Muon Background Mitigation

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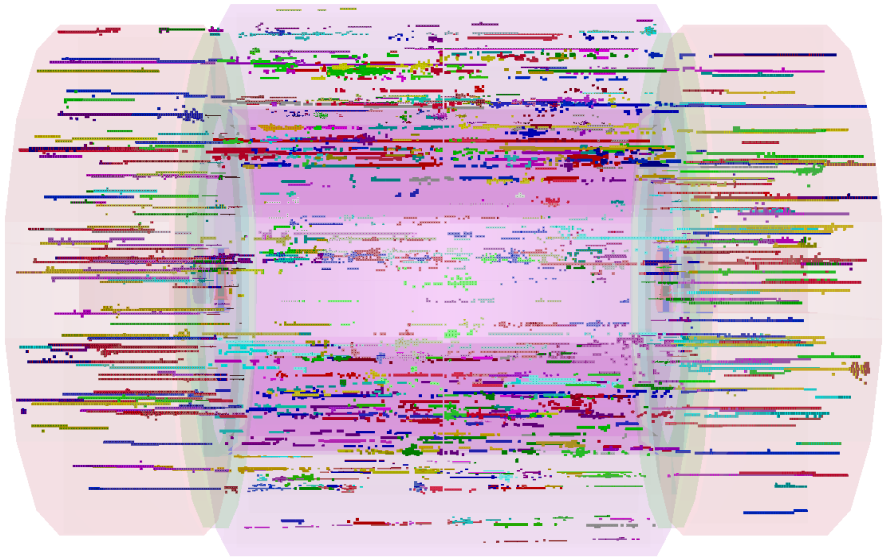


This Talk:

1. CLIC Timing Strategy
2. Beam Halo Muons
3. Software Mitigation
4. Impact on Physics
5. Conclusions

❶ CLIC Timing Strategy

- ★ Based on trigger-free readout of detector hits all with time-stamps
- ★ Assume can identify t0 of physics event in offline trigger/event filter
  - define "reconstruction" window around t0

- ★ Hits within window passed to track and particle flow reconstruction

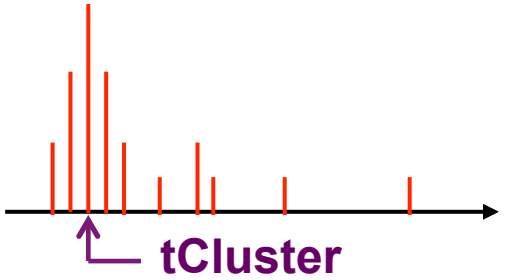
Subdetector	Reco Window	Hit Resolution
ECAL	10 ns	1 ns
HCAL Endcap	10 ns	1 ns
HCAL Barrel	100 ns	1 ns
Silicon Detectors	10 ns	10/√12
TPC (CLIC_ILD)	Entire train	n/a

← Integrate over most of bunch train in HCAL barrel

- ★ 1.2 TeV reconstructed background from $\gamma\gamma \rightarrow$ hadrons

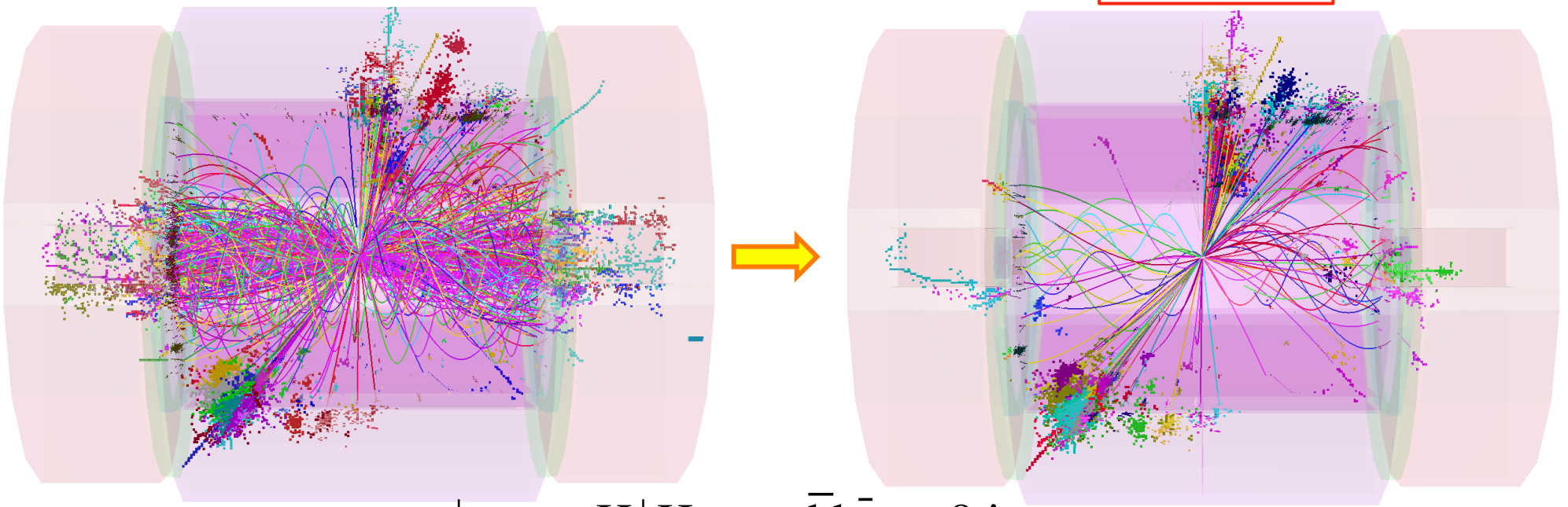
Reconstruction in Time

- ★ Tighter time cuts then applied at reconstructed "cluster time" level (details in CDR)
- ★ Using mean cluster time can cut at 1-2 ns level (not applied to high p_T particles)



1.2 TeV

100 GeV

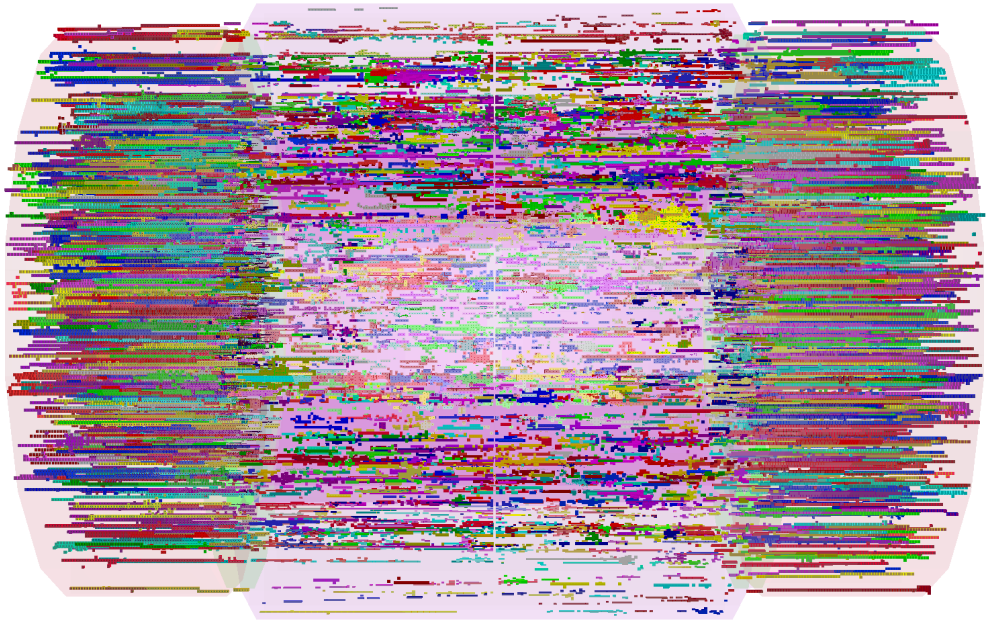


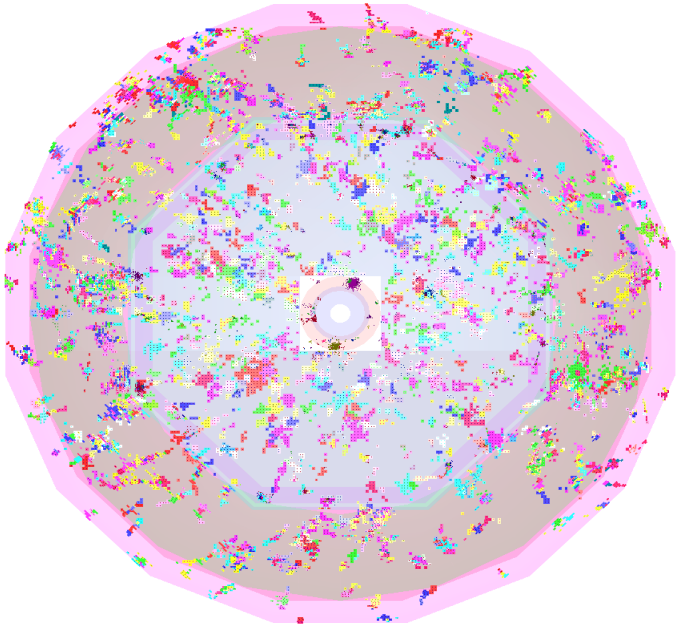
$$e^+e^- \rightarrow H^+H^- \rightarrow t\bar{b}\bar{b}t \rightarrow 8 \text{ jets}$$

❷ Beam Halo Muons

★ Simulated events with entire bunch train of beam halo muon background using files from Lawrence Deacon with spoilers
- conservatively assumed 5 muons/BX (1 + safety factor 5)
- full Geant 4 detector simulation
- full high granularity particle flow reconstruction

★ In 150 ns from start of bunchtrain:
- ECAL
  - Total = 1.5 TeV (54k hits)
  - Barrel = 0.8 TeV (18k)
  - Endcap = 0.7 TeV (36k)
- HCAL
  - Total = 10.8 TeV (128k hits)
  - Barrel = 5.3 TeV (32k)
  - Endcap = 5.5 TeV (96k)



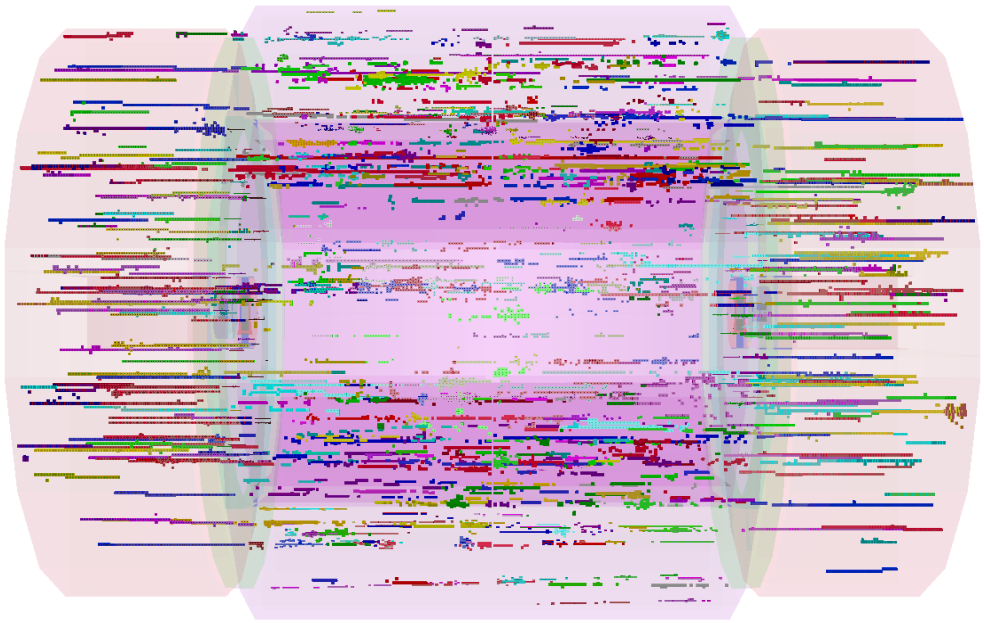


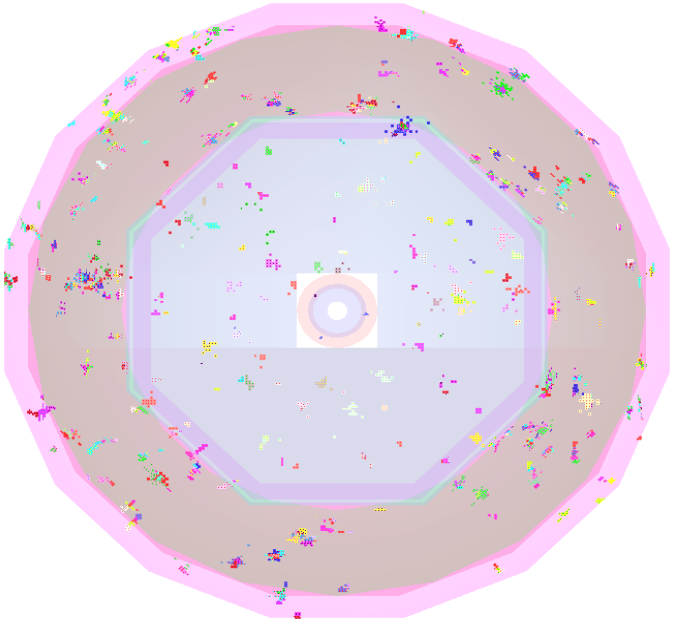
★ **From entire bunch train, 5 muons per BX**

Average energy deposition (per bunch train:

13.2 TeV

In-time Energy Deposit





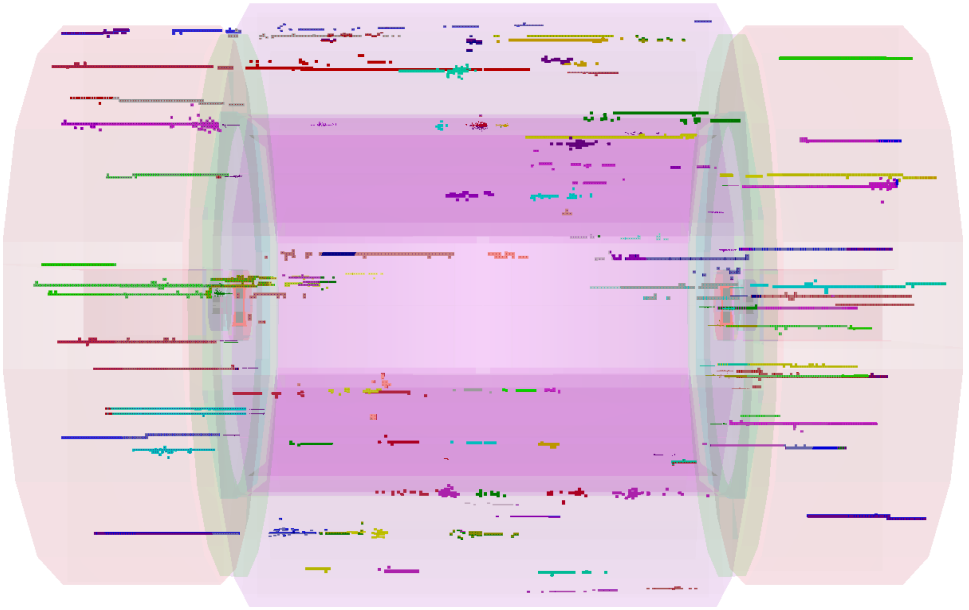
★ Only hits in calorimeter readout windows:
- ECAL integrates over 10 ns
- HCAL endcap integrates over 10 ns
- HCAL barrel (Tungsten) integrates over 50 ns

★ 5 muons per BX in time with assumed calorimeter readout

2.2 TeV

Offline timing cuts

- ★ Apply timing cuts to “offline” reconstructed clusters
  - “Tight” PFO Selection
  - Time cuts: require cluster within 1 - 2 ns of physics BX

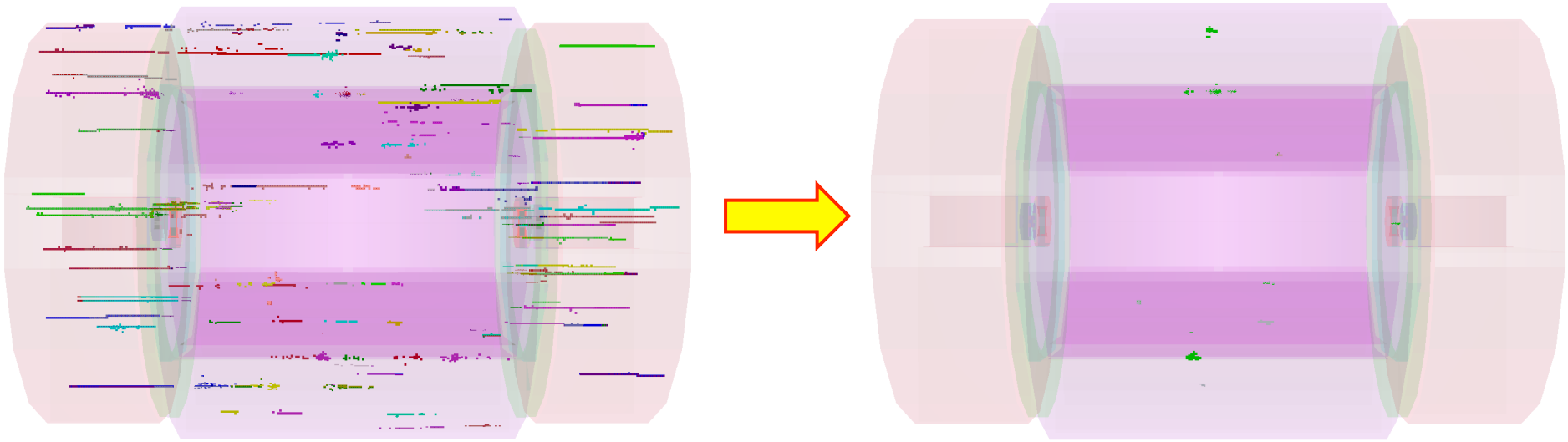


- ★ 5 muons per BX in time with O(1-2 ns) time cuts

420 GeV

❸ Software Mitigation

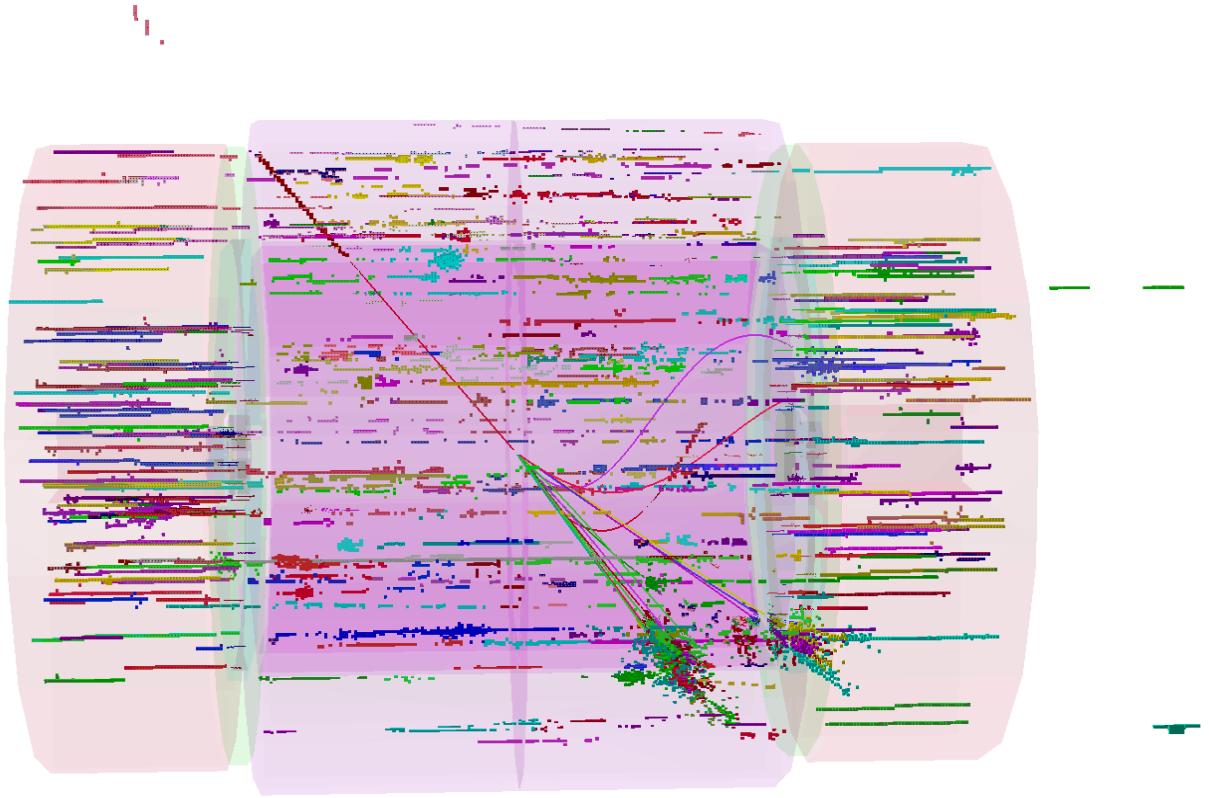
- ★ Implement algorithms in Particle Flow Reconstruction to remove "clusters" consistent with being from beam halo muons
  - Only uses shape information
  - Algorithm is run deep down in reconstruction chain
  - Quite sophisticated – approximation to realistic pattern recognition



420 GeV **30 GeV**

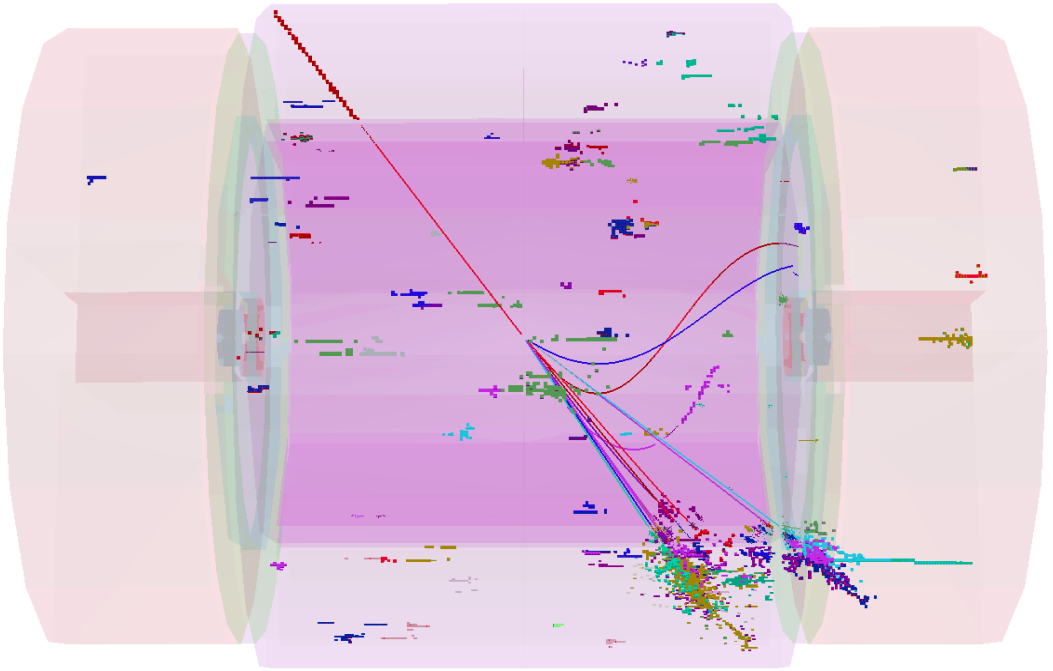
❹ Impact on Physics

- ★ Simulated 10000 WW-> qqμν events at 1 TeV
  - 500 GeV W-> qq
  - Overlay full bunch train of beam halo muns
  - Reconstruct event using 10/50 ns time windows in calorimeters



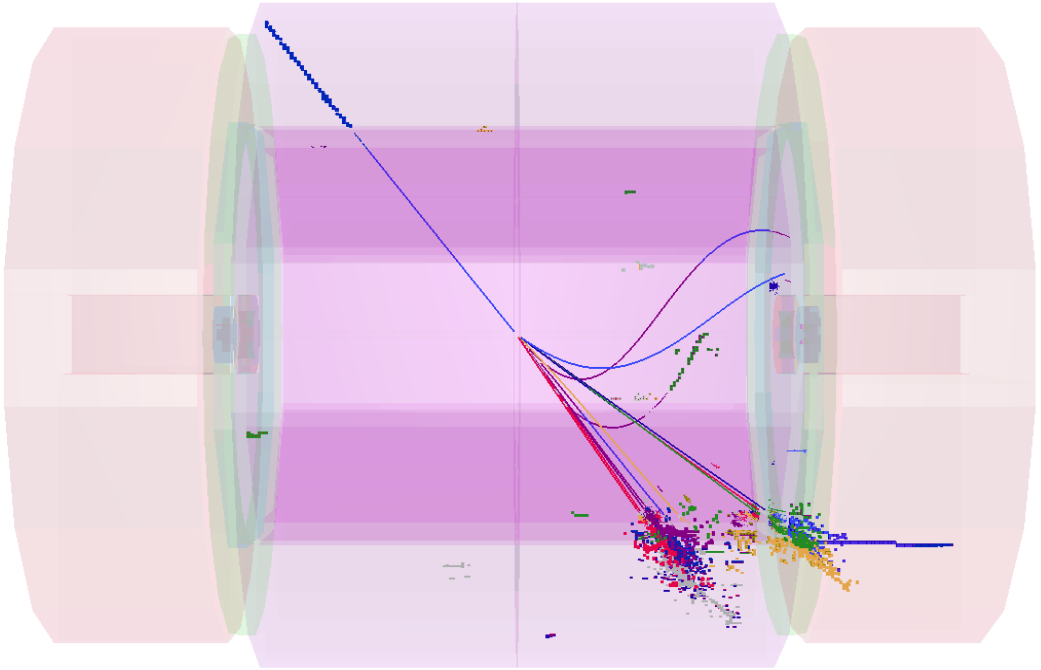
Tight Timing Cuts

- **Apply tight timing cuts**
  - **1-2 ns timing cuts on cluster time**



With modified reco.

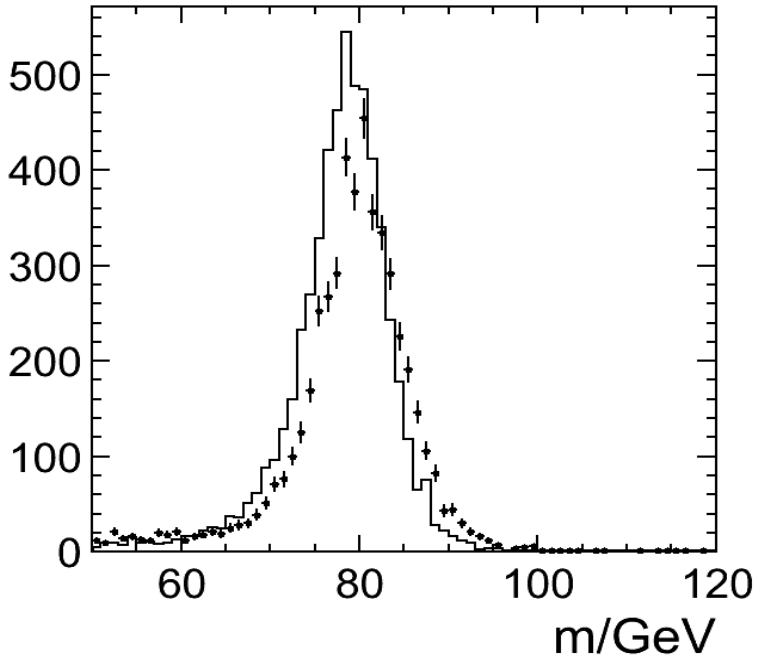
- **Two effects**
  - 30 GeV of energy in clusters from beam halo muons (mainly Brems)
  - Energy of reconstructed jets also biased "pick" up hits from muons ~30 GeV
  - Patrec could be improved: conservative estimate of impact



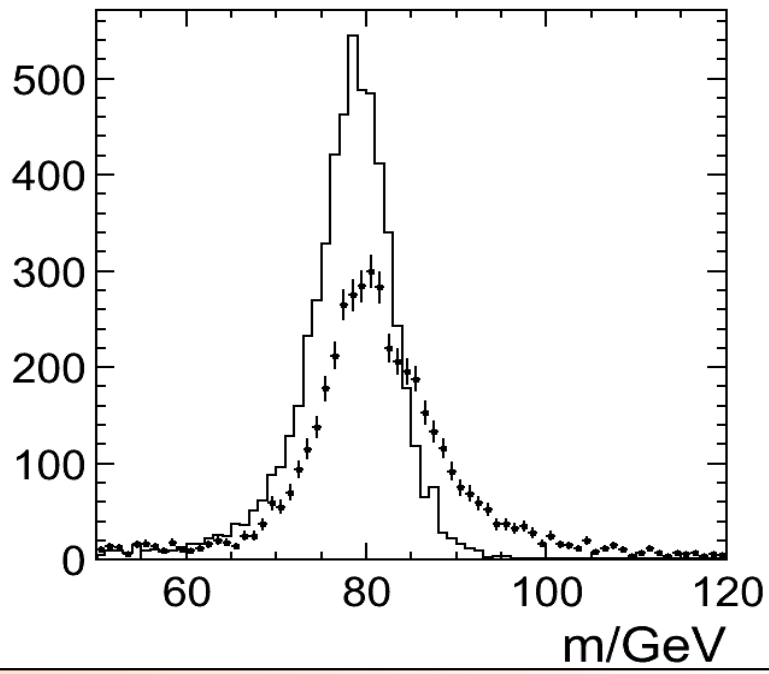
Impact on W Reconstruction

- ★ W reconstruction
  - Remove muon
  - Force remainder of event in to 2 jets – using k_T algorithm, R = 0.5
  - Plot di-jet mass resolution
  - Compare full reco no background, to full reco with background
  - For comparison look at impact of gamma gamma → hadrons

$\gamma\gamma \rightarrow$ hadrons



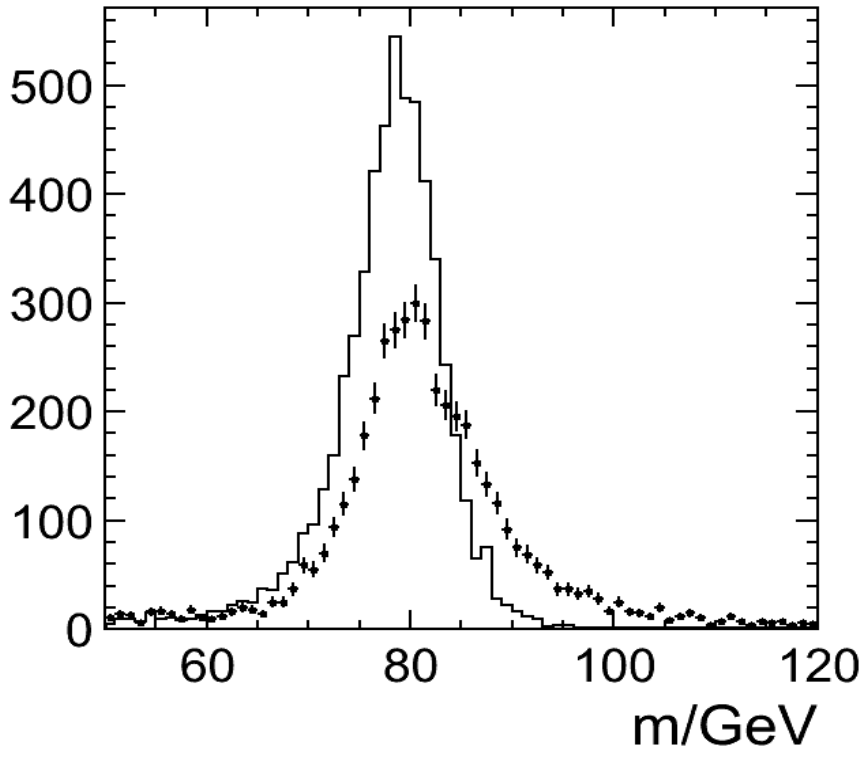
muon halo (5/BX)



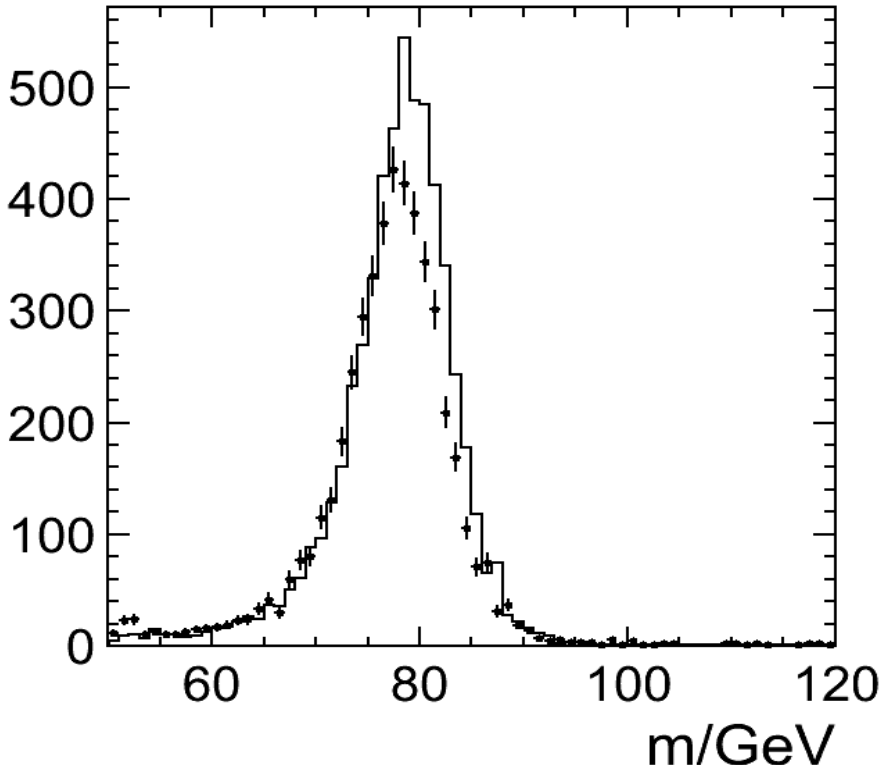
Impact on W Reconstruction

- ★ Compare impact of 5/BX to 1/BX
  - Beam halo background at level of 1 muon/BX is acceptable
  - "Safety-margin" of 5/BX is not safe from point of view of physics
  - PatRec could be improved but already quite sophisticated

muon halo (5/BX)



muon halo (1/BX)



❺ Conclusions

- ★ The impact of the muon background can be greatly reduced in software utilising highly granular detector
- ★ Beam halo muon background at level of 1/BX is survivable
- ★ At level of 5/BX physics, performance of the detector is compromised
- ★ Ideally would look to design machine for beam halo background at level of 0.1-0.2 per BX (allows factor 10 safety margin)
- ★ Improved reconstruction could help further – but not easy