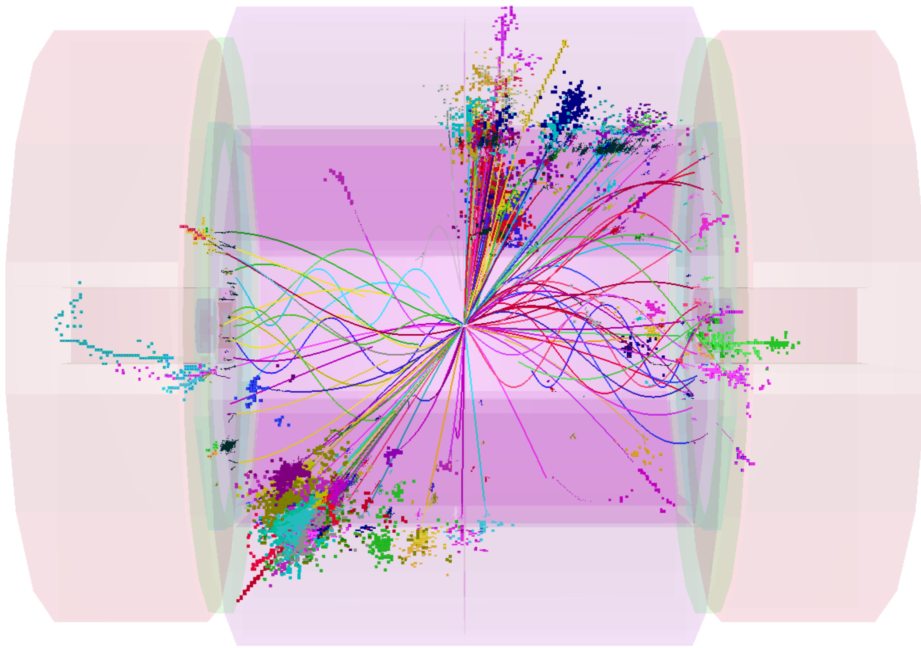
CLIC Detector and Physics

Mark Thomson
University of Cambridge

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 !

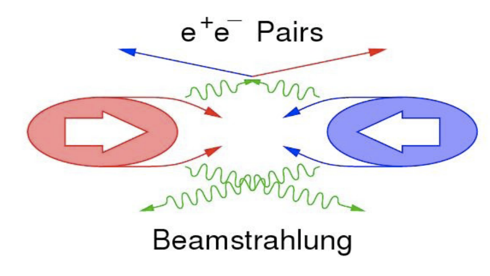
Machine Environment

CLIC Machine Environment

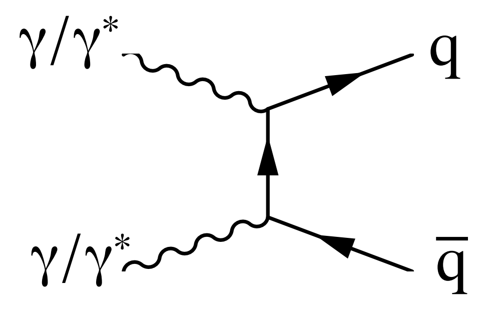
	CLIC 0.5 TeV	CLIC 3 TeV
L [$cm^{-2}s^{-1}$]	2.3×10^{34}	5.9×10^{34}
BX/train	354	312
BX sep	0.5 ns	0.5 ns
Rep. rate	50 Hz	50 Hz
L/BX [cm^{-2}]	1.1×10^{30}	3.8×10^{30}
$\gamma\gamma \to X$ / BX	0.2	3.2
σ_x/σ_y	202 / 2 nm	40 / 1 nm

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



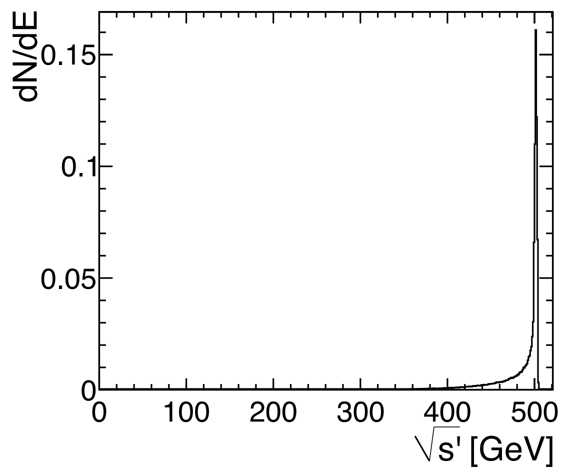
- **Bunch train structure:**
  - CLIC: BX separation 0.5 ns
    - Integrate over multiple BXs of $\gamma\gamma \to$ hadrons
    - 19 TeV visible energy per 156 ns bunch train

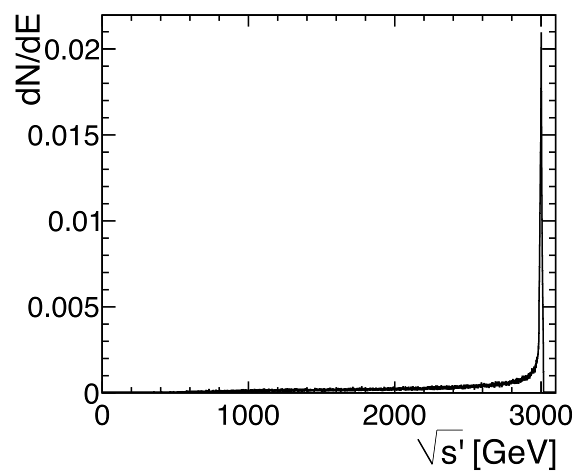


Beamsstrahlung

★ 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, √s' > 99 % √s
  - 62 % at 500 GeV
  - 35 % at 3 TeV





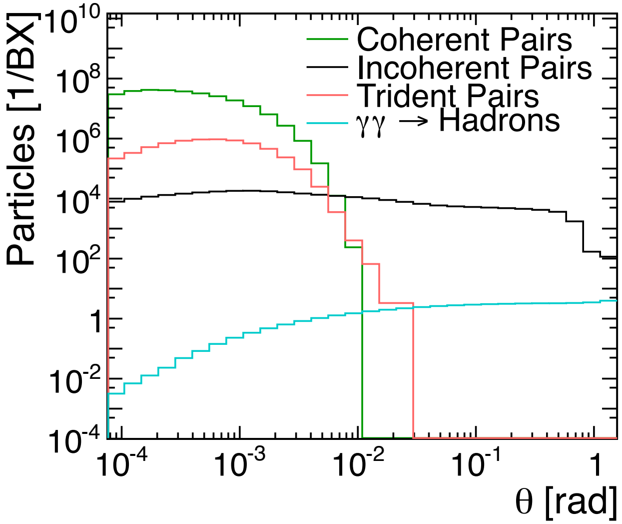
√s' /√s	0.5 TeV	3 TeV
> 99 %	62 %	35 %
> 90 %	89 %	54 %
> 70 %	99 %	76 %
> 50 %	~100 %	88 %

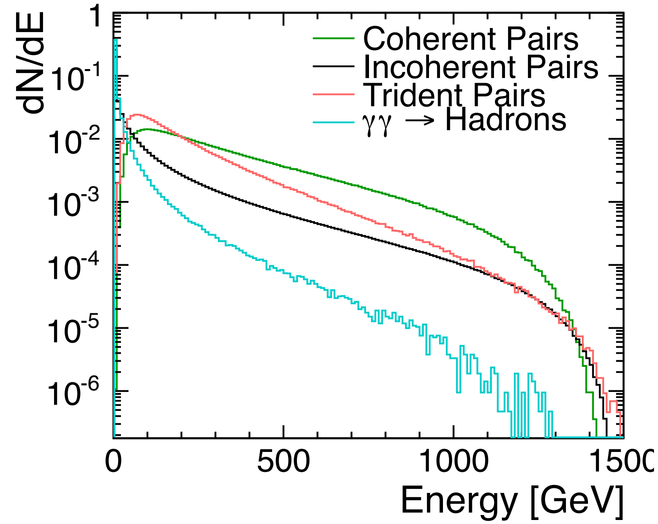
★ **Impact on physics** – depends on final state

- 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

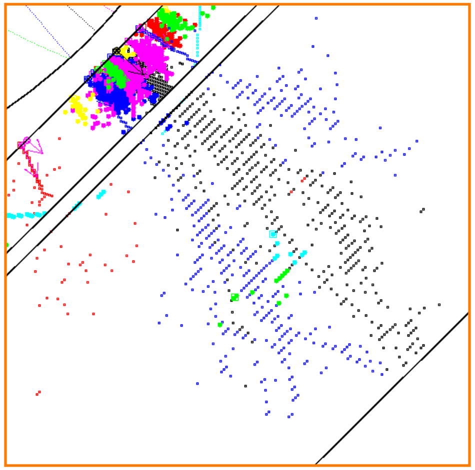




CLIC Detector Concepts

CLIC Detector Concepts

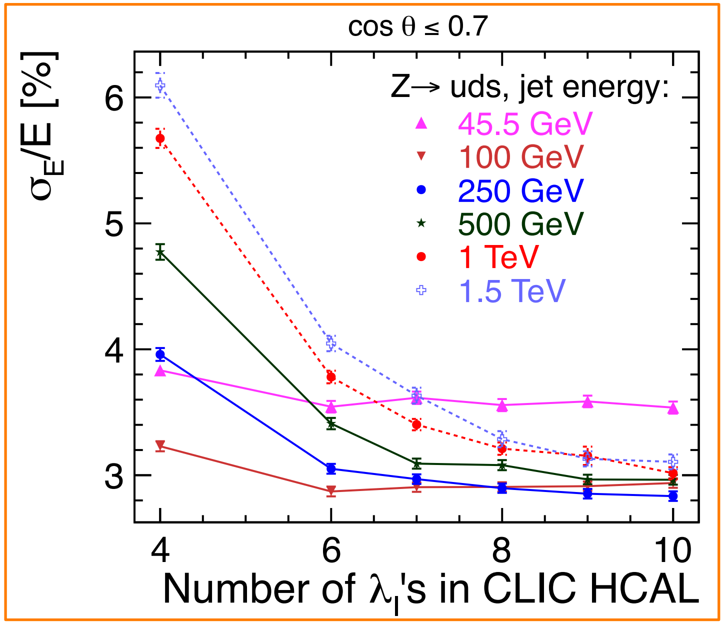
- ★ Detector requirements for CLIC
  - All those for the ILC + timing
  - Optimised for CLIC backgrounds
- ★ Starting point
  - Validated LoI detectors: **ILD** and **SiD**
  - High granularity calorimetry for:
    - jet energy resolution
    - improved background rejection



- ★ 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

⇒ $7.5\ \lambda_I$ HCAL

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



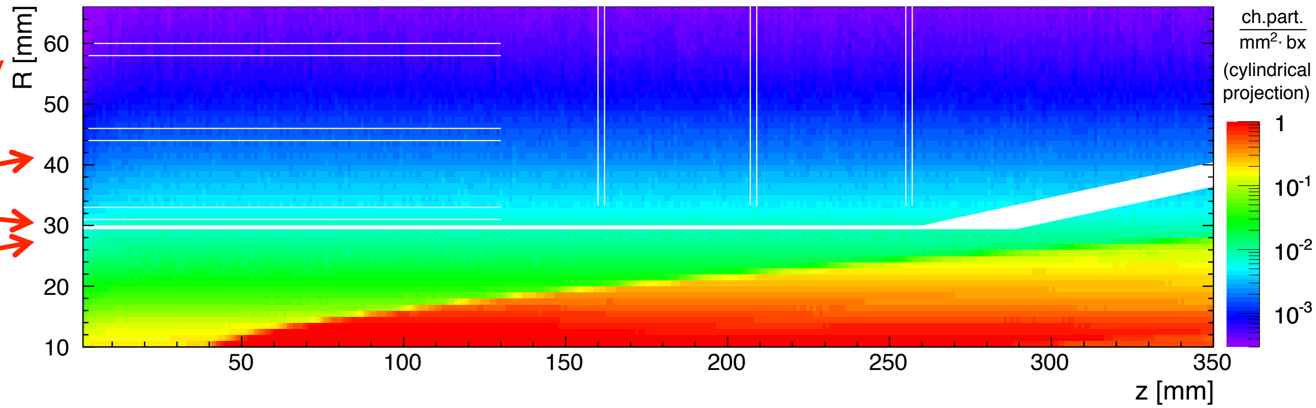
Impact of Background

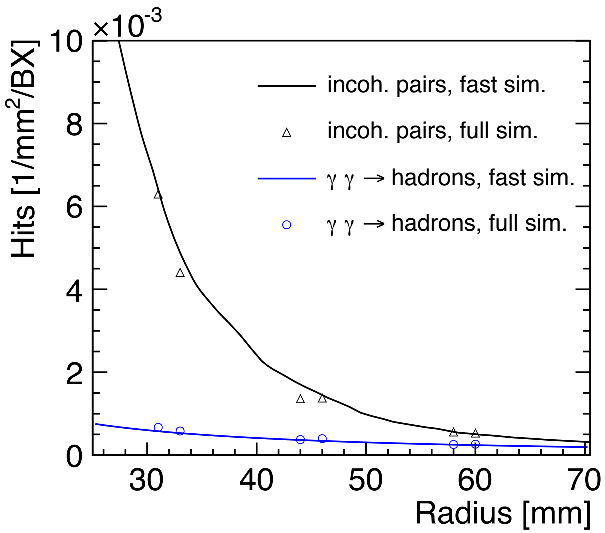
- ★ Core of incoherent pair background determines:
  - location of vertex detector; forward tracking discs; design of beam pipe…

e.g. CLIC_ILD
(3 TeV)

VTX

Beampipe



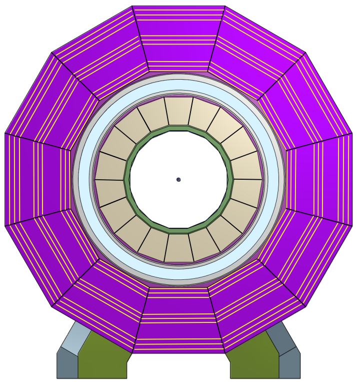


- ★ Pair background mostly at low radii
- ★ Inner radius of barrel vertex detector
  - CLIC_ILD: 31 mm
  - CLIC_SiD: 27 mm
- ★ Maximum occupancy
  - 1.9 % per bunch train

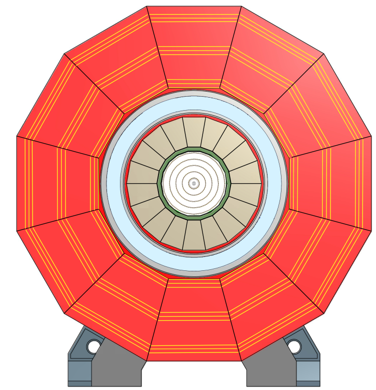
  (assumes 20 μm pixels and safety factor 5)

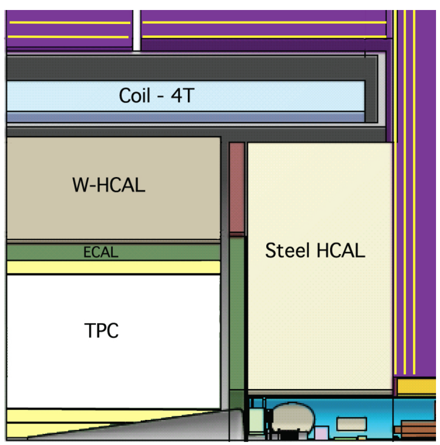
CLIC_ILD and CLIC_SiD

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

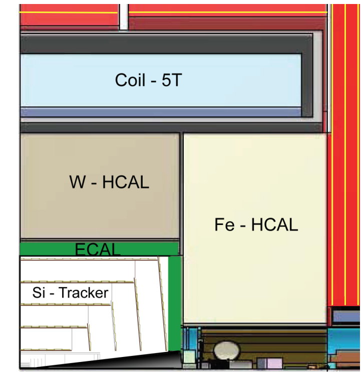


	CLIC_ILD	CLIC_SiD
Tracker	TPC, r = 1.8 m	Silicon, r = 1.2 m
B-field	4 T	5 T
ECAL	SiW	SiW
HCAL barrel	W-Scint	W-Scint
HCAL endcap	Steel-Scint	Steel-Scint



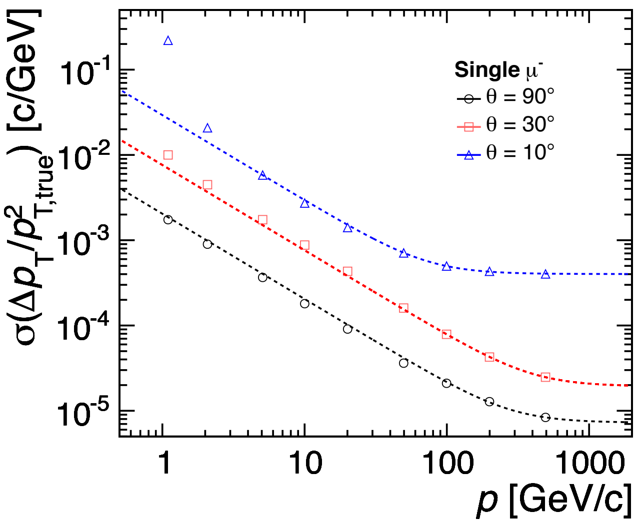


- ★ Detailed GEANT 4 models
- ★ Full reconstruction with background
- ★ Very similar performance at CLIC energies
- ★ Used interchangeably in physics studies

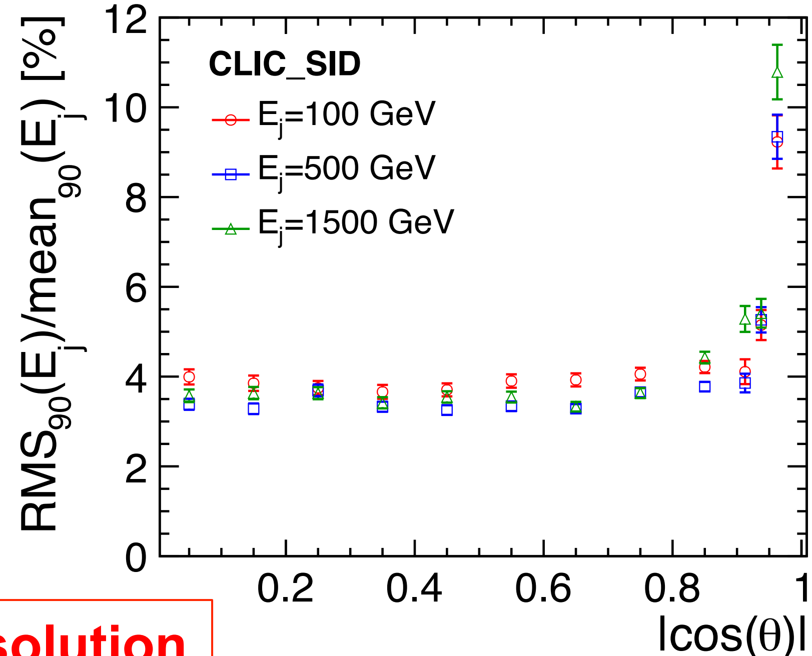


Underlying Detector Performance

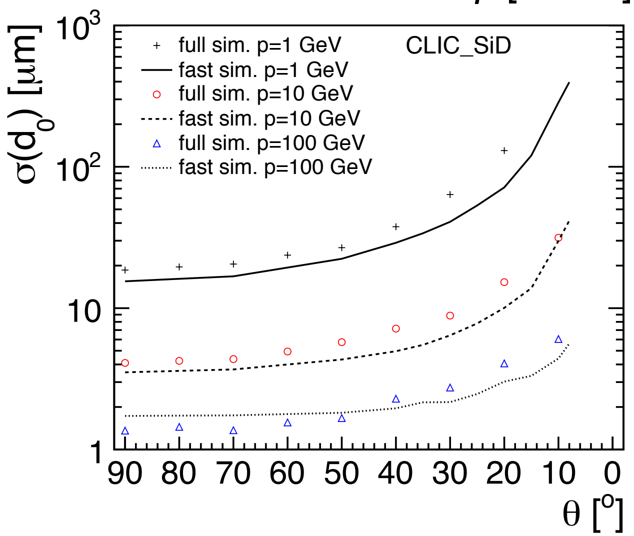
★ **Underlying performance of detectors meet requirements, e.g. CLIC_SiD**



Momentum resolution



Jet energy resolution

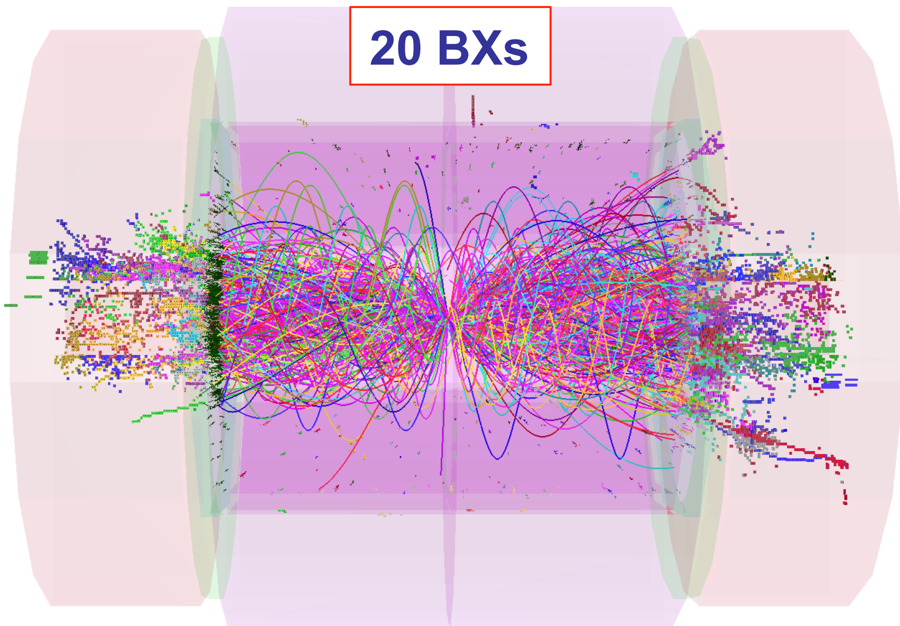


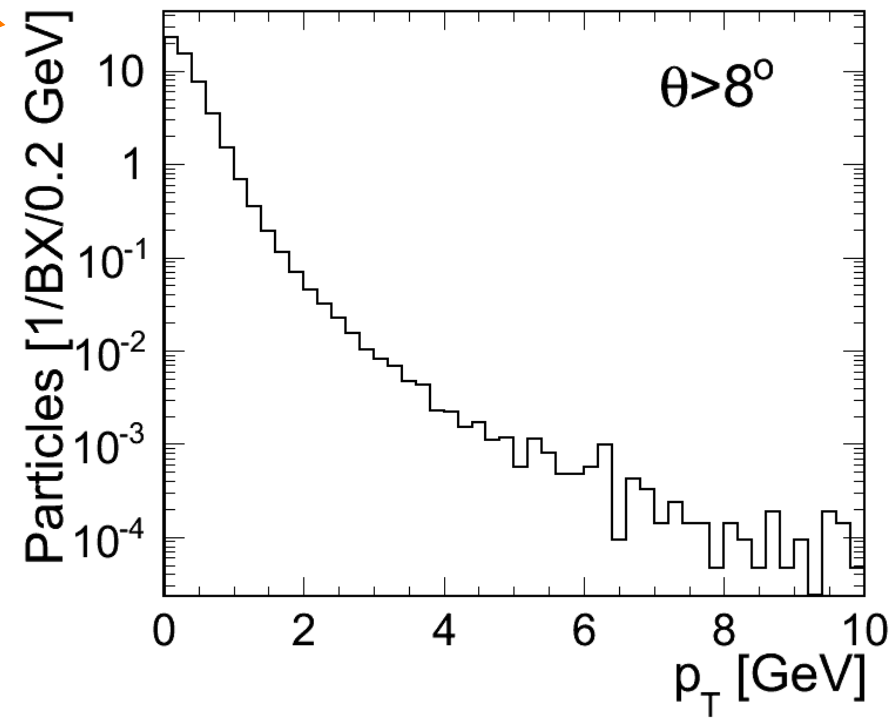
Impact par. resolution

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



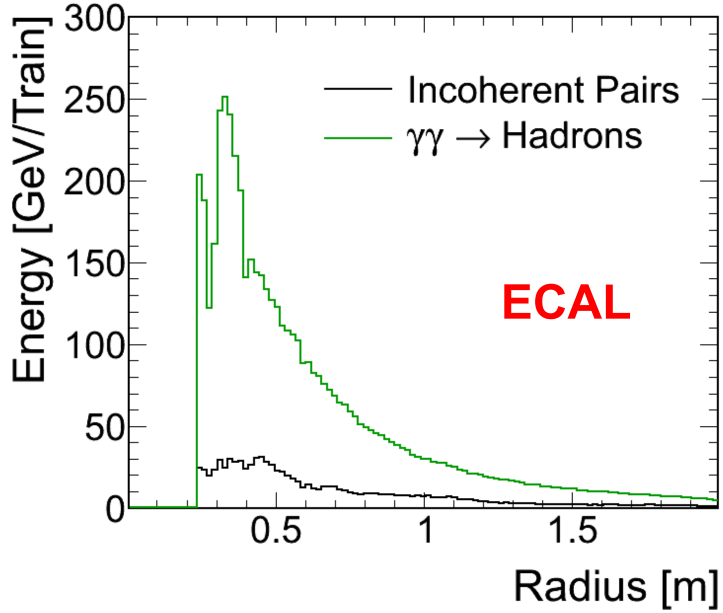


- ★ Irreducible background – it is physics

Backgrounds in the Calorimeters

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

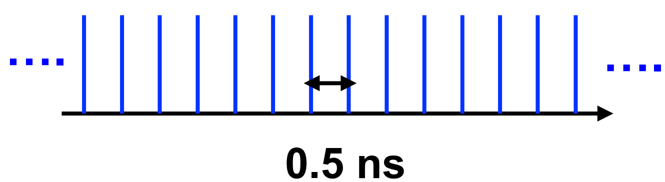
Detector	**$\gamma\gamma \to$ hadrons**
ECAL endcaps	**11 TeV**
ECAL barrel	1.5 TeV
HCAL endcaps	**6 TeV**
HCAL barrel	0.3 TeV
Total	19 TeV



★ **Calorimeter backgrounds per bunch-crossing are manageable, ~ 60 GeV**

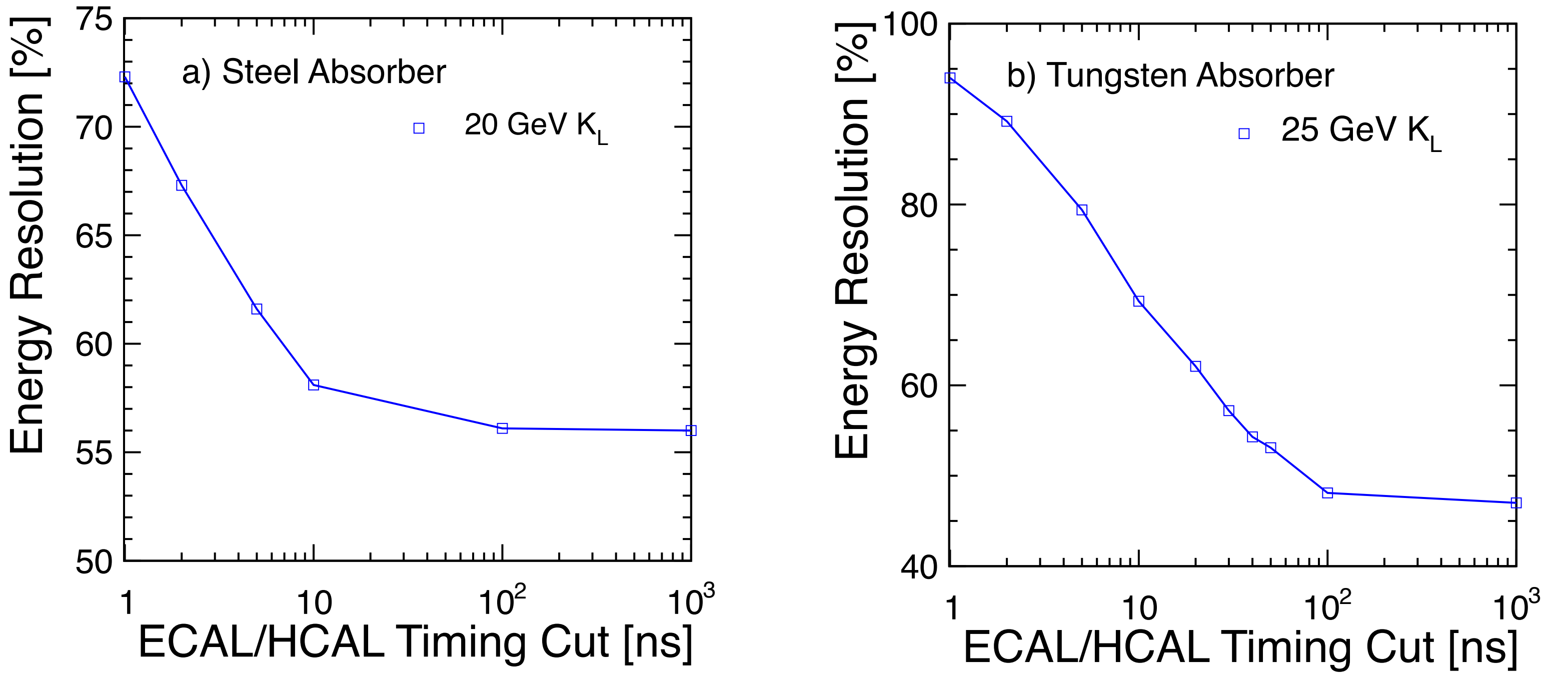
★ **Want to integrate over as few as possible BXs**

★ **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



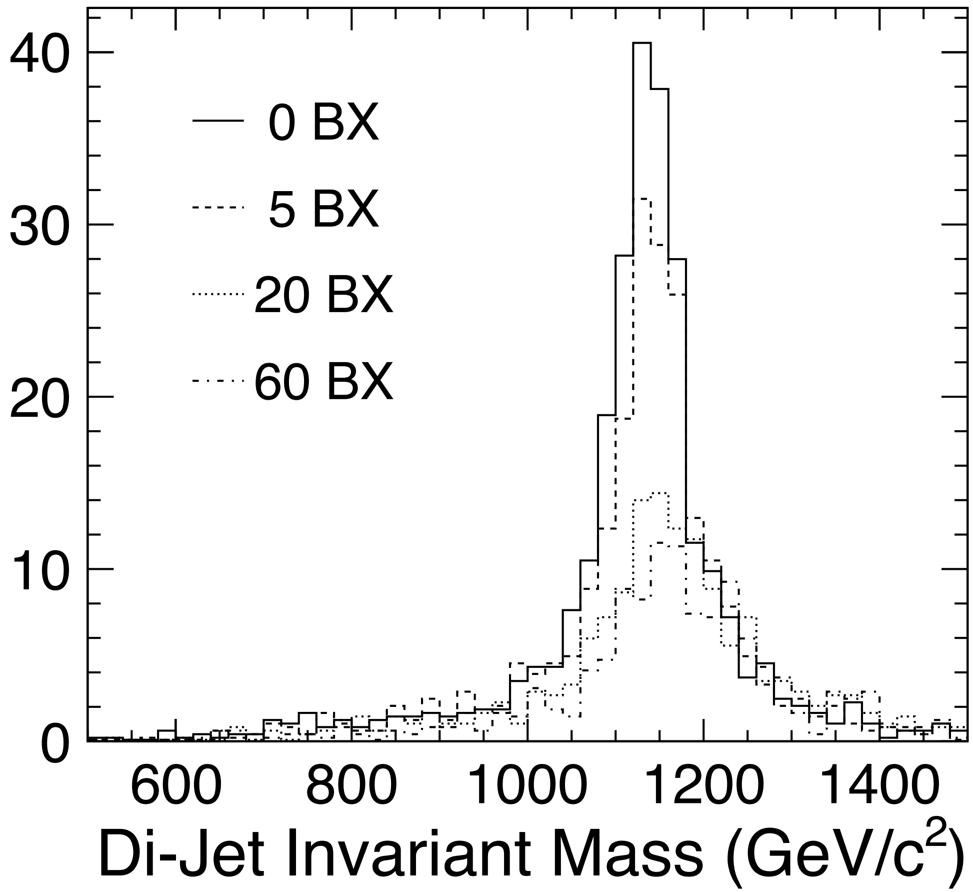
Steel (Endcap): ~10 ns

Tungsten (Endcap): ~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** $e^+e^- \rightarrow H^0A^0 \rightarrow b\bar{b}b\bar{b}$



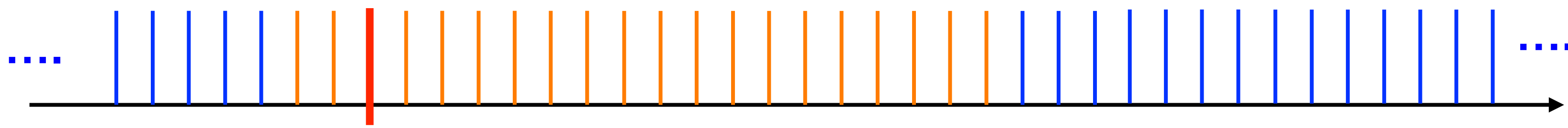
⇨ **< 5 BX**

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

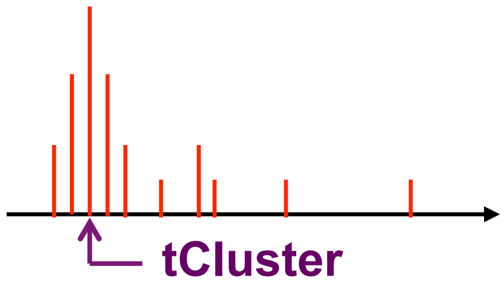
Sufficient calorimeter integration window (ECAL, HCAL Endcap, HCAL Barrel)

CLIC hardware requirements

★ **Still 1.2 TeV reconstructed background per event**

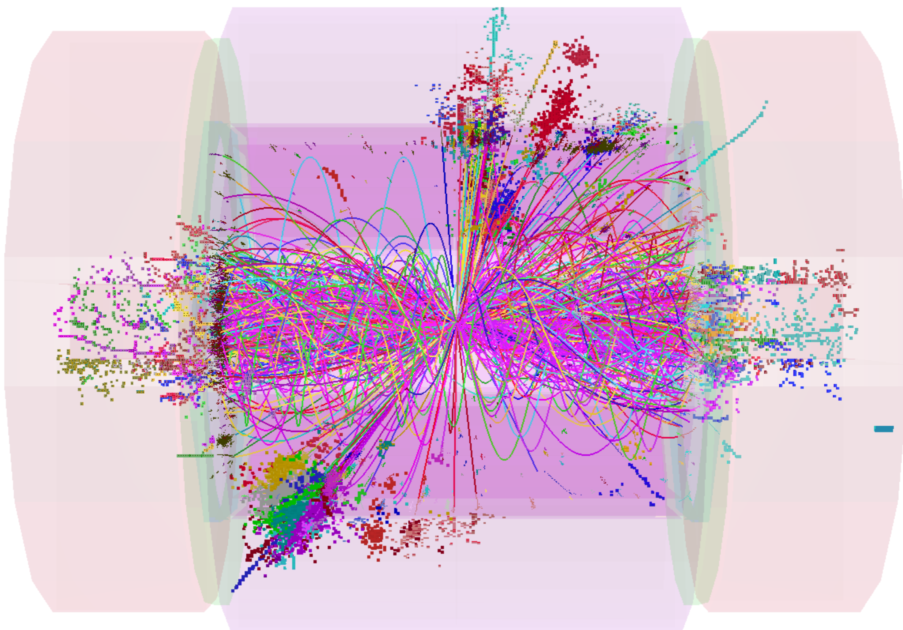
Reconstruction in Time

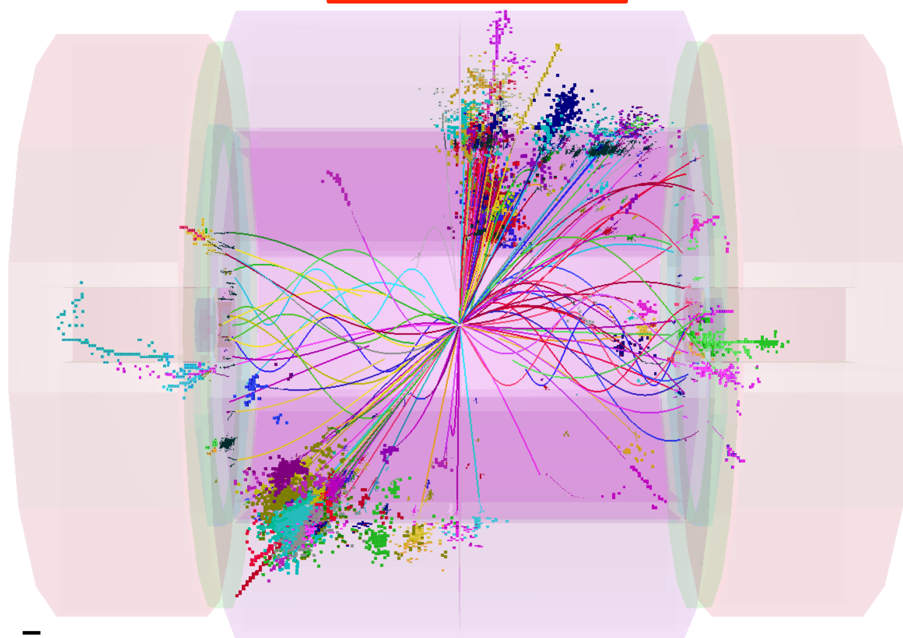
- ★ Tighter time cuts then applied at **reconstructed** "cluster time" level (details in CDR)
- ★ Using mean cluster time can cut at **1-2 ns** level (not applied to high p_T particles)



1.2 TeV

100 GeV

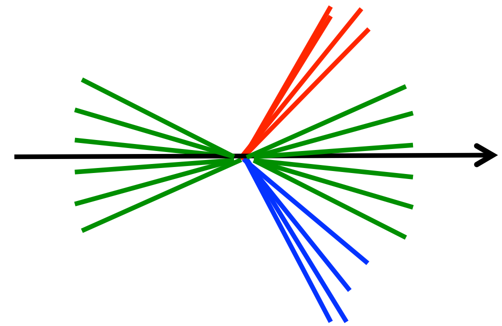




$$e^+e^- \rightarrow H^+H^- \rightarrow t\bar{b}b\bar{t} \rightarrow 8\ \text{jets}$$

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

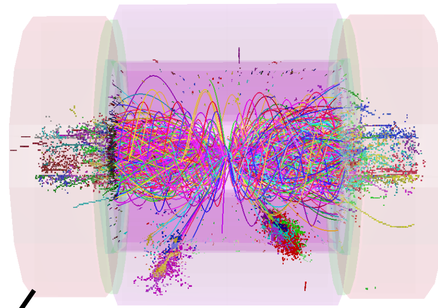


★ Events at CLIC
- significant background from forward-peaked $\gamma\gamma \rightarrow$ hadrons
- are often boosted along beam axis (beamsstrahlung)
- "hadron collider" type algorithms more appropriate

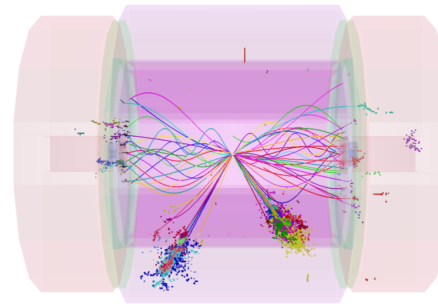
★ Jet finding at CLIC
- studied for benchmark physics analyses (FASTJET package)
- preferred option "k_T" with distance measure $\Delta R^2 = \Delta\eta^2 + \Delta\phi^2$
  - invariant under longitudinal boosts
- particles either combined with existing jet or beam axis
  - reduces sensitivity to $\gamma\gamma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

Jet Finding at CLIC

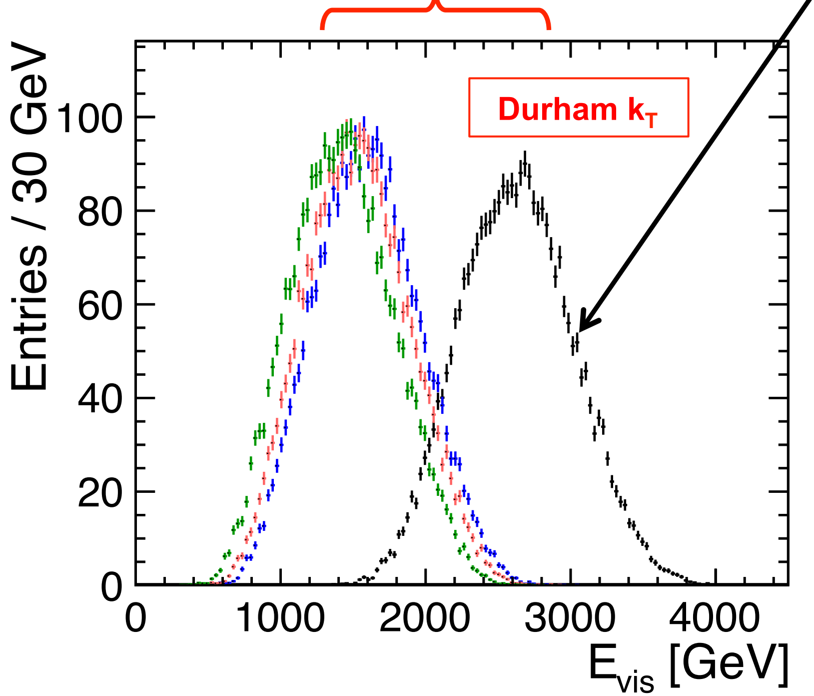
- e.g. $e^+e^- \to \tilde{q}_R\tilde{q}_R \to q\bar{q}\,\tilde{\chi}^0_1\,\tilde{\chi}^0_1$
  - two jets + missing energy

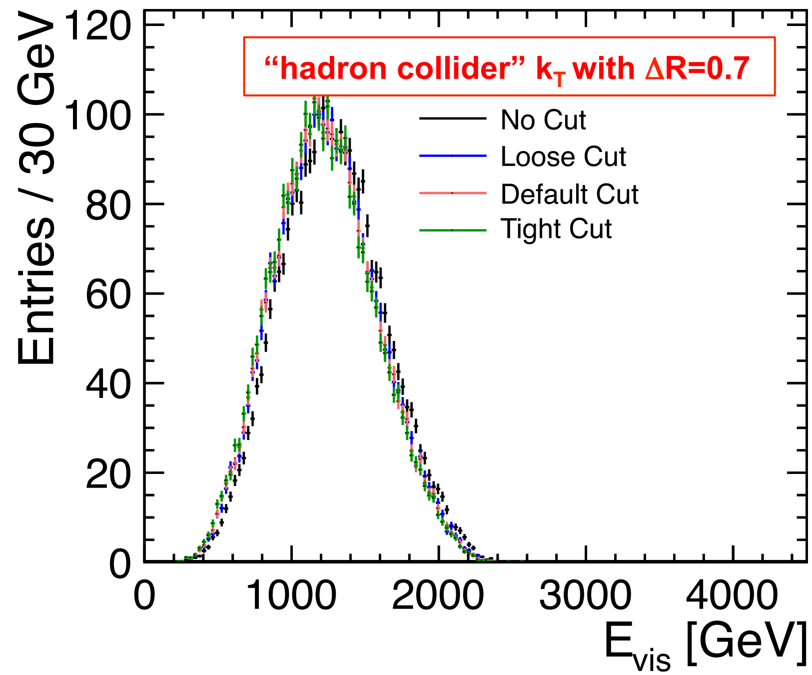


TIGHT timing



All particles clustered





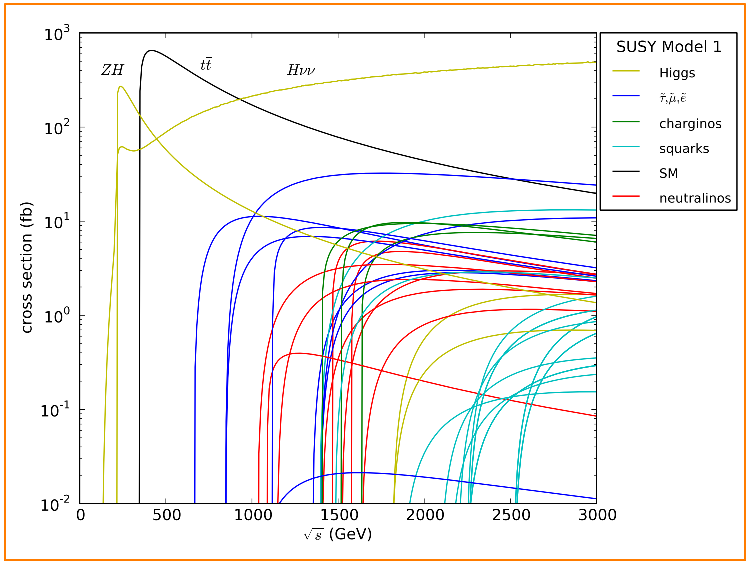
- Two "weapons" against background: timing cuts + jet finding

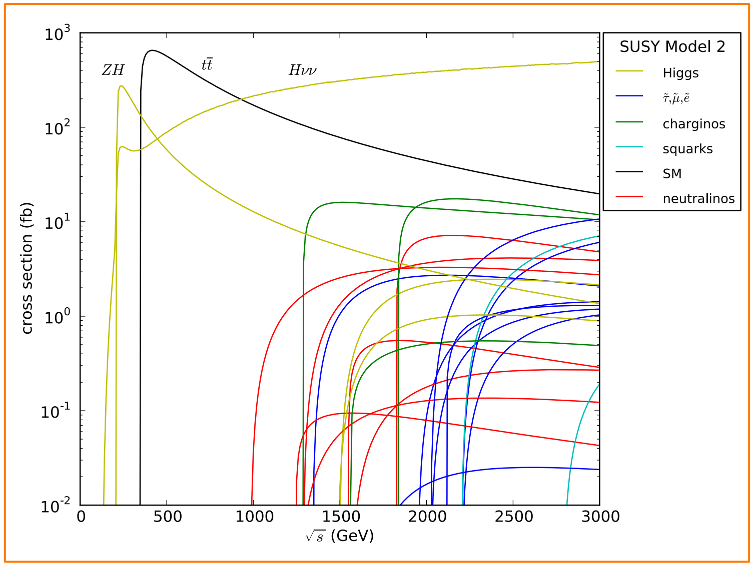
CLIC Benchmarks

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



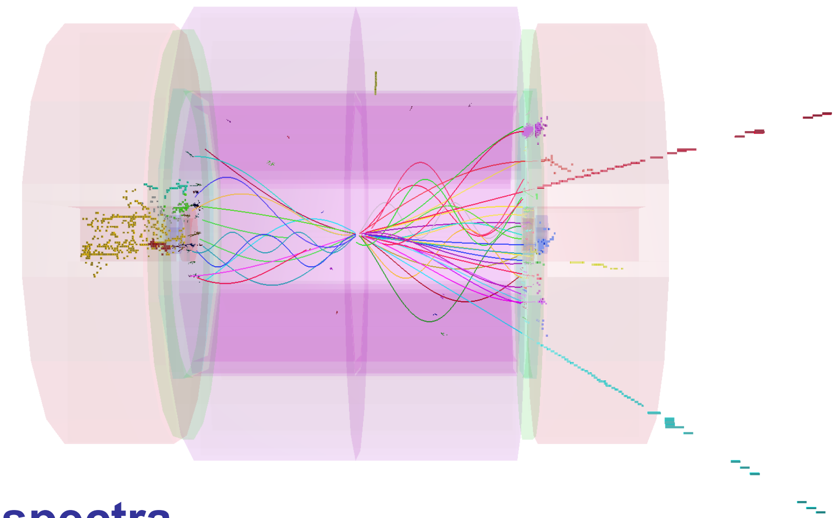


★ All studies use full simulation, full reconstruction and include background from $\gamma\gamma \rightarrow$ hadrons

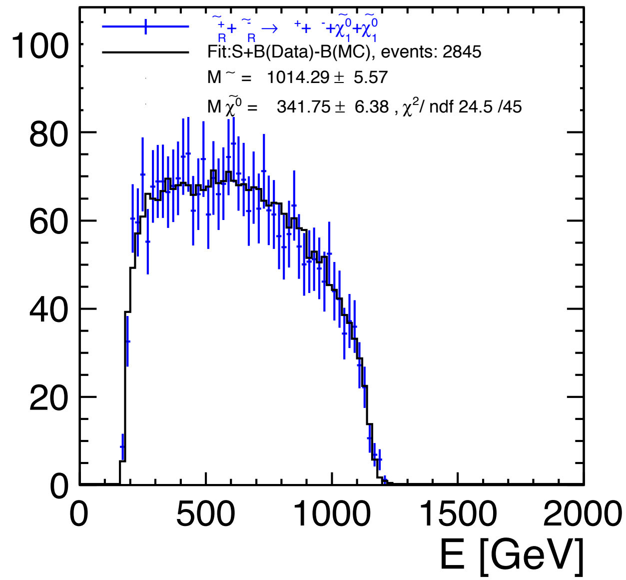
★ Some studies use CLIC_ILD others use CLIC_SiD

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

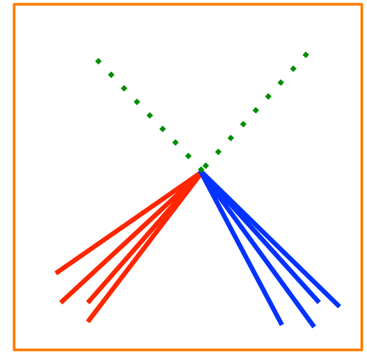


All channels combined

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

Squark Production

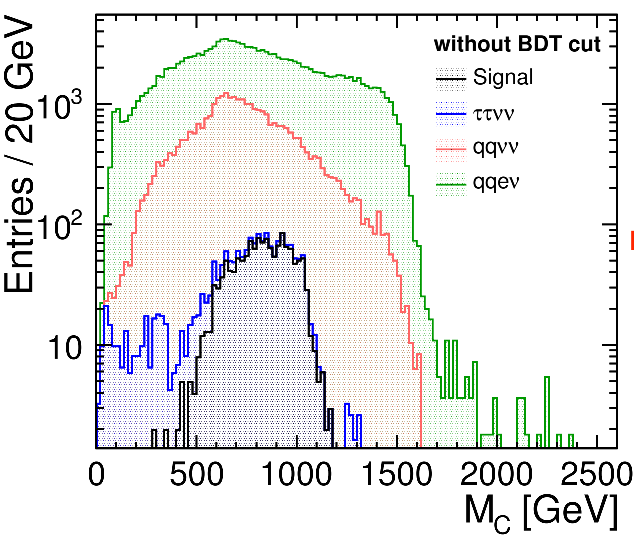
$$e^+e^- \rightarrow \tilde{q}_R\tilde{q}_R \rightarrow q\bar{q}\,\tilde{\chi}_1^0\,\tilde{\chi}_1^0$$

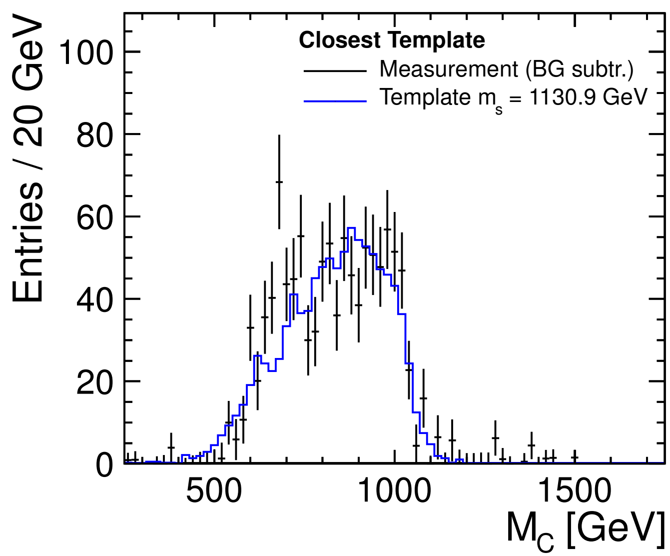


- ★ **Light flavour squarks tend to be heaviest SUSY particles**
  - **study in context of model-I :** $m_{\tilde{q}_R} = 1.123\,\text{TeV}$
  - **simple topology: two high energy jets + missing energy**
  - **mass reconstructed from "edge" of "mass" distribution**

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

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





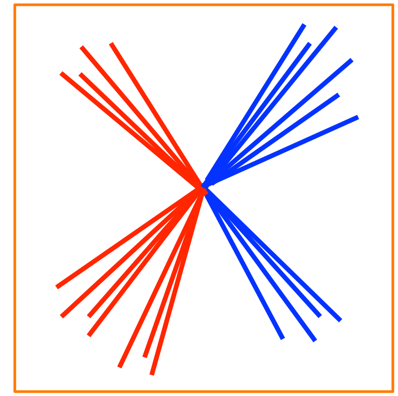
$m_{\tilde{q}_R}\ :\ \pm 6\,\text{GeV}$

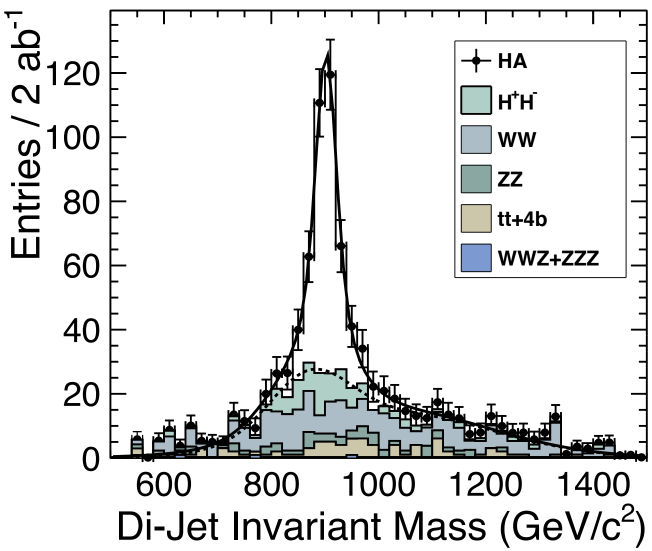
Heavy Higgs

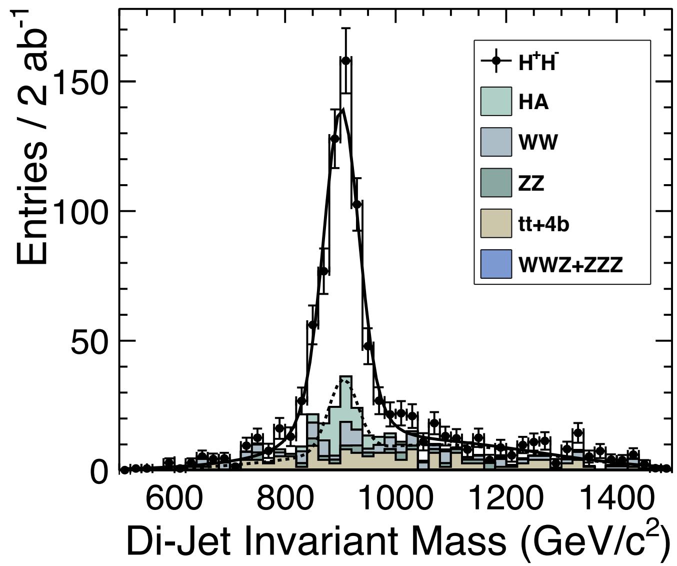
$e^+e^- \to H^0A^0 \to b\bar{b}b\bar{b}$

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

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

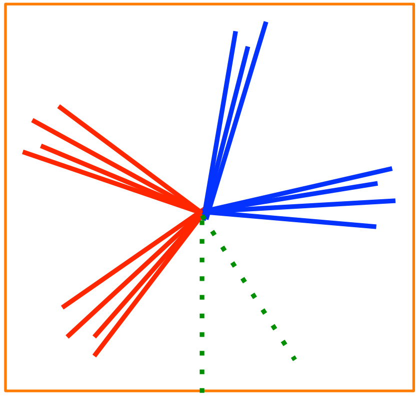
★ **Pair production and decay:**

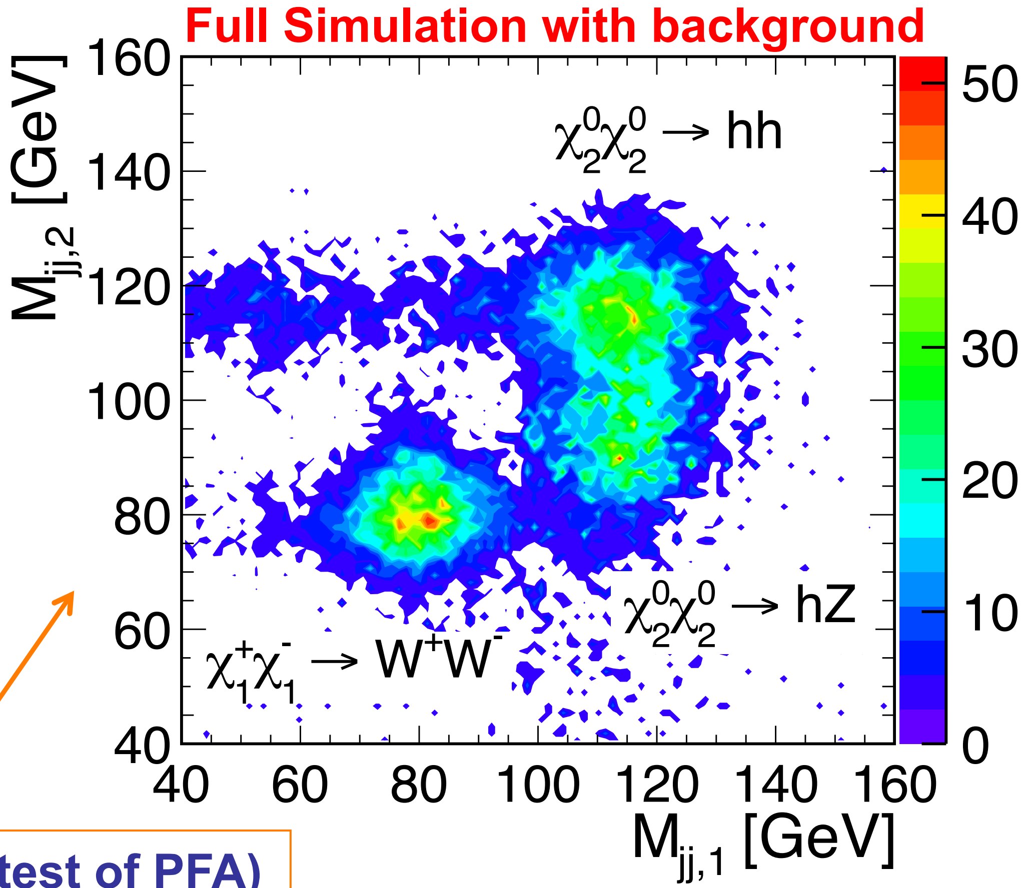
$$e^+e^- \to \tilde{\chi}_1^+ \tilde{\chi}_1^- \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 W^+W^-$$

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

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

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

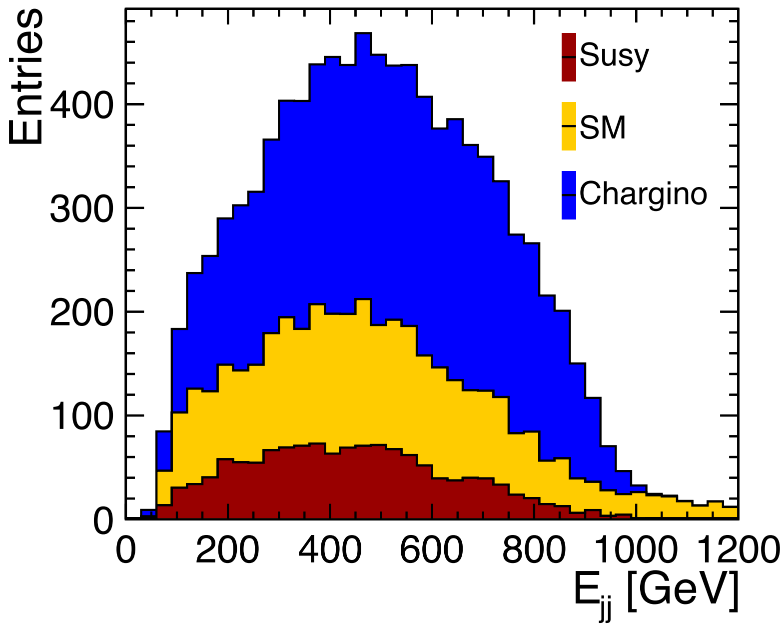


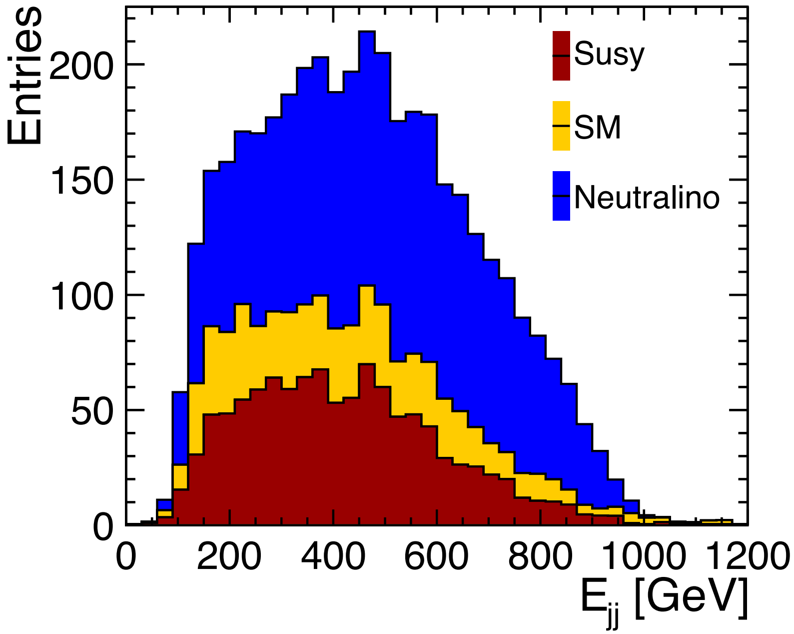


★ **Separate using di-jet invariant masses (test of PFA)**

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**





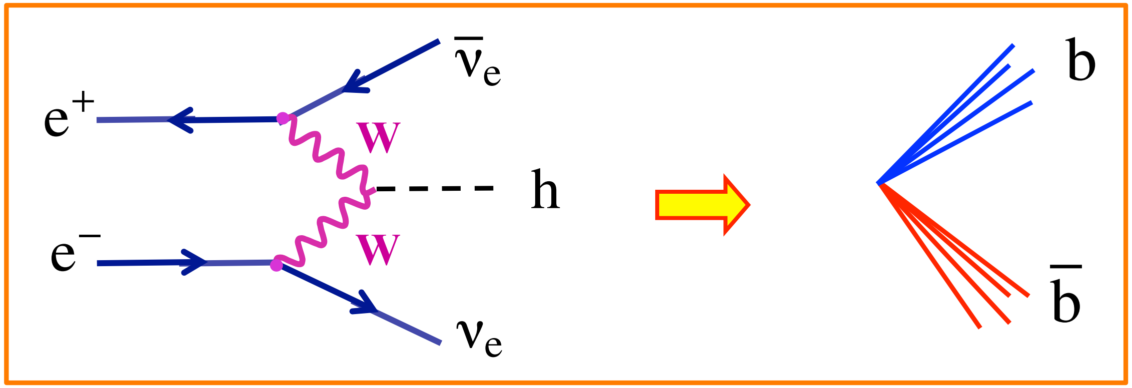
$$m(\tilde{\chi}_1^{\pm}) \; : \; \pm 7\,\mathrm{GeV}$$
$$m(\tilde{\chi}_2^{0}) \; : \; \pm 10\,\mathrm{GeV}$$

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**

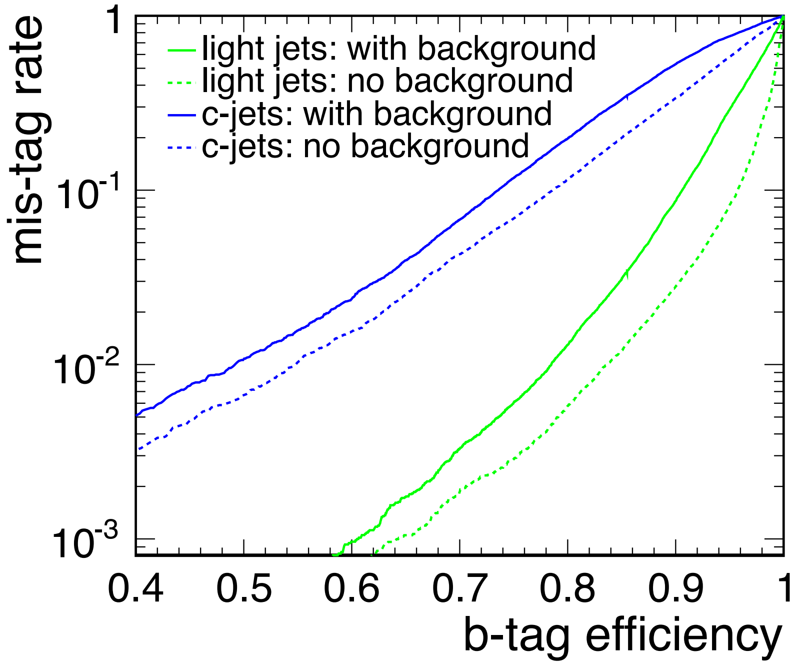


★ **Branching ratio analysis sensitive to:**

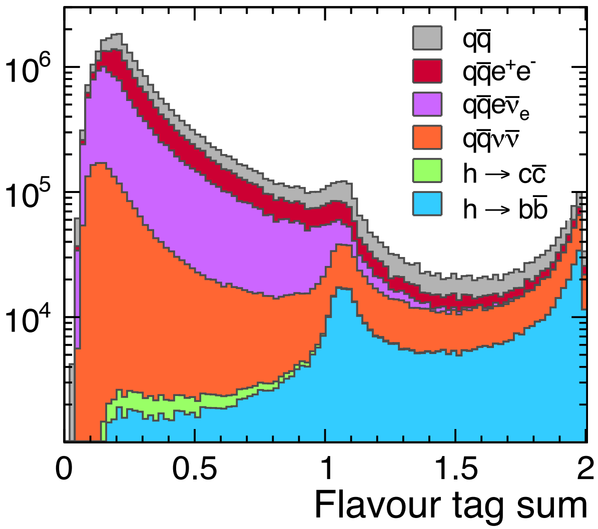
flavour tagging

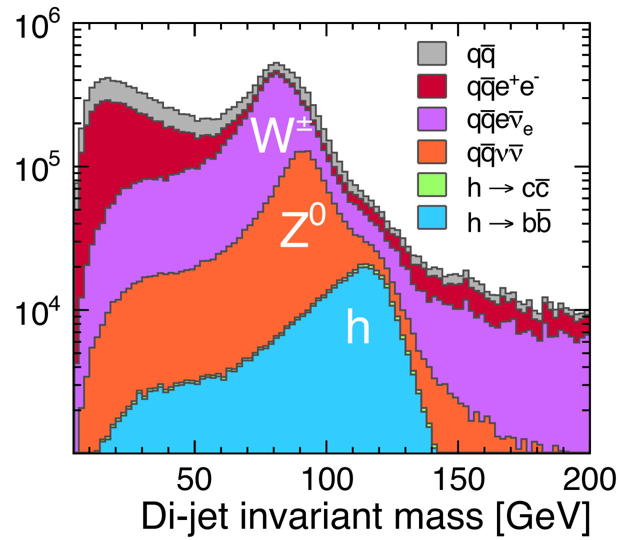
di-jet mass resolution

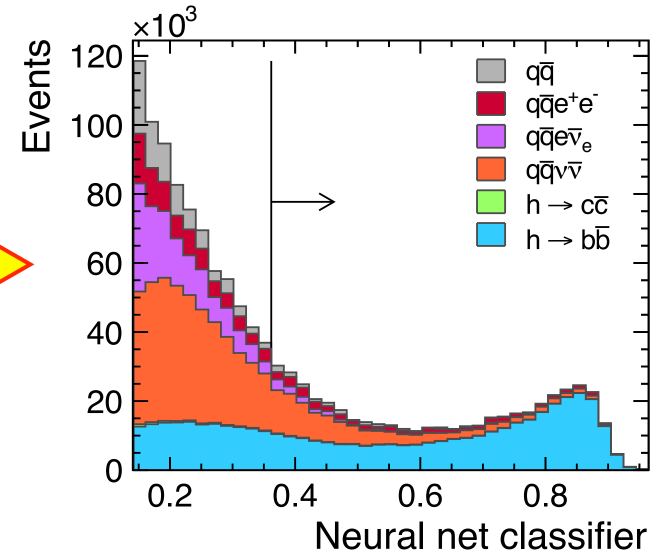
Does flavour-tagging survive background ?
- **some degradation**
- **but b-tag performance still v. good**
- **c-tagging also possible**



$h \to cc, bb, \mu\mu$





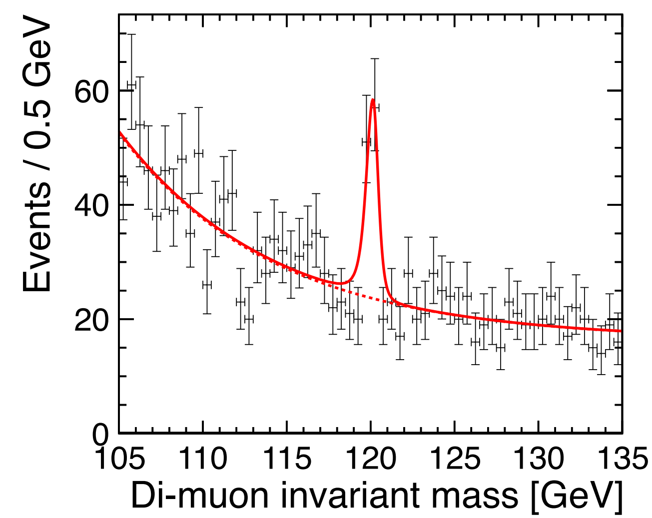


- ★ **Large data sample leads to very small stat. errors**

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

- ★ **Can also also observe*** $\mathrm{h} \to \mu^+\mu^-$

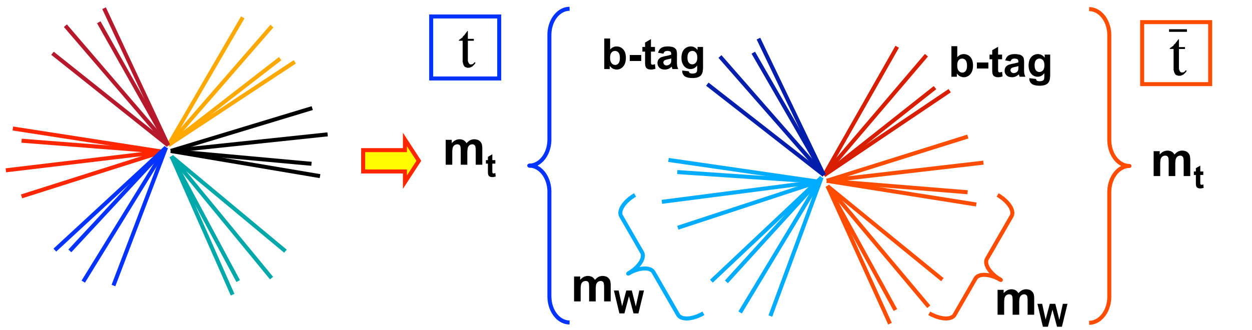
$$\sigma(BR(\mathrm{h} \to \mu^+\mu^-)) < 23\,\%$$



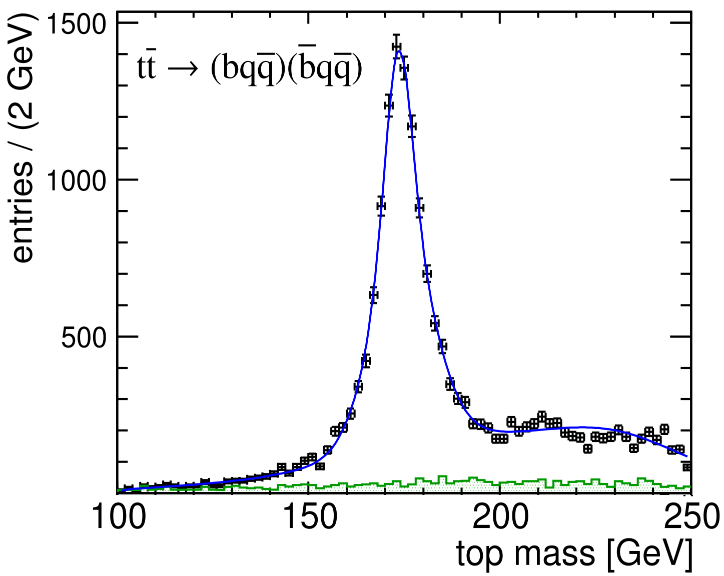
***NOTE: does not yet use tagging of forward electrons – will improve**

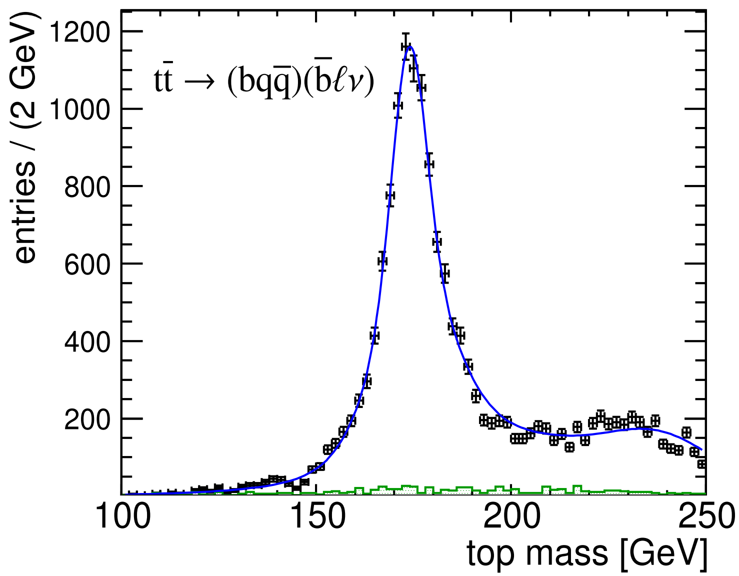
Top mass at 500 GeV

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

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**

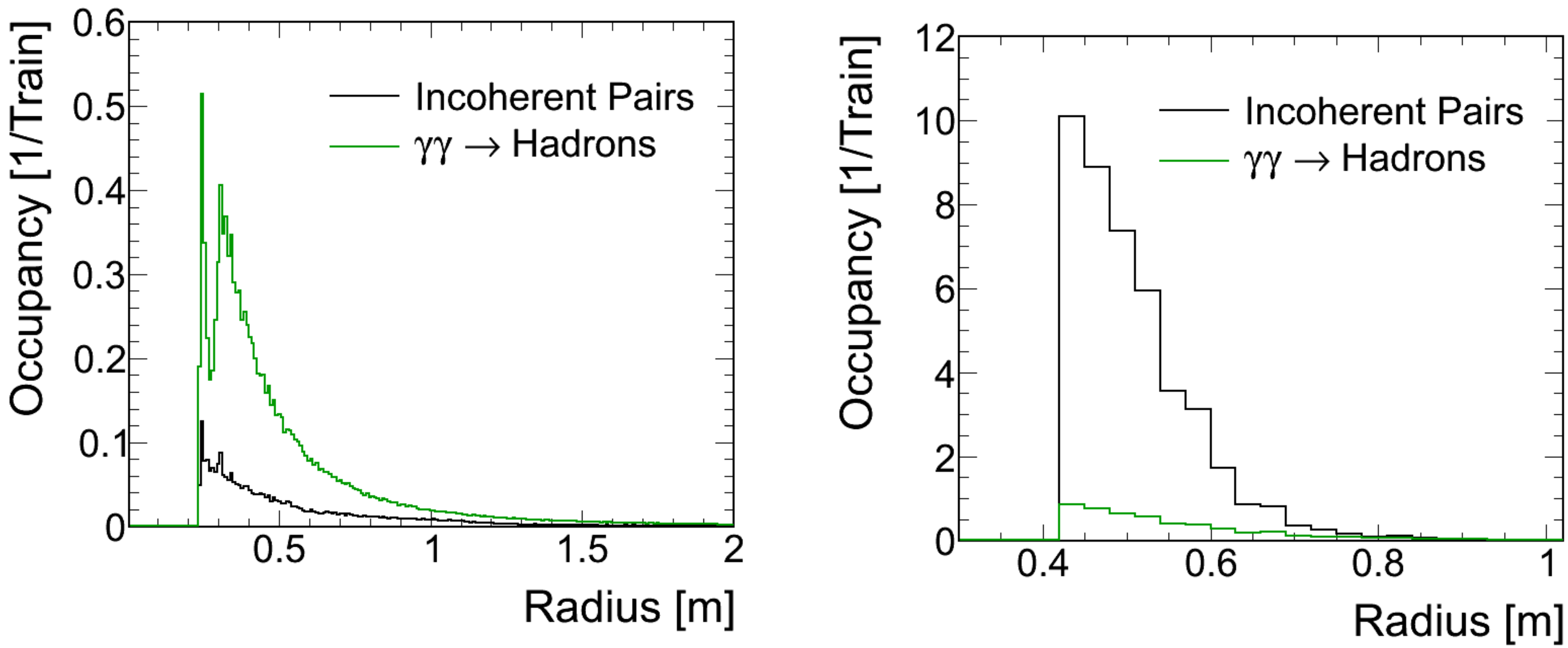
★ **Frozen draft version of CDR available**

- **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

Back-up Slides

Backup Calorimeter Occupancies

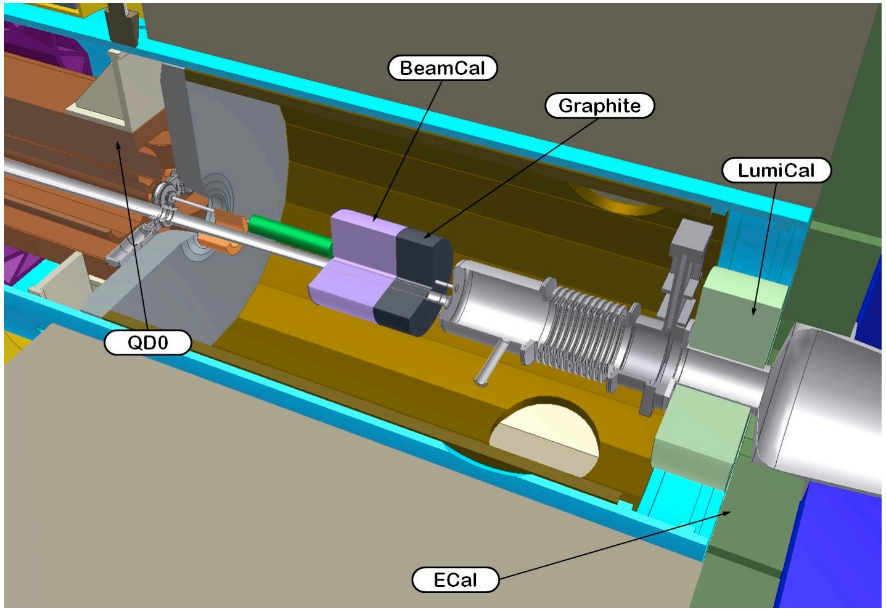


Backup: Benchmark Summary

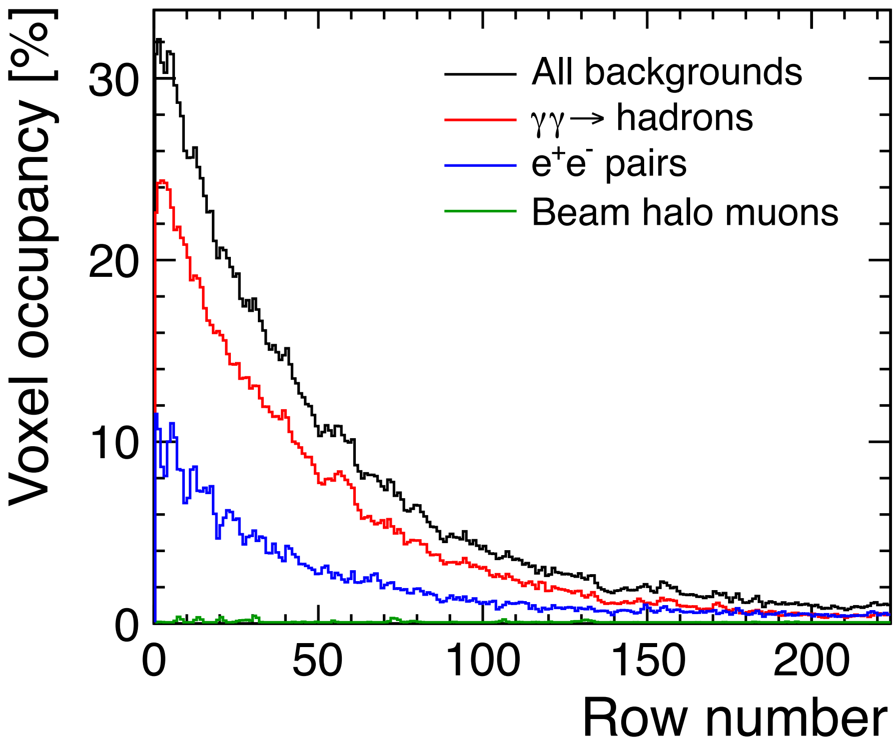
$\sqrt{s}$ (TeV)	Process	Decay mode	SUSY model	Observable	Unit	Generator value	Stat. uncertainty
3.0	Light Higgs production	$h \to b\bar{b}$		$\sigma \times$ Branching ratio	fb	285	0.22%
		$h \to c\bar{c}$				13	3.2%
		$h \to \mu^+\mu^-$				0.12	23%
3.0	Heavy Higgs production	$HA \to b\bar{b}b\bar{b}$	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%

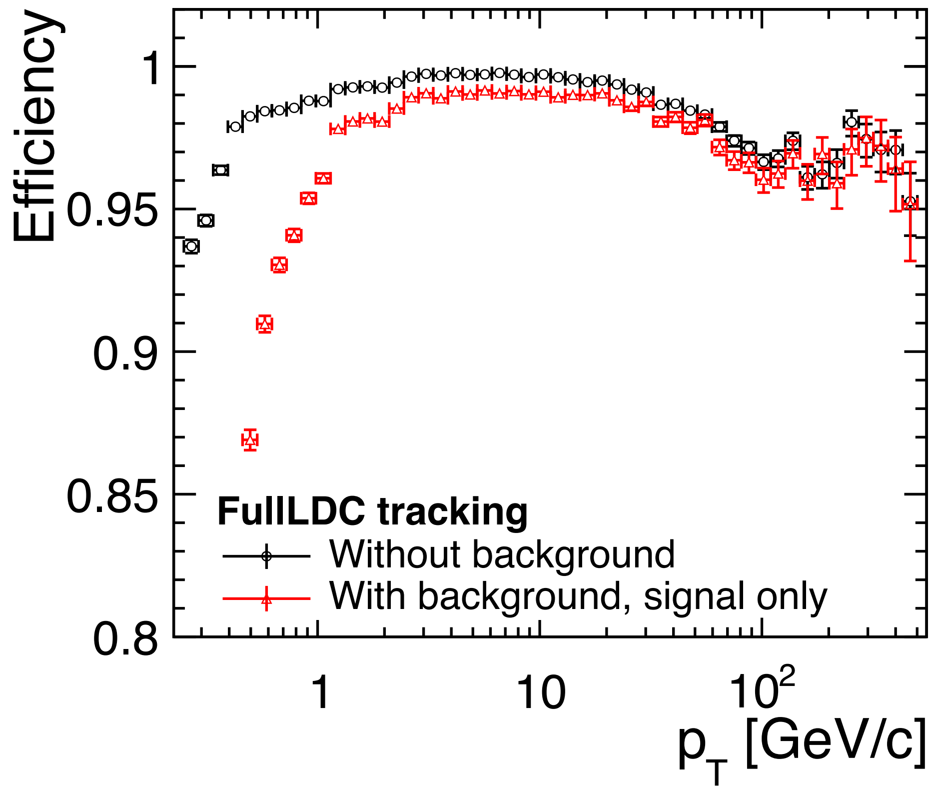
Backup: Impact of Background

- ★ **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**

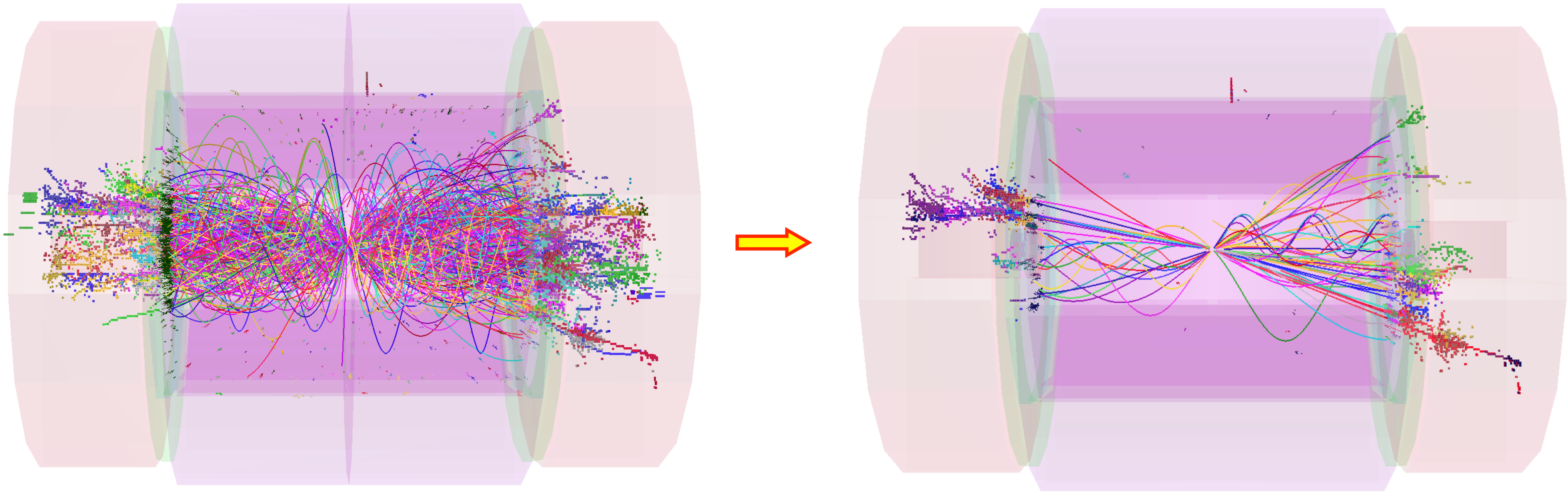


Backup: CLIC_ILD Tracking

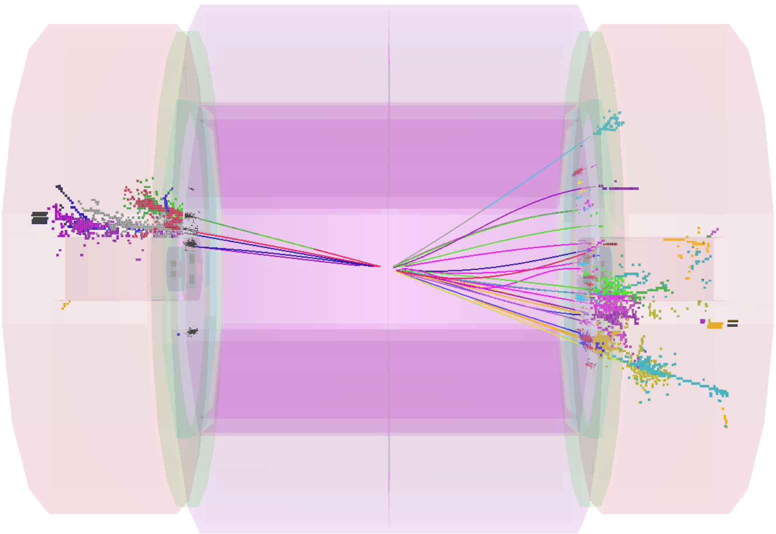




Backup: Forward WW

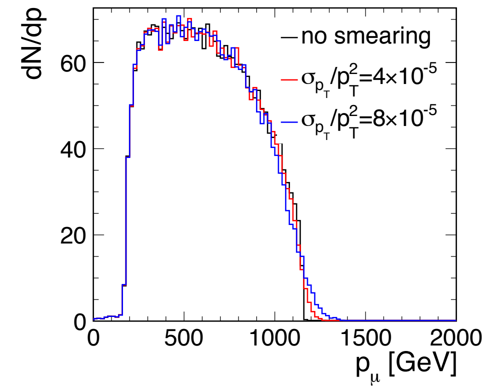


No background



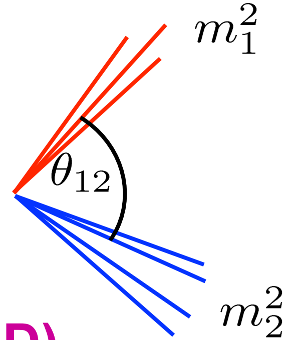
- ★ **momentum:** **(1/10 x LEP)**
  - **e.g. Smuon endpoint**
  - **Higgs recoil mass**

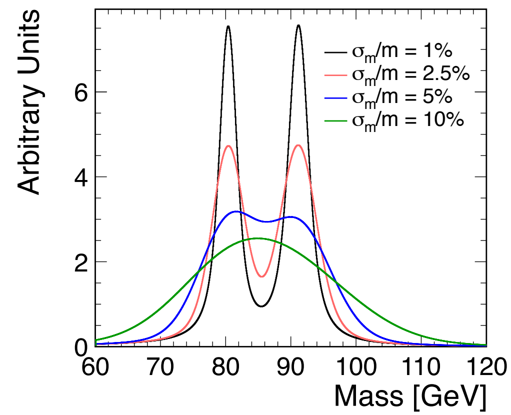
$$\sigma_{p_T}/p_T^2 \sim 2 \times 10^{-5}\ \mathrm{GeV}^{-1}$$



- ★ **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**