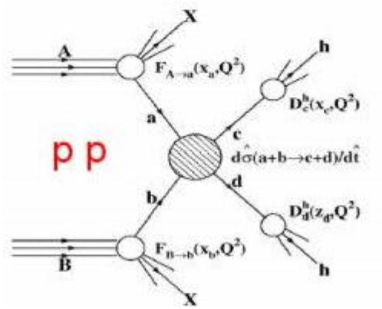
High-energy Lepton Colliders

D. Schulte

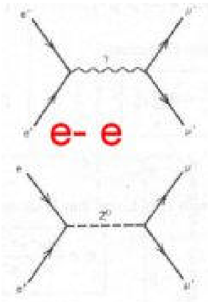
Lepton Colliders

- Japan-KEK: Consider hosting ILC
- European Strategy: Beyond LHC: FCC or CLIC to follow, ILC in Japan a welcome initiative
- Snowmass -> P5: Physics potential of ILC and US participation (within 2025 Horizon)
- China: CepC
- …

- Hadron collisions: compound particles
  - Mix of quarks, anti-quarks and gluons: variety of processes
  - Parton energy spread
  - QCD processes large background sources
  - Hadron collisions $\Rightarrow$ large discovery range



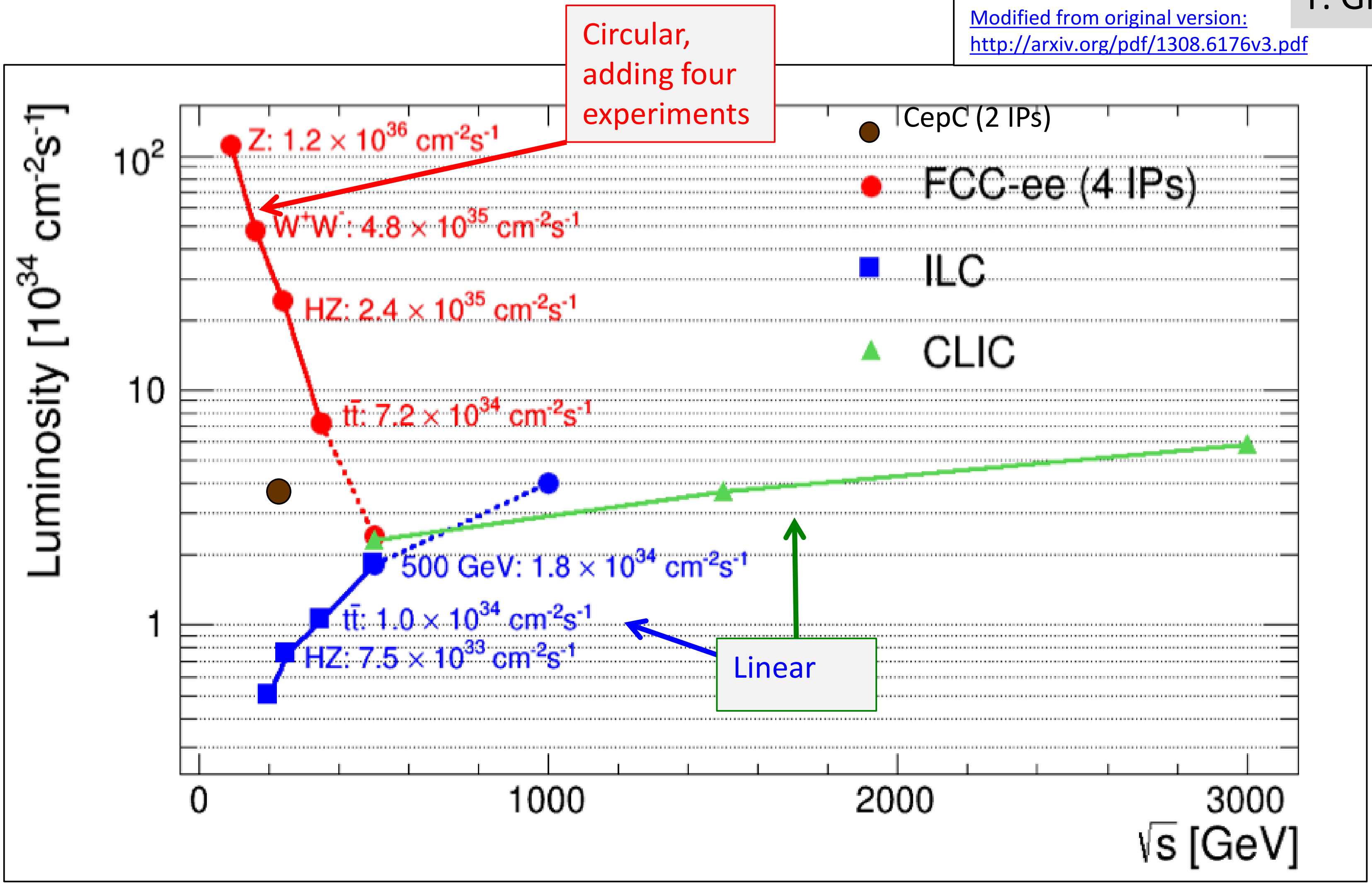
- Lepton collisions: elementary particles
  - Collision process known
  - Well defined energy
  - Less background
  - Lepton collisions $\Rightarrow$ precision measurements



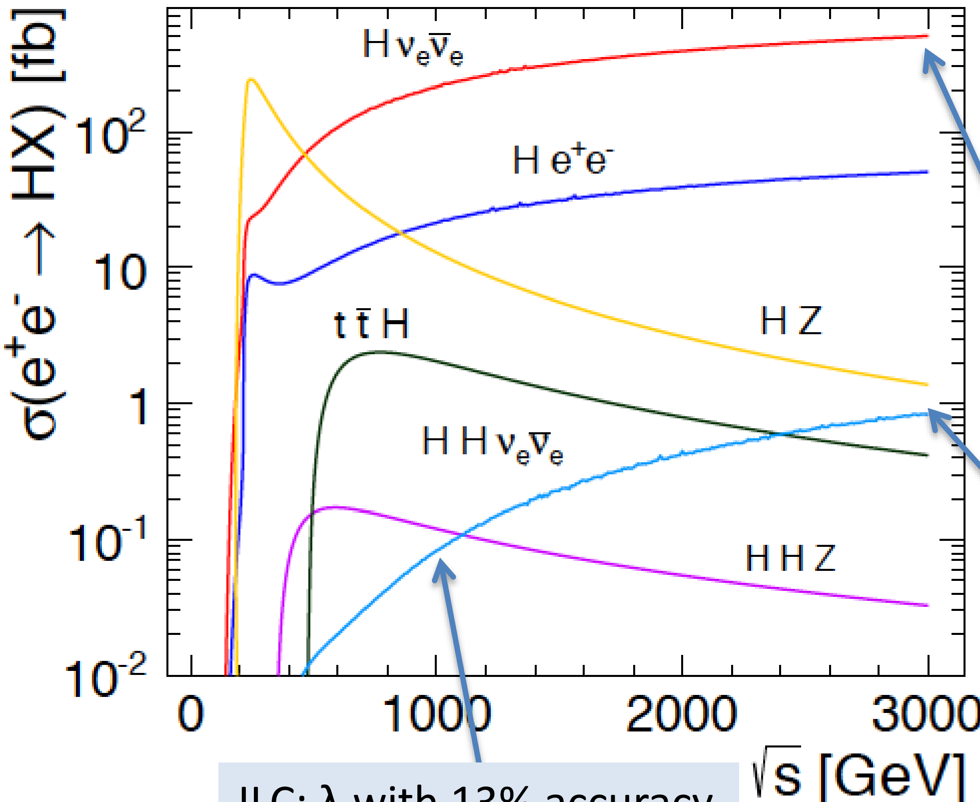
Circular vs. Linear Lepton Colliders

F. Gianotti

Modified from original version: http://arxiv.org/pdf/1308.6176v3.pdf



Higgs Physics

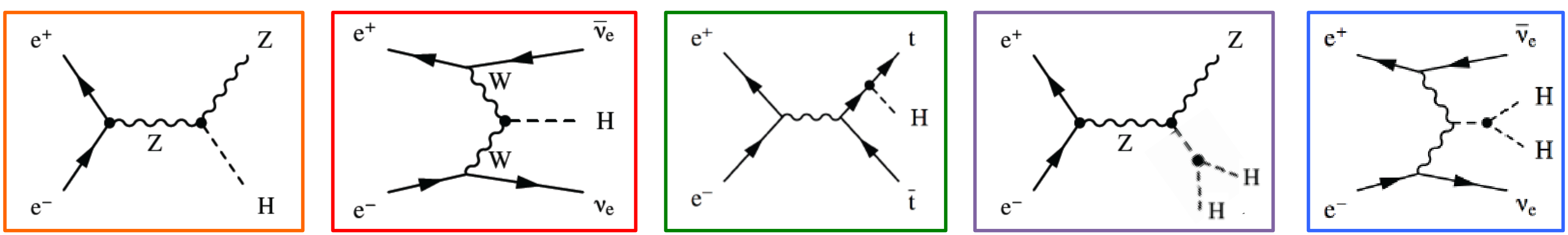


- **Precision Higgs measurements**
- Model-independent
  - Higgs couplings
  - Higgs mass
- Large energy span of linear colliders allows to collect a maximum of information:
  - ILC: 500 GeV (1 TeV)
  - CLIC: ~380 GeV – 3 TeV

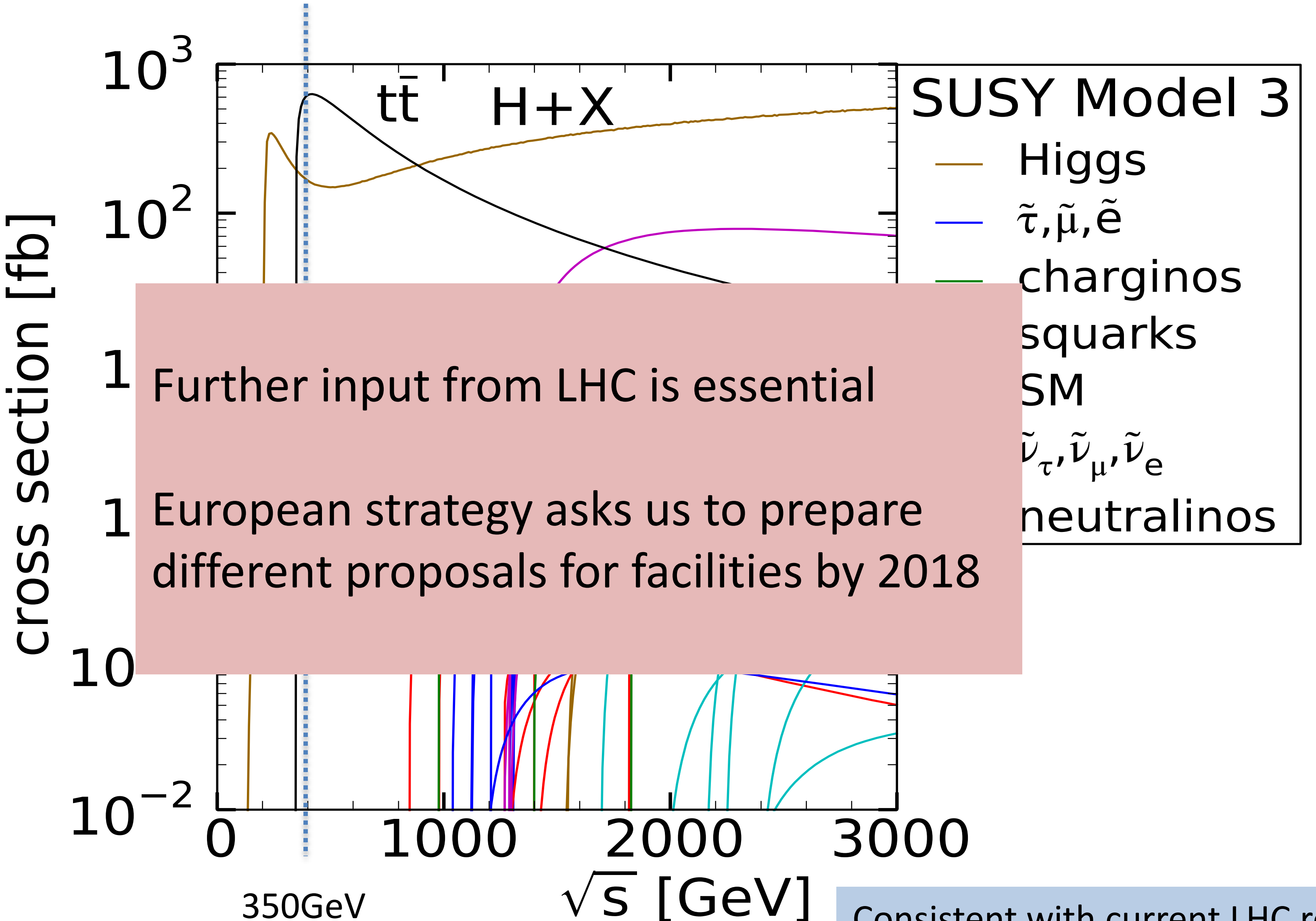
CLIC: 5×10^5 higgs/year

ILC: λ with 13% accuracy

CLIC: λ with 12% accuracy



Example of Potential SUSY Scenario

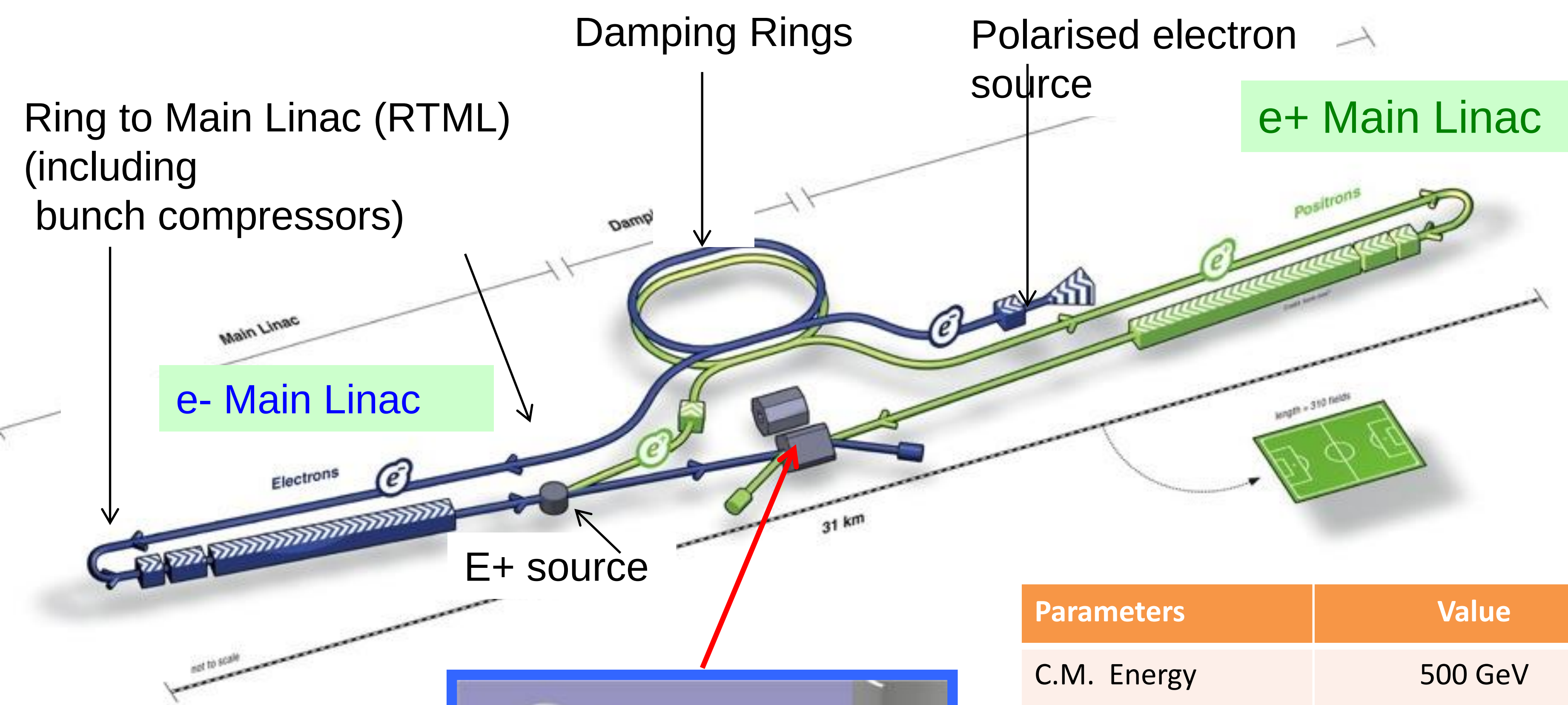


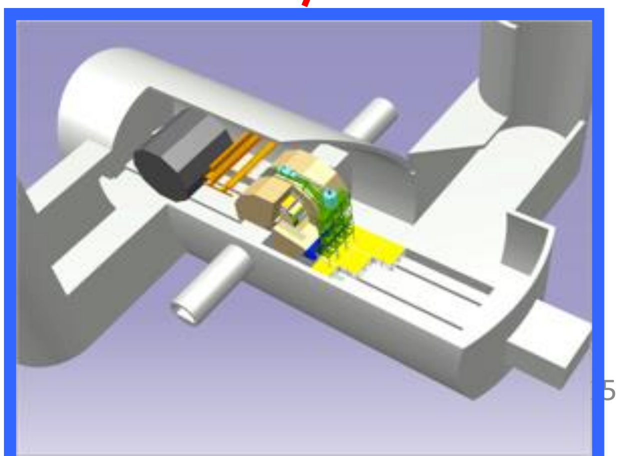
Further input from LHC is essential

European strategy asks us to prepare different proposals for facilities by 2018

Consistent with current LHC results

ILC





Parameters	Value
C.M. Energy	500 GeV
Peak luminosity	1.8 x10^{34} $cm^{-2}s^{-1}$
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Average current	5.8 mA (in pulse)
E gradient in SCRF acc. cavity	31.5 MV/m +/-20% Q_0 = 1E10

ILC Main Linac

ILC cavity:
- 1.3 GHz, superconducting
- Target effective operational 31.5MV/m
- 5 O(1ms) pulses with 1300 bunches per second

Cavity gradients scatter
- Aim for acceptance of 90%

Cavities are produced in Europe, Asia, Americas
- Required gradient has been demonstrated

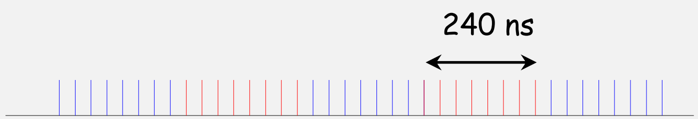
Mass production of cavities and modules is well advanced for European XFEL
- Lower gradient required

Very close to target

CLIC Layout at 3 TeV

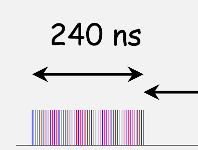
Drive Beam Generation

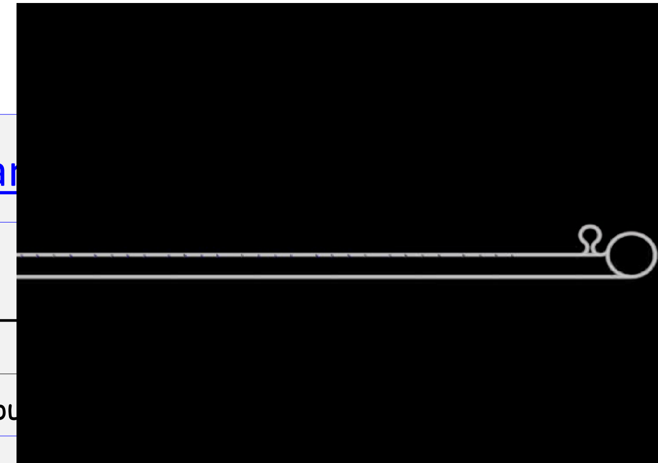
Drive beam time structure - initial

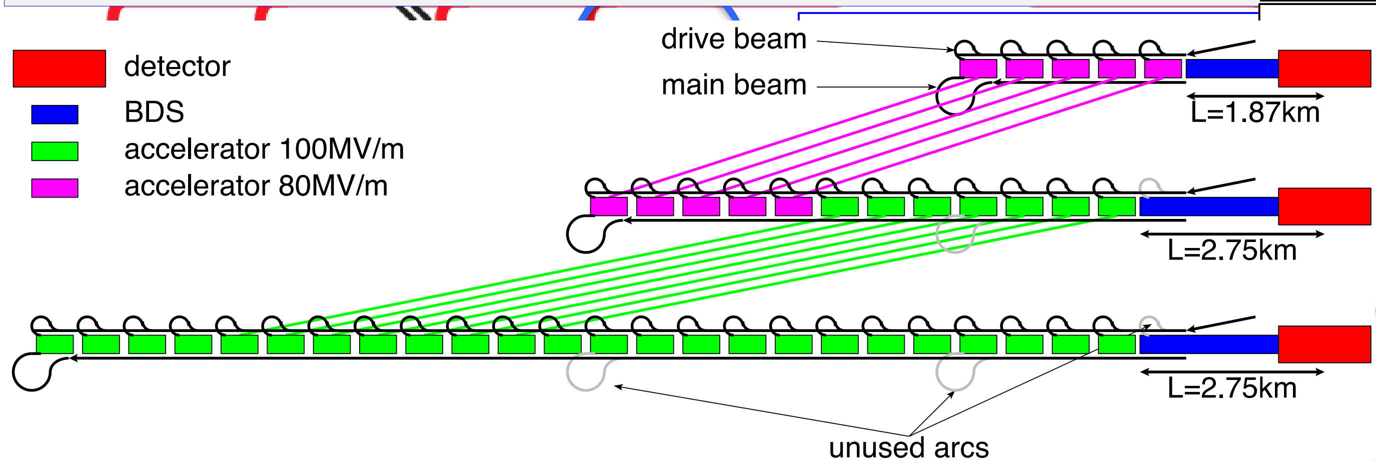


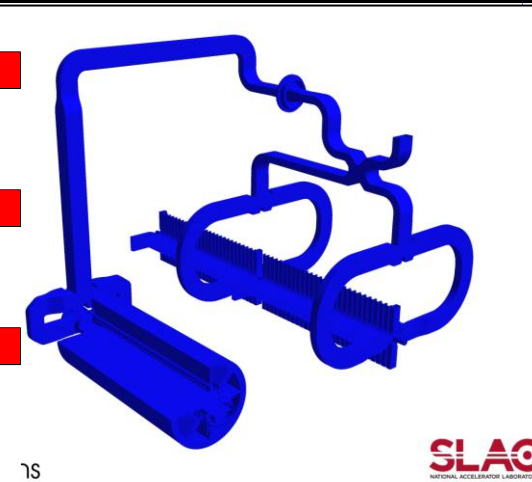
140 μs train length - 24 × 24 sub-pulses
4.2 A - 2.4 GeV – 60 cm between bunches

Drive bea





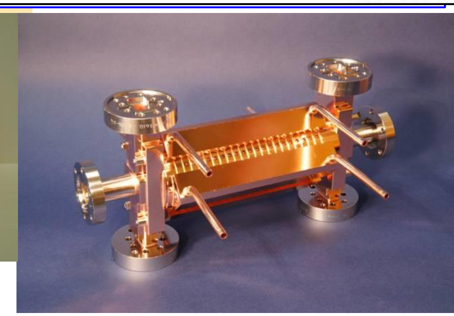




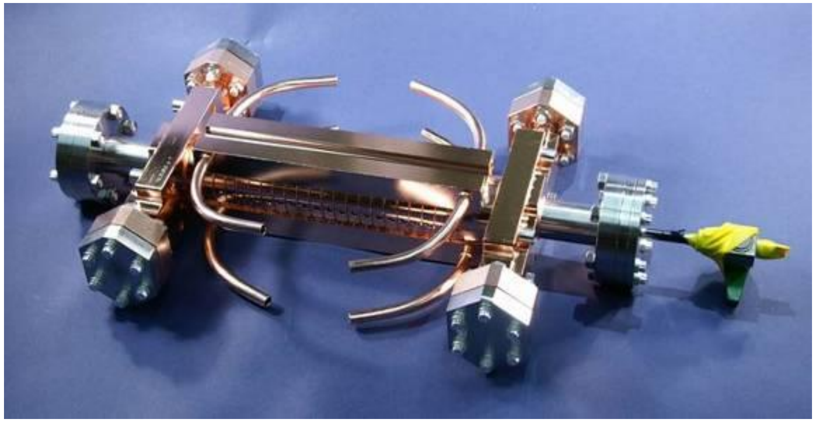
E_{cms}=380Gev, L=1.5x10^{34}cm^{-2}s^{-1}, $L_{0.01}$/L>0.6

E_{cms}=O(1.5TeV)

E_{cms}=3TeV, $L_{0.01}$=2x10^{34}cm^{-2}s^{-1}, $L_{0.01}$/L>0.3



CLIC Accelerating Structure



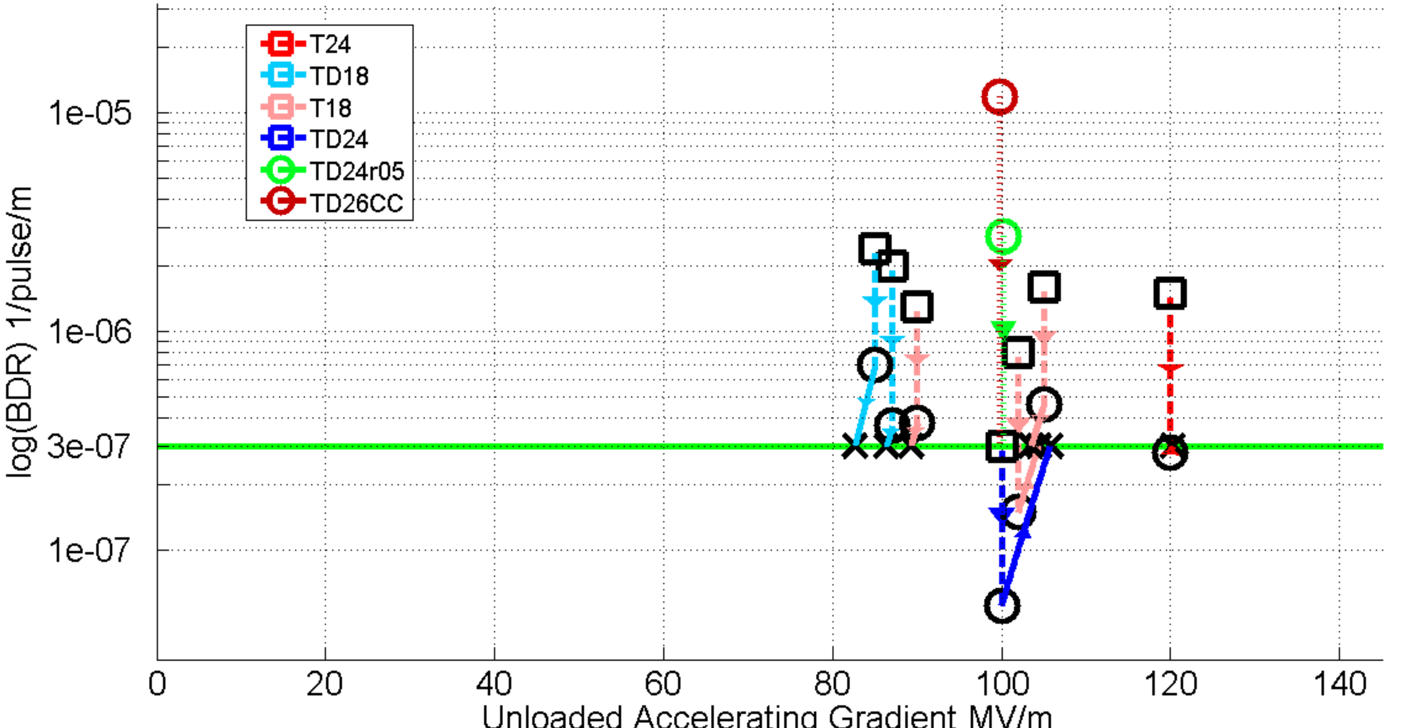
CLIC accelerating structure:

- 12 GHz, normal conducting
- Target loaded gradient 100MV/m
- 50 O(150ns) pulses with 312 bunches per second

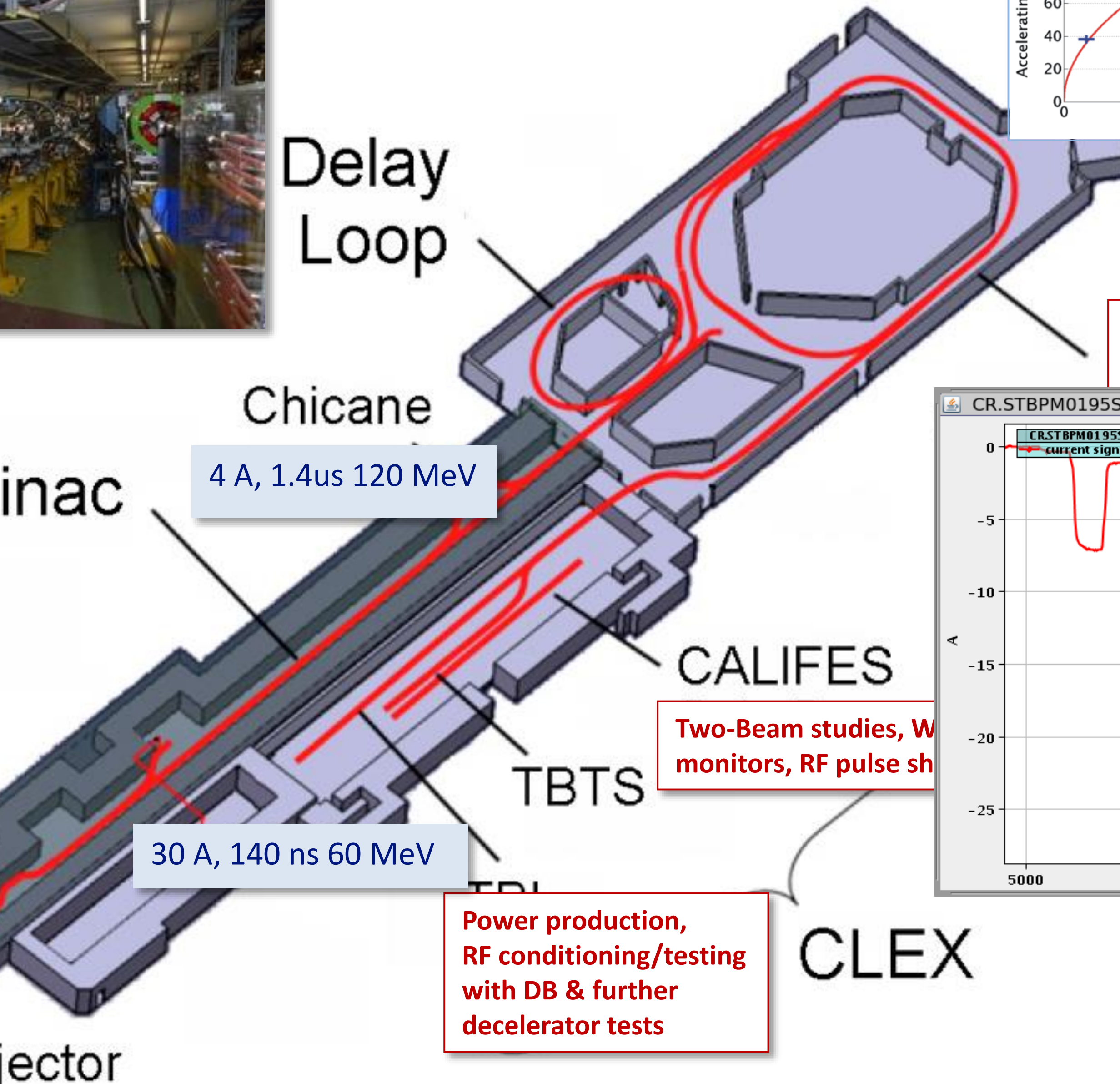
Gradient is close to target

Now focusing on

- Further improvements
- Preparation for mass production
- Cost reduction

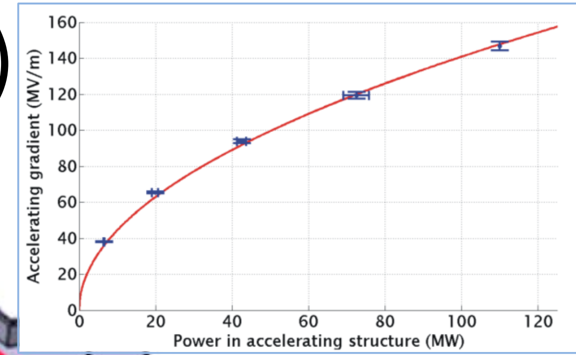


CLIC Test Facility (CTF3)

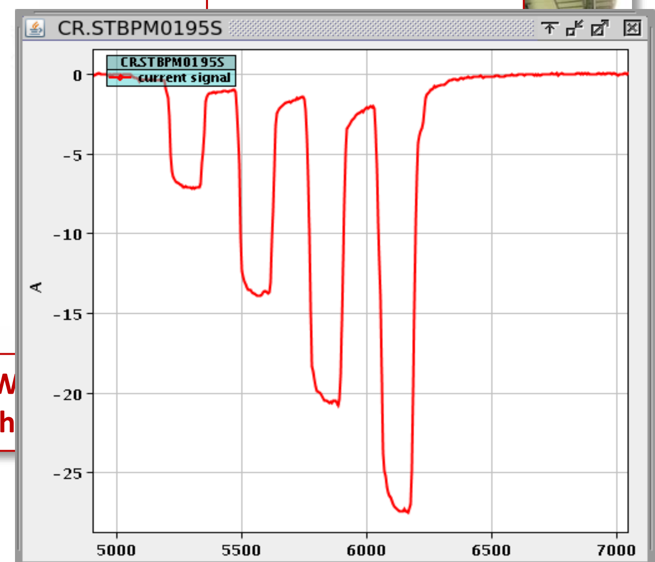


4 A, 1.4us 120 MeV

30 A, 140 ns 60 MeV

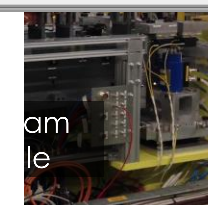


Phase feed-forward, DB stability studies



Two-Beam studies, W
monitors, RF pulse sh

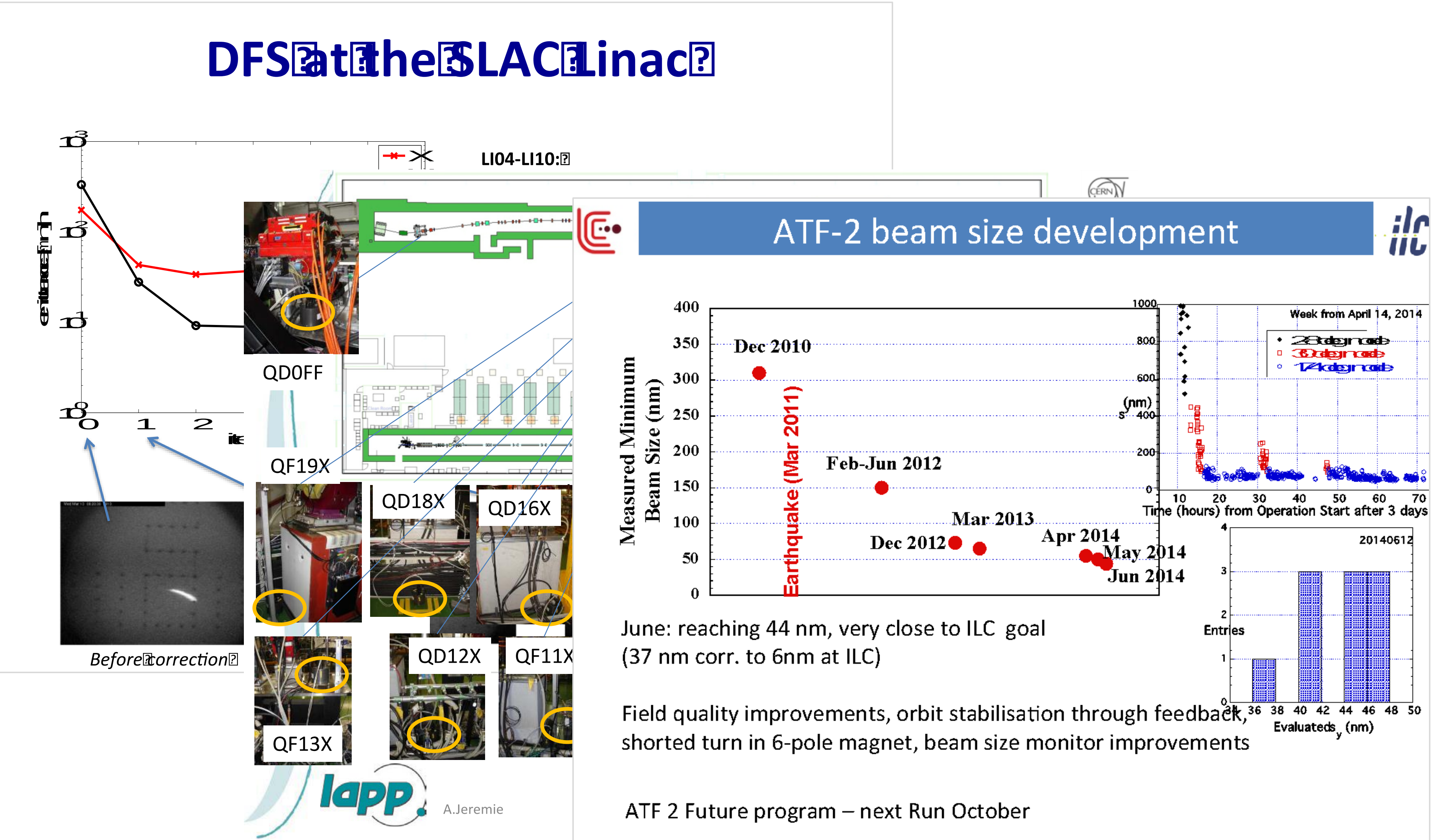
Power production, RF conditioning/testing with DB & further decelerator tests



Linear Collider Luminosity Issues

Many luminosity related studies have been performed

- High synergy between ILC and CLIC
- Damping rings, main linacs beam delivery system, …



ILC Status

	M&S Value (Ratio)	M&S Value (GILCU)	Labor (M person-hr)
			4.4
			4.4
			.6
			.9

http://v

Years	TDR baseline Scenario
1 - 2	Pre-preparation for 2yrs (for technical effort continuity)
3 - 6	Preparation (4 yrs)
7 - 15	Construction (9 yrs)
(12 -)	(start installation)
(13 -)	(start preparation for Operation)
16 -	Beam Commissioning start
17 –	Operation at 250 ~ 500 GeV (550 GeV)
TBD	Toward 500 GeV HL upgrade
TBD	Toward 1 TeV upgrade

MEXT's Organization for Studying ILC

based on SCJ's Recommendations

SCJ

Recommendation in 2013

MEXT

ILC Taskforce
formed in 2013

Academic Experts Committee
formed in 2014

Working groups are assessing the different aspects of such a project and its impact on Japan

Report in Spring 2016

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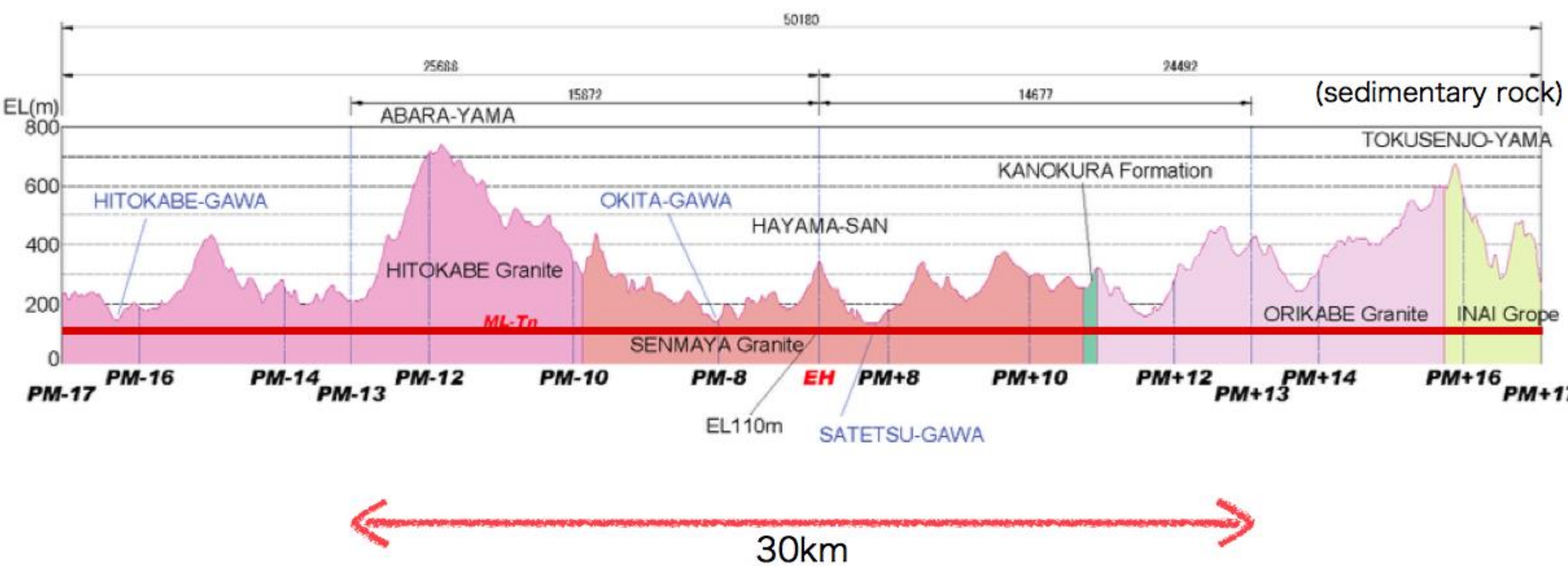
roup
2014

ILC preferred site - Kitakami

Site is being studied in detail



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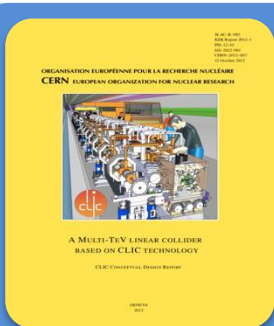
CDR 2013 -> input to strategy processes



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- CLIC conc
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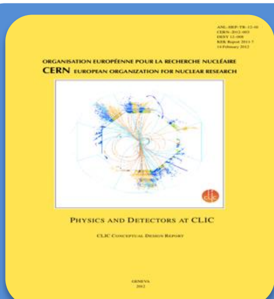

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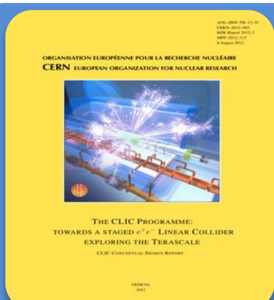

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- http://arxiv.org/pd

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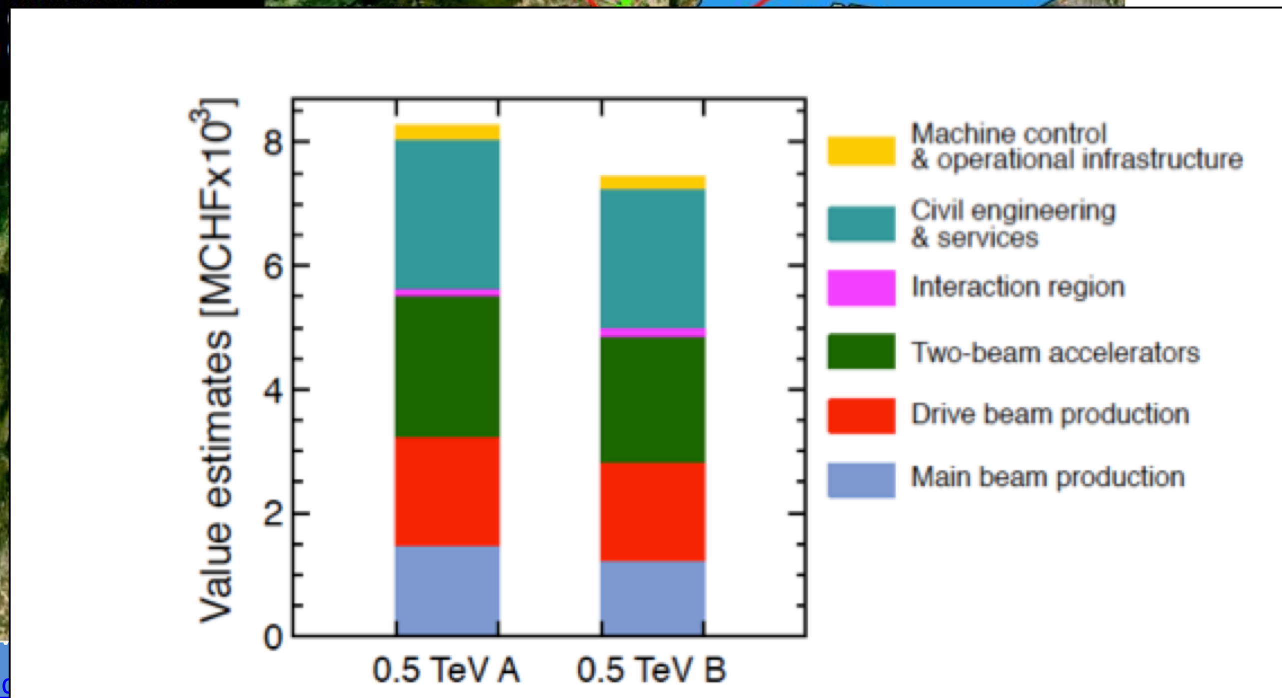


First to second stage: 4 MCHF/GeV (i.e. initial costs are very significant)

Caveats:

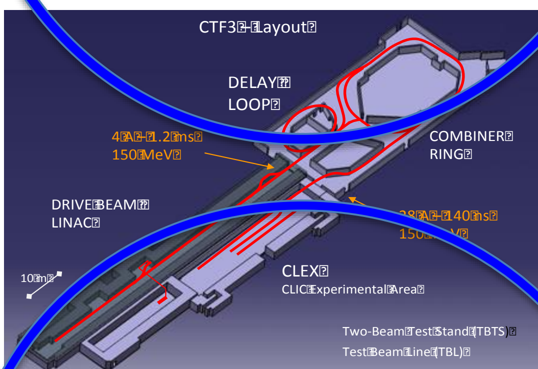
Uncertainties 20-25%
Possible savings around 10%
However – first stage not optimised (work for next phase), parameters largely defined for 3 TeV final stage

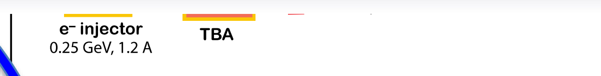
2013-18 Development Phase

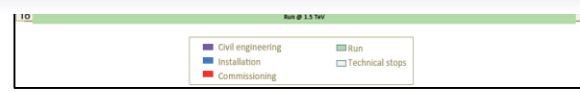
Develop a Project Plan for a staged implementation in agreement with LHC findings; further technical developments with industry, performance studies for accelerator parts and systems, as well as for detectors.

New institutes are joining:
In 2014 SINAP Shanghai and IPM Tehran

Detector collaboration operative with 23 institutes







2018-19 Decisions

On the basis of LHC data and Project Plans (for CLIC and other potential projects), take decisions about next project(s) at the Energy Frontier.

2024-25 Construction Start

Ready for full construction and main tunnel excavation.

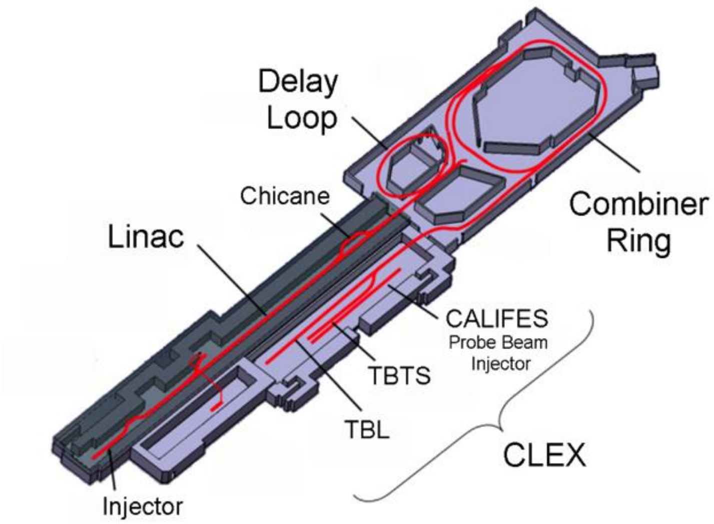
Commissioning

Becoming ready for data-taking as the LHC programme reaches completion.

S. Stapnes

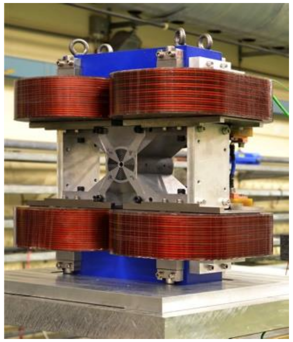
Main CLIC Activities

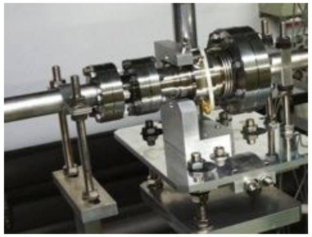
Parameters, Design and Implementation:
- Cost and power optimisation, optimal stages
- Links to experimental programme and integrate experimental results



Experimental verification
- Drive Beam and two beam scheme (CTF3)
- Emittance generation and preservation

Technical Developments
- Cost reduction
- Power reduction
- Key components for systemtests, machine performance

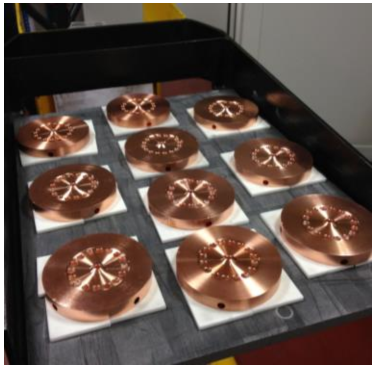


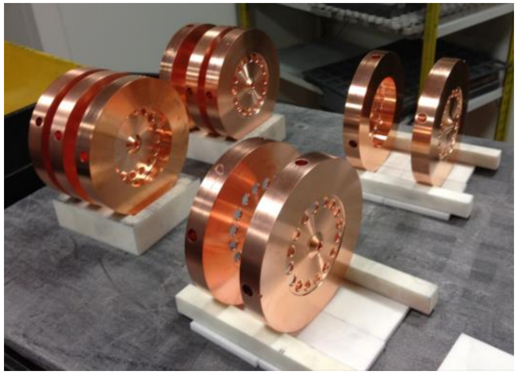


Main CLIC Activities

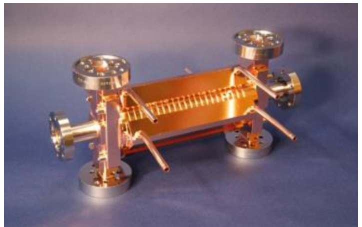
Core are X-band technologies

- High gradient structures and high eff RF
- New X-band High power Testing Facilities (x3)
- Use of Xband technologies for FELs
    - Similar to C-band SwissFEL, based on linear collider technology
    - Collaboration of Australian Light Source, Turkish Accelerator Centre, Elettra, SINAP, Cockcroft Institute, TU Athens, U. Oslo, Uppsala University, CERN





Xband disk, Xband teststand



Muon Collider Concept

Muon are heavy so they emit little synchrotron radiation

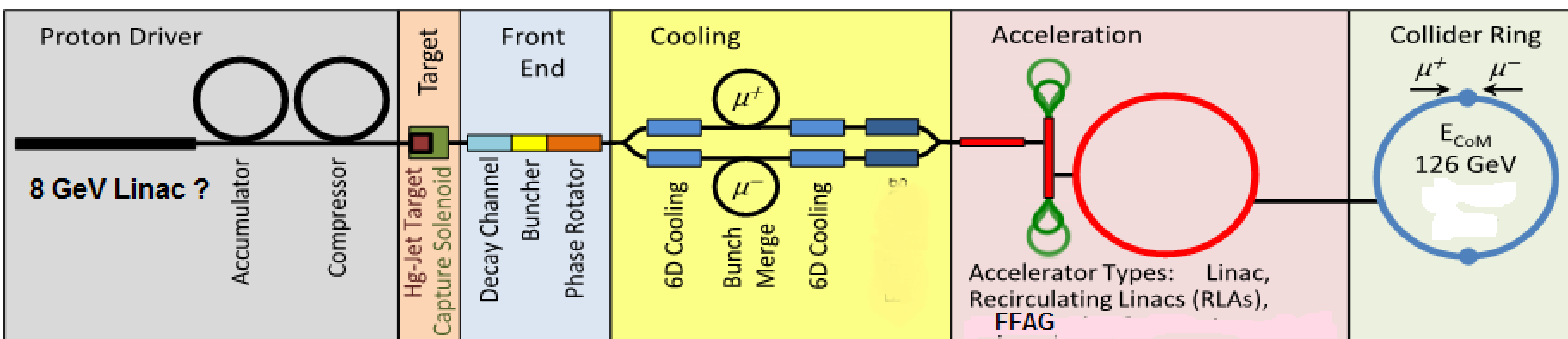
$$m_{m} » 106\,MeV/c^{2} » 207\,m_{e}$$

But they do not live very long

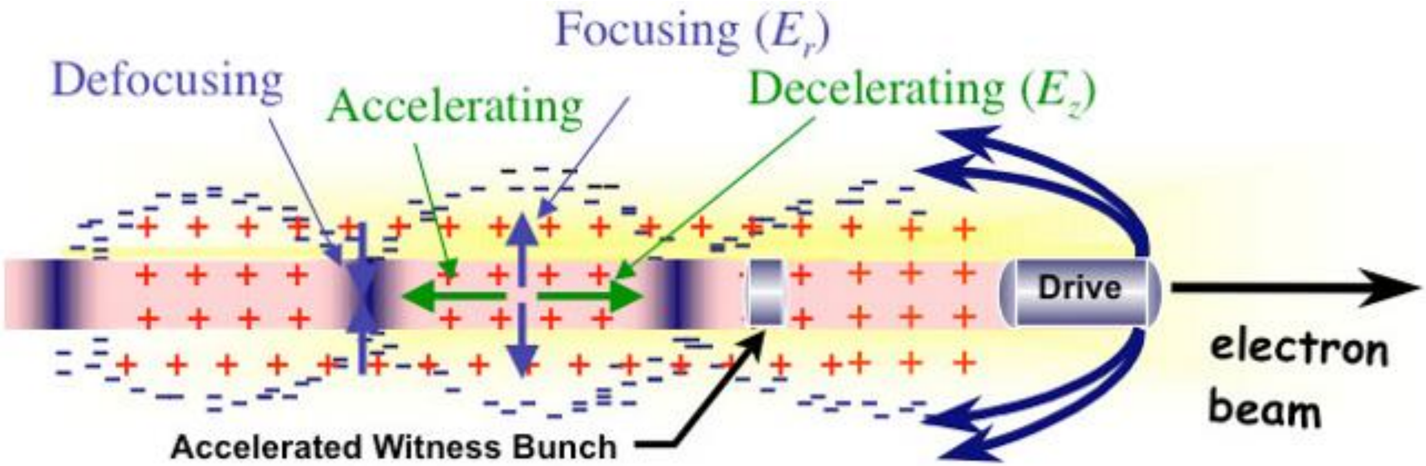
$$t_{m} » 2.2\,ms\ ´\ g$$

Produce them, cool them quickly and let them collide in a small ring

C of m Energy	1.5	3	TeV
Luminosity	0.77	3.4	10^{34} cm^{2}sec^{-1}
Beam-beam Tune Shift	0.087	0.087	
Muons/bunch	2	2	10^{12}
Total muon Power	9	15	MW
Ring <bending field>	6	8.4	T
Ring circumference	3.1	4.5	km
β^* at IP $= \sigma_z$	10	5	mm
rms momentum spread	0.1	0.1	%
Repetition Rate	15	12	Hz
Proton Driver power	4.8	4.3	MW
Muon Trans Emittance	25	25	pi mm mrad
Muon Long Emittance	72,000	72,000	pi mm mrad



Plasma Acceleration



42GeV acceleration (in 0.85m) has been achieved at SLAC

Could also use lasers or protons to drive plasma

Still in the experimental stage

Experimental programme includes

- Electron driven: FACETII at SLAC
- Laser driven: ELI
  - http://extreme-light-infrastructure.eu
- Proton driven: AWAKE at CERN
- …

Muon and Plasma Collider Prospects

- Muon collider
  - Effort in the US has basically stopped
  - Cooling is a most critical issue
    - MICE (UK) is struggling to demonstrate a test with 10% emittance damping
  - Radiation from decaying muons is a critical issue at high energies
    - load on the machine
    - background in the detector
    - radiation hazard for the public

- Plasma acceleration
  - Requires much more R&D
    - A long-term development that will take quite a while to become useful for colliders
    - Many open questions remain, e.g. beam quality, staging, …

Conclusion

ILC is waiting for the outcome of political process in Japan

CLIC is waiting for decision on direction for CERN
- either high energy leptons
- or FCC-hh, with potential intermediate step FCC-ee

Meanwhile linear collider technological maturity is fostered
- Strong synergy exists between linear colliders and light sources/FELs

Other options such as muon collider or plasma acceleration are interesting but require very substantial R&D and by far do not have a similar level of maturity

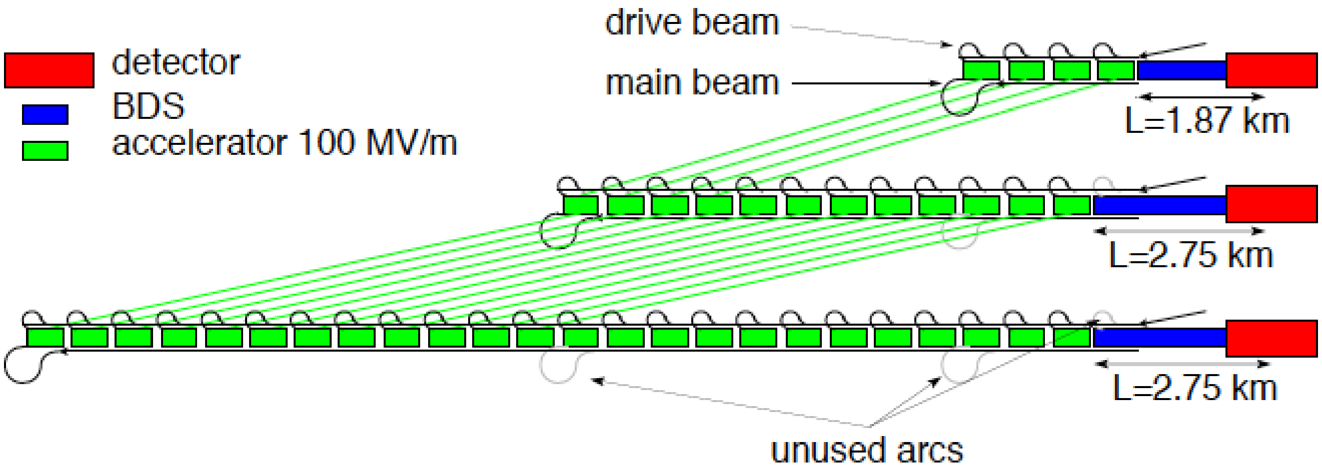
Reserve

ILC and CLIC Main Parameters

Parameter	Symbol [unit]	SLC	ILC	CLIC
Centre of mass energy	E_{cm} [GeV]	92	500	3000
luminosity	L [$10^{34}cm^{-2}s^{-1}$]	0.0003	1.8	6
Luminosity in peak	$L_{0.01}$ [$10^{34}cm^{-2}s^{-1}$]	0.0003	1	2
Gradient	G [MV/m]	20	31.5	100
Particles per bunch	N [10^9]	37	20	3.72
Bunch length	σ_z [μm]	1000	300	44
Collision beam size	$\sigma_{x,y}$ [nm/nm]	1700/600	474/5.9	40/1
Vertical emittance	$\varepsilon_{x,y}$ [nm]	3000	35	20
Bunches per pulse	n_b	1	1312	312
Distance between bunches	Δz [mm]	-	554	0.5
Repetition rate	f_r [Hz]	120	5	50

ILC has parameter sets from 250GeV to 1TeV
CLIC has parameter sets from 250GeV to 3TeV

Staged CLIC Design



E_{cms}=380Gev

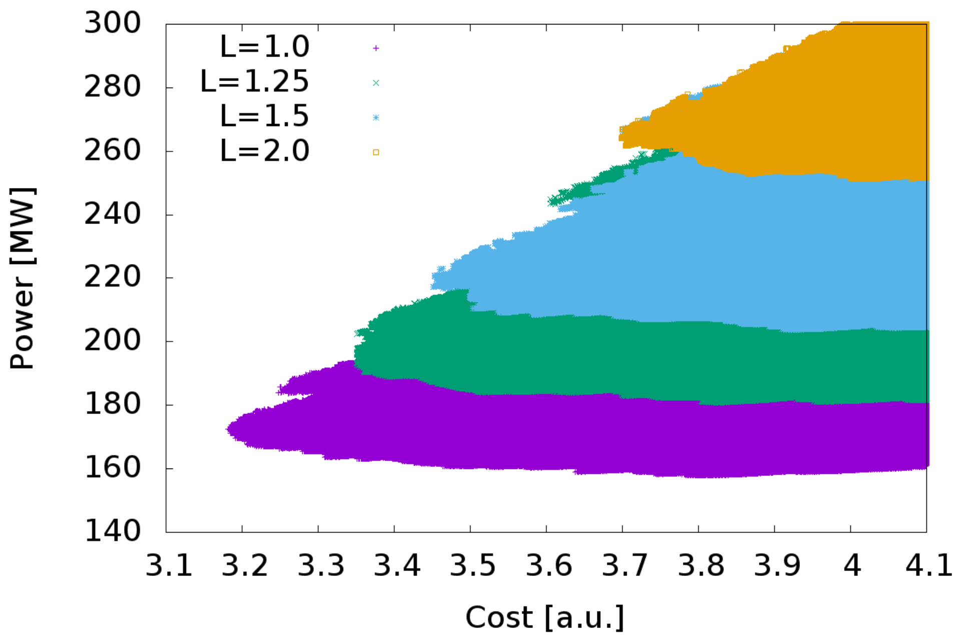
– $L=1.5x10^{34}cm^{-2}s^{-1}$, $L_{0.01}/L>0.6$

– Higgs and top

E_{cms}=O(1.5TeV)

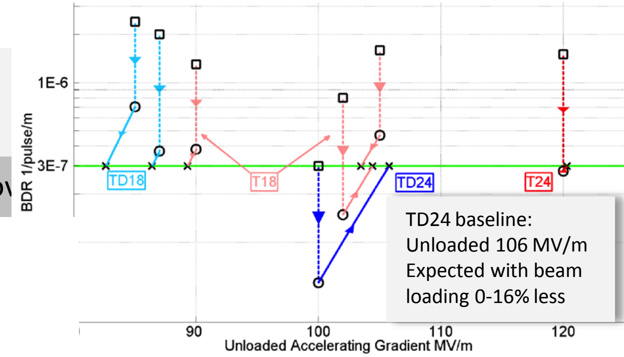
E_{cms}=3TeV

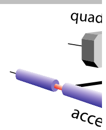
- $L_{0.01}=2x10^{34}cm^{-2}s^{-1}$, $L_{0.01}/L>0.3$



Conclusion of the Accelerator CDR Studies

Main linac gradient	–	Ongoing test close to or on target
	–	Uncertainty from beam loading being tested
Drive beam scheme	–	Generation tested, used to accelerate test beam abov





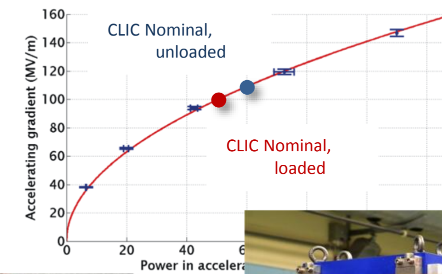
Links to reports:

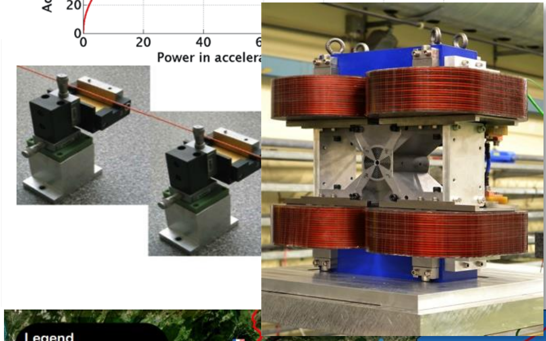
Accelerator:
https://edms.cern.ch/document/1234244/

Physics and detector:
http://arxiv.org/pdf/1202.5940v1

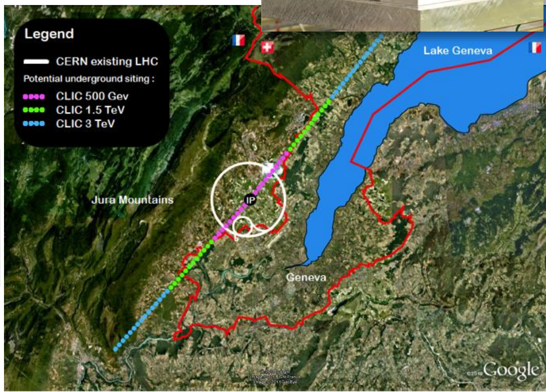
Executive summary:
http://arxiv.org/pdf/1209.2543v1

Input for European strategy:
http://arxiv.org/pdf/1208.1402v1





Luminosity		
Operation & Machine Protection		
Implementation		Consistent staged implementation scenario defined
	–	Schedules, cost and power developed and presented
	–	Site and CE studies documented



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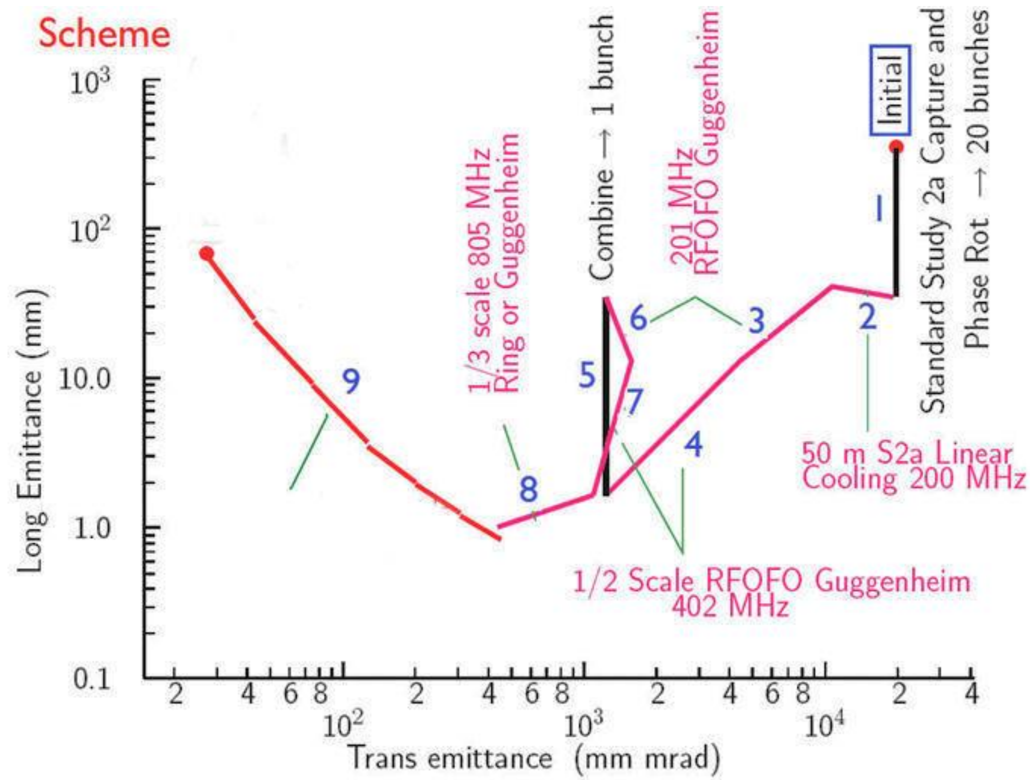

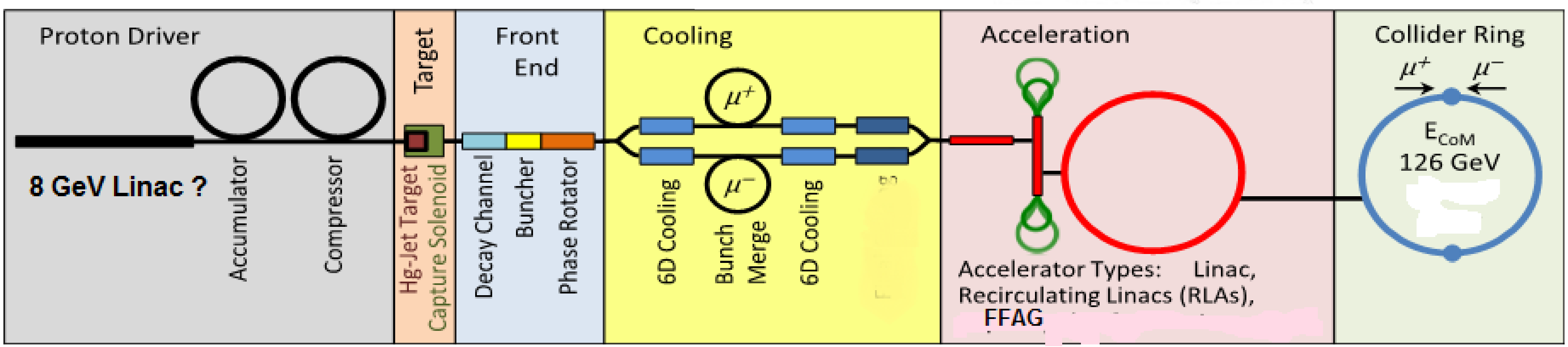

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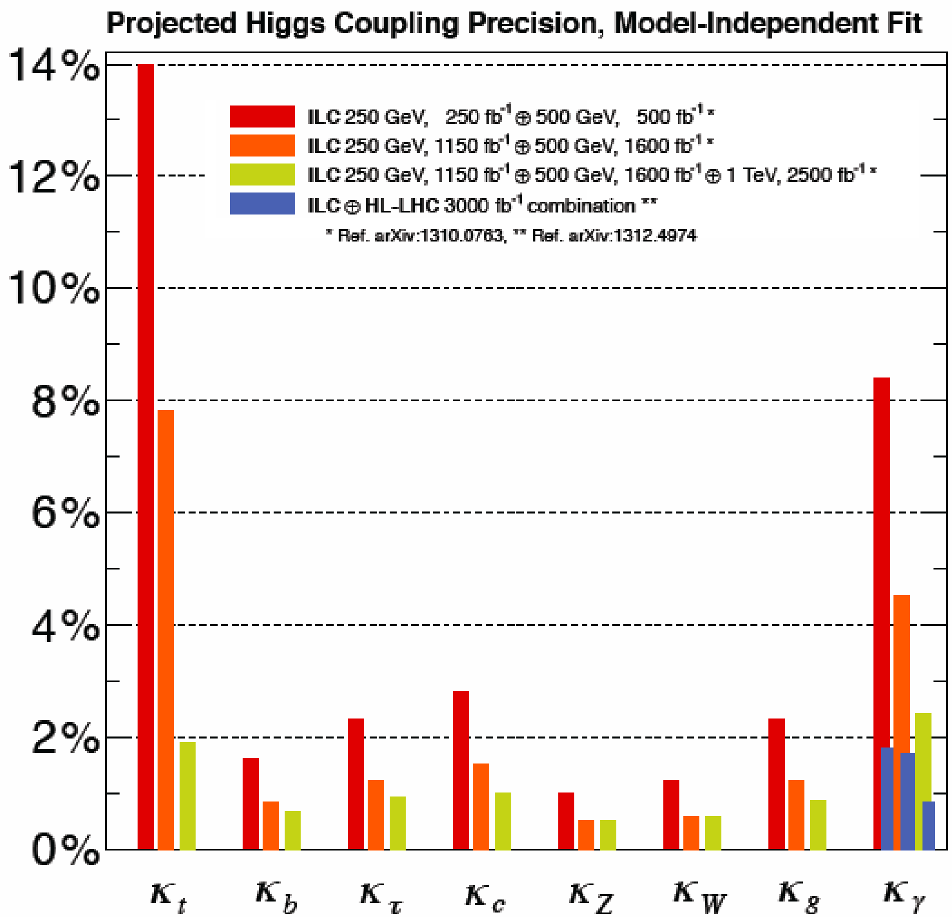
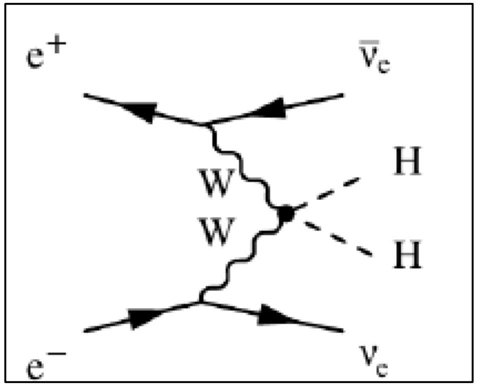


High-energy lepton colliders can still add to the Higgs studies

ILC
fully model-independent

K. Tackmann

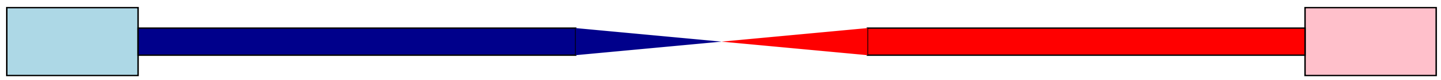


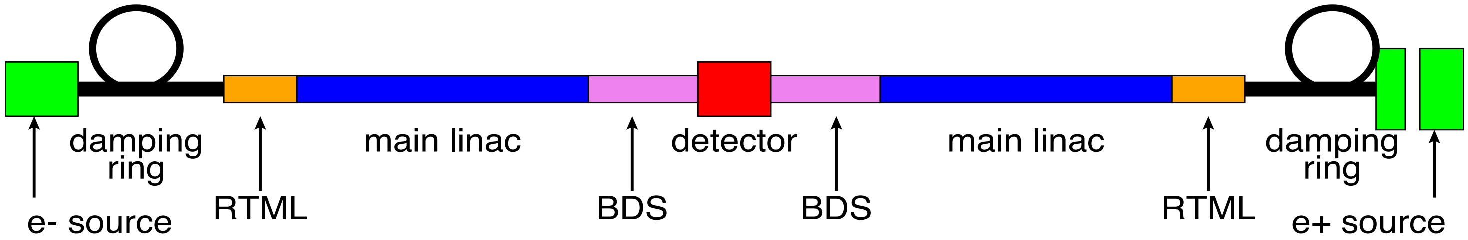
CLIC

E. Sicking

Measurement	Observable	Statistical precision 1.4 TeV 1.5 ab^{-1}	Statistical precision 3.0 TeV 2.0 ab^{-1}
$\sigma(HH\nu_e\bar{\nu}_e)$	g_{HHWW}	7% (prel.)	3% (prel.)
$\sigma(HH\nu_e\bar{\nu}_e)$	λ	32%	16%
with 80% e^- polarisation	λ	24%	12%

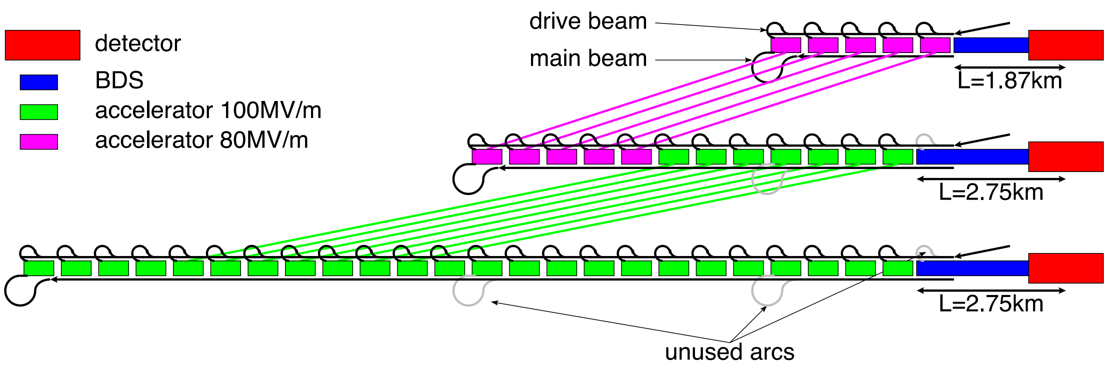
Generic Linear Collider





Challenges:

- Gradients
- Luminosity (nano beams)
- Power efficiency



E_{cms}=380Gev, L=1.5x10^{34}cm^{-2}s^{-1}, $L_{0.01}$/L>0.6

E_{cms}=O(1.5TeV)

E_{cms}=3TeV, $L_{0.01}$=2x10^{34}cm^{-2}s^{-1}, $L_{0.01}$/L>0.3

European Strategy

Identified four highest priorities

- Highest priority is exploitation of the LHC including luminosity upgrades

- Europe should be able to propose an ambitious project after the LHC
  - Either high energy proton collider (**FCC-hh**), potential intermediate step FCC-ee
  - Or high energy linear collider (**CLIC**)

- Europe welcomes Japan to make a proposal to host **ILC**

- Long baseline neutrino facility