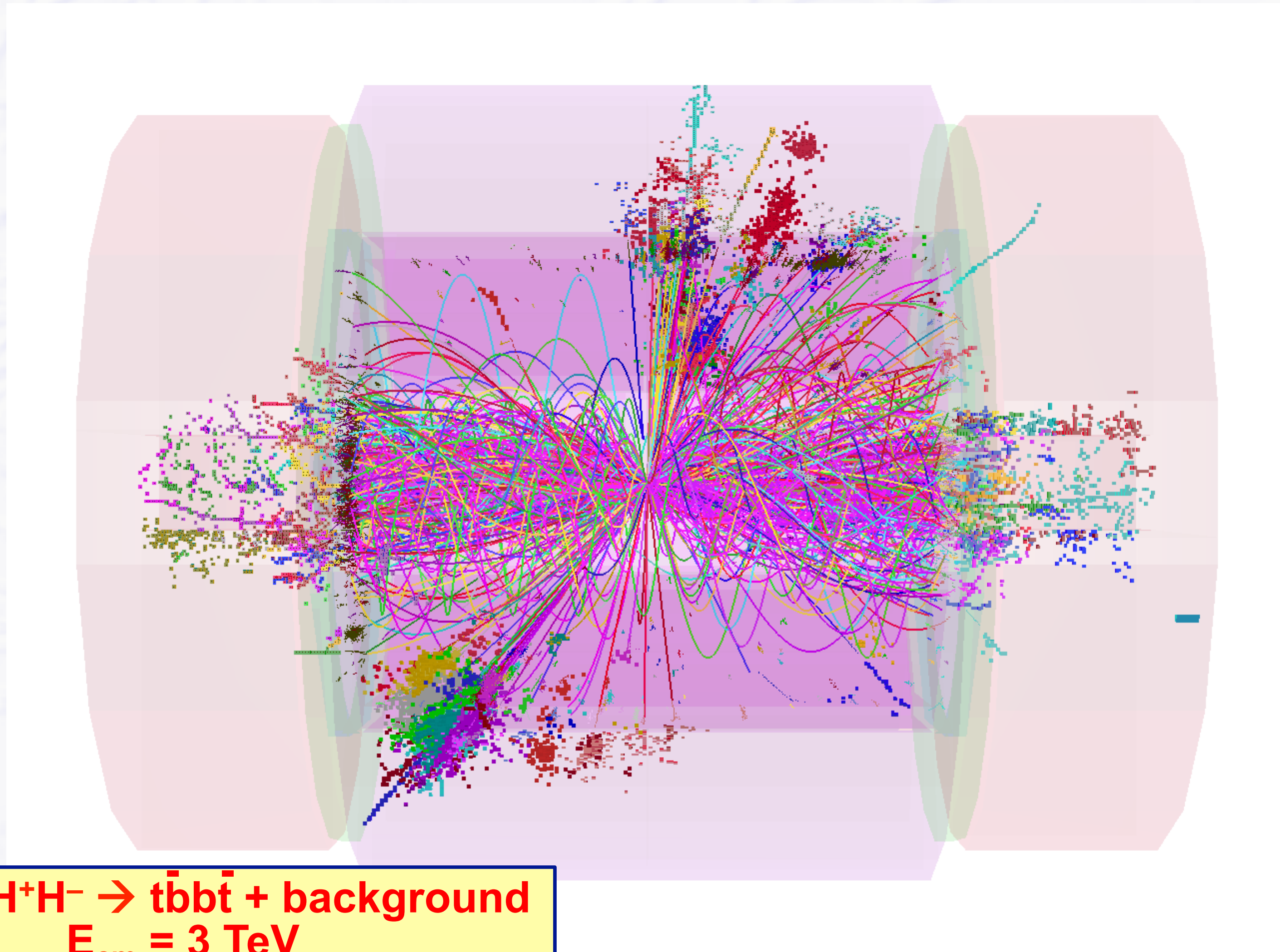
Tracking Performance in CLIC_ILD and CLIC_SiD



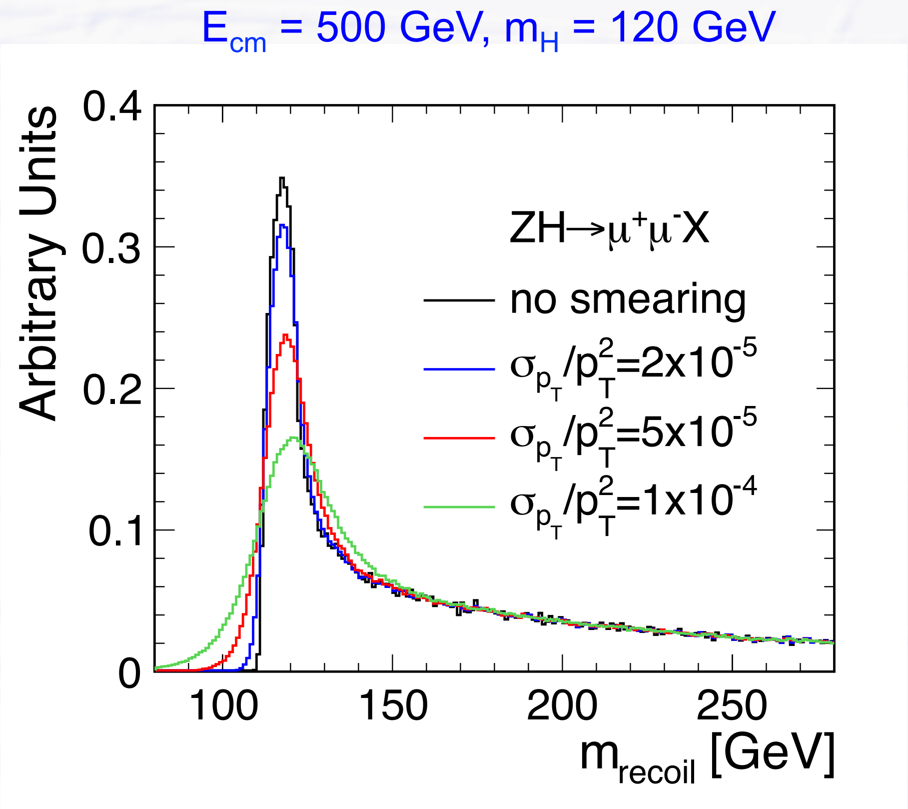
$e^+e^- \rightarrow H^+H^- \rightarrow t\bar{b}b\bar{t}$ + background
E_{cm} = 3 TeV

Momentum Resolution Requirements I

- Same as at ILC
  - momentum resolution dictated by Higgs mass determination from Higgsstrahlung process $e^+e^- \rightarrow Zh$
  - mass reconstruction from system recoiling against $Z \rightarrow \mu^+\mu^-$
- CLIC challenges
  - higher E_{CM} = higher track momenta
    - more stringent requirements as at ILC
- Required momentum resolution

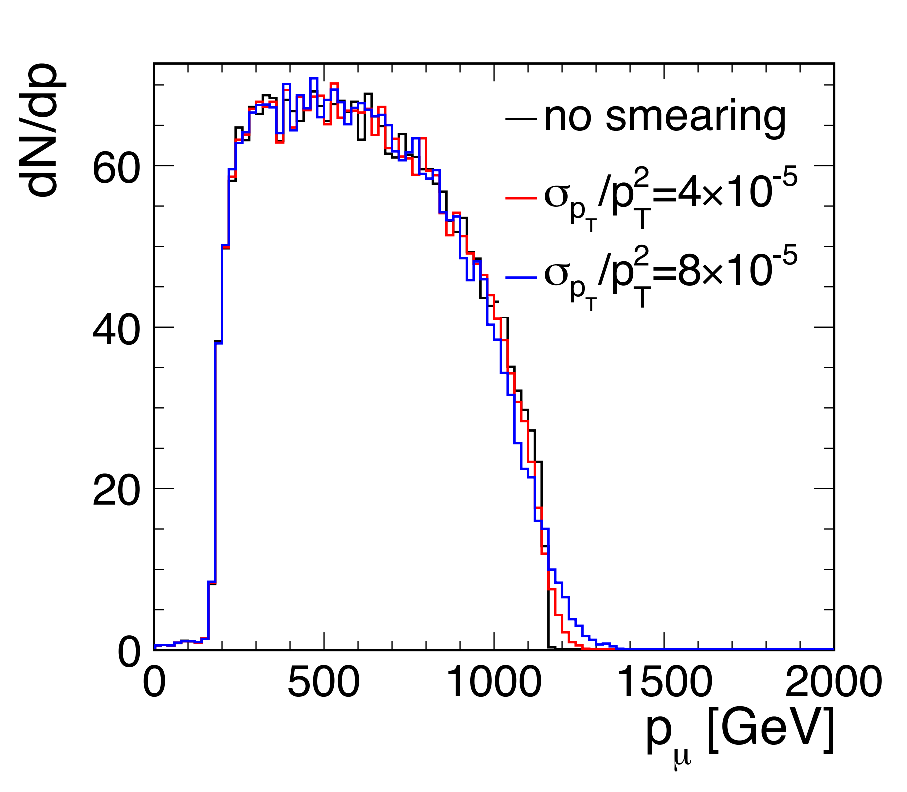
$$\sigma_{p_T}/p_T^2 \approx 2 \cdot 10^{-5}\ \mathrm{GeV}^{-1}$$

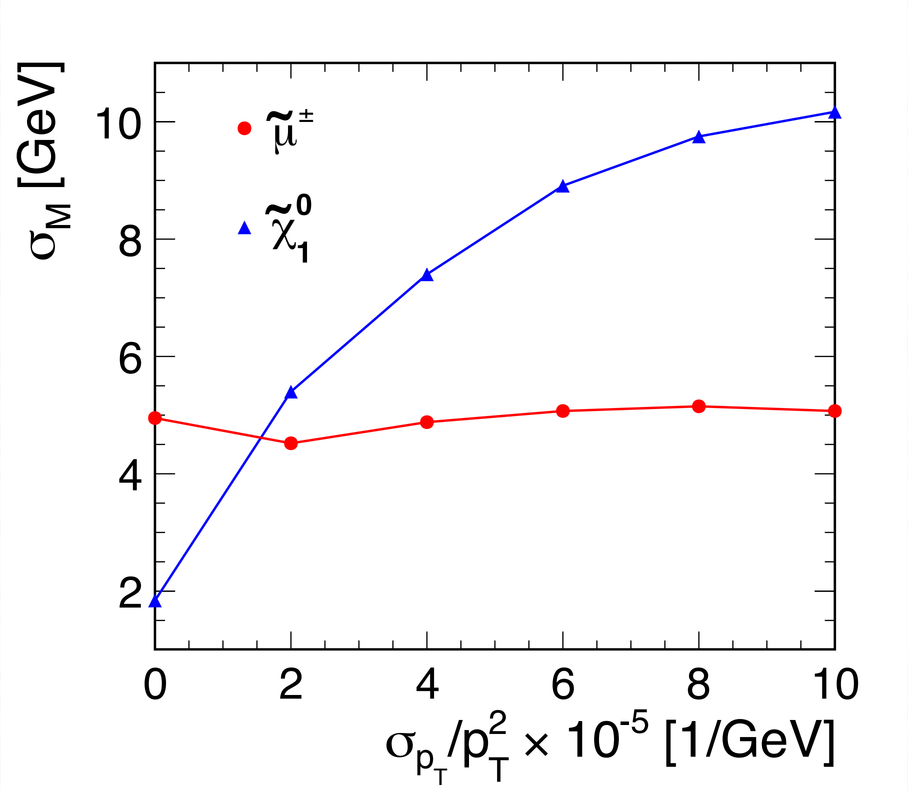
  - recoil mass spectrum significantly broader if momentum resolution $> 2 \cdot 10^{-5}\ \mathrm{GeV}^{-1}$
    - beamstrahlung spread dominates at $\sim 2 \cdot 10^{-5}\ \mathrm{GeV}^{-1}$



Momentum Resolution Requirements II

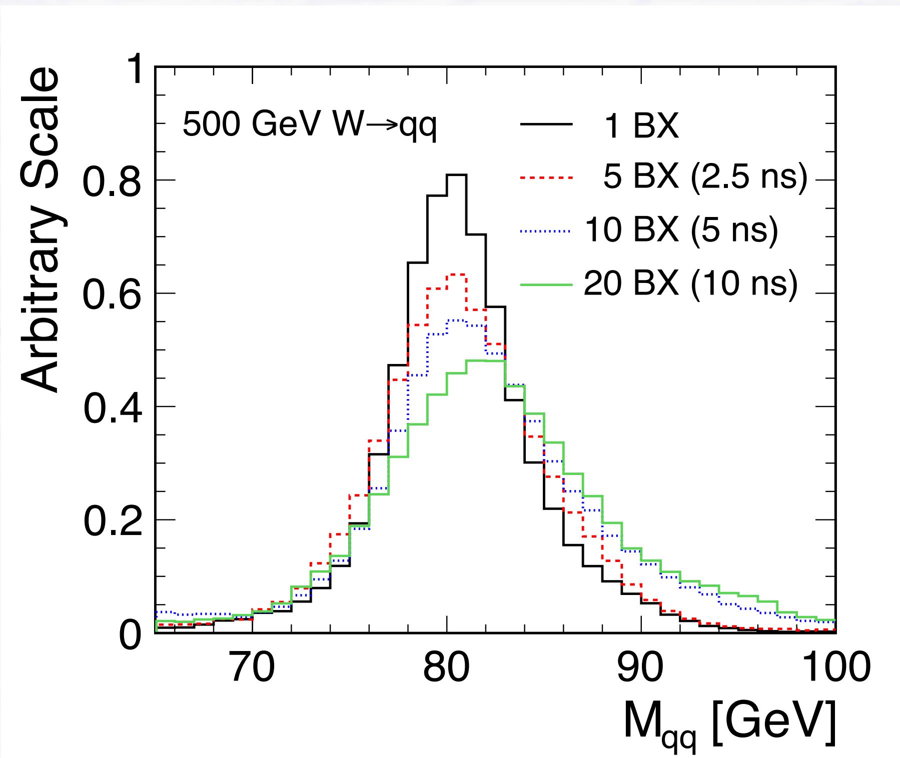
- **Determination of smuon and neutralino masses**
  - **from muon momentum distribution in $e^+e^- \rightarrow \tilde{\mu}\tilde{\mu} \rightarrow \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$**
  - **significant deterioration of high end mass spectrum if resolution > $4 \cdot 10^{-5}$ GeV^{-1}**

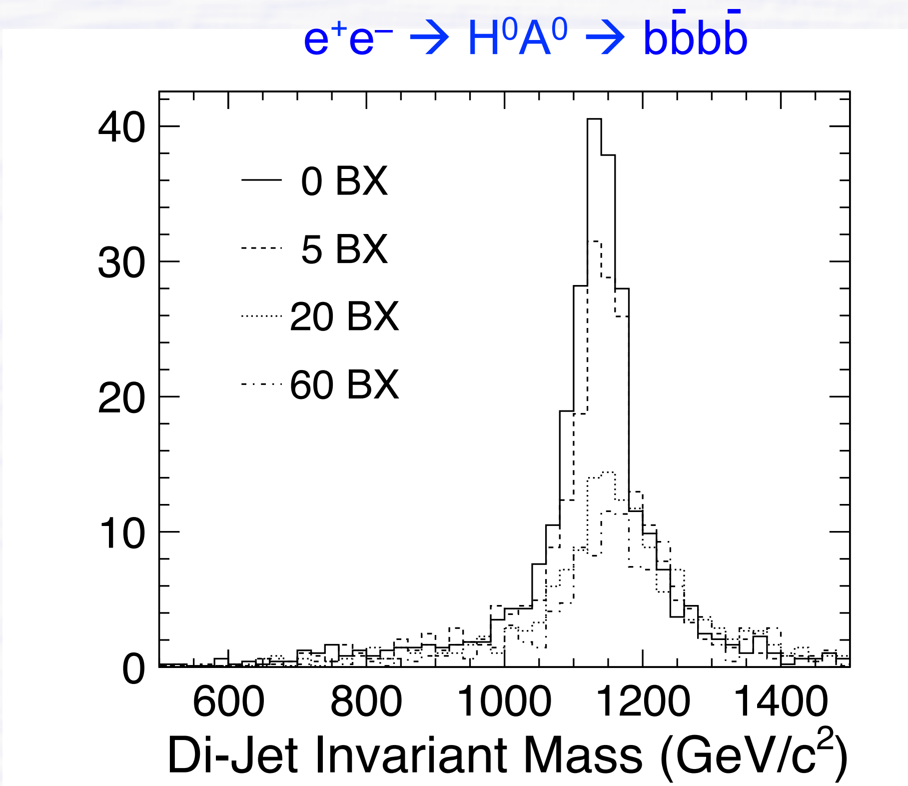




Time Stamping Requirements

- **CLIC bunch crossing rate is 0.5 ns**
  - **need "time-stamping": identification of tracks from individual BX**
    - **overlay of physics events with background from γγ → hadrons (3.2 events per BX)**
    - **time stamping of each individual BX would be extremely challenging (rather impossible)**
  - **physics performance not significantly degraded if time stamping accuracy is ~ 5 – 10 BX**





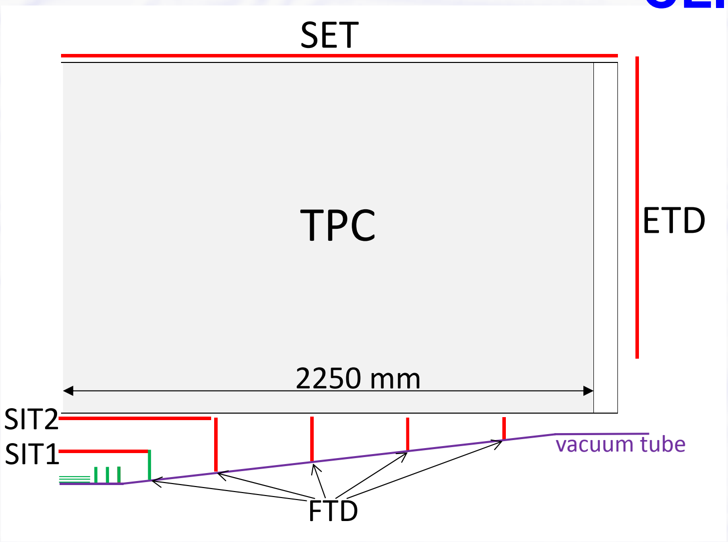
CLIC Detector Study + CDR

- **Early CLIC Detector Study finished in 2004**
  - very basic detector studies only (Toy MC)
  - not much progress until ~2008
- **Study relaunched in 2009 for a CLIC-CDR in December 2011**
  - starting point: use existing ILD and SiD detector concepts + software
  - modify where needed and create "CLIC flavours" of both ILC detectors
    - "ILD-like detector" @ CLIC @ 3 TeV = CLIC_ILD
    - "SiD-like detector" @ CLIC @ 3 TeV = CLIC_SiD
- **CLIC detector ≈ "90% ILC detector" + "10% CLIC specifics"**
  - CLIC is profiting a lot from ongoing ILC detector R&D and design studies
  - but ILC also profits from CLIC studies
    - CLIC detector = "extreme" ILC detector → win – win situation for both communities
    - e.g. common work on Particle Flow Algorithms
    - W-HCAL, TPC simulation, engineering studies (push – pull)

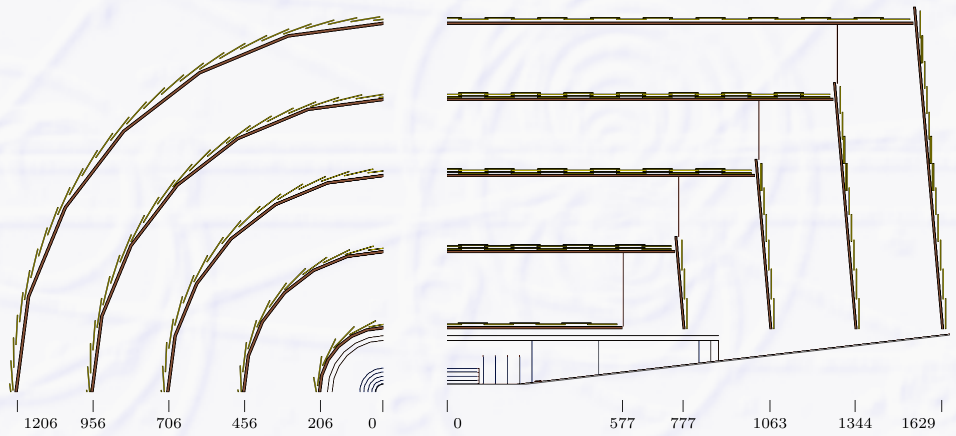
CLIC_ILD and CLIC_SiD tracking systems

- **Main tracking detectors identical to ILD (TPC) / SiD (5-layer Si)**
- **Main modification w.r.t. ILC in vertex detectors**
  - **vertex detector + beam pipe at larger radius to account for increased backgrounds**
  - **barrel vertex detector moved out by factor ~2 in inner radius**
    - **CLIC_ILD: 31 mm**
    - **CLIC_SiD: 27 mm**

CLIC_ILD



CLIC_SiD

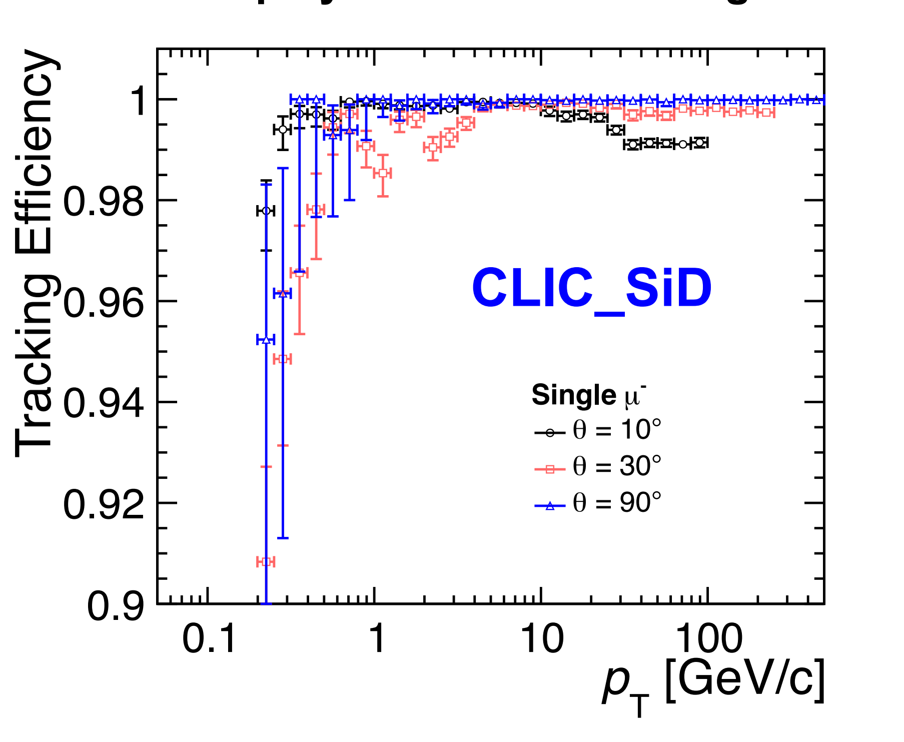


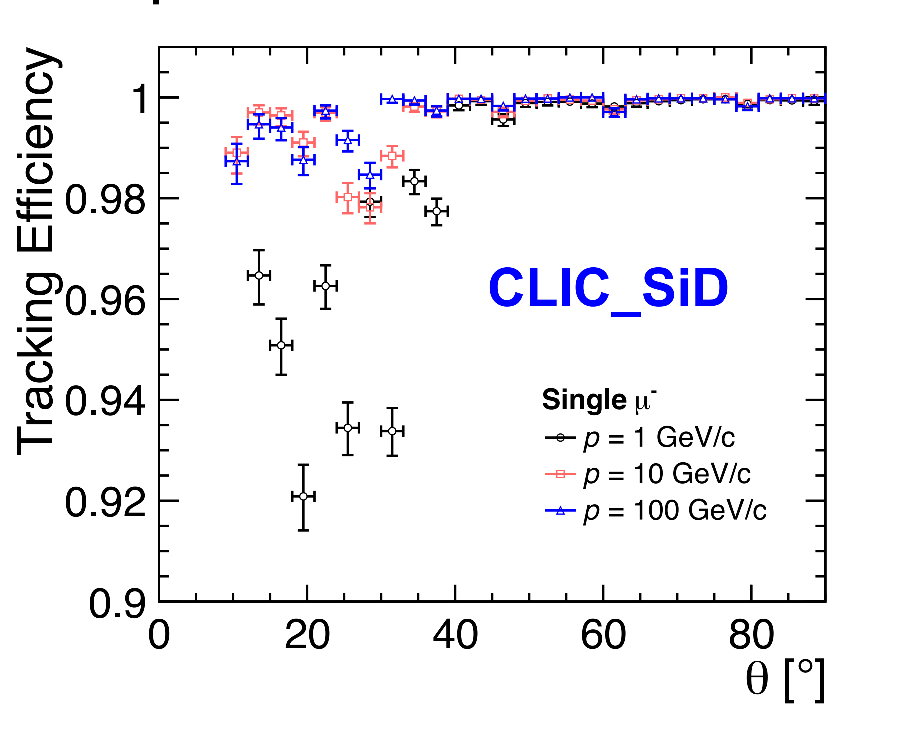
Tracking Algorithms

- **CLIC_ILD: 3 step tracking algorithm**
  - **pattern recognition + track fitting separately in TPC and Si detectors**
    - **tracks curling in TPC for p_T < 1.2 GeV**
      = many not connected low p_T helix segments in standalone TPC tracking
  - **execute FullLDC tracking**
    - **combines track segments from both TPC + Si and refit combined track**
    - **helix segments combined to a single track**
- **CLIC_SiD**
  - **SeedTracker algorithm in *org.lcsim***
    - **finding track seeds = looking for combinations of at least three hits that fulfill a helix fit**
    - **track seeds extended by successively adding more hits**
  - **vertex constraint to reduce number of possible combinations**
    - **±5 mm in rϕ, ±10 mm in z (loose enough to find tracks from displaced vertices)**

Tracking Efficiency (single muons)

- **CLIC_SiD**
  - **single muon tracking efficiency close to 100% for p_T > 0.3 GeV**
    - **slight drop for small polar angles**
      - **step drop for Θ < 7° (less than 7 Si hits)**
    - **drop by 2% at transition region barrel – endcap around 30°**

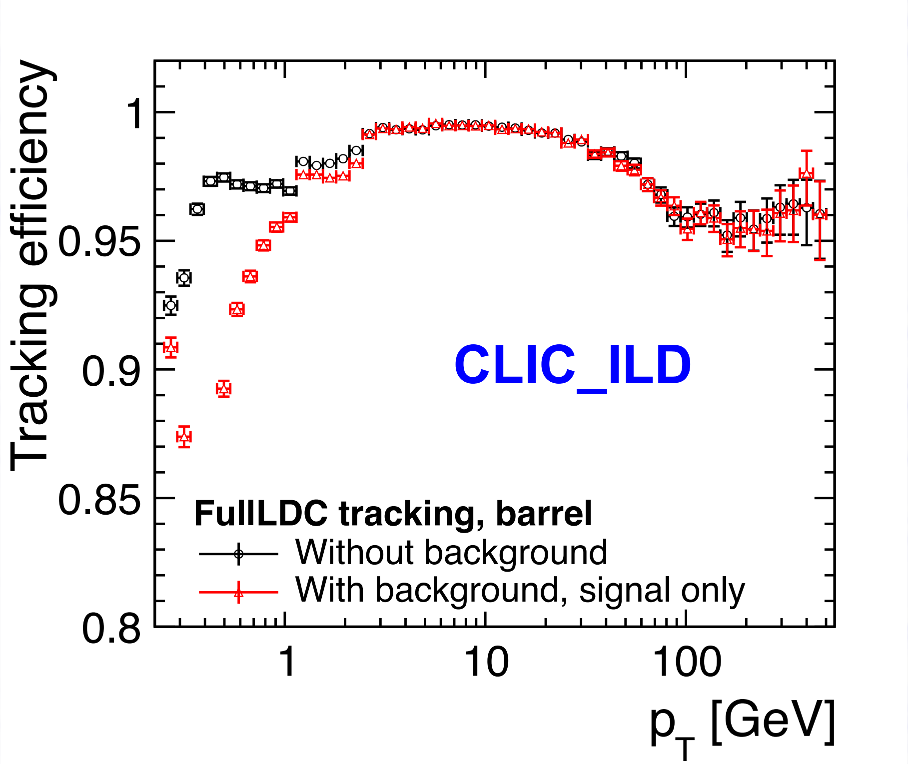


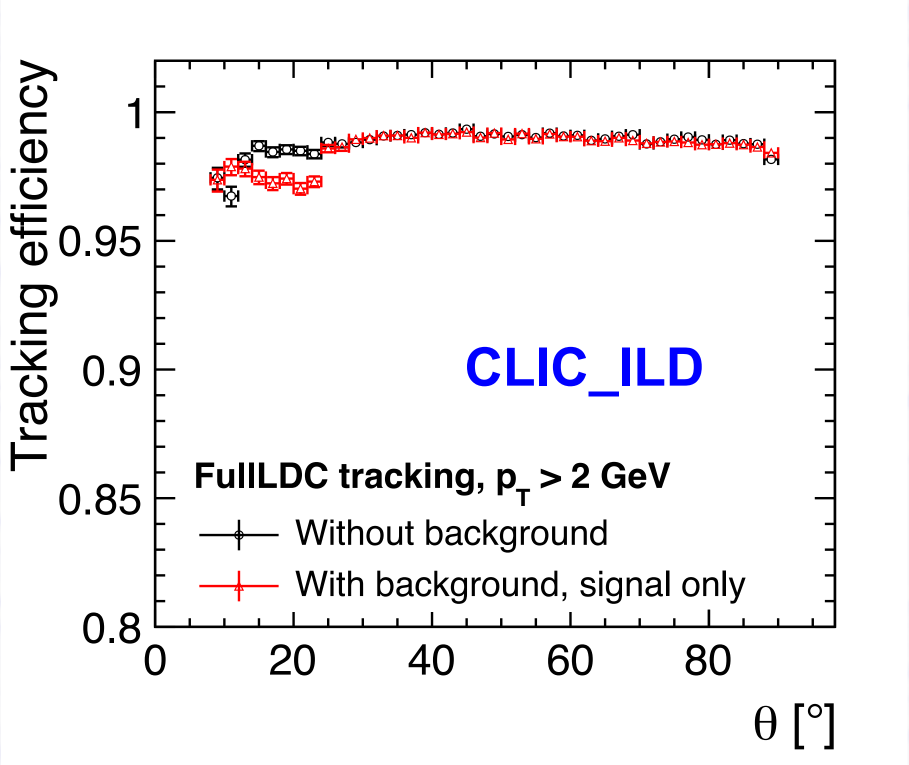


- **Very similar picture for CLIC_ILD**
  - **flat distribution, no drop in transition region**

Tracking Efficiency ($t\bar{t}$ events)

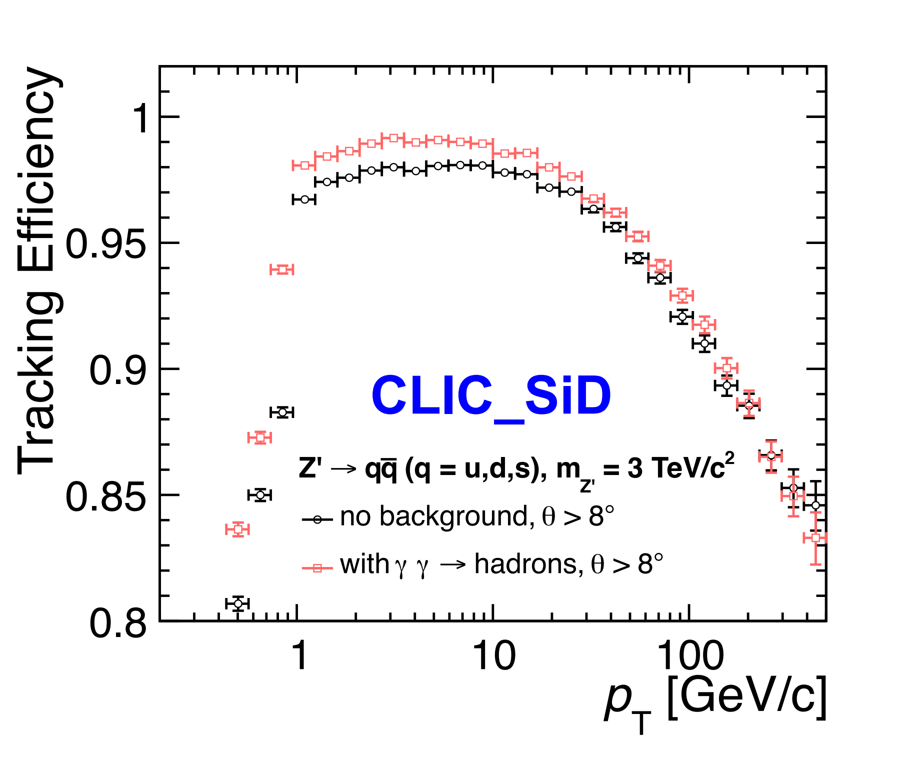
- **CLIC_ILD tracking efficiency still ~99% for p_T > 2 GeV**
    - **> 97% for p_T > 0.4 GeV**
    - **some drop for high momenta around 100 GeV (further studies needed)**
- **No effect for p_T > 1 GeV when adding background**
    - **background from γγ → hadrons, 3.2 events per BX, 60 BX overlayed**

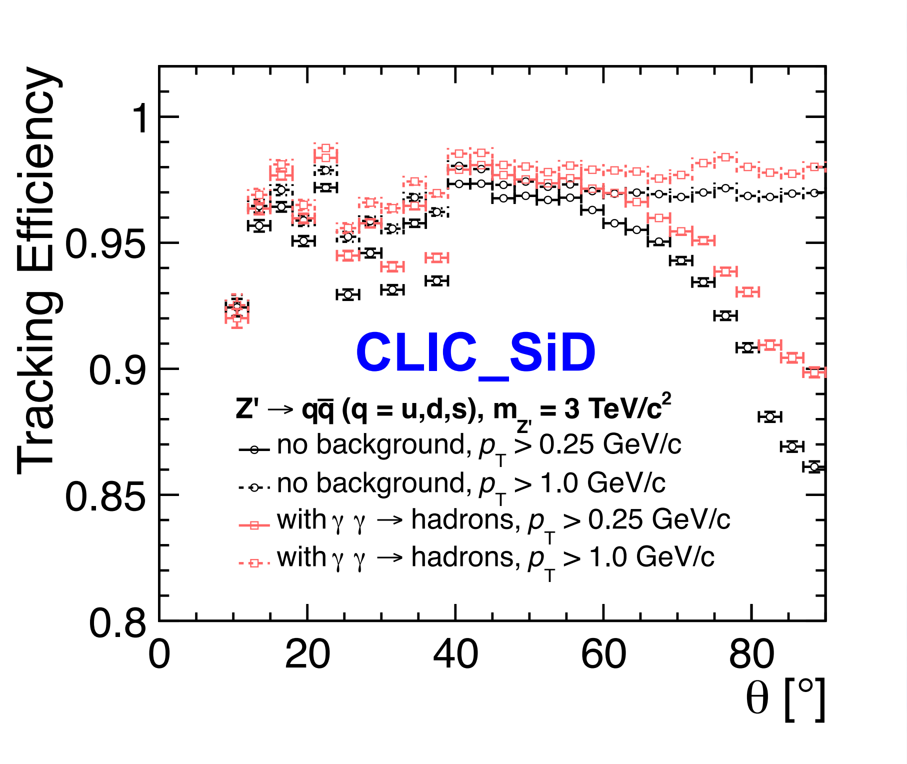




Tracking Efficiency (di-jets from Z' decays)

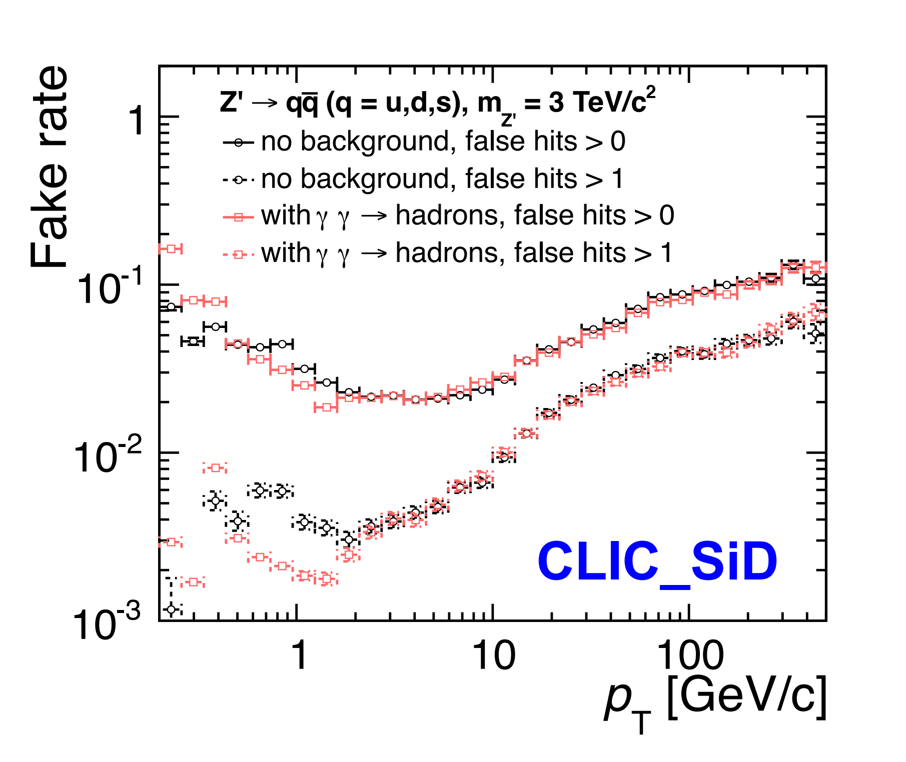
- Di-jets from Z' ($m_{Z'}$ = 3 TeV) → $q\bar{q}$ (q = u,d,s) even more challenging than $t\bar{t}$ events
  - 2 very narrow jets with high p_T tracks, challenging for pattern recognition
  - drop of efficiency (CLIC_SiD) at high p_T due to high occupancy
    - interesting effect: background (γγ → hadrons) helps for low p_T tracks
      - adding random background hits increases overall number of hits per track (tracks w/o background hits might fail minimum number of hits cut)

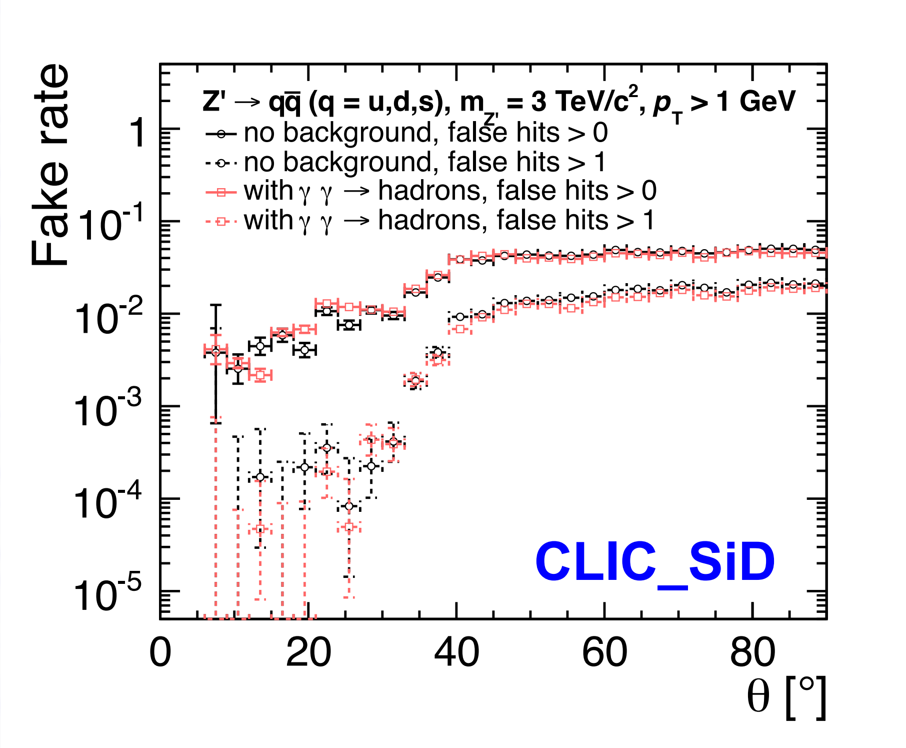




Fake Rate (di-jets from Z' decays)

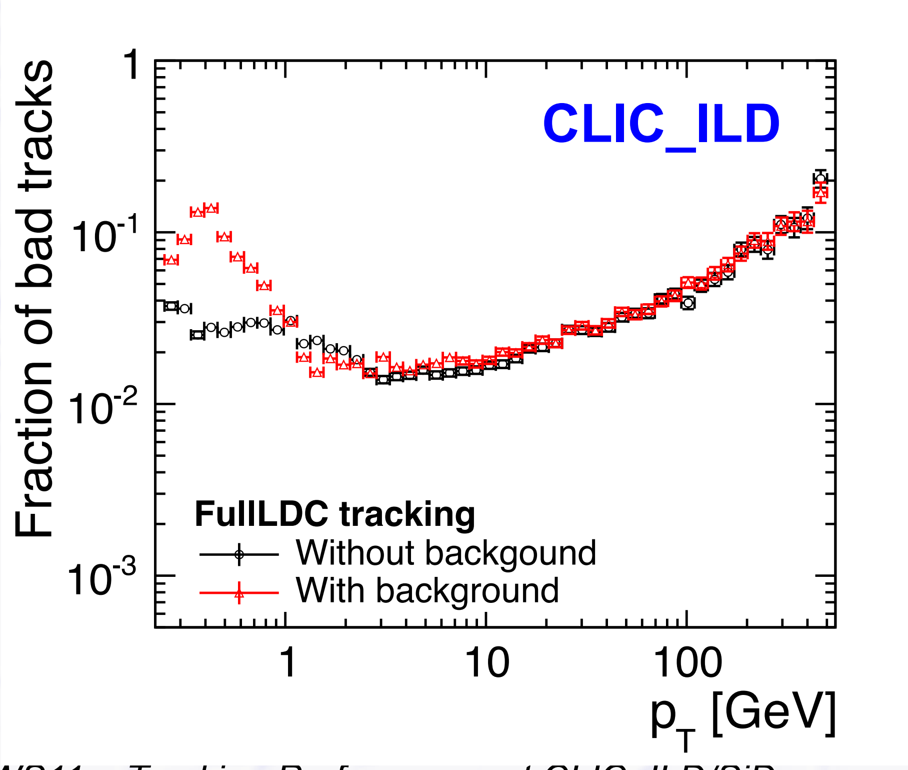
- **CLIC_SiD track quality cut**
  - track must have > 75% of correctly assigned hits (otherwise "fake")
    - only 1 wrongly assigned hit for tracks with 6 or 7 hits
- **Only few percent of tracks have > 1 wrongly assigned hit**
  - higher fake rate (~10%) for high p_T tracks (more likely in center of jet)
  - fake rate lower in forward region (more pixelated detectors)

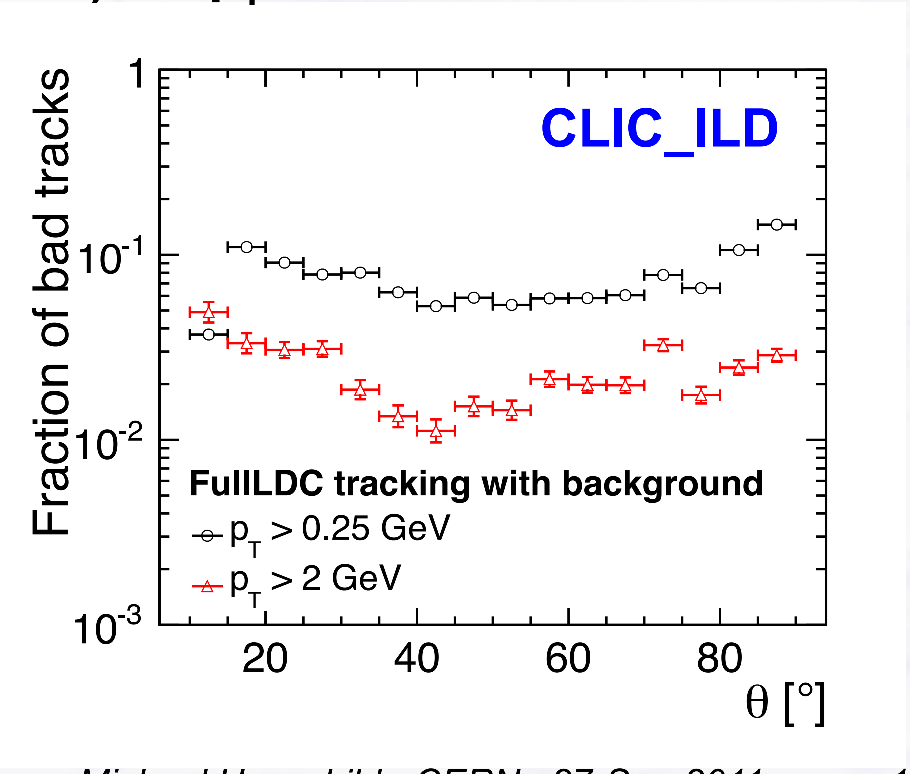




Fraction of Badly Rec. Tracks ($t\bar{t}$ events)

- **CLIC_ILD track quality cut**
  - **track must have > 96% of correctly assigned hits**
    - **no effects on resolution etc. if no more than 4% wrongly assigned hits**
- **1 – 3% fraction of badly reconstructed tracks for p_T < 25 GeV**
  - **raising to 10% for higher p_T**
  - **no effect of background (γγ → hadrons) for p_T > 1 GeV**





Momentum Resolution (Single Muons)

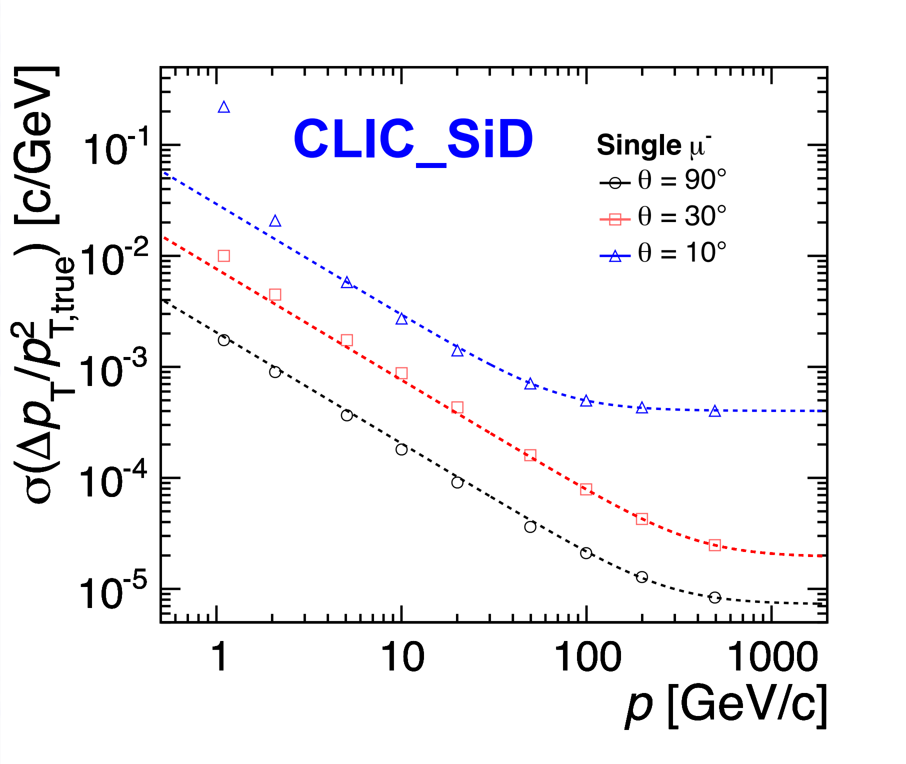
- **Momentum resolution parameterized**

$$\sigma\left(\Delta p_{\mathrm{T}}/p_{\mathrm{T}}^{2}\right) = a \oplus \frac{b}{p_{\mathrm{T}}} = a \oplus \frac{b}{p \sin\theta}$$

$\Delta p_T = p_{T,MC} - p_{T,rec.}$

a = contribution from curvature measurement

b = multiple scattering contribution



CLIC_SiD (single muons)

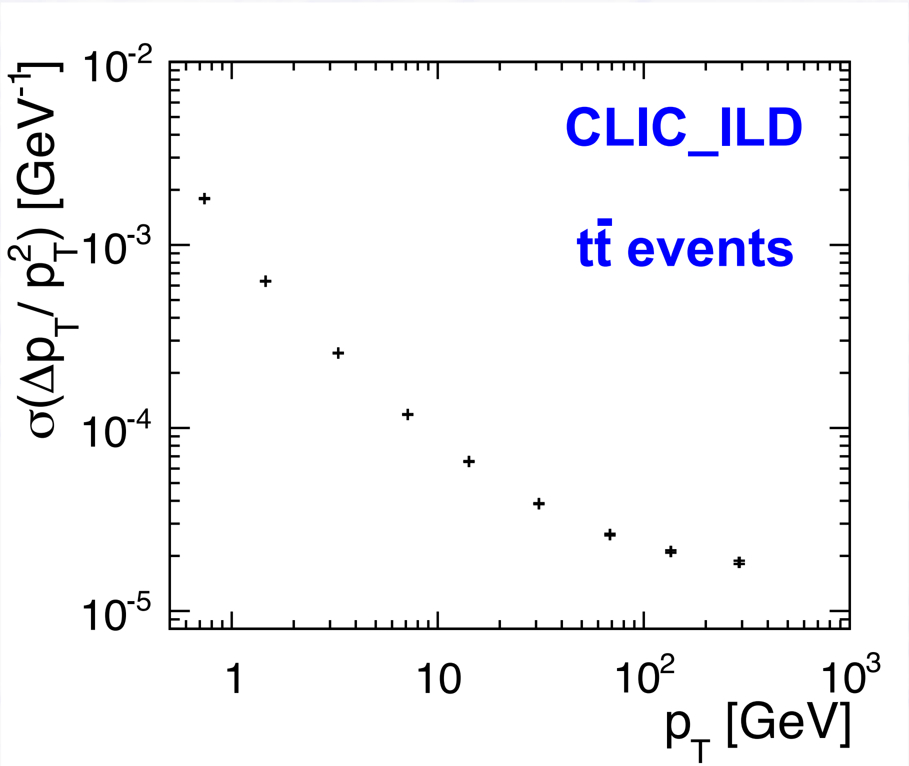
θ [°]	a [GeV^{-1}]	b
90	$7.3 \cdot 10^{-6}$	$2.0 \cdot 10^{-3}$
30	$1.9 \cdot 10^{-5}$	$9.5 \cdot 10^{-4}$
10	$4.0 \cdot 10^{-4}$	$1.5 \cdot 10^{-4}$

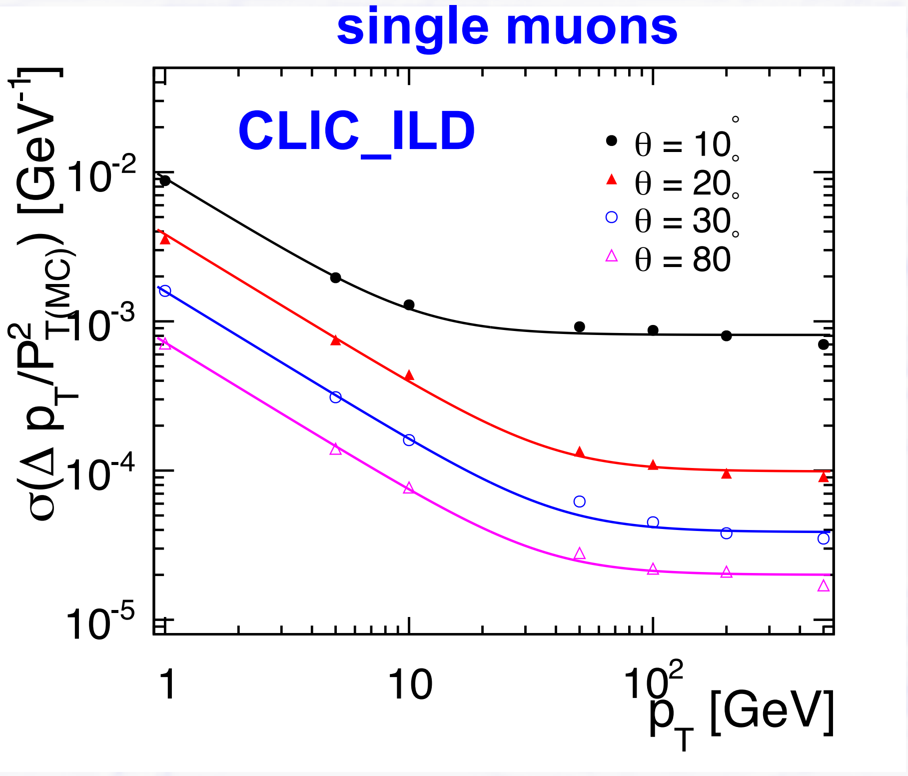
requirement of $\sigma_{p_T}/p_T^2 < 2 \cdot 10^{-5}\ \mathrm{GeV}^{-1}$ fulfilled

Momentum Resolution (Single μ + $t\bar{t}$ events)

- **Momentum requirement of < 2 * 10^{-5} GeV^{-1} also fulfilled in CLIC_ILD**
  - **both for single muons and in tt events**

θ [°]	a [GeV^{-1}]	b
10	$8.19 \cdot 10^{-4}$	$9.07 \cdot 10^{-3}$
20	$9.86 \cdot 10^{-5}$	$3.83 \cdot 10^{-3}$
30	$3.87 \cdot 10^{-5}$	$1.59 \cdot 10^{-3}$
80	$1.97 \cdot 10^{-5}$	$7.22 \cdot 10^{-4}$

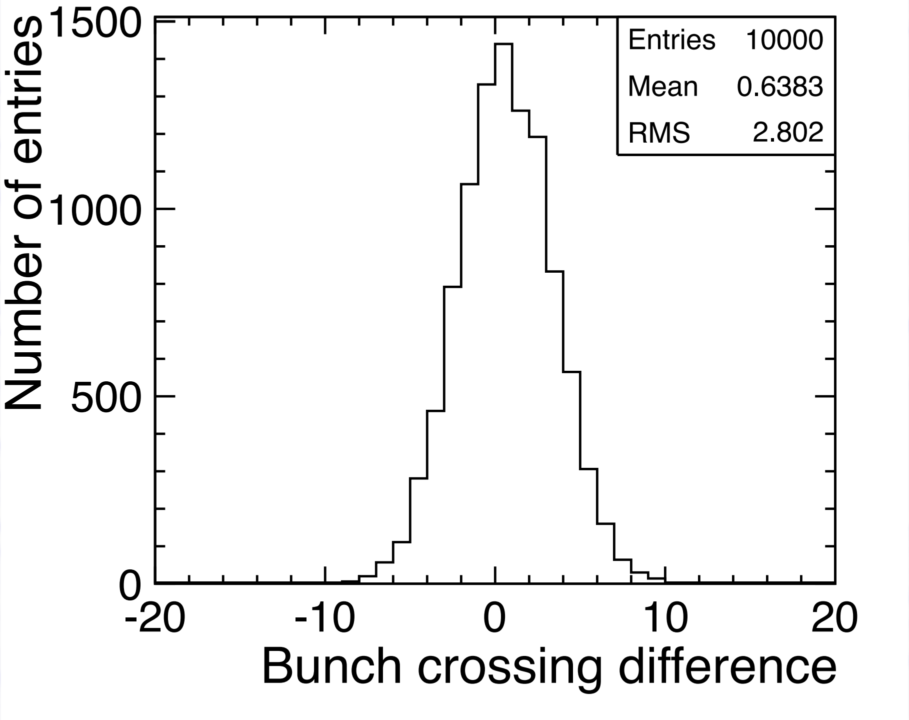




Time Stamping in CLIC_ILD

- **TPC does not provide direct time stamping information**
  - **z coordinate reconstruction requires BX time information**
    - $z_{TPC} = (t_{drift} + \Delta t_{BX} \cdot BX)\, v_{drift}$
- **TPC information can be combined with information from the outer silicon envelope SET**
  - **SET gives z coordinate (50 µm resolution), no timing information needed from SET**
    - **low occupancy of SET**
    - **matching is mostly unambiguous**
- **Time stamping accuracy 2.8 BX**
  - **90% of tracks can be correctly reconstructed within ±5 BX**

$BX_{MC} - BX_{rec.}$



Conclusions

- **Requirements from physics performance**
  - momentum resolution: $\sigma_{p_T}/p_T^2 \approx 2 \cdot 10^{-5}\,\mathrm{GeV}^{-1}$
  - time stamping accuracy: 5 – 10 BX (2.5 – 5 ns)
- **CLIC tracking systems adapted from ILD and SiD**
  - main tracker unchanged
  - inner radius of vertex detector further moved out (~2 x larger inner radius w.r.t. ILC)
- **Tracking efficiency**
  - 97 – 99% for tracks in tt events (CLIC_ILD) or di-jets (CLIC_SiD) from 2 – 20 GeV
    - slight drop at higher momenta (needs further study)
    - no degradation by background for $p_T > 2$ GeV
  - fake rate at percent level
- **Momentum resolution $\leq 2 \cdot 10^{-5}\,\mathrm{GeV}^{-1}$ fulfilled for both CLIC_ILD and CLIC_SiD**
  - time Stamping capabilities for CLIC_ILD demonstrated