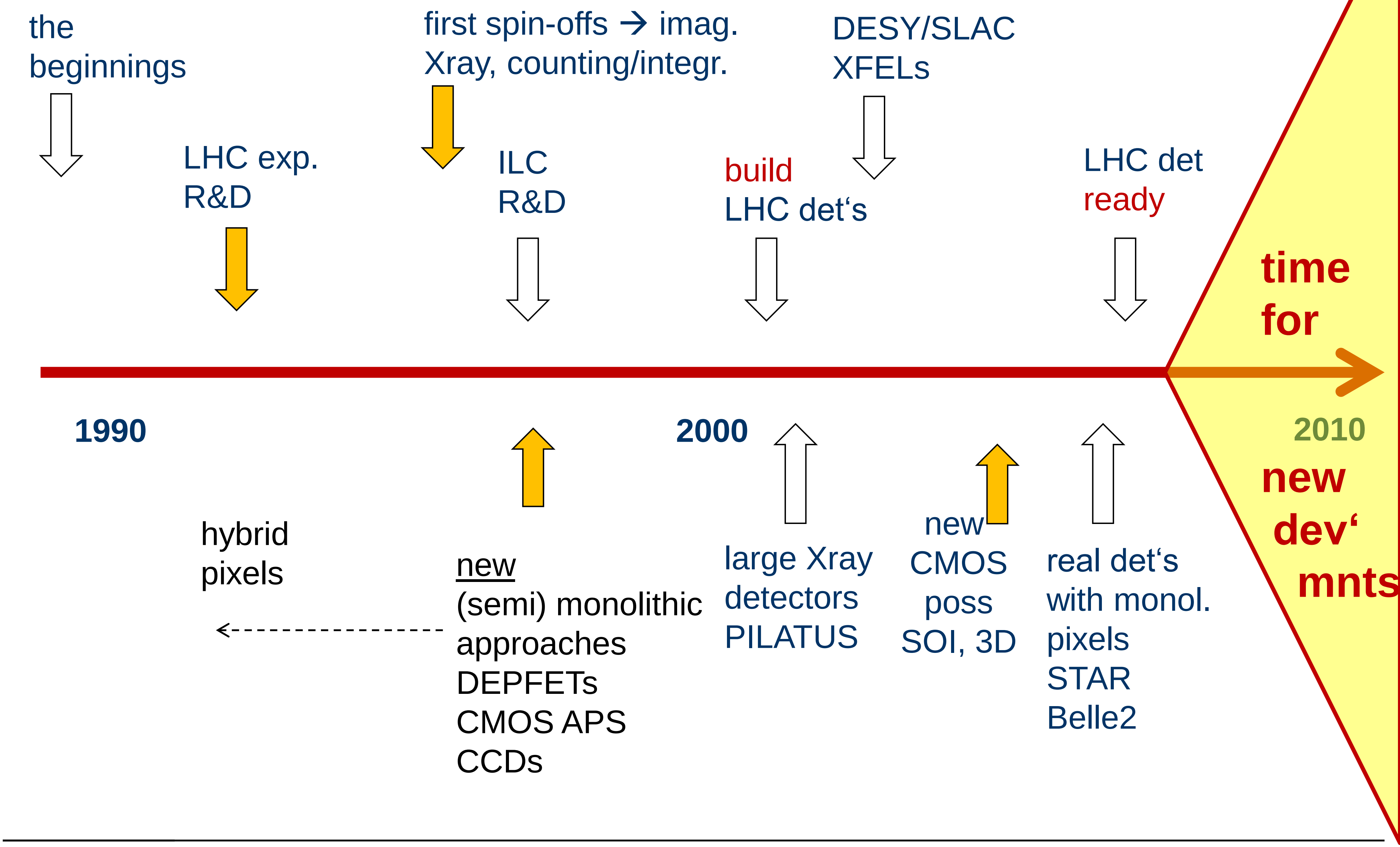
Pixel 2010

An attempt of a summary …

Norbert Wermes
Bonn University

… and apologies to those whose results I forgot or had to decide to drop in this “summary“

20 years of pixels … where are we now ? … my view



The new challenges

- Very high rates (i.e. sLHC)
  - → **need hybrid technology → 3D integration ?**
  - → **issues**
    - **radiation hardness and badwidth**
    - **material**
    - **size (area) → comp. materials**
- Somewhat lower rates (RHIC, SuperKEKB)
  - → **MAPS, DEPFET, etc.**
  - → **issues**
    - **complicated (but smaller) detectors**
    - **very low material budget**
- Imaging (Xray, synchr. light)
  - → **from light sources → XFELs**
  - → **issues**
    - **large photon flux → dyn. range**
    - **large frame rates**
    - **homogeneous response**

Rate and radiation challenges at the innermost pixel layer

Hybrid Pixels

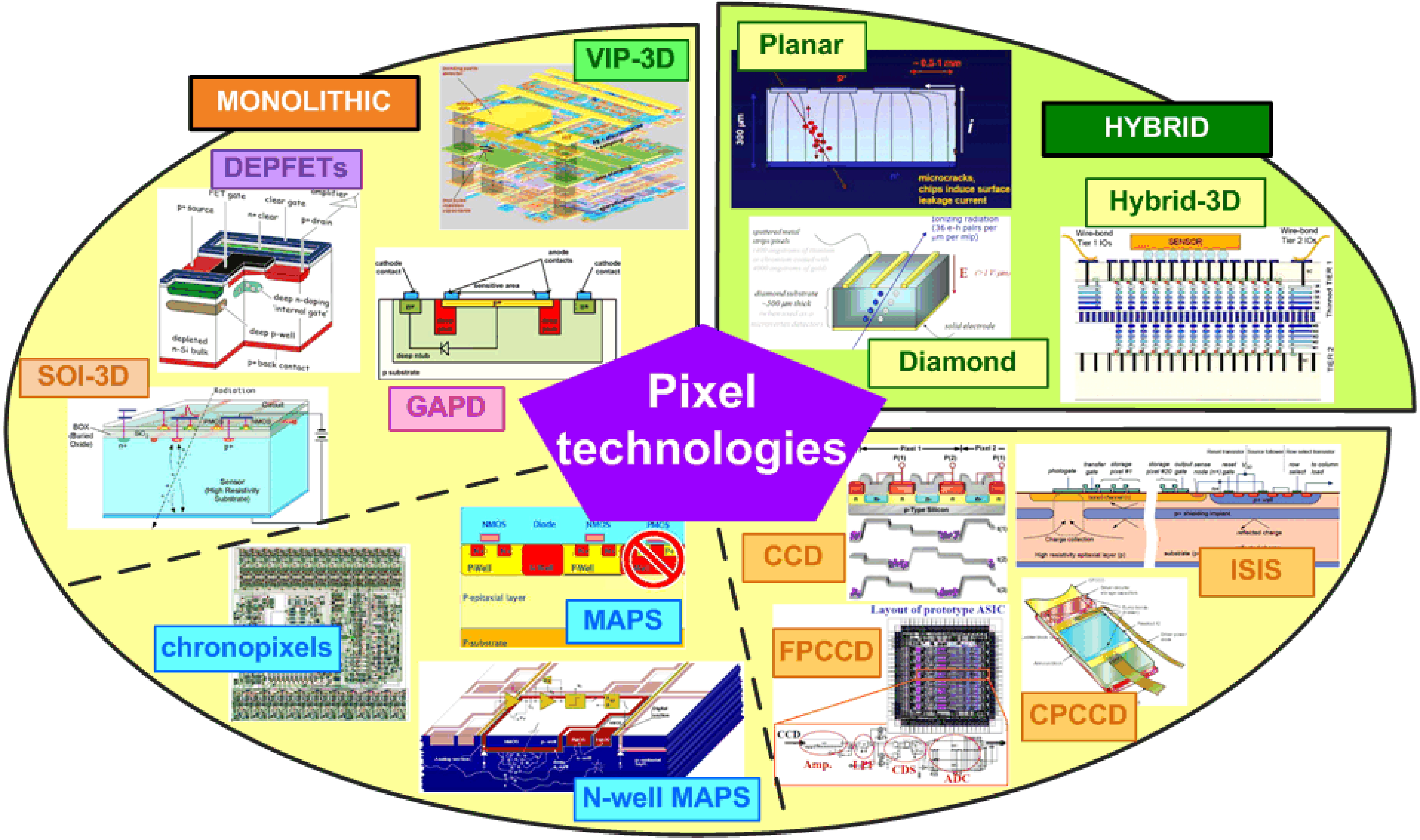
	BX time	Particle Rate	Fluence	Ion. Dose
	ns	kHz/mm^2	n_{eq}/cm^2 per lifetime*	kGy per lifetime*
LHC (10^{34} cm^{-2}s^{-1})	25	1000	1.0×10^{15}	790
sLHC (10^{35} cm^{-2}s^{-1})	25	10000	10^{16}	5000
SuperKEKB (10^{35} cm^{-2}s^{-1})	2	400	$\sim 3 \times 10^{12}$	50
ILC (10^{34} cm^{-2}s^{-1})	350	250	10^{12}	4
RHIC (8×10^{27} cm^{-2}s^{-1})	110	3,8	1.5×10^{13}	8

Monolithic Pixels

- **lower rates**
- **smaller pixels**
- **less material**

assumed lifetimes:
LHC, sLHC: 7 years
ILC: 10 years
others: 5 years

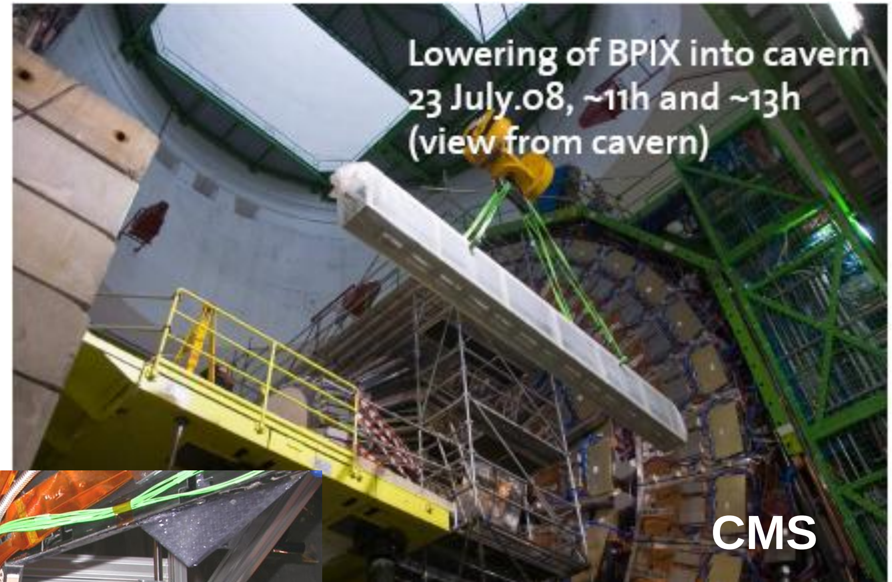
The variety of pixel technologies

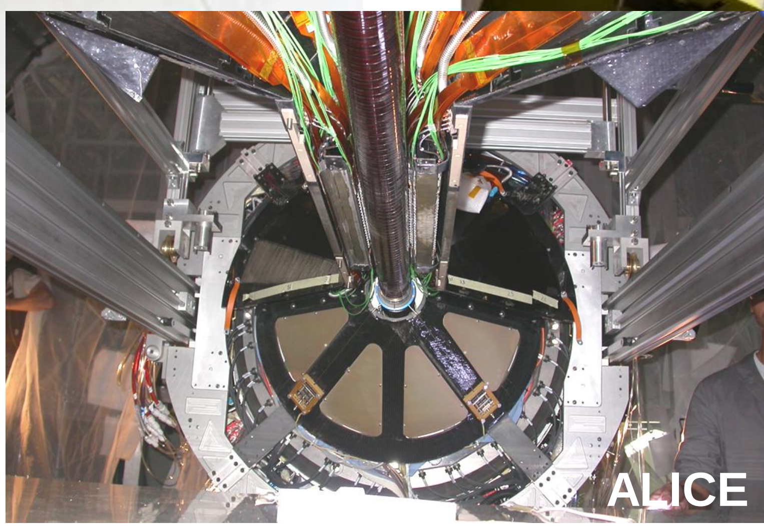


from Anna Arbat

First impression from PIXEL 2010 on Monday …

The big LHC detectors are marvelously working





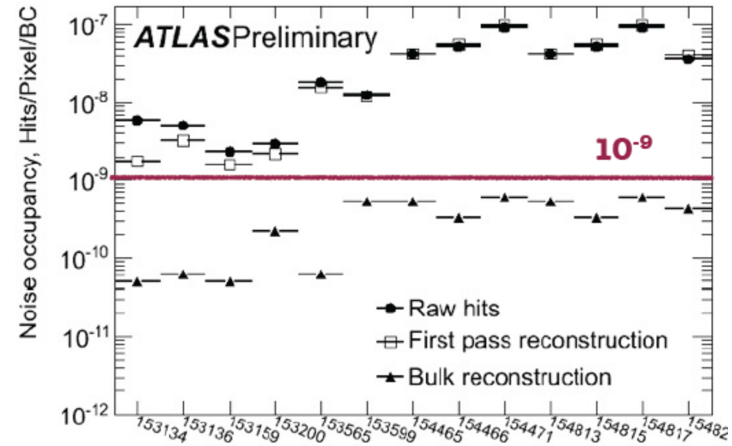
Joshua Moss
Markus Keil
Lidia Dell'Asta

Gino Bolla
Ben Kreis
Urs Langenegger

Petra Riedler

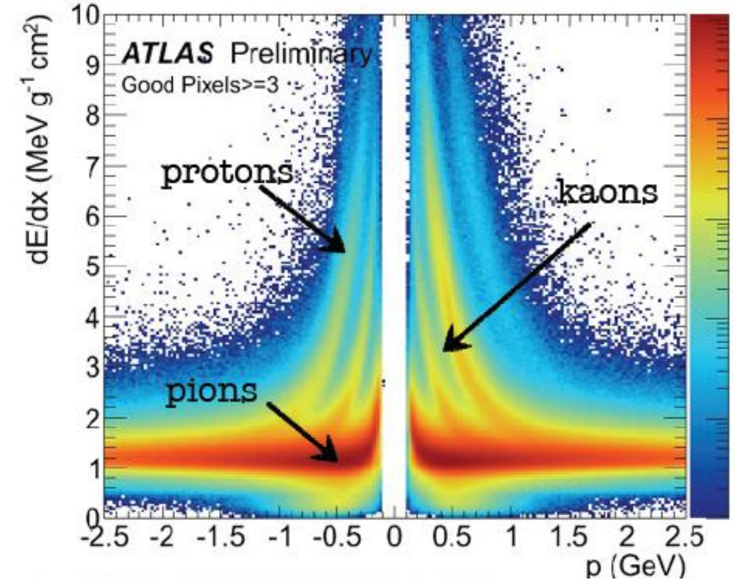
… the big LHC detectors

- essentially noiseless
  < 0.2 noise hits per event (after masking)



Lidia Dell'Asta

- high trigger rate cap. (to 80 kHz)
  @ modest thresholds (≥ 3000 e^-)
  high overall efficiencies (~99%)
  (Ben Kreis, Markus Keil)
- excellent charge resolution



- bad: material in ATLAS & CMS

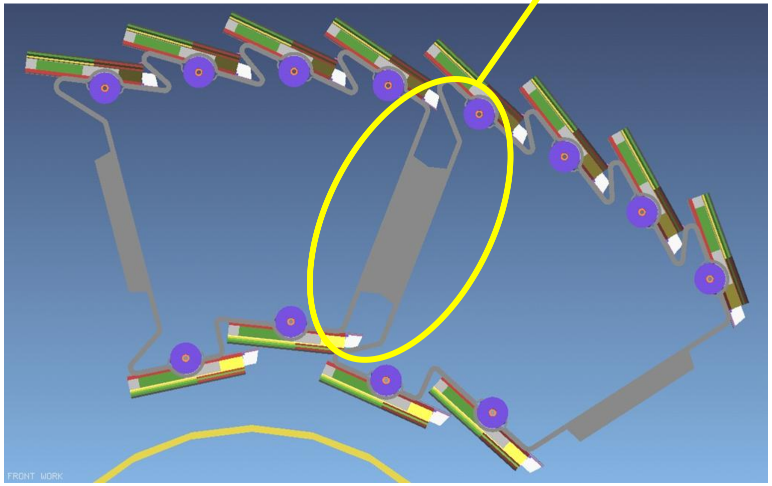
  >3% x/X_0 per layer

  - operation < 0^0 C
  - hybrid technology
  - first of their kind (parallel powering, copper, …)

except ALICE …

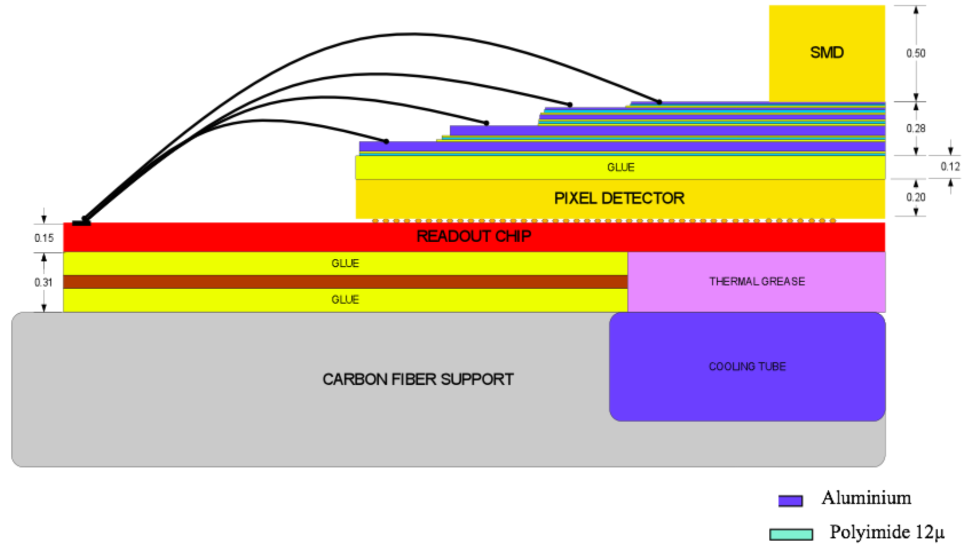
1.1 % x/X_0

not counted !



but also …

- **1.75 cm² chip with bumps → 150 µm !**
- **sensor 200 µm !**
- **advanced Al flex !**



because heavy ion collisions <u>can afford</u>

- **to not have homogeneous coverage**
- **to operate at room temperature ($L \sim 10^{27}\ cm^2\ s^{-1}$)**
- **to repair (have a bit easier access)**

Petra Riedler

… and … something to think about … spatial resolution

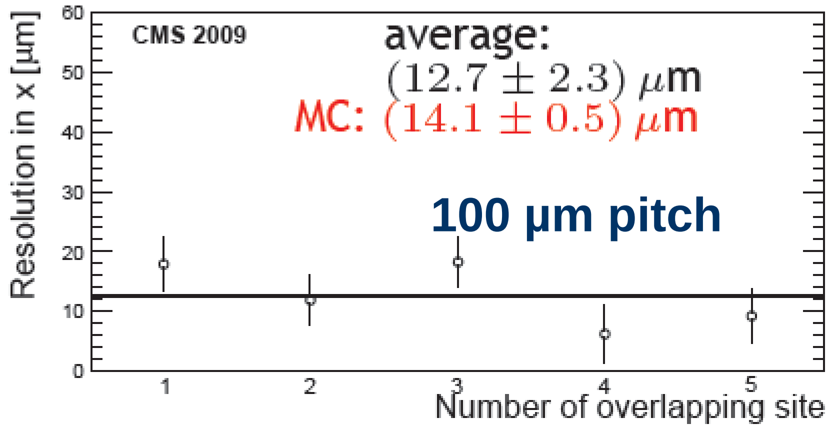
ATLAS CMS

- **need decide … little** (more signal after rad.) **or more charge sharing** (better interpolation)
  tune by Lorentz angle and module tilt

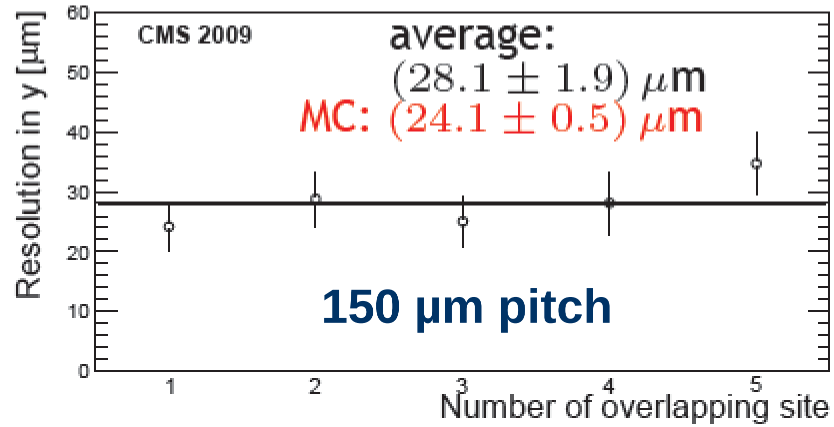
- ATLAS: 25 µm (quoted incl. tracking error) will become < 10 µm with 50 µm pitch
  CMS: 12.7 µm with 100 µm pitch !!

Urs Langenegger

100 µm/√12 ≈ 30 µm



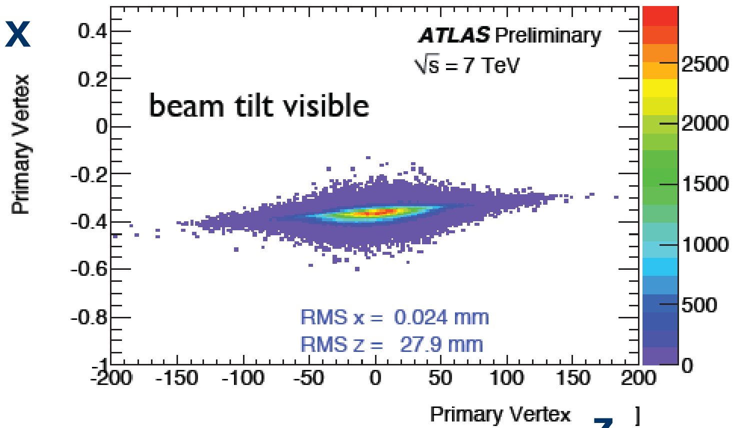
100 µm/√12 ≈ 45 µm

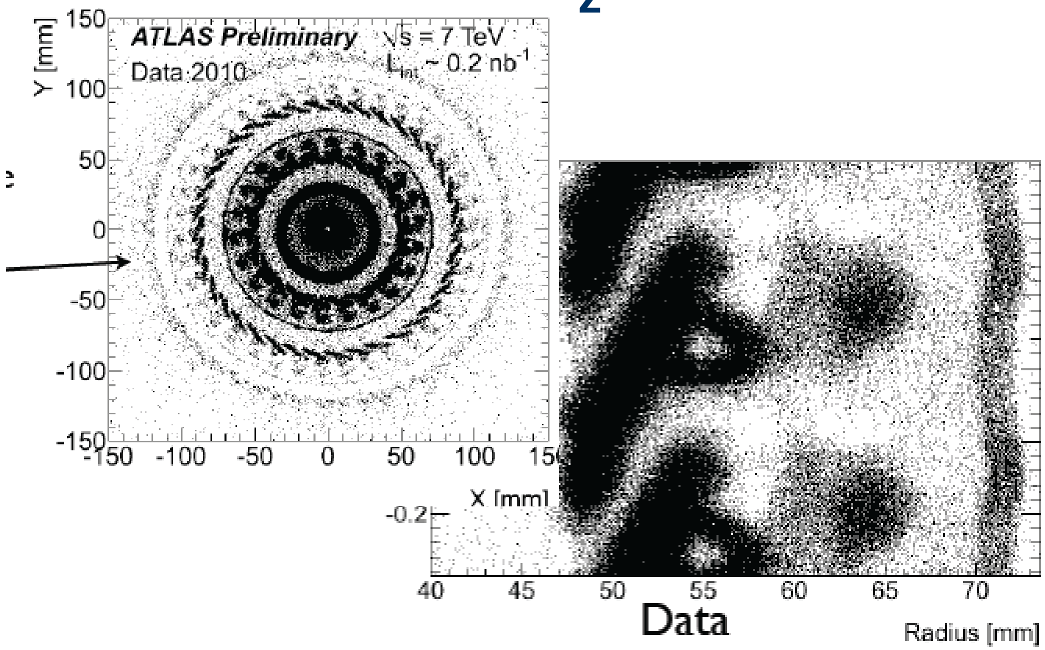


CMS will pay when radiation damage requires more V_{bias} (also demonstrated by Tilman Rohe): higher field, less mobility, less Lorentz angle → less charge sharing

… and the data are beautiful

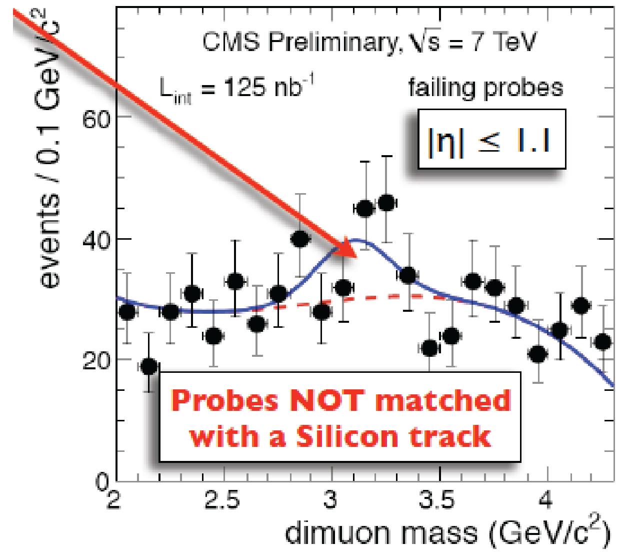
ATLAS: Florian Hirsch



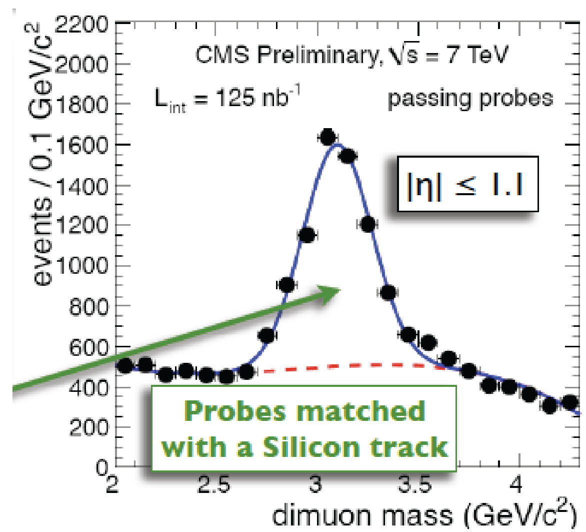


CMS: Mauro Dinardo

w/o tracker



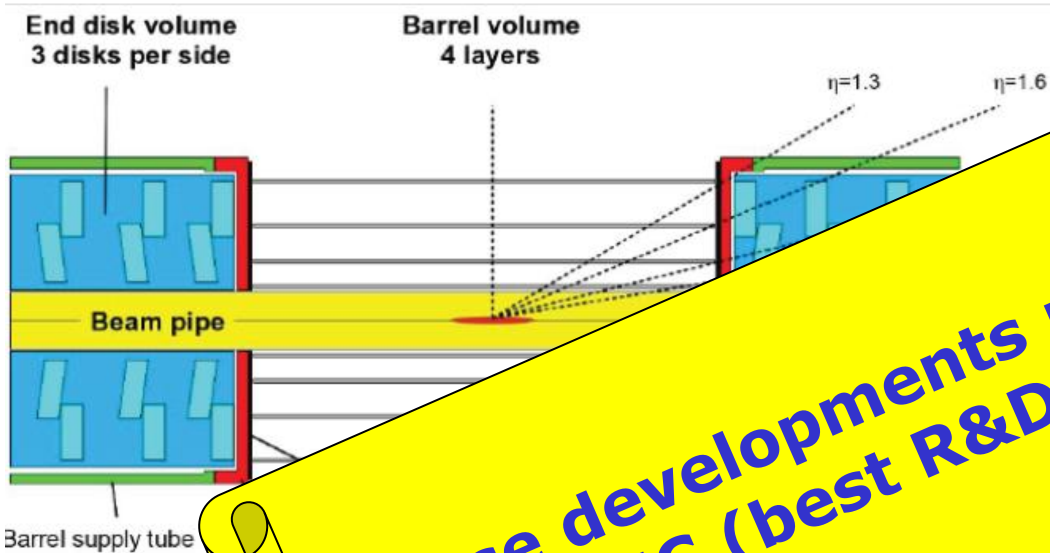
with tracker



… get ready for upgrades and sLHC

- **must be hybrid pixels again (rate and radiation)**
- **work on material budget !**

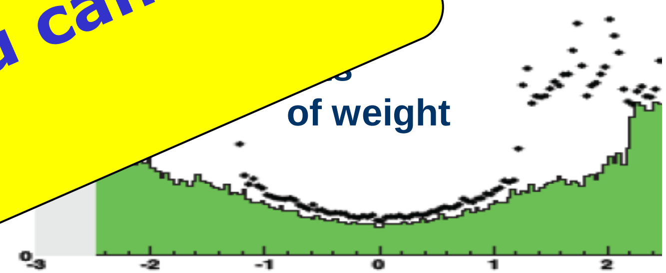
Alice Bean
Fabian Hügging



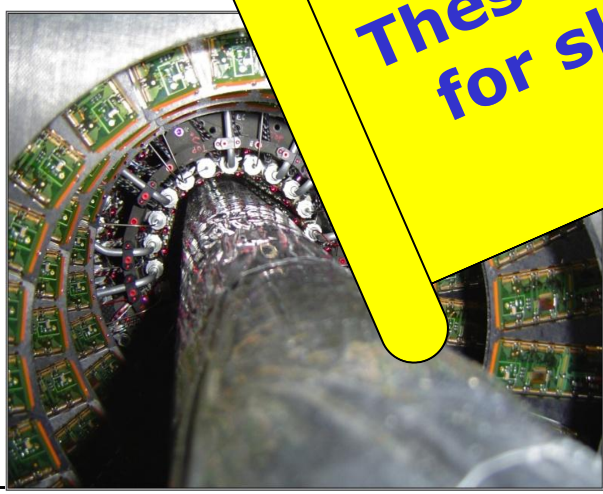
CMS

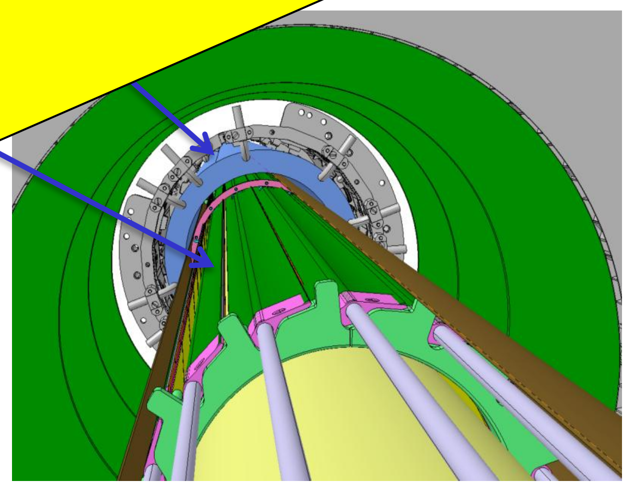
…ers, 3 new disks
…re buffers)
…und structure

of weight



These developments pave the way for sLHC (best R&D you can do)

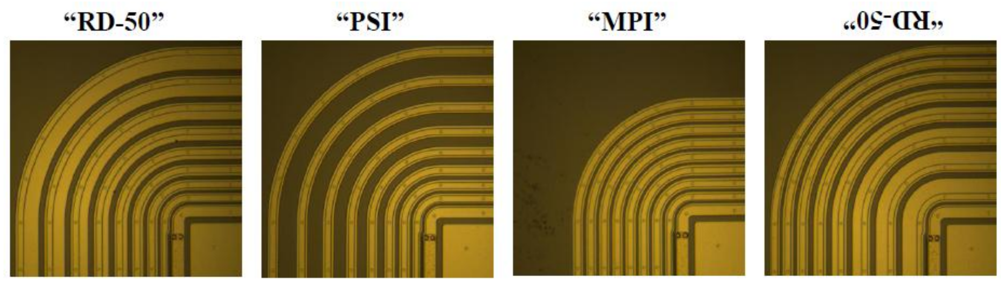




ATLAS
insert new innermost layer
FE-I4 chip ready (> 2 cm^2)
light weight structure
new sensor types
extreme IC thinning
➔ 1.5 % x/X_0

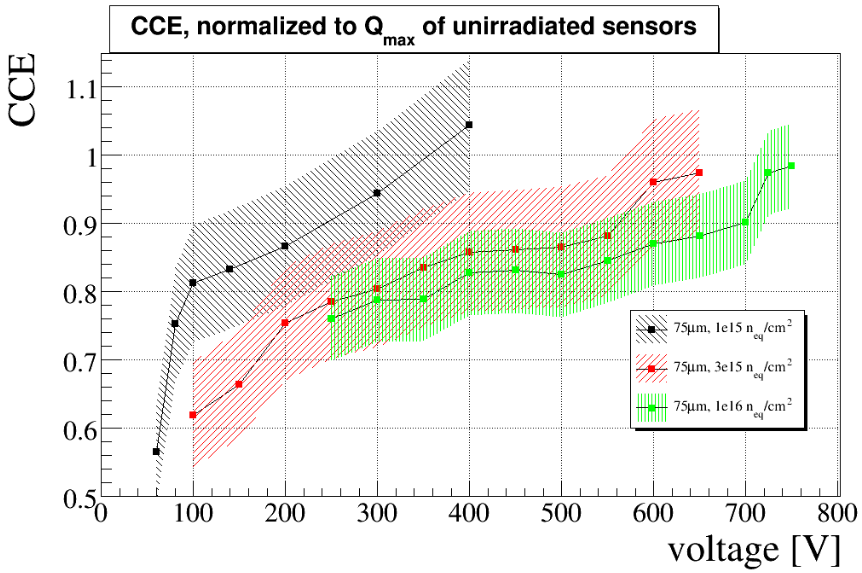
… which sensor to take best?

- **CMS:** **use the same type (planar n in n) as used so far**
  but take care of resolution degradation (Tilman Rohe)
  … perhaps consider 3D (Enver Alagoz)
- **ATLAS:** **study**
  - **thin planar n in n CiS (Daniel Münstermann)**
  - **thinned planar n in p (SOI process) (Anna Macchiolo)**
  - **thin planar n in p Hamamatsu (Nobu Unno)**
  - **planar n in p Micron (Ilya Tsurin)**
  - **various (slim) guard ring schemes**



  - **3D sensors (Andrea Micelli)**
  - **diamond sensors (Matt Hollingsworth → telescope)**
- **The issues:** **planar:** best understood, cheaper (specially n in p), needs very high voltage after high irradiation
  3D: lower drift distance, low $V_{dep,}$ large active area, efficiency in column, capacitance/noise, production yield
  diamond: low C, no i_{leak}, exc. therm. prop., … can one make them in large quantities?

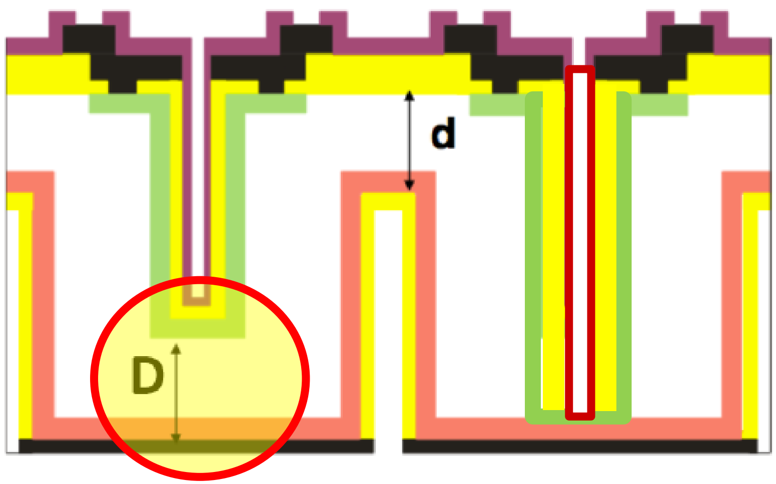
… planar or 3D silicon



Anna Macchiolo

thin (75 µm) planar Si sensors seem to stand 10^{16} n_{eq}/cm^2 with little loss of CCE at not too prohivitive voltages probably due to charge multiplication
… but is 6000 e^- enough?

FBK/CNM **Stanford/SINTEF**



Andrea Micelli

columns through or not through ?

inefficiency for straight tracks

leaves depleted part under column, but region of inhomogenous fields

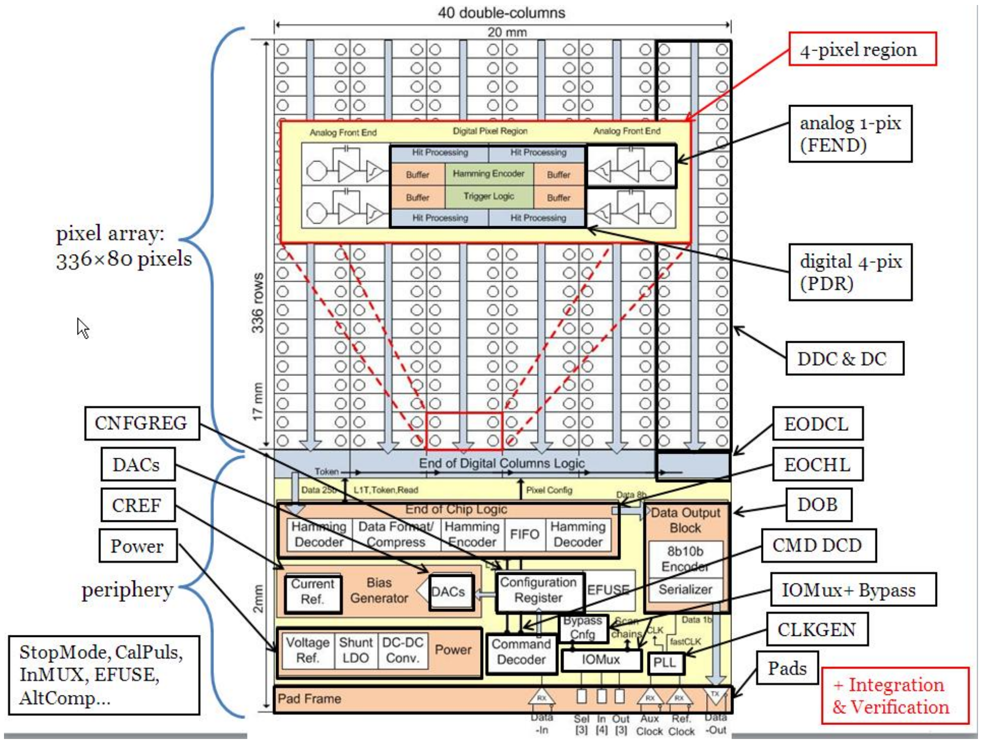
note: tracks are inclined
still: have to establish reliable production

… new tricks … to cope with high luminosity

FE-I4 Chip for ATLAS pixels **Marlon Barbero**

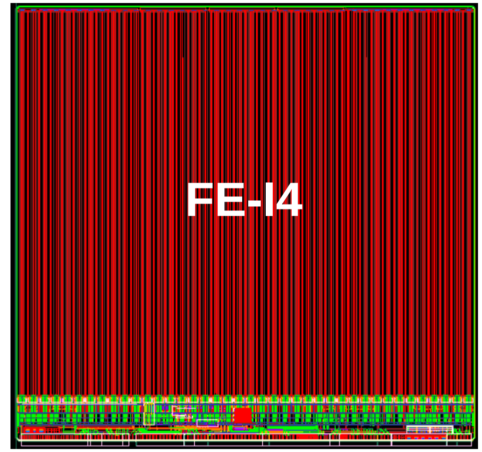
(large design effort, several groups)

many gadgets:
local hit storage until trigger
better clustering info
use against time walk …

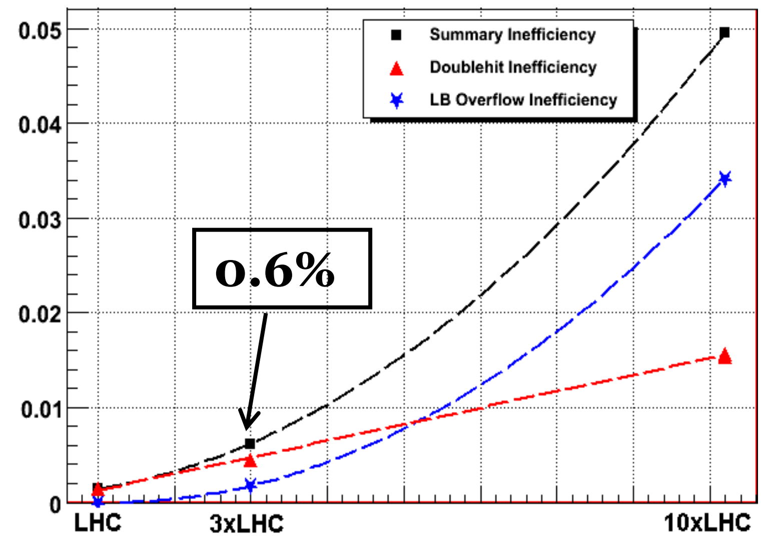


20.2 mm

16.8 mm



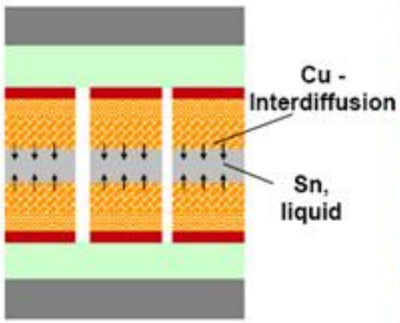
5%



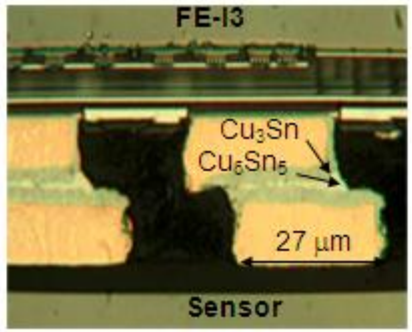
CMS: new chip in planning, more buffers
less vulnerable for losses in column drain

… aggressive addressing of the material budget

exploit: 3D integration for hybrid pixels, through silicon vias, wafer to wafer connection



Contact under Pressure
and Heat
~ 5 bar, 260 – 300 °C (Sn-melt)



Formation of
Eutectic Alloy;
T_{melt} > 600 °C

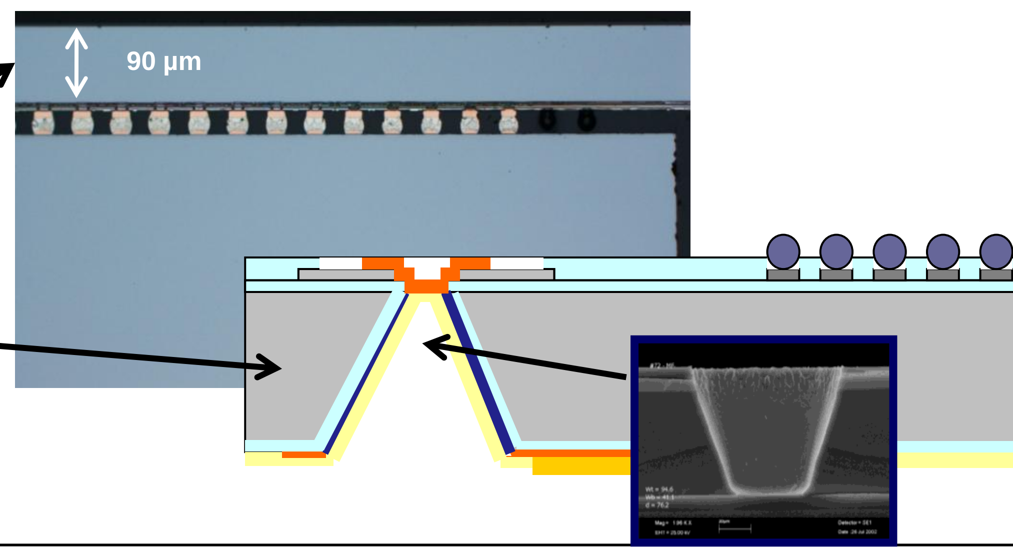
SLID
(IZM Munich)

Anna Macchiolo

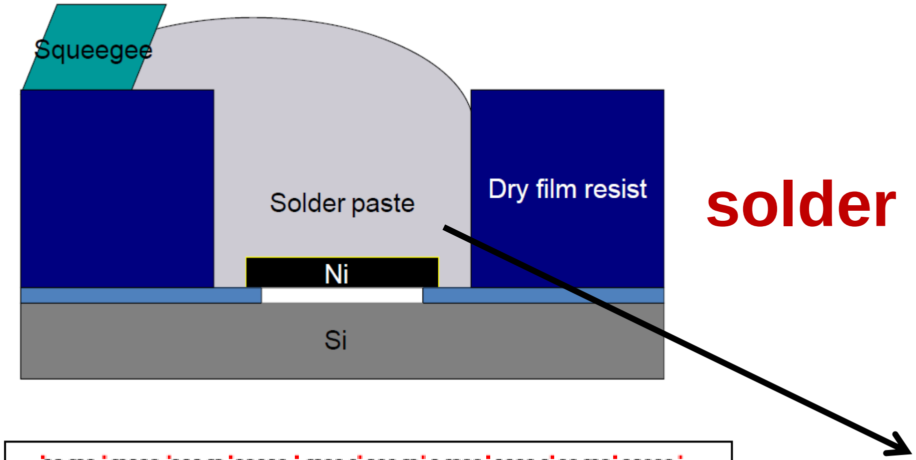
Laura Gonella

gain ~ 1% x/X_0 in ATLAS with

- **90 µm bumped FE-I4 chip**
- **thin Al flex**
- **serial powering**
- **TSV and backside metal routing**

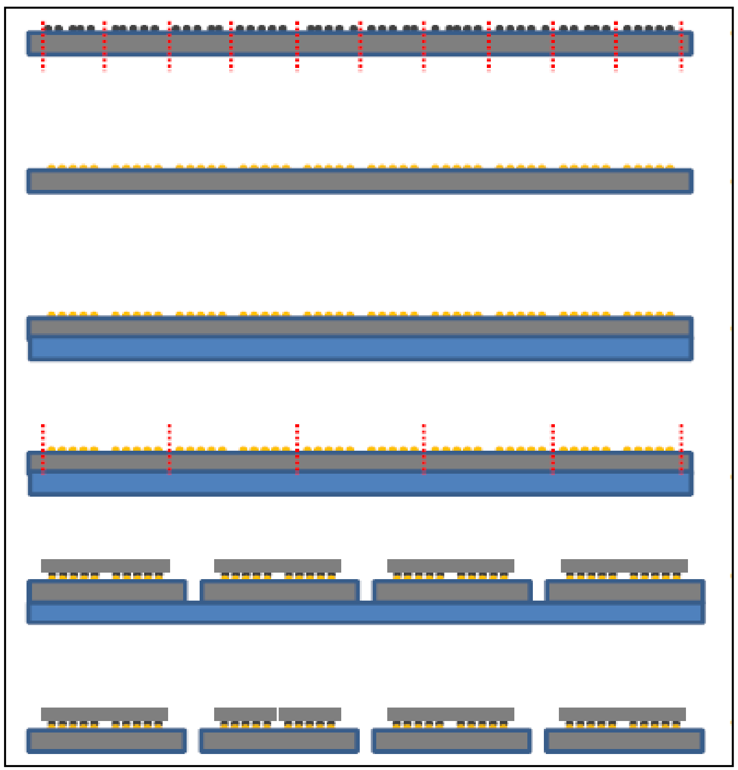


… and low budget for large trackers, e.g. @ sLHC



Thomas Fritzsch

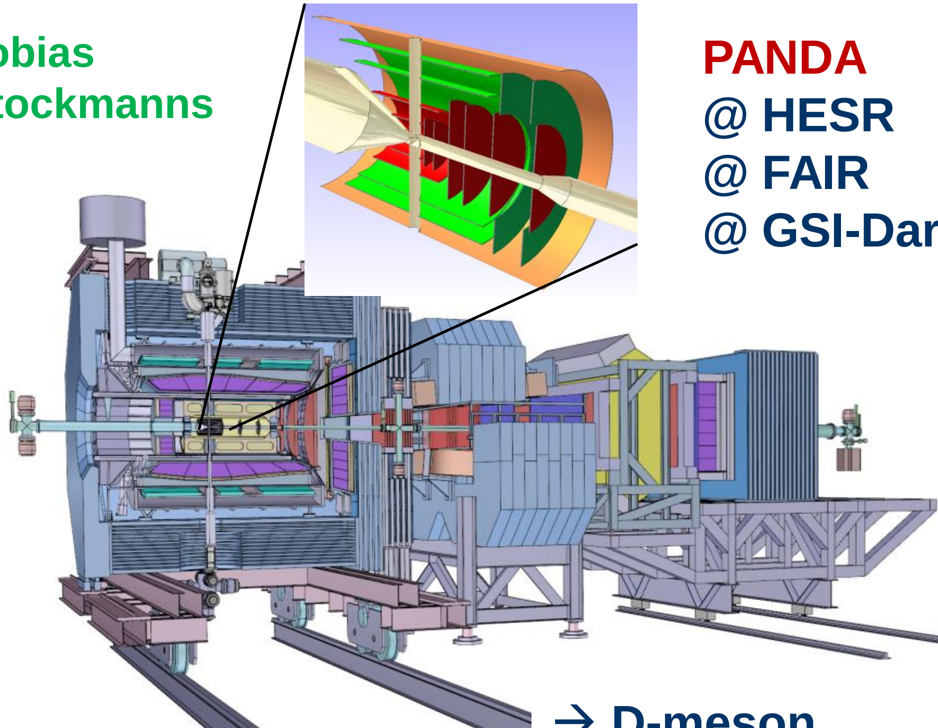
solder pasting (rather than electroplating)



chip to wafer FLIP-Chip assembly

… good experience in hybrid pixels … now used elsewhere

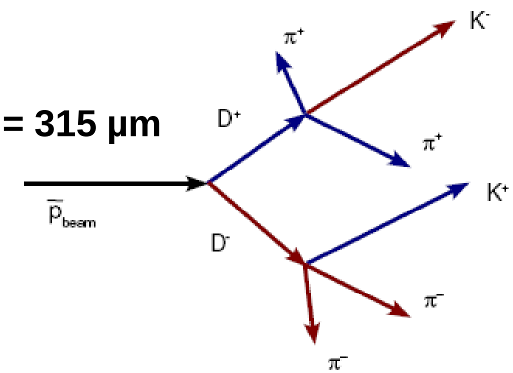
Tobias Stockmanns



PANDA
@ HESR
@ FAIR
@ GSI-Darmstadt

→ D-meson tagging
<2% x/X_0
no trigger

$c\tau$ = 315 µm

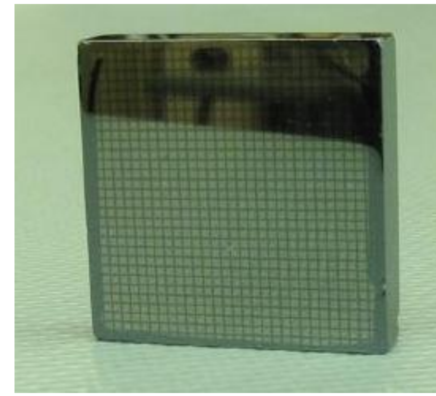


→ ATLAS-like modules
dedicated chip
epi-Si

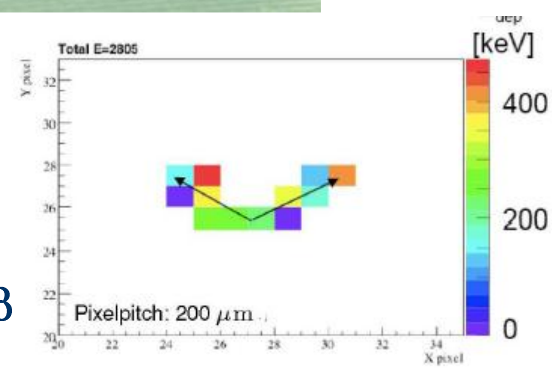
Maria Schwenke

COBRA @ Gran Sasso

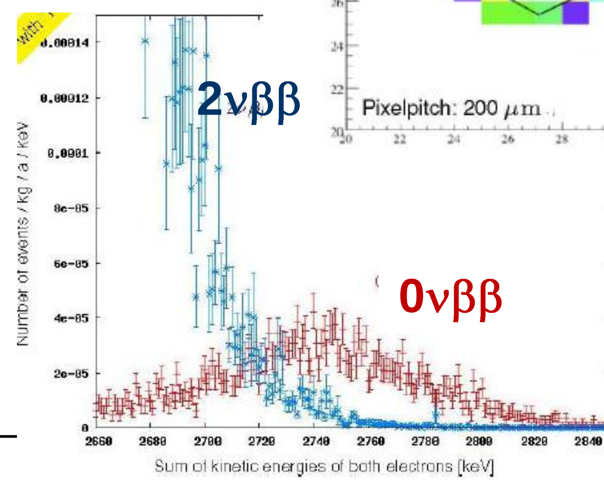
CZT



$0\nu\beta\beta$
search



use ^{116}Cd

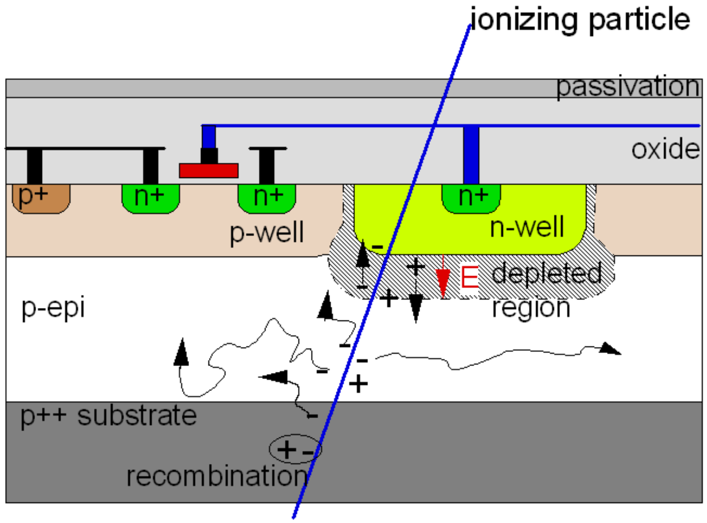


Timepix readout

New generation semi-monolithic pixel detectors have become reality …

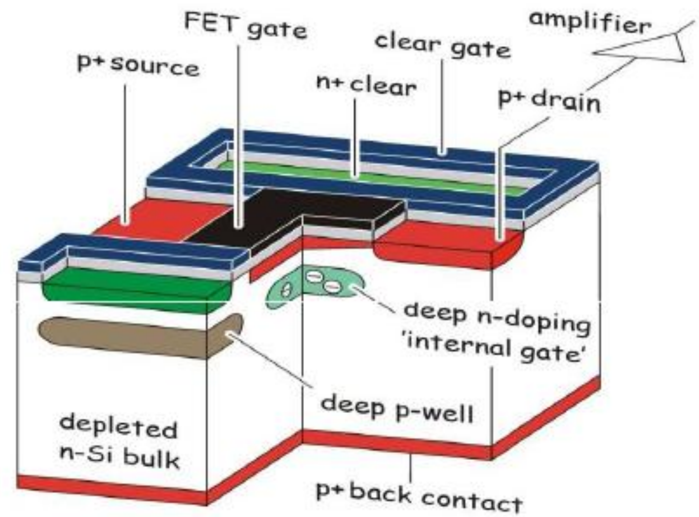
… as Vertex Detectors in big experiments (both ready ~2013)

MAPS → STAR @ RHIC



Q coll. in epi layer → small sig.
MOS circuitry in active area (low noise)

DEPFET → Belle 2 @ superKEKB



amplif. MOSFET in every pixel

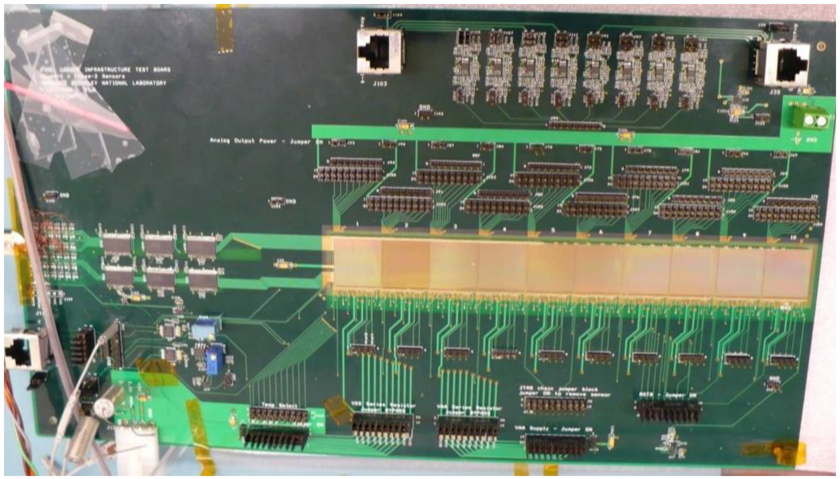
tot. area
0.16 m²

Leo Greiner
Andrei Dorokhov

- + **no bump bonding**
- + **very thin (50 μm resp. 75 μm) → ~0.2% x/X_0**
- + **small pixels (20x20 resp. 50x50 μm²)**
- + **low power → less cooling**
- – **radiation hardness**
- – **speed**

tot. area
0.014 m²

Carlos Marinas



TB with thinned 50 μm sensors is ready for testing

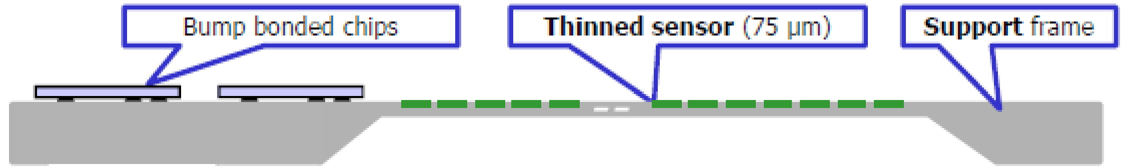
Pointing resolution	$(12 \oplus 19GeV/p{\cdot}c)$ μm
Layers	Layer 1 at 2.5 cm radius Layer 2 at 8 cm radius
Pixel size	20.7 μm X 20.7 μm
Hit resolution	6 μm
Position stability	6 μm rms (20 μm envelope)
Radiation length per layer	X/X_0 = 0.37%
Number of pixels	356 M
Integration time (affects pileup)	185.6 μs
Radiation requirement	20 to 90 kRad $2{*}10^{11}$ to 10^{12} 1MeV n eq/cm^2
Rapid detector replacement	< 8 Hours

DEPFET PXD @ Belle 2

Carlos Marinas

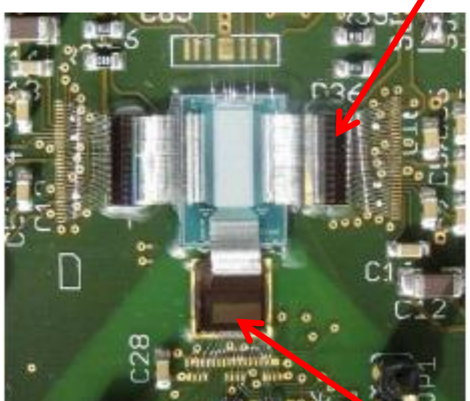
2-layer pixel vertex detector (PXD)

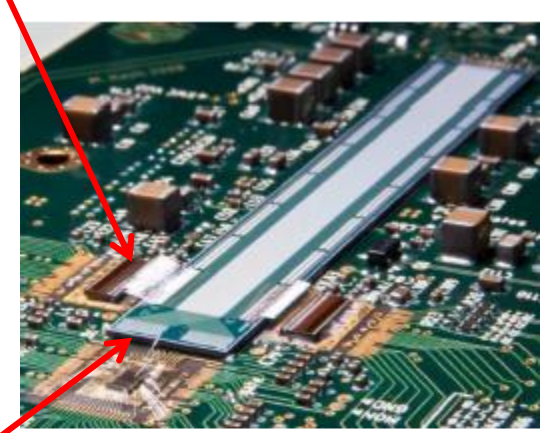
thinned by backside etching, leaving a frame

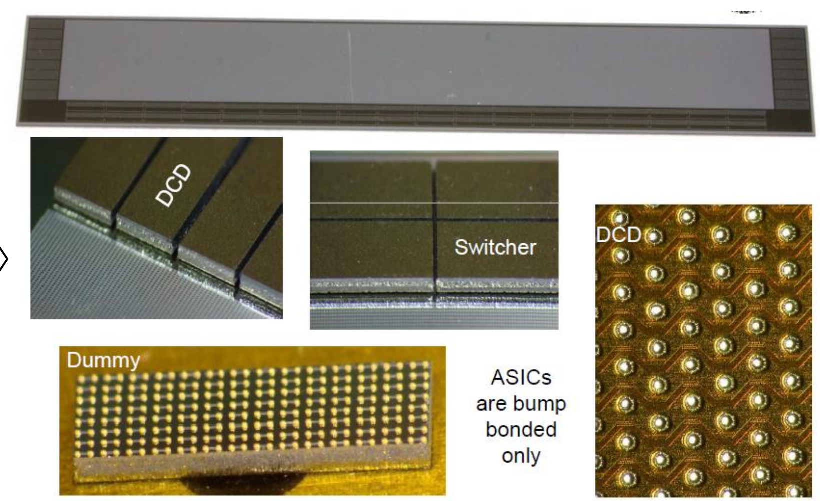


…. on their way to the final module
sensor + switcher + DCD + DHP

ladder control ICs

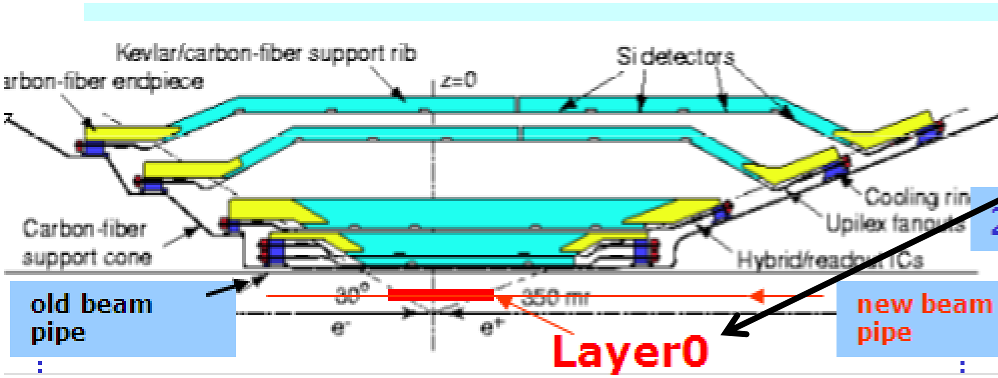






R/O ICs

… and SuperB …



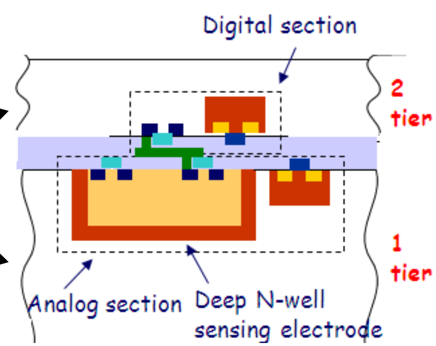
Giuliana Rizzo

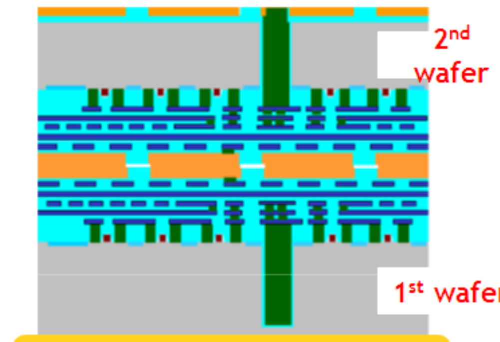
options
CMOS MAPS
or
3D MAPS (2 tiers)
or
3D hybrid pix (2 tiers)

3D – 2 tier - stack

dig

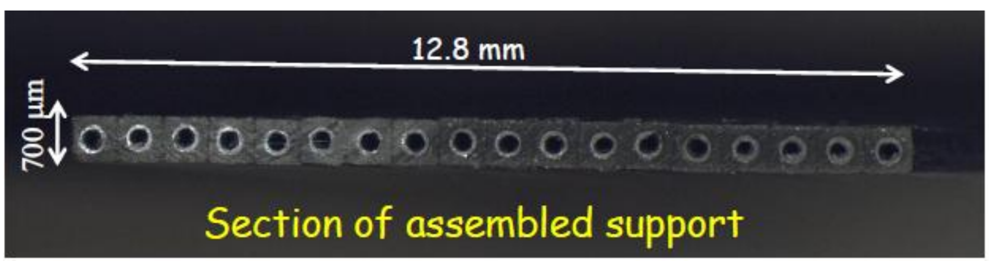
ana



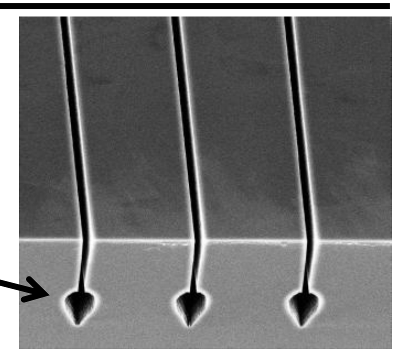


Filippo Bosi

HTC ~ (hydraulic diameter)$^{-1}$



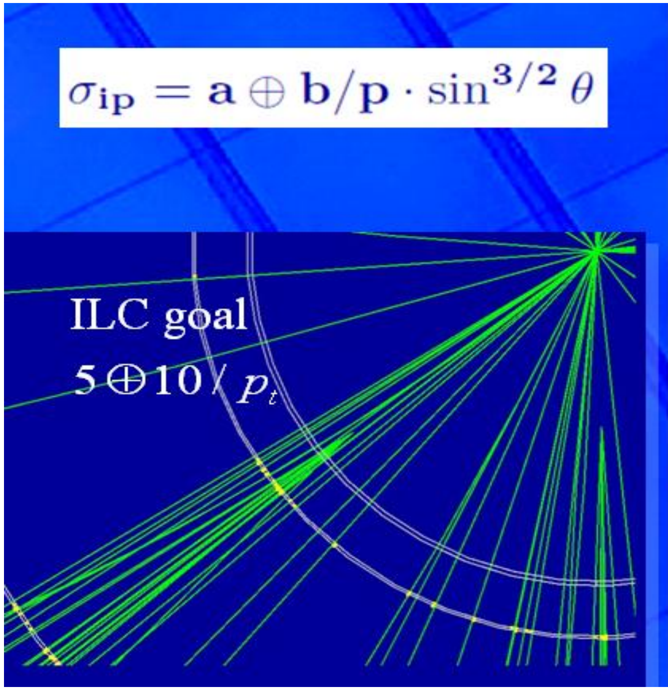
micro tubing
micro channels

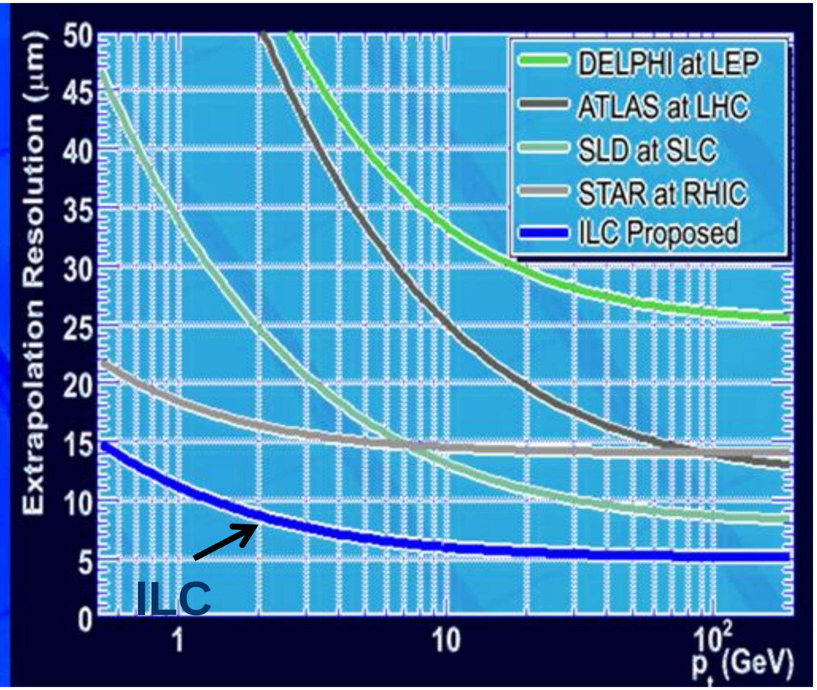


first experience
encouraging

… and for ILC …

… the best possible is just good enough to meet the goals



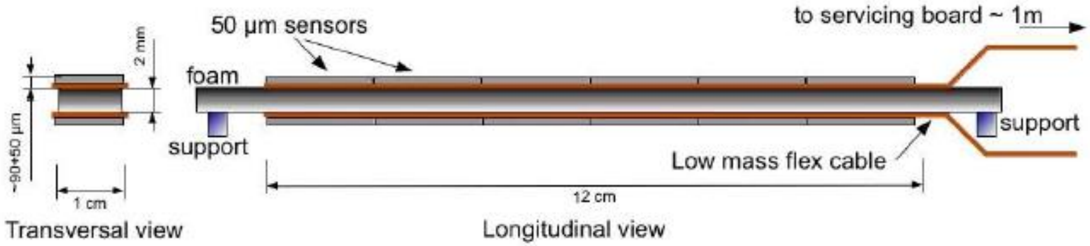


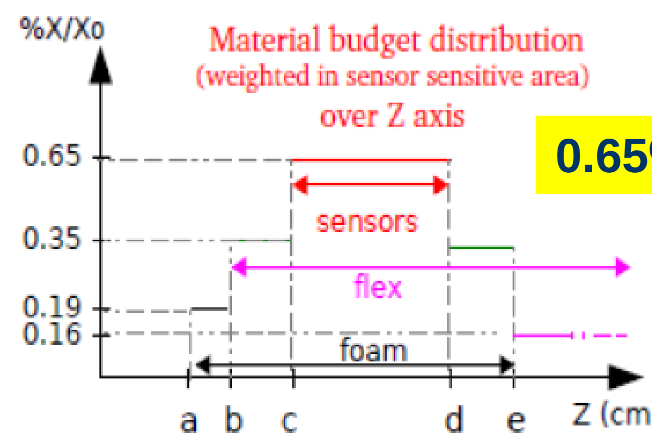
~50 μm Si thickness

0.1% x/X_0 per layer

~2μm space res.

plume ladder (ultra light) (Andrei Nomerotski)

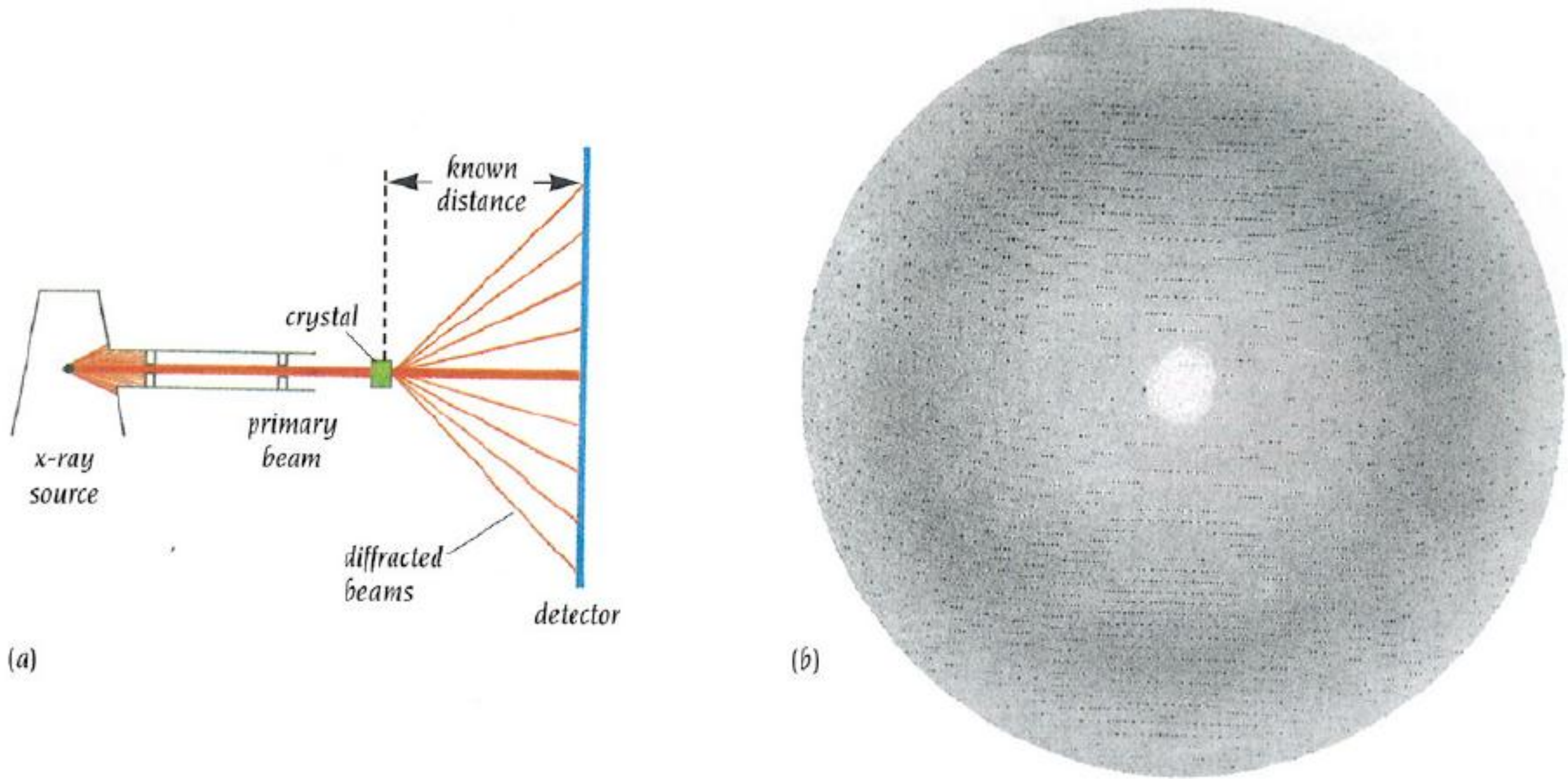




0.65%

Imaging

… a big step in Synchroton Light Imaging expts. ….



Bragg pattern
derive the atomic e- density

from Clemens Schulze - Briese

What they need … from SL-sources to XFELs

(simplified)

- count rates per pixel > MHz
- high frame rates (100 Hz – 10 kHZ → 5 MHz)
- huge dynamic range (1 photon to 10^6 photons)
- pixel size < 50 µm
- seamless detectors
- “no“ dead time

→ hybrid pixels with counting R/O chips (as compared to Imaging Plates, CCDs, et al.) have improved the imaging possibilities enormously.

→ pn frame CCDs (first images at XFELs) → DEPFET arrays

Clemens Schulze - Briese

PILATUS 6M

**from 15-16 bit (CCD)
to 20 bit dynamic range**

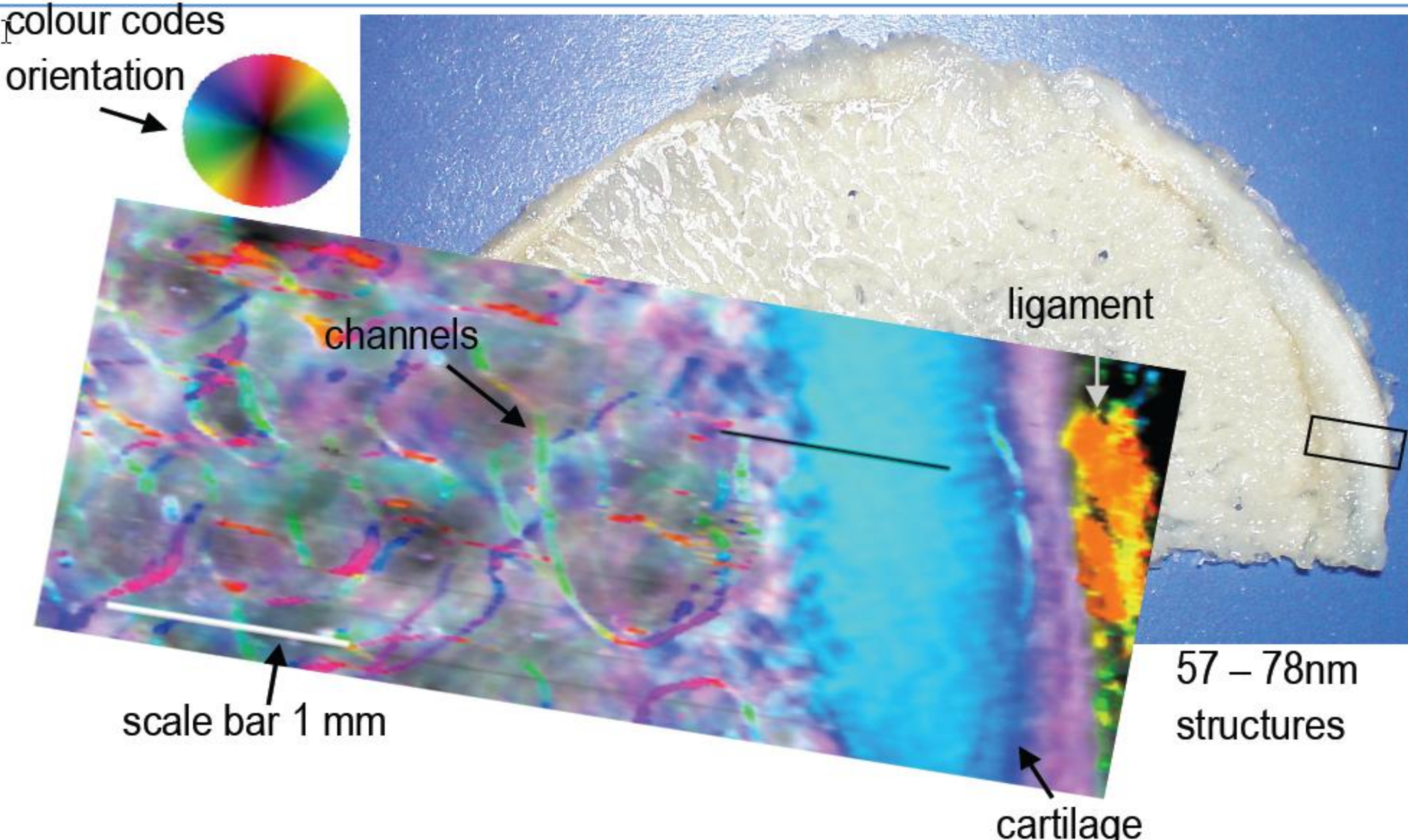
**a number of important
new possibilities**

- ➯ Continuous shutter-free data acquisition
- ➯ Fine φ-slicing in continuous mode
- ➯ Possibility to take high redundancy, low exposure data
- ➯ Simultaneous collection of low and high resolution data
- ➯ Diffuse scattering experiments
  T. Weber et al., J. Appl. Cryst. (2008), 41, 1
  A. Bosak et al., PRL **103**, 076403, (2009)
- ➯ Room temperature data collection with less radiation damage

max. count rate ~ several MHz/pix
frame rate 12.5 Hz, 3ms dead time

Clemens Schulze - Briese

Human femoral head: area with thick cartilage

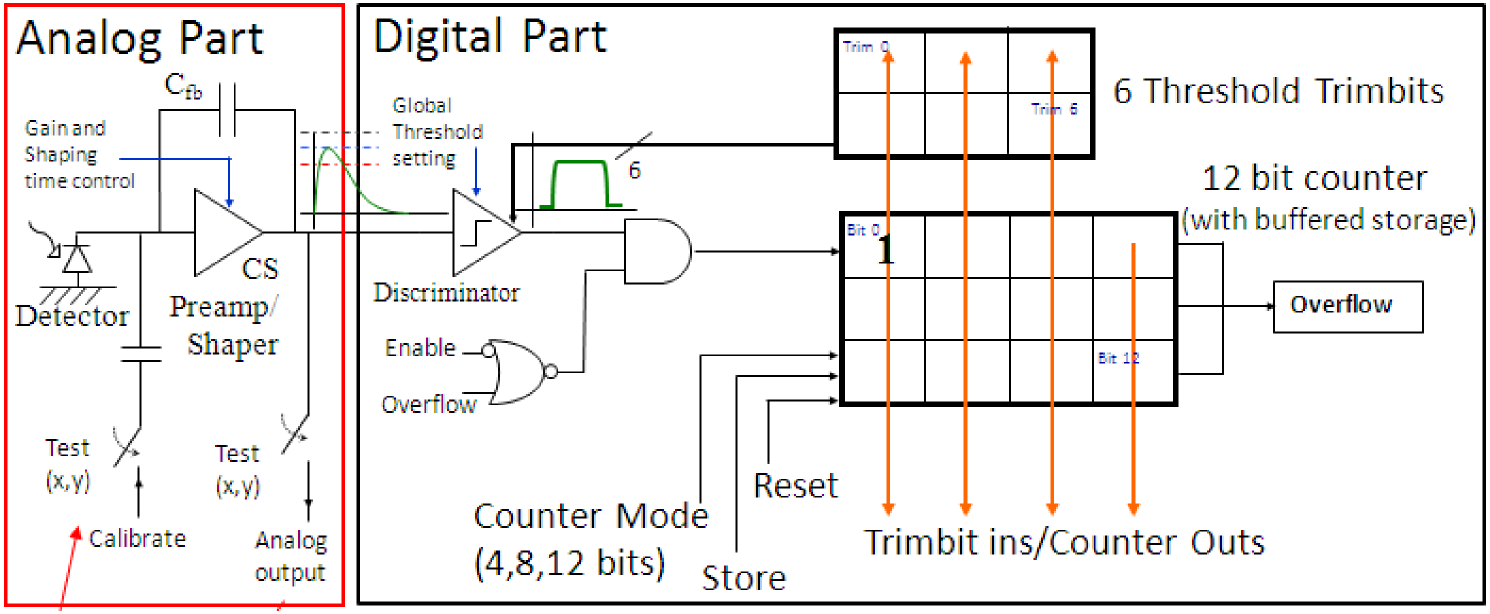


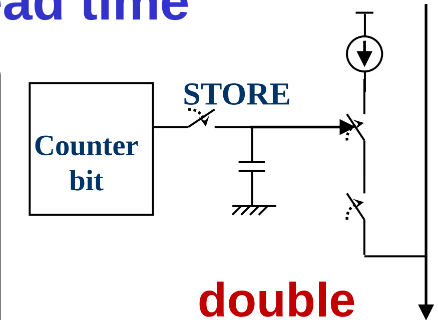
O. Bunk, A. Menzel (SLS), D. Bradley (U. of Surrey), M. Farquharson (McMaster)

The next generation …. EIGER

Roberto Dinapoli

→ smaller pixels (75x75 μm²) – larger frame rate – less dead time





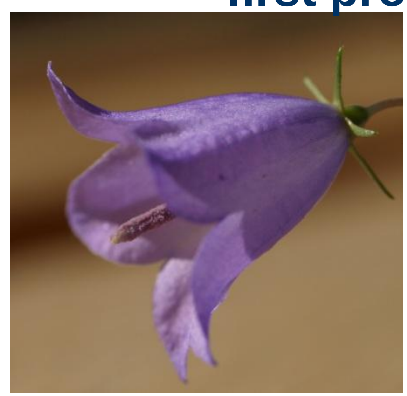
double buffer

⇩

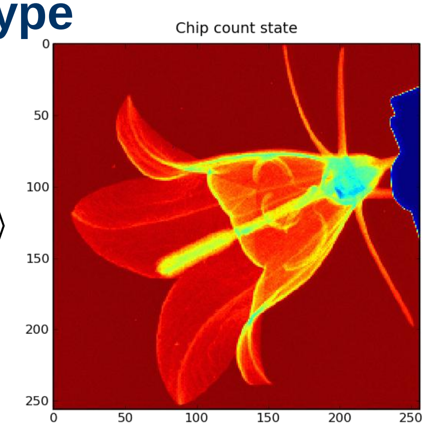
- **cont. R/O**
- **~zero DT**

EIGER Single Chip Detector

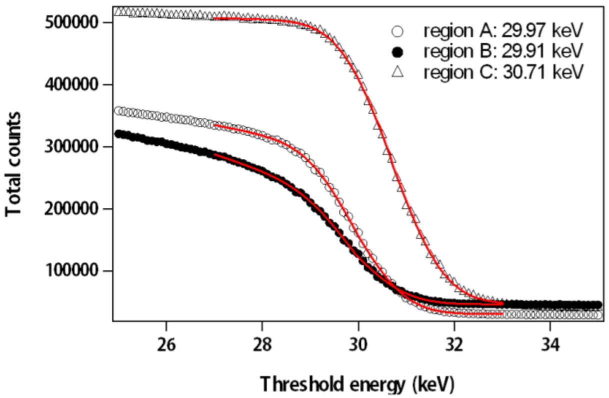
first prototype



⇨



Spring-8 … from PILATUS to CdTe … E-selective …

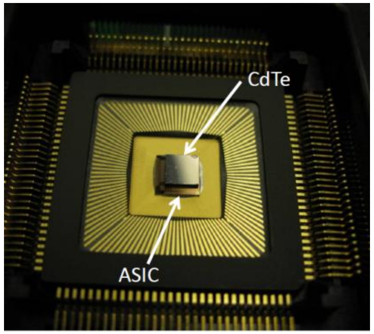


Hidenori Toyokawa

energy resolved Xray imaging by threshold scanning

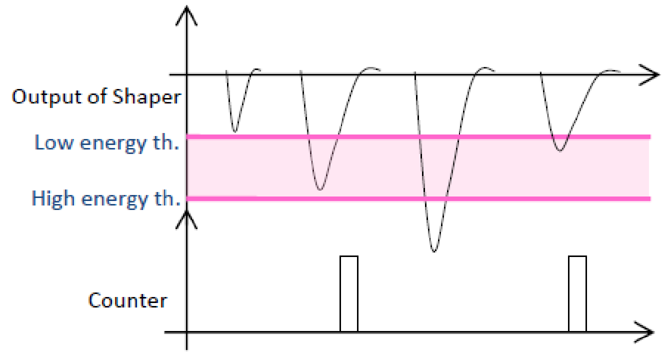
Toko Hirono

CdTe (for high absoption in >15 keV range)
+ window comparator
(low and high thersholds)



5x5 mm^2

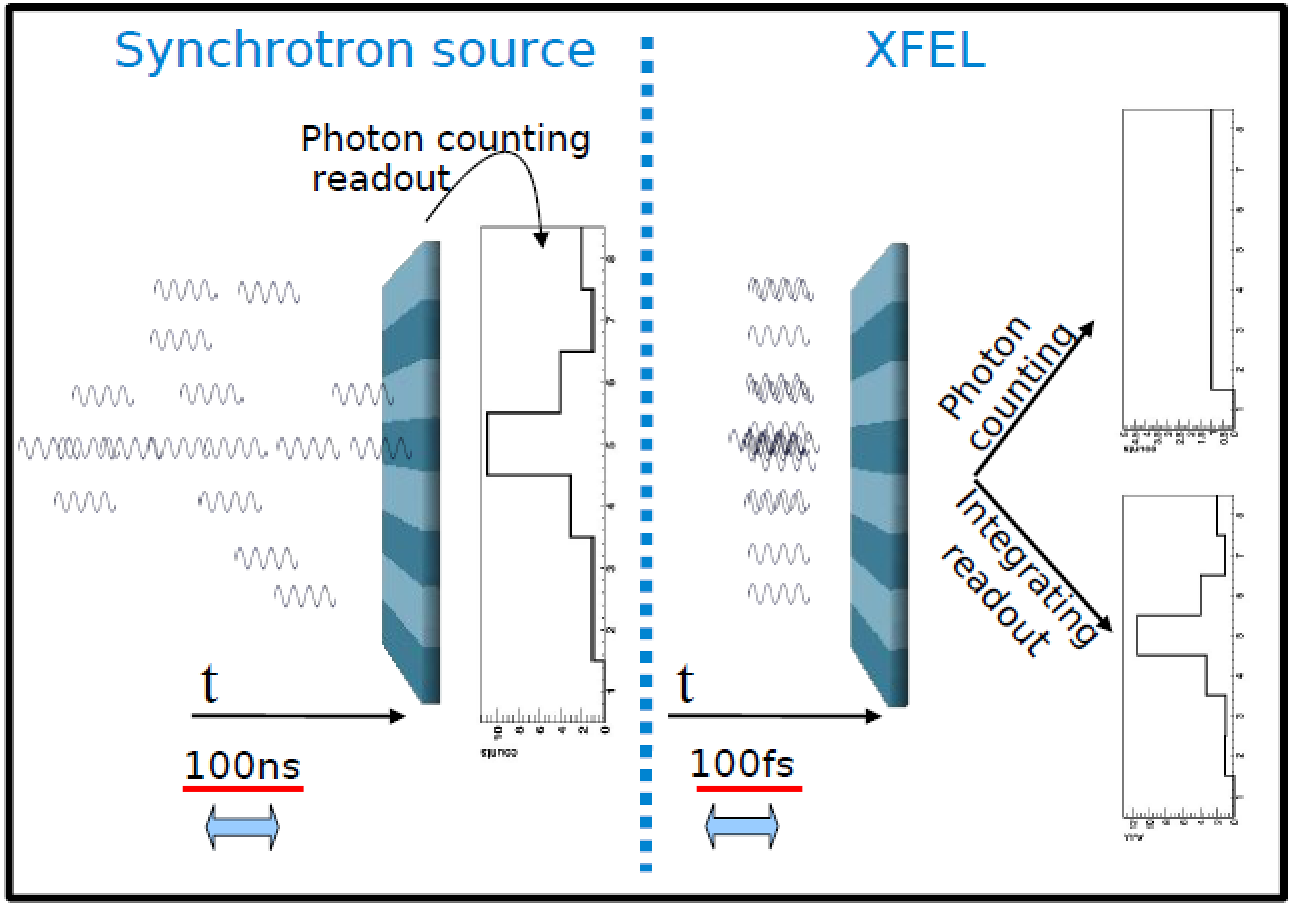
Schottky and ohmic CdTe devices



select an energy range

… next … pixels for XFEL imaging

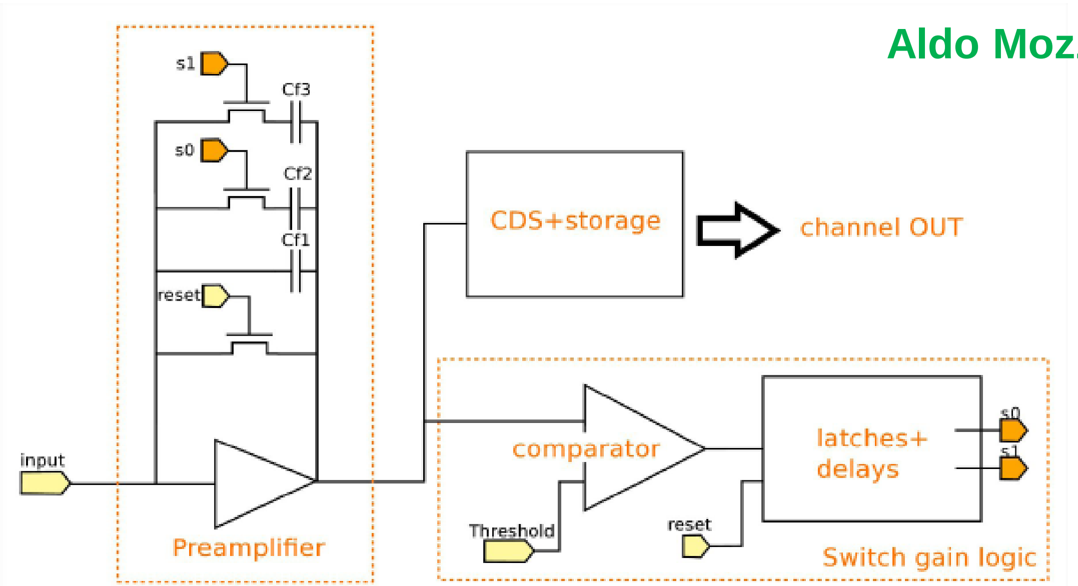
what is different ?



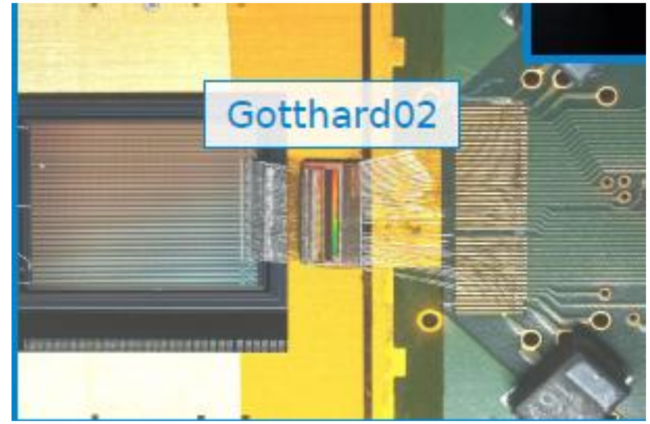
up to 10000 photons per pixel per bunch (200ns)
→ need **5 MHz** frame rate and
huge dynamic range

Aldo Mozzanica

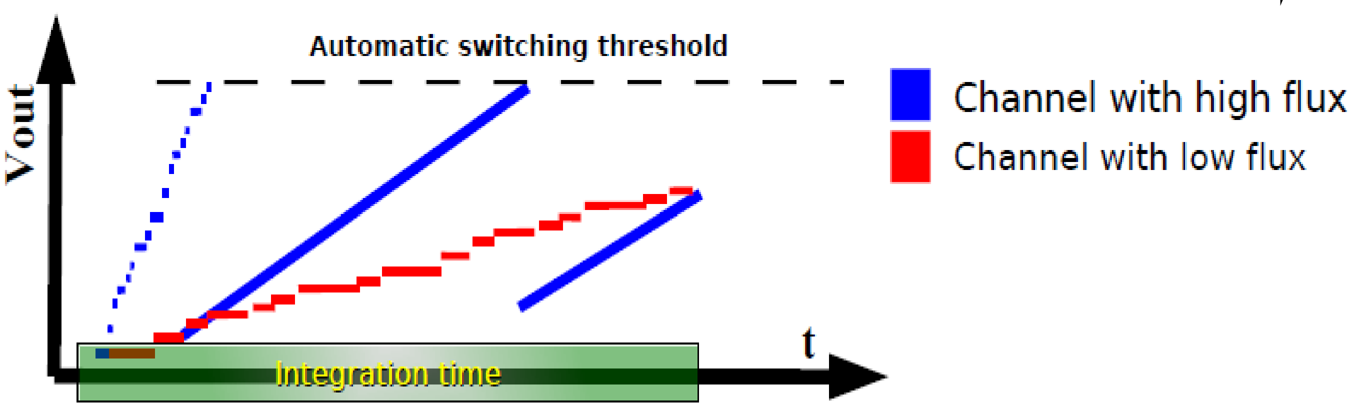
…how to cope ?



Aldo Mozzanica



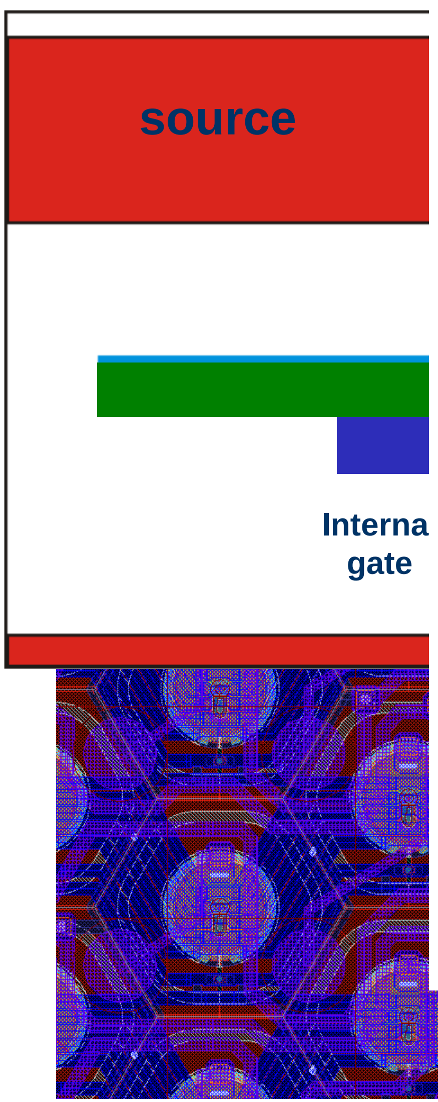
Gotthard (strips)

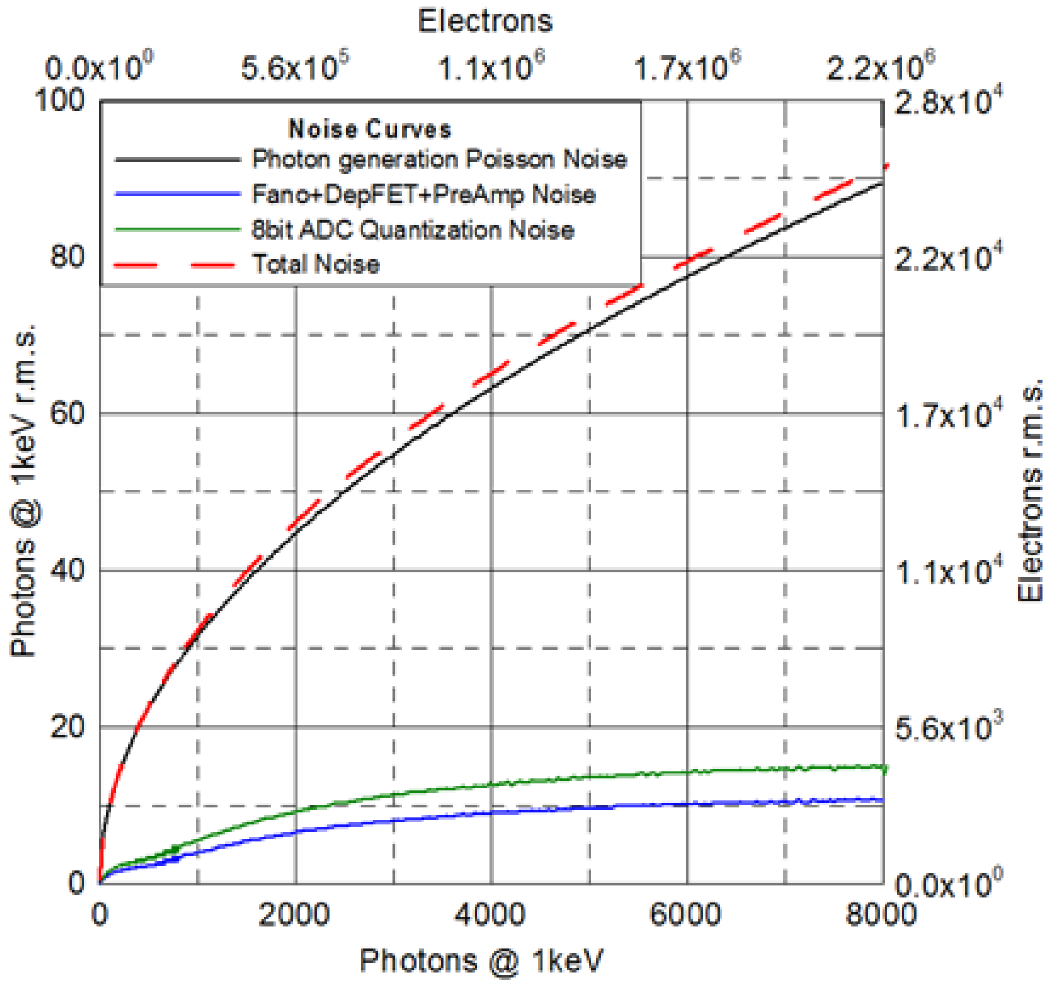


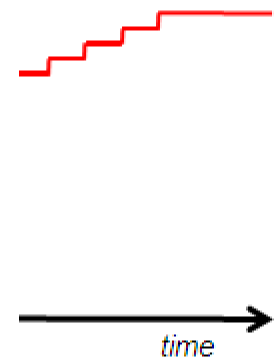
AGIPD (pixels)

… another approach ... non-linear DEPFET

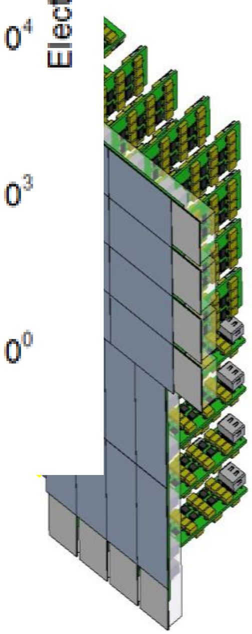
Matteo Porro







ready 2015



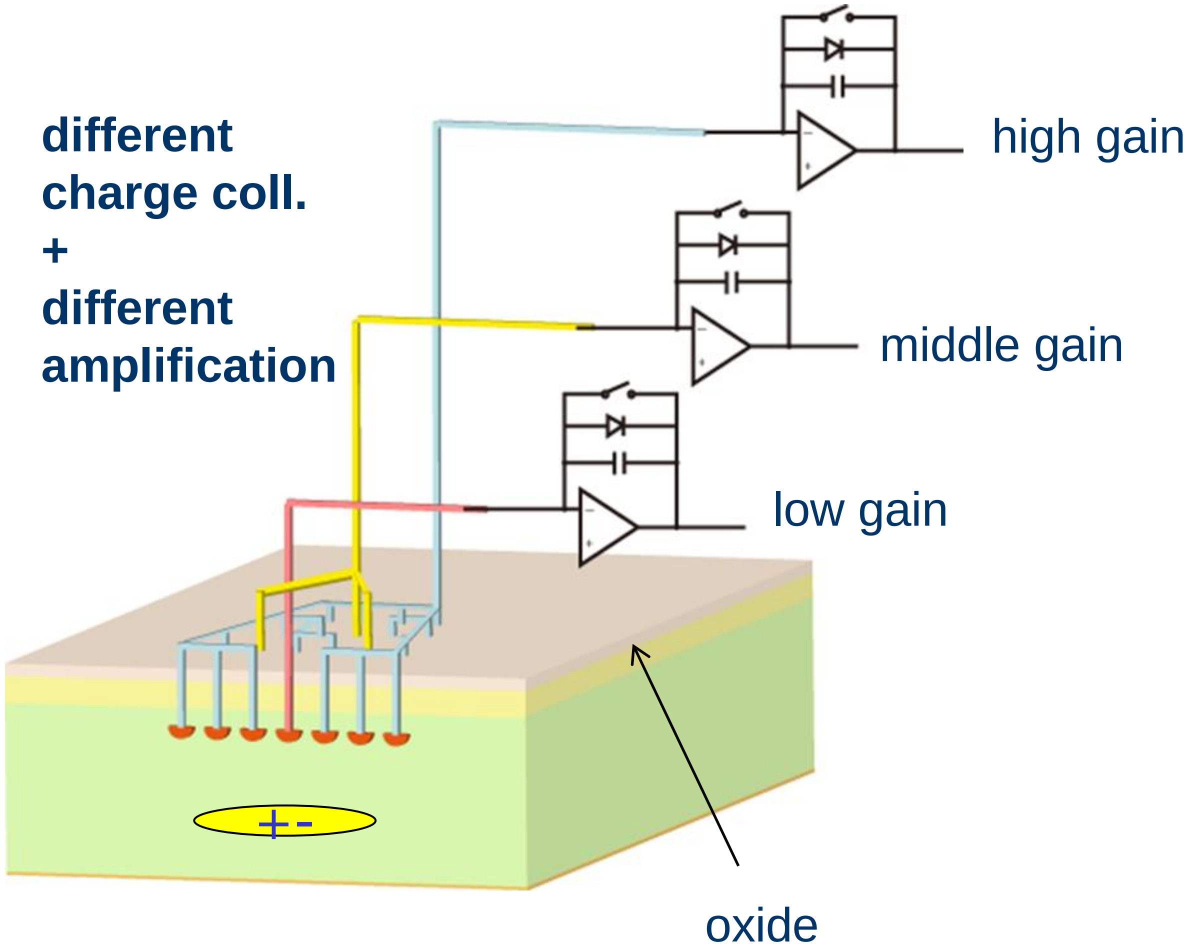
… towards free electron laser … addressing 10^5 dyn. range

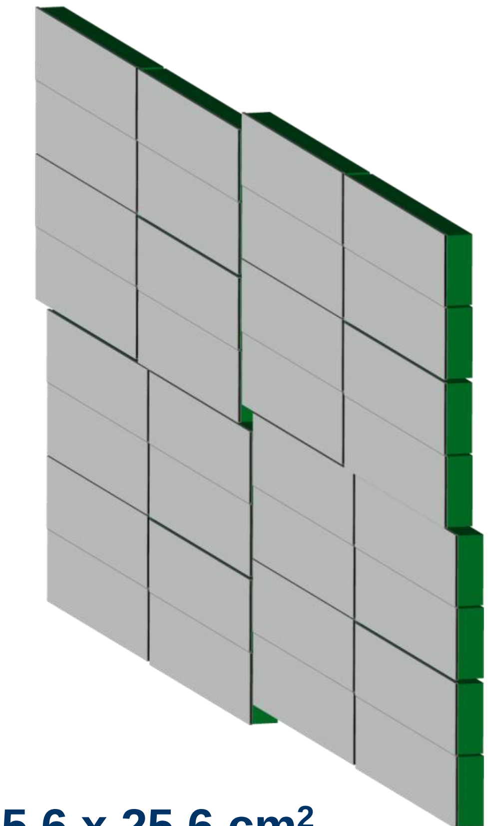
Takaki Hatsui

multi via approach with different gains using SOI technology

goal: 5.1 kpix x 5.1 kpix array

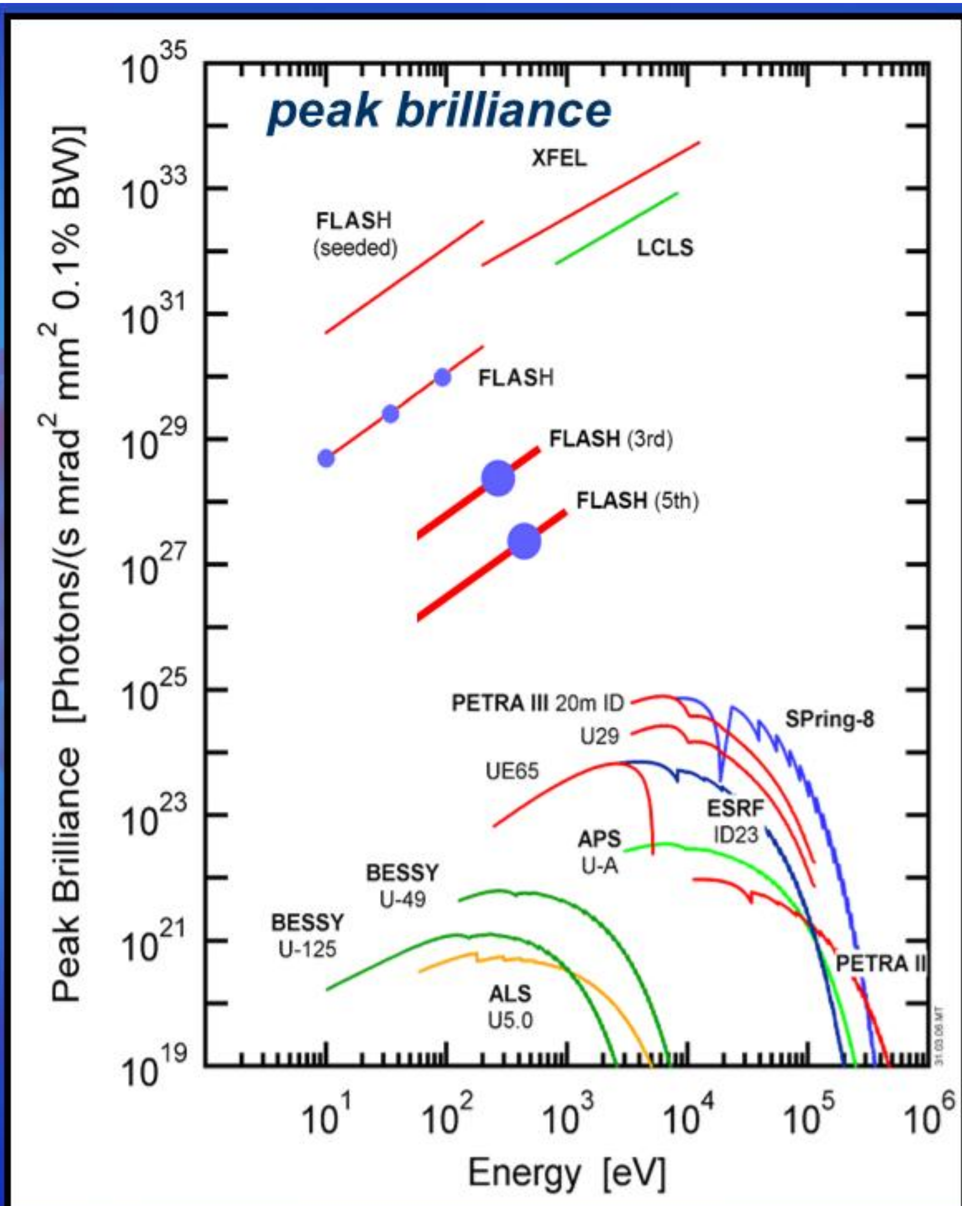
different charge coll.
+
different amplification





25.6 x 25.6 cm^2

Xray – FELs … a world wide effort

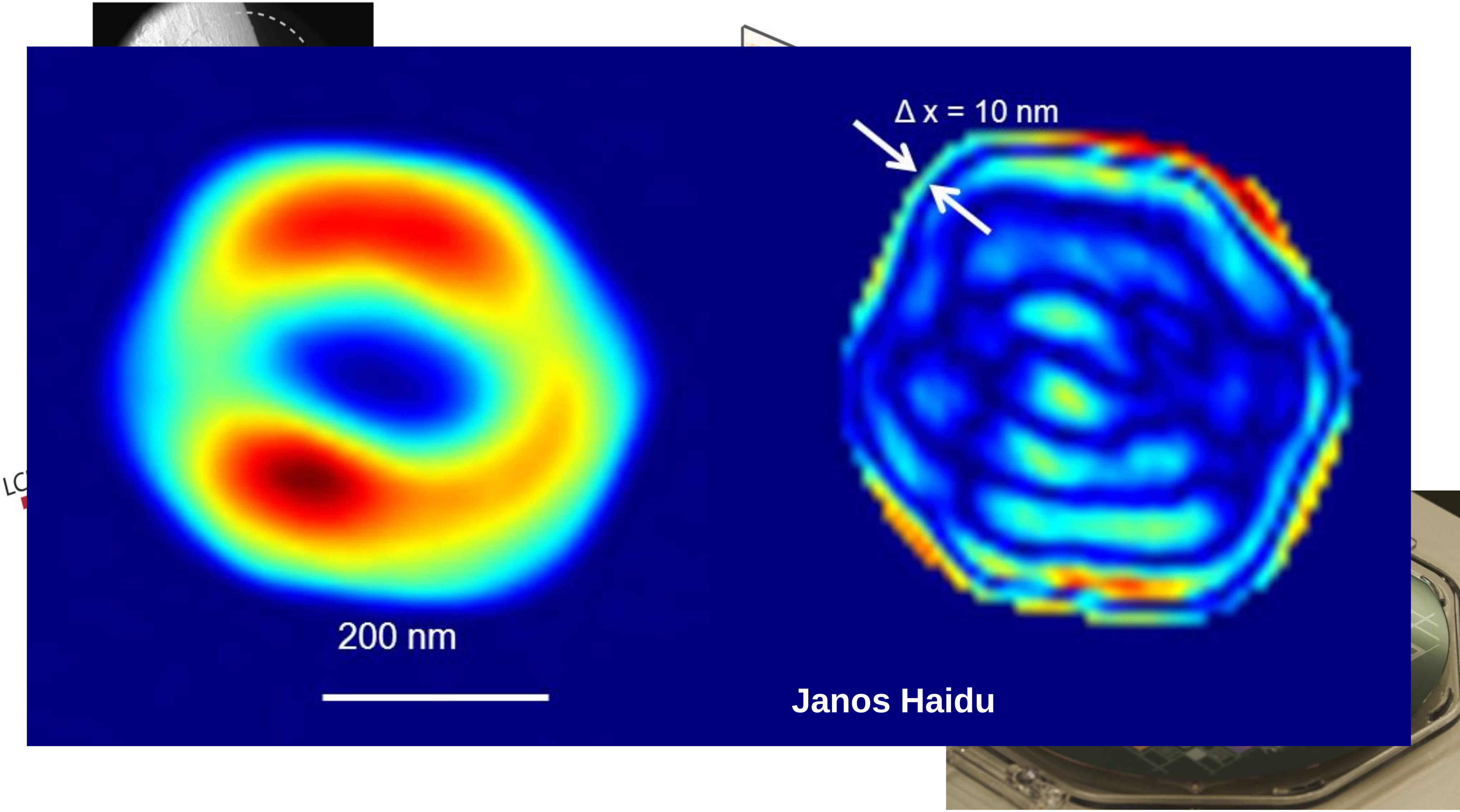


- *FLASH: 2005*
- *SCSS: 2008-10*
- *LCLS: 2009*
- *FERMI: 2009*
- *XFEL: 2013*

Lothar Strüder

Xray – FELs … a world wide effort

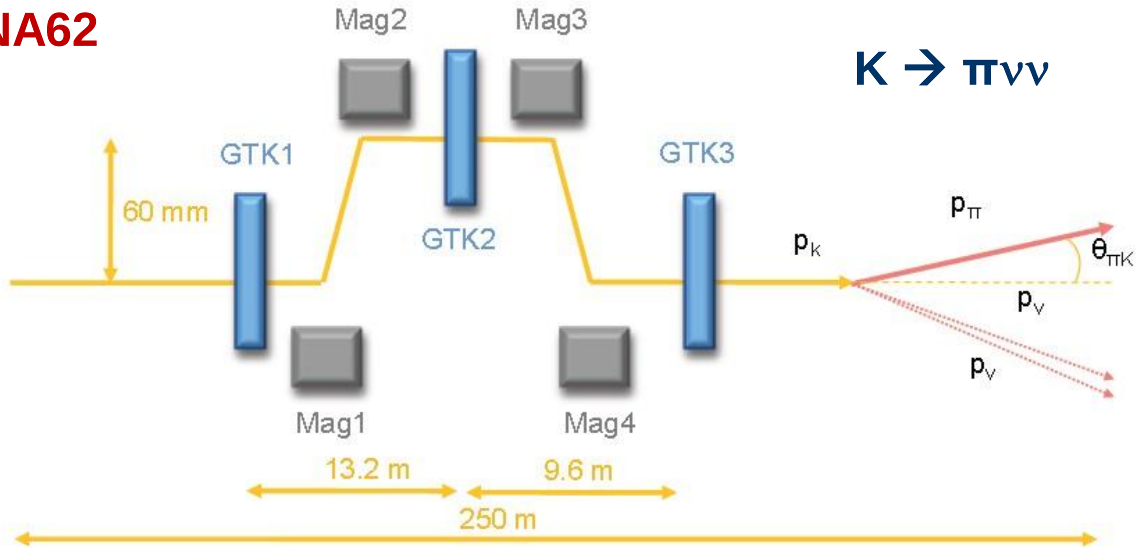
First measurements at FLASH. LCLS ….



Some fancy new chips for dedicated applications ….

NA62

Giulio Dellacasa

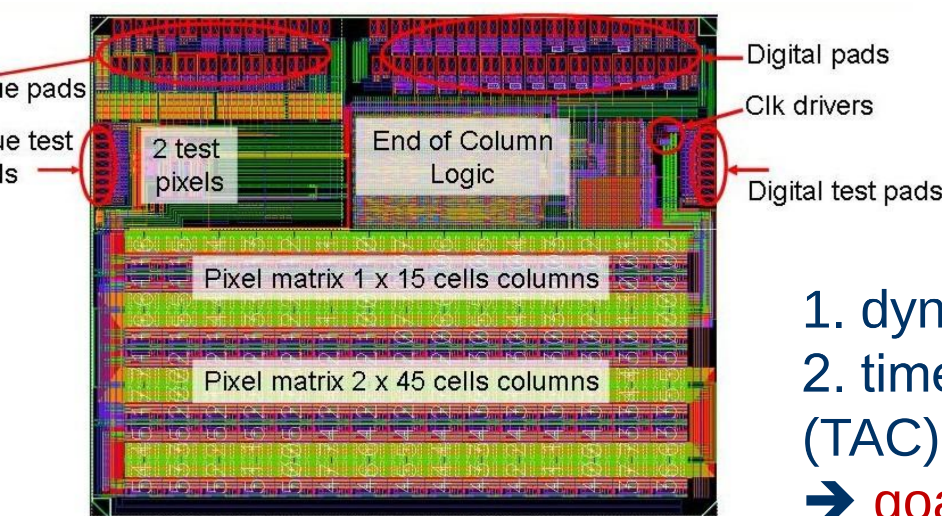


K → πνν

a very rare decay experiment (10^{-11})

⇩

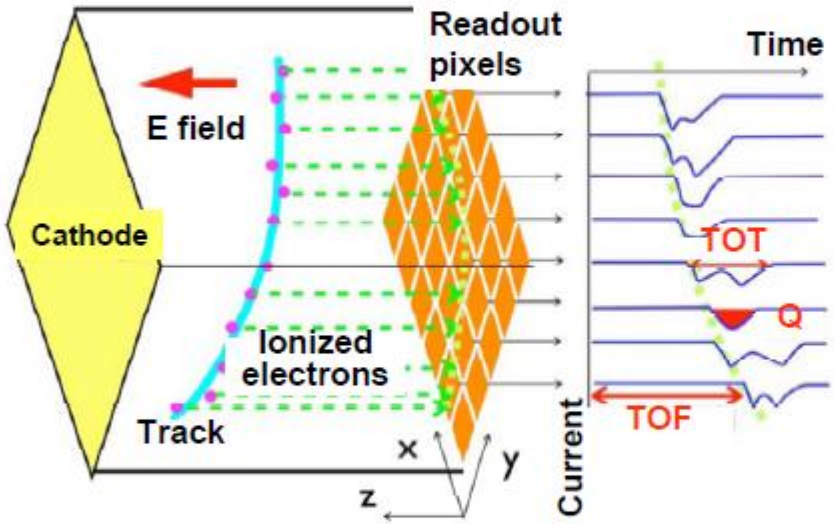
intense beam
measure very cleanly
→ excell. space resol.
→ excell. time resol.

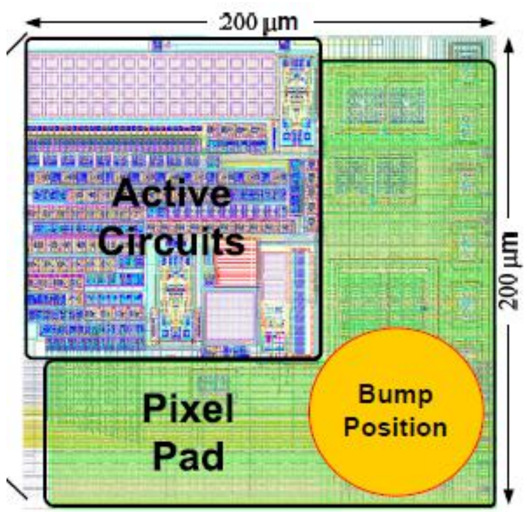


1. dyn. range requires time walk compensation
2. time information via „coarse“ (count) → „fine“ (TAC) measurement
➔ goal σ_{time} = 200 ps (so far on track)

some fancy new chips for dedicated applications ….

Qpix: x,y,time,Q Fei Li





similar function as TIMEPIX

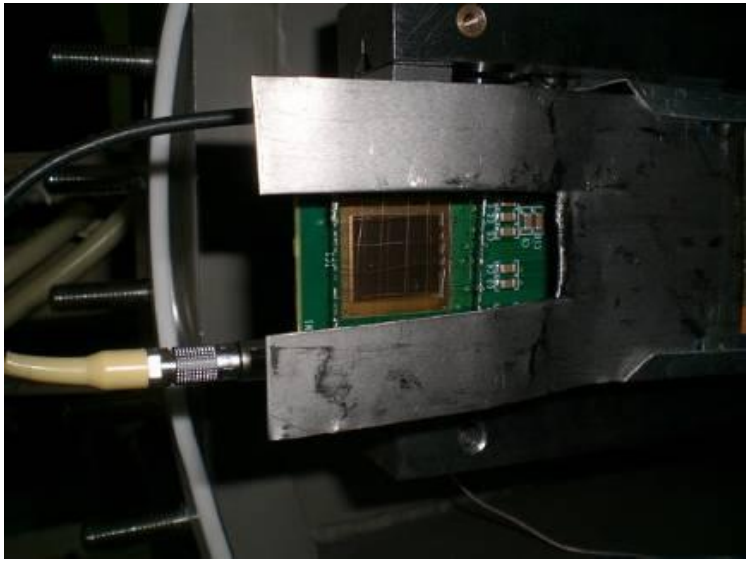
but for > 10 fC and 10 Msps ADC

Applications of the universal Timepix chip

Timepix study for e/γ discrimination
e.g. for dosimetry

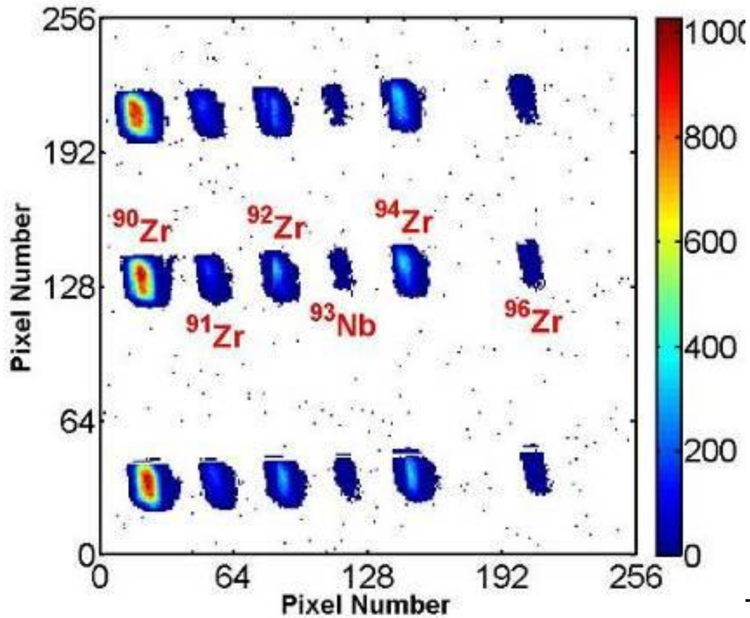
Cécile Teyssier

Timepix Metal Detector
(no Si but mesch in front of electrodes)
ions grate electron plasmons external field pulls them out leaving induced charge on amplifier input



Valery Pugatch

use for ion beam tuning

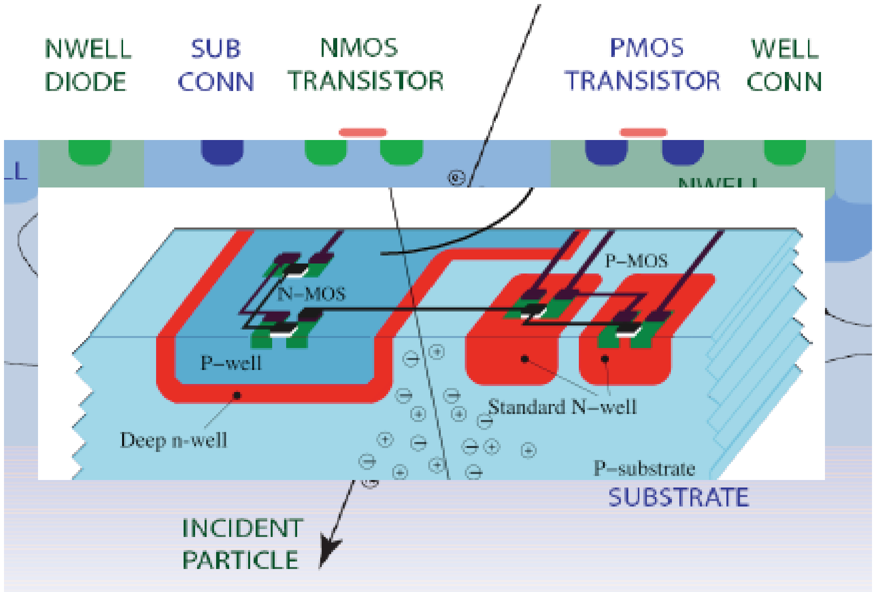


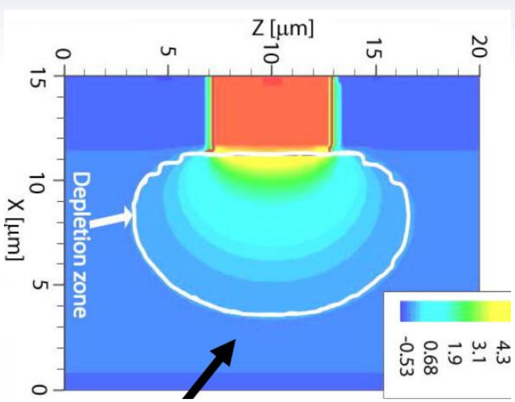
What‘s new
on
Monolithic Pixel Sensors ?

Monolithic active pixels (MAPS) … „all in one device“

A. Dorokhov G. Rizzo

- **in principle … „the dream of a detector physicist“**
- **developed since 1998 … matured as devices for detectors (e.g. STAR … SuperB)**





INMAPS

some problems/challenges addressed:

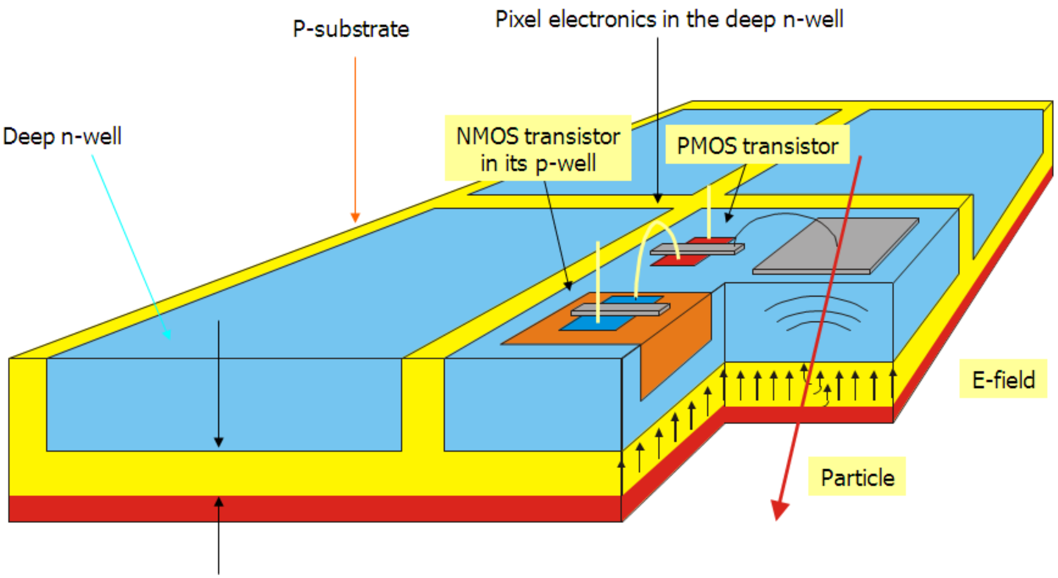
(1) only nMOST in active area, no pMOST
- **triple well process → large deep nwell for Q-collection, pMOST outside** **(Luigi Gaioni → 65nm, Giuliana Rizzo)**
- **shield PMOS-nwell by a pwell (quadruple well process)** **(Marcel Stanitzki)**

(2) radiation hardness → don‘t use for LHC

(3) small signal and Q-collection by diffusion
- **larger coll. diode**
- **higher resistance → higher Q-coll. eff.** **(Andrei Dorokhov, Marcel Stanizki)**

this also improves rad. tolerance x100
→ good progress, e.g. S/N ~ 90 (M.S.)

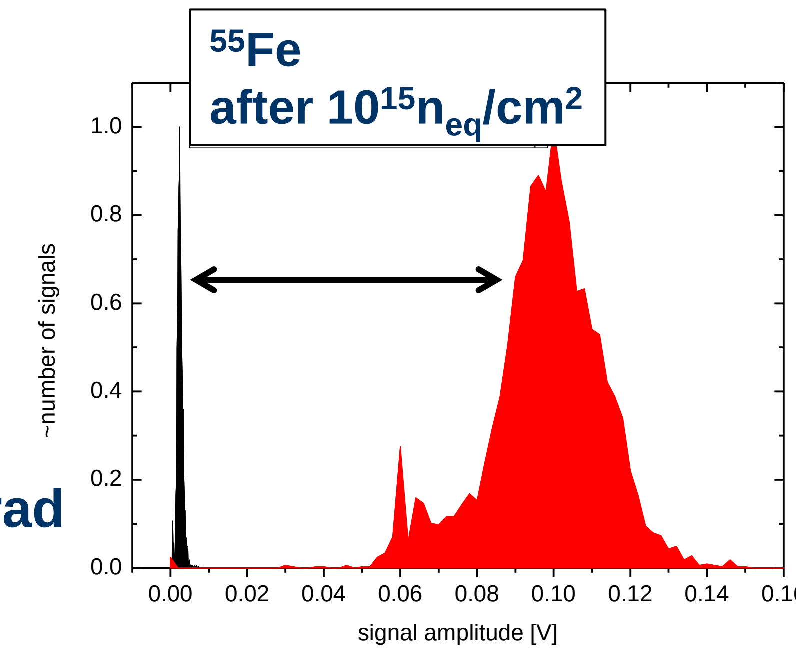
… new MAPS in HV technology (0.35 AMS)



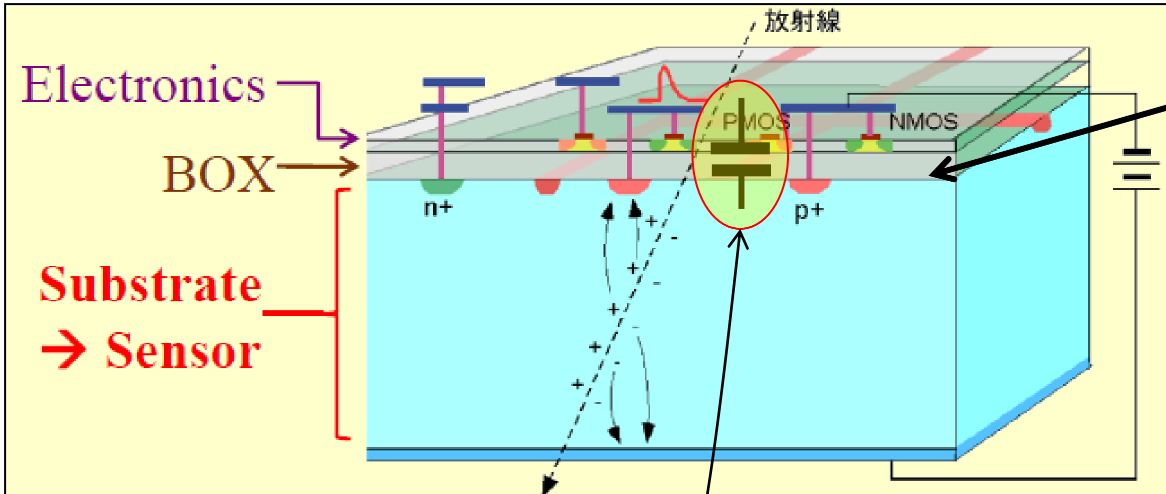
Ivan Peric

- **all electronics in same deep n-well**
- **Q-coll. in depl. volume by drift in E**

- **full CMOS**
- **~full charge collection efficiency**
- **high S/N (~100)**
- **small pixels (21x21 μm²)**
- **fast**
- **radiation hard to 10^{15} n_{eq} / cm^2 or 300 Mrad**
- **(3 + 8) μW / pixel**



… the other important monolithic appoach … SOI pixels



thick burried oxide (BOX)

"much progress with OKI technology (200 nm)"

Yasuo Arai, Piero Giubilato

R&D on e.g. …

- **back side effect**
- **thin wafers → 110 µm**
- **resistivity**
- **rad. hardness (c.f. BOX)** ⇨

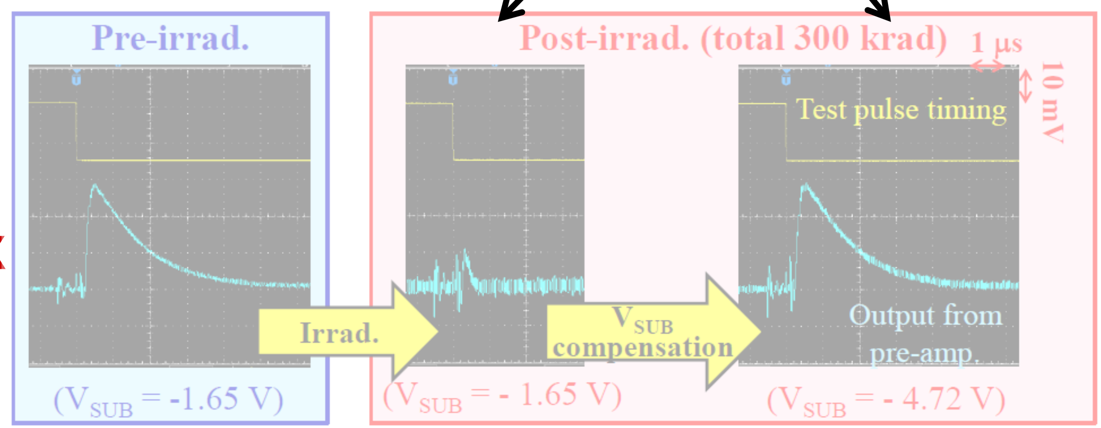
hole trapping in BOX

Yutaro Sato
Yasuo Arai

PRE-irr

POST-irr

V_{sub} V_{sub}-3V



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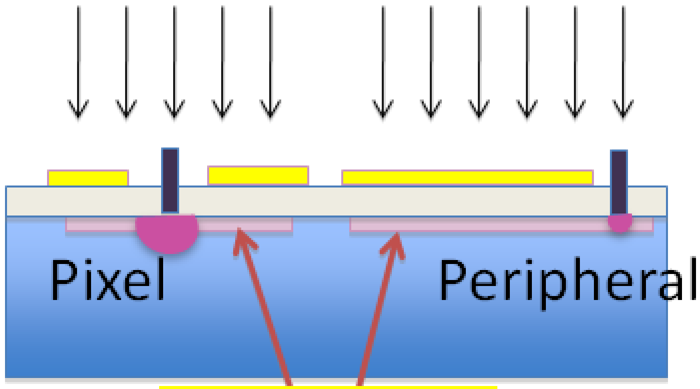
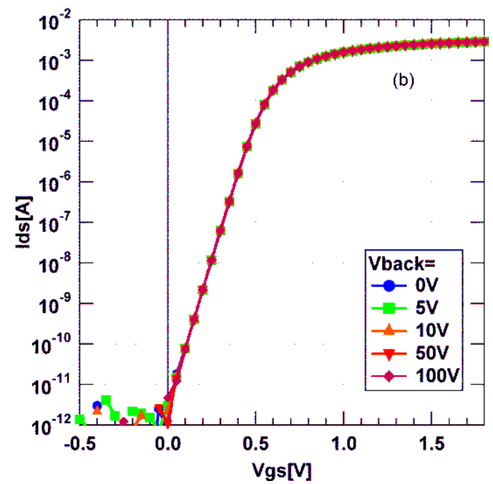


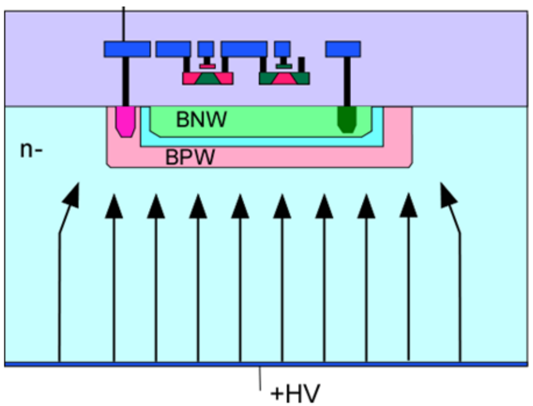
buried p-well

Y. Arai



backside effect gone

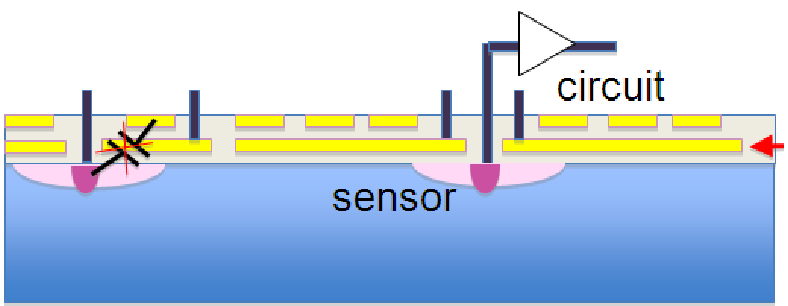
no threshold shifts observed



nested wells

Q-coll. vial p-well
back gate and x-talk shielded by n-well

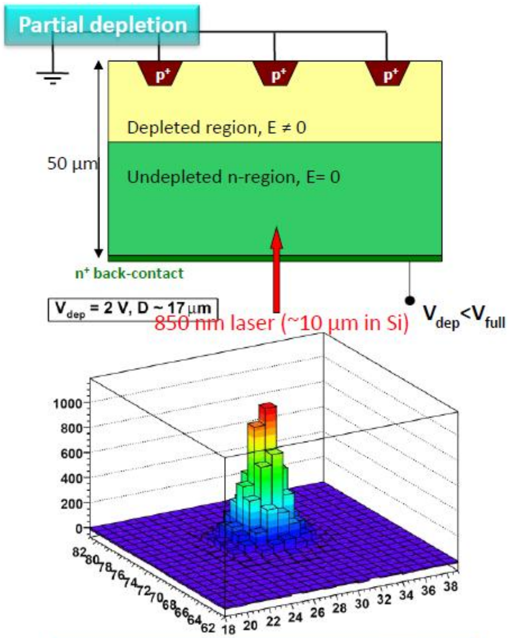
G. Deptuch, R. Yarema, Y. Arai



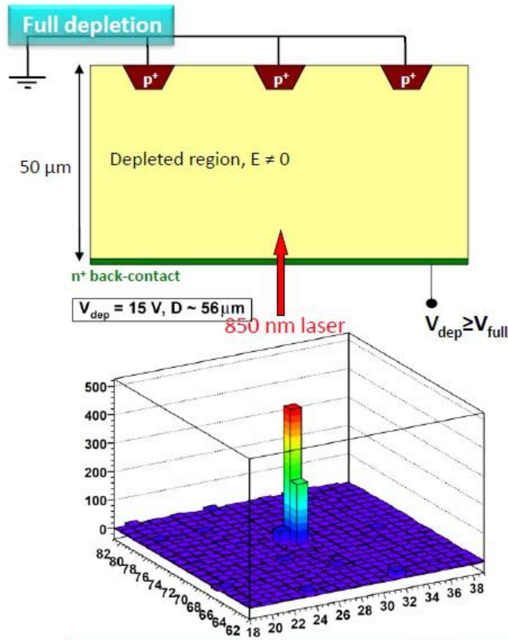
double SOI

shield sensor area from circuitry

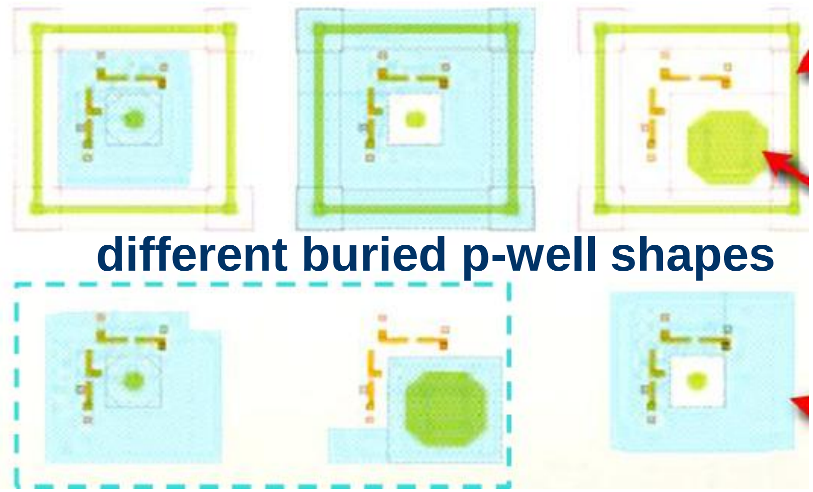
… the other important monolithic appoach … SOI pixels



half depletion

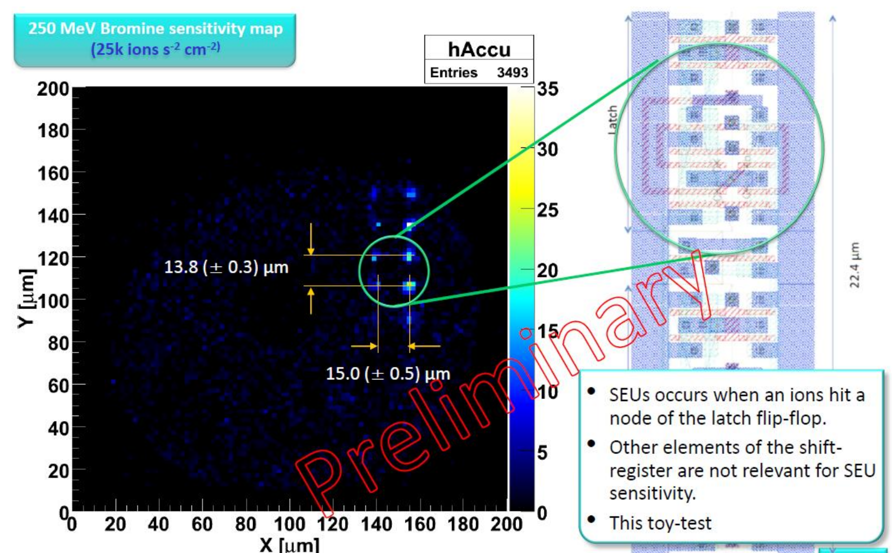


full depletion



different buried p-well shapes

study full depletion and back gate effect



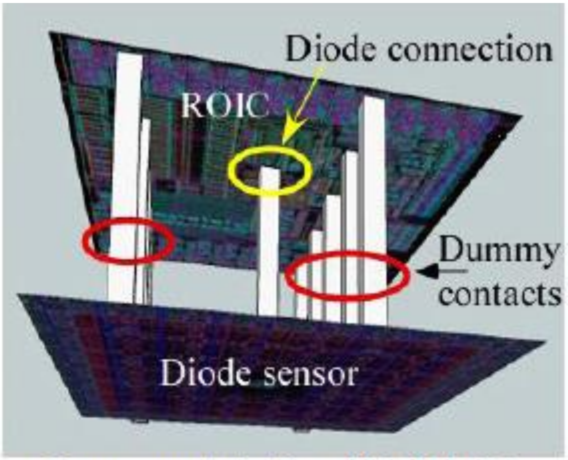
Piero Giubilato

particularly impressive

tracing of the transistor resonsible for SEU

… 3D integration … needs a long staying power

Ray Yarema



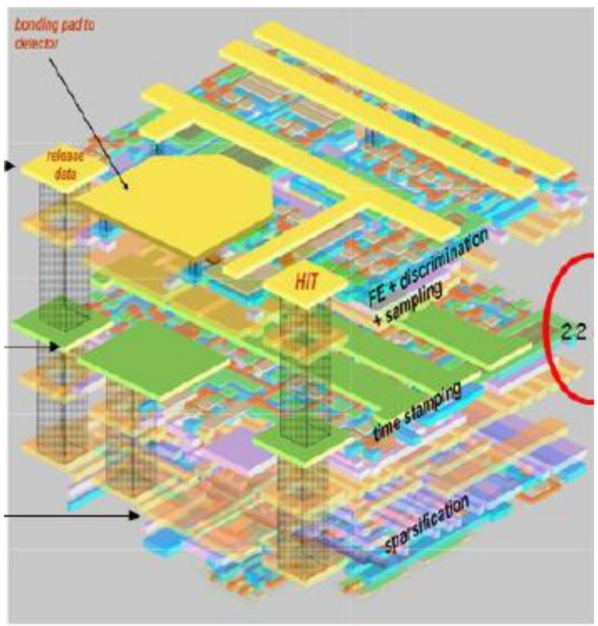
3D assembly for MAMBO3

Mambo3 (44x44 pix) (OKI 200 nm)

finally 3D assembled (vias „last“)
from two chips on same wafer
by T-micro (talk Makoto Motoyoshi)

prototypes with

- **OKI**
- **MIT LL**
- **Tezzaron/ Chartered**



3 tiers in 1 block (MIT LL)

- **VIP1 … many problems**
- **VIP2a … so far encouraging**

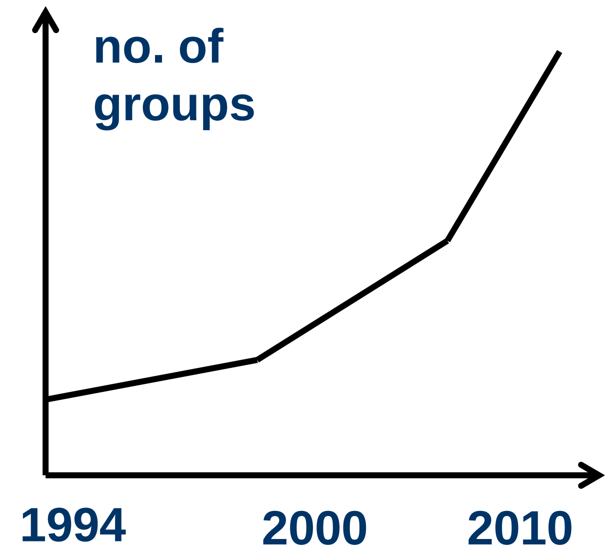
Apologies to those whose work was not mentioned here …

Mats Hollingsworth	Diamond Telecope
Anna Arbat	Geiger Mode APDs
Christian Brönnimann	DECTRIS
Gerhard Holst	sCMOS Chips (PCO AG)
Ralf Röder	CiS
Enver Alagoz	3D CMS
Makoto Motoyoshi	T-micron
Regina Moles-Valls	ATLAS ID Alignment
Frank Meier	CMS Tracker Alignment
Stefano Meroli	Grazing Angle Method

The Pixel Conference Series

WS on Semicond. pixel detectors (org. by E. Heijne)

- 1988, Leuven, 64 participants
- 1990, Leuven, 86 participants
- 1996 Bari, 100 participants



Pixel 2000, Genova, 84 participants

Pixel 2002, Camel, 55 participants

Pixel 2005, Bonn, 107 participants

Pixel 2008, Fermilab, 83 participants

Pixel 2010, Grindelwald, 93 participants

Pixel 2012, very likely in Japan, → 2xx participants

… and …

A big, big thank you

(esp. Andrey, Danek, Roland)

for the splendid organization

of this PIXEL 2010 conference

at Grindelwald

… and …

A big, big thank you

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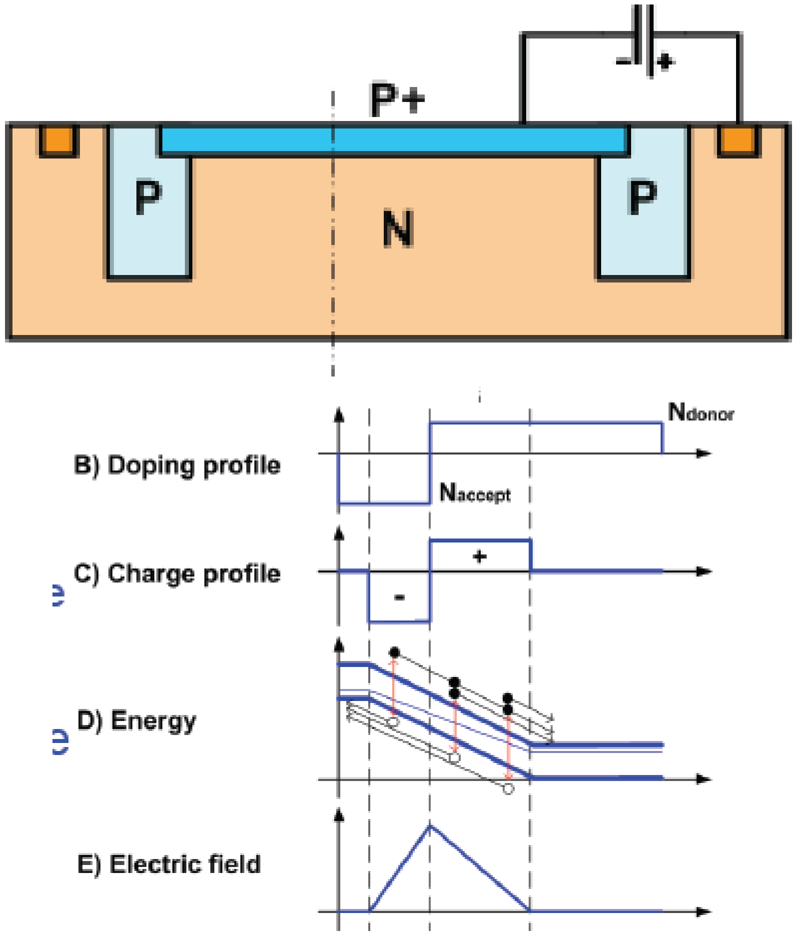
for the splendid organization
of this PIXEL 2010 conference
at Grindelwald

foto stolen from Nobu Unno

BACKUP SLIDES

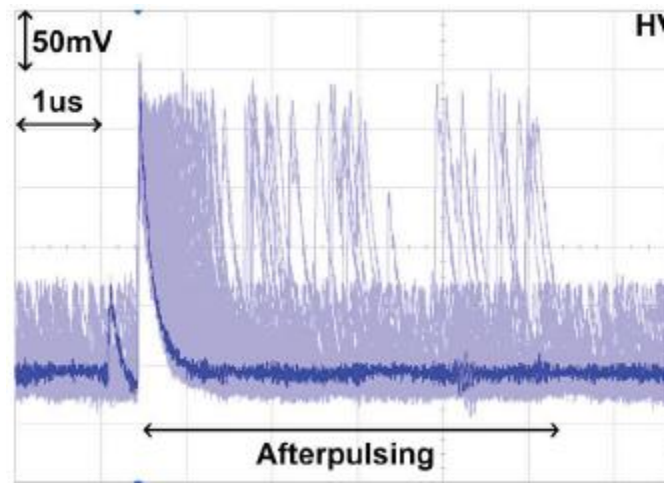
R&D for new detector types …



Anna Arbat

pixellated Avalanche Photo Diodes in Geiger mode

→ what to do with dark current and afterpulses ?



designed 0.35 AMS-HV CMOS structure with different quenching schemes

promising prototypes !

Monolithic active pixels (MAPS) … „all in one device“

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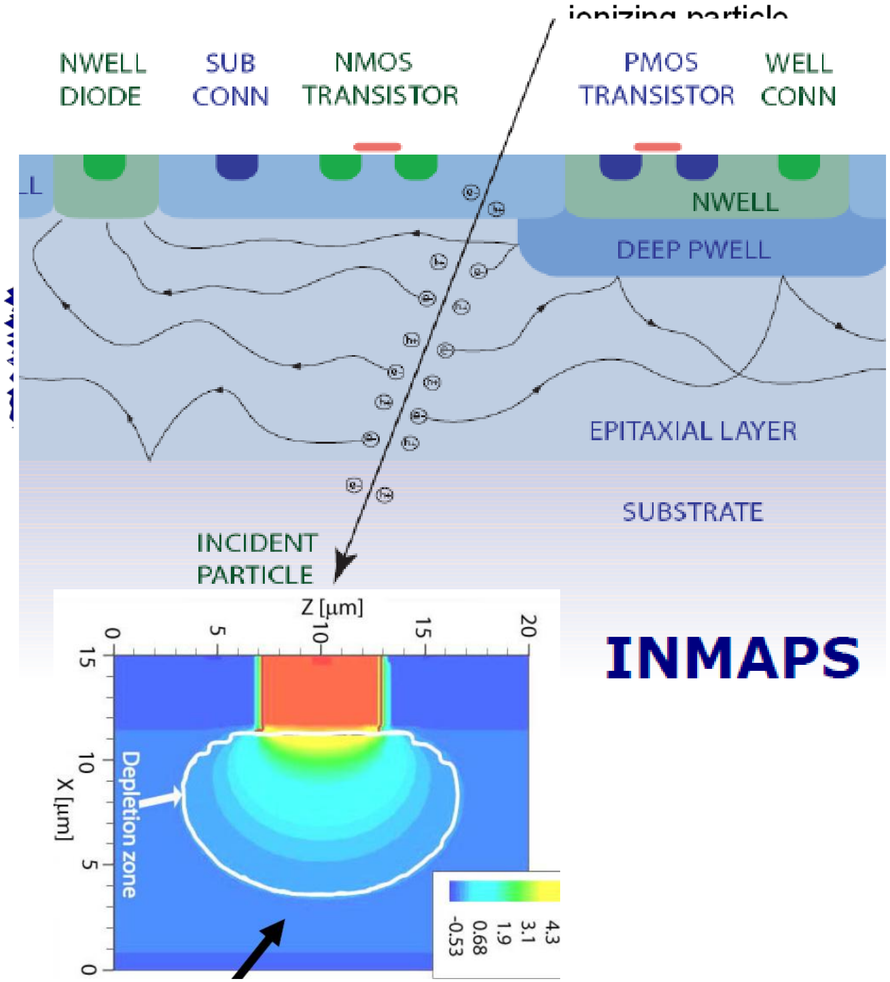
- **developed since 1998 … matured as devices for detectors (e.g. STAR … SuperB)**



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