Développement d'une échelle double face pour la trajectométrie en physique des hautes énergies.

Ph. D. defense

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DESY

February 13, 2017

Outlines

What is the Universe made of?

Matter:

Fermions

What is the Universe made of?

Matter:

Leptons

Fermions

What is the Universe made of?

Matter:

	Leptons		
Fermions	e^-	μ	τ
	ν_e	ν_μ	ν_τ

What is the Universe made of?

Matter:

	Leptons			Quarks
Fermions	e^-	μ	τ	
	ν_e	ν_μ	ν_τ	

What is the Universe made of?

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Fermions	e^-	μ	τ	u	c	t
	ν_e	ν_μ	ν_τ	d	s	b

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Forces:

Bosons

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Forces:

$\gamma \rightarrow$ E.M. interaction

Bosons

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Forces:

$$\gamma \rightarrow \text{E.M. interaction}$$
$$Z^0/W^\pm \rightarrow \text{Weak interaction}$$

Bosons

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Forces:

	γ	$\rightarrow$	E.M. interaction
	$Z^0/W^\pm$	$\rightarrow$	Weak interaction
Bosons	g	$\rightarrow$	Strong interaction

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	$Z^0/W^\pm$	$\rightarrow$	Weak interaction
	g	$\rightarrow$	Strong interaction
	graviton	$\rightarrow$	Gravitation

What is the Universe made of?

Matter:

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Forces:

Bosons	γ	$\rightarrow$	E.M. interaction
	$Z^0/W^\pm$	$\rightarrow$	Weak interaction
	g	$\rightarrow$	Strong interaction
	graviton	$\rightarrow$	Gravitation
	H	$\rightarrow$	Higgs field

Open questions

Limitations

- Free parameters
- Neutrino mass
- Dark matter and dark energy
- ...

Other theories

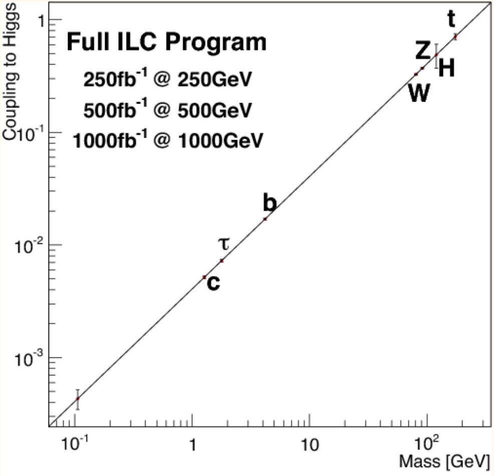
- SUSY
- GUT
- Technicolor
- ...

The Higgs boson discovery

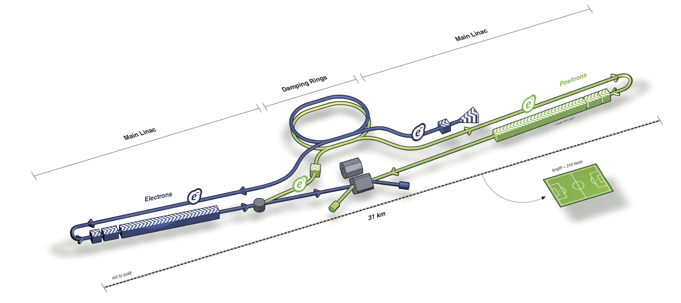
elele

- Discovery at the LHC (ATLAS and CMS)

Higgs Boson

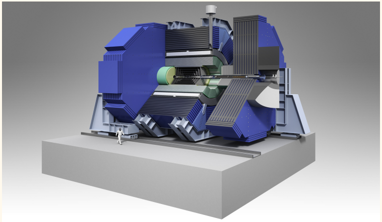

Full ILC Program
250fb^{-1} @ 250GeV
500fb^{-1} @ 500GeV
1000fb^{-1} @ 1000GeV
Coupling to Higgs
Mass [GeV]
t
Z
H
W
b
τ
c
1
10^{-1}
10^{-2}
10^{-3}
10^{-1}
1
10
10^{2}

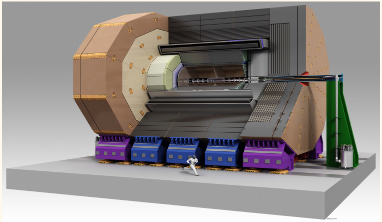
International Linear Collider



- Future e^+e^- linear collider at $\sqrt{s} = 250 - 500$ GeV (upgrade up to $\sqrt{s} = 1$ TeV)
- Polarised beam
- Luminosity $\simeq 2 \times 10^{34}$ cm^{-2}s^{-1}
- Candidate site: Kitakami in nothern Japan
- To study properties of the Higgs boson, top physics...

SiD and ILD





Silicon Detector

- Silicon tracking (radius = 1.2m)
- $B_{\mathtt{field}} = 5$ T

International Linear Detector

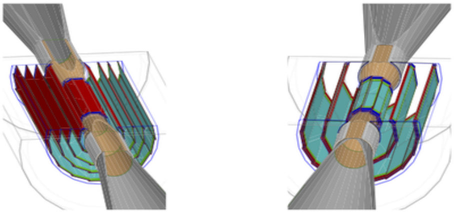
- TPC + silicon envelope (radius = 1.8 m)
- $B_{\mathtt{field}} = 3.5$ T

Both detectors designed for Particle Flow Calorimetry

- High granularity calorimeters (ECAL and HCAL) inside solenoid
- Low mass tracker to reduce interactions and conversions

The ILD Vertex Detector

Two geometry options



5 single-sided layers

3 double-sided layers

Impact parameter resolution

- $\sigma_{r\phi} \simeq \sigma_{rz} \simeq a \oplus \frac{b}{p \cdot \sin^{3/2}\theta}$
- Hit resolution: $a \simeq 5\mu m \Rightarrow \ \sigma_{spatial} < 3\mu m$
- Multiple scattering: $b \simeq 10 - 15\mu m \Rightarrow$ material budget per layer $\simeq 0.15\ \%\ X_0$

Outlines

Double-sided VXD: PLUME

PLUME = **P**ixelated **L**adder with **U**ltra-low **M**aterial **E**mbedding

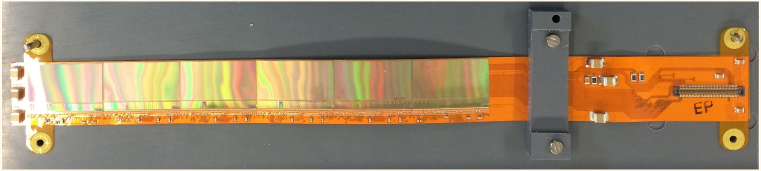
Motivation

ILD Vertex detector at ILC

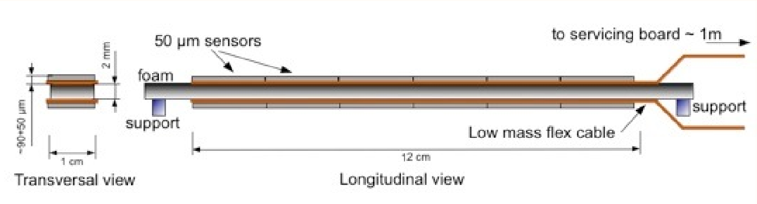
Design

- Double-sided ladder with an active area of 1x12cm^2
- On each side: six MIMOSA-26 CMOS sensors thinned to 50 μm on a kapton-metal flex cable
- 2 mm of silicon carbide foam as mechanical support and spacer between two modules

What does it look like?

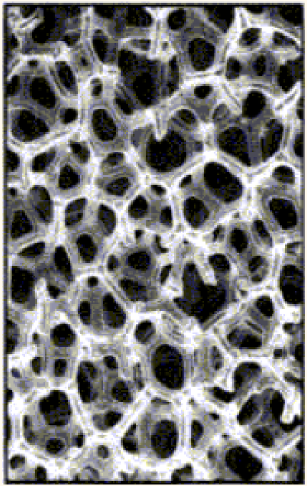


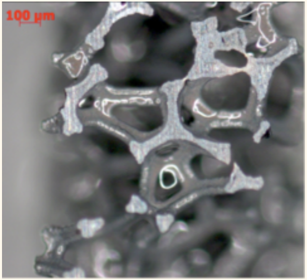
Picture of one module with copper traces.



Scheme of one PLUME ladder.

Foam support structure

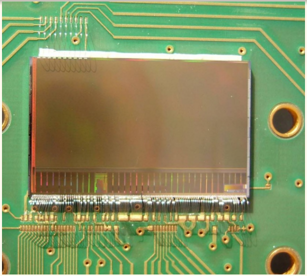


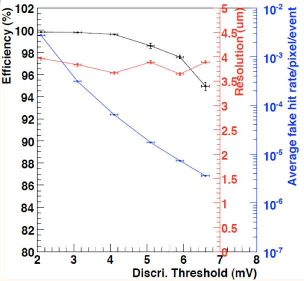


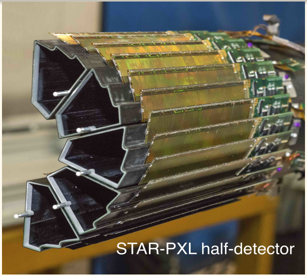
Properties

- Open-cell foam
- Macroscopically uniform
- No tensioning needed
- Density: 4 to 8 % (2-3 % possible)
- Low thermal and electrical conductivity (50 W/m/K)

MIMOSA-26 sensor







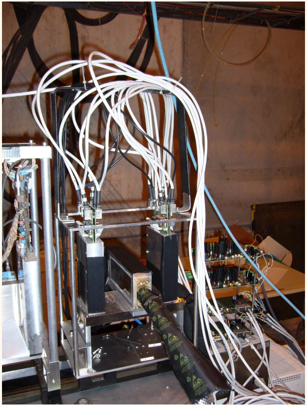
- Monolithic Active Pixels Sensor
- Pitch of 18.4 μm (square pixels)
- Active area: 10.6 x 21.2 mm^2 (576 rows x 1152 columns)
- Column-parallel readout: integration time of 115.2 μs (200 ns per line) for 80 MHz clock
- Zero suppression (to optimize data bandwith) with binary output
- Well known sensors $\Rightarrow$ used for EUDET telescope
- Extended to MIMOSA-28 exploited in STAR-PXL vertex detector @ RHIC-BNL since 2014

Main aims

- Constraint material budget $\Rightarrow \quad < 0.3\ \%\ X_0$
- Use a power pulsing (200 ms period) in a strong magnetic field with air cooling to decrease the power consumption of the ladder
- Study of the advantage to have two measurement points in the tracking of a particle (mini vectors)
- Study of the alignment and **the spatial resolution**

Outlines

Test beam @ SPS with 120 GeV π^- in November 2011



- Beam test on line H6a @ SPS
- Reference plane: 4 Mimosa 26
- Validation of the first PLUME double sided ladder equiped with 12 Mi26 sensors

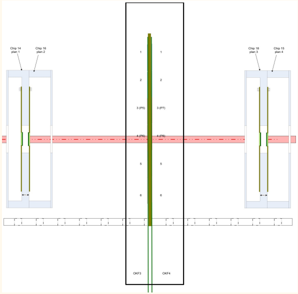
Scan on the ladder:

- In threshold (5 and 6 mV)
- In position (sensor 1-2, 3-4 and 5-6)
- Without and with angle (between 30 and 40 degres)
- With two differents air flow speed ($\simeq 3$ to 6 ms^{-1})

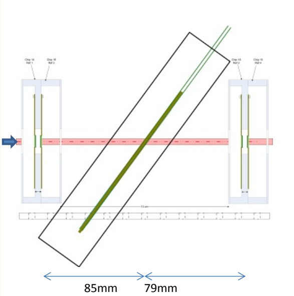
Jérôme Baudot, Gilles Claus, Loic Cousin, Mathieu Goffe, Rohrry Gold, Joel Goldstein, Ingrid Gregor, Robert Maria.

Test beam @ SPS with 120 GeV π^- in October 2011

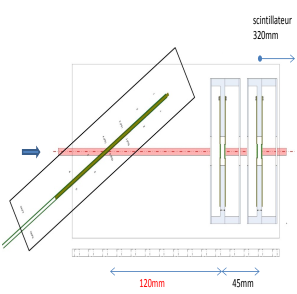
Three configurations studied:



Module perpendicular to the beam.



Module tilted (between 28°and 40°).

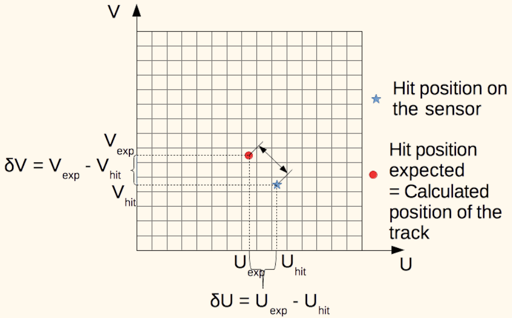


Module tilted ($\simeq$ 60°).

$\Rightarrow$ Study track-hit residual and the distribution of this residual as a function of the relative position of the beam on the sensor.

The analysis was performed with a software developed by IPHC-Picsel: TAF (TAPI Analysis Framework).

Track-hit residual

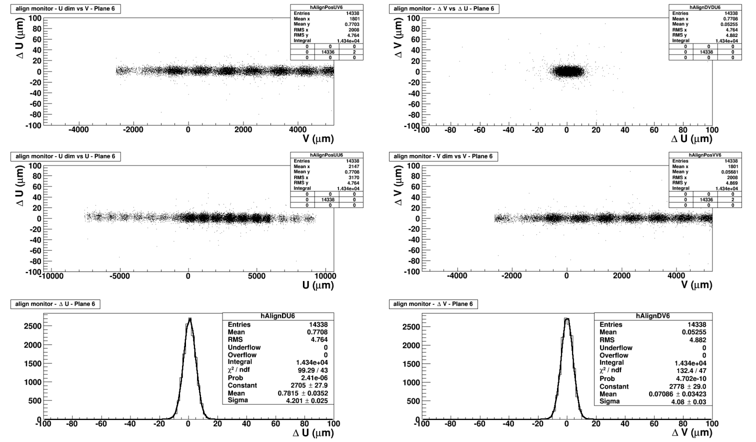


Alignment of the device under test (DUT)

- The track of a particle is defined by the telescope
- To align the DUT in the reference coordinates system:
  - Modify the coordinates of our DUT in the software (tilt and/or position)
  - Define a maximal range in which a hit can be associated to a track

Module perpendicular to the beam

Threshold of 6 σ, fan speed < 5m/s and 1.8M events.

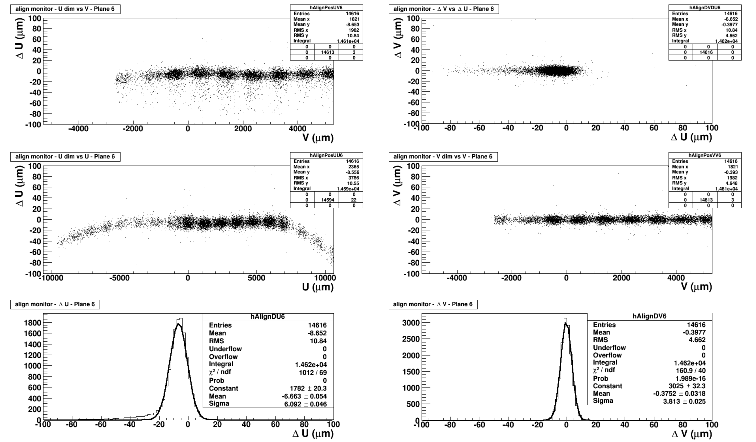


Spatial residual obtained after alignment:

$\sigma_U \simeq 4.2\ \mu m$ and $\sigma_V \simeq 4\ \mu m$

Module titled in one direction (w.r.t. to the beam axis)

Threshold of 6 σ, fan speed < 5m/s, 720k events and a tilt of 36 °.



Spatial residual obtained after alignment:

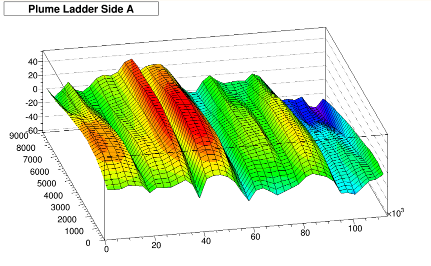
$\sigma_U \simeq 6.1$ μm and $\sigma_V \simeq 3.8$ μm

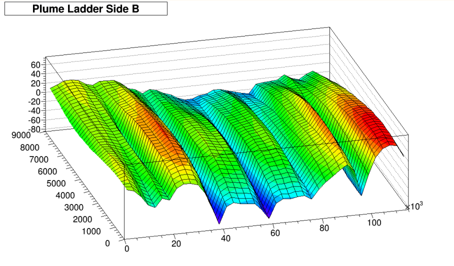
Origin of the deviations

Consequence of the ladder's characteristics

- Use of ultra-thin (50 μm) and precise sensors (spatial resolution less than 4 μm)
- Mechanical constraints induce permanent deformations ($\simeq$ 10 μm) which can not be flattened during the ladder assembly

Metrology of the module's surface (perfomed at Bristol)

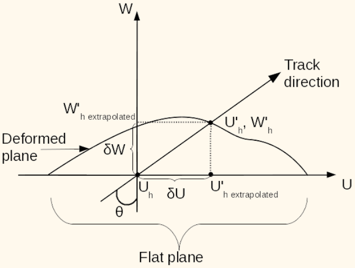




Origin of the devations

Artefacts from the modelling of our sensors during the analysis

- Modelling the sensors as completely flat planes
- The track extrapolation is sensitive to the exact position of the hit on the plane and the angle of incidence



Deviations of the residual

$$\delta W = \frac{\delta U}{\tan\theta}$$

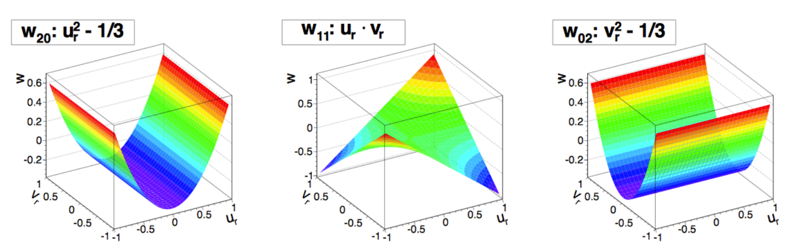
How to describe deviations from the flat plane?

arXiv:1403.2286 [physics.ins-det] CMS paper

- Sensor shape parametrised as a sum of products of modified Legendre polynomials:

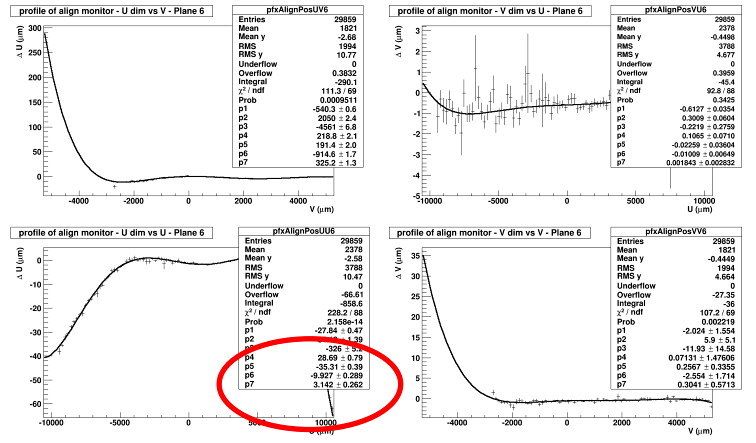
$$
\begin{aligned}
w(u_r, v_r) &= w \\
&+ w_{10} \cdot u_r + w_{01} \cdot v_r \\
&+ w_{20} \cdot (u_r^2 - 1/3) + w_{11} \cdot (u_r \cdot v_r) + w_{02} \cdot (v_r^2 - 1/3)
\end{aligned}
$$

- In our case, we used Legendre polynomials of the 7^{th} order only in the direction of the deformation.

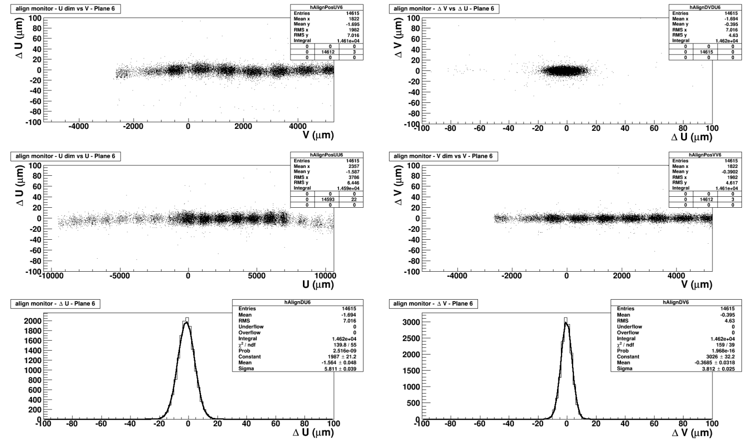


Parametrization of the deformation

Possibility to parametrise the deformation with Legendre polynomials of the 7^{th} order .



Correction of the deviations between real hits and extrapolated ones

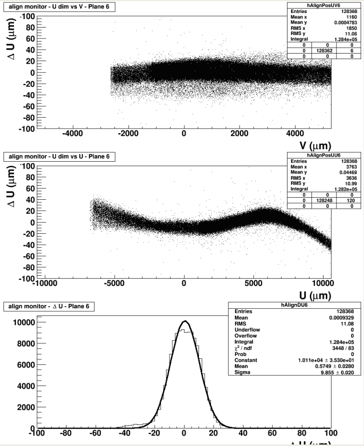


Spatial residual obtained after correction:
$\sigma_U \simeq 5.8\ \mu m$ instead of $\sigma_U \simeq 6.1\ \mu m$

Module tilted with an angle of 28°

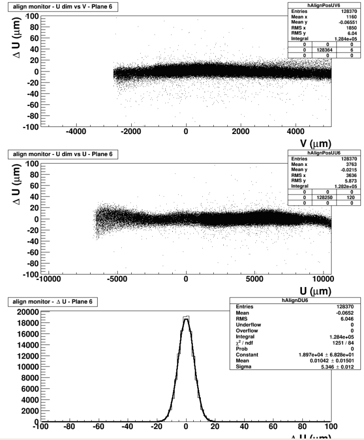
Threshold of 5 σ, fan speed of 6 m/s, 720k events.

Before correction



$\sigma = 9.855\mu m$

After correction



$\sigma = 5.346\mu m$

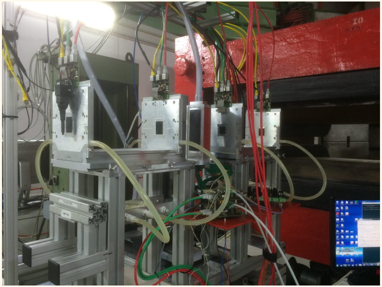
Summary of correction for different angles and same planes

Spatial residuals

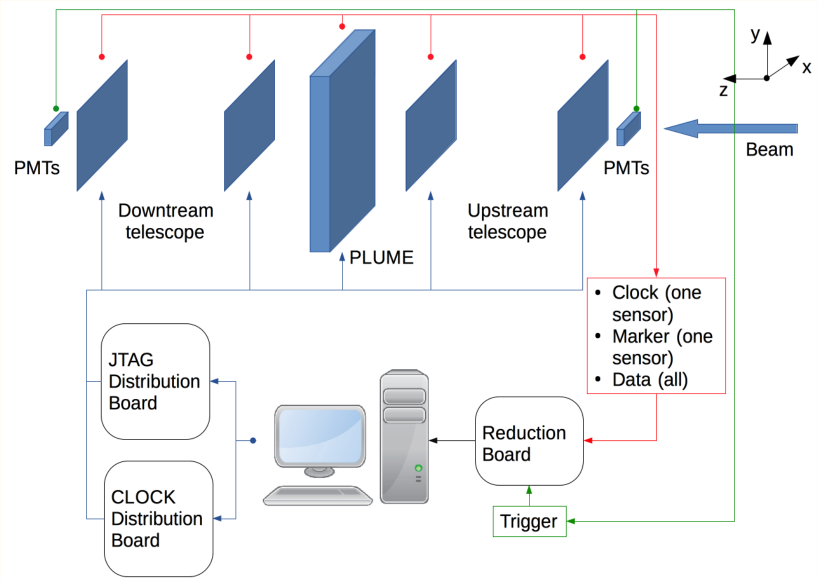
Side	Tilted angle (°)	σ_U^{Def} (μm)	σ_U^{Cor} (μm)	Improvement
Front	28	9.0 ± 0.1	4.9 ± 0.1	46.6 %
Back	28	5.7 ± 0.1	4.7 ± 0.1	17.5 %
Front	36	14.1 ± 0.1	6.1 ± 0.1	56.0 %
Back	36	6.8 ± 0.1	5.9 ± 0.1	13.2 %
Front	60	41.2 ± 0.15	25.8 ± 0.2	37.4 %
Back	60	23.3 ± 0.13	21.7 ± 0.1	6.8 %

$\sigma_{tel} = 2.2\mu m$ for 36°and $\sigma_{tel} = 18.8\mu m$ for 60°.

Test beam @ DESY with 5 GeV e^- (April 2016)



- Test Beam 21
- Reference plane: 4 EUDET telescope planes
- Goal: radiation length measureemnt


y
x
z
Beam
PMTs
PMTs
Downtream telescope
PLUME
Upstream telescope
Clock (one sensor)
Marker (one sensor)
Data (all)
JTAG Distribution Board
CLOCK Distribution Board
Reduction Board
Trigger

Estimation of the radiation length

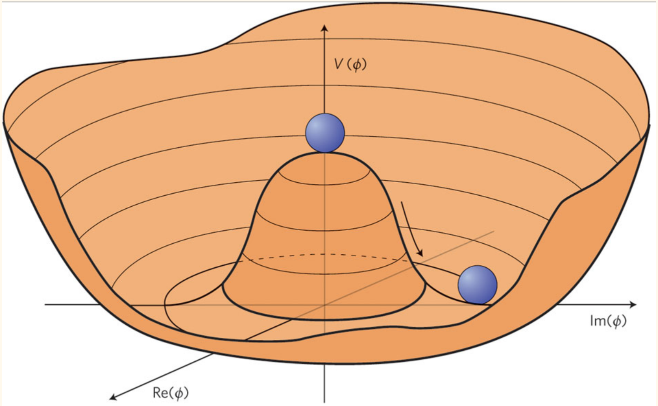
Beam passes through

- $2\times$ Mi-26 (thinned down to $\sim$ 50 μm): 0.053 % X_0
- $4\times$ glue layers: $\sim$ 0.01 % X_0
- $1\times$ SiC foam: $\sim$ 0.184 % X_0
- $2\times$ flex-cable: $\sim$ 0.084 — 0.092 % X_0

$\Rightarrow \frac{x}{X_0} \simeq 0.498 - 0.515$ % X_0

Thanks for your attention !!!

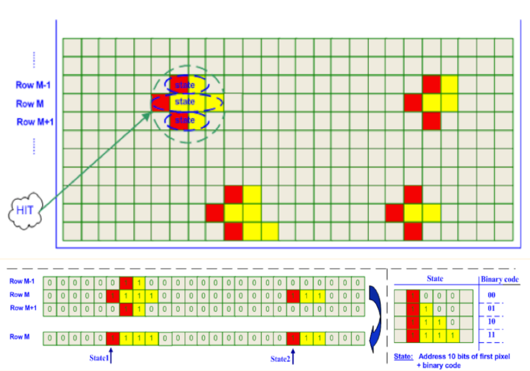
Higgs boson potential



Higgs boson physics at the ILC

- Same measurements as LHC: couplings, mass and spin
- Model independent measurement: no dependence on theory
- Total Higgs width
- $\mathrm{H} \to c\bar{c}/gg$
- Higgs self couplings

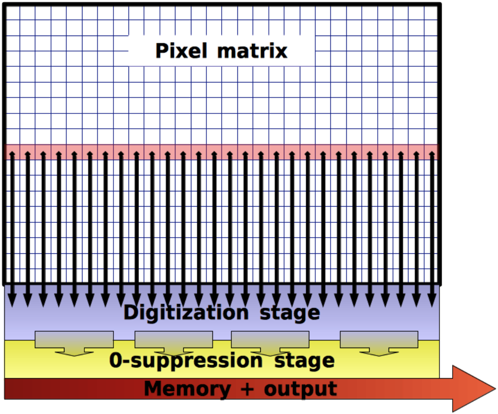
Zero Suppression logic (SUZE)



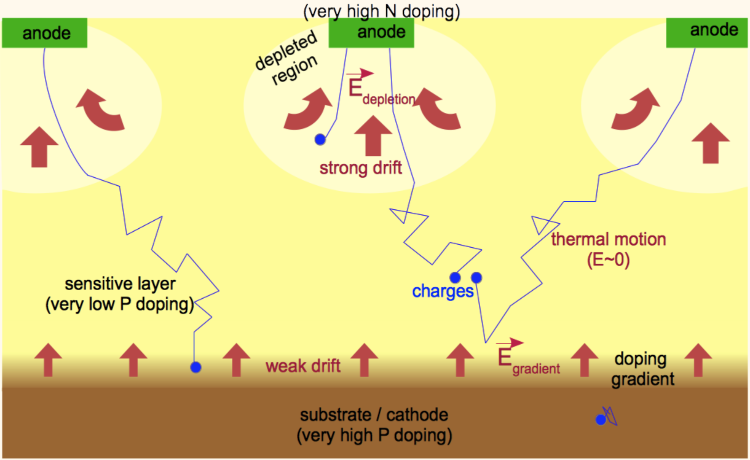
SUZE logic split in 3 blocks:

- **Sparse Data Scan (SDS)** Hit detection per line and data encoding, until 6 states consecutive pixels (1 to 4 pixels) per block of 64 columns;
- **Multiplexing Logic (Mux)** giving up to 9 states;
- **Memory storage** 2 blocks to store the states of the full frame, switching to avoid dead time (during one acquire states of event N, the other one transfer the information of frame N-1).

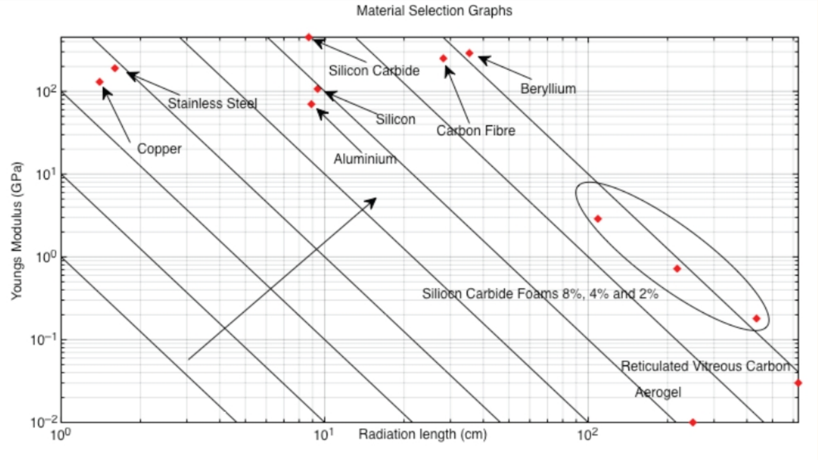
Column parallel readout



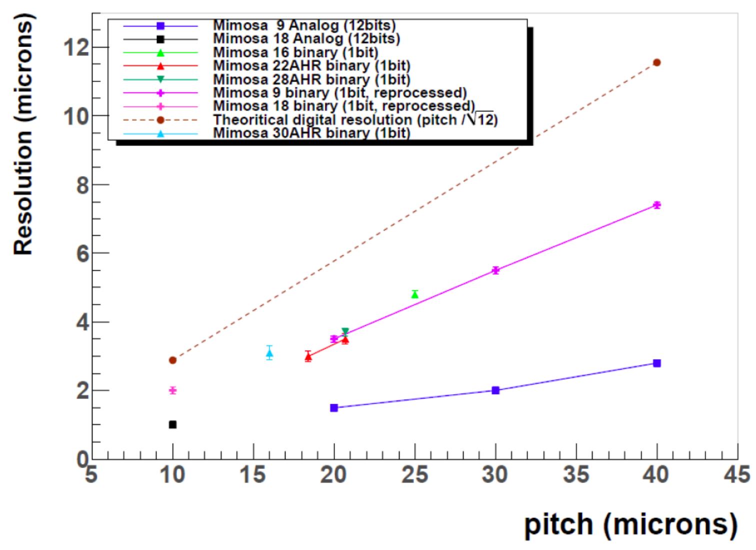
MAPS principle



Young Modulus



Spatial resolution for different pitch (IPHC-Strasbourg)



Higgs Strahlung kinematics

$$E_H = \frac{s - M_Z^2 + M_H^2}{2\sqrt{s}}$$

$$E_Z = \frac{s - M_H^2 + M_Z^2}{2\sqrt{s}}$$

$$|\overrightarrow{p_H}| = |\overrightarrow{p_Z}| = \frac{\sqrt{[s - (M_H + M_Z)^2] \cdot [s - (M_H - M_Z)^2]}}{2\sqrt{s}}$$

If $M_H = 125$ GeV, $M_Z = 91.2$ GeV and $\sqrt{s} = 350$ GeV, then:

$$E_H \simeq 185.4 \text{ GeV}$$

$$E_Z \simeq 164.6 \text{ GeV}$$

$$|\overrightarrow{p_H}| = |\overrightarrow{p_Z}| \simeq 68.5 \text{ GeV}$$

Detector performances

Vertexing

$$\sigma_{IP} = 5 \oplus \frac{10}{p \sin^{3/2}\theta} (\mu m)$$

Tracking

$$\sigma(1/p) = 2x10^{-5} (GeV^{-1})$$

Jet ernergy

$$\sigma_E/E = 0.3/\sqrt{E(GeV)}$$

Particle Flow Algorithm

- Typical jet:
  - Charged hadrons $\simeq$ 60 %
  - Photons $\simeq$ 30 %
  - Neutral $\simeq$ 10 %
- Standard approch
  - All jet components energy measured in ECAL/HCAL
  - $E_{jet} = E_{ECAL} + E_{HCAL}$
- Particle flow calorimetry
  - Measurement of charged particles in tracker
  - Measurement of photon in ECAL
  - Measurement of hadrons in HCAL
  - $E_{jet} = E_{Track} + E_{\gamma} + E_{n}$

Why a linear collider?

Limitations of e^+e^- colliders

- Synchroton radiation loss $\sim \mathrm{E}^4/\mathrm{r}$
- Synchroton cost: $\sim$ quadratically with energy
- Power consumption

Avantages of linear colliders

- Not limited by synchrotron radiation
- Cost: $\sim$ linear with energy
- Polarisation of both beams
- Detectors close to the IP $\Rightarrow$ optimum for c-tagging

ILC interaction region

- 1 interaction region for 2 detectors
- Push-pull:
  - Detectors mounted on movable platforms
  - Sharing of beam time
  - Switching time: 24h to 48h
  - Allow cross-checking

ILC environment

- Bunch spacing of $\sim$ 554 ns
- 1312 bunches in a 1 ms long pulse (train)
- Quiet time: 199 ms
- Occupancy dominated by beam background and noise
- Reading during quiet time possible