CERN/Thales meeting
High Efficiency Klystron R&D

… setting the scene

Erk Jensen, CERN

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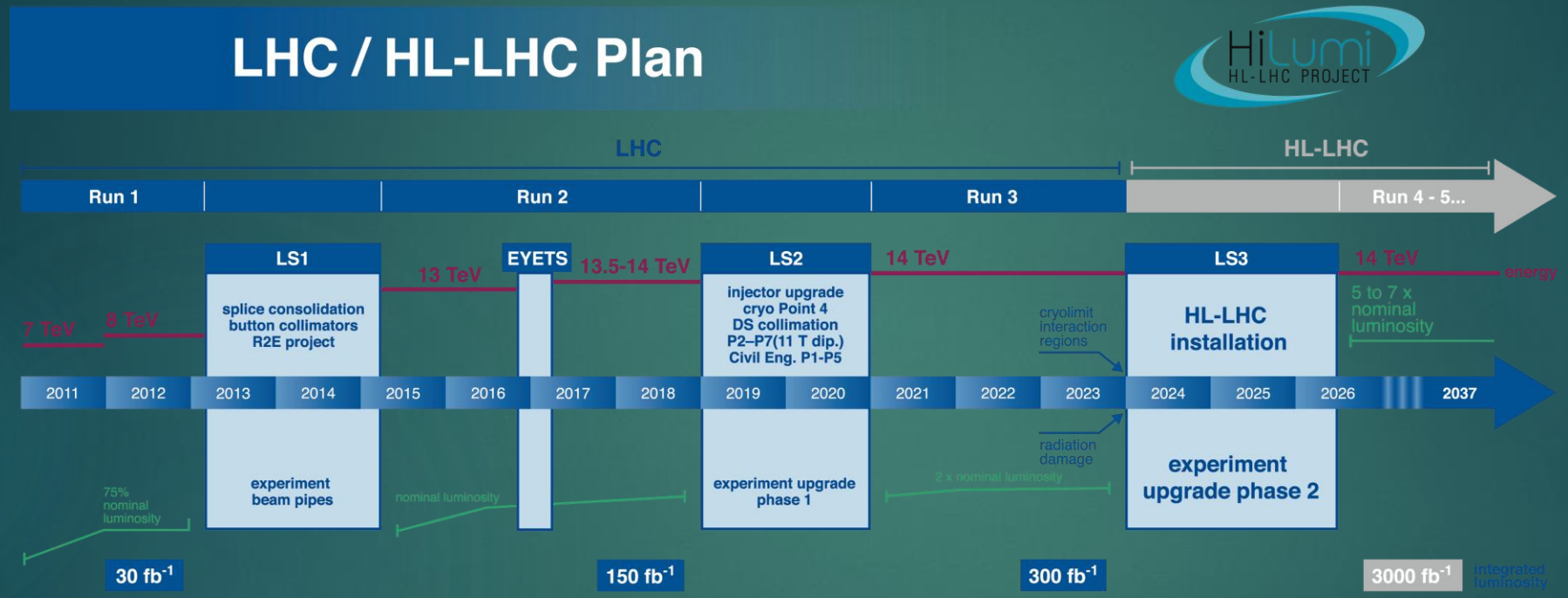
Meeting at CERN

… look 20 years ahead …

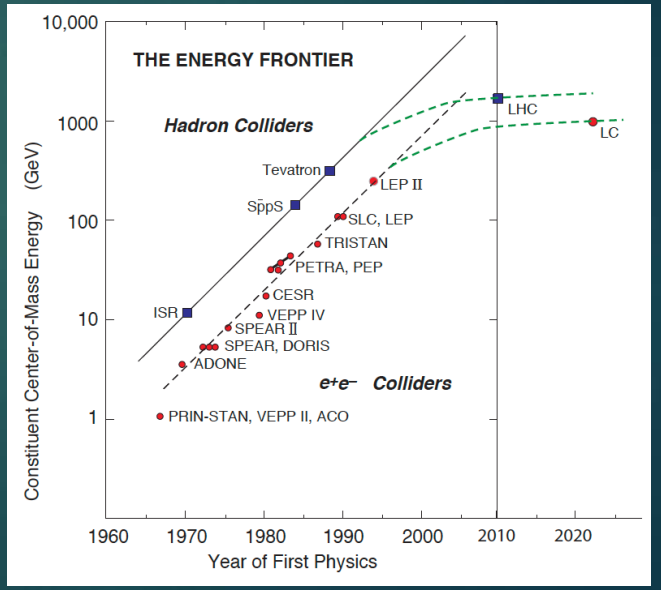
- LHC is scheduled to have integrated $\approx 3\ \mathrm{ab}^{-1}$ by then.
  → ***I guess we know some new physics by then!***



- The next large HEP collider project will be close to completion or operating (LC?, NCRF or SRF?) – decision expected around 2020 (based on LHC results from LHC Run2).

… in Europe:

- We'll have the next round of the European Strategy for High Energy Physics in 2019/20.
- Even without too much speculation, it is clear that the community should prepare the next possible post-LHC forefront machine(s):
- Quote from ESG 2013: **"Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14 TeV will be available."**
- This should be ambitious but in reach; candidates (guesswork):
  - toward a $\sqrt{s} \approx \mathcal{O}(100\ \mathrm{TeV})$ circular proton collider (FCC, possibly with HE-LHC as intermediate step)
  - toward a $\sqrt{s} \approx \mathcal{O}(10\ \mathrm{TeV})$ linear lepton collider (?, possibly with a $\sqrt{s} \approx 380\ GeV$ LC as intermediate step)
- This should guide the definition of an R&D program…



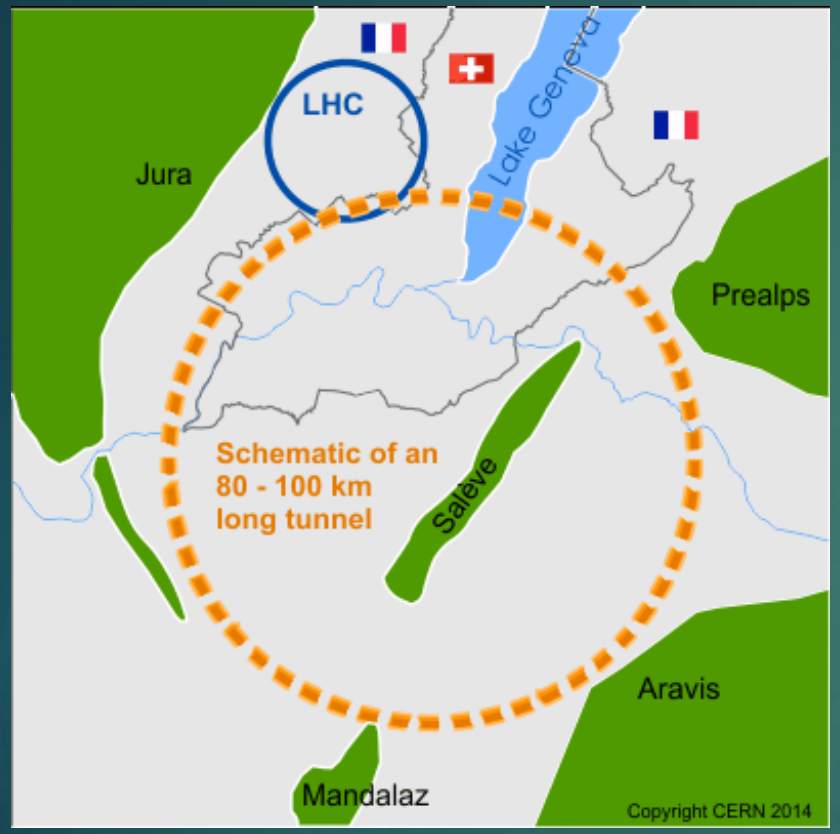
Jordan Nash: 2010 IOP Meeting

Ongoing R&D on RF Technologies

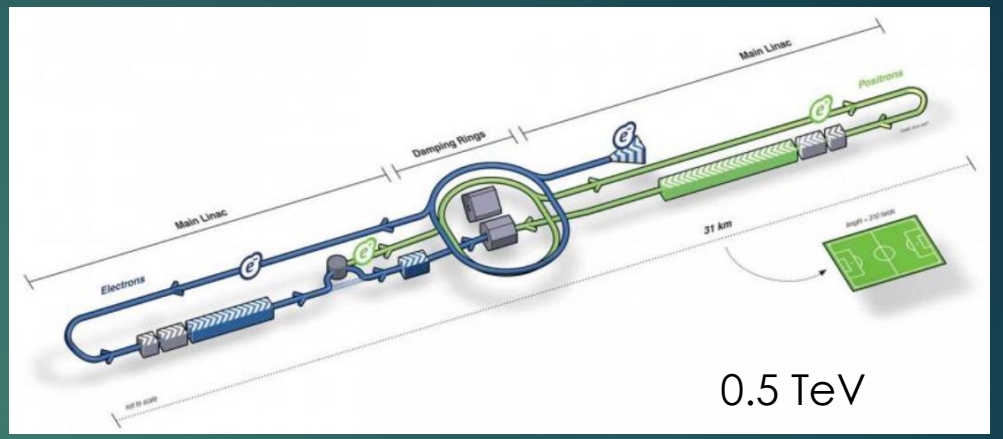
- NC RF
  - X-band technology (CLIC, but also for light source and medical applications)
  - 750 MHz RFQ (4th sub-harmonic of S-band)
  - S-band, L-band (e.g. S-band BW structure to follow the RFQ for hadron therapy)
  - New fabrication techniques
- SC RF
  - CERN: complementary to US – focus: Thin film technologies
  - Deflecting cavities (HL-LHC crab cavities)
  - toward FCC-ee: 100 MW CW (sic!)
- RF Power generation (**energy efficiency is a must!**)
  - Klystrons
  - IOTs – MB-IOT (ESS)
  - Solid state
- RF systems
  - High-availability
  - What's going to replace VME?

Average RF power needs

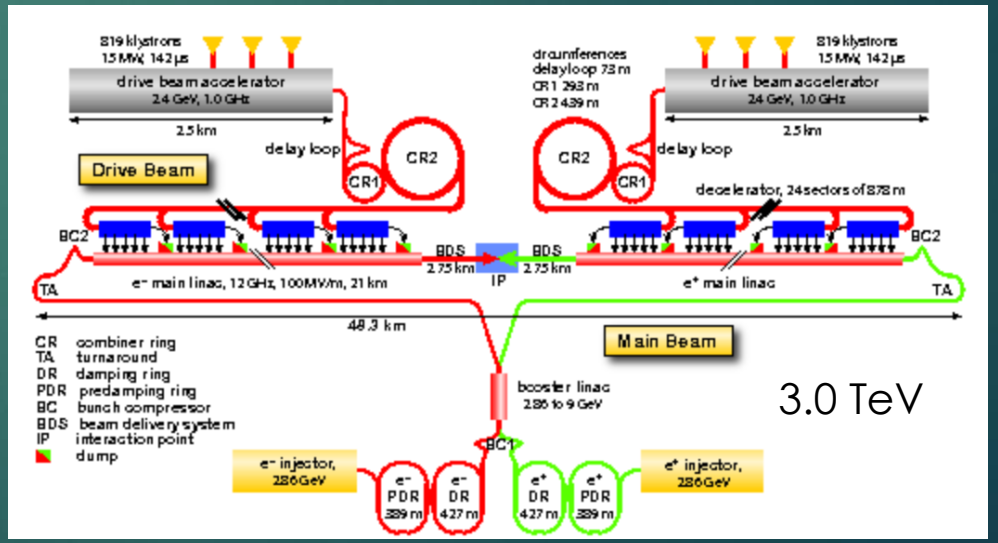
Future large scale colliders



FCC ^{ee}: CW, 0.8 GHz, $P_{\mathrm{RF,total}} = 110$ MW



ILC $^{e+e-}$: Pulsed, 1.3 GHz, $P_{\mathrm{RF,total}} = 88$ MW



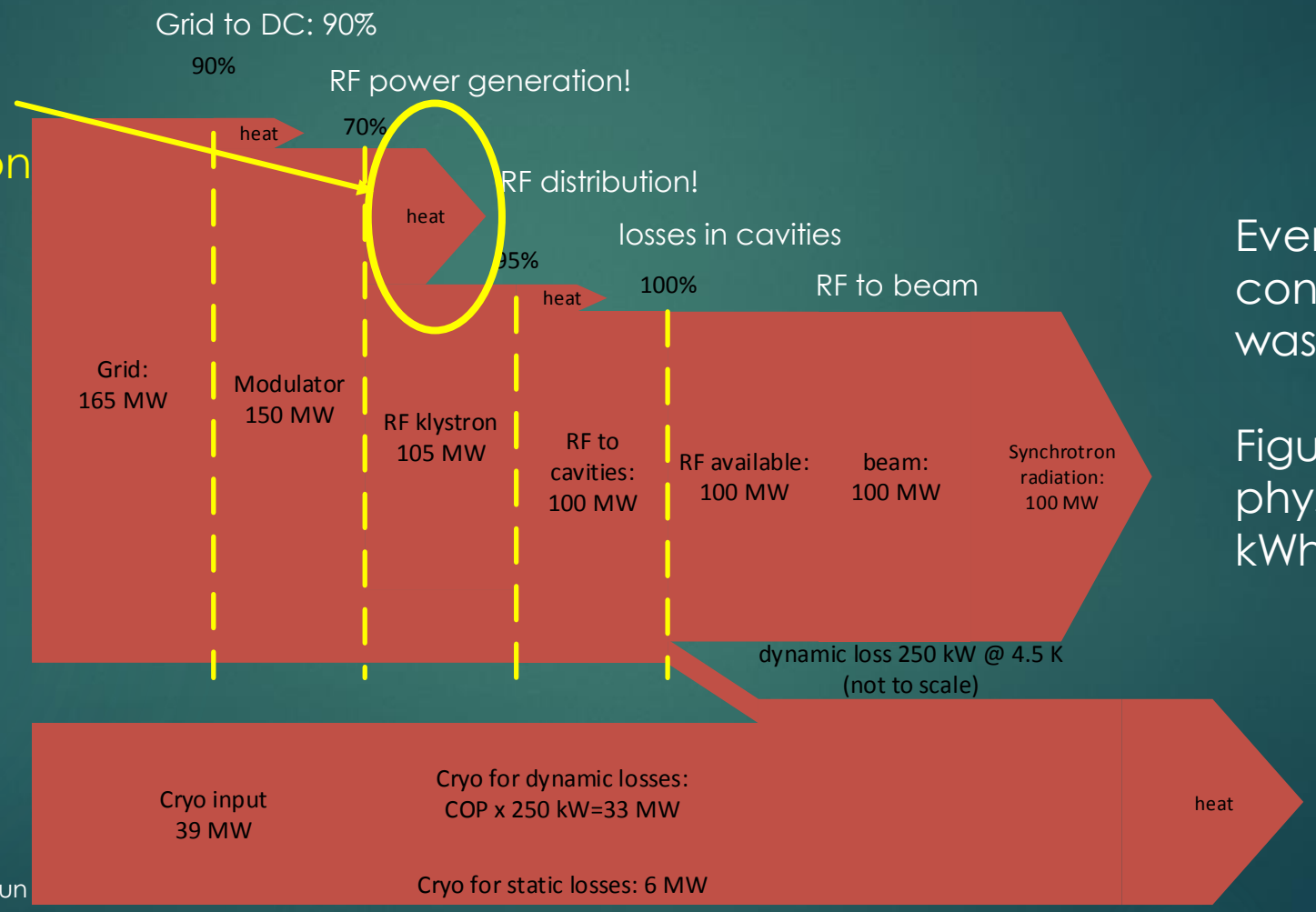
CLIC $^{e+e-}$: Pulsed, 1.0 GHz, $P_{\mathrm{RF,total}} = 180$ MW

Motivation: FCC Parameters

	FCC-hh	Z	Z	W	H	$t\bar{t}$
Beam energy [GeV]	**50,000**	**45.6**		**80**	**120**	**175**
Beam current [mA]	0.5	1450		152	30	6.6
Bunches / beam		30180	91500	5260	780	81
Bunch spacing [ns]	25	7.5	2.5	50	400	4000
Bunch population [10^{11}]	1.0	1.0	0.33	0.6	0.8	1.7
Crossing angle at IP [mrad]				30		
Bunch length [mm] (total)	300	6.7	3.8	3.1	2.4	2.5
Energy loss / turn [GeV]		0.03		0.33	1.67	7.55
Total RF voltage [GV]	0.032	0.4	0.2	0.8	3	10
RF frequency [MHz]			400			
cells×cavities×beams	1×25×2	1×150×2	1×75×2	2×150×2	2×400×2	2×1340
Luminosity/IP for 2IPs [10^{34} cm^{-2}s^{-1}]	5…30	207	89.4	19.1	5.1	1.3
SR power (total) ≈ total RF power [MW]	**5**			**100**		
Electric power for RF [MW]	**≈ 10**			**≈ 165**		
Total cryogenic power [MW]	**0.4**	**2**	**2**	**5**	**23**	**39**

Energy conversion efficiencies

Note: largest impact by RF power generation



Eventually, all is converted to waste heat!

Figure of merit: physics results per kWh!

RF Power needs

- Future (large) HEP facilities need hundreds of MW RF power!
- Maximizing efficiency will …
  - … minimize consumption (cost, e.g. 200 MW, 5000 h/year, €50/MWh means €50M/y!)
  - … minimize installation (power grid, PCs, HVAC …)
  - … minimize reject heat (waste) and its impact on environment!
  - … allow developing technology for efficient power conversion at large
- RF generation (efficiency in the order of 50%) is a large contributor to inefficiency – an improvement here will have significant impact.