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Future Accelerator Facilities

for Particle Physics

Brian Foster (Uni Hamburg/DESY/Oxford)

Natal School, October 2014

Outline

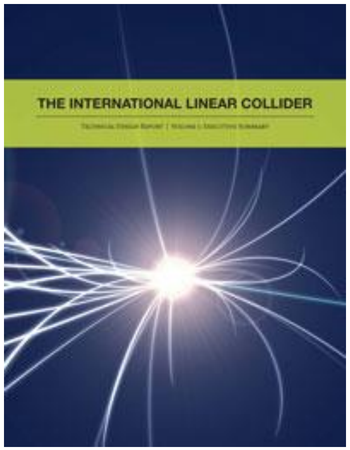
- ~~Lecture 1: Introduction to accelerators~~
  - ~~Historical development & status including LHC & upgrades~~
- ~~Lecture 2: Overview of ideas for future facilities~~
  - ~~Hadron-hadron machines – LHC (& beyond)~~
  - ~~Lepton-lepton Machines~~
    - ~~e^+e^- – linear (circular); $\mu^+\mu^-$~~
  - ~~Lepton-hadron machines~~
  - ~~Plasma-wave acceleration~~
- Lecture 3: The future in depth – the ILC Project – status & prospects

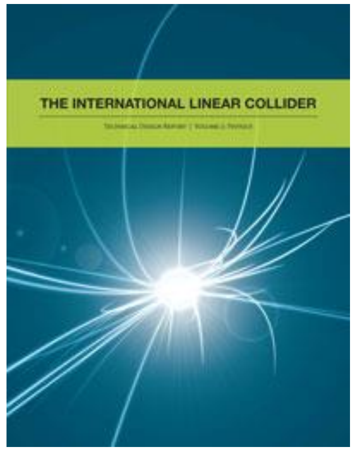
Lecture 3

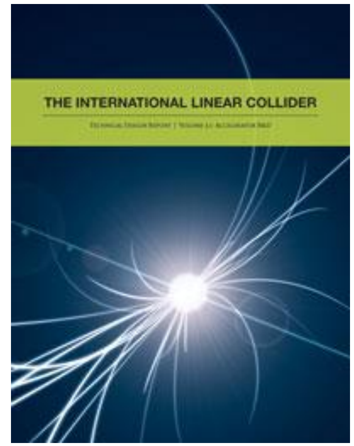
- A very brief resume of the physics case for ILC
- An even briefer mention of the detectors
- The ILC machine
  - SCRF, Damping Rings, Sources, Beam Delivery
- Site & Site-dependent design
- Political situation & prospects
- Summary & outlook

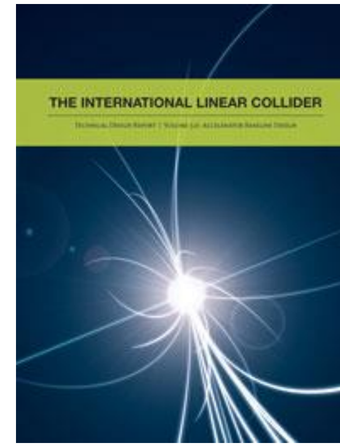
ILC - Introduction

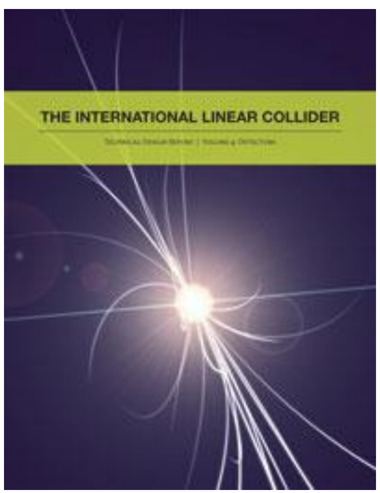
- On June 12th, 2013 ILC TDR was published in Worldwide Event.











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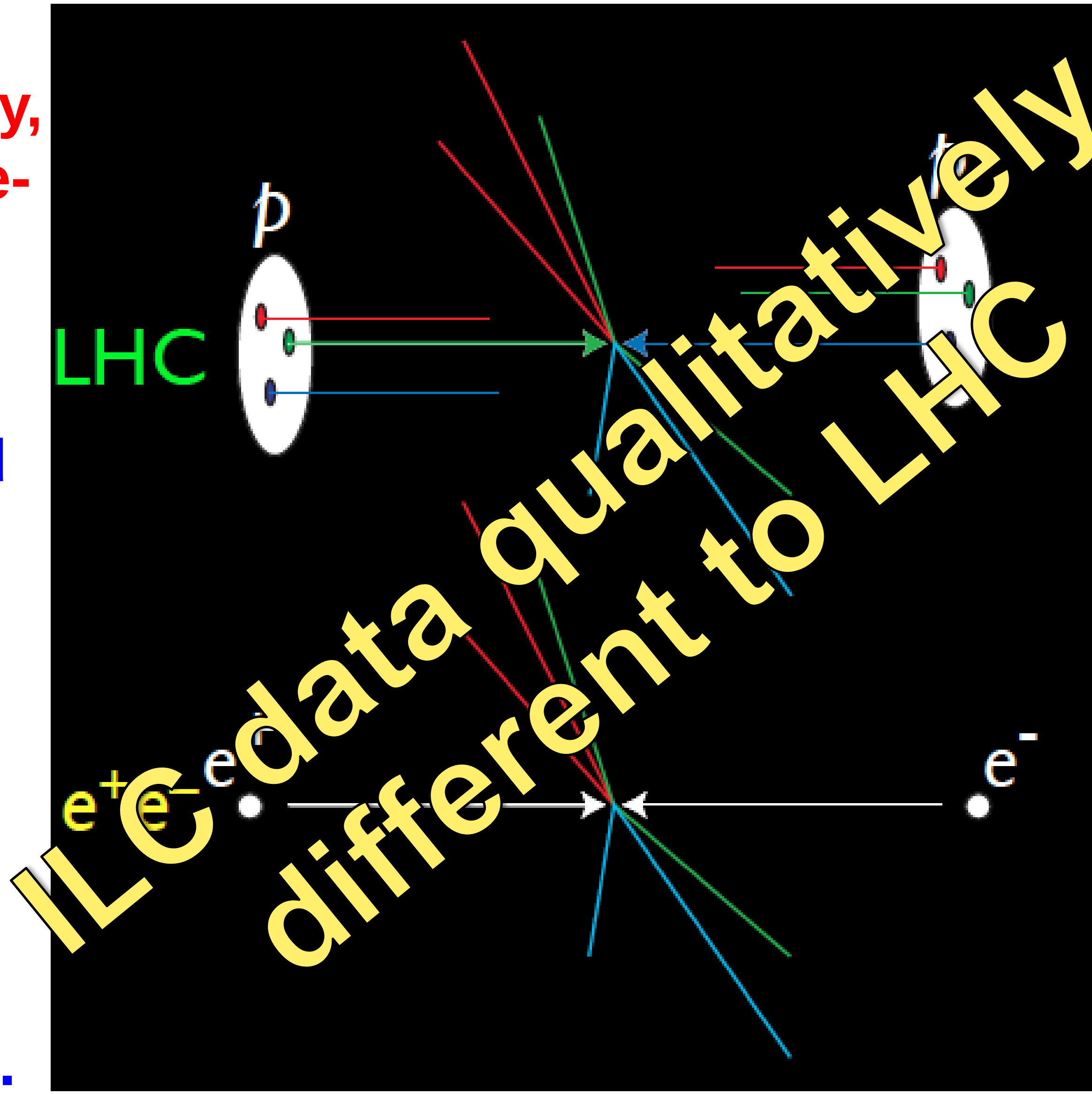
World-wide Event

- On June 12th, 2013 ILC TDR was published in Worldwide Event.

- End of major phase in ILC development – now what?

- **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

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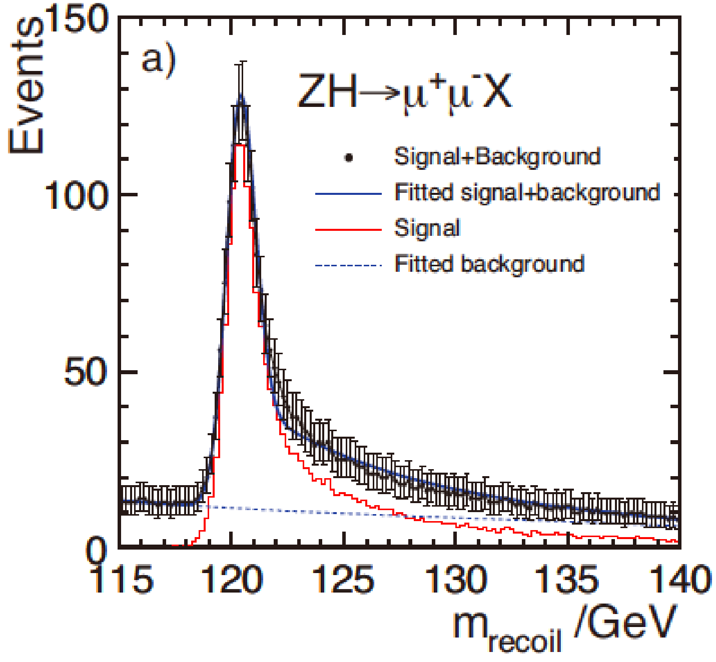
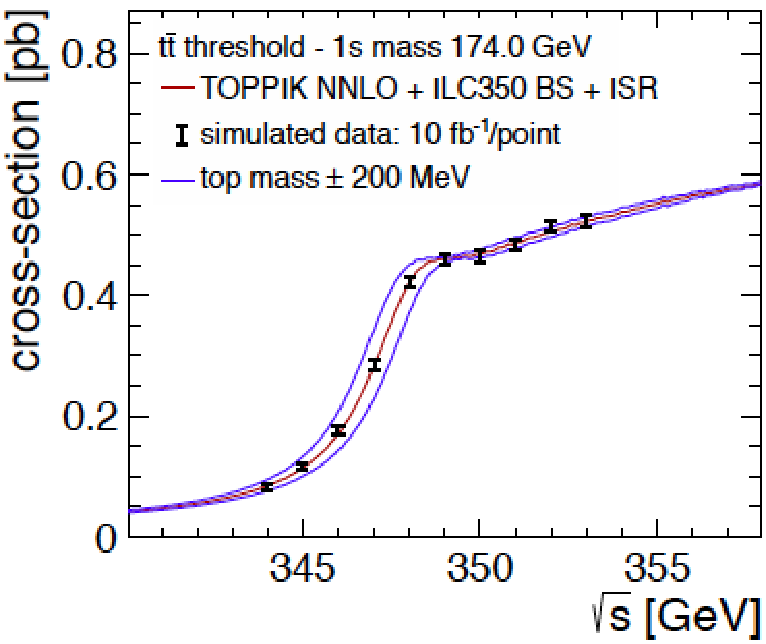
- Very difficult, but essential, to estimate what LHC will do before ILC can enter the scene.
- However, broad agreement that some physics channels unique to ILC – Higgs invisible BRs, c, light-quark couplings, precision top mass, many new physics signatures….





Brock Snowmass Summary

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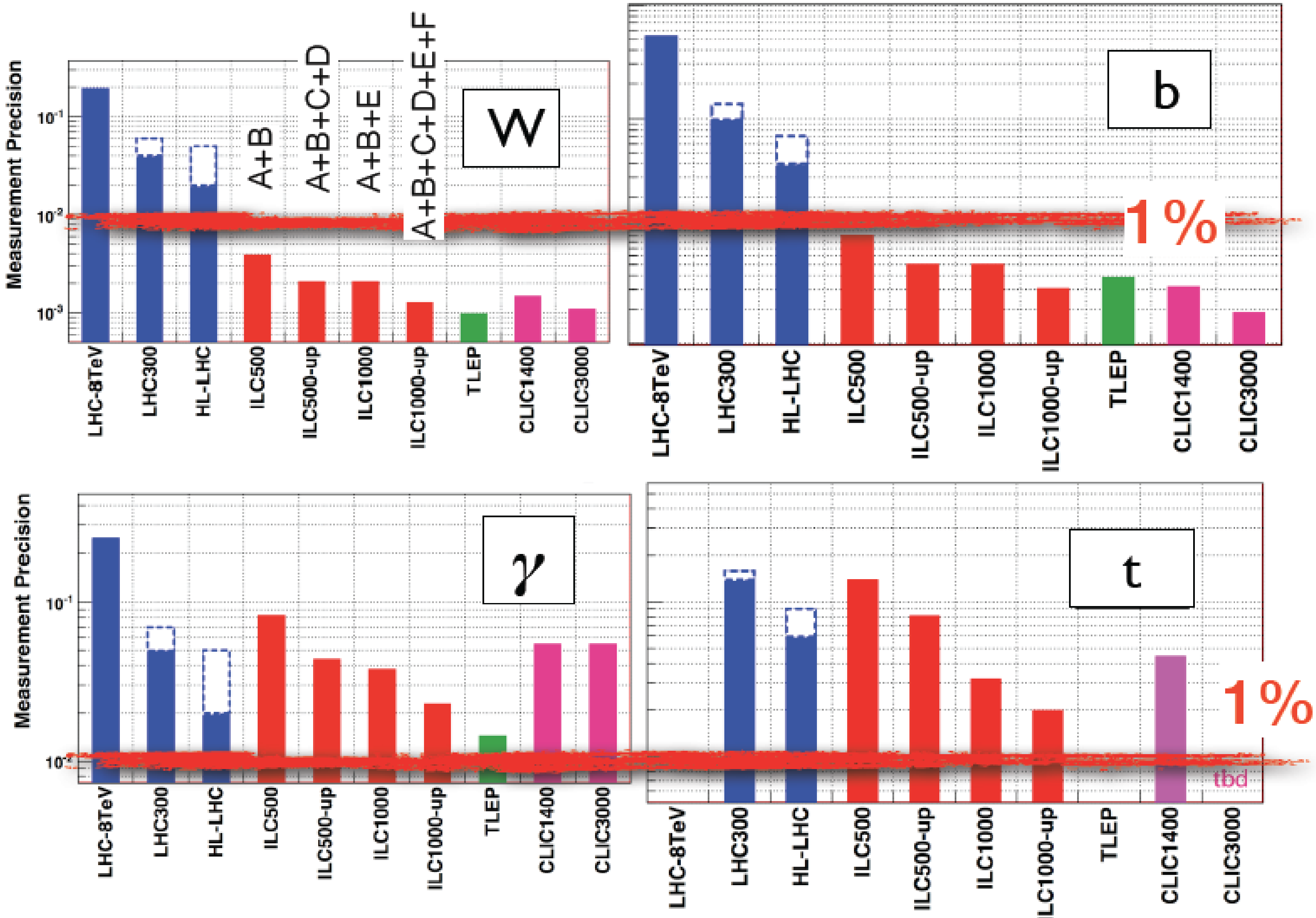
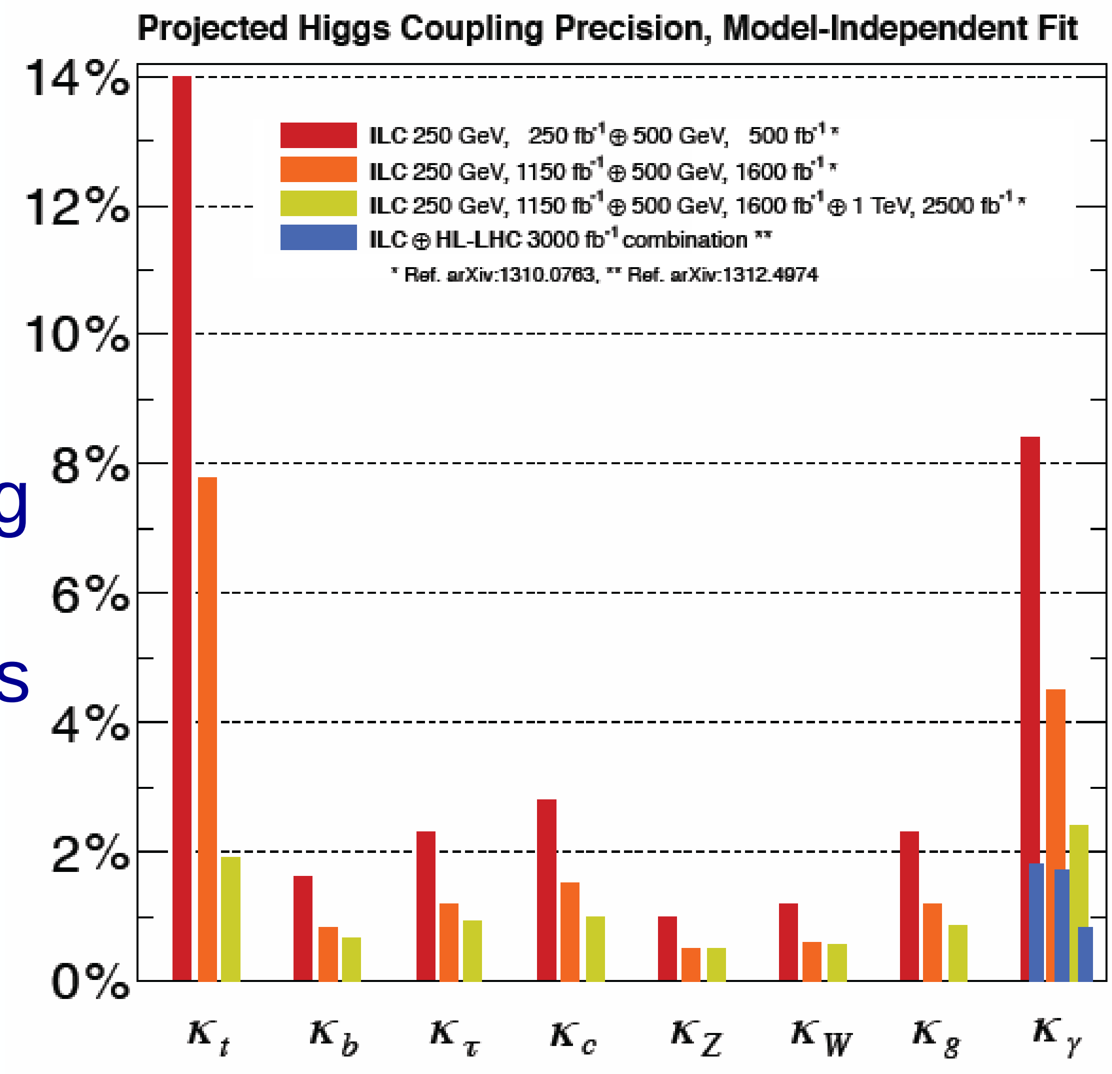
Precision in kappa by facility

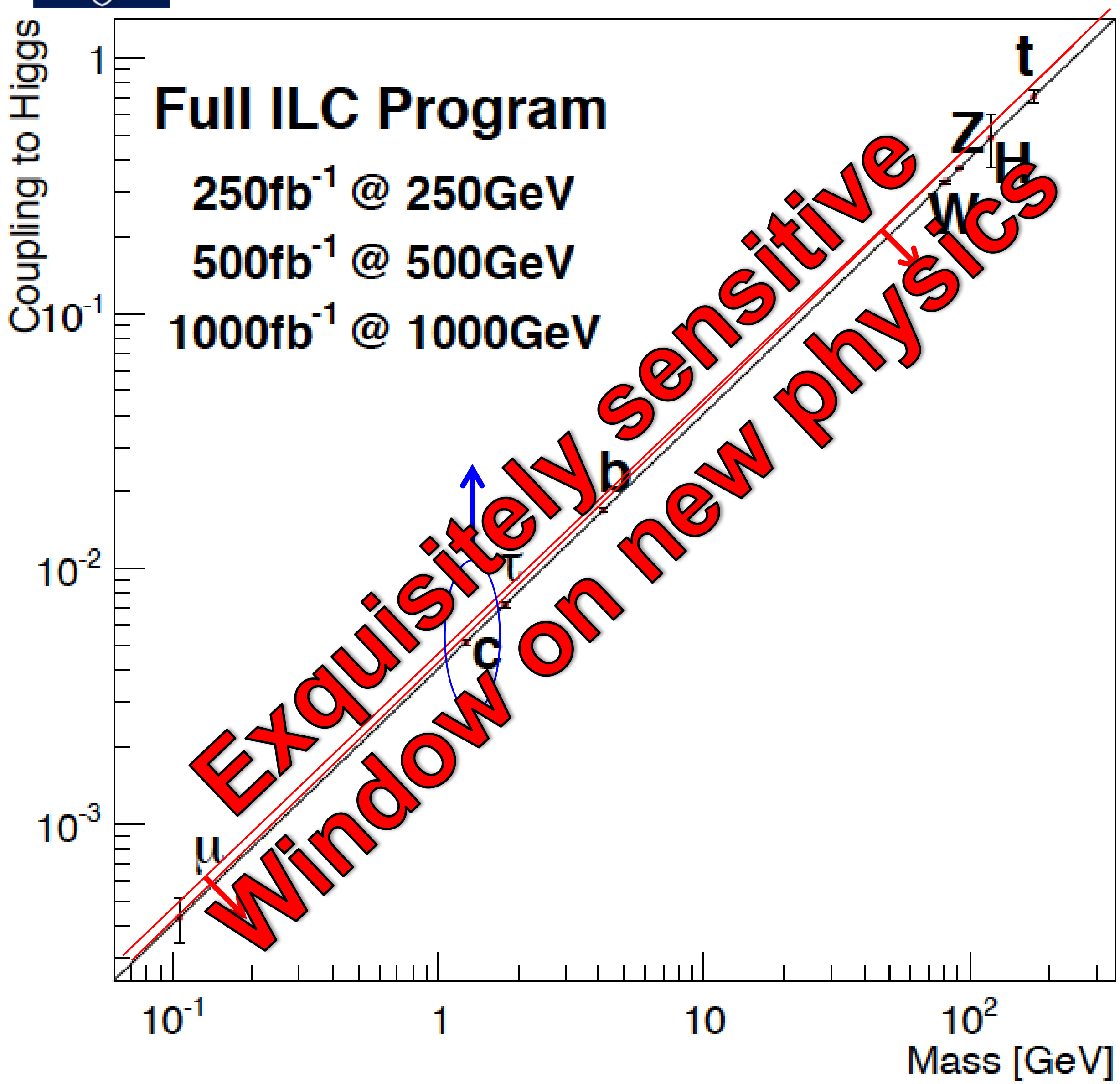


Model Independent Higgs

Running at 500 GeV (preferably 550 GeV) is essential to deliver this precision. Running Only @ 250 GeV is MUCH (at least factors 2-3) worse than leftmost column.



Higgs Couplings Summary



Extra Dimensions

Anomalous Couplings

Polarisation is another dimension

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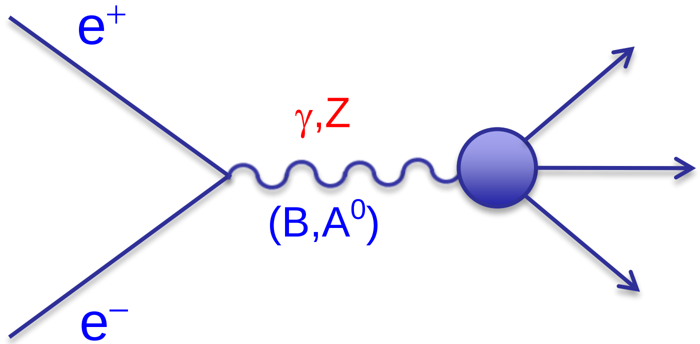
Specifies the intermediate state

- **Right-handed e^- turns off A^0**
  - **Information on the gauge structure of the final state**

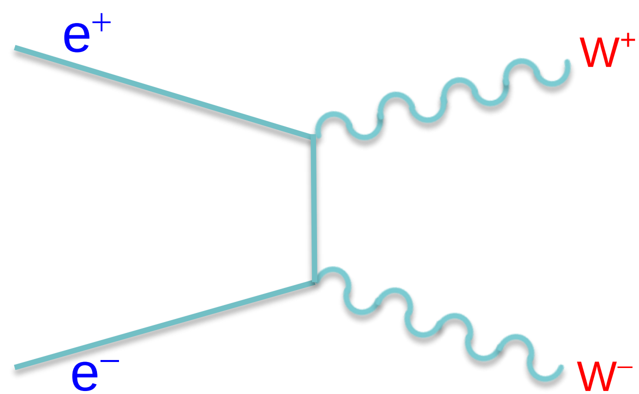


Increases rates

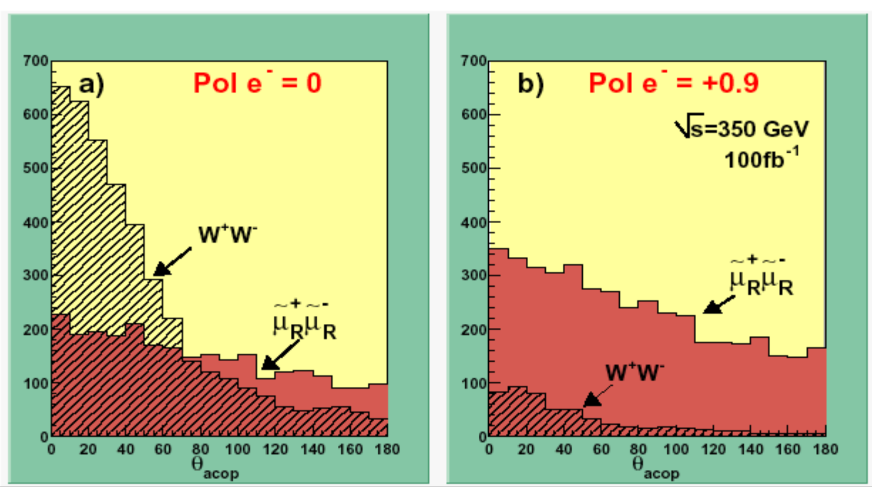
- **e.g. $P^- /P^+ = -0.8/0.3$:**

Increases the H production mode

$\sigma(\nu\nu H)$ by X 2.34 (=1.8 x1.3)



Background rejection



e.g. acoplanar muon pair produciton such as smuon pair production

Brock Snowmass Summary

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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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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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P5 conclusions on ILC

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- **Recommendation 11: Motivated by the strong scientific importance of the ILC and the recent initiative in Japan to host it, the U.S. should engage in modest and appropriate levels of ILC accelerator and detector design in areas where the U.S. can contribute critical expertise. Consider higher levels of collaboration if ILC proceeds.**

- The interest expressed in Japan in hosting the International Linear Collider (ILC) is an exciting development. Participation by the U.S. in project construction depends on a number of important factors, some of which are beyond the scope of P5 and some of which depend on budget Scenarios. As the physics case is extremely strong, all Scenarios include ILC support at some level through a decision point within the next 5 years.

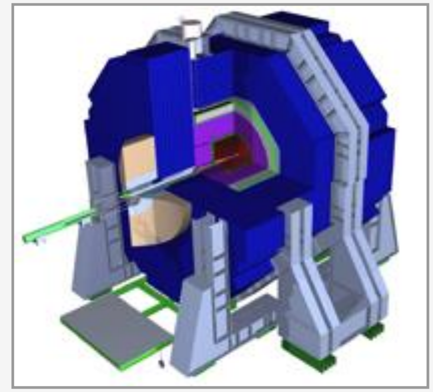
ILC Physics Case Summary

- Higgs is absolutely important
- HL-LHC the highest priority
- ILC has an evolutionary program on Higgs
  - 250GeV: *ZH*, branching fractions
  - 500GeV: W-fusion, *ttH*, self-coupling, top
  - 1TeV: much better *ttH*, self-coupling
- Guaranteed precision programs on *t*, *Z*, *W*
- at the same time, hope for new physics
  - the same approach as LEP with *Z* & *W*

2 Detector Concepts: Detailed Baseline Design

ILD

SiD



- Large R with TPC tracker
  - 32 countries,
  - 151 institutions,
  - ~700 members
- – B=3.5T, TPC+Si trackers, ECal(R=1.8m)

- High B with Si strip tracker
  - 18 countries,
  - 77 institutions,
  - ~240 members
- – B=5T, Si only tracker, Ecal(R=1.27m)

- Basic requirements:
  - E_{cm} : **200 – 500 GeV, and the ability to scan**
  - Luminosity : $\int Ldt$ = 500 fb^{-1} in 4 years
  - E stability and precision: < 0.1%
- Extendability:
  - Energy upgrade: **500 → 1,000 GeV**

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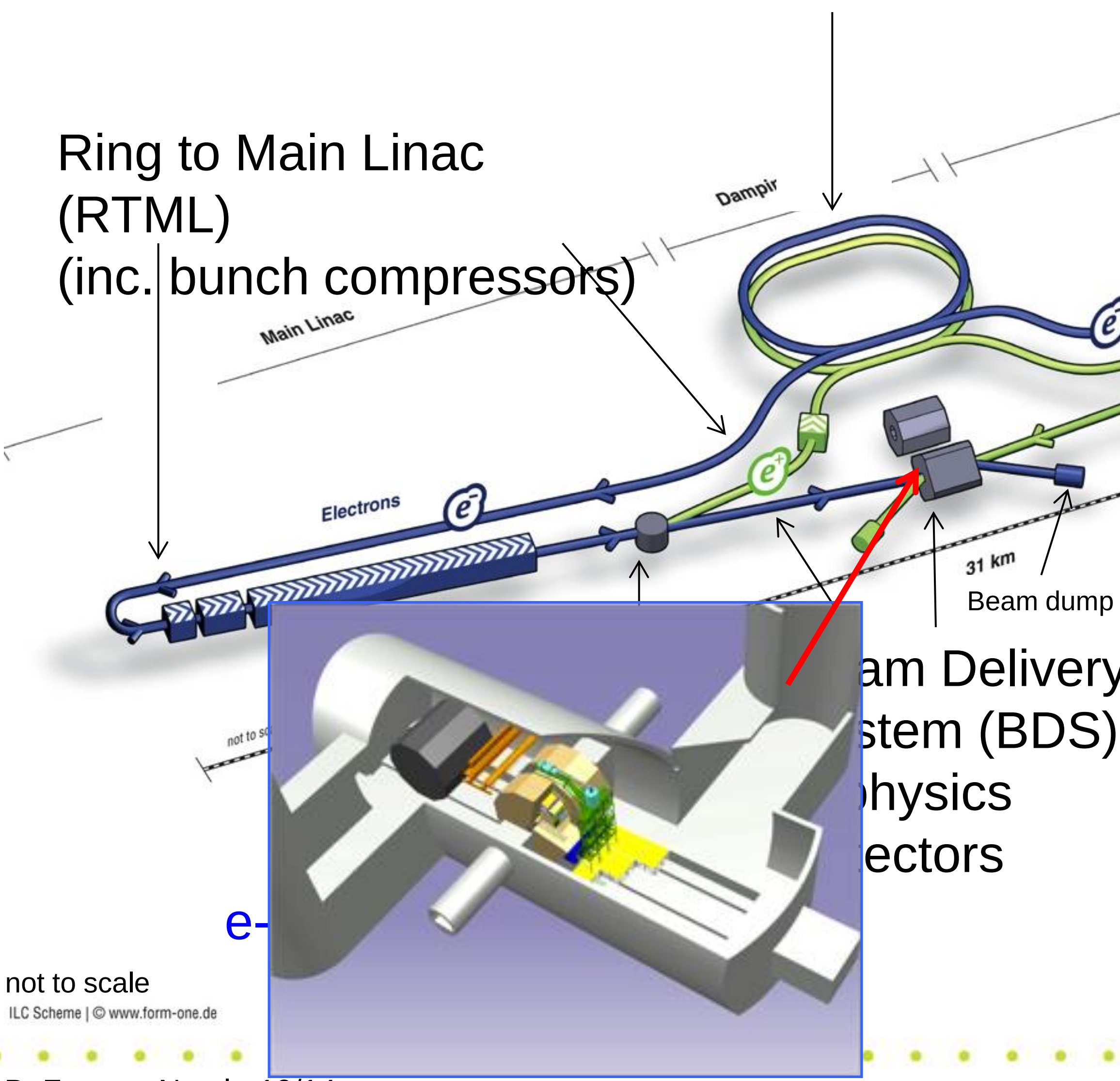
LC Overview



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

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

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Road to High Performance

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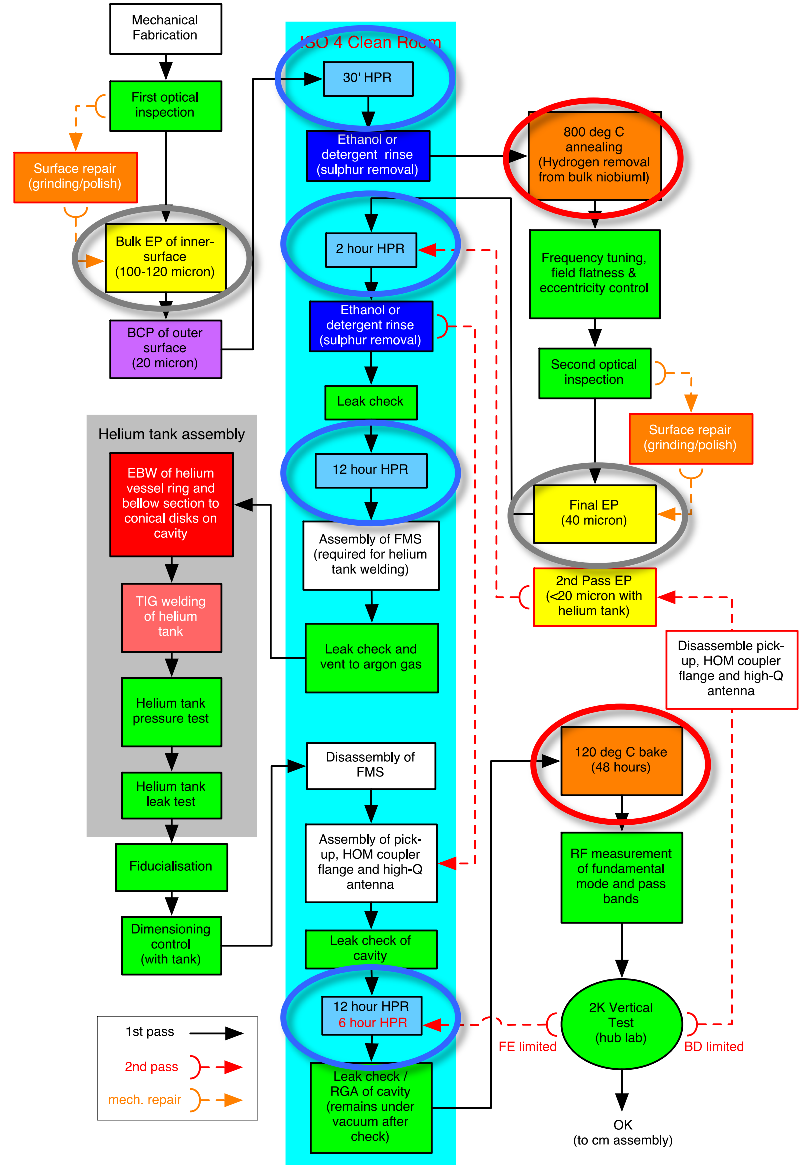
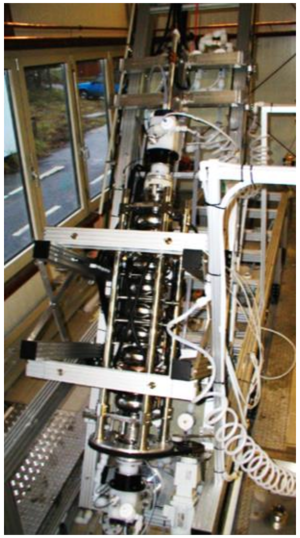
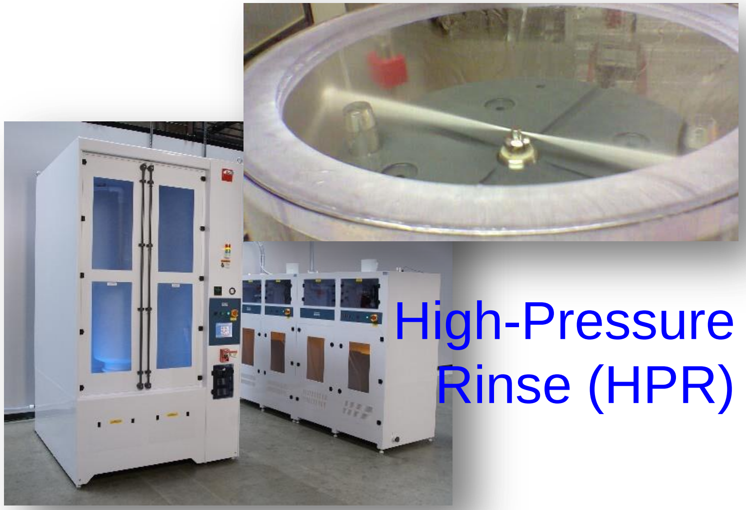




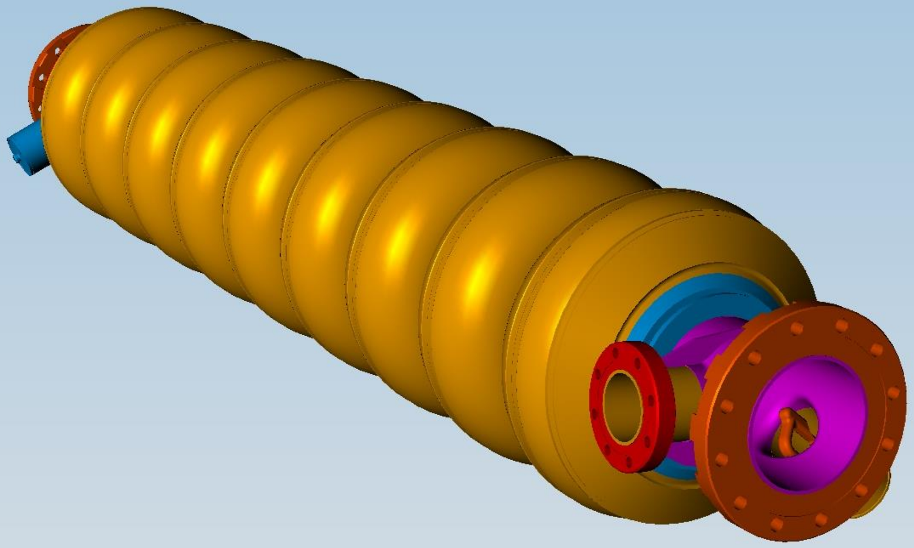
Electropolishing



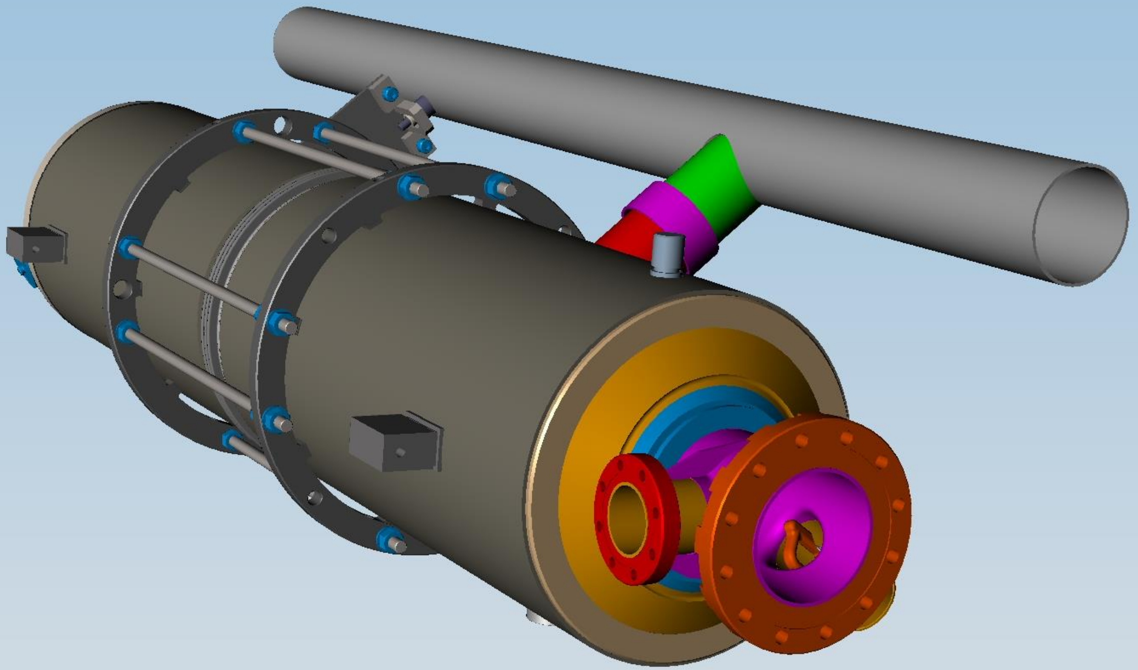
High-Pressure Rinse (HPR)

800° C annealing and 120° C baking

Cryomodule construction



Cryomodule construction



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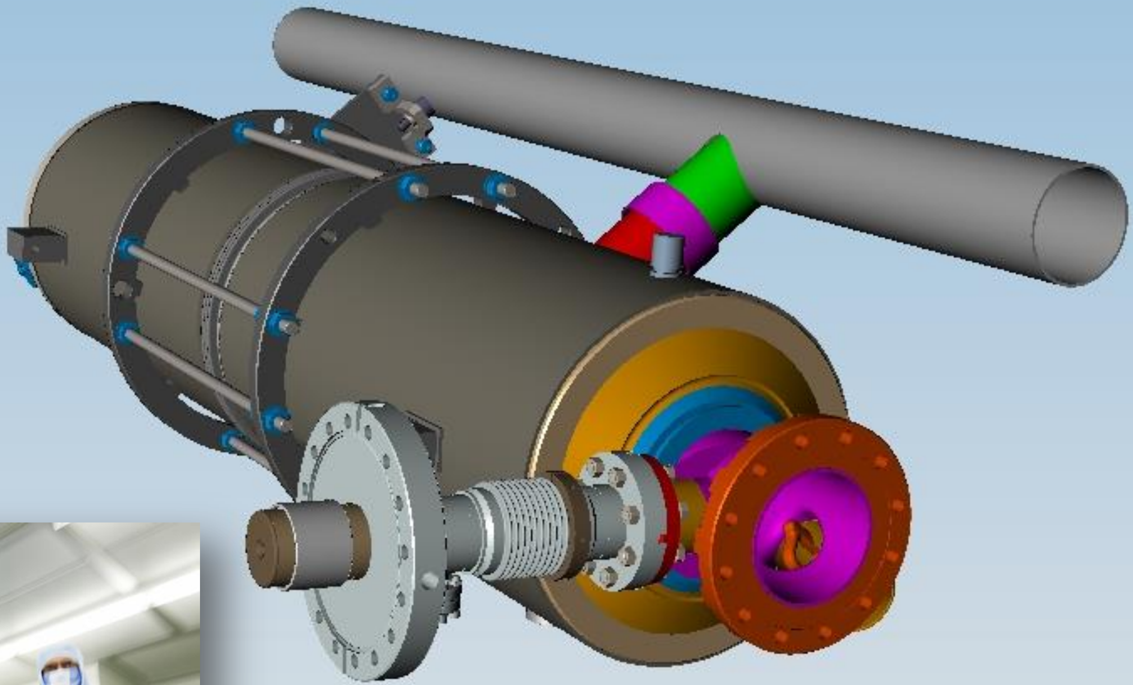

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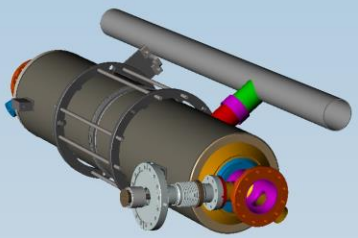
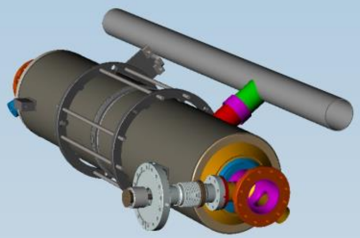


Cryomodule construction



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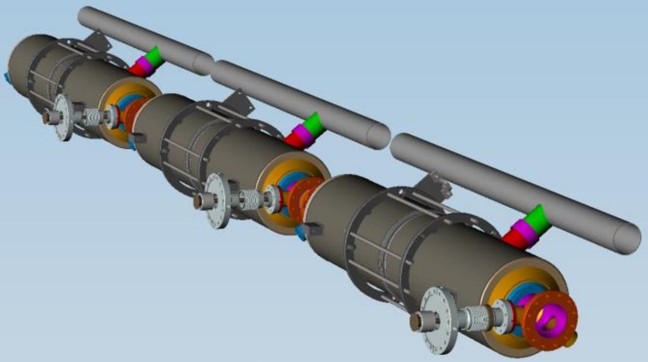

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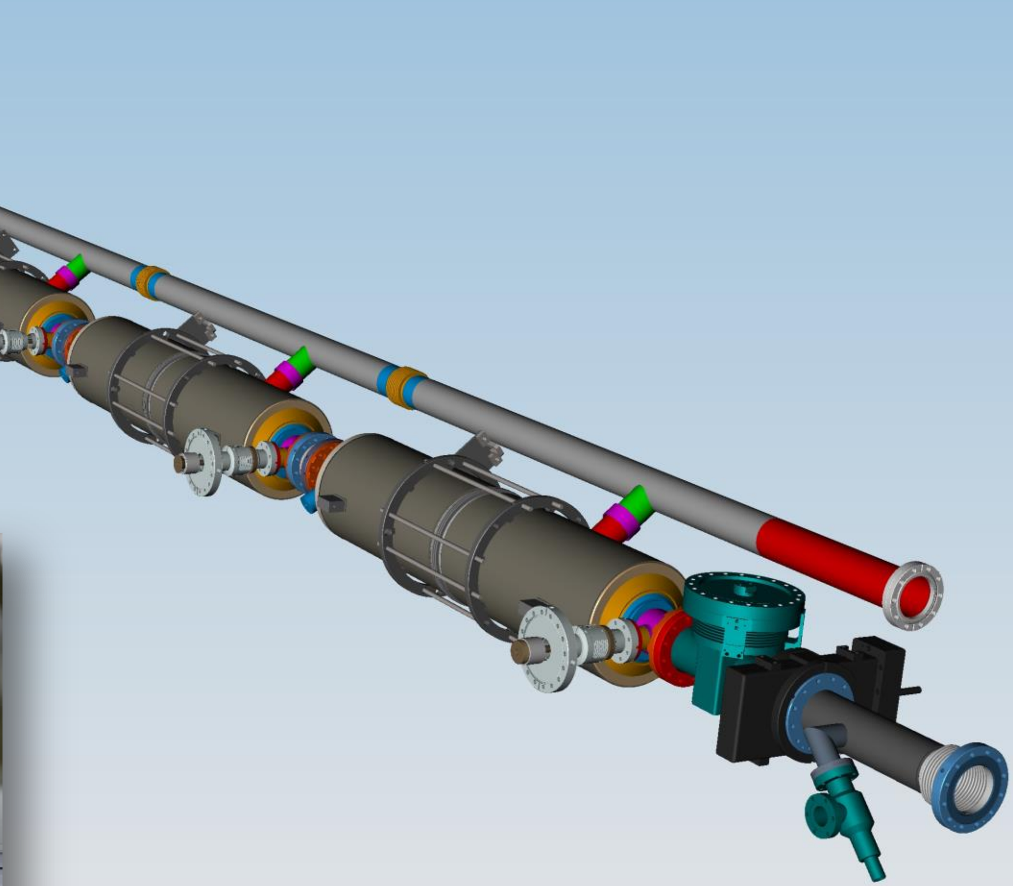
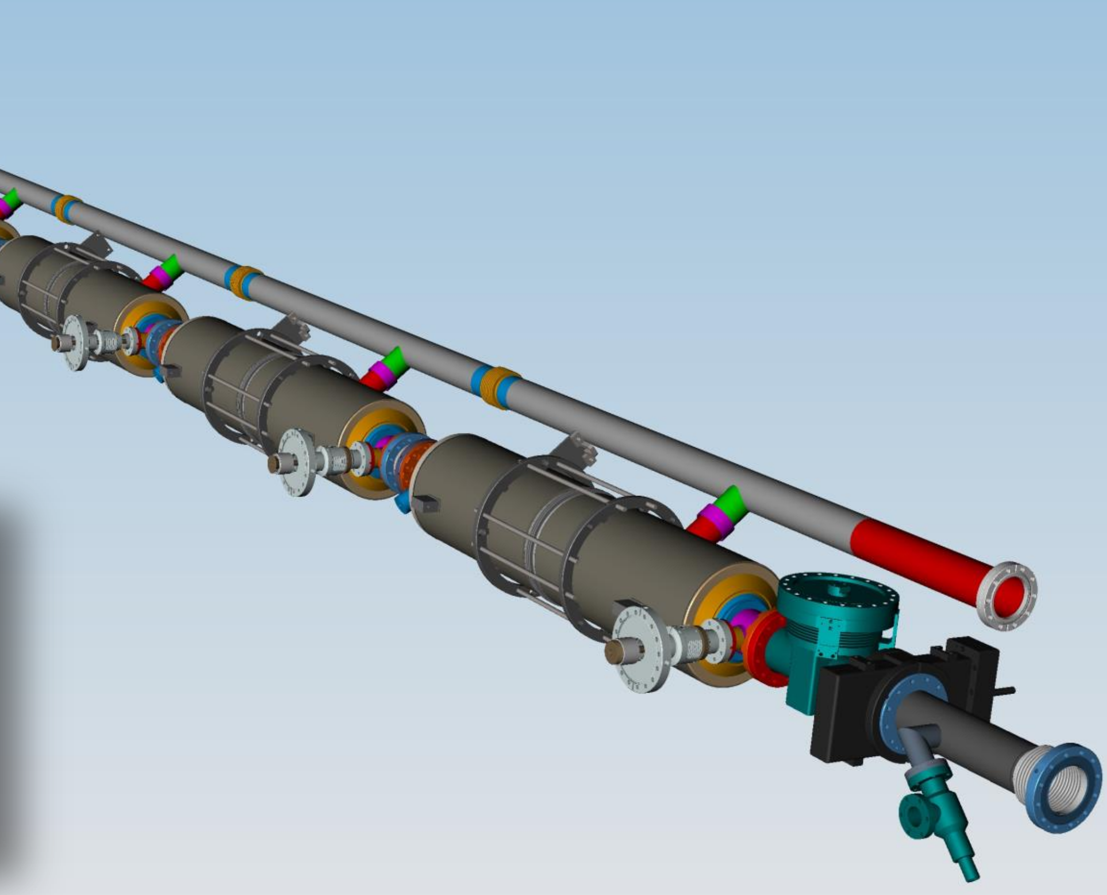
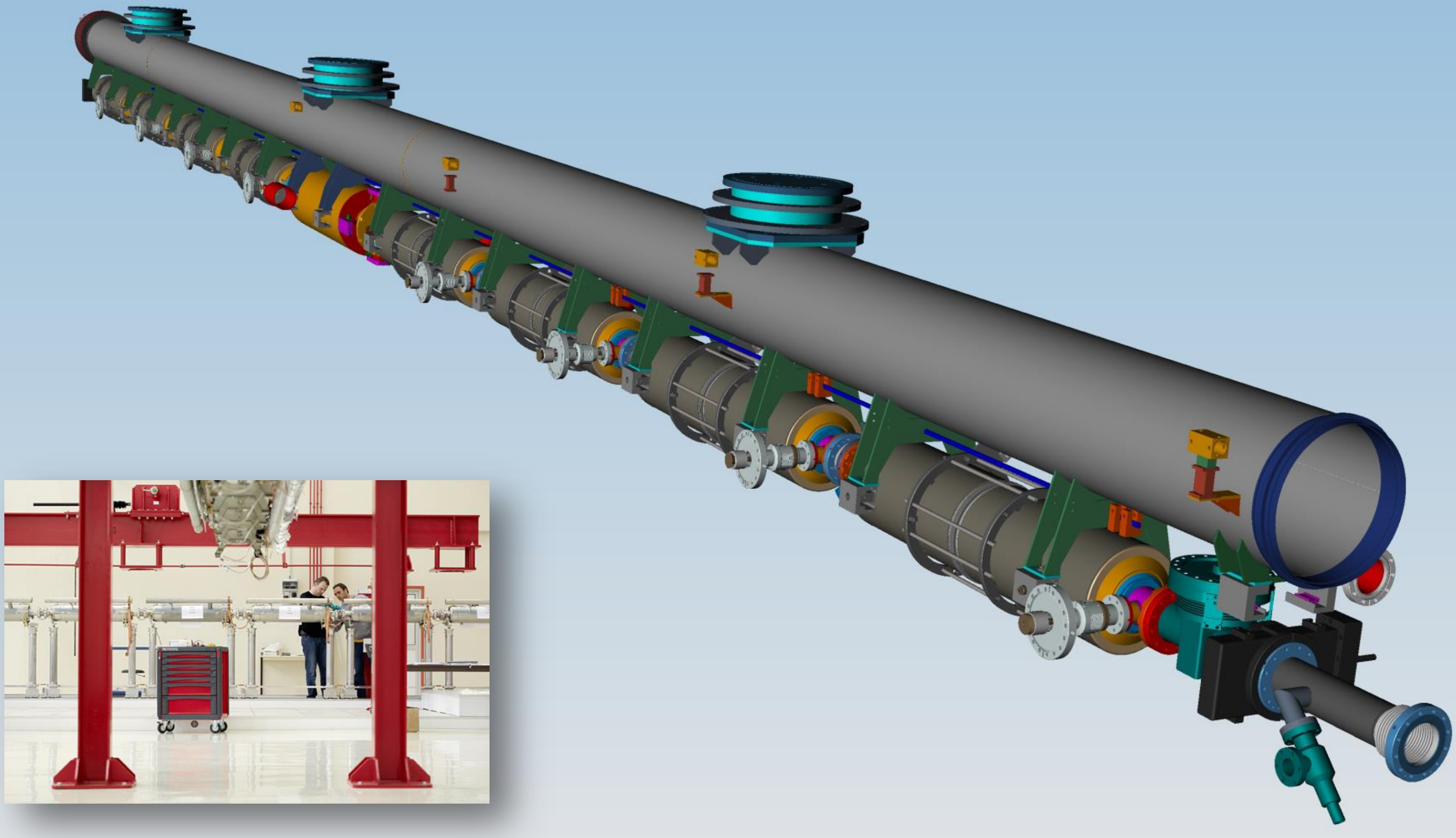


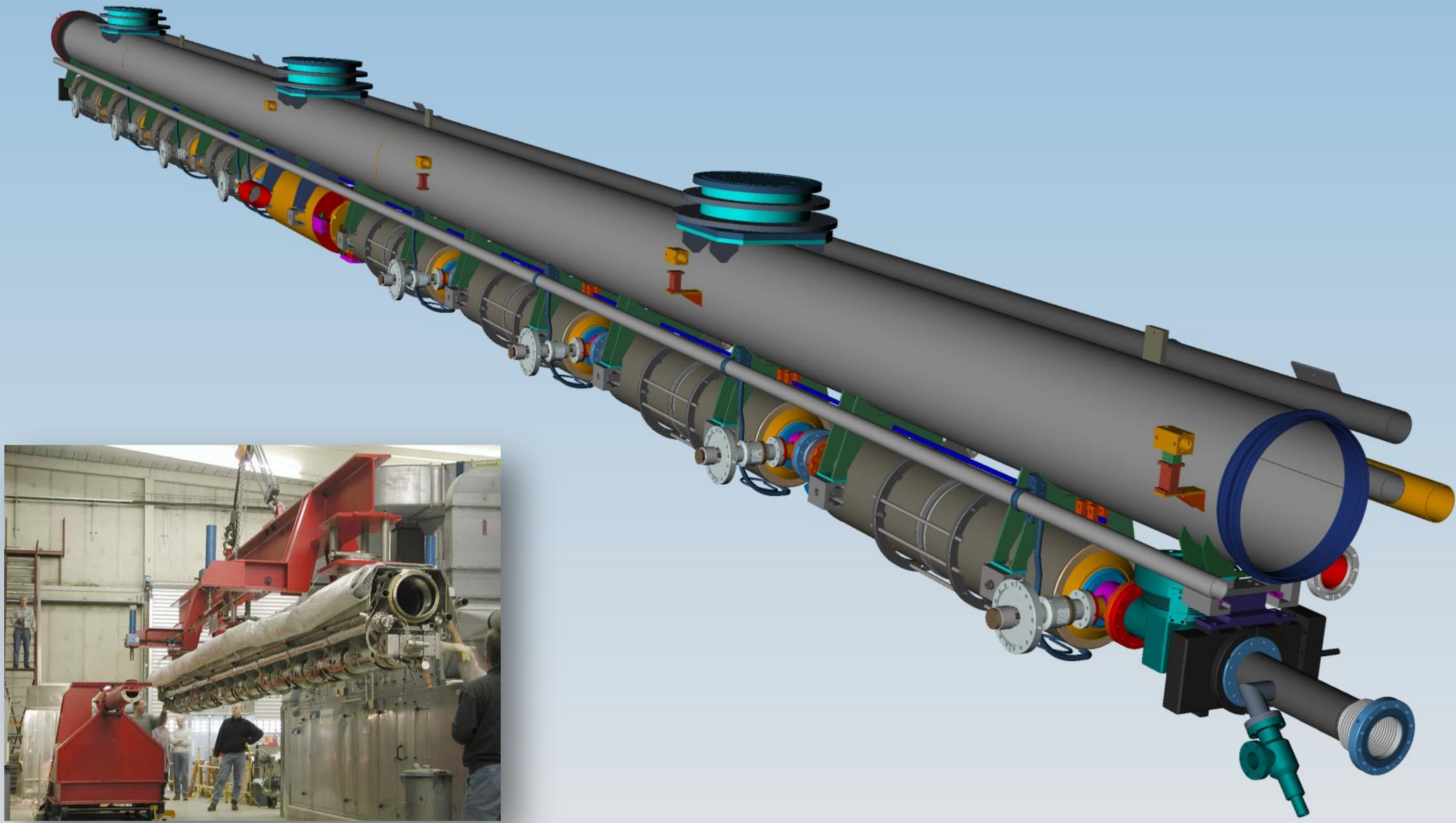
Cryomodule construction

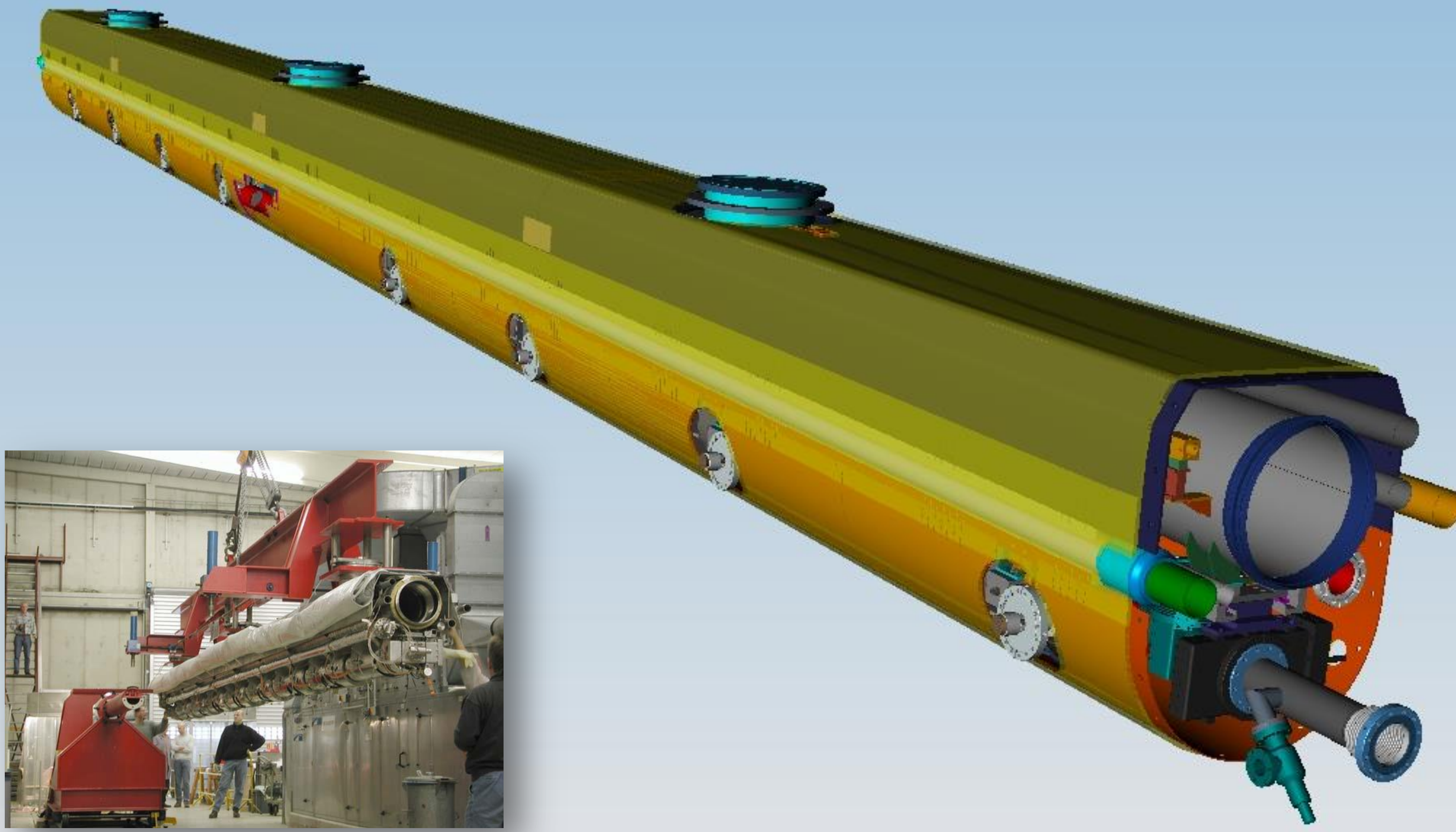


Cryomodule construction



Cryomodule construction





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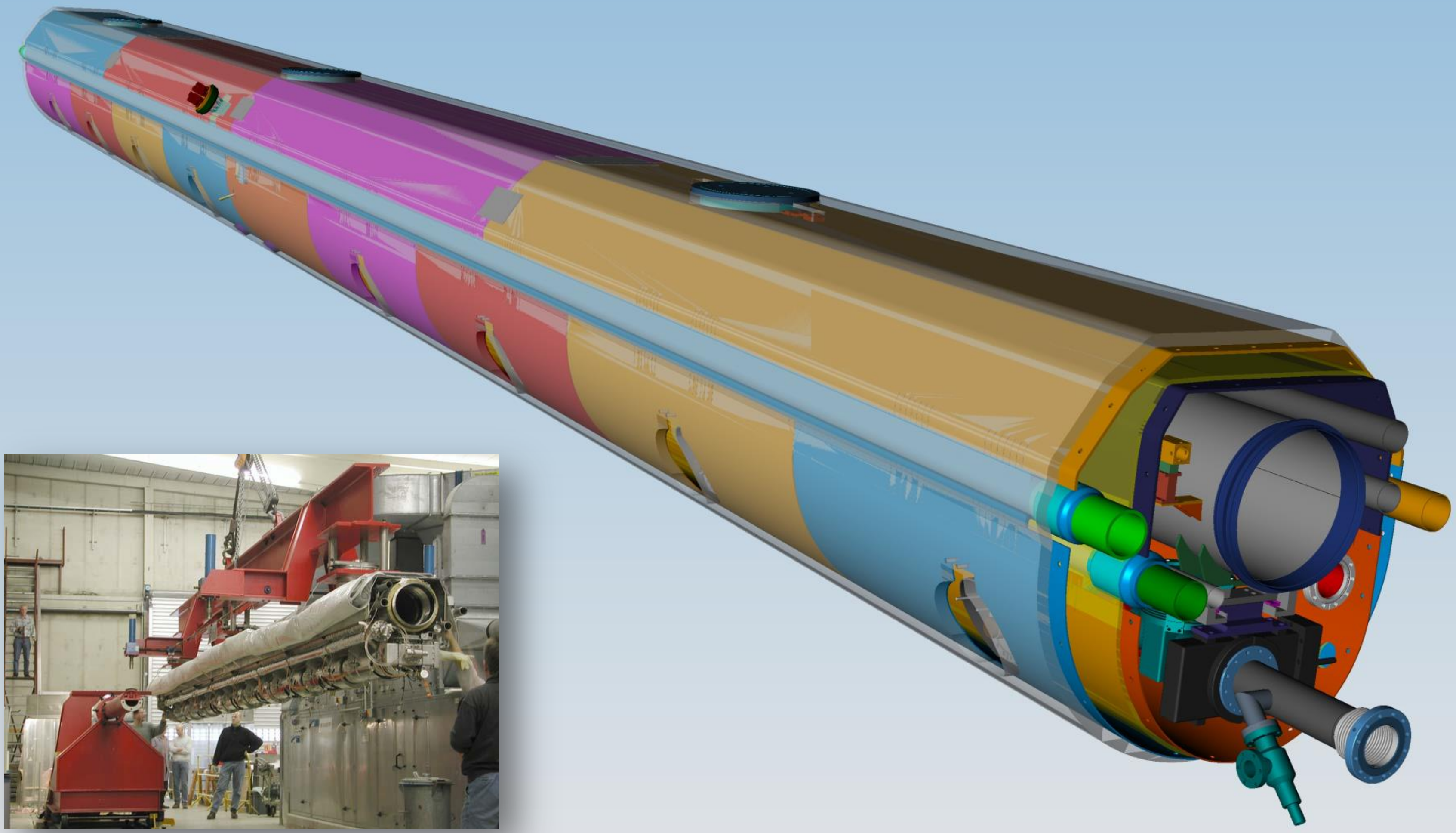

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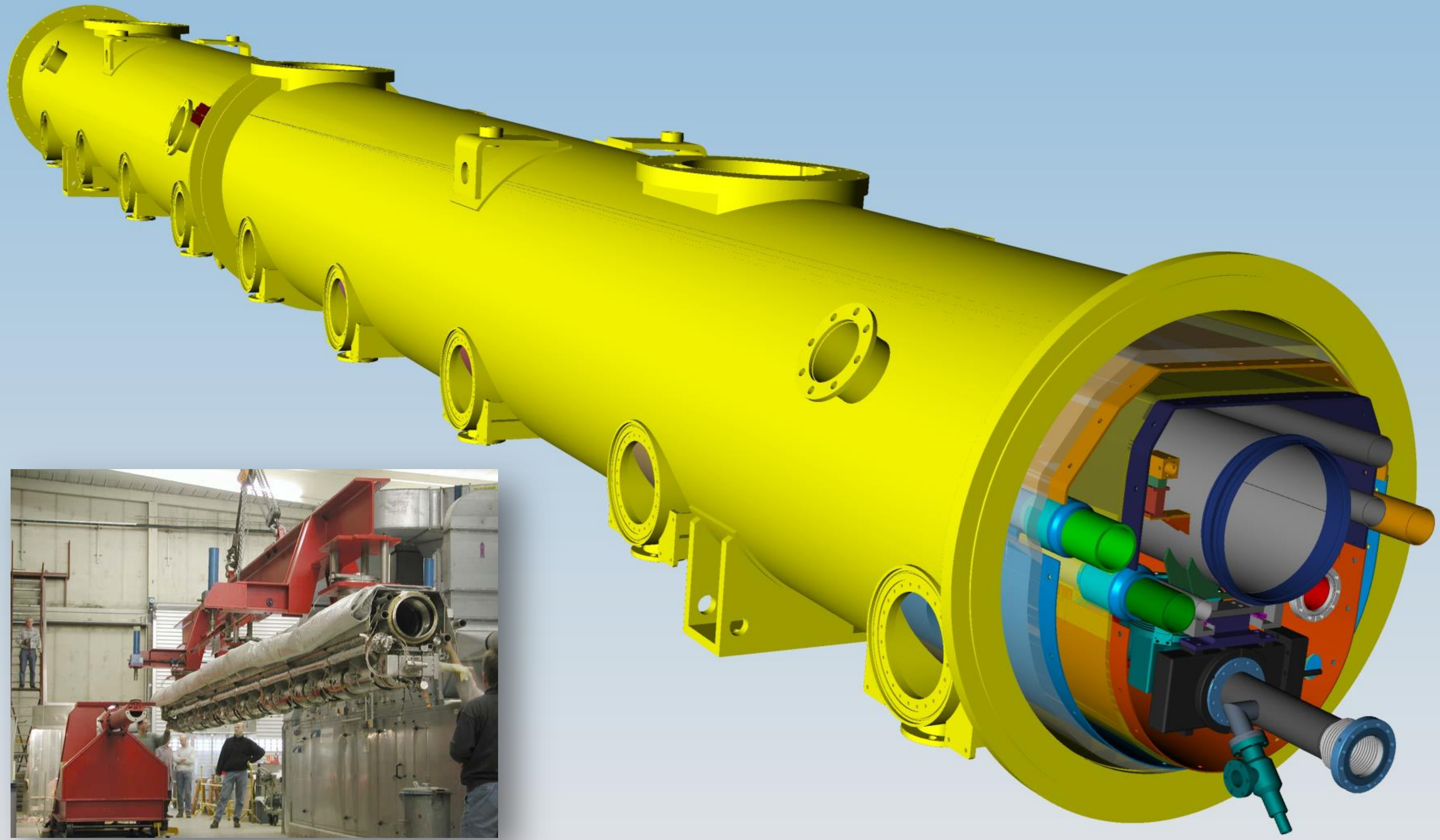

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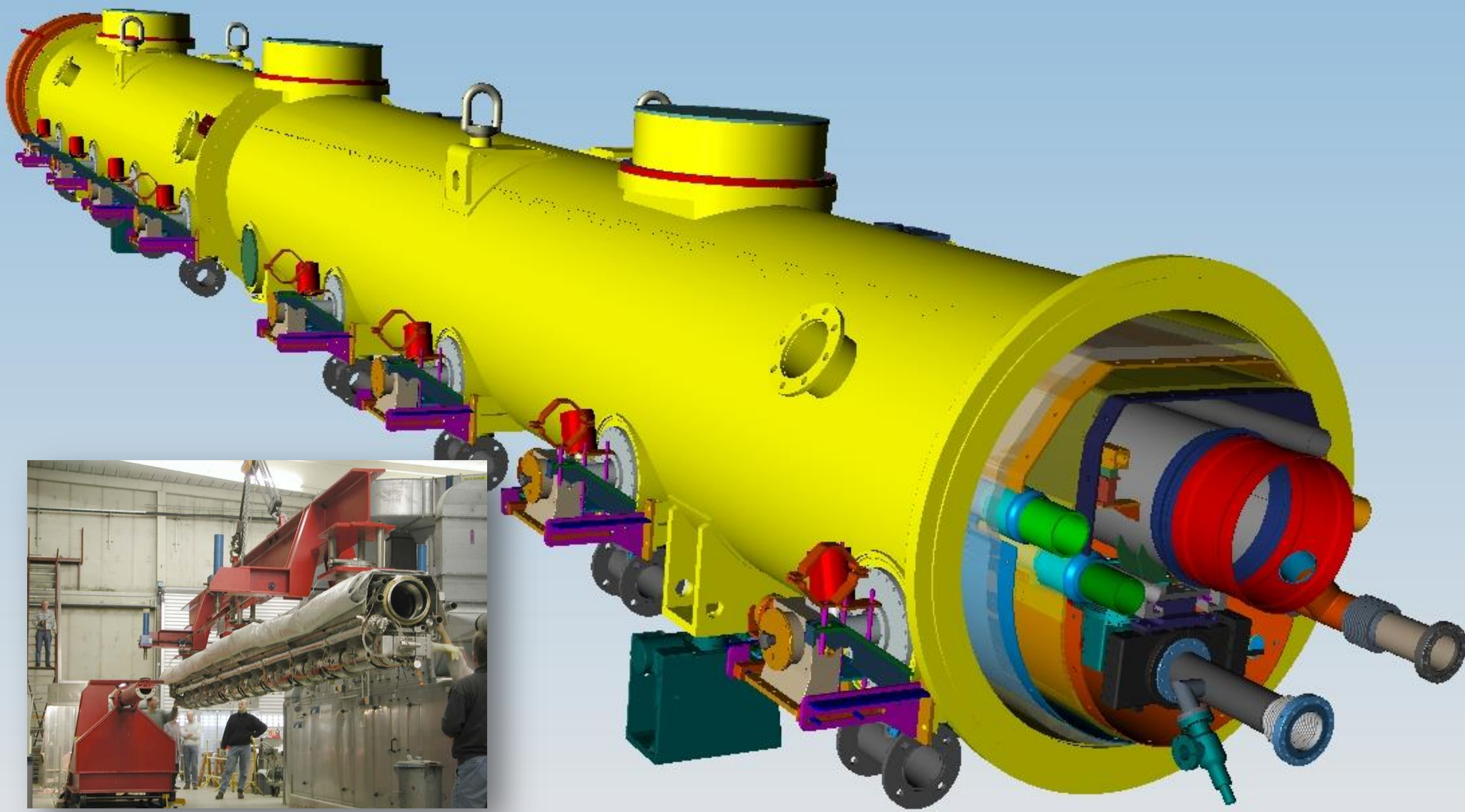

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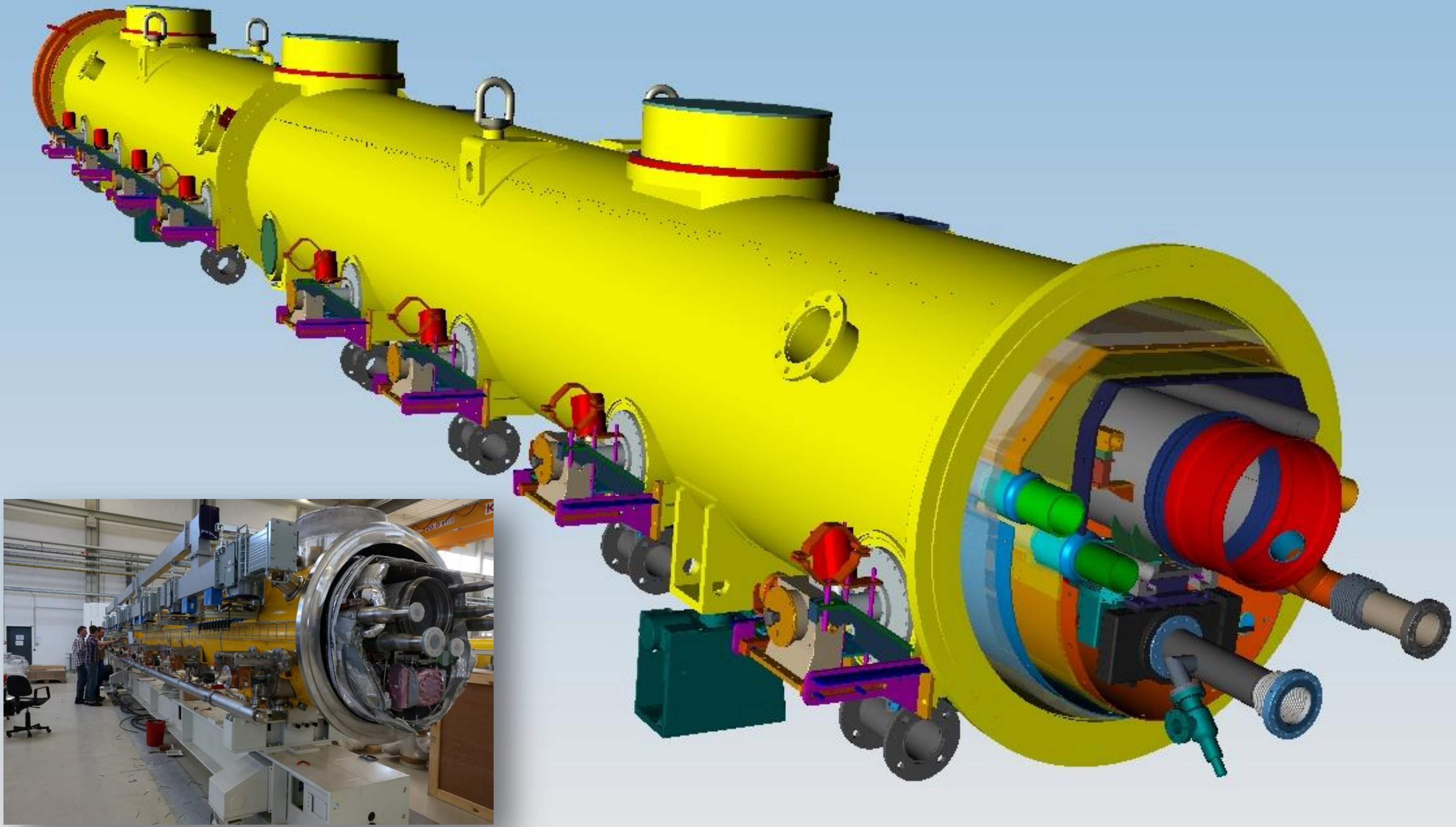
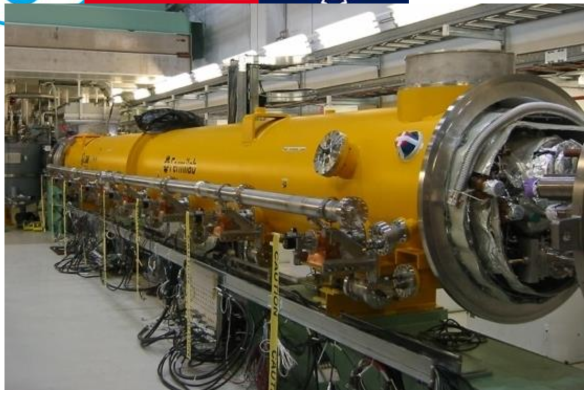
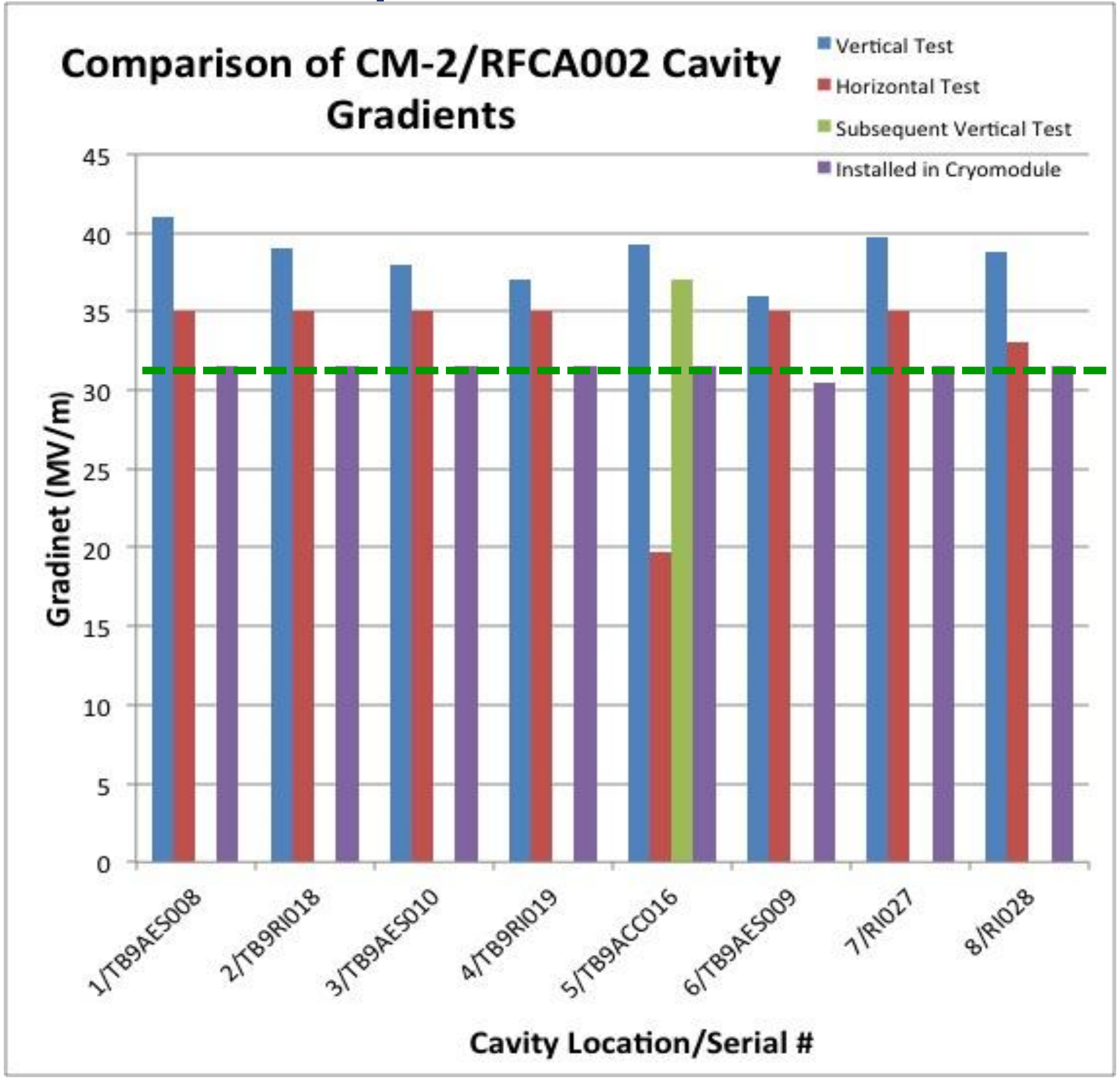
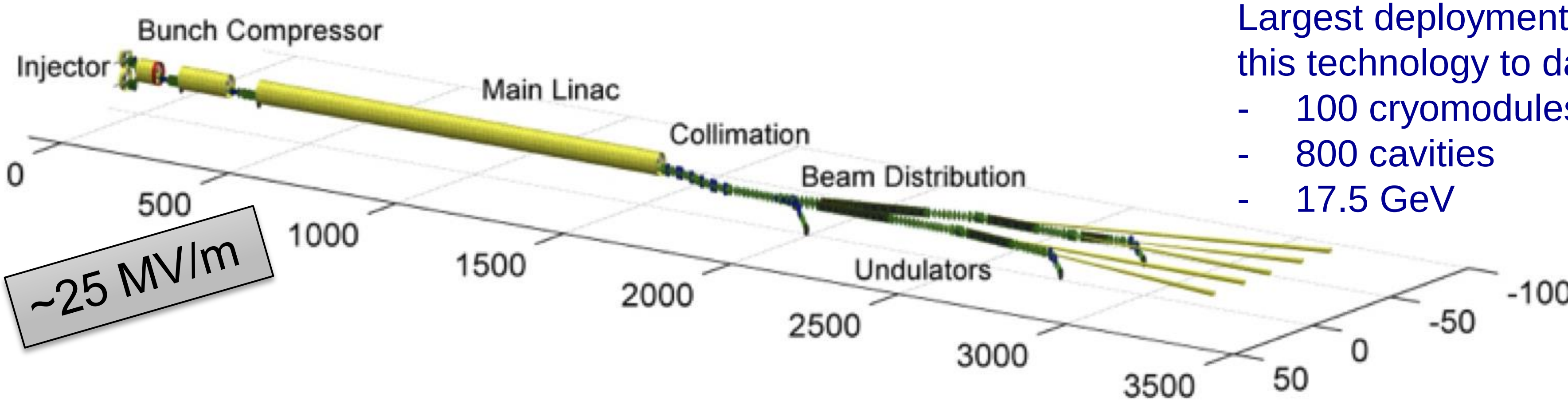


Worldwide Cryomodule Development





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 begins 2016

Industrial production - XFEL

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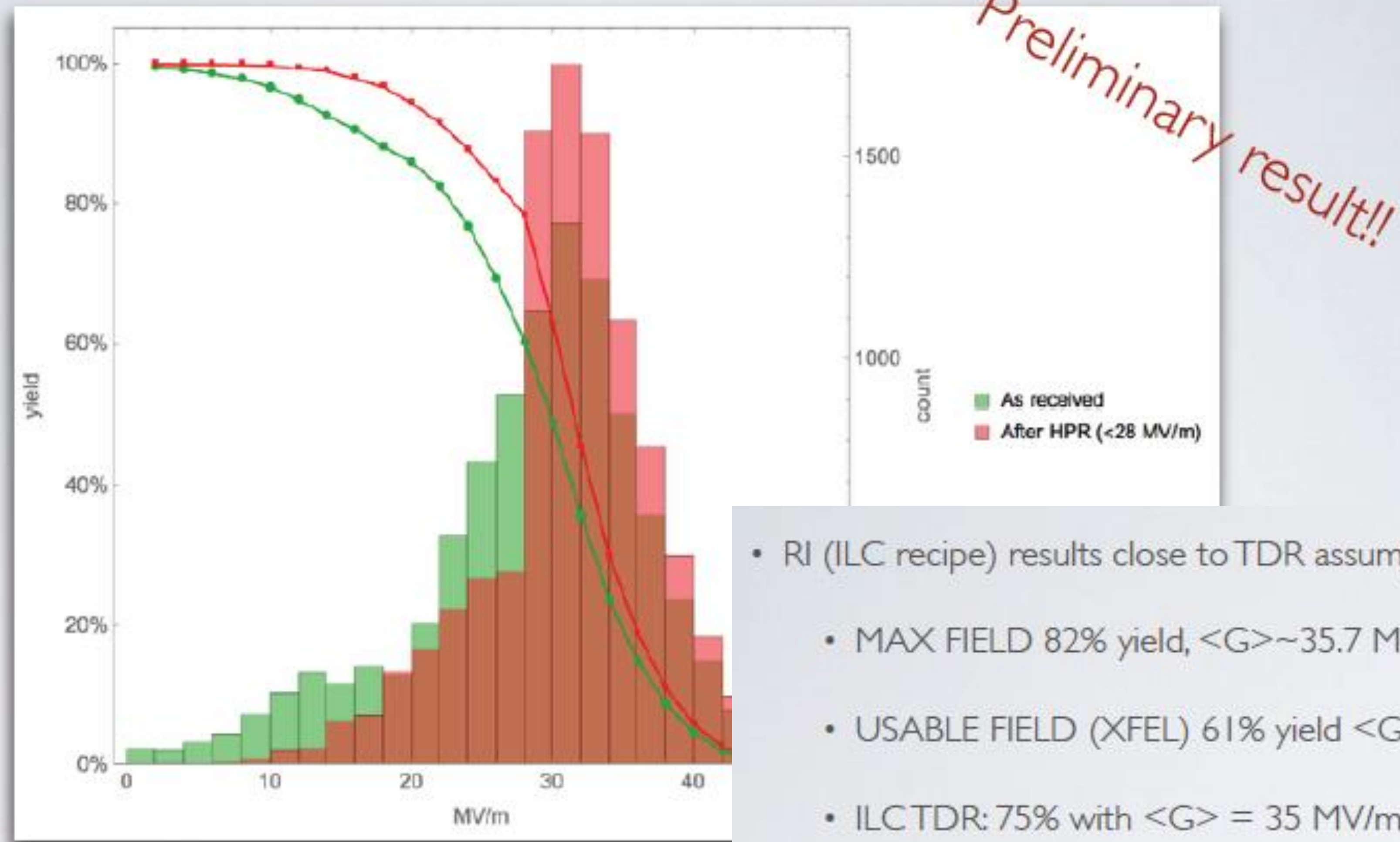
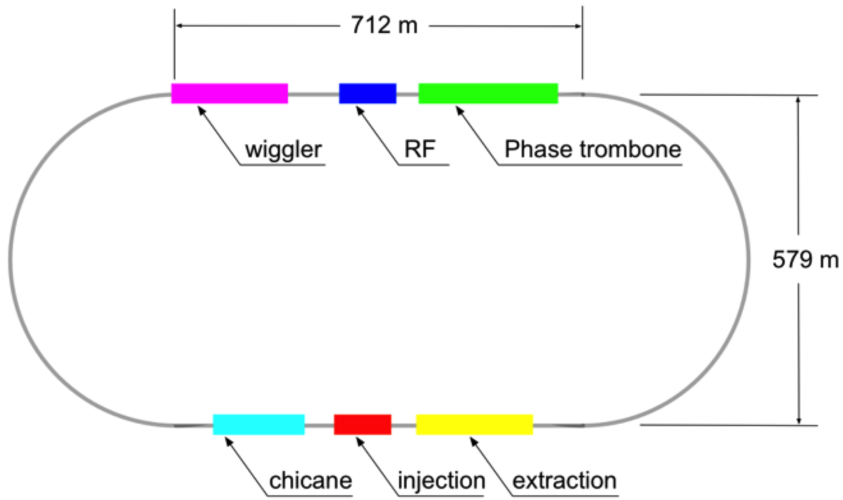
European XFEL
ENLIGHTENING SCIENCE



- RI (ILC recipe) results close to TDR assumptions
  - MAX FIELD 82% yield, <G>~35.7 MV/m
  - USABLE FIELD (XFEL) 61% yield <G>~33.4 MV/m
  - ILC TDR: 75% with <G> = 35 MV/m

Damping Rings



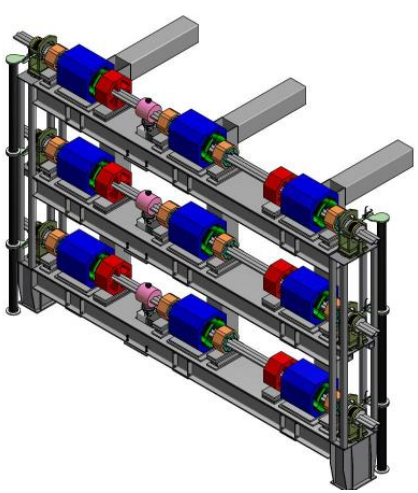
Circumference		3.2	km
Energy		5	GeV
RF frequency		650	MHz
Beam current		390	mA
Store time		200 (100)	ms
Trans. damping time		24 (13)	ms
Extracted emittance	x	5.5	μm
(normalised)	y	20	nm
No. cavities		10 (12)	
Total voltage		14 (22)	MV
RF power / coupler		176 (272)	kW
No.wiggler magnets		54	
Total length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

Values in () are for 10-Hz mode

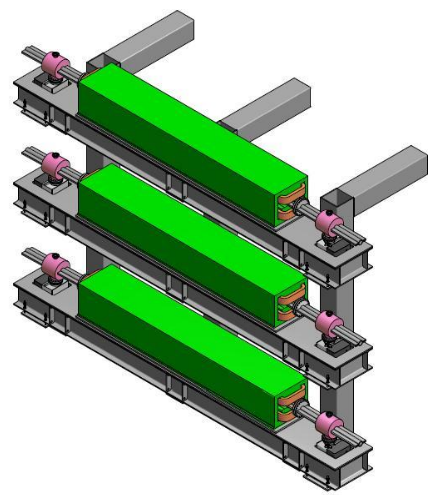
Positron ring (upgrade)

Electron ring (baseline)

Positron ring (baseline)



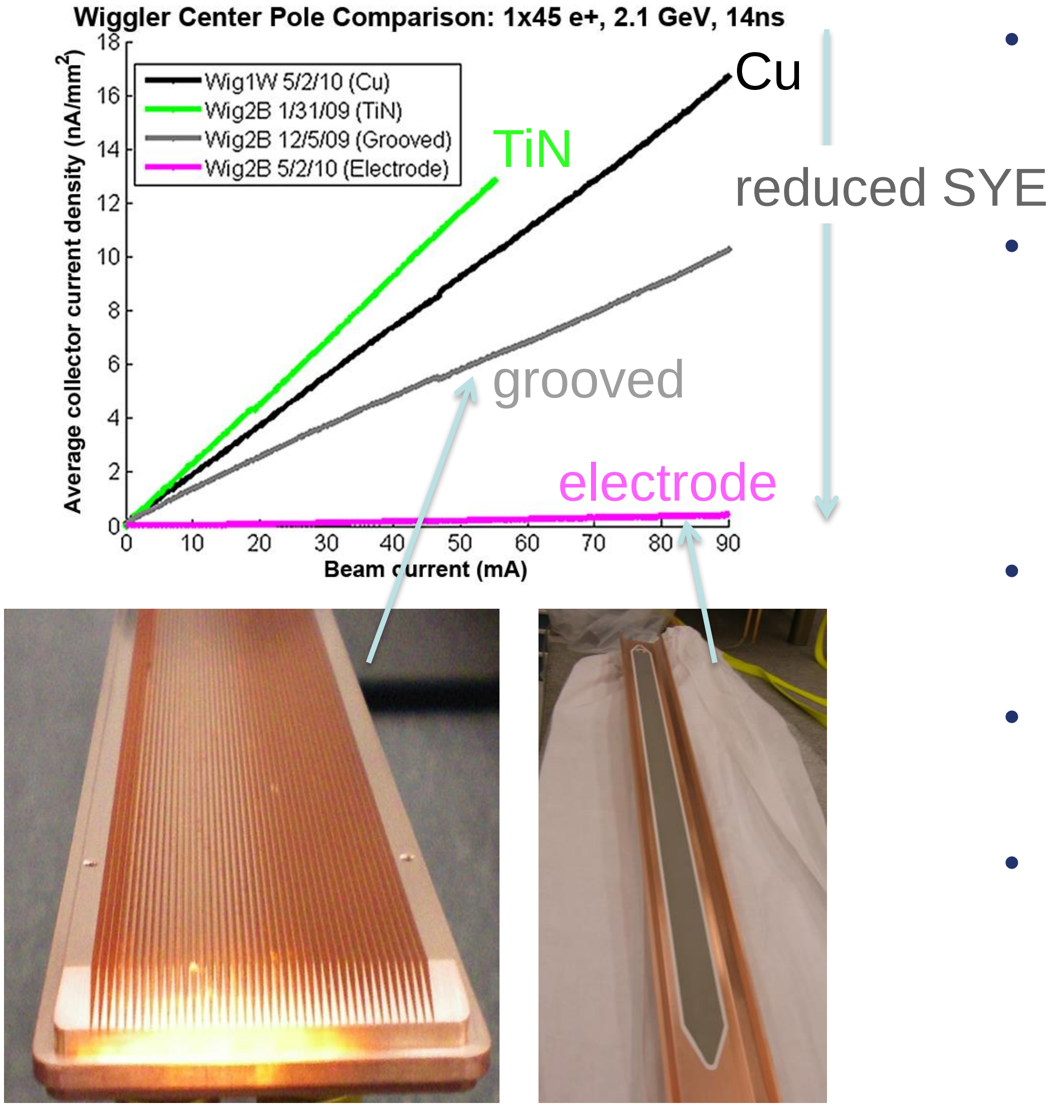
Arc quadrupole section



Dipole section

Many similarities to modern 3rd-generation light sources

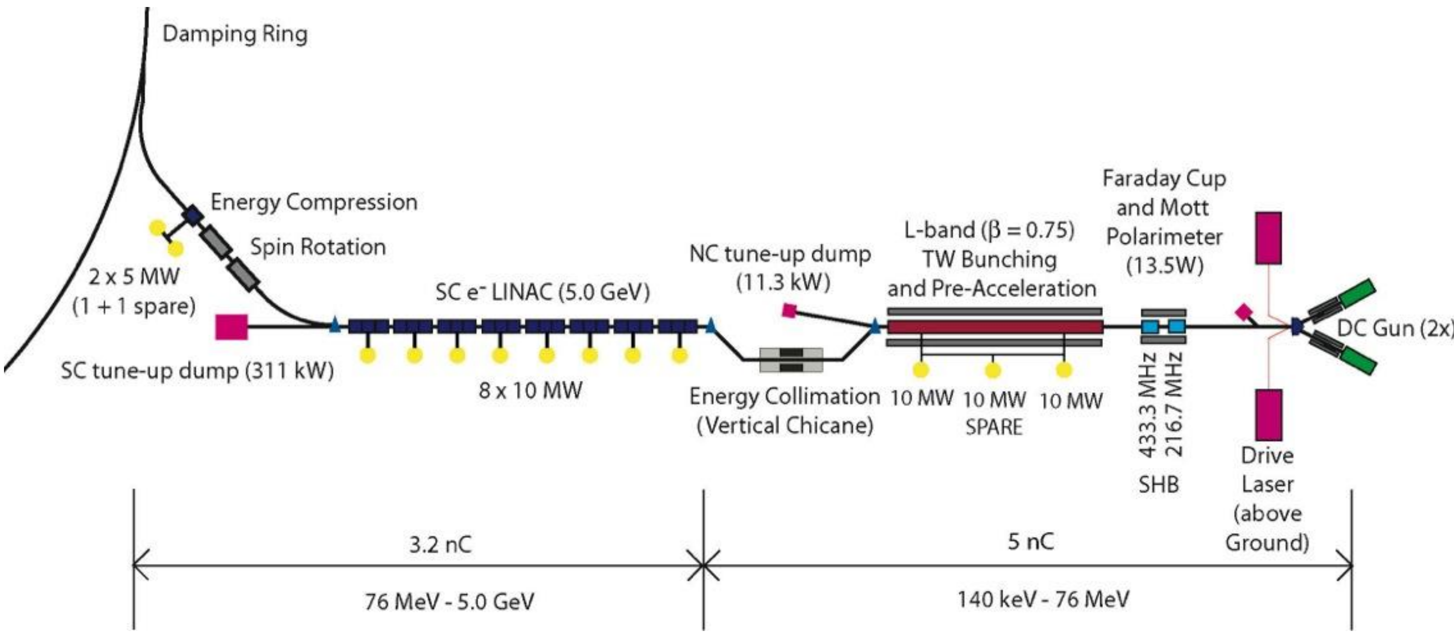
DR: Critical R&D (Electron Cloud)



- 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)**

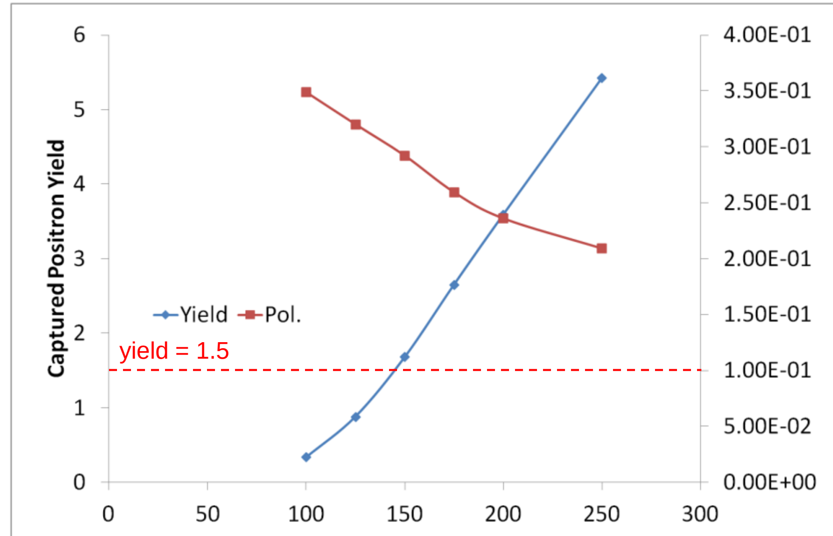
Polarised Electron Source

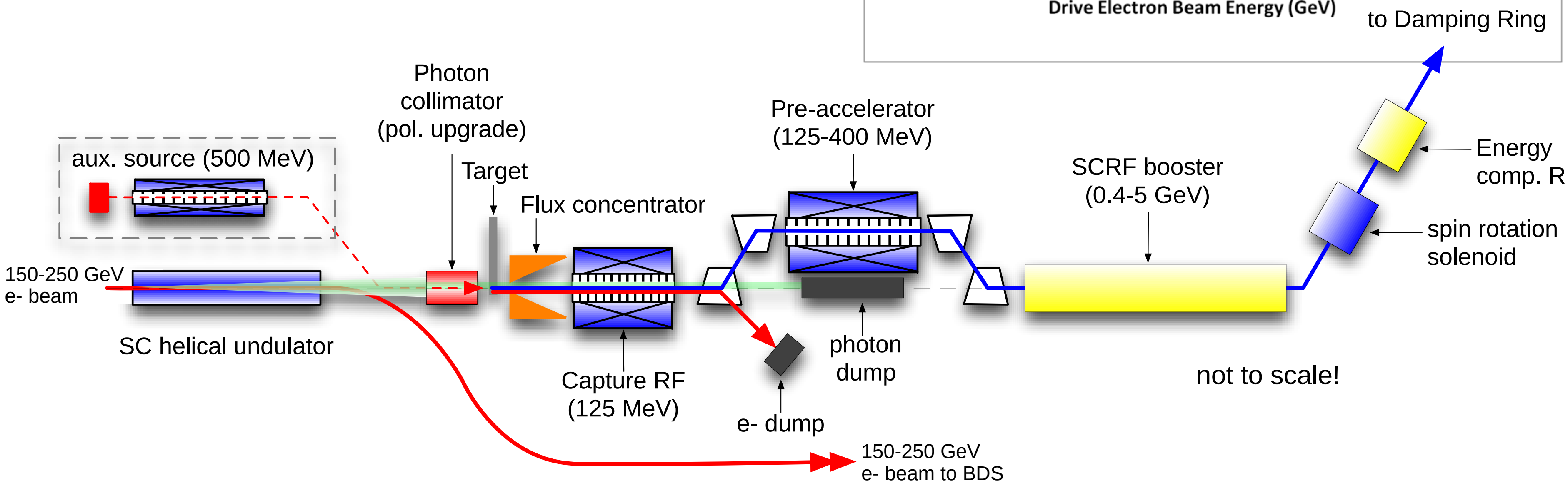
- Laser-driven photo cathode (GaAs)
- DC gun
- Integrated into common tunnel with positron BDS



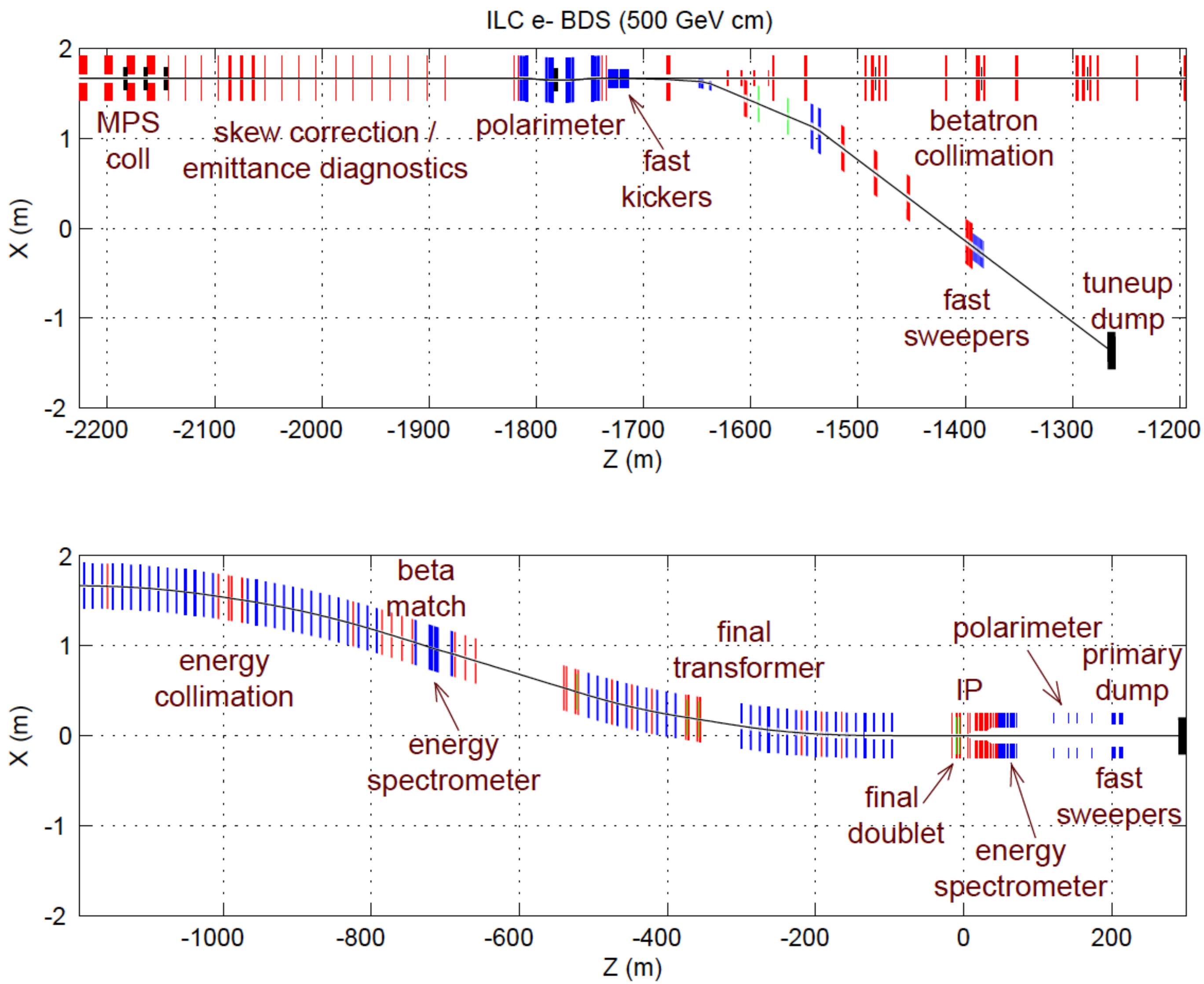
Positron Source

- 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

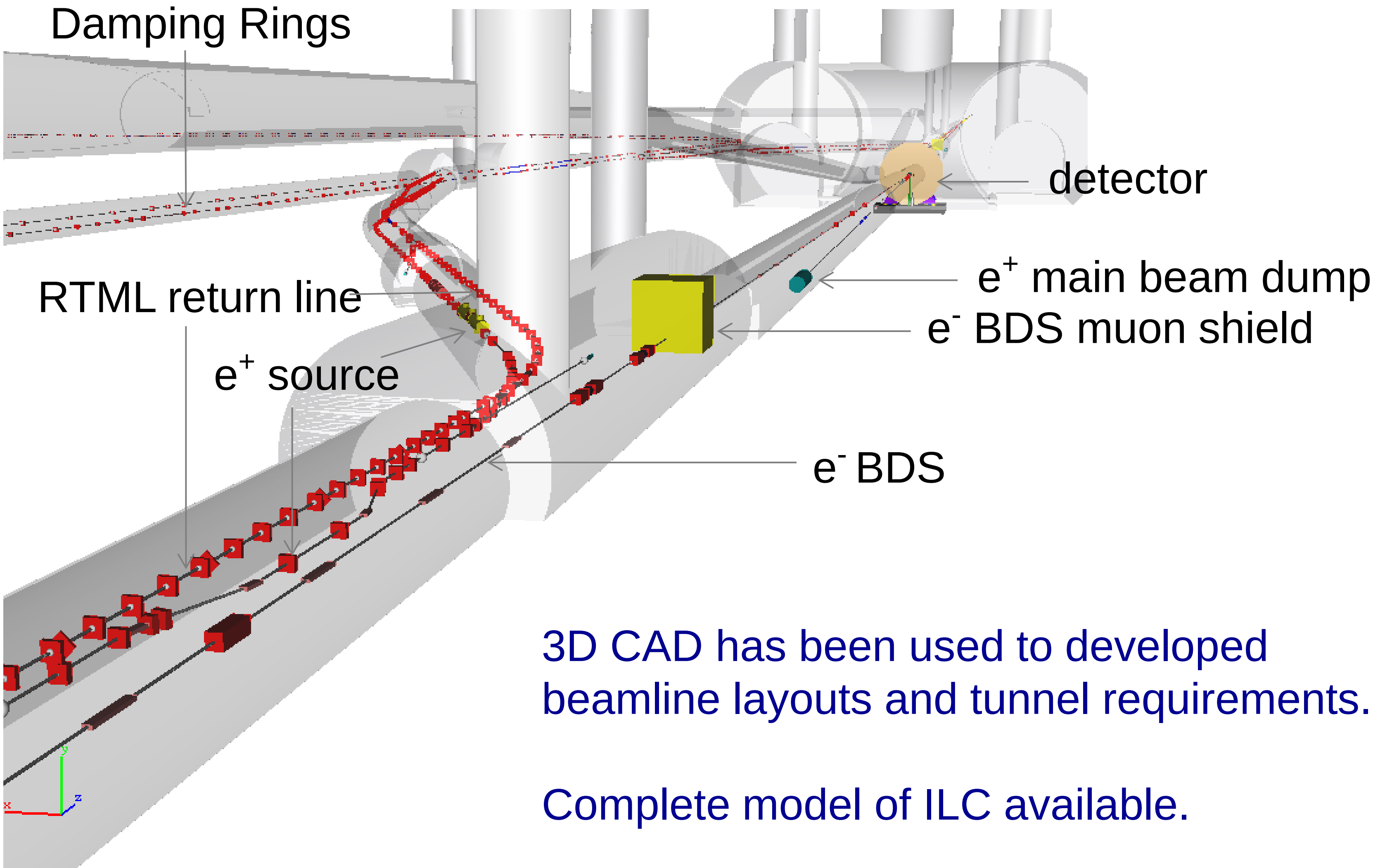




Beam Delivery System



Central Region Integration



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

Complete model of ILC available.

Japanese Sites for ILC

Japanese Site~~s~~ for ILC

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- Japanese Mountainous Site~~s~~ -

- LCC Directorate/CF&S official site visits taken place.

Japanese Site

Japanese Site

Site-specific work plan

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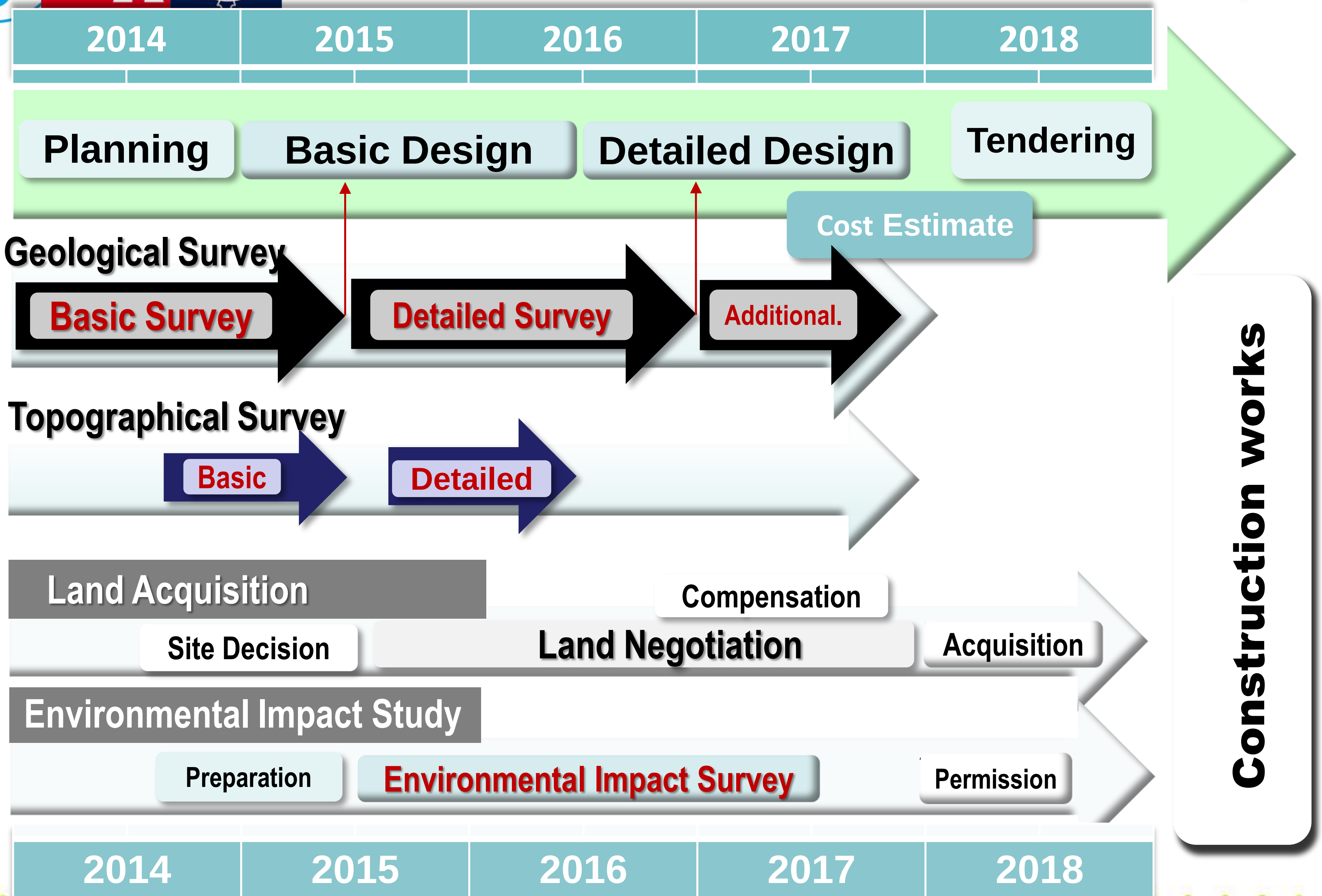

Virtual reality tools

Detector Hall Evolution

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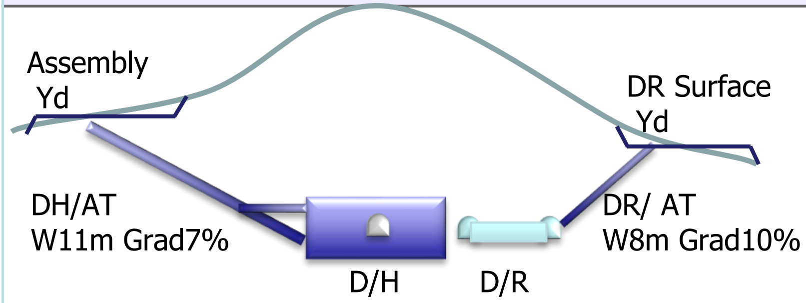
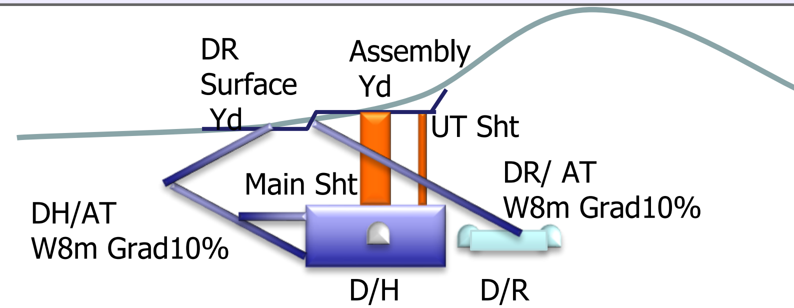
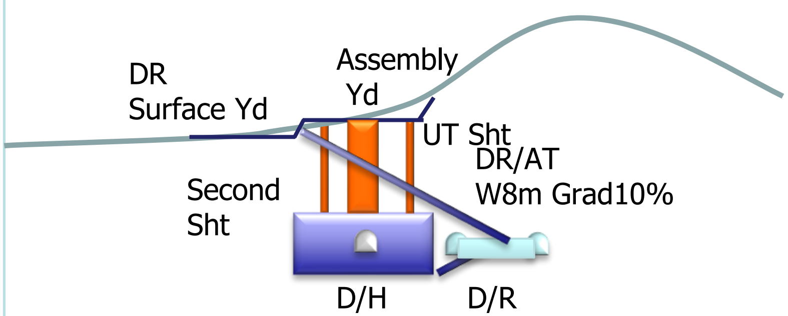
Baseline (TDR)



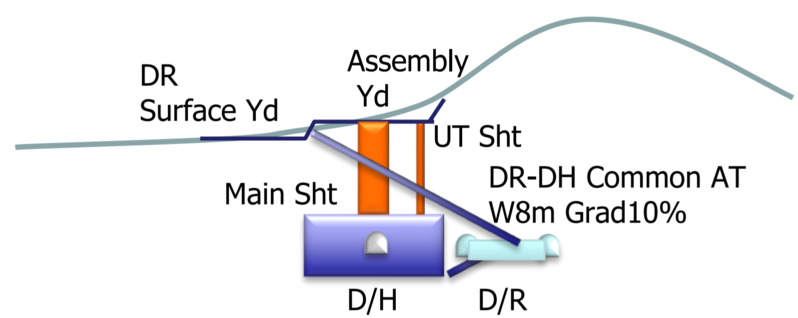
Hybrid - A (ADI-CFS Joint Meeting)



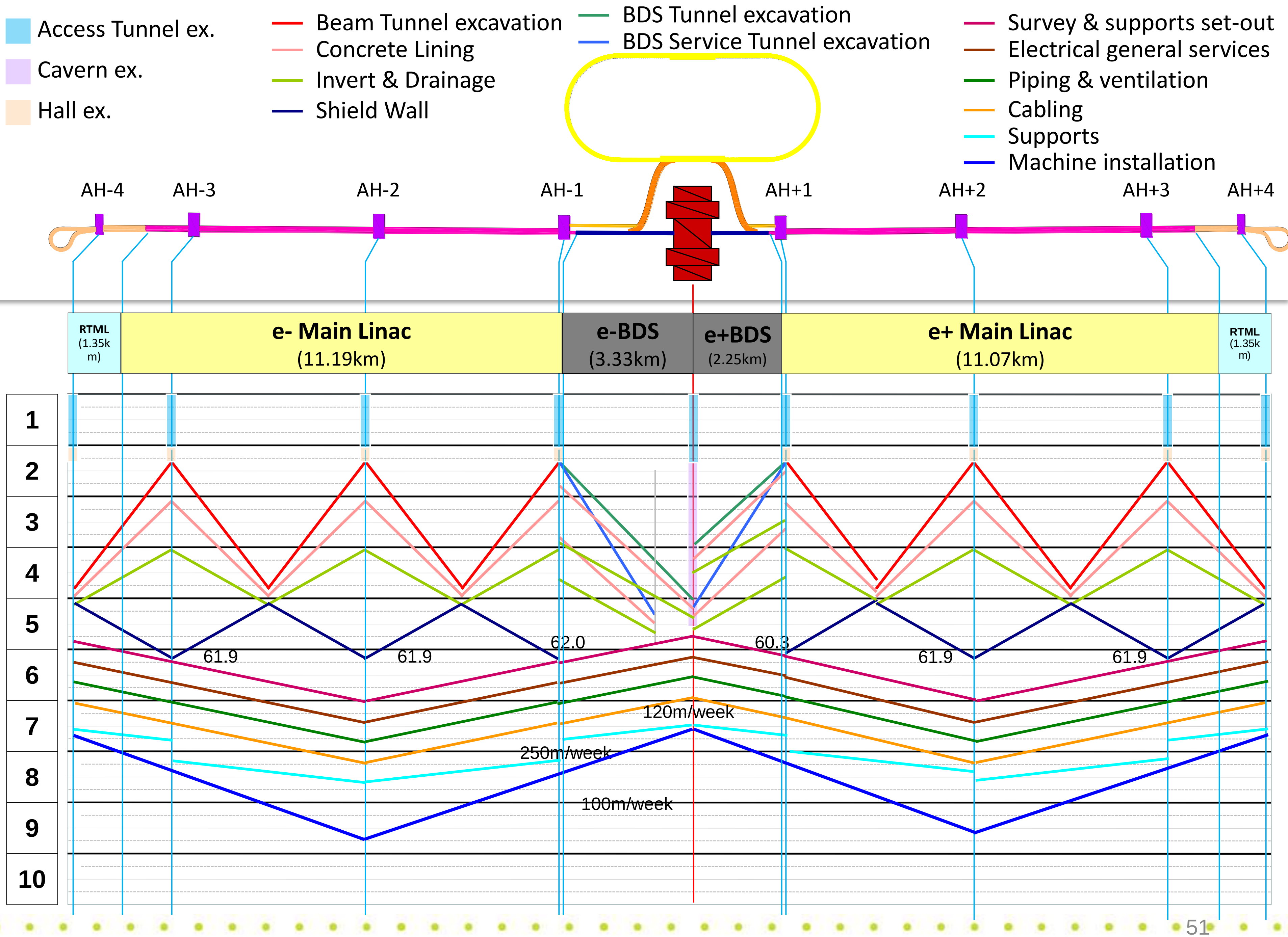
2 Vertical Shafts (SiD Proposal)



Hybrid - A’ (KEK-CFS Proposal)



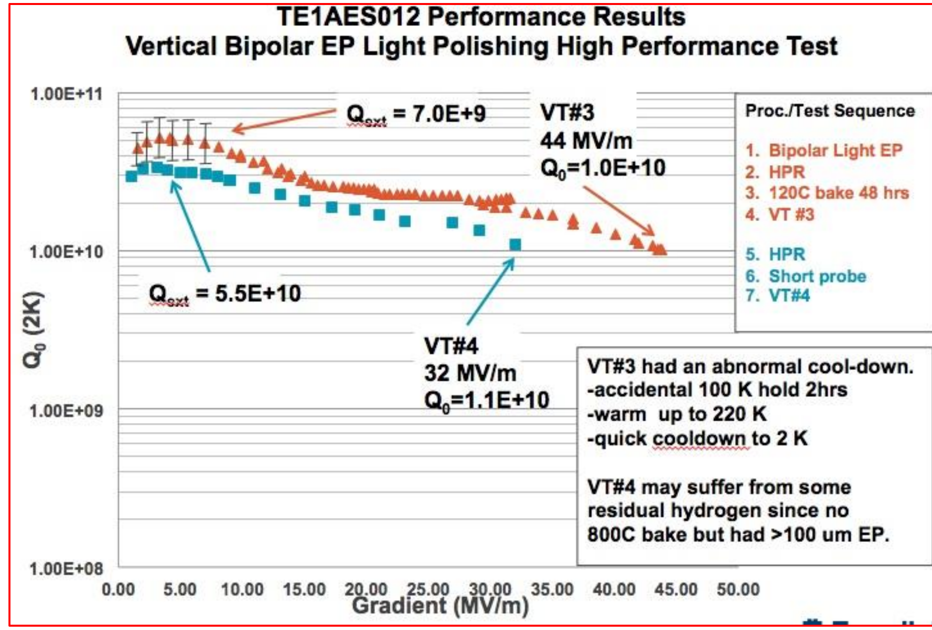
From Miyahara at al



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

Technology optimisation

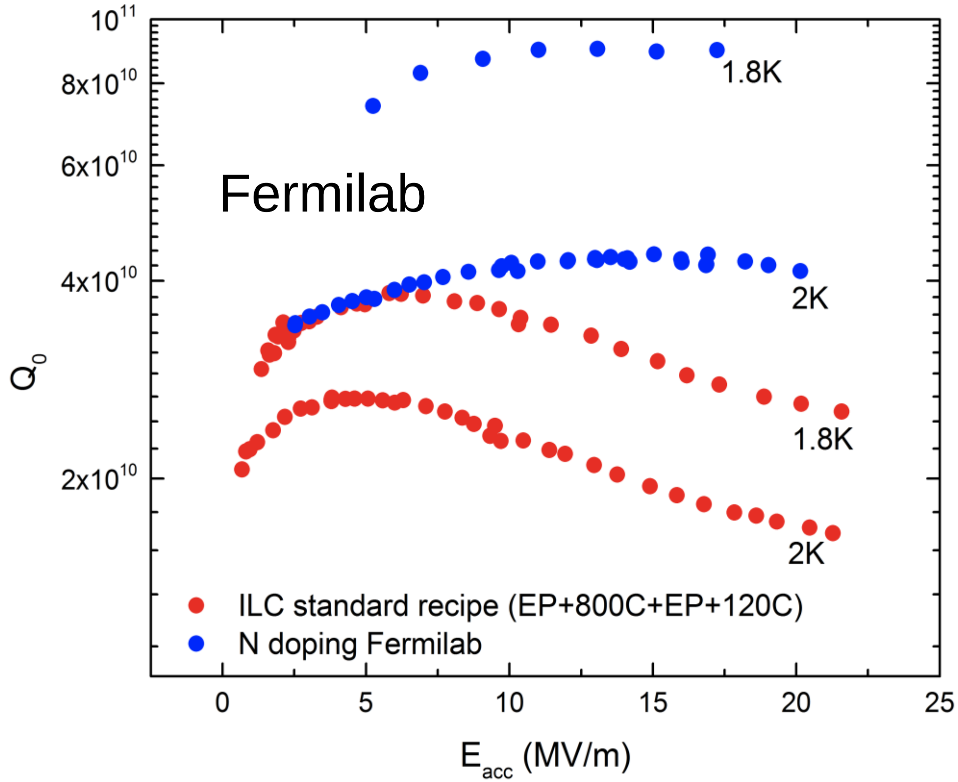
Vertical EP - Saclay

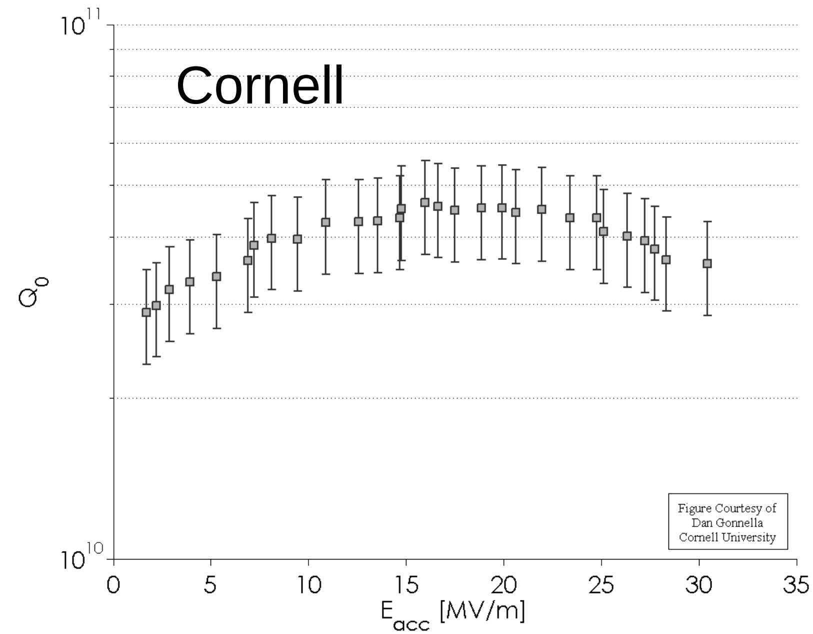


Bi-polar EP – Faraday Technology Co

Barrel Polishing DESY – No EP ?

Technology optimisation – N_2





- Higher Q via nitrogen doping surface processing
- High Q via efficient flux expulsion cooling
- No high gradient yet

Final Focus R&D – ATF2

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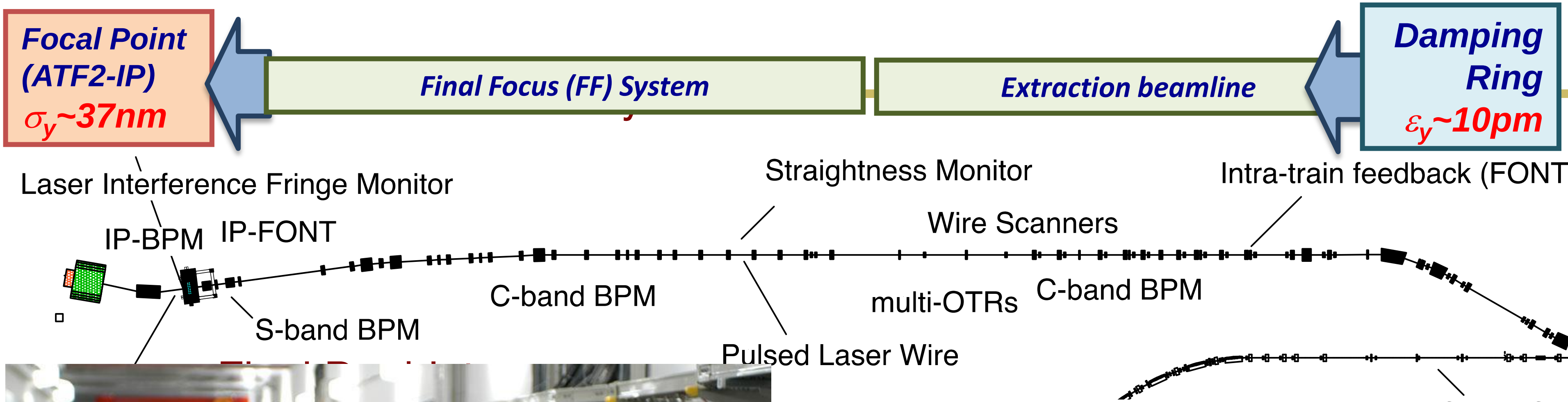

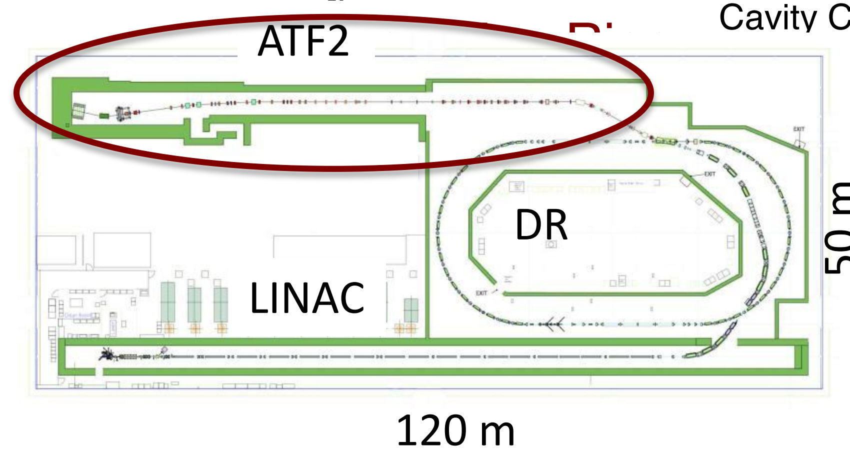

Formal international collaboration

ATF2 beam-size success

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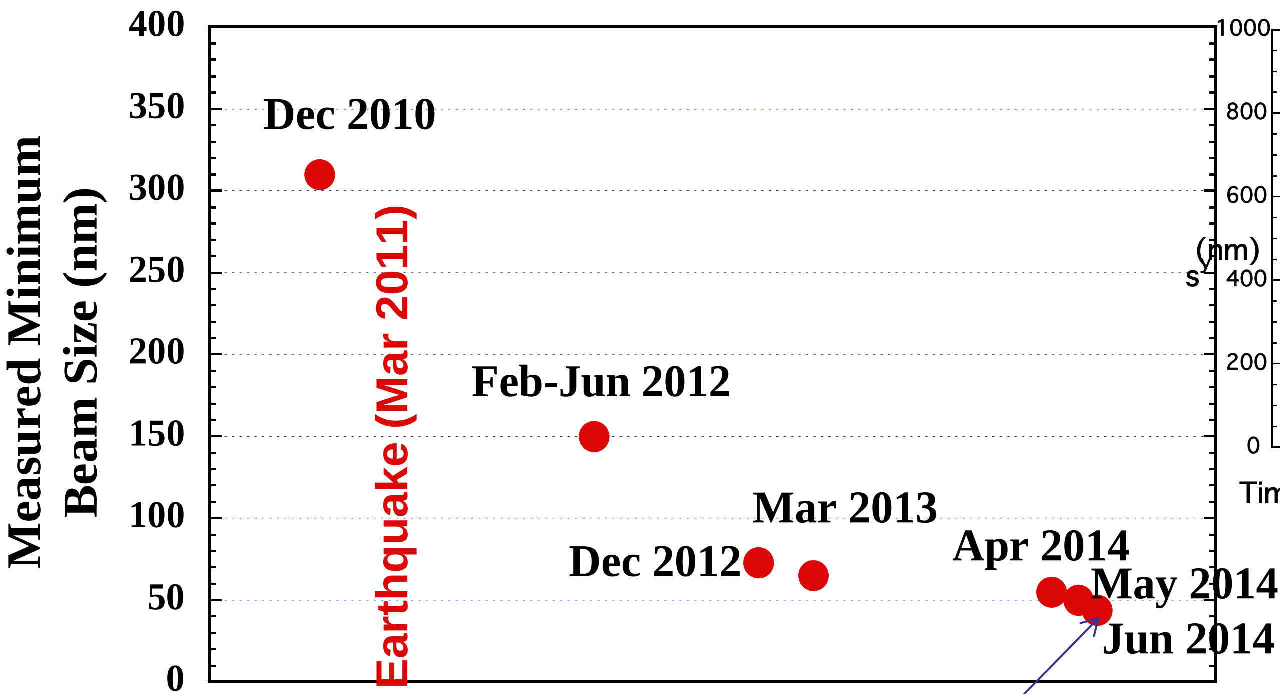

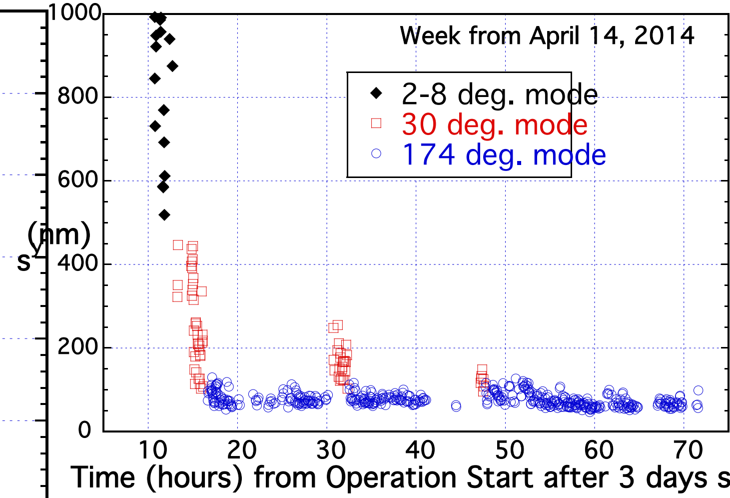

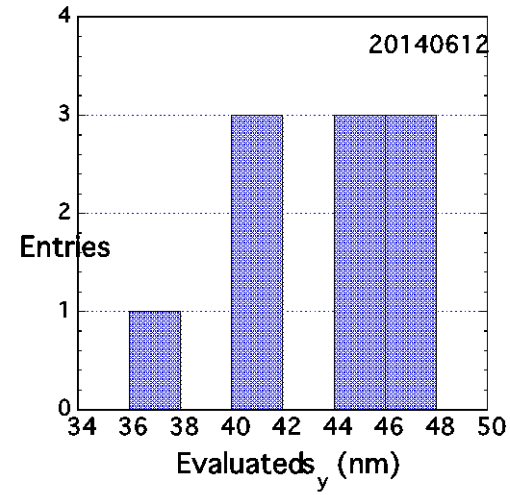

Beam Size 44 nm observed,
(Goal : 37 nm)

Field quality improvements, orbit stabilisation through feedback, shorted turn in 6-pole magnet, beam size monitor improvements

Political Developments on ILC

Lyn Evans, Profs. Koshiba & Murayama meet Prime Minister Abe & ex-Minister Kawamura ~1 year ago.

Lyn Evans, BF & H. Weerts meet Mr Kawamura & leaders of Diet Federation for ILC 6 months ago.

ILC Political Developments

- **Talk of Chair of Diet ILC Federation, Mr Kawamura@ LCWS Tokyo, Dec. 2013**

"The Technical Design Report of ILC was issued in December 2012 (sic)…I would again like to express my appreciation of this effort. I understand that it is now the turn of politicians to respond to this effort, and to construct a worldwide partnership to realize this project."

"I think that most Diet members' knowledge of physics is at high school students' level. If you allow me, let me take the liberty of pointing out that the understanding of political dynamics by most particle physicists is also at high school students' level. If physicists and politicians collaborate by using each other's area of expertise, it is certain that we can accelerate the realization of the ILC project."

ILC Political Developments

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- The MEXT Minister has visited the US Secretary of Energy in January; ILC was discussed at the meeting. In February he sent the Secretary of Energy a letter following up that discussion in which he proposes inter-governmental discussion of the ILC project. A similar letter was subsequently sent to DG – designated by Council as European contact - cc EU Commission.

- The MEXT Deputy Minister was in Europe in February and July and has had dinner meetings with the DG of CERN and Robert-Jan Smits, the Director of the EC Directorate of Research and Technology. The purpose of the meeting was to discuss ILC and the next steps. At the second meeting, representatives of funding authorities of major European countries and the USA also attended. All agreed that the meetings were very useful and further meetings are scheduled to follow.

Most Recent Developments

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- ILC was discussed again at ICFA meeting in Valencia, particularly in the context of Chinese proposal for a circular machine, starting with e^+e^- at 250 GeV and then moving to high-energy pp. Important statement agreed: "ICFA endorses the particle physics strategic plans produced in Europe, Asia and the United States and the globally aligned priorities contained therein. Here, ICFA reaffirms its support of the ILC, which is in a mature state of technical development and offers unprecedented opportunities for precision studies of the newly discovered Higgs boson. In addition, ICFA continues to encourage international studies of circular colliders, with an ultimate goal of proton-proton collisions at energies much higher than those of the LHC."

Summary and Outlook

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- The discovery of the Higgs and the necessity to understand this extraordinary particle has brought the case for a new e^+e^- machine even more sharply into focus. A LC has the advantage of energy flexibility and that a design exists for the ILC that is ready to build.
- There is a world-wide strategic consensus via regional roadmaps that the ILC is the right machine to build to explore the physics of the Higgs.
- Japan has expressed interest in hosting the ILC. A single site has now been selected and the political process has momentum. There is a great deal of activity, although much of it is necessarily behind the scenes.
- Ministerial-level meetings have begun – still in a very early stage.
- The next 2 – 3 years will be decisive…..