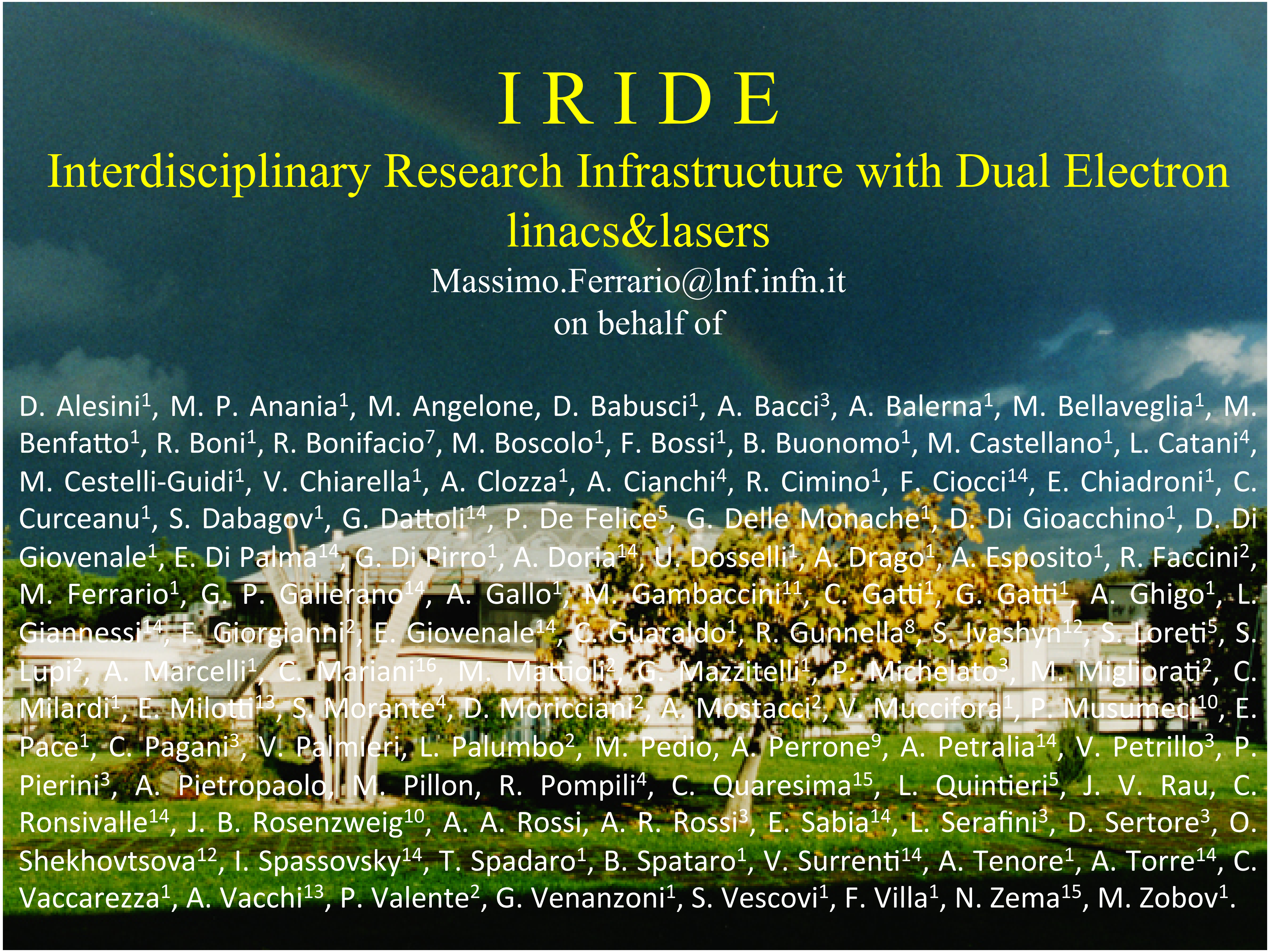

IRIDE

Interdisciplinary Research Infrastructure with Dual Electron linacs&lasers

Massimo.Ferrario@lnf.infn.it
on behalf of

D. Alesini[1], M. P. Anania[1], M. Angelone, D. Babusci[1], A. Bacci[3], A. Balerna[1], M. Bellaveglia[1], M. Benfatto[1], R. Boni[1], R. Bonifacio[7], M. Boscolo[1], F. Bossi[1], B. Buonomo[1], M. Castellano[1], L. Catani[4], M. Cestelli-Guidi[1], V. Chiarella[1], A. Clozza[1], A. Cianchi[4], R. Cimino[1], F. Ciocci[14], E. Chiadroni[1], C. Curceanu[1], S. Dabagov[1], G. Dattoli[14], P. De Felice[5], G. Delle Monache[1], D. Di Gioacchino[1], D. Di Giovenale[1], E. Di Palma[14], G. Di Pirro[1], A. Doria[14], U. Dosselli[1], A. Drago[1], A. Esposito[1], R. Faccini[2], M. Ferrario[1], G. P. Gallerano[14], A. Gallo[1], M. Gambaccini[11], C. Gatti[1], G. Gatti[1], A. Ghigo[1], L. Giannessi[14], F. Giorgianni[2], E. Giovenale[14], C. Guaraldo[1], R. Gunnella[8], S. Ivashyn[12], S. Loreti[5], S. Lupi[2], A. Marcelli[1], C. Mariani[16], M. Mattioli[2], G. Mazzitelli[1], P. Michelato[3], M. Migliorati[2], C. Milardi[1], E. Milotti[13], S. Morante[4], D. Moricciani[2], A. Mostacci[2], V. Muccifora[1], P. Musumeci[10], E. Pace[1], C. Pagani[3], V. Palmieri, L. Palumbo[2], M. Pedio, A. Perrone[9], A. Petralia[14], V. Petrillo[3], P. Pierini[3], A. Pietropaolo, M. Pillon, R. Pompili[4], C. Quaresima[15], L. Quintieri[5], J. V. Rau, C. Ronsivalle[14], J. B. Rosenzweig[10], A. A. Rossi, A. R. Rossi[3], E. Sabia[14], L. Serafini[3], D. Sertore[3], O. Shekhovtsova[12], I. Spassovsky[14], T. Spadaro[1], B. Spataro[1], V. Surrenti[14], A. Tenore[1], A. Torre[14], C. Vaccarezza[1], A. Vacchi[13], P. Valente[2], G. Venanzoni[1], S. Vescovi[1], F. Villa[1], N. Zema[15], M. Zobov[1].

IRIDE

Interdisciplinary Research Infrastructure with Dual Electron linac&laser

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on behalf of

(1) INFN-LNF
(2) INFN and Universita’ di Roma”La Sapienza”
(3) INFN and Universita’ di Milano
(4) INFN and Universita’ di Roma”Tor Vergata”
(5) Istituto Nazionale di Metrologia delle Radiazioni Ionizzanti, ENEA C R Casaccia.
(7) INFN and Universidade Federal da Paraiba, Brazil
(8) Universita’ di Camerino
(9) INFN and Universita’ del Salento
(10) UCLA, Los Angeles, USA
(11) INFN and Universita’ di Ferrara
(12) ITP NSC KIPT, Kharkov, Ukraine
(13) INFN and Universita’ di Trieste
(14) ENEA – Frascati
(15) CNR
(16) CNISM and Universita’ di Roma”La Sapienza”

IRIDE

An Interdisciplinary Research Infrastructure based on Dual Electron linac&laser

Giovedi' 14 Marzo – Auditorium Touschek – INFN-LNF

10:15 Welcome coffee

11:00 Welcome Address – U. Dosselli (LNF director)

11:15 Plenary session 1 – chair: Dr. U. Dosselli (LNF director)

11:15 IRIDE Overview – M. Ferrario (INFN-LNF)
11:45 Superconducting linac system – P. Pierini (INFN-Mi)
12:15 High energy laser system – L. Serafini (INFN-Mi)

13:00 Lunch break

14:00 Plenary session 2 – chair: Dr.ssa. R. Fantoni (ENEA-Frascati)

14:00 Electron-positron and electron-electron colliders - D. Babusci (INFN-LNF)
14:20 Electron-gamma collider – G. Venanzoni (INFN-LNF)
14:40 Photon-photon collider - E. Milotti (Uni. Trieste & INFN-Ts)
15:00 Free electron laser sources – G. Dattoli (ENEA-Frascati)
15:20 Free electron laser scientific case – M. Benfatto (INFN-LNF)
15:40 Detectors for free electron lasers – A. Castoldi (Politecnico-Mi)

16:00 Coffee break

16:30 Plenary session 3 – chair: Prof.ssa C. Petrillo (Universita' di Perugia)

16:30 Thz source – E. Chiadroni (INFN-LNF)
16:45 Thz source scientific case – S. Lupi (Uni. Roma – La Sapienza)
17:00 Neutron source – P. Valente (INFN-RM1)
17:15 Neutron source scientific case – T. Pietropaolo (ENEA-Frascati)
17:30 Nuclear photonics - G. Colo' (INFN-Mi)
18:00 Advanced accelerator concepts – A. R. Rossi (INFN-Mi)

18: 30 END of day 1

Venerdi' 15 Marzo – Auditorium Touschek - LNF

9:15 Plenary session 1 - Auditorium Touschek

9:15 Working group tasks and organization

10:15 Coffee break

10:45 Parallel sessions

Aula Seminari Div Acc.: **WG1 - Electron Machine (SC linac and RF) including:**
- Physics of and with FELs, Detectors,
- THz Source,
- Neutron Source

Aula Conversi: **WG2: Photon Machine (Lasers and Optics) including:**
- Physics of and with Comtpon Sources, Detectors
- γ–γ and e-γ colliders

Auditorium Touschek: **WG3: Electron-electron and electron-positron colliders**

13:00 Lunch break

14:00 Plenary session 2 – WG Summary and discussion - Auditorium Touschek

14:00 WG1 Summary A. Gallo (INFN-LNF)
14:15 WG2 Summary C. Vaccarezza (INFN-LNF)
14:30 WG3 Summary C. Gatti (INFN-LNF)
14:45 Discussion

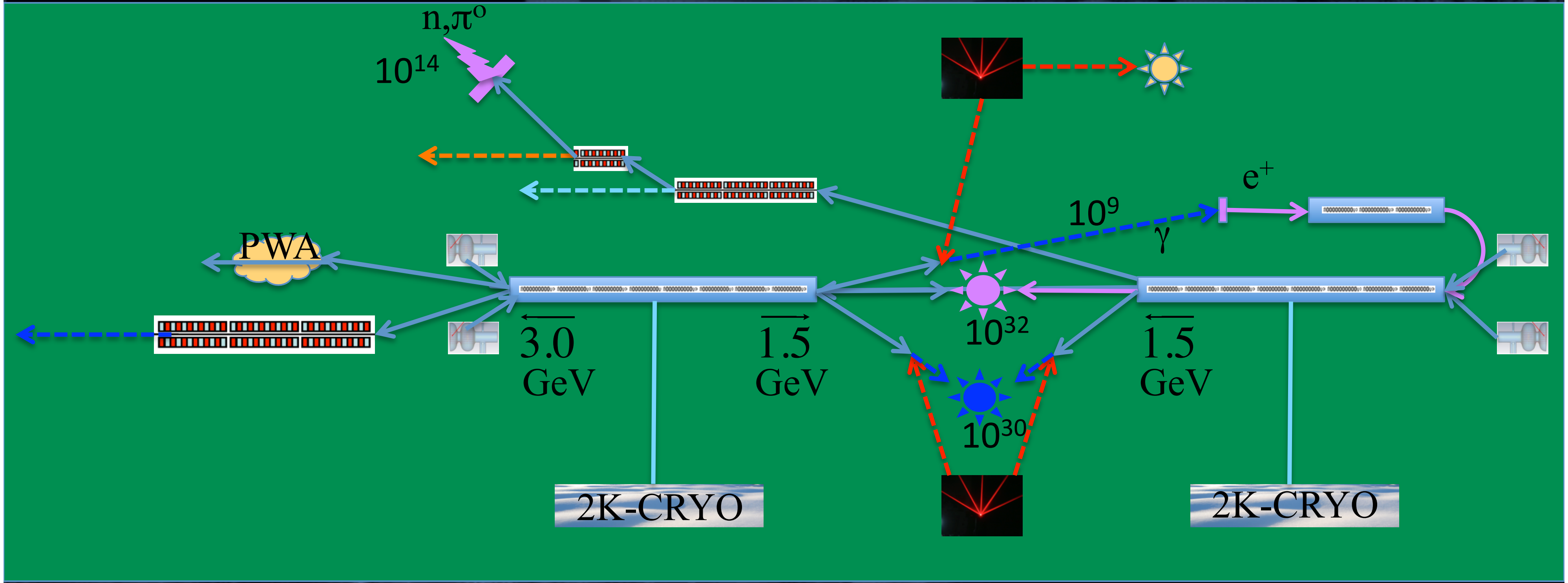
16:00 END of day 2

di Camerino
rsita' del Salento
Angeles, USA
ersita' di Ferrara
Kharkov, Ukraine
ersita' di Trieste
IEA
NR
' di Roma"La Sapienza"
(17) Politecnico di Milano and INFN-Mi

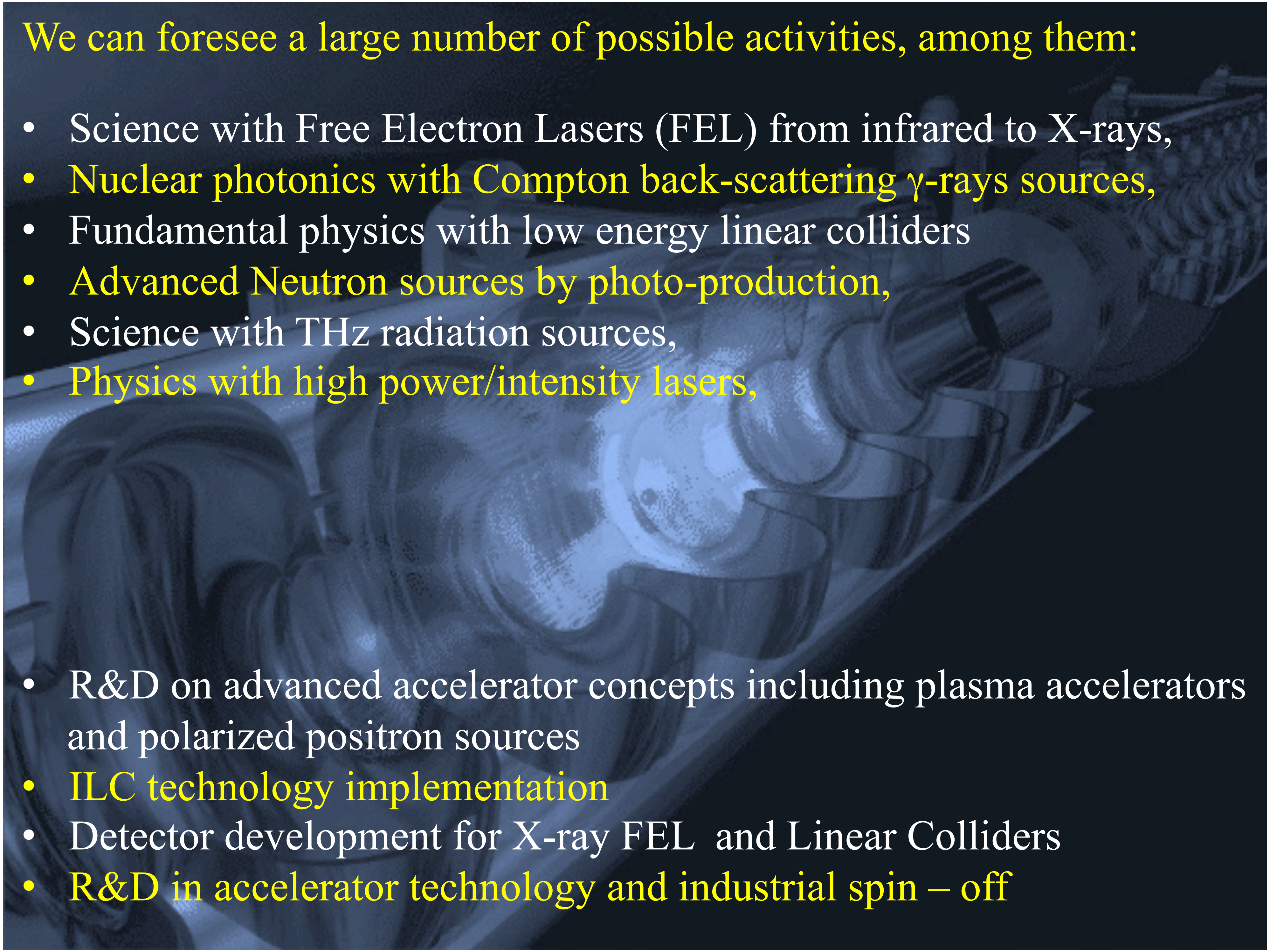
, Universities)
Id=6006)

https://agenda.infn.it/conferenceDisplay.py?ovw=True&confId=6006

IRIDE is a large infrastructure for fundamental and applied physics research. Conceived as an innovative and evolutionary tool for multi-disciplinary investigations in a wide field of scientific, technological and industrial applications, it will be a high intensity “particle beams factory”.



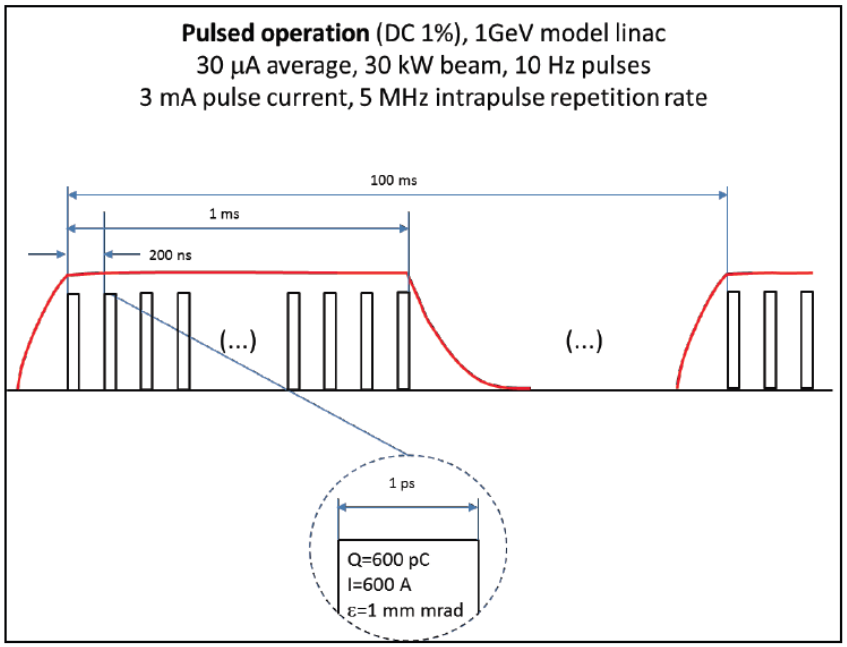
Based on a combination of a high duty cycle radio-frequency superconducting electron linac (SC RF LINAC) and of high energy lasers it will be able to produce a high flux of electrons, photons (from infrared to γ-rays), neutrons, protons and eventually positrons, that will be available for a wide national and international scientific community interested to take profit of the most advanced particle and radiation sources.



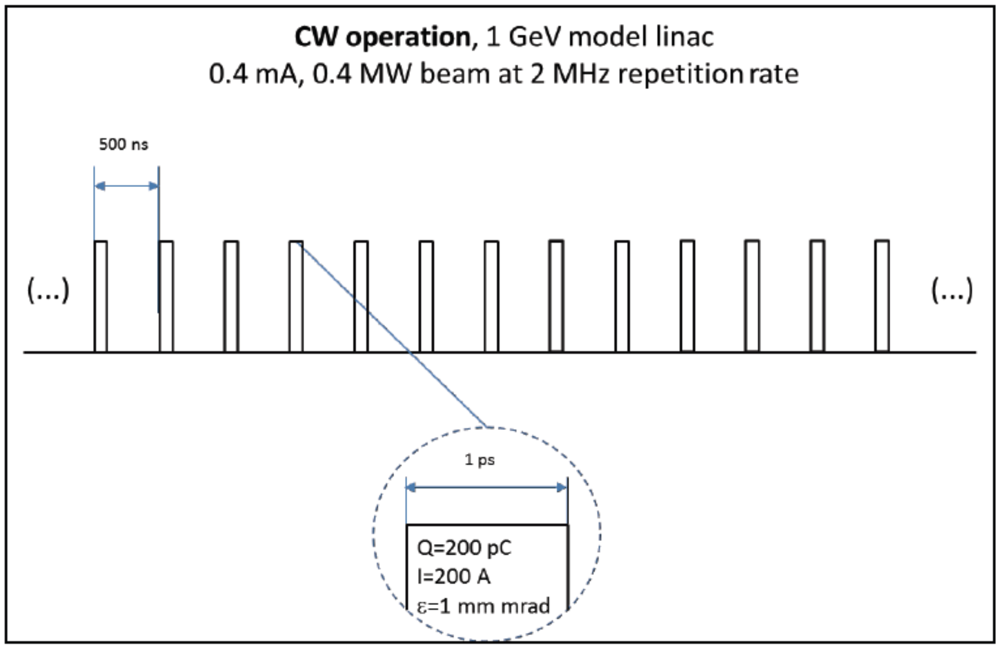
We can foresee a large number of possible activities, among them:

- Science with Free Electron Lasers (FEL) from infrared to X-rays,
- Nuclear photonics with Compton back-scattering γ-rays sources,
- Fundamental physics with low energy linear colliders
- Advanced Neutron sources by photo-production,
- Science with THz radiation sources,
- Physics with high power/intensity lasers,
- R&D on advanced accelerator concepts including plasma accelerators and polarized positron sources
- ILC technology implementation
- Detector development for X-ray FEL and Linear Colliders
- R&D in accelerator technology and industrial spin – off

The main feature of a SC linac relevant for IRIDE is the possibility to operate the machine in continuous (CW) or quasi-continuous wave (qCW) mode with high average beam power (>1 MW) and high average current (>300 μA).



Pulsed operation (DC 1%), 1GeV model linac
30 μA average, 30 kW beam, 10 Hz pulses
3 mA pulse current, 5 MHz intrapulse repetition rate



CW operation, 1 GeV model linac
0.4 mA, 0.4 MW beam at 2 MHz repetition rate

The CW or qCW choice, combined with a proper bunch distribution scheme, offers the most versatile solution to provide bunches to a number of different experiments, as could be envisaged in a multi-purpose facility.

IRIDE LINAC possible pulsed Configurations (single linac)

$$Q_{ext}^{opt} \approx \frac{V_{acc}}{(R/Q)I_b}$$

$$\frac{P_{ref}}{P_{fwd}} = |\rho|^2 \approx \frac{\left(Q_{ext}^{opt} - Q_{ext}\right)^2}{\left(Q_{ext}^{opt} + Q_{ext}\right)^2}$$

$$V_{asympt} \approx 2\sqrt{(R/Q)Q_{ext}P_{RF}}$$

	Pulse 1	Pulse 2	Pulse 3
E [GeV]	1	1,5	2
I (within pulse) [mA]	4	3	2
I (average) [mA]	0,47	0,28	0,12
Pulse rep. rate [Hz]	100	100	100
RF pulse duration [ms]	1,5	1,5	1,5
RF Duty cycle [%]	15	15	15
Beam pulse duration [ms]	1,16	0,93	0,60
Beam Duty cycle [%]	11,6	9,3	6,0
f_{RF} [MHz]	1300	1300	1300
E_{acc} [MV/m]	7,53	11,29	15,05
Cavity length L [m]	1,038	1,038	1,038
R/Q [Ohm]	1036	1036	1036
Q_0	1,50E+10	1,20E+10	1,00E+10
Q_{ext}_opt	1,89E+06	3,77E+06	7,54E+06
Q_{ext}	3,50E+06	3,50E+06	3,50E+06
Reflected RF power [%]	9,0	0.14	13,5
Cavity BW [Hz]	185,71	185,71	185,71
Cavity rise time [ms]	0,86	0,86	0,86
Rise-time to target V_{acc} [ms]	0,34	0,57	0,90
# of cavies	128	128	128
# of modlules	16	16	16
$P_{beam/}$cavity (pulse) [kW]	31,25	35,16	31,25
P_{beam}/cavity (ave) [kW]	4,69	5,27	4,69
P_{RF}/cavity (pulse) [kW]	34,06	35,20	35,44
P_{RF}/cavity (ave) [kW]	5,11	5,28	5,32
Available P_{RF}/cavity (pulse) [kW]	40,00	40,00	40,00
unloaded asyntotic voltage [MV]	24,09	24,09	24,09
P_{cryo}_RF (@ 2 K) [W]	75,41	212,09	452,46
P_{cryo}_static (@ 2 K) [W]	56,00	56,00	56,00
P_{cryo}_total (@ 2 K) [W]	131,41	268,09	508,46
Total P_{beam} (peak) [kW]	4000	4500	4000
Total P_{beam} (ave) [kW]	465,60	417,95	241,39
Linac length [m]	192	192	192

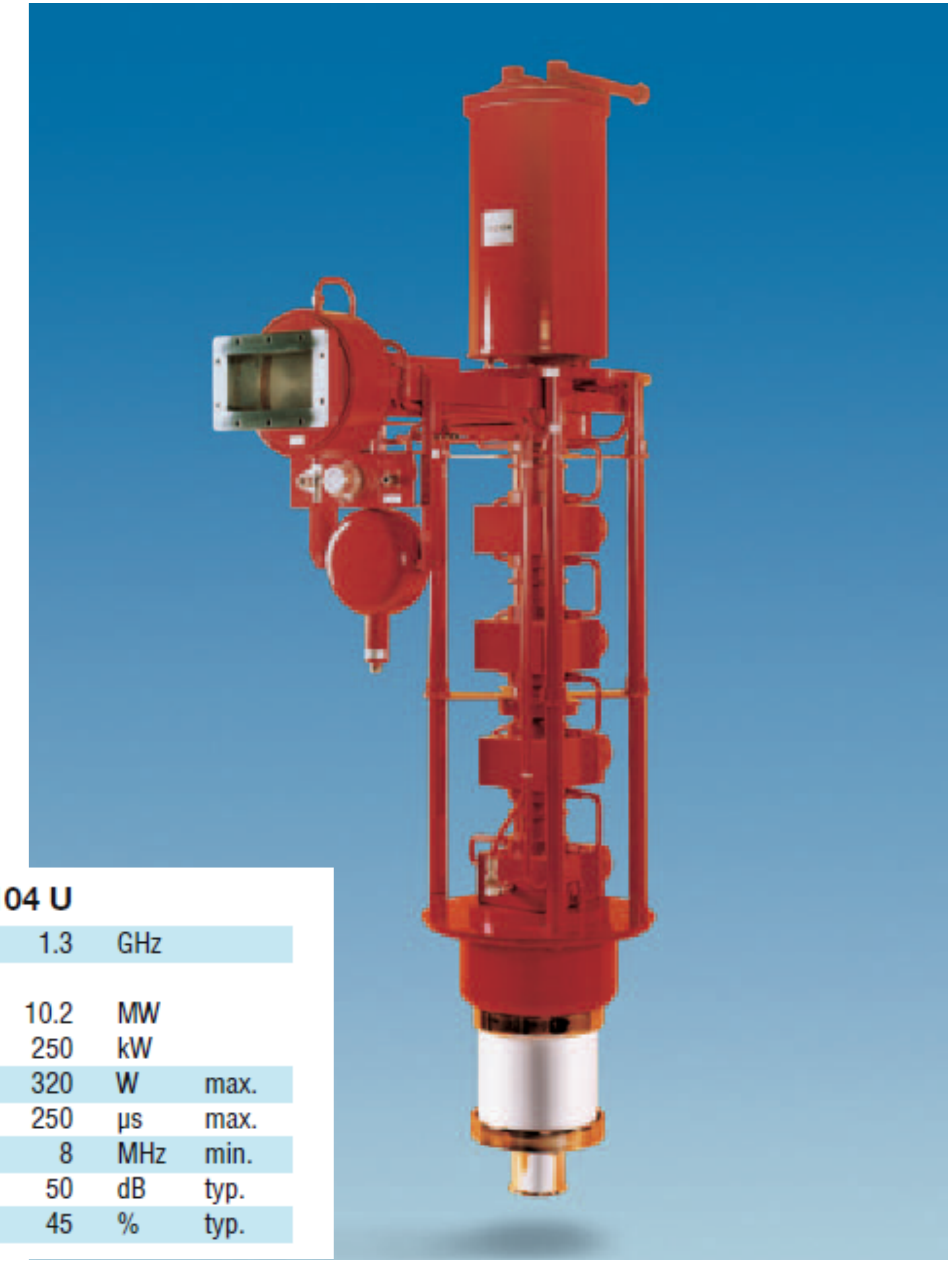
IRIDE LINAC

possible RF sources

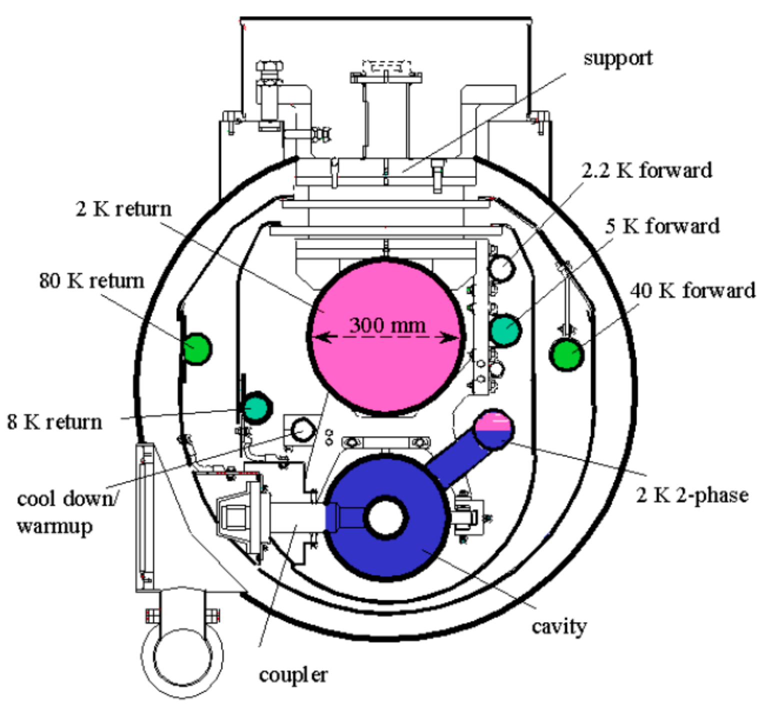
- x 3 pulse duration (from 0.5 to 1.5 ms);
- 1/3 peak power (from 5.1 to 1.7 MW);
- same rep rate (100 Hz) and ave Power (250 kW)

Reasonable but to be verified with manufacturer!

RF performance	**TH 2104 C**	**TH 2104 D**	**TH 2104 U**		
Frequency	1.3	1.3	1.3	GHz	
RF output power					
• peak	5.1	5.1	10.2	MW	
• average	100	250	250	kW	
Peak RF drive power	200	200	320	W	max.
RF pulse duration	2 000	500	250	µs	max.
- 1dB bandwidth	8	8	8	MHz	min.
Saturated gain	47	47	50	dB	typ.
Efficiency	46	45	45	%	typ.



INFN is in a leading position in the SC RF technology, with knowledge and strong capabilities in the design, engineering and industrial realization of all the main component of a superconducting radiofrequency accelerator.

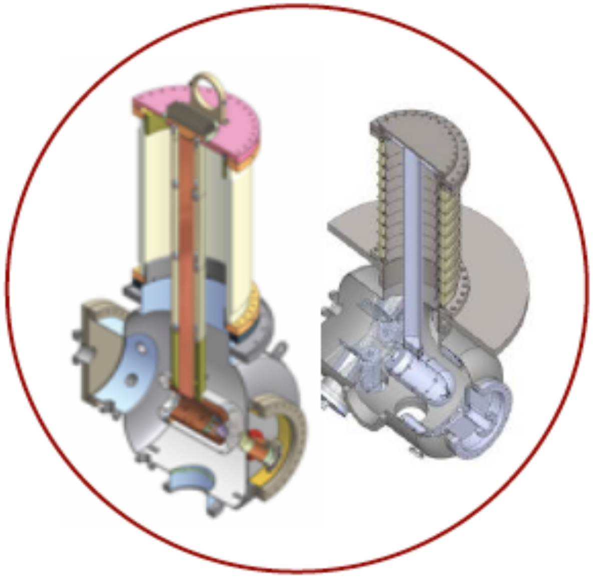


INFN strongly participated to TESLA since the early design stages through the final engineering and shares the know-how and has the recognized intellectual property of several main components one of which is the cryo-module concept and its evolution.

XFEL Italian In-Kind contribution

- **INFN** contributed to linac design
- Italian industry, with INFN supervision provides
  - **400/800** of the 1.3 GHz cavities
    - Fabricated, processed, ready for RF tests
  - **45/100** of the cryomodules
- INFN provides also
  - High QE photocathode preparation/transport system
  - Cavities/Cryomodule for the 3.9 GHz linearizer
- i.e. main components for a **9 GeV SC linac**...

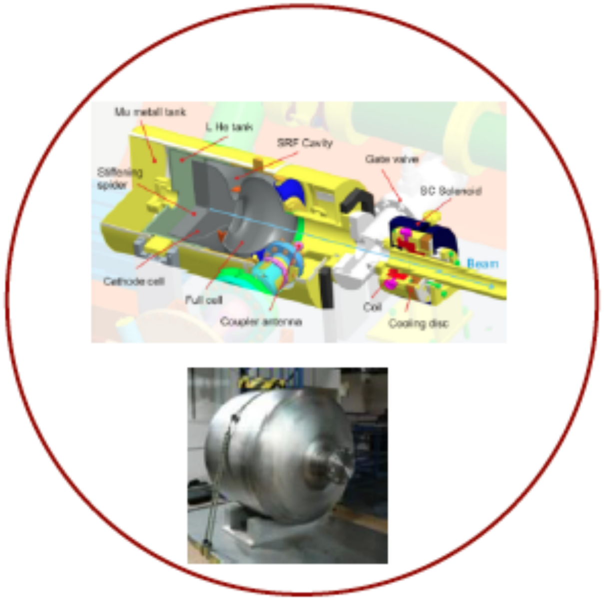
Electron Guns



DC guns

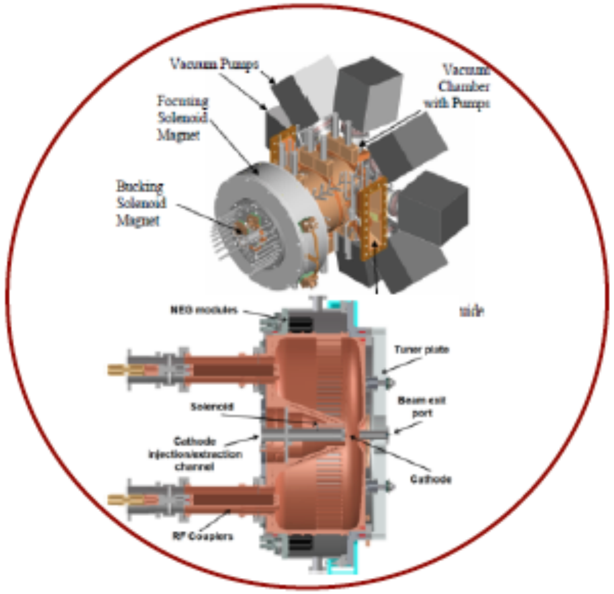
\+

Hybrid Schemes



SC RF guns

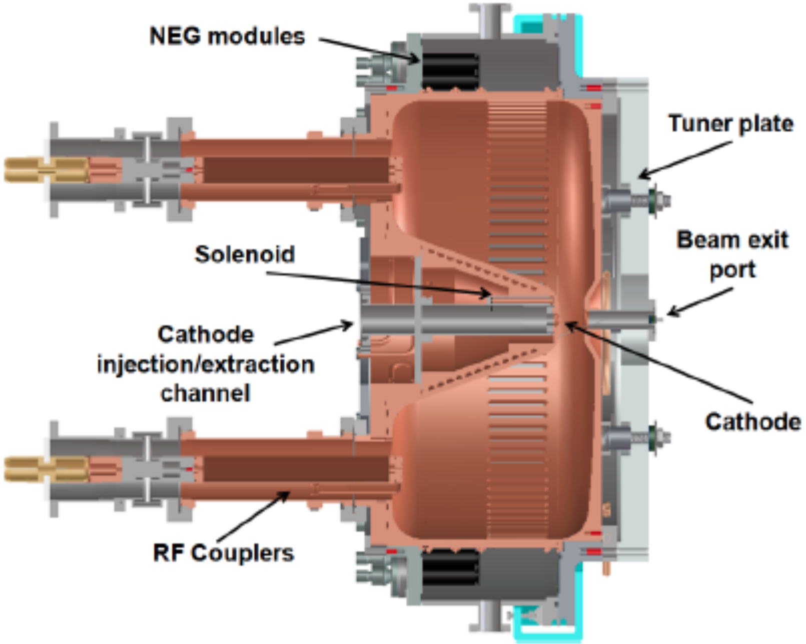
- CW operation
- High field
- Low pressure
- Low Dark current



Low freq. (<~ 700 MHz) NC CW RF guns

The LBNL VHF Gun

The Berkeley normal-conducting scheme satisfies all the LBNL FEL requirements simultaneously.



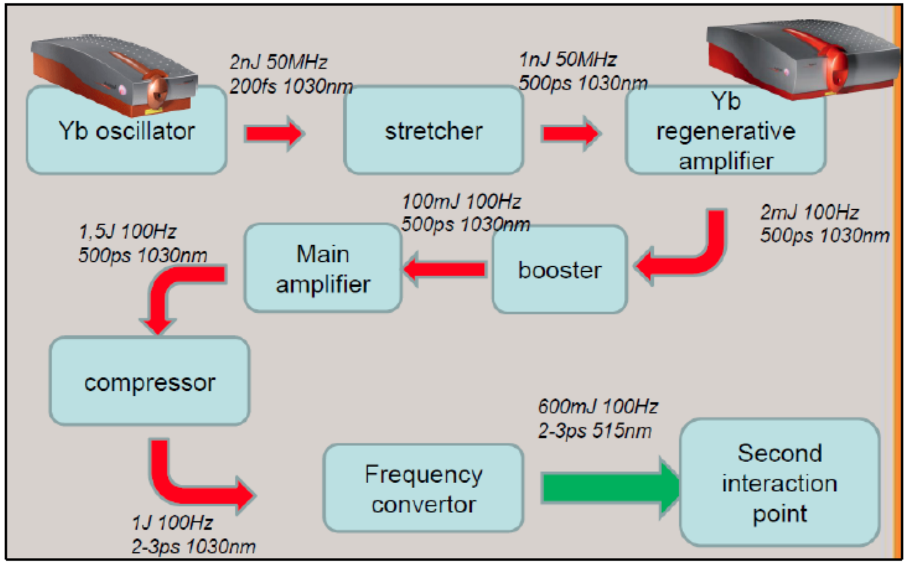
J. Staples, F. Sannibale, S. Virostek, CBP Tech Note 366, Oct. 2006

K. Baptiste, et al, NIM A 599, 9 (2009)

Frequency	186 MHz
Operation mode	CW
Gap voltage	750 kV
Field at the cathode	19.47 MV/m
Q_0 (ideal copper)	30887
Shunt impedance	6.5 MΩ
RF Power	100 kW
Stored energy	2.3 J
Peak surface field	24.1 MV/m
Peak wall power density	25.0 W/cm^2
Accelerating gap	4 cm
Diameter/Length	69.4/35.0 cm
Operating pressure	~ 10^{-11} Torr

- At the VHF frequency, the cavity structure is large enough to withstand the heat load and operate in CW mode at the required gradients.
- Also, the long λ_{RF} allows for large apertures and thus for high vacuum conductance
- Based on mature and reliable normal-conducting RF and mechanical technologies.

The laser system complex is deputed to deliver optical photon beams able to fulfill the several requirements of the IRIDE facility:



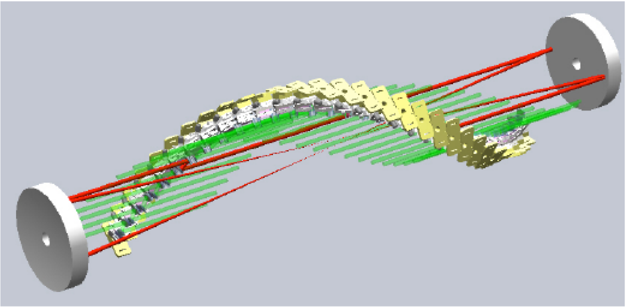


Fig. 133. **Schematic view of the re-circulating principle**

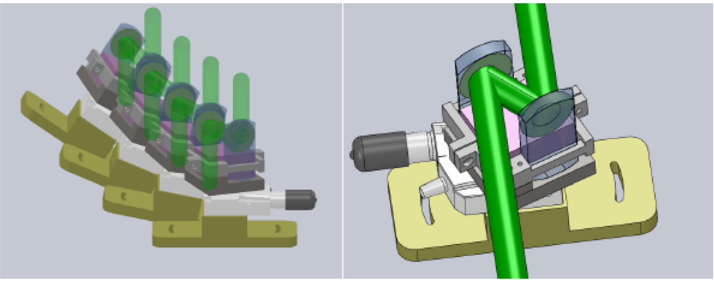
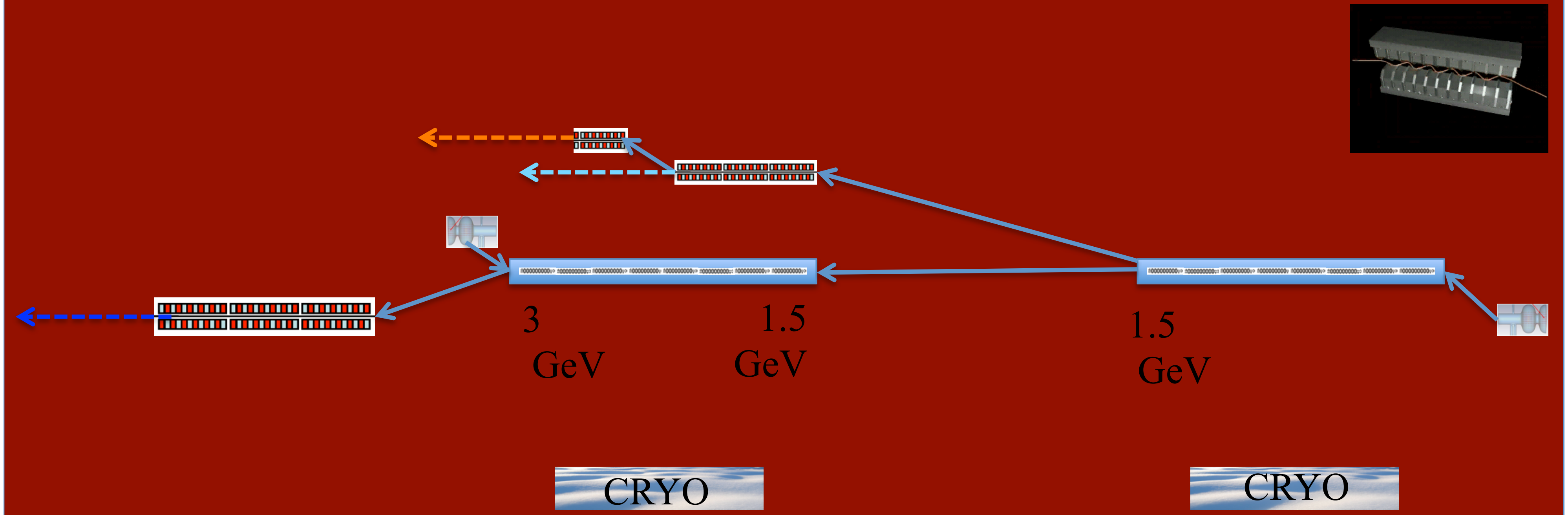


Fig. 134. **Schematic view of the motorized mirror pairs used in the re-circulator**

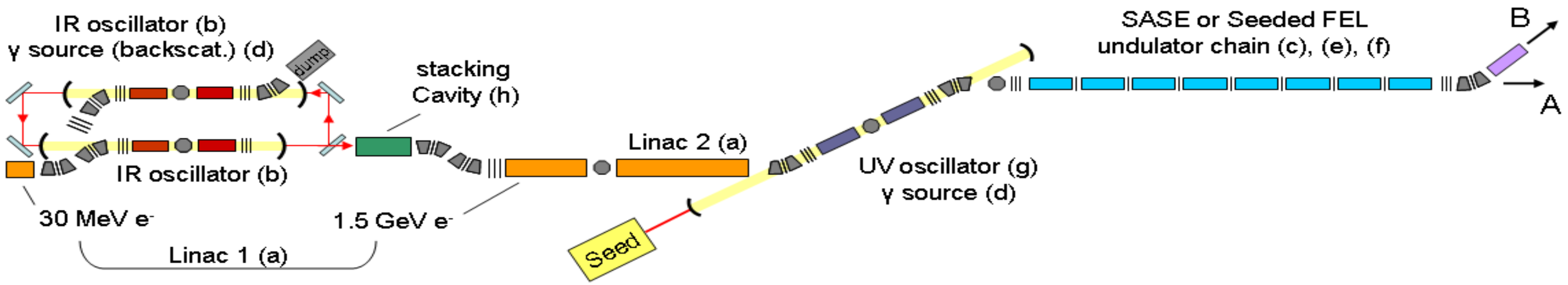
- drivers of photo-cathodes for electron beam generation
- colliding laser pulses to drive the back-scattering Compton (Yb:YAG, 100 W, 1 J, 0.1% bw)
- drivers for high advanced acceleration experiments (Ti:Sa, 1 PW, 10^{22} W/cm^2)

Free electron Lasers

The IRIDE project will provide a new concept of FEL facility by merging the two technologies of FEL oscillators and fourth generation radiation sources by developing a facility providing radiation from IR to EUV to the nm region down to Å level using a mechanism of emission already successfully tested at SPARC.



Integrated «architecture»



S-C-LINAC structures with 3-4 GeV maximum energy

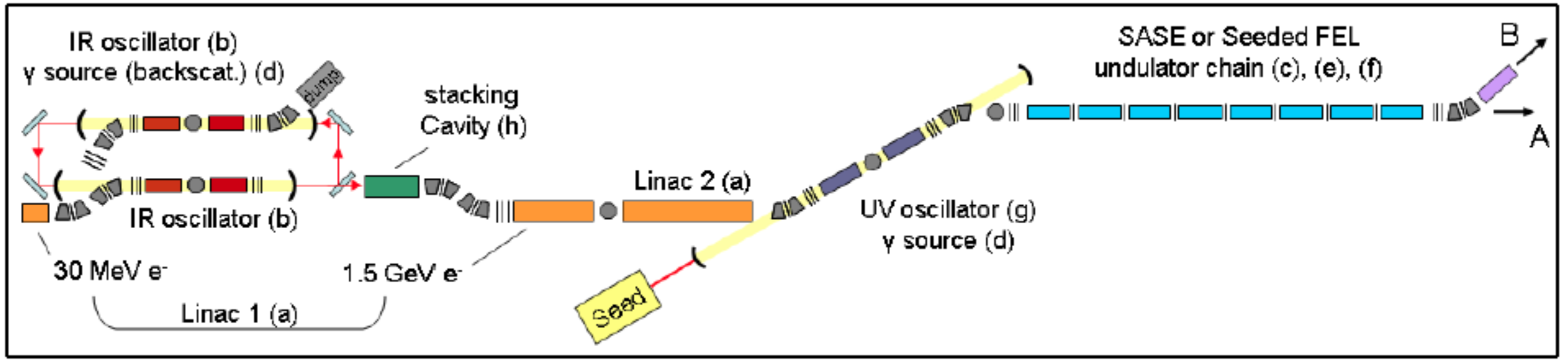
Between the two Linacs a double FEL oscillator, with a manifold role, is inserted

The undulator chain can be powered by the beam operating at full energy (3-4 GeV) or less

A second FEL oscillator is added for the operation in the UV region and for intra-cavity backscattering for the realization of a gamma source to be exploited for Nuclear Physics studies and the production of polarized electrons

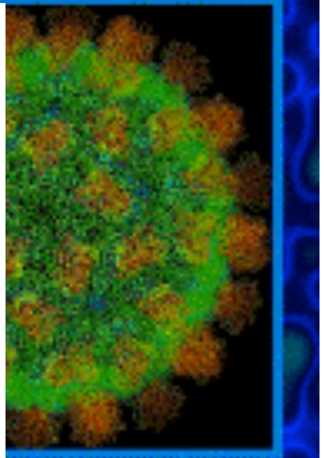
The third FEL section may operate in SASE or SEDEED mode

The seeding will be achieved by exploiting a conventional seeding procedure or by using the self-seeding scheme based on a kind of oscillator-amplifier device, according to the scheme first developed in Barbini et al. "In prospects for 1 Angstrom FEL" Sag Harbor 1990

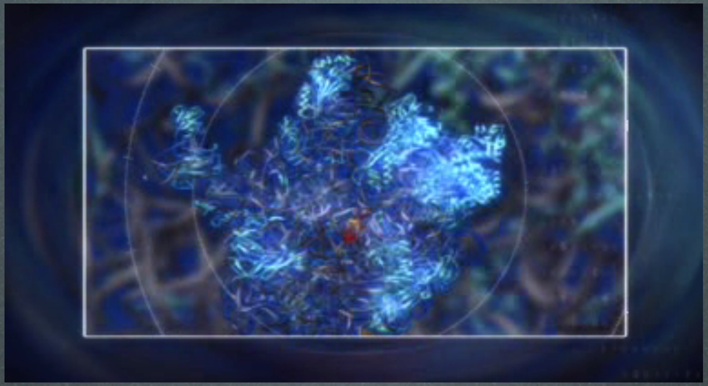


λ(nm/KeV)	1/1.24	0.3/3.72	0.2/6.2
Φ peak (n/s/- 0.1%BW)	$4.6*10^{25}$	$4.1*10^{23}$	$3.4*10^{22}$
B (n/s(mm.mrad)^2 - 0.1%BW)	$6.4*10^{31}$	$5.7*10^{29}$	$4.7*10^{28}$
τ (fs)	220	<200	<180
Φ (n/s) (medio)	$3.95*10^{22}$	$3.51*10^{20}$	$2.89*10^{19}$
photon/bunch	$1.01*10^{13}$	$9.02*10^{10}$	$7.48*10^{9}$

λ(nm/KeV)	4/0.413	1.33/1.23	0.8/2.07
Φ peak (n/s/- 0.1%BW)	$2.7*10^{26}$	$2.5*10^{24}$	$1.9*10^{23}$
B (n/s(mm.mrad)^2 - 0.1%BW)	$1.56*10^{30}$	$1.4*10^{28}$	$1.1*10^{27}$
τ (fs)	95	80	<100
Φ (n/s) (medio)	$1.03*10^{23}$	$9.32*10^{20}$	$7.33*10^{19}$
photon/bunch	$5.94*10^{13}$	$5.5*10^{11}$	$4,18*10^{10}$



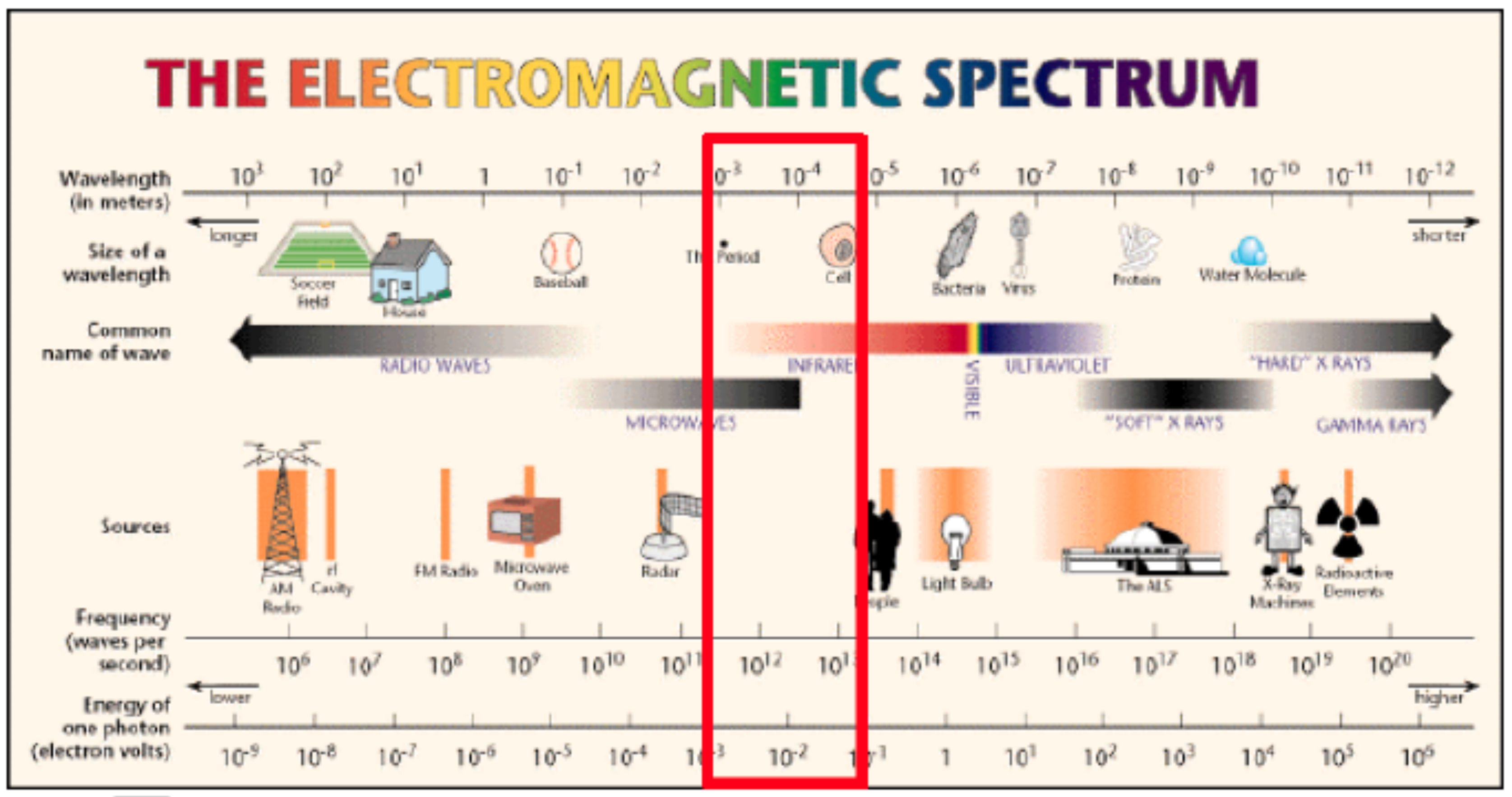
From the SPARX bio-scientific case

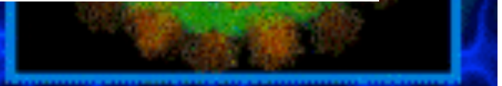


- Time-Resolved diffraction from protein nanochristals with spontaneous radiation: sub-picosecond pumps & probe structural and spectrometric investigations
- Structural characterization of biological systems, muscle contraction
- Small angle X-ray scattering of biological molecules
- Low density Atomic and Molecular processes with two photons spectroscopy
- X-ray microscopy with nanometer resolution
- Femtosecond Raman spectroscopy
- Single molecule imaging with hard X-rays

THz radiation source

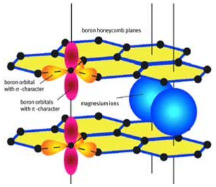
The interest for having high-power, sub-ps pulsed radiation covering the spectral range from THz to MIR is rapidly growing, both as it is a powerful tool for investigating the behavior of matter at low energy, and as it allows for a number of possible applications spanning from medical science to security.





THz radiation source

Condensed Matter Physics



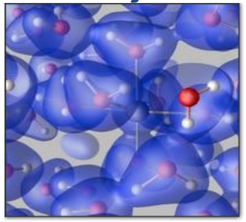
Superconductivity
- Energy gap
- Symmetry of the order parameter
- Direct determination of the superfluid density
- Dynamics of Cooper pairs

Low-dimensional materials
- Dimensionality crossover
- Non-Fermi liquid normal states
- Broken symmetry ground states

Coherent Phase Transitions
- Polarons
- Structural Phase Transitions

Magnetic sub-ps Dynamics

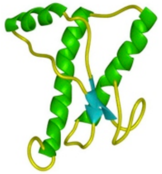
Physical and Analytical Chemistry



Polar liquids
- Hydrogen bond
- Van der Waals interactions
- Acoustic-Optic phonon mixing in water

Solutions
- Static and dynamic interactions between solvated ions and solvent

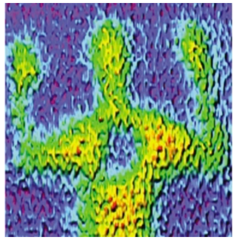
Life Sciences



Macromolecules conformation
- Secondary and tertiary structure
- Coherent dynamic development

Imaging
- 3D tomography of dry tissues
- Near-field sub-wavelenght spatial resolution

New Technologies



THz technologies
- Array THz detectors
- Metamaterials

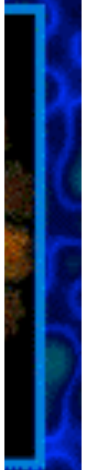
Medical diagnostic
- Skin cancer detection

Industrial production
- Material inspection
- Production line monitoring

Defense industry/Homeland security
- Detection of explosives and biohazards

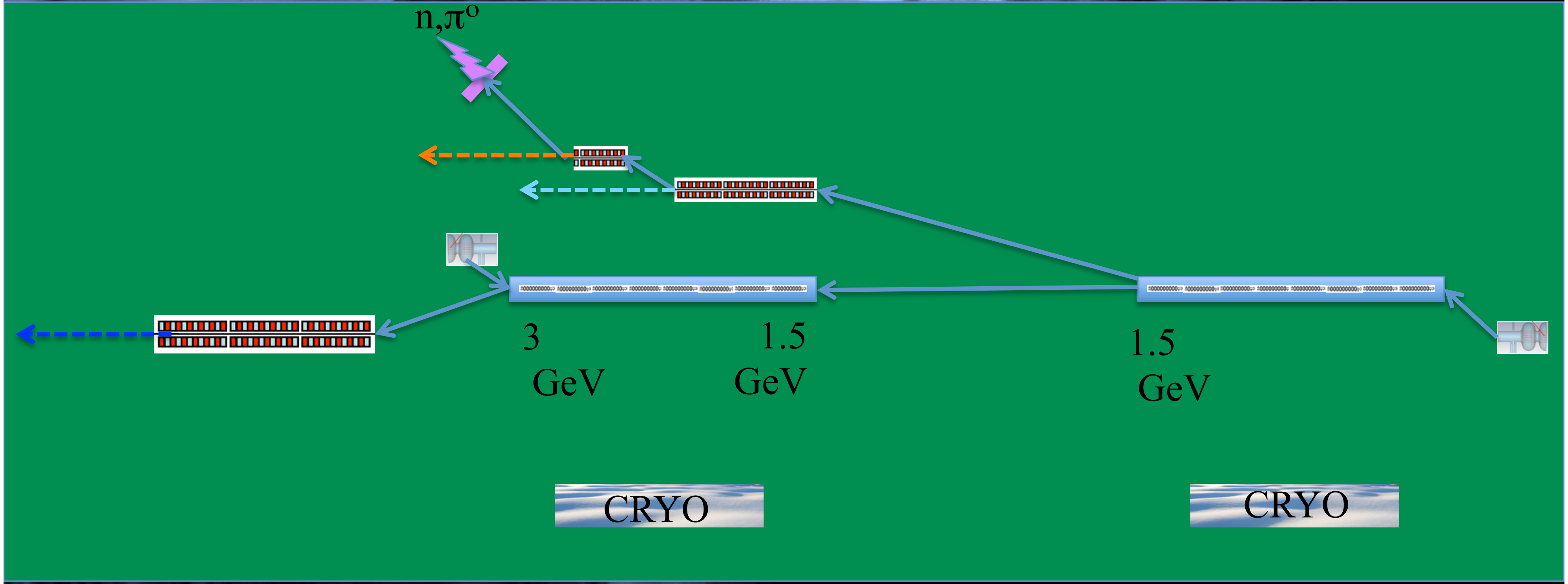
THz radiation source

Electron beam parameters	
Electron energy (GeV)	1.5 – 0.5
Charge/bunch (pC/bunch)	250
RMS bunch length (μm)	60
Normalized emittance (mm mrad)	1
Undulator	
Period (cm)	40
Number of periods	10
Magnetic field (T)	0.1 -1
Coherent Undulator Radiation parameters	
Wavelength (μm)	20 – 200
Peak power (MW)	100
Micropulse energy (mJ)	10
Micropulse duration (fs)	200
Coherent Diffraction Radiation parameters	
Wavelength (μm)	> 60
Peak power (MW)	100
Micropulse energy (μJ)	> 10
Micropulse duration (fs)	200



Neutron Source

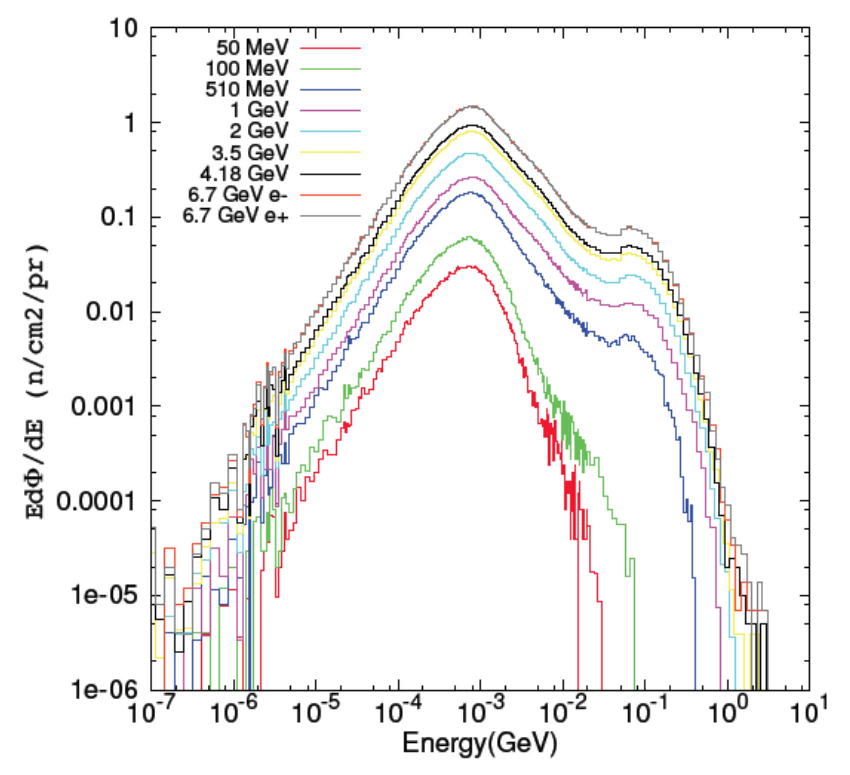
A Neutron Source can be realized by photo-production sending high energy electrons on a suitable high Z target. This kind of source allows to obtain neutrons with an energy spectrum that spans over more than 9 decades of energy from few meV up to hundred of MeV, even if most of them have energy around the nuclear equilibrium temperature of the target material (for W, it is around 1 MeV)



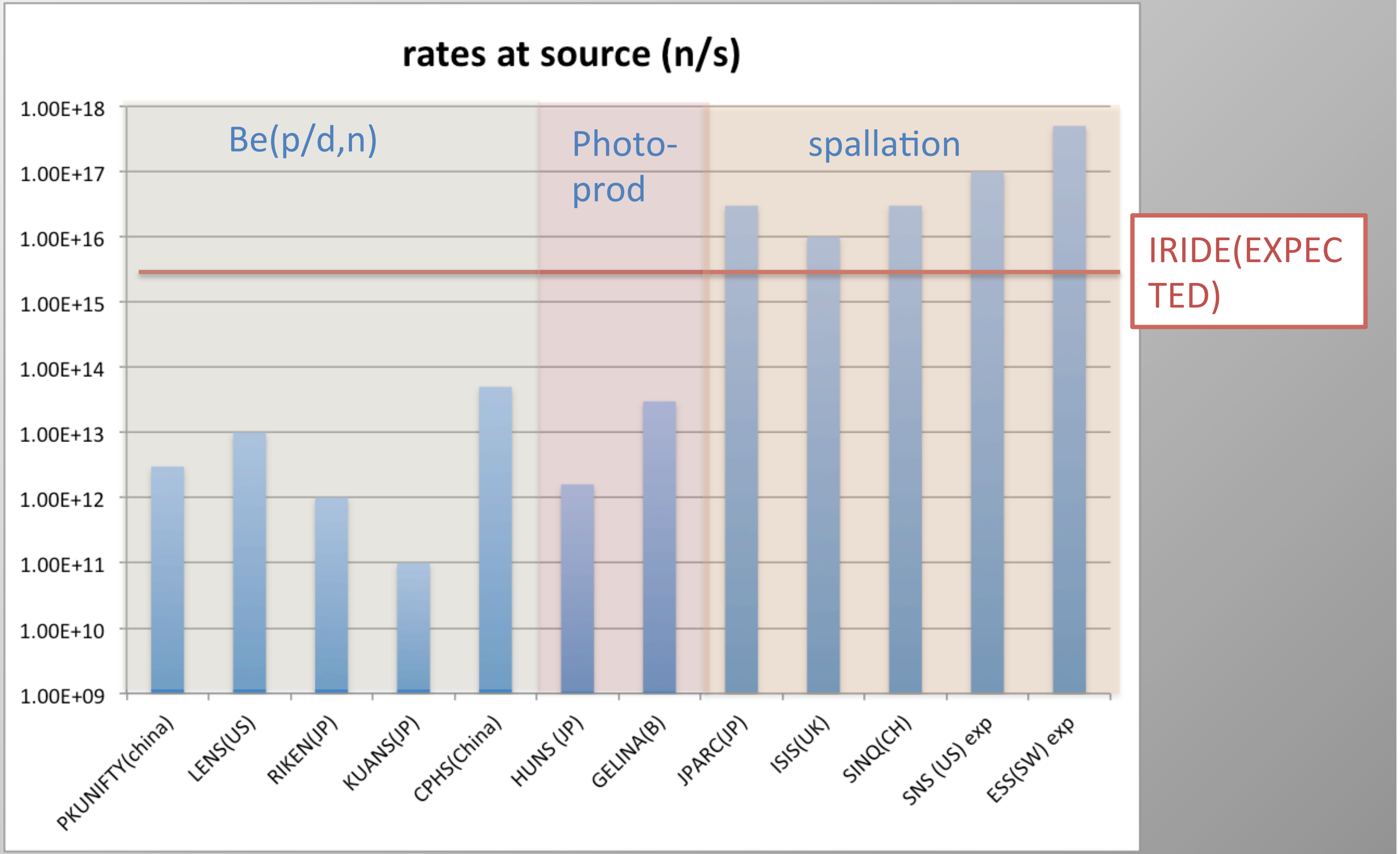
Neutron Source

This source may be suitable for multiple applications, ranging from material analysis for industrial and cultural heritages purposes to chip irradiation and metrology. These applications envisage the development of properly designed beam lines with neutron moderation and possibly cold/thermal neutron transport systems. The proposed new facility will represent a great opportunity for research and development of neutron instrumentation (e.g. detectors) as well as training of young scientist in the use and development of neutron techniques.

Deposited Power [kW]	Primary Electron Energy [GeV]	Expected Average Neutron Emission rate [n/s]
30	1	1.3 E+14
250	1	1.0 E+15
400	1	1.7 E+15
30	3	4.3 E+13
250	3	3.3 E+14
400	3	5.6 E+14



Comparison with other sources



Neutron Source

Neutron Resonance Capture Analysis (NRCA): Each resonance is the fingerprint of a nuclear specie (isotopical recognition) thus allowing for the elemental material analysis (qualitative and quantitative) especially on metallic samples (e.g. cultural heritages).

Bragg Edge Transmission (BET): By means of this technique, stresses and strain in bulky samples can be analysed. This analysis is very important for both industrial as well as cultural heritages applications.

Chip irradiation : In order to test the robustness of electronic devices to neutron field in a few minutes, neutron beams produced at facilities are desirable as the may provide an almost atmospheric-like neutron spectrum but several order of magnitude more intense.

Radiography and Tomography (NR, NT): By means of radiography it is possible to obtain an image of a object that evidences the internal structure, by rotating the sample with respect to the incident beam and collecting images for each angular position a 3D image of the object is obtained (tomography).

Neutron metrology: In this context, the Italian National Institute of Ionization radiation Metrology (INMRI) is interested in having in Italy (and especially in Roma area) a high energy neutron source in order to develop primary standards for neutron emission rate and energy spectrum calibration

The special feature of Neutrograph is it's intensity together with a moderate collimation.

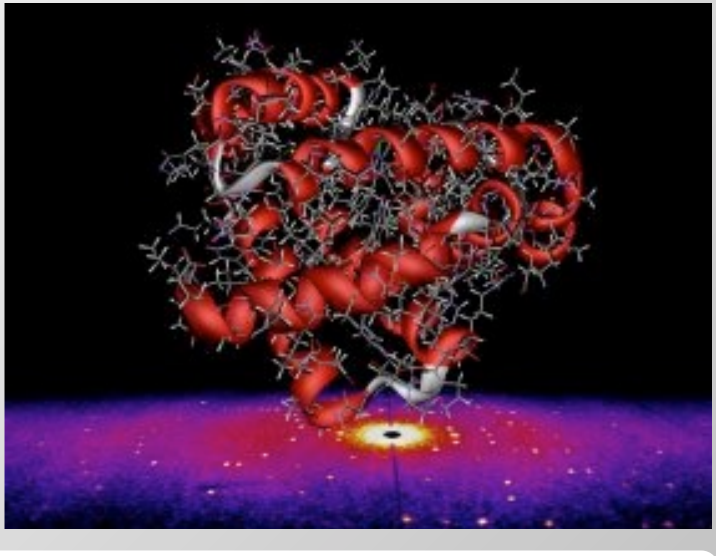
These properties allow the investigation of dynamic processes with an excellent time resolution and the transmittance through strongly absorbing and bulky materials.

A totally new spectrum of scientific and engineering applications could be developed.

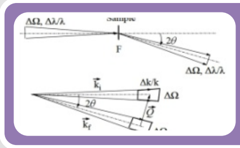
Among the experiments are investigations of heat exchangers and combustion engines, parts from aircrafts, fossils and historical heritage.

Institut Laue-Langevin (ILL) in Grenoble

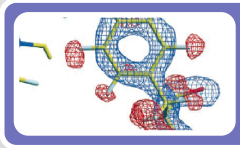
Health and Life Sciences



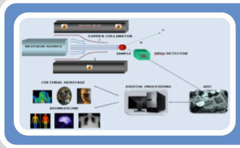
Neutrons can see the elements and the molecules of life in a way that is not possible with X-rays For example, the data of neutron scattering are providing important structural information relevant to degenerative diseases such as Alzheimer's disease and other diseases that are associated with the deposition of insoluble fibrils in the body. Neutron techniques are being used to study drug molecules and their interactions with a variety of biological molecules and for the production of radionuclides that are used in medical diagnosis. Recently there is an increasing interest in the development of approaches whereby neutron beams can be used to target and destroy tumors and for the development of new biomaterials for dental and bone implants.



Neutron Small Angle Scattering (SANS)

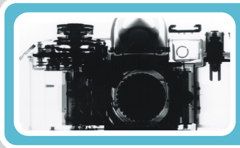


Elastic Incoherent Neutron Scattering (EINS)and Quasi-Elastic Neutron Scattering (QENS)

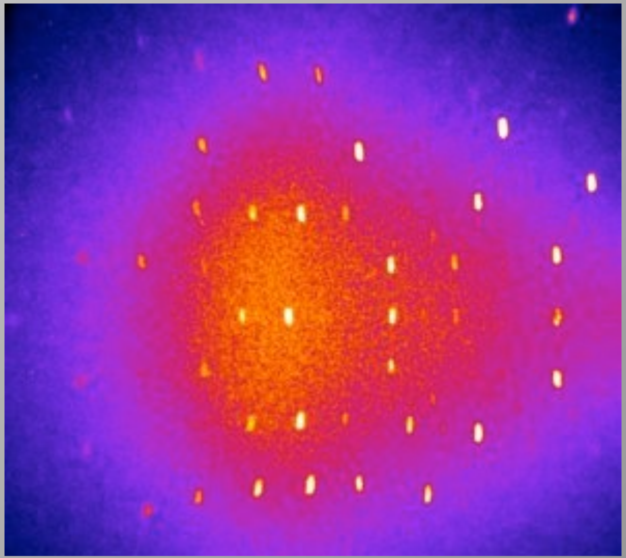


Prompt Gamma Activation Analysis (**PGAA**)

Neutron Activation Analysis (**NAA**)



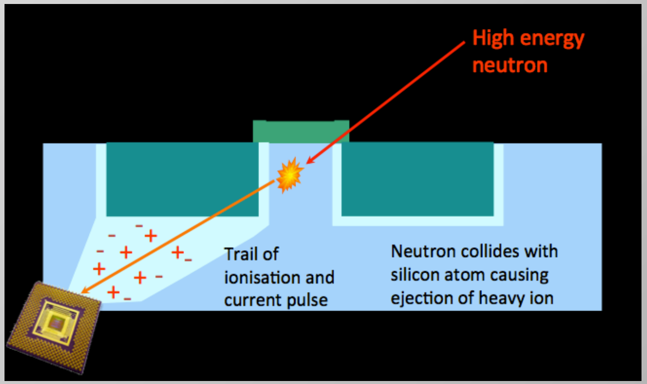
Neutron Imaging (NI)



Information and Communication technology (ctd.)

Chip Irradiation

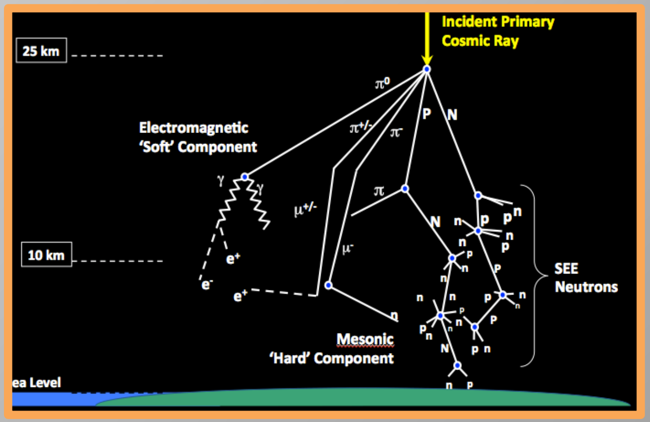
Study of the impact of neutron fluxes on performances of chips ➔ a universal industrial problem



Avionics

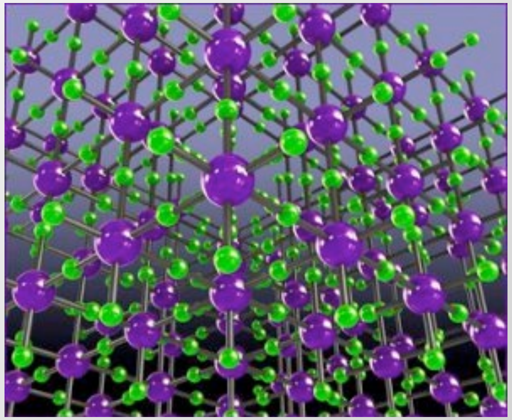
In 2001, the NASA Altair, Unmanned Air Vehicle (UAV) flew its first flight at an altitude of 100,000 feet. Designed by NASA-Dryden engineers and scientists, it is designed to fly for up to 48 hours to complete a variety of science research studies of Earth.

Because of the complexity of the computer systems (called avionics) onboard, and the very high altitudes being flown, special attention had to be paid to cosmic ray showers. These particles, mostly neutrons, pass through the walls of the aircraft and can affect computer circuitry.
IRIDE will allow to reproduce in few minutes the impact of cosmic ray neutrons collected in a year.



Also applies to IT infrastructures, motive, and medical applications

Nanoscience and Nanotechnology



Nanotechnology is the engineering of functional systems at the **molecular, or nano-scale** - from 1 to 100 nm. Neutrons cover all the length scales from the Angstrom scale of the atomic structure of individual building blocks to the configuration of assembled, functional structures, making them essential tools for the elucidation of nanostructures.

Neutrons have some built-in advantages compared to X-rays; namely their spin, mass, and the strong scattering cross section for the hydrogen isotope deuterium.

Small angle neutron scattering (SANS) is used to study polymer chains growing or aggregation on nanoparticles and polymer/nanoparticle interaction, for application in
materials science or medicine such as drug delivery or contrast imaging. SANS can also be used to analyse the aggregation of nanoparticles.

Mechanical properties can be investigated by stess-strain Diffraction Techniques and Elastic Neutron Scattering

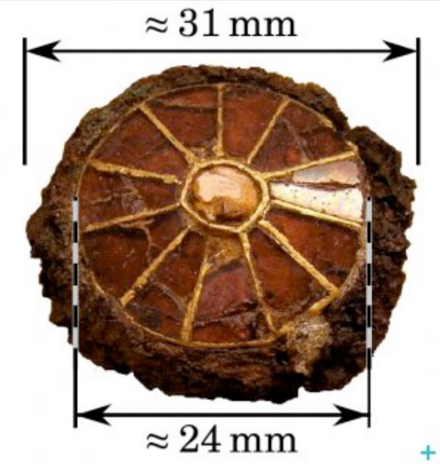
Heritage science

All crystalline material – metal, pigments, rock, ceramics – can be analyzed by neutron diffraction. Neutrons are an invaluable tool to analyze precious archaeological objects. Neutron tomography and radiography provide information about interesting inner parts of the object

Neutron Techniques

For archaeology and cultural heritage studies, **neutron diffraction** allows to quantitatively determine the crystallographic parameters and phase content of a material.

Nuclear analytical techniques such as Prompt Gamma Activation Analysis (**PGAA**), Neutron Activation Analysis (**NAA**) or Neutron Resonance Capture Analysis (**NRCA**) allow for non-destructive chemical analysis of historical artefacts, with little or no sample preparation.



Small-angle neutron scattering (SANS) has been used for studies on samples of different types of paper and ancient paper. These studies have yielded details of the surface morphology of cellulose fibres, the spatial distribution of water-filled pores, and the increasing dimension of water domains in cellulose as degradation occurs, and allowed for methods for the prevention of paper ageing to be developed.

Energy

With the growth of the world population, the basic needs becoming more and more difficult to meet. Although there are technological solutions to many problems, all of them are based on electrical or thermal energy. In view of the limited resources of fossil fuel electricity will increase in importance and for this reason it needs substantial improvement in order to meet the future needs of the world. Neutrons probe the atomic structure and are therefore well suited to investigate materials for energy research. Furthermore, neutron can penetrate massive material easily, which allows to study complex components in-situ under technical conditions.

energy storage

- Use of **neutron diffraction** to study the phase analysis of anode and cathode materials during charging and discharging of batteries and **radiographic imaging** of the filling level of batteries. **Elastic and Quasi-elastic neutron scattering** can help explain the dynamics of the lithium ions inside such batteries**. Small angle Neutron Scattering** allows to characterize the shape and dimension of storage units.

hydrogen storage

- Due to the high **sensitivity of neutrons** to hydrogen atoms, their transport properties in solid storage materials can be analyzed in detail. The filling of hydrogen in real devices under usage conditions reveals the technical details of the charging/discharging process. Suitable storage materials are being been analyzed in detail using **neutron diffraction**, especially for light weight materials as possible hydrogen storing materials for mobile applications.

energy transport

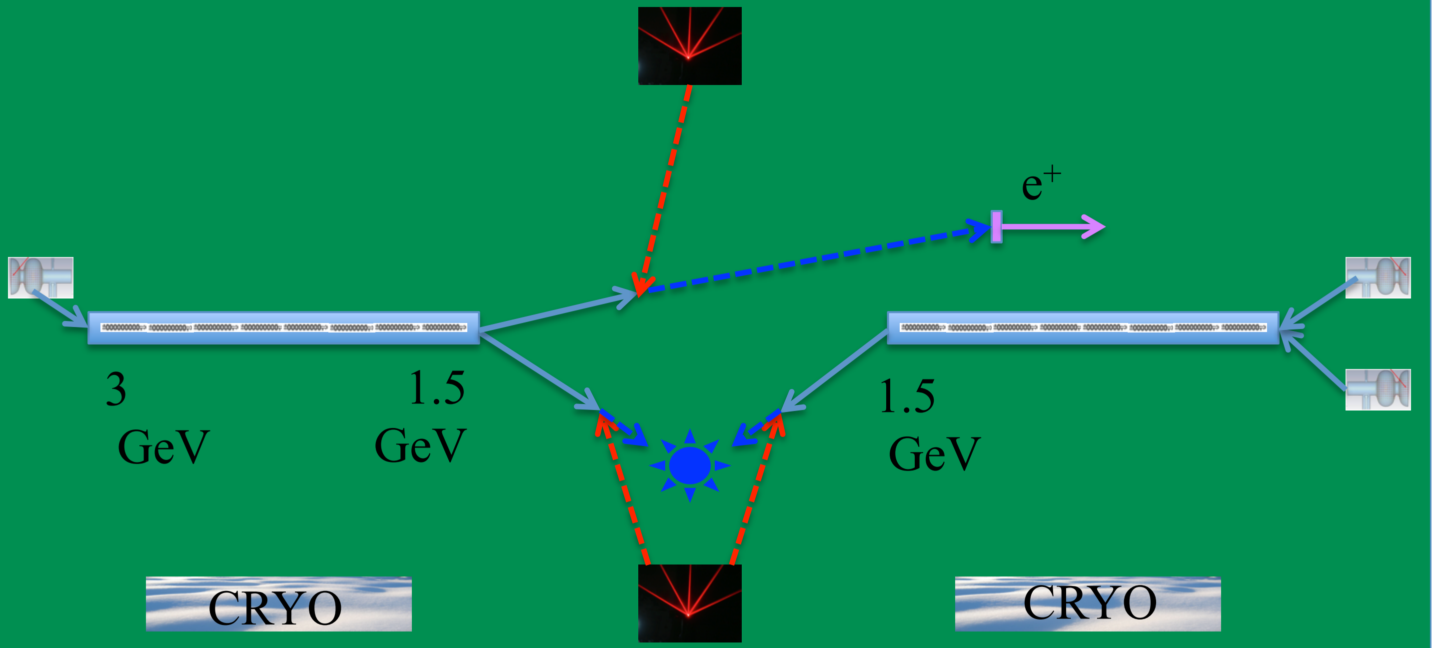
- The development of high temperature superconductors benefits from the basic understanding of material properties achieved by **neutron scattering**.

solar energy

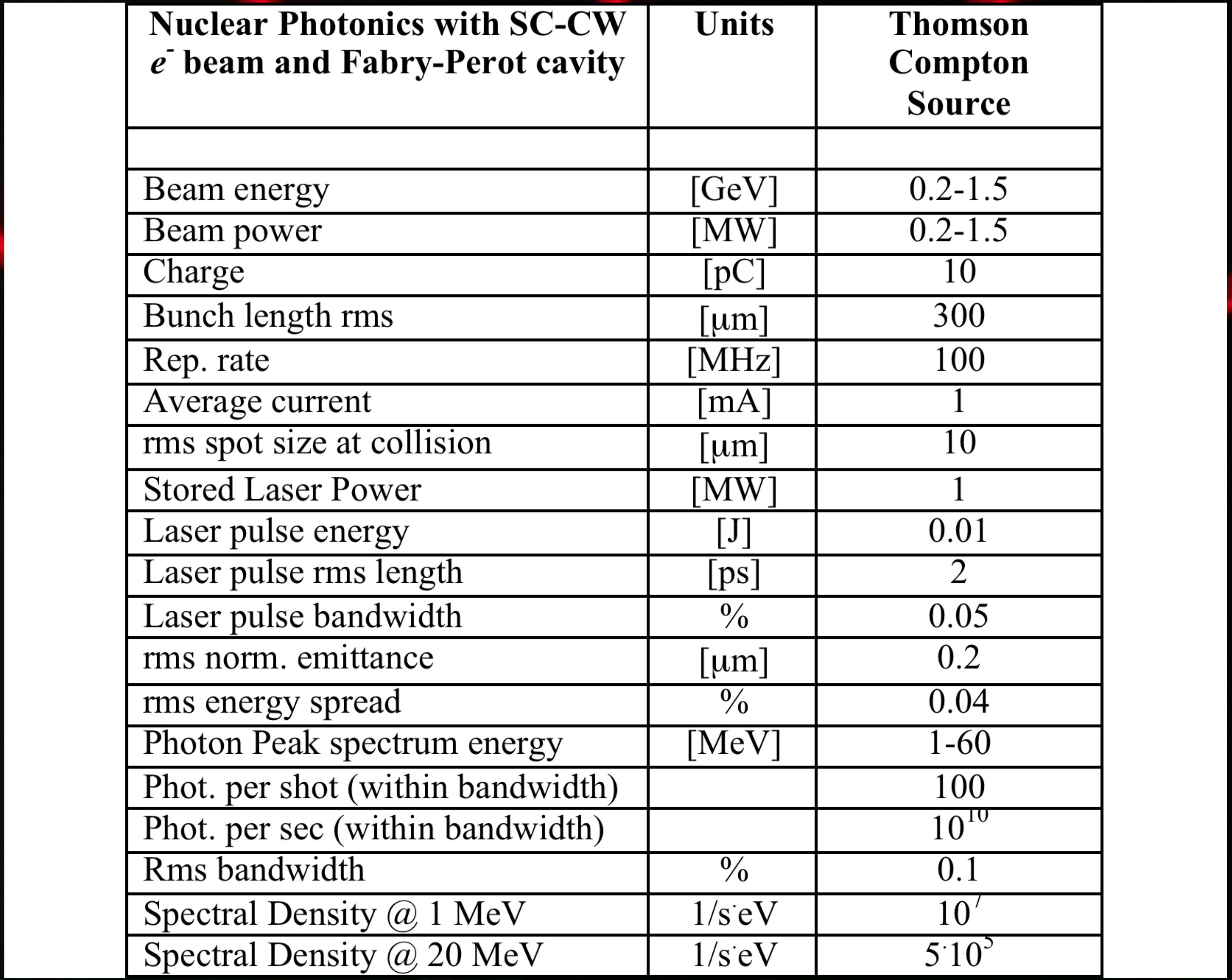
- In photovoltaics and solar energy research, **Elastic and Quasi Elastic Neutron Scattering** is used to characterize the mobility of species within solar cells.

Advanced γ-ray Compton Source

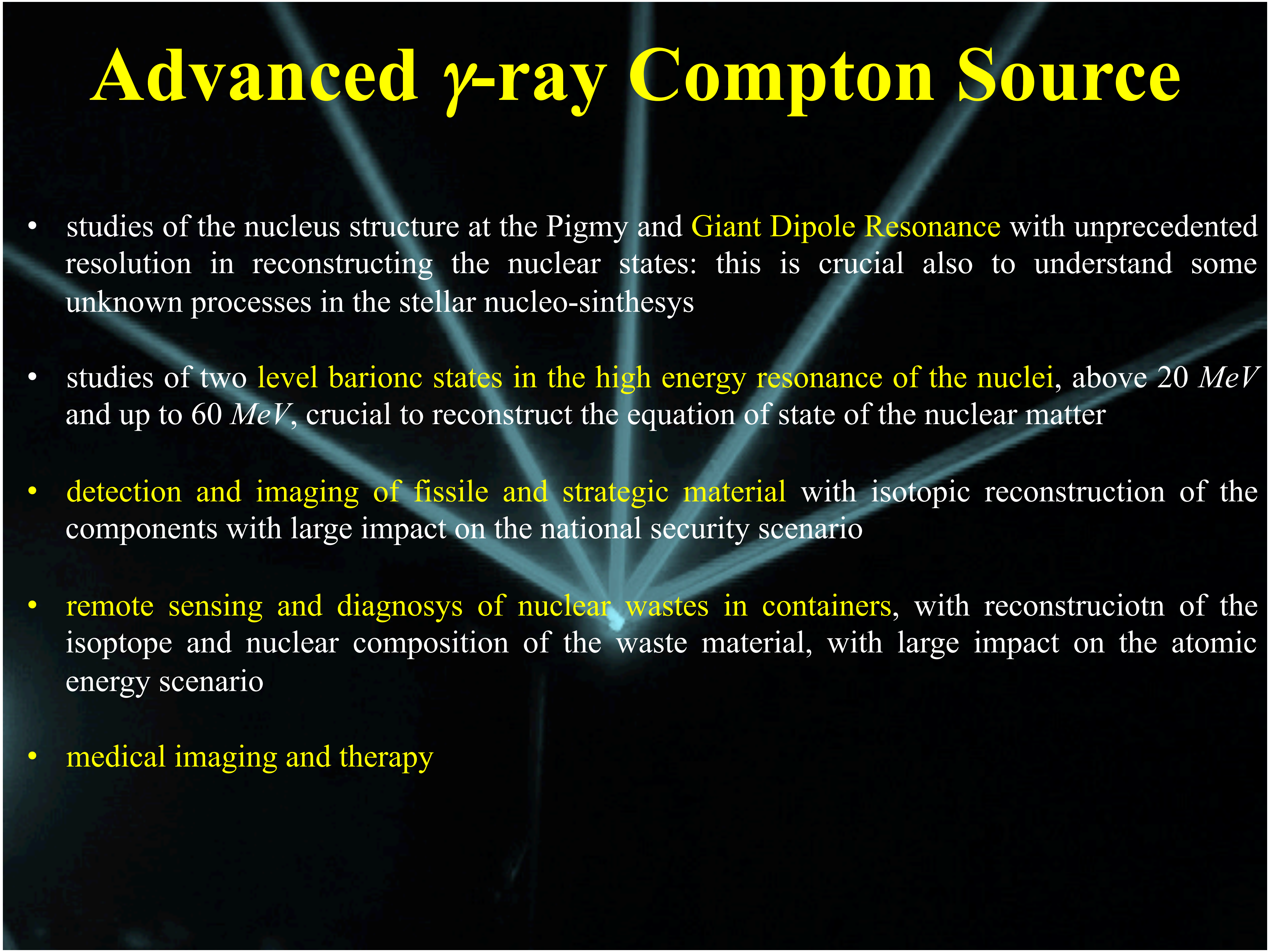
The state of the art in producing high brilliance/spectral density mono-chromatic γ-ray beams will be soon enhanced, stepping up from the present performances (γ-ray beams with bandwidth nearly 3% and spectral density of about 100 *photons/s·eV*) up to what is considered the threshold for Nuclear Photonics, *i.e.* a bandwidth of the γ-ray beam lower than 0.3% and a spectral density larger than 10^4 *photons/s·eV*.



Advanced γ-ray Compton Source



Nuclear Photonics with SC-CW e^- beam and Fabry-Perot cavity	**Units**	**Thomson Compton Source**
Beam energy	[GeV]	0.2-1.5
Beam power	[MW]	0.2-1.5
Charge	[pC]	10
Bunch length rms	[µm]	300
Rep. rate	[MHz]	100
Average current	[mA]	1
rms spot size at collision	[µm]	10
Stored Laser Power	[MW]	1
Laser pulse energy	[J]	0.01
Laser pulse rms length	[ps]	2
Laser pulse bandwidth	%	0.05
rms norm. emittance	[µm]	0.2
rms energy spread	%	0.04
Photon Peak spectrum energy	[MeV]	1-60
Phot. per shot (within bandwidth)		100
Phot. per sec (within bandwidth)		10^{10}
Rms bandwidth	%	0.1
Spectral Density @ 1 MeV	$1/s \cdot eV$	10^{7}
Spectral Density @ 20 MeV	$1/s \cdot eV$	$5 \cdot 10^{5}$



Advanced γ-ray Compton Source

- studies of the nucleus structure at the Pigmy and Giant Dipole Resonance with unprecedented resolution in reconstructing the nuclear states: this is crucial also to understand some unknown processes in the stellar nucleo-sinthesys

- studies of two level barionc states in the high energy resonance of the nuclei, above 20 *MeV* and up to 60 *MeV*, crucial to reconstruct the equation of state of the nuclear matter

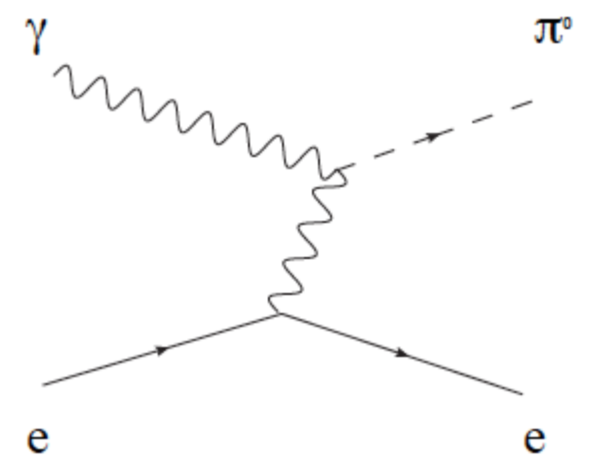
- detection and imaging of fissile and strategic material with isotopic reconstruction of the components with large impact on the national security scenario

- remote sensing and diagnosys of nuclear wastes in containers, with reconstruciotn of the isoptope and nuclear composition of the waste material, with large impact on the atomic energy scenario

- medical imaging and therapy

γ-e Linear Collider

The precise measurement of the π^0 width through the process $e\gamma \to \pi^0 e$ (*Primakoff effect*), and the search for light dark bosons in the energy region of few to hundreds MeV. These measurements, which provide important tests of the Standard Model, are not possible at present electron-photon colliders due to the low photon intensities of the machines.



π^0 width measurement: the axial anomaly of Adler, Bell and Jackiw (non-conservation of the axial vector current) is responsible for the decay of the neutral pion into two photons. It bridges in QCD the strong dynamics of infrared physics at low energies (pions) with the perturbative description in terms of quarks and gluons at high energies. The anomaly allows to gain insights into the strong interaction dynamics of QCD and has received great attention from theorists over many years.

γ-e Linear Collider

Search for dark forces: several puzzling astrophysical observations (PAMELA abundance of positrons, ATIC excess, WMAP haze, INTEGRAL signal) could be explained on a common ground by existence of a new, beyond-standard-model (BSM), weakly interacting boson "U". The mass of the U boson is expected to be at MeV or GeV scale. Such a particle would be a slim dark matter candidate and, technically, a gauge boson of a "hidden sector" abelian symmetry group U(1).

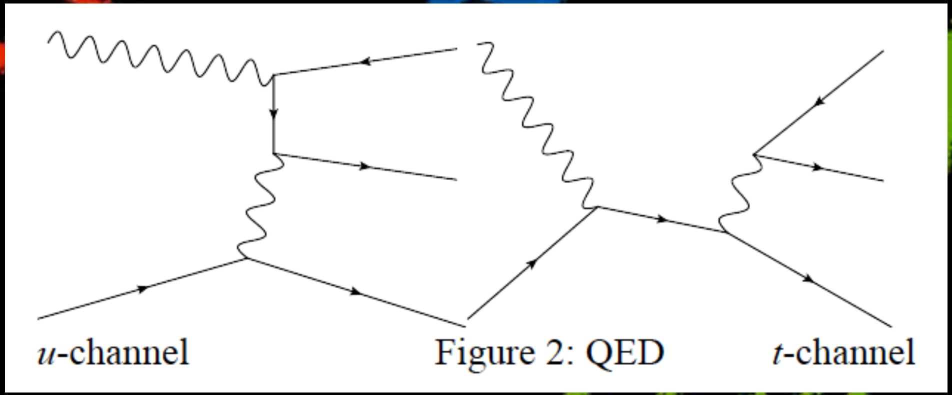
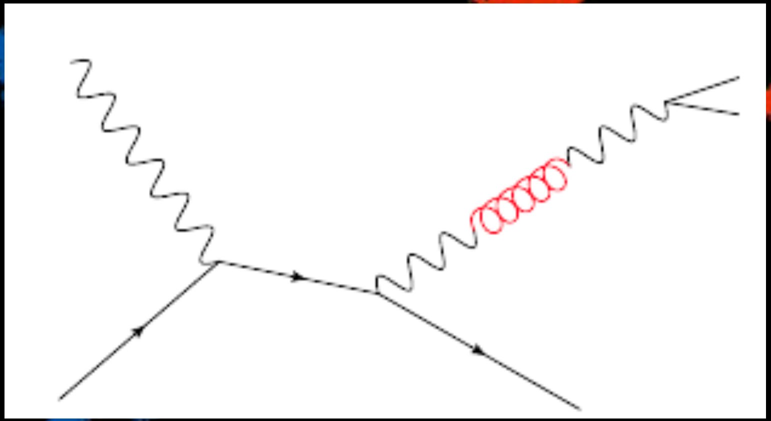


Figure 2: QED

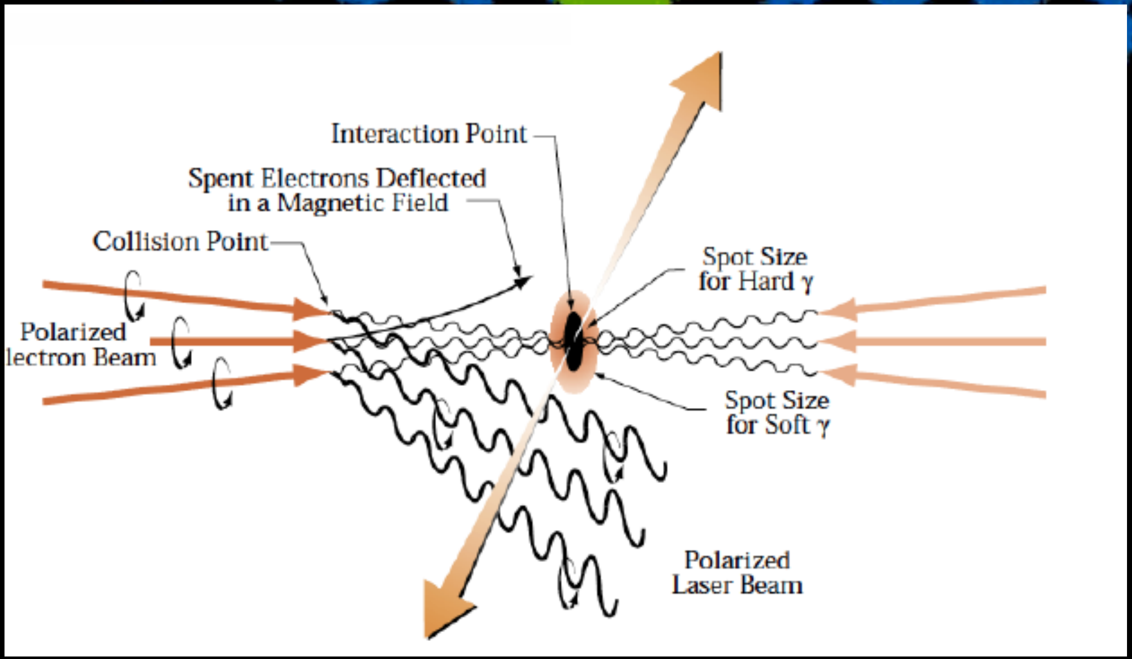


At IRIDE we can search for U boson via the lepton triplet production process in the electron-photon collision. The main QED process of the lepton triplet production is through *u* channel exchange ("BH diagram") and the *t* channel exchange ("VCS diagram").

The U-boson contribution is included as the *t*-channel part with the photon line modified by the mixing with the U.

γ-γ Linear Collider

The vacuum of QED poses some still unsolved challenges which are central not only in the context of field theory, but also of super-symmetry and string theory as well. The elastic photon-photon scattering offers unique opportunities to probe the nature of QED vacuum. We propose an experiment to observe photon-photon scattering in the range 1 MeV – 2 MeV CM energy, i.e., near the peak of the QED cross-section. In addition a low-energy photon-photon collider investigation could lead to the necessary technology developments and prepare the ground for a higher energy complex, while still providing a rich testing ground for QED, and, more generally, QFT.



γ-γ Linear Collider

The most striking failing of QFT is the huge mismatch between the measured energy density of vacuum and the energy density of the ground level of the fundamental fields which is wrong by something like 120 orders of magnitude.

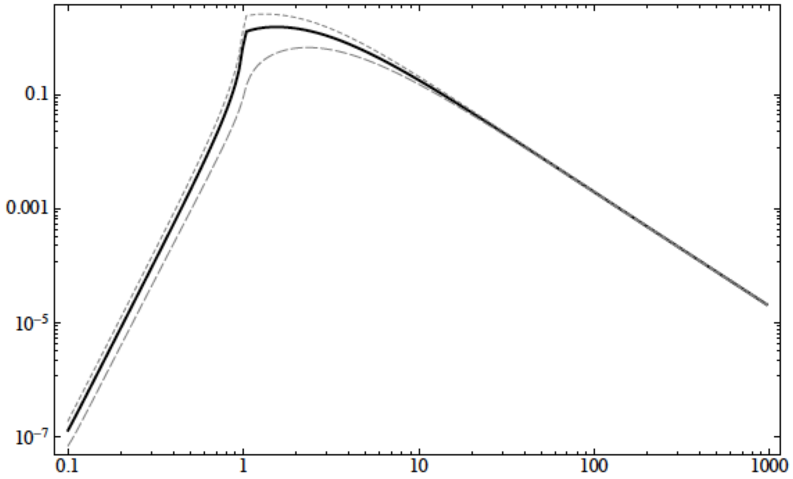
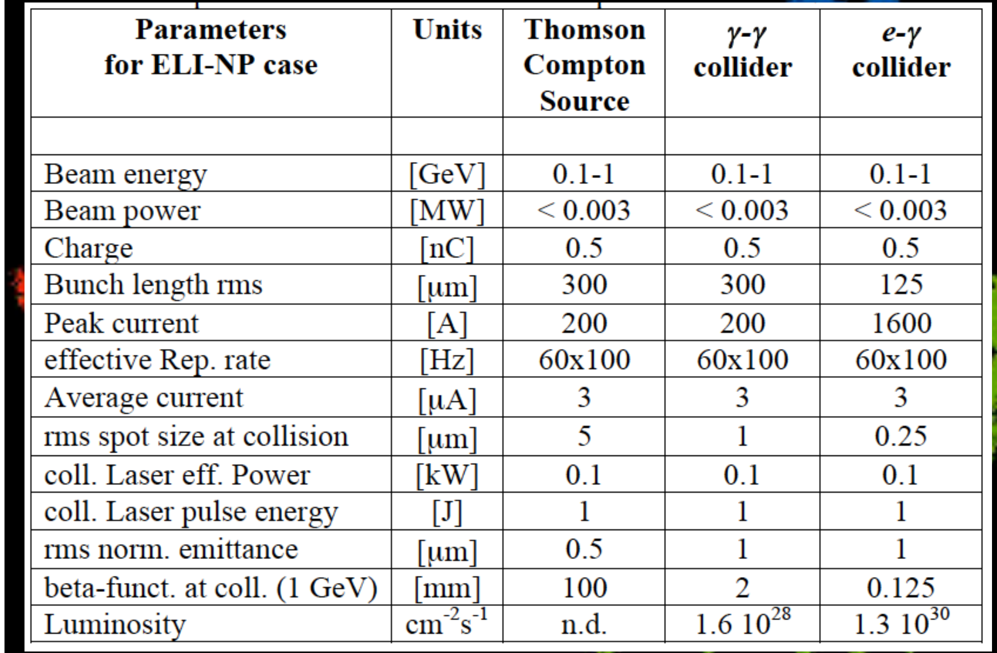


Figure 18: total cross-section (μbar) vs. CM energy (MeV). Solid line: cross-section averaged over initial photon polarizations. Dotted line: incoming photons have the same circular polarization. Dashed line: incoming photons have opposite circular polarization.

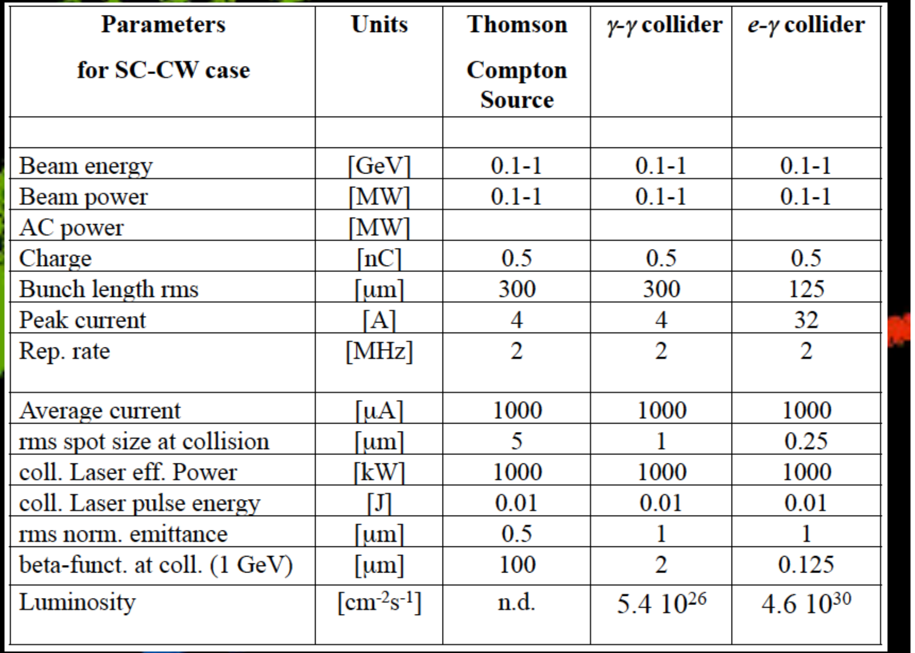
a photon-photon scattering experiment with photon energies in the 0.5-0.8 MeV range – where the cross-section is reasonably large, would be an important test of our understanding of the QED vacuum.

This experiment needs a low-energy photon-photon collider, and a photon detection apparatus which is very similar to that current PET scanners

Luminosity and beam requirements



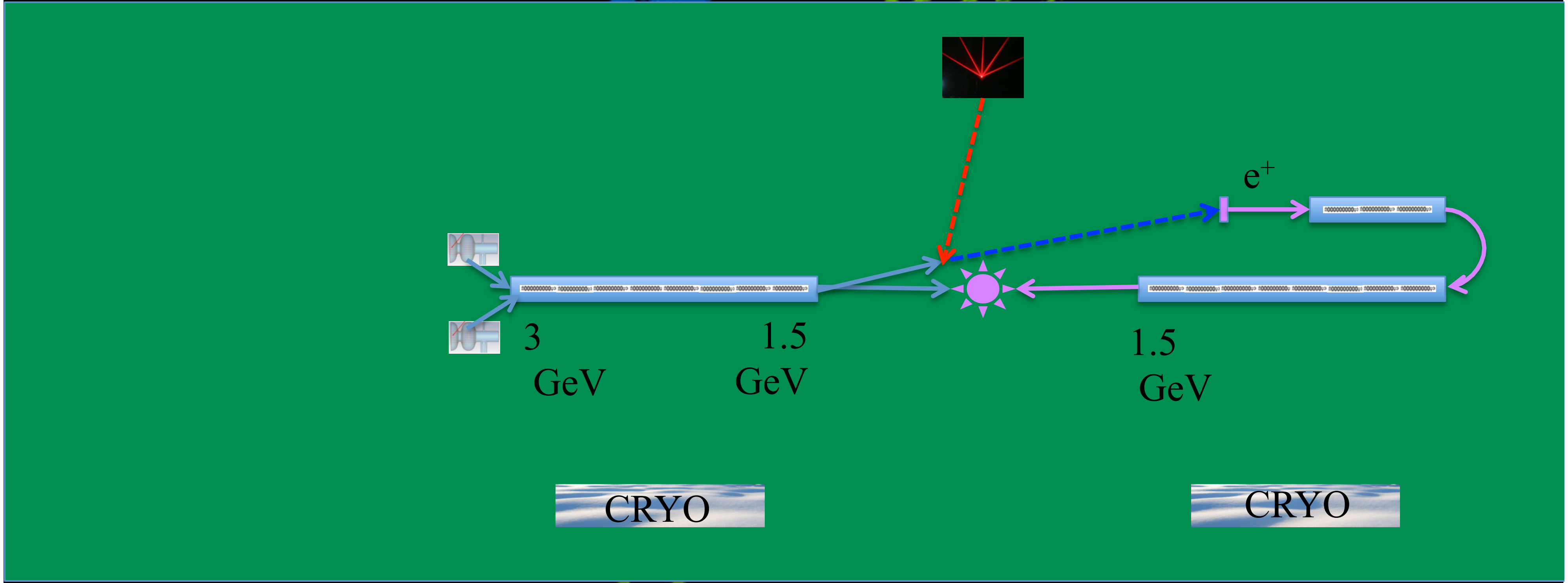
Parameters for ELI-NP case	**Units**	**Thomson Compton Source**	**γ-γ collider**	**e-γ collider**
Beam energy	[GeV]	0.1-1	0.1-1	0.1-1
Beam power	[MW]	< 0.003	< 0.003	< 0.003
Charge	[nC]	0.5	0.5	0.5
Bunch length rms	[μm]	300	300	125
Peak current	[A]	200	200	1600
effective Rep. rate	[Hz]	60x100	60x100	60x100
Average current	[μA]	3	3	3
rms spot size at collision	[μm]	5	1	0.25
coll. Laser eff. Power	[kW]	0.1	0.1	0.1
coll. Laser pulse energy	[J]	1	1	1
rms norm. emittance	[μm]	0.5	1	1
beta-funct. at coll. (1 GeV)	[mm]	100	2	0.125
Luminosity	$cm^{-2}s^{-1}$	n.d.	$1.6\ 10^{28}$	$1.3\ 10^{30}$



Parameters for SC-CW case	**Units**	**Thomson Compton Source**	**γ-γ collider**	**e-γ collider**
Beam energy	[GeV]	0.1-1	0.1-1	0.1-1
Beam power	[MW]	0.1-1	0.1-1	0.1-1
AC power	[MW]			
Charge	[nC]	0.5	0.5	0.5
Bunch length rms	[μm]	300	300	125
Peak current	[A]	4	4	32
Rep. rate	[MHz]	2	2	2
Average current	[μA]	1000	1000	1000
rms spot size at collision	[μm]	5	1	0.25
coll. Laser eff. Power	[kW]	1000	1000	1000
coll. Laser pulse energy	[J]	0.01	0.01	0.01
rms norm. emittance	[μm]	0.5	1	1
beta-funct. at coll. (1 GeV)	[μm]	100	2	0.125
Luminosity	$[cm^{-2}s^{-1}]$	n.d.	$5.4\ 10^{26}$	$4.6\ 10^{30}$

e^+ e^- Linear Collider

An electron-positron collider with luminosity of 10^{32} cm^{-2}s^{-1} with center of mass energy ranging from the mass of the φ-resonance 1 GeV up to ~3.0 GeV, would complement high-energy experiment at the LHC and future linear collider (ILC). Such a machine can easily collect an integrated luminosity of about 5 fb^{-1} in a few years of data taking.



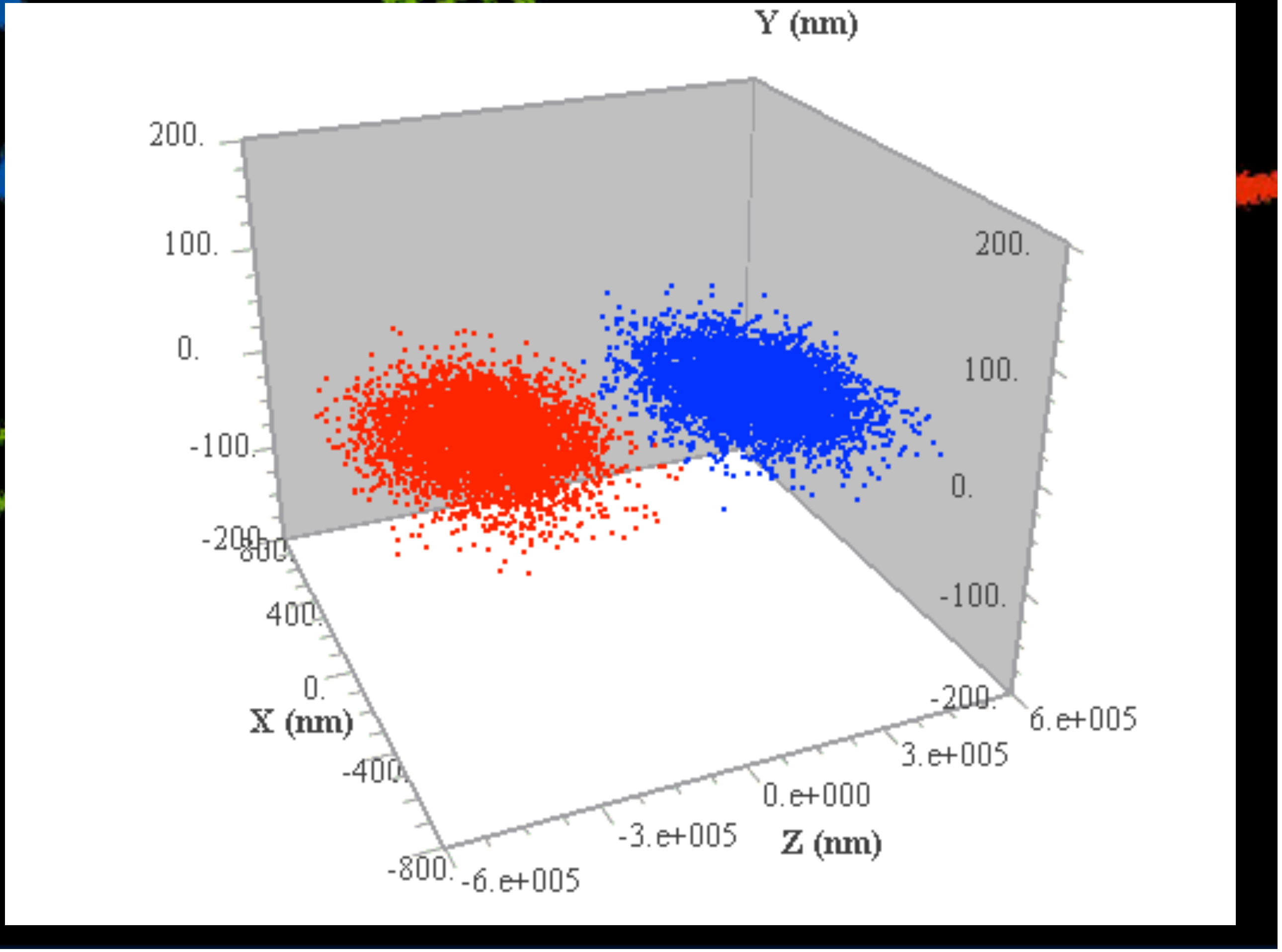
This will allow one to measure the e^+e^- cross section to hadrons with a total fractional accuracy of 1%, a level of knowledge that has relevant implications for the determination of SM observables, like, the *g*-2 of the muon and the effective fine-structure constant at the M_Z scale. The latter are, through quantum effects, sensitive to possible bSM physics at scales of the order of hundred GeV or TeV.

A primary effect of the electron-positron interaction is an enhancement of the luminosity due to the **pinch effect**, i. e. the reduction of the cross section of both beams occurring at the IP due to **self focusing forces** that is included in the luminosity definition through the factor **H_D**.

$$L = \frac{n_b N_e^2 f_{rep}}{4\pi\sigma_x^*\sigma_y^*} \times H_D = \langle I \rangle \times \frac{N_e}{4\pi\sigma_x^*\sigma_y^*} \times H_D$$

$$H_D = \frac{L}{L^*} = \frac{\sigma_x^*\sigma_y^*}{\sigma_x\sigma_y}$$

$$D_{x,y} \equiv \frac{2N_e r_e}{\gamma} \frac{\sigma_z}{\sigma_{x,y}\left(\sigma_x + \sigma_y\right)}$$

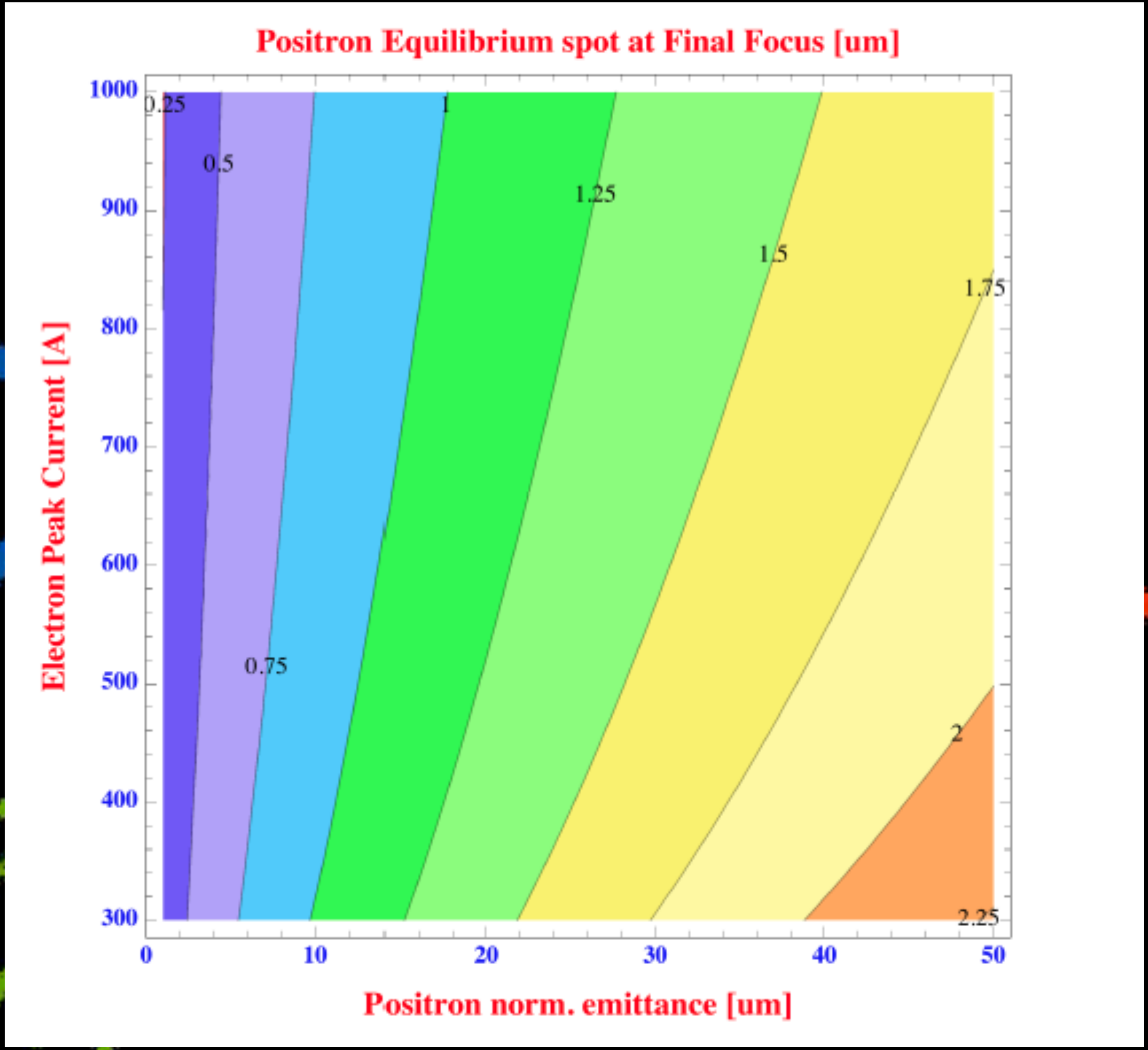


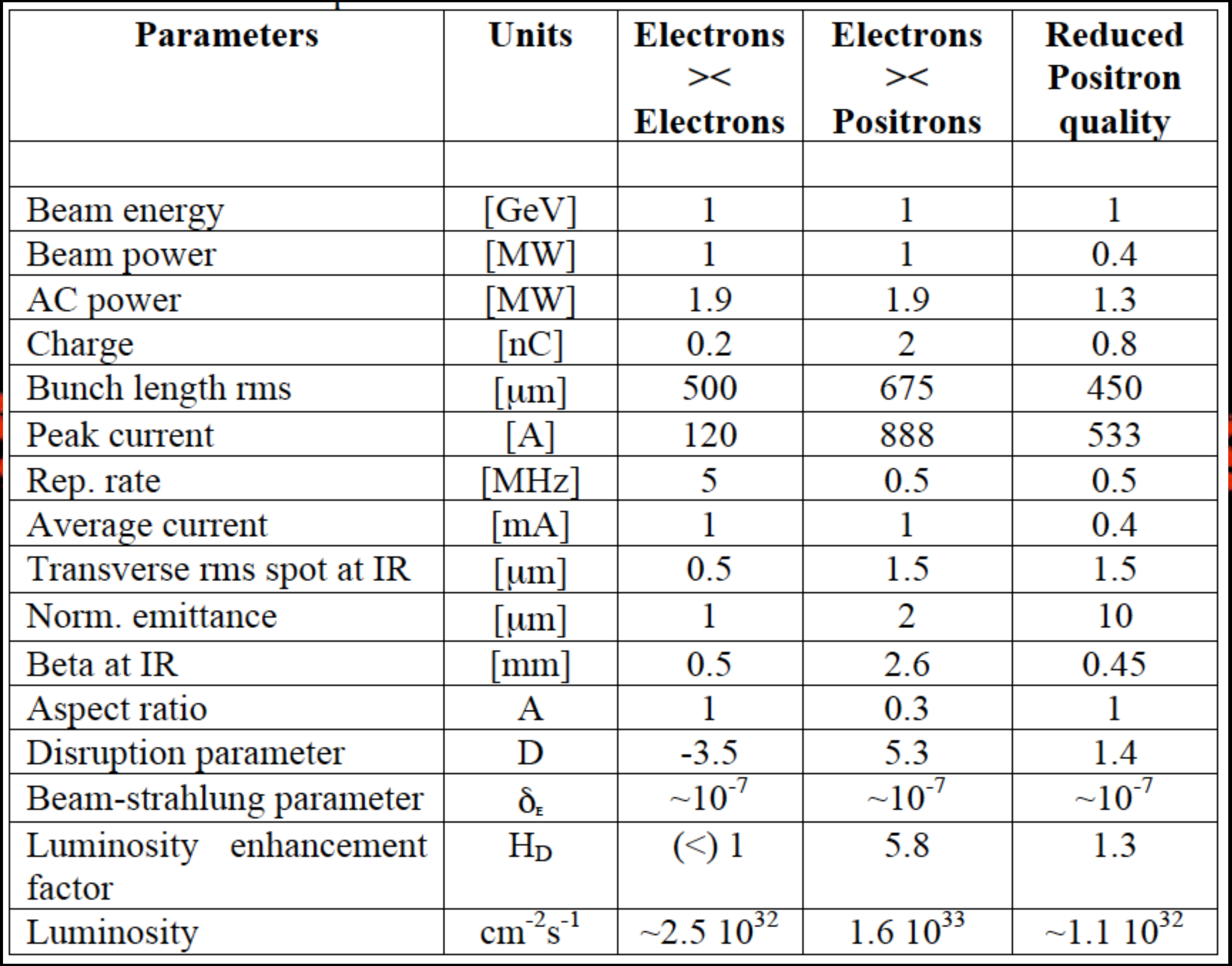
$$\sigma''_{pos,x} + \frac{k_{el}^2}{\gamma}\sigma_{pos,x} = \frac{\varepsilon_{pos,n}^2}{\gamma^2\sigma_{pos,x}^3}$$

$$k_{el}^2 = \frac{4I_{el}}{I_A\sigma_{el,x}^{*2}}$$

$$\sigma_{x,pos} = \sqrt[2]{\frac{\varepsilon_{n,pos}}{\sqrt{\gamma}k_{el}}}$$

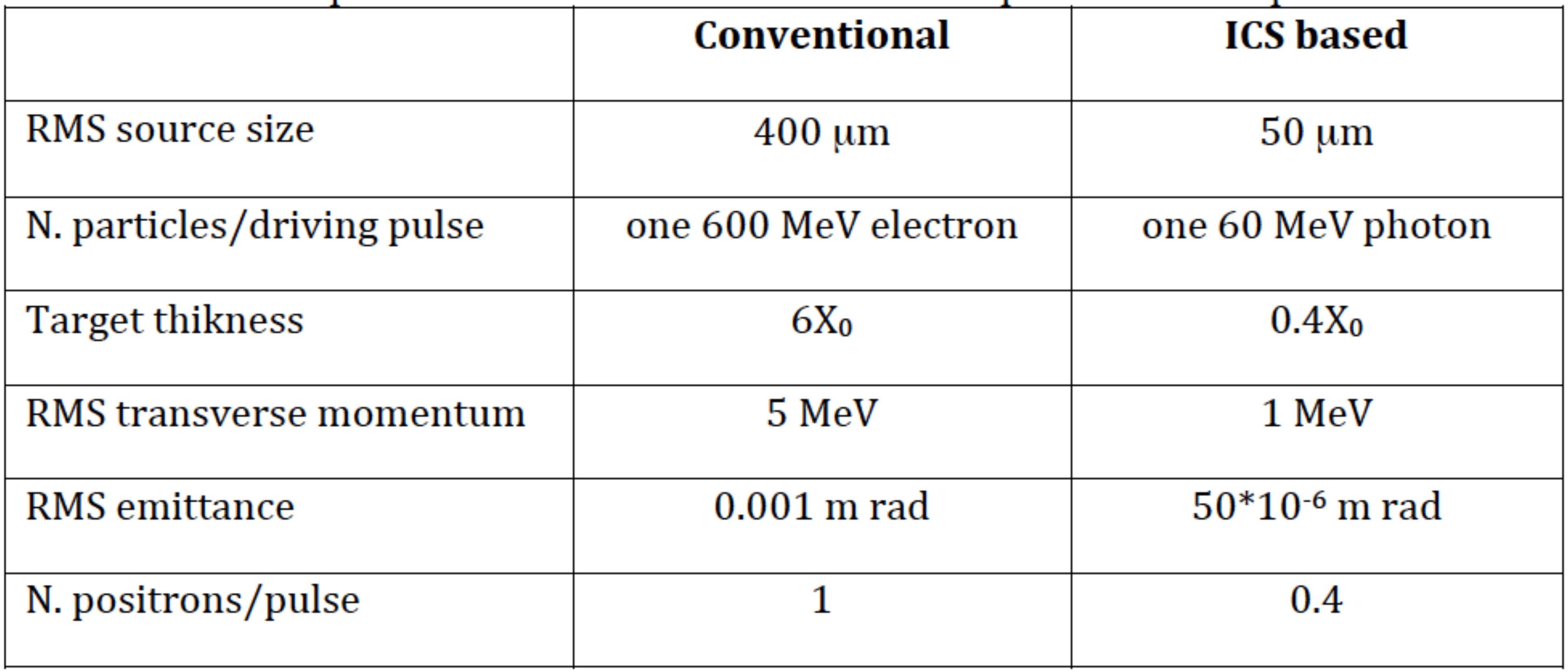
Under the previous condition the positron beam spot size remains constant during the interaction due to the balance between its own defocusing emittance pressure and the counter-propagating electron beam focusing effect.





Parameters	Units	Electrons >< Electrons	Electrons >< Positrons	Reduced Positron quality
Beam energy	[GeV]	1	1	1
Beam power	[MW]	1	1	0.4
AC power	[MW]	1.9	1.9	1.3
Charge	[nC]	0.2	2	0.8
Bunch length rms	[μm]	500	675	450
Peak current	[A]	120	888	533
Rep. rate	[MHz]	5	0.5	0.5
Average current	[mA]	1	1	0.4
Transverse rms spot at IR	[μm]	0.5	1.5	1.5
Norm. emittance	[μm]	1	2	10
Beta at IR	[mm]	0.5	2.6	0.45
Aspect ratio	A	1	0.3	1
Disruption parameter	D	-3.5	5.3	1.4
Beam-strahlung parameter	δ_ε	$\sim 10^{-7}$	$\sim 10^{-7}$	$\sim 10^{-7}$
Luminosity enhancement factor	H_D	(<) 1	5.8	1.3
Luminosity	$cm^{-2}s^{-1}$	$\sim 2.5\ 10^{32}$	$1.6\ 10^{33}$	$\sim 1.1\ 10^{32}$

Table 12: Comparison between Conventional and ICS positron source performances



	Conventional	**ICS based**
RMS source size	400 μm	50 μm
N. particles/driving pulse	one 600 MeV electron	one 60 MeV photon
Target thikness	$6X_0$	$0.4X_0$
RMS transverse momentum	5 MeV	1 MeV
RMS emittance	0.001 m rad	$50*10^{-6}$ m rad
N. positrons/pulse	1	0.4

For the peak brightness the main advantage of driving the conversion directly with a photon beam relies on the possibility of using thinner targets. The emittance of the positron beam emerging from the target is determined by the source size and the beam divergence.

e^+e^- collider

Physics opportunities with an e^+e^- collider with c.o.m. energy tunable within [~ 0.5, ~ 3.0] GeV

✓ hadronic cross-section meas. $e^+e^- \to \gamma^* \to$ had.

- hadronic contribution to muon a.m.m. a_μ
- hadronic contribution to α_{em}

✓ two-photon physics $e^+e^- \to e^+e^- \gamma^*\gamma^* \to e^+e^- +$ had.

- had. ≡ π^0, η, η' → light-by-light contribution to a_μ^{had}
- meson spectroscopy

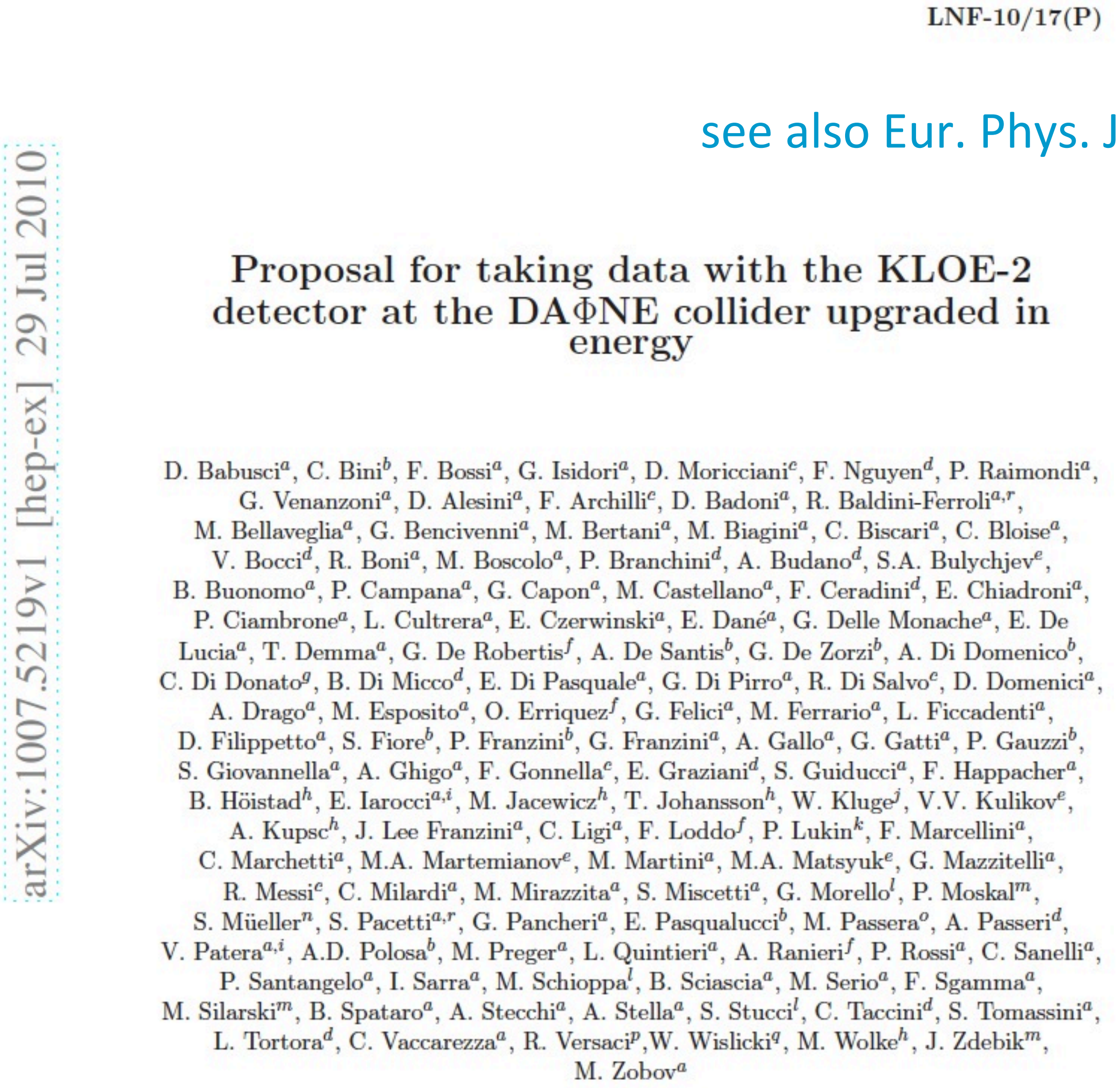
✓ exotics $e^+e^- \to \gamma\, U \to \gamma\, \ell^+\ell^-$,

$\to \gamma\, E_{miss.}$

- possible existence of low-energy (0.1 ÷ 1 GeV) new gauge interactions (dark forces)

e$^+$e- collider

see also Eur. Phys. J. C **50** (2007) 729



LNF-10/17(P)

Proposal for taking data with the KLOE-2 detector at the DAΦNE collider upgraded in energy

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e^+e^- - collider

Requests:

- ✓ luminosity $\sim 10^{32}\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}$
- ✓ energy $\sqrt{s} = (0.6 \div 3.0)\ \mathrm{GeV}$ (in steps of ~ 25 MeV)
- ✓ tagging systems for $\gamma\gamma$-physics

Positron source ⟶ Bethe-Heitler: $\gamma\, Z \longrightarrow e^+e^-\, Z$

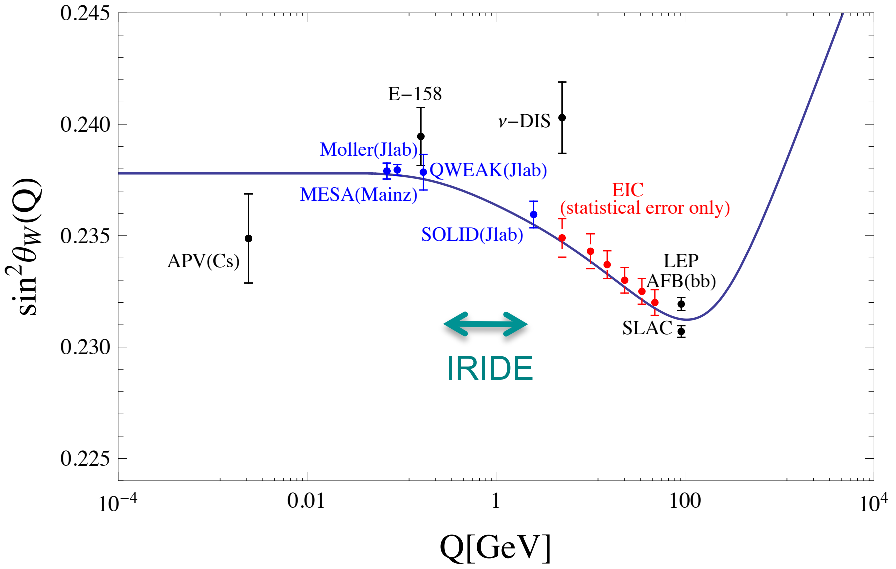
simulation (G4) in progress (collaboration w/ Rm2)

case under study: $E\gamma$ = 60 MeV on Pb (0.4 X_0)

e^- - target

✓ parity violating asymmetry meas. $e^{\uparrow\downarrow} Z \longrightarrow e Z$

- Q^2-evolution of weak mixing angle θ_W



$$Q = \sqrt{y\, s}$$

$$\left(y = \frac{1 - \cos\theta_{\rm cm}}{2} \right)$$

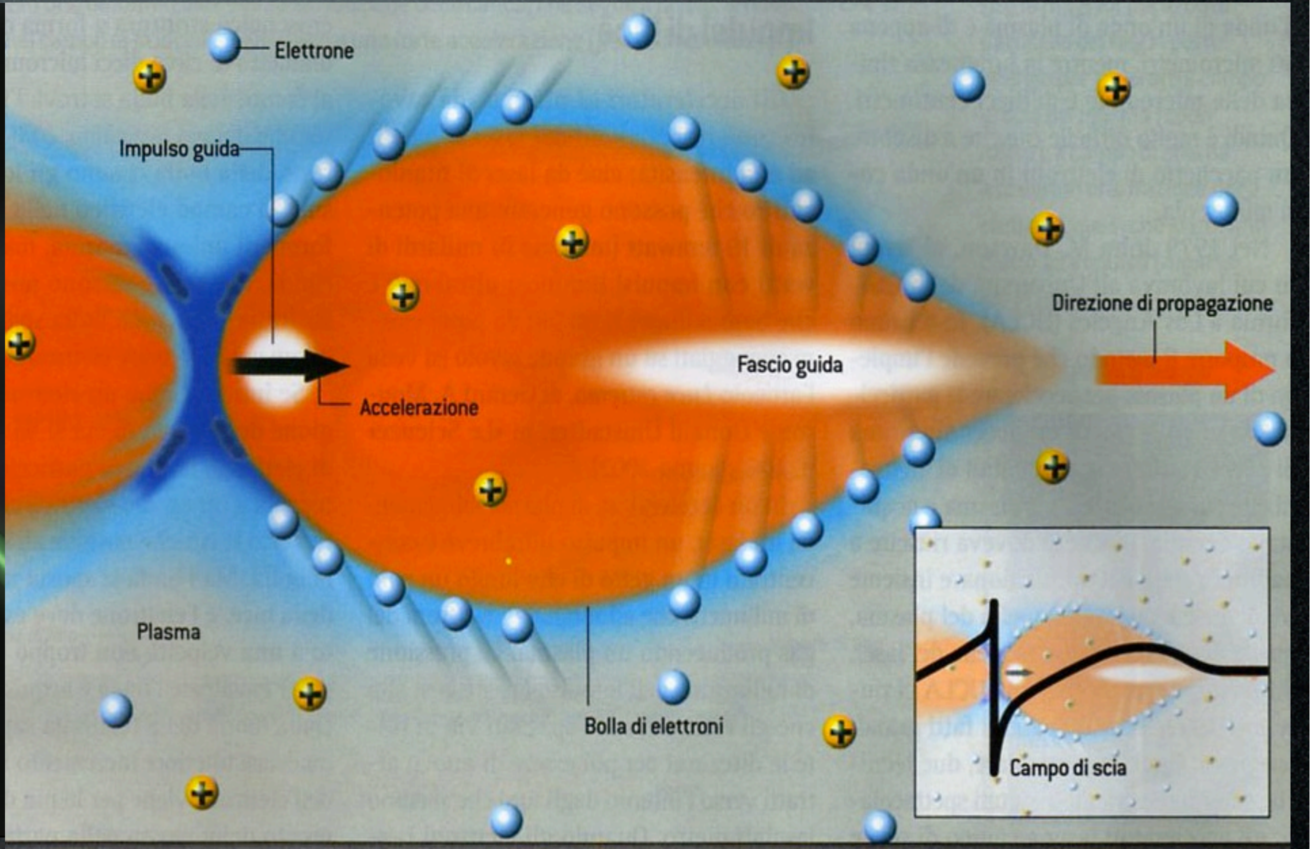
Requests:

✓ polarized beam (P ~ 90%; ΔP ~ 1%)

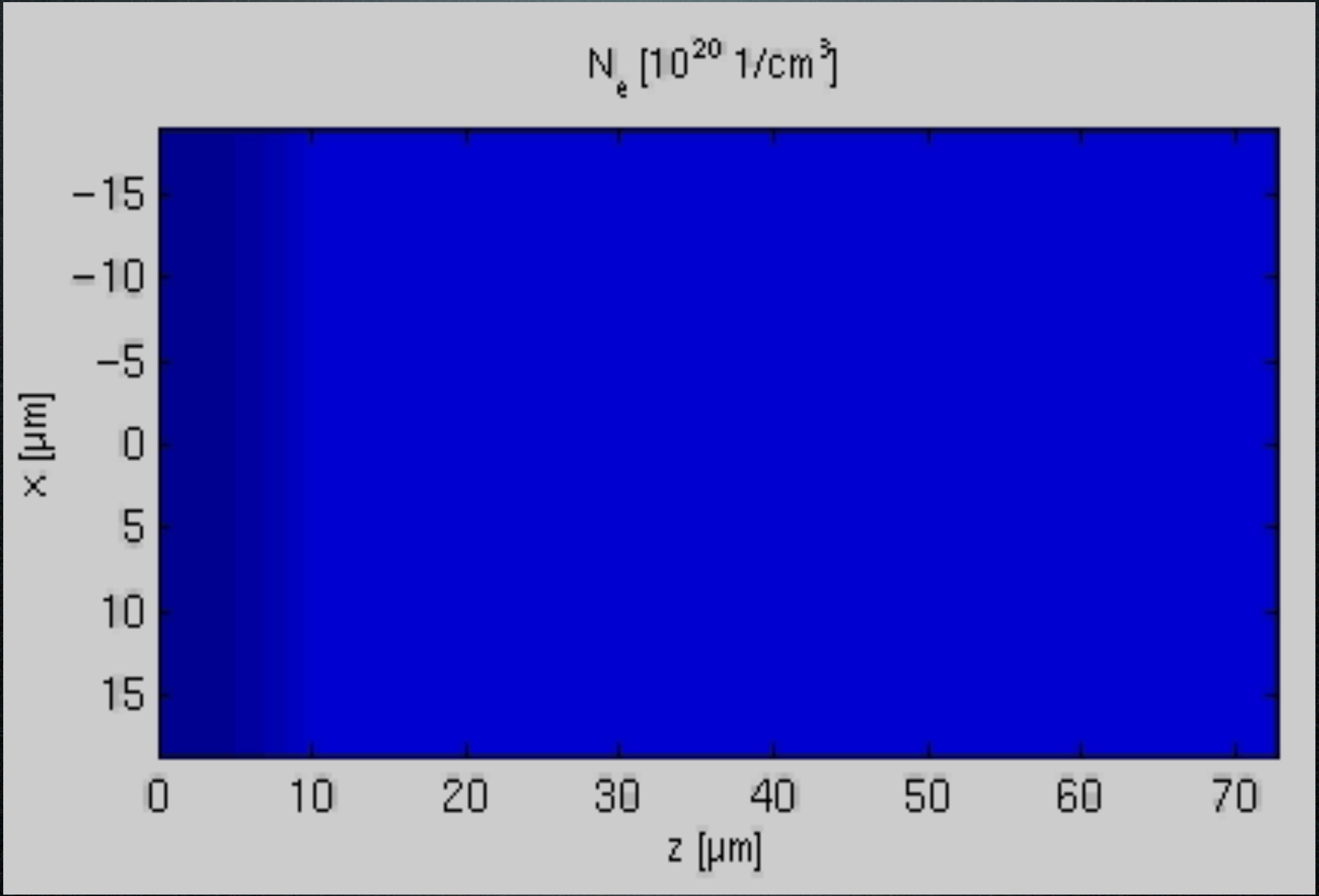
✓ average current > 200 μA

✓ dark forces searches $e Z \longrightarrow e Z \mu^+\mu^-$

Particle Wake Field Acceleration



Particle Wake Field Acceleration



IRIDE road map

- March –> June – Working Groups Meeting with int. experts
- July 31 - Conceptual Design Report ready
- By the end of 2013 IRIDE approval?

1. **General Introduction**
    - 1.1. General considerations
    - 1.2. Facility layout
    - 1.3. Upgrade potentials

2. **Electron Machine: the superconducting linac complex (Ferrario, Gallo, Pierini)**
    - 2.1. Introduction
    - 2.2. Superconducting L-band cavities and accelerator modules
    - 2.3. CW versus pulsed RF operation
    - 2.4. RF system and couplers
    - 2.5. Injector systems
    - 2.6. Beam parameters flexibility
    - 2.7. Beam dynamics
    - 2.8. Diagnostics
    - 2.9. Timing and Synchronization
    - 2.10. Cryogenic plant
    - 2.11. Cost analysis

3. **Free electron laser source (Benfatto, Castoldi, Dattoli)**
    - 3.1. Scientific opportunities
    - 3.2. Beam requirements and performances
    - 3.3. Bunch compressor
    - 3.4. Undulators chain
    - 3.5. Photon transport line
    - 3.6. Users beam line
    - 3.7. X-ray detectors (Castoldi)
    - 3.8. Cost analysis

4. **THz source (Chiadroni, Lupi)**
    - 4.1. Scientific opportunities
    - 4.2. Beam requirements and performances
    - 4.3. Users beam line
    - 4.4. Cost analysis

5. **Neutron source (Faccini, Valente)**
    - 5.1. Scientific opportunities
    - 5.2. Beam requirements and performances
    - 5.3. Neutron target
    - 5.4. Users beam line
    - 5.5. Detectors
    - 5.6. Cost analysis

6. **Photon Machine: lasers and optical system (Serafini, Villa)**
    - 6.1. Laser system and performances
    - 6.2. Compton source
    - 6.3. Optical system
    - 6.4. Cost analysis

7. **Nuclear Photonics (Colo’, Vaccarezza)**
    - 7.1. Scientific opportunities
    - 7.2. Beam requirements and performances
    - 7.3. γUsers beam line
    - 7.4. Cost analysis

8. **Electron-gamma collider (Serafini, Venanzoni)**
    - 8.1. Scientific opportunities
    - 8.2. Luminosity and beam requirements
    - 8.3. Photon source
    - 8.4. Interaction region
    - 8.5. Detector
    - 8.6. Cost analysis

9. **Gamma-gamma collider (G. Gatti, Milotti, Serafini)**
    - 9.1. Scientific opportunities
    - 9.2. Luminosity and beam requirements
    - 9.3. Photon source
    - 9.4. Interaction region
    - 9.5. Detector
    - 9.6. Cost analysis

10. **Electron-electron, electron-positron collider (Babusci, Bossi, Ferrario)**
    - 10.1. Scientific opportunities
    - 10.2. Luminosity and beam requirements
    - 10.3. Positron source
    - 10.4. Damping ring
    - 10.5. Final focus
    - 10.6. Detector
    - 10.7. Cost analysis

11. **Advanced accelerator experiments (Cianchi, Gizzi, Rossi)**
    - 11.1. Scientific opportunities
    - 11.2. Plasma wake field acceleration with lasers or beams
    - 11.3. Dielectric wake field acceleration
    - 11.4. IFEL
    - 11.5. Proton beams

Thank you