http://cern.ch/rd50

Recent results from RD50

- **SLHC**
- **RD50**
  - **Improving silicon detectors**
  - **New material**
  - **New structures**
- **Conclusions**

D. Bortoletto, Purdue University
Representing RD50

SLHC

- Summer 2001: two CERN tasks forces investigate Physics potential (CERN-TH-2002-078) and accelerator requirements (LHC Project report 626) of an LHC upgrade
- March 2002: LHC IR upgrade collaboration meeting : http://cern.ch./lhc-proj-IR-upgrade
- October 2002: ICFA seminar at CERN on "Future Perspectives in High Energy Physics"
- March 2003: LHC Performance workshop , Chamonix http://ab-div.web.cern.ch/Conferenced/Chamoix/2003/
- 2004: **C**oordinated **A**ccelerator **R**esearch in **E**urope on **H**igh Energy **H**igh Intensity **H**adron Beams (CARE-HHH) network created:
  - WP 1: Advancements in Accelerator Magnet Technologies (AMT)
  - WP 2: Novel Methods for Accelerator Beam Instrumentation (ABI)
  - WP 3: Accelerator Physics and synchrotron Design (APD)

http://care-hhh.web.cern.ch/

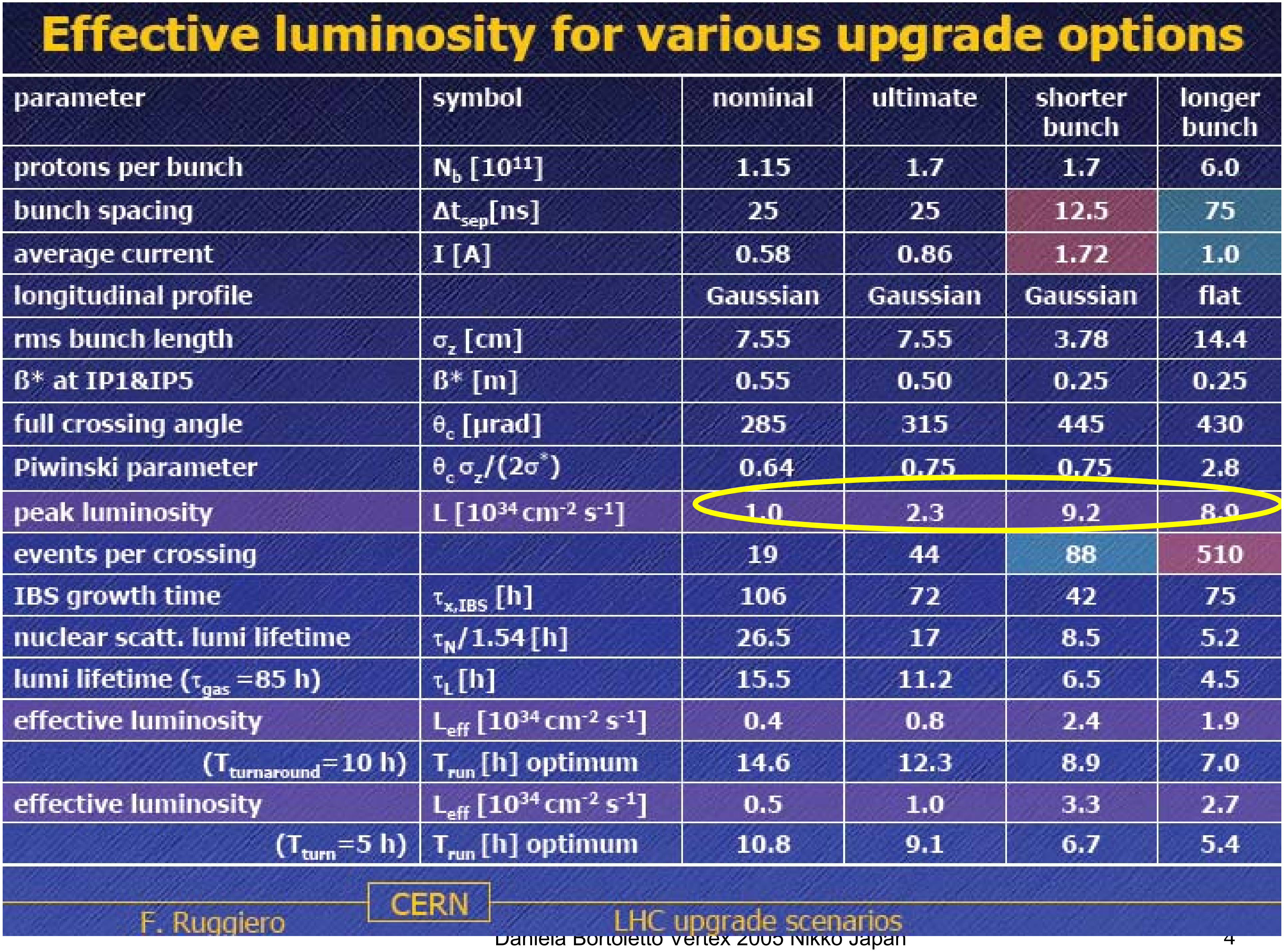
LHC upgrade scenarios

- **LHC phase 0: maximum performance w/o hardware changes**
- **LHC phase 1: maximum performance with arcs unchanged**
- **LHC phase 2: maximum performance with 'major' changes**

Nominal LHC performance at 7 TeV corresponds to L=10^{34} cm^{-2}s^{-1} in IP1 and IP5 (ATLAS and CMS), halo collisions in IP2 (ALICE) and low-luminosity in IP8 (LHC-b)

PHASE 2

- **Modify injectors to significantly increase beam intensity and brilliance beyond ultimate value (possibly together with beam-beam compensation schemes)**
- **Equip SPS with s.c. magnets, upgrade transfer lines, and inject at 1 TeV into LHC**
- **Install new dipoles with 15-T field and a safety margin of 2 T, which are considered a reasonable target for 2015 and could be operated by 2020 beam energy around 12.5 TeV**



Effective luminosity for various upgrade options

parameter	symbol	nominal	ultimate	shorter bunch	longer bunch
protons per bunch	N_b [10^{11}]	1.15	1.7	1.7	6.0
bunch spacing	Δt_{sep}[ns]	25	25	12.5	75
average current	I [A]	0.58	0.86	1.72	1.0
longitudinal profile		Gaussian	Gaussian	Gaussian	flat
rms bunch length	σ_z [cm]	7.55	7.55	3.78	14.4
β^* at IP1&IP5	β^* [m]	0.55	0.50	0.25	0.25
full crossing angle	θ_c [μrad]	285	315	445	430
Piwinski parameter	$\theta_c \sigma_z/(2\sigma^*)$	0.64	0.75	0.75	2.8
peak luminosity	L [10^{34} cm^{-2} s^{-1}]	1.0	2.3	9.2	8.9
events per crossing		19	44	88	510
IBS growth time	$\tau_{x,IBS}$ [h]	106	72	42	75
nuclear scatt. lumi lifetime	$\tau_N/1.54$ [h]	26.5	17	8.5	5.2
lumi lifetime (τ_{gas} =85 h)	τ_L [h]	15.5	11.2	6.5	4.5
effective luminosity	L_{eff} [10^{34} cm^{-2} s^{-1}]	0.4	0.8	2.4	1.9
($T_{turnaround}$=10 h)	T_{run} [h] optimum	14.6	12.3	8.9	7.0
effective luminosity	L_{eff} [10^{34} cm^{-2} s^{-1}]	0.5	1.0	3.3	2.7
(T_{turn}=5 h)	T_{run} [h] optimum	10.8	9.1	6.7	5.4

F. Ruggiero CERN LHC upgrade scenarios

Reference LHC Luminosity Upgrade: workpackages and tentative milestones

accelerator	WorkPackage	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	after 2015
LHC Main Ring	Accelerator Physics	🟥	🟥	🟨	🟨	🟩	🟩	🟩	🟩	🟩		
	High Field Superconductors	🟥	🟥	🟨	🟨	🟨	🟩	🟩	🟩			
	High Field Magnets		🟥	🟥	🟥	🟨	🟨	🟩	🟩	🟩	🟦	
	Magnetic Measurements			🟥	🟥	🟨	🟨	🟩	🟩	🟩	🟦	
	Cryostats					🟥	🟨	🟨	🟩	🟩	🟦	
	Cryogenics: IR magnets & RF		🟥	🟥	🟥	🟨	🟨	🟩	🟩	🟩	🟦	
	RF and feedback	🟥	🟨	🟥	🟥	🟨	🟨	🟩	🟩	🟩	🟦	
	Collimation&Machine Protection	🟥	🟨	🟨	🟩	🟦	🟥	🟥	🟥	🟥		
	Beam Instrumentation	🟥	🟥	🟥	🟥	🟥	🟨	🟨	🟩	🟩	🟦	
	Power converters					🟥	🟨	🟨	🟩	🟩	🟦	
SPS	SPS kickers			🟥	🟥	🟥	🟨	🟨	🟩	🟦		
	Tentative Milestones	Beam-beam compensation test at RHIC	SPS crystal collimation test	LHC collimation tests	LHC collimation tests	Install phase 2 collimation	LHC tests: collimation & beam-beam			Install new SPS kickers	new IR magnets and RF system	
	Other Tentative Milestones	Crab cavity test at KEKB	Low-noise crab cavity test at RHIC	**LHC Upgrade Conceptual Design Report**		LHC Upgrade Technical Design Report	Nominal LHC luminosity 10^34			Ultimate LHC luminosity 2.3x10^34	beam-beam compensation	Double ultimate LHC luminosity 4.6x10^34

LHC Upgrade Reference Design Report

R&D - scenarios & models	🟥
specifications & prototypes	🟨
construction & testing	🟩
installation & commissioning	🟦

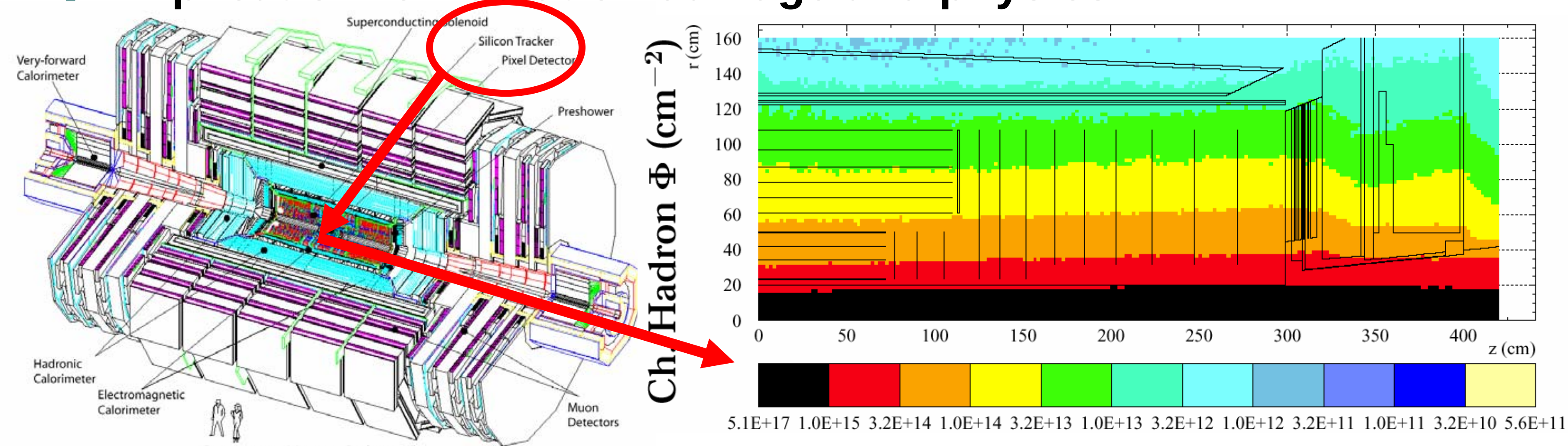
Reference LHC Upgrade scenario: peak luminosity 4.6x10^34/(cm^2 sec)
Integrated luminosity 3 x nominal ~ 200/(fb*year) assuming 10 h turnaround time
new superconducting IR magnets for beta*=0.25 m
phase 2 collimation and new SPS kickers needed to attain ultimate LHC beam intensity of 0.86 A
beam-beam compensation may be necessary to attain or exceed ultimate performance
new superconducting RF system: for bunch shortening or Crab cavities
hardware for nominal LHC performance (cryogenics, dilution kickers, etc) not considered as LHC upgrade
R&D for further luminosity upgrade (intensity beyond ultimate) is recommended: see Injectors Upgrade

SLHC and tracking

	LHC (2007)	SLHC (2015)
Proton Energy:	7 TeV	12.5 TeV
Collision rate:	40 MHz	80 MHz
Peak luminosity:	10^{34} cm$^{-2}\times$s^{-1}	10^{35} cm$^{-2}\times$s^{-1}
Int. luminosity:	500 fb^{-1}	2500 fb^{-1}

~ 100 pile-up events per bunch crossing for 12.5 ns bunch spacing compared to ~20 at 10^{34} cm^{-2} s^{-1} and 25 ns

- **If same granularity and integration time as now, the tracker occupancy and radiation dose increases by a factor of 10 ⇒ implication for radiation damage and physics**

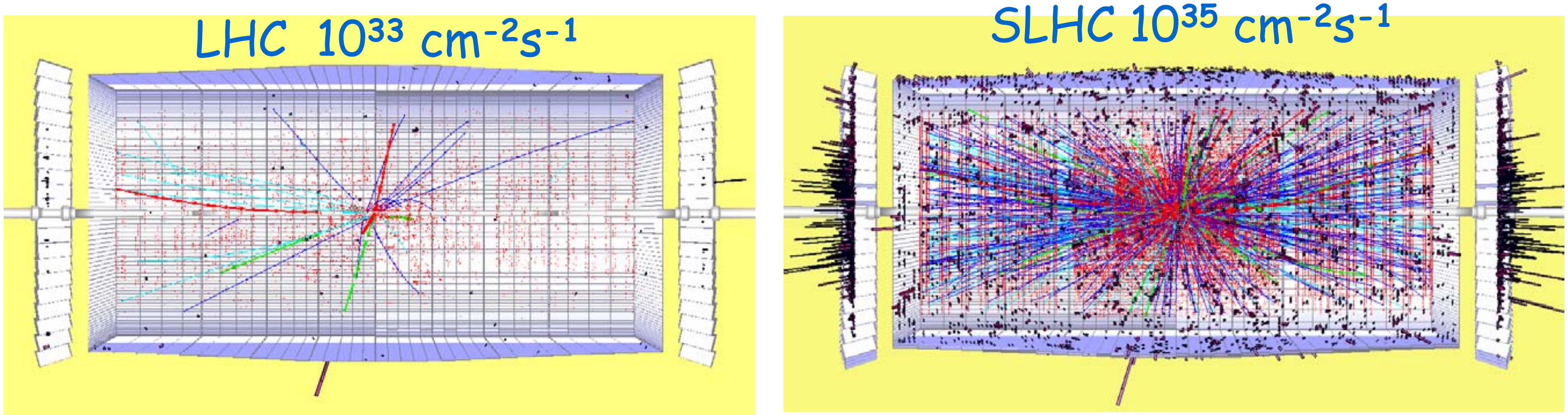


M. Hutinen: "Radiation issues for Super-LHC", SLHC Electronics Workshop, 26/2/04, CERN

SLHC and tracking

- $dn^{cha}/d\eta$/crossing ≈600 and ≈3000 tracks in tracker ⇒more granularity if we aim at same performance we expect from the LHC trackers

H→ZZ→eeμμ m(higgs)=300 GeV all tracks with p_T<1 GeV removed



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

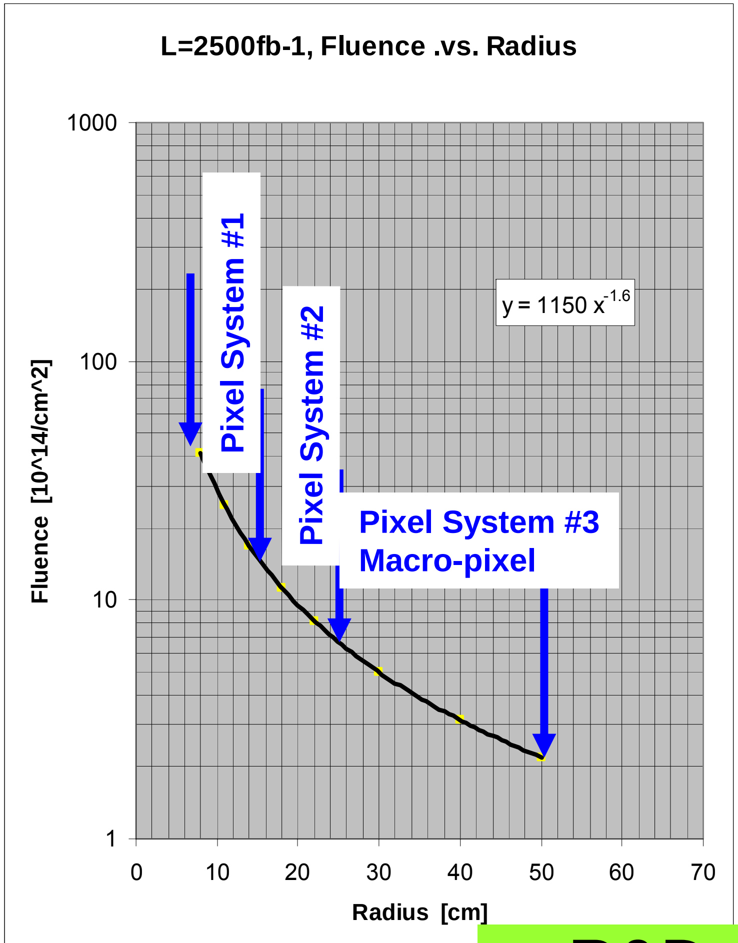
SLHC 10^{35} cm^{-2}s^{-1}

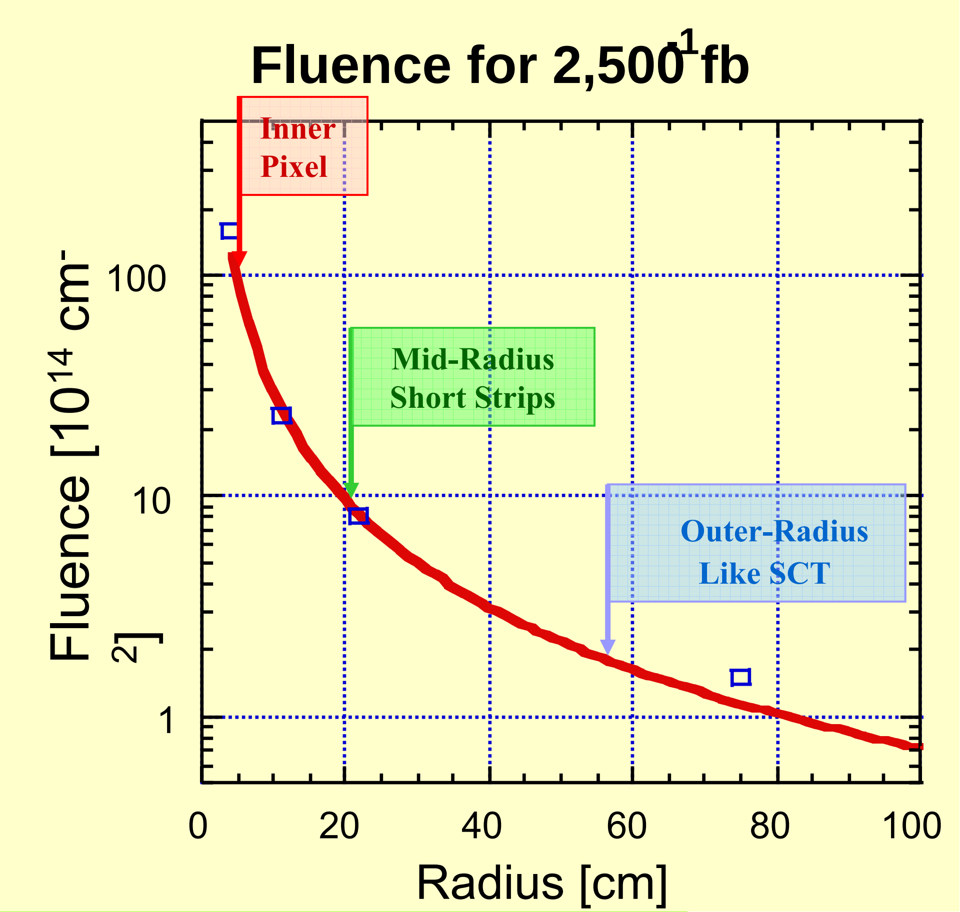
- **Integrated Luminosity (radiation damage) dictates the detector technology**
- **Instantaneous rate (particle flux) dictates the detector granularity**

R (cm)	Φ (p/cm^2)	Technology
>50	10^{14}	Present p-in-n (or n-in-p)
20-50	10^{15}	Present n-in-n (or n-in-p)
<20	10^{16}	RD needed

SLHC and tracking

- **CMS and Atlas are starting look at detector configurations:**





CMS-Horisberger

- **R&D needed below <20 cm**
- **Cost issues everywhere**

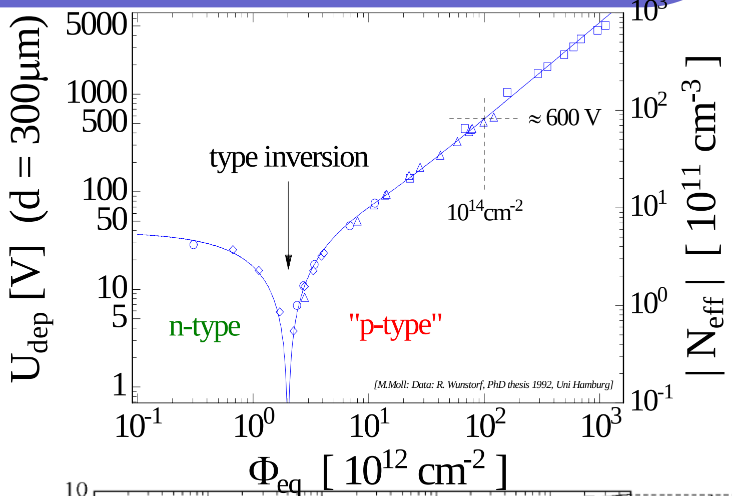
RD50

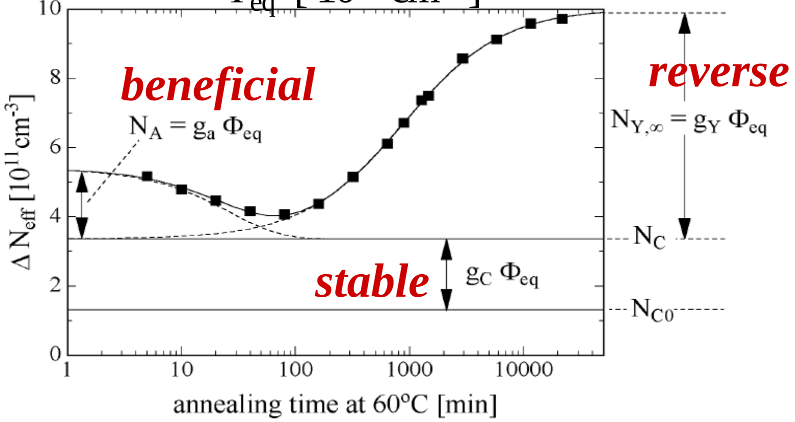
- **Objective:**
  - **Development of ultra-radiation hard semiconductor detectors for the luminosity upgrade of LHC to 10^{35} cm^{-2}s^{-1}**
- **Challenges:**
  - **Radiation hardness of semiconductor detectors up to hadron fluences of 10^{16} cm^{-2}**
    - **Fast signal collection** (25ns → 12.5 ns bunch crossing)
    - **Low mass** (reduce multiple scattering near interaction point)
    - **Cost** (big surfaces)
- **RD50 was formed in November 2001 and approved in June 2002. Presently there are 254 Members from 19 countries**

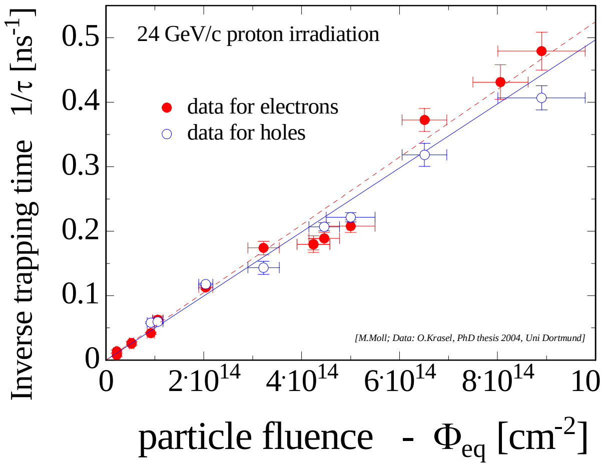
Belgium (Louvain), Belarussia (Minsk), Canada (Montreal), Czech Republic (Prague (2x)), Finland (Helsinki, Lappeenranta) , Germany (Berlin, Dortmund, Erfurt, Friburg, Hamburg, Karlsruhe), Israel (Tel Aviv), Italy (Bari, Bologna, Florence, Milano, Padova, Perugia, Pisa, Trento, Trieste, Turin), Lithuania (Vilnius), Poland (Warsaw (2x)), Norway (Oslo (2x)), Romania (Bucharest (2x)), Russia (Moscow, St.Petersburg), Slovenia (Ljubljana), Spain (Barcelona, Valencia), Switzerland (CERN, PSI), Ukraine (Kiev), United Kingdom (Exeter, Glasgow, Lancaster, Liverpool, Sheffield, Guilford), USA (Albuquerque, BNL, Fermilab, Purdue, Rochester, Rutgers, Santa Cruz, Syracuse)

Radiation Damage in Si

- **Bulk damage**
  - **Effective doping concentration change**
    - $V_{depletion}$ changes ⇒ space charge sign inversion (SCSI). Model with double junction are available and achieve better agreement with data (talk by VC)
    - S/N and charge collection efficiency (CCE) decrease
  - **Leakage current** increase
    - Shot noise increase, S/N decrease
    - Power dissipation
  - **Charge carrier trapping increase**
    - Decrease of carriers free path and CCE







- **Surface damage**
  - Accumulation of positive charges in oxide (SiO_2) and Si/SiO_2 interface
  - Affects: $C_{interstrip}$, $V_{breakdown}$…..

Radiation hard devices

- **Silicon Defect Engineering**
  - Understanding radiation damage
    - Macroscopic effects and Microscopic defects
    - Simulation of defect properties & kinetics
    - Irradiation with different particles & energies
  - Oxygen rich Silicon
    - DOFZ, Cz, MCZ, EPI
  - Oxy. dimer & hydrogen enriched Si
  - Pre-irradiated Si
  - Influence of processing technology
- **New Materials**
  - Silicon Carbide (SiC), Gallium Nitride (GaN)
  - Diamond: CERN RD42 Collaboration (HK's talk)
  - Amorphous silicon
- **Device Engineering**
  - p-type silicon detectors (n-in-p)
  - thin detectors
  - 3D and Semi 3D detectors
  - Stripixels
  - Cost effective detectors
  - Simulation of highly irradiated detectors
  - Monolithic devices
- **Change operational conditions**
  - CERN-RD39 "Cryogenic Tracking Detectors"

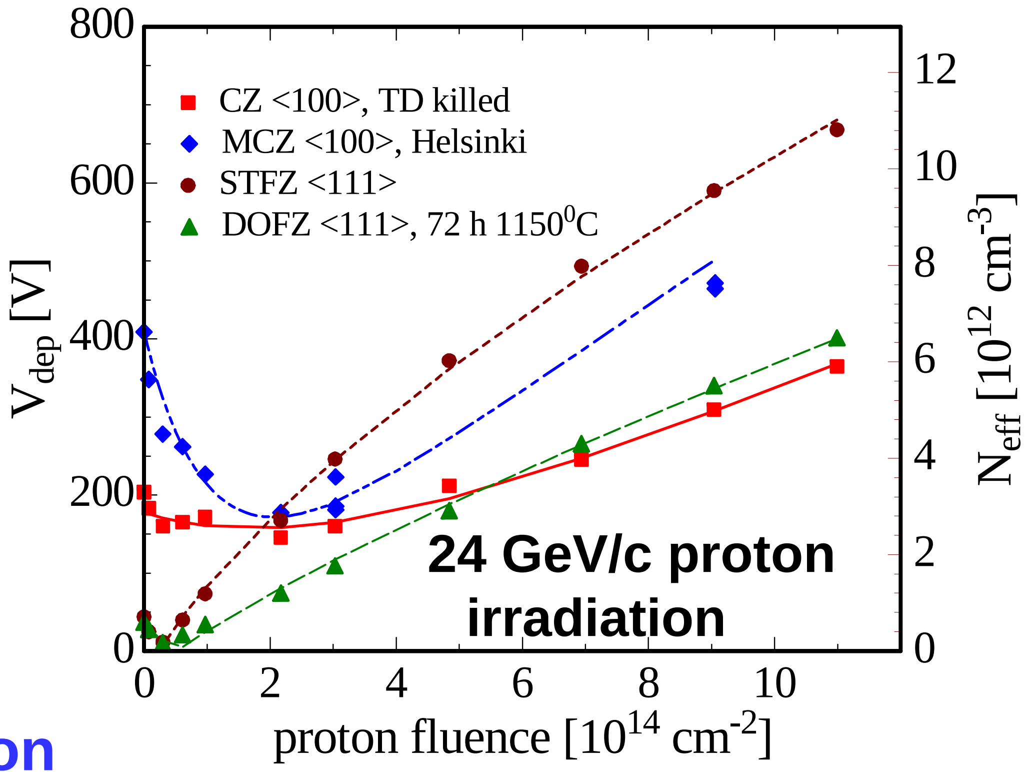
Oxygen in Silicon

- **Rd48 results showed that DOFz is more rad hard**
- **This stimulated interest in Cz silicon (also cheaper than FZ)**

SILICON MATERIAL	**Symbol**	**ρ (Ωcm)**	**$[O_i]$cm^{-3}**
Standard n or p-type FZ	FZ	$1\text{-}7 \times 10^3$	$<5\times10^{16}$
Diffusion Oxygenated FZ n or p-type	DOFZ	$1\text{-}7 \times 10^3$	$1\text{-}2\times10^{17}$
Magnetic Czochralski Okmetic, Finland	MCz	$\sim1 \times 10^3$	$8\text{-}9\times10^{17}$
Epitaxial on Cz, ITME	EPI	50-100	1×10^{17}

FZ, DOFZ, Cz and MCz Silicon

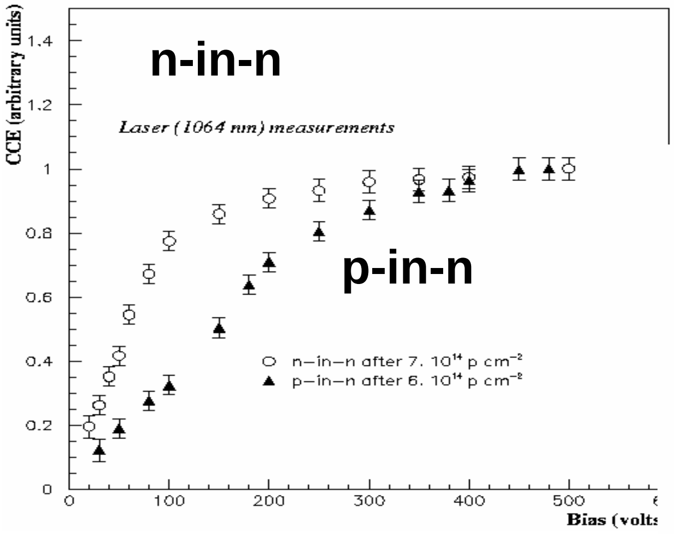
- **Standard FZ silicon**
  - type inversion at ~ 2×10^{13} p/cm^2
  - N_{eff} increase at high fluence
- **Oxygenated FZ (DOFZ)**
  - type inversion at ~ 2×10^{13} p/cm^2
  - reduced N_{eff} increase at high fluence



- **CZ silicon and MCZ silicon**
  - no type inversion in the fluence range (verified for CZ silicon by TCT) ⇒ donor generation overcompensates acceptor generation in high fluence range
- Common to all materials (after hadron irradiation):
  - reverse current increase
  - increase of trapping (electrons and holes) within ~ 20%

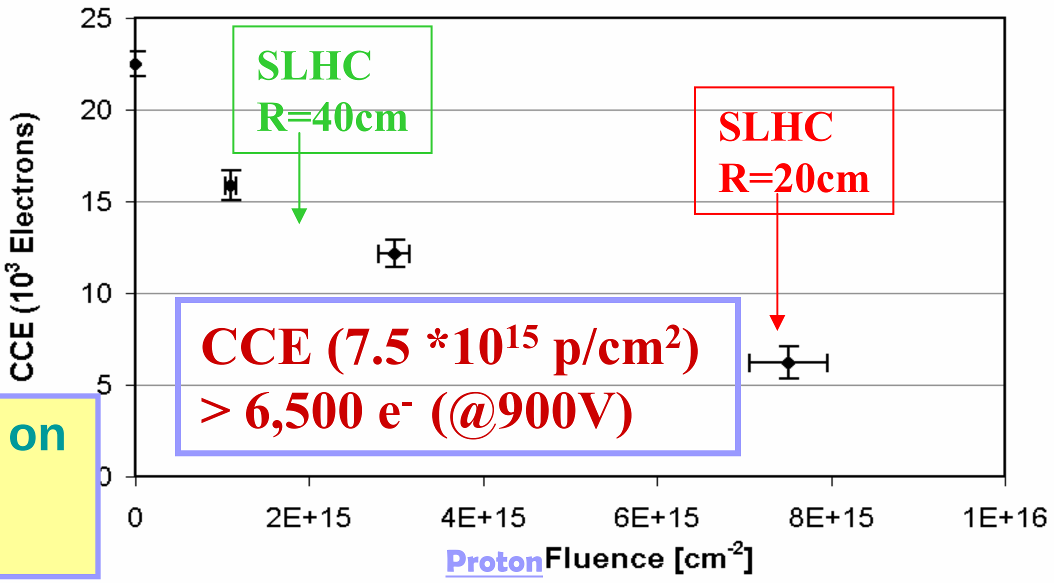
DOFZ n-in-p

- **N-side read-out** is advantageous and is used for ATLAS and CMS pixels, LHCb-VELO microstrips.



CCE Studies after annealing on p-type sensors show no adverse effects

- **P-type DOFZ silicon** for n-side read-out detectors (n-in-p).
- Benefit: Single sided processing (almost 50% cheaper than n-in-n, junction side always on read-out side).



CCE (7.5 *10^{15} p/cm^2)
> 6,500 e$^-$ (@900V)

Charge collection in planar silicon detectors might be sufficient for all but inner-most Pixel layer!

G. Casse talk at ATLAS upgrade meeting, Genova, July 2005

INFN SMART

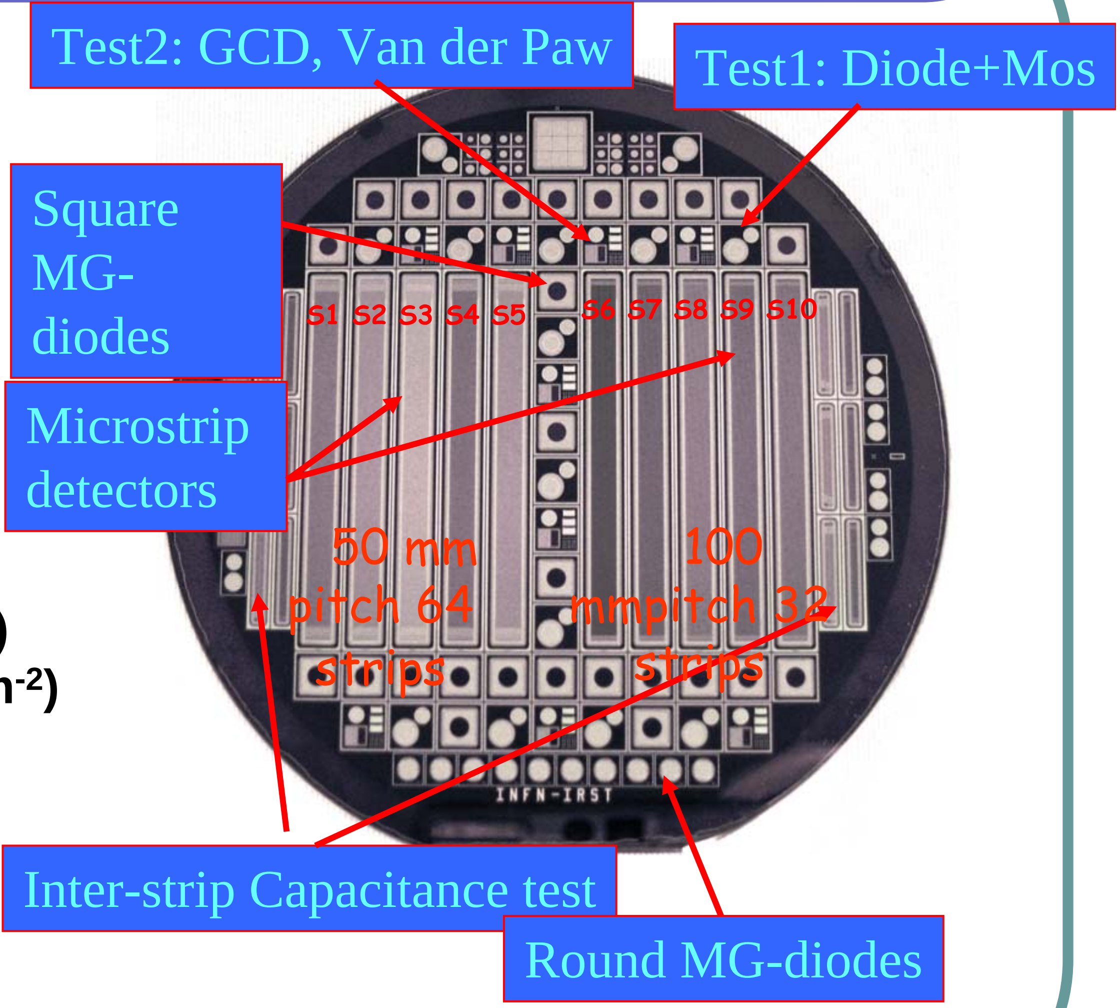
- **RD50 common wafer procurement with Okmetic**
- **Wafer Layout designed by the SMART Collaboration**
- **Masks and process by ITC-IRST: LTO, no LTO, different sintering temperatures (avoid thermal donors formation @400-600 ^{0}C)**
- **10 different strip geometries**
- **Low dose p-spray (3E12 cm^{-2})**
- **High dose p-spray (5.0E12 cm^{-2})**

Run I p-on-n

22 Wafers Fz, MCz, Epi

Run II n-on-p

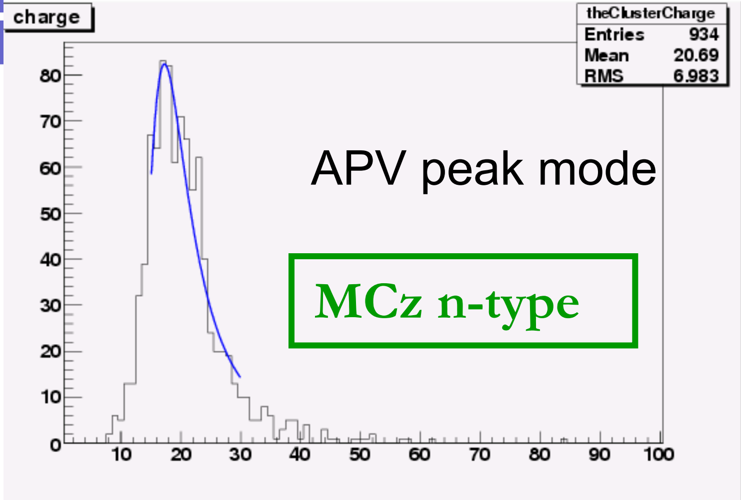
24 Wafers Fz and MCz



http://www.infn.it/esperimenti/esperimentien.php?gruppo=5&sigla_naz=SMART

Pre-irradiation studies

SMART

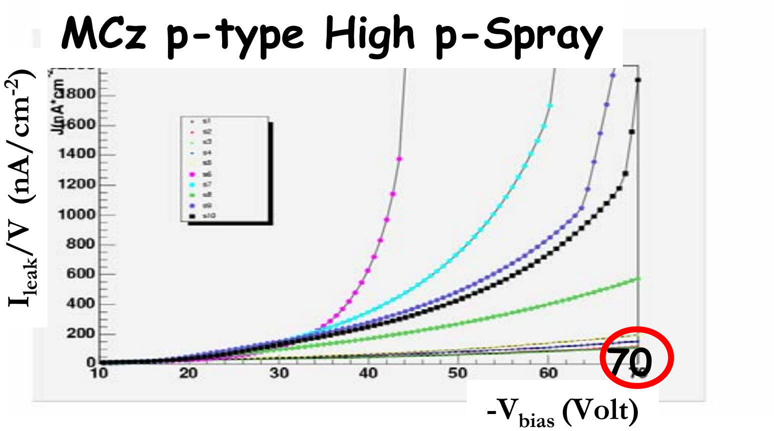


APV peak mode

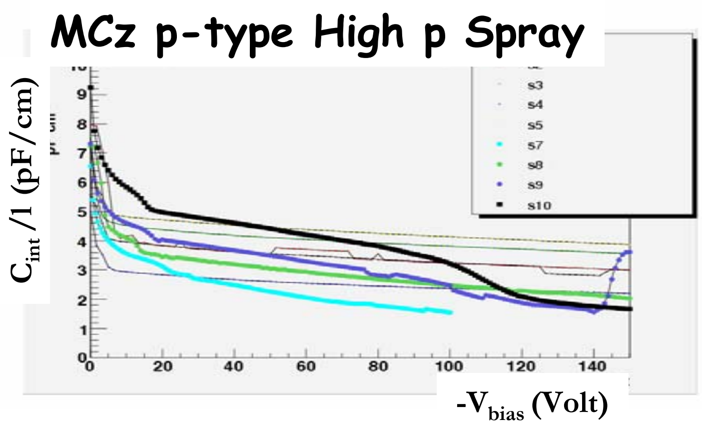
MCz n-type

- **n-type detectors:**
  - **Good performances of the detectors in terms of $_{\text{Vbreakdown}}$, and $_{\text{Cinterstrip}}$**
  - **CCE studies with LHC electronics: S/N ~17.5 @ 500 V (FZ S/N ~19.2 @ 200 V)**
- **p-type detectors:**
  - **Non-uniform wafer resistivity, explained by different O concentration leading to a spread in the thermal donor activation**
  - **Low breakdown for high ρ p-spray**
- $C_{interstrip}$ of p-type sensors decreases with V_{bias} reaching saturation at V>>Vdepletion (~100V)

MCz p-type High p-Spray



MCz p-type High p Spray

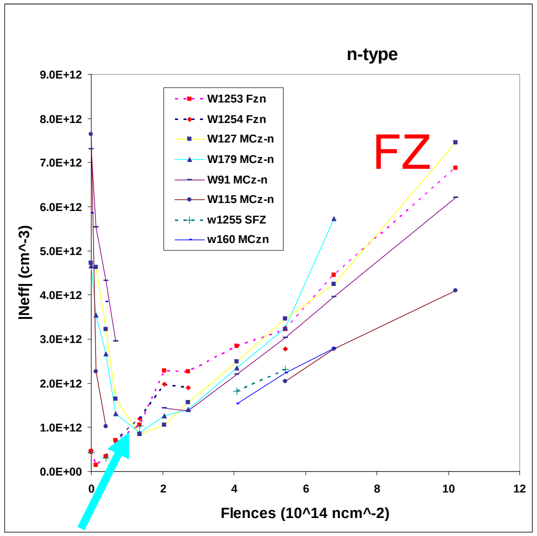


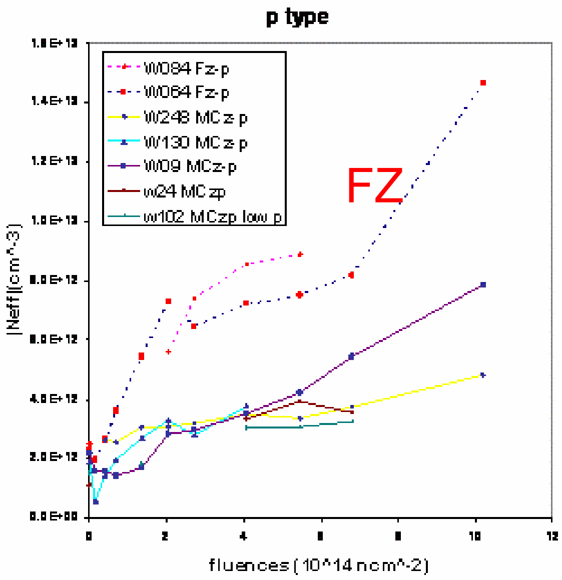
V. Radicci RD05 October 5-7, 2005 - Florence, Italy; Messineo @ 9th ICATAPP Como, October 2005

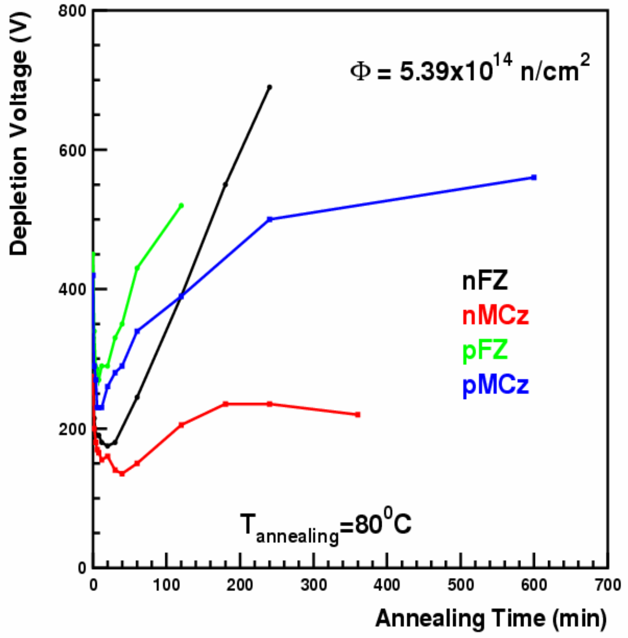
Irradiation studies

SMART

- **Irradiation with 24 Gev/c protons at CERN SPS 3 fluences: 6.0x10^{13}, 3.0x10^{14}, 3.4x10^{15} 1-MeV n/cm^2**
- **Irradiation with 26 MeV protons at the Cyclotron of the Forschungszentrum Karlsruhe 11 fluences: 1.4x10^{13} - 2.0x10^{15} 1-MeV n/cm^2**







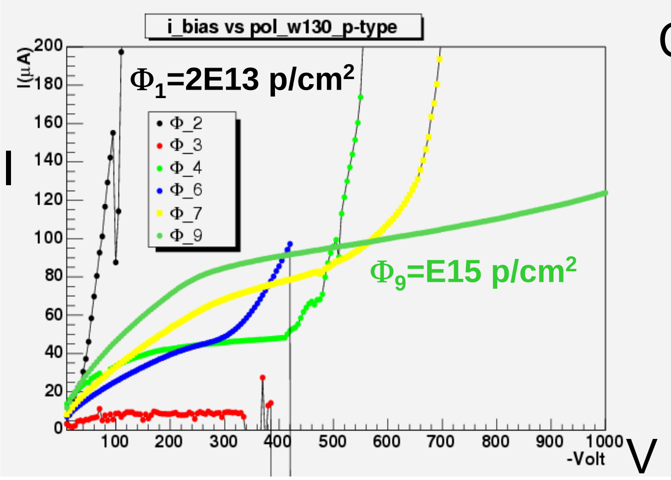
No type inversion (?) Confirmed by microscopic studies

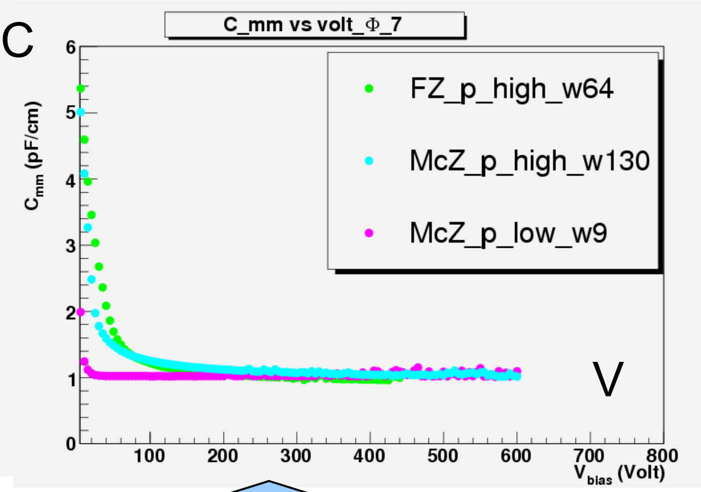
(see AB's talk)

MCz: improved reverse annealing **is expected to simplify the operational conditions**

Other studies

SMART

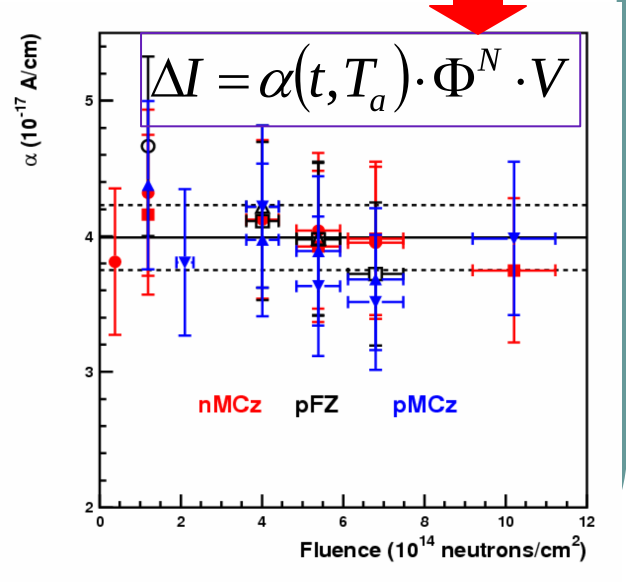




- Same radiation damage constant for p-on-n and n-on-p diodes of Fz and MCz silicon

- **Sensors with low p-spray have $V_{breakdown}$ comparable with n-type detectors in all the fluence range.**
- **Detectors with a high p-spray dose have breakdown problems for $\Phi < 4.0 \times 10^{14}$ 1-MeV n/cm^2. Excellent performance at highest Φ.**

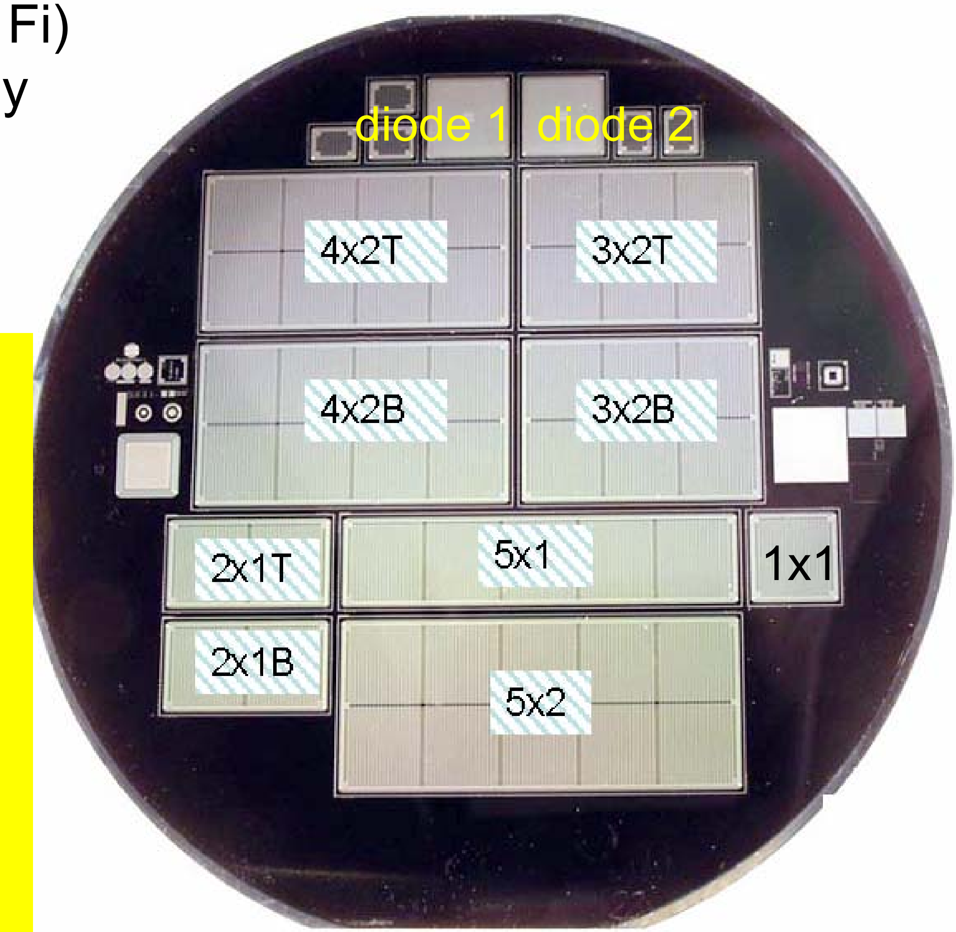
- **Saturation problem of the $C_{interstrip}$ improves after irradiation.**
- **The saturation is faster for low p spray and large pitches.**



$$\Delta I = \alpha(t, T_a) \cdot \Phi^N \cdot V$$

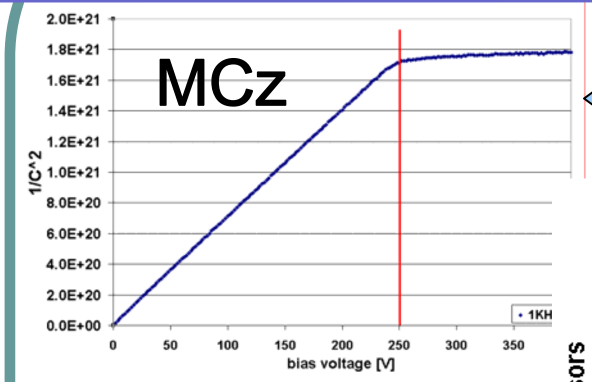
Purdue-USCMS MCz

- RD50 common wafer procurement (produced by Okmetic - Vantaa, Fi)
- 5 MCz wafers were processed by SINTEF (along with 15 standard wafers for preproduction of the FPiX CMS project).



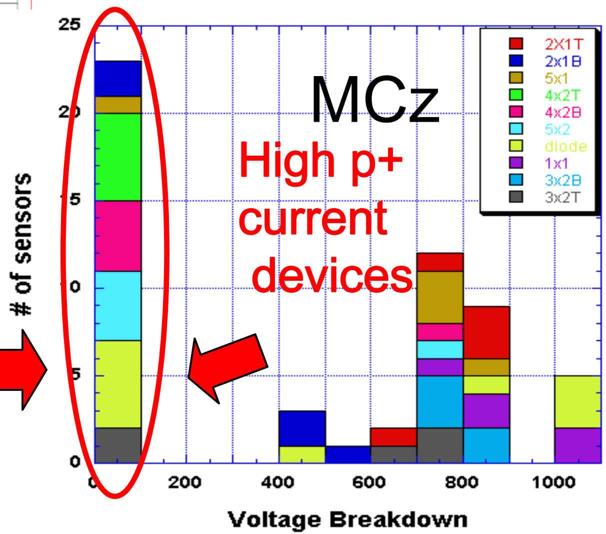
- n-type substrate with <100> direction
- Thickness: ~ 300 µm
- Two diodes and 9 sensors per wafer
- Resistivity:
  - 3~4KΩcm (standard)
  - 1~1.5KΩcm (MCZ)
- n –pixels on n-type MCz with p-stop isolation

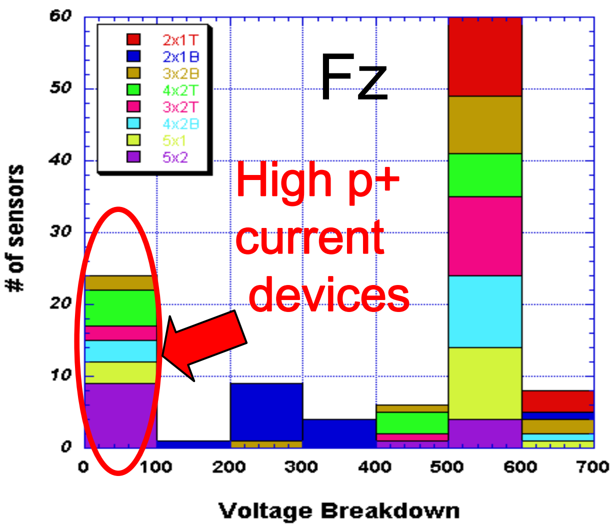
Pre-irradiation Studies



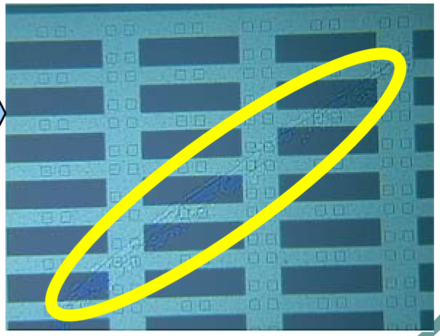
Depletion voltage: ~250V (MCZ)

- Average breakdown voltage is ~740V for MCZ and ~520V for FZ.





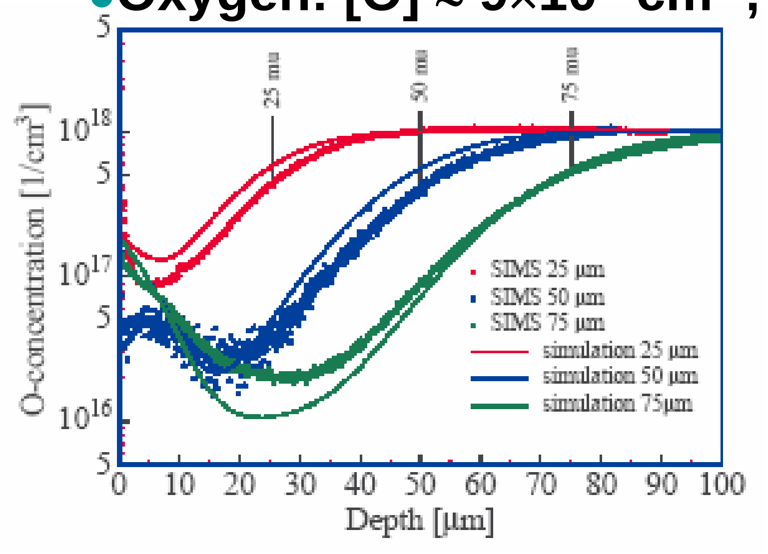
- **Yield measured requiring $V_{breakdown}$ > 300 V and $I_{leakage}$@300V < 1nA/mm^2 lower than expected.**
- **Sintef identified photolithographic defects causing large I at low V: n+ implant spots in the p+ implanted area.**
- **Further studies of MCz properties (including CCE) before and after irradiation will follow now that final ROC available.**



Epi Material Parameters

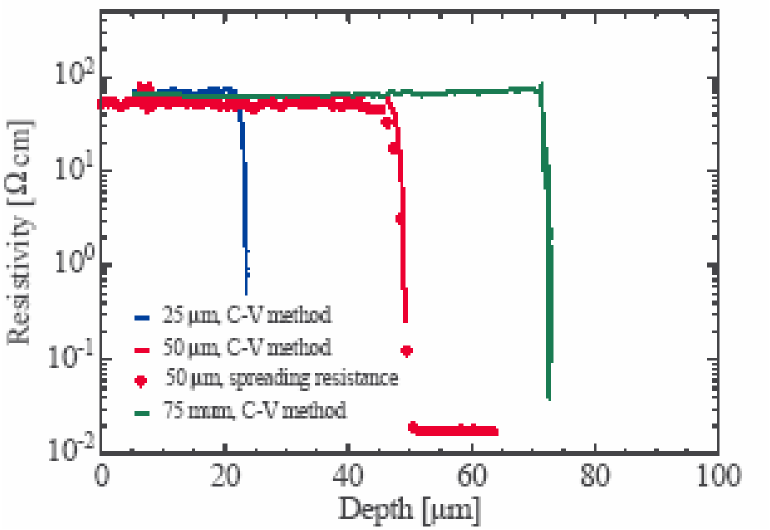
G.Lindström et al.,10th European Symposium on Semiconductor Detectors, 12-16 June 2005

- **Epitaxial silicon grown by ITME**
  - **Layer thickness: 25, 50, 75 μm; resistivity: ~ 50 Ωcm**
  - **Oxygen: [O] $\approx 9\times10^{16}$cm^{-3}; Oxygen dimers (detected)**



- **Oxygen depth profiles**
  - **SIMS measurements after diode processing**
  - **O diffusion from substrate to epi-layer**

SIMS-measurements: A. Barcz/ITME, Simulations: L. Long /CiS



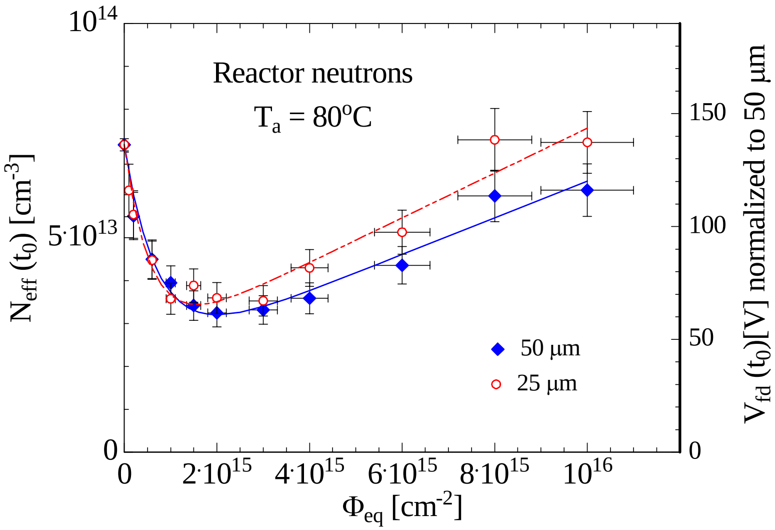
Resistivity profiles

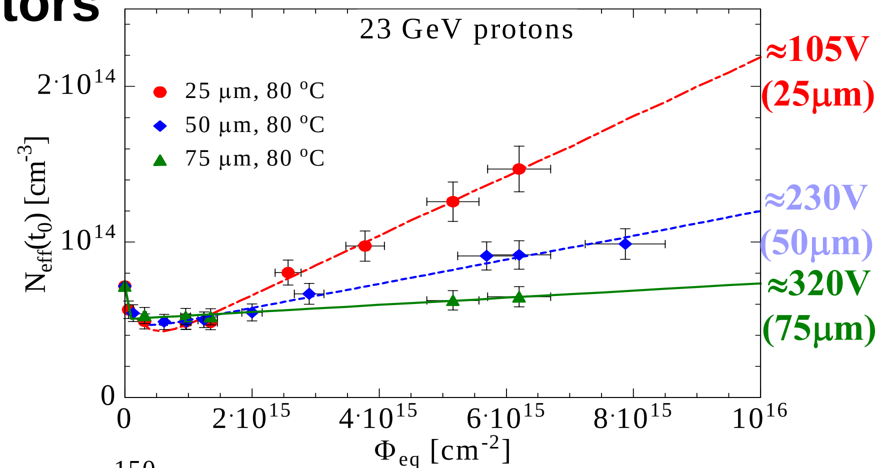
- **Excellent homogeneity in epi-layers**

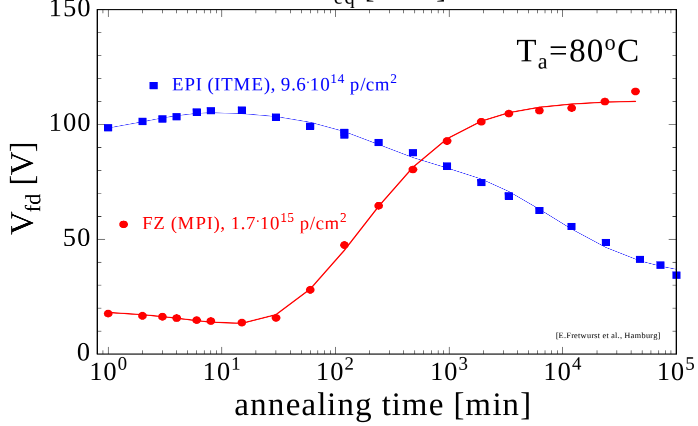
SR-measurements: E. Nossarzwwska, ITME

EPI Irradiation

- **No type inversion in the full range up to ~ 10^{16} p/cm^2 and ~ 10^{16} n/cm^2 (type inversion only observed during long term annealing)**
- **Proposed explanation: introduction of shallow donors bigger than generation of deep acceptors**



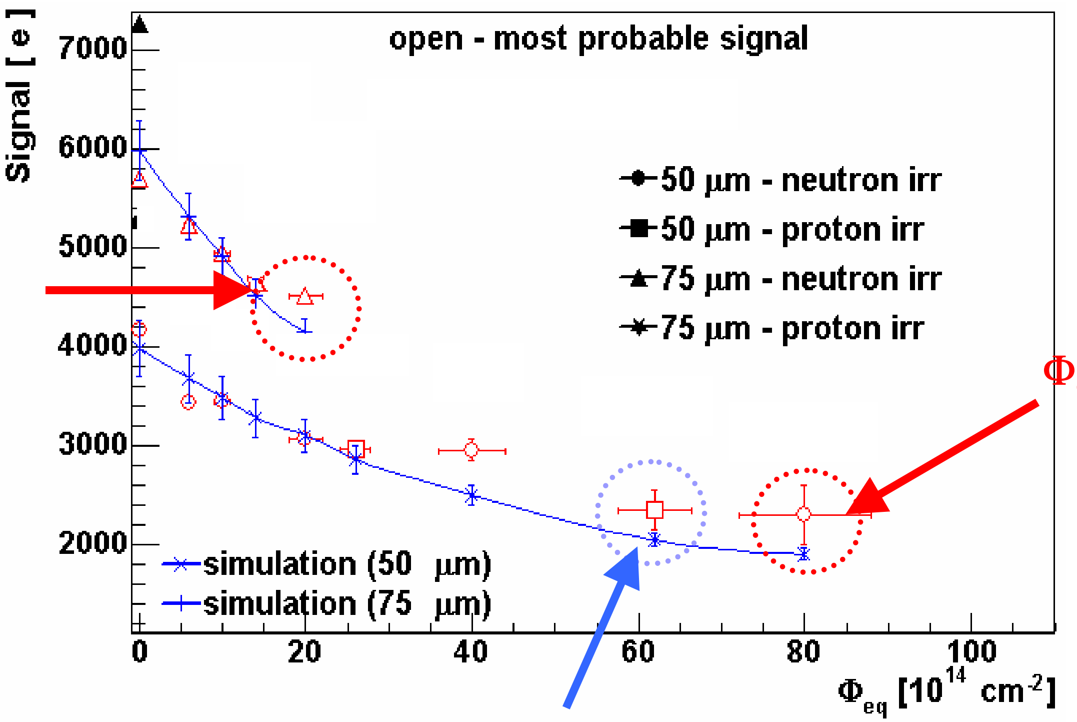




- **Epitaxial silicon:** **Decrease of $V_{depletion}$ with annealing time ⇒ No need for low temperature during maintenance of SLHC detectors!**

Signal in irradiated EPI

- **Epitaxial silicon: CCE measured with beta particles (^{90}Sr)**
  - **25ns shaping time**
  - **proton and neutron irradiations of 50 μm and 75 μm epi layers**



CCE (75 μm)
$\Phi = 2\mathrm{x}10^{15}$ n/cm^{-2},
4500 electrons

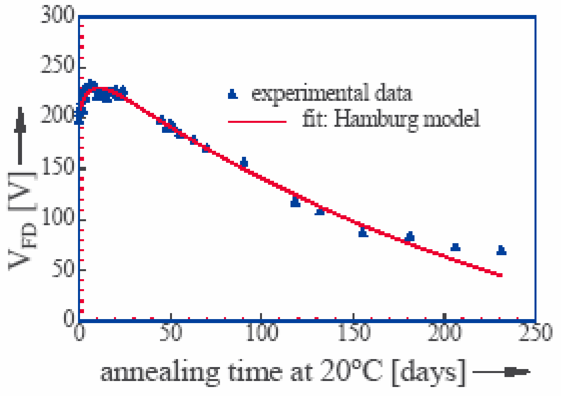
CCE (50 μm)
$\Phi_{eq} = 8\mathrm{x}10^{15}$ n/cm^{-2},
2300 electrons

CCE (50 μm): $\Phi = 6\mathrm{x}10^{15}$cm^{-2} (24GeV/c protons): 2400 electrons

[G.Kramberger et al.,RESMDD - October 2004]

EPI SLHC Scenarios

50 µm and Φ_p=1.1 10^{16}cm^{-2}

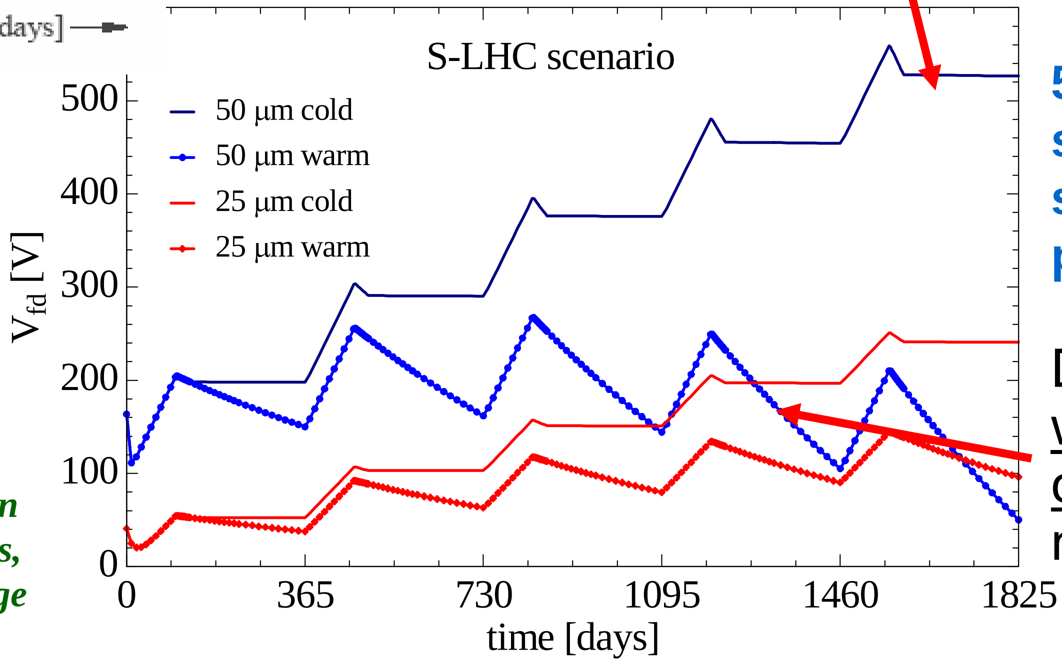


- Radiation @ 4cm: **Φ_{eq}(year) = 3.5 × 10^{15} cm^{-2}**
- SLHC-scenario:
  - **1 year = 100 days beam (-7°C)**
  - **30 days maintenance (20°C)**
  - **235 days no beam (-7°C or 20°C)**

Annealing measurements at 20^{0}C can be fitted with Hamburg model

G.Lindström et al.,10th European Symposium on Semiconductor Detectors, 12-16 June 2005 (Damage projection: M.Moll)

Detector with cooling when not operated



50 µm EPI silicon: a solution for pixels ?-

Detector without cooling when not operated

COST

Material	Cost euros/wafer
Siltronix (France) p-type (low quantities) (large quantities should similar to MCZ)	70
Okmetic MCz 4” DSP (only large orders >200 wafers)	44
Okmetic MCz 6” DSP (only large orders >2000 wafers)	50
EPI 4” ITME 150µm Small order of 9 wafers	100
EPI 4” ITME 75µm	70

Novel Materials

Property	**Diamond**	**GaN**	**4H SiC**	**Si**
E_g [eV]	**5.5**	**3.39**	**3.26**	**1.12**
$E_{breakdown}$ [V/cm]	10^7	$4\cdot10^6$	$2.2\cdot10^6$	$3\cdot10^5$
μ_e [cm^2/Vs]	1800	1000	800	1450
μ_h [cm^2/Vs]	1200	30	115	450
v_{sat} [cm/s]	$2.2\cdot10^7$	-	$2\cdot10^7$	$0.8\cdot10^7$
Z	6	31/7	14/6	14
ε_r	5.7	9.6	9.7	11.9
e-h energy [eV]	**13**	**8.9**	**7.6-8.4**	**3.6**
Density [g/cm^3]	3.515	6.15	3.22	2.33
Displacem. [eV]	**43**	**19.2±2**	**25**	**13-20**

- **Wide bandgap (3.3eV)**

⇒ < leakage current than silicon

- **Signal:**

Diamond	**36 e/μm**
SiC	**51 e/μm**
Si	**89 e/μm**

> charge than diamond

- **> displacement threshold than silicon**

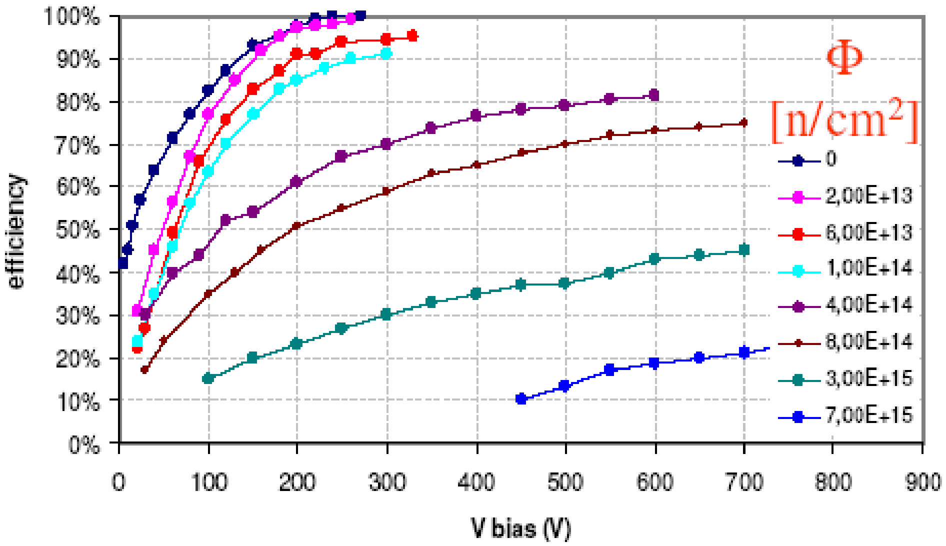
⇒radiation harder than silicon (?)

R&D on diamond detectors:
RD42 – Collaboration
http://cern.ch/rd42/

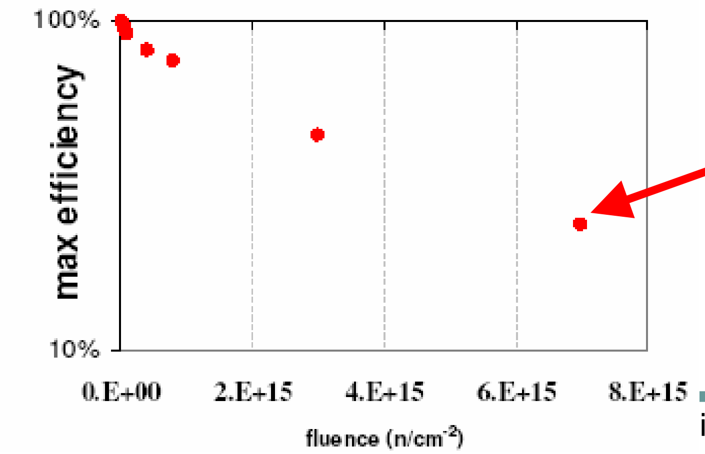
Recent review: P.J.Sellin and J.Vaitkus on behalf of RD50 "New materials for radiation hard semiconductor detectors", submitted to NIMA

SiC: CCE after irradiation

- Material: epitaxial layers by CREE Res. Inc. and IKZ (Institüt fur Kristallzüchtung, Berlin)
- Devices: Schottky diodes, Alenia Marconi Systems (Rome)
- Depletion depth: 20-40 μm
- Effective doping: 5.3×10^{14} cm^{-2}
- Irradiated with protons at CERN PS to 1.6×10^{16}/cm^2 and neutrons al Ljubjana to 7×10^{15}/cm^2
- CCE before irradiation: 1100 e$^-$ @400 V with α particles, 1400 e$^-$ at 200 V with MIPS (100% CCE)



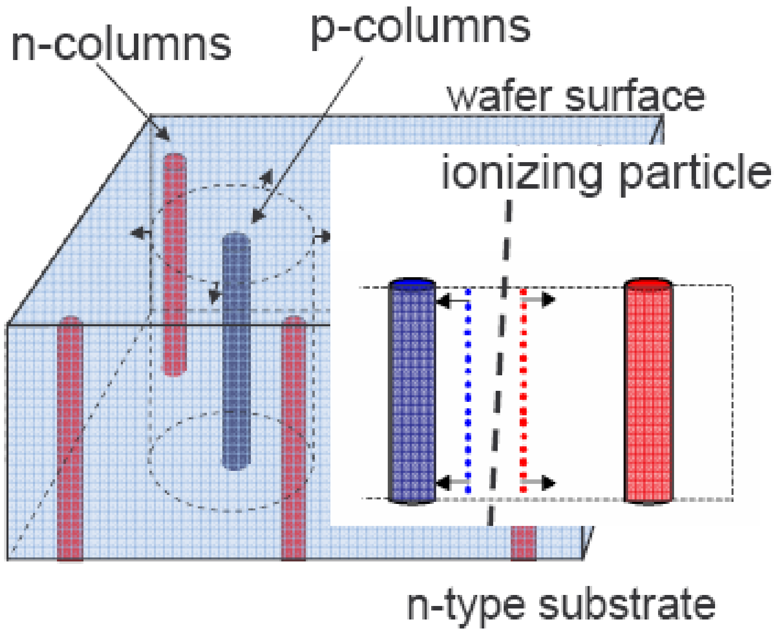
S.Sciortino et al., presented on the RESMDD 04 conference, in press with NIMA



- CCE after irradiation with α particles
  - neutron irradiated samples
  - 20% CCE (α) after $7\text{x}10^{15}$ n/cm^2!
  - 35% CCE (β) (CCD ~6μm ; ~ 300 e$^-$) after $1.4\text{x}10^{16}$ p/cm^2 much less than in silicon

Device Engineering: 3D detectors

(Introduced by S.I. Parker et al., NIMA 395 (1997) 328)



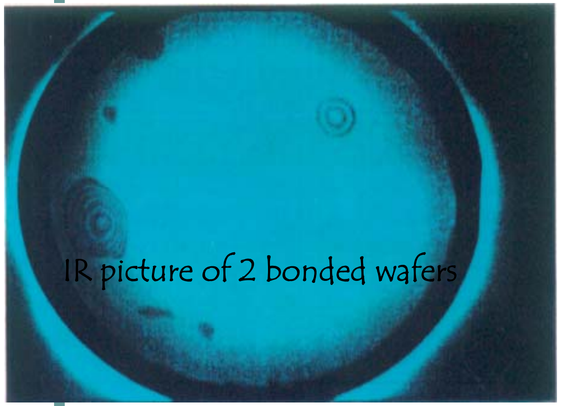
- Combine **VLSI** and **MEMS** (Micro Electro Mechanical Systems).
- **Electrodes:**
  - Narrow columns processed inside the bulk instead then implanted on surface: 3D
  - diameter: 10μm, distance: 50-100μm
- Lateral depletion:
  - lower depletion voltage
  - thicker detectors possible
  - short collection distance ⇒ fast signal
  - More rad hard
- Processing: Wafer bonding, Deep reactive ion etching , Low pressure chemical vapor deposition, Metal deposition

Production of 3D sensor matched to ATLAS Pixel readout chip under way (S.Parker, Pixel 2005)

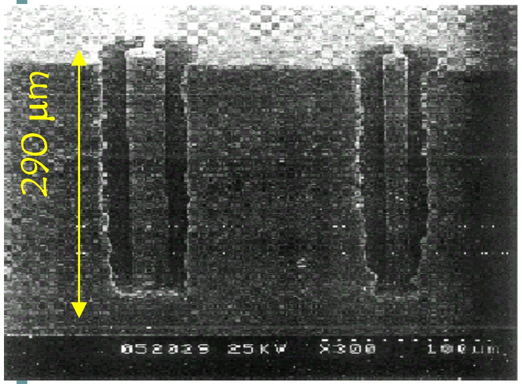
- **Drawback: Long, Complex and Not-standard fabrication process**
- **Mass production expensive**

3D DETECTOR FABRICATION

1) ETCHING THE ELECTRODES



WAFER BONDING
(mechanical stability)
Si-OH + HO-Si -> Si-O-Si + H_2O



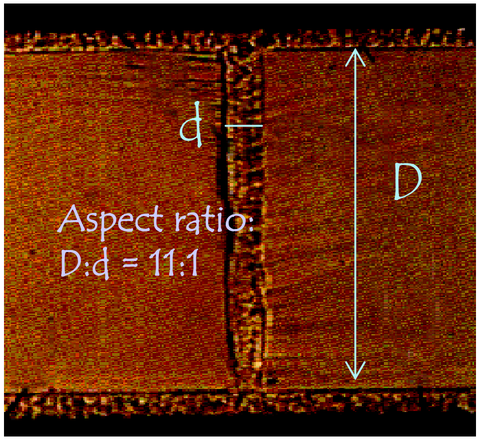
DEEP REACTIVE ION ETCHING
(electrodes definition)

Bosh process

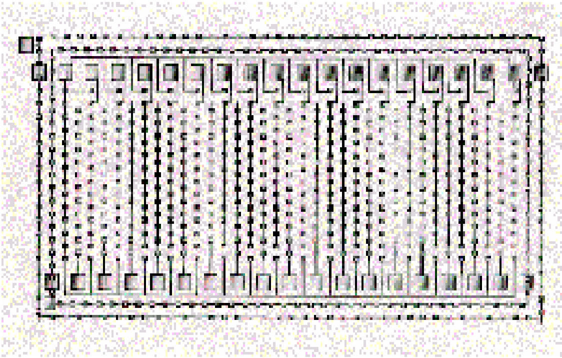
SiF_4 (gas) $+C_4F_8$ (teflon)

C shaped test structure
~1 µm difference between top and bottom

2) FILLING THE ELECTRODES



LOW PRESSURE CHEMICAL VAPOR DEPOSITION
(Electrodes filling with conformal doped polysilicon)
$2P_2O_5 + 5\,Si \rightarrow 4P + 5\,SiO_2$
$2B_2O_3 + 3Si \rightarrow 4\,B + 3\,SiO_2$



METAL DEPOSITION
Shorting electrodes of the same type with Al for strip electronics readout or deposit metal for bump-bonding

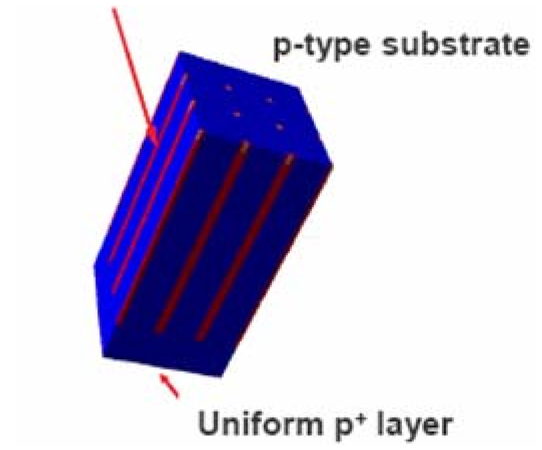
Device Engineering: 3D detectors

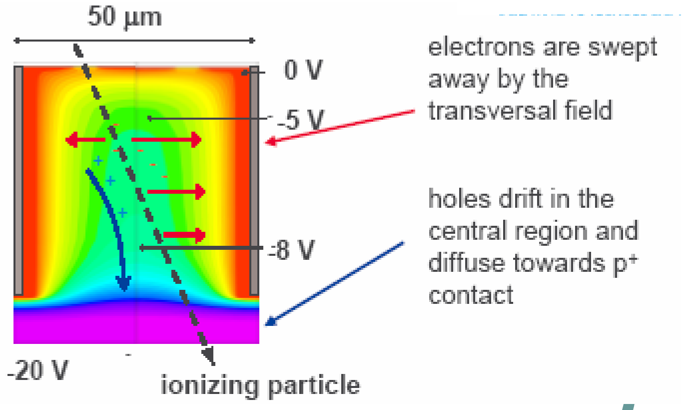
- **IRST-Trento and CNM Barcelona**

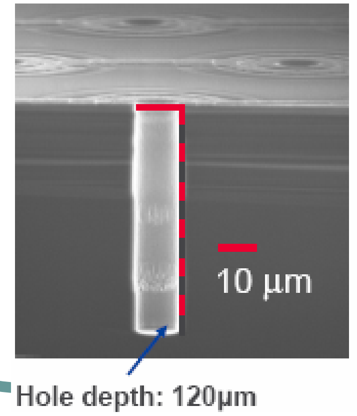
  3D Single Type Column (3D-STC) aiming at process simplification

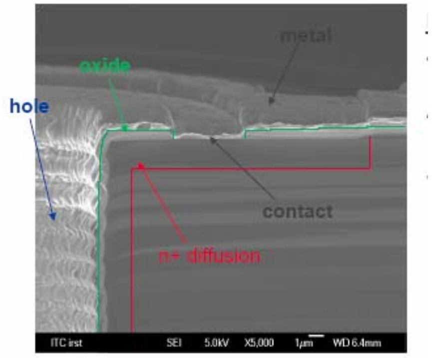
  - n+ columns in p-type substrate
  - Bulk contact provided by a uniform p+ contact on backside
  - Holes not etched through the wafer
  - No hole filling (holes are doped but not filled with polysilicon)
  - CNM: Hole etching (DRIE); IRST: other processing (contacts or polysilicon deposition, et

Pozza and Boscardin RD05 Florence

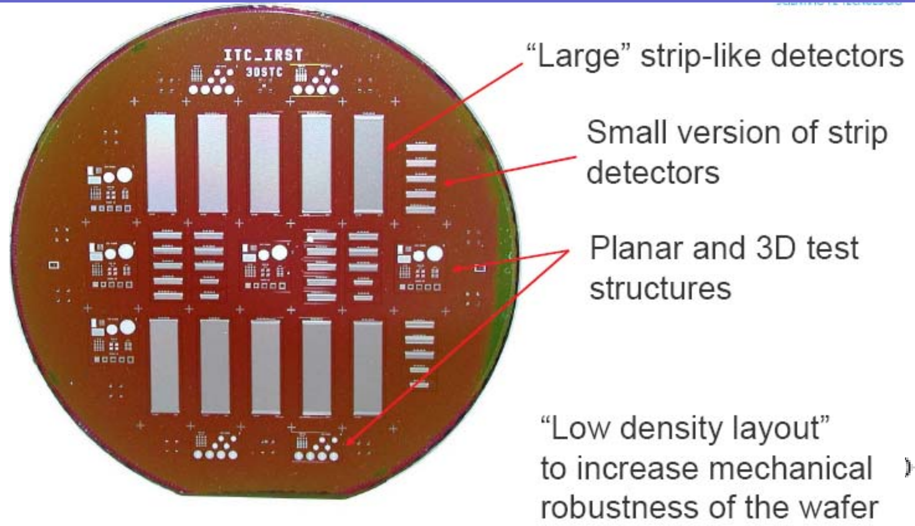


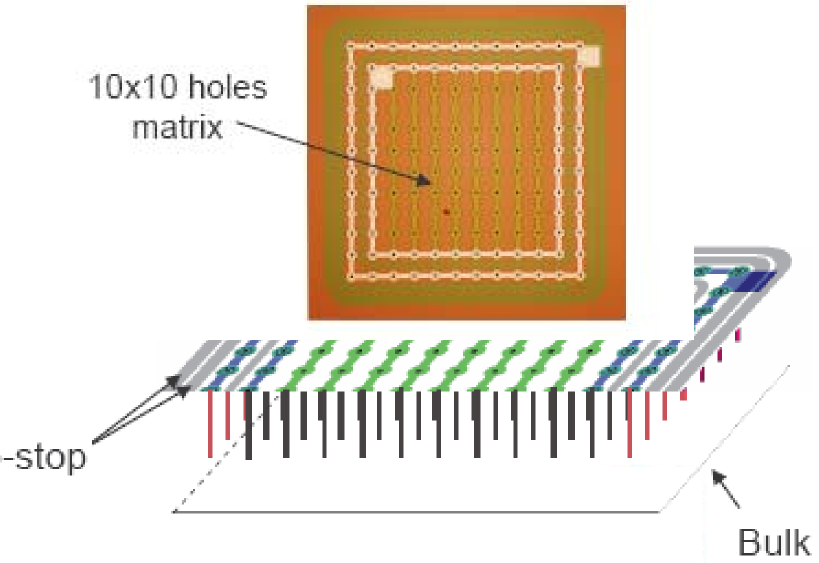






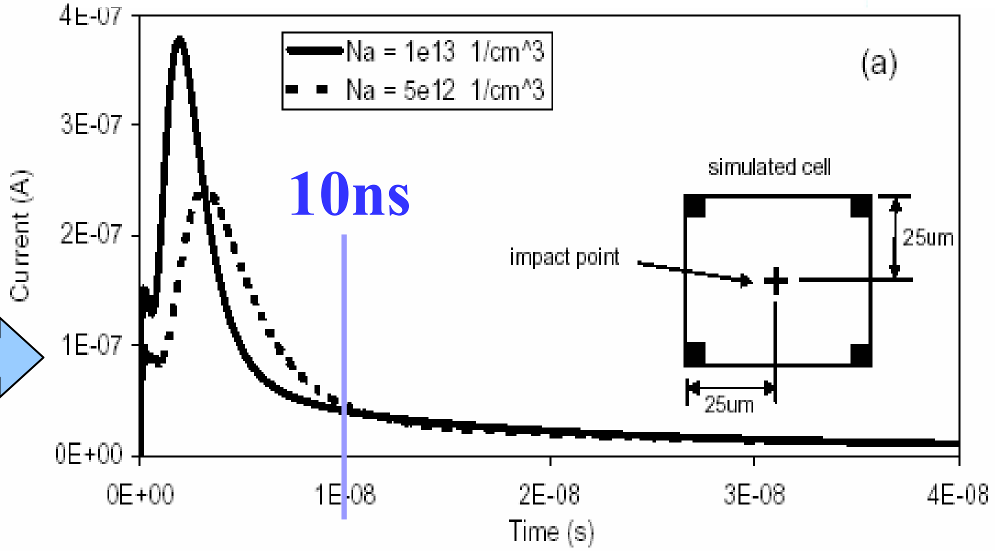
3D-SCT Detectors





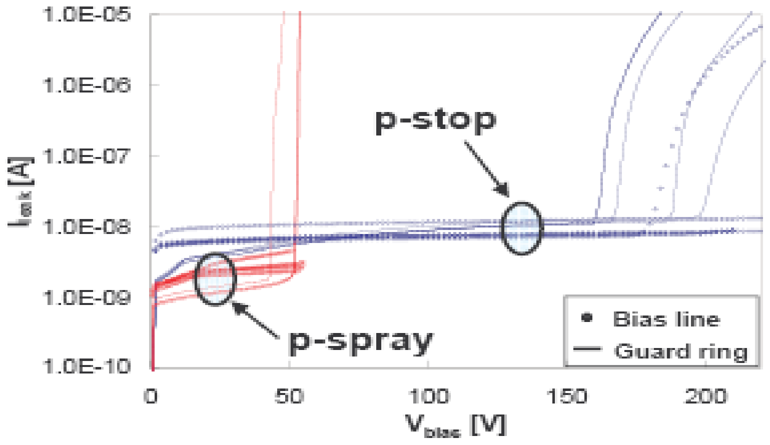
- P-type substrate:
  - FZ(500 μm) ρ= 5.0 KΩcm
  - Cz (300 μm) ρ= 1.8 KΩcm
- Sintering: FZ420 ^{0}C, Cz 380 ^{0}C
- Simulation
  - CCE within < 10 ns
  - worst case shown (hit in middle of cell)

[C. Piemonte et al., NIM A541 (2005) 441]

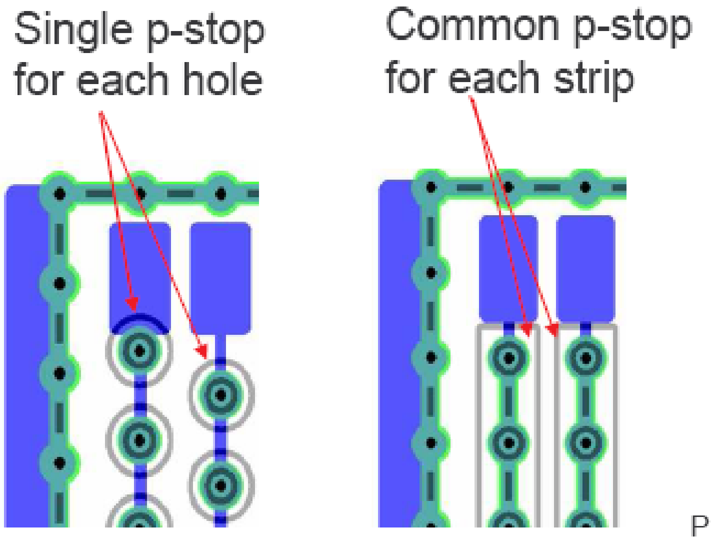


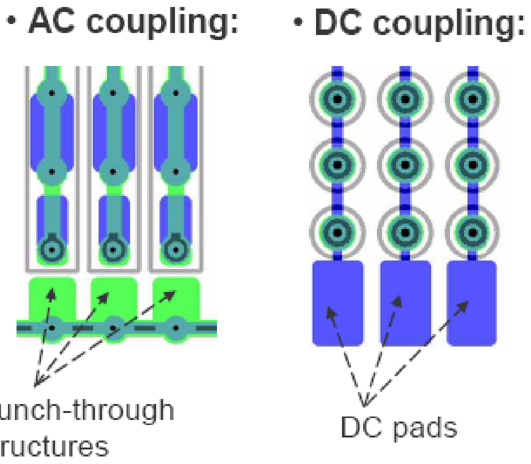
3D-SCT Detectors

- Strip detect layout:
  - No columns:12,000-15,000
  - Inter-column pitch 80-100μm
  - Holes d=6-10μm
  - P-stop and p-spray isolation
  - Two p-stop layouts
  - AC and DC coupling



- Average current per column <1 pA
- Early breakdown for p-spray pre- irradiation





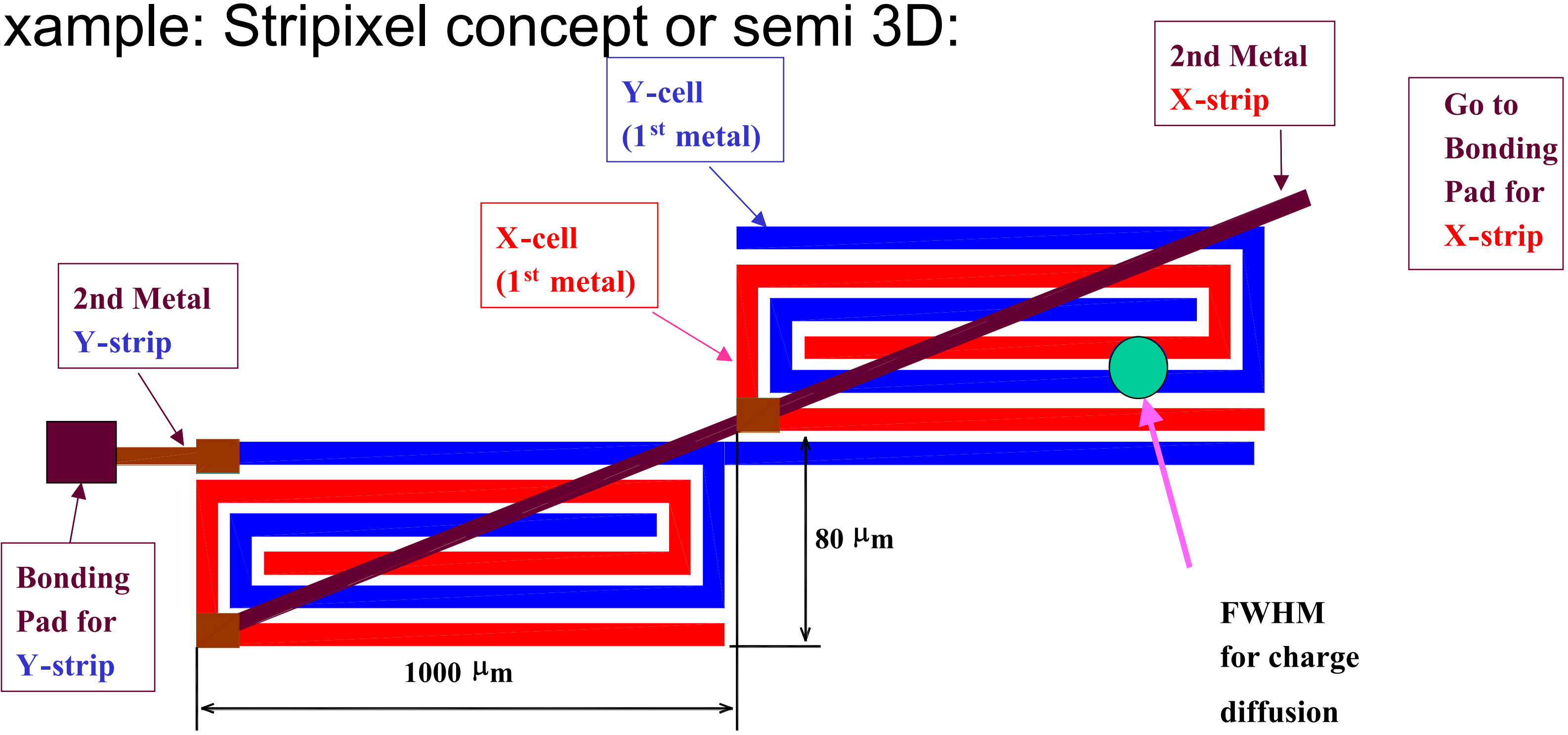
First results are very promising

DRIE does not affect device performance

Pozza and Boscardin RD05 Florence

Other new structures: Stripixel

- Several concepts for new **(planar and mixed planar & 3D)** detector structures aiming for improved radiation tolerance or less costly detectors **(see e.g. Li - 6th RD50 workshop, or Bortoletto- 5th RD50 Workshop)**
- Example: Stripixel concept or semi 3D:



Z. Li, D. Lissauer, D. Lynn, P. O'Connor, V. Radeka

Summary

- **At fluences up to 10^{15}cm^{-2} (Outer layers of a SLHC detector) the change of depletion voltage and the large area is the major problem:**
  - **CZ silicon detectors could be a cost-effective radiation hard solution (no type inversion, use p-in-n technology)**
  - **p-type silicon microstrip detectors show very encouraging results: CCE $\approx$ 6500 e; Φ_{eq}= 4×10^{15} cm^{-2}, 300μm, collection of electrons no reverse annealing observed in CCE measurement!**
- **At the fluence of 10^{16}cm^{-2} (Innermost layer of a SLHC detector) the active thickness of any silicon material is significantly reduced due to trapping. The promising new options are:**
- **Thin/EPI detectors: drawback: radiation hard electronics for low signals needed e.g. 2300e at Φ_{eq} $8\text{x}10^{15}$cm^{-2}, 50μm EPI,**
  …. thicker layers will be tested in 2005/2006
- **3D detectors: drawback: technology has to be optimized**
  ….. steady progress within RD50
- **New Materials like SiC and GaN (not shown) have been characterized . CCE tests show these materials to be still not radiation harder than silicon**