INFN initiatives towards future accelerators

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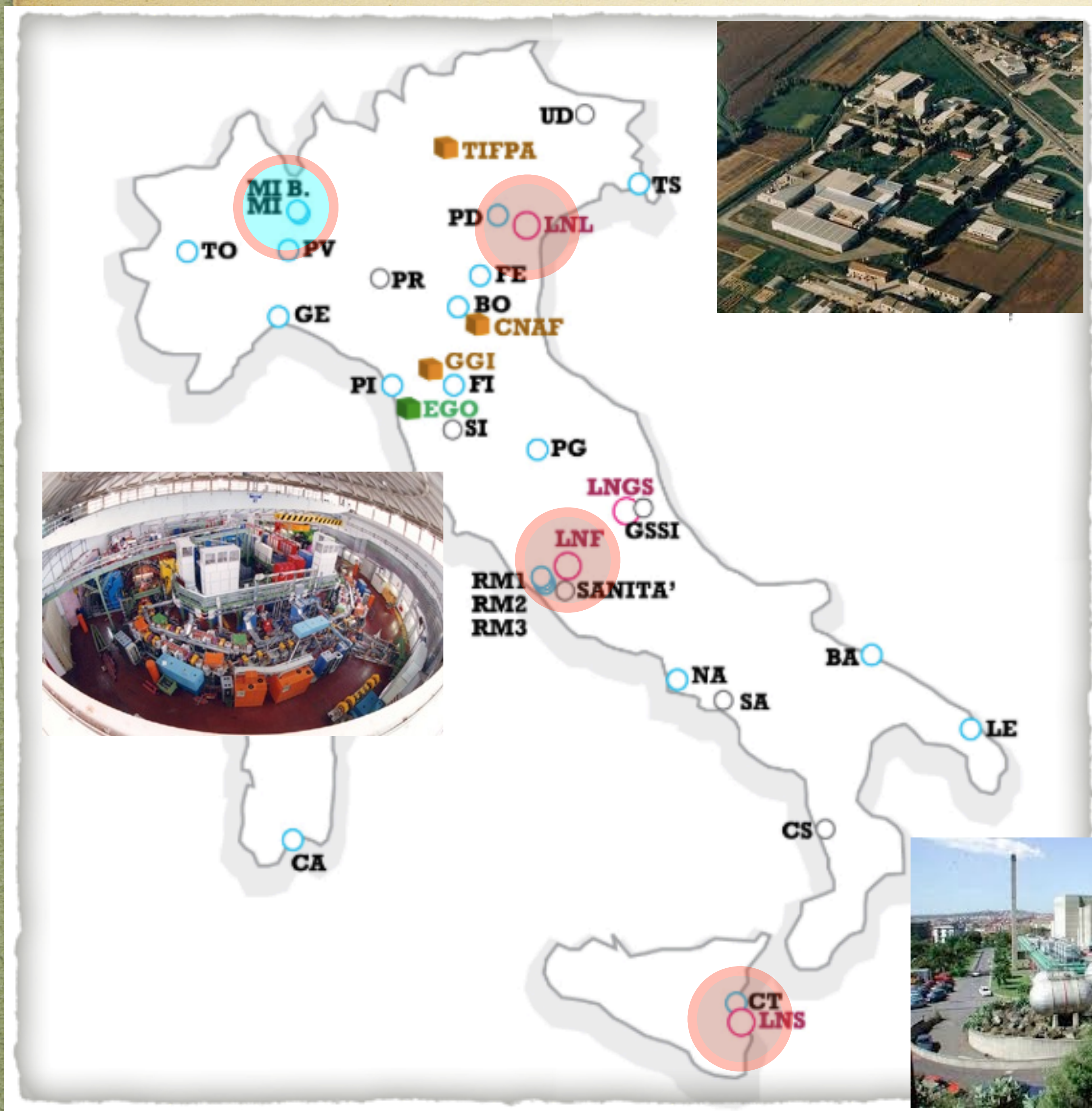
Les Rencontres de Physique de la Vallée d'Aoste 2018

INFN is a federal institute



- Laboratori Nazionali (4)
- Sezioni (20)
- Gruppi collegati (11)
- Centri Nazionali e Scuole (3)
- Consorzi (1)

with some Lab having accelerators at the core of their research

- LNL (Legnaro) with a 70 MeV, 200 μA and two beams. One for nuclear physics , one for radioisotopes for medical diagnostics and therapy (together with a private company).
- LNS (Catania) with a SC, 80 MeV/A. It will be significantly refurbished with a 15 ME investment (double charge exchange for the study of the NME useful for DBD).
- LNF (Frascati) with Dafne at the end of its life for particle physics and SPARC as a test of a future we'll talk about.

and a superconductivity center in Milano

a group of excellent accelerator physicist present all over

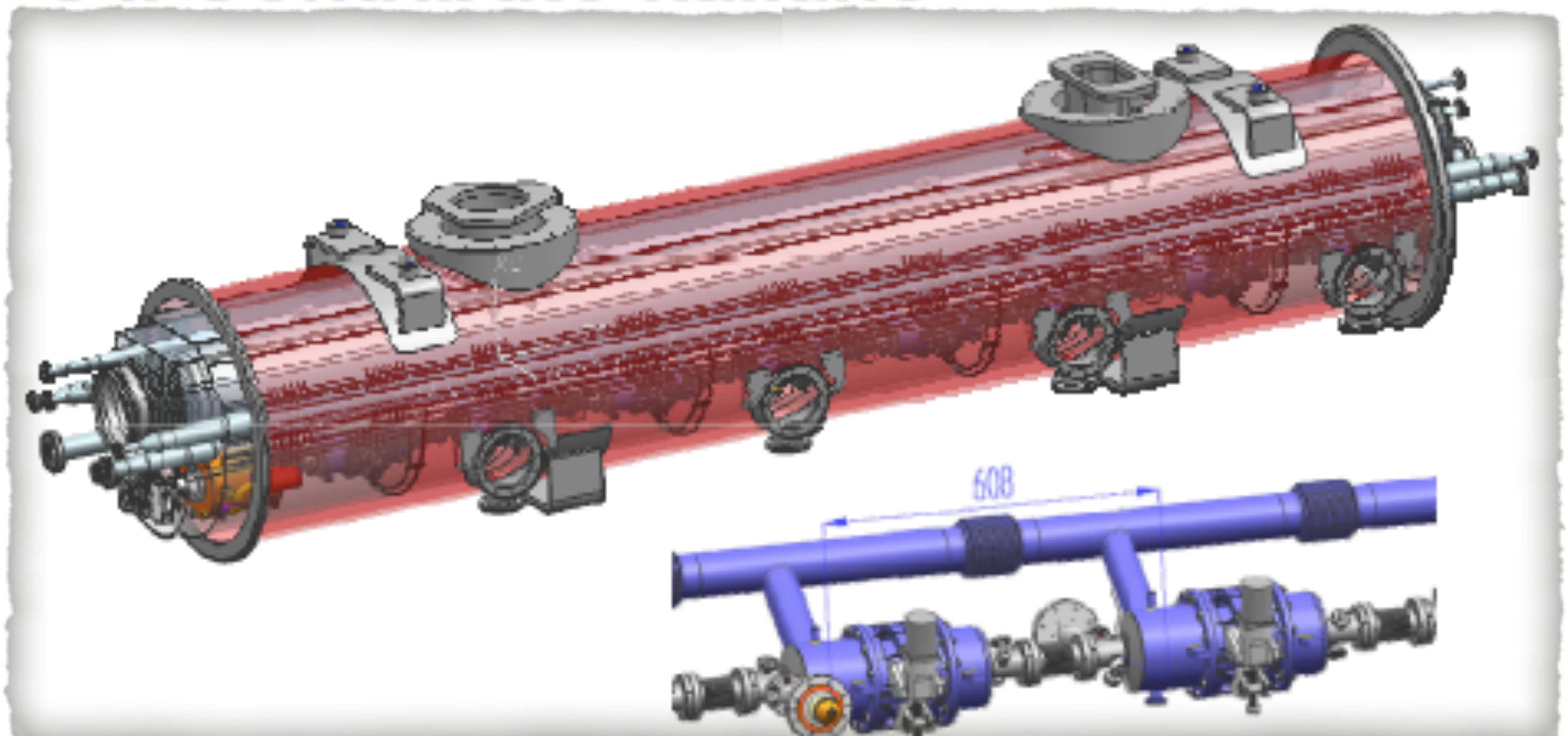
- European X-FEL (Amburgo)
- European Spallation Source (Lund)
- European Synchrotron Radiation Facility (Grenoble)
- Fermilab (Chicago)
- ELI-NP (Bucharest)
- SESAME (Amman)
- LCLS-II (Stanford)
- FAIR (Darmstadt)
- NICA (Dubna)
- **CERN** ....

In all these labs INFN has provided technology for accelerators and/or is building parts

in red laboratories directed by an italian

XFEL@DESY

- INFN
  - Design/procure: **cavities, tuners, cryomodule**
  - **Vertical testing** of all cavities, @ LASA
  - Join assembly/test @ DESY (up to commissioning)



European Spallation Source

Ion sources at ESS, Lund (gen.18)

First module of Drift Tube Linac (nov.17)

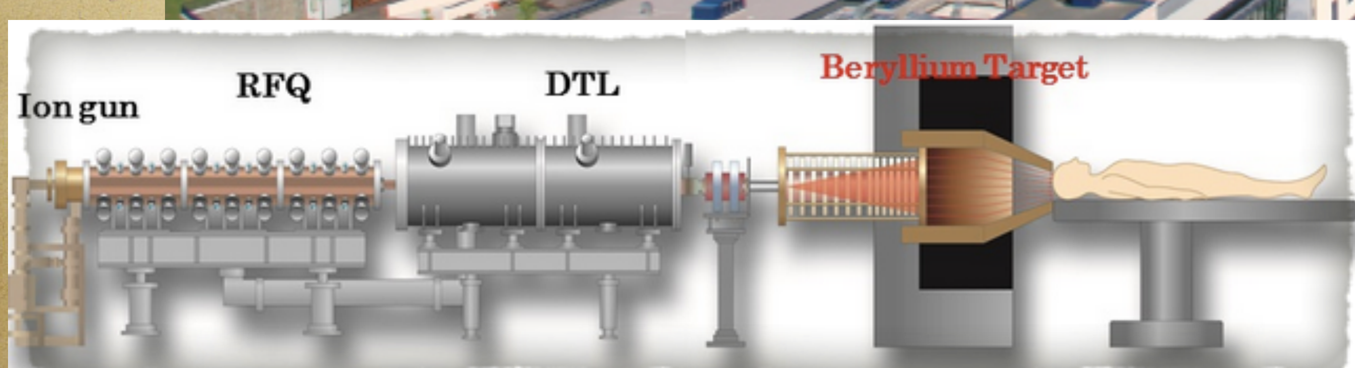
Drift Tube Linac construction at INFN-Legnaro is under way with a growing ramp: the most important contracts have been signed and the component of this part of the Linac will be available in 2018 and 2019.

First component of the ESS: Ion Source & LEBT built at INFN-LNS, Catania.
Source tested successfully in 2017 as for emittance, stability and beam current; delivered to Lund in due date. Installation at ESS Normal Conducting Front End area will be done by 2/2/2018.
Beam commissioning will be done in May 2018, after that ESS Safety Division would complete their activities and will receive from local authorities the permission to start.

Niobium boxes at INFN-Milano (dec.17)

The construction of medium beta superconducting cavities has started according to schedule; contracts have been signed and first boxes with Niobium arrived and they were checked. First cavities will be ready in spring 2018

always involved in hadrotherapy projects



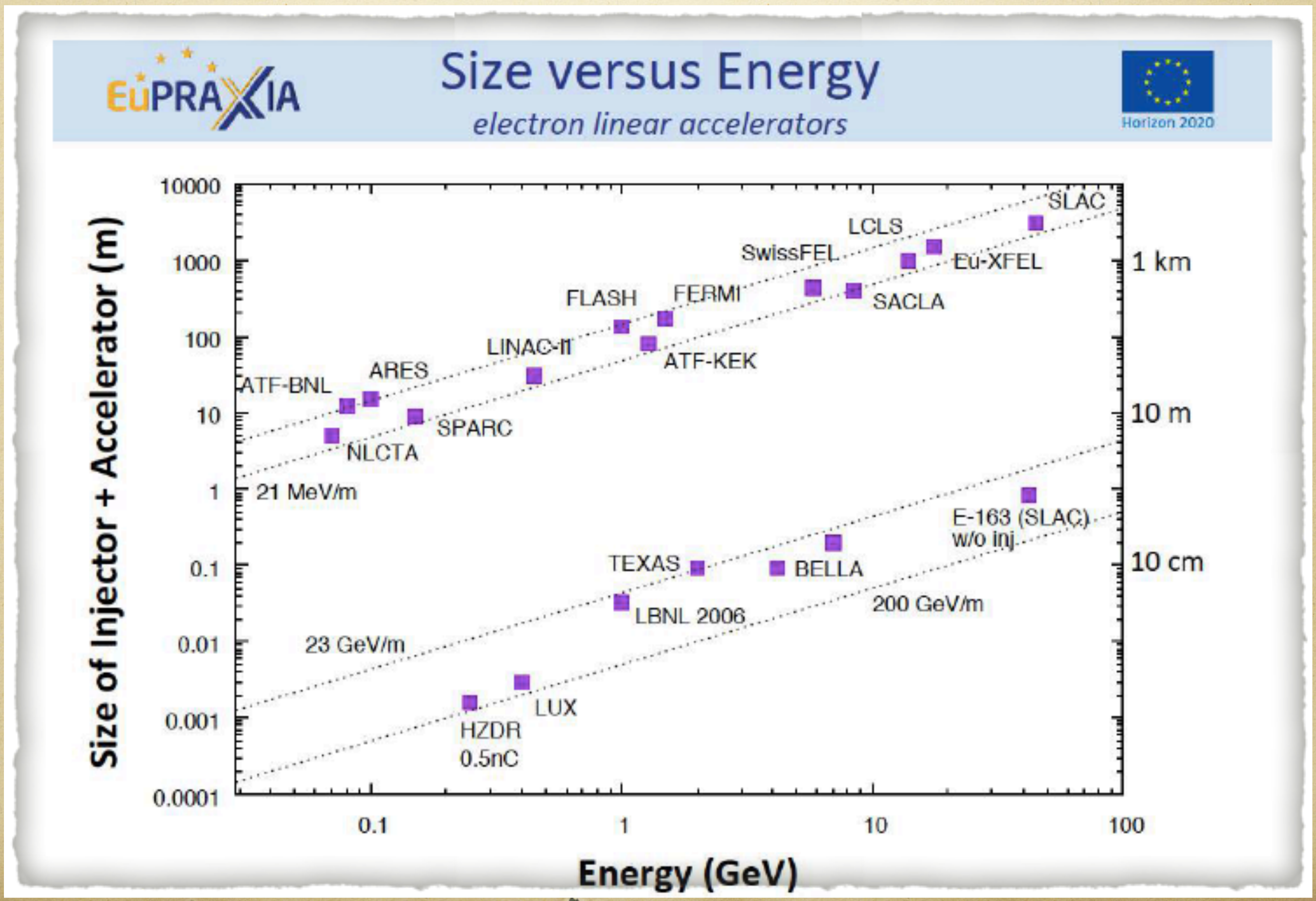
ALSHA

Advanced
Ion
Source for
Hadrontherapy

what next for INFN in the accelerator field

- budget too small to think big (inside the country)
- look for innovative solutions, new technologies, new concepts on the assumption that the main field is already well covered

shorter is better (if it works !)



Motivations

Horizon2020

PRESENT EXPERIMENTS

Demonstrating **100 GV/m** routinely

Demonstrating **GeV** electron beams

Demonstrating basic **quality**

EuPRAXIA INFRASTRUCTURE

Engineering a high quality, compact plasma accelerator

5 GeV electron beam for the 2020's

Demonstrating user readiness

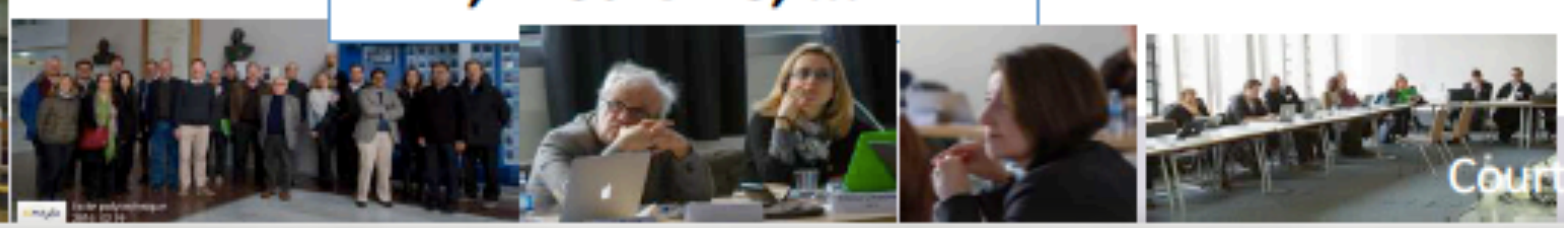
Pilot users from FEL, HEP, medicine, ...

PRODUCTION FACILITIES

Plasma-based **linear collider** in 2040's

Plasma-based **FEL** in 2030's

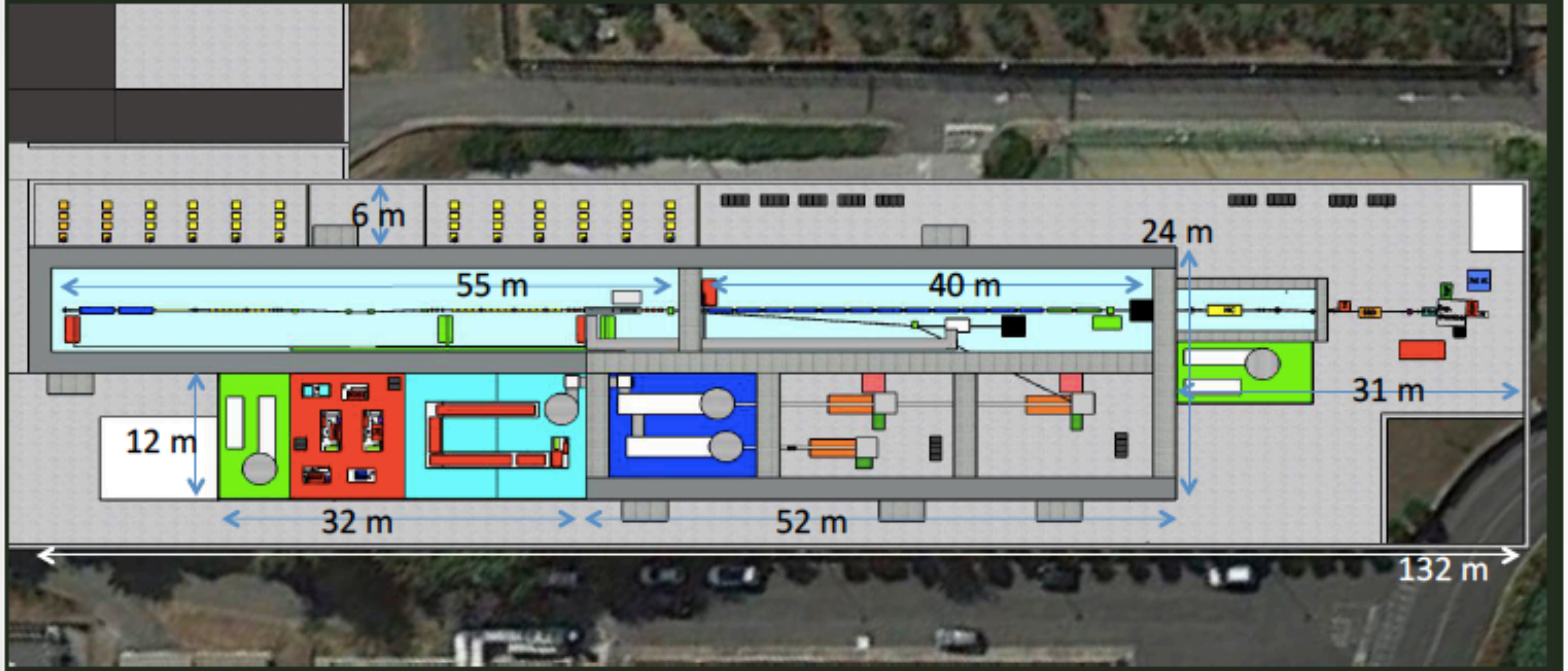
Medical, industrial applications soon

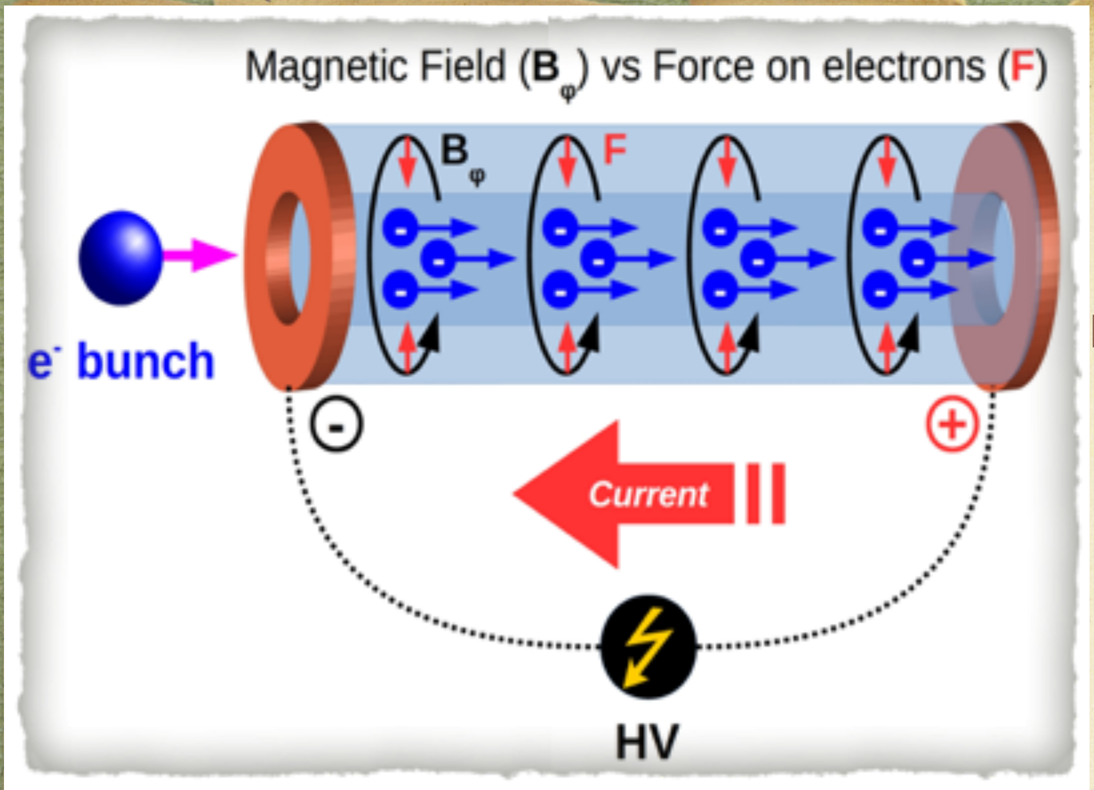
Courtesy R. Assmann

EuPRAXIA@SPARC_LAB

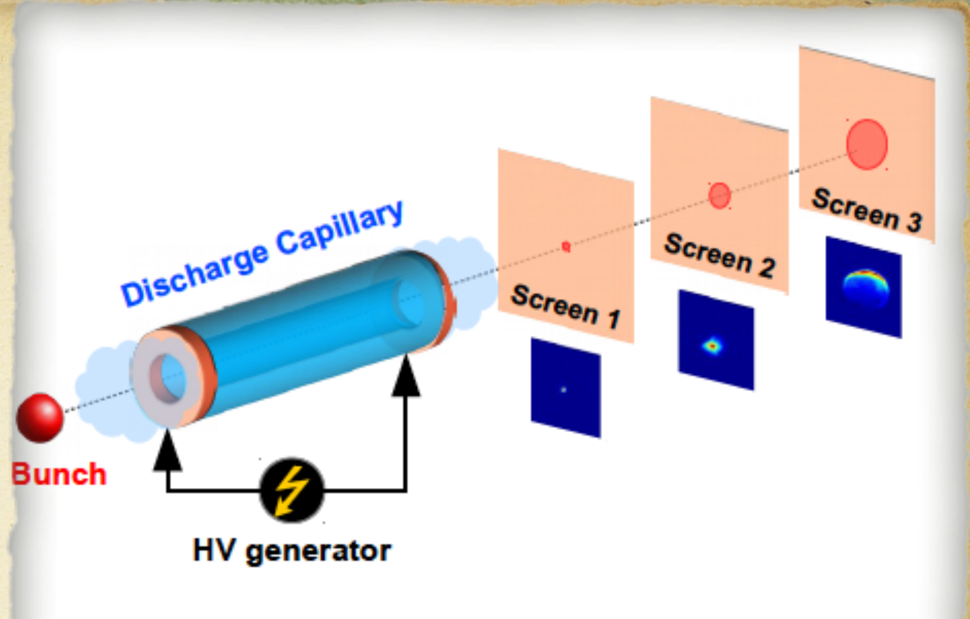
- Candidate LNF to host EuPRAXIA (1-5 GeV)
- FEL user facility (1 GeV – 3nm)
- Advanced Accelerator Test facility (LC) + CERN



- 500 MeV by RF Linac + 500 MeV by Plasma (LWFA or PWFA)
- 1 GeV by X-band RF Linac only
- Final goal compact 5 GeV accelerator



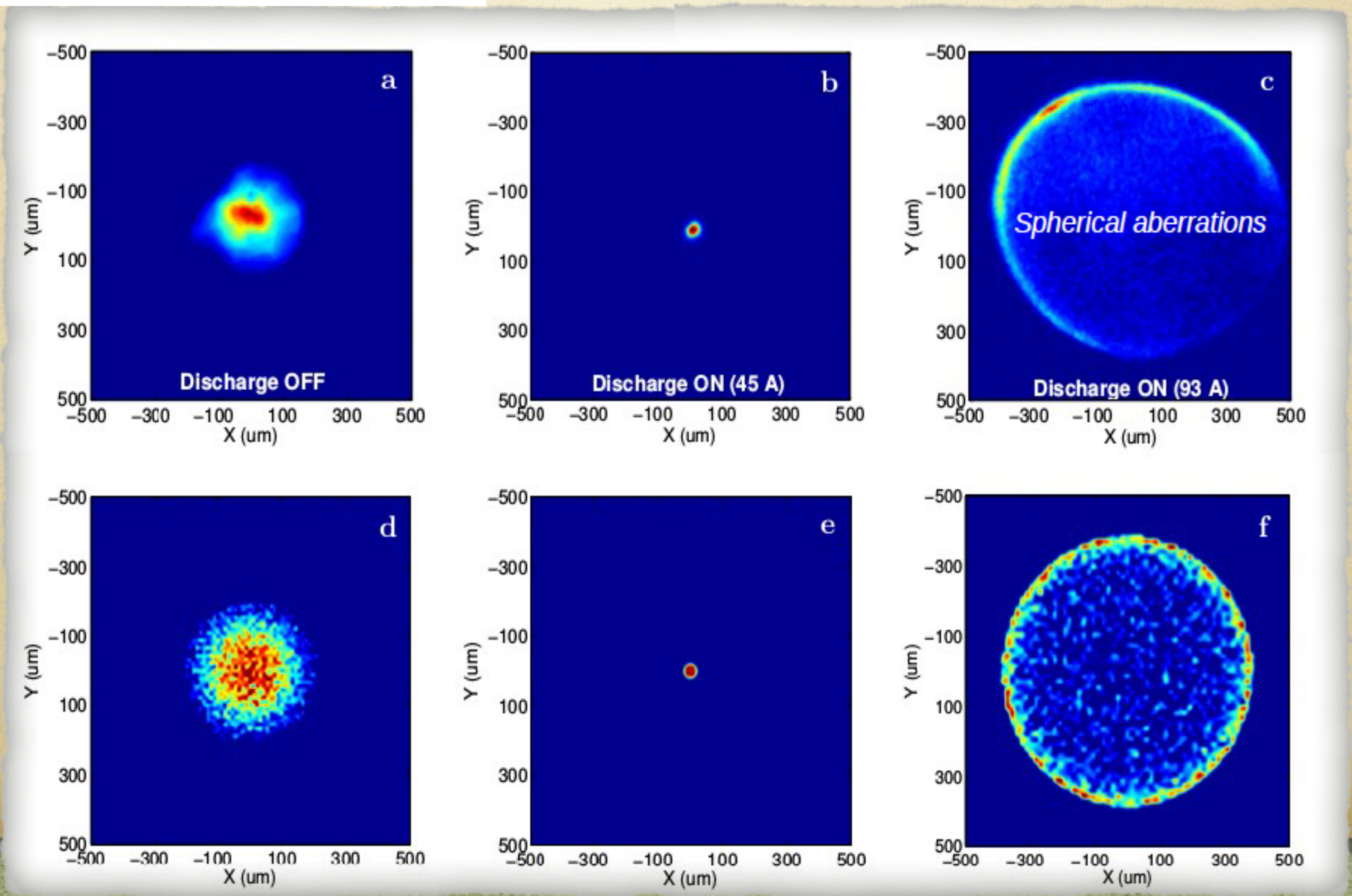
SPARC



'igure 1. Experimental layout. The beam passes through the 'ischarge-capillary and is then imaged on the three consecu-ve screens. The emittance is measured on the last one.

EXP

MC



with/without PLWA

FEL driven by X-band only

	Units	1 GeV with X-band linac only 100 pC	1 GeV with X-band linac only 200 pC
Bunch charge	pC	100	200
Bunch length rms	fs	38.2	55.6
Peak current	kA	2.	1.788
Rep. rate	Hz	10	10
Rms Energy Spread	%	0.1	0.05
Slice Energy Spread	%	0.018	0.02
Average Rms norm. emittance	μm	0.5	0.5
Slice norm. emittance	μm	0.35-0.24	0.4-0.37
Slice Length	μm	1.25	1.66
Radiation wavelength	nm	2.4 (0.52 keV)	2.87(0.42 keV)
ρ	$x\ 10^{-3}$	1.9(1.7)	1.55(1.38)
Undulator period	cm	1.5	1.5
K		0.987	0.987
Saturation length	m	15-25	16-30
Saturation power	GW	0.361-0.510	0.120-0.330
Energy	μJ	48-70	64-177
Photons/pulse		$5.9\text{-}8.4\ x\ 10^{11}$	$9.3\text{-}25.5\ x\ 10^{11}$
Bandwidth	%	0.13-2.8	0.24-0.46
Divergence	μrad	17.5-16	28-27
Rad. size	μm	65-75	120-200
Brilliance per shot	$(s\ mm^2\ mrad^2 bw\ (‰))^{-1}$	$Fx3.8\text{-}2.2\ 10^{28}$	$Fx2.5\text{-}1.4\ 11^{27}$

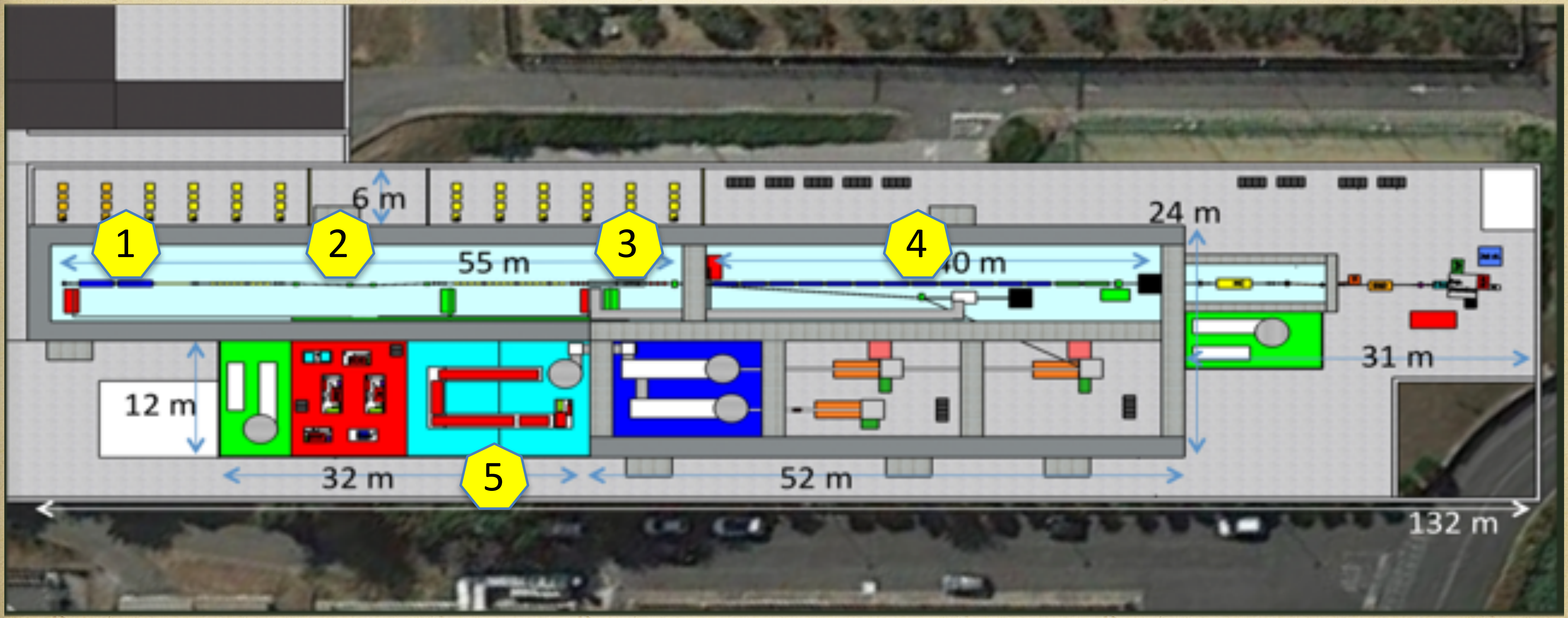
FEL driven by PLASMA

	Units	1 GeV PWFA with Undulator Tapering	1 GeV LWFA with Undulator Tapering
Bunch charge	pC	29	26.5
Bunch length rms	fs	11.5	8.4
Peak current	kA	2.6	3.15
Rep. rate	Hz	10	10
Rms Energy Spread	%	0.73	0.81
Slice Energy Spread	%	0.022	0.015
Average Rms norm. emittance	μm	0.6	0.47
Slice norm. emittance	μm	0.39-0.309	0.47
Slice Length	μm	1.39	1.34
Radiation wavelength	nm	2.79	2.7
ρ	$x\ 10^{-3}$	2	2
Undulator period	cm	1.5	1.5
K		0.987	1.13
Undulator length	m	30	30
Saturation power	GW	0.850-1.2	1.3
Energy	μJ	63	63.5
Photons/pulse		$8.8\ x\ 10^{11}$	$8.6\ x\ 10^{11}$
Bandwidth	%	0.35	0.42
Divergence	μrad	49	56
Rad. size	μm	210	160
Brilliance per shot	$(s\ mm^2\ mrad^2 bw\ (‰))^{-1}$	$0.83\ x\ 10^{27}$	$1.22\ x10^{27}$

EuPRAXIA@SPARC_LAB

- X-band RF technology implementation, CLIC collaborations
- Science with short wavelength Free Electron Laser (FEL)
- Physics with high powerlasers and secondary particle generation
- R&D on compact radiation sources for medical applications
- Detector development for X-ray FEL
- Science with THz radiation sources
- Nuclear photonics with γ-rays Compton sources
- R&D on polarized positron sources
- Quantum aspects of beam physics, Quantum-FEL development
- R&D in accelerator physics and industrial spin – off

Critical Components in the EuPRAXIA@SPARC_LAB design



1. High Brightness Photoinjector
2. X-band RF Accelerating Structures
3. Plasma Module
4. Free Electron Laser
5. High Power Ti:Sa Laser

All this steps tested at SPARC

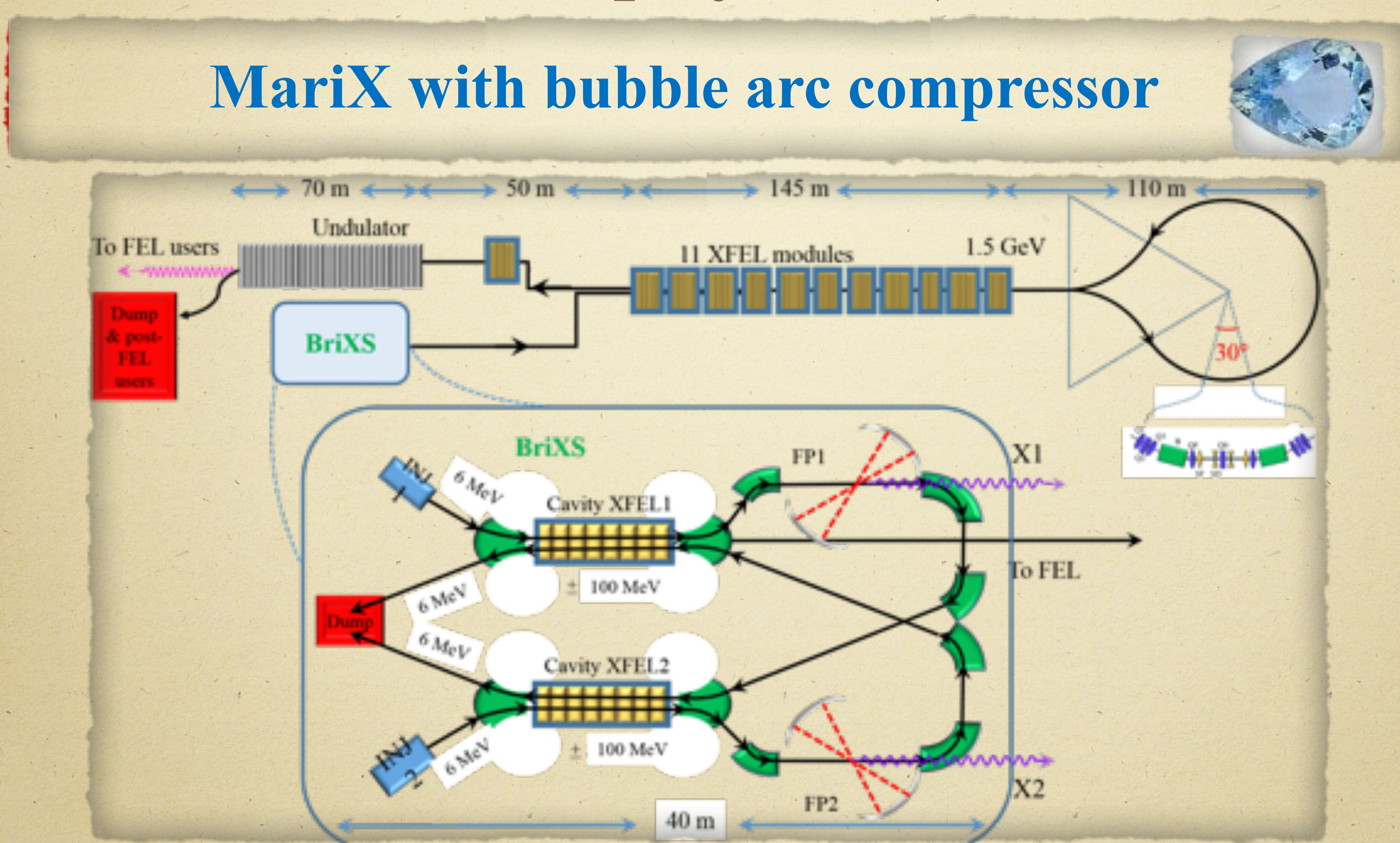
SPARC

set of achievements

- A new electron bunch compression scheme, called Velocity Bunching, has been successfully demonstrated together with the possibility to generate a train of short electron pulses, the COMB scheme as the one required to drive PWFA experiments with high transformer ratio.
- A Free Electron Laser has been commissioned producing coherent radiation tunable from 500 nm down to 37 nm (with harmonics) and new regimes of operation like Seeding, Single Spike, Harmonic Generation and Two Colors have been observed;
- A source of both broad band, narrow band (<30%) and high energy (> 40 μJ) THz radiation has been tested, experiments with users have been accomplished as reported also in a recent Nature Communication paper;
- Gamma-rays from Thomson back-scattering have been observed,
- Electrons have been accelerated up to 400 MeV in 2-4 mm long plasma wave excited by the high power laser FLAME with less than 20% energy spread;

- Electrons and photons beams have been synchronized at the scale of <50 fs, an essential requirement for the recent successful operation of the X-rays (~50 keV) Thomson back-scattering source and for the future investigation of new ultra-compact acceleration techniques (> 1 GV/m) based on external injection of high quality electron beams in a plasma wave.
-
- Reduction of relative arrival time jitter down to 19 fs (rms) between the electron bunch and the external photo-cathode laser by control of the longitudinal beam dynamics in a hybrid compression scheme (velocity bunching and dogleg) has been demonstrated.
- Active Plasma Lens experiments have been succesfully performed. Experimental optimization of compact Plasma Lens is underway.
- Innovative electron beam transverse and longitudinal diagnostics have been tested.
- Ion acceleration by Target Normal Sheath Acceleration (TNSA) has been tested and plasma diagnostics has been implemented.

if we could convince Gov that Milano deserves a state of the art research infrastructure in physics (beside medicine)



Intra-bunch time separation : 1 micro-second, 300 m
Beam time structure: 1 MHz repetition rate, single bunch CW

BriXS: 20-150 keV mono-chromatic X-rays up to 5.10^{12} photons/sec in 5% bdw

FEL Example 1: water window (lambda-rad=3 nm), Undulator λ_w=3 cm, a_w=2.5, length =25 m

Q=8-16 pC, I=2 kA, emitn=0.5 um $\Delta E/E=2.10^{-4}$, a_w=2.5, dt=2-3.5 fs

FEL	MariX	FERMI
Electron energy (GeV)	2.5	1.5
Und λ_w, L (cm,m)	3, 25	5, 40
Photon energy (keV)	0.45 (2.8 nm)	0.38 (4 nm)
Rep rate	**1 MHz**	10-50 Hz
Energy	8-16 uJ	5-10 uJ
Photons per shot	**3-7 10^{11}**	10^{11}
Bandwidth (%)	**0.1**	0.02-0.07
Photons / sec	**2-7 10^{17}**	5 10^{12}
Spectral density (N/s/%bw)	**2-7 10^{18}**	2.5 10^{14}
Coherence	Single Spike	**Full**


Tree Of Life
Symbolic tree structure
with water shows
Autostrada dei Laghi
Palazzo Italia
Waterstone - Expo 2015
Piazza Italia-Zona
Spettacoli della Scala e...
FEL beam lines
BriXS
1.5 GeV SC Linac
Bubble Arc
Open Air Theatre
San Carlo
100 m

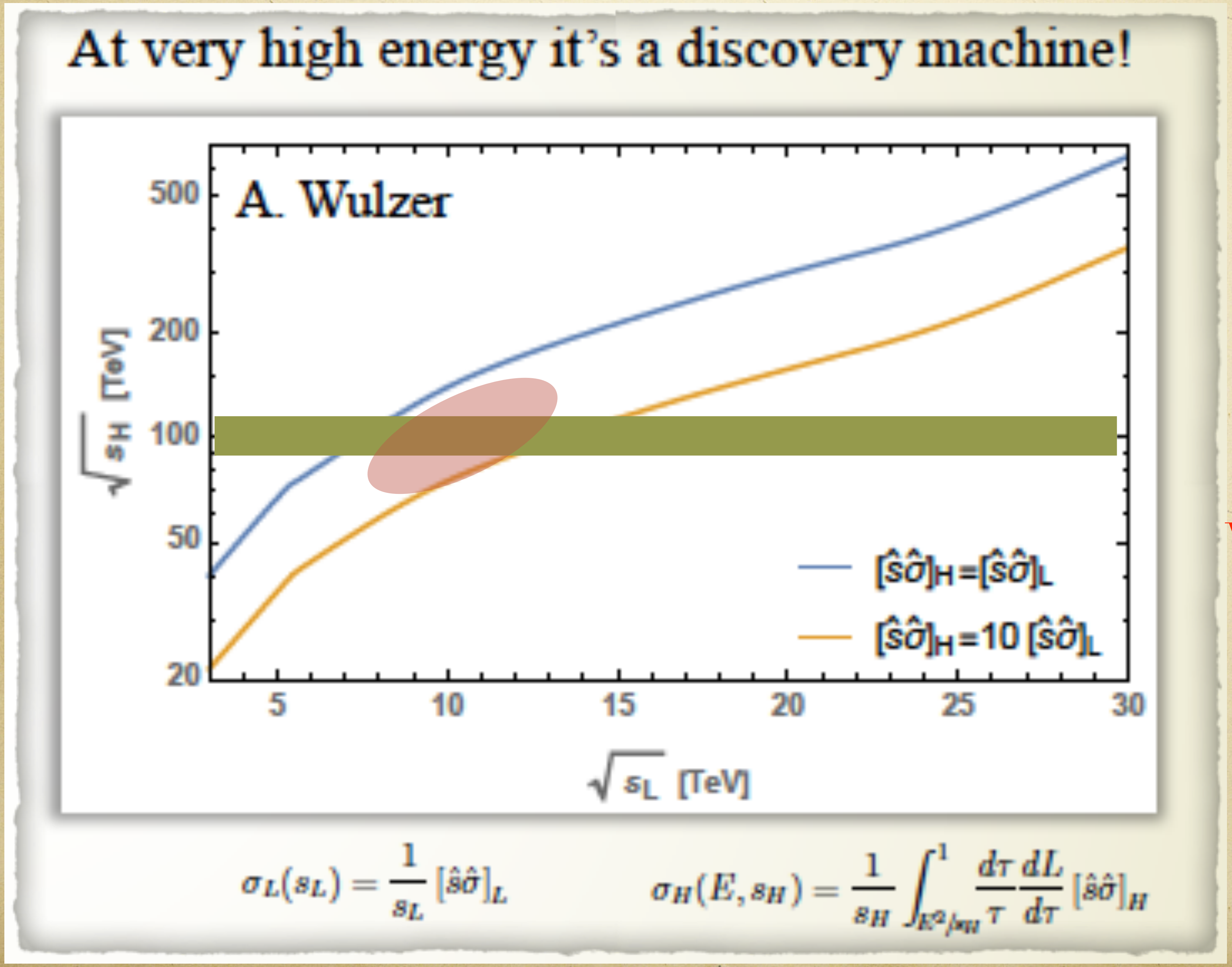
and finally the idea of a muon collider without the muon cooling

- we need another collider in the future
- a) to study the Higgs coupling (solid argument)
- b) to explore the multi-TeV region (never know !)
- try not to use brute force, make experimentalists happy (no background) and accelerator community excited (something new)

Higgs coupling

- I will not comment much on this
- CEPC is the perfect machine for this scope. ILC is second and HL-LHC third. Wait and see.
- Producing Higgs in s-channel would be great but I do not believe you can be competitive in terms of yield.

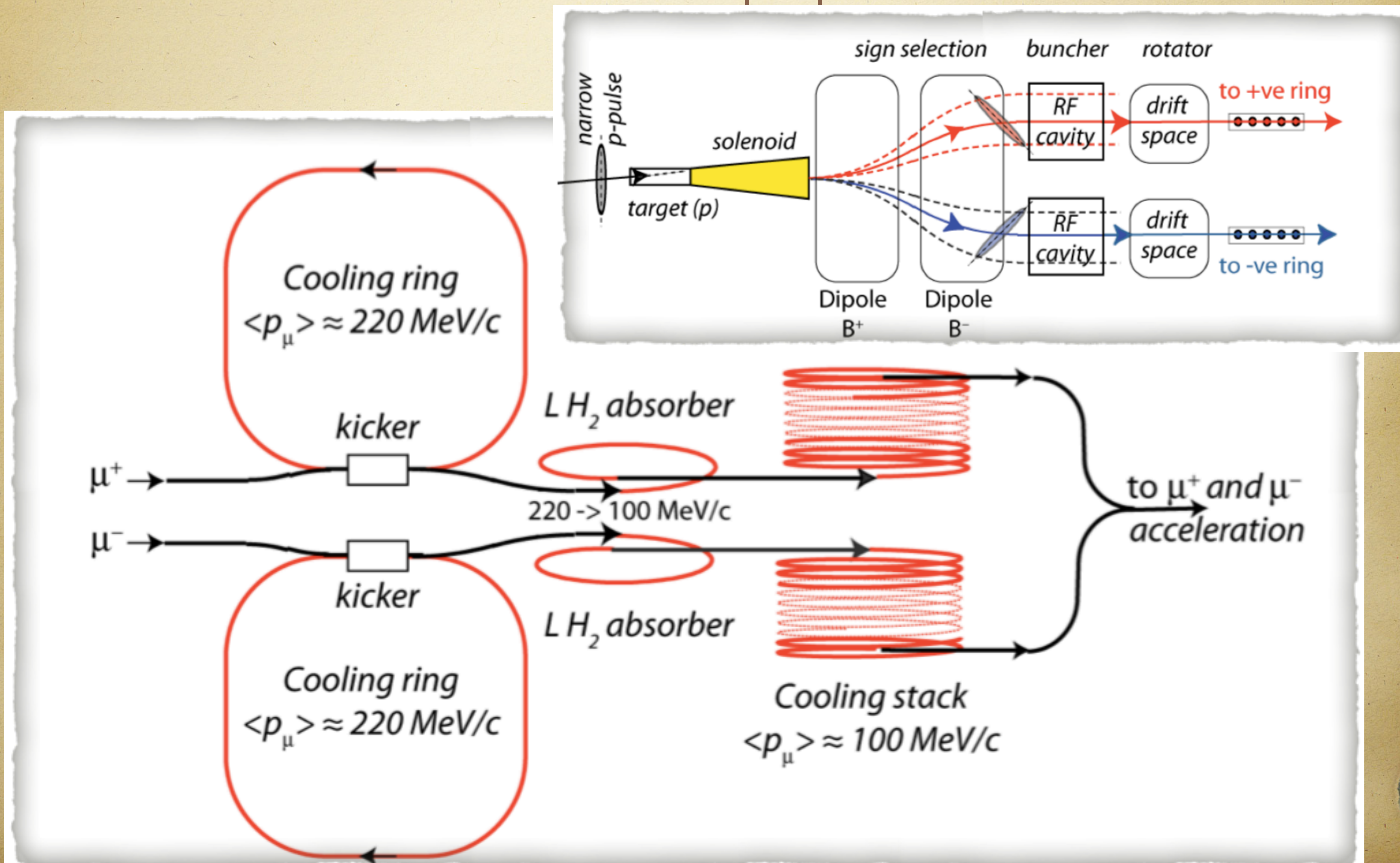
but…at high energy…



the tunnel would already exist !

Stay hungry, stay foolish

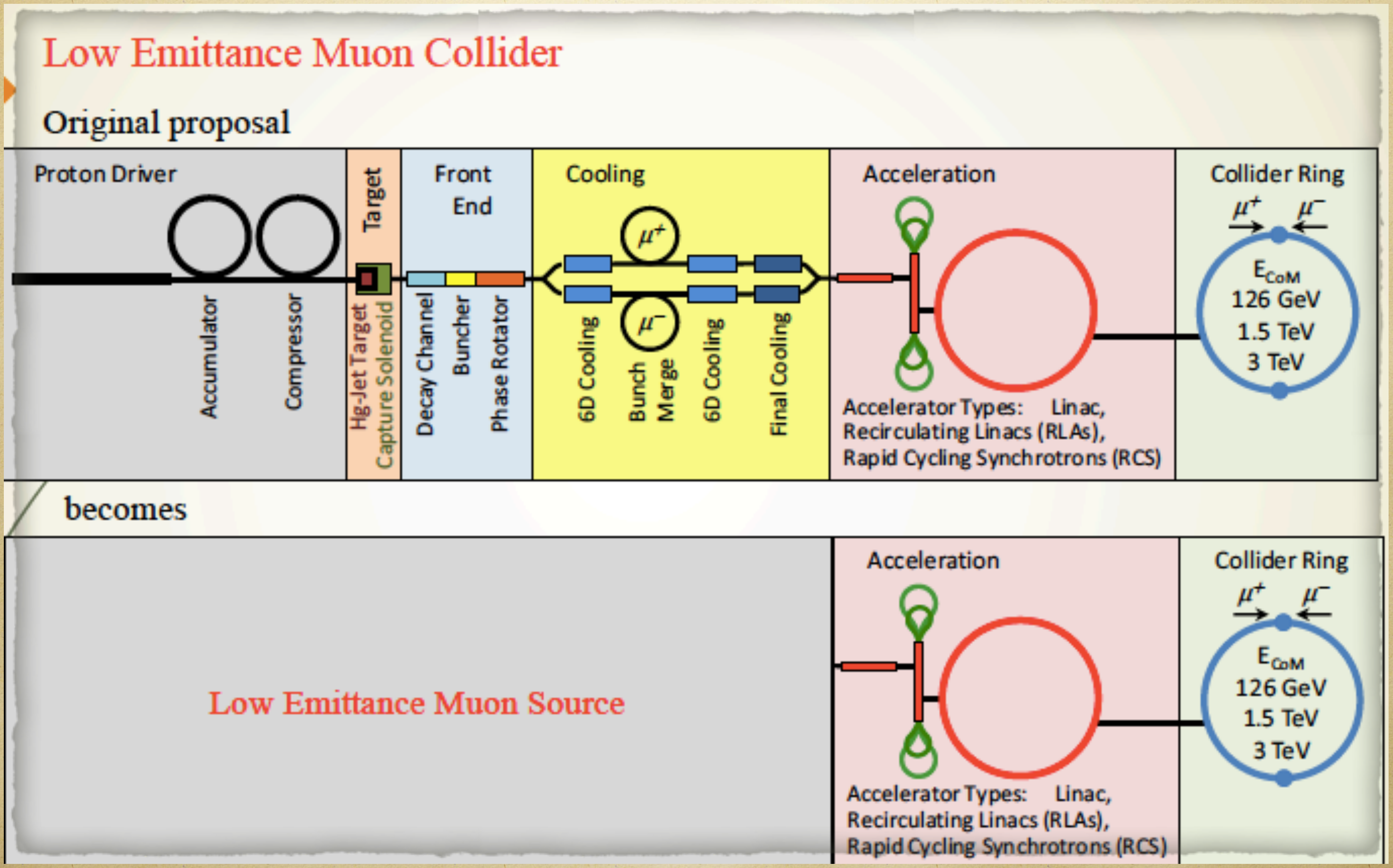
Carlo Rubbia proposal



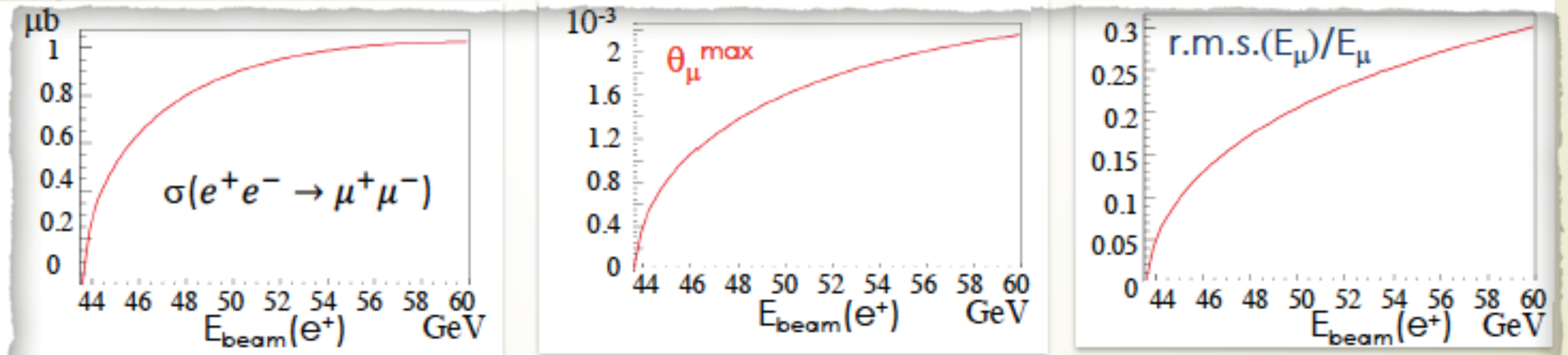
great idea, but….

- a machine design with few very critical issues and…
- a number of H produced (if everything goes well) only of a few 10000 /year
- not much margin of improvement (5 MW proton linac, 20% pion acceptance, still the need for cooling)

No cooling-High Energy

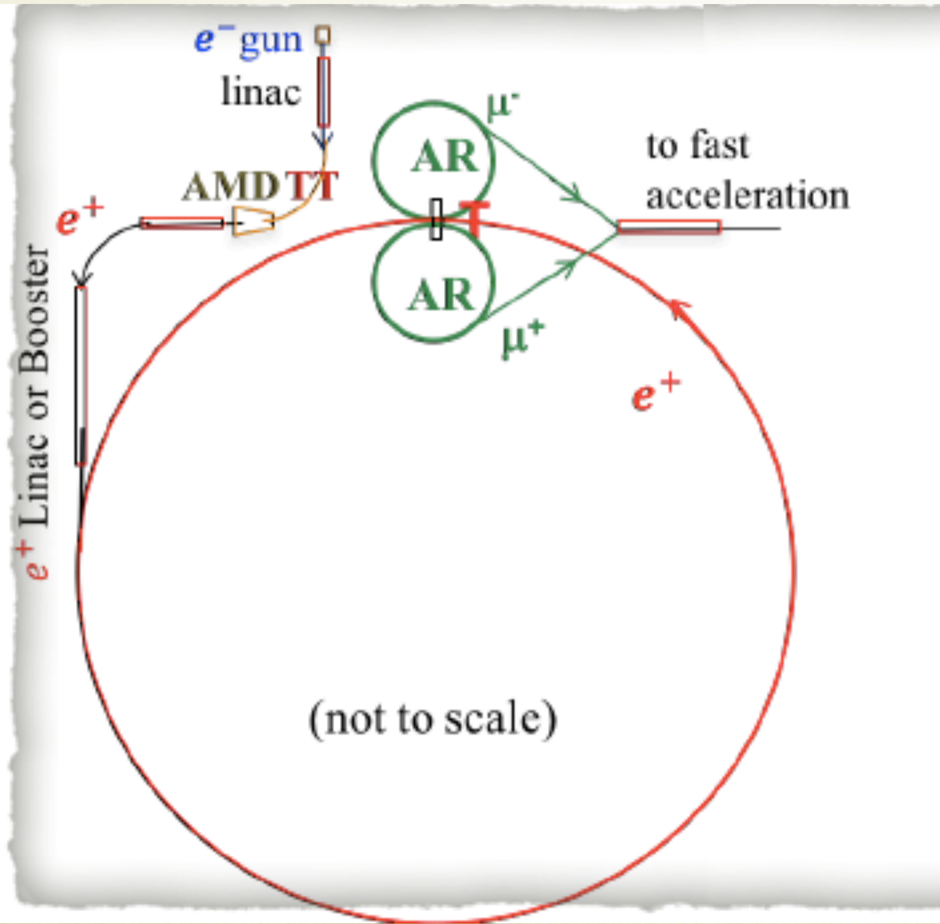


LEMS



$E_{beam}(e^+) = 45$ GeV is assumed
$\gamma(\mu) \approx 200 \Rightarrow$ laboratory lifetime of about 500 μs

"Natural" Beam Energy Spread 0.05



Positron Source
- e^- on conventional Heavy Thick Target (TT) for e^+e^- pairs production.
- Adiabatic Matching Device (AMD) for e^+ collection

Positron Ring
- Acceleration and injection (Linac/Booster)
- 6.3 km 45 GeV storage ring with target T for muon production

Muon Beams
- $\mu^\pm$ produced by e^+ beam on target T with E≈ 22GeV, $\gamma(\mu) \approx 200 \to \tau_{lab}(\mu) \approx 500\mu s$
- AR: 60 m isochronous and high momentum acceptance rings to recombine $\mu^\pm$ bunches in ~1 τ_μ^{lab} ≈2500 turns
- $\mu^\pm$ fast acceleration

if….

- if could be done
- it would be a great machine
- saving space and money
- producing clean physics
- and a great intellectual challenge to demonstrate
- hungry yes, not so foolish !

Conclusion

- analytical continuation and/or ballistic approach not necessarily the right way
- need to motivate with new challenges both experimentalists and accelerators physicist
- PWA for FELs
- Muon Collider for HE studies
- INFN community is ready to go in these directions