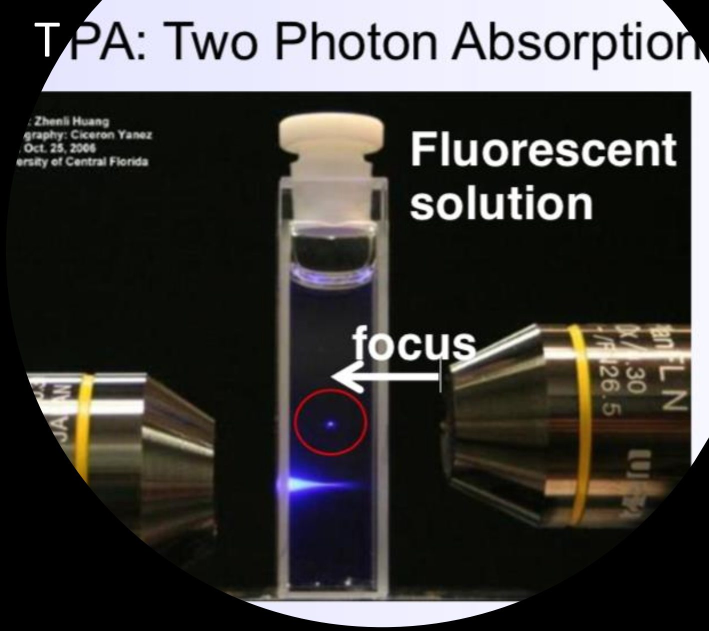
RD50
from Experiment perspective

Frank Hartmann – THANKS FOR ALLOWING ME TO TALK HERE

Well, we couldn't have done without RD50

What did we – THE EXPERIMENTS – get?

- Forum to discuss all
  - Reasonable and crazy ideas
- Recipes
  - What to build
  - How to operate
- Tools



A Forum –
a common goal

- Always difficult to understand which R&D effort is RD50 and what is experiment
  - **I consider this perfect.** It means we are sharing information on successes and failures
- I am unable to decide what is most efficient
  - The sessions with talks
  - The evening get-togethers
  - The coffee breaks
  - Lab visits

Well Ok, I can:

It's the coffee breaks plus the common goal!

I always enjoyed the clear and frank chats

Recipes

- **For LHC**
  - Oxygen is good – Carbon is bad
  - p-in-n is OK for Tracker
  - n-in-n is OK for Vertex *(oxygenated n-bulk)*
- **For HL-LHC**
  - Oxygen is good – Carbon is also good at some places
  - n-in-p is great
    - optimise thickness
  - 3D is better
  - Precise timing is possible

- **A WISE MAN SAID:**
  For p-in-n sensors, the donor removal component of the Hamburg model cannot be described by a simple process V + P → V P only. There is something more behind that and we still do not exactly understand what it is.

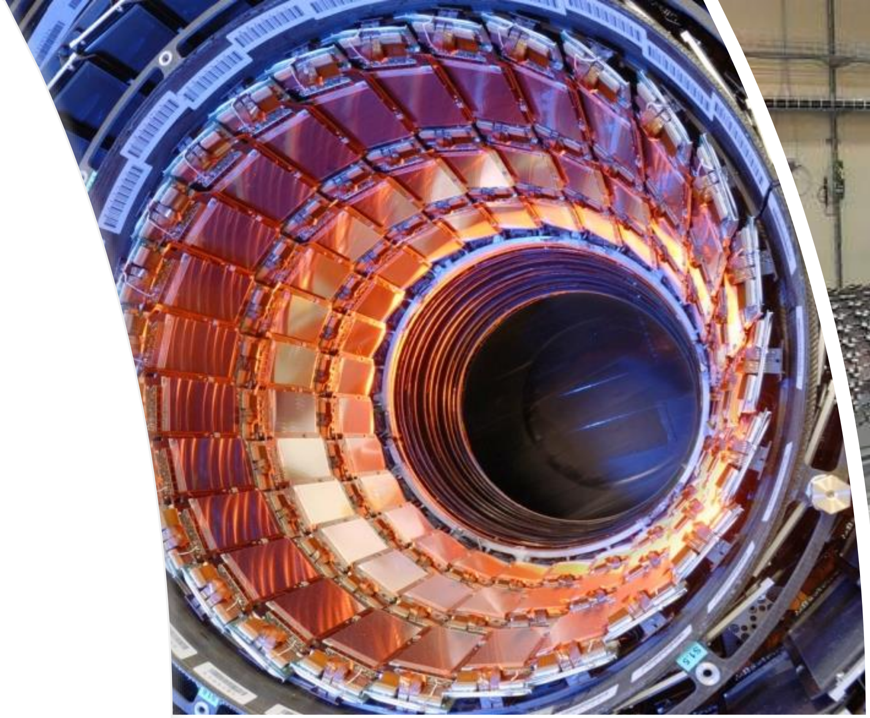
- **RD50 ALSO CLEARLY TOLD US:**
  But, while new materials seem to be more radiation tolerant, a complete evaluation of **each material must be conducted separately for neutron, proton and mixed irradiation**. **The correct radiation mixtures** at different radii in the experiment should be checked.

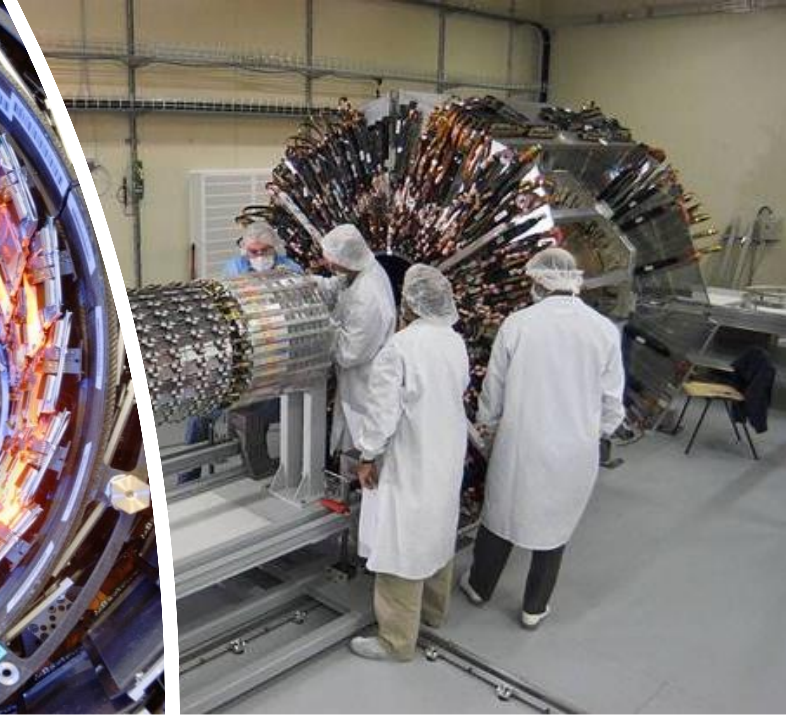
Thank you.
We did that.

RD50 and Hamburg Model said p-in-n is OK for E14

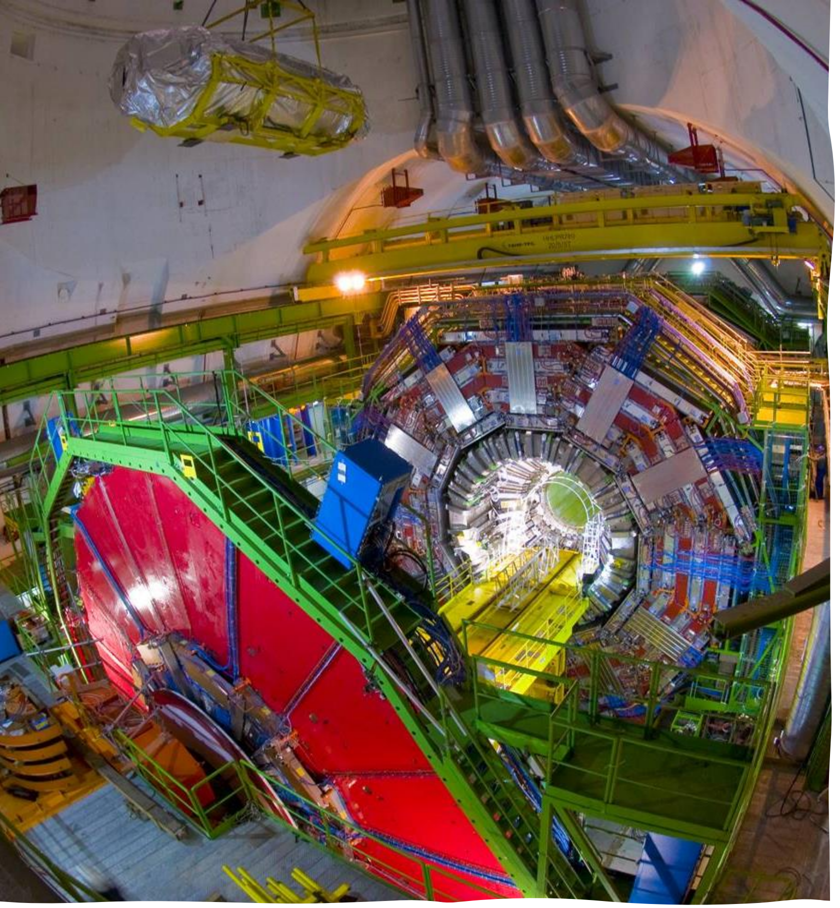
Seems you are right

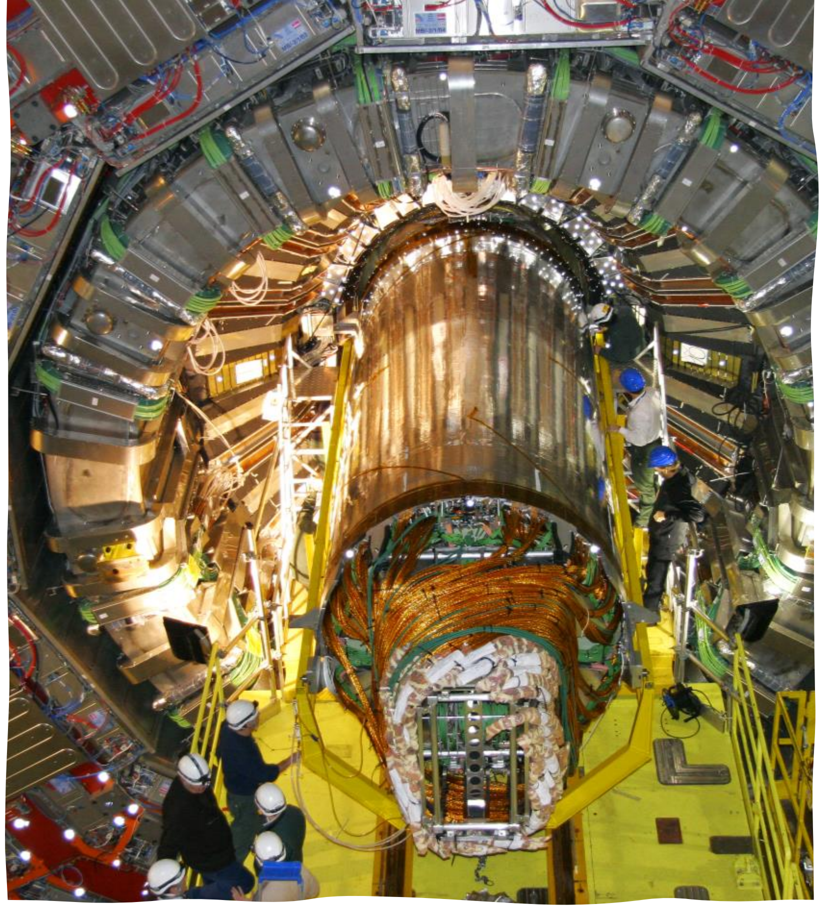
~270m^2 proves it

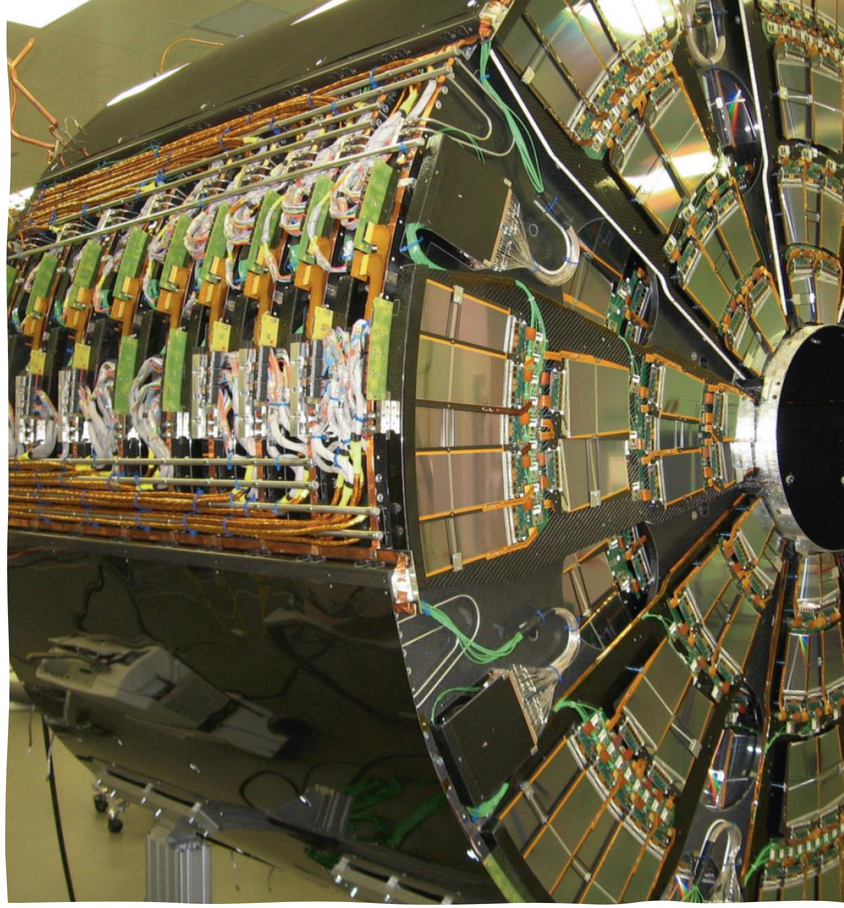




Btw. LHCb added early on an n-in-p plane

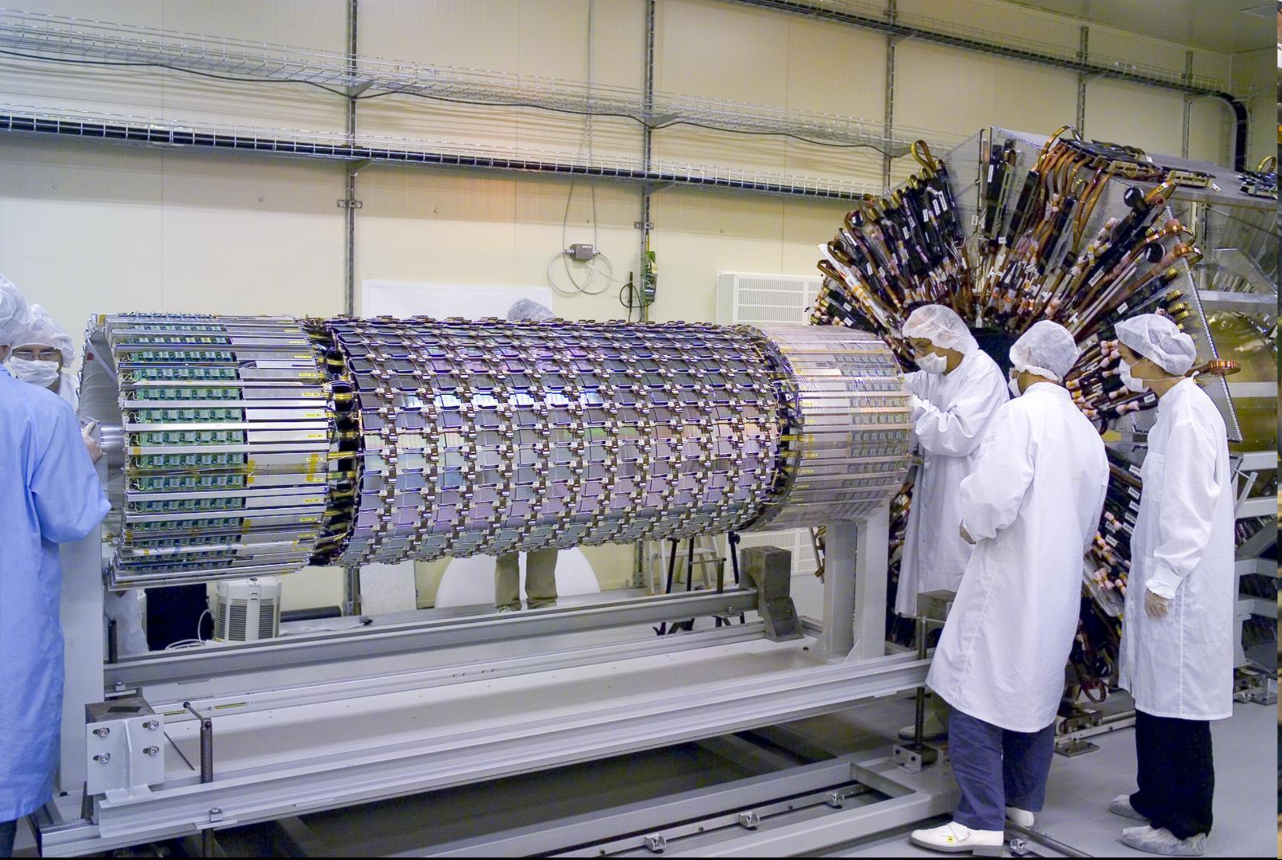


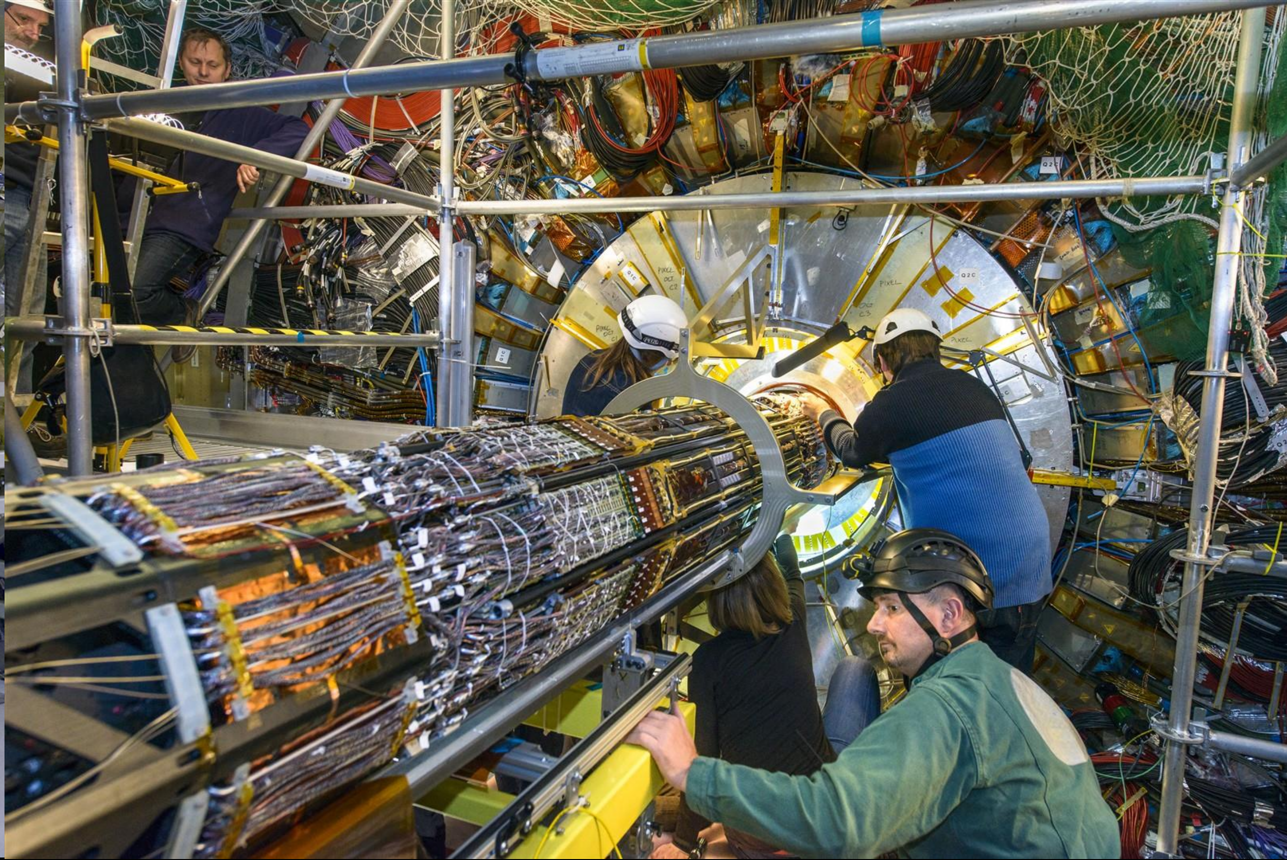




The CMS Tracker

- 200 m^2
- Strips and pixel detectors
- Operating > 1 decade





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The ATLAS Tracker

- $60\ m^2$
- Strips and pixel detectors
- Operating > 1 decade

LHCb until LS2

Strips

n-in-n plus some n-in-p

Detector has accumulated fluence of approximately 7 x 10^{14} 1MeV n_{eq}/cm^2

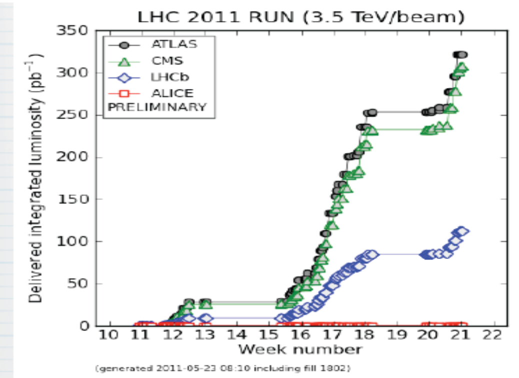
And RD50 followed-up if all is true

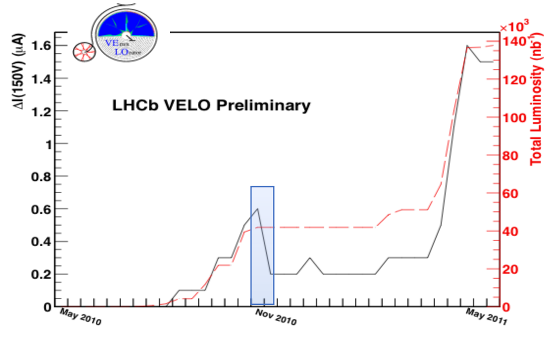
19th RD50 workshop, November 2011 at CERN,
especially in the session on **radiation damage observed in HEP experiments**

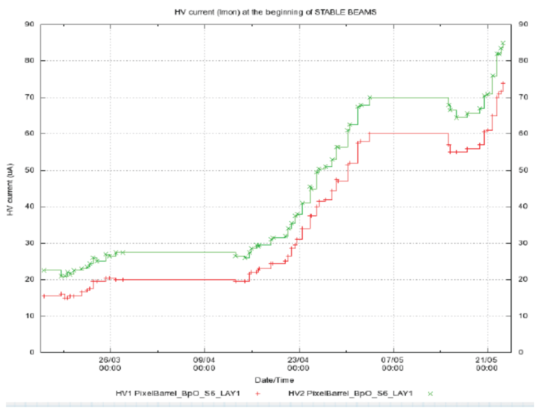
→ Inter-experiment radiation damage working group

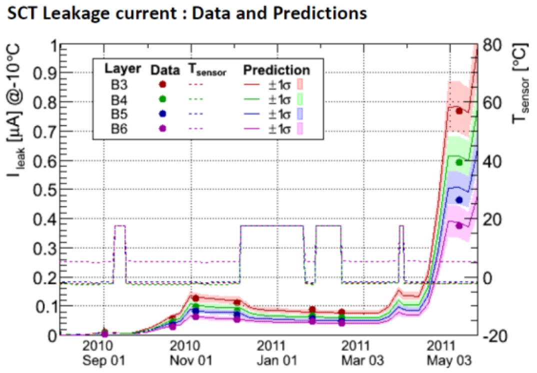
Radiation Damage and Annealing exists

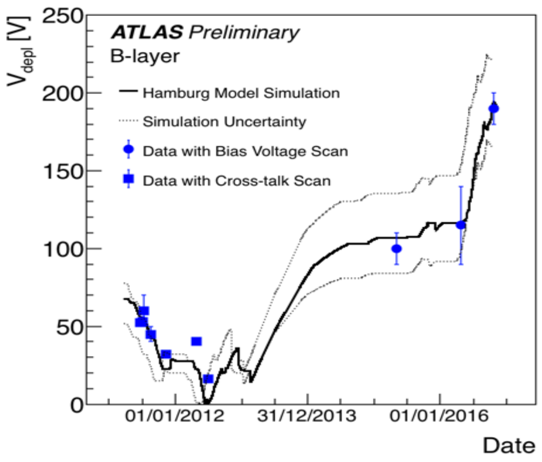
Inter-experiment radiation damage working group

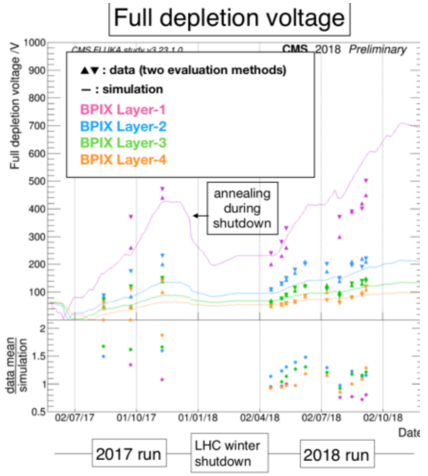




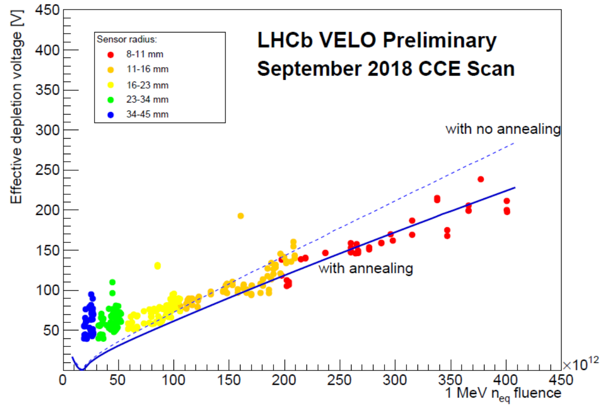






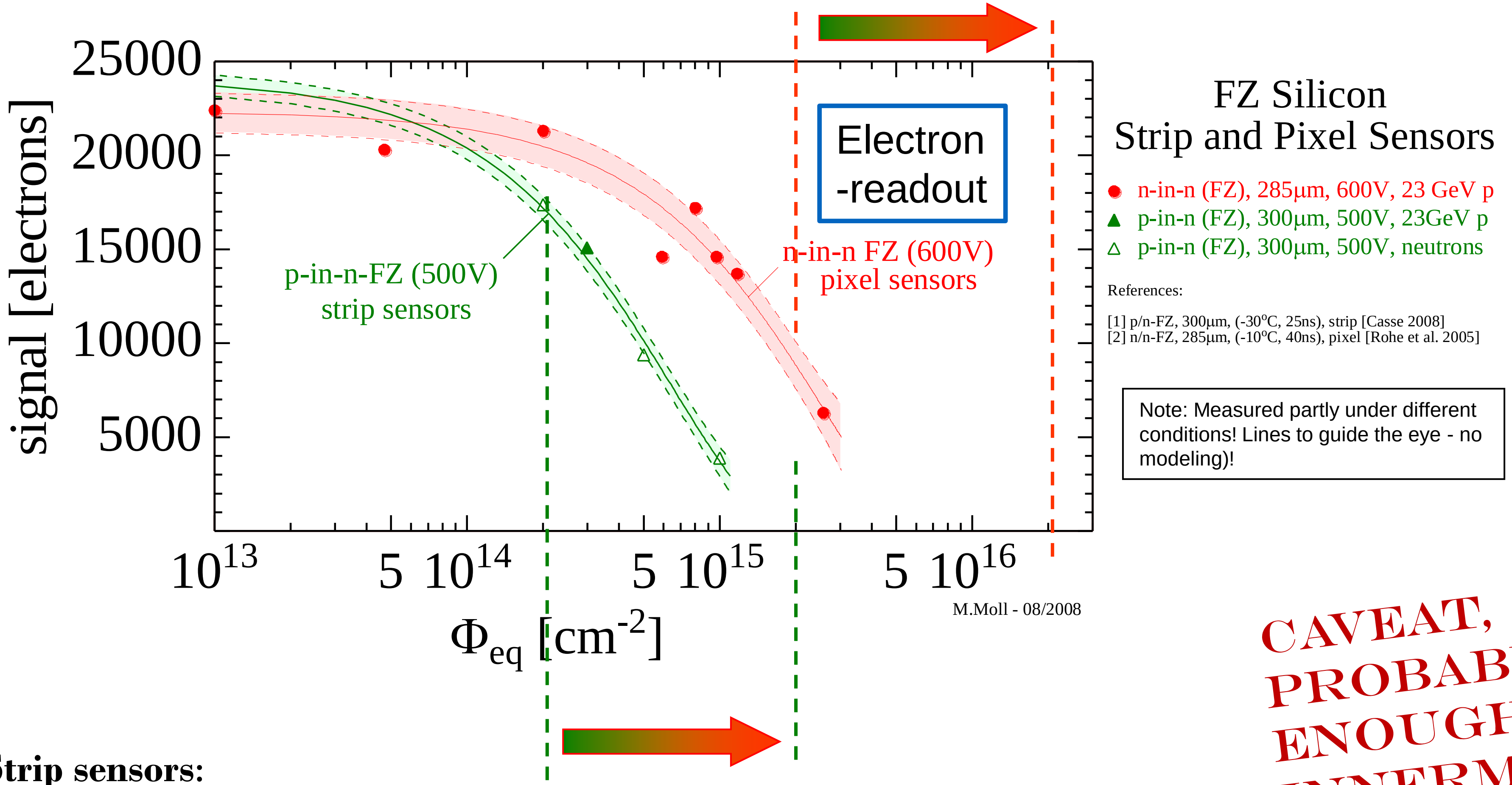


- **The Hamburg Model rocks**
  - Good recipe when to increase bias voltages
  - Parametric description of operation parameters (signal, trapping, current) as a function of fluence and temperature.



Then we learned, we should use 'ELECTRON READOUT'

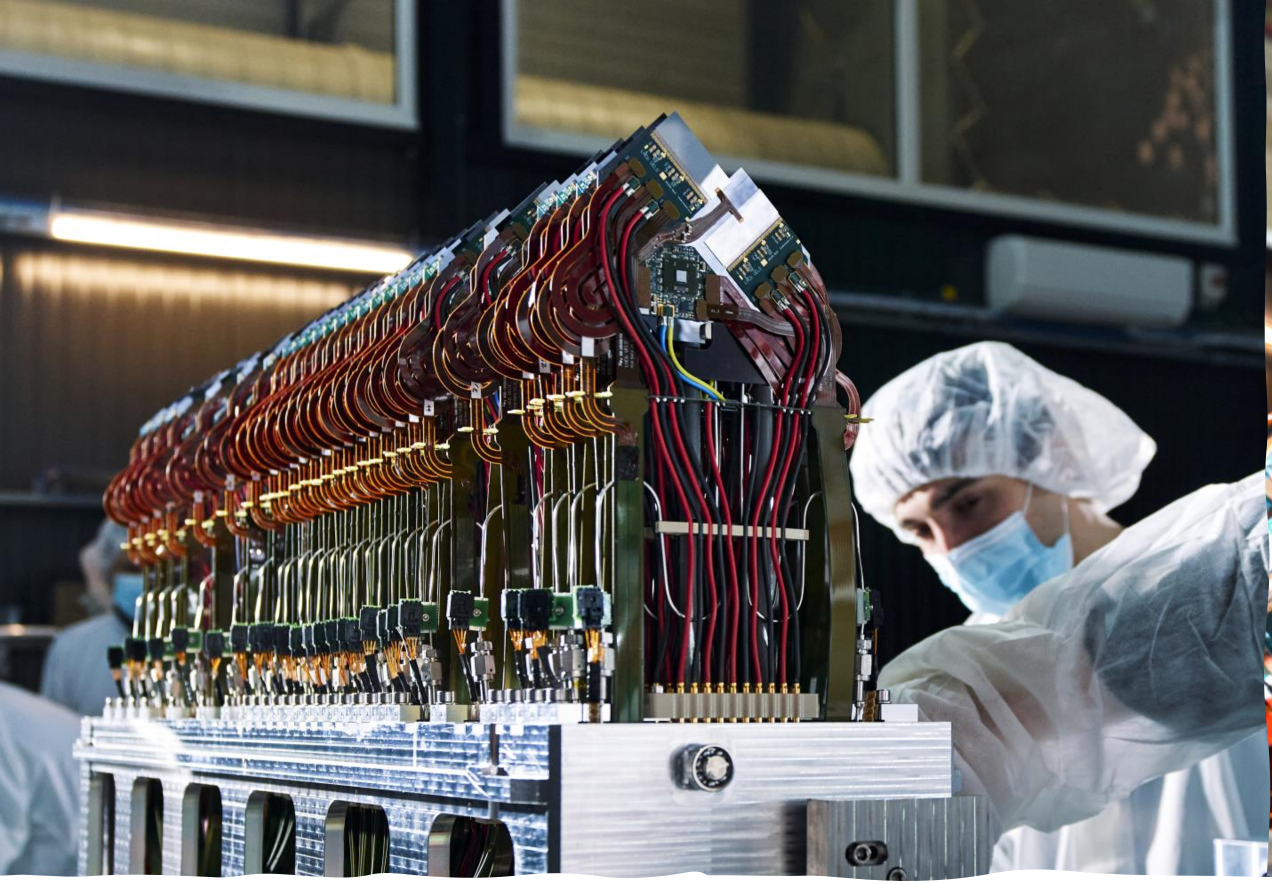
Pixel sensors:
max. cumulated fluence for LHC and HL-LHC

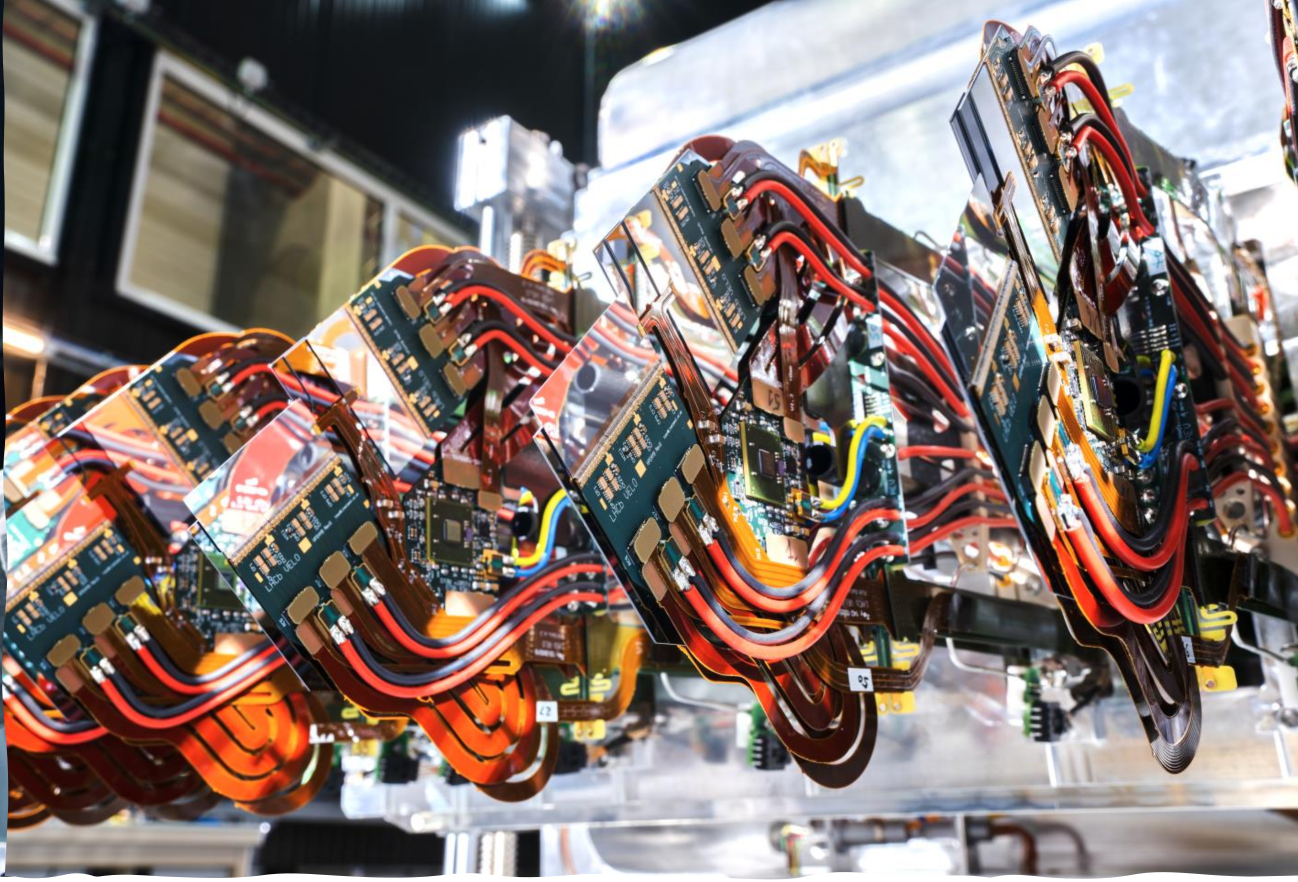


Strip sensors:
max. cumulated fluence for LHC and HL-LHC

CAVEAT, PROBABLY NOT ENOUGH FOR INNERMOST SENSORS

From RD50 (M. Moll)





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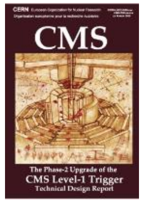
And, LHCB is ahead

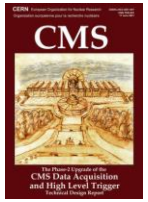
- New VEO with n-in-p pixels
    - Exchanged in LS2

HL-LHC – LS3

Ok, now we need
- X*E16
- And precision *timing*

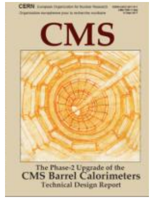


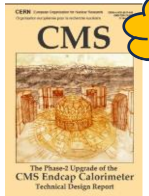
L1-Trigger
https://cds.cern.ch/record/2714892
- Tracks in L1-Trigger at 40 MHz
- Particle Flow selection
- 750 kHz L1 output
- 40 MHz data scouting



DAQ & High-Level Trigger
https://cds.cern.ch/record/2759072
- Full optical readout
- Heterogenous architecture
- 60 TB/s event network
- 7.5 kHz HLT output

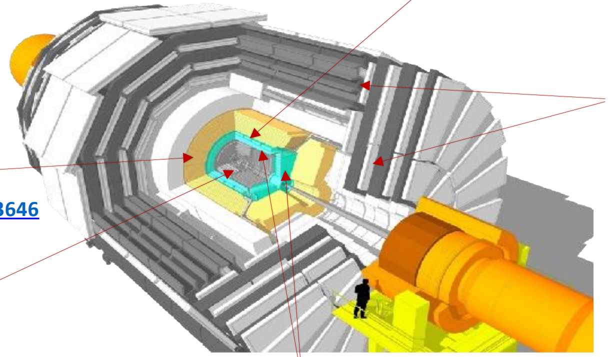
Barrel Calorimeters
https://cds.cern.ch/record/2283187
- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards



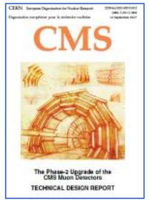


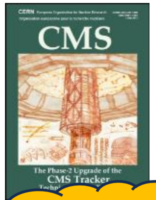
E16

Calorimeter Endcap
https://cds.cern.ch/record/2293646
- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS



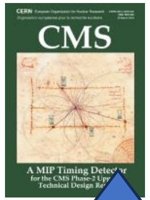
Muon systems
https://cds.cern.ch/record/2283189
- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC 1.6 < η < 2.4
- Extended coverage to η ≃ 3





E16

Tracker
https://cds.cern.ch/record/2272264
- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to η ≃ 3.8

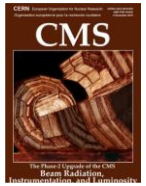


MIP Timing Detector
https://cds.cern.ch/record/2667167

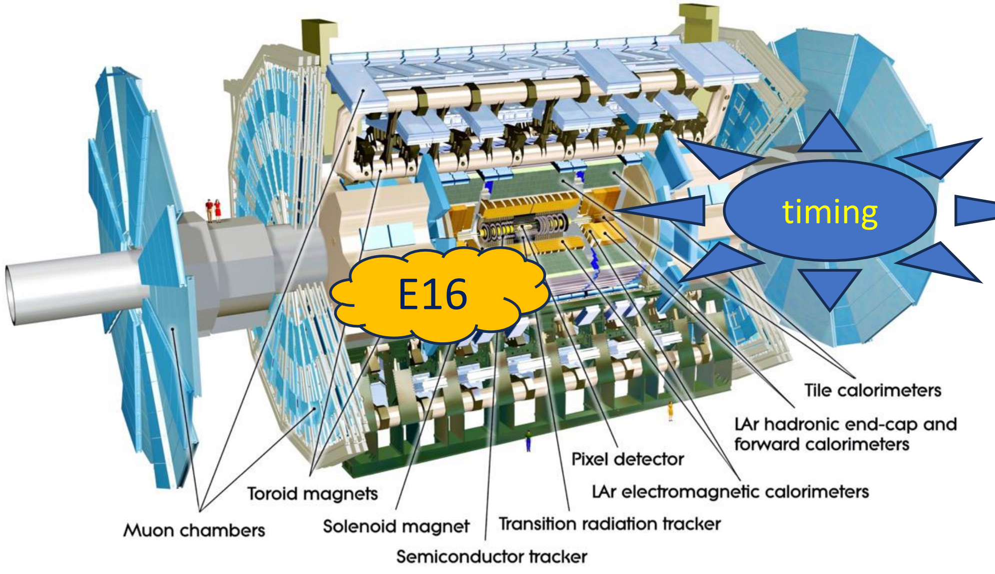
Precision timing with:
- Barrel layer: Crystals + SiPMs
- Endcap layer:
  Low Gain Avalanche Diodes

timing

Beam Radiation Instr. and Luminosity
http://cds.cern.ch/record/2759074
- Beam abort & timing
- Beam-induced background
- Bunch-by-bunch luminosity:
  1% offline, 2% online
- Neutron and mixed-field radiation



Let's increase to 1000 m^2



Axial field provided by solenoid (2 T) in the central region (momentum measurement)

High-resolution silicon detectors:
- 100 Mio. channels (50 μm x 250 μm)
- 6 Mio. channels (80 μm x 12 cm)

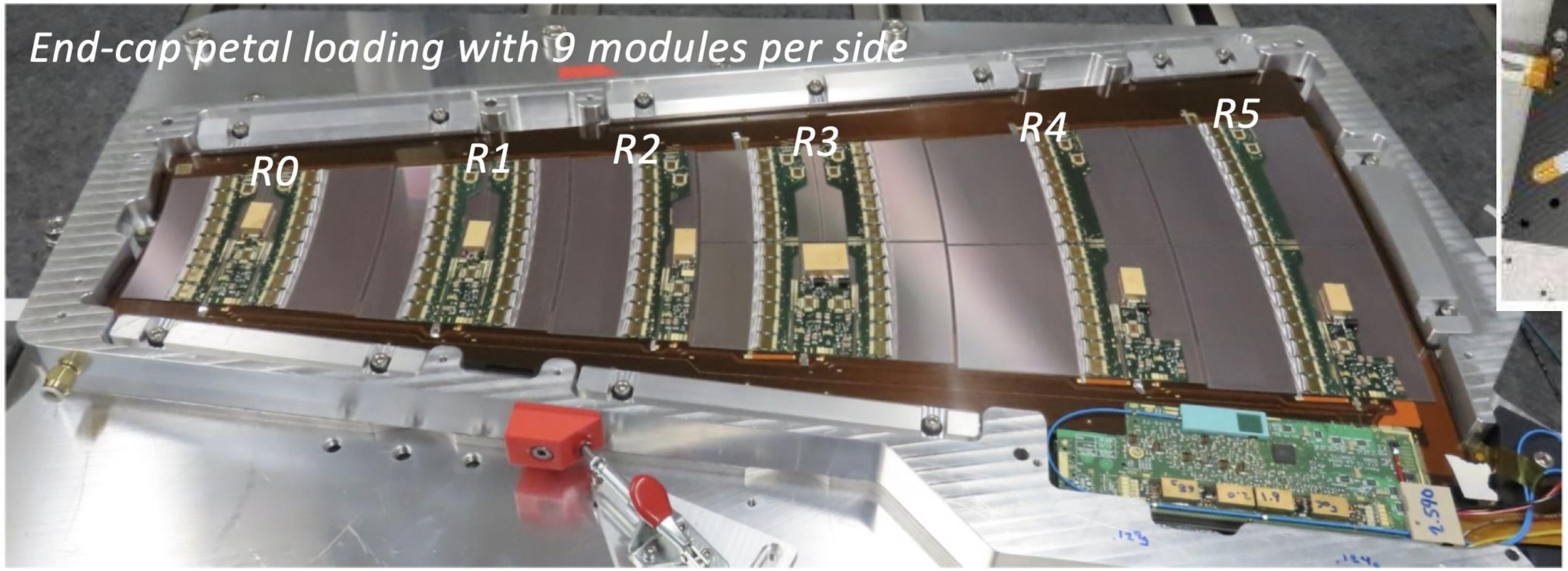
Spatial resolution ~15 μm (in azimuthal direction)

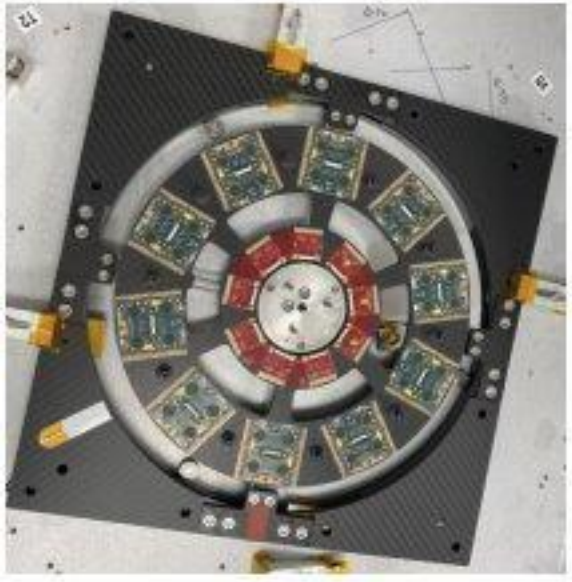
Precise energy measurement down to 1° to the beamline with a calorimeter system

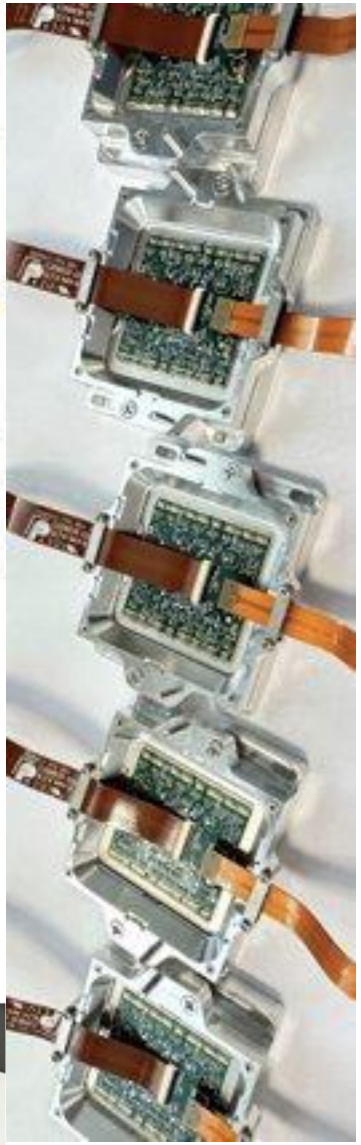
Independent muon spectrometer (superconducting toroidal magnet system)

Ultra-fast custom electronics and high-performance computers filter the collisions: only 1 out of 30,000 collisions is kept

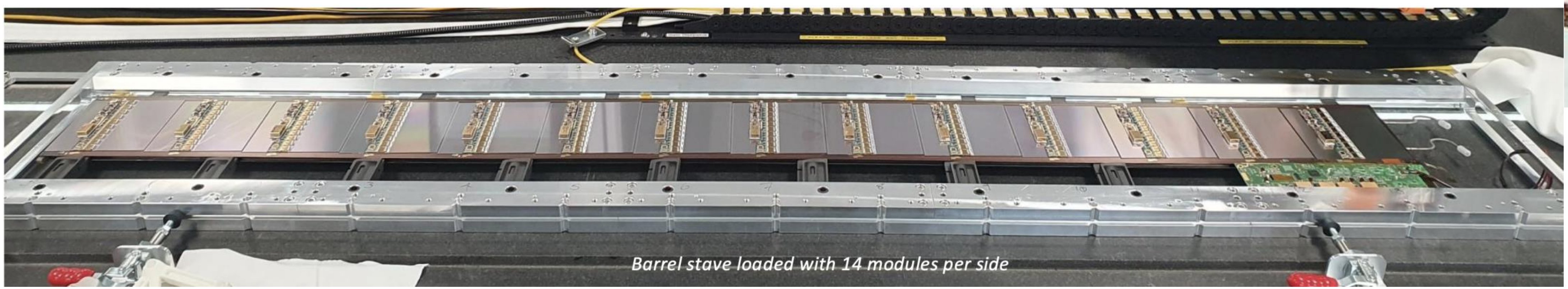
ATLAS Phase II





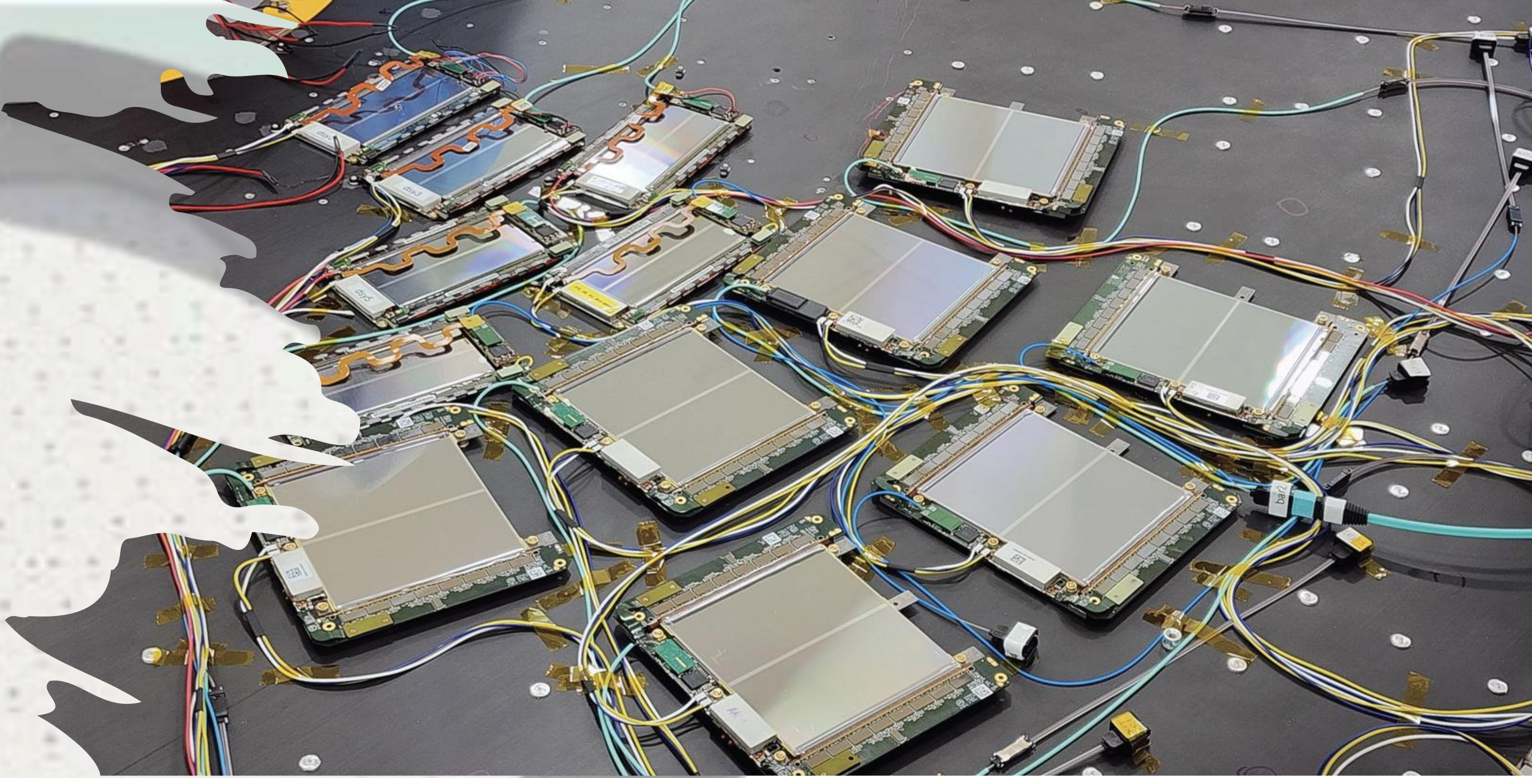


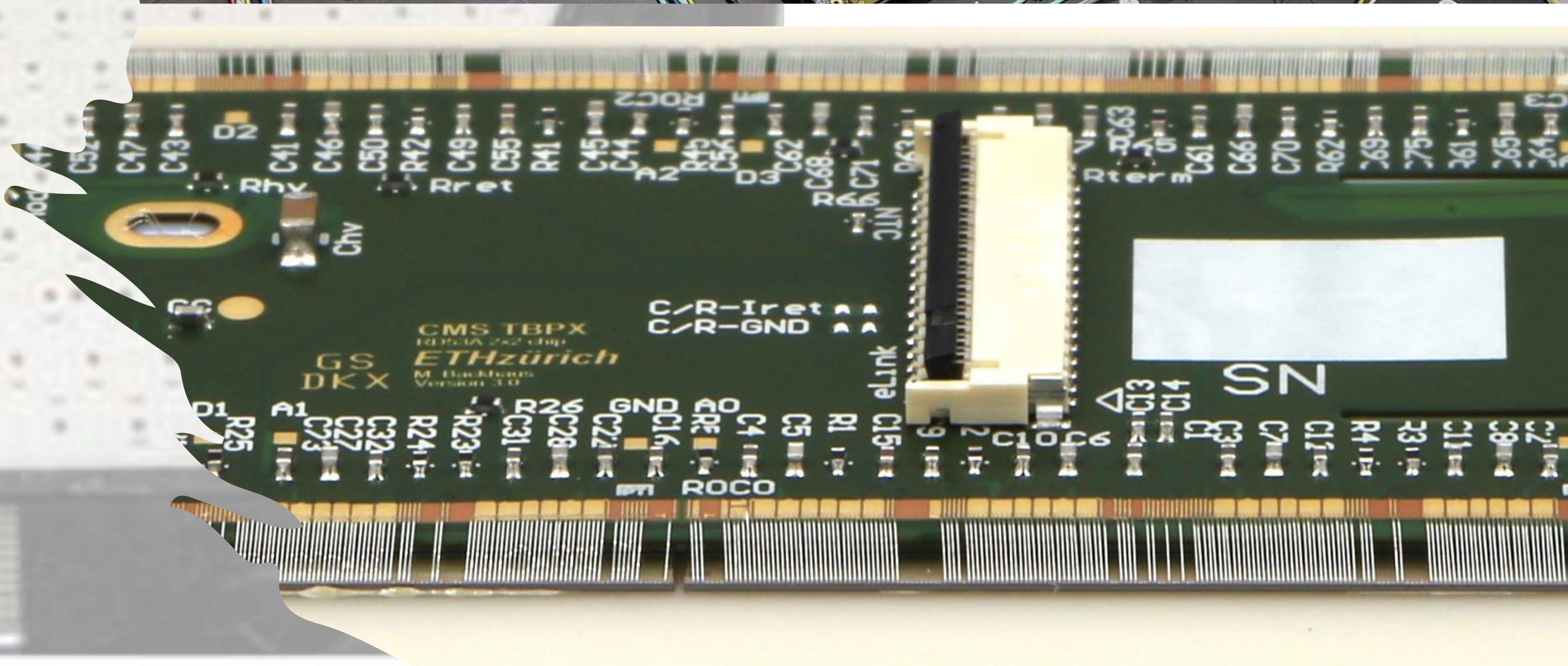
Strips & Pixel
All n-in-p



CMS Phase II

- Outer Tracker modules in final configuration
  – n-in-p
- Pixel Tracker module
  – n-in-p
- High Granularity Calorimeter
  – n-in-p (8 in.)

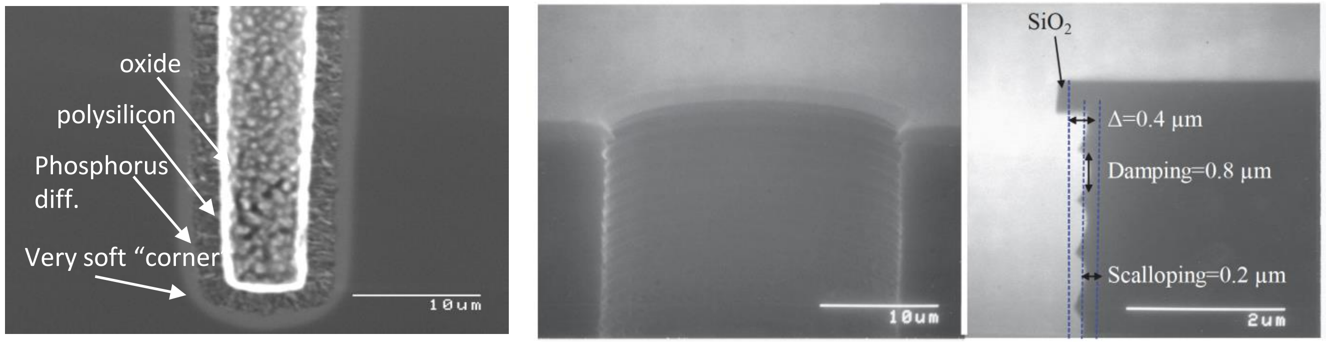




First RD50 workshop
Silicon 3D radiation sensors: general characteristics; irradiation test results
Sherwood Parker and Christopher Kenney (LBL Berkeley,USA)

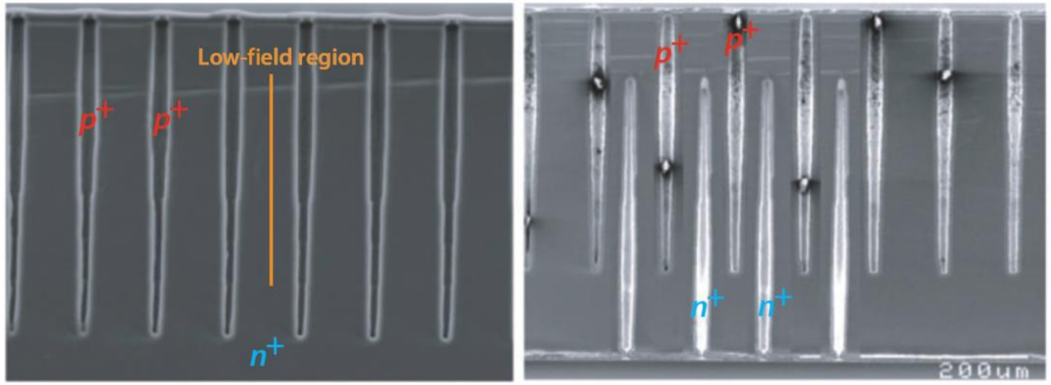
- Deep reactive-ion etching (DRIE)

Photos:
Courtesy of CNM-IMB (CSIC), Barcelona

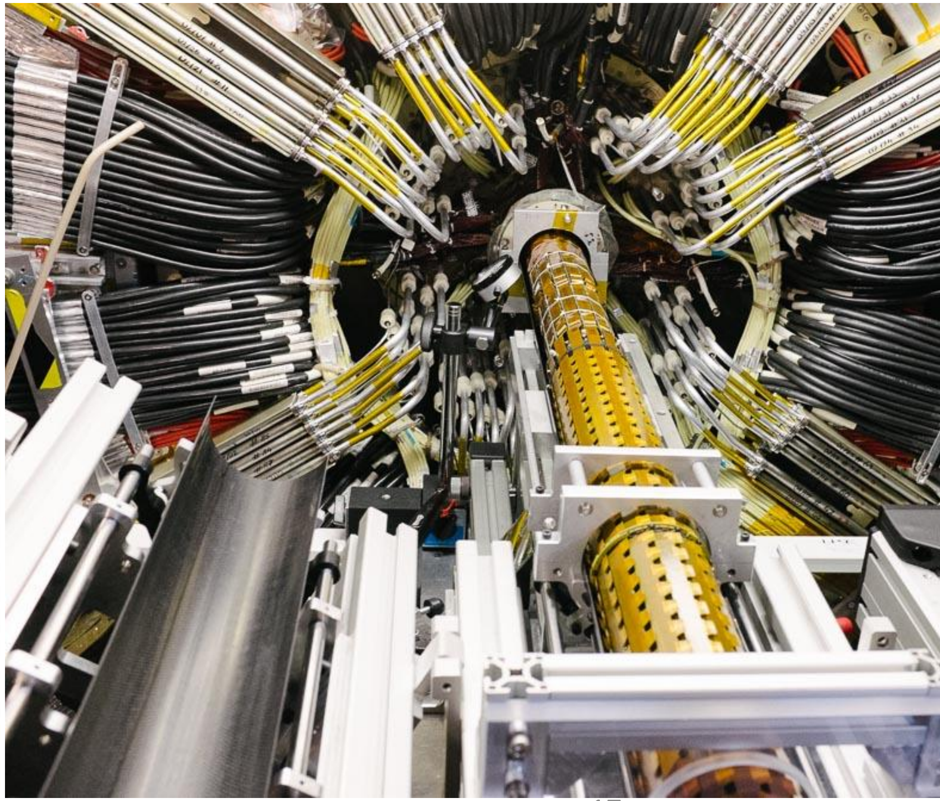


Evolution of 3D implementation

- Double or single type?
- Double or single sided?
- Full 3D-pass-through?
- Thin or thick?



➔ ATLAS APPRECIATES
- L0 AS FIRST USE-CASE



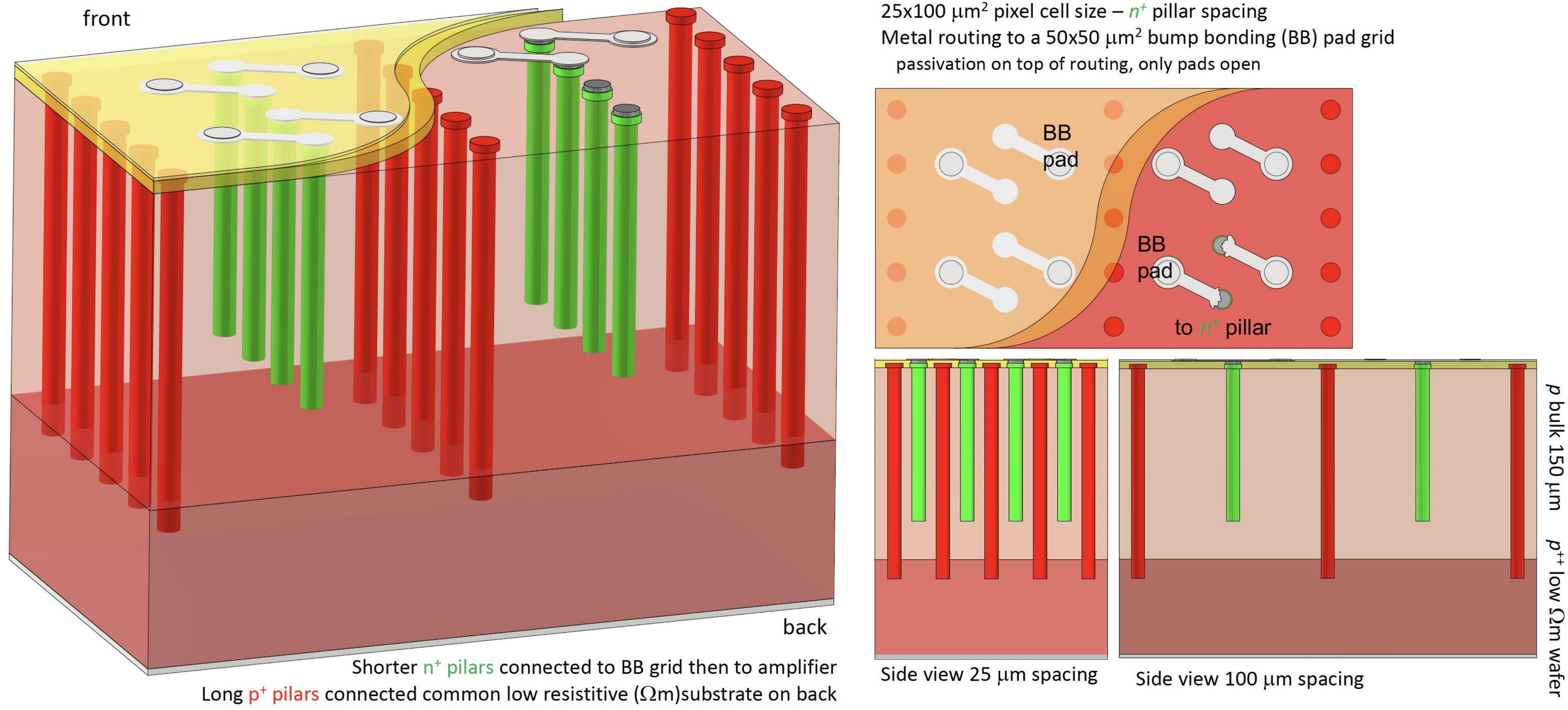
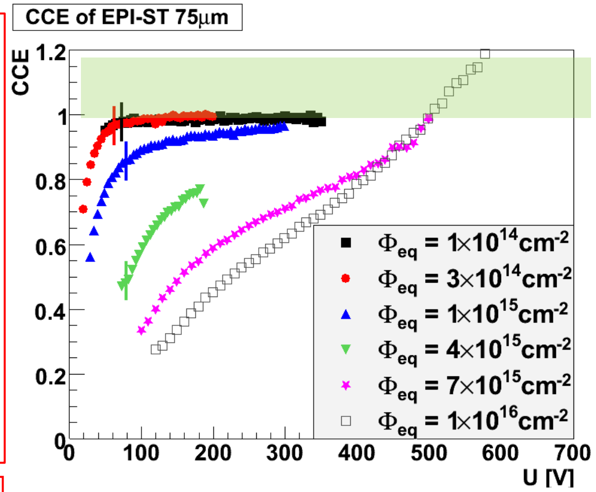
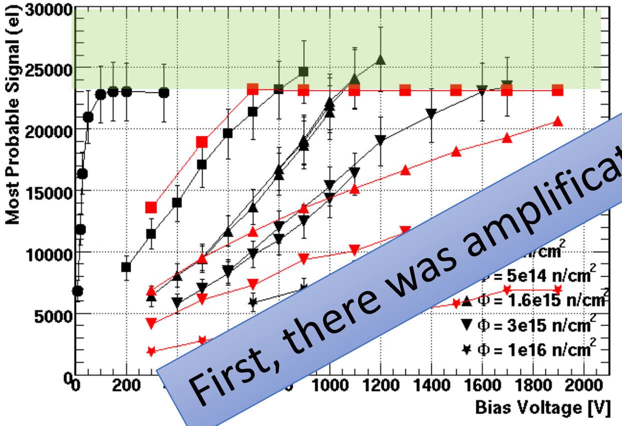


Fig. 2.27 The final HL-LHC 3D sensor layout with $25 \times 100\,\mu m^2$ pixel cells – 1E-scheme

Joern Lange, RD50 2009, EPI

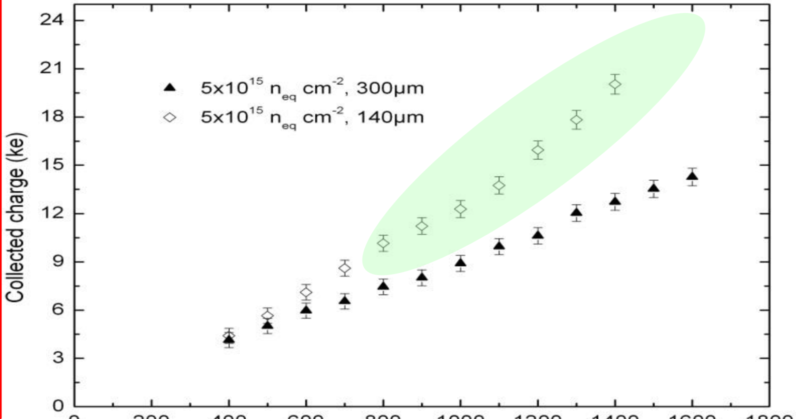


I. Mandić et al., RESMDD 2008



First, there was amplification

G. Casse, Vertex 2009, n-in-p



Then there was head scratching

Then we had daring ideas
'to use' the amplification

Then we re-invented reach-through diodes – optimised them – and called them LGADs

IEEE TRANSACTIONS ON ELECTRON DEVICES, JUNE 1972

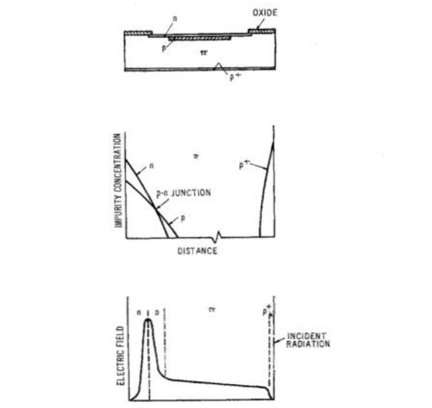
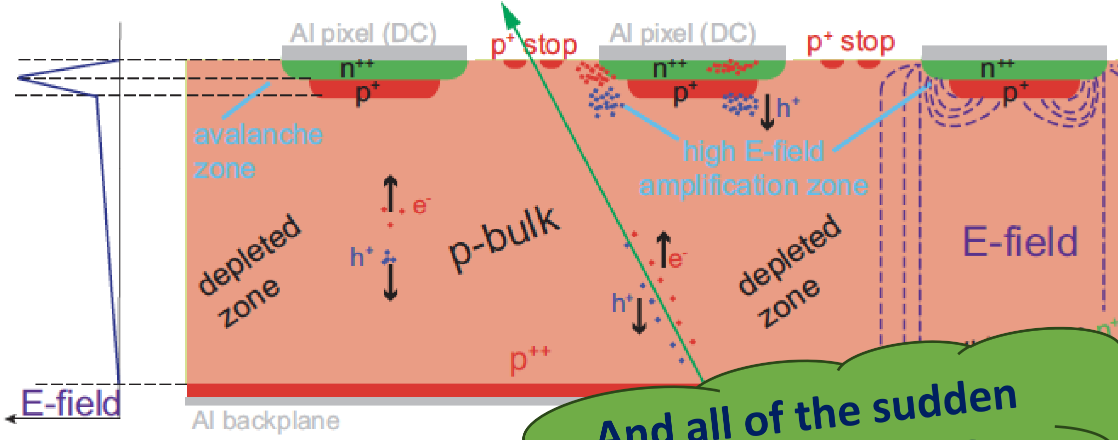
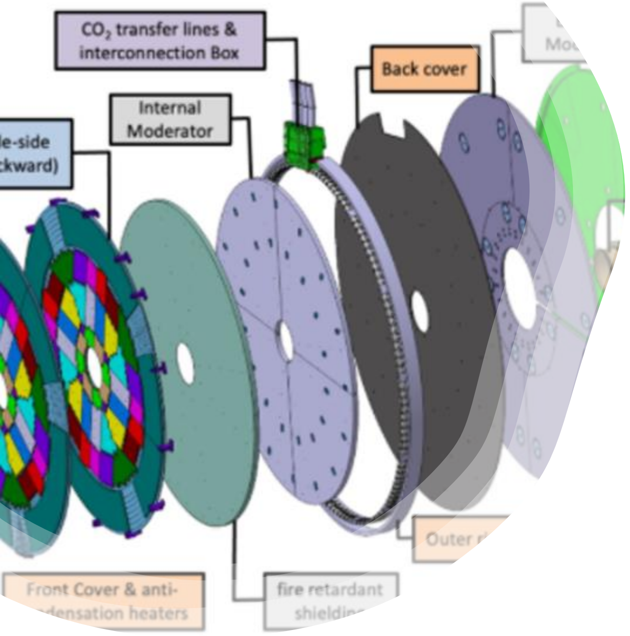
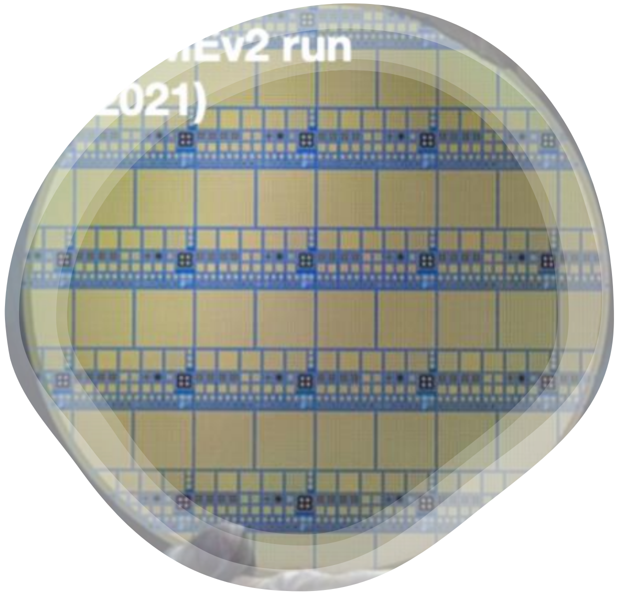


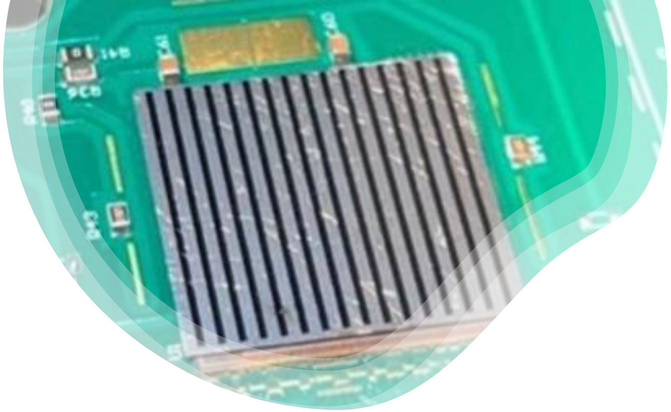
Fig. 1. Sketches of reach-through avalanche-diode structure, impurity-concentration profile, and electric-field distribution.

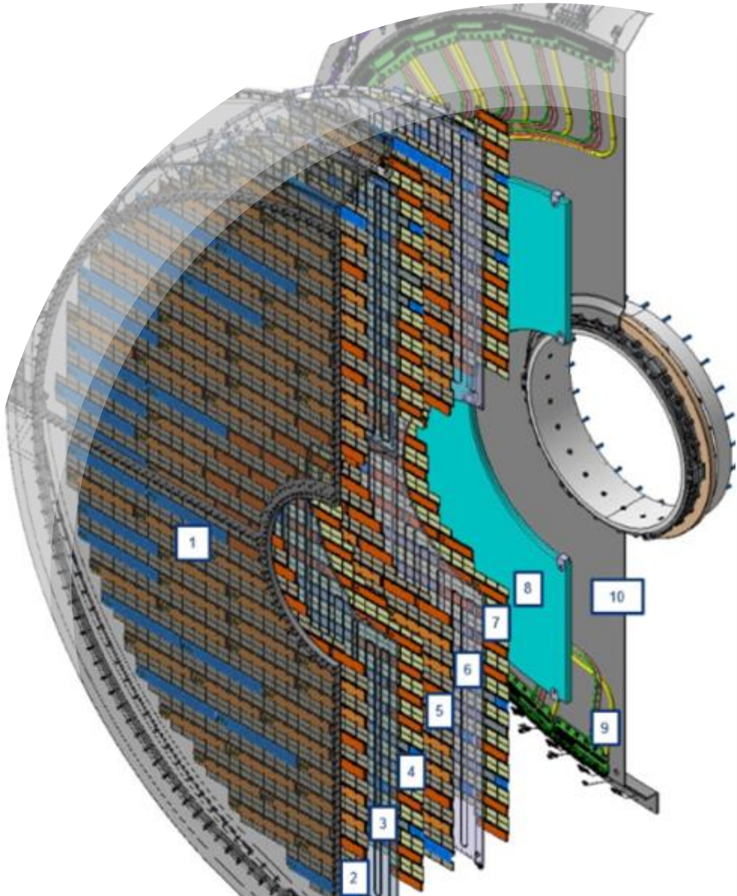


And all of the sudden
CARBON IS GOOD









ATLAS and CMS will equip their endcaps with LGADs to associate a timestamp to their tracks – 4D

Let’s put LGADs at work

LHCb – LS4

- Precision timing is key

… and do not forget spatial precision

➔ We need an upgrade on LGADs

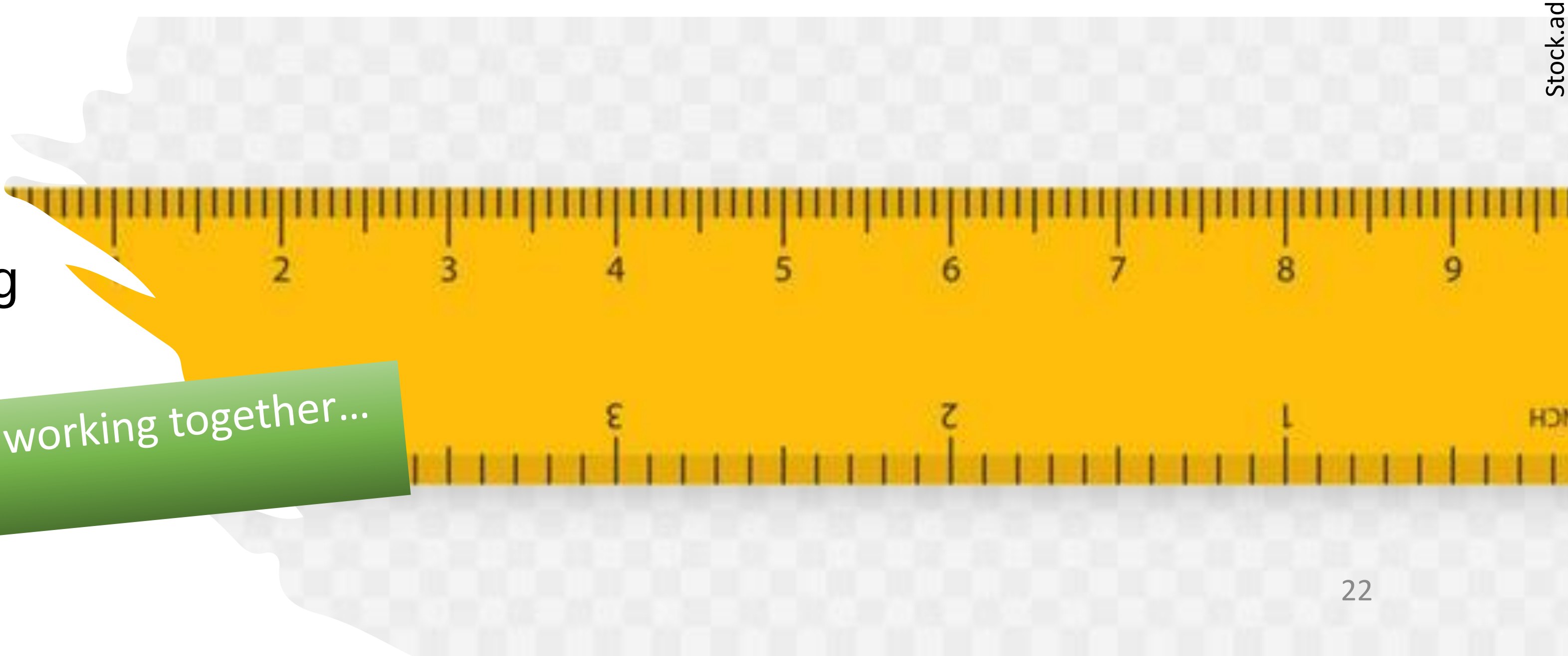
And I know of at least one additional LHC experiment having thoughts to use such ‘upgrades’

From Abe Seiden, Hartmut Sadrozinski and Nicolo Cartiglia pioneers on LGADs:

I'm wondering if we can do both measurements (space and time) in one object, a silicon detector with very good timing resolution.

We thought it was a dumb question...but over lunch, we jotted down some numbers.

... The main question is understanding the gain in silicon sensors

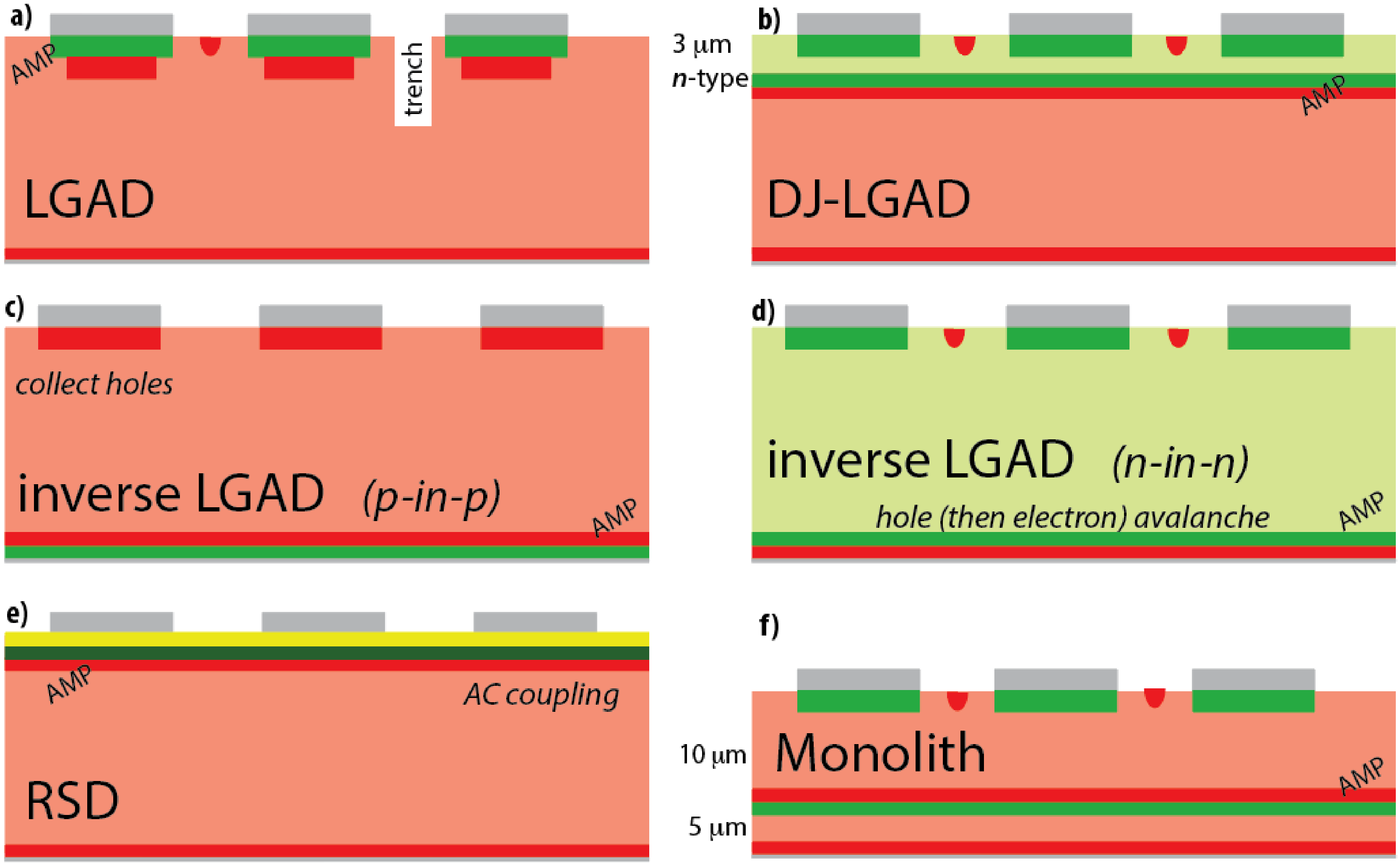


Stock.adobe.com

Watch out – people from different experiments working together...
-- Thanks for the framework – and the BLUR

In summary, I present THE ZOO

Anybody up for a bet?

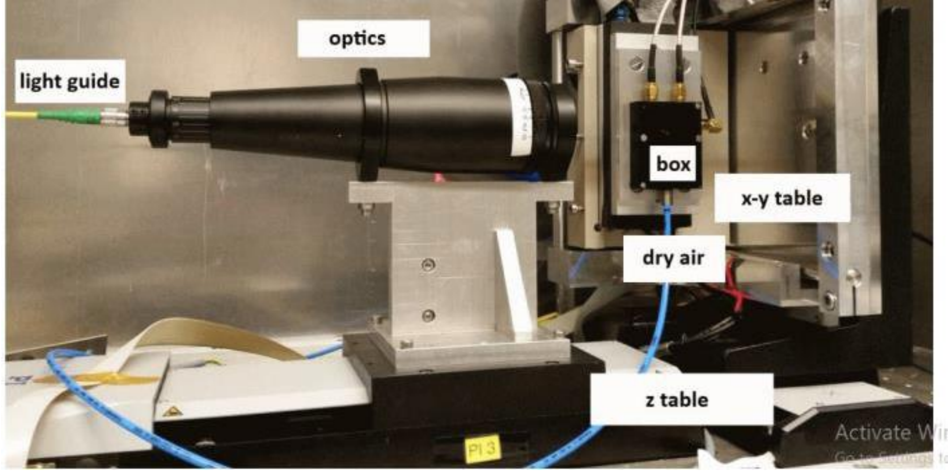


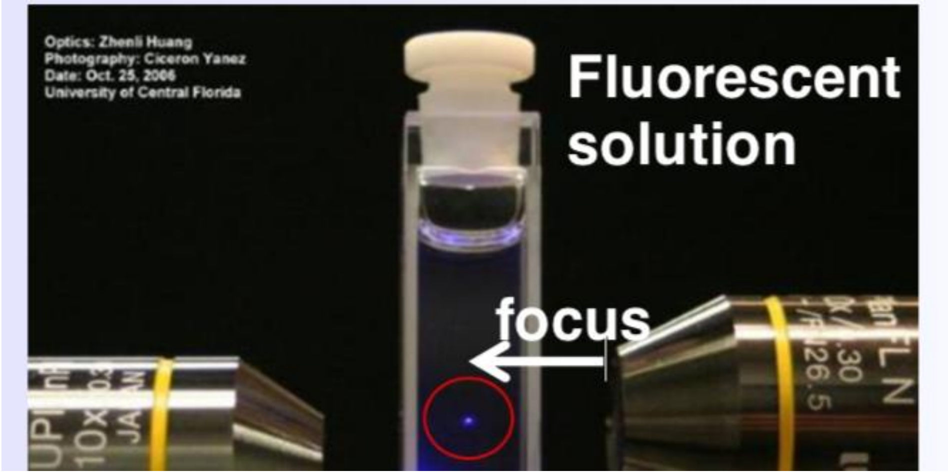
or the new DC-RSD (DC-LGAD)

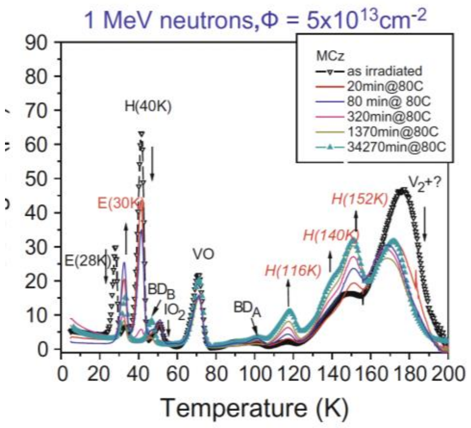
Tools, spearheaded, improved, standardized, distributed by RD50
- ANYHOW, THEY CHANGED OUR UNDERSTANDING SIGNIFICANTLY

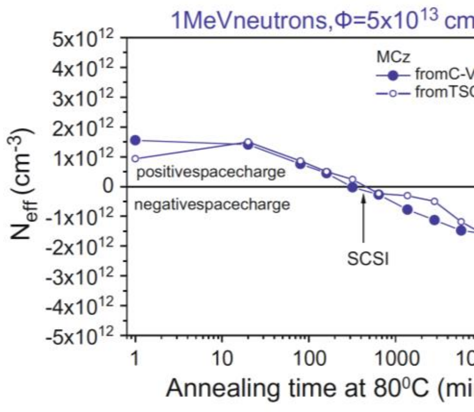
- TCT – front, back, edge and then TPA-TCT
- TSC, DLTS
- IV, CV
- Alibava
- Many more …

- Custom simulation tools
- Radiation defect models, Hamburg Model









THANK YOU RD50

- IT WAS FUN
- TOGETHER RD50 AND EXPERIMENTS
    - WE REALISED MARVELLOUS DETECTORS
- MORE TO COME BASED ON ALL THE GOOD WORK OF RD50