High Precision Tracking based on CMOS Pixel Sensors

M. Winter (PICSEL team of IPHC-Strasbourg)
Partnership between IPHC-Strasbourg & IHEP-Beijing

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  - ⋇ general remarks on highly pixelated and thin sensors
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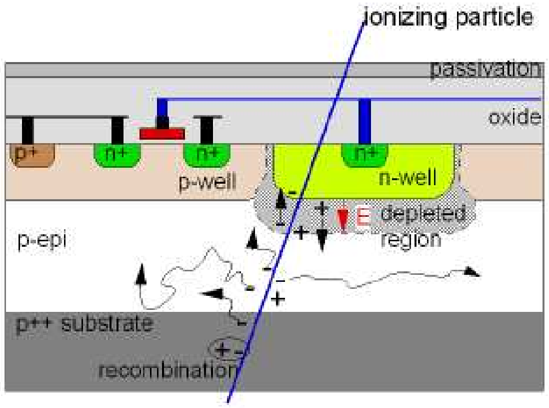
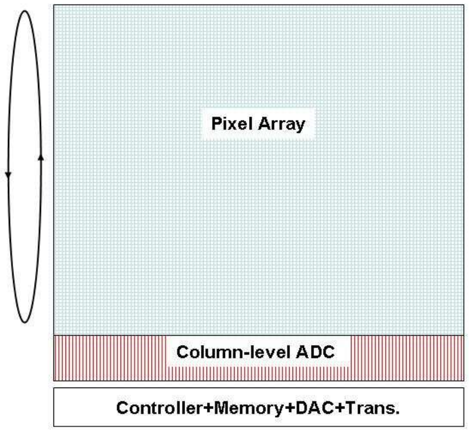
  - ⋇ Potential added-value of CMOS pixel sensors to cope with lumi increase
  - ⋇ Development actions: CMOS sensors, ultra-light ladders
- *Summary*

CMOS Pixel Sensors: State of the Art

- **Prominent features of CMOS pixel sensors:**
  - ⋇ high granularity ⇛ excellent (micronic) spatial resolution
  - ⋇ very thin (signal generated in 10-20 μm thin epitaxial layer)
  - ⋇ signal processing μ-circuits integrated on sensor substrate
    - ⇛ impact on downstream electronics (⇛ cost)



- **Organisation of MIMOSA sensors:**
  - ⋇ manufactured in 0.35 μm OPTO process
  - ⋇ signal sensing and analog processing in pixel array
  - ⋇ mixed and digital circuitry integrated in chip periphery
  - ⋇ read-out in rolling shutter mode
    (pixels grouped in columns read out in //)
    - ⇛ impact on power consumption



CMOS Pixel Sensors: Established Architecture

- **Main characteristics of MIMOSA sensor equipping EUDET BT:**

  ⋇ 0.35 μm process with high-resistivity epitaxial layer (coll. with IRFU/Saclay)

  ⋇ column // architecture with in-pixel amplification (cDS) and end-of-column discrimination, followed by $\emptyset$

  ⋇ binary charge encoding

  ⋇ active area: 1152 columns of 576 pixels (21.2$\times$10.6 mm^2)

  ⋇ pitch: 18.4 μm $\rightarrowtail$ $\sim$ 0.7 million pixels

  ▷ charge sharing $\Rrightarrow$ $\sigma_{sp} \sim$ 3.-3.5 μm

  ⋇ t$_{r.o.} \lesssim$ 100 μs ($\sim$10^4 frames/s) suited to $>$10^6 part./cm^2/s

  ⋇ JTAG programmable

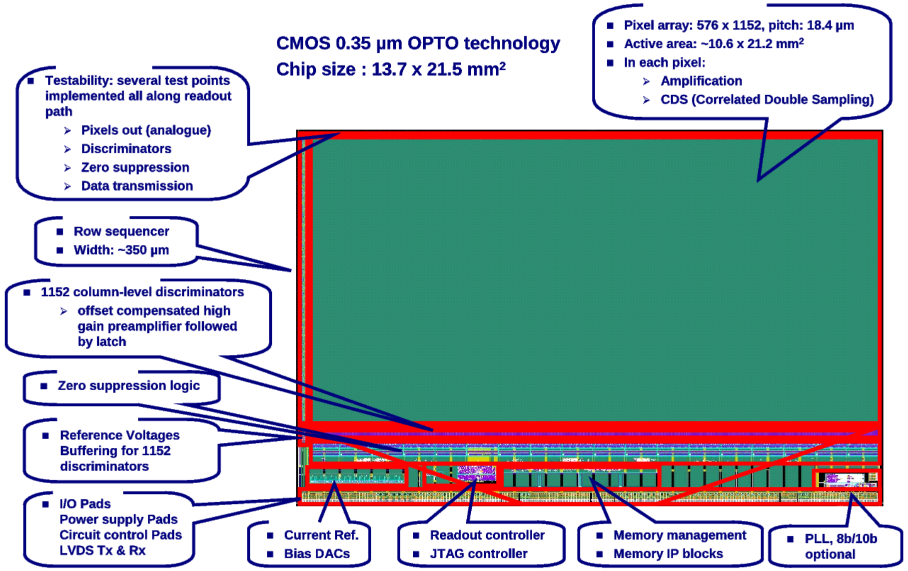
  ⋇ rolling shutter architecture

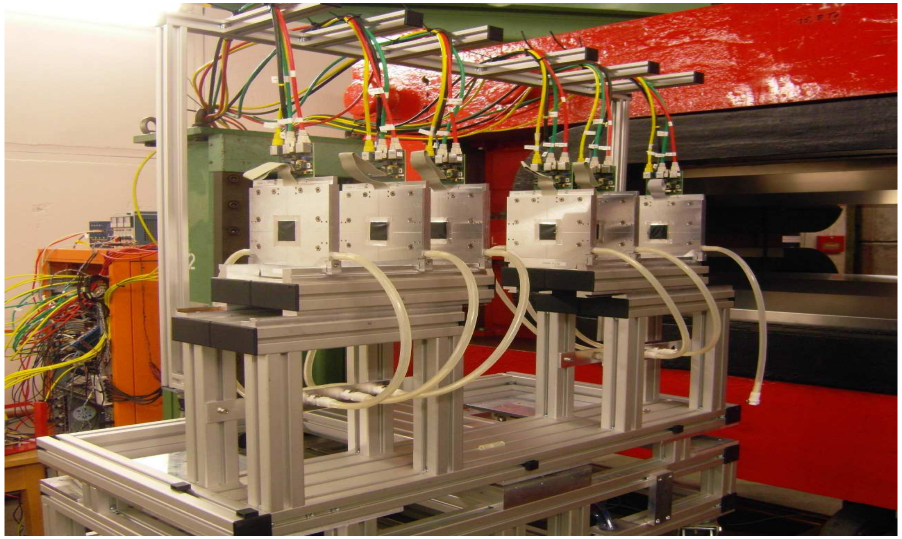
  $\Rrightarrow$ full sensitive area dissipation $\cong$ 1 row

  ▷ $\sim$ 250 mW/cm^2 power consumption (fct of N$_{col}$)

  ⋇ thinned to 50 μm

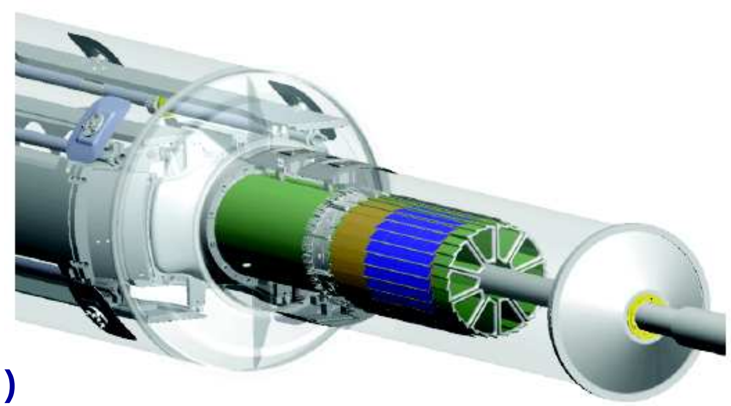
  ⋇ various appli. : VD demonstr., NA63, oncotherapy, dosimetry, ...

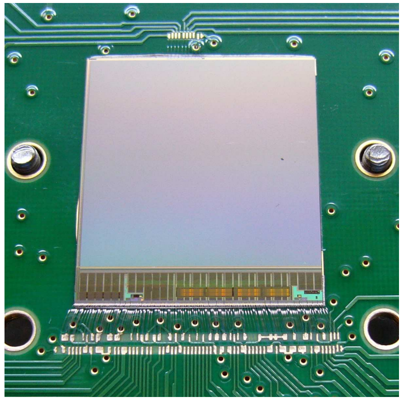




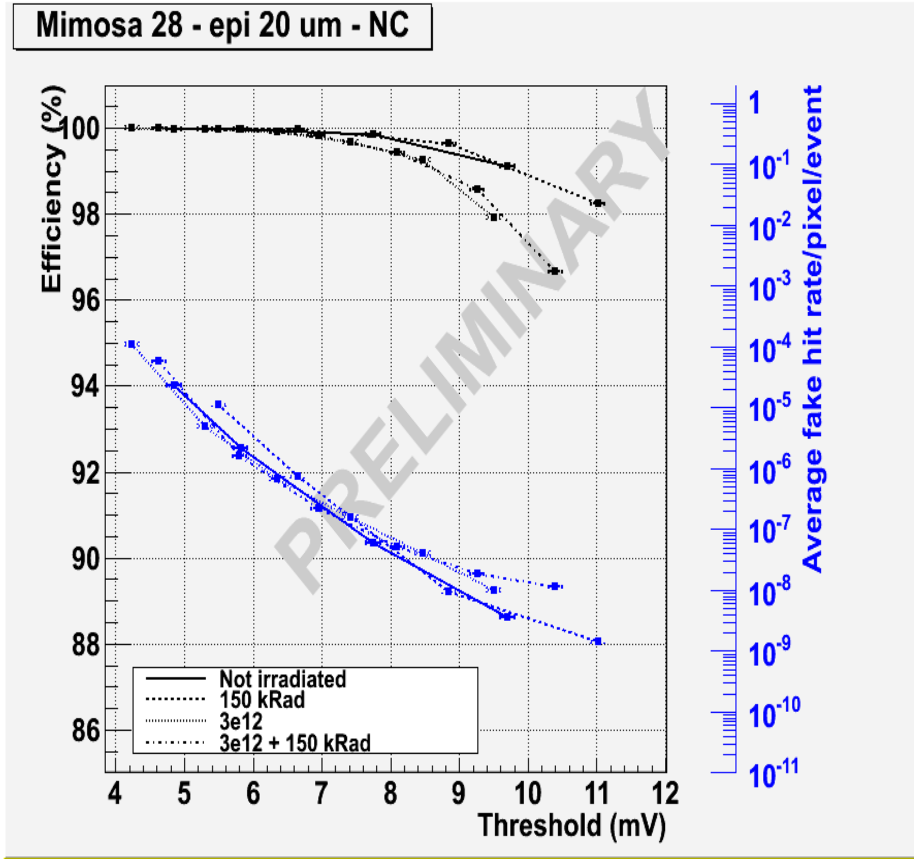
State-of-the-Art: MIMOSA-28 for the STAR-PXL

- **Main characteristics of ULTIMATE ($\equiv$ MIMOSA-28):**
  - ⋇ 0.35 μm process with high-resistivity epitaxial layer
  - ⋇ column // architecture with in-pixel cDS & amplification
  - ⋇ end-of-column discrimination & binary charge encoding
  - ⋇ on-chip zero-suppression
  - ⋇ **active area: 960 colums of 928 pixels (19.9$\times$19.2 mm^2)**
  - ⋇ **pitch: 20.7 μm $\rightarrowtail$ $\sim$ 0.9 million pixels**
    $\hookrightarrow$ **charge sharing $\Rrightarrow$ $\sigma_{sp} \gtrsim$ 3.5 μm**
  - ⋇ JTAG programmable
  - ⋇ **t$_{r.o.}$ $\lesssim$ 200 μs ($\sim$ 5$\times$10^3 frames/s) $\Rrightarrow$ suited to $>$10^6 part./cm^2/s**
  - ⋇ 2 outputs at 160 MHz
  - ⋇ $\lesssim$ 150 mW/cm^2 power consumption





▷▷▷ **Sensor almost fully evaluated :** (50 μm thin)
  - ⋇ N $\lesssim$ 15 e$^-$ ENC at 30-35°C (as MIMOSA-22AHR)
  - ⋇ CCE (^{55}Fe) similar to MIMOSA-22AHR
  - ⊸ Ionising rad. tolerance validated (150 kRad at 30°C)
  - ⊸ NI rad. tol. validated for 3·10^{12}n$_{eq}$/cm^2 at 30°C



▷▷▷ **Start of data taking early 2013**

FCPPL Project Perspectives

- **Problematics addressed :**

  Future of BESIII Central Tracker

※ BEPC-2 accelerator at IHEP
is steadily increasing luminosity

※ Will the beam-related background start
deteriorating the detection efficiency
of the BESIII central tracker ?

▷▷▷ **Could pixelated layers make the risk fade away ?**

※ IHEP-IPHC discussions going on since a few years exploring the question

$\hookrightarrow$ 4 face-to-face meetings in the last 2 years & 2 seminars at IHEP & IHPC

※ IPHC orienting its CMOS pixel sensor R&D towards large & thin tracker applications

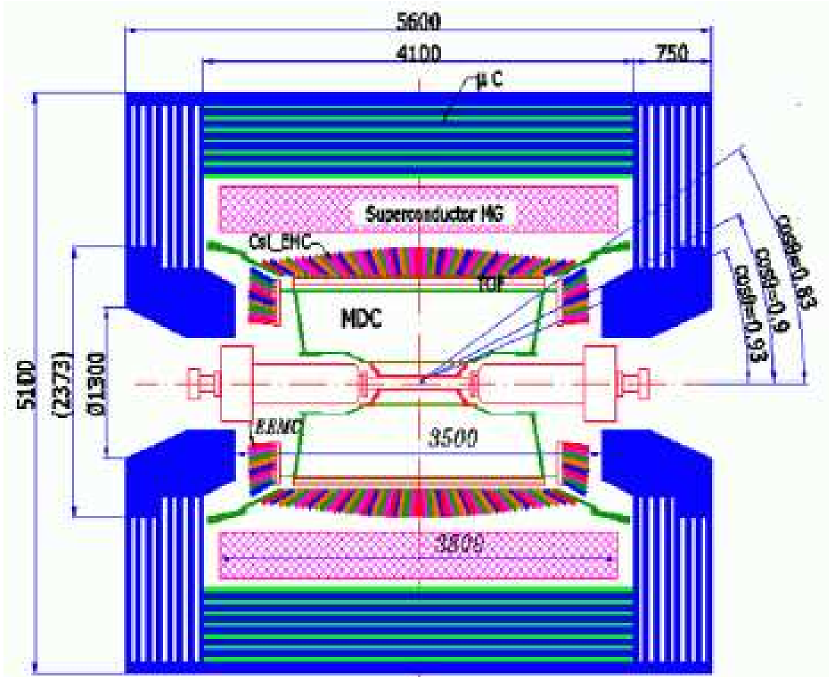
※ IHEP membres (2x2 people/week) testing CMOS pixels at IPHC

$\hookrightarrow$ CMOS sensor being tested IHEP since $\sim$ 1 year

The BESIII Experiment

- **Installed at BEPC-2 e^+e^- collider:**

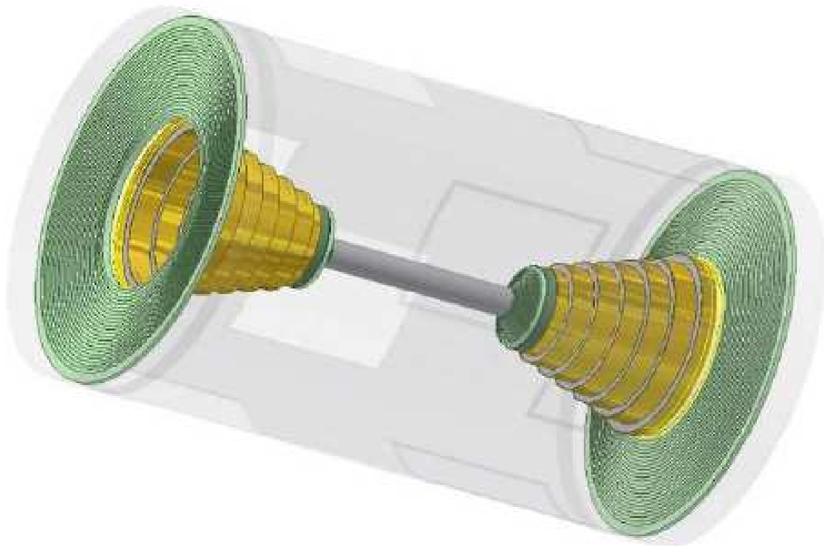
Ref: NIM A 614 (2010) pp 345-399



  - ⁕ E_{cm} = 2-4.6 GeV (tau-charm factory $> 10 \times \mathcal{L}_{\mathcal{CESR}\rfloor}$)
  - ⁕ $\mathcal{L}_{peak} \sim 10^{33}$/cm^2/s (2$\times$1.89 GeV)

    $\hookrightarrow$ 0.65$\cdot 10^{33}$/cm^2/s already achieved
  - ⁕ horizontal crossing angle = $\pm$ 11 mrad

- **Central tracker $\equiv$ (Main) Drift Chamber $\equiv$ MDC:**
  - ⁕ Radiii : 59 – 810 mm ⁕ Maximal length $\sim$ 2.6 m
  - ⁕ Conical end-caps to allow moving final focus quads near IP
  - ⁕ 43 wire layers : $\sim 22\cdot 10^3$ field wires & $7\cdot 10^3$ sensing wires
  - ⁕ 1 T experimental solenoidal field



- **MDC nominal performances:**
  - ⁕ average momentum in most final states $\sim$ 300 MeV/c

    $\hookrightarrow \sigma_{R\phi} \lesssim$ 130 $\mu m \Rrightarrow \Delta p/p \simeq$ 0.5% at 1 GeV/c
  - ⁕ wire stereo angles (-3.4°, +3.9°) $\rightarrowtail \sigma_Z^{IP} \simeq$ 2 mm

A Pixelated Upgrade of the MDC

- **Goal of the project:**

  ⋇ 3 innermost wire layers may be saturated at the higest machine luminosity

  ⇛ replace with pixel sensors to cope with beam related background (e.g. $\gamma_{synch.}$)

  ⋇ total surface to cover $\sim$ 1-2 m^2

  ⋇ single point resolution is not an issue : $\sigma_{sp} \gtrsim$ 10 μm all right

  ⋇ particle rate is not an issue : $t_{int} \sim$ 100 μs all right

- **Adapting CPS to tracker requirements raises 3 challenges:**

  ⋇ keep $\sim$ 100 % detection efficiency with large pixels

  ⋇ keep power consumption low enough despite large area ($>$ 1 m^2)

  ⋇ keep material budget compatible with $\Delta p/p \simeq$ 0.5% at 1 GeV/c

Adapting CPS to the MDC Inner Cells

- **Sensing system :**

  ⋇ develop sensing system for pixels of 64×64 to 80×80 μm^2

  ↪ avoid det. efficiency losses for impacts far from sensing diodes

  ⋇ optimise the number and the size of the diodes

  ↪ alleviate "capacitive" noise increase

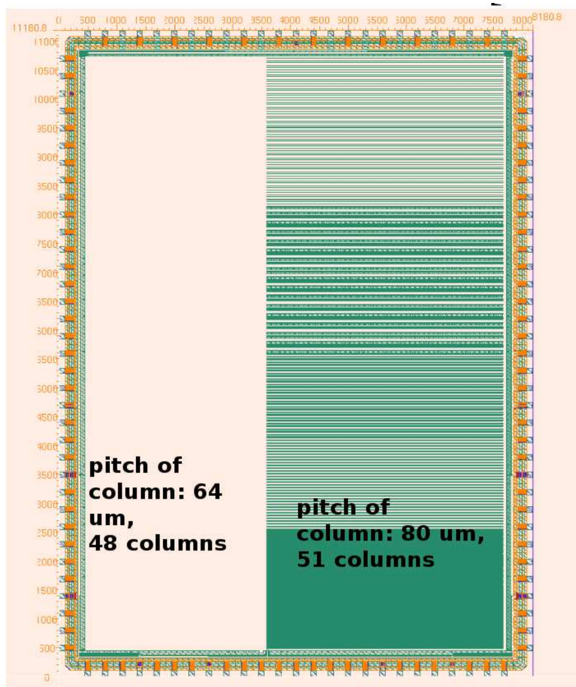
  ⋇ MIMOSA-29:

  ⊸ pixels of 16, 32, 48, 64×64 & 20, 40, 80×80 μm^2

  ⊸ 1, 2 or 4 sensing diodes (2 sizes)

  ⊸ some amplification variants

  ⊸ fabricated in 2011 ⇛ tests under way



- **Next steps: continue improving the low noise pixel design**

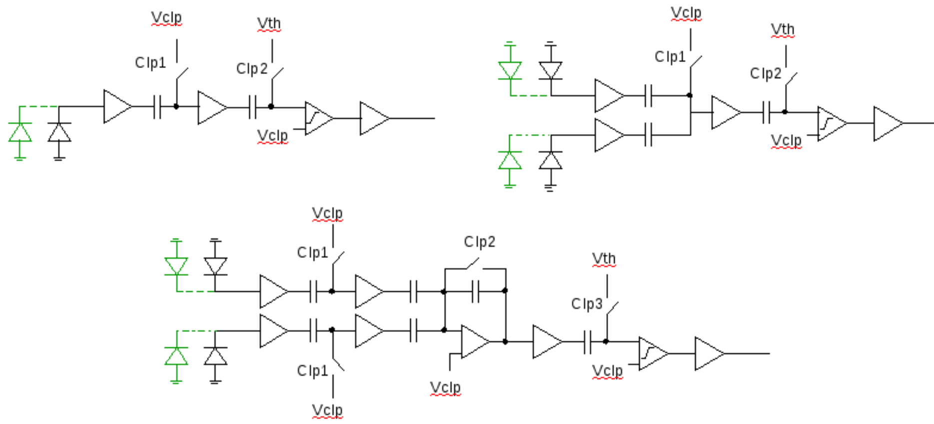
  ⋇ optimise balance between number and noise of sensing diodes

  ⋇ minimise power consumption

  ⋇ watch material budget (i.e. flex cable complexity, cooling, ...)

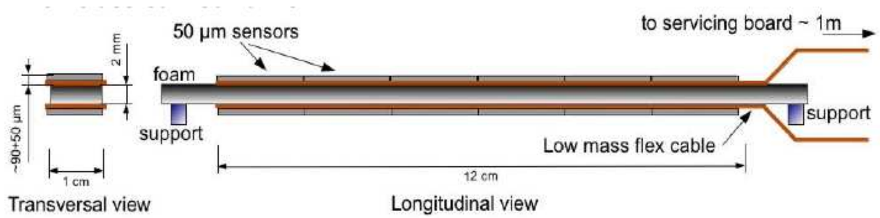
  ⇛ MIMOSA-22THR (0.18 μm process)

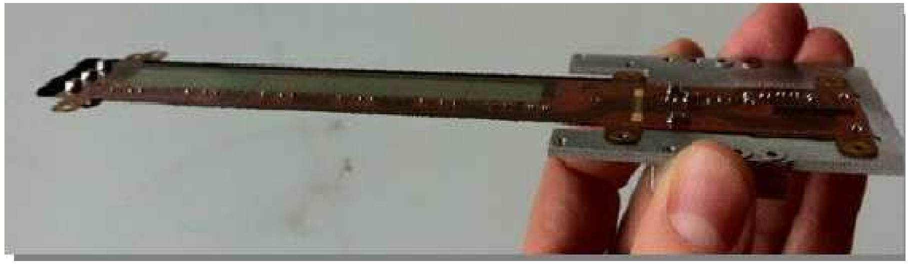
  to be fabricated in Q3-2012



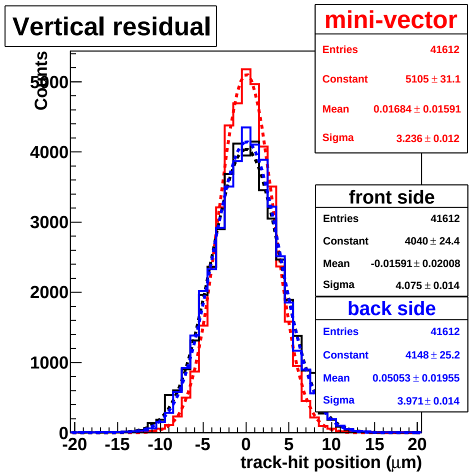
Ultra-light 2-Sided Ladder

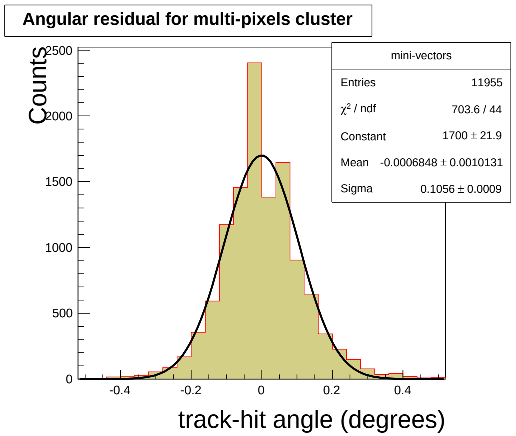
- **50 μm thin sensors mounted on 2-sided ladders:**
  - ⋇ *PLUME $\equiv$ Pixelated Ladder with Ultra-Light Material Embedding*
  - ⋇ *prototype $\equiv$ 6 MIMO-26 mounted on each side of mech. support*
  - ⋇ *mech. support $\equiv$ 2 mm thick, low density, SiC foam*
  - ⋇ *total material budget of 2011 proto: $\sim$ 0.6 % X_0*





- **PLUME prototype-2010 tested at SPS in Nov. 2011:**
  - ⋇ *Beam telescope: 2 arms, each made of 2 MIMO-26 sensors*
  - ⋇ *CERN-SPS beam : $\gtrsim$ 100 GeV "π^-"*
  - ⋇ *BT (track extrapolation) resolution on DUT : $\sim$ 1.8 μm*
  - ⋇ *PLUME perpendicular & inclined ($\sim$ 36°) wrt beam*
  - ⋇ *Prelim. results on combined impact & pointing resolution*





- **Next steps**
  - ⋇ *Next PLUME version (0.35 %X_0) under construction*
  - ⋇ *Tests foreseen at CERN-SPS in Dec.'12 or DESY early '13*
  - ⋇ *Alignment studies based on multi-ladder/layers set-up in 2014/15 (EU project AIDA)*

SUMMARY

- **IHEP-IHPC partnership studies the possibility of enhancing the capability of BESIII to face the highest luminosities achievable at BEPC-2**

- **Study addresses the possibility of complementing Main Drift Chambre :**
  - ⋇ with 3 layers of 50 μm thin CMOS pixel sensors based on the architecture developed at IPHC
  - ⋇ layers may be double-sided, exploiting the concept developed within the PLUME collaboration

- **Next steps :**
  - ⋇ IHEP continues exploring added-value of CMOS pixel sensors
  - ⋇ IPHC continues prototyping large pitch sensors and ultra-light ladders
  - ⋇ Discussions aiming at final evaluation through 2012

- **Partnership benefits from/to global effort towards pixelated large area trackers**

  $\hookrightarrow$ ALICE, ILC, ...