LINEAR COLLIDER COLLABORATION

Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

PICSEL GROUP

PHYSICS WITH INTEGRATED CMOS SENSORS AND ELECTRON MACHINES

Vertex detector for ILD: R&D at IPHC

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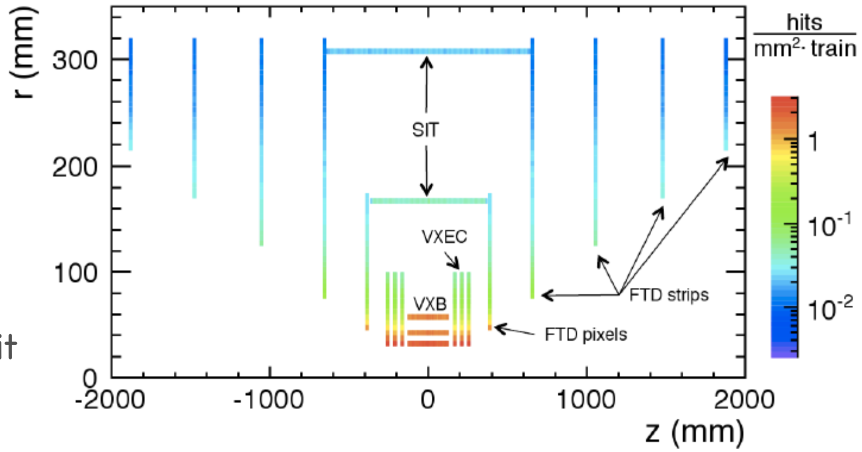
iphc.cnrs.fr/PICSEL

Journée Collisionneur Linéaire,
Lyon 13-14 juin 2013

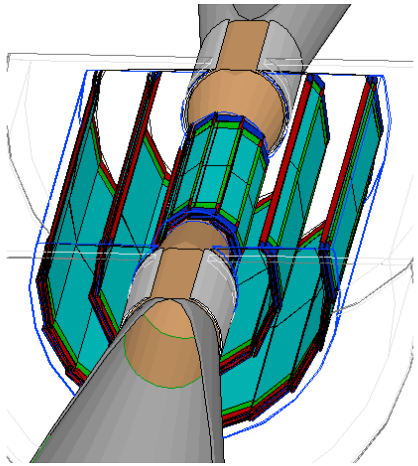
- Context of the Vertex Detector
- R&D on sensing tech.: CMOS Pixel Sensors (CPS)
- R&D on system integration
- R&D on tracking
- Summary & Conclusion

Context of the Vertex detector

- ## Known specifications
  - Impact parameter resolution $\sigma_{R\phi,Z} \leq \left(5 \oplus \frac{10}{p \sin^{3/2}(\theta)}\right)$ µm
    - Translate for each 3D measurement into:
      $\sigma_{s.p} \simeq 3$ µm and material budget 0.15 % X_0
      first measurement at radius ≃ 16 mm
  - Beam background handling ≃ 5 hits/cm²/BunchX
    - Translate into:
      either "fast" integration to limit #hits/frame
      either "extreme" granularity to individualize hits
  - ➡ Various potential technology optimisations
    - Analysis performances = sole and final figure of merit
    - Tracking performances provide indications



- ## Open questions
  - Uncertainty on beam background
    - Support fast read-out
  - Major tracking difficulty for $p_T \lesssim 1$ GeV/c
    - No satisfactory silicon standalone algorithm
  - Baseline geometry = 3 double-layers
    - Alternative = 5 single-layers
    - no clear indication for a choice, yet

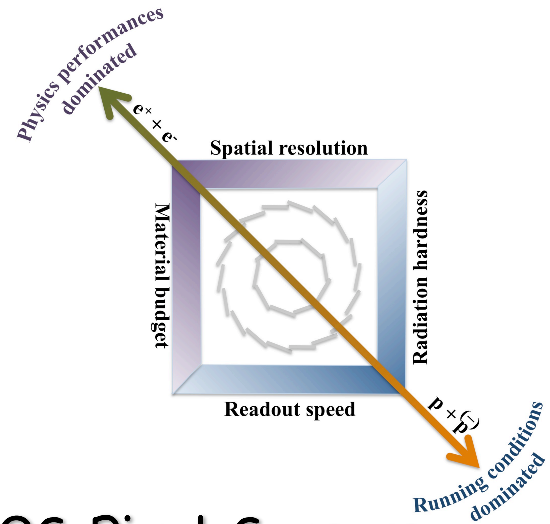


R&D on sensing technology: CMOS Pixel Sensors

- Current achievements with CPS
- Proposed VTX with CPS
- Ongoing developments

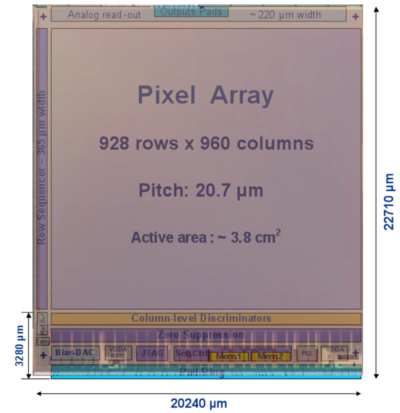
Current achievements

- **Problematic**



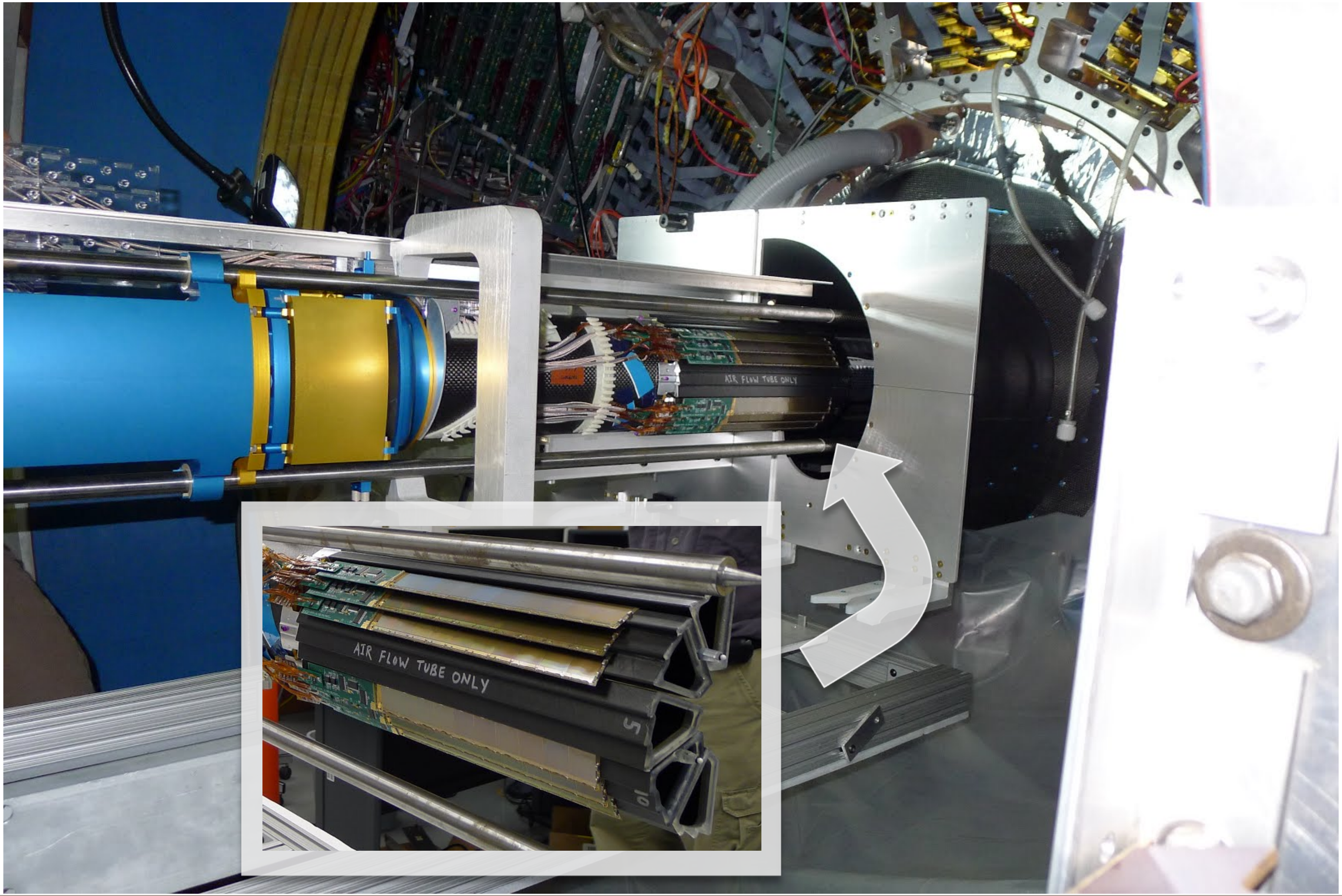
- **CMOS Pixel Sensors**
  - Industrial technology
  - Monolithic = combination of
    - Sensitive volume & sensing node
    - Signal treatment
      - Analogue (amplification)
      - Mixed Analogue-Digital (conversion)
      - Digital (zero-suppression, transmission)
  - Complete detection system
    → to be optimized / applications

- **State of the art solution**
  - Rolling-shutter readout
    & column level discrimination
  - MIMOSA 26/28
    - AMS 0.35 µm process



- **Applications**
  - EUDET beam telescope and many avatars
  - STAR-PXL
    - 3 sectors installed on 8 May 2013
  - Calorimetry
  - Hadrontherapy

STAR-PXL installation in 1 day



Example of proposed VTX with CPS

ILC √s		500 GeV			1 TeV			
Layer	Radius	$\sigma_{s.p}$	t_{int}	Sensor / digitazion	$\sigma_{s.p}$	t_{int}	Sensor / digitization	Power diss. average
1-inner	16 mm	3 µm	50 µs	MIMOSA / binary	Idem			5 W
1-outer	18 mm	6 µm	10 µs	AROM / binary	6 µm	2 µs	AROM-1 / binary	
2-inner	37 mm	4 µm	100 µs	MIMOSA / 4-bits adc	Idem			2.4 W
2-outer	39 mm	4 µm	100 µs	MIMOSA / 4-bits adc	10 µm	7 µs	AROM-2 / binary	
3-inner	58 mm	4 µm	100 µs	MIMOSA / 4-bits adc	Idem			4 W
3-outer	60 mm	4 µm	100 µs	MIMOSA / 4-bits adc	10 µm	7 µs	AROM-2 / binary	

MIMOSA: column-level digitization
AROM: pixel-level digitization

Air cooling compatible

Ongoing evelopments

Applications driving the R&D

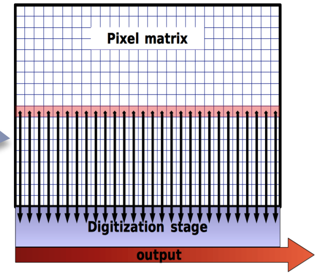
- ALICE Internal Tracking System: 50 μs with 4 μm and 10^7 hits/cm^2/s
  - Require readout acceleration
- AIDA Single Arm Large Area Telescope: Sensor sensitive area ≃ 25 cm^2
  - Require stitching
- CBM Micro-Vertex Detector
  - Require acceleration & radiation tolerance

Upgrading the technology

- Change from to *Tower-Jazz* 0.18 μm CIS 2D process
- First validation in 2011-2012: see Auguste Besson's talk

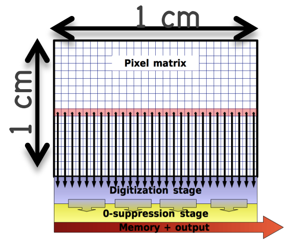
Advanced functionalities

- MIMOSA-32/34: further optimisation of q-collection, noise, ampli.
- MIMOSA-22-THR: pixel matrix + col-level discriminators
  - single and double rows read-out
- SUZE-02: zero-suppression circuitry
- AROM-0: matrix with in-pixel discriminator
- MIMADC: matrix with in-pixel 3-bits ADC



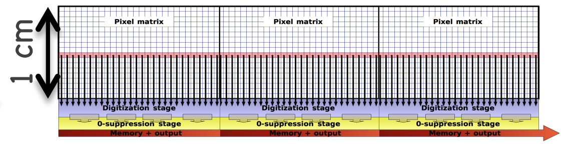
Full Scale Basic Blocs (FSBB)

- = complete functionality over ~1 cm^2
- Q4/2013: col-level discri. approach (→MISTRAL)
- Q4/2015: in-pixel discri. approach (→ASTRAL)



Final sensors

- Q4/2014: MISTRAL 22x33 μm2 pitch
  with 30 μs integration time (15 μs possible)
- Q4/2016: ASTRAL 15 μs integration time (2 μs possible)
- 2015: AIDA large area (4 × 6 cm2) beam telescope sensor



R&D on system integration

- Double-sided ladders
- The PLUME project
- Beam test results

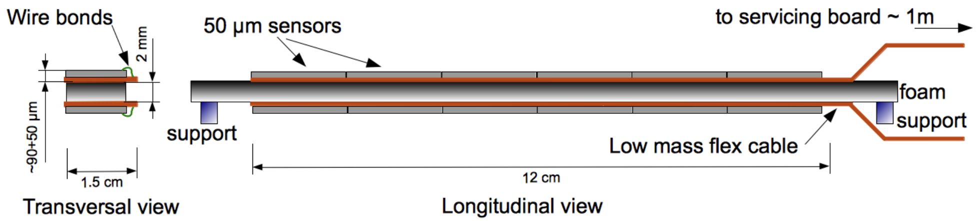
Rationale for double-sided ladders

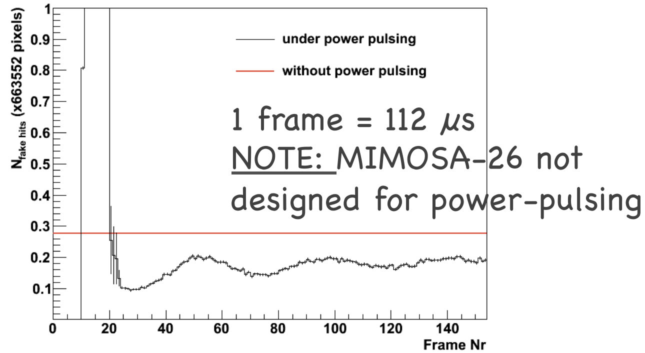
- **Mechanics**
  - One support for 2 sensitive layers ➡ benefit material budget hence resolution
- **Safety**
  - Hit redundancy ➡ benefit efficiency
- **Technology**
  - Mixing 2 different sensor optimizations ➡ alleviate technology limitation

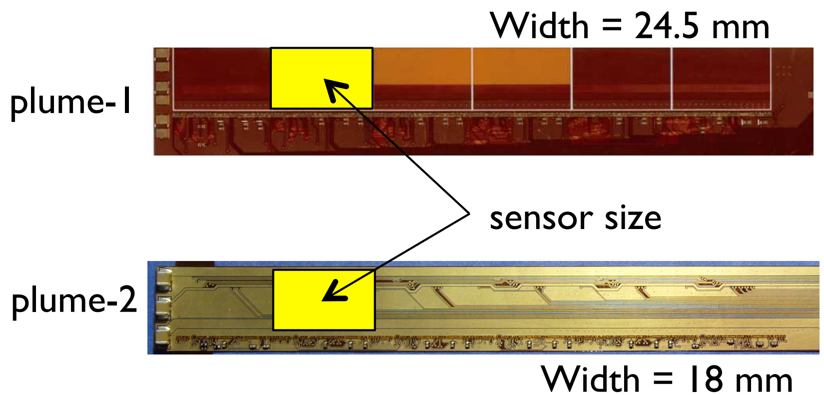
- **Alignment**
  - Additional geometric constraints ➡ benefit #tracks needed for a given precision
- **Tracking**
  - 2-hits make a mini-vector ➡ additional angular information
    ➡ improve hit-track association

The PLUME project

- Collaboration with
  - DESY + University of Bristol
  - Formerly with University of Oxford
- Previous achievements ≲ 2012
  - Ladders with material budget 0.6 % X_0
    - Full VTX inner layer geometry
  - Operated with air cooling on beam test
  - Operation with power pulsing in preparation (single sensor achieved)
- Moving toward final goal
  - Expected material budget 0.35 % X_0
    - Lighter (alu) flex cable & mechanical support
    - Two flex designs for symmetry and final ladder geometry
  - Readiness
    - First cables validated, rest to be produced
    - New assembly setup in production
    - First ladder by end of summer 2013

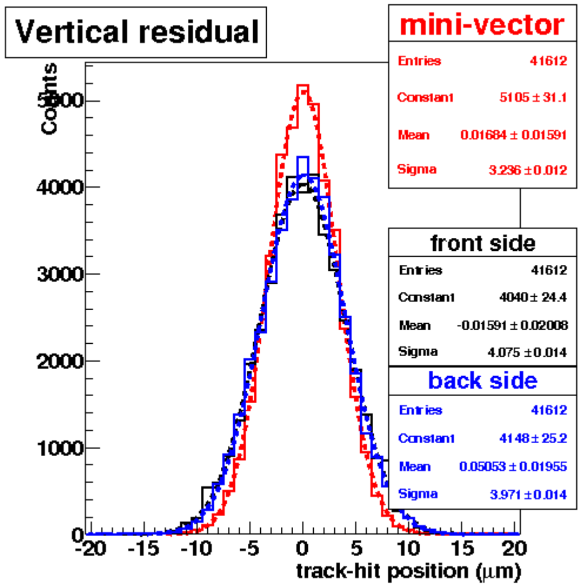


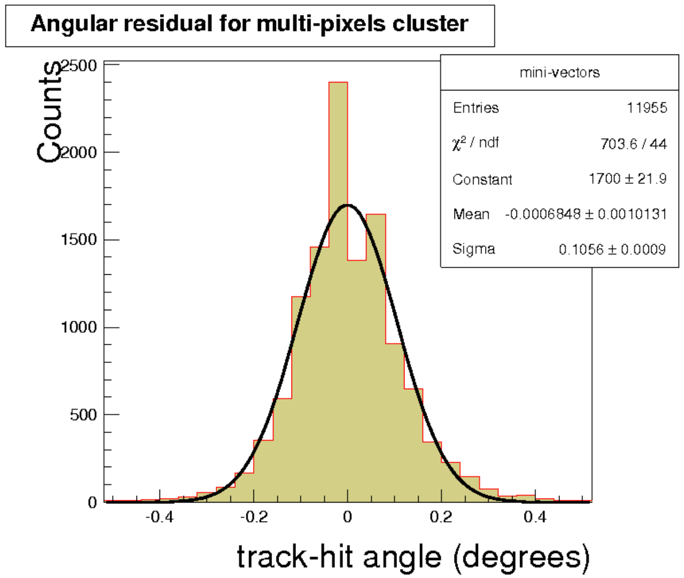




Beam test results on Ladder

- Beam test with 120 GeV π in November 2011
  - ➞ efficiency > 99% for fake hit rate<10^{-4}/pixel
  - ➞ σ(point)≃3 μm
  - ➞ σ(angle)≃0.1°
  - Analysis ongoing / alignment & cracks





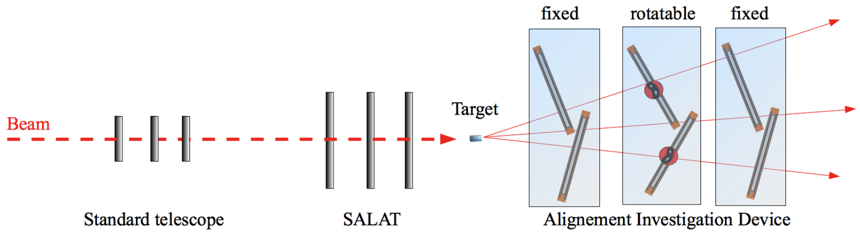
- Further beam test
  - With next 0.35% X0 prototype
  - Power pulsing in magnetic field
    - Check impact Lorentz forces

R&D on tracking

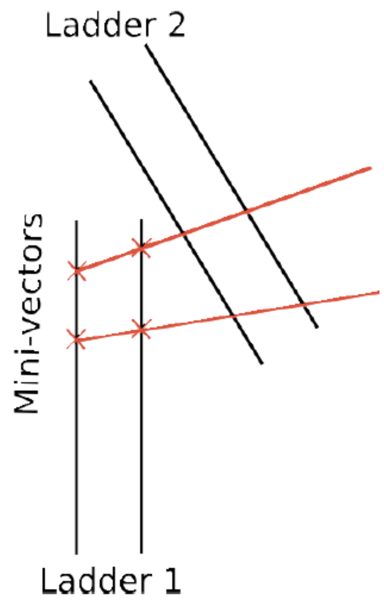
- Alignment studies
- Setup and simulation
- Tracking studies

Alignment studies

- **Context**
  - Thesis of Loic Cousin (2010-)
  - PLUME prototypes
  - AIDA EU-project
  - Alignment Investigation Device



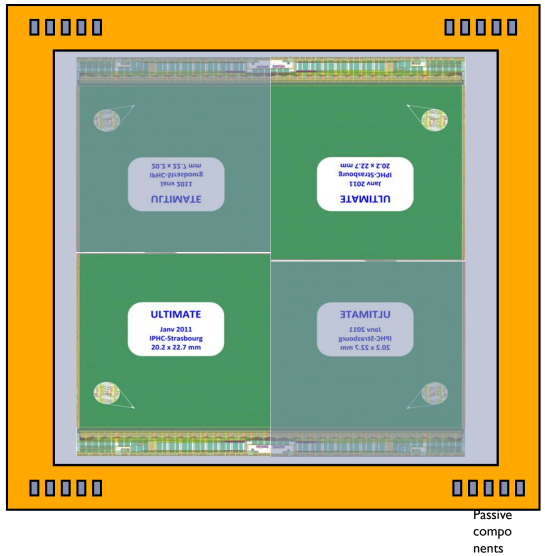
- **Layer auto-alignment**
  - Extrapolate mini-vectors to ladder on the other side of same layer, in ladders overlap area
  - Very preliminary results
    - recover 100 μm shifts + 2 deg rotations with 10k mini-vectors at 1μm level
  - Still no beam background included
  - Extension to "layer to layer" alignment ?
  - Competitive wrt global strategy using tracks ?

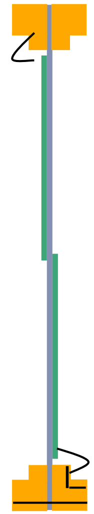


Setup for alignment studies

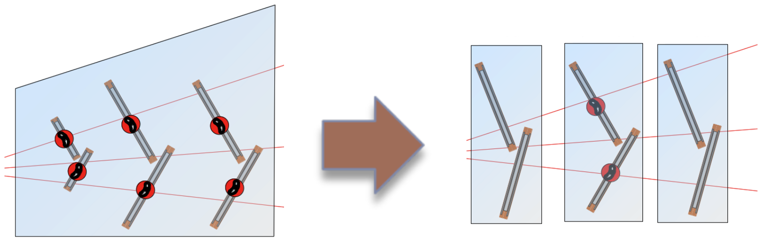
- **Single Arm Large Area Telescope**
  - SALAT (AIDA WP 9.3)
  - Demonstrator = 4 MIMOSA-28 sensors thinned to 50 μm mounted on a Mylar sheet
    - 1st sample May 2013
    - Complete arm (3 samples) Q1/2014
  - Final sensor = MIMAIDA 4x6 cm^2
    - 2015

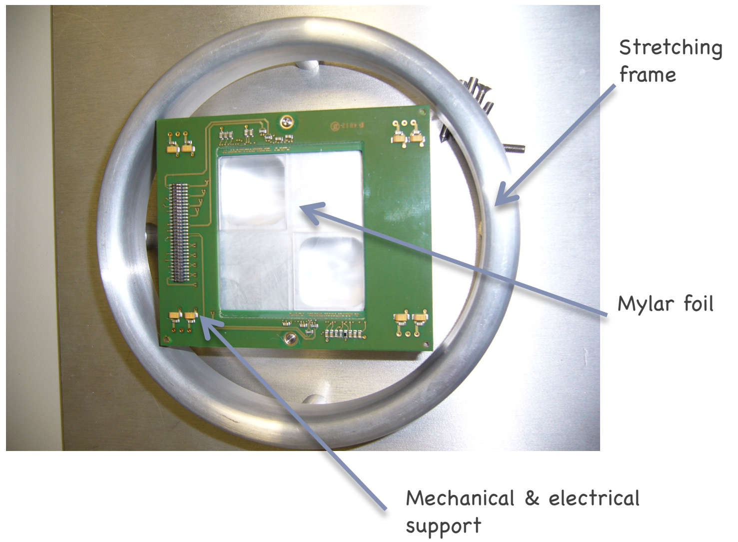
Sensing area = 4x 3.8 cm^2





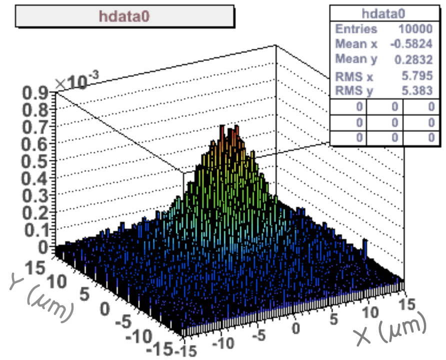
- **Alignment Investigation Device**
  - Downscale from a large box including 3 layers to three small supports
  - Dedicated mechanics (Bristol) for 2 PLUME ladders: July 2013



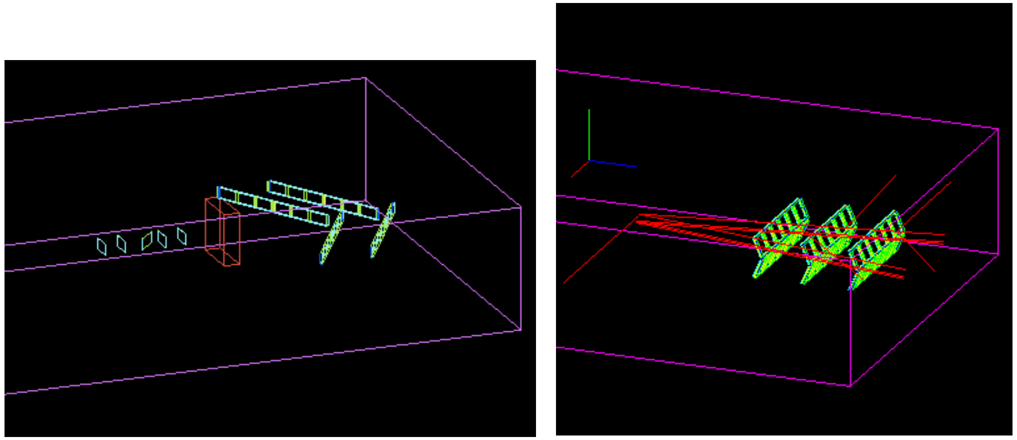


Simulation for alignment studies

- **CPS response**
  - Ad-hoc model based on charge spread functions
  - Parameterization from beam test
    - Validated for techno 0.35 µm
    - In progress for techno 0.18 µm



- **Geometry**
  - Detailed description of PLUME ladders
    - 8 Mpixels / ladder
    - Full response simulated
  - Several arrangements including
    - Target (for vertex generation)
    - Telescope arm upstream target
    - Layers with overlapping ladder downstream target

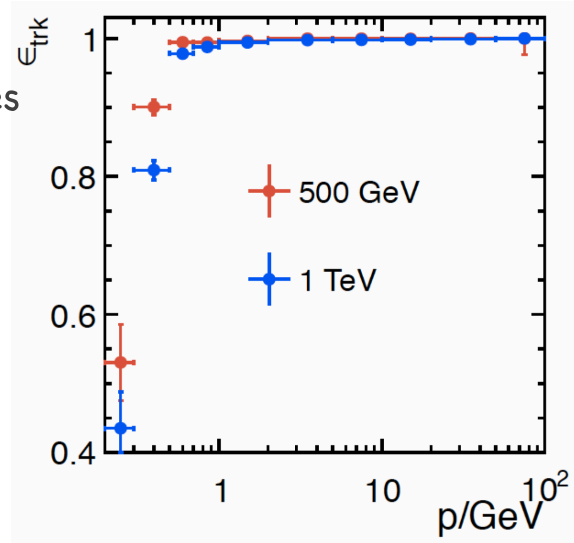


Examples of simulated AIDA-like setup

Tracking studies

- **Context**
  - Thesis of Yorgos Voutsinas (def.2012)
  - Collaboration with
    - Y.Voutisnas fellows at DESY (2013-2015)
    - New thesis starting this Fall 2013 at DESY
  - Simulation studies
    - DBD-style detector

Tracking efficiencies for $t\bar{t} \rightarrow 6\text{jets}$ (from DBD)



- **Silicon standalone tracking**
  - The problem at low p_T is track-seeding
    - 3 real 3D hits needed
  - With current strip-SIT configuration
    - Either not efficient enough 80% at p_T 500 GeV/c
    - Either two slow (270 s /event) when considering all combinations
  - Pixelated-SIT with 2 double-layers option
    - Offers 4 3D hits & mini-vectors
    - Cellular automaton algorithm under evaluation

- **Track extrapolation TPC➛SIT➛VTX**
  - Impact of pixelated-SIT (double-layers)

	strip		pixel	
	$\sigma_{s.p.}$ (μm)	t_{int} (μs)	$\sigma_{s.p.}$ (μm)	t_{int} (μs)
SIT - 1	7(R-ϕ) 50 (z)	< t_{BunchX}	4/15	100/7
SIT - 2			4	100

  - Efficiency TPC➛SIT strips > pixels
    - Benefit of short t_{int} / beam Background
  - Efficiency SIT➛VTX similar / both options
    - BUT pixel timestamping layer mandatory

Summary & Conclusion

- R&Ds ongoing at IPHC
  - CMOS pixel sensors
    - development driven now by ALICE (9 m^2) for 2015, AIDA for 2015 and CBM for 2018
    - ILC spec reachable ≲ 2015, CLIC goals more demanding (another technology upgrade)
  - System integration
    - generic project PLUME with ILC-oriented issues
    - Specific applications: STAR, ALICE, CBM ; developed by collaborations
  - Alignment and Tracking
    - Major steps for assessing benefits of a given technology and double-sided ladders

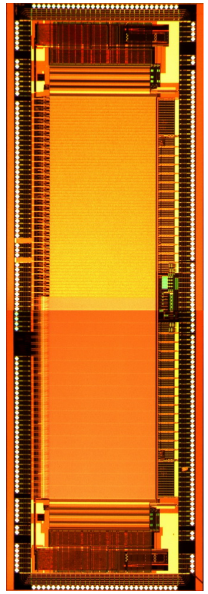
- From the past ten years
  - CPS are an R&D generated by ILC
  - Spin-off for
    - Subatomic physics
    - Other domains (photon-camera, hadrontherapy, dosimetry, …)

- For the ten coming years
  - Further progress of CPS expected, industrial technology moving forward
  - Further applications also opened up by integration progresses

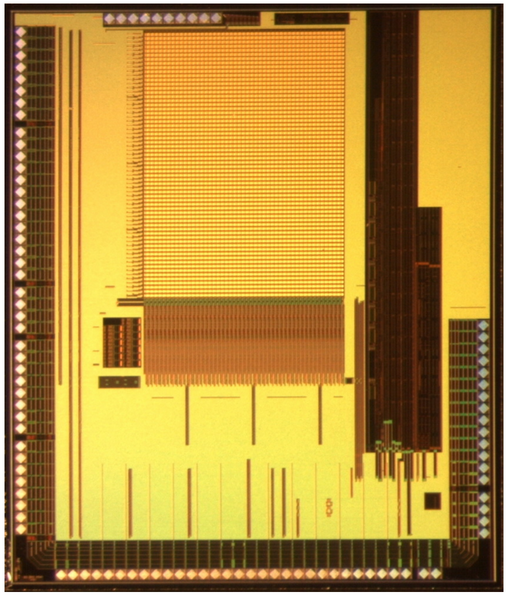
BACKUPS

Baseline CPS status

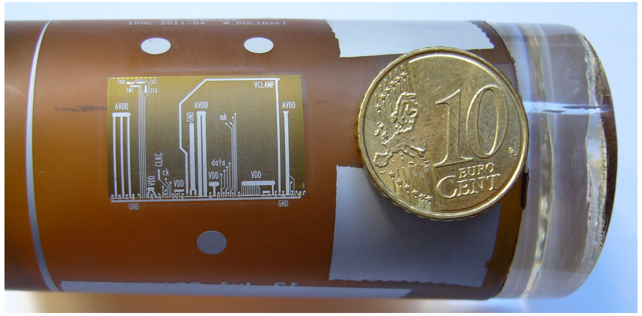
- **Inner layer** — 0.35 μm CMOS process
  - MIMOSA 30
    - 2 sided readout ($t_{r.o.}$ /2 for same sensitive area) with different pixel/side
    - Prototype dimension: column length ~ final sensor
  - High spatial resolution side:
    - Pitch 16x16 μm^2 → $t_{r.o.} \lesssim 50$ μs and expected $\sigma_{s.p.} \lesssim 3\mu m$
  - Time stamping side:
    - Pitch 16x64μm^2 → $t_{r.o.}$ = 10 μs and expected $\sigma_{s.p.} \simeq 3.5$ μm
  - Beam tests June 2012 for 16x16 μm^2:
    - Noise ~ 16 ENC
    - $\sigma_{s.p.} \simeq 3.0 \pm 0.1$ μm

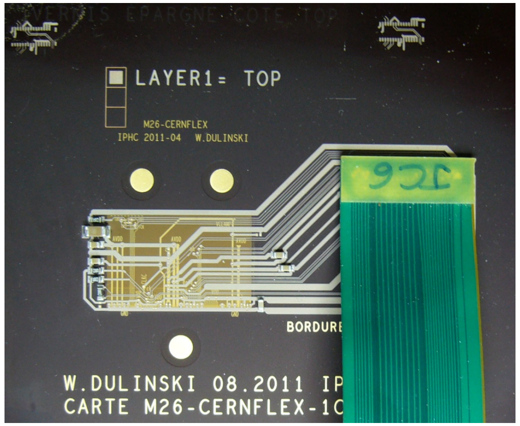


- **Outer layer**
  - MIMOSA 31
    - Column width = ADC width
    - 48 columns of 64 pixels with 35x35 μm^2
  - Column-level digitization
    - 4-bits ADC
    - expected $\sigma_{s.p.} \simeq 3.5$ μm



The SERNWIET project





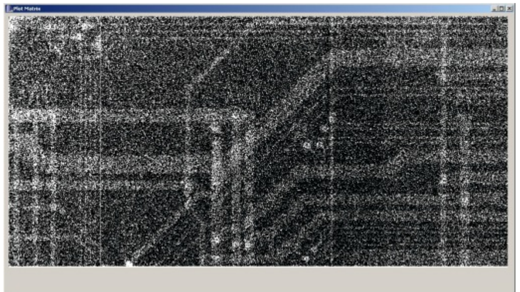
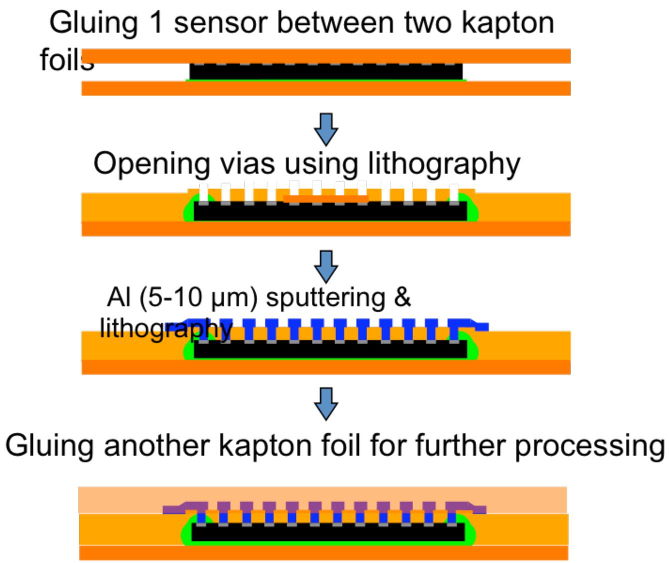
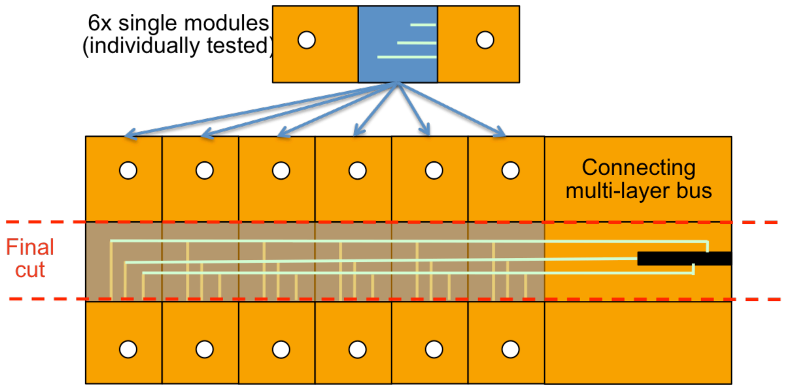
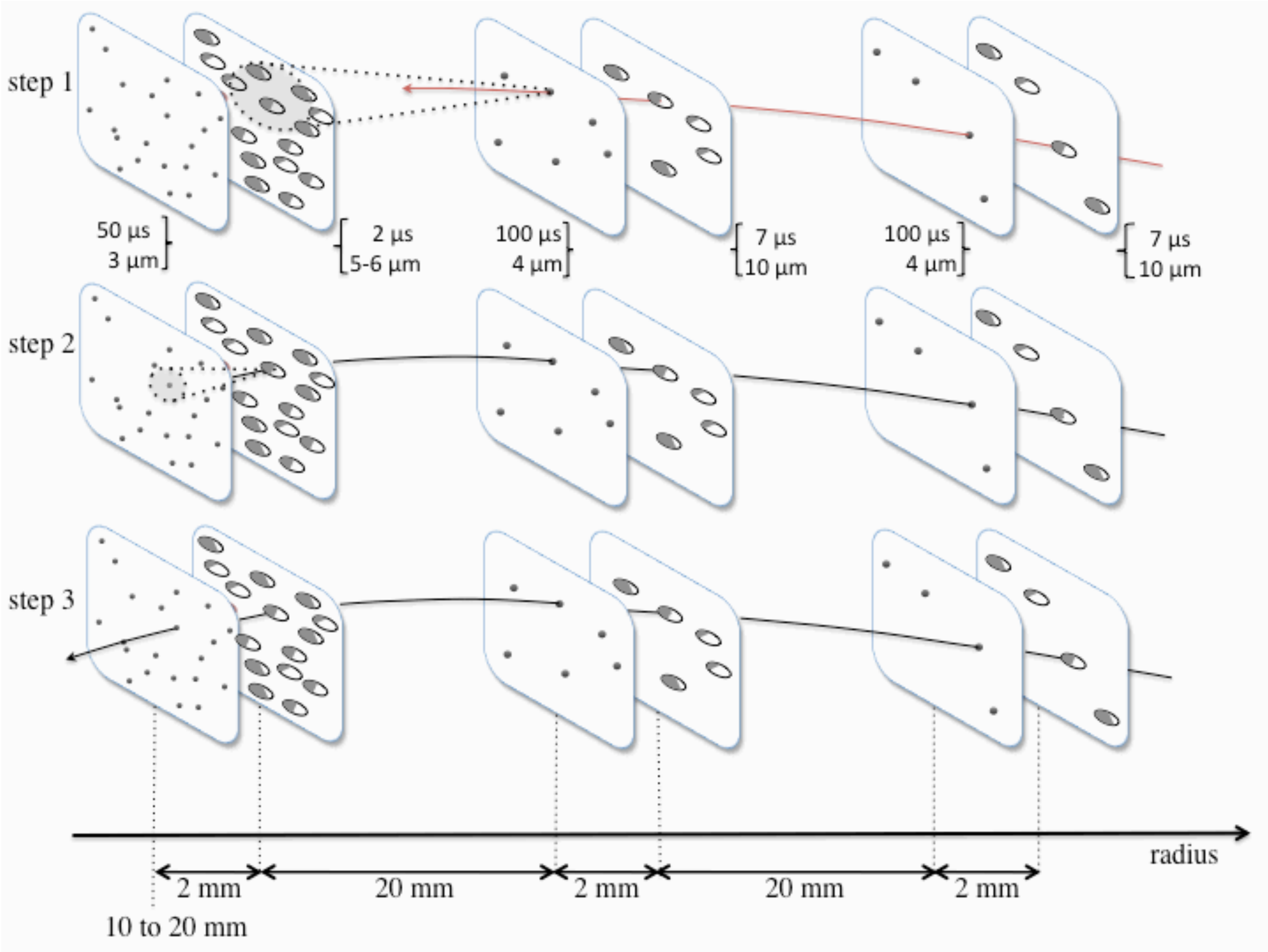


Image obtained
with 55Fe source,
X-rays detected by MIMOSA-26





Double-sided ladder tracking



The ALICE newITS