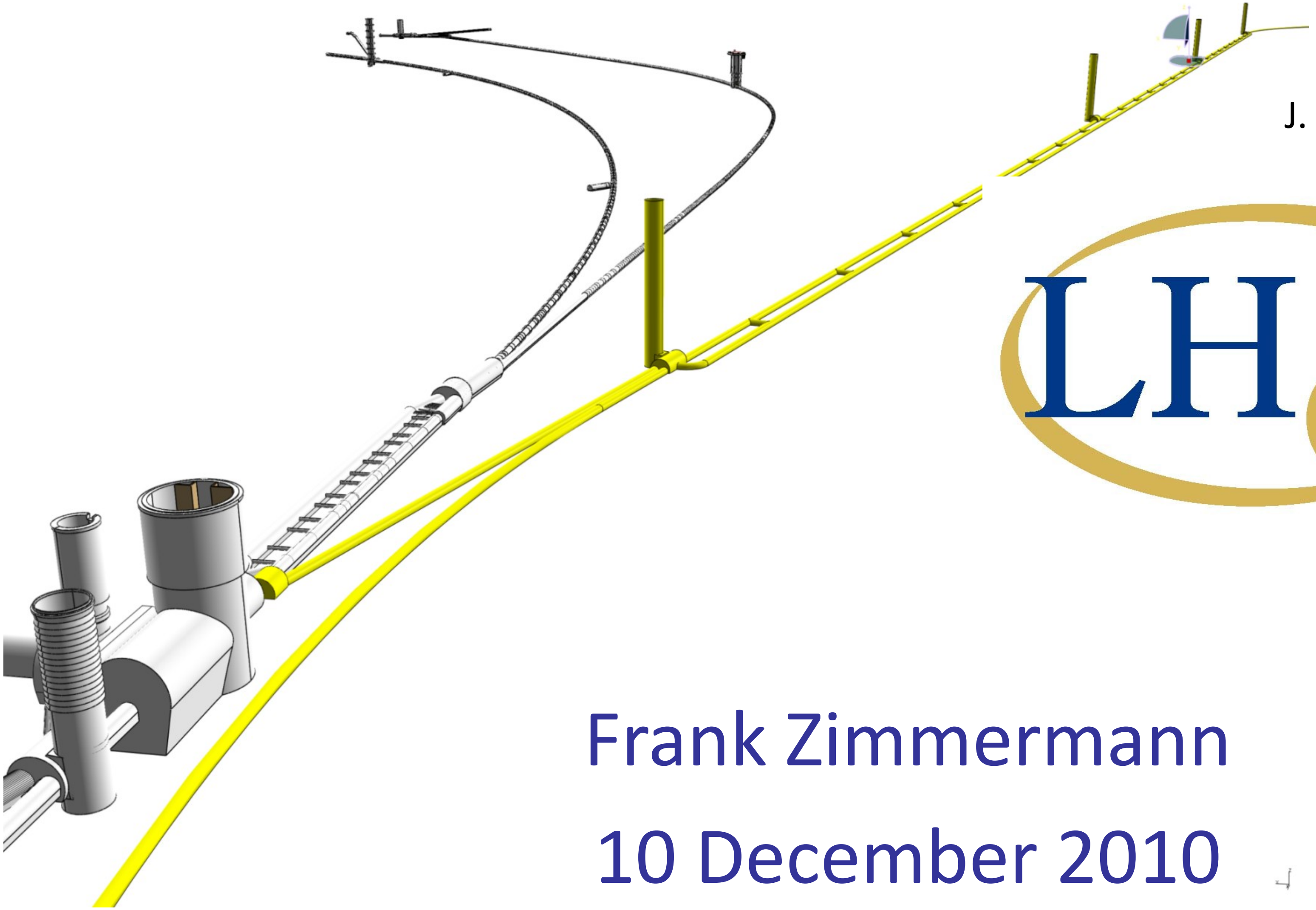
LHeC Linac Design Issues

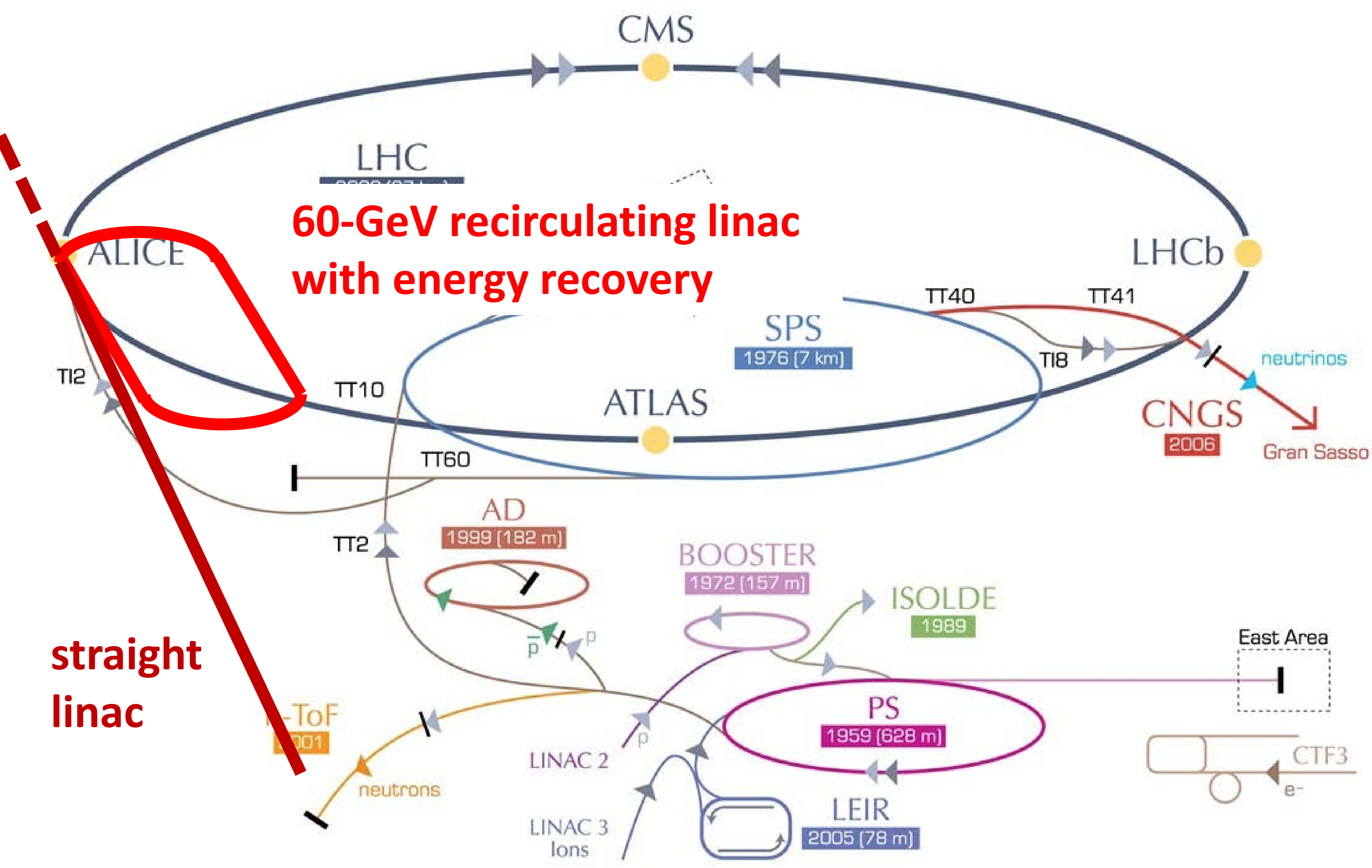


J. Osborne

Frank Zimmermann

10 December 2010

Linac-Ring LHeC – two options



60-GeV recirculating linac with energy recovery

straight linac

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$_3$Sn***

β^*=0.1 m

average e$^-$ current !

maximize geometric overlap factor

- **head-on collision**
- **small e- emittance**

θ_c=0

$H_{hg}\geq$0.9

R&D issues

- choice of RF frequency
- bulk Nb or sputtered Nb?
- cryo load
- RF power to control microphonics

- compensation scheme for SR U_{loss}
- IR synchrotron radiation handling
- ion clearing
- fast feedback

- positron production (70x ILC)

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
- availability of solid state RF sources

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**	**14-31 ?**	**<10**
power loss total [W/cav.]	13-37 (!?)	14-31	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

1.3 GHz dynamic cryo load

Estimate 1

Numbers from the ILC Reference Design Report August 2007 Accelerator
Accelerating gradient (table 1.1-1): 31.5 MV/m
Cryomodule length (table 2.6-4): 12.652 m
Pulse rate (table 1.1-1): 5.0 Hz
RF pulse length (table 1.1-1): ~1.6 ms
From table 3.8-2

	40-80K	5-8K	2K
Predicted module static heat load (W/mod)	59.19	10.56	1.70
Predicted module dynamic heat load (W/mod)	94.30	4.37	9.66
Efficiency (Watts/Watt)	16.45	197.94	702.98

0.48 W/m at 2 K at 31.5 MV/m with D=0.005

→ **31.3 W/m ay 18 MV/m in cw**

Estimate 2:

$(18\ \mathrm{MV/m})^2/(R/Q)/Q$

R/Q=1200 Ω (per m)

Q=2e10 → **13.5 W/m**

ERL electrical site power

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

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

700 "W per W" cryo efficiency

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

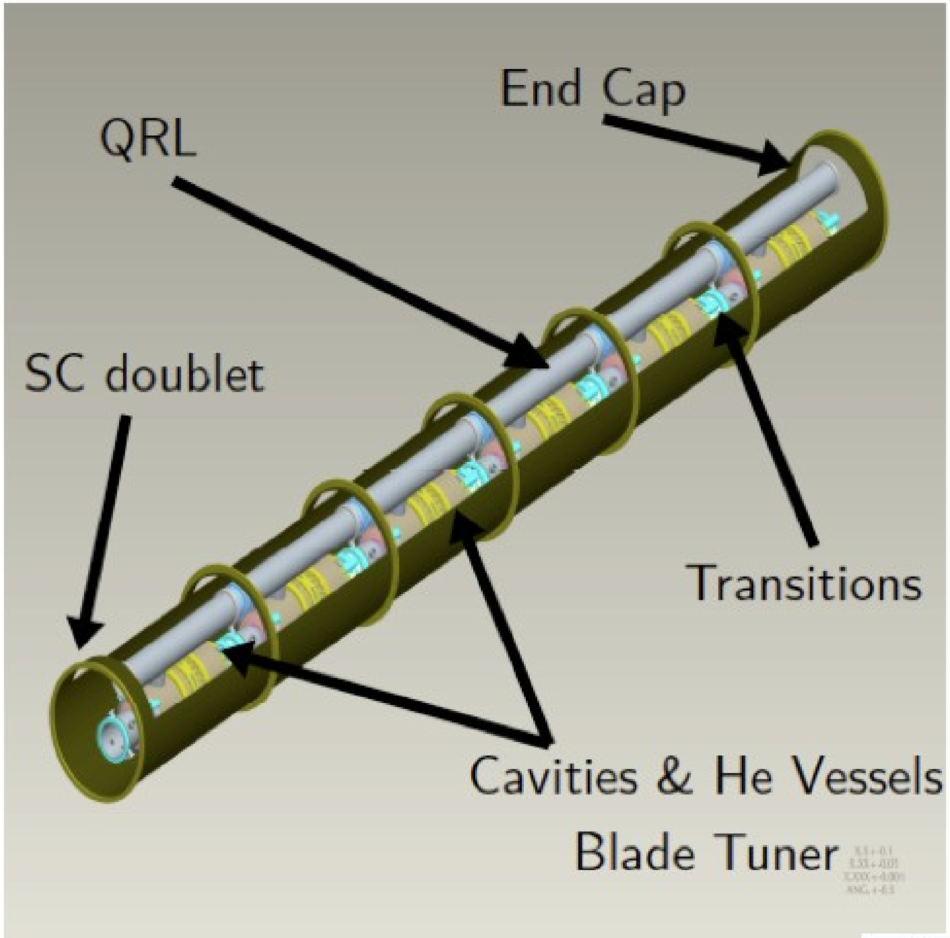
microphonics control for compensating RF: 1.6 MW

injector RF: 6.4 MW

500 MeV, 6.4 mA, 50% RF efficiency

magnets: 3 MW

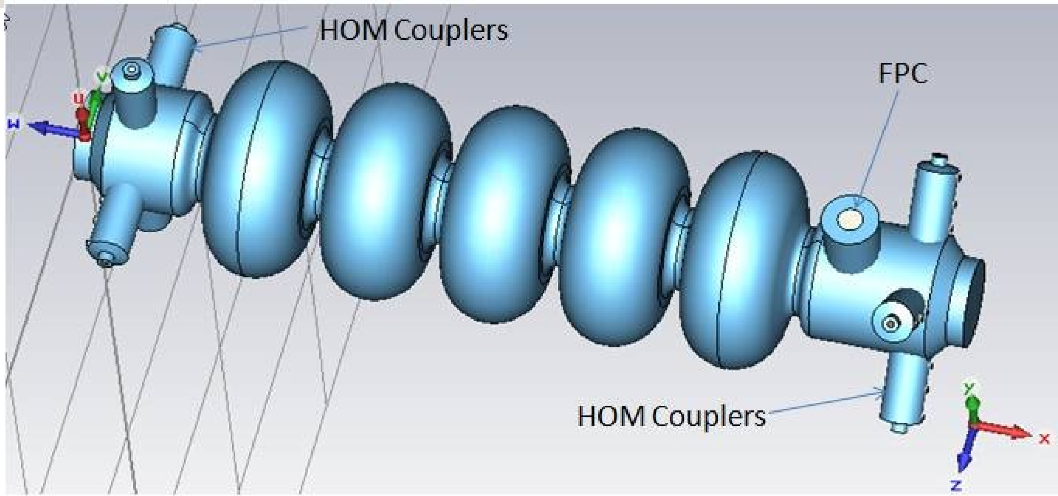
grand total = 88.3 MW



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

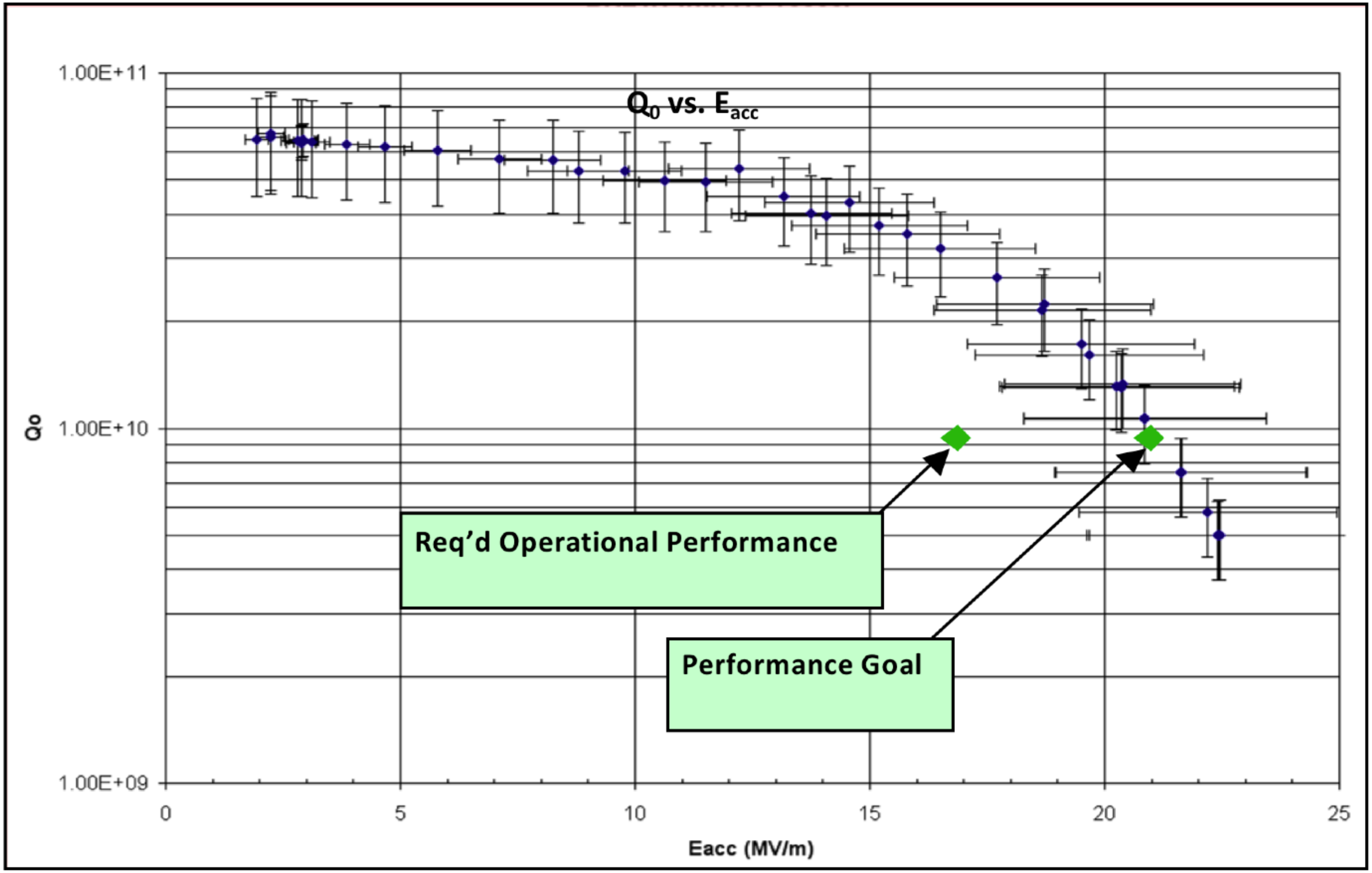
I. Ben-Zvi

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



Req’d Operational Performance

Performance Goal

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!)**

collaborations / joint R&D ?

SPL? – linac design (cavities, cryo module)

CLIC – e- source, injector, e+ source,
drive beam

CERN ILC effort

HIE-ISOLDE – sputtered cavities

JLAB

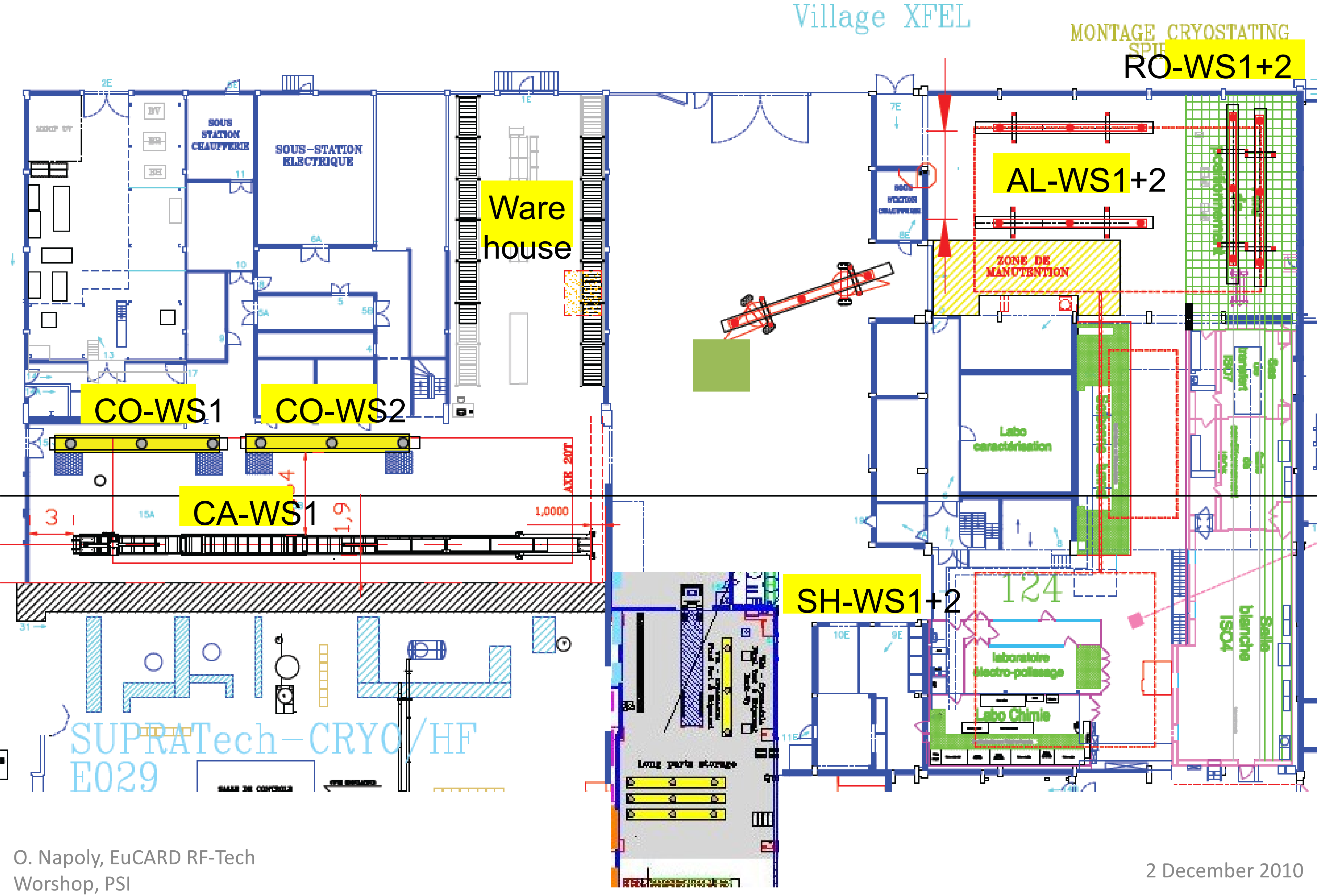
BNL/eRHIC – linac design

Saclay - cryomodule

ESS

Frascati, DESY?, KEK, Cockcroft Institute,…

Saclay Assembly Hall : Workstations

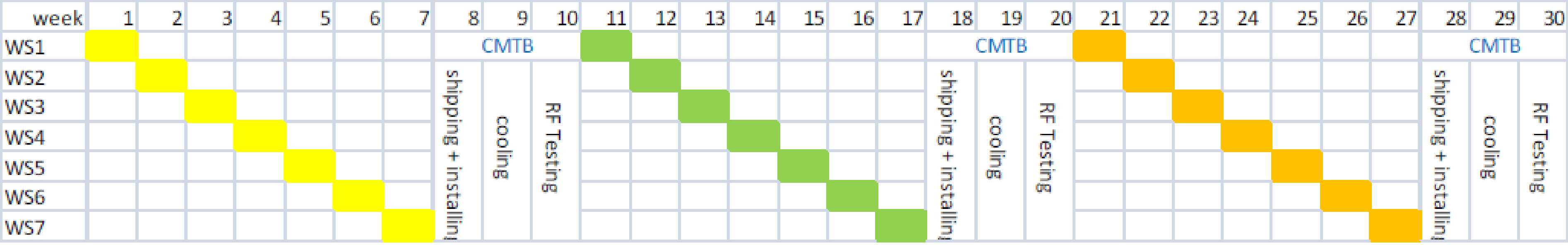


Organisation of Saclay Work Stations

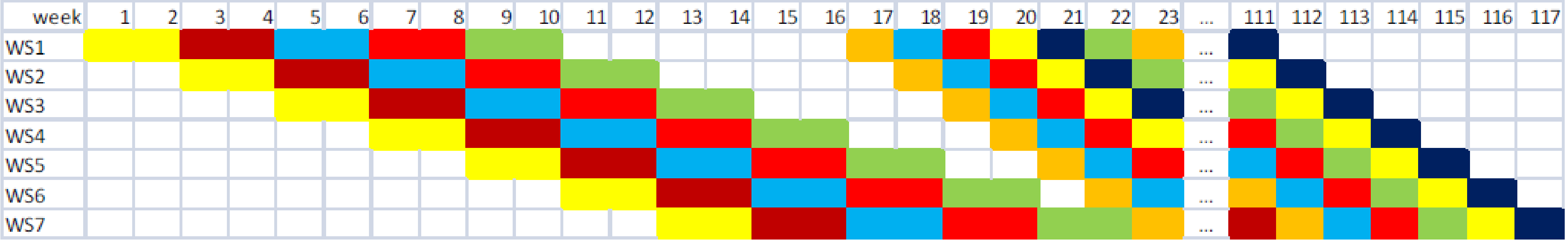
1. **Clean Room Cold Coupler Area** (IS04-CC-WS1)
    - Cold coupler assembly
2. **Clean Room String Assembly Area** (ISO4-SA-WS1, ISO4-SA-WS2)
3. **Roll-out Area** (RO-WS1, RO-WS2)
    - HOM adjustment, magnetic shielding, tuners,…
    - 2Ph-tube welding, cold-mass/string connection
4. **Alignment Area** (AL-WS1, AL-WS2)
    - Cavity and quadrupole fine alignment
    - Coupler shields and braids, tuner electric tests
5. **Cantilever Area** (CA-WS1)
    - Welding of 4K and 70 K shields, super insulation
    - Insertion into vacuum vessel and string alignment
6. **Coupler Area** (CO-WS1, CO-WS2)
    - Warm couplers + coupler pumping line
    - Quad current leads
7. **Shipment Area** (SH-WS1, SH-WS2)
    - Instrumentation
    - Control operations (electrical, RF), “acceptance test”
    - End-caps closing, N-insulation, loading.

Saclay: Ramping up industrial assembly

- P1: assembly of 3 pre-series modules in sequence for training of the first ½ teams by CEA and DESY personnel, assuming 7 week assembly interleaved by 3 weeks for CMTB qualification.
- P2: assembly of 5 modules in parallel during a ramp-up period (P2) for training of the second ½ teams by the first ½ teams, assuming 2 week assembly per module.
- P3: assembly 75 modules in parallel at the rate of 1 module/week.



Period 1: assembly of 3 pre-series modules, in sequence, interleaved with CMTB tests



Period 2: parallel assembly of 5 modules

Period 3: // assembly of 75 modules **1/week**

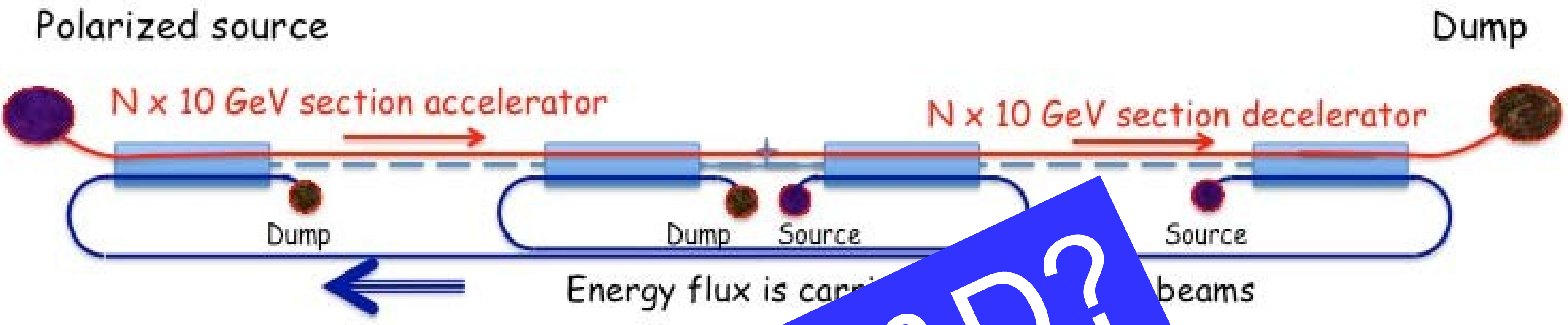
pulsed linac for 140 GeV

no R&D needed?

- linac could be ILC ty 720 MHz
- cavity gradient , Q=10^{10}
- extendab beam energies
- no energy very
- with 10 Hz, 5 ms pulse, H_g=0.94, N_b=1.5x10^9 :
  <I_e>=0.27 mA → L≈4x10^{31} cm^{-2}s^{-1}

highest-energy LHeC ERL option

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



any R&D?

High luminosity LHeC wi[illegible]ergy efficient ERL.
The main high-energy[illegible]pagates from left to right.
In the 1st linac it gains [illegible]eV (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