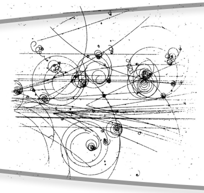
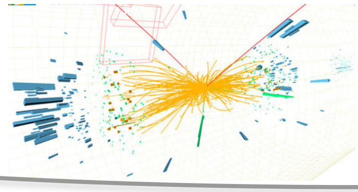
Next silicon tracking systems

-from CMS tracker Phase2 to future detectors-





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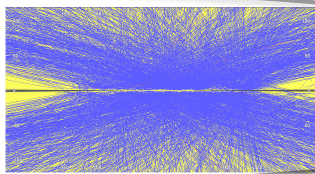

Livio Fanò

Università degli Studi di Perugia e INFN

CEPC-SppC Study Group Meeting —— 2-3 September 2016

Outlook

Physics requests and detector constraints

Cutting edge technology and ongoing R&D
- Radiation Tolerance
- pT Track and L1-Trigger

INFN - local expertise in
- Detector development
- Ongoing China/Italy partnership in particle detectors and industrial liaison

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Physics requests and detector constraints

A new energy frontier, beyond the EW sector

Higgs - Higher production rates, a completely new kinematical and dynamical regime for Higgs physics
Need extended η coverage, low pT thresholds in lepton triggering and reconstruction, b-tagging, em energy resolution, particle-ID

New Physics - i.e. Z' with high muon momentum resolution, di-jet resonance with high energy resolution and granularity with extended η coverage (VBF)

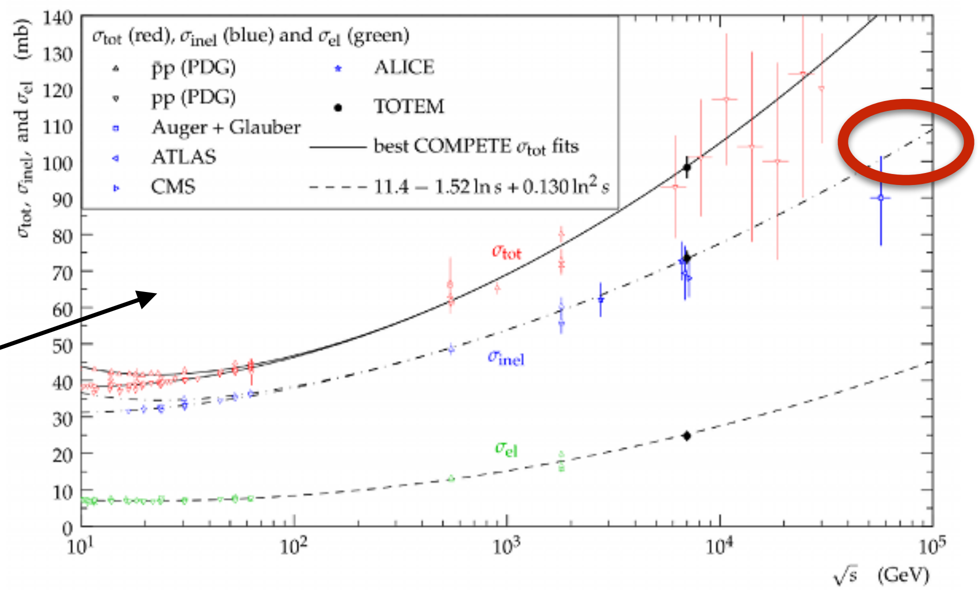
Constraints from physics:

- extended and precision tracking for vertexing and momentum spectroscopy *(many points, inner layers)*
- high efficiency for low-pT reconstruction and high resolution for high-pT tracks *(high spatial resolution, light material, reduced pitch)*
- fast tracking *(fast electronics and data processing)*

How far is HL-LHC from future colliders ?

parameter	FCC-hh		SPPC	HE-LHC* (*tentative)	(HL) LHC
collision energy cms [TeV]	100		71.2	>25	14
dipole field [T]	16		20	16	8.3
circumference [km]	100		54	27	27
# IP	2 main & 2		2	2 & 2	2 & 2
beam current [A]	0.5		1.0	1.12	(1.12) 0.58
bunch intensity [10^{11}]	1	1 (0.2)	2	2.2	(2.2) 1.15
bunch spacing [ns]	25	25 (5)	25	25	25
beta* [m]	1.1	0.3	0.75	0.25	(0.15) 0.55
luminosity/IP [10^{34} $cm^{-2}s^{-1}$]	5	20 - 30	12	>25	(5) 1
events/bunch crossing	170	<1020 (204)	400	850	(135) 27
stored energy/beam [GJ]	8.4		6.6	1.2	(0.7) 0.36
synchrotr. rad. [W/m/beam]	30		58	3.6	(0.35) 0.18

Luminosity >10^{35} with ~400 PU
($5*10^{34}$ and ~200 PU for HL-LHC)



Inelastic pp cross section expected
~ 100-110 mb (80 mb at 14 TeV)

Reasonably similar kinematics but
50% more in terms of charged multiplicity and <pT>, low pT is a “background” to TRG

Constraints from the machine:

- up to 4X PU level wrt HL-LHC (crowded final state, high granularity and vertices resolution needed)
- up to 50X radiation level (degrading detector response)

Physics requests and detector constraints

Extended and precision tracking for vertexing and momentum spectroscopy

many sampling points, inner layers

High efficiency for low-pT reconstruction and high resolution for high-pT tracks

high spatial resolution, light material, reduced pitch

Fast tracking

fast electronics and data processing

Up to 4X PU level wrt HL-LHC

crowded final state, high granularity needed

Up to 50X LHC radiation level

degrading detector response

Physics requests and detector constraints

Extended and precision tracking for vertexing and momentum spectroscopy

layout/module design

many sampling points, inner layers

High efficiency for low-pT reconstruction and high resolution for high-pT tracks

layout/technology choice/module design

high spatial resolution, light material, reduced pitch

Fast tracking

module design/technology choice

fast electronics and data processing

Up to 4X PU level wrt HL-LHC

module design/technology choice

crowded final state, high granularity needed

Up to 50X LHC radiation level

layout/technology choice

degrading detector response

Physics requests and detector constraints

Cutting edge technology and ongoing R&D

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INFN - local expertise in

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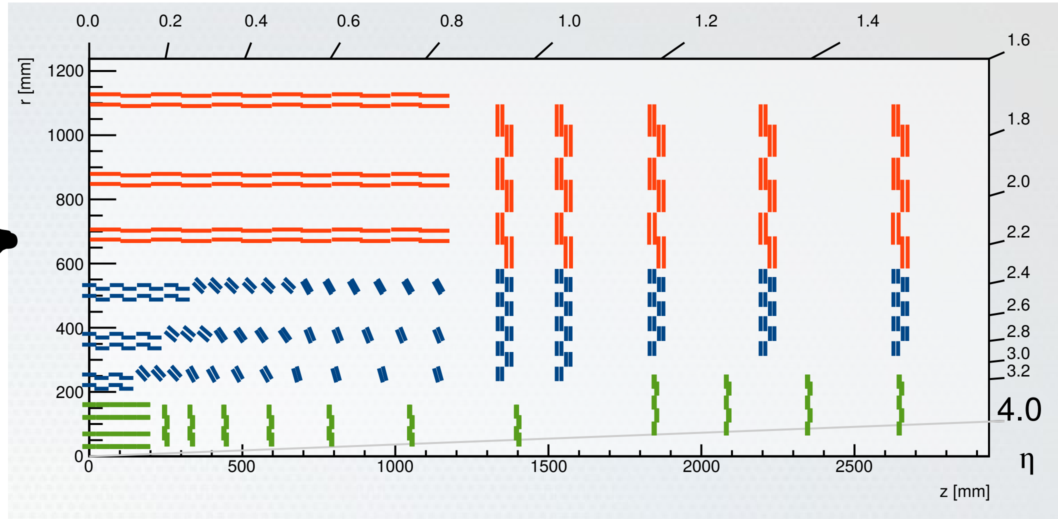
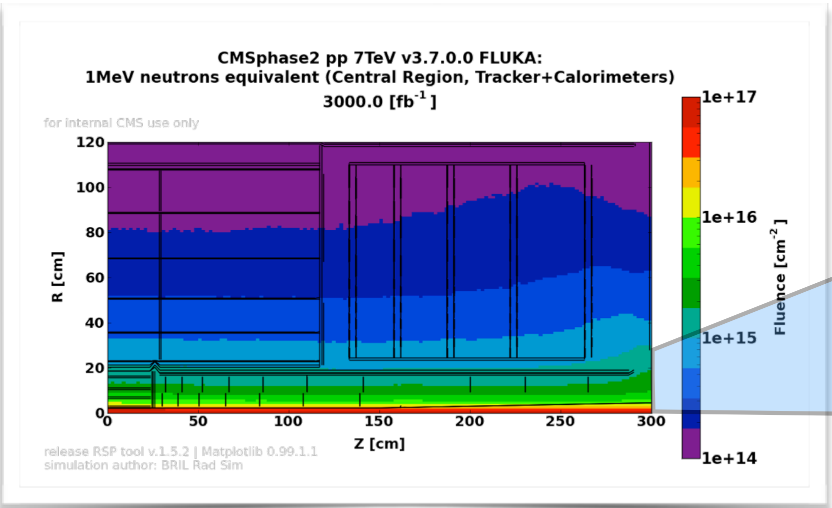
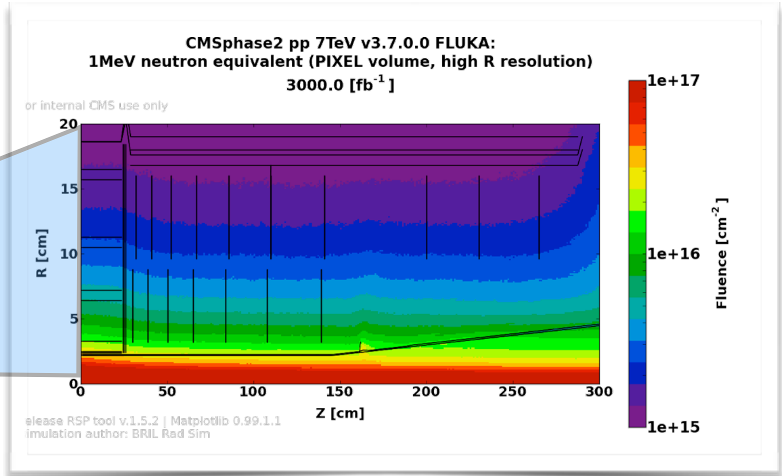
Radiation Tolerance

A realistic layout for **CMS Phase-2 Tracker** is optimized considering physics requests and machine constraints
(details discussed shortly…)



Expected radiation is > 10^{16} equivalent fluence in the innermost layer!





Largely depend on R than in Z

A robust solution for sensors and electronics is needed

Radiation Tolerance

Pixel Detector (1/2)

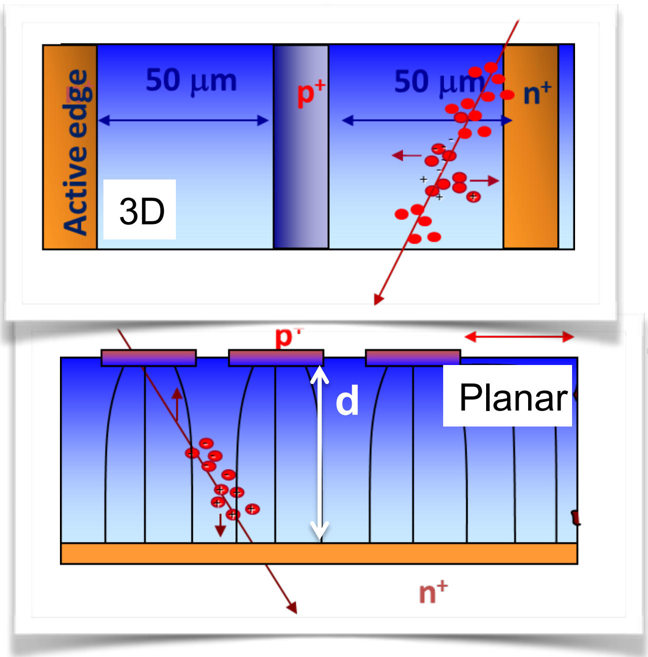
Sensors

radiation-hard -> thinner sensors, less charge (hit resolution)
occupancy -> small active area (expected 3 GHz/cm^2)

Electronics

TSMC 65 nm technology

Developing small-area pixels (i.e. 25 x 100 μm^2) - 3D and thin planar (100 μm < d < 200 μm)



3D sensors:
Thicker sensor possible

Drawback:
Higher capacity
Lower yield, Higher cost
Small pitches under study

Thin planar sensors:
Low total leakage after irradiation
Less material

Drawback:
Smaller initial signal (76e$^-$/μm)
Thinning step required
Thin sensors "bow"

Common advantages:

- Short drift path
- Higher fields at same V_{bias} (Lower operation voltage and Less power consumption)

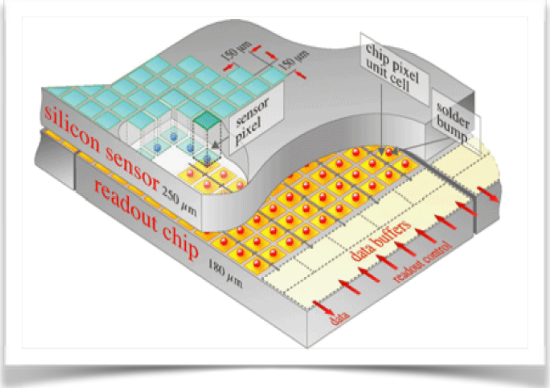
Common dis-advantages: bump bonding

Radiation Tolerance

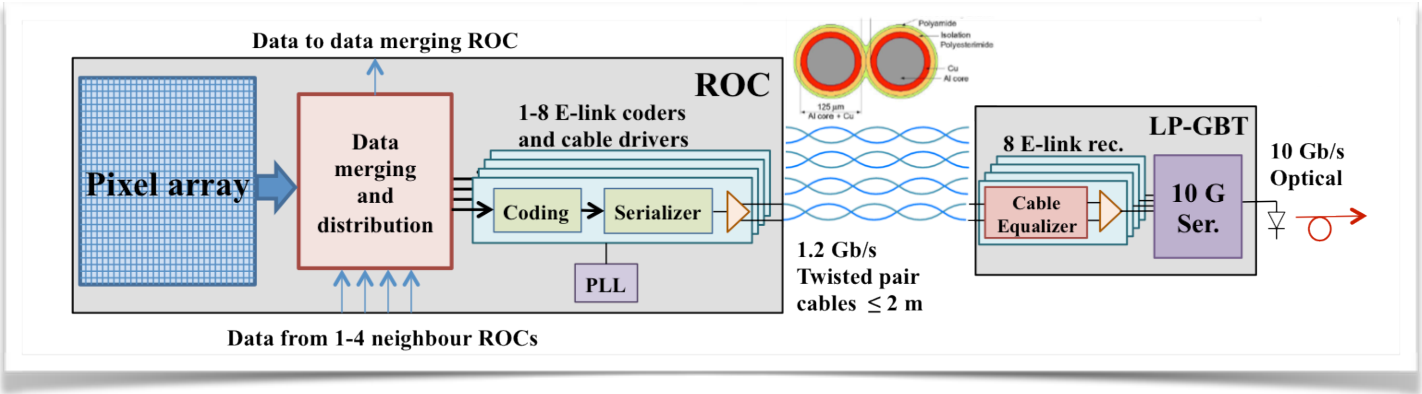
Pixel Detector (2/2)

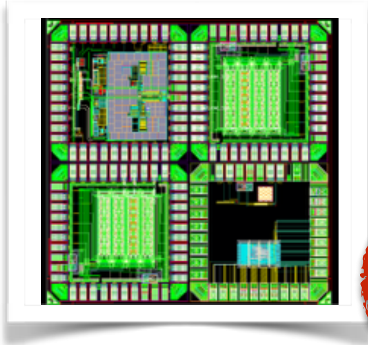
The Pixel ReadOut-Chip is developed in RD53, a large effort involving many Institutes

Testing to unprecedented levels (**1 Grad**)



Wrap up findings, derive design rules for optimal radiation tolerance





CHPIX65 project

Envisage modules with 1×4 and 2×4 chips in the barrel, possibly 1⁄2 length in the forward (1×2 and 2×2)

1.2 Gbps e-links up to 2m length from FE chips to LP-GBT

Data merging functionality: multiple links/chip (inner) and multiple chips/link (outer)

The chip can work with 1⁄2 or 1⁄4 of the channels operational

Fine-tune channel density and the link density in the different layers to reduce power and mass

Higher power but low voltage → large conductors → DC-DC not suitable → resume **serial powering**

Radiation Tolerance   Outer Tracker - Sensors (1/3)

Guidelines

Increased radiation tolerance

Online data reduction ("*pT modules*": from hits to trajectory stub)
- Tracks of charged particles with pT>~2 GeV at every bunch-crossing
- Novel concept of silicon detector modules
- Tracker into Level-1 Trigger decision

…is driving the design of modules and overall detector concept

Several sensor configurations under investigations form different foundries (FZ, dd-FZ, MCz, p-type, n-type, oxide, implants, thickness, geometry…) in order to evaluate radiation tolerance and measurement performances

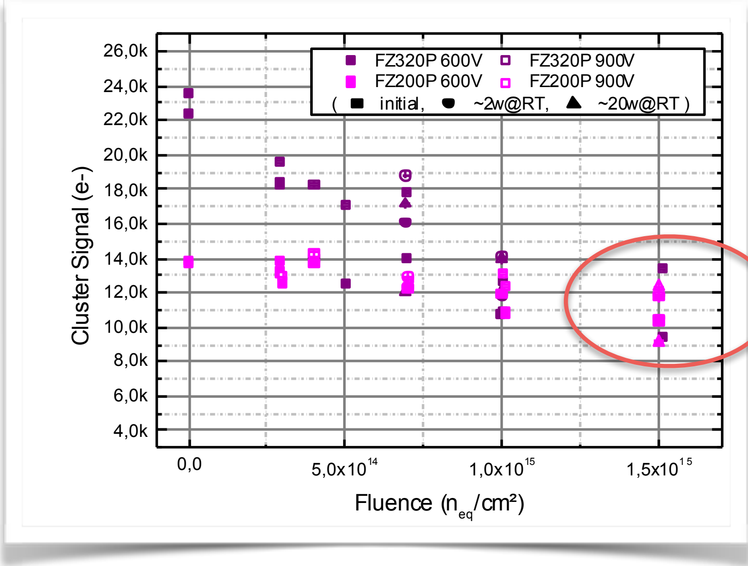
Different solutions under investigation for a L1 Track-Trigger

Outer Tracker - Sensors (2/3)

Charge collection

After heavy irradiation (~10^{15} equivalent flux) charge collected is comparable for 320 and 200 μm thick sensors (more trapping)

*In **200 μm** the leakage current is smaller (and can be operated at smaller bias)*



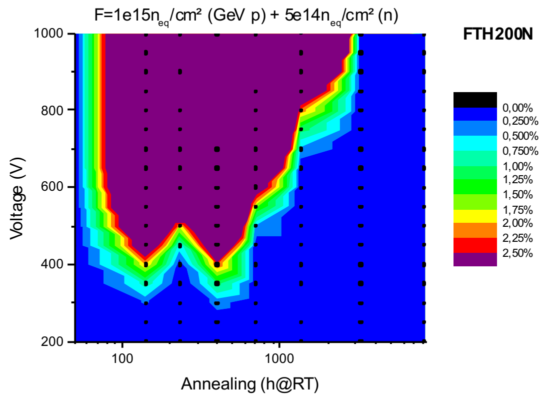


Fig: RGH in p-in-n type

In p-in-n sensors spurious signals observed (**R**andom **G**host **H**its - non gaussian noise)

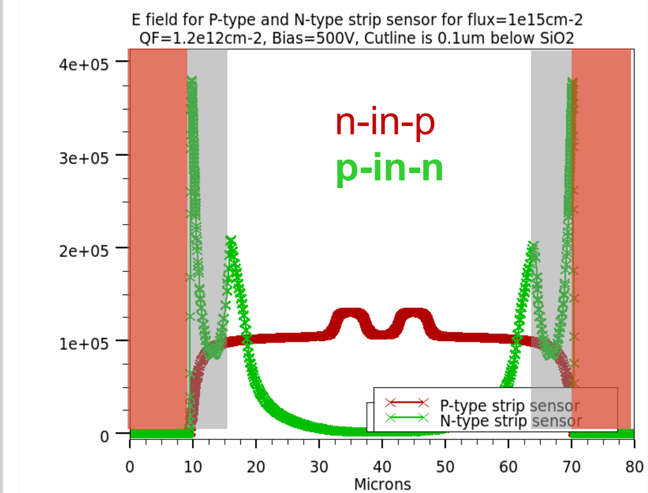
p-type not affected

T-CAD simulations:

RGH depends on p-stop concentration

Oxide charge increases (higher electric field in p-in-n, *lower in p-type*)

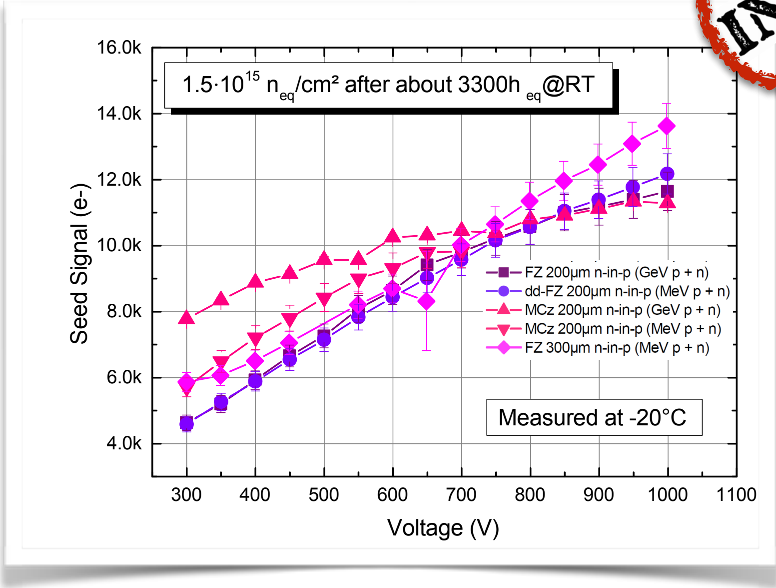
Higher electric fields at p-stop and strip edges -> "micro-discharges"



F=1×10^{15}cm^{-2} ; Q_F = 1.2×10^{12}cm^{-2}; U = 500 V; **5-trap model (Silvaco)**

Radiation Tolerance

Outer Tracker - Sensors (3/3)



Annealing

All thin p-type samples show seed signals >8ke- at 600V until about 20w@RT

+ i.e. reduce the leakage current by keeping the detector at RT for 2 weeks each year

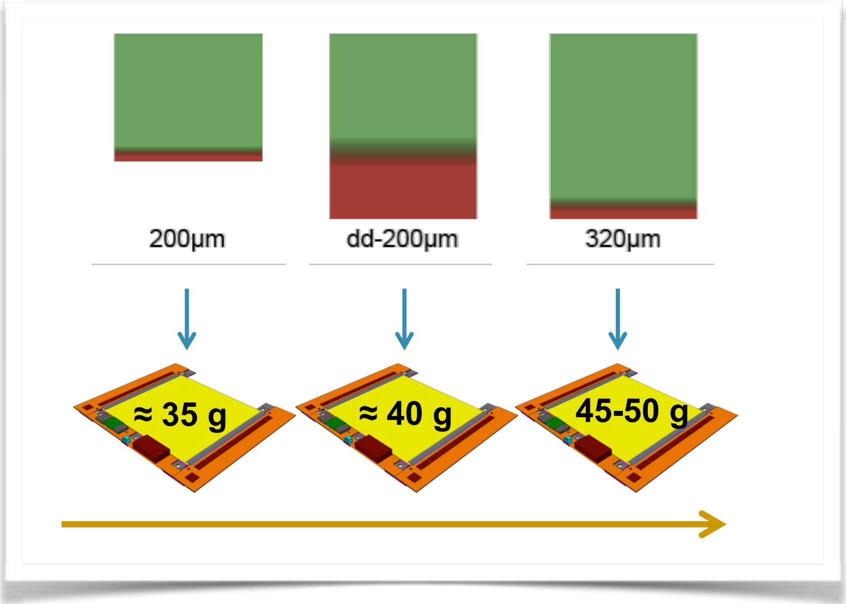
+ ***MCz material*** *shows significantly better behavior after long annealing time*

Sensor thickness

200 µm active thickness provides sufficient charge (smaller charge loss after irradiation)

Adding (inactive) silicon thickness (thermal management) increases the mass

With larger active thickness the leakage current is larger (Vbias would have to be larger)



Sensors R&D Summary and outlook

Material & Polarity

n-in-p offers robust performance after heavy irradiation

MCz would be the preferred option

+ Long annealing times with no adverse effects
+ Lower V_{bias}, mitigating cooling requests

Thickness

200 µm active and physical thickness is the preferred option

+ Sufficient charge, good annealing behavior, lower I_{dark} and V_{bias}

200 µm active 320 µm physical is a good backup

+ Adds 60 kg of inactive material uniformly distributed in the tracking volume
+ Active thickness can also be fine-tuned

Ongoing

Qualification of vendors, fine-tuning of sensor design and market survey

HPK - well-established reliable vendor, excellent quality; dd-320 µm FZ 6” material available at good price, thinning expensive

Infineon - development ongoing for several years; produced 300 µm p-in-n sensors with adequate quality; now moving to n-in-p, exploring thinning and production on 8”; dd-FZ material also available

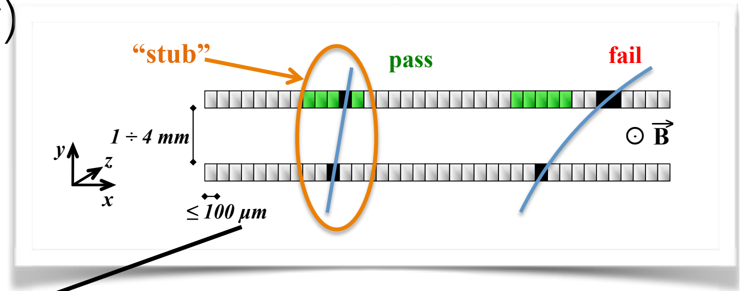
Work with other possible vendors (**SMIC/LFoundry**, **Novati**, **CiS**...)

Module prototyping and preparation for QA in several labs

General L1 Tracking and Tracker Layout

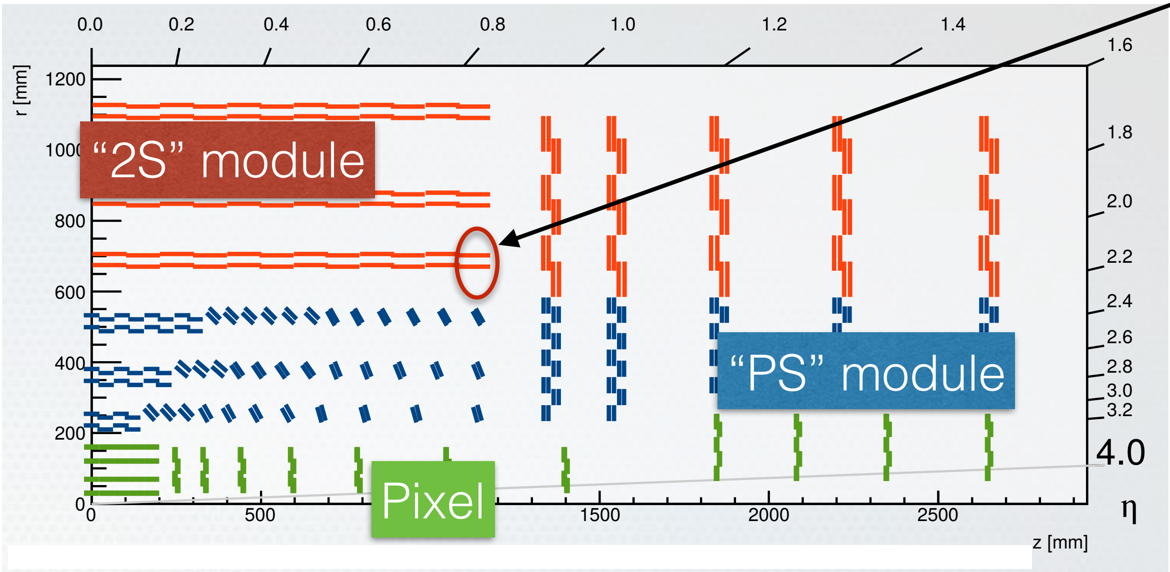
Expected rates from particles and jet rate -> **tracker have to join L1T** (lower kinematical threshold will exploit physics performances)

Tragets Reconstruct track with pT>2 GeV
Longitudinal resolution on primary vertex ~1 mm (PU rejection)
Tracker reconstruction in less than 12 μs (L1 latency)



How ? Design modules with **pT discrimination**
Correlate signals in two closely-spaced sensors

Form **HITS** to **STUBS**



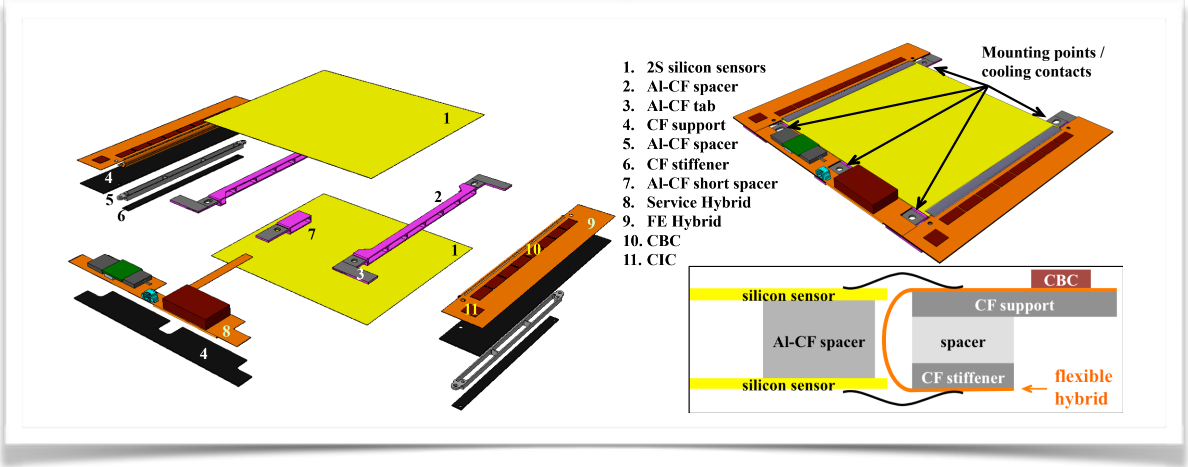
Sensitivity to pT from measurement of Δ(Rϕ)
- For a given pT, Δ(Rϕ) increases with R
- Barrel - ΔR is given directly by the sensors spacing
- End-cap - depends on the location (tg θ)

Optimize selection window and sensors spacing for a consistent pT selection

The concept works down to certain radius
- i.e. 2 GeV -> R~20 cm, 4T and 100 μm pitch

pT modules

2S - 2 strip sensors



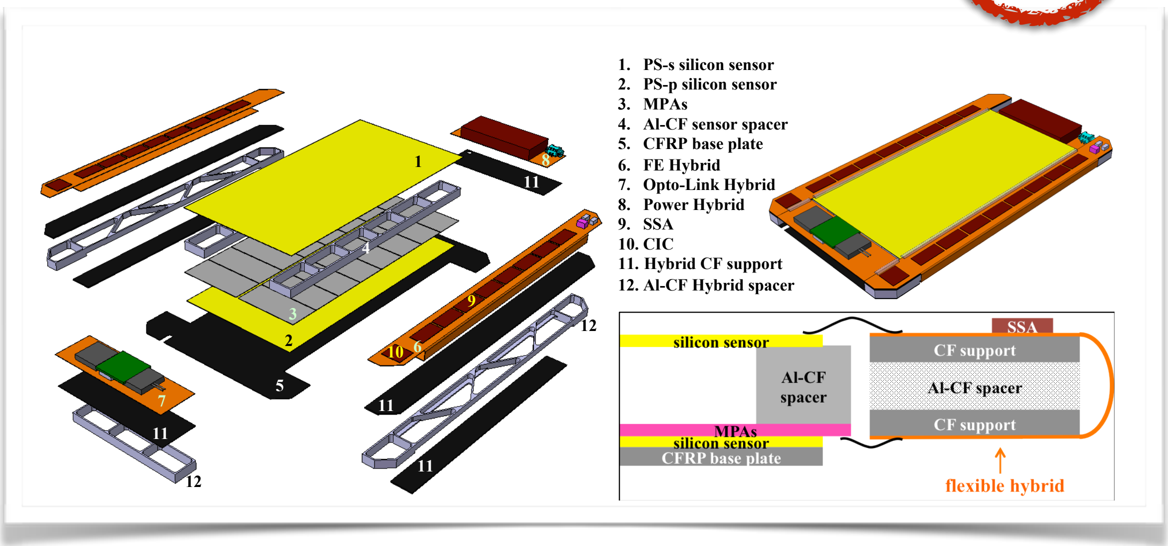
2×1016 Strips: 5 cm x 90 µm
2×1016 Strips: 5 cm x 90 µm
P~5W, ~ 90 cm2 active area
Spacing 1.8 mm and 4.0 mm

5 mounting/cooling points – peripheral cooling

Al-CF spacers provide good thermal conduction, and enable simple, high-precision assembly with ~ no CTE mismatch

Hybrids are laminated on the CF supports by the company

PS - mixed pixel/strip sensors



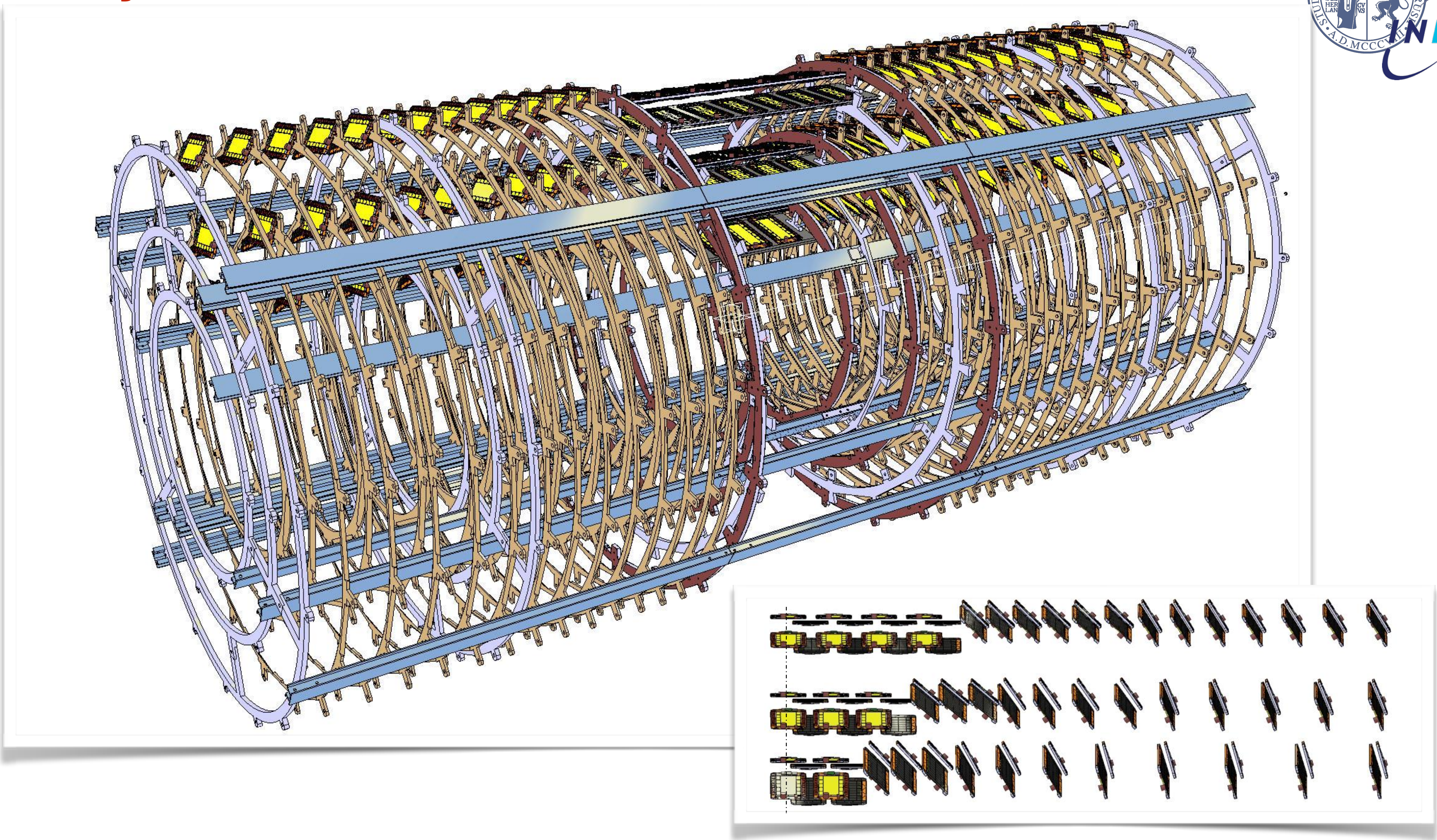
2×960 Strips: 2.5 cm × 100 µm
32×960 Pixels: 1.5 mm × 100 µm
P~7W, ~ 45 cm2 active area
Spacing 1.6 mm, 2.6 mm and 4.0 mm

Heat dissipation in the MPA requires large area cooling contact

Cooling through CF base plate, glued on a cold surface on the supporting mechanics

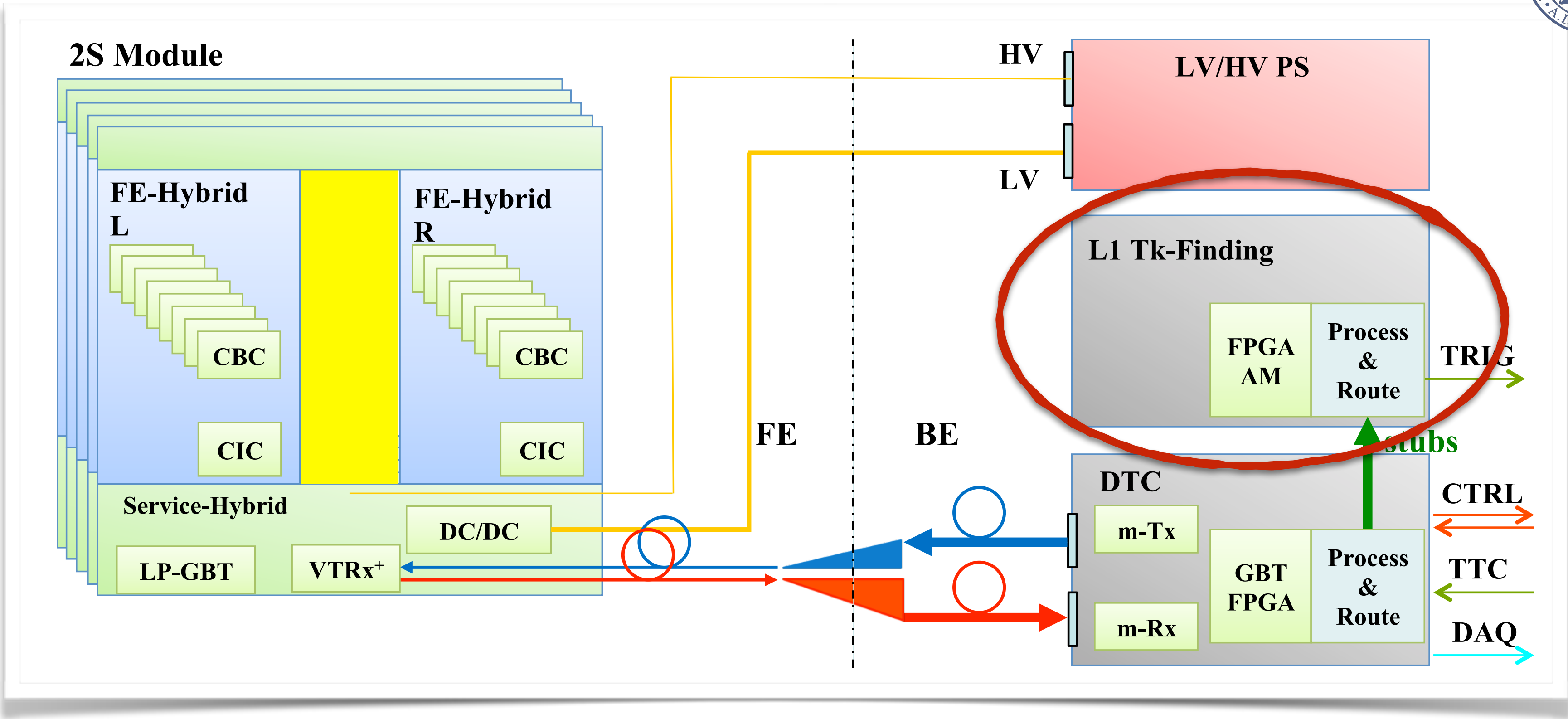
Module assembly starts from the base plate
Additional spacer under the Opto-Link Hybrid, wire-bonded to the FE Hybrids

3D Layout - inner



…in a tilted geometry: high stub-finding efficiency with less modules

Electronics and Data Flow



8 CBCs/side, 130CMOS, bump-bonded on the flex hybrids together with the passive components

+ 800 bumps @ 250 µm pitch
+ 127×2 channels, performs top-bottom correlations

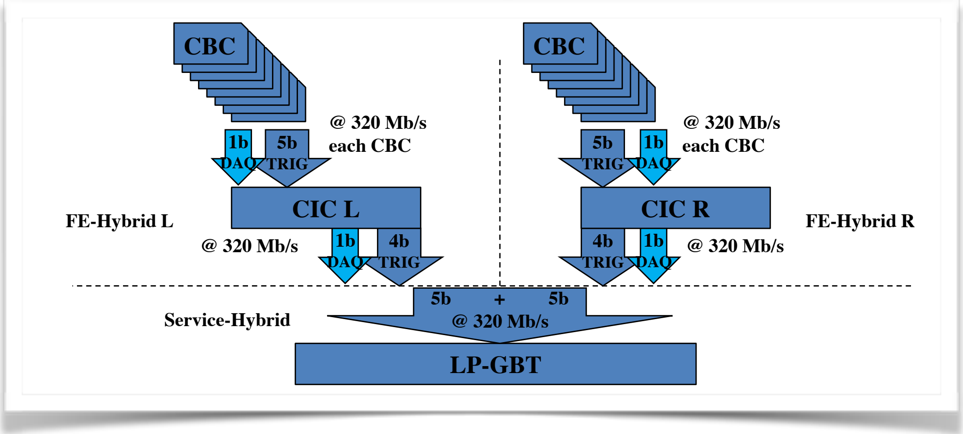
Sensors wire-bonded to high-density FE hybrid

Wirebonds from FE Hybrid to Service Hybrid

FE hybrid implements all line routing (data, control, power)

Sensors → CBCs (CMS Binary Chip), CBCs → CIC, CIC → LP-GBT on Service hybrids

Power from Service Hybrid to all chips



3.2 Gb/s available bandwidth in the LP-GBT

L1 Tracking

Three methods under study

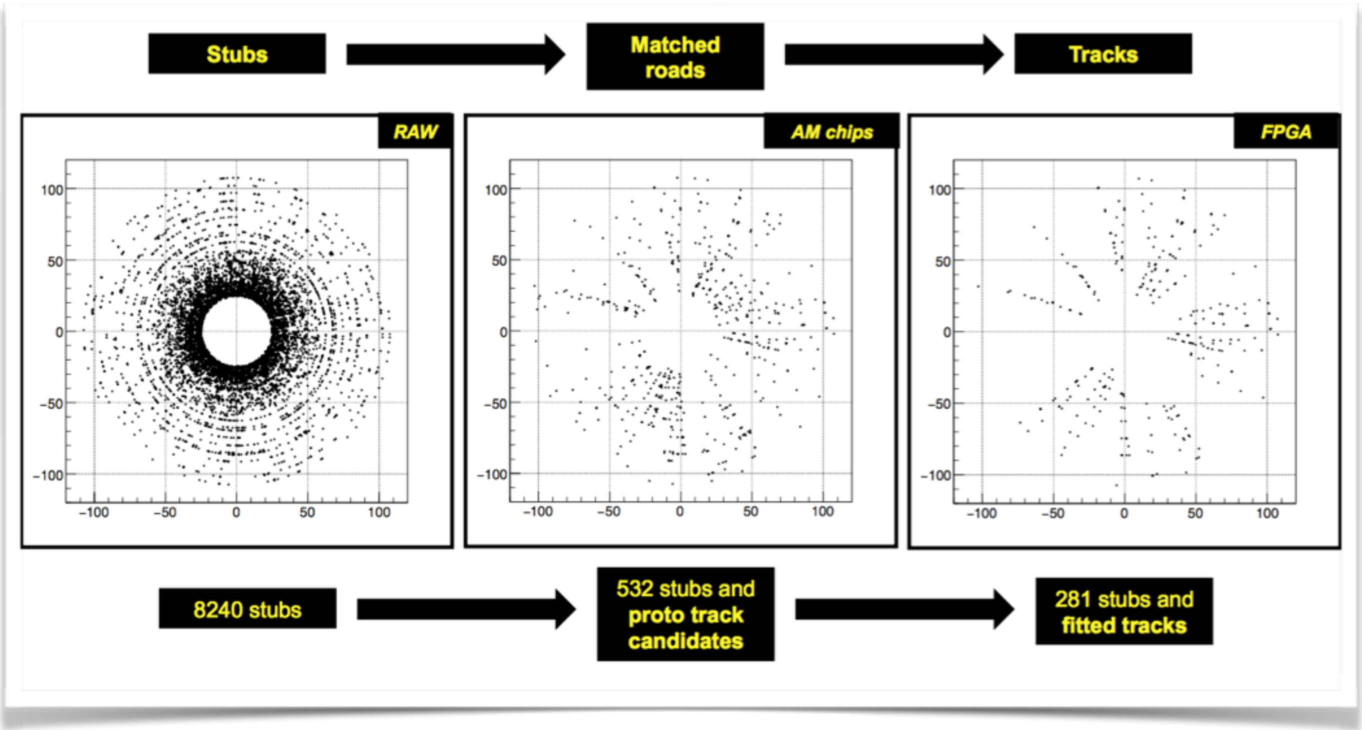
1) Associative Memories + track fitting (discussed here)

2) Time-Multiplexed architecture – Hough Transform + track fitting

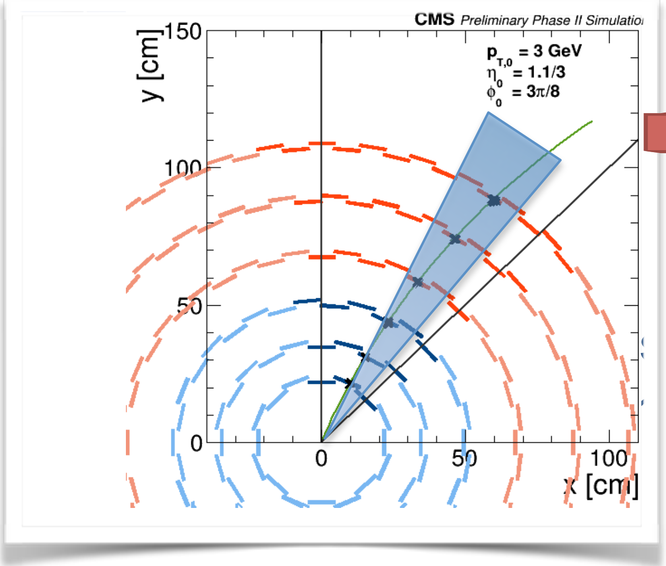
3) Tracklet-seeded road search

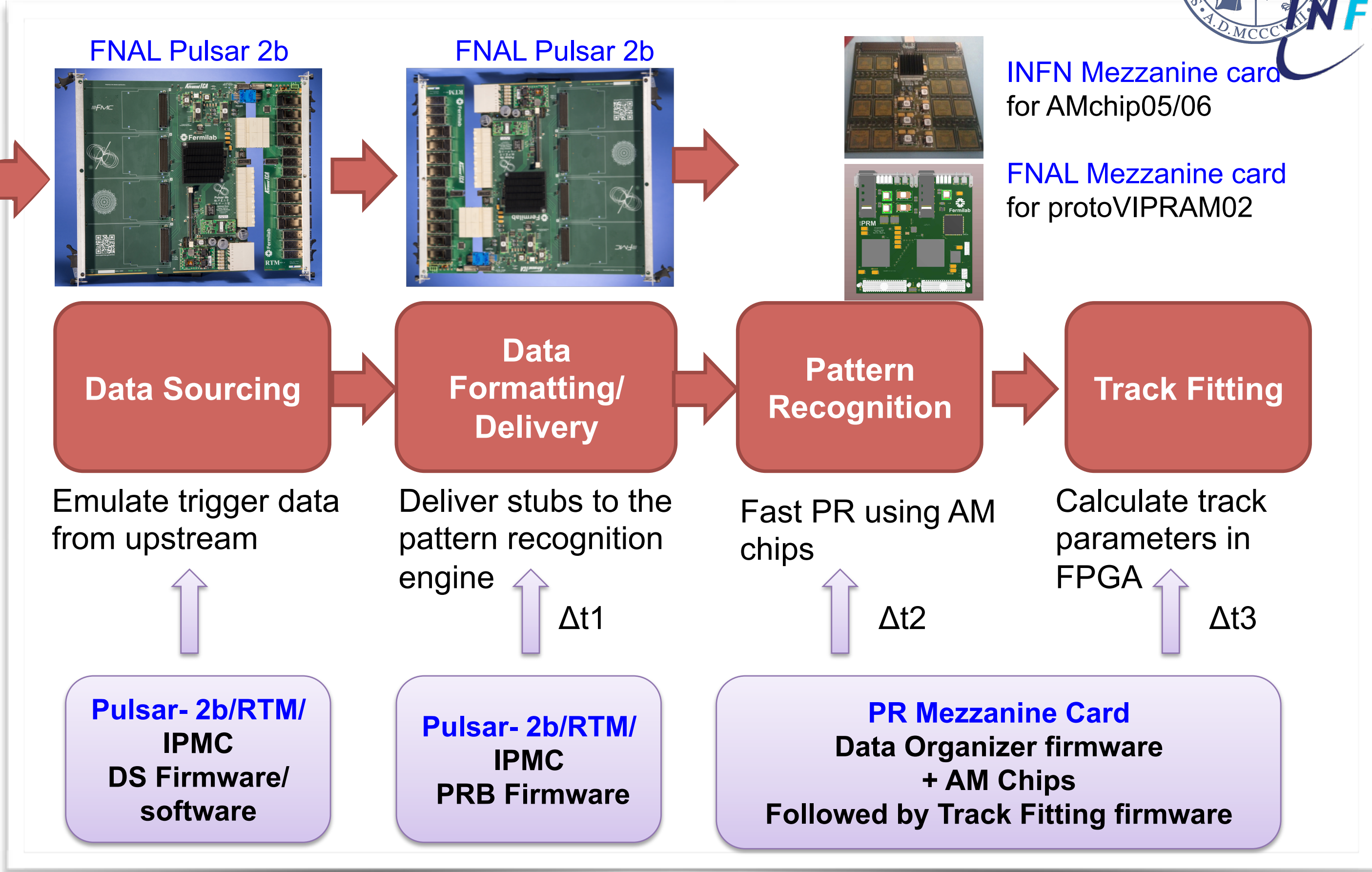
Large bank of patterns ("roads") stored in a dedicated Associative Memory chip

- Roads are defined with coarse-resolution coordinates
- Stub coordinates are loaded in the Memory
- Matched patterns are the track candidates
- Refit track candidates with full-resolution coordinates
- Achieve ultimate resolution, remove fake combinations / duplicates



L1 Tracking





Challenging: several thousand of tracks, high resolution parameter in few microsecond

Δt1 (Data Delivery) + Δt2(AM) + Δt3 (TF) ~ 6 us in order to fit available L1 latency

Full demonstrator (40 simulated modules) expected by the end of this year

Physics requests and detector constraints

Cutting edge technology and ongoing R&D

Radiation Tolerance

pT Track and L1-Trigger

INFN - local expertise in

Detector development

Ongoing China/Italy partnership in particle detectors and industrial liaison

CMS Tracking System and INFN

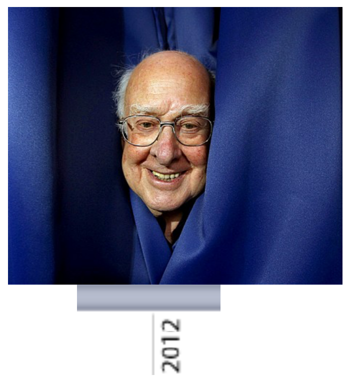
~ Jan 1990 R&D projects
Apr 1992 CMS Letter of Intent
Dec 1994 Technical Proposal
Apr 1998 Tracker Technical Design Report
Oct 1999 Front End Readout ASIC in 0.25μm CMOS
Dec 1999 Decision to construct all Silicon Tracker
Feb 2000 Tracker Technical Design Report Addendum

from R&D…

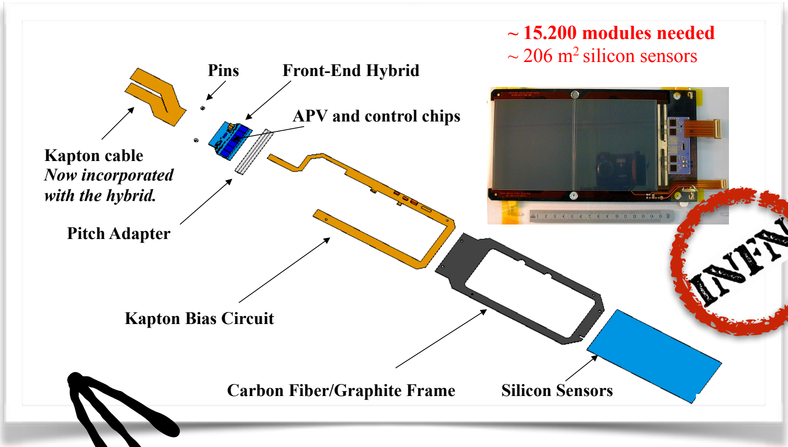
Apr 2006 Module production completed
Nov 2006 Tracker integration complete
Dec 2007 Tracker inserted in CMS
Mar 2008 Tracker connections completed
Nov 2009 Tracker ON with LHC beam

…to operations

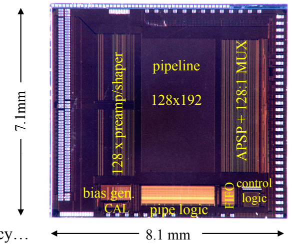
…

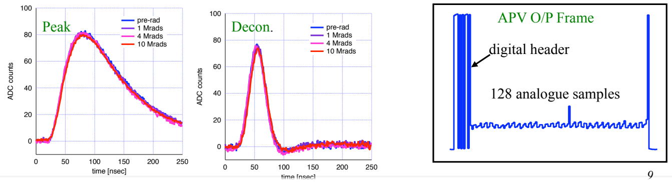


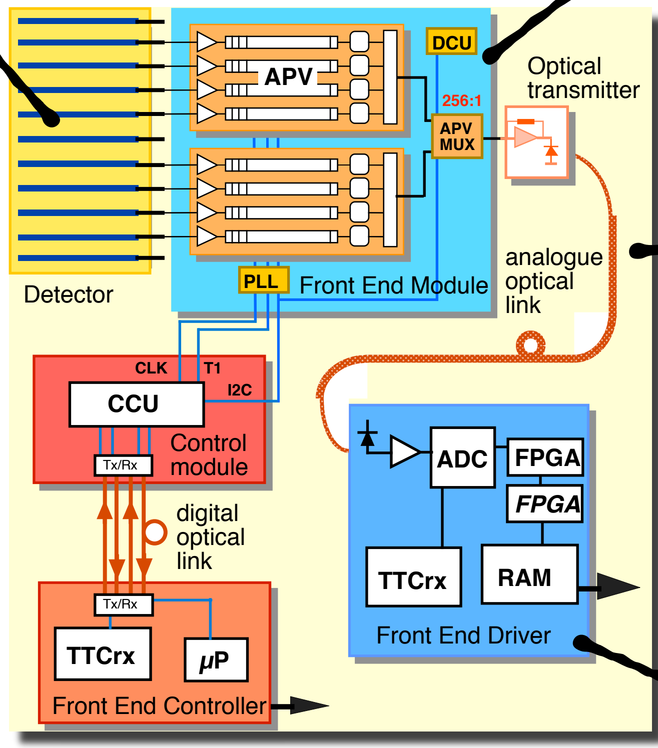
CMS Tracking System and INFN

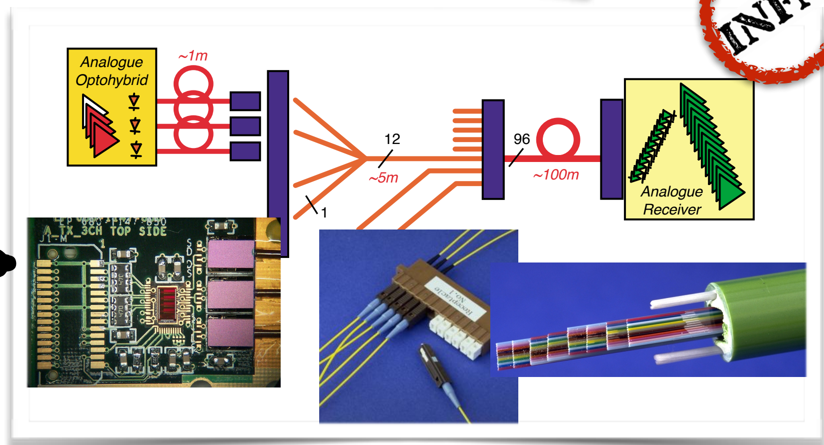


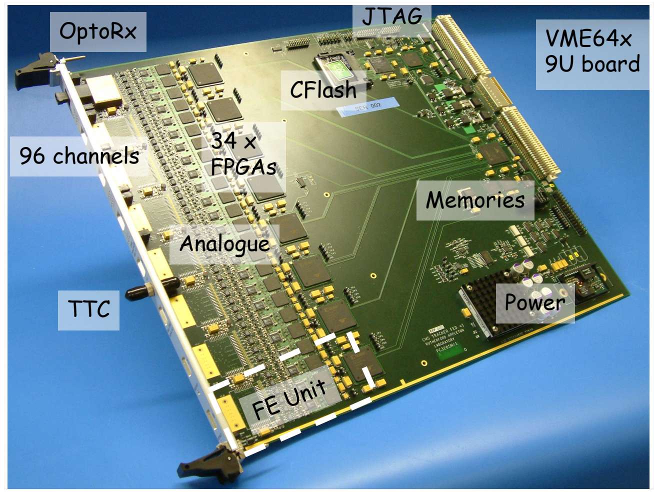
- Main features (innovative, at the time)
  - Commercial 0.25μm IBM CMOS
  - 128 readout channels
  - 50 ns CR-RC amplifier
  - 192 cell pipeline memory
  - alternate operating modes
    - peak & deconvolution
    - on-chip analogue signal processing
  - various ancillary functions
    - eg calibration, I²C, programmable latency…



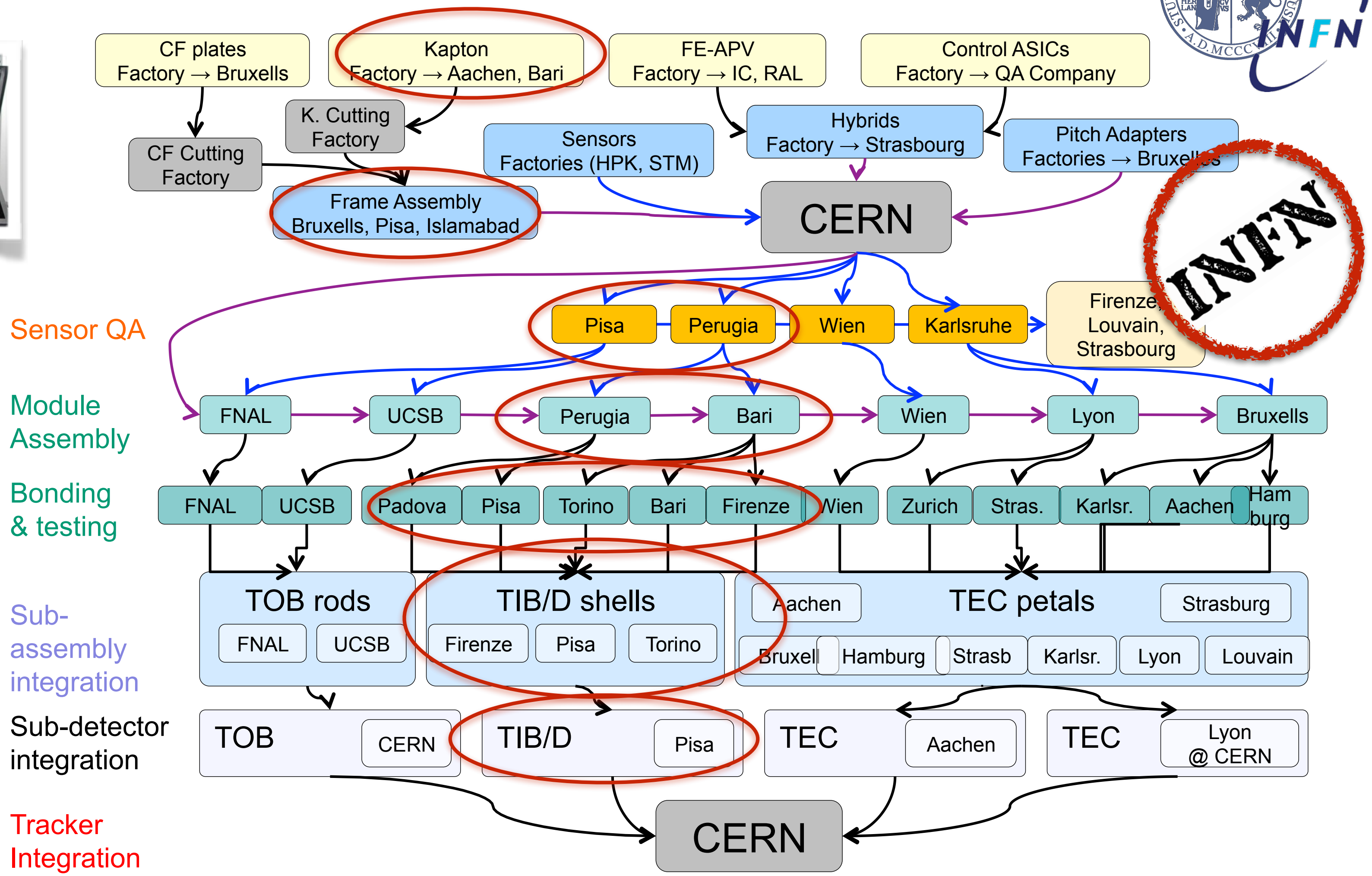


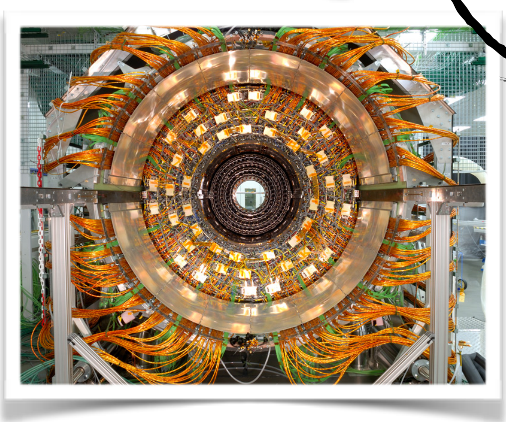


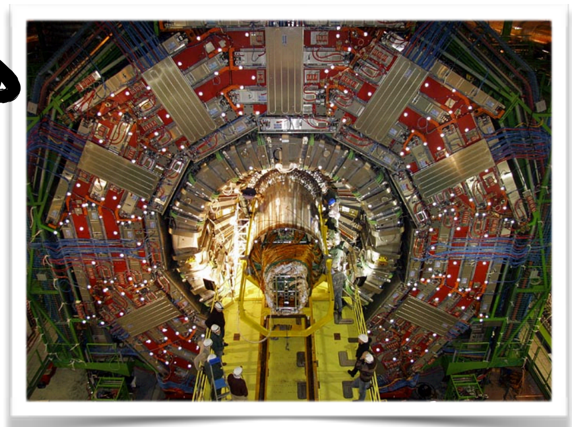


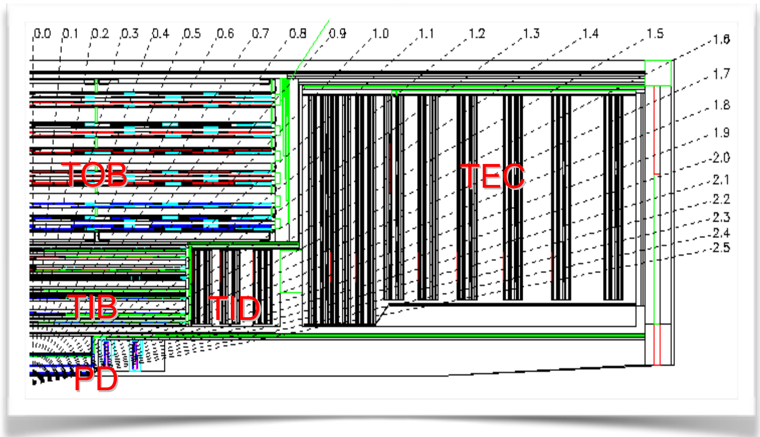


CMS Tracking System and INFN









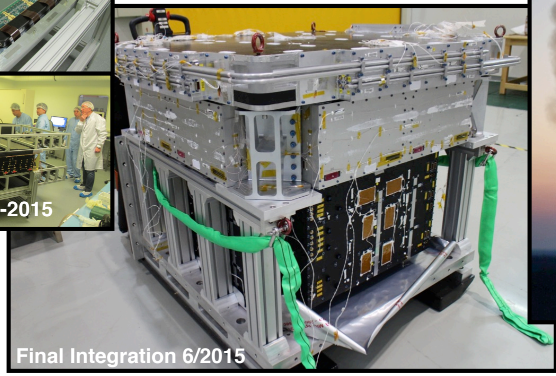
Partnership and Industrial Liaison

Chinese Research Centers, Universities and Chinese Space Agency together with INFN are involved on different projects, especially in the Astroparticle field. *Perugia-INFN* and few others are involved in partnerships for experiments design, tracking system construction and data analysis (i.e. AMS-02 and DAMPE for anti-matter search and cosmic rays physics, LIMADOU satellite to study ionospheric e.m. perturbation associated to earthquakes).

i.e. DAMPE


MOU - April 30th 2013 (CAS, Uni-Geneve and INFN)


STK Assembly (IHEP/INFN) 2014-2015


Final Integration 6/2015

DAMPE-STK collaboration and activity sharing:

Institute of High Energy Physics, CAS, Beijing
Prof. H. Wang, Dr. W. Peng et al.

INFN Perugia, Italy
Dr. G. Ambrosi, Dr. M. Ionica et al.

INFN Bari, Italy
Dr. F. Gargano, Dr. N. Mazziotta et al.

University of Geneva, Switzerland
Prof. M. Pohl, Prof. X. Wu et al.

IHEP
Coordination and interface with the satellite management
Readout and power electronics, interface with the satellite hardware and software

INFN and DPNC
Detector design and production
Detector quality assurance and performance
Detector performance test (cosmic, test beam)
Detector space qualification

Partnership and Industrial Liaison

LFoundry is an integrated circuit wafer foundry headquartered in Italy, which is owned by LFE and MI (Italy/Germany)

SMIC is the largest and most advanced foundry in Mainland China and one of the leading semiconductor foundries in the world, recently purchased a 70% stake of LFoundry

"The union of Chinese and Italian enterprises in the semiconductor industry will bring China market opportunities to LFoundry and more potential European customers to SMIC. Both SMIC and LFoundry can further develop the business potential of the Euro-Asia market." (press release)

INFN (Perugia, Trento, Torino…) and **LFoundry** collaborate in different interesting projects on silicon photomultipliers, embedded electronics, monolithic CMOS…

LFoundry/SMIC funded PhDs fellowships to University of Perugia for engineering topics also related to HEP projects

LFoundry/SMIC is participating to the CMS "qualification of vendors step" aiming to be selected to provide silicon sensors for HL-LHC CMS Tracker

(fine-tuning of sensor design and market survey is ongoing)

Conclusions

Some of the major challenges for a silicon tracker at future collider can be faced extending what has been learned in terms of past experience and present R&D activity for HL-LHC, especially radiation tolerance technology and L1-trigger implementation

INFN has a large and diversified experience in detector construction: sensors, electronics, mechanics and operations. Its participation to the HL-LHC is in both pixel and outer-tracker CMS detectors, an optimal starting point to future colliders

Any collaboration for future preparation to CEPC-SppC will benefit from present institutional collaborations (i.e. IHEP/INFN-Perugia is a very fruitful experience) and from the high quality potential of the ongoing industrial partnership

Backup slides

The talk will focus more specifically on hadronic interactions scenario which in some case can be generalized to electron-positron collisions

INFN has a long tradition and professional expertise in tracking detectors, the present CMS tracking system is an example

A brief discussion on the R&D for the HL-LHC tracking system will be given, a useful hint for future colliders. The INFN activity is highlighted

Legacy from HL-LHC preparation

Radiation tolerance up to 3000 fb^{-1}

rad-hard technology - inner part need to be repaired/changed

Operate up to 200 <PU>

high granularity

L1 decision and DAQ compatible with higher rate and longer latency

pT modules development and increase rate from 100 to 750 kHz (up to 12.8 us)

Extended tracking acceptance

up to $|\eta|\sim 4$ (jet/vertex match in forward region)

Reduce material in the tracking volume

MB limits overall performances

Radiation Tolerance

Pixel Detector (3/3)

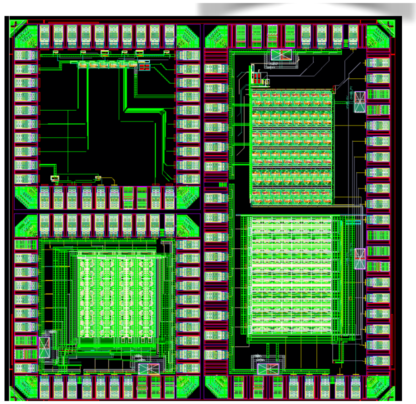
i.e. CHIPIX65 project

Radiation characterisation
- x-ray machine at LNL / Pd-INFN
  - Total Ionising Dose (TID)
  - 1 GRad in ~ 2 weeks
- Low-p at CN accelerator LNL
  - TID and Total Displacement damage
- TANDEM / SIRAD
  - Single Event Effects - with Heavy Ion
- Studies on n-MOS, p-MOS
- Irradiation of IP-block, Noise-measurements vs Irradiation

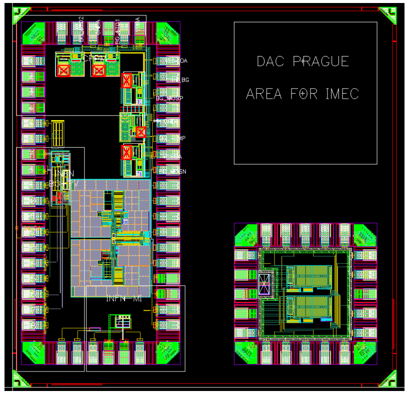
Digital Electronics:
- Simulation Framework
  - System-Verilog-UVM (VEPIX53)
- Digital Architecture Studies
- Input protocols definition
  - fast/efficient/continuos (while readout)
  - SEE robust

- Analog-VFE synch
- Analog-VFE synch

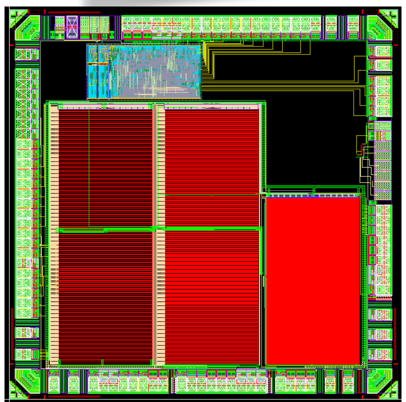
- Band Gap
- DAC
- SLVDS driver
- SLVDS receiver
- PLL
- SER
- DES
- Monitoring ADC
- SRAM EOC
- Dual Digital Cell
- DC-DC

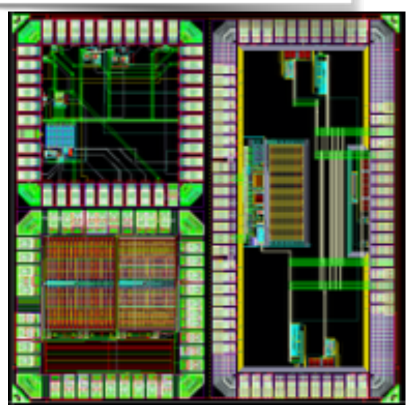


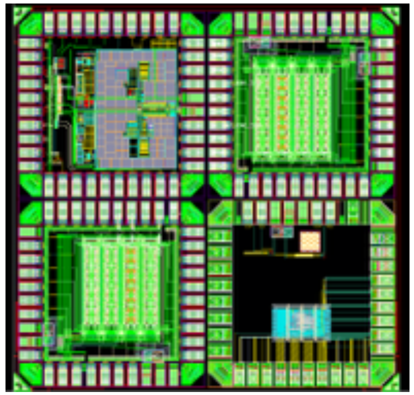
CHIPIX_VFE_1



CHIPIX_BIAS







CHIPIX_SRAM, CHIPIX_IP_3, CHIPIX_VFE_2

Pixel sensors submissions

Planar n-in-p
Test of design options and production technologies for fine pitch pixel (25 x 100 μm²)

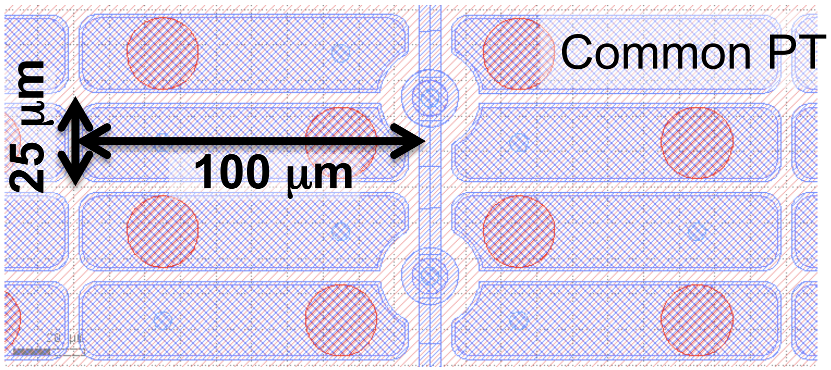
- Feasibility of small pitches
- Resolution (in test-beam)
- Radiation tolerance up to which layer?
- Spark protection

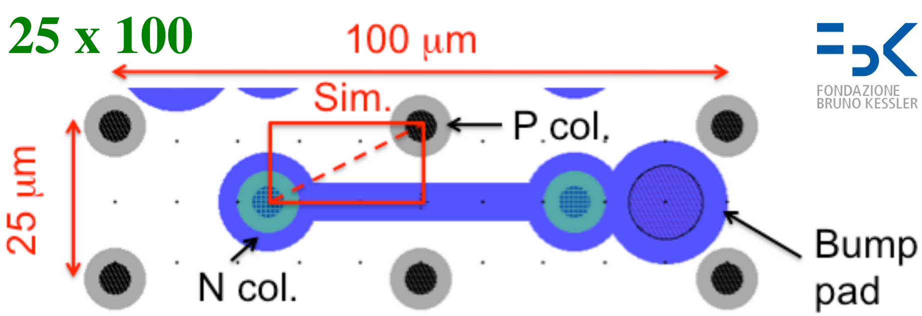
Details on the submission:

- N-in-p on 6" wafer
- 150 μm active, 200 μm physical thickness
- Comparison of p-spray and p-stop

3D
Two joint ATLAS & CMS submissions:

1. CNM
   - Test of new etching process (DRIE) to increase aspect ratio of columns
   - Trial with thicker 3D wafers
   - Radiation tolerance with fine pitch
2. FBK
   - Test of thin 3D sensors (100 μm & 130 μm)
   - Production on handle wafer
   - Radiation tolerance with thin 3D





Layout by G.-F. Dalla Betta, presented by R. Mendicino Trento Workshop 2015

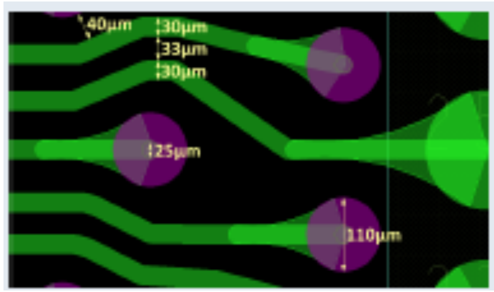
High density flex hybrids

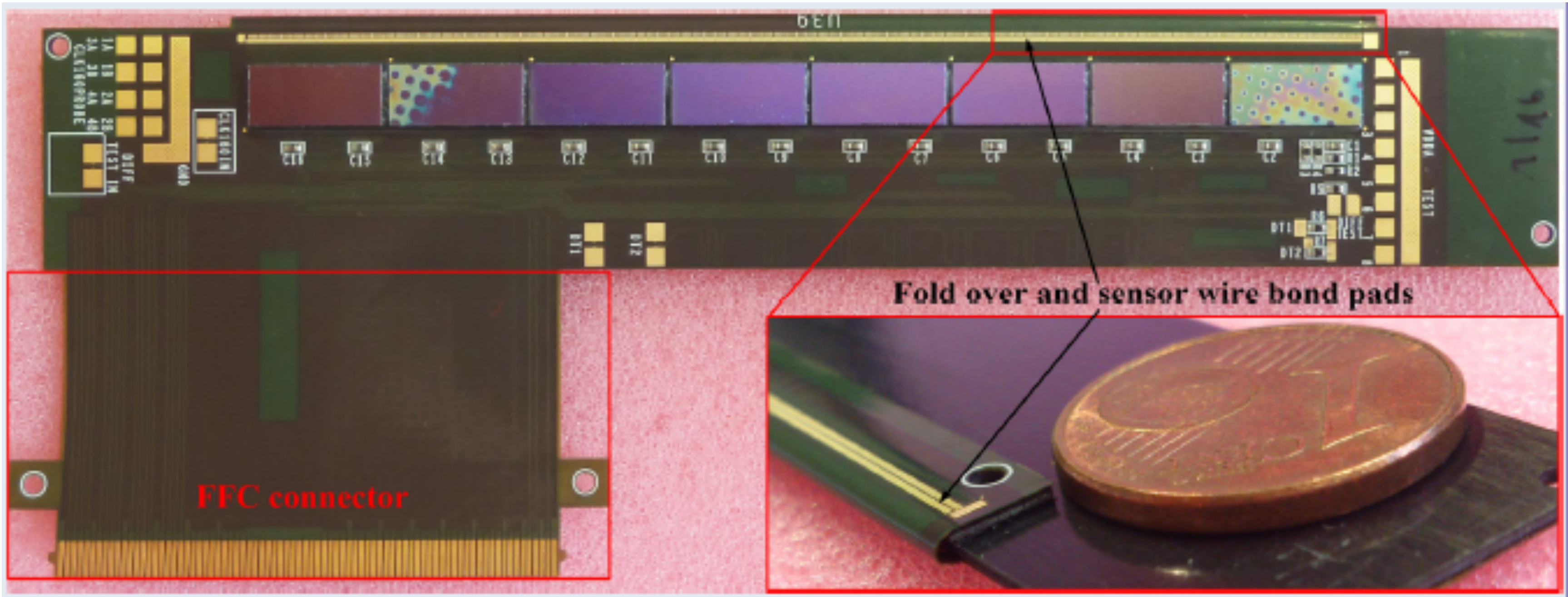
25 μm double-sided polyimide core layer, plus two single-sided 12.5 μm polyimide layers on either side. 25 μm coverlay on the bottom, solder mask on the top. Total thickness ~130 μm.

2S hybrid. Wirebonding pitch to sensor 90 μm × 2 sensors. Bump bonding pitch of CBC 250 μm, 800 bumps × 8 chips. High-density routing: thinnest line 30 μm with spacing 33 μm.

Prototype with Flat Flexible Connector (CIC not yet available).
Eventually will be wire bonded to the Service Hybrid.

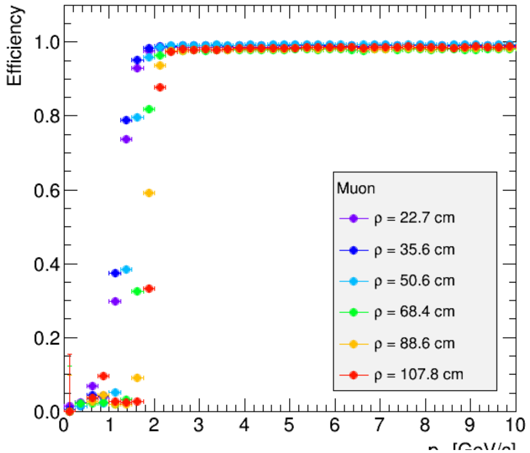
Key element for a lightweight module design!

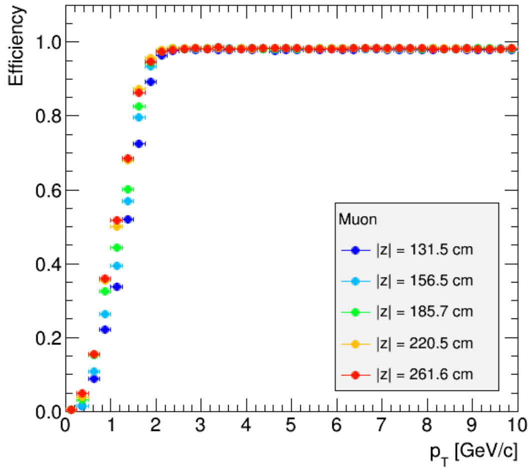


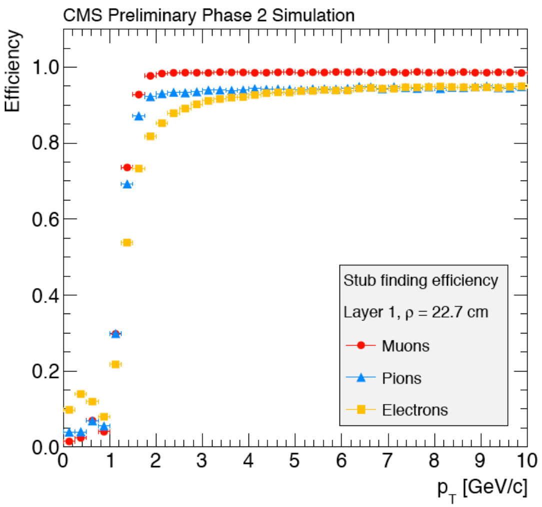


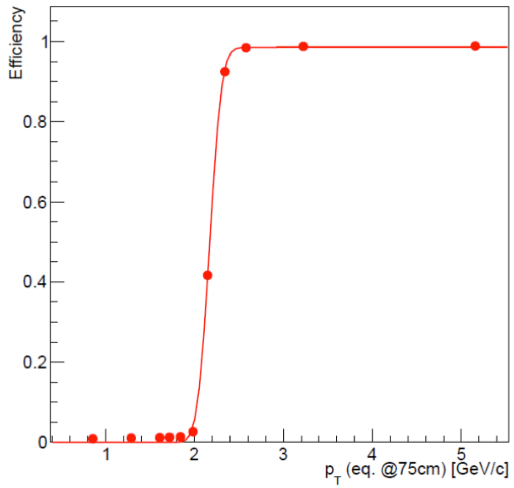
Stub finding performance

- Muon stub finding efficiency in all layers (barrel, endcap)
- Barrel layer 1 for muons, pion electrons
  - Effect of interactions
- Efficiency measured on DESY beam with 2-CBC2 module prototype









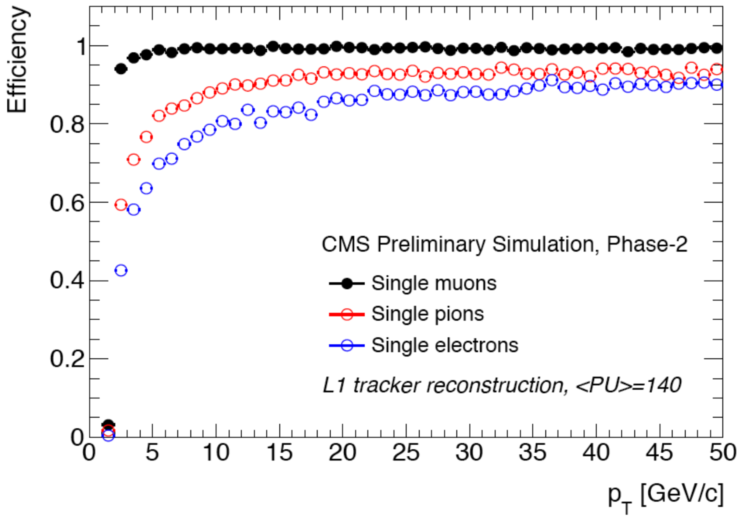
p_T simulated with module tilt

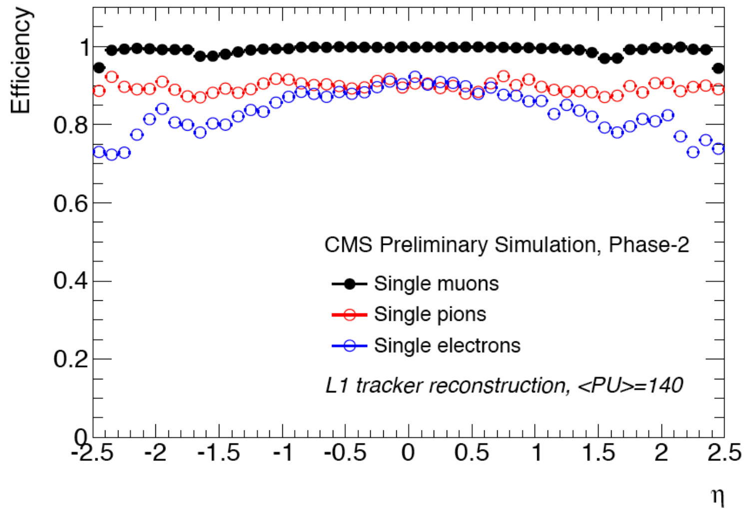
Selected threshold equivalent to a nominal p_T cut of 2.14 GeV @ 75 cm

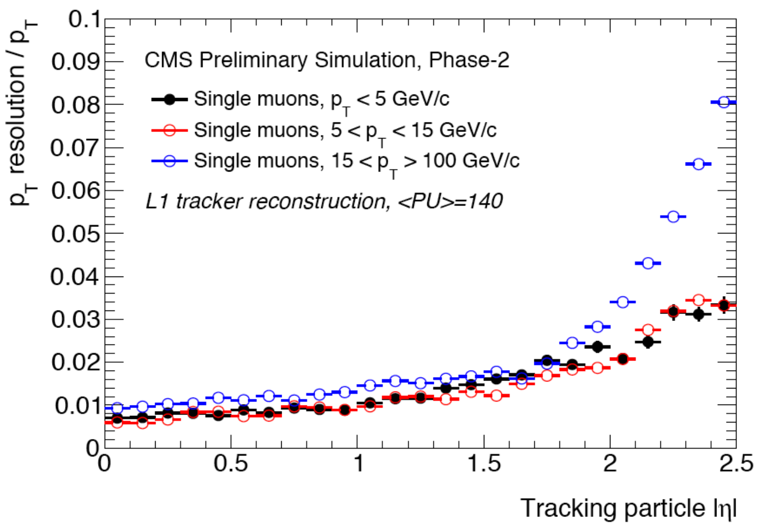
Fit to data gives effective threshold of 2.2 ± 0.1 GeV

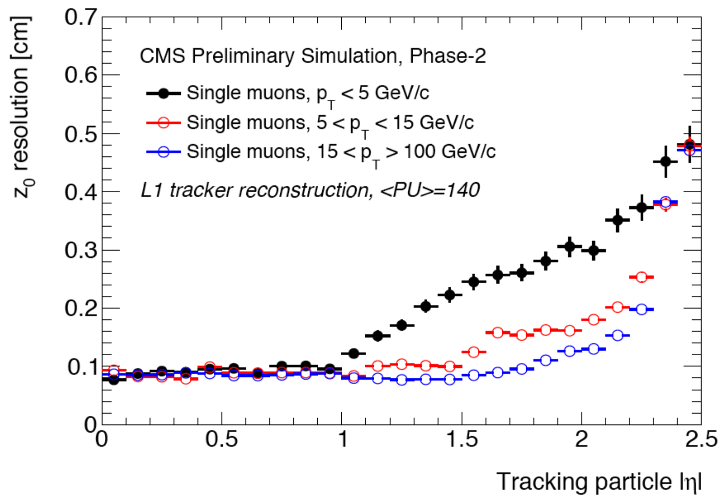
Level-1 track finding

- Track finding performance taken from “tracklet” method
  - N.B. Track finding not demonstrated in hardware
    - Indication of the performance that should be achievable









SMIC Acquires LFoundry and Enters into Global Automotive Electronics Market

AVEZZANO, Italy and SHANGHAI, China, June 24, 2016 - Semiconductor Manufacturing International Corporation ("SMIC"; NYSE: SMI; SEHK: 981), one of the leading semiconductor foundries in the world and the largest and most advanced foundry in mainland China, jointly announces with LFoundry Europe GmbH ("LFE") and Marsica Innovation S.p.A. ("MI"), the signing of an agreement on June 24, 2016 to purchase a 70% stake of LFoundry for a consideration of 49 million EUR. LFoundry is an integrated circuit wafer foundry headquartered in Italy, which is owned by LFE and MI. At the closing, SMIC, LFE and MI will own 70%, 15% and 15% of the corporate capital of the target respectively. This acquisition benefits both SMIC and LFoundry, through increased combined scale, strengthened overall technology portfolios, and expanded market opportunities for both parties to gain footing in new market sectors. This also represents the Mainland China IC foundry industry's first successful acquisition of an overseas-based manufacturer, which marks a major step forward in internationalizing SMIC; furthermore, through this acquisition, SMIC has formally entered into the global automotive electronics market.

As the leading semiconductor foundry in Mainland China, in the first quarter of 2016, SMIC recorded profit for the 16th consecutive quarter with revenue of US$634.3 million, an increase of over 24% year-on-year. In 2015, SMIC recorded annual revenue of US$2.24 billion. In fiscal year 2015, LFoundry revenue reached 218 million EUR.

This acquisition will bring both companies additional room for business expansion. At present, SMIC's total capacity includes 162,000 8-inch wafers per month and 62,500 12-inch wafers per month, which represents a total 8-inch equivalent capacity of 302,600 wafers per month. LFoundry's capacity amounts to 40,000 8-inch wafers per month. Thus, by consolidating the entities, overall total capacity would increase by 13%; this combined capacity will provide increased flexibility and business opportunities for supporting both SMIC and LFoundry customers.

SMIC has a diversified technology portfolio, including applications such as radio frequency ("RF"), connectivity, power management IC's ("PMIC"), CMOS image sensors ("CIS"), embedded memory, MEMS, and others—mainly for the communications and consumer markets. Complementarily, LFoundry's key focus is primarily in automotive, security, and industrial related applications including CIS, smart power, touch display driver IC's ("TDDI"), embedded memory, and others. Such consolidation of technologies will broaden the overall technology portfolios and enlarge the areas of future development for both SMIC and LFoundry.

Scientific Objectives of DAMPE

- High energy particle detection in space
  - Search for Dark Matter signatures with e, γ
  - Study of cosmic ray spectrum and composition
  - High energy gamma ray astronomy

Detection of 5 GeV - 10 TeV e/γ, 100 GeV - 100 TeV CR
Excellent energy resolution and tracking precision
Complementary to Fermi, AMS-02, CALET, CREAM, …

- Follow-up mission to both Fermi/LAT and AMS-02
  - Extend the energy reach to the TeV region, providing better resolution
  - Overlap with Fermi on gamma ray astronomy
  - Run in parallel for some time

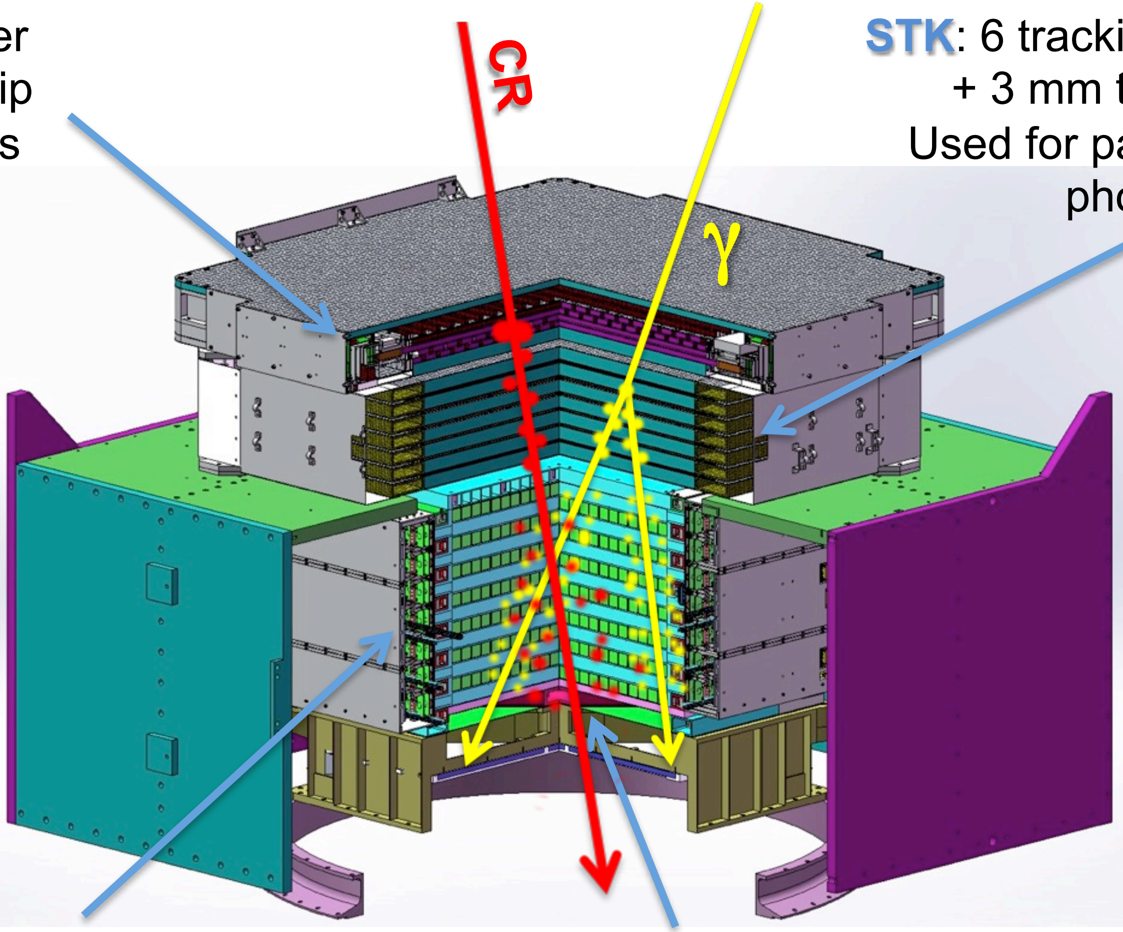
The DAMPE Collaboration

- China
  - Purple Mountain Observatory, CAS, Nanjing
    - Chief Scientist: Prof. Jin Chang
  - Institute of High Energy Physics, CAS, Beijing
  - National Space Science Center, CAS, Beijing
  - University of Science and Technology of China, Hefei
  - Institute of Modern Physics, CAS, Lanzhou
- Switzerland
  - University of Geneva
- Italy
  - INFN and University of Perugia
  - INFN and University of Bari
  - INFN and University of Lecce

The DAMPE Detector

PSD: double layer of scintillating strip detector acting as ACD

STK: 6 tracking double layer + 3 mm tungsten plates. Used for particle track and photon conversion



BGO: the calorimeter made of 308 BGO bars in hodoscopic arrangement (~31 radiation length). Performs both energy measurements and trigger

NUD: it's complementary to the BGO by measuring the thermal neutron shower activity. Made up of boron-doped plastic scintillator