



PERLE Potential Applications

Walid Kaabi

IJCLab / Université Paris-Saclay/ IN2P3-CNRS

On behalf of PERLE Collaboration



PERLE: Powerful Energy Recovery Linac for Experiments

➤ Demonstration of multi-turn and high current operation:

- Careful attention to machine design (Lattice, beam dynamics and collective effects, filling pattern, BBU...)
- Good control of the beams (shape, position, synchronisation, losses...)

➤ Validation of ambitious technical choices:

- High-charge electron gun: 500 pC at 40 MHz
- Optimized 800 MHz SRF system designed to maximize efficiency
- Switchyards and common circulation arcs for accelerated and decelerated beams
- Non-invasive diagnostics
- ...

➤ Experiments compatible with ERL functioning

- No/small impact on beam after interaction
- No important changes in beam path length during implementation
- Of interest for the lab/institute team/community.

➤ Special beam requirements:

- Injector and lattice flexibility: charge, emittance, bunch length, dispersion...
- Need of dedicated optics/diagnostics in IP region

➤ Impact on machine footprint

- Equipment/spectrometer/detector in IP region or elsewhere, additional shielding/cooling...

Foremost, PERLE is an ERL demonstrator:

- Its construction, commissioning, debugging and tuning up to the optimal parameters will require time.
- Further accelerator developments should still be possible and time should be allocated for it (implementation of new technology enhancing PERLE efficiency, new diagnostics...).

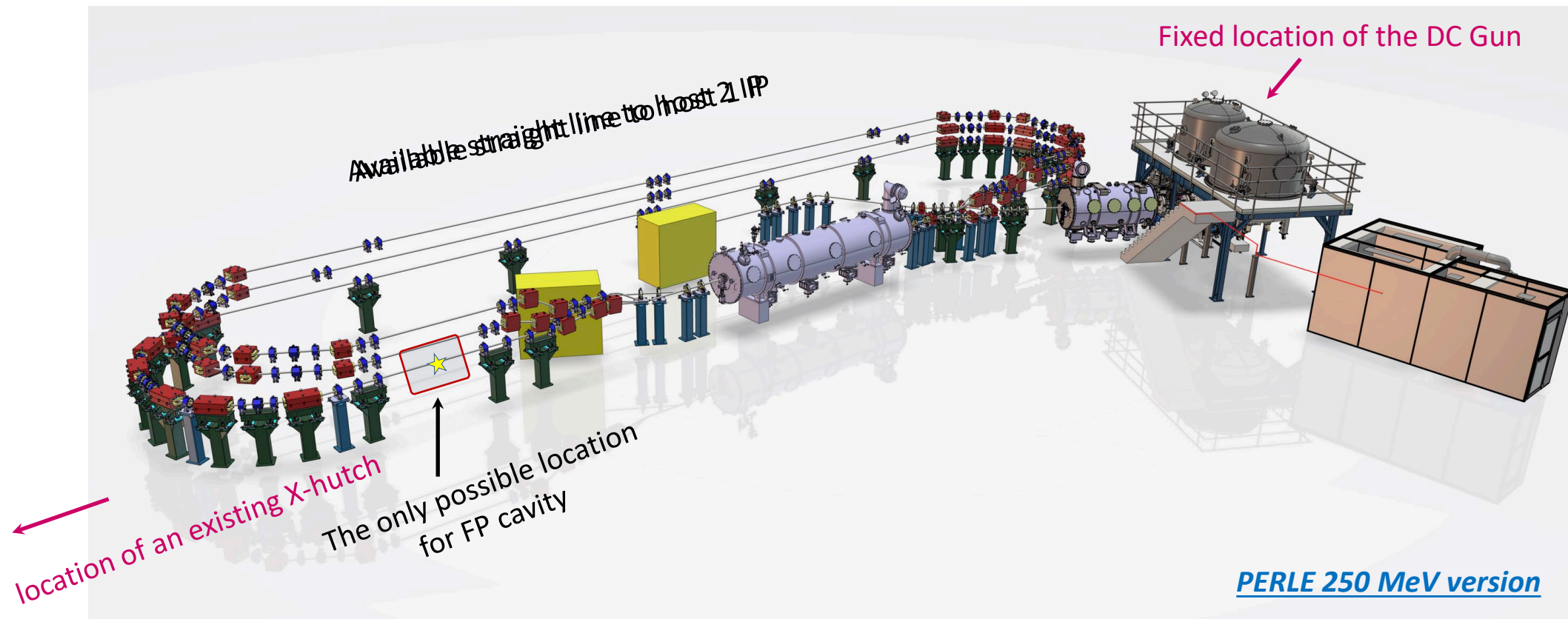
But, to fund the machine construction, cover its running cost and then ensure its longevity, we could not rely only on the demonstrator argument. Applications are always required by funding agencies, mostly on R&D fields or societal applications.

A trade off between a demonstration machine and a users facility was found

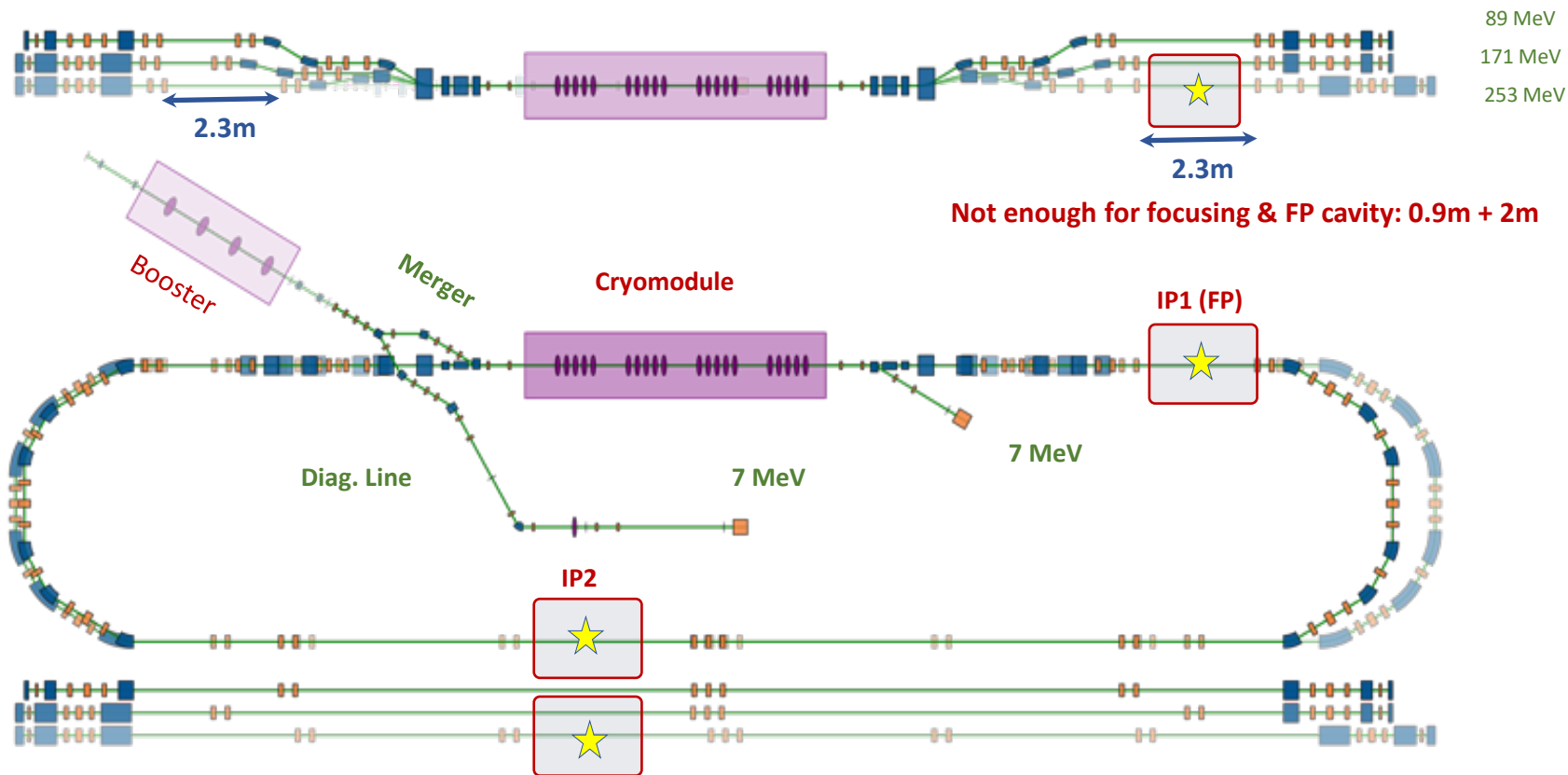
→ It is foreseen that PERLE will host 2 R&D set-up for :

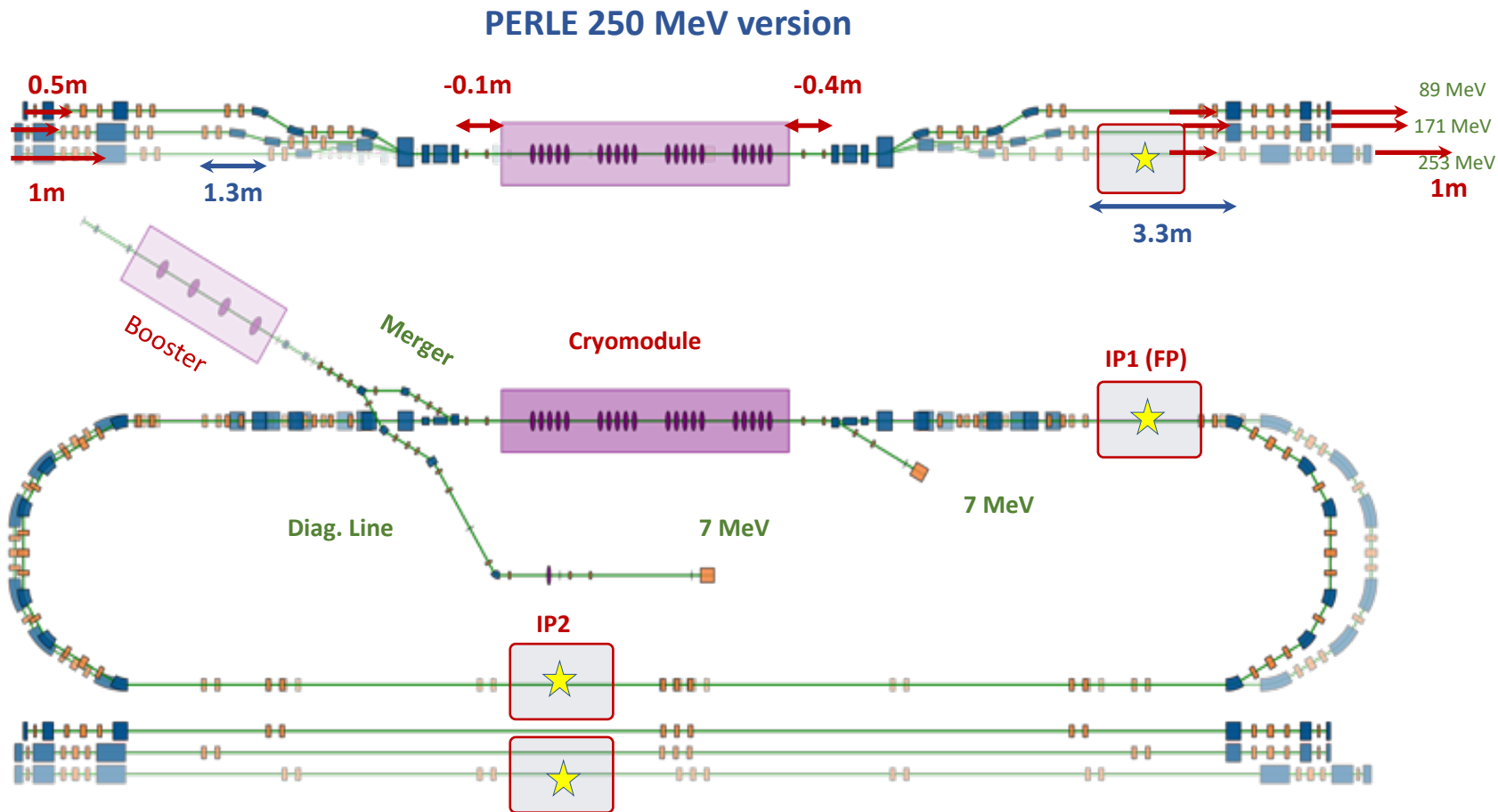
- Inverse Compton scattering source (ICS)
- Electron scattering on online produced Radioactive ion experiment.

The emplacement of the two experiments have to be anticipated in the design phase to avoid unwanted modification of the path length during implementation, the cross talk between magnetic elements at crowded regions...



PERLE 250 MeV version







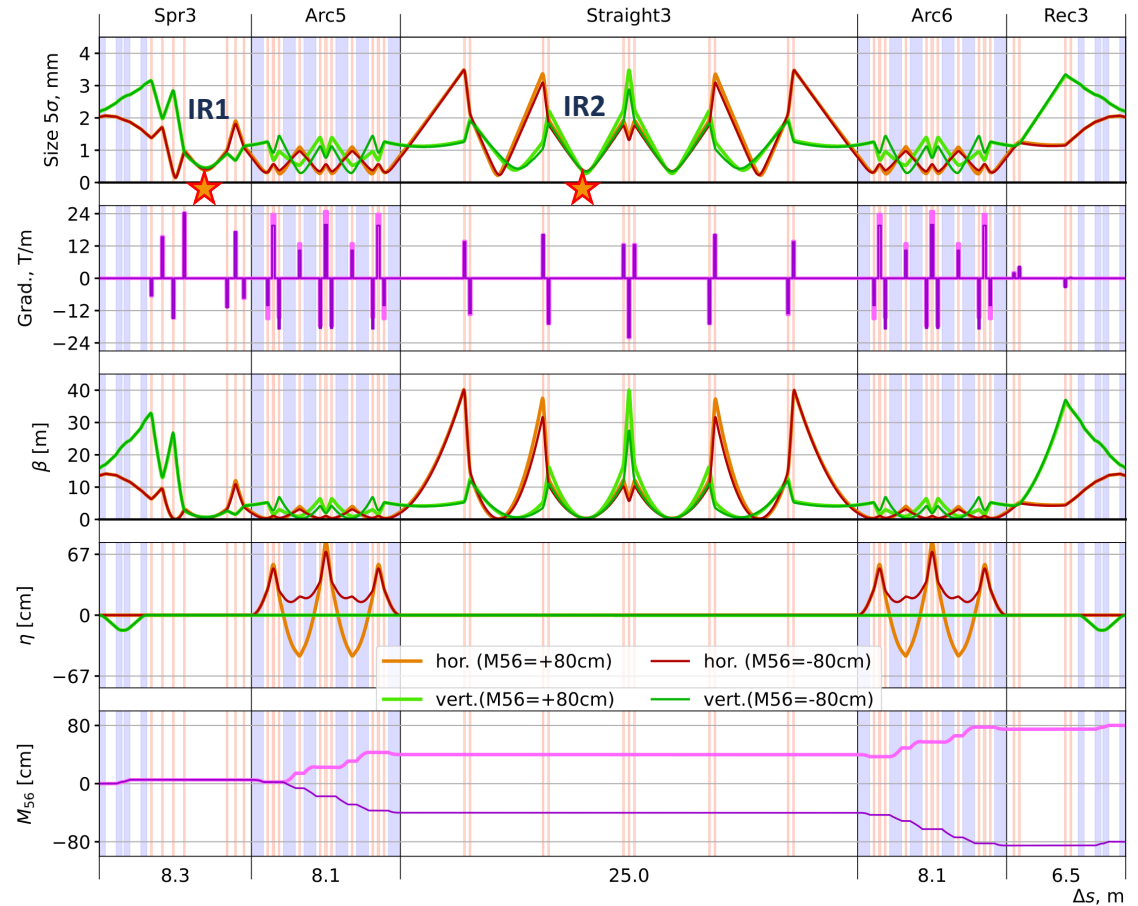
Interaction Points locations and constrains

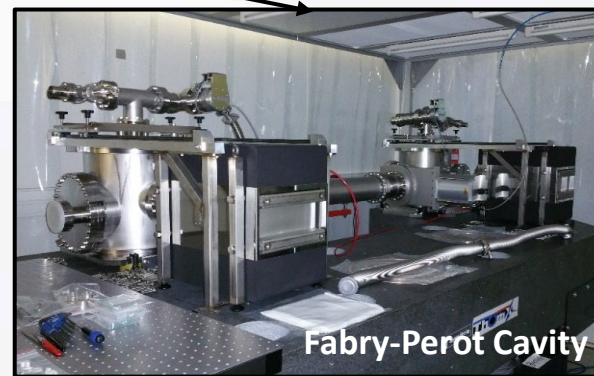
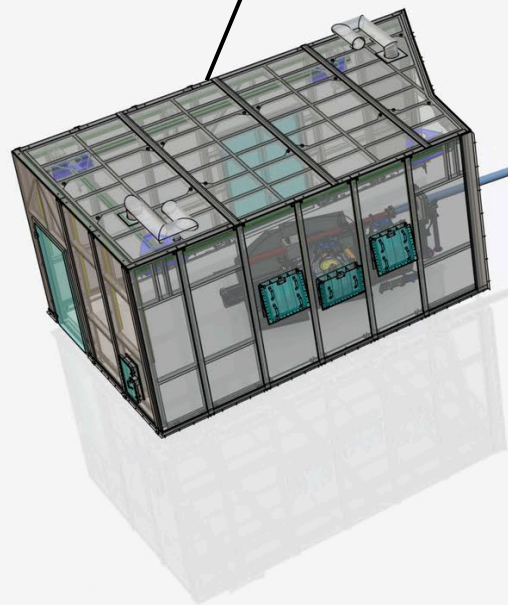
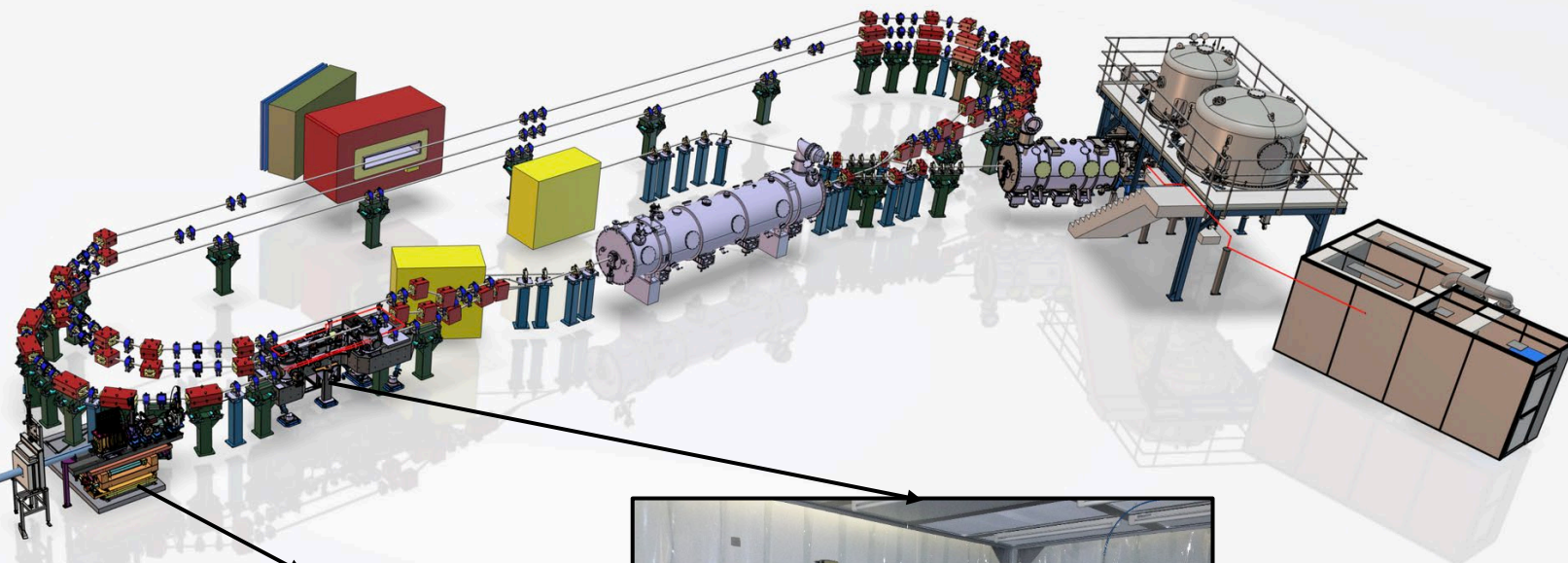
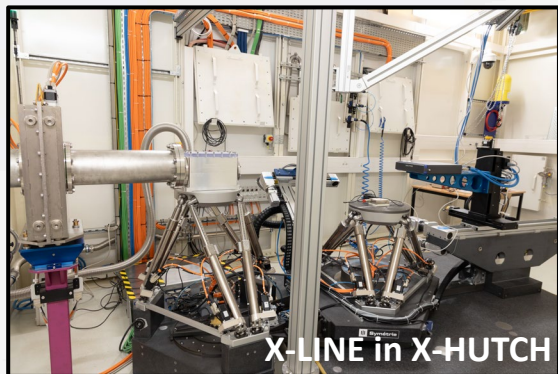
Optics of the 3rd Turn (updated)

- Spreader and Recombiner are not symmetric
- Quadrupoles in Arcs close the dispersion and compensate M56 of Spreader and Recombiner
- Low beta ($\beta=30\text{cm}$) regions for experiments
 - IR1: Fabry Perot (2m) in the Spreader section
 - IR2: scattering on unstable ions (in the straight section)
- Beam size (5σ) under 4 mm
- Maximal gradient of quadrupole magnets $< 24 \text{ T/M}$

Tuning M56 in the Arcs

- Possible to gain $M56 = \pm 80 \text{ cm}$ with minor change of beam properties or introduce a local bump of $M56 = \pm 40 \text{ cm}$ (probably more — ongoing studies)

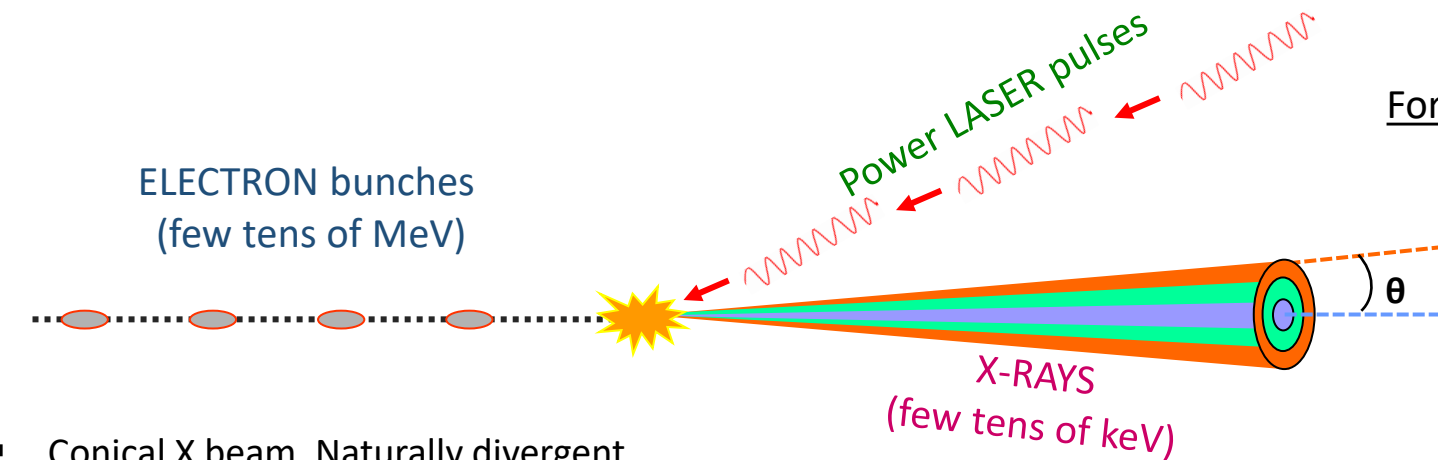




X-ray Compton sources: HOW ?

Courtesy to Marie Jacquet

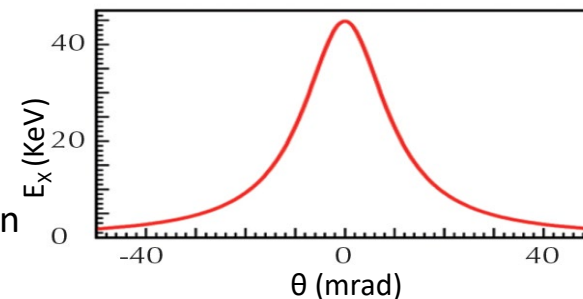
ELECTRON bunches
(few tens of MeV)



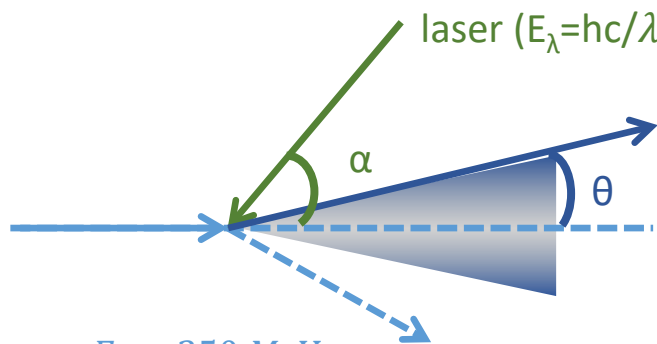
For ThomX: 50 MeV e⁻ beam
1030 nm laser

$\theta \sim 10$ mrad \rightarrow 22 keV

on-axis photons \rightarrow 45 keV



- Conical X beam, Naturally divergent
- Univocal relation between the energy E_x and the diffusion angle θ
--> Quasi-Monochromatic beam with a simple diaphragm. Price to pay \rightarrow Flux reduction

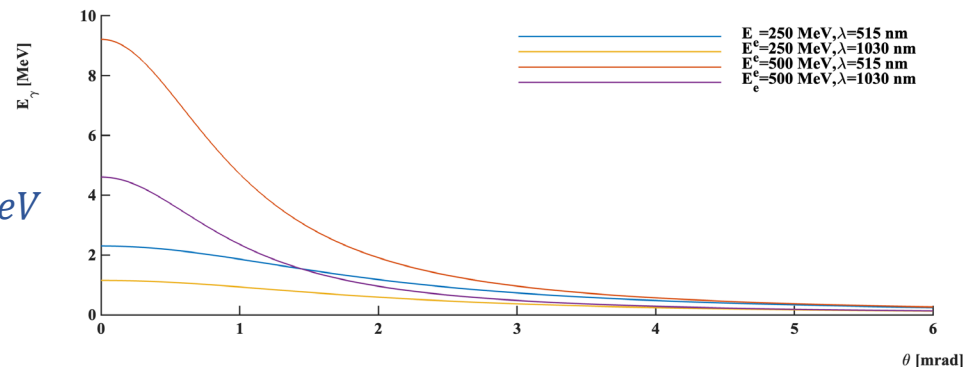


laser ($E_\lambda = hc/\lambda = 1.2$ eV)

Compton photon:

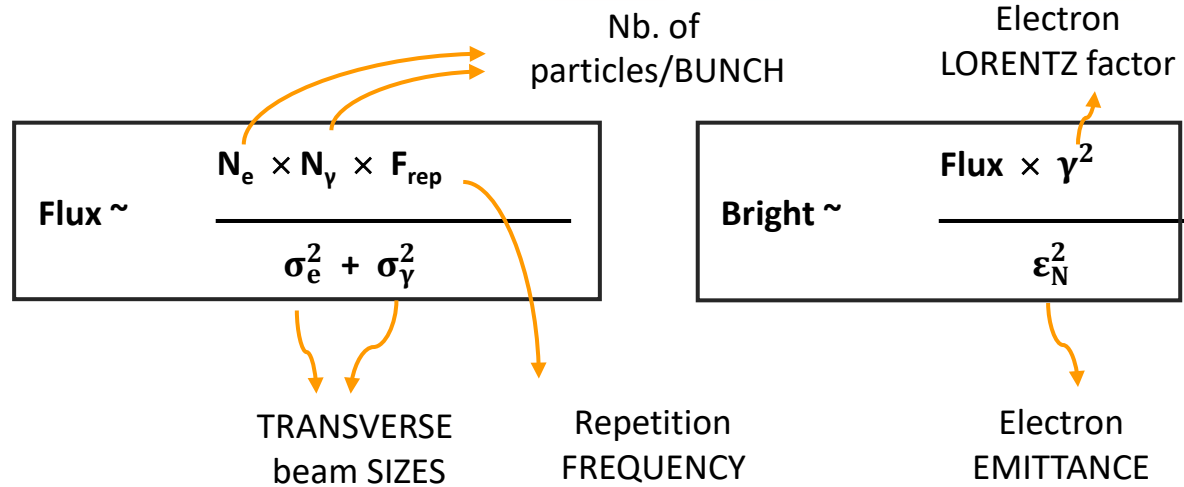
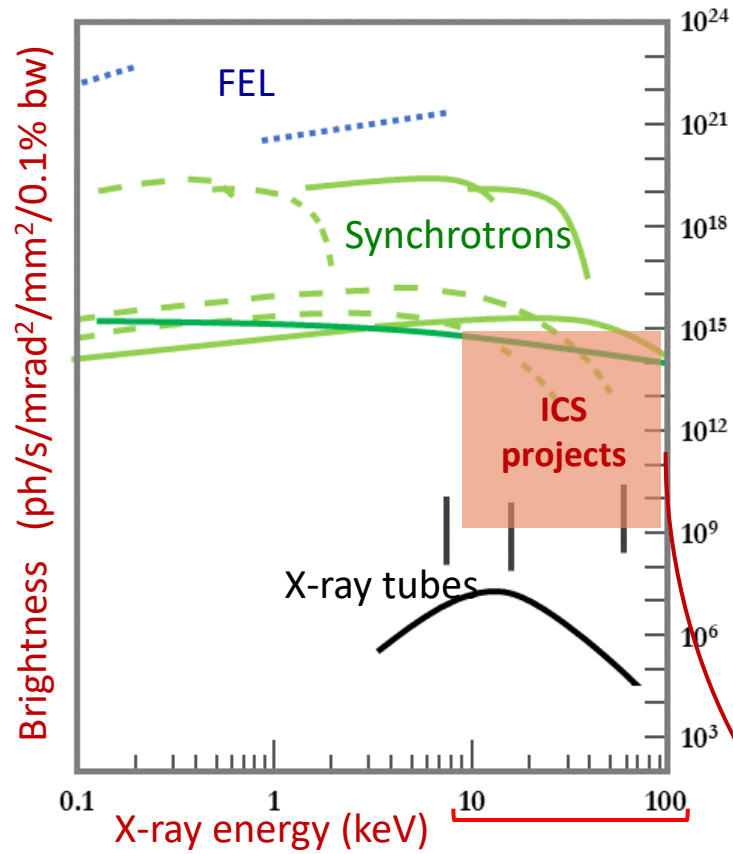
$$E_{X/\gamma} \approx \frac{4\gamma^2 \left(1 - \frac{\alpha^2}{4}\right)}{1 + \gamma^2 \theta^2} E_\lambda \approx 1.4 \text{ MeV}$$

e⁻ beam: $E_e = 250 \text{ MeV}$
 λ Laser = 1030 nm





High flux, high brightness: How?



Some powerful analyzes currently realized at synchrotrons and requiring a high brightness beam could be developed in a lab-size environment (hospitals, labs, museums).



Avg. Flux ~ $10^9 - 10^{14}$ ph/s Many projects in the last 15 years



Potentiality of an ICS on PERLE:

With PERLE 1 turn: 89 MeV → expected X-ray energy in the range of 100-300 keV (depending on used laser: Infra-red or green):

Most interesting applications areas are in this range of X-ray Energy:

- Cultural heritage field (imaging small statues, metallic relics),
- Palaeontology (large 10-20 cm thick fossils, skulls, bones, etc. from dinosaurs, mammut and hominids),
- Natural history (bones of large mammals as whales, but also horses etc.)
- monitoring rhinestones and fatigue of steel structures such as the hulls of merchant ships
- new field of investigation in radiotherapy applications. Examples include microbeam radiation therapy (MRT) or metal nanoparticle-based radiotherapy. A compact source with appropriate beam parameters provides a pathway to translating such applications into a clinical setting.

Courtesy to Aurélien Martens

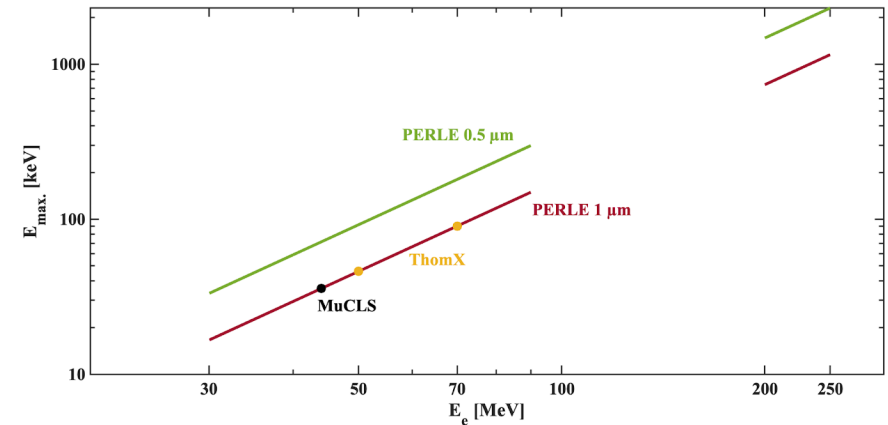


Figure 1: Maximum energy of photons produced with Compton backscattering X-ray sources as function of the electron beam energy. Different existing machines are indicated with points: MuCLS (black), ThomX at 50 and 70 MeV electron beam (orange). Thanks to the tunability of the electron beam in the PERLE accelerator, PERLE@1turn and PERLE@3turns are indicated with red and green lines for its use with an infrared or green laser



Elastic Scattering off radioactive Nuclei:

DESTIN @ PERLE (Deep Structure Investigation of exotic Nuclei):

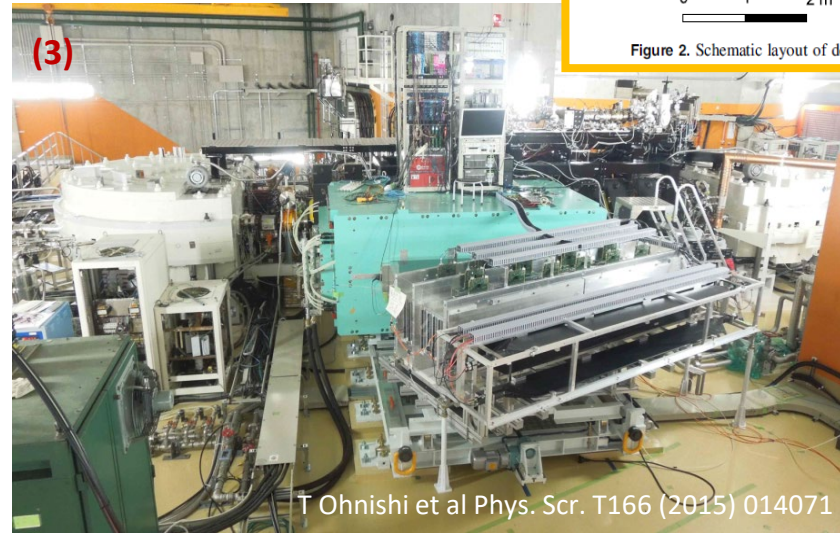
Perspectives for the study of form factors of exotic nuclei with PERLE with fixed target strategy : more compact, less resource demanding

This physics project at PERLE requires 3 major ingredients:

- a Radioactive Ion Beam (RIB) factory:
 - 1st option: acquire a Rhodotron (1)
 - 2nd option: build a photofission facility (e- beam 50 MeV 100uA).
- a Radioactive target preparation device (2): to be developed.
- an electron spectrometer (3)

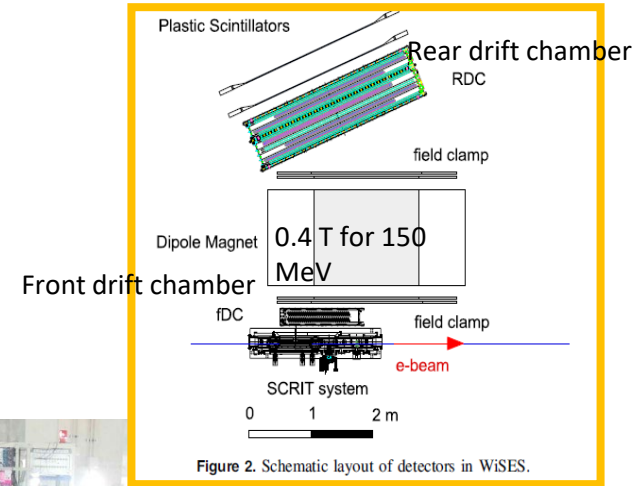


Rhodotron® TT300-HE
High Energy Electron Generator



T Ohnishi et al Phys. Scr. T166 (2015) 014071

Courtesy to David Verney

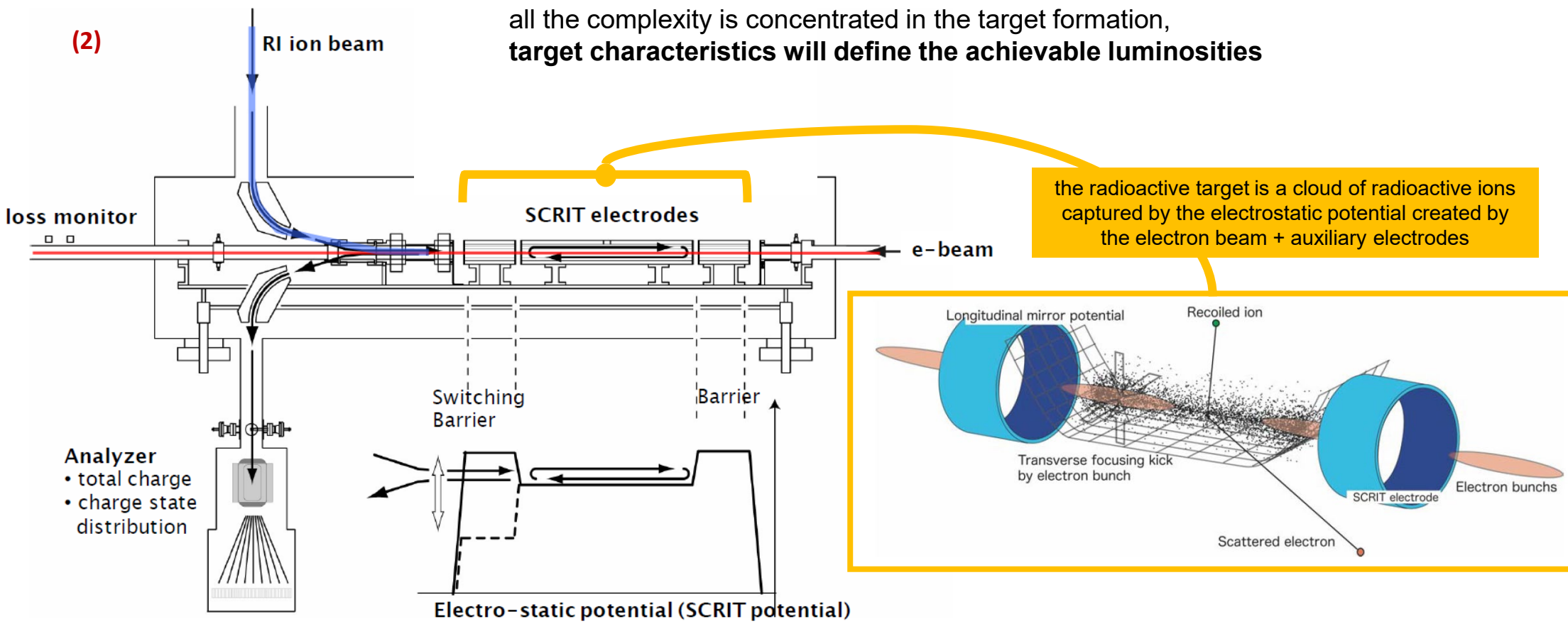




Elastic Scattering off radioactive Nuclei:

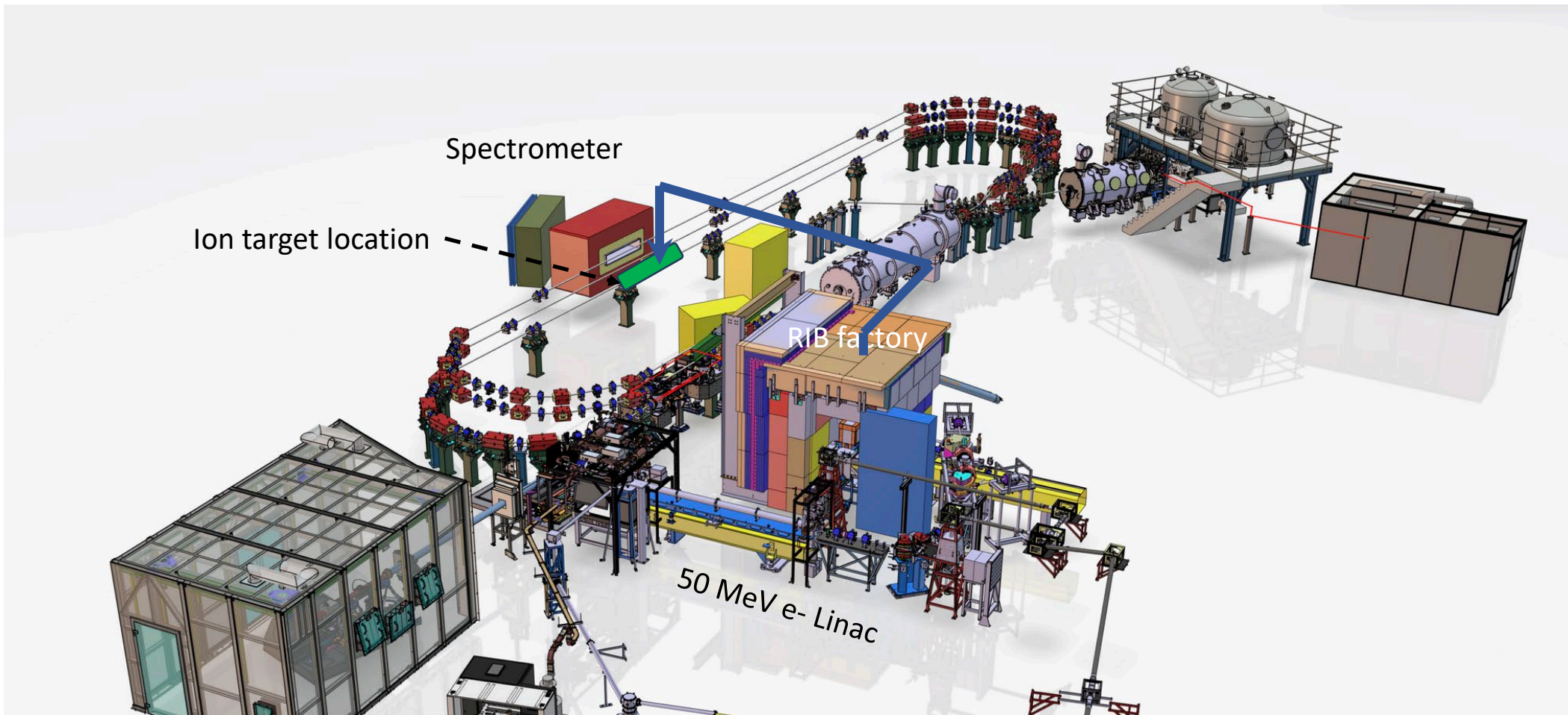
The radioactive target preparation device

(2)





Implementation of DESTIN @ PERLE:





Potentiality of an DESTIN @ PERLE:

past experiments on stable nuclei

- beam :

$I_e = 25 \mu\text{A}$

$E_e = 449.5 \text{ MeV}$; “energy spread” $\Delta E = 0.5 \text{ MeV}$

- target :

0.5 mm thick !

400 mg/cm² equiv. $4.1 \times 10^{21} \text{ atoms/cm}^2$

- luminosities upto : $\mathcal{L} \simeq 10^{32} \text{ cm}^{-2}\text{s}^{-1}$

3 orders of magnitude
more

10 to 11 orders of
magnitude less

future fixed-target RI experiments

- beam :

$I_e = 20 \text{ mA}$ (PERLE nominal)

- target :

a cloud of ions !

exact amount ? $10^{10-11} \text{ atoms/cm}^2$

- luminosity difficult to evaluate exactly (the size of the e beam is far from being the only driving parameter !)

- The ball is also in the court of nuclear physics : design and optimization of the “target”, need to invent new trapping strategies.
- A serious evaluation of the achievable luminosities can only be obtained thanks to more elaborate simulations: (eg charge state evolutions).
- A demonstrator is mandatory



Thank you for your attention