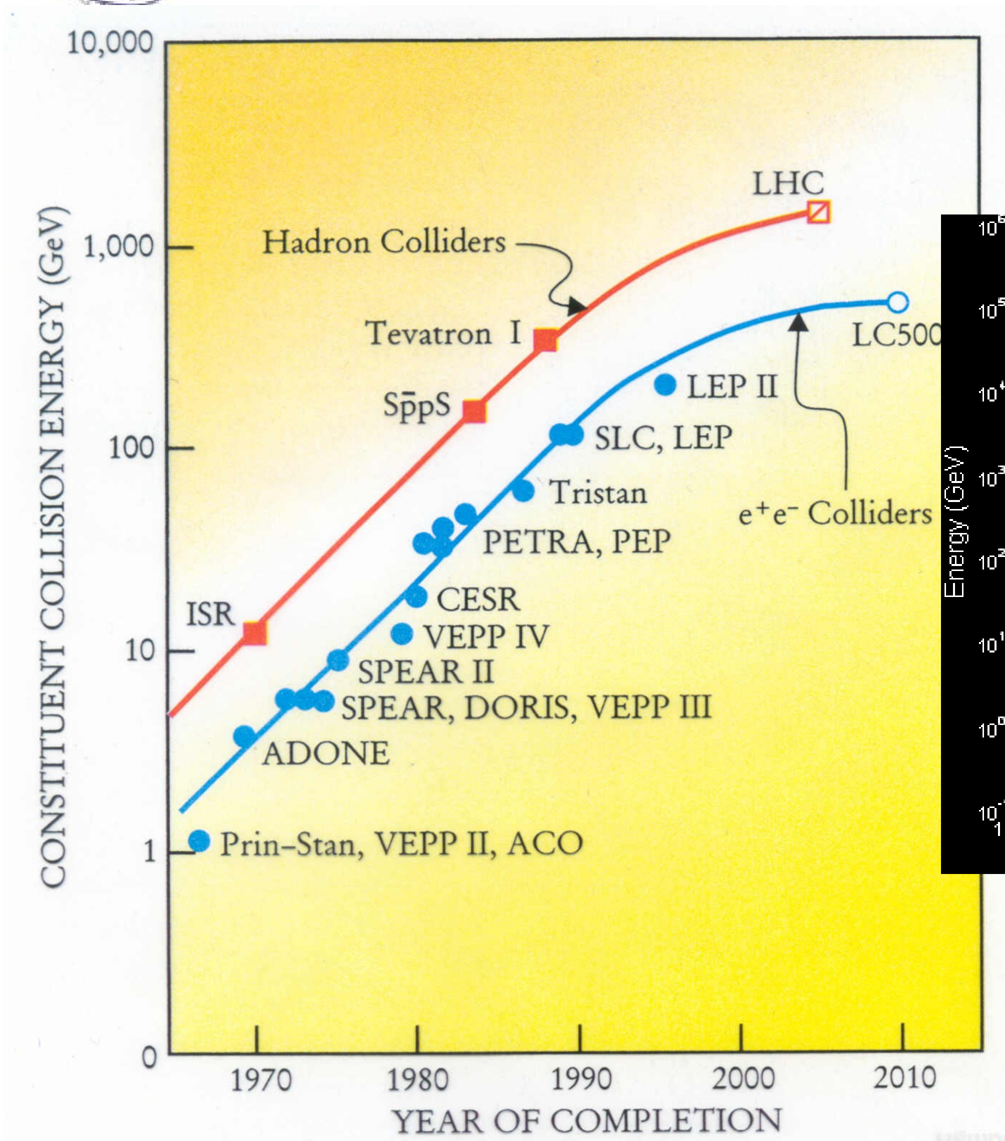
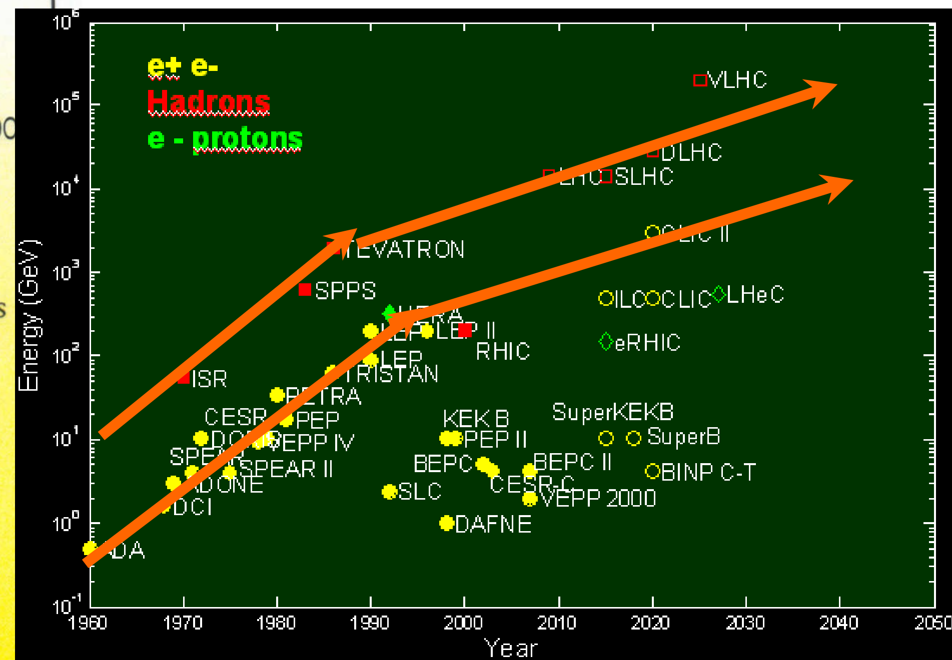
Colliders at the energy frontier

Brian Foster (JAI, Oxford)

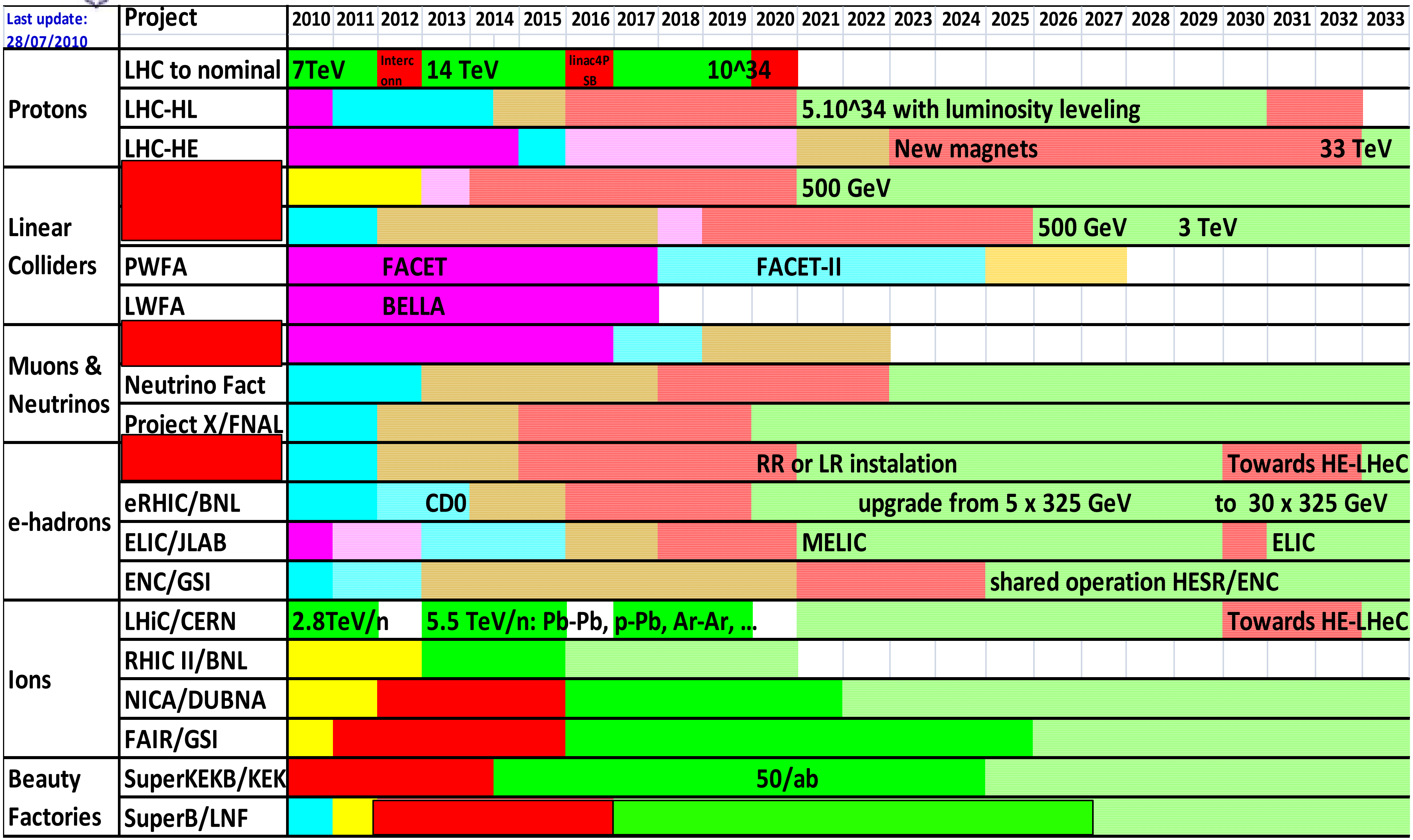
IoP NPPD Conference Glasgow

Lessons of history



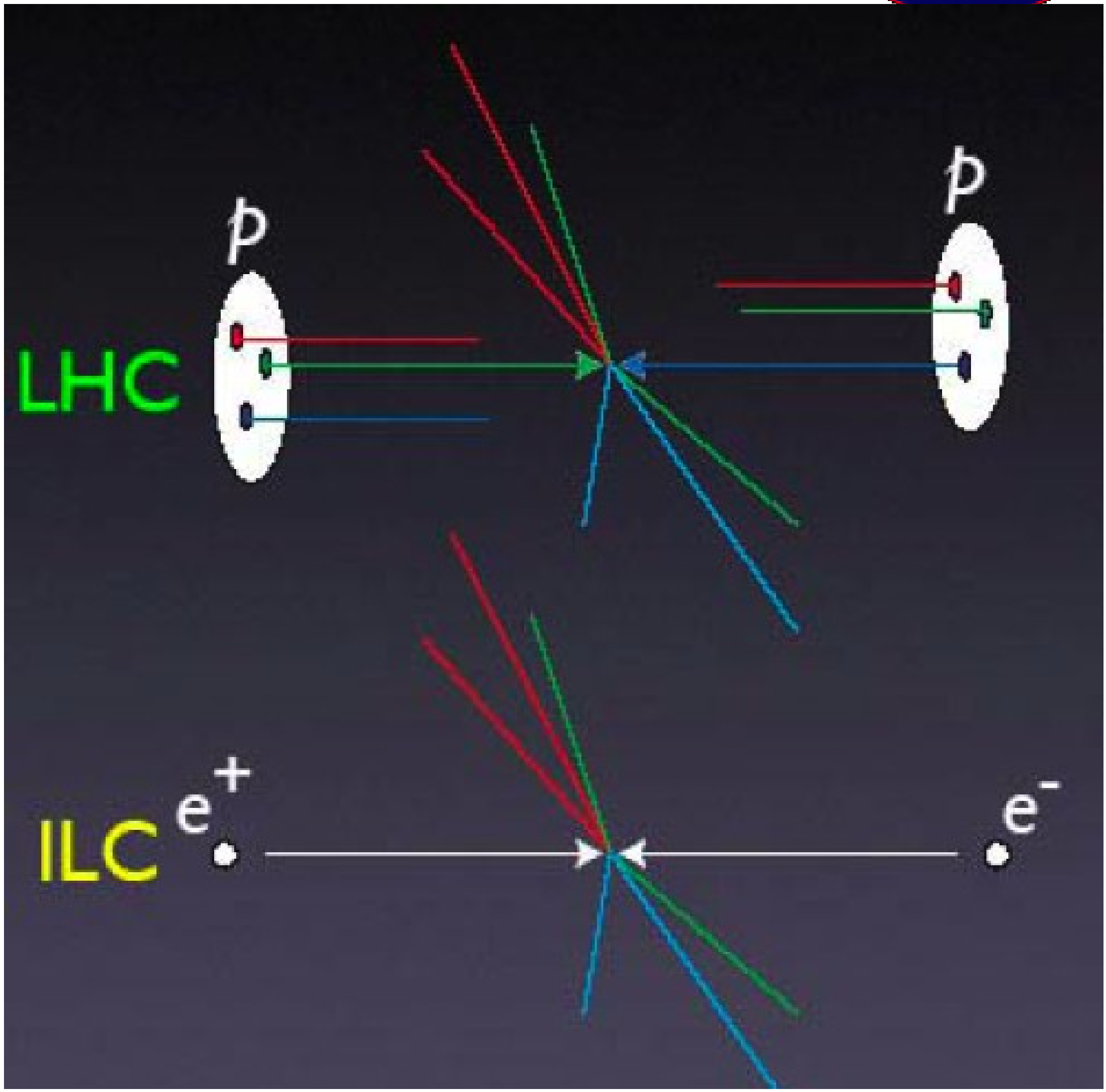


Tentative schedule new projects



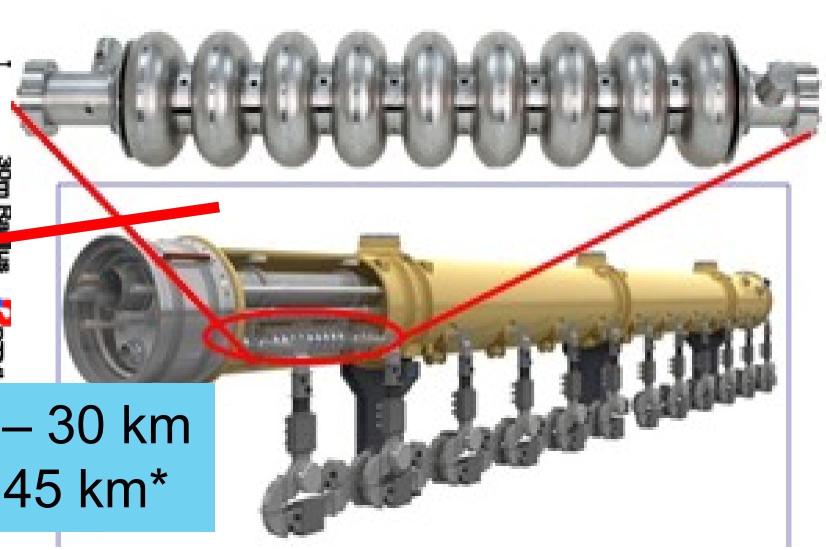
Why lepton colliders ?

- Simple particles
- Well defined: energy/ang. mom.
- E can be scanned precisely
- Particles produced democratically
- Final states generally fully reconstructable



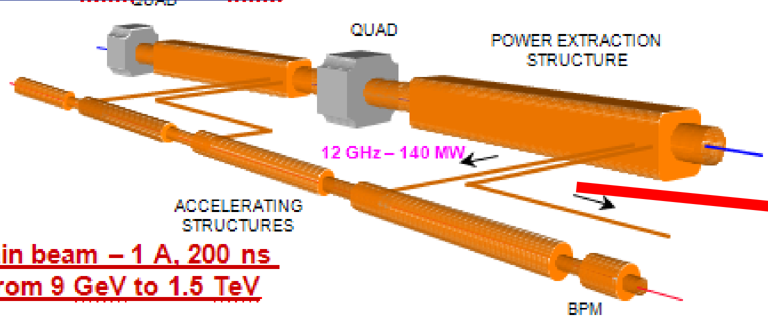
BUT – Synchrotron Rad. => Massive particles or LC!

e+e- colliders

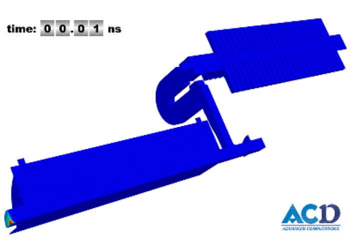


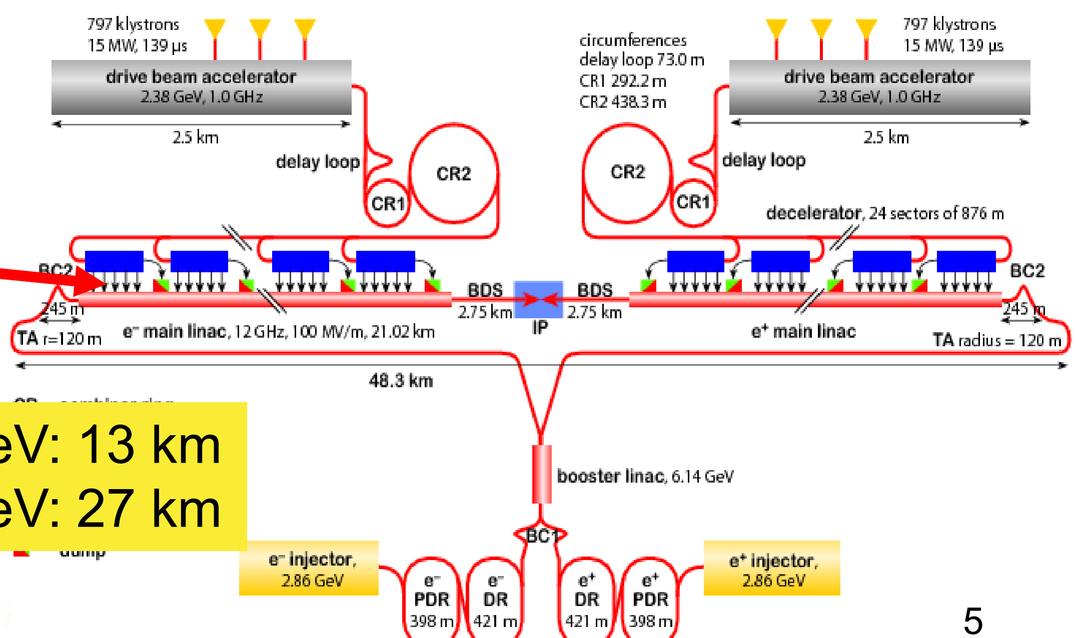
ILC 0.5 TeV – 30 km
ILC 1 TeV ~ 45 km*

Drive beam - 95 A, 300 ns from 2.4 GeV to 240 MeV



Main beam – 1 A, 200 ns from 9 GeV to 1.5 TeV



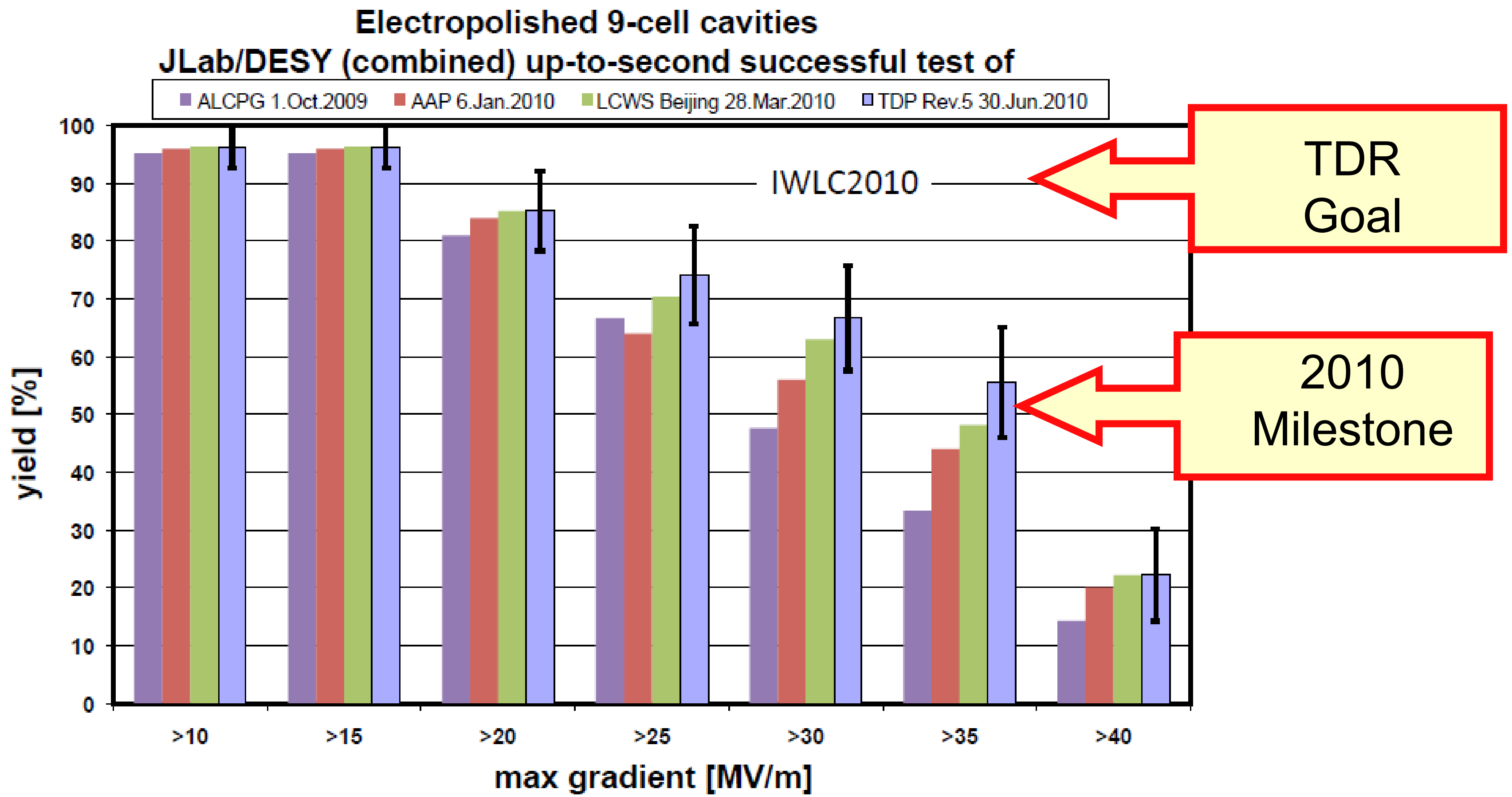


CLIC 0.5 TeV: 13 km
CLIC 1.5 TeV: 27 km

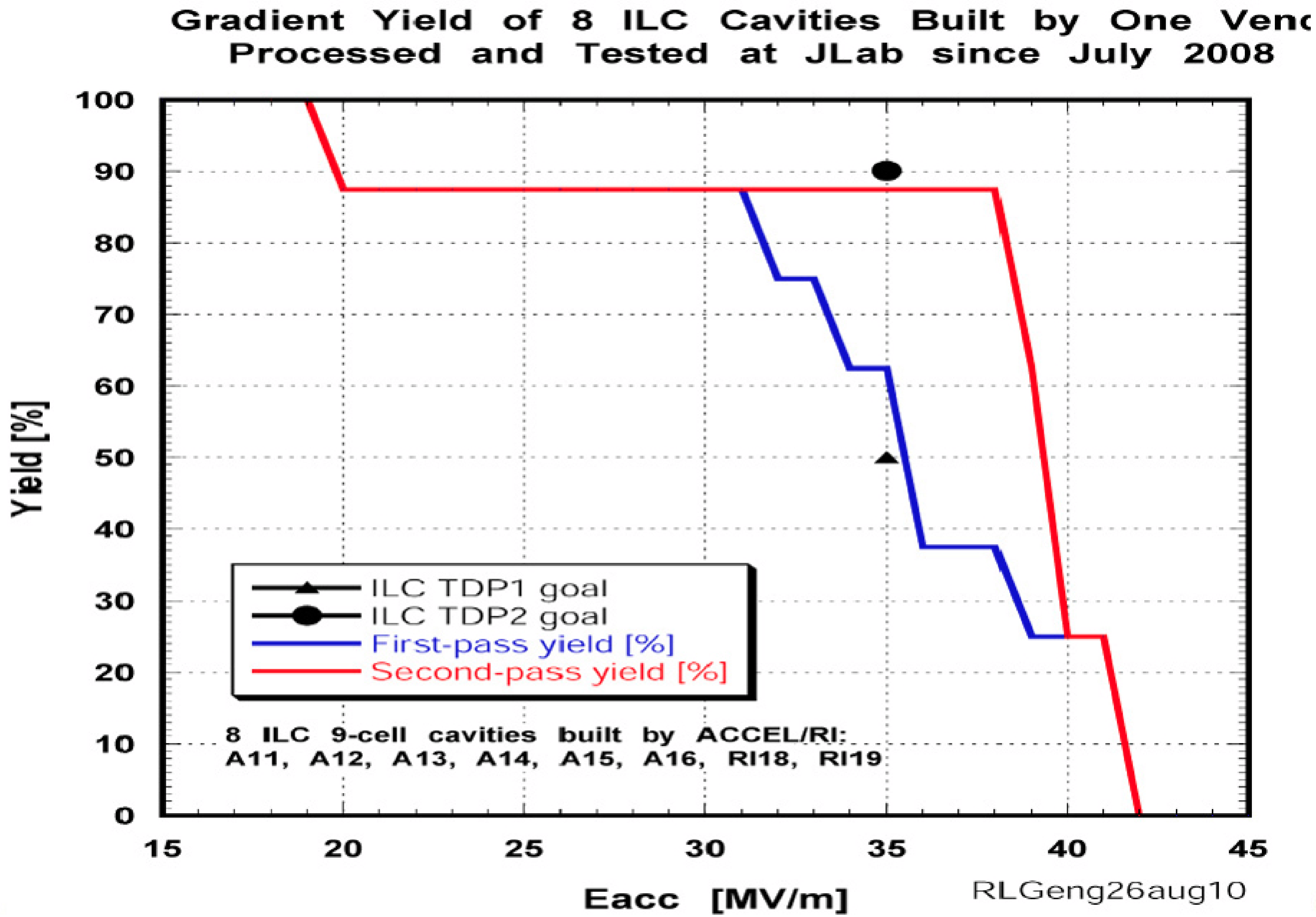
Parameters

Technology		CLIC	
Centre-of-mass energy (GeV)		500	3000
Total (Peak 1%) luminosity (10^{34})		2.3(1.4)	5.9(2.0)
Total site length (km)		13.0	48.3
Loaded accel. gradient (MV/m)		80	100
Main linac RF frequency (GHz)		12 (Normal Conducting)	
Beam power/beam (MW)		4.9	14
Bunch charge (10^9 e+/-)		6.8	3.72
Bunch separation (ns)		0.5	
Beam pulse duration (ns)		177	156
Repetition rate (Hz)		50	
Hor./vert. norm. emitt ($10^{-6}/10^{-9}$)		4.8/25	0.66/20
Hor./vert. IP beam size (nm)		202 / 2.3	40 / 1
Hadronic events/crossing at IP		0.19	2.7
Coherent pairs at IP		100	$3.8\ 10^8$
Wall plug to beam transfer eff		7.5%	6.8%
Total power consumption (MW)		241	568

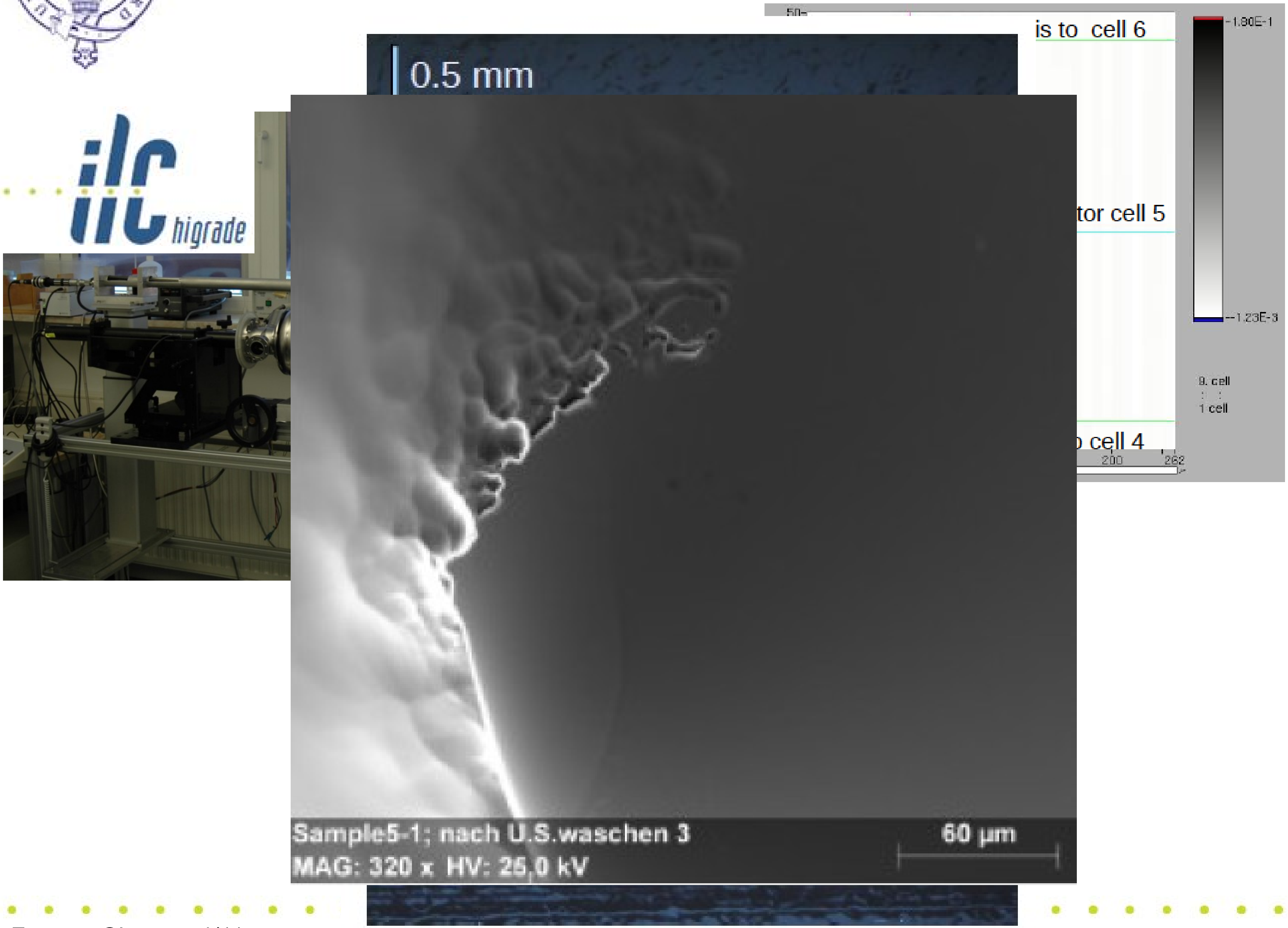
ILC SCRF progress continues



ILC SCRF progress continues

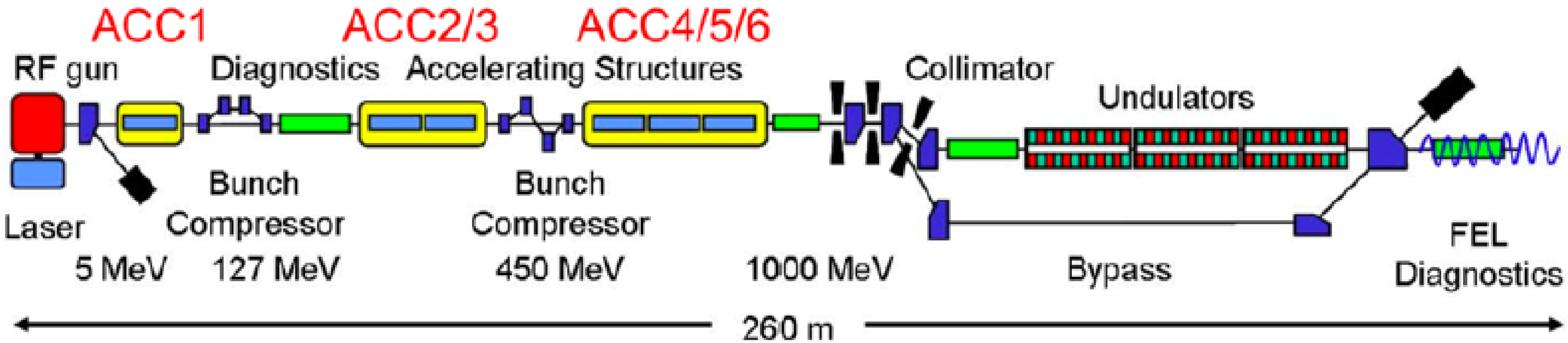


ILC SCRF progress continues



ILC SCRF proof of principle FLASH @ DESY

Full beam-loading long pulse operation → "S2"



		XFEL	ILC	FLASH design	9mA studies
Bunch charge	nC	1	3.2	1	3
# bunches		3250	2625	7200'	2400
Pulse length	µs	650	970	800	800
Current	mA	5	9	9	9

- Stable 800 bunches, 3 nC at 1MHz (800 µs pulse) for over 15 hours (uninterrupted)
- Several hours ~1600 bunches, ~2.5 nC at 3MHz (530 µs pulse)
- >2200 bunches @ 3nC (3MHz) for short periods

ILC COST

Summary

RDR "Value" Costs

Total Value Cost (FY07)

4.80 B ILC Units Shared

+

1.82 B Units Site Specific

+

14.1 K person-years

("explicit" labor = 24.0 M person-hrs @ 1,700 hrs/yr)

1 ILC Unit = $ 1 (2007)

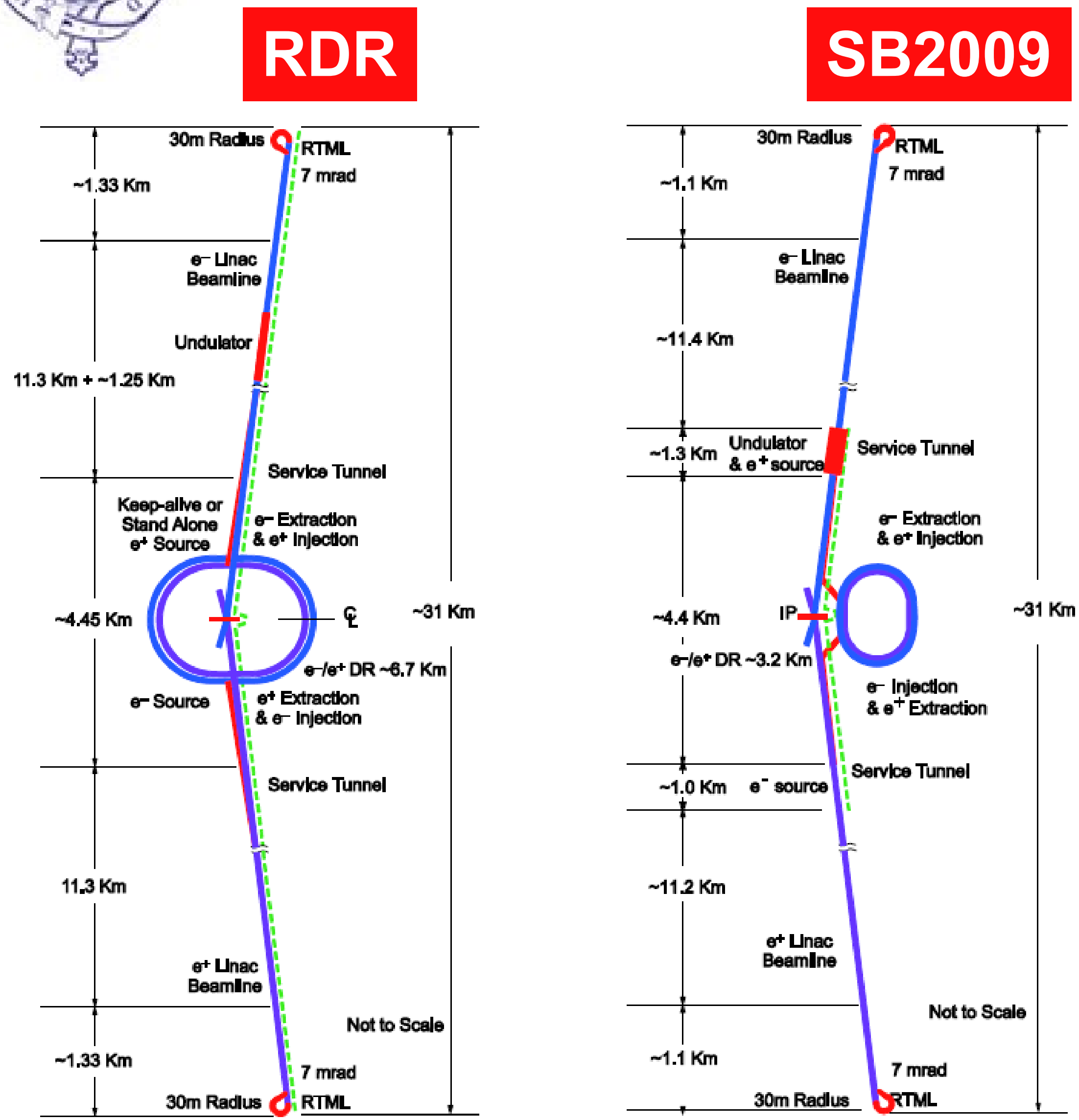
Σ Value = 6.62 B ILC Units

The reference design was "frozen" on 1-12-06 for RDR production, including costs.

Important to realise this is a snapshot; design will continue to evolve, due to R&D, accelerator studies & value engineering.

The value costs have already been reviewed many times; all reviews have been very positive and generally consider there is scope for further cost reductions.

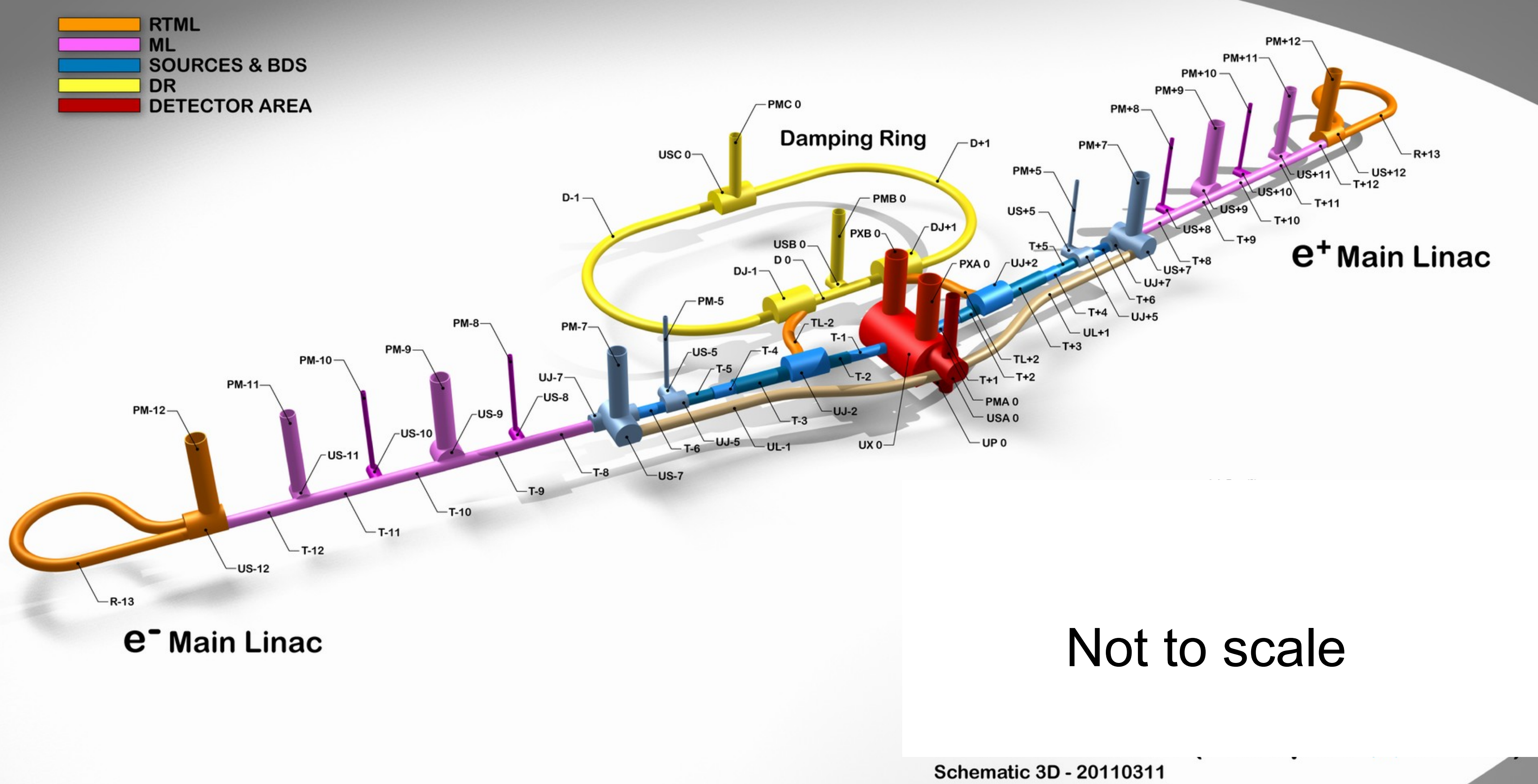
Towards the TDR in 2012



- **Single Tunnel for main linac**
- **Move positron source to end of linac**
- **Reduce number of bunches factor of two (lower power)**
- **Reduce size of damping rings (3.2km)**
- **Integrate central region**
- **Single stage bunch compressor ????**

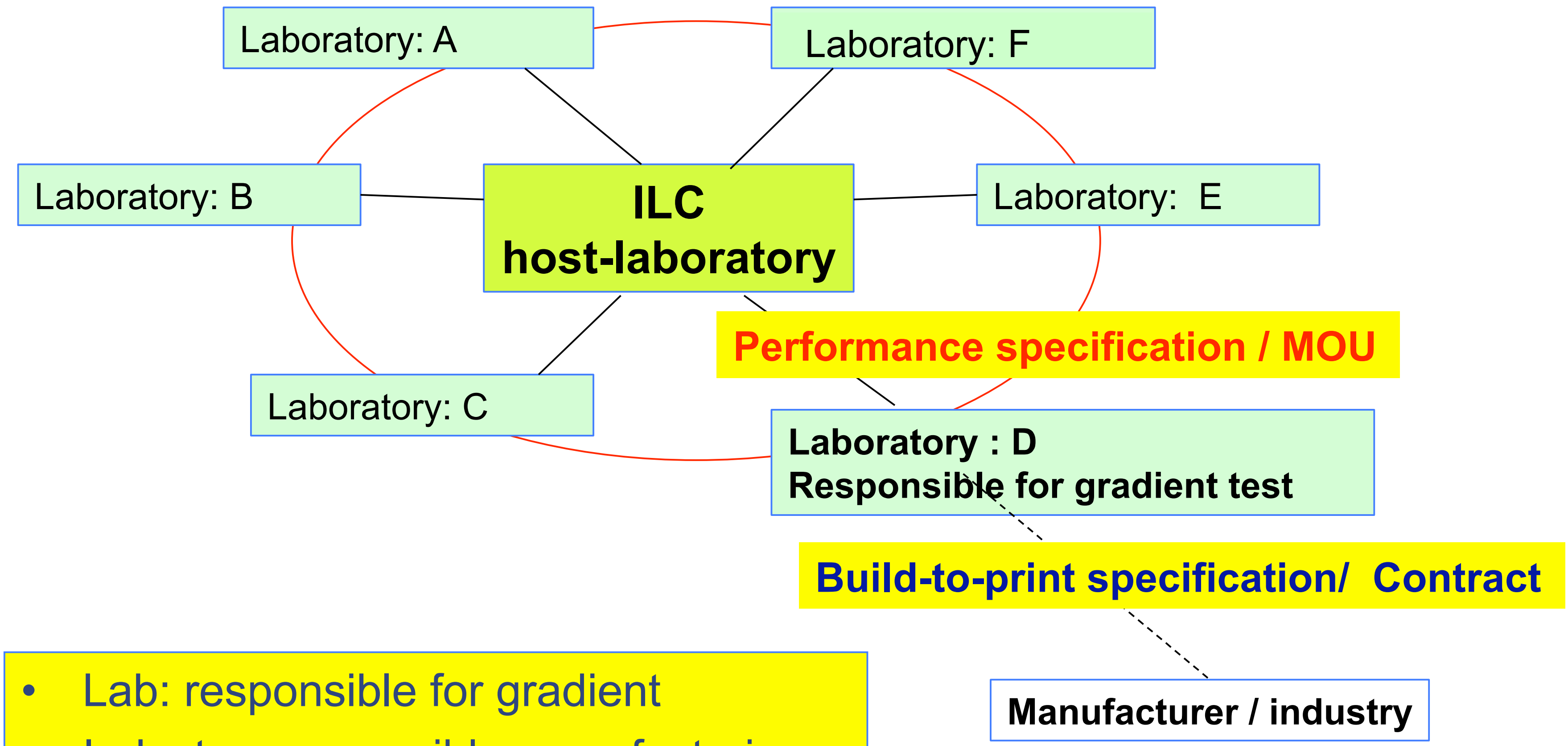
Towards the TDR in 2012

SB2009



Not to scale

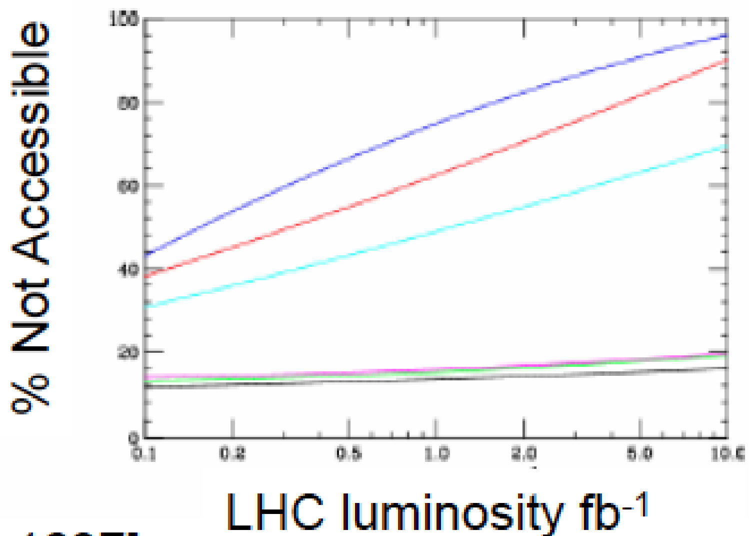
Industrialisation Model



- Lab: responsible for gradient
- Industry: responsible manufacturing

What about LHC results?

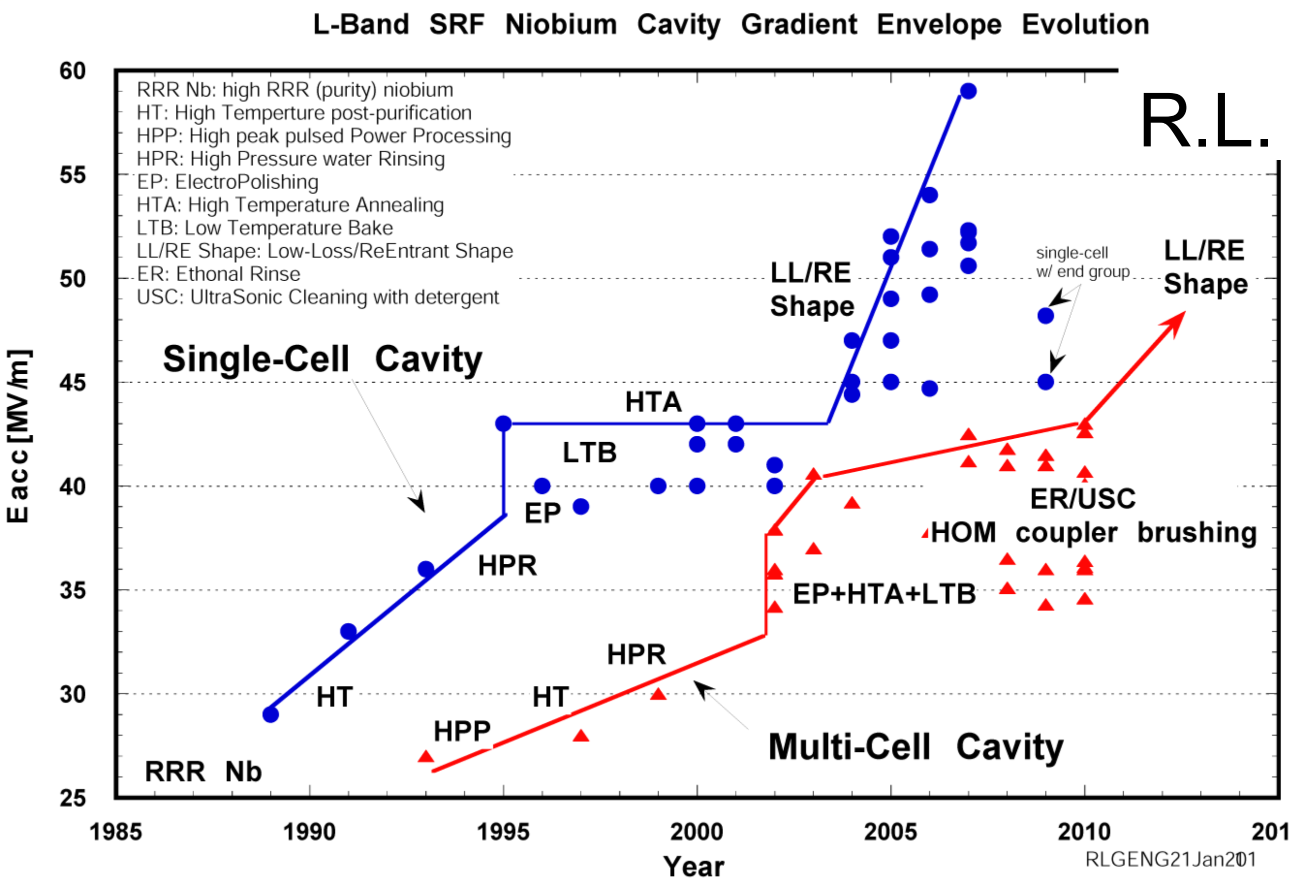
- Intuitively, the better the LHC SUSY exclusion limits, the less likely there will be SUSY particles kinematically accessible at a 500 GeV linear collider
- Try to quantify this: y-axis: % of generated models which escape LHC observation which have no SUSY particles accessible at 500 GeV LC



[Conley et al, arXiv:1103.1697]

S. Dawson ALCPG11

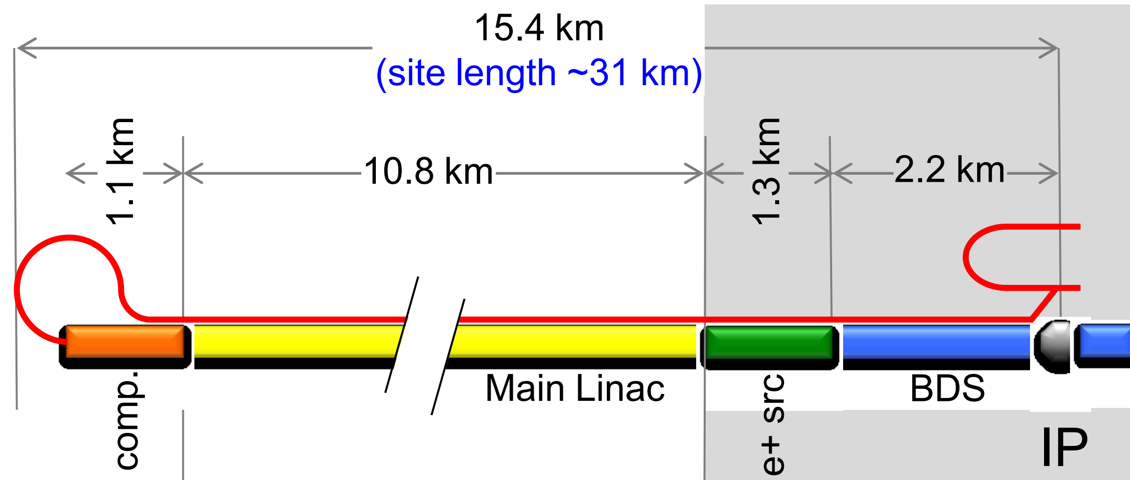
Increasing SCRF Gradient



R.L. Geng

Understanding in gradient limits and inventing breakthrough solutions are responsible for gradient progresses. This has been a tradition in SRF community and rapid gradient progress continues. Up to 60 MV/m gradient has been demonstrated in 1-cell 1300 MHz Nb cavity. 45-50 MV/m gradient demonstration in 9-cell cavity is foreseen in next 5 years.

From 500 GeV -> 1 TeV



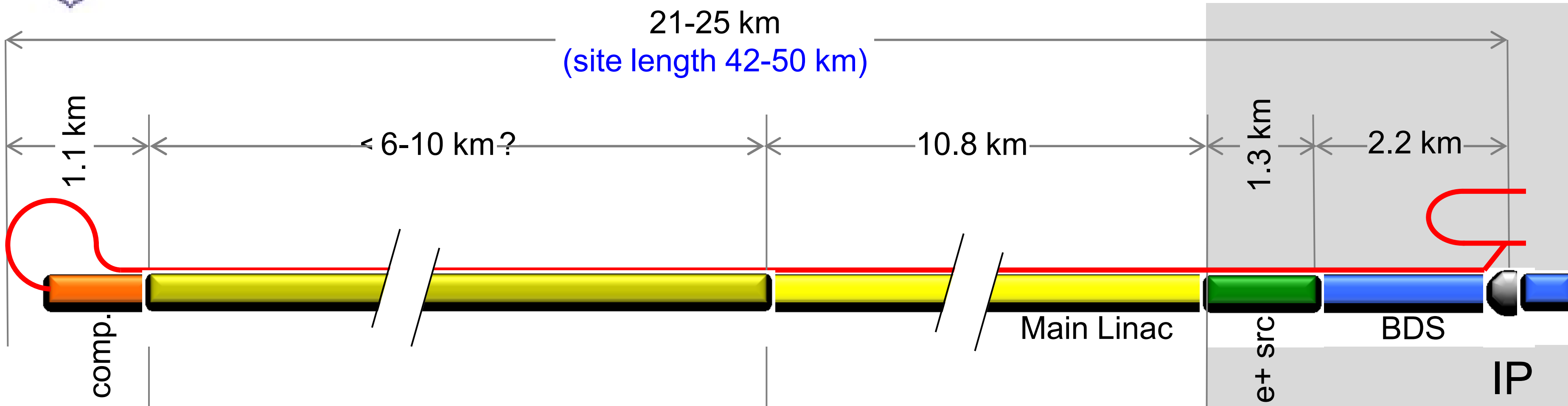
Main Linac

$\langle G_{cavity} \rangle$ = 31.5 MV/m

G_{eff} ≈ 22.7 MV/m

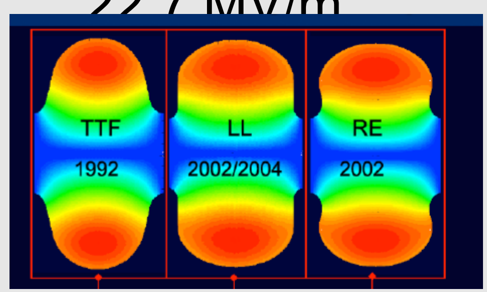
(fill fact. = 0.72)

From 500 GeV -> 1 TeV



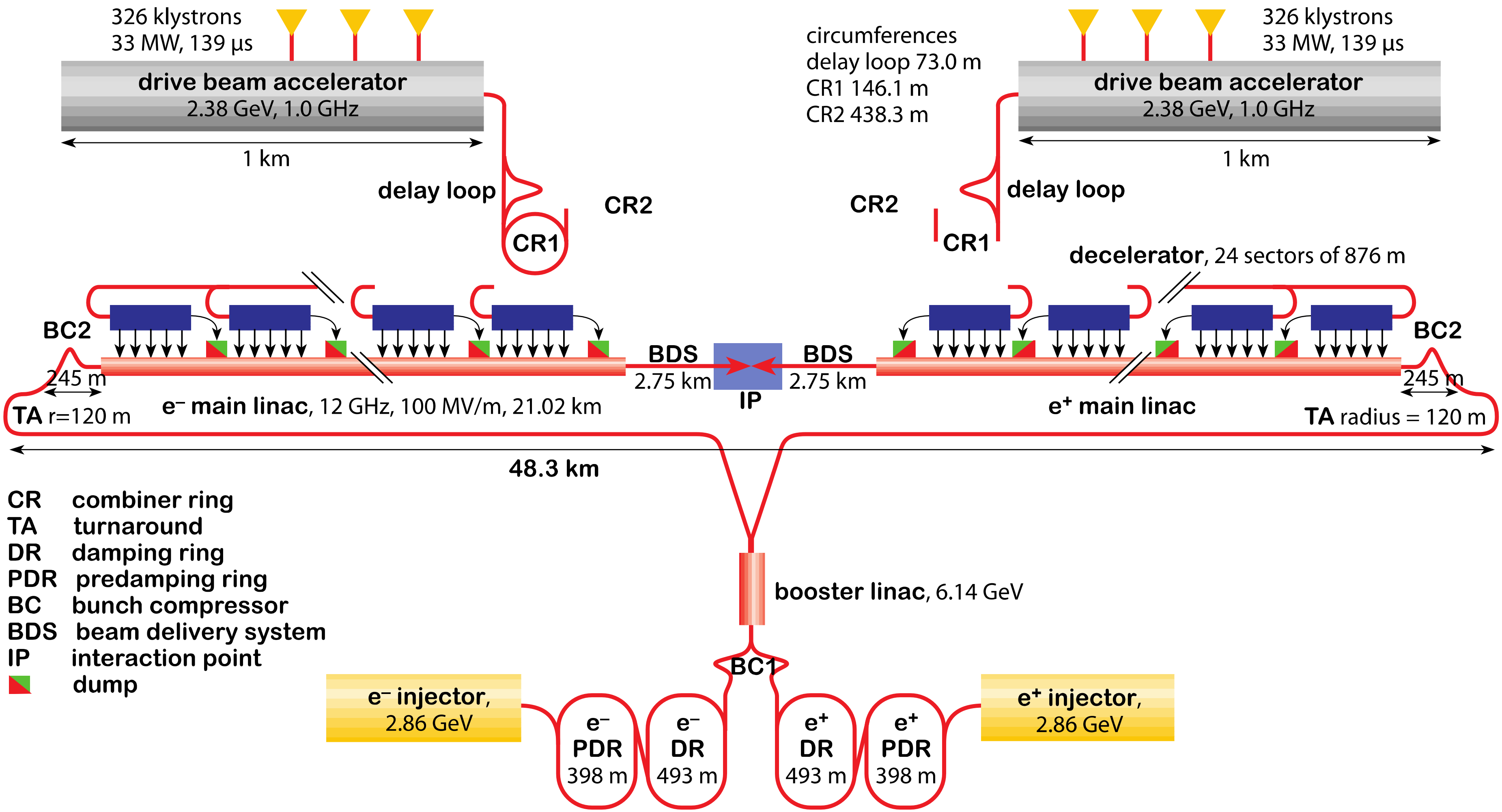
Main Linac
$\langle G_{cavity} \rangle$ = 31.5 MV/m
G_{eff} ≈ 22.7 MV/m

Snowmass 2005 baseline recommendation for TeV upgrade:
G_{cavity} = 36 MV/m ⇒ 9.6 km
(VT ≥ 40 MV/m)



Based on use of low-loss or re-entrant cavity shapes

CLIC



CR combiner ring
TA turnaround
DR damping ring
PDR predamping ring
BC bunch compressor
BDS beam delivery system
IP interaction point
dump

Parameters

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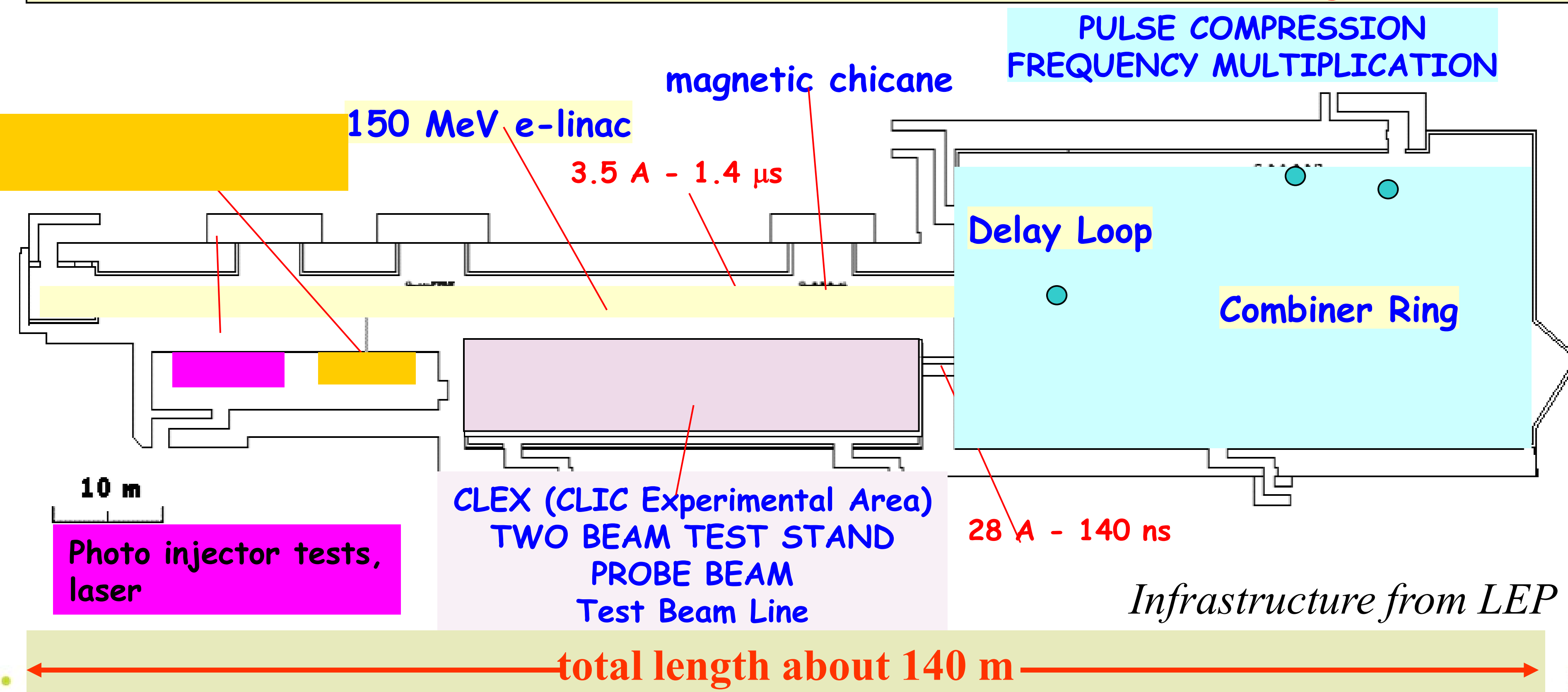
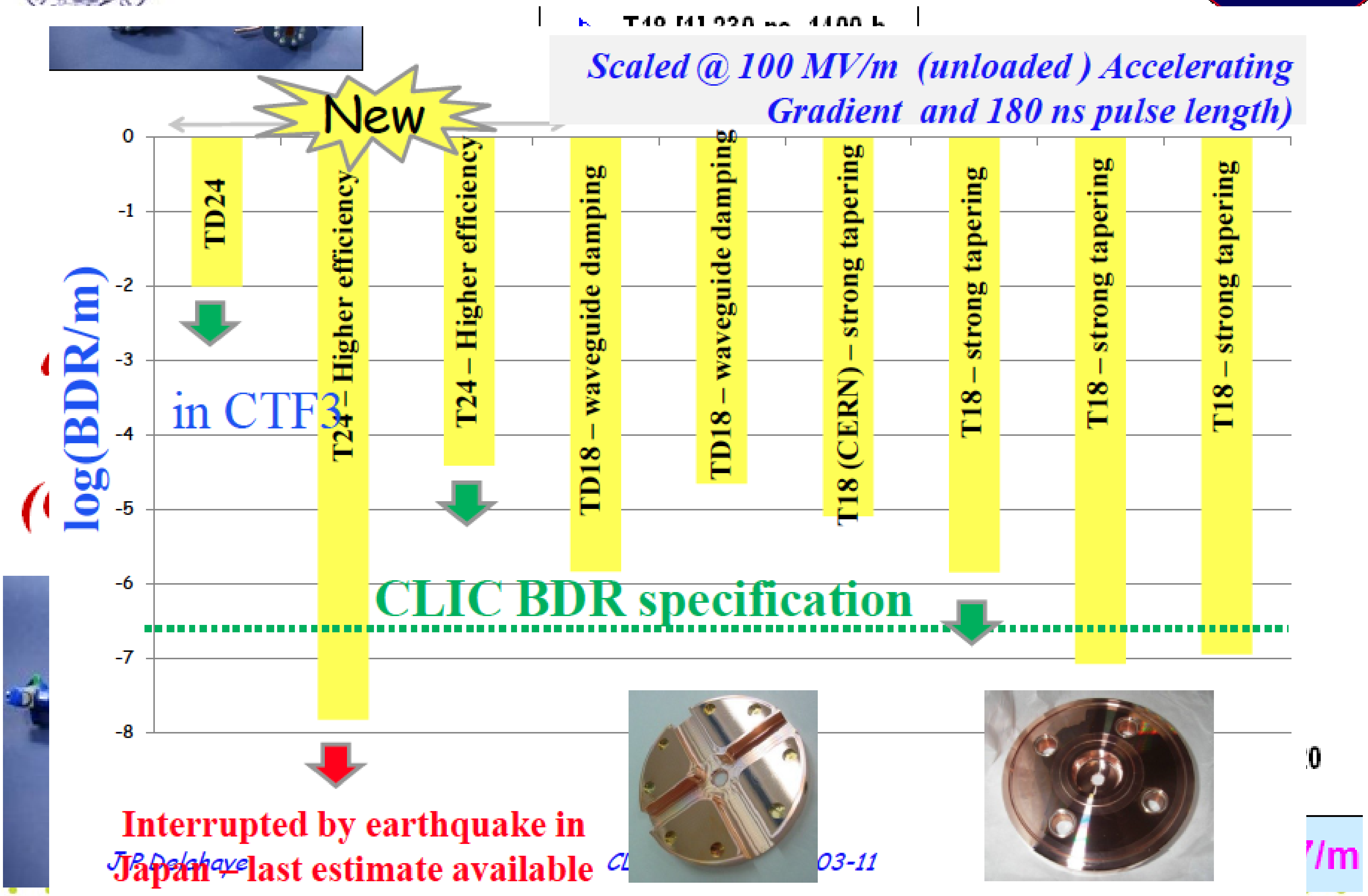
CTF3 @ CERN

- Demonstrate Drive Beam generation
  (fully loaded acceleration, beam intensity and bunch frequency multiplication x8)
- Demonstrate RF Power Production and test Power Structures
- Demonstrate Two Beam Acceleration and test Accelerating Structures

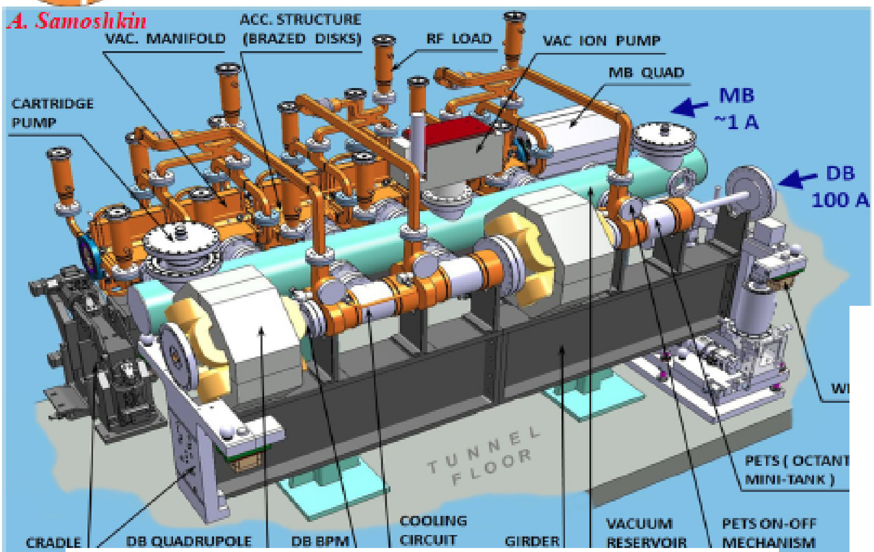


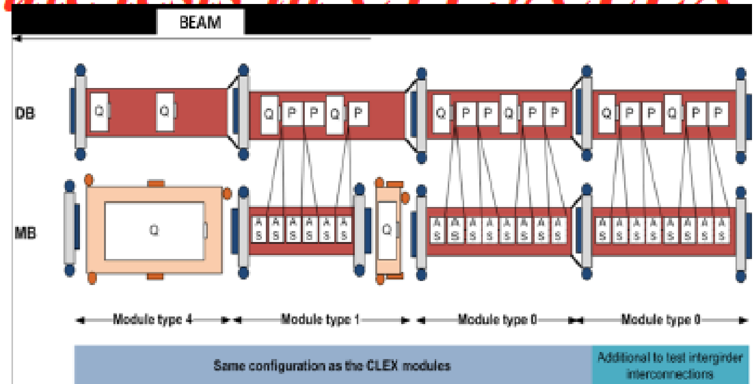
RF Structure Breakdown

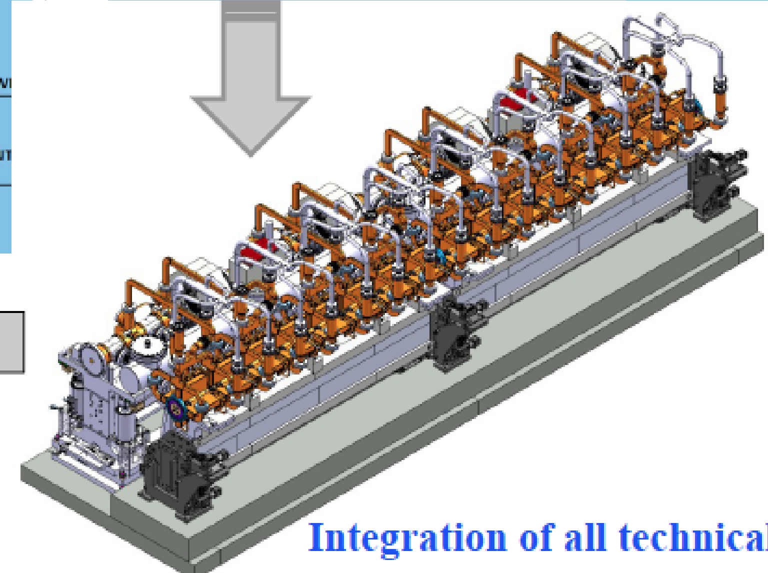


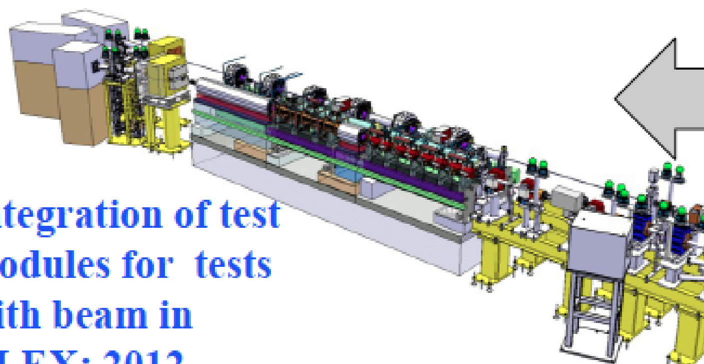
Two-Beam Module tests

Two Beam Module tests in CTF3/CLEX









Integration of test modules for tests with beam in CLEX: 2012

Integration of all technical systems for tests without beam in laboratory: 2011

Test module representing all module types & integrating all various components: RF structures, quadrupoles, instrumentation, alignment, stabilization, vacuum, etc

Muon Collider

COST

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PHYSICS

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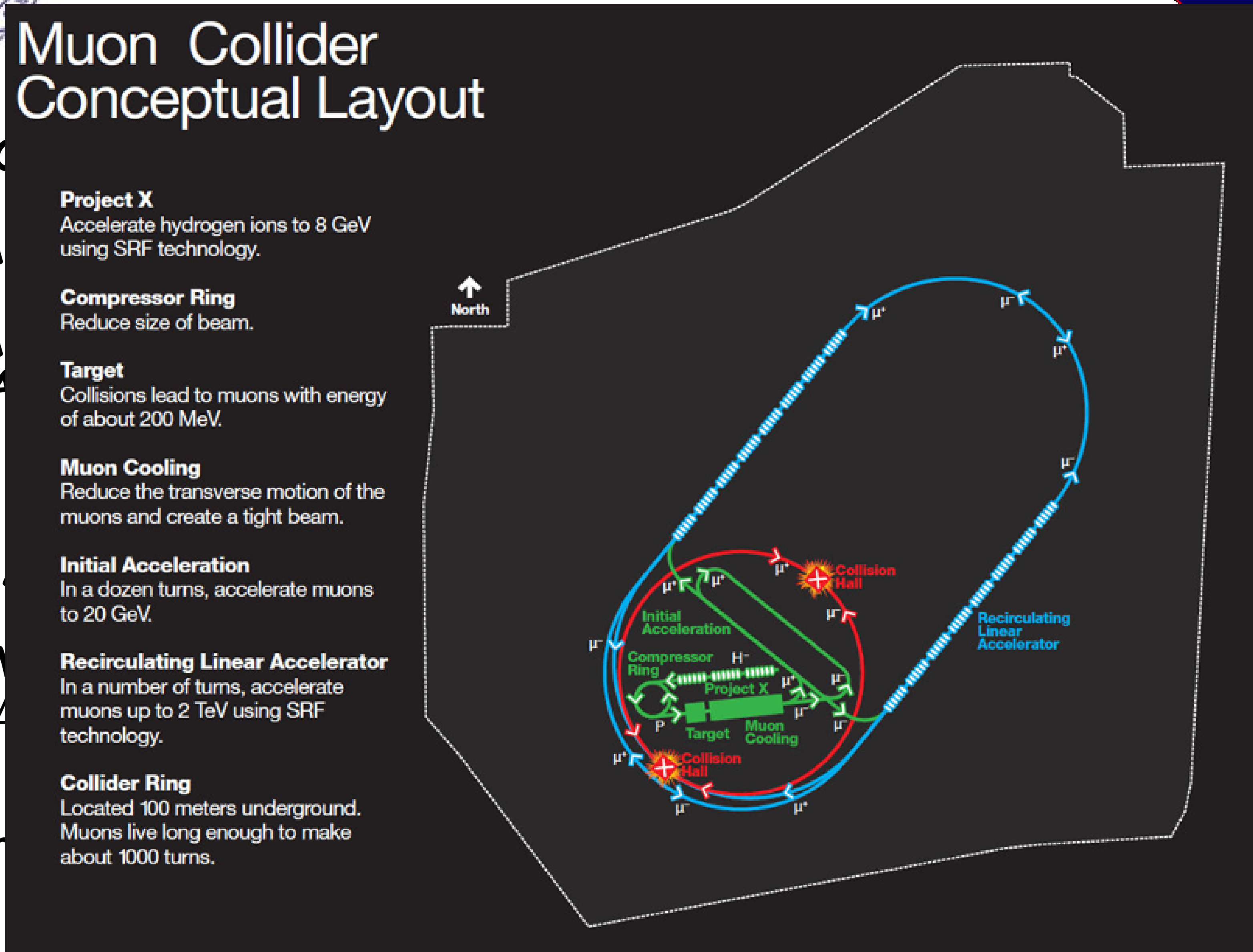
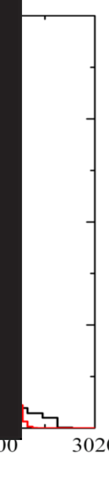
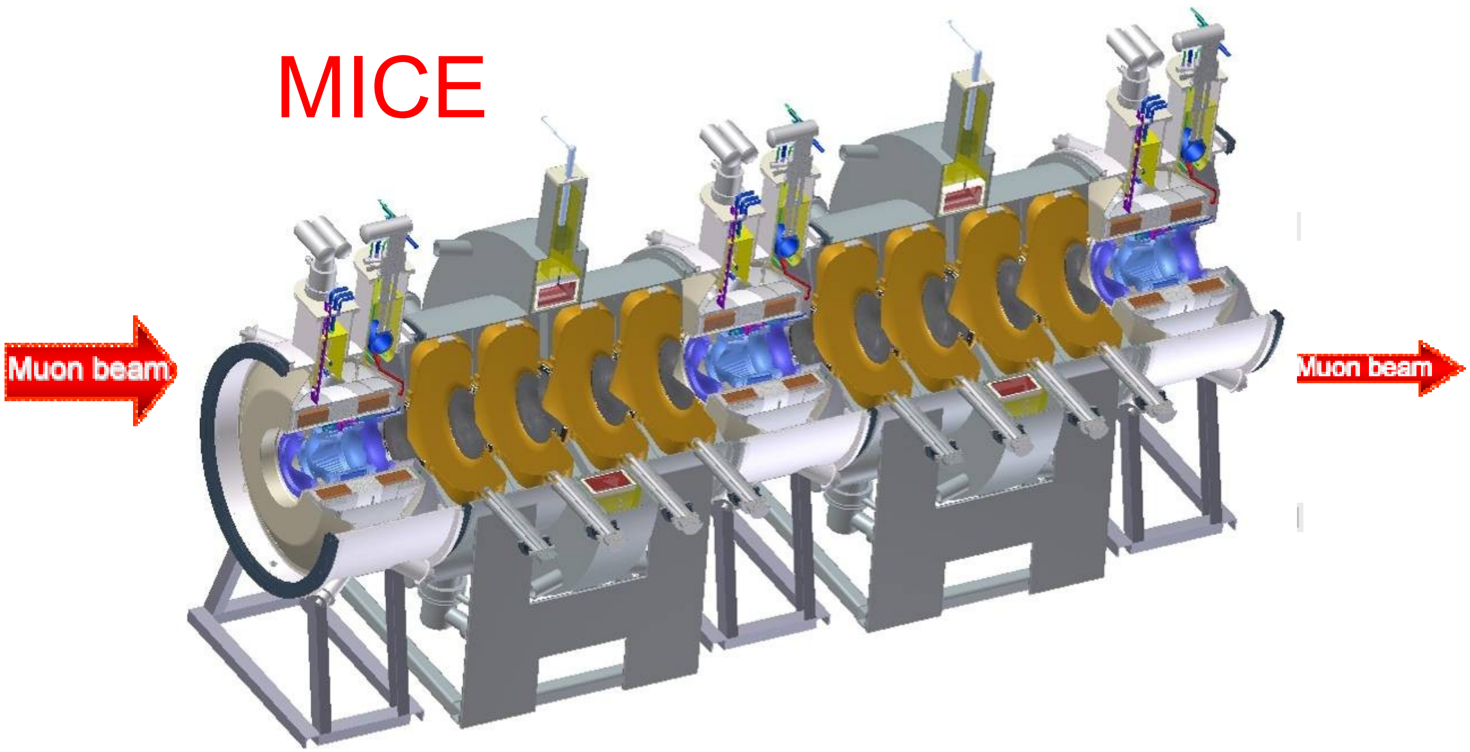




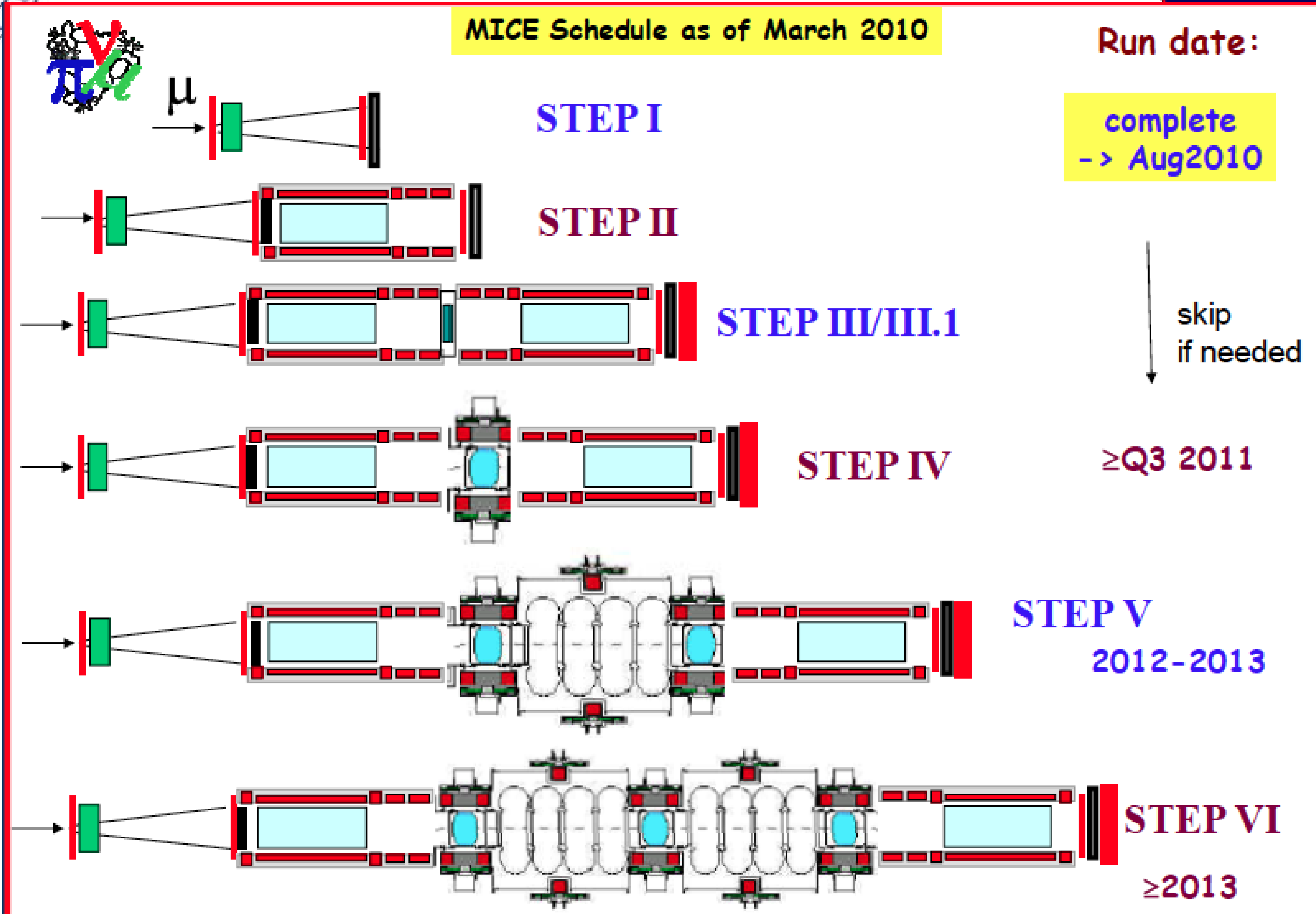
Muon Collider Cooling

- Ionization cooling analogous to familiar SR damping process in electron storage rings
  - **energy loss (SR or *dE/ds*) reduces p_x, p_y, p_z**
  - **energy gain (RF cavities) restores only p_z**
  - **repeating this reduces $p_{x,y}/p_z$ (⇒ 4D cooling)**

MICE

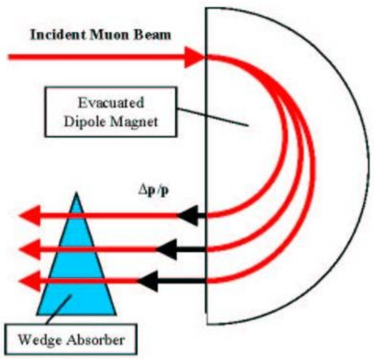


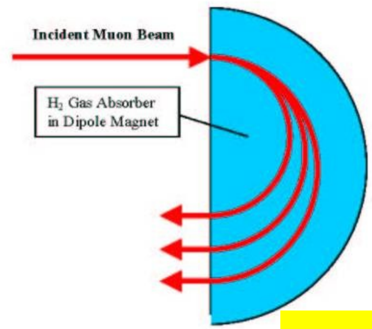
MICE Schedule



Muon Collider Cooling

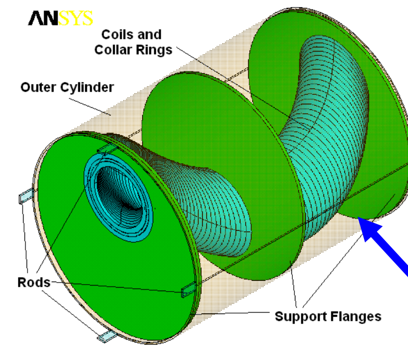
- Need 6D cooling (emittance exchange)
  - increase energy loss for high-energy compared with low-energy muons
    - put wedge-shaped absorber in dispersive region
    - use extra path length in continuous absorber



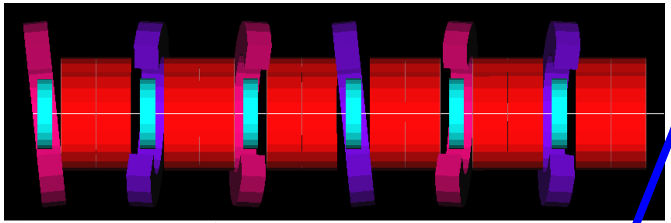


Muons, Inc.

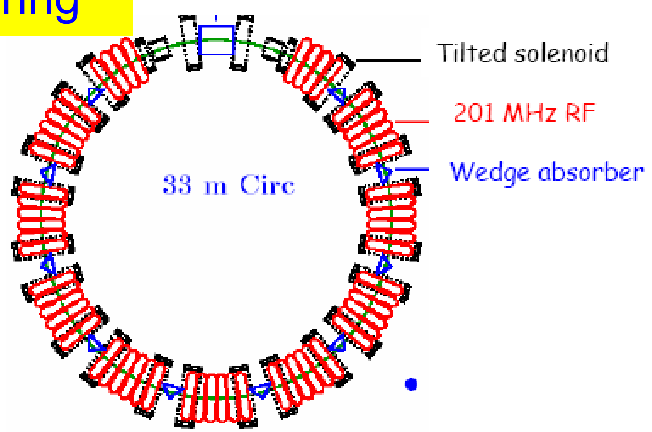
HCC

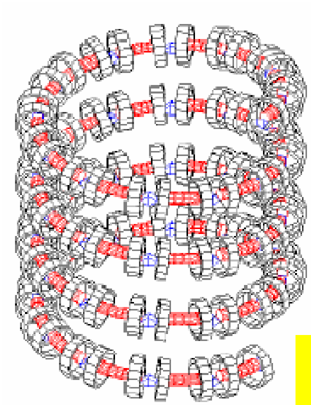


FOFO Snake



Cooling ring





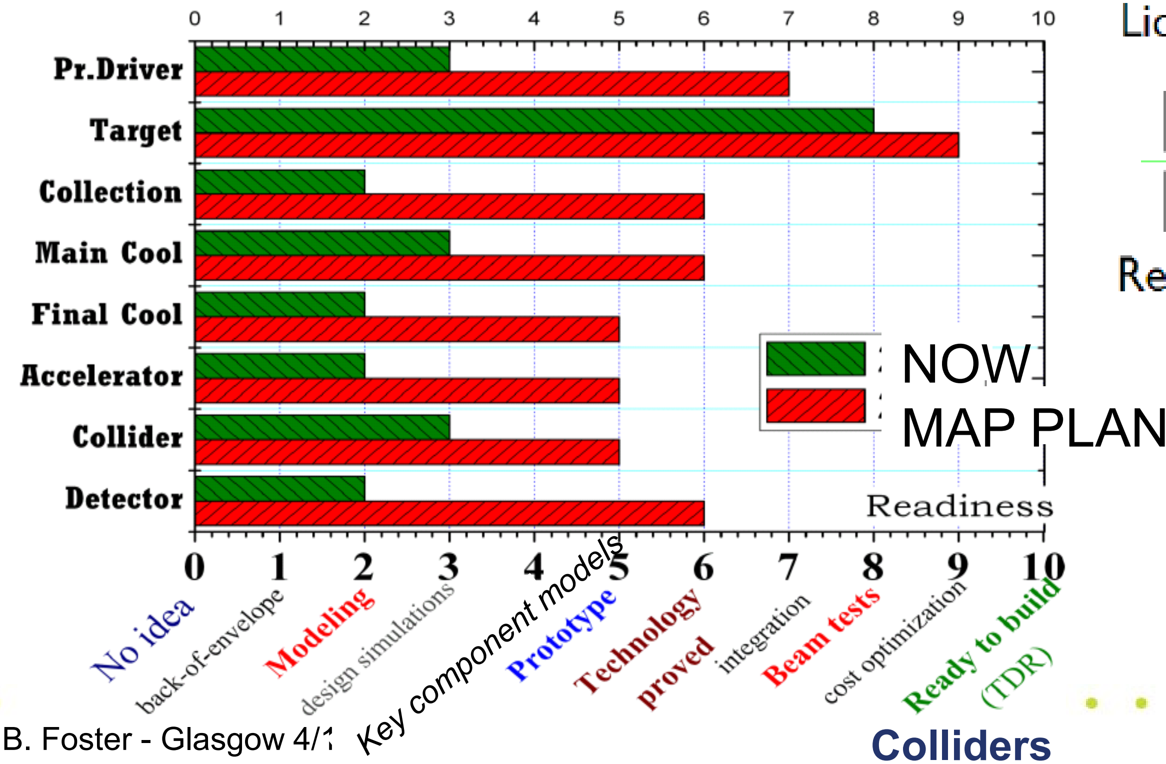
Single pass; avoids injection/extraction issues

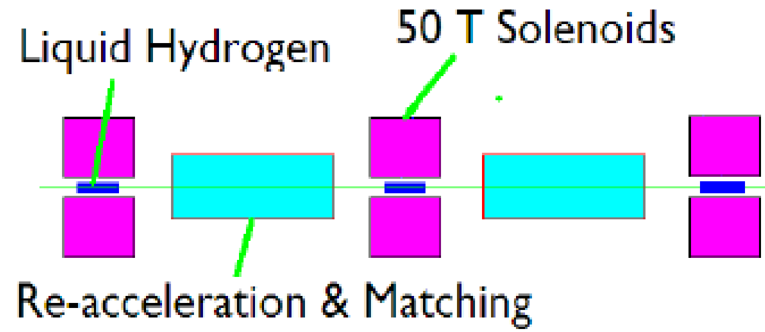
“Guggenheim” channel

Muon Collider Cooling

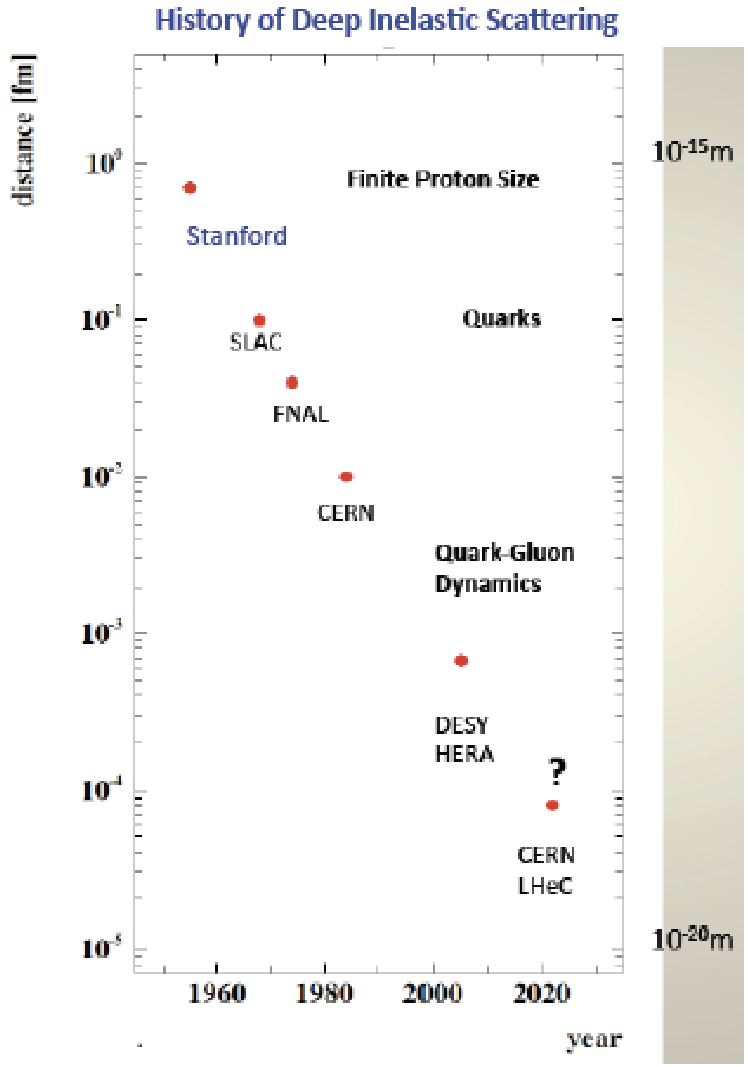
- **Final cooling to 25 μm emittance requires strong solenoids**
  - **— not exactly a catalog item ⇒ R&D effort**
  - **— latest design uses 30 T**
- **45 T hybrid device exists**
  - **— very high power device, so not a good "role model"**
  - **— exploring use of HTS for this task**

Palmer, Fernow





LHeC



Two options:

Ring-Ring

Power Limit of 100 MW wall plug

"ultimate" LHC proton beam

60 GeV $e^{\pm}$ beam

→ $L = 2\ 10^{33}\ cm^{-2}s^{-1}$ → $O(100)\ fb^{-1}$

LINAC Ring

Pulsed, **60 GeV**: $\sim 10^{32}$

High luminosity:

Energy recovery: $P=P_0/(1-\eta)$

$\beta^*=0.1m$

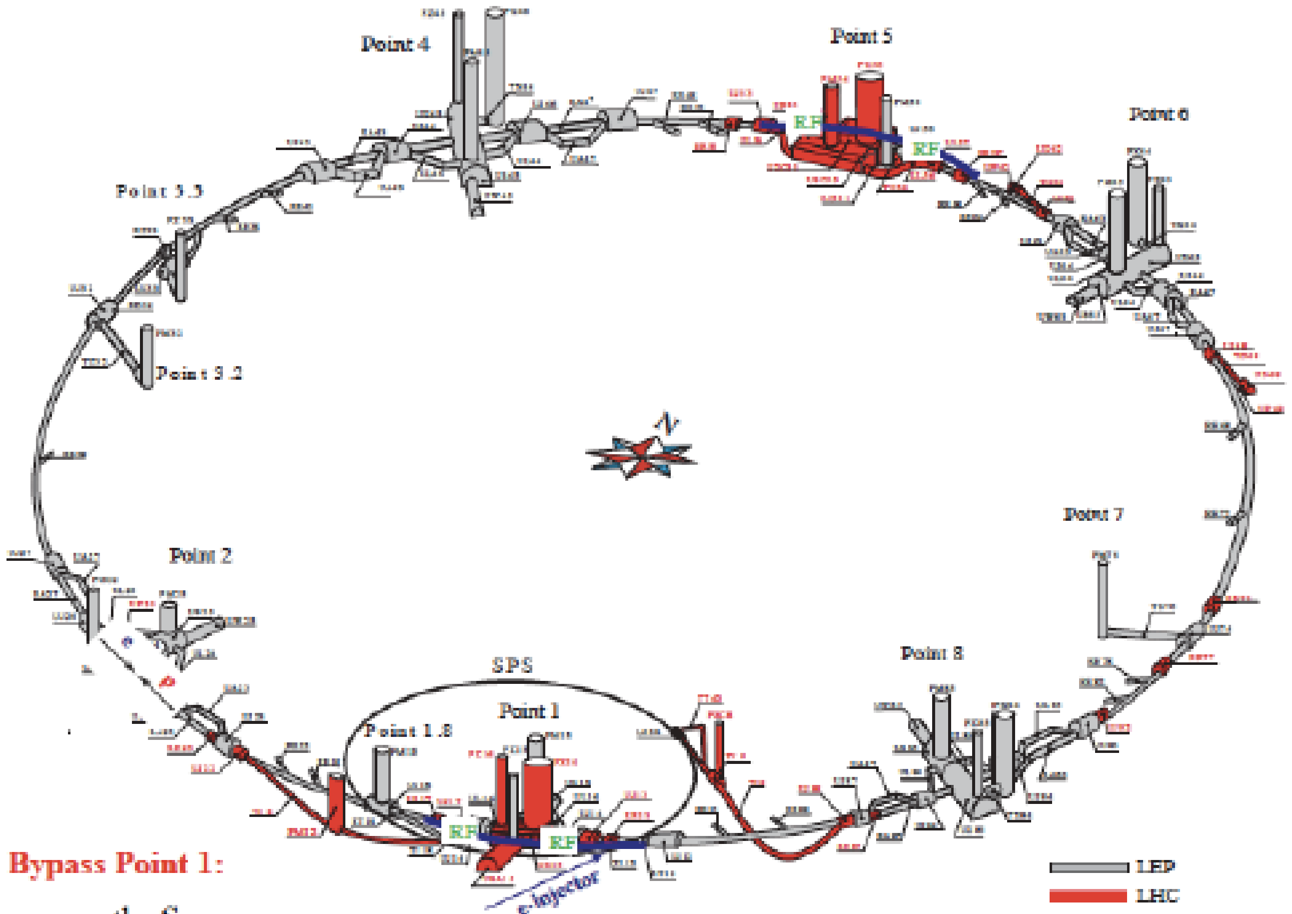
[5 times smaller than LHC by reduced l*, only one p squeezed and IR quads as for HL-LHC]

$L =\ 10^{33}\ cm^{-2}s^{-1}$ → $O(100)\ fb^{-1}$

LHeC Ring Option

Bypass Point 5:

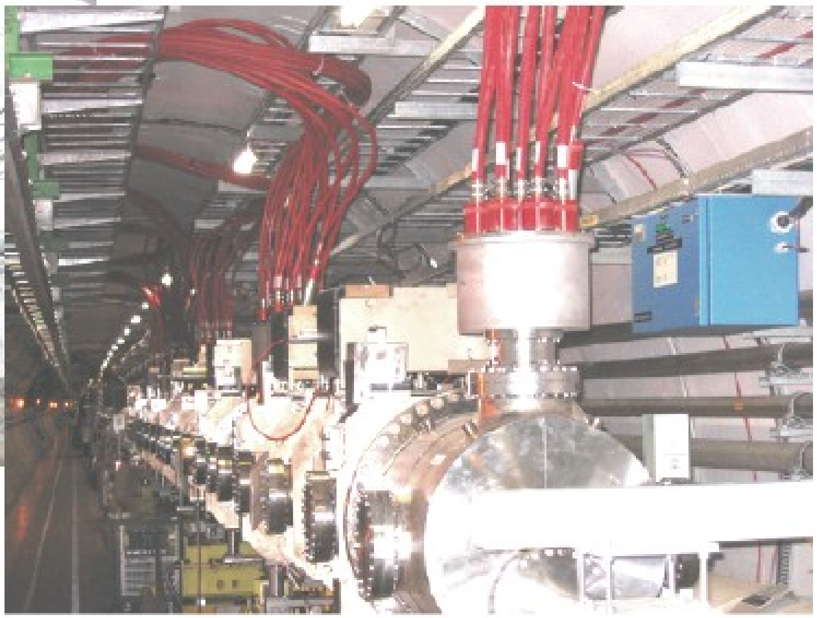
- adjustment of the circumference by varying the separation
- Δ=20.56 Meter



Bypass Point 1:

- uses the Survey Gallery
- Δ=16.25 Meter

LHeC Ring Option

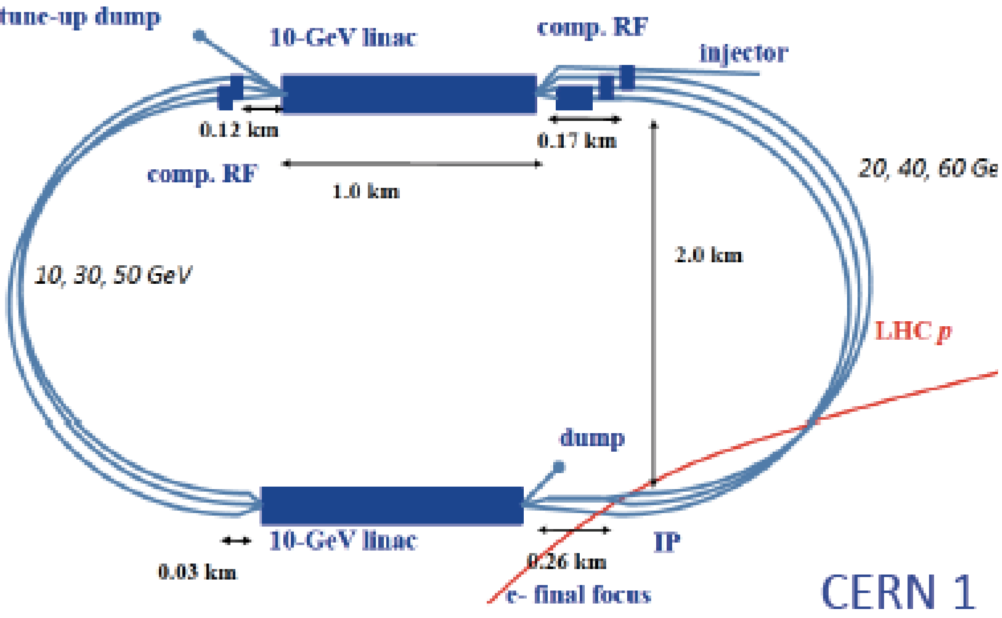


- Installation of an e ring is challenging
- Modifications of the existing installations will be necessary
- No show stopper

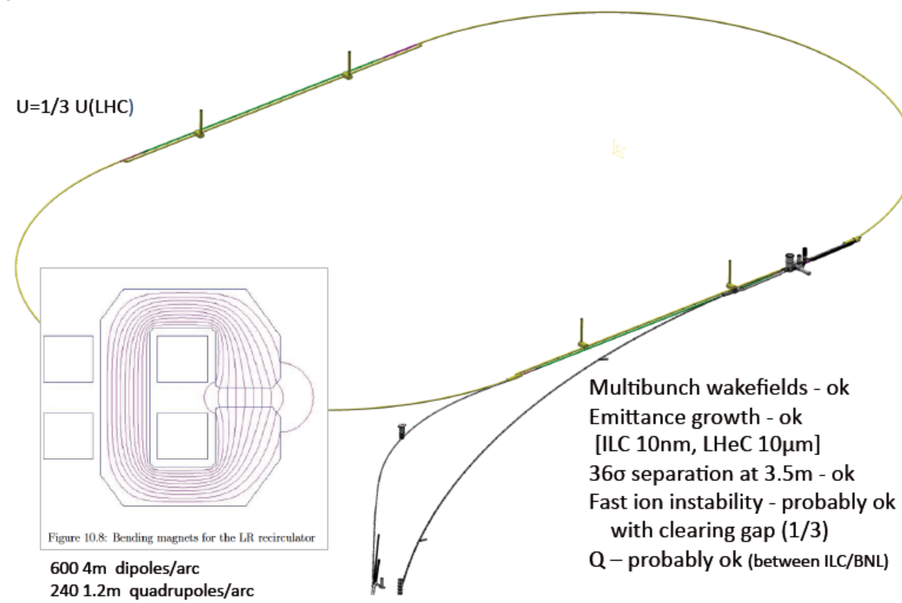
This is the big question for the ring option (interference, activation,..)

LHeC Linac Option

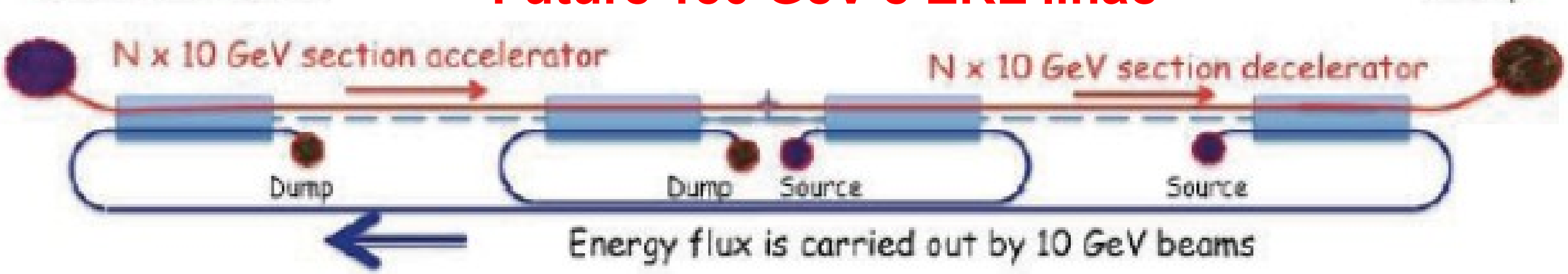
THREE-PASS ERL



Single-PASS 60 GeV ERL

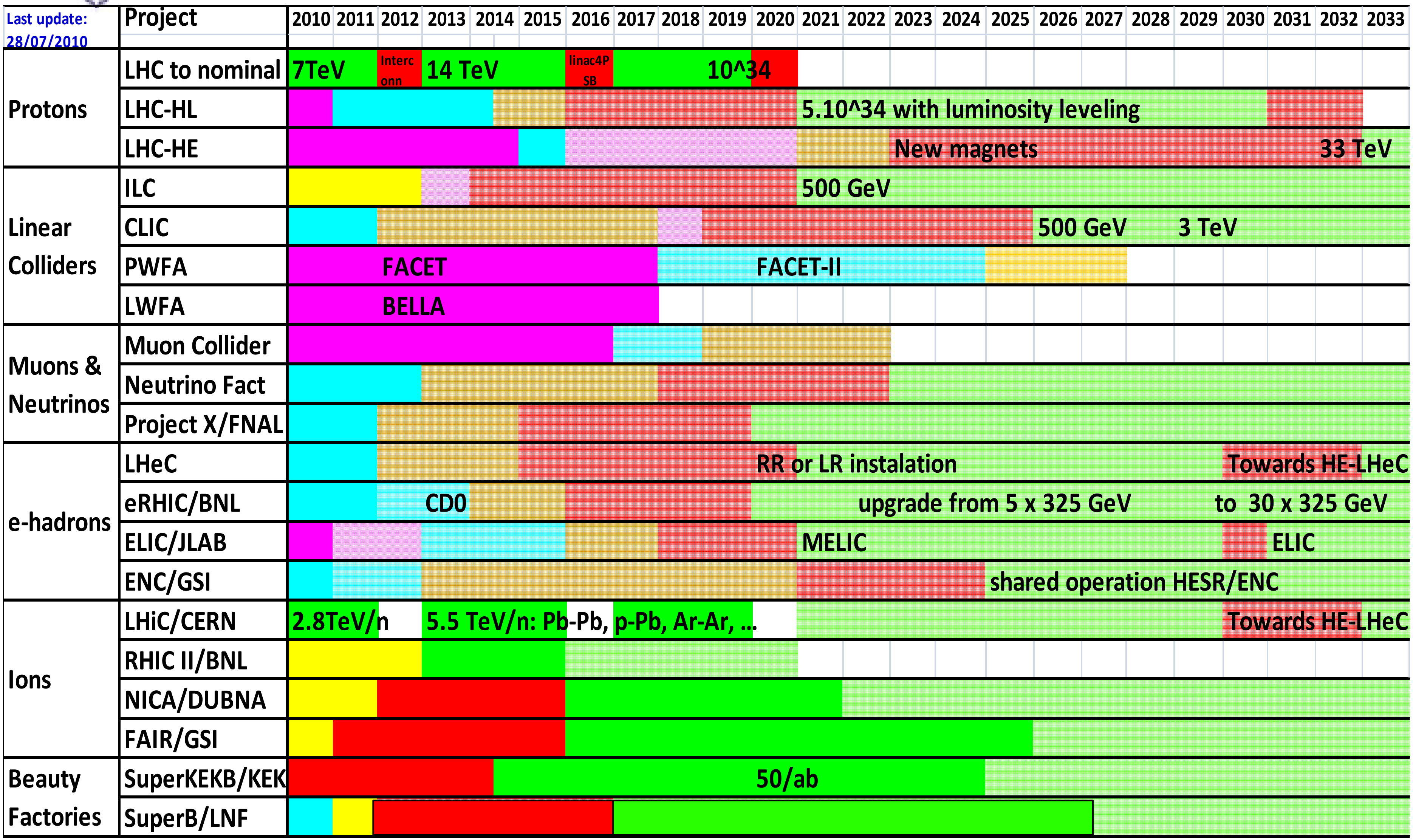


Future 150 GeV e ERL linac

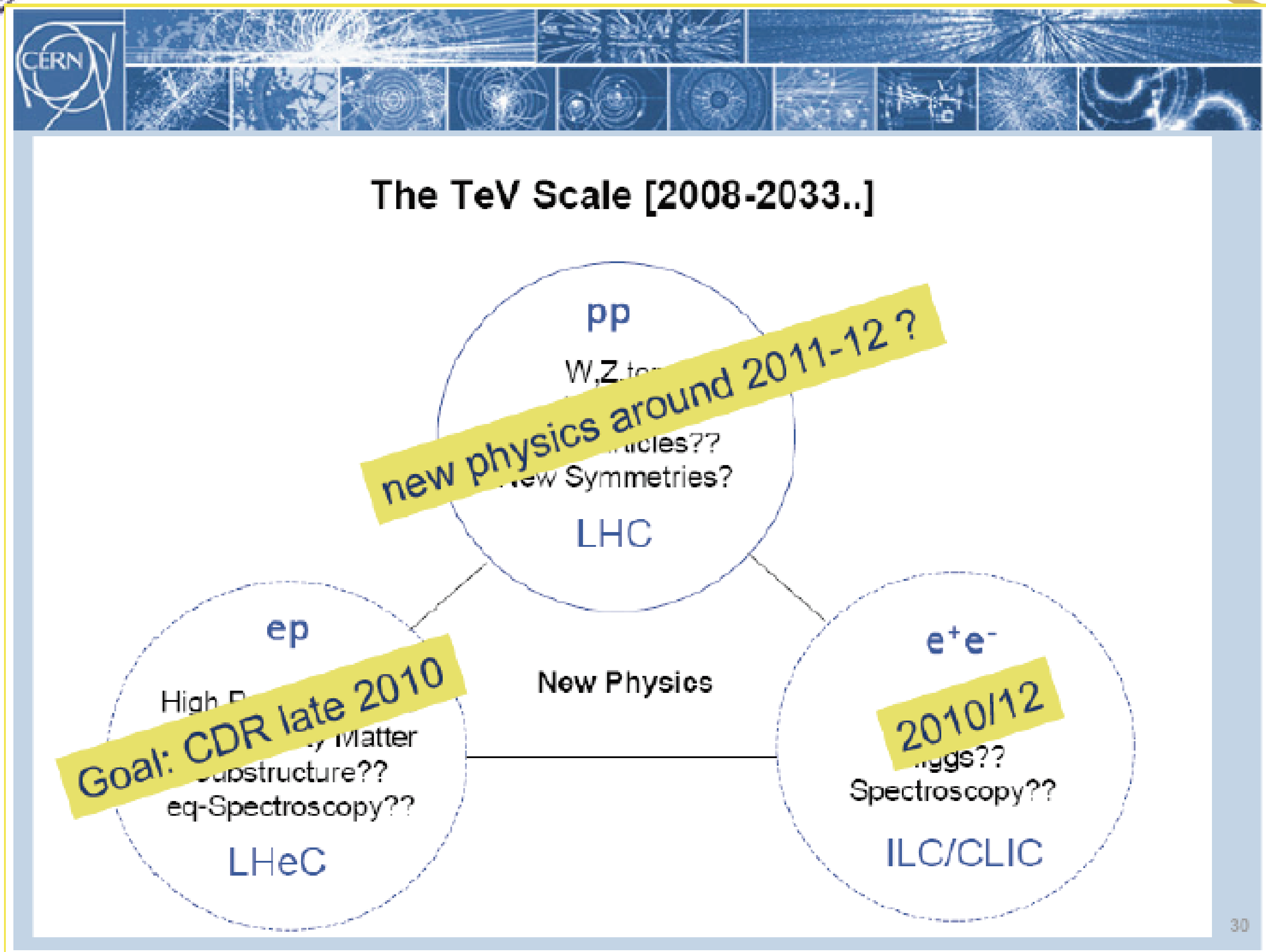


Tentative schedule new projects

Color code	approved	envisaged/proposed
R&D		
R&D to CDR		
Technical design to TDR		
Construction		
Operation		

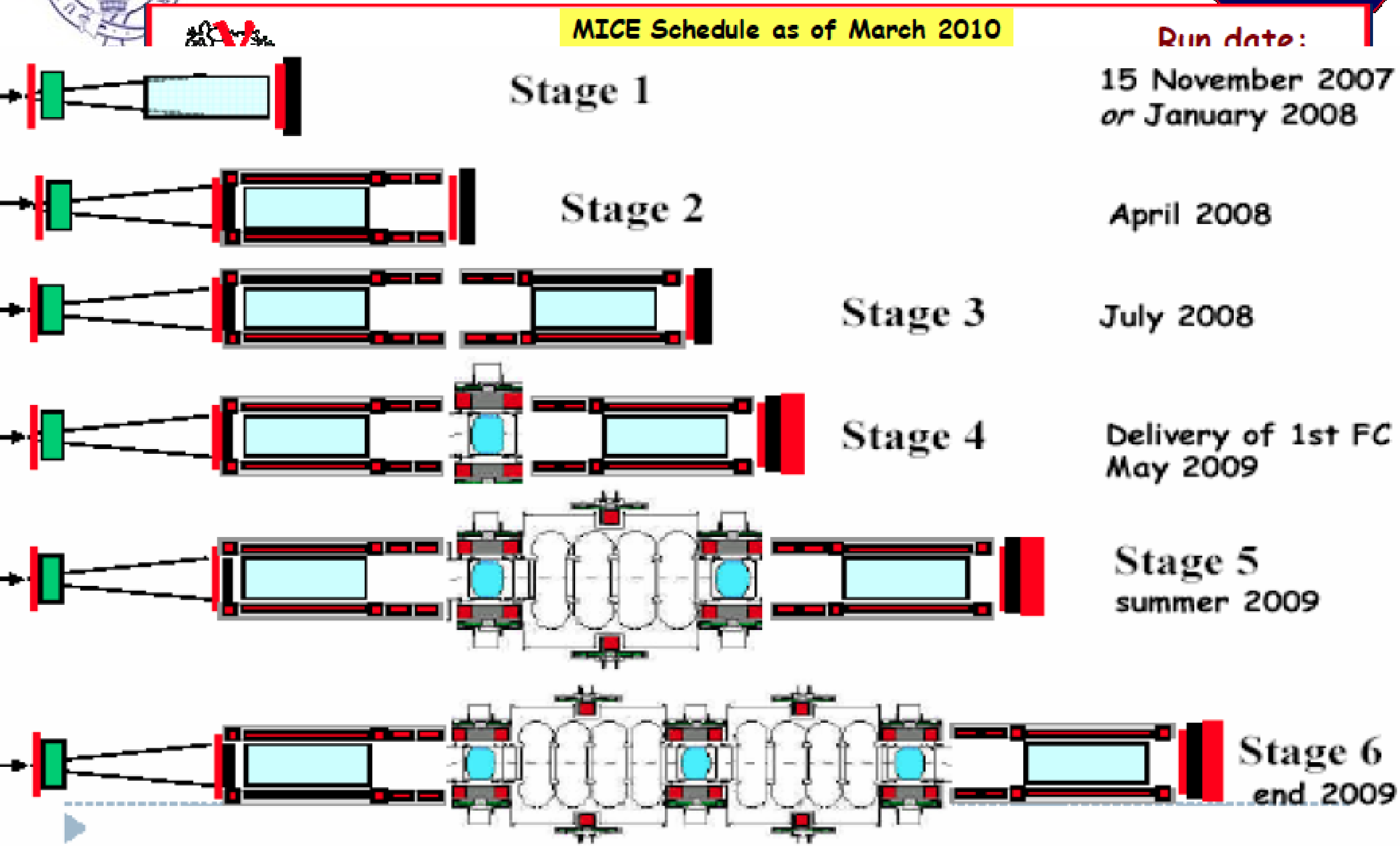


LHeC



Rolf Heuer: 3/4. 12. 09 at CERN: From the Proton Synchroton to the Large Hadron Collider
50 Years of Nobel Memories in High-Energy Physics

MICE Schedule



Summary and Outlook

- None of the projects I have discussed are very near realisation
- ILC – technically mature – but cost.
- CLIC – much development required – cost?

}CLOSE Collaboration

- MC – well, what can I say? It's a great idea….
- LHeC – technically "OK" probably – lots of details & a TDR.
- We have to be realistic about technical maturity, schedule and cost – I don't believe that we are at the moment and politicians can smell it.
- If we want a facility in addition to LHC within YOUR active lifetime – let alone mine - we need:
- **FOCUS ◆ REALISM ◆ DETERMINATION** + LUCK