I R I D E

Interdisciplinary Research Infrastructure with Dual Electron linacs

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on behalf of

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I R I D E

Interdisciplinary Research Infrastructure with Dual Electron linac&laser

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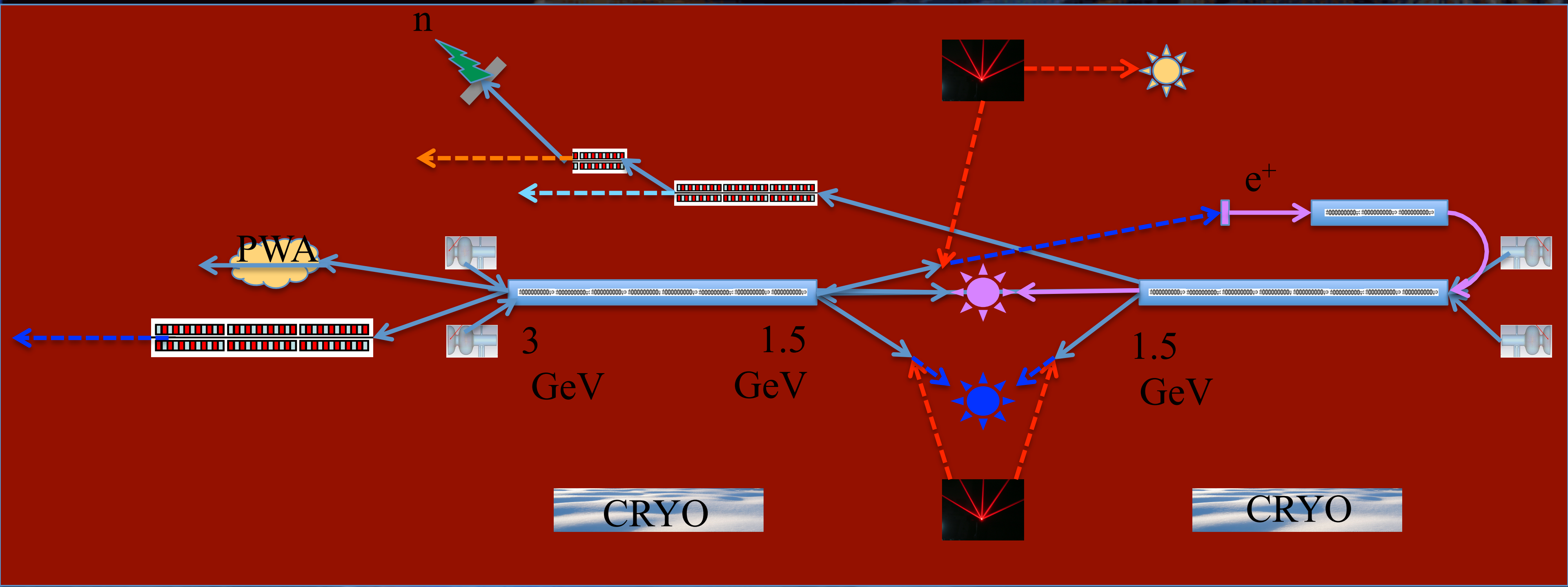
I R I D E is a large infrastructure for fundamental and applied physics research. Conceived as an innovative and evolutionary tool for multi-disciplinary investigations in a wide field of scientific, technological and industrial applications, it will be a high intensity "particle beams factory",



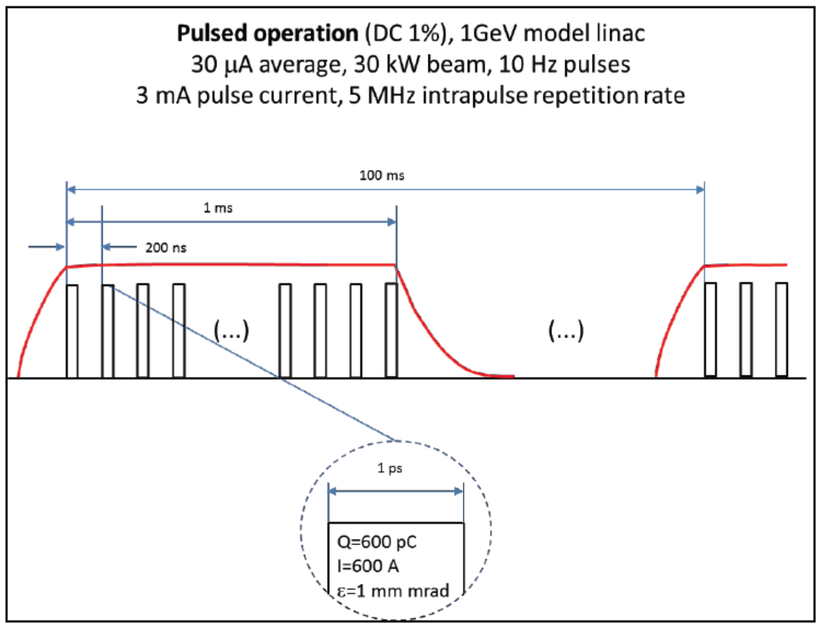
Based on a combination of a high duty cycle radio-frequency superconducting electron linac (SC RF LINAC) and of high energy lasers. It will be able to produce a high flux of electrons, photons (from infrared to γ-rays), neutrons, protons and eventually positrons, that will be available for a wide national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

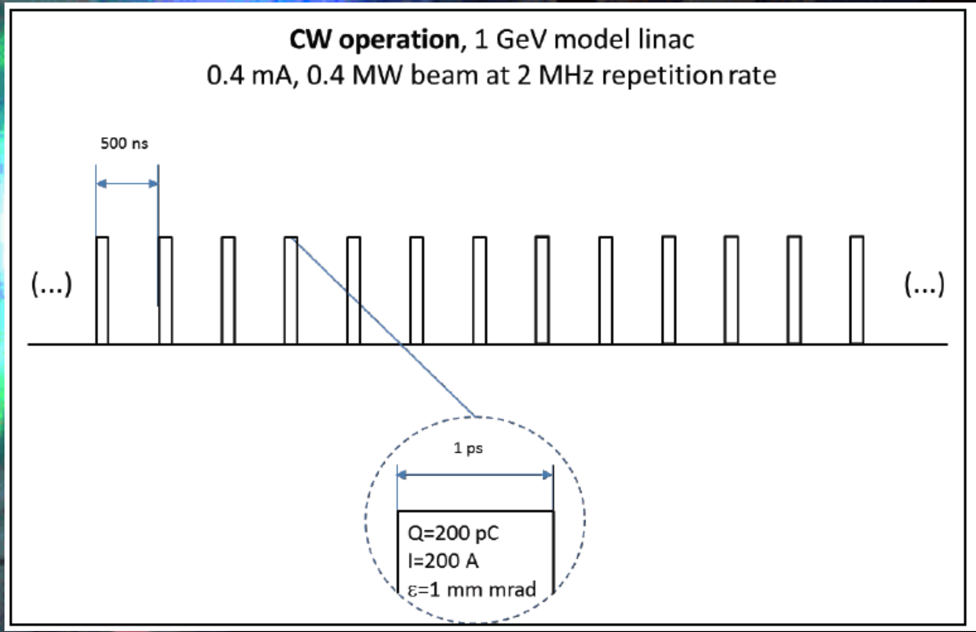
We can foresee a large number of possible activities, among them:

- Science with Free Electron Lasers (FEL) from infrared to X-rays,
- Nuclear photonics with Compton back-scattering g-rays sources,
- Fundamental physics investigations with low energy linear colliders
- Advanced Neutron sources by photo-production,
- Science with THz radiation sources,
- Physics with high power/intensity lasers,

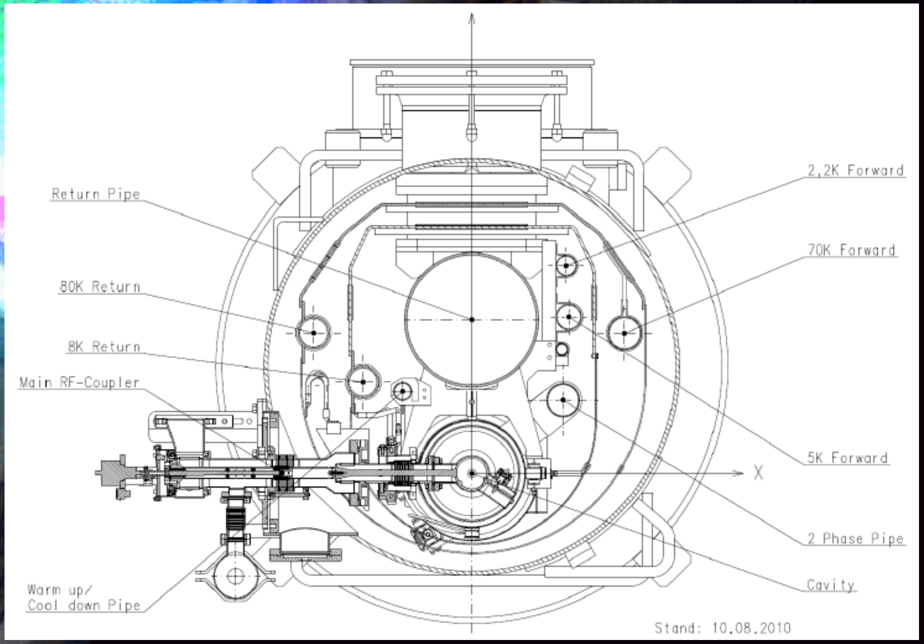
- R&D on advanced accelerator concepts including plasma accelerators and polarized positron sources
- ILC technology implementation
- Detector development for X-ray FEL and Linear Colliders
- R&D in accelerator technology and industrial spin – off

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). 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.



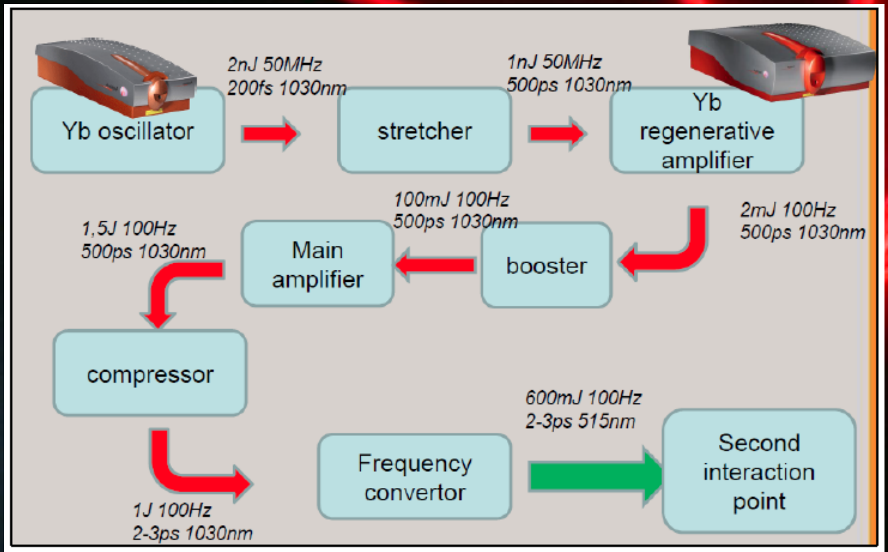


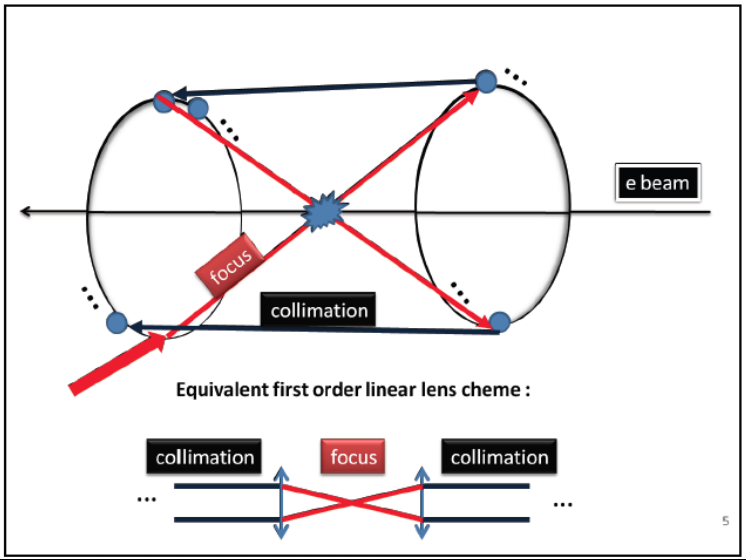
INFN is in a leading position in the SC RF technology, with knowledge and strong capabilities in the design, engineering and industrial realization of all the main component of a superconducting radiofrequency accelerator. INFN strongly participated to TESLA since the early design stages through the 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.



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

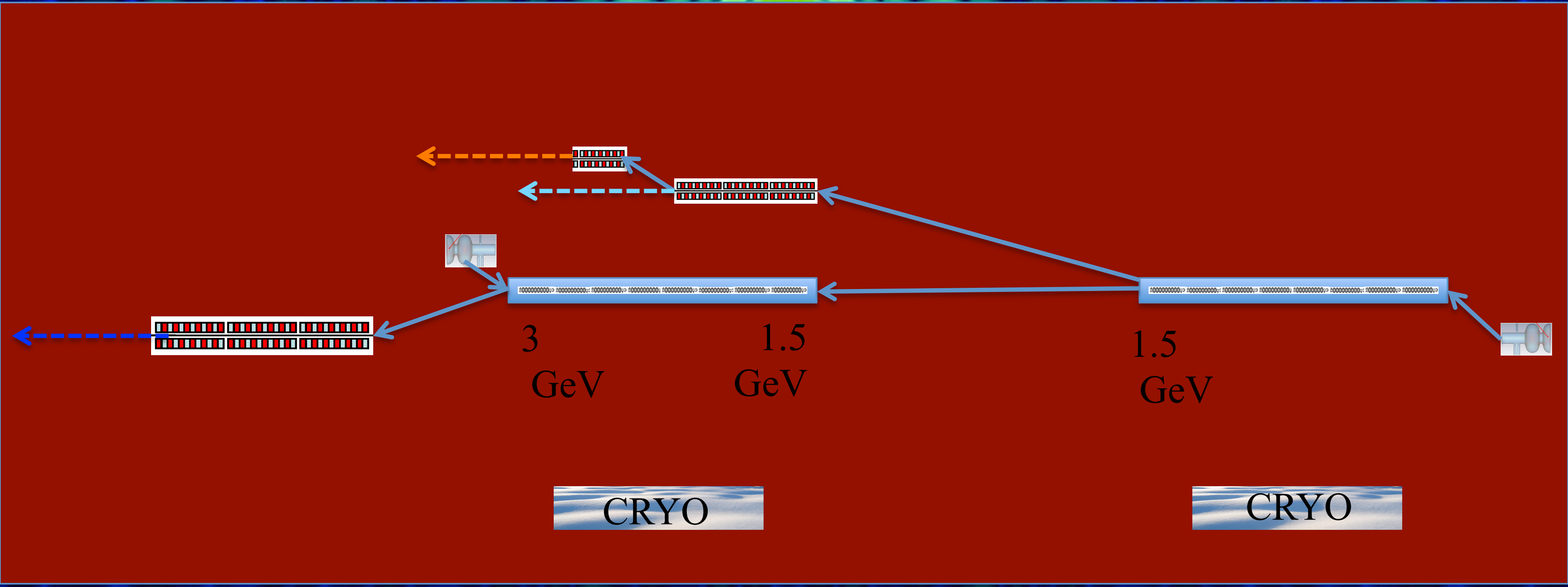
- drivers of photo-cathodes for electron beam generation
-
- colliding laser pulses to drive the back-scattering Compton (Yb:YAG, 100 W, 1 J, 0.1% bw)
- drivers for high advanced acceleration experiments (Ti:Sa, 1 PW, 10^{22} W/cm^2)



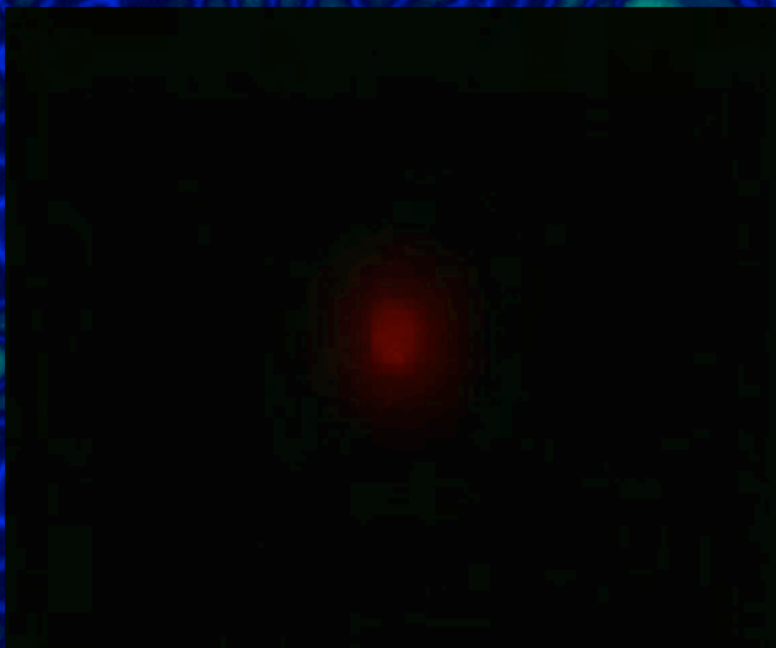


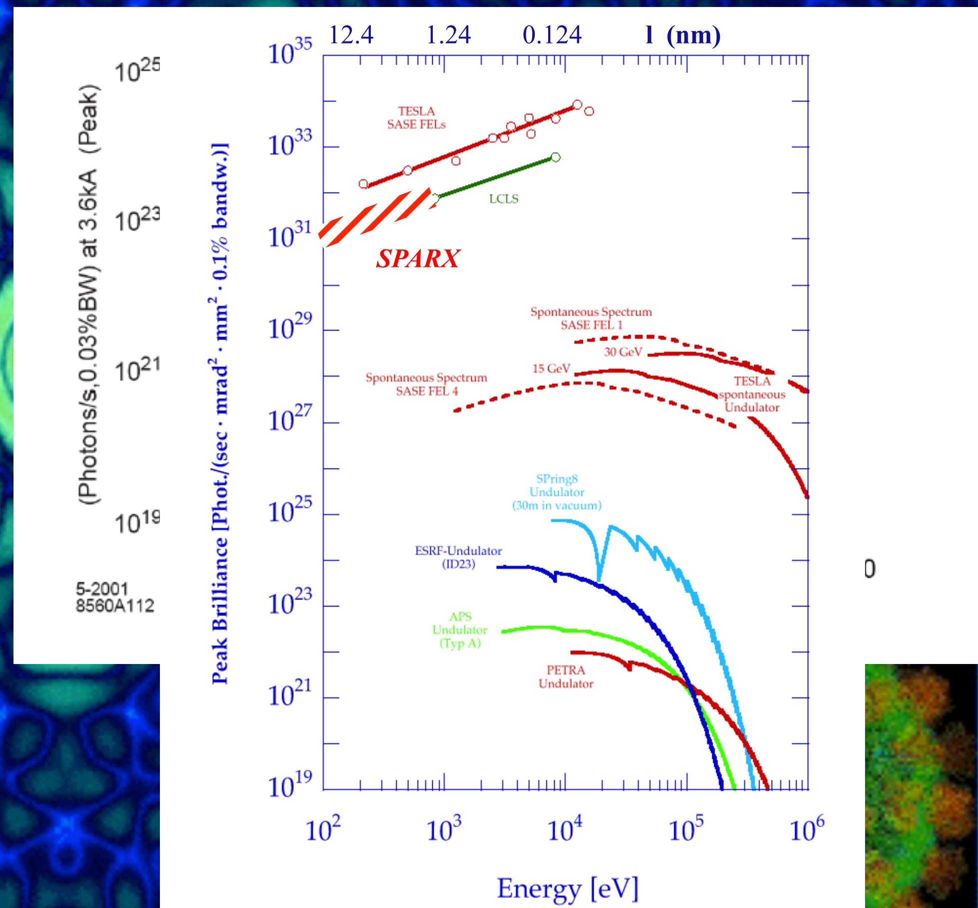
Science with FEL

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.



A Free Electron Laser is a device that converts a fraction of the electron kinetic energy into coherent radiation via a collective instability in a long undulator



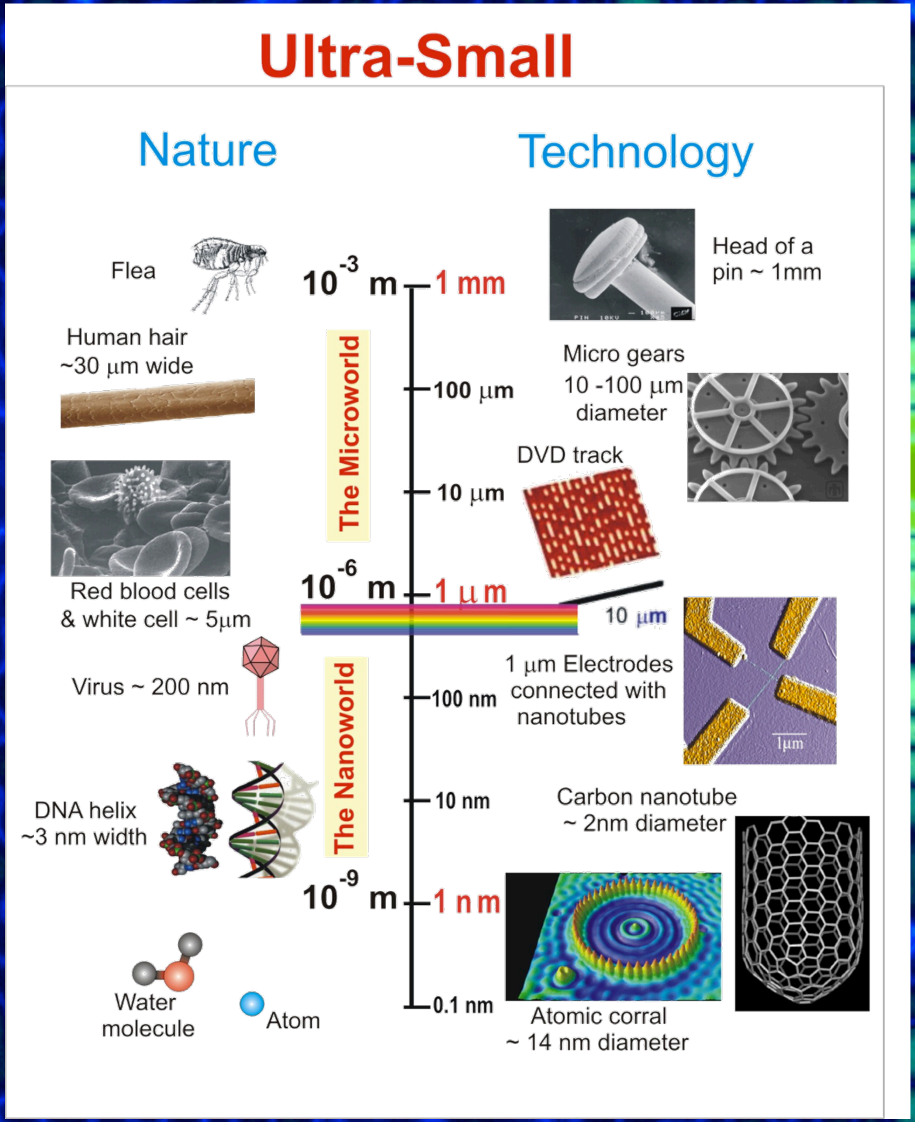


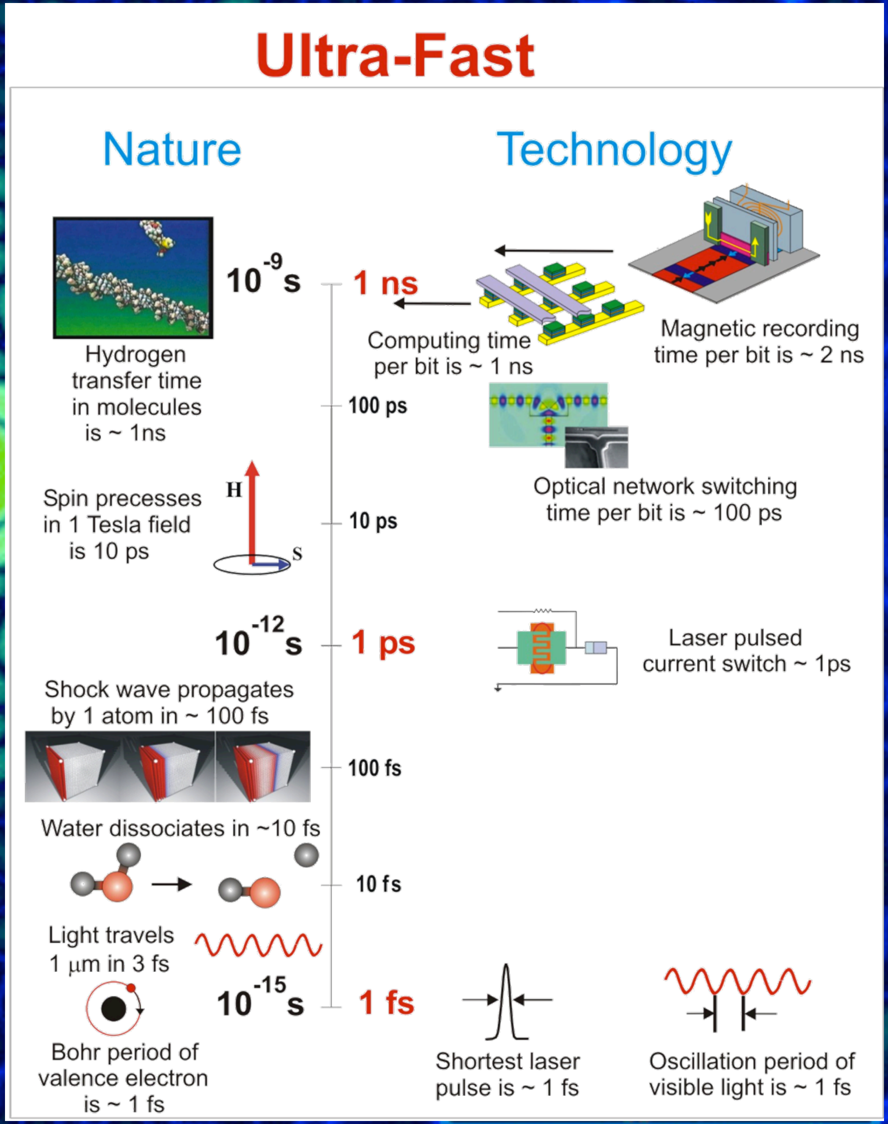
$$\lambda_{rad} \approx \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2} + \gamma^2\vartheta^2\right)$$

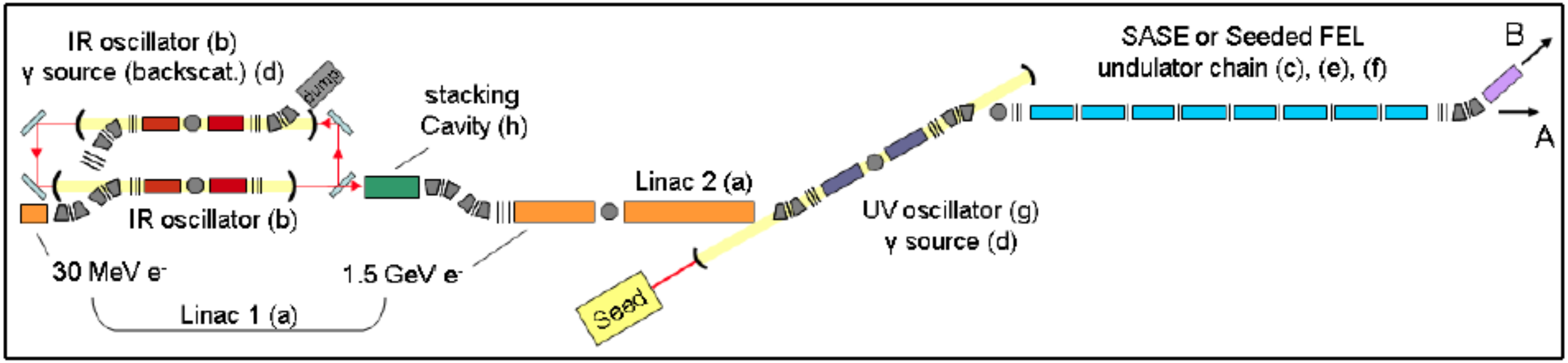
Radiation properties:

GW power - Monocromaticity - Tunability from IR to X– Short pulses

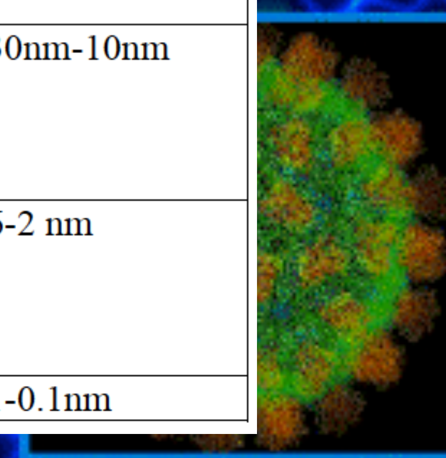
Science with FEL





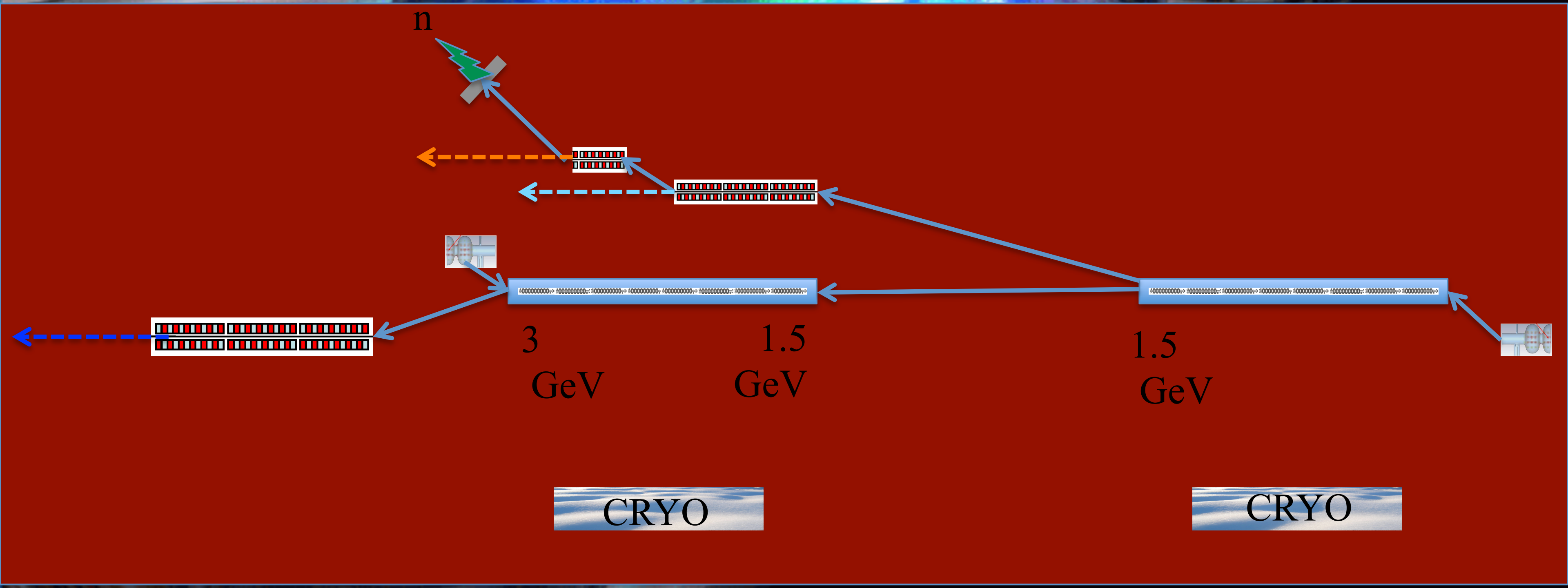


Electron beam energy	FEL osc_I	FEL osc_II	FEL osc_III	SASE&Seeding
50-100 MeV	10-0.1 X-ray intracavity generation			
750 Mev		120 nm+ Harmonics& Intracavity-scattering		30nm-10nm
2.28 GeV			13.5nm+ Harmonics &intracavity scattering	6-2 nm
3 GeV				1-0.1nm



Neutron Source

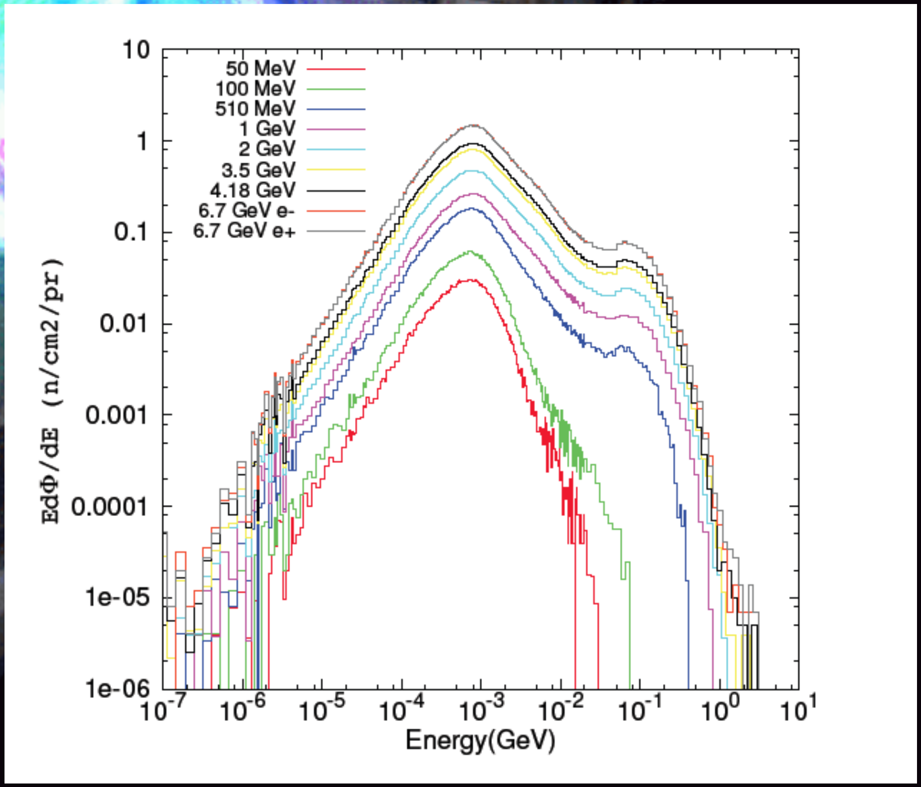
A Neutron Source can be realized by photo-production sending high energy electrons on a suitable high Z target. This kind of source allows to obtain neutrons with an energy spectrum that spans over more than 9 decades of energy from few meV up to hundred of MeV, even if most of them have energy around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



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.

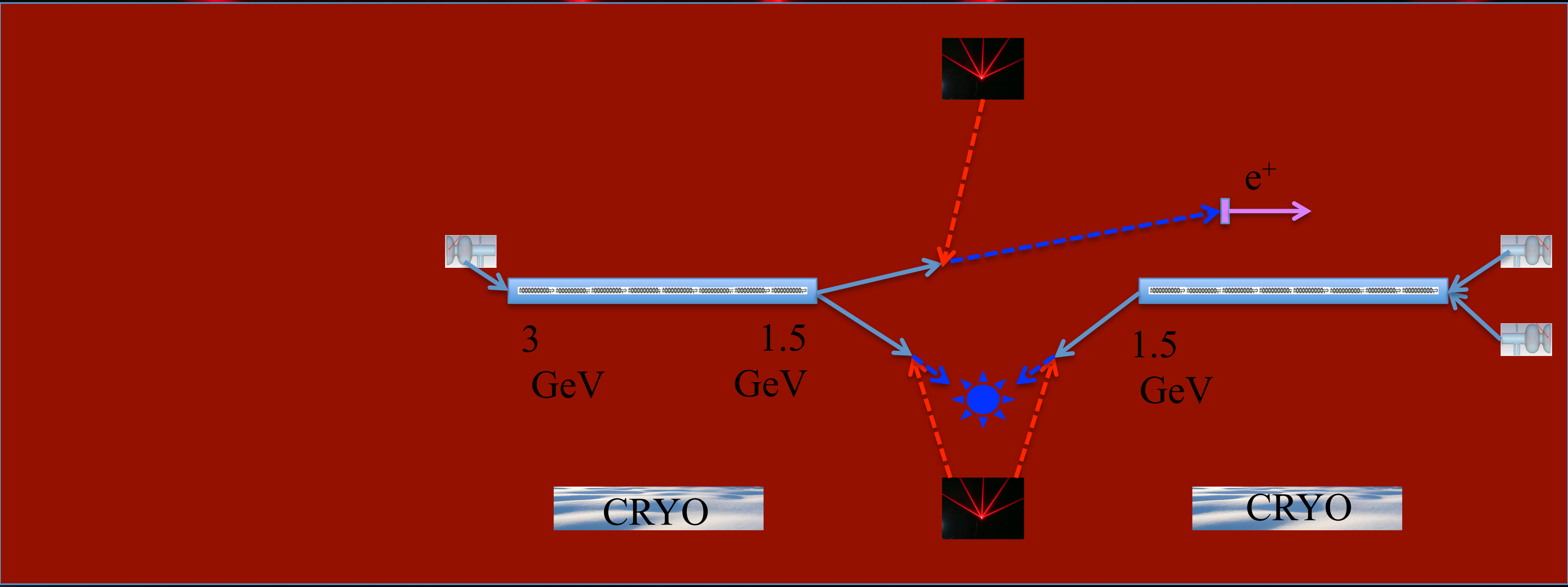
Chip irradiation : In order to test the robustness of electronic devices to neutron field in a few minutes, neutron beams produced at facilities are desirable as the may provide an almost atmospheric-like neutron spectrum but several order of magnitude more intense.

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

Advanced γ-ray Compton Source

Thestate 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*.

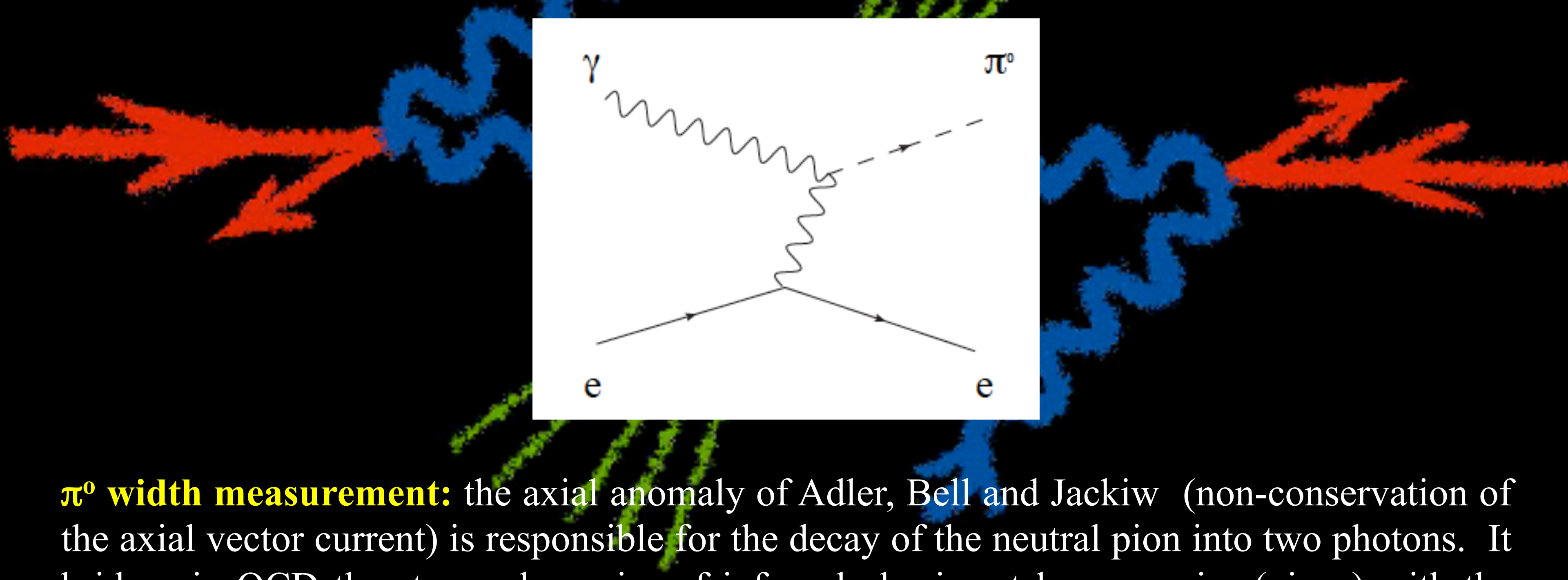


Advanced γ-ray Compton Source

- 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 $e\,\gamma \rightarrow \pi^0\, e$ (*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).

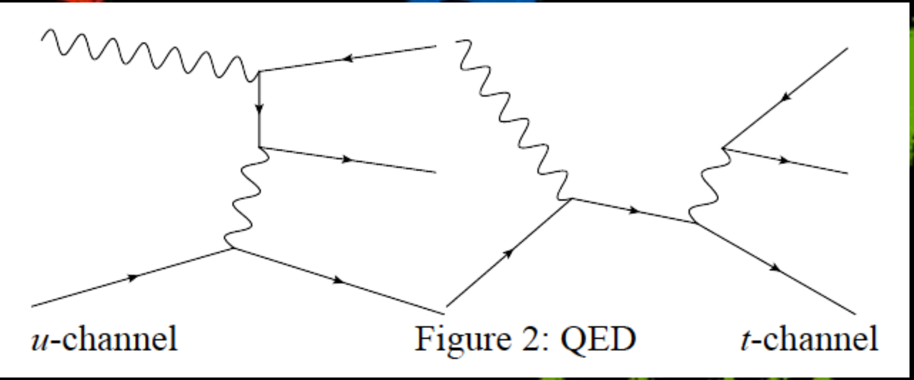
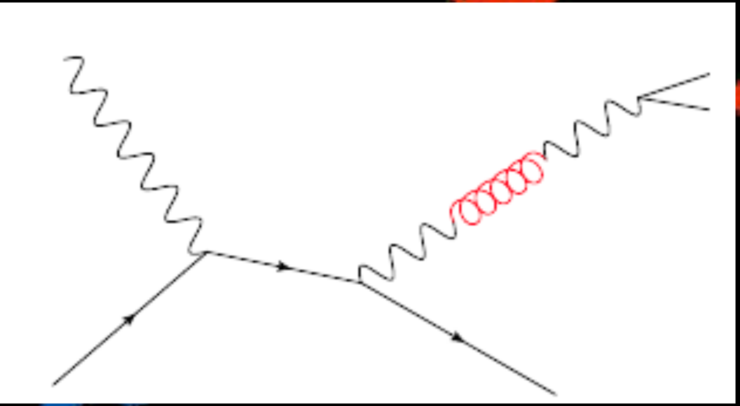


Figure 2: QED

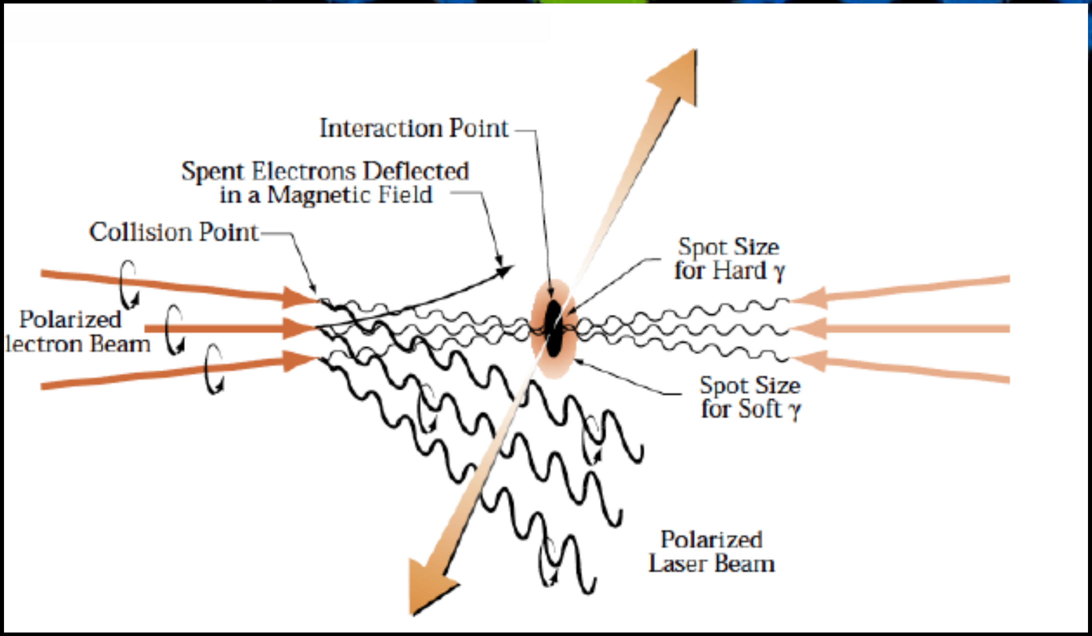


At IRIDE we can search for U boson via the lepton triplet production process in the electron-photon collision. The main QED process of the lepton triplet production is through u channel exchange (“BH diagram”) and the t channel exchange (“VCS diagram”).

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.

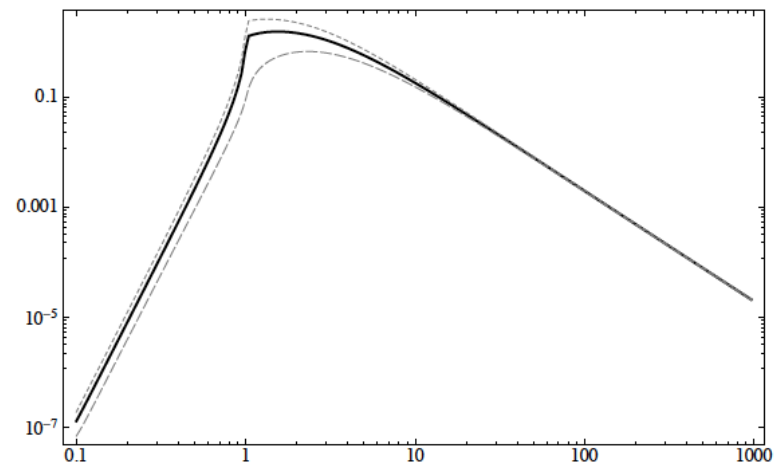


Figure 18: total cross-section (μbar) vs. CM energy (MeV). Solid line: cross-section averaged over initial photon polarizations. Dotted line: incoming photons have the same circular polarization. Dashed line: incoming photons have opposite circular polarization.

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

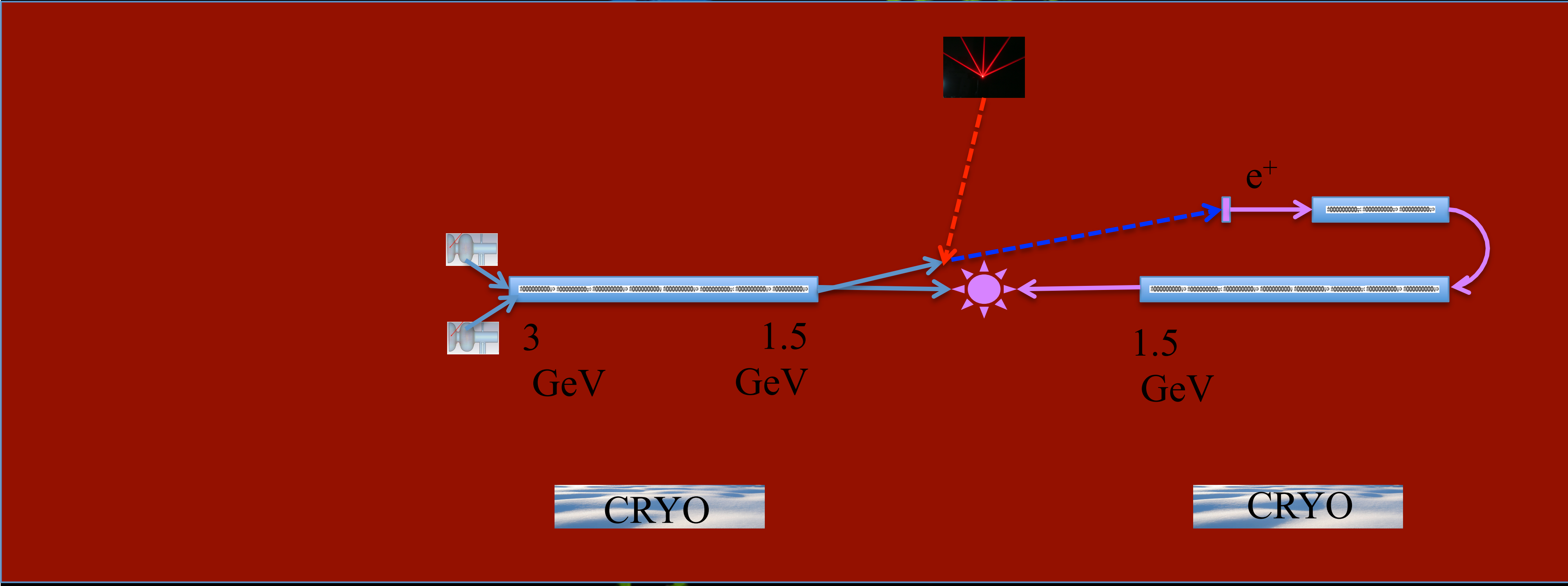
Luminosity and beam requirements

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
Charge	[nC]	0.01	0.01	0.01
Bunch length rms	[μm]	300	300	125
Peak current	[A]	4	4	32
Rep. rate	[MHz]	100	100	100
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)	[mm]	100	2	0.125
Luminosity	$cm^{-2}s^{-1}$	n.d.	$1.1\ 10^{25}$	$9.3\ 10^{28}$

$e^+ e^-$ 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.

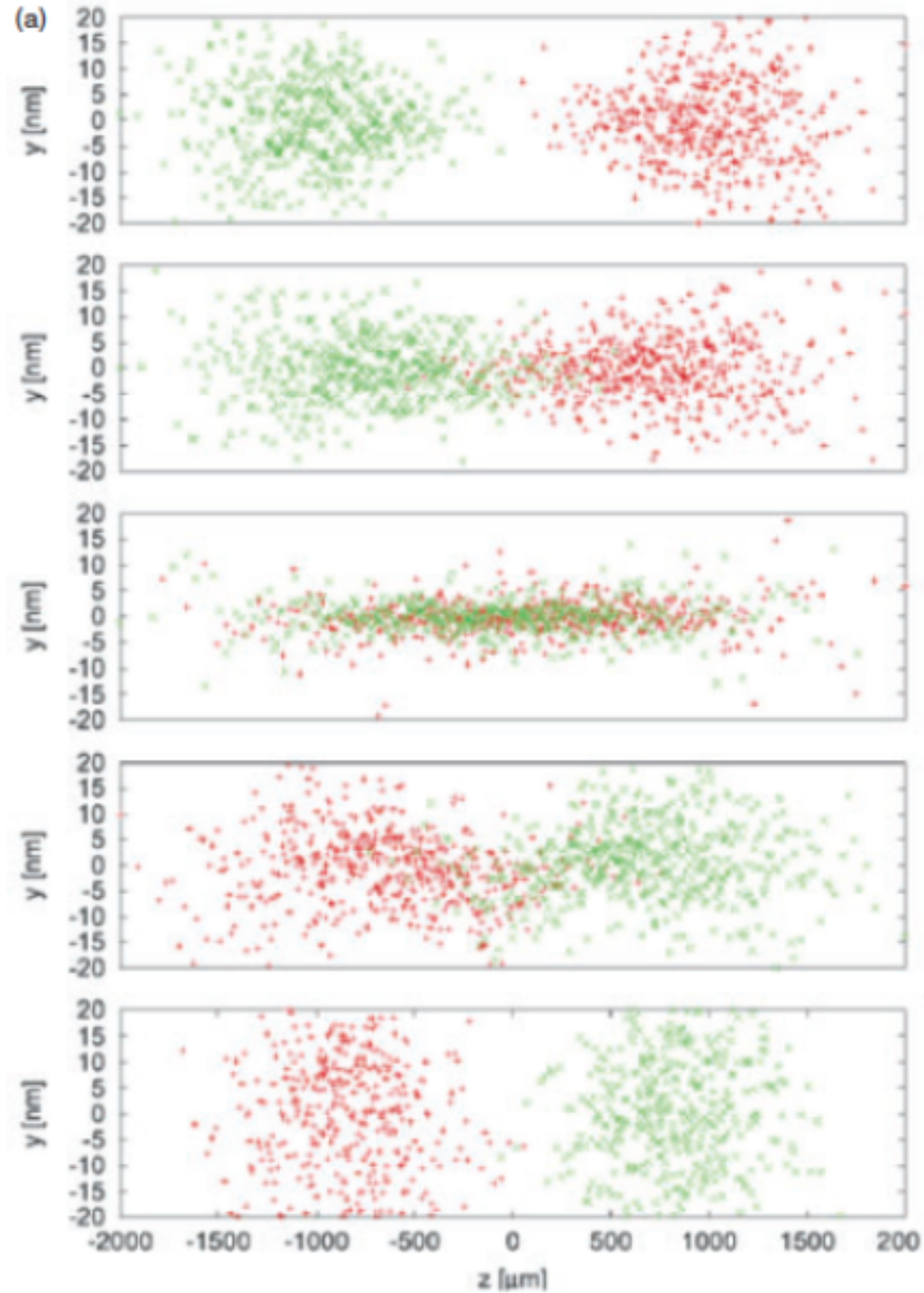


This will allow one to measure the e^+e^- cross section to hadrons with a total fractional accuracy of 1%, a level of knowledge that has relevant implications for the determination of SM observables, like, the *g*-2 of the muon and the effective fine-structure constant at the M_Z scale. The latter are, 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 [2], i. e. the reduction of the cross section of both beams occurring at the IP due to self focusing forces, see Fig. 22, that is included in the luminosity definition through the factor H_D.

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

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

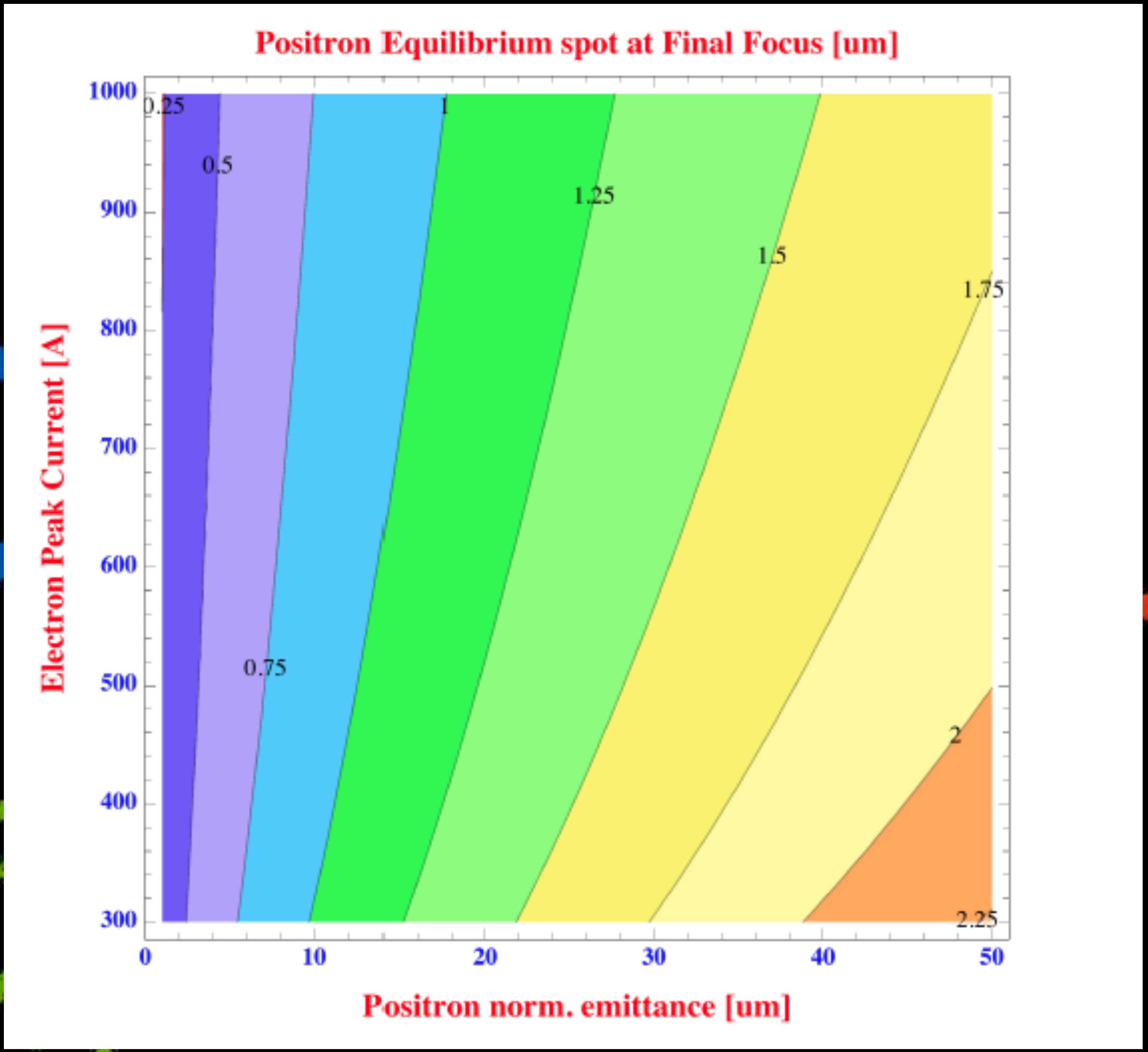


$$\sigma''_{pos,x} + \frac{k_{el}^2}{\gamma}\sigma_{pos,x} = \frac{\varepsilon_{pos,n}^2}{\gamma^2\sigma_{pos,x}^3}$$

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

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

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.



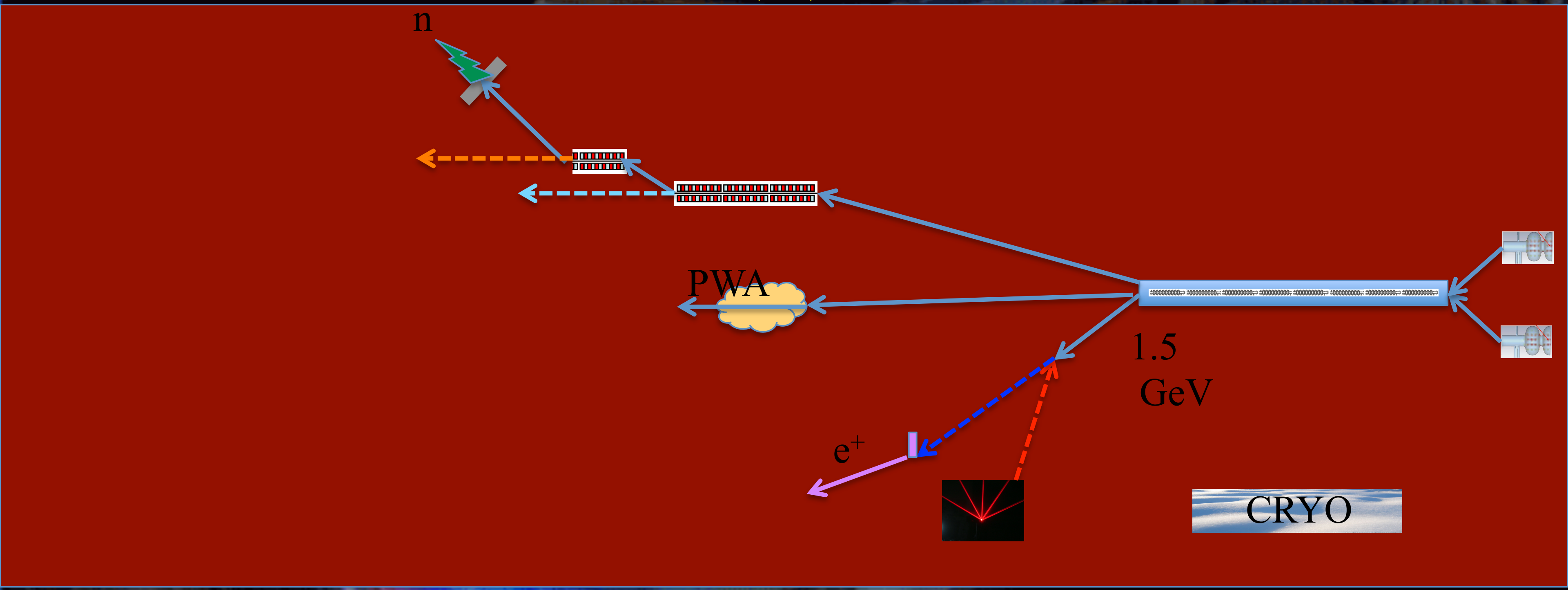
Parameters	Units	Electrons >< Electrons	Electrons >< Positrons	Reduced Positron quality
Beam energy	[GeV]	1	1	1
Beam power	[MW]	1	1	0.4
AC power	[MW]	1.9	1.9	1.3
Charge	[nC]	0.2	2	0.8
Bunch length rms	[μm]	500	675	450
Peak current	[A]	120	888	533
Rep. rate	[MHz]	5	0.5	0.5
Average current	[mA]	1	1	0.4
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.

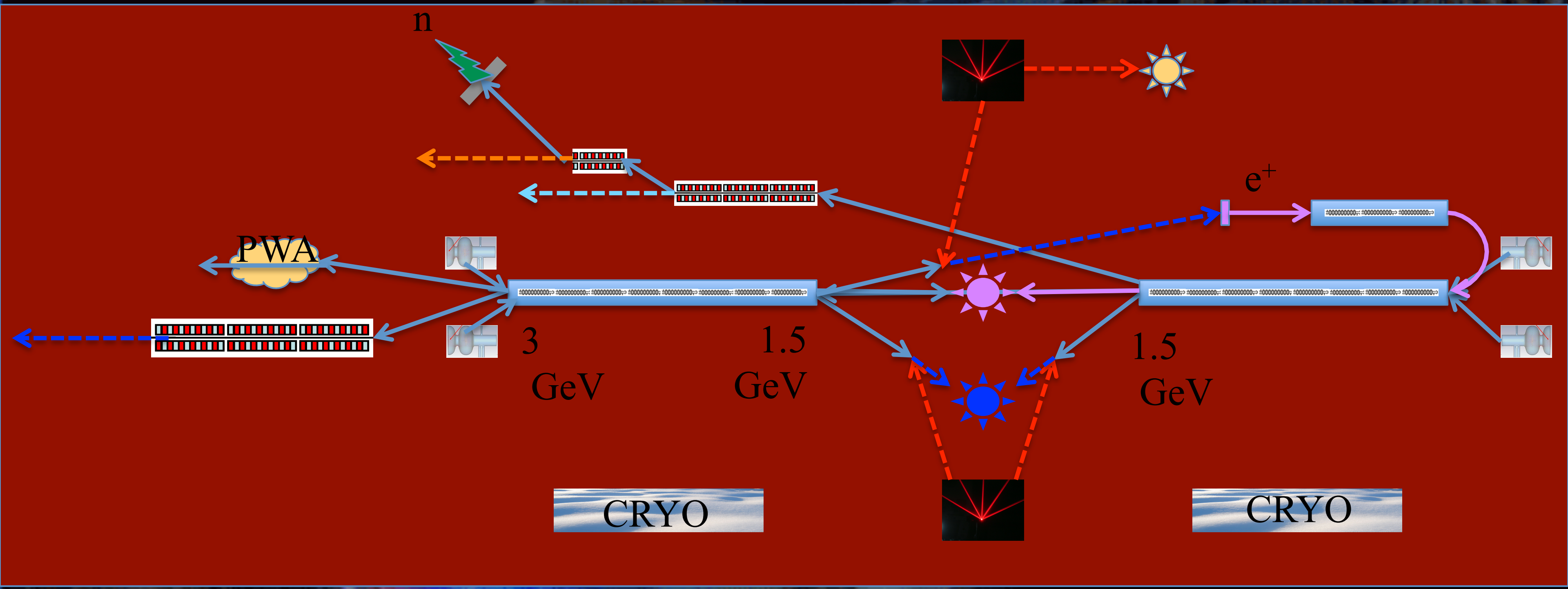
Preliminary cost evaluation – step 1 (?)



Preliminary cost evaluation – step 1

Components	M€
Injector 1	10
Linac 1 modules including CW RF	30
Cryogenic Plant 1	20
Total for Linac 1	**60**
FEL undulators	10
FEL Optics and user beam lines	20
Total for FEL	**30**
Neutron source	**5**
Advanced Accelerator Exp.	**5**
THz source	**3**
C-band Injector	13
High Energy Yb:YAG Laser 1	7
Interaction region and laser recirculator:	4
γ-ray beam collimation and diagnostics	3
Compton Users Beam Lines	10
Total for Compton source	**37**
Polarized positron source	**5**
GRAND TOTAL	**145**

Preliminary cost evaluation – step 2



Preliminary cost evaluation – step 2

Components	M€
Injector 2	10
Linac 2 modules including RF	30
Cryogenic Plant 2	20
Total for Linac 2	**60**
FEL undulators	20
FEL Optics and user beam lines	40
Total for FEL	**60**
High Energy Yb:YAG Laser 2	7
Detector e/γ γ/γ	10
Total for e/γ γ/γ **collider**	**17**
Positron surce	
Damping Ring ?	
Detector e^+e^-	
Total for e^+e^- **collider**	**To be evaluated**
GRAND TOTAL	**137**

To Do List

- Preliminary Proposal is almost ready
- Kick Off Meeting by the end of February
- One day international meeting on June 2 during EAAC 2013
- Conceptual Design Report ready for Summer

EAAC2013

1st European Advanced Accelerator Concepts Workshop

2-7 June 2013, La Biodola, Isola d'Elba, Italy

Novel schemes using advanced technologies (table-top FEL, plasma linear collider)
High gradient and multibunch acceleration in metallic structures (C-X-band and beyond) with innovative power generation schemes
Advanced beam diagnostics for beams and plasma
Dielectric structures and other novel technologies
Plasma accelerators driven by electron beams
Plasma accelerators driven by modern lasers
Plasma accelerators driven by proton beams
Computations for Accelerator Physics

INFN Istituto Nazionale di Fisica Nucleare

The European Advanced Accelerator Concepts workshop has the mission to discuss and foster methods of beam acceleration with gradients beyond state of the art in operational facilities. The most cost effective and compact methods for generating high energy particle beams shall be reviewed and assessed. This includes diagnostics methods, timing technology, special need for injectors, beam matching, beam dynamics with advanced accelerators and development of adequate simulations. This workshop is organized within the 7th European Programme by the European Network for Novel Accelerators (EuroNNAc), representing 52 European Research Institutes. The EAAC will be followed by a 1-day network meeting by invitation only.

CERN

DESY

On Friday 7th: EuroNNAc 2013 yearly meeting

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Jens Osterhoff (DESY)
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www.lnf.infn.it/conference/EAAC2013/

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