The versatile detectors used for research at ISOLDE

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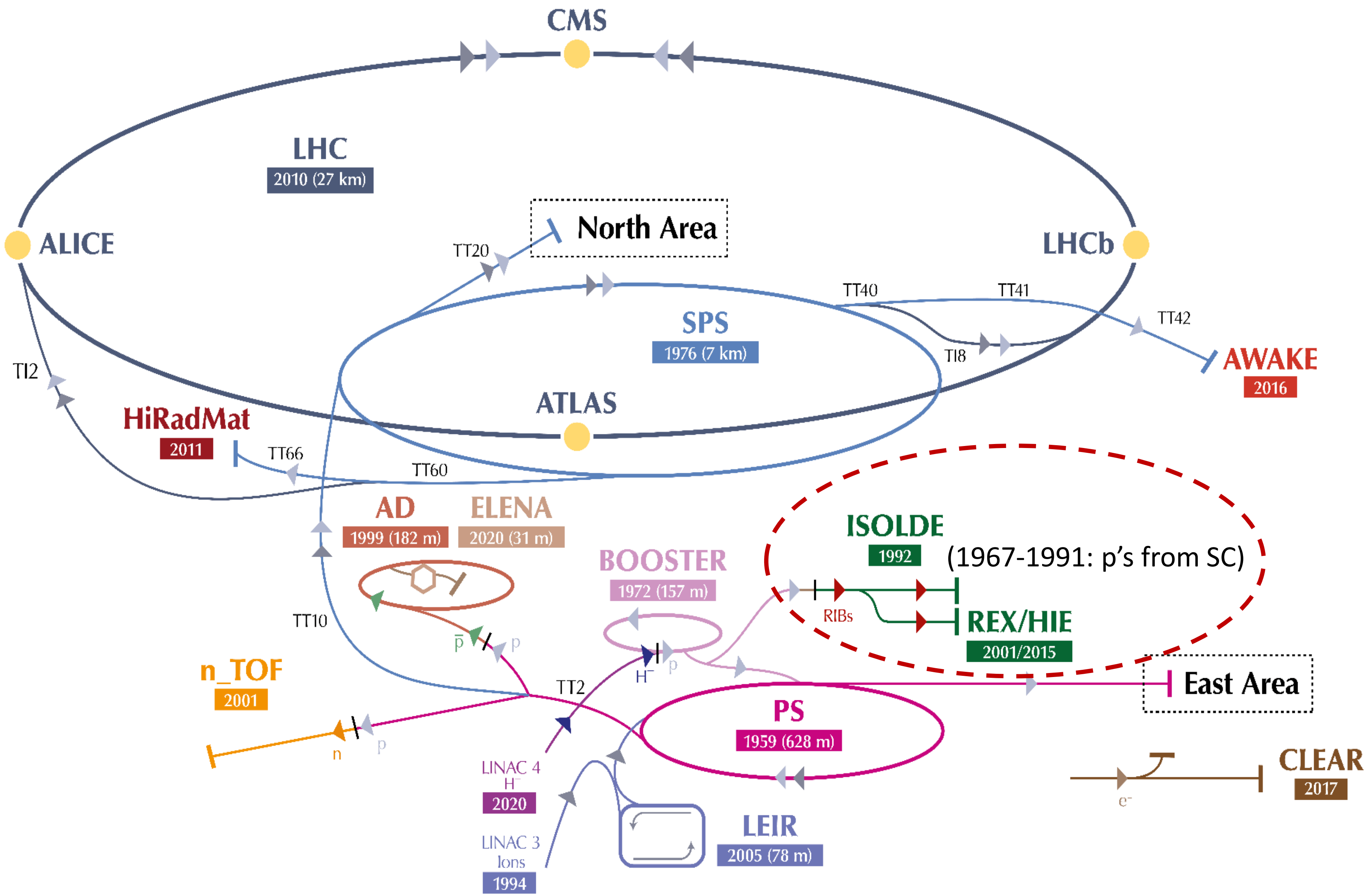
CERN,
on behalf of the ISOLDE physics team

With input from L. Fraile, R. Garcia Ruiz, R. Lica, S. Malbrunot-Ettenauer, M. Pfutzner, M. Mougeout, S. Sels, P. Van Duppen, U. Wahl

Outline

- **ISOLDE facility at CERN**
- **ISOLDE wide range of particle and photon detectors**
- **Selected examples**
- **Outlook and summary**

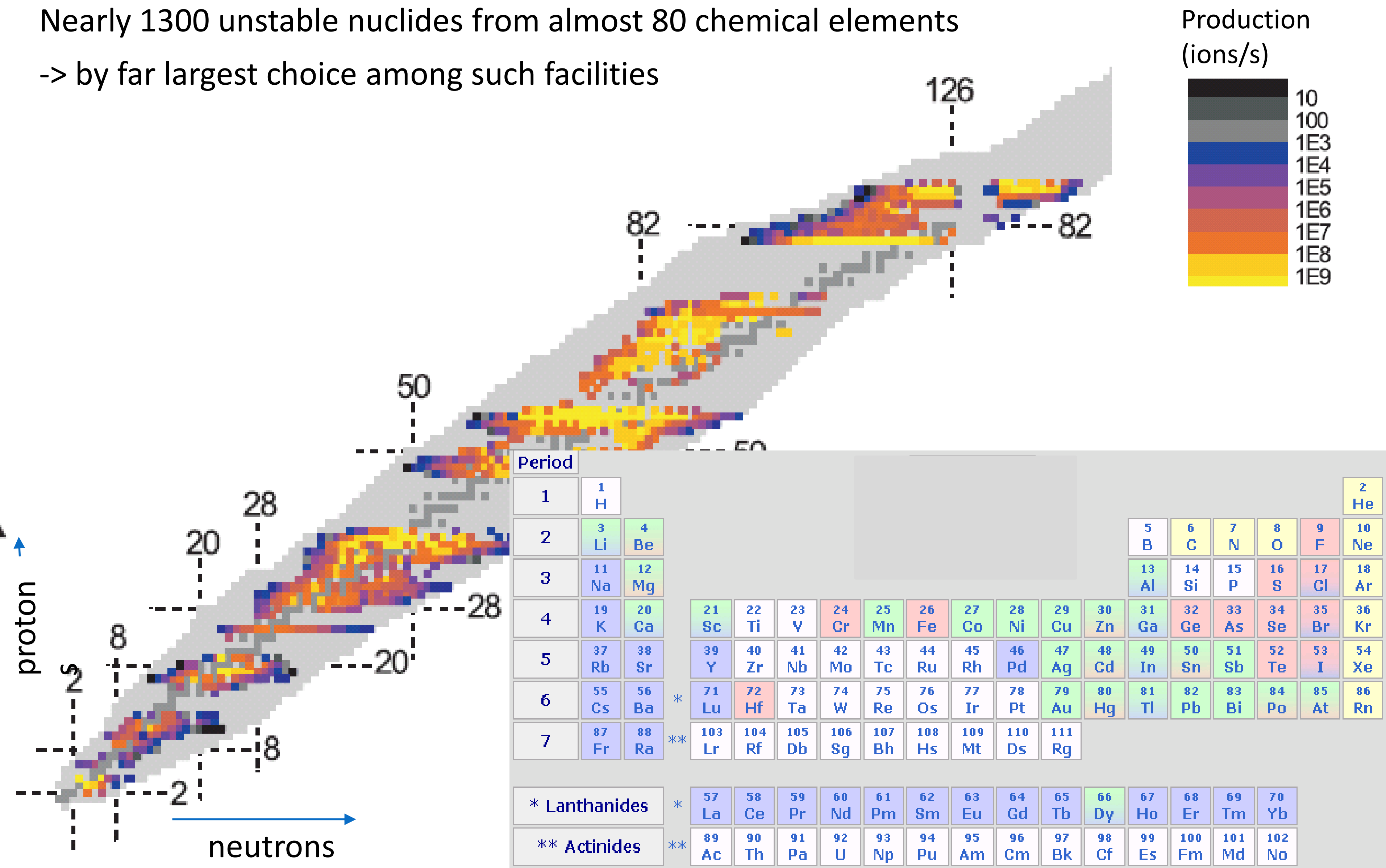
ISOLDE at CERN



ISOLDE radio-nuclei

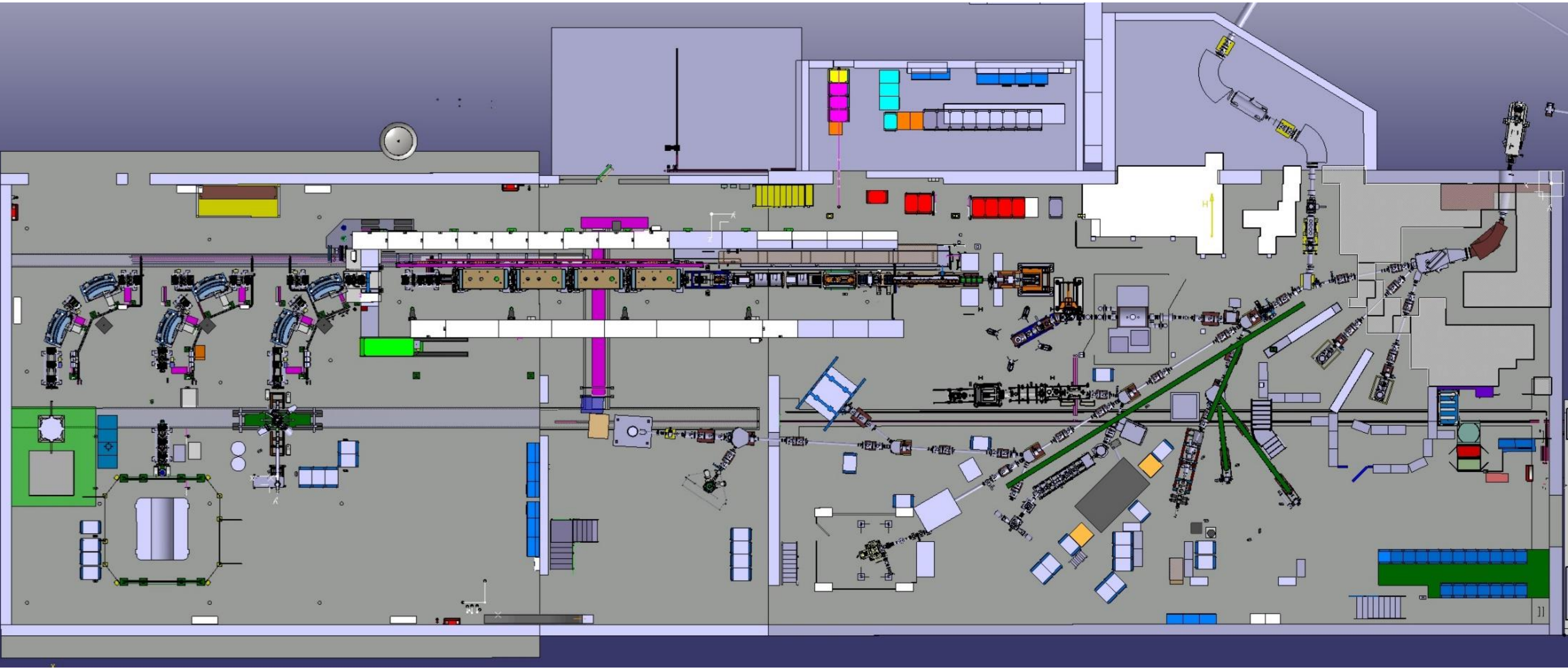
Nearly 1300 unstable nuclides from almost 80 chemical elements

-> by far largest choice among such facilities



ISOLDE experiments

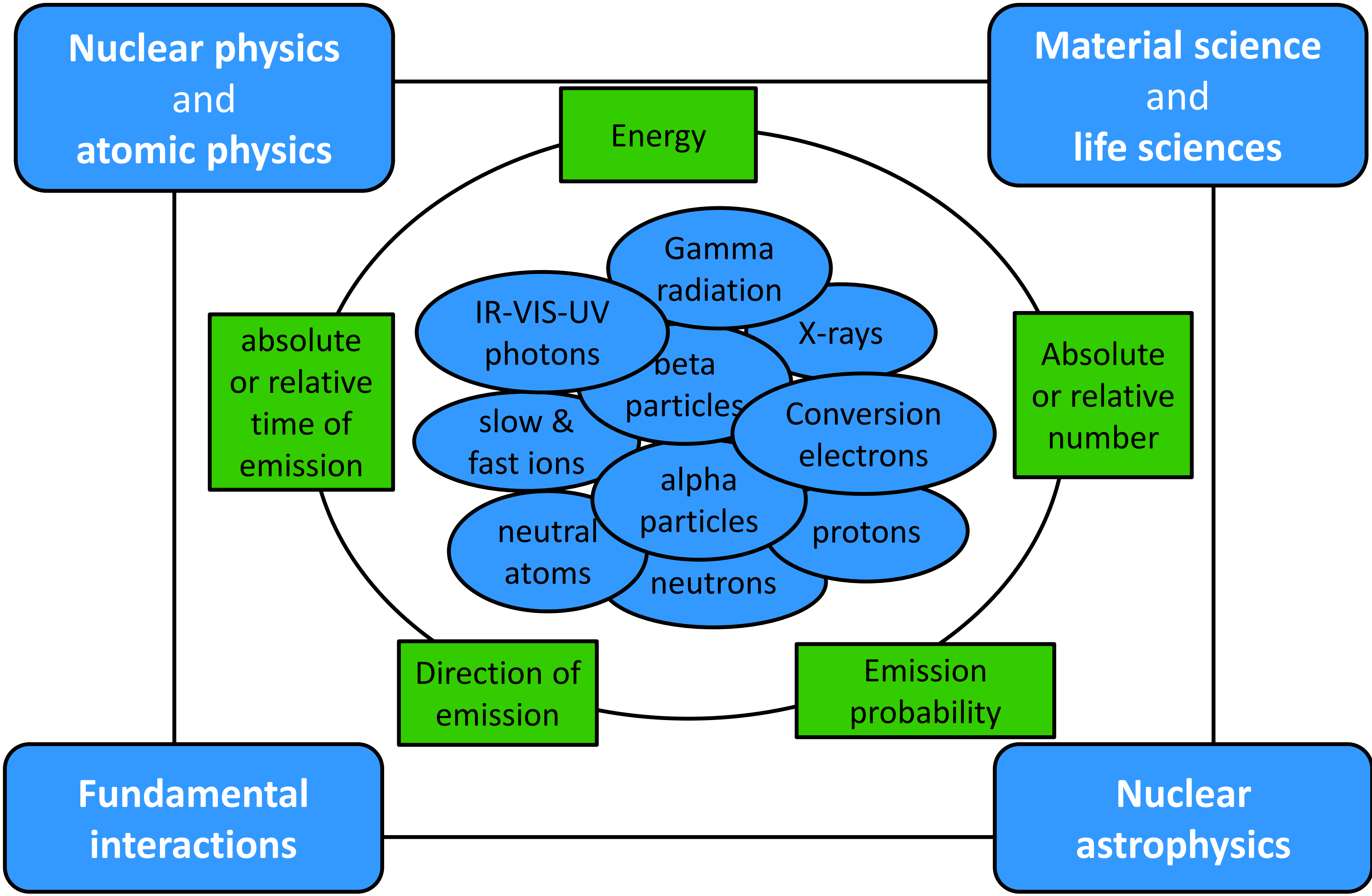
A dozen permanent and travelling experimental setups
100 scientific proposal approved by INTC committee
500 – 900 researchers from around the world



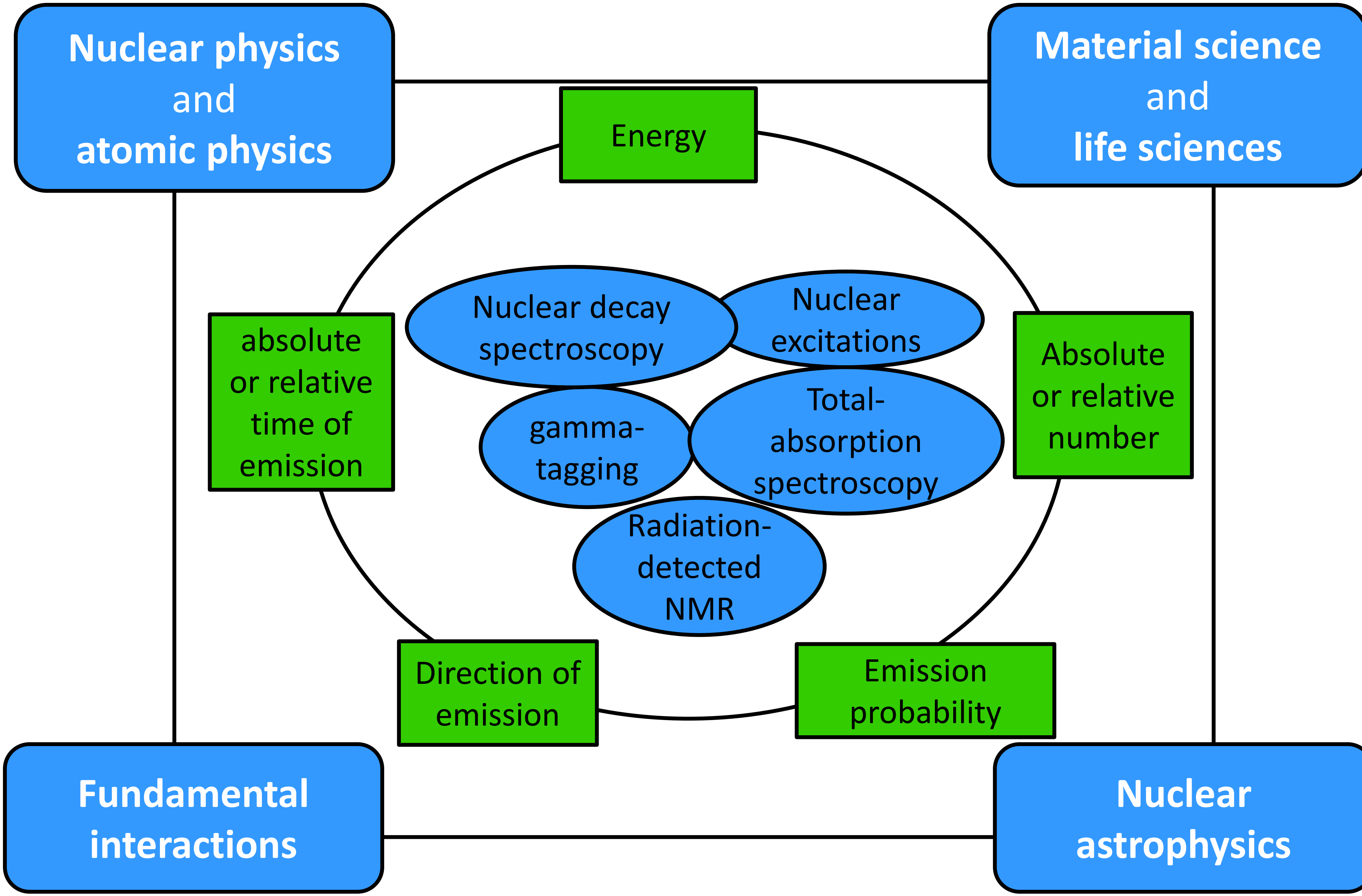
Post-accelerated RIBs, up to 10 MeV/u

Low-energy RIBs, up up to 60 keV energy

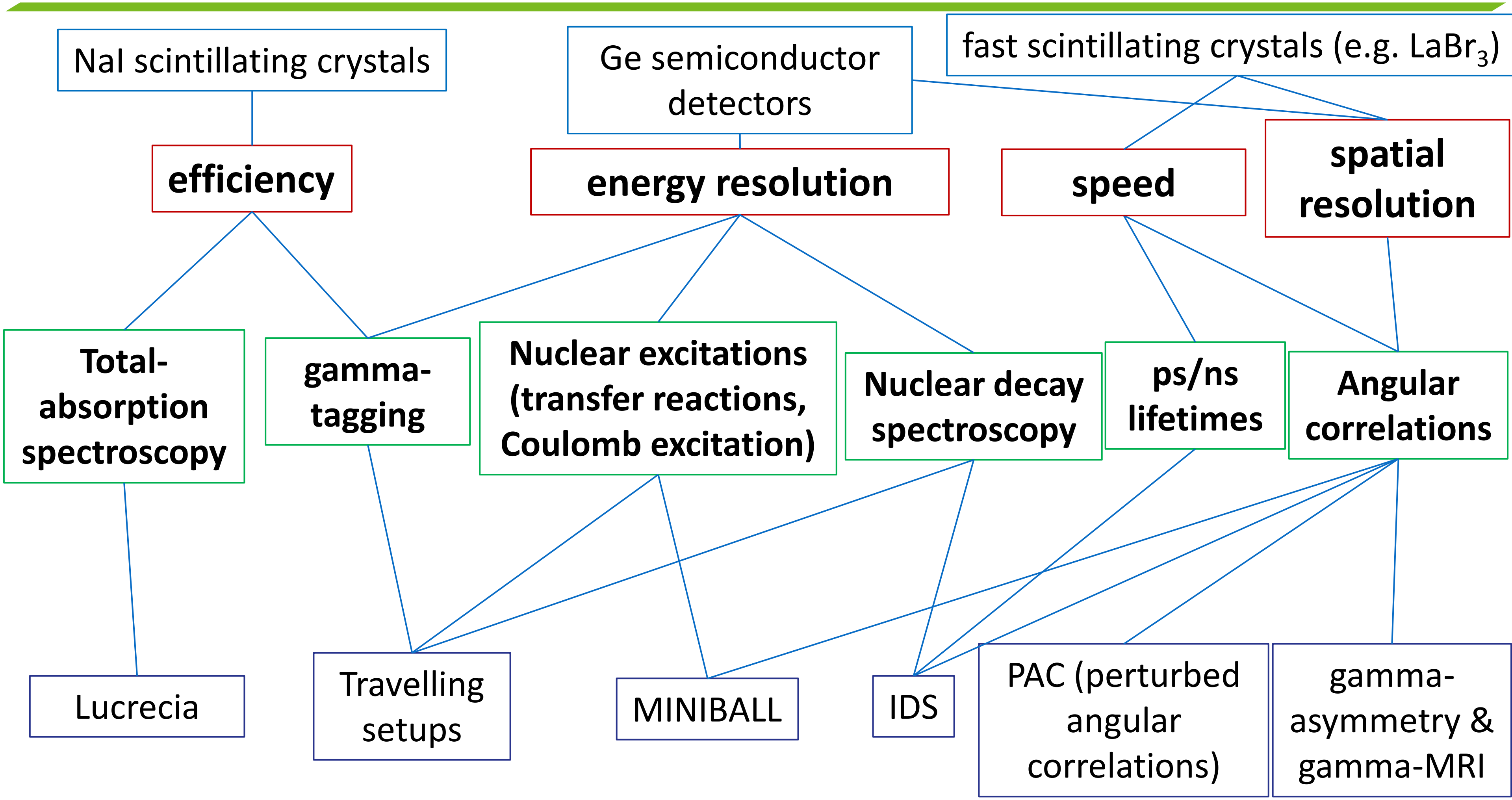
ISOLDE detectors and research topics



Gamma-ray detectors at ISOLDE



ISOLDE gamma-ray detectors



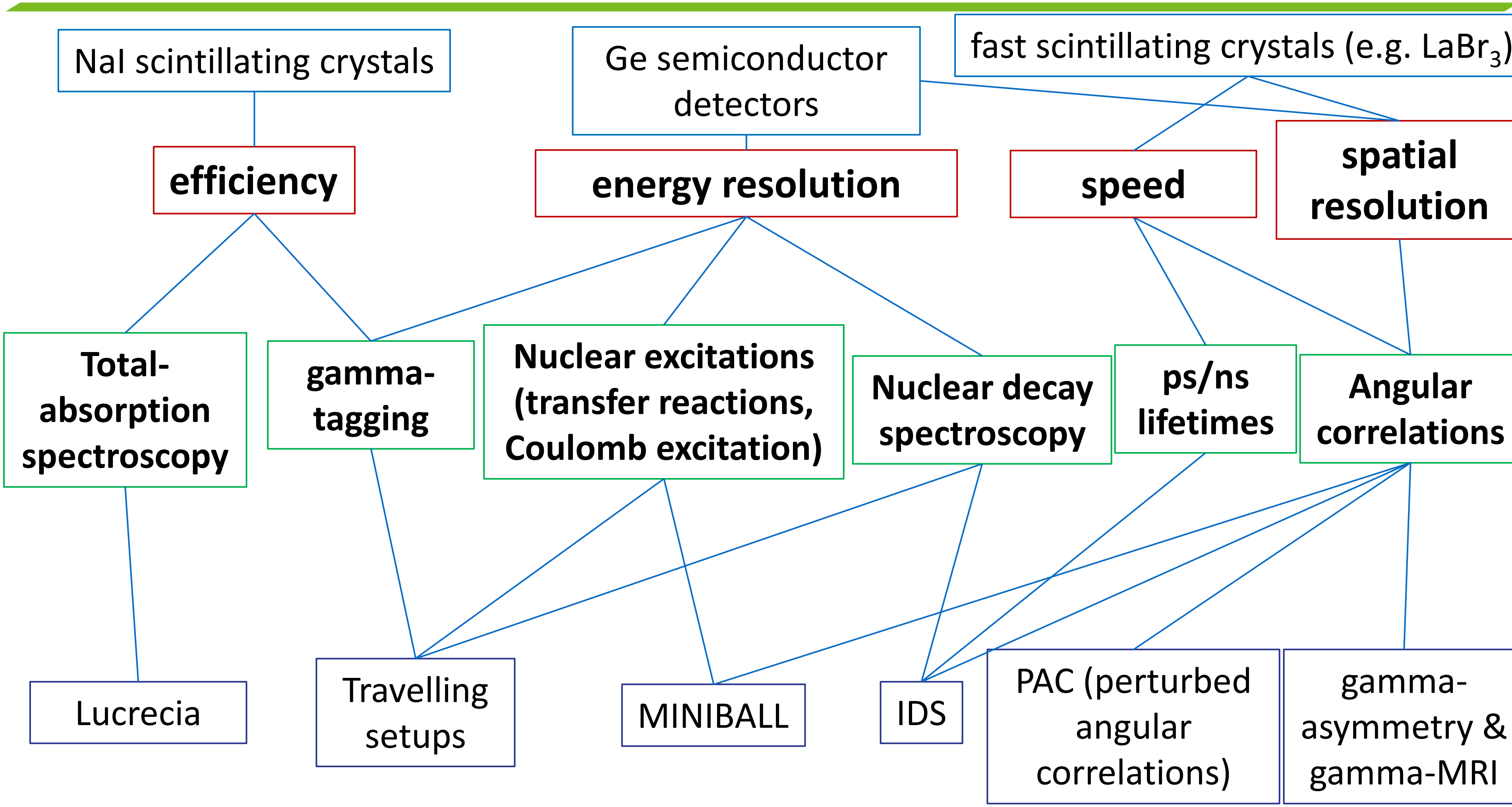
ISOLDE particle detectors

- **To detect particles emitted in decays or reactions of unstable nuclei:**
- Alphas
- Betas
- Protons
- Neutrons
- Other emitted (light particles), e.g. deuterons

- **What is required:**
- Energy
- Time of emission
- Emission direction

- **Used and tested types of detectors:**
- Si strip detector
- Time projection chamber
- TIMEPIX

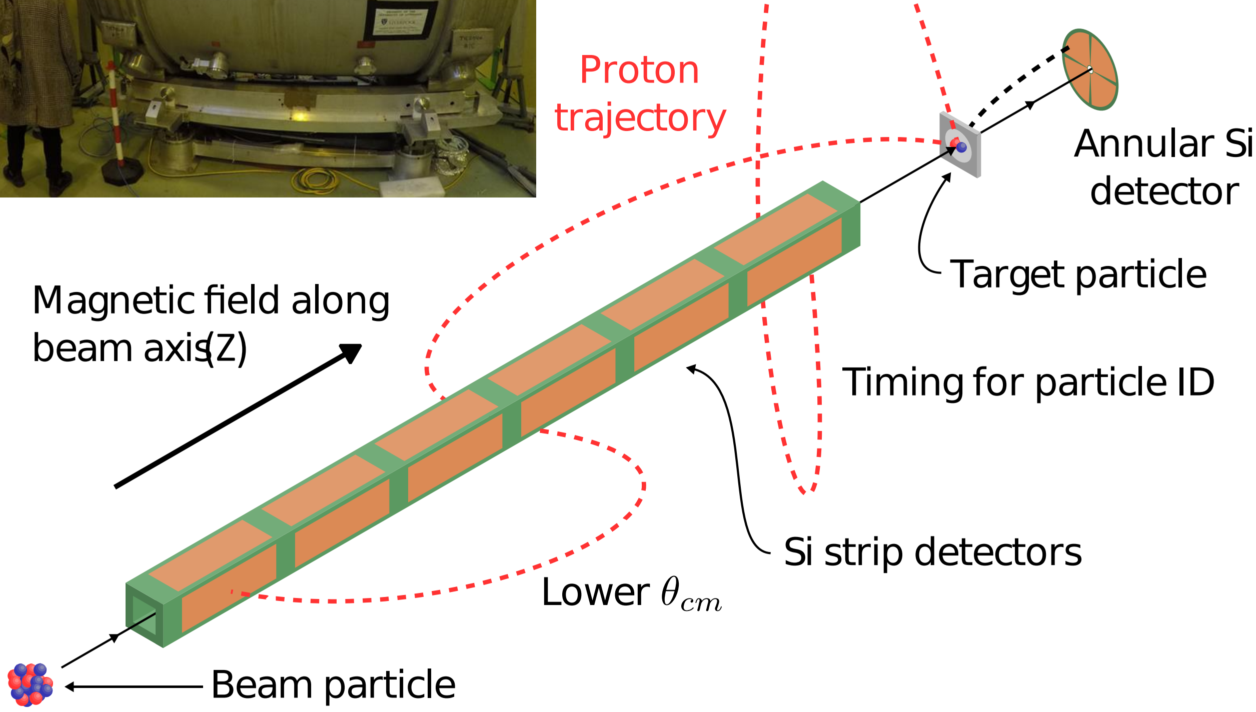
ISOLDE gamma-ray detectors



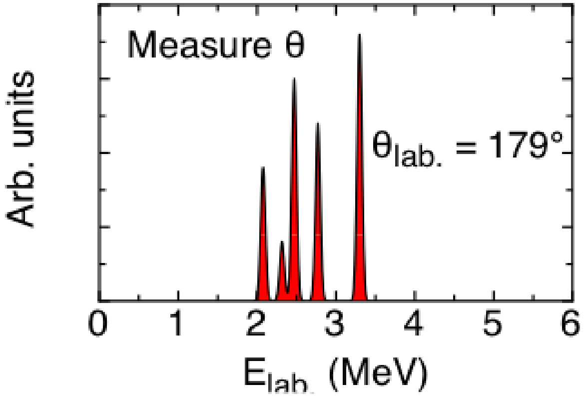
ISS: charged particle detection

ISOLDE Solenoidal Spectrometer

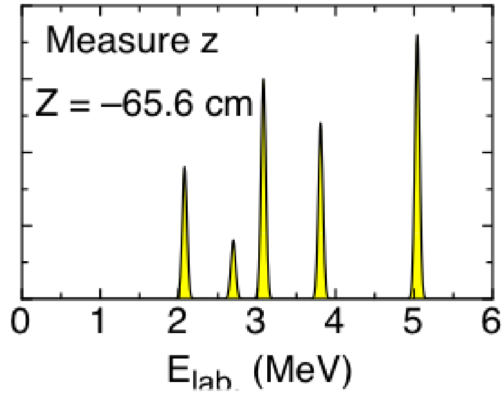
direct reactions at HIE-ISOLDE



Fixed angle



Solenoid

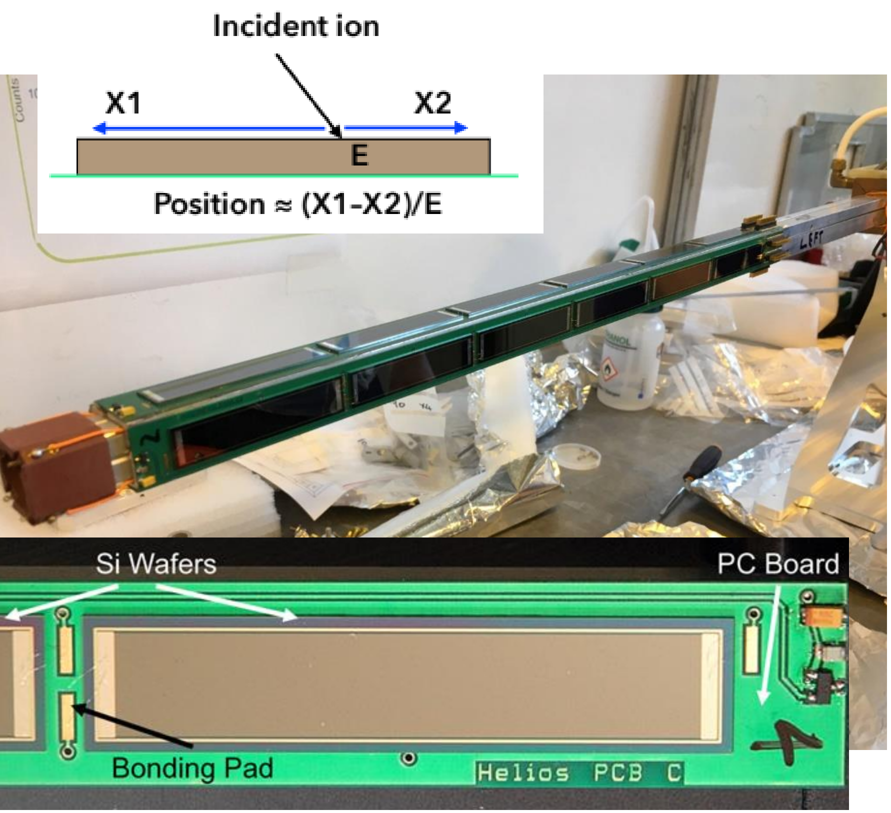


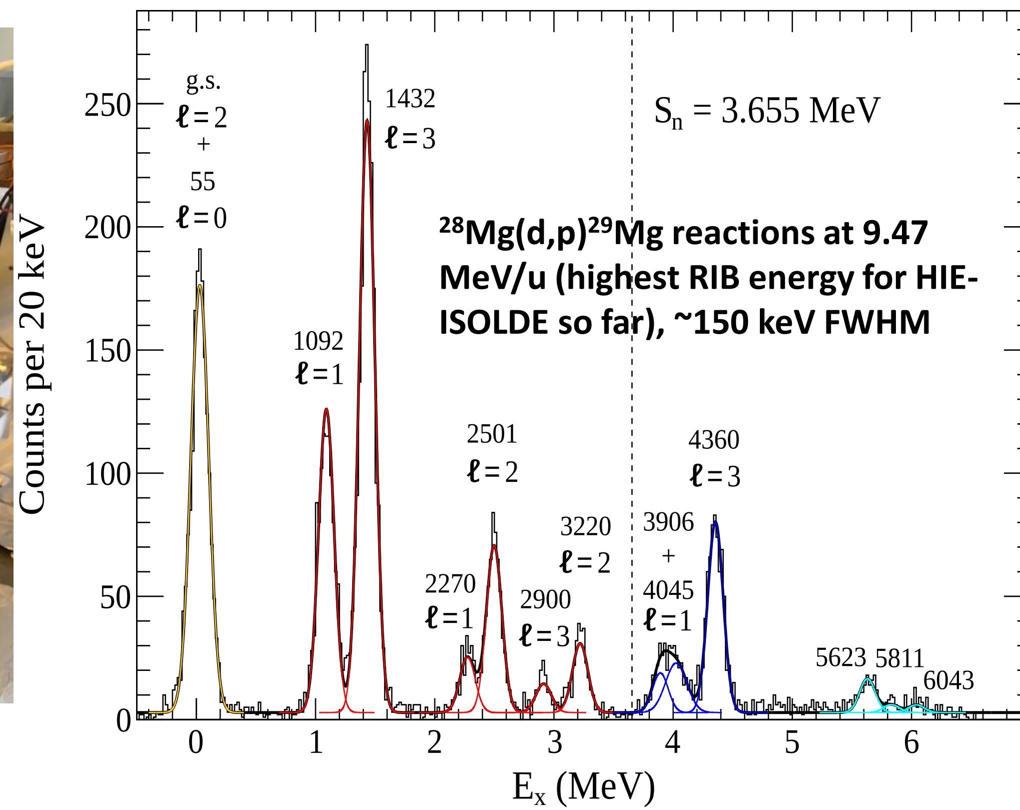
MEASURED: position z where light ejectile returns to axis, cyclotron period T_{cyc}, lab particle energy E_p

<u>no kinematic compression</u> of energy spectrum (unlike at fixed angles)
Linear relationship between E_{cm} and $E_{lab.}$

1st ISS detectors in 2018

- Used HELIOS solenoid (Argonne) 24 resistive strip detectors (PSD) + electronics and DAQ
- Position determined though comparison of signals from each side of detectors

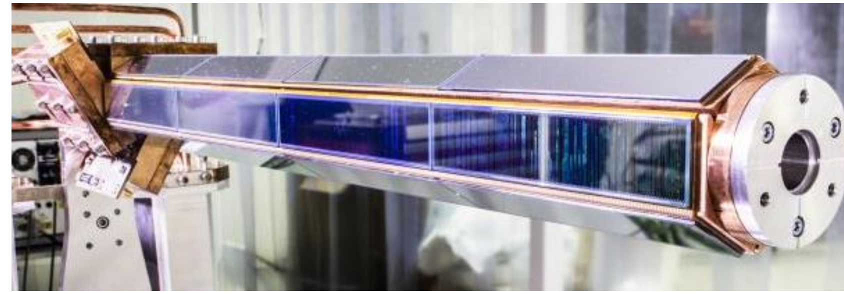


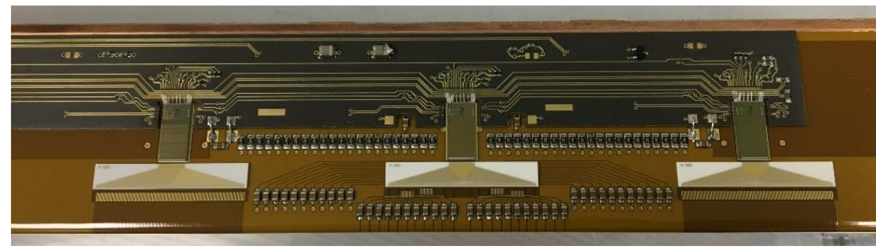


Contact: D. Sharp, U Manchester; L. Gaffney, U Liverpool, et al.

T.L. Tang et al., Phys. Rev. Lett. 124, 062502 (2020)

ISS detectors in 2021





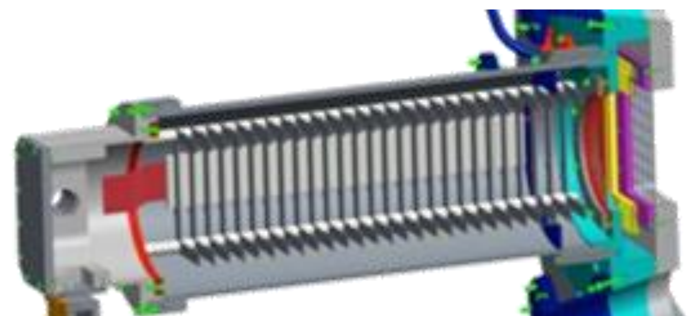
6-sided Si array: 4 double-sided silicon-strip (DSSS) detectors + ASICs readout on each side

Each detector:

- 128 x 0.95mm strips along detector length
- 11 x 2mm along width
- 3336 channels

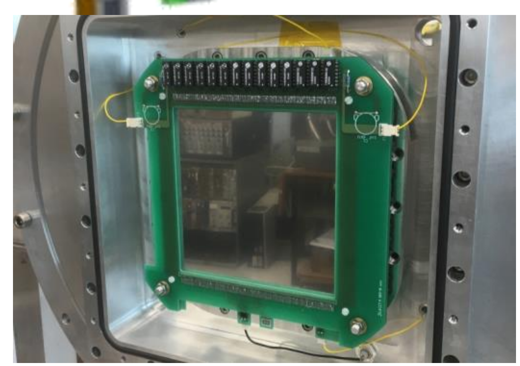
Total Si length: 510.4mm (486.4mm active)

- ~70% coverage in azimuthal angle
- Total coverage ~66% (2018: HELIOS PSD ~42%)



New gas-filled recoil detector for recoil identification:

- Position-sensitive multi-wire proportional counter
- Followed by segmented gas-filled ion chamber
- Digitized signals – sample full dE/dx.
- Count rate up to 100kHz



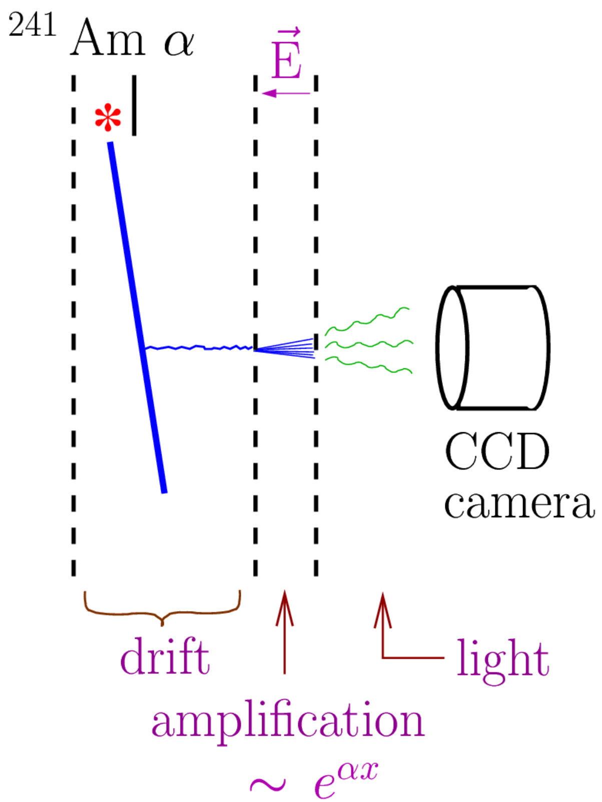
Contact: D. Sharp, U Manchester; L. Gaffney, U Liverpool

Optical TPC: charged-particle imaging

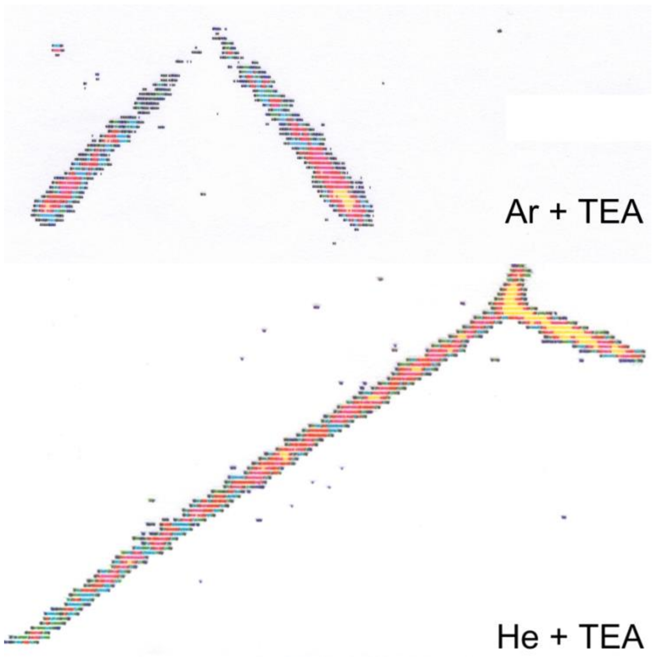
G. Charpak, W. Dominik, J. P. Farbe, J. Gaudaen, F. Sauli, and M. Suzuki,

"Studies of light emission by continuously sensitive avalanche chambers,"

NIM A269 (1988) 142



Example images of α-particle tracks



TEA = Tri-ethyl-amine $N(C_2H_5)_3$

Contact: M. Pfutzner, Warsaw University

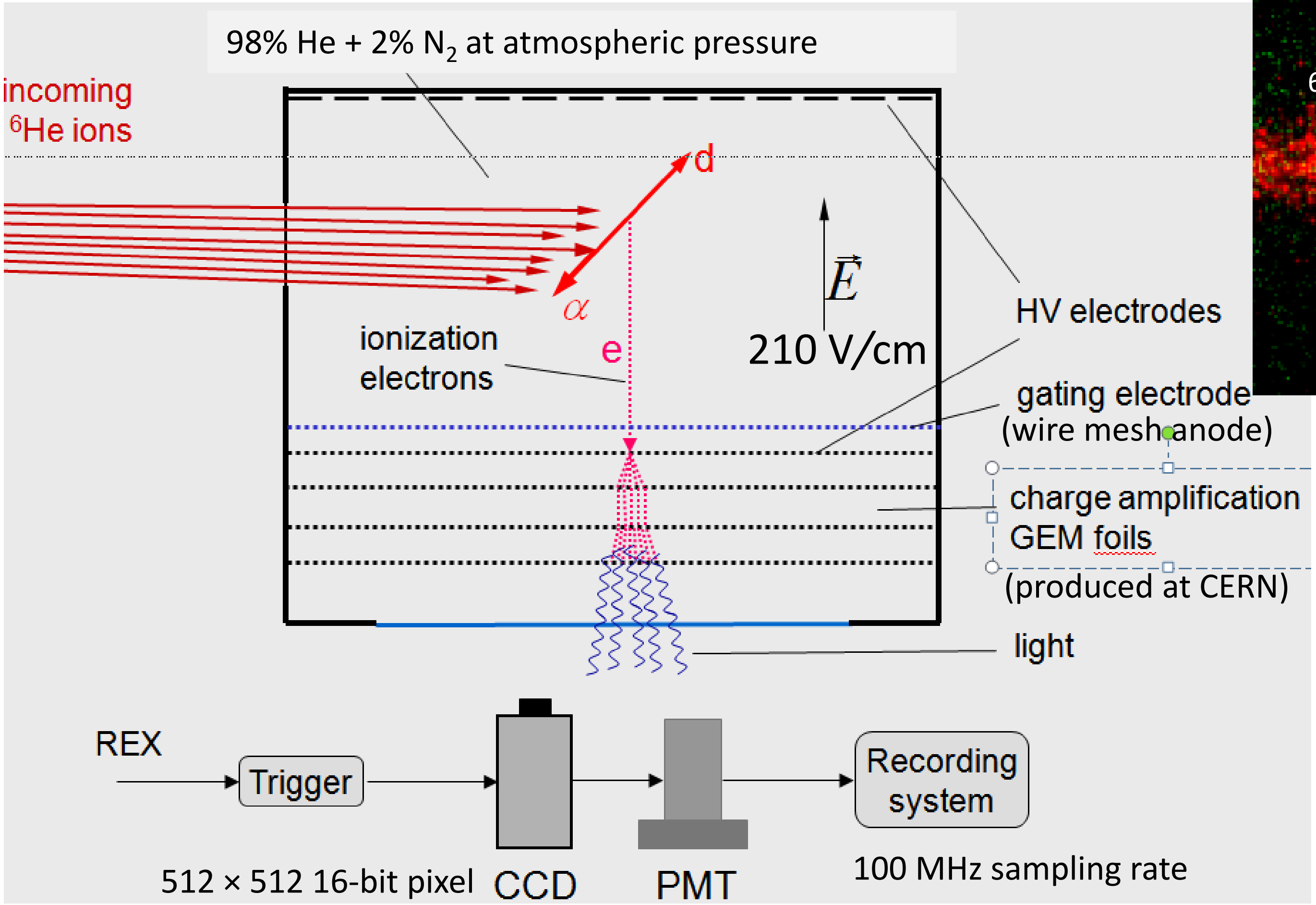
Warsaw OTPC at ISOLDE

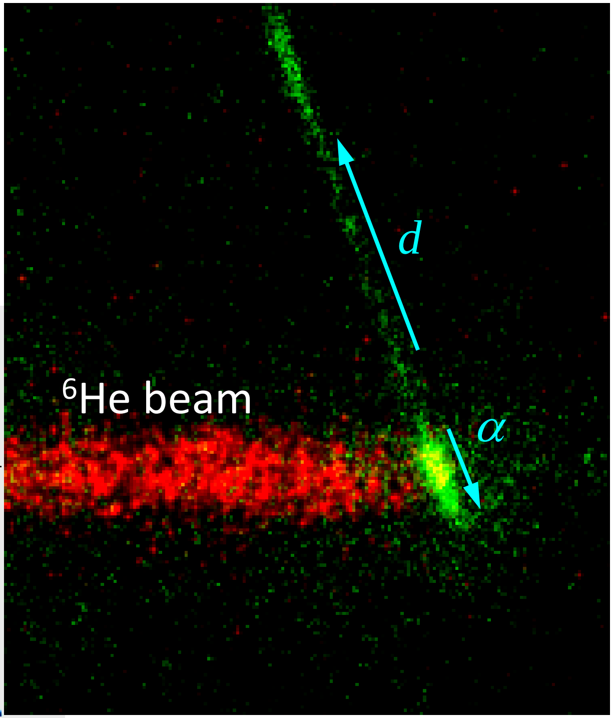
Studying rare decays with particle emission

Rare decay (branching ≈10^{-6}): ^{6}He → α + *deuteron*

-3 MeV/u bunches of about 10^4 ^{6}He ions

- Implantation into OTCP, 650 ms exposure => decays visible



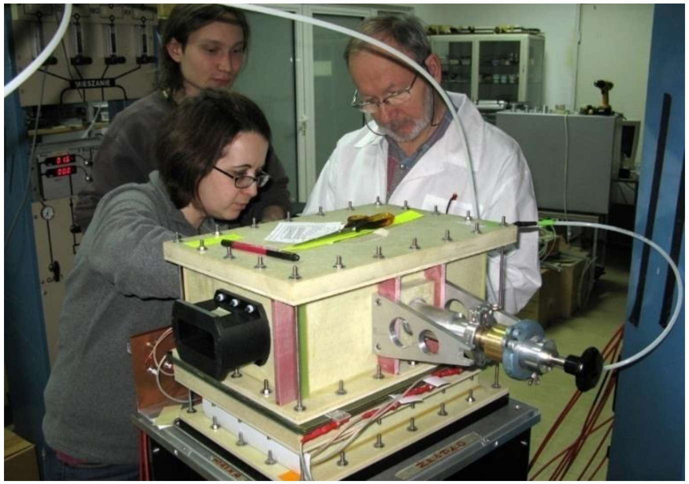


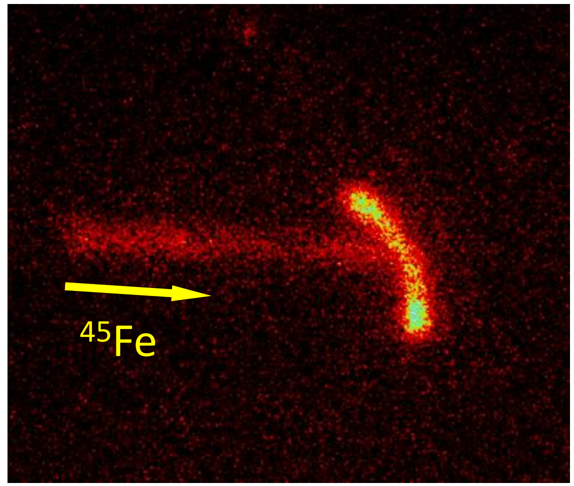
M.Pfutzner et al., Phys. Rev. C 92, 014316 (2015)

Warsaw OTPC at other facilities

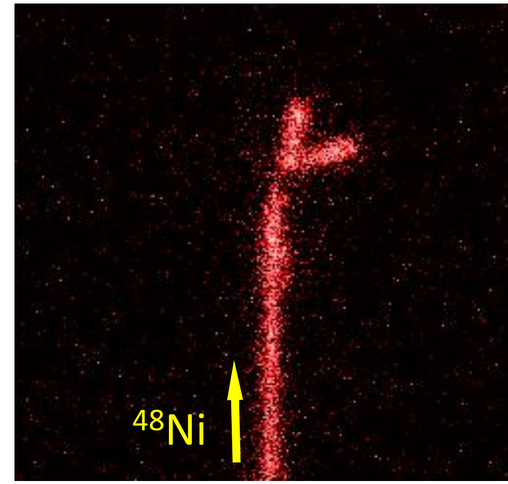
Evidence of 2-proton radioactivity

NSCL, USA: ^{58}Ni @ 161 MeV/u + Ni → ^{45}Fe, ^{48}Ni





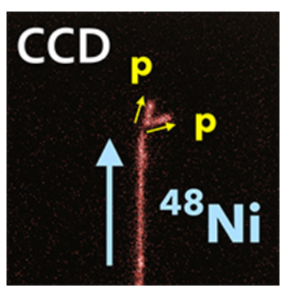
Miernik et al., Phys. Rev. Lett. 99 (2007) 192501



Pomorski et al., Phys. Rev. C 83 (2011) 061303(R)

Physical Review C 50th Anniversary Milestones

50 YEARS PHYSICAL REVIEW C



First observation of two-proton radioactivity in ^{48}Ni

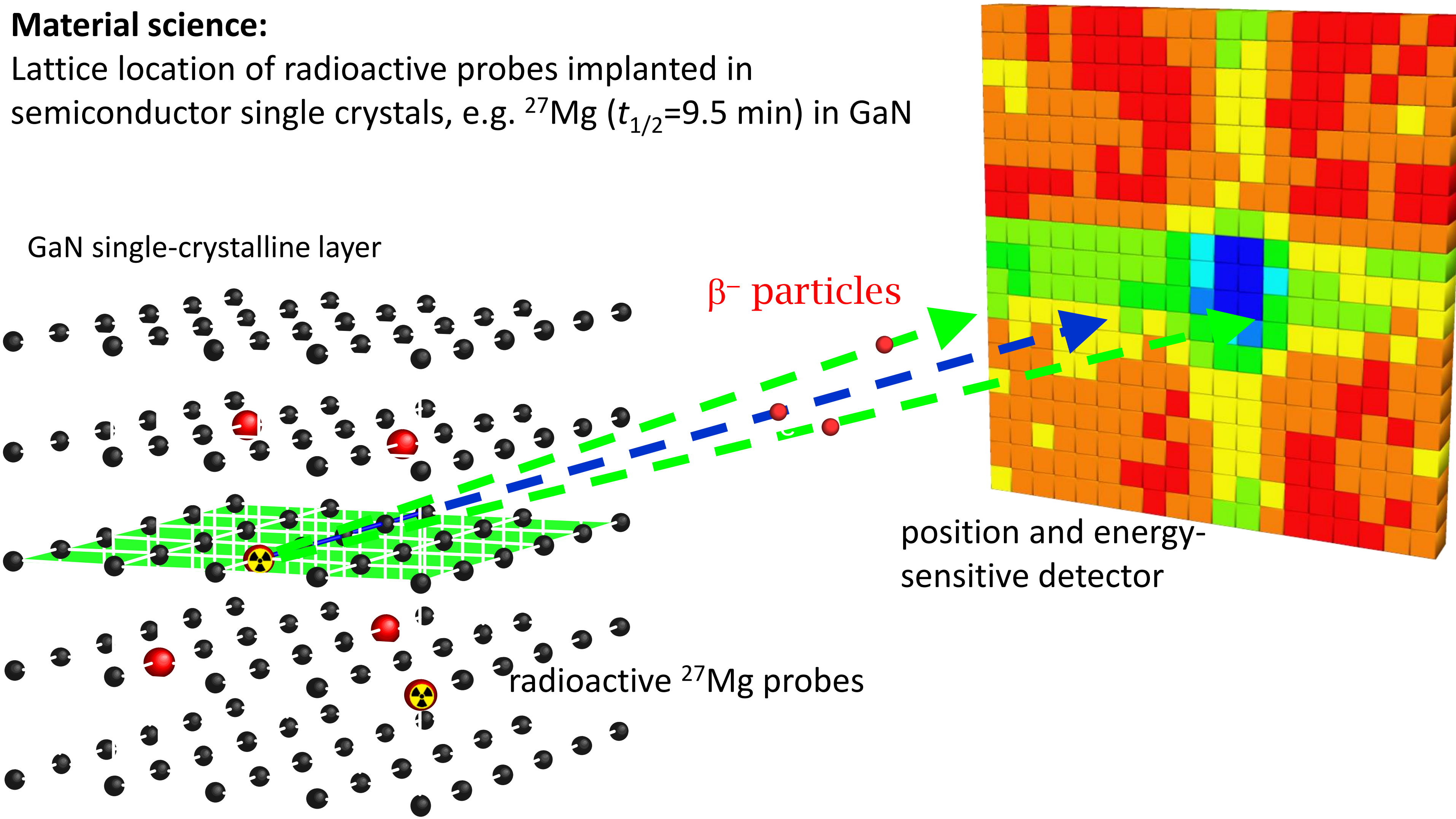
A rare form of radioactivity, in which a proton-laden nucleus decays toward stability via the simultaneous emission of two protons, was observed for ^{48}Ni. Using an optical time-projection chamber, the two-proton emission of four ^{48}Ni nuclei produced at the National Superconducting Cyclotron Laboratory was captured for the first time on CCD camera, marking a new era of optical detection of sub-atomic charged-particle processes in nuclear physics.

First observation of two-proton radioactivity in ^{48}Ni

M. Pomorski, M. Pfützner, W. Dominik, R. Grzywacz, T. Baumann, J. S. Berryman, H. Czyrkowski, R. Dąbrowski, T. Ginter, J. Johnson, G. Kamiński, A. Kuźniak, N. Larson, S. N. Liddick, M. Madurga, C. Mazzocchi, S. Mianowski, K. Miernik, D. Miller, S. Paulauskas, J. Pereira, K. P. Rykaczewski, A. Stolz, and S. Suchyta

EC-SLI: (beta) emission channeling

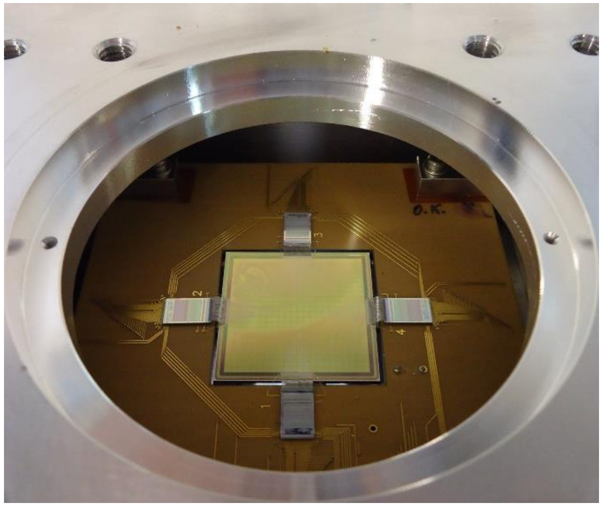
Material science:
Lattice location of radioactive probes implanted in semiconductor single crystals, e.g. ^{27}Mg ($t_{1/2}$=9.5 min) in GaN

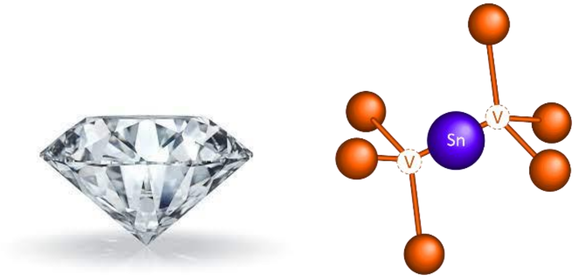


Depending on lattice site of probe atoms =>
emitted β^- particles are channeled or blocked on their way out of crystal

EC-SLI with Si pad detectors

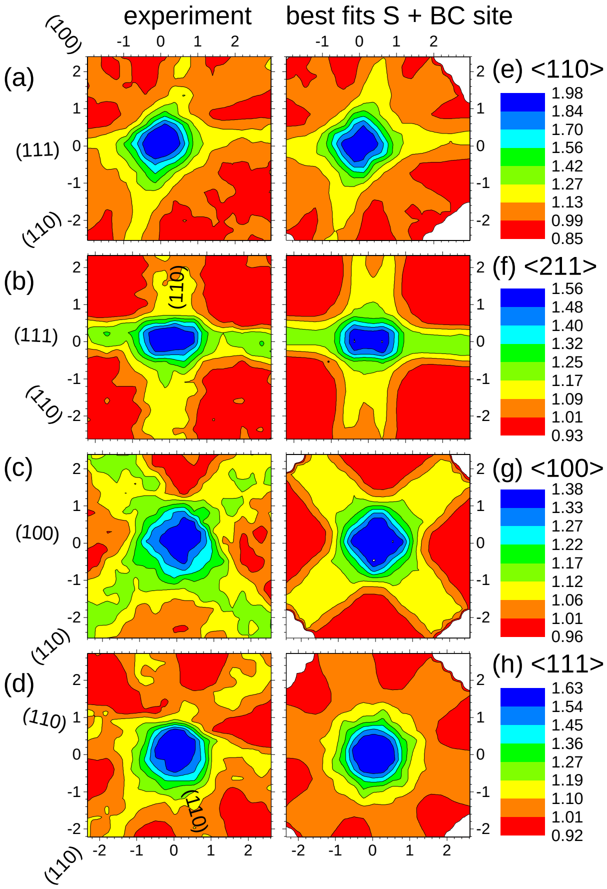
- 3x3 cm^2, 22x22 pixel (1.3x1.3 mm^2) detectors developed at CERN (Peter Weilhammer *et al*) in 1990s as X-ray detectors for PET demonstrators
- Self-triggered readout (VATA-GP3 chips): count rate 3.5 kHz with negligible dead time, saturation at 5 kHz, for on-line measurements
- EC-SLI "Workhorse" detectors since 20 years: a successful spin-off case of CERN detector development





^{121}Sn (27 h) in diamond

experiment simulation



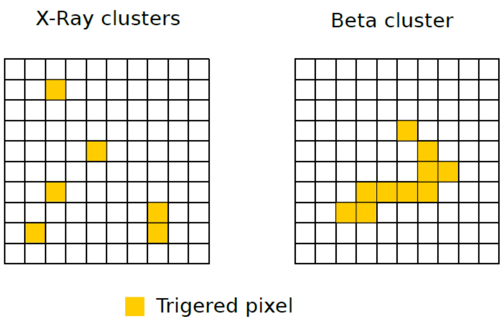
Contact: U. Wahl, Lisbon

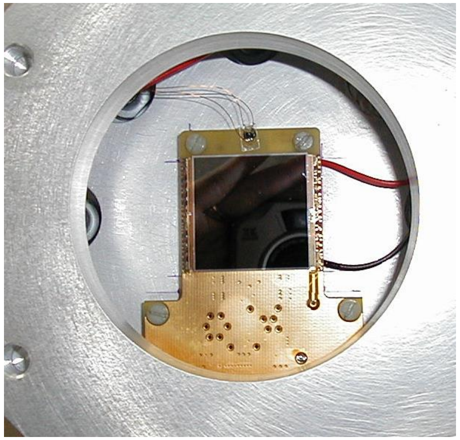
U. Wahl *et al.*, NIMA 524 (2004) 245
U. Wahl *et al.*, PRL 125 (2020) 045301

EC-SLI with Si Timepix quad detectors

- 3x3 cm2, 512x512 pixel (55´55 mm2) detectors developed by Medipix@CERN collaboration (Michael Campbell et al)
- Needs clustering algorithm

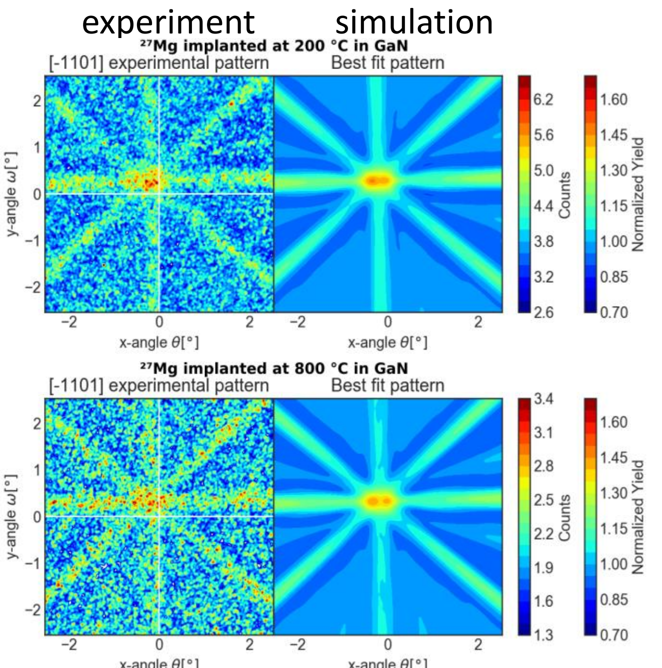
to identify β- tracks





- Tests successful, but frame-based readout of Timepix 2 (e.g. 4 kHz count rate requires 10 frames/s => 50% dead time) proved too slow for EC-SLI routine applications
- Timepix 3 detectors (with faster, data-driven readout in the Mcounts/s range) envisaged to replace the aging pad detectors in the near future

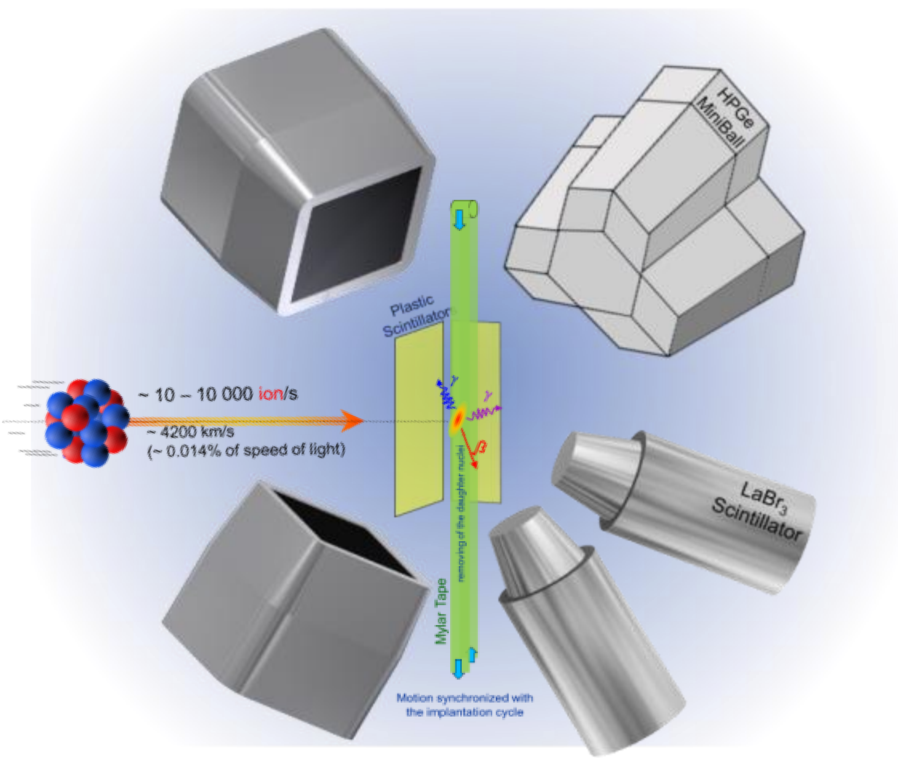
^{27}Mg (9.5 min) *p*-type dopant in GaN (material used in white LEDs)

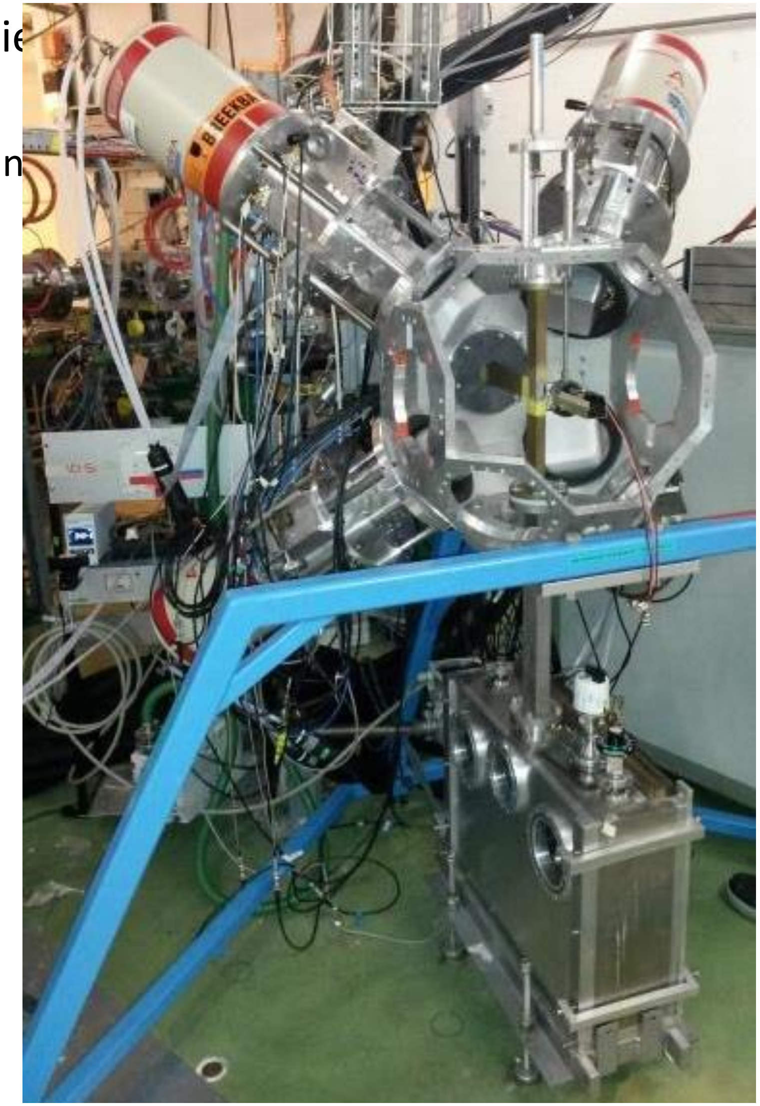


E. Bosne, Emission Channeling Lattice Location Studies in Semiconductors using Highly Pixellated Timepix Detectors, CERN Thesis 2020-239

IDS

- Flexible approach (for several decay types and studie
  - HPGe detectors (4 permanent Clovers + extra)
  - Ancillary detectors (LaBr3, plastic scintillator, silicon, n
  - Tape station
  - In-Source Laser Spectroscopy Studies

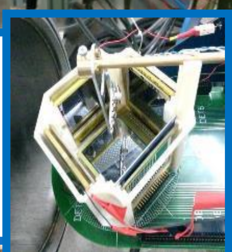




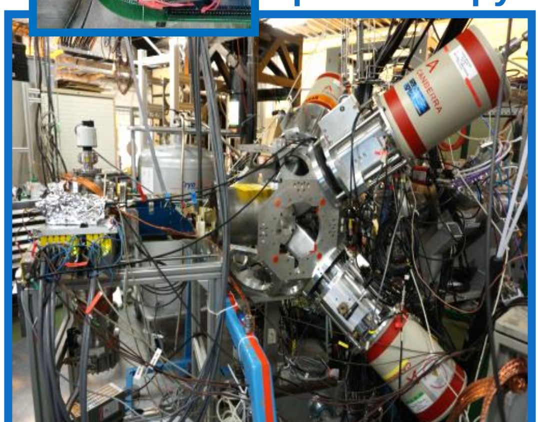
Contact: Razvan LICA, *IFIN-HH, Romania*

IDS

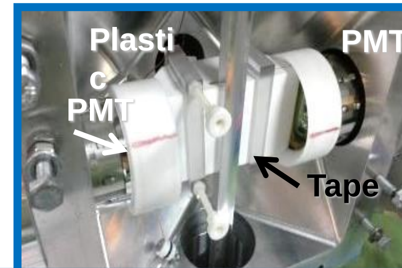
Neutron Spectroscopy

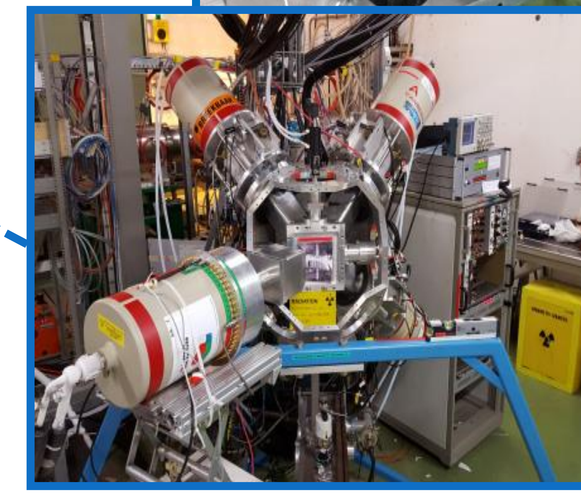


Particle Spectroscopy

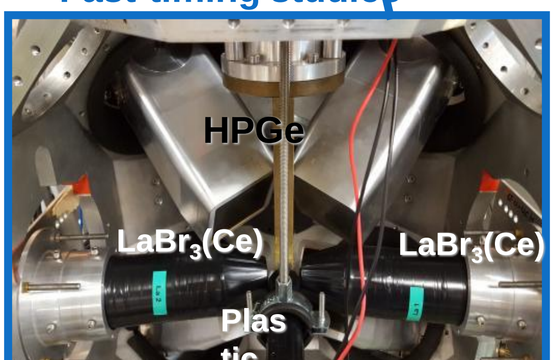


High beta-gamma efficiency

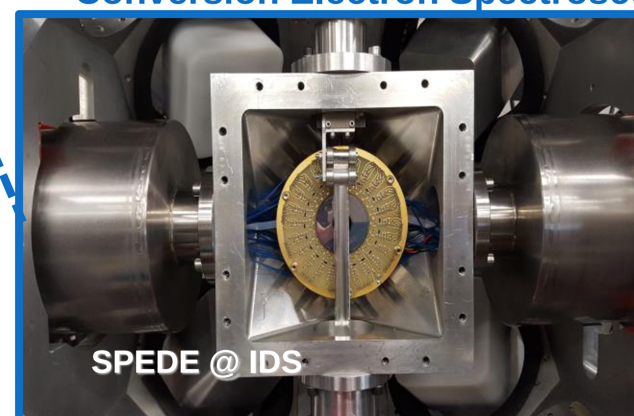




Fast-timing studies

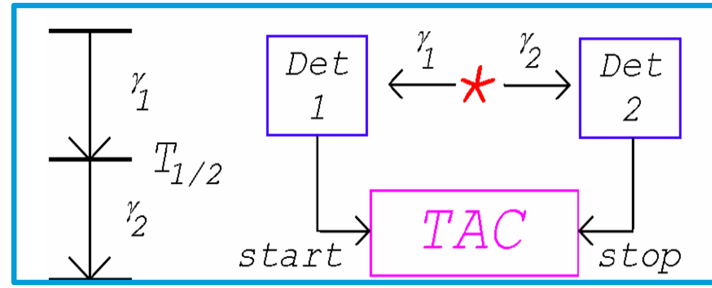


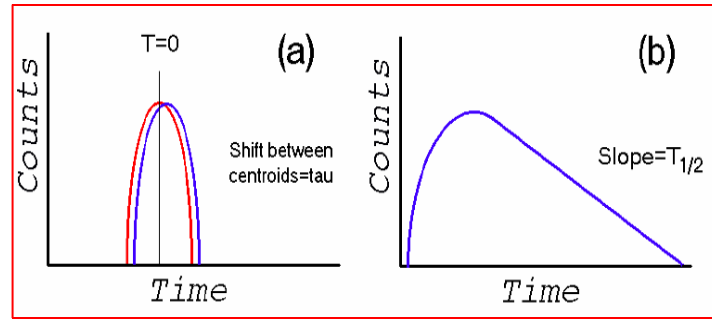
Conversion Electron Spectroscopy

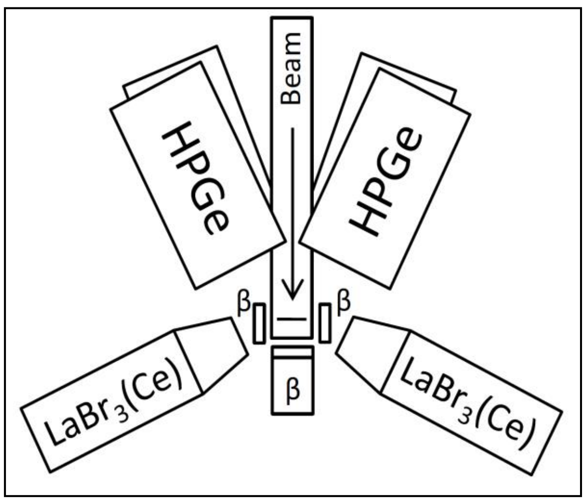


IDS + fast timing

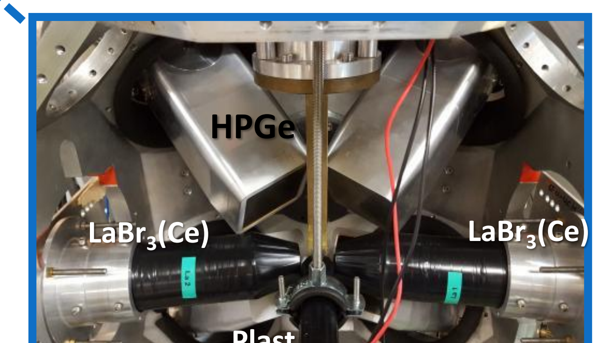
- Well established technique at IDS since 2014
- Detection system:
  - 4 Clover HPGe - 7% abs. eff. at 500keV
  - 2 $LaBr_3(Ce)$ - 3% abs. eff. at 500keV
  - 1 Plastic Scintillator - 20% abs. eff.







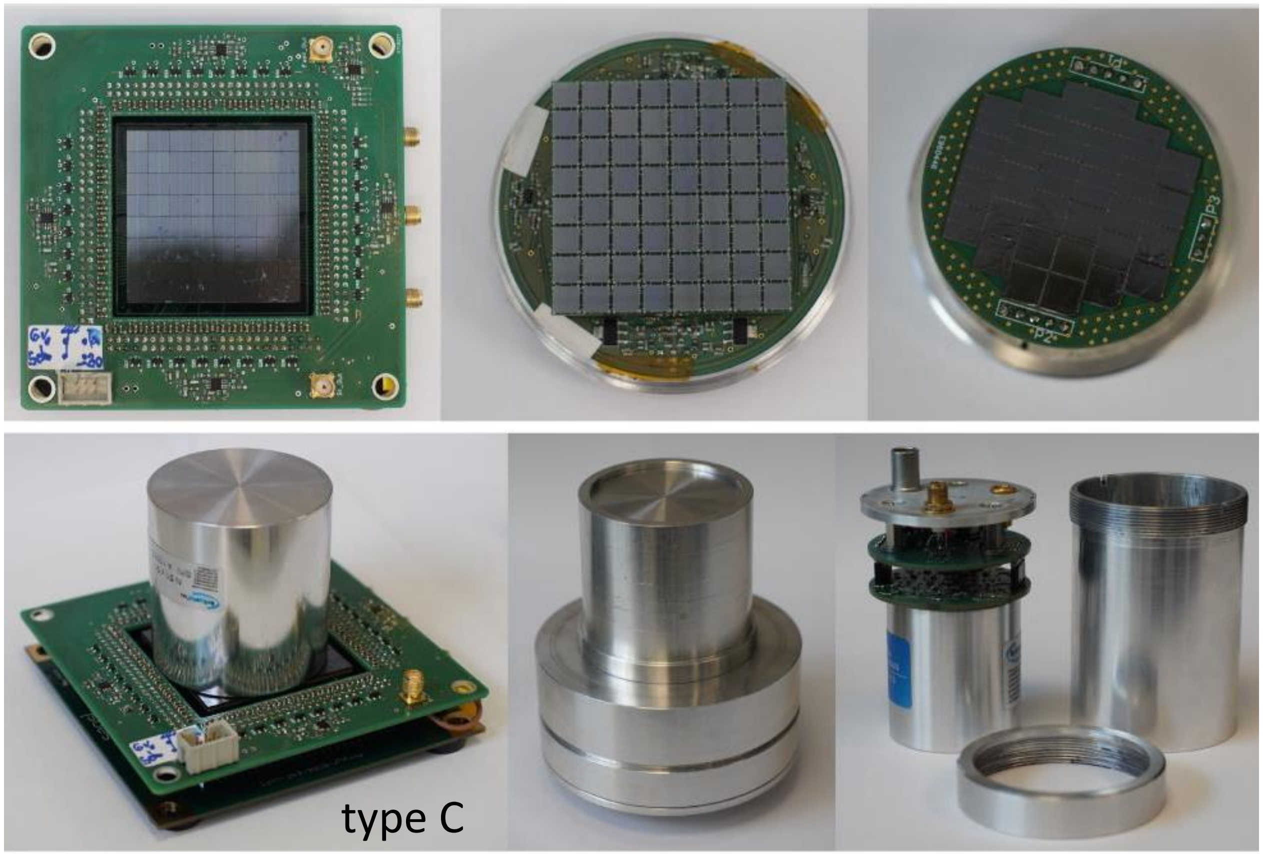
Ranges:
Centroid shift method: - **10 ps - 100 ps**
Slope method - **50 ps - 50 ns** (or longer)
[H. Mach et al. NIM A 280, 49 (1989)]



R. Lica et al., Phys. Rev. C 93, 044303 (2016).
R. Lica et al., J. Phys. G 44, 054002 (2017).
L.M. Fraile, J. Phys. G 44, 094004 (2017).
R. Lica et al., Phys. Rev. C 97, 024305 (2018).

IDS + fast timing

SiPMs developed in-house at IFIN-HH coupled to LaBr3(Ce)



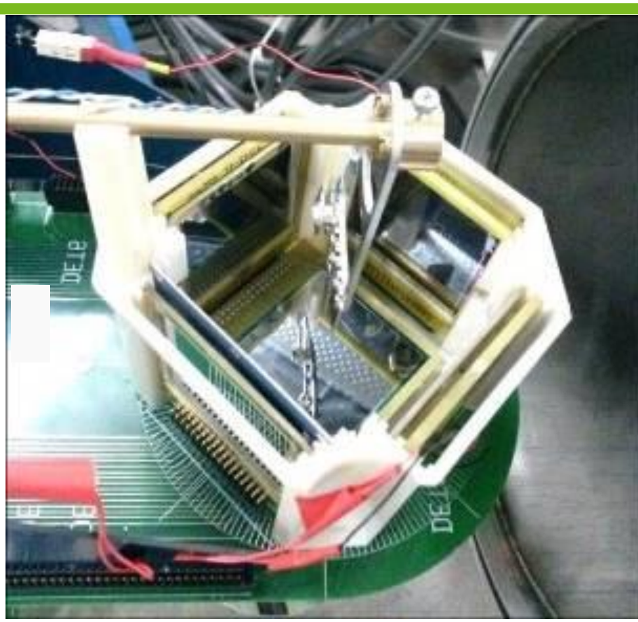
3” crystals with SiPM

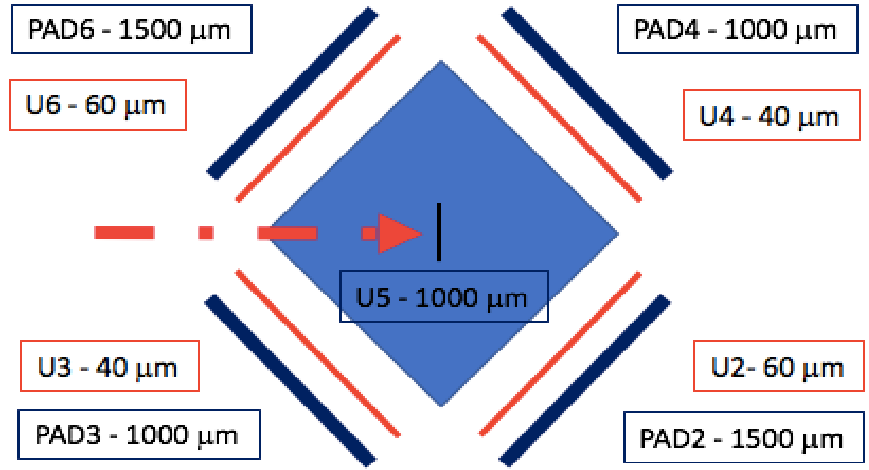
New plastic scintillators

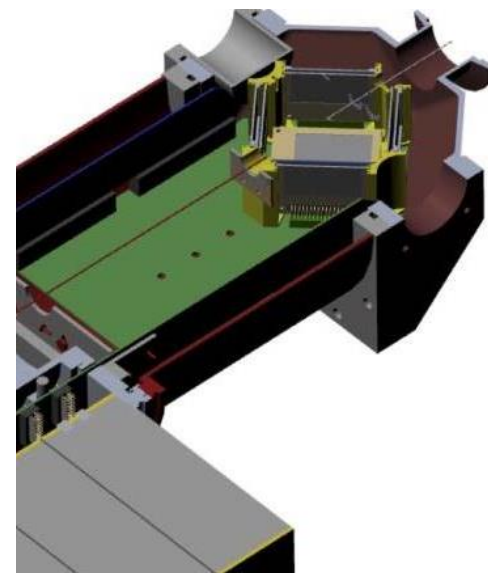
Contact: R. Lica, IFIN-HH, Romania, L. Fraile, Madrid

IDS particle detection

MAGISOL







- 4 HPGe Clover-shape detectors at forward angles
  + Si box: 5 Double-Sided Si Strip Detectors (DSSSD), 4 Pads
- **DAQ: ISOLDE MBS** and IDS Nutaq use in parallel (synchronized)
- Beam implanted on ^{12}C foil or tape

MAGISOL detectors, electronics and DAQ:

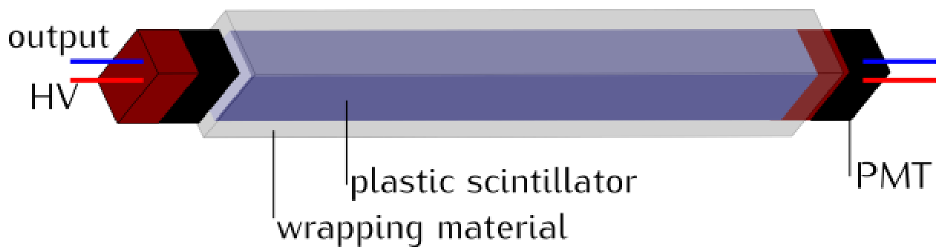
- 165 ch: **Mesytec** preamplifiers (2xMPR64, 2xMPR32)
- Mesytec STM16+ shapers

Contact: H. Fynbo, K. Riisager, U Copenhagen

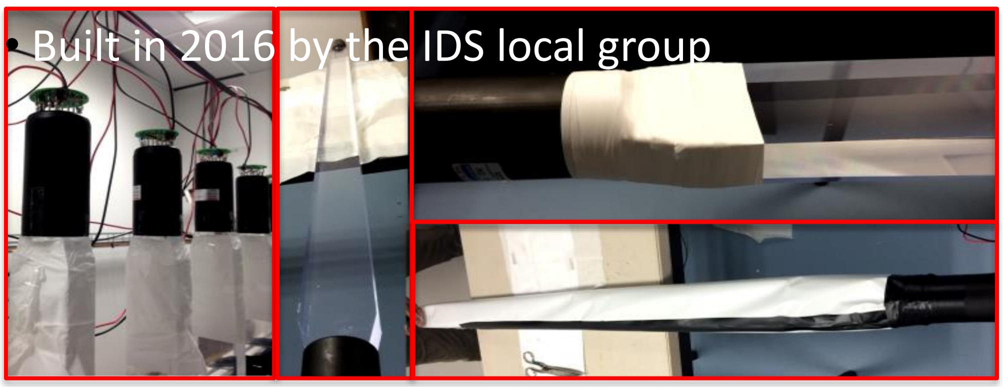
H. Fynbo, O. Tengblad, O. Kirsebom, J. Phys. G 44 (2017), 044005
O. Kisebom et al., Phys. Rev. Lett. 121, 142701 (2018)

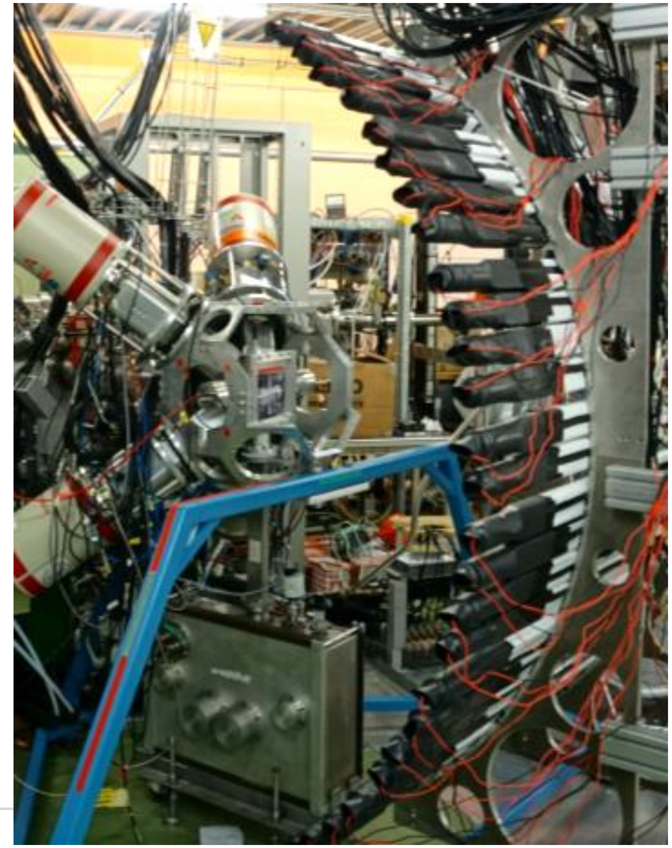
Neutron spectroscopy (INDiE)

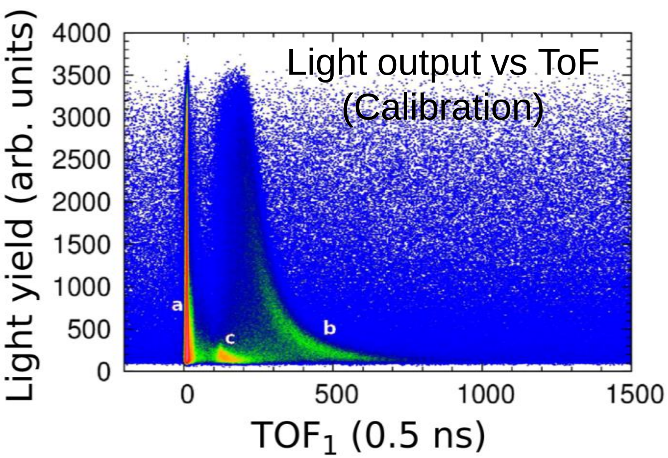
- TOF detector, inspired by VANDLE detector (UTK, USA)

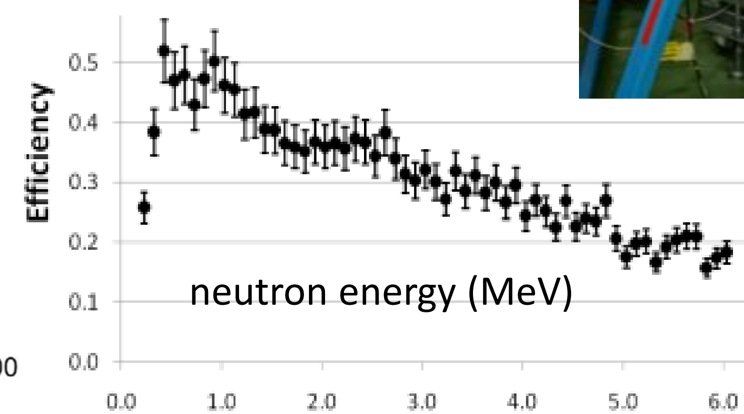


- Built in 2016 by the IDS local group









neutrons @ 1 MeV:

- 45% efficiency/bar
- 80 keV resolution
- Ω = 21.7% of 4π
- 90% β-trigger efficiency
  → 9 % total efficiency

Contact: M. Madurga, U Tennessee - Knoxville

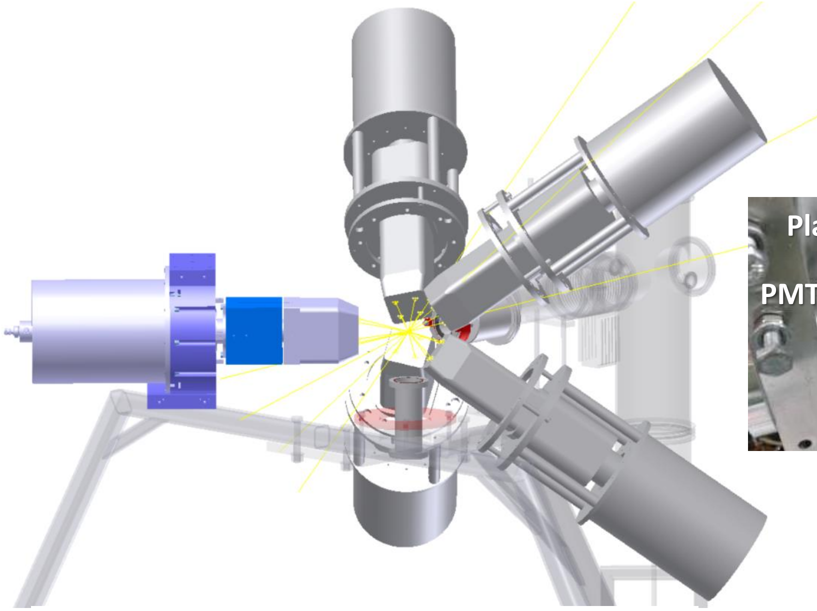
IDS high beta-gamma efficiency

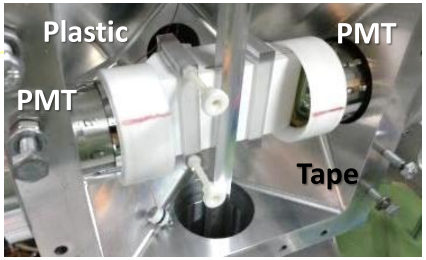
Detection setup

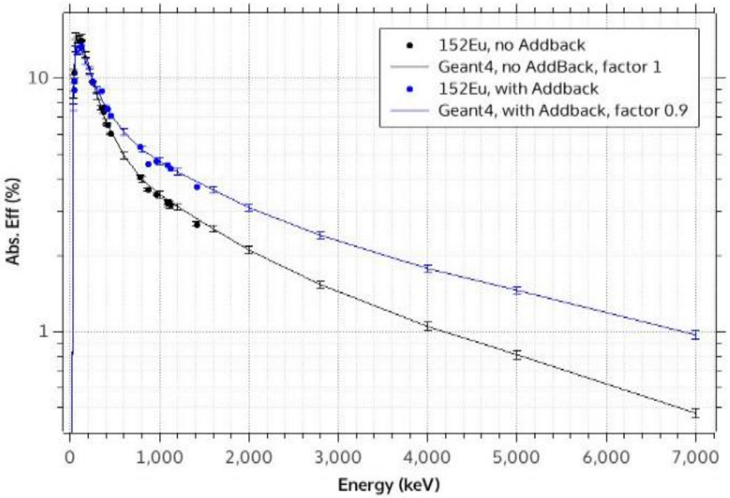
- 5 Clover-shape Ge detectors
- 4π plastic scintillator around implantation point
- 5th Clover detector can be placed at a specific angle to perform **angular correlation studies**.

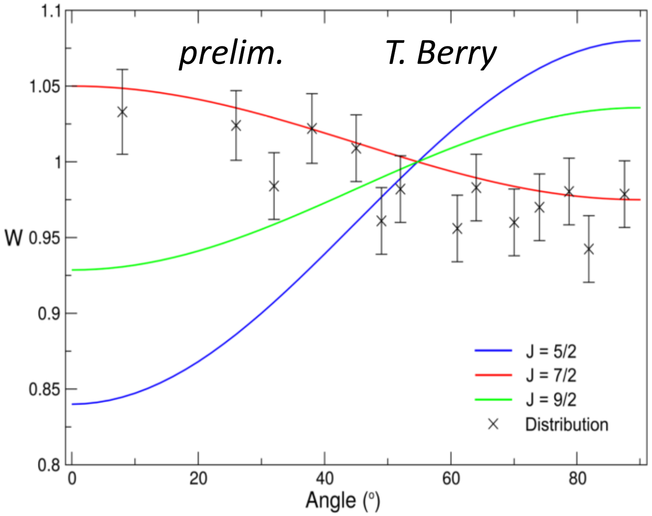
- **Absolute β efficiency - 90(5) %** (single/beta gated ratios)

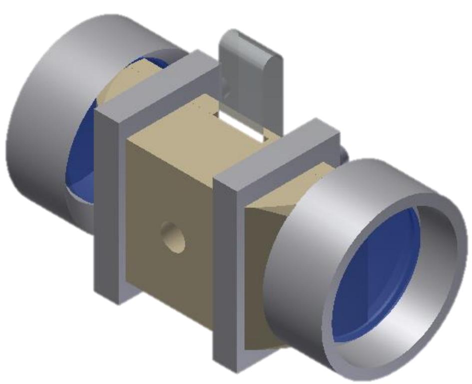
- **Absolute γ efficiency - 4% @1MeV**
Using GEANT4 to extrapolate







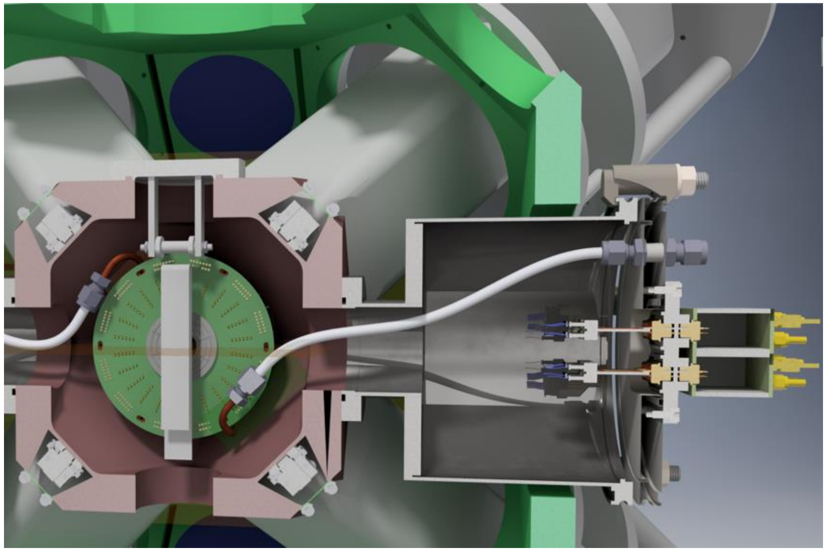




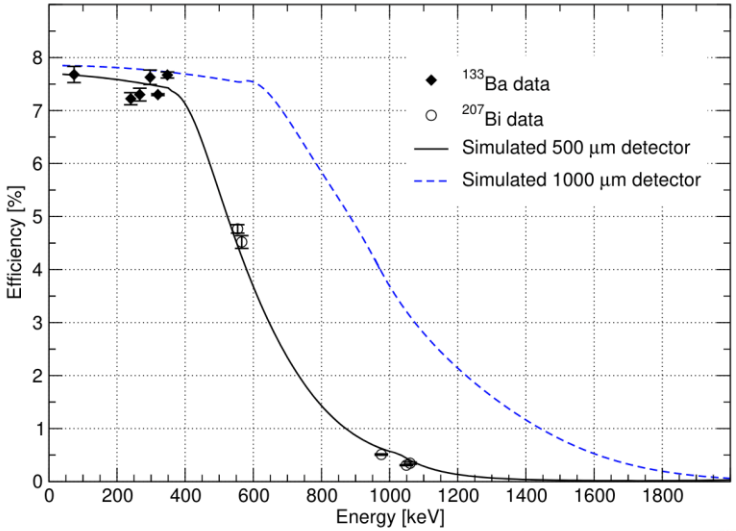
Contact: R. Lica

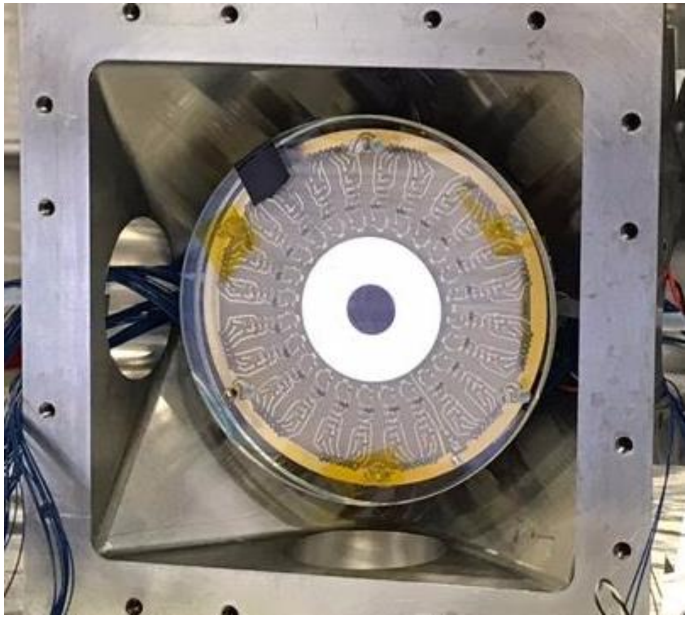
R. Lica et al., Phys. Rev. C 100, 034306 (2019)

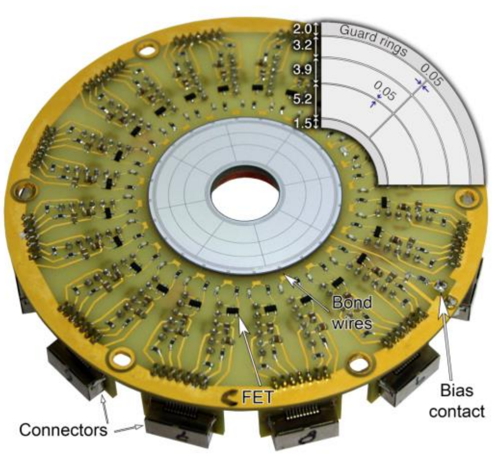
Conversion electron spectroscopy

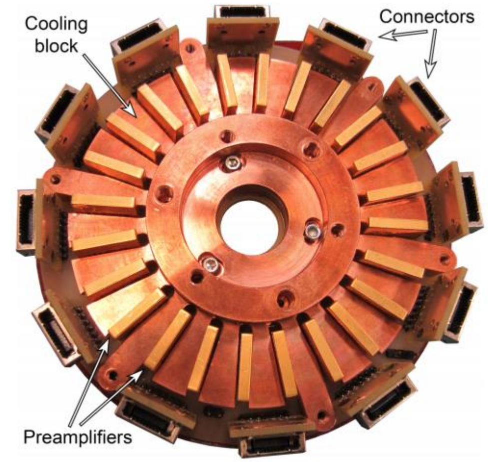


- Annular Si detector with 24 segments
- Ethanol cooled to -20°C
- FWHM at 320 keV around 6-8 keV energy









Contact: J. Pakarinen, Jyvaskyla

P. Papadakis et al., Eur. Phys. J. A. 54:42, 2018

IDS DAQ

Digital DAQ able to run all the different configurations

IDS Configuration	Detectors	Total Channels	OLD DAQ
Particle spectroscopy	4 Clovers + 5 DSSSDs (5 x 32 ch) + 4 PAD (4 x 2 ch) + Logic (6 ch)	**190**	NUTAQ + MBS
Neutron Spectr. (INDiE)	4 Clovers + 26 bars (26 x 2 ch, **traces**) + Beta (2 ch, **traces**) + Logic	**76**	PIXIE
Conversion Electron Spectroscopy	5 Clovers + SPEDE (24 ch) + Beta (1 ch) + Logic	**51**	NUTAQ
High beta-gamma efficiency	5-6 Clovers + Beta (2 ch) + Logic	**32**	NUTAQ
Fast-timing	4 Clovers (4 x 4 ch) + 2 LaBr + Beta (1 ch) + 3 TAC + Logic	**28**	NUTAQ

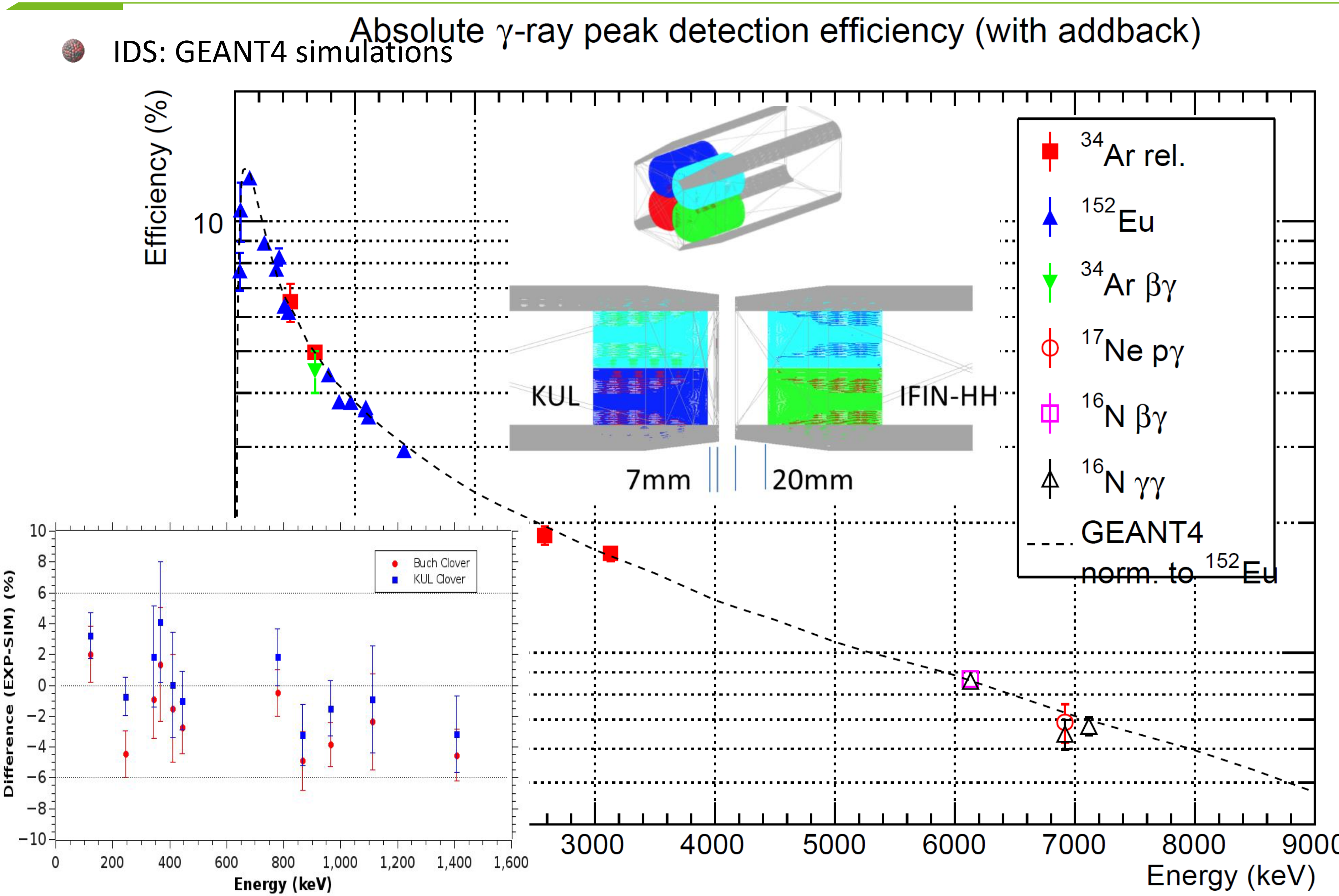
NUTAQ: 100 MHz, 14 bit ADC, **max. 80 ch (5 x 16)**

PIXIE: 250 MHz, 16 bit ADC, **max. 208 ch (13 x 16 / crate) ->** tested and installed in 2020

FEBEX: 100 MHz, 14 bit ADC, 16 ch / module. (v4)

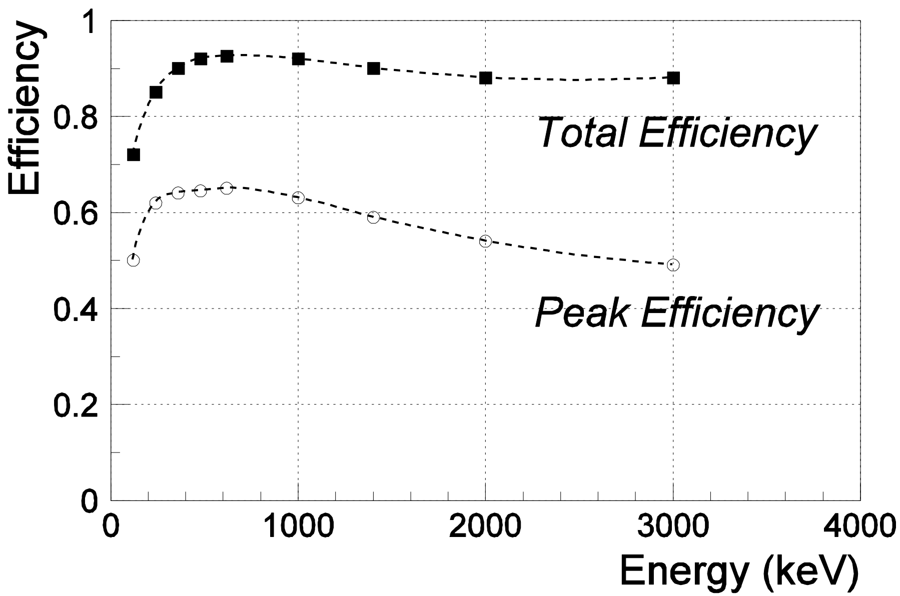
High-purity germanium gamma detectors

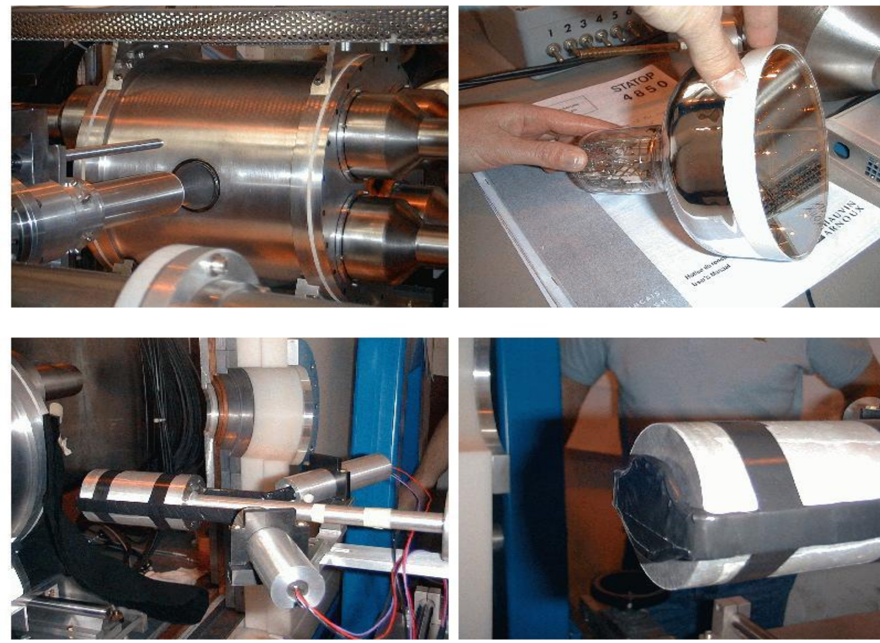
- IDS: GEANT4 simulations



LUCRECIA

- Permanent TAS setup at “Lucrecia”





- Main crystal: NaI(Tl) cilinder of big dimensions (∅38 cm x 38 cm);

- Ancillary detectors:
  - plastic scintillator
  - Ge telescope (planar/coaxial)

Summary and oulook

- Number and versatility of ISOLDE detectors matches that of the unstable nuclei it produces
- This talk: examples of detectors for gamma-rays, charged particles, neutrons
- Not covered in this talk: ion and atom detectors
- Aim: give an overview of ISOLDE detectors and trigger discussions, collaborations with the respective groups