/ p_T < 0.2**

Sum of neutral candidates

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- Sum of neutral candidates within $dR < 0.05$ from track
 - Photon + neutral hadrons



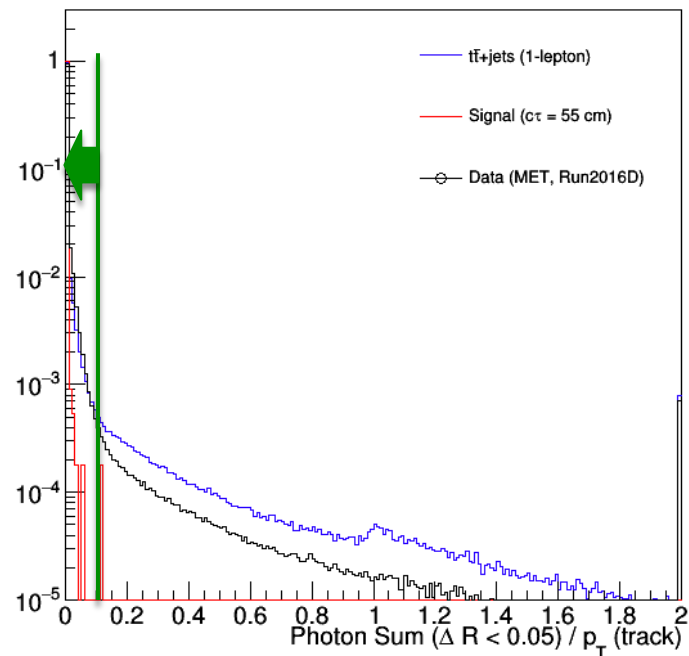
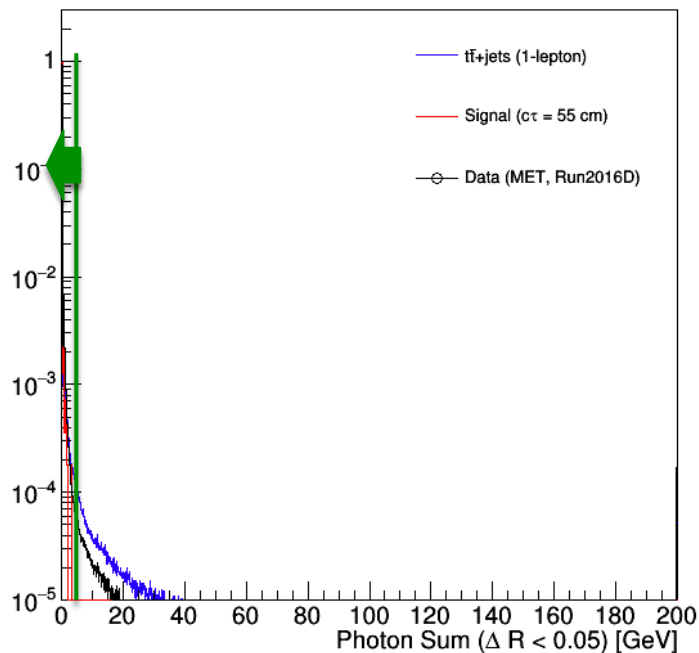
- For signal, expect small energy deposits from neutral candidates
 - ~Replacement for small calorimeter deposit requirement
- Select tracks with **neutral sum ($dR < 0.05$) < 5 GeV** & **neutral sum ($dR < 0.05$)/ $p_T < 0.1$**

Sum of photon candidates

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- Sum of neutral candidates within $dR < 0.05$ from track
 - Photon**



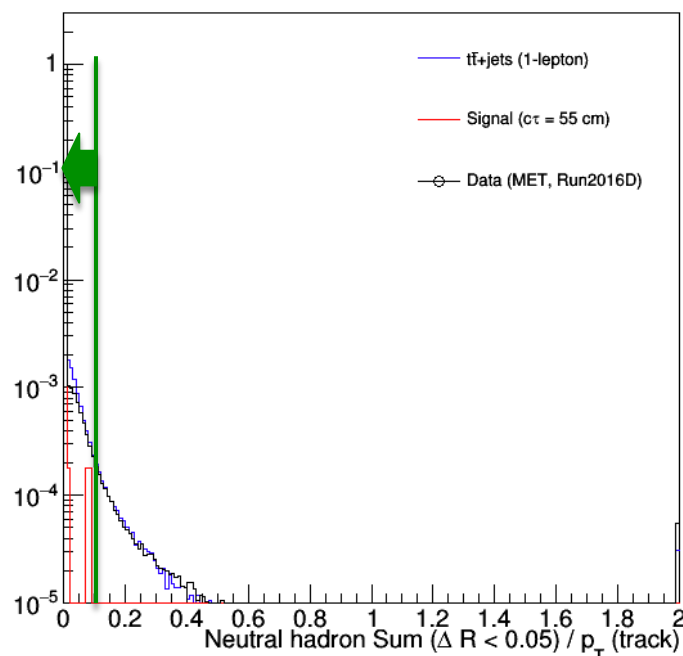
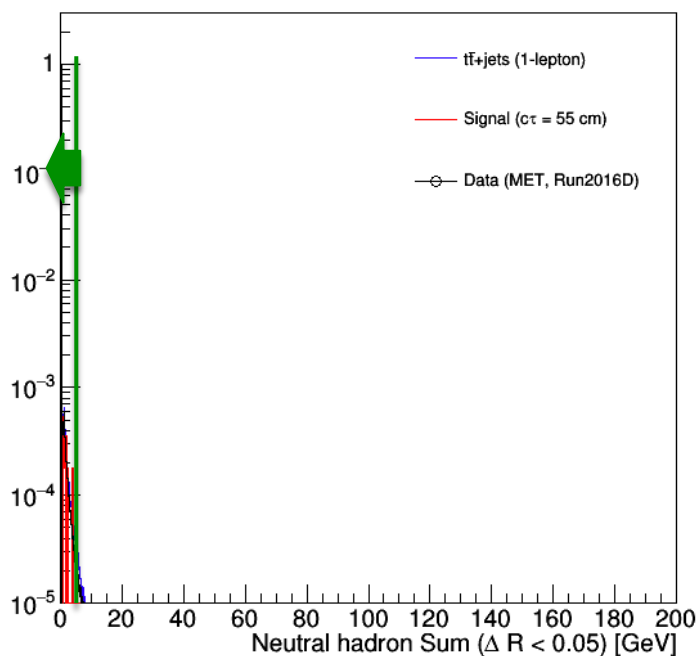
- For signal, expect small energy deposits from photon candidates
 - ~Replacement for small **EM** calorimeter deposit requirement
- Select tracks with **photon sum ($dR < 0.05$) < 5 GeV** & **photon sum ($dR < 0.05$)/ $p_T < 0.1$**

Sum of neutral hadron candidates

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- Sum of neutral candidates within $dR < 0.05$ from track
 - Neutral hadrons**



- For signal, expect small energy deposits from neutral hadron (neu. had.) candidates
 - ~Replacement for small **hadronic** calorimeter deposit requirement

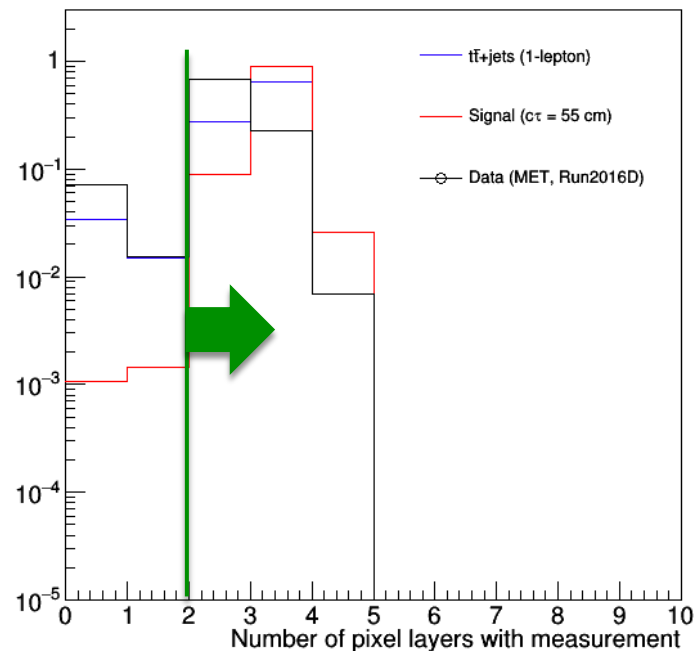
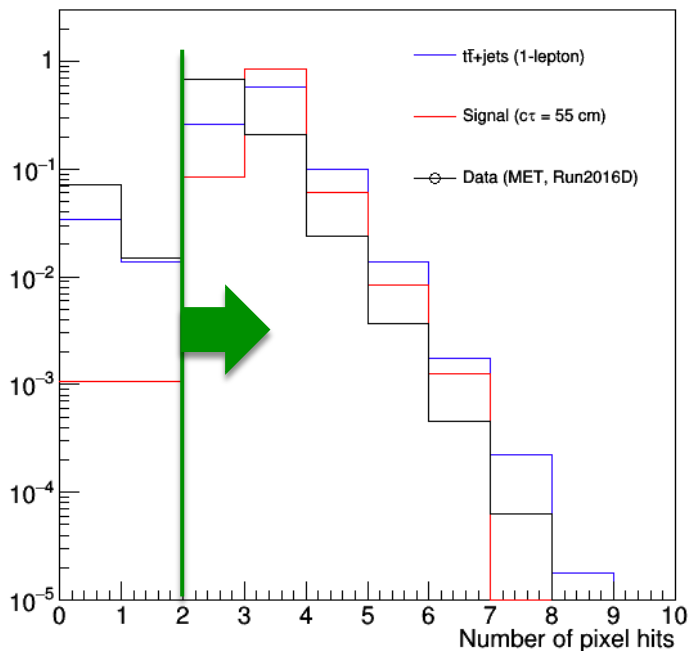
→ Select tracks with **neu. had. sum ($dR < 0.05$) < 5 GeV** & **neu. had. sum ($dR < 0.05$)/ $p_T < 0.1$**

Number of pixel hits

10

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- Number of pixel hits and number of pixel layers with measurement



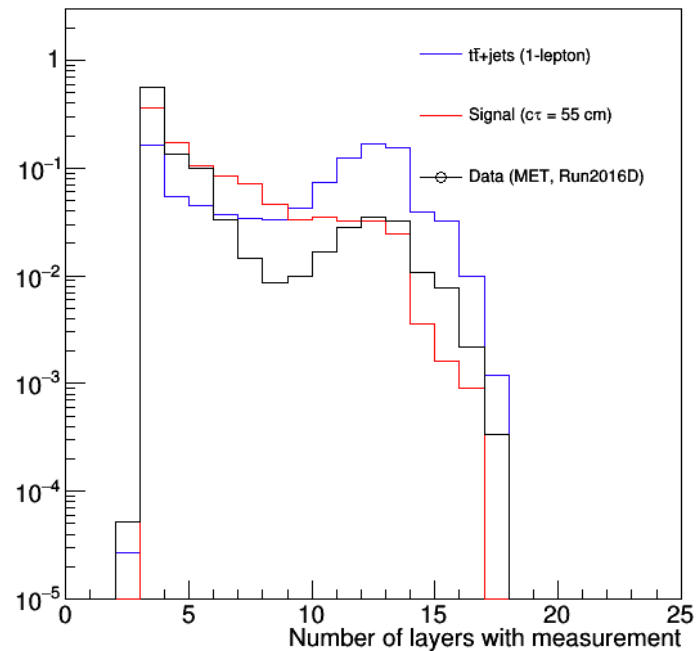
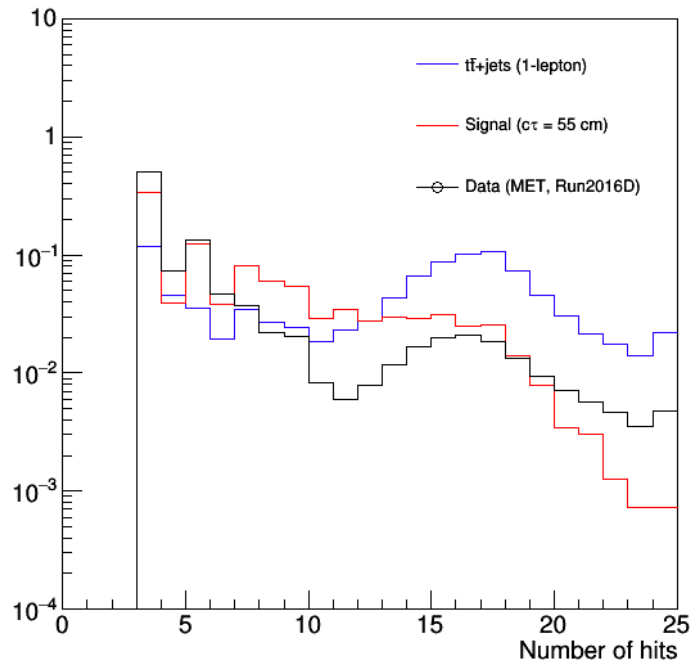
→ Require **at least 2 pixel hits & at least 2 pixel layers with measurement**

Number of valid hits

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- Number of hits and number of layers with measurement



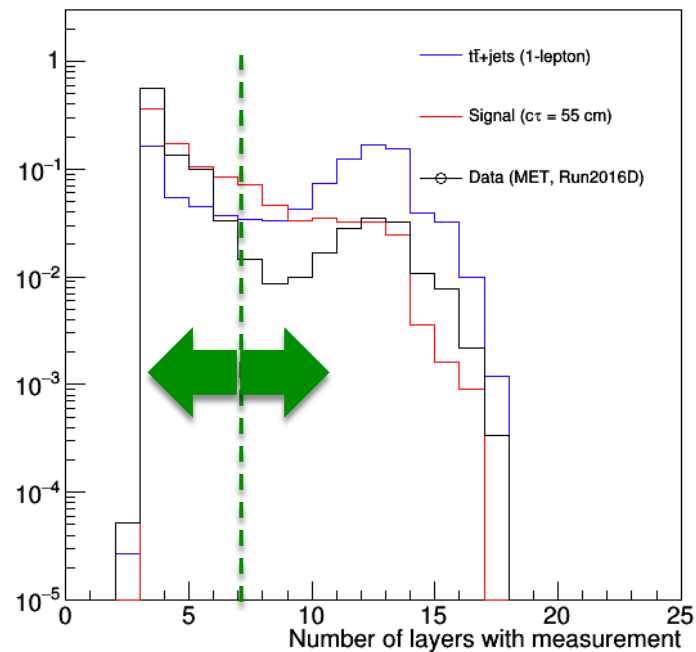
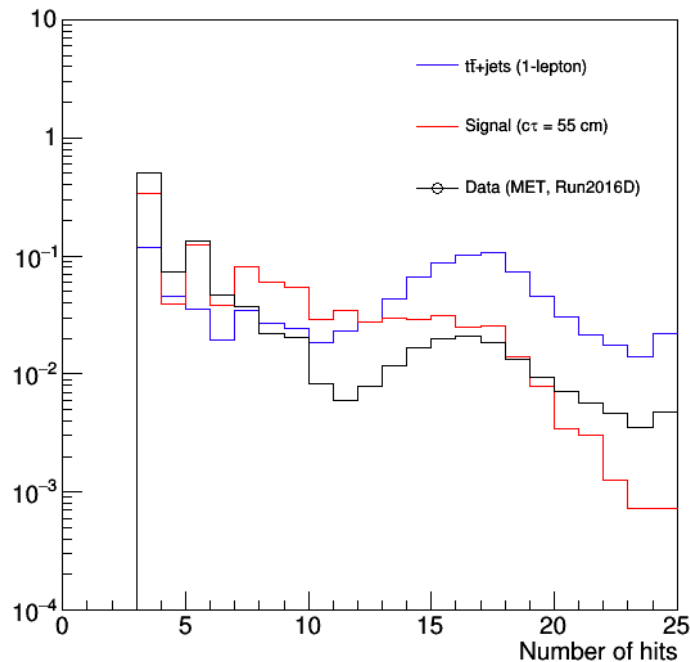
- May require a maximum number of hits, as the track is disappearing
- **However, large dependency on lifetime of SUSY LLP**
- **Prefer not to apply selection on total number of hits**

But can make good use of it

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- Number of hits and number of layers with measurement



→ May use this variable(s) to categorize tracks in terms of length

➤ I.e., ~categorization in terms of SUSY LLP decay length

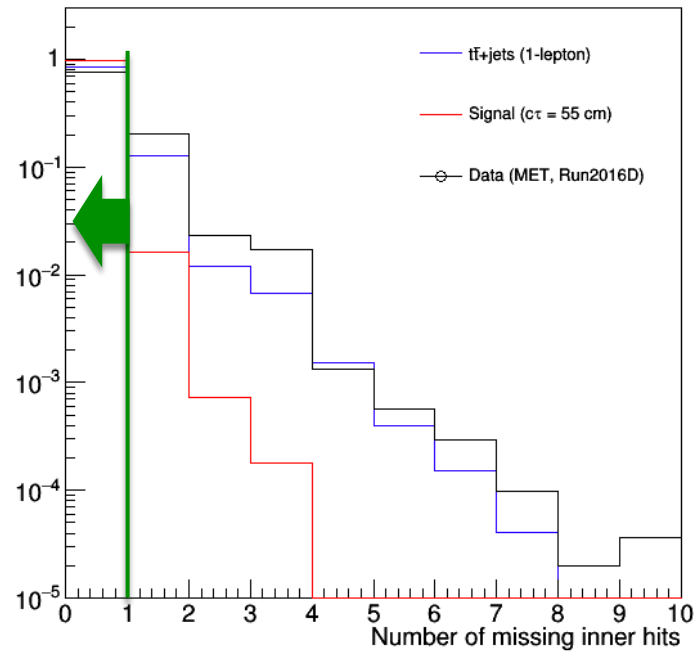
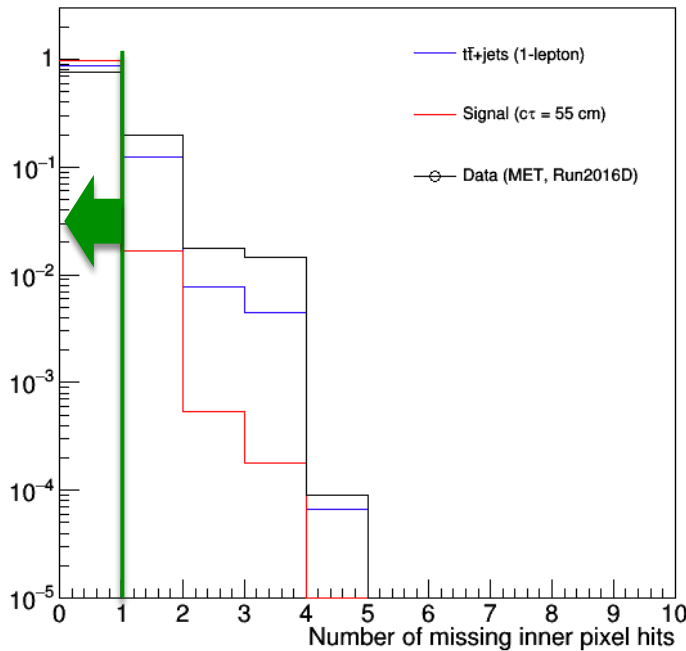
→ Will look at it again after defining full disappearing track selection

Number of missing inner hits

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- Number of missing inner hits (pixel and all)



→ Expect signal tracks to disappear in outer hits, not to miss inner hits

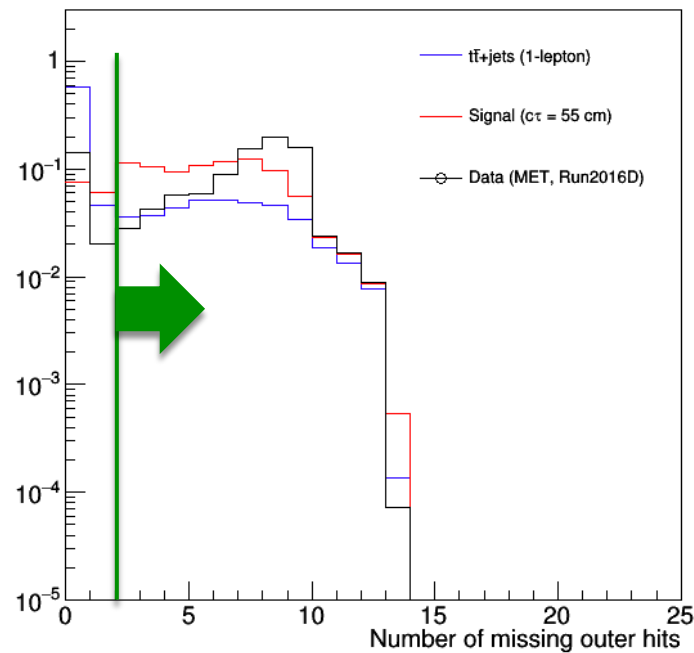
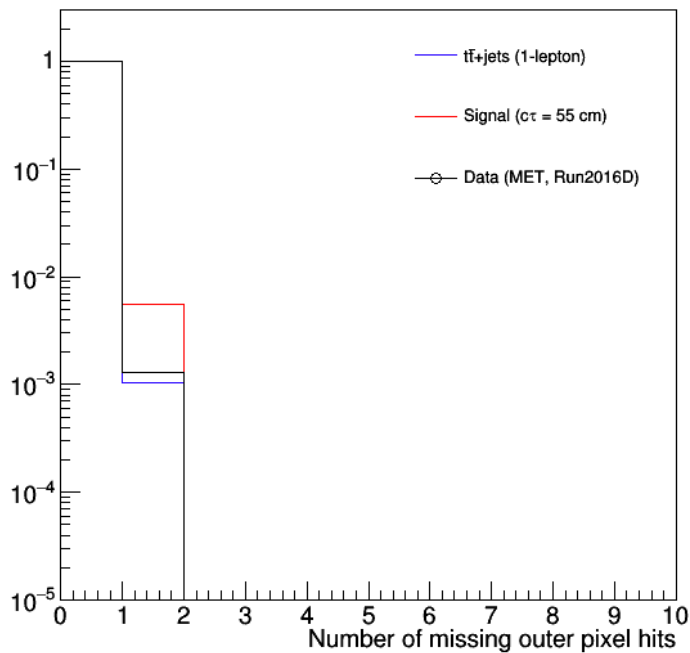
→ Require **no missing inner pixel hits & no missing inner hits**

Number of missing outer hits

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- Number of missing outer hits (pixel and all)



→ Expect signal tracks to disappear in outer hits

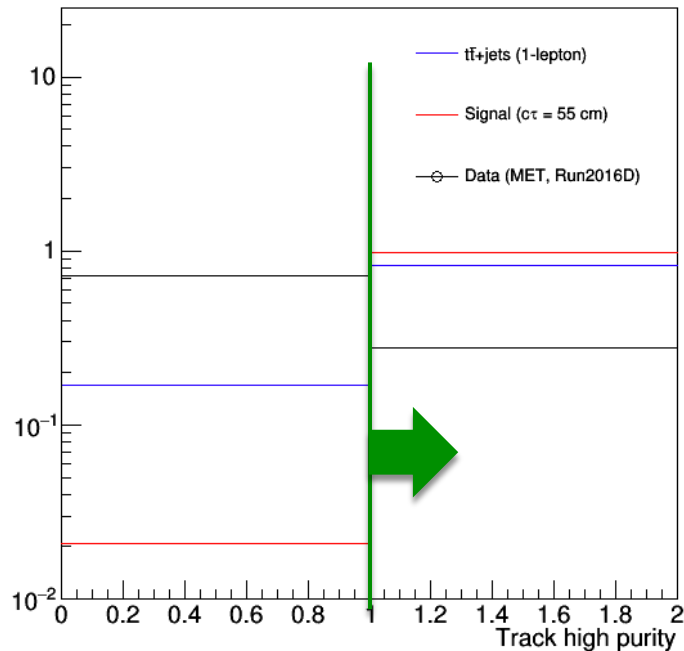
→ Require **at least 2 missing outer hits**

Track quality

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- Track quality: **high purity** tracks



- Observe a large fraction of tracks in data with low quality
 - Despite basic selection & isolation requirements
- Require **tracks to be categorized as high purity tracks**

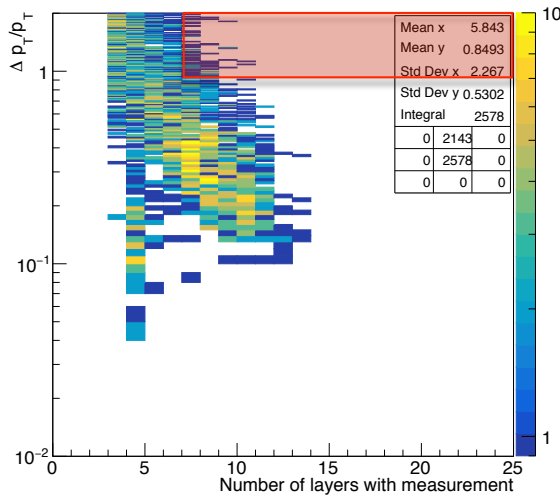
p_T resolution

16

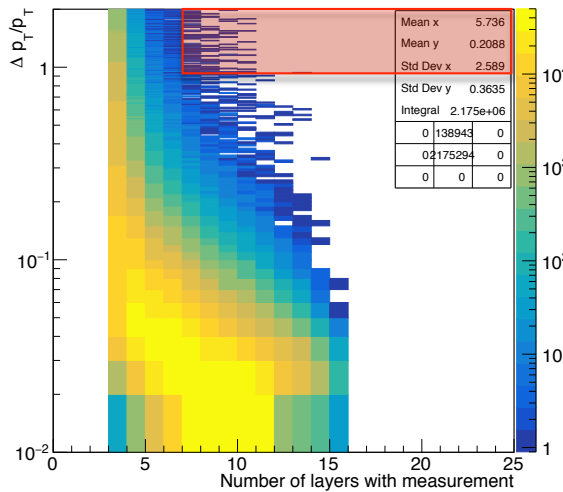
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- After basic track hit selection:

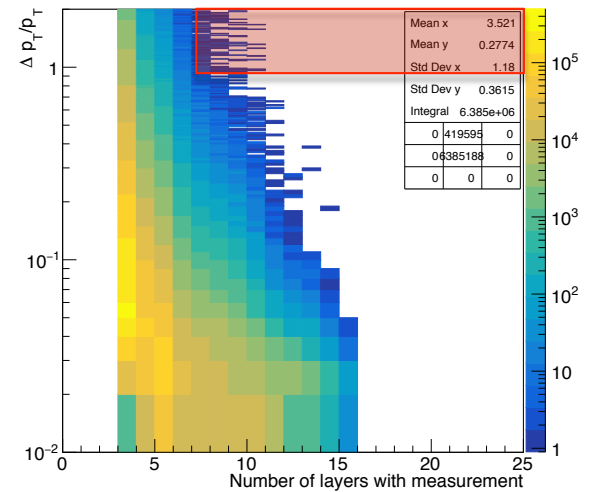
Signal



$t\bar{t}$ +jets



Data



→ Safety selection: $\Delta p_T/p_T < 1.0$ at $N(\text{layers}) \geq 7$ (i.e., for 'long' tracks)

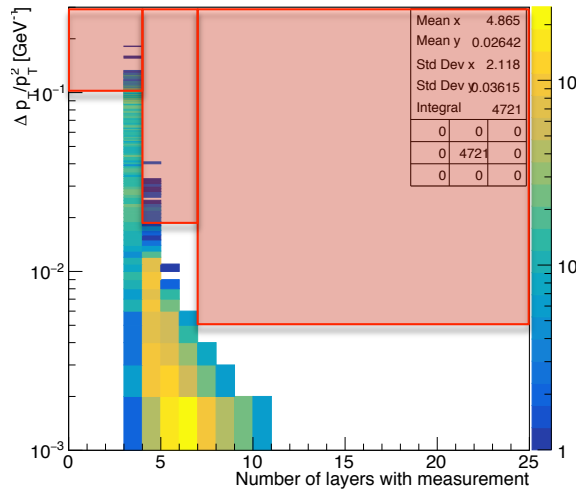
1/p_T resolution

17

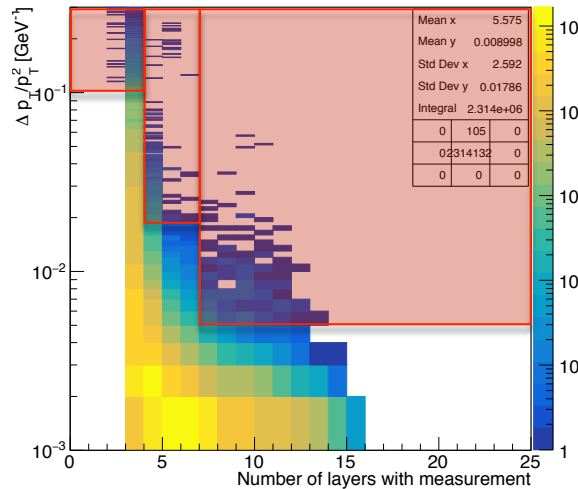
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- After basic track hit selection:

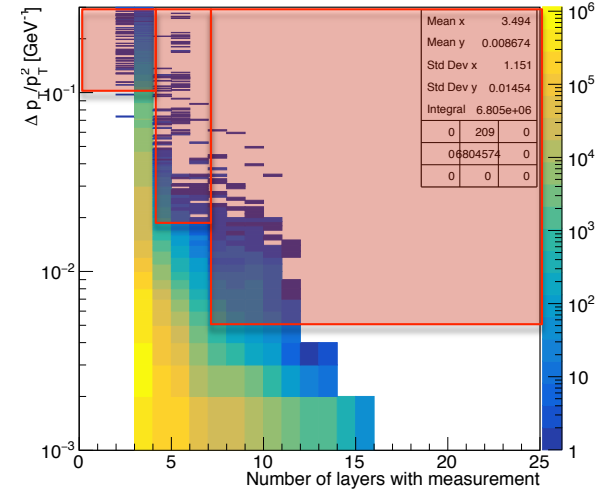
Signal



tt+jets



Data



→ $\Delta p_T/p_T^2 < 0.1$ for **pixel-only** tracks

→ $\Delta p_T/p_T^2 < 0.02$ if $N(\text{layers}) < 7$

→ $\Delta p_T/p_T^2 < 0.005$ if $N(\text{layers}) \geq 7$

Full track selection

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- $p_T > 15 \text{ GeV} \ \& \ |\eta| < 2.4$
- $d_{xy} < 0.02 \text{ cm}$
- $d_z < 0.1 \text{ cm}$
- $\text{PFAbsIso03} < 5 \text{ GeV} \ \& \ \text{PFRellIso03} < 0.2$
- $\text{Ch. sum} (dR < 0.01) < 10 \text{ GeV} \ \& \ \text{ch. sum} (dR < 0.01)/p_T < 0.2$
- $\text{Neu. sum} (dR < 0.05) < 5 \text{ GeV} \ \& \ \text{neu. sum} (dR < 0.05)/p_T < 0.1$
- $\text{Ph. sum} (dR < 0.05) < 5 \text{ GeV} \ \& \ \text{ph. sum} (dR < 0.05)/p_T < 0.1$
- $\text{N. h. sum} (dR < 0.05) < 5 \text{ GeV} \ \& \ \text{n. h. sum} (dR < 0.05)/p_T < 0.1$
- $N(\text{pixel hits}) \geq 2 \ \& \ N(\text{pixel layers w/ meas.}) \geq 2$
- $N(\text{missing inner hits}) = 0 \ \& \ N(\text{missing inner pixel hits}) = 0$
- $N(\text{missing outer hits}) \geq 2$
- High **purity**
- p_T resolution (“safety” selections)

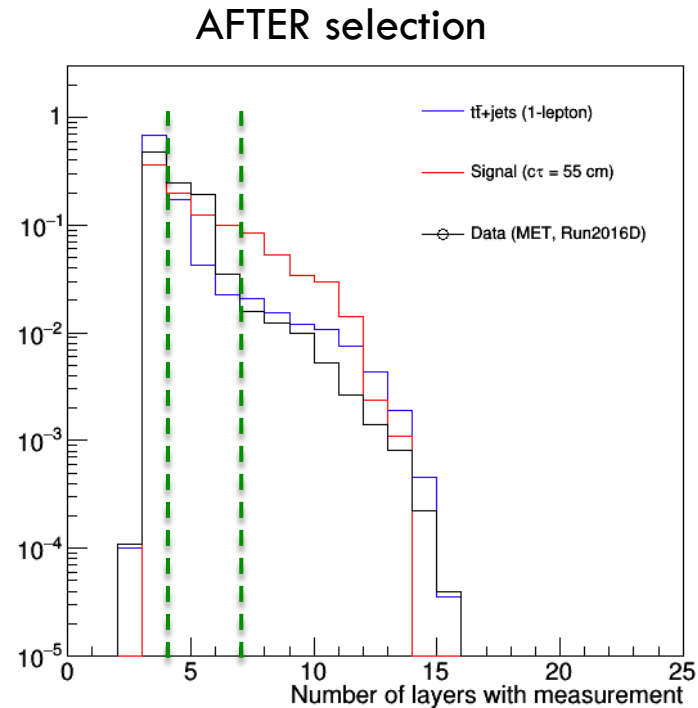
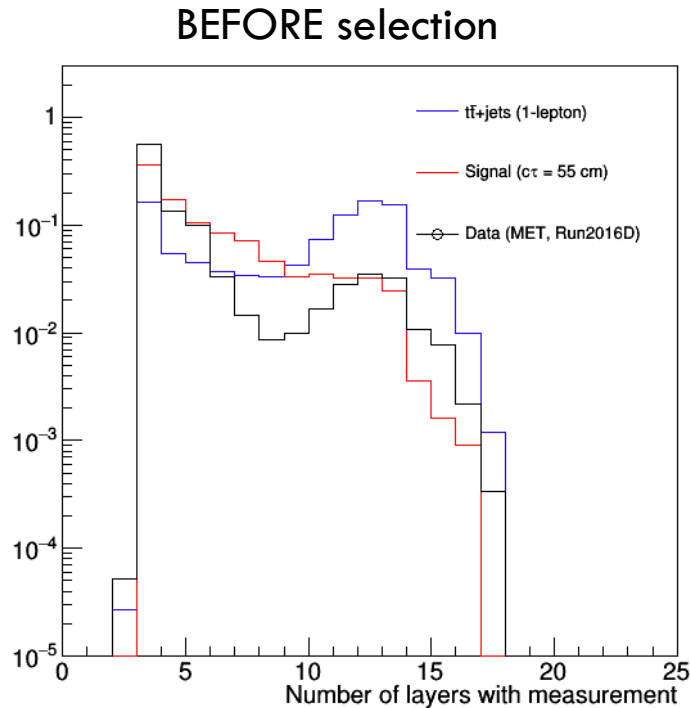
→ Bin in $N(\text{layers w/ meas.})$?

A look back at N(layers)

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- Number of layers with measurement:



→ May define **3 exclusive categories**, to maximize S/B:

1. Pixel-only tracks (tracker layers = pixel layers)
2. $N(\text{layers}) < 7$
3. $N(\text{layers}) \geq 7$

Additional handles

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- Not forgetting of other handles we have talked about:

→ Number of disappearing tracks

- Exactly 1
- >1

→ dE/dx (see **backup**)

- May depend on signal
- To be looked at again with (\sim final) SMS's
- Could either cut or categorize



Selection efficiency

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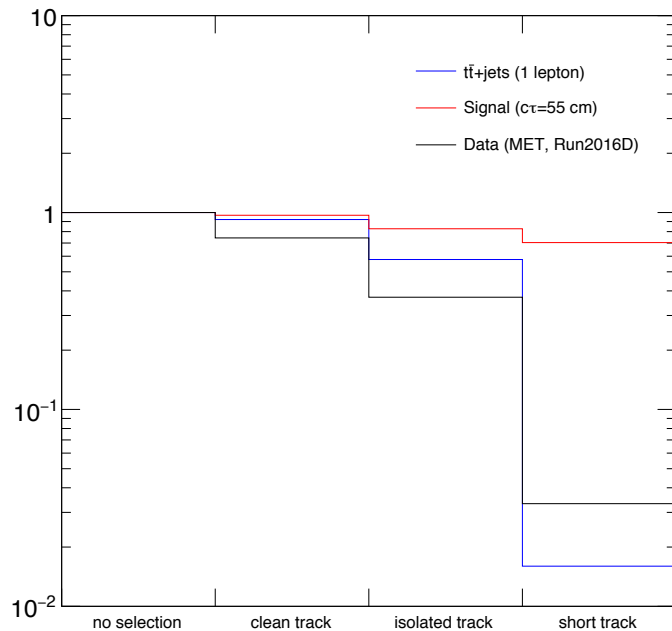
- Notes:
 - MET as read from AOD (pfMET)
 - Jets w/ $|\eta| < 2.4$ & $p_T > 30$ GeV
 - HT as from selected jets
 - 'Clean' track selection:
 - $p_T > 15$ GeV & $|\eta| < 2.4$
 - $d_{xy} < 0.02$ cm
 - $d_z < 0.1$ cm
 - Isolated track selection:
 - 'clean' track
 - $absIso03 < 5$ GeV
 - $relIso03 < 0.2$
 - Short track selection:
 - As in s. 18

Selection efficiency

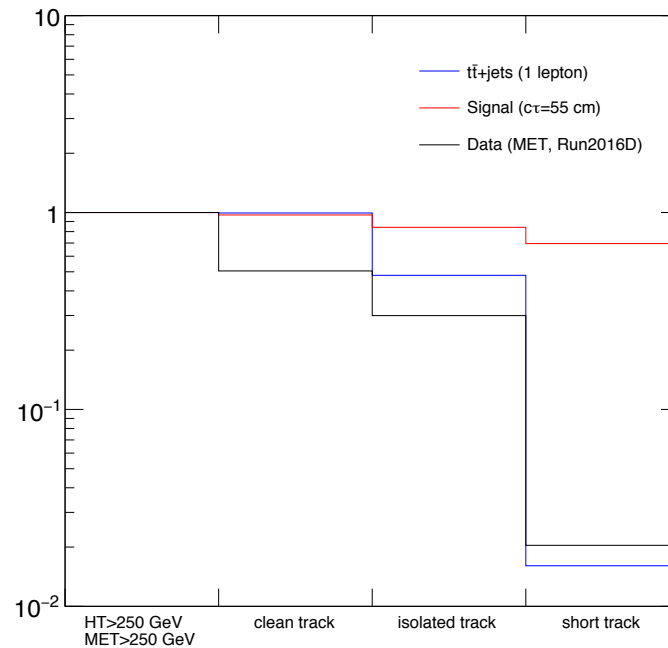
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NO kinematic selection



HT>250 & MET > 250 GeV



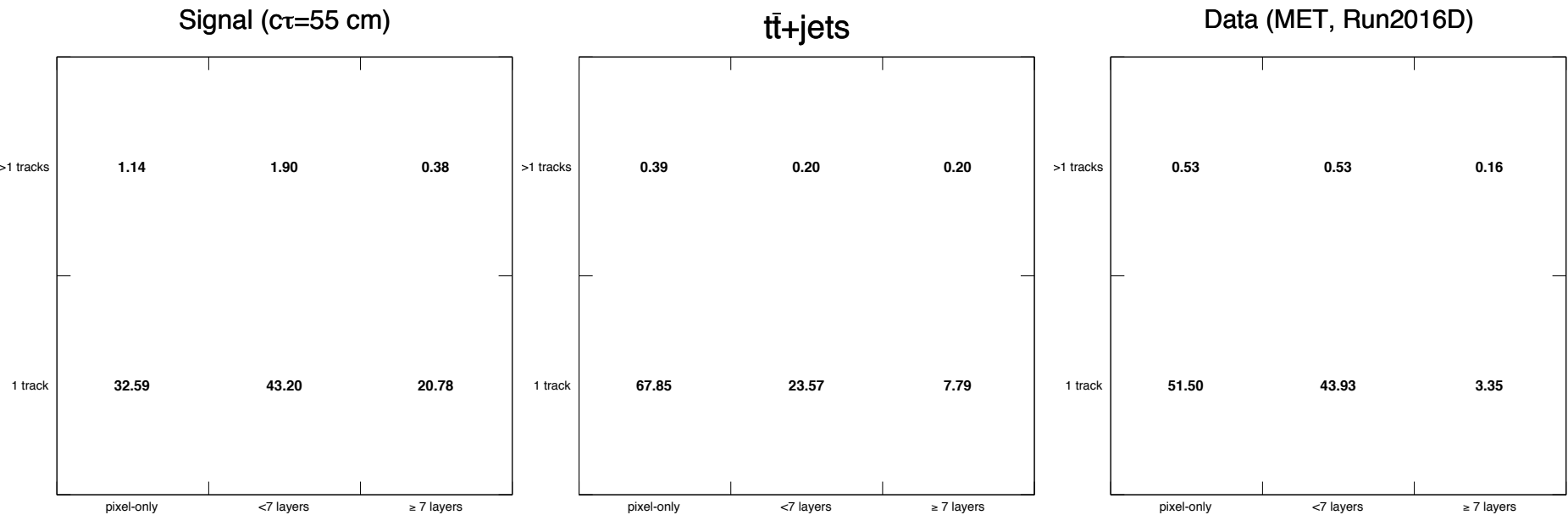
- Can reach reduction $\sim O(50)$ for background, while keeping large signal efficiency ($\gtrsim 70\%$ for a **particular** signal model)
- Can then enhance S/B by **categorizing** events vs **N(layers)** [s.19] in addition of requiring $=1$ or >1 disappearing tracks

Signal categorization

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- Fraction (%) of events per bin



→ Can reach reduction $\sim \mathbf{O(10^3)}$ for background for $N(\text{layers}) \geq 7$, while keeping significant signal efficiency ($\gtrsim 15\%$ for such signal)

→ May need extra handles for very short tracks

Cut flows

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- Point 0: total amount of events for different kinematic selections

Selection	Signal ($c\tau=55$ cm)	$t\bar{t}$ +jets (1-lep)	MET data
No selection	5720	11957043	20284873
MET>250	2633	64868	289396
HT>250	5346	6521178	5672255
HT>250 & MET>250	2612	63095	248429

CAVEATS:

- MET as read from AOD (pfMET)
- Jets w/ $|\eta| < 2.4$ & $p_T > 30$ GeV
- HT as from selected jets

More cut flows

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- Point 1: total amount of events for different kinematic selections and **with a 'clean' track**

Selection	Signal ($c\tau=55$ cm)	$t\bar{t}$ +jets (1-lep)	MET data
'Clean' track selection	5540	11017765	15074023
MET>250	2560	64314	148023
HT>250	5177	6408983	5464928
HT>250 & MET>250	2539	62760	125487

'Clean' track selection:

- $p_T > 15$ GeV & $|\eta| < 2.4$
- $d_{xy} < 0.02$ cm
- $d_z < 0.1$ cm

More cut flows

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- Point 2: total amount of events for different kinematic selections and with a 'clean' track that is **also isolated**

Selection	Signal ($c\tau=55$ cm)	$t\bar{t}$ +jets (1-lep)	MET data
Isolated track selection	4731	6903290	7533949
MET>250	2214	30870	85202
HT>250	4398	4092360	2071955
HT>250 & MET>250	2197	30271	74420

Isolated track selection:

- 'clean' track
- $absIso03 < 5$ GeV
- $rellso03 < 0.2$

More cut flows

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- Point 3: total amount of events for different kinematic selections and with a 'clean' track that is also isolated and **pass full selection** [s.18]

Selection	Signal ($c\tau=55$ cm)	$t\bar{t}$ +jets (1-lep)	MET data
Isolated track selection	4025	191235	673873
MET>250	1832	1042	5921
HT>250	3749	105994	149410
HT>250 & MET>250	1817	1014	5070

→ Can reach reduction $\sim O(50)$ for background, while keeping signal efficiency $\gtrsim 70\%$

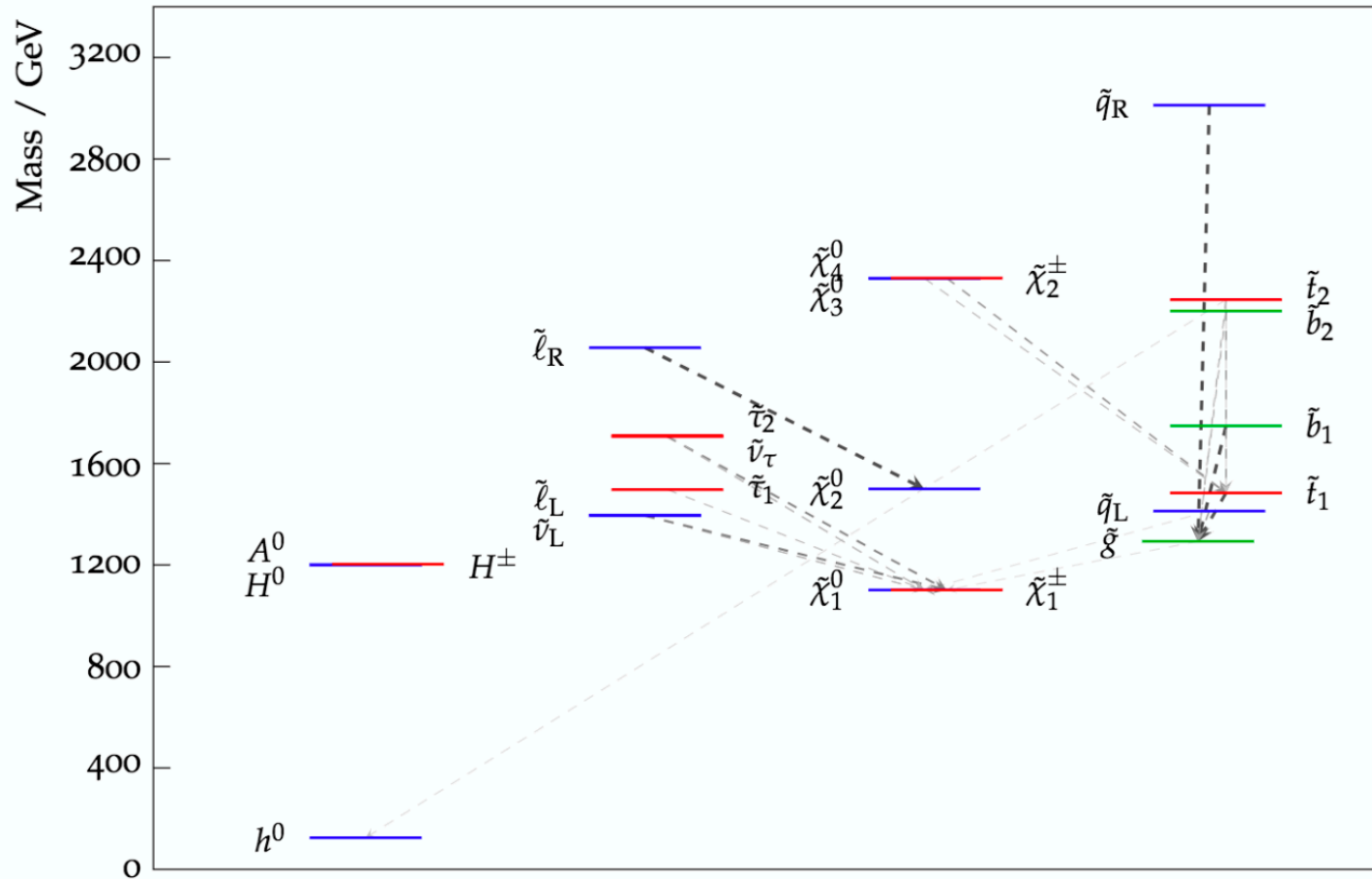
→ Can then enhance S/B by **categorizing** events vs **N(layers)** [s.19]
in addition of requiring $=1$ or >1 disappearing tracks

Signal samples: $c\tau(\chi_1^\pm) = 55 \text{ cm}$

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pMSSM12_MCMC1_10_374794



From Nadja and Sezen

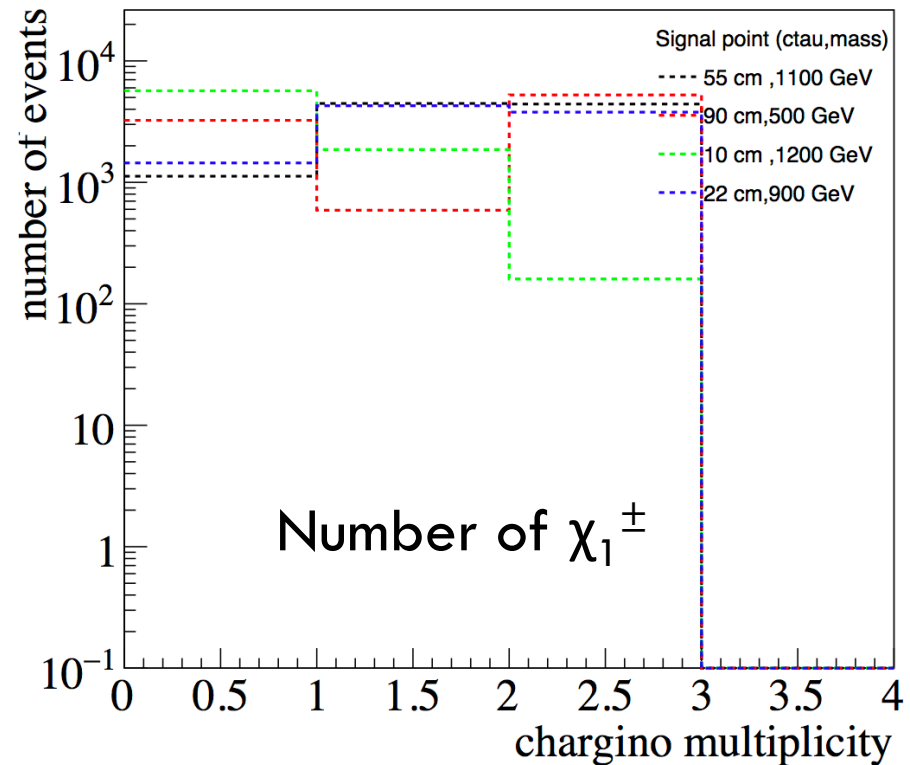
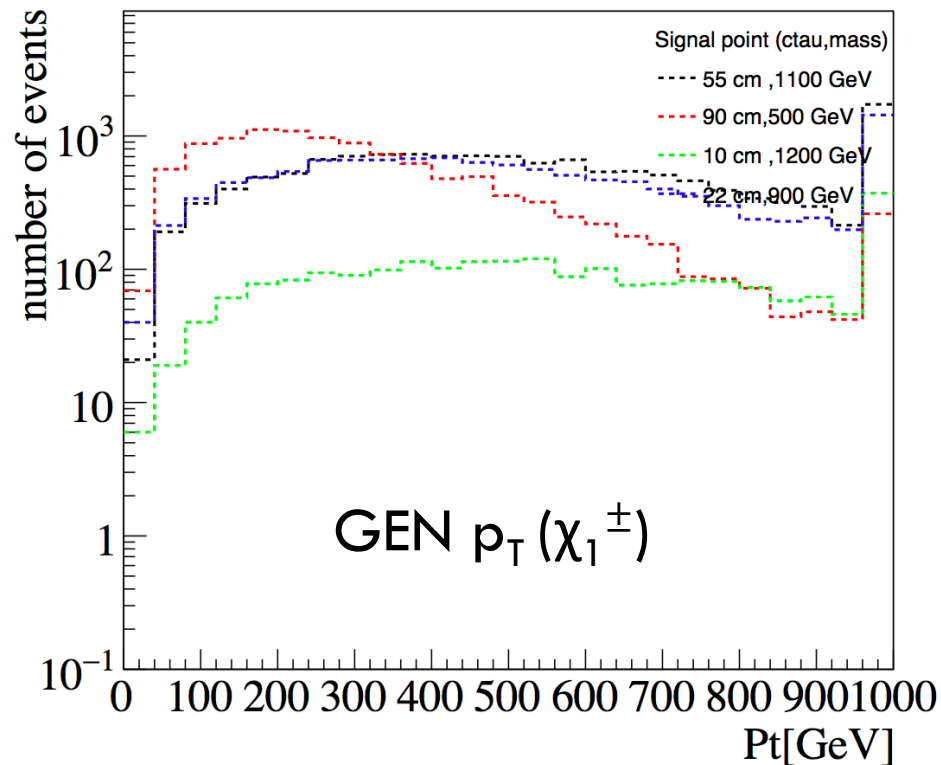
Long-lived χ_1^\pm

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80X

- Generator level information
 - Multiplicity of χ_1^\pm depends on benchmark scenario
 - χ_1^\pm is always very energetic



Event kinematics

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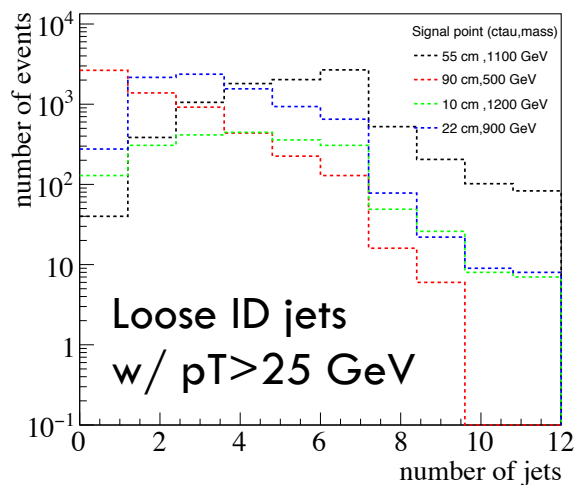
80X

- Reconstruction level information
- For events with at least one χ_1^\pm w/ $p_T > 30$ GeV

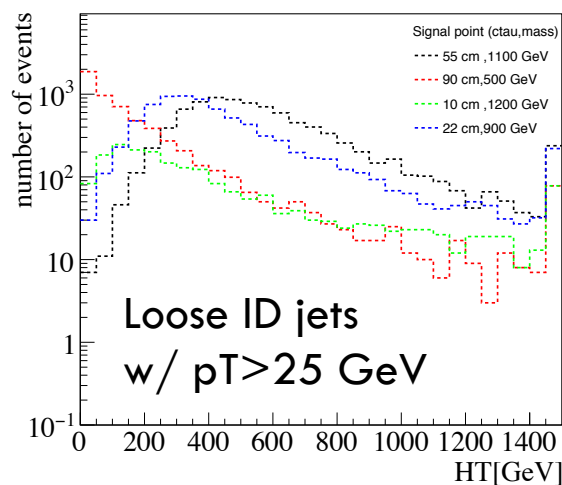
→ Event kinematics strongly depends on benchmark scenario

- Mostly on production mode

jet multiplicity



HT



PFMet

