CLIC vs. LHC
detector design parameters

Warning: these are draft slides.
Do not quote any of these numbers!

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Accelerator parameters

	LHC 14 TeV (nominal)	ILC 0.5 TeV	CLIC 3 TeV
#bunches / train	2808 (max. fill)	2670	312
Bunch crossing separation [ns]	25	308	0.5
Train freq. [Hz]	-	5	50
Instantaneous luminosity [cm^{-2}s^{-1}]	1×10^{34}	2×10^{34}	6×10^{34}
Total cross section [mb]	100	??	??
Crossing angle	200 μrad	14 mrad	20 mrad
IP size in x / y / z direction	15 μm / 15 μm / ~5 cm	600 nm / 6 nm / 300 μm	45 nm / 1 nm / 40 μm

In x/y-direction the values are gaussian parameters.
In z-direction it is not for the LHC; the simultaneous interactions in one bunch crossing take place over ~5 cm. The IP-spot cannot be used as constraint in track-reconstruction, at linear colliders it can.

Readout challenges

	LHC 14 TeV (nominal)	ILC 0.5 TeV	CLIC 3 TeV
# minimum bias events / BX	~23	-	-
# ($\gamma\gamma\rightarrow$hadrons) / BX	-	0.7	3
#Incoherent pairs / BX	-	1×10^5	3×10^5
Occupancy in 1st vertex detector barrel layer [#particles / mm^2 / BX]	0.05 (at R = 4 cm)	0.02 (at R = 1.5 cm)	0.005 + 0.001 (at R = 3 cm)

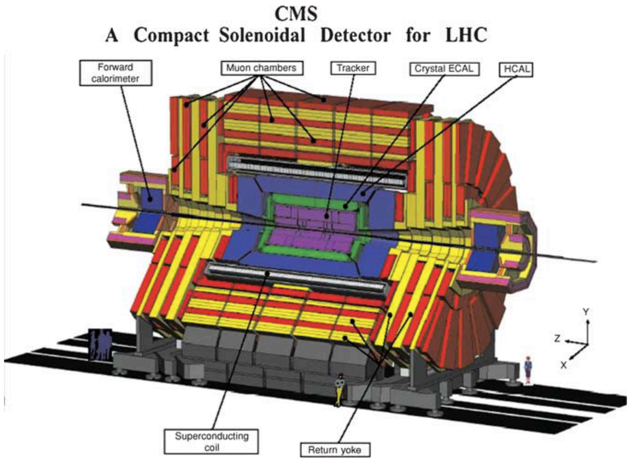
- Definition of Minimum Bias: depends on who you talk to.
  - Erik: the background events composed of mostly soft interactions
- The ratio of produced incoherent pairs to gg->hadrons is large.
  - Most pairs go down the beampipe. The contribution to the occupancy in the CLIC 1st layer is (pairs + gg): 0.005 + 0.001 per bunch crossing
  - The CLIC occupancy is lower than that at ILC, mostly because the conical beampipe is made thicker, shielding backscattered particles.

Event selection

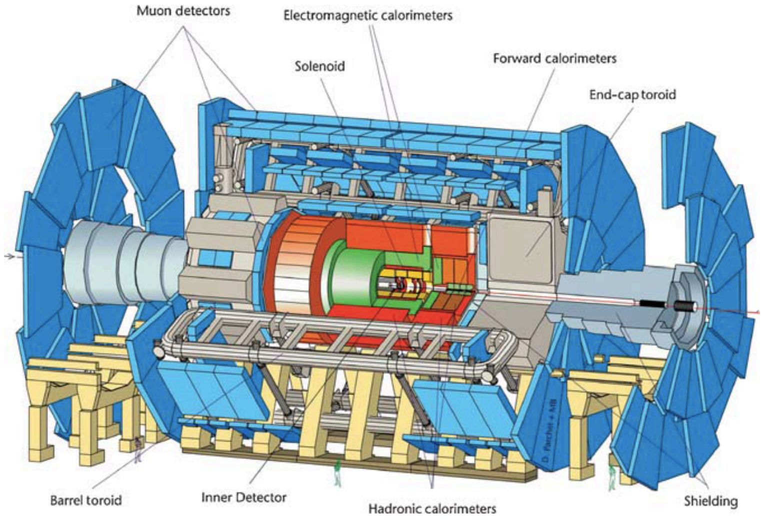
	LHC 14 TeV (nominal)	**ILC 0.5 TeV**	**CLIC 3 TeV**
Time stamping accuracy [ns]	25	–	5 - 10
Trigger sensitivity [#selected events : #total events]	$2{:}10^7$	1:1	1:1
Data rate, after trigger [MB/sec]	300	??	??

- One challenge for the LHC experiments is to trigger on the interesting physics among the many minimum bias events.
  - With a time stamping of 25 ns, pile-up of the minimum bias events over the triggered event in one BX will occur. Some sub-detectors have slower readout (calorimeters), thus pile-up of different BXs.
- Frequency of "interesting events" at CLIC is expected to be ~ 1 / train.
  - Depending on the occupancy in a sub-detector, different accuracies in time stamping are required. 0.5 ns is technologically feasible, but not in all sub-detectors. The most challenging is the vertex detector for which no technology available yet can reach the required 5-10 ns.

ATLAS & CMS overall designs



↕ ~ to scale



CMS chose a large strong solenoid with relative small calorimeter inside.

- Good tracking resolution
- Decreasing jet energy resolution for higher energies (might be improved with PFA)
- Muon system benefits from strong B-field in yoke, improving momentum measurement at high energies.

ATLAS chose a weaker and smaller solenoid, with a large calorimeter outside.

- Tracking resolution is worse
- Good E_T^{miss} and jet energy resolution (all energies)
- Large and yoke free muon spectrometer, with its own toroidal magnetic field: a benefit at high energy and in the forward region.

Magnets & yoke

	ATLAS	CMS	ILD_CDR	SiD_CDR
Full detector height & length [m]	H: 22 L: 46	H: 15 L: 20	H: 14 L: 14	H: 13 L: 12
Magnetic field [T]	2.0 (solenoid) 0.5 – 1.0 (toroid)	4.0 (operated at 3.8)	4	5
Solenoid inner radius + thickness [m]	1.2 + 0.2	3.0 + 0.6	3.4 + 0.7	2.7 + 0.8
Yoke inner radius + thickness [m]	HCAL: 2.3 + 1.6	4 + 3	4.5 + 2.7	3.8 + 2.9
Yoke mass : Detector mass [10^3 tons]	4 : 7	10 : 12.5	10 : 12	11 : 12.5

- ➢ For CLIC the design will be more CMS-like
  - – Calorimetry is to be placed inside the solenoid for accurate PFA analysis
- ➢ At LHC the length is greater than the height, at CLIC it is the inverse.
  - ➢ At CLIC the lengths are kept relatively short, as the beam stabilization must come as close as possible to the interaction point.

Vertex detector

	ATLAS	**CMS**	**CLIC 3 TeV**
Readout cell size [μm^2]	50 × 400	100 × 150	~ 20 × 20
Number of barrel layers	3	3	3 (double sided) or 5 (single sided)
Total material budget (at 90°)	~ 0.1 X_0	~ 0.1 X_0	~ 0.01 X_0
Non-ionizing energy loss in innermost layer [n_{eq} cm^{-2} y^{-1}]	$10^{14} - 10^{15}$	$10^{14} - 10^{15}$	~10^{10}
Transverse impact parameter resolution $\sigma_{r\phi}$ [μm] **$p_T = 1$ GeV** **$p_T = 1$ TeV**	 75 11	 90 9	 ~20 5

- R&D efforts for the inner detectors for CLIC aim at minimizing material and power consumption. The challenge lies in ensuring high granularity and precise time stamping.
- For LHC a major issue was radiation hardness; this is not a concern at CLIC.

(The value for radiation at CLIC stems from first studies; only $\gamma\gamma \rightarrow$hadrons and incoherent pairs were taken into account.)

Momentum resolutions

		ATLAS	CMS	CLIC 3 TeV
Inner Detector (at 90°)	**p = 1 GeV**	1.3%	0.7%	0.1%
	p = 100 GeV	3.8%	1.5%	0.2%
Incl. muon sys. (at 90°)	**p = 10 GeV**	1.4%	0.8%	0.1%
	p = 1000 GeV	10.4%	4.5%	2%
Incl. muon sys. (~ θ = 15°)	**p = 10 GeV**	2.4%	2.0%	2%
	p = 1000 GeV	4.4%	7.0%	10%

- The CMS tracker is very accurate in the stronger B-field
- The large ATLAS air-core muon spectrometer results in better momentum reconstruction in the forward region.
- Note: the CLIC muon system does not contribute to momentum measurement.

- The values for a CLIC detector are from a parametrization of

for $\theta = 90°$: $\sigma_{1/p_T} = \sqrt{[(2\times10^{-5})^2 + (10^{-3})^2/(p_T^2 \sin\theta))]}$

for $\theta = 15°$: see next slide

Momentum resolutions

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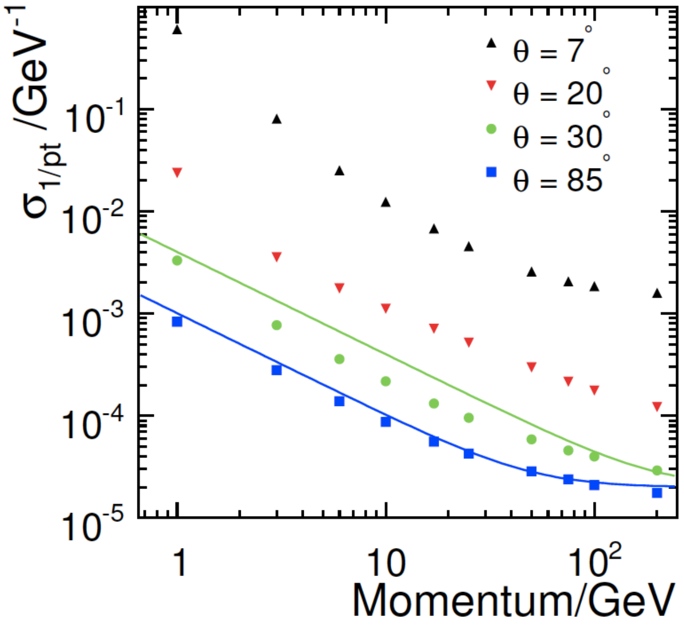
	p = 1000 GeV	10.4%	4.5%	2%
Incl. muon sys. (~ θ = 15°)	**p = 10 GeV**	2.4%	2.0%	2%
	p = 1000 GeV	4.4%	7.0%	10%

The values for a CLIC detector come from Fig. 3.2.3 of the ILD LOI, p.28 →



So for $\theta = 15°$:

p = 10 GeV → $\sigma_{1/pT} \sim 2\times10^{-3}$

p = 1 TeV → $\sigma_{1/pT} \sim 10^{-4}$

- CMS muon resolution is better than at CLIC, as CLIC detectors are shorter?

EM Calorimeter (barrel, at 90°)

	ATLAS	CMS	CLIC 3 TeV
#longitud. readout segments	4	1	29
Readout segment size [cm^3] (longitudinal × 'tilesize')	47 x 4 x 4 (main layer)	23 x 2.2 x 2.2	0.5 x 0.5 x 0.5 For first 19 layers
Absorber material	Lead + stainless steel	Lead tungstate crystals	Tungsten
Depth (radiation length) [X_0]	22	26	ILD: 24, SiD: 26
Intrinsic energy resolution $\sigma_E / E = a / \sqrt{E} \oplus b$	a = 10% b = 0.2%	a = 3% b = 0.5%	a = 16.6% b = 0.2% (from electron sim.)

- The resolution of the CLIC ECAL is worse than at LHC. No technology chosen, so no intrinsic resolution. Values obtained from electron simulation, see:
http://ilcagenda.linearcollider.org/getFile.py/access?contribId=108&sessionId=6&resId=0&materialId=slides&confId=1049
- At CLIC, it is all about being able to reconstruct the showers with PFA. The granularity is therefore more important than the resolution. → CLIC ECAL resolutions apply to photons, electron energies come from the tracking.

Hadronic calorimeter (barrel, at 90°)

	ATLAS	CMS	CLIC 3 TeV
#longitud. readout segments	3	1	75
Readout segment size [cm^3] (longitudinal × 'tilesize')	~ 20 x 20 x 20 For the first layer	96 x 20 x 20	1.7 x 3.0 x 3.0
Interaction length [λ_0]	~7.5	~5.5 (+3 for coil & tailcatcher)	7.5
Absorber material	Steel	Brass	Tungsten

- CLIC & CMS coil sizes are similar, yet the HCAL depth at CLIC is higher, due to the different absorber materials used
- LHC calorimeters are ϕ- η segmented, whereas for CLIC it will be one-size tiles.

Hadronic calorimeter (barrel, at 90°)

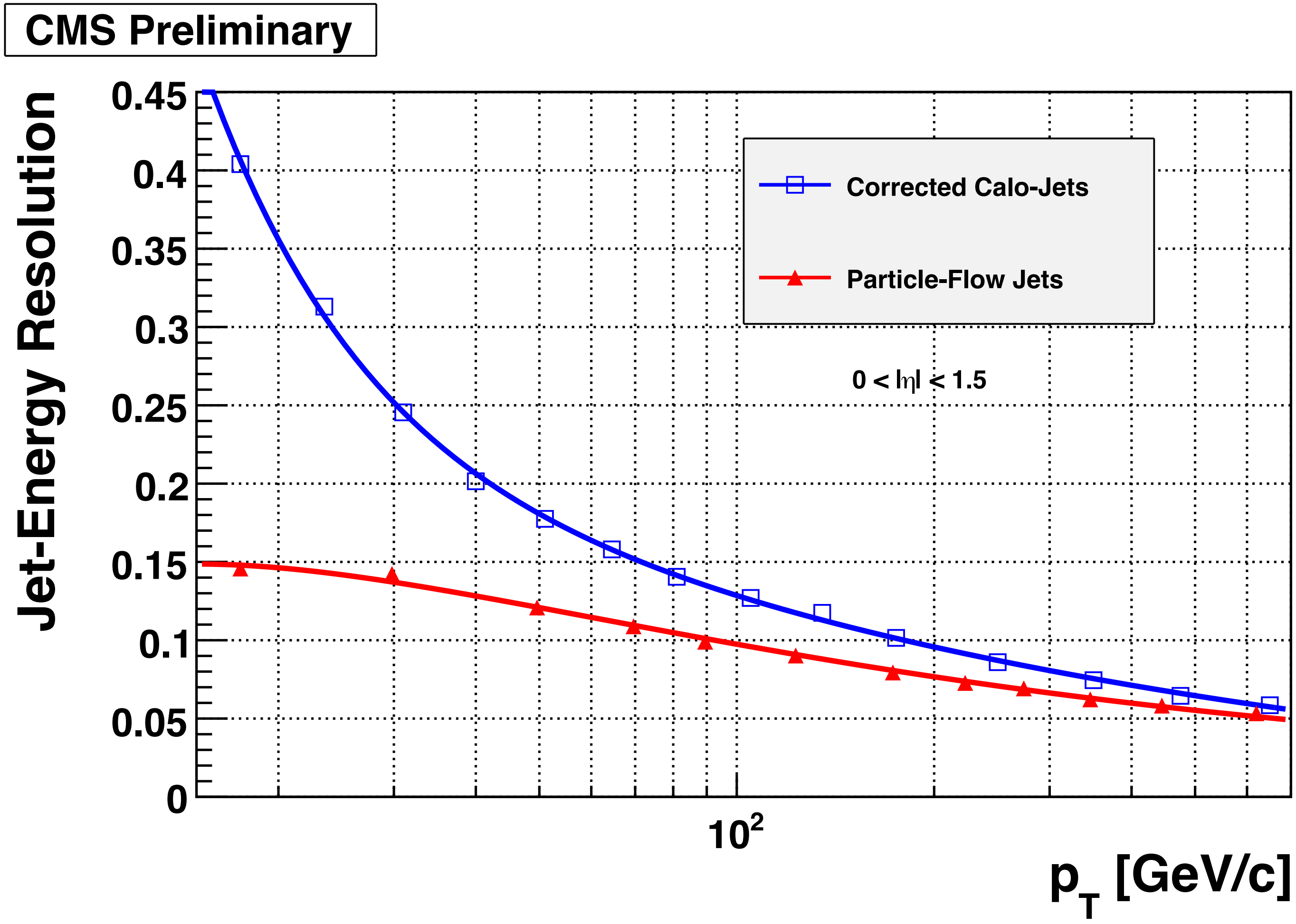
	ATLAS	**CMS**	**CLIC 3 TeV**
Intrinsic energy resolution $\sigma_E / E = a / \sqrt{E} \oplus b$	a = 45% b = 1.3%	a = 100% b = 7%	a = 43% b = 1.1%
Jet energy σ_E / E **p = 45 GeV** **p = 0.5 TeV**	15% 4%	19%, PFA → 12% 5%	4% 3%
E_T^{miss} **resolution [GeV]**	$0.48 \sqrt{(\Sigma E_T)}$	$0.97 \sqrt{(\Sigma E_T)}$	-

- Note: CLIC resolutions are $\mathbf{rms_{90}(E_j) / E_j}$. The values for LHC are not. This also applies to previous ECAL results.
- CMS results with PFA are preliminary, see backup slides.
- The missing energy resolution at CLIC cannot be stated; this will depend on technology used / noise / etc…

Backup slides

CMS jet energy resolution

From https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsPFT



Summary: vertex-detector parameters

Parameter	CLIC-ILD	CLIC-SiD
Magnetic field	4 T	5 T
Beam pipe (central region)	0.6 mm Beryllium, R=30 mm	0.5 mm Beryllium, R=25 mm
Barrel pixel layers	3 double layers 31 mm < R < 60 mm	5 single layers 27 mm < R < 77 mm
Forward pixel disks	3 double layers 160 mm < z < 257 mm	7 single layers 120 < z < 830 mm
Layer thickness	0.18% X0 / double layer	0.12% X0 / single layer
Pixel size	20 μm pitch, 50 μm silicon depth	
Total area	0.74 m^2	1.11 m^2
Total number of pixels	1.84G	2.77G
Readout	analog, σ_{SP}~3 μm	
projected IP resolution (90°)	$\sigma_{R\phi}=1.5\ \mu m \oplus 20\ \mu m\ GeV / p_T$	similar, t.b.c.
Power consumption target (air cooling; power pulsing)	< 100 mW/cm^2 (<0.4 μW/pixel)	
Background occupancy (ee)	~0.01 hits / mm^2 / ns (innermost layers)	
Radiation (pairs + $\gamma\gamma \rightarrow$ hadr.)	NIEL: ~10^{10} n_{eq} cm^{-2} y^{-1} ; TID: ~100 Gy y^{-1}	

CLIC parameters

Center-of-mass energy	ILC 500 GeV	CLIC 500 GeV	CLIC 3 TeV
Total (Peak 1%) luminosity $[\cdot 10^{34}]$	2(1.5)	2.3 (1.4)	5.9 (2.0)
Repetition rate (Hz)	5	50	
Loaded accel. gradient MV/m	32	80	100
Main linac RF frequency GHz	1.3	12	
Bunch charge $[\cdot 10^{9}]$	20	6.8	3.7
Bunch separation (ns)	370	0.5	
Beam pulse duration (ns)	950μs	177	156
Beam power/beam (MWatts)		4.9	14
Hor./vert. IP beam size (nm)	600 / 6	200 / 2.3	40 / 1.0
Hadronic events/crossing at IP	0.12	0.2	2.7
Incoherent pairs at IP	$1 \cdot 10^{5}$	$1.7 \cdot 10^{5}$	$3 \cdot 10^{5}$
BDS length (km)		1.87	2.75
Total site length km	31	13	48
Total power consumption MW	230	130	415

Crossing Angle 20 mrad (ILC 14 mrad)

Physics reach

	LHC 100 fb^{-1}	ILC 800 GeV 500 fb^{-1}	SLHC 1000 fb^{-1}	CLIC 3 TeV 1000 fb^{-1}	CLIC 5 TeV 1000 fb^{-1}
Squarks [TeV]	2.5	0.4	3	1.5	2.5
Sleptons [TeV]	0.34	0.4		1.5	2.5
New gauge boson Z′ [TeV]	5	8	6	22	28
Excited quark q* [TeV]	6.5	0.8	7.5	3	5
Excited lepton l* [TeV]	3.4	0.8		3	5
Two extra space dimensions [TeV]	9	5–8.5	12	20-35	30–55
Strong W_LW_L scattering	2σ	-	4σ	70σ	90σ
Triple-gauge Coupling (95%)	.0014	0.0004	0.0006	0.00013	0.00008

Integrated luminosities used are 100 fb–1 for the LHC, 500 fb–1 for the 800 GeV LC, and 1000 fb–1 for the SLHC and CLIC. Most numbers given are TeV, but for strong WLWL scattering the numbers of standard deviations, and pure numbers for the triple gauge cou

Frederic Teubert

Physics reach

This is from an old presentation, should be checked / updated!

	LHC **100 fb^{-1}**	**ILC** **800 GeV** **500 fb^{-1}**	**sLHC** **1000 fb^{-1}**	**CLIC** **3 TeV** **1000 fb^{-1}**
Squarks [TeV]	2.5	0.4	3	1.5
Sleptons [TeV]	0.34	0.4		1.5
New gauge boson Z' [TeV]	5	8	6	22
2 extra space Dimensions [TeV]	9	5-8.5	12	20-35
Triple-gauge Coupling (95%)	.0014	0.0004	0.0006	0.00013

Parameters by Hubert Gerwig

The following table 1 summarizes the main parameters:

Parameter	**CLIC_SiD**	**CLIC_ILD with end-coils**
Detector length	12.40 m	12.40 m
Overall length with shielding rings	12.80 m	12.80 m
Detector diameter on flat	14 m	13.98 m
Free bore	5448 mm	6852 mm
Coil inner diameter	5828 mm	7202 mm
Coil outer diameter	7008 mm	7888 mm
Coil length	6230 mm	7890 mm
L*	**3500 mm**	**4340 mm**
Bore in End-cap for support tube and anti-solenoid	1380 mm	1380 mm
Radial height vacuum tank	1020 mm	828 mm
Vacuum Tank length	6690 mm	8350 mm
Coil weight	201 tonnes	173 tonnes
Vactank weight	128 tonnes	173 tonnes
1 End-cap weight	2900 tonnes	2100 tonnes
Barrel weight	5000 tonnes	4700 tonnes
Complete return yoke	10800 tonnes	9900 tonnes
Detector total weight	**12500 tonnes**	**11800 tonnes**

Table 1: Main dimensions and weights