IDEA vs. CLD Detector Card Comparison – Effects of Reducing Tracker Hit Requirement

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Based on work by Magdalena Vande Voorde, Giulia Ripellino, Axel Gallén, Rebeca Gonzalez Suarez, link to recent talk

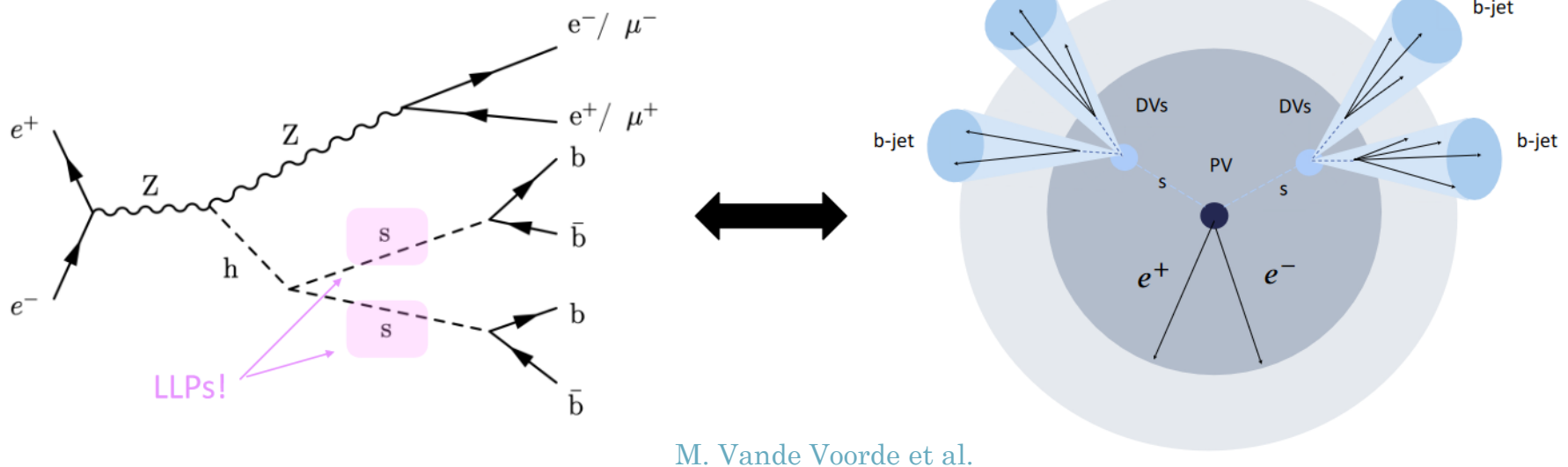
Recap from last talk

Signal Process

- Targeting **240 GeV, *Zh* production** stage w/ signal process:

$$e^+e^- \rightarrow Z\,h \text{ with } Z \rightarrow e^+e^- \text{ or } \mu^+\mu^- \text{ and } h \rightarrow ss \rightarrow b\bar{b}b\bar{b}$$

- This provides following experimental signatures:
  - **Reconstructed Z boson** from e^+e^- or $\mu^+\mu^-$ pairs
  - **Displaced vertices** from b pairs from long-lived scalar decay



M. Vande Voorde et al.

Signal Generation and Selection

- Generated new CLD samples with CLD-like Delphes Card (IDEA card w/ tracker geometry replaced by CLD tracker geometry), IDEA samples (from previous analysis) used Winter2023 IDEA Delphes card
  - Using MadGraph v3.5.3 (3.4.2 for IDEA samples) + Pythia8 + Delphes
  - 6 separate samples generated based on varied scalar mass, mixing angle

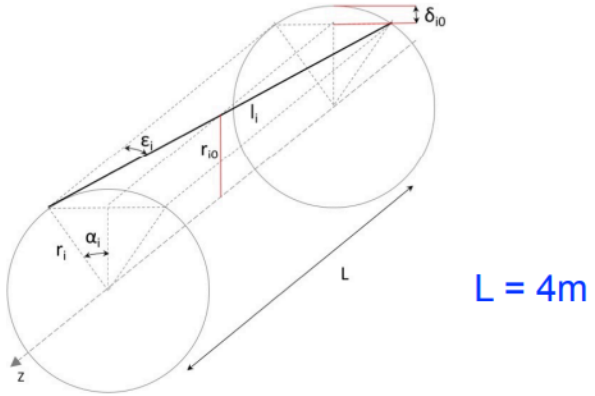
Mass of Scalar m_S [GeV]	Mixing angle $\sin\theta$	Mean proper lifetime $c\tau$ [mm]
20	1×10^{-5}	3.4
20	1×10^{-6}	341.7
20	1×10^{-7}	34167.0
60	1×10^{-5}	0.9
60	1×10^{-6}	87.7
60	1×10^{-7}	8769.1

- Event selection (from previous analysis):
  - Note: DV cut rejects all background events from WW, ZZ, ZH processes

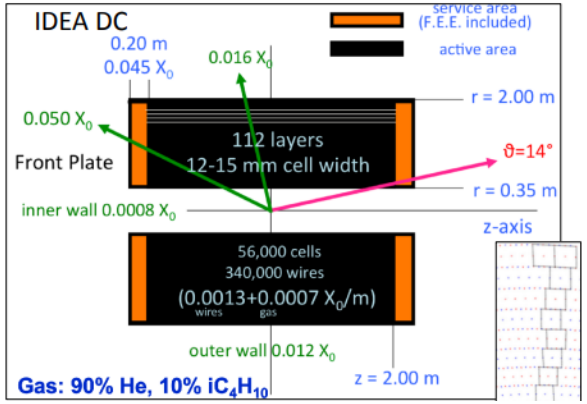
	WW	ZZ	ZH
Before selection	1.0	1.0	1.0
Pre-selection	0.131	0.026	0.059
$70 < m_{ll} < 110$ GeV	0.006	0.086	0.047
n_DVs ≥ 2	0.0	0.0	0.0

	Selection
Pre-selection	≥ 2 oppositely charged electrons or muons
Z boson tag	$70 < m_{ll} < 110$ GeV
Multiplicity of DVs	n_DVs ≥ 2

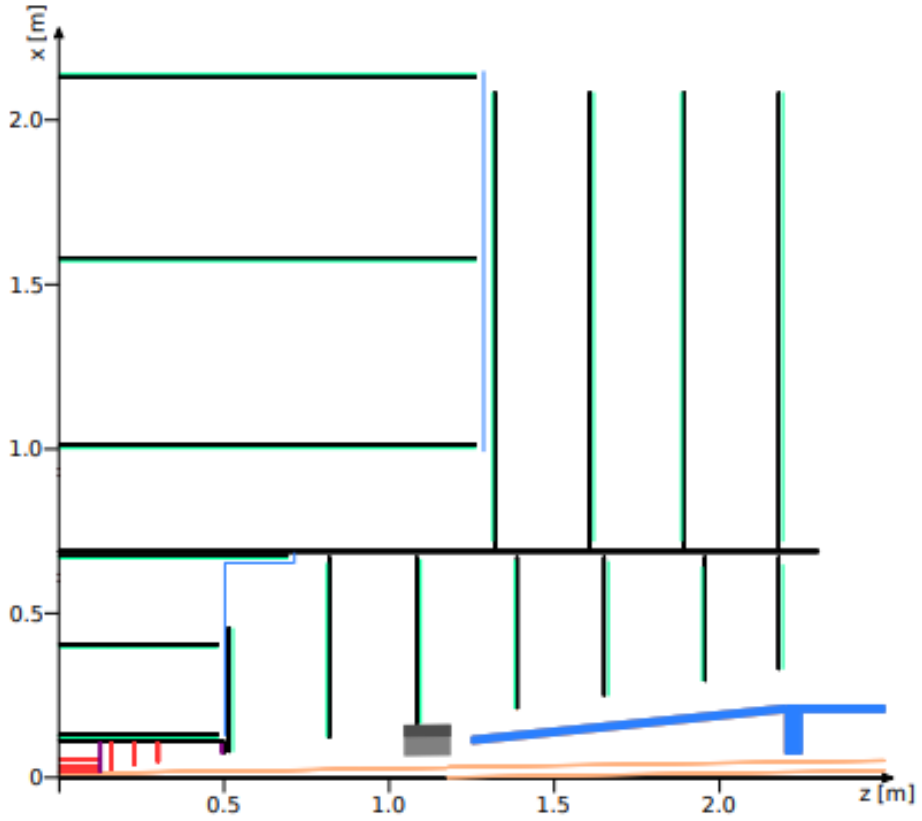
IDEA, CLD Tracking Differences



L = 4m



IDEA Drift Tube Geometry



CLD Tracker Geometry

Preliminary IDEA vs. CLD Results

- Applying cuts yielded following efficiencies for IDEA and CLD samples:

IDEA:

(from previous analysis by Magda Vande Voorde, et al.)

Signal Cut flow efficiencies:

	20 GeV, 1e-5	20 GeV, 1e-6	20 GeV, 1e-7
Before Selection	1.0	1.0	1.0
Pre-selection	0.957	0.950	0.949
$70 < m_{ll} < 110$ GeV	0.888	0.888	0.900
$N_{DVs} \geq 2$	0.091	0.672	0.014
	60 GeV, 1e-5	60 GeV, 1e-6	60 GeV, 1e-7
Before Selection	1.0	1.0	1.0
Pre-selection	0.957	0.957	0.951
$70 < m_{ll} < 110$ GeV	0.894	0.895	0.896
$N_{DVs} \geq 2$	0.0002	0.672	0.398

Events selected:

m_s, sin θ	n_DVs ≥ 2
20 GeV, 1e-5	5.0 ± 0.166
20 GeV, 1e-6	37.1 ± 0.453
20 GeV, 1e-7	0.8 ± 0.067
60 GeV, 1e-5	0.0033 ± 0.0023
60 GeV, 1e-6	10.96 ± 0.167
60 GeV, 1e-7	6.49 ± 0.103

Sensitive (> 3 events)

Sensitive, but significant decline

Not sensitive (< 3 events)

CLD:

Signal Cut flow efficiencies:

	20 GeV, 1e-5	20 GeV, 1e-6	20 GeV, 1e-7
Before Selection	1.0	1.0	1.0
Pre-selection	0.955	0.952	0.952
$70 < m_{ll} < 110$ GeV	0.891	0.896	0.903
$N_{DVs} \geq 2$	0.092	0.109	0.002
	60 GeV, 1e-5	60 GeV, 1e-6	60 GeV, 1e-7
Before Selection	1.0	1.0	1.0
Pre-selection	0.958	0.958	0.952
$70 < m_{ll} < 110$ GeV	0.895	0.897	0.899
$N_{DVs} \geq 2$	0.0002	0.654	0.0502

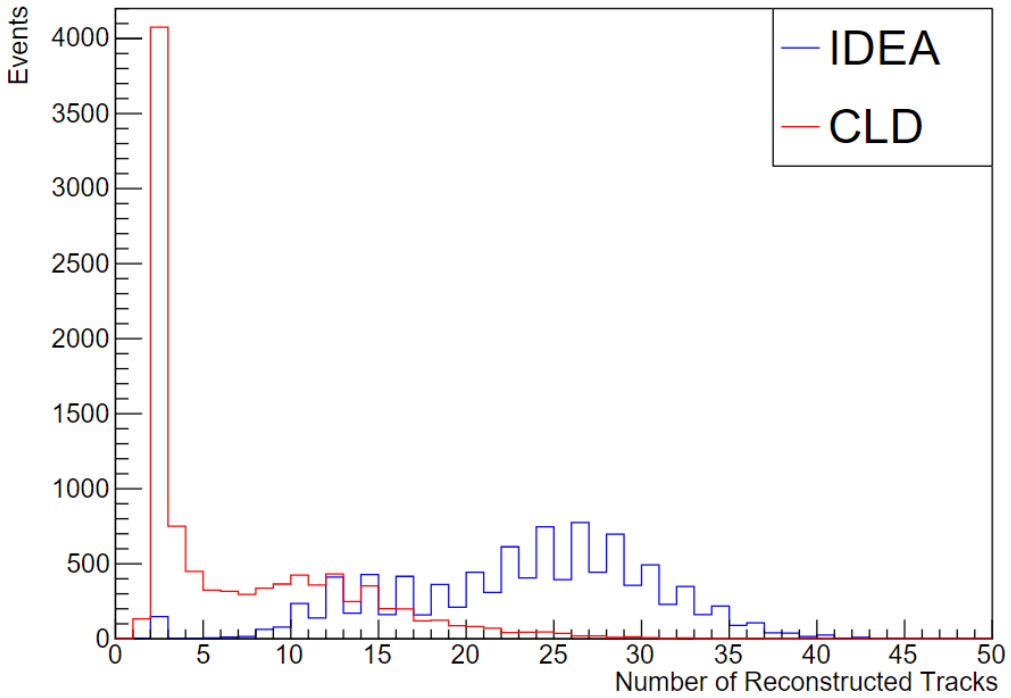
Events selected:

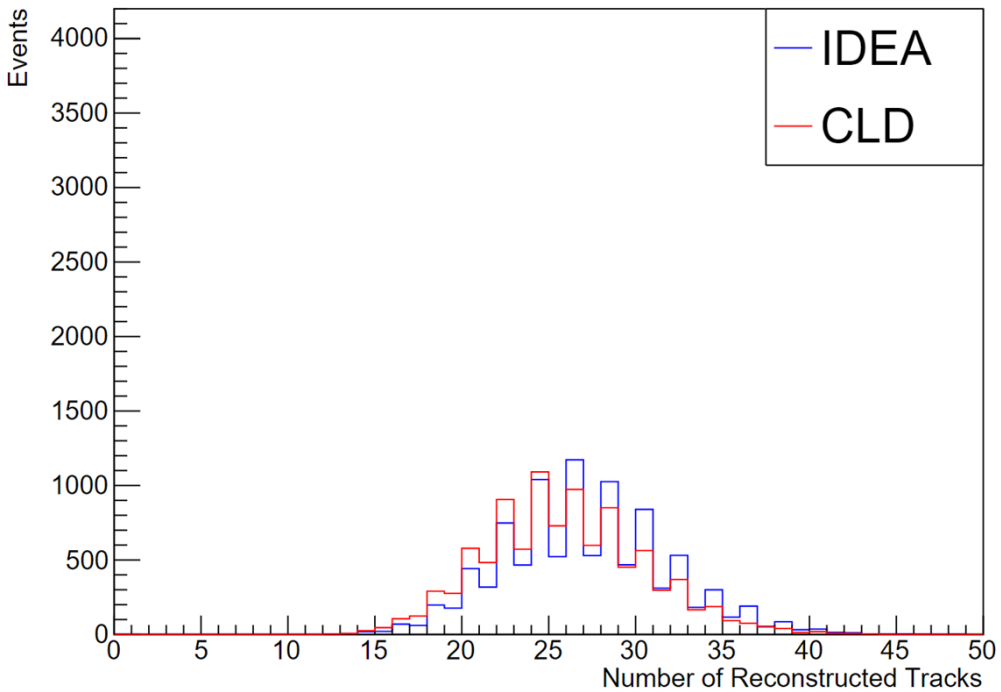
Note: given 1.46×10^6 Zh events

$m_s, sin\theta$	$n_{\mathrm{DVs}} \geq 2$	Mean proper lifetime $c\tau$ [mm]
20 GeV, 1e-5	5.10 ± 0.167	3.4
20 GeV, 1e-6	6.02 ± 0.182	341.7
20 GeV, 1e-7	0.11 ± 0.025	34167.0
60 GeV, 1e-5	0.003 ± 0.0023	0.9
60 GeV, 1e-6	10.67 ± 0.132	87.7
60 GeV, 1e-7	0.819 ± 0.036	8769.1

Tracks per Event: IDEA vs. CLD

Longer decay length CLD sample saw reduction in # reco. tracks, shorter decay length CLD sample saw similar # reco. tracks



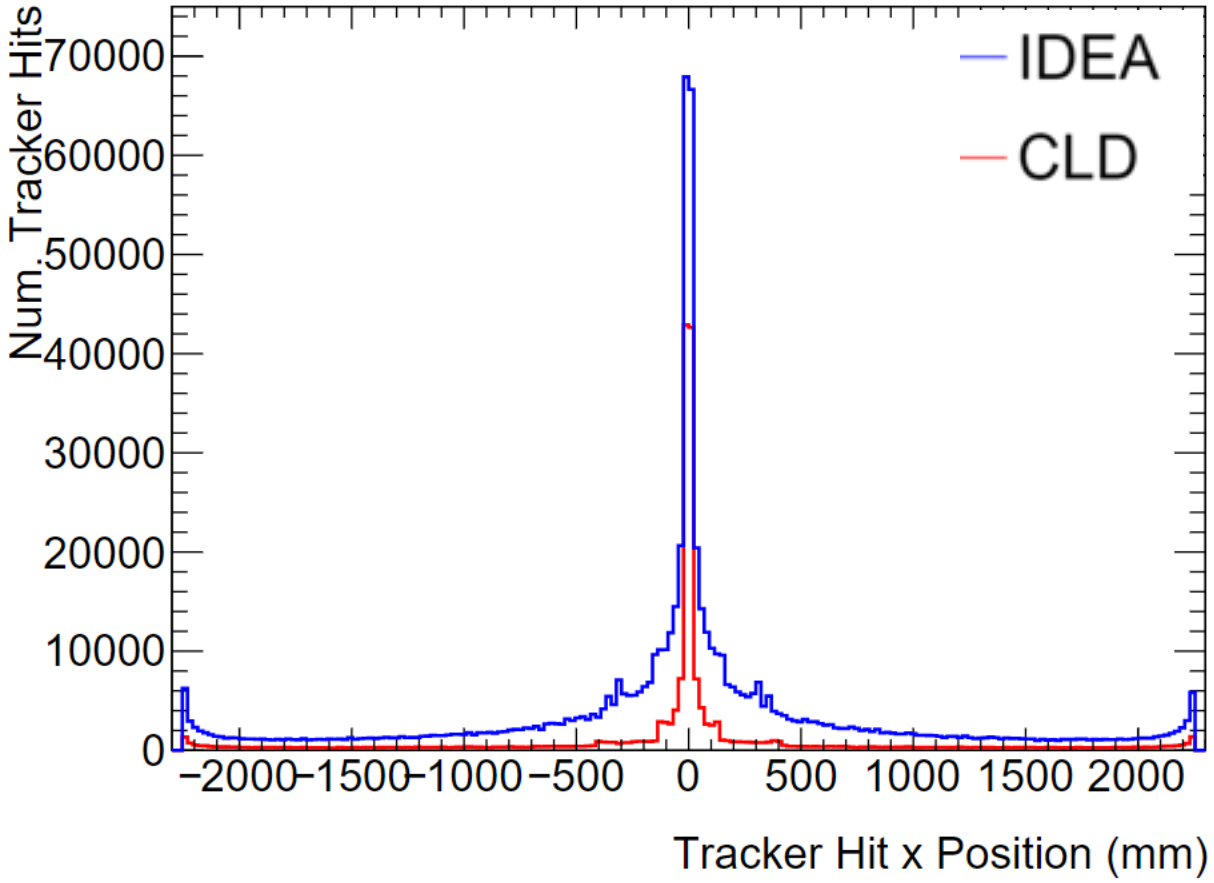


$m_s = 20\ GeV, \sin(\theta) = 1e-6, c\tau = 341.7\ mm$ sample saw significant decline in sensitivity

$m_s = 20\ GeV, \sin(\theta) = 1e-5, c\tau = 3.4\ mm$ sample saw similar sensitivity

Total Tracker Hits:

$m_s = 20\,GeV, \sin(\theta) = 1e-6, c\tau = 341.7\,mm$ sample (10,000 events)



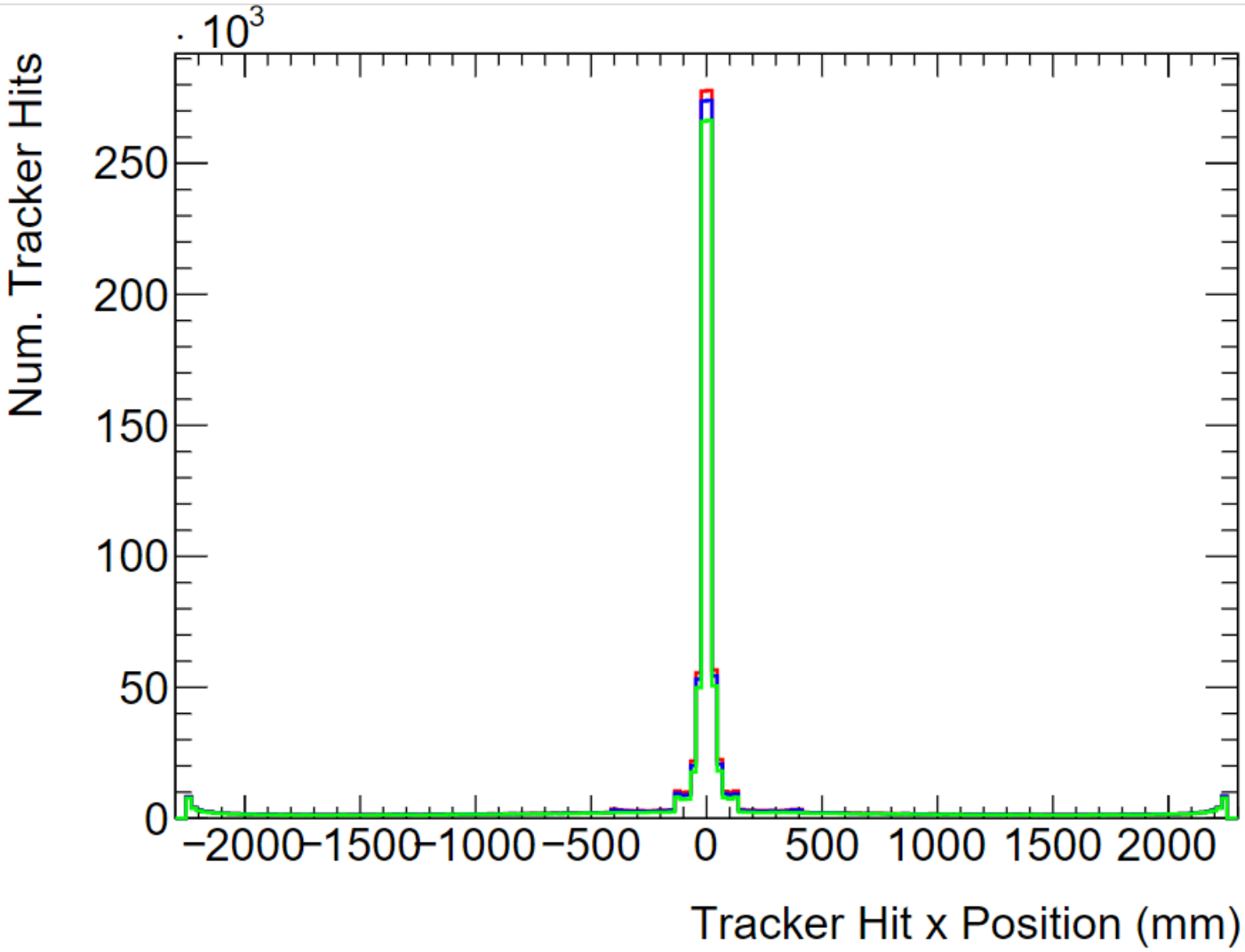
Tracker Hit Requirement

- CLD detector card contains a minimum number of hits to accept a track

```
## minimum number of hits to accept a track
set NMinHits 6
```

- Due to CLD geometry, this high requirement means many displaced tracks with vertex after first layer will not be accepted
- Want to see how changing this to 5 or 4 affects tracking performance → DV reconstruction → signal sensitivity
- Regenerated (using same unweighted events) CLD samples for each signal point using min. number of hits = 4, 5
  - Will show results for two most interesting signal points: $c\tau = 87.7\ mm, 341.7\ mm$

Trackers Hits: $c\tau = 87.7\ mm\ (m_s = 60\ GeV, \sin(\theta) = 10^{-6})$



4 min. hits to accept track

1.13 × 10^6 Total hits

5 min. hits to accept track

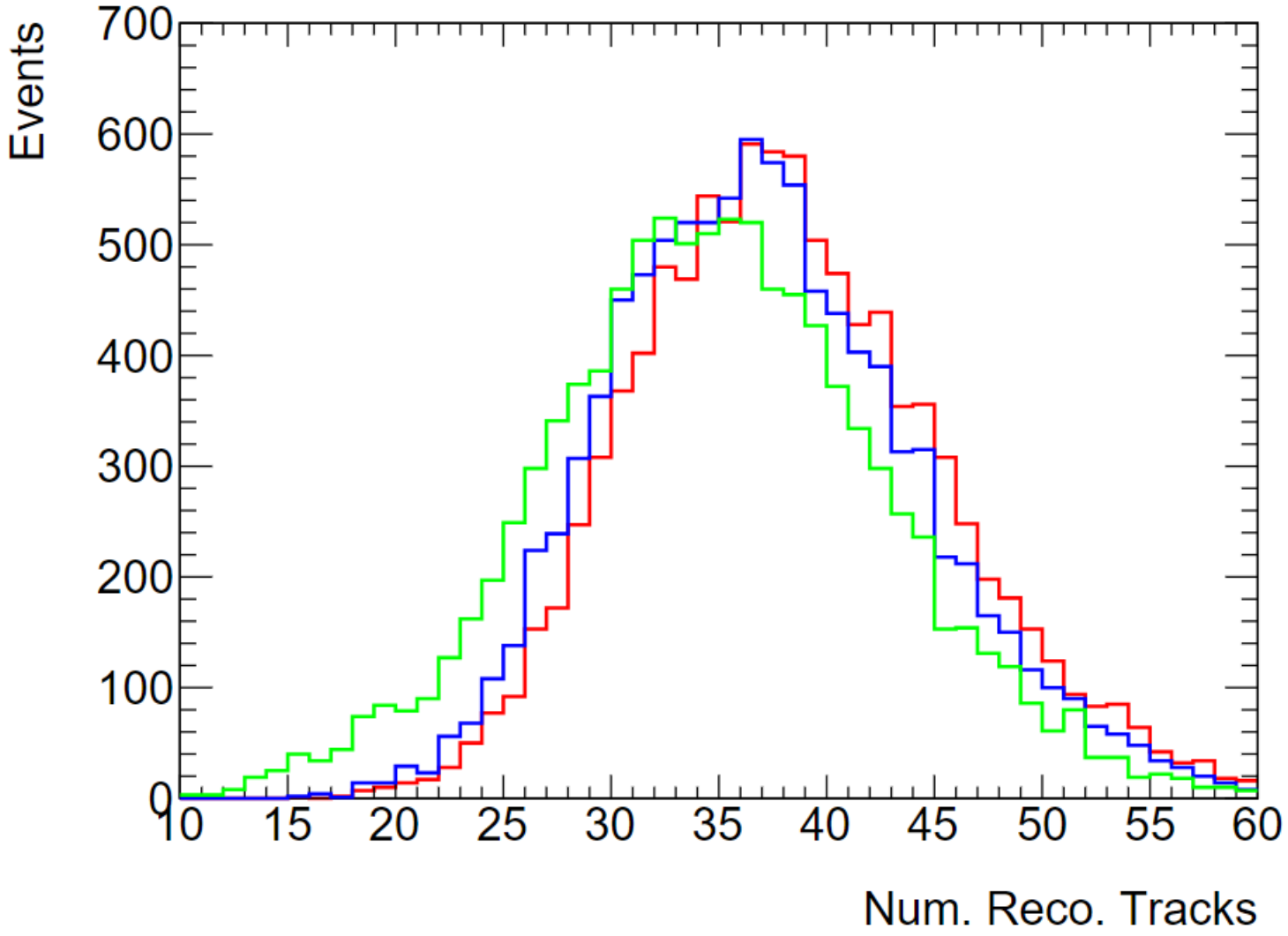
1.10 × 10^6 Total hits

6 min. hits to accept track

1.03 × 10^6 Total hits

Note: using 10,000 total events, 23 mm bins

Tracks per Event: $c\tau = 87.7\,mm$



4 min. hits to accept track

Mean tracks per event: 37.8

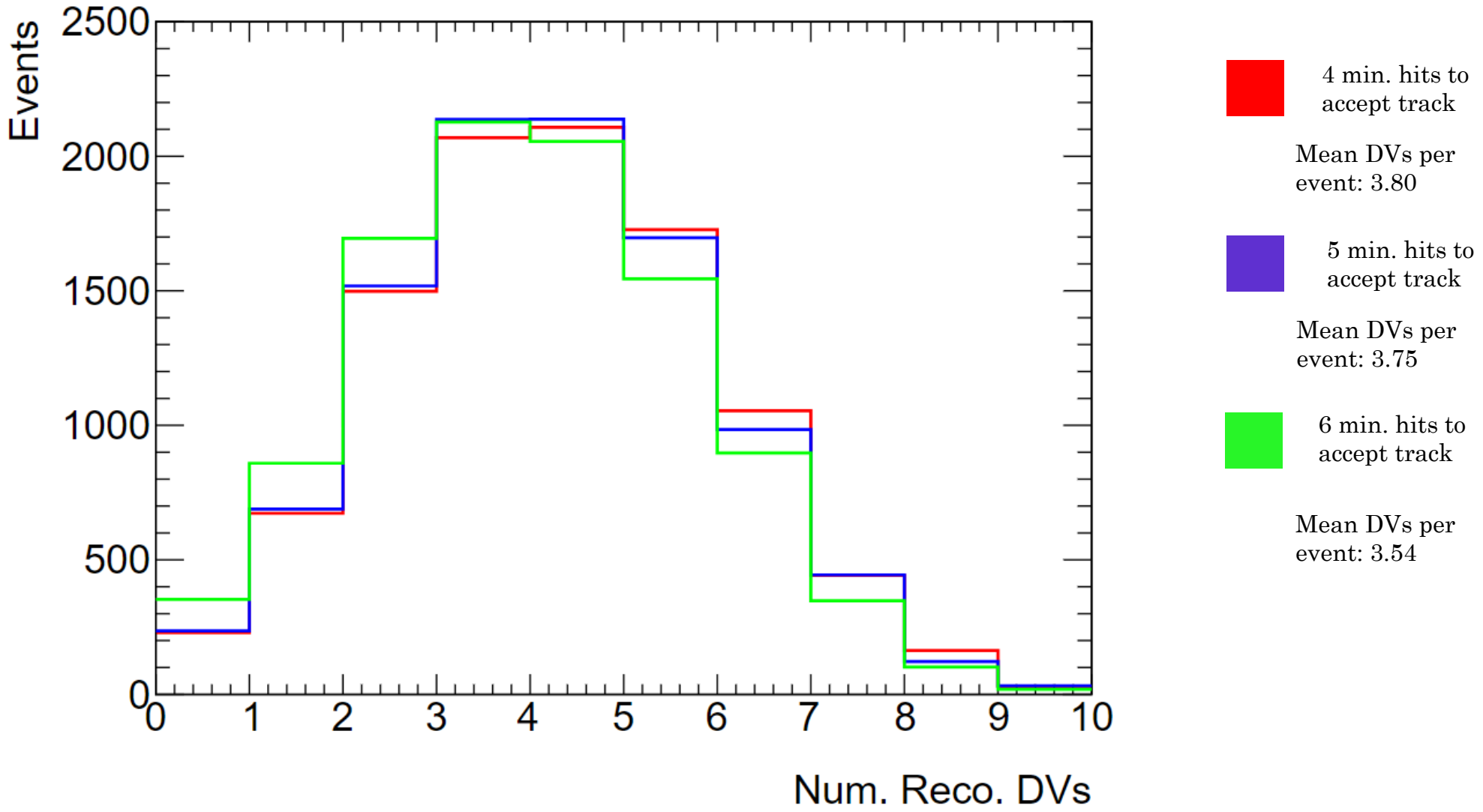
5 min. hits to accept track

Mean tracks per event: 36.6

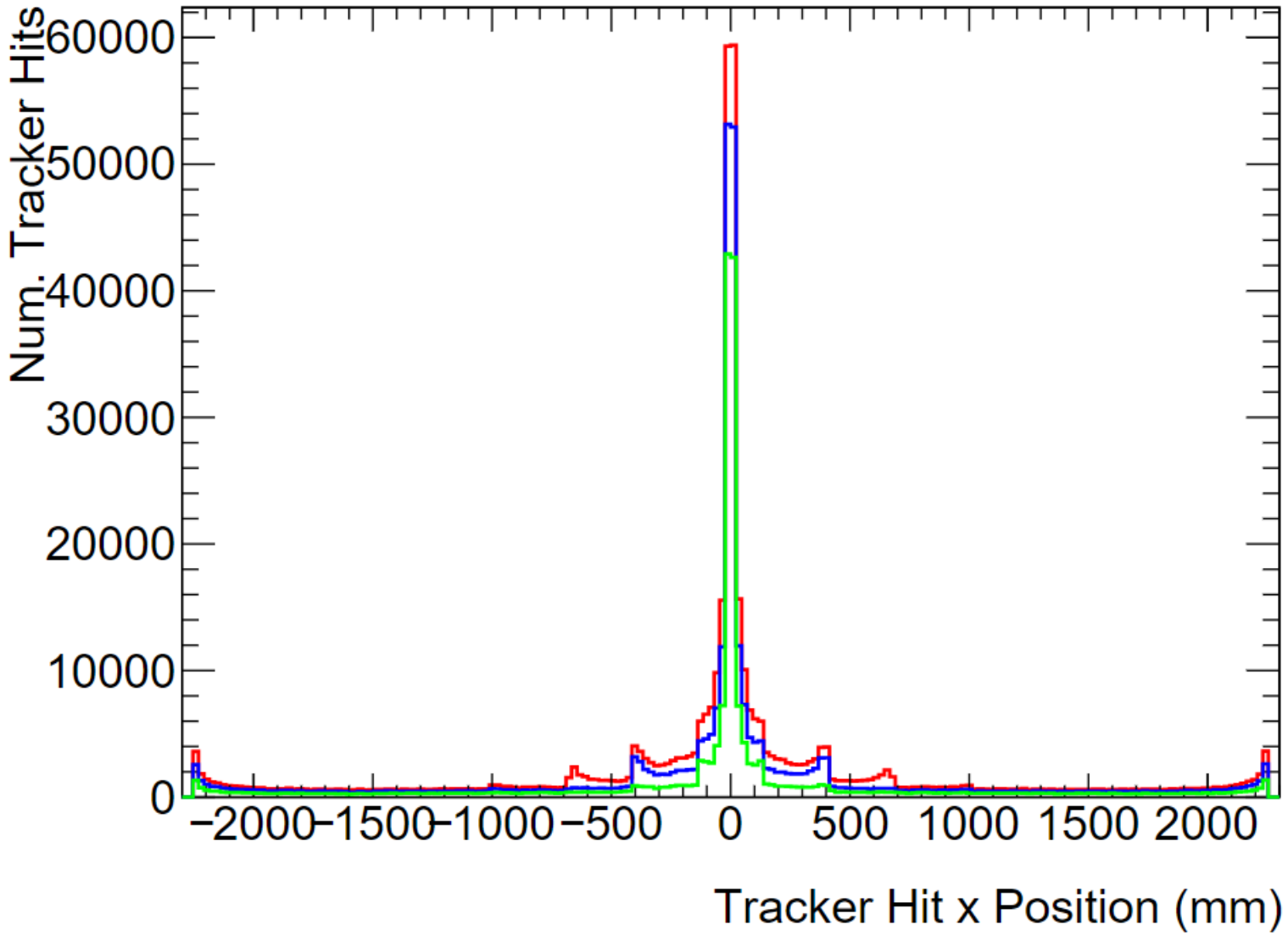
6 min. hits to accept track

Mean tracks per event: 34.4

DVs per Event: $c\tau = 87.7\ mm$



Trackers Hits: $c\tau = 341.7\,mm\ (m_s = 20\,GeV, \sin(\theta) = 10^{-6})$



4 min. hits to accept track

4.23×10^5 Total hits

5 min. hits to accept track

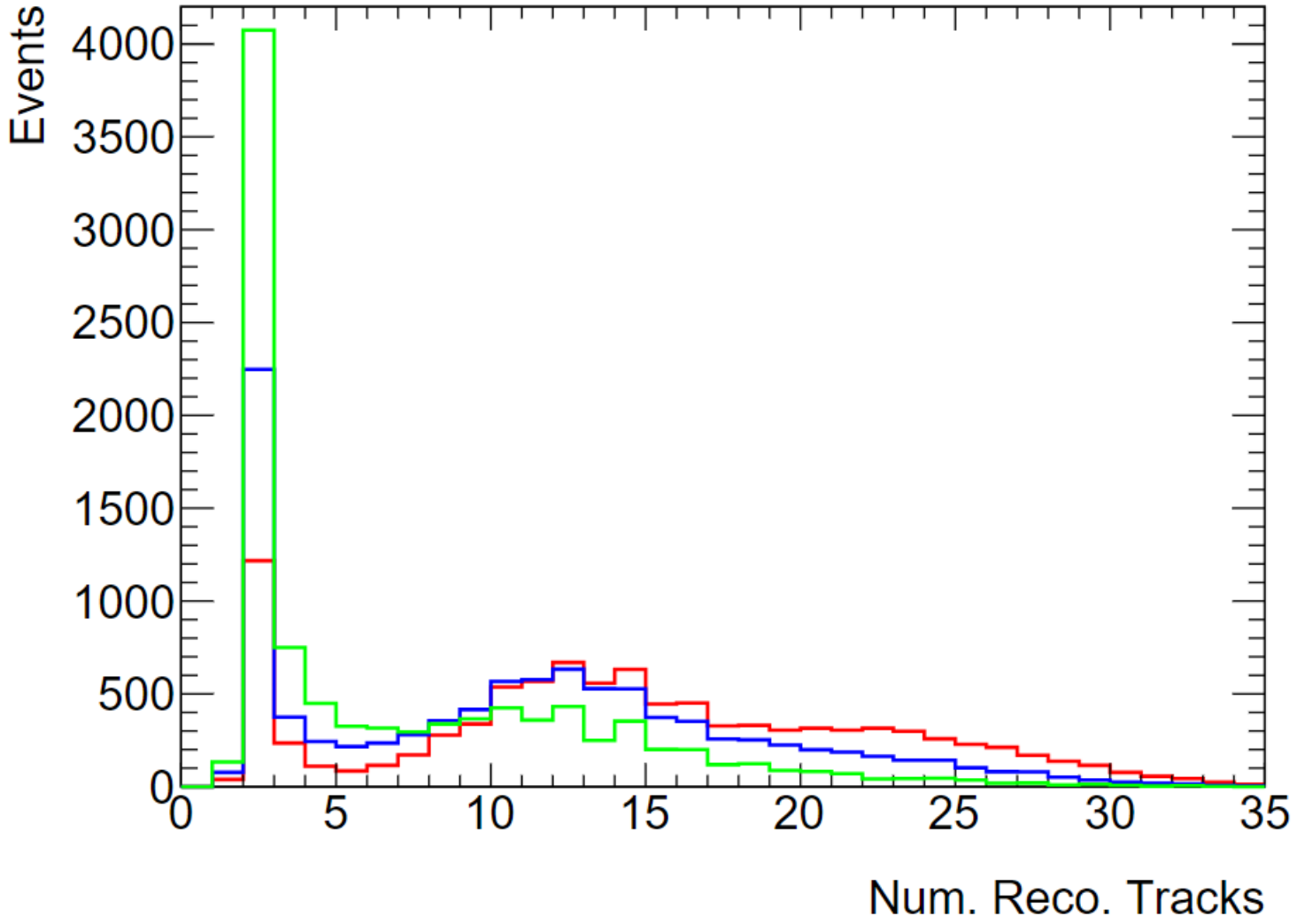
3.18×10^5 Total hits

6 min. hits to accept track

2.01×10^5 Total hits

Note: using 10,000 total events, 23 mm bins

Tracks per Event: $c\tau = 341.7\ mm$



4 min. hits to accept track

Mean tracks per event: 14.1

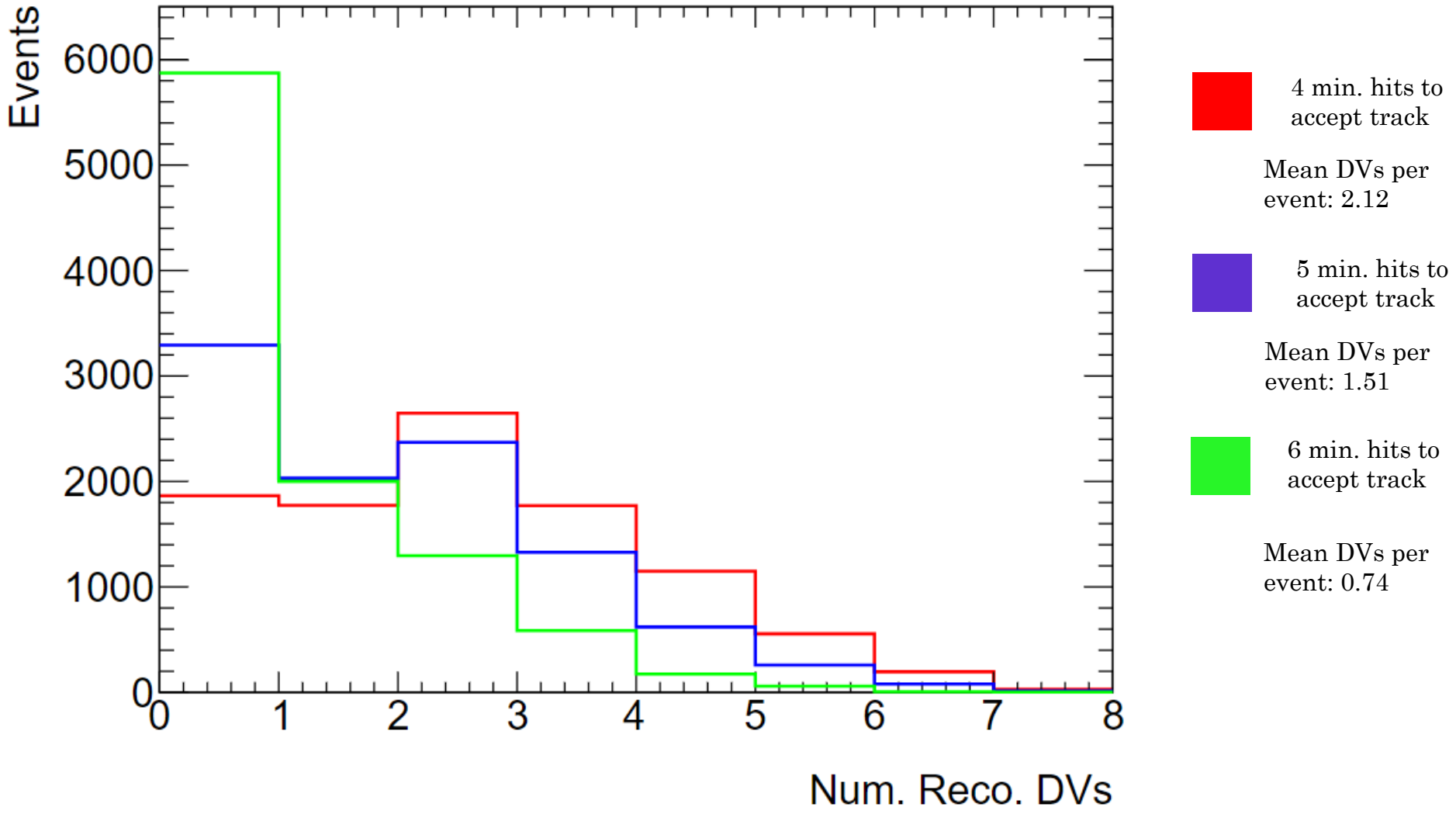
5 min. hits to accept track

Mean tracks per event: 10.6

6 min. hits to accept track

Mean tracks per event: 6.7

DVs per Event: $c\tau = 341.7\ mm$



4 min. hits to accept track

Mean DVs per event: 2.12

5 min. hits to accept track

Mean DVs per event: 1.51

6 min. hits to accept track

Mean DVs per event: 0.74

Signal Sensitivities

Final Cut Efficiencies:

$N_{DVs} \geq 2$ Efficiencies	20 GeV, 1e-5	20 GeV, 1e-6	20 GeV, 1e-7	60 GeV, 1e-5	60 GeV, 1e-6	60 GeV, 1e-7
IDEA	0.091	0.672	0.014	0.0002	0.672	0.398
CLD (min. hits = 6)	0.092	0.109	0.002	0.0002	0.654	0.0502
CLD (min. hits = 5)	0.094	0.293	0.0042	0.0003	0.684	0.123
CLD (min. hits = 4)	0.096	0.441	0.0056	0.0002	0.687	0.183

Final Events Selected:

$N_{DVs} \geq 2$ Events	20 GeV, 1e-5	20 GeV, 1e-6	20 GeV, 1e-7	60 GeV, 1e-5	60 GeV, 1e-6	60 GeV, 1e-7
IDEA	5.02	37.09	0.77	0.003	10.97	6.50
CLD (min. hits = 6)	5.08	6.02	0.11	0.003	10.67	0.82
CLD (min. hits = 5)	5.19	16.17	0.23	0.005	11.16	2.01
CLD (min. hits = 4)	5.30	24.34	0.31	0.003	11.21	2.99

Sensitive (> 3 events)

Not sensitive (< 3 events)

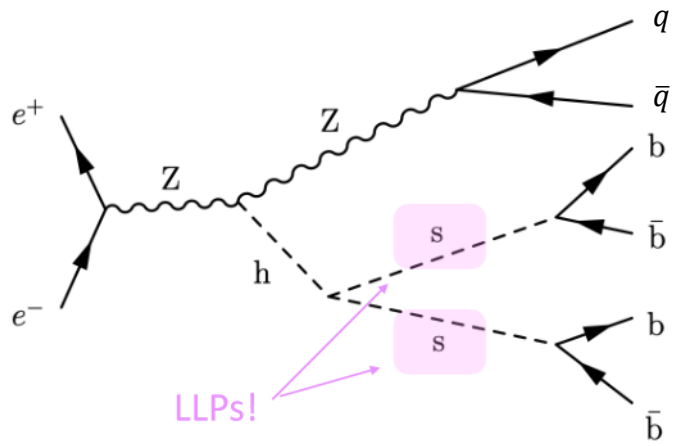
Summary & Future Work

- Track and DV reconstruction significantly improved for min. hits = 4, 5 samples, especially for longer mean decay time samples
- Significant improvement in signal yield for all samples, relative to original CLD samples
  - Expected events even slightly exceeding IDEA for 2 samples
  - Sensitivity not regained for $c\tau = 8770\ mm$ sample that lost with original CLD results (though just on border at 2.99 events for min. hits = 4)
  - Expected events increased by 4 times relative to original CLD results for $c\tau = 342\ mm$, min. hits = 4
- What further studies / track parameters do we want to do to investigate this issue with DV reconstruction in CLD?

Incorporating Hadronic Decays of Z to Signal Update

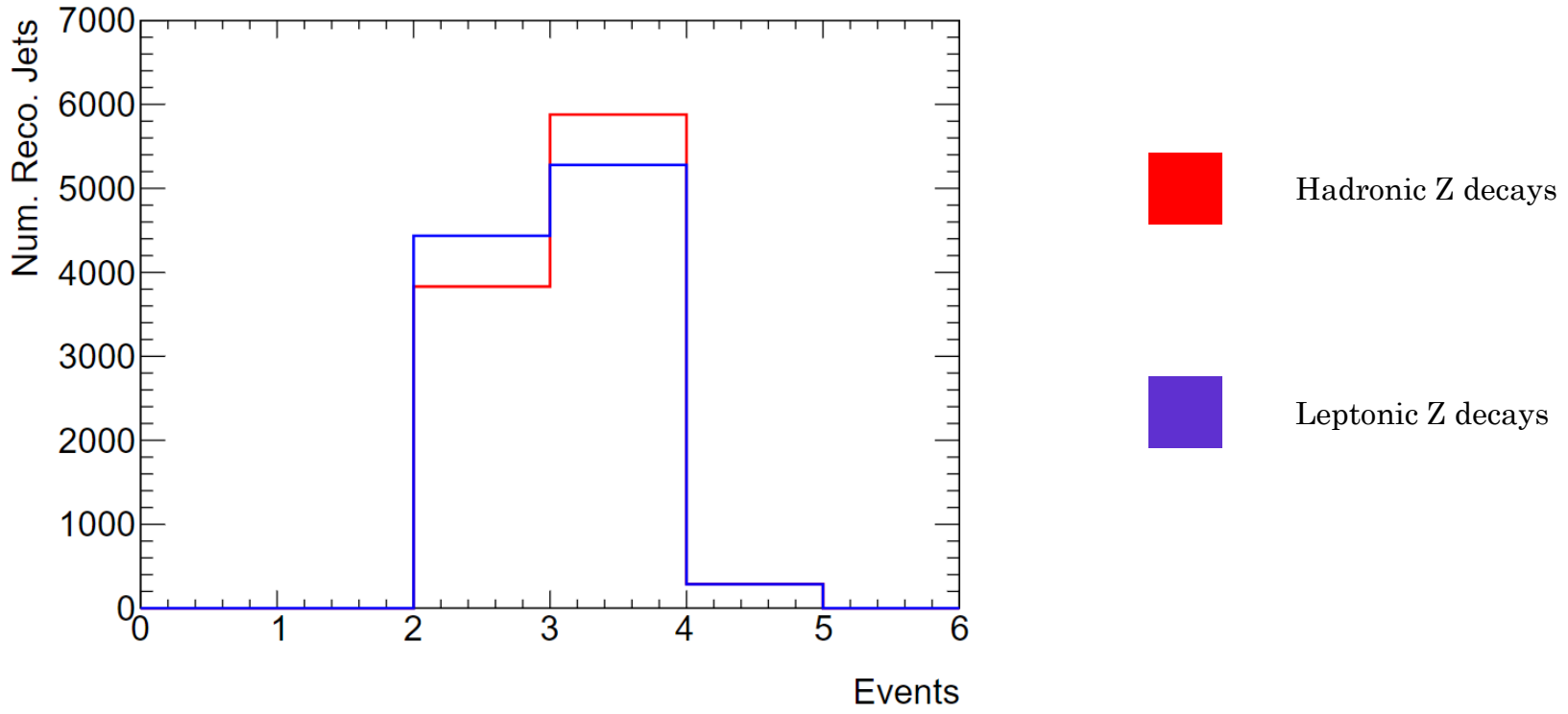
Sample Generation and Reconstruction

- Regenerated same signal processes, but with $Z \rightarrow q\bar{q}, q = u, d, c, s, b$ with MadGraph v3.5.4, Winter2023 IDEA card
- Will use Winter2023 backgrounds:
  - WW, ZZ inclusive decays
  - ZH | $Z \rightarrow q\bar{q}$, $H \rightarrow WW, b\bar{b}$
- Added jet parameters to Reco. Analysis Script:
  - Jet energy, momentum, θ, φ, η, charge
  - Sum of jet energies (motivated by fully hadronic ZH analysis cuts)
  - Number of reco. jets
    - This parameter seems inconsistent with what we expect (and hence so does jet energy, etc.)



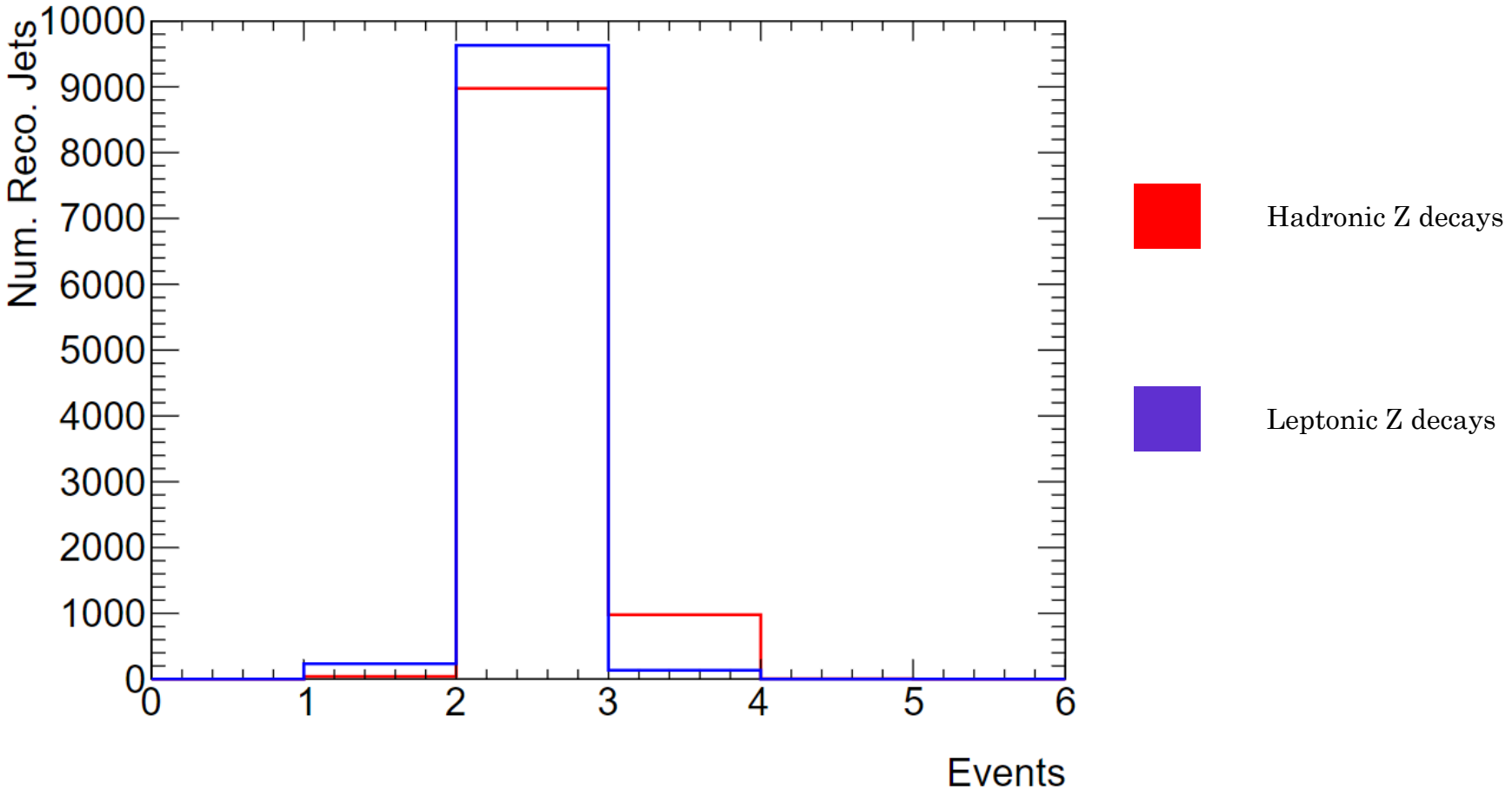
Number of Jets Discrepancies

- For hadronic decays expect 6 jets, for leptonic decays expect 4 (if both scalar particles decay within detector and have 100% reco. efficiency)



$c\tau = 3.4\,mm, m_s = 20\,GeV, \sin(\theta) = 10^{-5}$ sample

$c\tau = 34000\,mm, m_s = 20\,GeV, \sin(\theta) = 10^{-7}$ Sample



Note: looking at # reco. electrons, muons supports Z is indeed decaying leptonically and hadronically respectively

Delphes Jet Algorithm

- Seems that each electron, muon is being reconstructed as a jet, and 4 b's are being reconstructed in total as only 1 jet
- Winter 2023 IDEA card used uses exclusive Durham-k_t algorithm in n jets = 2 mode
- Does anyone know what may be going on here or whom I could ask about this?
  - Need to fix these inconsistencies before developing a cut-flow

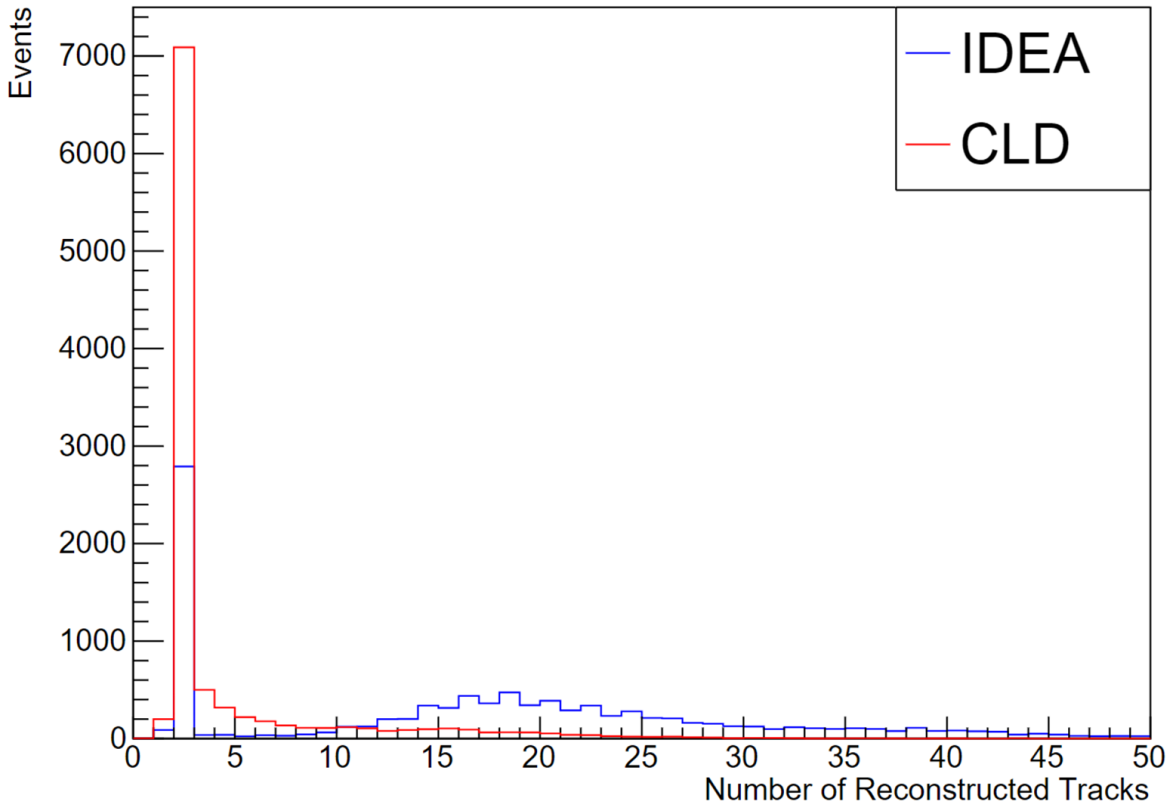
```
#################################
# Jet finder Durham exclusive
#################################

module FastJetFinder FastJetFinderDurhamN2 {
#  set InputArray Calorimeter/towers
  set InputArray EFlowMerger/eflow

  set OutputArray jets

  # algorithm: 11 ee-durham kT algorithm
  # ref: https://indico.cern.ch/event/1173562/cont
  # to run exclusive njet mode set NJets to int
  # to run exclusive dcut mode set DCut to float
  # if DCut > 0 will run in dcut mode

  set JetAlgorithm 11
  set ExclusiveClustering true
  set NJets 2
  # set DCut 10.0

}
```

From IDEA card

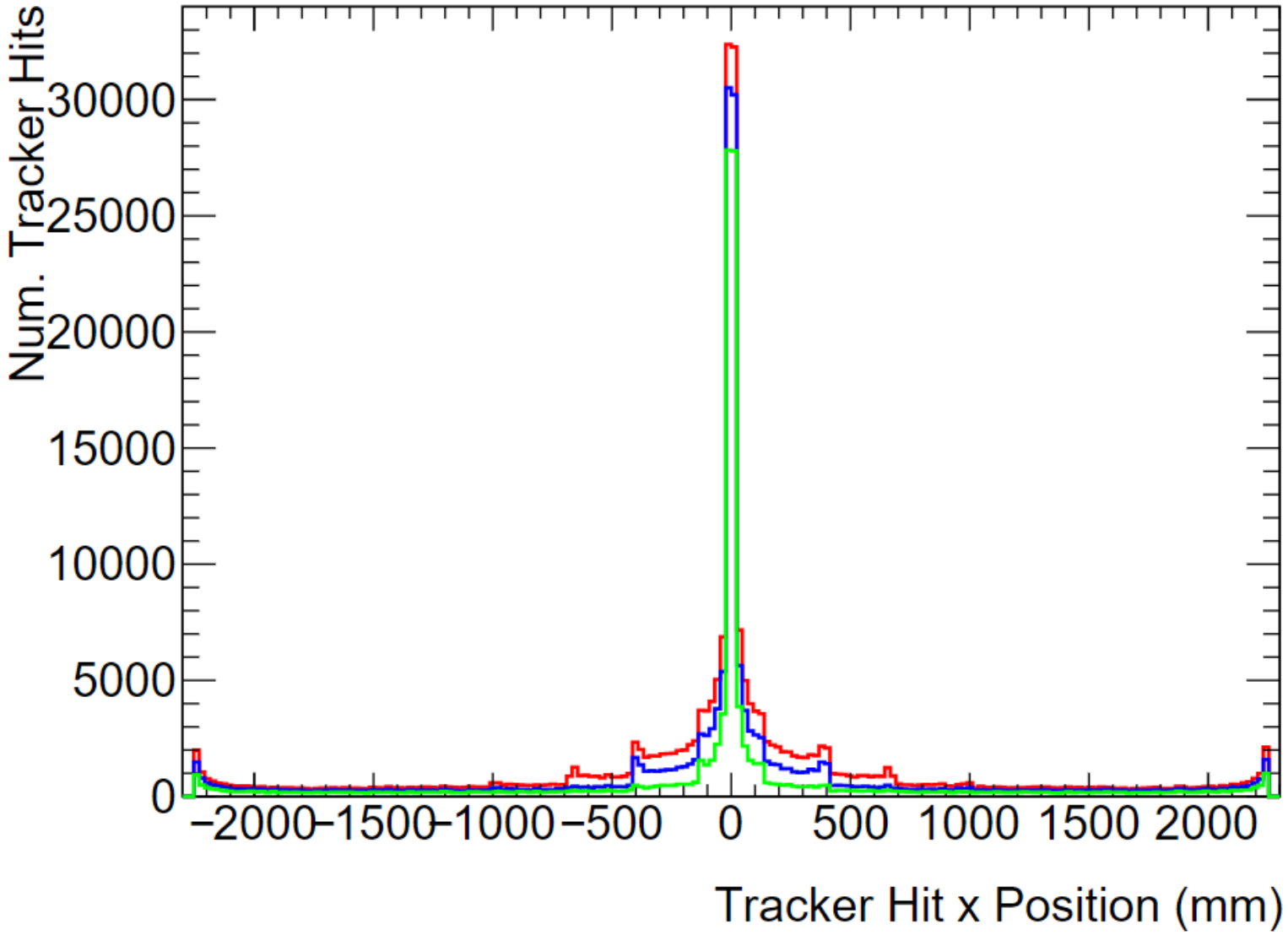
Backup

Tracking Performance: IDEA vs. CLD

- $m_s = 60\ GeV, \sin(\theta) = 1e-7, c\tau = 8769.1\ mm$ sample saw significant decline in sensitivity
- Supports evidence for poor CLD tracking performance with longer decay lengths



Trackers Hits: $c\tau = 8769\,mm\,(m_s = 60\,GeV, \sin(\theta) = 10^{-7})$



4 min. hits to accept track

2.44×10^5 Total hits

5 min. hits to accept track

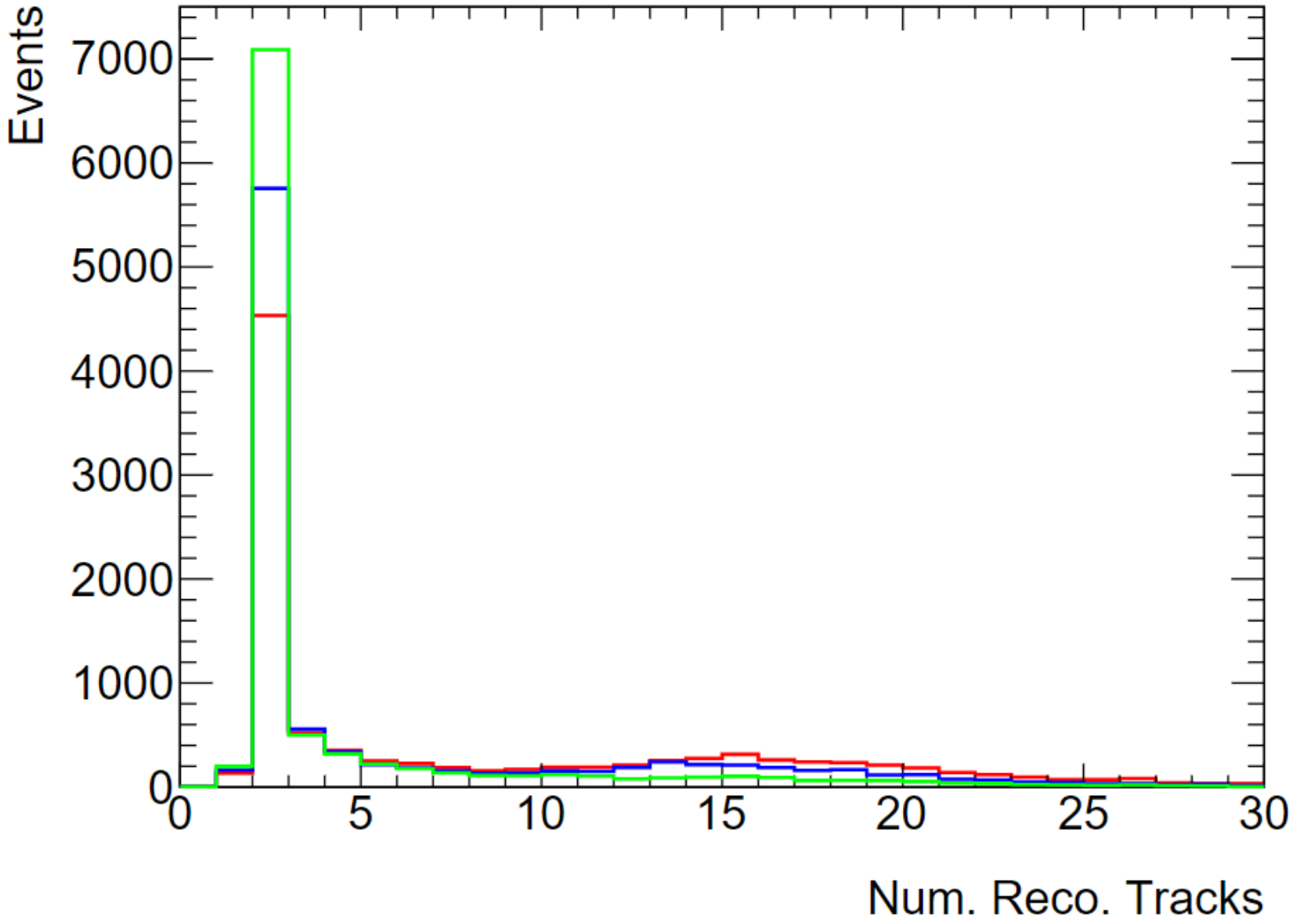
1.80×10^5 Total hits

6 min. hits to accept track

1.22×10^5 Total hits

Note: using 10,000 total events, 23 mm bins

Tracks per Event: $c\tau = 8769\ mm$



4 min. hits to accept track

Mean tracks per event: 8.1

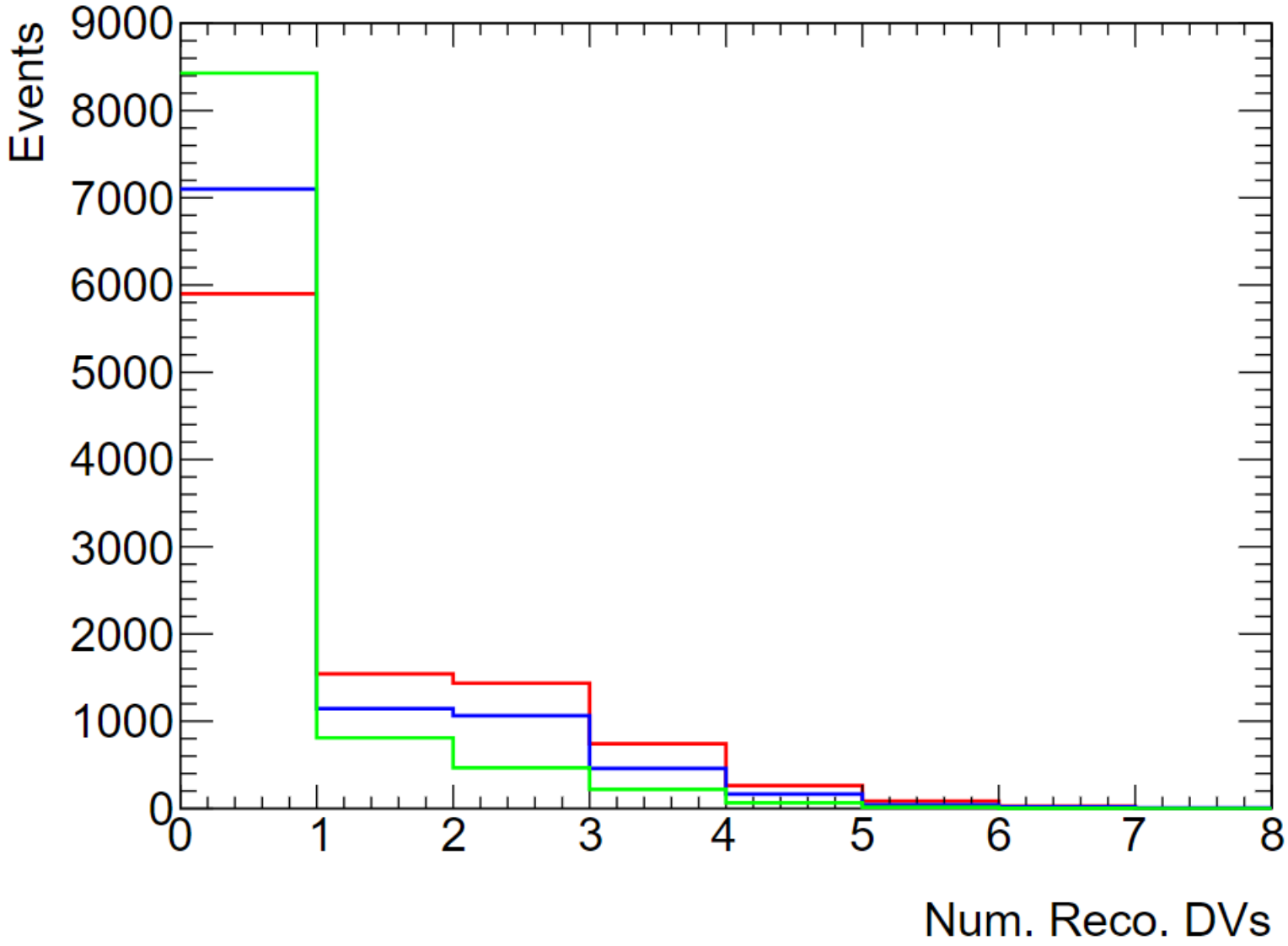
5 min. hits to accept track

Mean tracks per event: 6.0

6 min. hits to accept track

Mean tracks per event: 4.1

DVs per Event: $c\tau = 8769\ mm$



4 min. hits to accept track

Mean DVs per event: 0.83

5 min. hits to accept track

Mean DVs per event: 0.57

6 min. hits to accept track

Mean DVs per event: 0.27

Sensitive (> 3 events)

Not sensitive (< 3 events)

Signal Sensitivities

IDEA:

	20 GeV, 1e-5	20 GeV, 1e-6	20 GeV, 1e-7
Before Selection	1.0	1.0	1.0
Pre-selection	0.957	0.950	0.949
$70 < m_{ll} < 110$ GeV	0.888	0.888	0.900
$N_{DVs} \geq 2$	0.091	0.672	0.014
	60 GeV, 1e-5	60 GeV, 1e-6	60 GeV, 1e-7
Before Selection	1.0	1.0	1.0
Pre-selection	0.957	0.957	0.951
$70 < m_{ll} < 110$ GeV	0.894	0.895	0.896
$N_{DVs} \geq 2$	0.0002	0.672	0.398

CLD (original):

	20 GeV, 1e-5	20 GeV, 1e-6	20 GeV, 1e-7
Before Selection	1.0	1.0	1.0
Pre-selection	0.955	0.952	0.952
$70 < m_{ll} < 110$ GeV	0.891	0.896	0.903
$N_{DVs} \geq 2$	0.092	0.109	0.002
	60 GeV, 1e-5	60 GeV, 1e-6	60 GeV, 1e-7
Before Selection	1.0	1.0	1.0
Pre-selection	0.958	0.958	0.952
$70 < m_{ll} < 110$ GeV	0.895	0.897	0.899
$N_{DVs} \geq 2$	0.0002	0.654	0.0502

CLD (min. hits = 4):

	20 GeV, 1e-5	20 GeV, 1e-6	20 GeV, 1e-7
Before Selection	1.0	1.0	1.0
Pre-selection	0.955	0.956	0.949
$70 < m_{ll} < 110$ GeV	0.889	0.894	0.901
$N_{DVs} \geq 2$	0.096	0.441	0.0056
	60 GeV, 1e-5	60 GeV, 1e-6	60 GeV, 1e-7
Before Selection	1.0	1.0	1.0
Pre-selection	0.957	0.955	0.955
$70 < m_{ll} < 110$ GeV	0.896	0.892	0.900
$N_{DVs} \geq 2$	0.0002	0.687	0.183

Note: have 2.986 events

CLD (min. hits = 5):

	20 GeV, 1e-5	20 GeV, 1e-6	20 GeV, 1e-7
Before Selection	1.0	1.0	1.0
Pre-selection	0.955	0.955	0.950
$70 < m_{ll} < 110$ GeV	0.896	0.894	0.901
$N_{DVs} \geq 2$	0.094	0.293	0.0042
	60 GeV, 1e-5	60 GeV, 1e-6	60 GeV, 1e-7
Before Selection	1.0	1.0	1.0
Pre-selection	0.955	0.956	0.953
$70 < m_{ll} < 110$ GeV	0.891	0.894	0.900
$N_{DVs} \geq 2$	0.0003	0.684	0.123