Recent advances in Emission Channeling measurements and relevance to Hyperfine Interactions

J.G.Correia
on behalf of IS453 **EC-SLI** experiment
Emission **C**hanneling with **S**hort-**L**ived **I**sotopes

ISOLDE CERN

Lisboa *Porto* *Leuven* *Faure* Göttingen

U. Wahl
J.G. Correia
M.R. da Silva

S. Decoster
L. Amorim

L. Pereira

E. Bosne

HFI/NQI 201012-17 September 2010 *CERN*

OUTLINE

ABOUT EMMISSION CHANNELING

principles and recent progress

LATTICE LOCATION CASE STUDIES

^{121}Sn (27h) : Ge (off-line)

^{56}Mn (2.6h) : Ge (on-line)

^{27}Mg(9.46m) : GaN, AlN (on-line preliminary)

“BRIEF BRIEFING”

of Timepix 512x512 ch detectors

(high position resolution + energy)

Interest of accurate impurity lattice location studies

- **Functional properties of impurities are influenced by lattice location**
- **Local crystal field near impurity influences electronic configuration, magnetic spin**
- **High quality input information for atomic scale models and simulations**

…

EMMISSION CHANNELING ALLOWS:

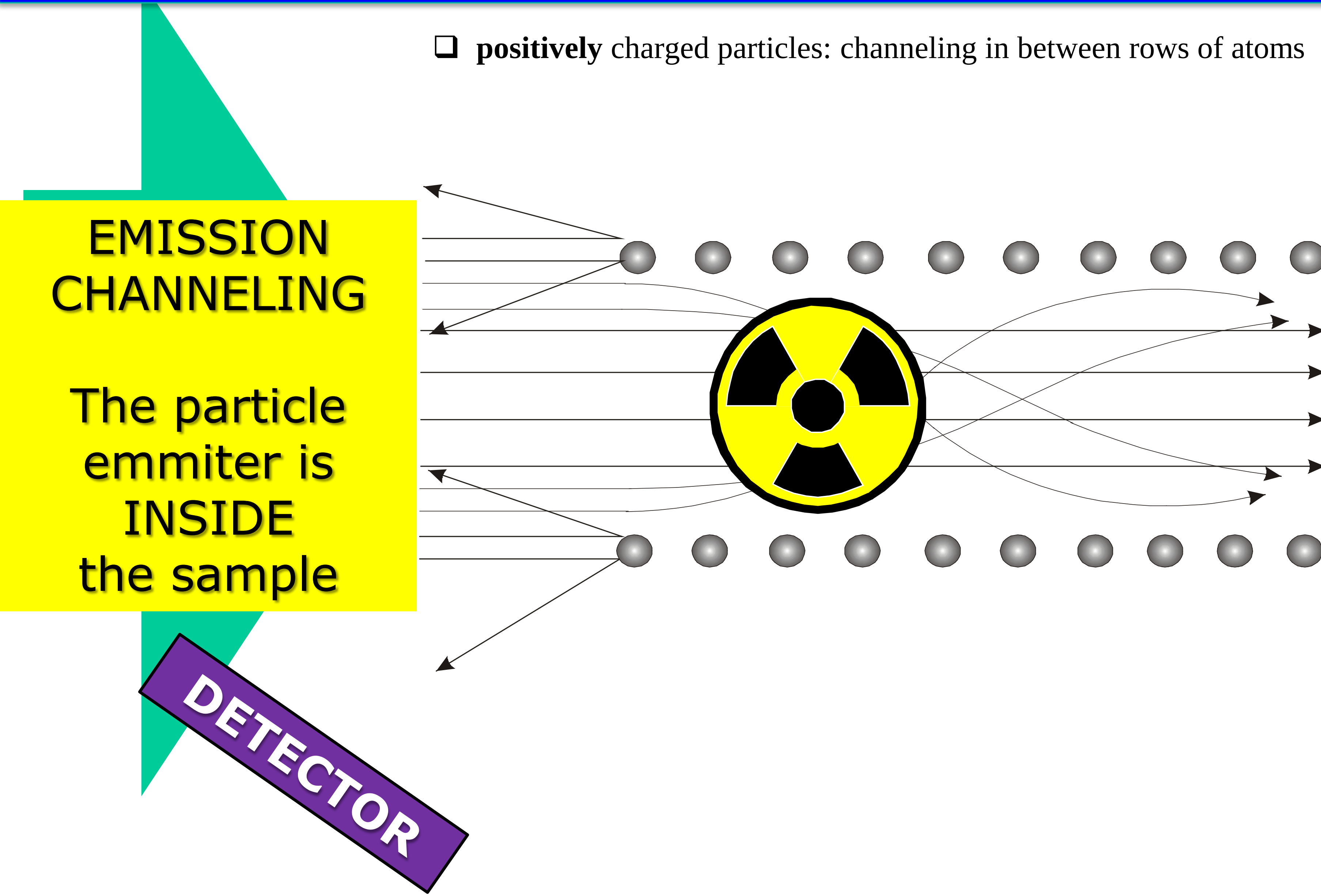
- determining lattice sites of impurities in **single-crystalline** materials
- **substitutional** site vs. many different interstitial sites
- **quantitative** determination

- **highly sensitive: down to ppm range**
- **lattice location accuracy: down to 0.1 - 0.2 Å**
- **unique worldwide**

(a consequence of the variety and purity of ISOLDE radioactive beams combined with position sensitive electron detectors)

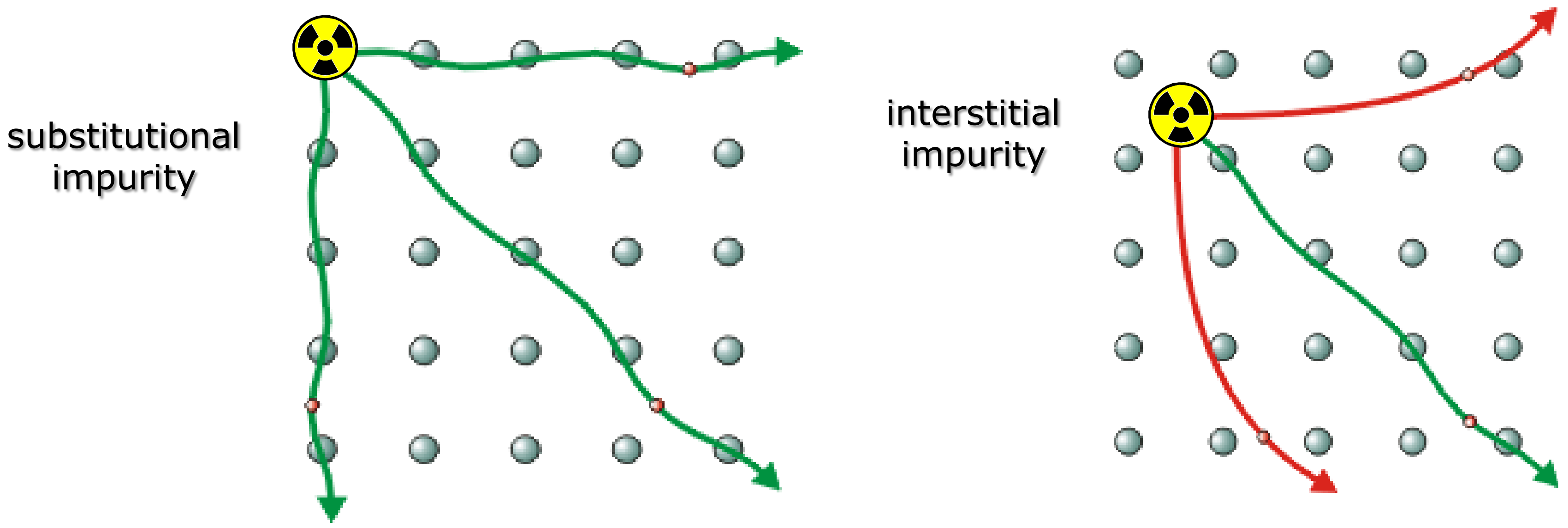
Channeling (RBS/C) versus Emission Channeling

- **positively** charged particles: channeling in between rows of atoms



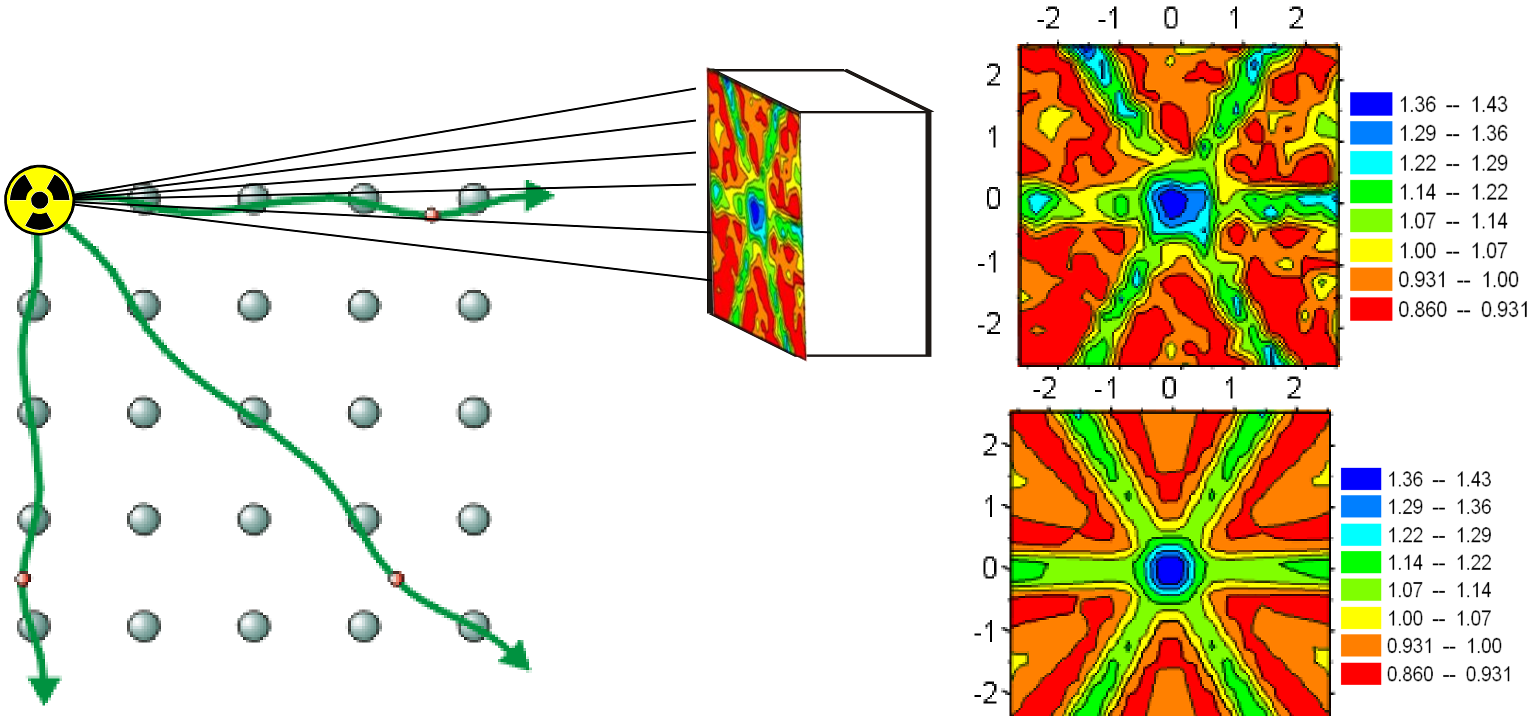
Electron Emission Channeling

- **negatively** charged particles
- electrons are emitted by **radioactive** isotope (C.E. or β^-)
- channeling or blocking effect – depends on lattice location of impurity
- anisotropic electron emission



Emission Channeling Detection and Analysis

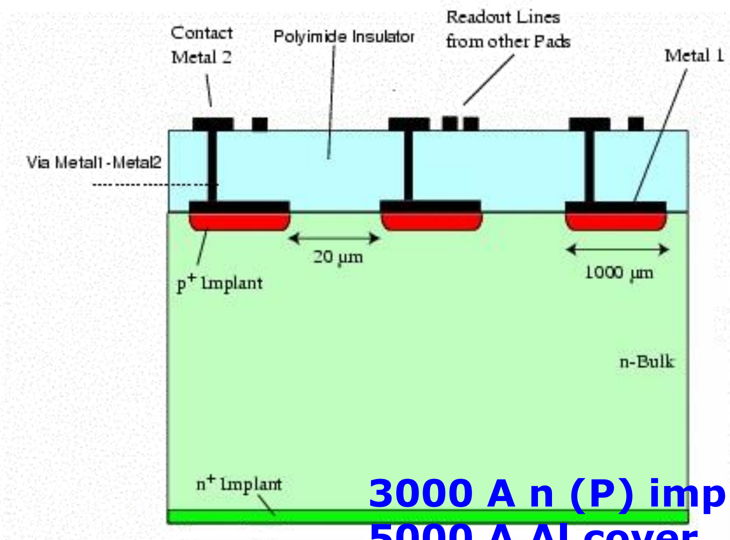
- 2D energy- and position-sensitive detector
- analysis = fitting experimental pattern to library of calculated patterns



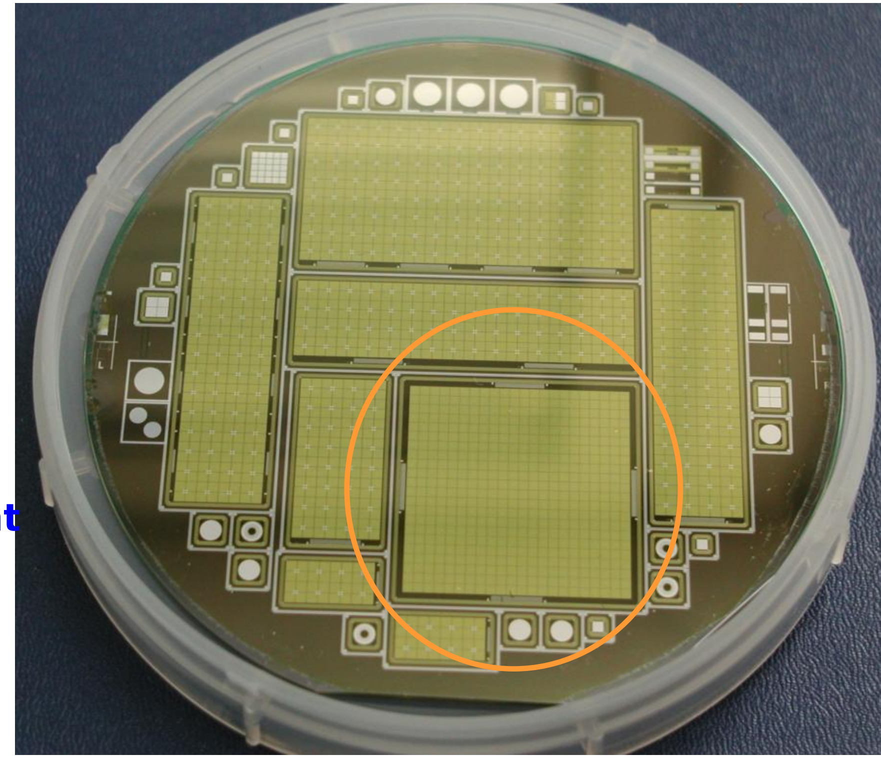
What do you need to do Emission Channeling

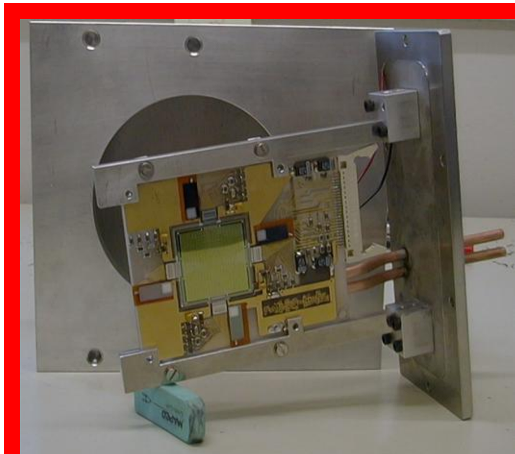
Si PAD electron detectors

5μm kapton
2μm SiO2
0.3mm p (B) implant



3000 A n (P) implant
5000 A Al cover

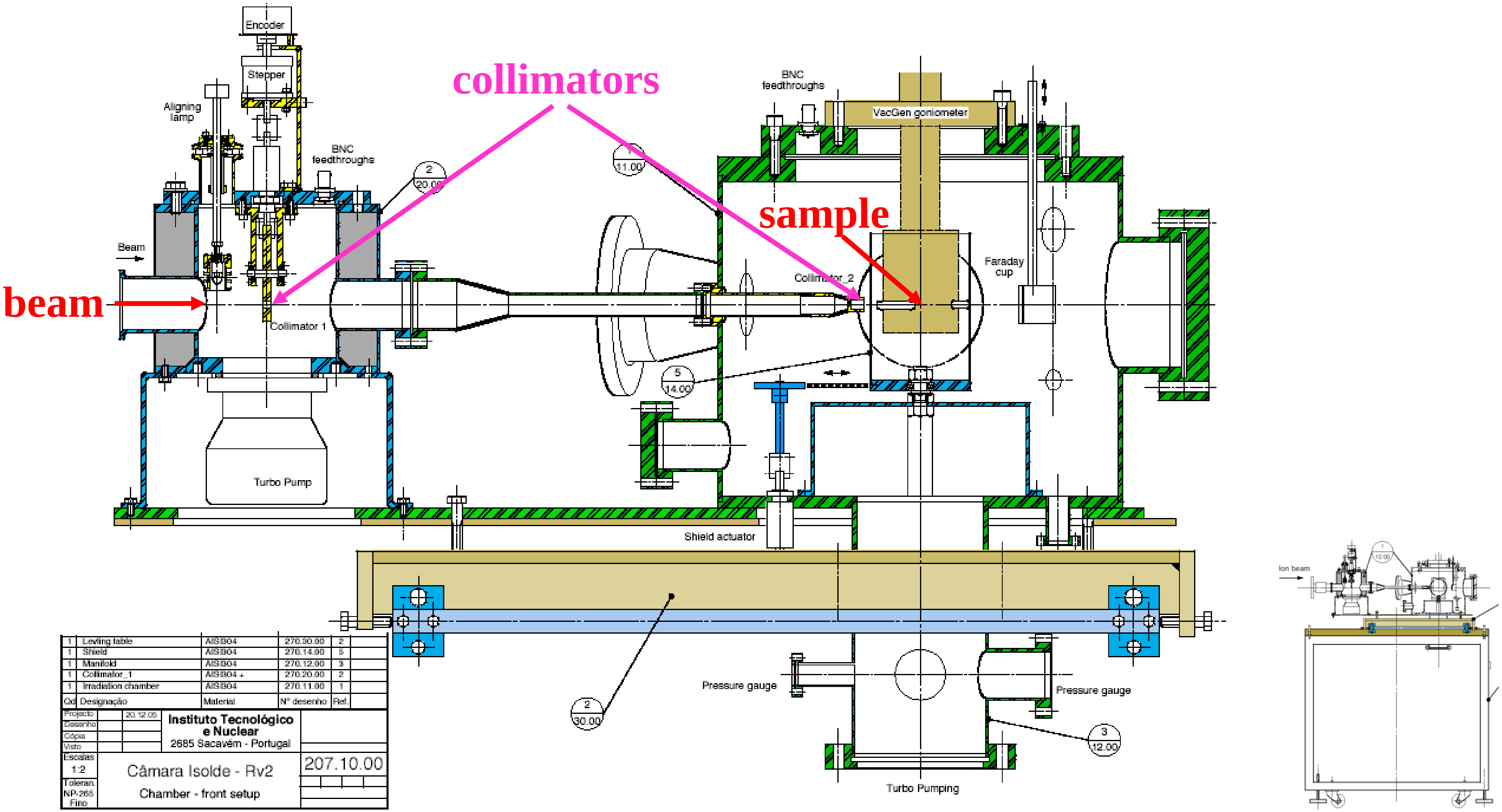




Position-sensitive detector

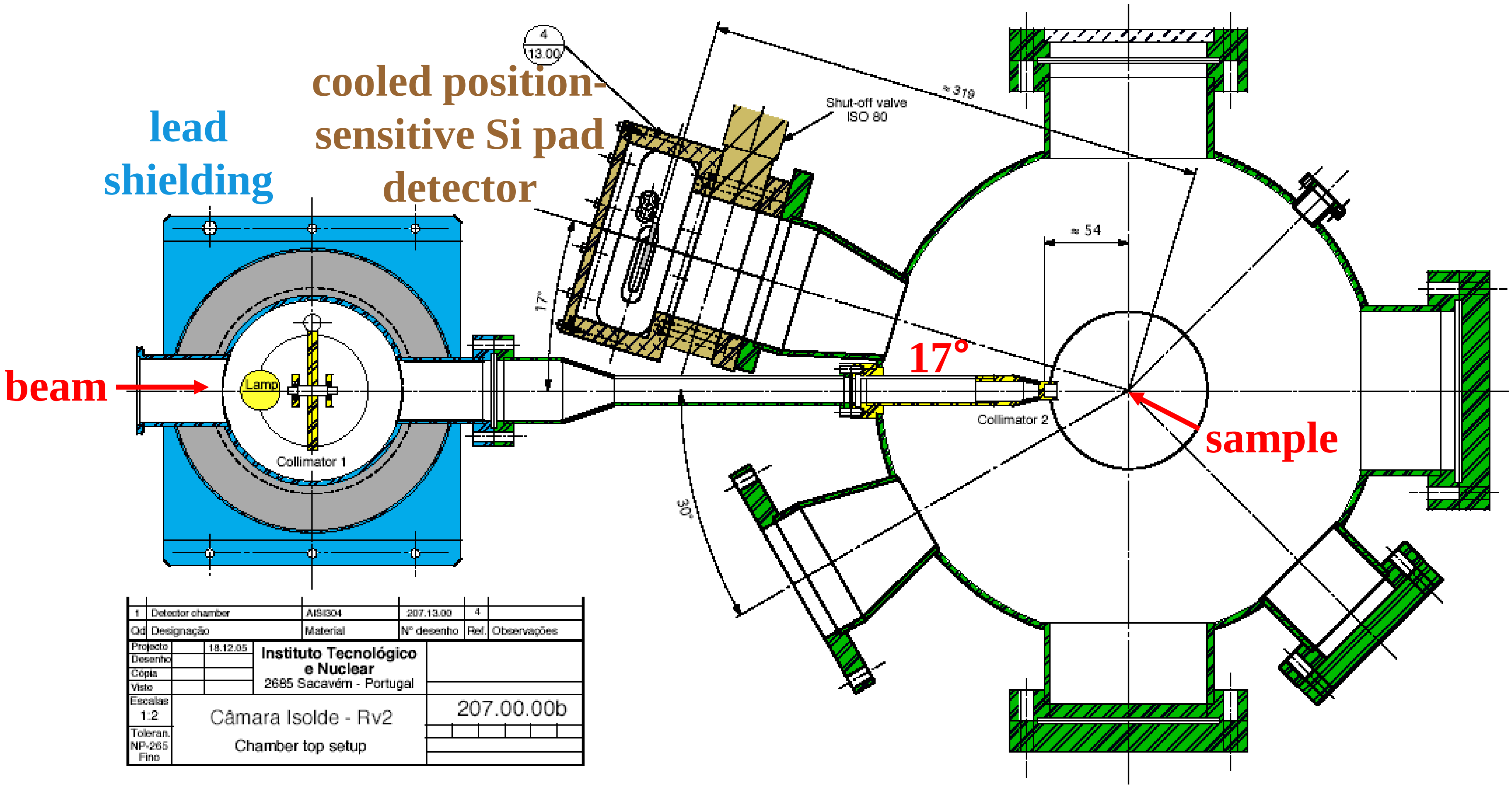
Good energy resolution ~3 keV
Large pad – 1.4x1.4 mm2
Dead / unbonded channels
Leakage current limiting depletion
15keV << E(e^-) << 300 keV
Readout → 200Hz ... 5 kHz(new)!!

New ITN on-line emission channeling setup: side view



- ISOLDE beam is collimated by 2 apertures (1st variable size, 2nd ∅ 1 mm) on the sample
- sample mounted in remote controlled 3-axis goniometer

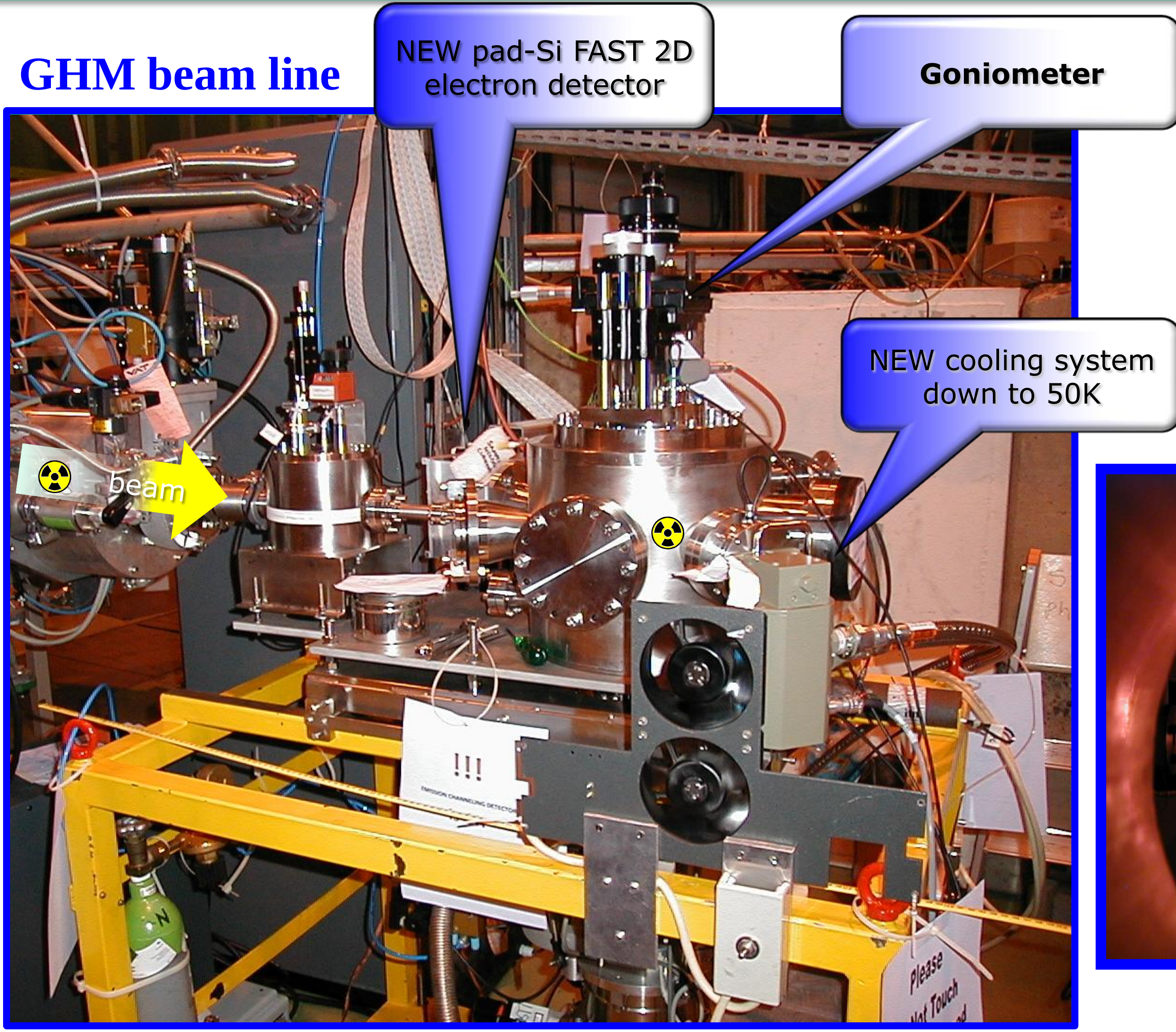
New ITN on-line emission channeling setup: top view

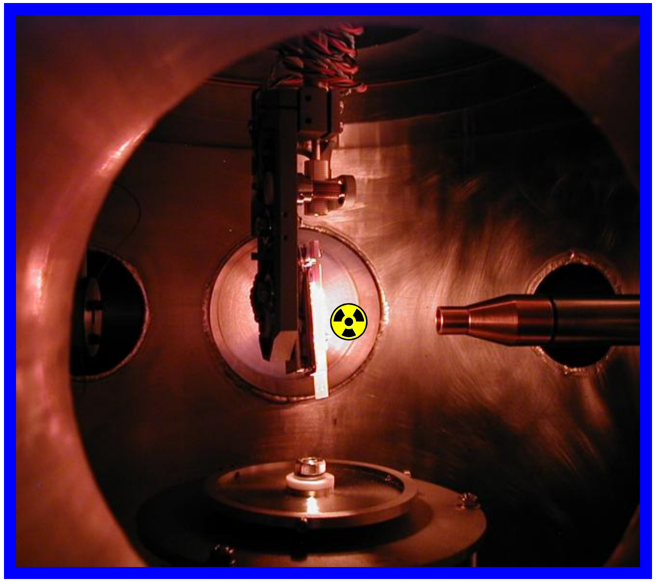


- detector at 17° backward geometry for simultaneous implantation and measurement
- valve in front of detector allows to maintain detector vacuum during sample exchange
- lead shielding around 1st collimator lowers background

NEW on-line EC-SLI setup for short lived isotopes

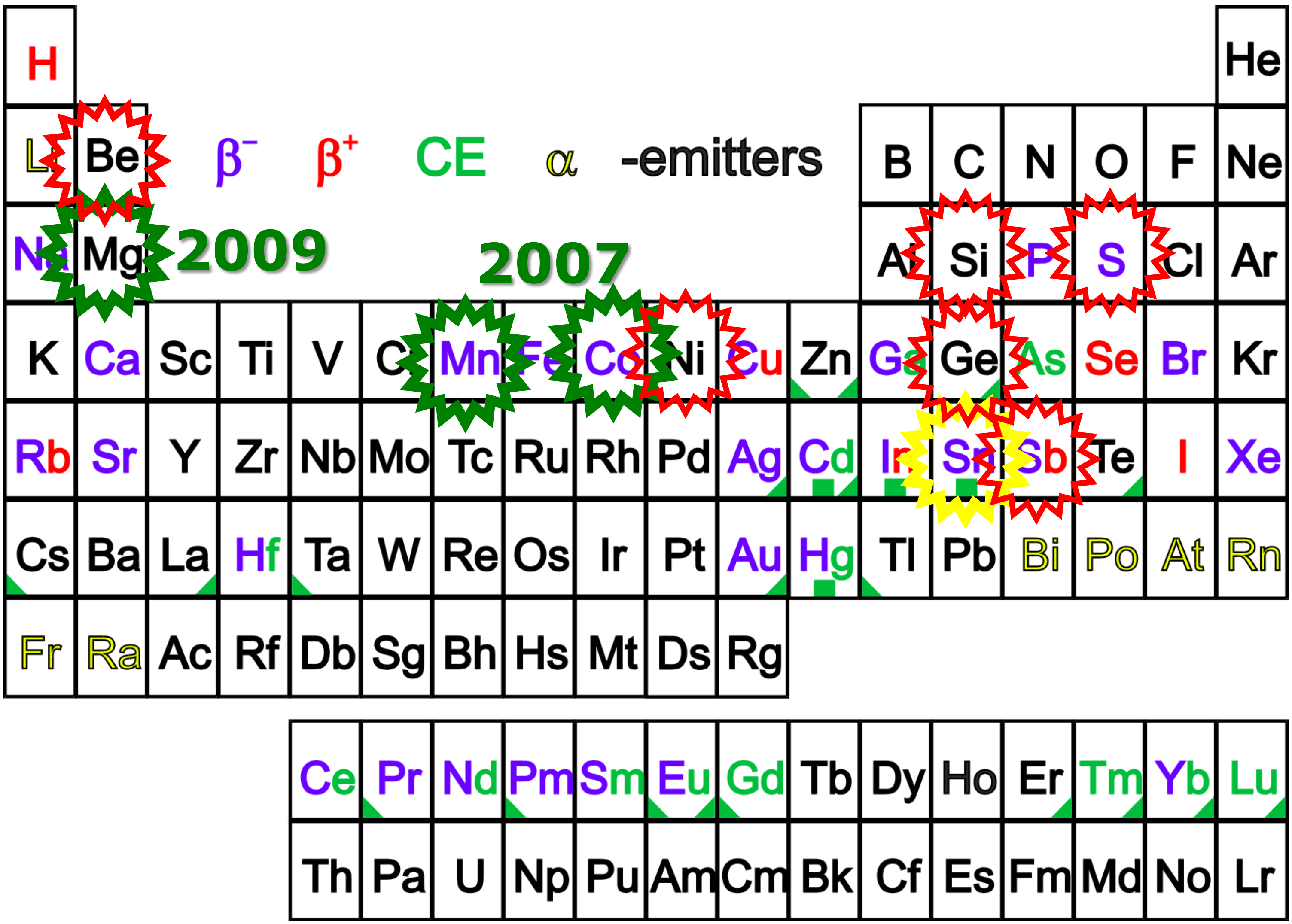
GHM beam line

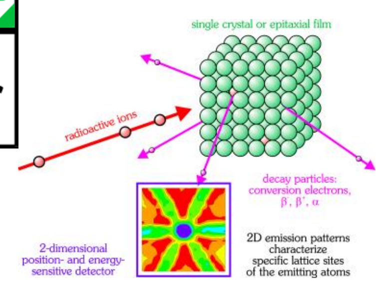




Inside view during sample annealing

Elements for which emission channeling experiments have been published





Lattice location study of implanted ^{121}Sn (27h) : Ge

MOTIVATION

- group IV impurity = expected on S site in Ge
- no direct experimental info
- Sn-related defects → important for growth of GeSn!

EXPERIMENTAL

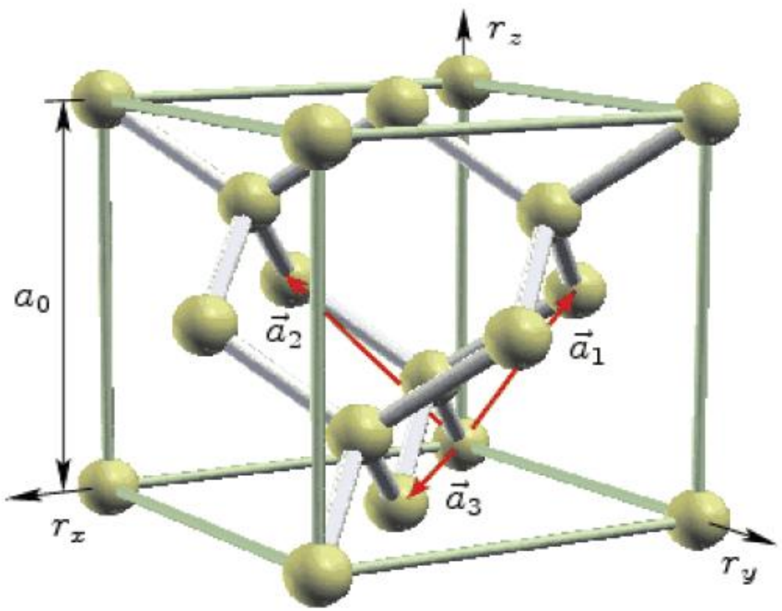
- radioactive isotope: ^{121}Sn (27 h)
- implantation @ ISOLDE (CERN, Geneva)
- 60 keV, room temperature
- fluence: 2 – 4 □10^{12} cm^{-2}
- measurements @ room temperature

  as implanted

  after several annealing steps up to 500°C

  (10 min in vacuum)
- triangulation along 4 different directions:

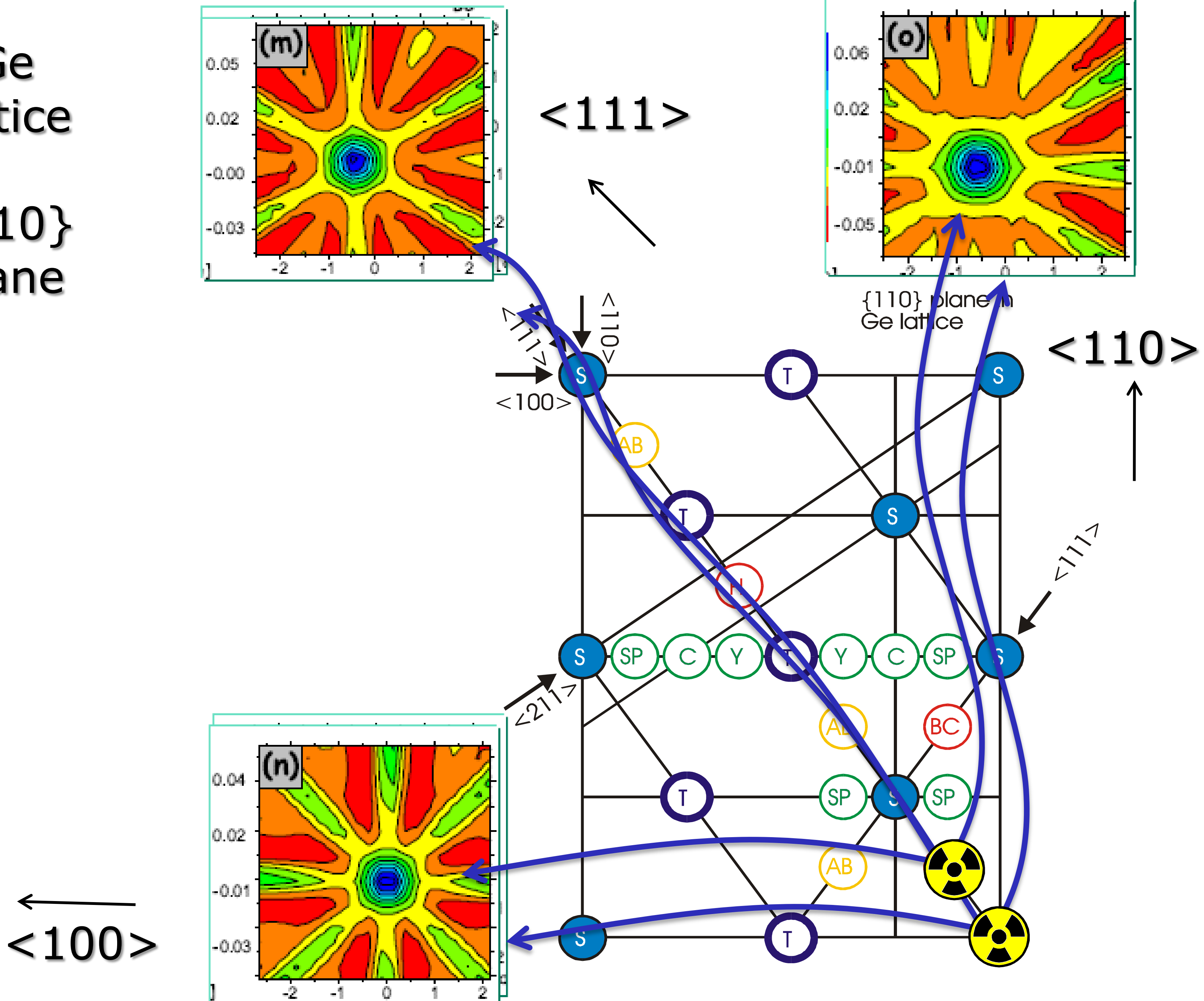
  <111>, <100>, <110> and <211>



Decoster *et al.*
PRB 81, 155204 (2010)

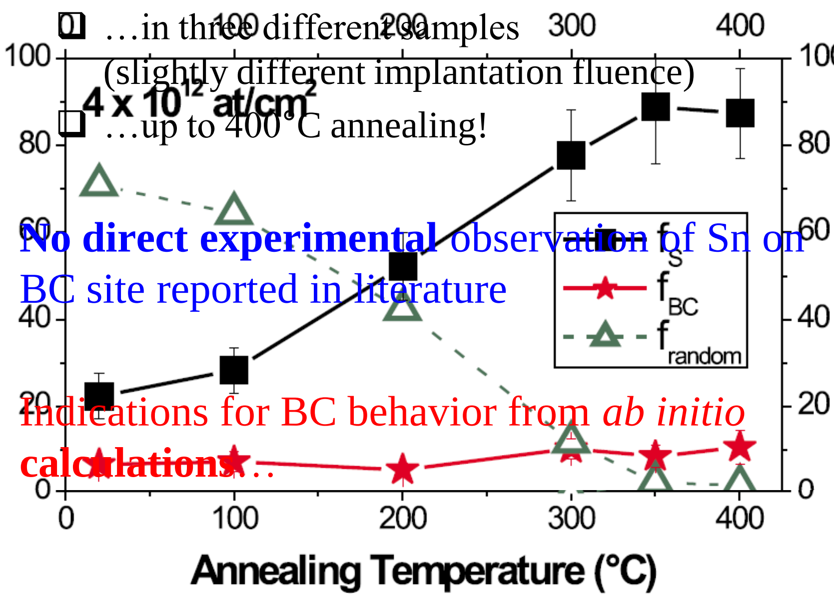
Ge
lattice

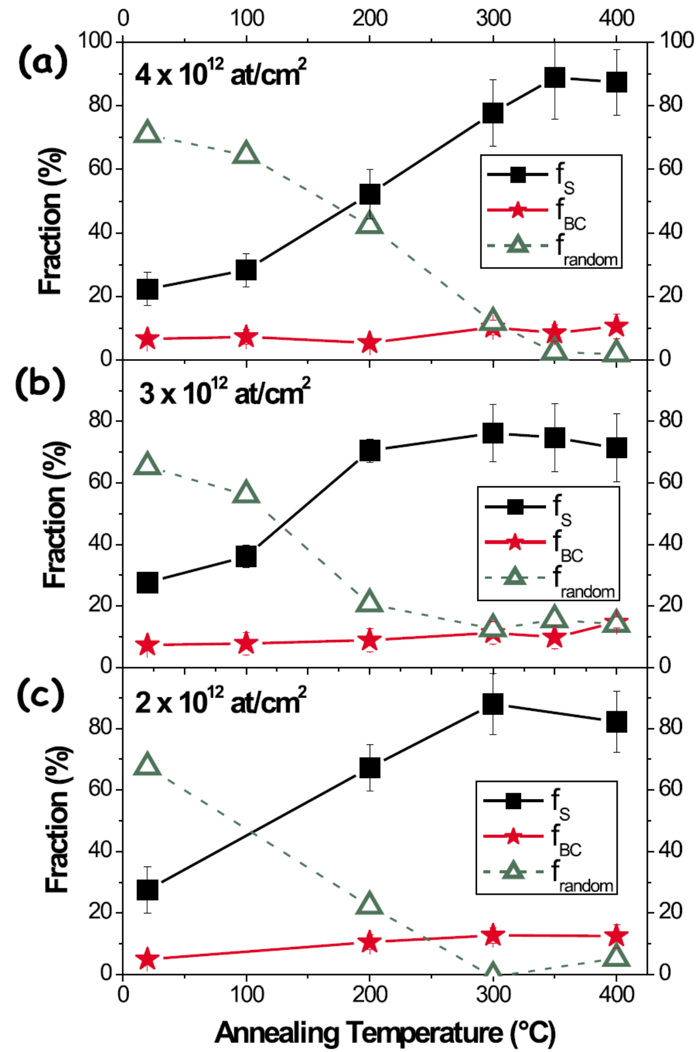
{110}
plane



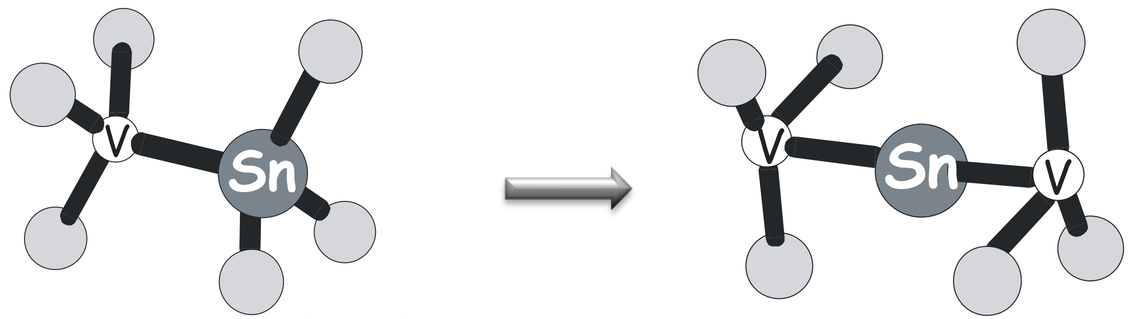
RESULTS - Lattice location study of implanted ^{121}Sn (27h) : Ge

- visual inspection of spectra: **substitutional** Sn
- detailed fitting procedure:
  majority on S site but also fraction on **BC site!**
- **BC** fraction is observed …
  - …in three different samples
    (slightly different implantation fluence)
  - …up to 400°C annealing!
- **No direct experimental** observation of Sn on BC site reported in literature
- Indications for BC behavior from *ab initio* **calculations**…





Ab initio calculations for Sn defects complexes in Ge
STABILITIES



Single vacacny + Sn (S)
NOT STABLE

Sn on BC sites (split vacancy)

Sn on …	**ΔH_f (eV)**
Sn on S site	0.19
Sn on T site	3.96
Sn on BC site (split-vacancy)	1.86
Sn on BC site (no vacancies)	3.83
Sn on S site + Ge self-interstitial	3.51
Ge vacancy	2.23

$$\Delta H_{f,\ subst.} + \Delta H_{f,\ vacancy} > \Delta H_{f,\ BC}$$

spontaneous capture of vacancies by substitutional Sn

Previous – controversial - publications Höhler et al., PRB 71, 035212 (2005) and Coutinho et al., PRB 73, 235213 (2006)

Ab initio calculations for Sn defects complexes in Ge
Isomer shift and hyperfine parameters

	SIMULATIONS			Mossbauer		
	ΔH_f (eV)	$\delta_{(calc)}$ (mm/s)	$\Delta E_{Q(calc)}$ (mm/s)	Mössbauer spectroscopy line[a,b]	$\delta_{(exp)}$ (mm/s)	$\Delta E_{Q(exp)}$ (mm/s)
Sn_S	0.19	1.75	0.0	2 Sn(S)	1.90	0.0
Sn_T	3.96	3.19	0.0	4 Sn(T)	3.27	0.0
Sn_{BC} (split vacancy)	1.86	2.24	0.10	3 Sn(S)-V	2.36	0.3[a]–0.4[b]
Sn_{BC} (no vacancies)	3.83	3.25	0.82			
Sn_S+Ge_T (self-int.)	3.51	1.84	0.64			
unknown				1 Sn(BC)-V	1.41	0.0

G. Weyer et al., Phys. Lett. 76A, 321(1980)
G. Weyer et al., Hyp. Int. 10, 775 (1981)
Damgaard, A. el atl., Phys. Scr. 22, 640 (1981)

Good agreement for Sn on S and T site

Mossbauer values for "Sn(S)-V defect" is in very good agreement with Sn-V defect in split-vacancy configuration (i.e. with Sn_{BC}) !!

Study of Sn defects complexes in Ge
CONCLUSIONS

- From EC: Majority of Sn on S site + significant fraction on BC site
- From *ab initio* calculations:
  - vacancies will be trapped by substitutional Sn
  - Sn(S)-V defect relaxes towards split-vacancy configuration, i.e., **Sn on BC site**

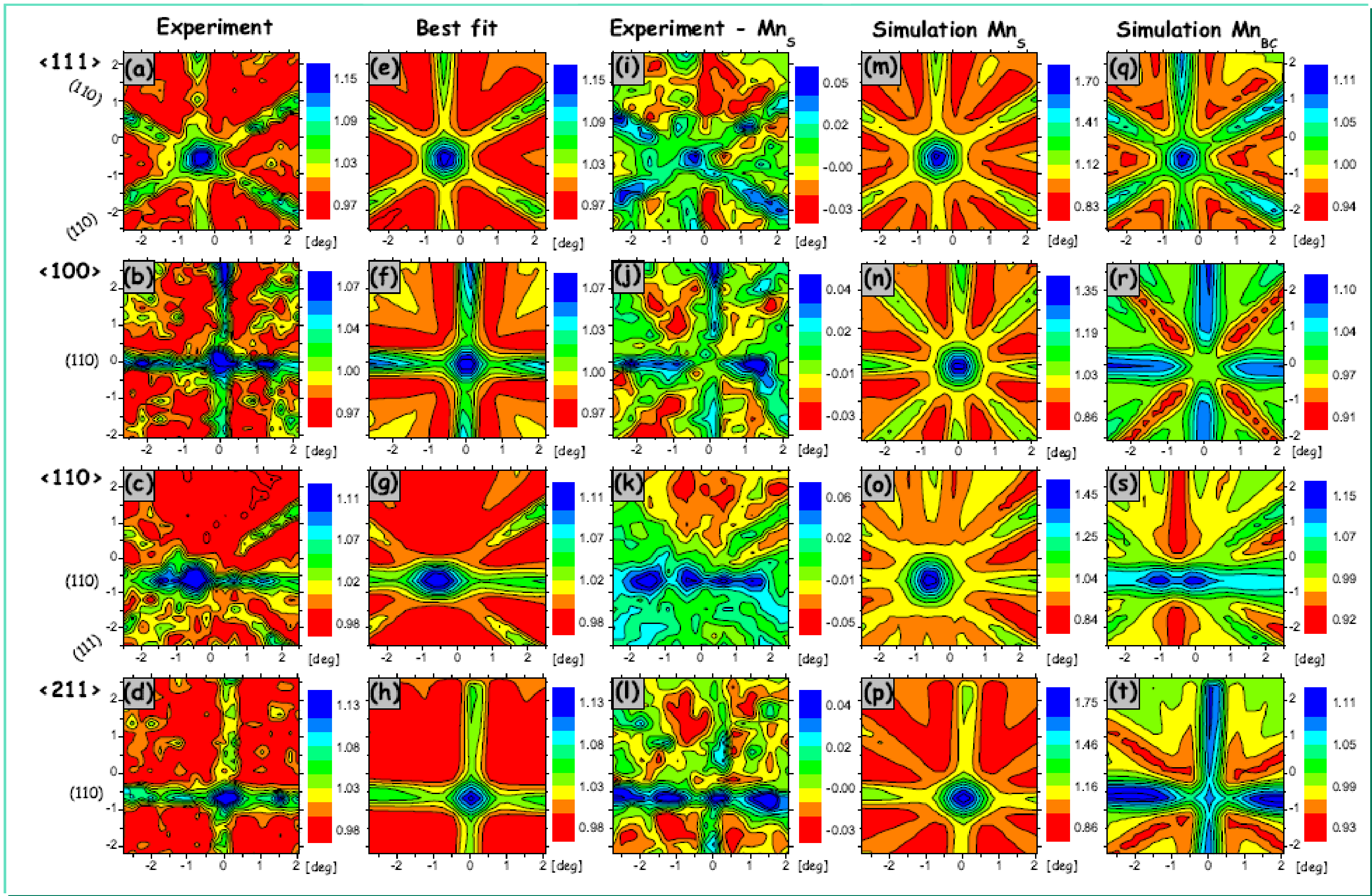
creating vacancies → Sn_S gets displaced to Sn_{BC}

- Our experiments:
  Implantation creates many vacancies
- vacancy creation during MBE-growth of GeSn ?
- Ventura *et al.*, PRB **79**, 155202 (2009):
  Split-vacancy defect in diluted GeSn could be nucleation point of metallic Sn

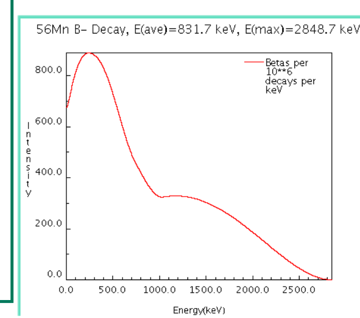
Lattice location study of implanted ^{56}Mn (2.6h) : Ge Implantation at 300°C

(accepted by Applied Physics Letters 2010)

Mn-doped Ge →(?)→ spintronic devices, Mn_x*Ge_{1-x}* → *ferromagnetic 25 and 116 K,*
TC increases linearly 0.6% <[Mn] < 3.5%.
Cho *et al. showed ferromagnetic ordering* in $Ge_{0.94}$*$Mn_{0.06}$ close to room temperature (285 K)2. The origin of ferromagnetism* is not fully understood and has been related to Mn-rich precipitates.

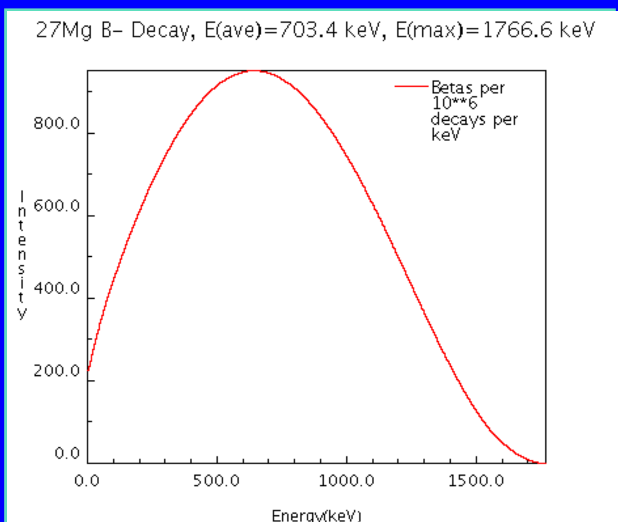


38(7)% Mn(S) + 59(8)% Mn(BC)

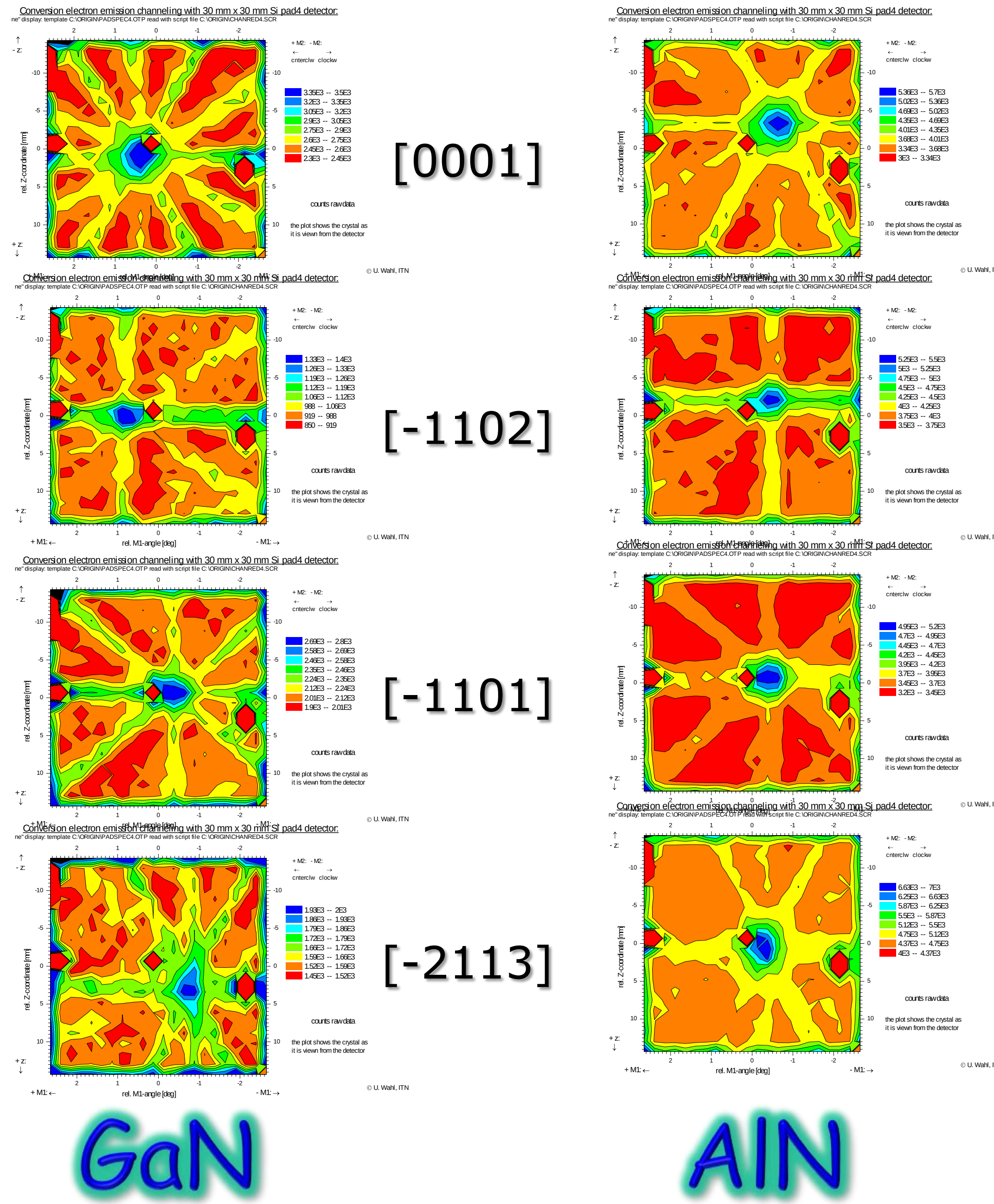


2009

First emission channeling experiments with ^{27}Mg(9.46m)

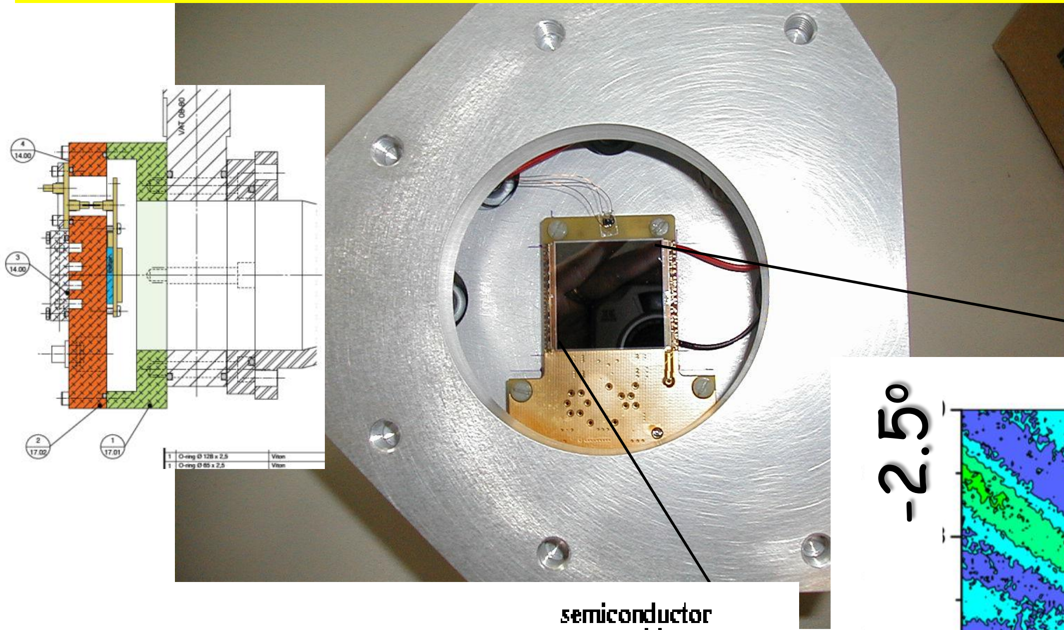


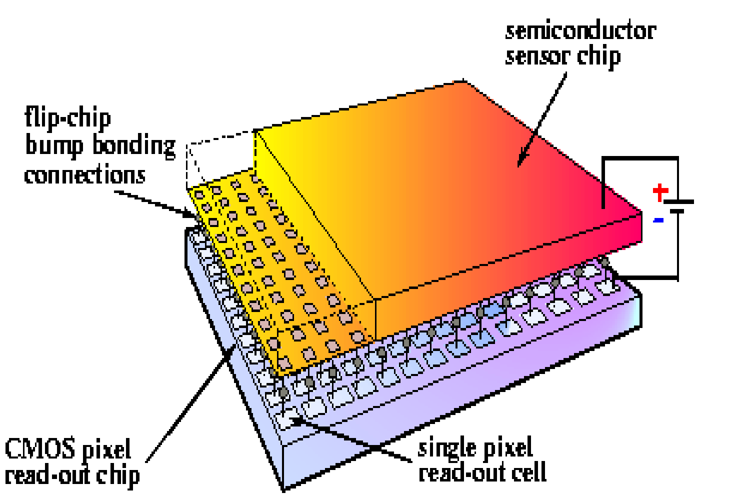
(no precise data analysis yet)



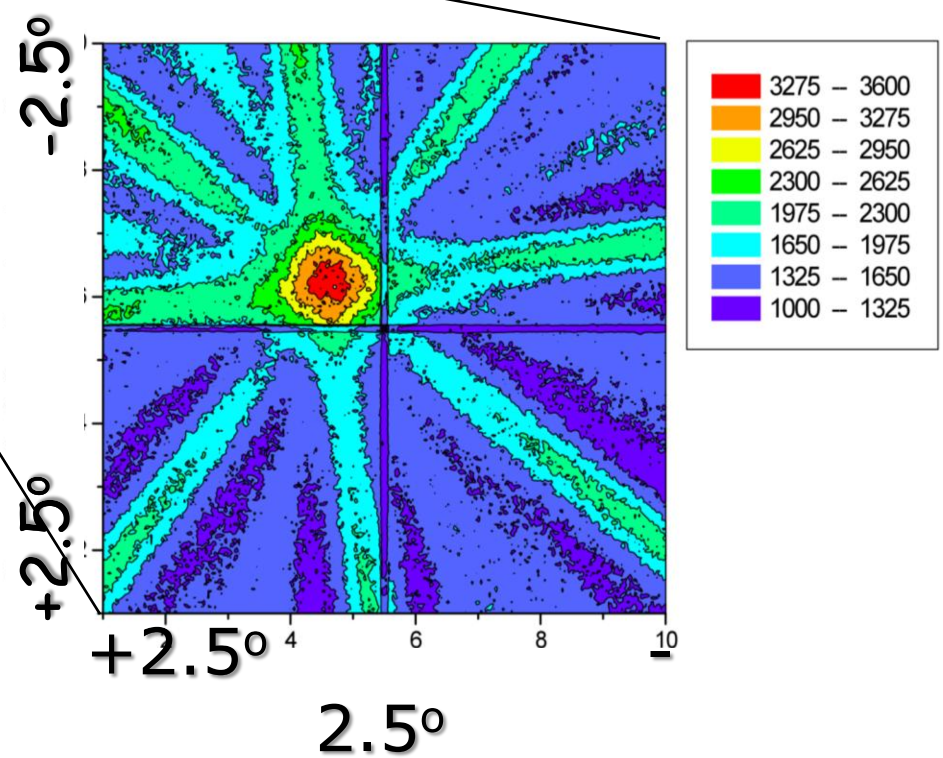
HIGHLY PIXILATED and energy resolving electron detectors TIMEPIX (MEDIPIX COLLABORATION @ CERN)

TIMEPIX 512 x 512 ch ; 30 x 30 mm^2 ; 300μm thick



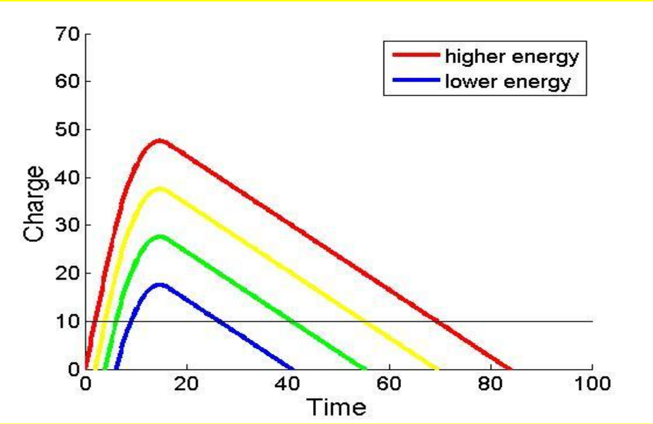


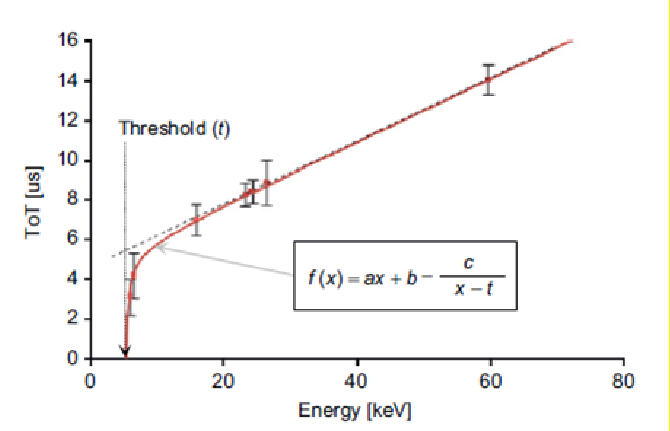
89Sr : $SrTiO_3$
After air annealing
1050 C°
<100>



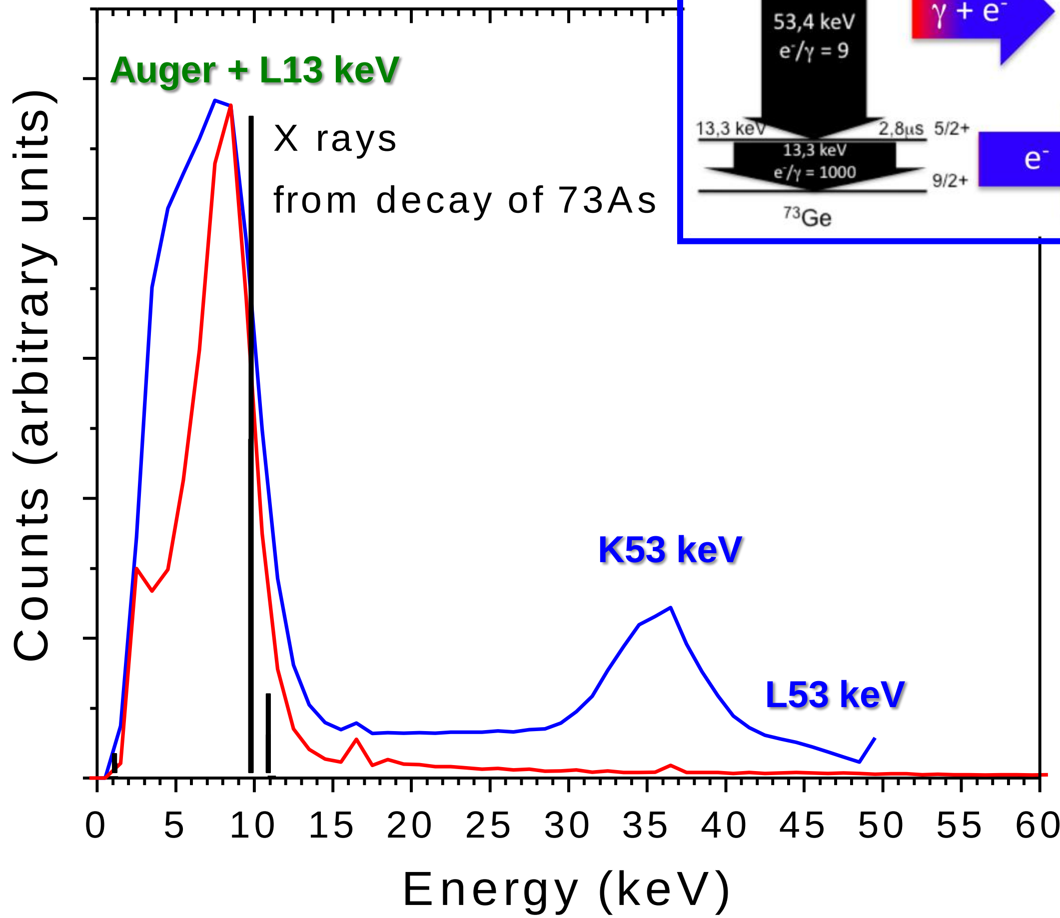
Highly pixilated and ENERGY RESOLVING electron detectors TIMEPIX (MEDIPIX COLLABORATION @ CERN)

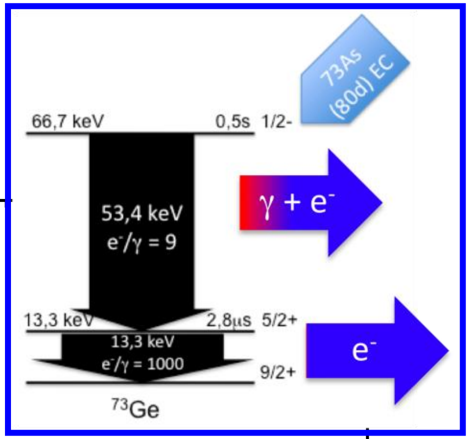
Energy determination Time Over Thereshold (TOT) method





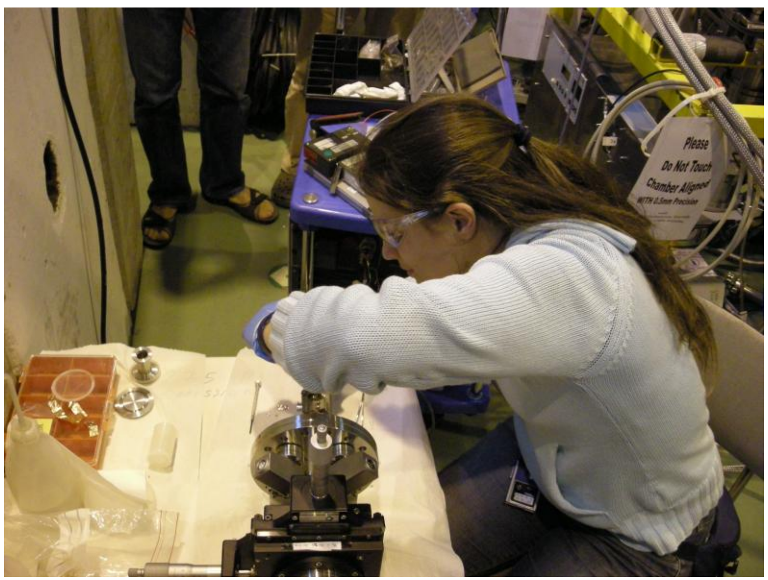
73As → 73Ge






!!!
is ON
Please
KEEP OUT
NEVER OPEN
IF:
VALVE IS OPEN
AND
DETECTOR is ON


DETECTOR
ON


Please
Do Not Touch
Chamber Aligned
WITH 0.5mm Precision