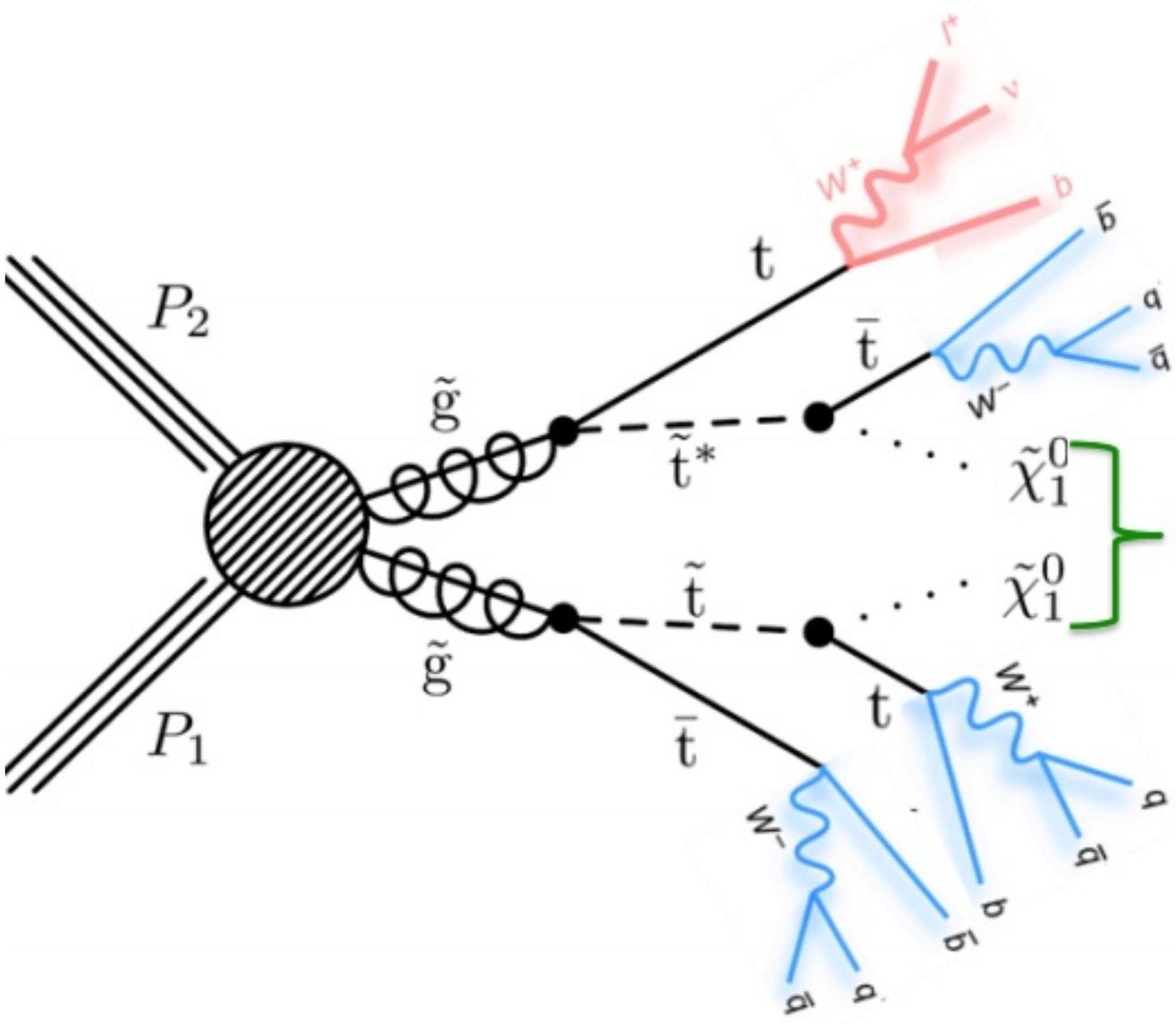
Chargino search

Disappearing track analysis

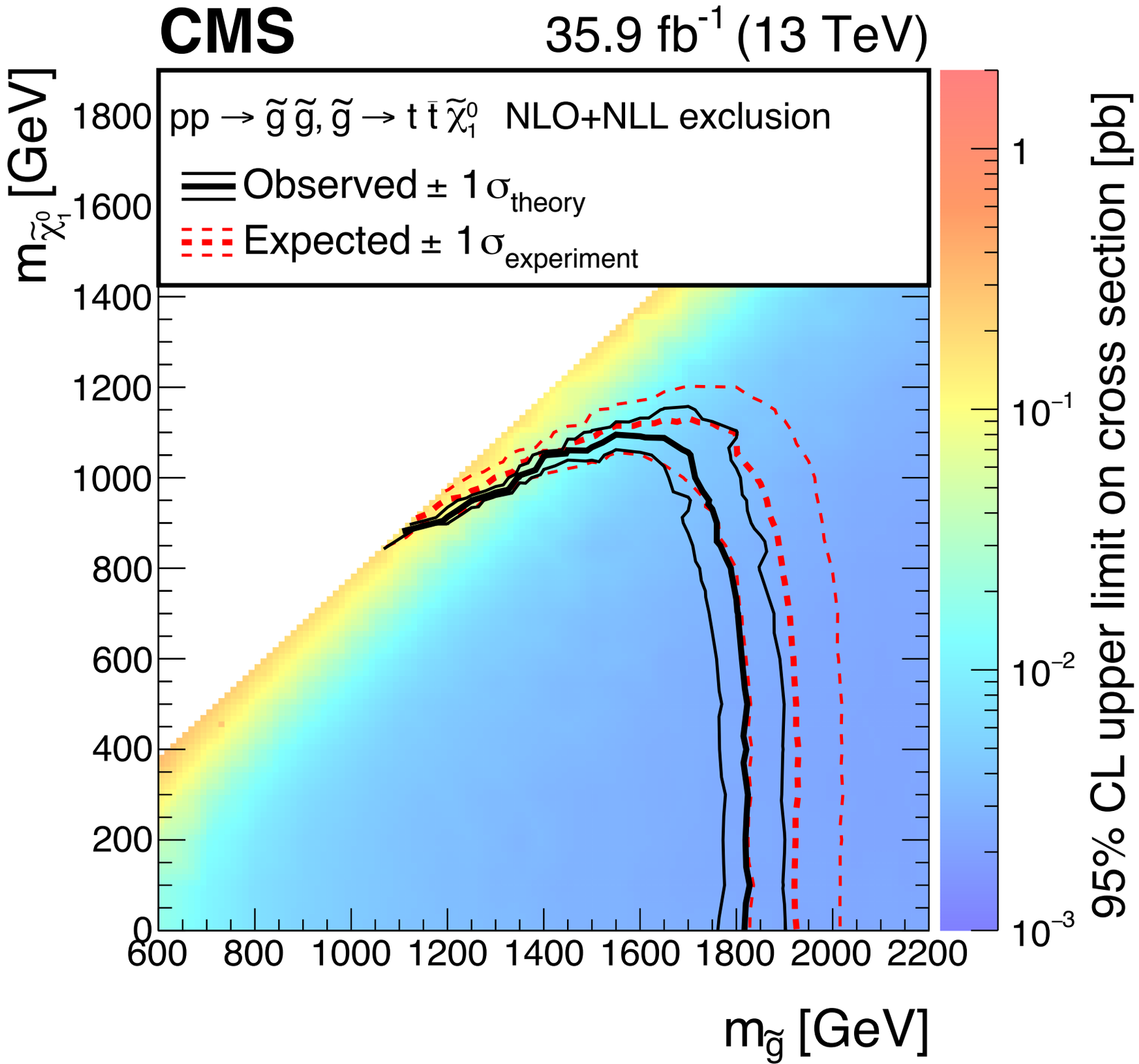
T1tttt: Signal model



Final State

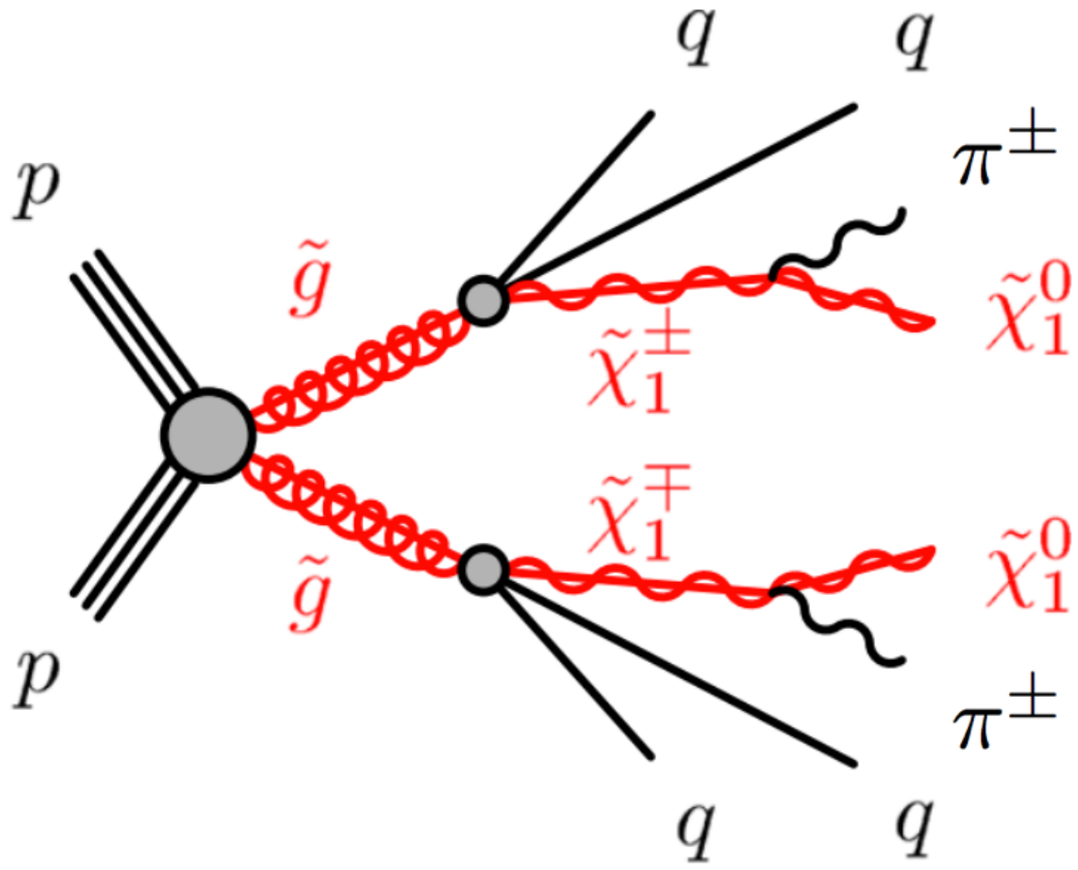
- One isolated lepton
- High jet multiplicity
- Multiple b-jets
- High MET

Exclusion limits



Chargino production

- Direct production via electroweak interactions.
- Indirect production; emitted in cascade decay of coloured particles.
- Multiple energetic jets
- Large missing transverse energy from Neutralinos
- At least one disappearing track



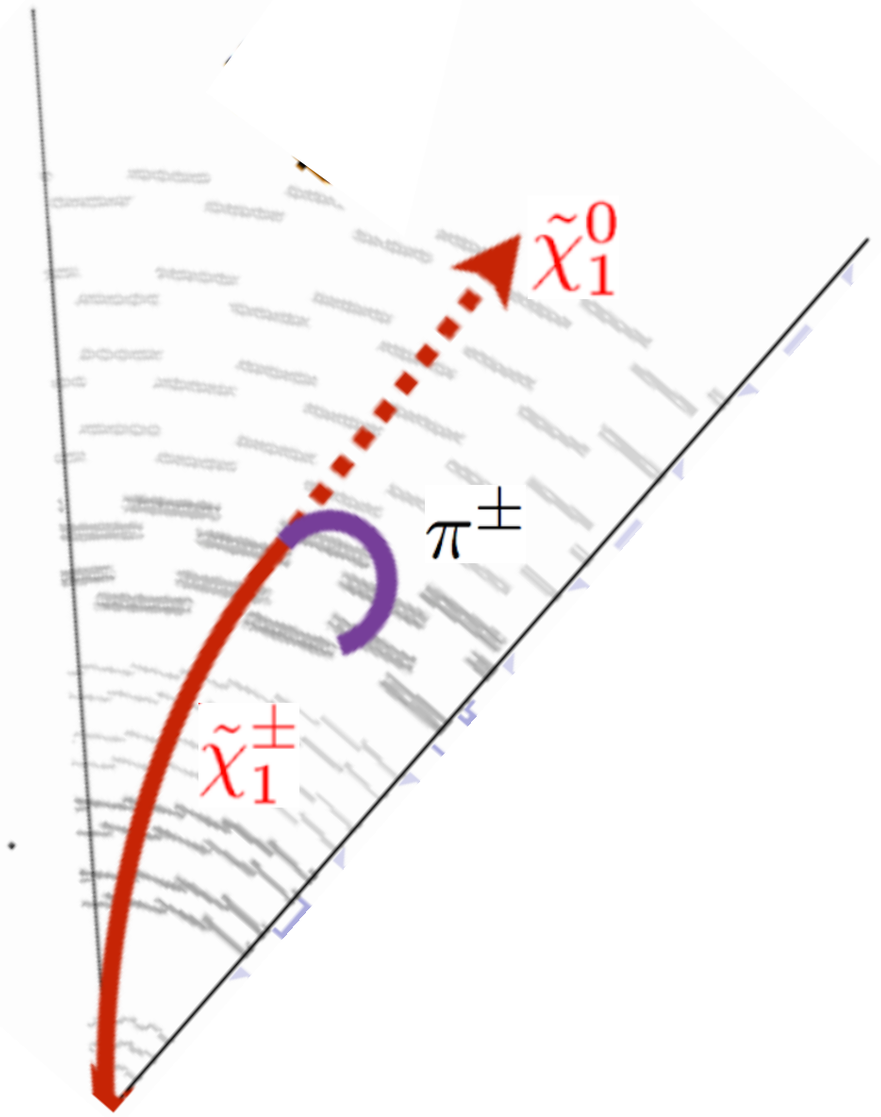
T1qqqq: Signal Model

Signature of the chargino

- Chargino decays to neutralino and a W boson;
- If chargino-neutralino mass splitting is of the order of pion mass, charginos are long lived;
- W boson is assumed to go to a pion with transverse momentum given by:

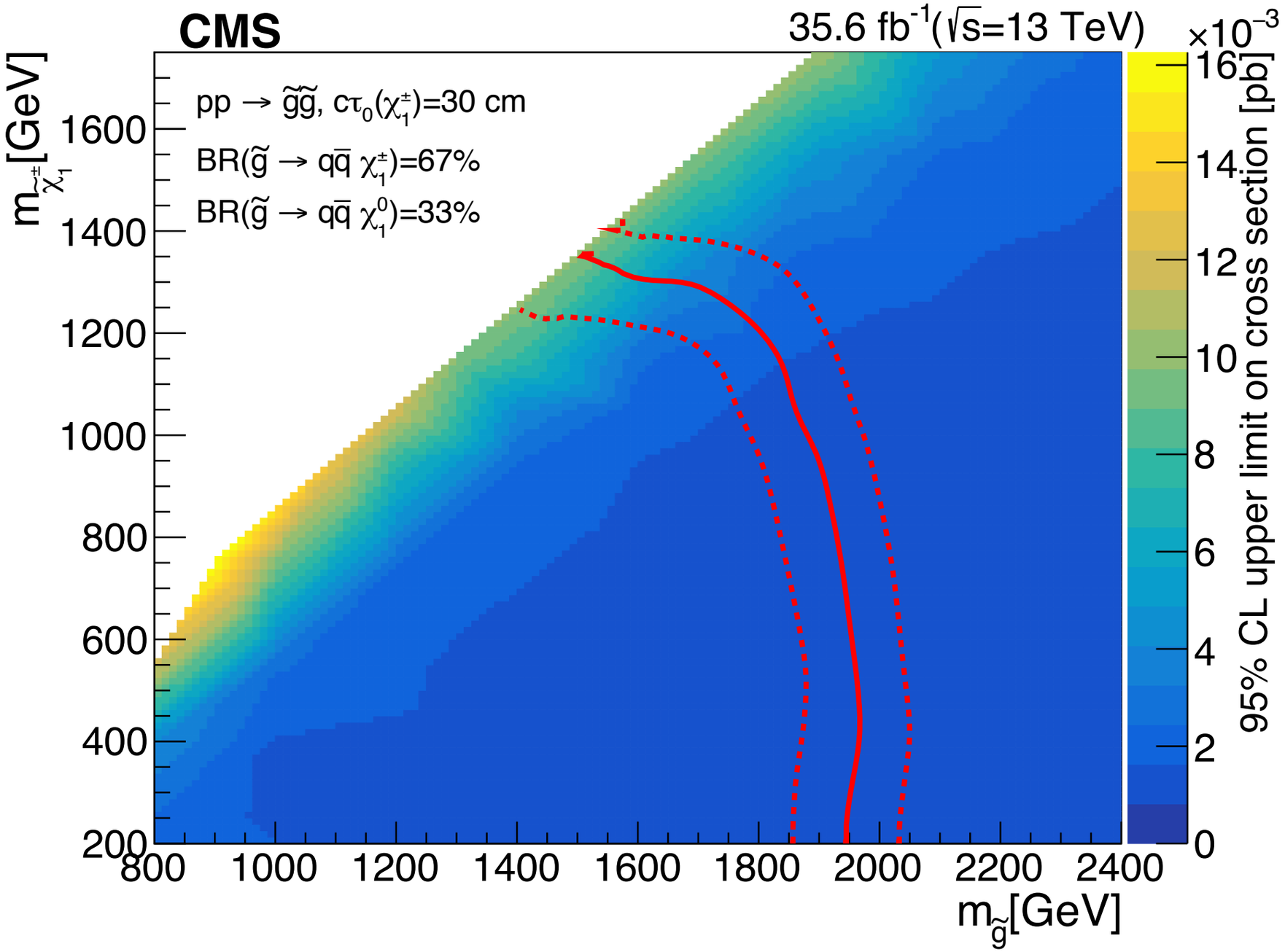
$$p_\pi = \sqrt{(m_{\tilde{\chi_1}^\pm} - m_{\tilde{\chi_1}^0})^2 - m_\pi^2}$$

- The chargino track appears to disappear as pion is not reconstructed.



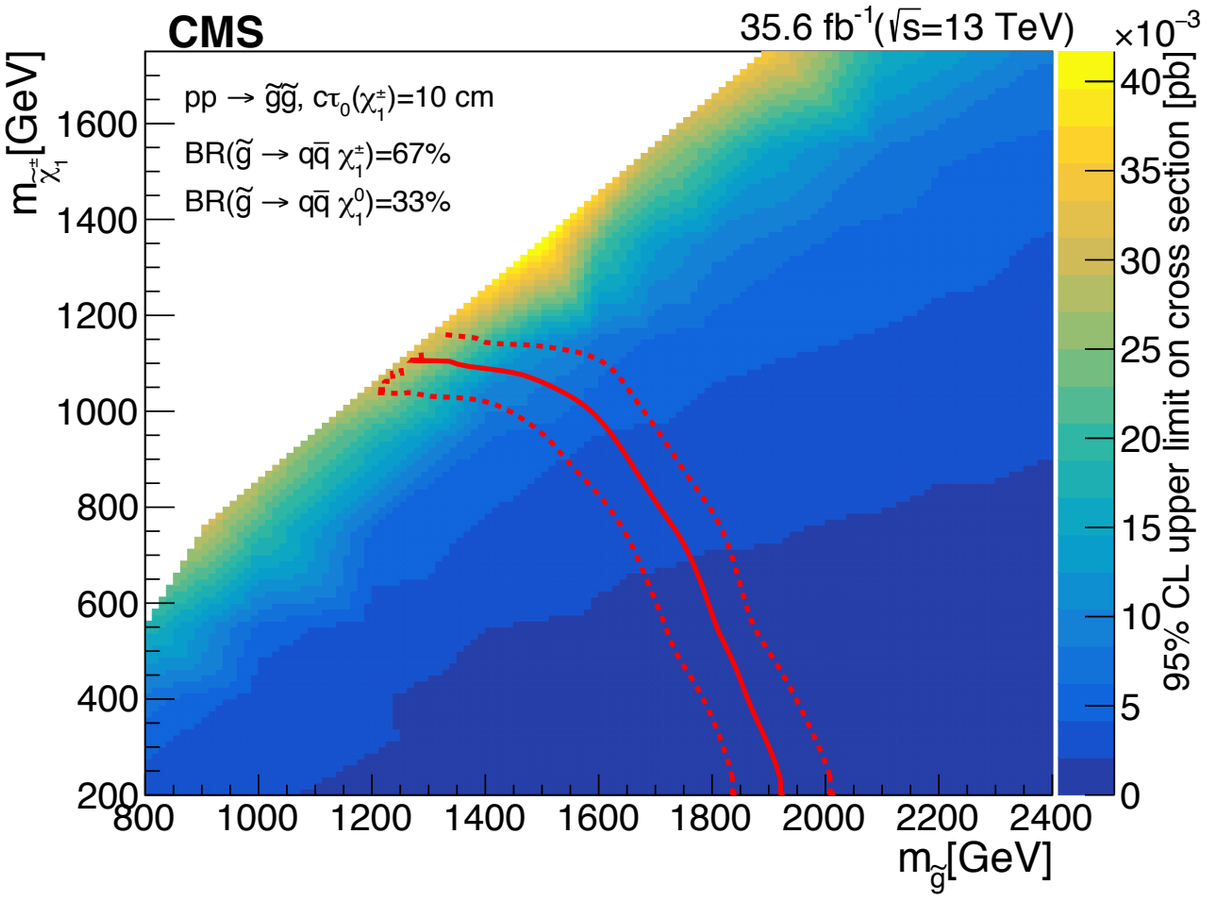
Expected Exclusion limits

Proper lifetime = 1 ns

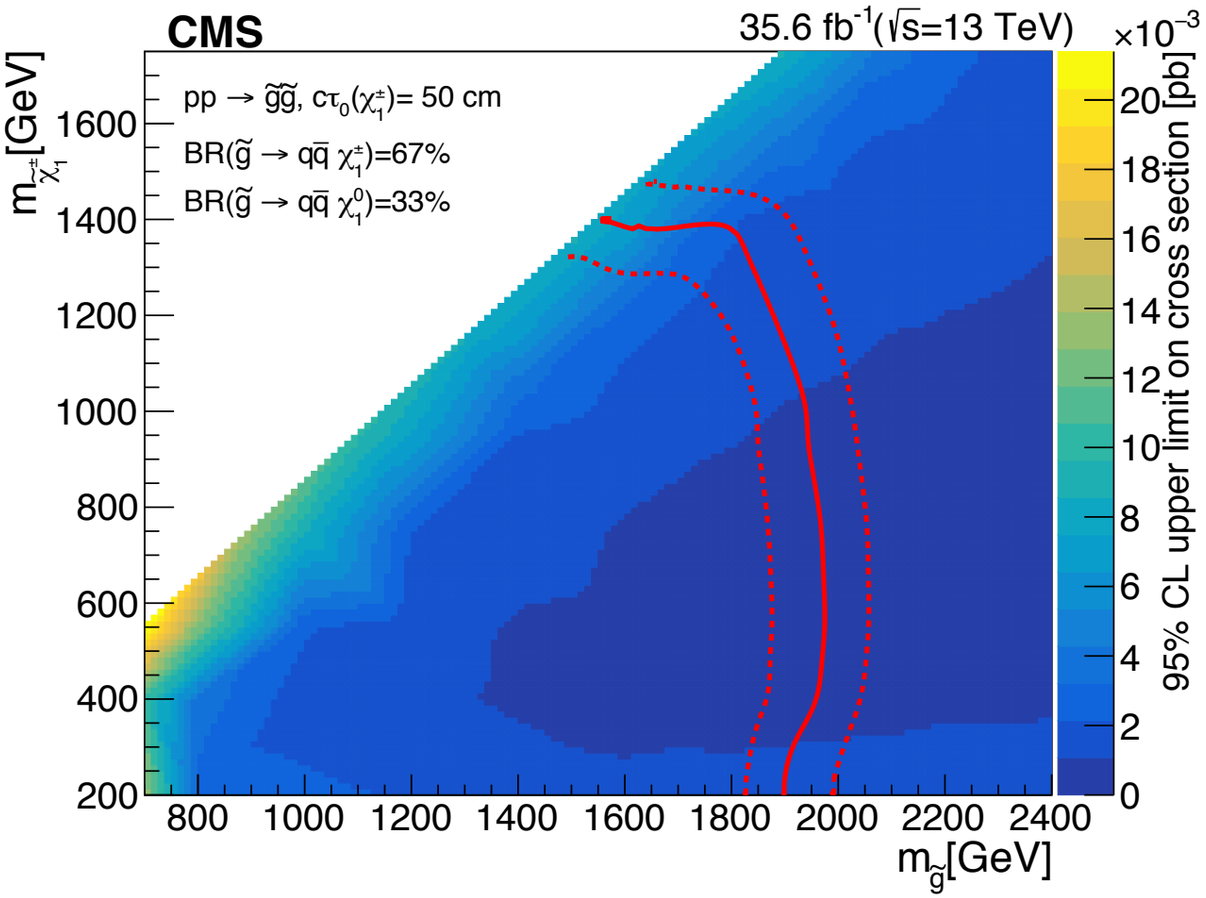


Expected Exclusion limits

Proper lifetime = .33 ns



Proper lifetime = 1.67 ns



Thanks!

Disappearing track selection

- passes baseline track selection
- $d_{xy} < 0.01$ cm and $d_z < 0.02$ cm
- absolute (relative) isolation from charged PF candidates < 10 GeV (0.01)
- absolute (relative) isolation from neutral PF candidates < 10 GeV (0.01)
- energy deposited in ECAL < 10 GeV in cone of $dR < 0.5$
- relative isolation of the track < 0.2
- missing inner hits $= 0$
- $p_T^{error}/p_T^2 < 0.2$ for short , < 0.05 for medium and < 0.02 for long tracks
- missing outer hits ≥ 2 for medium and long tracks

Search variables

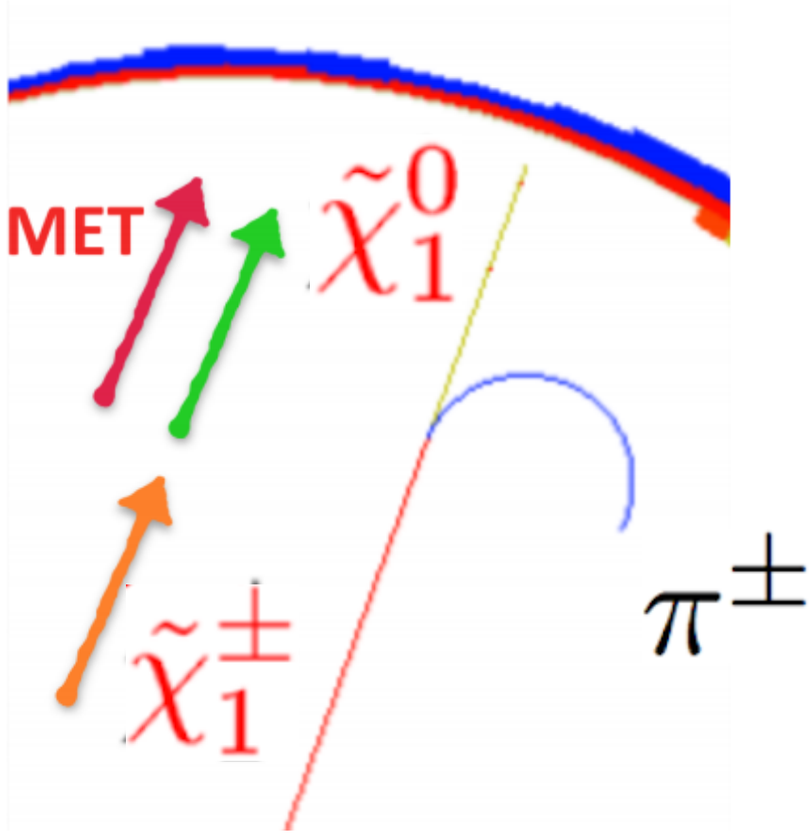
- Chargino decays to a soft pion and a neutralino;

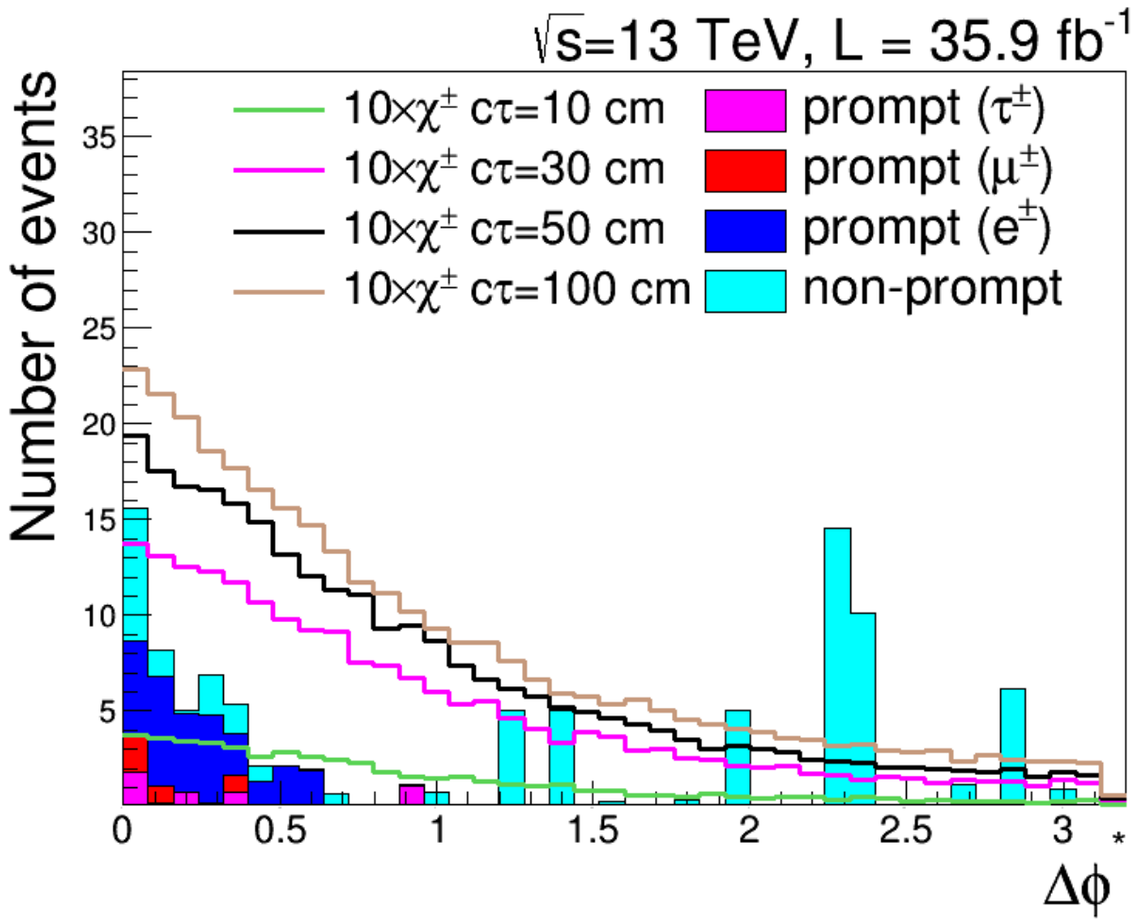
- To a very good approximation the sum of the disappearing tracks is same a missing transverse energy in an event;

$$\Delta\Phi^* = \Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \sum_{1}^{\mathrm{n}} \tilde{\mathrm{P}}_{\mathrm{T}}^{\mathrm{n}})$$

- Fake background is reduced by 20% for delta phi < 2.5 selection.

- Facilitates background prediction.





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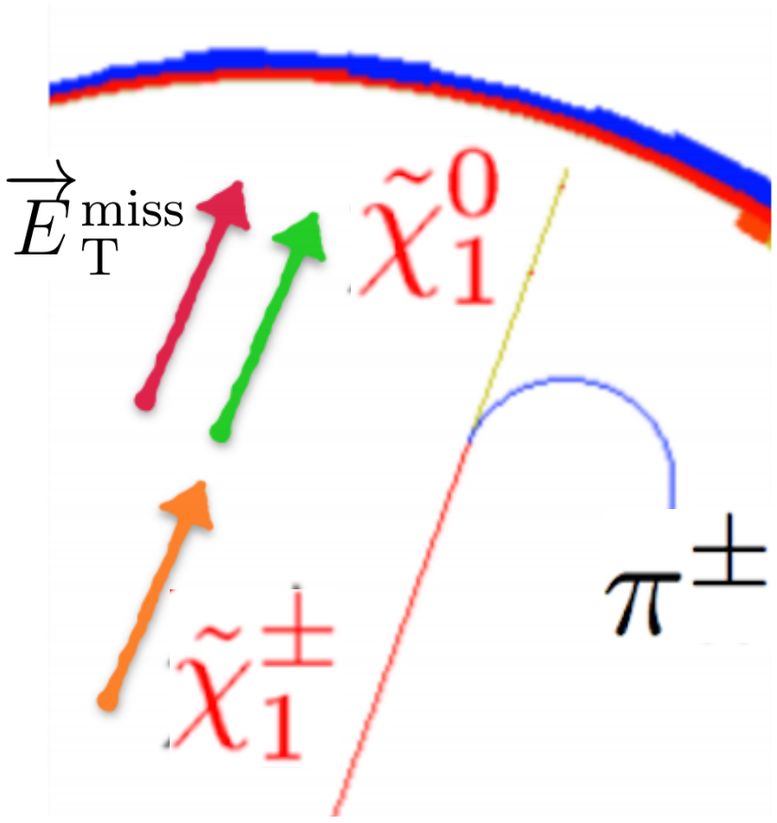
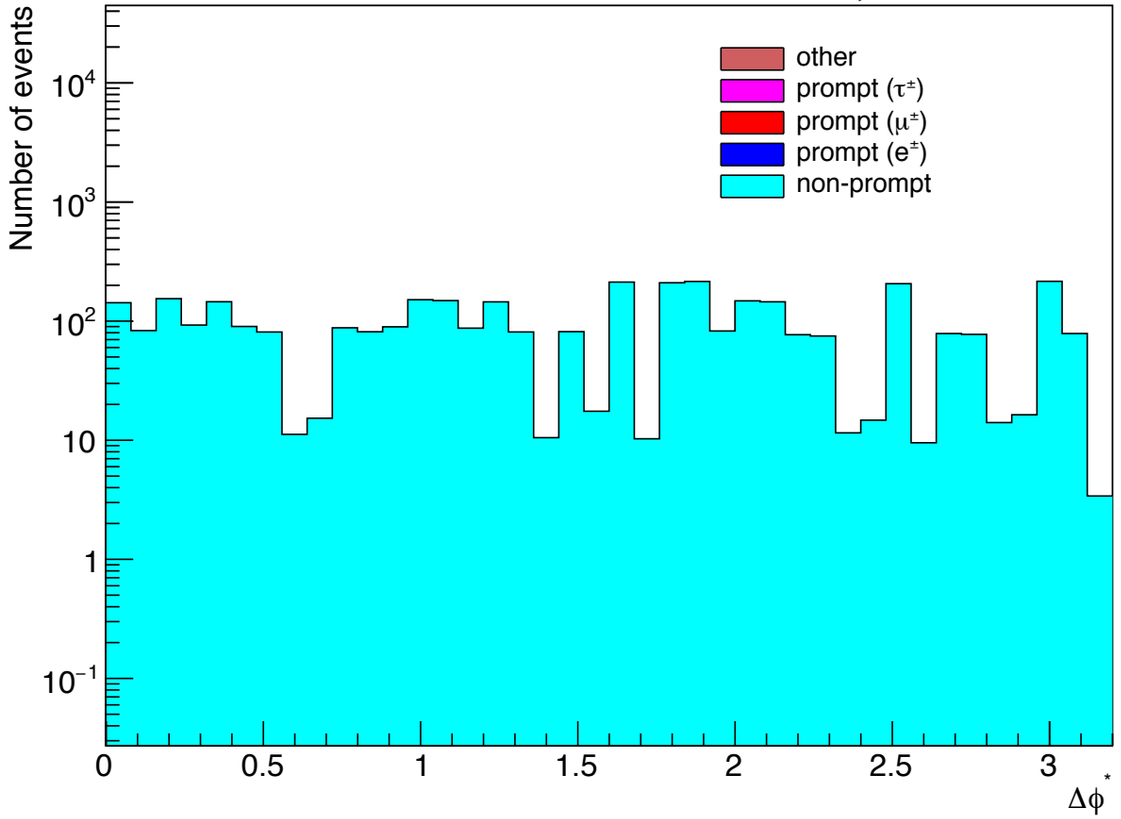


$\sqrt{s}$=13 TeV, L = 35.9 fb^{-1}



Z to Nu Nu : events

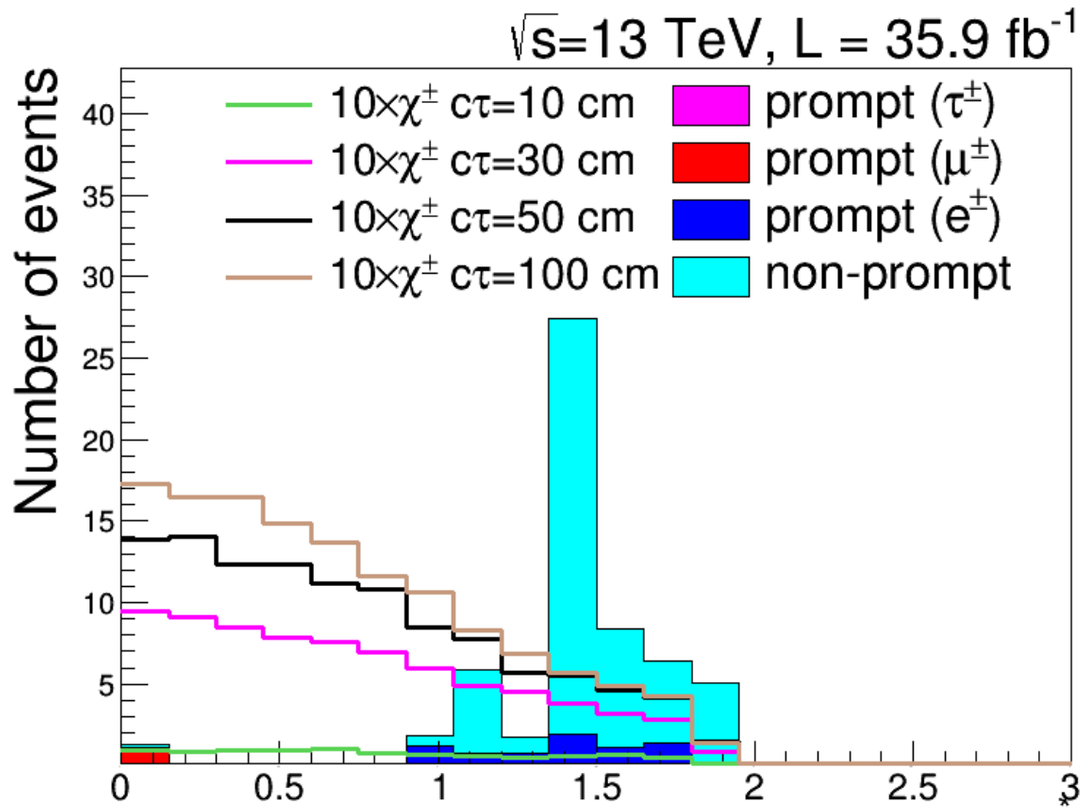
Search variables

- Variable to compare the magnitude of MET and the sum of disappearing tracks;

$$\mathcal{R}^* = 2 \cdot \frac{||\overrightarrow{E}_{\mathrm{T}}^{\mathrm{miss}}| - |\sum_1^{\mathrm{n}} \tilde{\mathrm{P}}_{\mathrm{T}}^{\mathrm{n}}||}{|\overrightarrow{E}_{\mathrm{T}}^{\mathrm{miss}}| + |\sum_1^{\mathrm{n}} \tilde{\mathrm{P}}_{\mathrm{T}}^{\mathrm{n}}|}$$

- Distribution for long and medium tracks; falling from zero to two (top);

- Distribution for short tracks; increasing from zero to two(bottom);



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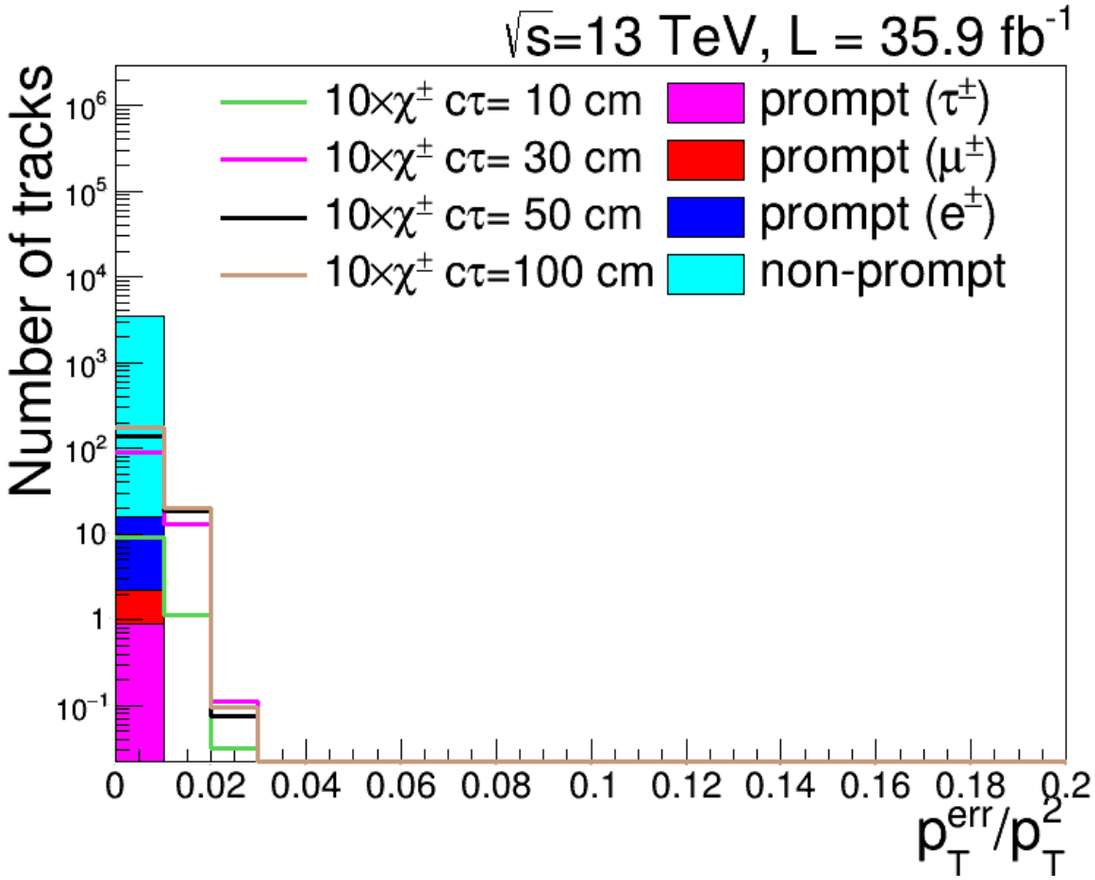
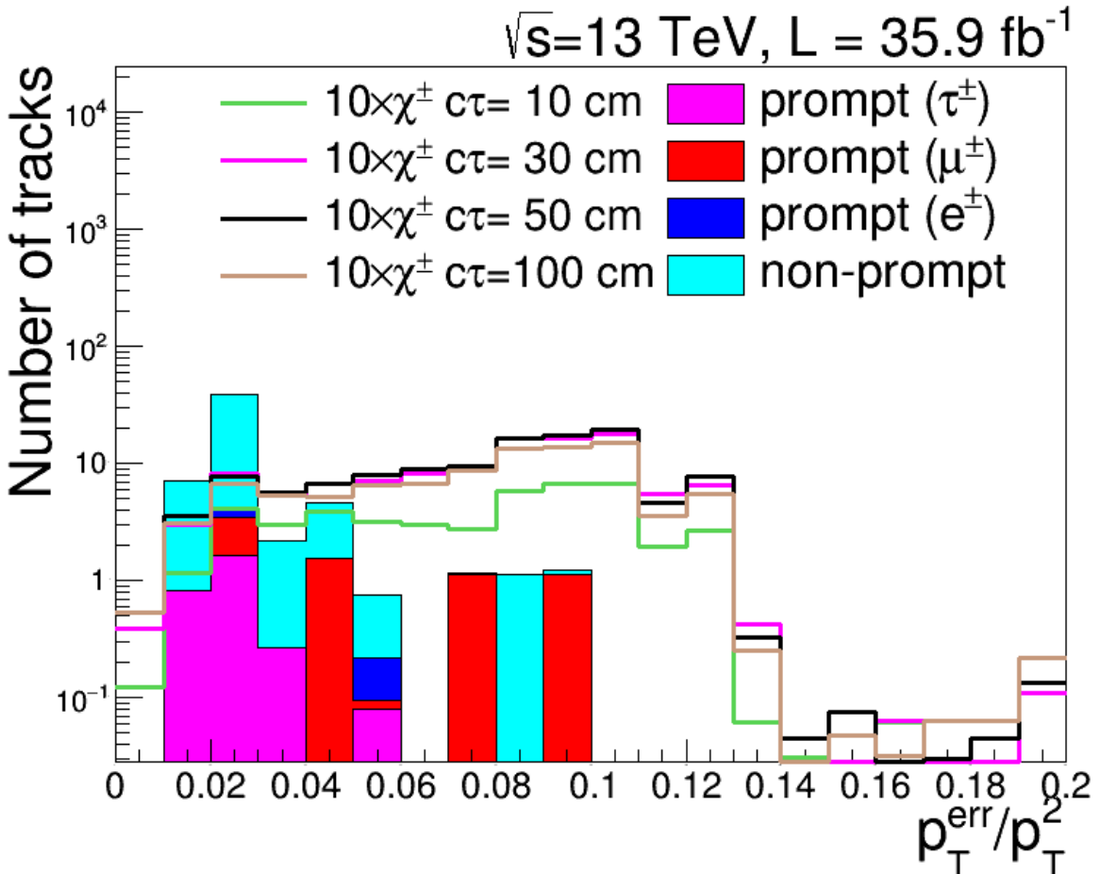
- Distribution for long and medium tracks; have good Pt resolution (top);
- Distribution for short tracks; have bad Pt resolution (bottom);
- Used for binning the search region.





Search region

- number of disappearing tracks ≥ 1
- $H_T > 250$ GeV, $H_T = \sum p_T^{jets}$
- $MHT > 250$ GeV, $MHT = -\sum \vec{p}_T^{jets}$
- number of jets ≥ 1
- number of veto leptons $= 0$
- $\Delta\Phi^* < 2.5$, $\Delta\Phi^* = \Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \sum \tilde{\mathrm{p}}_{\mathrm{T}}^{\mathrm{tracks}})$

Search regions

- Search is binned into 8 search regions;
- Binning in **R**, makes the search sensitive to the different chargino **lifetimes**;
- Binning in HT and MHT makes the search sensitive to different mass parameters of the signal model.

$\mathcal{R}^*$	MHT [GeV]	H_T [GeV]
[0,1]	[250,400]	$[250, 600]$
		$(600, \infty]$
	$(400, \infty]$	$[250, 600]$
		$(600, \infty]$
(1,2]	[250,400]	$[250, 600]$
		$(600, \infty]$
	$(400, \infty]$	$[250, 600]$
		$(600, \infty]$

Eight search regions

Leptonic background estimation

- Estimated by measuring a transfer factor kappa as a function of transverse momentum and pseudo rapidity as:

$$\kappa = \frac{\mathcal{P}(\text{disappearing track}||\text{true lepton})}{\mathcal{P}(\text{lepton}||\text{true lepton})}$$

- Control region ; events with exactly one veto lepton

$$(\text{Signal Region})_{\text{events}} = \kappa \times (\text{Control Region})_{\text{events}}$$

- Kappa is measured by tag-and-probe method in data.
- Smearing of probe leptons using smearing templates.

Kappa calculation

- Calculation by tag-and-probe:

$$\kappa = \frac{\text{Number of probes identified as disappearing track}}{\text{number of probes identified as an lepton}}$$

- In simulated samples; using generator information;
  - Generator level lepton is treated as true lepton;
  - Used to prove the independence of kappa from event dynamics.

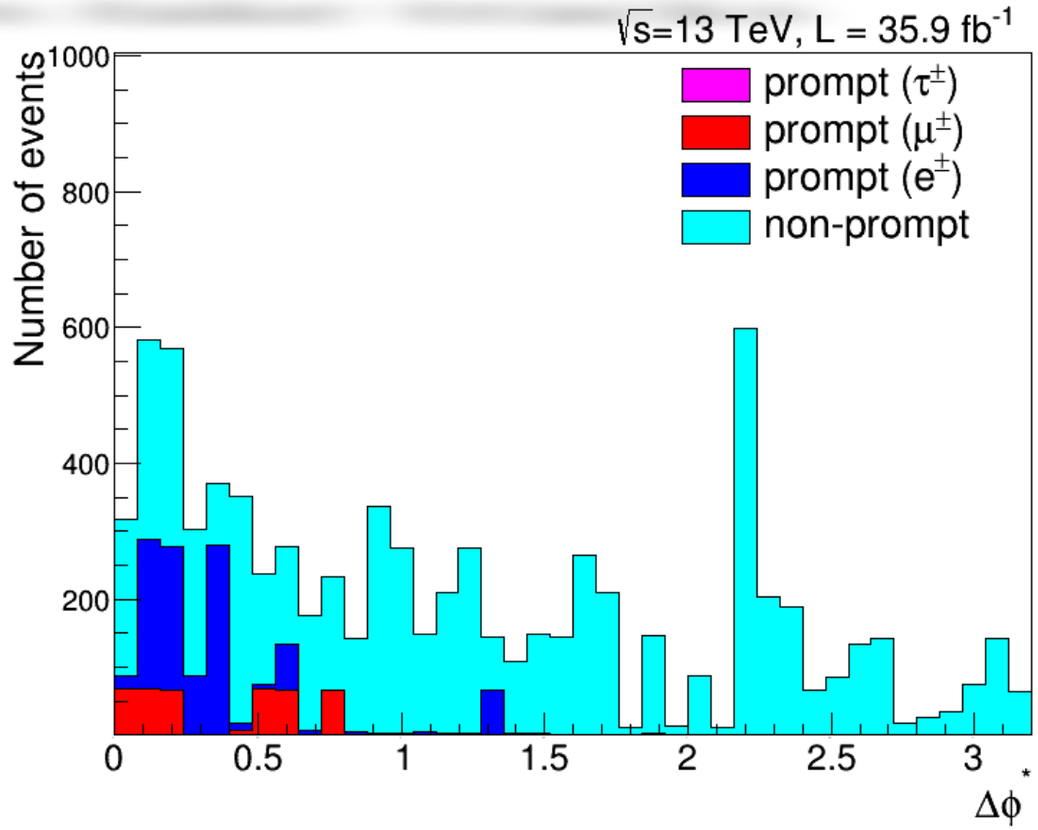
Contamination from fake tracks

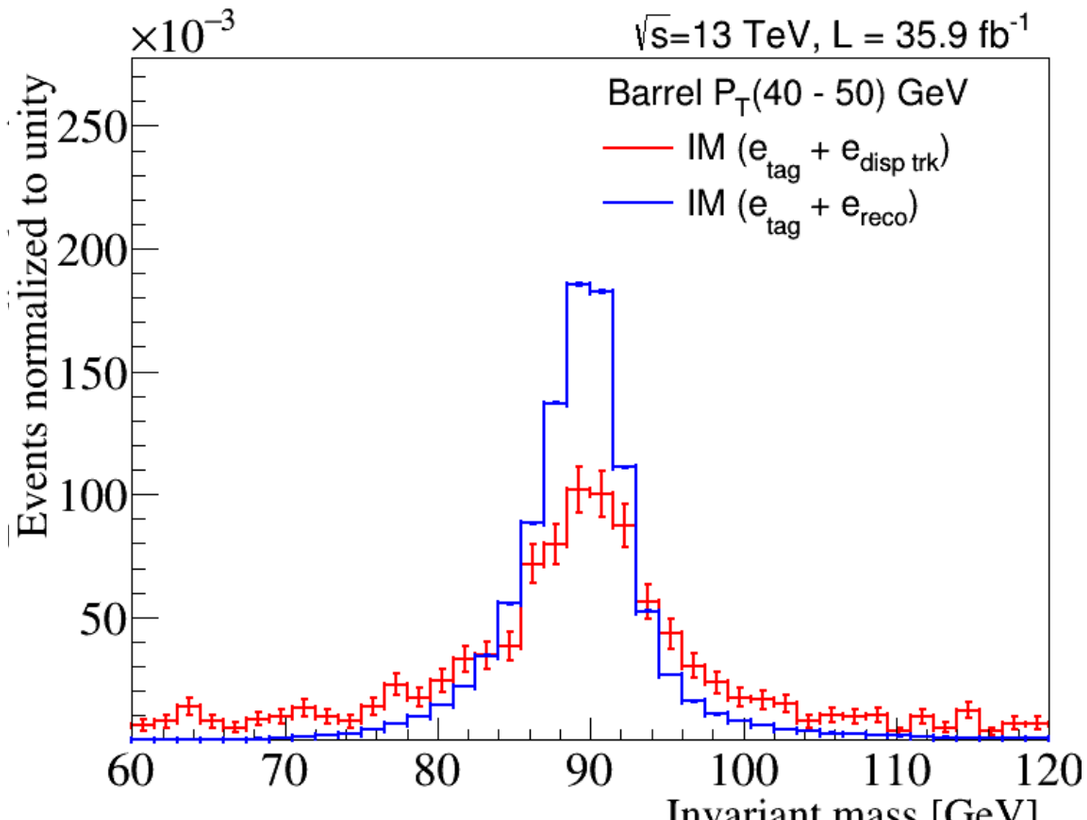
- Delta Phi distribution of probes; disappearing tracks in events with on tag lepton and no b-jets (top);

- Remove fake contamination using:

$$\Delta\Phi^* = \Delta\phi(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \sum_{1}^{\mathrm{n}} \tilde{\mathrm{P}}_{\mathrm{T}}^{\mathrm{n}})$$

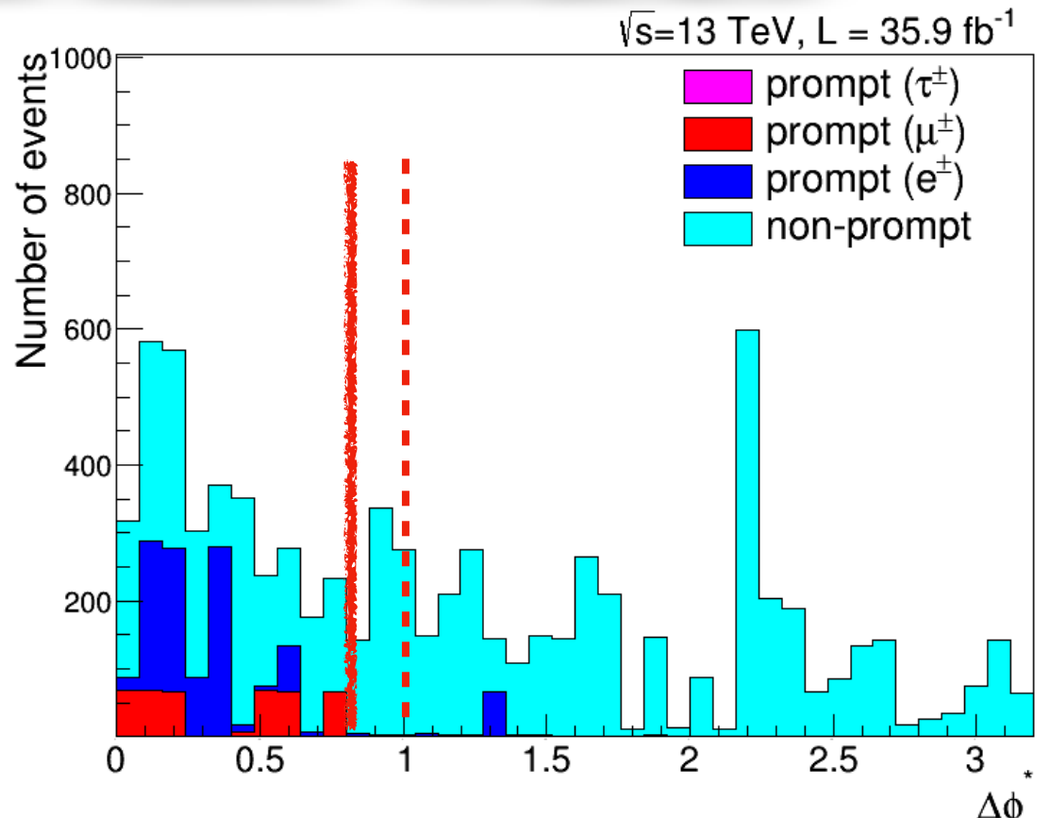
- Invariant mass distribution in data for tag electron with reco electron and disappearing tracks with no selection on Delta Phi (bottom).

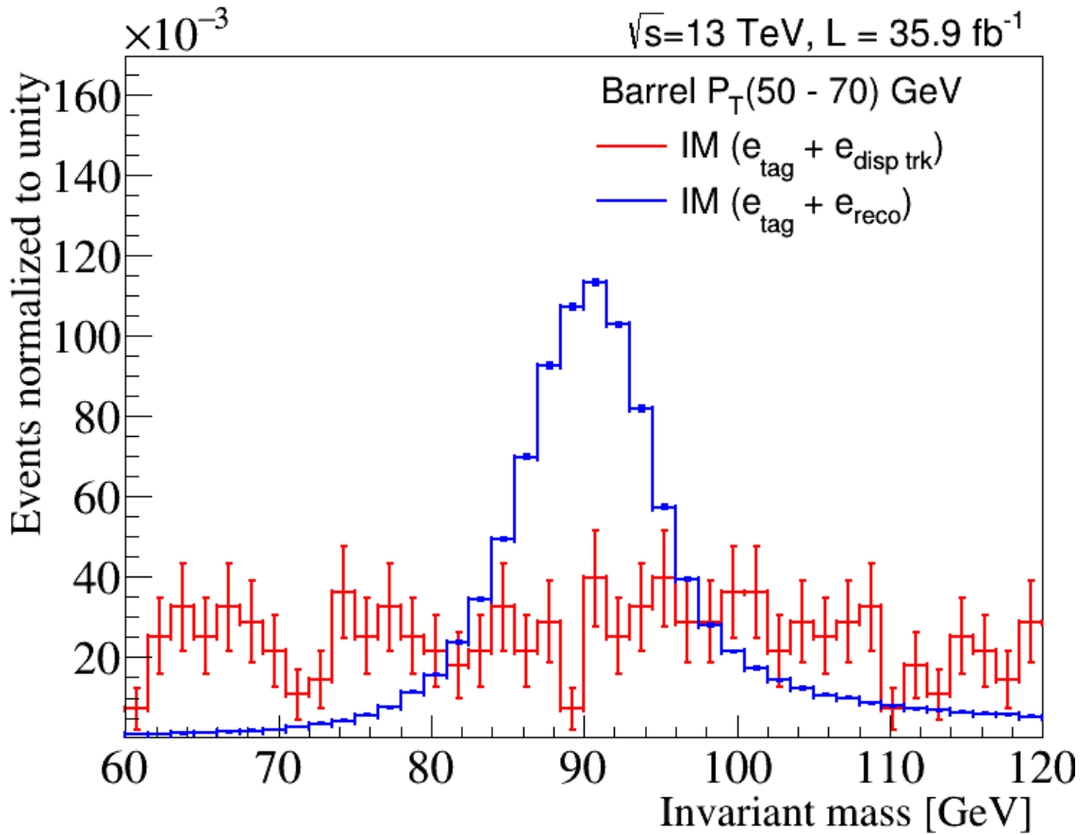




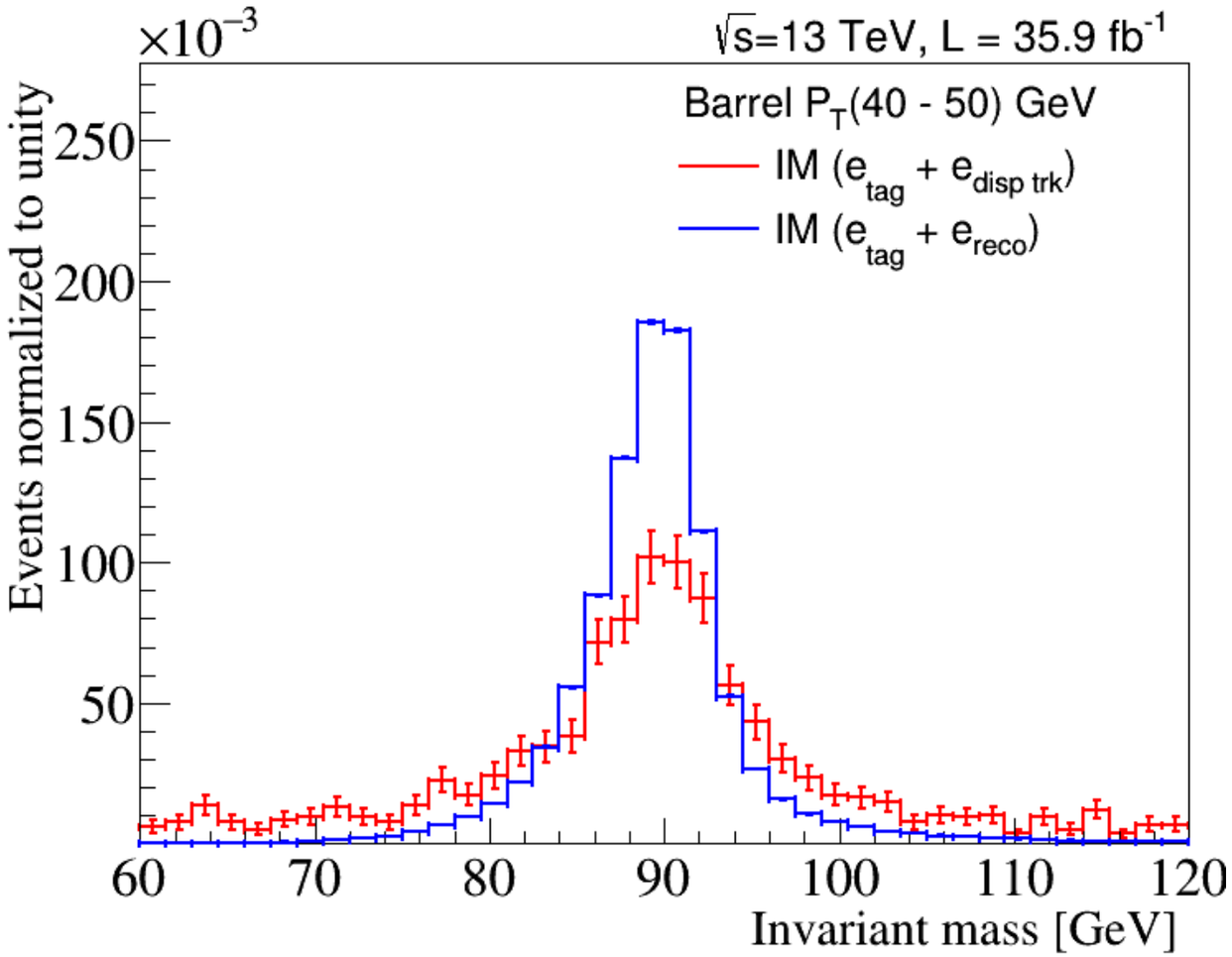
Contamination from fake tracks

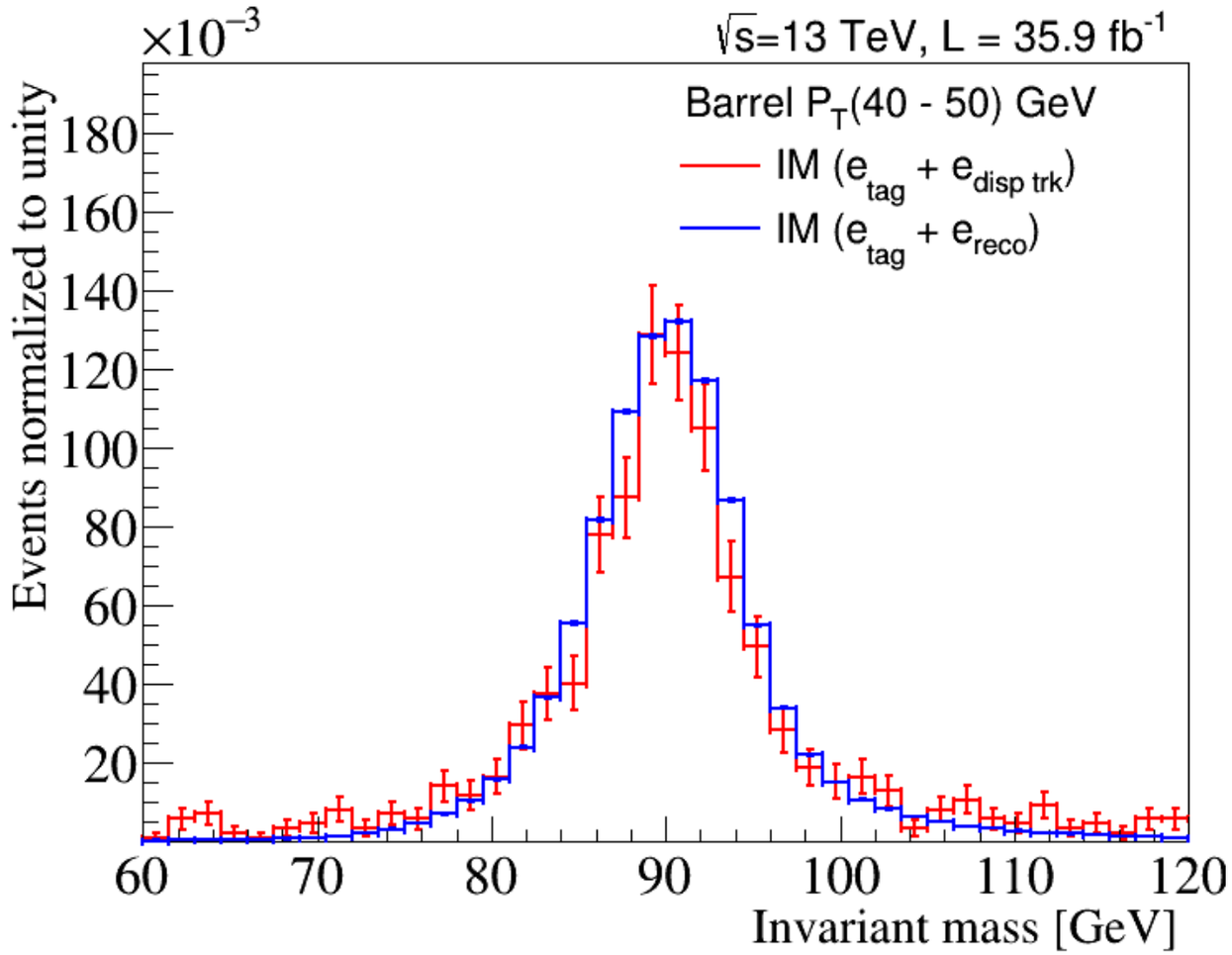
- Delta Phi distribution of probes; disappearing tracks in events with on tag lepton and no b-jets (top);
- Veto disappearing tracks with:
  - $\Delta\Phi^* < 0.8;\ \mathrm{p_T^{error}}/\mathrm{p_T^2} < 0.05$
  - $\Delta\Phi^* < 1.0;\ \mathrm{p_T^{error}}/\mathrm{p_T^2} \geq 0.05$
- Invariant mass distribution for tag electron with reco electron and disappearing tracks with inverted selection on Delta Phi (bottom).





Effect of corrections

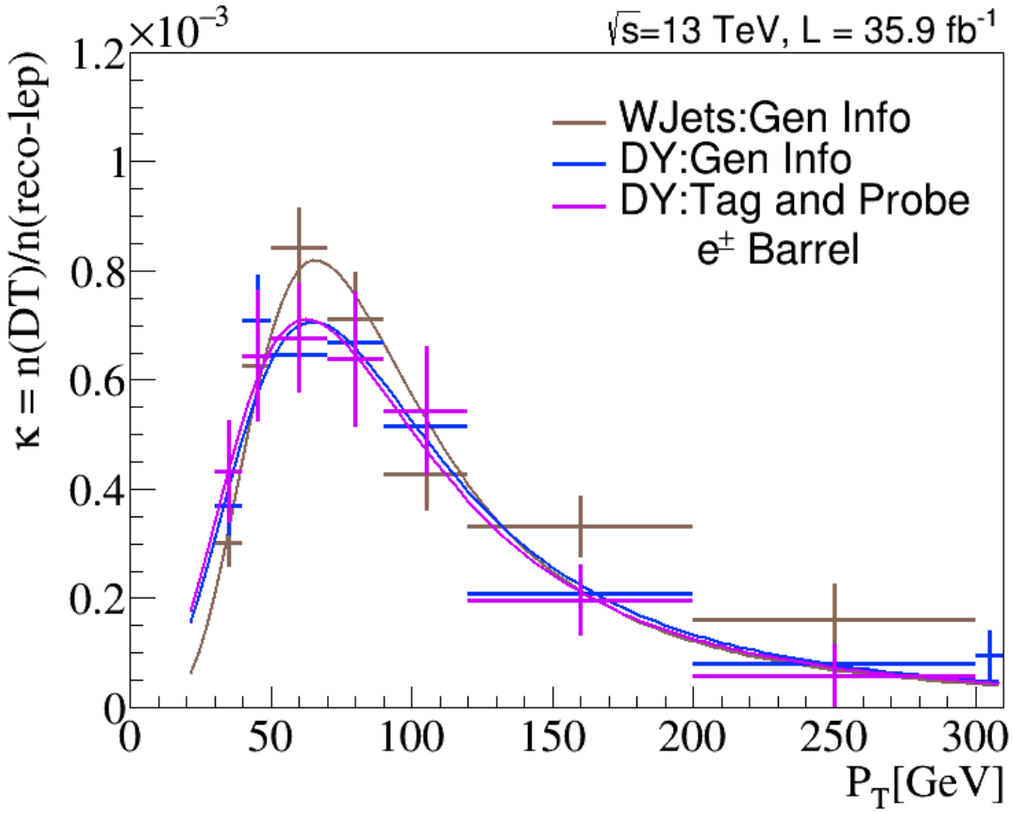


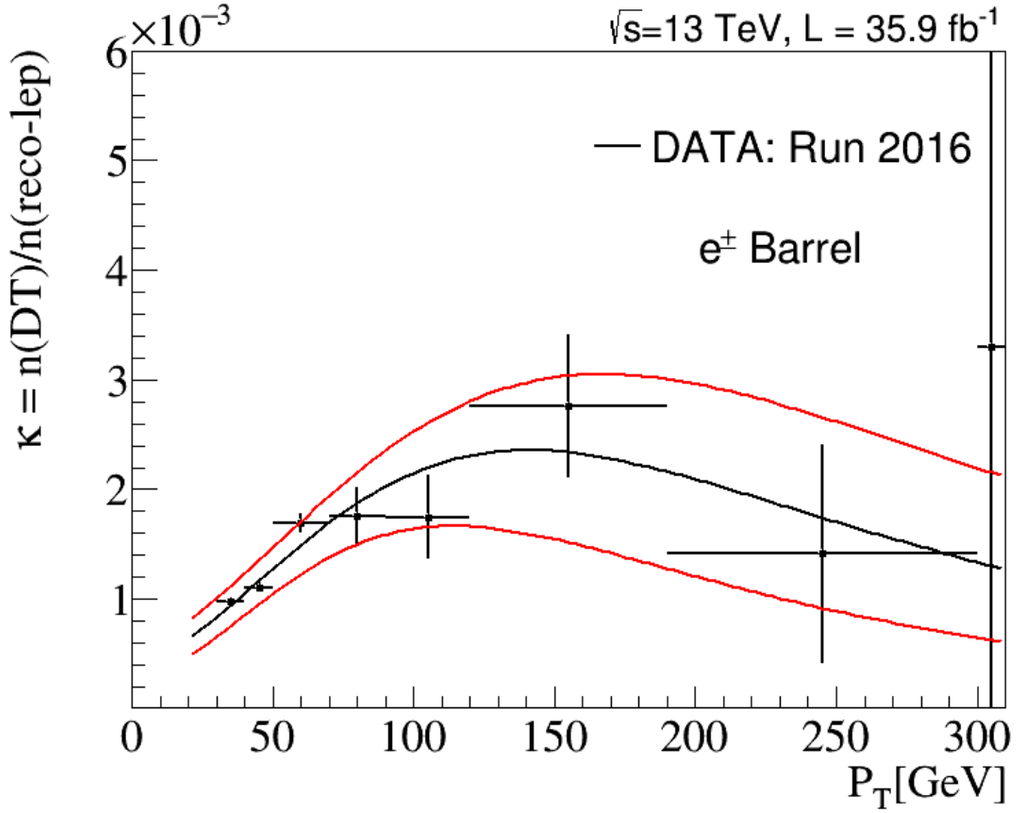


Comparable distributions give accurate kappa values

Kappa values in simulation and Data

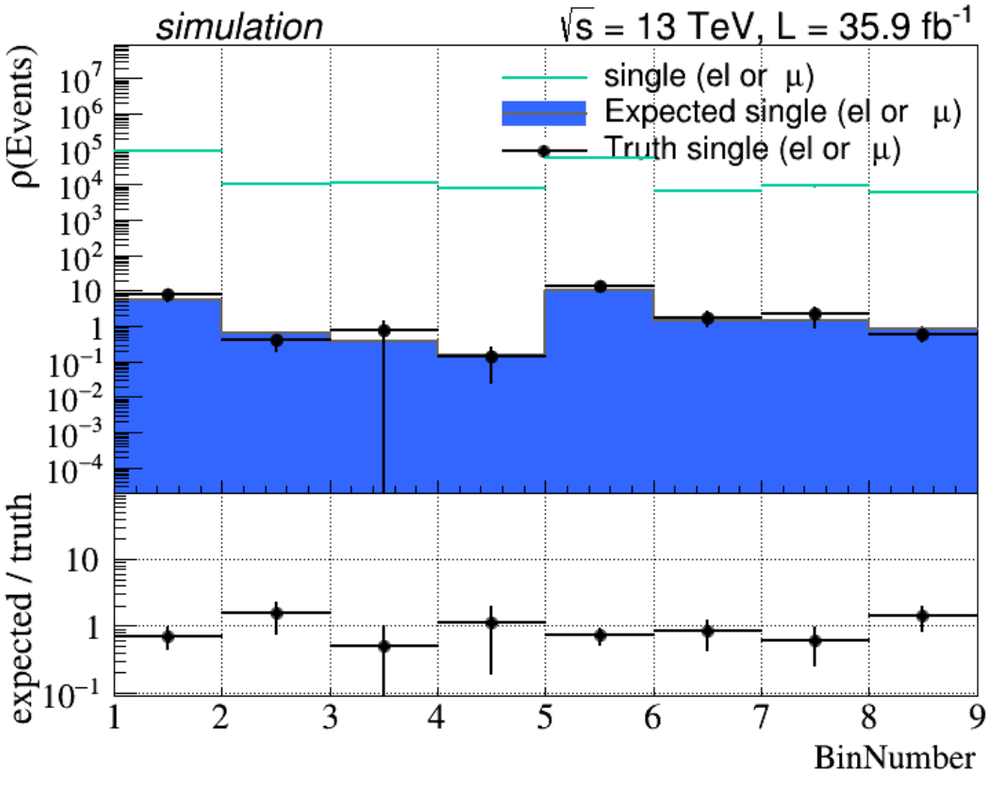
- Kappa for electrons in simulation; W+jets and Drell-Yann (top);
  - Kappa is independent of event dynamics;
  - Tag-and-probe method is viable method for kappa calculation.
- Kappa for electrons in data (bottom).

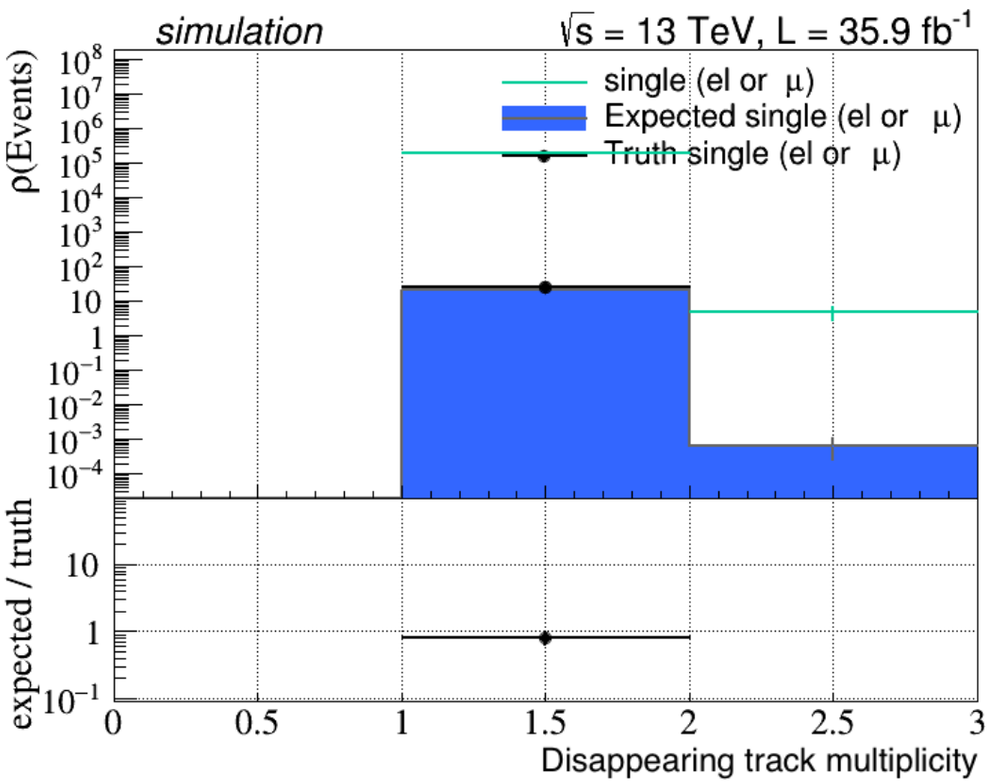




Validation with simulated samples

- Kappa is calculated in Drell-Yann sample with tag-and-probe;
- Validated in W+jets sample for electrons and muons background;
  - Closure in 8 signal regions (top) and disappearing track bins (bottom).





Fake background estimation

- Estimated using a transfer factor alpha measured in pure Drell-Yann events selected as:
  - Number of muons $= 2$ with $p_T > 30$ GeV and $|\eta| < 2.4$
  - Both muons pass tight muon ID
  - $\mu^1_{\text{charge}} + \mu^2_{\text{charge}} = 0$
  - $|\text{IM}_{\mu\mu} - \text{M}_\text{Z}| < 10$ GeV
- Any track except for those from muons is a fake track.

Alpha calculation

- A ‘control region fake track’ and a ‘signal region fake track’ are defined depending on impact parameter:
  - ‘Control region fake track’: $|\mathrm{d_{xy}}| < 0.01$ cm
  - ‘Signal region fake track’ : $0.02 < |\mathrm{d_{xy}}| < 0.1$ cm

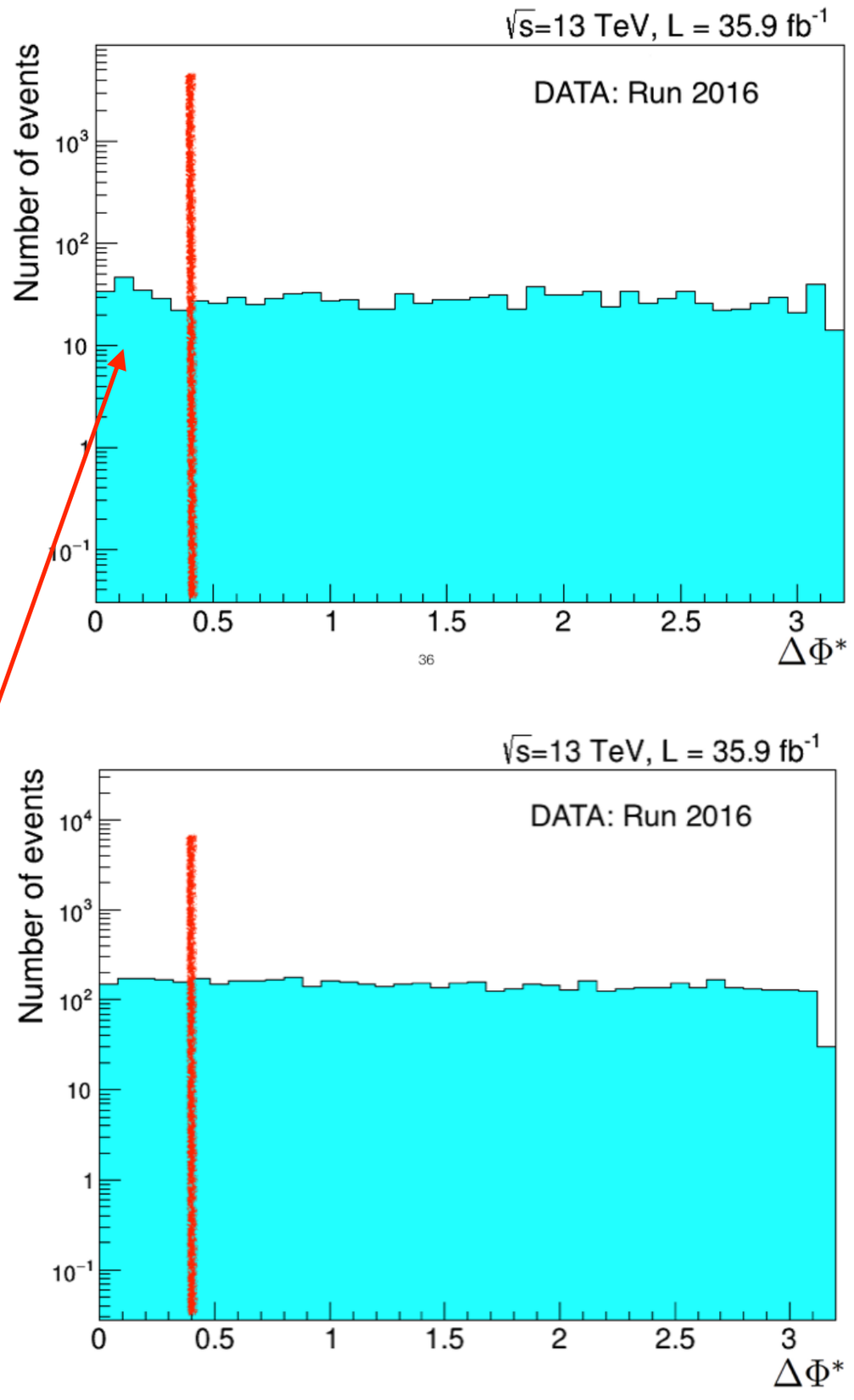
$$\alpha = \frac{\mathrm{N}_{(|\mathrm{dxy}|<0.01)}}{\mathrm{N}_{(0.02<|\mathrm{dxy}|<0.1)}}$$

- Estimate ‘signal region fake tracks’ in signal regions as:

$$\mathrm{N}_{(|\mathrm{dxy}|<0.01)} = \alpha \times \mathrm{N}_{(0.02<|\mathrm{dxy}|<0.1)}$$

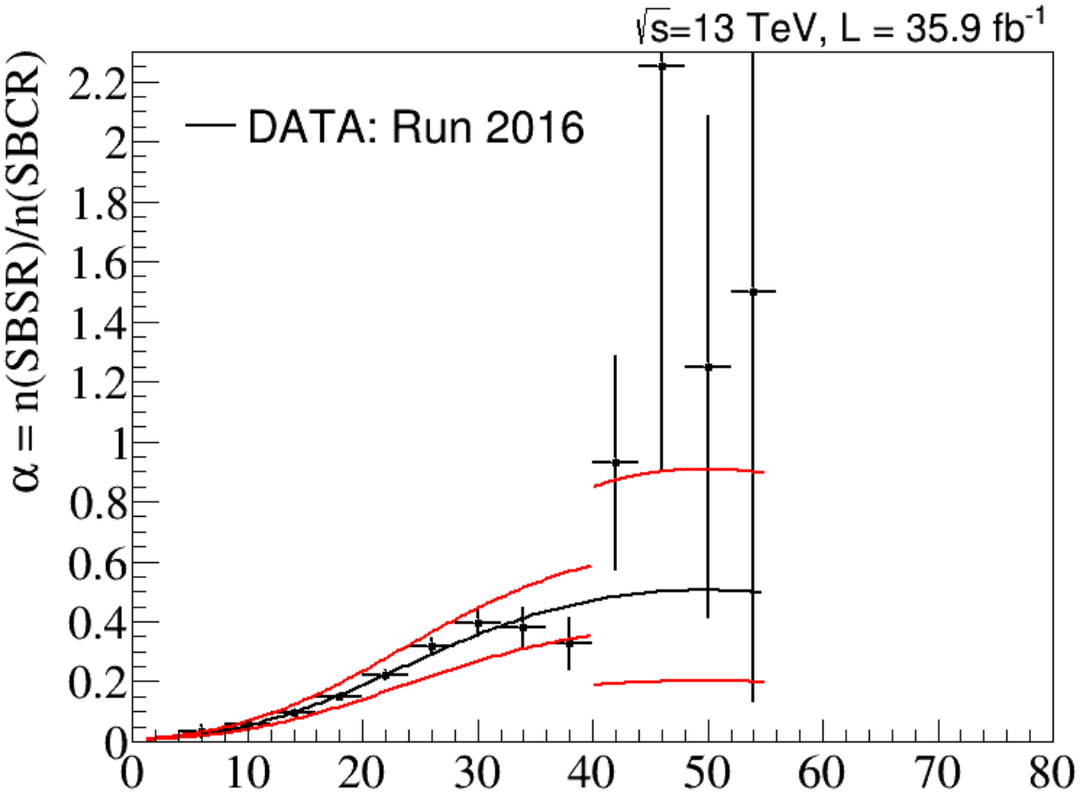
Alpha calculation

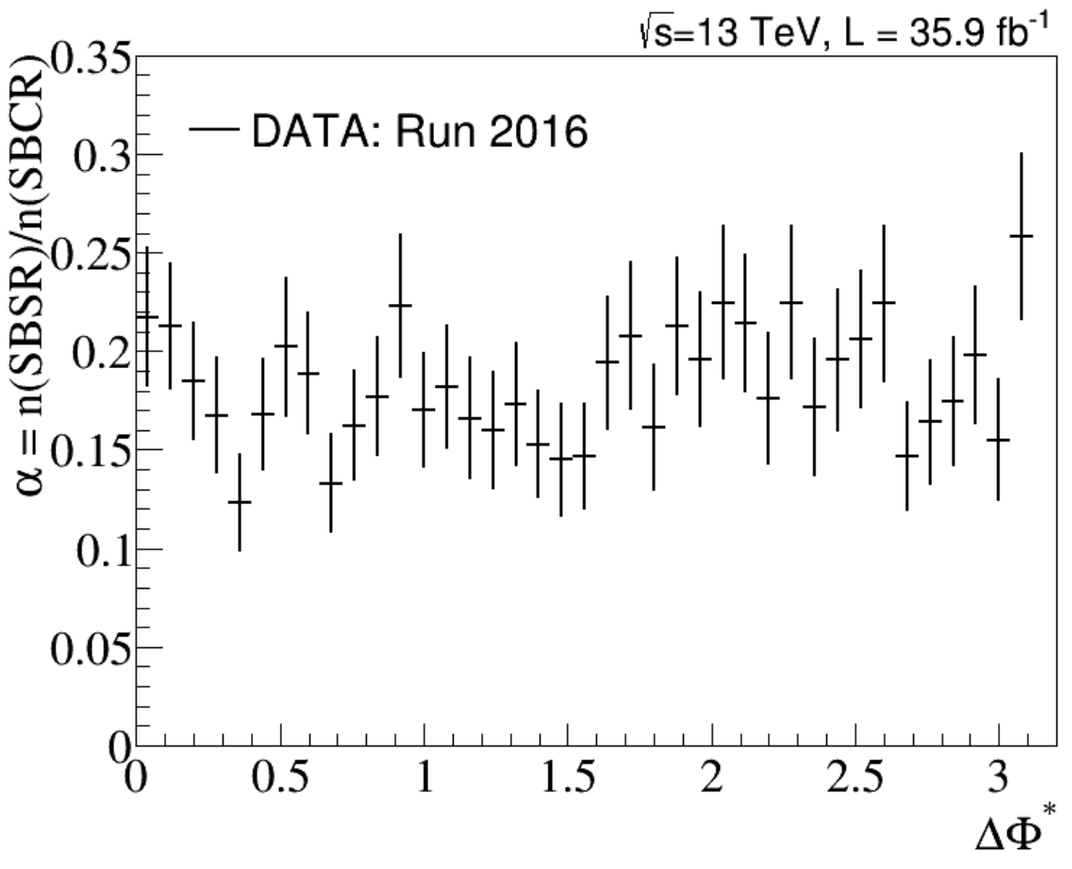
- Estimation in Drell-Yann events in data; distribution of disappearing tracks in data
  - ‘Signal region fake track’ distribution (top)
  - ‘Control region fake track distribution’ (bottom)
  - Alpha calculated only in the events with $\Delta\Phi^* > 0.4$
  - Prompt tracks peak at $\Delta\Phi \rightarrow 0$



Alpha values

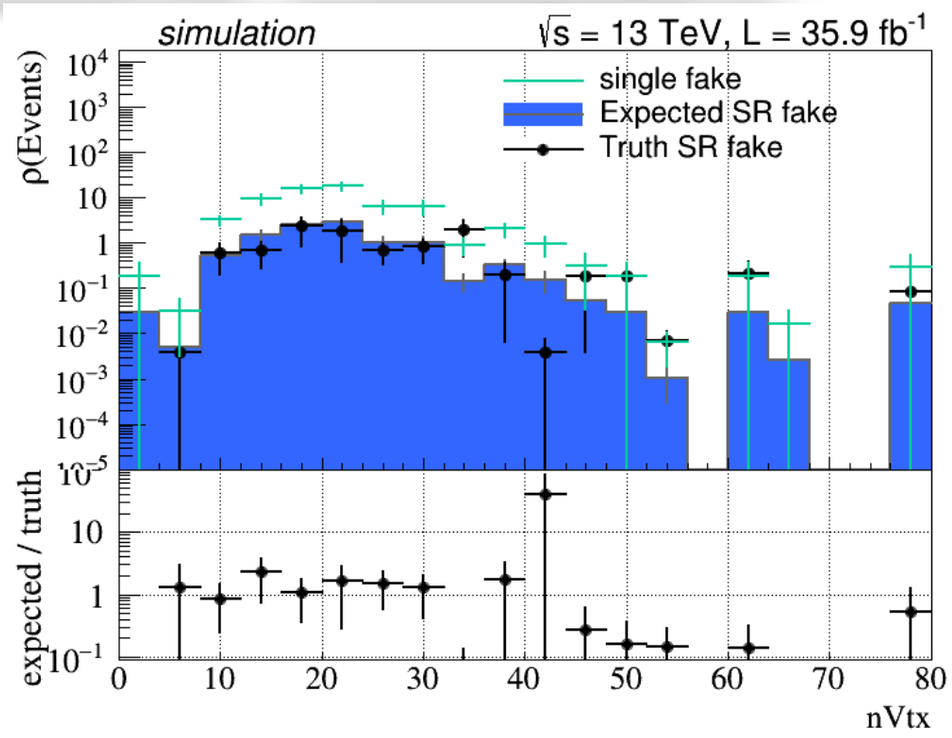
- Fake tracks originate from pileup tracks and noise
  - Alpha as a function of number of verticals is used for background estimation
- Alpha almost constant in other variables
  - Alpha values as a function of R.

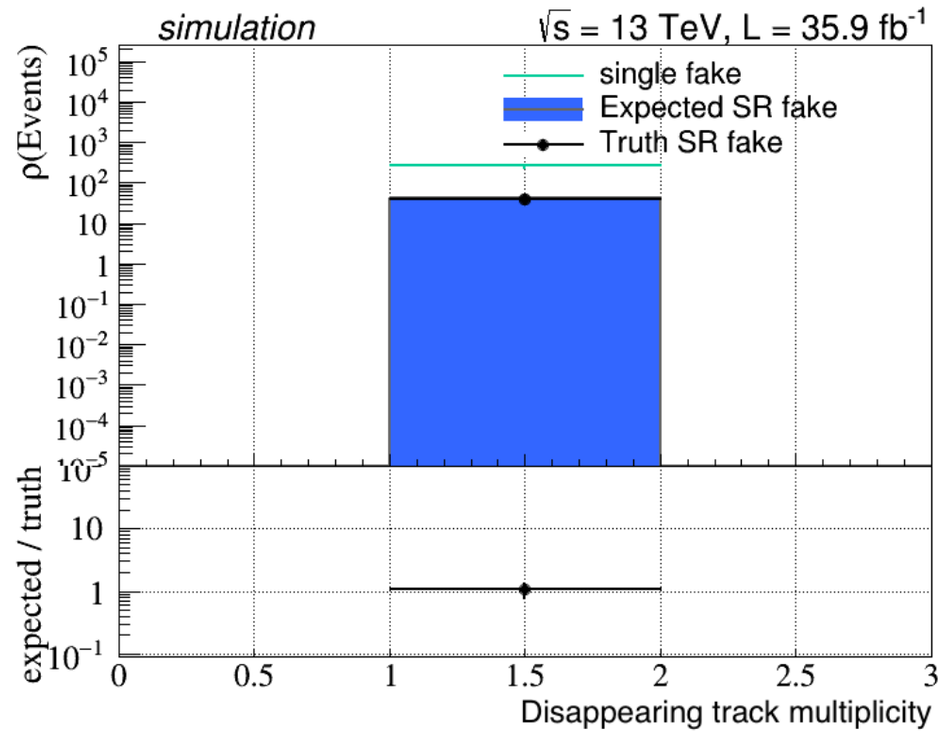




Validation with simulated samples

- Alpha measured in Drell-Yann events;
- Estimation validated in t-tbar, QCD, and W-jets.
- Signal region: number of vertices (top).
- Signal region: in bins of disappearing track multiplicity.

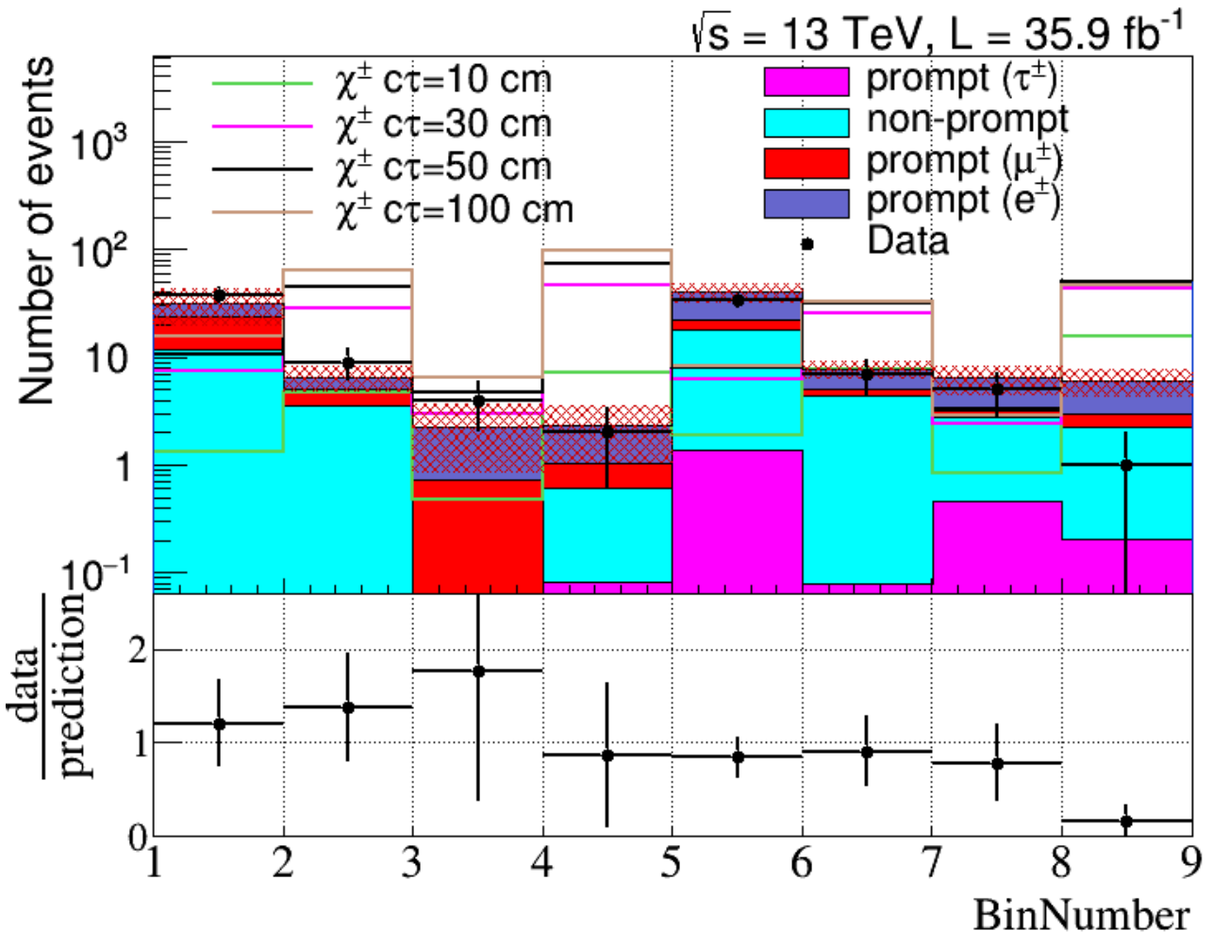


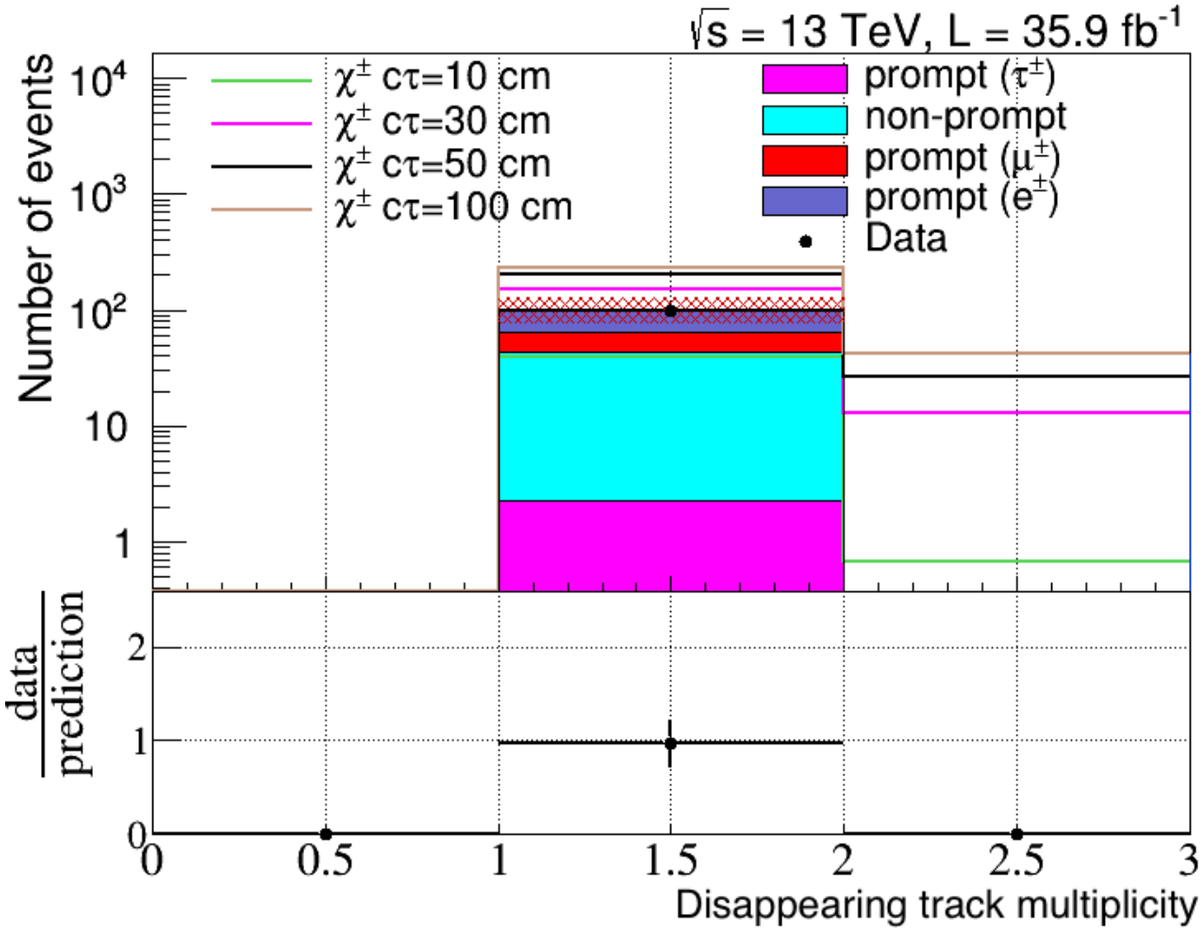


Background with two tracks

- Both fake tracks:
    - Weigh a two CR fake track event by alpha*alpha
- Both leptonic tracks:
    - Weigh a one lepton and a disappearing track event by kappa; assuming the disappearing track is leptonic
- One fake and one leptonic track:
    - Counted in both leptonic category where the disappearing track is a fake;
    - For separate counts; weigh the two lepton region by kappa*kappa and subtract from the combined counts.

Prediction and Observation



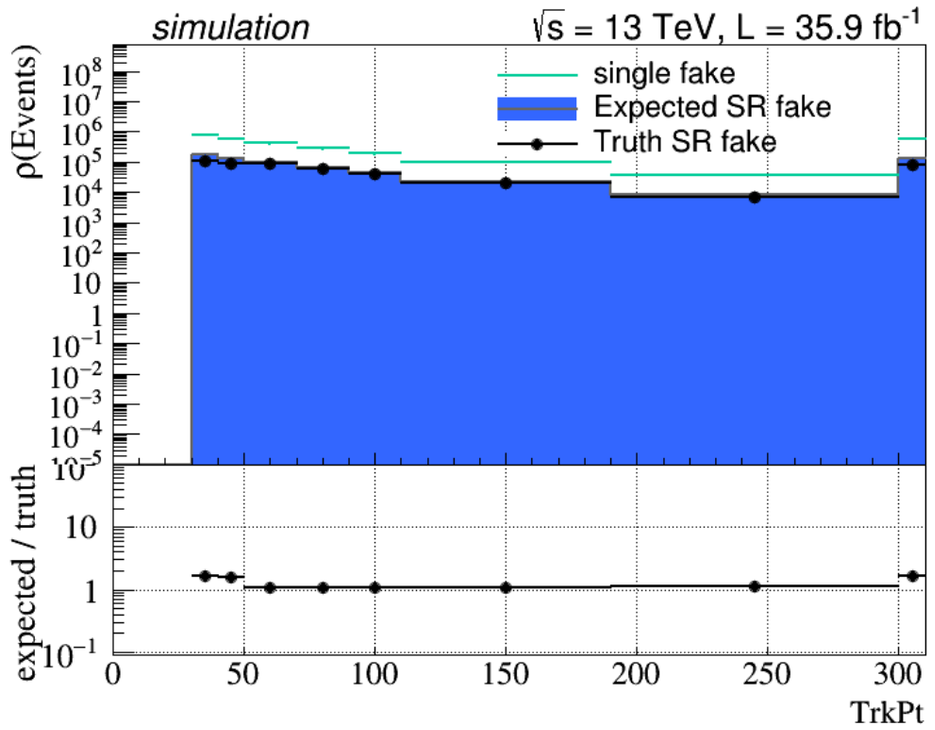


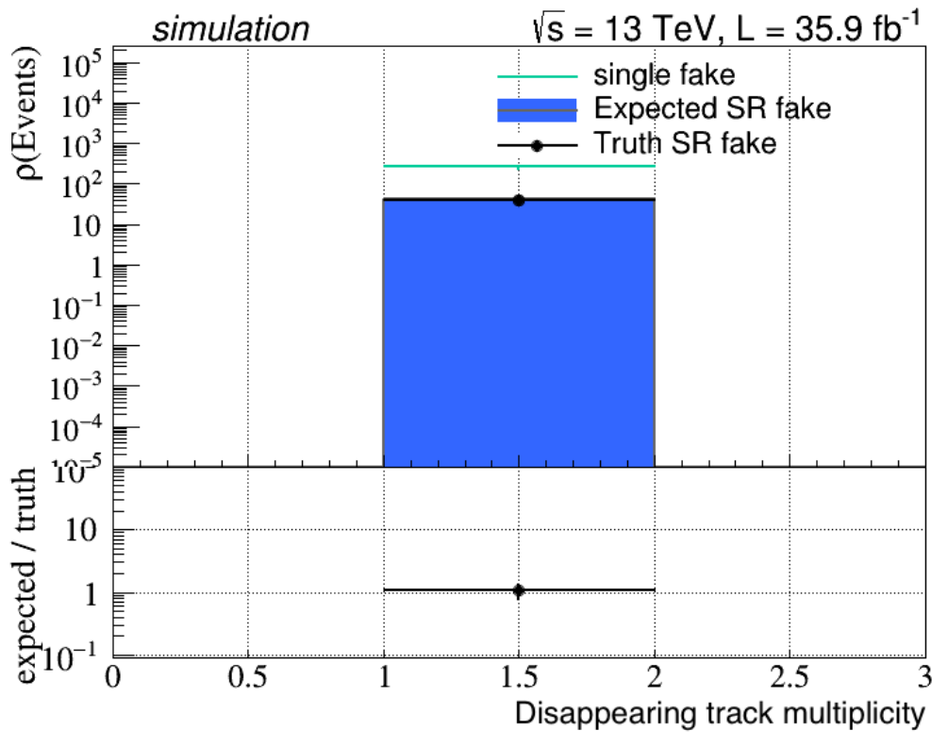
- Systematic uncertainties; fit parameters varied in their uncertainties.

- No significant excess; limits to be set using profile likelihood ratio as test static.

Validation with simulated samples

- Alpha measured in Drell-Yann events;
- Estimation validated in t-tbar, QCD, and W-jets.
- No cuts: in track Pt bins (top).
- Signal region: in bins of disappearing track multiplicity.





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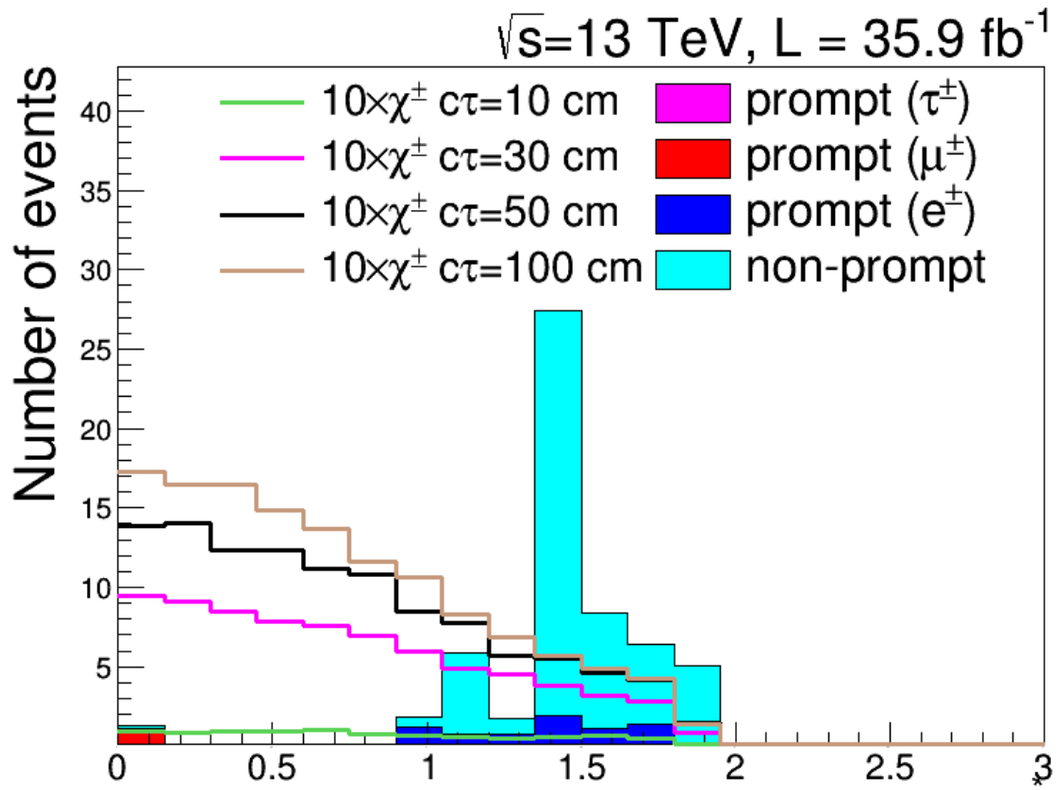
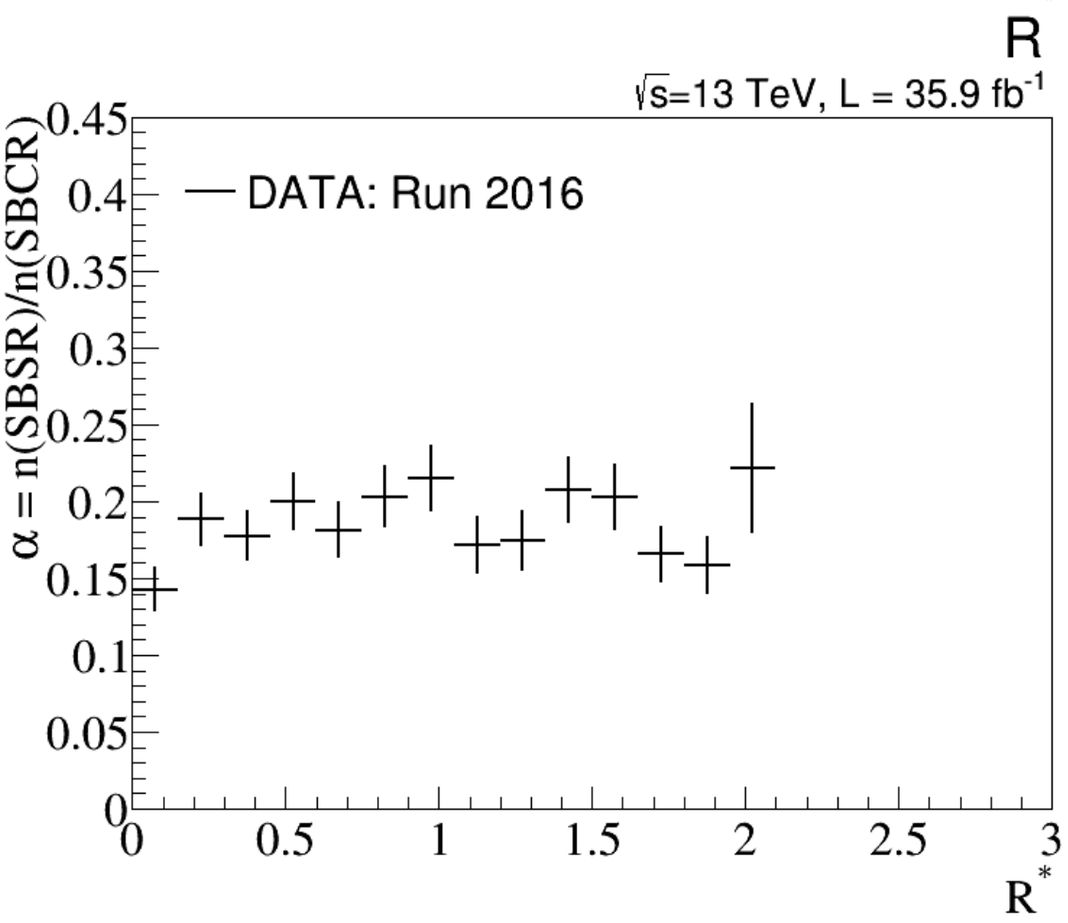
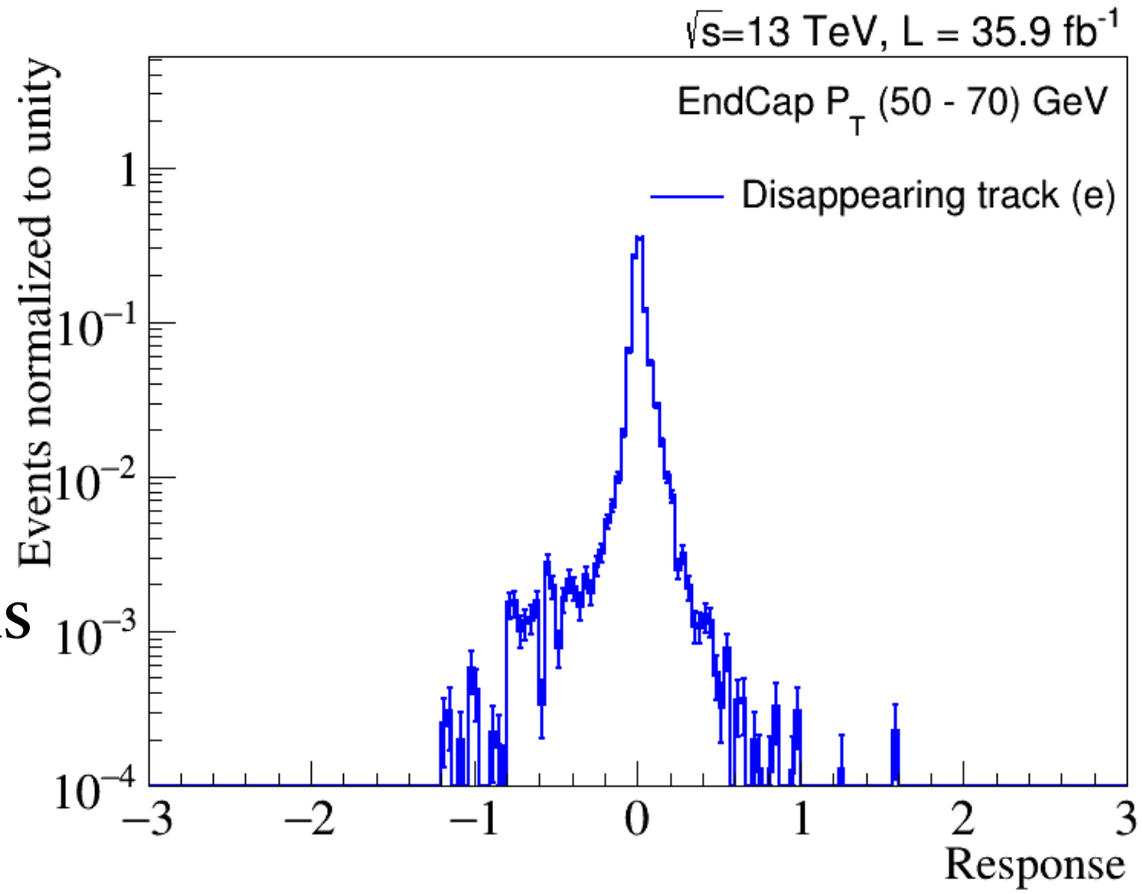




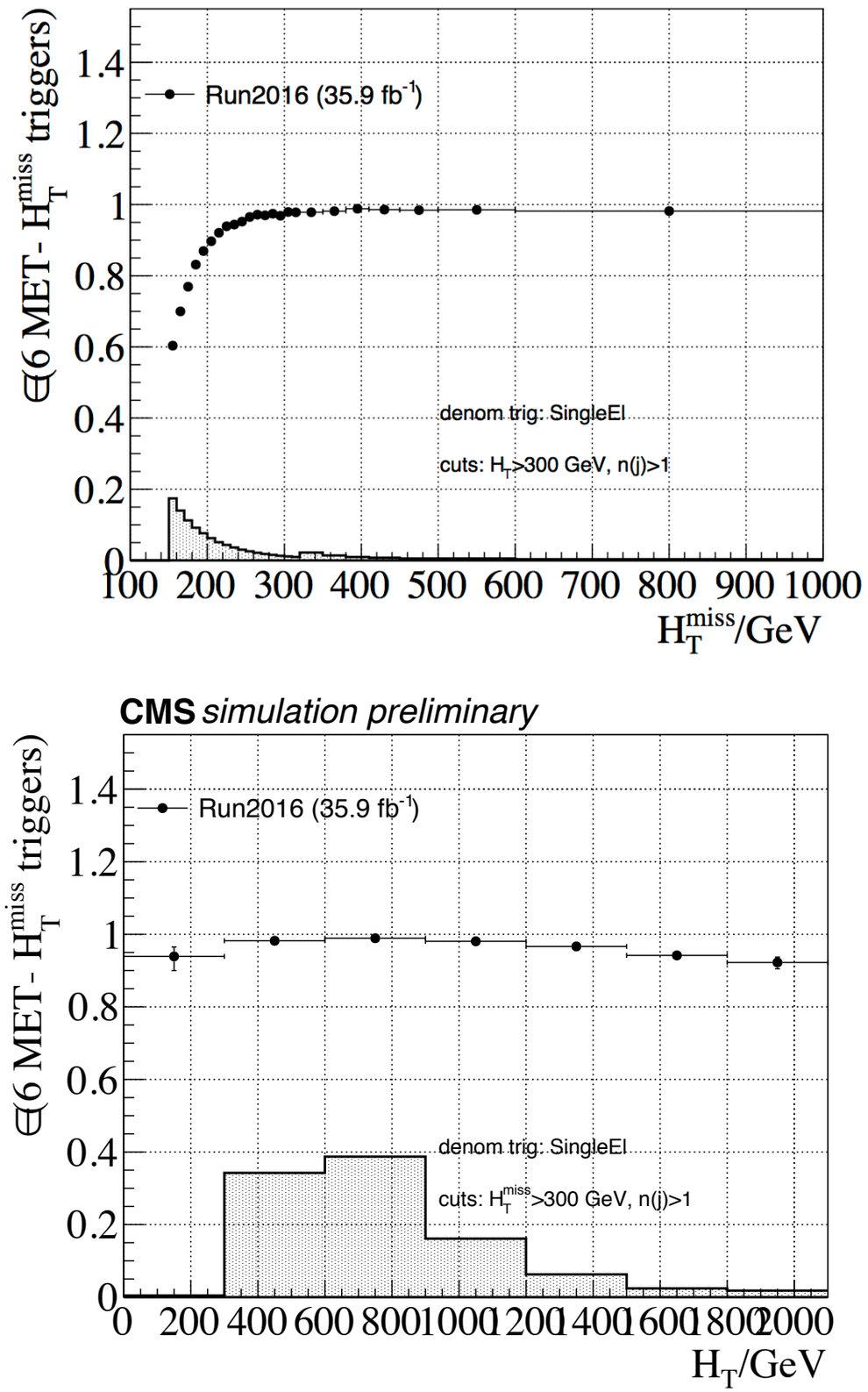
Probe lepton smearing in data

- Tracker hits of the reconstructed lepton are removed in RECO dataset and reconstruction is run again;
- The original Pt is taken as true Pt.
- Smearing templates are made in bins of number of missing outer hits;
- Normalized by missing outer hits distribution of disappearing tracks in data.



Trigger selection

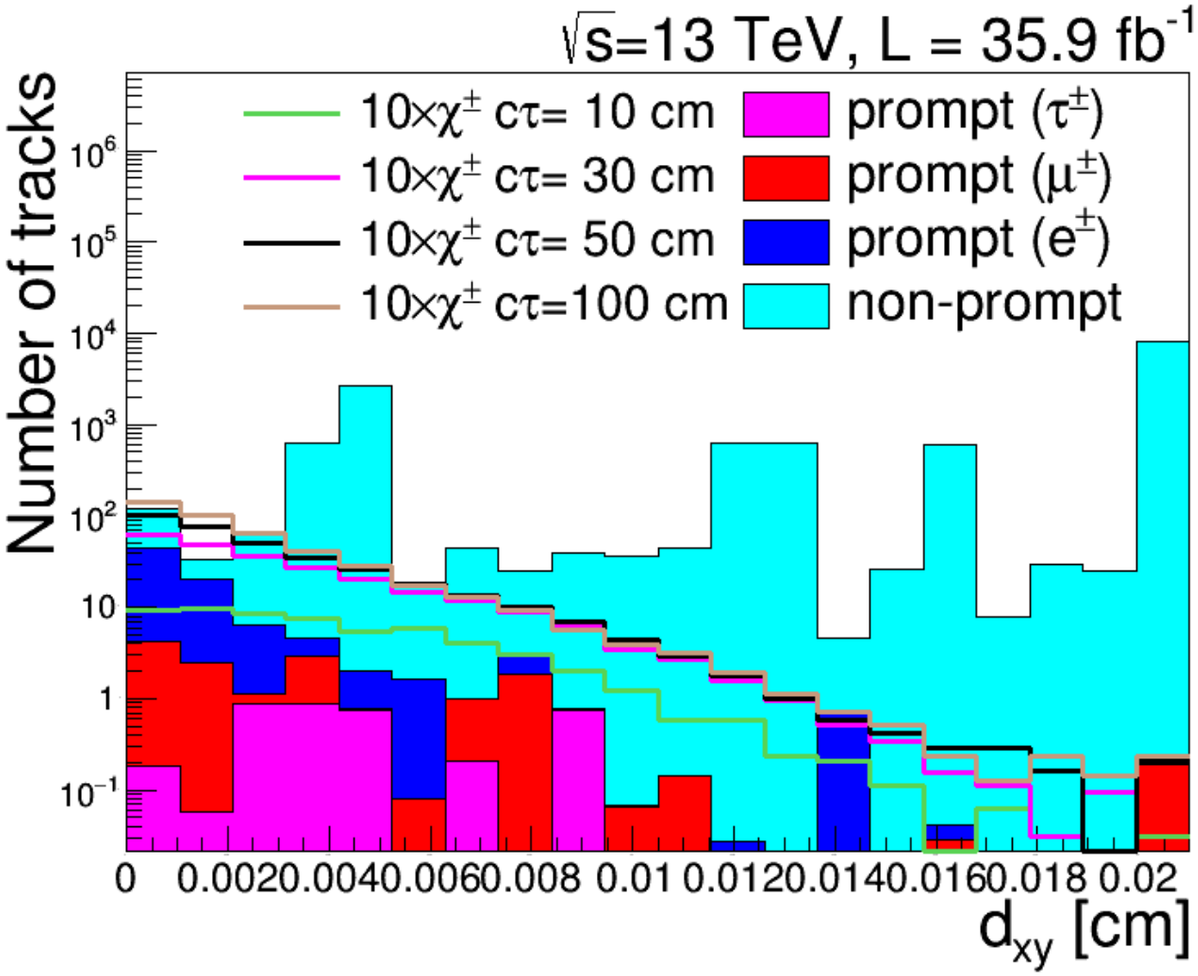
- 6 MET-MHT tigger
- Trigger efficiencies at event selections
- > 97 % for MHT > 250.
- > 98 % for HT > 350.

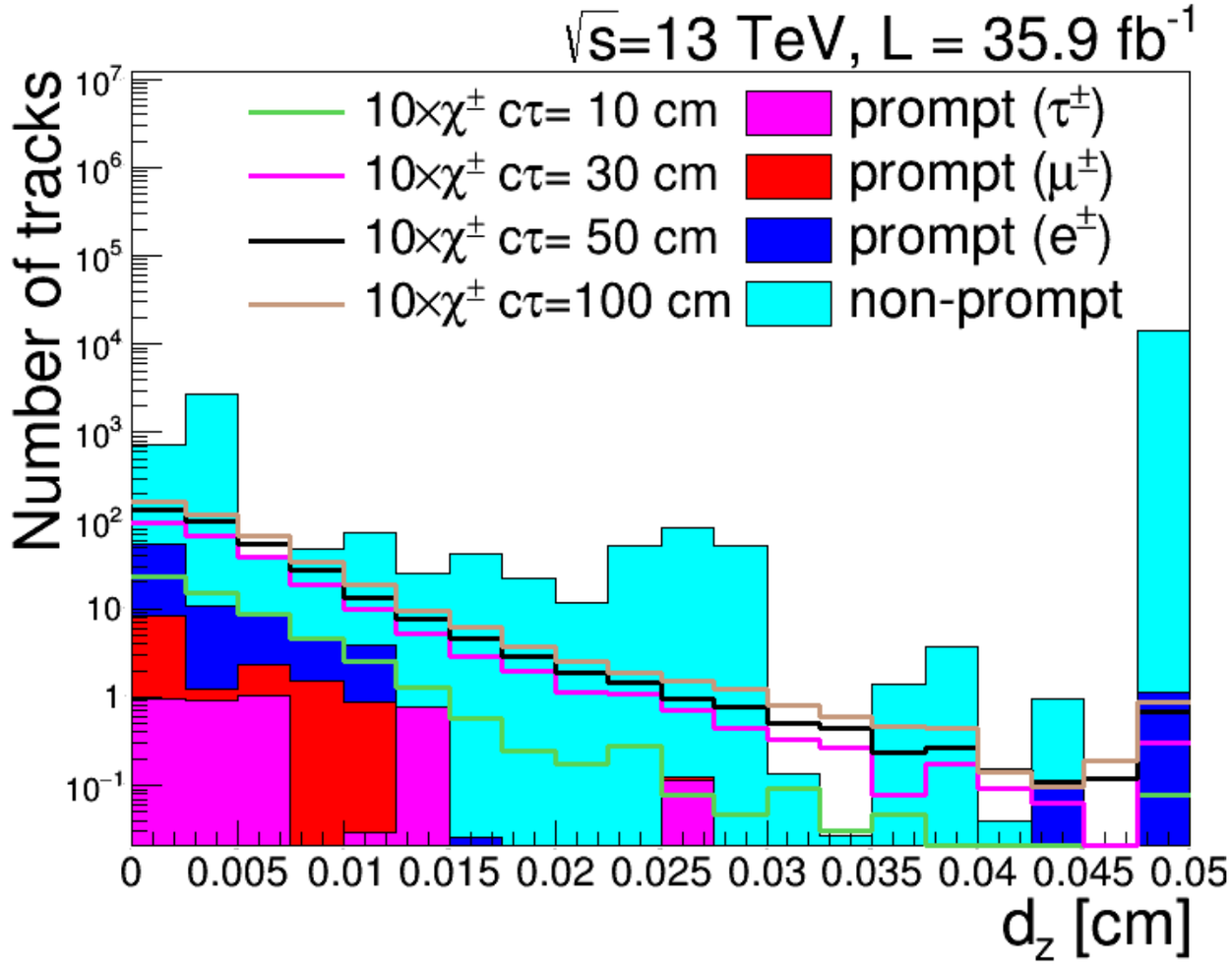


Object Definitions

- Baseline track
  - Track $p_T > 30$ GeV
  - Track $|\eta| < 1.442$ or $1.566 < |\eta| < 2.4$
  - Flagged as a high purity track
  - Tracker layers of measurement ≥ 3
- Disappearing track category:
  - short tracks: tracks with three layers of measurement (pixel only tracks)
  - medium tracks: tracks with > 3 tracker layers of measurement and < 7 tracker layers of measurement
  - long tracks: tracks with $\geq$ seven tracker layers of measurement.

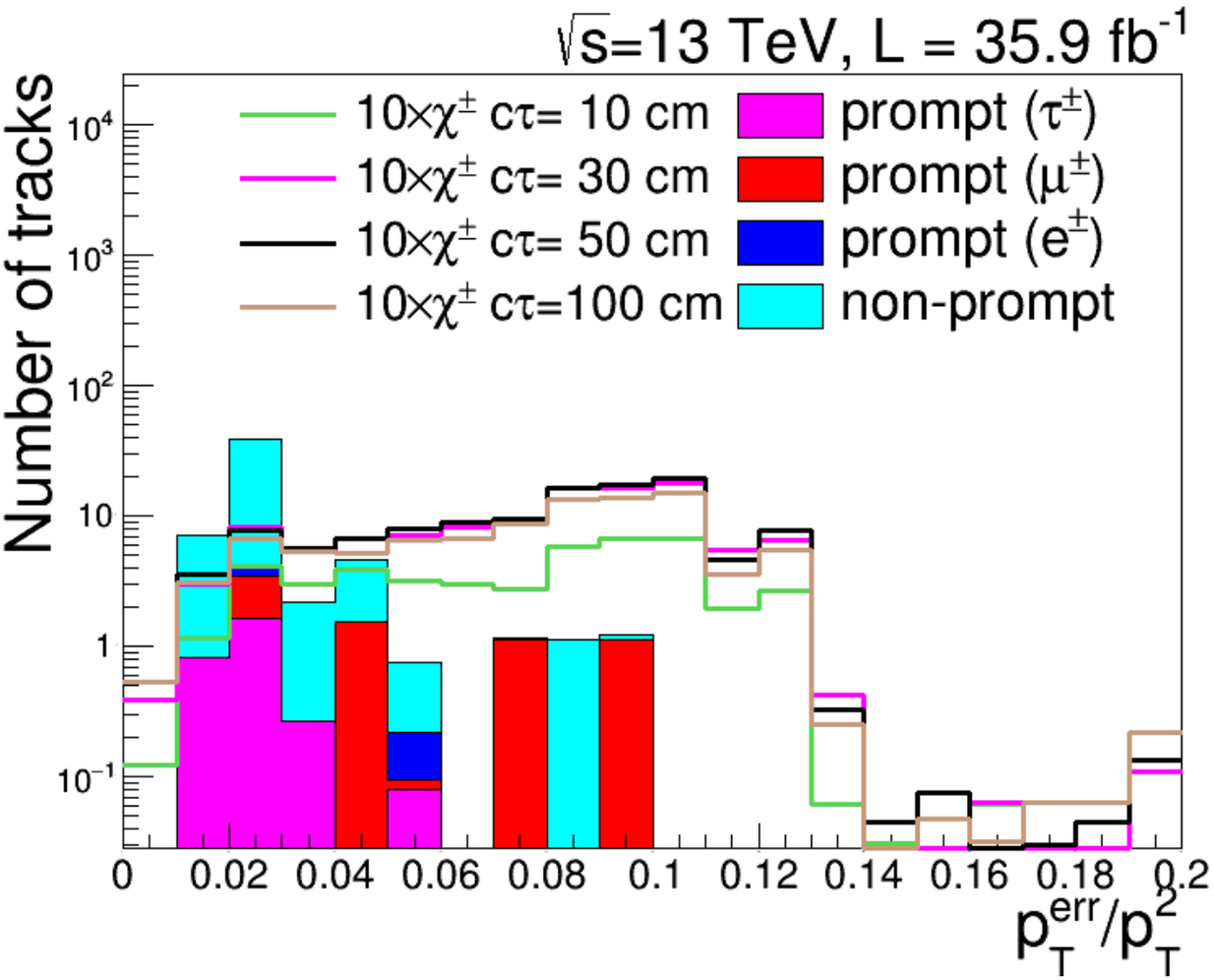
Impact parameters

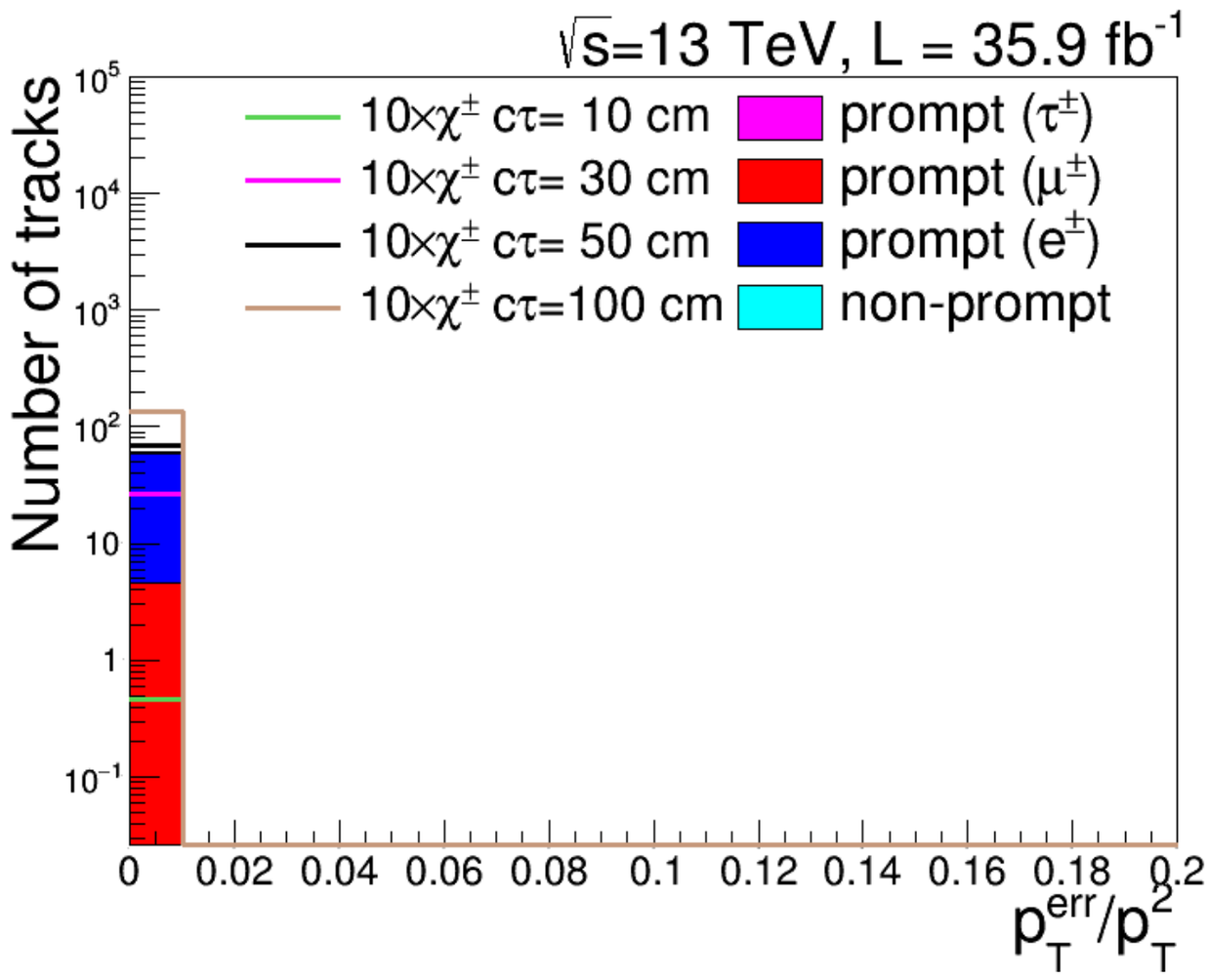




- $d_{xy} < 0.01$ cm and $d_z < 0.02$ cm

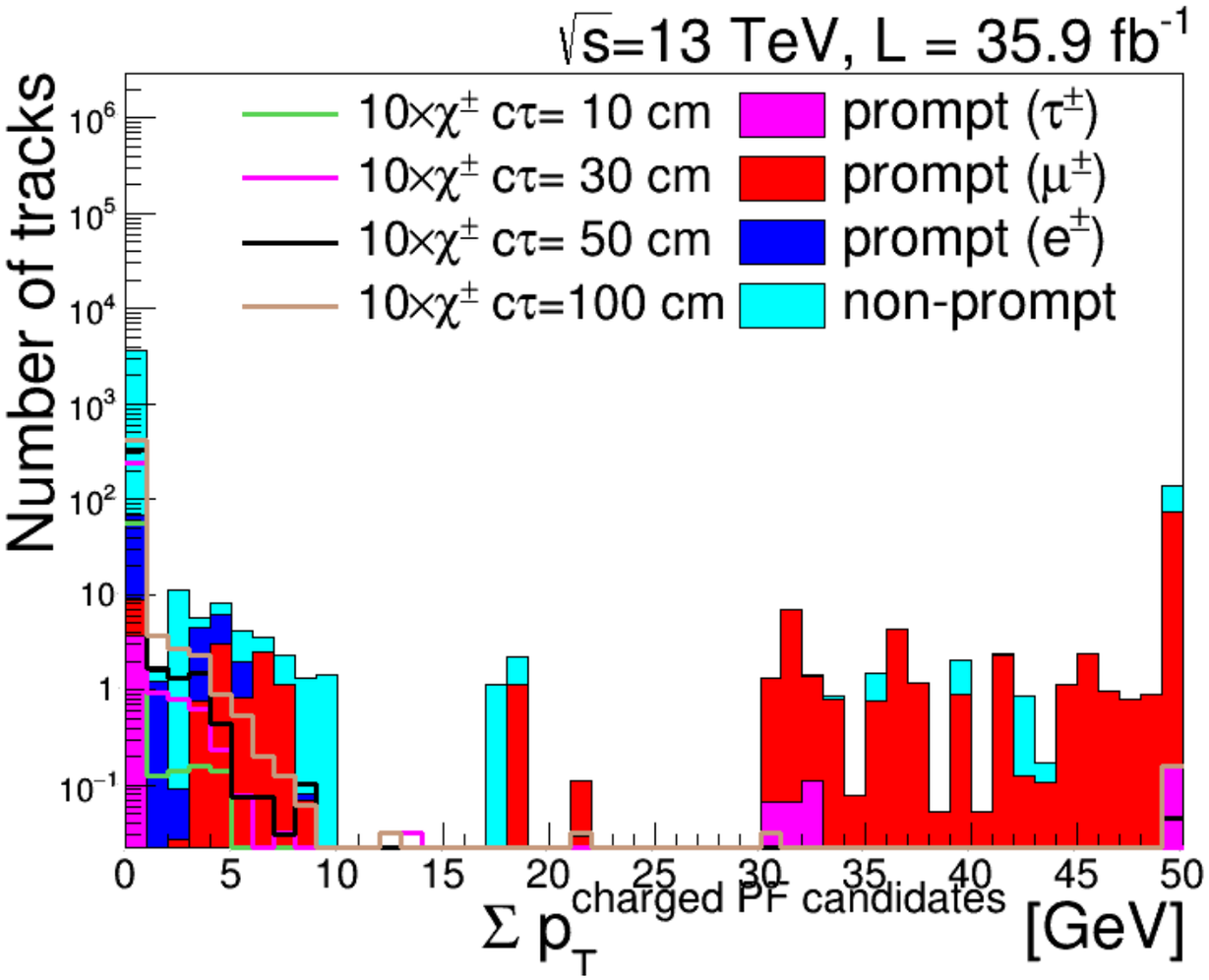
Track resolution

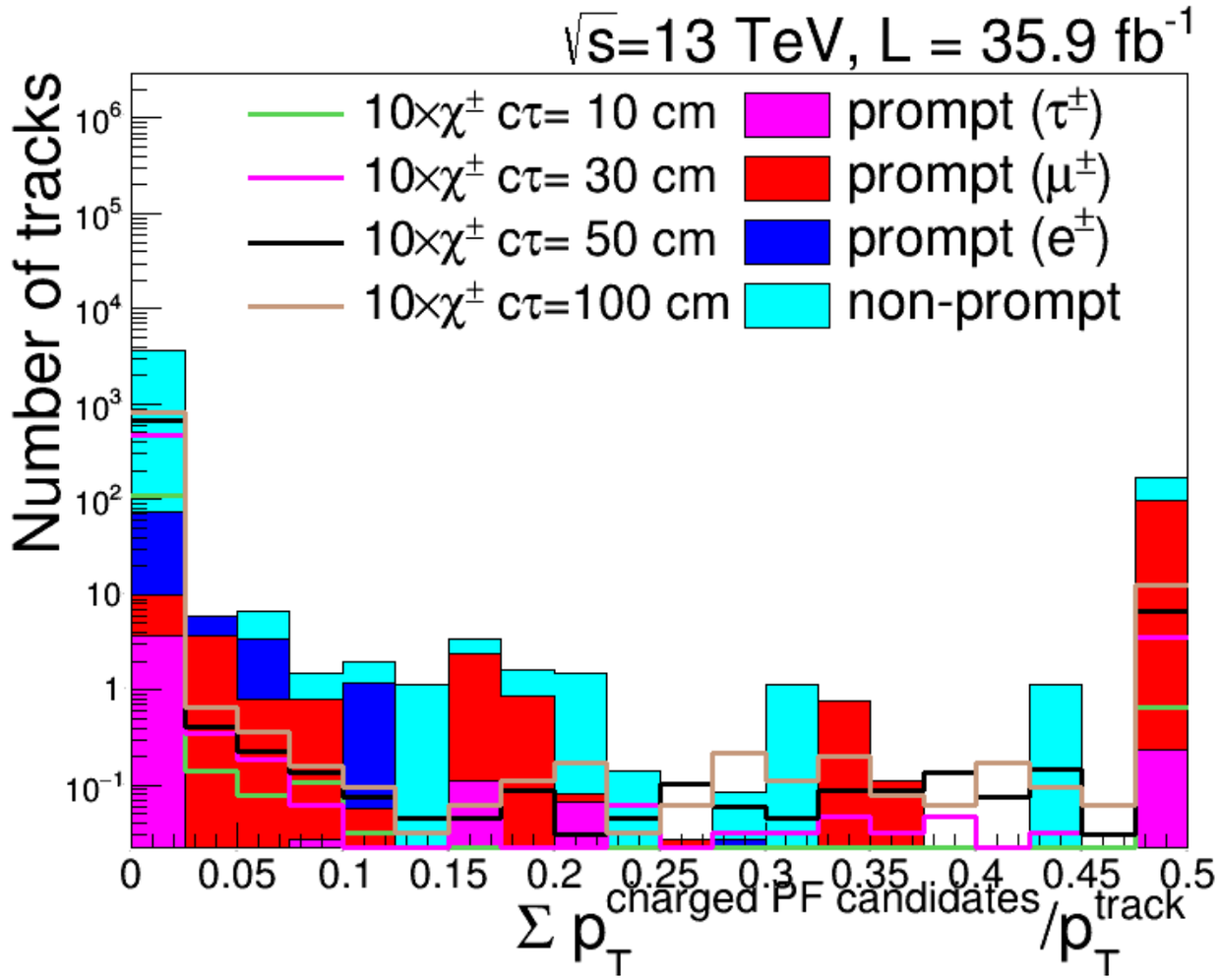




- $p_T^{error}/p_T^2 < 0.2$ for short ; < 0.05 for medium and < 0.02 for long

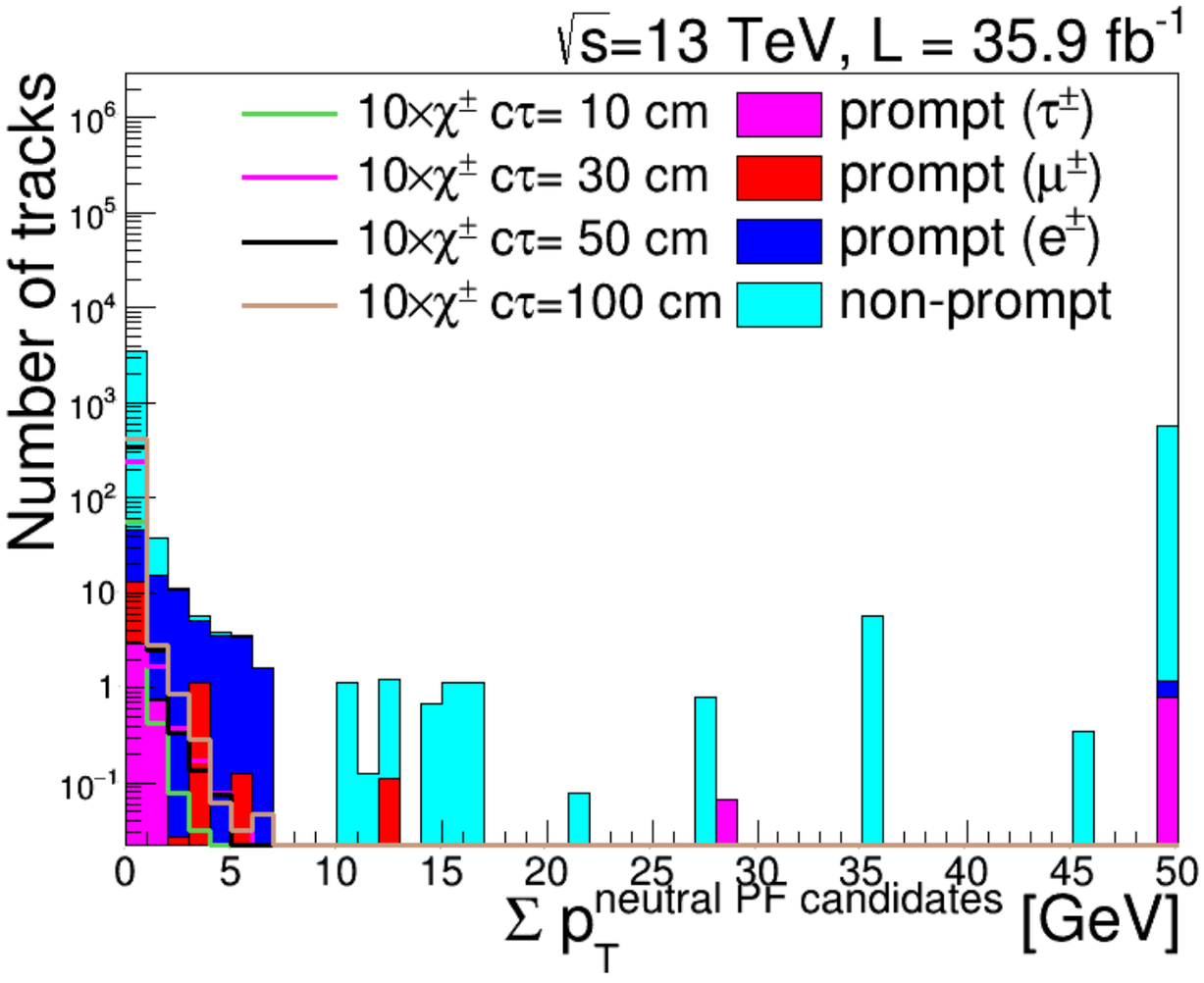
Isolation from charged particles

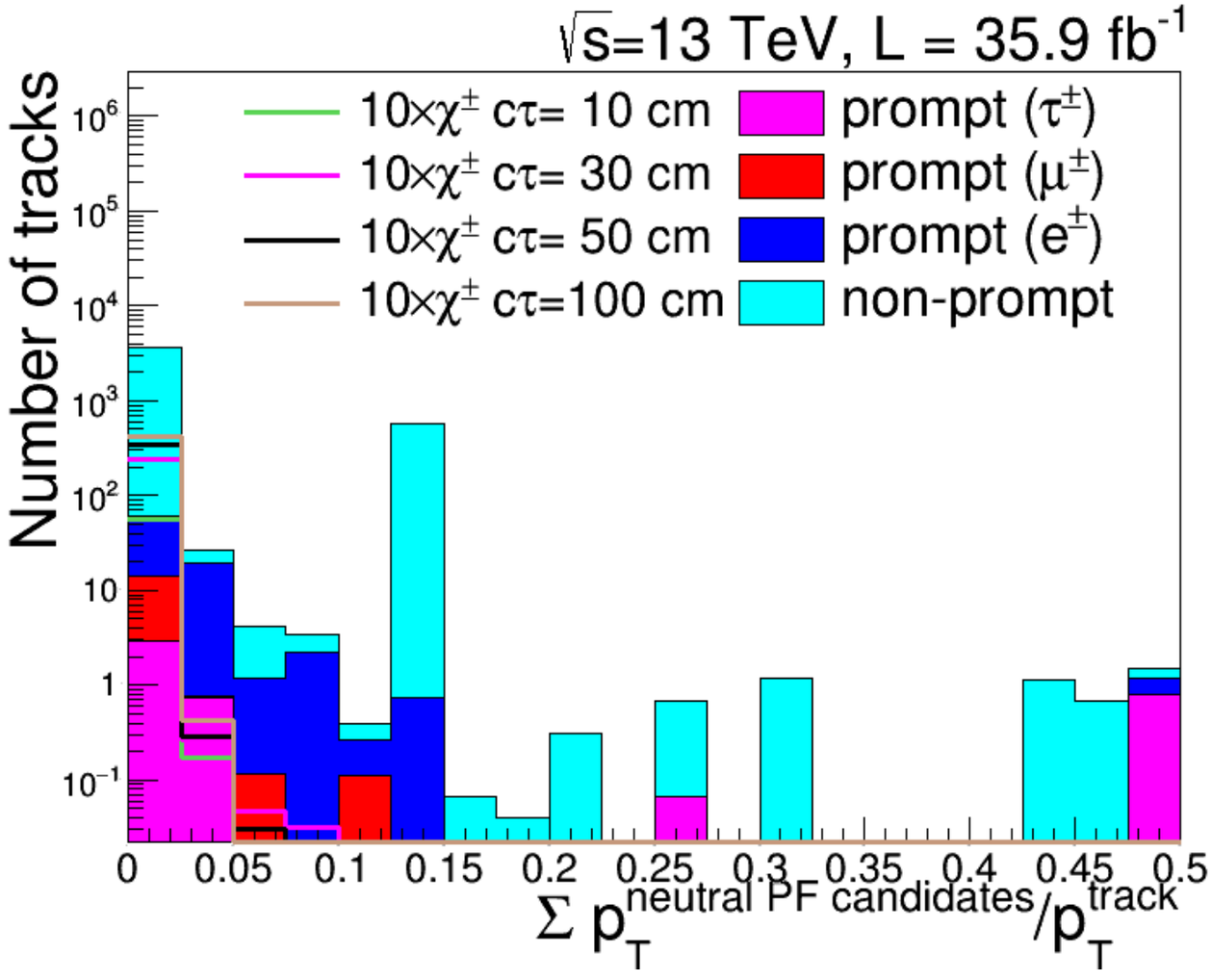




- Absolute (relative) isolation < 10 GeV (0.01); dR < 0.01

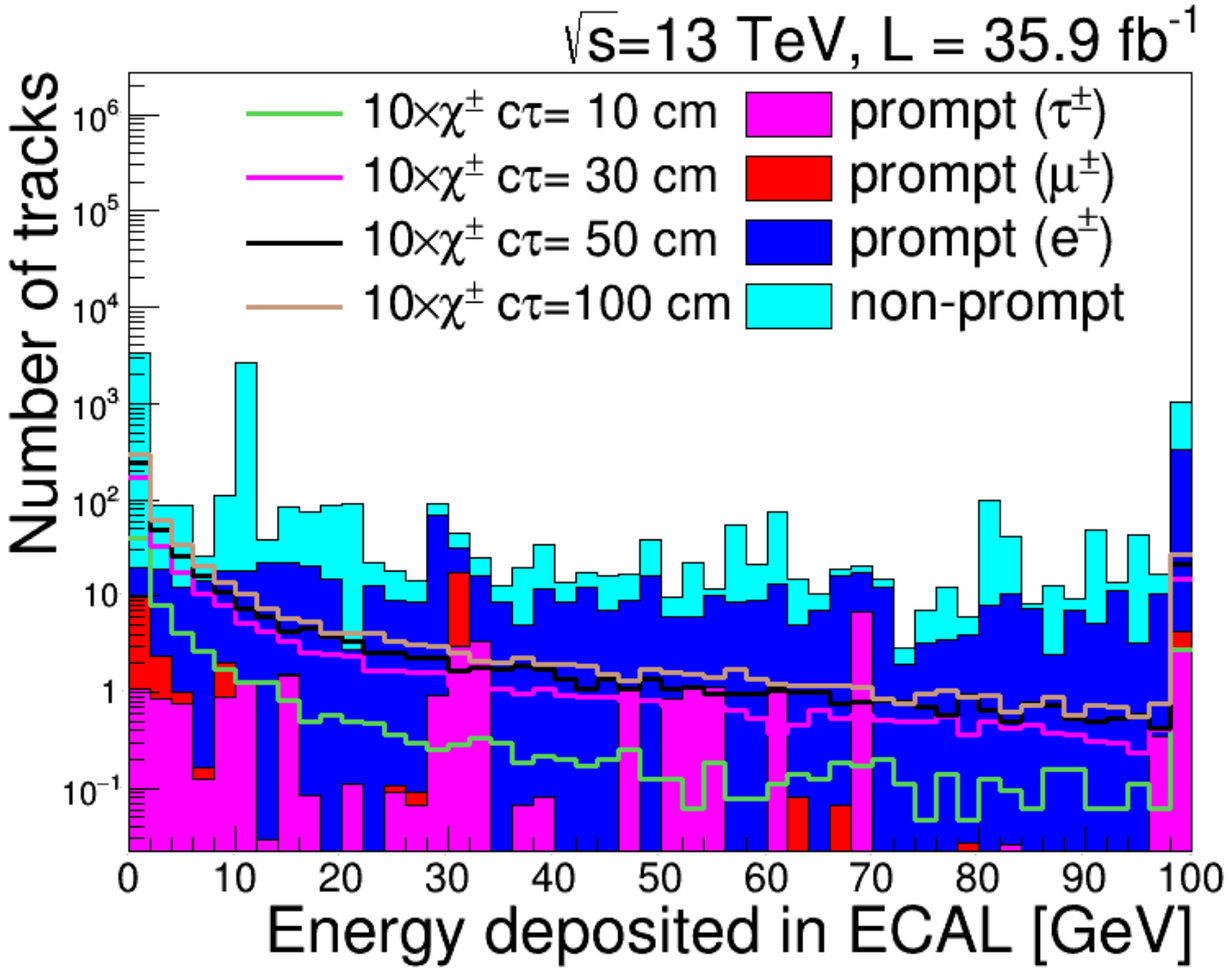
Isolation from neutral particles

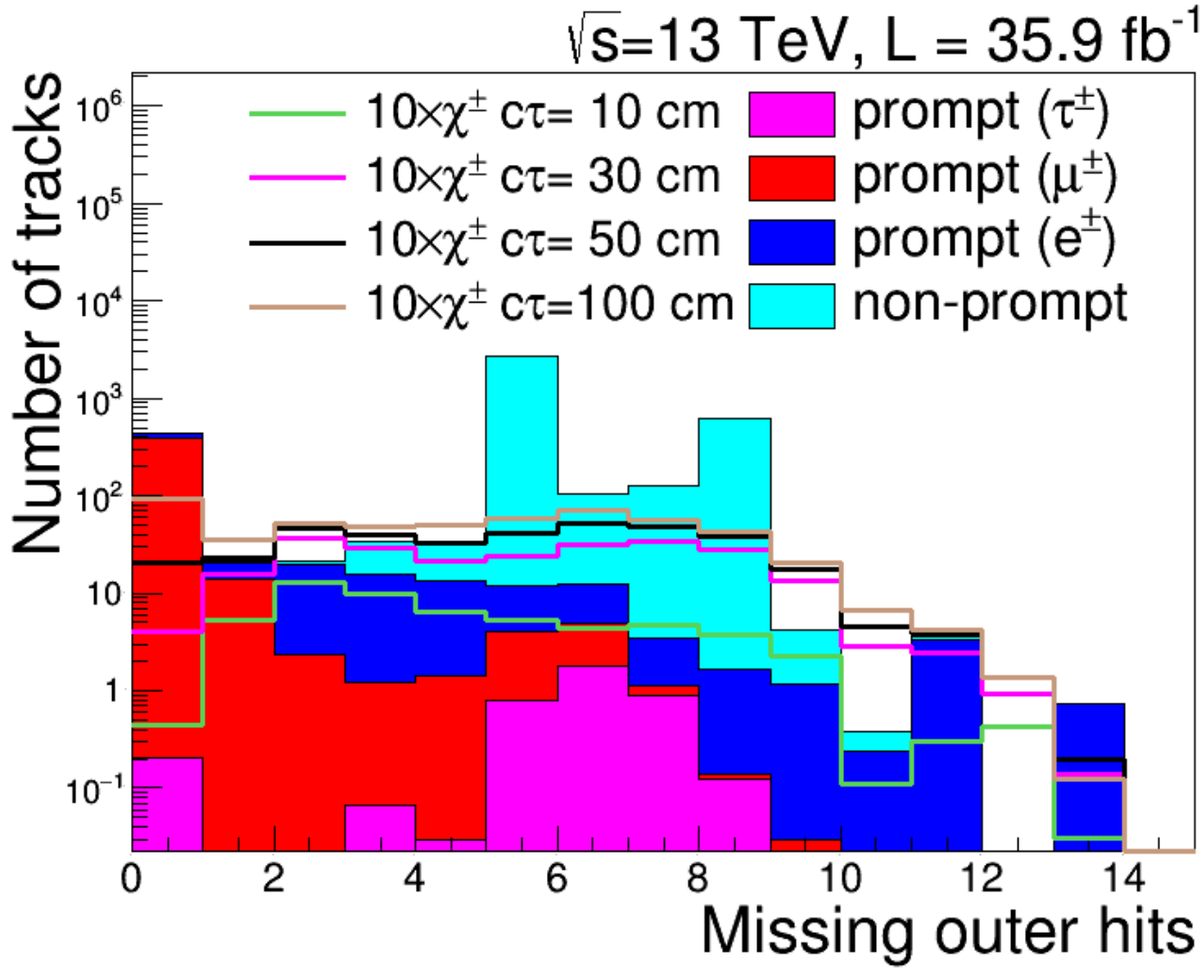




- Absolute (relative) isolation < 10 GeV (0.01); dR < 0.05

Energy deposition and missing hits

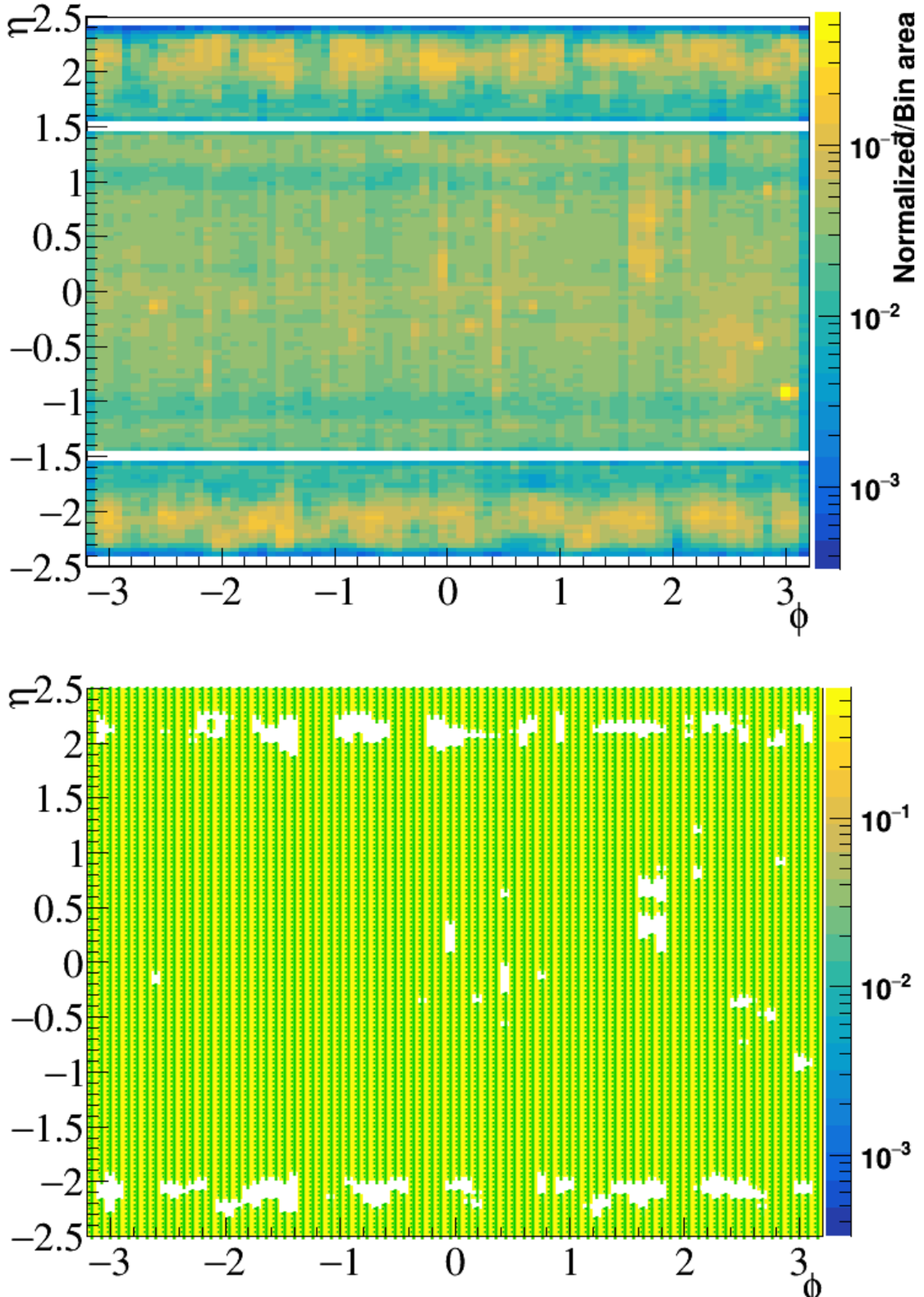




- Energy deposited in cone of dR = 0.5; < 10 GeV
- Missing outer hits > 1

Detector masks

- Distribution of disappearing tracks in eta-phi plane in data. (top)
- Distribution peaks at certain regions of detector with defects.
- Detector mask to veto the tracks pointing towards the region with defects; shown in white (bottom).
- Thus, the fiducial selection is added to the baseline track definition.



Kappa calculation

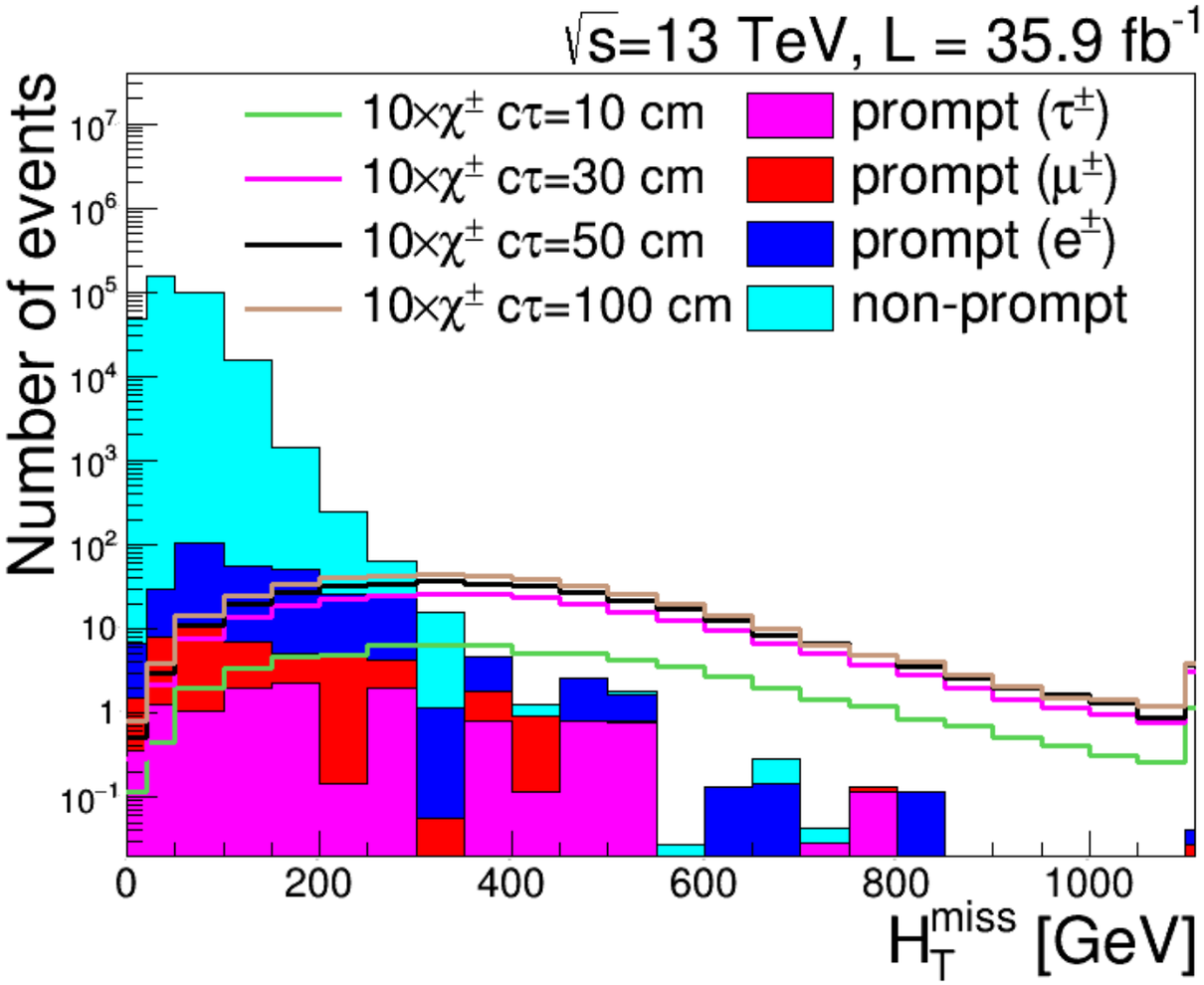
Tag is selected as:

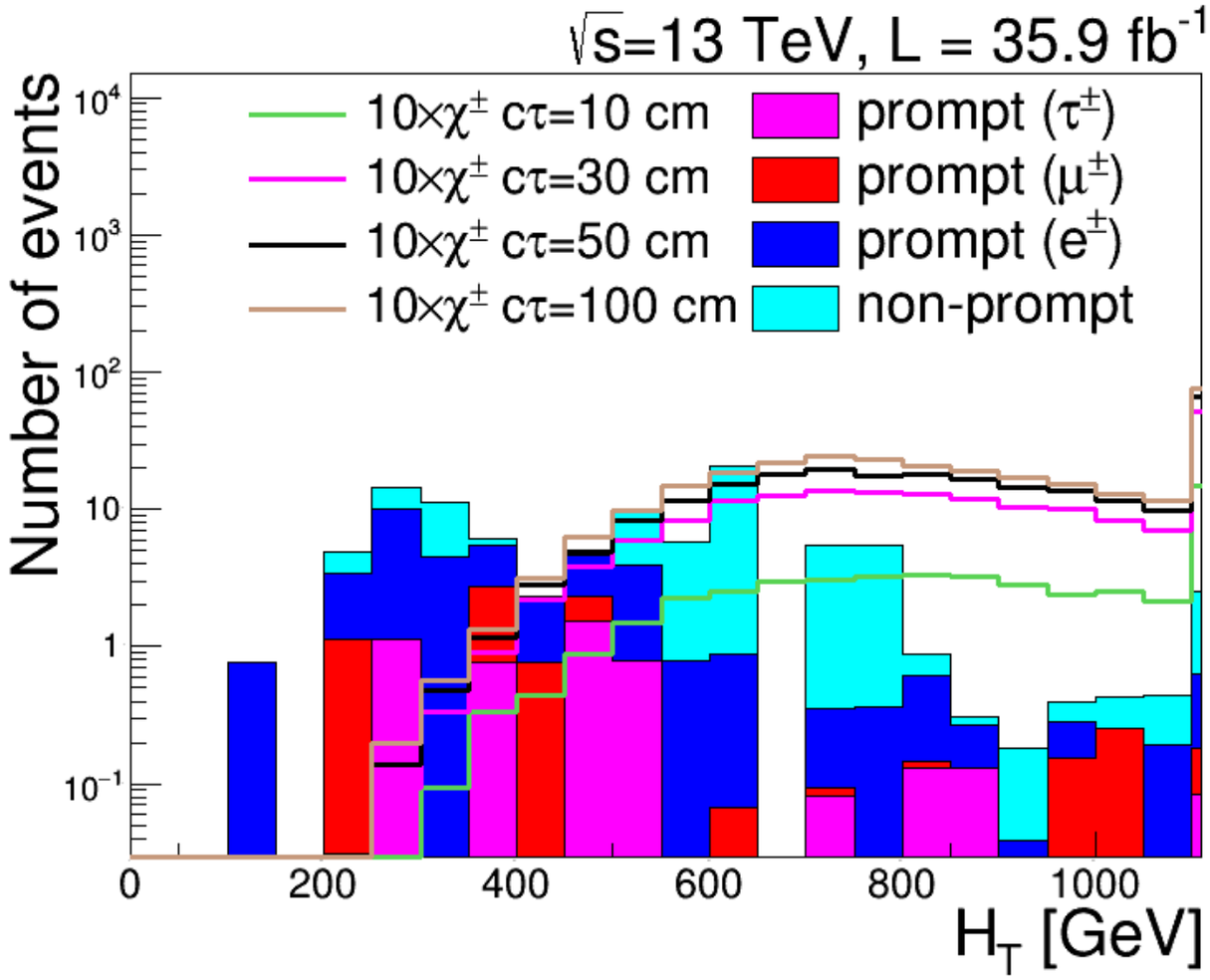
- $p_T > 30$ GeV and $0 < |\eta| < 2.4$
- pass tight lepton ID

Probe is selected as:

- $p_T > 30$ GeV
- $|\eta| < 1.442$ or $1.566 < |\eta| < 2.4$
- $(\mathrm{IM})_{\mathrm{tag+probe}} - \mathrm{M_Z} < 15$ GeV
- $\mathrm{e}^{\mathrm{tag}}_{\mathrm{charge}} + \mathrm{e}^{\mathrm{probe}}_{\mathrm{charge}} = 0$

Search variables





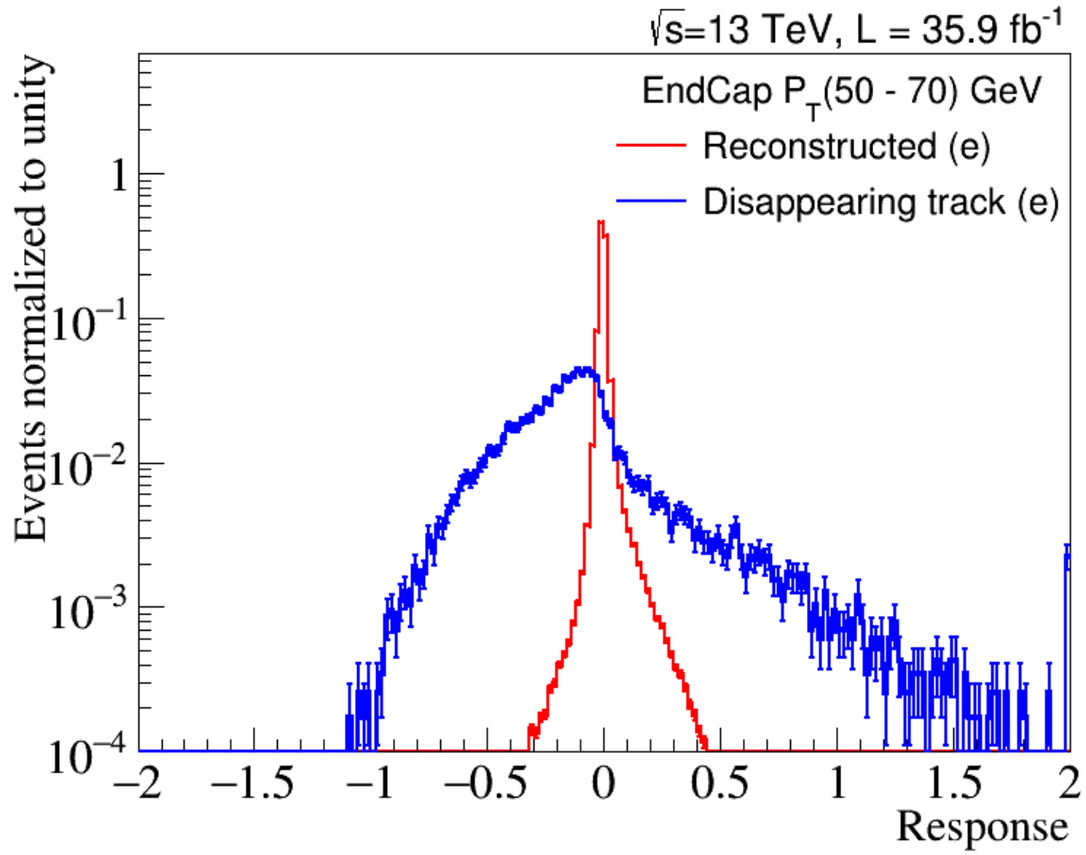
- $MHT > 250$ GeV, $MHT = -\sum \vec{p}_T^{jets}$
- $H_T > 250$ GeV, $H_T = \sum p_T^{jets}$

Probe lepton smearing in simulation

- Resolution of reconstructed leptons is different from disappearing tracks;

- Smearing templates are reconstructed in bins of Pt and eta. Using response defined as:

$$\text{response} = \log_{10}\left(\frac{p_T^{\text{reco}}}{p_T^{\text{true}}}\right)$$



- In simulation, the generator level Pt is considered as true Pt.