ILC-CLIC

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Tracker Read-out at ILC & CLIC

Presented by Alexander Kluge

TWEPP 2009, Sept 21 – 25 , 2009

A. Kluge

Outline

- Introduction: What is ILC & CLIC ?
- Linear Collider Electronics and Detector Specifications
  - From LEP and LHC to linear colliders
  - Bunch crossing timing structure, read-out time and trigger
  - Position resolution, material budget and cooling
- Conclusion

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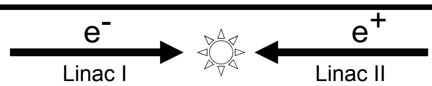
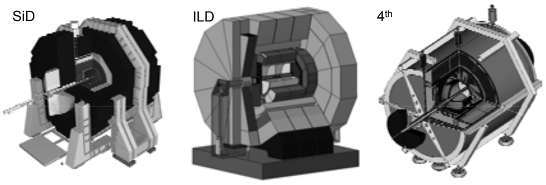
Introduction: What is ILC & CLIC ?

CLIC-Compact Linear Collider ILC-International Linear Collider



- Electron - positron collider
- Center of mass energy 3 / 0.5 TeV
- Luminosity of a few 10^{34} $cm^{-2}s^{-1}$
- Total length of 48 / 31 km
- Total power consumption of 500/250 MW (LEP @ 100 GeV was 237 MW)

Detector concepts for the Linear Collider



http://silicondetector.org LOI validated

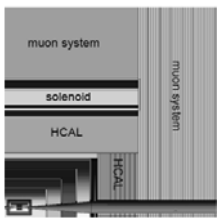
http://www.ilcild.org/ LOI validated

http://www.4thconcept.org/

3 LoI documents submitted 31/3/2009

Lucie Linssen, SPC, 15/6/2009

LC Detector Concepts - SiD

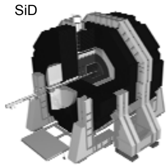


- Silicon based vertex detector and tracker
- Si/W ECAL
- HCAL
- Solenoid Magnet (5T)
- Muon system
- 12 m x 12 m

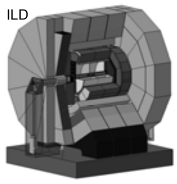
ILC Talk, ICHEP2008, 20080805

CLIC detector

SiD



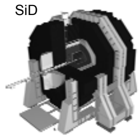
ILD



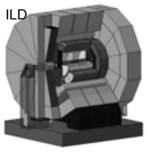
- Collaboration of the LC detector community:
- CLIC detector is LC detector: adapted to the CLIC requirements

CLIC detector

SiD



ILD

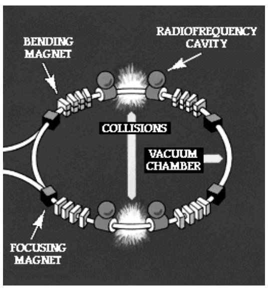


- Silicon based vertex detector and tracker
  - 5 layers of pixels
  - 5 layers of Si strips
  - or <5 layers strips + TPC for tracking
- ECAL
- HCAL
- Solenoid Magnet (5T)

ILC/CLIC Electronics and Detector Specifications

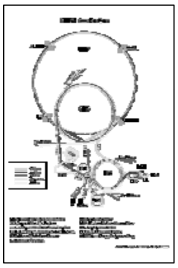
From LEP and LHC to linear colliders

Accelerator Basics



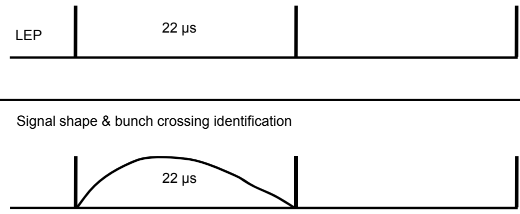
LEP - Large Electron Positron Collider

LEP



centre of mass energy	91GeV -> 200 GeV (Z_0,W)
bunch spacing / bunch crossing frequency	22 µs / 45 kHz
number of bunches	4
length	27 km
bunch train repetition frequency	continous
beam profile dimensions	200 µm x 3 µm
bunch length	0.5 – 4 cm

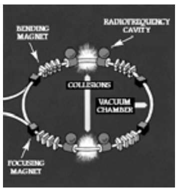
LEP timing structure



LHC - Large Hadron Collider

Higher energy & Synchotron radiation

- Charged particles radiate when accelerated v close to c and gamma = $(E/(m_0*c^2)) >> 1$



Energy of particle

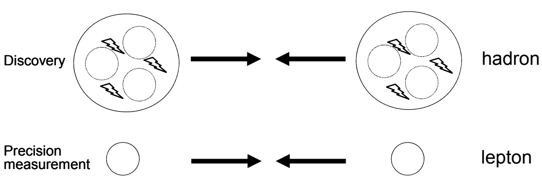
$$P = \frac{2}{3}\frac{r_e c}{(m_o c^2)^3}\frac{E^4}{\rho^2}$$

Mass of particle Radius of acceleration

http://wlap.physics.lsa.umich.edu/cern/lectures/academ/2000/wilson/09/real/f003.htm
http://hasylab.desy.de/science/studentsteaching/primers/storage_rings__beamlines/index_eng.html
ssrl.slac.stanford.edu/ ~txrf/spear.htm

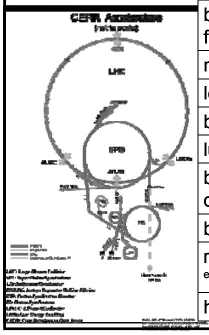
Lepton/Hadron collision

- Hadron machine to overcome synchrotron radiation
- Collision per collision energy uncertainty
- Centre of mass energy: 14 TeV



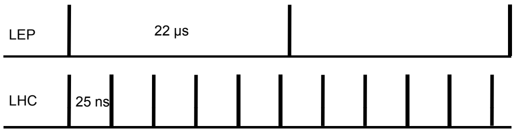
Energy distribution

LHC

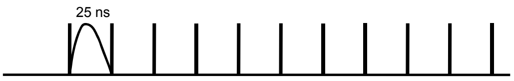


LHC	
centre of mass energy	14 TeV
bunch spacing / bx frequ.	25 ns / 40 MHz
number of bunches	2808
length	27 km
bunch train repetition	continous
luminosity	10^{34} cm^{-2} s^{-1}
beam profile dimensions	16.7 x 70.9 µm^2
bunch length	7.55 cm RMS
radiation level (tracker) equivalent to 1 MeV neutron flux	10 Mrad/yr, $5*10^{14}$ cm^{-2} s^{-1}
hit occupancy (CMS pixel)	0.01 hit mm^{-2} bx^{-1}

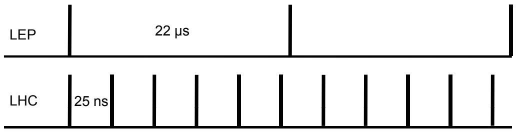
LHC timing structure



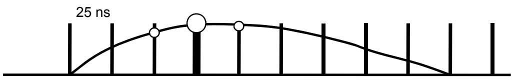
Signal shape & bunch crossing identification: i.e. Silicon pixel detectors
Charge collection time and shaping time adapted
Direct bunch crossing identification



LHC timing structure



Signal shape & bunch crossing identification: i.e. Calorimeter
Indirect bunch crossing identification with sampling at 40 MHz



LC - Physics

ILC physics at 500 GeV

- Precision measurements of Higgs physics
- Top-quark physics
- Supersymmetry

CLIC physics at 3 TeV

- In addition to above even more refined precision measurement of:
- Higgs physics
- Supersymmetry
- And in addition
  - Probe for theories of extra dimensions
  - New heavy gauge bosons (e.g. Z')
  - Excited quarks or leptons

LC need for low material budget

- efficient and pure identification of heavy jets
- separation of b from c jets (Higgs sector, SUSY, etc)
  - tell primary from secondary particles
  - identify most of secondary particles (to separate b from c). In multi-jet final states typical momentum of those particles tracks are just a few GeV -> minimise multiple scattering for extrapolation accuracy
- minimal material in front of calorimeter to avoid conversion of photons
- Inner tracker 0.1 – 0.2 % X_0 per layer

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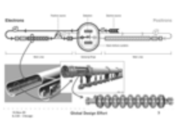
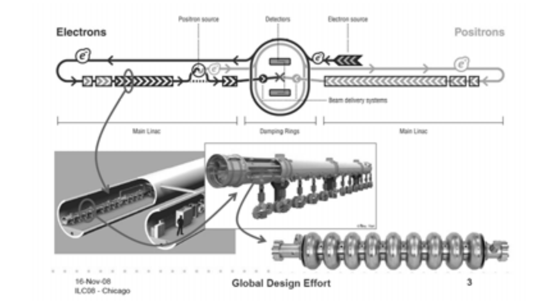
ILC - International Linear Collider

ILC

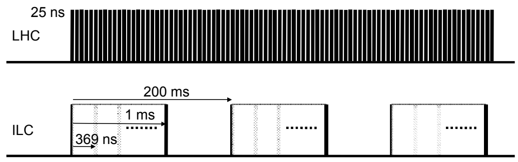
ILC	
centre of mass energy	0.5 TeV
bunch spacing / bx frequ.	337 ns / 3 MHz
number of bunches	2625 -> 0.969 ms
length	31 km
bunch train repetition	5 Hz / 200 ms
duty cycle	0.005
luminosity	2 * 10^{34} cm^{-2} s^{-1}
beam profile dimensions	620 x 5.7 nm^2
bunch length	300 µm RMS
radiation level (tracker) equivalent to 1 MeV neutron flux William Morse ILC R&D April 19, 2006	10 MGy/yr, ?*10^{14} cm^{-2} s^{-1}
hit occupancy	0.03 hits mm^{-2} bx^{-1}



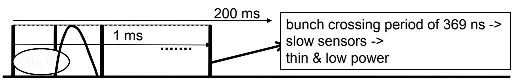
ILC



ILC timing structure

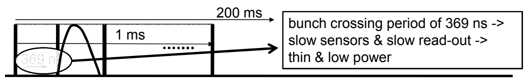


Signal shape & bunch crossing identification
Direct bunch crossing identification



ILC timing structure

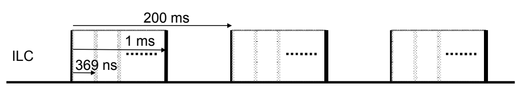
Signal shape & bunch crossing identification
Direct bunch crossing identification

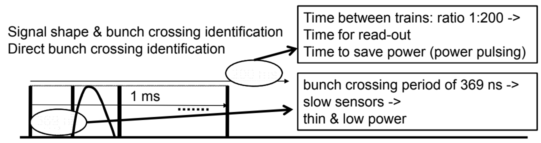


LHC use of depleted Silicon detectors: fast, rather large, radiation hard, => high power consumption and high material budget

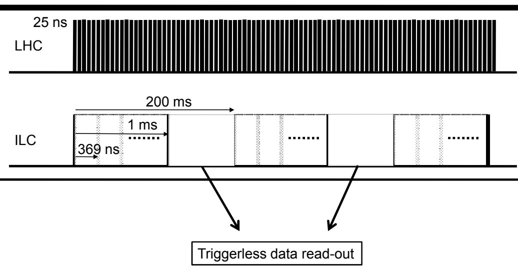
Large bunch crossing period & low radiation opens possibility for different technologies

ILC timing structure





ILC timing structure



CLIC

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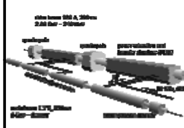
CLIC



CLIC	
centre of mass energy	3 TeV
bunch spacing / bx frequ.	0.5 ns / 2 GHz
number of bunches	312 -> 156 ns
Length (2 LINACs)	48 km
bunch train repetition	50 Hz / 20 ms
duty cycle	$8 * 10^{-6}$
luminosity	$6 * 10^{34}\ cm^{-2}\ s^{-1}$
beam profile dimensions	$40 \times 1\ nm^2$
bunch length	44 µm RMS

CLIC

- ILC – International Linear Collider
  - superconducting cavities
  - 31.5 MV/m, maximum: after that supra conduction breaks down
- CLIC - Compact Linear Collider
  - normal conducting acceleration structures (100 MV/m)
    - are good for high gradient (V/m) but only for short time -> bx = 0.5 ns
    - no individual RF power sources (klystrons)
    - two beam system, where a drive beam supplies energy to the main beam using power extraction and transfer structures (PETS)

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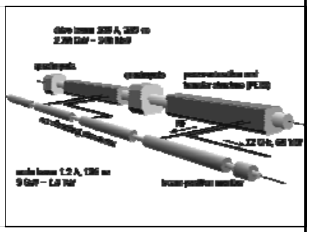
The CLIC Two Beam Scheme

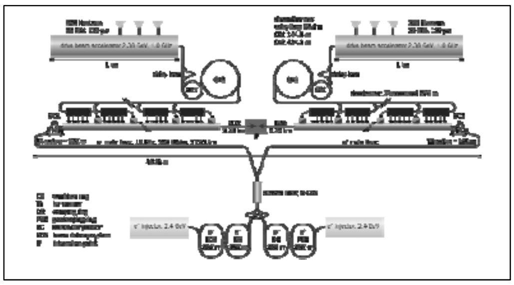
- Drive Beam supplies RF power
  - Low energy
  - High current
- Main beam for physics
  - High energy
  - Current 1.2 A



No individual RF power sources

Lucie Linssen, EUDET Amsterdam 7/10/2008

CLIC



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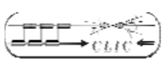
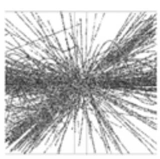
CLIC detector issues

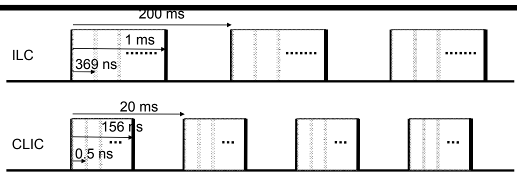




Lucie Linssen, EUDET Amsterdam 7/10/2008

- Beam timing structure
- Short interaction region
- Beam induced back ground, high energy and short bunch crossing
  - CLIC 3TeV beamstrahlung (higher than ILC)
  - Coherent pairs (3.8×10^8 per bunch crossing) <= disappear in beam pipe
  - Incoherent pairs (3.0×10^5 per bunch crossing) <= suppressed by strong B-field
  - γγ interactions => hadrons
- Consequences on detector granularity (space, time)

CLIC timing structure



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Detector challenges

- Material budget
- Power dissipation
- Bunch separation
- Position resolution

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Material budget

- 0.1 % to 0.2 % of X_0 per layer
- What does it mean?
- ***Electron looses 64% of its energy when traversing X_0.***

The amount of matter traversed is called the radiation length X_0, measured in gcm $^{-2}$ where in the mean distance over which a high-energy electron loses all but 1/e (36%) of its energy by bremsstrahlung, and 7/9 of the mean free path for pair production by a high-energy photon.

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Material budget

- **Example of Copper cable 1 mm thickness**
  - Copper X_0 = 12.86 g/cm², density = 8.96 g/cm³
  - Proportion of radiation length [%] =
    100 * thickness * density / radiation length =
    100 x 0.1 cm x 8.96 g.cm³ / 12.86 g/cm² = 7 %
- **1 mm Copper = 7% X_0**
- **Requirements in LC: 0.1 – 0.2 % per layer**
- **LHC tracker: ~ 2 % (CMS/ATLAS), ~ 1 % (ALICE) per layer**

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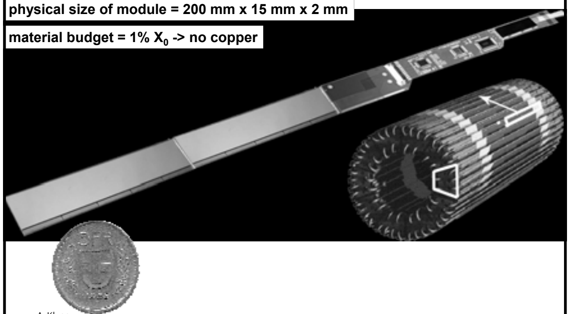
ALICE Silicon Pixel Detector

physical size of module = 200 mm x 15 mm x 2 mm

material budget = 1% X_0 -> no copper



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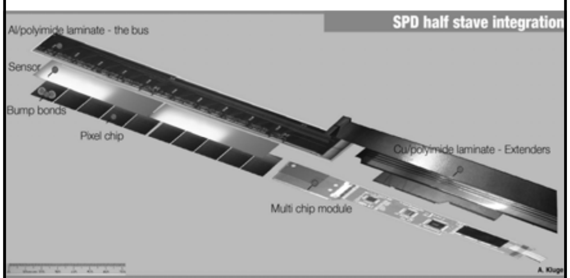
ALICE Silicon Pixel Detector module



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ALICE Silicon Pixel Detector module

SPD Element	Thickness µm	%X0
Al Bus		
Kapton	60	0,02
Al power	100	0,11
Al signals [50%]	17,5	0,02
Glue Epoxy	70	0,02
SMD components	16,4	0,17
	Total	0,34
Other Components		
Pixel chip	150	0,16
Sensor	200	0,21
Bump bonds Sn 60%+Pb 40%	0.18+0.12	0,00
Grounding Foil-Kapton/Al	50+10	0,03
Glue Epoxy/thermal grease	200	0,05
Carbon fiber	200	0,11
	Total	0,56

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CLIC: Resolution, speed, material budget

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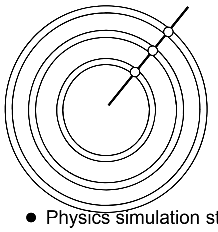
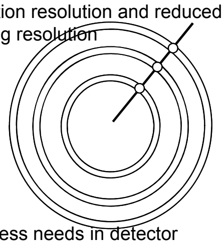
2 corner scenarios as starting point

- All layers of inner tracker similar
- one dedicated time stamping layer and all others with good position resolution and reduced timing resolution





- Physics simulation studies assess needs in detector granularity (space, time) and material budget

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Examples for corner scenarios as starting point

1) All layers of inner tracker similar
2) one dedicated time stamping layer and all others good in position resolution with reduced timing resolution

Parameter	1)	2)
tracking layer: pixel size	30 µm x 30 µm	10 µm x 10 µm
tracking layer: time resolution	20-25 ns	≥ 150 ns
tracking layer: material budget	≥0.2 % X_0	0.2 % X_0
time stamping layer: pixel size	-	100 µm x 100 µm
time stamping layer: time resolution	-	15 ns
time stamping layer: material budget	-	>0.2 % X_0

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Resolution

- **First simulation results indicate**
- **Time resolution of 10 – 20 ns**
- **Position resolution ~ 20 µs**

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Data rate & Power pulsing

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Data rate and power pulsing

can power pulsing be done or is the read-out rate too high?

- **occupancy: 10 (-50) hits /mm²/312 bx**
- **assume chip of: 10 mm x 10 mm and pixel size of 20 µm x 20 µm**
  =>
  500 x 500 pixel = 250000 pixels = 18 bit address
  time stamping 1 bx out of 312 = 9 bit
  10 hits/mm² * 100 mm²= 1000 hits
- **No trigger reduction: Chip Data rate / bx train =>**
  1000 hits * 32 bit = 32000 bit
- **32 kbit / (bx train + off time) (20ms) = 1.6 Mbit/s**
- **32 kbit / bx train (156 ns) = 200 Gbit/s**

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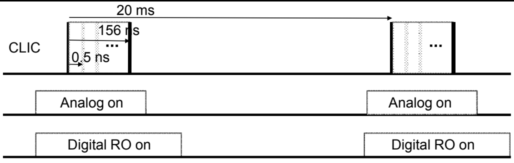
Data rate and power pulsing



For example:
analog 1 ms on before bx train, 1 ms off after bx train
digital 1 ms on before bx train, 4 ms off after bx train

=> data rate: 32 kbit / 4 ms = 8 Mbits/s

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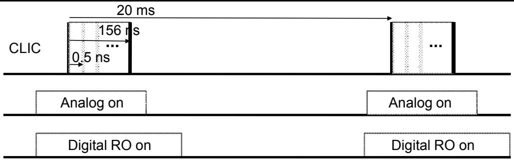
Data rate and power pulsing



For example:
analog 1 ms on before bx train, 1 ms off after bx train
digital 1 ms on before bx train, 4 ms off after bx train

Analog duty cycle: 10 %
Digital duty cycle: 25 %

Steady power consumption * duty cycle

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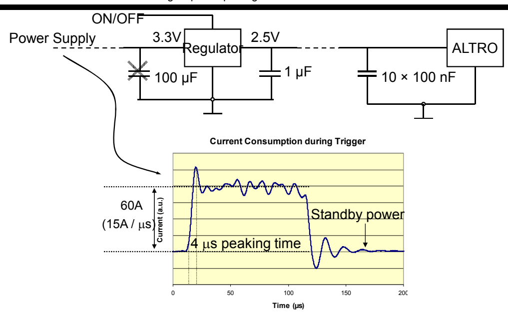
ALICE TPC power pulsing experience (L. Musa)

Digital power pulsing with ALICE TPC FEC



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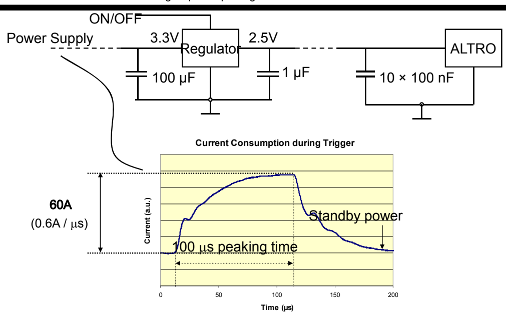
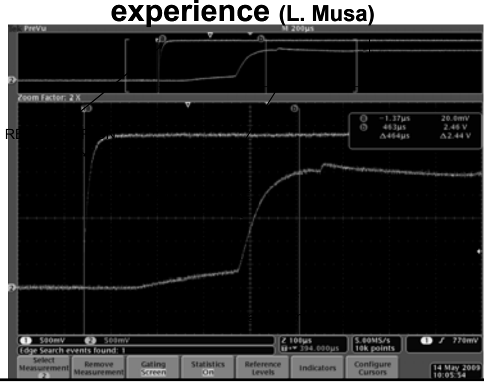


ALICE TPC power pulsing experience (L. Musa)

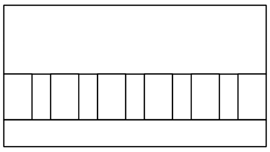


Cooling

Cooling

- Industry will reach power limit for PC chips?
- Will we be able to benefit from this?
- Micro channel cooling

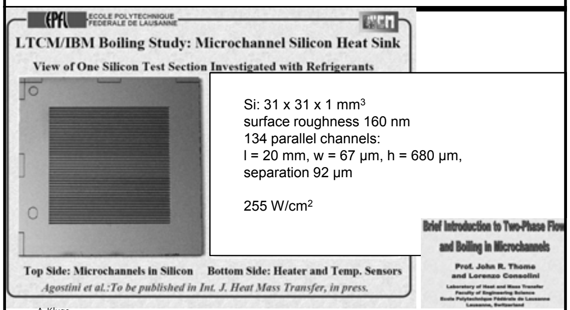
Micro channel cooling



Si: 31 x 31 x 1 mm³
surface roughness 160 nm
134 parallel channels:
l = 20 mm, w = 67 µm, h = 680 µm,
separation 92 µm

255 W/cm²

Micro channel cooling



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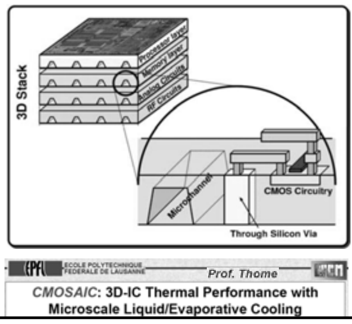
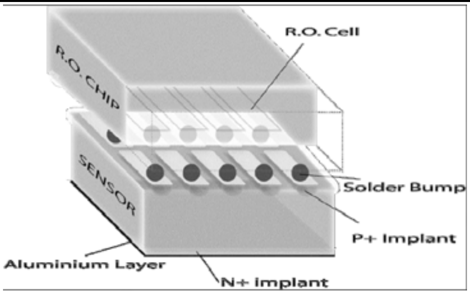
255 W/cm²

3D micro channel cooling



Detectors

Hybrid pixel detector



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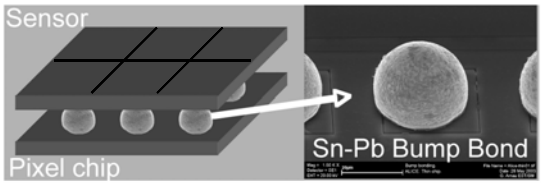
Hybrid pixel detector



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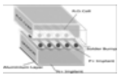
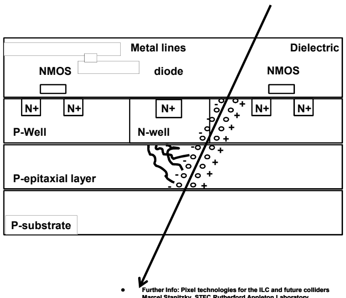
MAPS
Monolytic Active Pixel Sensors



- **Charge is collected by diffusion -> slow > 100 ns Integration over bx train**
- **Integrated read-out but slow, low power, small resolution**
- **No bump bonds**
- **Not yet available**



- Further info: Pixel technologies for the ILC and future colliders Marcel Stanitzky, STFC Rutherford Appleton Laboratory http://www2.warwick.ac.uk/fac/sci/physics/research/epp/seminars/seminar-warwick020409.pdf

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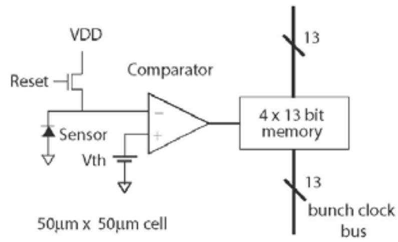
J. E. Brau, N. B. Sinev, D. M. Strom
University of Oregon, Eugene

C. Baltay, H. Neal, D. Rabinowitz
Yale University, New Haven

Chronopixel Sensors for the ILC



Nick Sinev
SiD Design Study Workshop Fermilab
LCWS08, University of Illinois at Chicago

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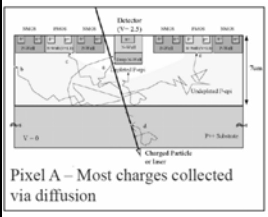
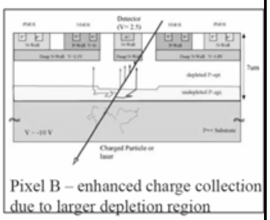
Chronopixel Sensors for the ILC





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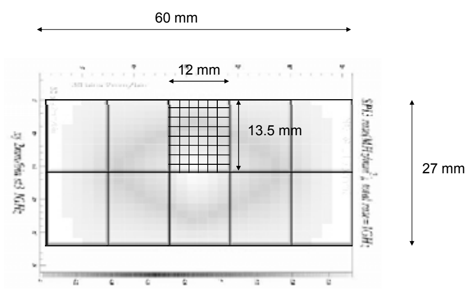
Giga Tracker for the NA62 rare Kaon decay experiment at CERN



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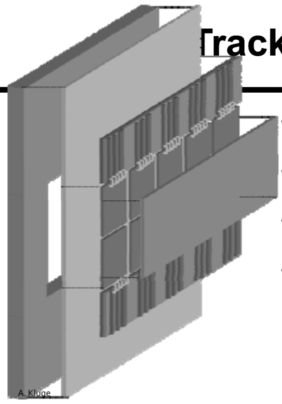
Tracker setup



- Sensor&bonds: 0.24% X_0 (200 µm Silicon)
- RO chip: 0.11% X_0 (100 µm Silicon)
- Structure: 0.10% X_0 (100 µm Carbon fiber)
- Total: 0.45% X_0 uniform

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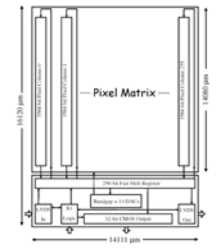
☐Timepix

Timepix, a 65k programmable pixel readout chip for arrival time, energy and/or photon counting measurements

X. Llopart*, R. Ballabriga, M. Campbell, L. Tlustos, W. Wong



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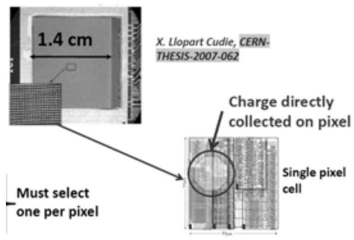
☐Timepix



A TPC with Triple-GEM Gas Amplification and TimePix Readout

LCWS 2008 – Chicago

Andreas Bamberger, Uwe Renz, Markus Schumacher, Andreas Zwerger

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Summary

- Linear colliders are required to complement the measurements in LHC
- Summarized the specifications for ILC and CLIC detector electronics
- Detector electronics implementation provides sufficient challenge for us to contribute

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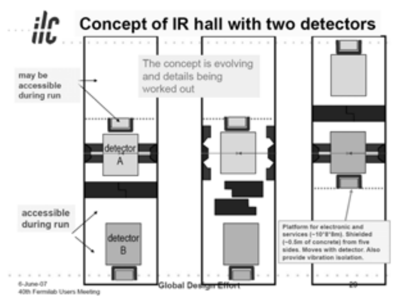
Notes

A. Kluge February 3, 2009

ILC push pull principle



Time schedule

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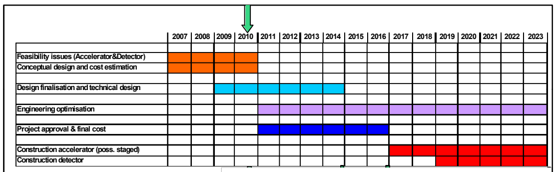
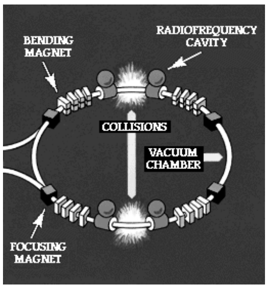
CLIC schedule



CLIC CDR foreseen for 2010
CLIC TDR foreseen for 2015

Lucie Linssen, EUDET Amsterdam 7/10/2008

Accelerator Basics



ILC physics at 500 GeV

Higgs physics:
•Study of light standard-model Higgs boson (< ~225 GeV) properties using ZH radiation and WW fusion process.
  •Precise measurement of Higgs mass (50 MeV) and width (7%)
  •Higgs coupling to gauge bosons and quarks (to ~10% precision)

Top-quark physics:
Precision top measurements (at √s=350 GeV)
Measurement of top mass (to~150 MeV) and width (5% of predicted 1.4 GeV width)

These precision measurements allow to look for departures of standard model and constrain parameters of new physics models.

Supersymmetry:
•Complete study of light sparticles
•Discovery of heavy sparticles

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CLIC physics at 3 TeV

If the CLIC technology will be chosen, CLIC will start at a lower energy (e.g. 500 GeV), so CLIC shall cover the ILC physics reach and in addition can cover physics uniquely accessible to multi-TeV energies.

Higgs physics:
•Complete study of the light standard-model Higgs boson (< ~225 GeV) properties (cross section is factor ~5 higher than ILC), including rare decay modes
  •Higgs coupling to leptons
  •Study of triple Higgs coupling using double Higgs production
•Study of heavy Higgs bosons (supersymmetry models)

Supersymmetry:
•Complete study of light sparticles
•Discovery of heavy sparticles

And in addition:
•Probe for theories of extra dimensions
•New heavy gauge bosons (e.g. Z')
•Excited quarks or leptons

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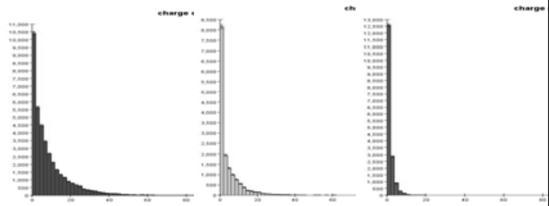
Chronopixel Sensors for the ILC



Pixel A   Pixel B, 0V on substrate   Pixel B, 10V on substrate

A. Kluge   Nick Sinev   LCWS08, University of Illinois at Chicago   November 18, 2008