The International Large Detector: Tracking System

First ECFA WORKSHOP.
on e^+e^- Higgs / Electroweak / Top Factories
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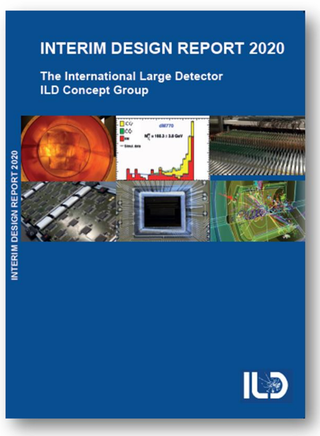
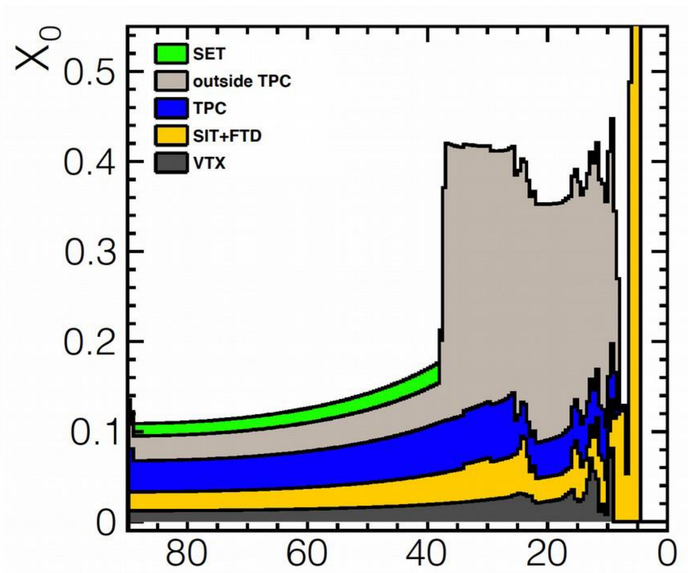
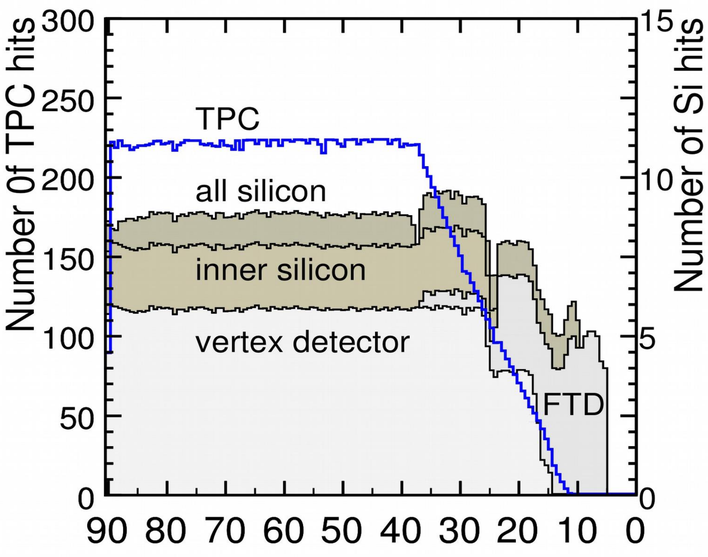
ILD (Silicon + Gas) Tracking Concept:

- Vertex: Barrel of 3 double layers of Si-pixels (e.g. CMOS MAPS, DEPFET, CCD, SoI, …)
  0.3% X_0 / layer, $\sigma_{sp} \lesssim 3\ \mu m$
- Intermediate Si-tracker (SIT, SET, FTD)
  - SIT/FTD: silicon pixel sensors (e.g. CMOS)
  - SET: silicon strip sensors
- Time Projection Chamber with MPGDs
  - High hit redundancy (200 hits / track)
    → 3D tracking / pattern recognition;
    → dE/dx (dN/dx) information for PID



Most recent paper on ILD:
ILD interim design report
arXiv: 2003.01116





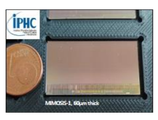
ILD Vertex Technologies:

- **Exploiting the ILC low duty cycle 0(10^{-3}): triggerless readout, power-pulsing**
- **Readout strategies:**
  → continuous during the train with power cycling → mechanic. stress from Lorentz forces in B-field
  → delayed after the train → either ~5μm pitch for occupancy or in-pixel time-stamping

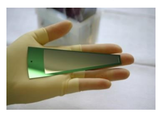
Physics driven requirements		Running constraints		Sensor specifications	
$\sigma_{s.p.}$	2.8um			Small pixel	~16 μm
Material budget	0.15% X_0/layer			Thinning to	50 μm
		Air cooling		low power	50 mW/cm²
r of Inner most layer	16mm	beam-related background		fast readout	~1 μs
		radiation damage		radiation tolerance	≤3.4 Mrad/year ≤6.2×10¹² n_{eq}/(cm² year)

Technology	FPCCD	DEPFET	SOI	CMOS	iLGAD
Added value (example)	Very granular	Low material budget	2 tier process (high density μcircuits)	Industry evolution	PID

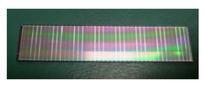
CMOS (CPS): continuous readout, stiching (STAR)



DEPFET: continuous readout, 75 / 50 um thick (Belle II)

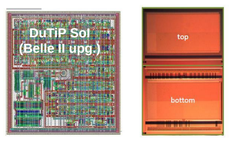


Fine pixel CCD: delayed readout, 5 um pitch, 50 um thickness



SOI: delayed / continuous readout; suited for 3D integration

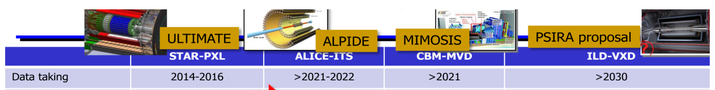
SoI-based 3D integration: rely on high-density in-pixel circuitry, with double-tier "3D" in CMOS TJ 180nm process



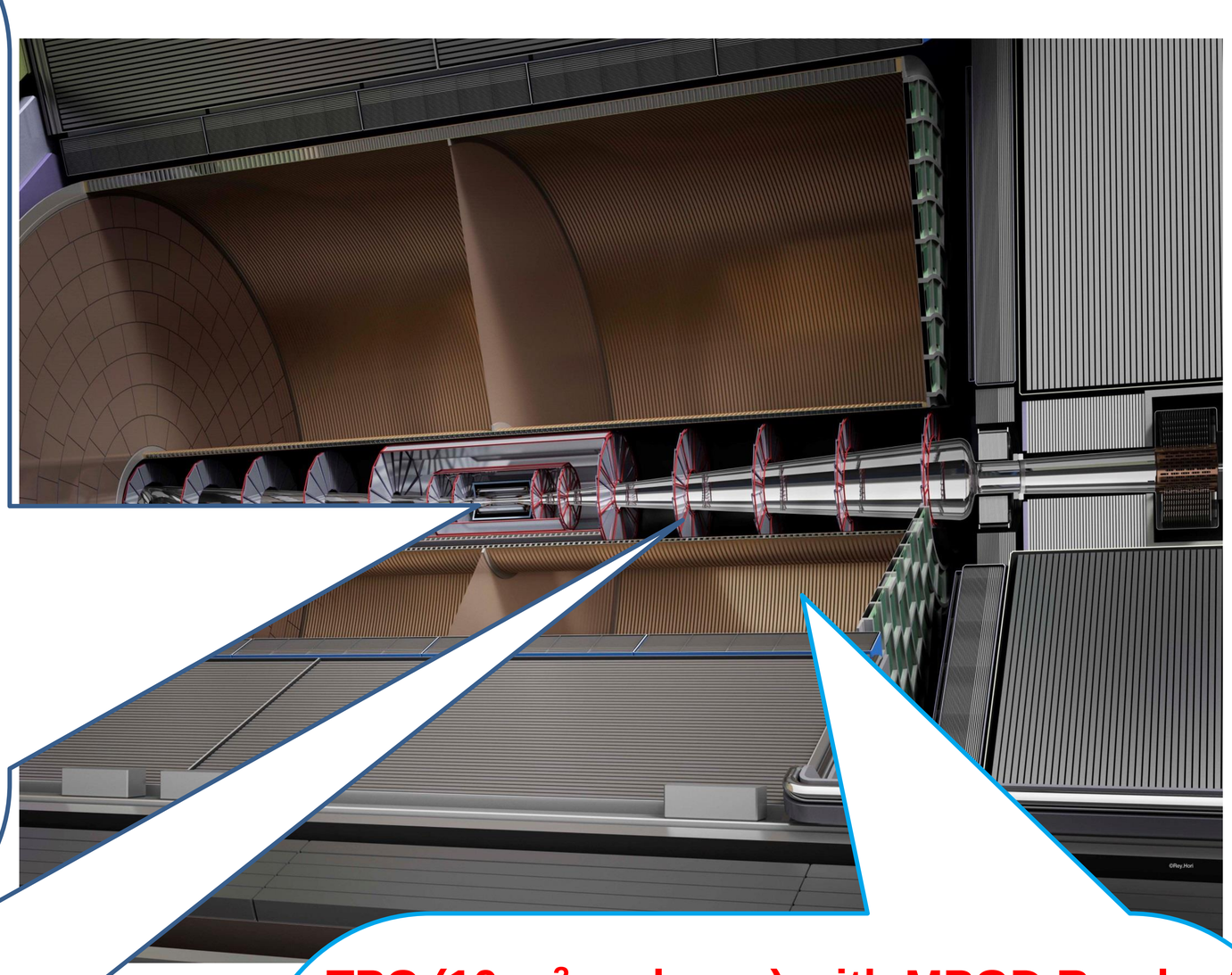
Examples of recent CMOS – MAPS developments:

ALICE-ITS3 upgrade drives important R&Ds:

- ✓ Bending thin (50 um) Si-layers (MAPS): truly cylindrical, supportless CPS (65 nm)
- ✓ Industrial stitching & large surfaces for low-mass detectors



	STAR-PXL	ALICE-ITS	CBM-MVD	ILD-VXD
Data taking	2014-2016	>2021-2022	>2021	>2030
Technology	AMS-opto 0.35 μm	**0.18 μm**	0.18 μm	0.18 μm (conservative) < 0.18 μm ?
	4M	HR, V_{bias} ~-6V Deep P-well	HR, Deep P-well	?
Architecture	Rolling shutter + sparsification + binary output	**Asynchronous r.o. In pixel discri.**	Asynchronous r.o. In pixel discri.	Asynchronous r.o. (conservative)
Pitch (μm²) / Sp. Res.	20.7 x 20.7 / 3.7	27 x 29 / 5	22 x 33 / <5	~ 22 / ~ 4
Time resolution (μs)	~185	**5-10**	5	**1 – 4**
Data Flow		~10^6 part/cm²/s Peak data rate ~ 0.9 Gbits/s	peak hit rate @ 7 x 10^5 /mm²/s **>2 Gbits/s output (20 inside chip)**	~375 Gbits/s (instantaneous) ~1166Mbits / s (average)
Radiation	O(50 kRad)/year	2x10^{11} n_{eq}/cm² 300 kRad	3x10^{13} n_{eq}/cm²/yr & 3 MRad/yr	O(100 kRad)/year & O(1x10^{11} n_{eq}(1MeV)) /yr
Power (mW/cm²)	< 150 mW/cm²	**< 35 mW/cm²**	< 200 mW/cm²	~ 50-100 mW/cm² + Power Pulsing
Surface	2 layers, 400 sensors, 360x10^6 pixels 0.15 m²	7 layers, 25x10^3 sensors **> 10 m²**	4 stations Fixed target	3 double layers 10^3 sensors (4cm²) 10^9 pixels ~0.33 m²
Mat. Budget	~ 0.39 % X_0 (1st layer)	~ 0.3% X_0 / layer		~ 0.15-0.2 % X_0 / layer
Remarks	1st CPS in colliding exp.	(with CERN)	Vacuum operation Elastic buffer	Evolving requirements

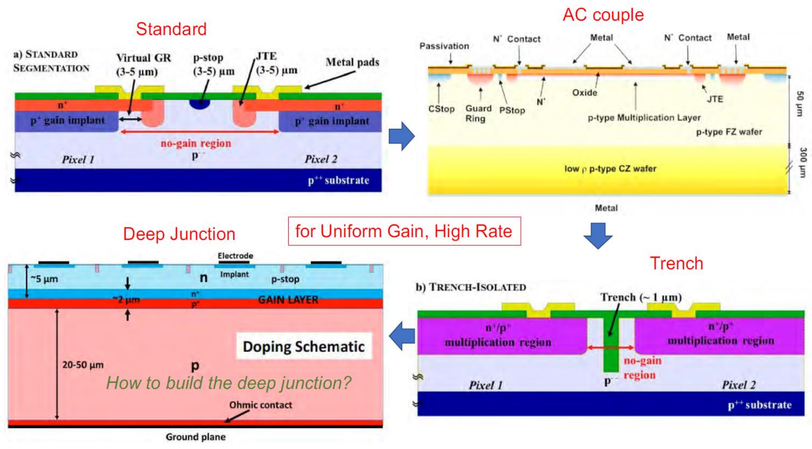


Intermediate Silicon Tracker:

Baseline solution: **silicon-microstrip tracker; also some enabling technologies (e.g. based on LGAD concept)**

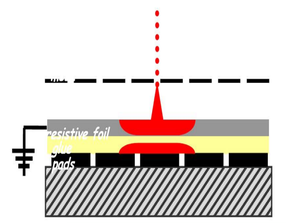
Timing Detectors open up 4D (and 5D) tracking:

- ✓ High-precision tracking → a few um per layer
- ✓ High-precision timing → tens of ps per layer
- ✓ Optimal geometrical acc. (large fill-factor).
- ✓ Low material (50 μm thickness per plane).



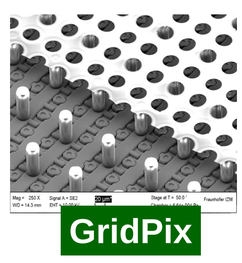
TPC (10 m² endcaps) with MPGD Readout:
Ionization for PID and continuous tracking

Baseline technologies: GEMs, Micromegas, GridPix

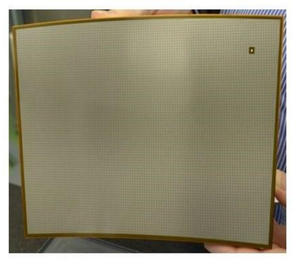


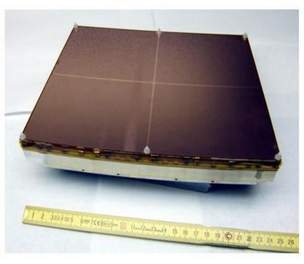
Micromegas

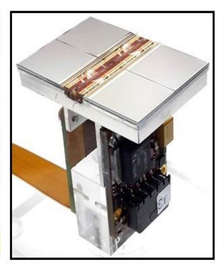
GEM



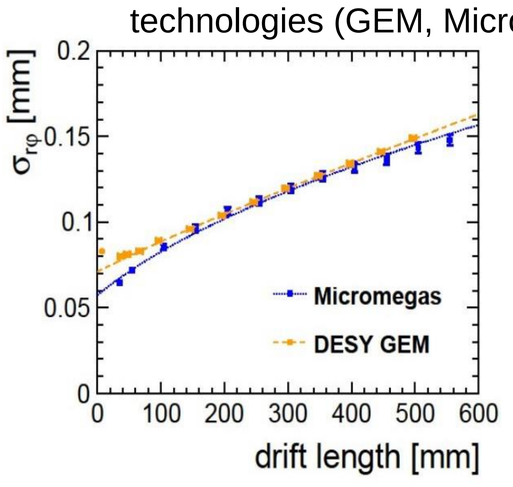
GridPix

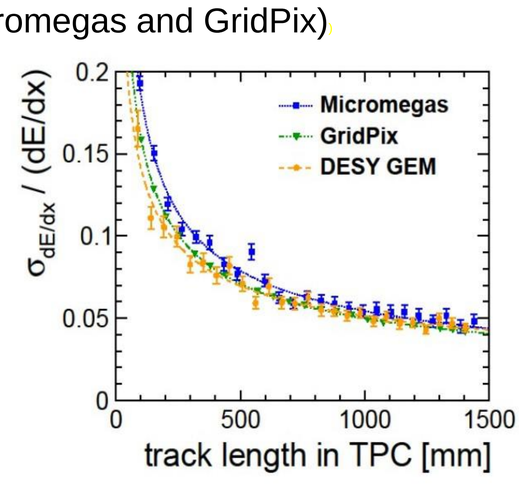






Target requirement of a spatial resolution of 100 μm in transverse plane and dE/dxresolution < 5% have been reached with all technologies (GEM, Micromegas and GridPix)





STRATEGICAL ISSUES related to adaptation of ILD to other colliders than ILC. Work plan:

- ✓ Optimize acceptance in the forward region, taking into account specific background conditions
- ✓ Bunch and train time structure : revise power management and heat removal to adapt to almost continuous beams
- ✓ Explore how an ILD-like TPC can perform under these high-ionization and high space charge conditions.
- ✓ Adapt calibration and alignment strategies to these conditions