CLIC Detector - Status and Plans

Christian Grefe, CERN

on behalf of the CLIC Detector and Physics Study

27. May 2013

Outline

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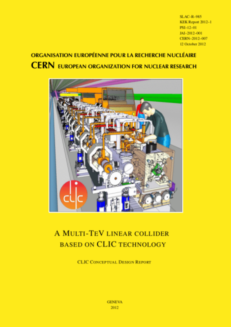
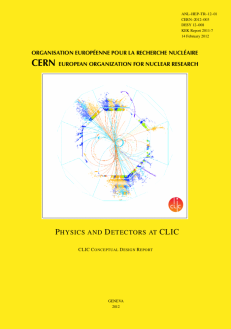
The CLIC Detector and Physics Study

- Collaboration-like structure based on "Memorandum on Cooperation" (MoC): `http://lcd.web.cern.ch/lcd/Home/MoC.html`
- Currently 17 institutes from 14 countries:

  Australia: ACAS; Belarus: NC PHEP Minsk; Czech Republic: Academy of Sciences Prague; Denmark: Aarhus Univ.; Germany: MPI Munich; Israel: Tel Aviv Univ.; Norway: Bergen Univ.; Poland: Cracow AGH + Cracow Niewodniczanski Inst.; Romania: Inst. of Space Science; Serbia: Vinca Inst. Belgrade; Spain: Spanish LC network; UK: Birmingham Univ. + Cambridge Univ. + Oxford Univ.; USA: Argonne lab; + CERN
- CERN acts as host laboratory
- **More contributors most welcome!**

CLIC Conceptual Design Report (CDR)





- Volume 1: A Multi-TeV Linear Collider based on CLIC Technology, CERN-2012-007, http://cds.cern.ch/record/1500095
- Volume 2: Physics and Detectors at CLIC, CERN-2012-003, http://cds.cern.ch/record/1425915
- Volume 3: The CLIC Programme: towards a staged e^+e^- Linear Collider exploring the Terascale, CERN-2012-005, http://cds.cern.ch/record/1475225

CLIC Detector Concepts

- Based on ILC detector concepts

Outline

CLIC Detector R&D Challanges

Vertex and Tracking Detectors

- Very high granularity
- Dense integration of functionalities including $\simeq 10$ ns time-stamping
- Super light materials
- Low-power design and power pulsing capability
- Air cooling

ultra-light

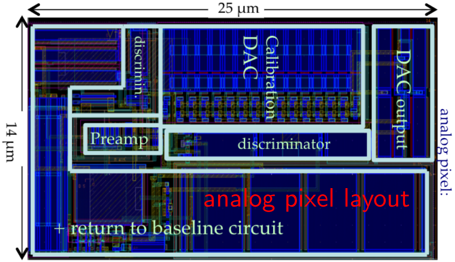
Calorimetry

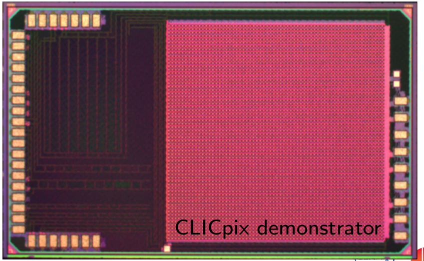
- Fine segmentation in r, ϕ and z
- Time resolution $\simeq 1$ ns
- Ultra-compact active layers
- Pushing integration to the limits
- Power pulsing capability

ultra-heavy and compact

CLICpix Demonstrator Chip

- Demonstrator chip with fully functional 64 × 64 pixel matrix
  - 65 nm CMOS technology
  - 25 μm × 25 μm pixel pitch
  - Simultaneous 4-bit time and energy measurement
  - Front-end time slicing $< 10\,\text{ns}$
  - Pixel-, cluster- or column-based zero suppression
  - $P_{\text{analog}} \simeq 2\,\text{W/cm}^2$ (peak)
  - $P_{\text{avg}}^{\text{power pulsing}} < 50\,\text{mW/cm}^2$
- 100 chips delivered in February 2013
- Readout development at CERN
  - Spartan6 based readout
  - 1 Gb/s ethernet data link
  - Compatible with EUTelescope framework

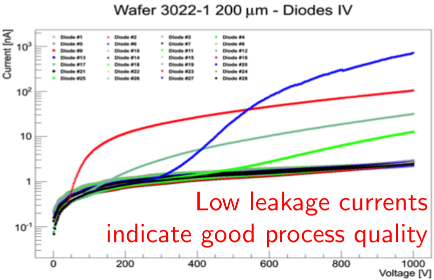


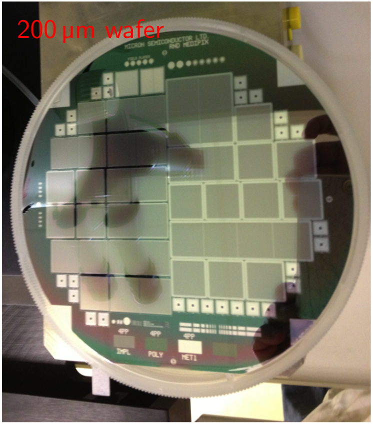


⇒ Samir Arfaoui - R&D on sensors and readout for the CLIC vertex detector

Sensor Production

- Wafer production at Micron: sensor matching TimePix footprint (end of 2012)
  - Demonstrate production and assembly of thin sensors: 100, 150, 200 and 300 µm delivered
  - Sensor UBM deposited at IZM, next: dicing
  - Flip-chip thin sensors to 100 µm thin demonstrator ASICs (summer 2013)

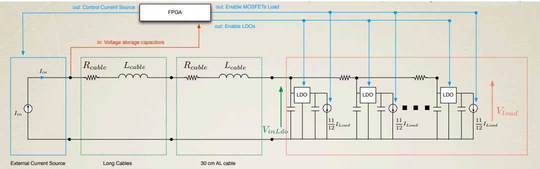


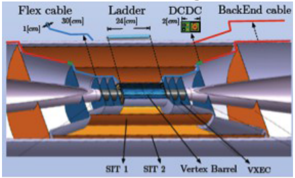


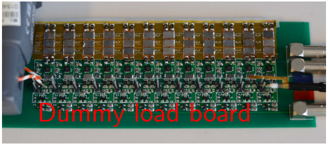
- Wafer with sensor matching CLICPix footprint for end of 2013

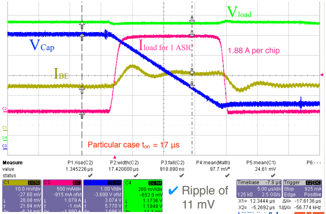
⇒ Samir Arfaoui - R&D on sensors and readout for the CLIC vertex detector

Vertex Detector Power Pulsing and Delivery







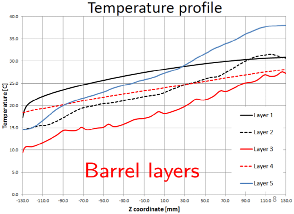


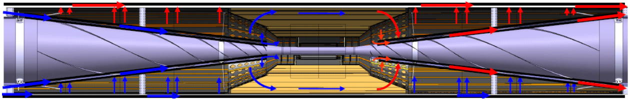
- Power pulsing scheme for analog electronics
- Silicon Capacitor + Low-dropout Regulators (LDO) close to the load
- Current material budget X $\simeq$ 0.06% X_0 (half seems feasible)
- Tests using dummy load board
  - Voltage regulation stability $\simeq 10\,\text{mV}$ ($< 50\,\text{mV}$ required)
  - Power loss/dissipation (analog) $< 10\,\text{mW/cm}^2$ (leaves $40\,\text{mW/cm}^2$ for digital)

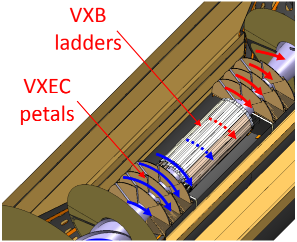
⇒ Cristian Fuentes - Power pulsing scheme based on a back-end current source for the analog electronics of the vertex detectors at CLIC

Vertex Detector Cooling and Mechanical Design

- Need to remove $P_{\text{vertex}} \simeq 500\,\text{W}$
- Spiral disks allow air flow through detector
- ANSYS finite element simulation:
  air cooling seems feasible!
- Next: validate simulations in mock-up (temperature, vibrations)
- In addition: mechanical support solution designed, possible layout of services, modular assembly sequence defined



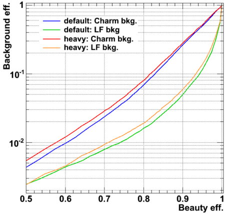


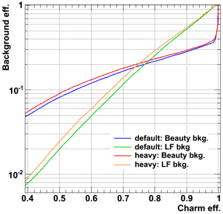


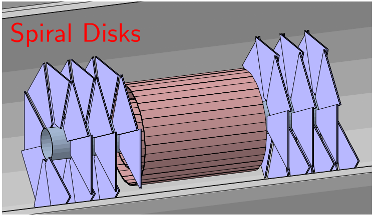
⇒ Fernando Ramos - Engineering studies for the inner region of the CLIC_ILD detector concept

Vertex Detector Geometry Studies

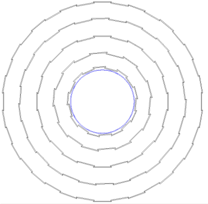
- Systematic full simulation studies of impact parameter resolution and flavor tagging for various vertex detector geometries
  - Layer placement
  - Variation of material budget
  - Single vs. double layer geometry
  - Spiral disk geometry



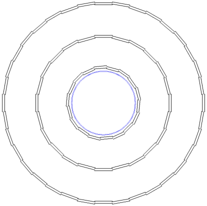




5 single layers



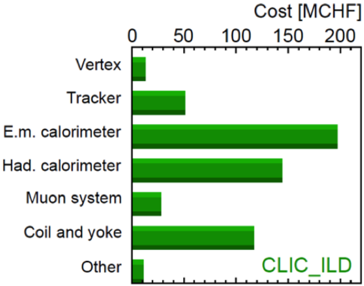
3 double layers



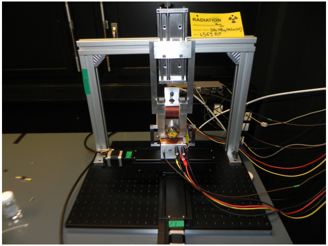
⇒ Philipp Roloff - Physics-performance optimization of the CLIC vertex detector

Scintillator ECAL Studies

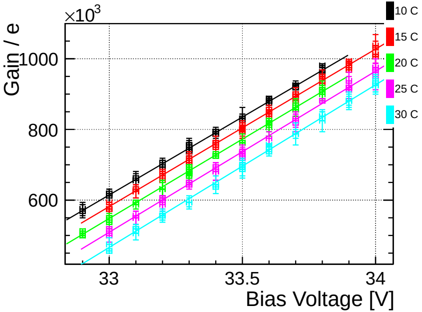
- CLIC (and ILC) detector concepts propose a Silicon-Tungsten ECAL
- Major cost driver for all the concepts: Si surface 2600 m^2 (CLIC_ILD), 1100 m^2 (CLIC_SiD)
- Investigate possibility of more cost-effective ECAL: use thin scintillator tiles or strips for all or parts of the ECAL
- Hardware and software studies to asses feasibility within CALICE



ECAL Lab at CERN

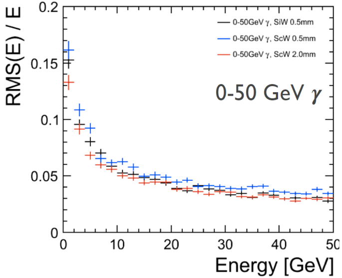


- Dark room with x-y scanning station
- Sr90 electron gun with momentum selection capabilities
- Climate chamber for temperature studies
- Characterization of assembled scintillator tile + SiPM: uniformity, gain, noise, ...
- Aim for thin active layers to achieve small Moliere radius

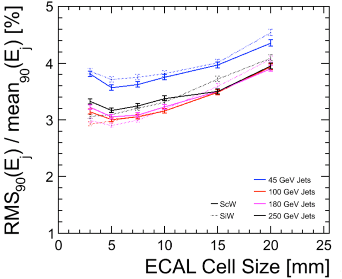


⇒ Erik van der Kraaij - SiPM temperature characterization for adaptive power supply

ECAL Simulation Studies



- Systematic full simulation studies to understand performance dependence on
  - active material and thickness
  - absorber material and thickness
  - segmentation
- Stand-alone studies studies: dependence of energy resolution and two particle separation
- Full-detector simulation: impact of PandoraPFA parameters for calibration and algorithms, and performance in jet events

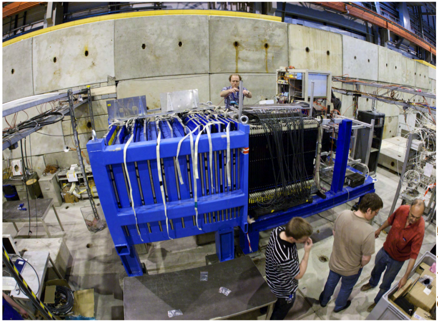


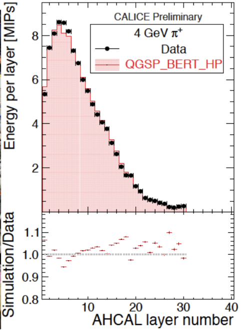
⇒ John Marshall - PFA with SiW and ScW ECAL Models

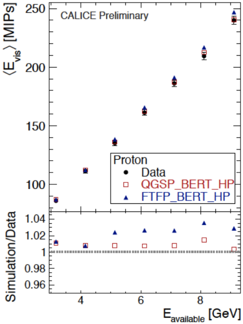
⇒ Tohru Takeshita - Reconstruction of the scintillator strip calorimeters

Analog HCAL: Tungsten + Scintillator

- Analog HCAL: Scintillator + SiPM with 3 cm × 3 cm cells
- Tungsten absorber stack: 10 mm layer thickness
- CERN PS: 1 GeV–10 GeV (2010), CERN SPS: 10 GeV–300 GeV (2011)
- Analysis well advanced, good agreement between data and Monte Carlo

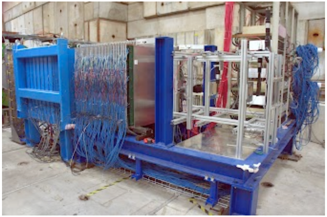


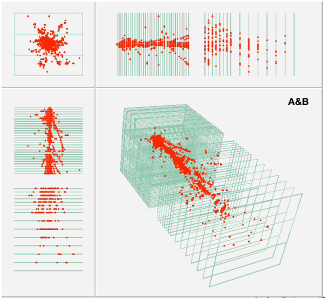




Digital HCAL: Tungsten + RPC

- 54 RPC layers, single threshold:
  39× tungsten absorber (main stack),
  15× steel absorber (tail catcher)
- Each layer instrumented with 96 × 96
  $1\,\text{cm}^2 \times 1\,\text{cm}^2$ pads ⇒ ∼ 500000 channels
- Successful beam test at CERN in 2012
- PS (1 GeV–10 GeV): 1 run period of 2 weeks
- SPS (10 GeV–300 GeV): 2 + 1 + 1 weeks
- In total ∼ 30 million events recorded
- Analysis on-going . . .





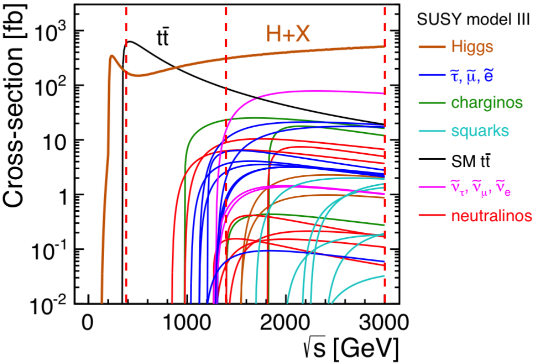
Towards a New CLIC Detector Model

- CLIC_ILD and CLIC_SiD models frozen for CDR studies (2011):
  it is time for a new round of detector optimization studies
- Revisit several design decisions with the insight gained over past years
  ⇒ arrive at refined detector concept(s) at the end of 2014
  ⇒ schedule aligned with new geometry software package
- Vertex detector:
  more realistic material budget, spiral endcaps, single vs. double layers, layer placement in view of occupancy using more realistic digitization
- Other silicon tracking:
  finer segmentation (short strips, pixels) where appropriate
- ECAL:
  instrumentation (Silicon pixel and/or Scintillator tiles), number of layers and absorber thicknesses
- Forward region:
  overall optimization for impact on the physics (study QD0 outside detector option; finer calorimeter segmentation to mitigate occupancy)

Outline

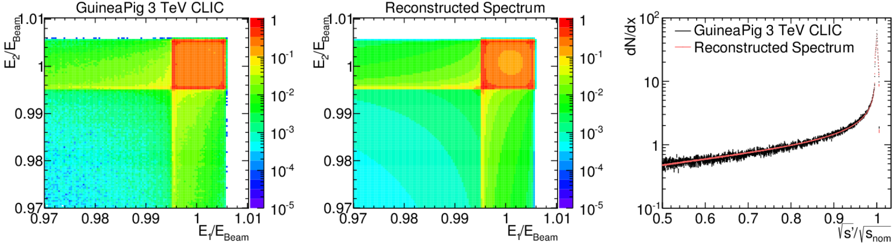
Physics Program at CLIC

- Physics program will require energy staging
- $\sqrt{s} \simeq 375\,\mathrm{GeV}$:
  SM precision measurements, Higgs-recoil, top mass
- $\sqrt{s} = 1.4\,\mathrm{TeV}$:
  rare Higgs decays, Higgs self-coupling, discovery of new physics
- $\sqrt{s} = 3\,\mathrm{TeV}$:
  highest precision for rare decays and self-coupling, highest discovery reach



Luminosity Measurement

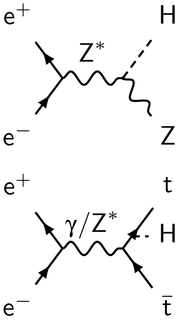
- Determine luminosity from measurement of large-angle Bhaba scattering
- Include beam spread, ISR, FSR and detector resolution
- Build model to calculate underlying energy spectrum from the measurement
- Resulting fit describes $\sqrt{s'}$ spectrum within 5% over the full range

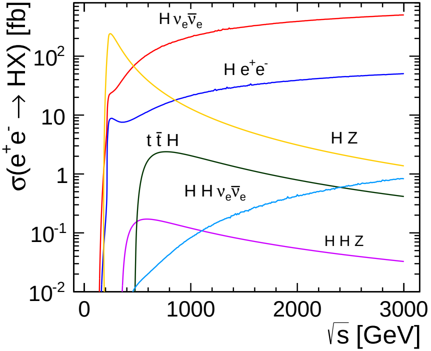


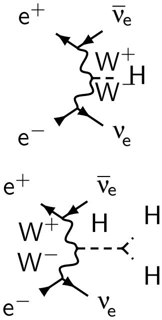
⇒ André Sailer - Slepton Mass Measurements and the Luminosity Spectrum at CLIC

⇒ Strahinja Lukic - Precise luminosity measurement in the forward region at CLIC

Higgs Physics at CLIC







E_{cm}	250 GeV	350 GeV	500 GeV	1 TeV	1.5 TeV	3 TeV
$\sigma(e^+e^- \rightarrow ZH)$	240 fb	129 fb	57 fb	13 fb	6 fb	1 fb
$\sigma(e^+e^- \rightarrow H\nu_e\bar{\nu}_e)$	8 fb	30 fb	75 fb	210 fb	309 fb	484 fb
Integrated $\mathcal{L}$	250 fb^{-1}	350 fb^{-1}	500 fb^{-1}	1000 fb^{-1}	1500 fb^{-1}	2000 fb^{-1}
# ZH events	60 k	45.5 k	28.5 k	13 k	7.5 k	2 k
# $H\nu_e\bar{\nu}_e$ events	2 k	10.5 k	37.5 k	210 k	460 k	970 k

CLIC Higgs Benchmark Results

- Results based on full GEANT4 simulations including $\gamma\gamma \to$ hadrons background
- 4 years of operation with 50% efficiency assumed at each energy stage
- Assume unpolarized beams, Higgs production cross-sections 80% larger for -80% polarization of electron beam

$\sqrt{s}$ [GeV]	Observable	Precision
350 GeV	$\sigma(\mathrm{HZ})$	4%
	m_{H} (from recoil)	120 MeV
	$\sigma \times \mathrm{BR}(\mathrm{H} \to \tau^+\tau^-)$	5.7%
500 GeV	$\sigma(\mathrm{HZ})/\sigma(\mathrm{H}\nu\bar{\nu})$	5%
	m_{H} (from recoil)	100 MeV
1.4 TeV	$\sigma \times \mathrm{BR}(\mathrm{H} \to \tau^+\tau^-)$	$< 3.6\%$
	self-coupling λ	30%
	$\sigma(\mathrm{t\bar{t}H})$	8%[a]
3 TeV	$\sigma \times \mathrm{BR}(\mathrm{H} \to \mathrm{b\bar{b}})$	0.2%
	$\sigma \times \mathrm{BR}(\mathrm{H} \to \mathrm{c\bar{c}})$	3.2%
	$\sigma \times \mathrm{BR}(\mathrm{H} \to \mu^+\mu^-)$	15%
	self-coupling λ	16%

[a] extrapolated from ILC study

Higgs Physics at CLIC

- Currently working towards a comprehensive assessment of the full SM Higgs programme
- $\sqrt{s} = 350\,\text{GeV}$:
  - Model-independent mass and cross section from recoil method
  - $H \to b\bar{b}$, $H \to c\bar{c}$, $H \to gg$, $H \to \tau^+\tau^-$, $H \to WW^*$
- $\sqrt{s} = 1.4\,\text{TeV}$:
  - $H \to b\bar{b}$, $H \to c\bar{c}$, $H \to gg$, $H \to \tau^+\tau^-$, $H \to WW^*$, $H \to Z\gamma$, $H \to \gamma\gamma$, $H \to \mu^+\mu^-$
  - top Yukawa coupling from the $t\bar{t}H$ cross section
  - Higgs self-coupling from $HH\nu\bar{\nu}$ cross section (improvements expected)
  - Higgs production in ZZ-fusion
- $\sqrt{s} = 3.0\,\text{TeV}$:
  - $H \to b\bar{b}$, $H \to c\bar{c}$, $H \to gg$, $H \to WW^*$, $H \to \mu^+\mu^-$
  - Higgs self-coupling from $HH\nu\bar{\nu}$ cross section (improvements expected)
- Final results expected in summer

CLIC Higgs Benchmarks at this Workshop

- Tomas Lastovicka - Measurement of the Higgs couplings to b- and c-quarks and to gluons at 350 GeV, 1.4 TeV and 3 TeV at CLIC
- Eva Sicking - Measurement of the Higgs couplings to gauge bosons at CLIC
- Astrid Münnich - Measurement of the Higgs boson decay to tau leptons at a CLIC collider operating at 350 and 1400 GeV
- Ivanka Bozovic-Jelisavcic - Measurement of the Higgs boson decay to muons at a CLIC collider operating at 1.4 and 3 TeV
- Sophie Redford - Measurement of the top Yukawa coupling at a 1.4 TeV CLIC collider
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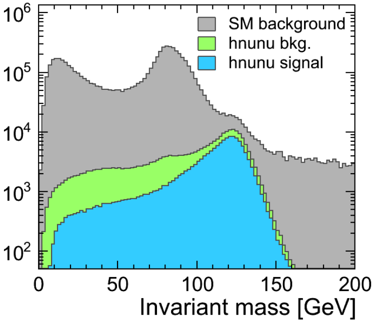

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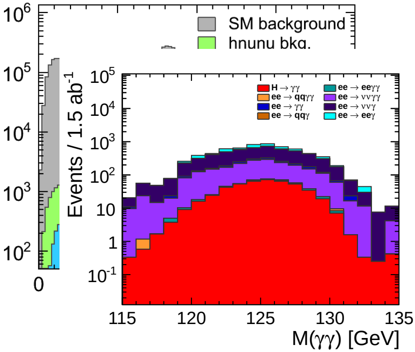

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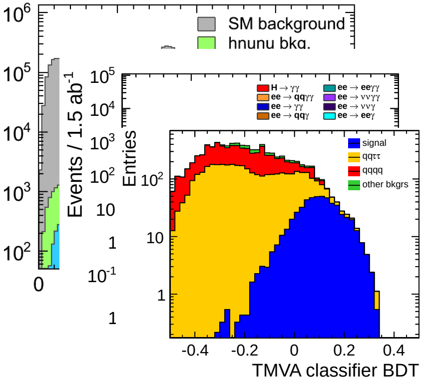

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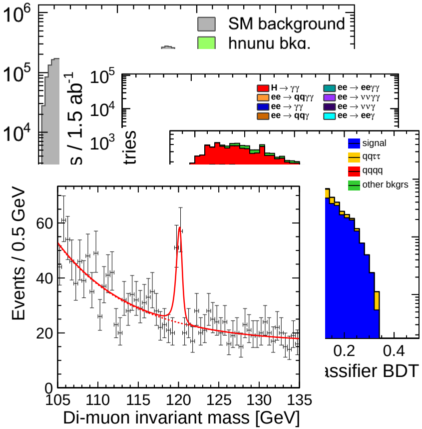

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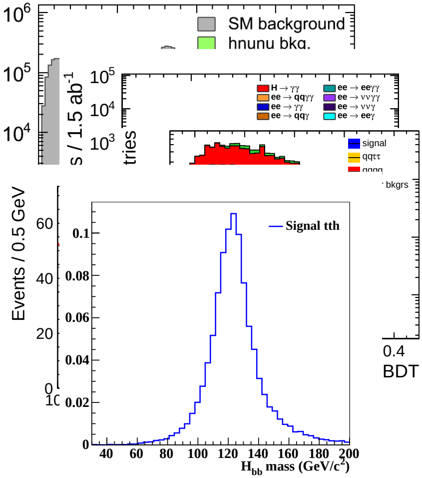
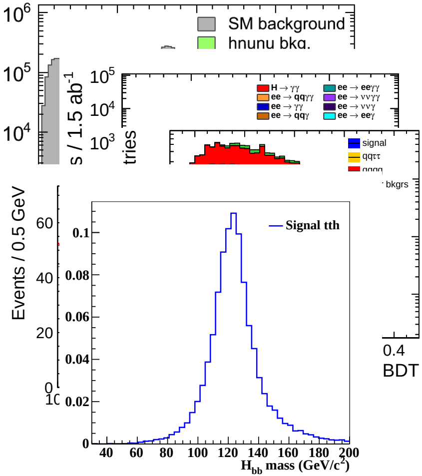
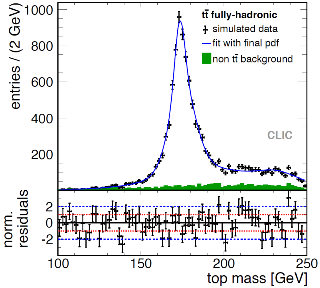


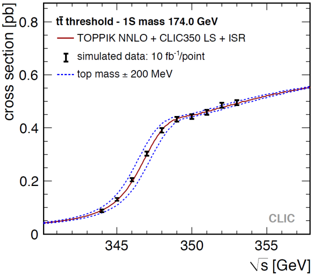
CLIC Higgs Benchmarks at this Workshop

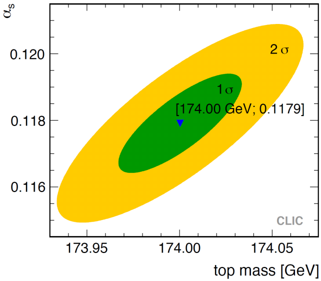
- Tomas Lastovicka - Measurement of the Higgs couplings to b- and c-quarks and to gluons at 350 GeV, 1.4 TeV and 3 TeV at CLIC
- Eva Sicking - Measurement of the Higgs couplings to gauge bosons at CLIC
- Astrid Münnich - Measurement of the Higgs boson decay to tau leptons at a CLIC collider operating at 350 and 1400 GeV
- Ivanka Bozovic-Jelisavcic - Measurement of the Higgs boson decay to muons at a CLIC collider operating at 1.4 and 3 TeV
- Sophie Redford - Measurement of the top Yukawa coupling at a 1.4 TeV CLIC collider
- Jan Strube - Measurement of the Higgs self-coupling at 1.4 and 3 TeV



Top Physics



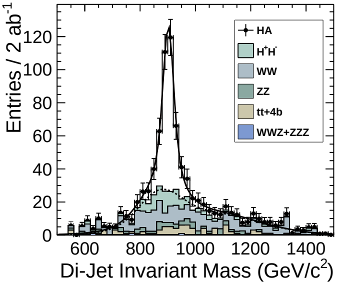




- Top mass measurement for $100\,\mathrm{fb}^{-1}$ at $\sqrt{s} = 500\,\mathrm{GeV}$ (fully-hadronic + semi-leptonic): $\Delta m_t = \pm 80\,\mathrm{GeV}$ (stat.)
- Simultaneous extraction of α_s and m_t from threshold scan: $\Delta m_t = \pm 34\,\mathrm{MeV}$, $\Delta\alpha_s = \pm 0.0009$ (stat.)

⇒ Frank Simon - Top quark mass measurements at and above threshold in e^+e^- collisions at Linear Colliders

Beyond the Standard Model



- Three different SUSY models studied
  - Heavy Higgs
  - Selectrons and Smuons
  - Staus
  - Gauginos

⇒ Frank Simon - Overview of SUSY studies for CLIC

⇒ André Sailer - Slepton Mass Measurements and the Luminosity Spectrum at CLIC

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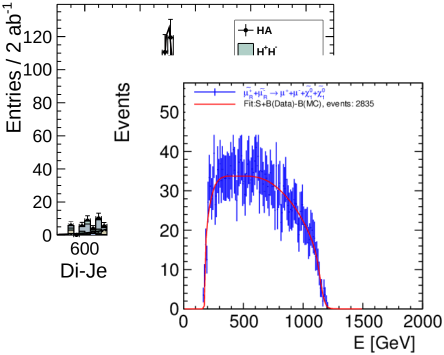

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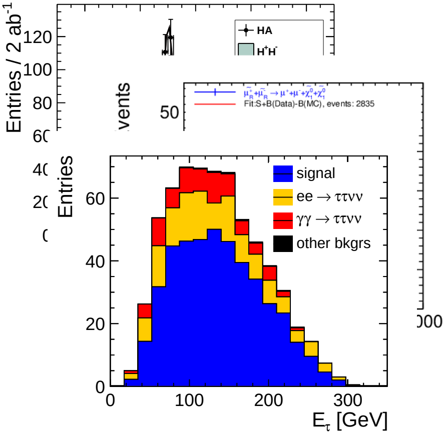

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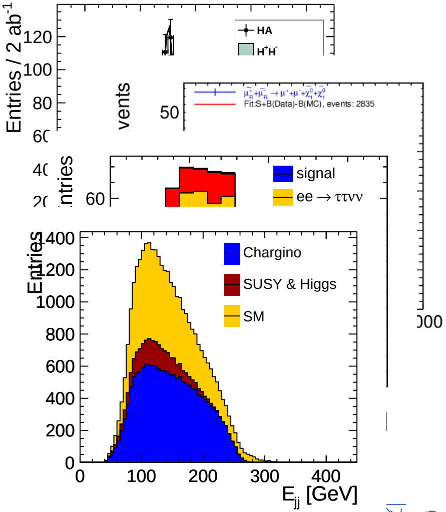

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SUSY Benchmark Results (1.4 TeV)

$\sqrt{s}$ (TeV)	Process	Decay mode	SUSY model	Measured quantity	Unit	Generator value	Stat. error
1.4	Sleptons production	$\tilde{\mu}_R^+\tilde{\mu}_R^- \to \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$	III	σ	fb	1.11	2.7%
				$\tilde{\ell}$ mass	GeV	560.8	0.1%
				$\tilde{\chi}_1^0$ mass	GeV	357.8	0.1%
		$\tilde{e}_R^+\tilde{e}_R^- \to e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0$		σ	fb	5.7	1.1%
				$\tilde{\ell}$ mass	GeV	558.1	0.1%
				$\tilde{\chi}_1^0$ mass	GeV	357.1	0.1%
		$\tilde{\nu}_e\tilde{\nu}_e \to \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^- W^+W^-$		σ	fb	5.6	3.6%
				$\tilde{\ell}$ mass	GeV	644.3	2.5%
				$\tilde{\chi}_1^\pm$ mass	GeV	487.6	2.7%
1.4	Stau production	$\tilde{\tau}_1^+\tilde{\tau}_1^- \to \tau^+\tau^-\tilde{\chi}_1^0\tilde{\chi}_1^0$	III	$\tilde{\tau}_1$ mass	GeV	517	2.0%
				σ	fb	2.4	7.5%
1.4	Chargino production	$\tilde{\chi}_1^+\tilde{\chi}_1^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$	III	$\tilde{\chi}_1^\pm$ mass	GeV	487	0.2%
				σ	fb	15.3	1.3%
	Neutralino production	$\tilde{\chi}_2^0\tilde{\chi}_2^0 \to h/Z^0 h/Z^0 \tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\chi}_2^0$ mass	GeV	487	0.1%
				σ	fb	5.4	1.2%

SUSY Benchmark Results (3 TeV)

$\sqrt{s}$ (TeV)	Process	Decay mode	SUSY model	Measured quantity	Unit	Generator value	Stat. error
3.0	Sleptons production	$\tilde{\mu}_R^+\tilde{\mu}_R^- \rightarrow \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$	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%
		$\tilde{e}_R^+\tilde{e}_R^- \rightarrow e^+e^-\tilde{\chi}_1^0\tilde{\chi}_1^0$		σ	fb	6.05	0.8%
				$\tilde{\ell}$ mass	GeV	1010.8	0.3%
				$\tilde{\chi}_1^0$ mass	GeV	340.3	1.0%
		$\tilde{e}_L^+\tilde{e}_L^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^- hh$ $\tilde{e}_L^+\tilde{e}_L^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^- Z^0Z^0$		σ	fb	3.07	7.2%
		$\tilde{\nu}_e\tilde{\nu}_e \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 e^+e^- W^+W^-$		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 production	$\tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^-$	II	$\tilde{\chi}_1^\pm$ mass	GeV	643.2	1.1%
				σ	fb	10.6	2.4%
	Neutralino production	$\tilde{\chi}_2^0\tilde{\chi}_2^0 \rightarrow h/Z^0 h/Z^0 \tilde{\chi}_1^0\tilde{\chi}_1^0$		$\tilde{\chi}_2^0$ mass	GeV	643.1	1.5%
				σ	fb	3.3	3.2%
3.0	Production of right-handed squarks	$\tilde{q}_R\tilde{q}_R \rightarrow q\bar{q}\tilde{\chi}_1^0\tilde{\chi}_1^0$	I	Mass	GeV	1123.7	0.52%
				σ	fb	1.47	4.6%
3.0	Heavy Higgs production	$H^0A^0 \rightarrow b\bar{b}b\bar{b}$	I	Mass	GeV	902.4	0.3%
				Width	GeV		31%
		$H^+H^- \rightarrow t\bar{b}b\bar{t}$		Mass	GeV	906.3	0.3%
				Width	GeV		27%

Outline

R&D Objectives for 2013–2016

- Vertex detector:
  Demonstration modules meeting requirements for high precision, 10 ns time-stamping and ultra-low mass
- Main tracker:
  Demonstration modules, including manageable occupancies in the event reconstruction
- Calorimeters:
  Demonstration modules, technological prototypes + addressing control of cost
- Electronics:
  Demonstrators, in particular in view of power pulsing
- Magnet systems:
  Demonstrators of conductor technology, safety systems and moveable service lines
- Engineering and detector integration:
  Harmonized with hardware R&D demonstrators

Summary and Outlook

- Collaboration-like structure for CLIC Detector and Physics Study
- Develop demonstrators for all detector components
- Detector optimization studies towards refined CLIC detector model(s)
- Explore the CLIC physics potential in full simulation studies:
  - Complete picture of Higgs measurement prospects
  - EW precision measurements
  - Discovery reach for BSM physics (input from LHC results)

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