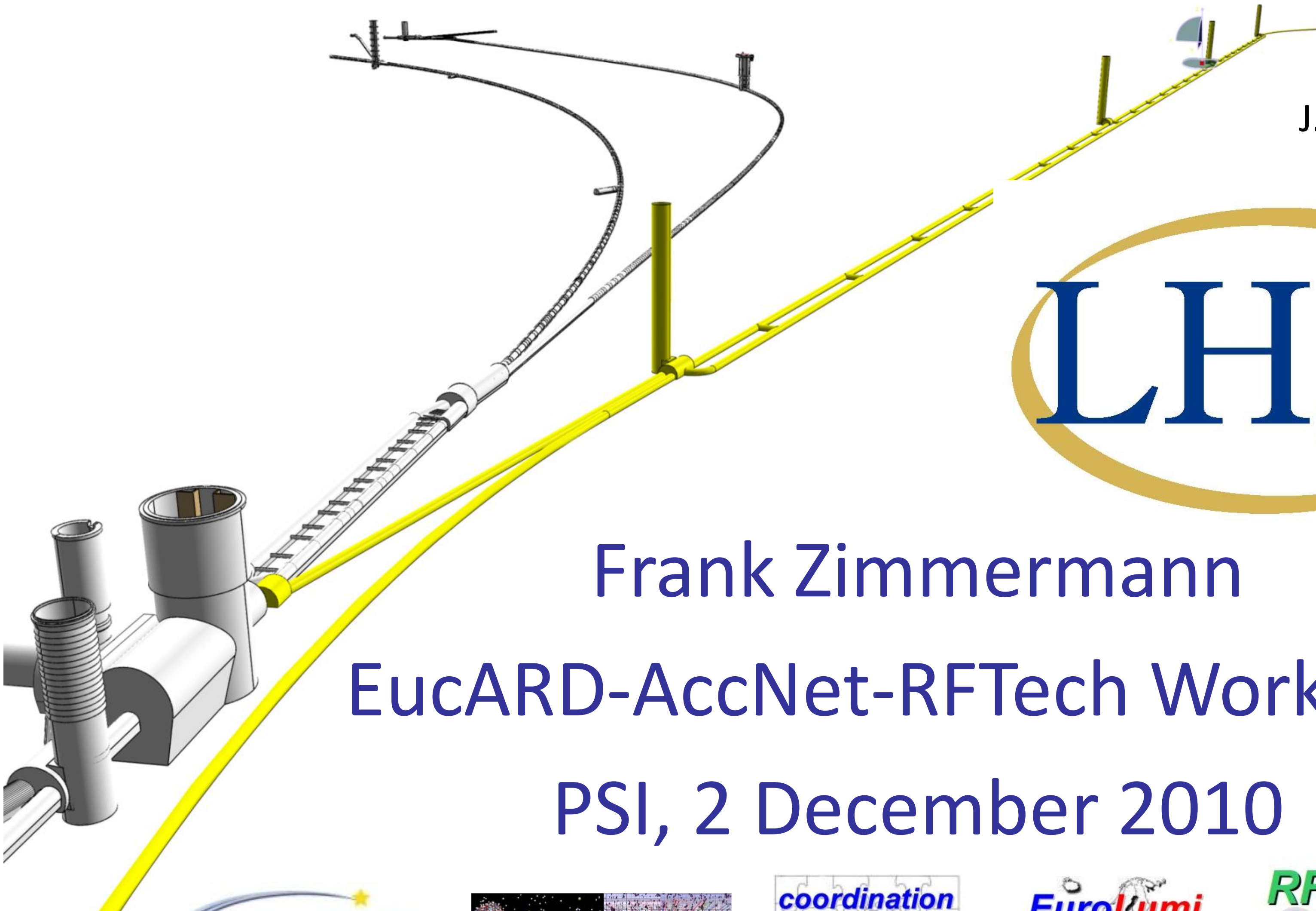
LHeC Linac-Ring Option



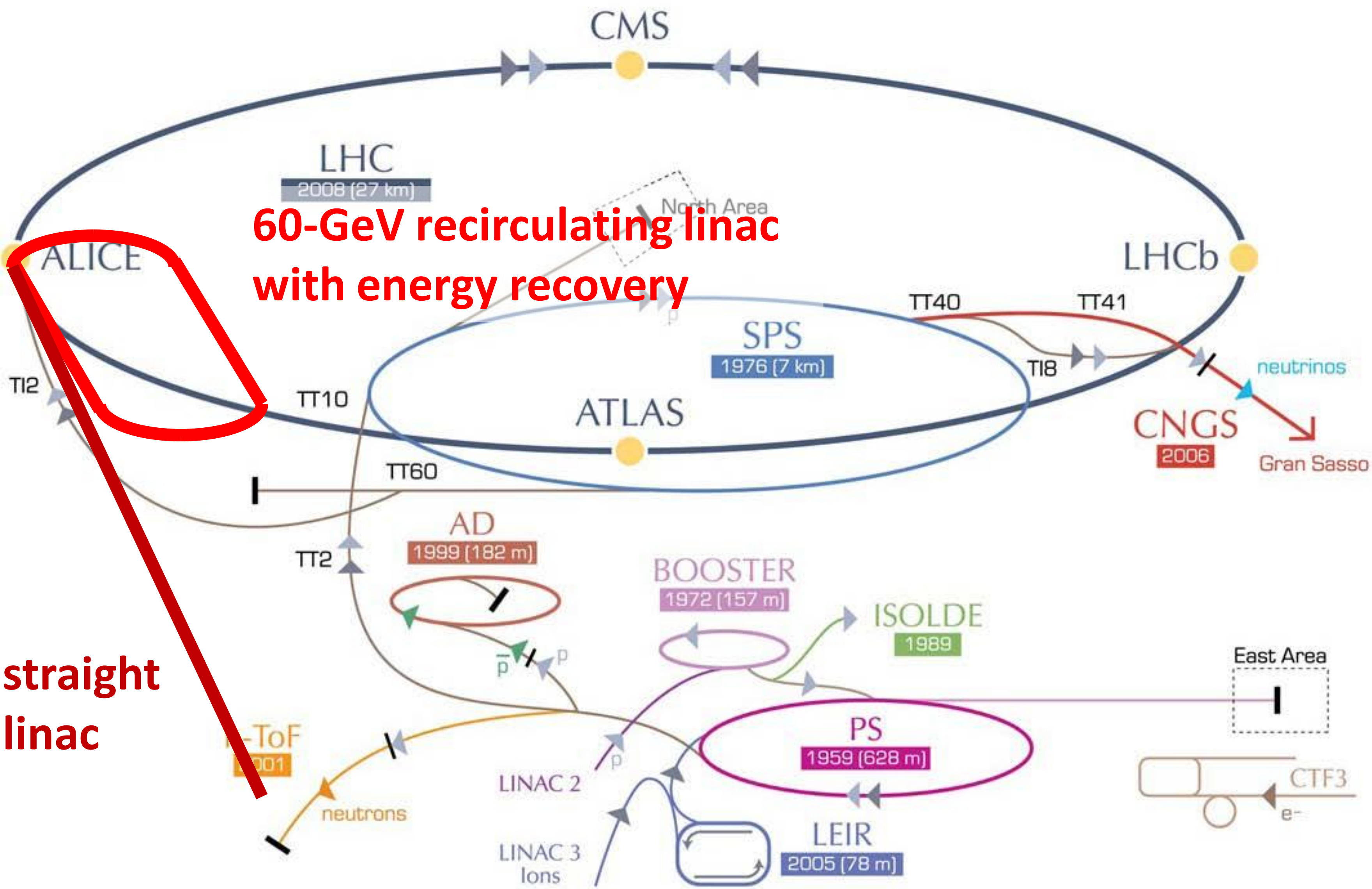
J. Osborne

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

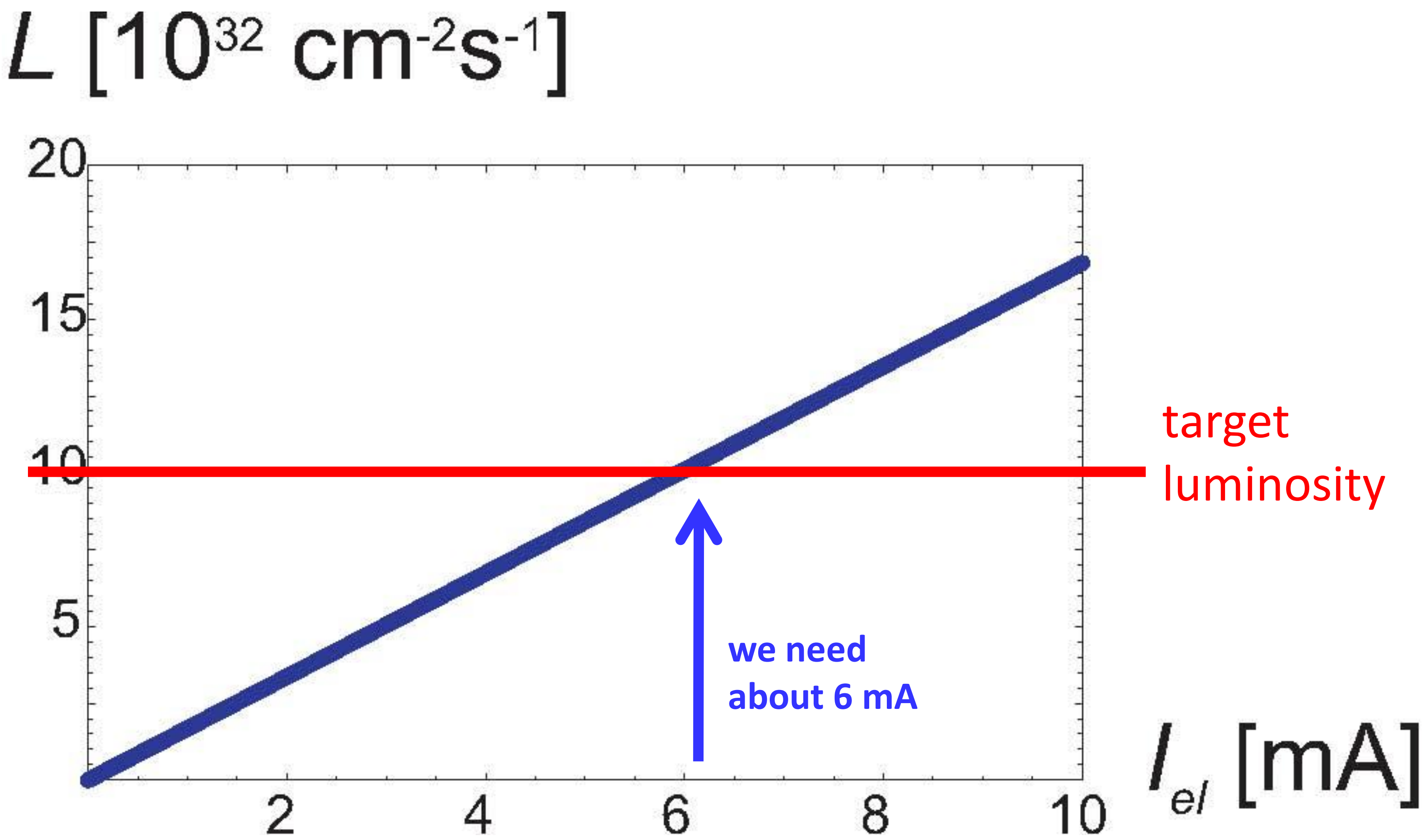
H_{hg}≥0.9

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 $(1-\eta_{ERL})$

→ **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

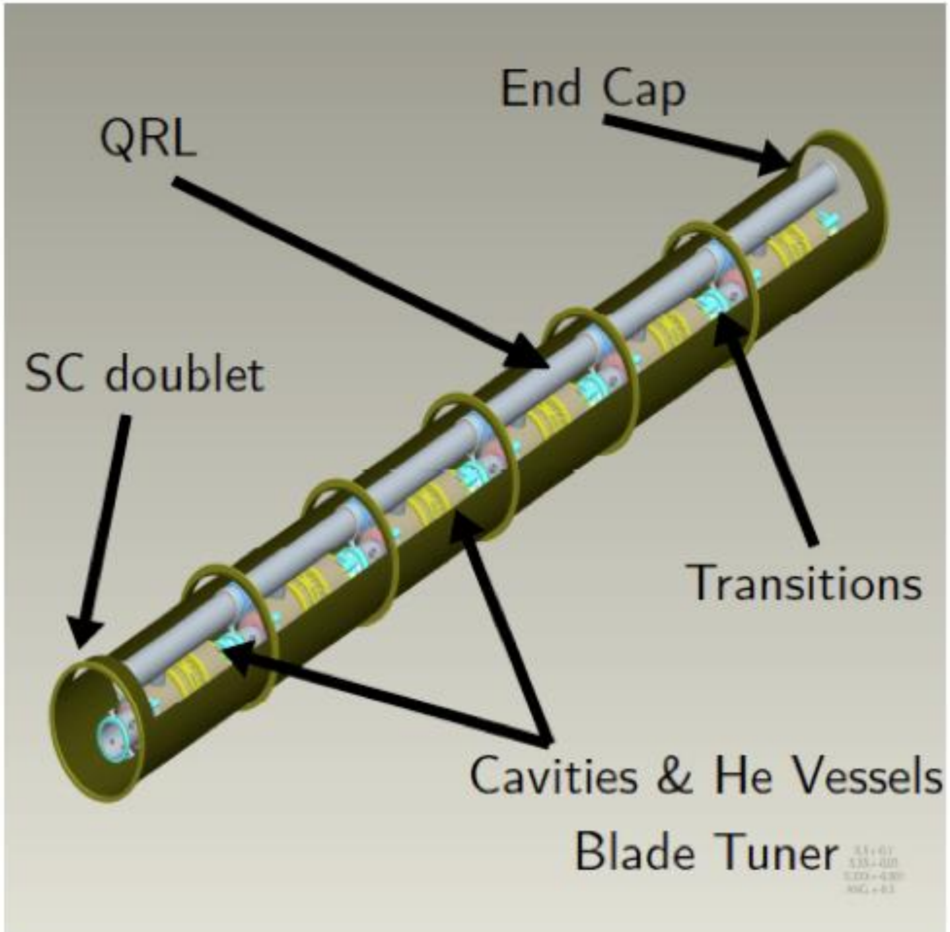
microphonics control for compensating RF: 1.6 MW

injector RF: 6.4 MW

500 MeV, 6.4 mA, 50% RF efficiency

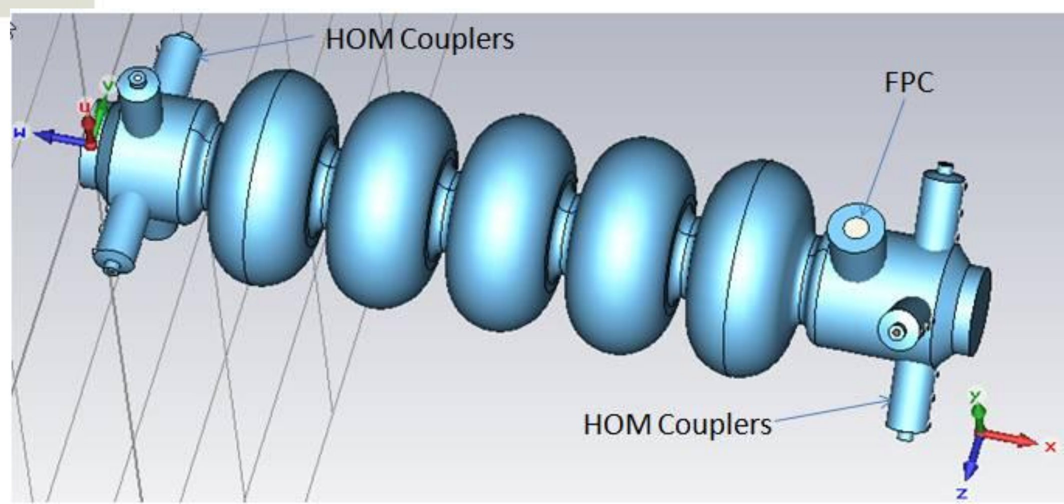
magnets: 3 MW

grand total = 88.3 MW



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

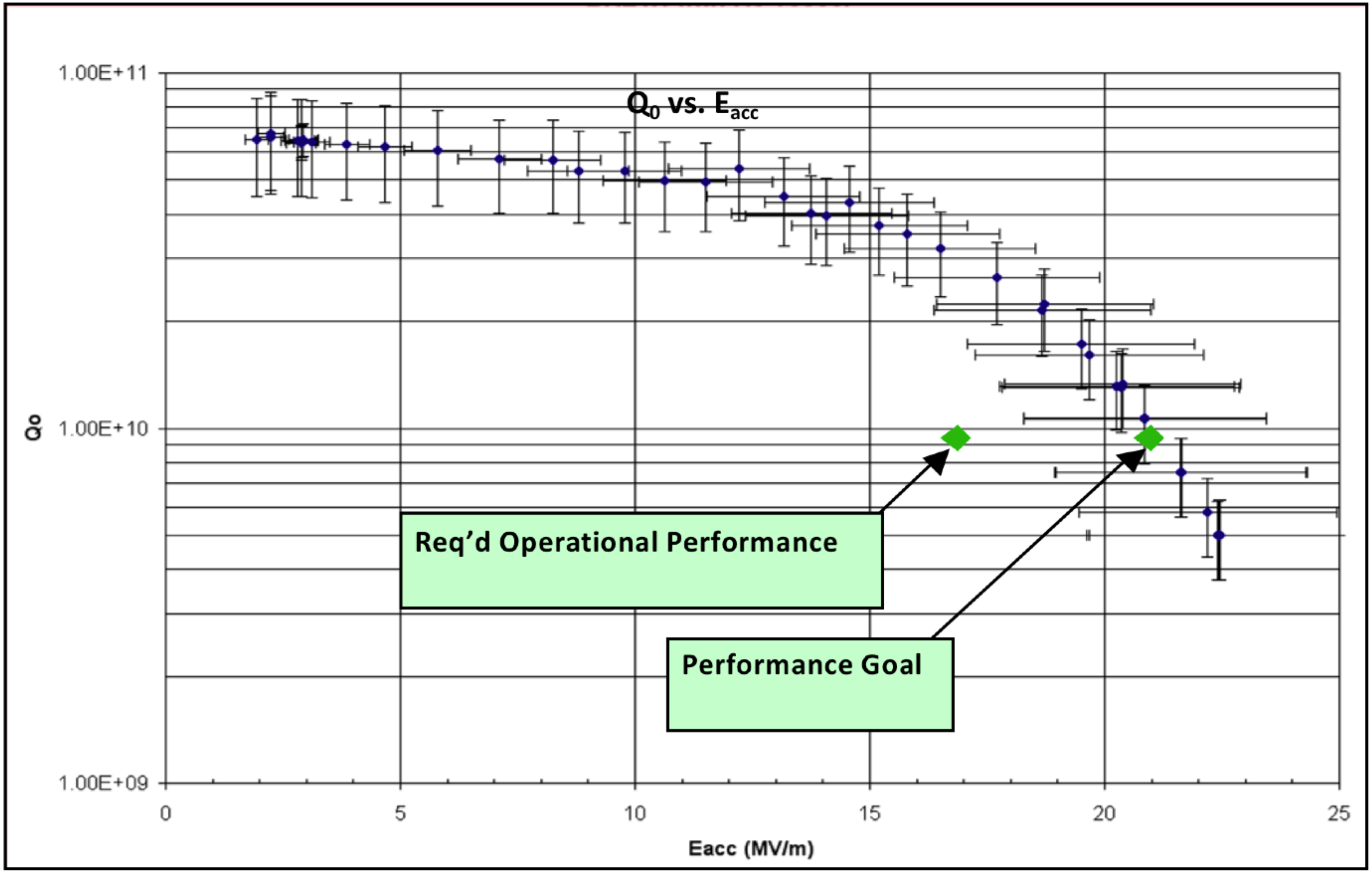
I. Ben-Zvi



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

<u>Calculation:</u>

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

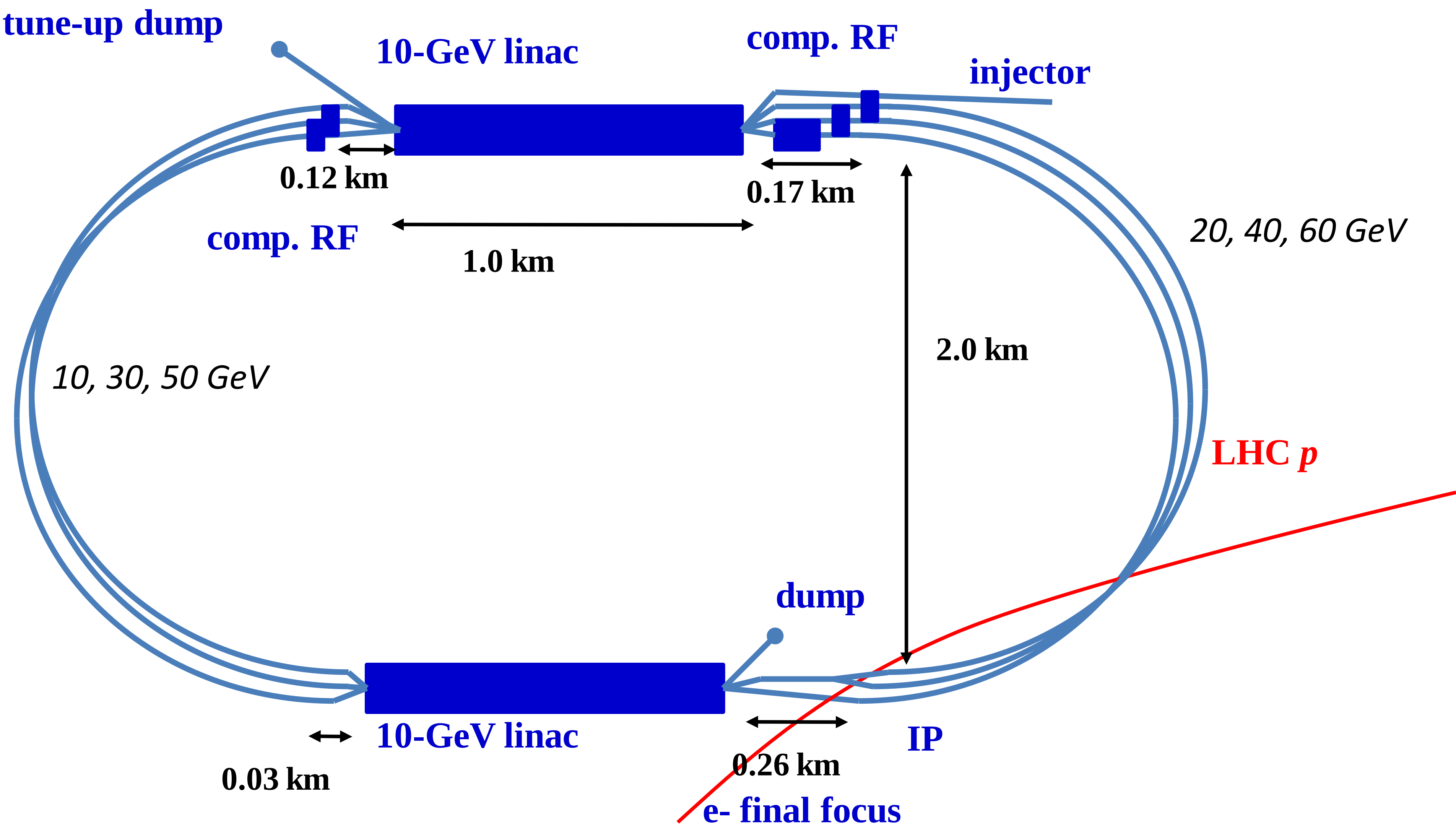
Take SPL type cavity @18 MV/m (similar to BNL design for eRHIC)

- 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 + margin ~10%

- 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
- Question 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)

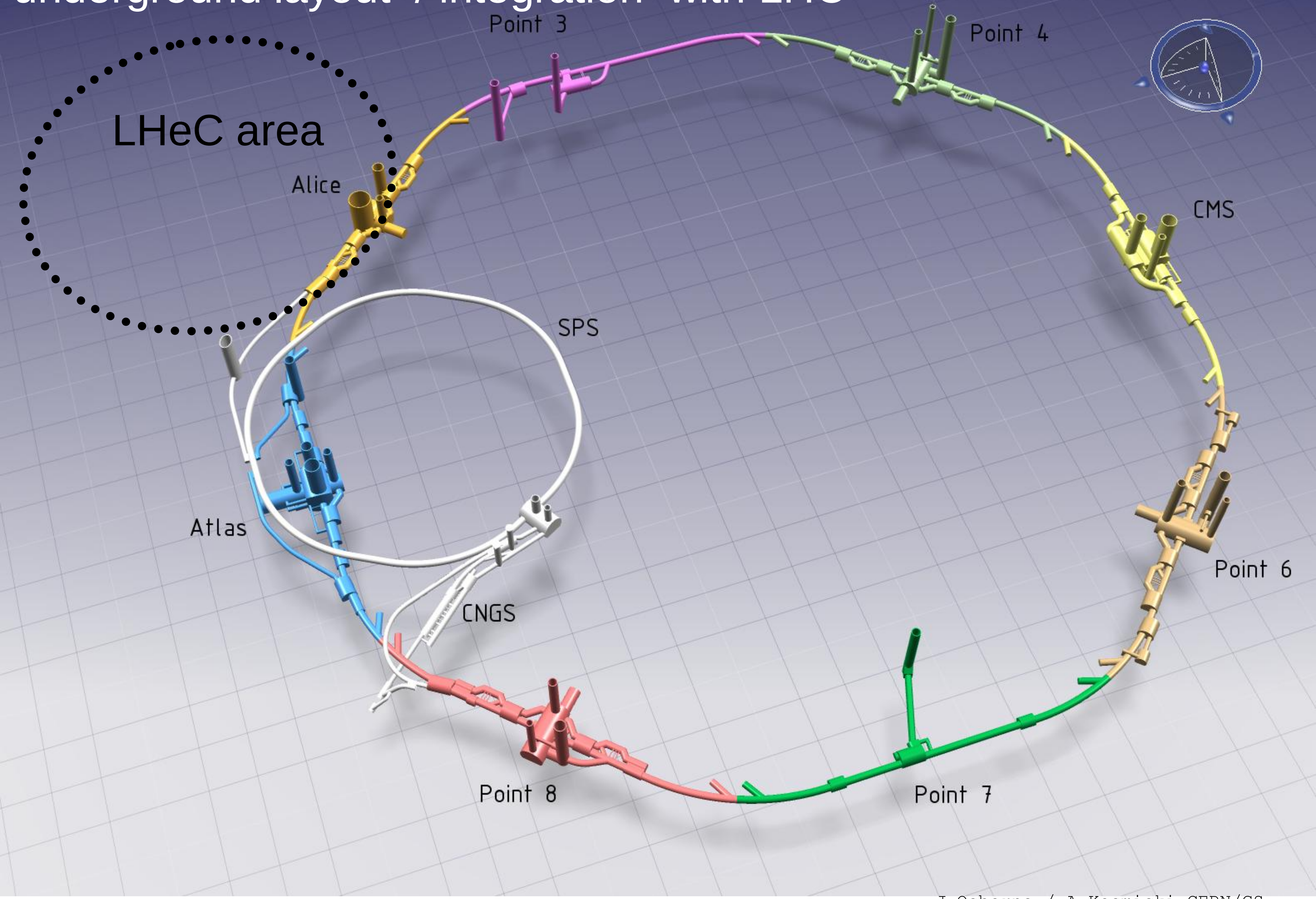
SRF compensation linac: maximum 84 m [at 60 GeV]

combiners & splitters: 20-30 m each

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

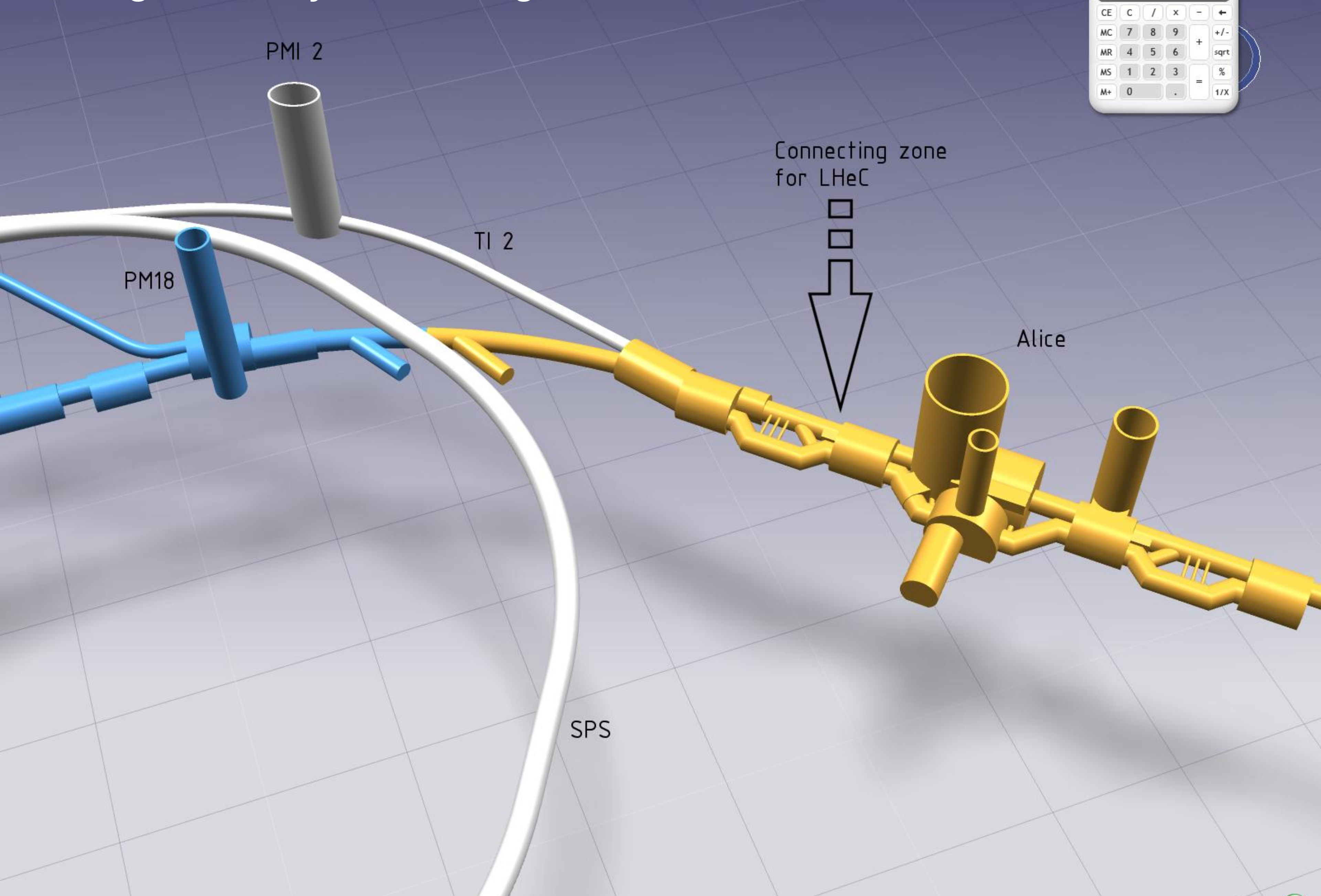
total circumference = LHC circumference / 3 (D. Schulte)

underground layout / integration with LHC



J.Osborne / A.Kosmicki CERN/GS

underground layout / integration with LHC



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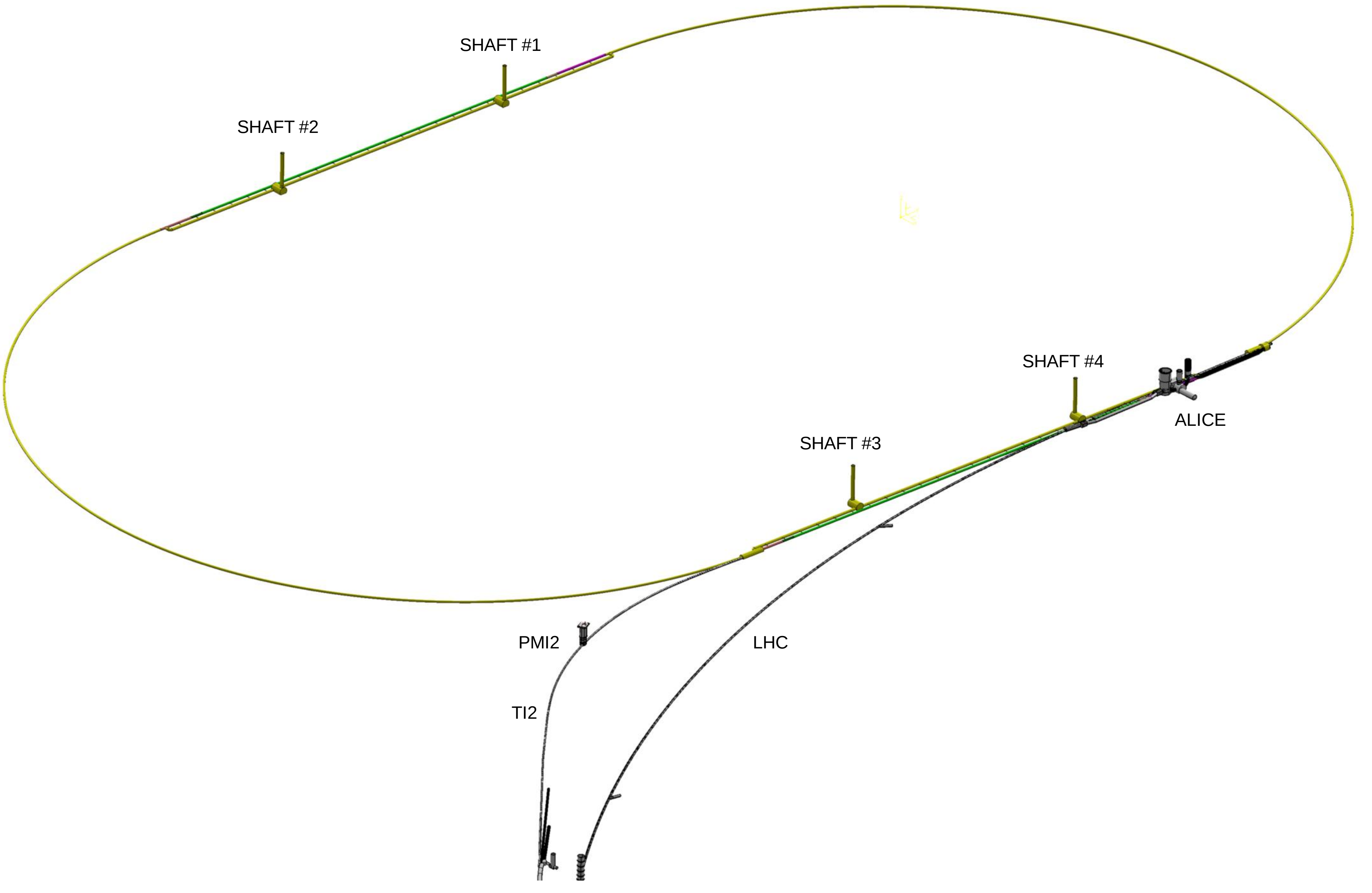

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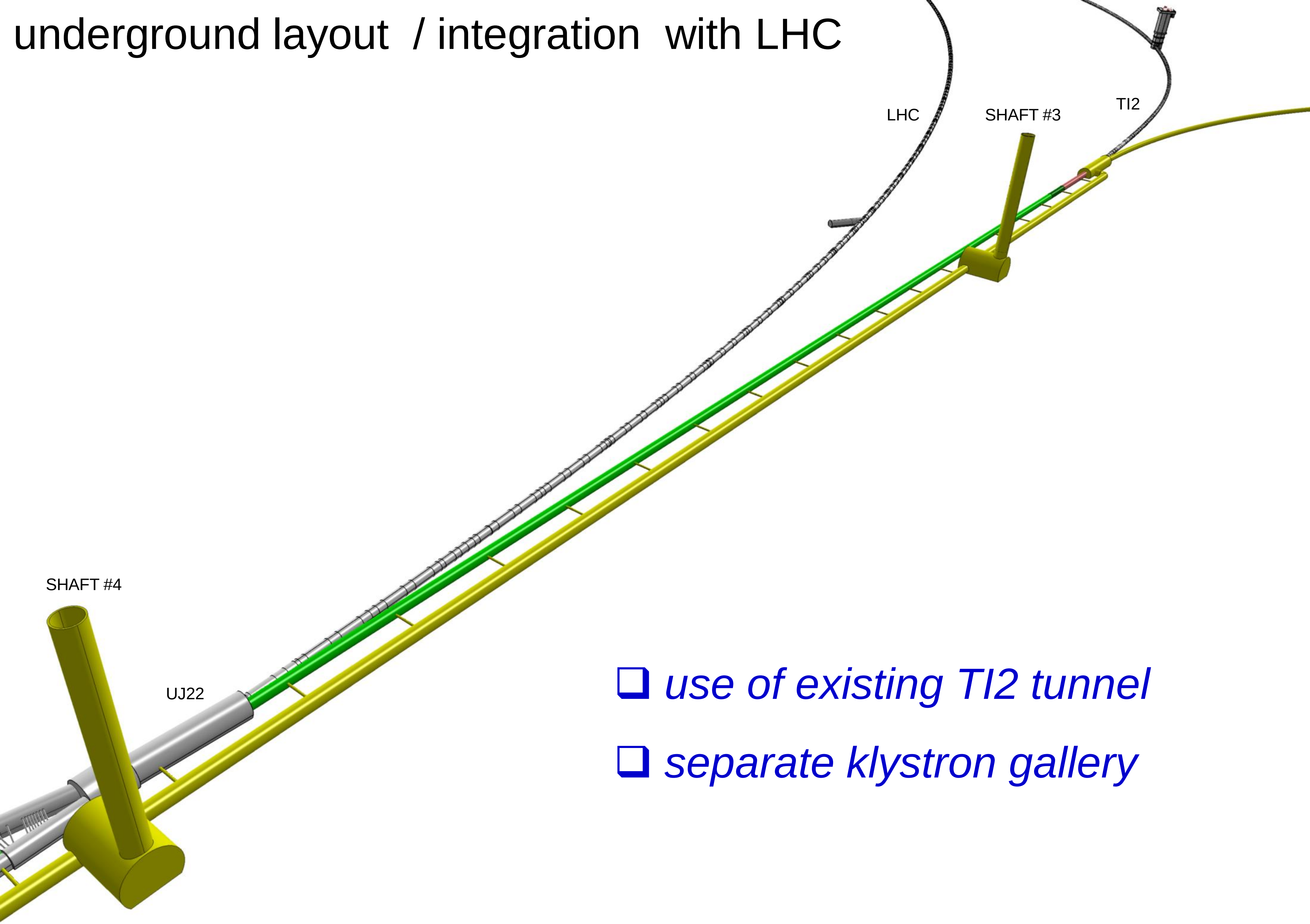


- *use of existing TI2 tunnel*
- *separate klystron gallery*

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	1.7×10^{11}	2×10^{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]

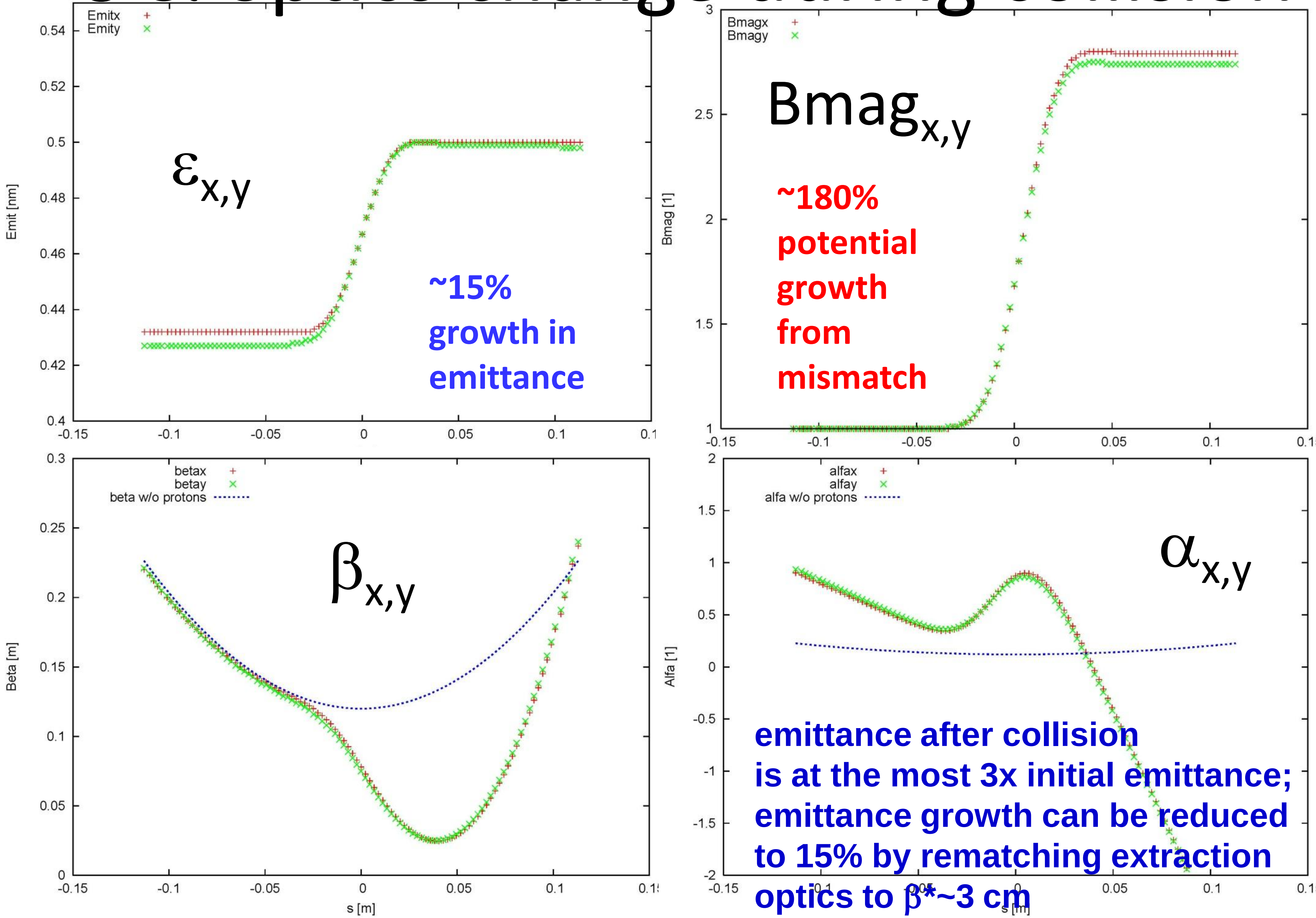
can we achieve this stability?

electrons

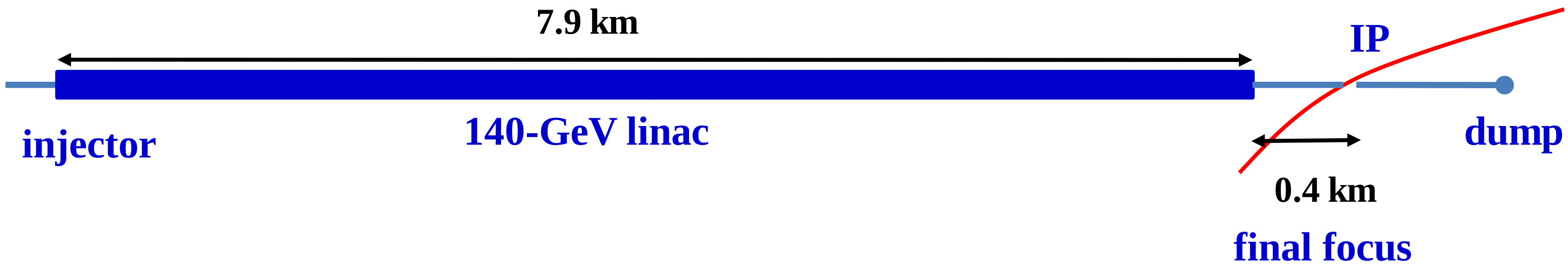
- **disruption**

  $D_{x,y}\approx 6$, $\theta_0\approx 600$ μrad (≈10$\sigma^{*\prime}$) ***large***

ε & optics change during collision



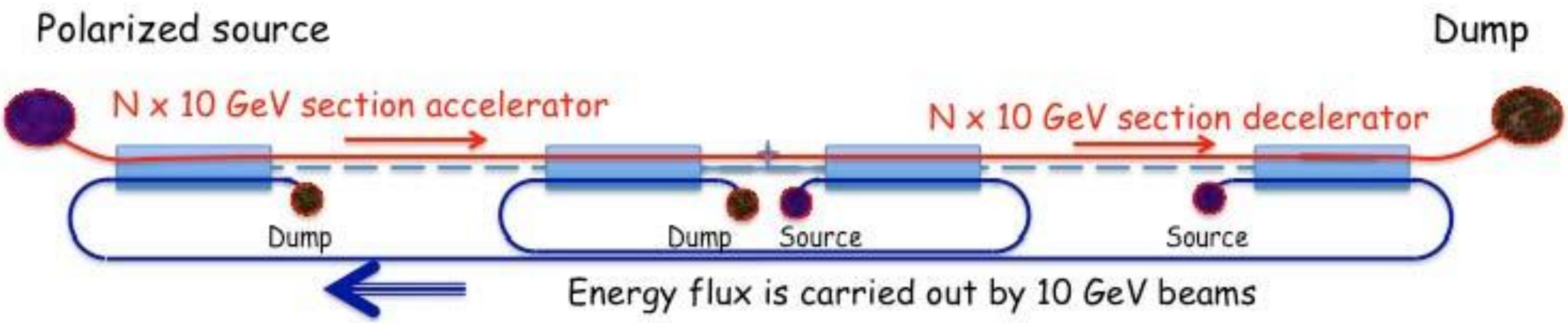
pulsed linac for 140 GeV



- 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, $H_g=0.94$, $N_b=1.5\text{x}10^9$:
  $\langle I_e \rangle=0.27$ mA → $L\approx 4\text{x}10^{31}$ 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 1^{st} 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,
2^{nd} 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

S. Bettoni, C. Bracco, O. Brüning, H. Burkhardt, E. Ciapala, B. Goddard, F. Haug, B. Holzer, B. Jeanneret, M. Jimenez, J. Jowett, A. Kosmicki, K.-H. Mess, J. Osborne, L. Rinolfi, S. Russenschuck, D. Schulte, H. ten Kate, H. Thiesen, R. Tomas, D. Tommasini, F. Zimmermann, *CERN, Switzerland;* C. Adolphsen, M. Sullivan, Y.-P. Sun, *SLAC, USA;* A.K. Ciftci, R. Ciftci, K. Zengin, *Ankara U.,Turkey;* H. Aksakal, E. Arikan, *Nigde U., Turkey;* E. Eroglu, I. Tapan, *Uludag U., Turkey;* T. Omori, J. Urakawa, *KEK, Japan ;* S. Sultansoy, *TOBB, Turkey;* J. Dainton, M. Klein, *Liverpool U., UK;* R. Appleby, S. Chattopadhyay, M. Korostelev, *Cockcroft Inst., UK;* A. Polini, *INFN Bologna, Italy;* E. Paoloni, *INFN Pisa, Italy;* P. Kostka, U. Schneekloth, *DESY, Germany;* R. Calaga, Y. Hao, D. Kayran, V. Litvinenko, V. Ptitsyn, D. Trbojevic, N. Tsoupas, V. Yakimenko , *BNL, USA;* A. Eide, *NTNU, Norway ;* A. Bogacz, *JLAB, USA ;* N. Bernard, *UCLA, USA*

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many thanks for your attention!