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 Quarks

Fermions

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Matter:

	Leptons			Quarks
Fermions	e^-	μ	τ	
	ν_e	ν_μ	ν_τ	

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	ν_e	ν_μ	ν_τ	d	s	b

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Forces:

Bosons

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Fermions	e^-	μ	τ	u	c	t
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Forces:

$\gamma \quad \rightarrow \quad$ E.M. interaction

Bosons

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Matter:

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

Forces:

Bosons

$$\gamma \rightarrow \text{E.M. interaction}$$

$$Z^0/W^\pm \rightarrow \text{Weak interaction}$$

What is the Universe made of?

Matter:

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

Forces:

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

What is the Universe made of?

Matter:

	Leptons			Quarks		
Fermions	e^-	μ	τ	u	c	t
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Forces:

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	graviton	$\rightarrow$	Gravitation

What is the Universe made of?

Matter:

	Leptons			Quarks		
Fermions	e^-	μ	τ	u	c	t
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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

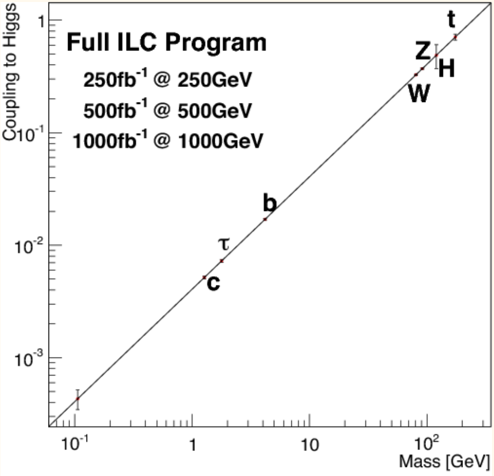
- SUSY
- GUT
- Technicolor
- ...

The Higgs boson discovery

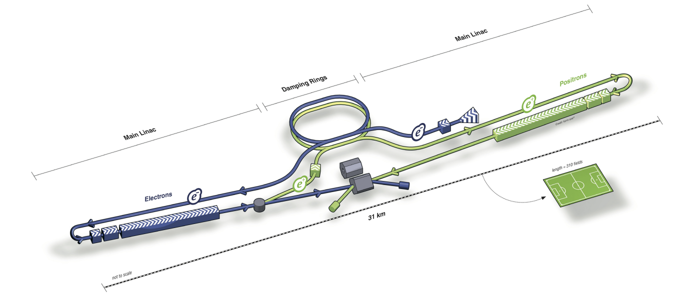
elele

- Discovery at the LHC (ATLAS and CMS)

Higgs Boson

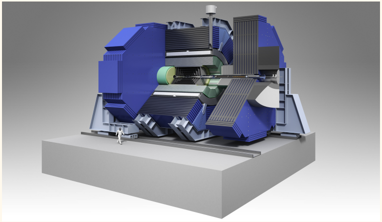

Full ILC Program
250fb-1 @ 250GeV
500fb-1 @ 500GeV
1000fb-1 @ 1000GeV
Coupling to Higgs
Mass [GeV]
1
10-1
10-2
10-3
10-1
1
10
102
t
Z
H
W
b
τ
c

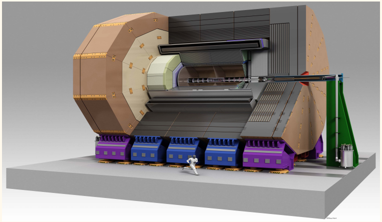
International Linear Collider



- 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

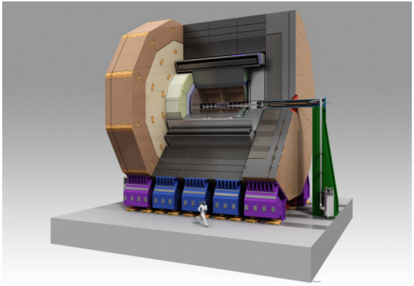
International Linear Detector

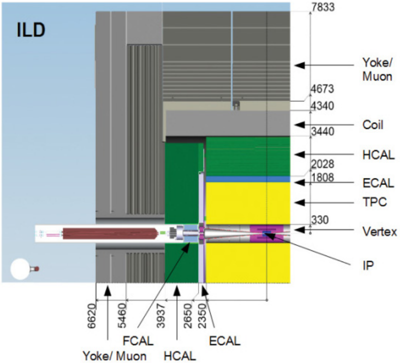
- TPC + silicon envelope (radius = 1.8 m)
- $B_{\mathtt{field}}$ = 3.5 T

Both detectors designed for Particle Flow Calorimetry

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

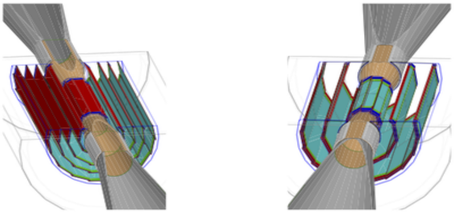
Overview of the ILD





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

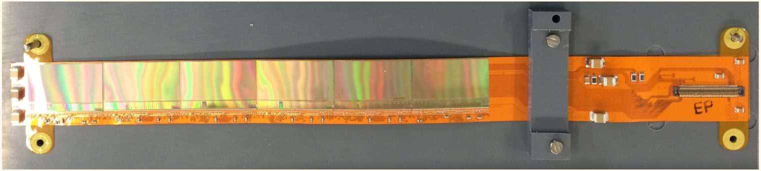
Motivation

ILD Vertex detector at ILC

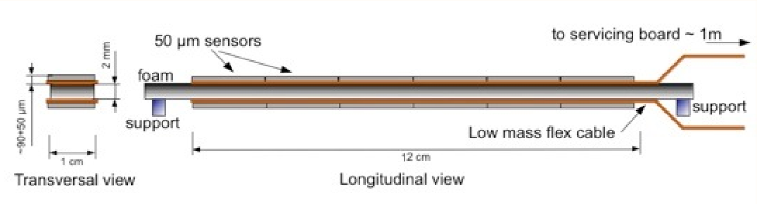
Design

- Double-sided ladder with an active area of 1x12cm^2
- On each side: six MIMOSA-26 CMOS sensors thinned down to $\sim$ 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?

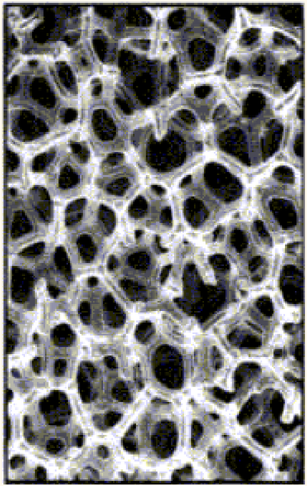


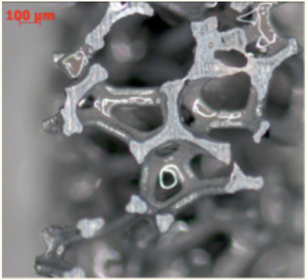
Picture of one module with copper traces.



Scheme of one PLUME ladder.

Foam support structure

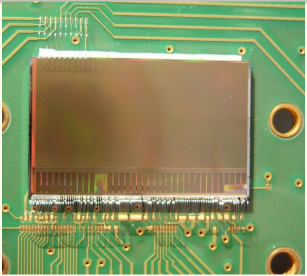


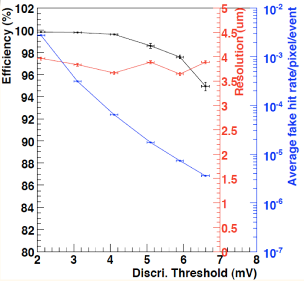


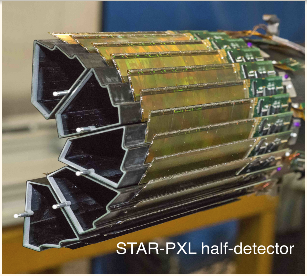
Properties

- 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 (MAPS)

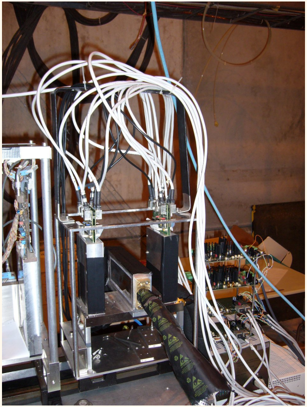
- Pitch: 18.4 μm (square pixels)
- Active area: $10.6 \times 21.2\text{mm}^2$ (576 rows x 1152 columns)
- Integration time: 115.2 $\mu(s)$ (200 ns per line)
- Binary output with Zero suppression
- Well known sensors $\Rightarrow$ used for EUDET telescope
- Extended to MIMOSA-28 exploited in STAR-PXL vertex detector @ RHIC-BNL since 2014

Main aims

- Constraint material budget $\Rightarrow < 0.3\ \%\ X_0$
- Study how to implement power pulsing and its impact on a strong magnetic field
- Study the advantage of having two measurement points (mini vectors)
- Study impact of the mechanical structure on sensor performance

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 double-sided ladder equipped with 12 Mi26 sensors

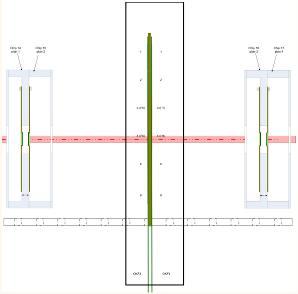
Ladder performance studies:

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

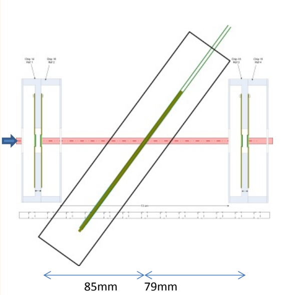
Jérôme Baudot, Gilles Claus, Loic Cousin, Mathieu Goffe, Rohrry Gold, Joel Goldstein, Ingrid Gregor, Robert Maria.

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

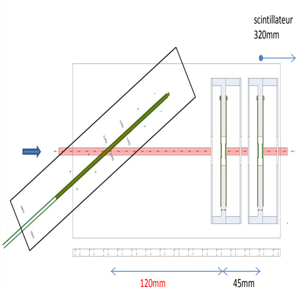
Three configurations studied:



Module perpendicular to the beam.



Module tilted (between 28°and 40°).

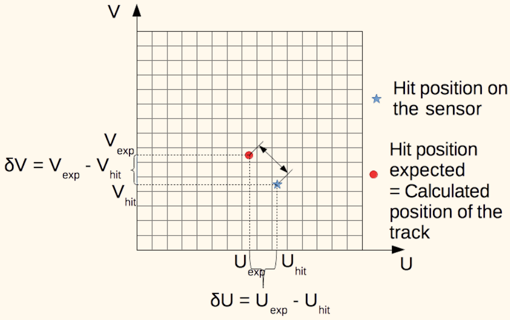


Module tilted ($\simeq$ 60°).

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

Analysis performed with TAF (TAPI Analysis Framework).

Track-hit residual

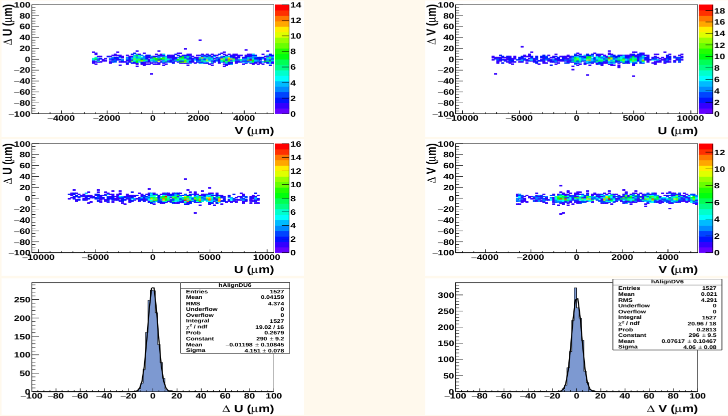


Device Under Test (DUT) alignment:

- Telescope planes defined particle's track
- Alignment of DUT in local coordinate system:
  - Define a maximal range in which a hit can be associated to a track
  - Find the best tilt and position to minimise the distance between a hit and its associated track.

Module perpendicular to the beam

Threshold 6 σ, air flow speed < 5m/s and 1.8M events.

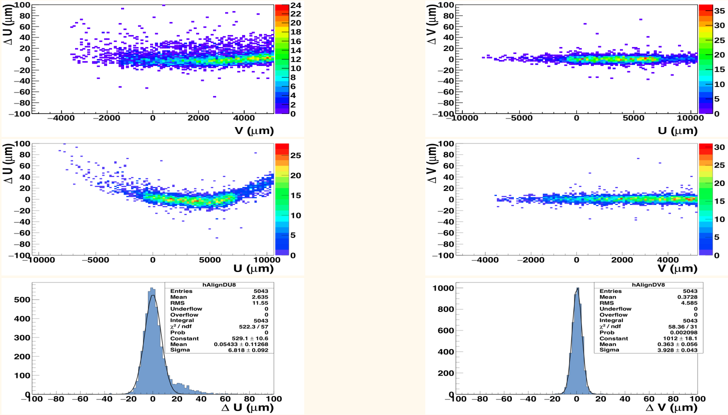


Spatial residual obtained after alignment:

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

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

Threshold 6 σ, air flow speed < 5m/s, 720k events and 36°tilt.



Spatial residual obtained after alignment:

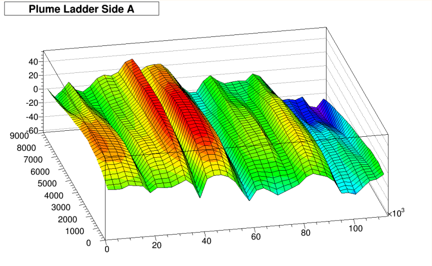
$\sigma_U \simeq 6.1$ μm and $\sigma_V \simeq 3.8$ μm

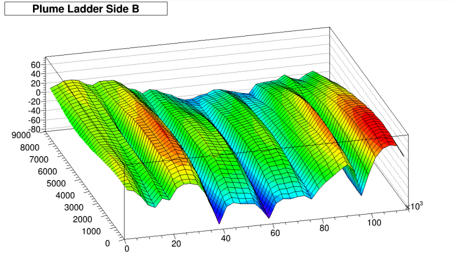
Origin of deviations

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 (≃ 10 μm) which can not be flattened during the ladder assembly

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

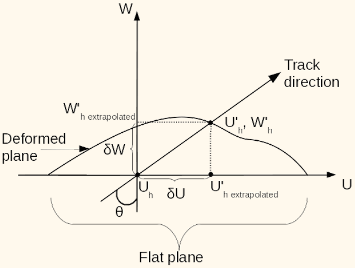




Origin of the deviations

Artefacts from the modelling of our sensors during the analysis

- Sensors modeled 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

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

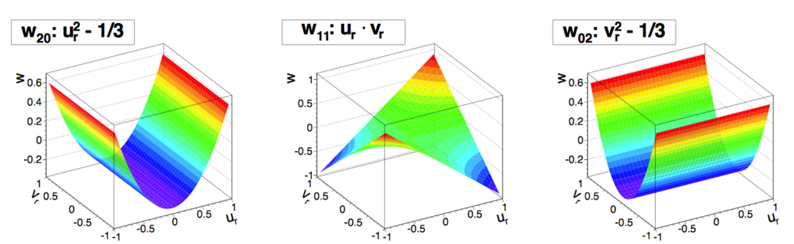
How to describe deviations from the flat plane?

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

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

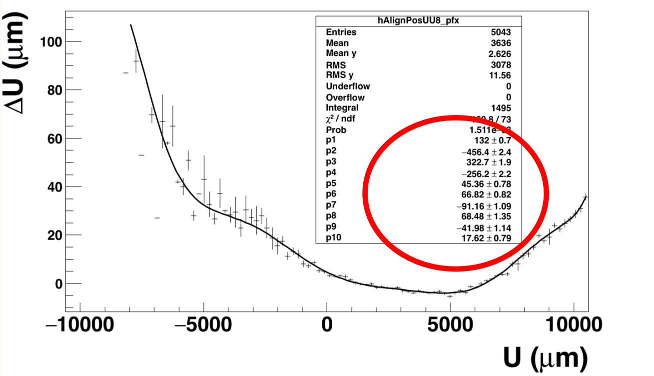
$$\begin{aligned} w(u_r, v_r) &= w \\ &+ w_{10} \cdot u_r + w_{01} \cdot v_r \\ &+ w_{20} \cdot (u_r^2 - 1/3) + w_{11} \cdot (u_r \cdot v_r) + w_{02} \cdot (v_r^2 - 1/3) \end{aligned}$$

- In our case, we used Legendre polynomials of the 11^{th} order only in the direction of the deformation.

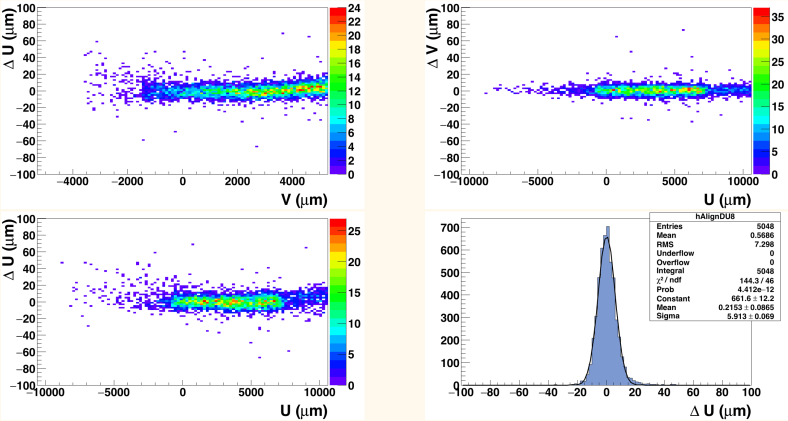


Deformation's parametrisation

Possibility to parametrise the deformation with Legendre polynomials of the 11^{th} order .



Correction of the deviations between real hits and extrapolated ones

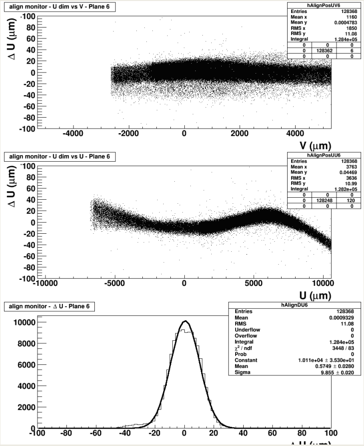


Spatial residual obtained after correction:
$\sigma_U \simeq 5.9\ \mu m$ instead of $\sigma_U \simeq 6.1\ \mu m$

Module tilted with an angle of 28°

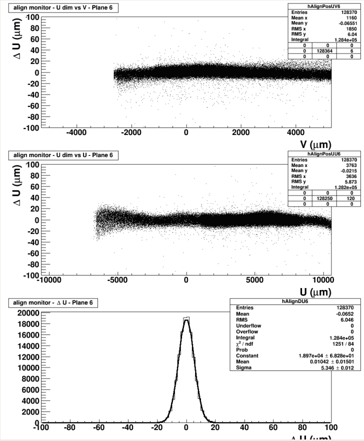
Threshold: 5 σ, air flow speed: 6 m/s, 720k events.

Before correction



$\sigma = 9.855\mu m$

After correction



$\sigma = 5.346\mu m$

Summary of correction for different angles and same planes

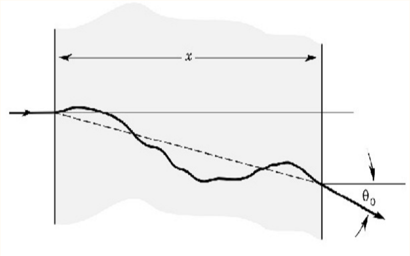
Spatial residuals

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

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

Outlines

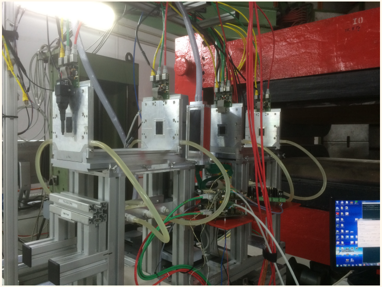
Multiple scattering



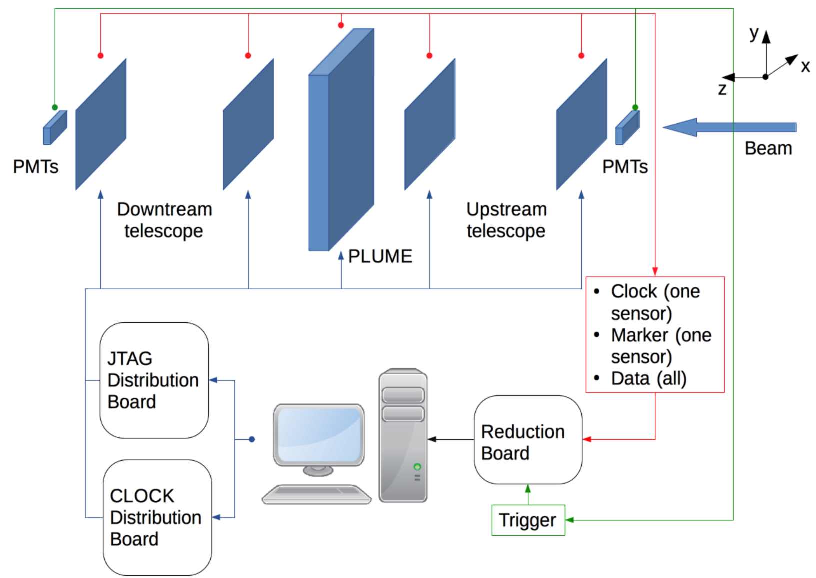
Multiple scattering and radiation length

$$\theta_0 = \frac{13.6(MeV)}{p}\left(\frac{x}{X_0}\right)^{0.555}$$

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

Estimation of the radiation length

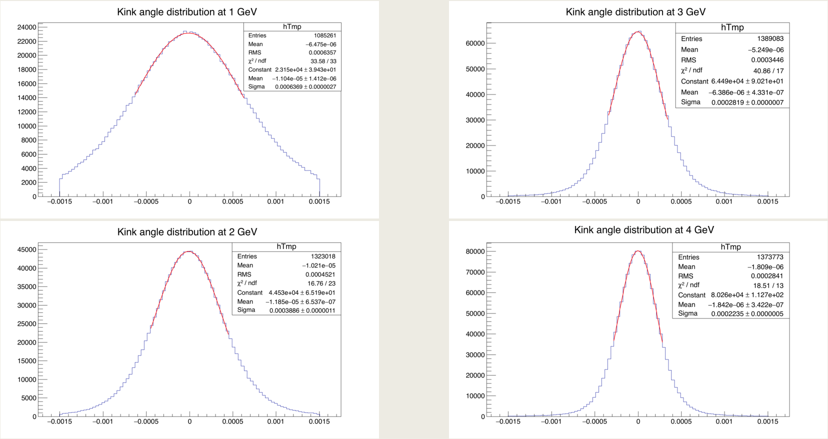
Beam passes through

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

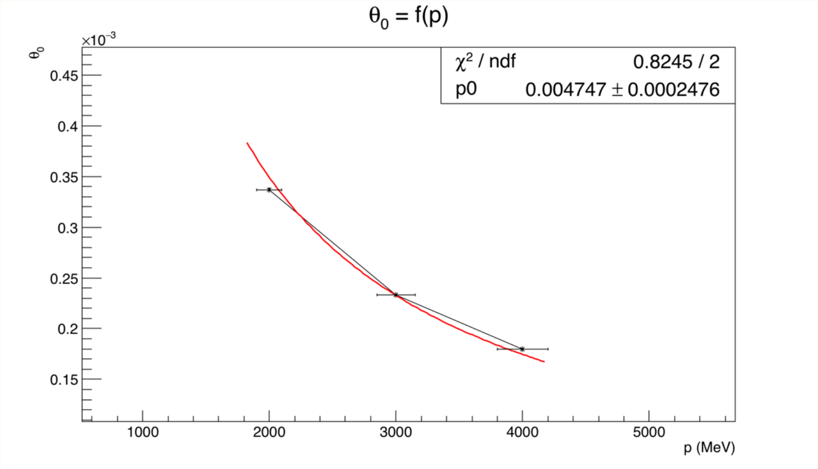
$$\Rightarrow \frac{x}{X_0} \simeq 0.498 \ - \ 0.515\ \%\ X_0$$

Kink angle measurement between 1 and 4 GeV

Fitted kink angle distributions



Material budget



$$\frac{x}{X_0}\Big|_{\text{estimated}} \simeq 0.498 - 0.515\ \%\ X_0$$

$$\frac{x}{X_0}\Big|_{\text{measured}} \simeq 0.47 \pm 0.02\ \%\ X_0$$

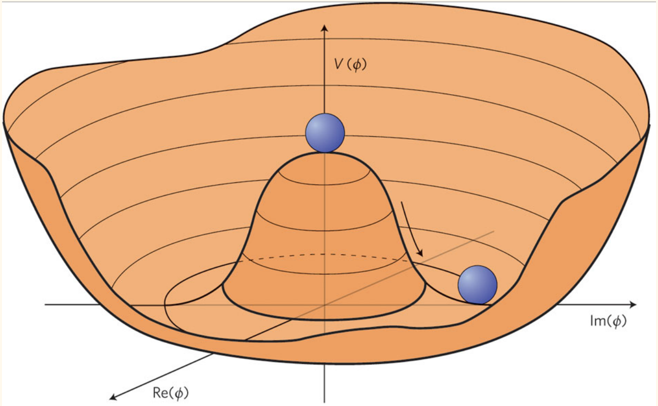
Conclusion

- rgmgr

Outlook

Thanks for your attention !!!

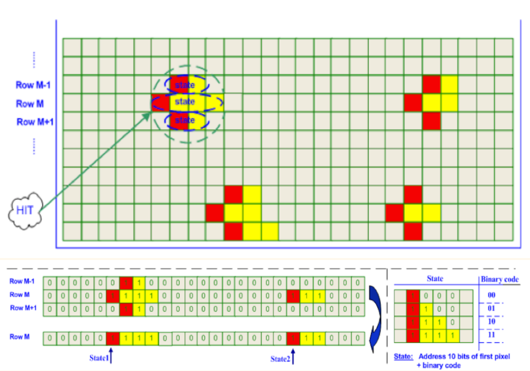
Higgs boson potential



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

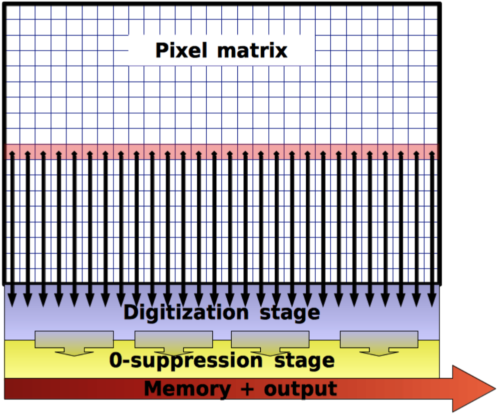
Zero Suppression logic (SUZE)



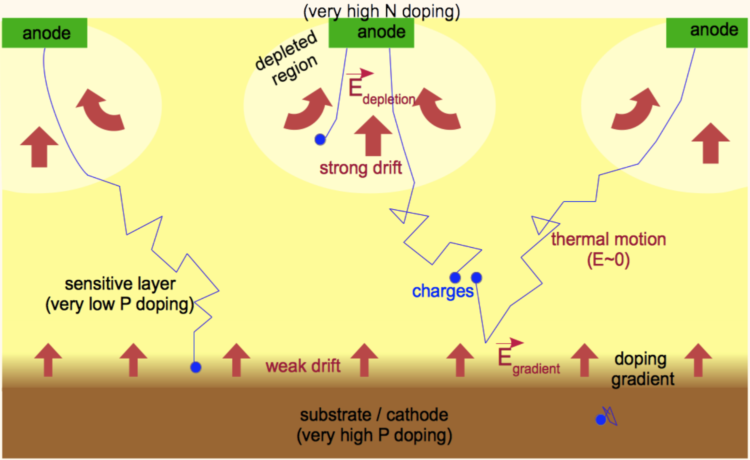
SUZE logic split in 3 blocks:

- **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).

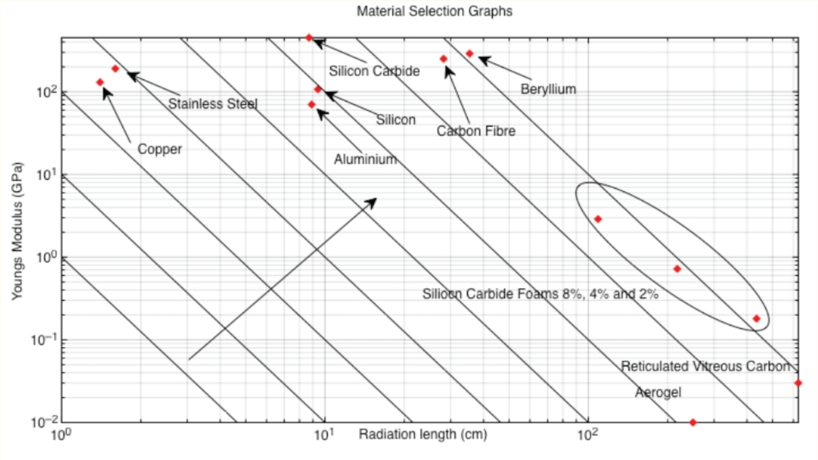
Column parallel readout



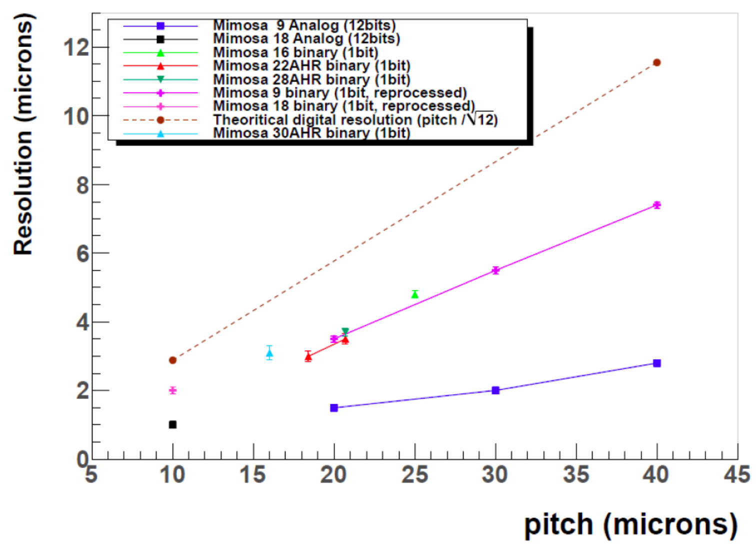
MAPS principle



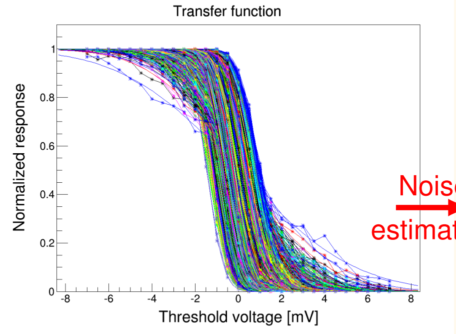
Young Modulus



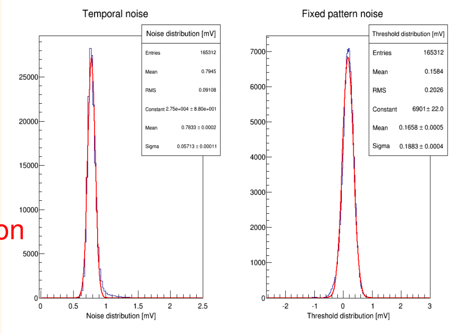
Spatial resolution for different pitch (IPHC-Strasbourg)



Characterization of one sensor



Noise estimation



Threshold scan

Normalised response of pixels in a sub-matrix (288 discriminators) as a function of threshold applied (mV).

Noise performances

- Temporal noise (derivative of the S-curve): 0.79 mV
- Fixed pattern noise (thresholds' dispersion for a mid-point): 0.2 mV
- Offset: 0.16 mV

$\Rightarrow$ **Can now define different thresholds**

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 $\sim \mathrm{E}^4/r$
- 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

Beam polarisation

Simulated data: 100 % left or right events

$$\sigma_{P_{(e+,e-)}} = \left(\frac{1-P_{e-}}{2}\right)\left(\frac{1+P_{e+}}{2}\right)\sigma_{RL} + \left(\frac{1+P_{e+}}{2}\right)\left(\frac{1-P_{e-}}{2}\right)\sigma_{LR}$$

$$\sigma_{P_{(e+,e-=\mathbf{0.3},-\mathbf{0.8})}} = 0.585 \cdot \sigma RL + 0.035 \cdot \sigma_{LR}$$