# Strategy for Radiation Tolerance Assurance of the A&T electronic Equipment

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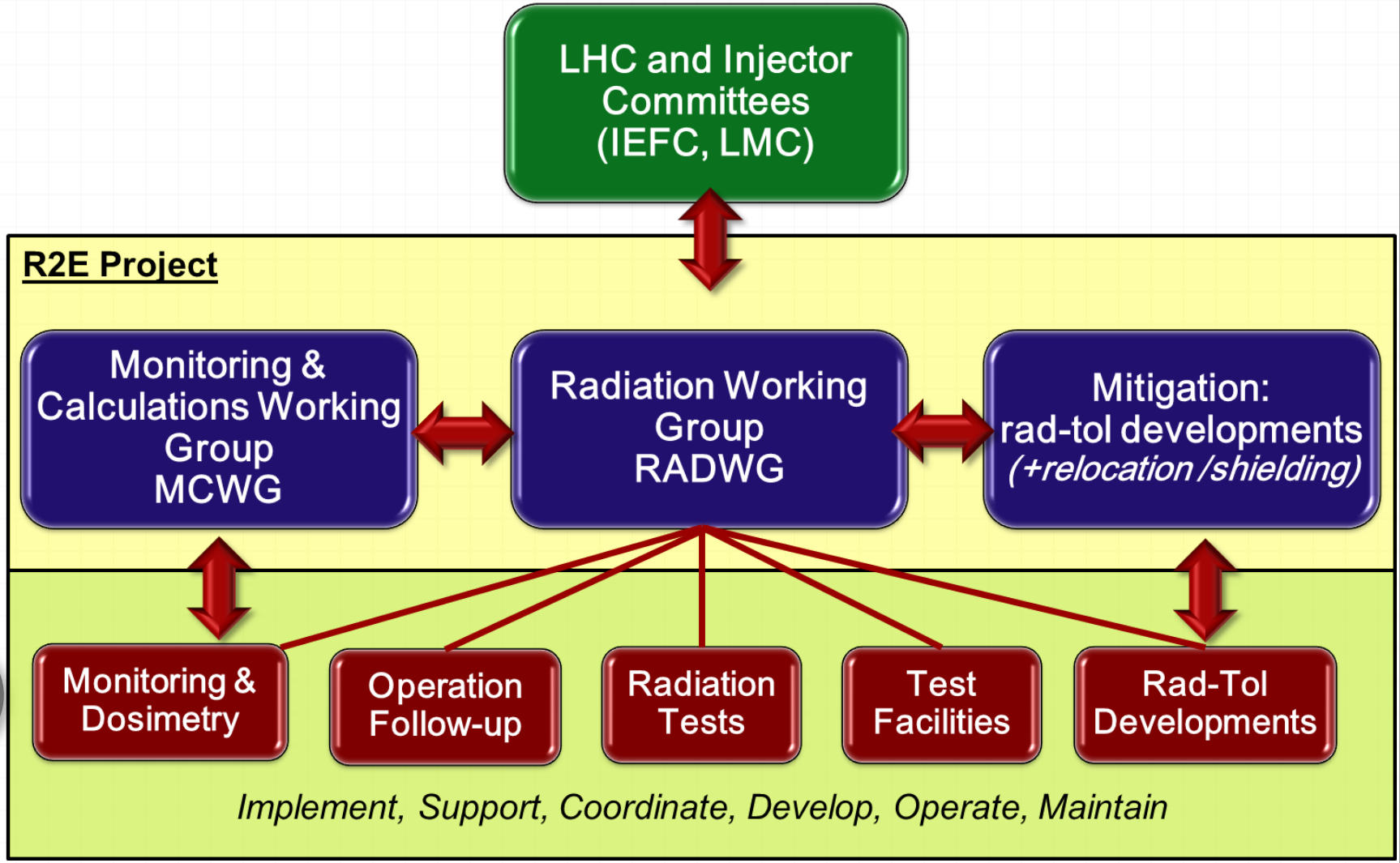
On behalf of the RADiation Working Group

# Outline

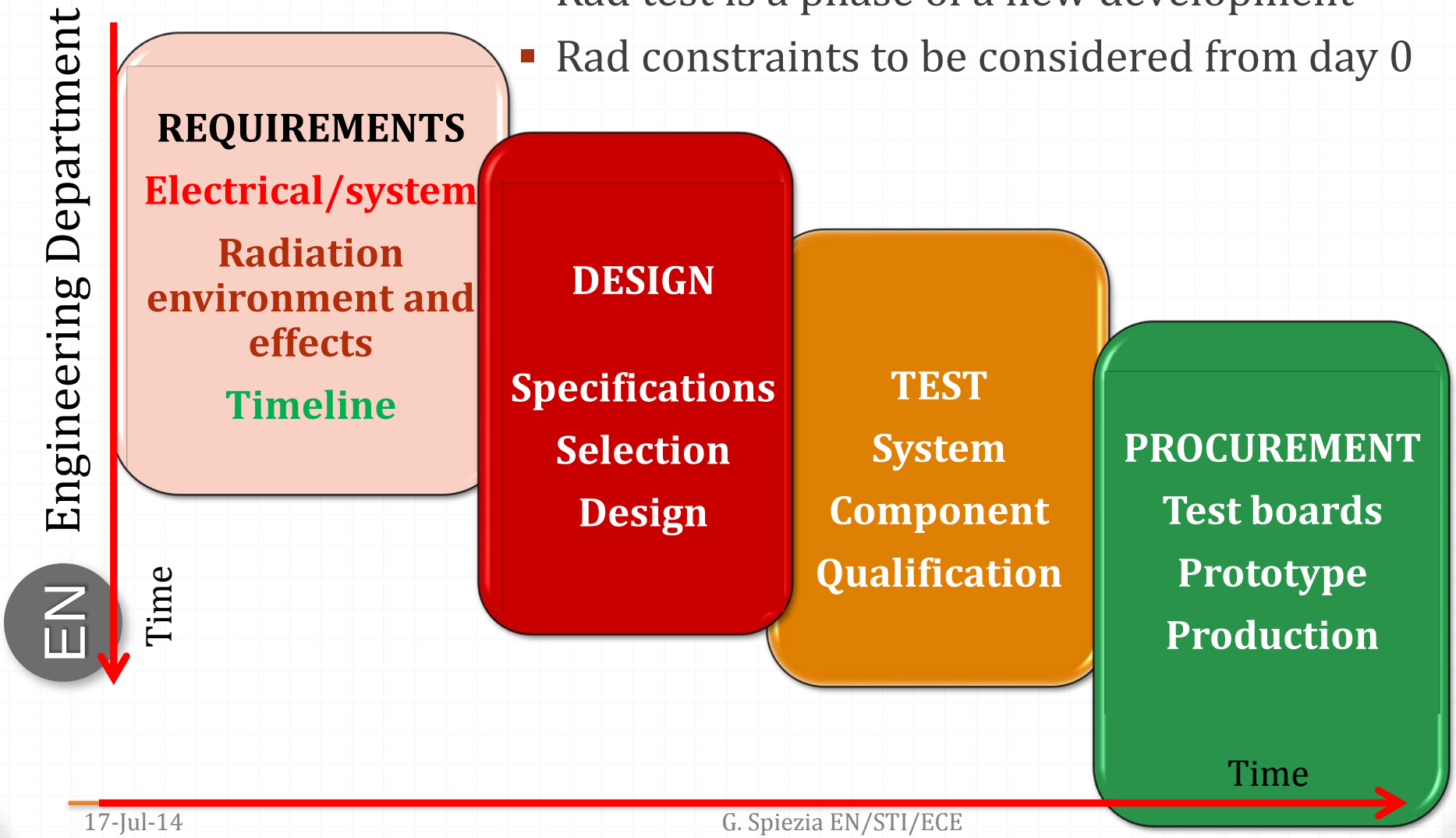
- Radiation Working Group: Mandate and goals
- Strategy: constraints and dependencies
  - Environment and test facility
  - Equipment
  - Focus on custom developments
- Main radiation tolerant developments and possible requirements for ASICS
- Conclusion

# R2E project and RadWG Mandate

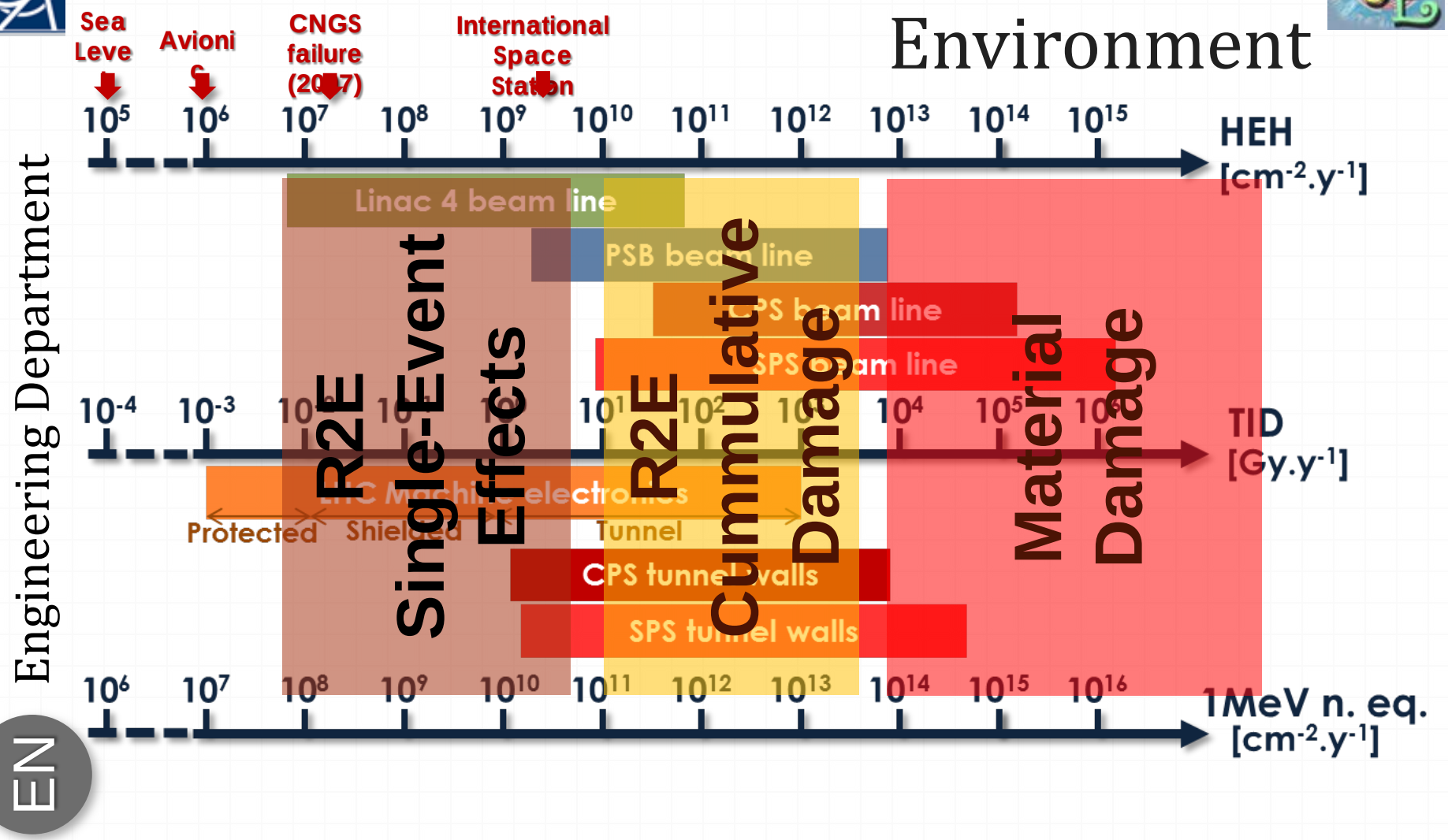


# Strategy

- Rad test is a phase of a new development
- Rad constraints to be considered from day 0



# Environment

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COTS Systems

Hardened Electronics

Electronics

Custom Boards with COTS

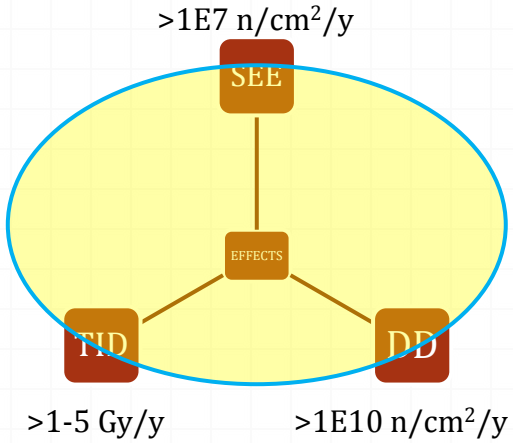
Damage

# Effects and Target test



- Rad test required if

| Radiation levels | |
|---|---|
| TID (Gy) | >1-5 Gy/y |
| DD (1 MeV n. Eq. n/cm²) | >1E10 n/cm²/y |
| HEH (n/cm²) | >1E7 n/cm²/y |




- From the radiation levels we apply the radiation tolerant criterions to fix the Target tests (radiation levels to be reached during the test)
- Target tests depend also on
  - Life time to be reached (important for TID, DD)
  - Number of components/systems-- > Failure Impact
    - *Number Errors* = *Cross Section* x *Flux* x ***Number of Components***
    - *Failure Impact* = *Number Errors* x ***Downtime***

# Environment

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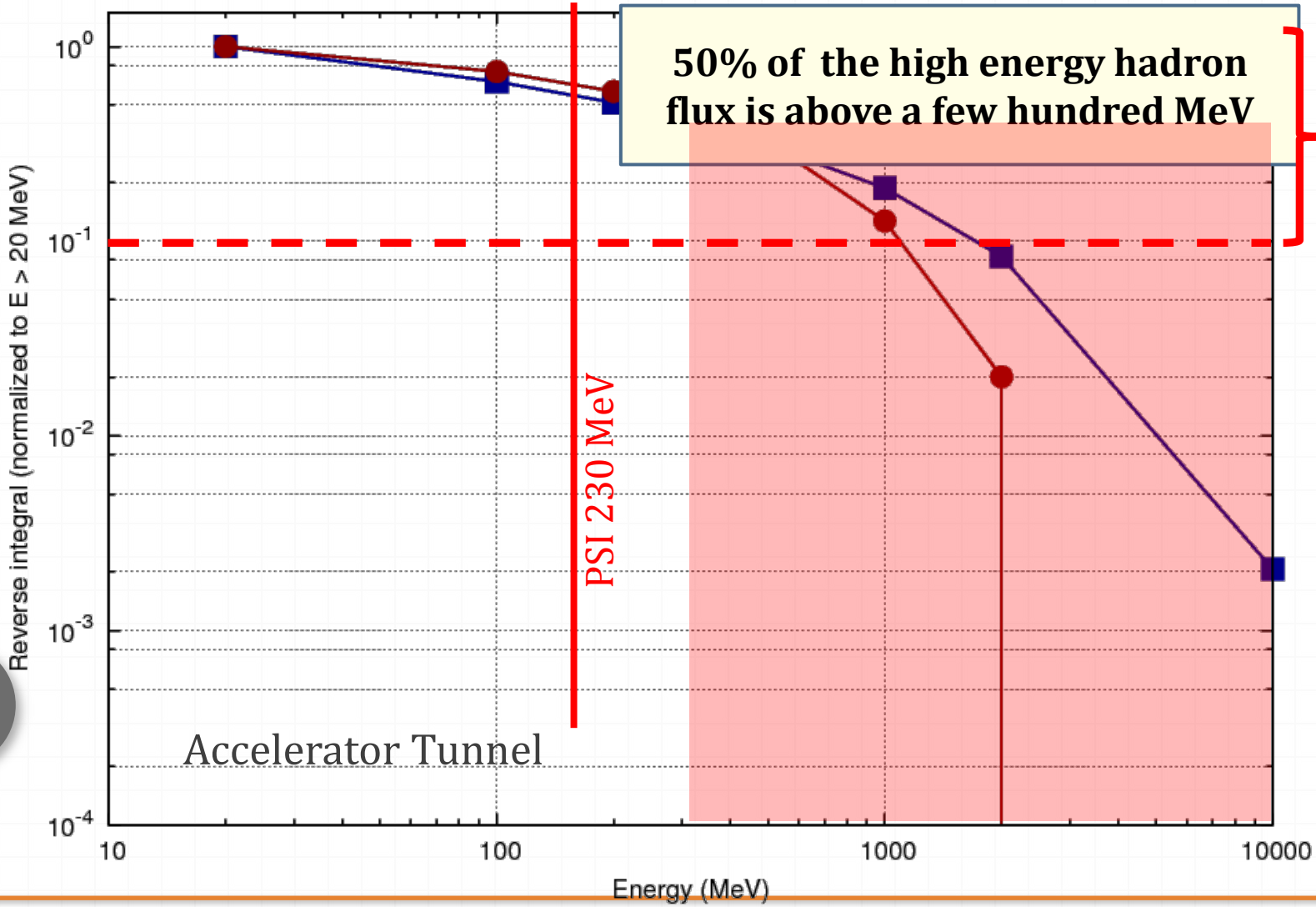


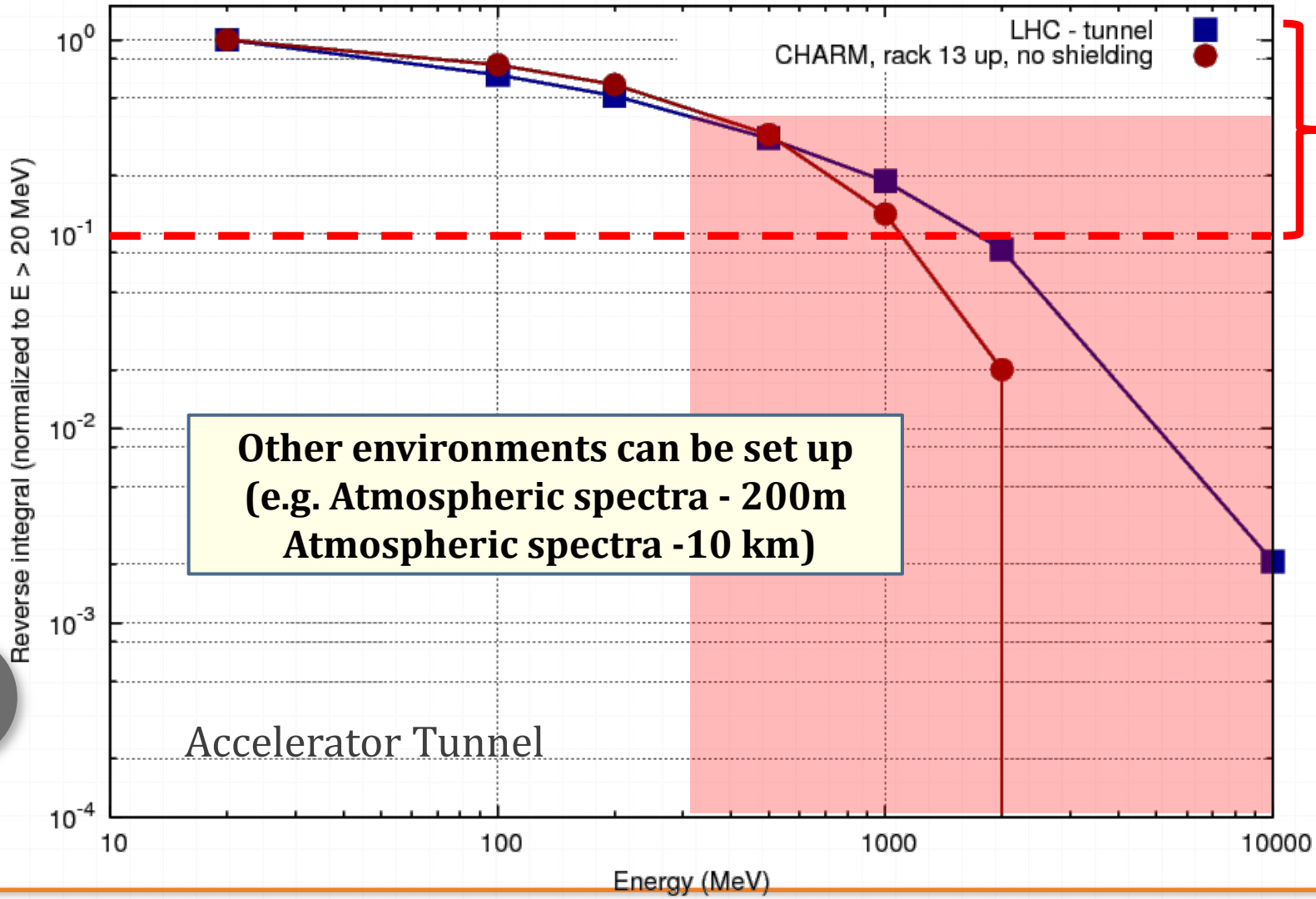
# Need to test at high Energies

- **CERN tests area**
  - **Most adapt solution**
  - **SEE, TID and DD tested at the same time**
  - **Representative environment**

## CHARM

## **C**ern **H**igh Energy **A**ccele**R**ator **M**ixed Field/Facility

# CHARM

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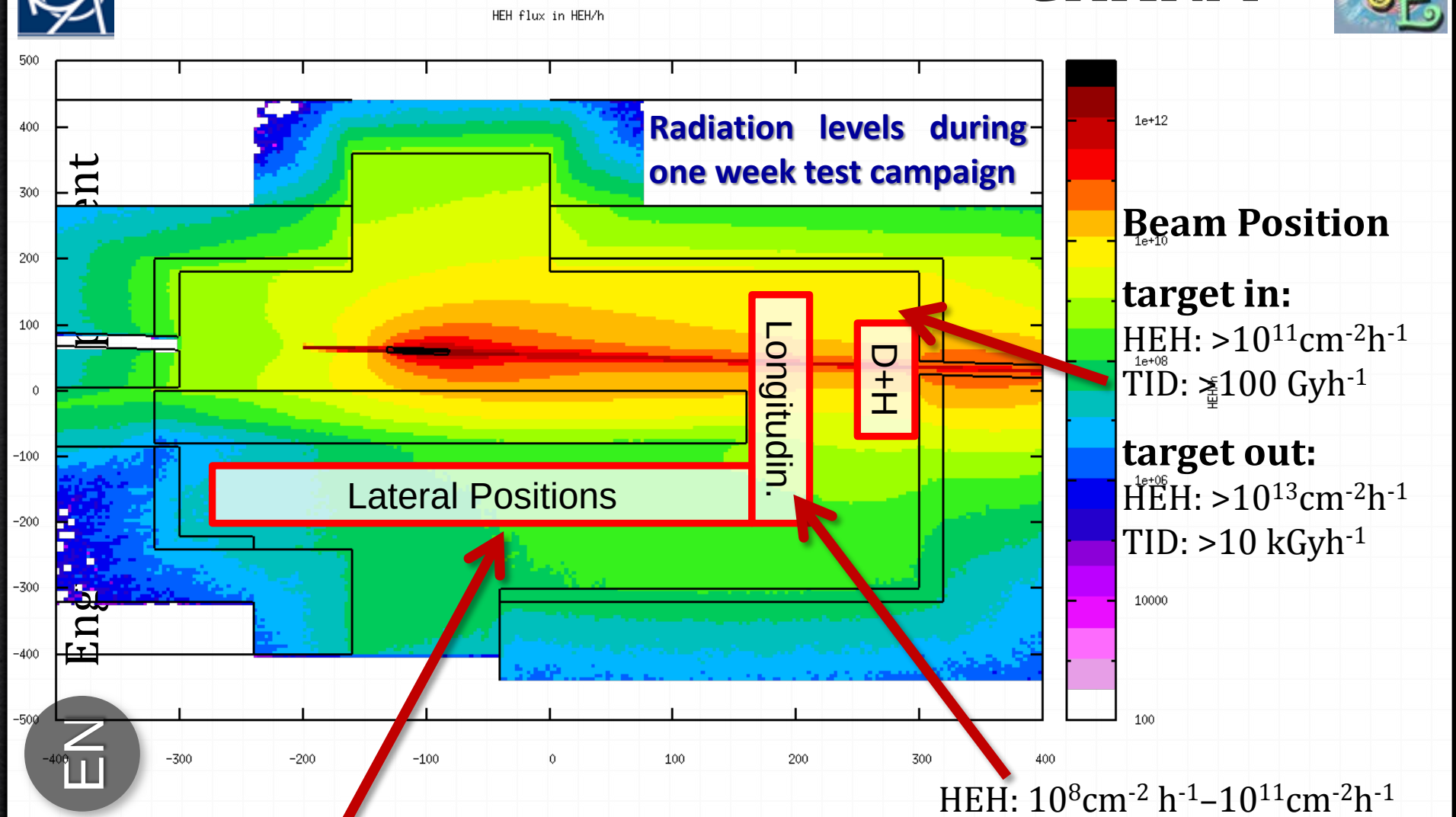
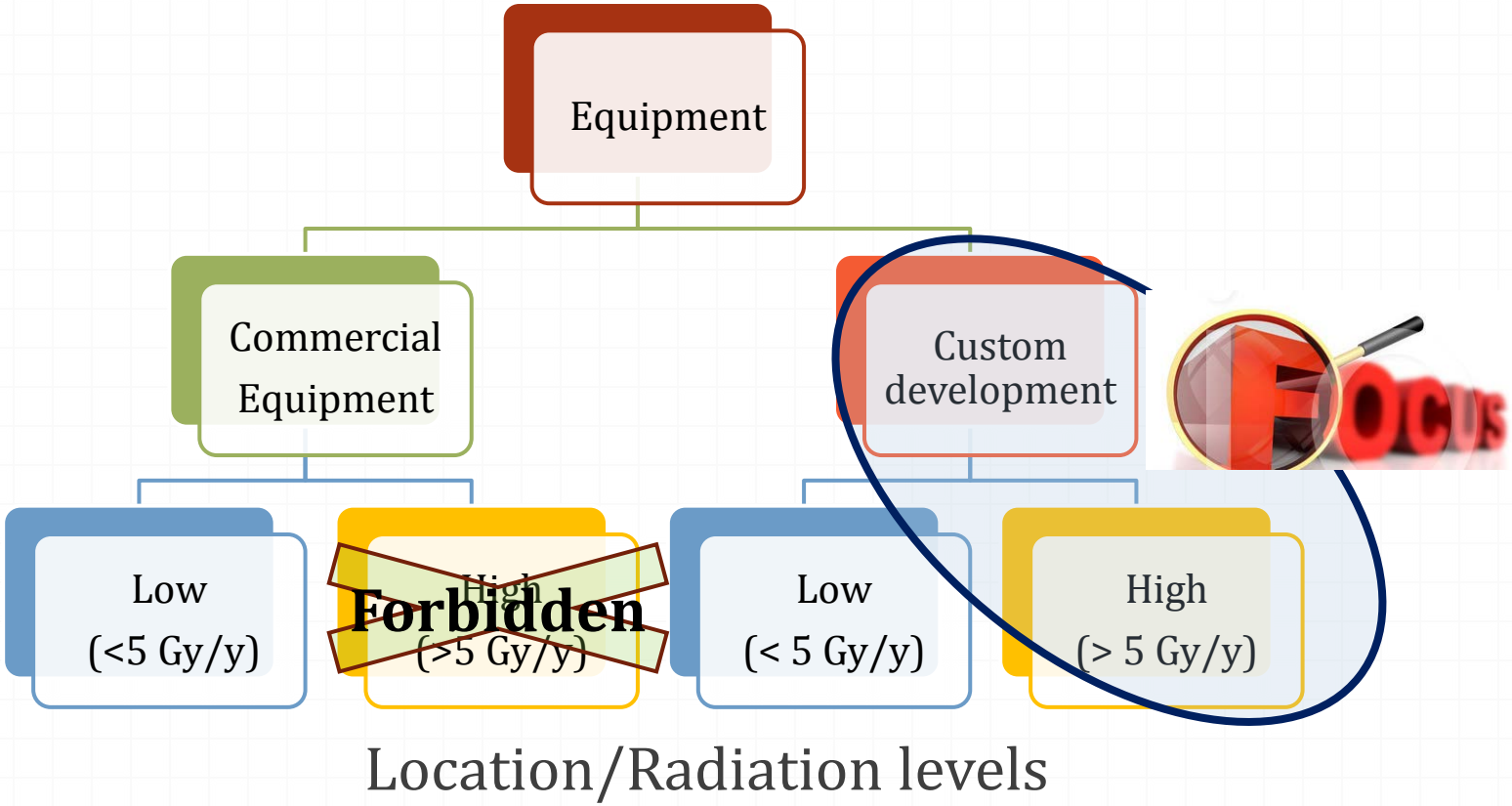
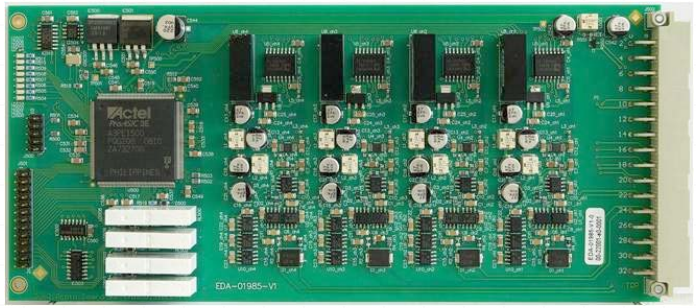
# CHARM

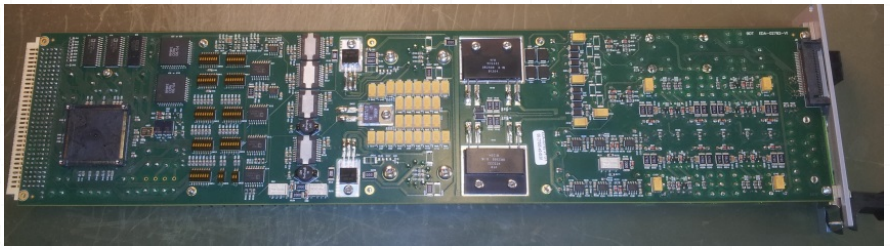

HEH flux in HEH/h
Radiation levels during one week test campaign
Longitudin.
D+H
Lateral Positions
Beam Position
target in:
HEH: >10^11 cm^-2 h^-1
TID: >100 Gyh^-1
target out:
HEH: >10^13 cm^-2 h^-1
TID: >10 kGyh^-1
HEH: 10^8 cm^-2 h^-1–10^11 cm^-2 h^-1
TID: 0.1Gyh^-1 – 100Gyh^-1
(gradients to be considered)
Full racks, crates, set of cards, components
HEH: 10^7 cm^-2 h^-1 –10^10 cm^-2 h^-1, TID: 10mGyh^-1 – 10Gyh^-1

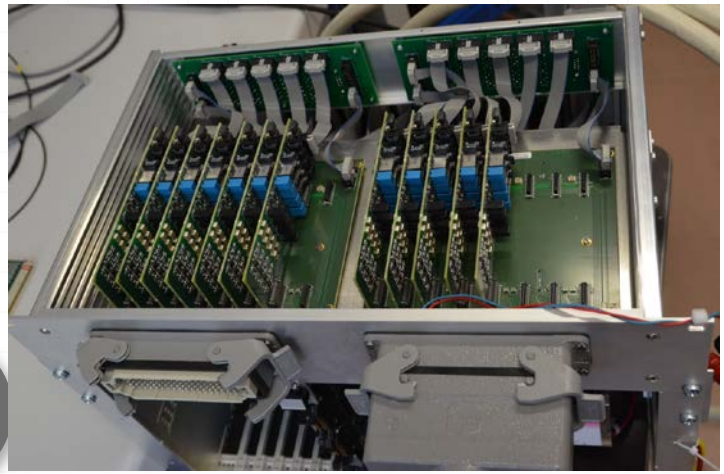
# Strategy- Type of Equipment

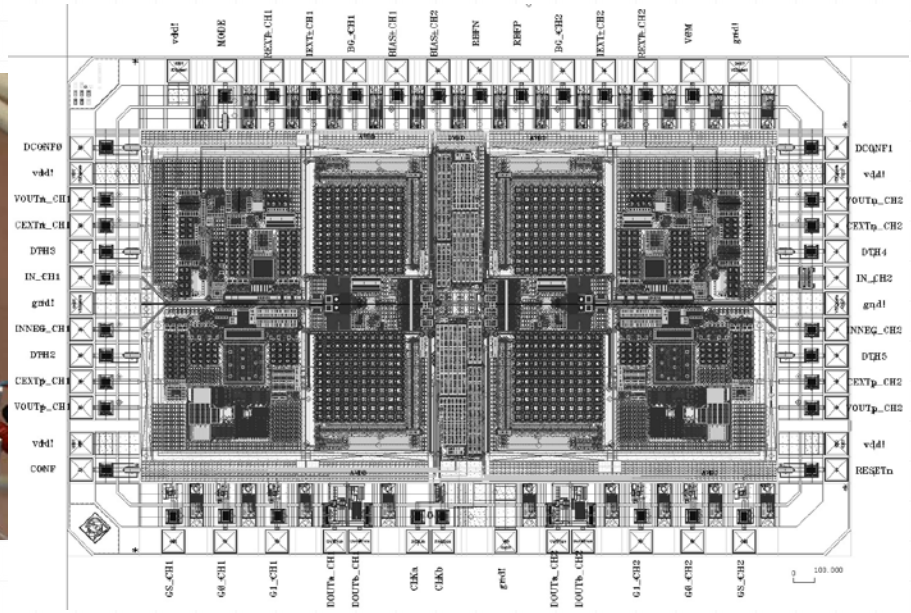


# Type of Equipment: custom board







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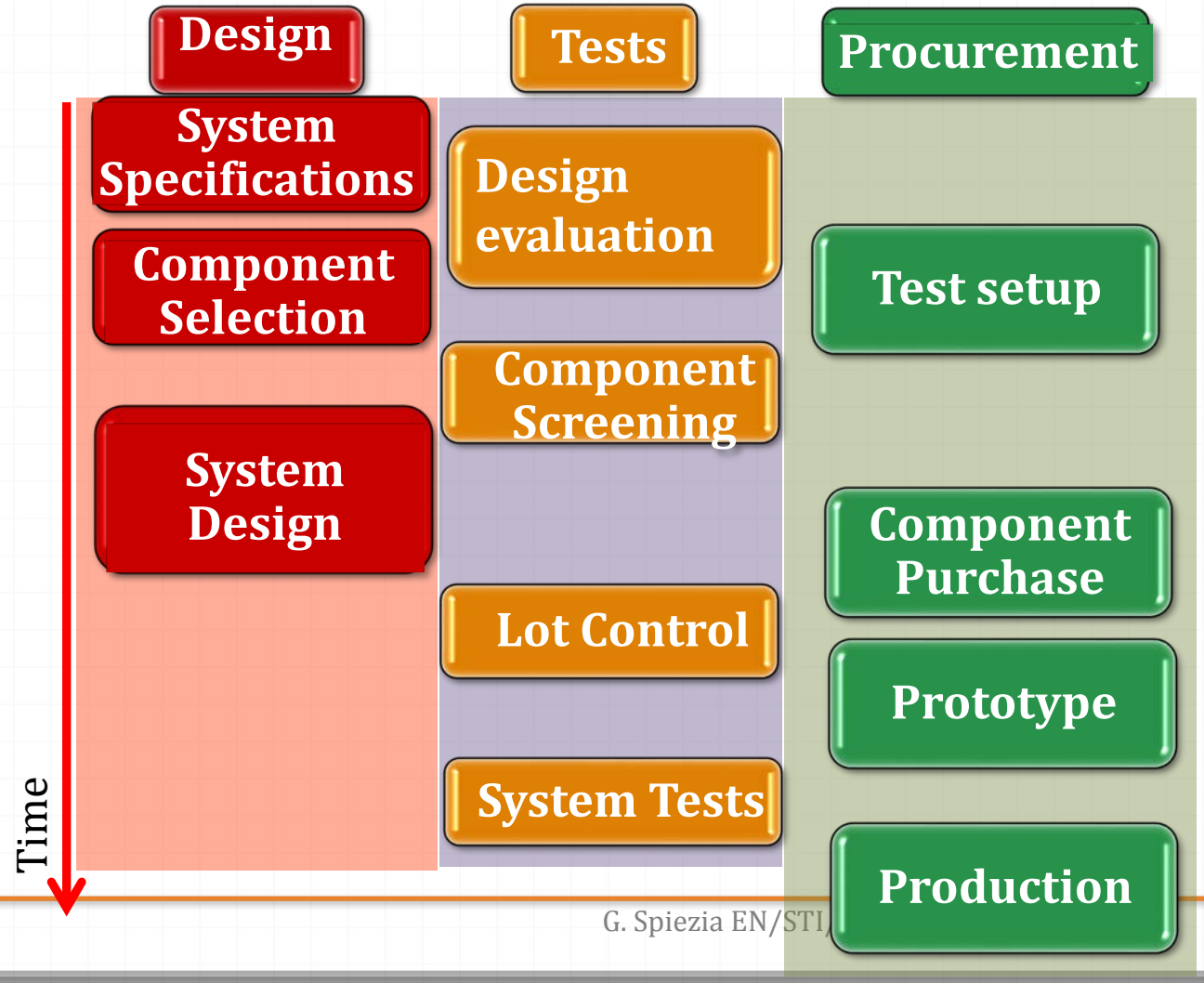
# Focus on Full Strategy

- Custom development with significant radiation levels



# Typical test campaign

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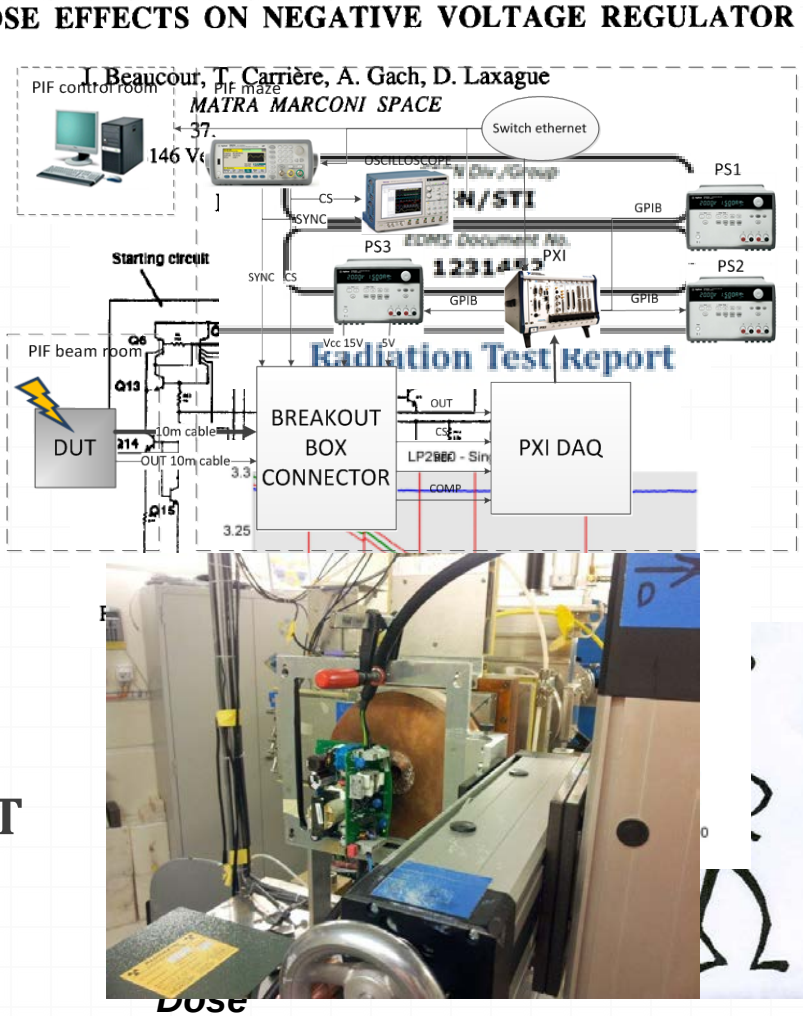
- Environment study and monitoring
- Study of the literature and Analysis of the electronic boards
- Choice of the test facility according to the device location and request collections
- Test Setup preparation (pSpice, pcb, measurement method → up to 2 months preparations)
- Test campaign
- Data analysis and report

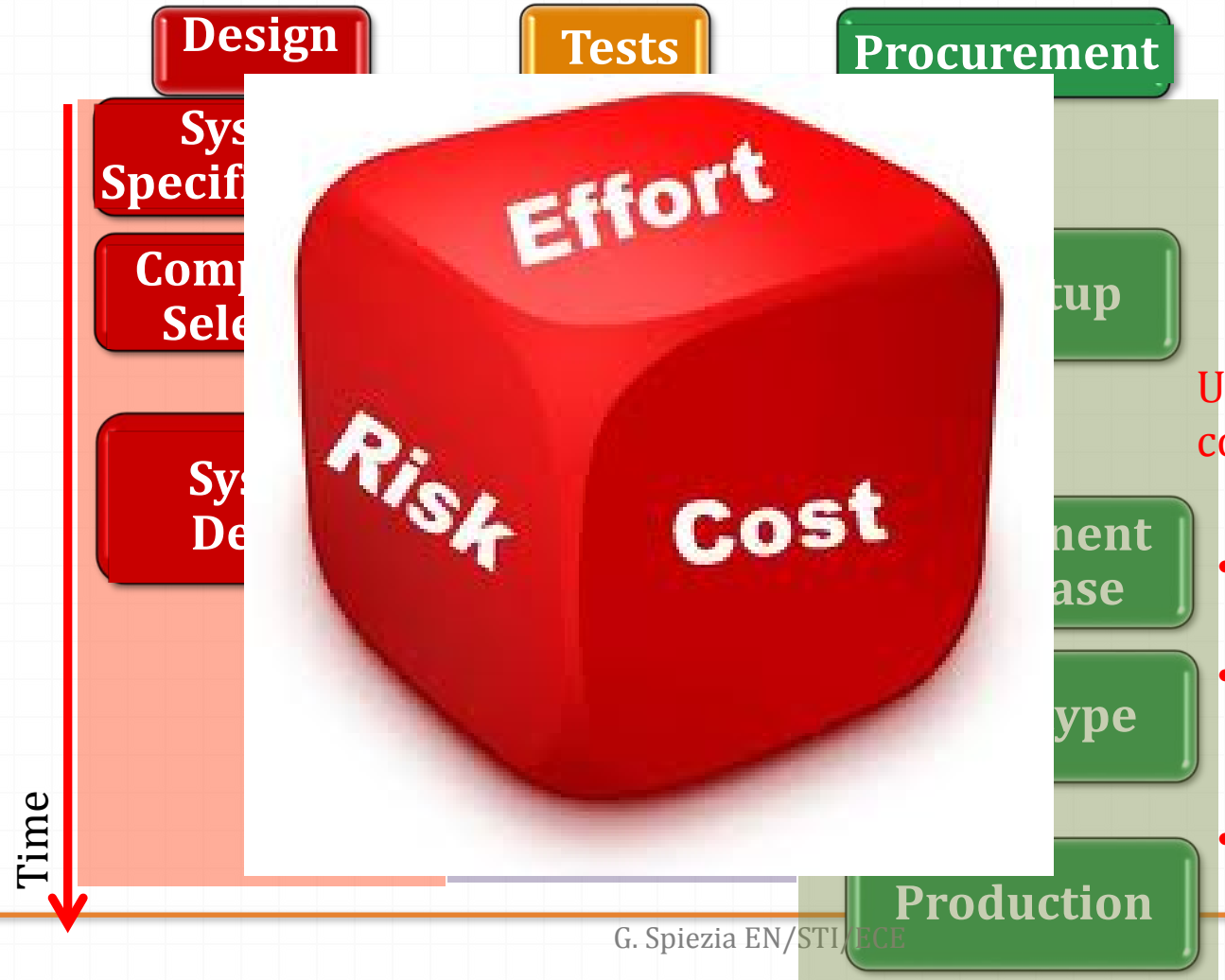
✓ **Test of ~80 components for the AT groups in the last 3 years**

✓ **Coordination via RADWG www.cern.ch/radwg**



# Full Strategy

- Custom development with significant radiation levels

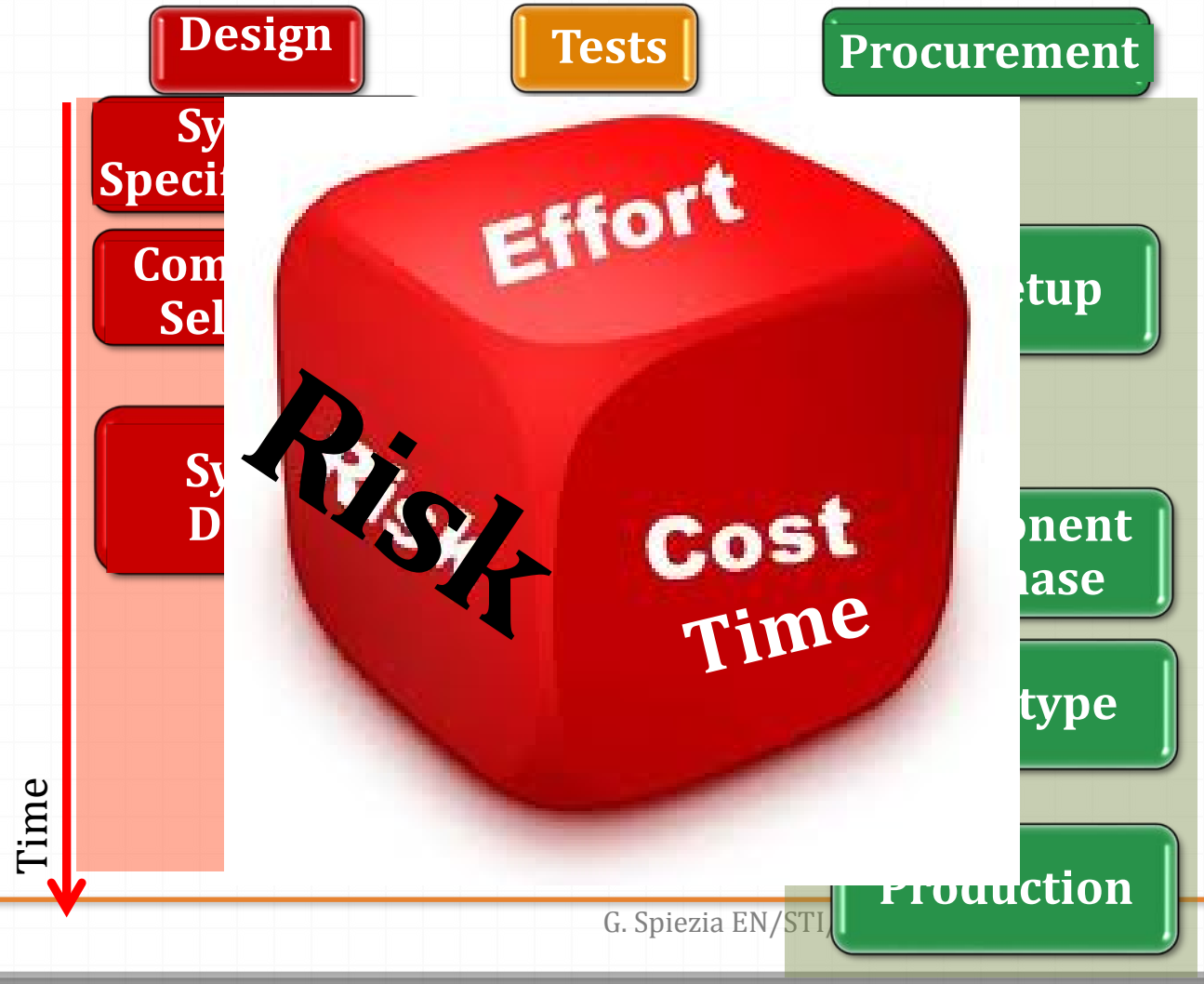



Use known components

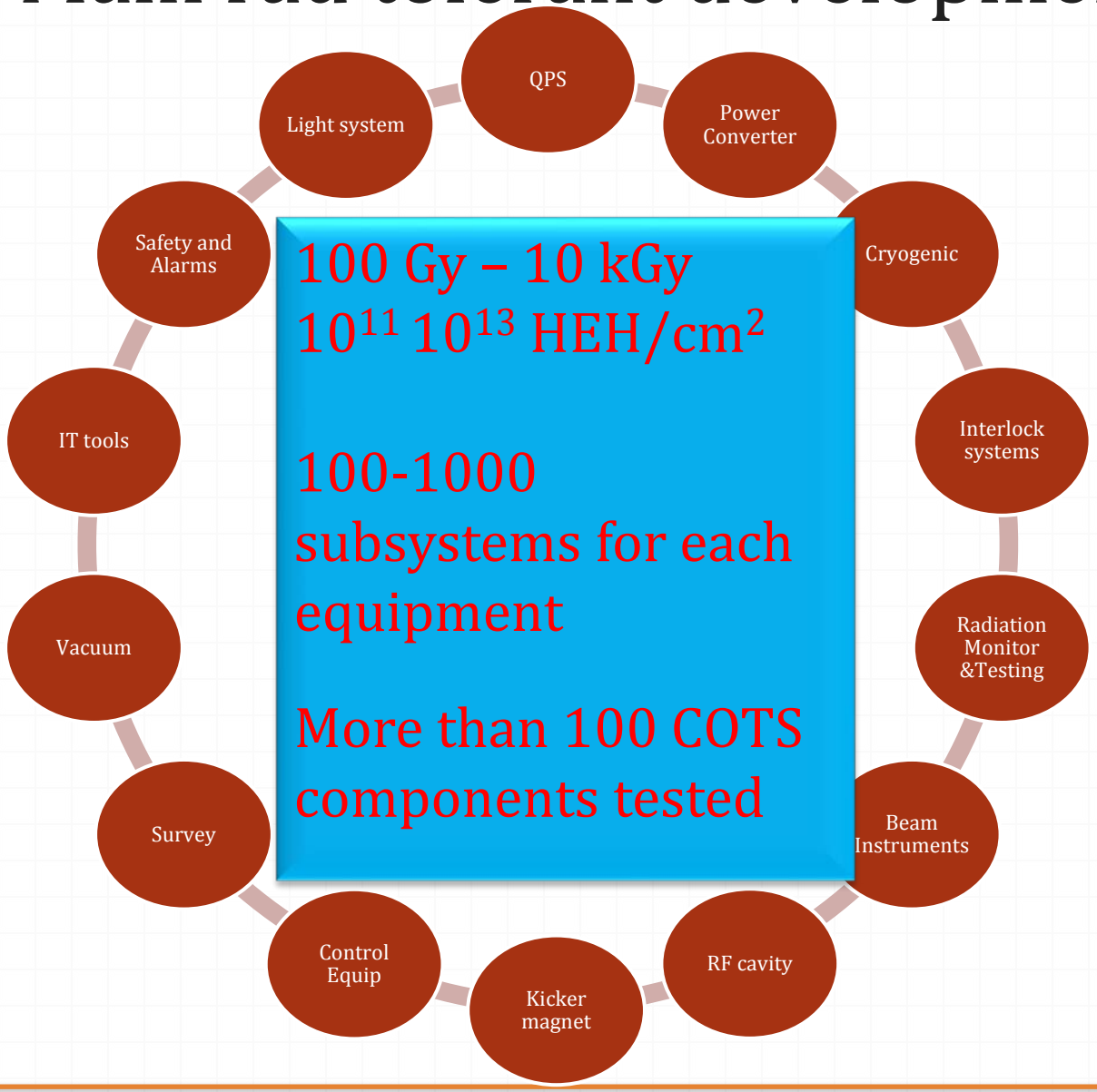
- Trace the lot anyway
- Apply safety margin
- System test mandatory

# Full Strategy

- Custom development with significant radiation levels



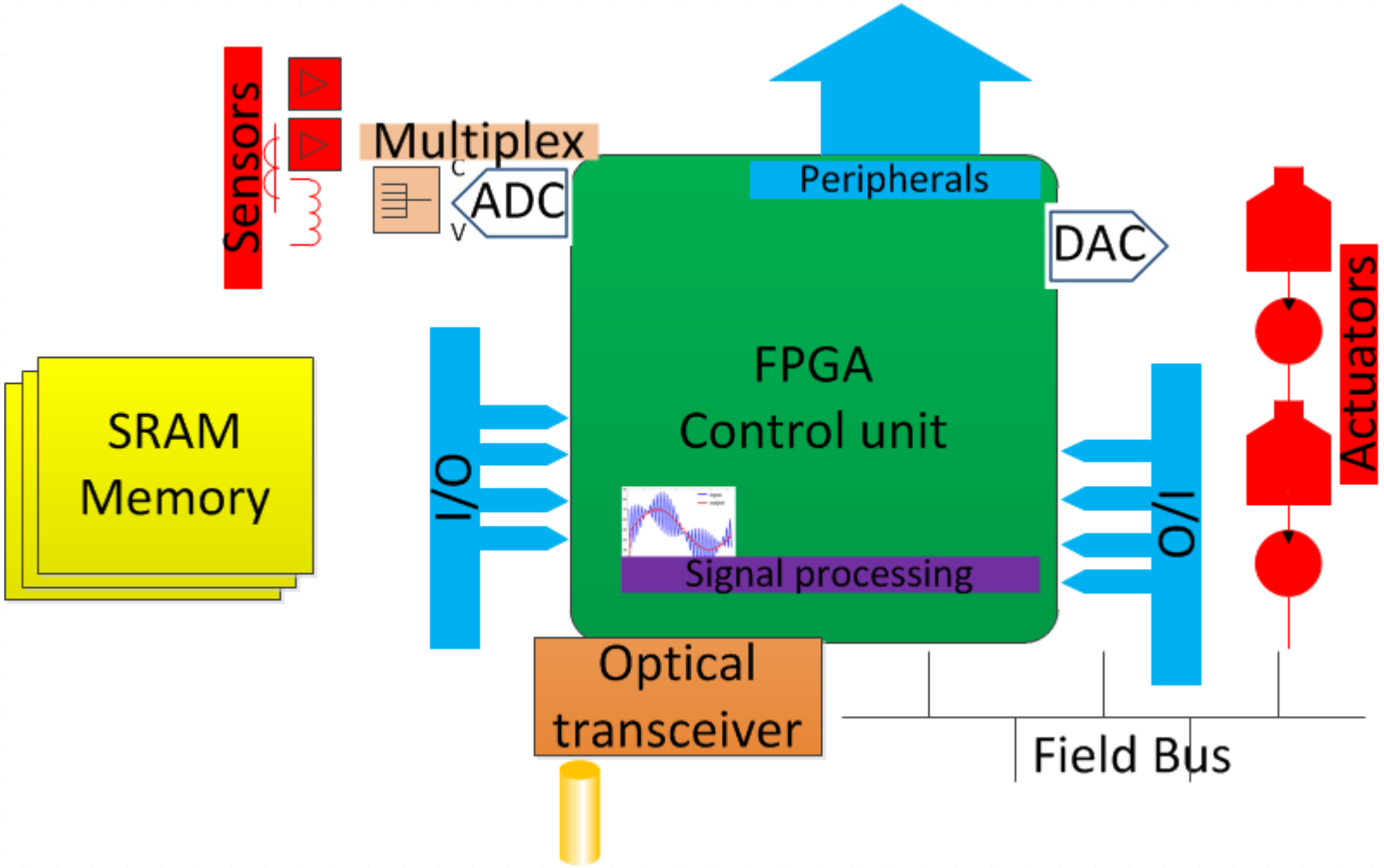
# Main rad tolerant developments



# Main groups activities

| Team | Activity | Devices components | | | System | Type |
|---|---|---|---|---|---|---|
| | | Analog | Digital Mixed | Power | | |
| TE/MPE | QPS | x | x | | Custom | COTS |
| TE/EPC | Power Converter | x | x | x | Custom | COTS |
| TE/CRG | Cryogenics | x | x | | Custom | COTS/Rad hard |
| TE/MPE | Interlock and Kicker | x | x | x | Semi-Custom | COTS |
| EN/STI | Radiation Monitor | x | x | | Custom | COTS |
| BE/BI | Beam instrumentation | x | x | | Custom | COTS/Rad hard |
| BE/RF | RF Cavities | x | | x | Custom | COTS |
| BE/CO | Control equipment | x | x | | Custom | COTS |
| EN/MEF | Survey | x | x | | Custom | COTS |
| TE/VSC | Vacuum equipment | x | x | | Semi-Custom | COTS |
| IT | IT tools | | x | | Semi-Custom | COTS |
| EN/EL | Light, LED | x | | | Semi-Custom | COTS |
| GS/ASE | Safety, Alarms | x | x | | Semi-Custom | COTS |
| EN/STI | Radiation test activities | x | X | x | - | - |

# Typical system architecture




# Wished ASICS

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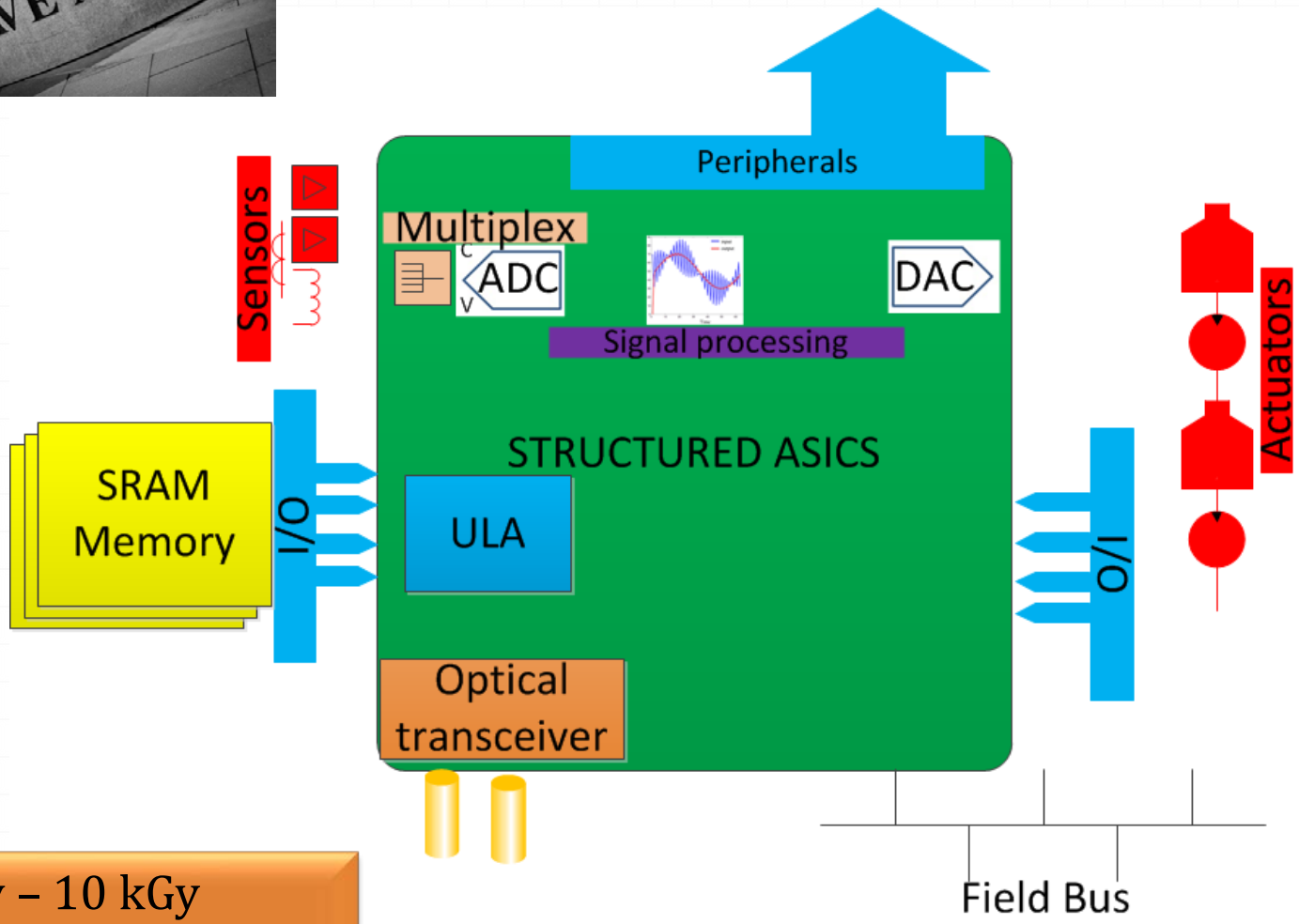


100 Gy – 10 kGy
$10^{11}$ $10^{13}$ HEH/cm$^2$

# Wished features

| | |
|---|---|
| ADC | • 18-24 bit resolution, Sampling rate 10-50 kSps<br>• 16-18 bit resolution, Sampling rate 50-200 kSps<br>• 14-16 bit, Sampling rate 60 MSps |
| DAC | • 12-16 bit resolution<br>• 10 V range |
| Signal process | • FIR filter<br>• Median filter |
| MUX | • Multiple channels for AD/DA |
| Peripheral Management | • ADC, DAC (if not embedded)<br>• Field bus<br>• Optical transceivers<br>• Serial ports |
| ULA | • Programmable logic |
| I/O | • 100 to 200<br>• LVDS drivers<br>• SERDES input for optical transceivers (2.4 Gb/s-5 Gb/s) |
| SRAM | • No SEL (> 40 MeV.cm$^2$/mg)<br>• No SEFI on the reading/writing circuitry<br>• Limited TID effect<br>• Sensitive to SEU to measure hadron fluence |

# Conclusion

- Radiation strategy for the Accelerator sector takes into account constraints based on radiation levels, equipment type, failure impact
  - CHARM test facility to have a representative environment
- For custom developments, mainly COTS components are used
  - → Huge effort for testing and quality assurance
- A custom rad-tol ASICS with AD, DA, Logic programmable units would fit with on-going and future projects
  - 4-5 types of equipment with 100 of subparts/subsystems

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# Thank you

# Useful links

- RADWG: www.cern.ch/radwg
  - List of the tested components http://radwg.web.cern.ch/RadWG/Pages/Summary_Table.htm
  - Test reports: https://edms.cern.ch/nav/P:CERN-0000083951:V0/P:CERN-0000091191:V0/TAB3
- List of test facilities: http://radwg.web.cern.ch/RadWG/Pages/test_facilities.htm
- CHARM www.cern.ch/charm
- R2E project: www.cern.ch/r2e

# Back-up

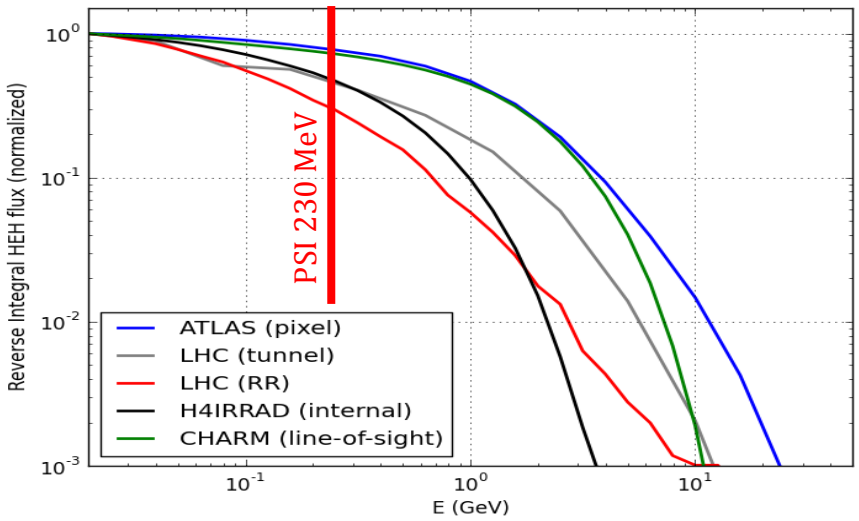
# SEE

- A Complex Programmable Logic Controller (CPLD) was tested using 60 MeV protons
- No SEEs were observed for the three devices tested before these started failing due to total ionizing dose effects (cumulative) after 120 Gy.

- The component was then exposed to high energy particle radiation at an LHC-environment. Permanent destruction of the part occurred in the early stage of the test.
- Importance of testing in the actual operation environment (not always feasible in a systematic way) and of being able to model/predict the error rate (energy dependence knowledge, for example)

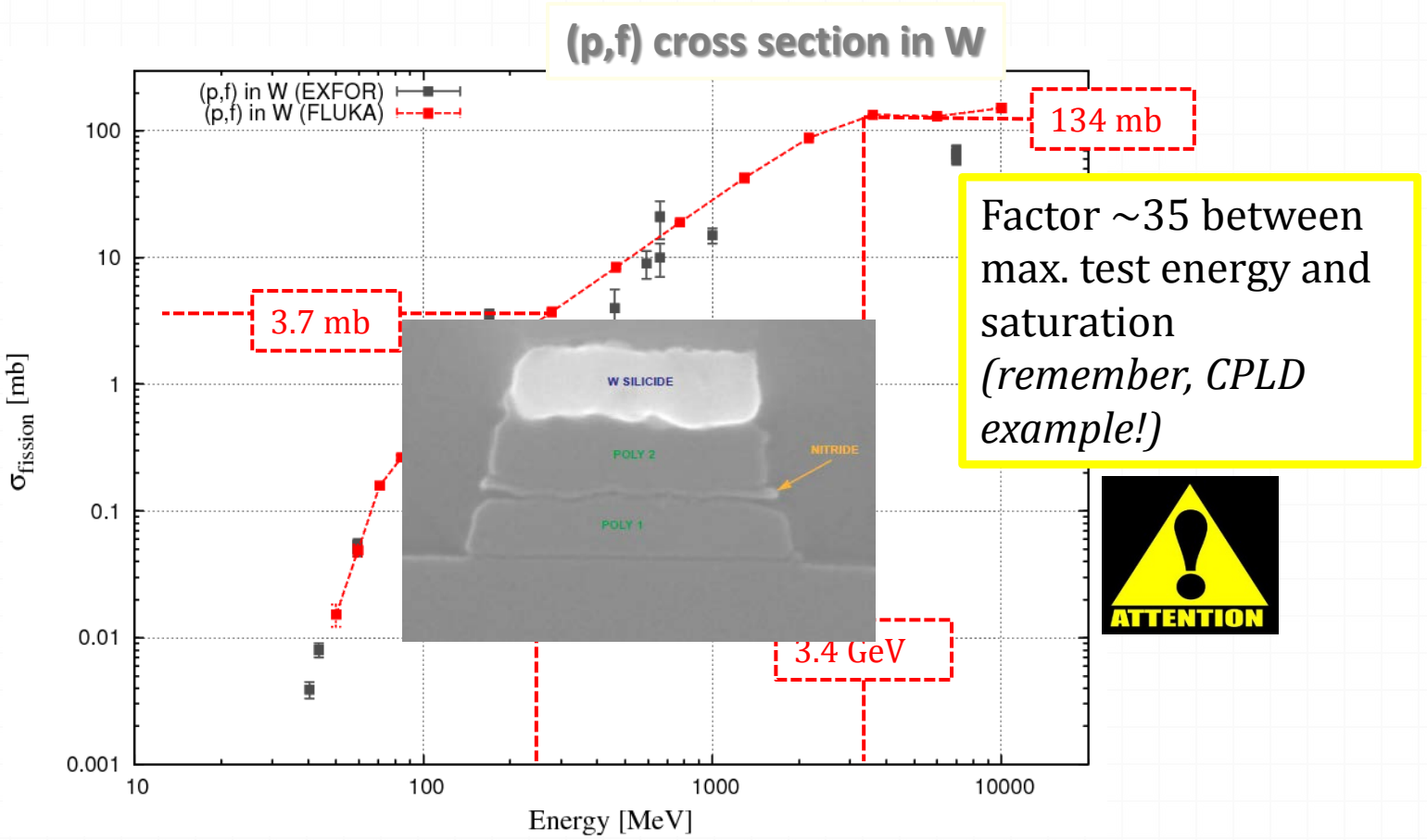
# SEE

- Destructive events can be caused by recoils products created by HE particles impinging on HiZ device materials
  - Interaction cross section is a function of the impinging particle energy, material and its location
  - Type of materials and location are often unknown
  - Max LET of recoil is 40 MeV.cm$^2$/mg (W fission)
- LHC environment: Energy up to 1 GeV
- Proton facilitv: max 230 MeV



# SEE

- Destructive events are caused by recoils products




Factor ~35 between max. test energy and saturation *(remember, CPLD example!)*

# SEE

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- Importance of testing in the actual operation environment (not always feasible in a systematic way) and of being able to model/predict the error rate (energy dependence knowledge, for example)

# Full Strategy

- Component classifications
- Choice of the test facility(ies)

| Class | Radiation response | Sourcing | Components |
|---|---|---|---|
| Class-0 (potentially sensitive) | Quite resistant or moderate sensitivity to radiation | Easily replacement Different manufacturers and types on the market | To be defined for each case |
| Class-1 (potentially critical) | Potentially susceptible to radiation, not on system's critical path | Substitution possible (list of preferable replacements is defined) | |
| Class-2 (highly critical) | Potentially susceptible to radiation, on system's critical path | Difficult to replace as no equivalents on the market | |

FGC Lite use case

| Class | Mixed-Field | Proton (PSI) | Heavy-ion |
|---|---|---|---|
| Class-0 (potentially sensitive) | **Mandatory** Component tests or tests of the complete | N/A | N/A |
| Cl (pot cr | | | N/A |
| Class-2 (highly critical) | Component tests or tests of the complete board for SEE and TID | Component tests for SEE and TID (margin to account for >1GeV) | **Mandatory** Component tests for better SEL assessment |

To be tailored for each case

# Full Strategy

| Test | Facility | How |
|---|---|---|
| **SEE** | CHARM<br>PSI<br>Heavy Ion | Test points for SET<br>Current consumption<br>SEE on numeric data |
| **TID** | Fraunhofer ESTEC<br>PSI<br>CERN | Test points for drift checking and parameter degradation |
| **DD** | CEA, Fraunhofer | Test points for drift an parameter degradation |