CLIC Detector and Physics

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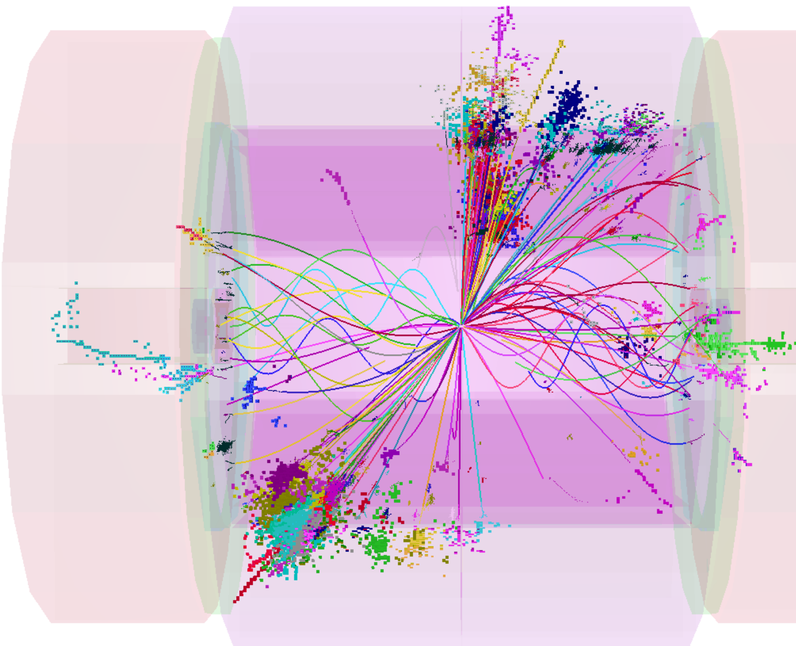
on behalf of CLIC Physics and Detector Study



This Talk:

- Introduction: CLIC CDR
- CLIC Machine Environment
- CLIC Detector Concepts
- Background and Timing
- Physics Benchmark Studies
- Conclusions

Introduction: CLIC CDR

★ CLIC provides the potential for e^+e^- collisions up to $\sqrt{s}$ = 3 TeV
- But machine environment is much more challenging than ILC
- Detailed studies of physics in this environment described in CLIC CDR

★ Draft of CLIC CDR Volume 2 "Physics and Detectors" now available
- Will be reviewed by a panel of experts in October (chair: Soldner-Rembold)
- https://edms.cern.ch/document/1160419

★ Main points covered in "Physics and Detectors" Volume
- Physics case
- Interplay between machine and detector
- Detector concepts for CLIC
  - based on the ILC detector concepts: ILD and SiD
- Related sub-detector design and R&D
- Physics benchmarks

Introduction cont.

★ **Assumptions**

- CLIC will be a staged in energy
  - Initial energy could be at around $\sqrt{s}$ = 0.5 TeV
  - Ultimate energy of $\sqrt{s}$ = 3.0 TeV
- Integrated luminosity of 2 ab^{-1} in four year run at 3 TeV

★ **CDR Studies**

- Majority performed at $\sqrt{s}$ = 3.0 TeV
  - worst case for beamsstrahlung and backgrounds
- Majority based on full Geant 4 detector simulations including background
  - essential to demonstrate conclusively the physics capability

★ **Main goals of CDR**

- Demonstrate physics capability in CLIC machine environment
- Understand detector requirements

★ **CDR would not have been possible without close collaboration with:**

- ILC detector concepts
- ILC software experts
- R&D Collaborations

} Thank you for all the hard work !

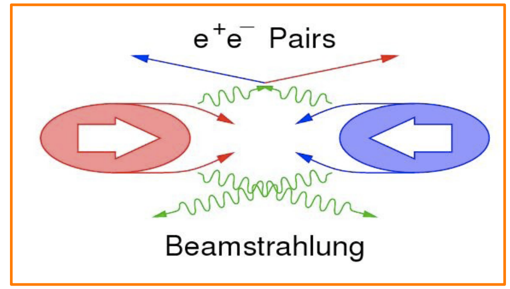
Machine Environment

CLIC Machine Environment

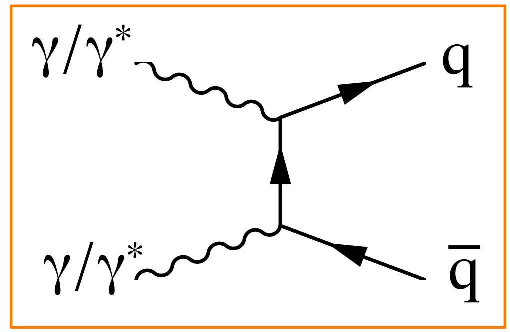
	CLIC 0.5 TeV	CLIC 3 TeV
L [cm^{-2}s^{-1}]	2.3×10^{34}	5.9×10^{34}
BX/train	354	312
BX sep	0.5 ns	0.5 ns
Rep. rate	50 Hz	50 Hz
L/BX [cm^{-2}]	1.1×10^{30}	3.8×10^{30}
$\gamma\gamma\rightarrow X$ / BX	0.2	3.2
σ_x/σ_y	202 / 2 nm	40 / 1 nm

Drives timing Requirements for CLIC detector

- ★ **Beam related background:**
  - Small beam profile at IP leads very high E-field;
    - Beamsstrahlung
    - Pair-background
    - Effects much more pronounced at CLIC

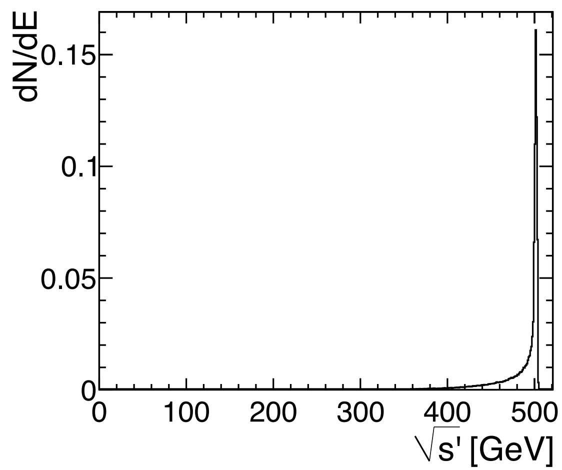


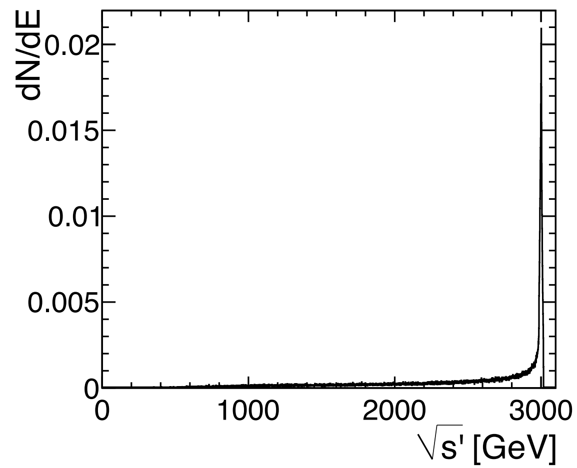
- ★ **Bunch train structure:**
  - CLIC: BX separation 0.5 ns
    - Integrate over multiple BXs of $\gamma\gamma\rightarrow$ hadrons
    - 19 TeV visible energy per 156 ns bunch train



Beamsstrahlung

- ★ Radiation of photons in the strong EM field of the beams results in a distribution of centre-of-mass energies, the luminosity spectrum
  - Large effect at CLIC due to small beam size, $\sqrt{s'} > 99\ \%\ \sqrt{s}$
    - 62 % at 500 GeV
    - 35 % at 3 TeV





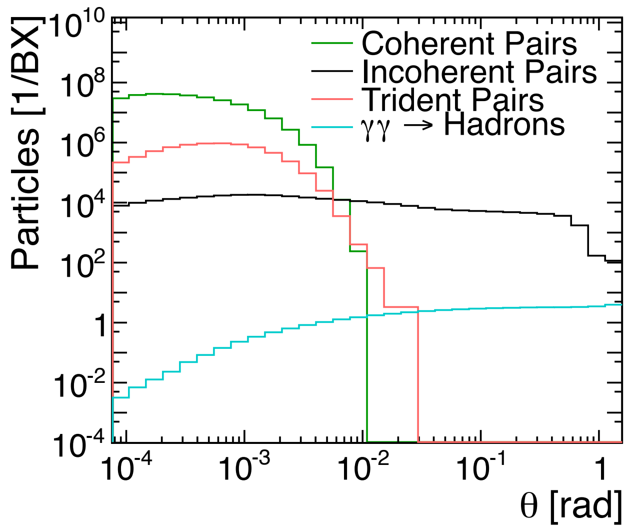
$\sqrt{s'}/\sqrt{s}$	0.5 TeV	3 TeV
> 99 %	62 %	35 %
> 90 %	89 %	54 %
> 70 %	99 %	76 %
> 50 %	~100 %	88 %

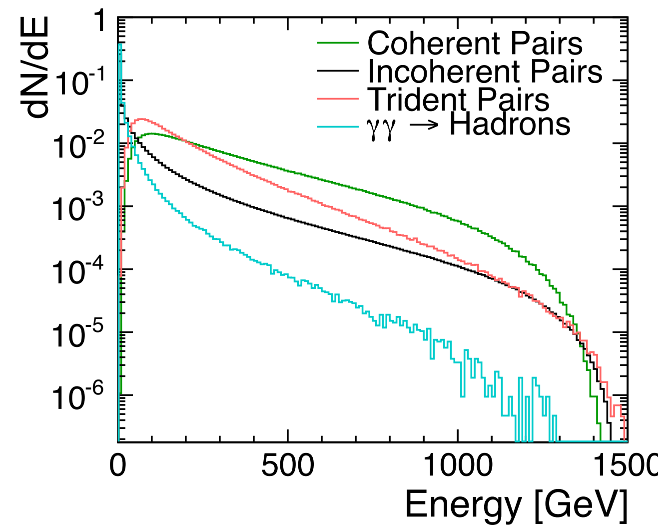
- ★ **Impact on physics** – depends on final state
  - Reduces effective luminosity at highest centre-of-mass energy
    - not so important for processes well above threshold
  - When above threshold, system can be boosted along beam axis
    - can distort kinematic edges, e.g. in SUSY searches

Backgrounds

★ Large backgrounds from interactions of real (Beamstrahlung) and virtual photons

- Coherent e^+e^- pairs (real) and "trident" pairs (virtual)
  - 7 x 10^8 per bunch crossing (BX) at 3 TeV
  - but mainly collinear with beams – impacts design of forward region
- Incoherent e^+e^- pairs
  - 3 x 10^5 per BX (mostly low p_T)
  - impact design of low angle tracking/beam pipe
- $\gamma\gamma \rightarrow$ hadrons (real and virtual) - "pile-up of mini-jet events"
  - only 3.2 per bunch crossing
  - main background in central tracker/calorimeters

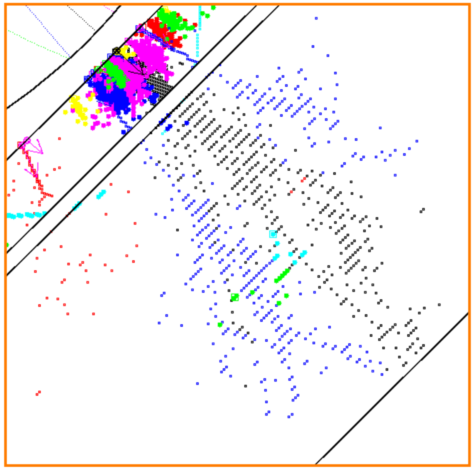




CLIC Detector Concepts

CLIC Detector Concepts

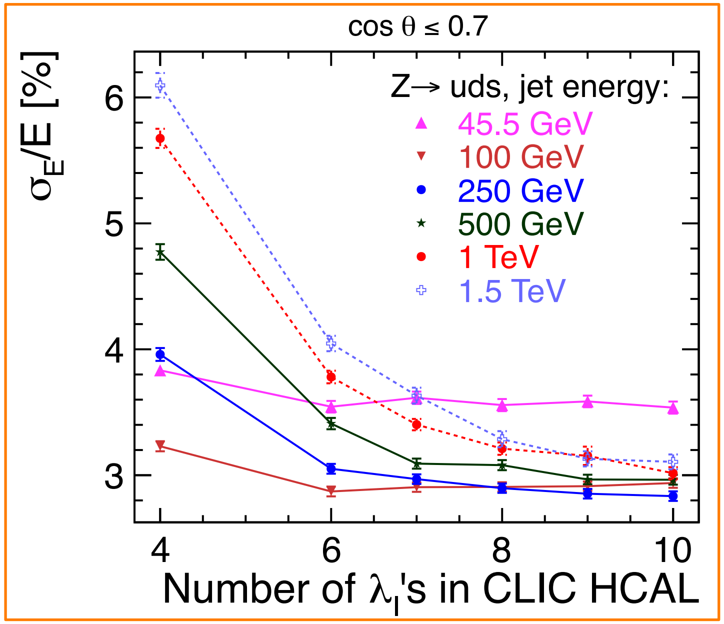
- ★ **Detector requirements for CLIC**
  - **All those for the ILC + timing**
  - **Optimised for CLIC backgrounds**
- ★ **Starting point**
  - **Validated LoI detectors: ILD and SiD**
  - **High granularity calorimetry for:**
    - **jet energy resolution**
    - **improved background rejection**



- ★ **Main modifications**
  - **Location of vertex detector/beam pipe to account for increased backgrounds**
  - **Forward region due to background and location of QD0**
  - **Increased HCAL depth to contain showers**
    - **Jet energy resolution studies**

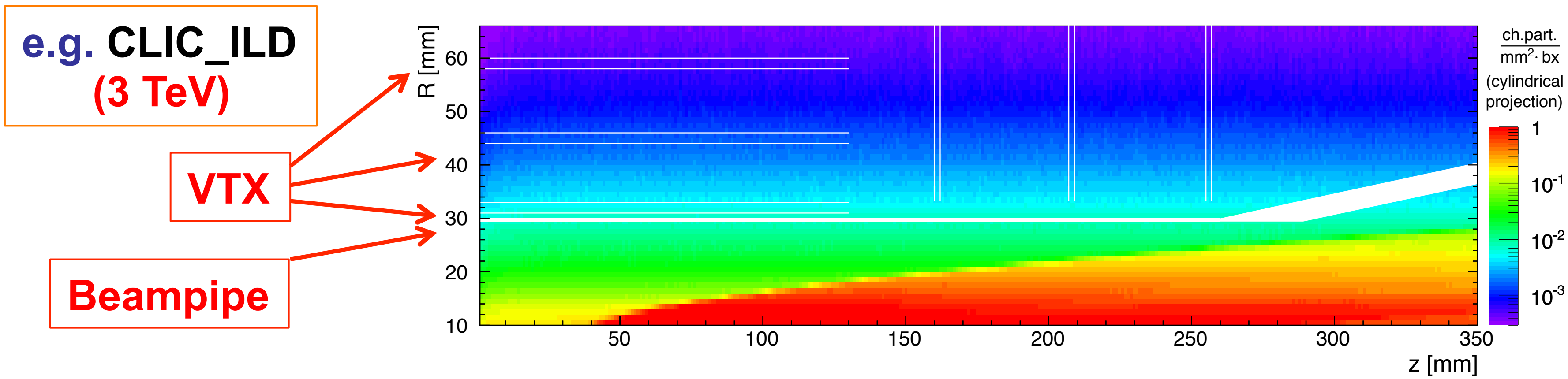
⇒ **7.5 λ_I HCAL**

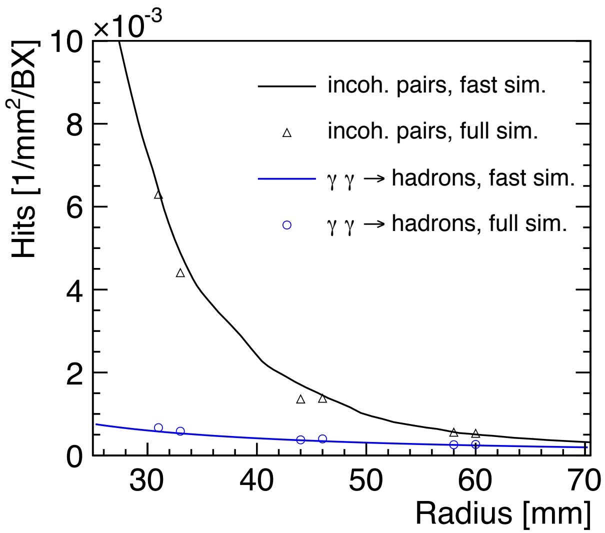
- **To maintain reasonable solenoid radius assume Tungsten as absorber in barrel**



Impact of Background

- ★ **Core of incoherent pair background determines:**
  - **location of vertex detector; forward tracking discs; design of beam pipe…**



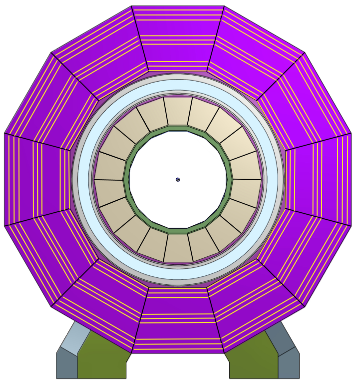


- ★ **Pair background mostly at low radii**
- ★ **Inner radius of barrel vertex detector**
  - **CLIC_ILD: 31 mm**
  - **CLIC_SiD: 27 mm**
- ★ **Maximum occupancy**
  - **1.9 % per bunch train**

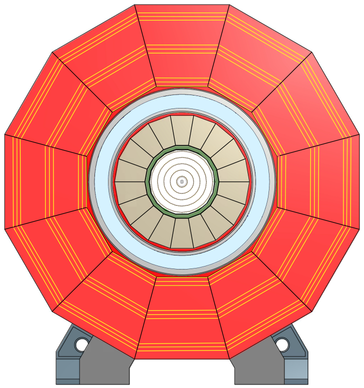
  (assumes 20 μm pixels and safety factor 5)

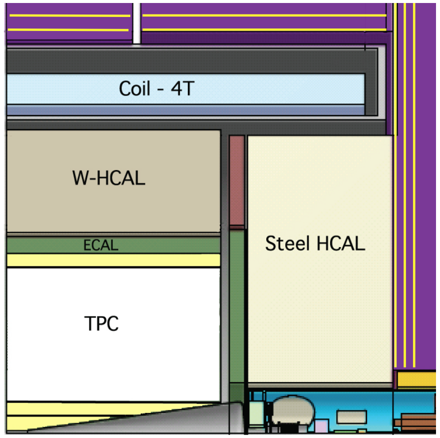
CLIC_ILD and CLIC_SiD

★ For studies define **two GEANT 4 detector models:** **CLIC_ILD** and **CLIC_SiD**

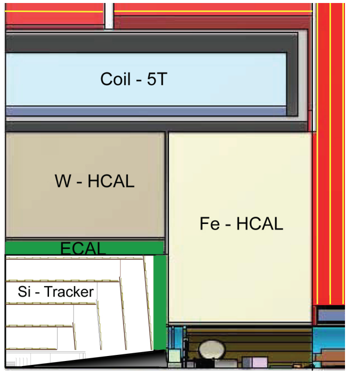


	CLIC_ILD	CLIC_SiD
Tracker	TPC, r = 1.8 m	Silicon, r = 1.2 m
B-field	4 T	5 T
ECAL	SiW	SiW
HCAL barrel	W-Scint	W-Scint
HCAL endcap	Steel-Scint	Steel-Scint



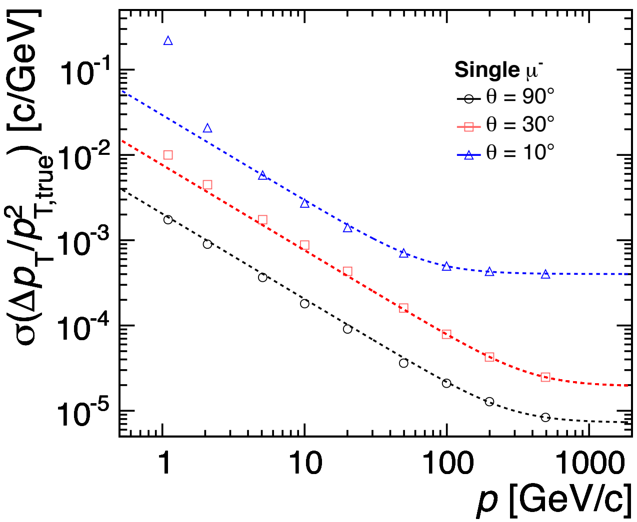


- ★ Detailed GEANT 4 models
- ★ Full reconstruction with background
- ★ Very similar performance at CLIC energies
- ★ Used interchangeably in physics studies

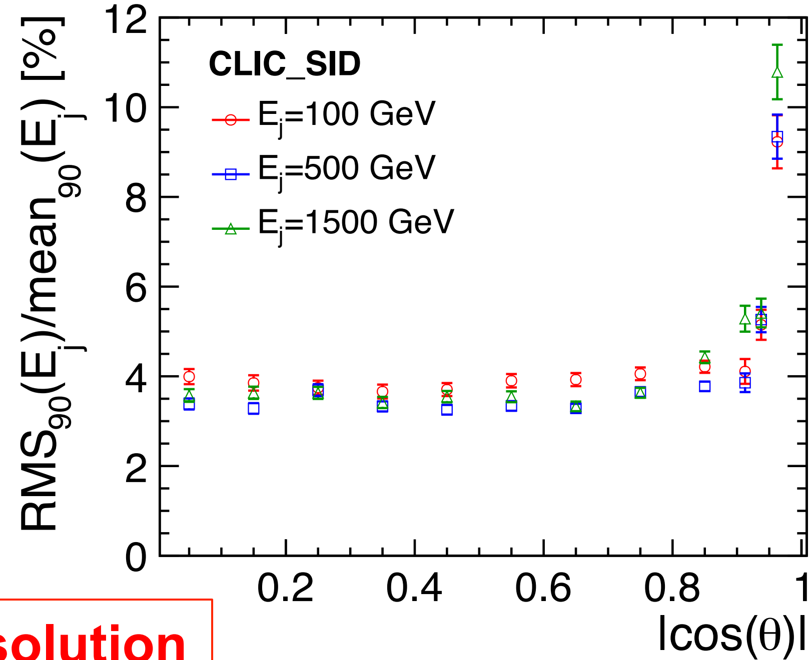


Underlying Detector Performance

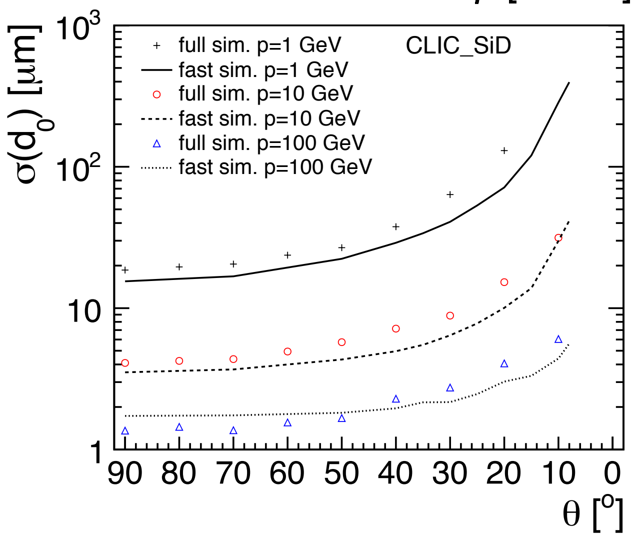
★ **Underlying performance of detectors meet requirements, e.g. CLIC_SiD**



Momentum resolution



Jet energy resolution

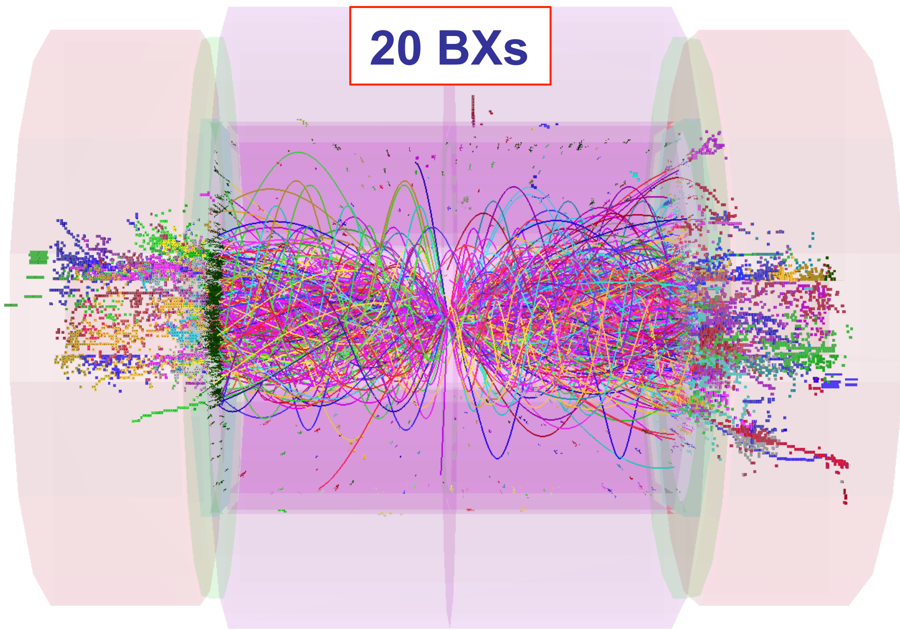


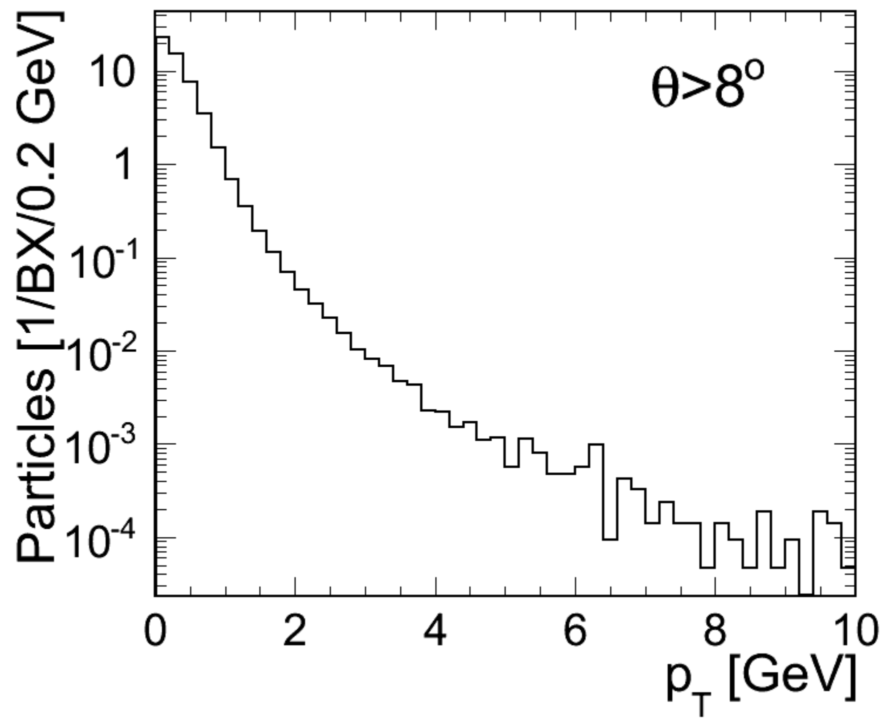
Impact par. resolution

Background from $\gamma\gamma\rightarrow$ hadrons and Timing Requirements

Background from $\gamma\gamma\rightarrow$ hadrons

- ★ Pair Background largely affects very low angle region
- ★ Background in calorimeters, central tracker dominated by $\gamma\gamma\rightarrow$ hadrons "mini-jets"
- ★ At 3 TeV, average 3.2 events per BX (approximately 5 tracks per event)
- ★ For entire bunch-train (312 BXs)
  - 5000 tracks (mean momentum 1.5 GeV) giving total track momentum : 7.3 TeV
  - Total calorimetric energy (ECAL + HCAL) : 19 TeV
- ★ Largely low p_T particles



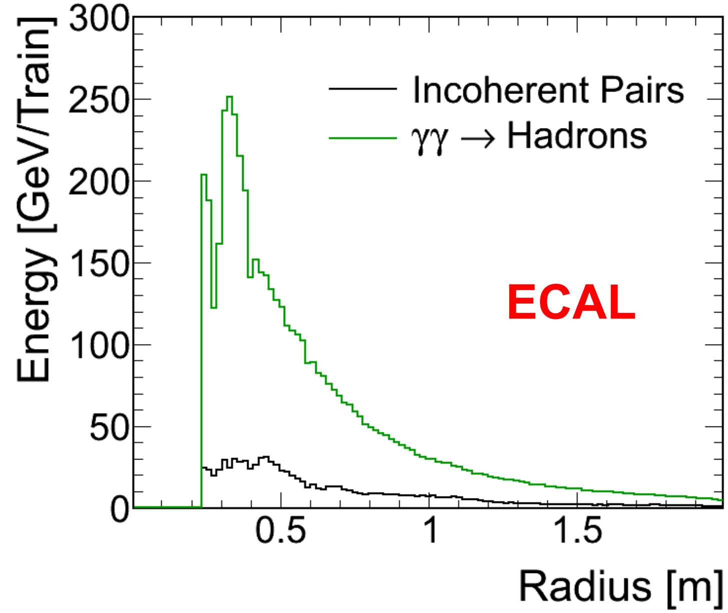


- ★ Irreducible background – it is physics

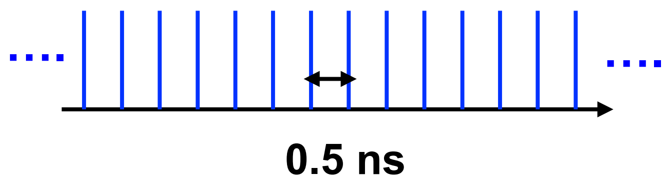
Backgrounds in the Calorimeters

★ **Calorimeter backgrounds per bunch-train (3 TeV)**

Detector	**$\gamma\gamma \rightarrow$ hadrons**
ECAL endcaps	**11 TeV**
ECAL barrel	1.5 TeV
HCAL endcaps	**6 TeV**
HCAL barrel	0.3 TeV
Total	19 TeV

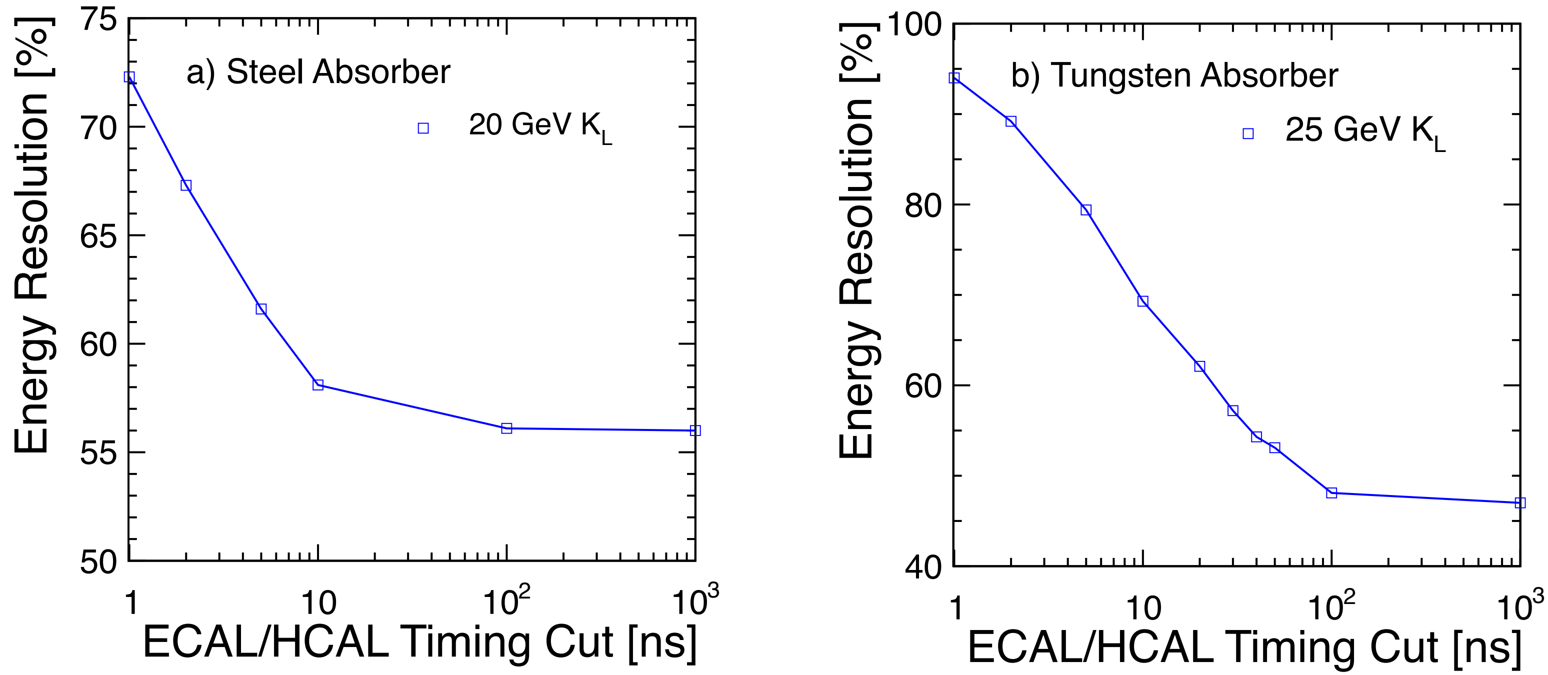


★ **Calorimeter backgrounds per bunch-crossing are manageable, ~ 60 GeV**
★ **Want to integrate over as few as possible BXs**
★ **Tight timing requirements !**



Calorimeter Timing

- ★ **But can't make calorimeter time window arbitrarily short…**
- ★ **Time needed to accumulate all calorimetric energy (due to low energy particles, nuclear break-up etc.) significant compared to 0.5 ns Bx**
- ★ **HCAL resolution depends on time window**



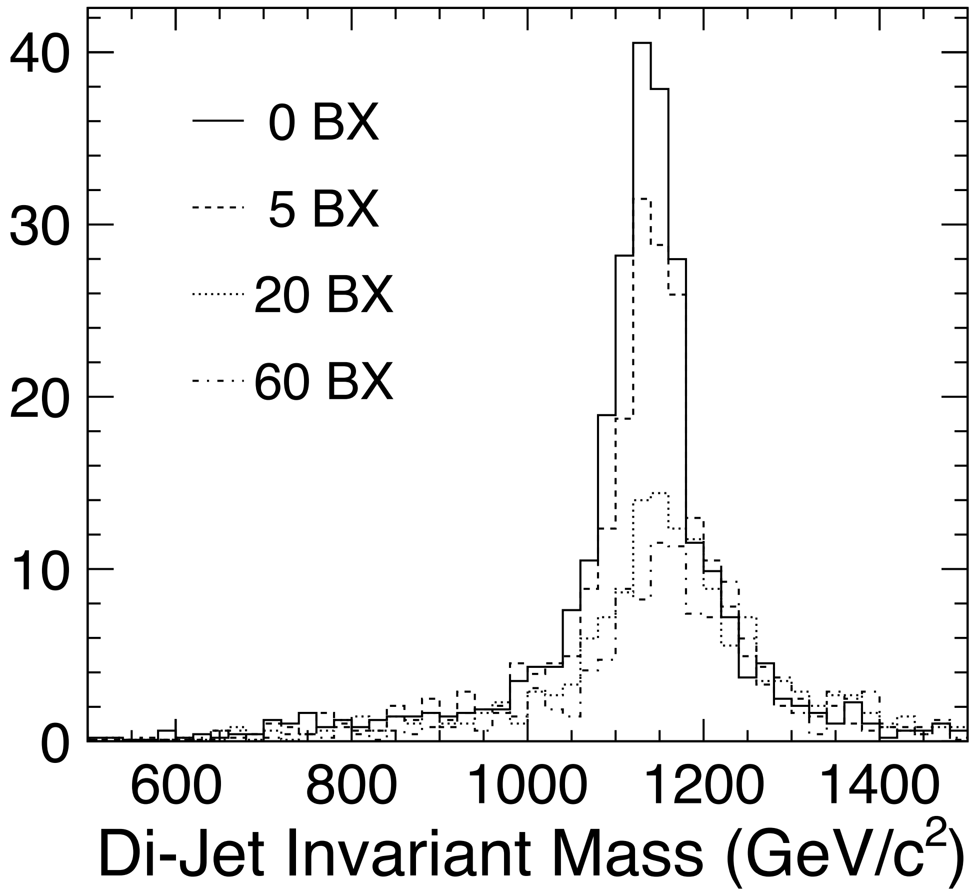
Steel (Endcap): ~10 ns

Tungsten (Barrel): ~100 ns

CLIC Timing cont.

★ Tension between calorimeter integration time and desire to minimize number of BXs of $\gamma\gamma \rightarrow$ **hadrons** background

- e.g. reconstructed di-jet mass in $e^+e^- \rightarrow H^0A^0 \rightarrow b\bar{b}b\bar{b}$

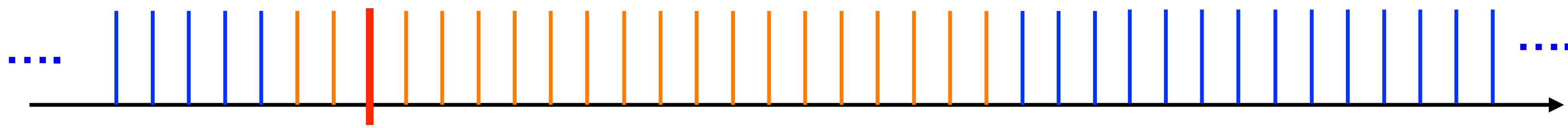


⇨ **< 5 BX**

But < 2.5 ns not long enough for calorimetry

CLIC Timing Strategy

- ★ Based on trigger-free readout of detector hits all with time-stamps
  - assume multi-hit capability of 5 hits per bunch train
- ★ 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

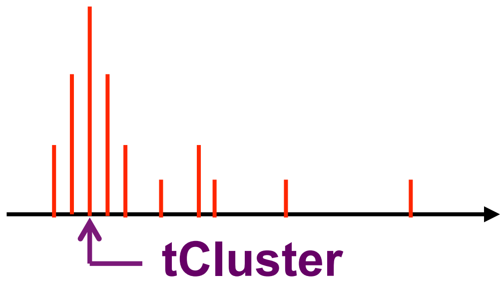
Sufficient calorimeter integration window

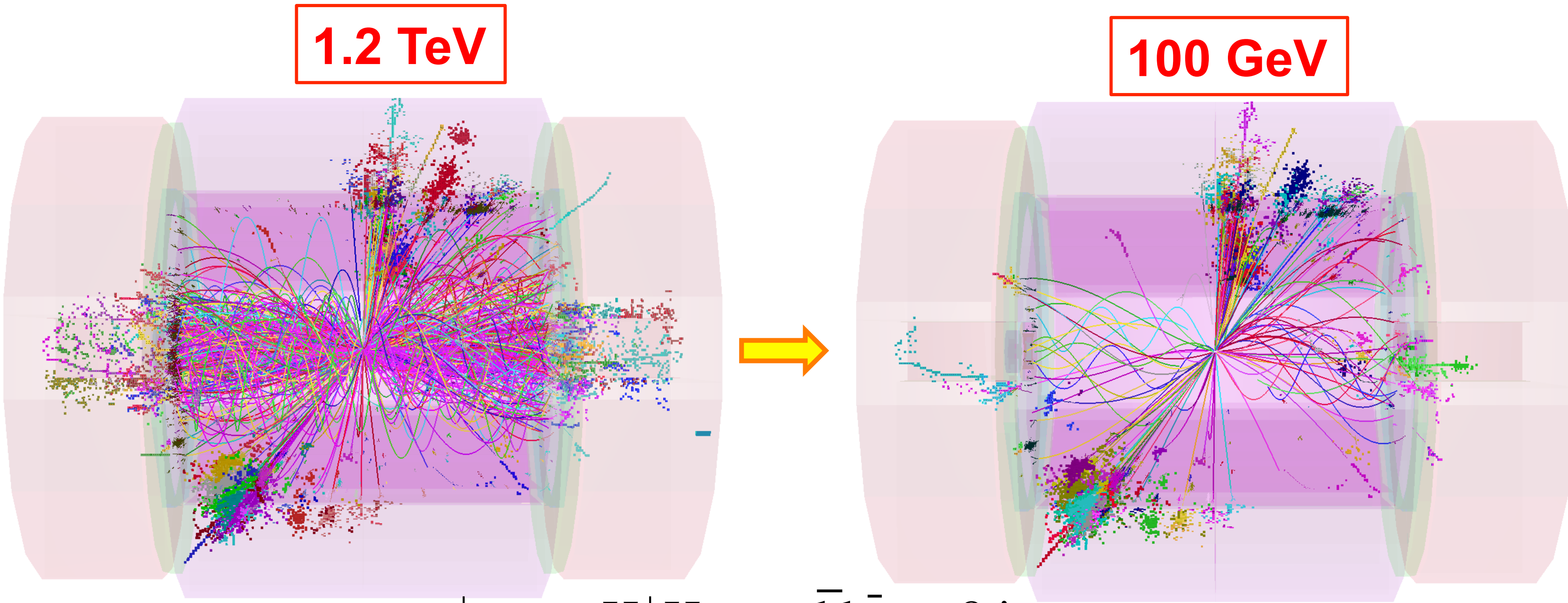
CLIC hardware requirements

- ★ Still 1.2 TeV reconstructed background per event

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)

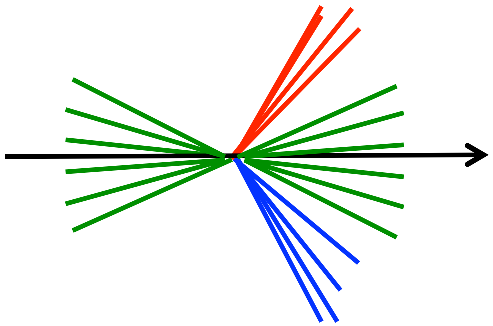




$$e^+e^- \rightarrow H^+H^- \rightarrow t\bar{b}b\bar{t} \rightarrow 8 \text{ jets}$$

Jet Finding at CLIC

★ At LEP, preferred jet-finding algorithm: Durham k_T
- all particles in event clustered into the jets
- not appropriate for CLIC



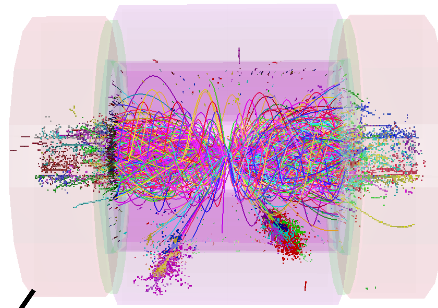
★ Events at CLIC
- significant background from forward-peaked $\gamma\gamma \rightarrow$ hadrons
- are often boosted along beam axis (beamsstrahlung)
- "hadron collider" type algorithms more appropriate

★ Jet finding at CLIC
- studied for benchmark physics analyses (FASTJET package)
- preferred option "k_T" with distance measure $\Delta R^2 = \Delta\eta^2 + \Delta\phi^2$
  - invariant under longitudinal boosts
- particles either combined with existing jet or beam axis
  - reduces sensitivity to $\gamma\gamma \rightarrow$ hadrons

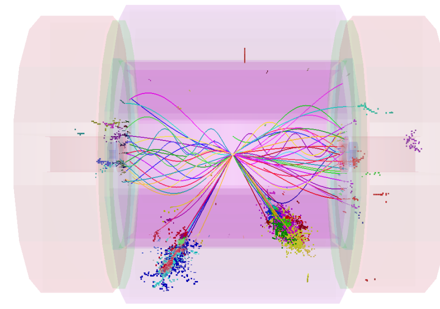
Jet Finding at CLIC

★ **e.g.** $e^+e^- \to \tilde{q}_R\tilde{q}_R \to q\bar{q}\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$

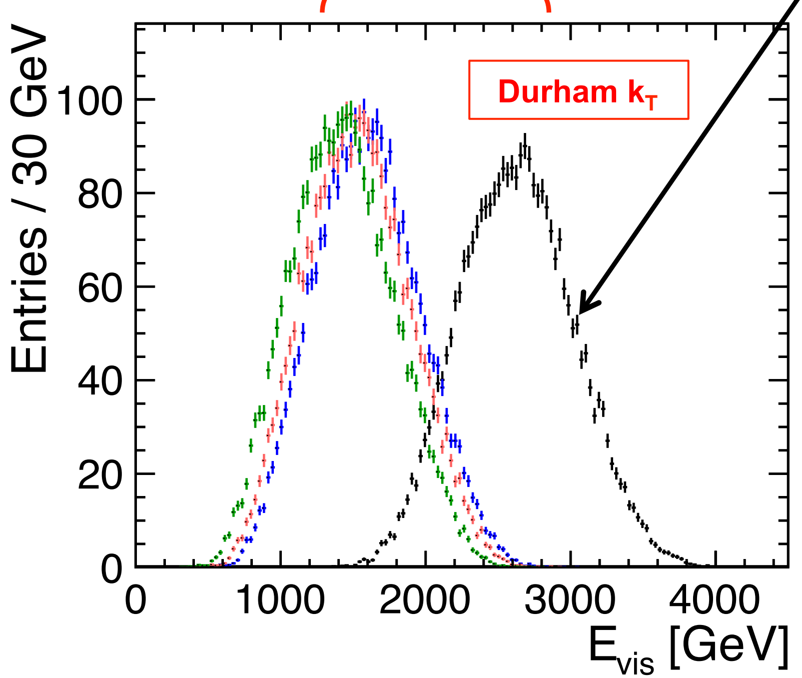
- **two jets + missing energy**

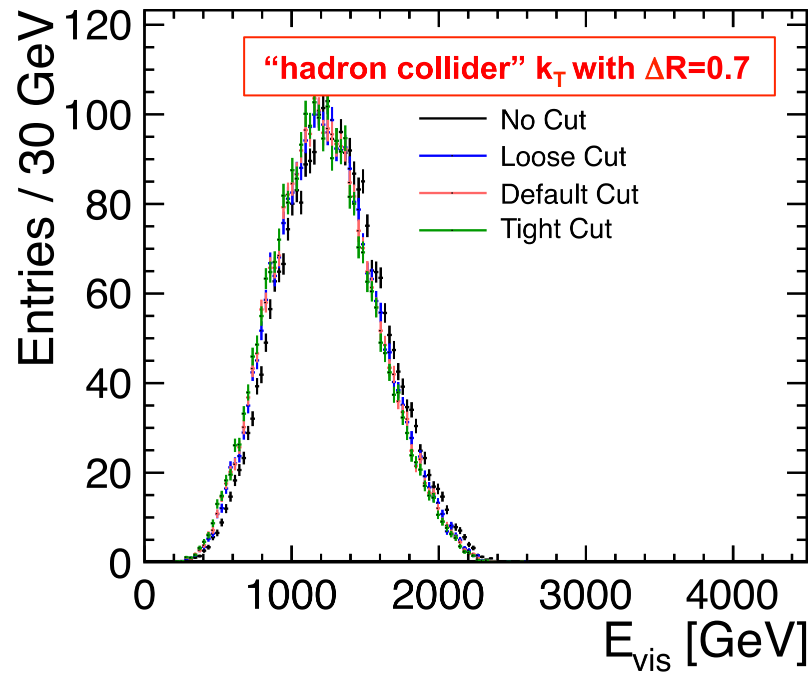


TIGHT timing ⇒



All particles clustered



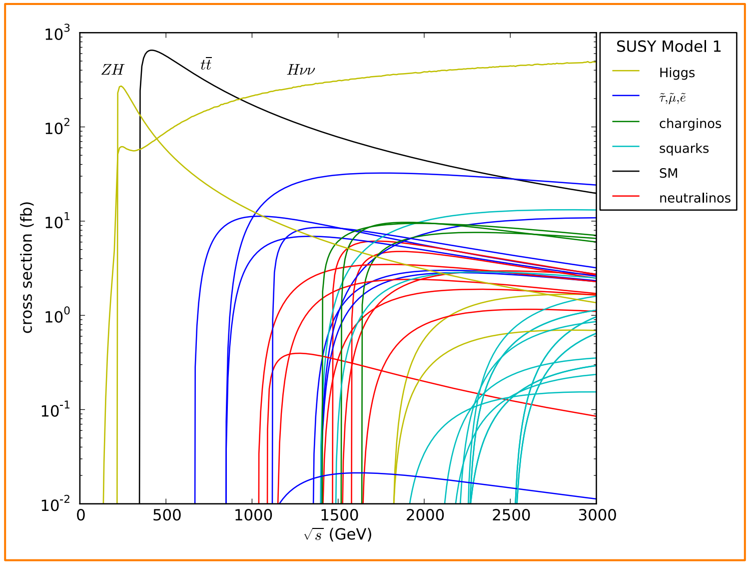


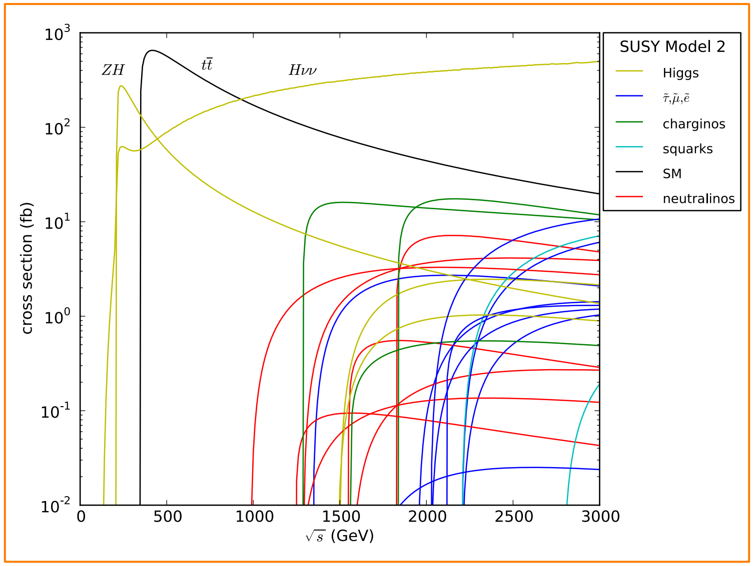
★ **Two "weapons" against background: timing cuts + jet finding**

CLIC Benchmarks

CLIC Benchmarks

- ★ Detector performance in presence of background demonstrated in CLIC benchmark analyses (+ studies at single physics object level)
- ★ Benchmarks chosen to demonstrate aspects of detector performance
  - Light Higgs (120 GeV)
  - Two SUGRA SUSY points with non-unified gaugino masses
    – chosen to emphasise detector performance

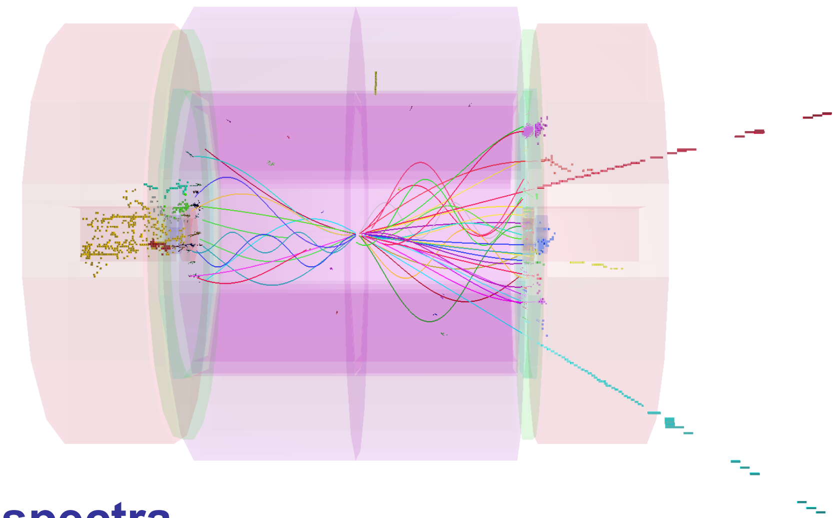




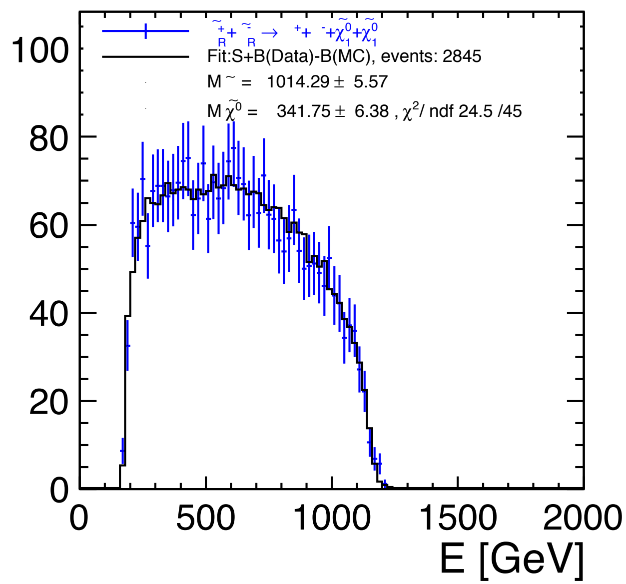
- ★ All studies use full simulation, full reconstruction and include background from $\gamma\gamma \rightarrow$ hadrons
- ★ Some studies use CLIC_ILD others use CLIC_SiD

Slepton Production

- ★ Slepton production at CLIC very clean
- ★ Use SUSY model II: slepton masses ~ 1 TeV
- ★ Channels studied include
  - $e^+e^- \rightarrow \tilde{\mu}_R^+\tilde{\mu}_R^- \rightarrow \mu^+\mu^- \, \tilde{\chi}_1^0\,\tilde{\chi}_1^0$
  - $e^+e^- \rightarrow \tilde{e}_R^+\tilde{e}_R^- \rightarrow e^+e^- \, \tilde{\chi}_1^0\,\tilde{\chi}_1^0$
  - $e^+e^- \rightarrow \tilde{\nu}_e\tilde{\nu}_e \rightarrow e^+e^-W^+W^- \, \tilde{\chi}_1^0\,\tilde{\chi}_1^0$
- ★ Acoplanar leptons and mssing energy
- ★ Masses from analysis of endpoints of energy spectra



e.g. smuon production

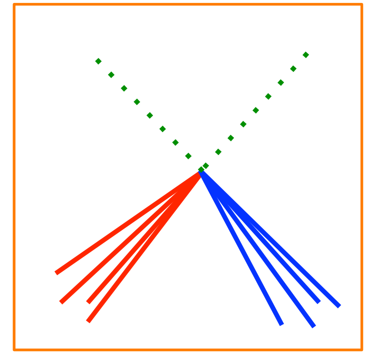


All channels combined

$$m(\tilde{\mu}_R) \; : \; \pm 5.6\,\mathrm{GeV}$$
$$m(\tilde{e}_R) \; : \; \pm 2.8\,\mathrm{GeV}$$
$$m(\tilde{\nu}_e) \; : \; \pm 3.9\,\mathrm{GeV}$$
$$m(\tilde{\chi}_1^0) \; : \; \pm 3.0\,\mathrm{GeV}$$
$$m(\tilde{\chi}_1^\pm) \; : \; \pm 3.7\,\mathrm{GeV}$$

Squark Production

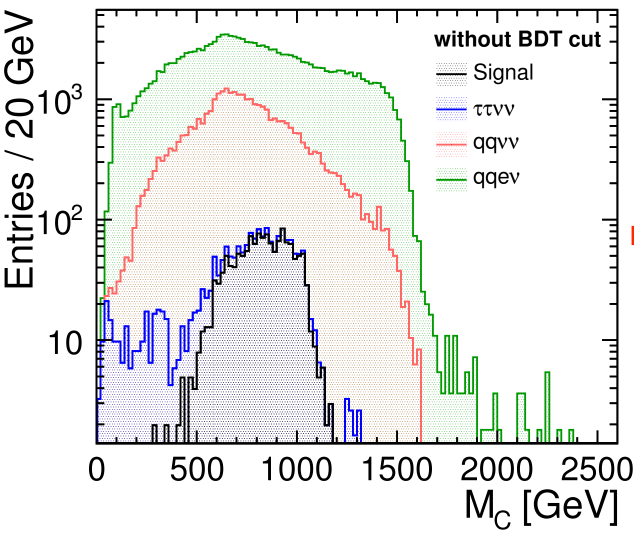
$$e^+e^- \rightarrow \tilde{q}_R\tilde{q}_R \rightarrow q\bar{q}\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$$

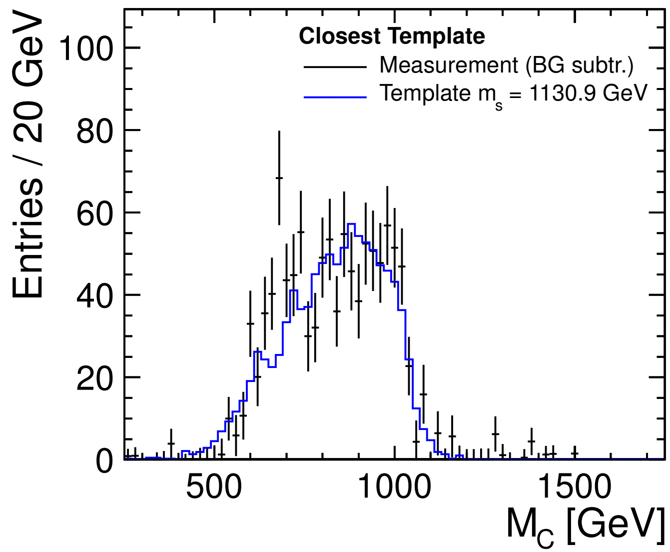


★ **Light flavour squarks tend to be heaviest SUSY particles**
- **study in context of model-I :** $m_{\tilde{q}_R} = 1.123\,\mathrm{TeV}$
- **simple topology: two high energy jets + missing energy**
- **mass reconstructed from "edge" of "mass" distribution**

$$M_C = (2E_1E_2 + \mathbf{p}_1 \cdot \mathbf{p}_2)^{1/2}$$

★ **Main issue is large SM background**
- **reduced using multivariate analysis: BDT**





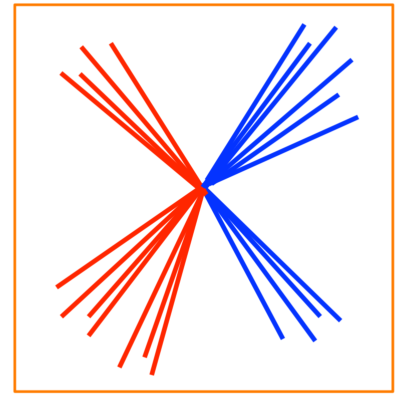
$m_{\tilde{q}_R}$: $\pm 6\,\mathrm{GeV}$

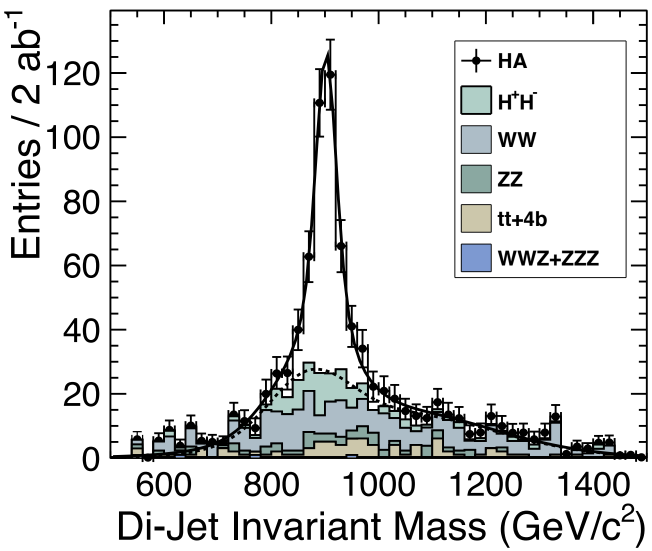
Heavy Higgs

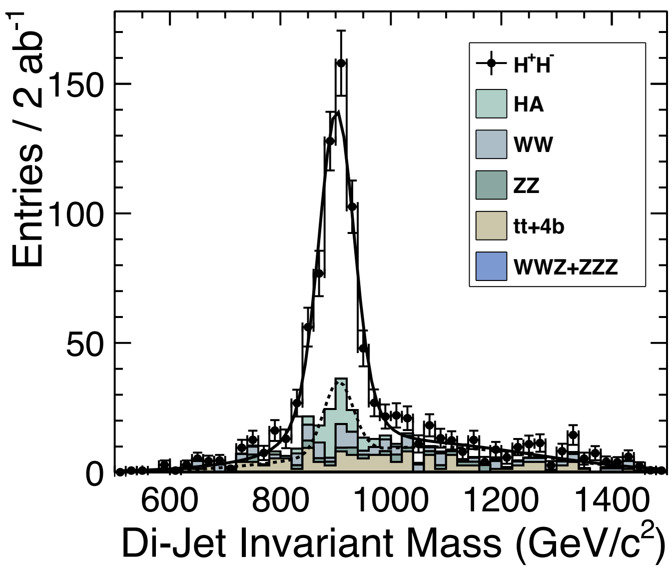
$e^+e^- \rightarrow H^0A^0 \rightarrow b\bar{b}b\bar{b}$

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

- SUSY (and in general 2HDMs) give heavy Higgs states (900 GeV in model I)
- Analysis:
  - force events into four jets (the top quarks highly boosted)
  - use b-tagging, kinematic fits, top-tagging (jet structure)
  - Heavy Higgs mass from di-jet mass distribution
  - tests: b-tagging and jet energy res. for high mass states







2 ab^{-1}

m_{A^0/H^0} : ± 2.8 GeV

$m_{H^\pm}$: ± 2.4 GeV

Gaugino Pair Production

★ **Test of particle flow reconstruction of boosted low mass (EW scale) states**

- **SUSY model II :** $m(\tilde{\chi}_1^0) = 340\,\mathrm{GeV} \quad m(\tilde{\chi}_2^0), m(\tilde{\chi}_1^+) \approx 643\,\mathrm{GeV}$

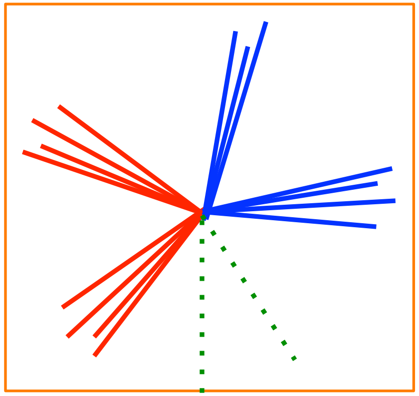
★ **Pair production and decay:**

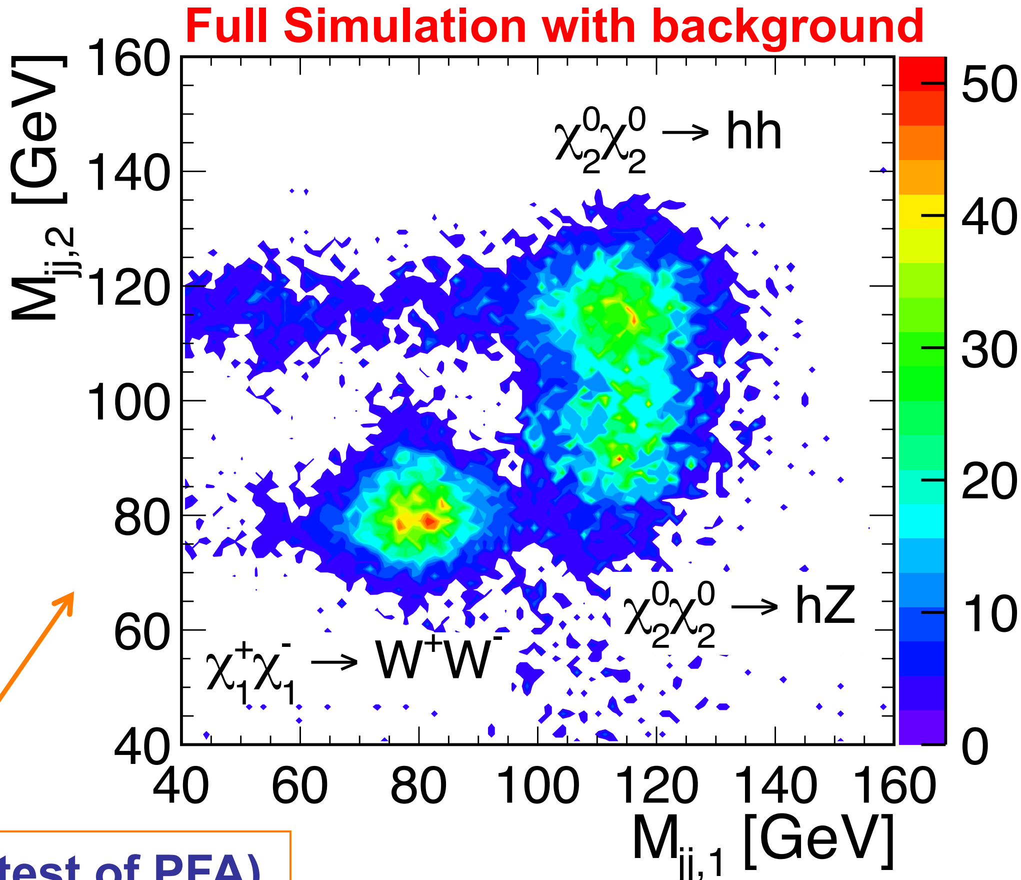
$$e^+e^- \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 W^+W^-$$

$$e^+e^- \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_2^0 \rightarrow hh\, \tilde{\chi}_1^0 \tilde{\chi}_1^0 \quad \textbf{82 \%}$$

$$e^+e^- \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_2^0 \rightarrow Zh\, \tilde{\chi}_1^0 \tilde{\chi}_1^0 \quad \textbf{17 \%}$$

★ **Largest decay BR has same topology for all final states**

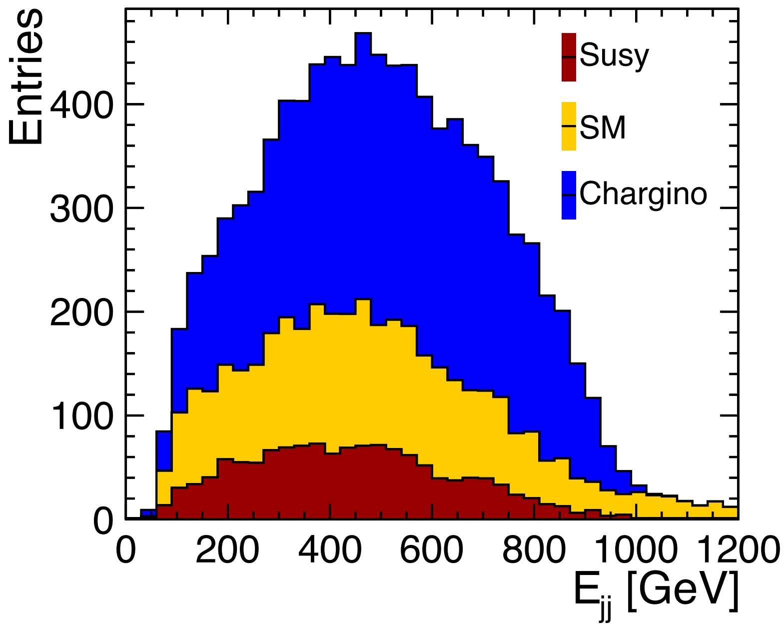


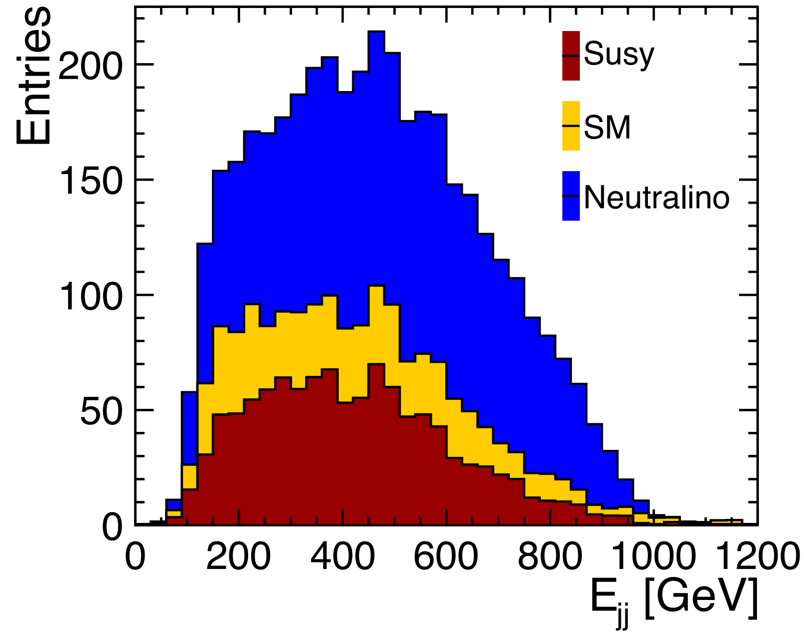


★ **Separate using di-jet invariant masses (test of PFA)**

Gaugino Pair Production cont.

- ★ **Significant SM background**
  - **Multivariate Chargino and Neutralino event selections (BDT)**
    - **Invariant mass plays a central role in selections**
  - **Chargino/Neutralino masses extracted from di-jet energy distributions**





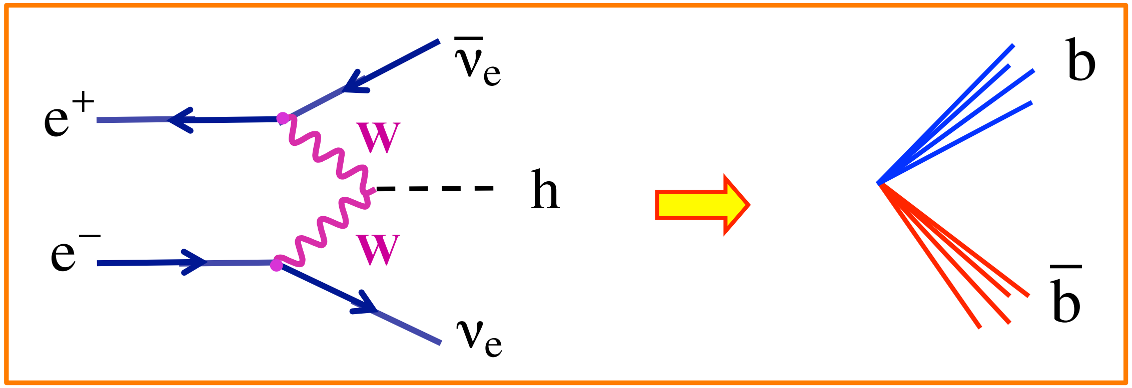
$$m(\tilde{\chi}_1^{\pm}) \ : \ \pm 7\,\mathrm{GeV}$$
$$m(\tilde{\chi}_2^{0}) \ : \ \pm 10\,\mathrm{GeV}$$

From sleptons used

$$m(\tilde{\chi}_1^{0}) \ : \ \pm 3\,\mathrm{GeV}$$

Higgs Decay

★ **Light Higgs production has very large WW fusion cross section at 3 TeV: 420 fb**



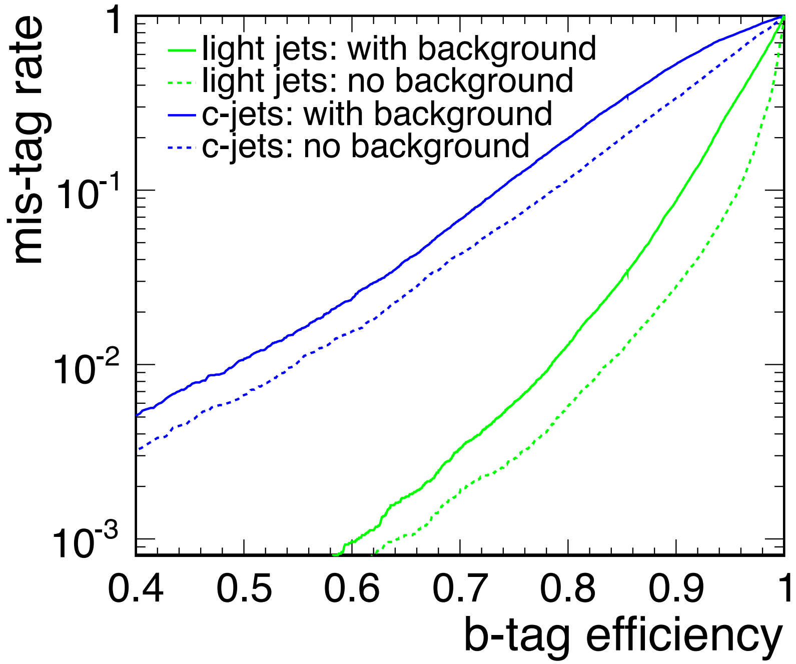
★ **Branching ratio analysis sensitive to:**

flavour tagging

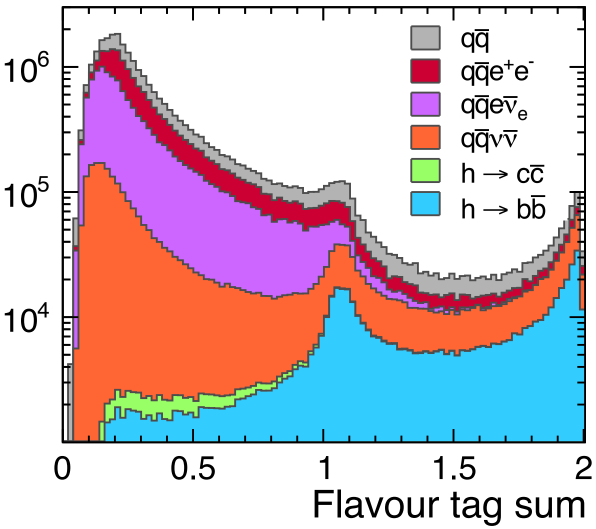
di-jet mass resolution

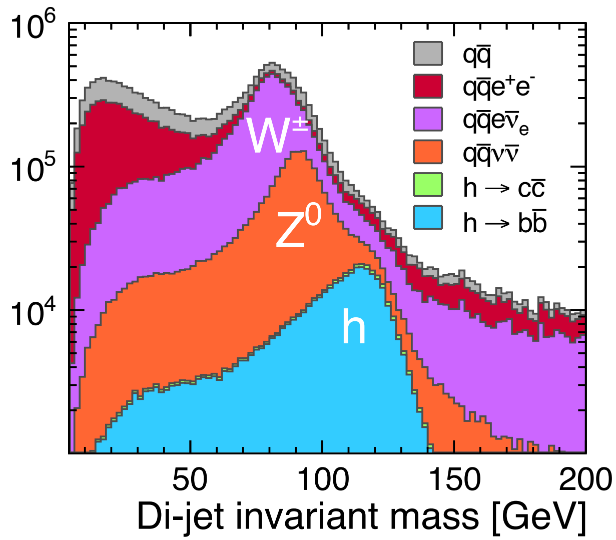
Does flavour-tagging survive background ?

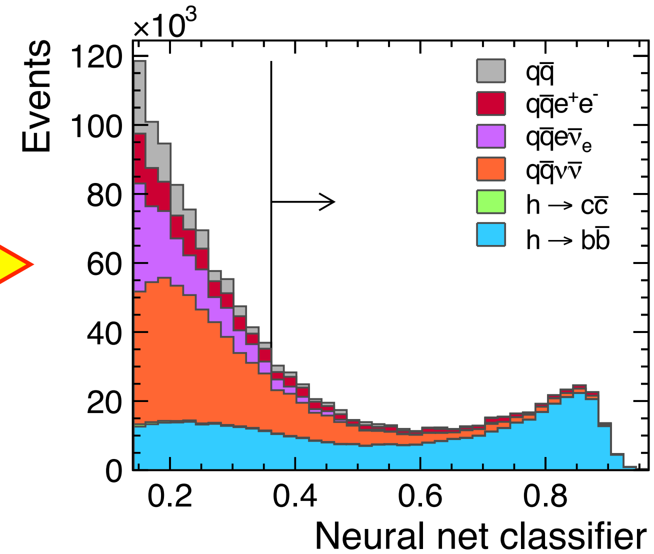
- **some degradation**
- **but b-tag performance still v. good**
- **c-tagging also possible**



$h \rightarrow cc$, bb, μμ





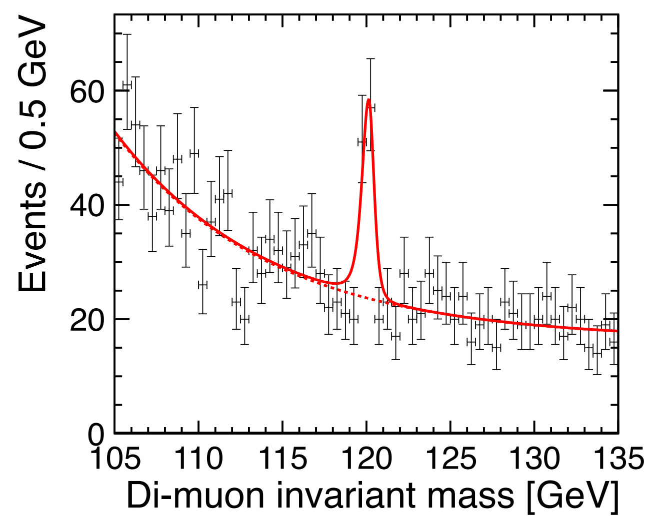


★ **Large data sample leads to very small stat. errors**

$$\sigma(BR(h \rightarrow b\bar{b})) = 0.2\,\%$$
$$\sigma(BR(h \rightarrow c\bar{c})) = 3\,\%$$

★ **Can also also observe*** $h \rightarrow \mu^+\mu^-$

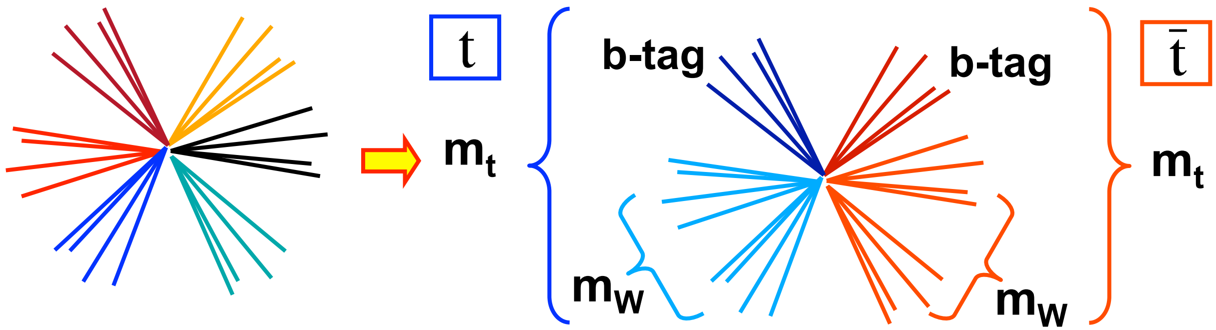
$$\sigma(BR(h \rightarrow \mu^+\mu^-)) < 23\,\%$$



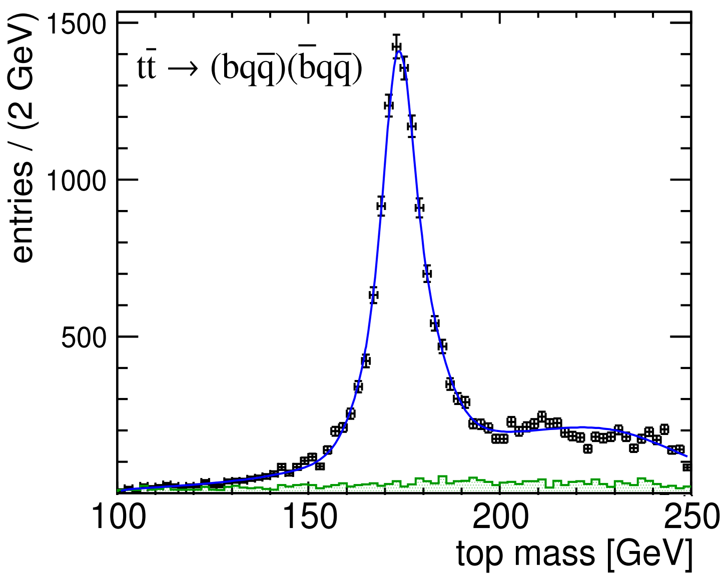
***NOTE: does not yet use tagging of forward electrons – will improve**

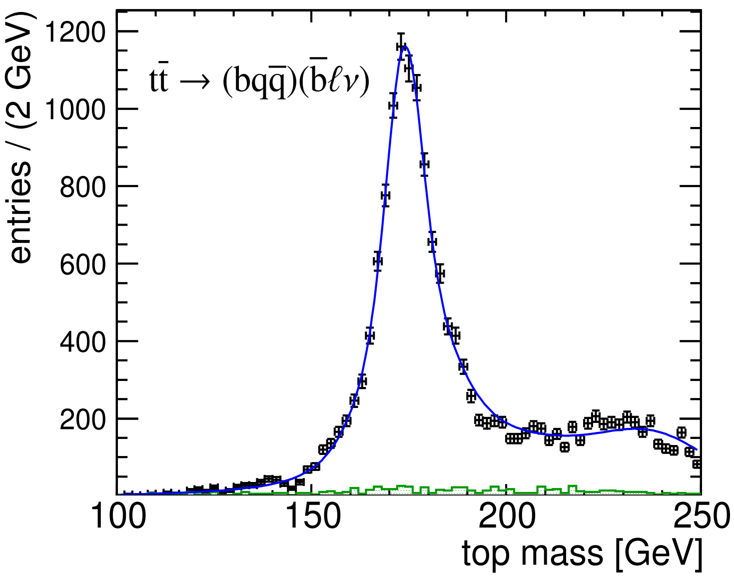
Top mass at 500 GeV

★ Study top production at $\sqrt{s}$ = **500 GeV** under CLIC background conditions
- fully hadronic $t\bar{t} \to (bq\bar{q})(\bar{b}q\bar{q})$ and semi-leptonic $t\bar{t} \to (bq\bar{q})(\bar{b}\ell\nu)$
- complex analysis, e.g. jet combinatorics



Use:
- b-tagging
- Invariant masses
- Kinematic fits





100 fb^{-1}

m_t : ± 60 MeV

Benchmark Summary

★ **Wide range of channels studied**
- **Excellent physics performance achieved in all**
- **Both CLIC_ILD and CLIC_SiD concepts are viable options**
- **For details refer to CDR and the detailed LCD-Notes**

Conclusions

★ **Understanding of Detectors at CLIC has made great progress**

- **Have demonstrated precision physics in CLIC environment**
- **Defined detector requirements which will guide future R&D**

★ **Frozen draft version of CDR available**

- **https://edms.cern.ch/document/1160419**
- **please read**
- **if you wish to support the CLIC physics case, you are invited to sign-up !**

https://indico.cern.ch/conferenceDisplay.py?confId=136364

Related talks at LCWS

Speaker	Title	Session Code	Date/Time
Jan Strube	**Analyses of light Higgs decays for the CLIC CDR**	R&D1	27th Sep. at 12h20
Marco Battaglia	**Study of Heavy Higgs Bosons in 3 TeV e+e- Collisions**	R&D1	27th Sep. at 12h00
Jean-Jacques Blaising	**Determination of Heavy Slepton Mass at CLIC**	R&D2	27th Sep. at 15h36
Frank Simon	**Mass and Cross Section Measurements of light-flavored Squarks at CLIC**	R&D2	27th Sep. at 15h00
Philipp Roloff	**Measurement of Chargino and Neutralino production at CLIC**	R&D2	28th Sep. at 15h54
Katja Seidel	**Top mass measurement with the CLIC_ILD detector at 500 GeV**	R&D3	27th Sep. at 12h00
John Marshall	**Lepton Identification at CLIC**	R&D5	29th Sep. at 11h00
Jan Strube	**Flavour tagging at CLIC**	R&D5	28th Sep. at 15h40
Astrid Munnich	**Particle Flow Performance at CLIC**	R&D5	29th Sep. at 11h20
Stephane Poss	**Monte Carlo production for the CLIC CDR**	R&D5	27th Sep. at 17h00
Andre Sailer	**Radiation Levels and Occupancies**	R&D5 + R&D6	28th Sep. at 08h30
Katja Seidel	**Machine background suppression at CLIC**	R&D5 + R&D6	28th Sep. at 09h30
Mark Thomson	**Muon background mitigation**	R&D5 + R&D6	28th Sep. at 09h50

Related talks cont.

Speaker	Title	Session Code	Date/Time
Andrea Gaddi	**Main solenoid progress**	R&D6 + AWG5	27^{th} Sep at 13h00
Fernando Duarte Ramos	**Passive Isolation R&D**	R&D6 + AWG5 + AWG8	29^{th} Sep. at 12h20
Maciej Herdzina	**Detector movements on CLIC cavern**	R&D6 + AWG5 + AWG8	29^{th} Sep. at 11h00
Juan Trenado	**Background Studies for Vertex and Forward Tracking Optimisation**	R&D7	27^{th} Sep. at 11h20
Bill Cooper	**CLIC Vertex Detector Mechanics**	R&D7	29^{th} Sep. at 08h50
Michael Hauschild	**Tracking performance in CLIC_ILD and CLIC_SiD**	R&D7	27^{th} Sep. at 16h00
Shaojun Lu	**Operation and Calibration of the CALICE Tungsten HCAL**	R&D8	28^{th} Sep. at 15h00
Frank Simon	**CALICE T3B: Measurements of the Time Structure of Hadronic Showers in a Scintillator-Tungsten HCAL**	R&D8	28^{th} Sep. at 15h20

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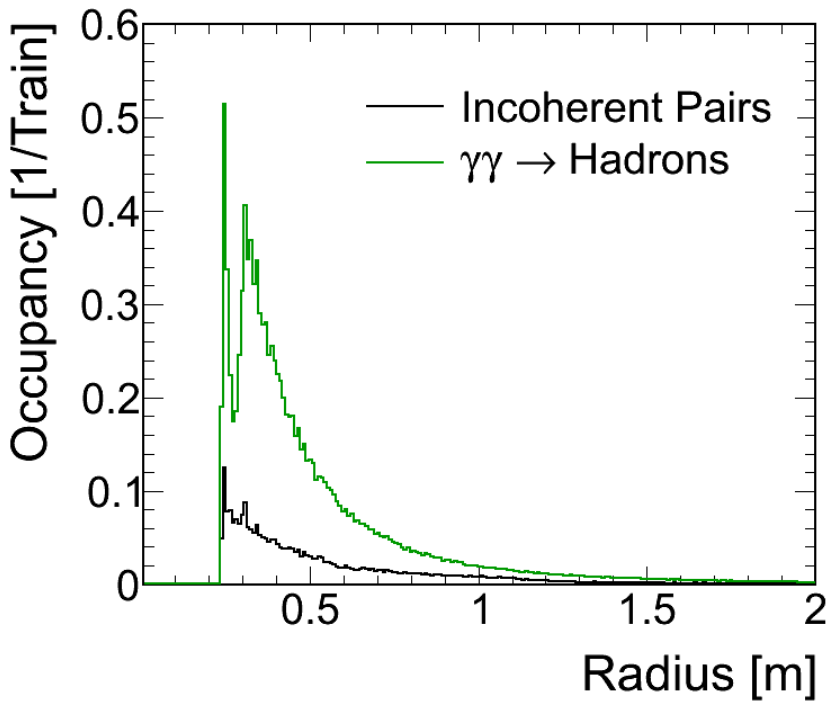
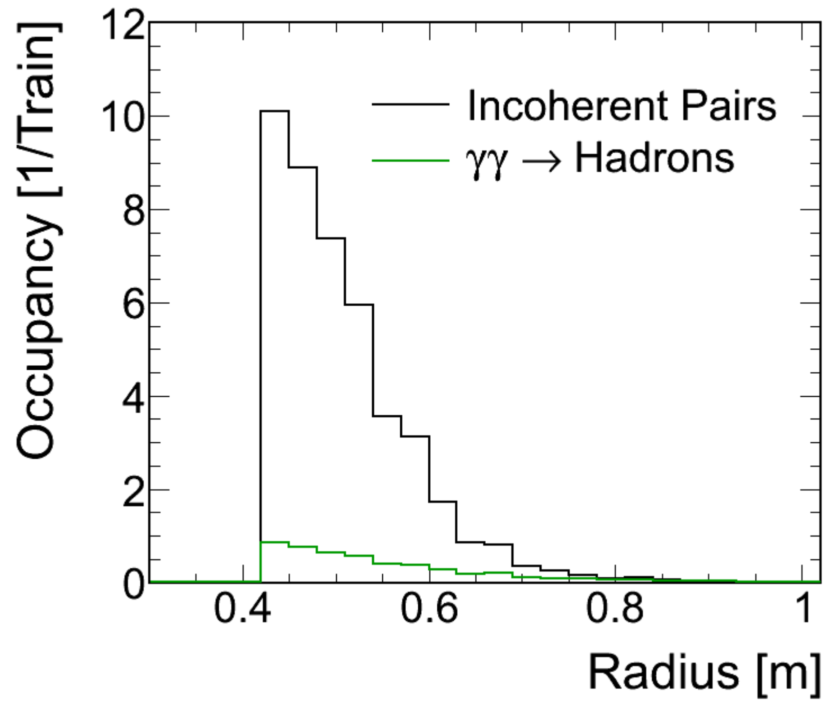
Back-up Slides

Backup Calorimeter Occupancies



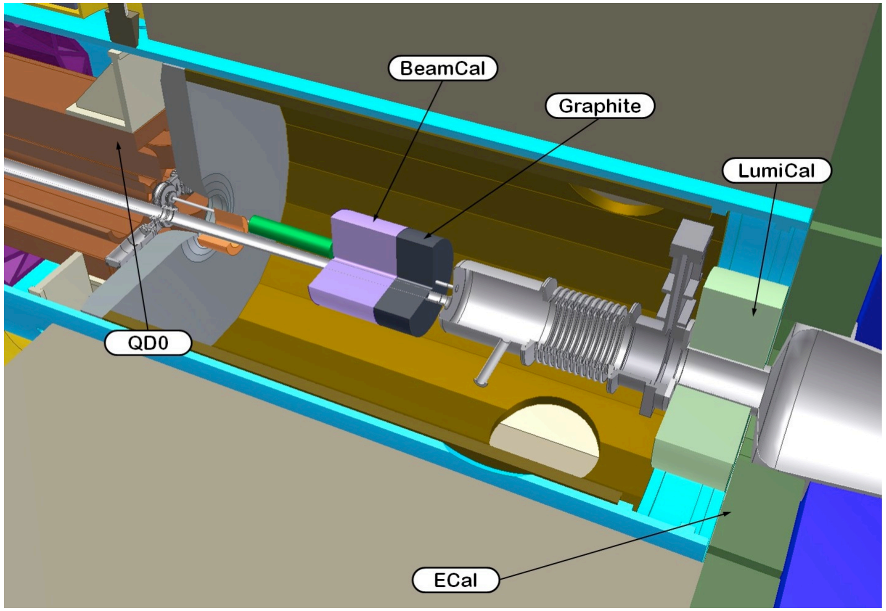


Backup: Benchmark Summary

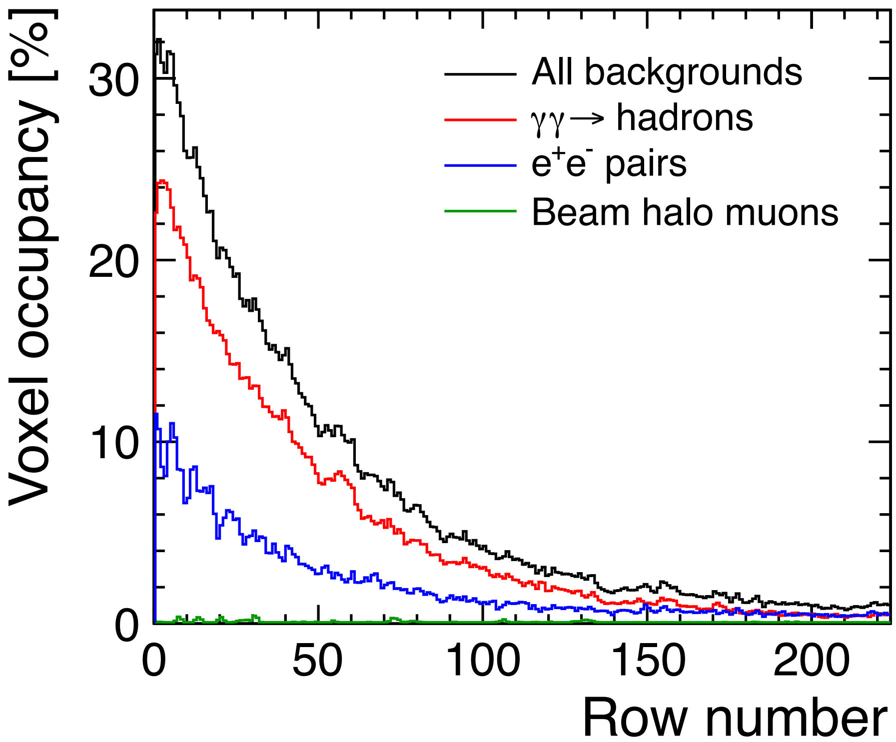
$\sqrt{s}$ (TeV)	Process	Decay mode	SUSY model	Observable	Unit	Generator value	Stat. uncertainty
3.0	Light Higgs production	$h \to b\bar{b}$		$\sigma \times$ Branching ratio	fb	285	0.22%
		$h \to c\bar{c}$				13	3.2%
		$h \to \mu^+\mu^-$				0.12	23%
3.0	Heavy Higgs production	$HA \to b\bar{b}b\bar{b}$	I	Mass	GeV	902.4	0.3%
				Width	GeV		31%
			II	Mass	GeV	742.0	0.2%
				Width	GeV		17%
		$H^+H^- \to t\bar{b}b\bar{t}$	I	Mass	GeV	906.3	0.3%
				Width	GeV		27%
			II	Mass	GeV	747.6	0.3%
				Width	GeV		23%
3.0	Production of right-handed squarks	$\tilde{q}_R\tilde{q}_R \to q\bar{q}\tilde{\chi}_1^0\tilde{\chi}_1^0$	I	Mass	GeV	1123.7	0.52%
				σ	fb	1.47	4.6%
3.0	Sleptons production	$\tilde{\mu}_R^+\tilde{\mu}_R^- \to \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$	II	σ	fb	0.72	2.8%
				$\tilde{\ell}$ mass	GeV	1010.8	0.6%
				$\tilde{\chi}_1^0$ mass	GeV	340.3	1.9%
		$\tilde{e}_R^+\tilde{e}_R^- \to e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0$		σ	fb	6.05	0.8%
				$\tilde{\ell}$ mass	GeV	1010.8	0.3%
				$\tilde{\chi}_1^0$ mass	GeV	340.3	1.0%
		$\tilde{e}_L^+\tilde{e}_L^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^- hh$ $\tilde{e}_L^+\tilde{e}_L^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^- Z^0Z^0$		σ	fb	3.07	7.2%
		$\tilde{\nu}_e\tilde{\nu}_e \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^- W^+W^-$		σ	fb	13.74	2.4%
				$\tilde{\ell}$ mass	GeV	1097.2	0.4%
				$\tilde{\chi}_1^\pm$ mass	GeV	643.2	0.6%
3.0	Chargino and neutralino production	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$	II	$\tilde{\chi}_1^\pm$ mass	GeV	643.2	1.1%
				σ	fb	10.6	2.4%
		$\tilde{\chi}_2^0\tilde{\chi}_2^0 \to h^0/Z^0h^0/Z^0\tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\chi}_2^0$ mass	GeV	643.1	1.5%
				σ	fb	3.3	3.2%
0.5	$t\bar{t}$ production	$t\bar{t} \to (q\bar{q}b)(q\bar{q}b)$		Mass	GeV	174	0.046%
				Width	GeV	1.37	16%
		$t\bar{t} \to (q\bar{q}b)(\ell\nu b)$, $\ell = e, \mu$		Mass	GeV	174	0.052%
				Width	GeV	1.37	18%

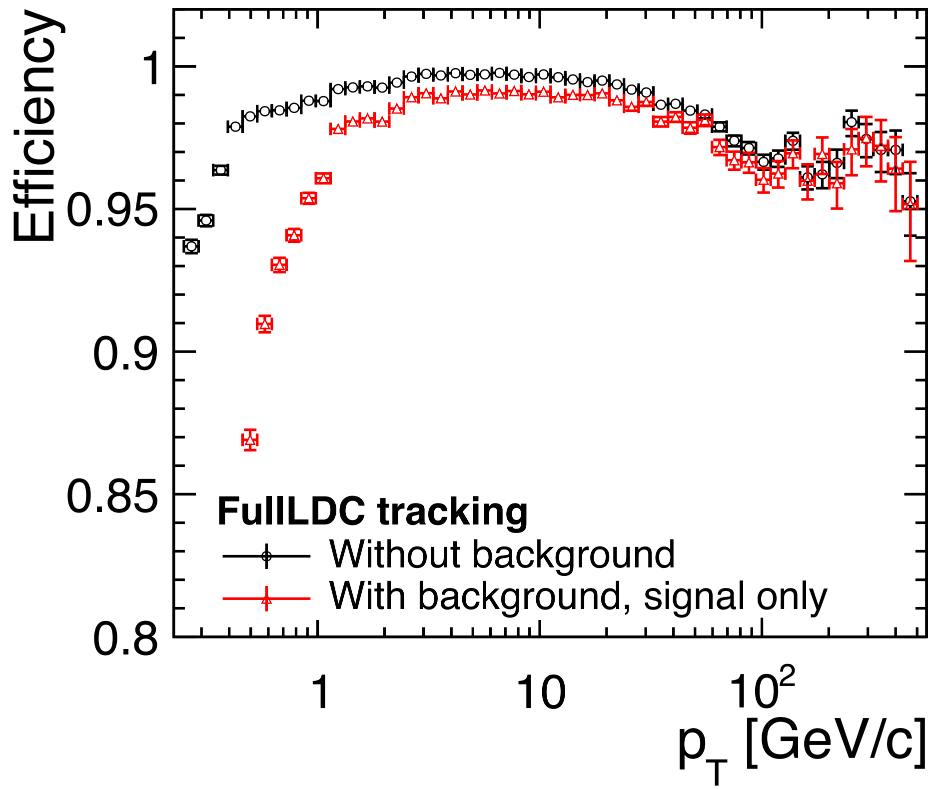
Backup: Impact of Background

- ★ Incoherent pair background also impacts:
  - location of forward tracking discs
  - design of beam pipe
  - design of forward region
- ★ Direct pairs shielded by thick (mm) steel conical (10 mrad) beampipe
- ★ Backscattered pair background reduced by 10cm layer of graphite in front of low angle beam calorimeter
  - Optimised to reduce back-scattered background in tracking volume

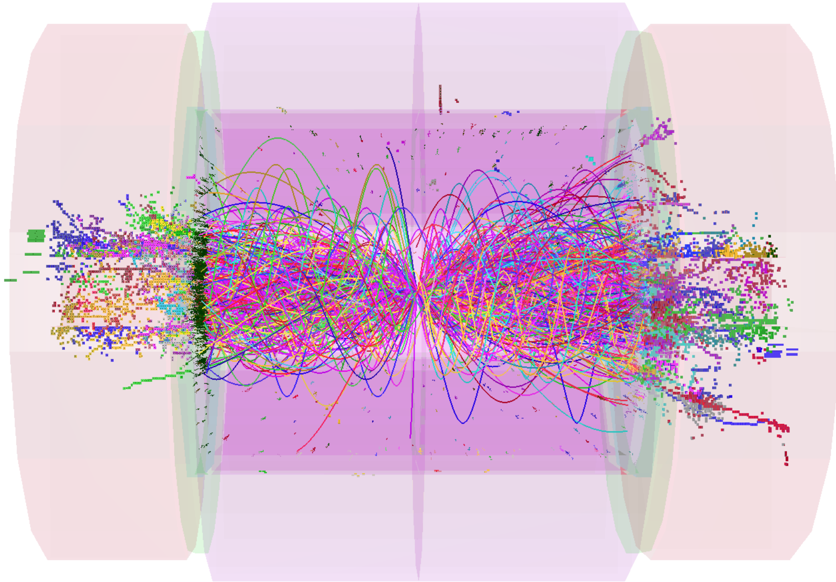


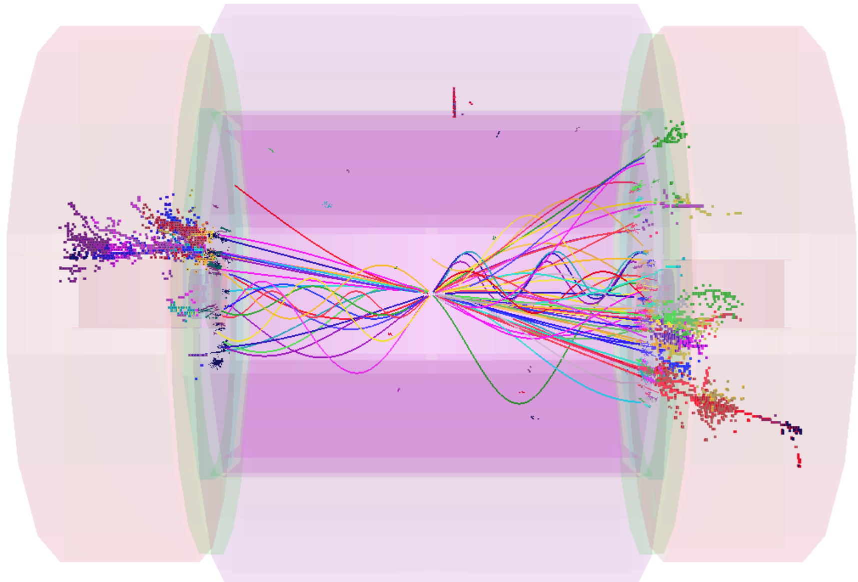
Backup: CLIC_ILD Tracking



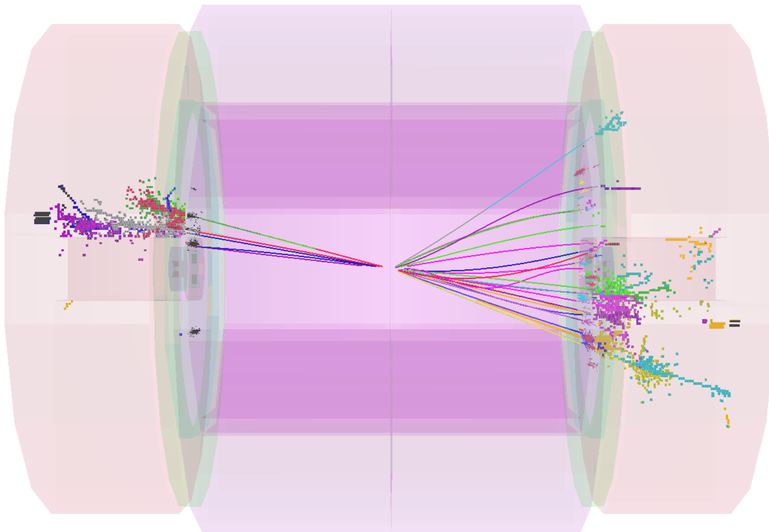


Backup: Forward WW





No background



Backup: CLIC Detector Requirements

★ **momentum:** (1/10 x LEP)

e.g. Smuon endpoint

Higgs recoil mass

$$\sigma_{p_T}/p_T^2 \sim 2\times 10^{-5}\,\mathrm{GeV}^{-1}$$

★ **jet energy:** (1/3 x LEP/ZEUS)

e.g. W/Z di-jet mass separation

SUSY signals

$$\frac{\sigma_E}{E} \sim 3.5-5\,\%$$

★ **impact parameter:** (1/3 x SLD)

e.g. c/b-tagging

Higgs BR

$$\sigma_{r\phi} = 5 \oplus 15/(p[\mathrm{GeV}]\sin^{\frac{3}{2}}\theta)\,\mu\mathrm{m}$$

★ **Hermetic:** e.g. missing energy signatures in SUSY