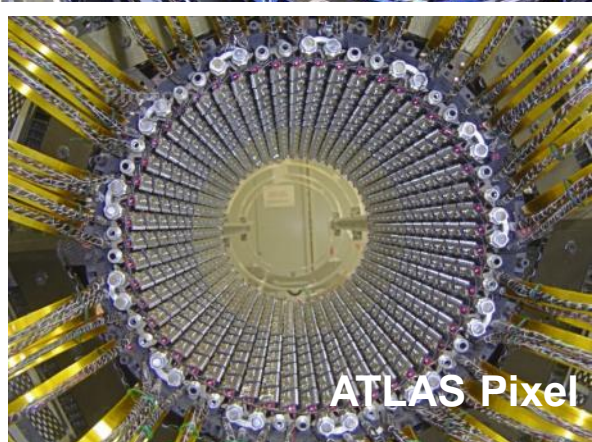# New trends in Silicon tracking detectors for High Energy Physics

Doris Eckstein
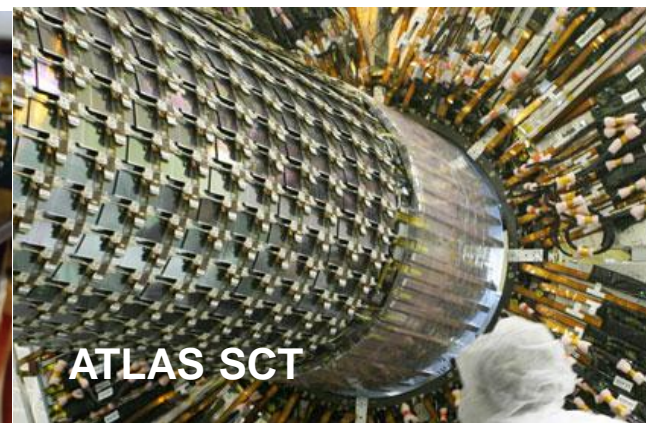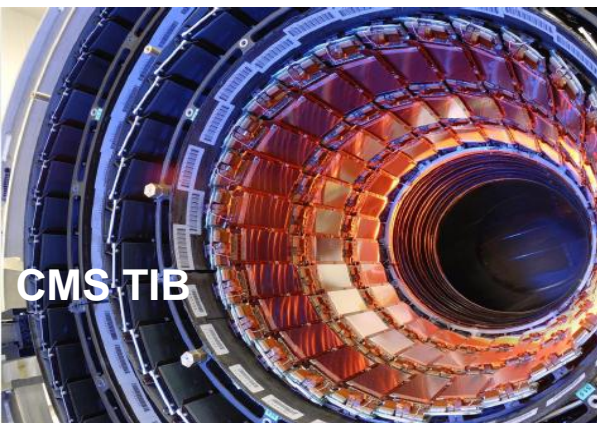AIDA 1st Annual Meeting
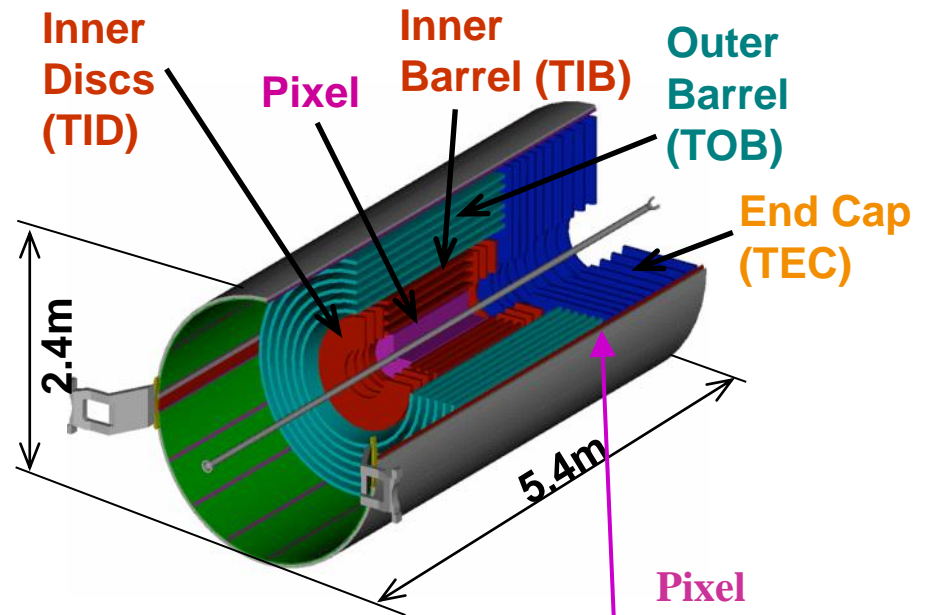Students Tutorial
27 March 2012, DESY

HELMHOLTZ | ASSOCIATION

DESY

Outline
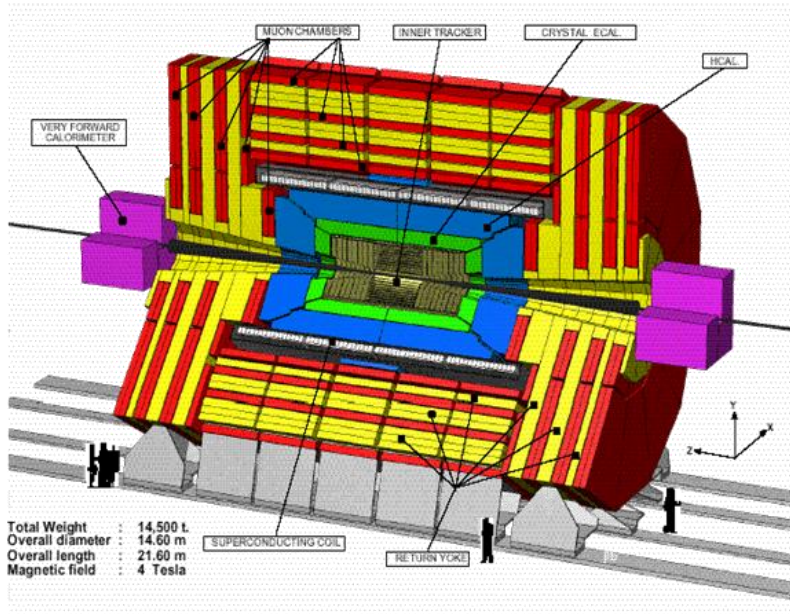
> Todays Detectors

> Requirements for future detectors

> The high-luminosity LHC challenge:

   → radiation damage

   → concepts for rad-hard sensors

   → upgrade examples (ATLAS-IBL, CMS pT modules)

> Towards a vertex detector for a linear collider (PLUME)

Currently at the LHC

CMS TIB

LHCb VELO

ATLAS SCT

ATLAS Pixel

ALICE Pixel

CMS

LHC Example – CMS Tracker

Total Weight : 14,500 t.
Overall diameter : 14.60 m
Overall length : 21.60 m
Magnetic field : 4 Tesla

Inner Discs (TID) **Pixel** **Inner Barrel (TIB)** **Outer Barrel (TOB)** **End Cap (TEC)**

2.4m

5.4m

Pixel

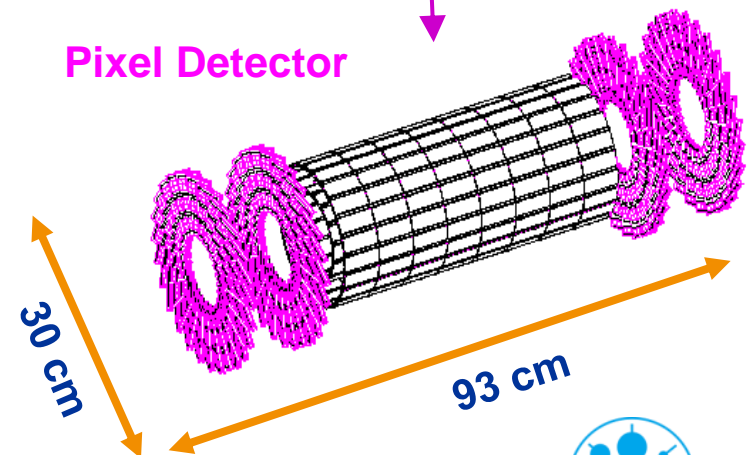**Pixel Detector**

30 cm

93 cm

- **Largest silicon tracker**
  - **Micro Strip Tracker:**
  - ~ 214 m² of silicon strip sensors, 11.4 million strips
  - **Pixel:**
  - Inner 3 layers: silicon pixels (~ 1m²)
  - 66 million pixels (100x150μm)
  - Precision: $\sigma(r\varphi) \sim \sigma(z) \sim 15\mu m$
  - Most challenging operating environments (LHC)

Strip vs. Pixel

★ A strip detector measures 1 coordinate only. Two orthogonal arranged strip
detectors could give a 2 dimensional position of a particle track. However, if
more than one particle hits the strip detector the measured position is no
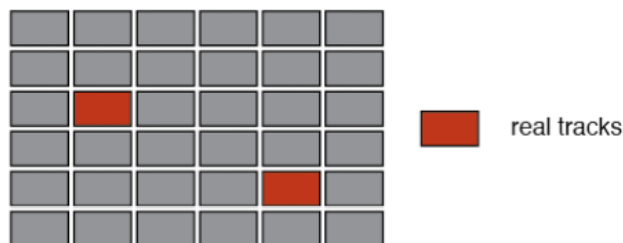longer unambiguous. "Ghost"-hits appear!

True hits and ghost hits in two
crossed strip detectors in case
of two particles traversing the
detector:

✗ real tracks
○ "ghosts"

Use strips for
outer radii

★ Pixel detectors produce unambiguous hits!

Measured hits in a pixel detector
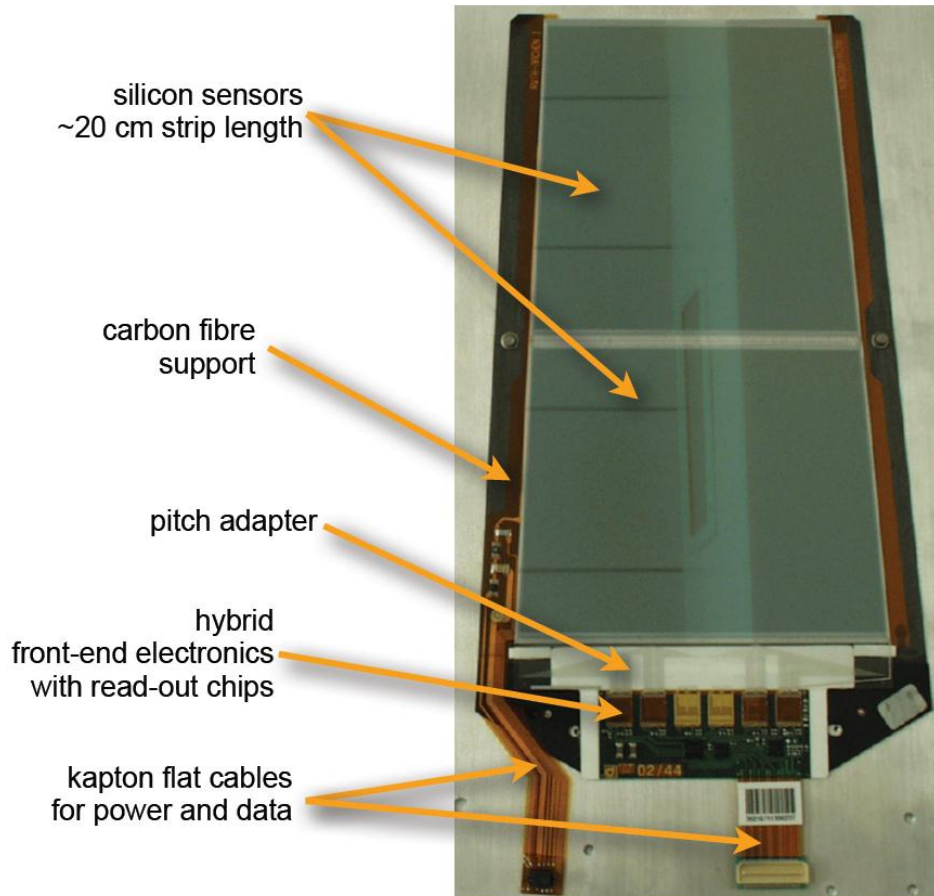in case of two particles
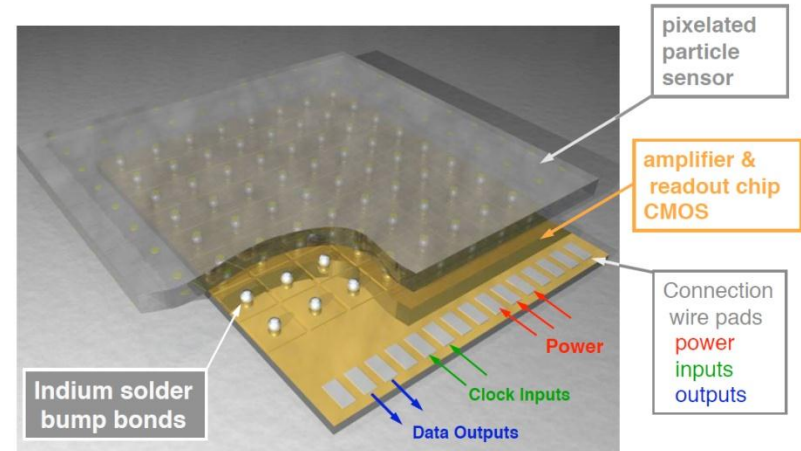traversing the detector:

■ real tracks

Use pixels for
inner radii
(high occupancy)

✓ Small pixel area → low detector capacitance (≈1fF/Pixel)
   → large signal-to-noise ratio (e.g. 150:1).
✓ Small pixel volume → low leakage current (≈1 pA/Pixel)

– Large number of readout channels
– Expensive to cover large areas

Strips, hybrid and monolithic pixel technologies

Strip detectors

silicon sensors
~20 cm strip length

carbon fibre
support

pitch adapter

hybrid
front-end electronics
with read-out chips

kapton flat cables
for power and data

Hybrid Pixel Detectors Principle

pixelated particle sensor

amplifier & readout chip CMOS

Connection wire pads
power
inputs
outputs

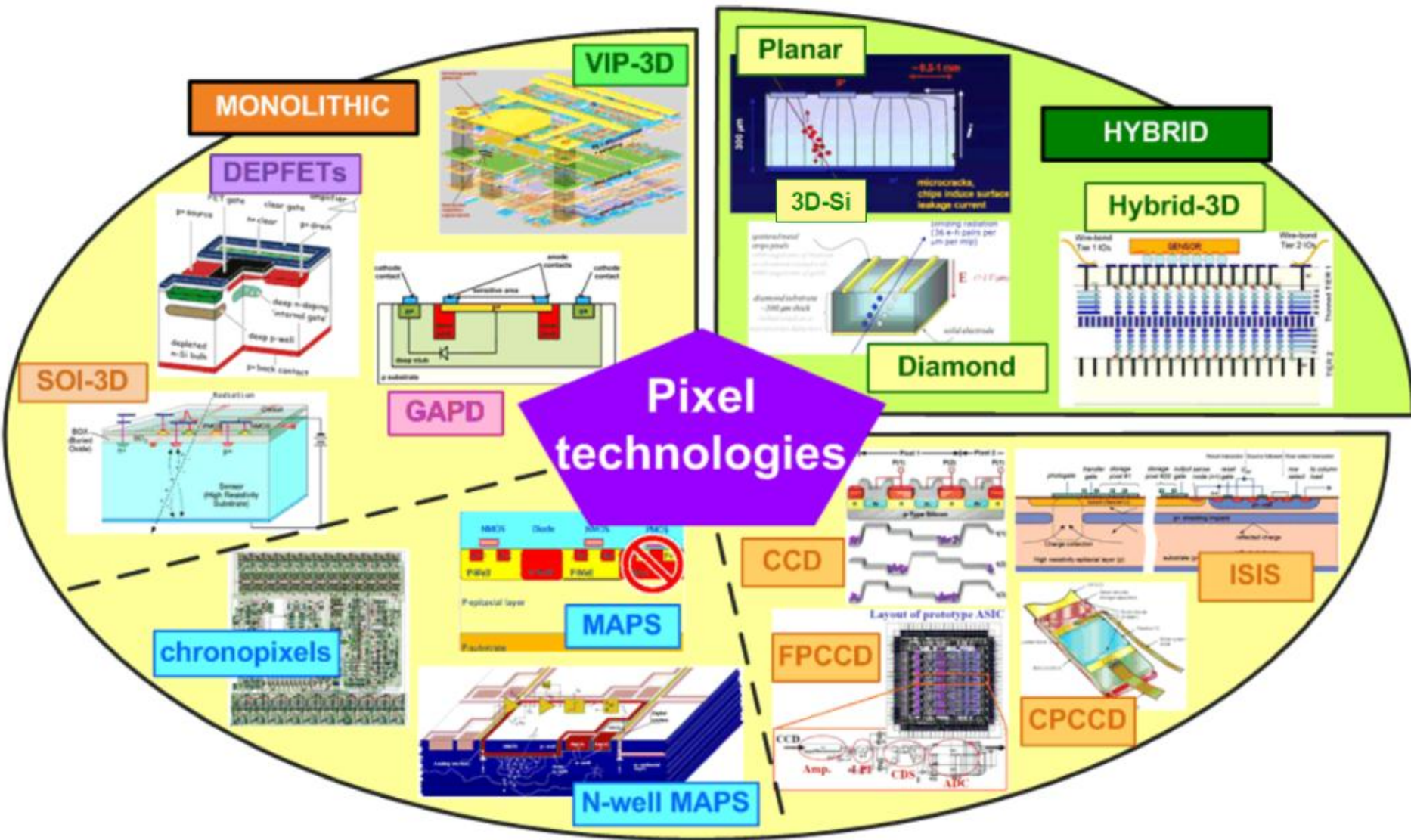Indium solder bump bonds

Power

Clock Inputs

Data Outputs

Sensor and FE chips decoupled

Monolithic Pixel Detetcors

Generation & processing of signal in same substrate

The variety of pixel technologies

Slide: N.Wermes at annual workshop of the Helmholtz Alliance Dec.2011, Bonn

What defines the Future ?

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
SuperBFs (10^{35} cm^{-2}s^{-1})	2	400	$\sim 3 \times 10^{12}$	100
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
lower radiation
smaller pixels
less material

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

Slide: N.Wermes at annual workshop of the Helmholtz Alliance Dec.2011, Bonn

What drives the Future ?

> Physics requirements

> Experimental conditions

> Developers ambition

	Hybrid pixels	MAPS/DEPFET
Good S/N	yes	no/yes
~µm space resolution	~10µm (4µm possible)	possible
~ns time resolution	yes (at LHC)	slow (rolling shutter)
>10 MHz/mm^2 rate capability	tbd for hl-LHC	<0.4 MHz/mm^2
Radiation hard to 5MGy	tbd for hl-LHC	< 100kGy
Radiation length per layer <0.2% x/X$_0$	3.4%	possible
monolithic	hybrid	more or less

after: N.Wermes at annual workshop of the Helmholtz Alliance Dec.2011, Bonn
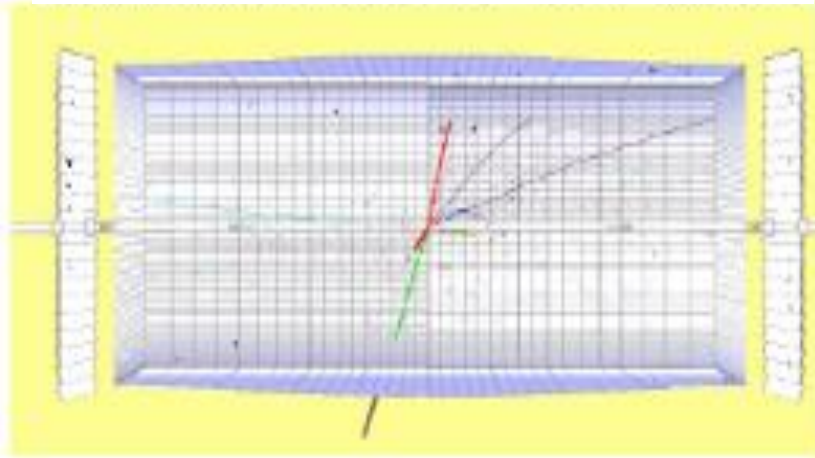
LHC detector upgrades
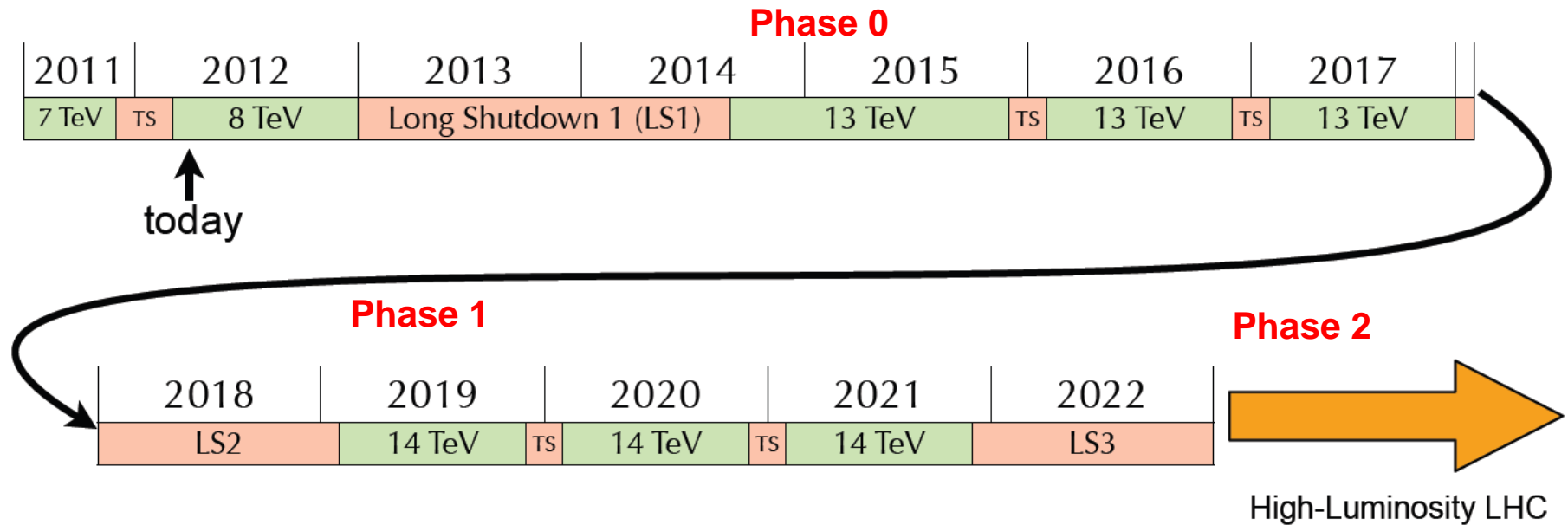
- Several upgrades planned for LS1 and LS2
- After LS3 high-luminosity era starts
- Examples for upgrades:
  - IBL (Phase 0)
  - 4-layer CMS Pixel, LHCb VELO upgrade (Phase 1)
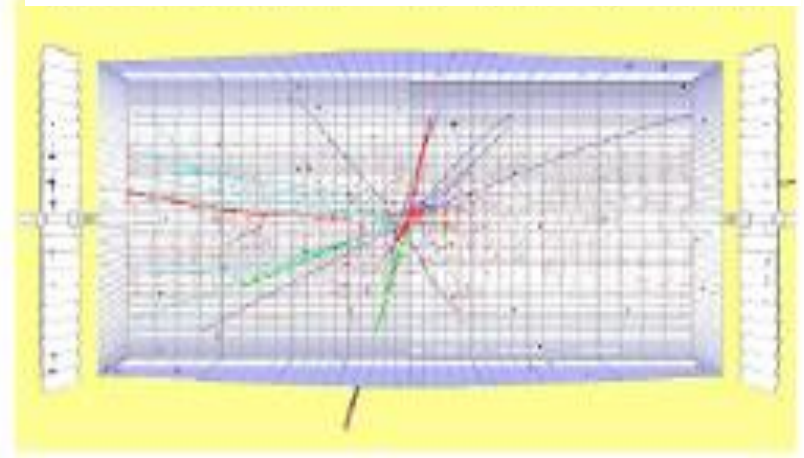 - new trackers for Phase 2
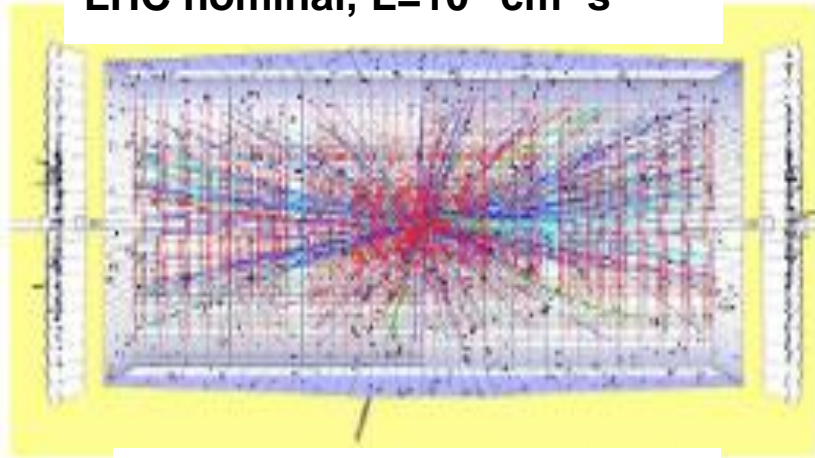
The high-luminosity LHC Challenge
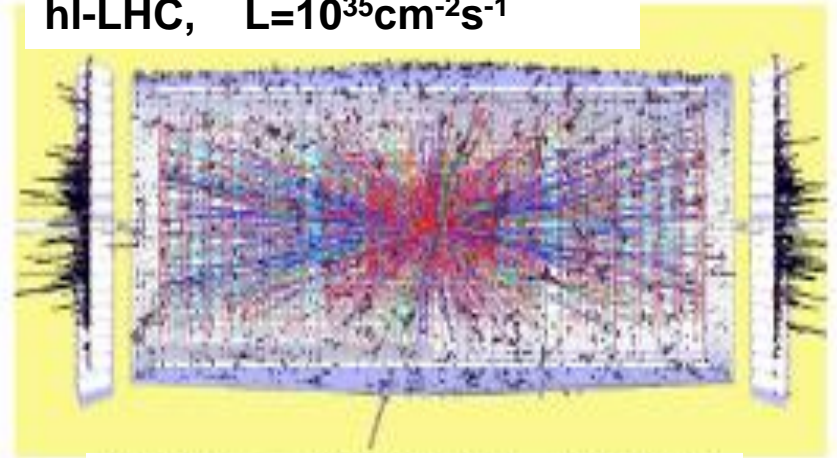
LHC initial,   L=10^{32}cm^{-2}s^{-1}

LHC initial,   L=10^{33}cm^{-2}s^{-1}
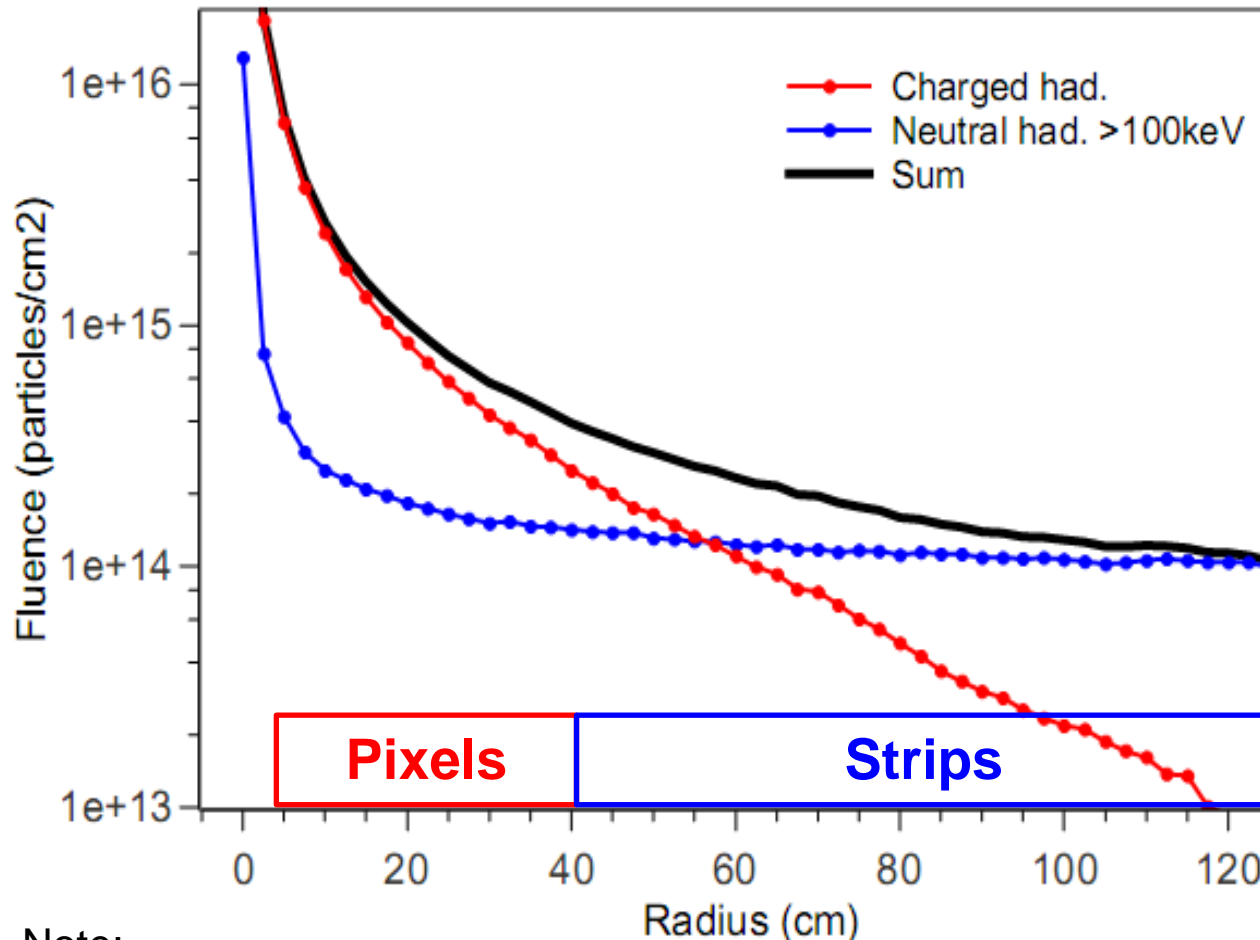

LHC nominal, L=10^{34}cm^{-2}s^{-1}

hl-LHC,   L=10^{35}cm^{-2}s^{-1}

Radiation Environment at the HL-LHC

What we expect in the CMS experiment (very similar to ATLAS)

$L_{int} = 3000\ fb^{-1}$ @14 TeV   z=0cm

S. Müller, PhD thesis, KIT, 2011

Radiation hardness requirements for:
- Innermost Pixels
$$\Phi_{eq} \approx 2 \times 10^{16}\ cm^{-2}$$
- Innermost Strips
$$\Phi_{eq} \approx 1 \times 10^{15}\ cm^{-2}$$

Occupancy influences choice of geometry: Pixel, strixel, strip
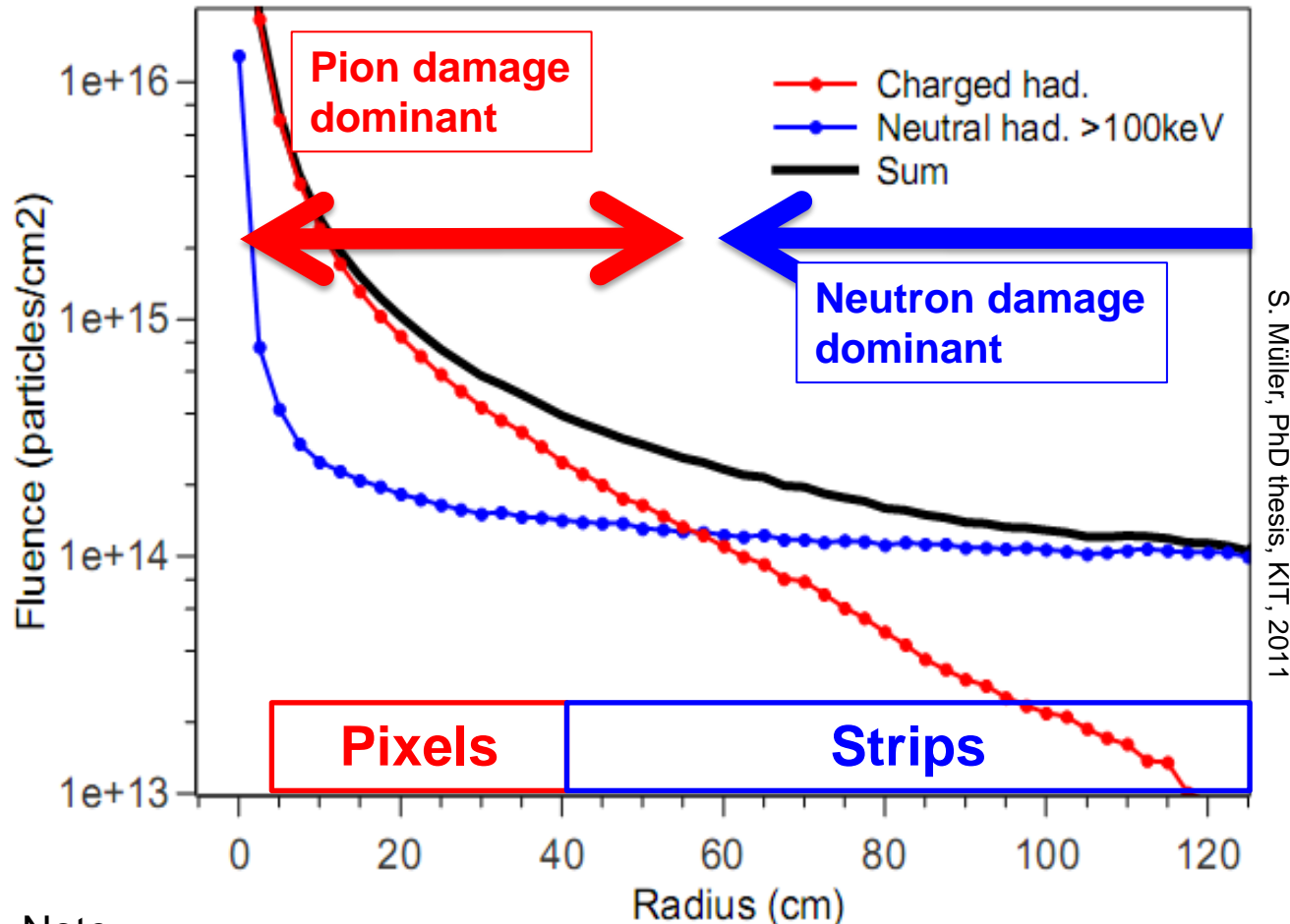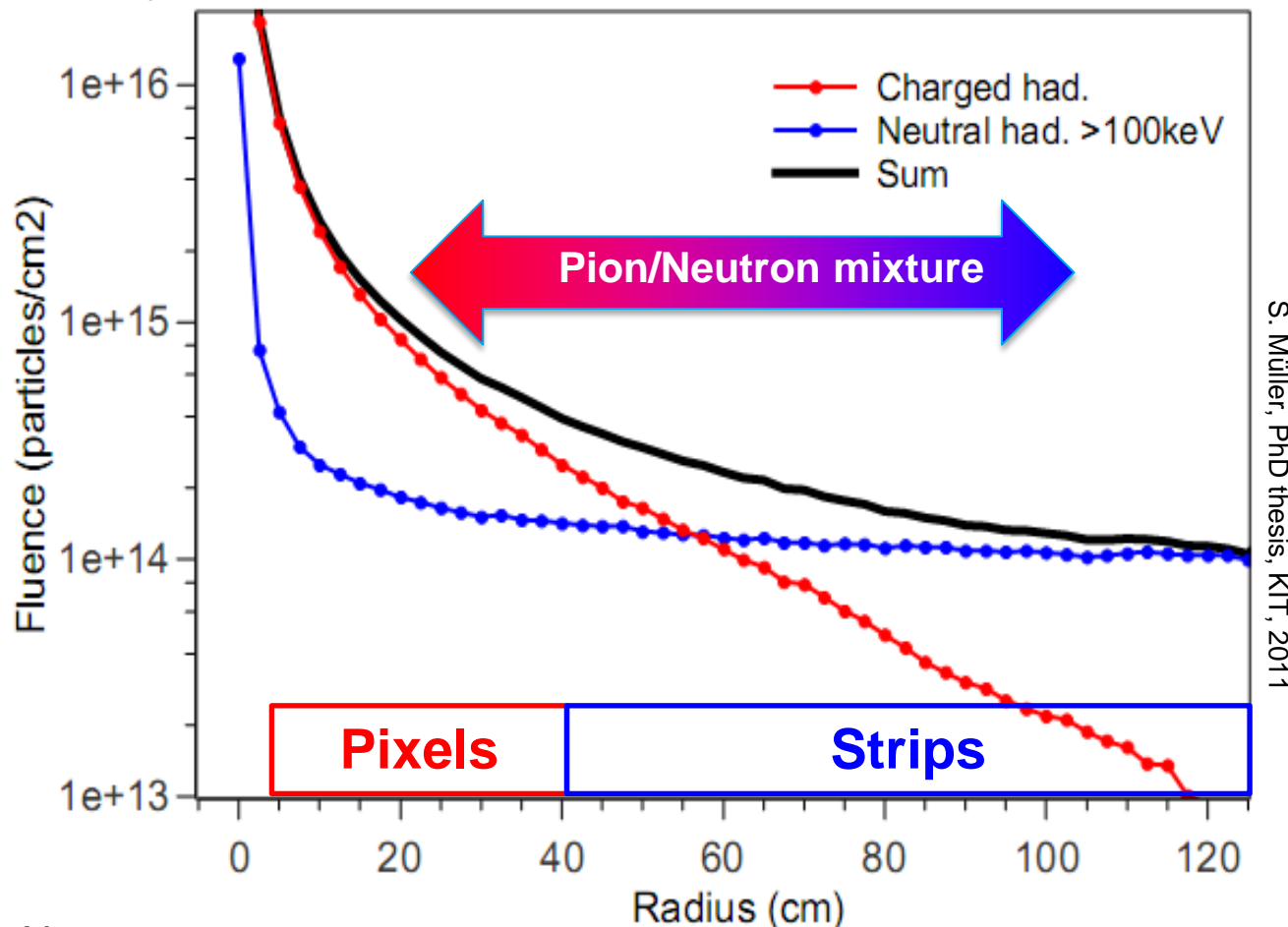
Note:
Particle Fluences are shown!

Radiation Environment at the HL-LHC

What we expect in the CMS experiment (very similar to ATLAS)

L_{int}=3000 fb^{-1} @14 TeV   z=0cm

Pion damage dominant

Charged had.
Neutral had. >100keV
Sum

Neutron damage dominant

Pixels

Strips

S. Müller, PhD thesis, KIT, 2011

Radiation hardness requirements for:
- Innermost Pixels
          $\Phi_{eq} \approx 2 \times 10^{16}$ cm^{-2}
- Innermost Strips
          $\Phi_{eq} \approx 1 \times 10^{15}$ cm^{-2}

Note:
Particle Fluences are shown!

What we expect in the CMS experiment (very similar to ATLAS)

$L_{int}=3000$ fb^{-1} @14 TeV   z=0cm

Fluence (particles/cm2) vs Radius (cm)

Legend:
- Charged had.
- Neutral had. >100keV
- Sum

Pion/Neutron mixture

Pixels   **Strips**

S. Müller, PhD thesis, KIT, 2011

Radiation hardness requirements for:
- Innermost Pixels
  $\Phi_{eq} \approx 2 \times 10^{16}$ cm^{-2}
- Innermost Strips
 $\Phi_{eq} \approx 1 \times 10^{15}$ cm^{-2}
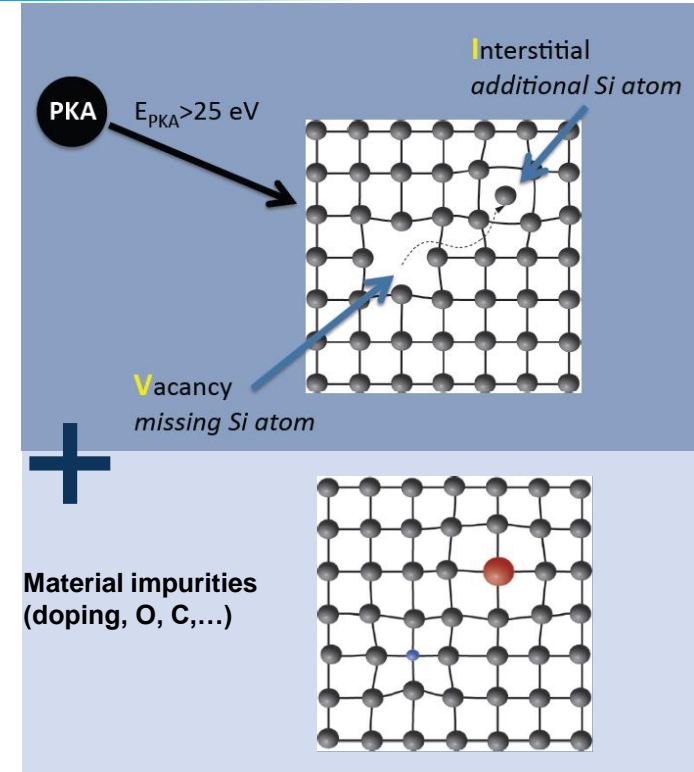
Note:
Particle Fluences are shown!

DESY

Radiation Damage in Silicon Sensors

AC coupled strip detector:

• Particles passing through silicon material loose energy through
- interaction with shell electrons (**I**onizing **E**nergy **L**oss)
  - ➜ surface damage (relevant for XFEL)
  - → local charges accumulate in surface
    (charges cannot recombine in insulating surface
     - amorphous Si, SiO_2
     thus it causes damage in the surface)
  - → damage caused primarily through photons, charged particles

  - → IEL is used for particle detection
  - → fast recombination in silicon bulk ➜ no damage in the bulk

- interaction with atomic core or whole atom (**N**on **I**onizing **E**nergy **L**oss)
  - ➜ bulk damage (relevant for LHC)
  - → Displacement of atoms in the lattice
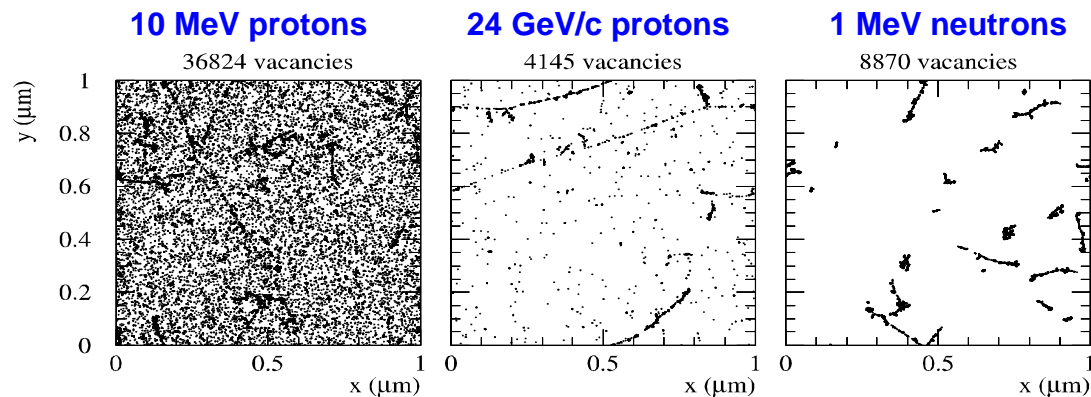 - → Caused by massive particles as protons, pions, neutrons
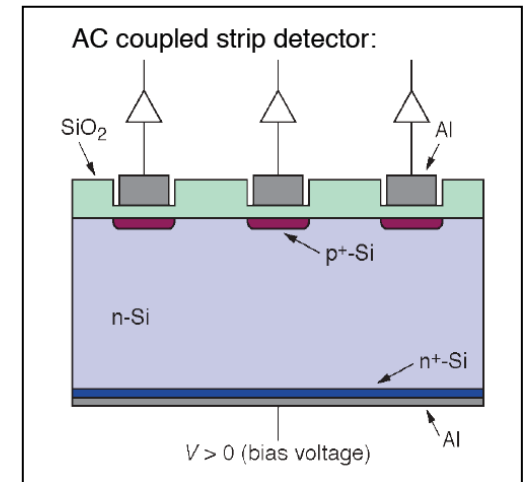
Radiation Damage – some Basics

- **P**rimary **K**nock on **A**tom displaced out of lattice site
  → Frenkel Pair
  E_d ~25eV displacement threshold Energy

- Interstitials and Vacancies are very mobile at T>150K
- → migrate through lattice
- → Annihilate (no damage remaining) or
- → React with each other and impurities (V_2, VO,…)

- Along path of recoil → formation of more defects

- At the end clusters (disordered regions) are formed
  E_c~5keV threshold Energy for clusters

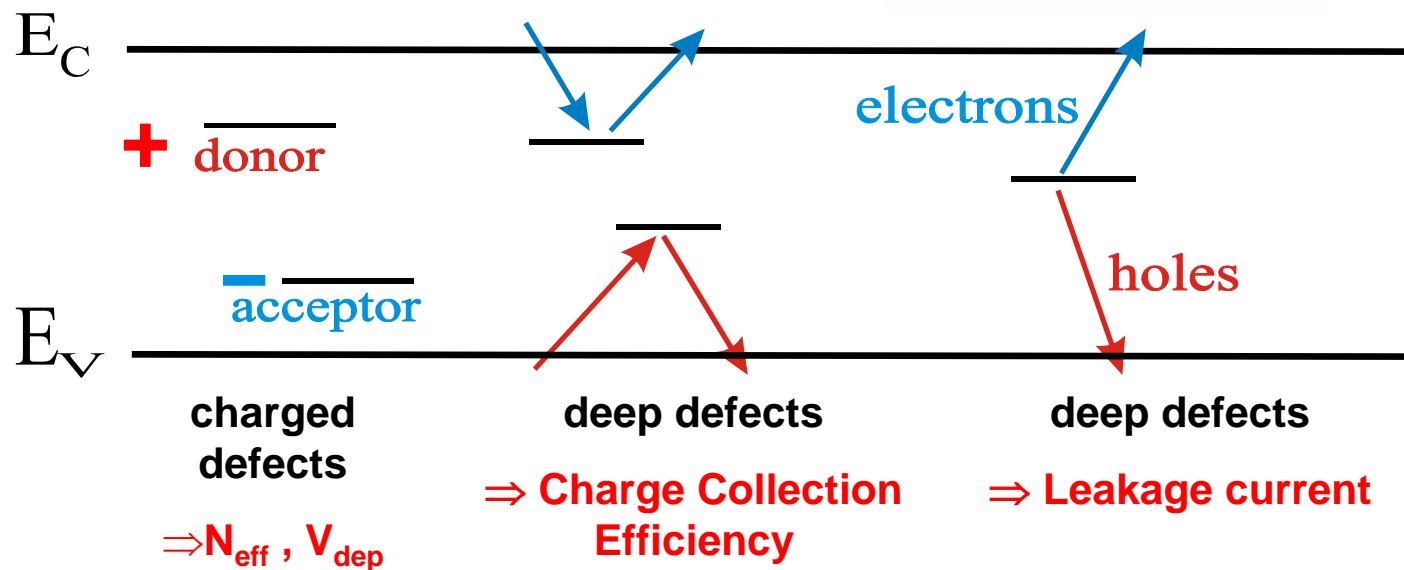**I**nterstitial
additional Si atom

PKA E_{PKA}>25 eV

Vacancy
missing Si atom

Material impurities
(doping, O, C,…)

Simulation:

Initial distribution of vacancies in (1μm)³ after 10¹⁴ particles/cm²

[Mika Huhtinen NIMA
491(2002) 194]

10 MeV protons
36824 vacancies

24 GeV/c protons
4145 vacancies

1 MeV neutrons
8870 vacancies

Radiation Damage in Silicon

- defects in the crystal
- point defects and "cluster" defects
➜ energy levels in the band gap filled

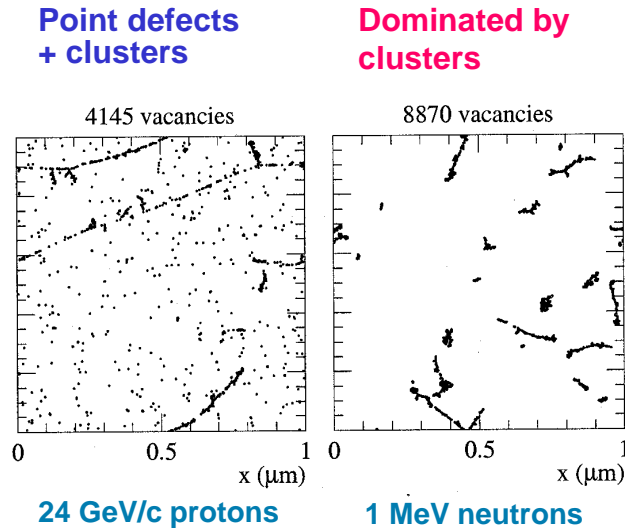E_C ——————————————————————————————

+ $\overline{\text{donor}}$ electrons

$\overline{\text{acceptor}}$

E_V ——————————————————————————————   holes

charged
defects

$\Rightarrow N_{eff}$, V_{dep}

deep defects

$\Rightarrow$ **Charge Collection**
Efficiency

deep defects

$\Rightarrow$ **Leakage current**

NIEL Scaling– Normalization of damage from different particles

Scale to "1 MeV neutron equivalent" with

Point defects + clusters

Dominated by clusters

Hardness factor:

$$\kappa = \frac{\int D(E)\phi(E)dE}{95\,MeV\,mb\cdot\Phi} = \frac{\Phi_{eq}}{\Phi}$$

4145 vacancies

8870 vacancies

24 GeV/c protons   **1 MeV neutrons**

> Proton damage can be scaled to neutron damage

> Proton & neutron damage ADD UP

> "1 MeV neutron equivalent"

1MeV
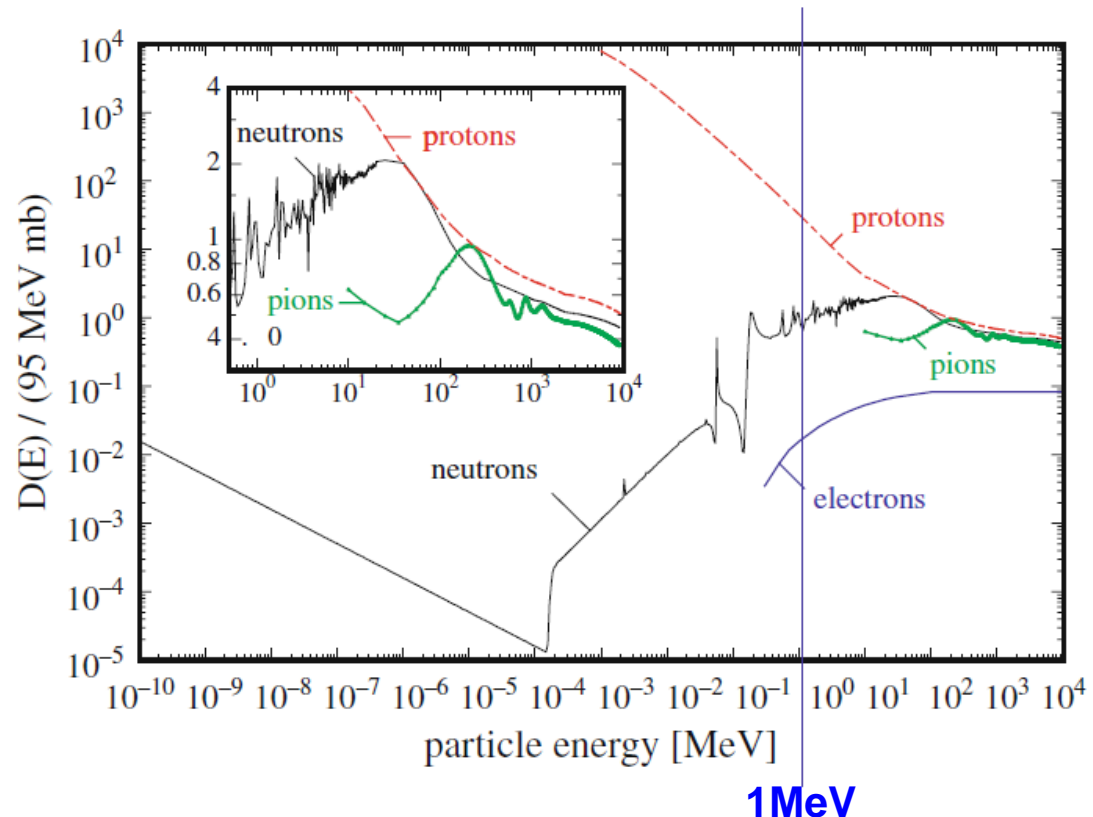
Radiation Damage: Leakage Current

…fluence dependent

[M.Moll PhD Thesis]
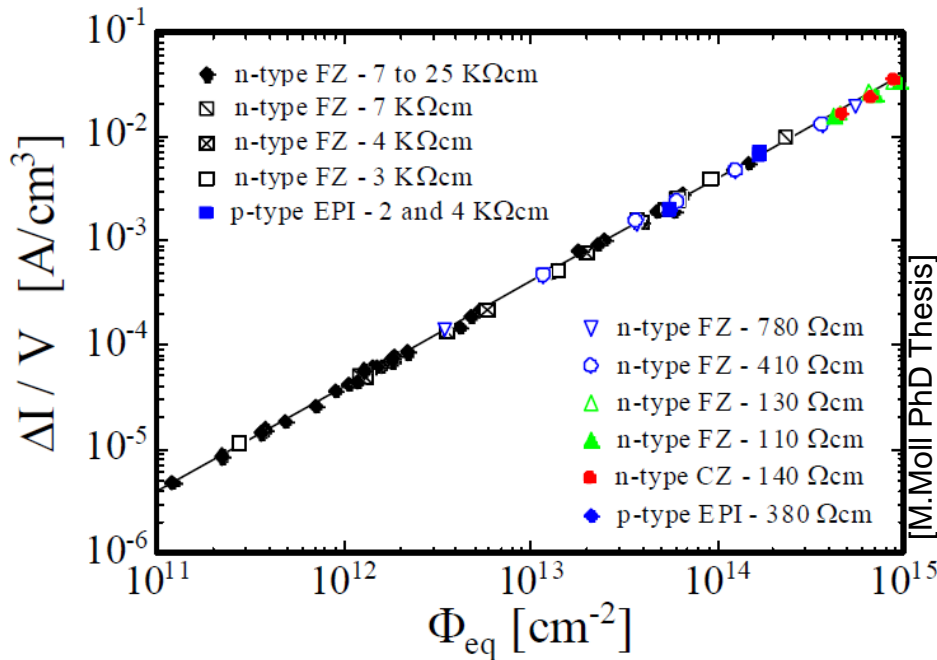
$$\Delta I = \alpha \cdot V \cdot \Phi_{eq}$$

Damage parameter α is universal
- independent of material
- Independent of type of irradiation

Deep defects act as generation centres

Increase of leakage current is due to radiation induced defects

Current increase results in
→ Increase of shot noise
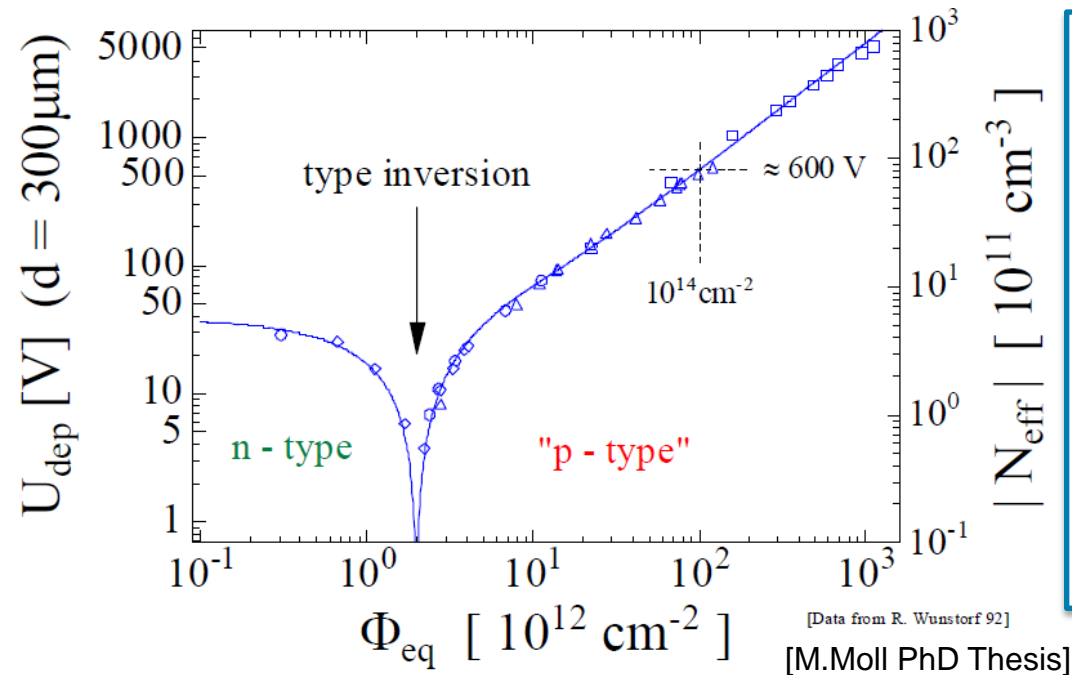→ Increase of power dissipation
→ Risk of thermal runnaway

Leakage current is strongly T dependent
(doubles every 8⁰C)

→ **Cooling helps!**

Down to ~-20⁰C for hl-LHC

…fluence dependence

[Data from R. Wunstorf 92]
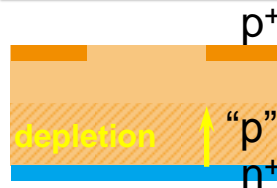
[M.Moll PhD Thesis]

$$V_{dep} = \frac{q_0}{\varepsilon\varepsilon_0} \cdot \left| N_{eff} \right| \cdot d^2$$

• Acceptors compensate original doping
• Type inversion from n- to p-type
• Increase of depletion voltage after Space Charge Sign Inversion
➔ Detector becomes p-in-p

➔ p-n-junction from wrong side
➔ Loss of resolution
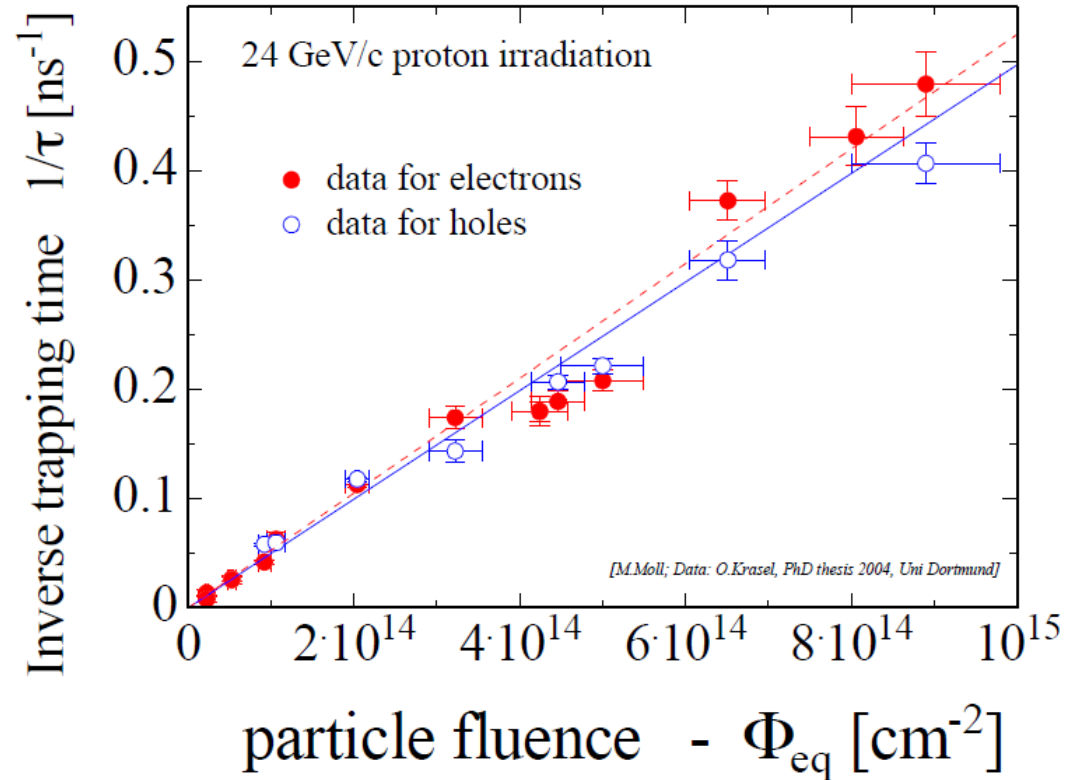

before inversion:

after inversion:

• Need depletion from strip-side!
• Change of N_{eff} depends on material!
➔ Needs prediction of N_{eff} for specific material

Radiation Damage: Trapping

- Defects act as trapping centres
  - ➔ Reduction of collected charge
- Trapping is dominant effect at $\Phi > 1 \times 10^{15}$ cm^{-2}

- Effective trapping times for e$^-$ und h$^+$
- Trapping of e$^-$ und h$^+$ similar
  - ➔ No influence of material seen

But:

- Collection time 3x smaller for e$^-$
  - ➔ Collect e$^-$!
- Needs n-side read-out

24 GeV/c proton irradiation

- ● data for electrons
- ○ data for holes

[M.Moll; Data: O.Krasel, PhD thesis 2004, Uni Dortmund]

Inverse trapping time $1/\tau$ [ns^{-1}]

particle fluence $- \Phi_{eq}$ [cm^{-2}]

$$\tau_{eff}(10^{15} n_{eq}) = 2 ns \qquad w = v_{sat}\tau_{eff} = 200 \mu m$$

$$\tau_{eff}(10^{16} n_{eq}) = 0.2 ns \qquad w = v_{sat}\tau_{eff} = 20 \mu m$$

How to obtain radiation-hard sensors
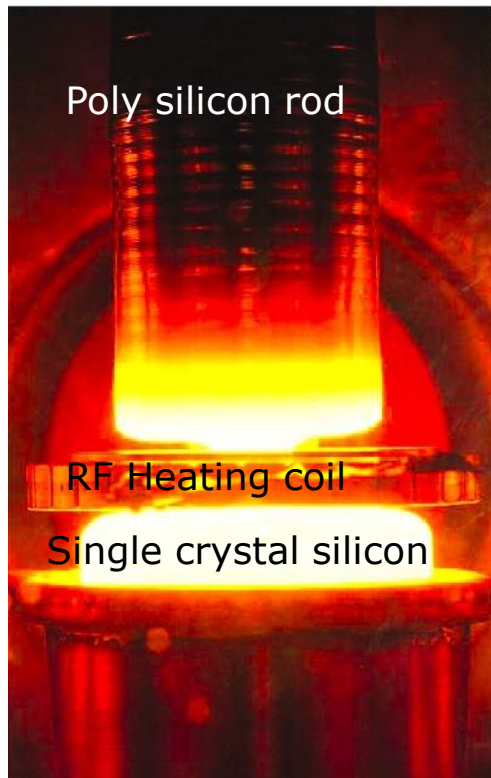
Material Engineering

- Silicon materials – FZ, MCZ, DOFZ, EPI
- Other semiconductors

Device Engineering

- p-in-n, n-in-n and n-in-p sensors
- 3D sensors
- thin devices
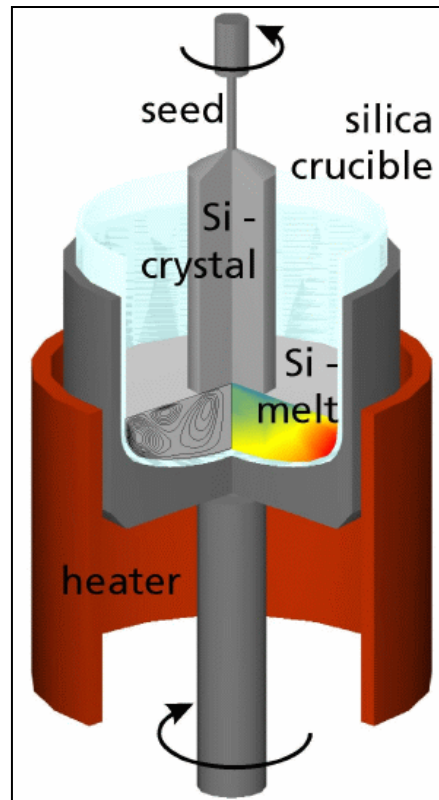
Material: FZ, MCz and EPI

Float Zone process (FZ)

Poly silicon rod

RF Heating coil

Single crystal silicon

- All strip detectors made of FZ
- Some pixels use DOFZ

Oxygen enrichment (DOFZ)
Oxidation of wafer at high temperatures

Czochralski silicon (Cz)

seed · silica crucible · Si - crystal · Si - melt · heater

- Used by IC industry
- Difficult to produce high resistivity

Epitaxial silicon (EPI)

- Chemical-Vapor Deposition (CVD) of Si

- up to 150 µm thick layers produced

- growth rate about 1µm/min

- CZ silicon substrate used
  ⇨ in-diffusion of oxygen

Effect of Oxygen

24 GeV/c proton irradiation

Standard FZ silicon

- <u>type inversion</u> at ~ 2×10^{13} p/cm^2
- strong N_{eff} increase at high fluence

Effect of Oxygen

24 GeV/c proton irradiation

Standard FZ silicon

- <u>type inversion</u> at ~ 2×10^{13} p/cm^2
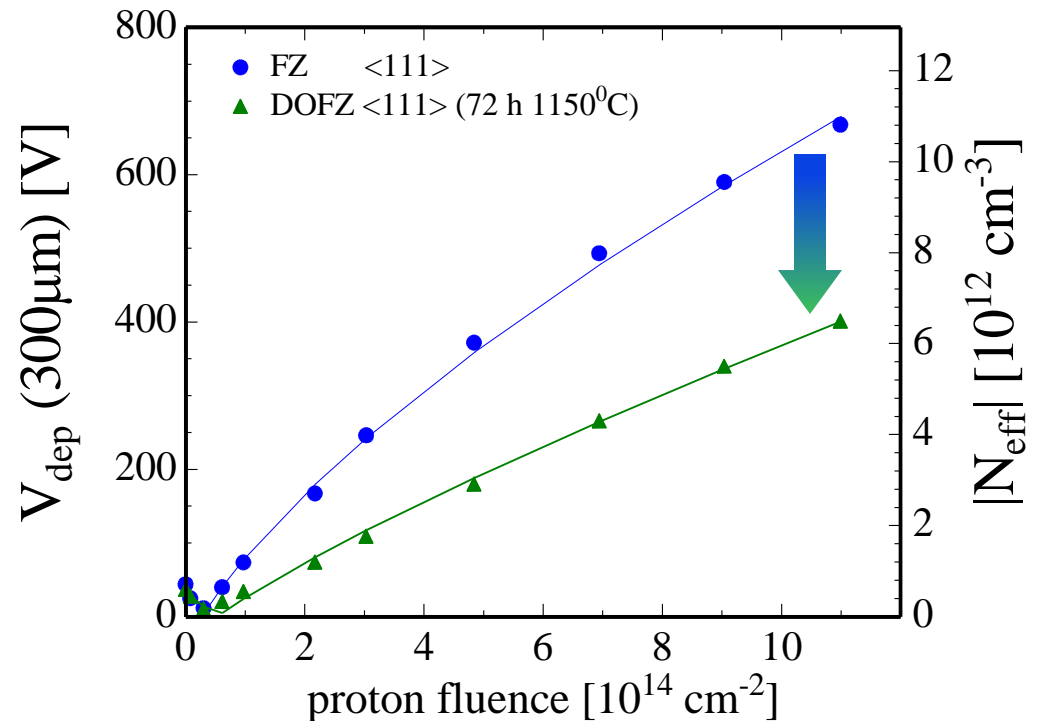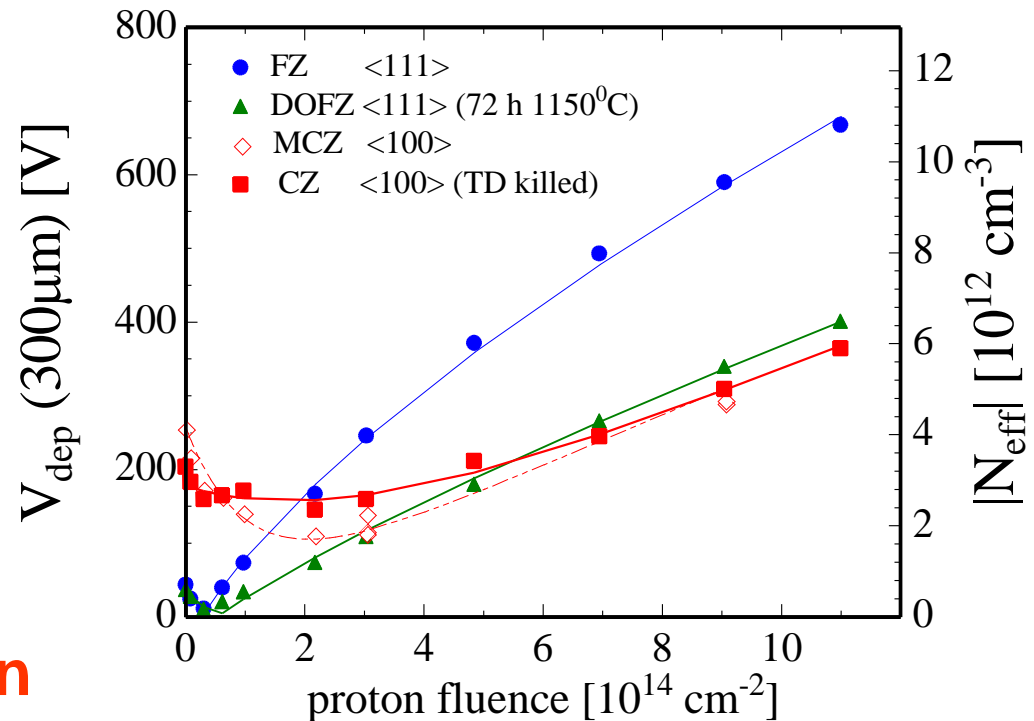- strong N_{eff} increase at high fluence

Oxygenated FZ (DOFZ)

- <u>type inversion</u> at ~ 2×10^{13} p/cm^2
- reduced N_{eff} increase at high fluence

Effect of Oxygen

24 GeV/c proton irradiation

Standard FZ silicon

- type inversion at ~ 2×10^{13} p/cm^2
- strong N_{eff} increase at high fluence

Oxygenated FZ (DOFZ)

- type inversion at ~ 2×10^{13} p/cm^2
- reduced N_{eff} increase at high fluence

CZ silicon and MCZ silicon

- "no type inversion" in the overall fluence range

Legend:
- FZ   <111>
- DOFZ <111> (72 h 1150^{0}C)
- MCZ   <100>
- CZ   <100> (TD killed)

y-axis left: V_{dep} (300μm) [V]
y-axis right: $|N_{eff}|$ [10^{12} cm^{-3}]
x-axis: proton fluence [10^{14} cm^{-2}]

- **Common to all materials** *(after hadron irradiation, not after γ irradiation)***:**
  - **reverse current increase**
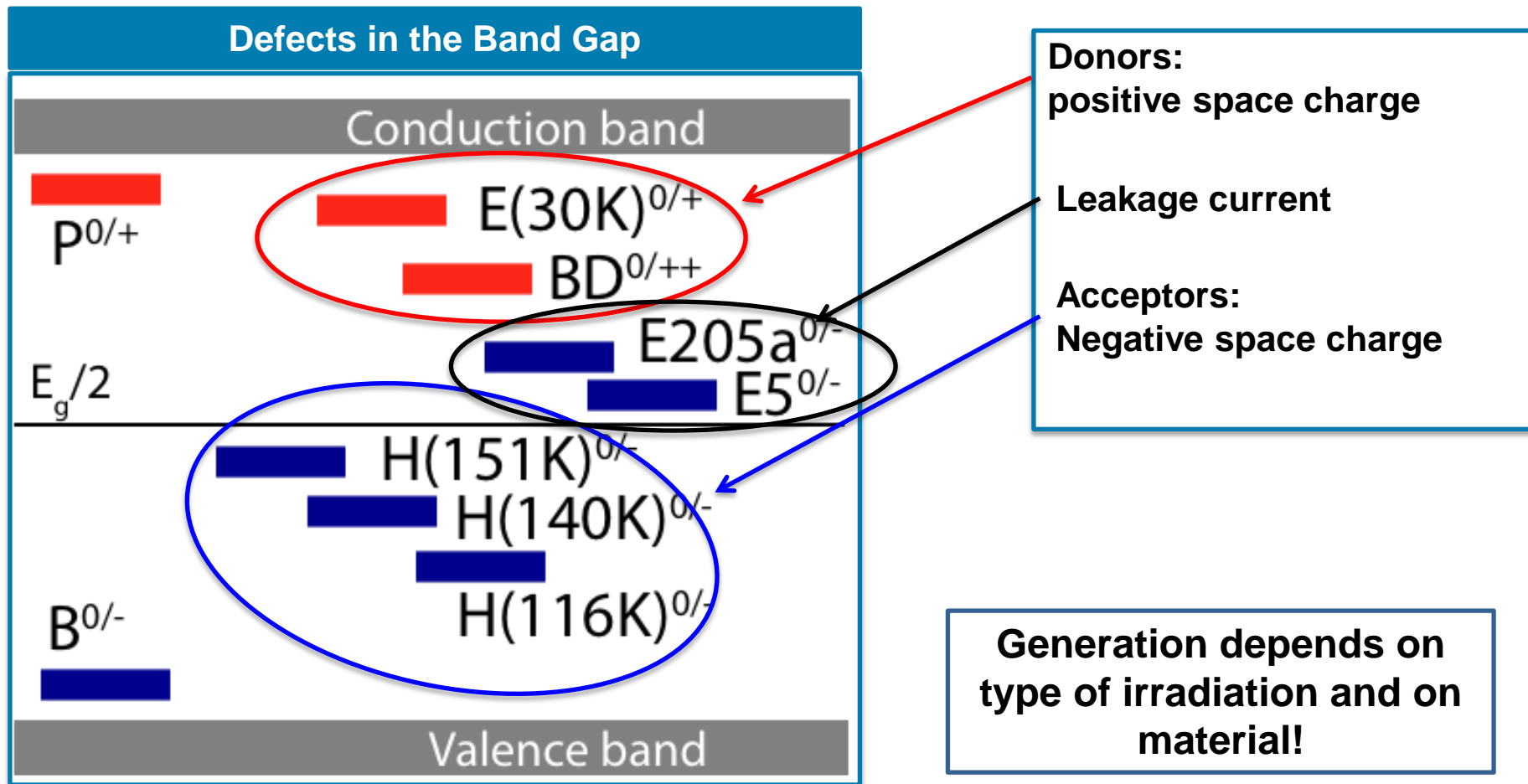 - **increase of trapping (electrons and holes) within ~ 20%**

- Epitaxial silicon irradiated with <u>23 GeV protons</u> vs <u>reactor neutrons</u>
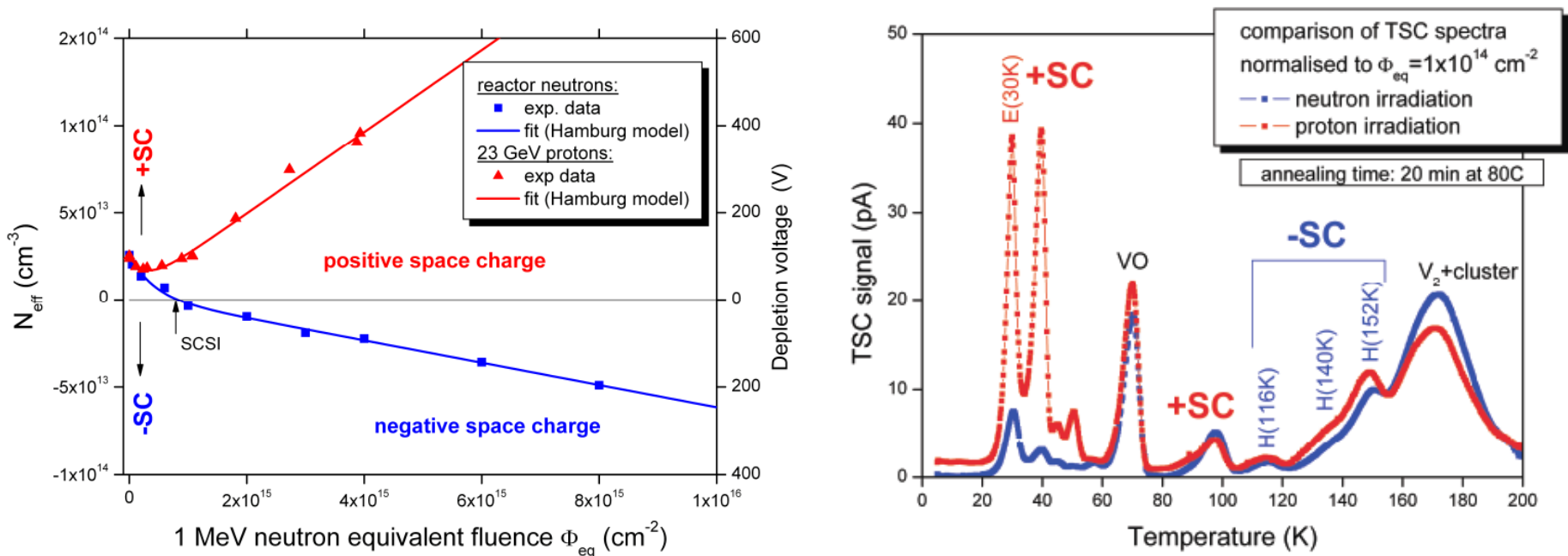
- SCSI after neutrons but not after protons !
- donor generation enhanced after proton irradiation
- microscopic defects explain macroscopic effect at low Φ_{eq}

[Pintilie, Lindstroem, Junkes, Fretwurst, NIM A 611 (2009) 52–68]

Radiation-induced Defects

Defects in the Band Gap

Conduction band

$P^{0/+}$

$E(30K)^{0/+}$

$BD^{0/++}$

$E205a^{0/-}$

$E5^{0/-}$

$E_g/2$

$H(151K)^{0/-}$

$H(140K)^{0/-}$

$H(116K)^{0/-}$

$B^{0/-}$

Valence band

Donors:
positive space charge

Leakage current

Acceptors:
Negative space charge

Generation depends on type of irradiation and on material!

DESY

Irradiations in mixed fields

Expose FZ and MCz sensors to
- Pions or Protons first
- Neutrons on top
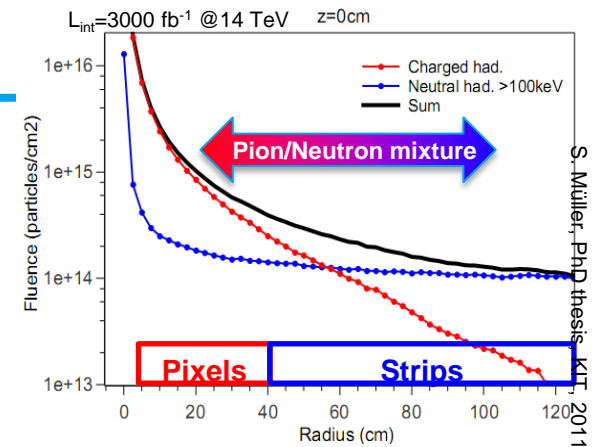
FZ: damage accumulated
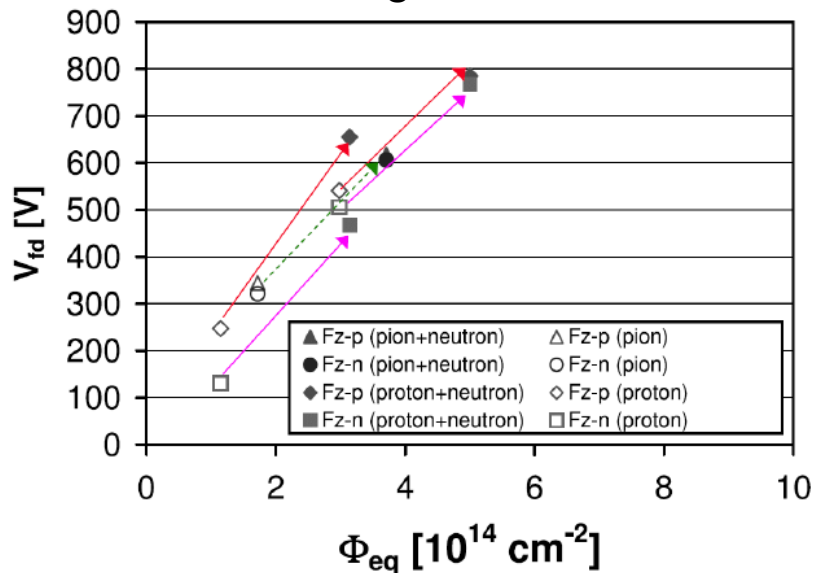
MCz: damage compensated
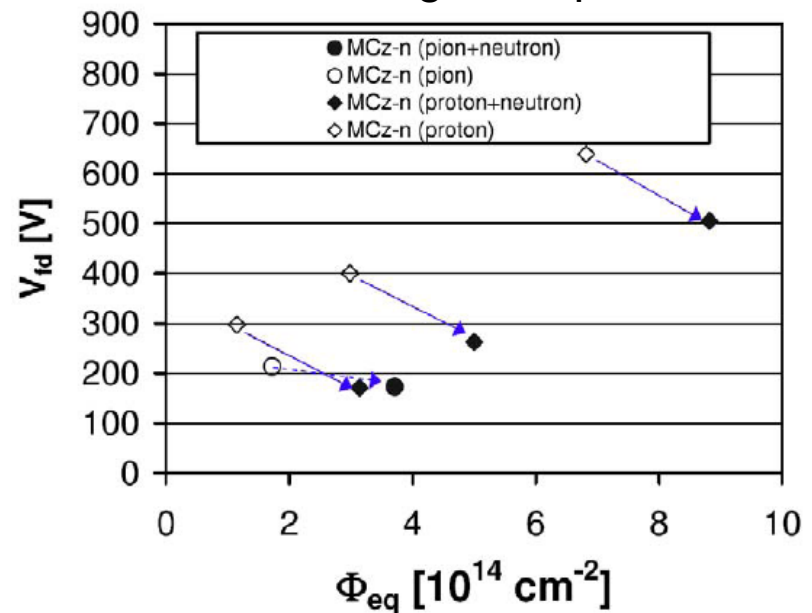
→ donors introduced in p irradiation compensated by acceptors introduced in n irradiation

NIEL scaling – does it really work??
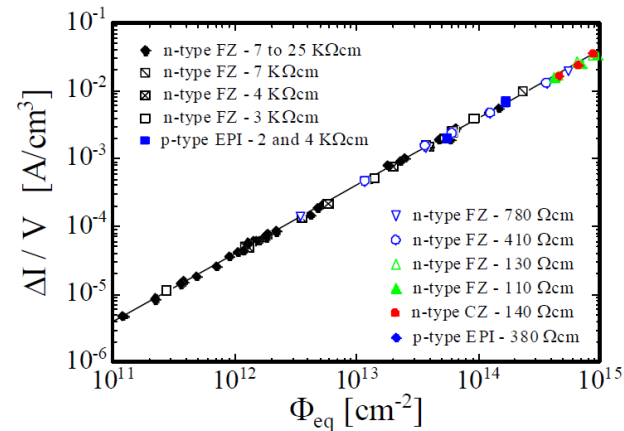
> Be careful!

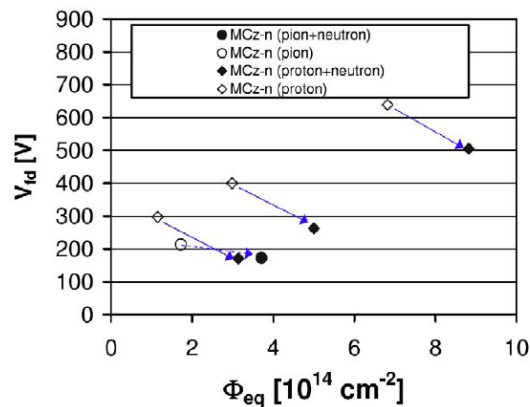> NIEL Scaling works extremely well for leakage current

  - Independent of particle type, material
  - Can be used as fluence monitor
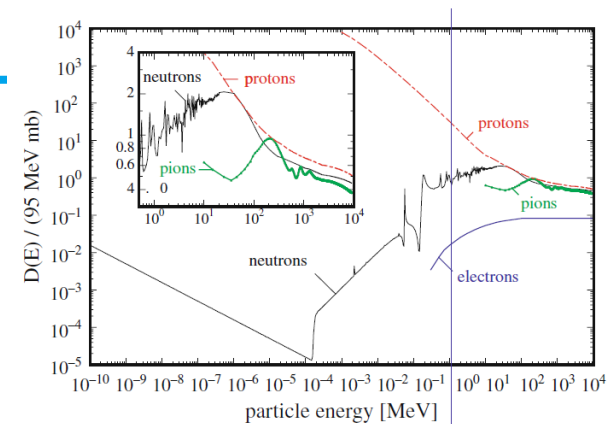
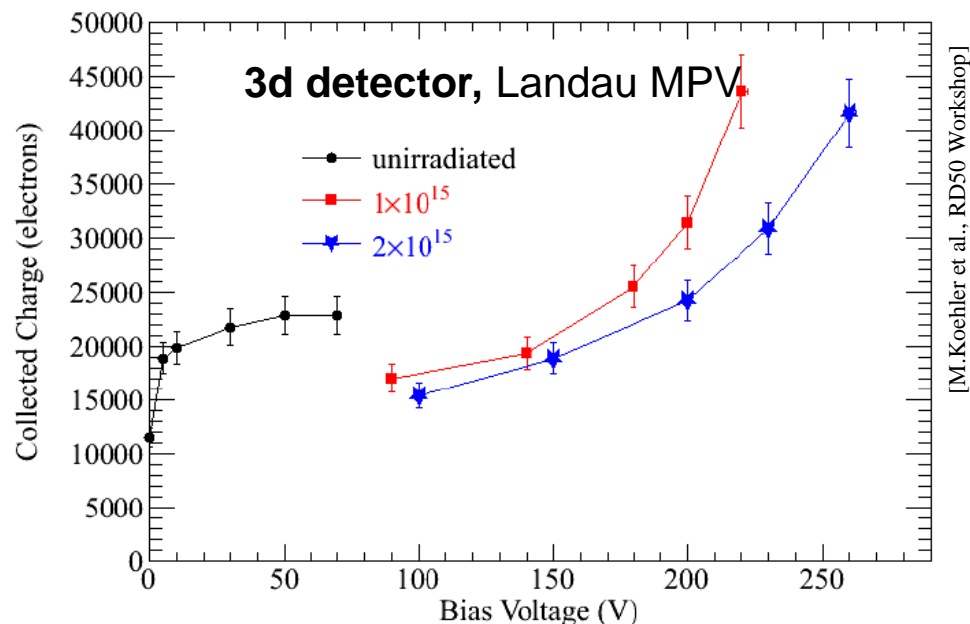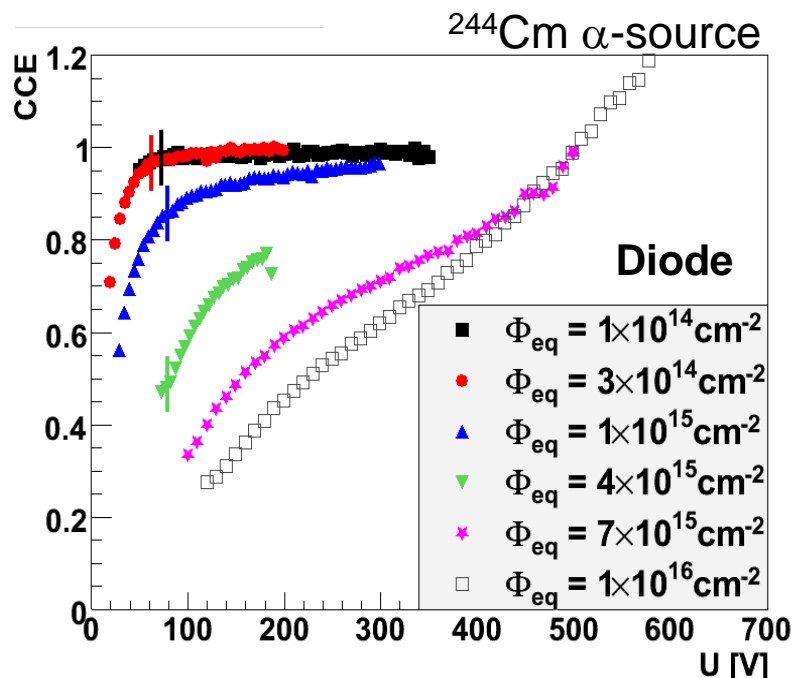> For new (oxygen rich) materials NIEL Scaling does not work!

> Damage depends on particle type and material

  - Neutrons, protons, pions ?
  - Which energy ?
  - What type of material concerning initial N_{eff}, content of Oxygen, Carbon,…?

Charge Multiplication – Signal Enhancement

Charge Collection Efficiency (CCE) exceeds 1
Observed in simple diodes, planar strips, pixels and 3d devices

^{244}Cm α-source

Diode

- ■ $\Phi_{eq} = 1 \times 10^{14} \text{cm}^{-2}$
- ● $\Phi_{eq} = 3 \times 10^{14} \text{cm}^{-2}$
- ▲ $\Phi_{eq} = 1 \times 10^{15} \text{cm}^{-2}$
- ▼ $\Phi_{eq} = 4 \times 10^{15} \text{cm}^{-2}$
- ✳ $\Phi_{eq} = 7 \times 10^{15} \text{cm}^{-2}$
- □ $\Phi_{eq} = 1 \times 10^{16} \text{cm}^{-2}$

J.Lange et al., 13th RD50 Workshop, June 2009

3d detector, Landau MPV

- unirradiated
- 1×10^{15}
- 2×10^{15}

[M.Koehler et al., RD50 Workshop]

Explanation: Avalanche multiplication in high field region

Can this effect be used for particle detectors?
How do noise, S/N and resolution behave?

Charge Multiplication - Trenching

P-type strip detector with small gain ➔ Similar signal before and after irradiation
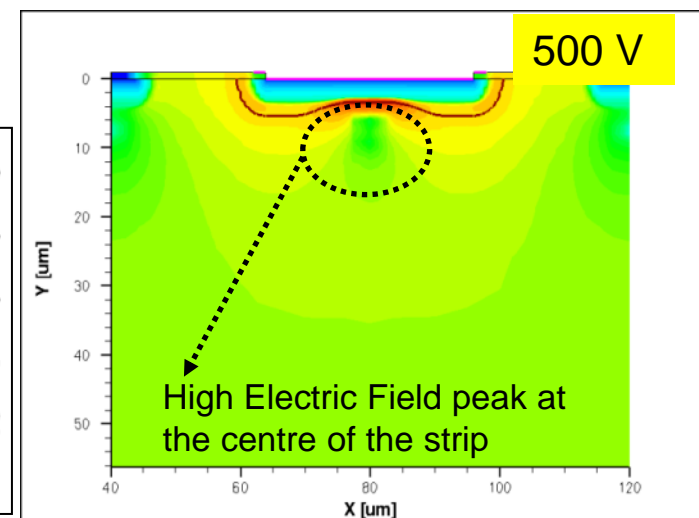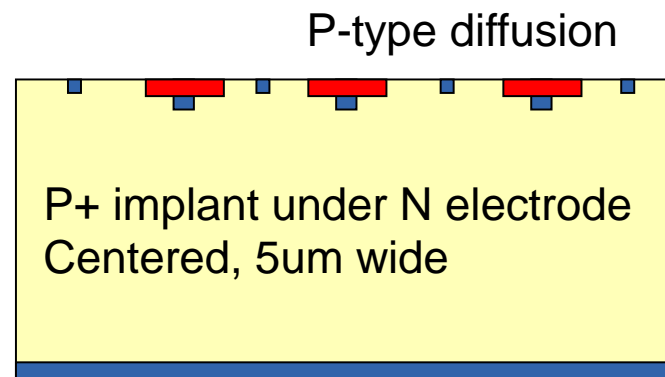
- Gain limited between 2 and 10

- Multiplication occurs at low bias voltage

Problems:

Avoid Crosstalk

Avoid exceeding the dynamic range of

readout electronics

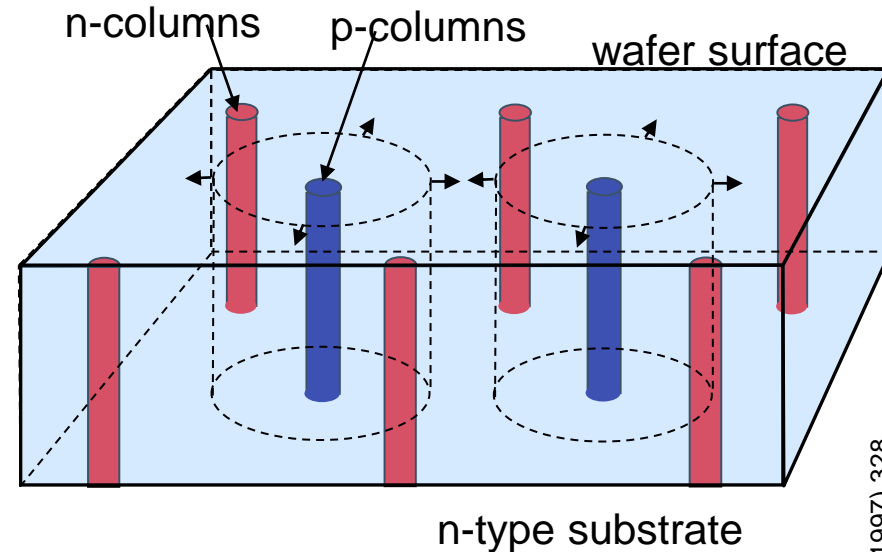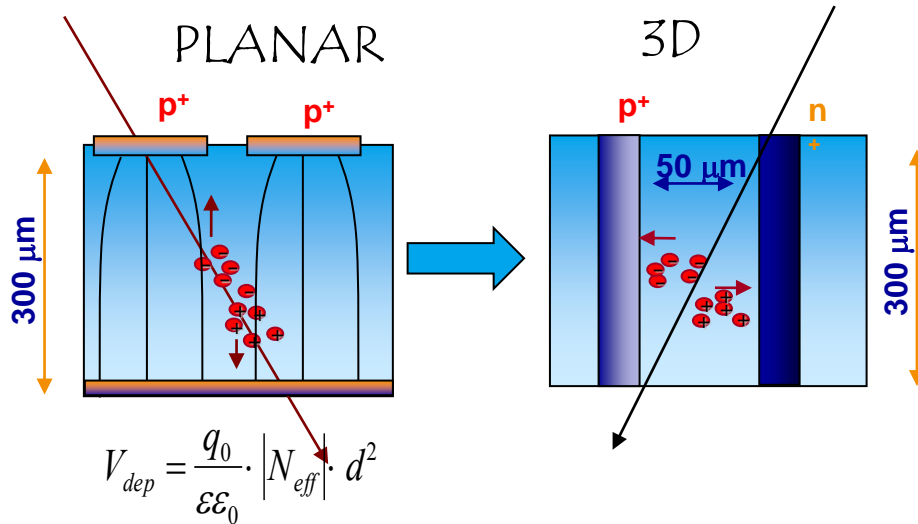Avoid higher capacitance -> Higher noise

P-type diffusion

P+ implant under N electrode
Centered, 5um wide

First production of structures finished
They work!
➔ CM observed

Problems:
• Leakage current high
• High cross talk

500 V

High Electric Field peak at
the centre of the strip

3d detectors - concept

PLANAR

p^+ p^+

300 μm

$$V_{dep} = \frac{q_0}{\varepsilon\varepsilon_0} \cdot \left| N_{eff} \right| \cdot d^2$$

3D

p^+ n $^+$

50 μm

300 μm

n-columns   p-columns   wafer surface

n-type substrate

- **"3D" electrodes:** - narrow columns along detector thickness,
  - diameter: 10μm, distance: 50 - 100μm

- **Lateral depletion:** - lower depletion voltage needed
  - thicker detectors possible
  - fast signal
  - radiation hard

low-field region

STC

p+
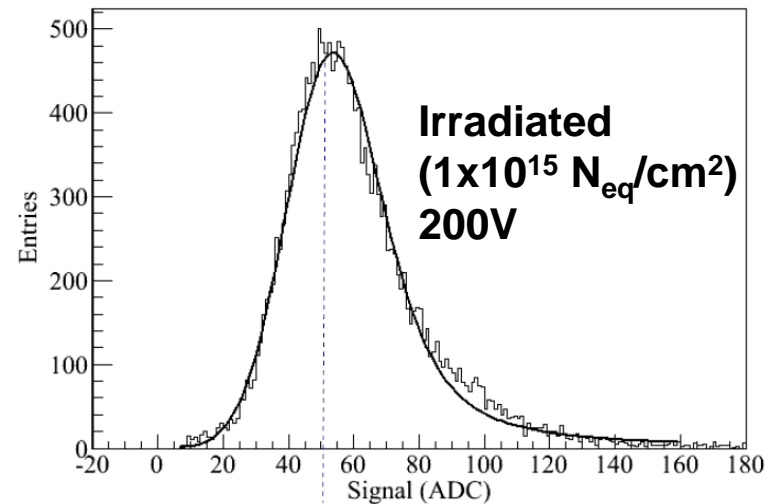
n+

DDTC

p+

n+

200μm

3d detectors
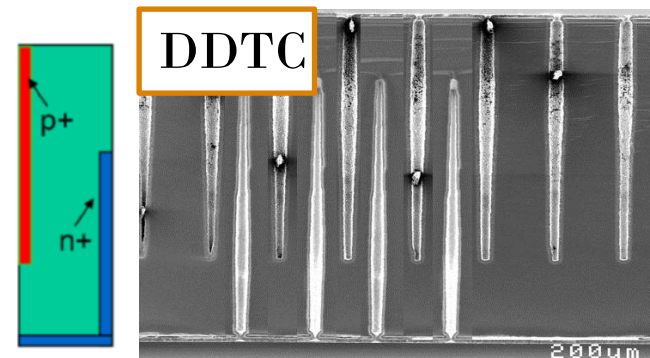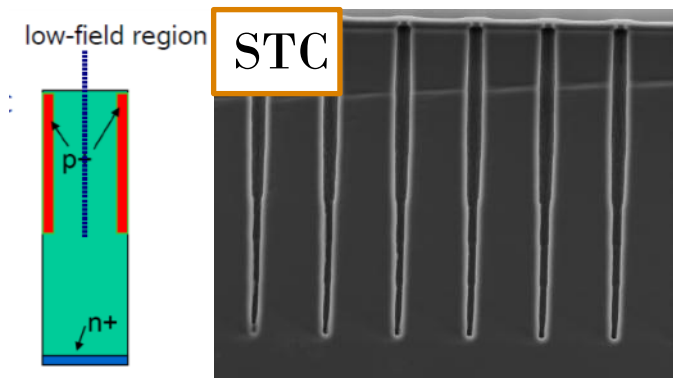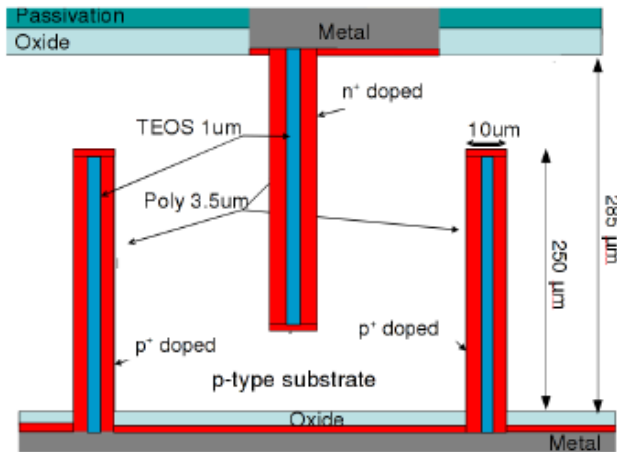
- CNM Double Sided 3d Sensors in SPS Testbeam

- Irradiation at the Karlsruhe cyclotron with 25MeV protons

- Higher signal after irradiation than before
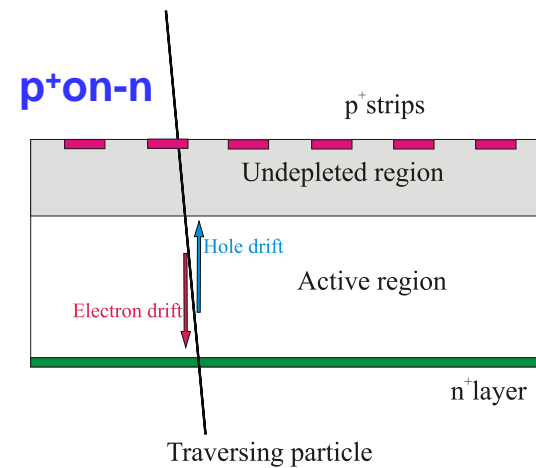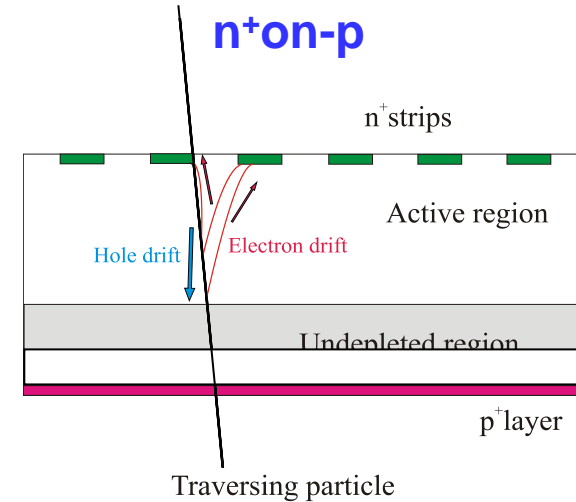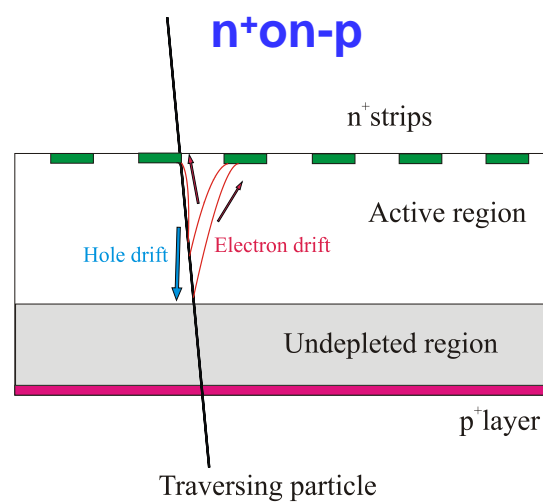 → **Charge multiplication**

Unirradiated 70V

Landau MPV: 35 ADC

Irradiated (1x10^{15} N$_{eq}$/cm^2) 200V
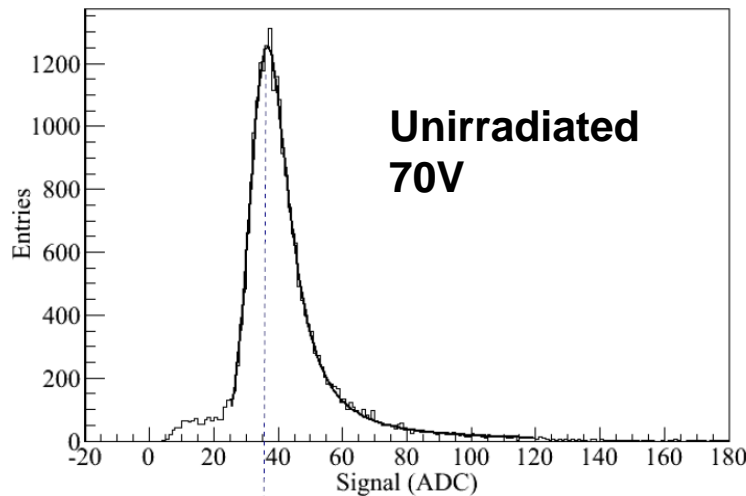
Landau MPV: 49 ADC

P-type silicon

n-type silicon after high fluences:
(type inverted)

p-type silicon after high fluences:
(still p-type)

p$^+$on-n

p^+strips

Undepleted region

Hole drift

Electron drift

Active region

n^+layer

Traversing particle

n$^+$on-p

n^+strips

Active region

Hole drift   Electron drift

Undepleted region

p^+layer

Traversing particle

n$^+$on-p

n^+strips

Active region

Hole drift   Electron drift

Undepleted region

p^+layer

Traversing particle

p-on-n silicon, under-depleted:

- **Charge spread – degraded resolution**

- **Charge loss – reduced CCE**

n-on-p silicon, under-depleted:

- **Limited loss in CCE**

- **Less degradation with under-depletion**

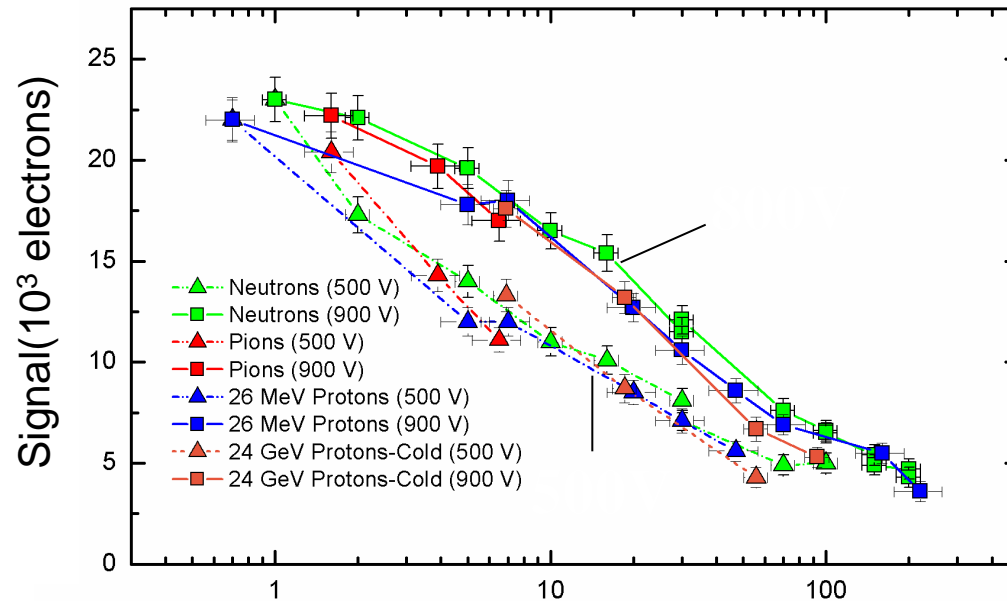- **Collect electrons (3 x faster than holes)**

Dominant junction close to n+ readout strip for FZ n-in-p

Comments:
- Instead of n-on-p also n-on-n devices could be used

FZ n-in-p microstrip detectors (n, p, p - irrad)

> n-in-p microstrip p-type FZ detectors (Micron, 280 or 300μm thick, 80μm pitch, 18μm implant)
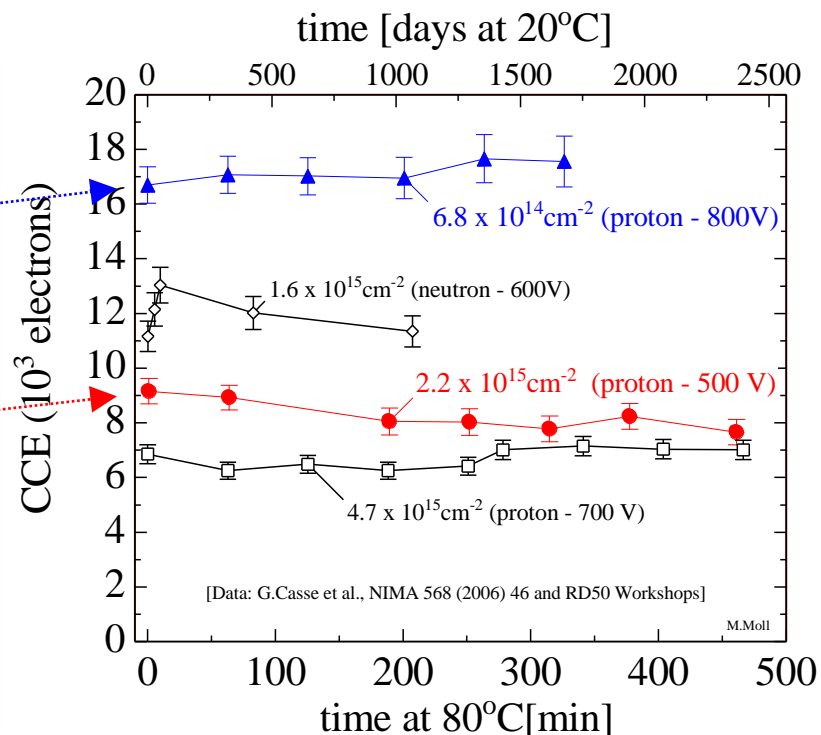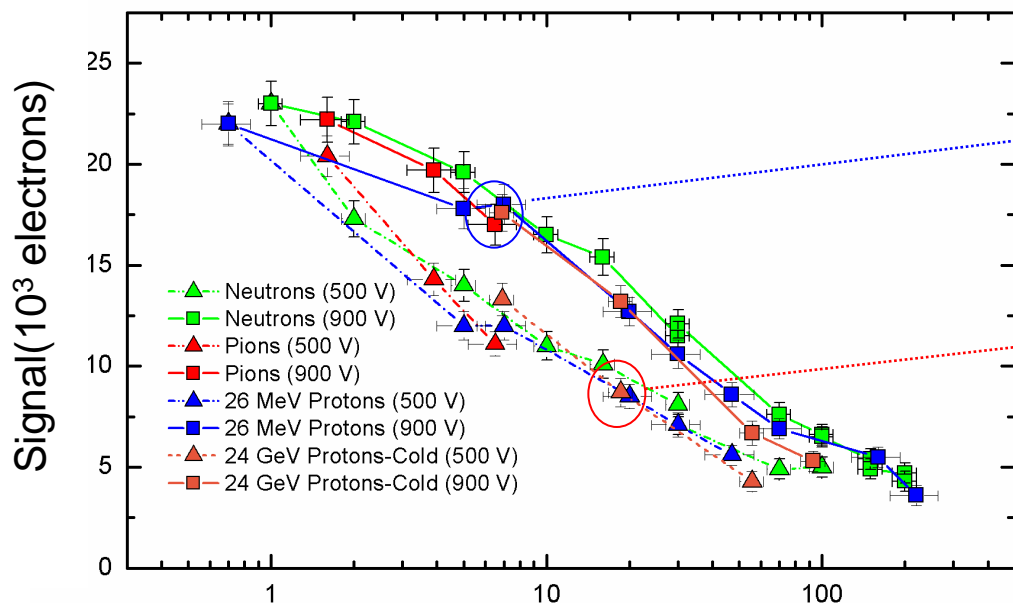
> Detectors read-out with 40MHz (SCT 128A)

- CCE: ~7300e (~30%)
        after ~ 1$\times$10^{16}cm^{-2} 800V
- n-in-p sensors are strongly considered for ATLAS upgrade (previously p-in-n used)

FZ n-in-p microstrip detectors (n, p, p - irrad)

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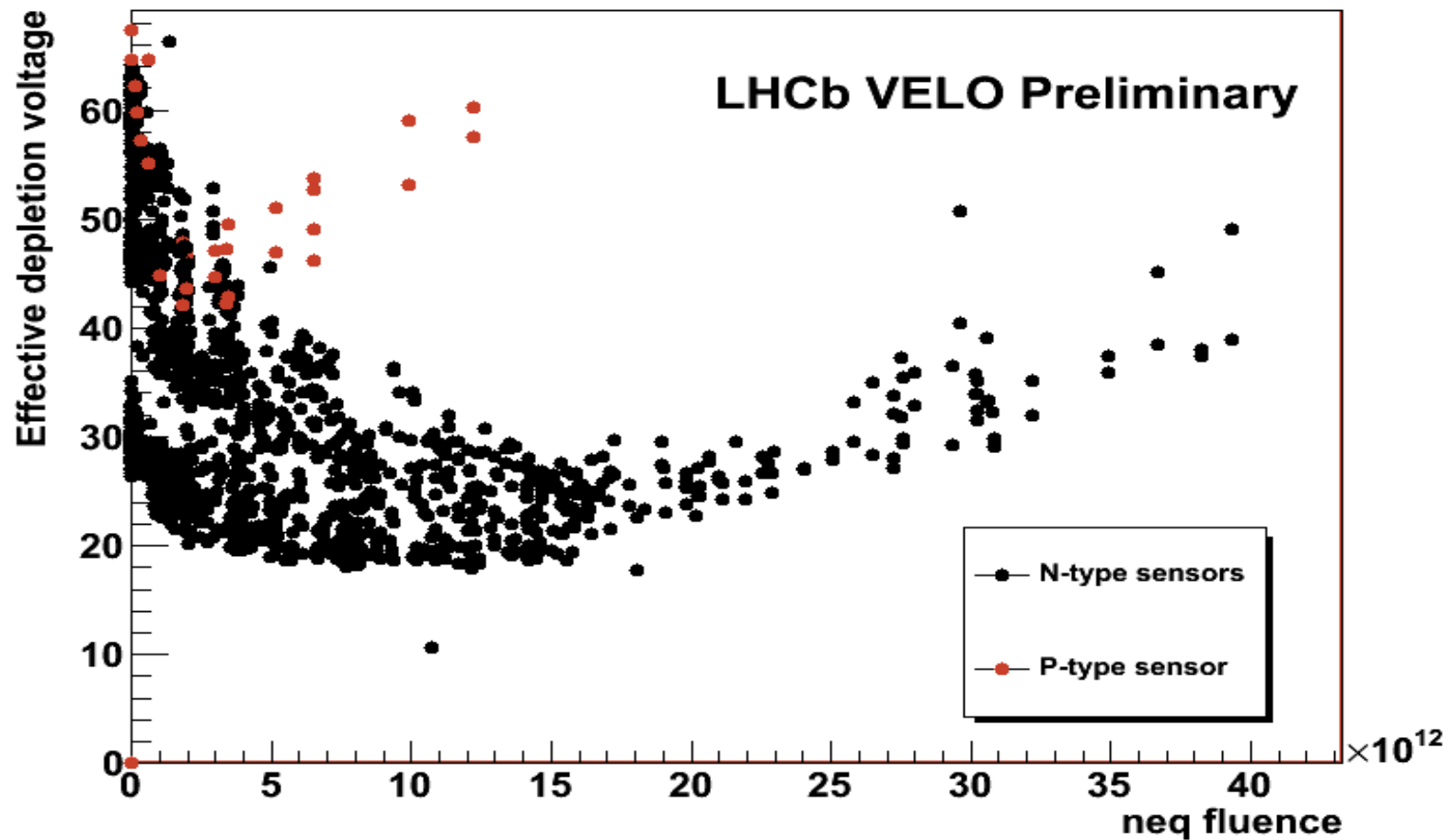[A.Affolder, Liverpool, RD50 Workshop, June 2009]

- CCE: ~7300e (~30%)
  after ~ 1×10^{16}cm^{-2} 800V
- n-in-p sensors are strongly considered for ATLAS upgrade (previously p-in-n used)

- no reverse annealing in CCE measurements
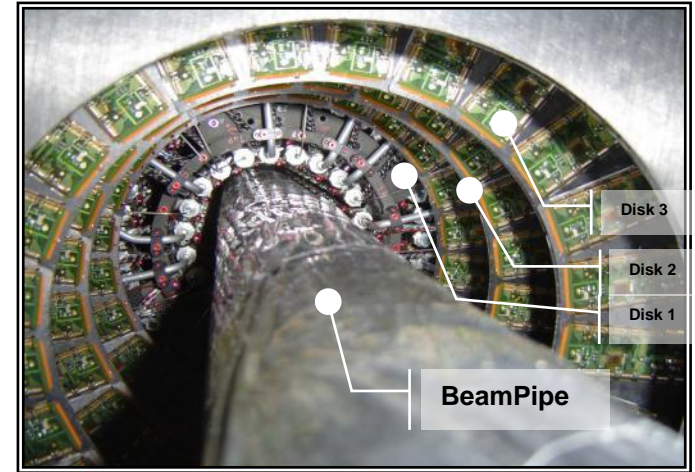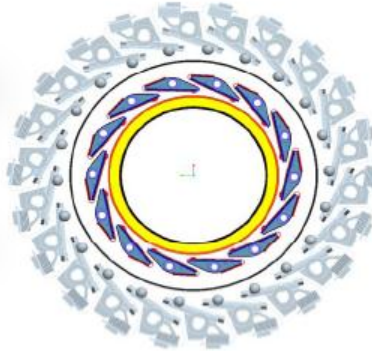 for neutron and proton irradiated detectors

Effective depletion voltage vs fluence

The ATLAS Insertable B-Layer (2013/14)

- 4th layer inside existing detector
- 3.4 cm to the interaction point
- smaller pixels (50 x 250 μm^2)
- better sensors, better R/O chip
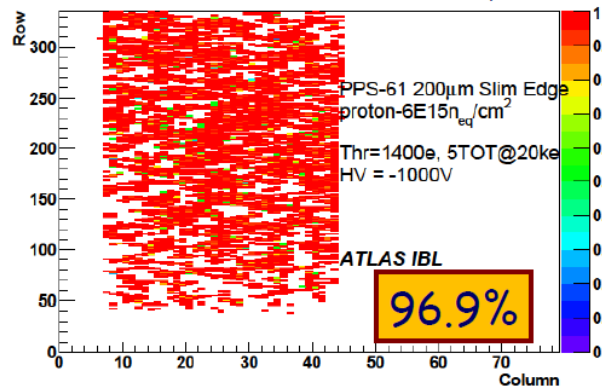

Disk 3
Disk 2
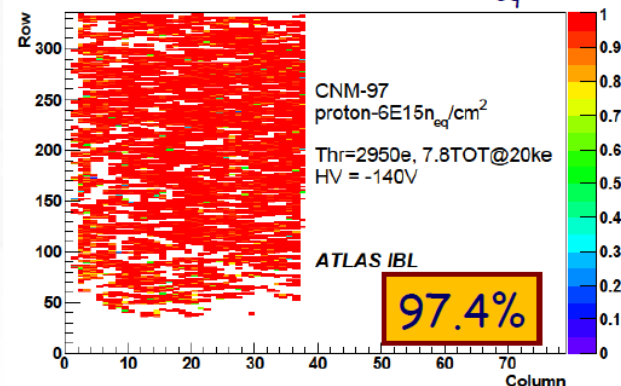Disk 1
BeamPipe

$\Rightarrow$ Will be equipped with
- ¼ 3d sensors in case of sufficient yield
- oxygenated n-in-n silicon 200 µm thick

Full sensor efficiency map for an irradiated planar and a 3D sensor

SCC61: Planar 6x10^{15} $n_{eq}cm^{-2}$

SCC97: 3D CNM 6x10^{15} $n_{eq}cm^{-2}$


PPS-61 200µm Slim Edge
proton-6E15n$_{eq}$/cm^2

Thr=1400e, 5TOT@20ke
HV = -1000V

ATLAS IBL
96.9%

CNM-97
proton-6E15n$_{eq}$/cm^2

Thr=2950e, 7.8TOT@20ke
HV = -140V

ATLAS IBL
97.4%

[I.Rubinskiy, 8th Hiroshima Symposium]

# Detector systems for the LHC upgrade – CMS pT Modules

- Need to reduce data rate --> particle momentum estimated in module

- Modules to provide trigger signals for high-pT tracks → use in level-1 trigger

- two parallel sensors at distance 1-4mm
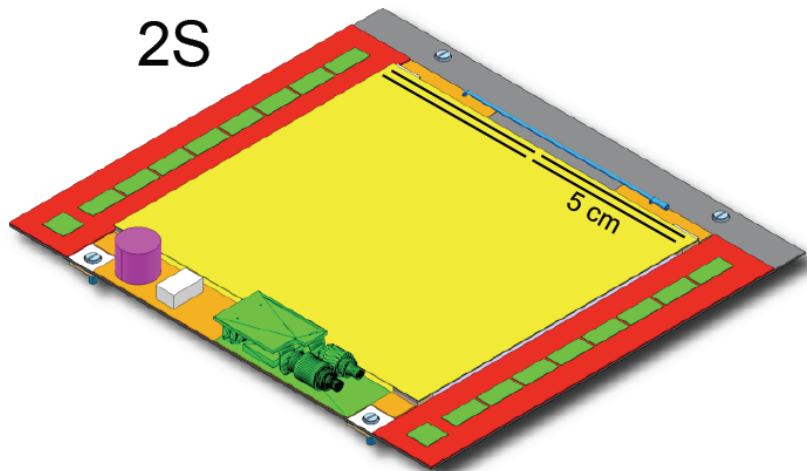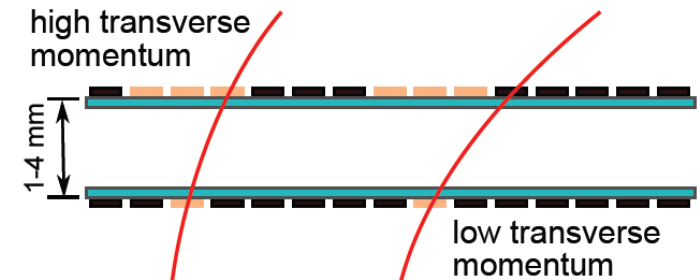
2S:Module with two strip sensors

2 x AC coupled strip sensor with 90 μm pitch
Area: 10 x 10 cm
Strips: 2 x 1016 sensor
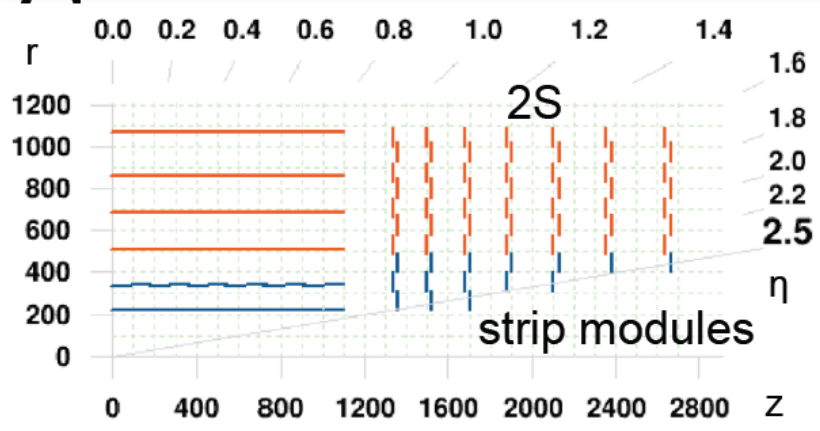= 4064 Channels per module
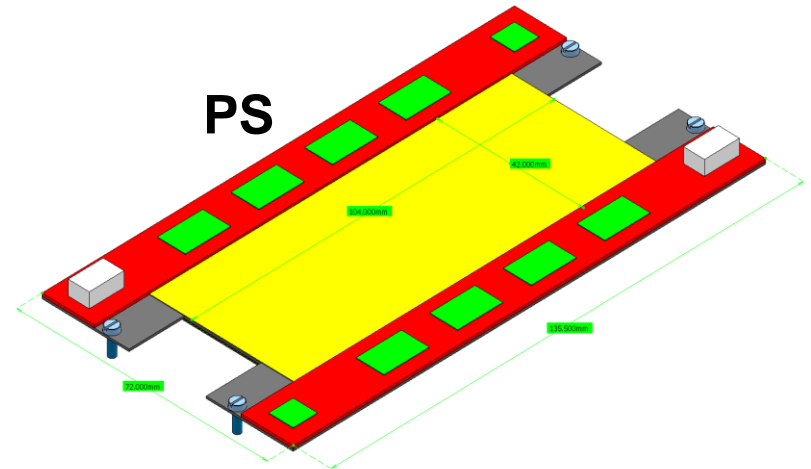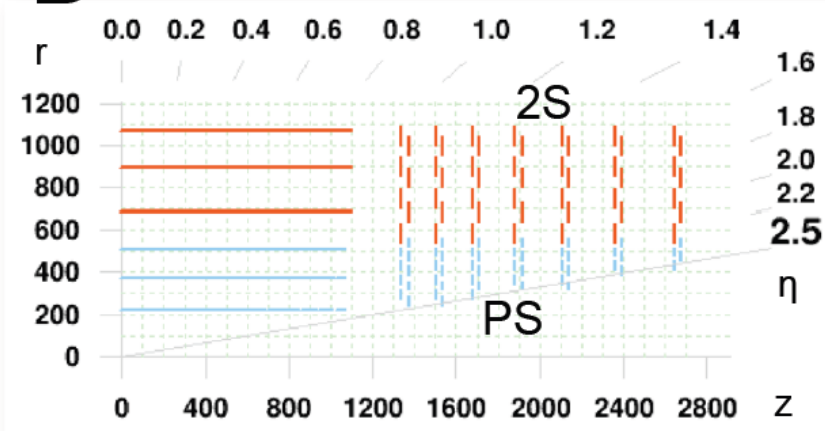
PS: Module with one strip and one pixel sensor

1 x AC coupled strip sensors with 100 μm pitch
1 x DC coupled macro-pixel ~ 1-2 mm length
Area: 10 x 4 cm size (6" wafers)
Channels: 32.768 pixels + 2032 strips

CMS tracker layout options

A barrel & end-cap design

2S

strip modules

B barrel & end-cap design

2S

PS

> A: standard strip modules at r < 50 cm

> B & C

  ▪ PS modules at r < 50 cm

  ▪ 2S modules at r > 50 cm

> More design options under investigation

C long barrel design

2S

PS

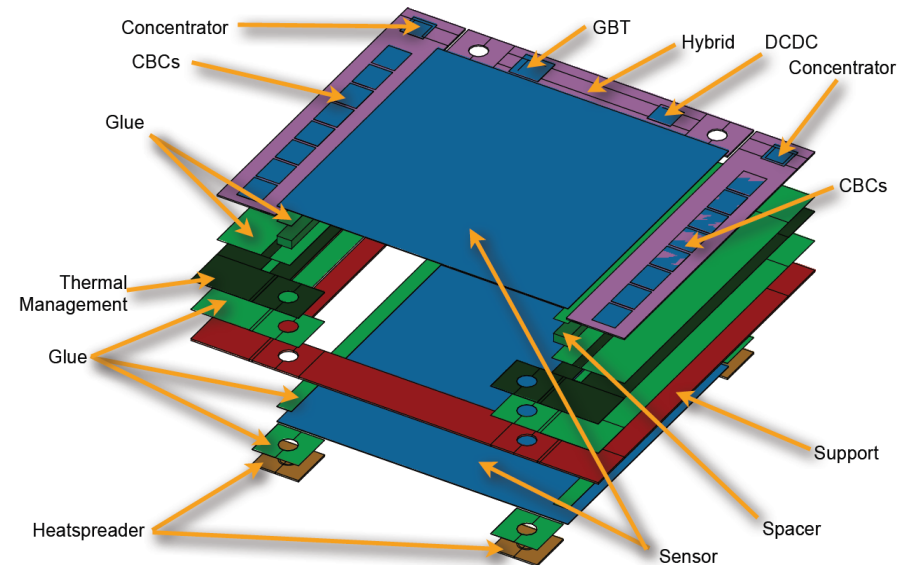*Studies by S. Mersi et al. (CERN)*
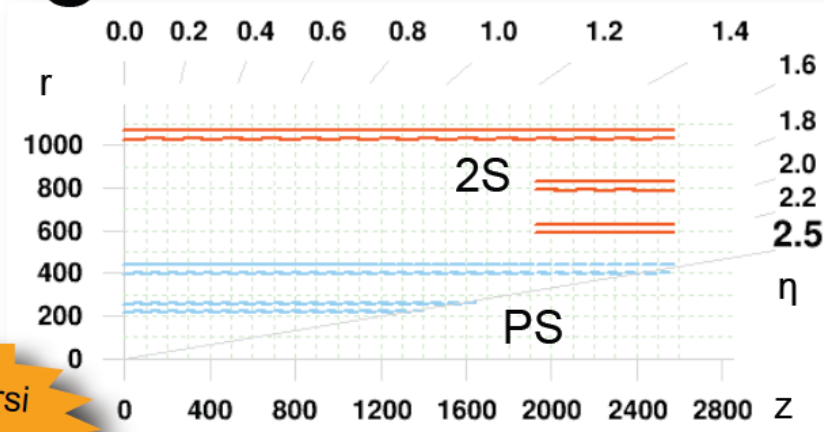
Sensor material + layout, tracker configuration not yet chosen

Finite Element Modeling of Modules

2S

5 cm

Concentrator
CBCs
Glue
Thermal Management
Glue
Heatspreader

GBT
Hybrid
DCDC
Concentrator
CBCs
Support
Spacer
Sensor
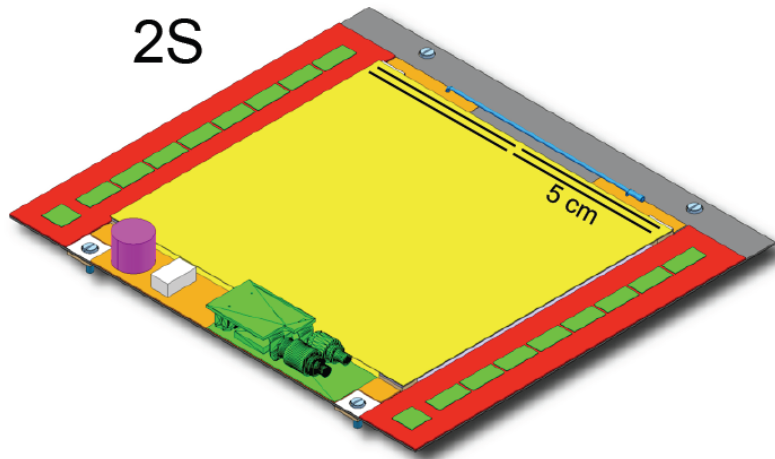
- Model materials (sensors, CF structures, glues, heat spreaders,…)
- Model thermal loads of chips and of sensors after irradiation

→ Tune temperature of thermal contact to reach < 20°C in sensor

-25.2   -15.3

-22.0   -20.0

What defines the Future ?

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
SuperBFs (10^{35} cm^{-2}s^{-1})	2	400	$\sim 3 \times 10^{12}$	100
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
lower radiation
smaller pixels
less material

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

Slide: N.Wermes at annual workshop of the Helmholtz Alliance Dec.2011, Bonn

The Vertex Detector at the ILC

Measure impact parameter, charge for every charged track in jets, and vertex mass.

Need:

- Good angular coverage with many layers close to vertex:
  - $|\cos\theta| < 0.97$.
- First measurement at r ~ 15-16 mm.
- 5-6 layers out to r ~ 60 mm.
- Efficient detector for very good impact parameter resolution
- **Material ~ 0.1% X_0 per layer.**
- Capable to cope with the ILC beamstrahlungs background
- Single point resolution better than **3 μm**.

ILD vtx det. concept
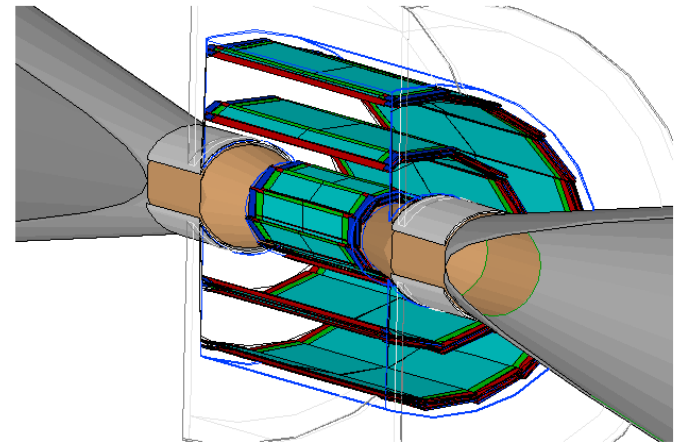
Barrel geometry

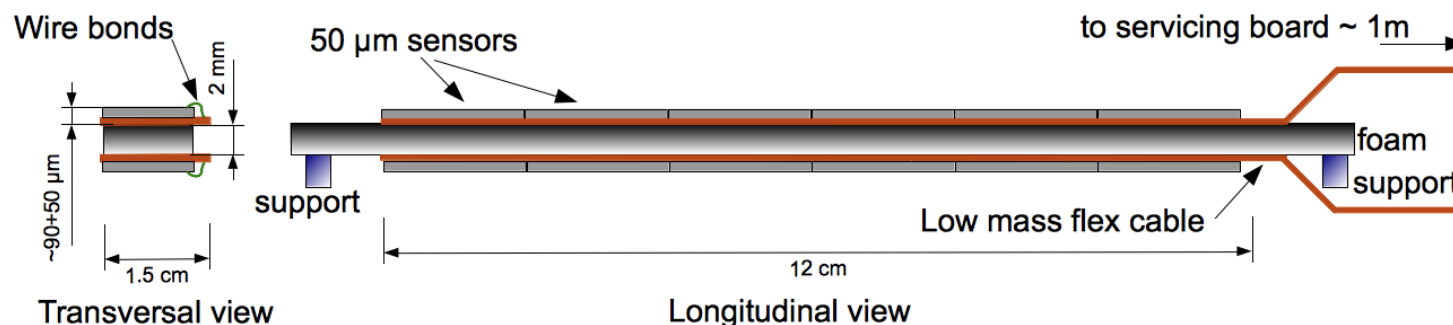- **small pixels, thin sensors, thin r/o electronics, low power (gas cooling)**

Pixelated **L**adder with **U**ltralow **M**aterial **E**mbedding

Small collaboration:

❑ ILC-oriented

- ✗ Double-sided ladders
- ✗ Air cooled
- ✗ Power pulsed @ T=200ms
- ✗ 125 mm long
- ✗ Material budget goal ~ 0.3 % X_0
- ✗ Results expected for mid-2012

● Double-sided ladders benefits

- ✗ Redundancy
- ✗ Alignment: faster and/or more robust
- ✗ Track finding boosted by mini-vectors
- ✗ Note: material budget increase by about 0.1% X0 between single- and double-sided options

Wire bonds
2 mm
50 µm sensors
to servicing board ~ 1m
~90+50 µm
support
foam
support
1.5 cm
Low mass flex cable
12 cm
Transversal view
Longitudinal view

Current concept :

- ● **6 x MIMOSA26 thinned down to 50µm**
- ● **Kaptonmetal flex cable**
- ● **Silicon carbide foam (8% density) stiffener, 2mm thickness**
- ● **Wire bonding for flex - outer world connection**
- ● **Digital readout**

Prototypes

- very first prototype in 2009
- first full-scale ladders were designed and fabricated in 2011
  - micro-cables are made of two 20 µm thick metal layers of copper interleaved with 100 µm thick polyimide
  - spacer material was chosen as silicon carbide foam with an 8 % density

Protype 2011

8 Mpixels, mass 10 g equivalent to 0.6 % X_0 (cross section) and sensitive surface of 12.7 × 1.1 cm^2

- Good electrical and mechanical performance
- First beam test in November 2011: data is being analyzed
- Next step: reduce to 0.3 % X_0 in 2012

MAPS

MAPS = Monolithic Active Pixel Sensor
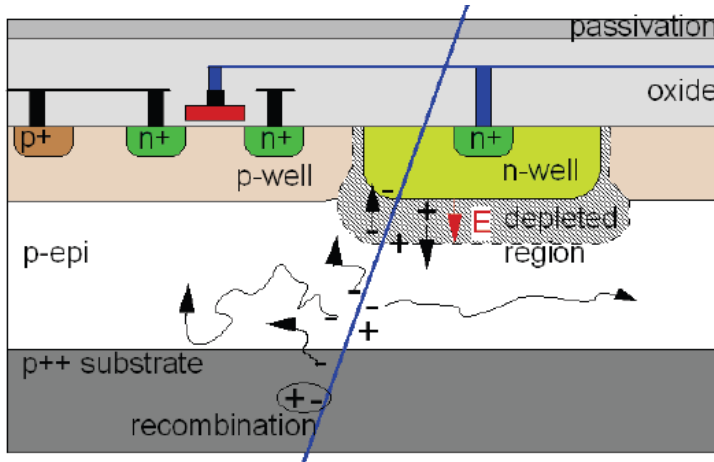
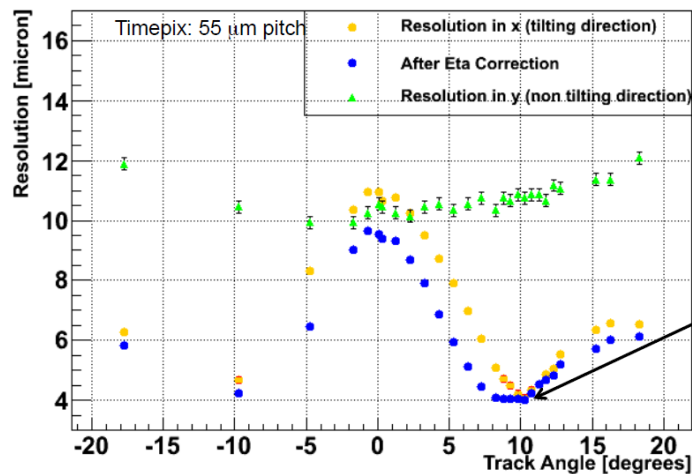

- CMOS process

- Signal generated in epi layer (~10 μm thickness)
  → small (<1000e)
- Charge collected by diffusion
  → slow
- Charge collected in n-well/p-epi junction

- Can produce small pixels (10x10 μm)
  → High resolution
- Can thin down to ~50 μm, possibly less
- signal processing μcircuits integrated in the sensors

MIMOSA 26
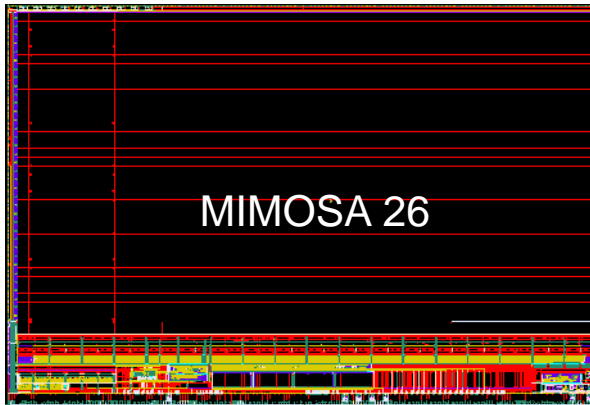
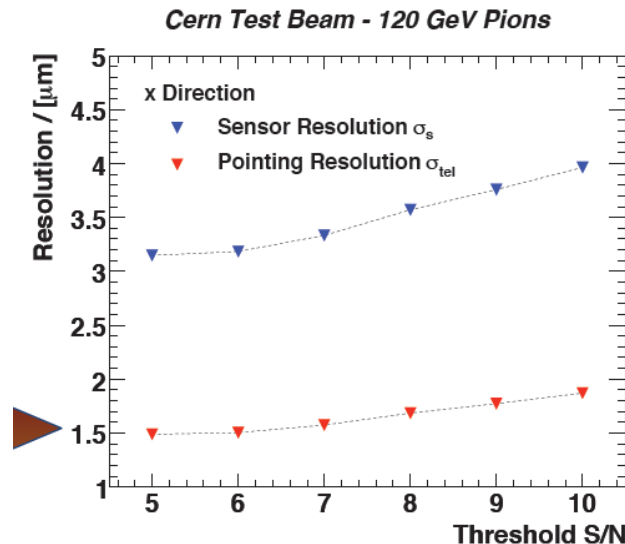used in EUDET Telecope

Telescopes within AIDA now

Timepix Telescope:

8 planes, 55um pitch, angled

Resolution at Device Under Test (with 8 planes) 1.6um

Fast, LHC speed

EUDET Telescope:

6 planes with Minosa26(50um thin, 18.4 um pitch)

Sensor resolution < 3.5 um
Pointing resolution < 2 um

Small material budget (suitable for DESY testbeam)

Summary

> Radiation hardness is a main challenge for the LHC trackers

> Probably, for the LHC upgrades, hybrid solutions will be used

  - Rad-hard sensors

  - High-speed readout electronics

> For Linear Colliders and all other applications in HEP monolithic solutions will thin materials or highly integrated devices will dominate

The variety of pixel technologies
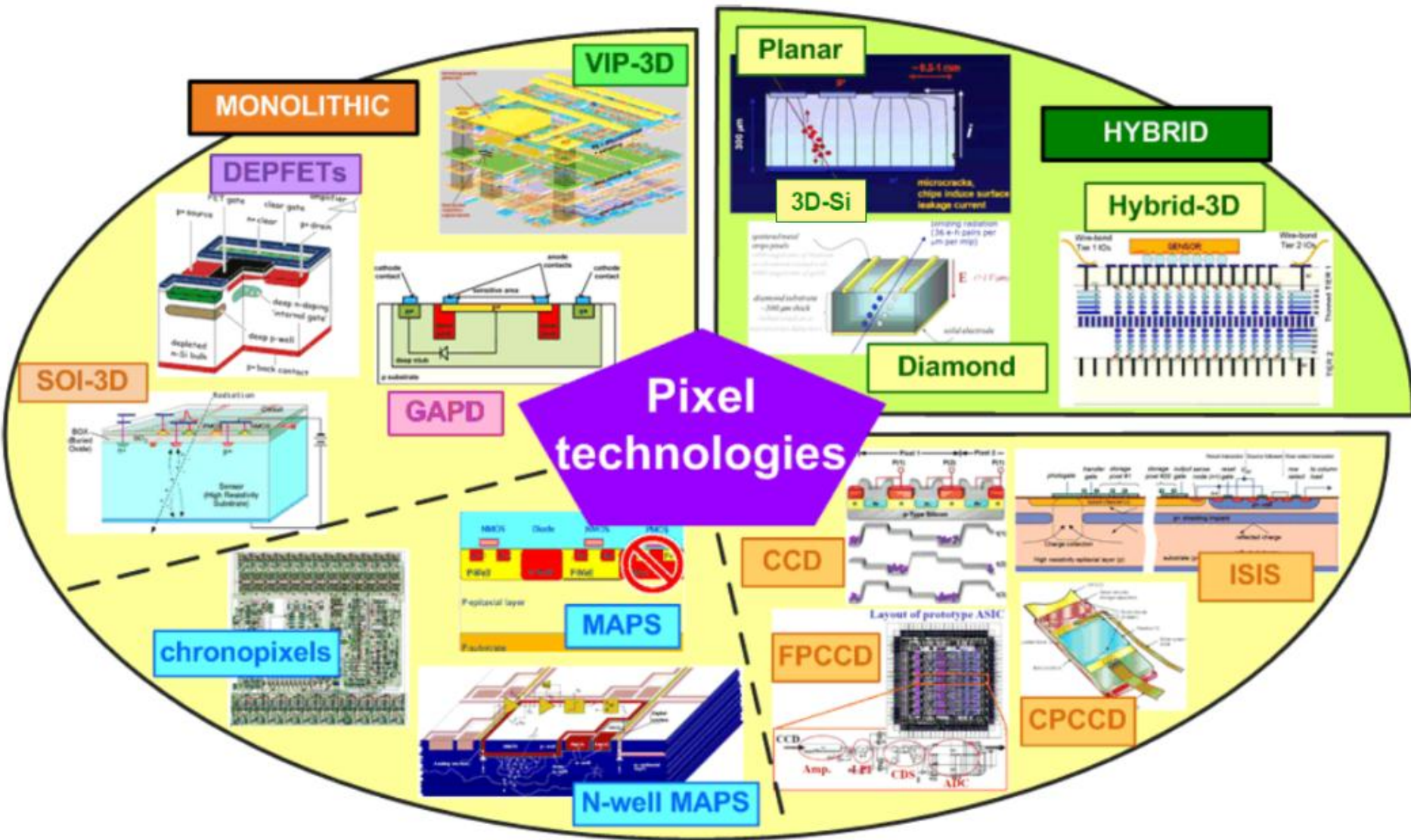
Slide: N.Wermes at annual workshop of the Helmholtz Alliance Dec.2011, Bonn

Acknowledgements and further reading

> N.Wermes at annual workshop of the Helmholtz Alliance Dec.2011, Bonn

> A. Junkes

> M.Moll

> F.Hartmann

> A. Mussgiller

> T. Bergauer

> J. Baudot

> I.Gregor

For current detector developments look at:

> AIDA Academia meets Industry:

https://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=158354

 talks on HEP community needs

For more basics on silicon detectors:

> EDIT2011 school talks

> and many more….