Disappearing tracks at the muon collider

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Targets of the study

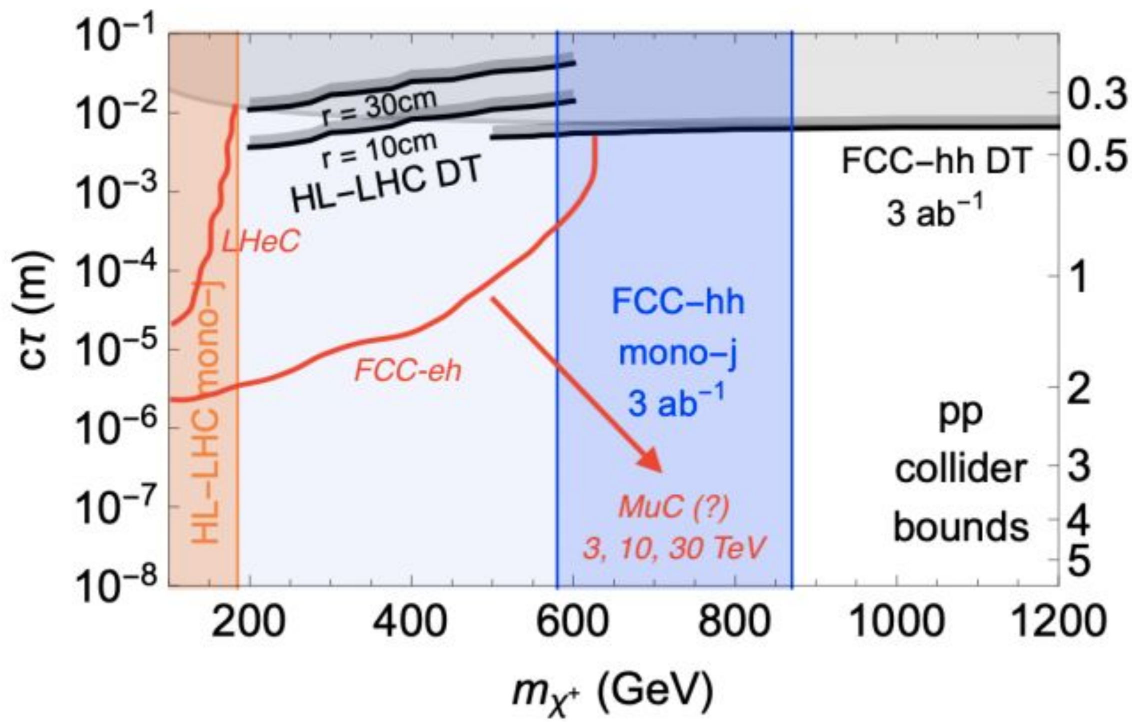
Electroweak Multiplets can appear in several BSM models:

- WIMP Dark Matter, FIMP DM, Seesaw Type-III, (g-2) muon, etc.

WIMP DM: Naturally small mass splitting between the components of the multiplet (from radiative corrections).

LLP signatures:

- Displaced vertices
- Disappearing tracks
- Kinked tracks

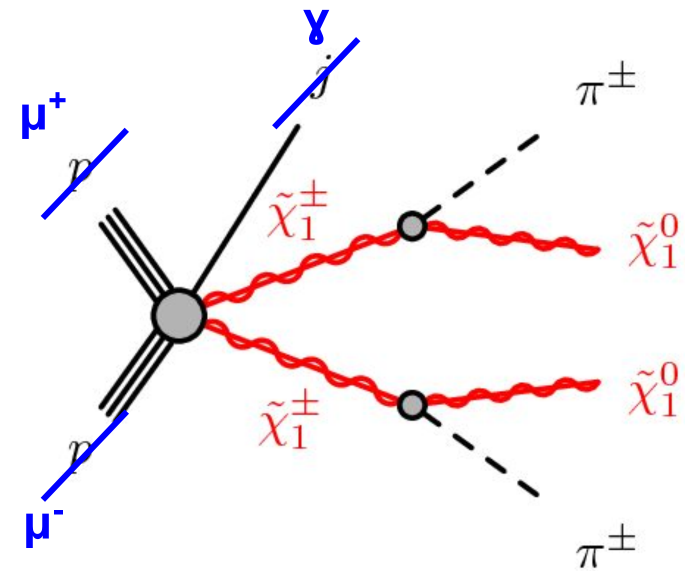


We want to study the reach of a possible high-energy muon collider.

Overall strategy

- Focus on 10 TeV collisions first, repeat for 3 TeV and 14 TeV later
- Use Madgraph+pythia for the signal generation/shower
- Study reconstruction effects with full simulation
- Implement smearing functions in custom Delphes module to get “reconstructed” charginos, together with other reco objects (photon, missing energy)
- Optimise the final event selection
- Evaluate the sensitivity in the mass vs lifetime plane, for different multiplet hypotheses

The tricky bits



Detector signature: tracks (tracklets) that disappear

Full simulation needed to properly assess:

- tracklet reconstruction efficiency vs p_T, $\eta(\Theta)$, decay position in the detector
- effect of disappearing condition (veto on tracker layer)
- tracklet momentum resolution
- background tracks (combinatorial fakes and BIB)

The next slides show some *very preliminary/work-in-progress* results towards achieving this.

Signal generation and simulation

Focused on wino C1C1 production

Model: MSSM_SLHA2

- aMC@NLO 2.7.3 + Pythia 8.2

```
MG5_aMC > generate mu+ mu- > vm vm~ x1+ x1-
MG5_aMC > add process mu+ mu- > x1+ x1-
MG5_aMC > add process mu+ mu- > x1+ x1- mu+ mu-
```

- Need special ISR plugin to get ISR photons

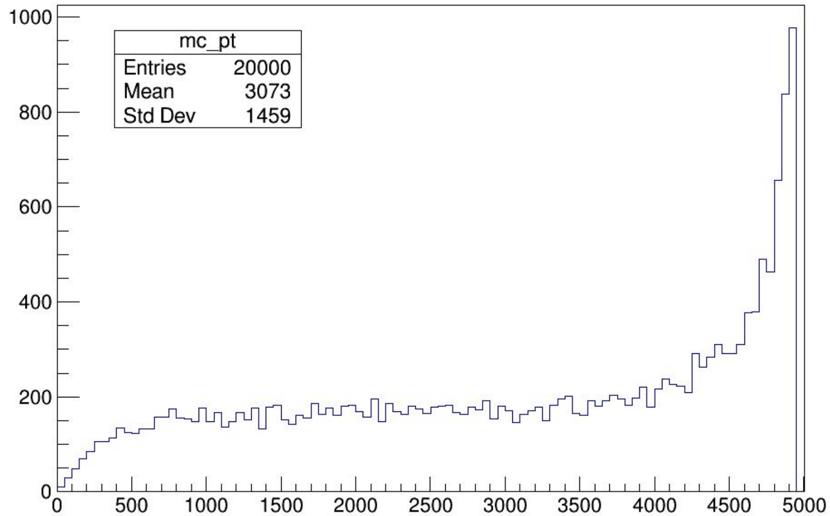
Simulation in dd4hep

- Good support for BSM particles
- GEANT physics list automatically generated from list of "extra particles"
- Lifetimes are arbitrary (specified in mm)
  - C1 lifetime set to 100 mm

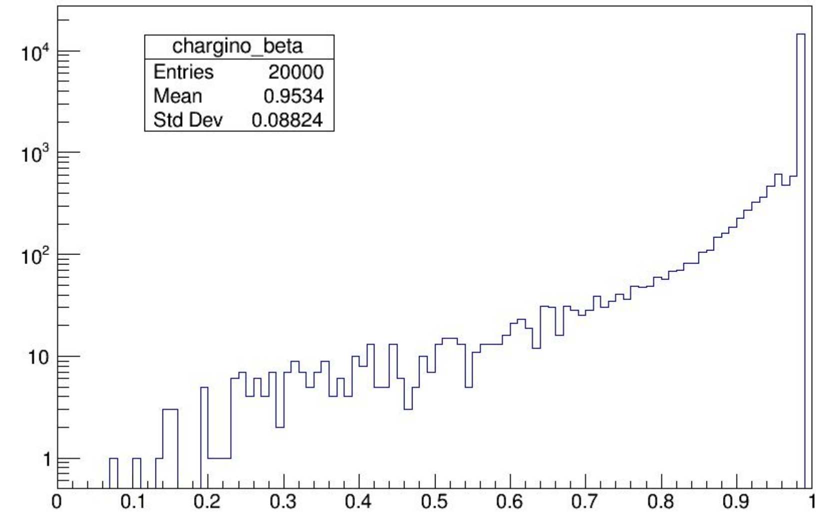
```
Block MASS   # Scalar and gaugino mass spectrum
#  PDG code   mass                 particle
         5     4.80000000E+00   # b-quark pole ma
         6     1.72500000E+02   # t-quark pole ma
        15     1.77682000E+00   # tau pole mass
        23     9.11876000E+01   # Z pole mass (n
        24     8.04229965E+01   #  W^+
        25     1.17354164E+02   #  h^0
        35     6.99664014E+03   #  H^0
        36     6.95080322E+03   #  A^0
        37     6.99698096E+03   #  H^+
   1000001     7.43424219E+03   #  dnl
   1000002     7.43383691E+03   #  upl
   1000003     7.43424219E+03   #  stl
   1000004     7.43383691E+03   #  chl
   1000005     6.38580225E+03   #  b1
   1000006     5.10177637E+03   #  t1
   1000011     4.83639551E+03   #  el-
   1000012     4.83417090E+03   #  nuel
   1000013     4.83639551E+03   #  mul-
   1000014     4.83417090E+03   #  numl
   1000015     4.78479004E+03   #  tau1
   1000016     4.82647363E+03   #  nutl
   1000021     6.08901953E+03   #  glss
   1000022     8.99637451E+02   #  z1ss
   1000023     2.93977783E+03   #  z2ss
   1000024     8.99811523E+02   #  w1ss
   1000025    -4.83659033E+03   #  z3ss
   1000035     4.83768994E+03   #  z4ss
   1000037     4.84269434E+03   #  w2ss
   2000001     7.51731982E+03   #  dnr
   2000002     7.47251123E+03   #  upr
   2000003     7.51731982E+03   #  str
   2000004     7.47251123E+03   #  chr
   2000005     7.46611328E+03   #  b2
   2000006     6.42913818E+03   #  t2
   2000011     4.79959424E+03   #  er-
   2000013     4.79959424E+03   #  mur-
   2000015     4.82940039E+03   #  tau2
```

Some (ugly) truth-level distributions

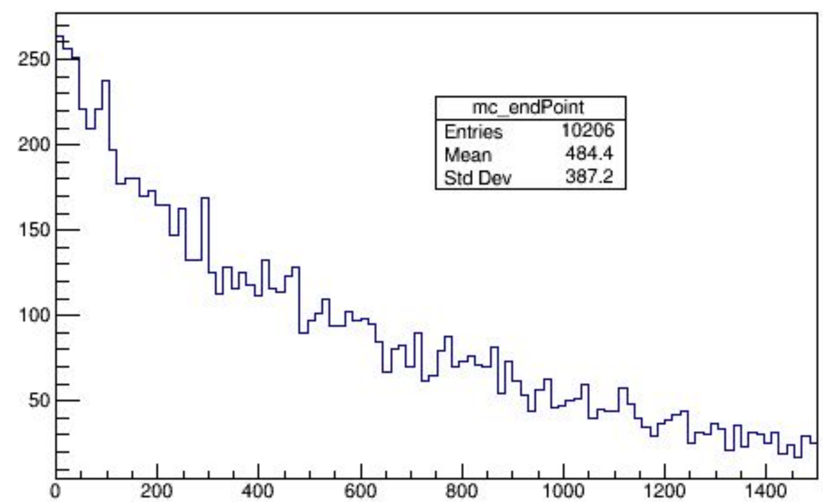
For 900 GeV charginos



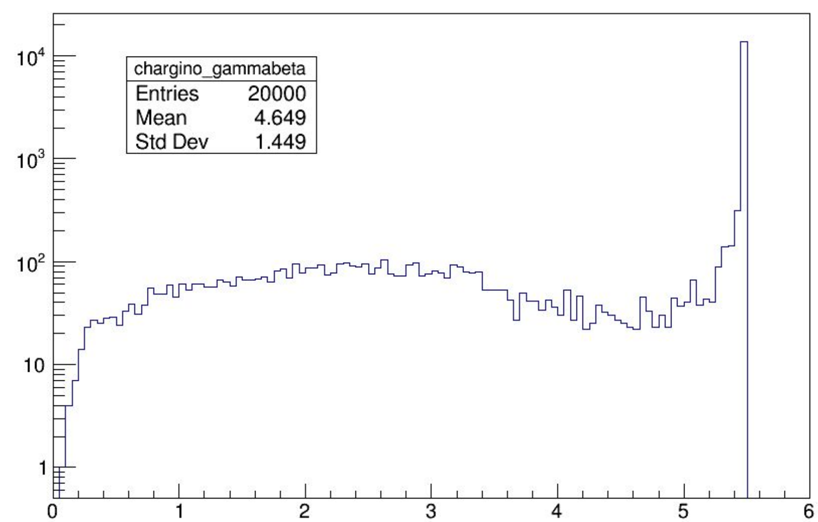
C1 p_T [GeV]



C1 β



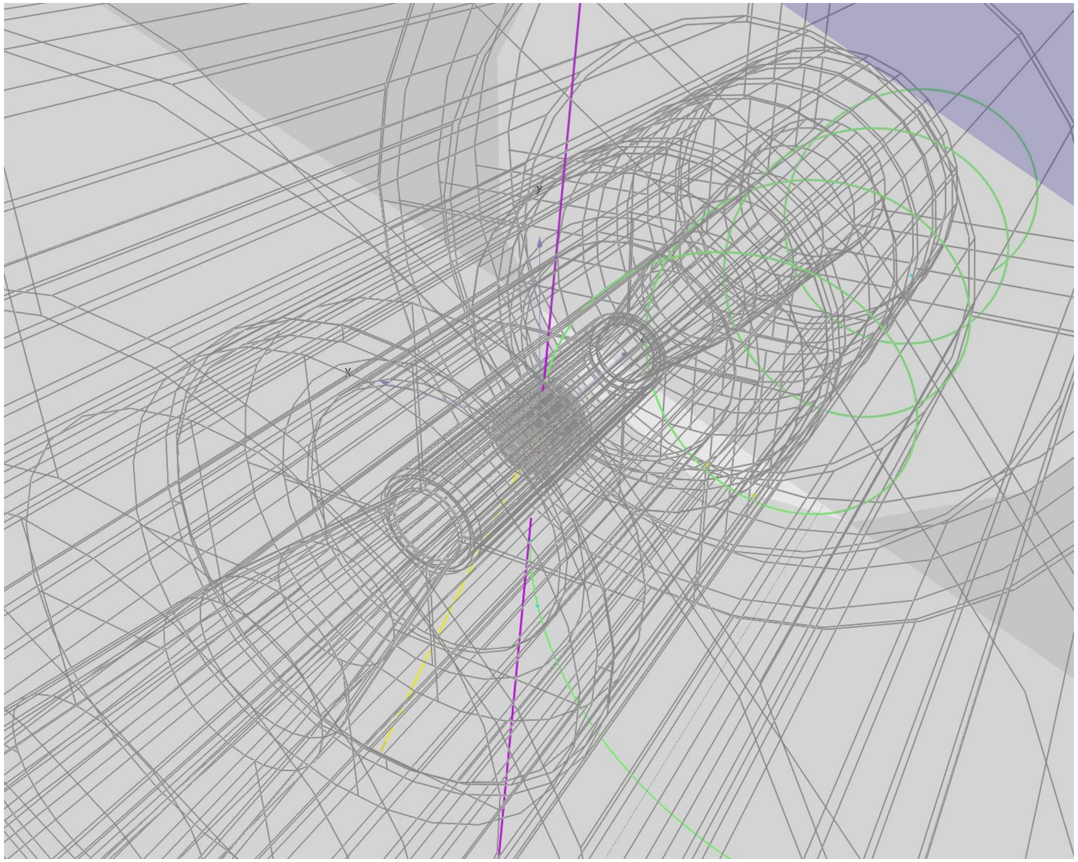
C1 decay r [mm]

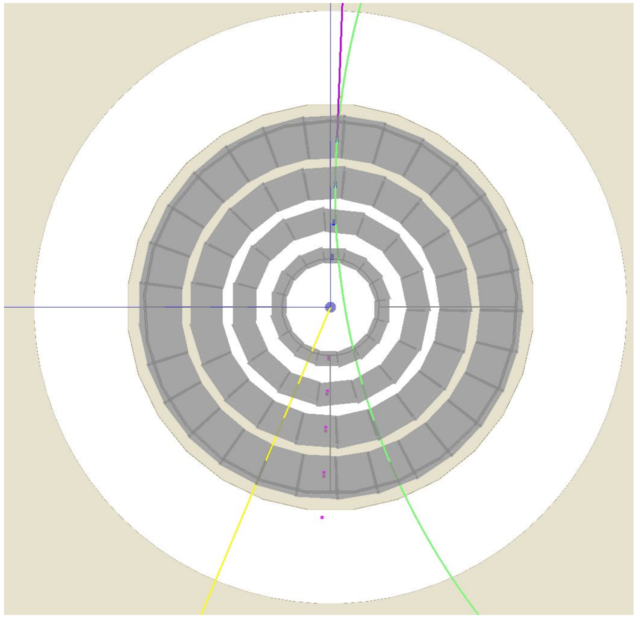


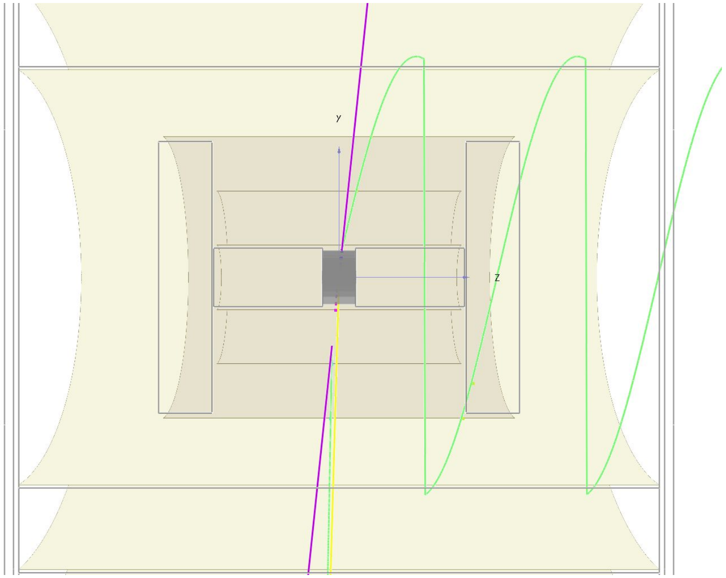
C1 γβ

Example event display

No Beam Induced Backgrounds

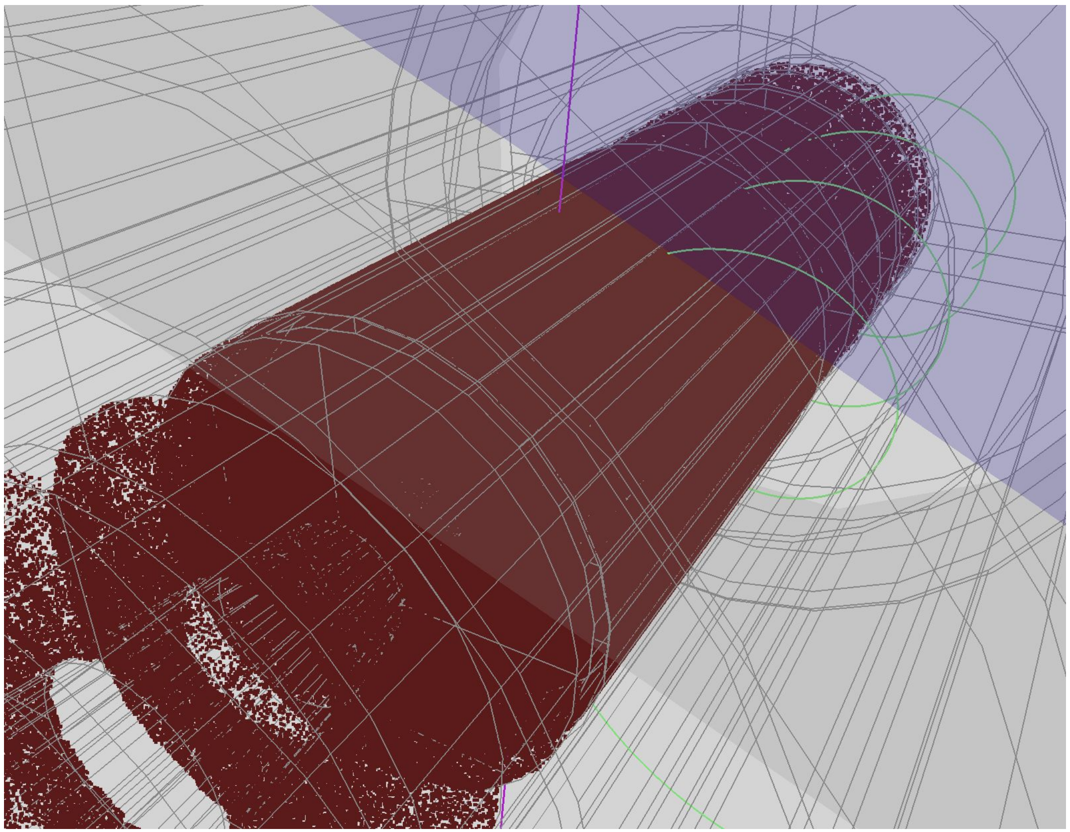






Example event display

Full Beam Induced Backgrounds



Same event as before.

- The red/brown dots represent simulated detector hits from the BIB

Simulation available only for √s=1.5 TeV (use as pessimistic baseline)

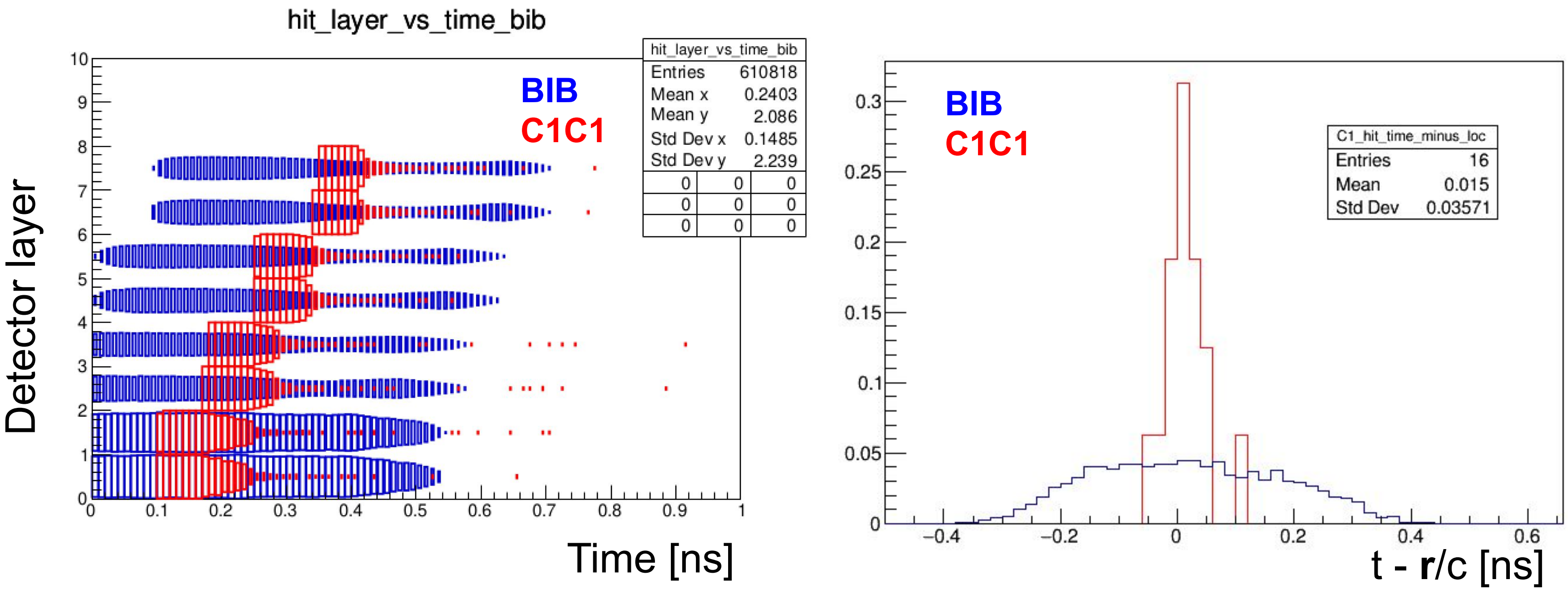
- low-energy photons, electrons/positrons (~1-10 MeV)
- neutrons (~100 MeV)
- The large multiplicity of hits (several millions) makes tracking extremely challenging

BIB rejection

With timing

Exploit particle arrival times to reduce BIB

- Beware for low-beta particles!
- Timing cuts will kill hits from the displaced pion!



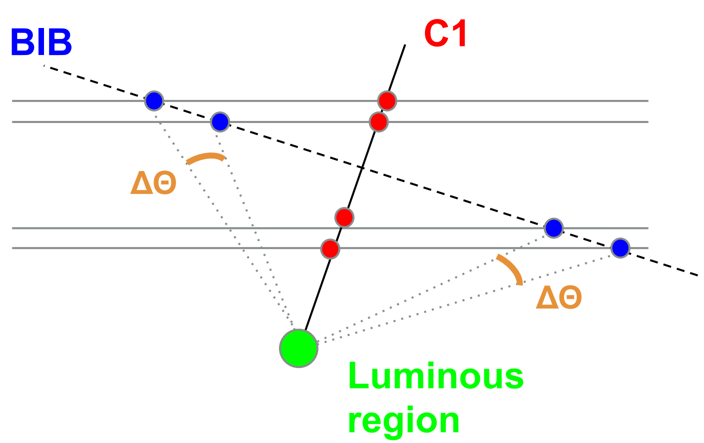
For now, assume another hard object in the event (e.g. ISR photons) can be timed

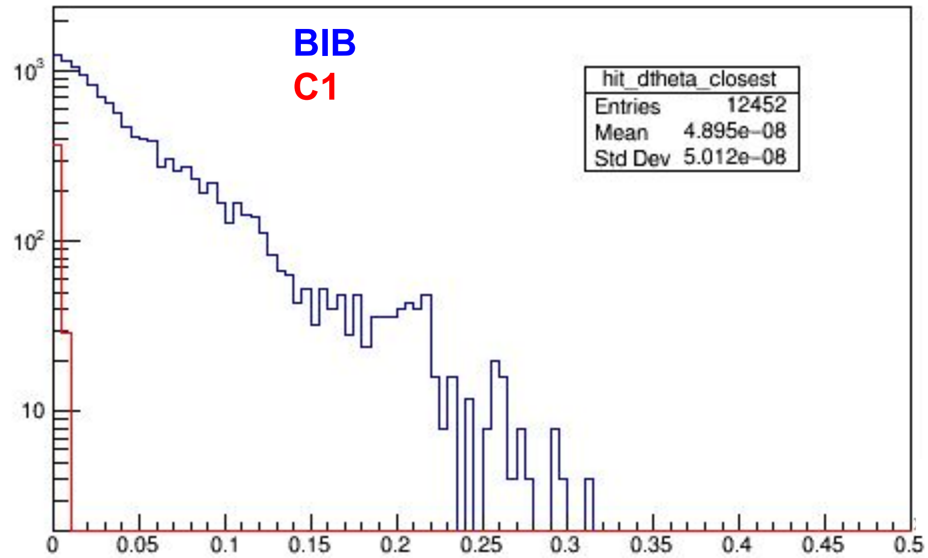
BIB rejection

With geometry

The current pattern recognition algorithms don't exploit in any way the double layer layout in the vertex detector.

- Can filter input hits based on whether there is another hit in the closeby layer with small ΔΘ.





ΔΘ with closest hit in nearmost layer

BIB rejection

Summary of selections

Timing:

- -0.15 ns $< t - \mathbf{r}/c < 0.15$ ns

Geometry:

- Reject all hits for which the closest hit in $\Delta R = \sqrt{(\Delta\varphi^2 + \Delta\Theta^2)}$ has $\Delta\Theta > 0.02$
- Could add a cut on $\Delta\varphi$ too

To reduce combinatorics and speed up tracking, the hits are split in subcollections in theta with this binning: [0, 30, 50, 70, 90, 110, 130, 150, 180]

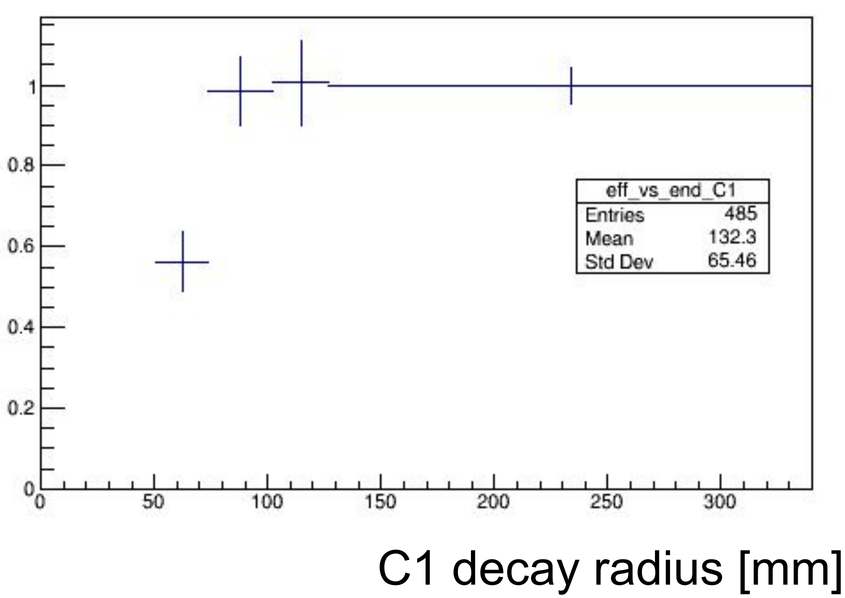
- Only (50, 70, 90, 110, 130) considered in the following

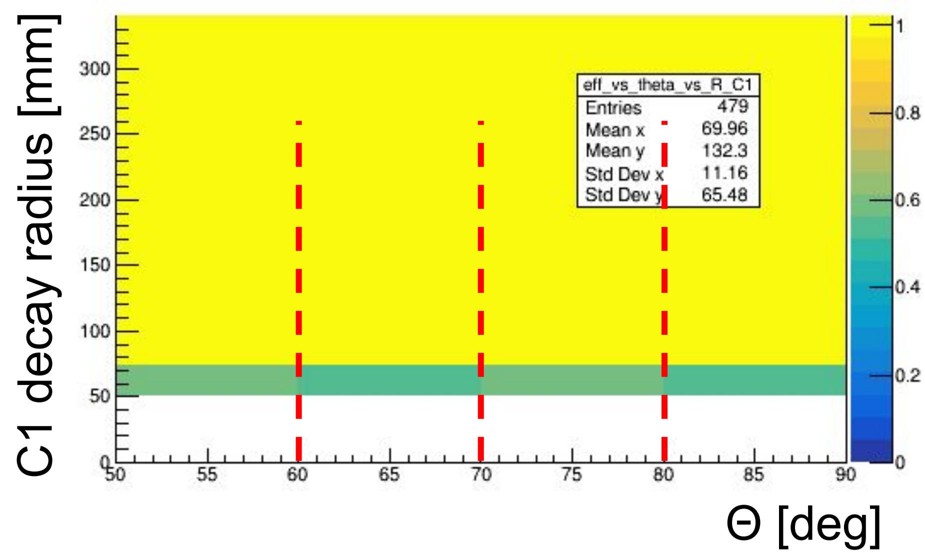
Reconstruction efficiencies

No BIB, but after BIB rejection cuts

Efficiencies evaluated with truth matching to C1 particles.

- Reconstructable tracks are defined as tracks from C1 with at least 4 hits.
- Evaluated vs the C1 decay radius R and vs (Θ, R)
  - Bin boundaries in R defined by position of tracking layers



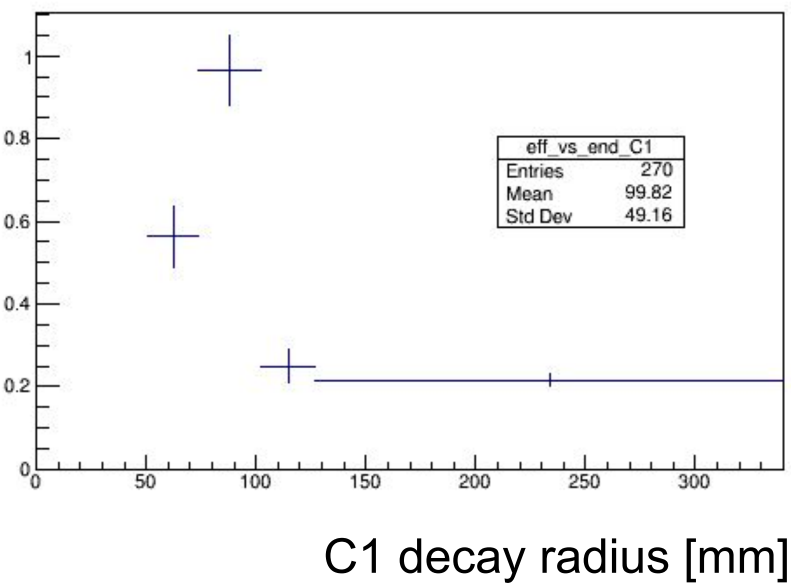


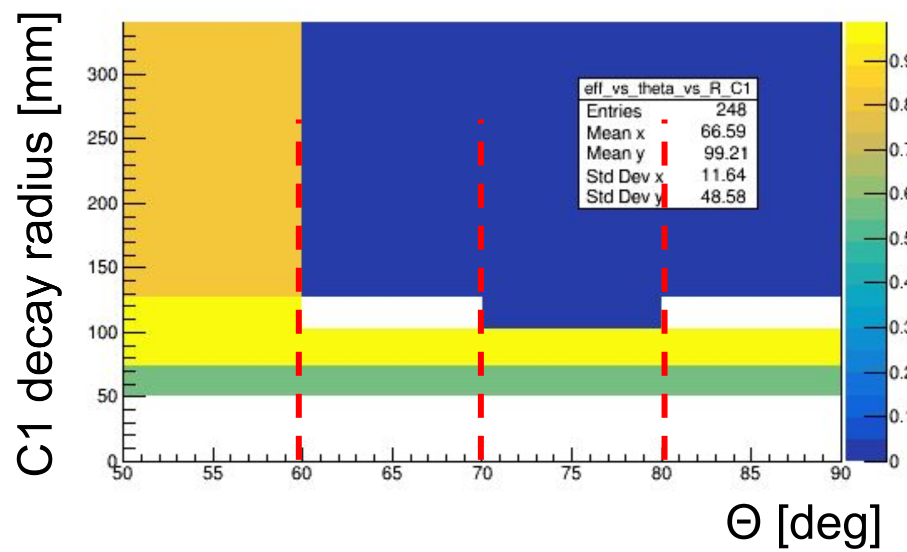
Effect of disappearing condition

No BIB, but after BIB rejection cuts

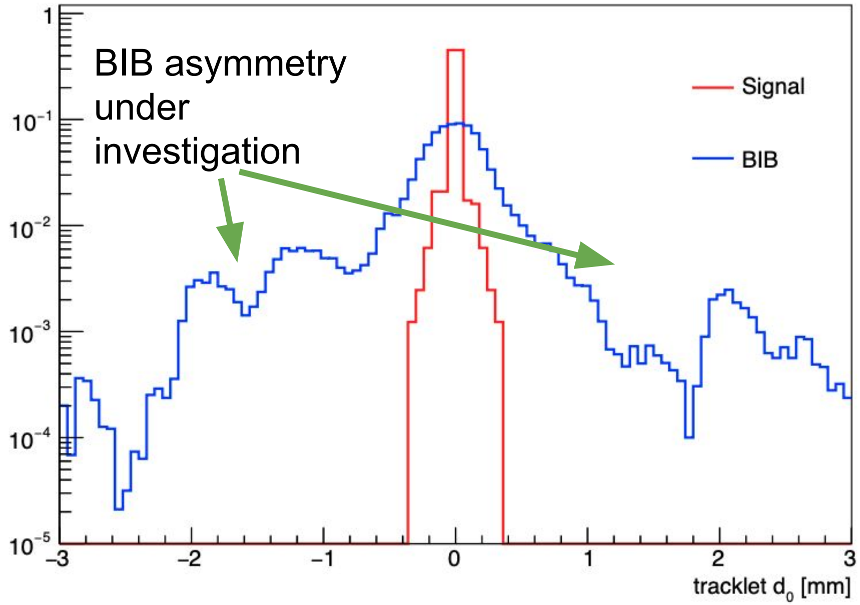
Acceptance * efficiency evaluated with truth matching to C1 particles.

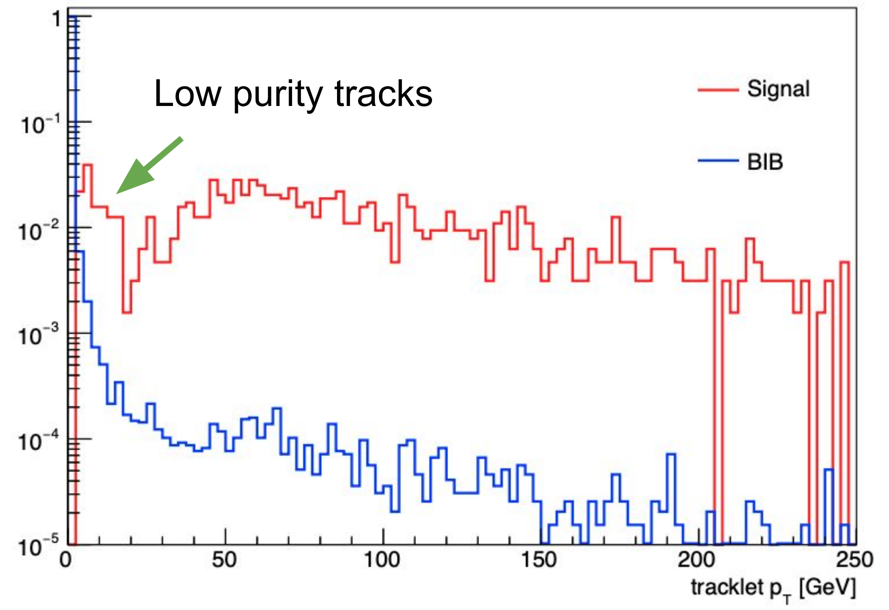
- Reconstructable tracks are defined as tracks from C1 with at least 4 hits.
- Disappearing condition - veto on last layer of Vertex detector (10.2 cm)
- Evaluated vs the C1 decay radius R and vs (Θ, R)
    - Bin boundaries in R defined by position of tracking layers
    - Plan to use this map to parameterise efficiencies





Disappearing tracks quantities





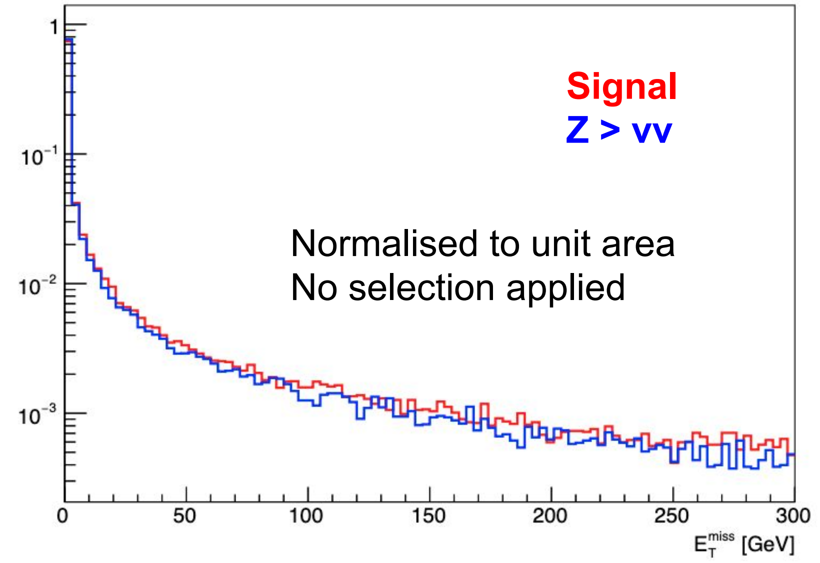
Background estimation plans

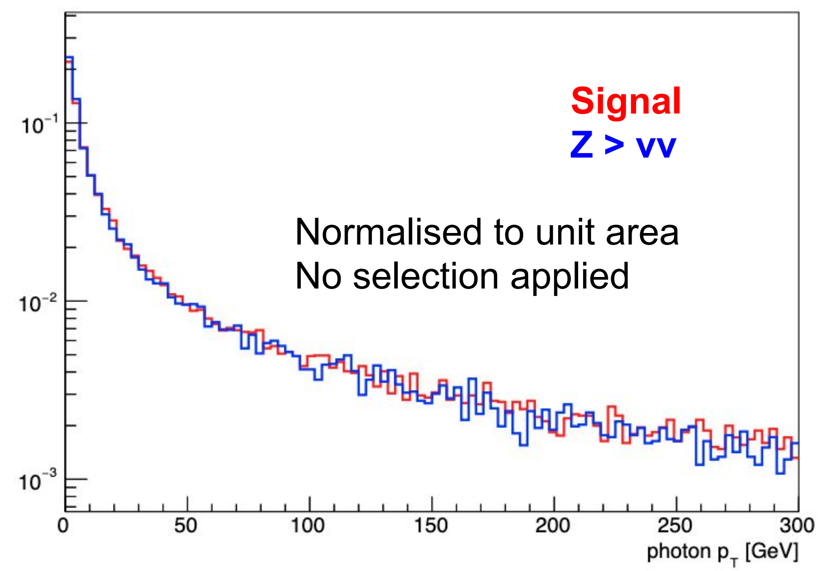
Consider background from material interactions negligible (as in LHC searches).

Focus on Z>vv, with tracklets from BIB

- Plots from Delphes using muon collider card (v0) by M.Selvaggi
- Overlay to each event (background and signal) a set of BIB tracks extracted from full simulation

Next: optimise selection





Next steps

Add momentum smearing for signal tracklets

Re-run efficiency study increasing detector acceptance

- Aim to cover a η region similar to LHC searches
- Move disappearing condition to first layer of Inner tracker

Include BIB at 3 TeV

Interpret expected results

Repeat exercise at $\sqrt{s}$ = 3 TeV and $\sqrt{s}$ = 14 TeV, possibly for a few integrated luminosity assumptions

Thank you!

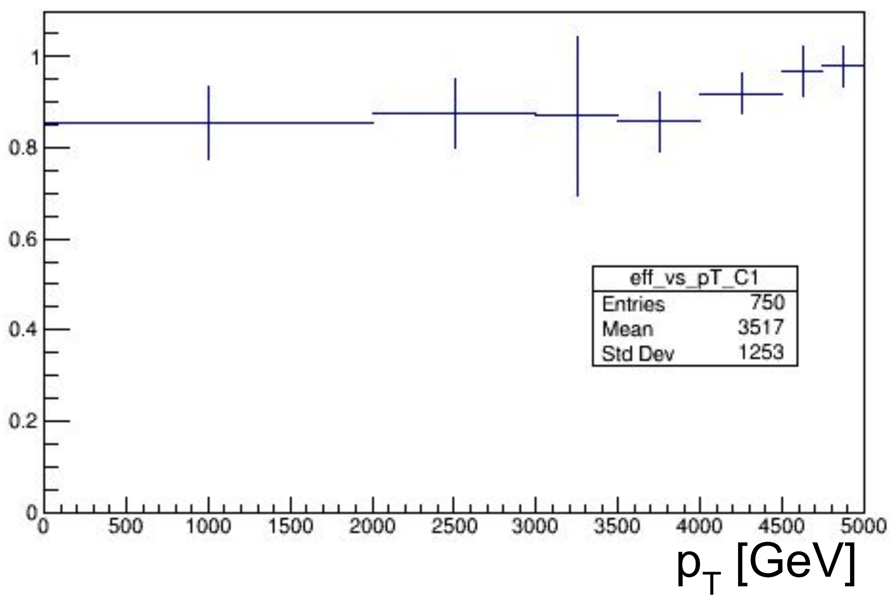
Reconstruction efficiencies

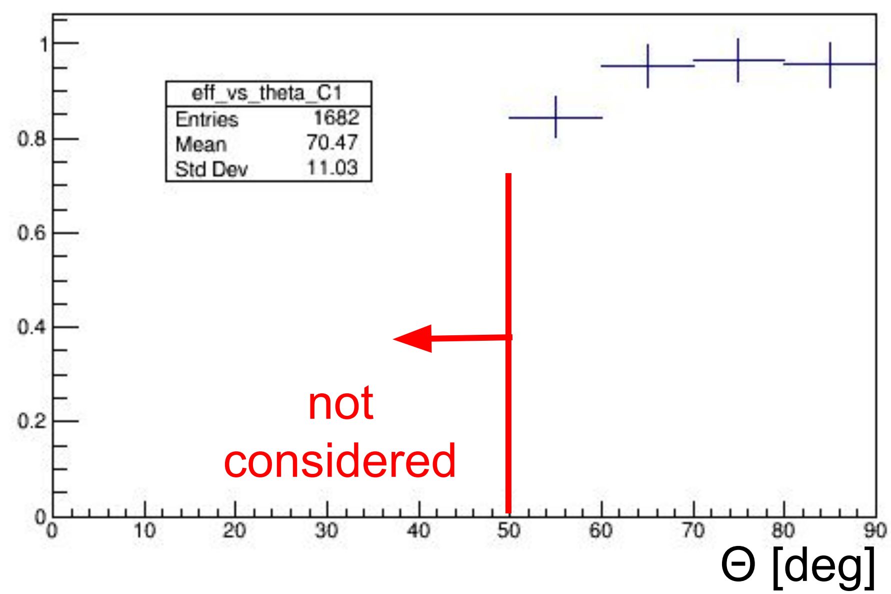
No BIB, but after BIB rejection cuts

```
--- n_reconstructable_C1 = 3500
--- n_reconstructed_C1 = 3251
--- efficiency_C1 = 0.9288571428571428
```

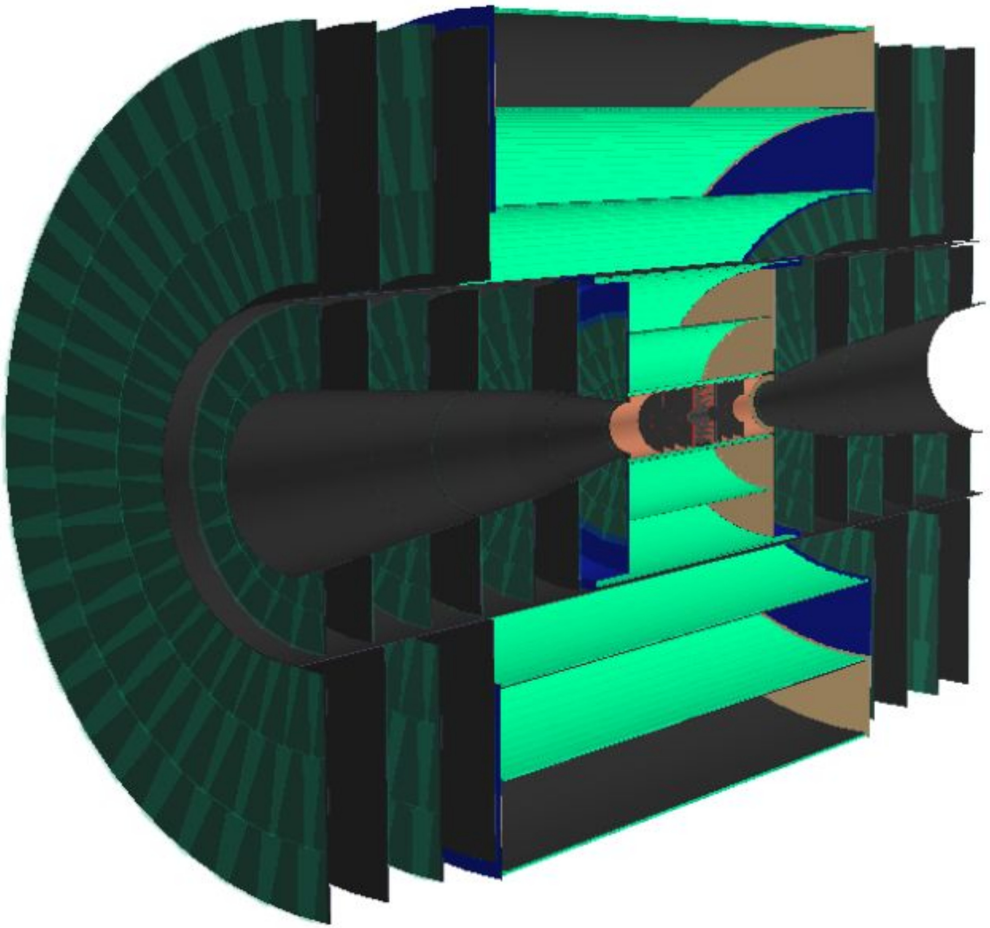
Efficiencies evaluated with truth matching to C1 particles.

- Reconstructable tracks are defined as tracks from C1 with at least 4 hits.
- Considering we are neglecting the hits in the endcaps, relatively ok





The tracking system



- Vertex Detector (VXD)
  - 4 double-sensor barrel layers:
    - at r = 3.1, 5.1, 7.4, 10.2 cm;
    - 50-μm thick Si sensors;
  - 4+4 double-sensor disks:
    - at |Δz| = 8.0, 12.0, 20.0, 28.0 cm;
    - 50-μm thick Si sensors.
- Inner Tracker (IT)
  - 3 barrel layers (100-μm thick):
    - at r = 12.7, 34.0, 55,4 cm;
  - 7+7 disks (100-μm thick):
    - at |Δz| = 52.4, 80.8, 109.3, 137.7, 166.1, 194.6, 219.0 cm;
- Outer Tracker (OT)
  - 3 barrel layers (100-μm thick):
    - at r = 81.9, 115.3, 148.6
  - 4+4 disks (100-μm thick):
    - at |Δz| = 131, 161.7, 188.3, 219 cm.

Machine parameters

Parameter	Unit	3 TeV	10 TeV	14 TeV
L	$10^{34}\ cm^{-2}s^{-1}$	1.8	20	40
N	10^{12}	2.2	1.8	1.8
f_r	Hz	5	5	5
P_{beam}	MW	5.3	14.4	20
C	km	4.5	10	14
$\langle B \rangle$	T	7	10.5	10.5
ε_L	MeV m	7.5	7.5	7.5
σ_E / E	%	0.1	0.1	0.1
σ_z	mm	5	1.5	1.07
β	mm	5	1.5	1.07
ε	µm	25	25	25
$\sigma_{x,y}$	µm	3.0	0.9	0.63