Tracking Performance of the Modified Sidloi3 Detector

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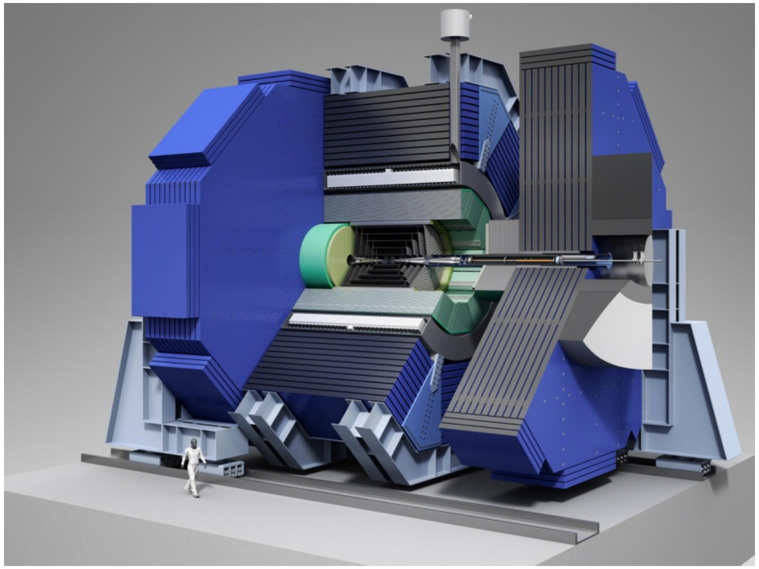
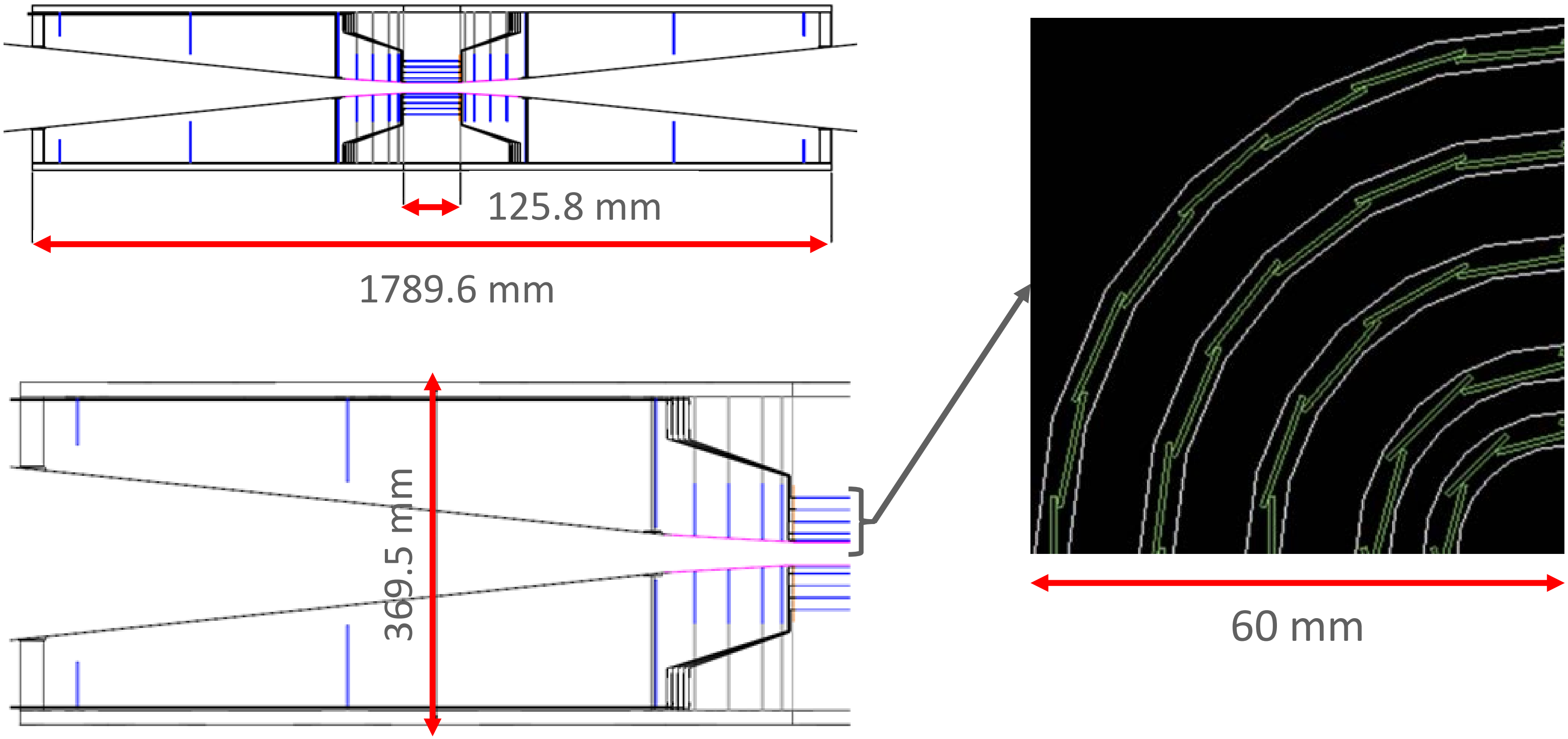
Second SiD Optimization Meeting

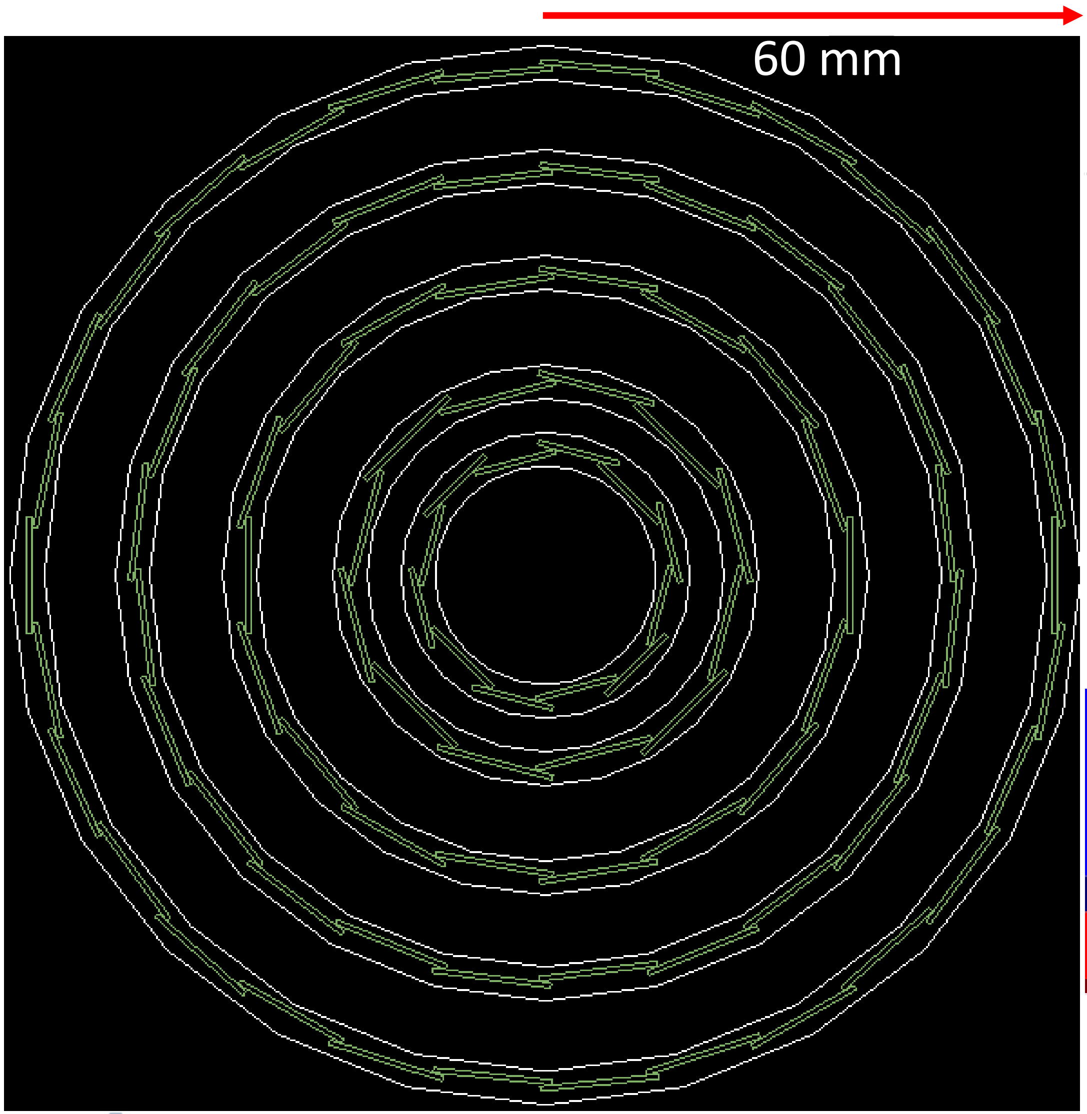
July 30th, 2014



Sidloi3 Vertex Detector Layout

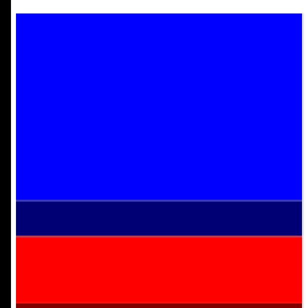


Sidloi3 Vertex Barrel Geometry



Layer Number	Radius (mm)	Module (mm)
Layer 1	15.05	9.6 x 125.0
Layer 2	23.03	13.8 x 125.0
Layer 3	35.79	13.8 x 125.0
Layer 4	47.50	13.8 x 125.0
Layer 5	59.90	13.8 x 125.0

Module Cross Section:



Carbon Fiber Support (.26 mm)

Epoxy (0.5 mm)

Silicon non-sensitive layer (0.093 mm)

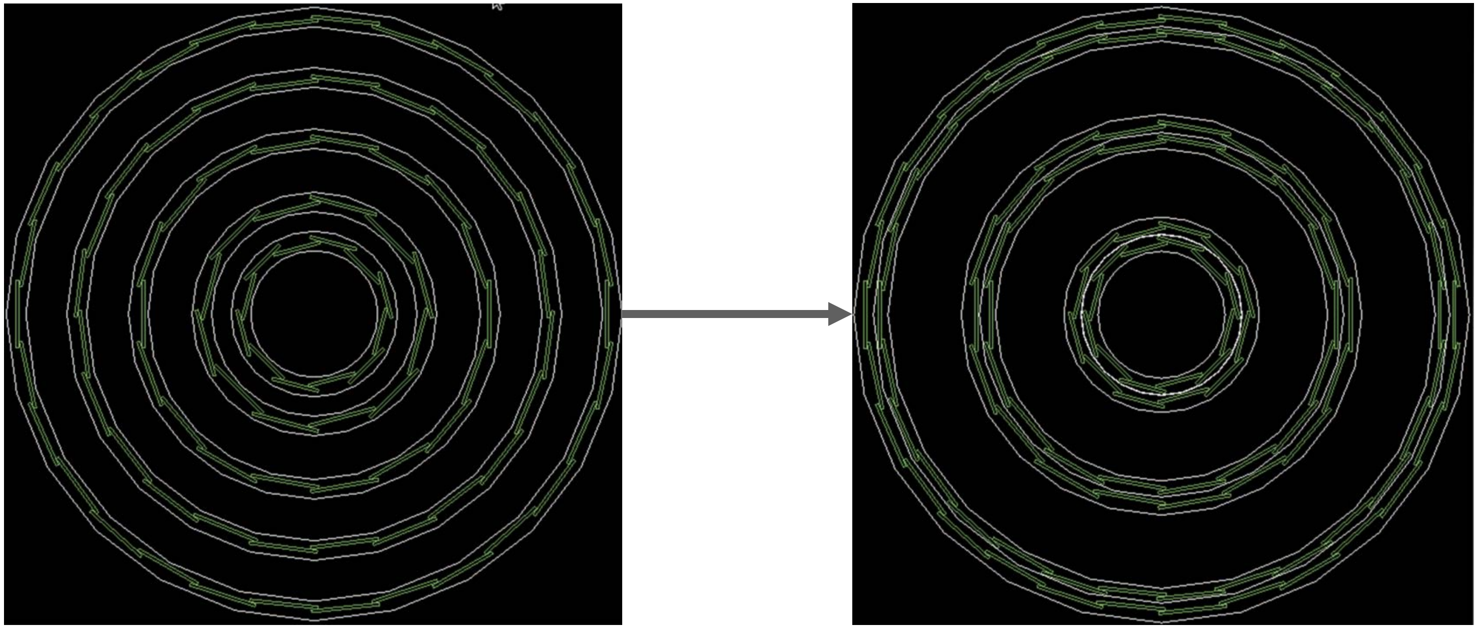
Silicon sensitive layer (.02 mm)

Goals

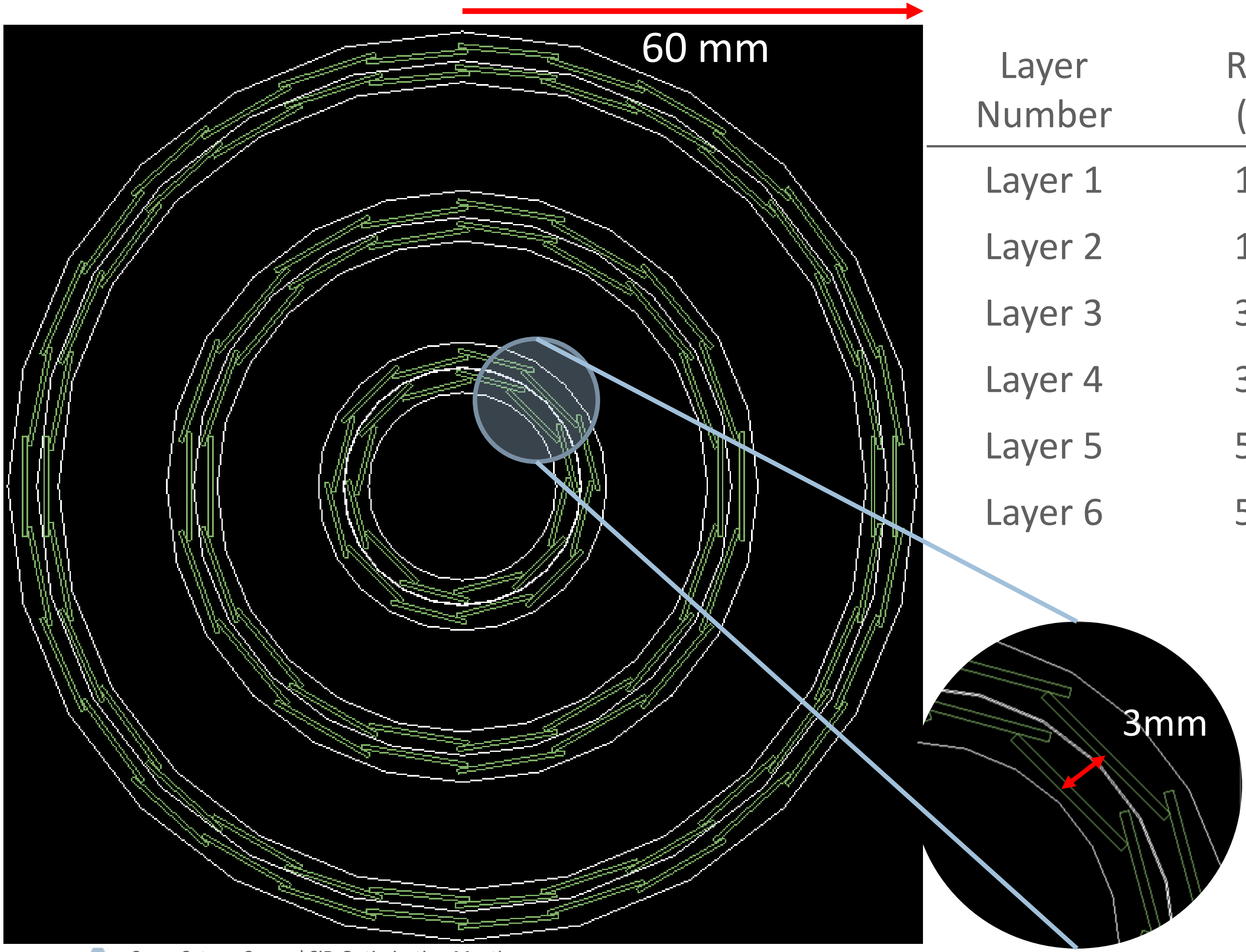
- Optimize Sidloi3 detector geometry
  - Study tracking performance of modified detector
  - Compare with Sidloi3 performance
- Modifications:
  - Vertex barrel geometry (5 single layers → 3 ‘doublet’ layers (total 6 layers)
  - Reduced material budget (0.5 silicon layers in vertex barrel modules)
    - Results pending
  - Pixelation of layers in tracker barrel (strips → pixels)
    - Results pending

Overview: Vertex Geometry Modification

- Modification to inner barrels of Sidloi3
  - 5 single layers → 3 'doublet' layers (total 6 layers)
  - No changes to rest of detector



Modified Vertex Barrel Geometry

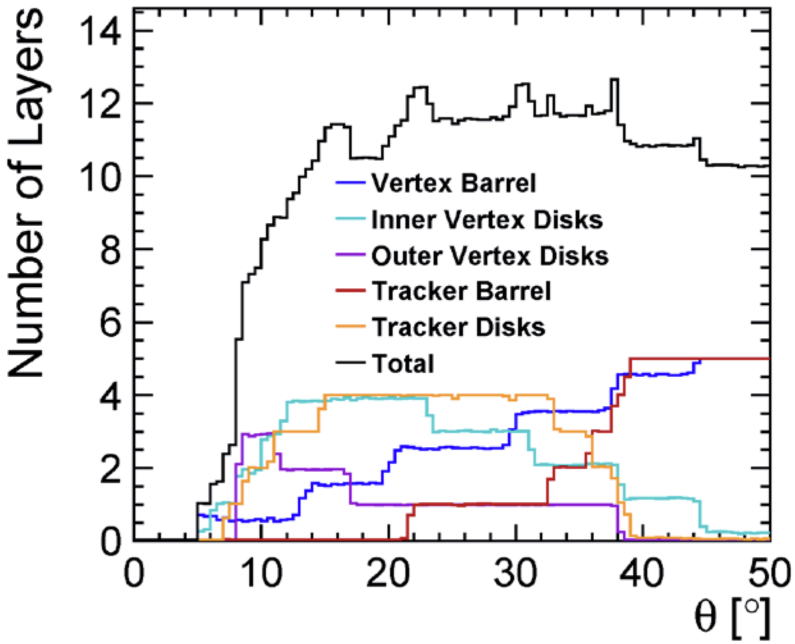


Layer Number	Radius (mm)	Module (mm)
Layer 1	15.05	9.6 x 125.0
Layer 2	18.05	10.6 x 125.0
Layer 3	35.79	13.8 x 125.0
Layer 4	38.79	14.8 x 125.0
Layer 5	56.90	13.8 x 125.0
Layer 6	59.90	13.8 x 125.0

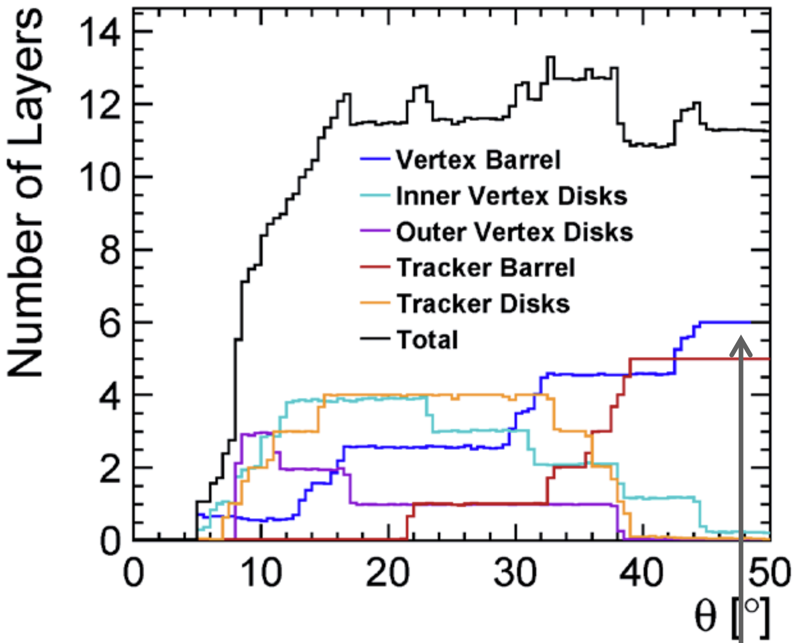
- Material budget per layer unchanged
- Modules for layers 2, 4 widened 1 mm to provide good overlap

Tracker Coverage vs. θ

Sidloi3



Modified Detector



Coverage same for all tracking systems except vertex barrel

Notice sixth layer for vertex barrel @ θ > 45 °

Overview: Tracking Studies

- Tracking performance studied with modified inner barrel
- Compared to tracking performance of Sidloi3
  - Single μ^-
    - Tracking efficiency vs. p_T, θ, Number of Hits
    - $\sigma(d_0)$, $\sigma(z_0)$ vs. θ (impact parameter resolutions)
    - $\sigma(p_T)/p_T^2$ vs. p (transverse momentum resolutions)
  - 6f_ttbar at 500 GeV
  - ttbb_6q_all at 1 TeV
    - Tracking efficiency vs. p_T, θ, Number of Hits, Distance to Closest Hit
    - $\sigma(d_0)$, $\sigma(z_0)$ vs. θ (impact parameter resolutions)
    - Fake rate vs. p_T, θ

Software for Simulation, Reconstruction, Analysis

- SLIC v3r0p3 (Geant4)
- org.lcsim 2.5
- LCIO v02-04-03, ROOT 5.34.03
  - pyLCIO, pyROOT bindings
- ILCDIRAC v6r8p28

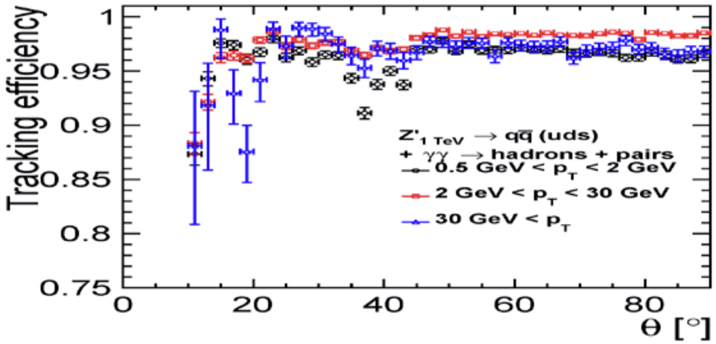
Tracking Strategies for Modified Detector

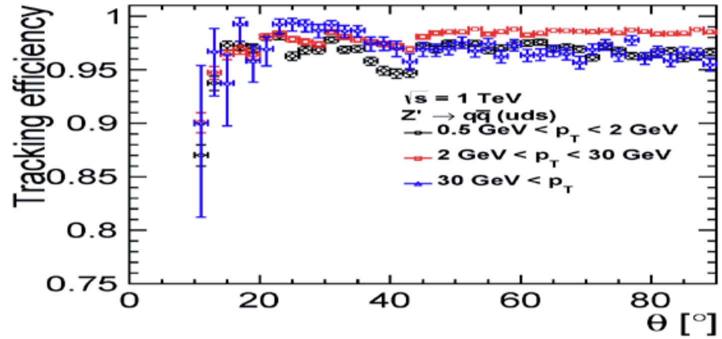
- Built locally (SLIC, lcsim) using simulations:
  - 500 ttbar events (for single μ^-, ttbar)
  - 500 ttbb_6q_all events (for ttbb)
- 'StrategyBuilder' driver steered to lcsim
  - Picks up tracks of MC particles in simulations
  - Generates groups of layers which cover all acceptable tracks
  - 3 'seed' layers, 1 'confirm' layer, additional 'extend' layers
  - "Inside-out" strategies, as in DBD
    - Two innermost vertex barrel layers excluded from seeding
    - Any layer can be an 'extend' layer

Comparison to Sidloi3 Z_qq_uds, 1 TeV DBD Plots (Software check)

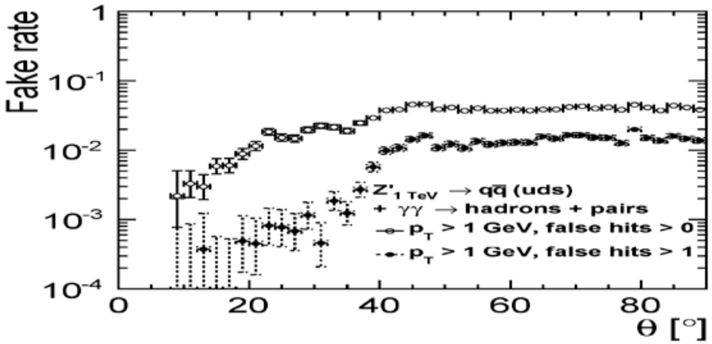
DBD | Our plots

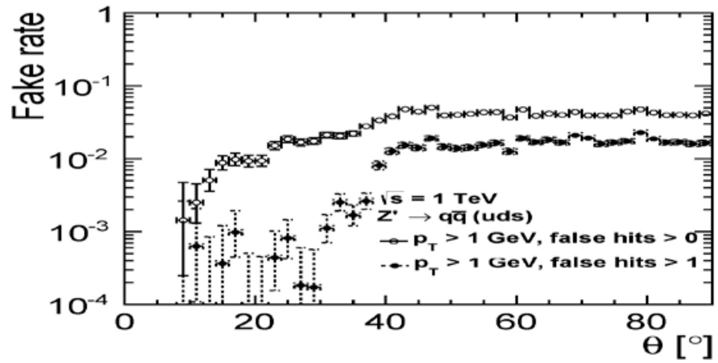
Efficiency vs. θ



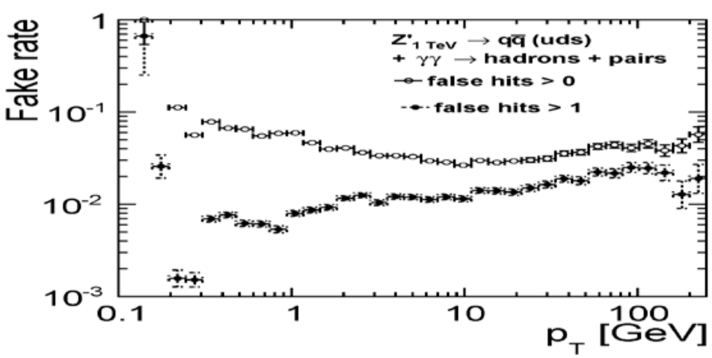


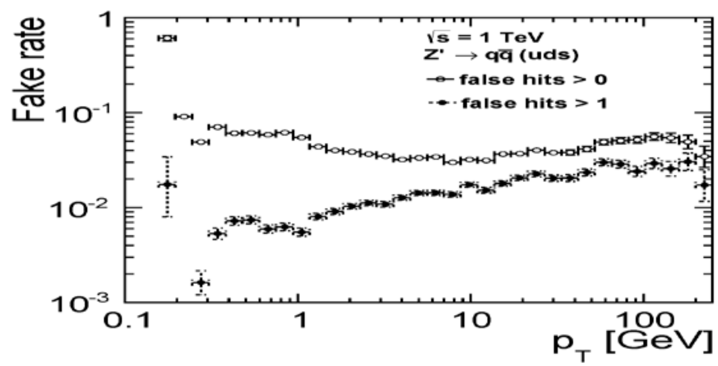
Fake Rate vs. θ





Fake Rate vs. p_T

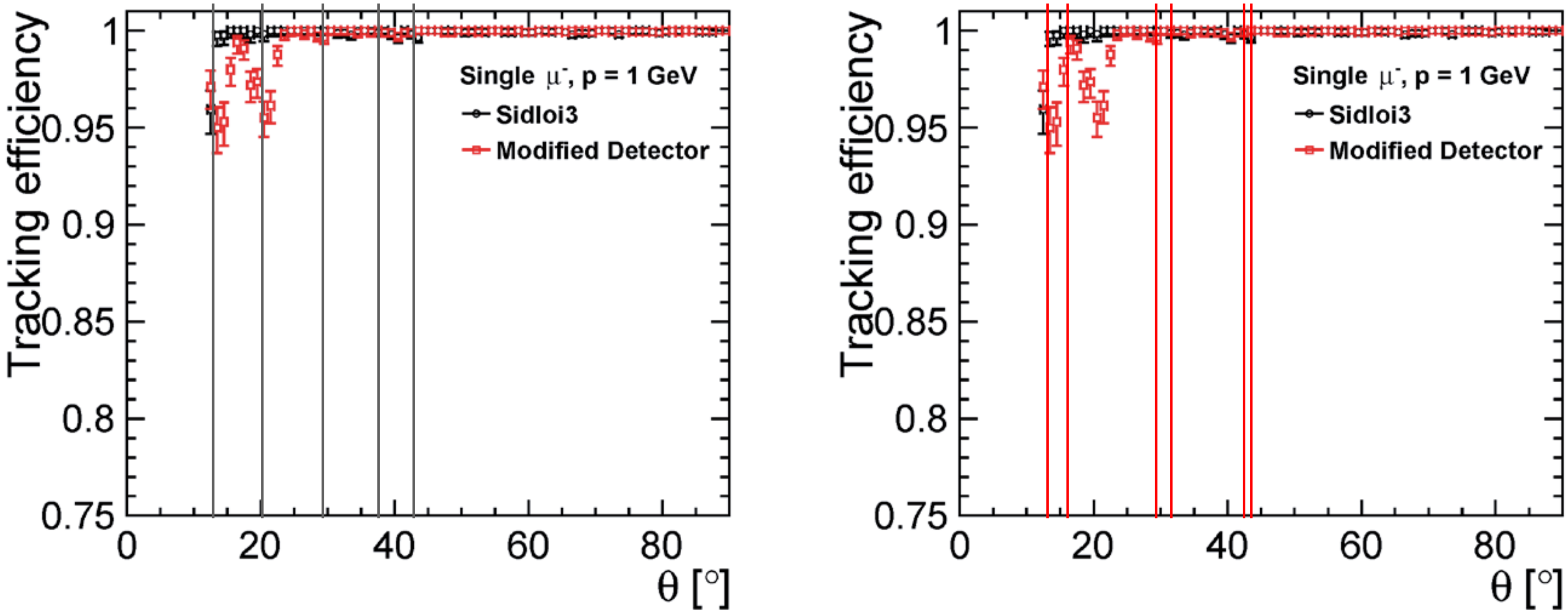




(Our data do not include beam induced background.)

Tracking Performance
Single μ^-

Tracking Performance
Single μ⁻, Efficiency vs. θ

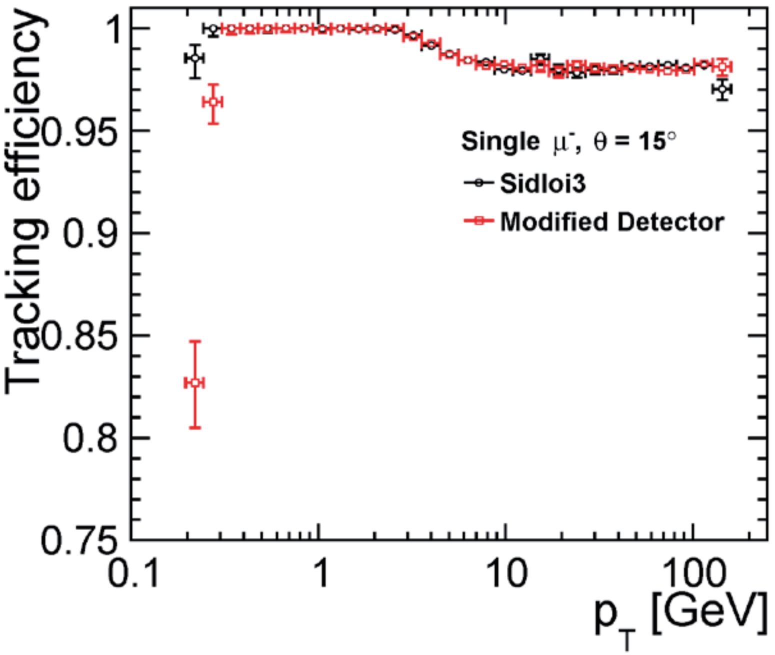


Vertical bars illustrate vertex barrel, endcap junctions

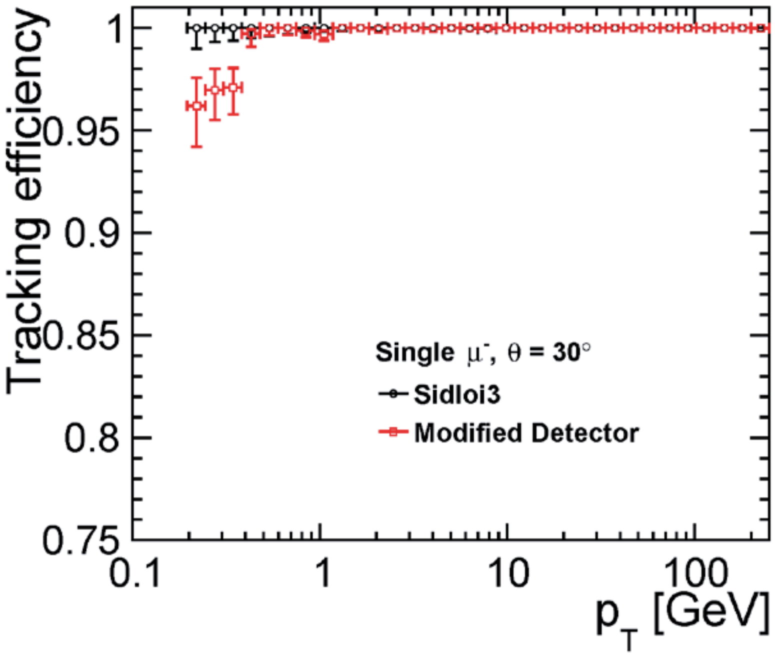
Modified detector shows lower efficiency for p = 1 GeV at θ < 30°

Tracking Performance
Single μ^-, Efficiency vs. p_T

θ = 15°



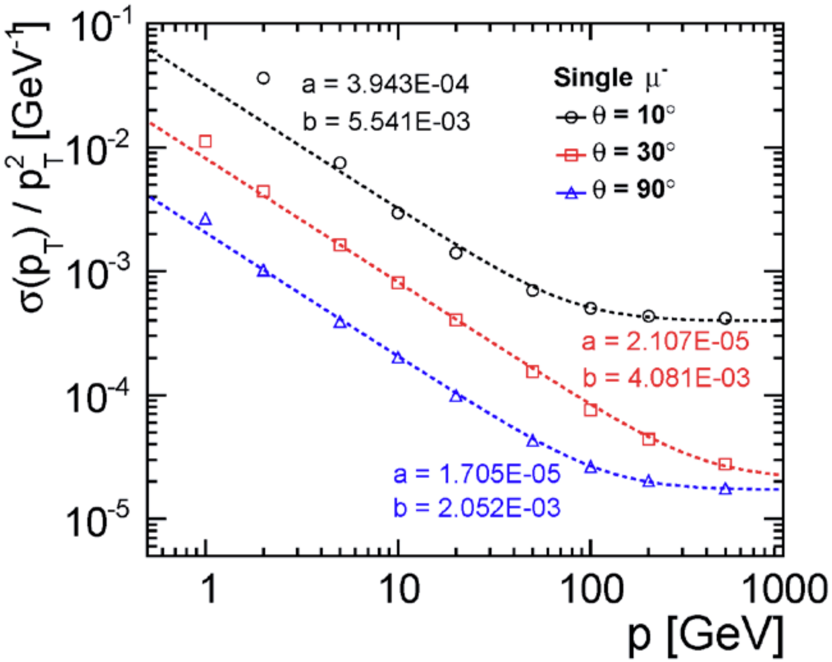
θ = 30°



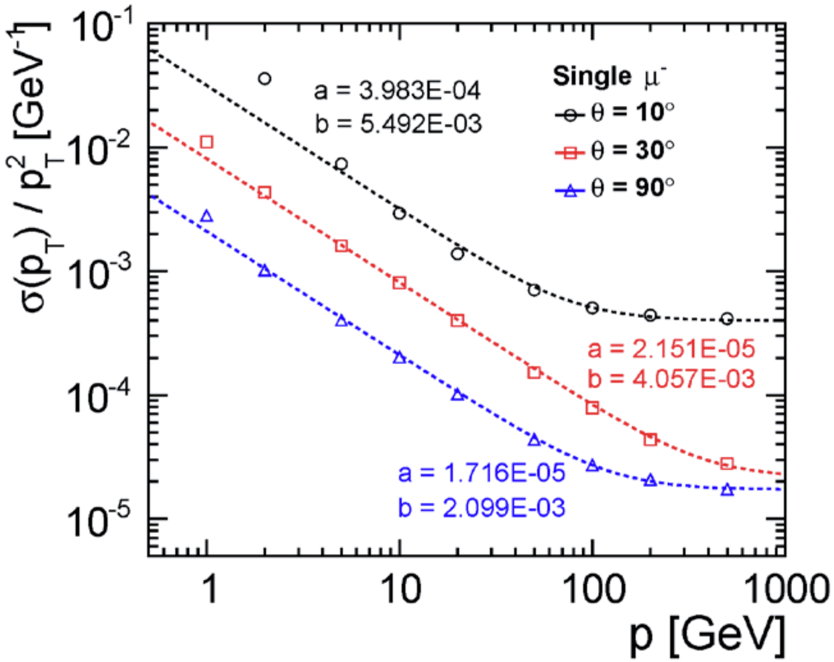
Modified detector shows slightly lower efficiency for θ = 15°, 30° at $p_T < 1$ GeV

Tracking Performance
Single μ$^-$, $\sigma(p_T)/p_T^2$

Sidloi3



Modified Inner Barrel

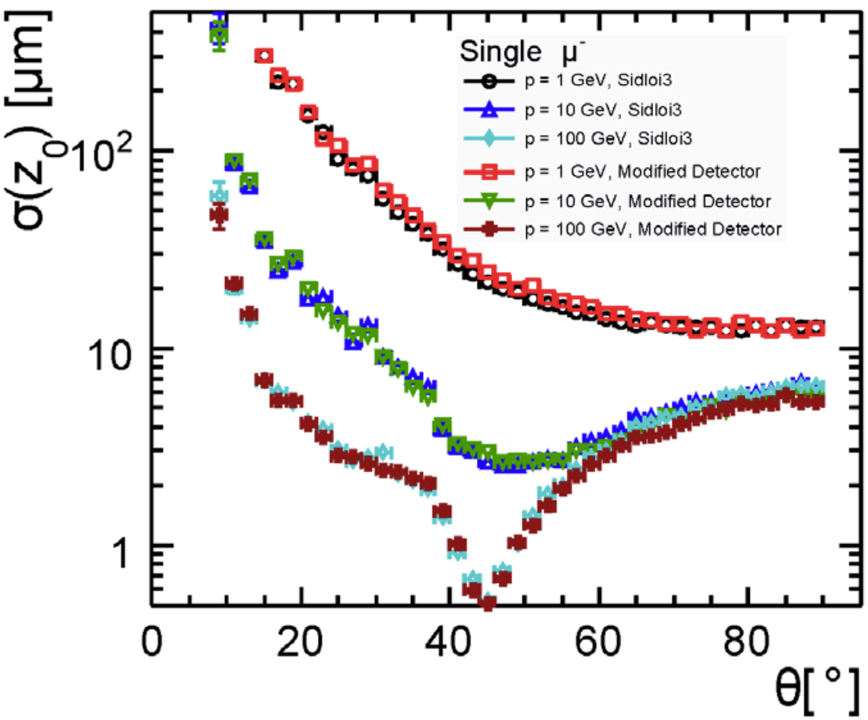


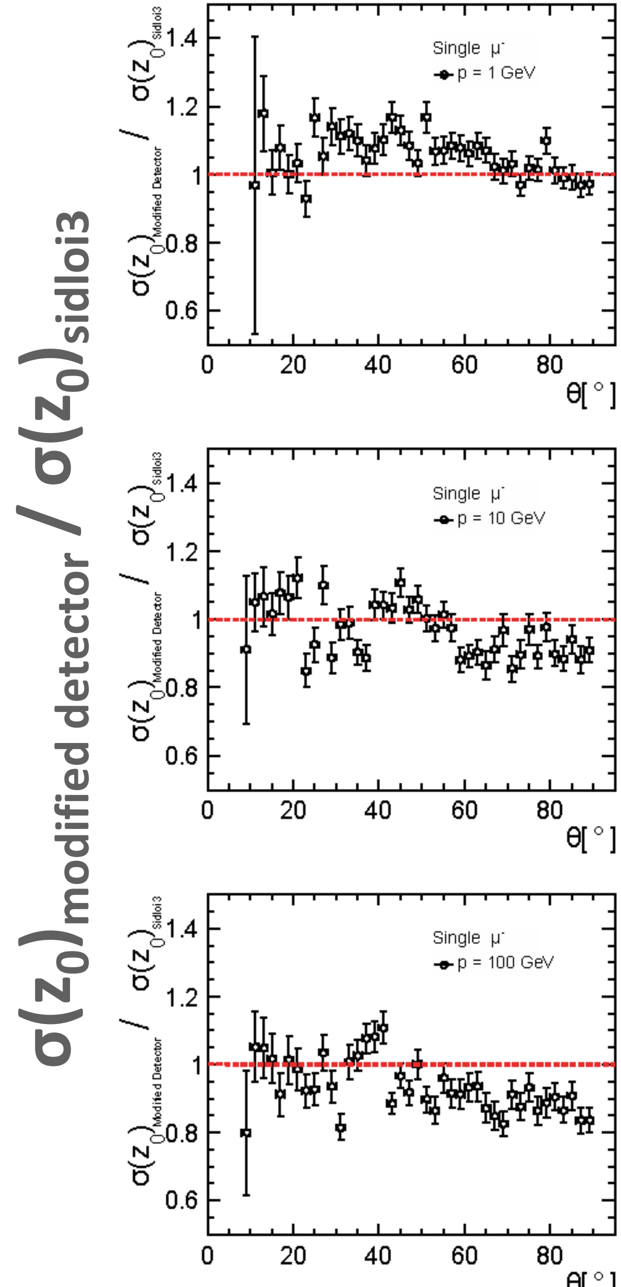
Parameterization: $\frac{\sigma(p_T)}{{p_T}^2} = \mathrm{a} \oplus \frac{b}{p \sin\theta}$

No significant change in p_T resolution

Tracking Performance
Single μ⁻, $\sigma(z_0)$ vs. θ

$\sigma(z_0)$ vs. θ





p = 1 GeV

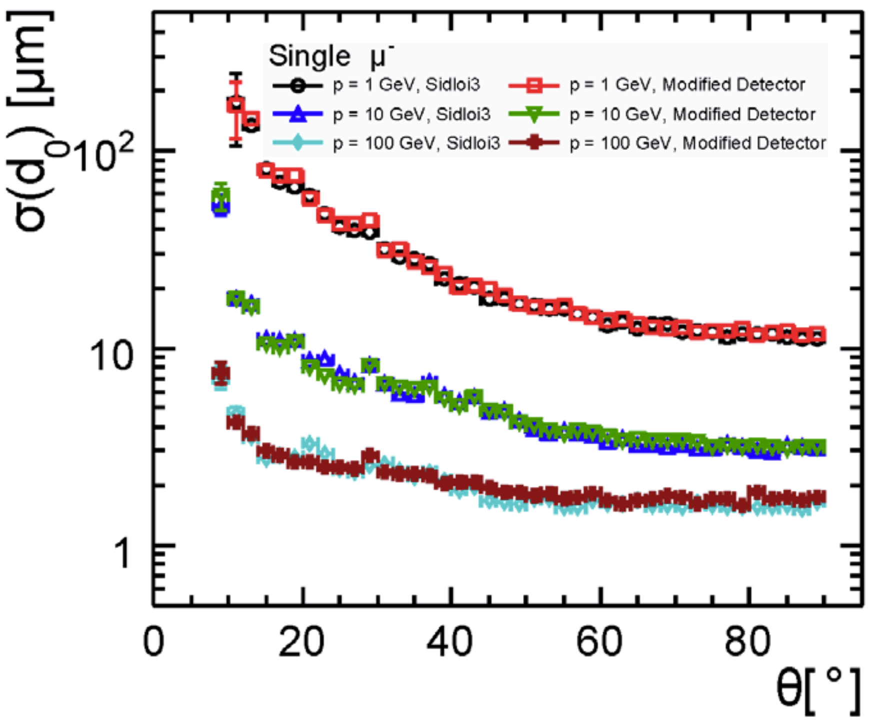
p = 10 GeV

p = 100 GeV

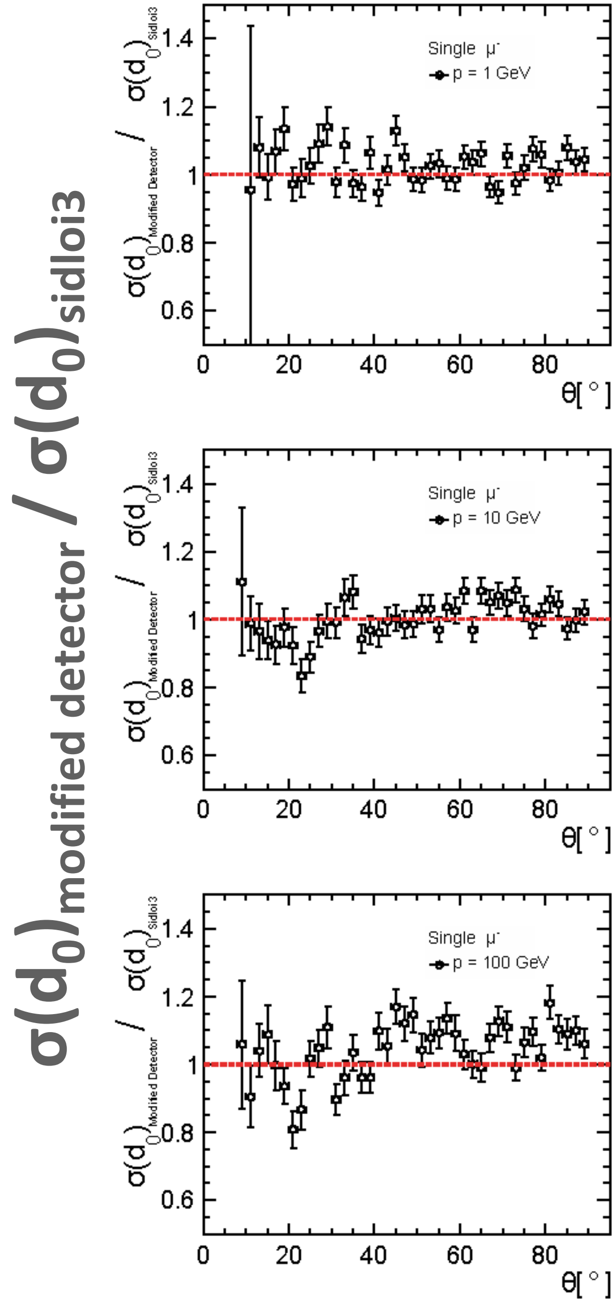
Modified detector has better z-axis impact parameter resolution for θ > 60°,
worse z-axis impact parameter resolution for θ < 60°

Tracking Performance
Single μ⁻, σ(d$_0$) vs. θ

σ(d$_0$) vs. θ



Modified detector has worse transverse impact parameter resolution for most polar angles



p = 1 GeV

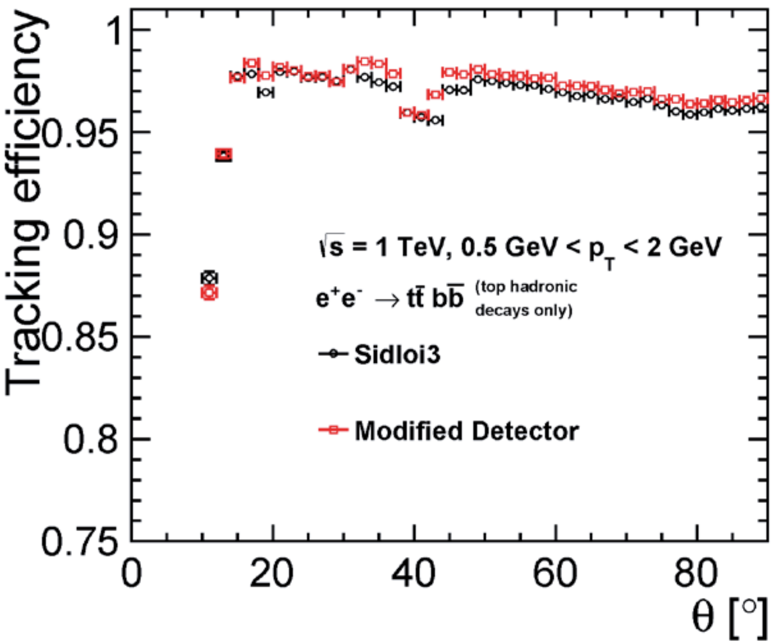
p = 10 GeV

p = 100 GeV

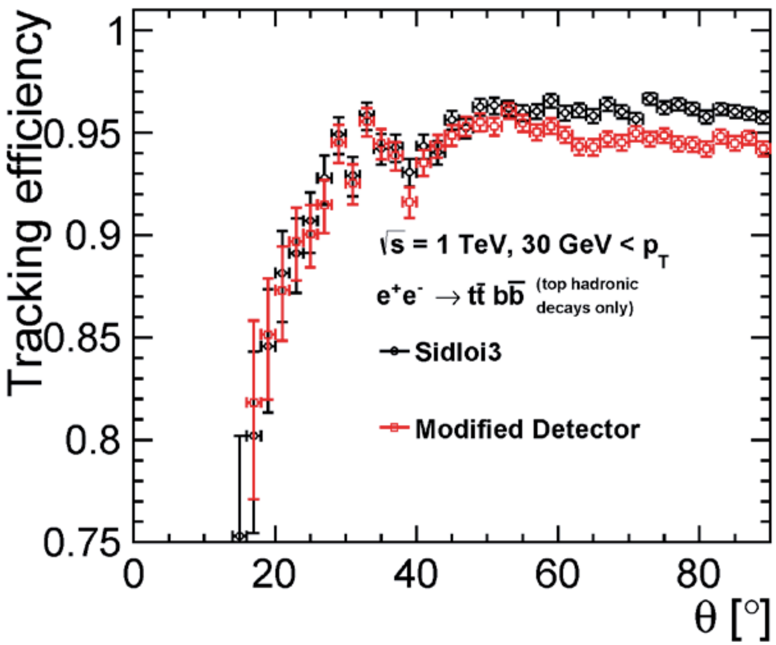
Tracking Performance
ttbb_6q_all, $\sqrt{s}$ = 1 TeV

Tracking Performance
ttbb_6q_all, $\sqrt{s}$ = 1 TeV, Efficiency vs. θ

0.5 GeV < p_T < 2 GeV



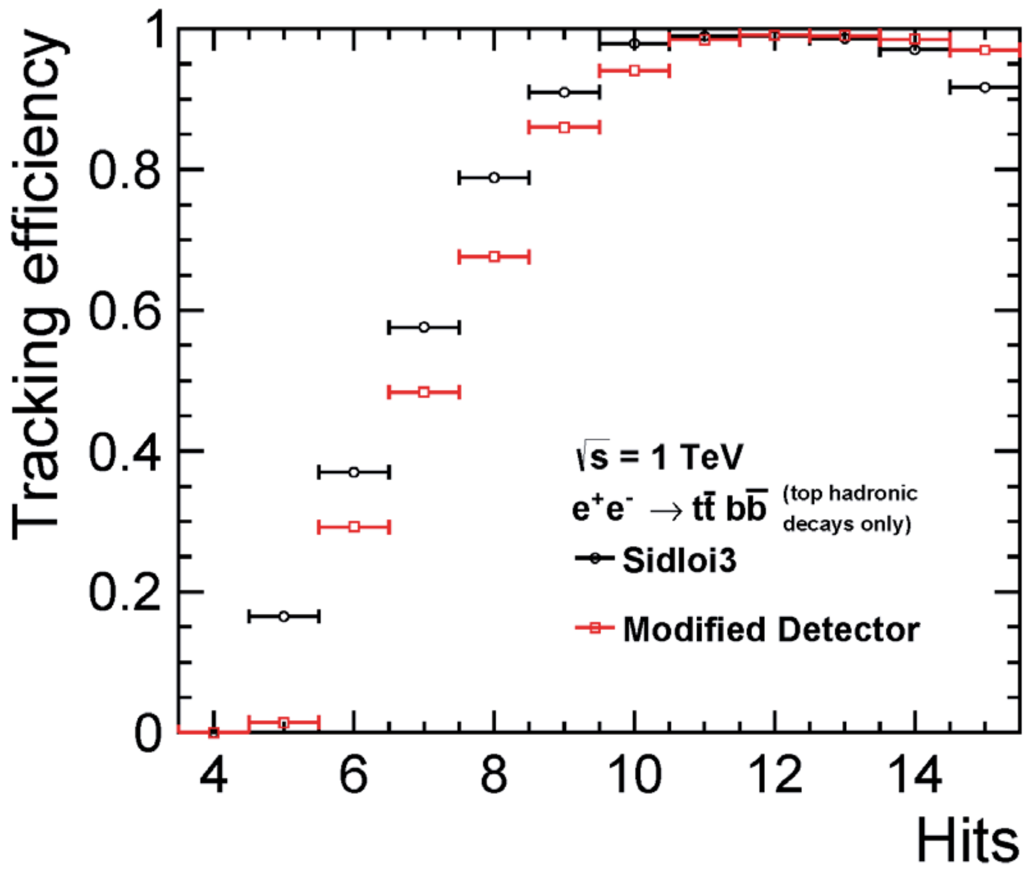
p_T > 30 GeV



Modified detector shows lower efficiency for p_T > 30 GeV at θ > 40°

Modified detector shows slightly higher efficiency for 0.5 GeV < p_T < 2 GeV at θ > 35°

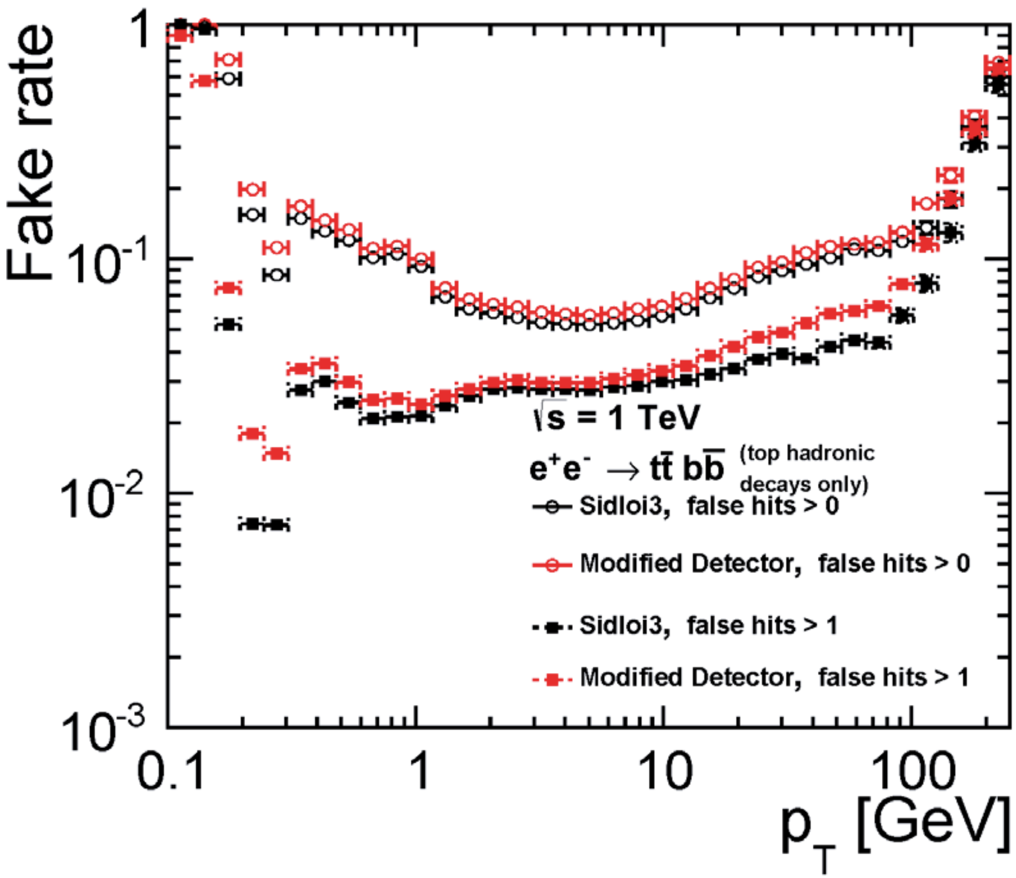
Tracking Performance
ttbb_6q_all, $\sqrt{s}$ = 1 TeV, Efficiency vs. Number of Hits



Modified detector shows lower efficiency for lower numbers of hits

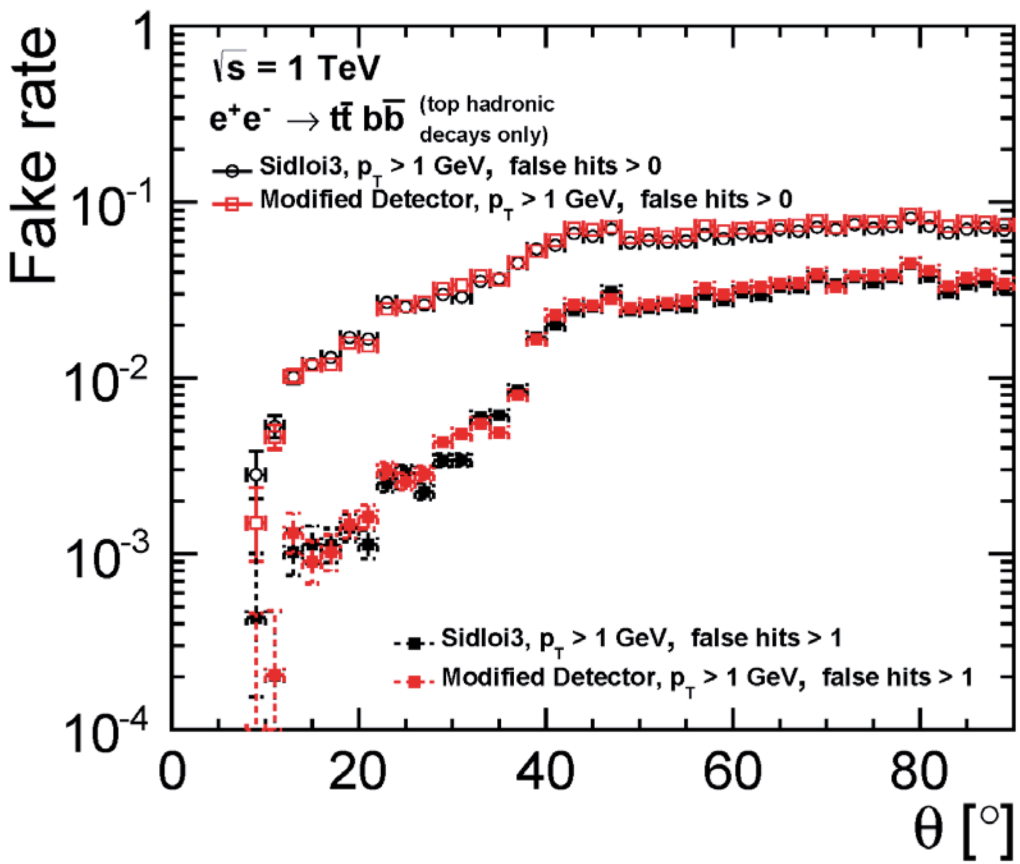
As numbers of hits increase, both detectors reach same peak efficiency

Tracking Performance
ttbb_6q_all, $\sqrt{s}$ = 1 TeV, Fake Rate vs. p_T



Modified detector shows higher fake rate for wide range of p_T

Tracking Performance
ttbb_6q_all, $\sqrt{s}$ = 1 TeV, Fake Rate vs. θ

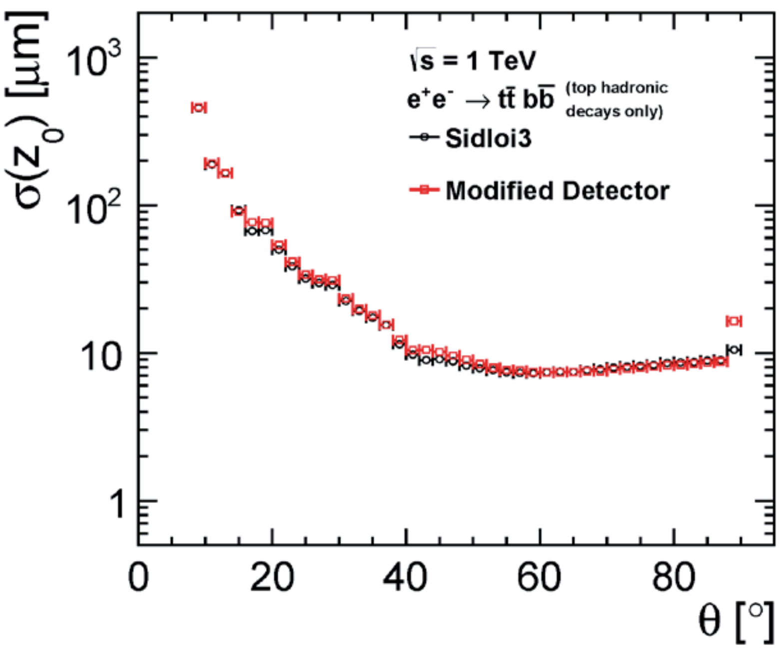


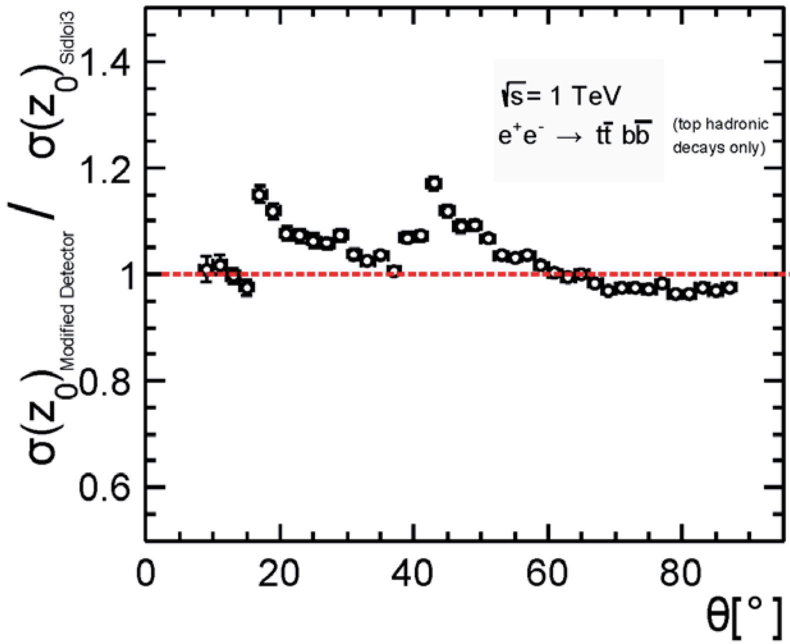
Modified detector shows higher fake rate for wide range of θ

Difference in fake rate not as pronounced at low θ (< 40°)

Tracking Performance
ttbb_6q_all, $\sqrt{s}$ = 1 TeV, $\sigma(z_0)$ vs. θ

Z-axis Impact Parameter Resolution **$\sigma(z_0)_{\text{modified detector}} / \sigma(z_0)_{\text{sidloi3}}$**

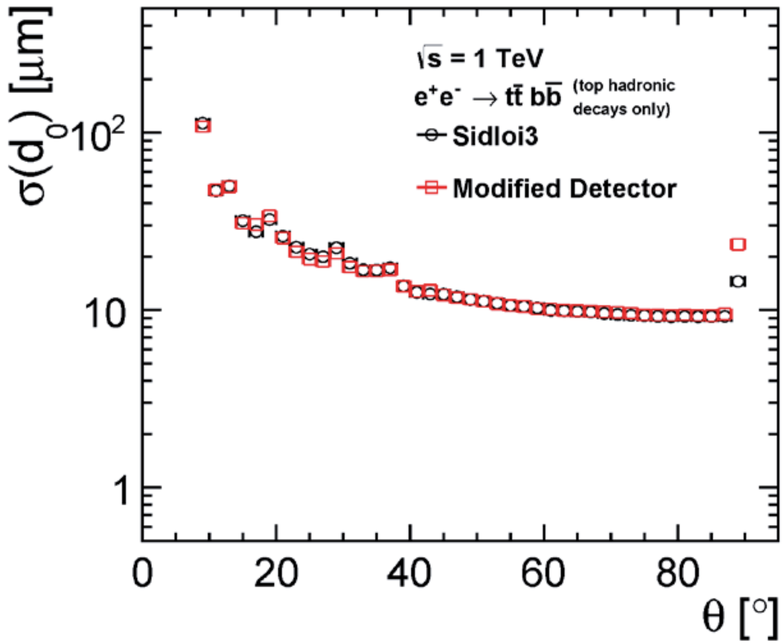




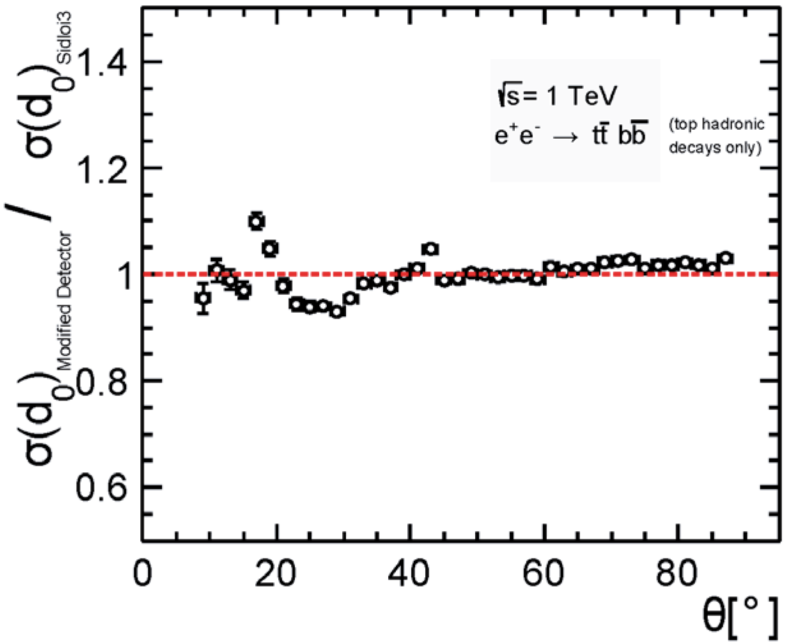
Modified detector shows slightly better z-axis impact parameter resolution for θ > 60°, worse z-axis impact parameter resolution for θ < 60°

Tracking Performance
ttbb_6q_all, $\sqrt{s}$ = 1 TeV, $\sigma(d_0)$ vs. θ

Transverse Impact Parameter Resolution



$\sigma(d_0)_{\text{modified detector}}$ / $\sigma(d_0)_{\text{sidloi3}}$

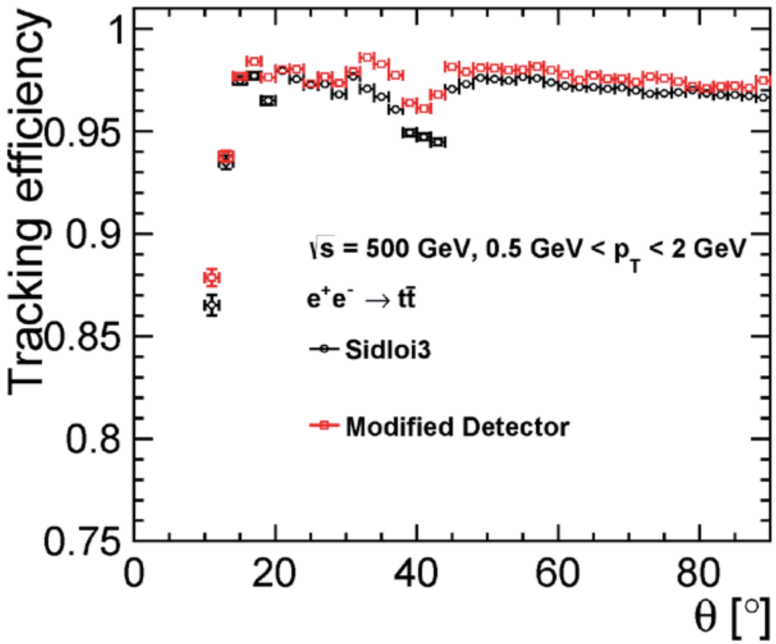


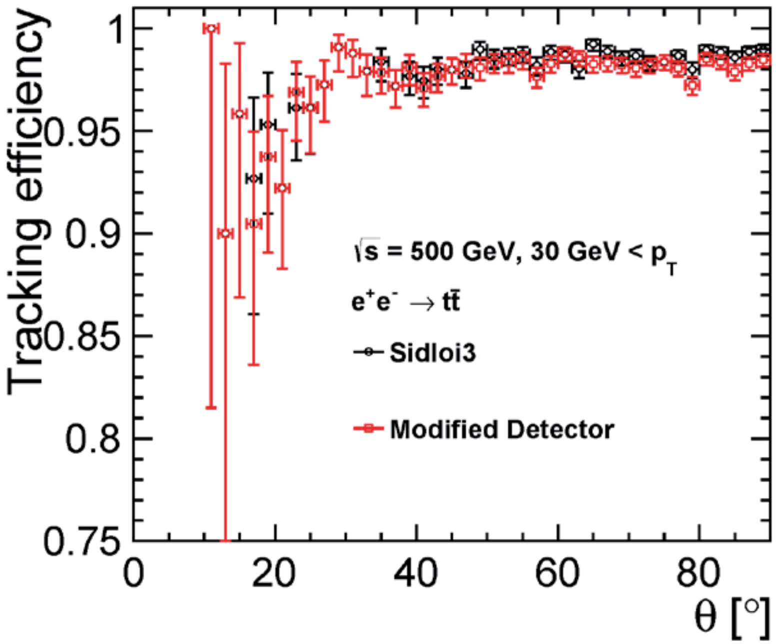
No significant change in transverse impact parameter resolution

Tracking Performance
6f_ttbar, $\sqrt{s}$ = 500 GeV

Tracking Performance
6f_ttbar, $\sqrt{s}$ = 500 GeV, Efficiency vs. θ

0.5 GeV < p_T < 2 GeV **p_T > 30 GeV**

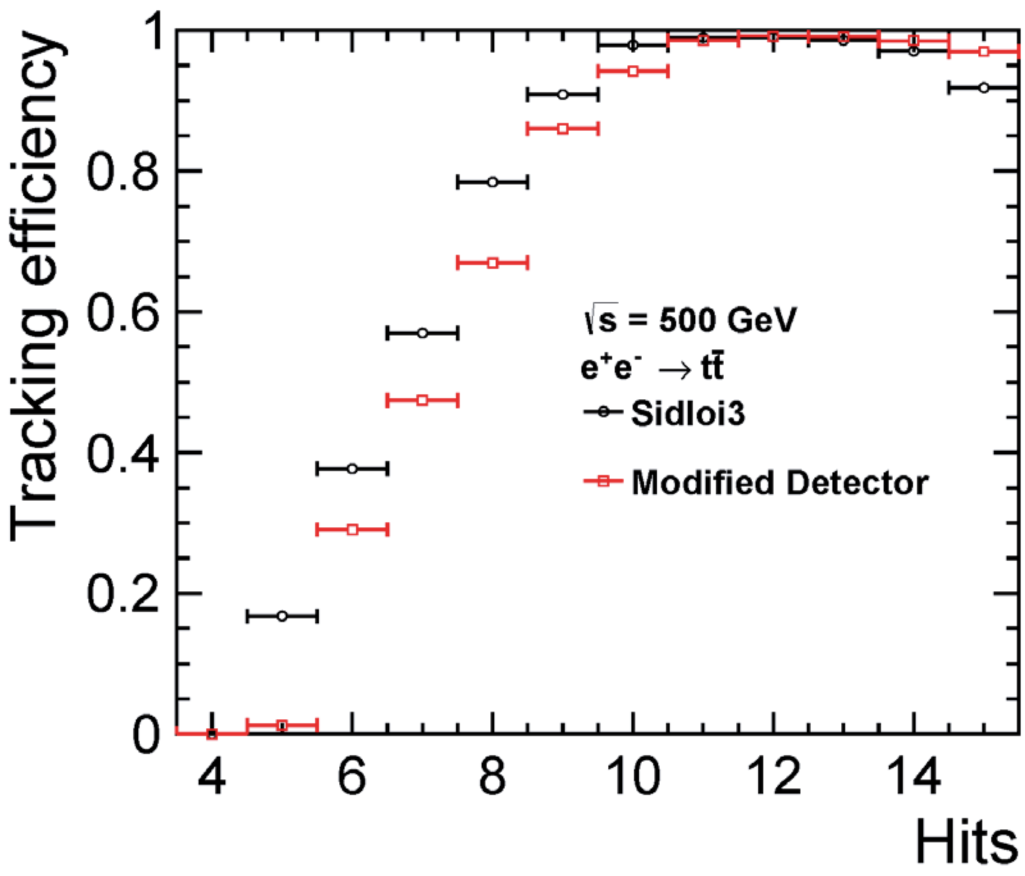




Modified detector shows slightly lower efficiency for p_T > 30 GeV at θ > 40°

Modified detector shows slightly higher efficiency for 0.5 GeV < p_T < 2 GeV for θ > 35°

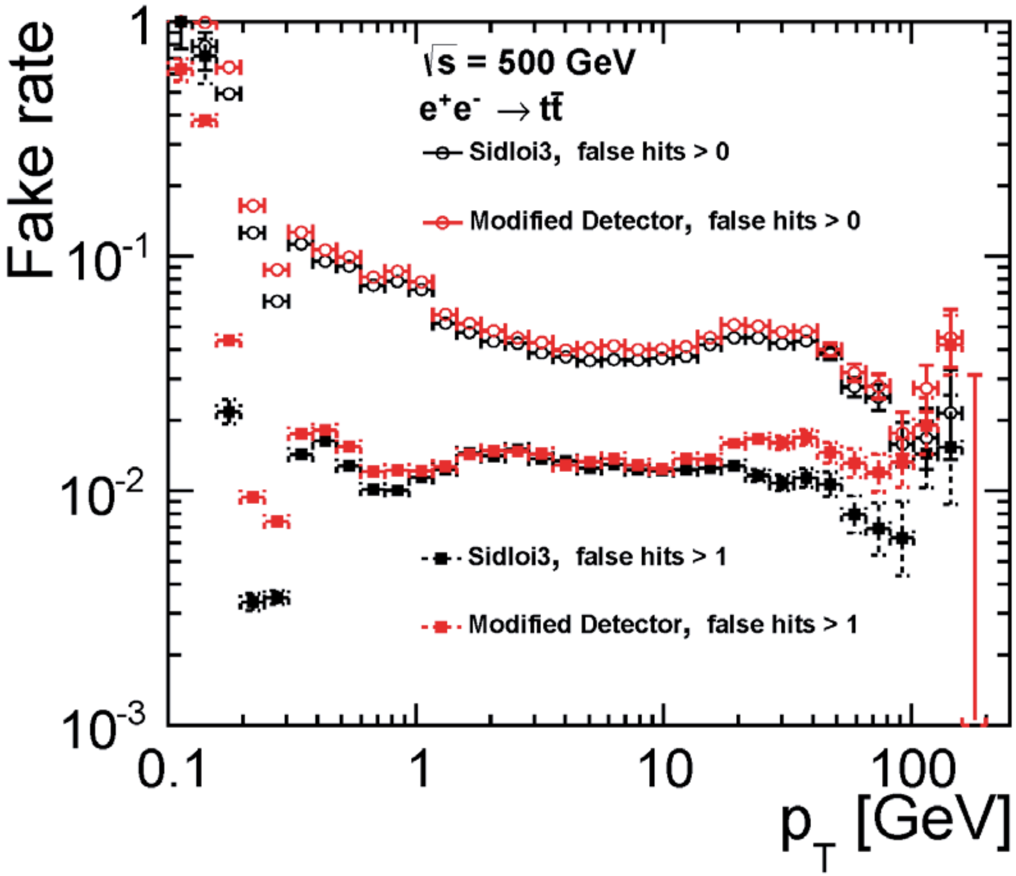
Tracking Performance
6f_ttbar, $\sqrt{s}$ = 500 TeV, Efficiency vs. Number of Hits



Modified detector shows lower efficiency for lower numbers of hits

As numbers of hits increase, both detectors reach same peak efficiency

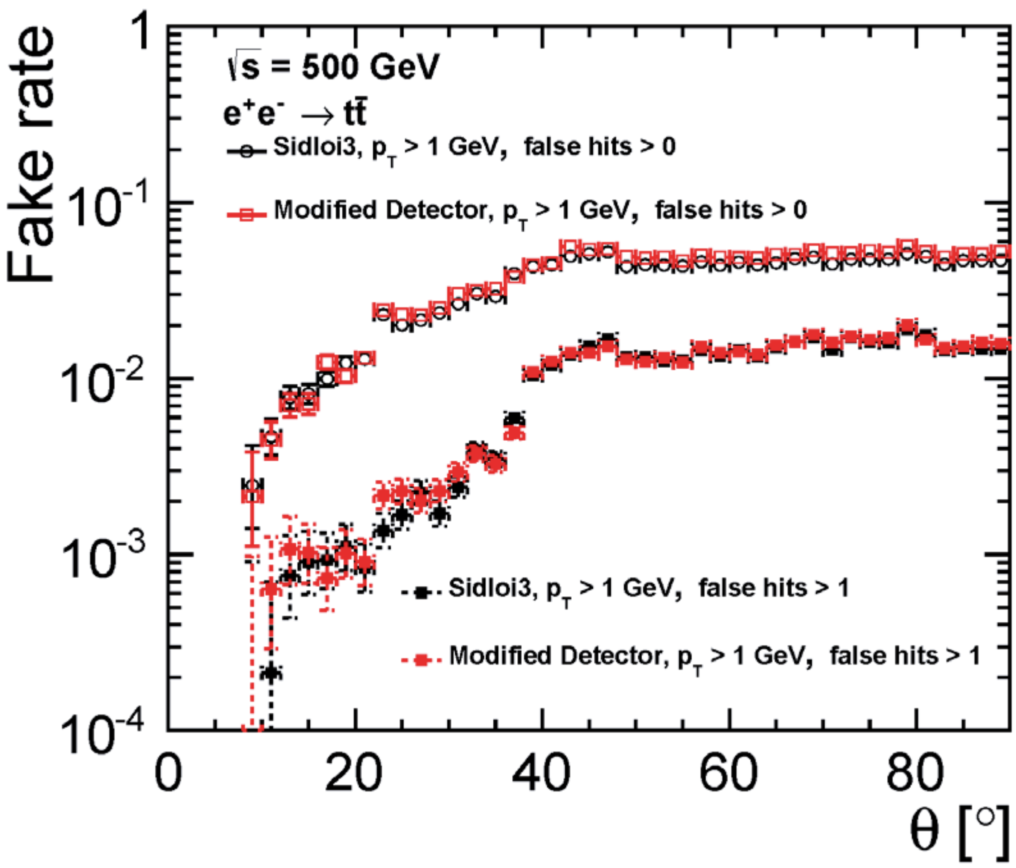
Tracking Performance
6f_ttbar, $\sqrt{s}$ = 500 GeV, Fake Rate vs. p_T



Modified detector shows higher fake rate wide range of p_T

Difference in fake rate not as pronounced for 2 GeV < p_T < 10 GeV

Tracking Performance
6f_ttbar, $\sqrt{s}$ = 500 GeV, Fake Rate vs. θ

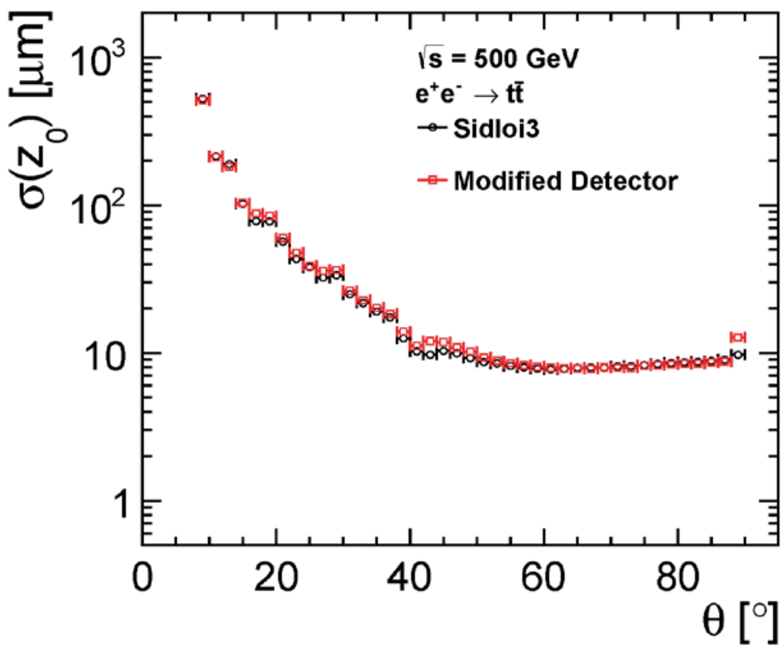


Modified detector shows higher fake rate for 5° < θ < 90°

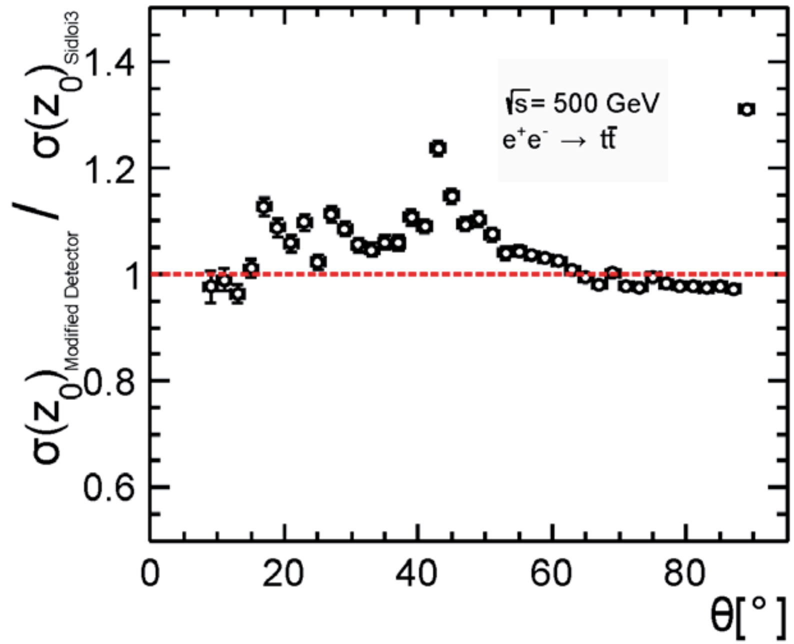
Difference in fake rate not as pronounced at θ < 20°

Tracking Performance
6f_ttbar, $\sqrt{s}$ = 500 TeV, $\sigma(z_0)$ vs. θ

Z-axis Impact Parameter Resolution



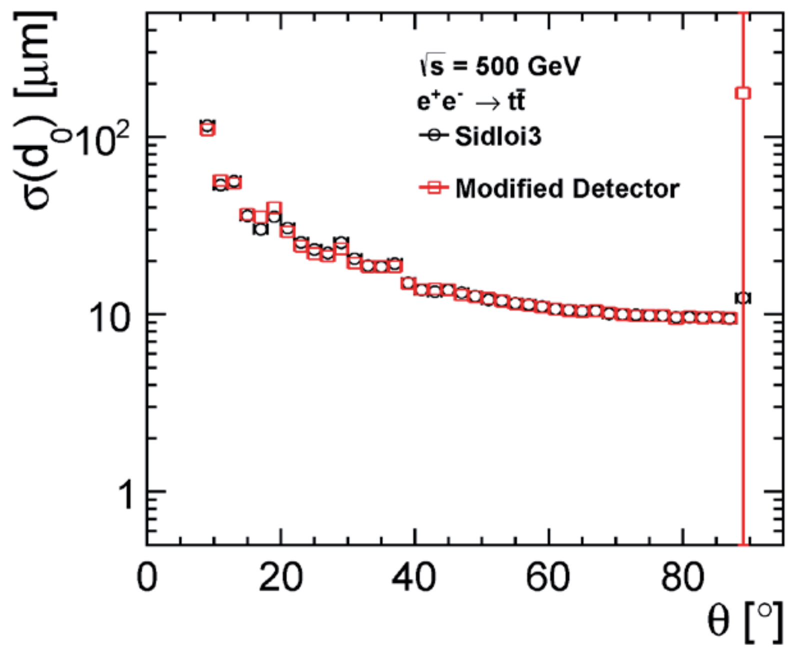
$\sigma(z_0)_{modified\ detector}$ / $\sigma(z_0)_{sidloi3}$



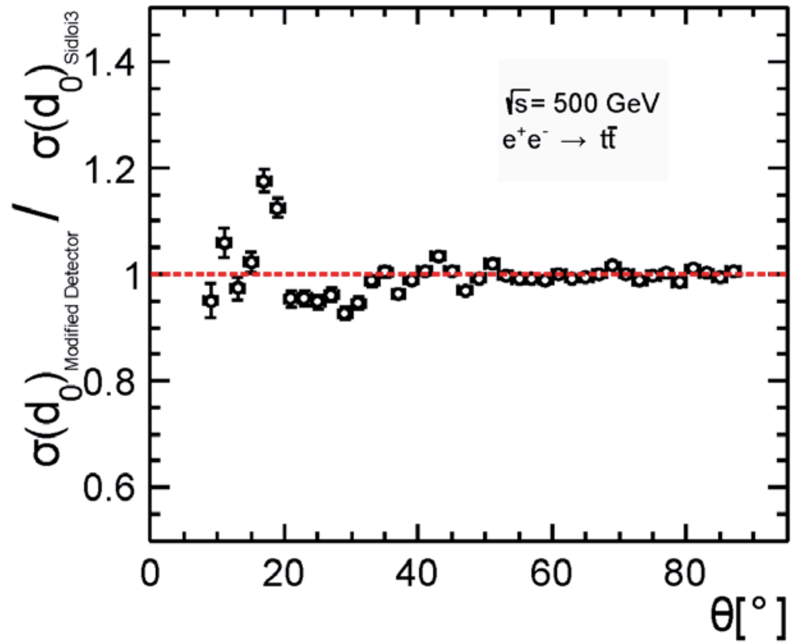
Modified detector shows slightly better z-axis impact parameter resolution θ > 60°, worse z-axis impact parameter resolution for θ < 60°

Tracking Performance
6f_ttbar, $\sqrt{s}$ = 500 TeV, $\sigma(d_0)$ vs. θ

Transverse Impact Parameter Resolution



$\sigma(d_0)_{\text{modified detector}}$ / $\sigma(d_0)_{\text{sidloi3}}$



No significant change in transverse impact parameter resolution

Summary

- Tracking performance of Sidloi3 with inner barrel modification
  - 5 single layers → 3 'doublet' layers (total 6 layers)
  - Rest of detector remains the same
- Single μ^-, ttbb_6q_all at 1 TeV, 6f_ttbar at 500 GeV

- Modified detector has higher fake rate for $5° < \theta < 90°$, 0.2 GeV $< p_T < 200$ GeV
- Modified detector has higher efficiency for low p_T particles at $\theta > 35°$
- Modified detector has lower efficiency for low p_T muons at $\theta < 30°$
- Modified detector has lower efficiency for high p_T (> 30 GeV) particles at $\theta > 40°$
- Modified detector has better z-axis impact parameter resolution for $\theta > 60°$, worse for $\theta < 60°$
- Other measures of performance (momentum resolution, transverse impact parameter resolution) similar for both detectors

Conclusions

- Our studies indicate that:
  - Double layer geometry has a significantly higher fake rate for wide range of transverse momentum and polar angle
  - Double layer geometry performs worse for low momentum, low polar angle tracks
  - Double layer geometry performs slightly better for low momentum, high polar angle tracks
  - No conclusions yet for reduced material budget and pixelated tracker geometries

- Thanks to Christian Grefe for indispensable assistance, plotting code, software introduction
- Thanks to Lucie Linssen for my stay at CERN
- Thanks to Norman Graf, Jeremy McCormick for software help

Additional Slides

Some Analysis Details

- Findable particle definition:
  - Charged particles originating within ±5 cm from interaction point with line-of-sight distance at least 5 cm
- Successfully reconstructed criterion:
  - Only tracks with at most one falsely assigned hit are considered successfully reconstructed
- Tracking efficiency = $N_{\text{successfully reconstructed}} / N_{\text{findable}}$

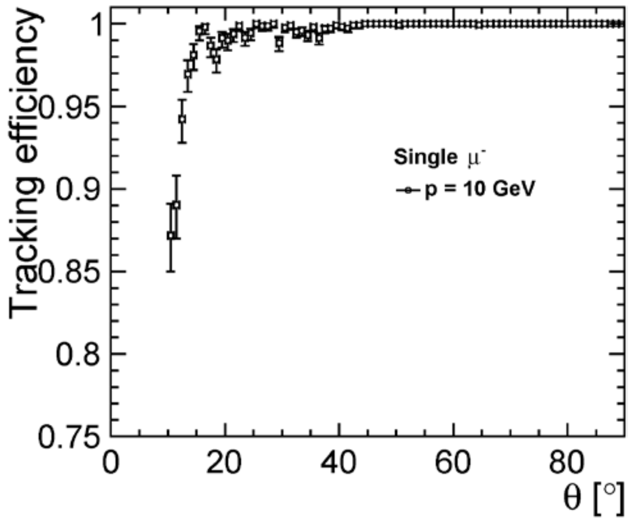
Cuts for Acceptable Tracks for Tracking Strategies

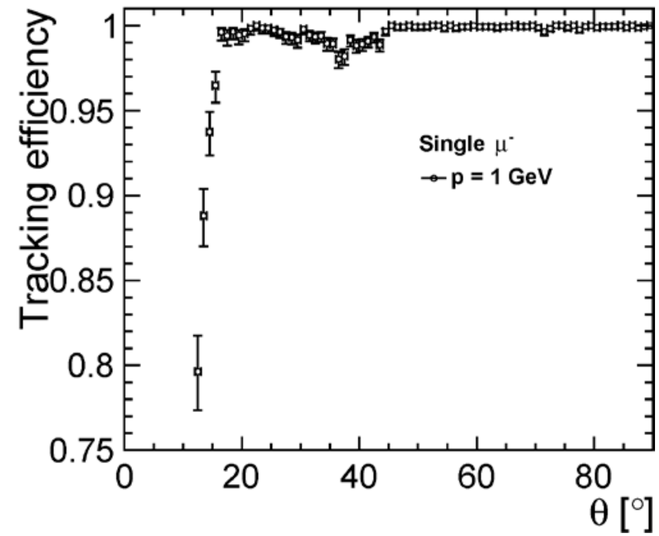
- Default cuts:
  - MinPT = 0.2
  - MinHits = 7
  - MinConfirm = 1
  - MaxDCA = 5.0
  - MaxZ0 = 10.0
  - MaxChisq = 10.0
  - BadHitChisq = 5.0
- Starting strategy cut (barrel only, for low momentum, high polar angle particles)
  - MinHits = 6
  - Rest is same as default cuts

Comparison to Sidloi3 Muon DBD Plots (Software check)
Single μ⁻, Efficiency vs. θ

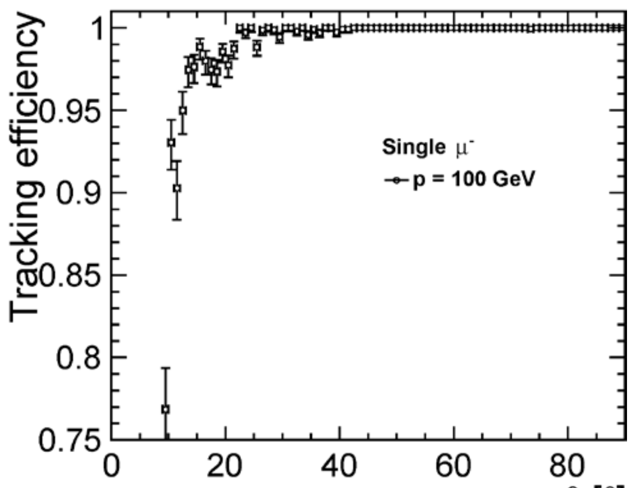
DBD plots

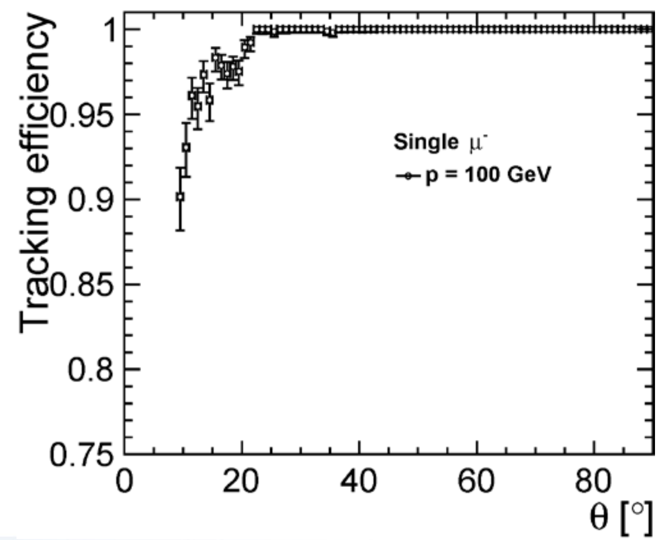
Our plots





p = 10 GeV

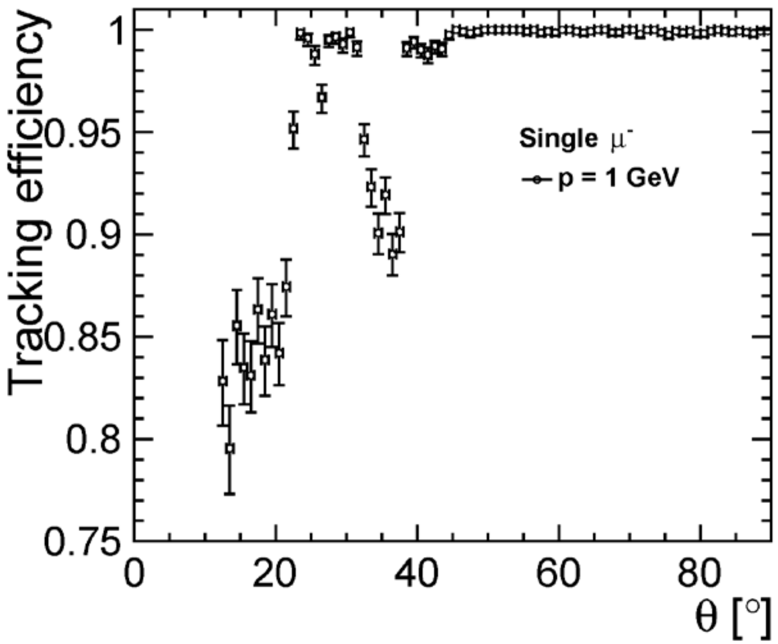




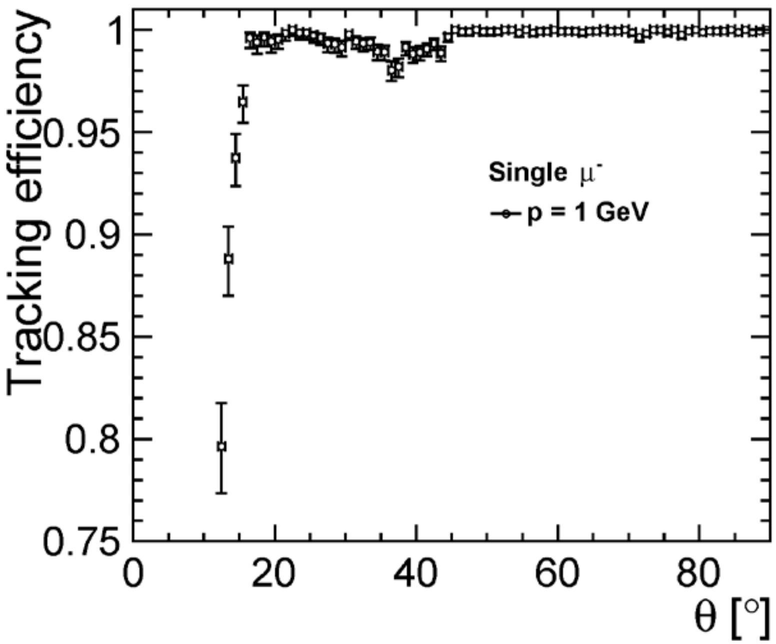
p = 100 GeV

Discrepancy with Sidloi3 Muon DBD Single μ^-, 1 GeV, Efficiency vs. θ

DBD Plots

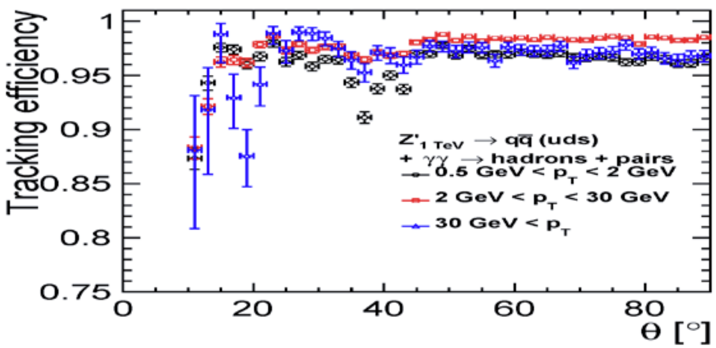


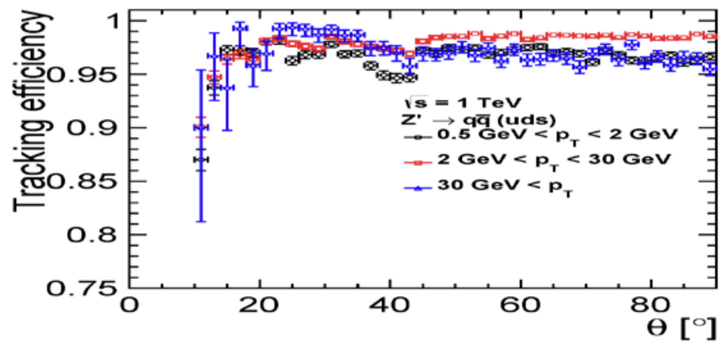
Our Plots



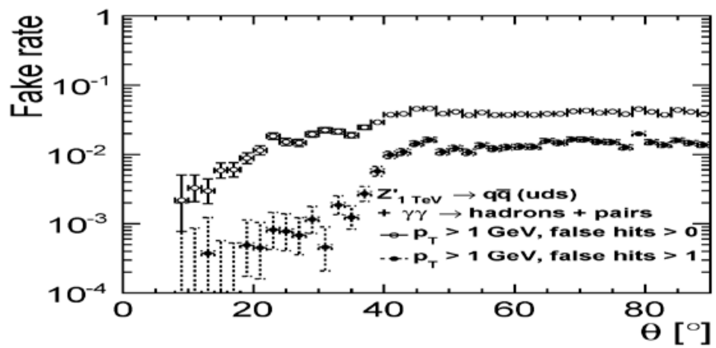
Comparison to Sidloi3 Z_qq_uds, 1 TeV DBD Plots (Software check)

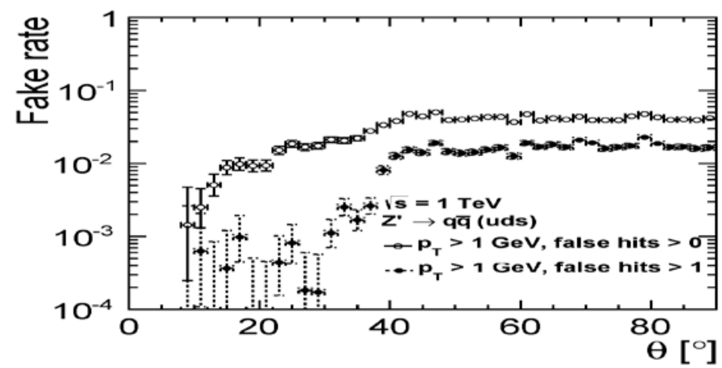
DBD | Our plots



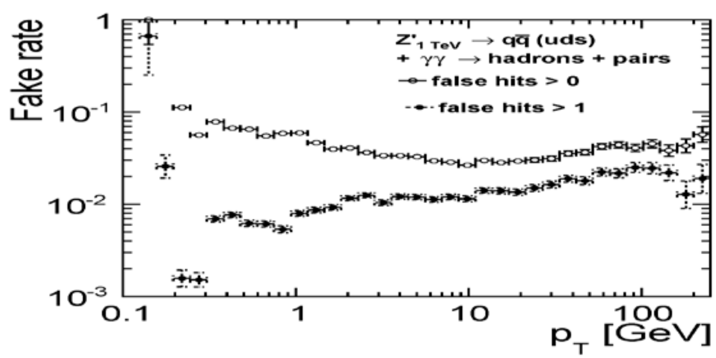


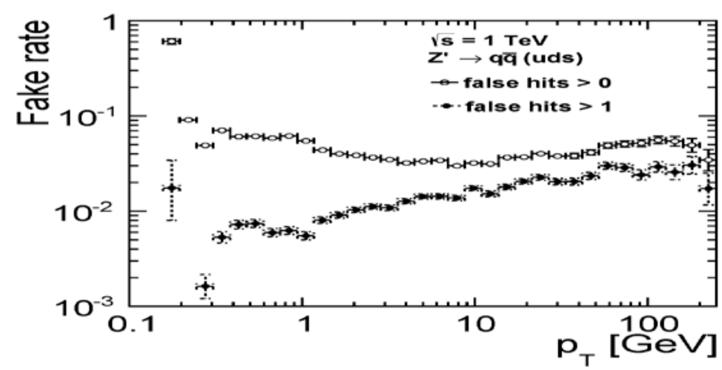
Efficiency vs. θ





Fake Rate vs. θ



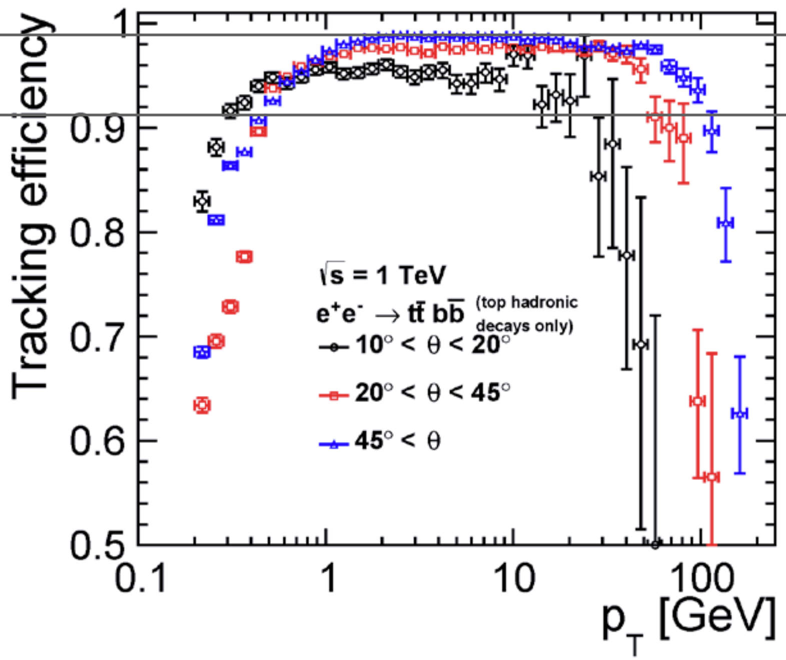


Fake Rate vs. p_T

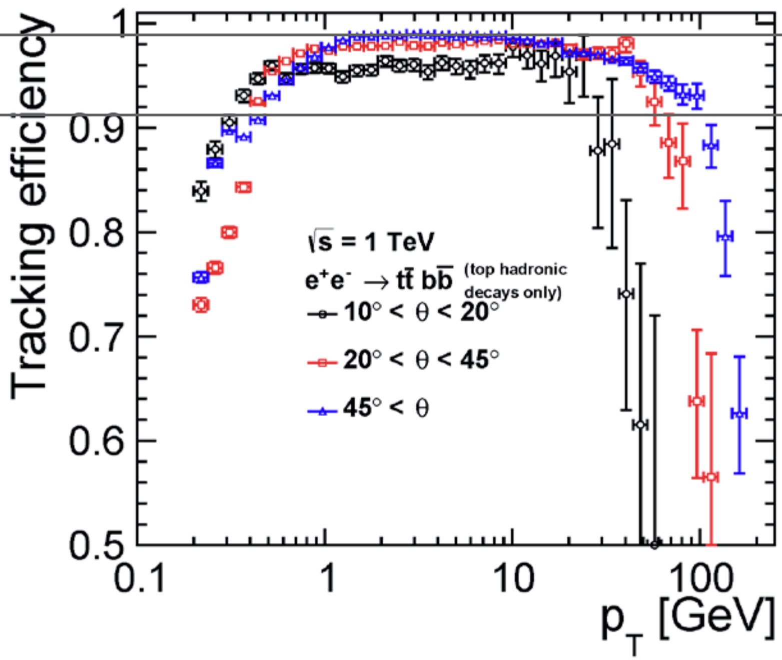
(Our data do not include beam induced background.)

Tracking Performance
ttbb_6q_all, $\sqrt{s}$ = 1 TeV, Efficiency vs. p_T

Sidloi3

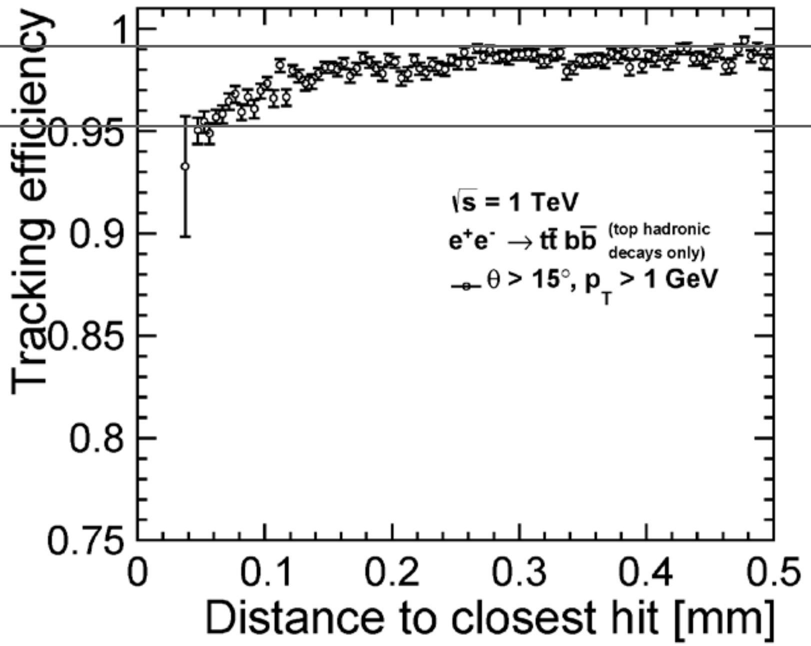


Modified Detector

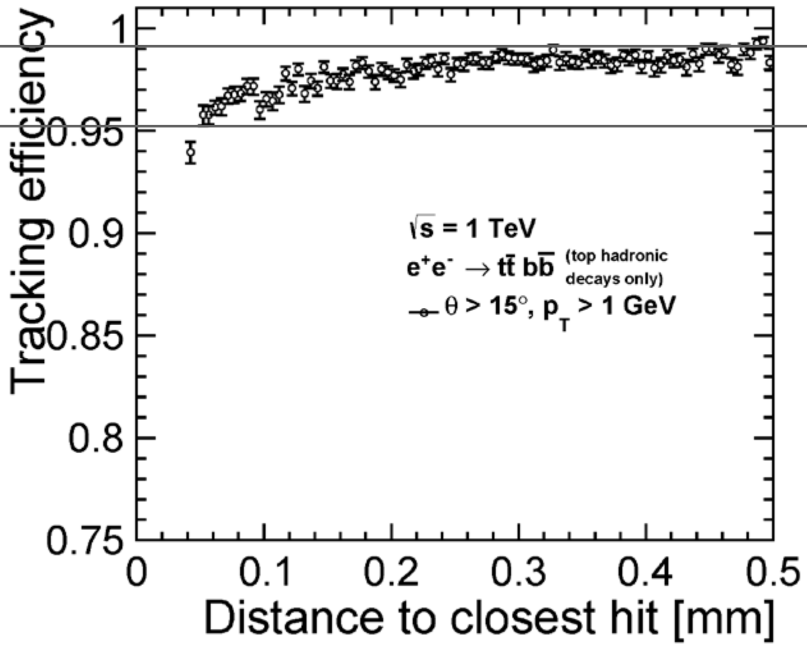


Tracking Performance
ttbb_6q_all, $\sqrt{s}$ = 1 TeV, Efficiency vs. Distance to Closest Hit

Sidloi3

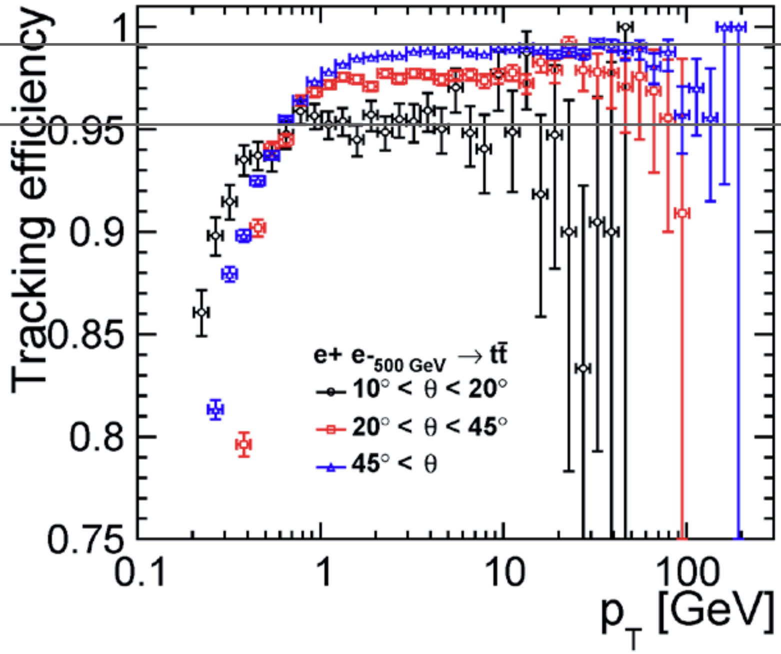


Modified Detector

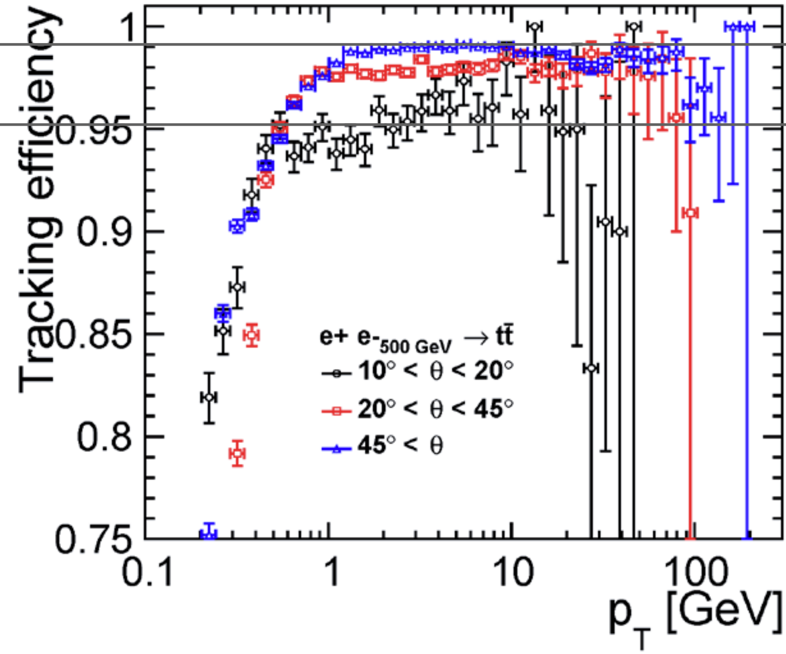


Tracking Performance
6f_ttbar, $\sqrt{s}$ = 500 GeV, Efficiency vs. p_T

Sidloi3

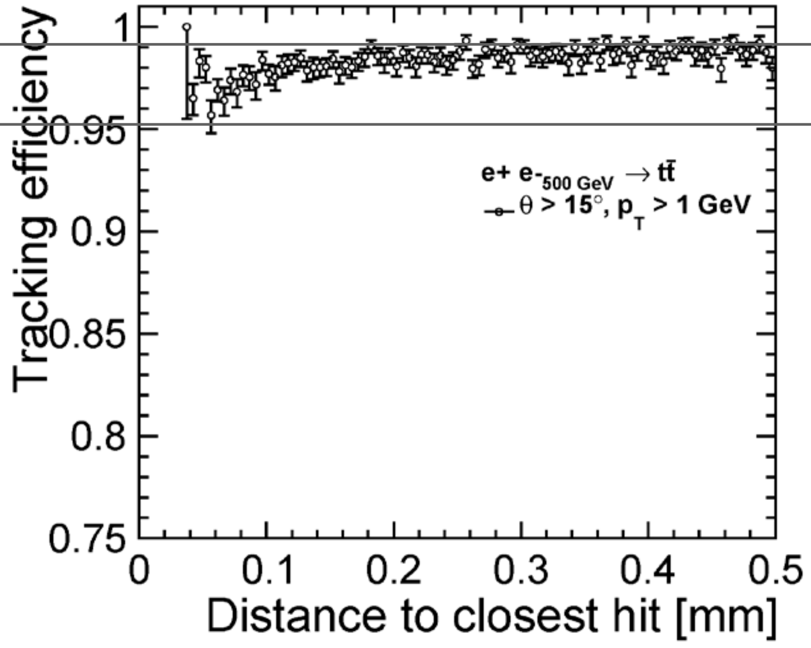


Modified Detector



Tracking Performance
6f_ttbar, $\sqrt{s}$ = 500 GeV, Efficiency vs. Distance to Closest Hit

Sidloi3



Modified Detector