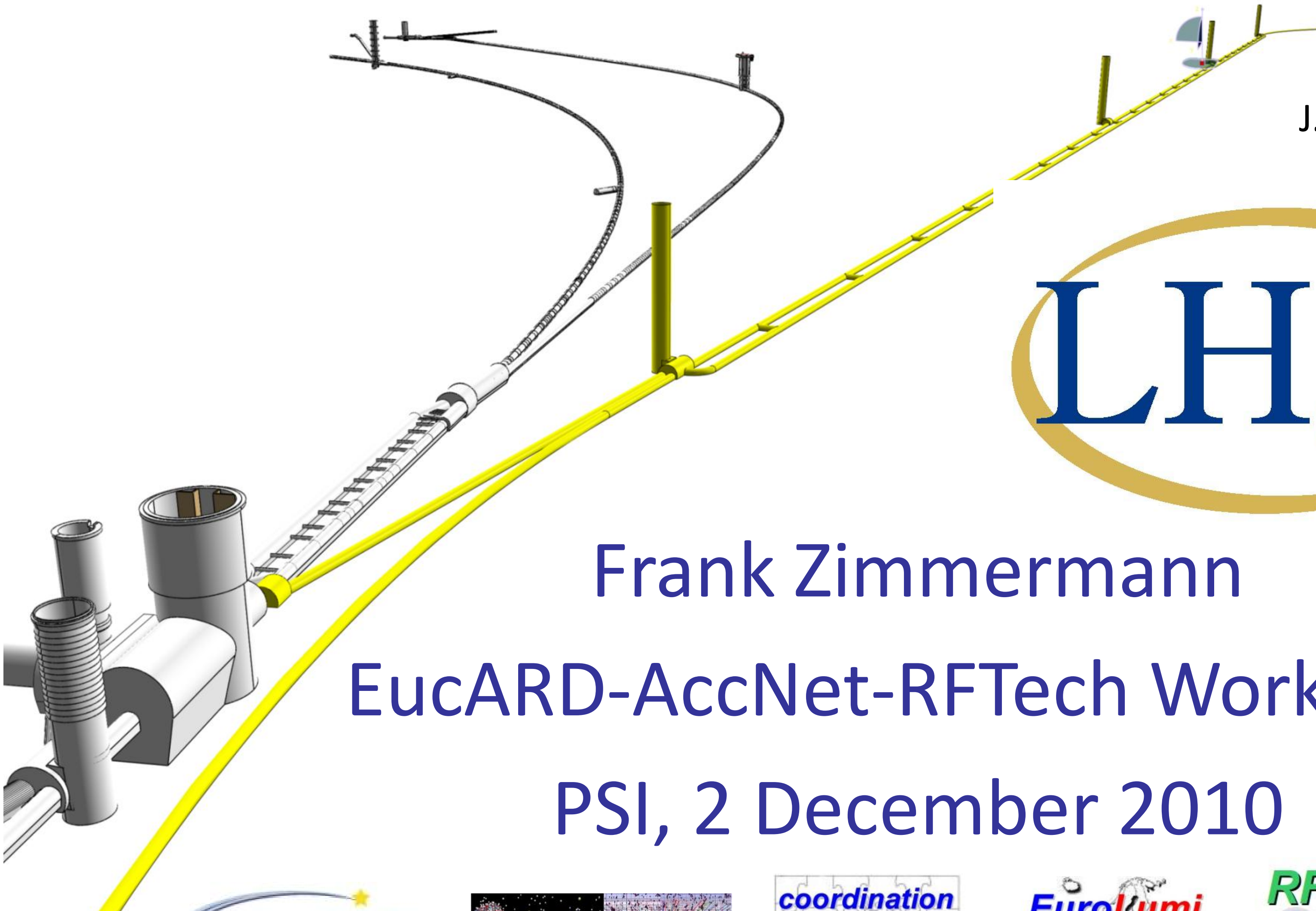
LHeC Linac-Ring Option



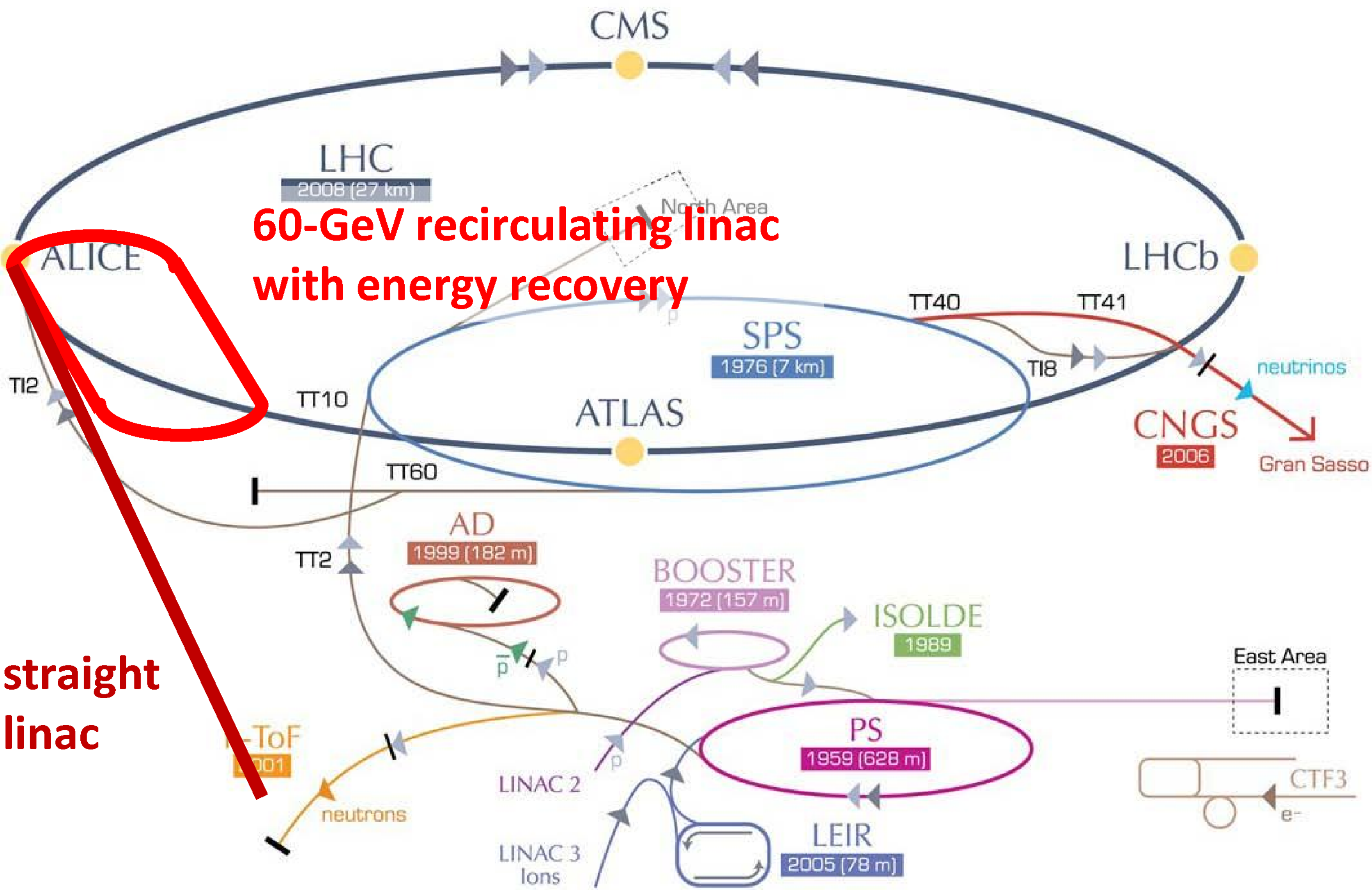
J. Osborne

Frank Zimmermann

EucARD-AccNet-RFTech Workshop

PSI, 2 December 2010

Linac-Ring LHeC – two options



performance targets

e- energy ≥60 GeV

luminosity ~10^{33} $cm^{-2}s^{-1}$

total electrical power for e-: ≤100 MW

$e^{+}p$ collisions with similar luminosity

simultaneous with LHC *pp* physics

e^{-}/e^{+} polarization

detector acceptance down to 1^{o}

getting all this at the same time is very challenging

road map to 10^{33} cm^{-2}s^{-1}

luminosity of LR collider:

(round beams)

$$L = \frac{1}{4\pi e}\frac{N_{b,p}}{\varepsilon_p}\frac{1}{\beta_p^*} I_e H_{hg}$$

highest proton
beam brightness “permitted”
(ultimate LHC values)

$\gamma\varepsilon$=3.75 μm

N_b=1.7x10^{11}

bunch spacing 25 or 50 ns

smallest conceivable
proton β* function:
- reduced *l** (23 m → 10 m)
- squeeze only one *p* beam
- new magnet technology *Nb_3Sn*

β*=0.1 m

average e$^-$ current !

maximize geometric
overlap factor
- head-on collision
- small e- emittance

θ_c=0

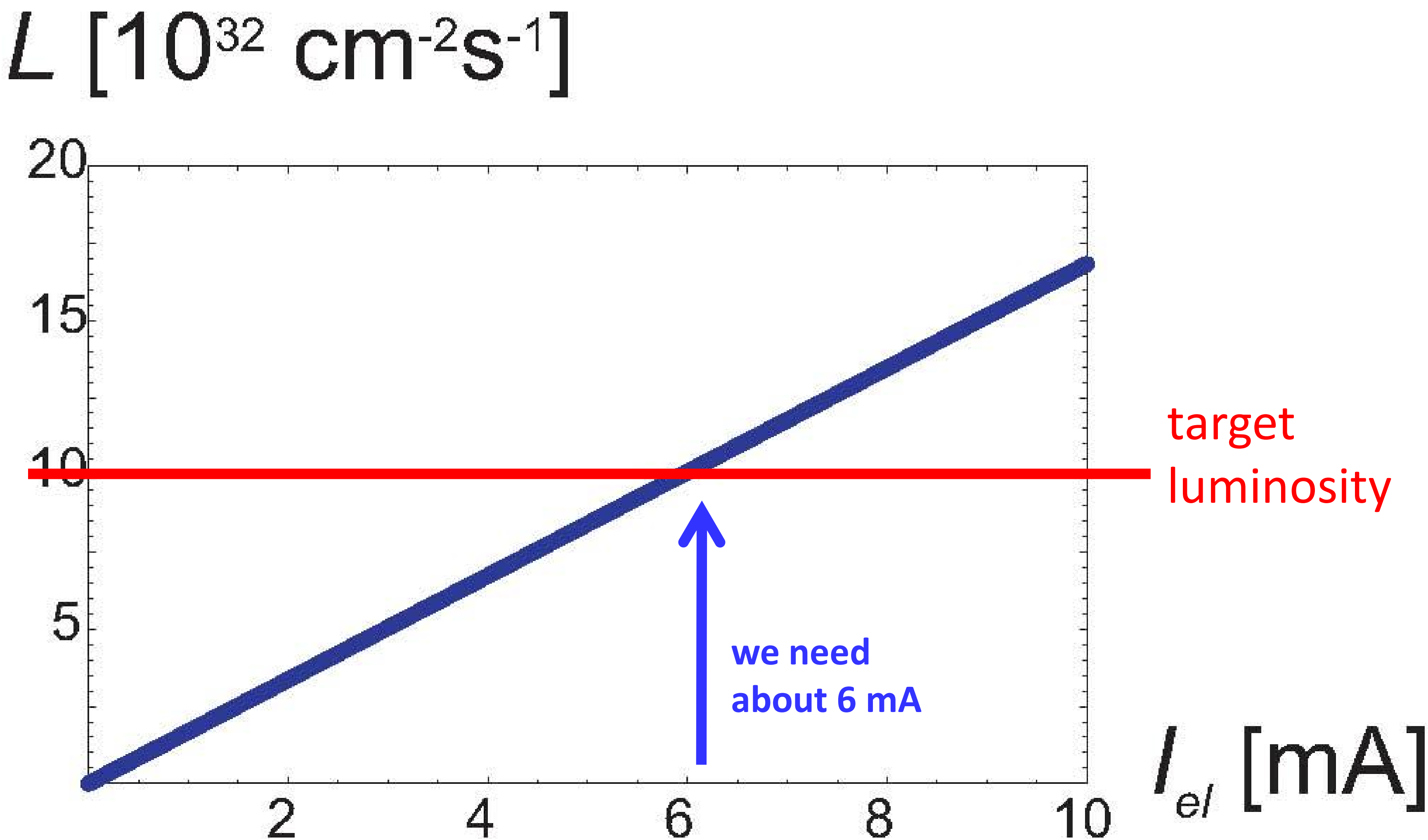
H_{hg}≥0.9

electron beam

e- emittances and β^* not critical
(protons are big, ~7μm!)

most important parameter:
average beam current

in addition: bunch structure
and polarization



CLIC main beam ~ 0.01 mA (factor 600 missing)

lowering voltage, raise bunch charge & rep rate → 0.06 mA (NIMA 2007)

CLIC drive beam (30 mA, but 2.37 GeV)

ILC design current ~ 0.05 mA (factor ~100 missing)

SC linacs can provide higher average current, e.g. by increasing the duty factor 10-100 times, or even running cw, at lower energy & lower gradient

example design average currents:

CERN HP-SPL: ~2.5 mA (50 Hz)
Cornell ERL ~100 mA (cw)
eRHIC ERL ~ 50 mA at 20 GeV (cw)

LHeC needs ~6 mA at 60 GeV

beam power

6.4 mA at 60 GeV

→ **384 MW beam power !**

→ **~800 MW electrical power !!??**

need for energy recovery!

power reduced by factor (1-η_{ERL})

→ **LHeC ERL high-luminosity baseline**

one more ingredient

choice of SC linac RF frequency:

1.3 GHz (ILC)?

~720 MHz?!

- requires less cryo-power (~2 times less from BCS theory); true difference ↔ residual resistance, [J. Tückmantel, E. Ciapala]
- better for high-power couplers? [O. Napoly]
  but the couplers might not be critical
- fewer cells better for trapped modes [J. Tückmantel]
- synergy with SPL, eRHIC and ESS

linac RF parameters

	ERL 720 MHz	ERL 1.3 GHz	Pulsed
duty factor	cw	cw	0.05
RF frequency [GHz]	0.72	1.3	1.3
cavity length [m]	1	~1	~1
energy gain / cavity [MeV]	18	18	31.5
R/Q [100 Ω]	400-500	1200	1200
Q_0 [10^{10}]	**2.5-5.0**	**2 ?**	**1**
power loss stat. [W/cav.]	5	<0.5	<0.5
power loss RF [W/cav.]	**8-32**	**13-27 ?**	**<10**
power loss total [W/cav.]	13-37 (!?)	13-27	11
"W per W" (1.8 k to RT)	700	700	700
power loss / GeV @RT [MW]	**0.51-1.44**	**0.6-1.1**	**0.24**
length / GeV [m] (*filling*=0.57)	97	97	56

ERL electrical site power

cryo power for two 10-GeV SC linacs: 28.9 MW

MV/m cavity gradient, 37 W/m heat at 1.8 K

700 “W per W” cryo efficiency

RFTech guidance requested!

RF power to control microphonics: 22.2 MW

10 kW/m (eRHIC), 50% RF efficiency

RF for SR energy loss compensation: 24.1 MW

energy loss from SR 13.2 MW, 50% RF efficiency

cryo power for compensating RF: 2.1 MW

1.44 GeV linacs

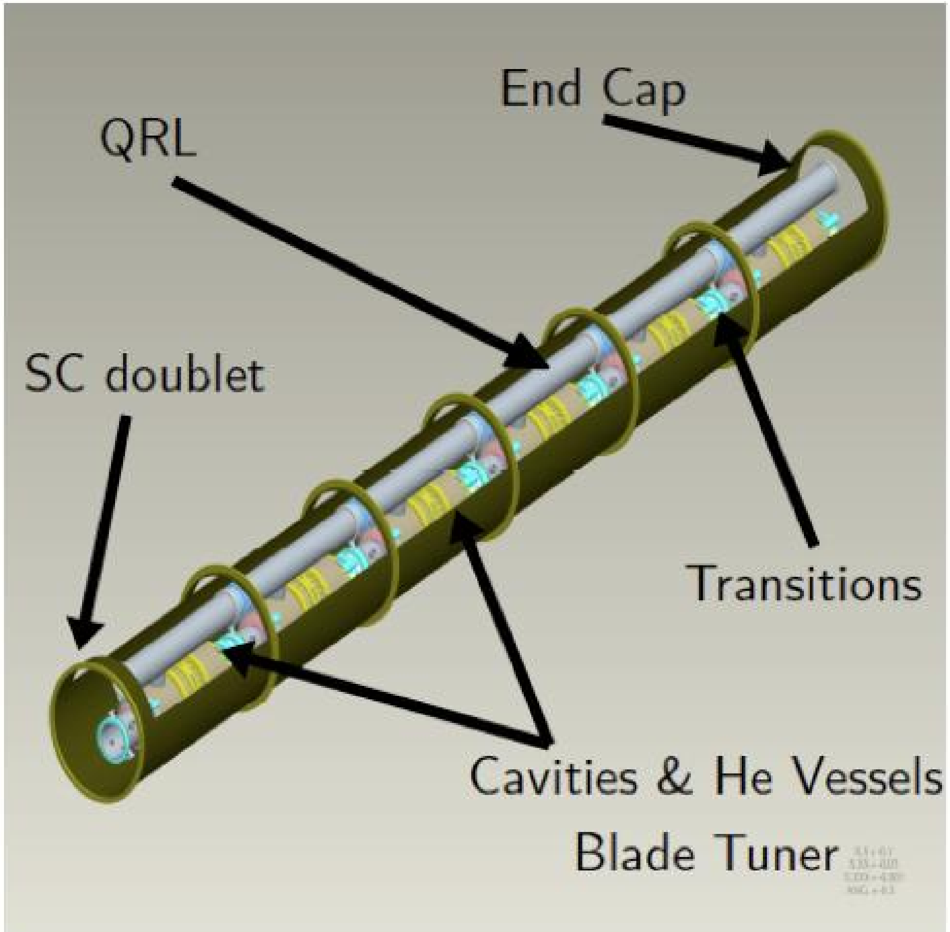
microphonics control for compensating RF: 1.6 MW

injector RF: 6.4 MW

500 MeV, 6.4 mA, 50% RF efficiency

magnets: 3 MW

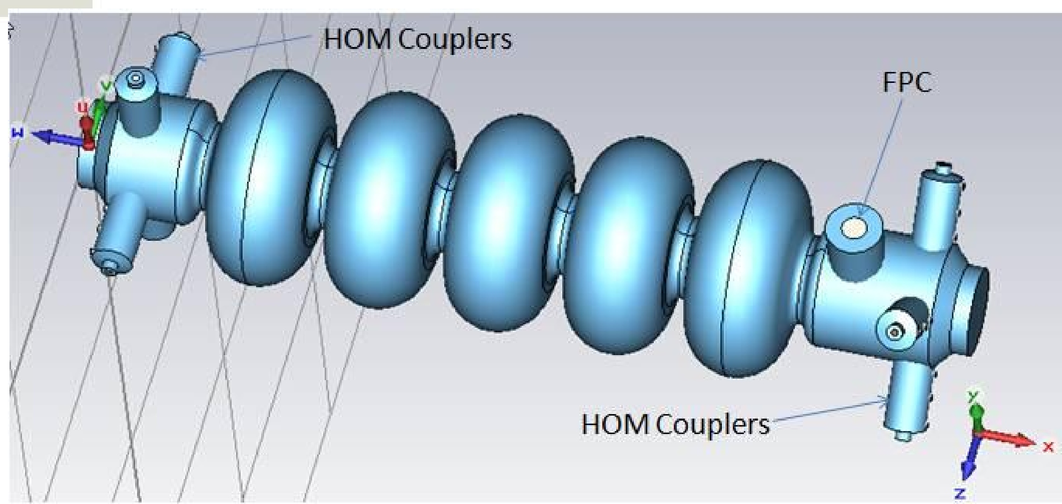
grand total = 88.3 MW



The eRHIC-type cryo-module containing six 5-cell SRF 703 MHz cavities.

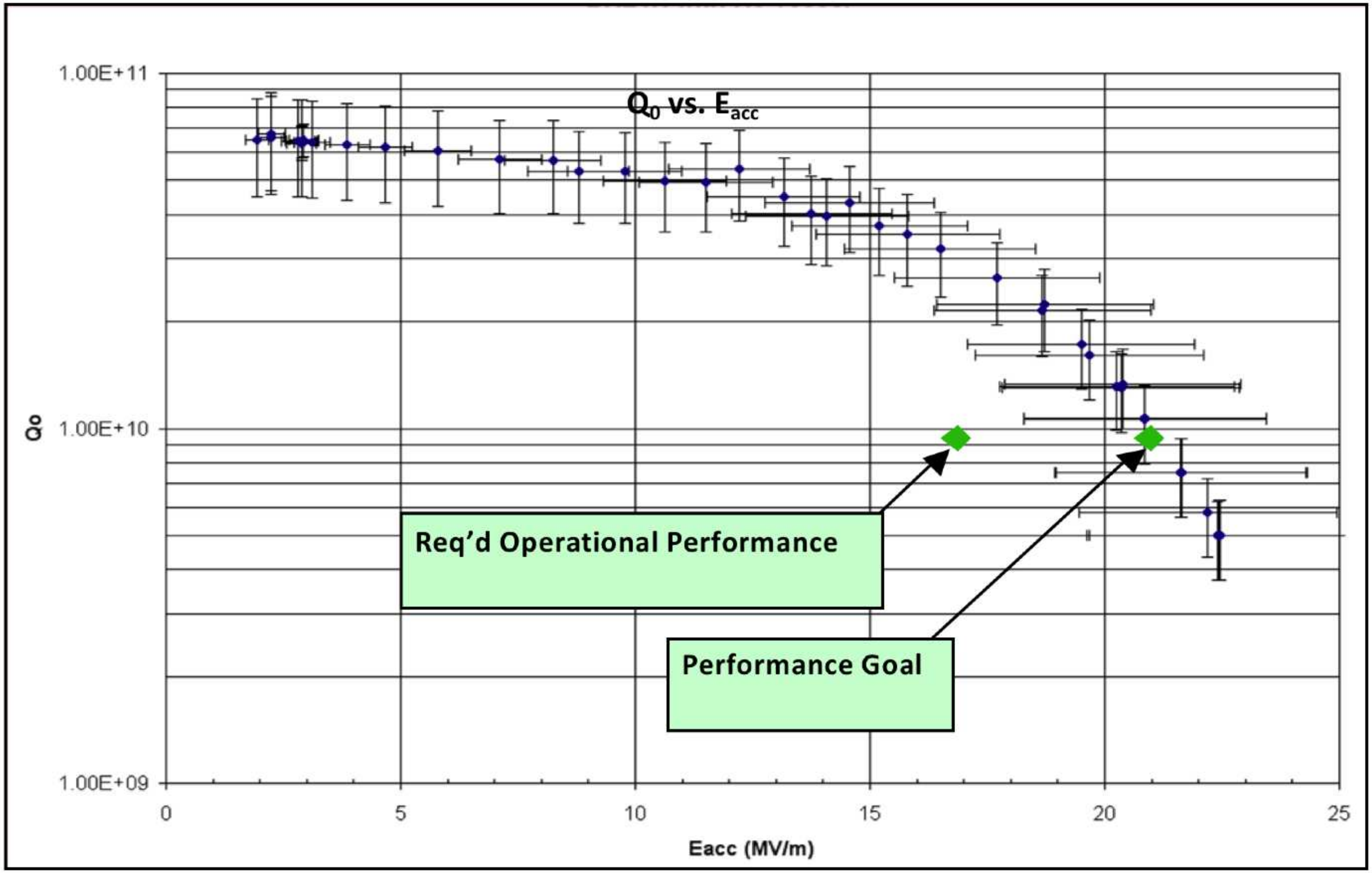
I. Ben-Zvi

Model of a new 5-cell HOM-damped SRF 703 MHz cavity.



measured Q vs. field for the 5-cell 704 MHz cavity built and tested (BNL -I)

I. Ben-Zvi



predicted cryopower based on eRHIC

I. Ben-Zvi

The relevant parameters for BNL-I cavity and for new 5-cell cavity upon which we based our calculations (BNL-III) are:

Parameter	Units	Value BNL-I	Value BNL-III
Geometry factor	Ohms	225	283
R/Q per cell	Ohms	80.8	101.3
Bpeak/Eacc	mT/MV/m	5.78	4.26

Calculation:

Assume Q vs. E as measured for BNL-I. Assume 18 MV/m operation. Assume losses scale with surface magnetic field.
For comparison with measured results, scale field by the magnetic field ratio of BNL-III to BNL-I, giving 13.3 MV/m.
The measured Q for BNL-I at this field is 4E10.
Assume losses scale down by the geometry factor, that leads to a **Q of 5E10. With this Q at 18 MV/m** the cryogenic load is **13 W/cavity at 1.8 K (instead of 37 W/cavity!)**

LHeC ERL RF system at 721 MHz

E. Ciapala, LHeC 2010

Energy = 3 * 20 GeV, 2 x 10 GeV Linacs, 6.6 mA, Take 721 MHz, to allow 25 ns bunches

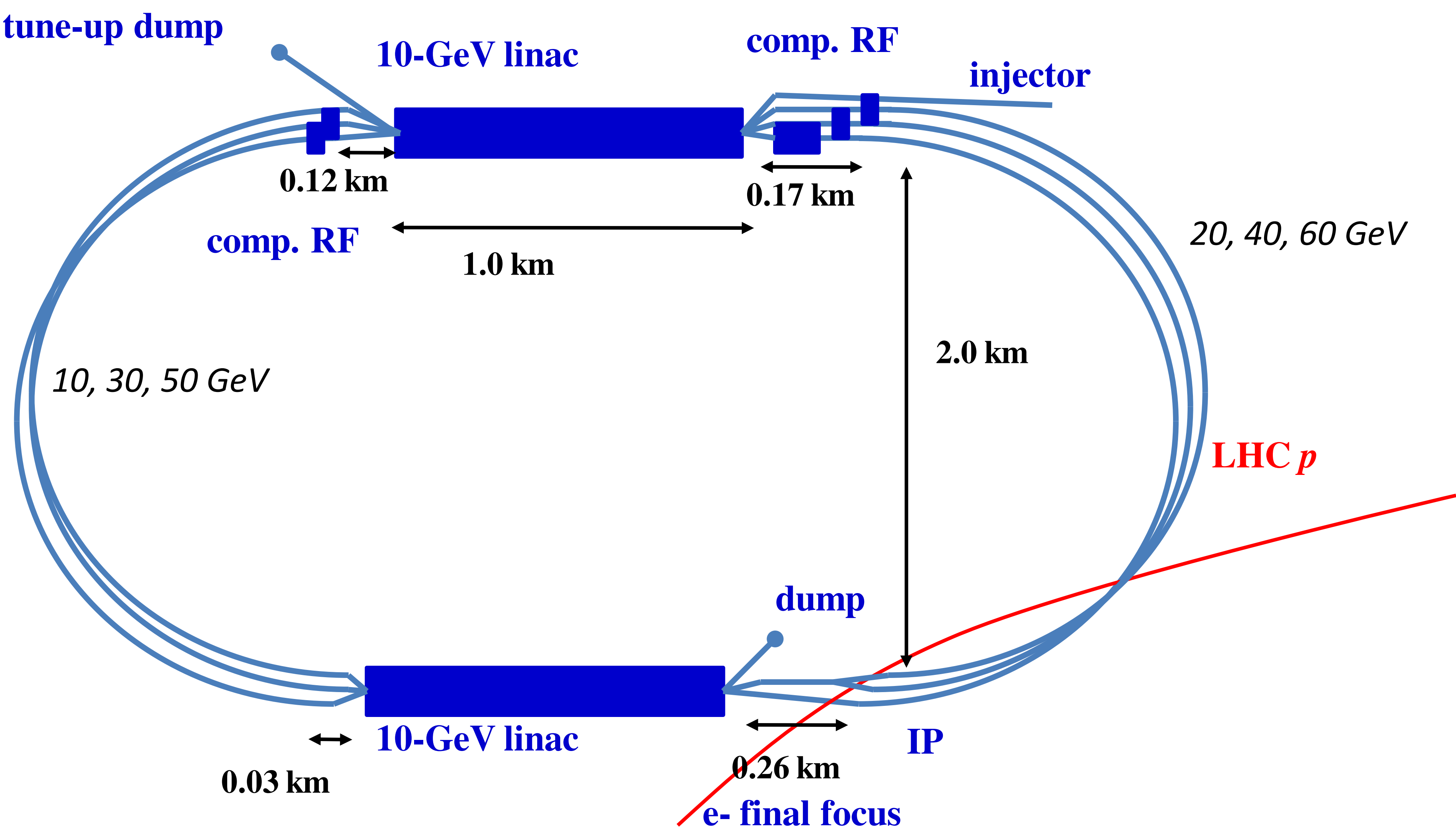
<u>Take SPL type cavity @18 MV/m</u> (similar to BNL design for eRHIC)

- 1.06 m/cavity => 19.1 MV/cav => 1056 cavities total (=132 x 8)
- Take **8 cavities in a 14 m cryomodule** (cf SPL) => **66 cryomodules/linac**

Total length = 924 m/linac + <u>margin ~10%</u>

- Power loss in arcs = 14.35 MW, 13.6 kW/cavity, Take P_{rf} = 20 kW/cavity with overhead for feedbacks, total installed RF 21 MW.
- **No challenge for power couplers, power sources – could be solid state**
- However, still **need adjacent gallery to house RF equipment** (high gradient = radiation !) 4-5 m diameter sufficient
- **Synchrotron radiation losses in arcs: Energy difference accelerated and decelerated beam**
- Can it be fully **compensated by adjusting phases in the linacs**, or do we need **re-accelerating 'mini'-linacs**? – Needs further study
- <u>Question</u> Could **hardware prototyping** be initiated, on SC cavities, - **good synergy with SPL Proton driver study** which is well underway, **test of ERL concept** at CERN ?

ERL configuration



total circumference ~ 8.9 km

ERL component lengths

10-GeV linac length: 1008 m

cavity length 1 m, 56 m long FODO cell with 32 cavities, #cavities/linac = 576, cavity filling factor = 57.1%

effective arc radius = 1000 m

bending radius = 764 m, dipole filling factor = 76.4% (A. Bogacz)

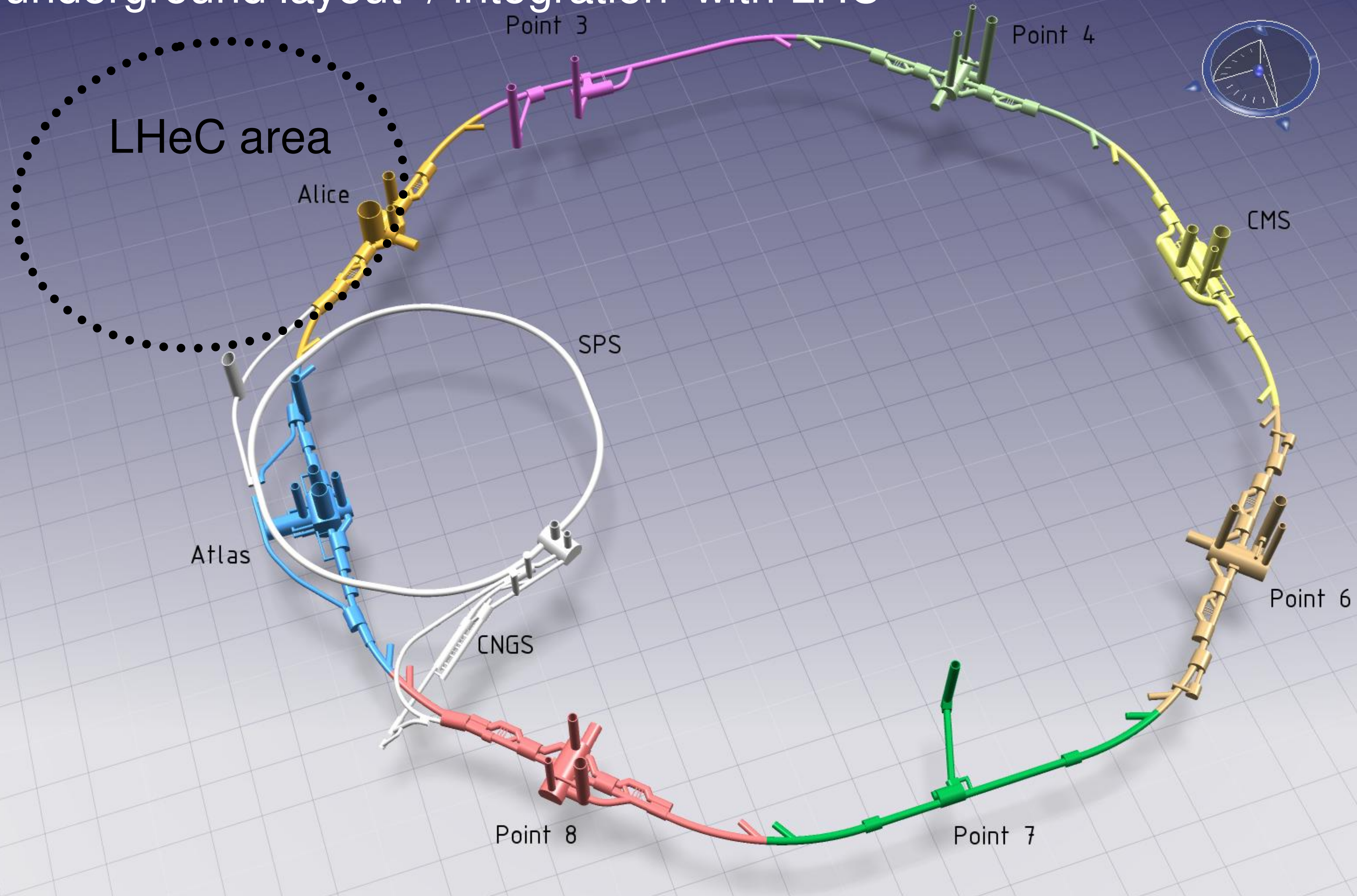
SRF compensation linac: maximum 84 m [at 60 GeV]

combiners & splitters: 20-30 m each

e- final focus: 200-230 m (R. Tomas)

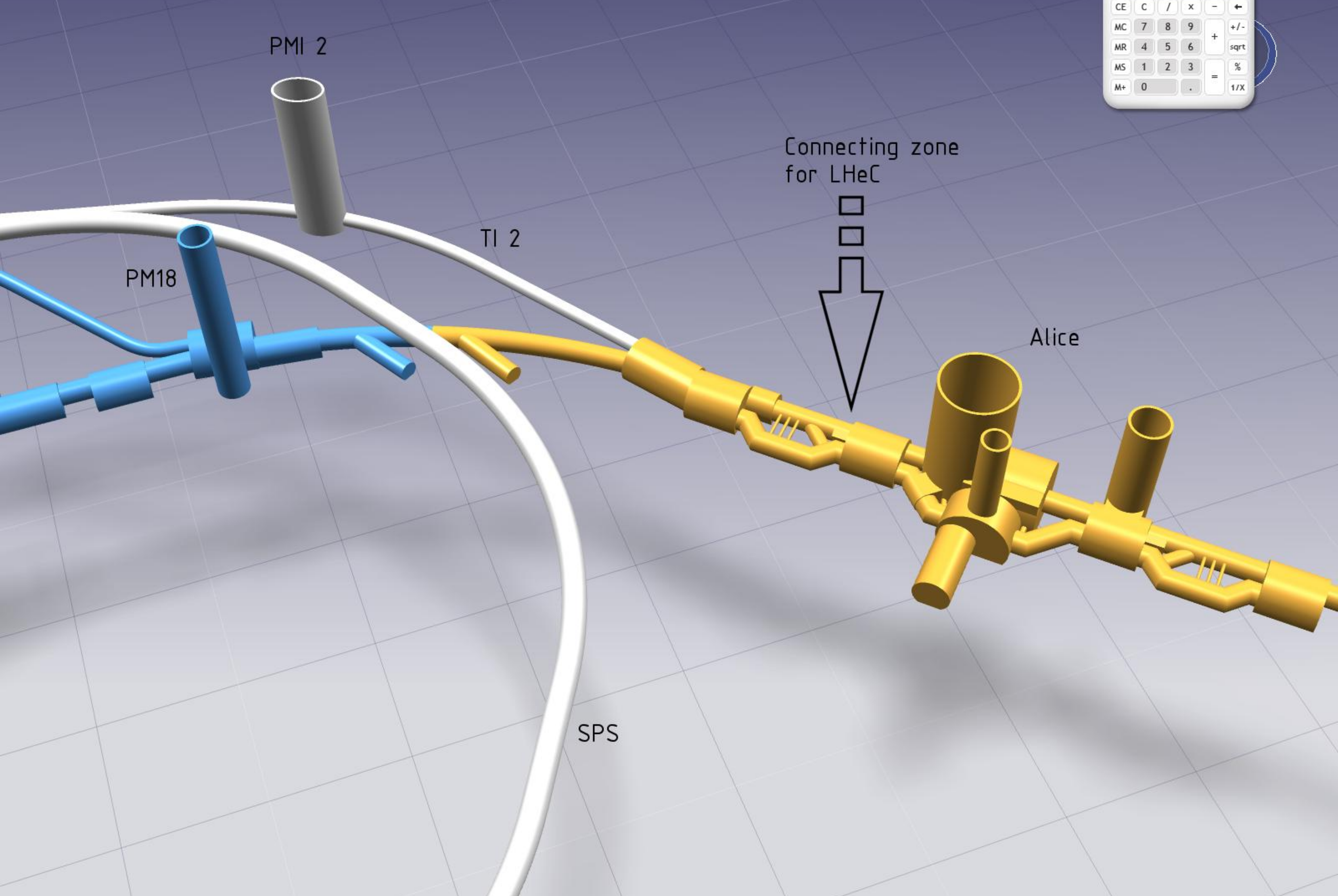
total circumference = LHC circumference / 3 (D. Schulte)

underground layout / integration with LHC



J.Osborne / A.Kosmicki CERN/GS

underground layout / integration with LHC



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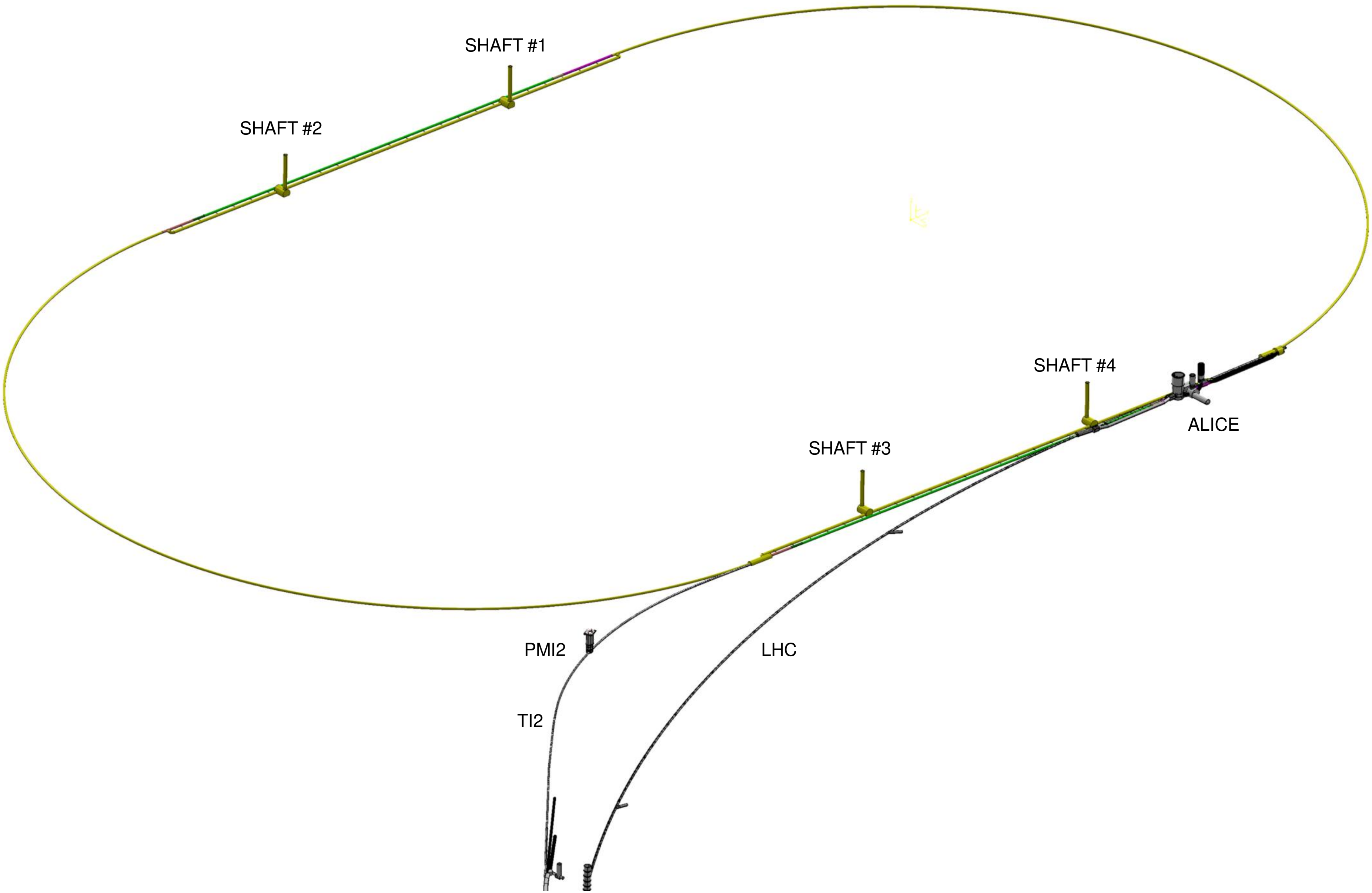

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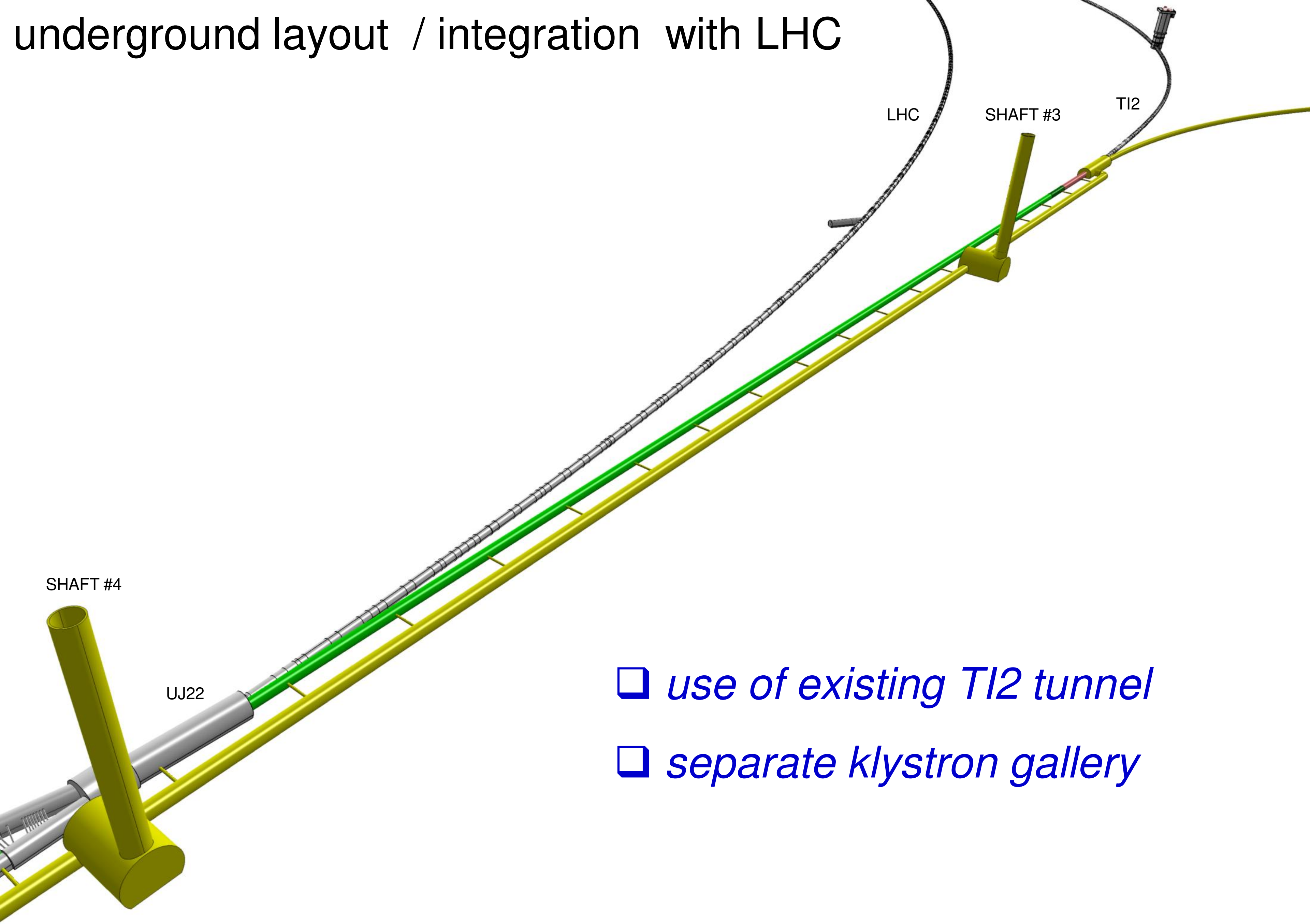


- use of existing TI2 tunnel
- separate klystron gallery

J.Osborne / A.Kosmicki CERN/GS

IP parameters

	protons	electrons
beam energy [GeV]	7000	60
Lorentz factor γ	7460	117400
normalized emittance $\gamma\varepsilon_{x,y}$ [μm]	3.75	50
geometric emittance $\varepsilon_{x,y}$ [nm]	0.50	0.43
IP beta function $\beta^*_{x,y}$ [m]	0.10	0.12
rms IP beam size $\sigma^*_{x,y}$ [μm]	7	7
rms IP divergence $\sigma'_{x,y}$ [μrad]	70	58
beam current [mA]	≥430	6.6
bunch spacing [ns]	25 or 50	50
bunch population	$1.7\text{x}10^{11}$	$2\text{x}10^{9}$
crossing angle	0.0	

beam-beam effects

protons

- **head-on tune shift:** ΔQ=0.0001 ***tiny***
- **long-range effect:** ***none***

  36 σ_p separation at s=3.75 m
- **emittance growth** due to **e-beam position jitter**

  p kick 10 nrad (~$10^{-4}\sigma^{*\prime}$) for 1σ offset,

  e- turn-to-turn random orbit jitter ≤ 0.04σ

  [scaled from K. Ohmi, PAC’07;
  see also D. Schulte, F. Zimmermann, EPAC2004]

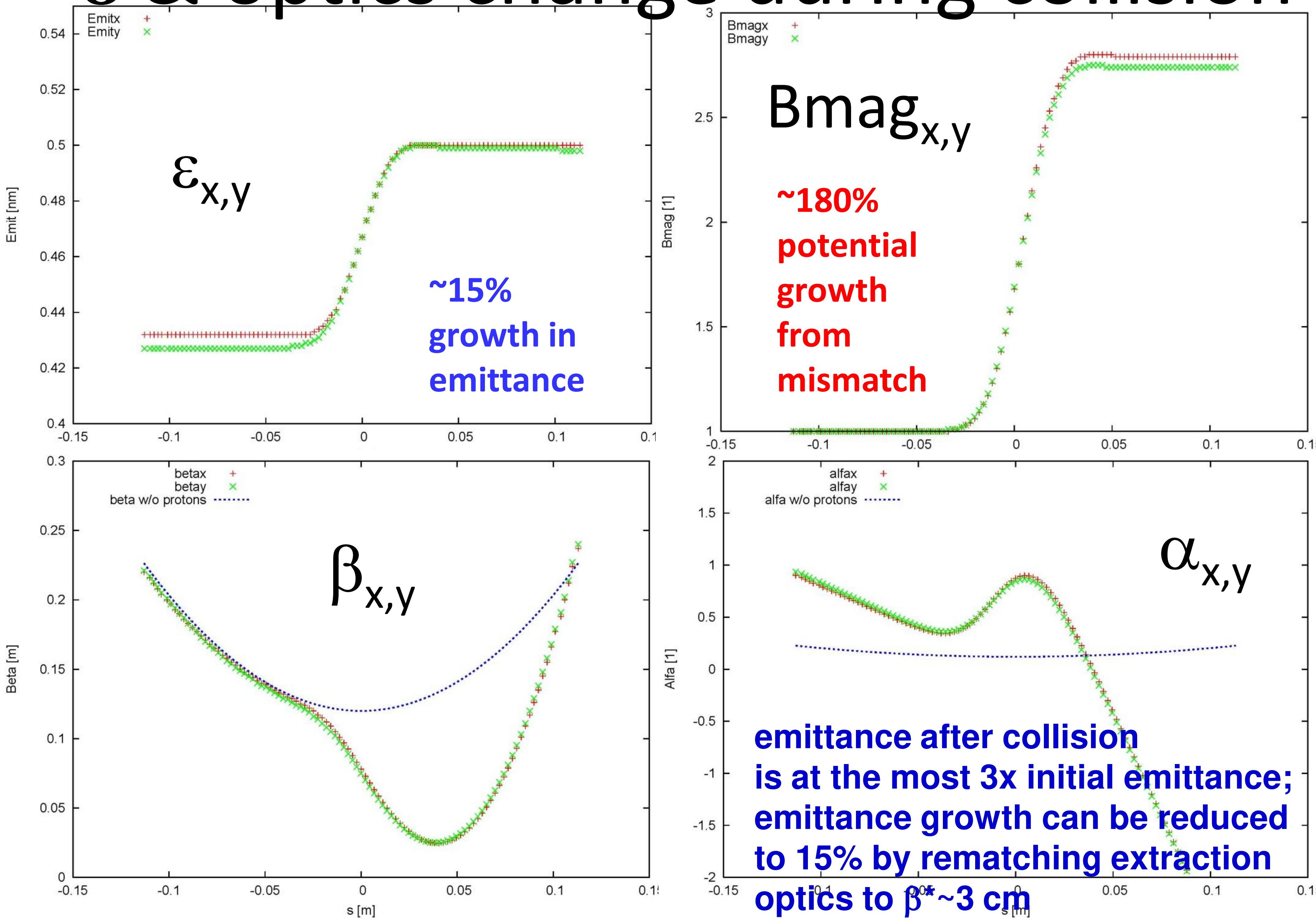
can we achieve this stability?

electrons

- **disruption**

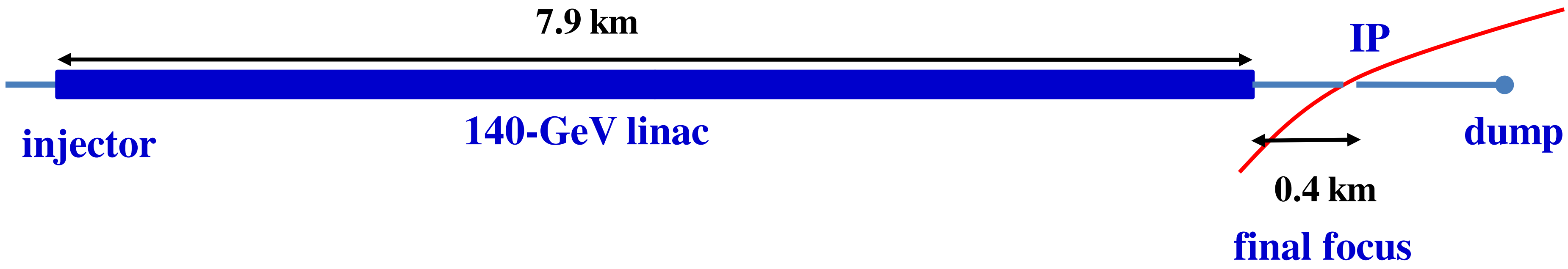
  $D_{x,y}$≈6, θ_0≈600 µrad (≈10$\sigma^{*\prime}$) ***large***

ε & optics change during collision



emittance after collision is at the most 3x initial emittance; emittance growth can be reduced to 15% by rematching extraction optics to β^*~3 cm

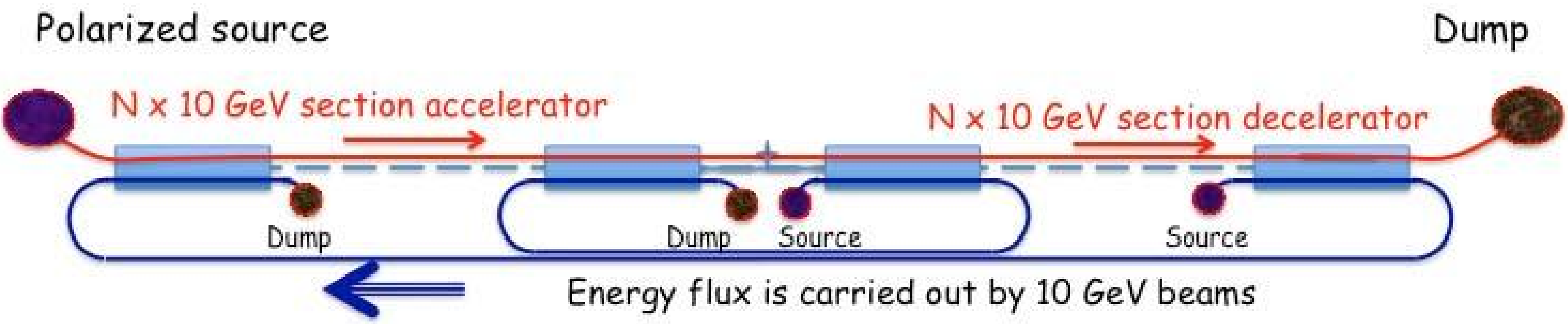
pulsed linac for 140 GeV



- linac could be ILC type (1.3 GHz) or 720 MHz
- cavity gradient: 31.5 MV/m, Q=10^{10}
- extendable to higher beam energies
- no energy recovery
- with 10 Hz, 5 ms pulse, H_g=0.94, N_b=1.5x10^9 :
  $\langle I_e \rangle$=0.27 mA → $L \approx 4 \times 10^{31}$ cm^{-2}s^{-1}

highest-energy LHeC ERL option

high energy e- beam is not bent; could be converted into LC?



High luminosity LHeC with nearly 100% energy efficient ERL.
The main high-energy e- beam propagates from left to right.
In the 1st linac it gains ~150 GeV (N=15), collides with the hadron beam and is then decelerated in the second linac.
Such ERL could push LHeC luminosity to 10^{35} cm^{-2}s^{-1} level.

this looks a lot like CLIC 2-beam technology

V. Litvinenko,
2nd LHeC workshop
Divonne 2009

summary

ERL (60 GeV):
10^{33} $cm^{-2}s^{-1}$, <100 MW, < 9 km circumference,
about 21 GV RF

pulsed linac (140 GeV)
$4x10^{31}$ $cm^{-2}s^{-1}$, <100 MW, < 9 km length,
with γ-p option

high polarization possible, beam-beam benign,
e+ difficult

questions to RFTech experts

LHeC ERL: 721 MHz or 1.3 GHz?

Cryo power (heat load at 1.8 K in cw)?

Power to control microphonics?

Linac position jitter?

contributors

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many thanks for your attention!