PRAE: a new platform for Research and Applications with Electrons in Orsay

Dominique Marchand, Institut de Physique Nucléaire d'Orsay

GDR QCD
ANNUAL MEETING

November 8-10, 2016 – IPN Orsay

Multi-disciplinary platform

- **PRAE: a multi-disciplinary site** based on the **high-performance electron beam** with energy range **50 MeV** - **140 MeV**.
- **Strong complementary expertise** of IMNC, IPNO and LAL groups.

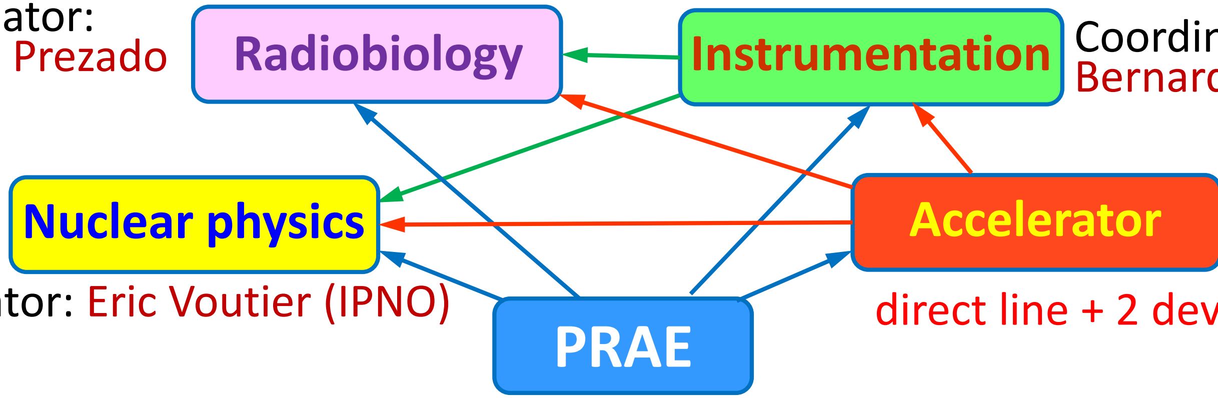
Imagerie et Modélisation en Neurobiologie et Cancérologie

Institut de Physique Nucléaire

Laboratoire de l'Accélérateur Linéaire

Coordinator: Yolanda Prezado (IMNC)

Coordinator: Bernard Génolini (IPNO)



Coordinator: Angeles Faus-Golfe (LAL)

Coordinator: Eric Voutier (IPNO)

direct line + 2 deviated lines

Project coordinator: **Sergey Barsuk** (LAL);
Technical coordinator: **Patricia Duchesne** (IPNO)

Outline

- the electron accelerator: foreseen properties, R&D status, site

- Instrumented line for users: generic detector test bench

- Radiobiology: roadmap towards pre-clinical studies

- Nuclear physics: ep scattering => Proton Electric Form Factor at very low Q^2

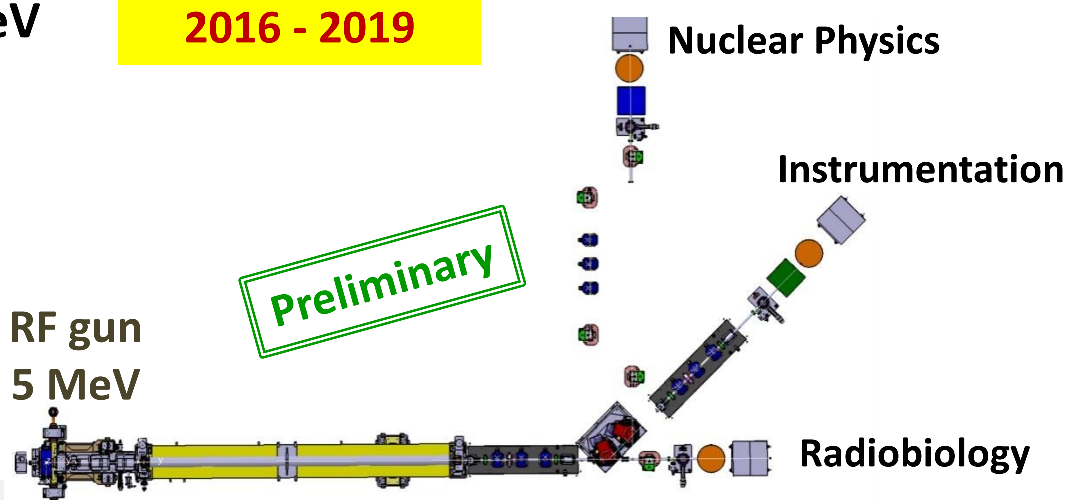
- Summary

PRAE: time phases of the project

❑ **Phase 1:** **RF gun at 50 Hz; 50-70 MeV**

2016 - 2019

Direct + 2 deviated lines; scanning dipole for radiobiology; spectrometer for instrumentation; magnetic chicane for nuclear physics.



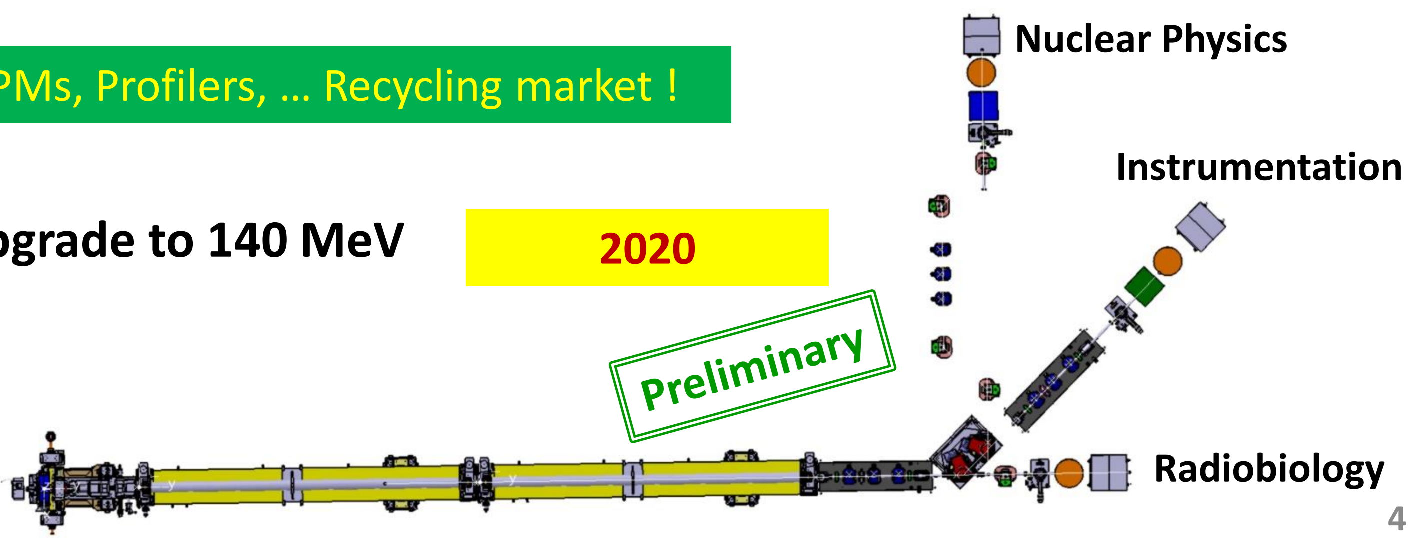
M. EL Khaldi, L. Garolfi, "RF Design of a high gradient S-Band Travelling wave accelerating structure for THOMX LINAC", Proceedings of IPAC2015, Richmond, VA, USA.

High Gradient S-band cavity (25 MV/m)
Collaboration with PMB-Alcen company

Modulators, BPMs, Profilers, … Recycling market !

❑ **Phase 2:** **energy upgrade to 140 MeV**

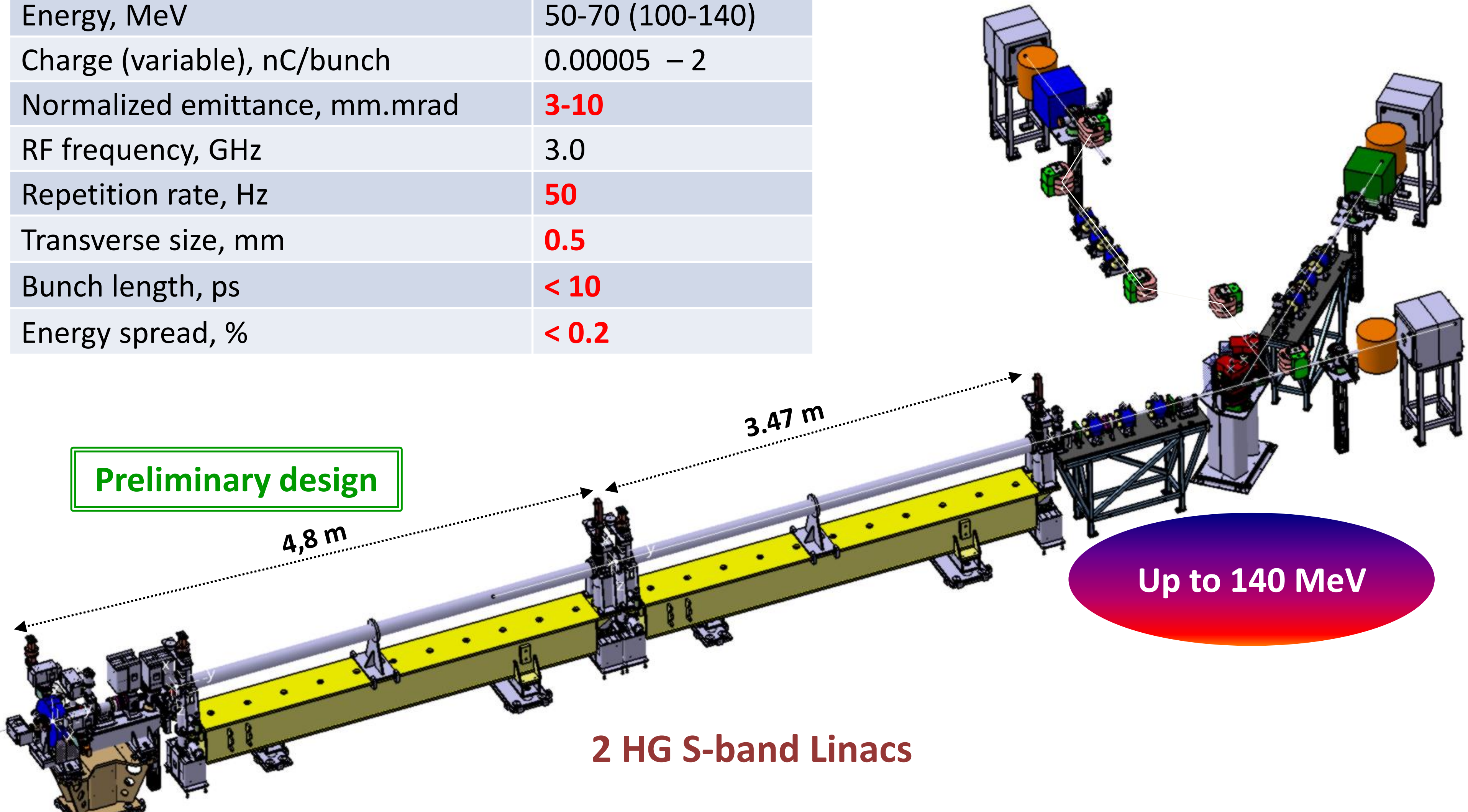
2020



Electron accelerator: design and parameters

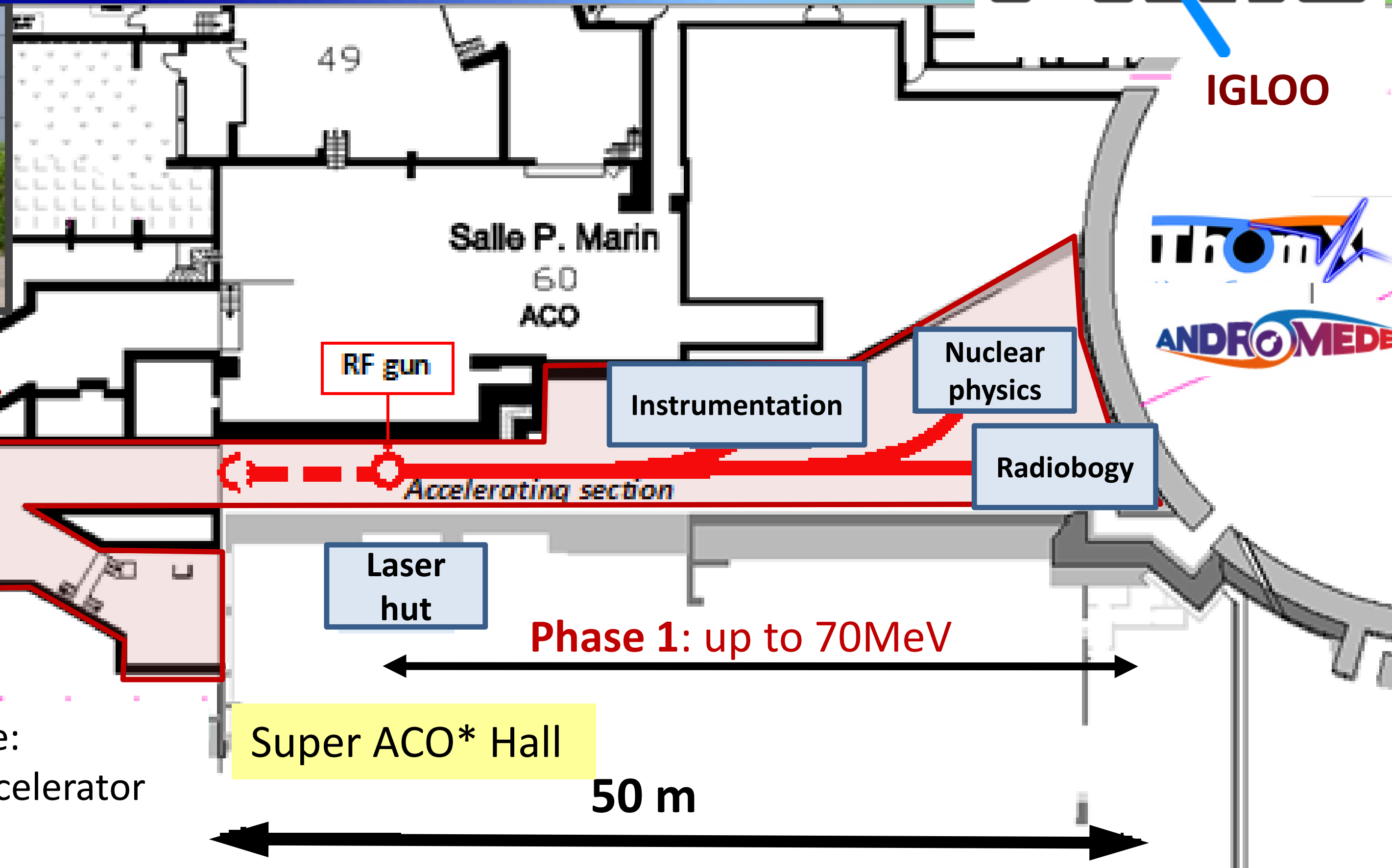
Beam parameters	Time phase 1 (2)
Energy, MeV	50-70 (100-140)
Charge (variable), nC/bunch	0.00005 – 2
Normalized emittance, mm.mrad	3-10
RF frequency, GHz	3.0
Repetition rate, Hz	50
Transverse size, mm	0.5
Bunch length, ps	< 10
Energy spread, %	< 0.2

Preliminary design

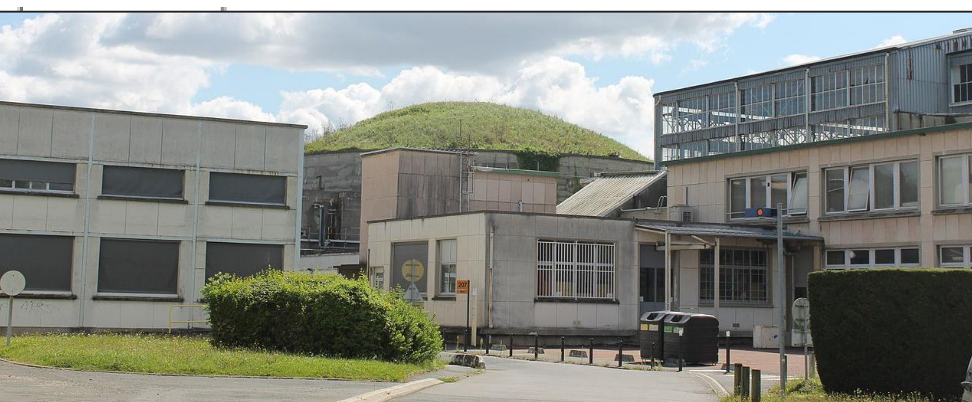


Re-use of the **unique site of the former Linear Accelerator** and its infrastructure

PRAE infrastructure (LAL building)



PRAE infrastructure: former site of linear accelerator (1959-2003)

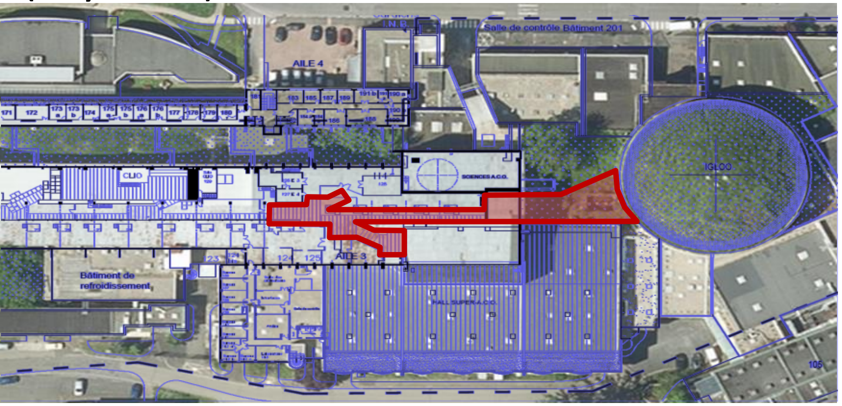


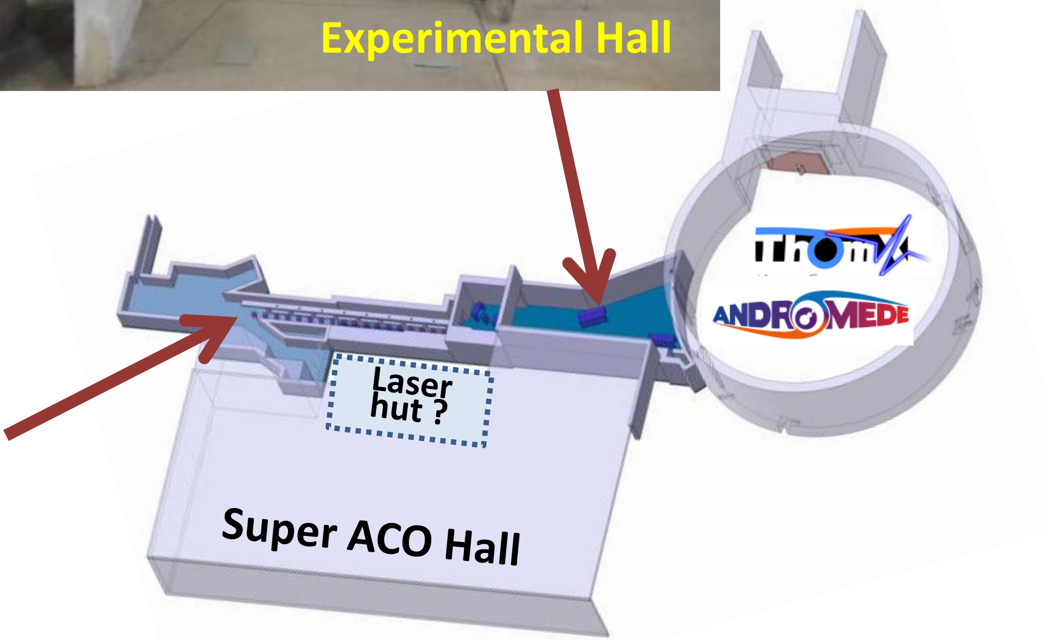
Classification waved now !

*ACO: Anneau de collision d'Orsay

PRAE infrastructure in LAL building

(Sky view)





Intrumentation R&D

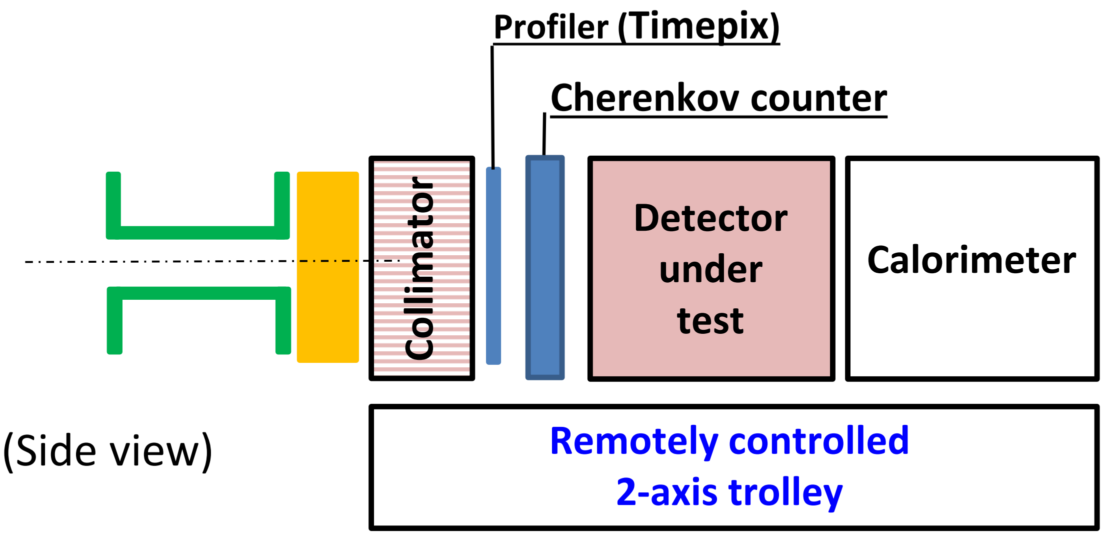
Fully-equipped versatile tool for precision instrumentation R&D based on high-performance electron beam

- **Excellent technical performance**
  - **Timing** reference, < 10 ps bunch length
  - **Charge accuracy**, RMS < 2×10^{-3}
  - Low straggling (energy >> 1 MeV)

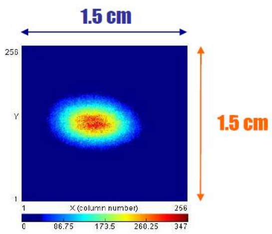
- **High-performance, remotely controlled tools**
  - **Beam position, profile and monitoring**
  - 60 digitization channels for users on NARVAL-based **data acquisition**
  - Motorized **moving table for scans**, accuracy < 500 μm

High-quality test bench for tests and optimization of detectors of users from research and indusdrial media

Intrumentation R&D

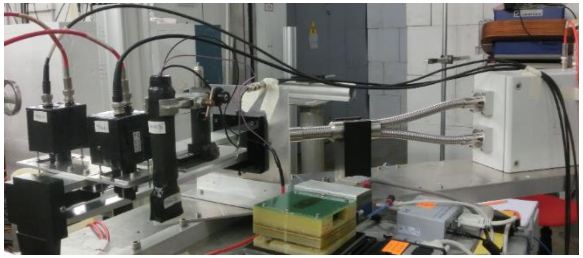


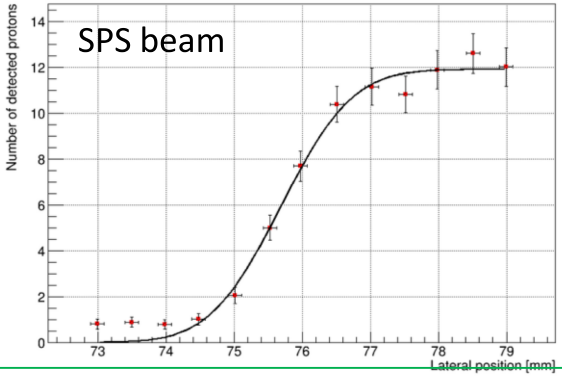
Timepix detector for precision spot measurement



Cherenkov quartz counter for intensity monitoring

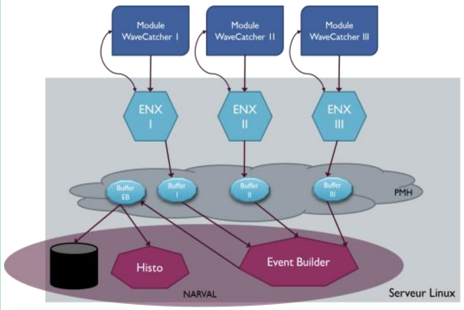
2 channel Cherenkov counters (LAL) tested at BTF (Frascati); installed in the SPS (CERN) beam pipe





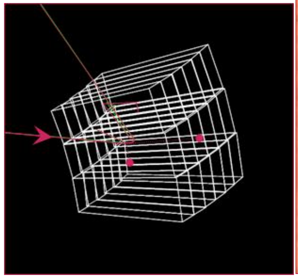
DAQ + slow control

- 60 user digitization signals (WaveCatcher)
- DCOD = NARVAL + ENX



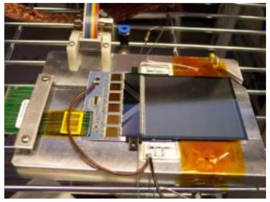
Calorimeter for energy monitoring

BGO scintillator crystals in compact matrix geometry

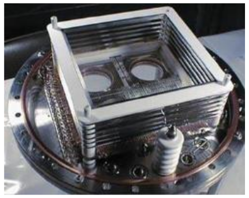


Example of a calorimeter realized at IPN

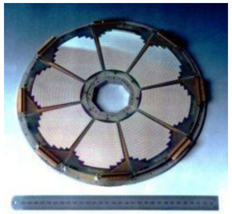
Instrumentation R&D: examples



- **Detector tests** (time and charge response, uniformity)
  - Electromagnetic calorimeters (ILC, FCC)
  - R&D / tests for PRAE nuclear physics and radiotherapy setups
  - Particle channeling with bent crystals (UA9 project at CERN)
  - Cherenkov Detectors (Tau-Charm factory)
  - Gaseous detectors (ALERT R&D on drift chamber for JLAB, Micromegas R&D for TPC developments)
  - R&D on diamond detectors (LHC upgrades, KEK, …)
  - ../…



- **Irradiation study of semiconductor devices**
  - Monolithic Pixel Sensors (MAPS) for future vertex detectors
  - DEPFET pixel detectors for X-ray astronomy
  - Vertex detectors for ILC and FCC



A **test platform** for major **instrumentation projects in Particle Physics, Nuclear Physics, Astrophysics, Solid Physics, …**

Radiobiology: motivation (1)

- ❑ Radiotherapy (RT) is one of the most frequently used method for **cancer** treatment
- ❑ Treatment of some **radio resistant tumors** and tumors close to a delicate structure (i.e. spinal cord) is currently **limited**

Normal tissue complication probability **versus** **Tumor destruction efficiency**

The main challenge in RT is to find **novel** approaches leading to an increase of the normal tissue resistance

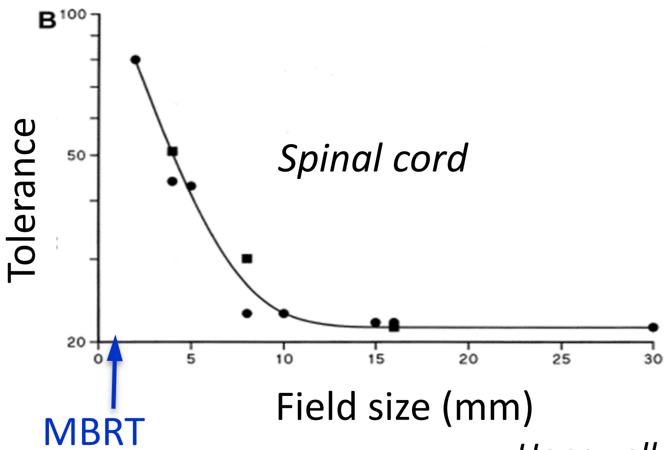
- **Free parameters:** particle, beam energy and intensity, way to deliver dose (in space & time)
- **Protons:** well defined path, precise location of the energy deposition (peak of Bragg) **BUT** too few treatment centers due to a high cost (e.g. 2 in France, …)
- At hospitals mainly **photons** and **electrons** (**2-25 MeV**) are used => superficial tumors Lateral scattering = > normal tissue damage, field sizes > cm^2

Radiobiology: spatial fractionnated dose

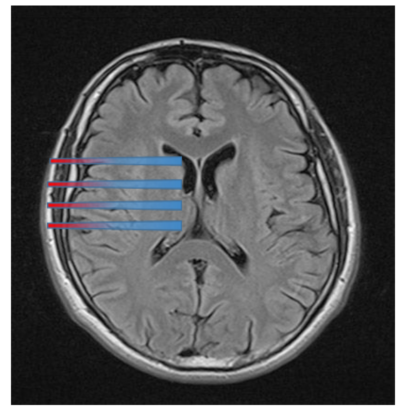
X-ray minibeam radiation therapy (MBRT)

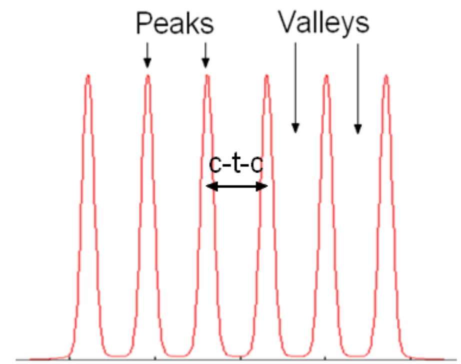
submillimetric field sizes + **spatial fractionation of the dose**

instead of several cm^2 — *instead of homogeneous distributions*



Hopewell 2000





- ❑ Exponential increase of normal (rat) brain resistance.

Y. Prezado et al., Rad. Research 84 (2015) 314

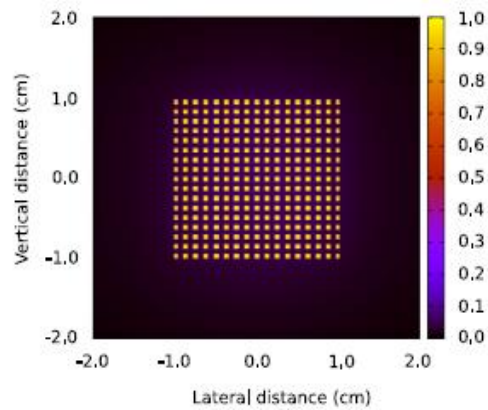
- ❑ It opens the path for a **dose escalation in the tumor**.

Combining these 2 effects allows to increase the dose delivered to a tumor as normal tissues are much more preserved

Radiobiology: « Very High » Energy Electrons

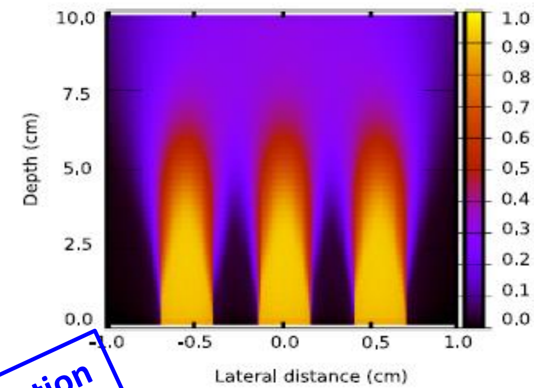
Advantages of very **high energy electrons** (VHEE): **120-250 MeV:**

- **Beams get wider in depth** due to multiple Coulomb scattering
- Normal tissues benefit from **spatial fractionation** of the dose while a (quasi) homogeneous dose distribution is achieved in the tumor.



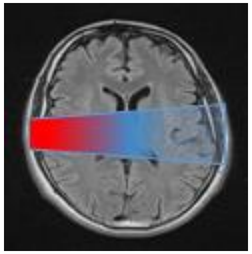
View of the *virtual* grid (use of a scanning dipole)

Simulation



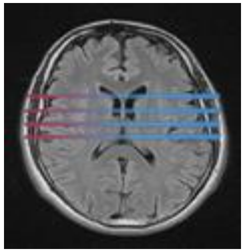
2D dose distributions

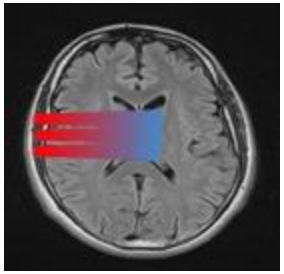
Very high energy electrons (VHEE)



+

Spatial fractionation of the dose (MBRT)





Very high energy electron Grid Therapy (*eHGRT*)
Promising principle
⇨ biological effects to be evaluated

Martinez and Prezado, Med. Phys. 2015

How radiation physical parameters impact biological response ?

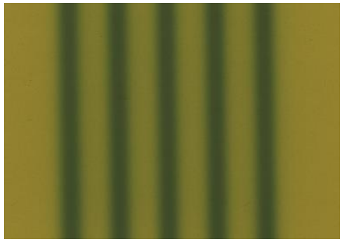
Physical dose

Biological dose

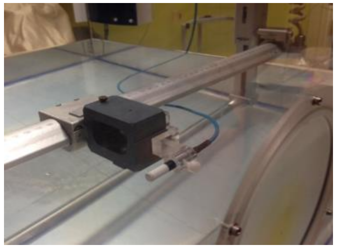
Radiobiology: pre-clinical studies program

- Innovative **dosimetry for very small field sizes**

<u>Experimental dosimetry</u>



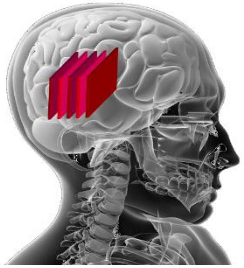
Film



Microdiamond detector

and

<u>Dose calculation engine Monte-Carlo based</u>



→ Treatment planning

- **Confirmation of the hypothesis of high normal tissue resistance**

Whole rat brain irradiation protocol

> - Evaluation of acute and long-term effects (one year follow-up):
> - ***Clinical status*** *(survival, neurological damages)*
> - ***Follow up*** *(blood brain barrier breakdown, edemas, hemorrhages)*
> - ***Histological analysis*** *(tissue integrity, demyelination, neuronal cell loss, necrosis)*

Nuclear Physics: Proton charge radius puzzle

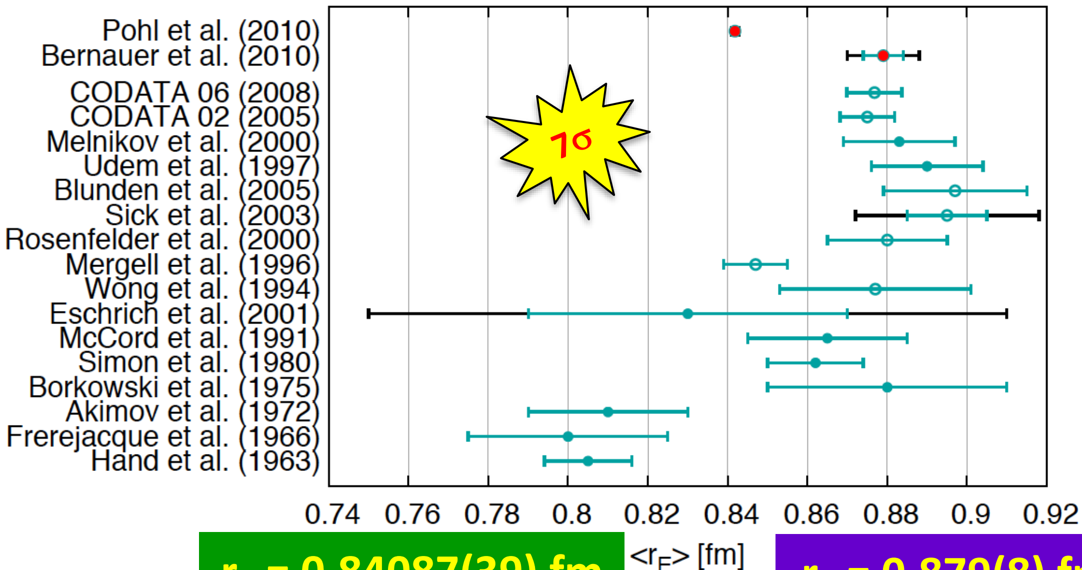
- Determination of the proton charge radius from

  muonic hydrogen Lamb shift

  significantly differs from that using

  electronic hydrogen Lamb shift and **electron scattering**.

Courtesy of M. Distler



r_p = 0.84087(39) fm

r_p = 0.879(8) fm

- Search for **explanations from experimental issues, theory, …** :

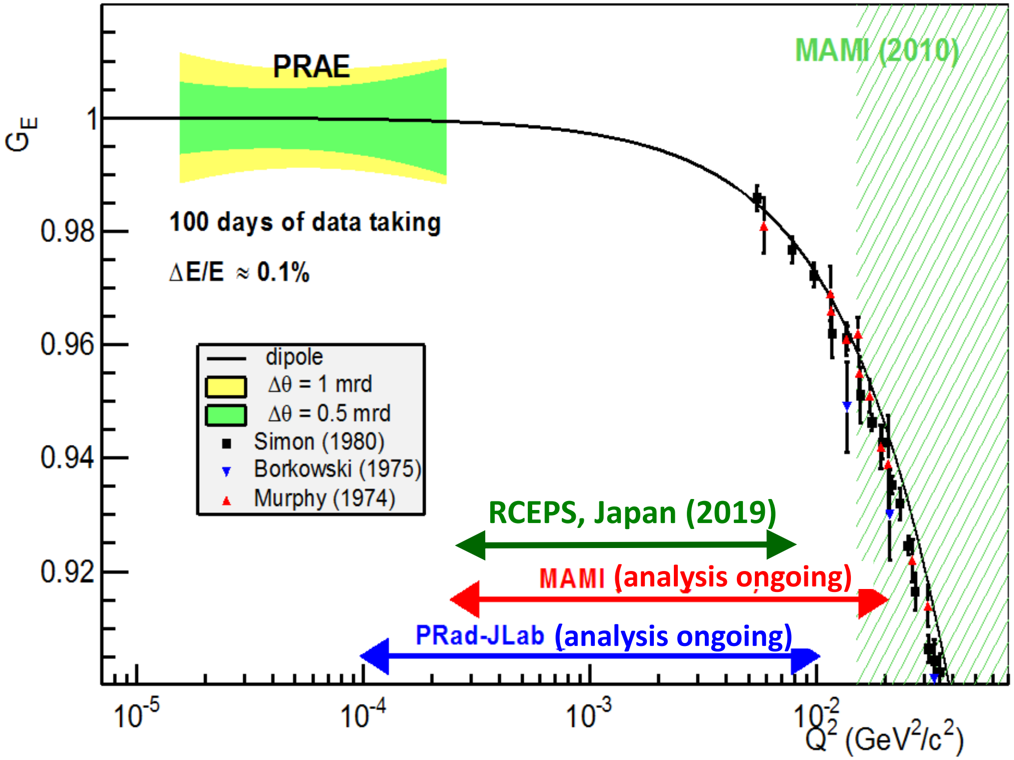
  Underestimated uncertainties / Bad radius determination / Lepton non-universality / New force/particles / Novel hadronic physics / … → no consensus.

- **More data / different experiments needed !**

ProRad@PRAE

- The **ProRad** experiment at **PRAE** aims at accurate measurements (**≤1%**) of the electric form factor of the proton $\mathbf{G_E(Q^2)}$ at **very low** four-momentum transfer squared $\mathbf{Q^2}$.

$$\frac{d^2\sigma}{d\Omega} \equiv \frac{d^2\sigma}{d\Omega}\bigg|_{Mott} G_E\left(Q^2\right) \quad \Rightarrow \quad r_p^2 = -\frac{6\hbar^2}{G_E(0)} \frac{\partial G_E\left(Q^2\right)}{\partial Q^2}\bigg|_{Q^2=0}$$



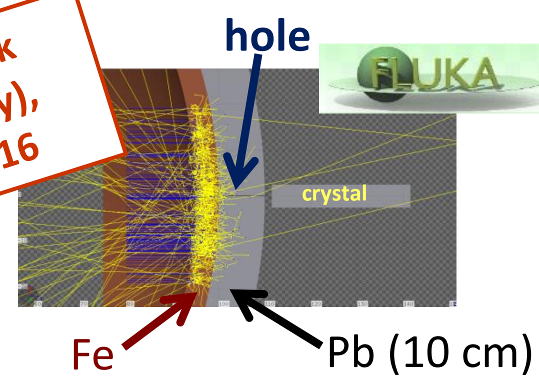
- Measurements in the **unexplored** Q^2-range $\mathbf{1.5\times10^{-5}}$ **-** $\mathbf{3\times10^{-4}}$ **(GeV/c)²** will **constrain** the **Q^2- dependence** of $\mathbf{G_E}$ and the **extrapolation to zero** important for the determination of the **proton charge radius**.

- Any **deviation from 1** would indicate **genuine effects**

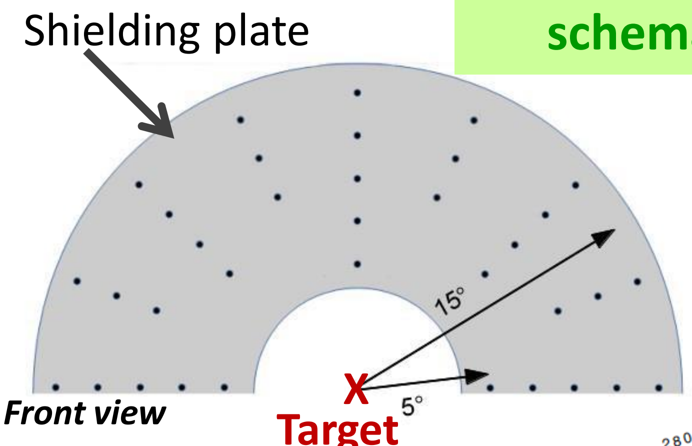
ProRad@PRAE: apparatus concept

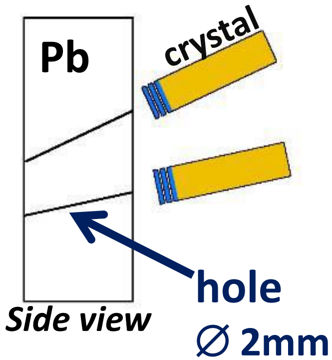
- Measurements of the **ep elastic** scattering cross section **(< 1% level)** between **5°** and **15°**
- Windowless thin solid hydrogen target (10 - 20 μm thick)
- Mechanical definition of scattering angles via small holes drilled in a thick shielding plate (no B nor tracking)

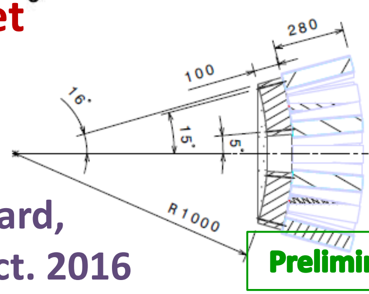
S. Cholak's work (Kiev University), Sept.-Oct. 2016

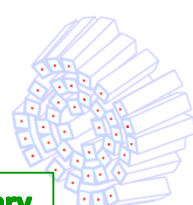


Very preliminary and schematical design









C. Le Galliard, IPNO/RDD, Oct. 2016

2 year post-doctoral position available

NOW !

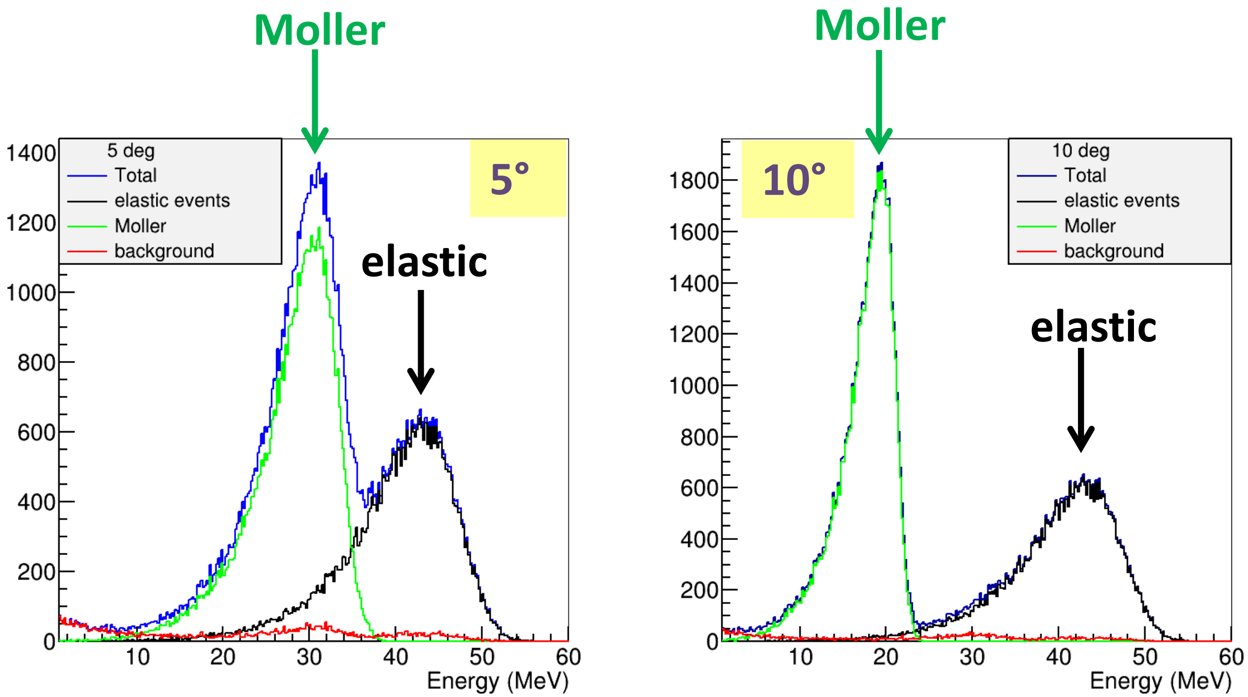
(Starting 1st trimester 2017)

http://ipnwww.in2p3.fr/?lang=en

voutier@ipno.in2p3.fr

Nuclear Physics: experimental technique

- The **energy deposit spectra** in a calorimeter allow separation between **elastic** and **Møller** electrons scattered in the same direction



- Absolute **normalization** from **simultaneous** measurement of **ep elastic** and **ee Møller** scattering within the **same detector** using **kinematic** separation.

Requirements:

- Precise **beam**: $\Delta E/E = 10^{-3}$, $\sigma_{x,y} < 0.5$ mm, $\Delta\theta < 1$ mrad
- Control of **radiative effects**

Summary

- PRAE is a new innovative multi-disciplinary project in the heart of the Paris-Saclay Valley site for science, R&D and applications as well as education relying on complementary IMNC – IPN – LAL expertise, and based on an electron linear accelerator (50-140 MeV)
- The fully equipped instrumentation platform will be available for users from academic and industrial for detector R&D and tests
- Radiotherapy with high energy electrons (140 MeV): potential to be demonstrated (biological effect)
- Nuclear physics: contribution to solve the proton charge radius puzzle increasing the number of data on electric form factor in a Q^2 range from 10^{-5} – 10^{-4} $(GeV/c)^2$

Design started before summer 2016, 1st results expected by end of 2020

Perspective:

- *Infrastructure and PRAE design allows an upgrade to 300 MeV*

The collaboration: up to now ~60 people

P. Ausset, S. Barsuk, M. Ben Abdillah, L. Berthier, P. Bertho, J. Bettane, J.-S. Bousson, L. Burmistrov, F. Campos, V. Chaumat, J.-L. Coacolo, O. Duarte, R. Dupré, P. Duchesne, N. El Kamchi, M. El Khaldi, A. Faus-Golfe, L. Garolfi, B. Genolini, A. Gonnin, M. Guidal, H. Guler, P. Halin, G. Hull, M. Imre, M. Josselin, M. Juchaux, W. Kaabi, R. Kunne, M. Langlet, P. Laniece, F. Lefebvre, C. Le Galliard, P. Lepercq, C. Magueur, B. Mansoux, D. Marchand, A. Maroni, B. Mathon, B. Mercier, H. Monard, C. Muñoz Camacho, T. Nguyen Trung, S. Niccolai, M. Omeich, Y. Peinaud, L. Pinot, Y. Prezado, K. Pressard, V. Puill, B. Ramstein, S. Rousselot, A. Said, A. Semsoum, C. Sylvia, A. Stocchi, C. Vallerand, M.A. Verdier, O. Vitez, E. Voutier, J. van de Wiele, S. Wurth

IMNC
Imagerie et Modélisation en Neurobiologie et Cancérologie

IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY
Institut de Physique Nucléaire

LAL LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE
Laboratoire de l'Accélérateur Linéaire

P2IO Physique des 2 Infinis et des Origines

îledeFrance

CNRS

UNIVERSITÉ PARIS SUD

université PARIS-SACLAY

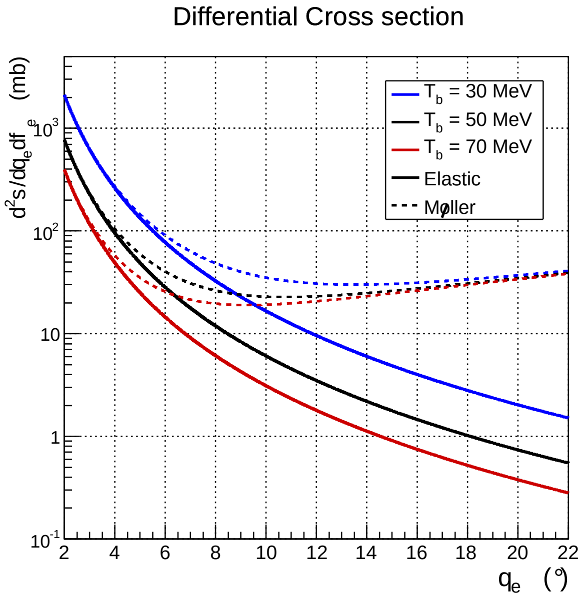
Everyone is welcome !

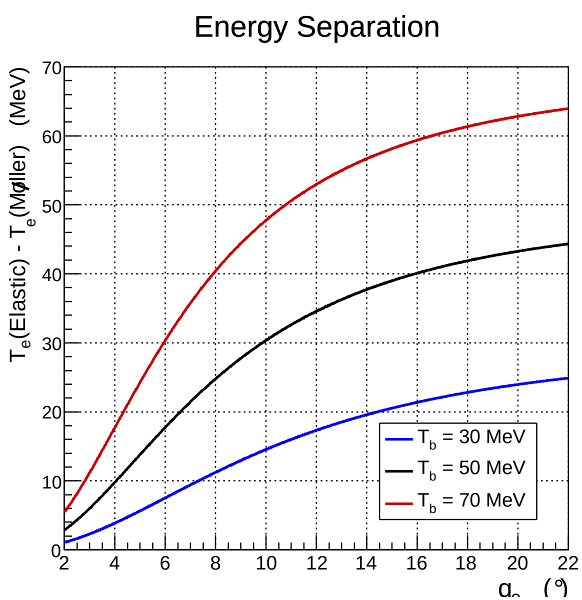
Propositions of subjects which can be addressed at PRAE are highly encouraged !

1st PRAE workshop in Spring 2017

Thank you for your attention

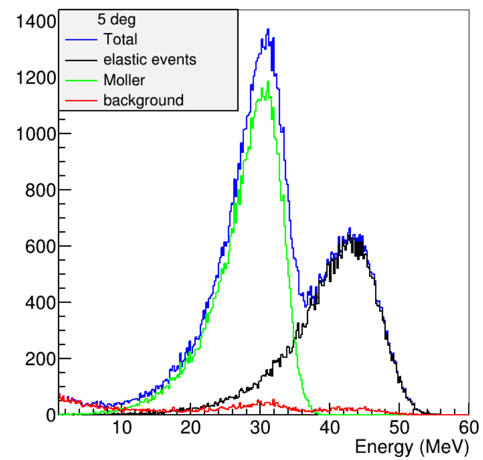
Nuclear Physics: experimental technique

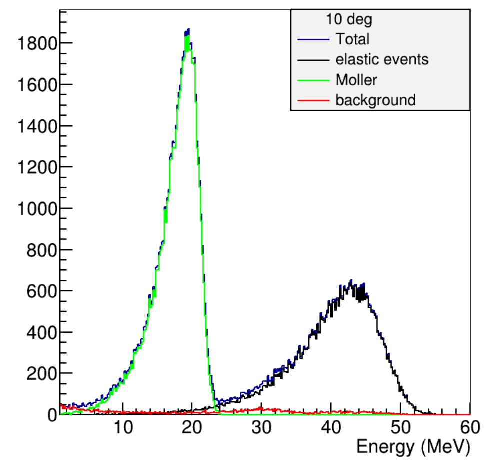




- ❑ Measurements of the **ep elastic** scattering between **5°** and **15°** in **absence** of any **magnetic field** and **tracking system**.

- ❑ The **energy deposit spectra** in calorimeter allow separation between **elastic** and **Møller** electrons





- ❑ Absolute **normalization** from **simultaneous** measurement of **ep elastic** and **ee Møller** within the **same detector** using scattered electron kinematic separation.

- ❑ Precise **beam**:

$$\Delta E/E = 10^{-3},\ \sigma_{x,y} < 0.5\ \text{mm},\ \Delta\theta < 1\ \text{mrad}$$