# Landscape of European Facilities Delivering Protons and Heavy Ions:

## Status and Perspectives

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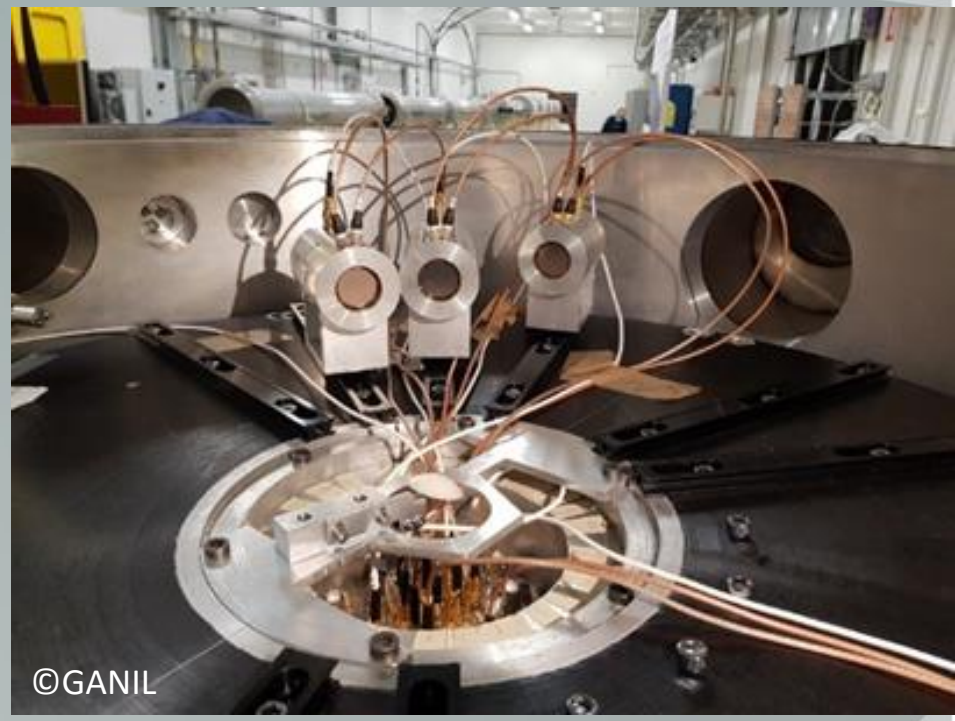
# Facilities for Single Event Effect (SEE) testing

**Motivation for this talk**

Feedback of the users:

- Not easy to choose the right facility
- Availability for beamtime is key

- Irradiation Facilities from RADNEXT and More
- High level overview
- Navigation through the Zoo
- Giving guidelines for selection
- Recent updates and future perspectives



# Proton facilities

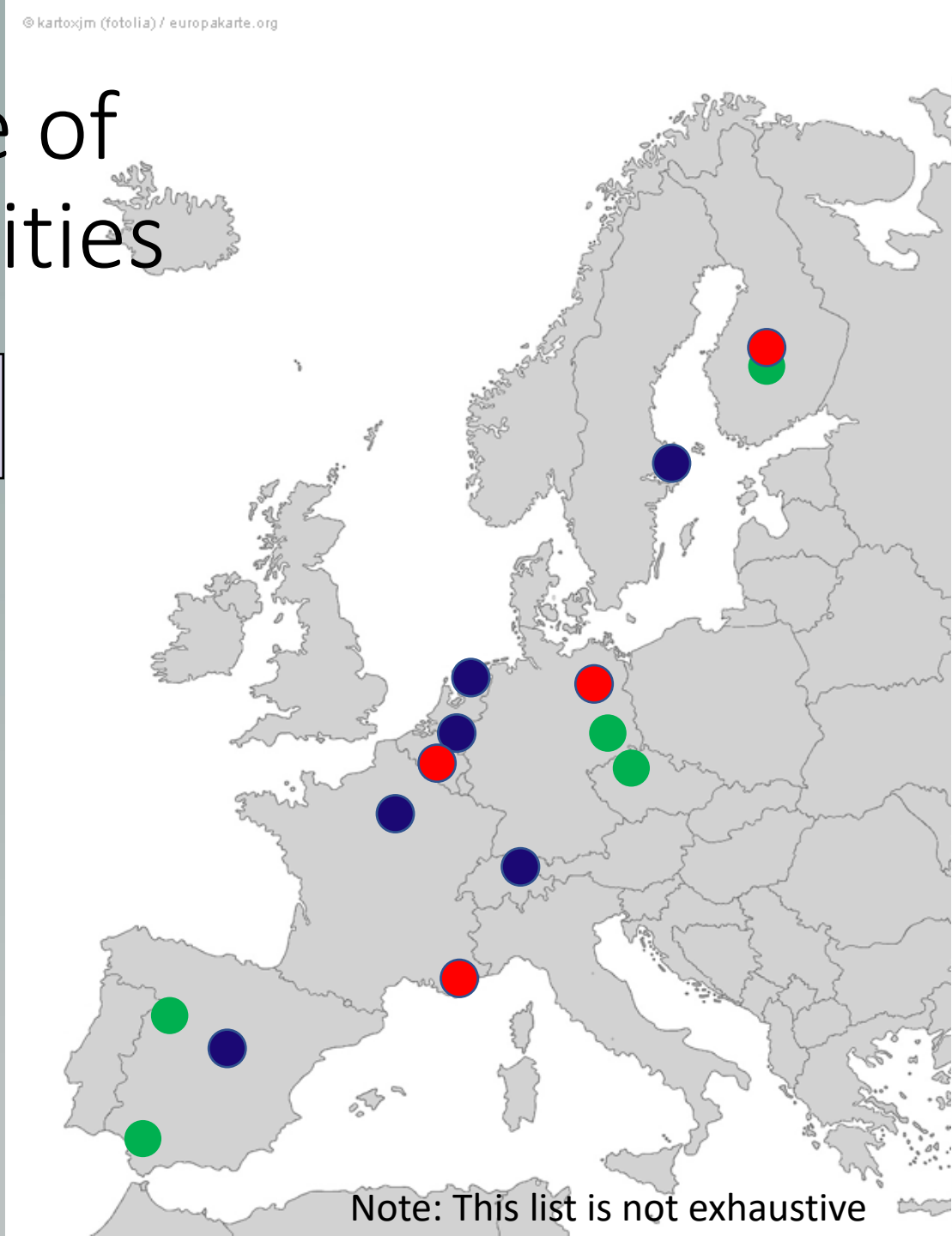
# Landscape of Proton facilities

- There are 3 Energy regimes
  - high (up to 200 MeV) SEE
  - Energies around 20-70 MeV (also for DD)
  - Energies < 20 MeV (e.g. direct ionization)

Talk: Stefan Höffgen

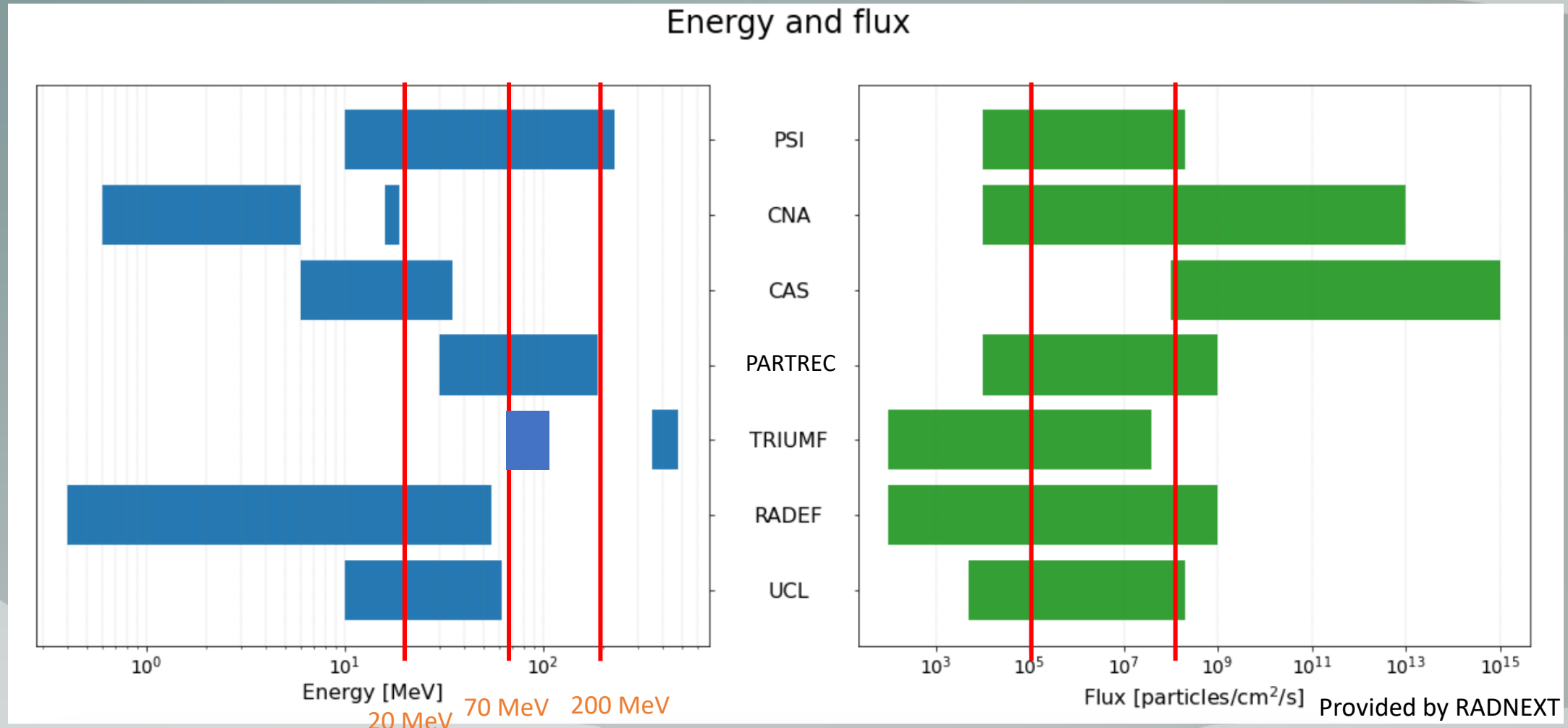
Applications

- Space
- Ground-level (e.g. accelerator application, automotive, green energy, data centers…)




Note: This list is not exhaustive

# RADNEXT Proton Facilities




Provided by RADNEXT

# Energies up to 200 MeV

RADNEXT:

- PSI, Switzerland 10 - 230 MeV (PT facility)
- PARTREC, The Netherlands 30 - 190 MeV (research facility)
- Holland PTC, The Netherlands (PT facility)

Talk:
Marta Rovituso

**Proton Therapy facilities in Europe:**

- Over 30 in operation for cancer treatment
- Energies 70 to 230 MeV
- Similar technical beam parameters (flux, beam size, field size, …)
- Not all open to radiation effect users
- Some consider to offer RHT beamtime service
  - CPO, Orsay, France
  - Quironsalud, Madrid, Spain
  - Skandionkliniken, Upsala, Sweden

# Mid and Low Energy

Mid energy (few tens of MeV)

- UCL, Belgium: 10 – 62 MeV (up to 1x$10^9$ p/$cm^2$/s)
- RADEF, Finland: 10 – 55 MeV (up to 3x$10^8$ p/$cm^2$/s)
- Nice, France: 20 – 59 MeV (up to 1x$10^9$ p/$cm^2$/s)
- HZB, Germany: 68 MeV
- NPI-CAS, Czech Republic: 6 – 35 MeV

Low energy (< 20 MeV) and alternative probes

- RADEF: 0.4 – 8 MeV (mono-energetic)
- CAN, Spain: 0,6 – 6 MeV & 18 MeV (mono-energetic)
- HZDR, DRACO, Germany: laser pulsed proton spectrum up to 100 MeV
- CLPU VEGA, Spain: laser plasma accelerated protons

# Selection of facility

- Energy regime
- Facility type
  - PT center
  - Research facility
- Change of energy
  - Energy distribution
  - Time to change
- Flux

Pre-selection of accelerator

- Access modalities
- Working hours: ”patient first”
- Parasitic use (potentially)

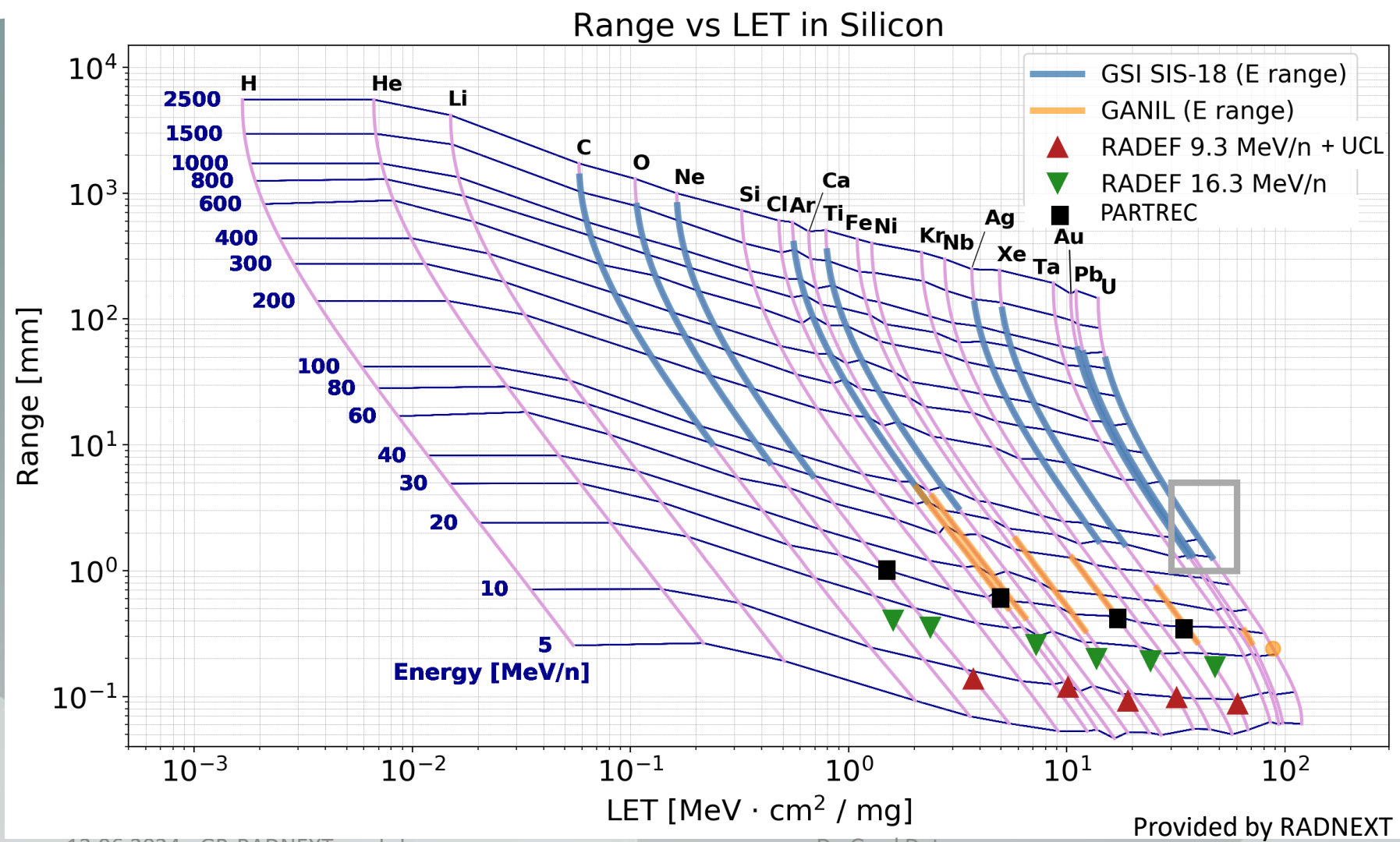
- At cyclotron level (Partrec)
- Degrader
  - near target → Increased energy spread
  - near accelerator (PT) → Flux reduction (up to factor 100)

Time to change energy:
1 s to 1 min

Duration of measurements

# Heavy Ion Facilities

# Heavy ion facility overview




Users want
- different LET
- enough penetration/range

Accelerator physicists
- Ion species
- Energy / nucleon

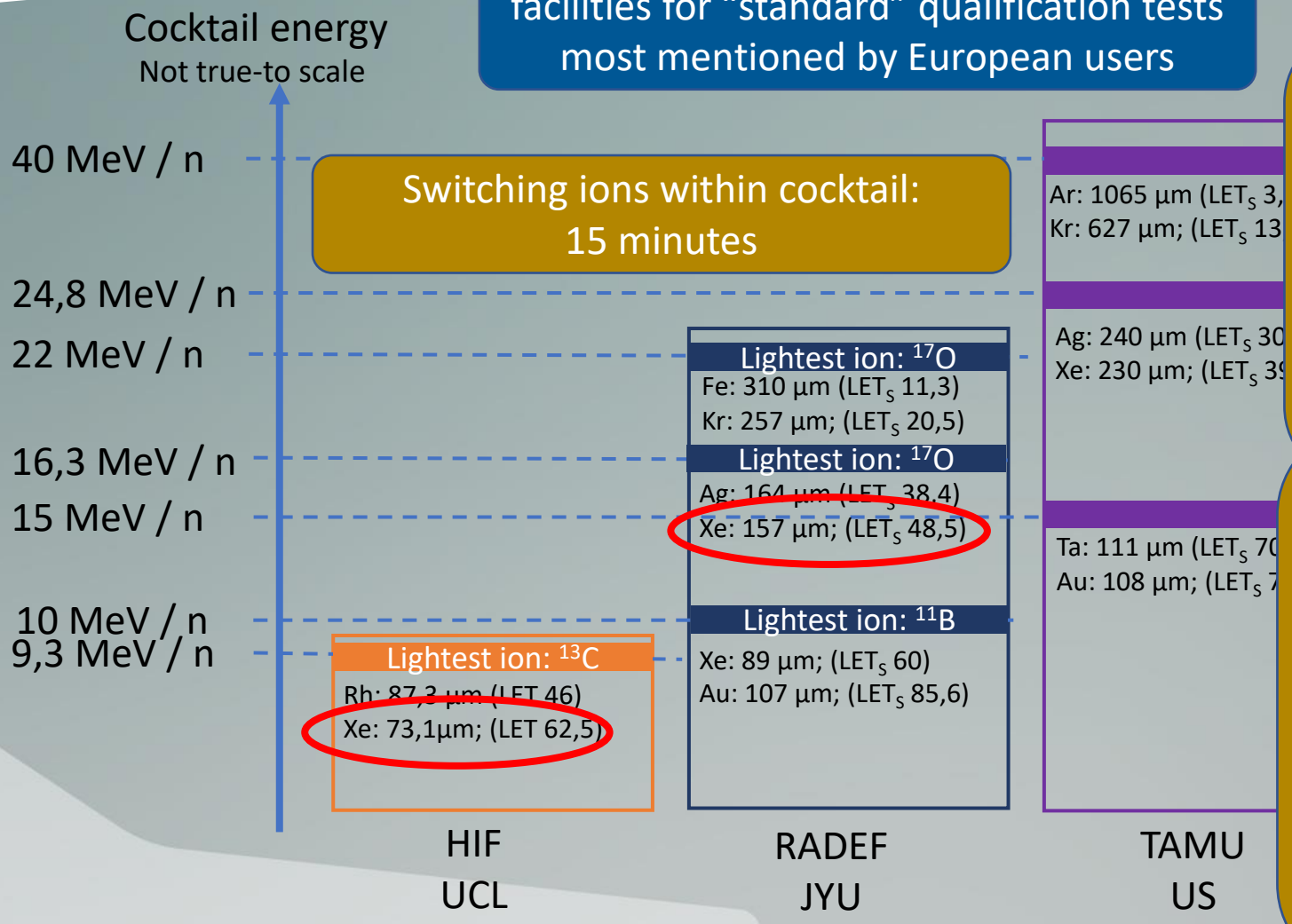
In general acceleration of 1 ion at 1 energy

Cocktail vs single ion

Time to change ion/energy

# Facilities with cocktails

facilities for “standard” qualification tests most mentioned by European users




UCL upgrades in future:
New Target chamber available soon

- Larger chamber
- Higher flux
- Larger spot sizes

Upgrade to 15 MeV/n cocktail expected

RADEF:

- “Enriched” 10 MeV/n cocktail: 9 ions up to $^{197}$Au
- Switching time between cocktails reduced: 30-45 min
- Plan to include more ion in 22 MeV/n

- Recommissioning MCC-30 cyclotron; Proton beam expected end of 2024.

-> Free’s beam-time at K-130 cyclotron

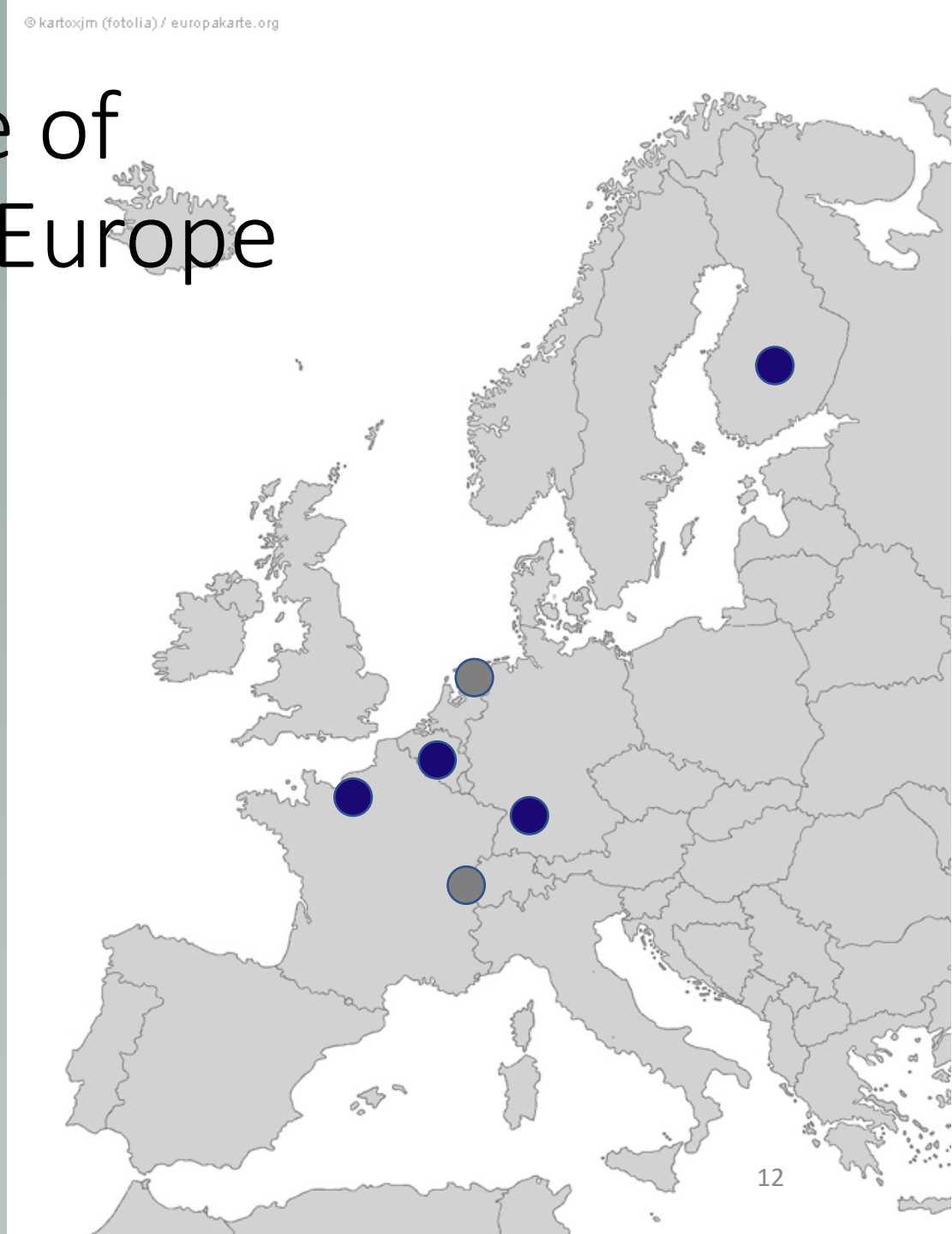
# Landscape of HI facilities in Europe

<u>Facilities with cocktails</u>

- UCL (Belgium)
- RADEF (Finland)
- PARTREC (The Netherlands) ”in preparation”

<u>Facilities with single ions</u>

- GANIL (France)
- GSI (Germany)
- HEARTS at CERN (Switzerland) ”in preparation”



# Higher energy facilities

GANIL (France)

Energy: 50 MeV/n

Ions: Xenon (3 weeks)

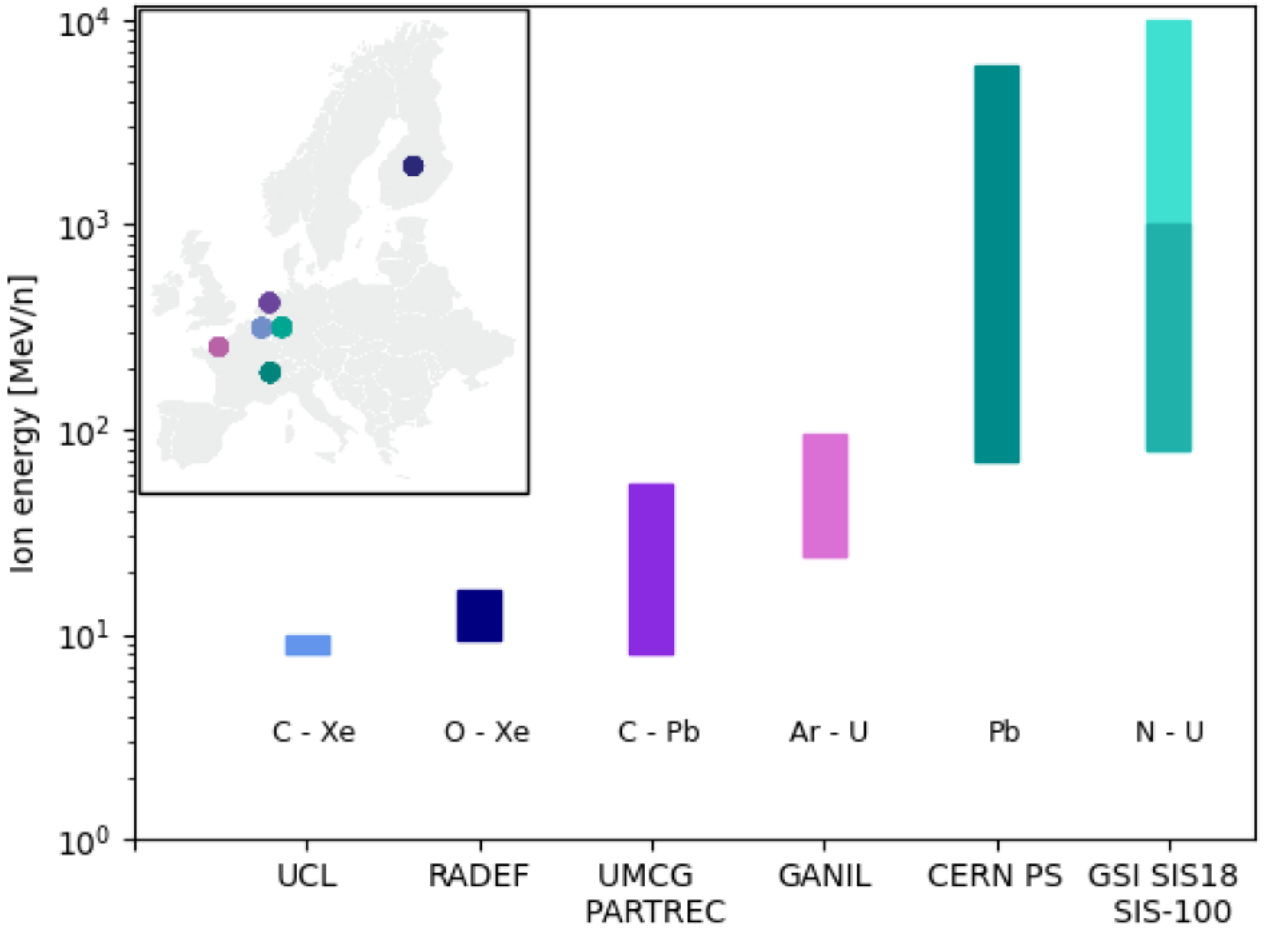
Krypton (1 week)

In 2 – 4 separated blocks

Availability: 400 h (2025 – 26)

Flux: 100 – 10.000 p/cm$^2$/s

New 2025:
Change between Xe and Kr
(within one block)




Heavy-ion facilities available in Europe.
Credit: CERN

# GSI-FAIR

## GSI – SIS 18 (Germany)

Energy: 100 -950 MeV/n

Ions: depends

Extraction: up to $10^7$ /s

Availability: 24 h (2025 – 27)

## GSI – Microprobe (Germany)

Energy: 3,6 - 8,6 MeV/n

Ions: depends

Beam size 1-2 µm

Talk:
Günther Dollinger
Corinna Martinella

Future: FAIR facility (2028)
SIS 100
Energy: 1 – 10 GeV/n
Higher availability

Upgrades 2024:
Introduce user control system

# CHARM / HEARTS / CHIMERA
## What's the difference?

Same experimental area

Talk: Ruben Garcia

### CHARM

- Beam: 24 MeV protons (From PS) on a copper target
- 5.5 GeV Pb
- Radiation: Mixed-Field

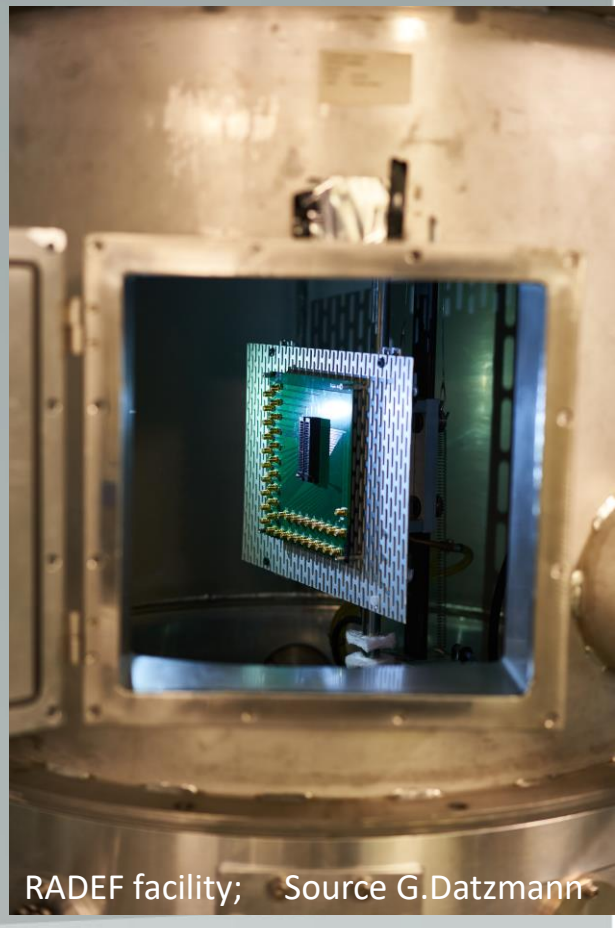
CERN; Source J. Ordan

Talk: Marta Bagatin

### HEARTS at CERN

- Beam: Pb with 100 MeV/n up to 2 GeV/n
- Radiation: Pb beam on target (DUT)
- Range(in Si): 1 mm – 100 mm)
- LET: ~12 – 37 MeV $cm^2$ /mg
- Variable energy (spill by spill)
- First ext. users planned for Oct. 2024

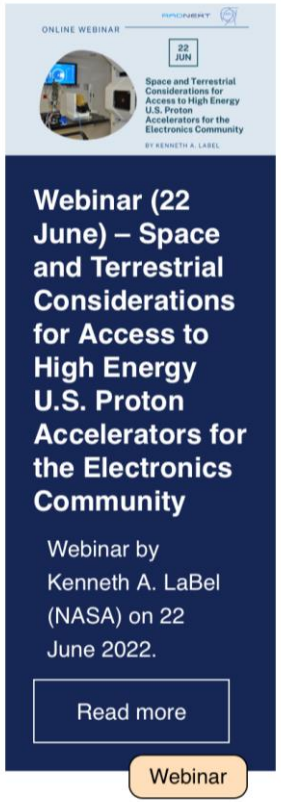
# More facility information



RADEF facility; Source G.Datzmann

# Facility information

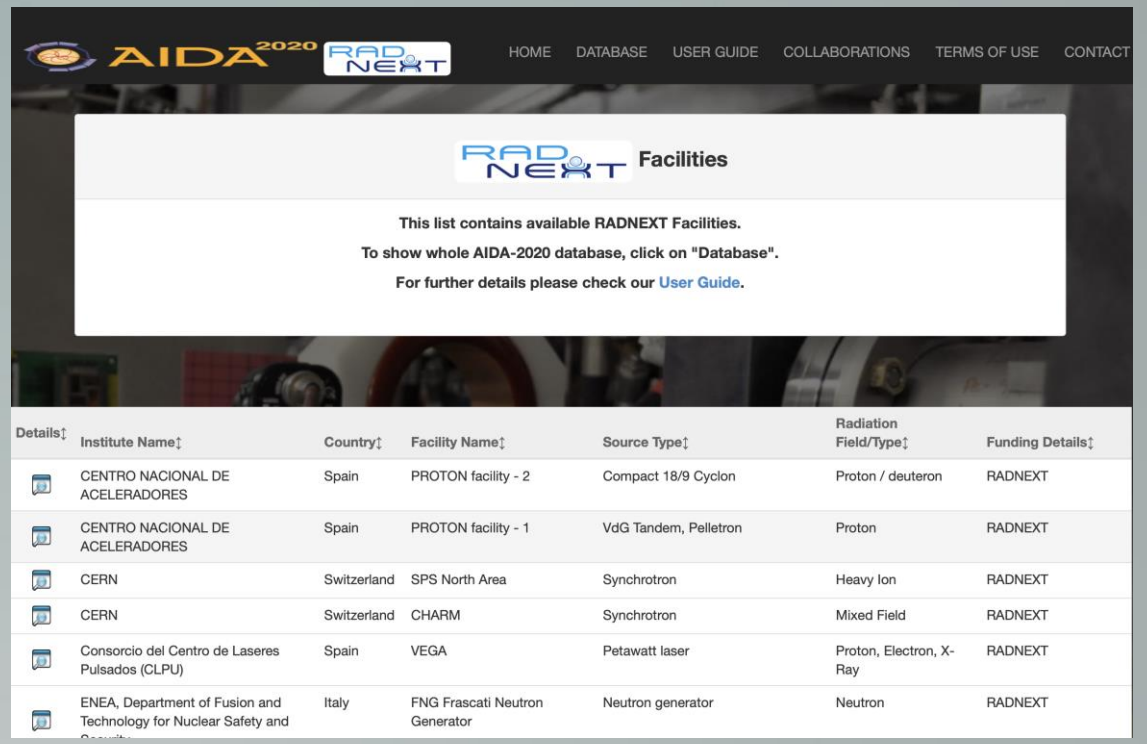
## RADNEXT webinars




On demand at RADNEXT webpage!

## Survey among all 21 RADNEXT facilities

## Technical data in the AIDA database




| Details | Institute Name | Country | Facility Name | Source Type | Radiation Field/Type | Funding Details |
|---|---|---|---|---|---|---|
| | CENTRO NACIONAL DE ACELERADORES | Spain | PROTON facility - 2 | Compact 18/9 Cyclon | Proton / deuteron | RADNEXT |
| | CENTRO NACIONAL DE ACELERADORES | Spain | PROTON facility - 1 | VdG Tandem, Pelletron | Proton | RADNEXT |
| | CERN | Switzerland | SPS North Area | Synchrotron | Heavy Ion | RADNEXT |
| | CERN | Switzerland | CHARM | Synchrotron | Mixed Field | RADNEXT |
| | Consorcio del Centro de Laseres Pulsados (CLPU) | Spain | VEGA | Petawatt laser | Proton, Electron, X-Ray | RADNEXT |
| | ENEA, Department of Fusion and Technology for Nuclear Safety and | Italy | FNG Frascati Neutron Generator | Neutron generator | Neutron | RADNEXT |

https://irradiation-facilities.web.cern.ch/radnext.php

# Facility representatives

Facility representatives at this workshop:

- Protons: CNA, Holland PTC, TRIUMF
- Neutrons: ISIS(ChipIr), ESS, ENEA Frascati, ILL, ANIS
- Alternative: ESRF, CERN, ELI beamlines, HZDR
- Fraunhofer INT, RADTEST

Poster Session

# Current Challenges

Demand for testing is growing

- New Space, ground level, accelerators …
- COTS components

Lack of heavy ions testing

- High penetration of sample
- Board and System level testing

Companies need access and availability

- Quick
- Easy
- Professional service

Not easy to ramp-up beam time capacity at the facilities

RADNEXT has been investigating the needs of the users and the capabilities of the facilities

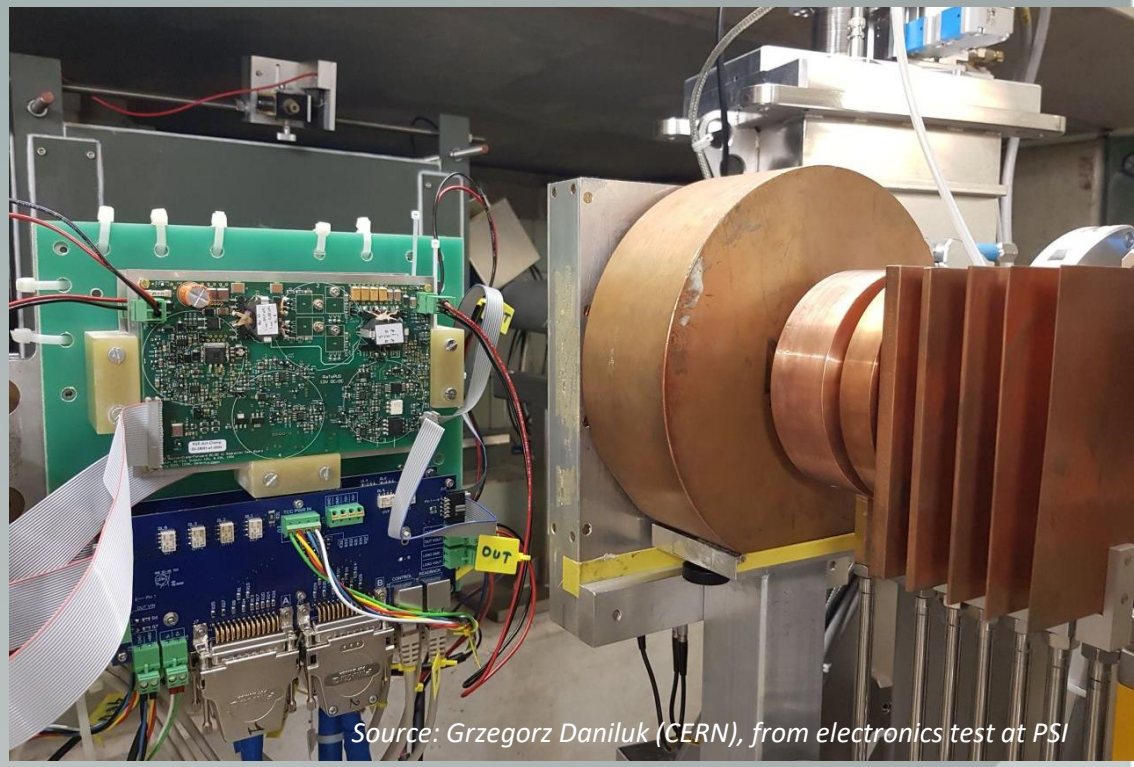
RADNEXT is building a network / community

RADNEXT fosters a discussion forum for bridging the gaps

# RADNEXT Transnational Access

Next call for proposals opens on September 1st

Transnational Access: 1-year extension granted



*Source: Grzegorz Daniluk (CERN), from electronics test at PSI*

# Thanks for your attention

Did I forget a facility?
Please contact me!

If you have questions
concerning irradiation facilities
Please contact me **info@datzmann.eu**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No **101008126**

# Facilities for Single Event Effect (SEE) testing

Why Is there a lack of beamtime?

- User demand is a free market
- Service provision is not “free market”
  - Irradiation facilities are publicly funded
  - Particle accelerators are expensive to
    - Build
    - Operate
    - Maintain
  - No business plan
  - Policy to dedicate beamtime for ext. users

RADNEXT goal:
Foster creation of availability for beam time

# CHARM / HEARTS / CHIMERA
## What's the difference?

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### CHARM

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- Beam: Pb with 100 MeV/n up to 2 GeV/n
- Radiation: Pb beam on target (DUT)
- Range(in Si): 1 mm – 100 mm)
- LET: ~10 – 40 MeV cm$^2$ /mg
- Variable energy (spill by spill)
- Lighter ions planned
- Access:
  - 1 beam time block (2-3 weeks) per year
  - Open to users from science and industry
- Commissioning
  - 2-week beam development and characterization in Oct 2024
- First ext. users planned for Oct. 2024

<u>GSI-FAIR:</u>

- Establish harmonization between CERN and GSI

# Demand for higher penetration

**Concreteness of statement**

A look into the future

Demand will grow, because any time you want to test a memory SDRAM you have to go from the backside. It can go up to 50 %

Could be turning to 20 – 30% in 5 years

Something like 10 - 20 % of the future needs for heavy ion testing will require significantly higher energies

in 5 years, something like 30 to 40 % will require deeper and more energetic beam in order to solve the issues. It could be 50%.

Maybe we would not consume as many hours as for lower energies

Its hard to say. Upgrading the facility, that would provide a competitive edge to European products on the international market

Situation will be worse. This is something which is absolutely sure

It is really hard to predict

No statement

difficult to make a guess

**Demand for high penetration testing**

# Is there a sweet spot for penetration?
## First results from the survey

*The RWG expressed the wish to have access to a European facility that would use a combination of ion, light to heavy species, covering LET values up to at least 38 MeV cm²/mg in Silicon at the device sensitive volume.*
*And with penetration range of at least 1 mm.*

300 µm. And this is from my point of view where we have to go

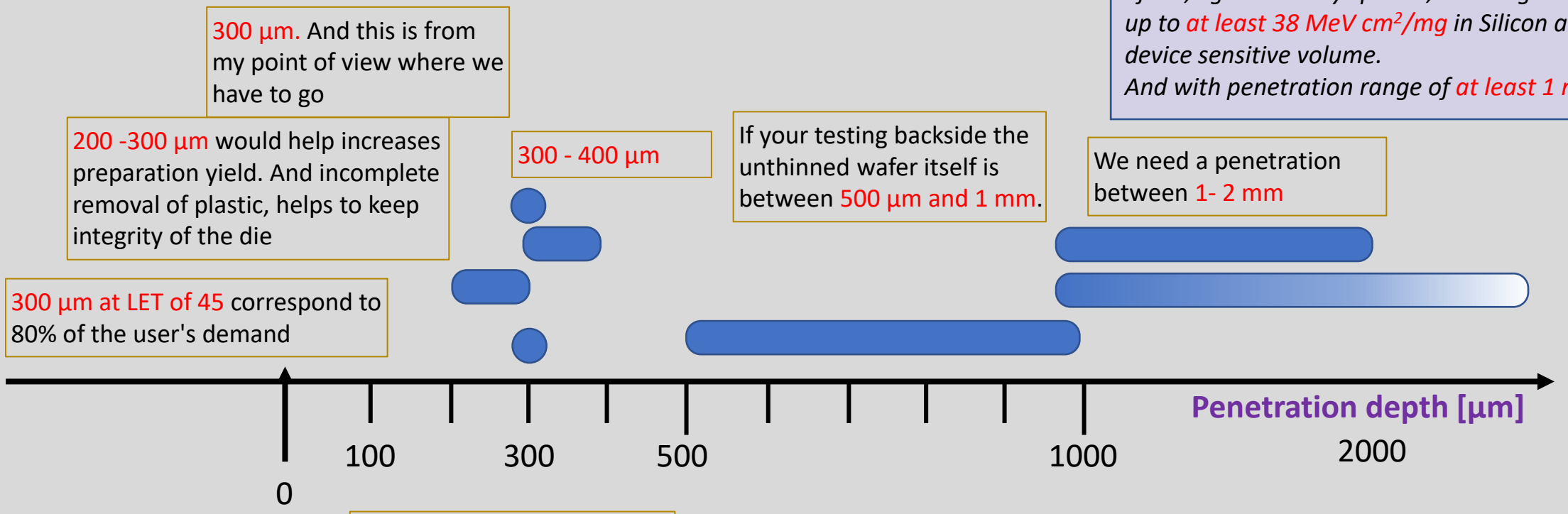
200 -300 µm would help increases preparation yield. And incomplete removal of plastic, helps to keep integrity of the die

300 - 400 µm

If your testing backside the unthinned wafer itself is between 500 µm and 1 mm.

We need a penetration between 1- 2 mm

300 µm at LET of 45 correspond to 80% of the user's demand




I think we do not need to go beyond TAMU.

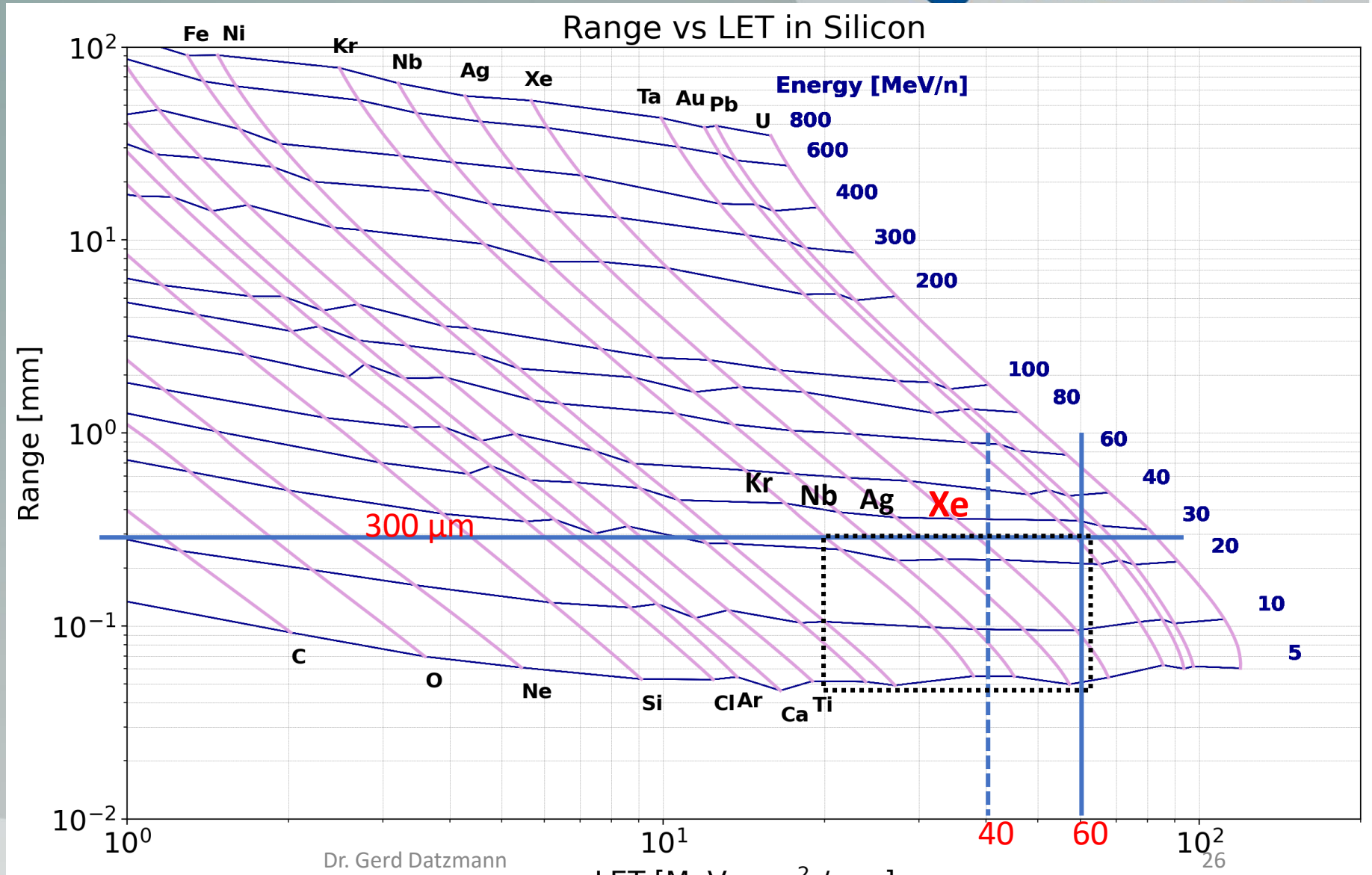
Study with a broad base of heavy ion users
specifying ~100 devices of interest
Evaluating the required penetration depth

# Example: Penetration 300µm

drastic drop in GCR flux

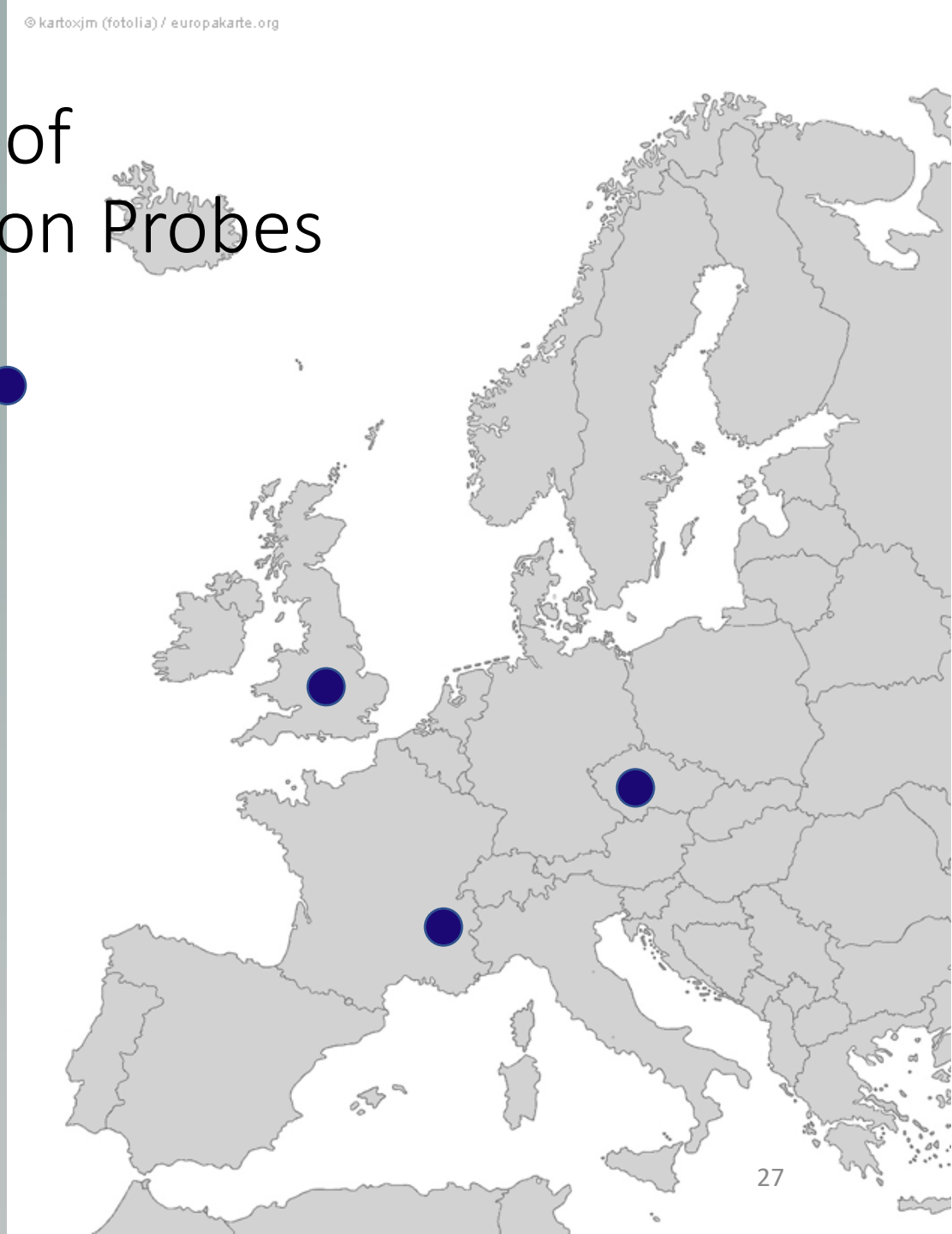
Fe: LET 38 MeV cm$^2$ /mg

Many companies test at least up to LET of 38




Source: Giuseppe Lerner

# Landscape of Alternative Radiation Probes




Muons

- TRIUMF (Canada)?? When I remember it Mr. Hashimoto did not measure at Triumf, right?

Laser Plasma Accelerated Ions

- ELI Beams (Czech Republic)

Synchrotron X-rays

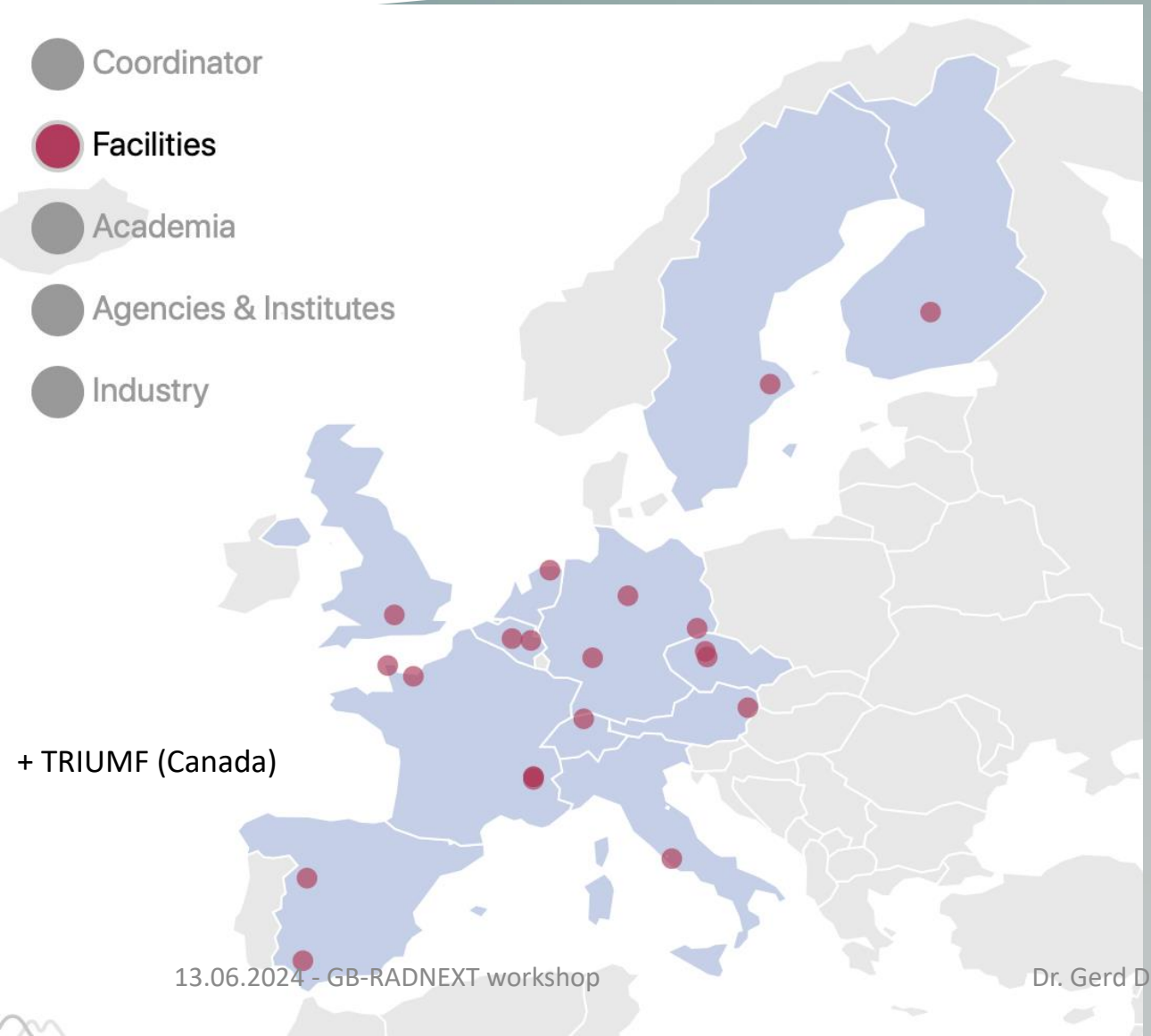
- ESRF (France)

Pulsed LASER (focused)

- RADTEST (UK)

# Backup

# RADNEXT facilities




+ TRIUMF (Canada)

**TRANSNATIONAL ACCESS**
**Creating availability**

- More than 6000 beam time hours are awarded (in 2021-2025) via a competitive **proposal process**
- **Quarterly calls** for proposals (evaluated by experts)
- **Free of cost** to users (funded by EU)
- Both **academic and industrial** groups are eligible
- Types of beams:
  proton, heavy ion, neutron,
  **mixed-field, synchrotron X-rays, electron, photon, laser-driven beams**

# Demand for higher penetration heavy ions Today

"We need penetration 1 -2 mm"

Summary:

- Not everybody has the same demand
- 4 out of 9 interviewees have an urgent need
- 5 say it is "nice to have" or only in special cases
- 7 out of 9 consider flip chip tests as a challenge

"At the moment we always manage to perform satisfying test, just opening the packages"

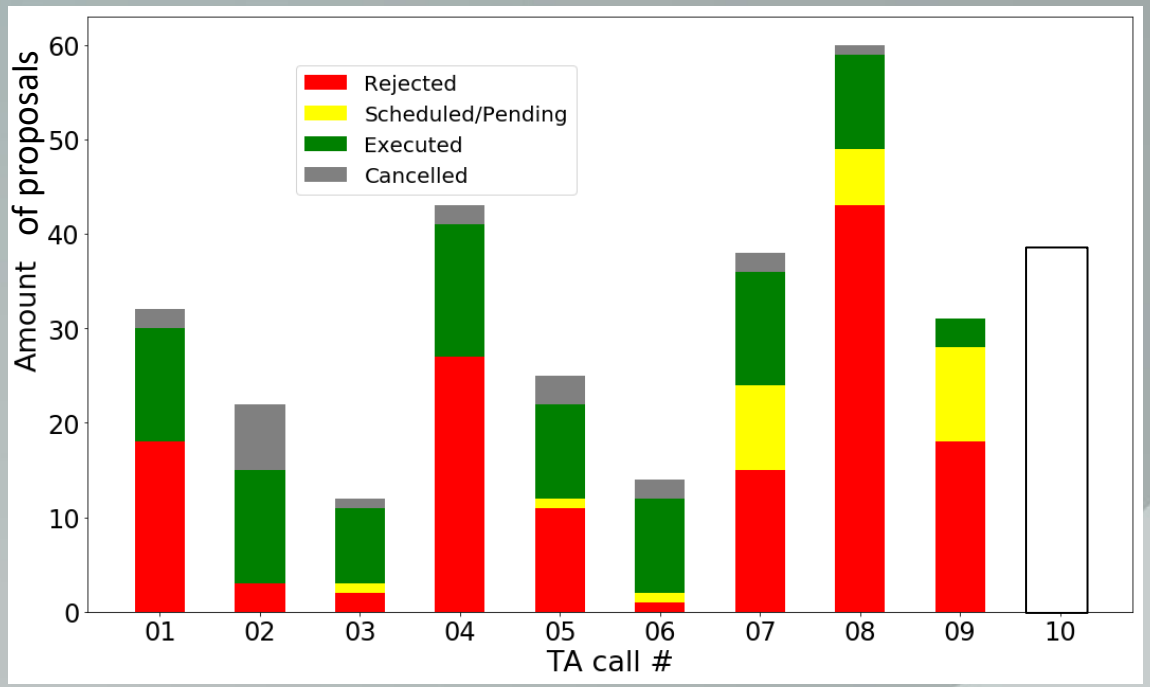
# Statistics and Results

Status Feb. 2024

- Total number of submissions: 315 (in 10 calls)
- Total number of accepted: 164 (52%)

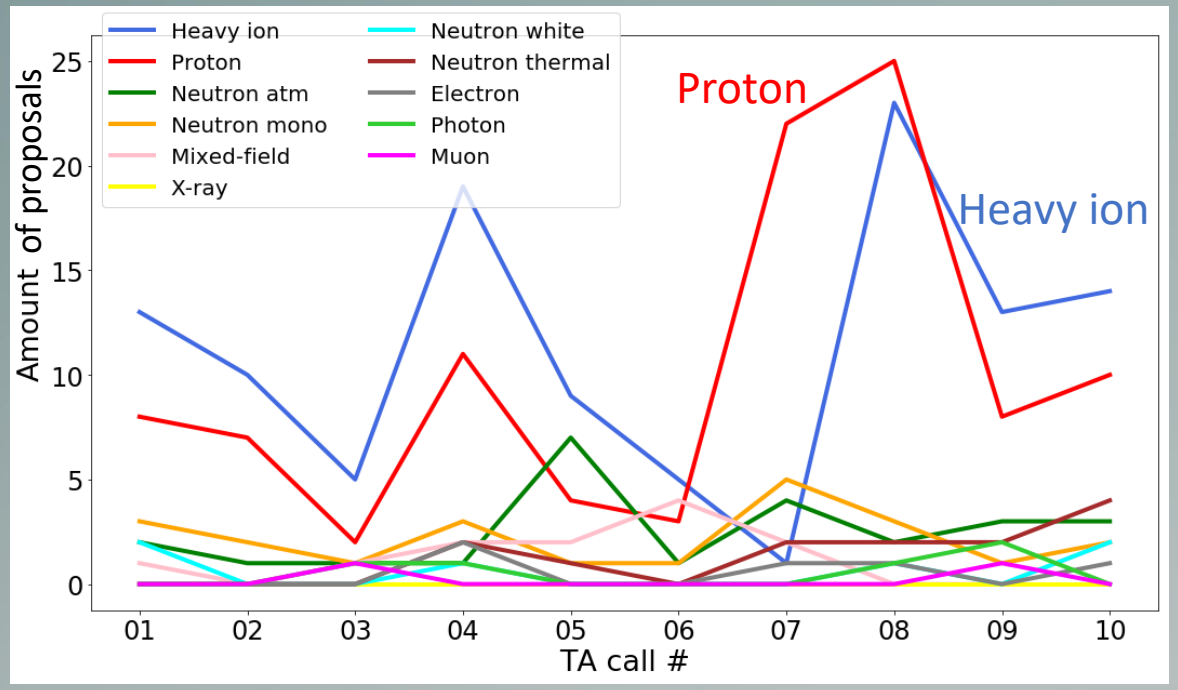
After 2.5 years of RADNEXT TA:

- Almost 3000 hours of beam time delivered
- Additional 1000 hours assigned



# Statistics and Results

Status Feb. 2024



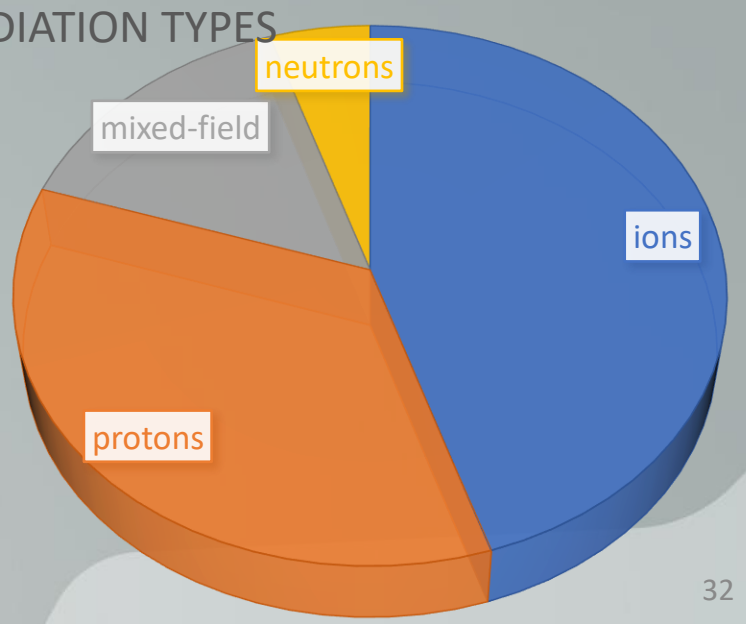

**Industry :**

20 campaigns accepted

16 campaigns performed: 512 hours

13 individual companies

- Big and small companies



# The three pillars

Network Activities (NA)

Joint Research Activities (JRA)

Transnational Access (TA)

10 Work packages

20 Work package leaders

12 PhD students + PostDocs

# G-RADNEXT workshop series
# The RADNEXT-to-Industry Event
# Putting industry at the center


G-RADNEXT workshop at CERN Nov. 2023

80+ Participants on-site