2015-20 R&D Plans for an ILC Vertex Detector based on CMOS Pixel Sensors (CPS)

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ILD MEETING, Oshu, 8th Septembre 2014

Outline

- *Starting points : STAR-PXL & ALICE-ITS*
- *General strategy : 2-sided ladders with different CPS on L1, L2, L3-6*
- *Plans for the coming years (extrapolating from present achievements*
- *Summary*

CMOS Pixel Sensors (CPS): A Long Term R&D

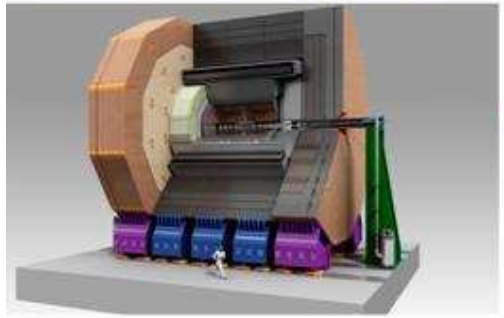
- ***Initial objective: ILC, with staged performances***
  - *CPS applied to other experiments with intermediate requirements*

EUDET 2006/2010

Beam Telescope

ILC >2020

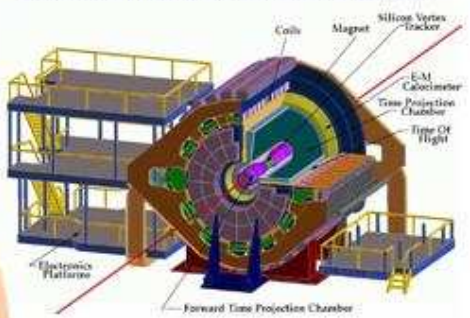
International Linear Collider



EUDET (R&D for ILC, EU project)
STAR (Heavy Ion physics)
CBM (Heavy Ion physics)
ILC (Particle physics)
HadronPhysics2 (generic R&D, EU project)
AIDA (generic R&D, EU project)
FIRST (Hadron therapy)
ALICE/LHC (Heavy Ion physics)
EIC (Hadron physics)
CLIC (Particle physics)
BESIII (Particle physics)
...

STAR 2013

Solenoidal Tracker at RHIC

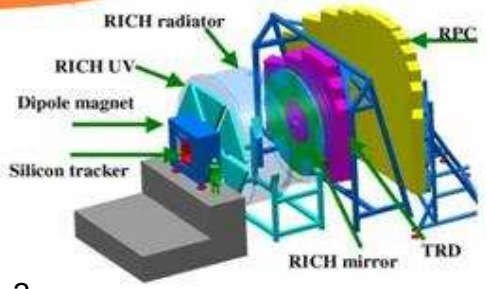


ALICE 2018

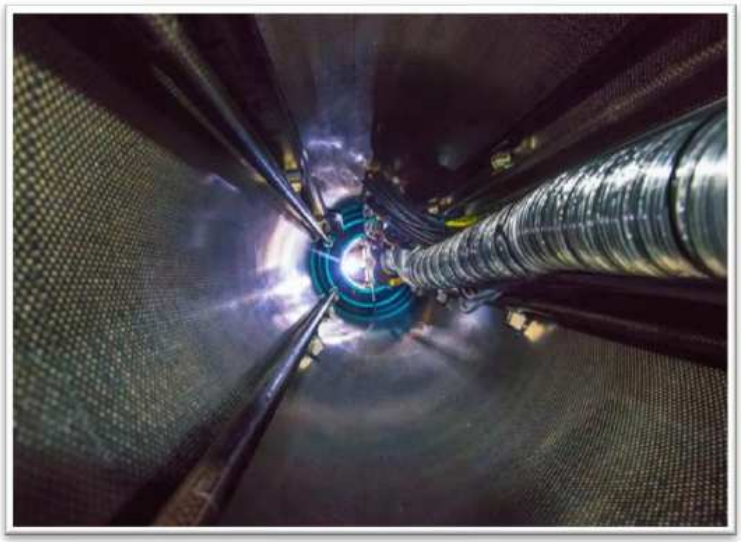
A Large Ion Collider Experiment

CBM >2018

Compressed Baryonic Matter



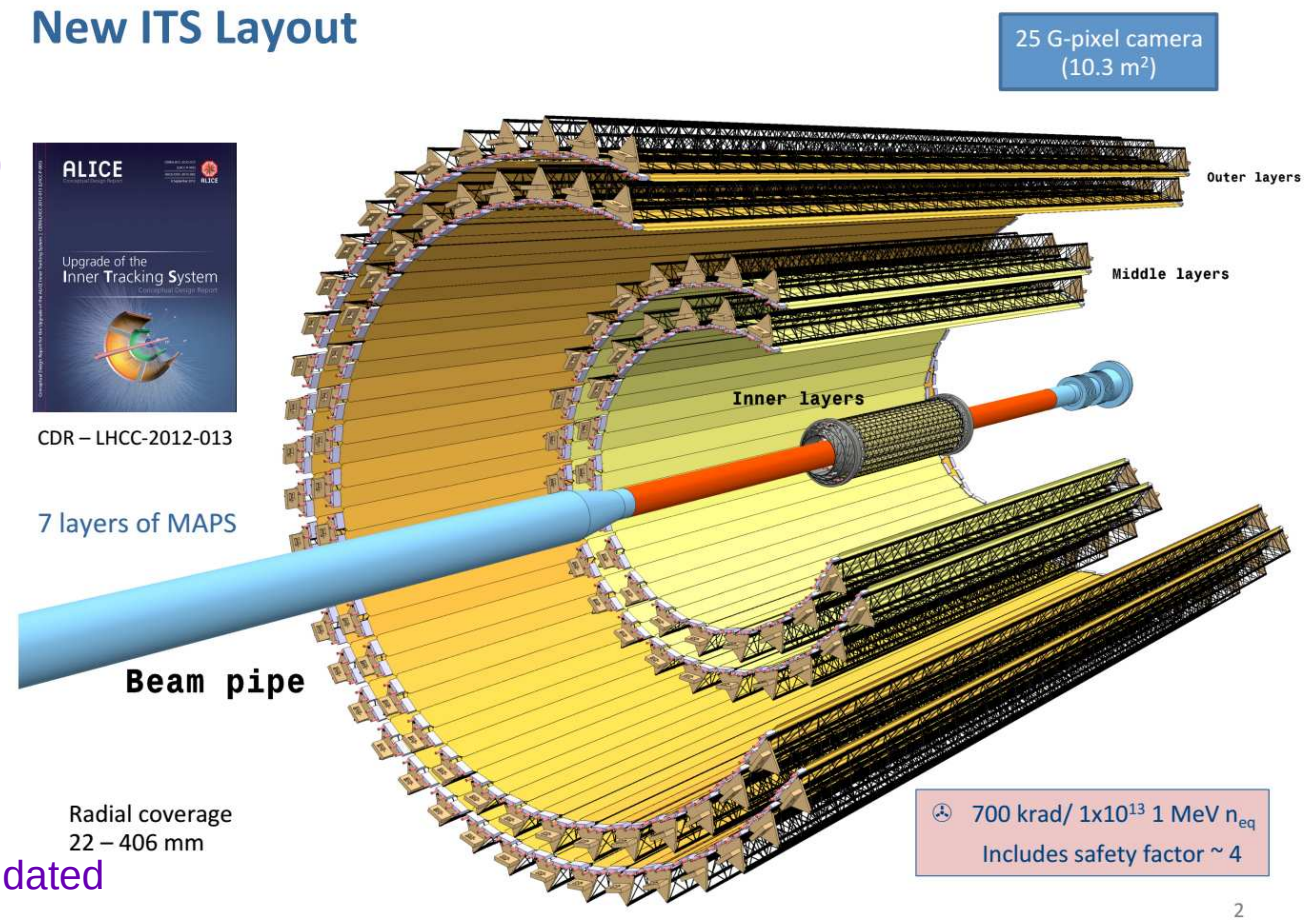
Starting point: Ultimate chip in STAR



Next Progress Carrier : ALICE-ITS Upgrade

- Vx Det. (3 layers) + Tracker (4 layers, 10 m^2) : 5 μm, 20-30 μs, 700 kRad & 10^{13}n$_{eq}$/cm^2 at 30°C

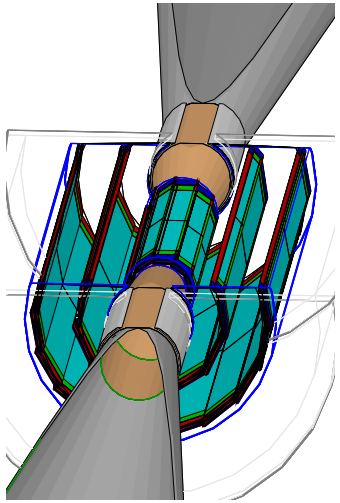
- 3 alternative & complementary sensors being developped (CERN main partner):
  - Conservative: **MISTRAL** (end-of-col. discri.)
    $\hookrightarrow \gtrsim 30\ \mu s, < 200$ mW/cm^2
  - Fast option: **ASTRAL** (in-pixel discri.)
    $\hookrightarrow \gtrsim 15\ \mu s$, 85 mW/cm^2
  - Ambitious: **ALPIDE** (token ring archi.)
    $\hookrightarrow \lesssim 5\ \mu s, \lesssim 50$ mW/cm^2



- Status :
  - MISTRAL : real scale proto. operational
    $\hookrightarrow$ (5 μm, 40 μs)
  - ASTRAL : in-pixel dicriminator prototype validated
    $\hookrightarrow$ (5 μm, 20 μs)
  - ALPIDE : full scale proto. functional $\mapsto$ (5-6 μm, 5 μs)

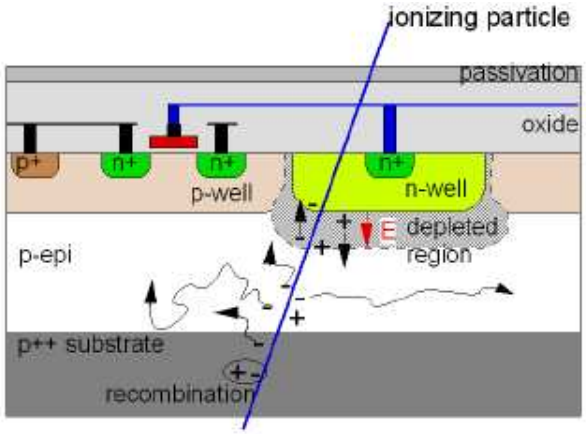
- **Comment :** read-out time is for 1.3/1.4 cm long columns $\simeq$ 2-2.5 $\times$ VXD-L1 column length

Topics Addressed by the R&D

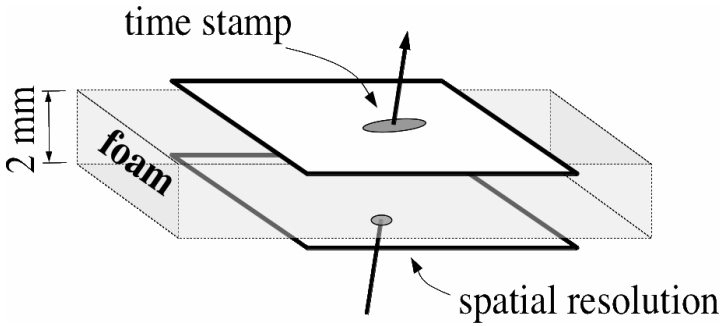


- VERTEX DETECTOR CONCEPT :
  - Cylindrical geometry based on 3 concentric 2-sided layers
  - Layers equipped with 3 different CMOS Pixel Sensors (CPS)

- PIXEL SENSOR DEVELOPMENT:
  - Exploit CPS potential & IPHC (25-30 members) expertise
  - R&D performed in synergy with other applications
    $\hookrightarrow$ EUDET-BT, STAR, ALICE, CBM, ...
  - CPS $\equiv$ unique technology being simultaneously
    granular, thin, integrating full FEE, industrial & cheap
  - Address trade-off between spatial resolution & read-out speed



- DOUBLE-SIDED LADDER DEVELOPMENT:
  - Develop concept of 2-sided ladder using 50 μm thin CPS
  - Develop concept of mini-vectors providing
    high spatial resolution & time stamping
  - Address the issue of high precision alignment
    & power cycling in high magnetic field



CMOS Pixel Sensors for the ILD-VXD

- **Two types of CMOS Pixel Sensors :**
  - ⁕ **Inner layers** ($\lesssim$ 300 cm^2) :

    Priority to read-out speed & spatial resolution

    ↪ small pixels (17×17 / 33 μm^2)

    with binary charge encoding

    ↪ $t_{r.o.} \sim$ 50 / 8 μs; $\sigma_{sp} \lesssim$ 3 / 5 μm

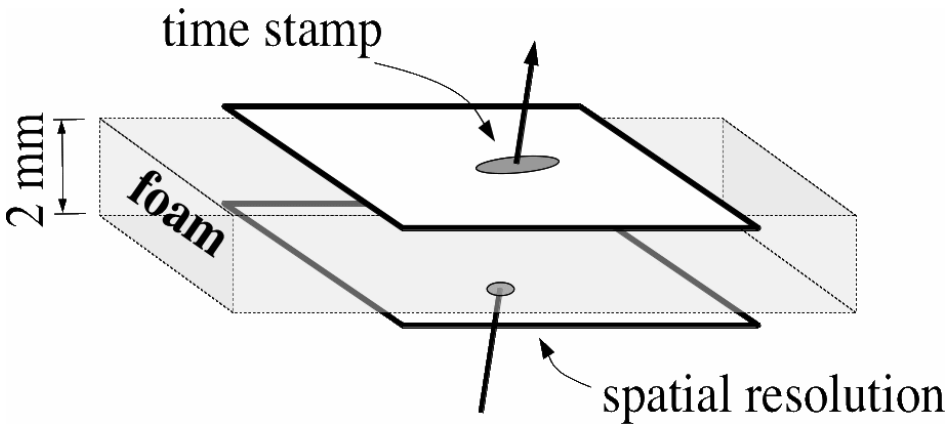
  - ⁕ **Outer layers** ($\sim$ 3000 cm^2) :

    Priority to power consumption and good resolution

    ↪ large pixels (25/35×35 μm^2)

    with 3-4 bits charge encoding

    ↪ $t_{r.o.} \sim$ 60 μs; $\sigma_{sp} \lesssim$ 4 μm



⁕ Total VXD instantaneous/average power $<$ 600/12 W (0.18 μm process)

- **2-sided ladder concept for inner layer :**

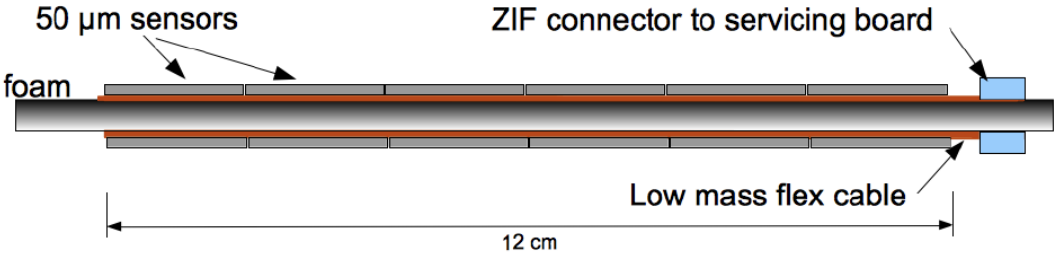
  ↪ PLUME collaboration

  - ⁕ **Square pixels** (17×17 μm^2)

    on internal ladder face ($\sigma_{sp} \lesssim$ 3 μm)

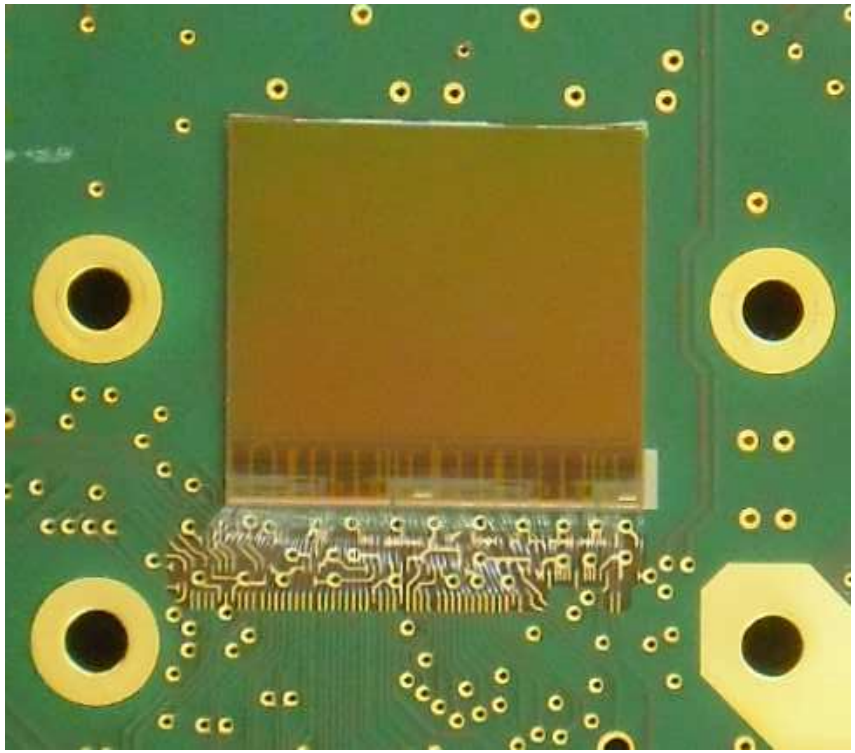
  - ⁕ **Elongated pixels** (22/17×33/102 μm^2)

    on external ladder face ($t_{r.o.} \sim$ 8 $\mapsto$ few μs)



Upcoming Sensors (Partly) Based on the ALICE Development

- **Spin-off of MISTRAL :**
  - best suited to reach $\lesssim$ 2.8 μm resolution in L1
  - BUT pixels of 17 $\mu m \times$ 17 $\mu m \Rrightarrow$ $\sim$ 50 μs r.o. time
- **Spin-offs of ASTRAL :**
  - L2 : pixels of 17 $\mu m \times$ 102 $\mu m \Rrightarrow$ $\sim$ 7 $\mu m \oplus$ 2.5 μs
  - L1 & L2 : pixels of 22 $\mu m \times$ 33 $\mu m \Rrightarrow$ 5 $\mu m \oplus$ 8 μs
    $\hookrightarrow$ mini-vectors $\equiv$ 3.5 $\mu m \oplus$ 4-8 μs
  - L3-L6 : pixels of $\lesssim$ 22 $\mu m \times$ 33 $\mu m \Rrightarrow$ 4-5 $\mu m \oplus$ 8 μs
- **Spin-offs of ALPIDE :**
  - L2 : pixels of 25 $\mu m \times$ 25 $\mu m \Rrightarrow$ 5 $\mu m \oplus <$ 5 μs
  - L2 : pixels of 15 $\mu m \times$ 125 $\mu m \Rrightarrow$ 8 $\mu m \oplus <$ 1 μs reachable ?
- **Spin-offs of MIMOSA-31, MISTRAL & MIMADC :**
  - L3-L6 : pixels of 35 $\mu m \times$ 35 $\mu m \Rrightarrow$ 4 $\mu m \oplus$ 30-60 μs
  - L1-L2 : pixels of 25 $\mu m \times$ 25 $\mu m \Rrightarrow$ 3 $\mu m \oplus$ 20 μs or 25 $\mu m \times$ 35 $\mu m \Rrightarrow$ 3.5 $\mu m \oplus$ 15 μs ???
- **MIMOSA-33 :** Fine Pixels of 4 $\mu m \times$ 4 μm with delayed (analogue) read-out



MISTRAL Proto. (2/3)

SUMMARY

- **CPS are validated for vertex detectors :** STAR-PXL physics run of Spring 14
- **New CPS generation (ALICE-ITS)** provided 1st full scale proto. : 1st tests confirm expectations
- **Next steps :**
  - finalise ALICE-ITS sensor prototyping in 2015
  - start deriving CPS for VXD in 2016/17 $\mapsto$ baseline $\triangleright$

Layer	σ_{sp}	t_{int}
ILD-VXD/In	$<$ 3/5 μm	50/8 μs
ILD-VXD/Out	$\sim$ 3.5/4 μm	60/100 μs

  - Investigate alternative or more challenging CPS approaches :
    - few $\mu s \mapsto \lesssim$ 1 μs fast sensors for bunch tagging
    - FPCPS with delayed read-out
    - 2-tier CPS combining 2 different CMOS processes
    - CPS (and ladders) optimised for trackers
- 2-SIDED LADDERS : PLUME collaboration
  - Prototype based on MIMOSA-26 sensors on the way to achieve 0.35 % X_0
  - Upcoming years : beyond 2014
    - Validate concept of complementary sensors with ASTRAL/MIMOSA-26
    - Validate power pulsing in strong magnetic field
    - Assess added value of double-sided ladders
    - Investigate possibilities to still reduce the ladder material budget $<$ 0.3% X_0