ERL FACILITY AT CERN FOR APPLICATIONS

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ERL 2015
Workshop on Energy Recovery Linacs

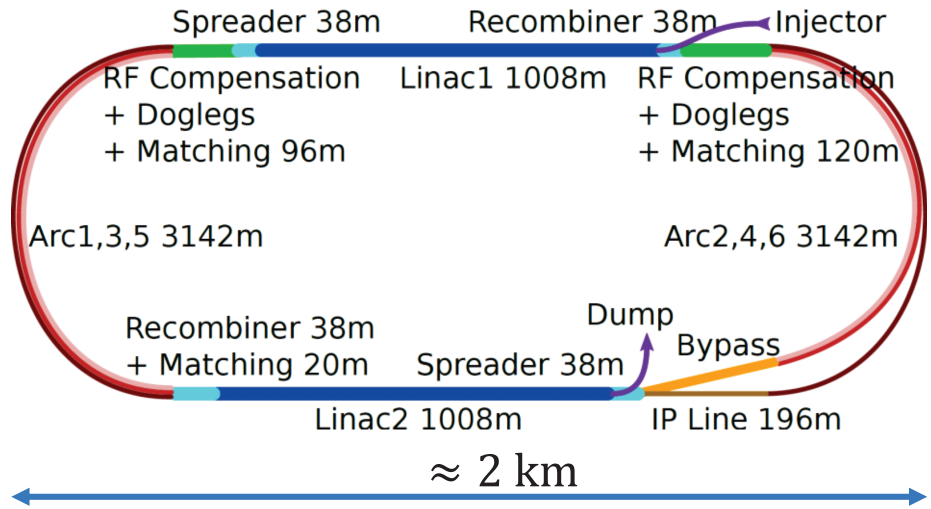
Outline

- What is the ERL Facility at CERN
- Possible applications:
  - Test of SRF Cavities/Cryomodules
  - Test of Beam Instrumentation
  - Controlled Quench & Damage Tests of SC wires and magnets
  - γ source by Compton Scattering
- Summary

The context: LHeC

The **LHeC** could complement the existing LHC with a 60-GeV ERL to allow hadron-lepton collision experiments.

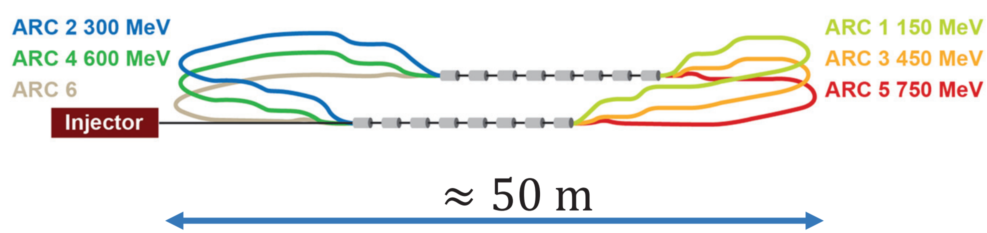
The baseline design consists of a 3-pass ERL to provide a 60 GeV, high-current e- beam.



The **ERL Facility at CERN** is much smaller: the baseline is a 3=pass ERL to provide up to 900 MeV, to be constructed in stages.

It would allow to

- validate LHeC design choices,
- gain experience with an ERL,
- build up expertise

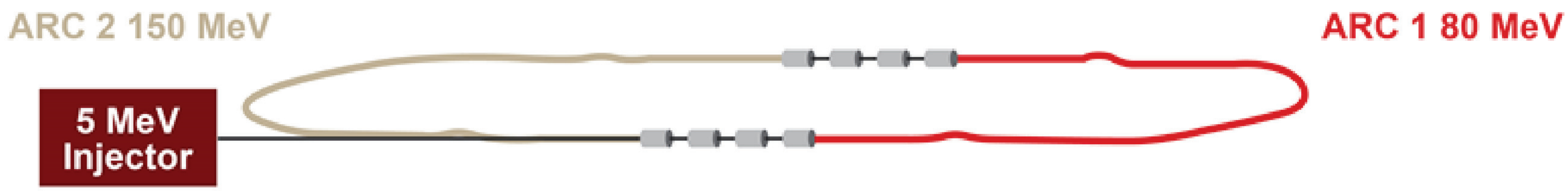


Purpose of ERL Facility at CERN

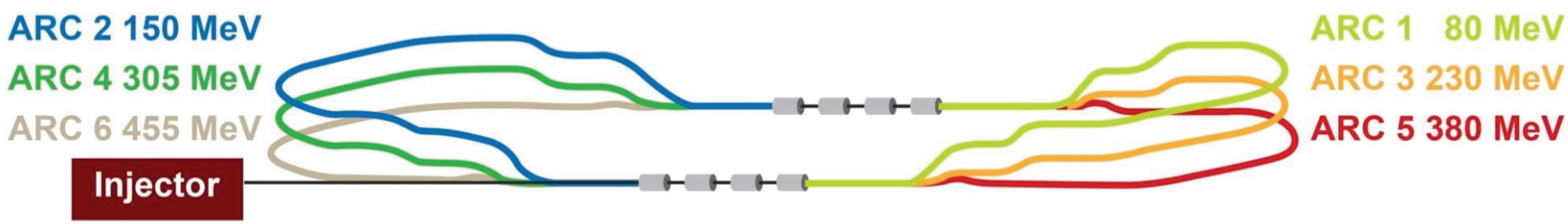
- Study an ERL – to gain expertise and to train staff
  - conceive, design, engineer, construct,
  - build the real thing,
  - test, commission, operate.
- Test SRF cavities/cryomodules
  - Present concept allows to test at 704, 802 and 1300 MHz
  - Complements vertical cryostats and horizontal CM bunkers at CERN for **tests with beam**.
  - Have a real facility – not interfering with HEP – that the next generation of accelerator scientists can work with.
  - Strongly synergetic with other projects – SRF R&D needed in many future accelerators (LHC upgrades, FCC study…)
- But later – it can be used for other applications!
  - possibly it even could become an injector ERL for the LHeC ERL?

Possible staged construction

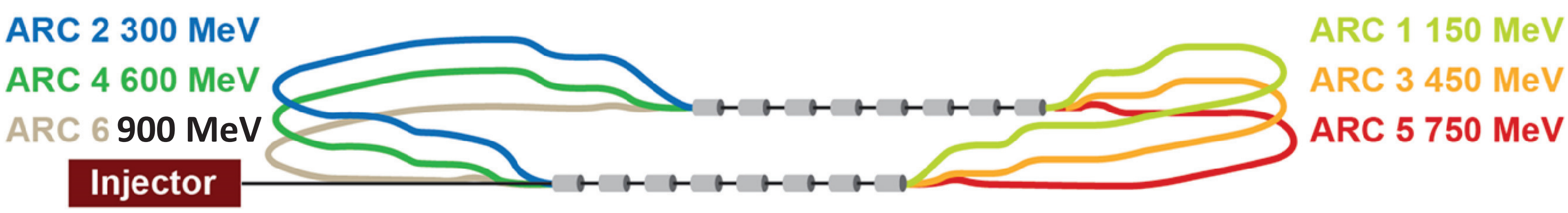
Stage 1 – 2 CMs, test installation – injector, cavities, beam dump.



Stage 2 – 2 CMs, set up for energy recovery, 2…3 passes



Stage 3 – 4 CMs, set up arcs for higher energies – reach up to 900 MeV



Example Application 1:

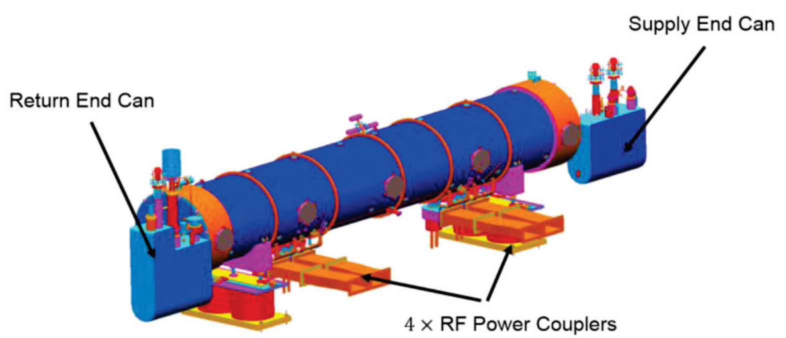
Test of SRF Cavities/Cryomodules

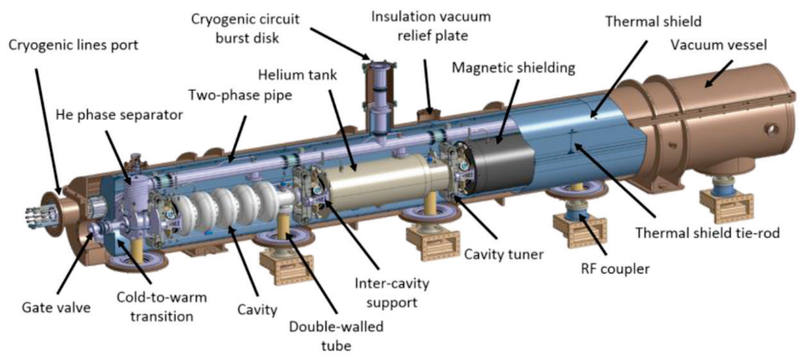
800 MHz Cavity R&D

Parameter	Value
Acceleration gradient	$< 20\ \mathrm{MV/m}$
# cells/cavity · cavities/CM · CMs	$5 \cdot 4 \cdot 2\ (4)$
Accelerating voltage/cavity	$18\ \mathrm{MV}$
$5 \cdot \lambda/2$, total cavity length	$935\ \mathrm{mm},\ 1.2\ \mathrm{m}$
Operation frequency	$801.58\ \mathrm{MHz}$
RF power/CM	$< 50\ \mathrm{kW}$
Bunch charge	$2 \cdot 10^9\ e = 320\ \mathrm{pC}$
Beam current	$4 \cdot \frac{320\ \mathrm{pC}}{25\ \mathrm{ns}} \approx 50\ \mathrm{mA}$
Duty factor	CW

Cryomodule work

- Collaboration with JLAB established – work has started.
- CM design based on SNS 805 MHz CM (left)
- Alternative design: SPL CM (right)



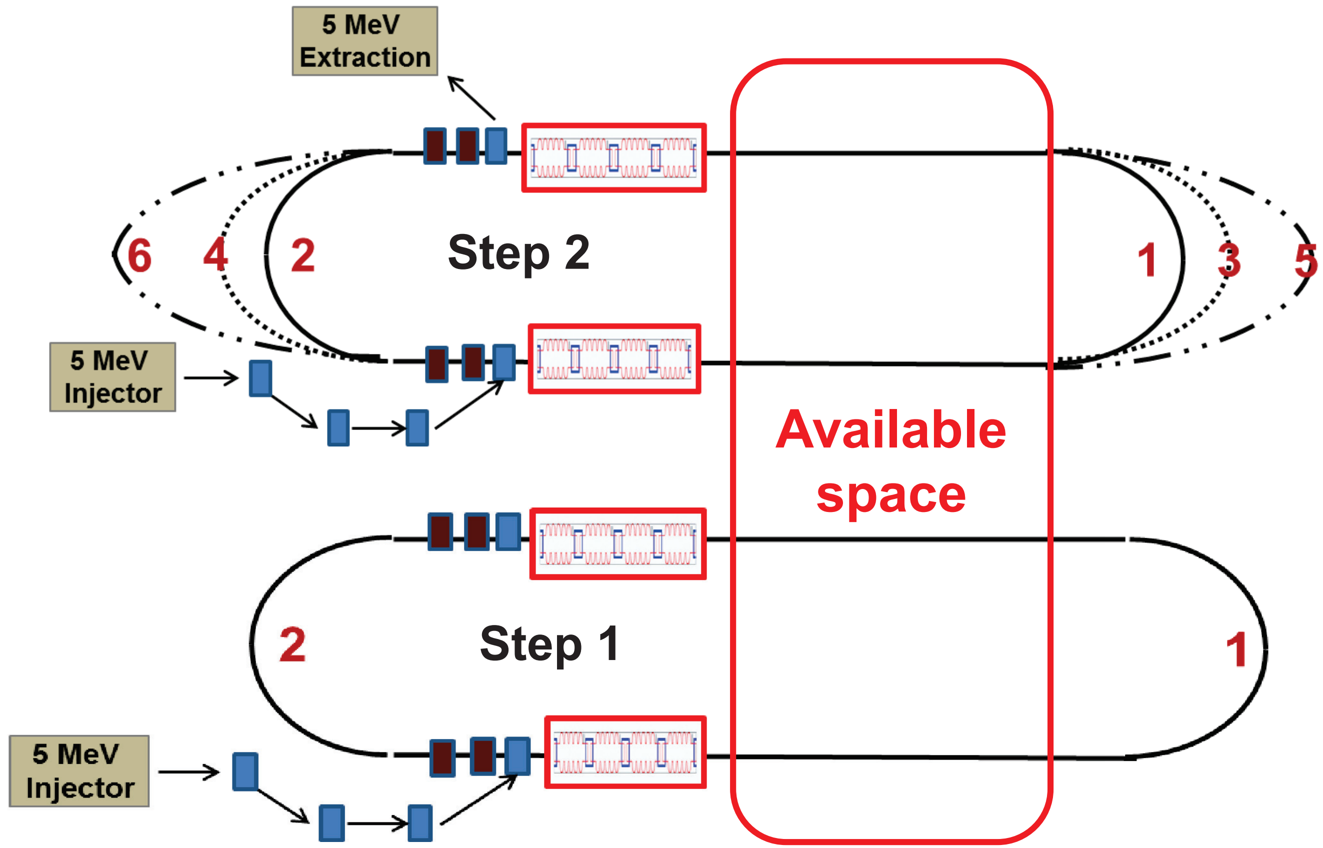


- Multiple f possible (e.g. with 12 MHz rep rate):
$(802\ \mathrm{MHz}, 704\ \mathrm{MHz}, 1300\ \mathrm{MHz}) = (66, 58, 107) \cdot 12.15\ \mathrm{MHz}$
- Tests relevant & interesting for LHC, LHC upgrades and FCC study

Example Application 1:

Test of Beam Instrumentation

Possible @ stage 2



Beam parameters for BI tests

- Energy >200 MeV if possible
  - Electrons start to radiate in useful wavelength range with a small enough opening angle
  - Gamma is close to LHC injection & SPS flat-top
  - Can test associated monitors
  - An electron energy as high as possible also ensures a stiff beam which should be stable & reproducible enough for beam size studies below 100 microns.
  - A few GeV would obviously be good for testing monitors based on radiation for LHC top energy & FCC injection!!
- CW operation
  - Allows study of impedance effects for various devices
  - Rep rate of 40 MHz or multiple thereof would allow testing of BI electronics destined for LHC, HL-LHC and FCC.
- Bunch length
  - Down to below 100 fs interesting for short bunch length diagnostics
- Bunch charge
  - Range 200-1000 pC interesting

Proposed Beam Instrumentation tests:

- Test of BI based on the measurement of radiation produced by charged particles.
- Test of electronics for future BI upgrades (all machines, but especially HL-LHC era diagnostics & FCC if rep rate can be made to match)
- Test of BI for high resolution transverse & longitudinal diagnostics (making use of the short bunches)
- With a dedicated test beam line (non-ER mode):
  - Test of particle detectors for beam losses or physics.
  - Radiation effects to electronics

Example Application 3:

Controlled Quench & Damage Tests of SC wires and magnets

Controlled quench and damage tests

MOTIVATION:
FACILITY FOR TESTING QUENCH AND DAMAGE LEVELS OF SC WIRES AND SC MAGNETS

Advantages comparing to the existing at CERN facilities:

- Beam will directly hit a sample (straightforward calculation of loss distribution, no need to account for the beam dynamics over the turns as in case of a circulating beam)
- SC wires, magnets/prototypes could be tested (not only the magnets that are already in the machine)
- Possibility to have cryogenic environment in the experimental area (none of the existing testing facilities at CERN have cryogenic installation)
- Fast losses (μs) and steady-state (s) are well described by our electro-thermal models and the experiments at LHC; intermediate (ms ... s) need to be better understood.
- With the ERL facility the whole time range (ns - several s) would be available to test - e.g. HiRadMat maximum length of losses is $7\ \mu s$ every $\approx 40\ s$.
- LHC: performing quench tests with such a sophisticated machine is far from ideal.

Question:
Are the intensities at extraction and repetition rates sufficient for the tests?

Controlled quench and damage tests

MOTIVATION
FACILITY FOR TESTING QUENCH AND DAMAGE LEVELS
OF SC WIRES AND SC MAGNETS

Question:
Are the intensities at extraction and repetition rates sufficient for the tests?

Quench threshold level depends on

- Current
- Cooling
- Energy deposition
- Pulse duration

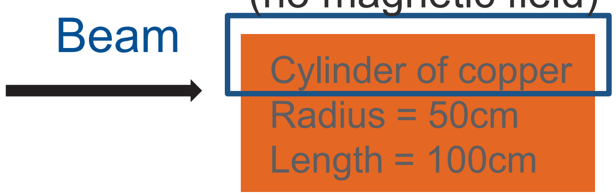
Damage threshold depends on

- Cooling
- Material
- Impact duration
- Beam size (the volume that needs to be melted to qualify as a damage)

Beam parameters to deposit a given amount of energy

CALCULATIONS AND FLUKA SIMULATIONS

Copper target
(no magnetic field)



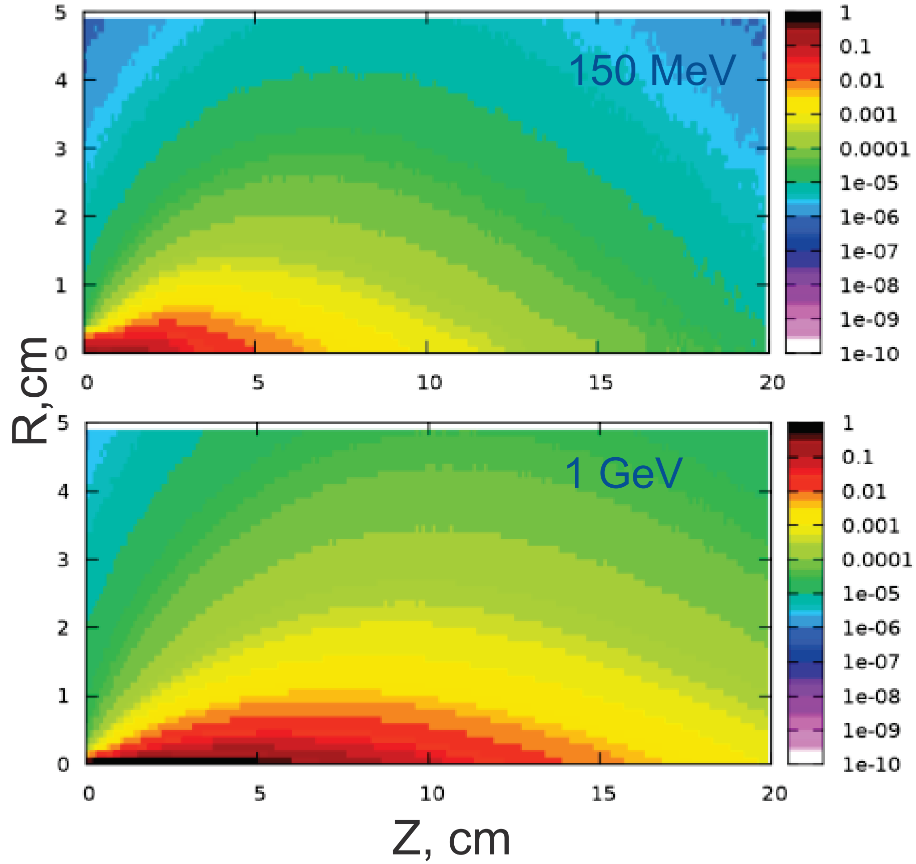
Beam parameters

Energy, MeV	Emittance, m	Sigma, cm	FWHM, cm
150	1.70E-07	0.092	0.22
300	8.52E-08	0.065	0.15
450	5.68E-08	0.053	0.13
600	4.26E-08	0.046	0.11
750	3.41E-08	0.041	0.10
900	2.84E-08	0.038	0.09
1000	2.55E-08	0.036	0.08

Results are given for half of bulky target because of symmetry

Binning: 1 mm^3 bins

Energy deposition, $GeV/cm^3/e^-$



V. Chetvertkova, D. Wollmann

Beam parameters to deposit a given amount of energy

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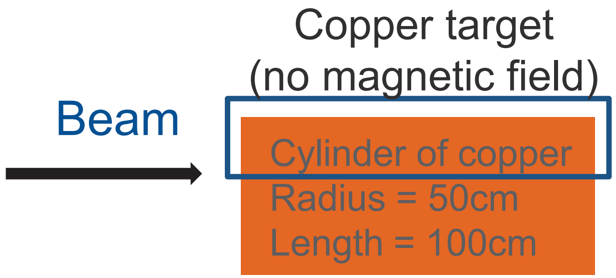

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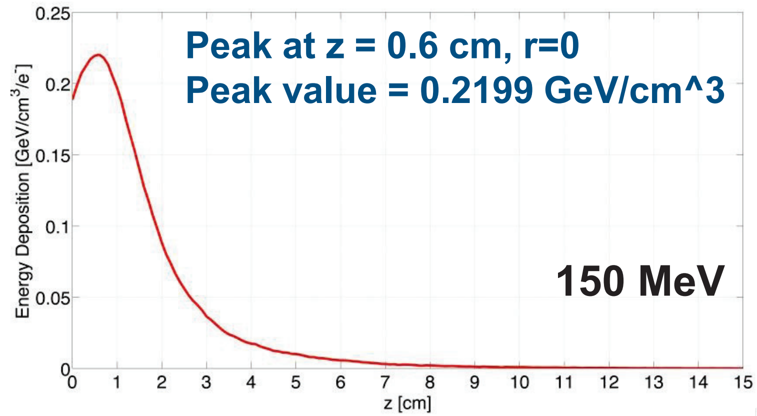

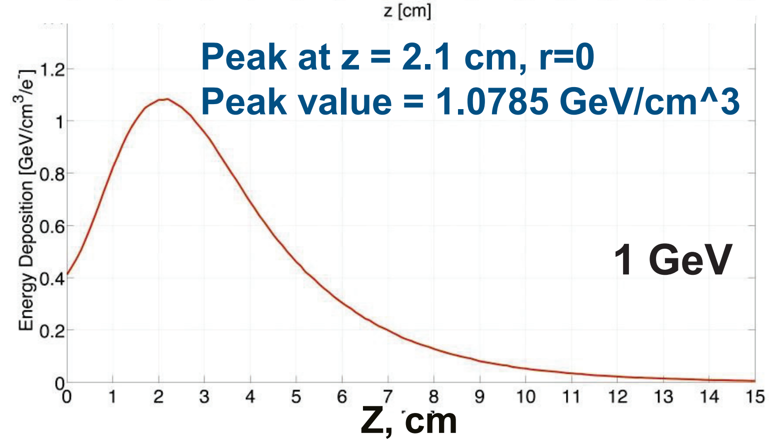

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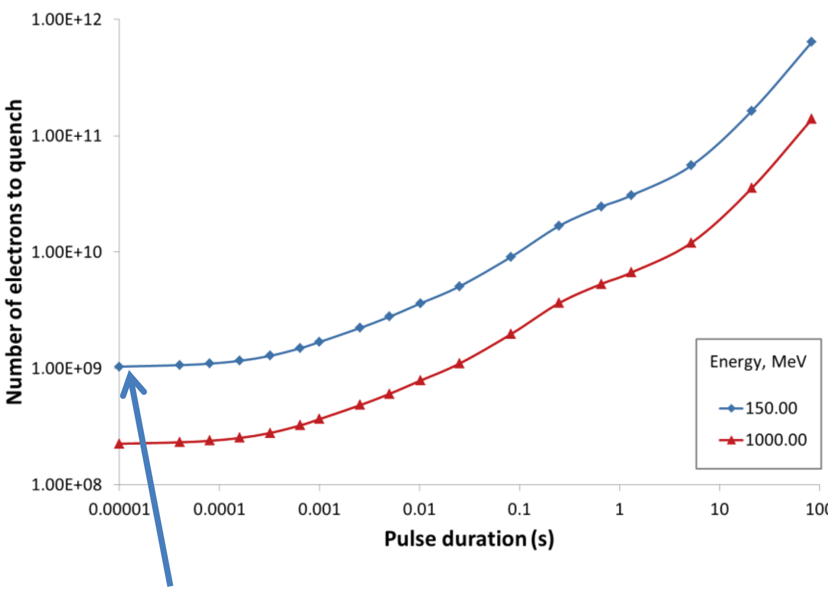
Quench & Damage

For **quenching** an LHC MB (main dipole magnet) a certain amount of energy should be deposited in 1mm^3

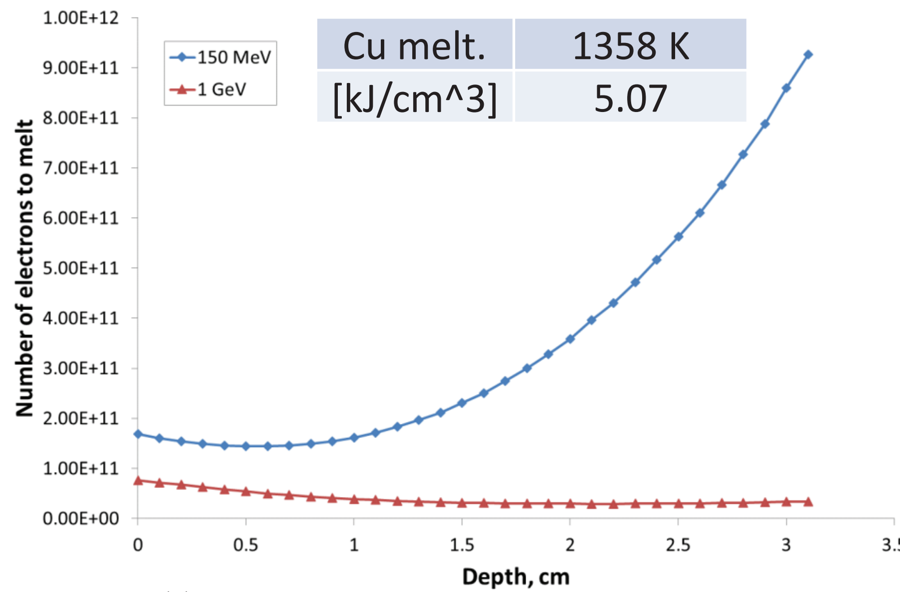
$$\text{\# electrons needed to quench the magnet} = \frac{\text{Quench threshold}}{\text{Maximum value for the energy deposition}}$$



Can easily quench with a single bunch at 150MeV
Bunch charge $2 \cdot 10^9$ > quench threshold $1 \cdot 10^9$

Damage limit in present studies is defined as a number of electrons needed for melting 1 mm^3 of Cu

Number of electrons for melting Cu should be delivered to the target within <u>several hundreds ms</u> in order to avoid heat transfer



$2 \cdot 10^{11}$ electrons required over 0.1 s to melt $1\ \text{mm}^3$!

Available intensities

- Assuming 13 mA with 25 ns bunch spacing:

  $320\ \mathrm{pC}$ or $2 \cdot 10^9\ e$ every $25\ \mathrm{ns}$.

- Stored in the ERL (3 turns):

  40 bunches, $13\ \mathrm{nC}$ or $8 \cdot 10^{10} e$.

- These numbers are compatible with the quench tests given above – they fall short to melt $1\ \mathrm{mm}^3$ of Cu.

- Extraction from Arc 6 to a dedicated test beam line, non-ER mode.

Controlled quench tests: future steps

Types of tests that could be performed:

- Real magnet tests (requires: Power Converters, Quench Protection System, Energy Extraction System, cryogenics)
- Disadvantages: high cost and space requirements
- Tests of prototype magnets and SC cables (requires: material samples, external field, cryogenics)
- Relevant & interesting for LHC, LHC upgrades and FCC study

SUGGESTING staged approach. Start with a small facility for tests of SC cables and foresee **enough space** for later extension.

Design of the facility

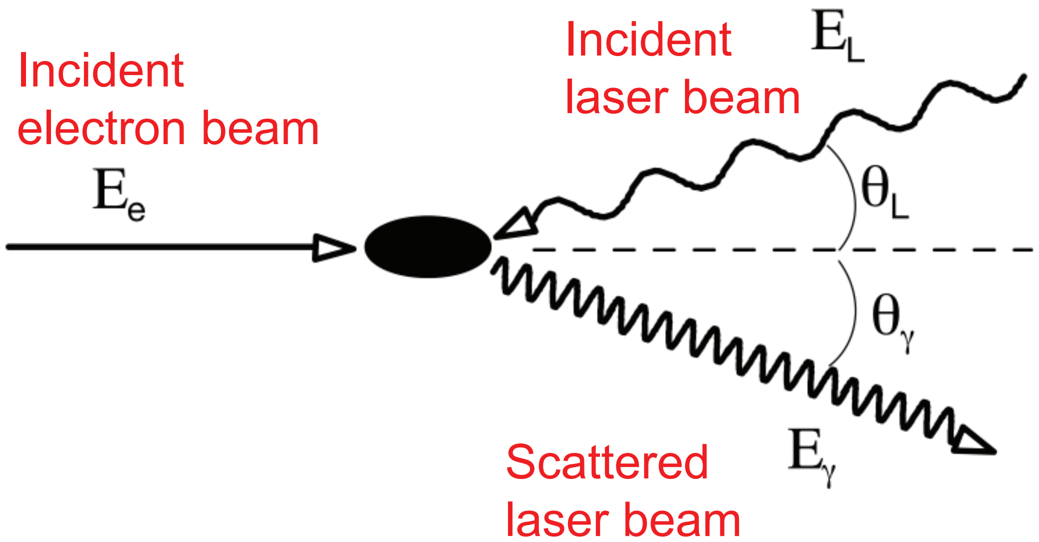
- Transfer line (optics, vacuum window, dump)
- Cooling capacity (cryogenics)
- Equipment:
  - Power Converters, Quench Protection System, Energy Extraction.
  - Infrastructure: cooling water, cranes etc.

Example Application 4:

γ source by Compton Scattering

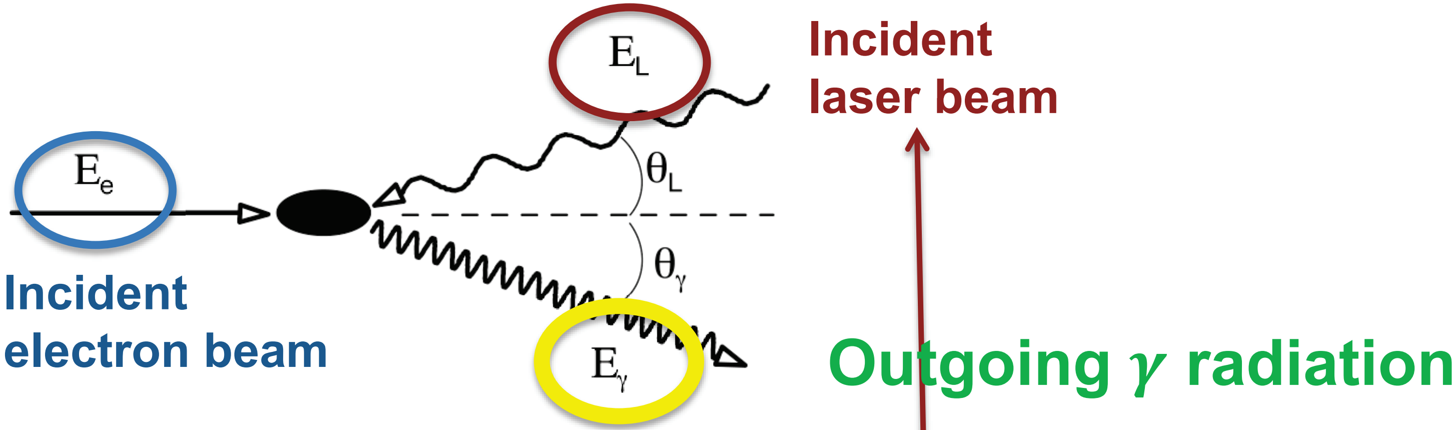
γ beams at the ERL Facility

GOAL: Generation of high-energy monochromatic polarized photons via Compton backscattering of laser light from relativistic electrons for nuclear physics research



$$E_\gamma = 2\gamma_e^2 E_L \frac{1+\cos\theta_L}{1+\left(\gamma_e\theta_\gamma\right)^2+\left(\frac{eE_0}{m_0 c\,\omega_0}\right)^2+\frac{4\gamma_e E_L}{m_0 c^2}}$$

γ beams at the ERL Facility: input parameters

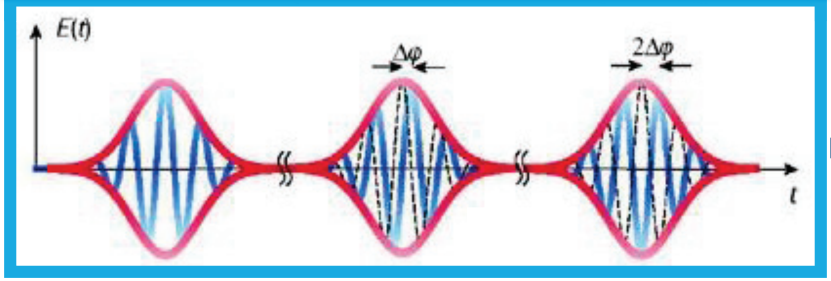


ELECTRON BEAM PARAMETERS	
Energy	900 MeV
Charge	320 pC
Bunch Spacing	25 ns
Spot size	30 um
Norm. Trans. Emittance	5 um
Energy Spread	0.1 %

LASER BEAM PARAMETERS	
Wavelength	515 nm - 1030 nm
Average Power	300kW - 600 kW
Pulse length	3 ps
Pulse energy	7.5mJ - 15 mJ
Spot size	30 um
Bandwidth	0.02 %
Repetition Rate	40 MHz

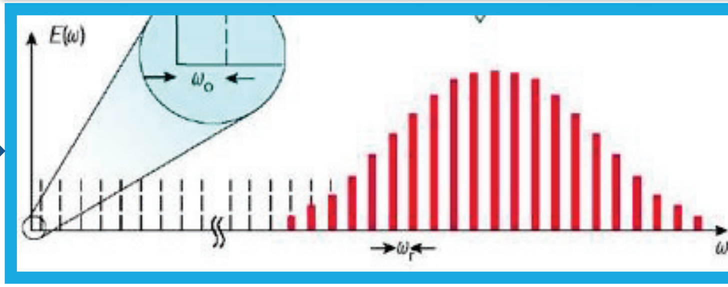
Input laser beam

Mode locked laser beam : electric field



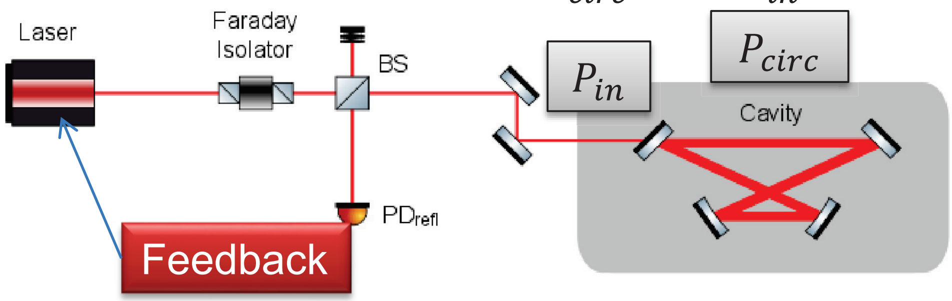
FT

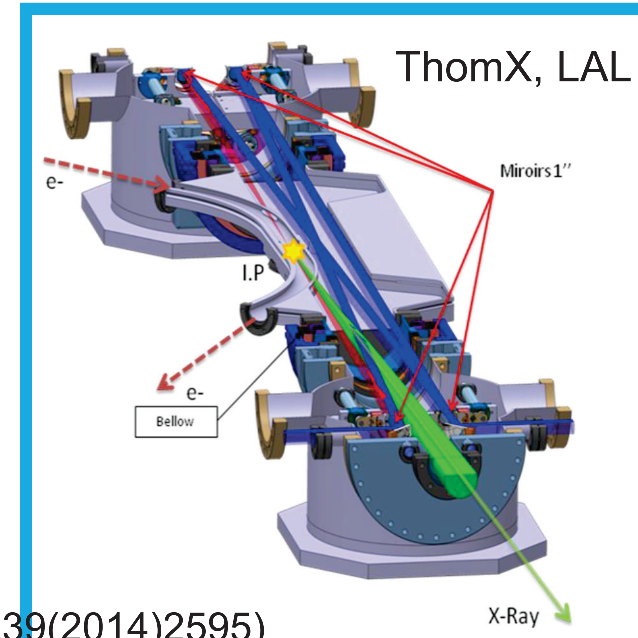
"frequency comb"



Four mirror cavity resonator :
Each tooth of the comb locked to a cavity mode

$$P_{circ} = G \cdot P_{in}$$





State of the art (average power/ ~10 ps pulses) :

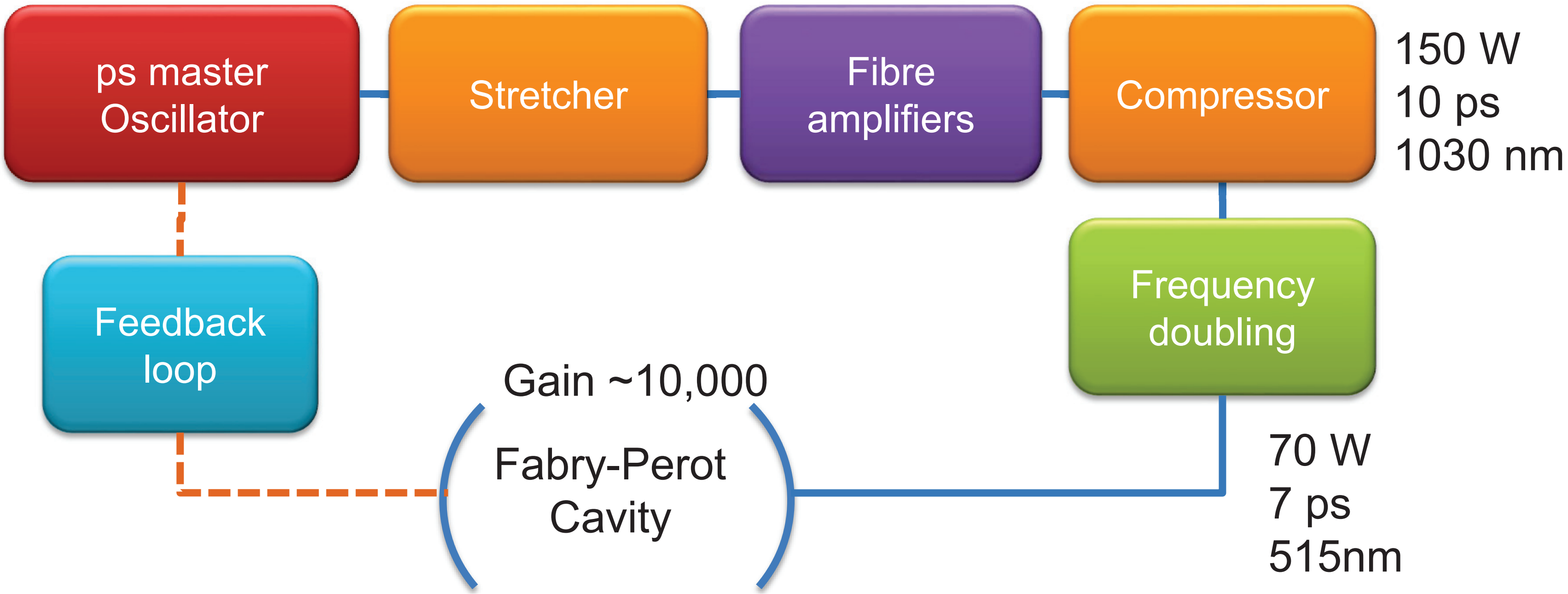
$P_{circ} \approx 670$ kW for $P_{in} = 315$ W (250 MHz; table top; Garching, OL39(2014)2595)

$P_{circ} \approx 50$ kW for $P_{in} < 10$ W (178.5 MHz;

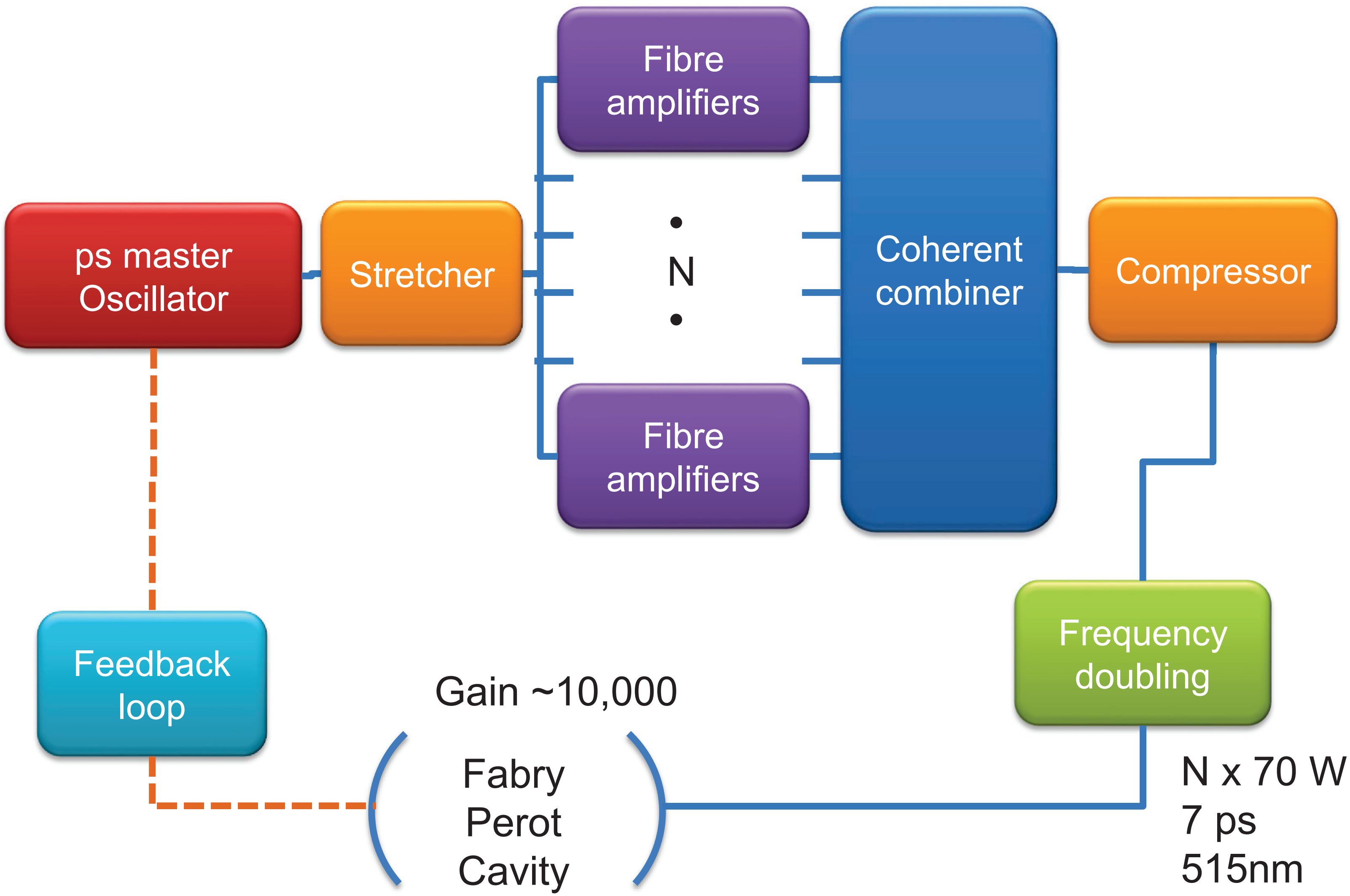
Gamma-ray exp. at ATF/KEK, CELIA/KEK/Hiroshima/LAL/LMA)

Input laser beam: Configuration 1

Configuration for CERN ERL gamma source :
~same as ThomX project (CELIA, LAL)
R&D going on at LAL and CELIA Labs.



Configuration 2: ERL γ source



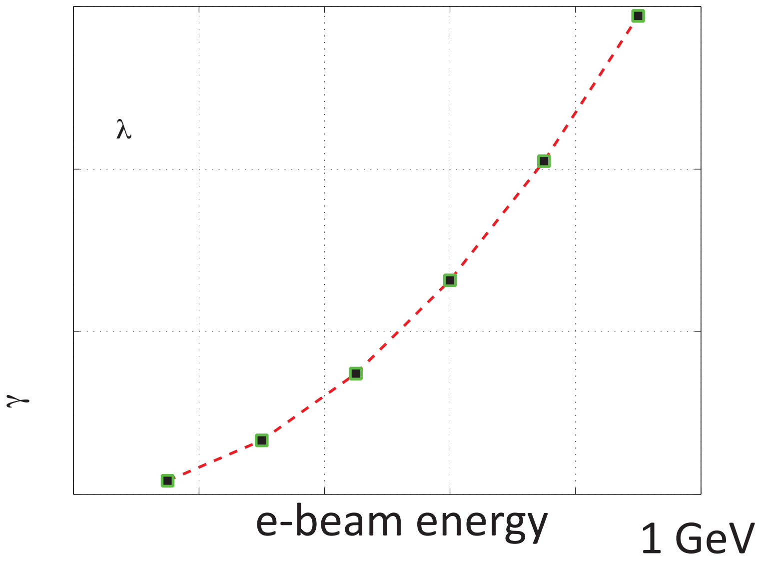
Electron and laser beams at the ERL facility

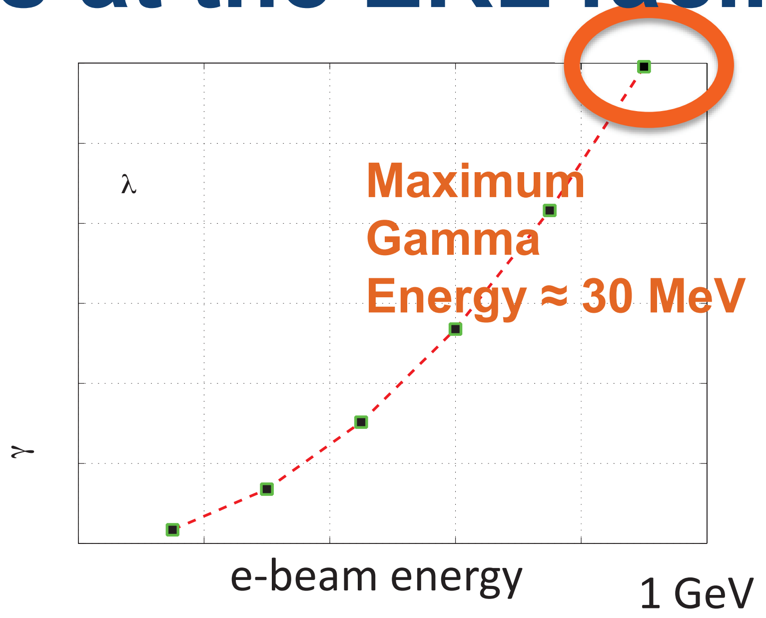
ELECTRON BEAM PARAMETERS	
Energy	900 MeV
Charge	320 pC
Spot size	30 um
Norm. Trans. Emittance	1.5 um
Energy Spread	0.1 %

LASER BEAM PARAMETERS 1*	
Wavelength	1030 nm
Average Power	600 kW
Pulse length	3 ps
Pulse energy	15 mJ
Spot size	30 um
Bandwidth	0.02 %
Repetition Rate	40 MHz

LASER BEAM PARAMETERS 2*	
Wavelength	515 nm
Average Power	300 kW
Pulse length	3 ps
Pulse energy	7.5 mJ
Spot size	30 um
Bandwidth	0.02 %
Repetition Rate	40 MHz

γ beam properties at the ERL facility





GAMMA BEAM PARAMETERS	
Energy	30 MeV
Spectral density	$9*10^4$ ph/s/eV
Bandwidth	< 5%
Flux within FWHM bdw	$7*10^{10}$ ph/s
ph/e$^-$ within FWHM bdw	10^{-6}
Peak Brilliance	$3*10^{21}$ ph/s*mm^2*mrad^2 0.1%bdw

Summary

- CERN and collaborating labs presently perform a conceptual study of an ERL Facility.
- Primary goal is … to study an ERL! …and to learn!
- Initial applications include test of SRF cavities/CMs with beam and beam instrumentation tests.
- Possible later applications are taken into consideration during the design phase.
- Both controlled quench tests and γ Compton source seem possible.
- A test beam line for non-ER operation would be an asset.

Thank you very much!

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