LHeC: Summary of Accelerator Sessions

- Four sessions plus some presentations from plenary
- Over 20 presentations covering:
  - -LHeC proper (parameters; performance and layout)
  - -Optics and Beam stability
  - -Cryogenics and SC magnet design
  - -Arc magnet design and transfer lines and dumps
  - -RF (frequency, HOM and collaborations)
  - -new ideas (FFAG, CSR, p-beam cooling)
  - -CERN Test Facility (auxiliary applications, layout)
  - -Collaborations and ERLs plans around the world
- Lots of discussions: Future needs and integration into FCC

LHeC: Summary of Accelerator Sessions

- Presentations can be grouped into 5 main areas:

  -LHeC ERL baseline design

  -Performance optimization in light of the Higgs
  ➔ $L \geq 10^{34} cm^{-2} s^{-1}$ (beam current, SRP, bb & HL-LHC!)

  -LHeC integration into the HL-LHC:
  IR and optics design and beam dynamics studies

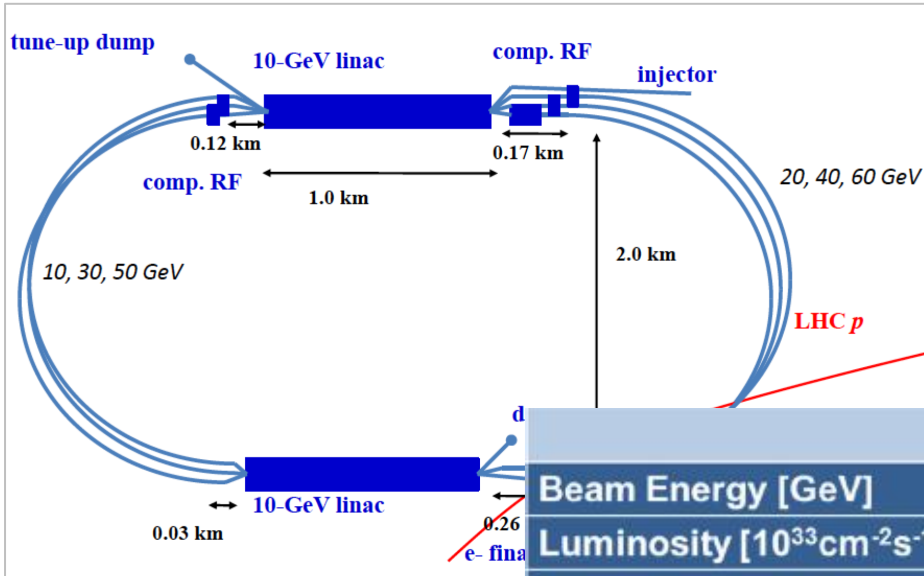
  -CERN Test Facility design
  (auxiliary applications, layout)

  -Collaborations and ERL activities around the world

LHeC: Baseline Linac-Ring Option

LHeC

- Super Conducting Linac with Energy Recovery & high current (> 6mA)



Two 1 km long SC linacs in CW operation ($Q > 10^{10}$)

➔ requires Cryogenic

	PROTONS	ELECTRONS
Beam Energy [GeV]	7000	60
Luminosity [$10^{33}cm^{-2}s^{-1}$]	1	1
Normalized emittance $\gamma\varepsilon_{x,y}$ [µm]	3.75	50
Beta Function $\beta^*_{x,y}$ [m]	0.10	0.12
rms Beam size $\sigma^*_{x,y}$ [µm]	7	7
rms Divergence $\sigma'_{x,y}$ [µrad]	70	58
Beam Current [mA]	(860) 430	6.6
Bunch Spacing [ns]	25 (50)	25 (50)
Bunch Population	1.7×10^{11}	$(1 \times 10^9)\ 2 \times 10^9$

- Relatively large retu
  - ➔ ca. 9 km undergrou
  - ➔ total of 19 km bend
  - ➔ same magnet desig

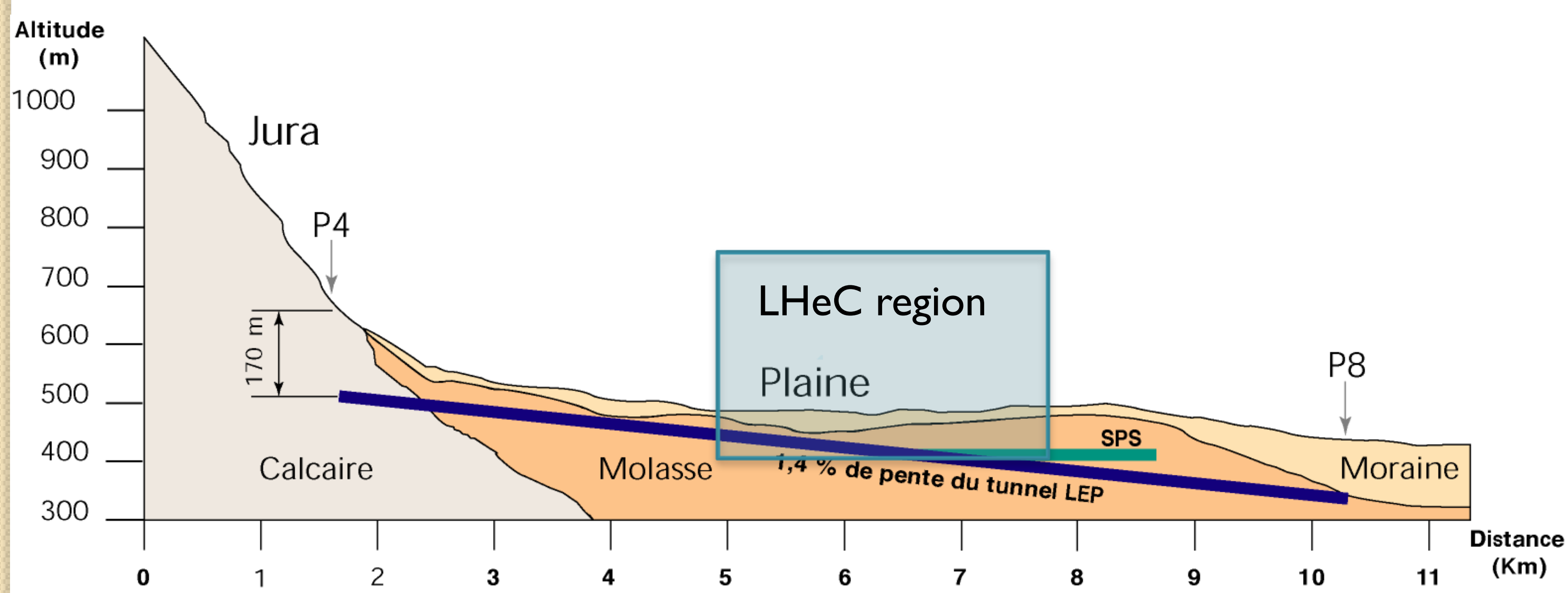
LHeC: Summary of Accelerator Sessions

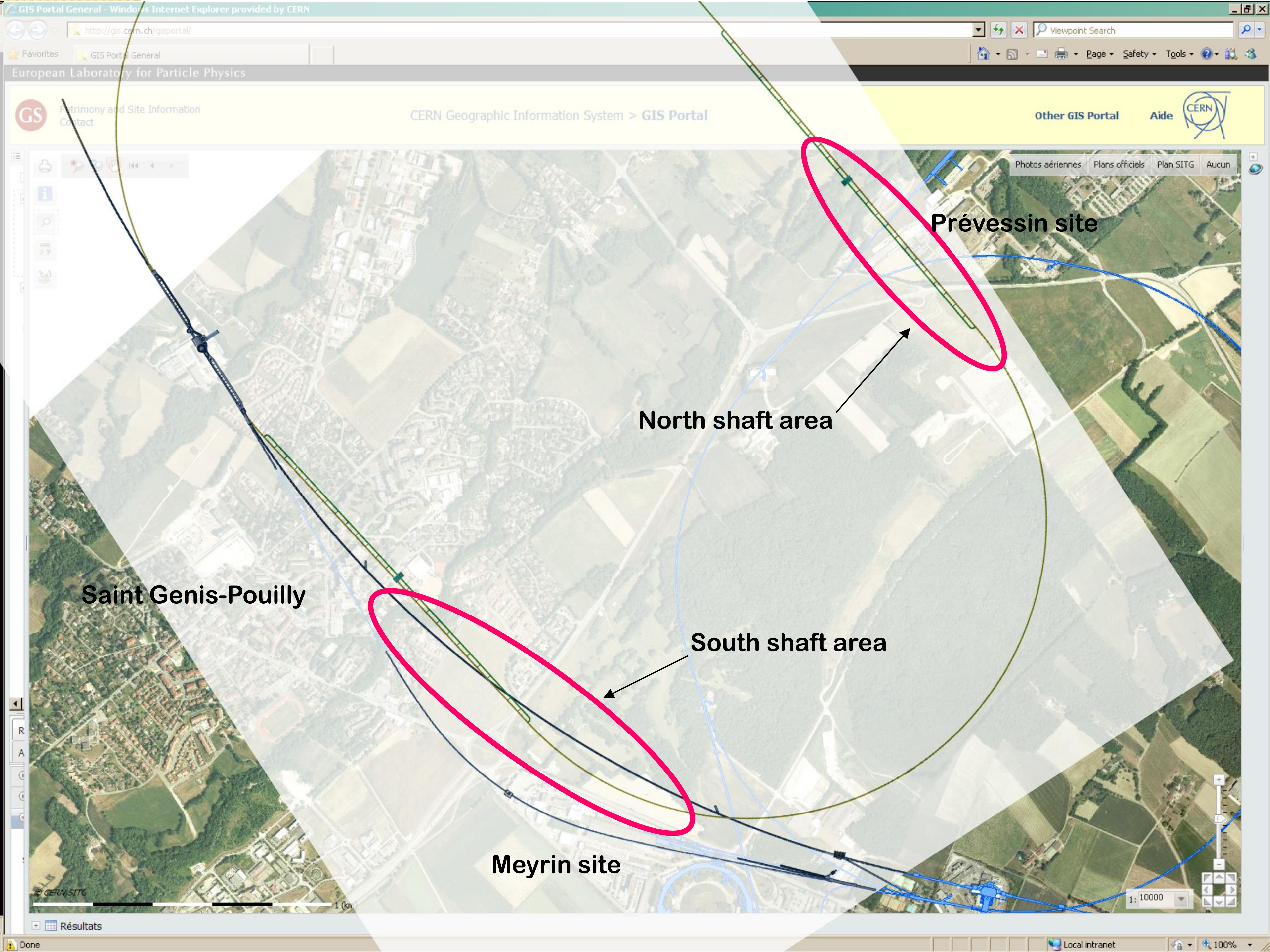
- We have a first estimate for civil engineering [John Osborne]:
  -Layout, cost estimate and construction planning (4y)

Site Features *geology*

- Geology:
  - Molasse – Moraine
    - Profile LHeC region (showing also location of LHC and SPS)

John Osborne





GIS Portal General - Windows Internet Explorer provided by CERN
European Laboratory for Particle Physics
Patrimony and Site Information
Contact
CERN Geographic Information System > GIS Portal
Other GIS Portal
Aide
Photos aériennes
Plans officiels
Plan SITG
Aucun
Prévessin site
North shaft area
Saint Genis-Pouilly
South shaft area
Meyrin site
© CERN SITG
1 km
1: 10000
Résultats
Done
Local intranet
100%

LHeC: Summary of Accelerator Sessions

LHeC

- We have a good baseline:
  -Layout, cost estimate and construction planning (4y)

- Cryogenic estimates [Friedrich Haug]:
  -30kW @ 2K for CW operation with $Q_0 = 2.5\ 10^{10}$
  -1/COP @ 2K = 700 ➔ 21 MW total power
  -proposal of installation with 8 cryoplants

➔ need to re-evaluate with HOM estimates & damping

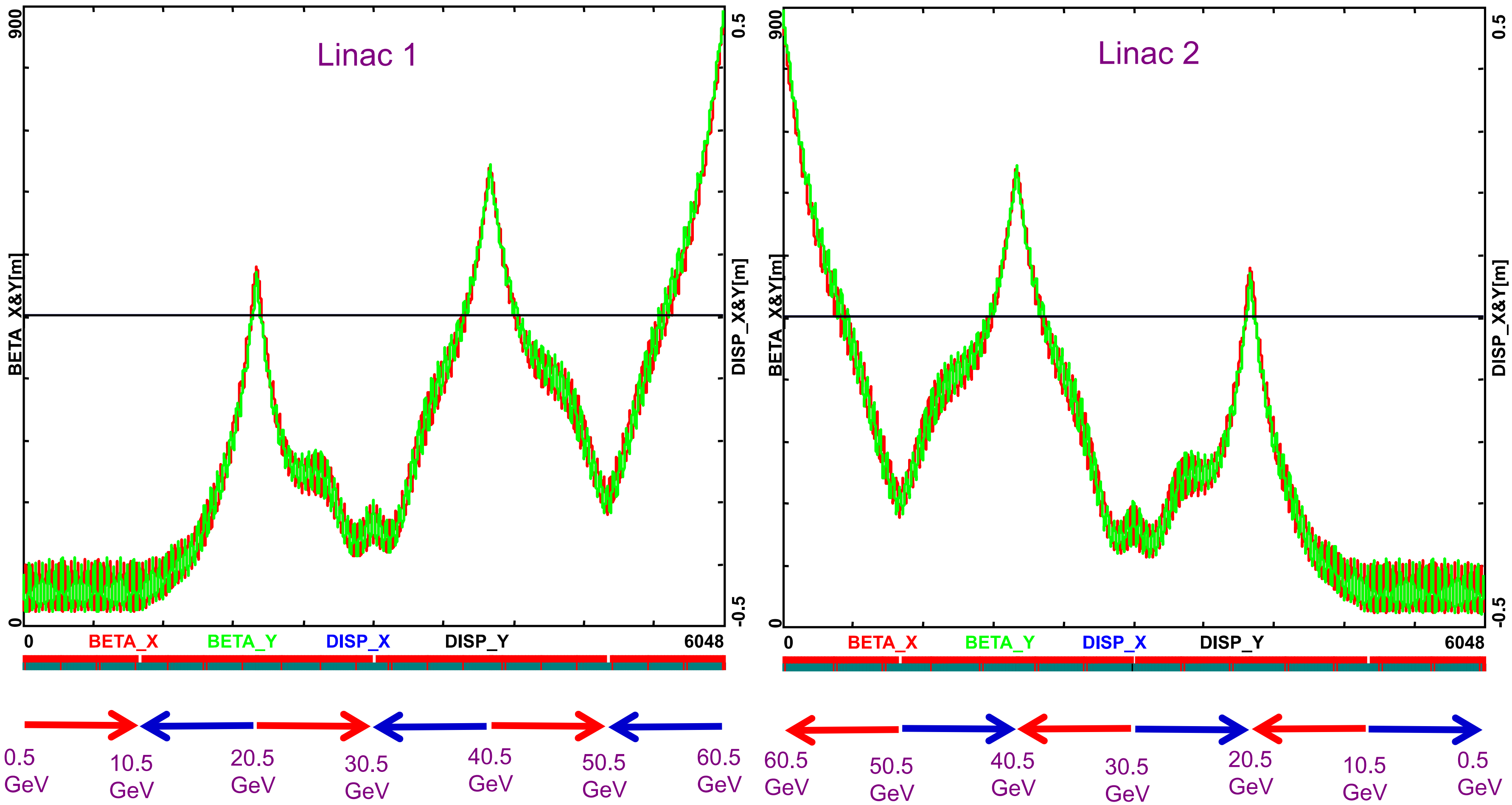
LHeC: Summary of Accelerator Sessions

- We have a good optics baseline for ERL:

Linac 1 and 2 – Multi-pass ER Optics

Alex Bogacz

Acceleration/Deceleration



Arc Optics – Emittance preserving FMC cell

$$\Delta\varepsilon^N = \frac{55\, r_0}{48\sqrt{3}} \frac{\hbar c}{mc^2} \gamma^6 \langle H \rangle \frac{\theta}{\rho^2}$$

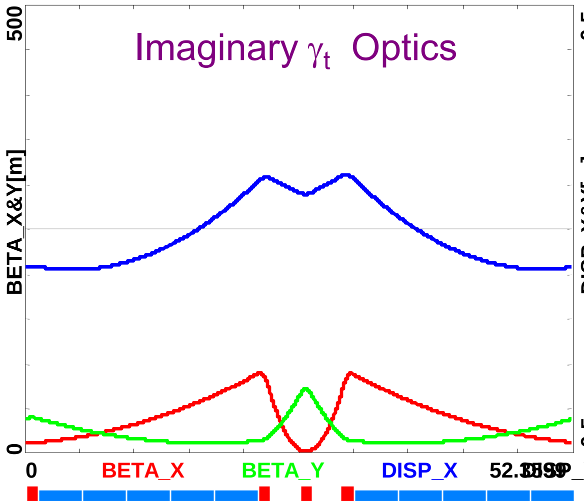
$$H = \gamma D^2 + 2\alpha D D' + \beta D'^2$$

Alex Bogacz

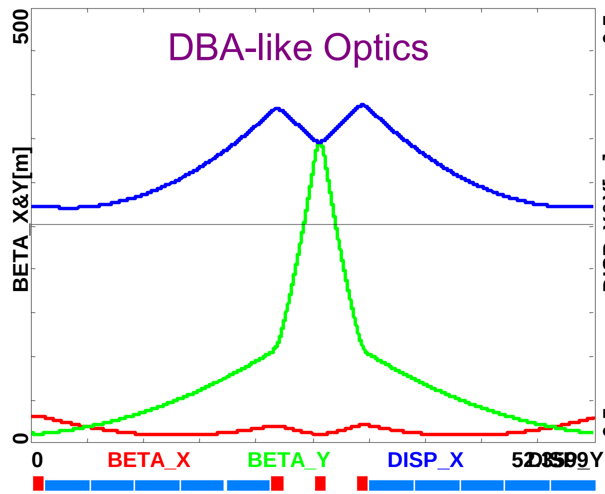
Arc 1 , Arc2

Arc 3, Arc 4

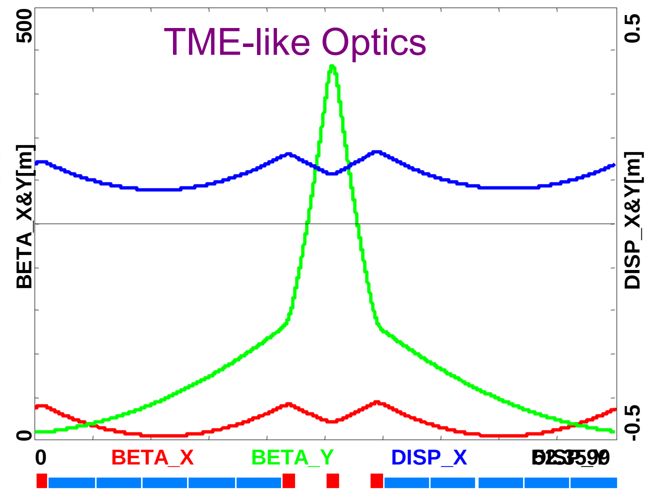
Arc5, Arc 6



$$\langle H \rangle = 8.8 \times 10^{-3}\ m$$



$$\langle H \rangle = 2.2 \times 10^{-3}\ m$$



$$\langle H \rangle = 1.2 \times 10^{-3}\ m$$

factor of 18 smaller than FODO

FMC = Flexible Momentum Compaction

total emittance increase in Arc 5: $\Delta\varepsilon_x^N$ = 4.268 μm rad

Energy Loss and Emittance Dilution in Arcs

ARC	E [GeV]	ΔE [MeV]	σE/E [%]
1	10.4	0.678	0.00052
2	20.3	9.844	0.00278
3	30.3	48.86	0.00776
4	40.2	151.3	0.01636
5	50.1	362.3	0.02946
6	60	751.3	0.04829
7	50.1	362.3	0.06366
8	40.2	151.3	0.08065
9	30.3	48.86	0.10808
10	20.3	9.844	0.16205
11	10.4	0.678	0.31668
dump	0.500	0	6.66645

Energy loss and Integrated energy spread induced by SR

Total loss per particle about ~1.9 GeV

Compensated by additional linacs
20.3 MW

ARC	E [GeV]	$\Delta\varepsilon_{ARC}$ [μm]	$\Delta\varepsilon_t$ [μm]
1	10.4	0.0025	0.0025
2	20.3	0.140	0.143
3	30.3	0.380	0.522
4	40.2	2.082	2.604
5	50.1	4.268	6.872
6	60	12.618	19.490
5	50.1	4.268	23.758
4	40.2	2.082	25.840
3	30.3	0.380	26.220
2	20.3	0.140	26.360
1	10.4	0.0025	26.362

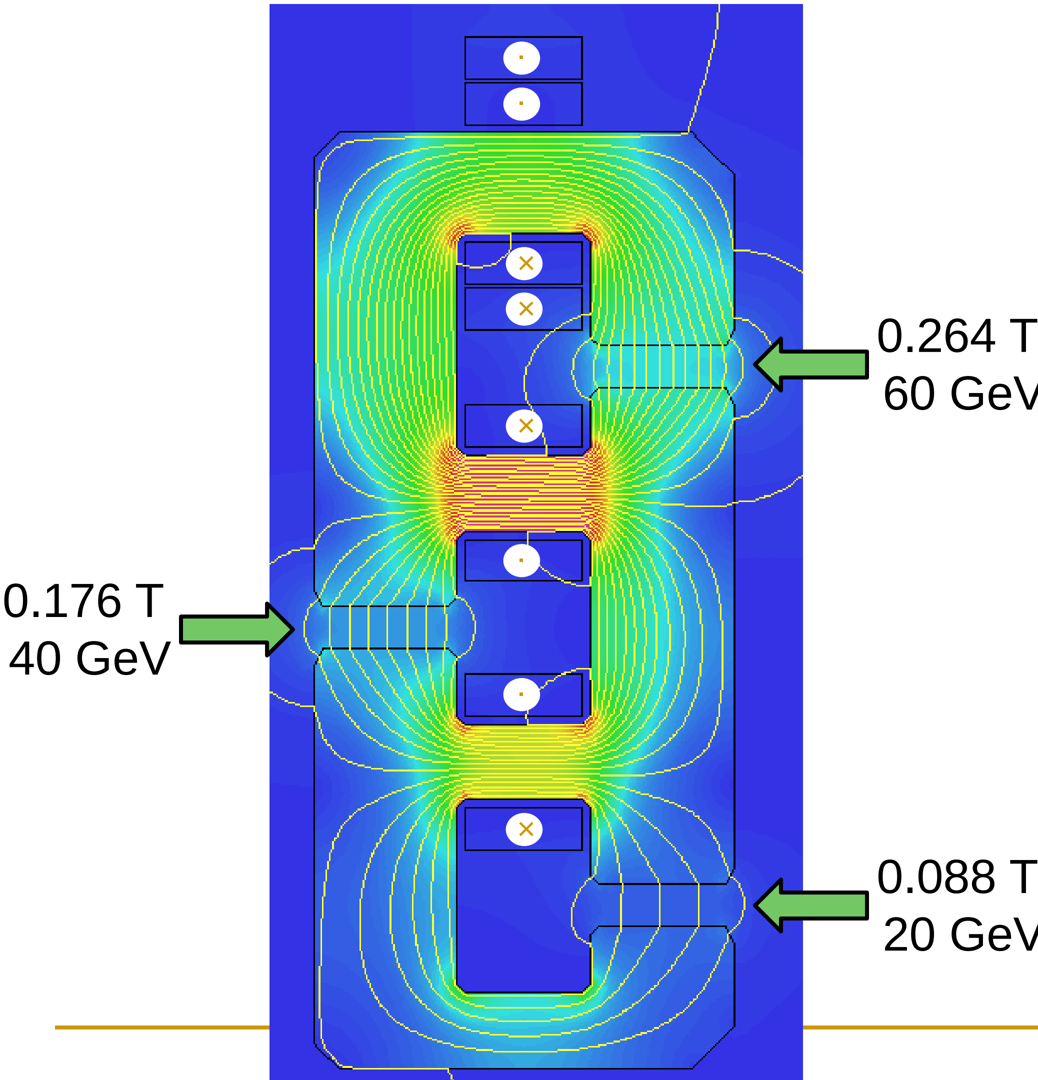
Integrated Emittance growth including all previous arcs

Before the IP a total growth of ~ 7 μm is accumulated
The final value is ~ 26 μm

A. Valloni

Dipoles in post-CdR

Attilio Milanese

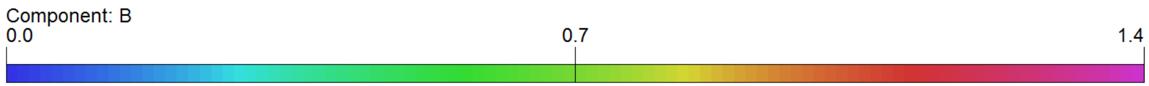


Alternative coil arrangement

- keep the idea of recycling Ampere-turns
- stack the apertures vertically but offset them also transversally
- same vertical gap, 25 mm
- simple coils / bus-bars, same powering circuit
- as before, trim coils can be added for two of the apertures, to give some tuning

Dipoles in post-CdR

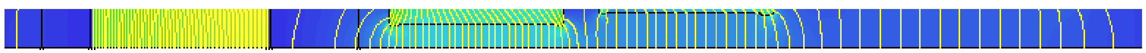
Attilio Milanese



Side-by-side

Interesting area for Prototype Development!

en
)

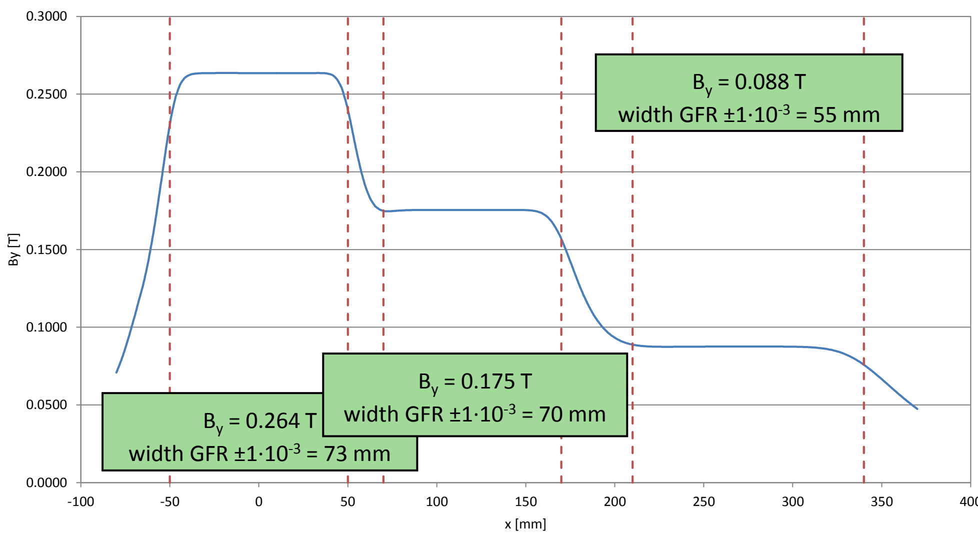


keep a flat enough field distribution

- the Ampere-turns are fully recycled for the three energies
- trim coils can be added for two of the apertures, to give some tuning

(1/2 of the dipole shown)

field across the three apertures



LHeC: Summary of Accelerator Sessions

- We have a good optics baseline for ERL [Alex Bogaz]:

- Several new ideas for discussions:
  - -CSR (probably not an issue for LHeC)
  - -non-scaling FFAG for return arcs [Dejan Trbojevic]
    - ➔ synchrotron radiation issues for LHeC?
  - -ERL as proton or ion cooler

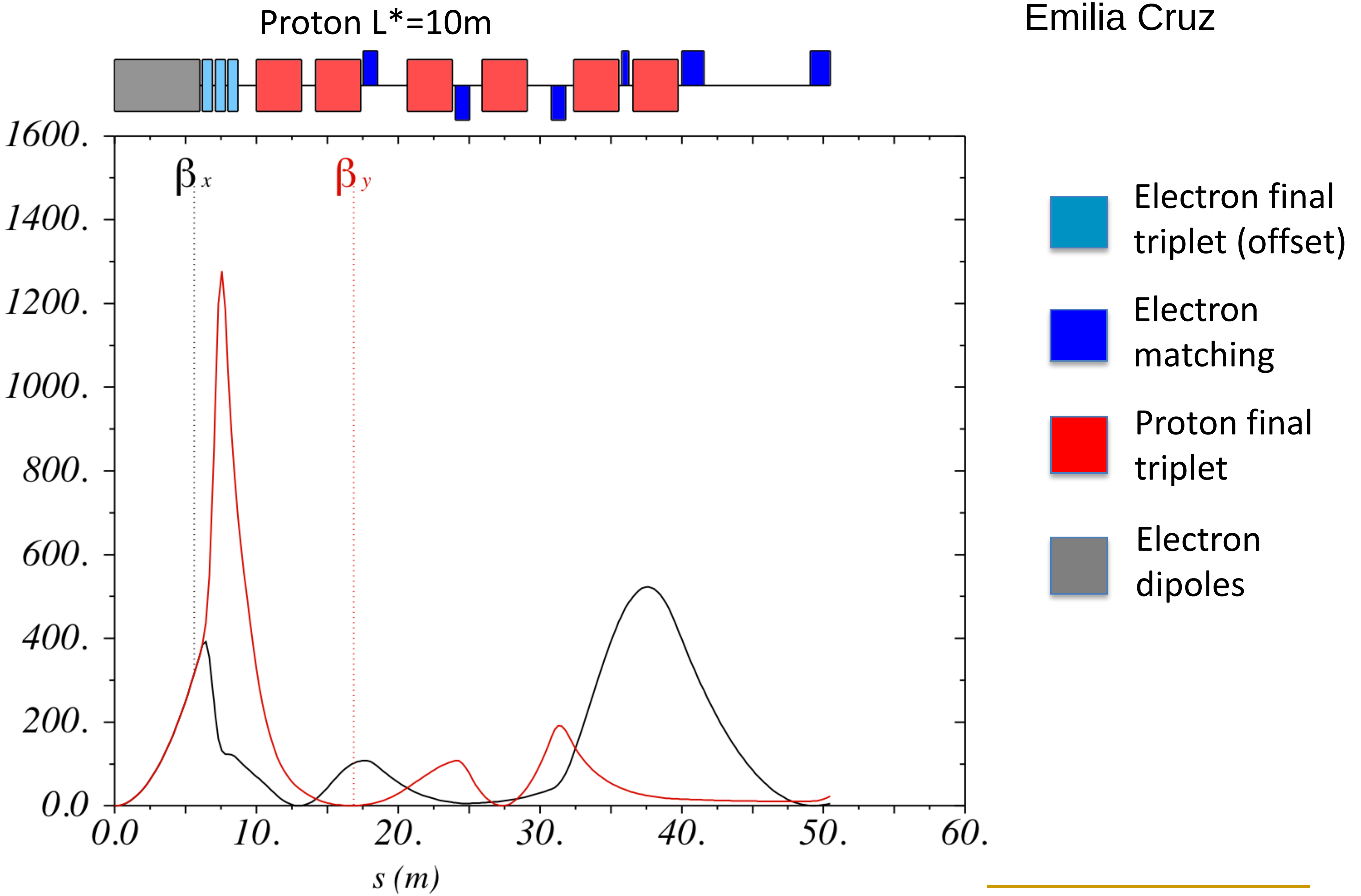
LHeC: Summary of Accelerator Sessions

- We have a first p-optics integration into HL-LHC [Rogelio Thomas, Luke Thompson, Emilia Cruz]

- Ongoing optimization for Interaction Region:
  - -Performance need in light of Higgs & FCC integration
  - -optimization of L* (SRP, magnet design, luminosity)
    - ➔ ATS optics and Q' correction
    - ➔ synchrotron radiation issues for LHeC

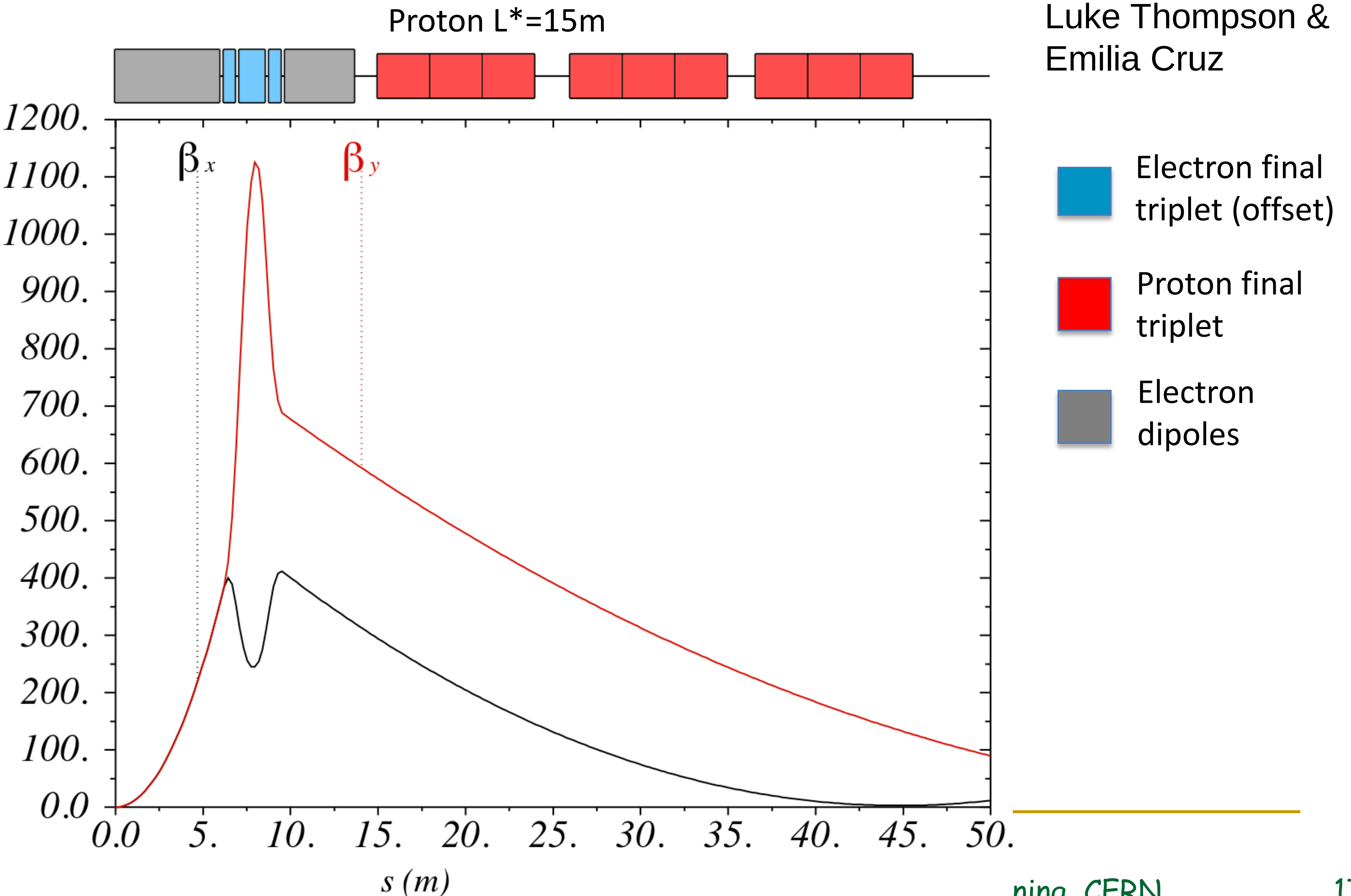
Electron IR Optics – Half-Quadrupole

Luke Thompson & Emilia Cruz

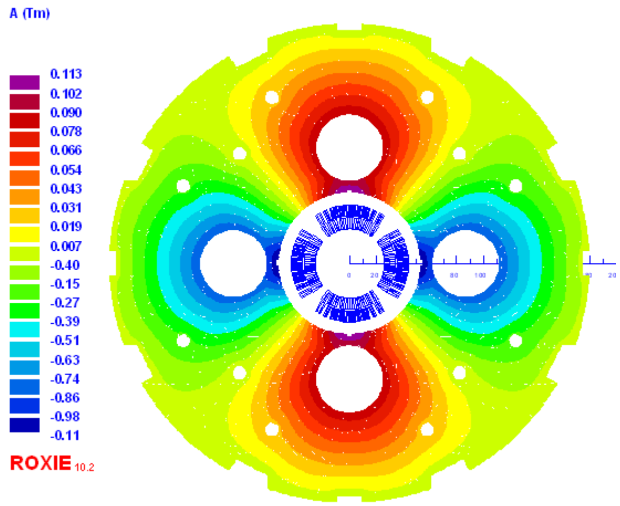


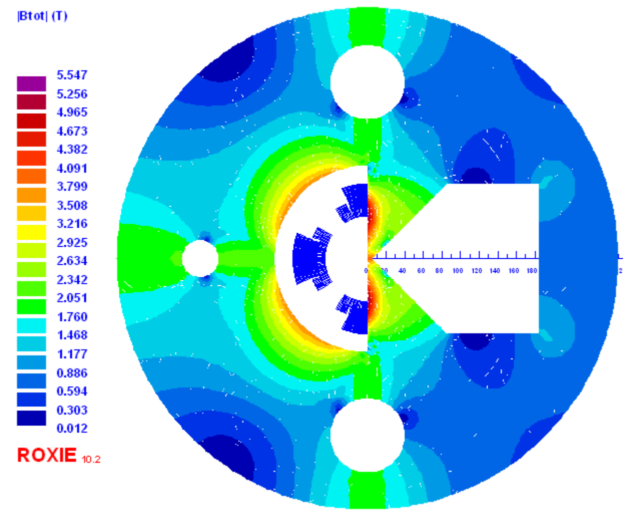
Electron IR Optics – No Half-Quadrupole

Luke Thompson & Emilia Cruz



Comparison Q1 for Ring-Ring and Linac-Ring





NbTi: 6700 A, 248 T/m at 88% LL Nb3Sn: 8600 A, 311 T/m, at 83% LL	NbTi: 4500 A, 145 T/m, 3.6 T at 87% Nb3Sn: 5700 A, 175 T/m, 4.7 T at 82% on LL
23 mm aperture 87 mm septum	46 mm (half) aperture 63 mm septum (space for p and e-beams)
0.03 T, 3.5 T/m in e-beam pipe 0.09 T, 9 T/m in e-beam pipe	0.37 T, 18 T/m 0.5 T, 25 T/m

LHeC: Summary of Accelerator Sessions

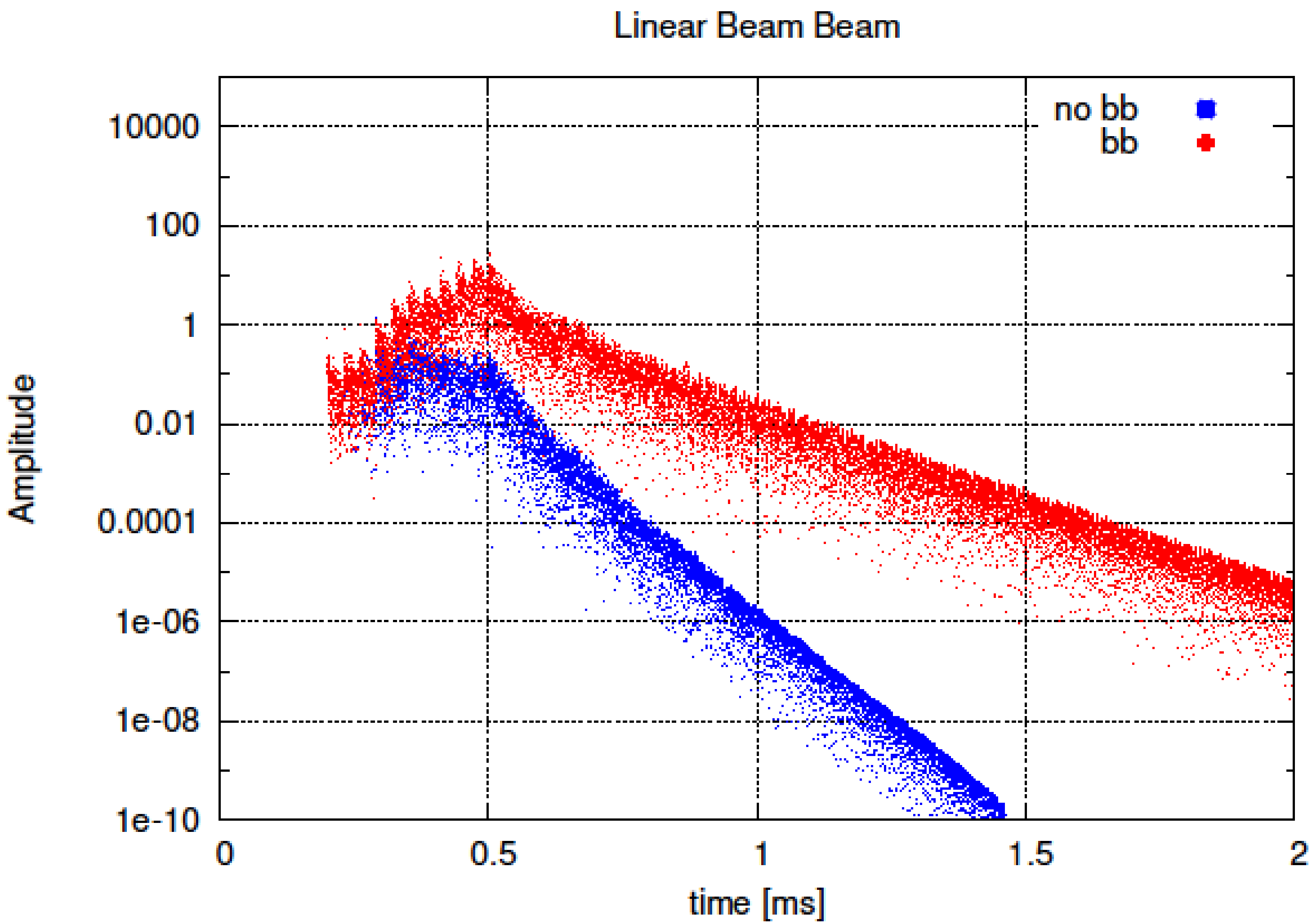
- Beam Dynamic Studies:

  -Beam stability of the electron beam in the ERL
  (wake fields, HOM and beam-beam,
  beam disruption and losses?)

  -Impact of the beam-beam on proton beam
  (parasitical operation;
  beam-beam with high luminosity parameters, noise!)

Linear Beam-Beam effect

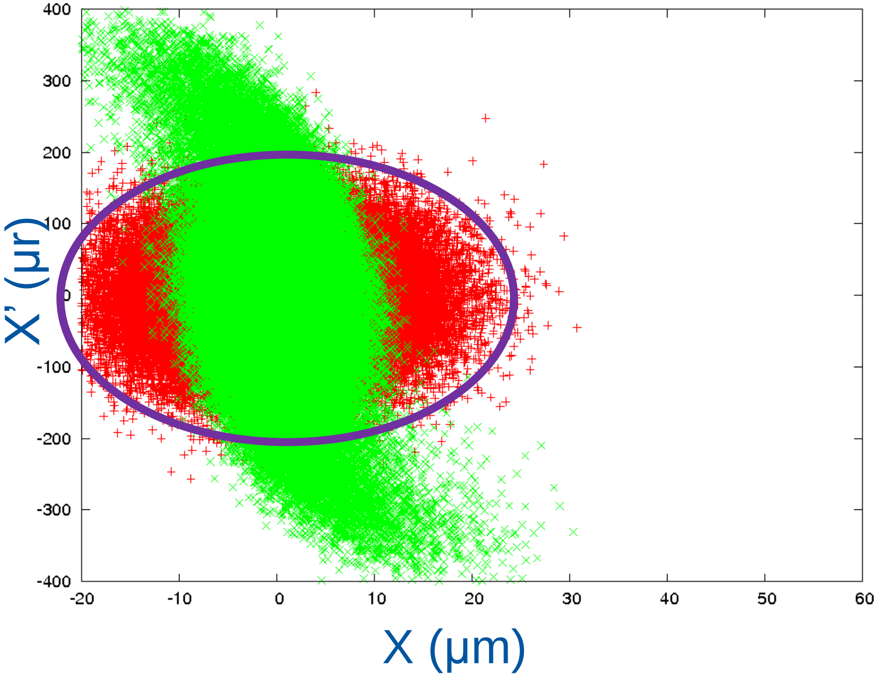
Dario Pellegrini



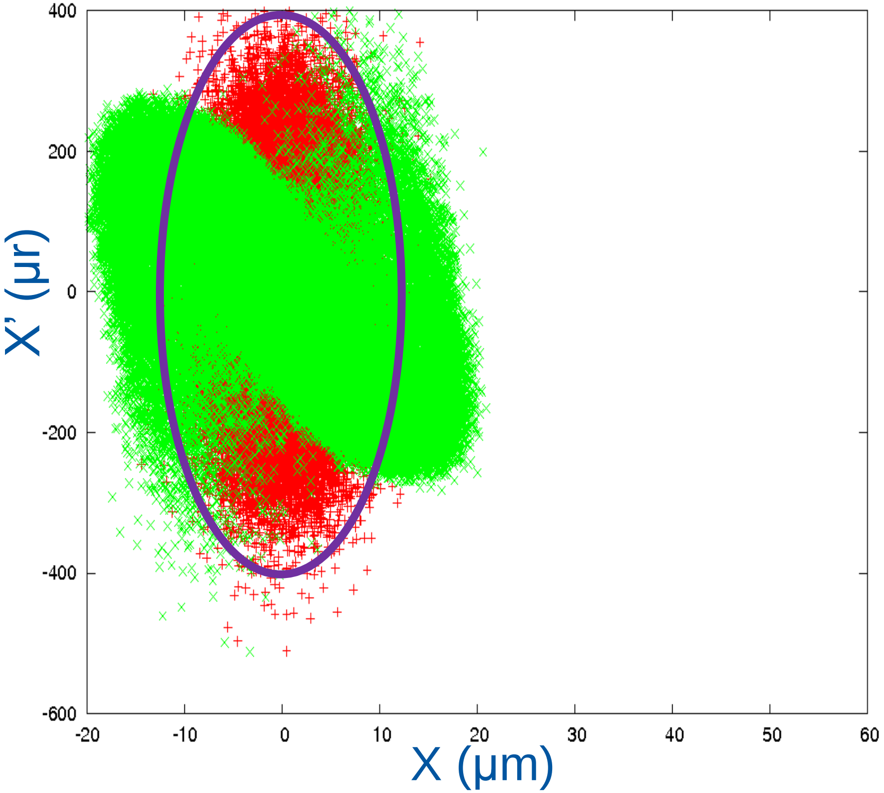
Spent Electron Beam

Edward Nissen

Nominal Parameters



High Luminosity



Red particles show the beam without beam-beam effects, green particles show the electron beam with beam-beam effects. Each frame is a single interaction at an increasing offset.

LHeC: Summary of Accelerator Sessions

- Beam Dynamic Studies:
  - -Beam stability of the electron beam in the ERL
  (wake fields, HOM and beam-beam,
  beam disruption and losses?)
  - -Impact of the beam-beam on proton beam
  (beam-beam with high luminosity parameters, noise!)

- Studies in Preparation of an ERL Test Facility @ CERN
  - -site choice
  - -auxiliary applications (magnet test facility, physics etc)
  - -RF preparations

- B. 180 Magnet recovery facility
- B. 112 Brazing + LHC Klystrons
- B. 378 TE/EPC testing
- B. 193 AD + ELENA
- B. 513 Computer Center
- B. 3185 ATLAS shafts

B. 133 Recovery material
B. 170 ISOLDE
B. 150 LEAR
B. 157 EAST HALL
B. 100 Main Workshop
B. 510 Main building
B. 400 LINAC 4

Nuria Catalan

- B. 889 SPS Access point
- B. 897 Central Storage
- B. 867 Radioactive facility

B. 888 COMPASS
B. 887 North Hall
B. 890 EN-CV for North Hall

Nuria Catalan

Building 2275. Point 2

LEP power converters and klystrons spares. Current use under investigation.

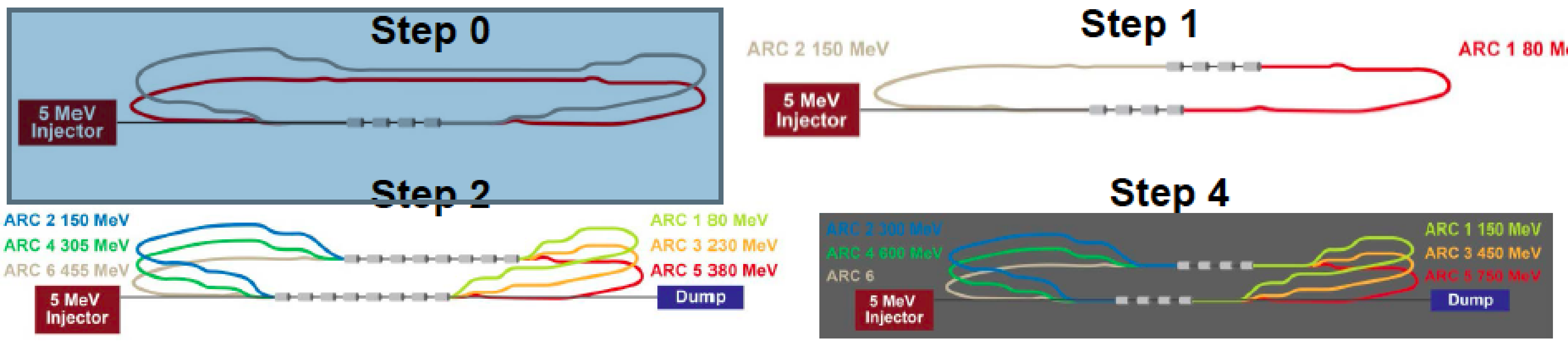
Power converters already in place.
Geographically perfect as injector for LHeC ERL

Slightly narrower than required
Can it be extended?

Nuria Catalan

Planning for each stage

Alessandra Valloni



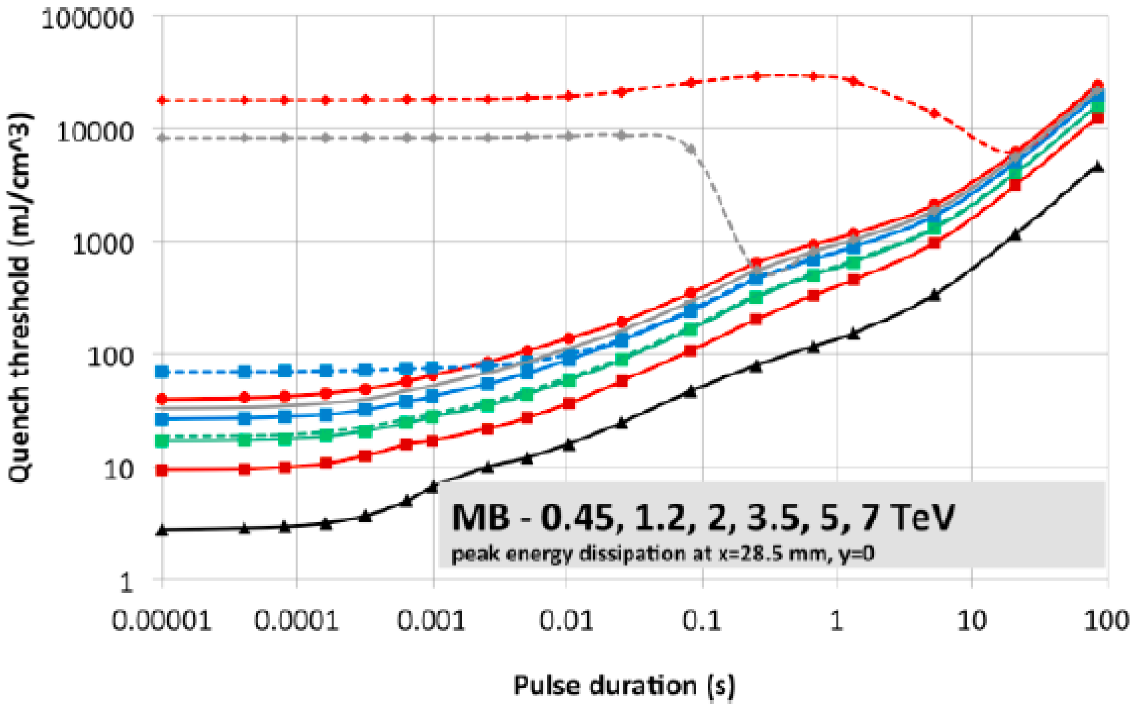
ARC	Step 0	Step 1	Step 2	Step 3
ARC 1	80 MeV	80 MeV	80 MeV	150 MeV
ARC 2	155 MeV	155 MeV	155 MeV	305 MeV
ARC 3			230 MeV	455 MeV
ARC 4			305 MeV	605 MeV
ARC 5			380 MeV	755 MeV
ARC 6			455 MeV	905 MeV

Controlled quench tests of SC magnets

Alessandra Valloni

Study beam induced quenches (quench thresholds, quenchino thresholds) at different time scales for:

- SC cables and cable stacks in an adjustable external magnetic field
- Short sample magnets
- Full length LHC type SC magnets



Quench limits of LHC dipole as expected from QP3 simulations for different pulse durations

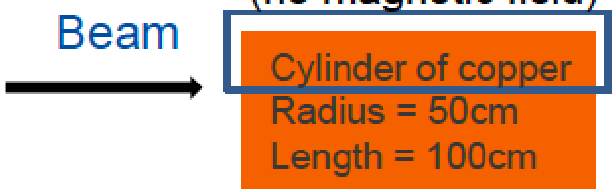
Courtesy A. Verweij

Beam parameters to generate a given amount of energy deposition

Alessandra Valloni

CALCULATIONS AND FLUKA SIMULATIONS

Copper target
(no magnetic field)



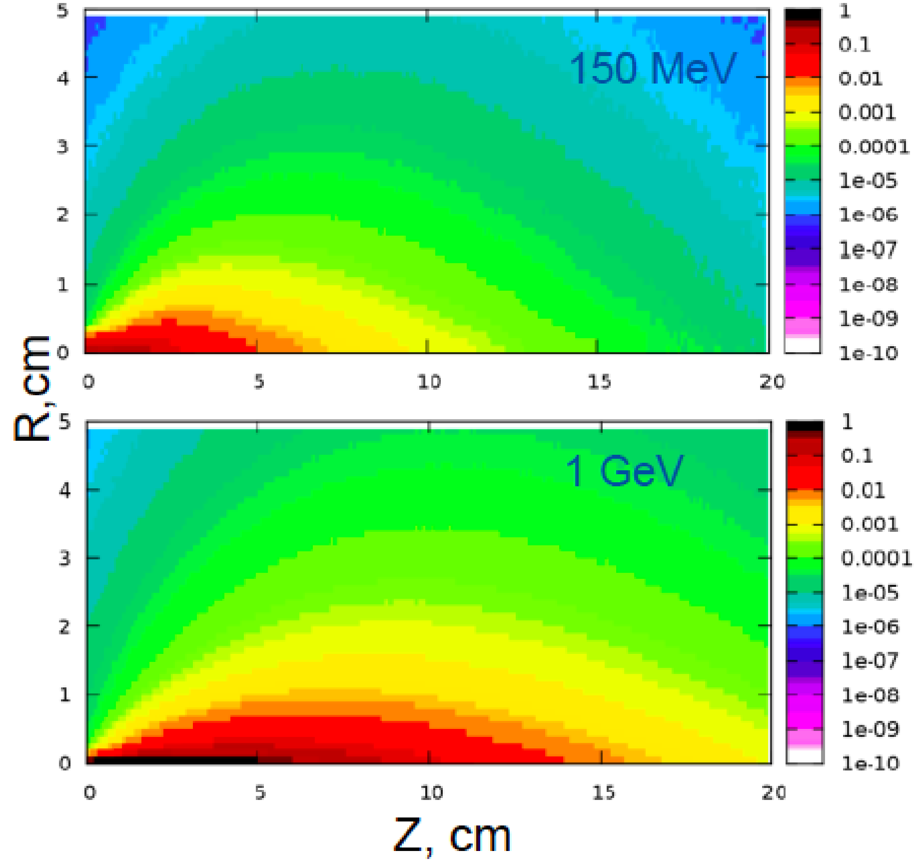
Beam parameters

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

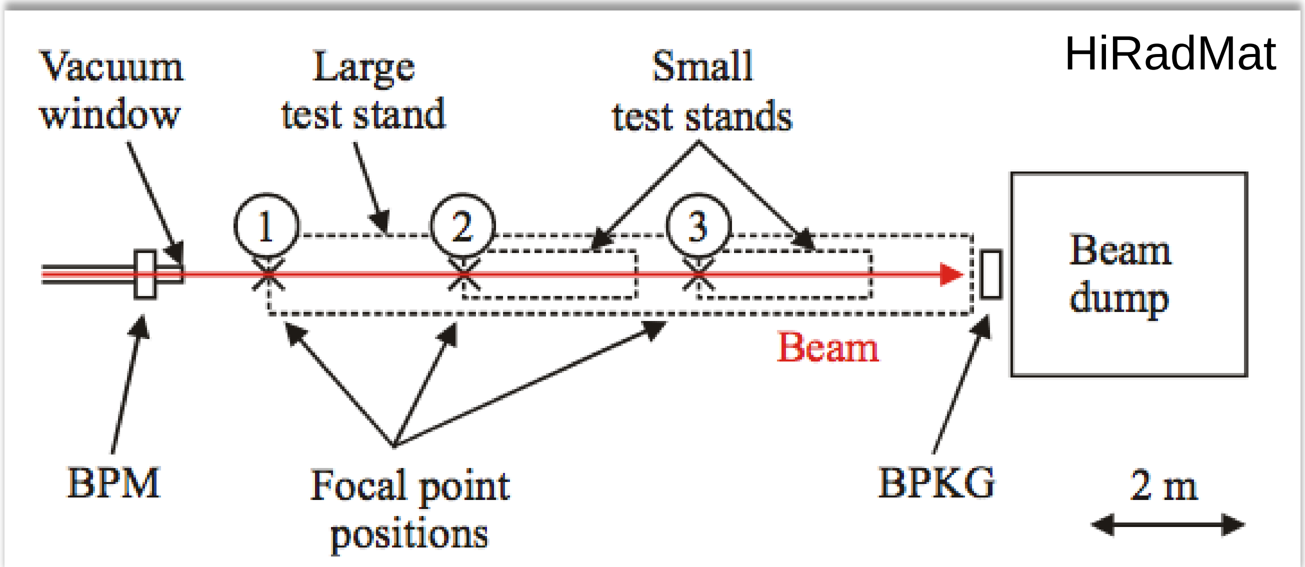
Energy deposition, GeV/cm^3/e$^-$



Test Facility in Extraction Line

- Use same logic as in HiRadMat

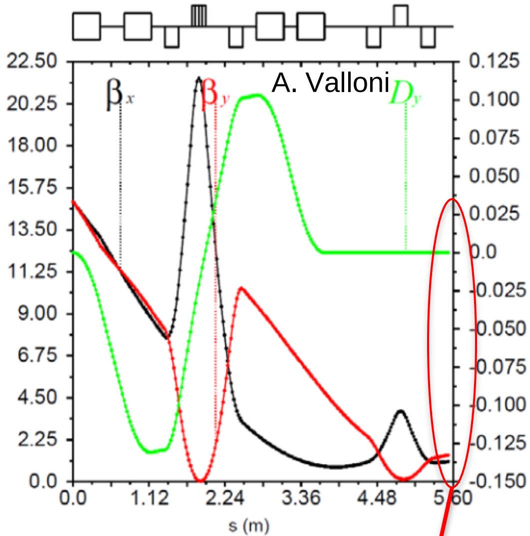
Chiara Bracco

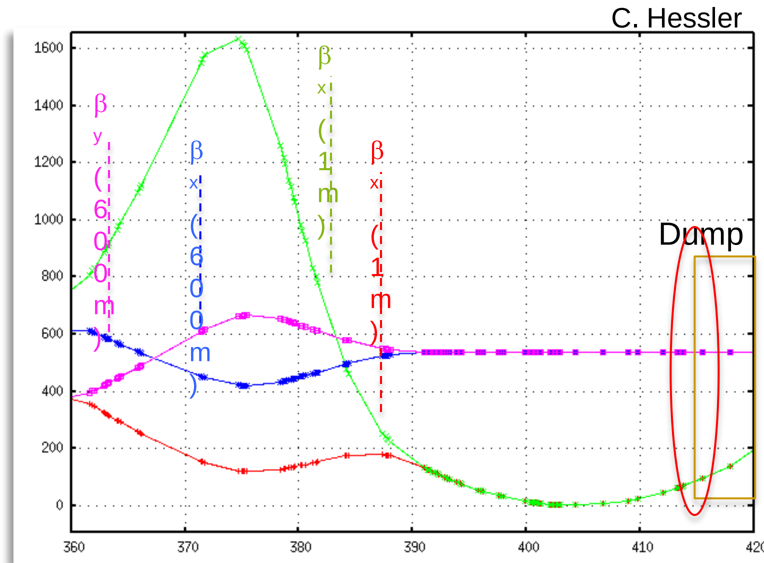


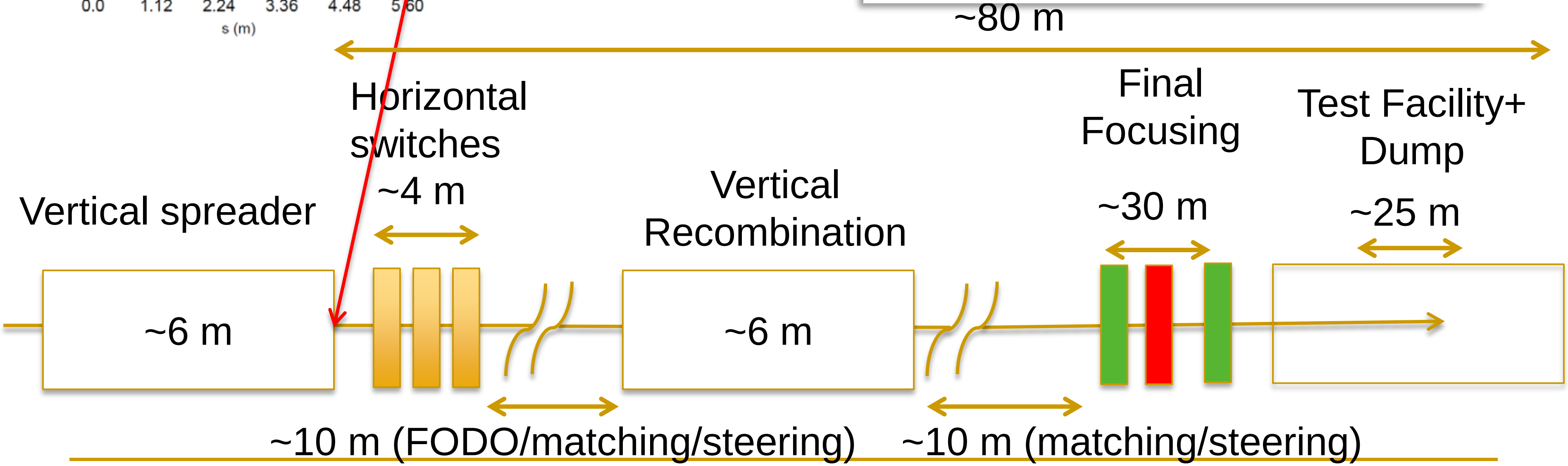
- Different focal points and different beam sizes possible:
  - From 0.1 mm (β = 1m) up to 2 mm (β =600 m) for HiRadMat (440 GeV p+)
  - This would correspond to: from 0.4 mm (β = 1m) up to 4 mm (β =600 m) for ERL-TF (detailed optics studies to be performed)

Schematic View of TL

Chiara Bracco







LHeC: Summary of Accelerator Sessions

LHeC

Upcoming Tasks and Opens Issues:

-SC RF design with HOM damper and cryostat

-ERL TF design with options / phases and specific site proposal (SC magnets & physics) ➔ leading to CDR

-'Finalize' high L LHeC (Higgs) option / parameters (dump [13MW], beam-beam, SRL in detector)

-Full integration into HL-LHC (and FCC?) (L^*, injection optics, layout, transfer lines, dump etc)

-Beam dynamic studies (ERL full cycle with disruption; proton beam with beam-beam and 'noise')

LHeC: Summary of Accelerator Sessions

- Collaborations and International Activities:

  -MESA @ University Mainz

  ➔ SC RF cavity and cryostat prototypes

  ➔ includes collaboration with JLab

  -JLab ERL (‘LHeC like’, injector, halo, op. experience)

  -BNL SC RF activities & ERL
  (HOM, eRHIC, applications, frequency choice, cost and complexity)

  -Cornell ERL (frequency choice, high Q_0, errors, HOM)

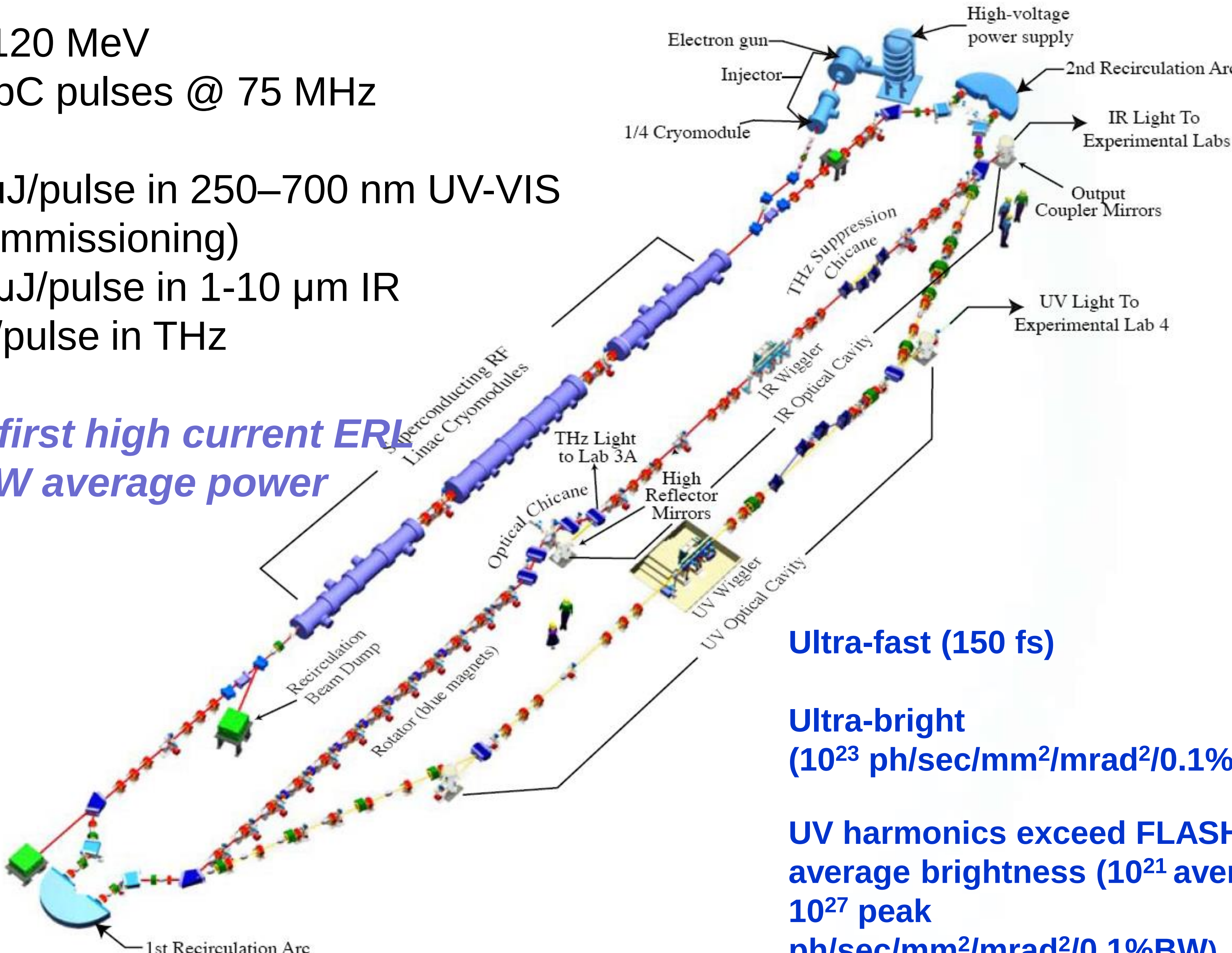
  -ALICE ERL and UK (operational experience)

Existing JLab 4th Generation IR/UV Light Source

E = 120 MeV
135 pC pulses @ 75 MHz

(20 μJ/pulse in 250–700 nm UV-VIS in commissioning)
120 μJ/pulse in 1-10 μm IR
1 μJ/pulse in THz

The first high current ERL
14 kW average power



Ultra-fast (150 fs)

Ultra-bright
(10^{23} ph/sec/mm^2/mrad^2/0.1%BW)

UV harmonics exceed FLASH average brightness (10^{21} average, 10^{27} peak ph/sec/mm^2/mrad^2/0.1%BW)

Major R&D Efforts Around the World

- Injector, injector, injector! No existing injector delivers required CW brightness. Many groups are working on this: LBNL, Cornell, Wisconsin, JLab, KEK, Daresbury, BNL, PKU…
- Brightness preservation: Solutions to coherent synchrotron radiation (CSR) emittance degradation, longitudinal space charge (LSC) in pulse compression
- Halo control essential for CW – non-Gaussian tails!!! $< 1\mu A$ local loss allowed
- High order mode & beam breakup control in cavities
- Wakefield and propagating mode damping

High HOM power lost at srf temps?

- Handling sizeable (~ 20 kW! @ 100 mA) THz radiation in bends
- Resistive wall heating in undulators 100W/m at 4mA on JLab IR FEL
- Reducing srf dynamic load to lower refrigerator costs; probably more important than increasing gradient

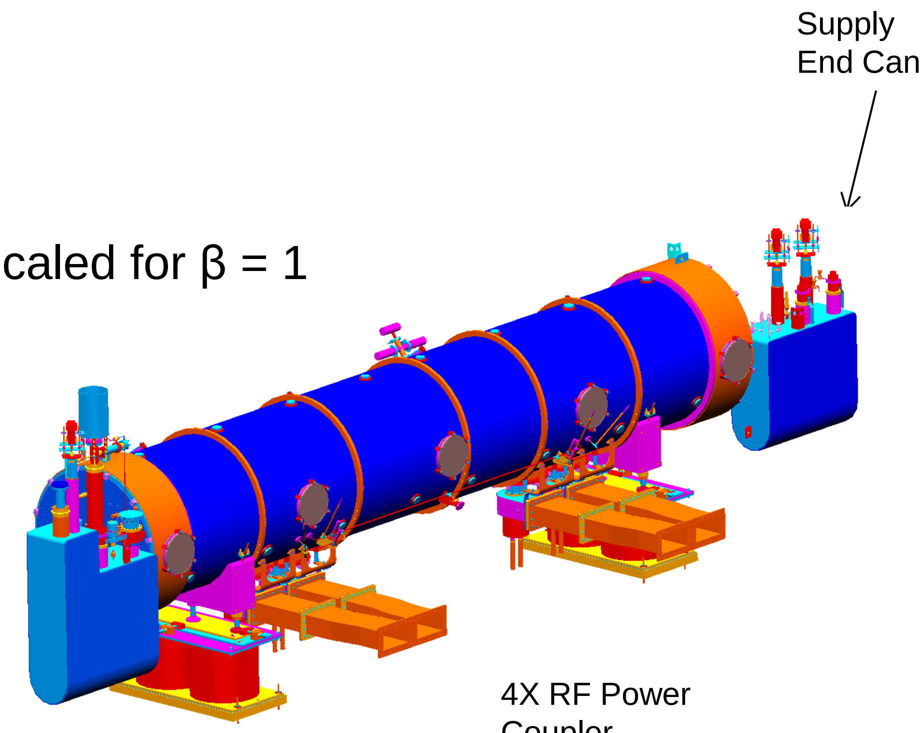
Proposal : SNS-Style Cryomodule
4 cavities per CM, 802.5 MHz

- Based on SNS CM
  - 5-cell Low Loss Shape
  - Coaxial Fundamental Power Coupler
  - Single RF Window
  - DESY-style HOM Couplers
  - Cold Tuner Drive

Scaled for β = 1

- Overall Length – 7.524 m
- Beamline Length – 6.705 m

- End Cans include integral heat exchanger for improved efficiency at 2K operations



Slide 35

Example of Low-Loss Cavity Parameters (805 MHz) to be modified for 802.5 MHz

- 0 degree wall angle
- Same shape for mid & end cell
- Could use SNS cryomodule
- N^2/k~3000, better than JLab-LL
- Assuming E_a=15MV/m, then E_p=36MV/m, B_p=50mT.
- Assume Rres~10nΩ at 2K, so Q_0~2.0e10, P_{loss}~12.6W at 15MV/m
- MP and HOM NOT investigated yet

Frequency [MHz]	805
Cavity inner diameter [mm]	316.7
Beam pipe diameter [mm]	75.74
Cavity total length [mm]	1165
Cavity active length [mm]	925.2
Ep/Ea	2.40
Bp/Ea [mT/(MV/m)]	3.34
Geometry factor [Ω]	288
Ra/Q [Ω]	764
Ra*Rs (=G*Ra/Q) [Ω^2]	2.20 x 10^5
Cell-to-cell coupling k	0.84%

SuperFish File of 5 cell cavity, frontend developed by herphase F = 804.99118 MHz