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The International Linear Collider

Brian Foster (Uni Hamburg/DESY/Oxford)

International Conference on New Frontiers in Physics

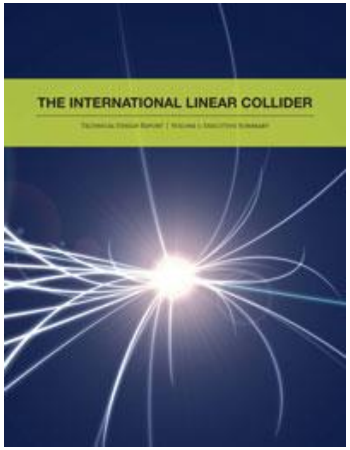
Crete

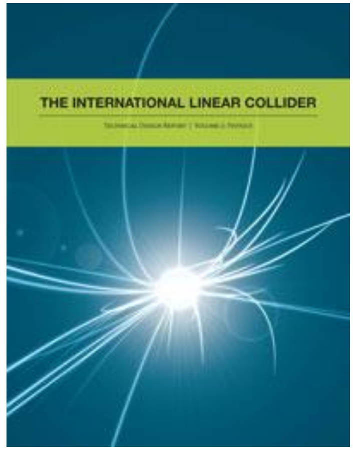
5.9.2013

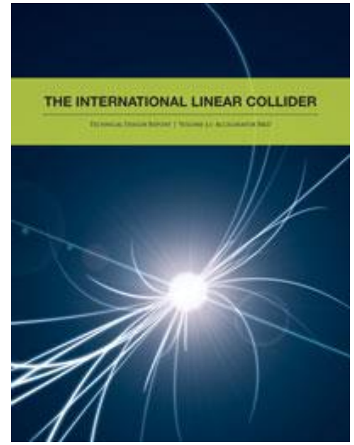
Acknowledgements & thanks –100s of people whose 1000s of person-years of work over > 10 years has brought the project to this stage.

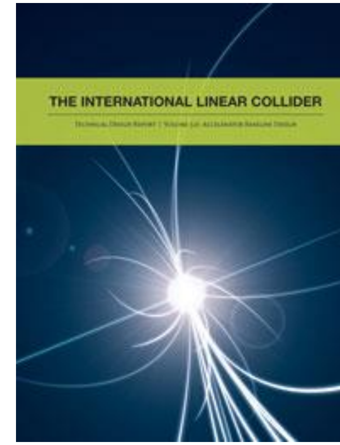
Introduction

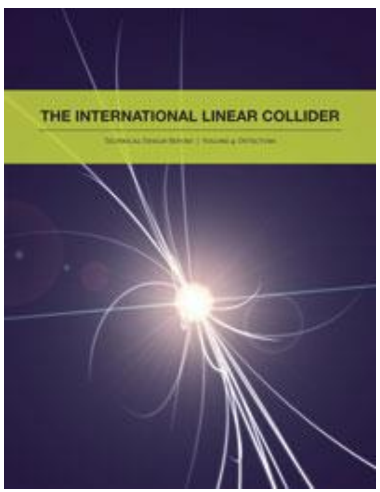
- On June 12th, ILC TDR was published in Worldwide Event.







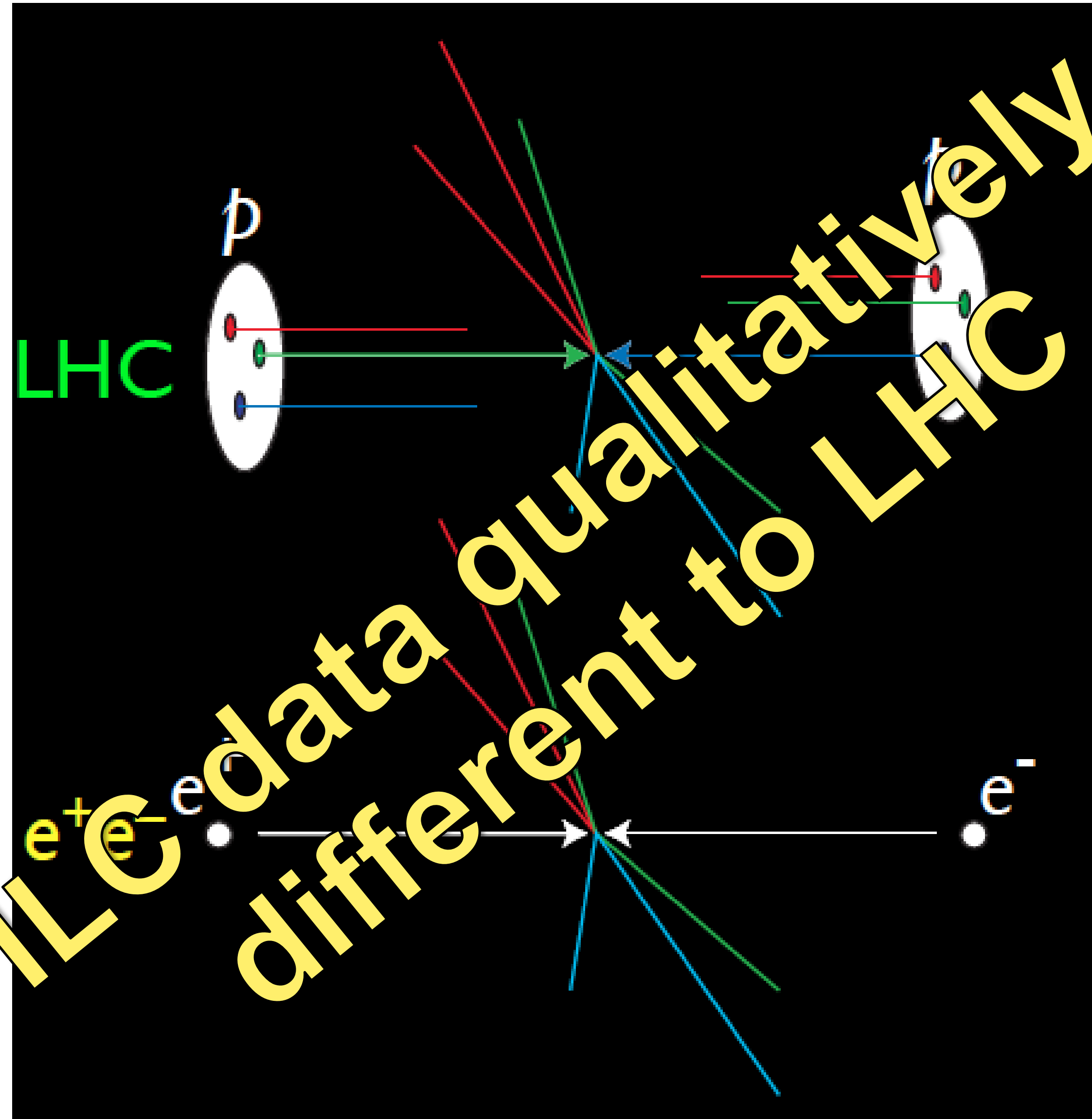




- I will attempt to summarise – work of 100s of people and 1000s of person-years of work – in 25 minutes.

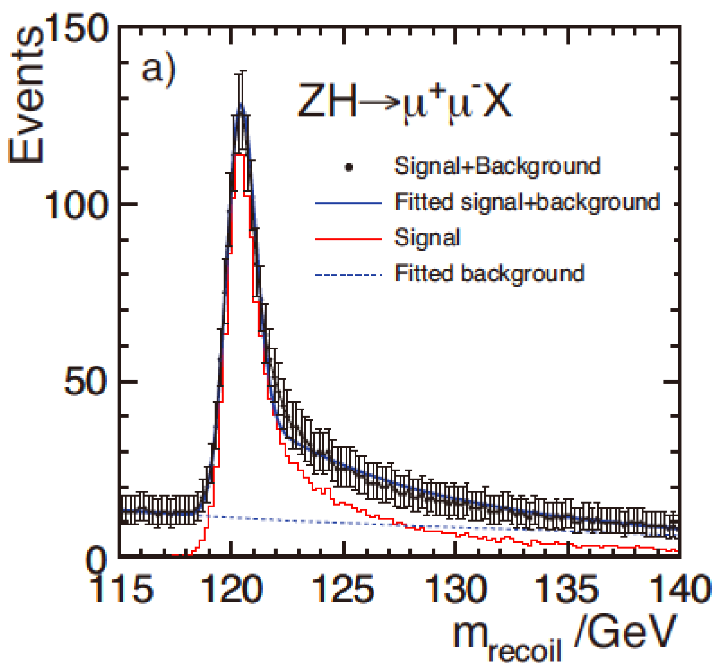
ILC Physics Overview

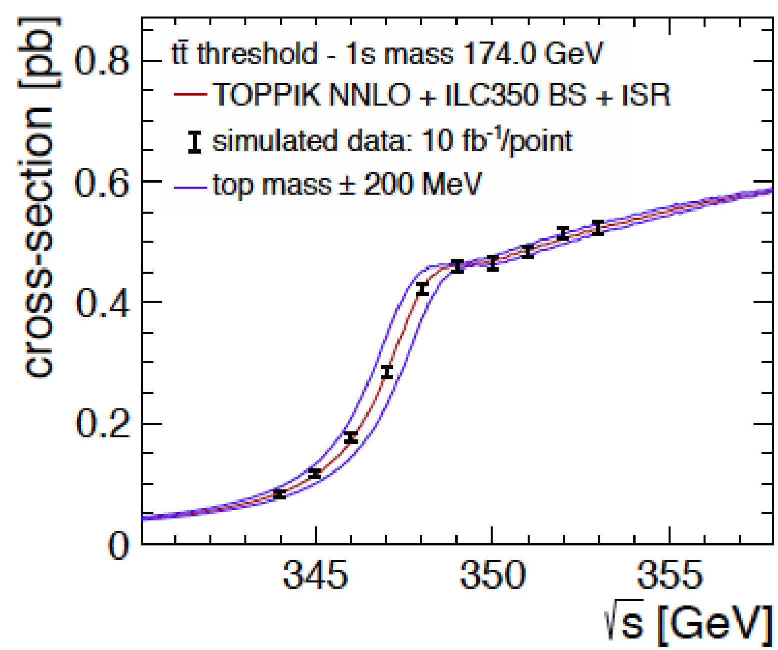
- **Simple particles**
  - **Well defined energy, angular mom., e+/e- polarisation**
- **E can be scanned precisely**
- **Particles produced ~ democratically**
- **Final states fully reconstructable**
- **Backgrounds ~ 0 -> triggerless DAQ -> no trigger bias**
- **Theoretical interpretation clean.**



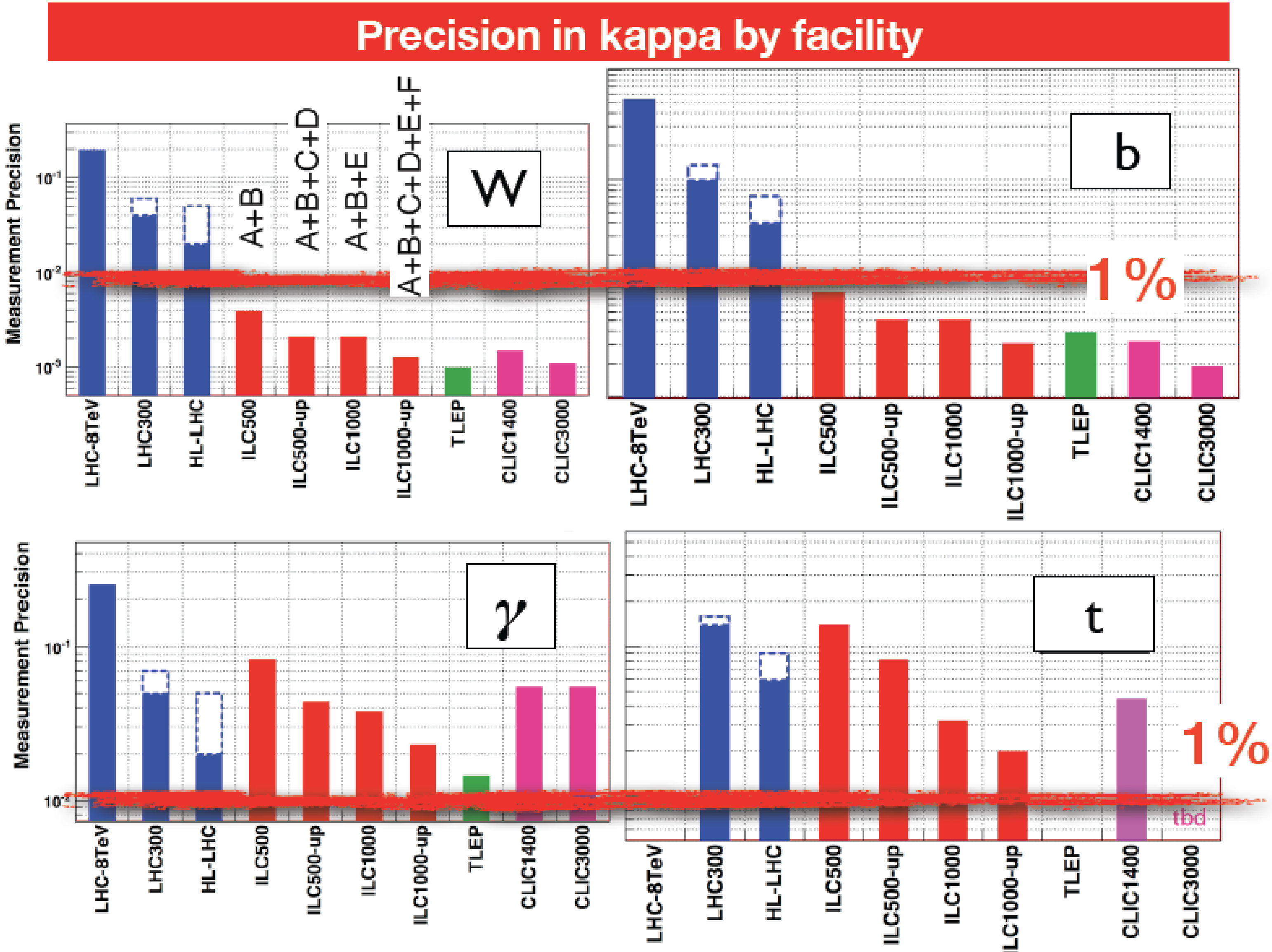
ILC Physics Overview

- **Very difficult, but essential, to estimate what LHC will do before ILC can enter the scene.**
- **However, broad agreement that some physics channels unique to ILC – Higgs invisible BRs, c, light quark couplings, precision top mass, many new physics signatures….**

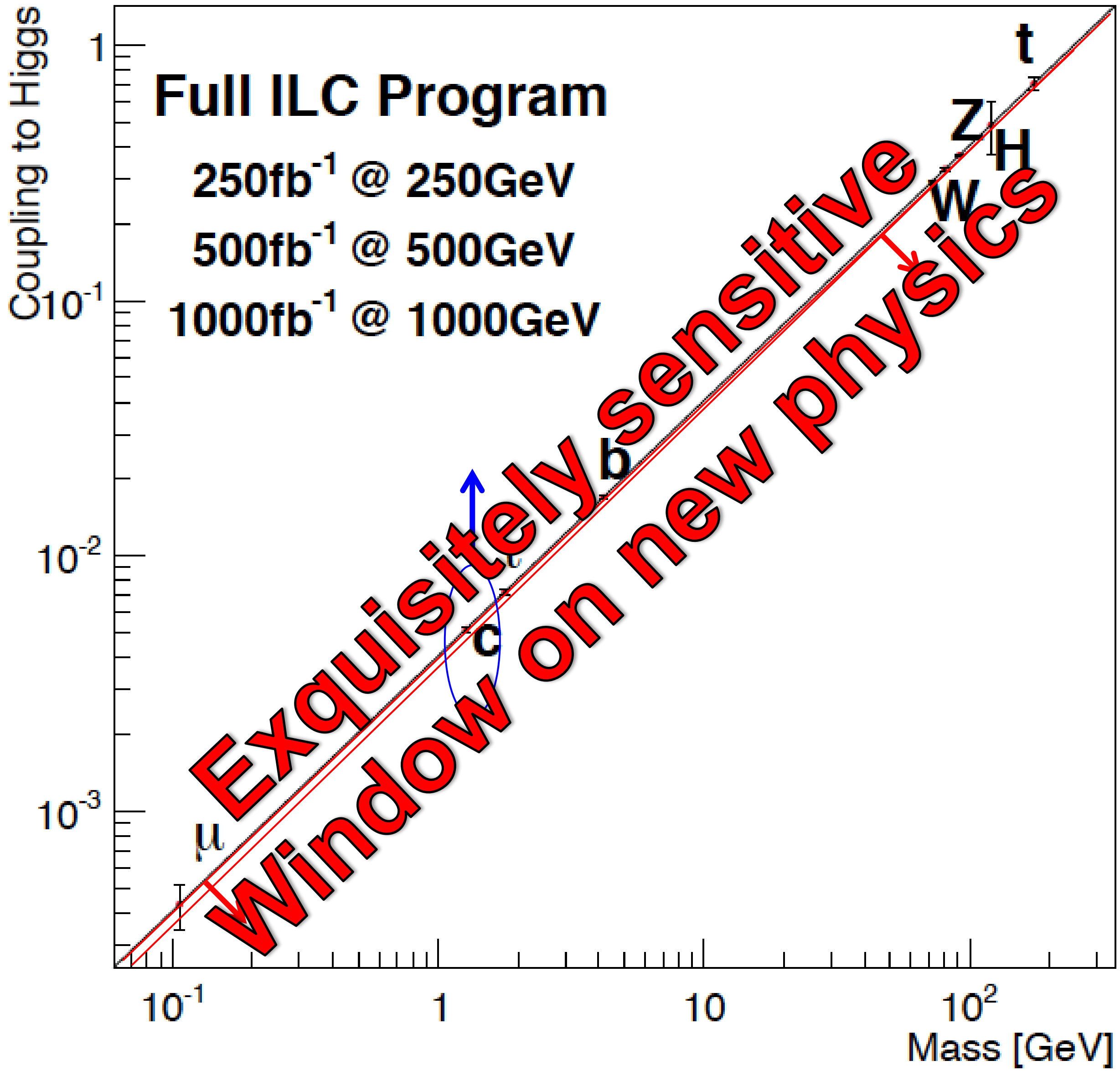




Brock Snowmass Summary



Higgs Couplings Summary



Extra Dimensions

Anomalous Couplings

Brock Snowmass Summary

ILC, up to 500 GeV

1. **Tagged Higgs study in e+e–> Zh: model-independent BR and Higgs Γ, direct study of invisible & exotic Higgs decays**
2. **Model-independent Higgs couplings with % accuracy, great statistical & systematic sensitivity to theories.**
3. Higgs CP studies in fermionic channels (e.g., tau tau)
4. **Giga-Z program for EW precision, W mass to 4 MeV and beyond.**
5. Improvement of triple VB couplings by a factor 10, to accuracy below expectations for Higgs sector resonances.
6. Theoretically and experimentally precise top quark mass to 100 MeV.
7. **Sub-% measurement of top couplings to gamma & Z, accuracy well below expectations in models of composite top and Higgs**
8. Search for rare top couplings in e+e- -> t cbar, t ubar.
9. Improvement of α_S from Giga-Z
10. No-footnotes search capability for new particles in LHC blind spots -- Higgsino, stealth stop, compressed spectra, WIMP dark matter

Higgs EW Top QCD NP/flavor

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Brock Snowmass Summary

ILC 1 TeV

1. Precision Higgs coupling to top, 2% accuracy
2. **Higgs self-coupling, 13% accuracy**
3. Model-independent search for extended Higgs states to 500 GeV.
4. Improvement in precision of triple gauge boson couplings by a factor 4 over 500 GeV results.
5. **Model-independent search for new particles with coupling to gamma or Z to 500 GeV**
6. Search for Z' using e+e- -> f fbar to ~ 5 TeV, a reach comparable to LHC for similar models. Multiple observables for Z' diagnostics.
7. **Any discovery of new particles dictates a lepton collider program:**

   search for EW partners, 1% precision mass measurement, the complete decay profile, model-independent measurement of cross sections, BRs and couplings with polarization observables, search for flavor and CP-violating interactions

Higgs EW Top QCD NP/flavor

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ILC Detectors

- **To exploit qualitative difference in physics potential, detectors need order of magnitude improvement over LHC**
  - Vertexing $(h \to b\bar{b}, c\bar{c}, \tau^+\tau^-)$
    - ~1/5 $r_{beampipe}$,1/50~1/1000 pixel size, ~1/10 resolution (wrt LHC)

$$\sigma_{IP} = 5 \oplus \frac{10}{p \sin^{3/2}\theta} (\mu m)$$

  - Tracking $(e^+e^- \to Zh \to \ell^+\ell^- X; \quad \text{incl.}\ h \to \text{nothing})$
    - ~1/6 material, ~1/10 resolution (wrt LHC)

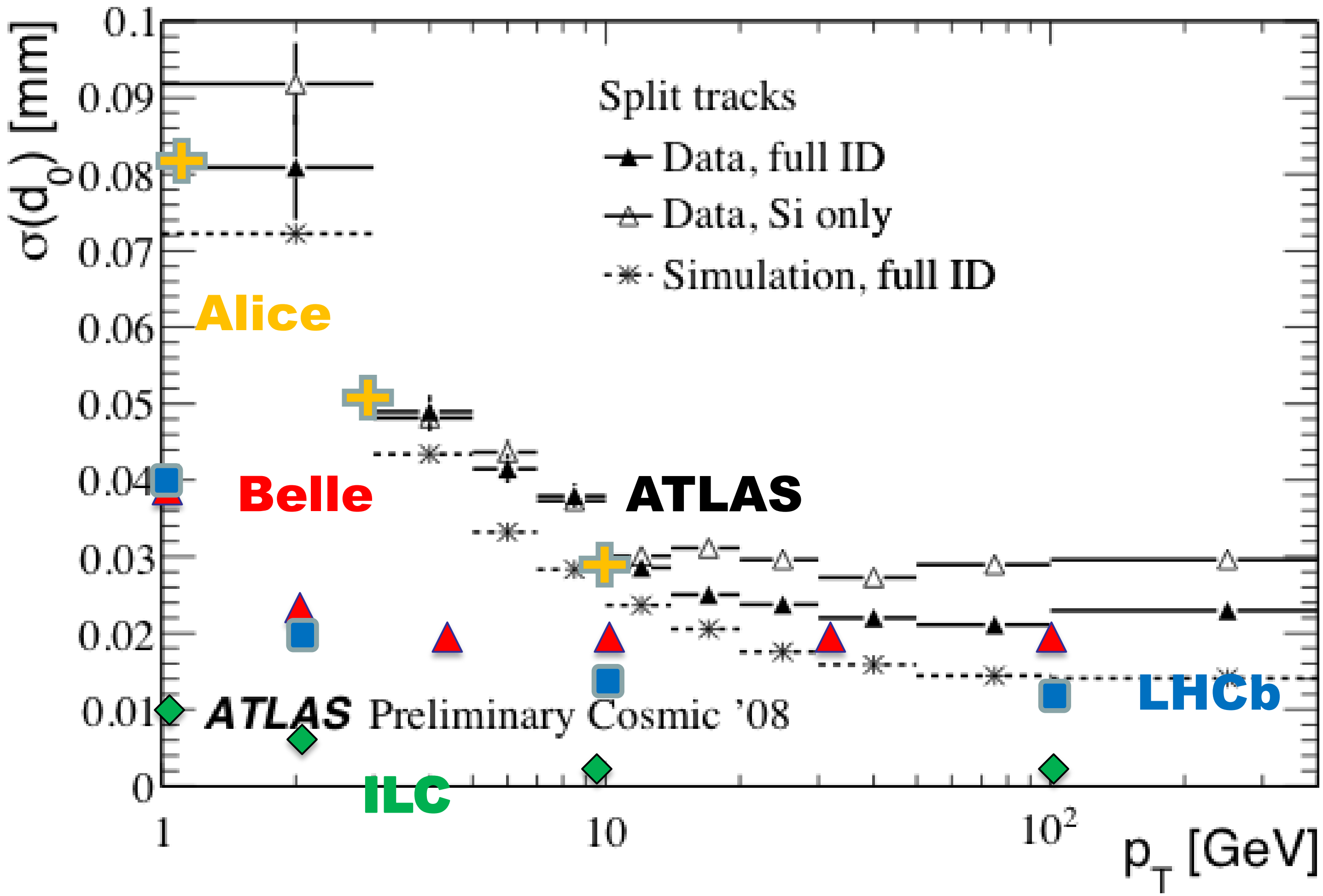
$$s(1/p) = 2 ´\ 10^{-5} (\mathrm{GeV}^{-1})$$

  - Jet energy (quark reconstruction)
    - 1000x granularity, ~1/2 resolution (wrt LHC)

$$s_E / E = 0.3/\sqrt{E(\mathrm{GeV})}$$

Above performances achieved in realistic simulations based on actual detector R&Ds.

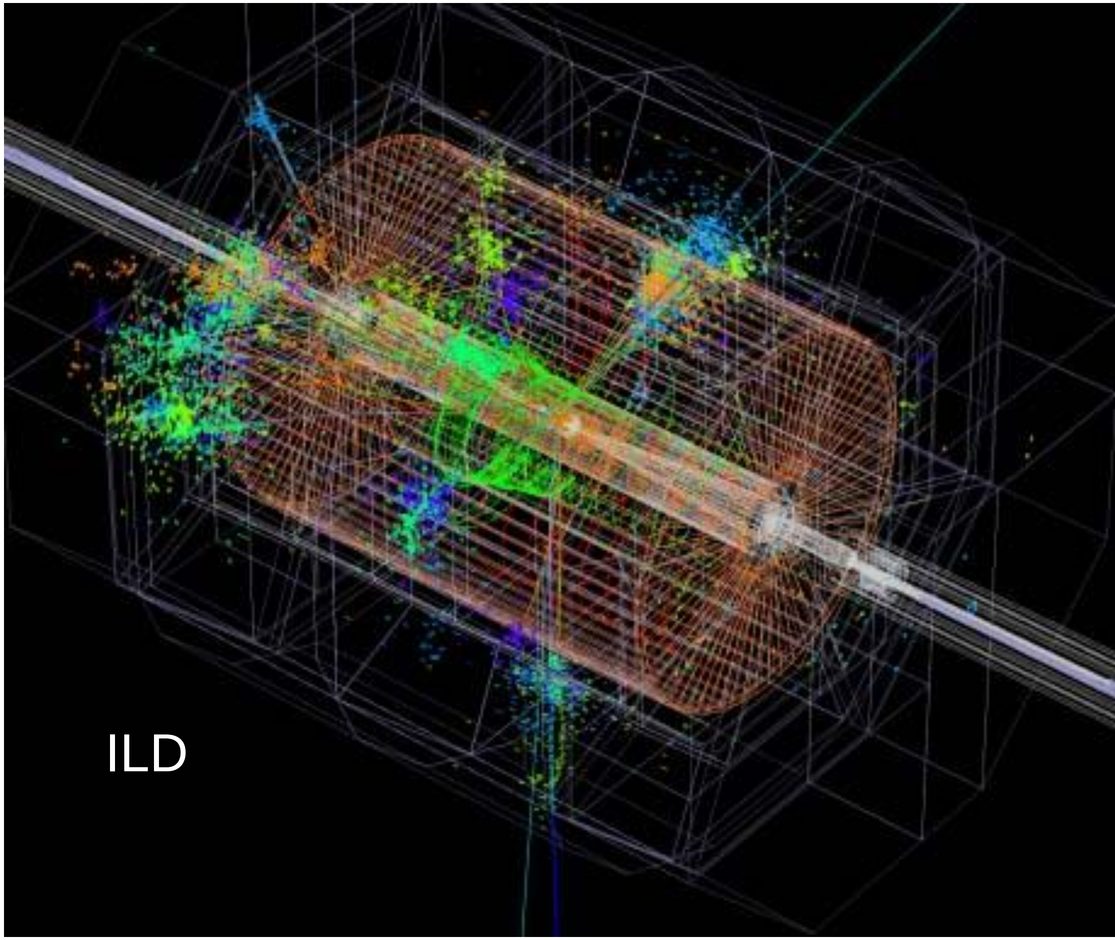
Impact parameter resolution



A new paradigm for calorimetry

Particle Flow Algorithm

- Charged particles
  - **Use trackers**
- Neutral particles
  - **Use calorimeters**
- Remove double-counting of charged showers
  - **Requires high granularity**

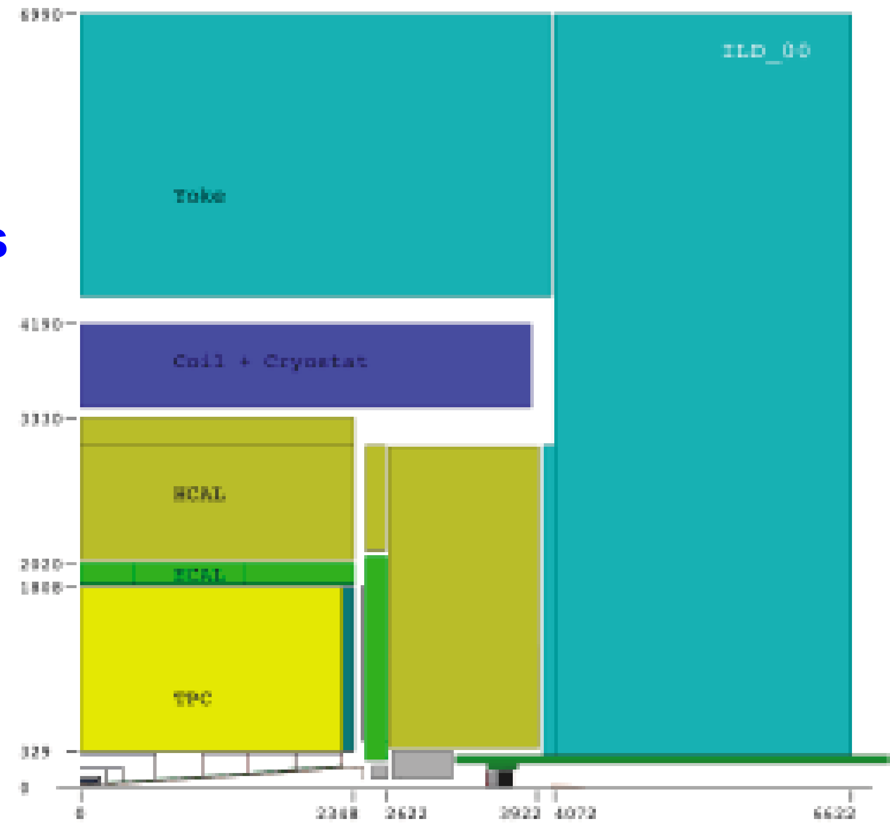


#ch	ECAL	HCAL
ILC (ILD)	100M	10M
LHC	76K(CMS)	10K(ATLAS)

X10^3 for ILC
Need new technologies !

Summary of ILD

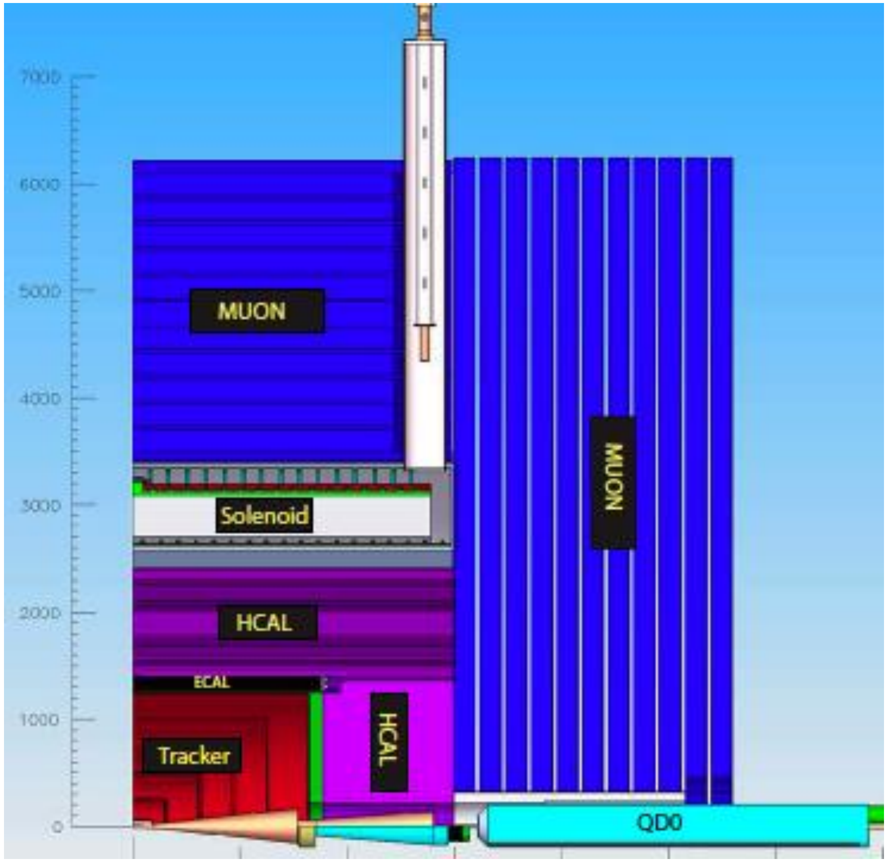
- B: 3.5 T
- Vertex pixel detectors
  - **6 (3 pairs) or 5 layers (no disks)**
  - **Technology open**
- Si-strip trackers
  - **2 barrel + 7 forward disks (2 disks are pixel)**
  - **Outer and endcap of TPC**
- TPC
  - **GEM or MicroMEGAS for amplification**
  - **Pad (or si-pixel) readout**
- ECAL
  - **Si-W or Scint-W (or hybrid)**
- HCAL
  - **Scint-tile or Digital-HCAL**



All inside solenoid

Summary of SiD

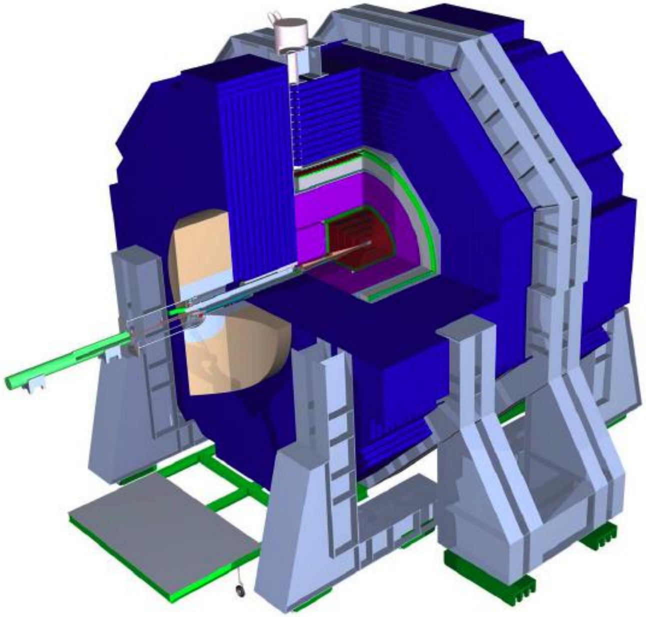
- B: 5T
- Vertex pixel detectors
  - **5 barrel layers +**
    (4 disks+3 fwd)/side
  - **Technology open (3D)**
- Si-strip-trackers
  - **5 barrel layers + 4 forward disks/side**
- EMCAL
  - **Si-W 30 layers, pixel ~$(4mm)^2$**
- HCAL
  - **Digital HCAL with RPC or GEM with $(1cm)^2$ cell**
  - **40 layers**

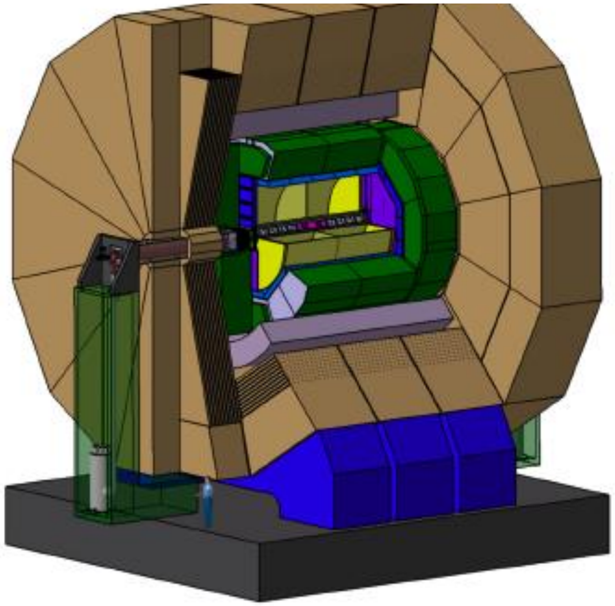


All above inside solenoid

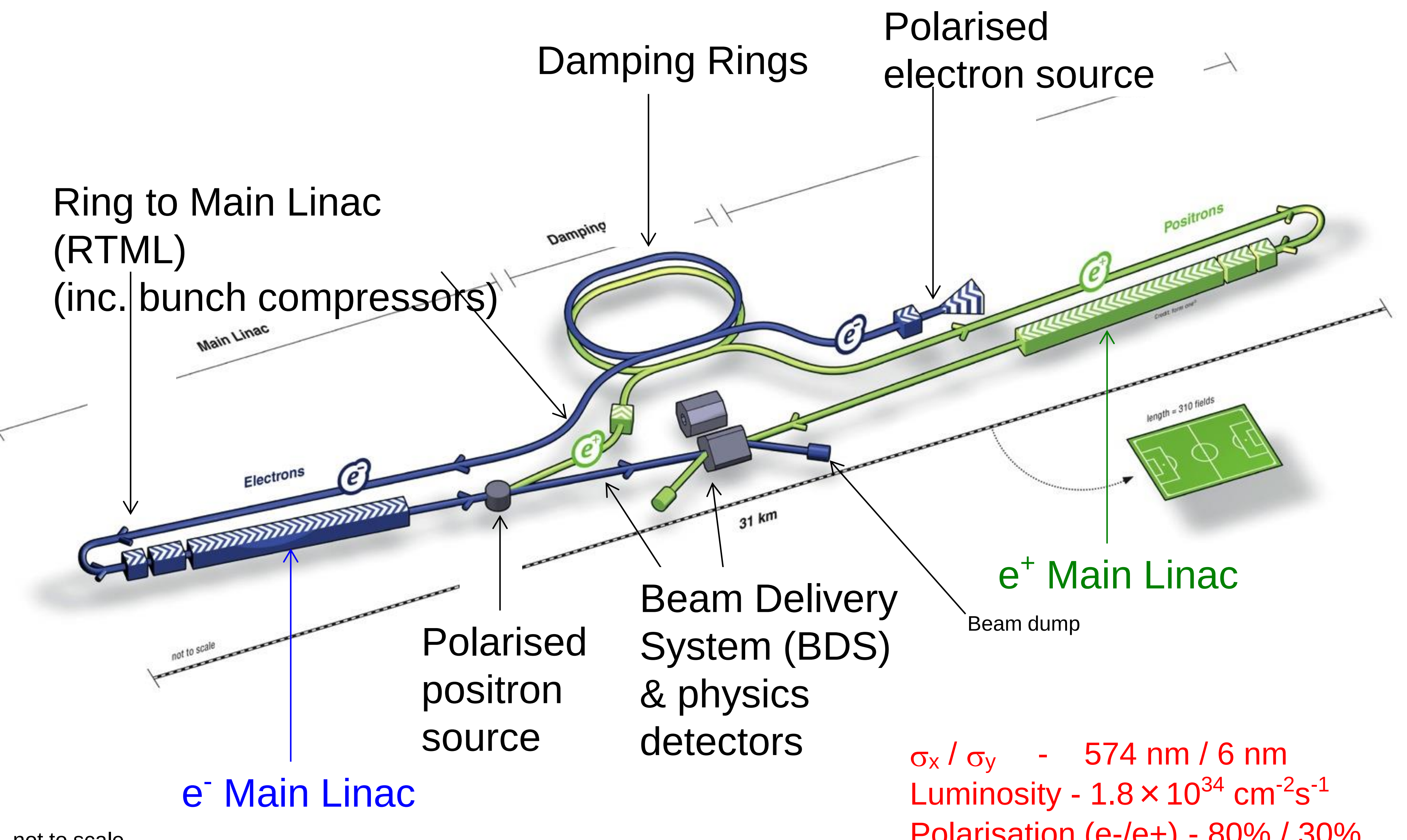
Detector Overview

- SiD
  - **High B field (5 Tesla)**
  - **Small ECAL ID**
  - **Small calorimeter volume**
    - Finer ECAL granularity
  - **Silicon main tracker**
- ILD
  - **Medium B field (3.5 Tesla)**
  - **Large ECAL ID**
    - Particle separation for PFA
  - **Redundancy in tracking**
  - **TPC for main tracker**





ILC Machine Overview



σ_x / σ_y - 574 nm / 6 nm
Luminosity - 1.8×10^{34} $cm^{-2}s^{-1}$
Polarisation (e-/e+) - 80% / 30%

not to scale

ILC Scheme | © www.form-one.de

SCRF Linac Technology

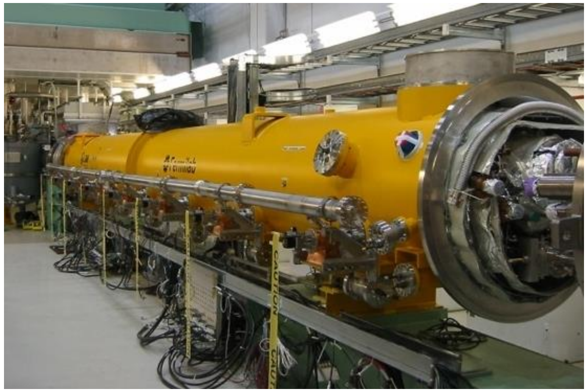
- solid niobium
- standing wave
- 9 cells
- operated at 2K (Lqd. He)
- 35 MV/m
- $Q_0 \geq 10^{10}$

1.3 GHz Nb 9-cell Cavities	16,024
Cryomodules	1,855
SC quadrupole package	673
10 MW MB Klystrons & modulators	436 / 471*

* site dependent

Approximately 20 years of R&D Worldwide → Mature technology

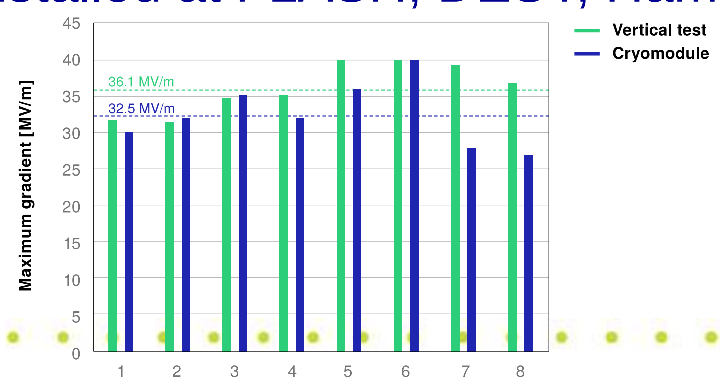
Worldwide Cryomodule Development



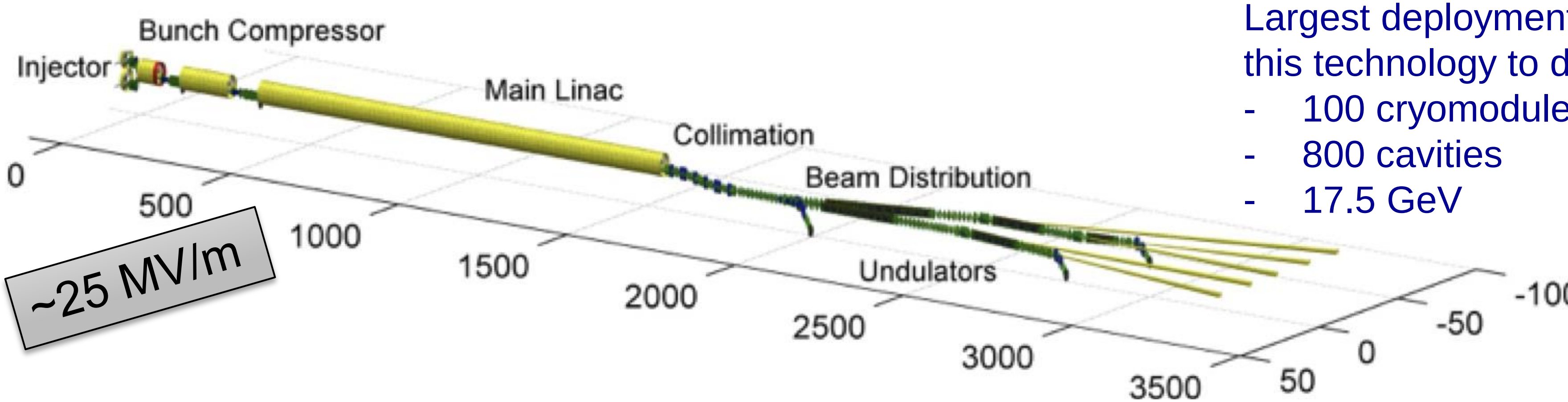
CM1 at FNAL NML module test facility

S1 Global at KEK SRF Test Facility (STF)

PXFEL 1 installed at FLASH, DESY, Hamburg

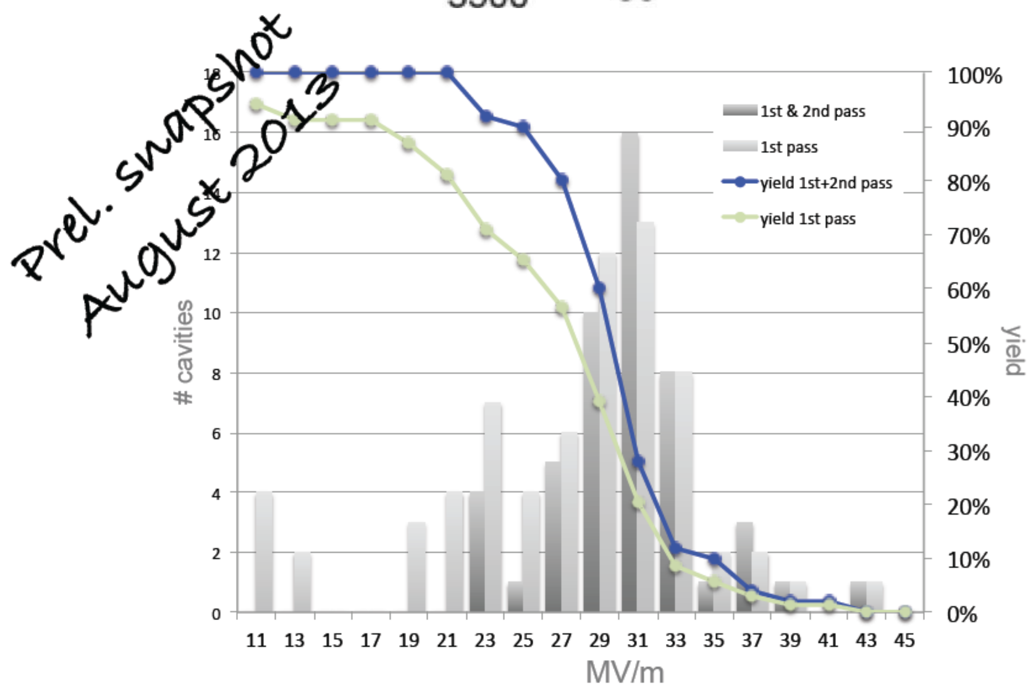


European XFEL @ DESY



Largest deployment of this technology to date

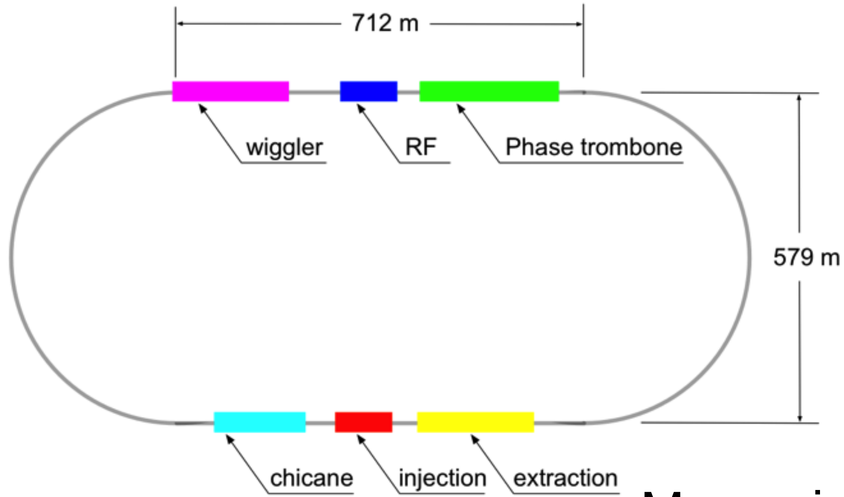
- 100 cryomodules
- 800 cavities
- 17.5 GeV



The ultimate ‘integrated systems test’ for ILC. Commissioning with beam 2^{nd} half 2015


shield wall removed
©Rey.Hori/KEK

Damping Rings



Many similarities to modern 3rd generation light sources

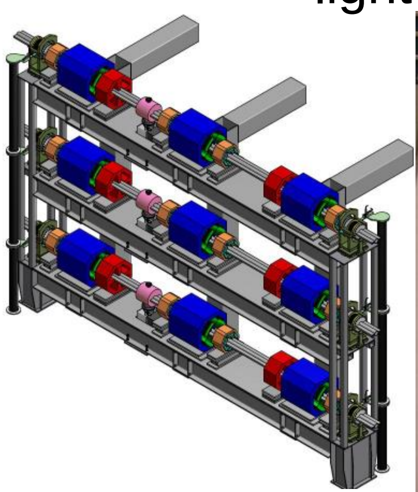
Circumference		3.2	km
Energy		5	GeV
RF frequency		650	MHz
Beam current		390	mA
Store time		200 (100)	ms
Trans. damping time		24 (13)	ms
Extracted emittance	x	5.5	µm
(normalised)	y	20	nm
No. cavities		10 (12)	
Total voltage		14 (22)	MV
RF power / coupler		176 (272)	kW
No.wiggler magnets		54	
Total length wiggler		113	m
Wiggler field		1.5 (2.2)	T
Beam power		1.76 (2.38)	MW

Values in () are for 10-Hz mode

Positron ring (upgrade)

Electron ring (baseline)

Positron ring (baseline)

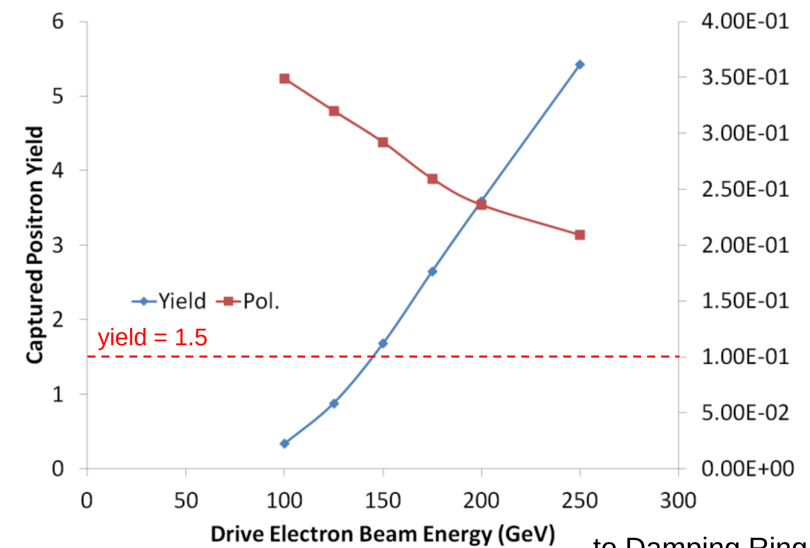


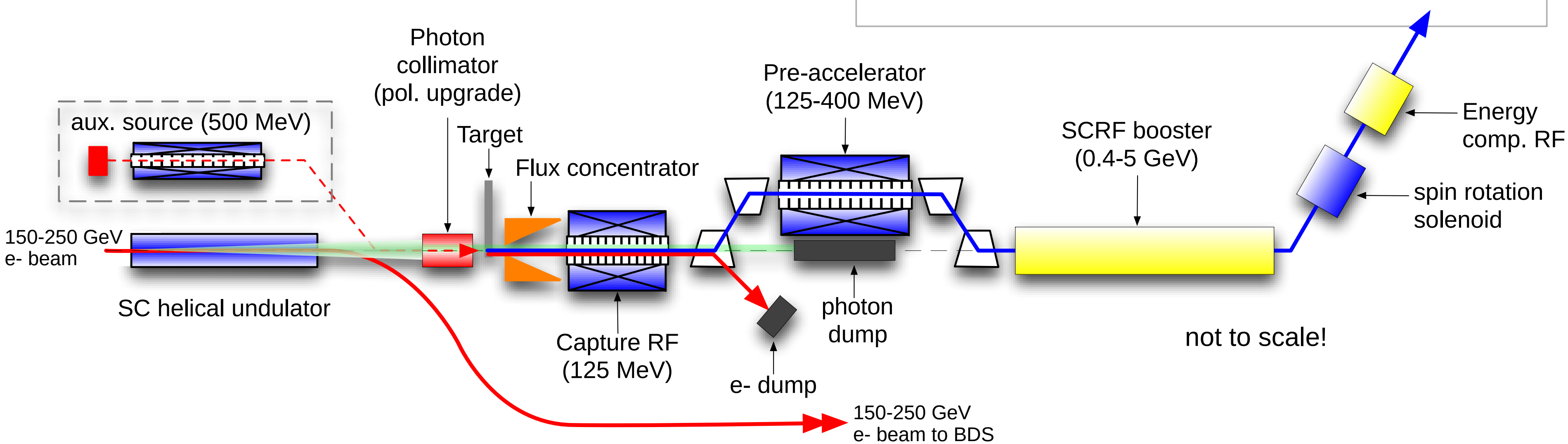
Arc quadrupole section

- Extensive R&D programme at CESR, Cornell (CesrTA) solved electron-cloud problem

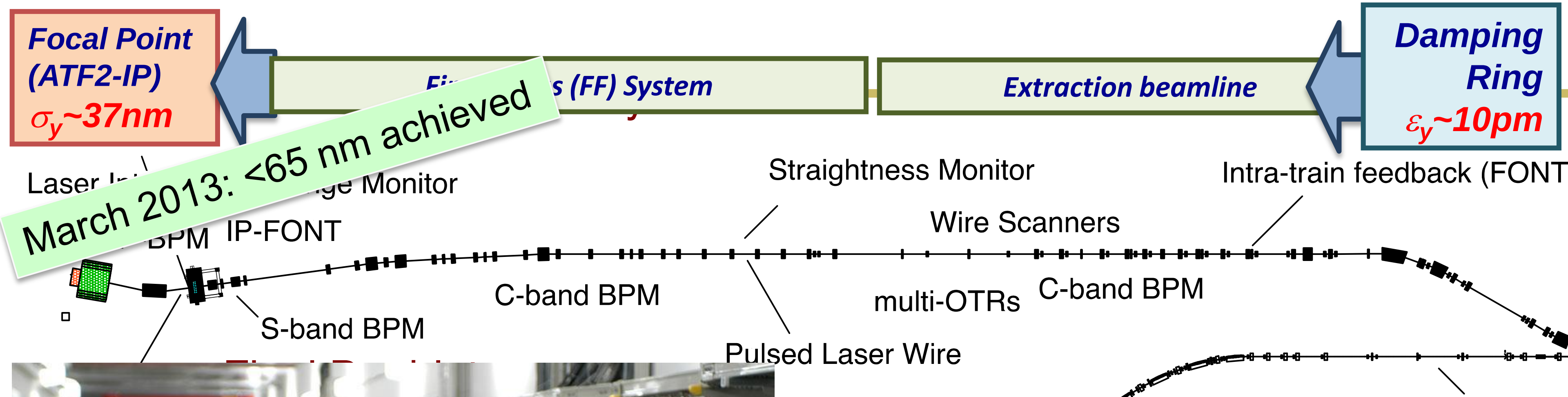
Positron Source

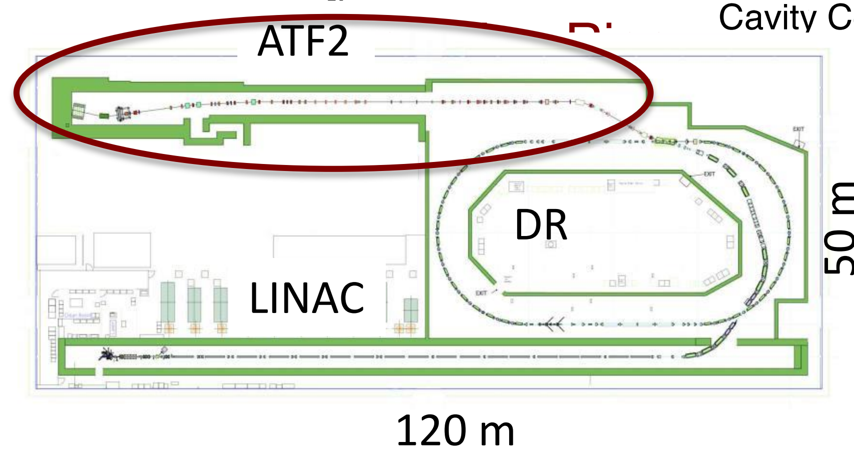
- located at exit of electron Main Linac
- 147m SC helical undulator
- driven by primary electron beam (150-250 GeV)
- produces ~30 MeV photons
- converted in thin target into e^+e^- pairs





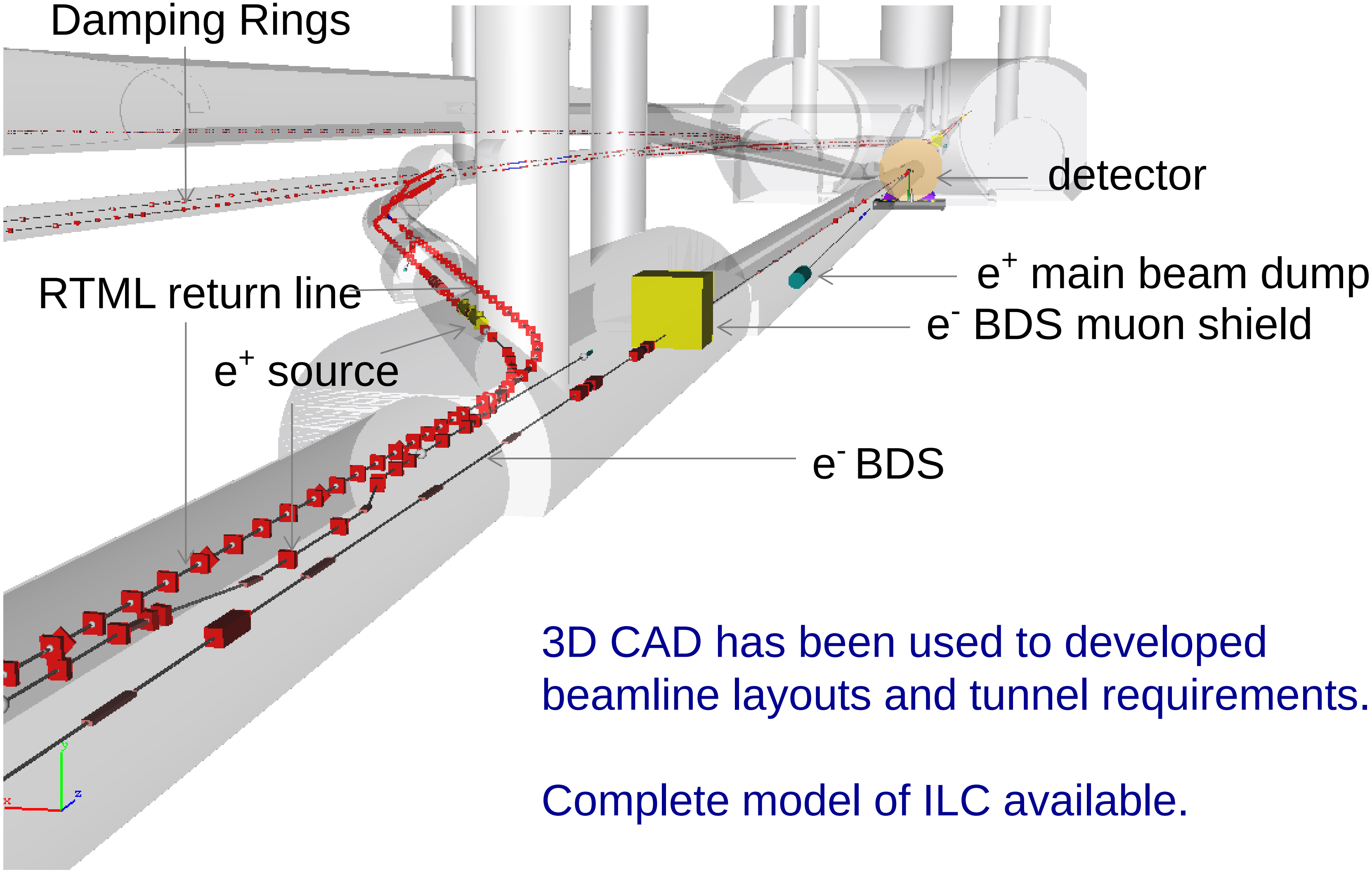
Final Focus R&D – ATF2





Formal international collaboration

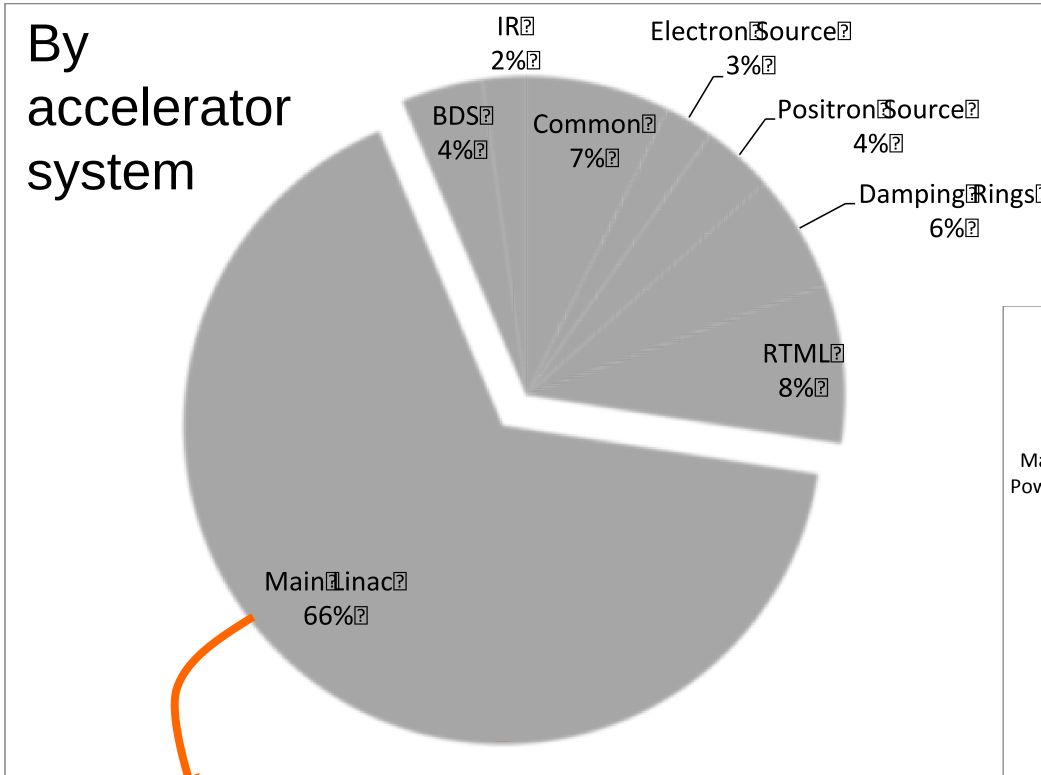
Central Region Integration



3D CAD has been used to developed beamline layouts and tunnel requirements.

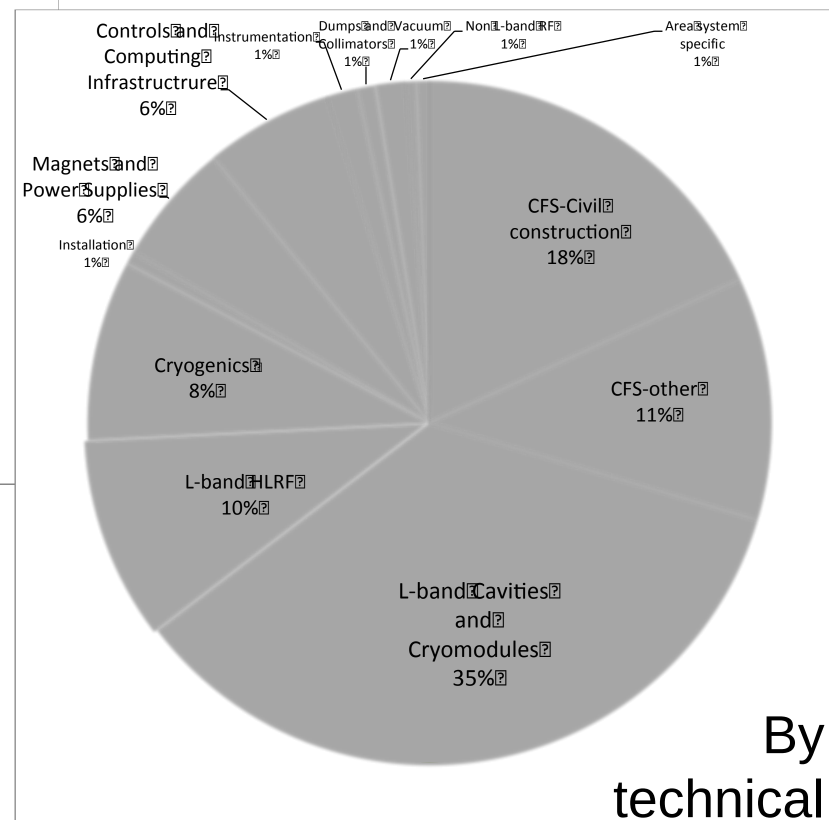
Complete model of ILC available.

Cost

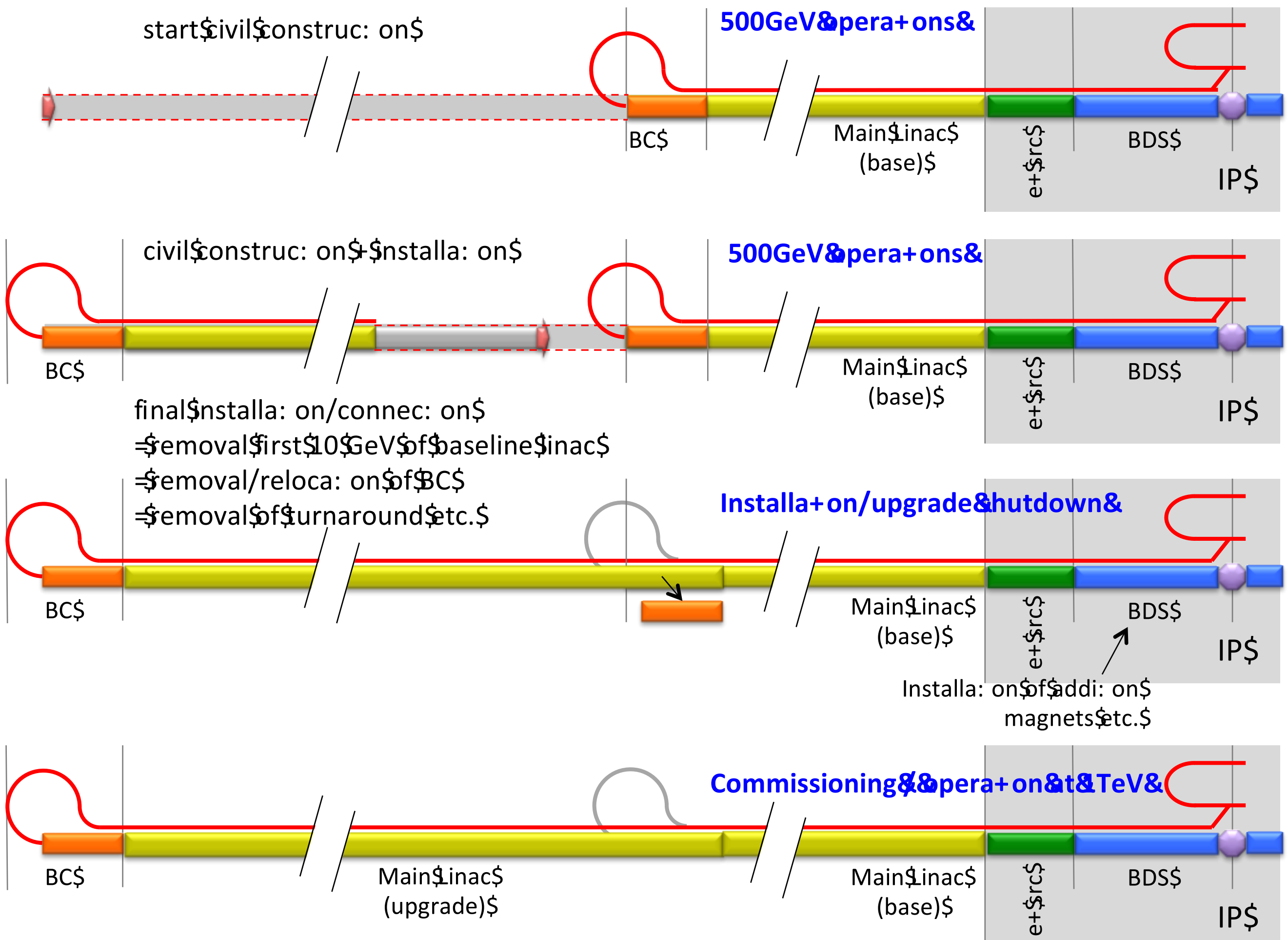


CFS-Civil construction	10%
CFS-other	6%
L-band Cavities and Cryomodules	32%
L-band HLRF	9%
Cryogenics	7%
Controls	2%
TOTAL Main Linac	**66%**

7.8 Billion ILCU
22.6 Million person-hours

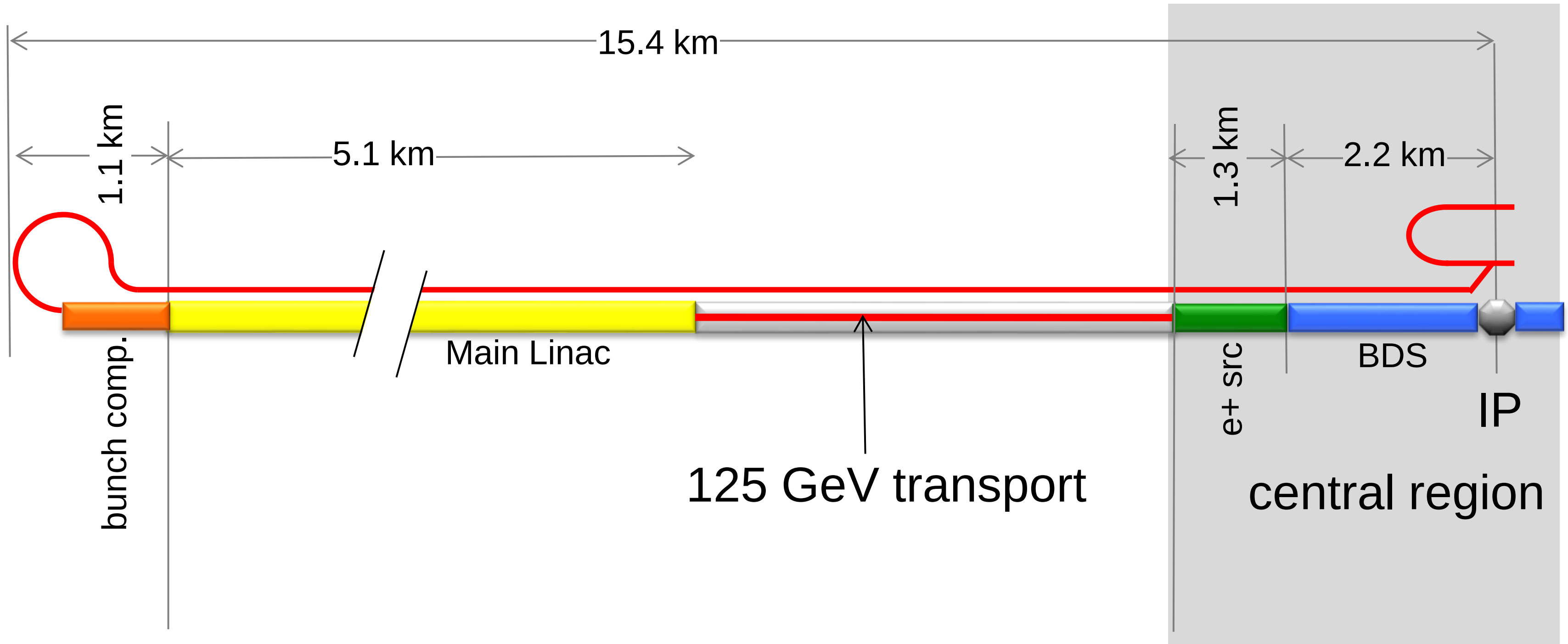


1 TeV Upgrade



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.

Initial Higgs Factory



Half the linacs
Full-length BDS tunnel & vacuum (TeV)
½ BDS magnets (instrumentation, CF etc)
5km 125 GeV transport line

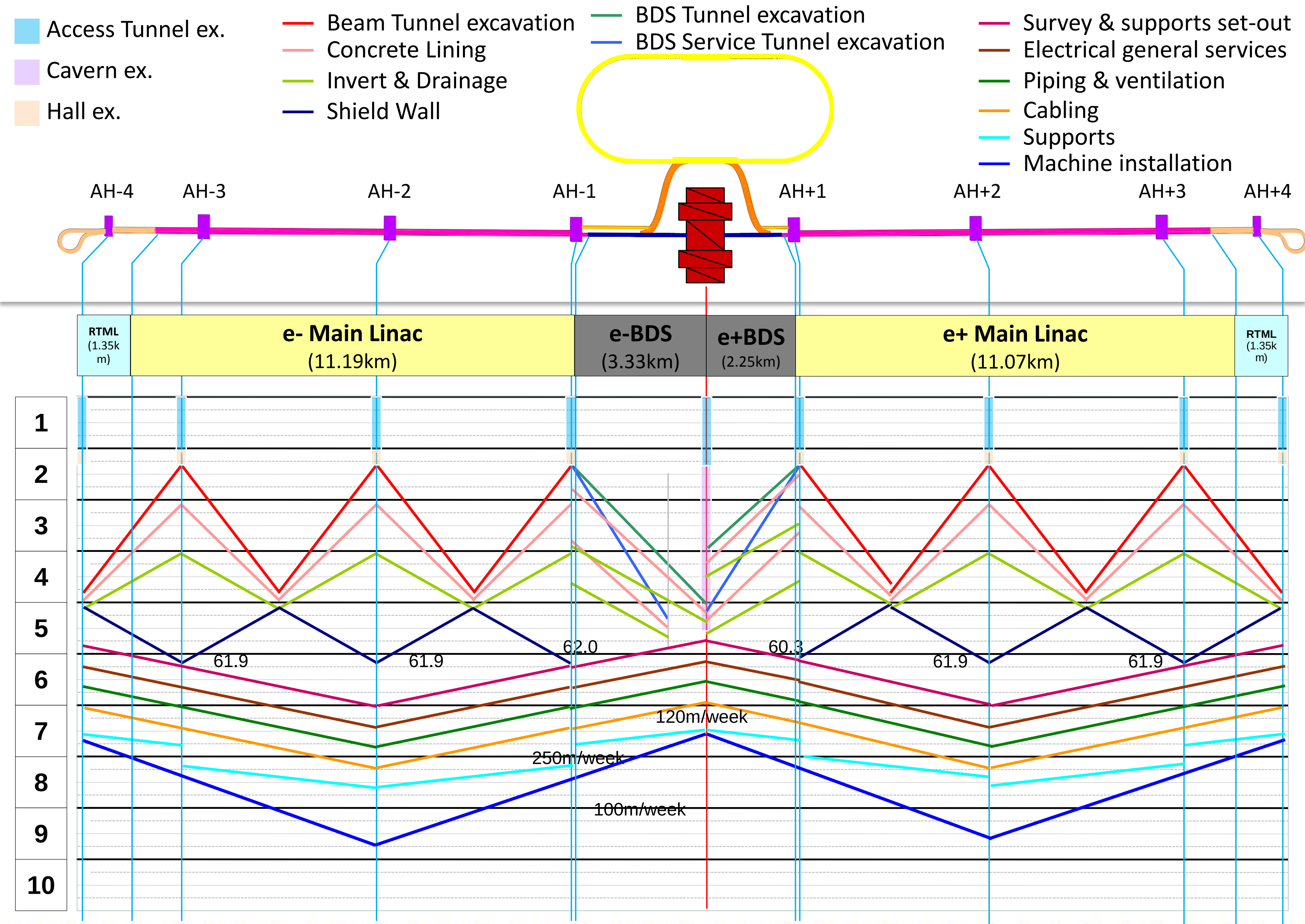
quasi-adiabatic energy upgrade?

Japanese Sites for ILC

- GDE-CFS group visited two sites, Oct., 2011.
- GDE EC visit in Jan. 2012.

Japanese Sites for ILC

- LCC Directorate official site visit next month.


Access Tunnel ex.
Cavern ex.
Hall ex.
Beam Tunnel excavation
Concrete Lining
Invert & Drainage
Shield Wall
BDS Tunnel excavation
BDS Service Tunnel excavation
Survey & supports set-out
Electrical general services
Piping & ventilation
Cabling
Supports
Machine installation
AH-4
AH-3
AH-2
AH-1
AH+1
AH+2
AH+3
AH+4
RTML (1.35km)
e- Main Linac (11.19km)
e-BDS (3.33km)
e+BDS (2.25km)
e+ Main Linac (11.07km)
RTML (1.35km)
1
2
3
4
5
6
7
8
9
10
61.9
61.9
62.0
60.3
61.9
61.9
120m/week
250m/week
100m/week

Snowmass Energy Frontier WG convener: Chip Brock

bottom line

This Higgs Boson changes everything.

We're obligated to understand it using all tools.

Brock/Peskin Snowmass 2013

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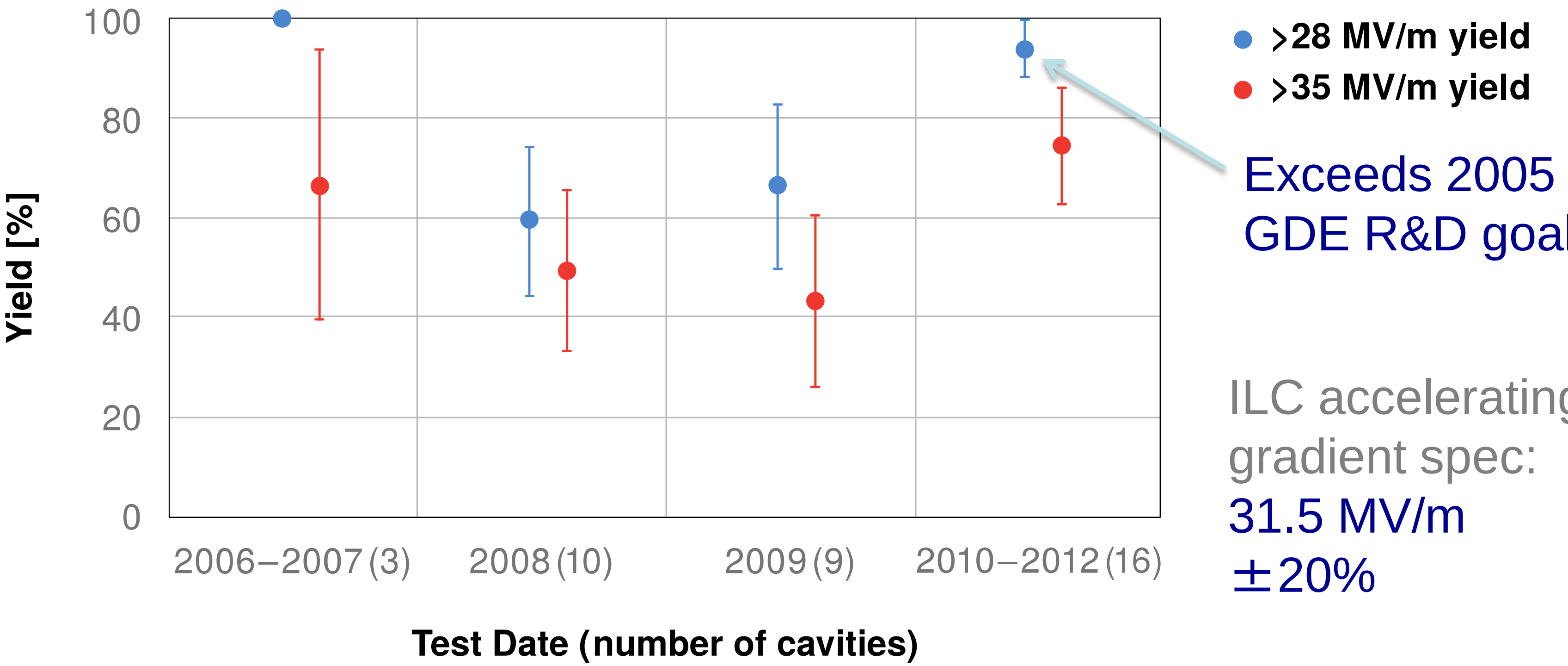
Summary and Outlook

- Rarely has the next large project in particle physics had such a strong physics case on phenomena known to exist or been based on such mature technology.
- Japan, a major player in particle physics, is expressing growing interest in hosting the ILC. In doing so, very substantial new resources would enter the subject. The European Strategy, Snowmass and ACFA processes welcome this development.
- The TDR is the evidence that the ILC can be built now within a carefully costed envelope based on real XFEL project costs.
- A single site has now been selected and the political process has momentum.
- We are at a crucial point - the ILC is a project whose time has come.

Signpost to the Future?

Backup slides

Gradient performance worldwide



ILC accelerating gradient spec: 31.5 MV/m ±20%

GDE global database Asia – KEK; Europe – DESY; US – JLab, FNAL, ANL

Qualified cavity vendors Asia – 2; Europe – 2; US – 1

500 GeV ILC Overview

Physics

Max. E_{cm}	500 GeV
Luminosity	1.8×10^{34} $cm^{-2}s^{-1}$
Polarisation (e-/e+)	80% / 30%
δ_{BS}	4.5%

tiny emittances
nano-beams at IP
strong beam-beam

Beam (interaction point)

σ_x / σ_y	574 nm / 6 nm
σ_z	300 μm
$\gamma\varepsilon_x$ / $\gamma\varepsilon_y$	10 μm / 35 nm
β_x / β_y	11 mm / 0.48 mm
bunch charge	2×10^{10}

High-power high-current beams. Long bunch trains.
→ SCRF

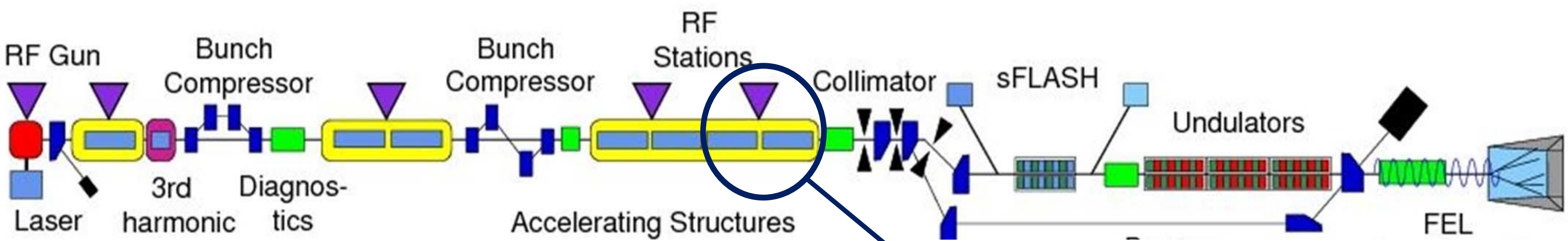
…structure)

Number of bunches / pulse	1312
Bunch spacing	554 ns
Pulse current	5.8 mA
Beam pulse length	727 μs
Pulse repetition rate	5 Hz

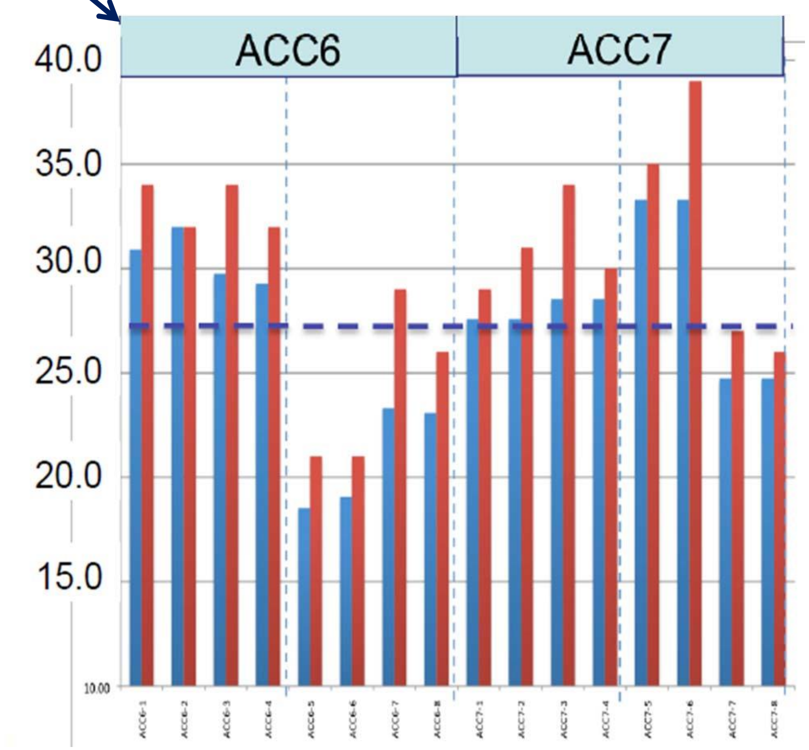
Accelerator (general)

Average beam power	10.5 MW (total)
Total AC power	163 MW
(linacs AC power	107 MW)

FLASH Achievements



		XFEL	ILC (upg.)	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



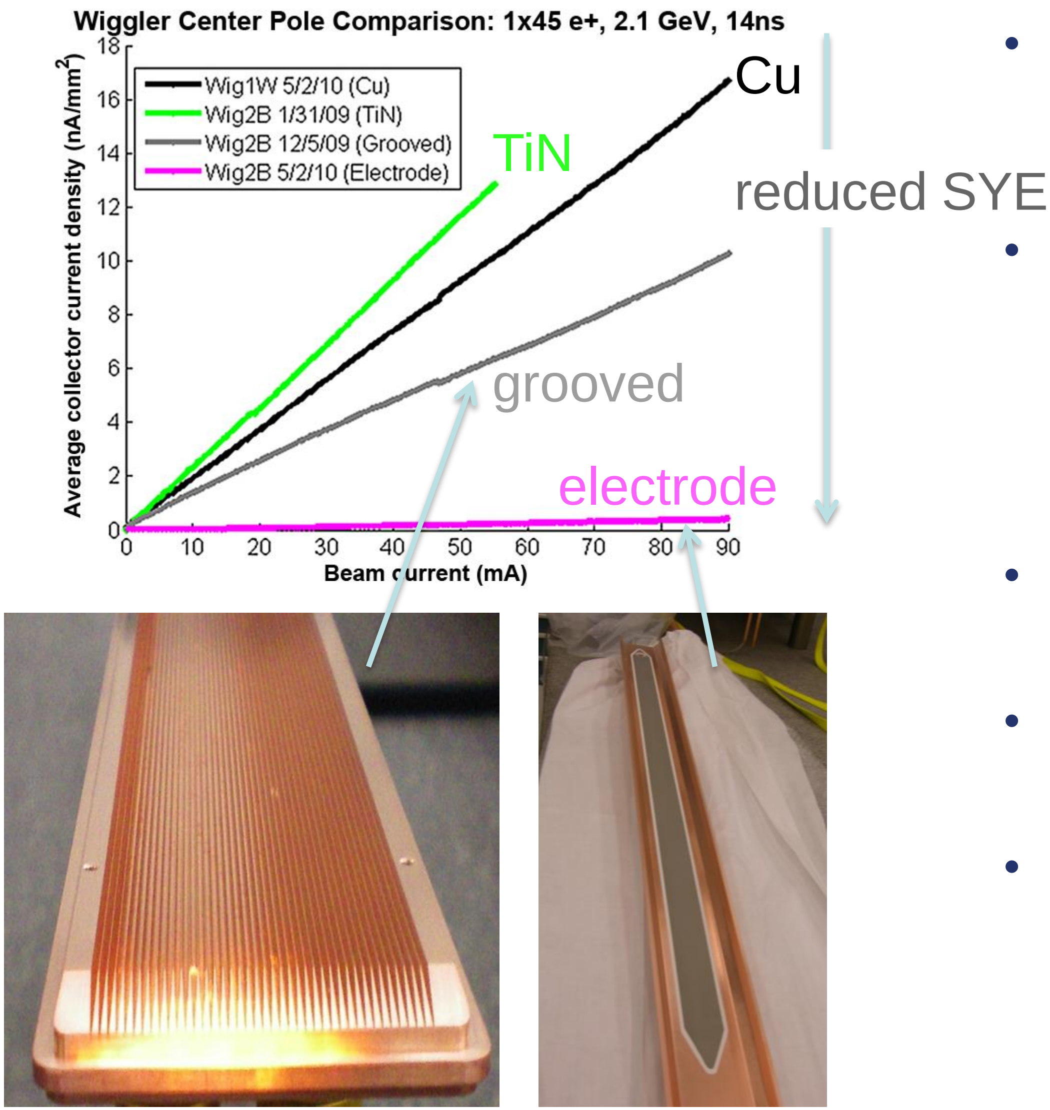
Many basic demonstrations:

- heavy beam loading with long bunch trains
- operation close to quench limits
- klystron overhead etc.

Development (LLRF & controls):

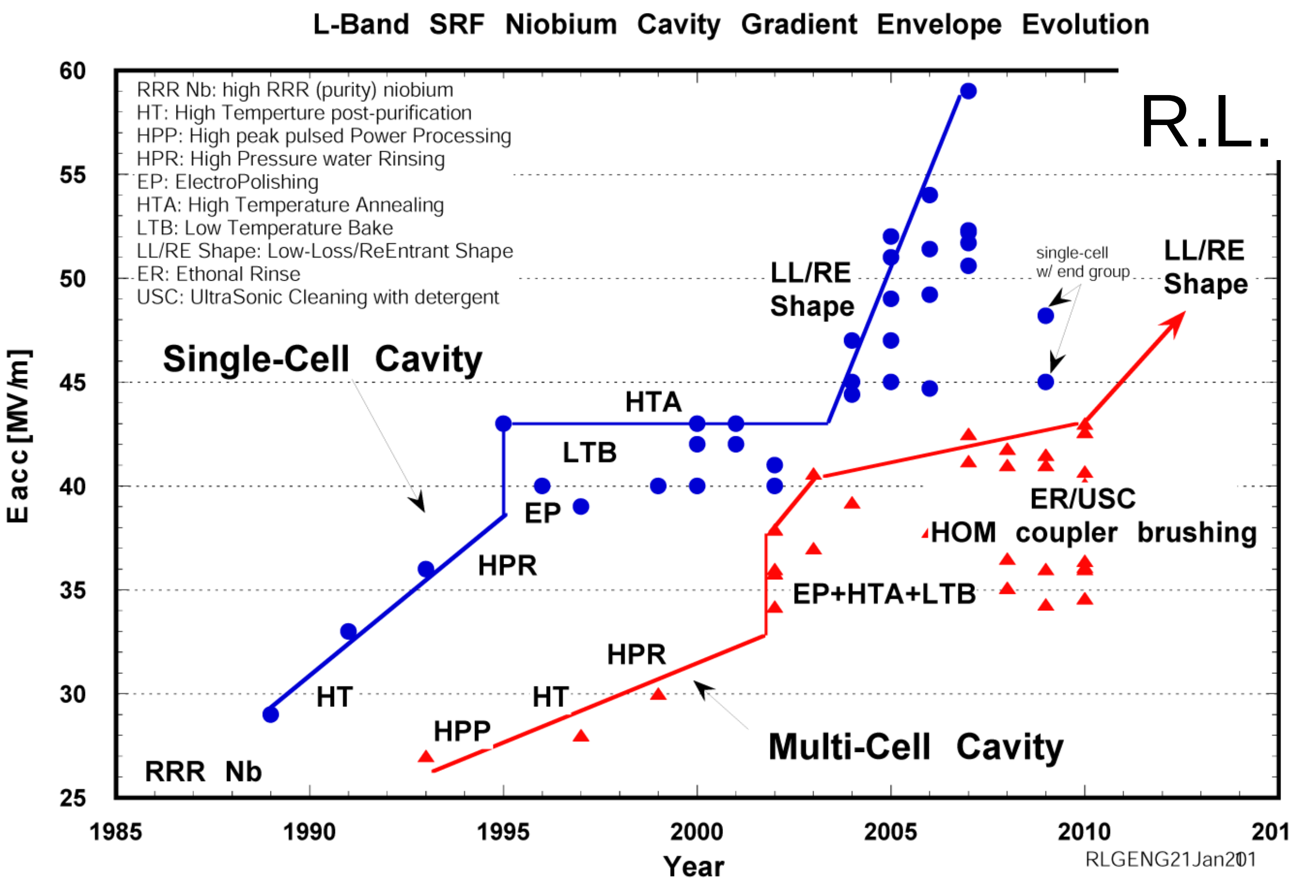
- tuning algorithms
- automation
- quench protection etc.

DR: Critical R&D (Electron Cloud)



- Extensive R&D programme at CESR, Cornell (CesrTA)
- Instrumentation of wiggler, dipole and quad vacuum chambers for e-cloud measurements
  - RFA
- low emittance lattice
- Example: wiggler vacuum chamber
- Benchmarking of simulation codes
  - cloud build-up
  - beam dynamics (head-tail instabilities)

Upgrades - 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.

Luminosity Upgrade

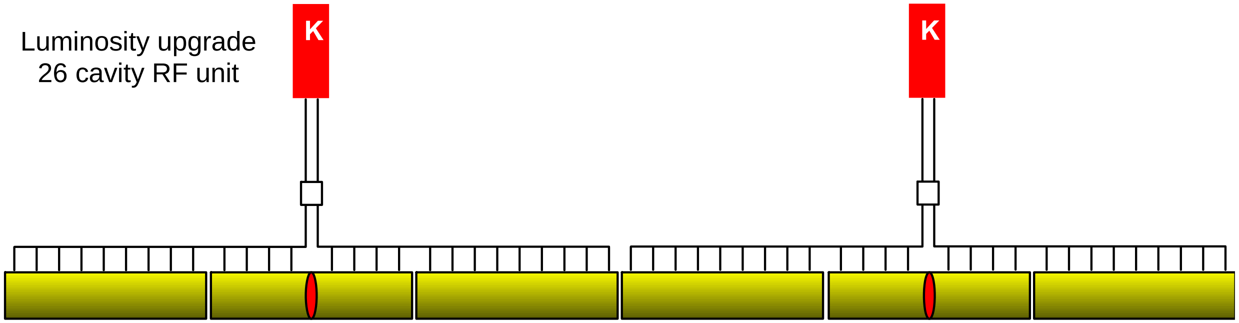
- Concept: increase n_b from 1312 → 2625
  - **Reduce linac bunch spacing 554 ns → 336 ns**

- Doubles beam power → $\times 2$ L = 3.6×10^{34} cm^{-2}s^{-1}

- AC power: 161 MW → 204 MW (est.)
  - **shorter fill time and longer beam pulse results in higher RF-beam efficiency (44% → 61%)**

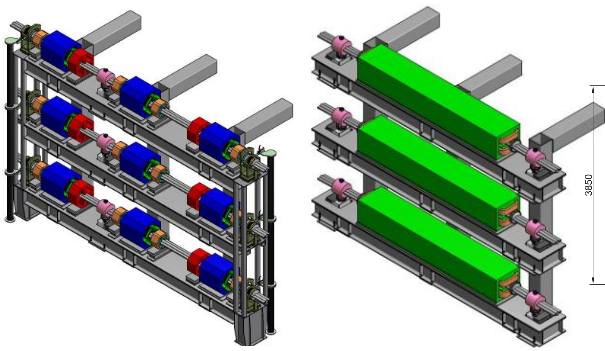
Luminosity Upgrade

Adding klystrons (and modulators)



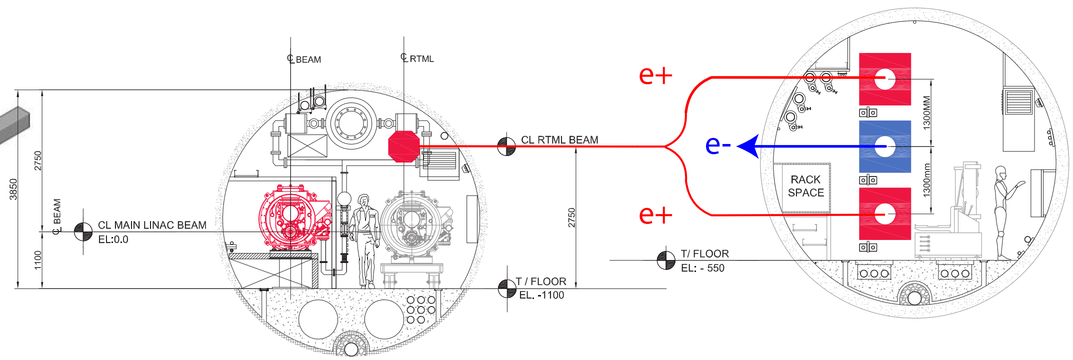
Damping Ring:

Positron ring (upgrade)
Electron ring (baseline)
Positron ring (baseline)



Arc quadrupole section

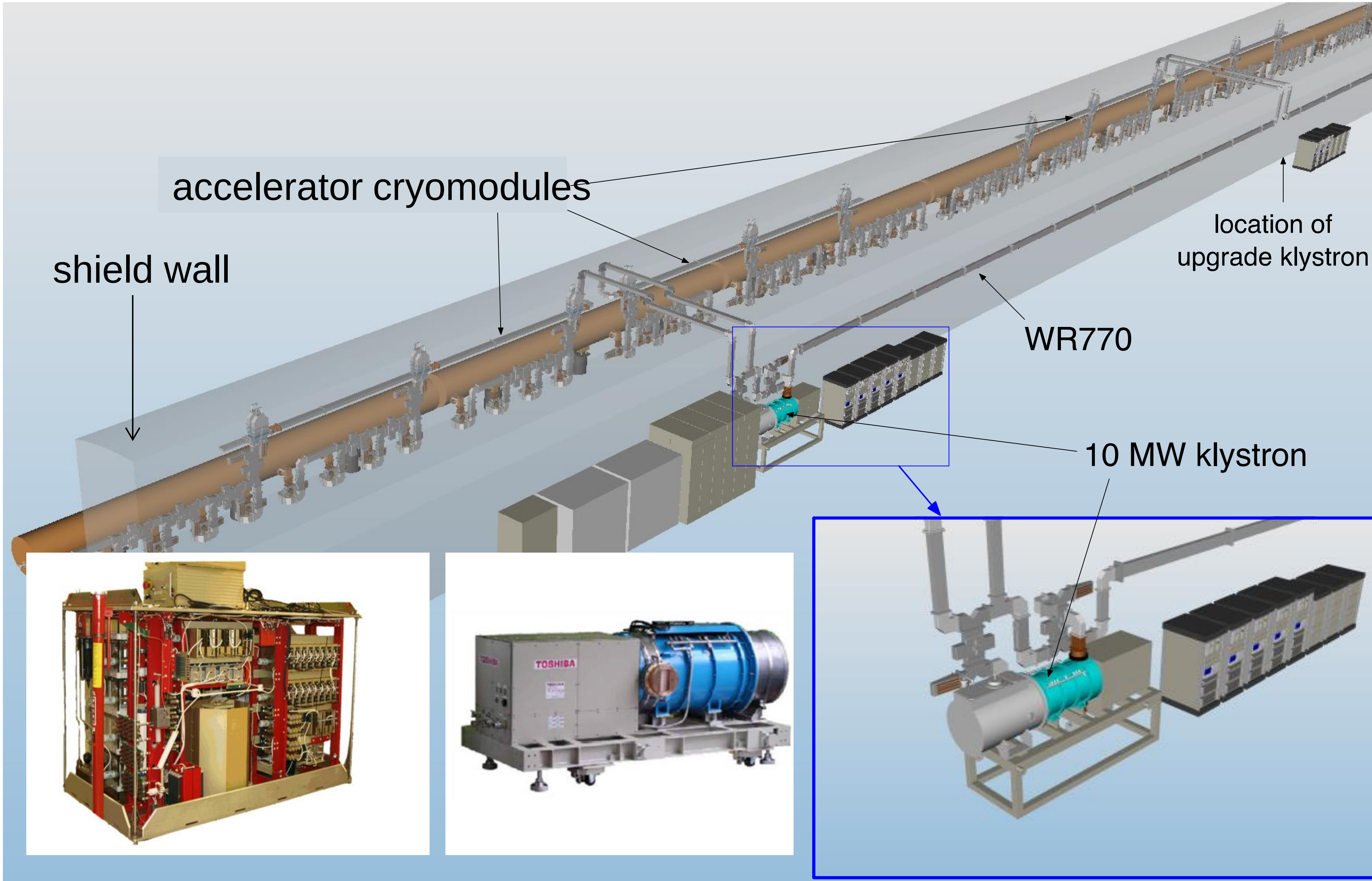
Dipole section



Main Linac Tunnel

Damping Ring Tunnel

RF Power Generation



gamma-gamma

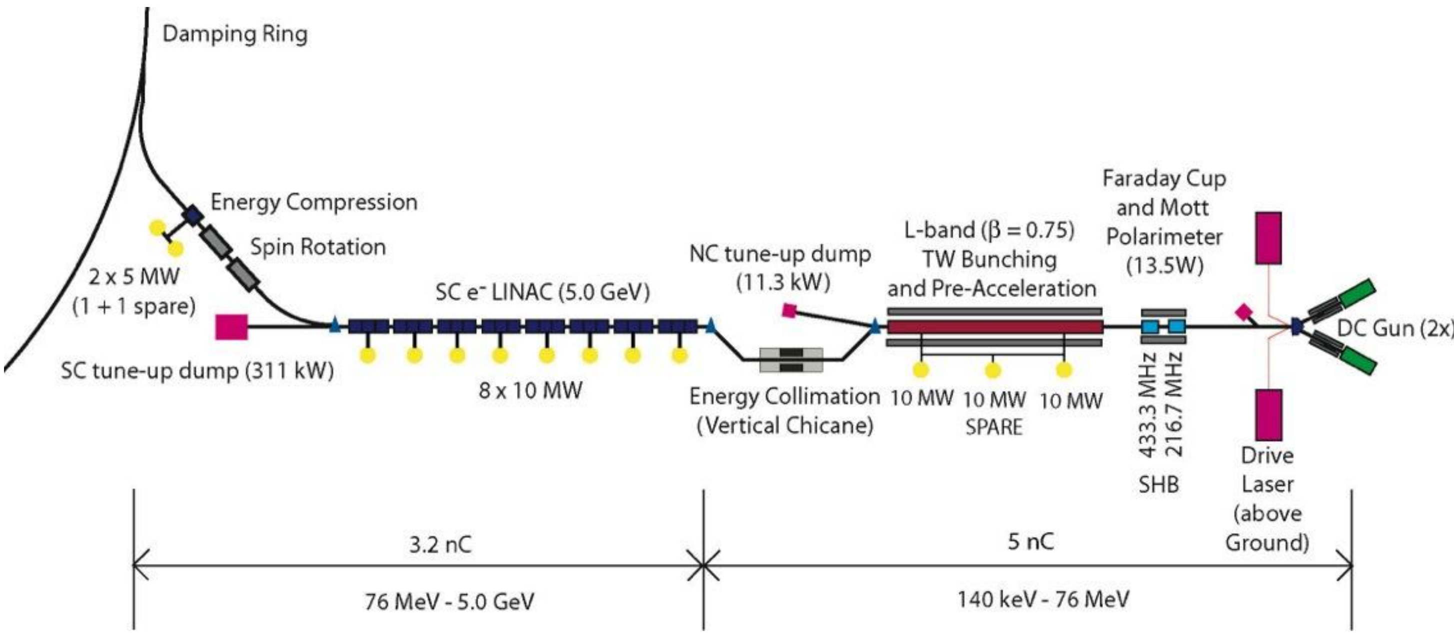
Gamma-Gamma General Status

- γ-γ technology is still premature
  - need > 5 years of R&D
- Cannot start with γ-γ at the lowest energy if early start is planned
  - need 100% confidence at the time of project approval
- From technology view point it is reasonable to start with e^+e^- at ZH and, if needed, convert to γ-γ later
  - importance of γ-γ must be evaluated before the construction of e+e- (possible constraints in IR, e.g., the crossing angle)

(Yokoya LCWS12)

Polarised Electron Source

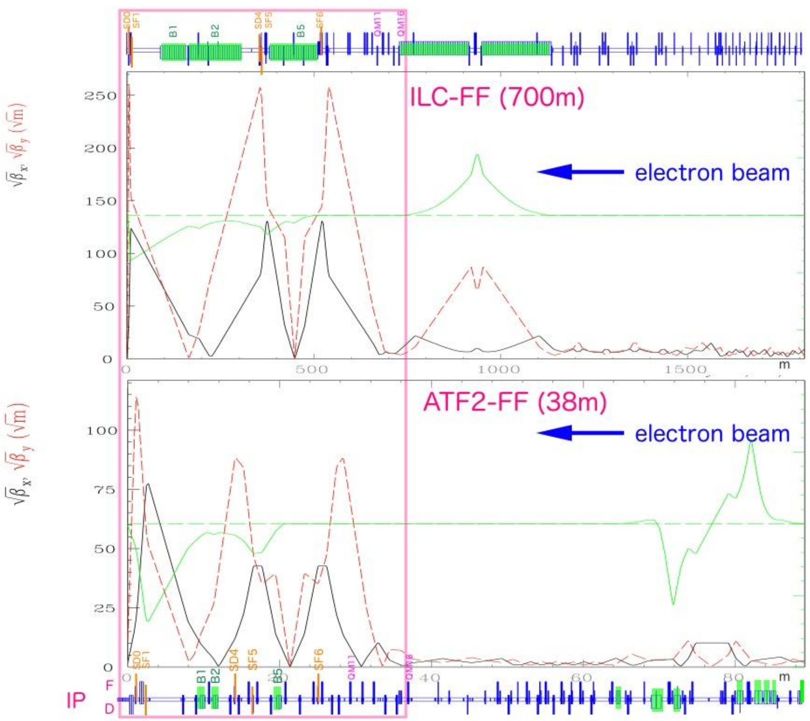
- Laser-driven photo cathode (GaAs)
- DC gun
- Integrated into common tunnel with positron BDS

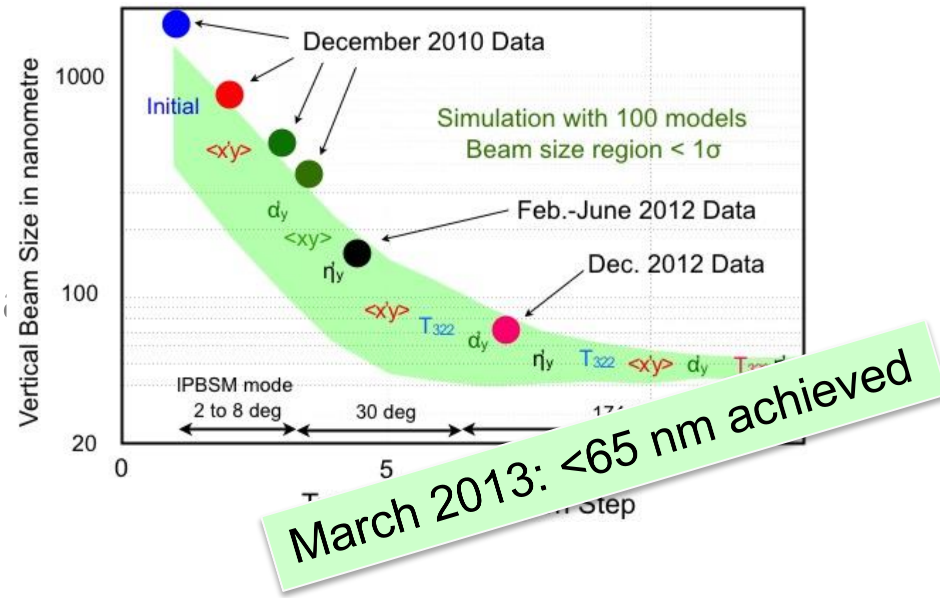


Final Focus R&D – ATF2

Test bed for ILC final focus optics

- strong focusing and tuning (37 nm)
- beam-based alignment
- stabilisation and vibration (fast feedb
- instrumentation





IP beam size monitor