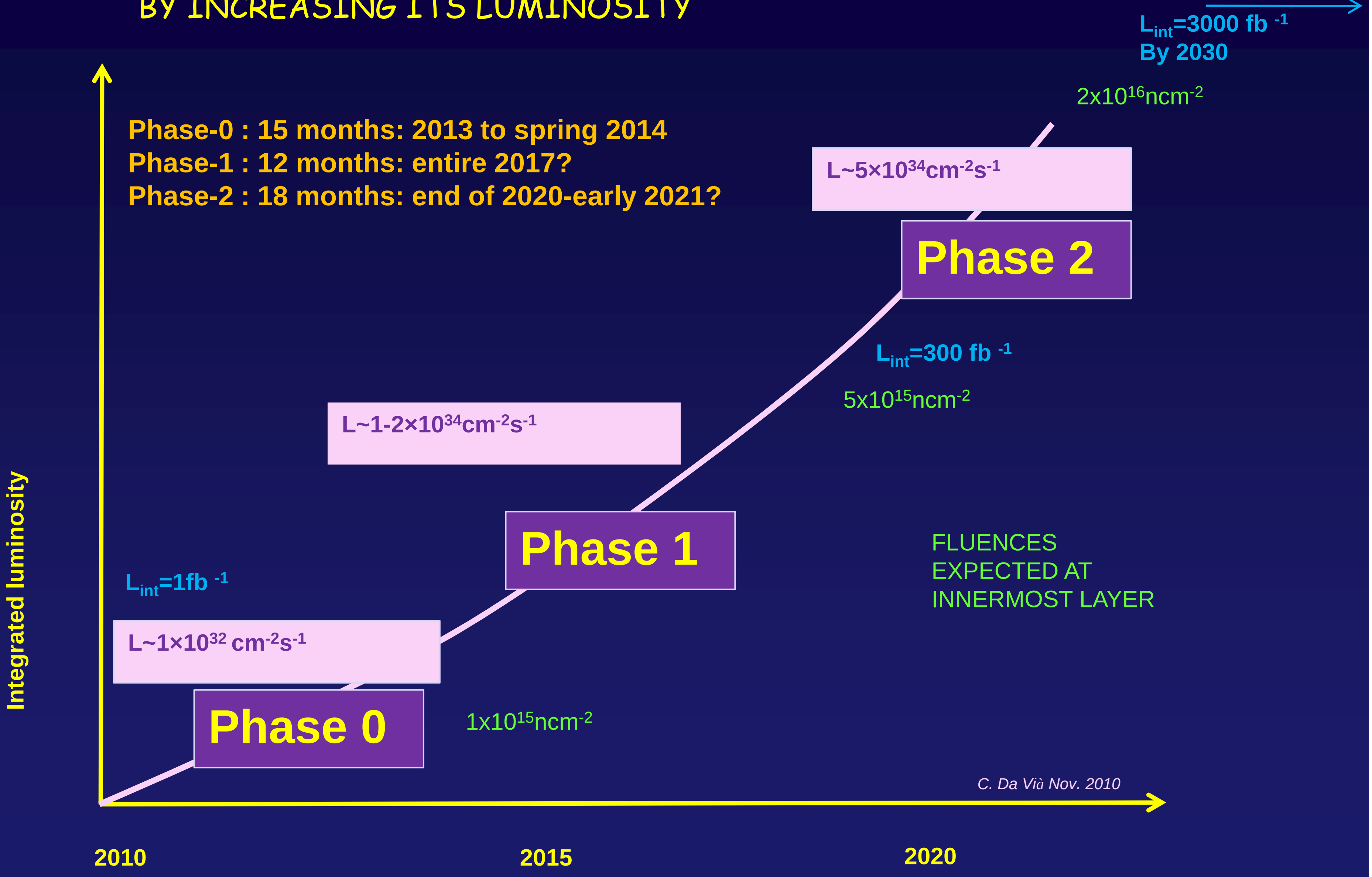
3D Silicon Qualification for the ATLAS IBL project

Cinzia Da Vià, The University of Manchester, UK

- ❖Introduction
- ❖The first ATLAS upgrade: Insertable B-Layer
- ❖3D silicon technology for IBL: Specs, Status
- ❖Current strategy
- ❖Summary and Conclusions

THE DISCOVERY POTENTIAL OF THE LHC CAN BE ENHANCED BY INCREASING ITS LUMINOSITY



Phase-0 : 15 months: 2013 to spring 2014
Phase-1 : 12 months: entire 2017?
Phase-2 : 18 months: end of 2020-early 2021?

L_{int}=3000 fb $^{-1}$
By 2030

$2x10^{16}ncm^{-2}$

$L\sim5\times10^{34}cm^{-2}s^{-1}$

Phase 2

L_{int}=300 fb $^{-1}$

$5x10^{15}ncm^{-2}$

$L\sim1\text{-}2\times10^{34}cm^{-2}s^{-1}$

Phase 1

FLUENCES
EXPECTED AT
INNERMOST LAYER

L_{int}=1fb $^{-1}$

$L\sim1\times10^{32}$ $cm^{-2}s^{-1}$

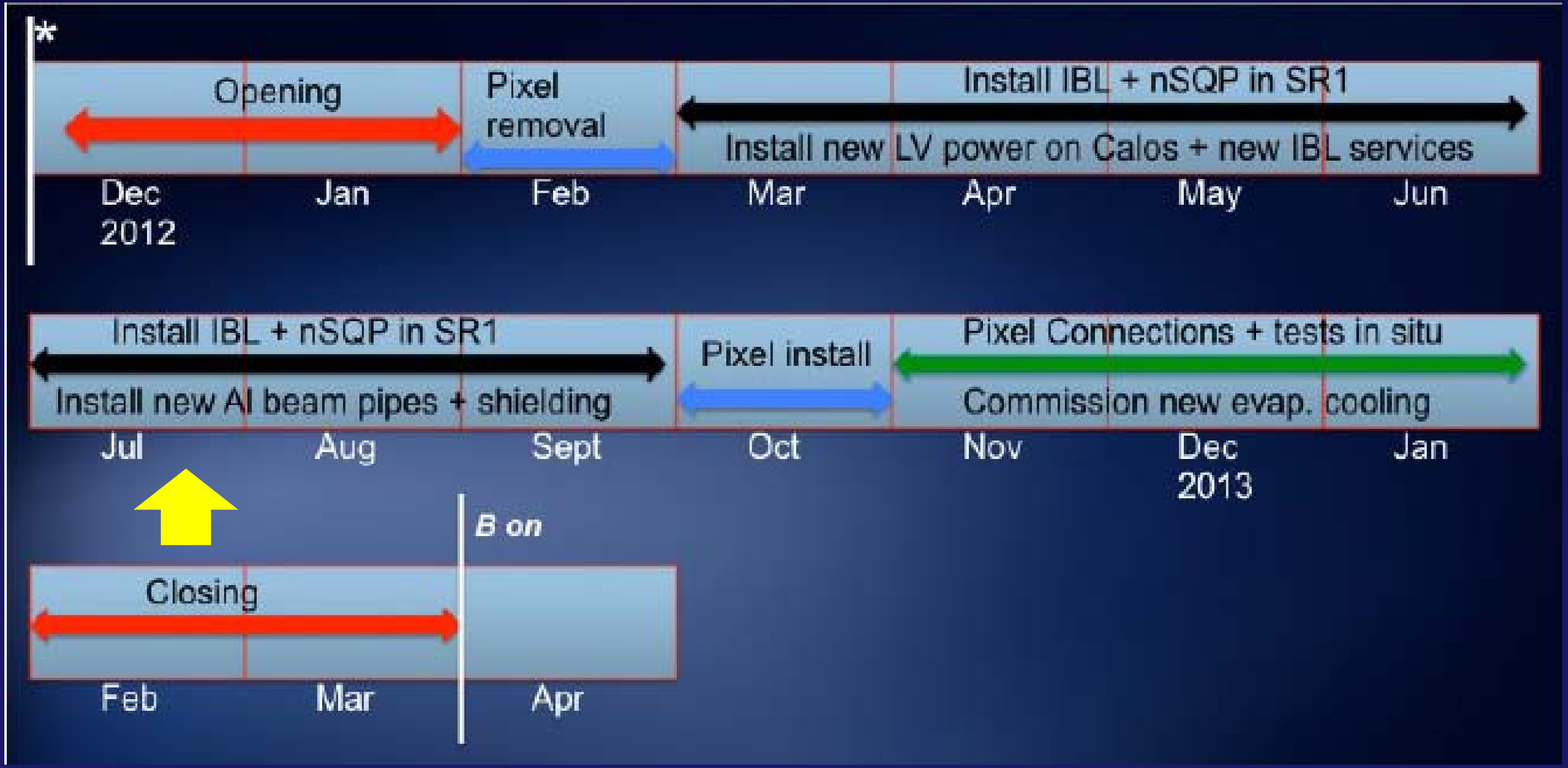
Phase 0

$1x10^{15}ncm^{-2}$

C. Da Vià Nov. 2010

Data from Steve Myers
CERN sLHC 23rd June 2010.

The FT-IBL installation plan in 2013 Programme shorter of 2 years from original plan



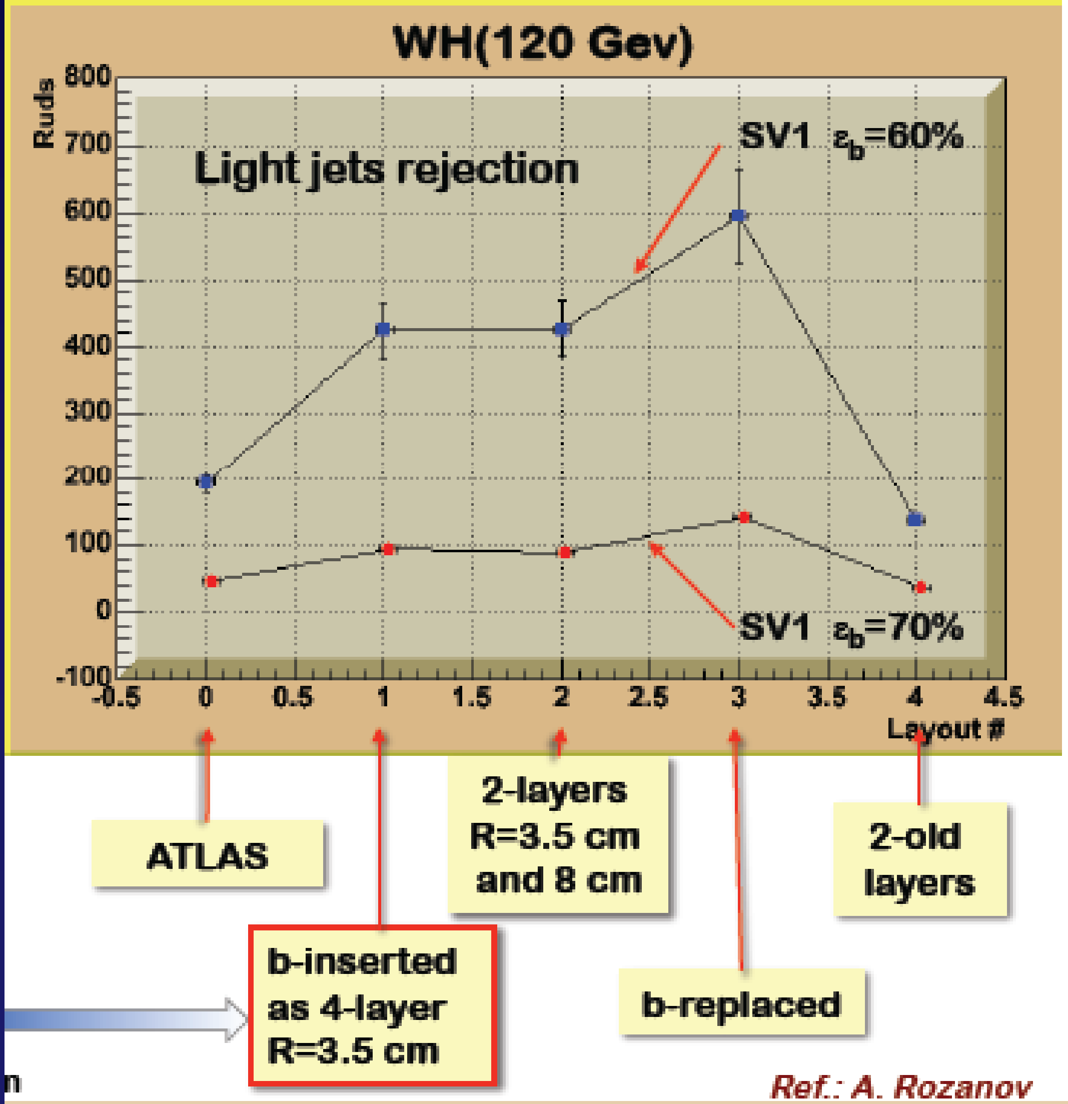
From M Nessi

Why is the IBL needed

Physics performance studies ongoing for the IBL TDR (ATHENA/GEANT4).

- *Preliminary studies (ATLSIM/ GEANT3) show improved performance with the addition of IBL (see low mass Higgs b-jet tagging plot on the right).*
- *Performance improvement due to low mass and smaller radius*
- *Low mass is crucial otherwise improvements might be overcome by multiple scattering*

Component	% X_0 (*)
beam-pipe	0.6
New BL @ R=3.5 cm	1.5
Old BL @ R=5 cm	2.7
L1 @ R=8 cm	2.7
L2 + Serv. @ R=12 cm	3.5
Total	*11.0*

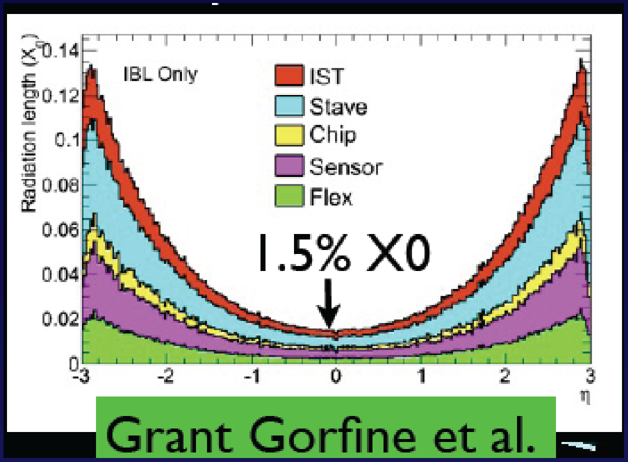


Ref.: A. Rozanov

IBL detectors technical challenges

- Material budget –less multiple scattering, better primary vertex resolution

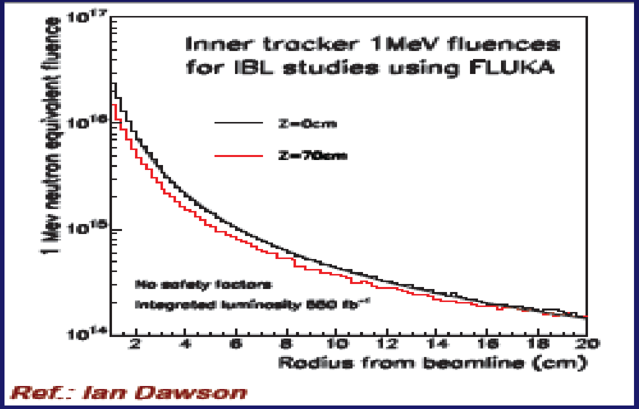
Thin/small beam-pipe
Ultra-light detectors
Many channels to reduce occupancy
High data rates – X_0 =1.5%



Grant Gorfine et al.

- High-precision detectors very close to IP up to 500 fb^{-1} integrated luminosity

➢ **Ultra radiation hard detectors**
Radiation hardness up to
$5X10^{15}ncm^{-2}$ ($3.3x10^{15}ncm^{-2}$+safety)



Ref.: Ian Dawson

➡ Ultimately Signal/threshold in
a ns stable operational conditions

Cinzia Da Viá , the University of Manchester Trento Workshop, 2^{nd} March 2011

Atlas IBL construction parameters

- Baseline layout decided
  - 14 Staves, “reverse turbine”

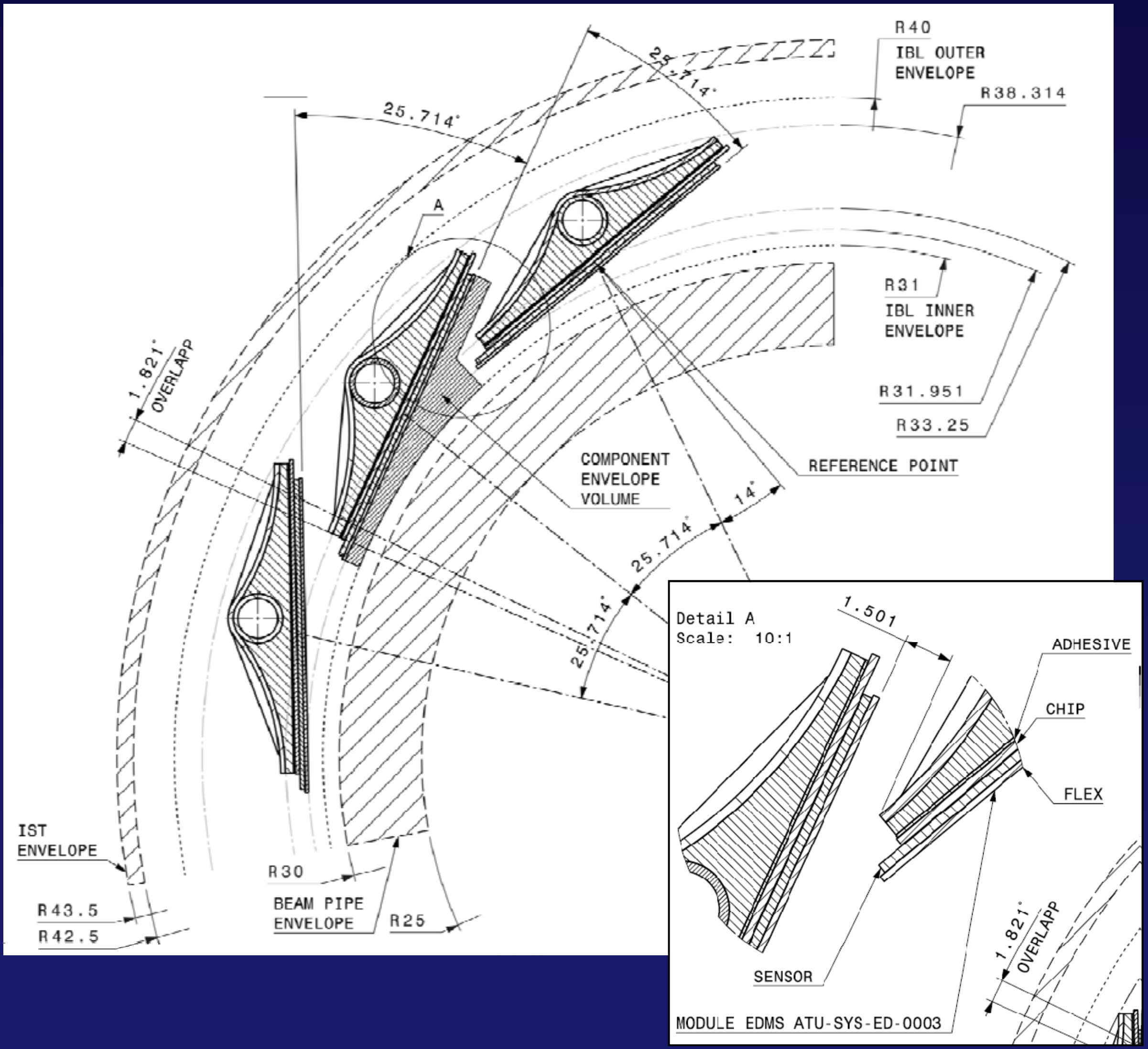
- Beam-pipe reduction:
  - Inner R: 29 → 25 mm

Very tight clearance:

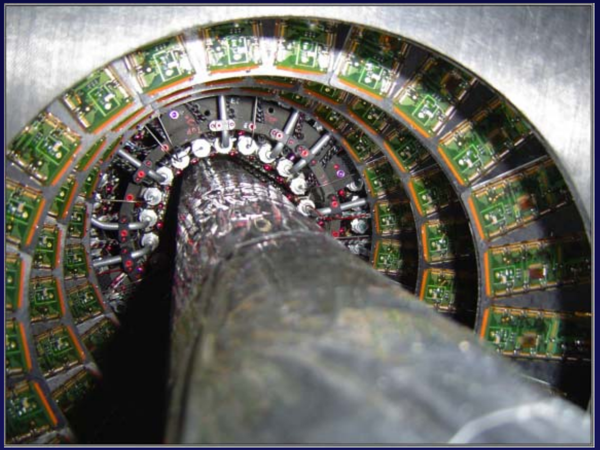
- “Hermetic” to straight tracks in Φ (1.8° overlap)
- No overlap in Z: minimize gap between sensor active area.

Layout parameters:

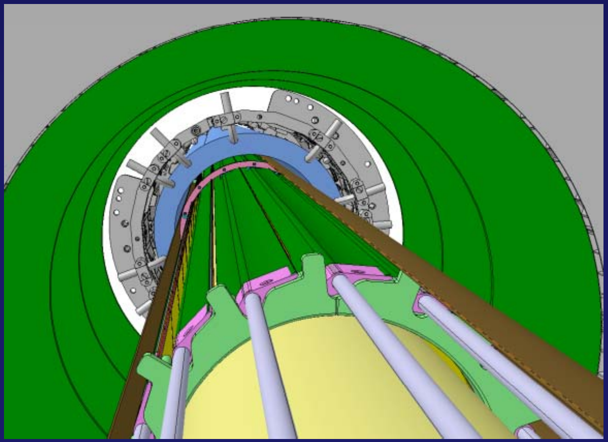
- IBL envelope: 9 mm in R
- 14 staves.
- <R> = 32 mm.
- Z = 60 cm (active length).
- η = 2.5 coverage.



How the IBL will look like

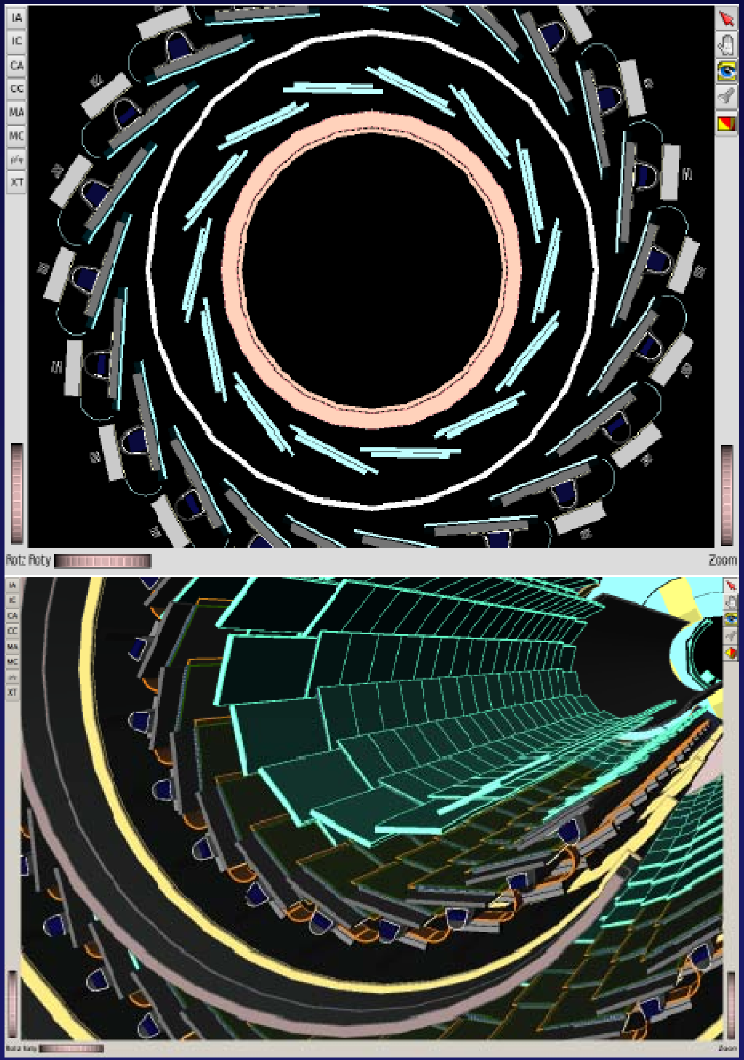


Picture of the current pixel detector after installation



Rendering of the new IBL with reduced beampipe

Reverse turbine layout



IBL geometrical arrangement

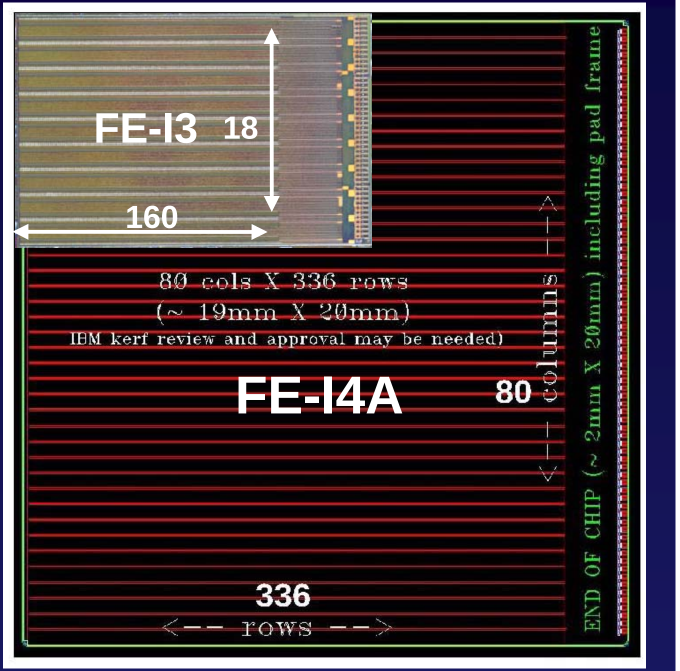
From IBL-TDR

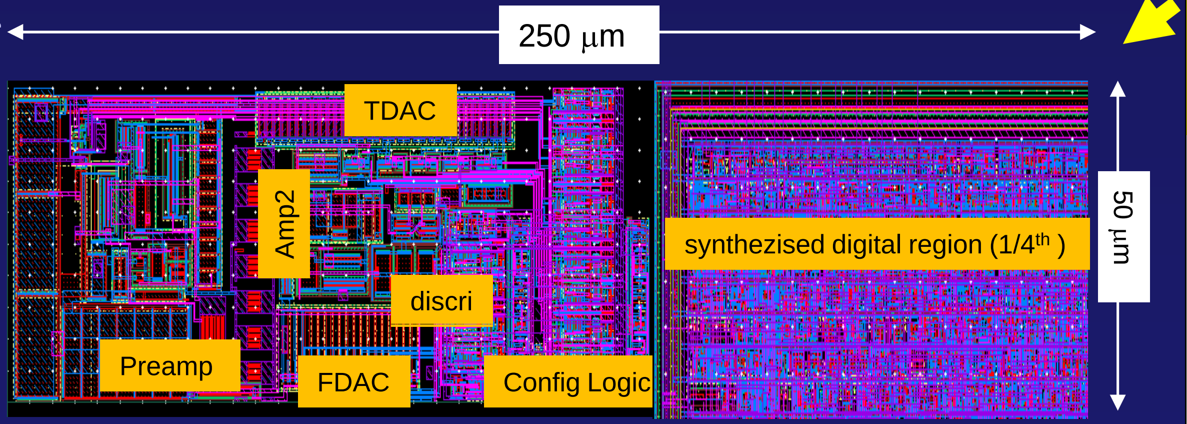
IBL Sensors Specifications

- FE-I4 compatible layout x1 x2 MultiChip
- Radiation tolerance up to 500fb^{-1}
- <450 µm inactive edge
- < 200 mW/cm2 at 5 x 10^{15} neq/cm^2 (after annealing)
- 1000 V of bias voltage (safely) applicable after 5 . 10^{15} neq/cm^2

S/T > 2 after 5 . 10^{15} neq/cm^2

- Agreed pre-production of 50 wafers of 3D and planar sensors
- Review in June 2011





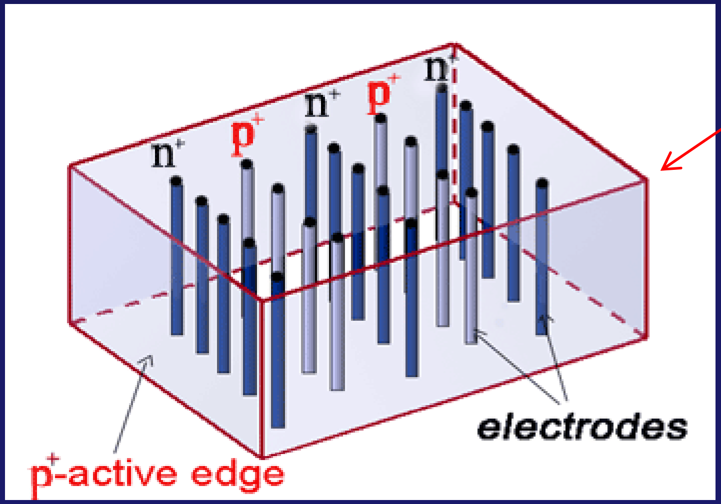
FE-I4 Single pixel dimensions and logic

	FE-I3	FE-I4
Pixel Size [µm²]	50×400	50×250
Pixel Array	18×160	80×336
Chip Size [mm²]	7.6×10.8	20.2×19.0
Active Fraction	74 %	89 %
Analog Current [µA/pix]	26	10
Digital Current [µA/pix]	17	10
Analog Voltage [V]	1.6	1.4
Digital Voltage [V]	2	1.2
pseudo-LVDS out [Mb/s]	40	160

Original 3D for IBL : 2 designs with equivalent Electrical performance

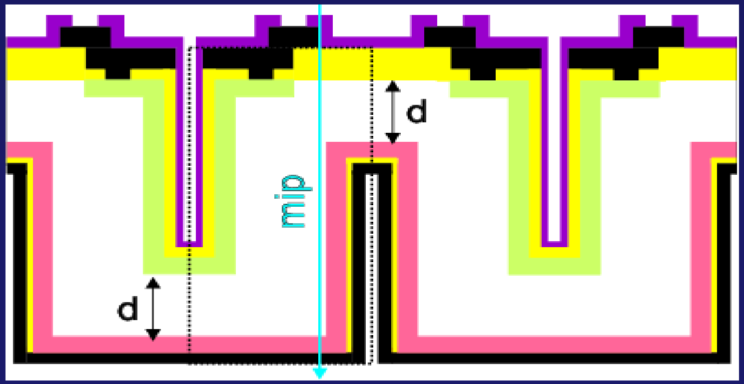
3D CONSORTIUM

FULL 3D WITH ACTIVE EDGES

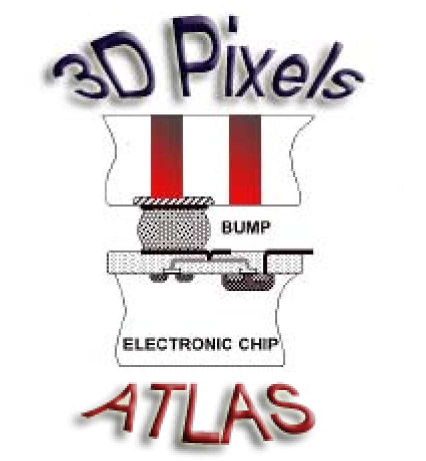


AGREED BASELINE

DOUBLE COLUMN DESIGN



ATLAS 3D Silicon Sensors R&D Collaboration

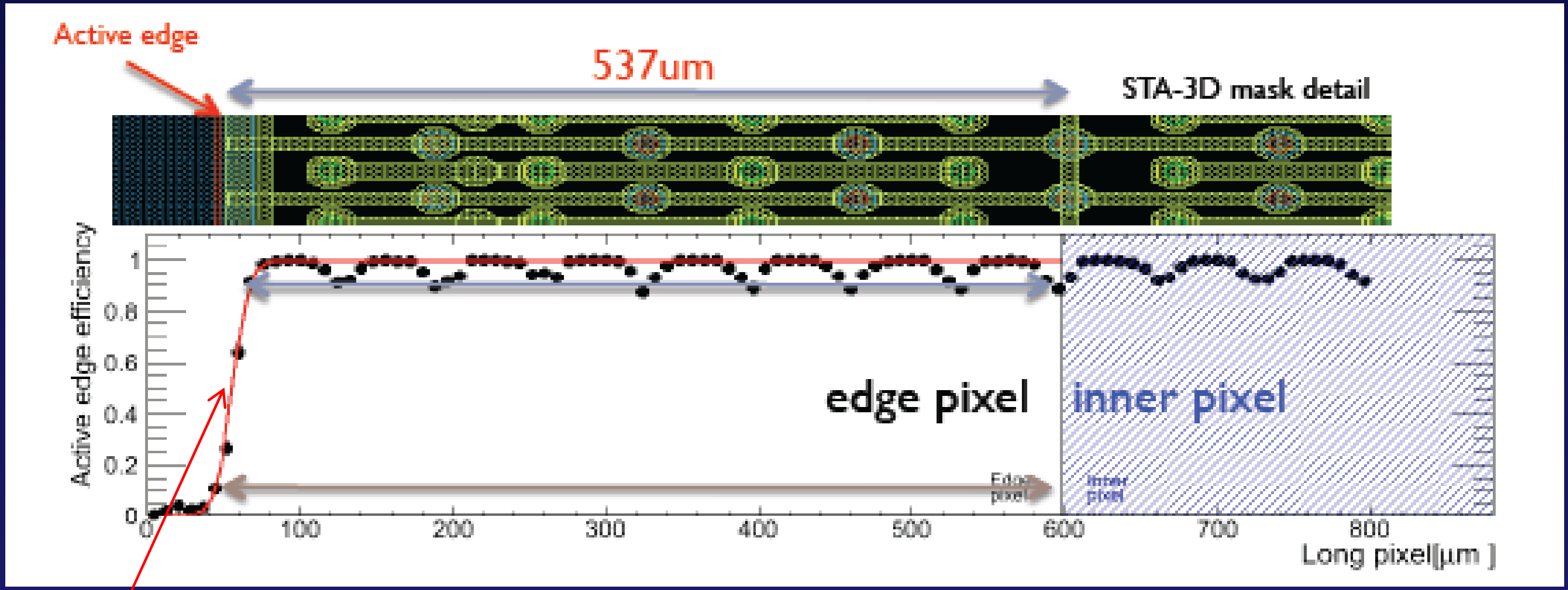


B. Stugu, H. Sandaker, K. Helle, (Bergen University), M. Barbero, F. Hügging, M. Karagounis, V. Kostyukhin, H. Krüger, J-W Tsung, N. Wermes (Bonn University), M. Capua; S. Fazio, A. Mastroberardino; G. Susinno (Calabria University), B. Di Girolamo; D. Dobos, A. La Rosa, H. Pernegger, S. Roe (CERN), T. Slavicek, S. Pospisil (Czech Technical University), K. Jakobs, M. Köhler, U. Parzefall (Freiburg University), N. Darbo, G. Gariano, C. Gemme, A. Rovani, E. Ruscino (University and INFN of Genova), C. Butter, R. Bates, V. Oshea (Glasgow University), S. Parker (The University of Hawaii), M. Cavalli-Sforza, S. Grinstein, I. Korokolov, C. Padilla (IFAE Barcelona), K. Einsweiler, M. Garcia-Sciveres (Lawrence Berkeley National Laboratory), M. Borri, C. Da Vià, J. Freestone, S. Kolya, C. Li, C. Nellist, J. Pater, R. Thompson, S.J. Watts (The University of Manchester), M. Hoeferkamp, S. Seidel (The University of New Mexico), E. Bolle, H. Gjersdal, K-N Sjoebaek, S. Stapnes, O. Rohne, (Oslo University) D. Su, C. Young, P. Hansson, P. Grenier, J. Hasi, C. Kenney, M. Kocian, P. Jackson, D. Silverstein (SLAC), H. Davetak, B. DeWilde, D. Tsybychev (Stony Brook University). G-F Dalla Betta, P. Gabos, M. Povoli (University and INFN of Trento) , M. Cobal, M-P Giordani, Luca Selmi, Andrea Cristofoli, David Esseni, Andrea Micelli, Pierpaolo Palestri (University of Udine)

Processing Facilities: C. Fleta, M. Lozano G. Pellegrini, (CNM Barcelona, Spain); (M. Boscardin, A. Bagolini, P. Conci, G. Giacomini, C. Piemonte, S. Ronchin, E. Vianello, N. Zorzi (FBK-Trento, Italy) , T-E. Hansen, T. Hansen, A. Kok, N. Lietaer (SINTEF Norway), J. Hasi, C. Kenney (Stanford). J. Kalliopuska, A. Oja (VTT , Finland)*

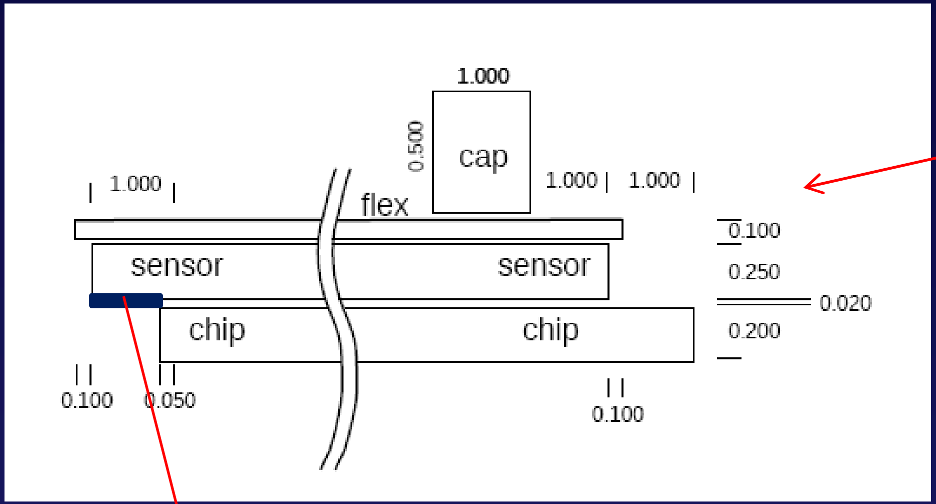
18 institutions and 5 processing facilities

Full 3D with active edges

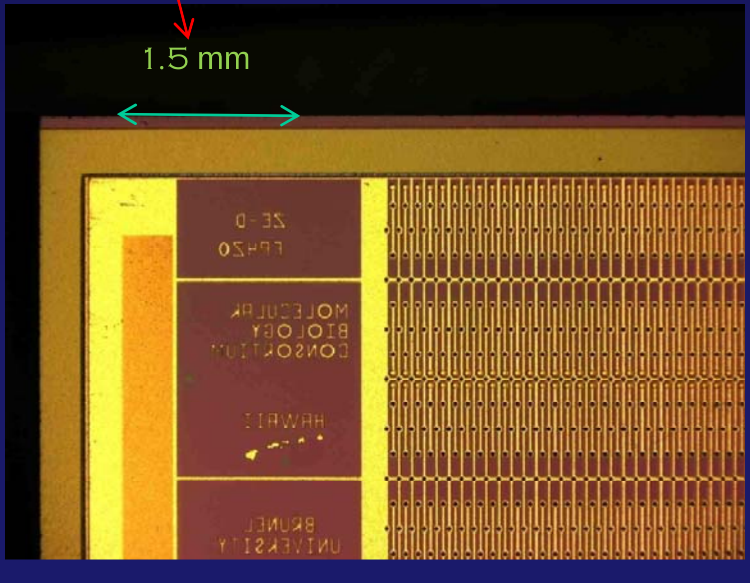


6 microns 10-90% slope

Full 3D with active edges- HV supply and support Wafer removal



Bias tab



- ❖Full 3D requires a support wafer
For mechanical stability

H

- ❖HV is supplied through the active edge
On the front side

- ❖Solutions to carry the bias to the back
side ongoing

- ❖Tests to remove the support wafer
Made at VTT and will start at
SINTEF and CNM

Bias tab=1.5mm
External pixels
250+200=450μm

Spin etched wafer at VTT
J. Kalliopusca

Performance of the considered 3D designs

Simulations and data shows that
The response of full 3D and
3D-DDTC is very close if the
electrode penetration
stops 25 mm from the surface
Before and after irradiation

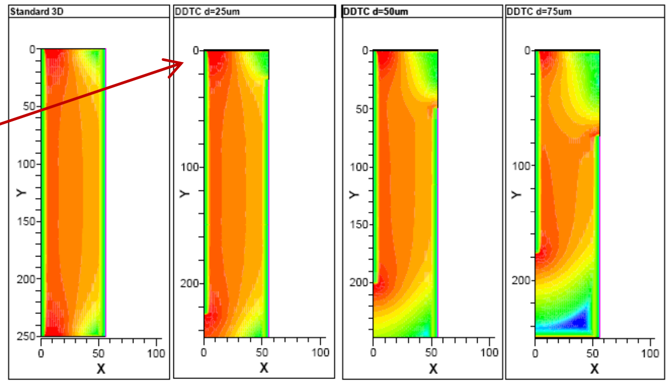


Figure 6.2: Electric field distribution taken from a 2-D cross section of the 3-D structure along the diagonal that connects two columns of opposite doping types. Four cases are here represented: one standard 3D detector and three 3D-DDTC detectors with d spacing of 25, 50 and 75 μm.

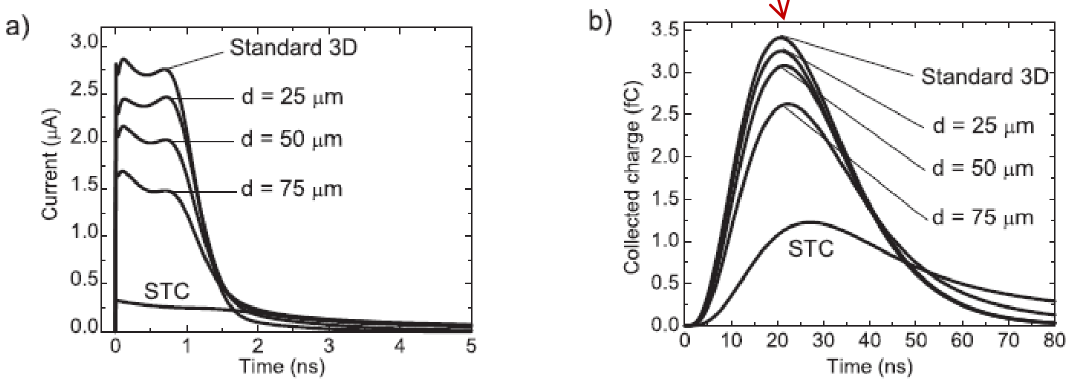
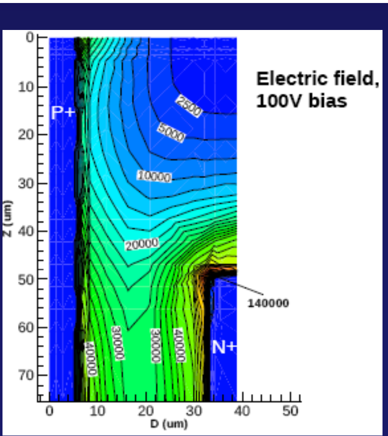


Figure 6.3: Simulated transient signals in 3D detectors of different geometries, biased at 16V, in response to a MIP particle: a) current signal; b) equivalent charge signal at the output of a semi-gaussian shaper with 20ns peaking time.



Simulations (from A. Zoboli
PhD thesis, Trento, March 2009)
D. Pennicard, Glasgow IEEE/NSS 08

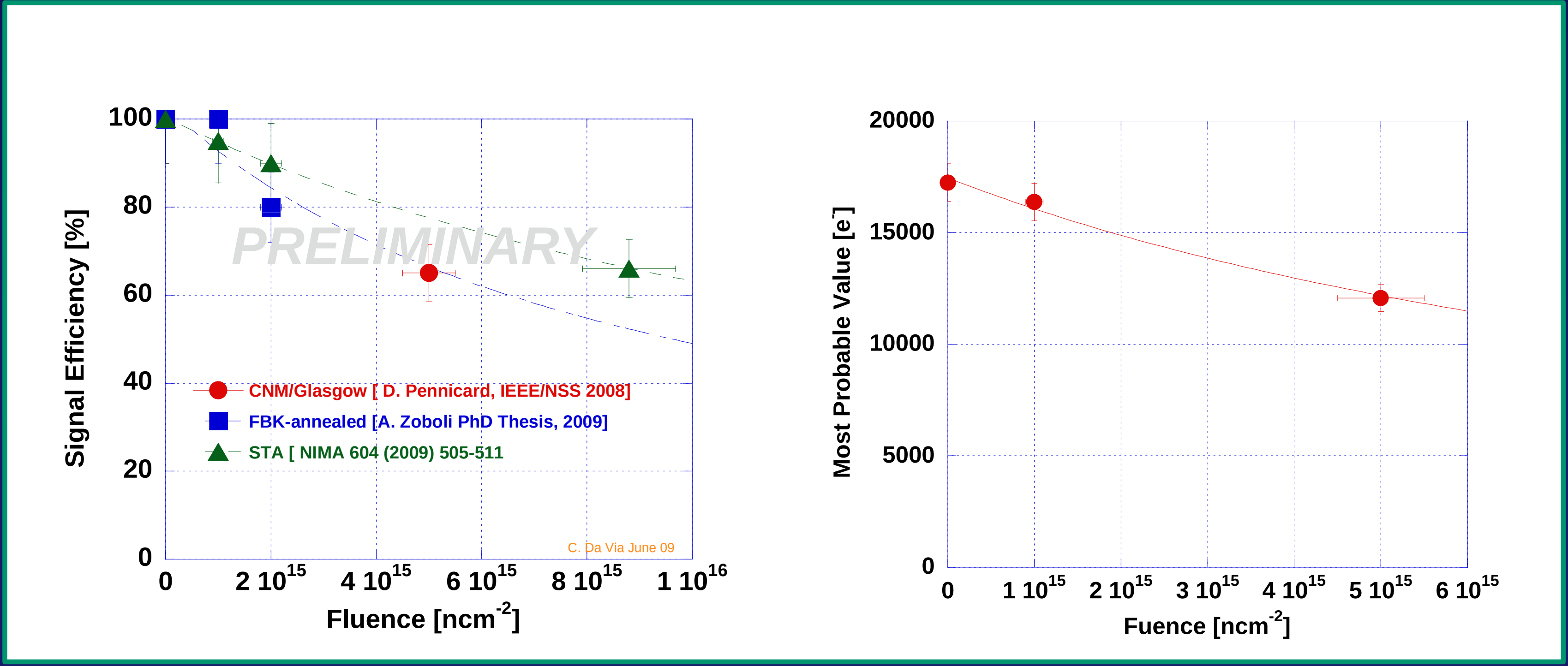
Most probable signal after IBL fluence

Compilation of Stanford, CNM,FBK

Last summer status

MPS=230μm x 75e^- = 17 250

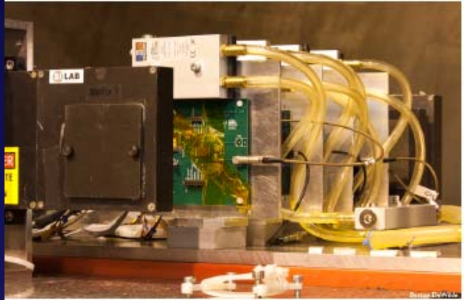
Fluence [ncm^{-2}]	MPS [e^-]
0	17250
1×10^{15}	16380
5×10^{15}	12075



Performance of FBK devices after irradiation
Test beam June 2010

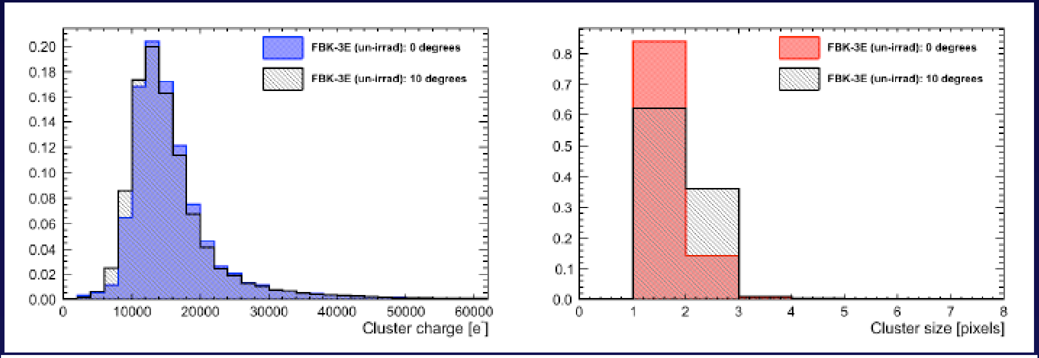
B. De Wilde and 3D test beam crew

FBK p-irradiated
1x10^{15}ncm^{-2} at Karshrue
bump-bonded to FE-I3

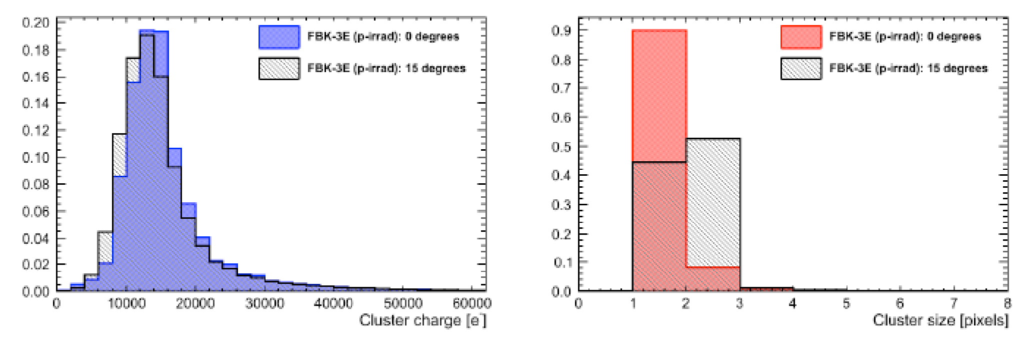


EUDET telescope
Tracking resolution
3um

Non irradiated



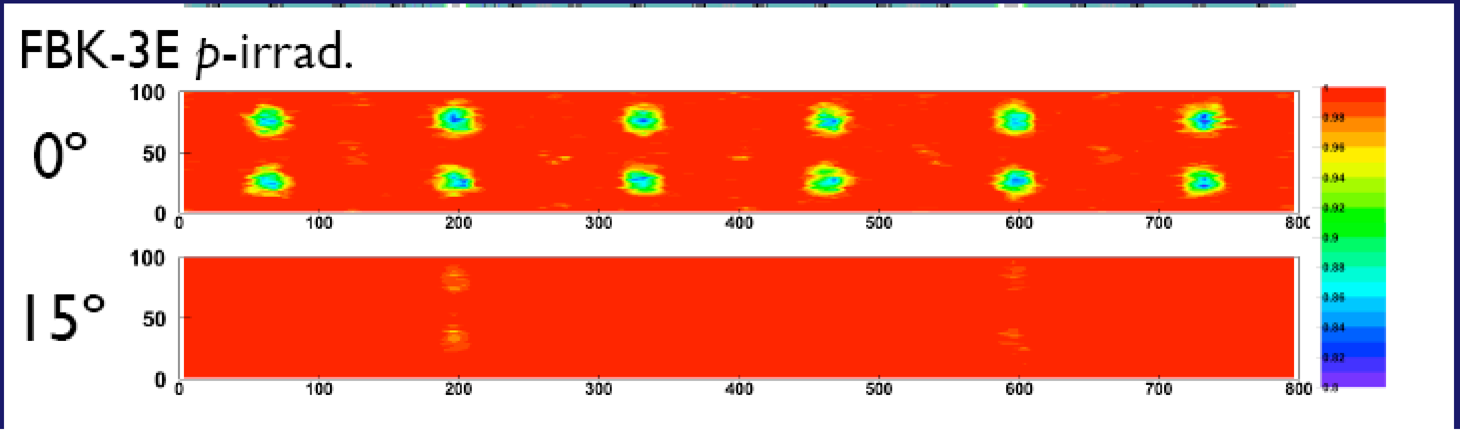
Irradiated



Tracking efficiency

99.0%

99.9%

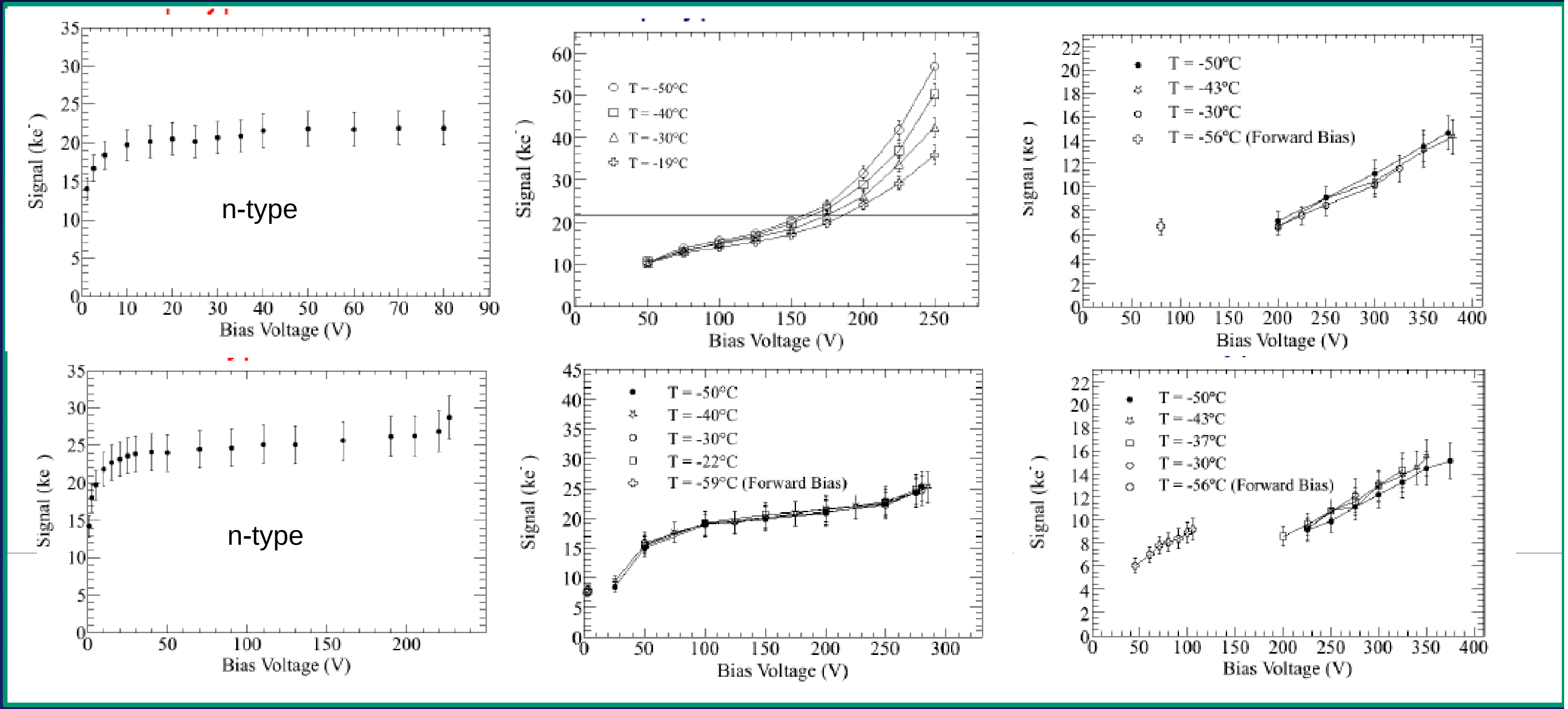


DS 3D from CNM irradiated
Uni-Freibugh with Alibava system (See M. Kohler talk)

Before irradiation
total charge 22000e

$2x10^{15}ncm^{-2}$
$22000e^{-}$ at 100-150V

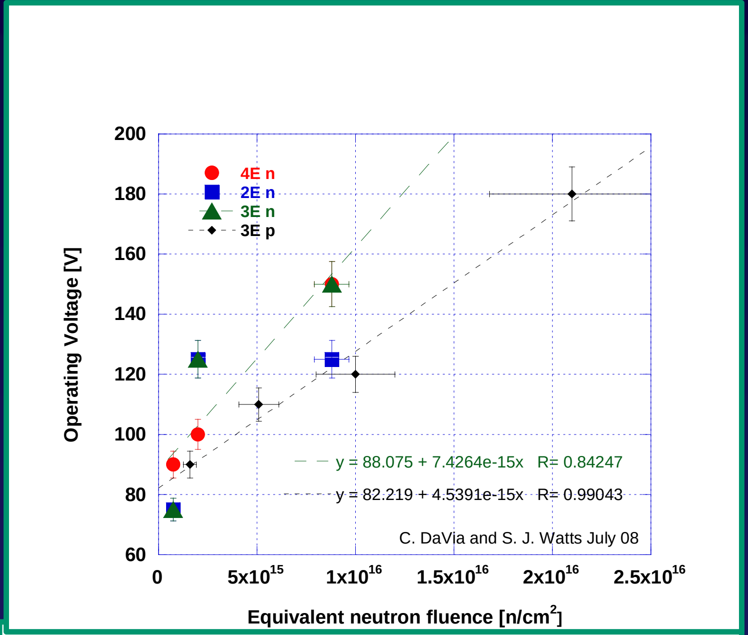
$2x10^{16}ncm^{-2}$
$15000e^{-}$ at 350-380V



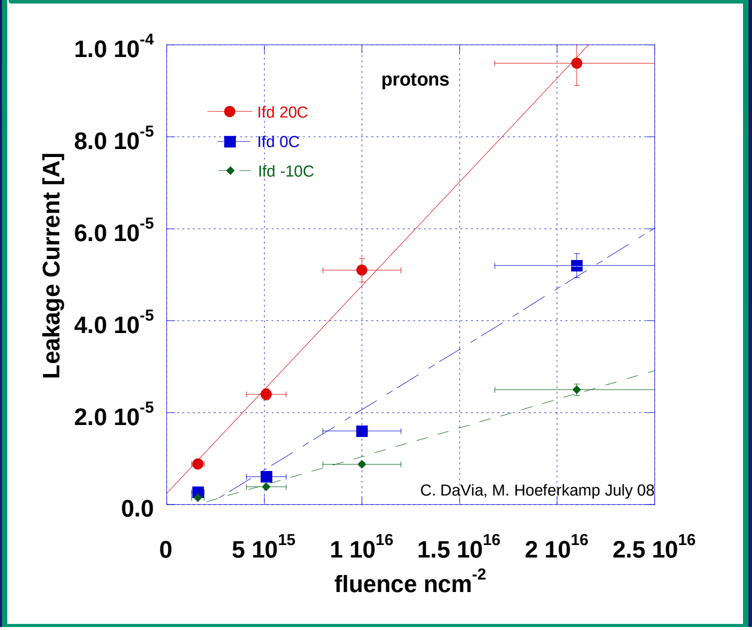
250 um column overlap, IES= 56 microns
Detectors irradiated at the proton cyclotron Karlsruhe with 25 MeV protons
Annealing state: ~ 5 days at RT (only p-type detector, $2x10^{16}$ neq/cm2: ~30 days)
Noise at $2x10^{16}$is 1000e- at -45 °C -50 °C

Power dissipation

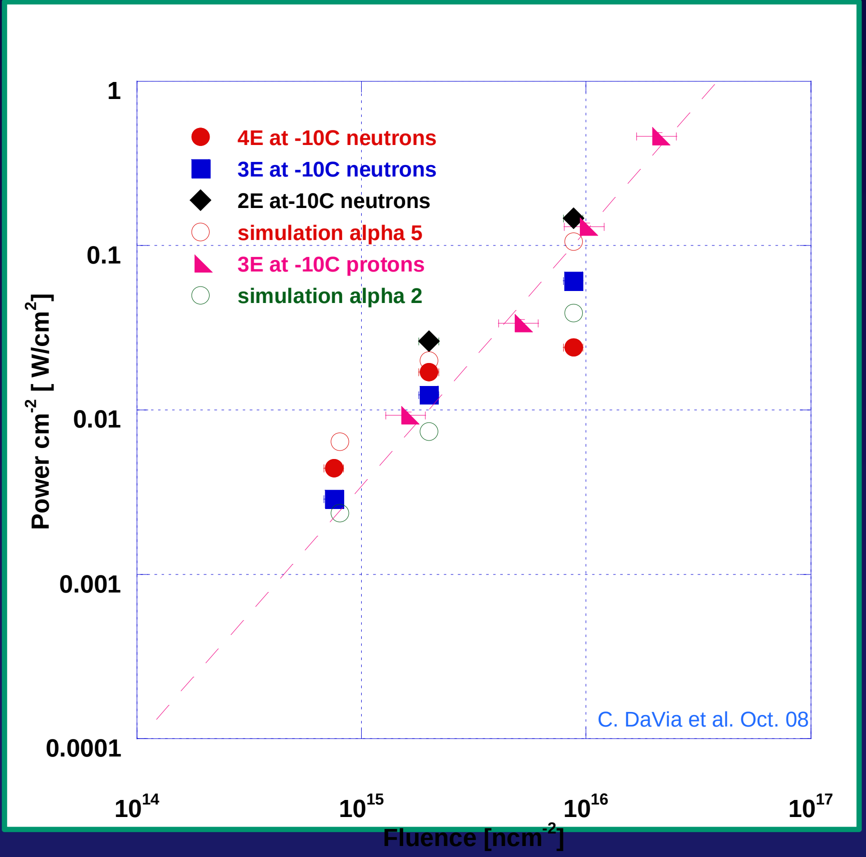
Processing: J. Hasi Manchesteri, C. Kenney, MBC
Measurements: M.Hoeferkamp UNMT. Slavicek Prague
Analysis and simulation C.DaVia, S.Watts, Manchester



C. DaVia and S. J. Watts July 08



C. DaVia, M. Hoeferkamp July 08



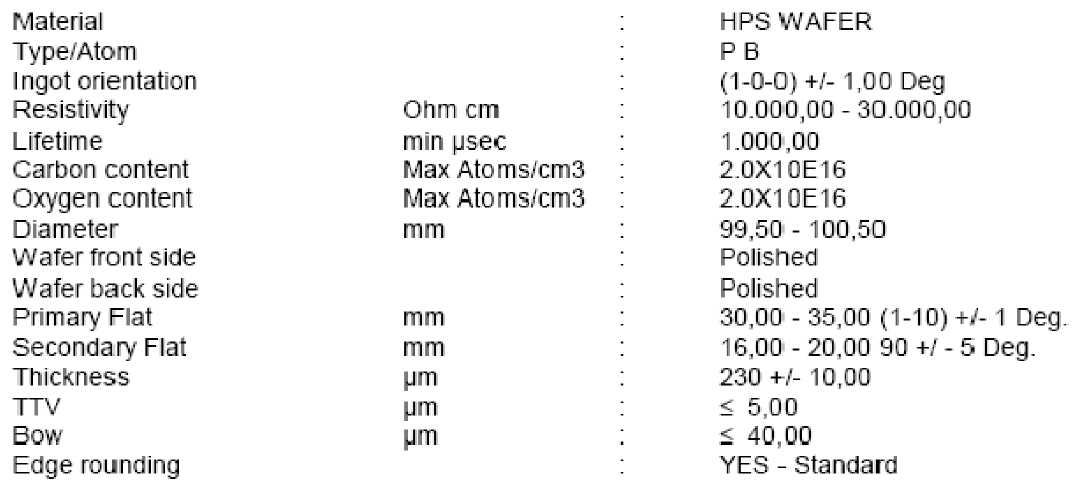
C. DaVia et al. Oct. 08

Power/cm^2 at -10°C

At 1.0×10^{15} ncm^{-2} ~ 3 $mWcm^{-2}$
At 5.0×10^{15} ncm^{-2} ~ 33 $mWcm^{-2}$
At 1.0×10^{16} ncm^{-2} ~ 120 $mWcm^{-2}$
At 2.1×10^{16} ncm^{-2} ~ 443 $mWcm^{-2}$

3D silicon IBL-Fast Track technical specs:

Due to the tight schedule for IBL in 2013
-> 3D will qualify Double-Side with 200 microns fences for FT-IBL
->qualification of full3D with active edges for phase1

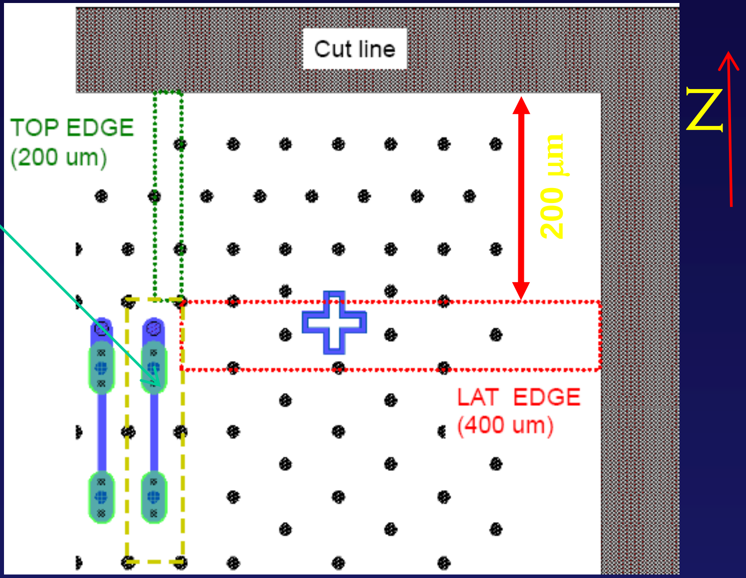


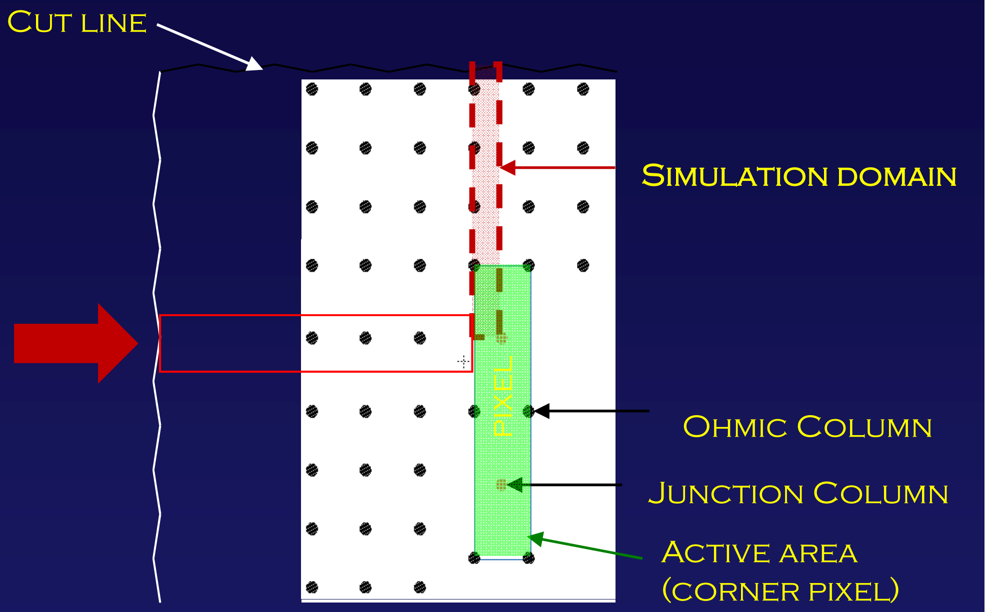
Material		:	HPS WAFER
Type/Atom		:	P B
Ingot orientation		:	(1-0-0) +/- 1,00 Deg
Resistivity	Ohm cm	:	10.000,00 - 30.000,00
Lifetime	min µsec	:	1.000,00
Carbon content	Max Atoms/cm3	:	2.0X10E16
Oxygen content	Max Atoms/cm3	:	2.0X10E16
Diameter	mm	:	99,50 - 100,50
Wafer front side		:	Polished
Wafer back side		:	Polished
Primary Flat	mm	:	30,00 - 35,00 (1-10) +/- 1 Deg.
Secondary Flat	mm	:	16,00 - 20,00 90 +/ - 5 Deg.
Thickness	µm	:	230 +/- 10,00
TTV	µm	:	≤ 5,00
Bow	µm	:	≤ 40,00
Edge rounding		:	YES - Standard

❖Sensor thickness	230±10 µm
❖Sensor active area	18860 X 20560 (+scribe line)
❖ Dead region in Z	200µm guard fence
❖Separation gap between adjacent modules in Z	100 µm
❖Sensor operational voltage before and after $5x10^{15}ncm^{-2}$	35-120V
❖Most probable signal before and after irradiation	17250 -12075 e^-
❖ENC noise with FE-I3	< 200e
❖Power dissipation per cm^2 (at 0°C)	$0.089Wcm^{-2}$
❖Tracking efficiency at 15°	99.9%

Double side approach : 200 um guard fences

Design and simulation
GF Dalla Betta, Trento





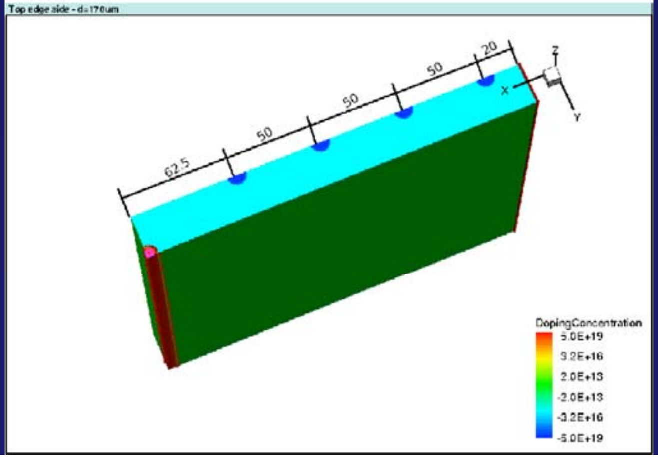
Cut line

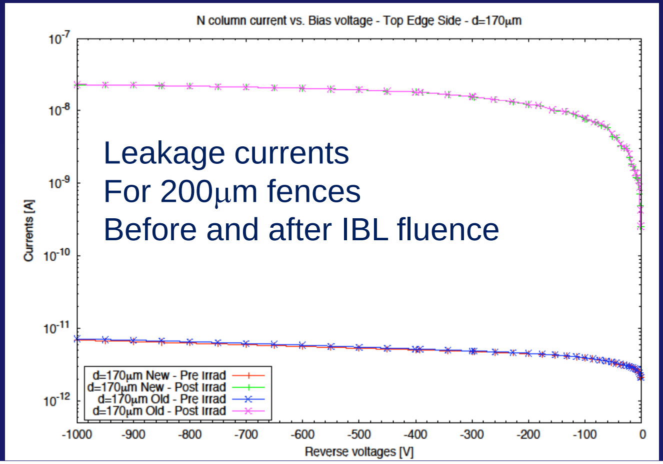
Simulation domain

Ohmic Column

Junction Column

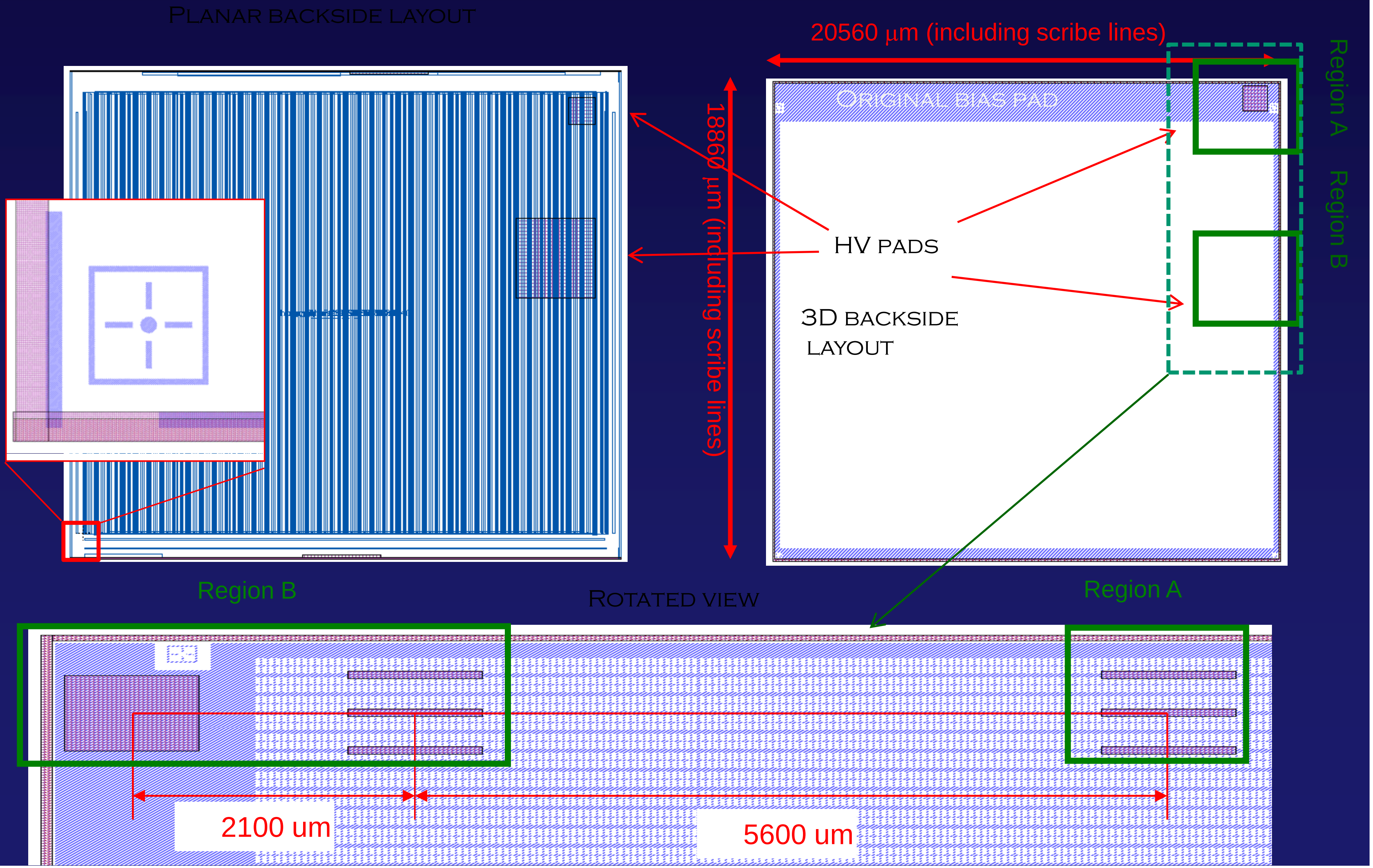
Active area
(corner pixel)



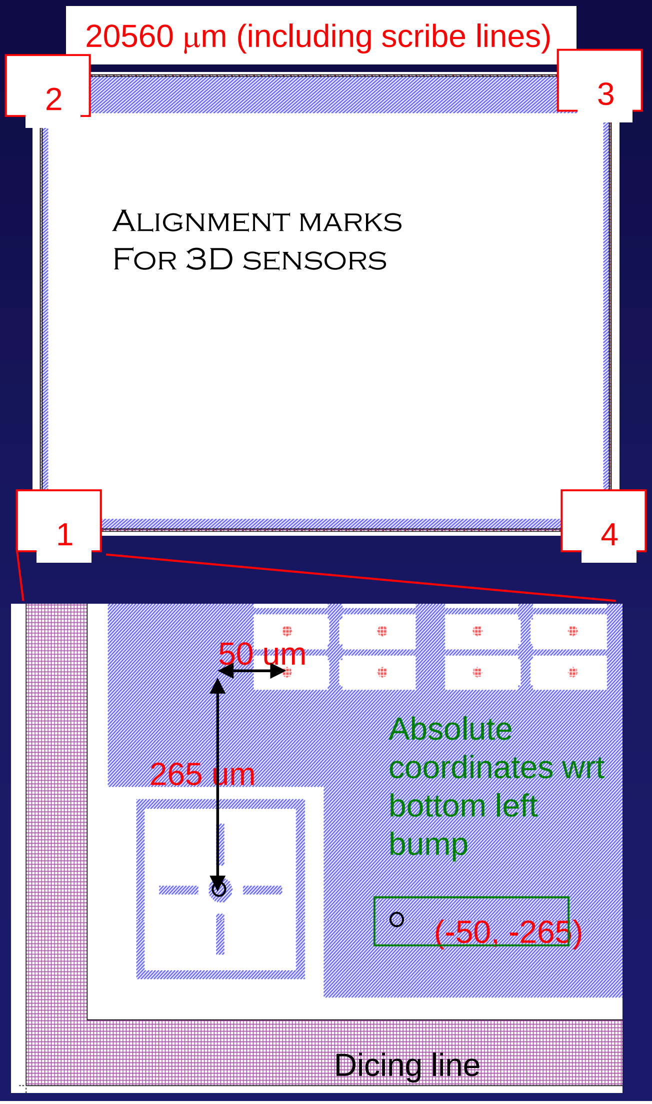


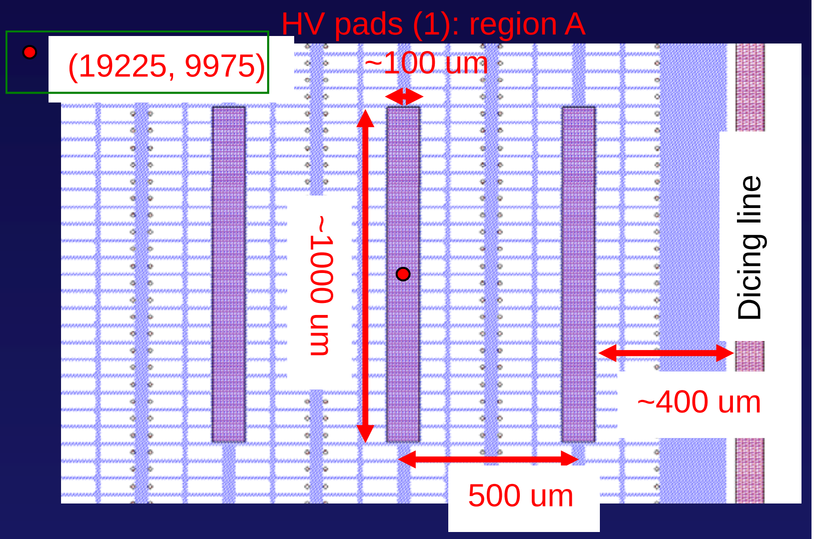
Leakage currents
For 200µm fences
Before and after IBL fluence

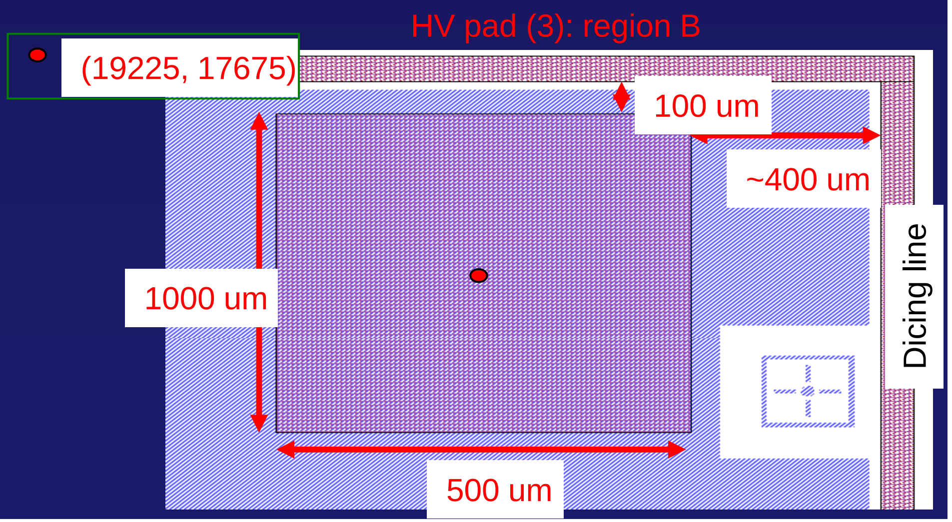
Stave Loading and bias voltage wirebonding Compatibility (design by GF Dalla Betta)



Details of 3D backside Bias pads and alignment marks (design by GF Dalla Betta)







A new aggressive schedule for fast track: Can 3D make it?

3D is a new technology. A 'fast track' industrialization programme started
1.5 years ago with the agreement on the common-floor plan layout amongst
All collaborating processing facilities.

KEY MILESTONES for 3D
qualification:

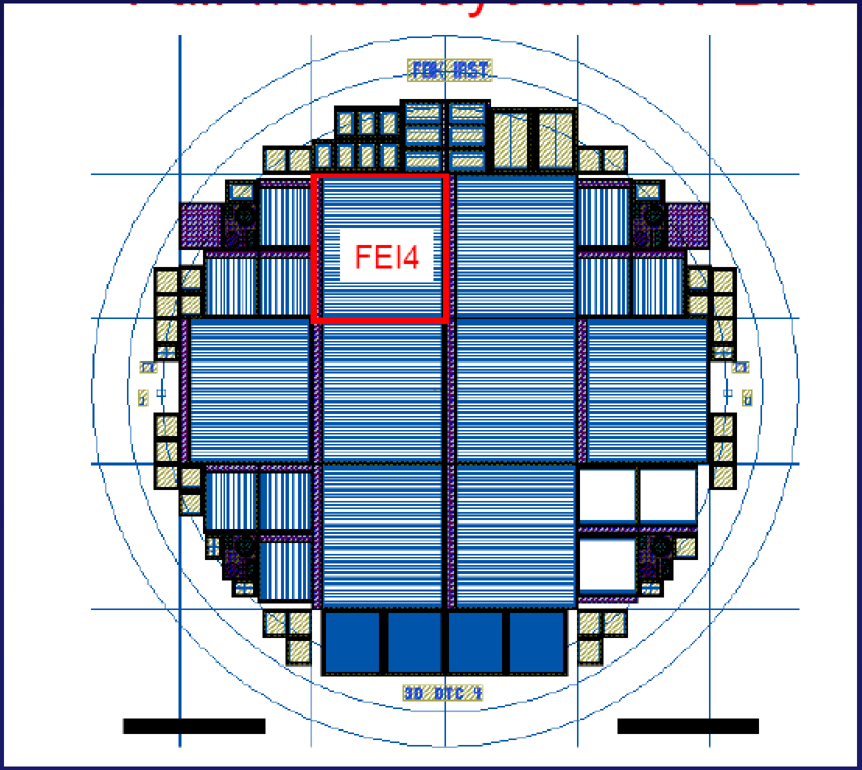
Fwbruary-March 11. CNM and FBK FE-I4
Waferst o IZM (3FBK at IZM since 8-2)

March-April 2011 Test and irradiation
of CNM and FBK FE-I4

April 2011 2nd DESY test beam

May-June 2011 irradiated FE-I4 tested in
the SPS beam line

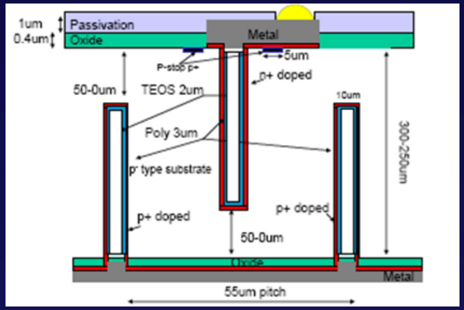
Yield is the main parameter
we are focusing on. So far we
Forecast ~50% but we are also
Considering worse cases due to the size of Fe-I4



qualification run Status Of Double Side Sensors at CNM

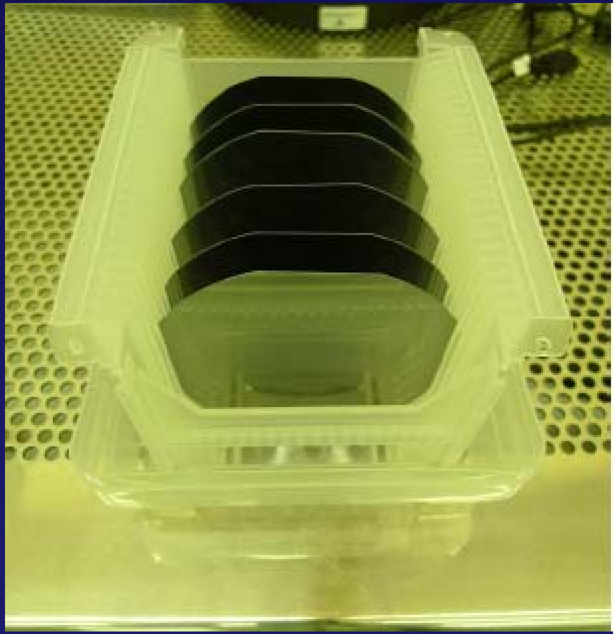
Double side with 200um slim edges

- ❖6 wafers 230 um thick
- ❖8 wafers 285 um thick



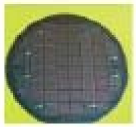
Currently concentrating on 230 um wafers:

- At the moment, wafer yield 100%
- Three wafers had high warping due to stress after doping. We decided to investigate the problem with a parallel test run.
- Doping process has been changed and optimized,
- Metallization on both sides and passivation left to do.
- Expected termination by mid March
- 48 SC FE-I4 with IBL specification resulting from this run

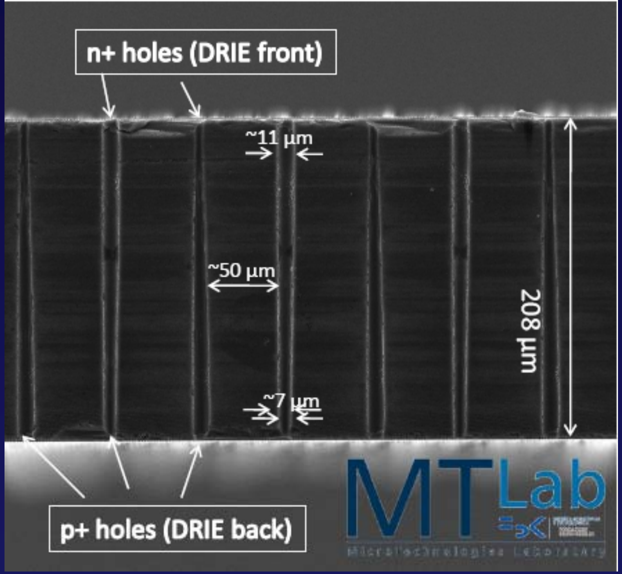


See dedicated CNM talks

Qualification run status of Double Side Sensors at



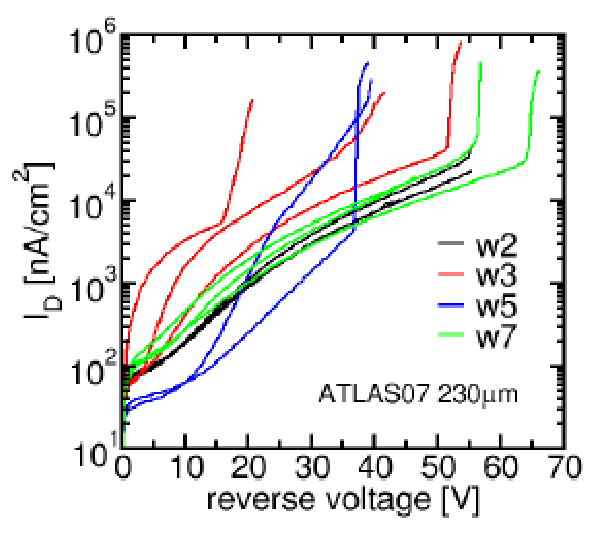
Full through electrodes



Batch name	FE	No. of wafers	Wafer thickness [µm]	Comments	Status
Atlas 07	I4	4	230	bowig ~100µm	sent to IZM for bump-bonding
Atlas 07	I4	4	200	bowig ~100µm	electrical tests in progress
Atlas 09	I4	10 8 5	200 230 250		first DRIE done

8 wafers completed = 64 SC FE-I4
8+15 completed by April= 64 + 120 (200 and 250 um)

IV measurements
On wafer
(test structures)



Diced wafer after UBM
Curtesy of T. Fritzsch, IZM

See dedicate FBK talks

FT-IBL Pre-production Status

Batch	Facility	Thickness µm	Edges 200µm	Wafers #	Status	Completion timescale weeks
Atlas10	FBK	230	Y	22	started	24
Atlas11	FBK	230	Y	22	started	24
RUN1	CNM	230	Y	24	step5	36
RUN2	CNM	230	Y	24	will start Beginning of March	36

❖FBK will finish by the end of June 2011 both runs - 4
4x8= 352 (x yield)

❖CNM will end by the end of October 2011- 10% (~1 month) contingency is included to account for machine downtime, tests etc.
48x8 = 384 (x yield)

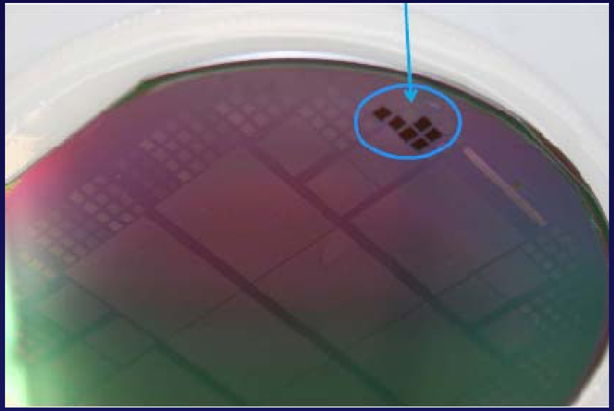
Additional 86 wafers have been bought already (order time is currently 6 months) So additional runs can be started at any time in case of problem.

86 x 8 = 688 (x yield)

Qualification run for full3D with active edges – status at Sintef/Stanford – for phase 1

See SINTEF talks

Test structures



14 wafers 230 um thick with support wafer

Remaining processing steps:
- Implantation of p-contacts
- Metallisation
- Test metal layer
- Measurement
- Final metal layer
- Passivation and litho

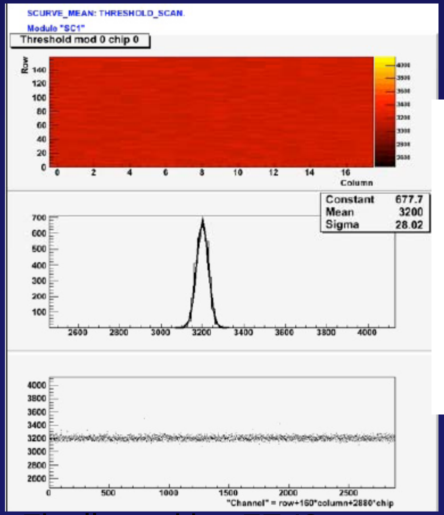
Delays due to:
- extra poly deposition
- extra poly etching
- Downtime of RIE tool and charging of oxide

- Expected completion date – end of March –will decide how to proceed with bump-bonding

STANFORD started an independent run which will end in May 2011

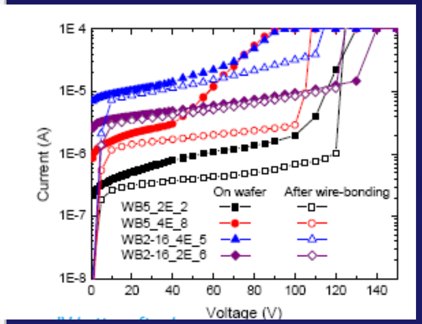
18 wafers of the FE-I3 run were completed at the end of 2009.

We bump-bonded 30 FE-I3 and lost >20 because of the guard ring bump. Now the remaining work fine. All CMS devices from same batch worked



Finally working FE-I3

Thanks to A. La Rosa



CMS devices

CONCLUSIONS

- 3D sensors are good candidates for the ATLAS IBL

Advantages are:

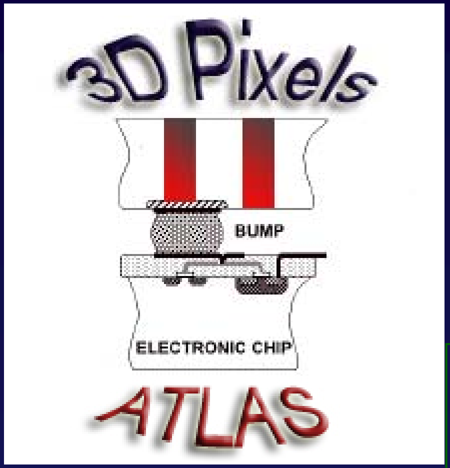
Low bias voltage and power dissipation (cooling and system)
High signal (decouples generation and detection paths)
after irradiation

Processing being performed with common floor plan design in
Different facilities : qualification and pre-processing ongoing

3D needs to demonstrate Yield
Working hard with intense processing plan and QA tests
QUALIFICATION review of 3D and planar Summer 2011

- Also preparing for Phase2 with full3D with active edges

ATLAS 3D Silicon Sensors R&D Collaboration



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18 institutions and 5 processing facilities