The Si Detectors in the **CMS Tracker**, commissioning, operation, future perspectives

HEPHY
Institute of High Energy Physics

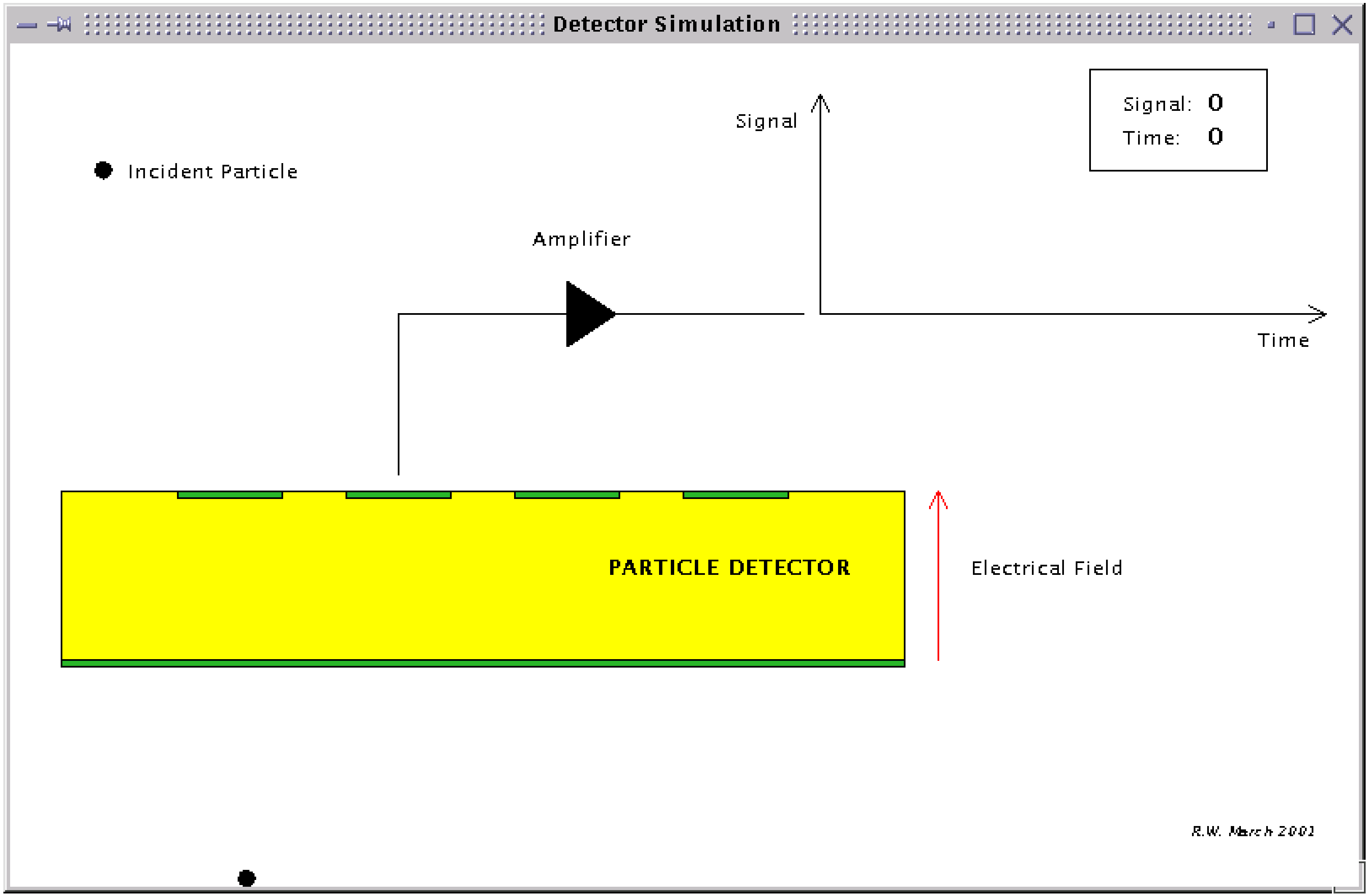
Michael Hoch 2. June 2010

ÖAW
Österreichische Akademie der Wissenschaften

Outline :

- CMS Si Detector
- Commissioning to Operation
- Radiation Damage
- Upgrade
- LHC planning

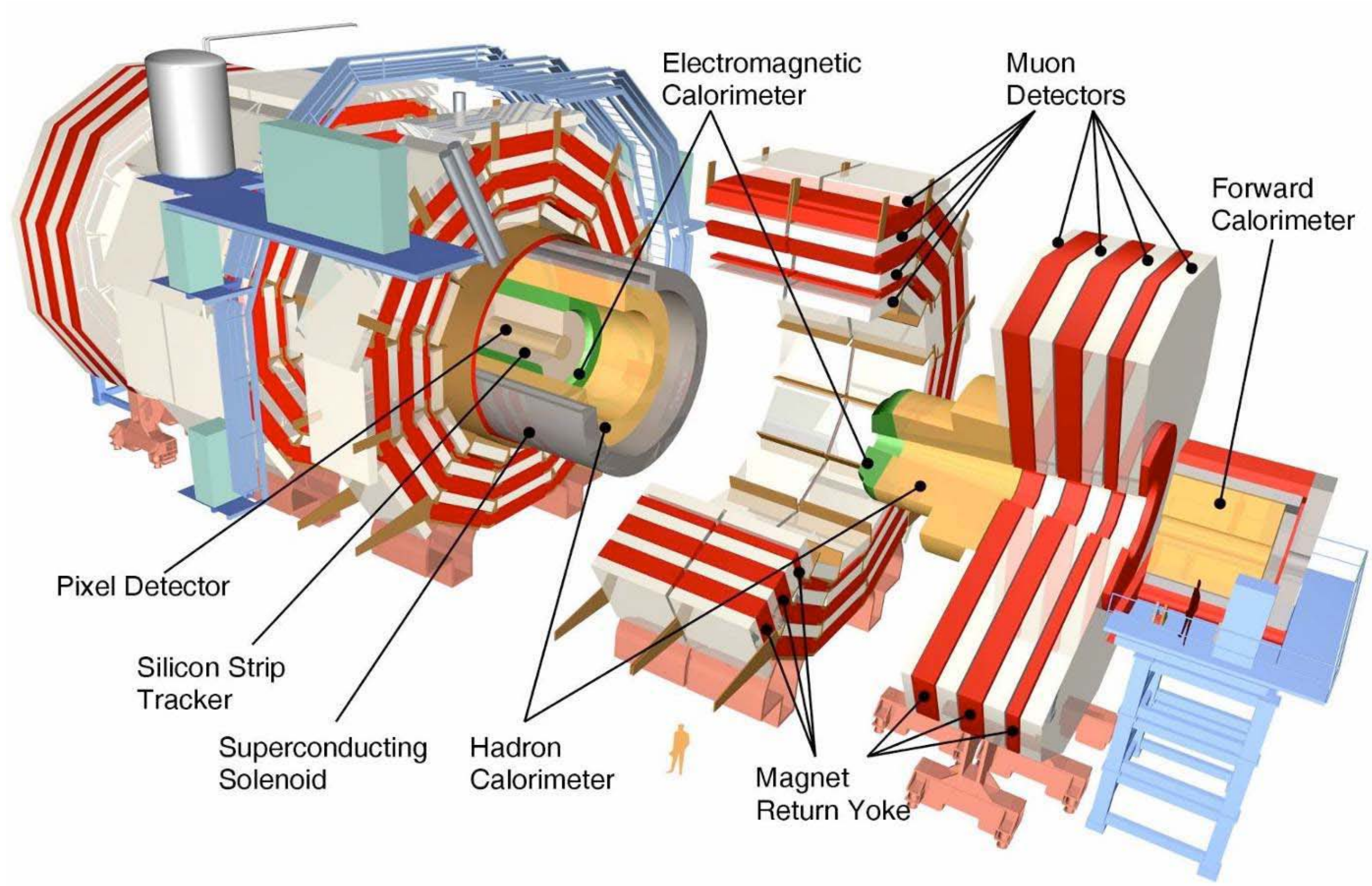
Working principle of a Si detector



Animation by R.W. HEPHY

The Si detector, a sophisticated reversed biased diode, which allows due to charge collection on their segmented structure a position information of traversing particles.
Rudi Wedenig

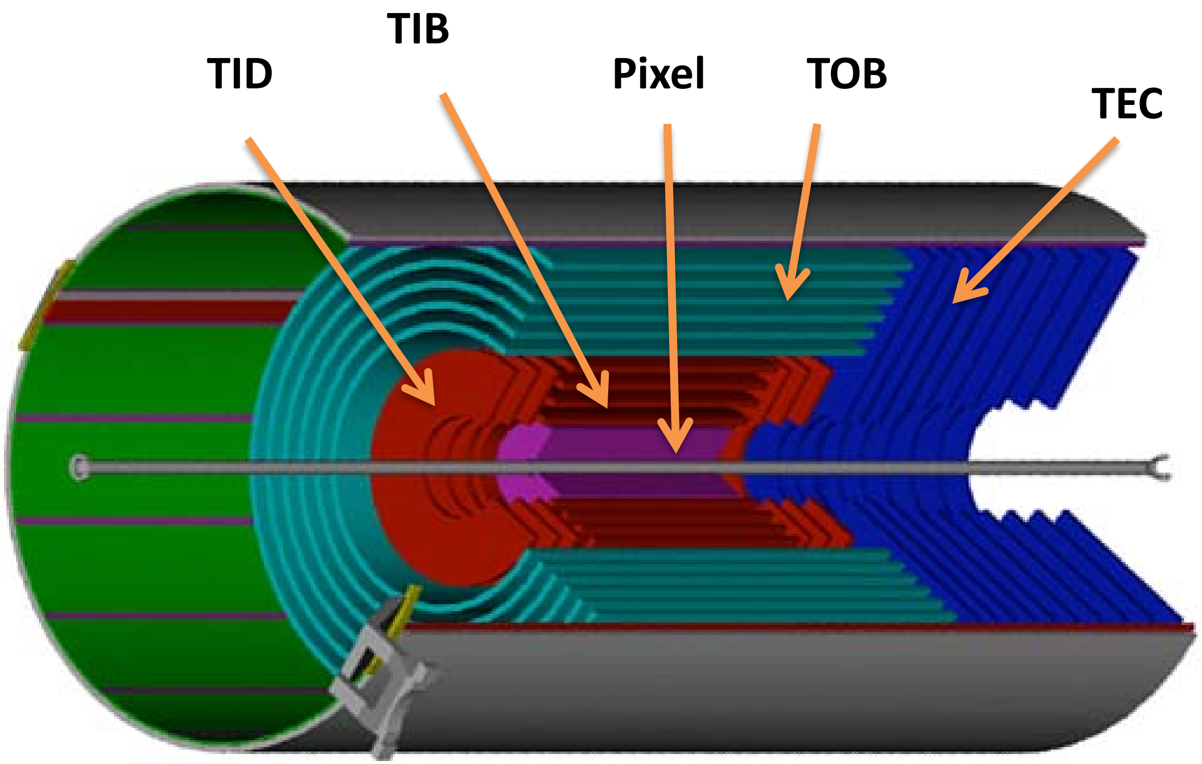
CMS



Tracker: Si-pixel, Si-strip **ECAL:** PbWO4
HCAL: Brass/Copper absorber with plastic scintillatior
Muon system: DT, CSC, RPC **Magnet:** superconductive coil l=12m d=6m B=3.8T

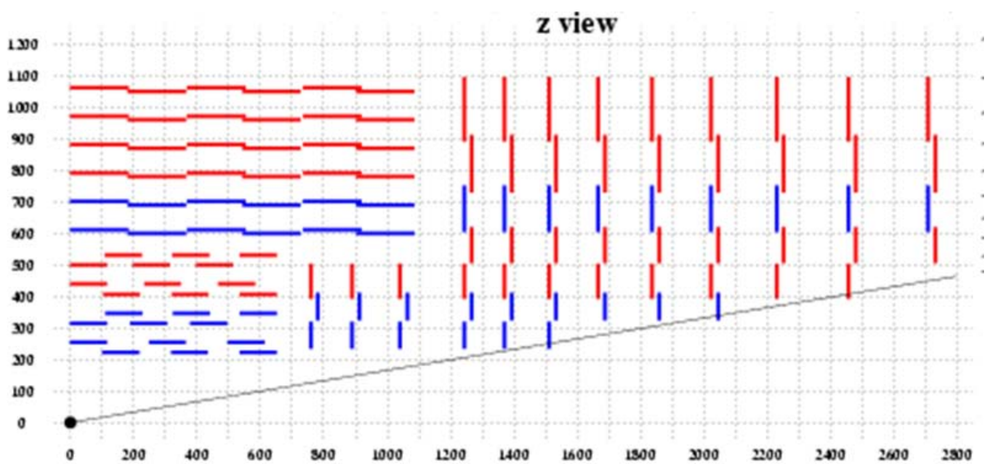
Total weight: 14000 t Overall diameter: 15 m Overall length 21.6 m

CMS Tracker

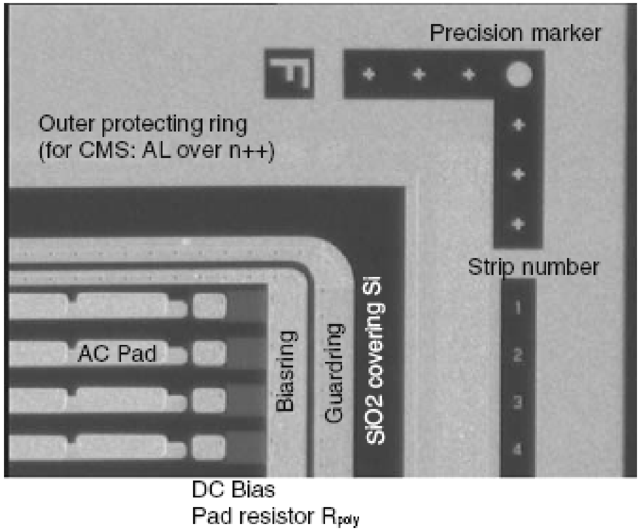


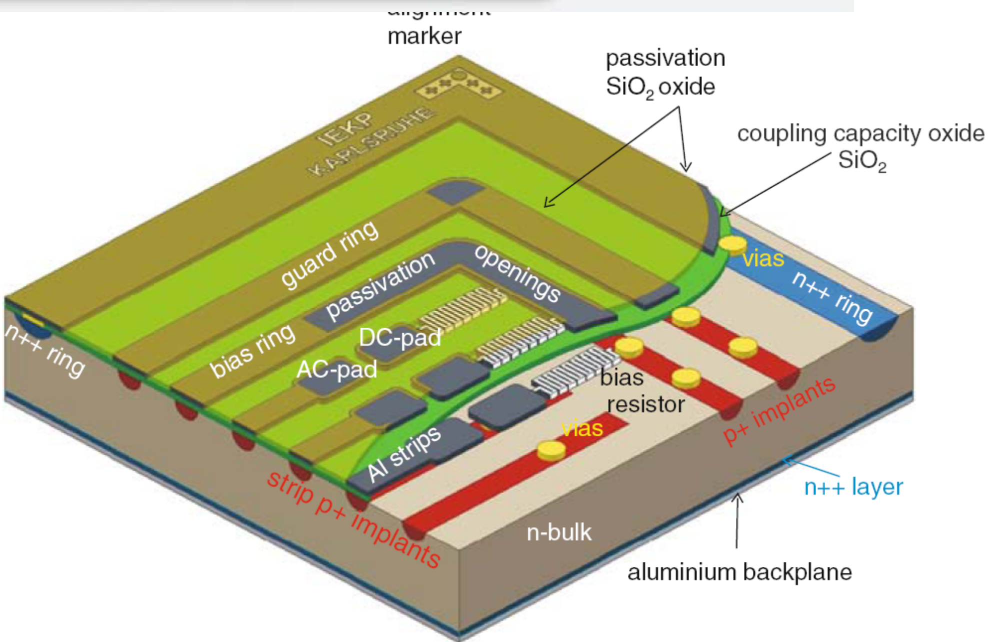
~15 000 detector modules
10 million strips
Volume 24.4 m^3 ,
T= -10 ^{0}C (Dry)

Single sided layer and
double sided layer

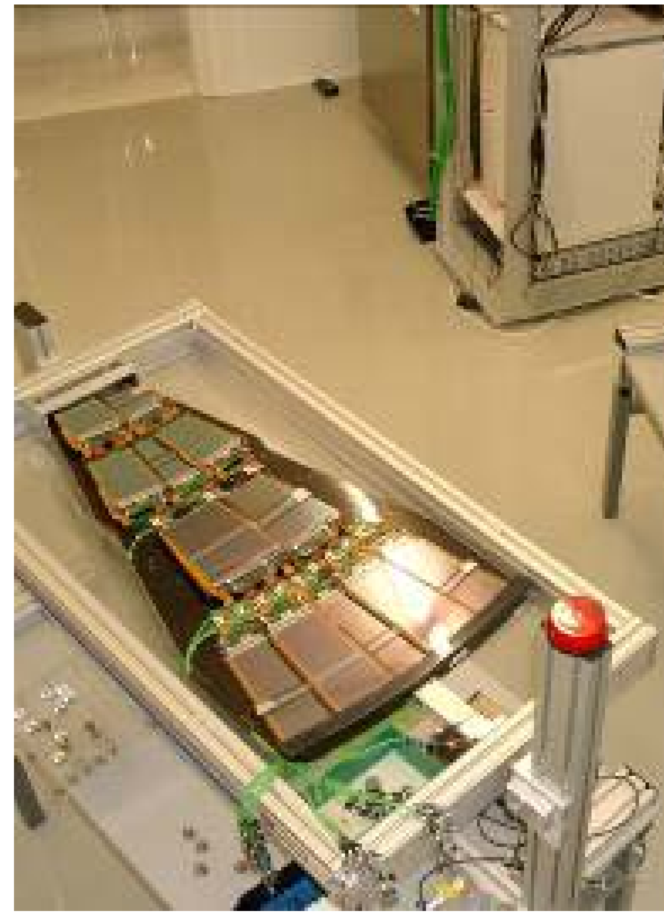


CMS Si sensor





CMS Si sensor

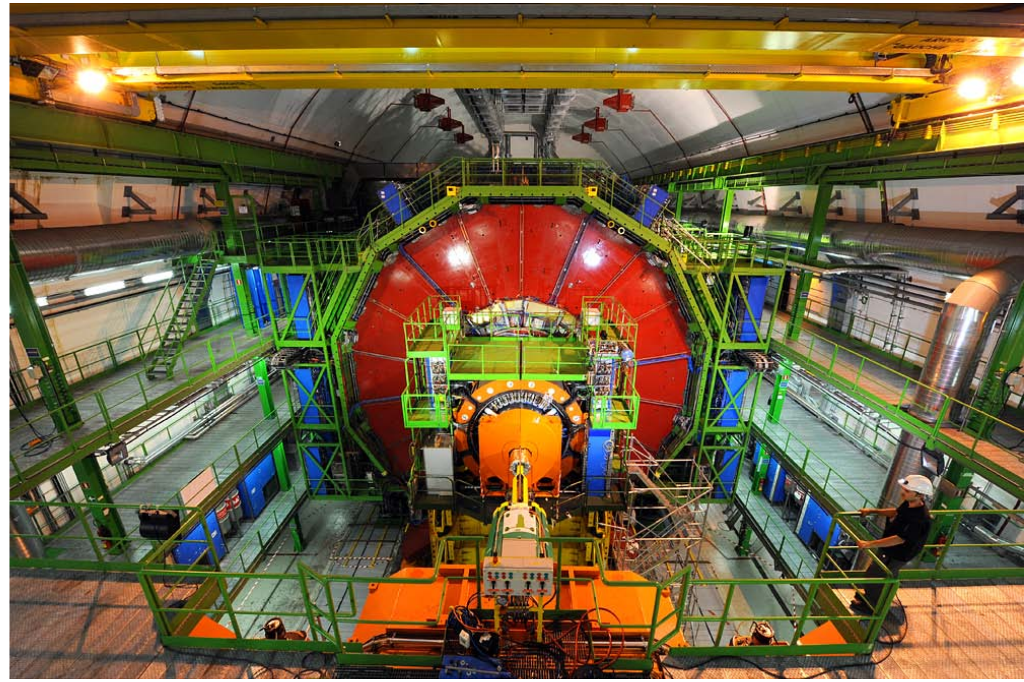


From Commissioning To Operation

Tracker Power system

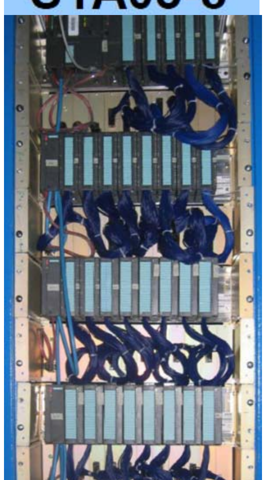
Service Cavern USC55

Experimental Cavern UXC55



S4F01

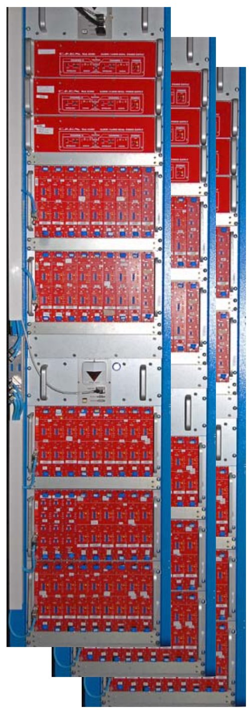
S1A03-8



48V dc primary Service power

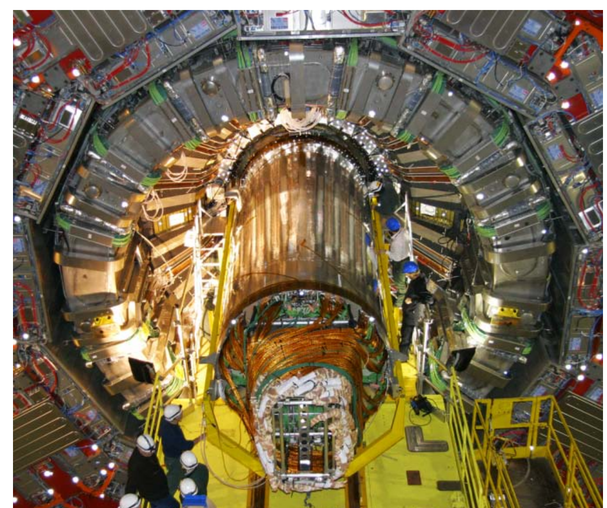
Control

Temp & Humidity

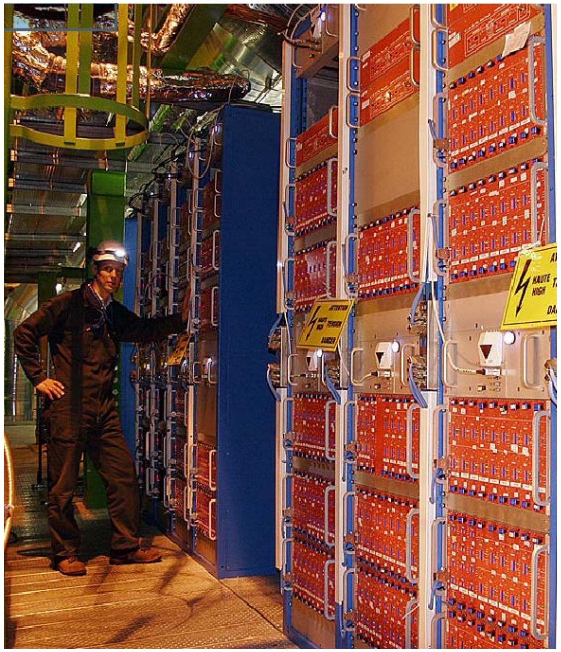


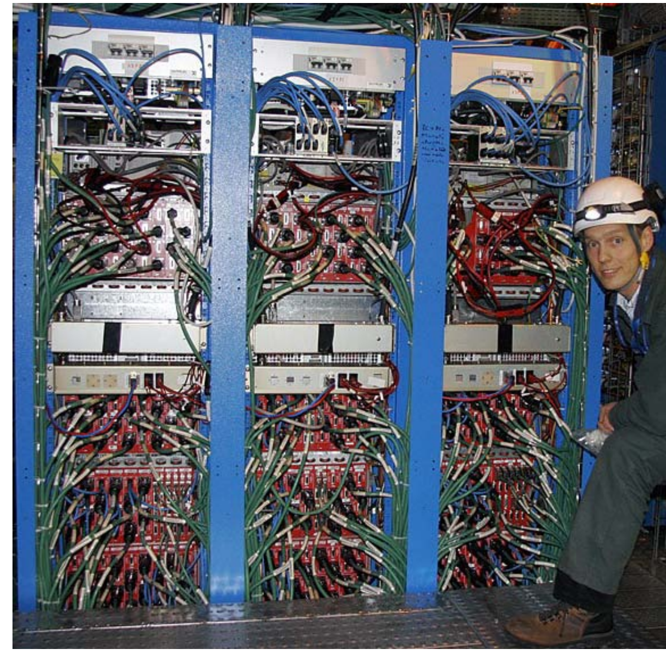
LV & HV

Temp & Humidity



Tracker Power system





Some numbers of the Tracker Power Supply System :

	Strip	Pixel
Mainframes	4(8)	1
Branch Controller	29	2
Rack	29	2
Crate	129	10
A3486 (MAO)	79	6
A4601 / A4603H	983	50
A4602	110	14

Power in (380V) 110 - 135kW
Power out (cable) 65 - 90 kW
Power to Tracker 36 - 45 kW

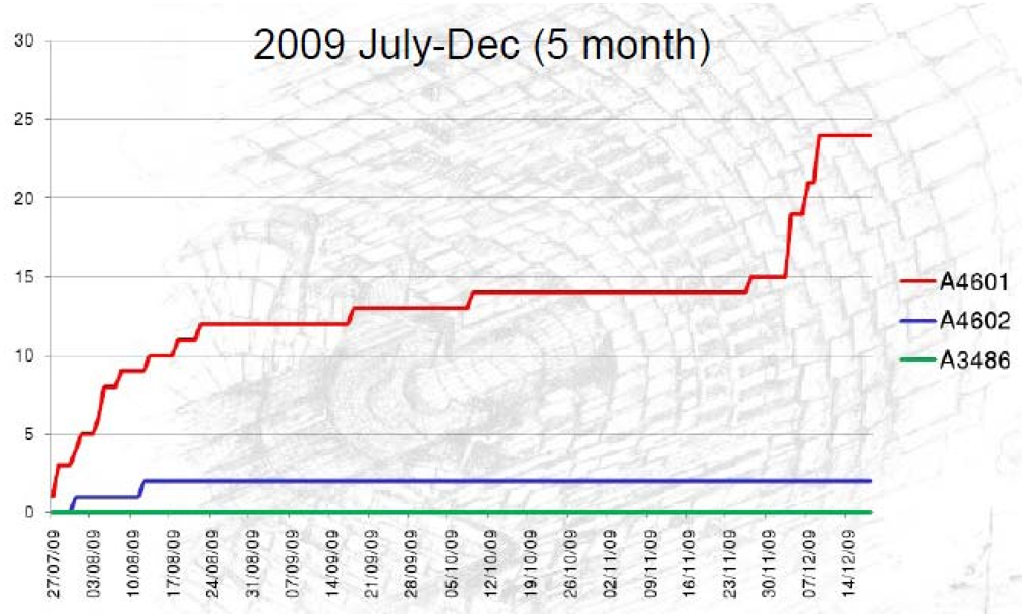
Exchange rate :

List TO DO:

See at:

http://twiki.cern.ch/twiki/view/CMS/PendingOperationList

CRC error	j.Fulcher
Reset & monitoring test	M.Hoch/G.Dirkes
TSSS noisy probes	M.Hoch/G.Dirkes
DCU readout	A.Giassi/F.Palmonari
Noise Vdep scan	M.Hoch/F.Palmonari
Laser Vdep scan	M.Hoch/F.Palmonari
Timing Val.	DAQ expert
Latency scan for 2628	A.Linn
TS S1B13 & 14	A.Tsirou
A1676 firmware update	M.Hoch
SS2 tank refill	J.Daguin
Brine leak fix	J.Daguin
Tracker crash button test	F.Hartmann
PS monitoring test	M.Hoch/I.Ahmed
Test new noise run	S.Lowette

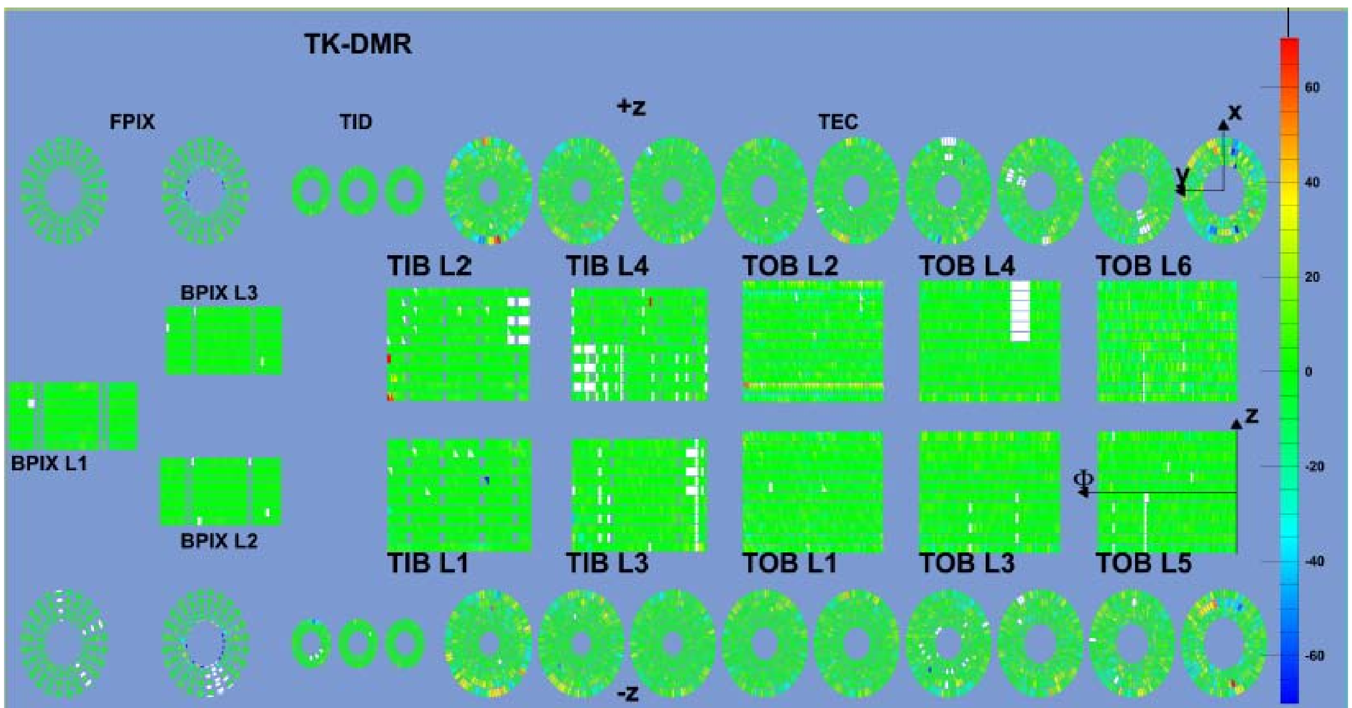


Tracker status @ start 7TeV collisions

2010 Tracker starts the 7eV collision period with remarkable 98.1% working detector

The Tracker Map shows the marvelous efficiency for each module. Just the white modules have been excluded because it is known to be bad.

Grouped inefficient spots: some individual modules with HV problems,
TOB-> control group
TIB -> shorted power group (LV)



.

- TIB/TID 96.25%
- TOB 98.33 %
- TEC+ 98.81%
- TEC- 99.13%

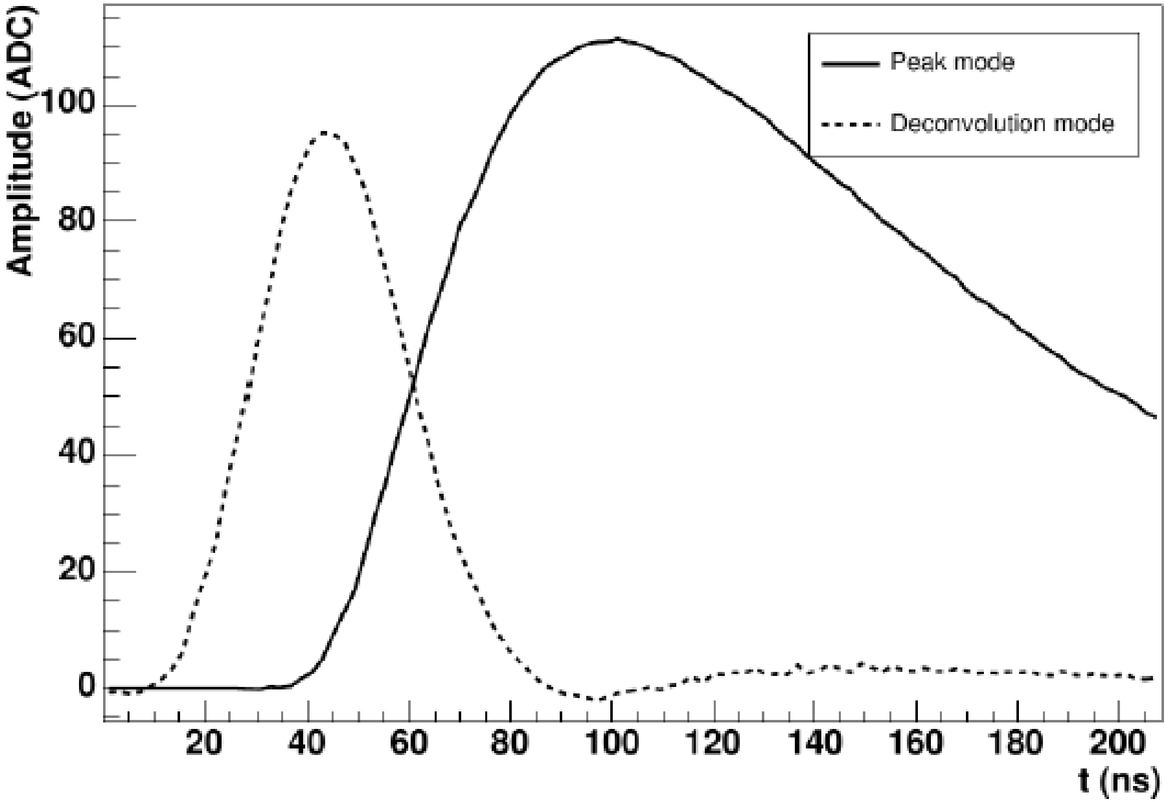
Total: 98.10%

Commissioning

- Establish communication with devices
- Synchronization of read out
  - using Tick mark as a reference (APV 70 clock cycles)
- Laser gain calibration to reach optimal dynamic range (using tick mark height)
- Determine pedestals and noise threshold for zero suppression –> FED

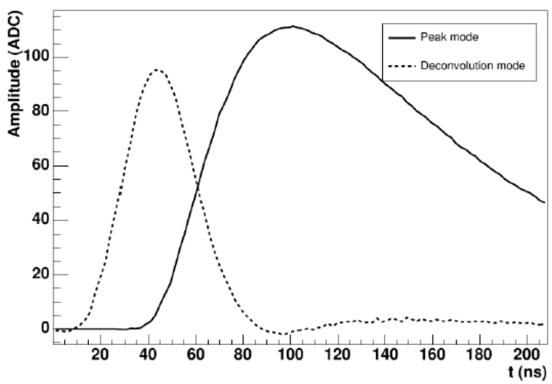
Timing of the detector with collisions

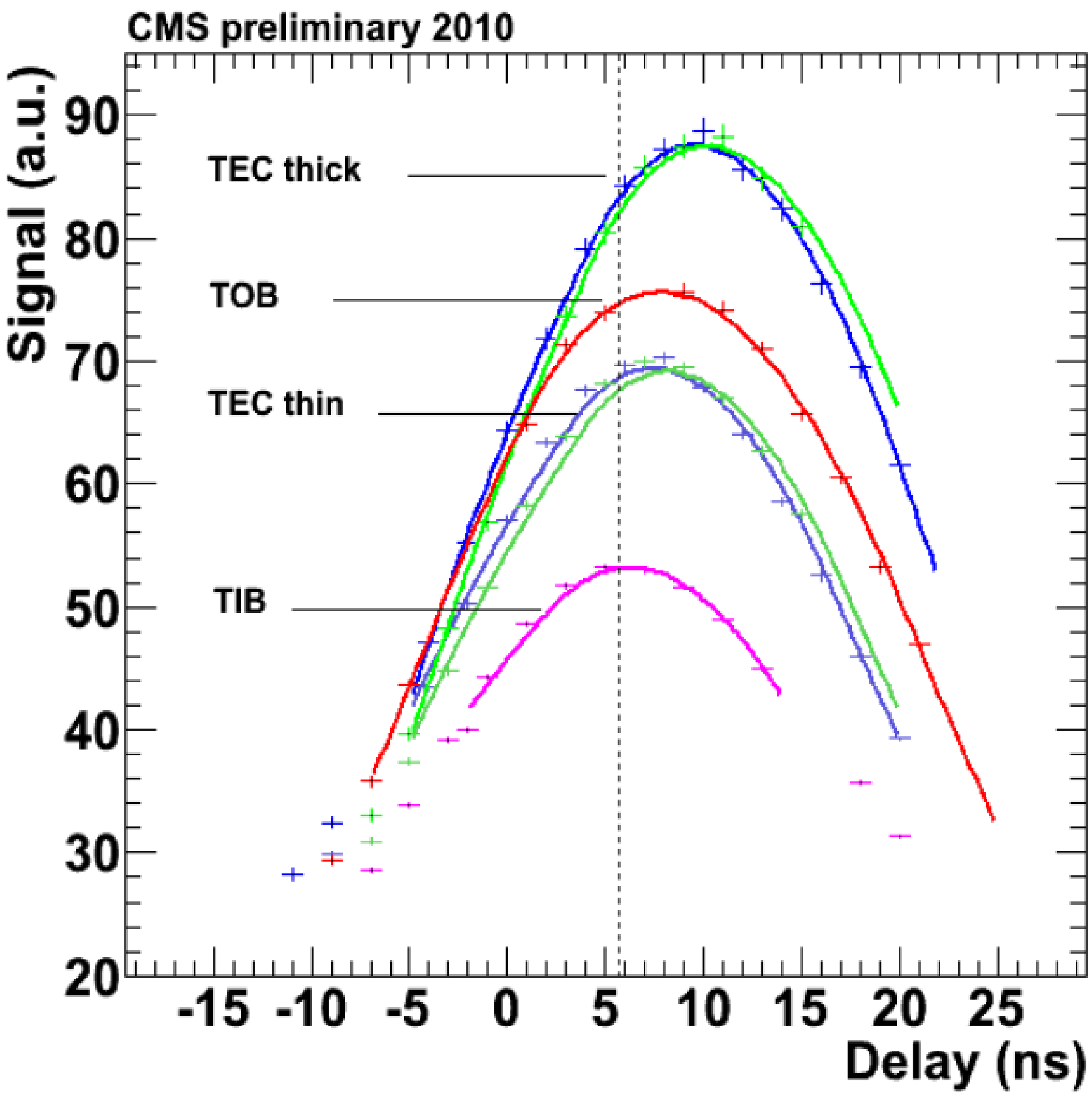
- Front End Amplifiers can work in two modes:
  - Peak mode: debug and early commissioning
  - Deconvolution mode : nominal operation



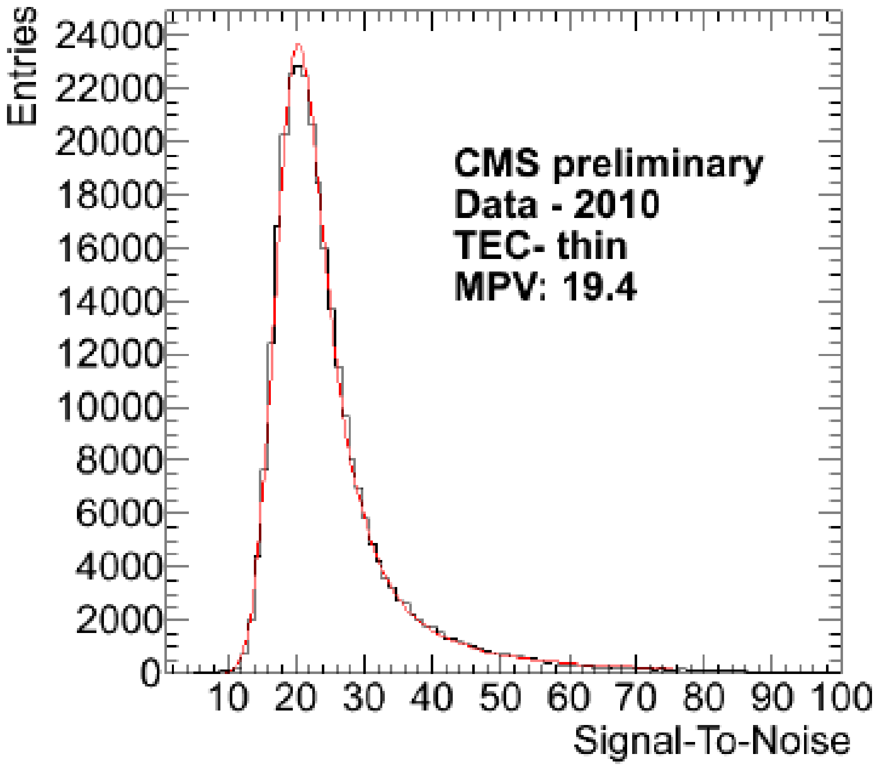
Timing of the detector with collisions

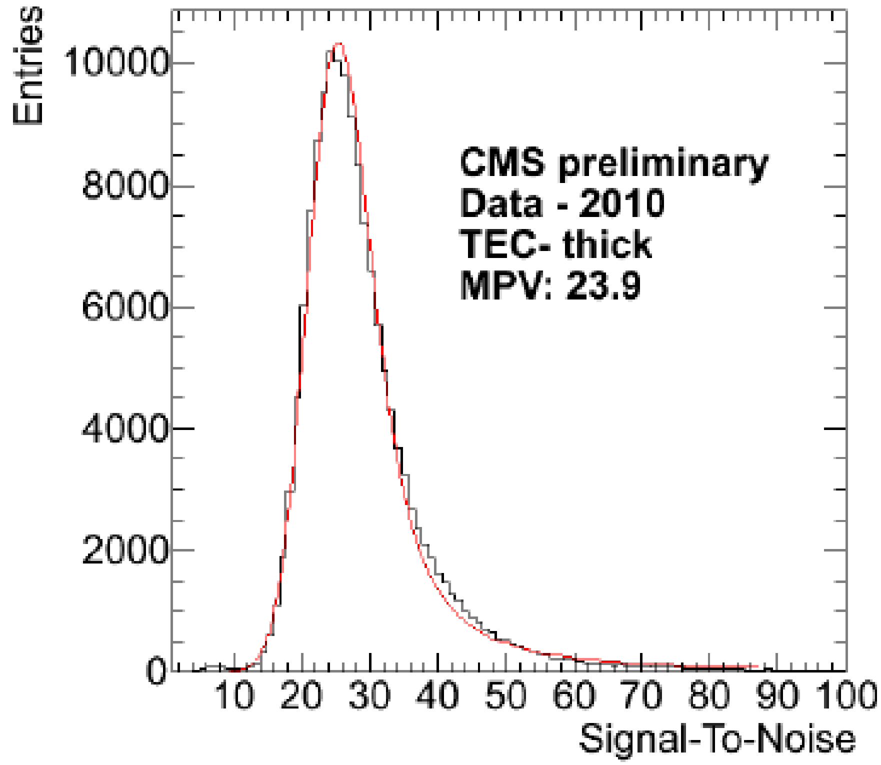
- Determine the optimal sampling point for particles from collisions
- Timing measured independently for each partition





S/N in Si strip tracker



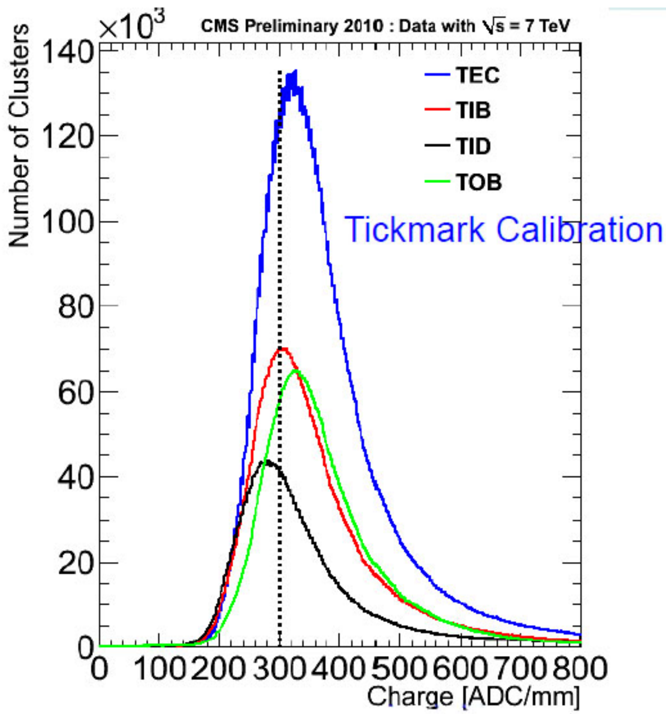


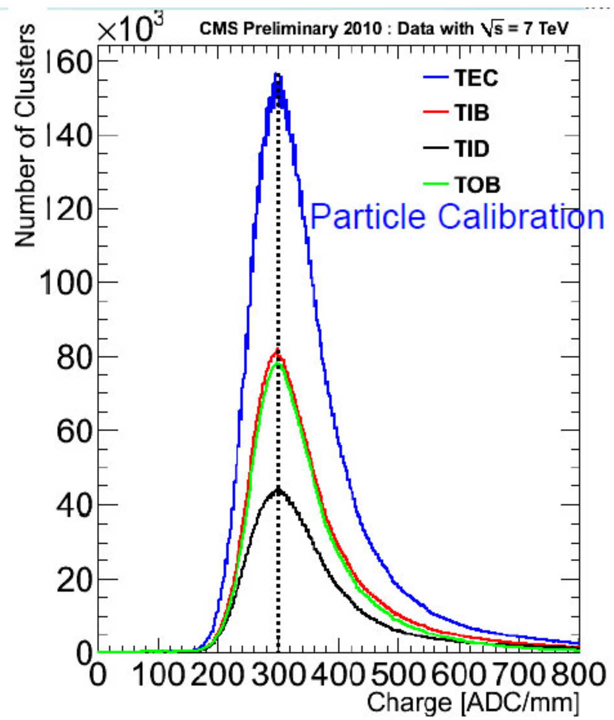
S/N distribution :

- Signal depends on the thickness
- Noise depends on the strip length

Two different thicknesses:

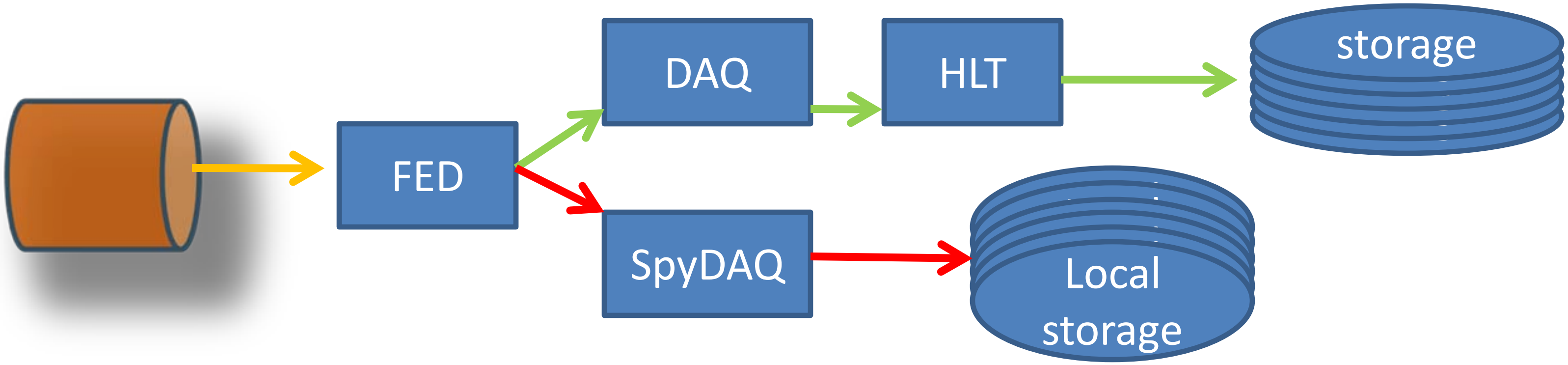
- 320μm (TIB, TID and part of TEC)
- 500 μm (TOB and part of TEC)

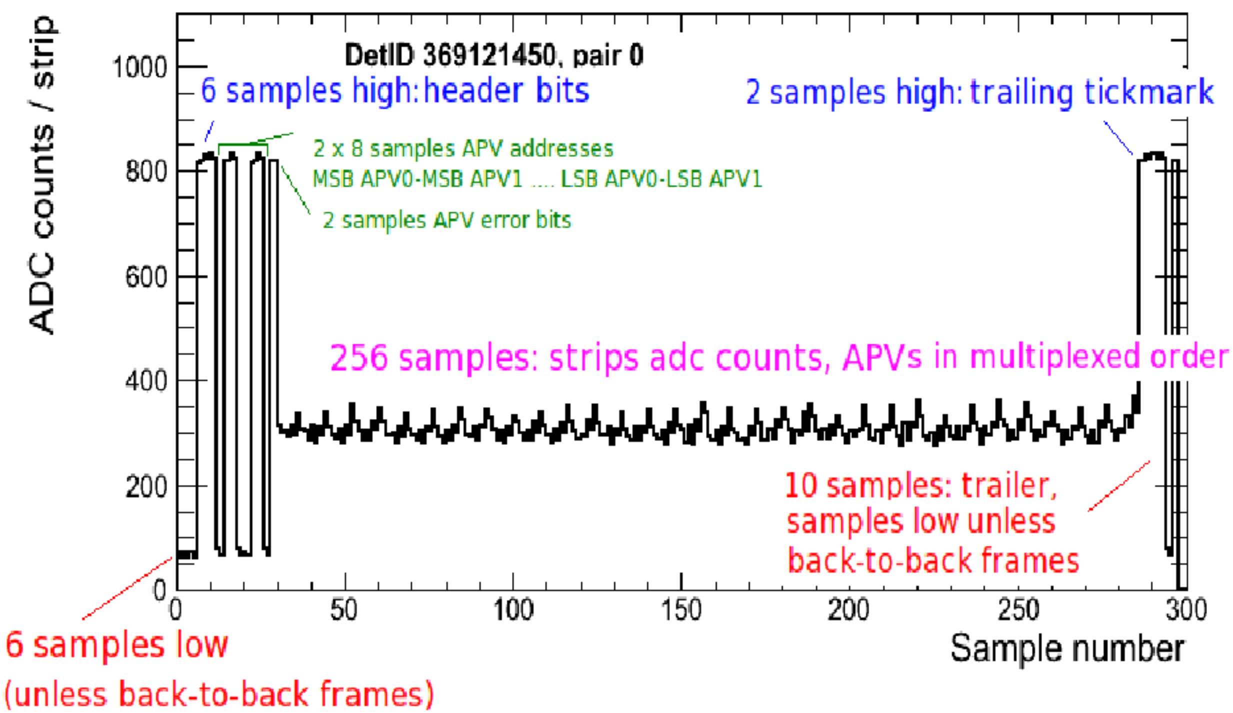




- **Path- length Corrected Charge Distribution with**
  - **calibration with Tickmarks only**
  - **calibration with Tickmarks and Particles.**

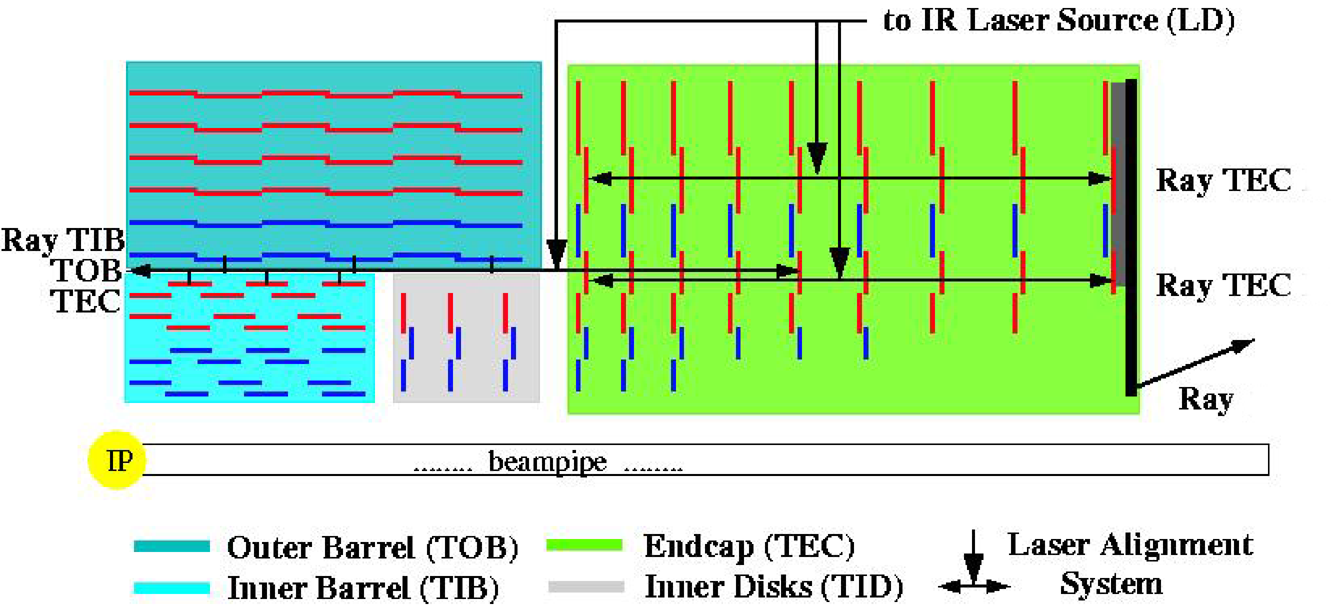
Tools : Spy Channel

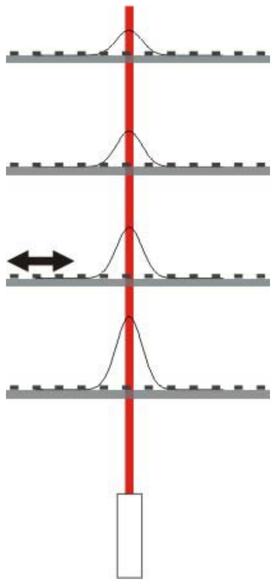




- Captures APV frame directly
- Read out via VME; separate data stream : 0.3Hz
- During physics collision indepent of HLT decision
- So called 'raw data'

Tools : Laser System



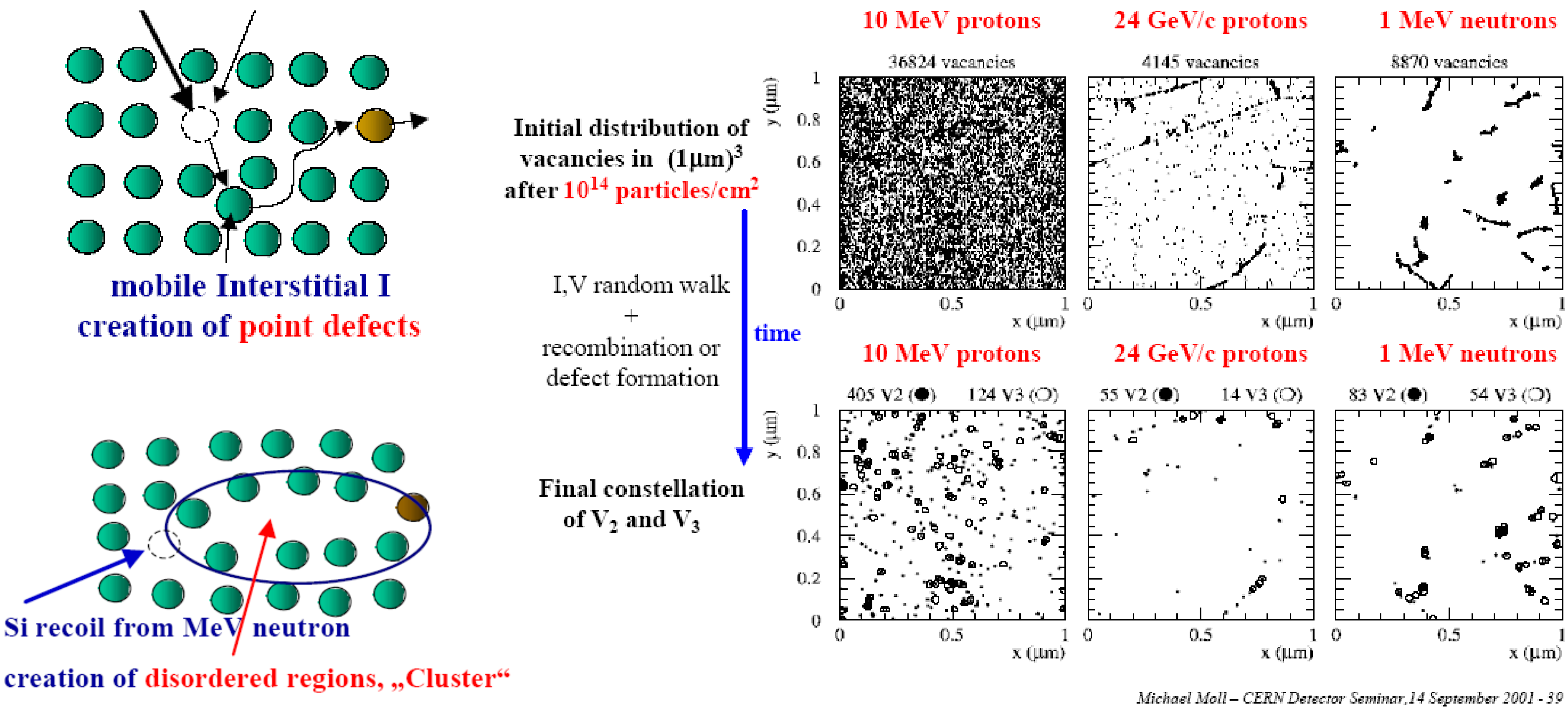


- The Laser Alignment System has to monitor movements and deformations of the tracker support structure at a level of less than 100 micron
- Other purpose under test : V_{dep} scan during no beam breaks (see later)
  - Further info : https://twiki.cern.ch/twiki/bin/viewauth/CMS/TKLas?topic=TkLasHome

Radiation Damage in Si detectors
And
Ongoing measurements for the
CMS tracker

- Constant monitoring of all essential detector parameter should allow us to built a strategy to optimize the long term behavior of the CMS tracker in high radiation aria . -> The Hamburg model
- CMS will validate the Hamburg model and will try to optimize the Annealing effects. This will be done by adapting the temperatures cycles during shut down periods according

V, V_2 and V_3 Formation - Particle Dependence

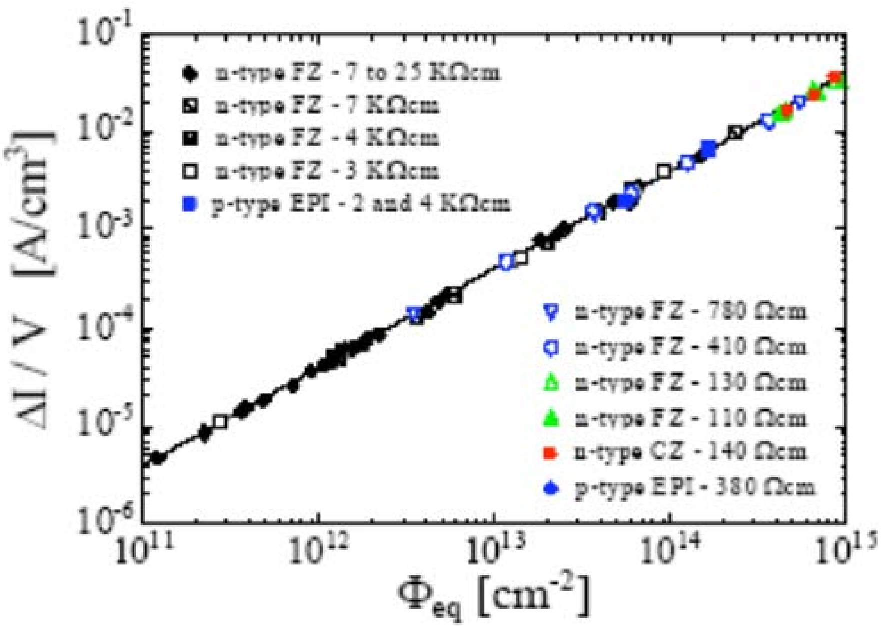


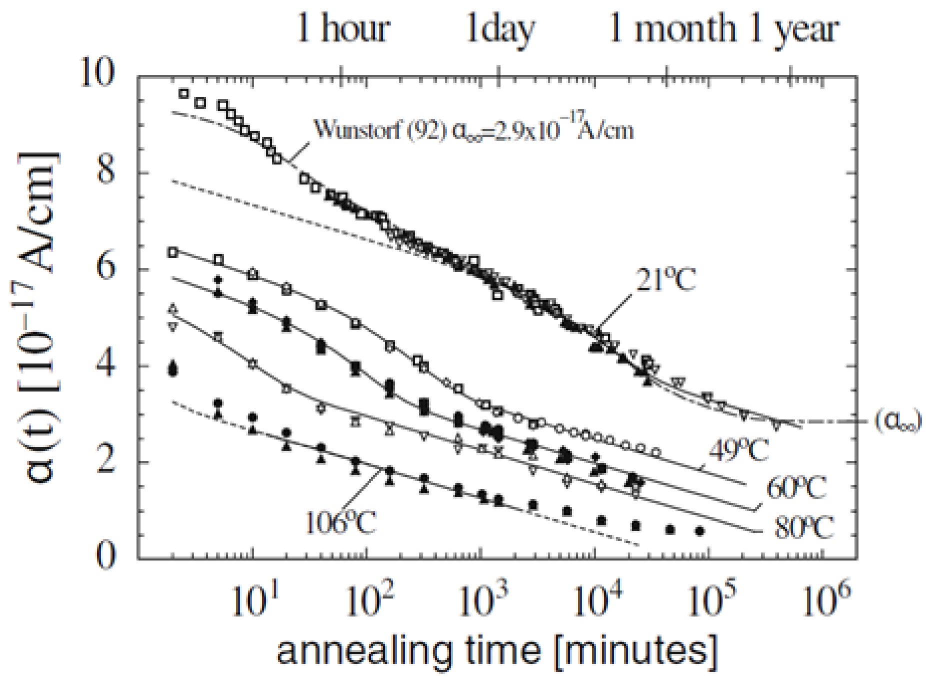
Michael Moll – CERN Detector Seminar, 14 September 2001 - 39

[Mika Huhtinen ROSE TN/2001-02]

Si recoil from MeV neutron or a proton may create disordered regions, so called ‘clusters’ → increase of dark current until break through

Current related damage rate depends on the Temperature α(T)





$$\frac{\Delta I}{V} = \alpha \, \Phi_{eq}$$

V = Sensor Volume

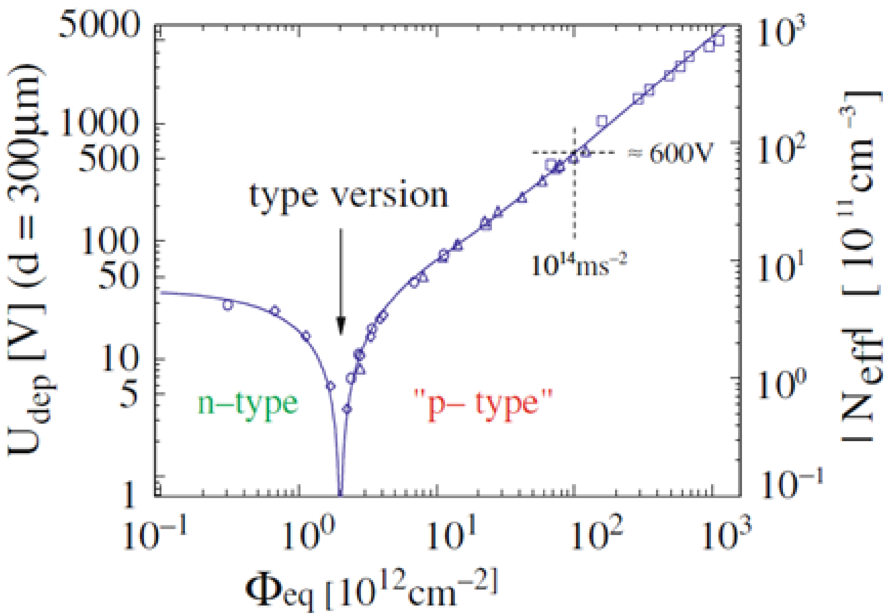
ΔI = delta Leakage current

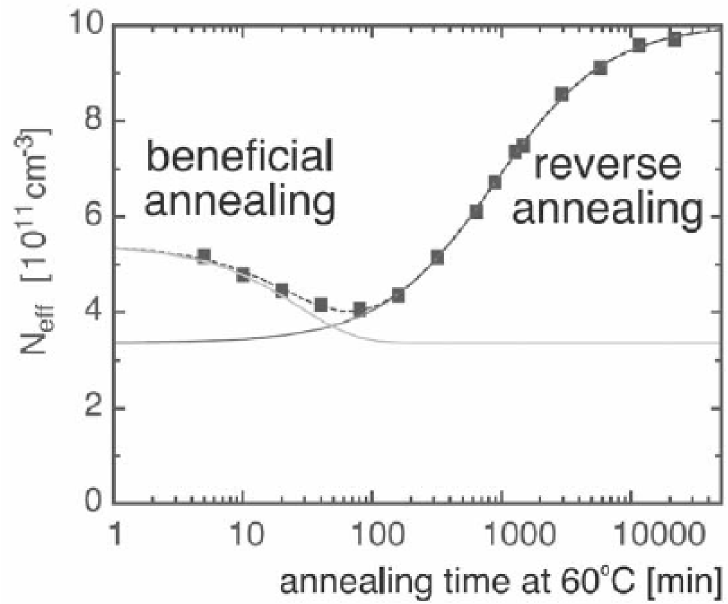
Φ_{eq} = equivalent fluency

α = Current related damage rate

Find the best compromise

Dependence on fluence and temperature





The Hamburg Model

$$\Delta N_{eff}(\Phi_{eq}, t, T) = N_C(\Phi_{eq}) + N_A(\Phi_{eq}, t, T) + N_Y(\Phi_{eq}, t, T)$$

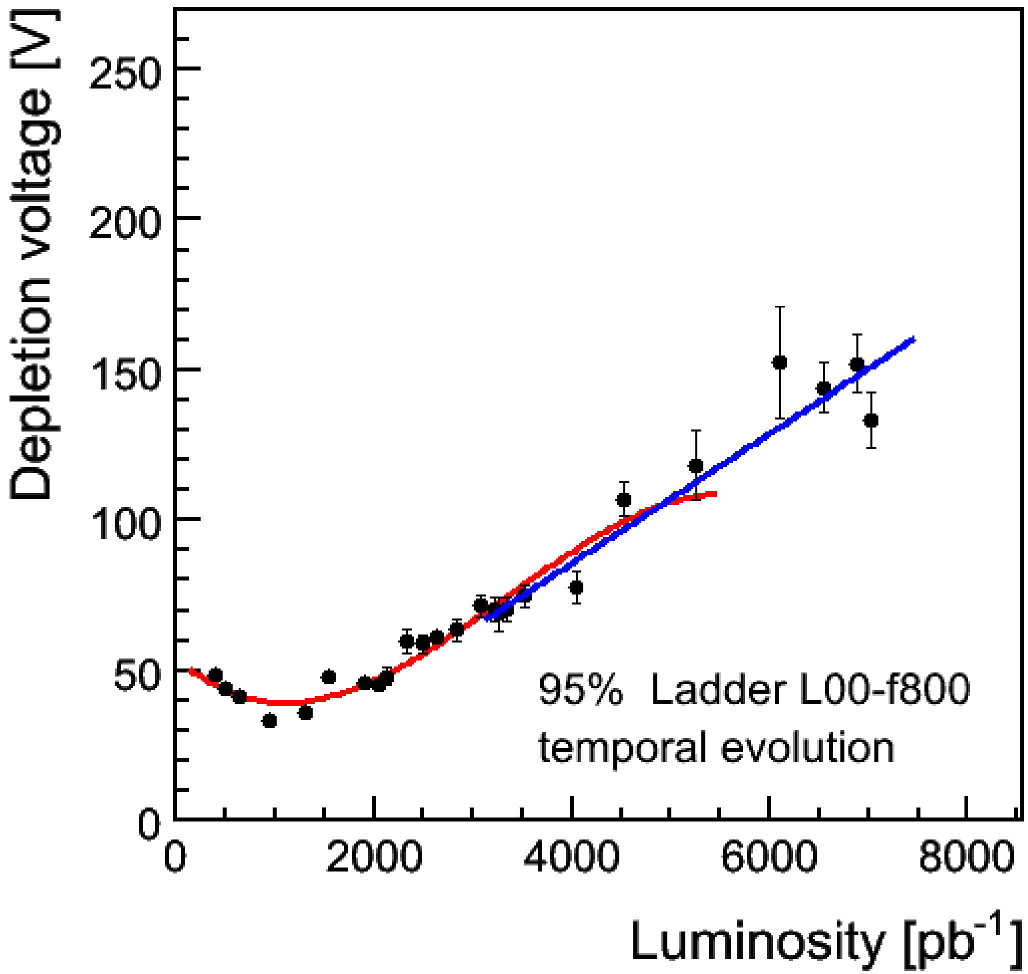
N_C – stabile damage / N_A - beneficial annealing / N_Y - reverse annealing

$$N_A(\Phi_{eq}, t, T) = \Phi_{eq} g_a e^{-\frac{t}{\tau_a(T)}}$$
$$N_Y(\Phi_{eq}, t, T) = \Phi_{eq} g_y (1 - e^{-t/\tau_y(T)})$$

Annealing terms with different temperature & time constants

T [°C]	τ_a	τ_Y
-10	306 d	516 y
0	53 d	61 y
10	10 d	8 y
20	55 h	475 d
40	4 h	17 d
60	18 min	21 h

CDF measurement



CDF and D0 show good agreement with the Hamburg Model

Sergio Jindarini, Fermilab CDF, VCI2010

Proposed to measure V_{dep}

Capacity versus voltage :

- During production measured -> data base
  - Significant HEPHY participation

Particles:

- Signal of particles in the whole tracker
  - Important measurement to determine two other methods
  - Loss of physic run time

Noise:

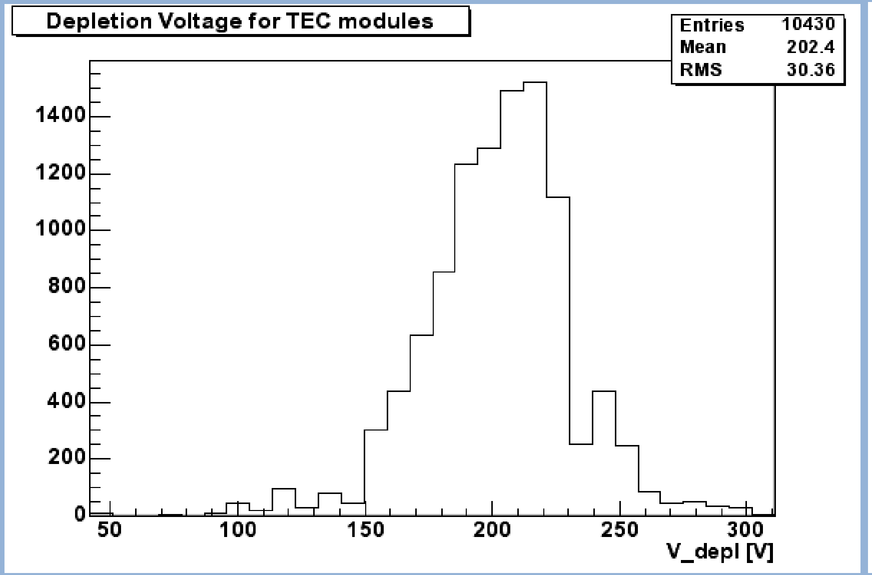
- Noise vs Bias -> measurement of C
  - Any time during shut down or beam stop

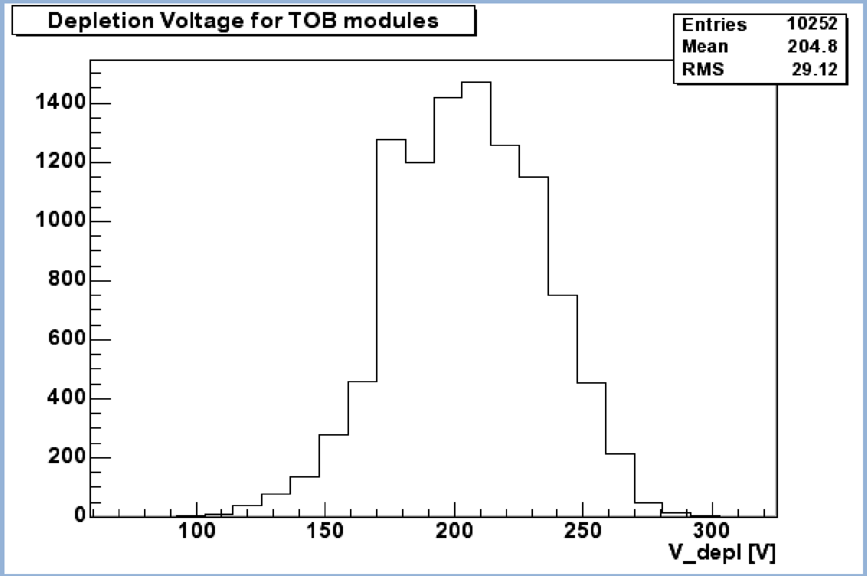
Laser:

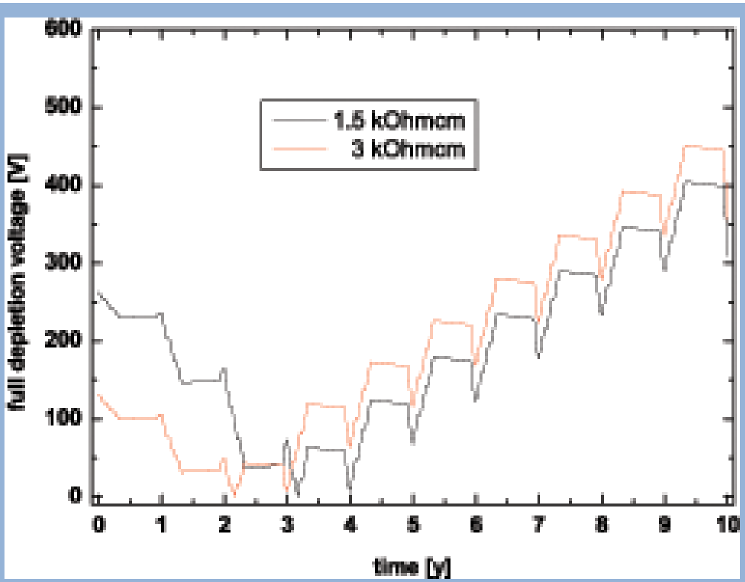
- Signals of the laser in few modules
  - Any time during shut down or beam stop

V_{dep} during production

- V_{dep} measured during the production line





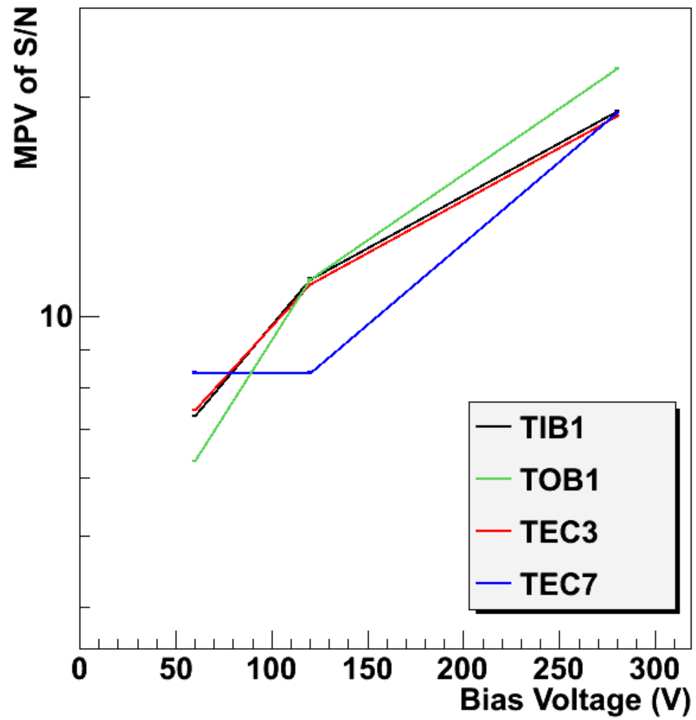


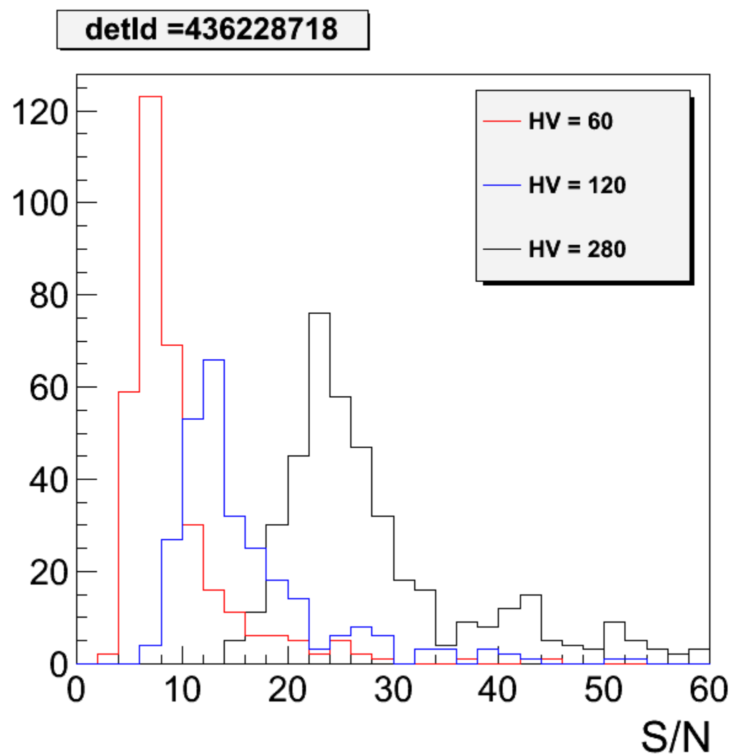
Hamburg model simulation of V_{dep} development during 10 Years of LHC operation

CMS Tracker signal evolution

<u>First test measurements on the whole CMS tracker</u>

- CMS Magnet Off
- 3 Layers used (TIB, TOB TEC)
  - Each one run with 280/120/60V
- High fake rate due to higher noise in TIB seeding layer



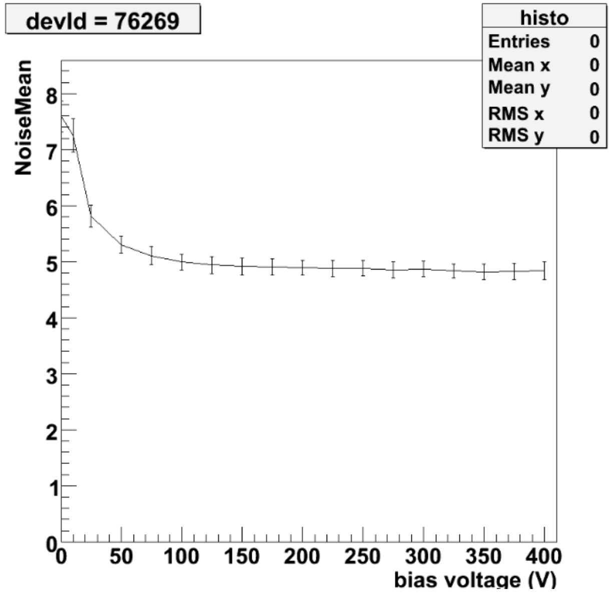


<u>Depletion Voltage:</u>

- Maximal for a fully depleted sensor
- Study charge collection as function of V_{BIAS}
- Identify charge of Most Probably Value (MPV) in each distribution

V_{dep} Noise methode

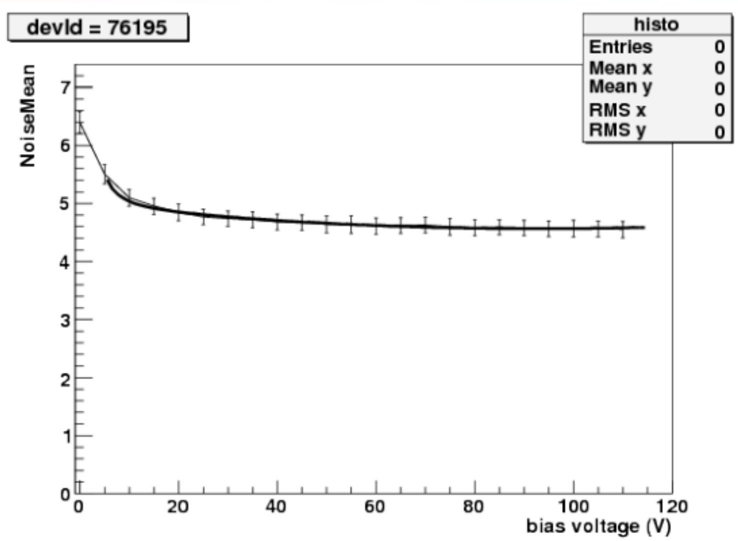
- First tested on the Cosmic Rack
- Analysis designed and tested



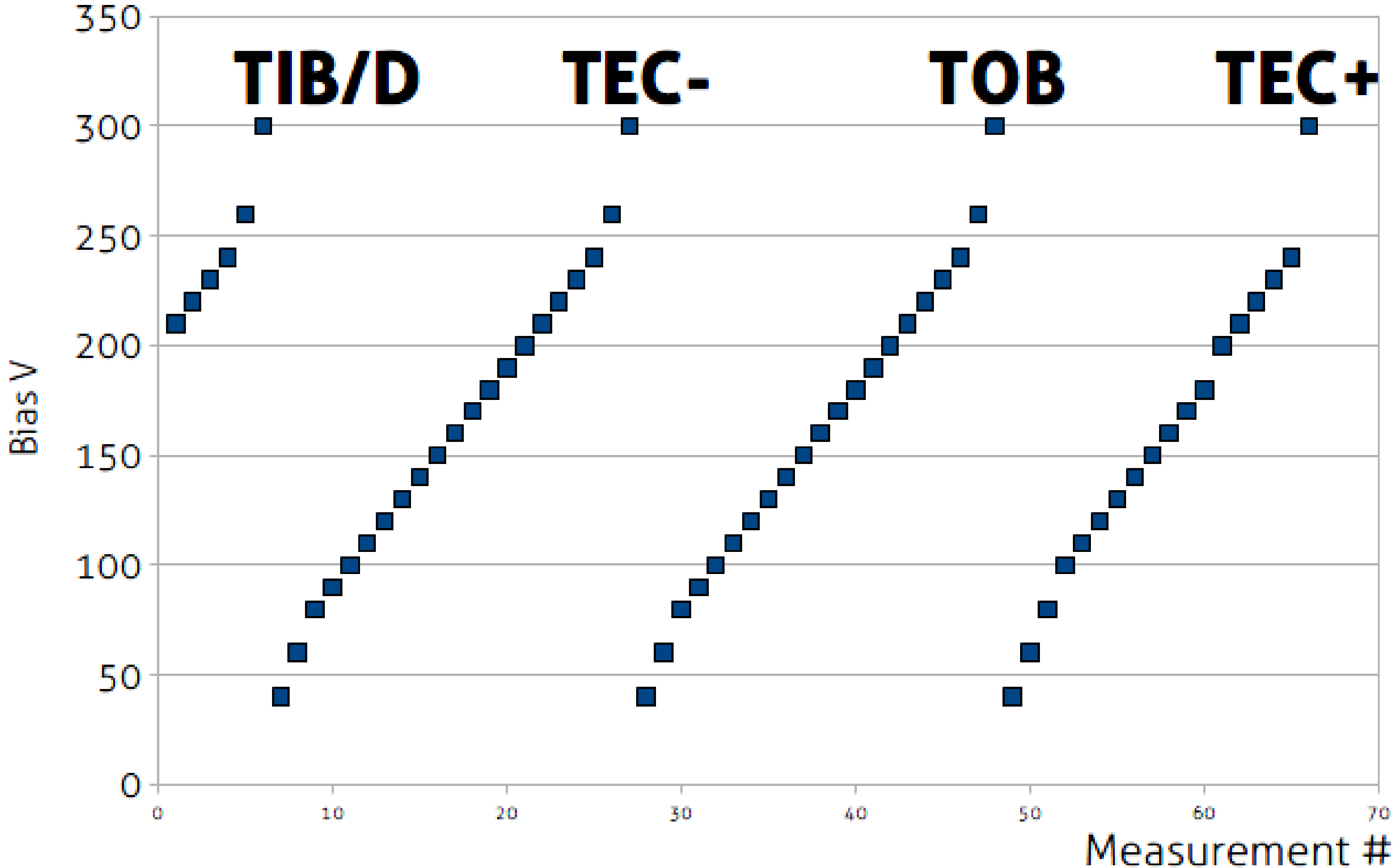
- Noise fit:

$$n(V) = \begin{cases} a + b \times \sqrt{V_0/V} & V < V_0 \\ a + b & V > V_0 \end{cases}$$

$$n'(V) = \sqrt{n(V)^2 + n_L^2}$$



First V_{dep} measurement on the whole CMS tracker with noise

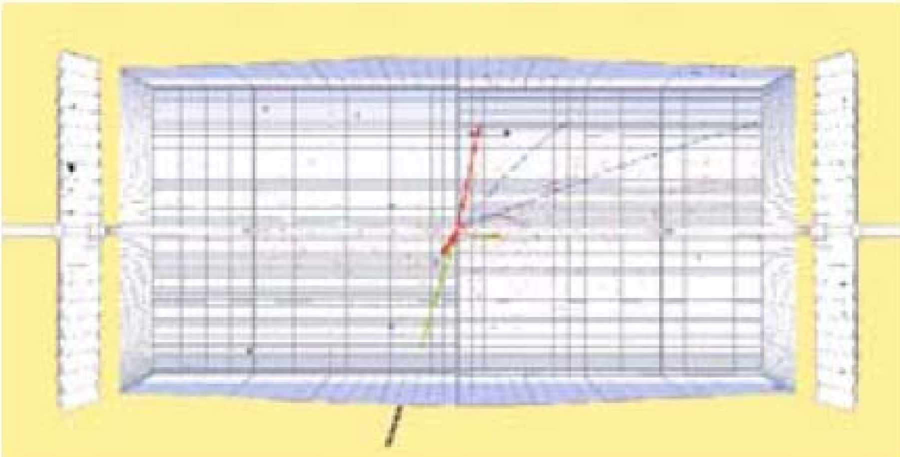


Next Challenges :

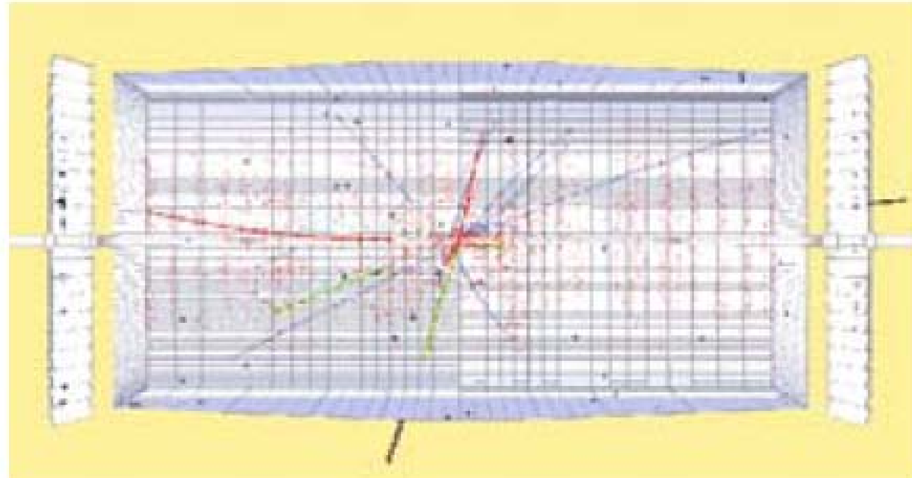
Get ready for the Upgrade
!

Future challenge

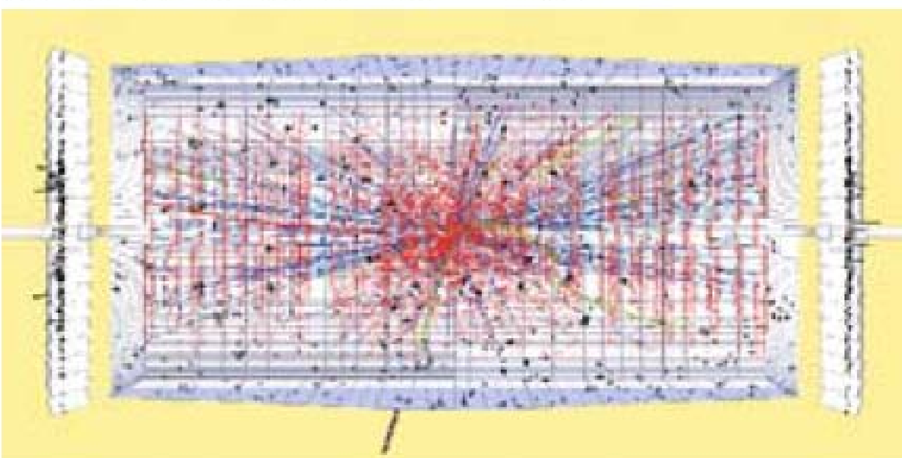
LHC initial: 10^{32} cm^2 s^{-1}



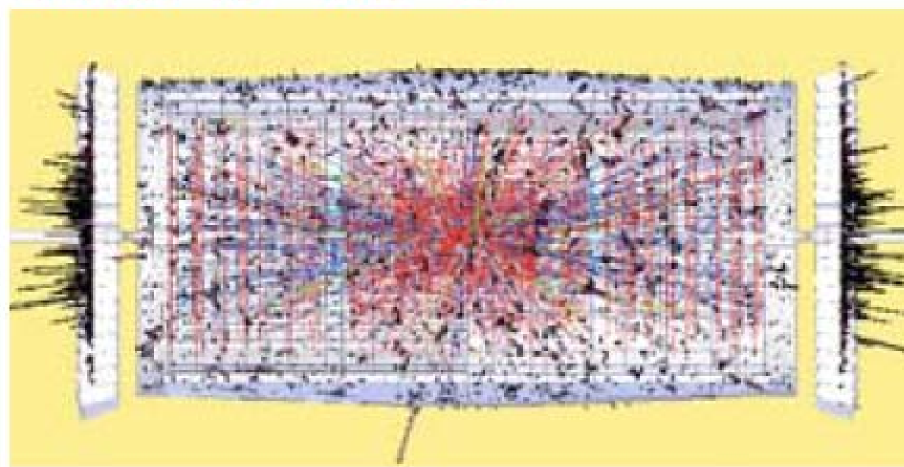
LHC initial: 10^{33} cm^2 s^{-1}



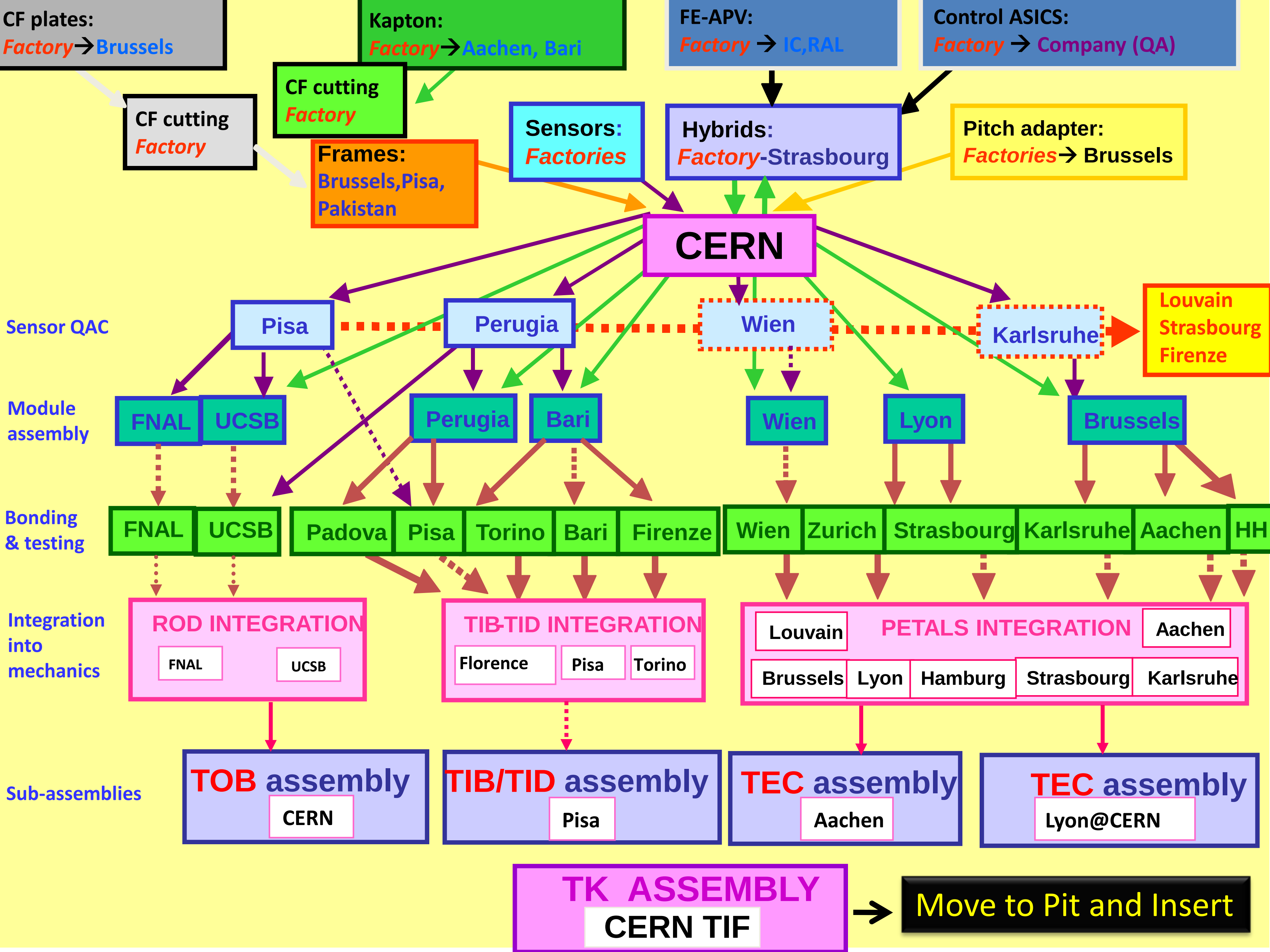
LHC nominal: 10^{34} cm^{-2} s^{-1}



SLHC: 10^{35} cm^{-2} s^{-1}



- 2000 design fixed ready for production
- 2001 production and test lines prepared
  - Institutes (Vienna, Karlsruhe, Pisa, Perugia
    - Padova, Torino, Bari, Firenze, Zurich, Strassburg Aachen, Lyon, Brussels
- 2007/ Feb Tr assembly finished @ CERN ready for tests
- 2007/ Dec. Tracker inserted in CMS
- 2008/Sept. Tracker operational
- 2010 Tracker up grade to be defined
- 2012 shut down to get 14TeV
- 2015 shut down higher luminosity >70fb^{-1}/year
- 2020 Tracker exchange ? Up grate >200fb^{-1}/year


CF plates: Factory→Brussels
Kapton: Factory→Aachen, Bari
FE-APV: Factory → IC,RAL
Control ASICS: Factory → Company (QA)
CF cutting Factory
CF cutting Factory
Frames: Brussels,Pisa, Pakistan
Sensors: Factories
Hybrids: Factory-Strasbourg
Pitch adapter: Factories→ Brussels
CERN
Sensor QAC
Pisa
Perugia
Wien
Karlsruhe
Louvain Strasbourg Firenze
Module assembly
FNAL
UCSB
Perugia
Bari
Wien
Lyon
Brussels
Bonding & testing
FNAL
UCSB
Padova
Pisa
Torino
Bari
Firenze
Wien
Zurich
Strasbourg
Karlsruhe
Aachen
HH
Integration into mechanics
ROD INTEGRATION
FNAL
UCSB
TIB-TID INTEGRATION
Florence
Pisa
Torino
Louvain
PETALS INTEGRATION
Aachen
Brussels
Lyon
Hamburg
Strasbourg
Karlsruhe
Sub-assemblies
TOB assembly
CERN
TIB/TID assembly
Pisa
TEC assembly
Aachen
TEC assembly
Lyon@CERN
TK ASSEMBLY
CERN TIF
Move to Pit and Insert

Hamamatsu Submission

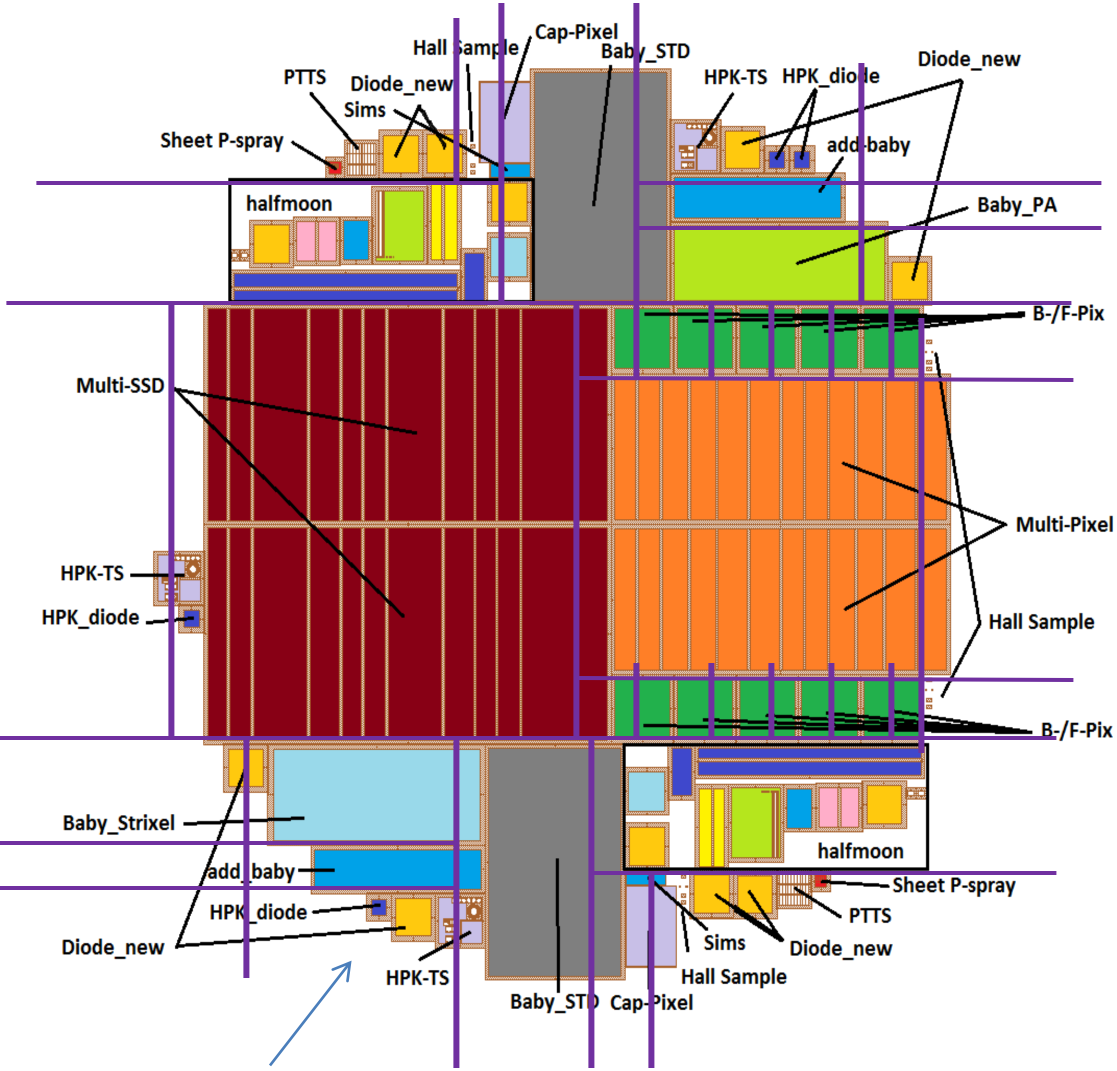
The largest campaign to compare different:

technologies / thicknesses / geometries / structures with different measurable

Should allow us to choose the appropriate technology

substrate type & Active Thickness	FZ 200um carrier	MCZ 200um thinning	FZ 100um carrier	epi 100um	epi 75um	FZ 300um	Total
P-on-N Production	6	6	6	6	6	6	36
N-on-P Production p-spray	6	6	6	6	6	6	36
N-on-P Production p-stop	6	6	6	6	6	6	36
2'nd metal production P-on-N	6						6
2'nd metal production N-on-P p-stop	6						6
2'nd metal production N-on-P p-spray	6						6
Total	36	18	18	18	18	18	126

Cutting



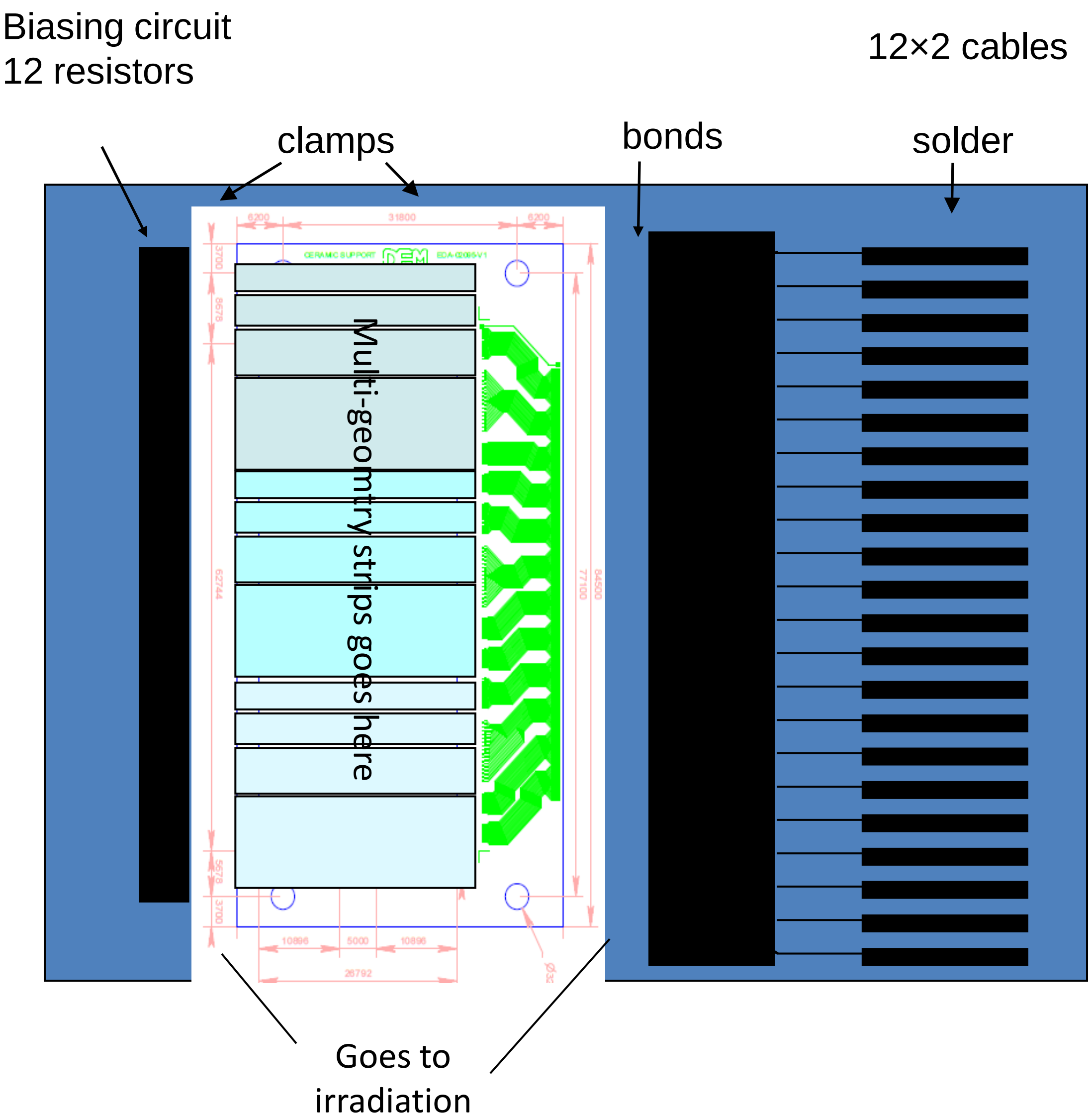
Diodes to be cut further (backup slides)

- Pixel
- Multi-geometry strips
- Multi-geometry pixel
- Baby_std
- Baby_PA
- Baby_Strixel
- Diodes
- Test-structures
- Add_Baby aka Lorentz angle sensor
  - Lorentz Angle measurement
  - Neutron and proton irradiation cross calibration

~ 30 pieces per wafer ➔ 3800 pieces

All cut pieces come in an individual envelope

E.g. Multi-geometry strips, electrical



31 strips in each group bonded together

Measuring Program:

[in the Vienna Box]

$C_{interstrip}$

CV and IV curves

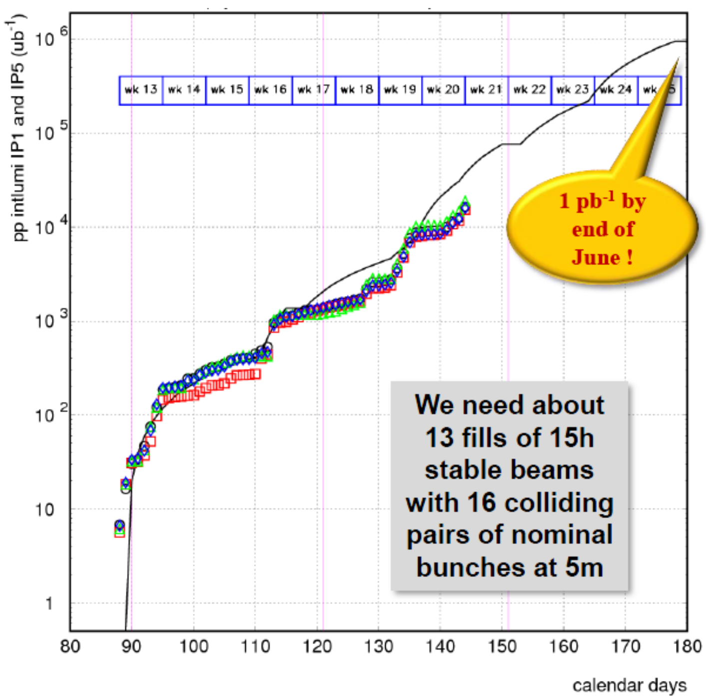
S/N & resolution

Position resolution

- Before irradiation
- After first irradiation
  - With p and n
  - Vienna, Ljubljana (n) & Karlsruhe
- After second (mixed) irradiation
- (possibly additional annealing study

LHC
Planning
2010 - 2020

Planning LHC



Last week-end we received the first fills with 8 bunches colliding in IP1 and IP5
$\mathcal{L}$ **~2x10^{29}cm-2 s-1**

Latest update for End of June integrated Luminosity 0.3 pb^{-1}

1st Shut Down (2012):

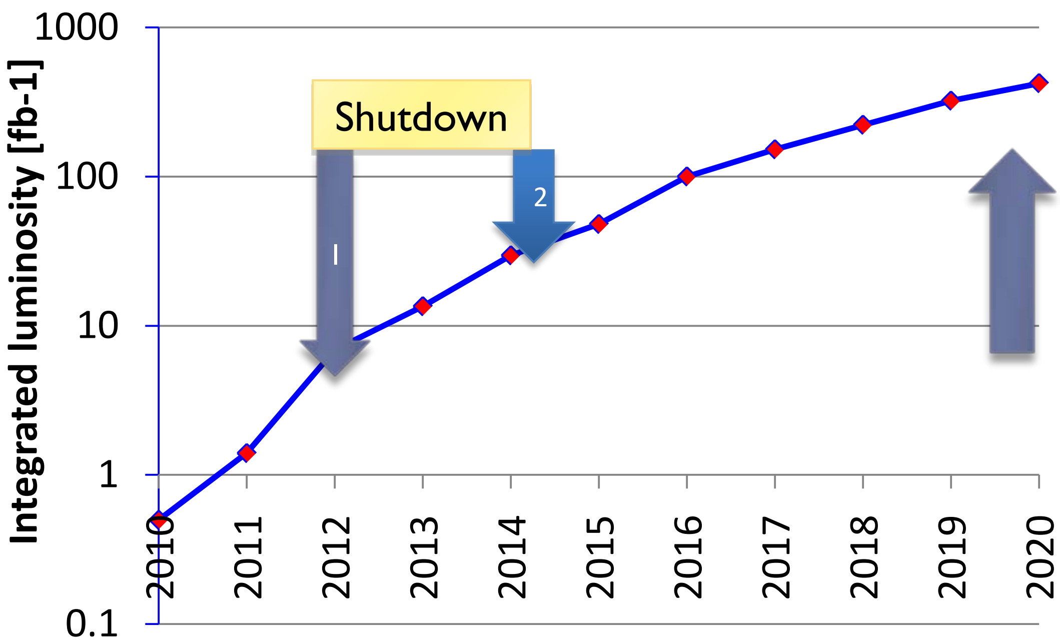
to raise Energy to 13- 14TeV **->** safety clamps

- CMS exchanges the beam pipe for Pixel upgrade

2nd Shut Down: (2014)

raise Luminosity to >70 fb-1/year **->** Linac 4 & improvement in collimator system

- CMS exchange of Pixel detector



Planning SLHC

- In Phase 2 to reach >200fb^{-1}/year for 2020 – 2030:
  - LHC operation beyond a few 100/fb^{-1} will require substantial modification of both the **machine and detector elements**
  - The goal is to achieve 3000/fb^{-1}
  - Need to be able to integrate ~300/fb^{-1}-yr
  - Will require new tracking detectors for ATLAS/CMS
  - Will require modifications of the LHC machine, its mode of operation and parts of the injector complex to achieve the higher integrated luminosities

conclusion

- CMS tracker in marvelous shape and performance
- Important ongoing monitoring tasks on the existing CMS tracker
- P&D needed to develop solution to cope with SLHC environment
- Time scale does not allow much

Thank you for your attention