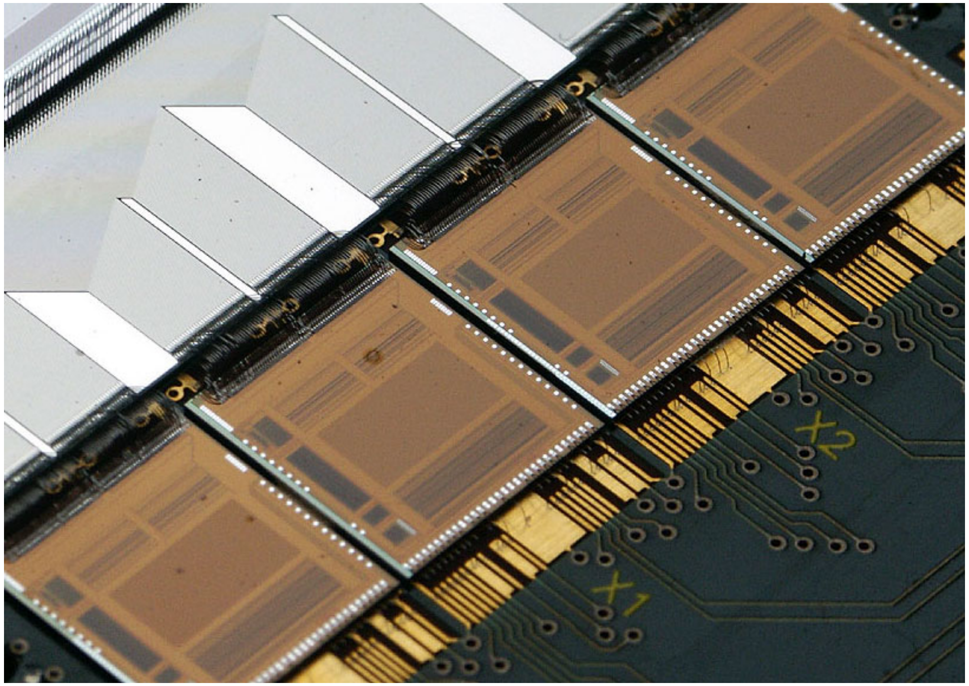


Detector Development at HEPHY

Thomas Bergauer (HEPHY Vienna)

Dark Matter Workshop

16 October 2013

Outline

- HEPHY introduction
  - Technologies
  - Groups and departments involved in Hardware
  - Equipment
- Present Hardware Projects at HEPHY
  - CMS Tracker and Trigger Operation and Upgrade
  - Belle II Silicon Vertex Detector
- Summary
  - Synergies with DM Experiments

HEPHY INTRODUCTION

- Austrian Academy of Sciences
  - Largest non-university research organization in Austria (for *basic* research)
  - 43 institutes, commissions and research units with ~1100 staff

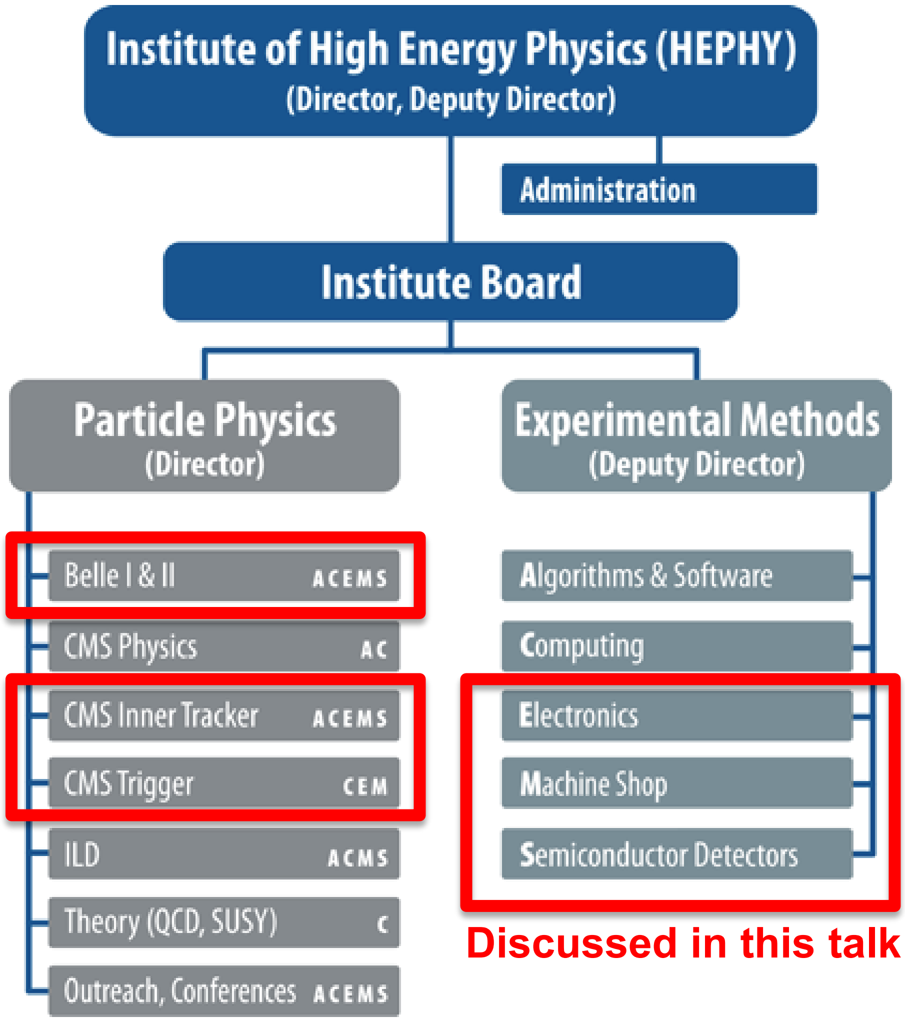
Österreichische Akademie der Wissenschaften
Hauptgebäude, Ignatz Seipel Platz

- Institute of High Energy Physics (HEPHY)
  - Located in Vienna
  - Founded in 1966 as the Austrian contribution to CERN
  - 60 employees

Institut für Hochenergiephysik

Organization Chart of HEPHY

- HEPHY has matrix-like ("orthogonal") structure of
  - **Experimental methods** (called *Fachbereiche*, i.e. groups)
  - **Particle Physics** (called *Projekte*, i.e. involvement in experiments)

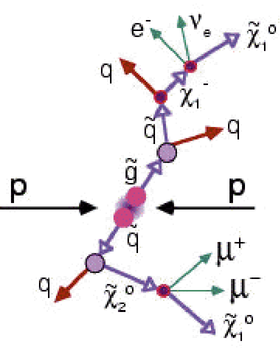


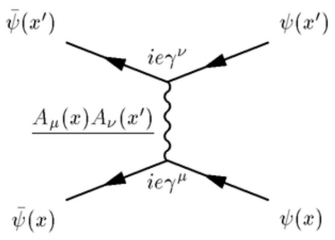
Participation in HEP Experiments (Hardware & Physics analysis):

Past	Present	Future
UA1	CMS	ILC
DELPHI	Belle	
NA48		

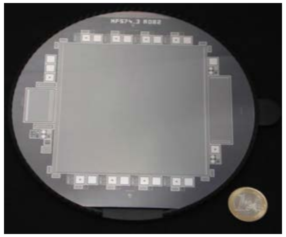
HEPHY Research Topics

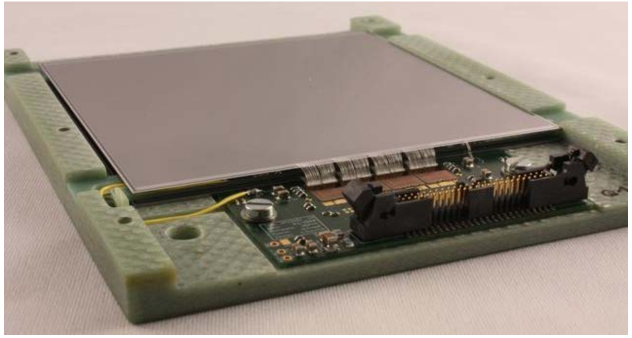
Particle physics theory: **SU**per**SY**mmetry

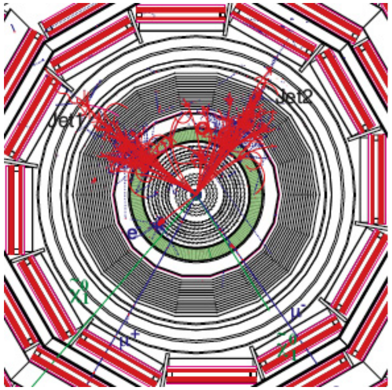




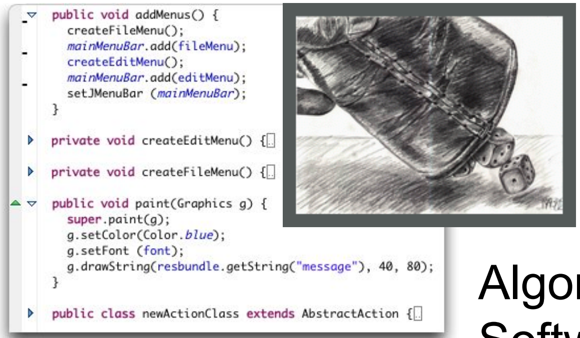
Development of
Silicon Detectors



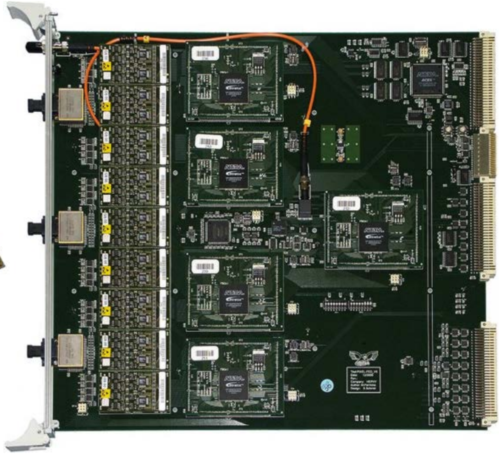




Data analysis for
CMS and Belle

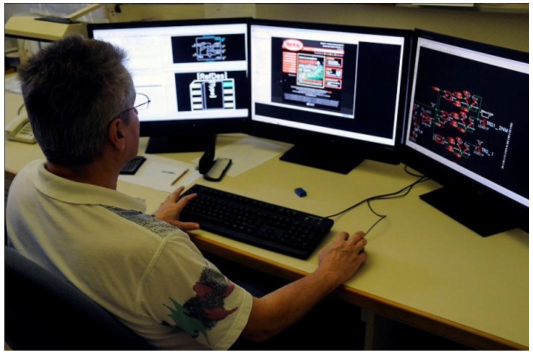


Algorithms und
Software development



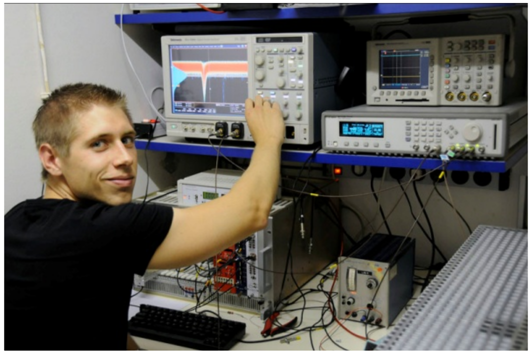
Electronics

Skills and Expertise of Hardware groups

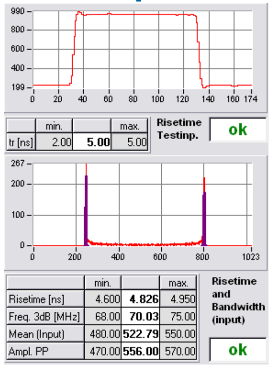


System design, PCB layout

Testing



Software development

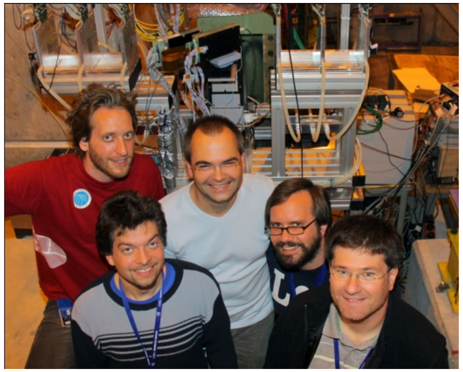


Assembly

Machining Prototyps, small series

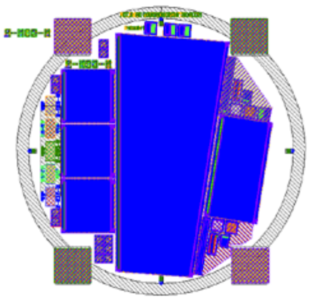
FPGA programming & simulation

Beam tests

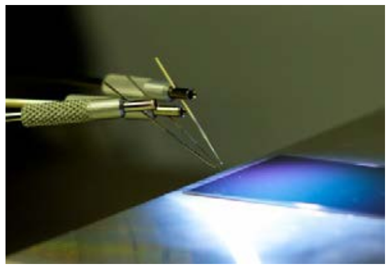


Structure & Cooling Design, etc.

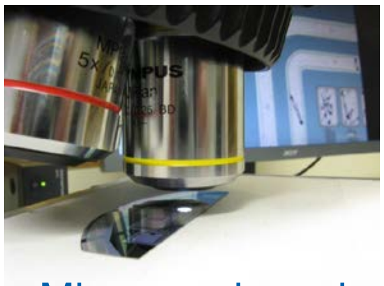
Skills and Expertise of Hardware groups



Silicon Sensor Design



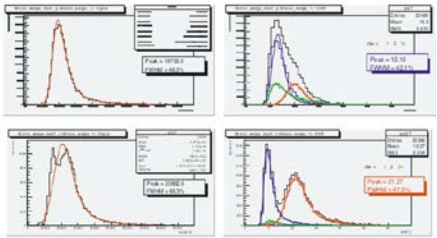
Wafer Electrical Characterisation



Microscopic and Spectroscopic Analyses

Detector Module Design and Construction

Cooperation with Institutes and Companies



Data Analysis

Beam Tests

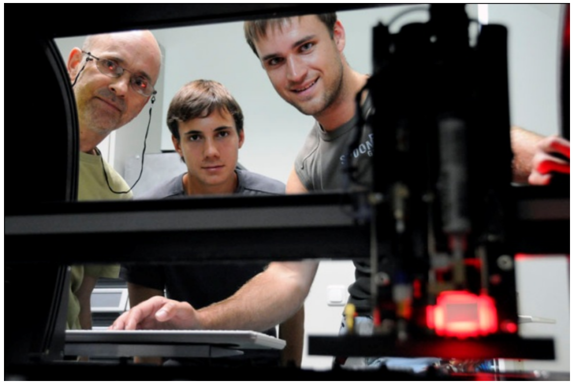
Proton-, Neutron- and Gamma-Irradiation

Equipment (highlights)

BGA soldering machine

CNC milling machine

8 GHz real time oscilloscope



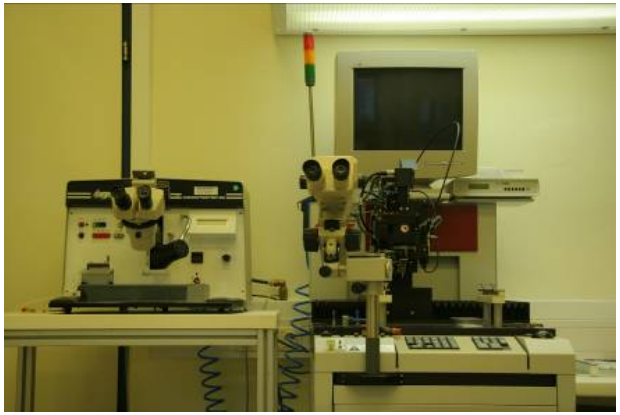
Pick & place machine

Vapor phase soldering machine

Equipment (highlights)

Several silicon wafer test stations

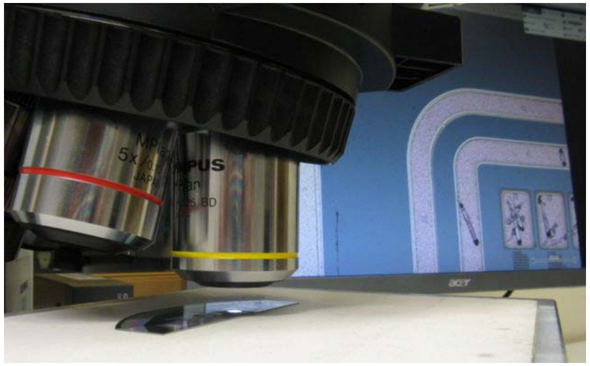
Coordinate measurement machine



Fully automatic thin-wire bonding station

Climate chamber

Microscopes with Cameras and XY-Tables



Present Activities

- **Construction of the Belle II Silicon Vertex Detector (SVD)**
  - Responsibility for Detector layout (3D CAD Design level)
  - Silicon sensors: from design to mass production (-2014)
  - Module and Ladder design, construction, assembly, testing (-2015)
  - Beam tests, Irradiation, quality control, Full readout chain (-2015)
  - Commissioning (2016)

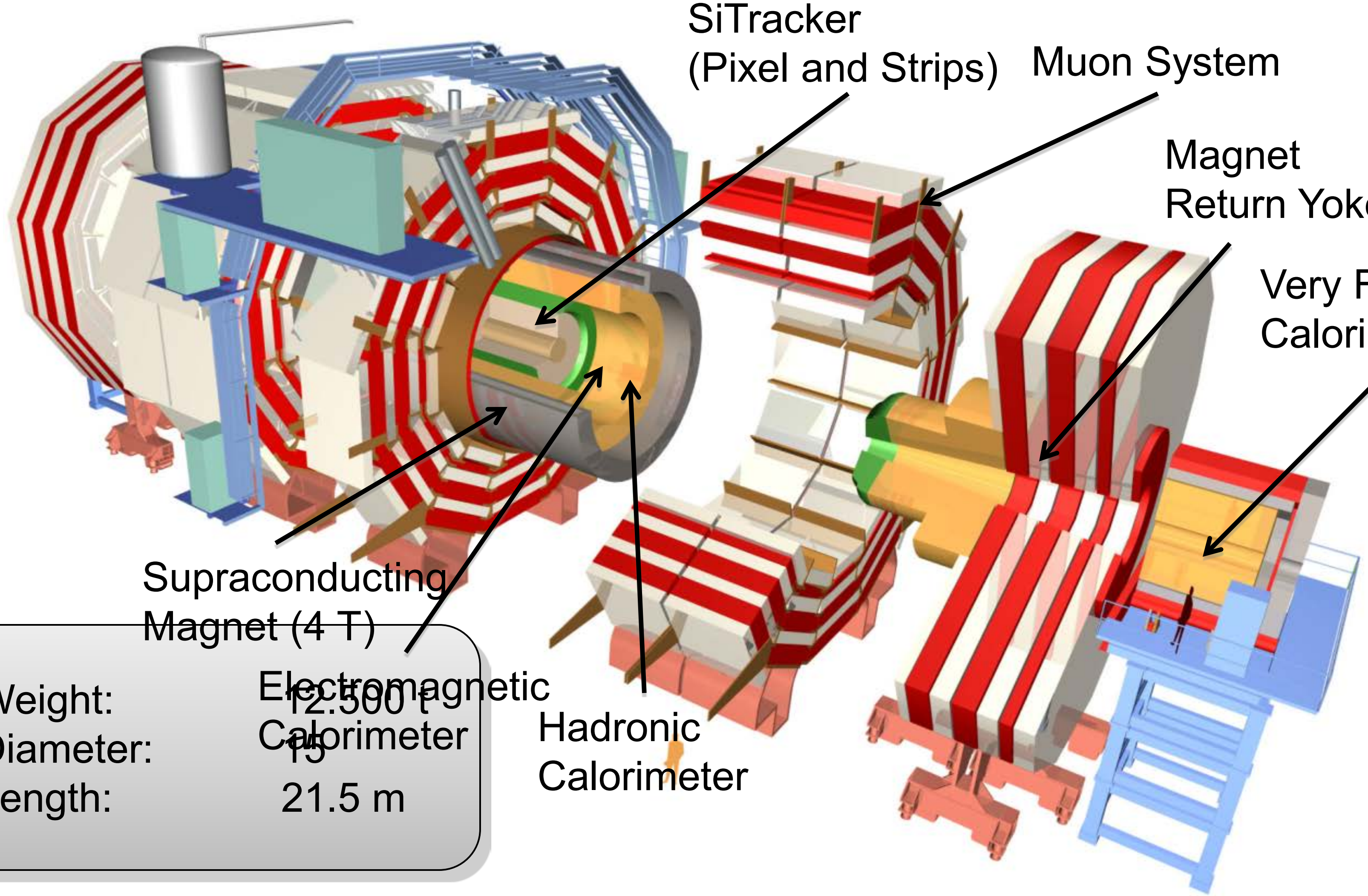
- **CMS Trigger & Tracker Upgrade**
  - Trigger & Pixel: firmware improvements, maintenance (-2016)
  - electronics R&D for CMS upgrade (VME -> μTCA); -2016
  - Development of radiation-hard silicon sensors with Austrian semiconductor company (-2023)

- **Silicon Detectors for an International Linear Collider experiment**
  - Different EU-funded projects (detector development)
  - Long-term prospective (2030?)

Present Hardware Projects at HEPHY

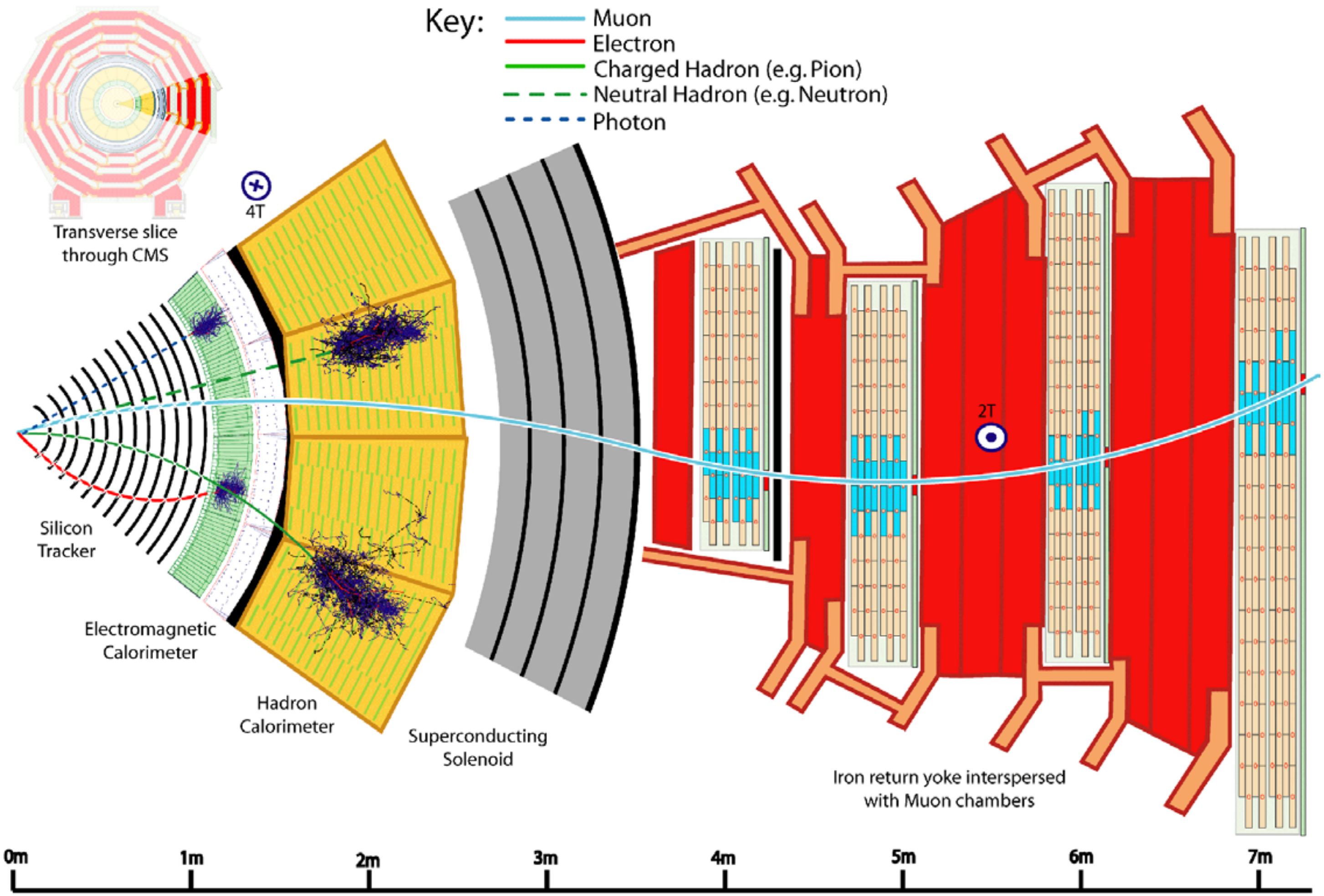
CMS TRIGGER AND TRACKER

CMS: Compact Muon Solenoid

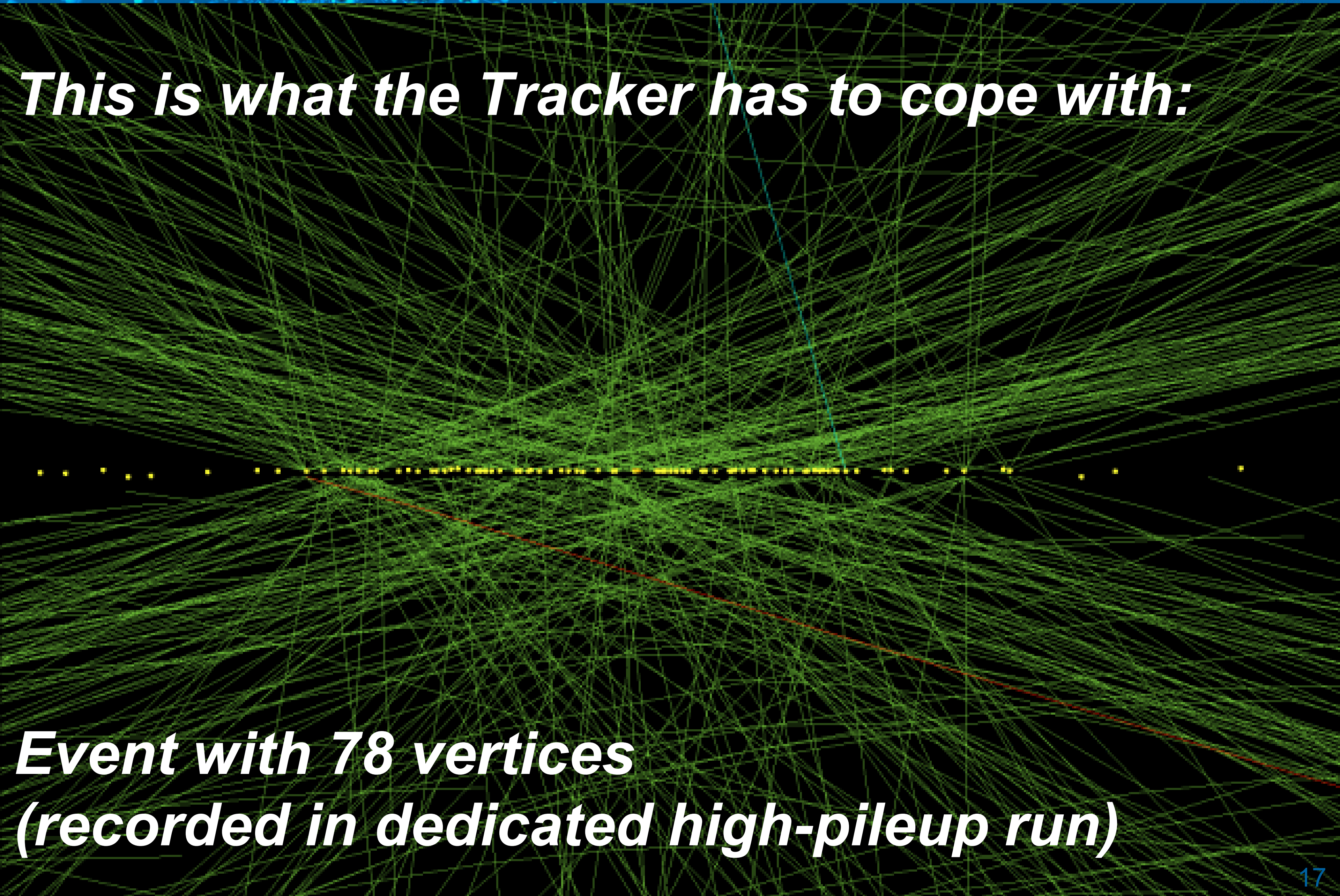


Weight: 12.500 t
Diameter: 15
Length: 21.5 m

Compact Myon Solenoid

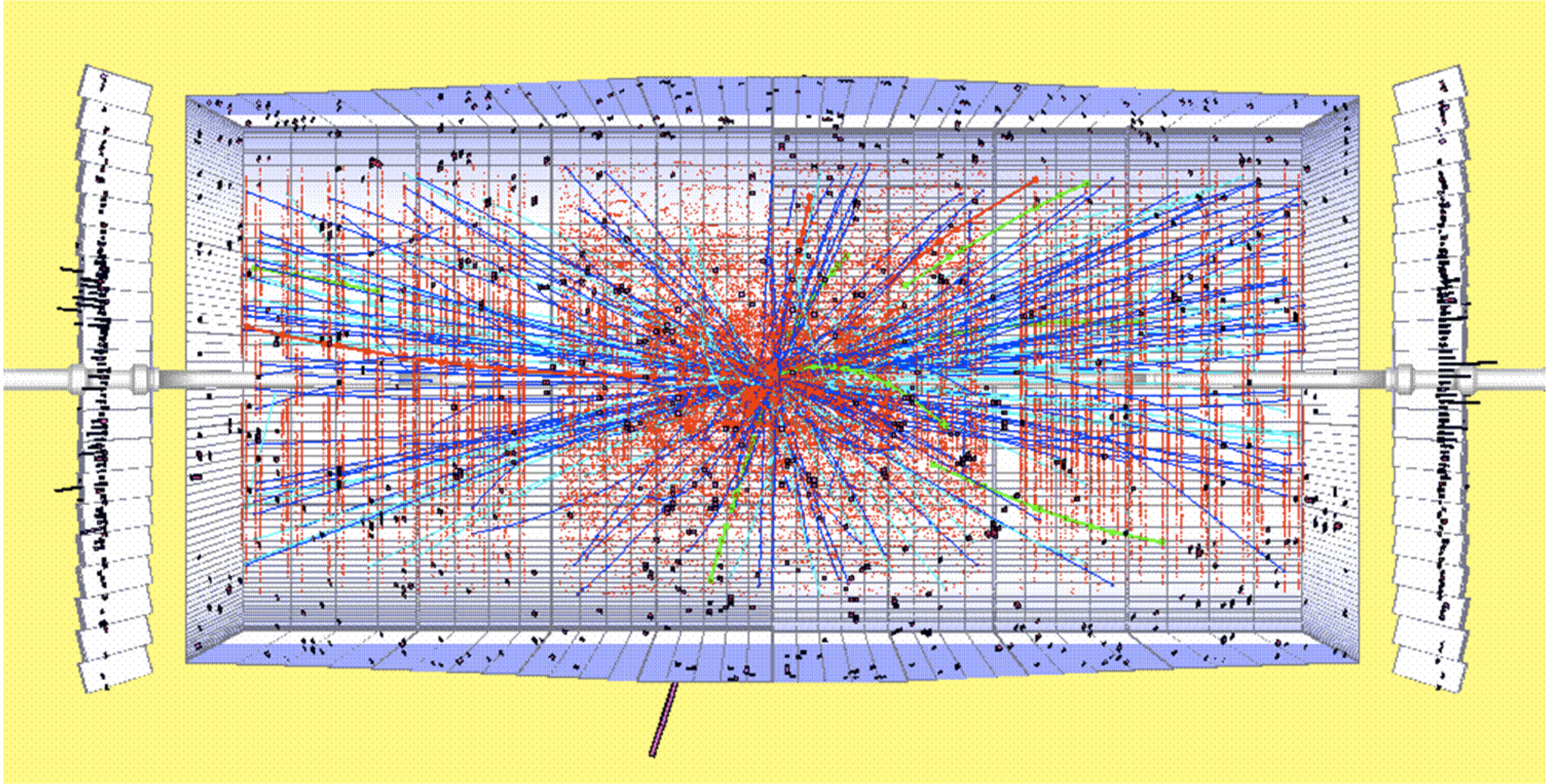


This is what the Tracker has to cope with:



Event with 78 vertices
(recorded in dedicated high-pileup run)

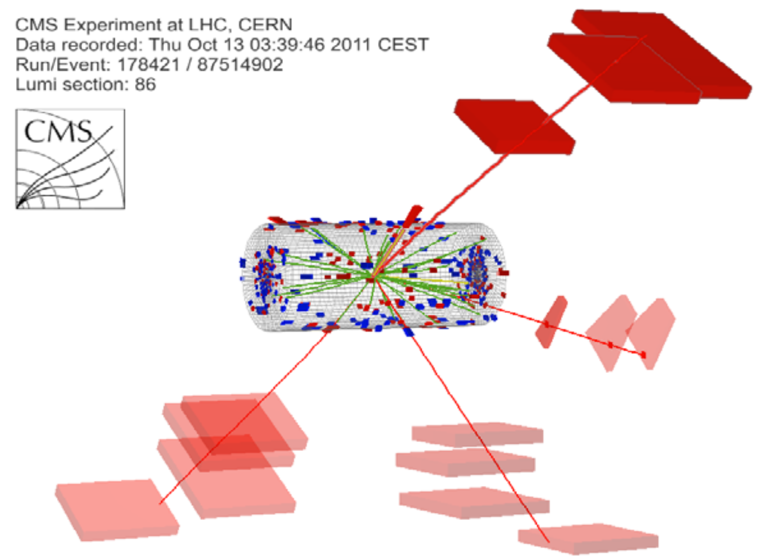
Track Density at 10^{34} $cm^{-2}s^{-1}$

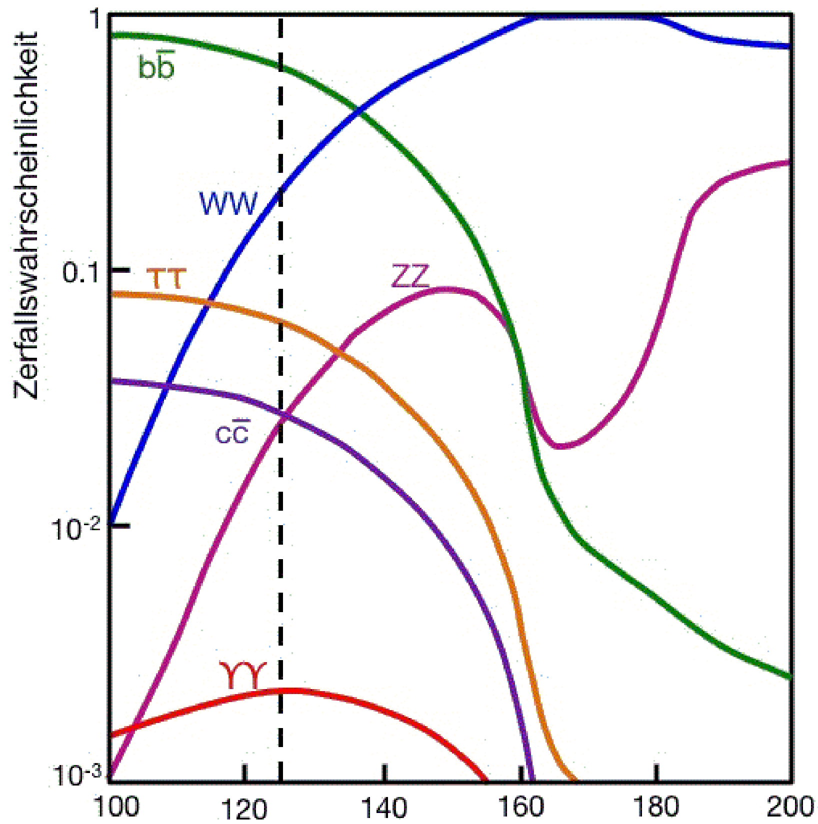


Higgs Decay modes

Higgs Bosons decays into

- 2 Photons
- 2 W or 2 Z bosons, each decays into 2 leptons



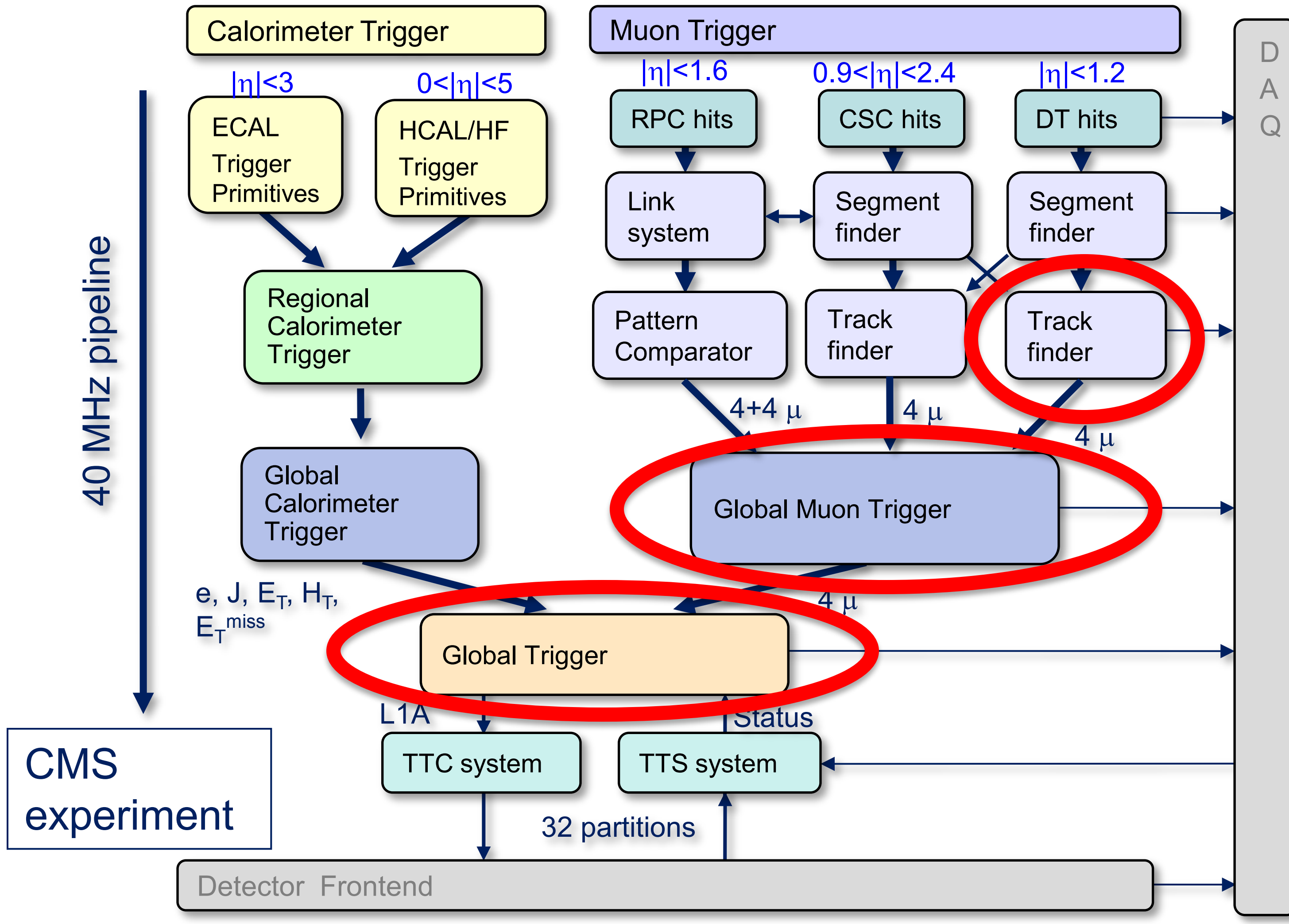


- The CMS Trigger selects physically meaningful data to reduce the rate from up to 40 MHz delivered by the LHC accelerator to a manageable volume of a few hundred Hz.
  - Major parts of the Level-1 Trigger are under HEPHY responsibility.

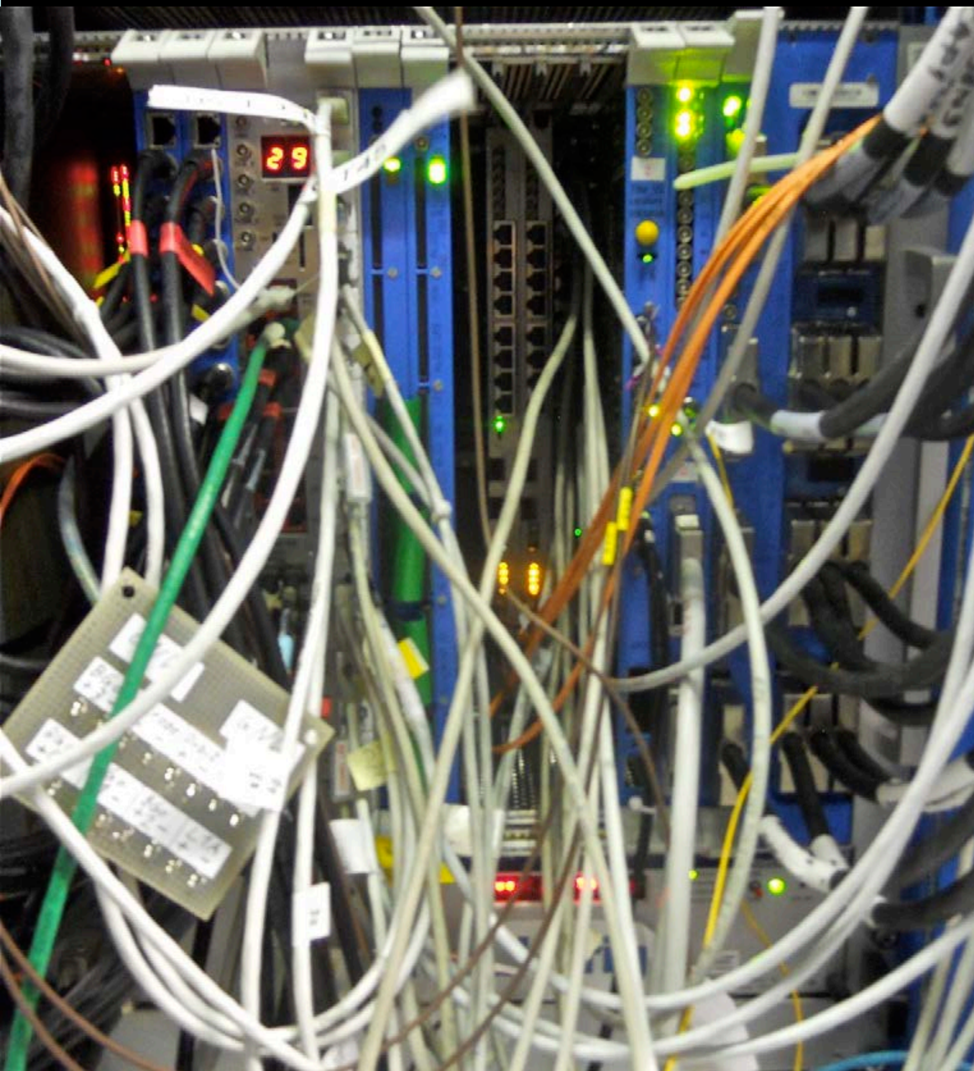
The good ones go into the pot,
the bad ones go into your crop.

Cinderella

The CMS Level-1 Trigger setup



Global Trigger and Global Muon Trigger

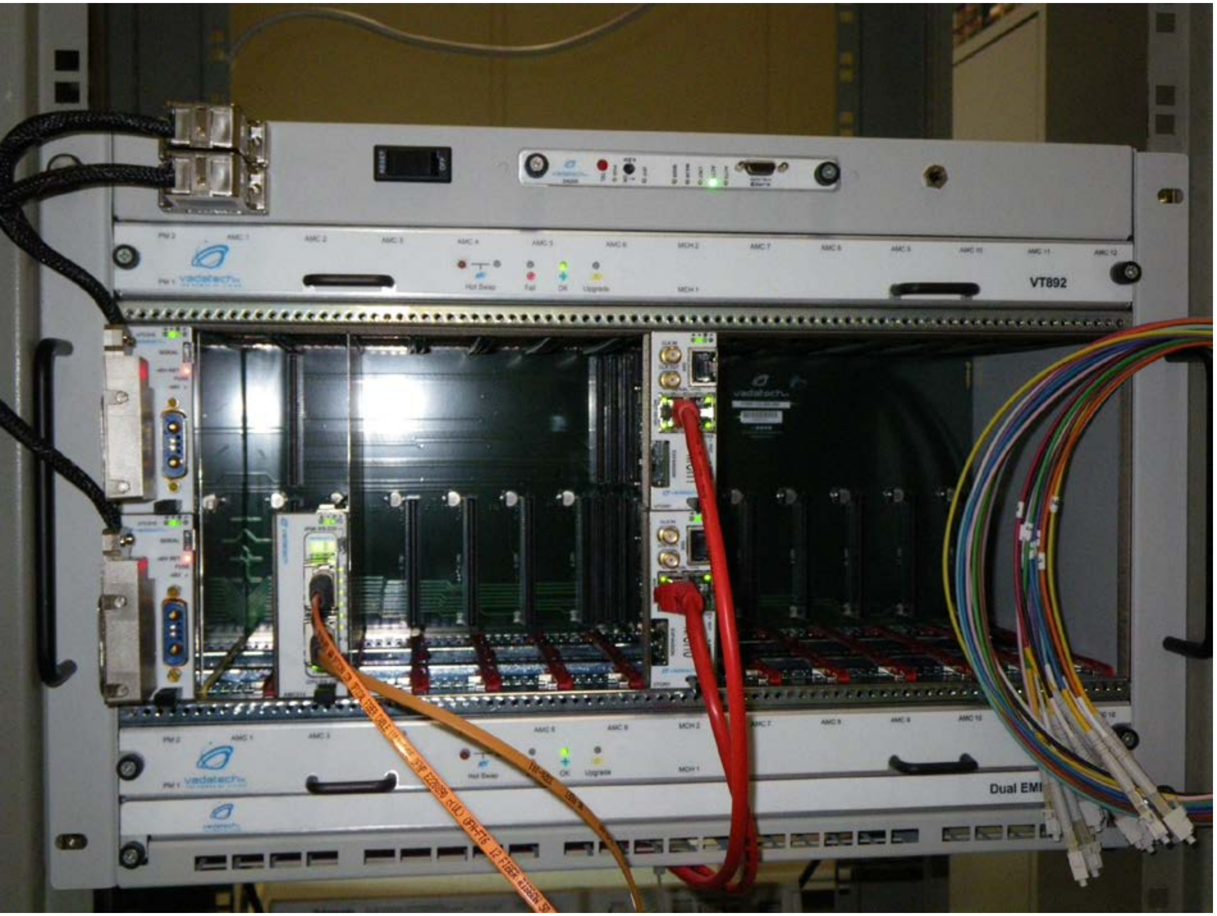


Drift Tube Track Finder

Global Trigger upgrade

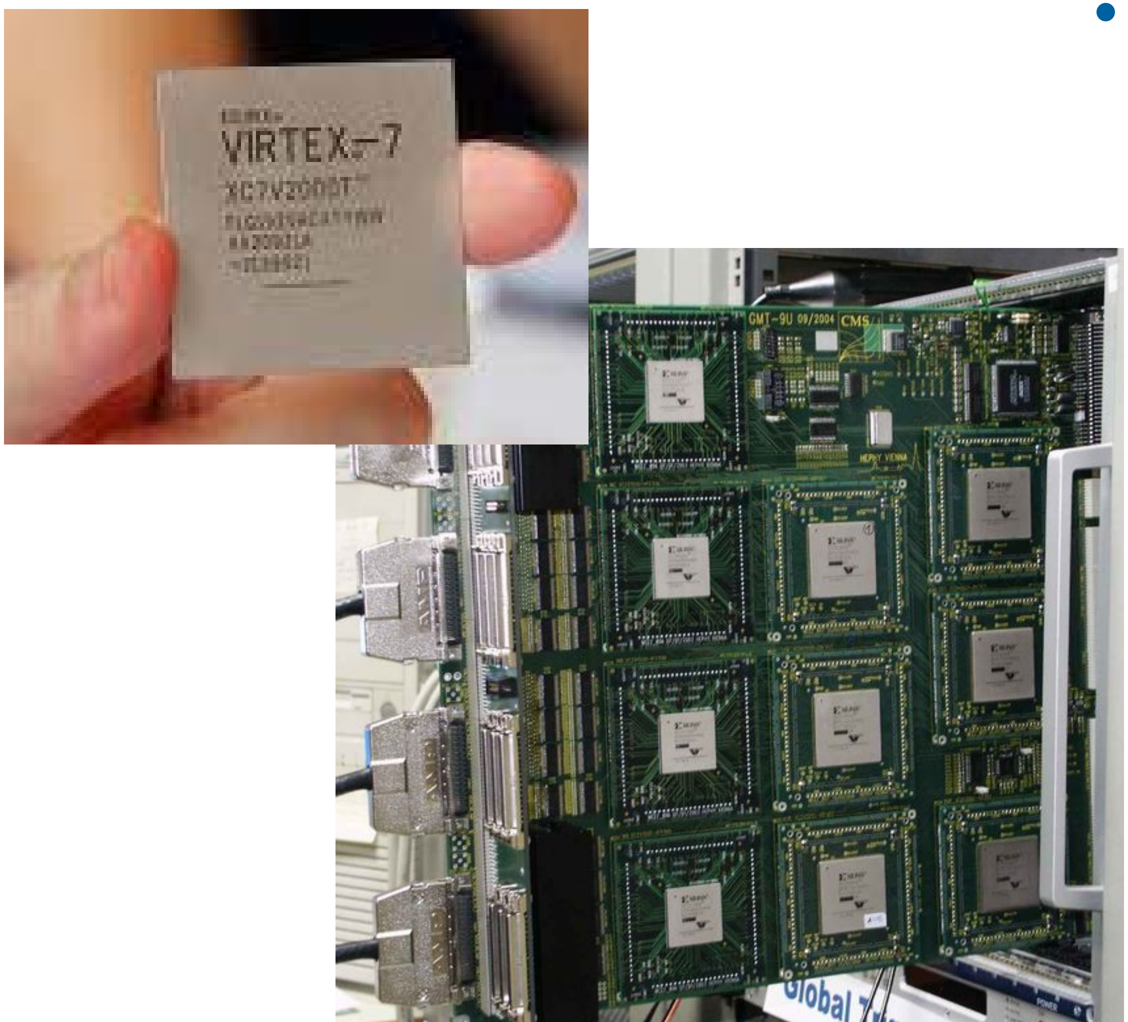
- Increase number of "Instances" for each Object Type
  - e.g. at present 4 muon candidates → 8 muon candidates
- Increase number of bits per Object
  - higher precision in coordinates
    - phi (azimuth), eta (pseudorapidity), pT (transverse momentum) or ET (transverse energy)
- → Increase input bandwidth and processing power of Global Trigger and Global Muon Trigger

Global Trigger / Global Muon Trigger upgrade *infrastructure*



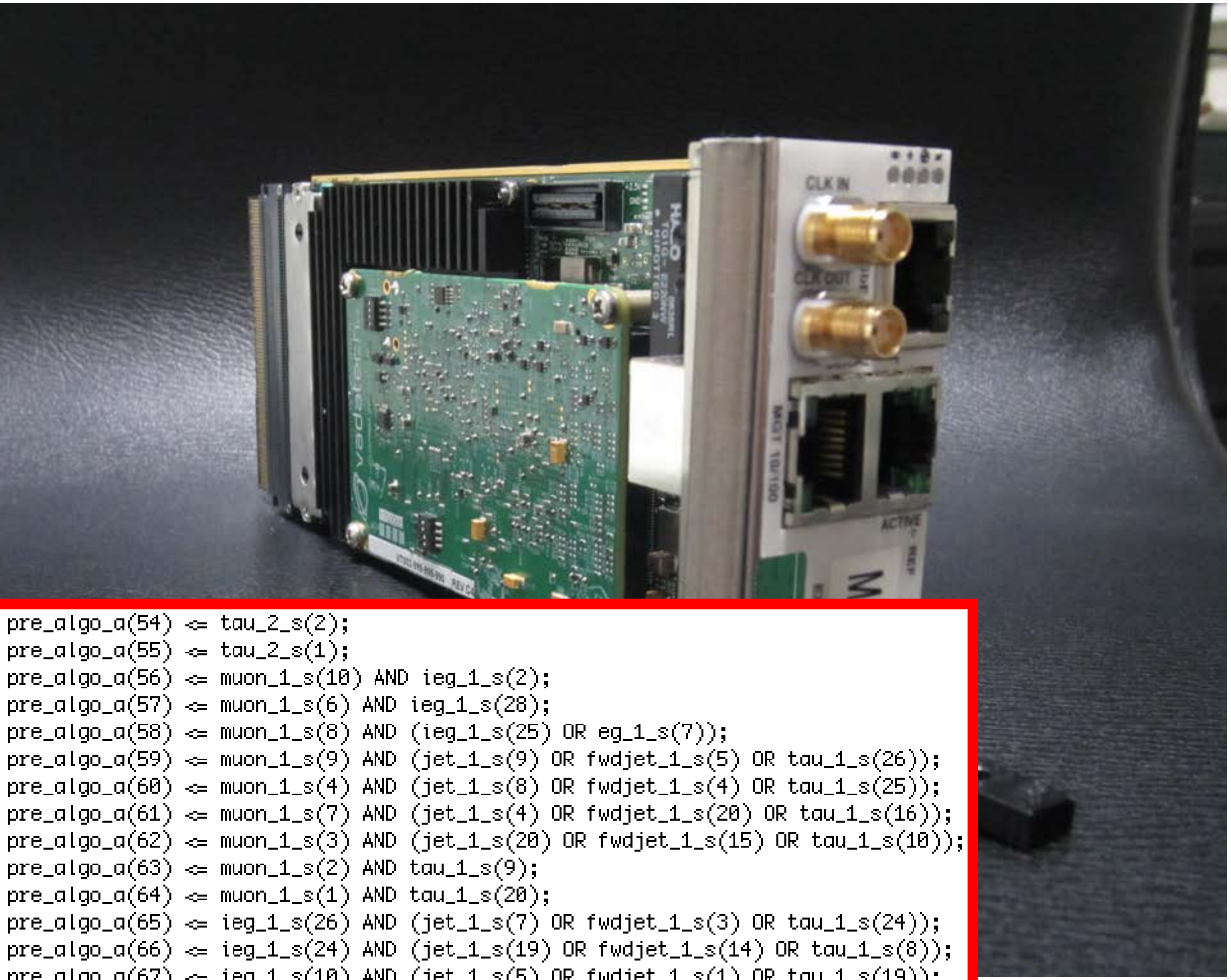
- Use robust modern architecture
  - microTCA instead of VME standard
- High bandwidth optical links

Global (Muon) Trigger upgrade *technology*



- Using the most powerful FPGA chips available allows us to reduce system size and cross-communication overhead while improving performance

Global (Muon) Trigger upgrade *philosophy*



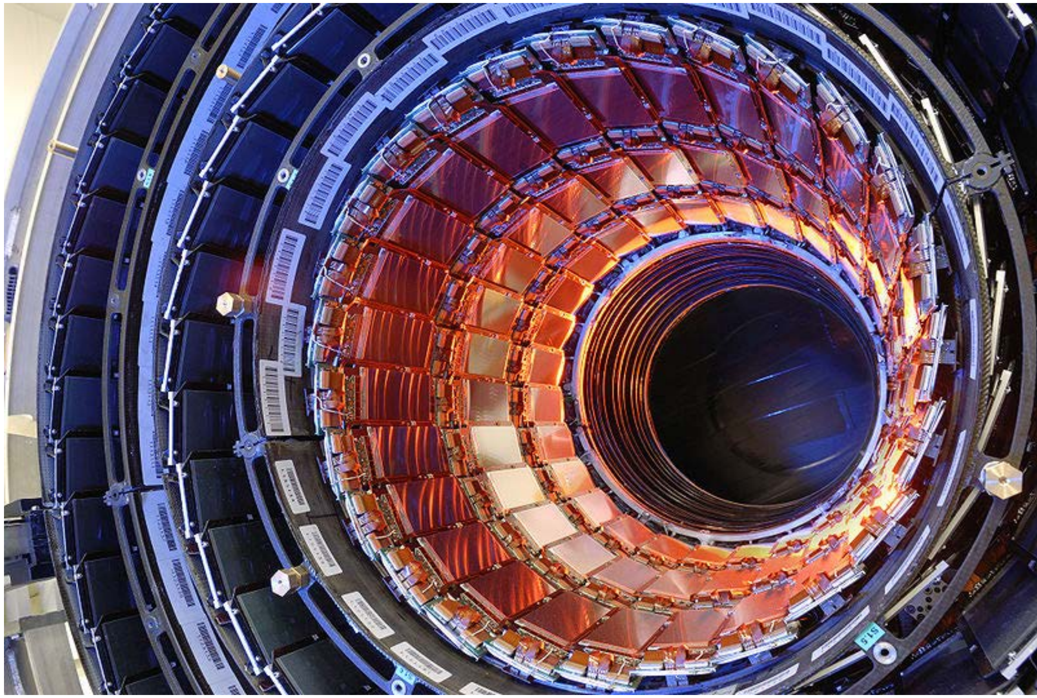

```
pre_algo_a(54) <= tau_2_s(2);
pre_algo_a(55) <= tau_2_s(1);
pre_algo_a(56) <= muon_1_s(10) AND ieg_1_s(2);
pre_algo_a(57) <= muon_1_s(6) AND ieg_1_s(28);
pre_algo_a(58) <= muon_1_s(8) AND (ieg_1_s(25) OR eg_1_s(7));
pre_algo_a(59) <= muon_1_s(9) AND (jet_1_s(9) OR fwdjet_1_s(5) OR tau_1_s(26));
pre_algo_a(60) <= muon_1_s(4) AND (jet_1_s(8) OR fwdjet_1_s(4) OR tau_1_s(25));
pre_algo_a(61) <= muon_1_s(7) AND (jet_1_s(4) OR fwdjet_1_s(20) OR tau_1_s(16));
pre_algo_a(62) <= muon_1_s(3) AND (jet_1_s(20) OR fwdjet_1_s(15) OR tau_1_s(10));
pre_algo_a(63) <= muon_1_s(2) AND tau_1_s(9);
pre_algo_a(64) <= muon_1_s(1) AND tau_1_s(20);
pre_algo_a(65) <= ieg_1_s(26) AND (jet_1_s(7) OR fwdjet_1_s(3) OR tau_1_s(24));
pre_algo_a(66) <= ieg_1_s(24) AND (jet_1_s(19) OR fwdjet_1_s(14) OR tau_1_s(8));
pre_algo_a(67) <= ieg_1_s(10) AND (jet_1_s(5) OR fwdjet_1_s(1) OR tau_1_s(19));
pre_algo_a(68) <= ieg_1_s(9) AND (jet_1_s(3) OR fwdjet_1_s(19) OR tau_1_s(15));
pre_algo_a(69) <= ieg_1_s(8) AND tau_1_s(7);
```

Using commercial modules helps saving development costs and allows engineers to concentrate on firmware development

- The CMS Tracker is the core of the CMS detector and provides precision information on charged-particle tracks.

HEPHY involvement:

- design and construction of the tracker
- commissioning
- readout electronics
- reconstruction algorithms
- R&D for radiation tolerant silicon sensors (upgrade)

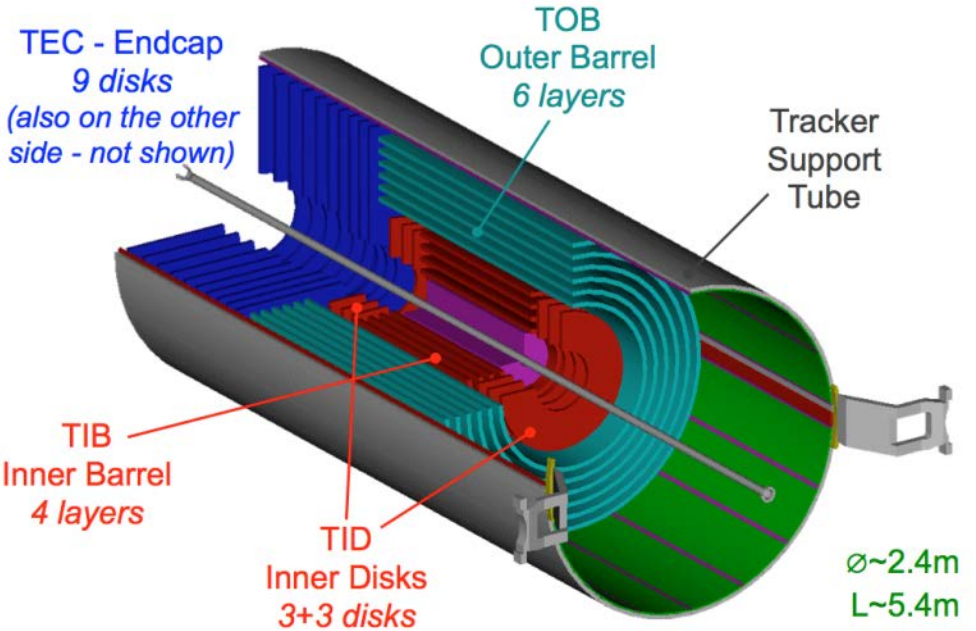


CMS Tracker Numbers

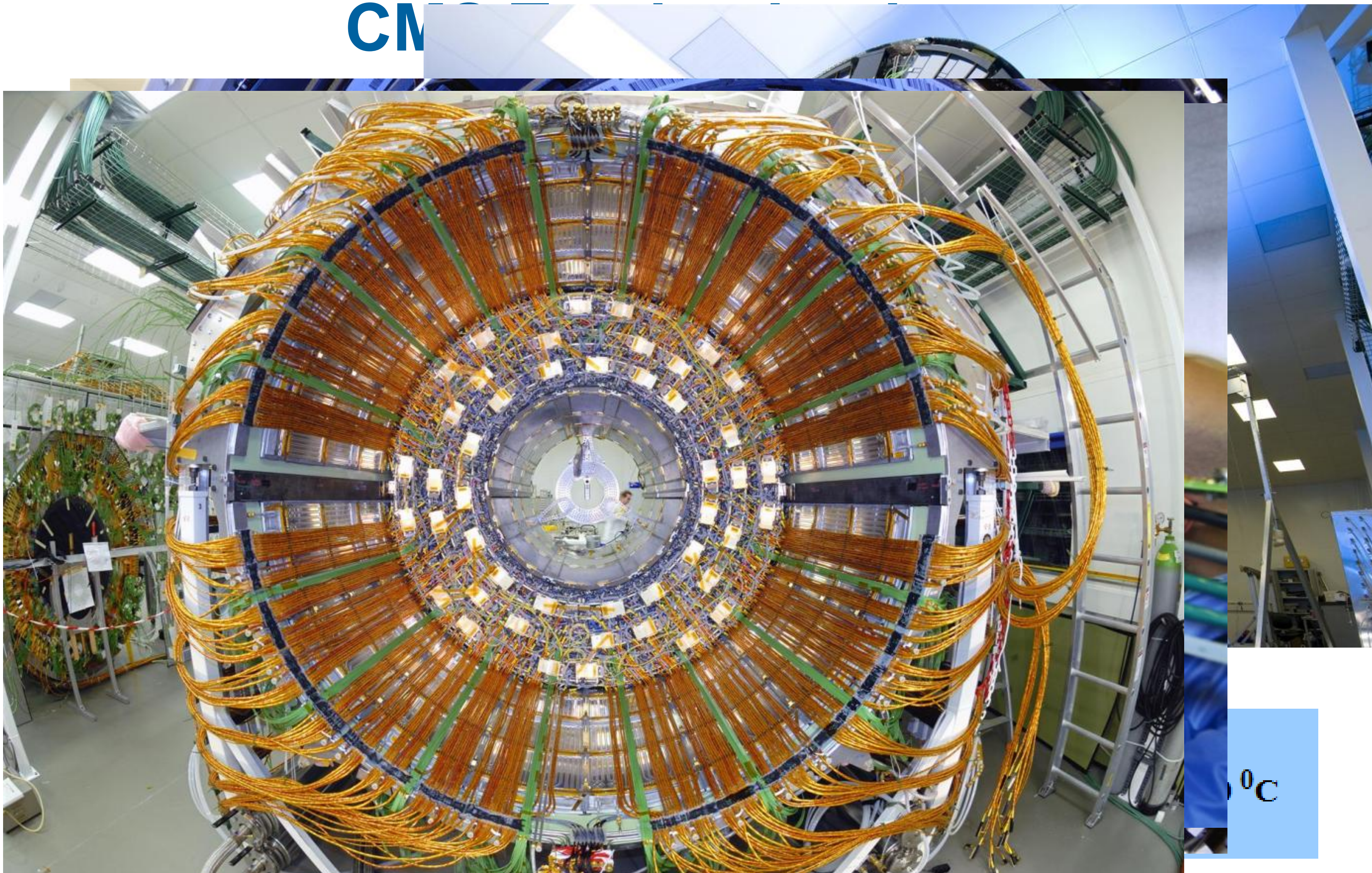
- 6.136 thin detectors with one thin sensor (TIB, TID, inner TEC)
- 9.096 modules with two thick sensors (TOB, outer TEC)

- 29 module designs
- 16 sensor designs
- 12 hybrid designs
- 9.648.128 Strips (electronics channels)
- 75.376 readout chips (APV25)
- 26.000.000 Bond wires
- 37.000 optical links
- 3000 km optical fibers

- Size: 2,4 m x 5,4 m
- Operating T: -20° C
- Dry atmosphere for 10 years
- Radiation Levels $> 1.6*10^{14}$ 1MeV Neq./cm²

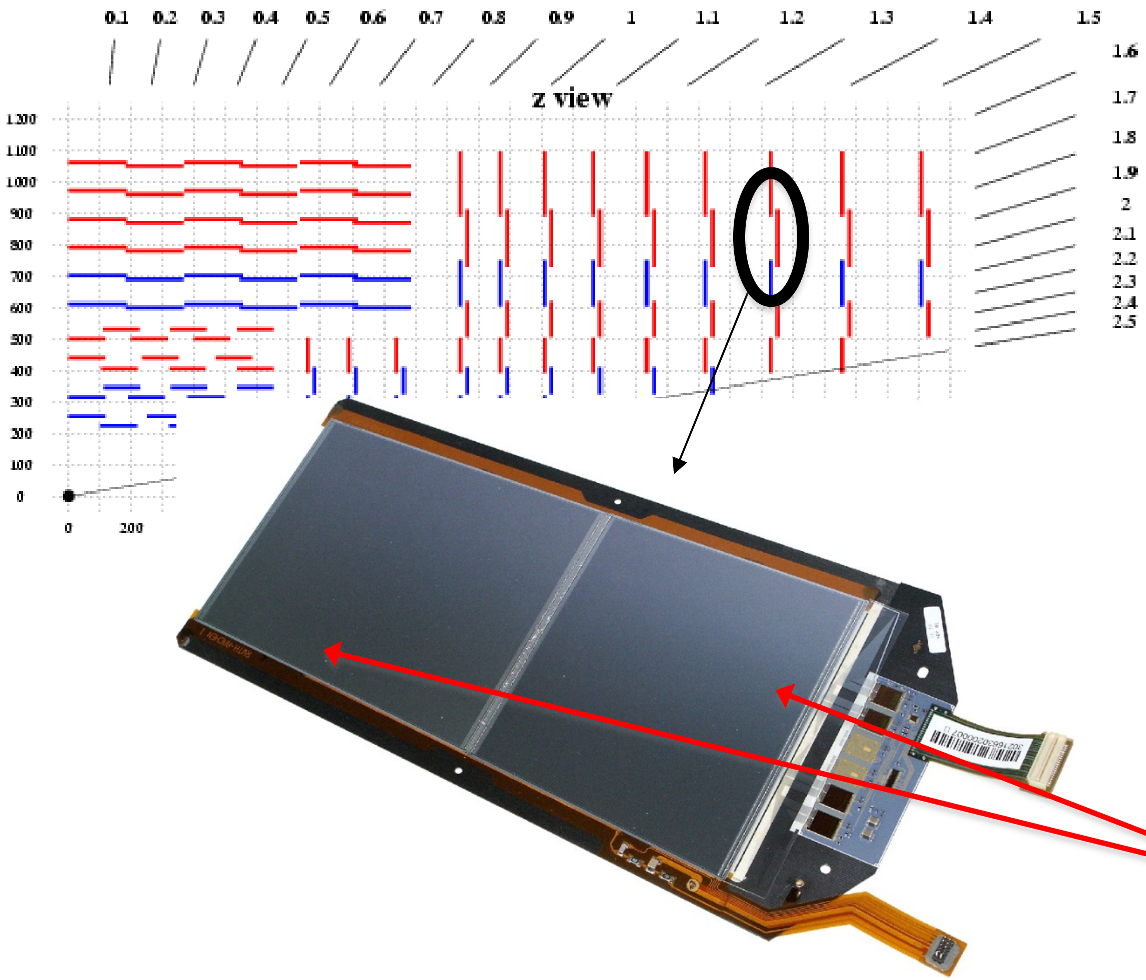


CM



^{0}C

CMS Strip Tracker: Elementary Parts

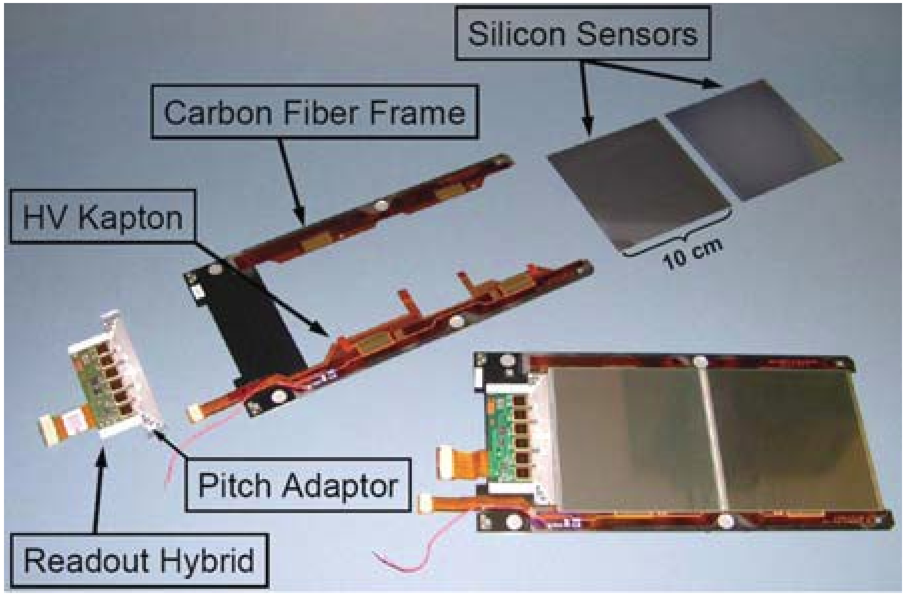


One quarter of silicon strip tracker: blue and red lines represent each elementary component:

Detector Module

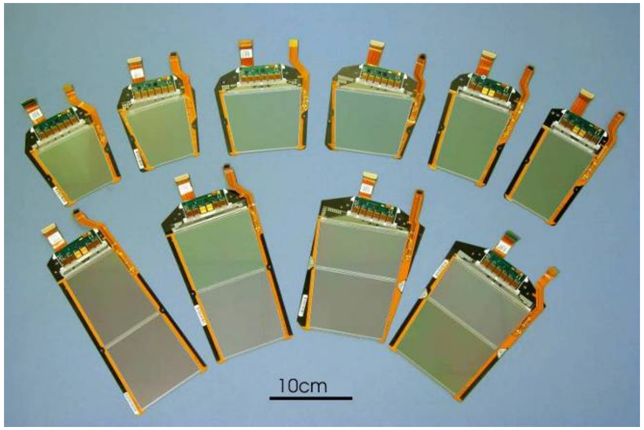
- 15.148 pieces in total
  - Red: single sided modules
  - Blue: double sided modules
- Different Geometries
  - 4 rectangular (TIB und TOB)
  - 11 trapezoid (TID und TEC)
- Components
  - Carbon fiber/graphite frame
  - Front End Hybrid housing readout chip
  - One or two silicon sensors

Basic Element of the Tracker: Module



Components:

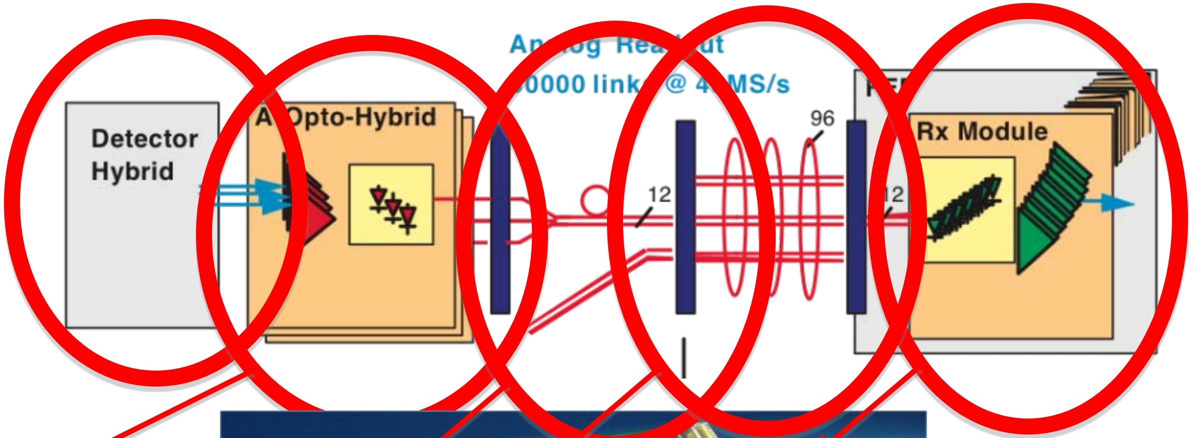
- Carbon fiber/graphite frame
- Kapton flex circuit for HV supply
- Front End Hybrid housing readout chip
- Pitch Adaptor
- One or two silicon sensors

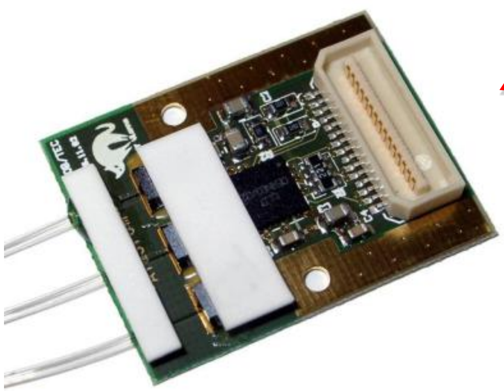


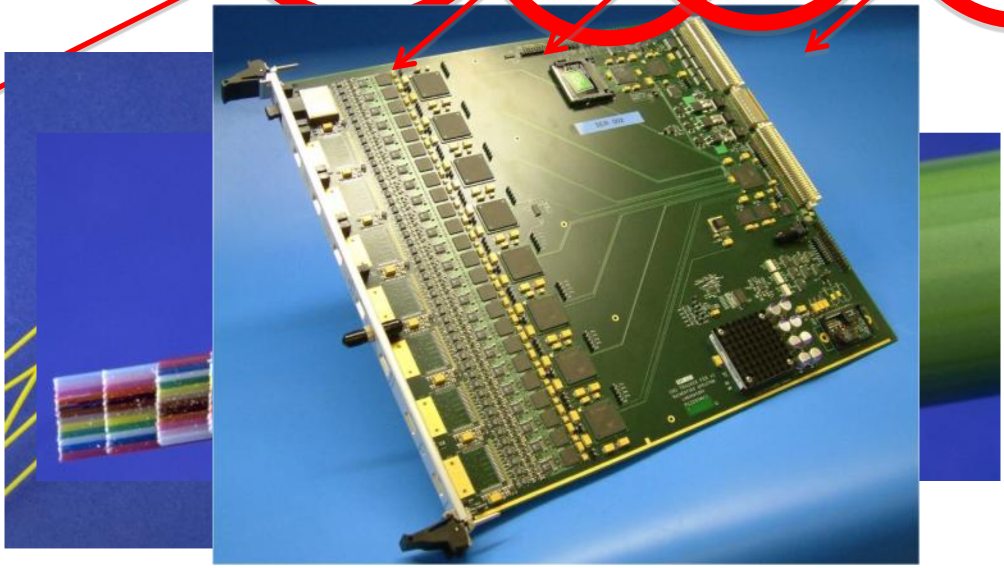
Total:

- 29 module designs
- 16 sensor designs
- 12 hybrid designs

Readout Chain: Data Path

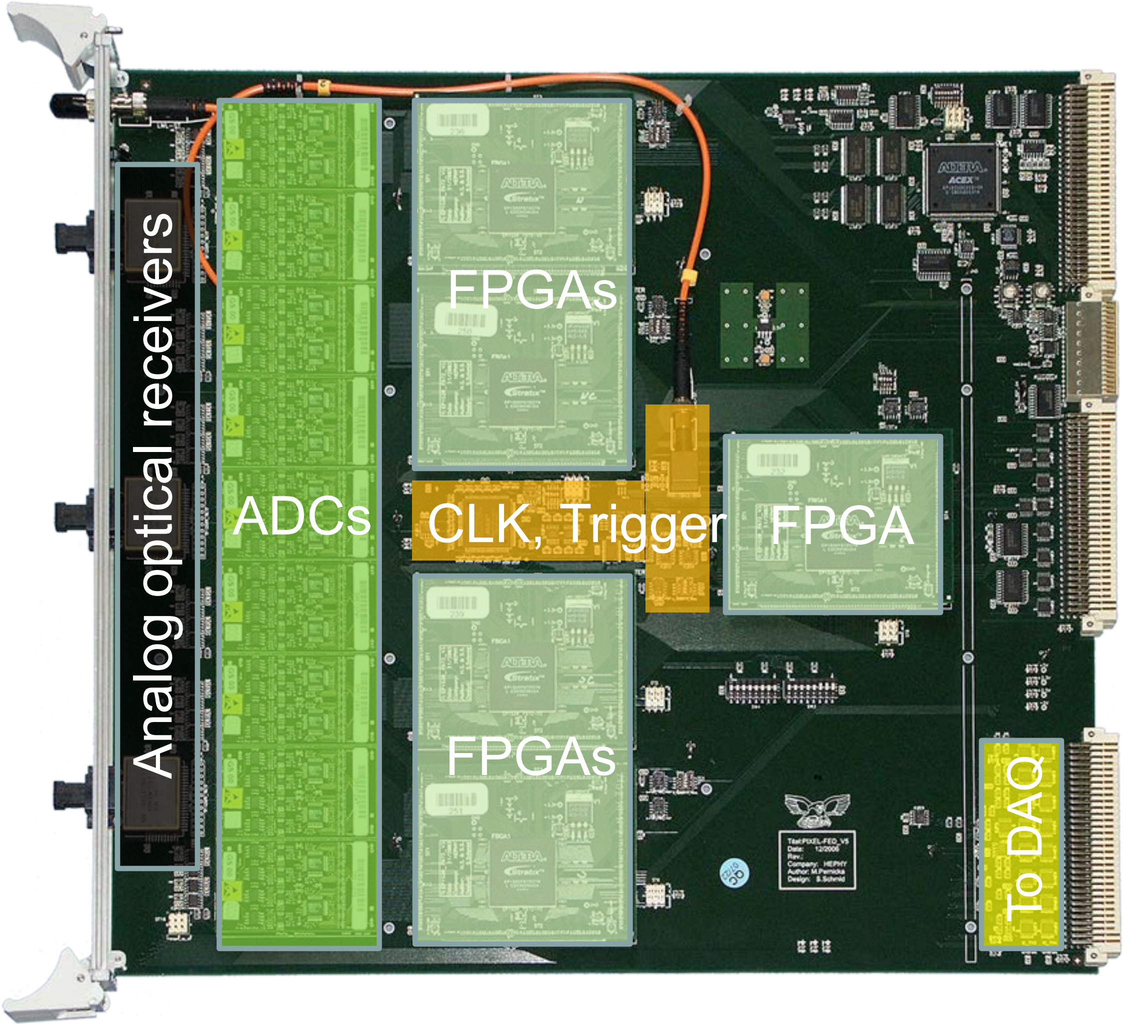






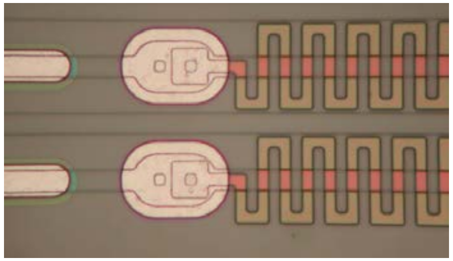
FED Board

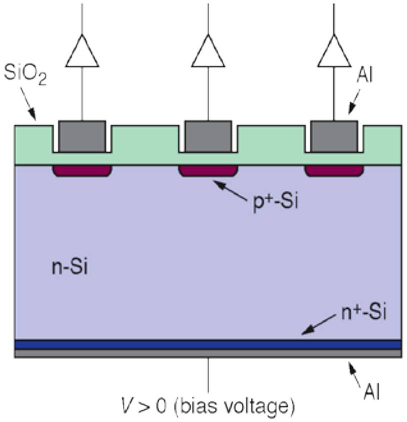
- FED means "Front End Driver" (misleading)
- 9U VME Board
- Contains
  - analog optical receivers,
  - ADCs,
  - Clock and Trigger processors
  - Reads out 96 channels



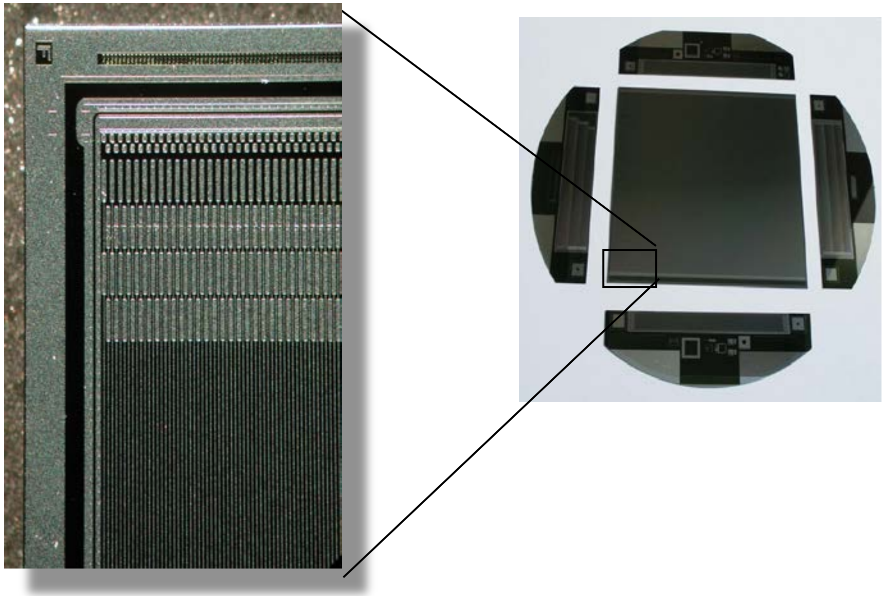
Silicon Sensors

- 35,000 wafers produced by two companies (HPK, STM)
- Tested in four different test centers (including HEPHY)



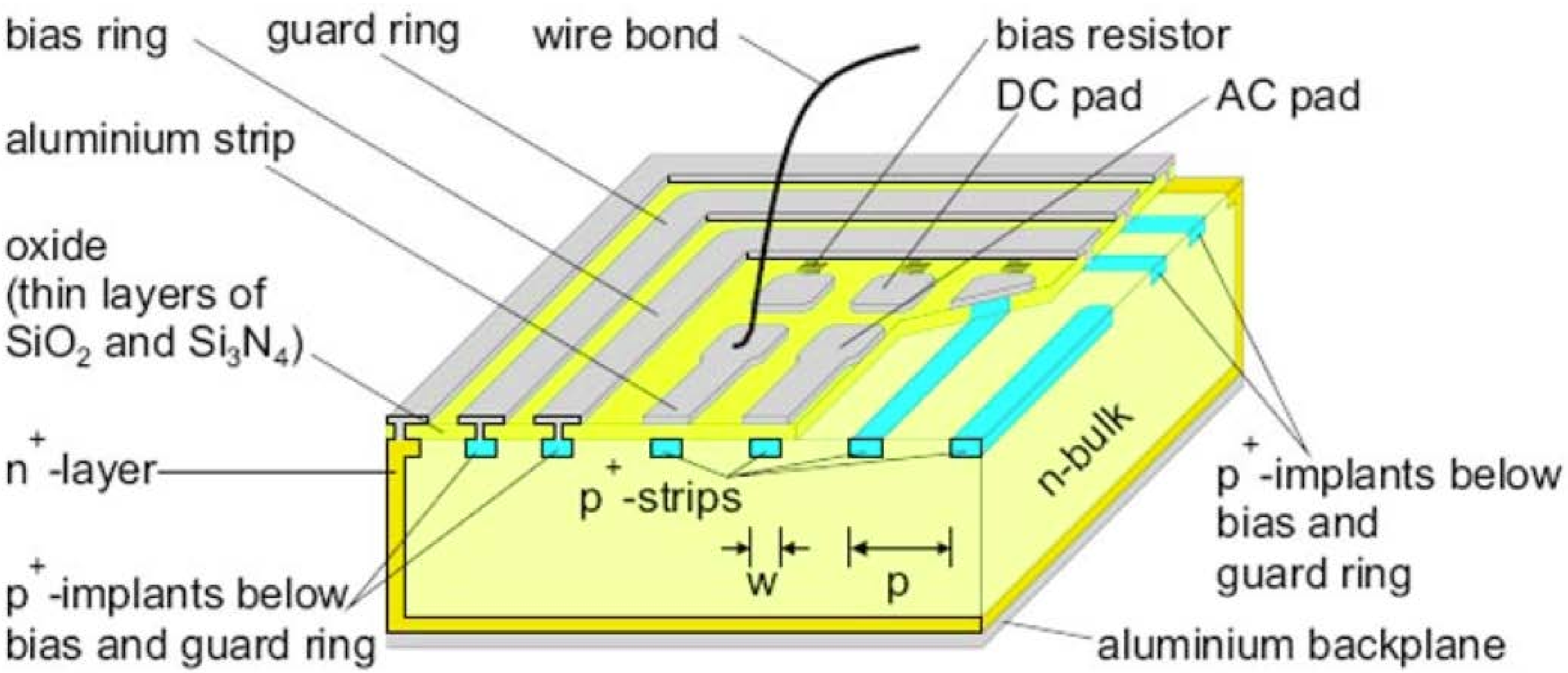


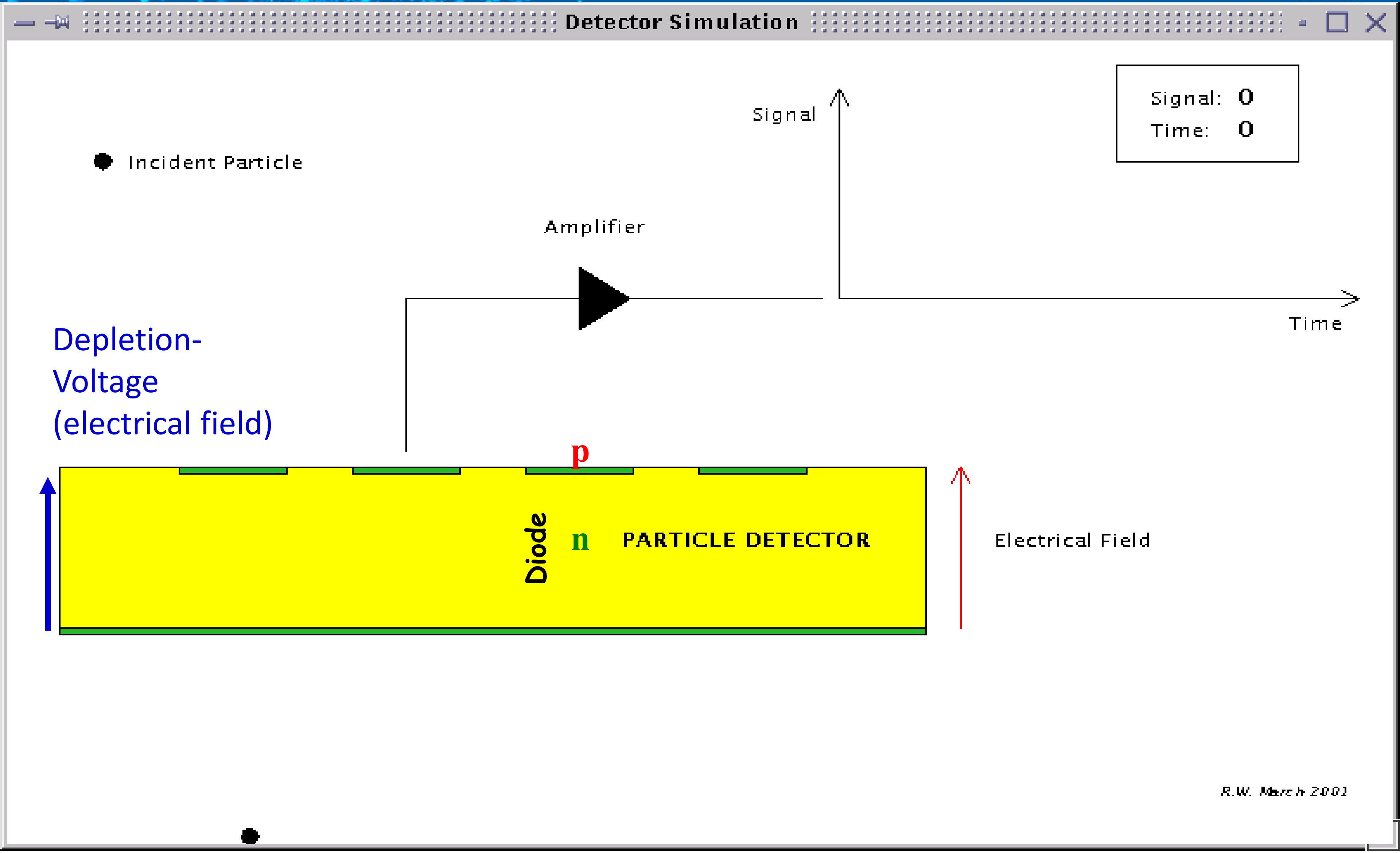
- Single-sided AC coupled strip detectors with poly-silicon bias resistors
  - 320 µm or 500 µm thick
  - One device per 6" wafer (10x10 cm)
  - Operating voltage up to 600 V
  - 768 strips



Typical AC-coupled Sensor in HEP

Most commonly used scheme using poly-Si bias resistor




Detector Simulation
Signal
Signal: 0
Time: 0
Incident Particle
Amplifier
Time
Depletion-
Voltage
(electrical field)
p
Diode
n
PARTICLE DETECTOR
Electrical Field
R.W. March 2001

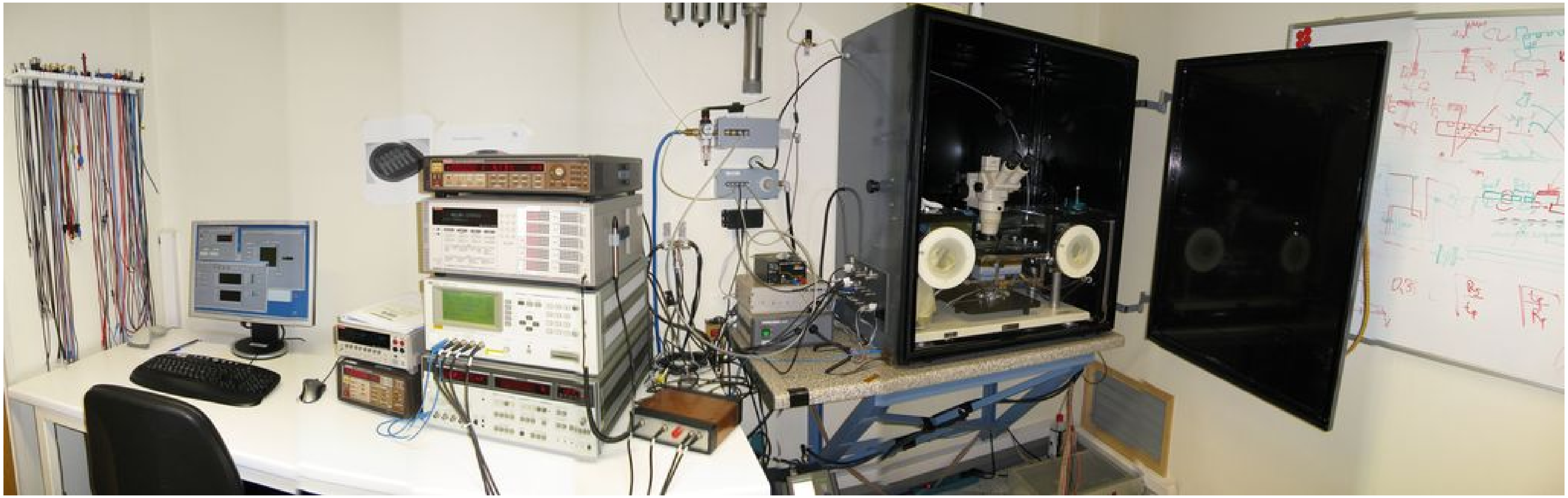
Expertise: Sensor Characterisation

Available Setups:

- Global IV, CV measurements
- Fully automatic strip-by-strip measurements performed by motorized XYZ-table
- Cold chuck to test at different temperatures

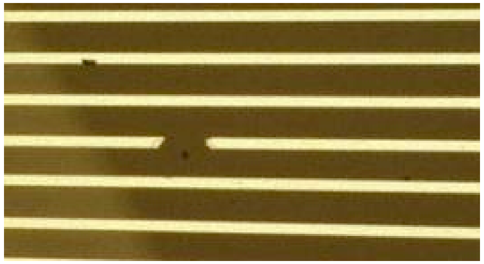
Goals are:

- Quality assurance for mass production (e.g. CMS, soon Belle II)
- Report back to producer
- Select good sensors for module production

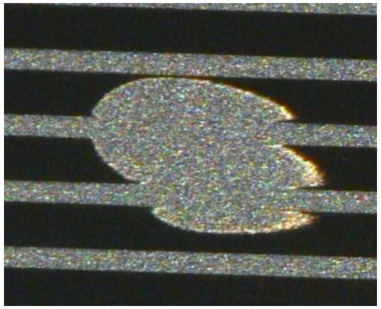


Common strip failures

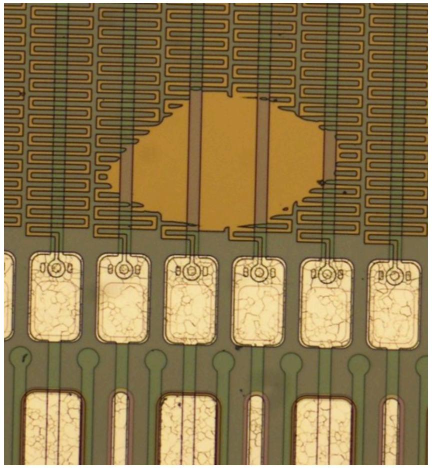
Open Strip:



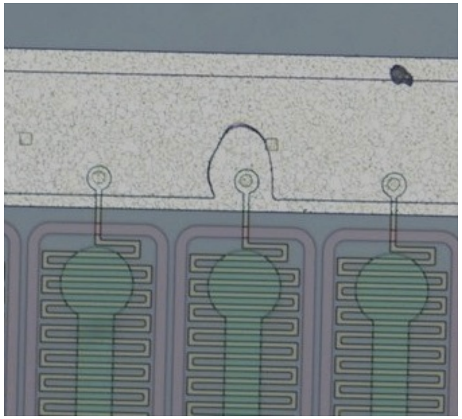
Shorted Strip:



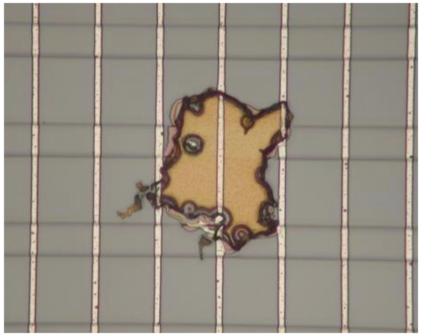
Open bias resistor:



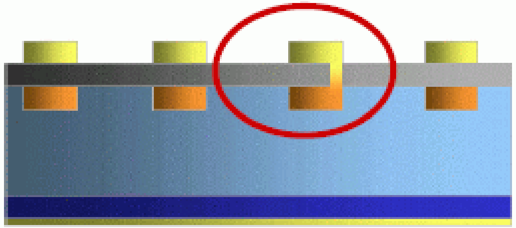
Open implant at via:



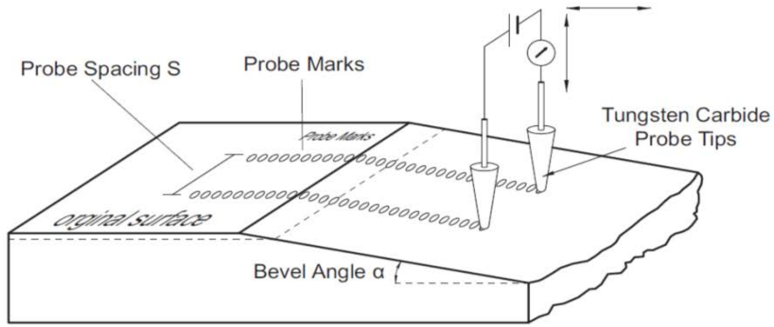
Open implant:

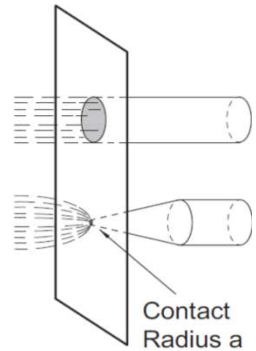


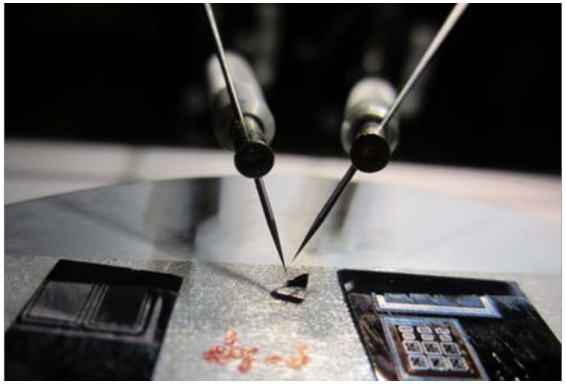
"Pinhole" (short between implant and metal):



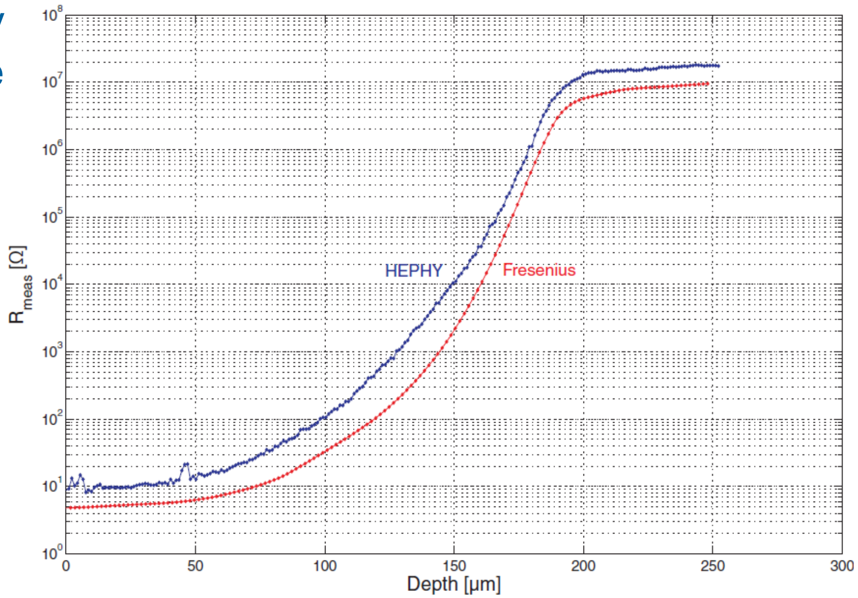
Resistivity measurements on wafer “in-house”





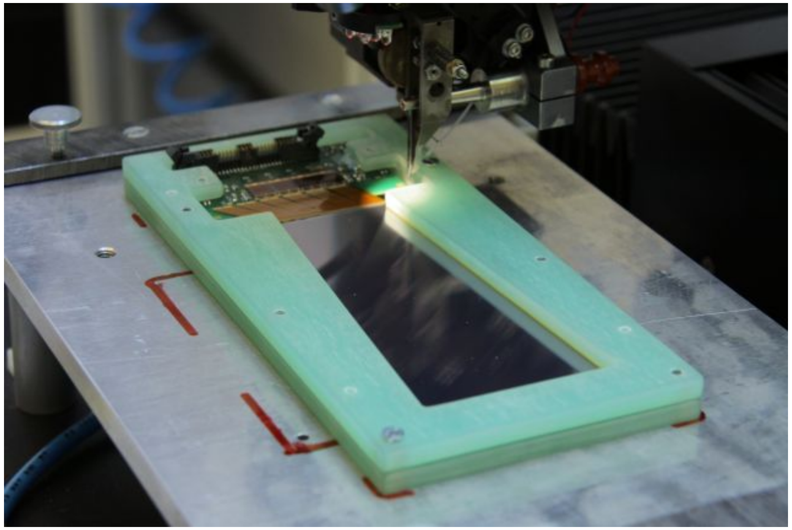


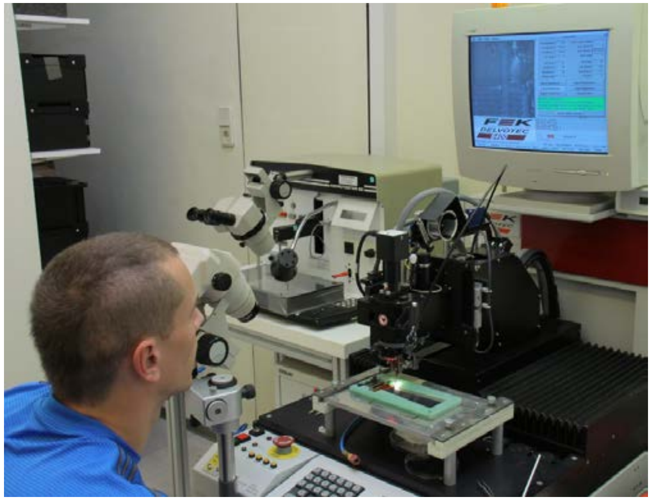
- **Principle Scanning Resistance Profiling**
  - Due to current spreading effects the resistivity and doping concentration of a material can be measured locally (ca. 100x100µm)
  - Adequate preparation enables the measurement of doping profiles with a resolution below 100nm
- **Results:**
  - Development and evaluation of the method
  - Application to CMS sensor process control and Belle II sensor development



Expertise: Module Construction

- Tasks to perform:
  - Gluing, metrology, wire-bonding
- Modules for
  - CMS Tracker mass production
  - Trapezoidal prototype modules for Belle II

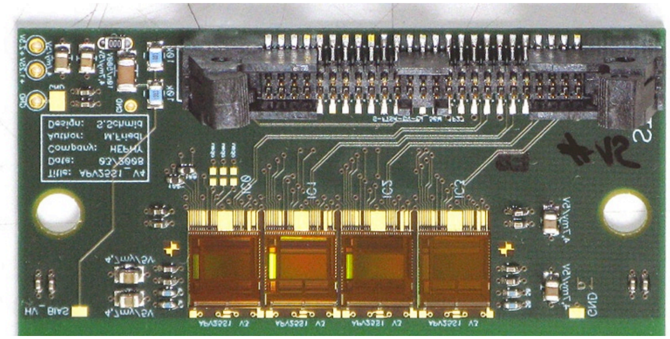


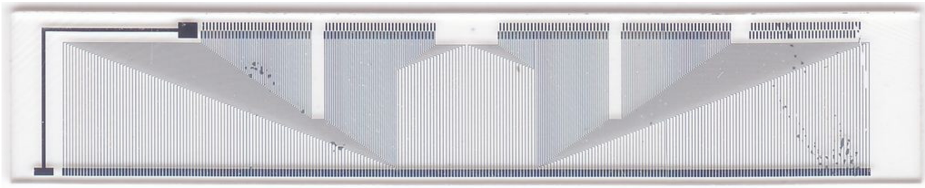


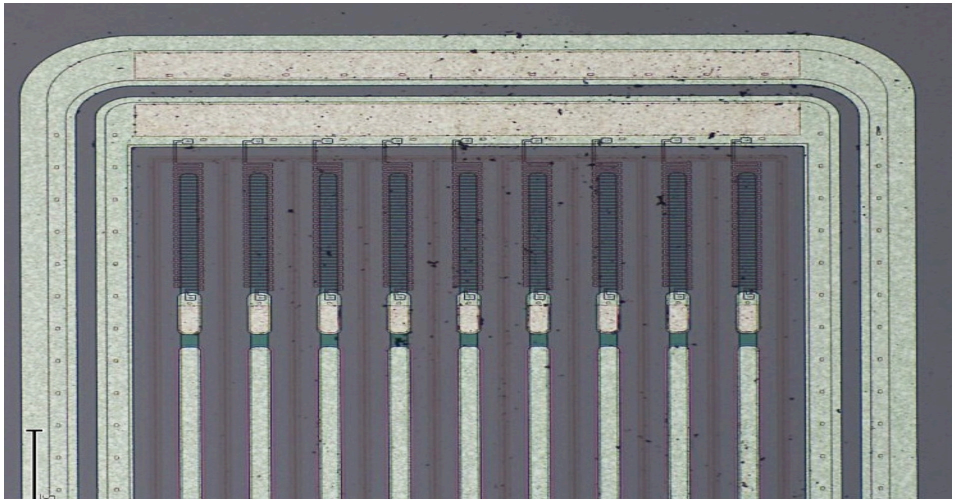
Detector Modules

- A detector module consists of
  - Front-end hybrid containing readout chips
  - Pitch adapter
  - Silicon Sensor
  - frame/support (not shown)

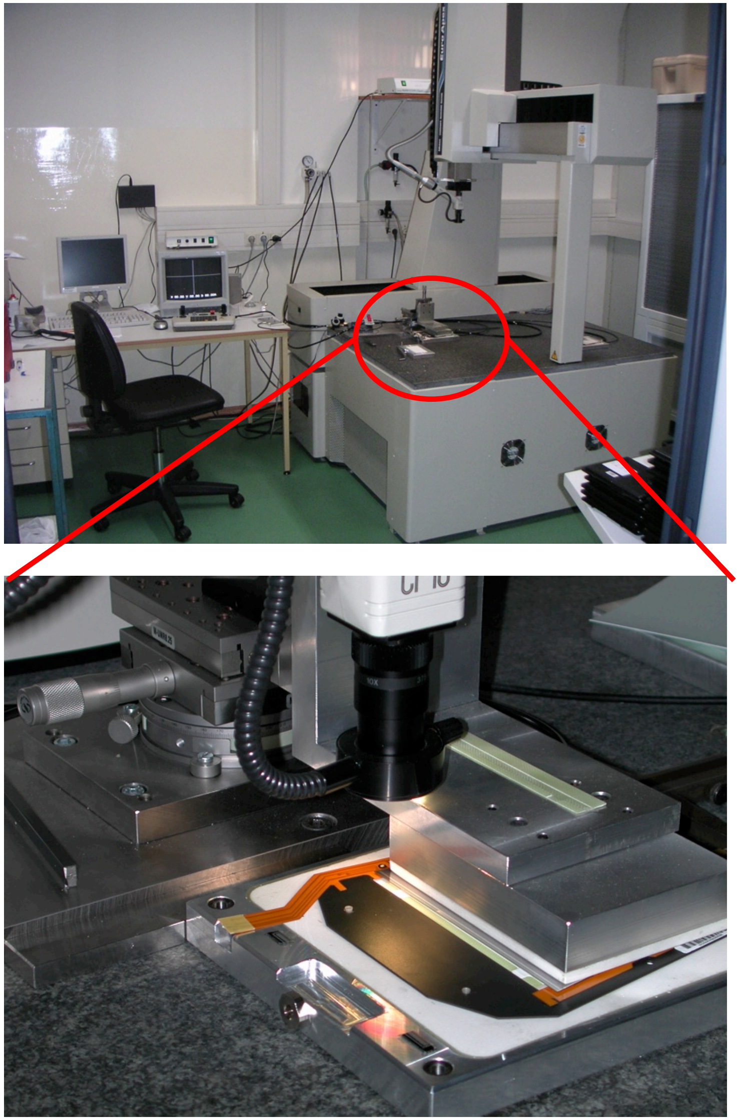
- Wire bonding for connections







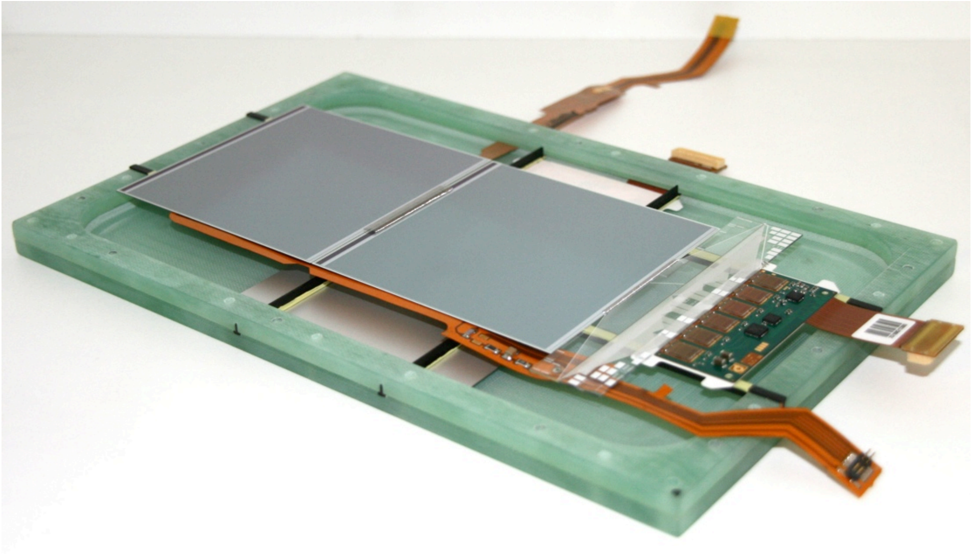
Module Assembly

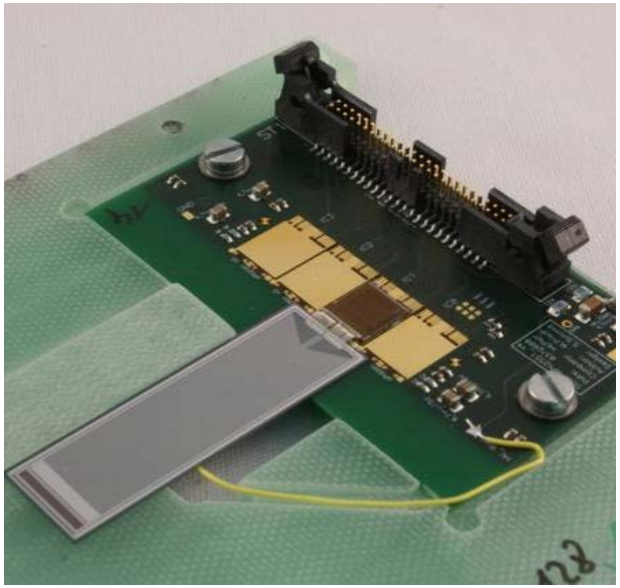


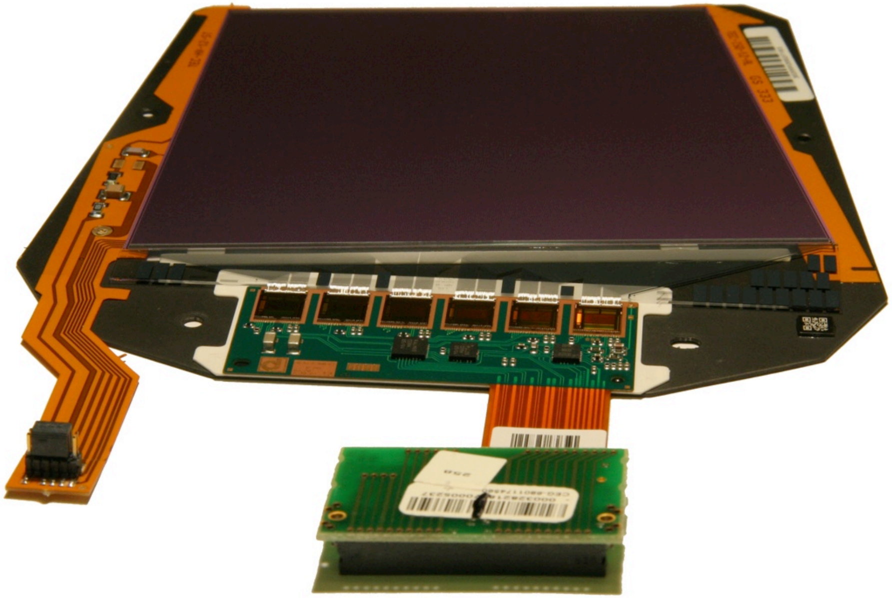
Module assembly for CMS was manual process in Vienna:

- CF frame was fixed with vacuum support
- Glue dispensed
- Sensor put onto frame using gantry positioning system
- Glue curing
- Using 3D coordinate measurement machine for measurement of assembly precision (<10 micron)

- Throughput: 4 modules per day







The High Luminosity LHC and CMS

Upgrade of the LHC by 2022 to achieve **5x** the current design luminosity: **5×10^{34} $cm^{-2}s^{-1}$**

- Original LHC integrated luminosity: **~300 fb^{-1}**
- Integrated luminosity with upgrade: **~ 3000 fb^{-1}**

→Significant gain in collected events!

Current CMS Tracker was designed to operate for 10 years in LHC environment

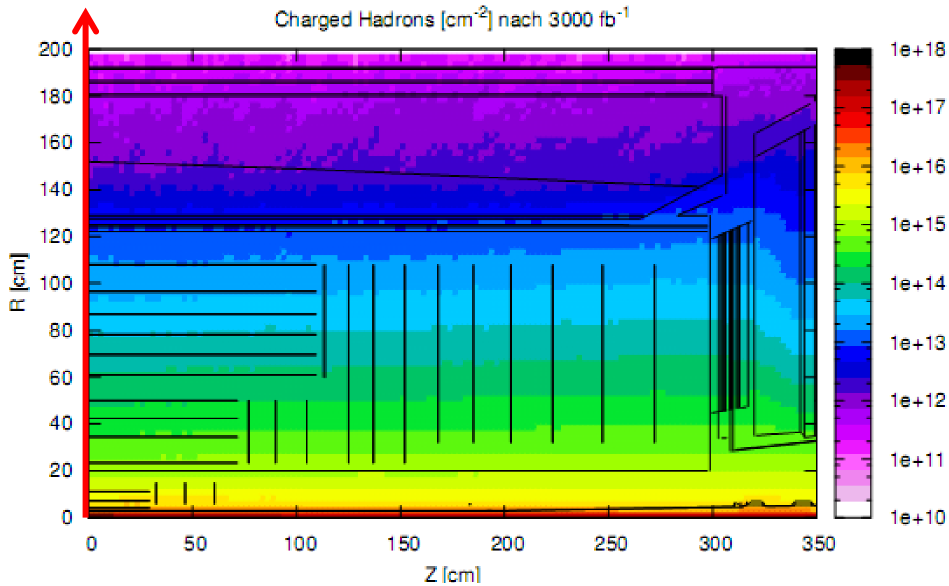
- End of lifetime reached by ~2020

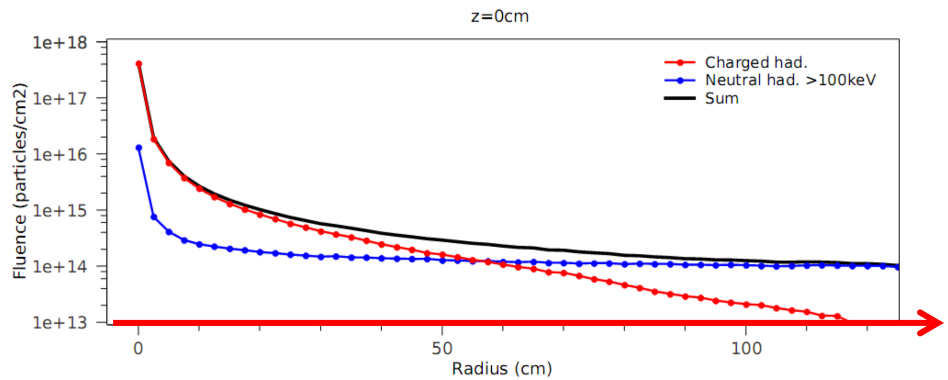
→ Replacement necessary to keep CMS running

Motivation

- High luminosity LHC
  - $L=10^{34}cm^{-2}s^{-1}$ to $L=5*10^{34}cm^{-2}s^{-1}$
- CMS Tracker performance affected by higher luminosity
- More radiation damage in silicon sensors
  - Higher leakage current
  - Higher depletion voltage
  - Lower signal (signal to noise)
- More protons per bunch
  - More tracks
  - Higher occupancy
- Phase II Upgrade of CMS Tracker
  - Campaign to find sensor baseline for the future CMS Tracker

Integrated Luminosity $L_{int}=3000fb^{-1}$





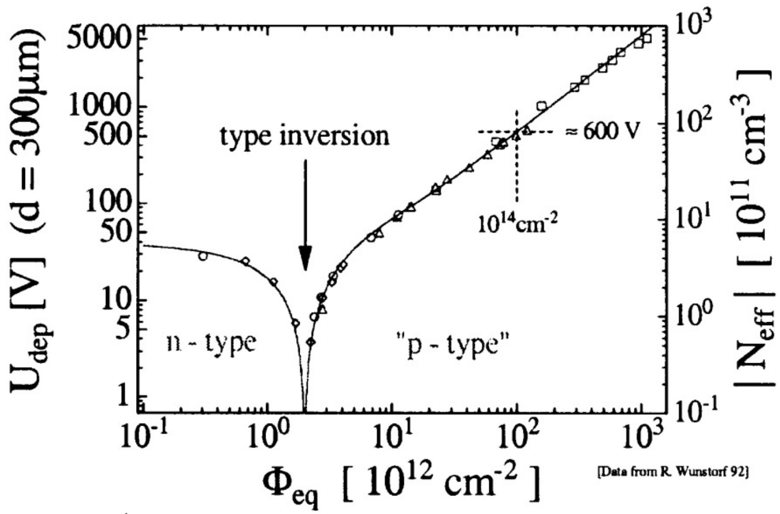
[S.Müller, phd thesis, KIT 2011]

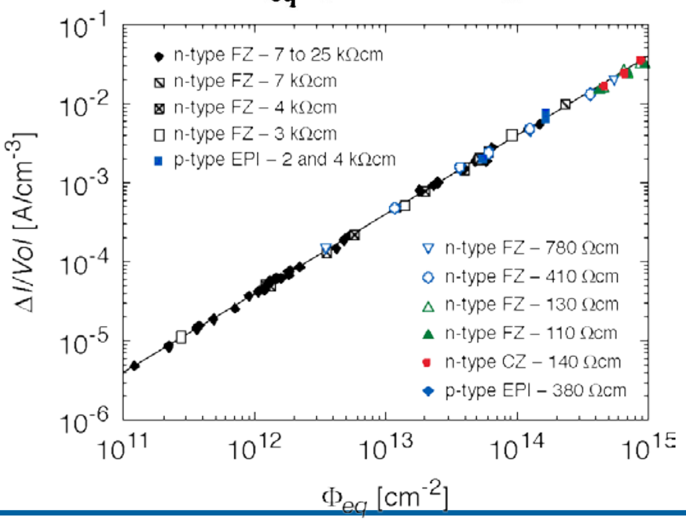
Effects of Radiation Damage to Silicon

Macroscopic Effects:
1. Change of the full depletion voltage
2. Increase of leakage current

Microscopic Effects:
- **Change of effective doping concentration of bulk material including type inversion**
- Increase of resistivity of undepleted material
- Charge trapping and thus reduction of signal

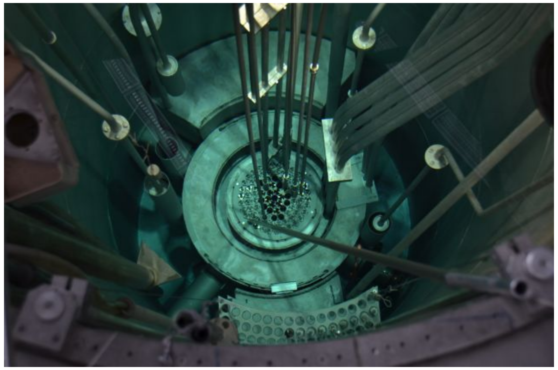
Surface Effects:
- Change of oxide charges
- Change of flat band voltage, surface current, inter-strip capacitance
- Inter-strip capacitance increases
- Inter-strip resistance drops

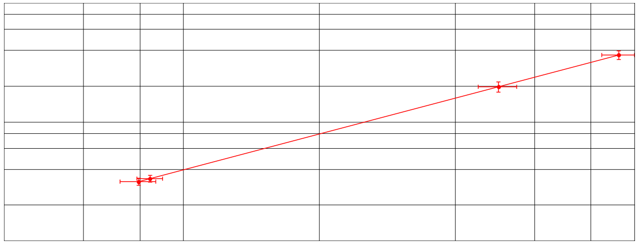


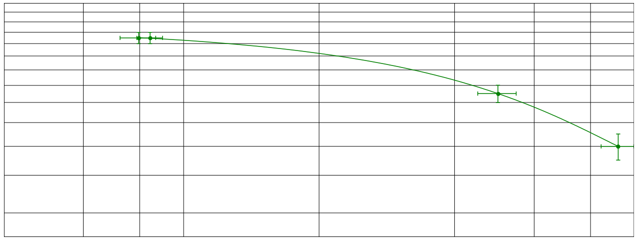


Irradiations at Vienna Nuclear Reactor

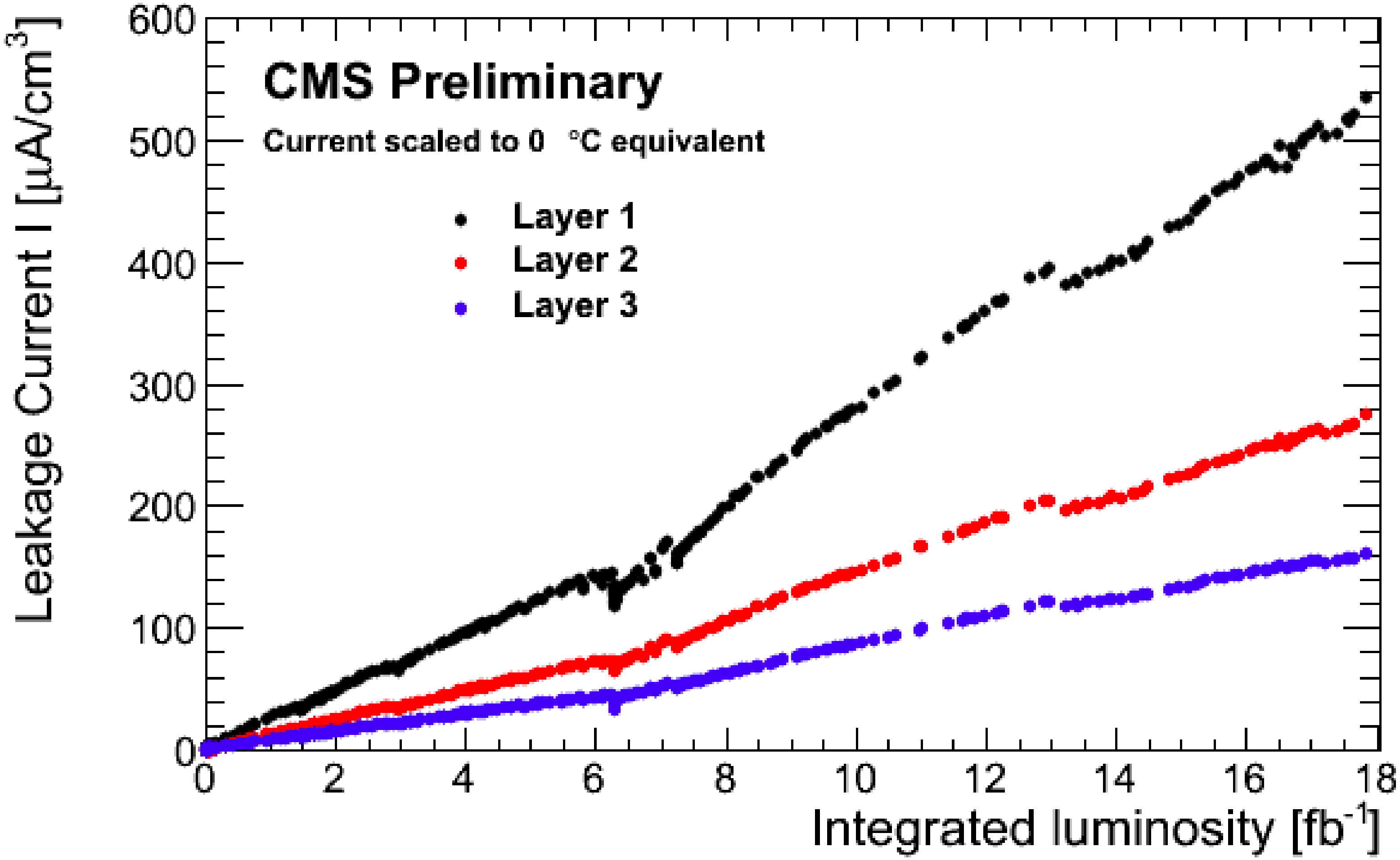
- Triga Mark II research reactor of ATI Vienna (Atominstitut, TU Wien) available for neutron irradiations
  - 250kW: 10^{13} n/cm^{2}s^1 in central irradiation channel
  - Easy access
  - No official dosimetry







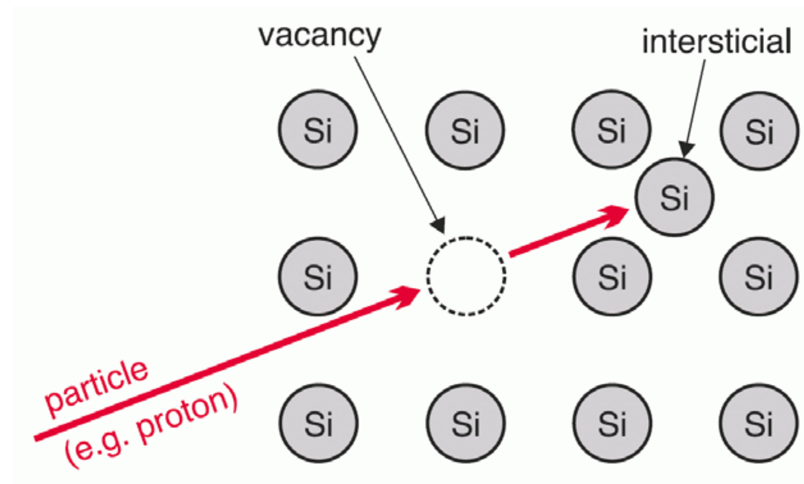
Dark current increase in CMS



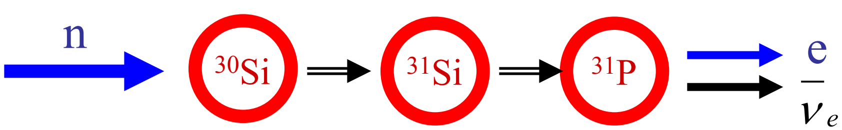
What happens exactly in the silicon?

Particles traversing silicon sensors create damage in the silicon lattice

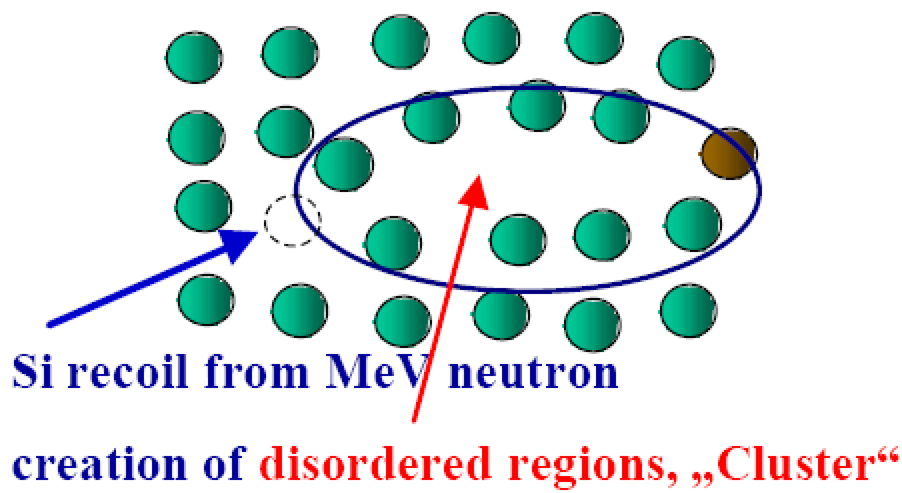
- displacements via em-force (compton scattering):
  - point defects (Frenkel Pairs)
    - interstitials (I)
    - vacancies (V)



- nuclei reactions, e.g. (point defects

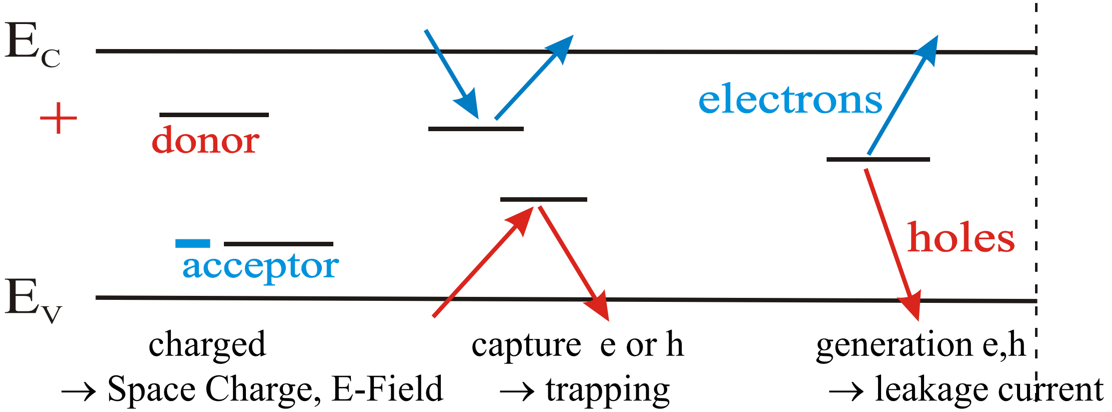


- Clusters created by Primary Knock On Atoms (PKA)



Defects

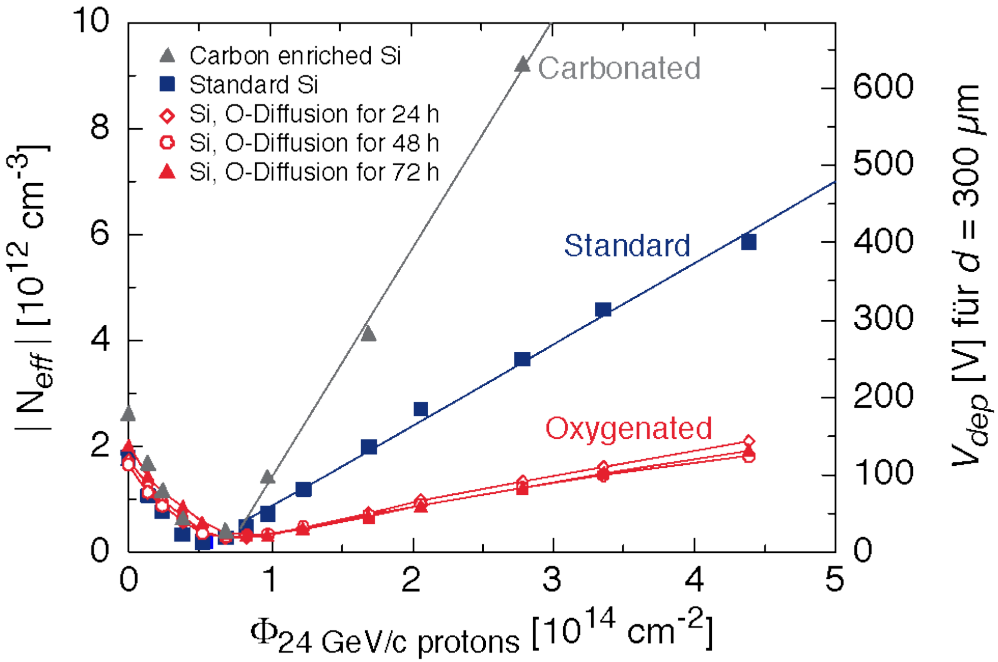
- Defect generation can depend on material (remember: oxygenated silicon)
- Electronic defect properties rule the impact on the device
- Different consequence depending on position within band gap:
  - **e or holes capturing**: Trapping -> signal loss -> lower CCE
  - **Generation of e,h pairs**: increased leakage current



Defect parameters:

$\sigma_{n,p}$: cross sections
ΔE : ionization energy
N_t : concentration
type : acceptor, donor,…

Radiation Hard Silicon



- Oxygen concentration in typical floatzone (FZ) material <10^{16} cm^{-3}
- DOFZ (diffusion-oxygenated FZ): 10^{17} cm^{-3}

Try materials naturally rich in Oxygen:

Czochralski silicon

- Pull Si-crystal from a Si-melt contained in a silica crucible while rotating.
- Dissolving oxygen into the melt ⇨ high concentration of O in CZ
- Material used by IC industry (cheap), now available in high purity for use as particle detector (MCz)

Epitaxial silicon

- Chemical-Vapour Deposition (CVD) of Silicon
- CZ silicon substrate used ⇨ diffusion of oxygen
- Excellent homogeneity of resistivity
- 150 µm thick layers produced (thicker is possible)

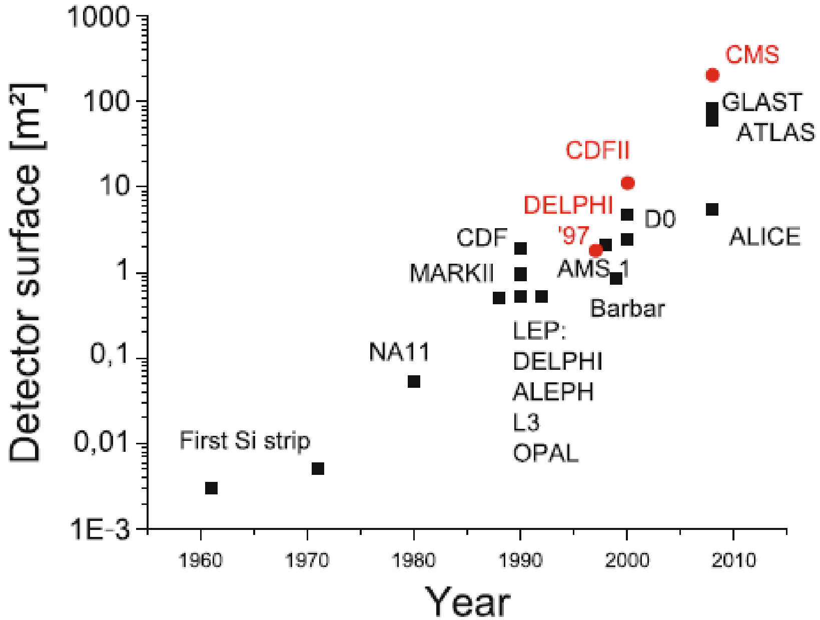
What has changed since the 90ies?

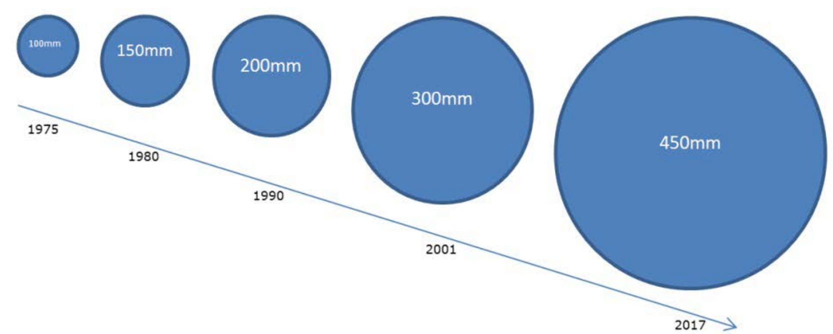
CMS Design was done ~1995

- Silicon surface
  - Today: Up to 200 m² (CMS)
  - Similar demand for upgrades of CMS and ATLAS
- Wafer Size
  - NA11 started with 2" and 3"
  - Today 6" (150 mm) is standard

→ **Introduced in the Industry in the 80ies!**

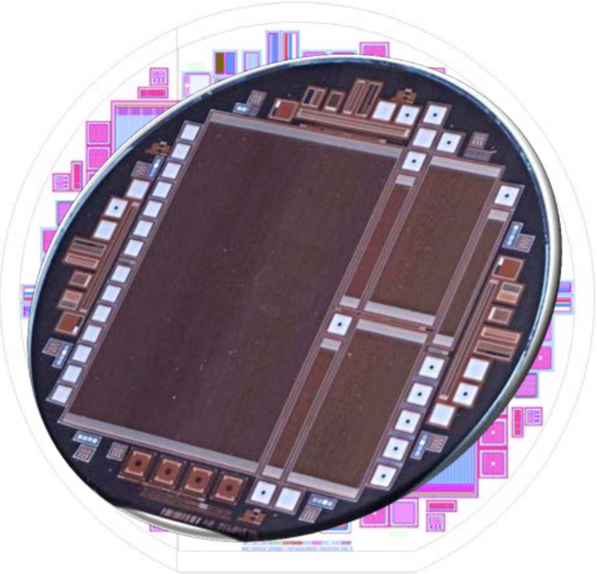
→ **Effort to bring silicon detector vendors to invest in 8" production technology.**





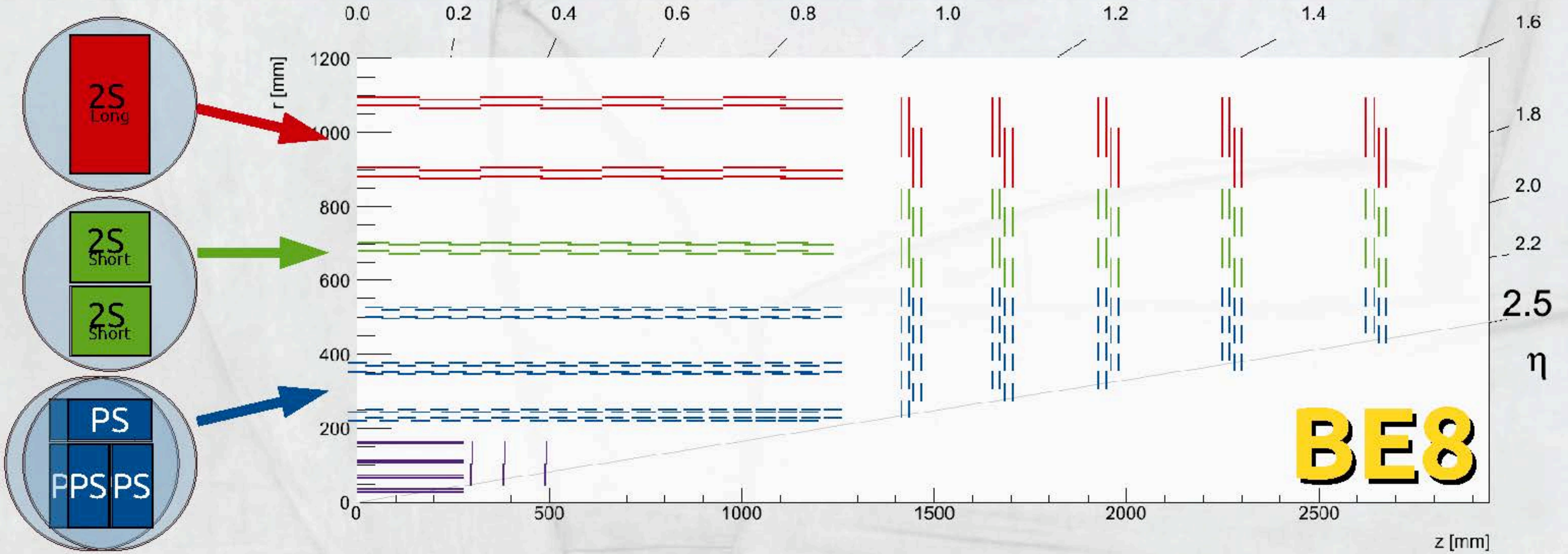
Silicon Strip Sensors made by Infineon

- Small scale R&D production:
  - Many institutes and companies are able to produce a few 10-100 wafers per year
  - 6 inch is usually available at many sites
  - The sensors differ in a broad spectra of quality and price
- Large scale commercial production:
  - Currently only one company is able to produce a few 1.000 – 10.000 high quality wafers per year
- Possible new producer: **Infineon**
  - Production on thinned 8 inch wafers could be possible



→ Dual or multi-source strategy would be preferable

Barrel+Endcap 8" wafers



	$2S_L$	$2S_S$	PS	Total
Modules	3'680	3'696	6'846	14'222
Sensors	7'360	7'392	6'846 strip 6'846 pixel	28'444
Wafers	**7'360**	**3'696**	**2'282 strip** **2'282 pixel**	**15'620**
Power [kW] (FE+sensors)	10.0+2.0	10.0+1.4	34.3+3.1	54.4+6.4

Ratio: 1.05

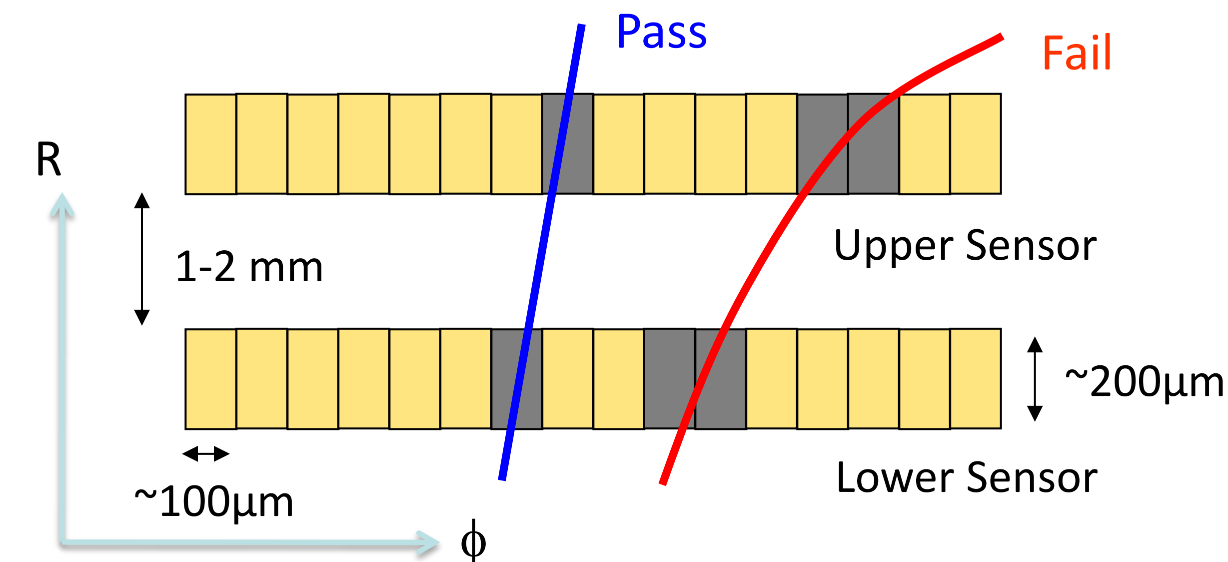
Reasonably large gain

Ratio: 1.49

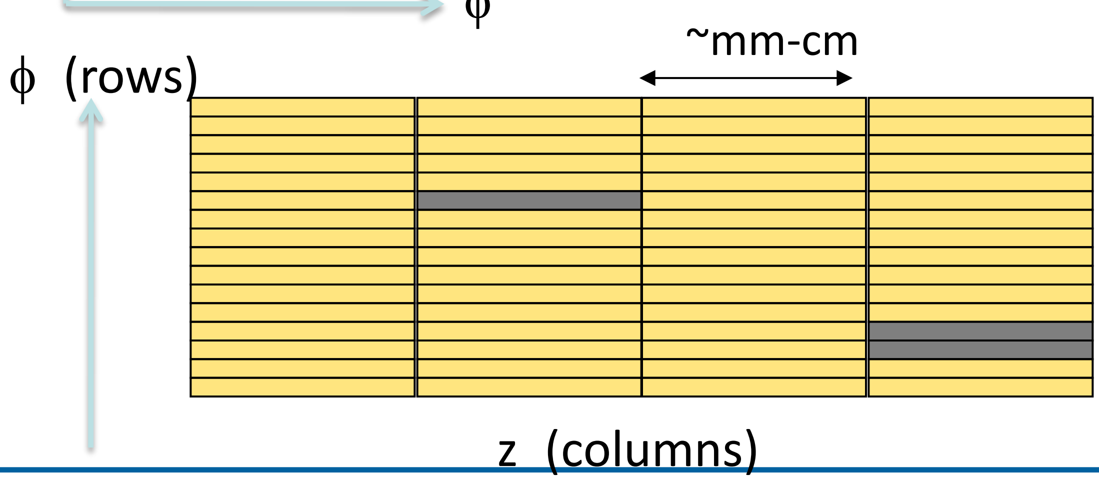
23'308 wafers (6" baseline)

Basic trigger module concept

- Compare binary pattern of hit pixels on upper and lower sensors

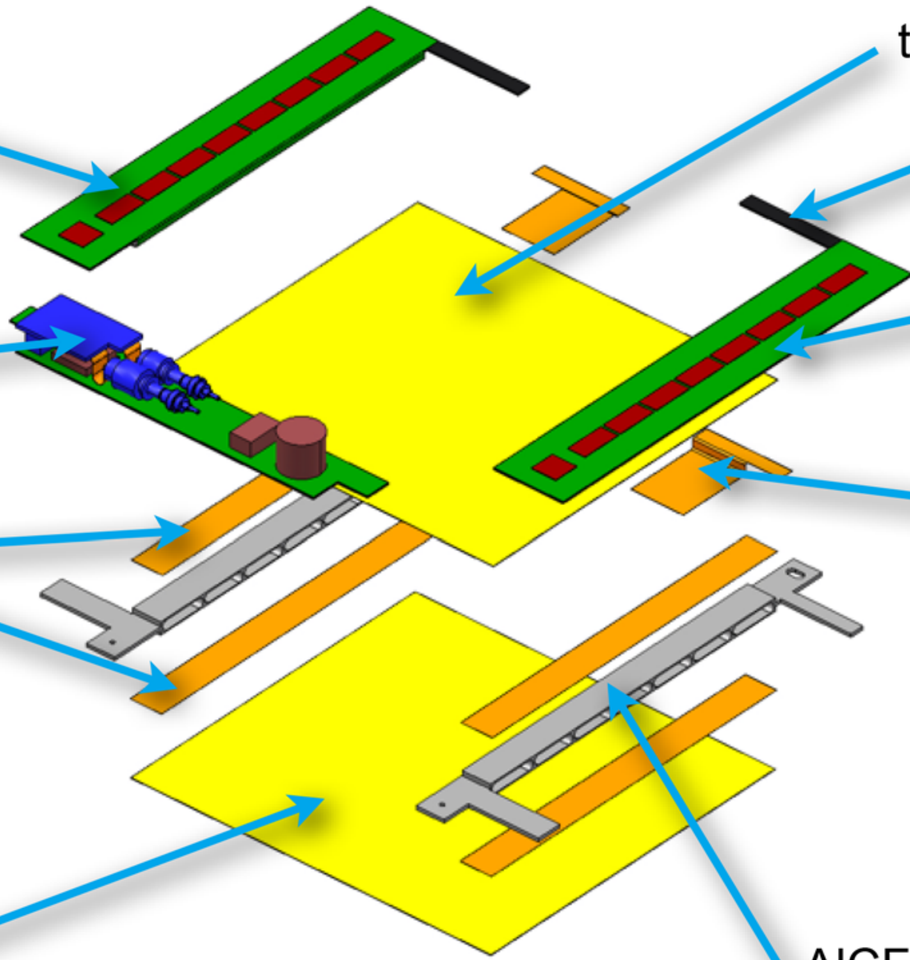


High p_T tracks can be identified if hits lie within a search window in R-ϕ (rows) in second layer

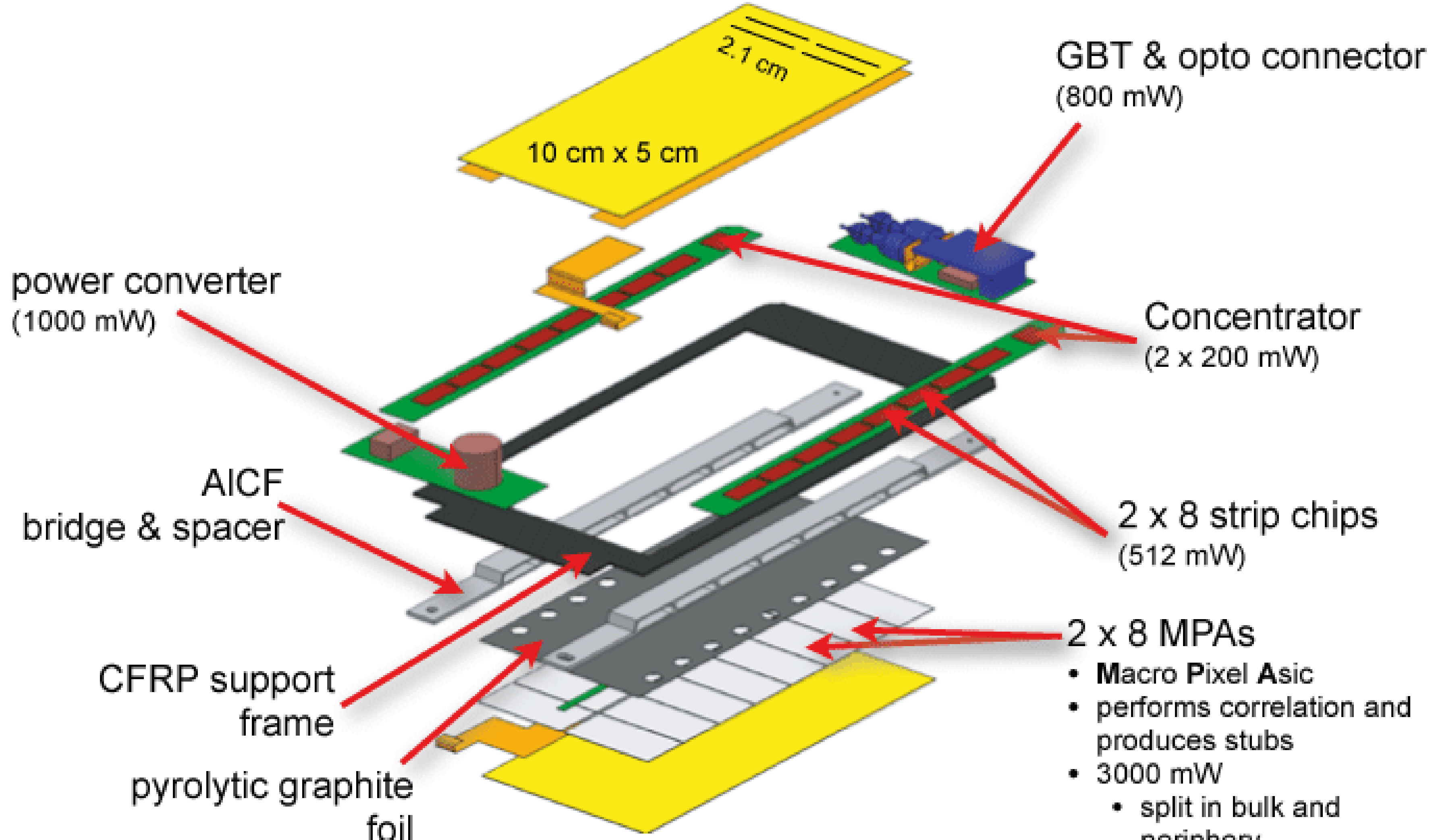


Sensor separation and search window determines p_T cut
z-segmentation determines vertex capability

2S Module

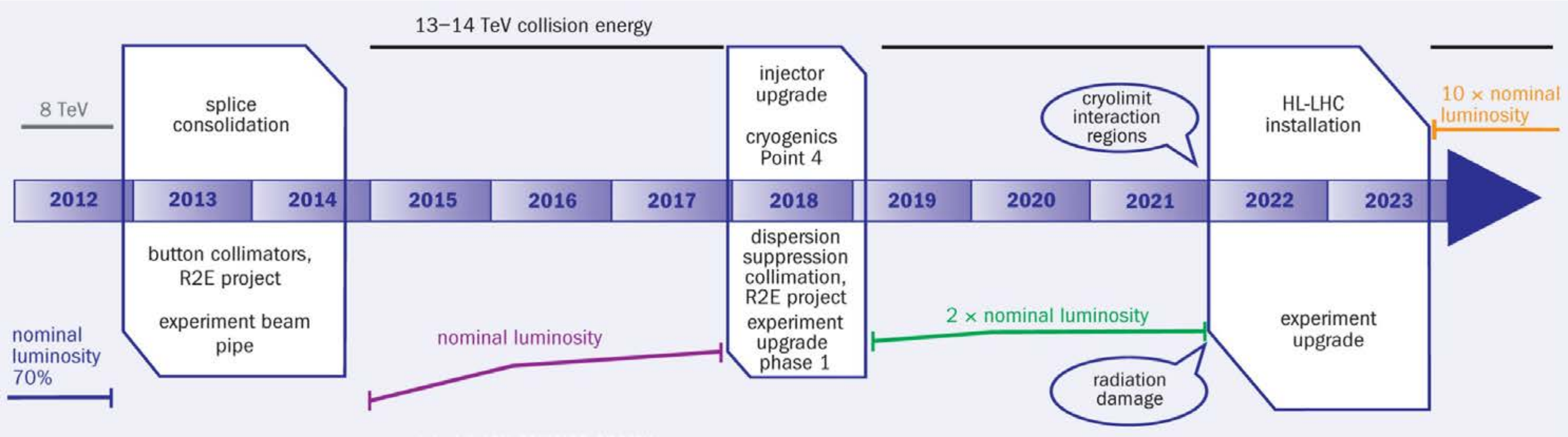

hybrid
top sensor
CFRP support
hybrid
service board
flex for bias connection
Kapton
bottom sensor
AlCF bridge & spacer

PS Module



- **M**acro **P**ixel **A**sic
- performs correlation and produces stubs
- 3000 mW
  - split in bulk and periphery

Timeline for Sensor Procurement

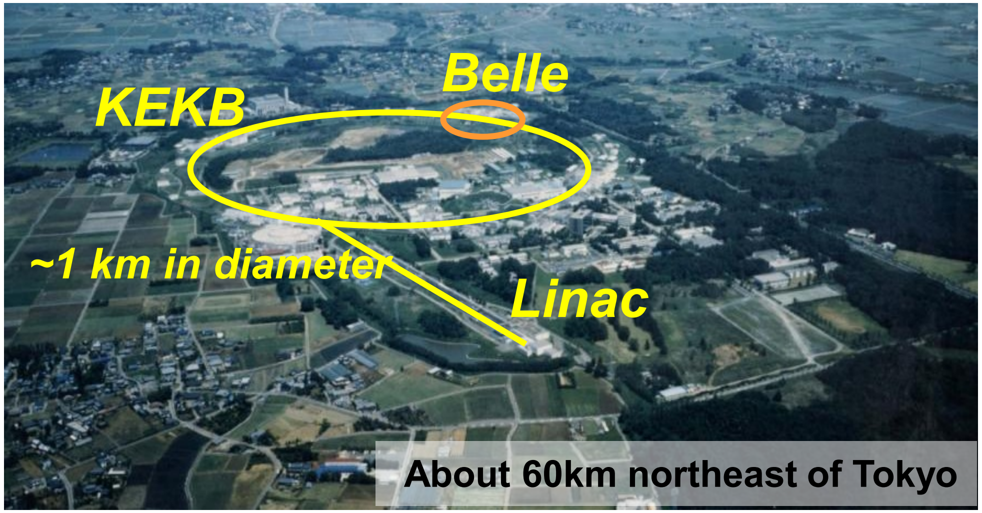


- Tentative sensor procurement timeline:
  - Mid 2014: Market survey
  - Then define detailed specs with qualified vendors
  - 2016: Tender
  - 2016 - 2017: Preproduction
  - 2017 – 2018: Production

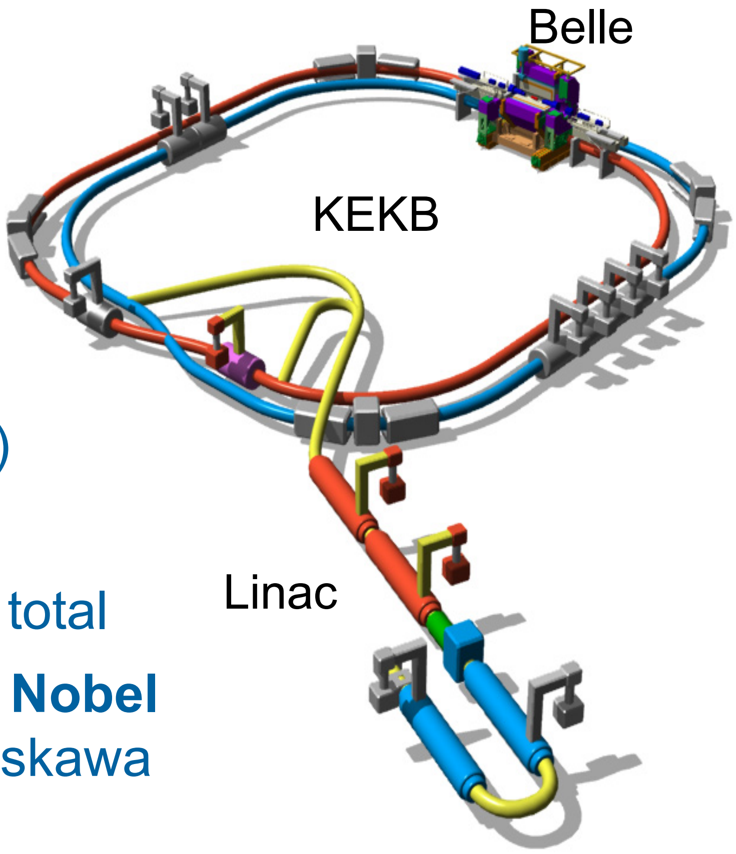
Present Hardware Projects at HEPHY

BELLE II SILICON VERTEX DETECTOR

KEKB and Belle @ KEK (1999-2010)



- **Asymmetric** machine: 8 GeV $\mathbf{e^-}$ on 3.5 GeV $\mathbf{e^+}$



- Center of mass **energy**: Υ(4S) (10.58 GeV)
- **High intensity** beams (1.6 A & 1.3 A)
- Integrated luminosity of **1 ab^{-1} recorded** in total
- Belle mentioned explicitly in **2008 Physics Nobel Prize** announcement to Kobayashi and Maskawa

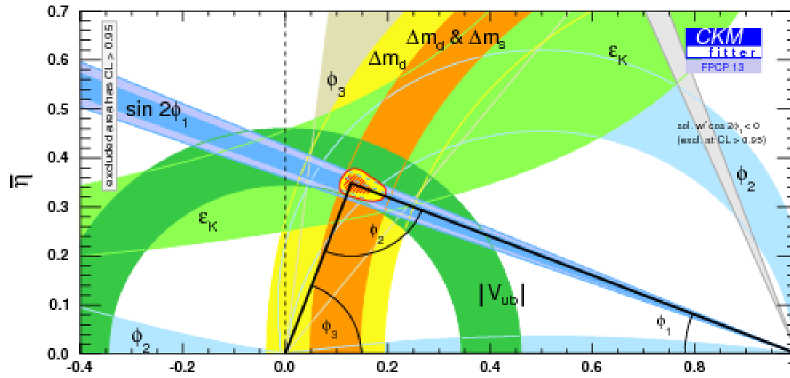
Belle I at the KEKB accelerator (1999-2010)

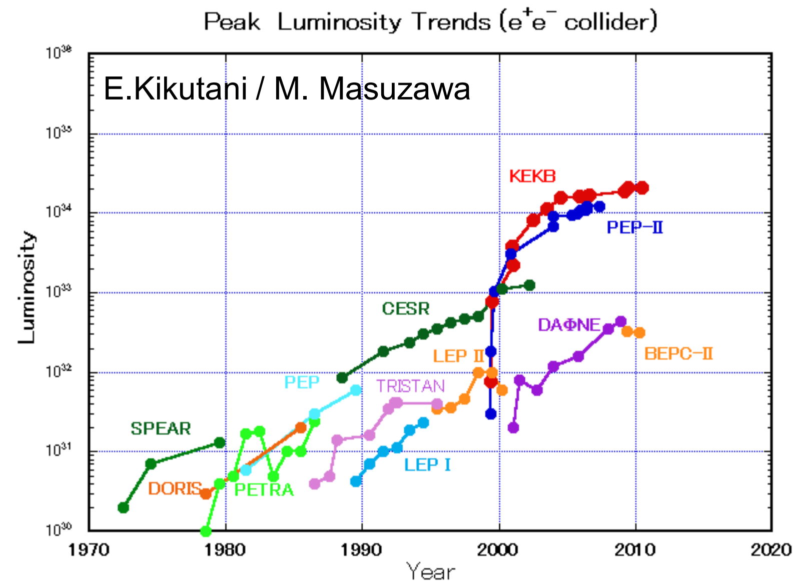
Belle I:

- Measurements of CKM matrix elements and angles of the unitary triangle
- CP & T & CPT test
- Observation of direct CP violation in B decays
- probe for new sources of CPV

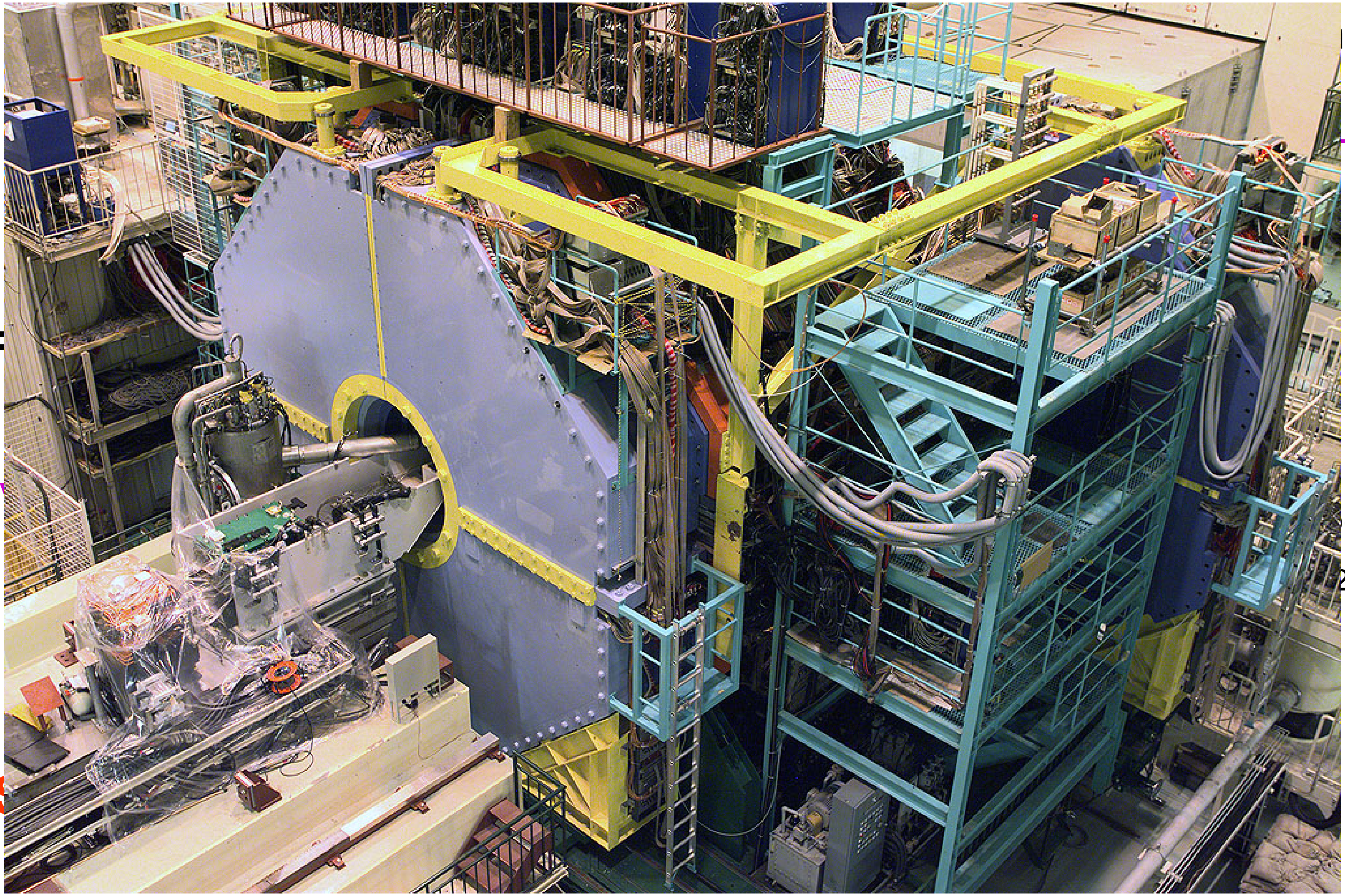
KEKB accelerator:

- Center of mass **energy**: Υ(4S) resonance (10.58 GeV)
- **High intensity** beams (1.6 A & 1.3 A)
- Integrated luminosity of **1 ab^{-1} recorded** in total





Belle Detector (1999–2010)



ter

TOF

8 Ge

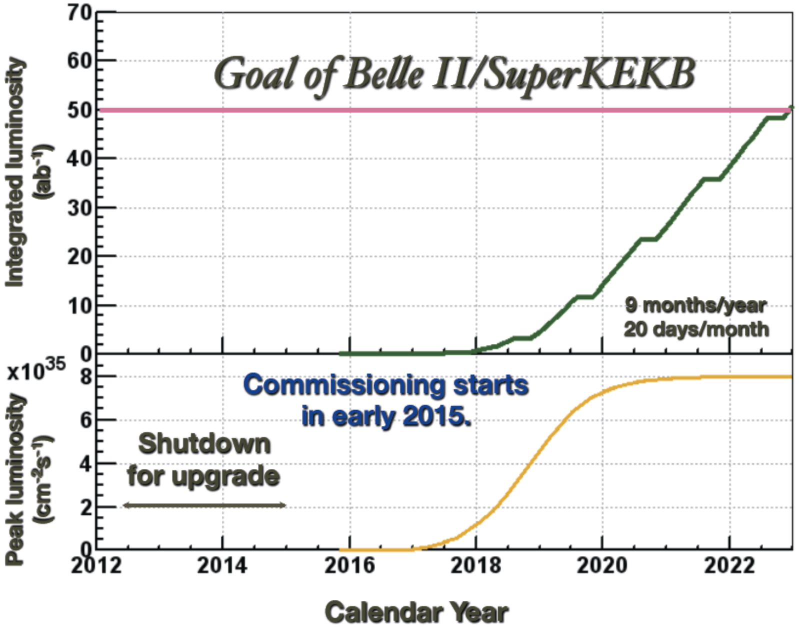
er

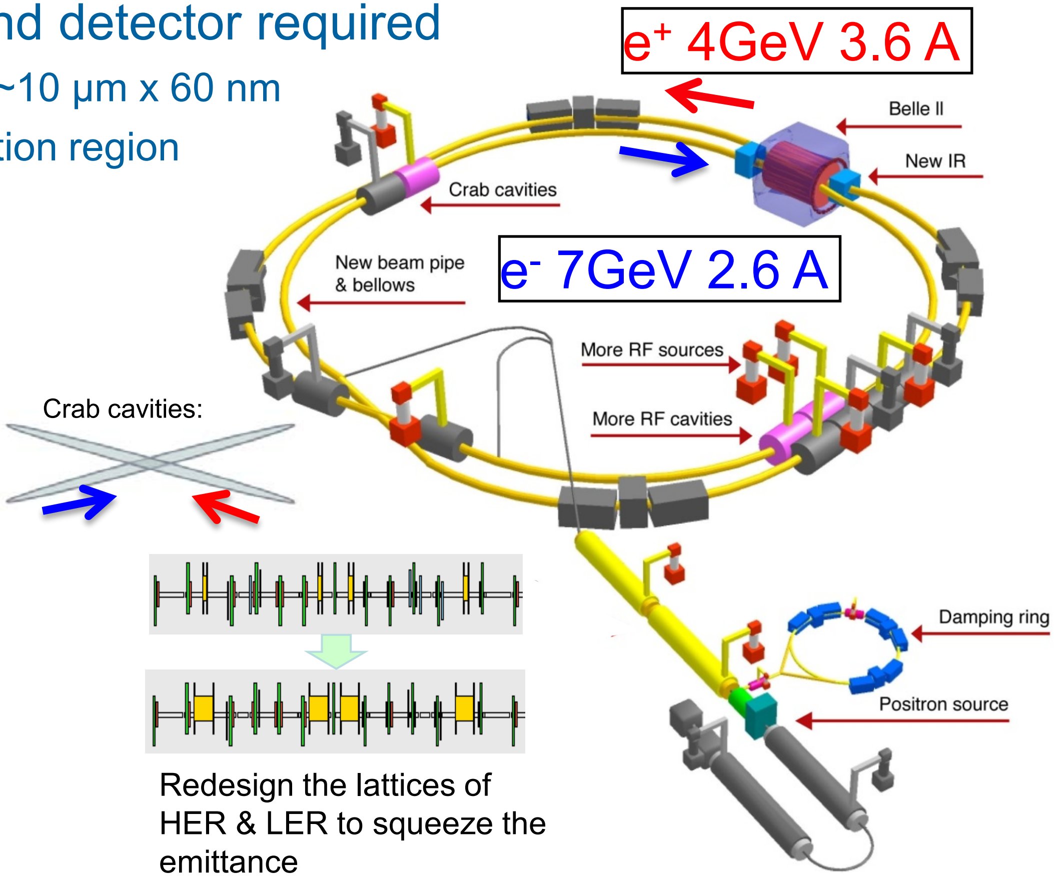
H_5

S

SuperKEKB/Belle II Upgrade: 2010–2015

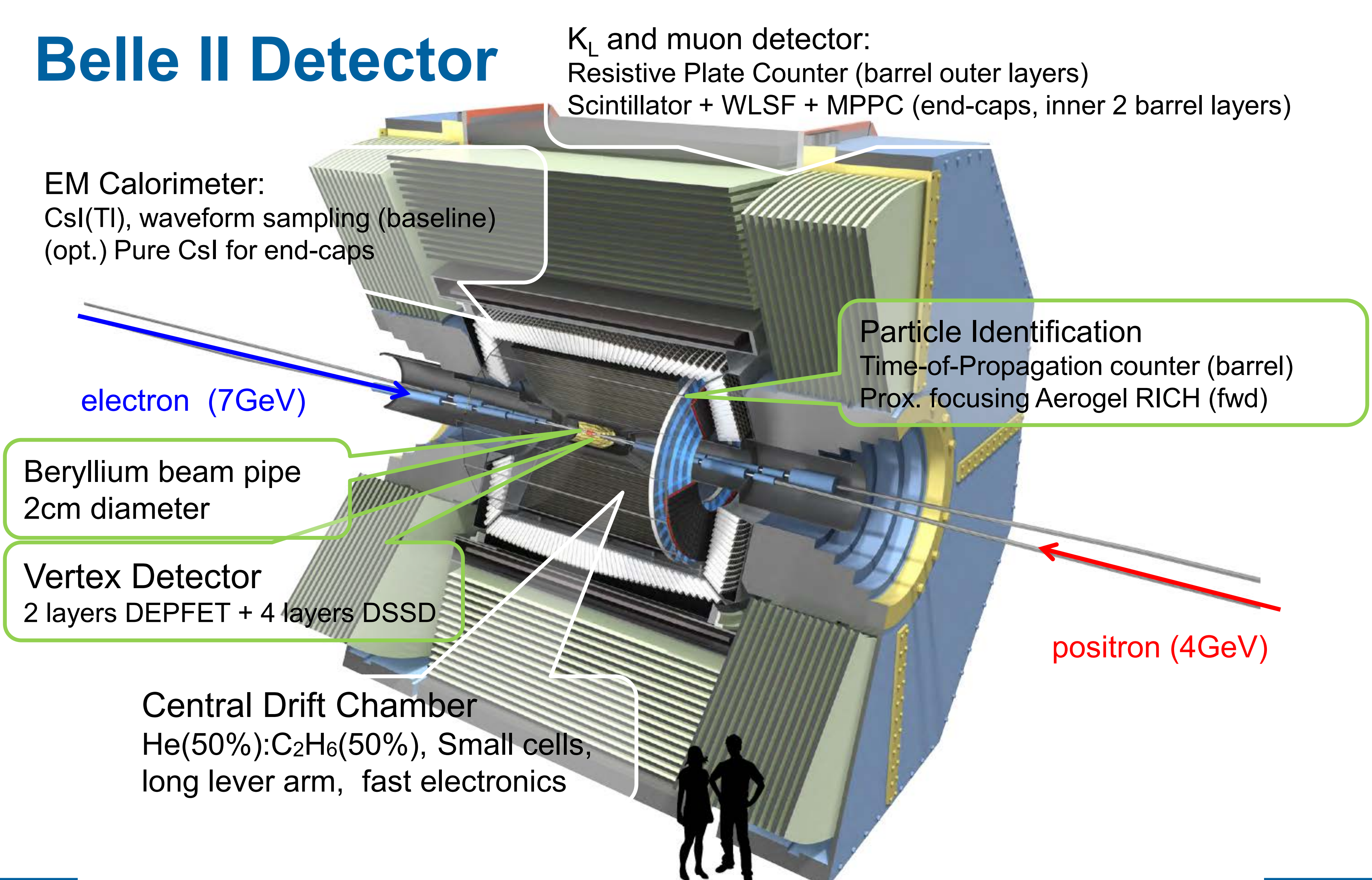
- 40-fold increase in peak luminosity to 8×10^{35} $cm^{-2}s^{-1}$ $\rightarrow$ 1×10^{10} $B\bar{B}$ / year
- 50-fold increase in integrated luminosity until 2023 w.r.t. Belle I
- Refurbishment of accelerator and detector required
  - nano-beams with cross-sections of ~10 µm x 60 nm
  - 2 cm diameter beam pipe at interaction region





Redesign the lattices of HER & LER to squeeze the emittance

Belle II Detector

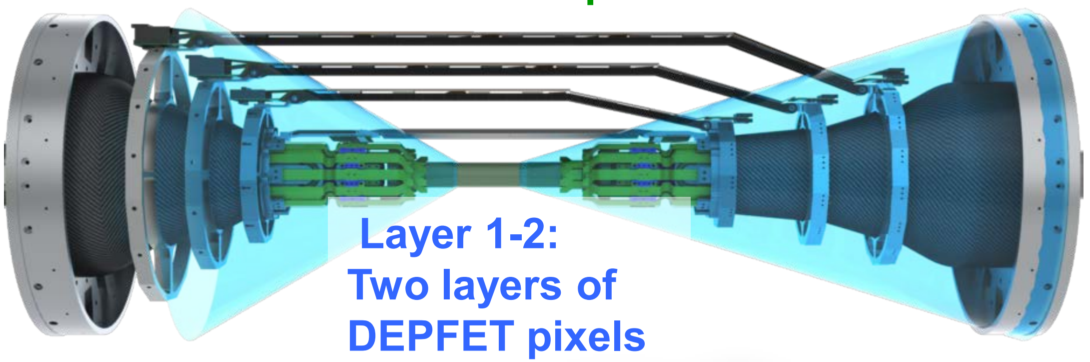


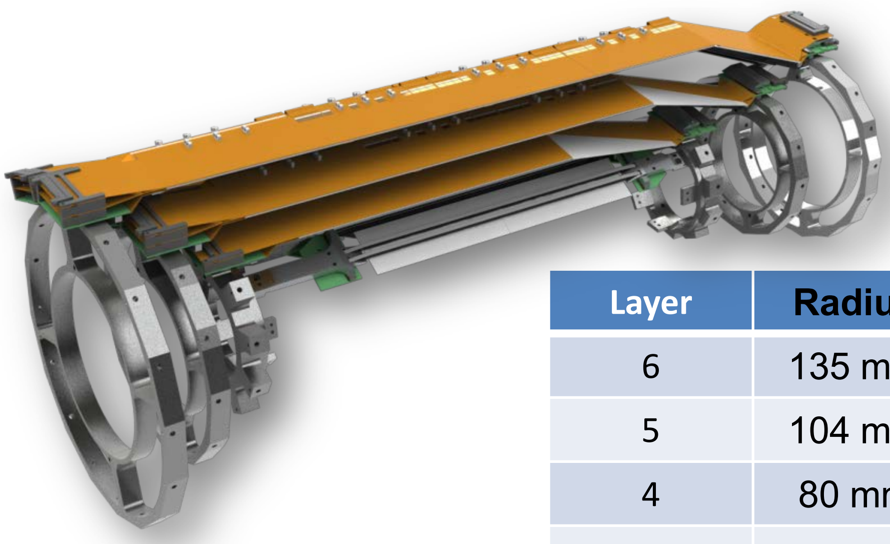
New Belle II SVD (2015-)

Four layers with 6” **double-sided strip detectors at larger radii** and **forward part**

HEPHY contributions:

- Detector concept
- 3D CAD design
- Silicon Sensors
- Front-end electronics
- Full readout chain
- Mechanical support ribs
- Tracking software



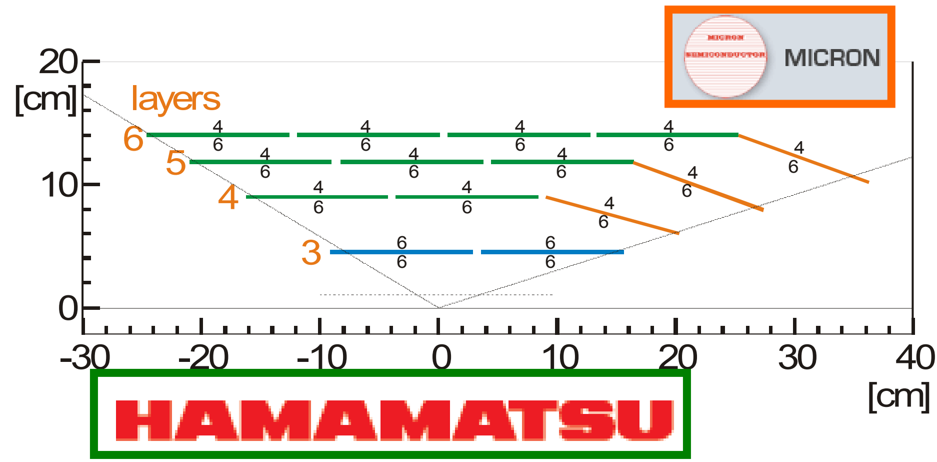


Layer	Radius	Ladders
6	135 mm	16
5	104 mm	12
4	80 mm	10
3	38 mm	7

Double-sided strip sensors from 6” wafers

Sensor Properties:

- Double-sided with perpendicular strips
- AC-coupled readout with poly-silicon resistor
- N-bulk, 300/320 micron thickness
- Three layouts only:
  - Rectangular small for layer 3 (HPK)
  - Rectangular large for layers 4-6 (HPK)
  - Trapezoidal for forward layers 4-6 (Micron)

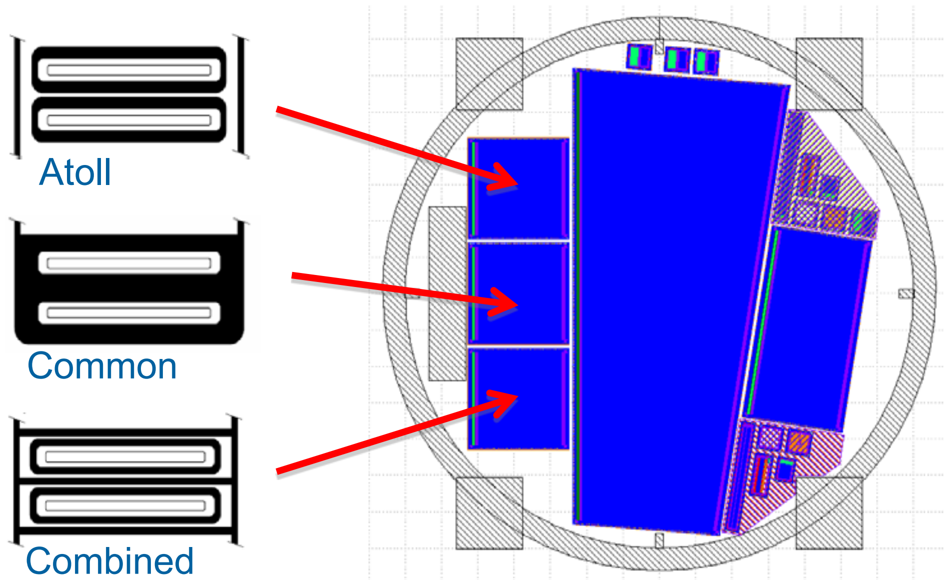


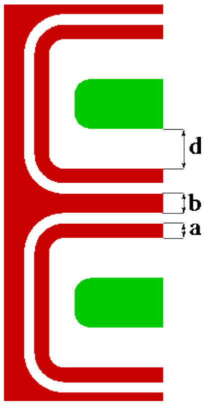
	Readout strips(p/Rϕ)	Readout strips(n/z)	Readout pitch (p/Rϕ)	Readout pitch(n/z)	Sensors # (+ spares)	Active area (mm^2)
Large	768	512	75 µm	240 µm	120+18	122.90x57.72 =7029.88
Trapezoidal	768	512	50-75 µm	240 µm	38+6	122.76x(57.59+38.42)/2 =5893.09
Small	768	768	50 µm	160 µm	14+4	122.90x38.55 =4737.80

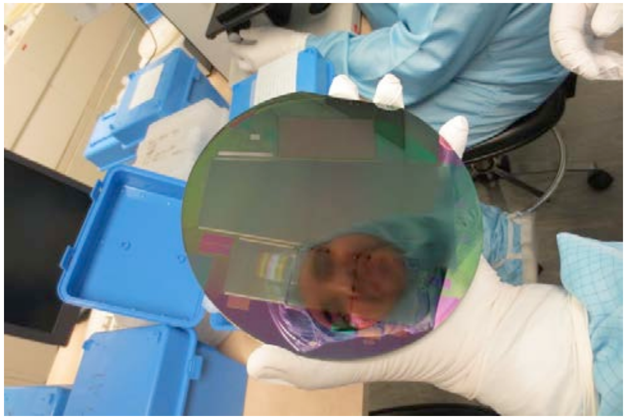
Trapezoidal Sensors for Forward Region

MICRON SEMICONDUCTOR ltd

- Trapezoidal sensor for forward region
- Different p-stop layouts on test sensors
- Each layout type with four variants (narrow/half narrow/ wide / half wide)
  - Testbeam and irradiation study to determine best structure

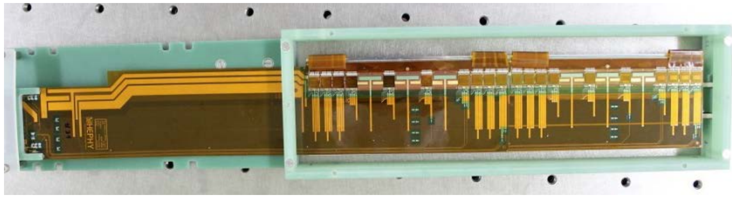




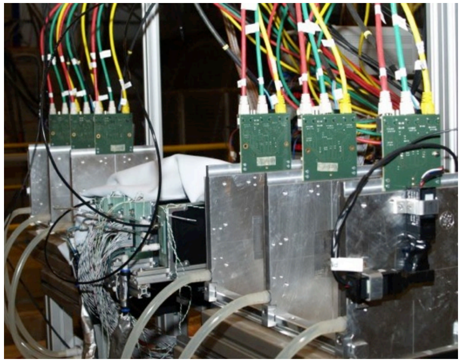


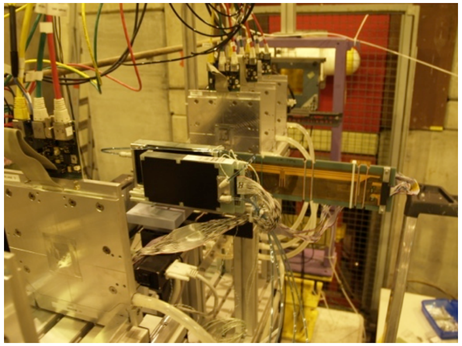
Beam test results

- Performance of full modules verified in several beam tests at CERN (2008-2012)
  - Including CO_2 cooling
  - With Gamma irradiation in between

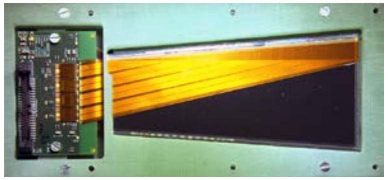


Double Origami module



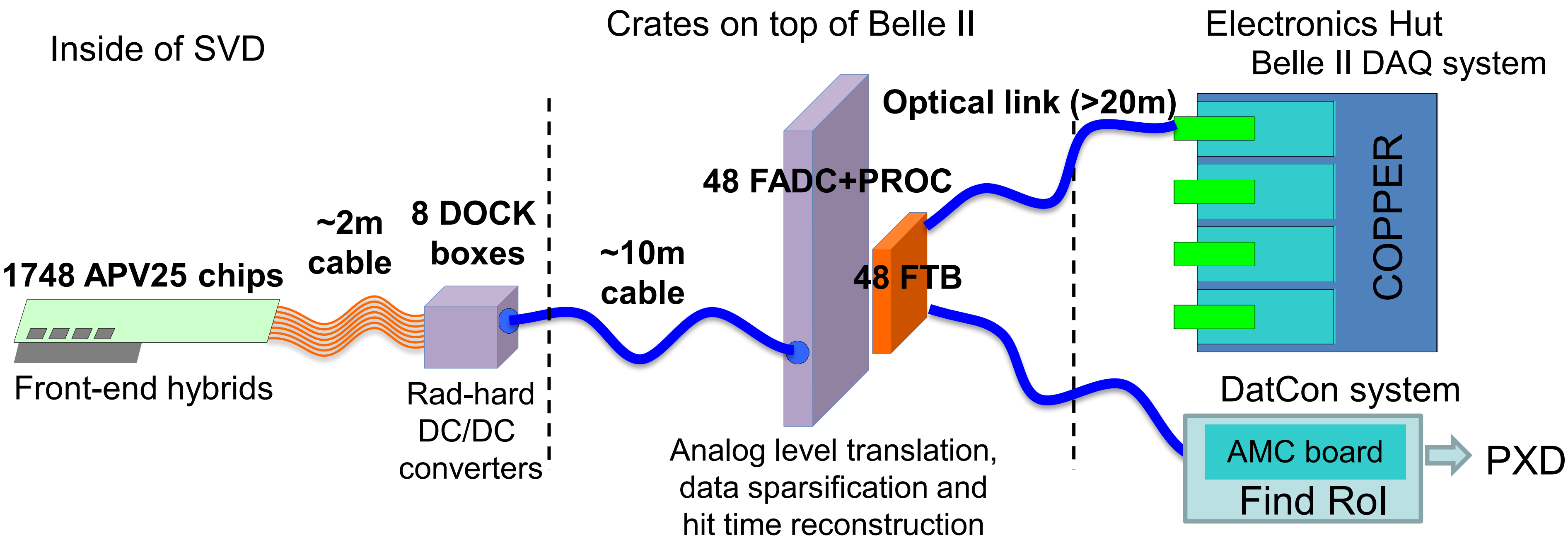


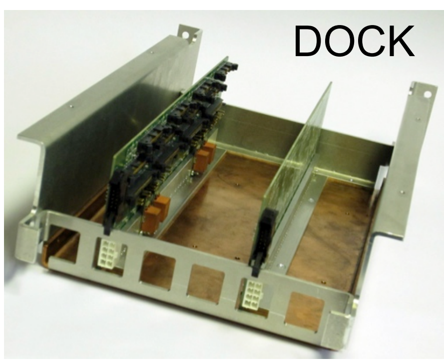
FW wedge module

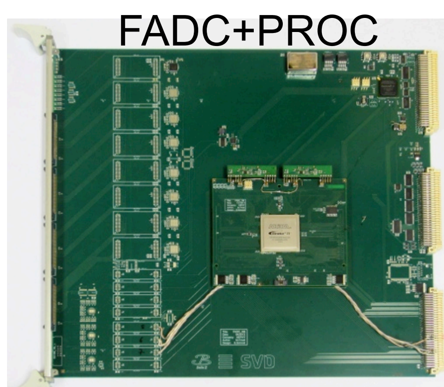


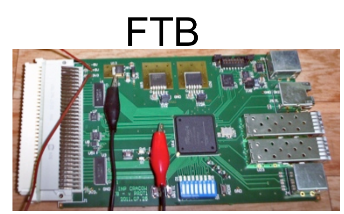
Irrad	Origami #4		Origami #3		Wedge #1	
	p	n	p	n	p	n
Before	12.2	22.7	12.0	23.4	14.9	13.0
After	11.9	16.0	12.6	23.4	12.6	12.0

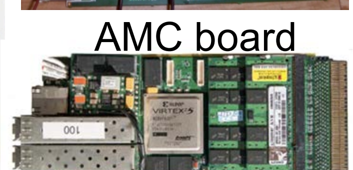
Readout System Concept

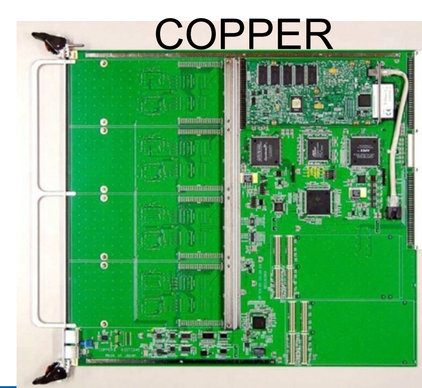






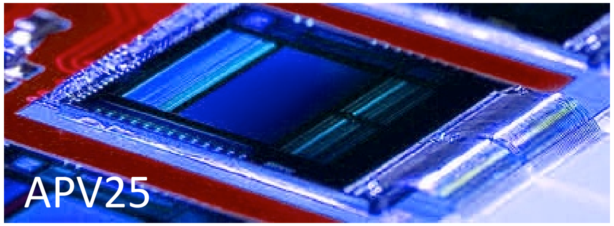


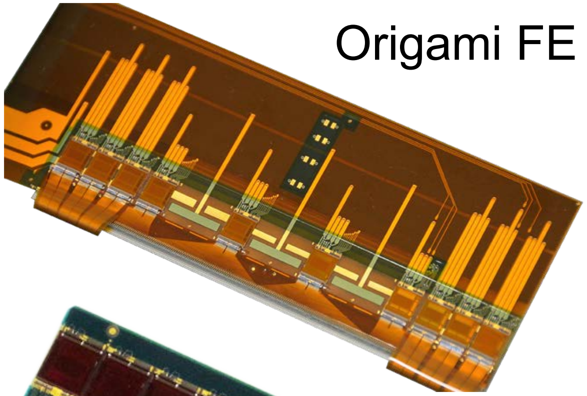


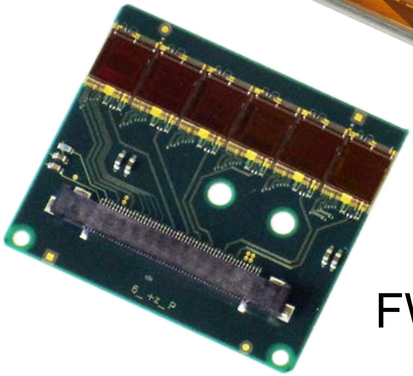


Readout Chip: APV25

- Developed for **CMS** (LHC) by *Imperial College London* and *Rutherford Appleton Lab*
  - 70.000 chips installed
- 0.25 µm CMOS process (**>100 MRad tolerant**)
- 128 channels
- **192 cell analog pipeline** → almost no dead time
- **50 ns shaping time** → low occupancy
- **Multi-peak mode** (read out several samples along shaping curve)
- **Noise:** 250 e + 36 e/pF → must minimize capacitive load!!!
- **Thinning** to 100µm successful

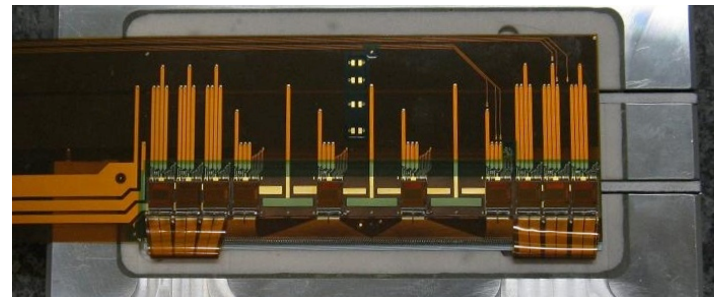


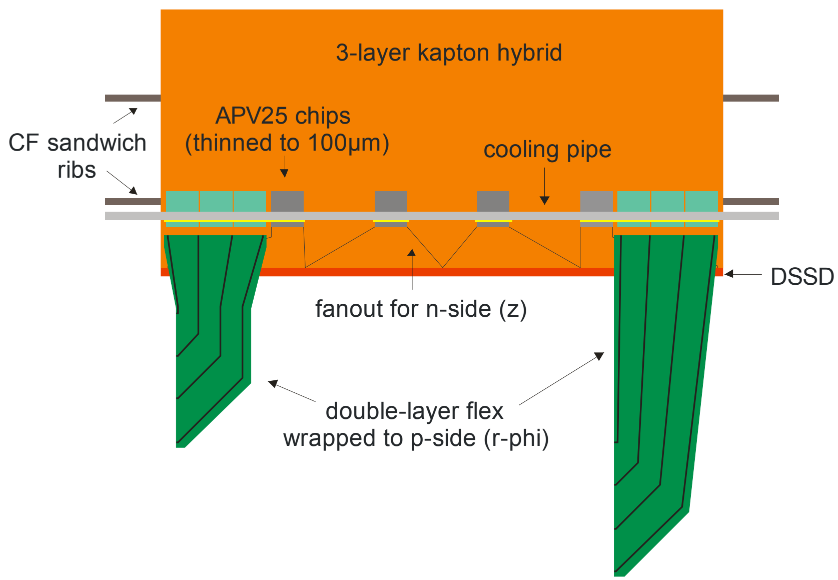

Origami FE

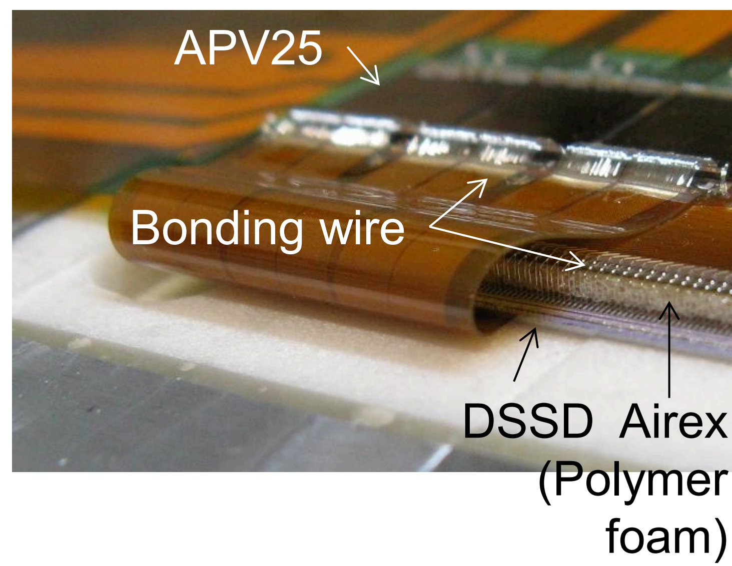

FW+BW FE

Origami Chip-on-Sensor Concept

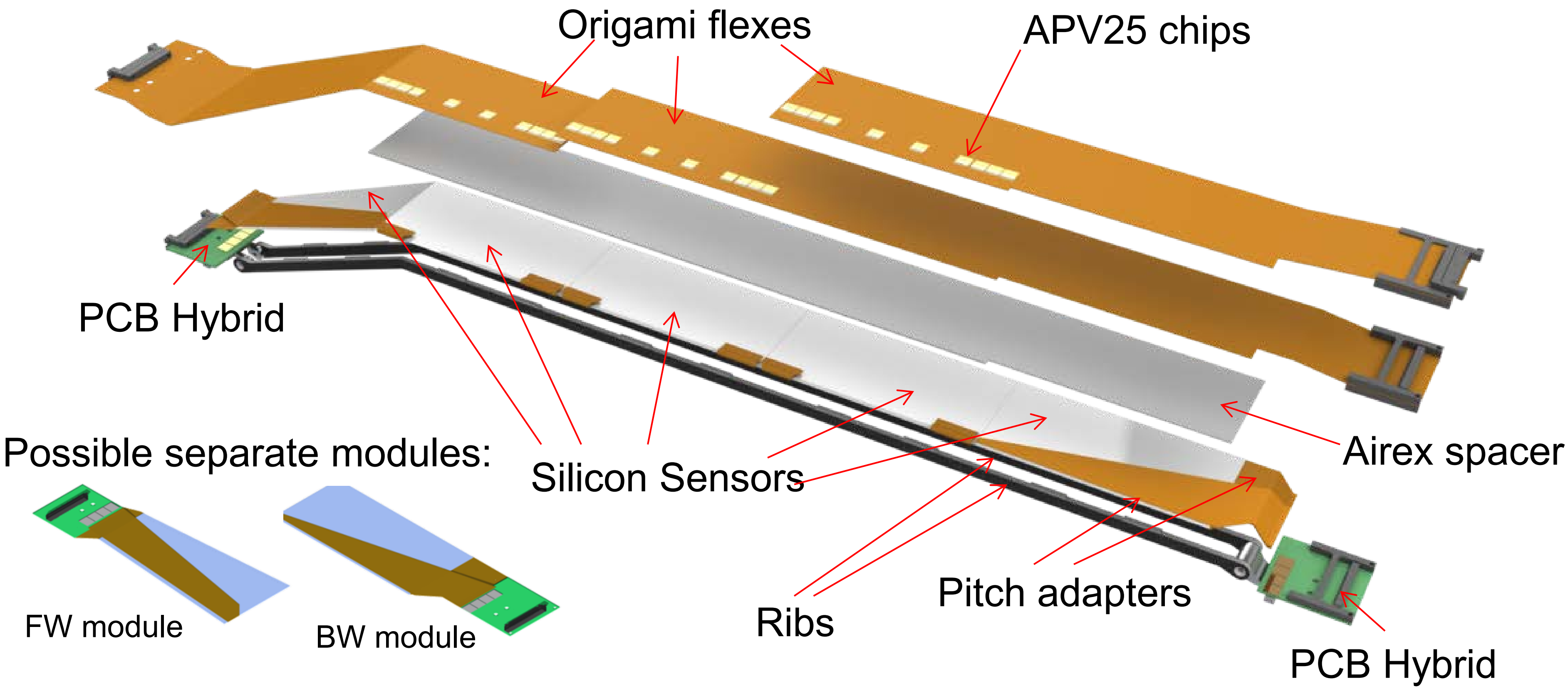
- **Chip-on-sensor** concept for **double-sided readout**
- **Flex fan-out** pieces **wrapped** to opposite side (hence "Origami")
- All chips aligned on one side → **single cooling pipe**





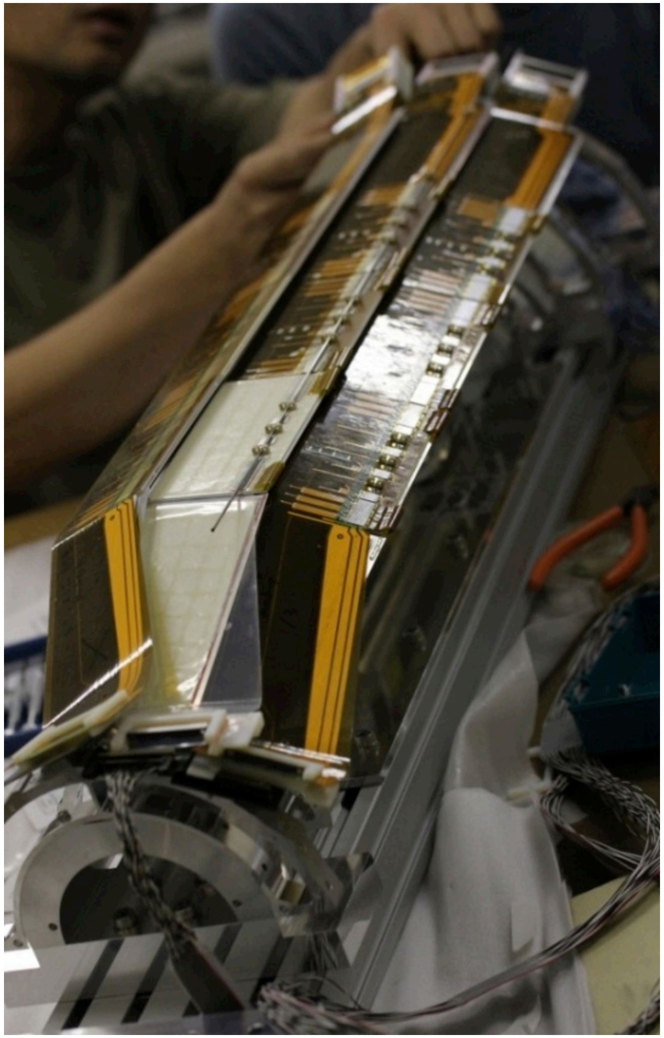


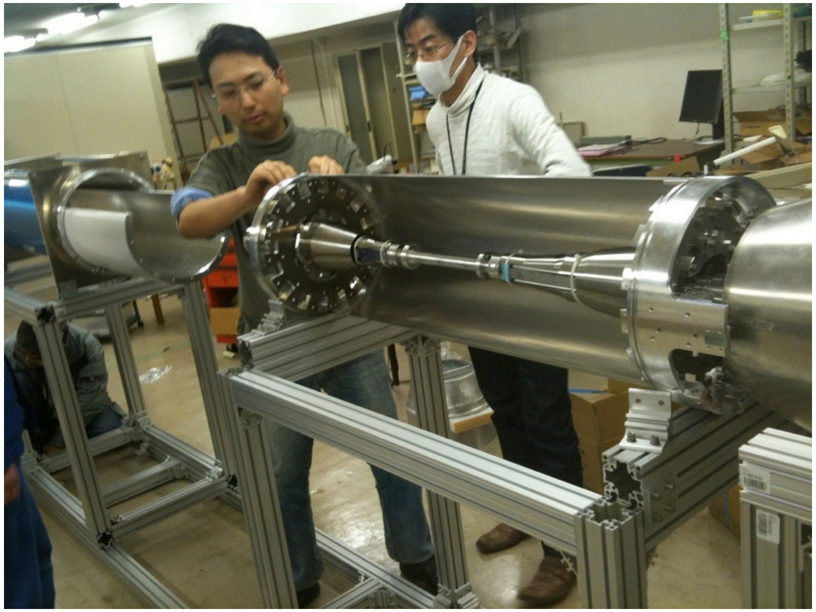
Ladder of Layer 6

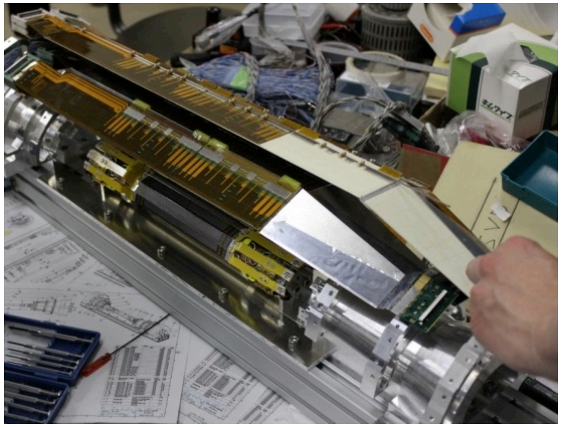


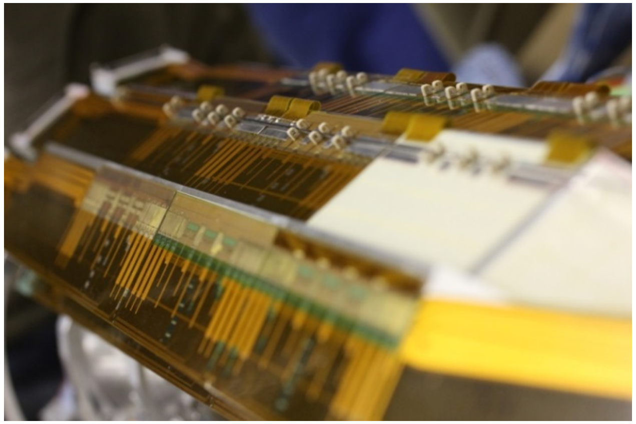
- Basic element “atomic unit” is one ladder
- Only FW and BW module can be assembled independently
- No single Origami module with one sensor possible

Mockup IR-PXD-SVD





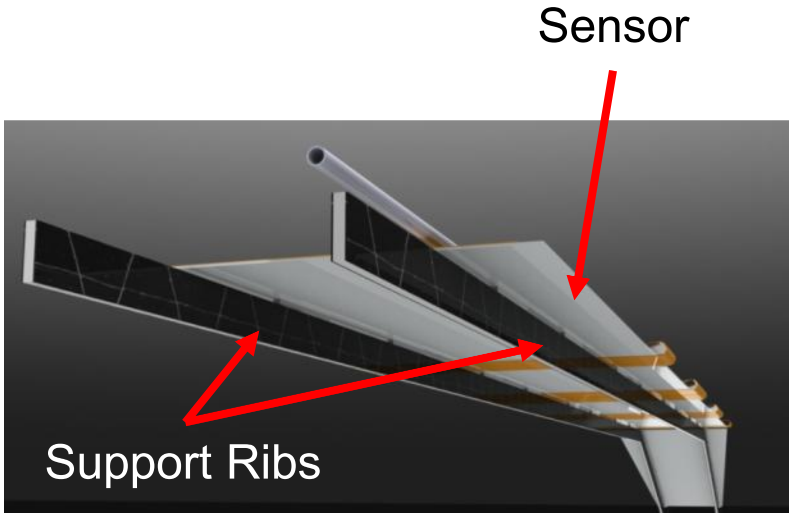


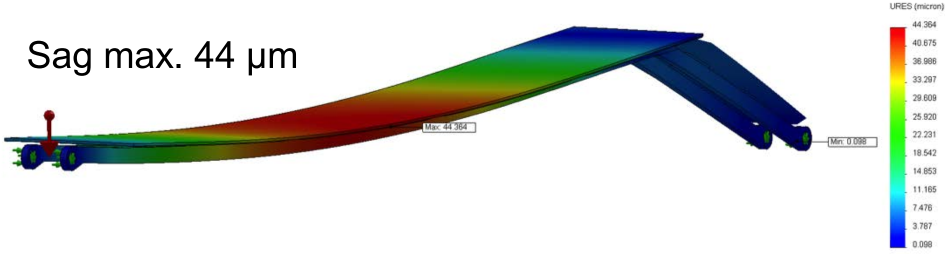


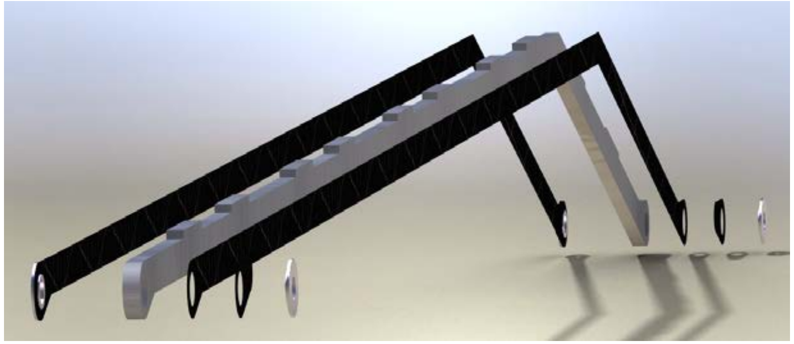
mockup study
@ KEK

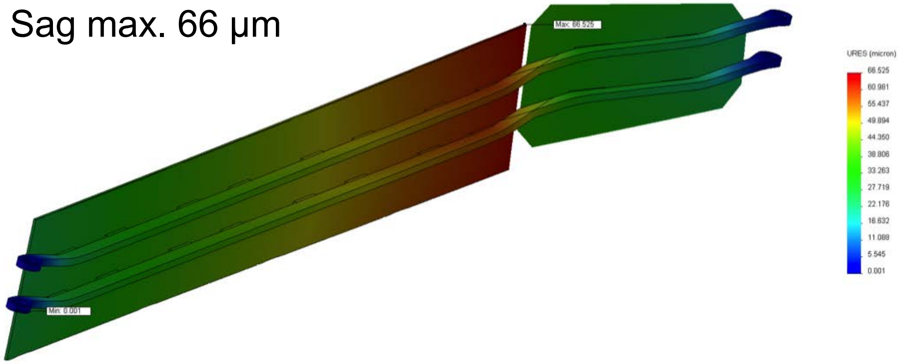
Support Ribs

- 3mm Airex core with laminated 0.15mm CF sheets
- Very stiff, yet lightweight thanks to the sandwich construction







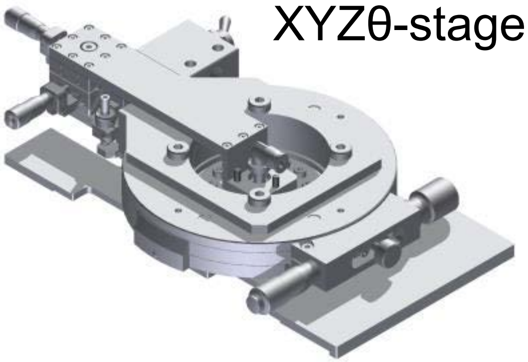


Assembly Jigs

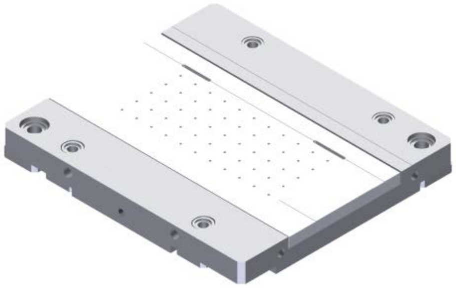
Huge number of different jigs (up to 17) necessary:

Nr.	Jig name	Purpose of jig	Status (L5)
1	Assembly base	Align jigs to each other	designed
2	Assembly bench	Carry Origami sensor, align jigs	designed
2.1	Forward sensor inlay	Carry forward sensor during assembly	
2.2	Backward sensor inlay	Carry backward sensor during assembly	
2.3	Origami sensor inlay	Support Origami sensors	
3	Sensor jig	Fix sensors to attach bottom-side pitch adapters	produced
4	PA1 jig	Align and glue PA1	produced
5	PA2 jig	Align and glue PA2	produced
6	xytheta stage	Precise alignment of sensors	
7	Airex jig	Align and attach Airex sheet	
8	Origami alignment jig	Align Origami flexes	
9	Origami ce jig	Pick up and glue Origami ce flex	
10	Origami -z jig	Pick up and glue Origami -z flex	
11	PF2 jig	Attach pitch adapter (PF2)	
12	PB2 jig	Attach pitch adapter (PF2)	
13	Slant jig	Glue forward sensor onto ribs	
14	Backward jig	Glue backward sensor onto ribs	
15	Rib jig	Mount and align ribs	
16	CO2 clamp jig	Attach CO2 cooling pipe clamps	designed

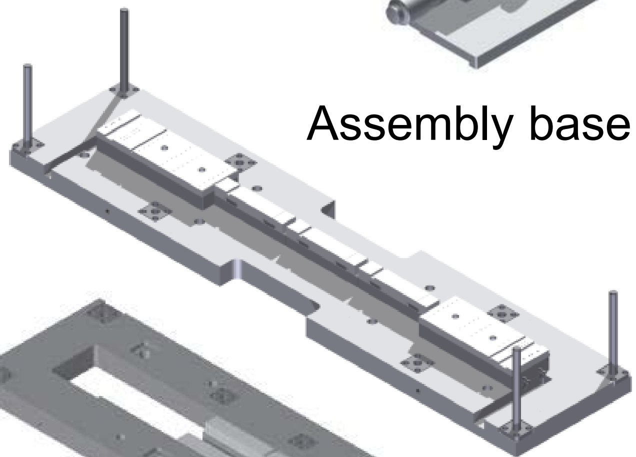
	CMM	XYZθ–stg	bench	base	Sensor-jig	Status
Melbourne	Mitsutoyo QV-PRO302	KIPMUdesign+ 1comp	✓	Draft design	Draft design	
TIFR	Sharing with KIPMU	Sharing	manufacturing	✓	✓	
HEPHY	Mitsutoyo Euro-C776	In progress	designed	designed	✓	
KIPMU	Mitsutoyo QV-606	✓	✓	✓	✓	Finalizing?
INFN	Mitsutoyo F604	designing	-	-	designing	



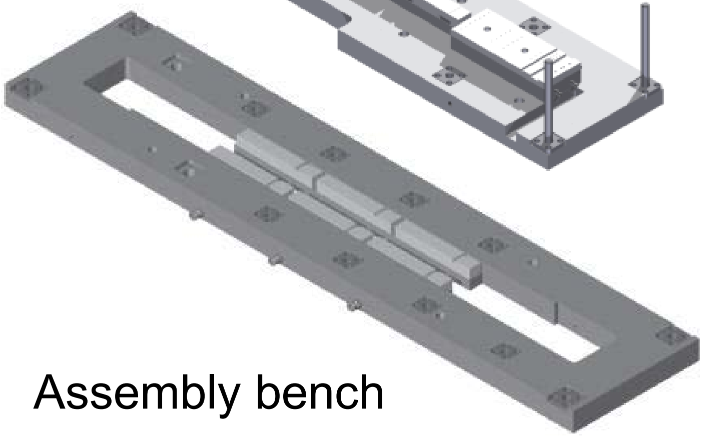
XYZθ-stage



Sensor jig



Assembly base



Assembly bench

SUMMARY

Summary

- HEPHY involved in large-scale HEP experiments for long time
- Rich research program includes design, construction, commissioning, operation and upgrades of
  - CMS Trigger & Tracker
  - Belle II Silicon Vertex Detector
- Covering Si detectors, mechanics, readout electronics, software

- Possible synergies with DM experiments related to detector development (in my opinion)
  - **Electronics** (low noise readout, FPGAs, DAQ)
  - **Semiconductor detectors** (design, characterization, industrialization)
  - **Mechanical workshop** (building detector assemblies, wire-bonding, precise machining)

THE END.