Experience with CNM 3D sensors for the ATLAS IBL

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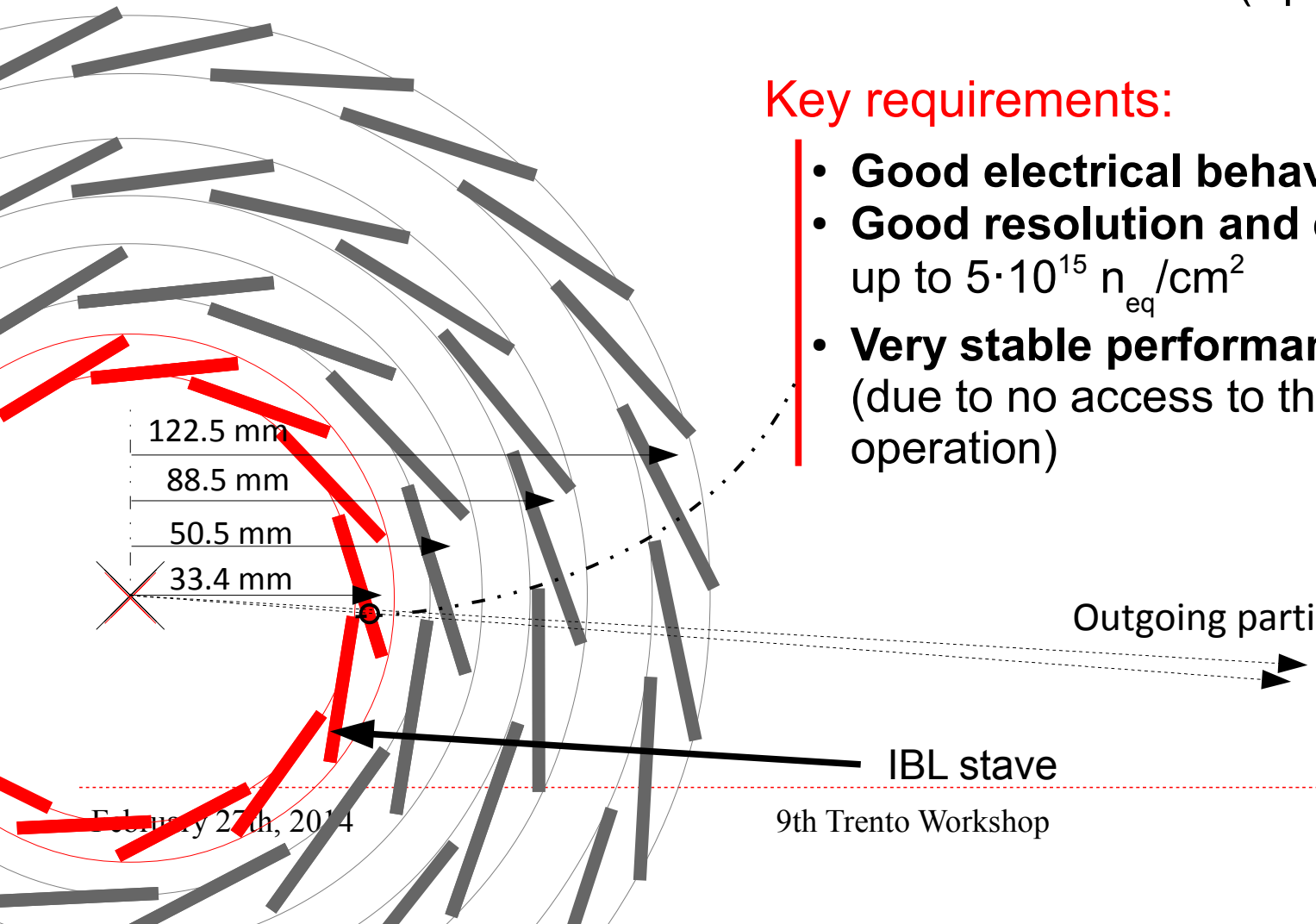
Insertable B-Layer

- ATLAS new layer of pixel detectors
  ~3 cm away from the beam
  → **3D Pixel Silicon Sensors [25%]** (+ planars [75%])
  - 3D sensors fabricated at CNM (Spain) and FBK (Italy)

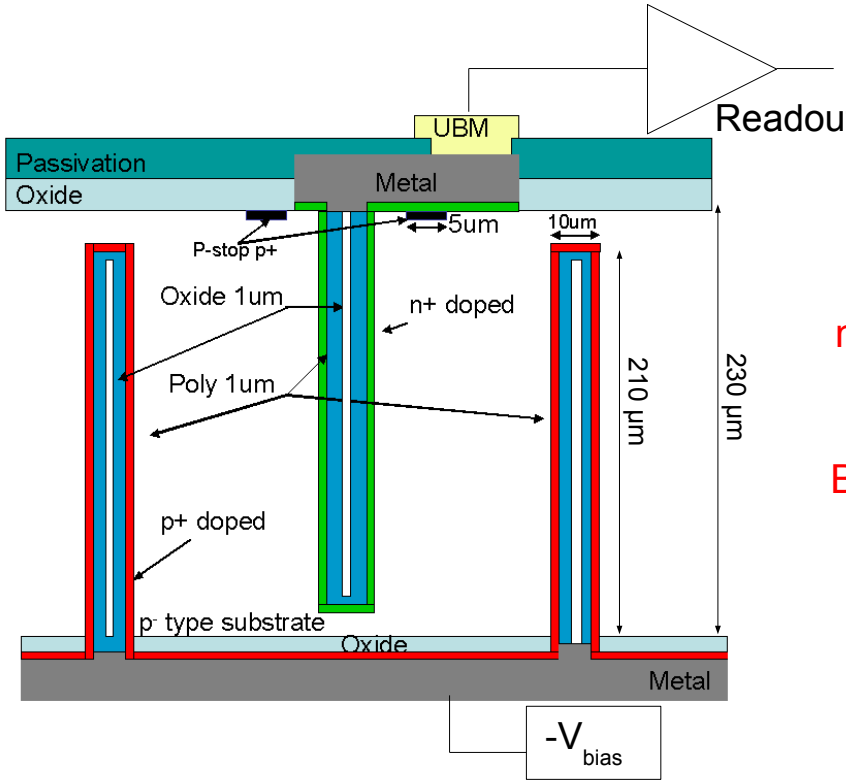


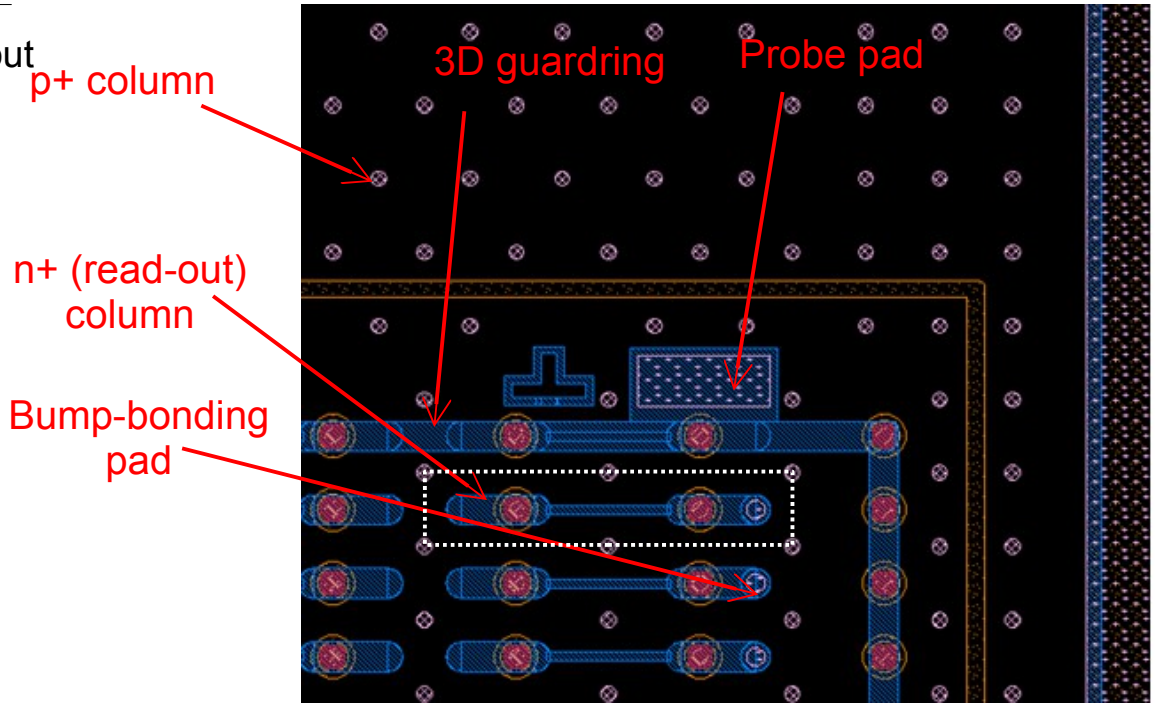
Key requirements:

- **Good electrical behaviour**
- **Good resolution and efficiency**
  up to $5 \cdot 10^{15}$ n_{eq}/cm^2
- **Very stable performance**
  (due to no access to the detector while in operation)

CNM sensors in IBL

- Sensor fabricated at CNM-Barcelona and UBM'ed/flip-chipped at IZM
- Double sided process, p-bulk 230 μm thick
- 210 μm columns – **do not** fully penetrate the substrate
- 3D guard-ring with probe pad for IV measurements
- FE-I4 front-end for IBL
  - Array of 80x336 pixels, 50x250 μm^2 each





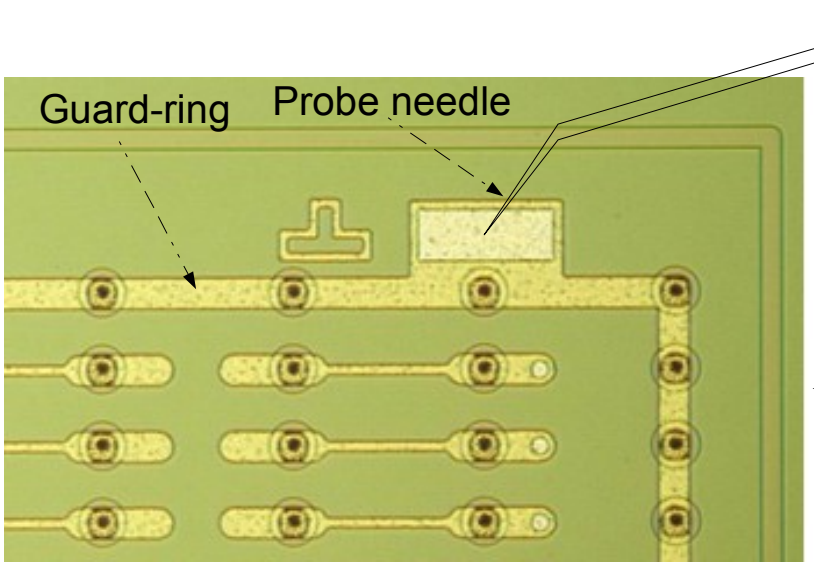
Selecting CNM sensors for IBL

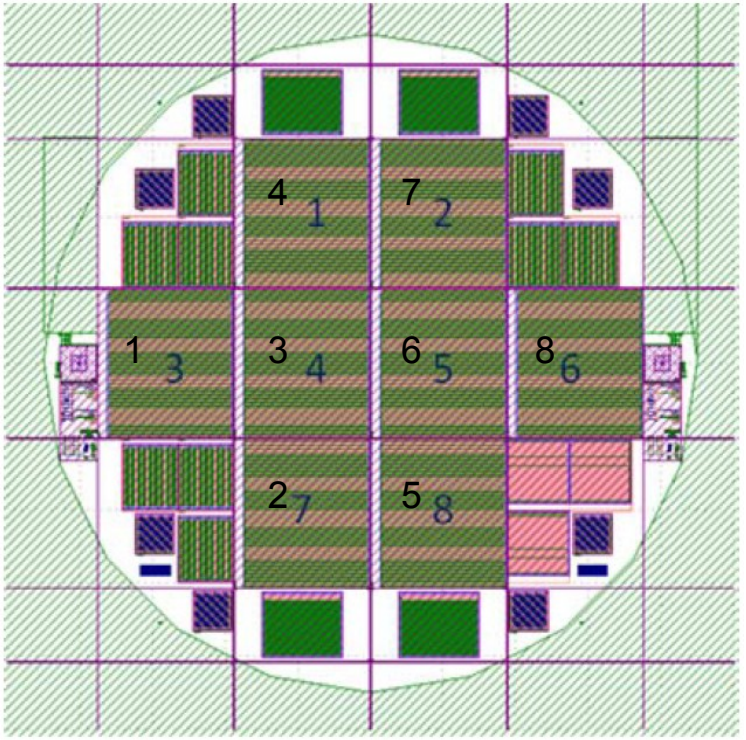
Leakage current versus bias voltage is a critical indicator of the quality of the sensor:

- ➔ Low breakdown prevents reaching depletion voltage
- ➔ High leakage current leads to large noise

Selection of good CNM tiles for flip-chip:

- ➔ IV measurement through 3D guard-ring at wafer level





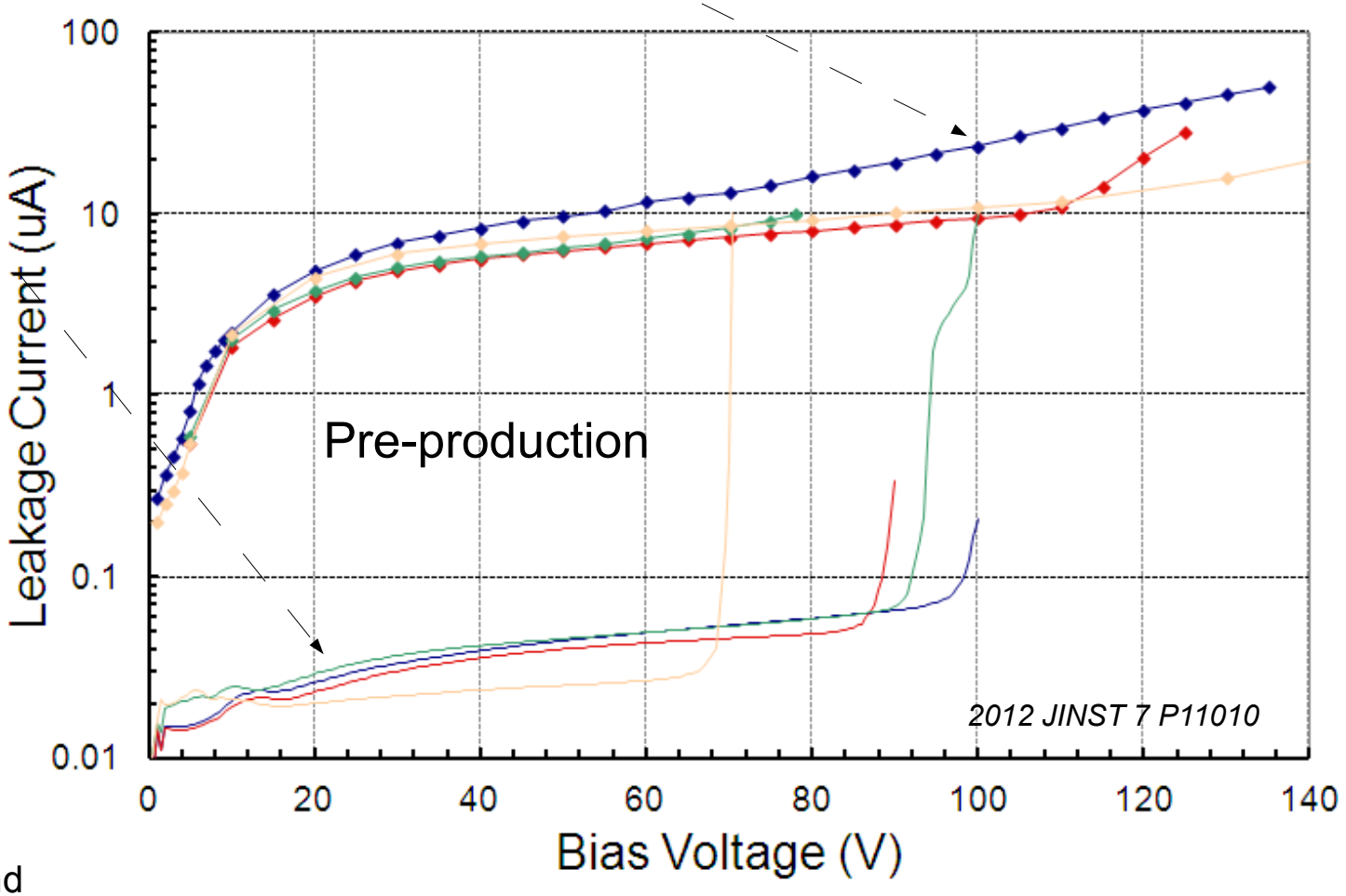
CNM sensor IV measurement through 3D GR

Selecting CNM sensors for IBL

➔ 3D guard-ring procedure was tested with <u>pre-production</u> run:

➔ <u>Wafer IV</u> quality consistent with <u>after flip-chip IVs</u>
(high V_{bd} sensors at wafer level* ↔ high V_{bd} sensors after flip-chip**)

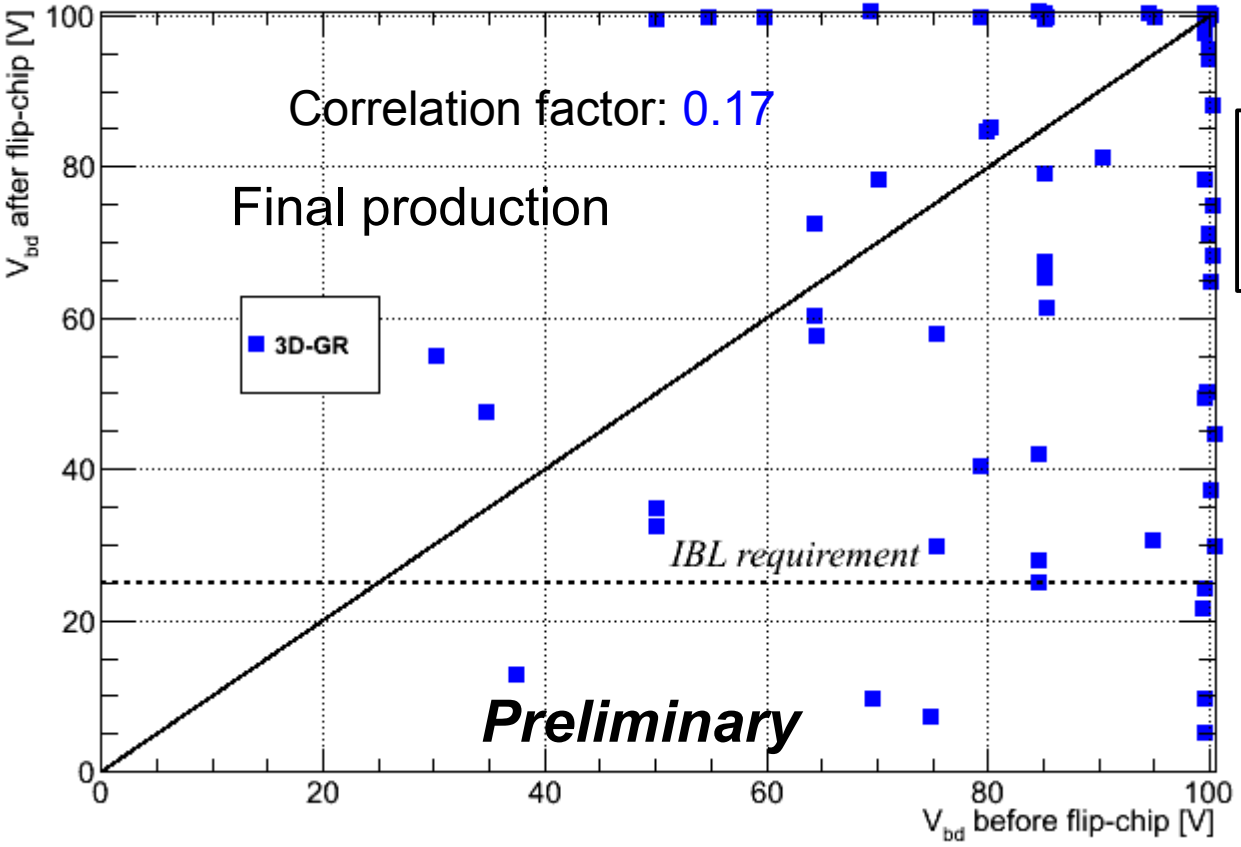
BUT:
low statistics
+
only good sensors were tested



*i.e. measured trough 3D guardring
**i.e. measured trough front-end

Selecting CNM sensors for IBL

- Measured V_{bd} before (3D GR) and after flip-chipping on IBL production CNM sensors
  - Measurements show poor correlation
    - ➔ Guardring IV measurements not optimal for electrical characterisation
    - ➔ Need an alternative method to select good sensors

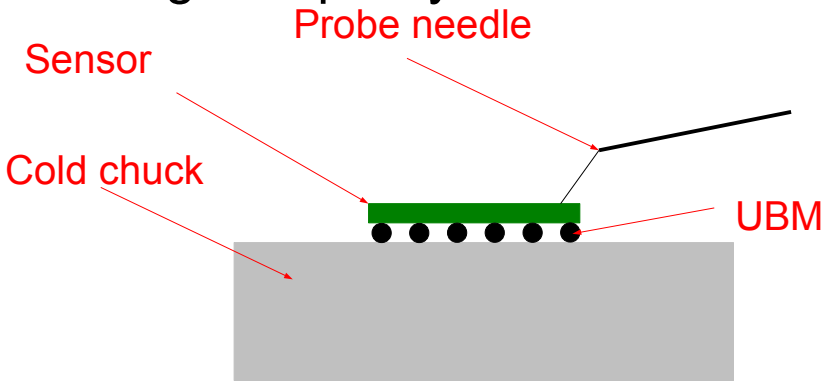


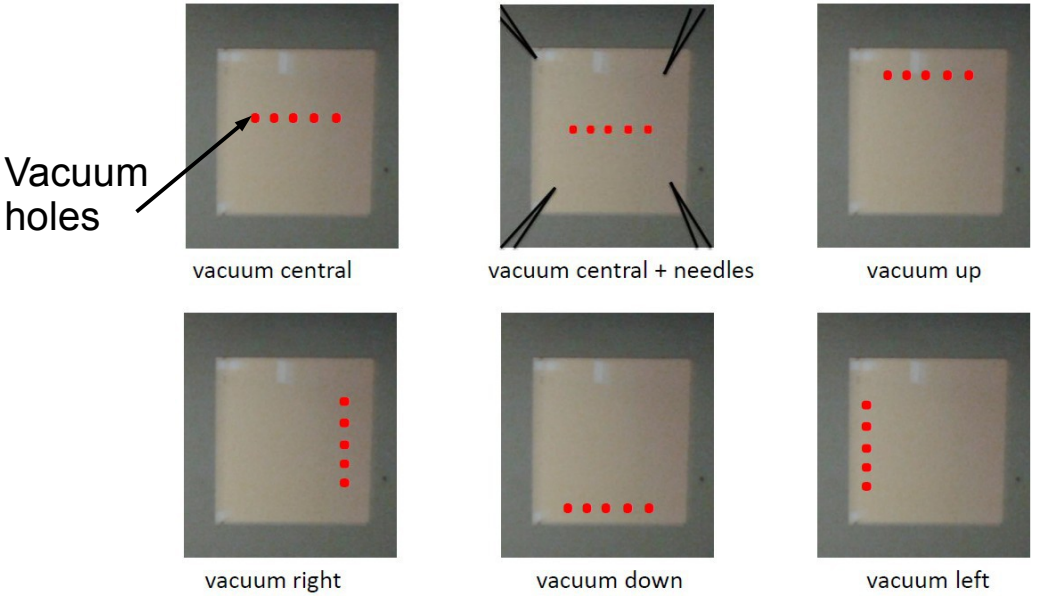
Reason:
Only edge region bias:
→No information about inner pixels

3D GR measurements done at CNM

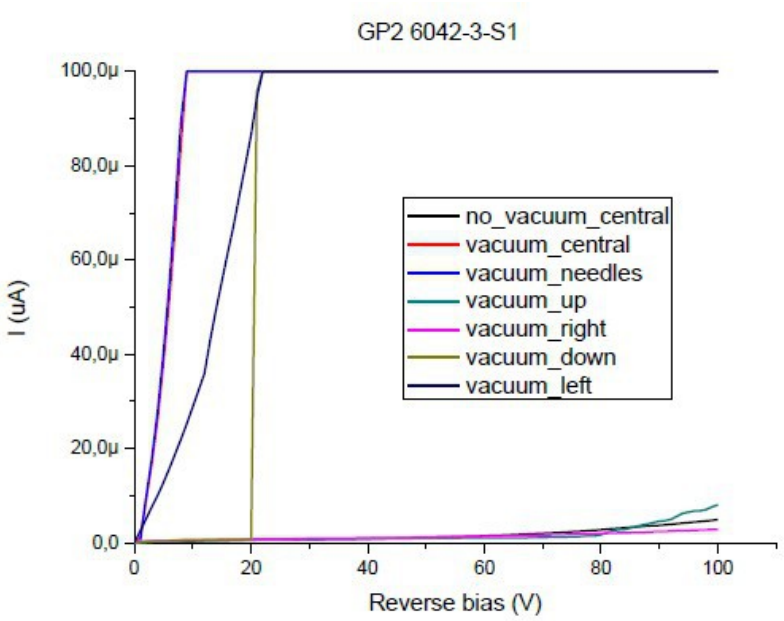
Selecting CNM sensors for IBL

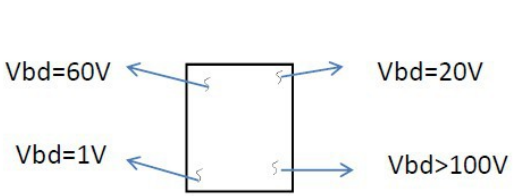
- ➔ Sensors at IZM sent sensors to CNM to redo measurements
- ➔ Select good quality sensors for IBL through UBM





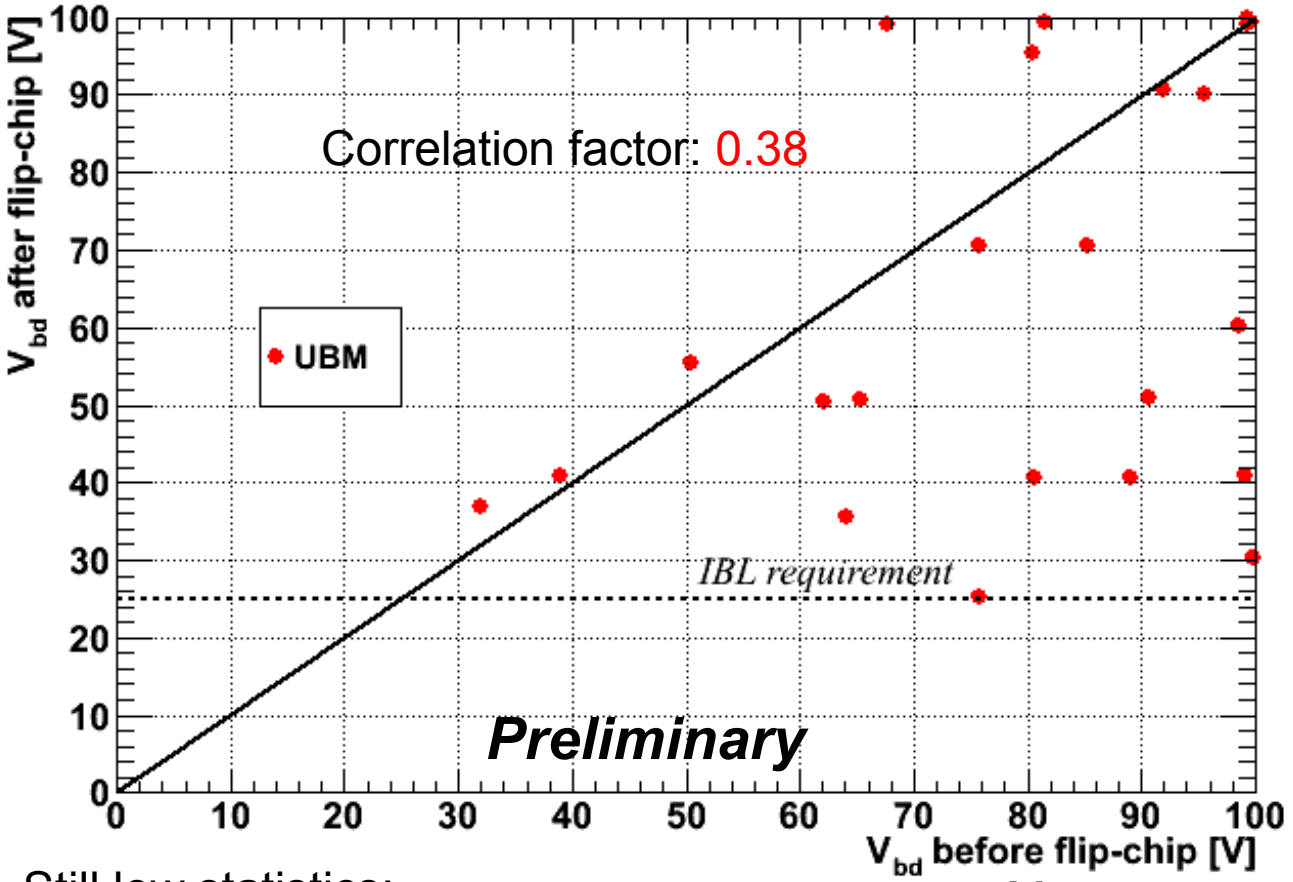
Measure IV with sensor on different positions
→ Take the lowest V_{bd}





IV measurements done by **Sergi Esteban (CNM)**

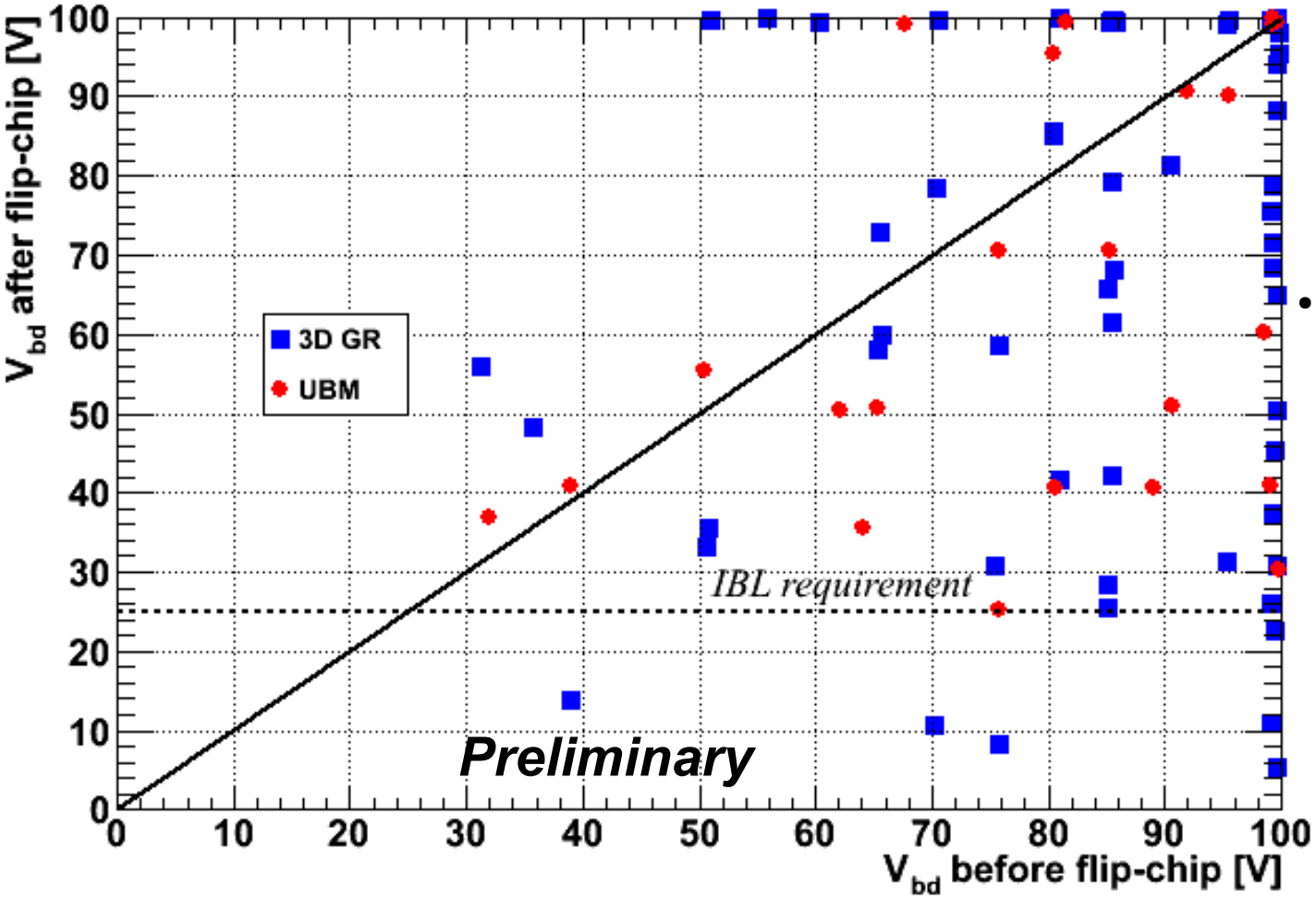
Selecting CNM sensors for IBL



IV measurements before flip-chip done by Sergi Esteban (CNM)

- Still low statistics:
  - Sensors not yet assembled/still at IZM
- Inconsistency in naming makes tracking down modules difficult...
- Measurement procedures not entirely consistent between institutes
  - e.g. not the same current limitation →worsens consistency of measurements

Selecting CNM sensors for IBL



Correlation factors:
- 3D GR: 0.17
- UBM: 0.38
- FBK*: 0.66

- UBM method is much more consistent but not as good as full sensor measurements (*a la* FBK)

See Sonia's talk for more details

* From Andrea Gaudiello

- 92 good sensors identified and sent back to IZM for flip chipping

Test beam studies

Qualification for IBL:

➔ **Goal:** Investigate efficiency with (non-) irradiated sensors

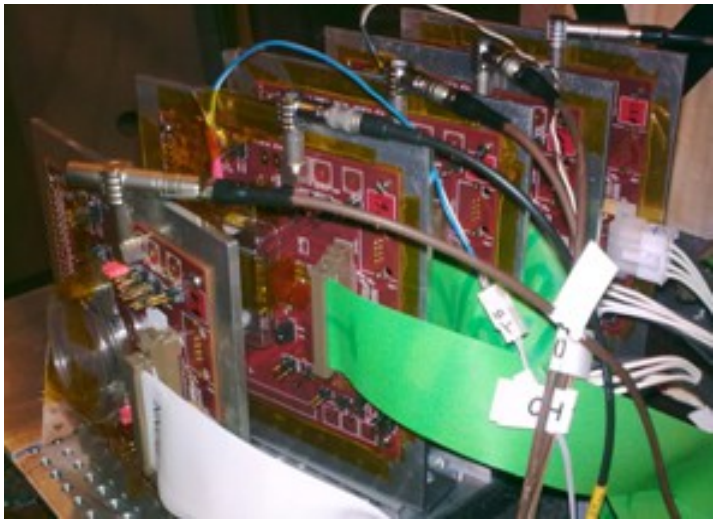
➔ Test beam facilities:

- CERN: 120 GeV pions
- DESY: 4 GeV electrons

➔ List of IBL testbeams with CNM samples

- April 2011 (DESY)*
- June 2011 (CERN)
- September 2011 (CERN)
- April 2012 (DESY)
- May 2012 (DESY)

*only FE-I3 CNM devices



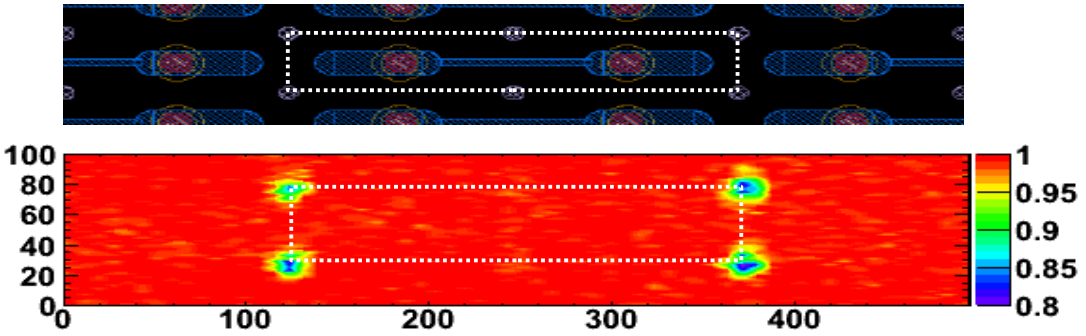
Sample	Irradiation facility	Dose [n_{eq}/cm^2]	Testbeam
CNM34	KIT (p)	$5 \cdot 10^{15}$	June+Sept 2011 (CERN), April 2012 (DESY)
CNM36	KIT (p)	$6 \cdot 10^{15}$	May 2012 (DESY)
CNM55	Un-irrad	–	June+Sept 2011 (CERN), April 2012 (DESY)
CNM81	TRIGA (n)	$5 \cdot 10^{15}$	Sept 2011 (CERN)
CNM82	TRIGA (n)	$5 \cdot 10^{15}$	June 2011 (CERN)
CNM97	KIT (p)	$5 \cdot 10^{15}$	June 2011 (CERN)

Test beam results (I)

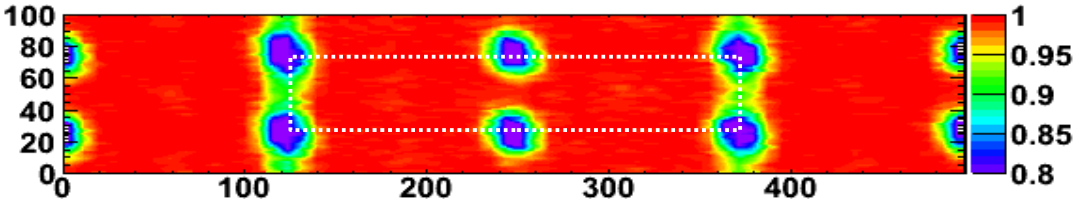
Pre-production results met IBL requirements:

- IBL CNM sensors have shown an excellent overall **efficiency**
  > 97 % even after **$5 \cdot 10^{15}$ n_{eq}/cm^2**
- Good position resolution of FE-I4**A** sensors have been meassured:
  ~10 μm resolution on short pixel direction

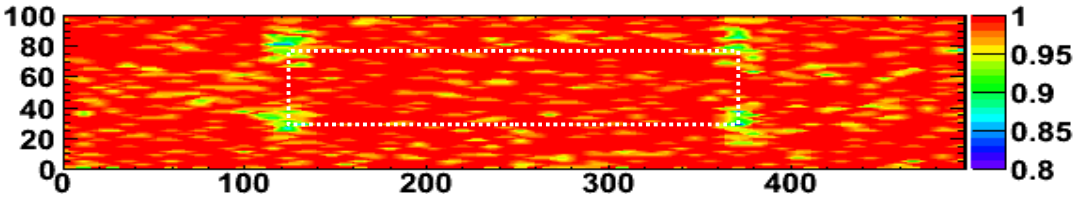
Pre-production CNM module



SCC55 **CNM-3D**, un-irrad, HV=20V, **Eff.=99.4%**



SCC81 **CNM-3D**, n-irrad, HV=160V, **Eff.=97.46%**

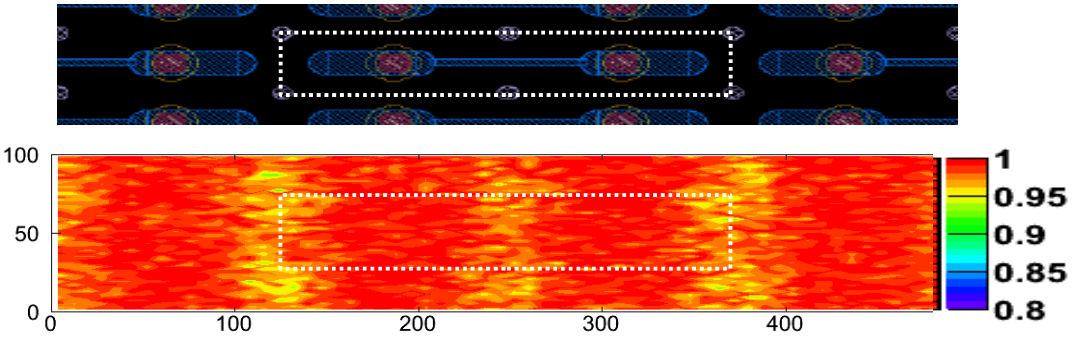


SCC34 **CNM-3D**, p-irrad, HV=160V, **Eff.=98.96%**

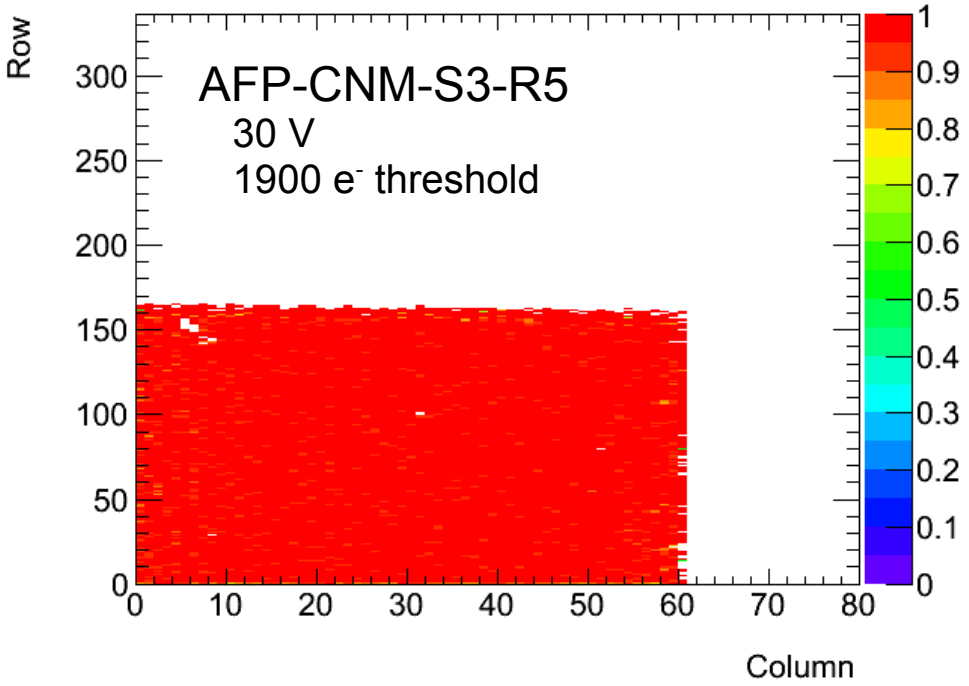
Test beam results (II)

Test-beam on June 2013 at DESY with full IBL modules FE-I4**B** (un-irradiated)

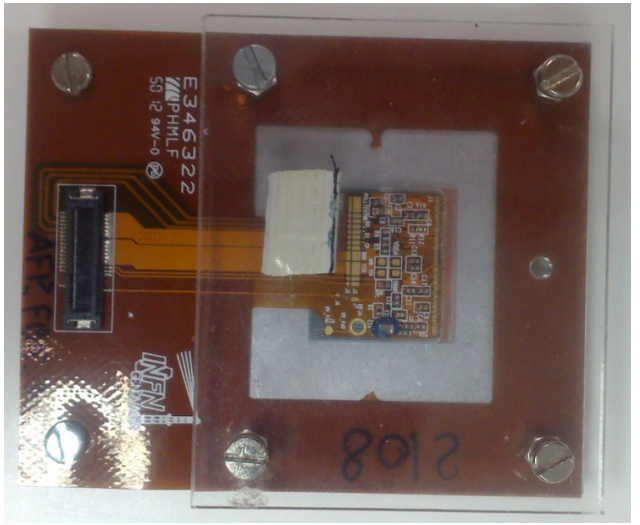
- Results consistent with pre-production results
  > 98 % efficiency



AFP-CNM-S3-R5 **CNM-3D**, un-irrad, HV=20V, **Eff.=98.3%**



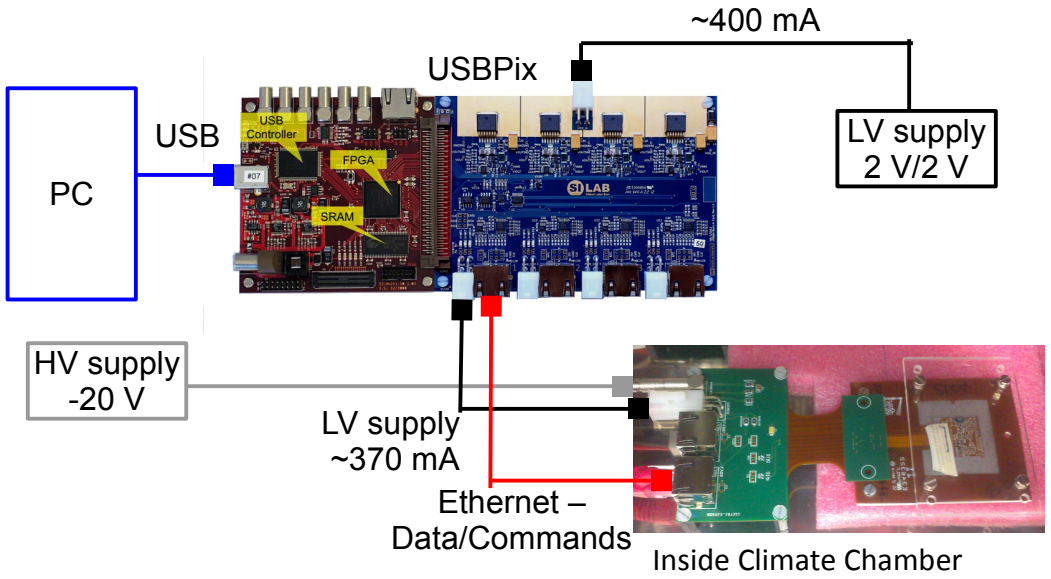
Telescope resolution at DESY TB ~12-17 μm
→ columns not fully visible

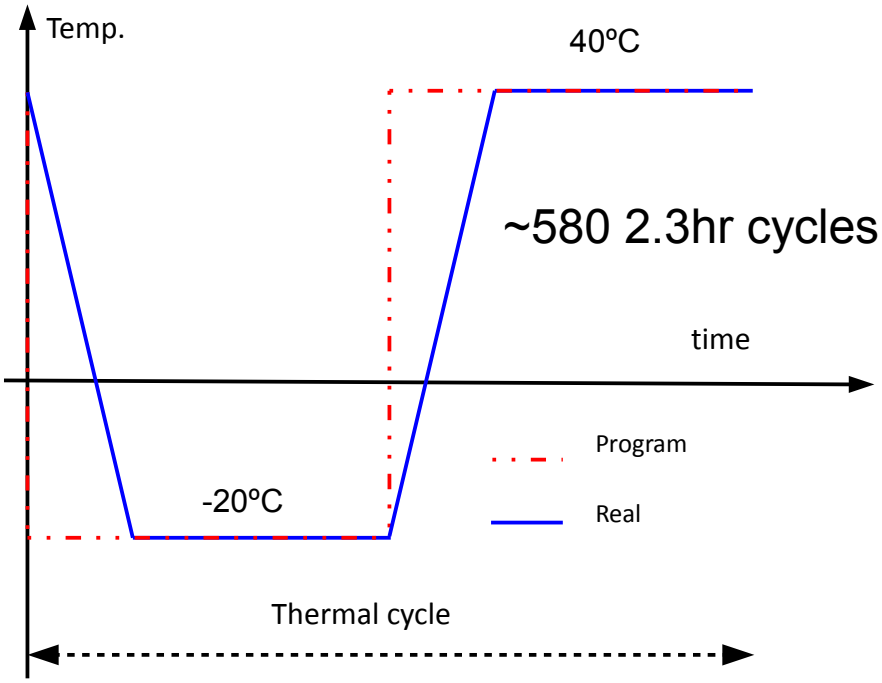


Final IBL production module

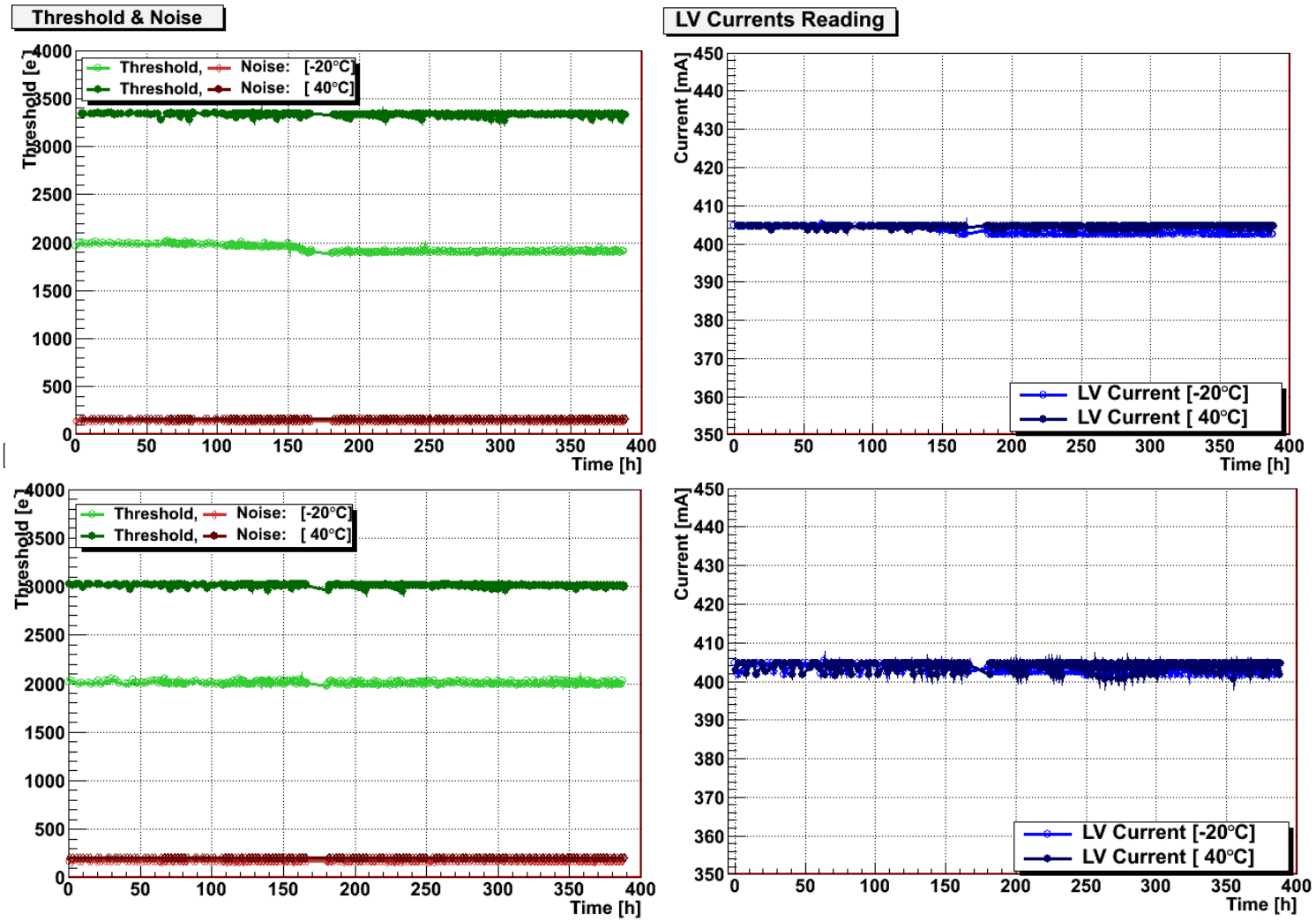
Ageing studies (I)

- Long term operation of devices during thermal cycles to ensure stable performance
  - 2 CNM (and 2 FBK) devices under test
  - 57 days of thermal cycle from -20 to 40ºC (wider range than expected during operation)
  - Measurement performed periodically:
    - Threshold distribution
    - Noise distribution
    - ToT distribution
    - Temperature
    - LV supply current





Ageing studies (II)



➔ Calibration parameters stable during operation

Conclusions

Lessons learned from IBL:

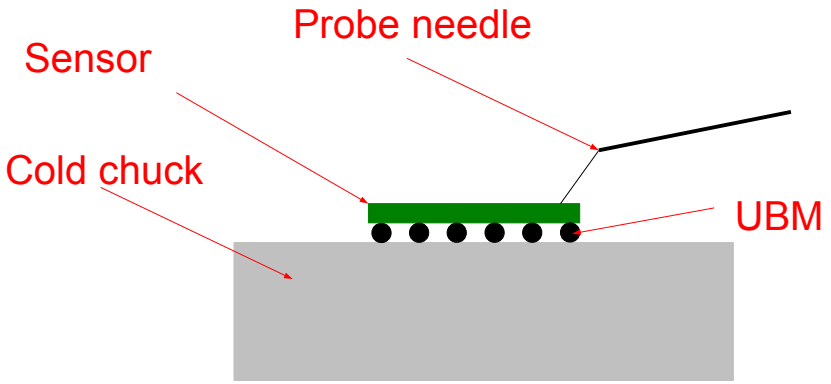
- 3D Guard ring method is not good for sensor selection
- Consistent measurement methods between institutions recommended
- Naming system could have been better...

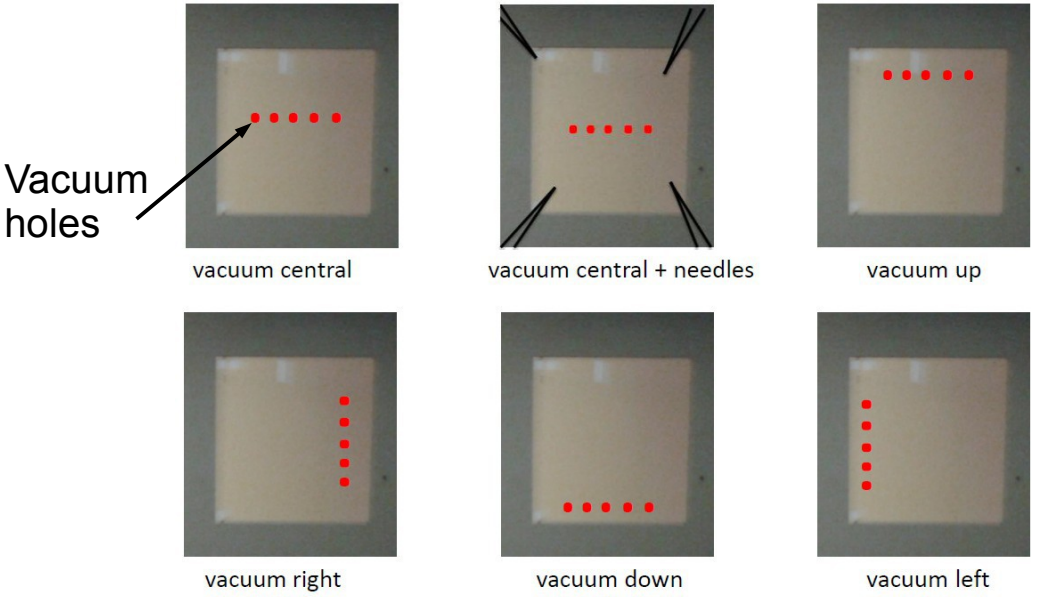
- In summary CNM sensors fulfill the IBL requirements:
  - ✔ **Good electrical behaviour**
  - ✔ **Good resolution and efficiency**
  - ✔ **Radiation hardness**
  - ✔ **Very stable performance**

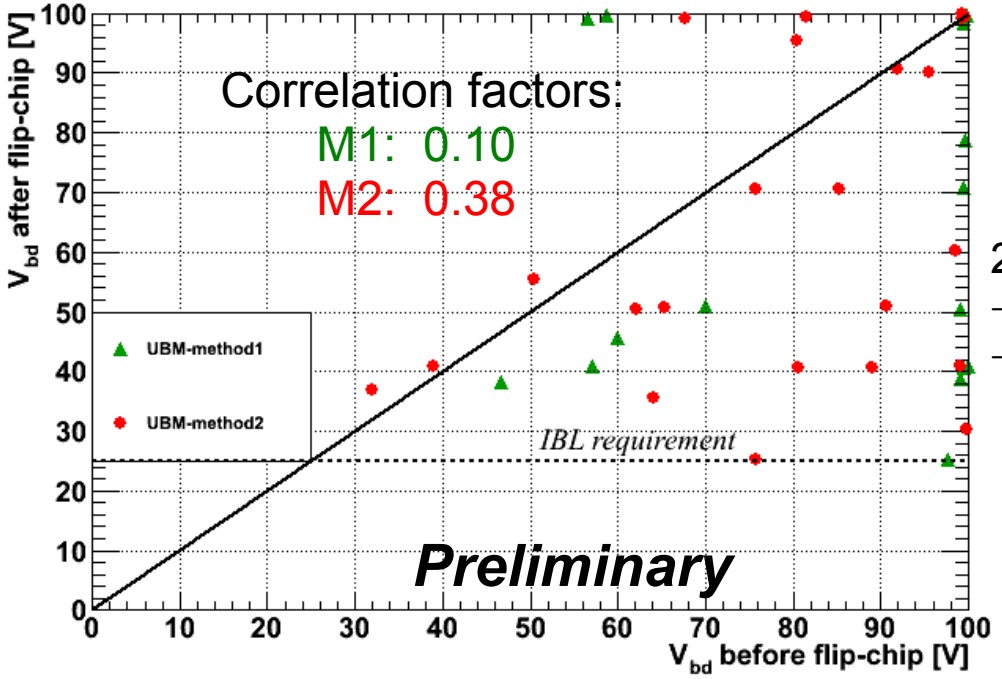
Thank you for your attention

Back up

Selecting CNM sensors for IBL



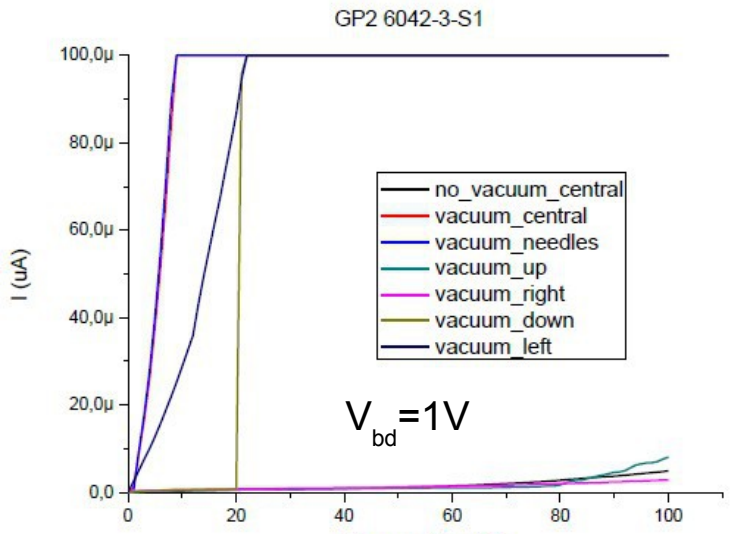


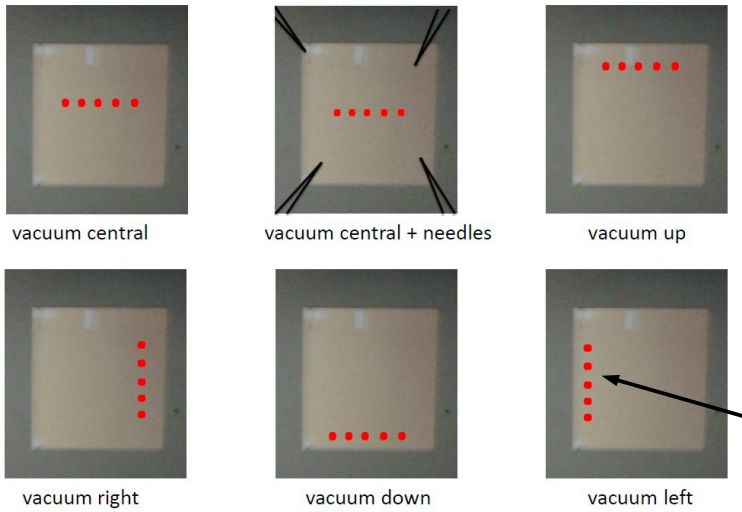


2 options
→ Measure only one position [vacuum central] (method1)
→ Measure ALL positions, take lowest V_{bd} (method2)

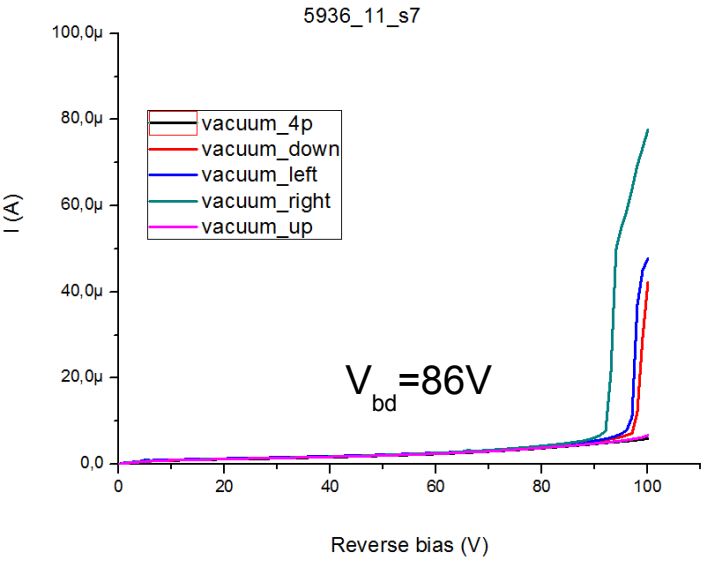
Measurements done by Sergi (CNM)

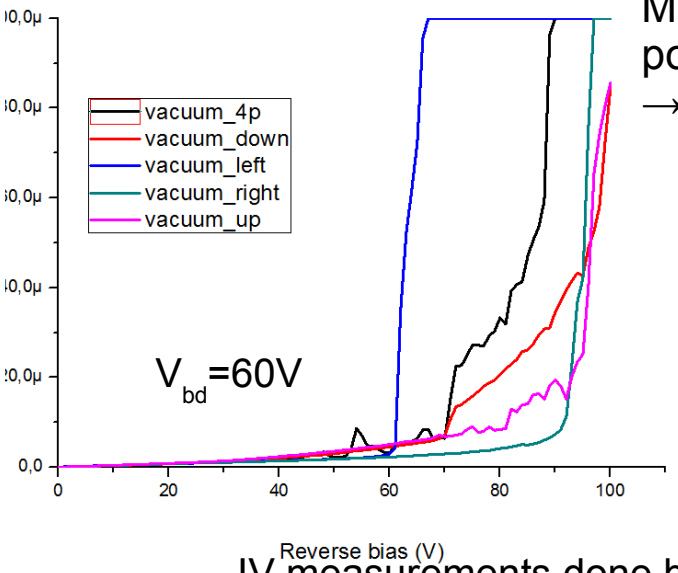
Selecting CNM sensors for IBL





Vacuum holes





Measure IV with sensor on different positions
→ Take the lowest V_{bd}

IV measurements done by **Sergi Esteban (CNM)**