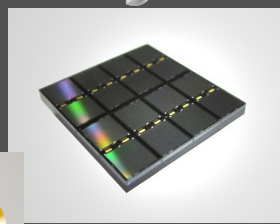
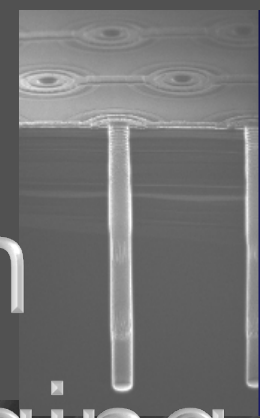
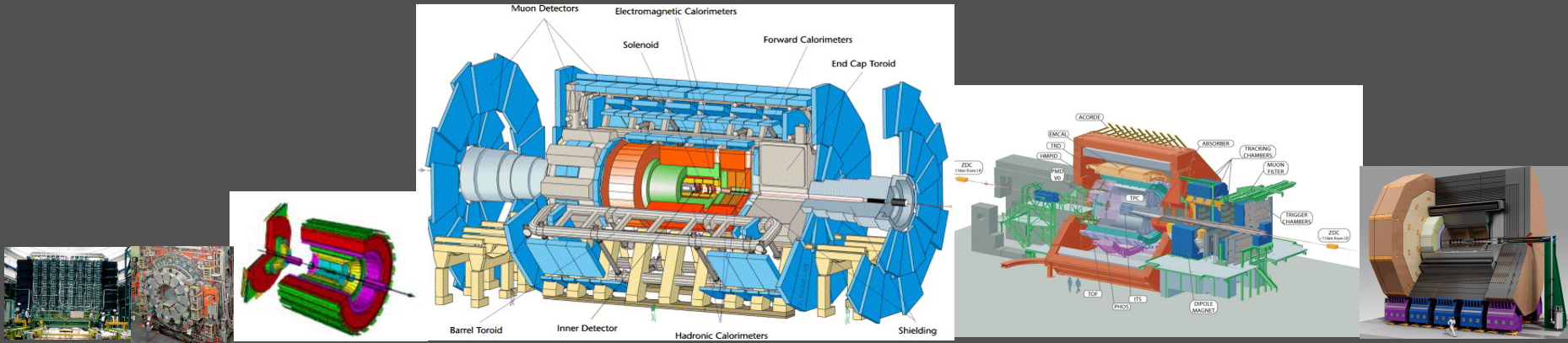


# Status and main challenges for imaging detectors in High Energy Physics

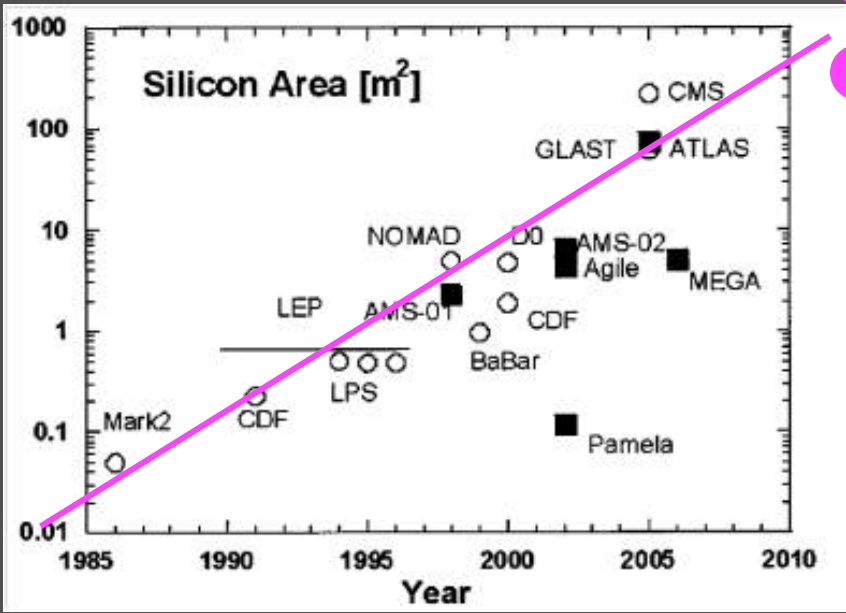


# where are the imaging detectors in HEP?



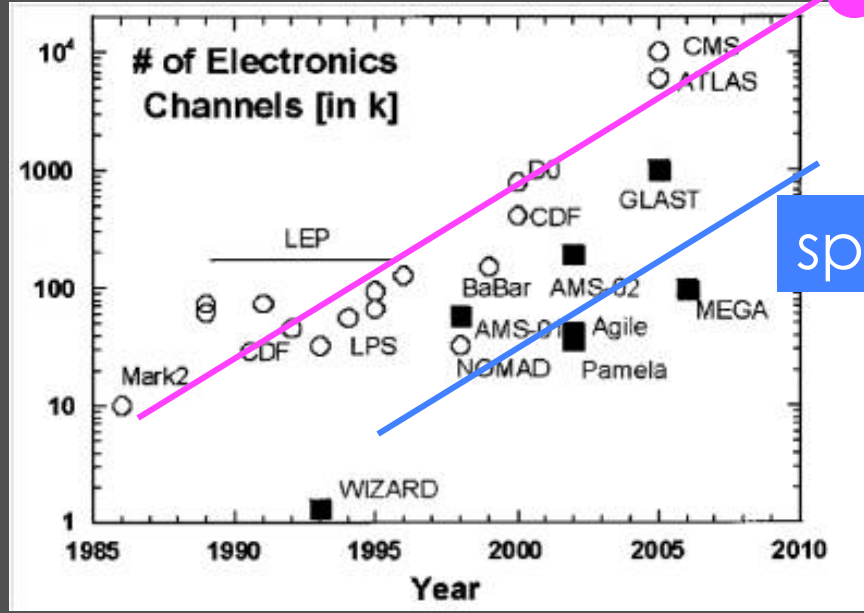
- vertex
  - internal trackers  $\rightarrow$  solid state or gaseous
  - particle identification.  
RICH, DIRC, TOP.... advanced TPC
  - extreme calorimetry
- $\checkmark$  light

radius ↑



● Linear Collider  
● imaging calorimetry  
~2500 m<sup>2</sup> Si strip

● accelerator



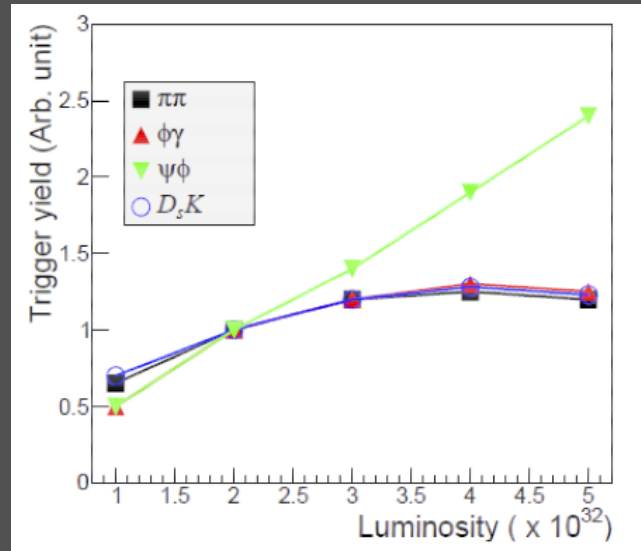
● space

# Vertex detectors and Trackers

requirements for upgrades and future experiments → higher granularity  
→ radiation hardness  
→ hermeticity

- **HL-LHC** increase in the number of pile-up events up to 200 per bunch-crossing @  $5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
- **SuperKEK** will experience instantaneous luminosity of  $8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$
- **LC** and Belle II heavily rely on the Identification of heavy flavours
- all experiments need 2-tracks separation in the core of hadronic jets
- fluences of the order of  $10^{16} \text{ 1 MeV } n_{\text{eq}}/\text{cm}^2$

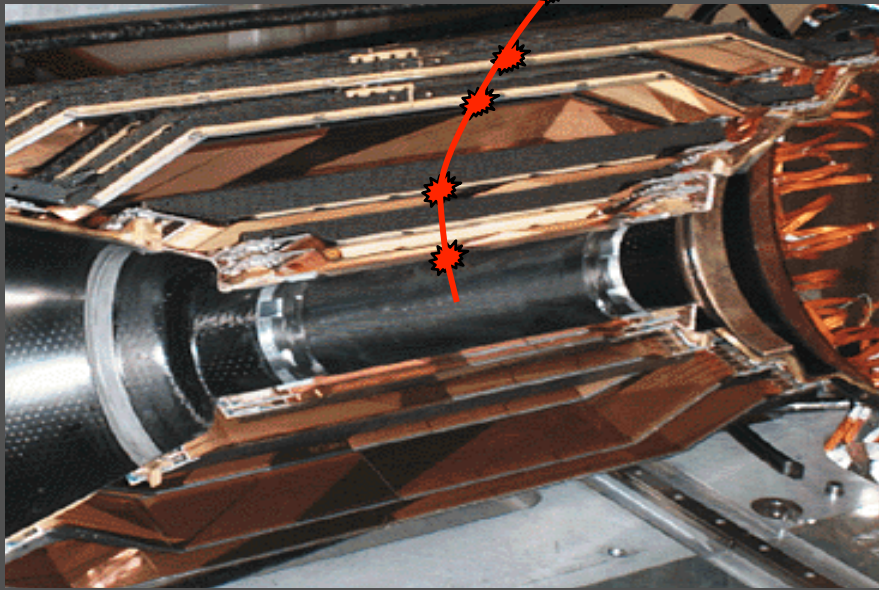
# implications of “higher granularity”



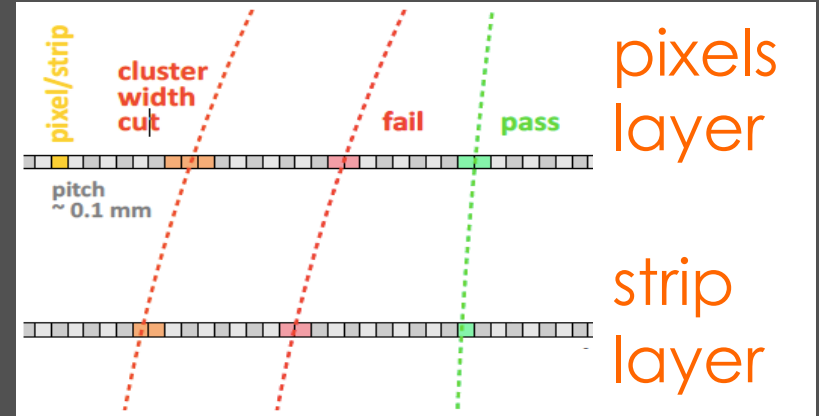
LHCb, a simple example of degradation of physics

**straightforward** → increase number of channels to achieve pitches of some 10-20 μm for the pixels and <<100 for the trackers to achieve a more “effective” L1 trigger

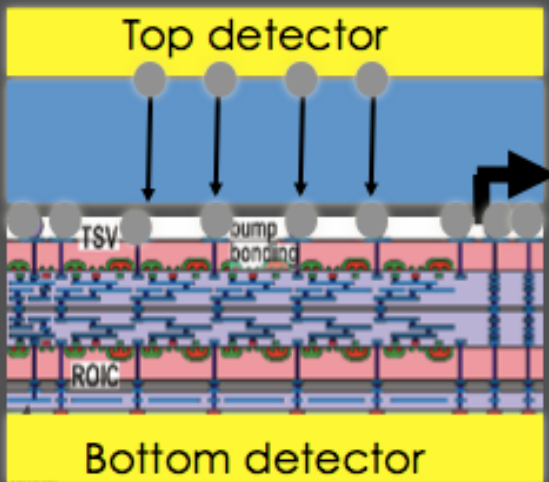
**more sophisticated** → adopt a new strategy like on-detector processing to improve triggers and reduce background



each "layer" is composed by a set of two active detectors closely spaced

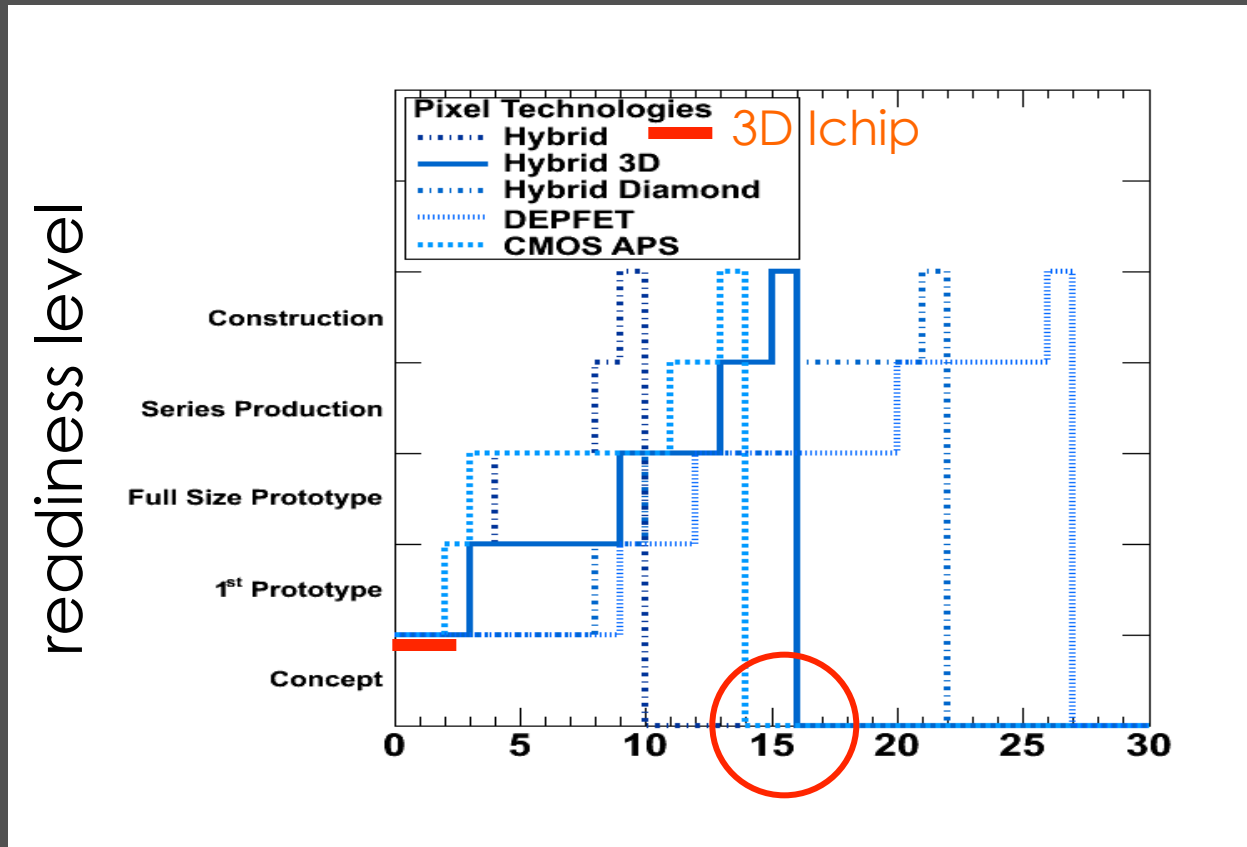


the coincidence from the two active detectors defines a high  $p_{\perp}$  track that enters at L1,2 trigger



Analog signals from top and bottom detectors go through a thin spacer are processed by a 3D vertically integrated chip

# how long does it take to bring to conclusion an innovative R&D in HEP?



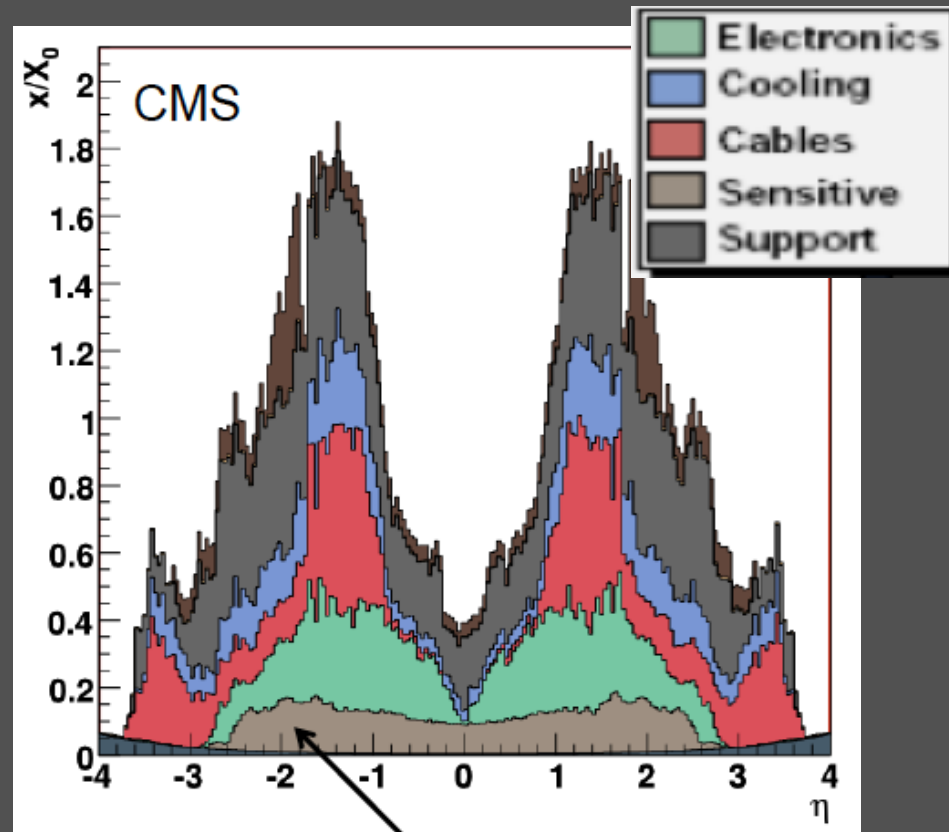
- invest on technologies surely supported by industry
- guarantee a long term funding plan

- increasing the granularity (e.g. # of channels)
- increasing the functionality on-detector
- moving fine-grained information from the detector to the trigger at high rate

= bringing more power on-detector → increase

$X_0$

thinner substrates  
→ 75 – 50  $\mu\text{m}$





achieving a reasonable trigger rate without jeopardizing the Physics, will be possible only if we pursue a coordinated R&D program in ALL these areas

- Advanced powering
- Advanced materials and integration
- Heat management embedded in the detector design

where are we now?  
follows few examples →

# ● Advanced powering

## surprising !!

at the last “TOP” conference

→ 2/123 potential papers & mentioned 4 times

### 1) Rad Hard DC-DC converters

developed for future CMS-Pixel upgrade  
adopted by ORIGAMI Vertex Belle II

### 2) Inter-bunches power pulsing

developed by PLUME collaboration  
for Mimosas 26 @ LC

**space for improvements**

# Advanced materials and integration

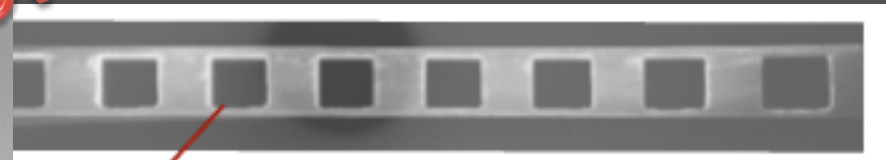
PLUME collaboration for Mu3e vertex → the HV-MAPS are supported by prisms of 25  $\mu\text{m}$  thick Kapton foil



# Advanced cooling embedded in the detector

micro-channels etched in Si and sealed by oxidation

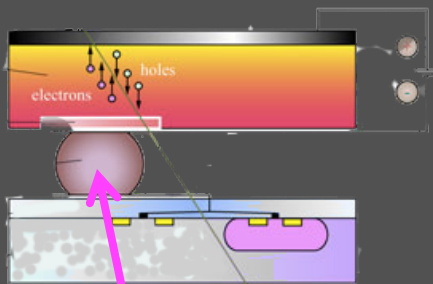
many excellent ideas but need to join the engineering efforts space for improvements



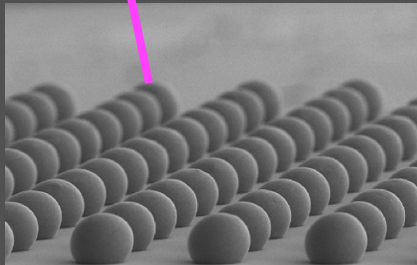
# recall on pitches vs technologies

today pitch  
50 – 100s  $\mu\text{m}$

Hybrid



bump bonding

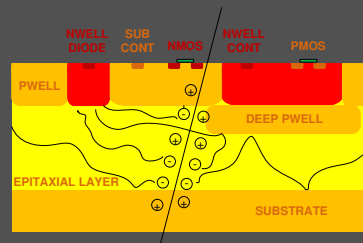


tomorrow 50 – 25  $\mu\text{m}$

→ R&D on connectivity

- bb facilities
- Through Silicon Vias
- micro bb

→ MONOLITHIC

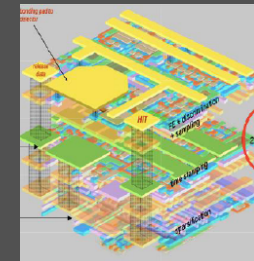


less  $X_0$

day after tomorrow  
25  $\mu\text{m}$  and less

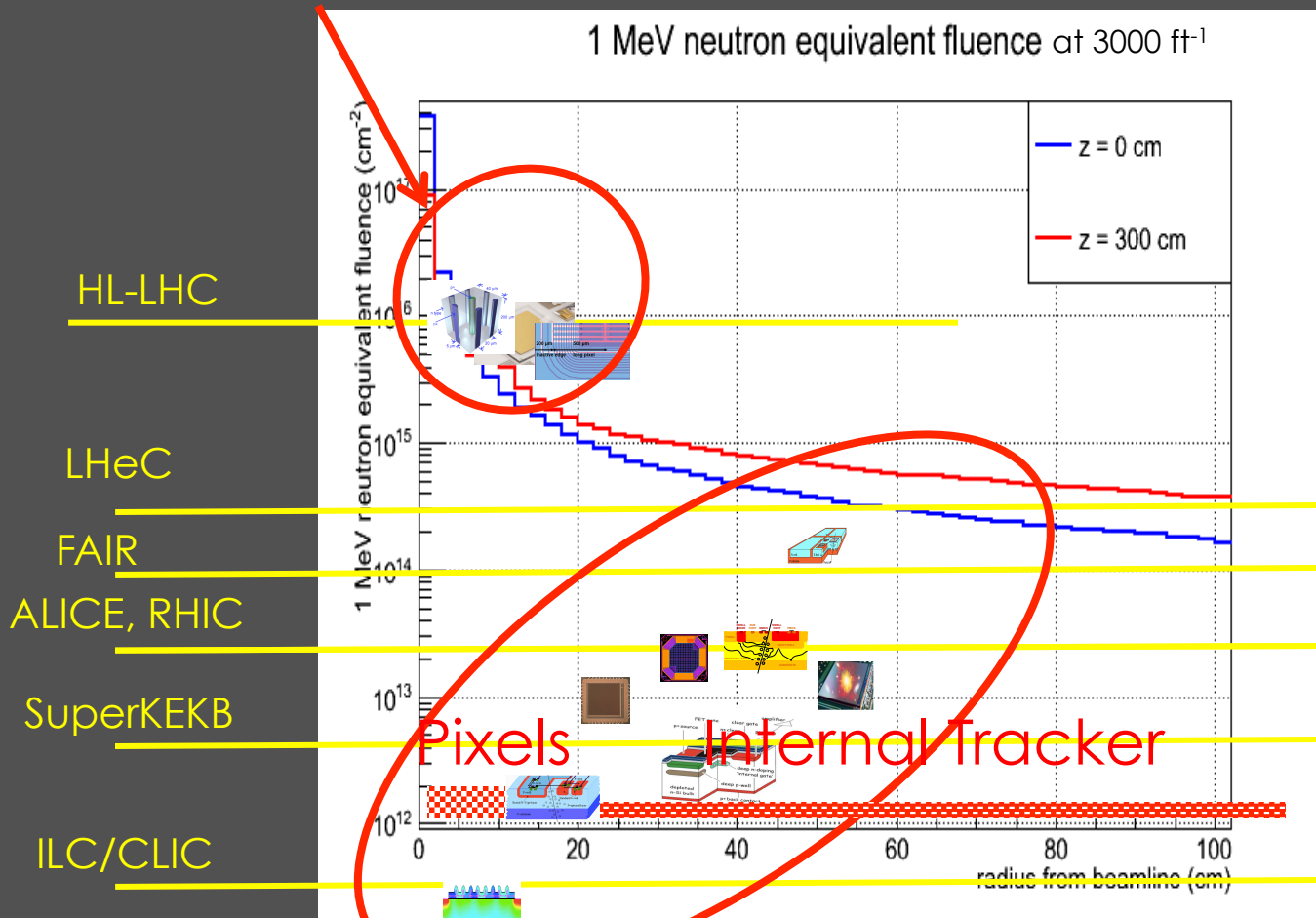
→ Invest on R&D on

- Monolithic
- 3D vertical integration



is there a link with the radiation hardness??

hybrid techniques →  
granularity yet to be improved

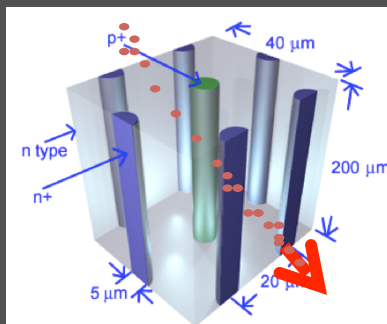
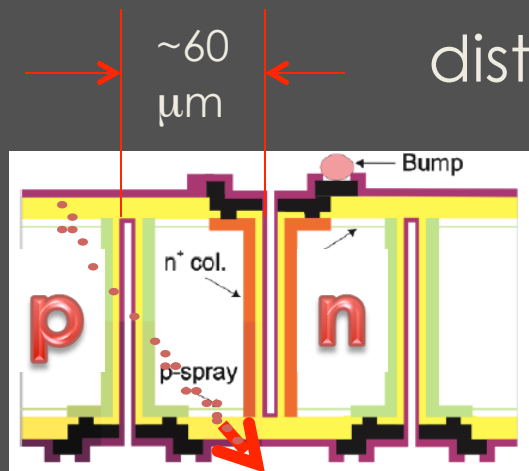


monolithic →  
inherently higher granularity

one shot on Rad Hard & hermeticity

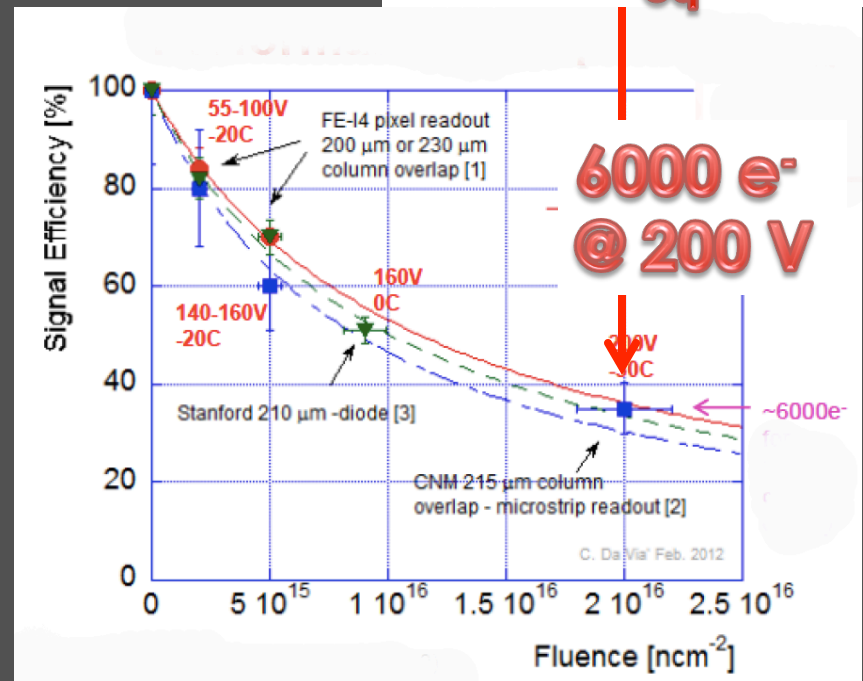
de facto: 2 morphologies

# 3D pillars: more recent technology



pillars can be positioned till the edges naturally edge-less  $\rightarrow$  hermetic

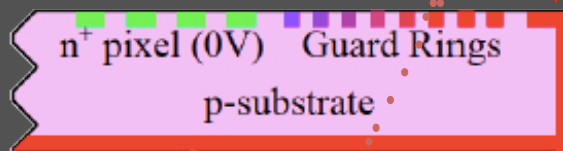
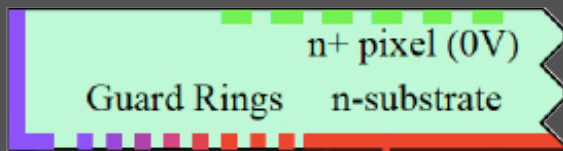
$2 \times 10^{16} \text{ n}_{\text{eq}} \text{ cm}^{-2}$



# one shot on Rad Hard & hermeticity

## de facto: 2 morphologies

### planar sensor

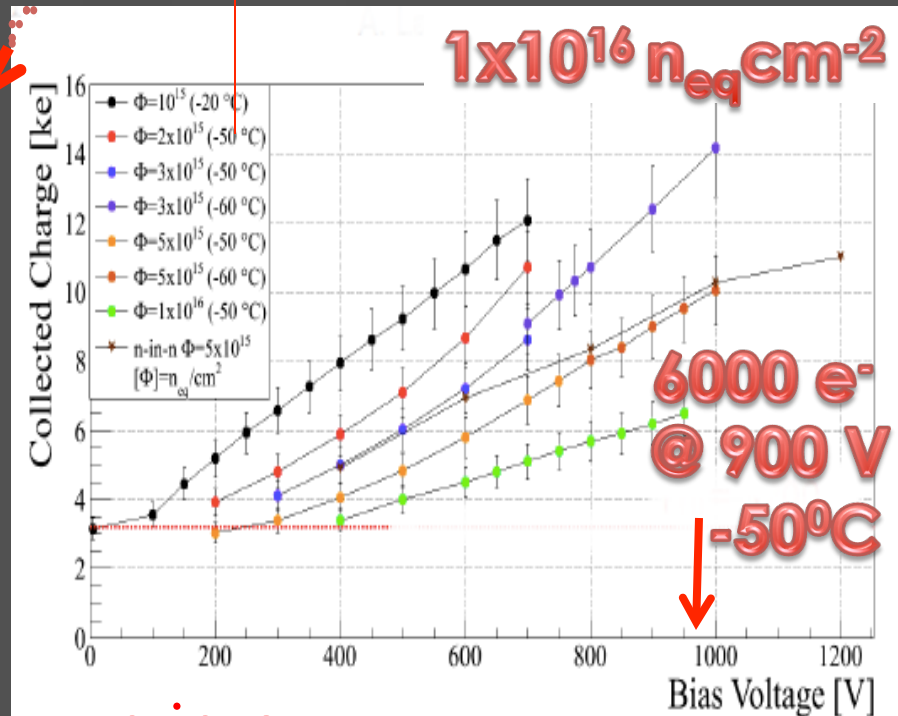


~few hundreds  $\mu\text{m}$   
distance  $\sim P_{\text{trapping}}$

0 Volt ← HV

P+ HV

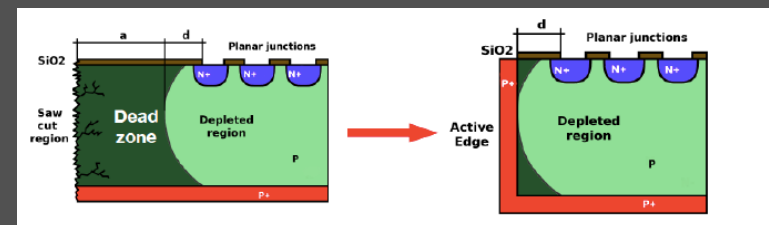
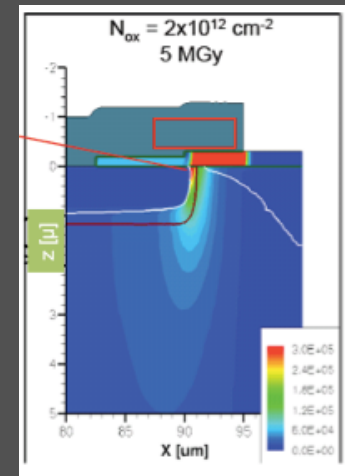
the high voltage dependence is a clear indication of an going amplification process !!



# fertile points of investigation

random order

- Solid simulation campaign
  - Charge amplification
  - Profound understanding of the aging mechanism “a la XFEL”
    - **simulation of the Oxide charge density**  
 $N_{ox}$  @ 0 and 5 MGy  
→ influence and changes of the E-field
  - Edge shape and field optimization





# fertile points of investigation

- Radiation hardness of monolithic pixels, to equip the outer layers of futuristic trackers
- Radiation hardness of on-detector electronics and supporting materials
- Interconnections of hybrid pixels and Si strips detectors  
*Through Silicon Vias, micro BB, Solid Liquid Inter Diffusion*

# Cerenkov-light based detectors for Particle IDentification and $\gamma$ -detection

crucial to identify hadrons & decay products in B-physics experiments

- High gain  $> 5 \cdot 10^5$  sometime inside B-field
- Very high time resolution  $\ll 100$  ps
- High detection efficiency (very few  $\gamma$  !)
- High rate stability (several MHz/cm<sup>2</sup>)
- Long lifetime

**sort of established tradition...**

large surface → gaseous  $\gamma$ -detectors

small surface → solid state  $\gamma$ -detectors (pitch  $\sim 50$   $\mu\text{m}$ )  
can be one can afford

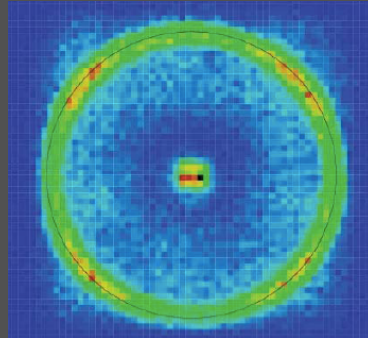
ALICE  
Belle2  
COMPASS  
LHCb  
PANDA  
SuperB  
.....

# change of tendency in this tradition... SiPM



T2K

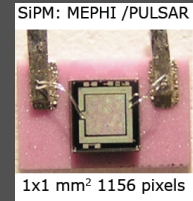
scintillators  
WLS fiber  
60000 SiPM



Belle2, PANDA  
RICHs  
single  $\gamma$   
with SiPM



CMS  
HCAL  
 $2 \times 10^3$  SiPM



ILC  
 $8 \times 10^6$   
SiPM

whoever uses the chains, RICH, DIRC, TORCH, TOP, TOF, scintillators + WLS in calorimetry or tracking is investing on R&D in SiPM-based devices

.....many, many groups that work independently!

# Outlook and reflections -1-



- in HEP the R&D on detectors and electronics is mainly done within large experiments!  
( 84% of FTE from the 2012 survey)

**BUT: none of the major detection techniques that we exploit today, were conceived within and for an “ad hoc” experiment.....**

# Outlook and reflections -2-



- R&D in HEP is much too much an “upgrade driven” effort, we risk to leave behind some technology!
- many fragmented efforts and duplications
- we work more and more close to industry (pixels, photo-detectors, electronics....), but not always we are the driven force!  
→ for long lasting applications or upgrade, one needs to carefully chose the technological nodes that will persist longer.