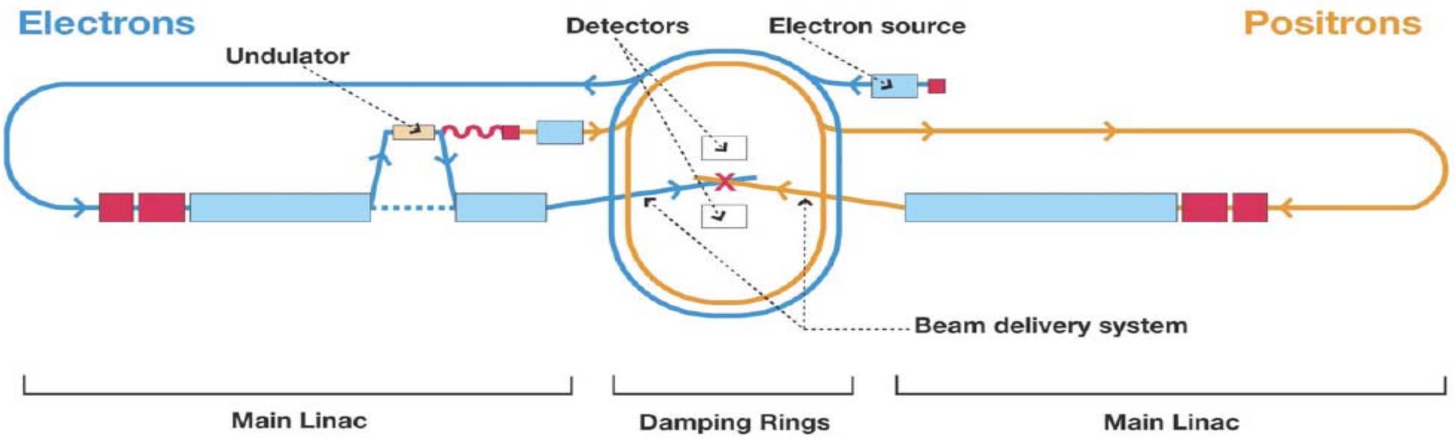
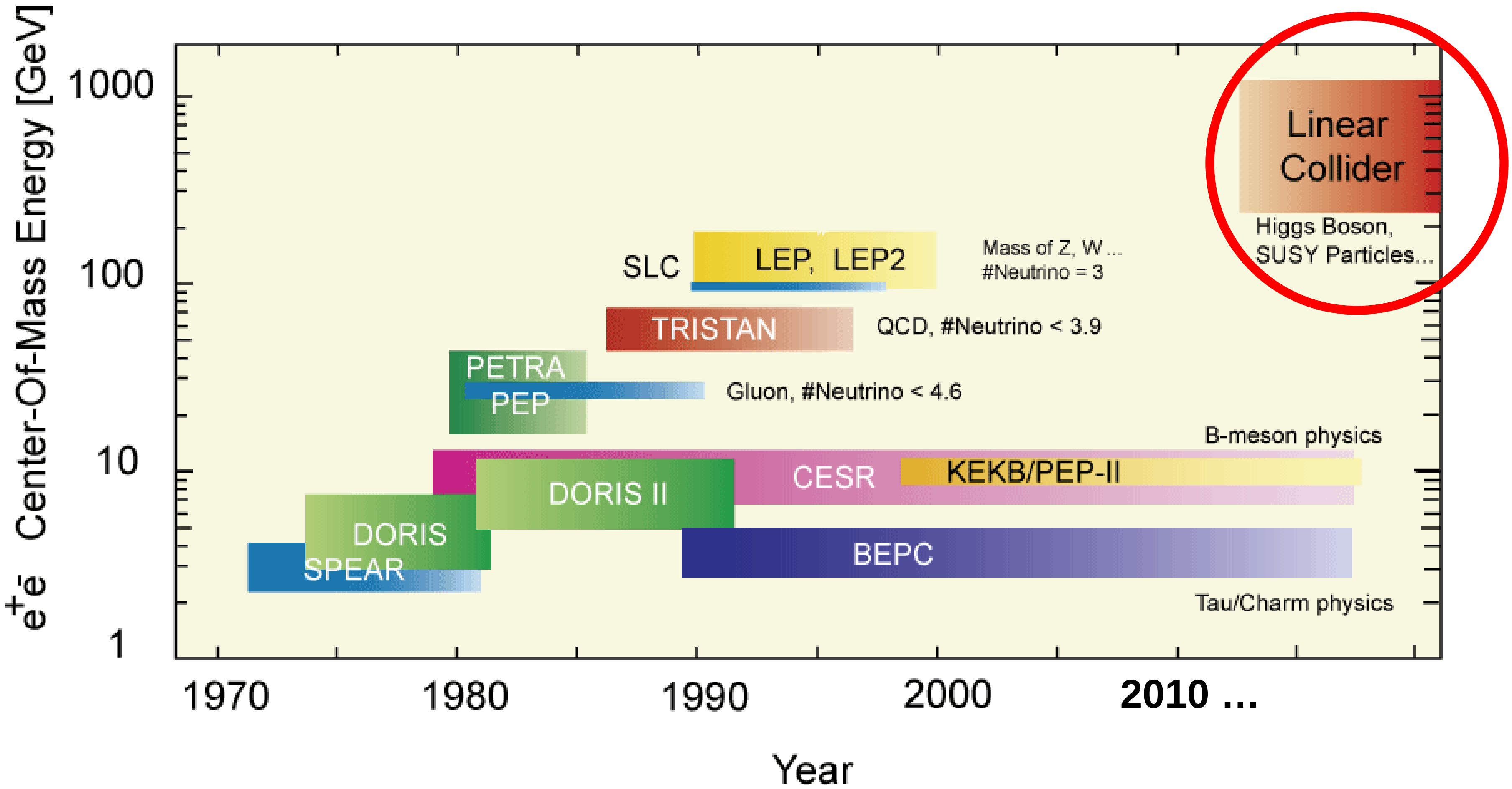
International Linear Collider



Robert S. Orr

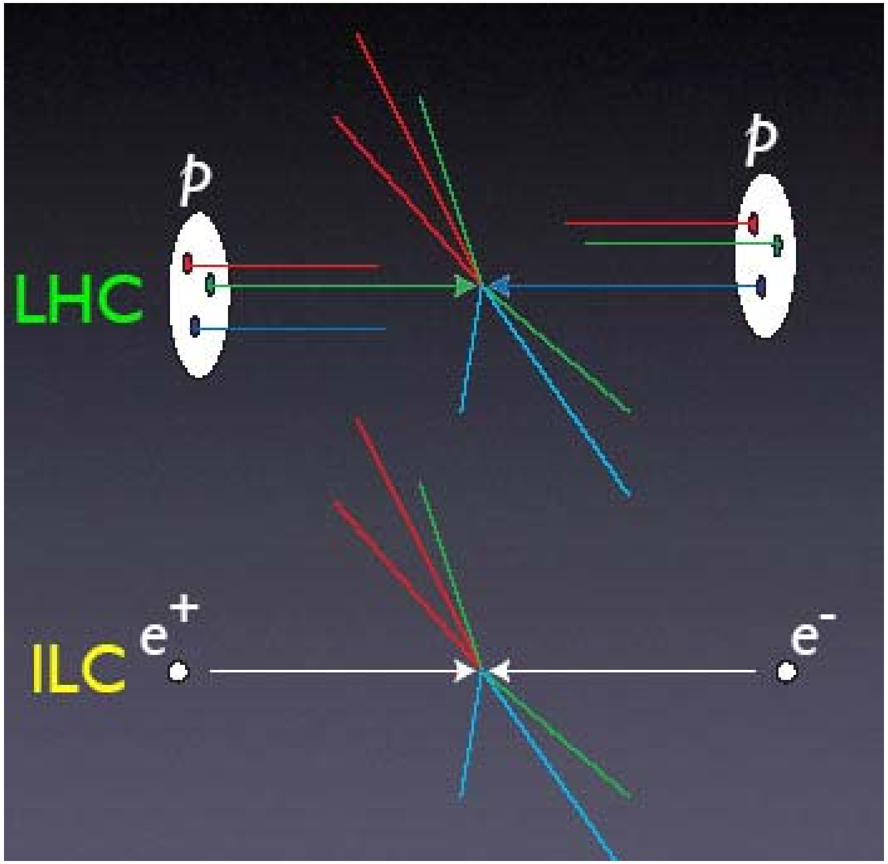
University of Toronto

ILC as N'th Generation e+e- Collider

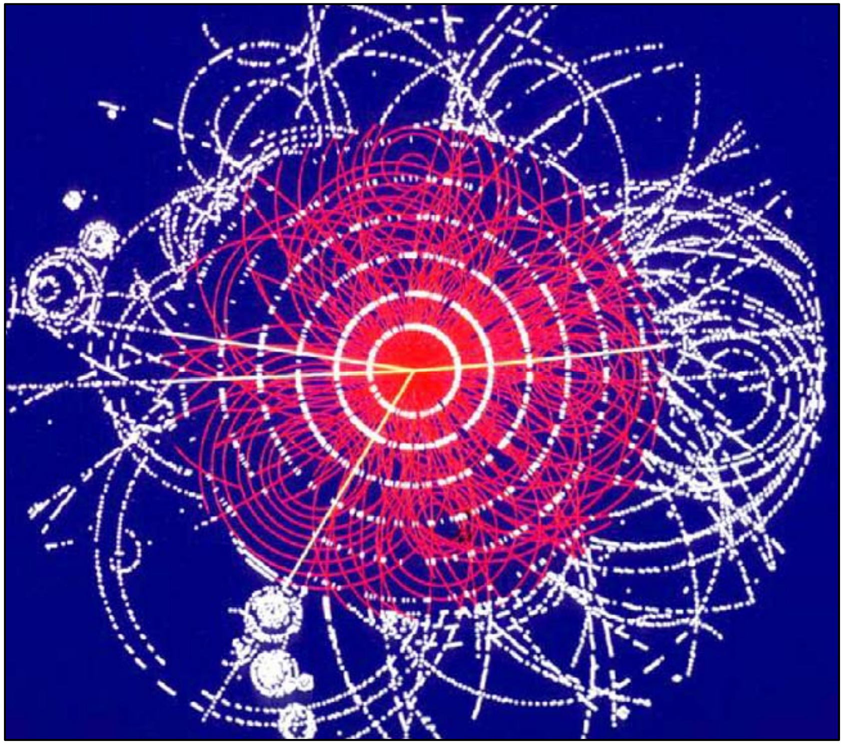


Precision Physics at the Terascale

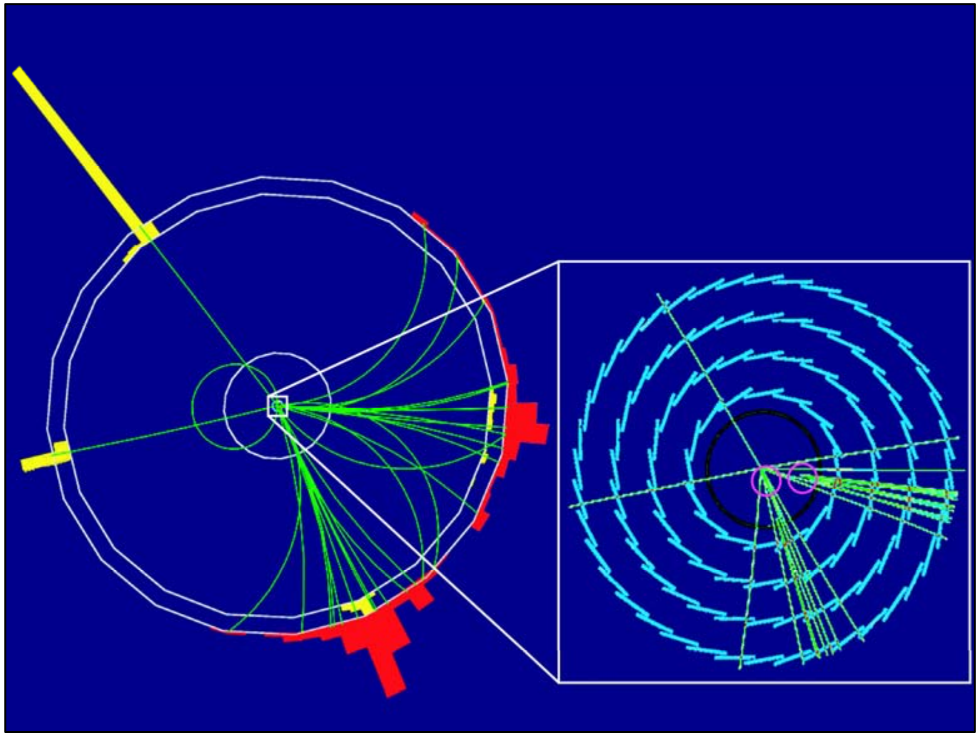
- Elementary particles
- Well-defined
  - energy
  - angular momentum
- Uses full CoM energy
- Produces particles democratically
- Can mostly fully reconstruct events
- Need to know what energy is interesting



Higgs Event Topology



LHC



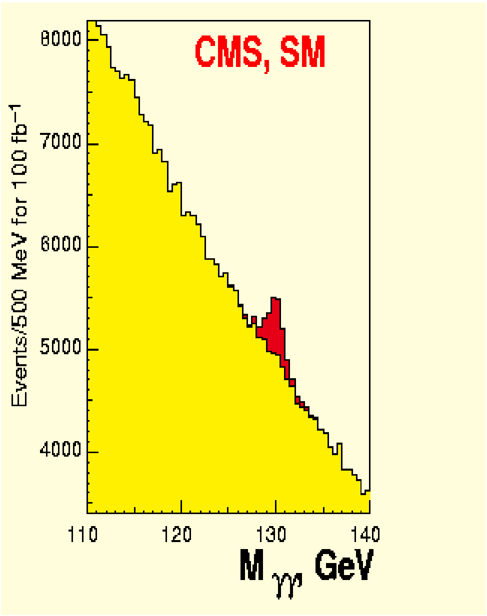
ILC

$e^+ e^- \rightarrow ZH$

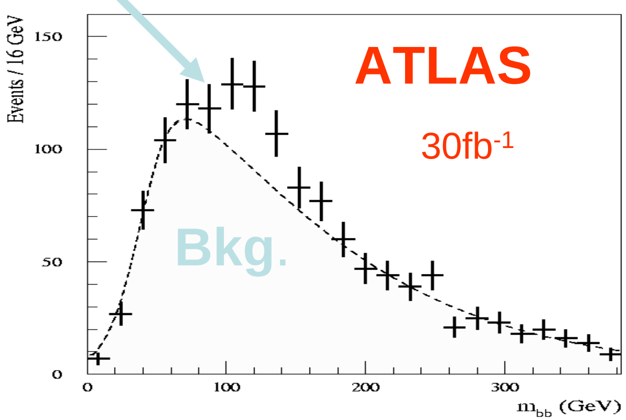
$Z \rightarrow e^+ e^-, H \rightarrow b\bar{b}$

LHC & ILC Higgs Signals

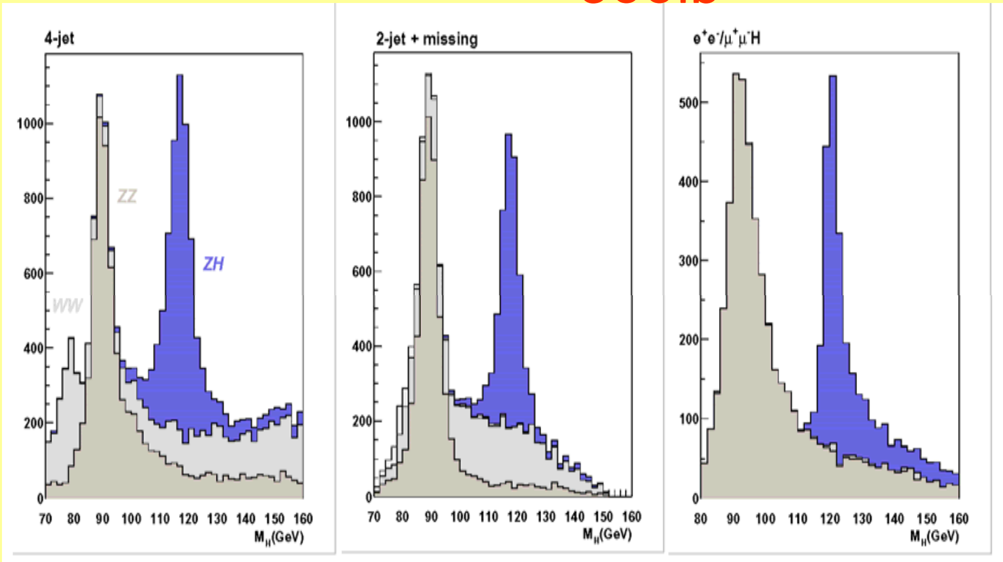
H→ γγ

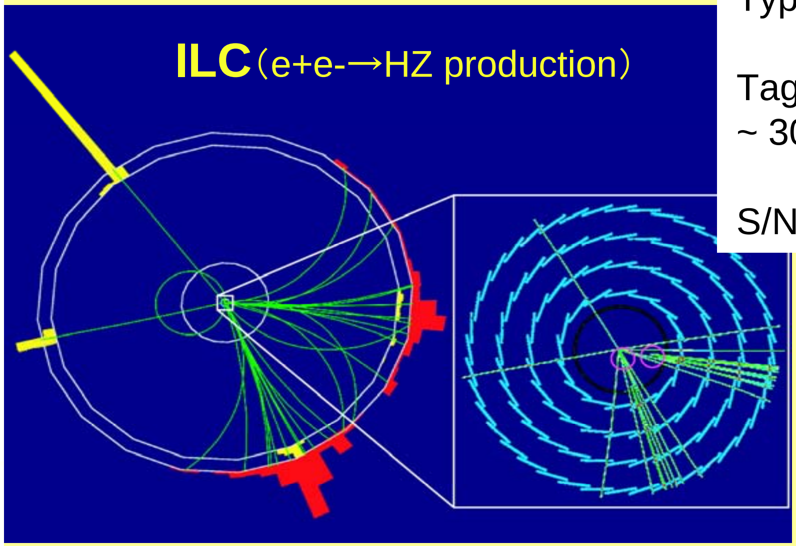


ttH→WbWbbb→lνjjbbbb



500fb^{-1}





Typical numbers

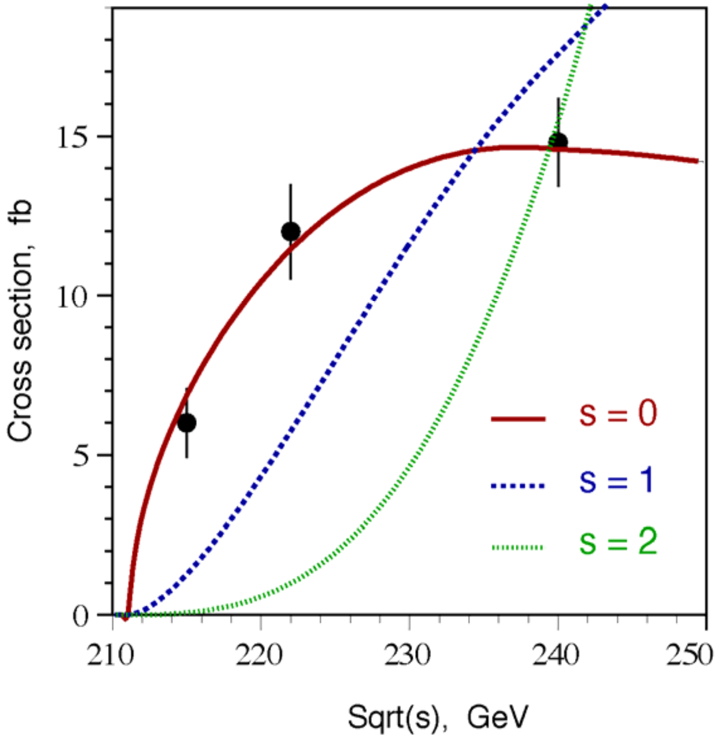
Tagging efficiency ~ 30-50 %

S/N > 1

What Kind of “Higgs” is it ?

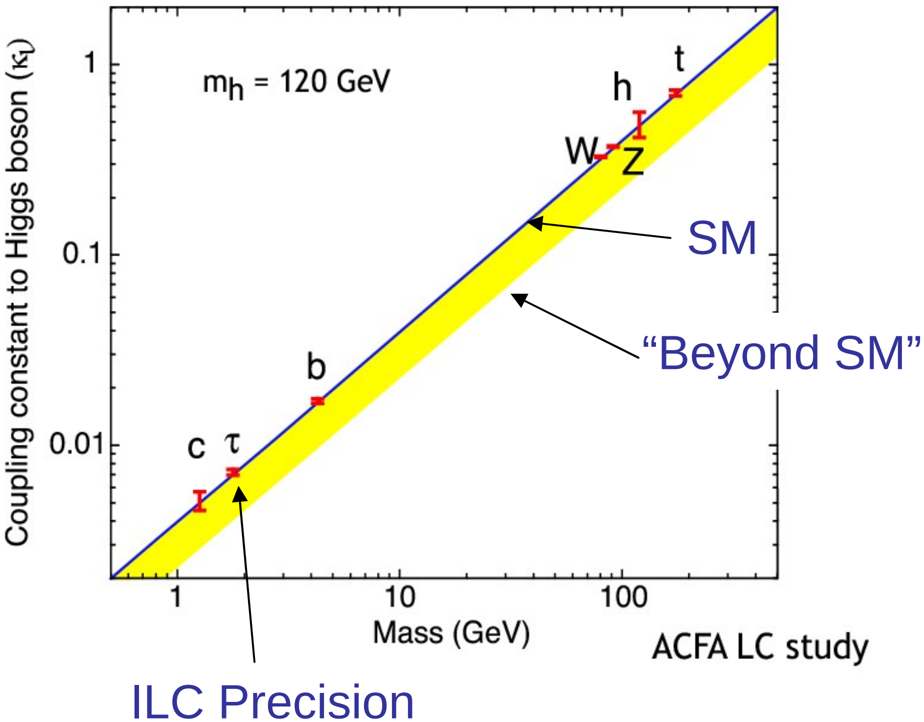
Measure the quantum numbers.
The Higgs is a scalar

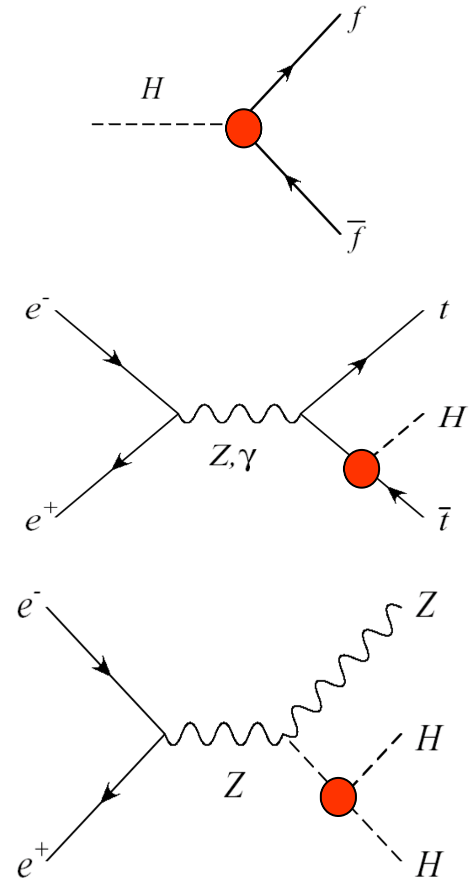
M_h = 120 GeV



- The ILC can measure the spin of any “Higgs” produced
- Measure the energy dependence of the production cross section from threshold

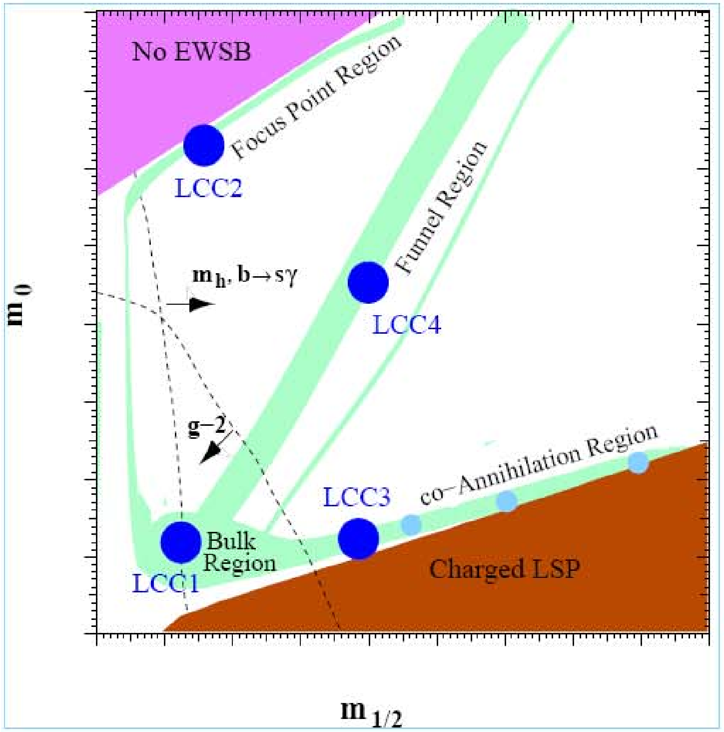
Precision Measurement of Higgs Couplings

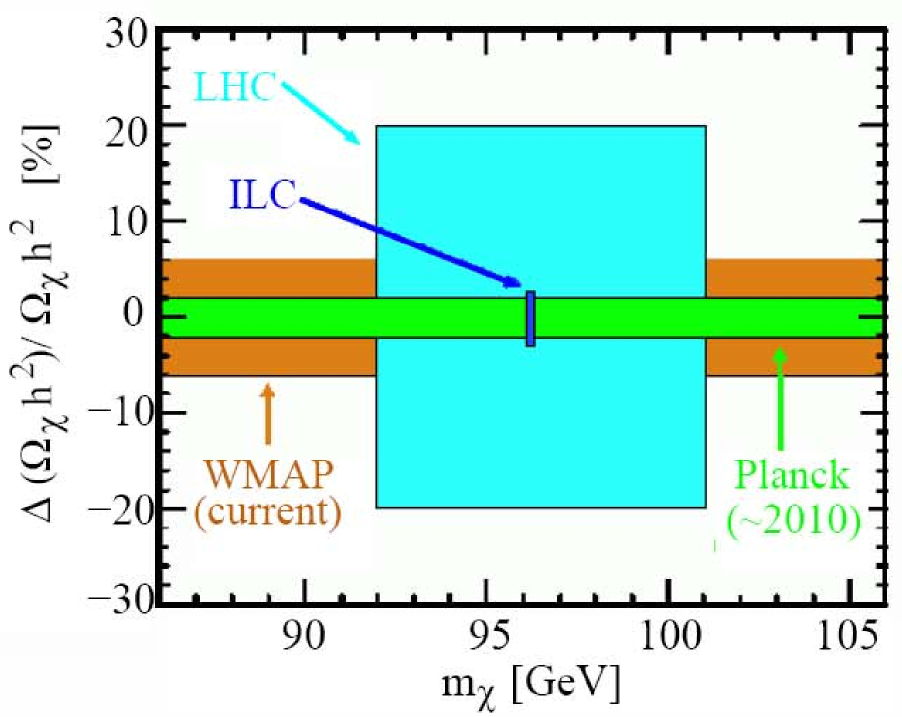




$$m_i = v \cdot \kappa_i$$

SUSY and Dark Matter

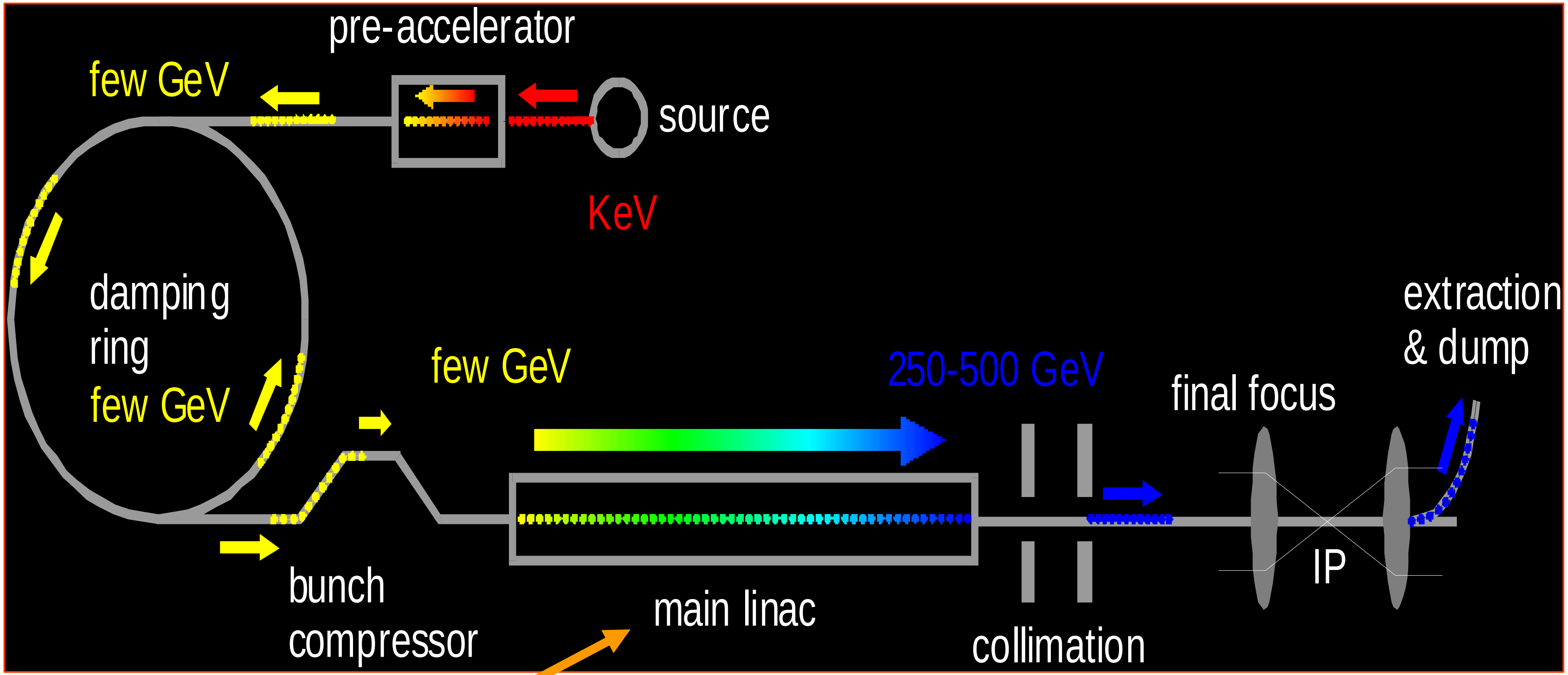




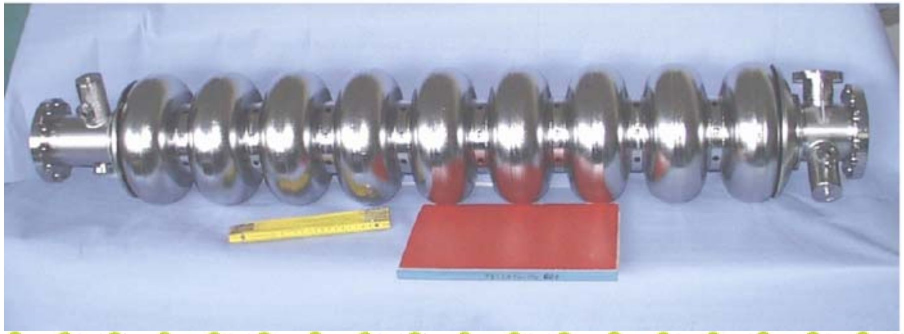
Dark Matter favored regions in cMSSM parameter space

LSP neutralino mass and precision on relic density at LCC1

Designing a Linear Collider



Superconducting RF
Main Linac



Luminosity & Beam Size

$$L = \frac{n_b N^2 f_{rep}}{2\pi \Sigma_x \Sigma_y} H_D$$

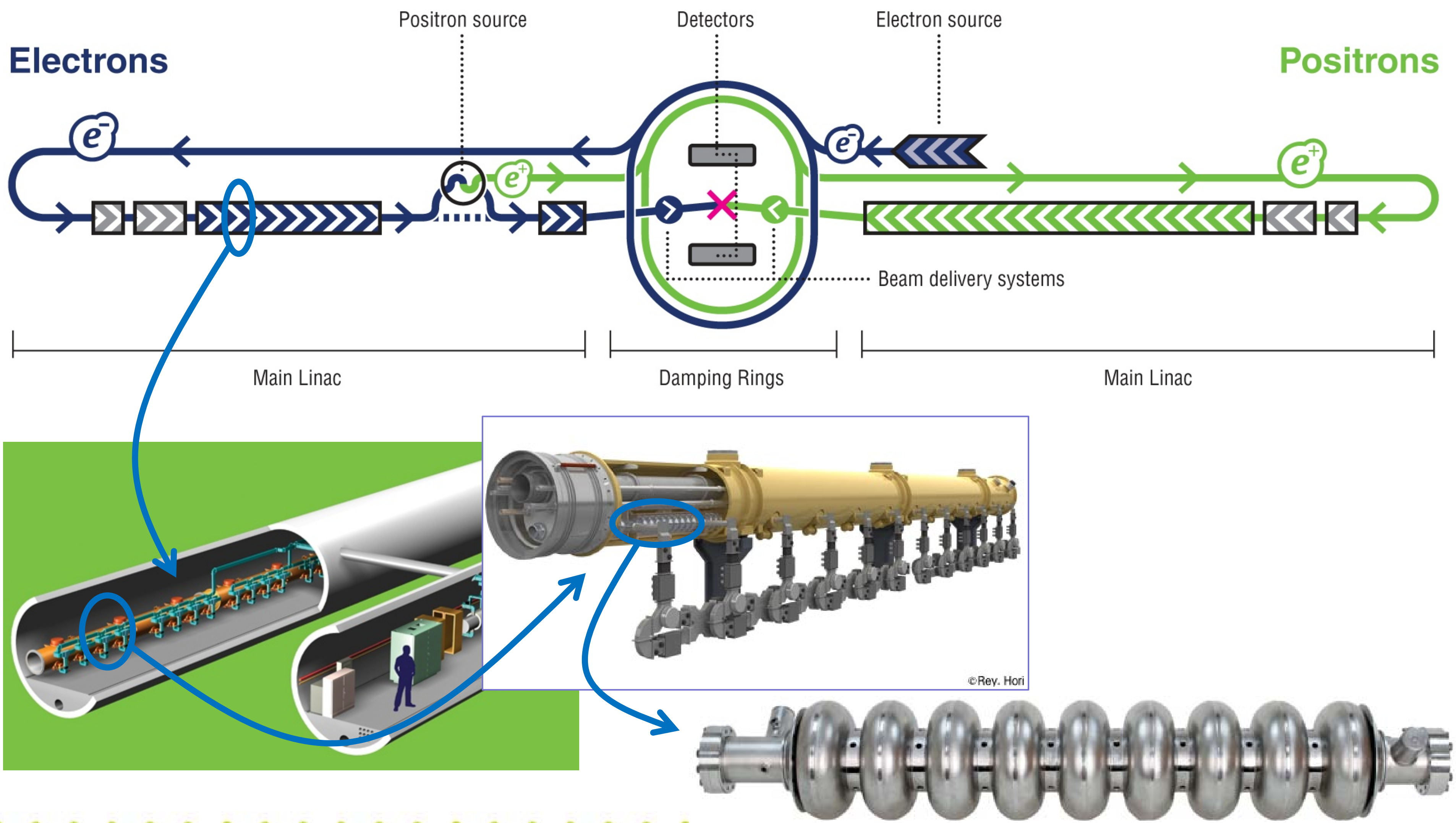
- f_{rep} * n_b tends to be low in a linear collider

	L	f_{rep} [Hz]	n_b	N [10^{10}]	σ_x [μm]	σy [μm]
ILC	2×10^{34}	5	3000	2	0.5	0.005
SLC	2×10^{30}	120	1	4	1.5	0.5
LEP2	5×10^{31}	10,000	8	30	240	4
PEP-II	1×10^{34}	140,000	1700	6	155	4

- The beam-beam tune shift limit is much looser in a linear collider than a storage rings → achieve luminosity with spot size and bunch charge
  - Small spots mean small emittances and small betas:

σ_x = sqrt (β_x ε_x)

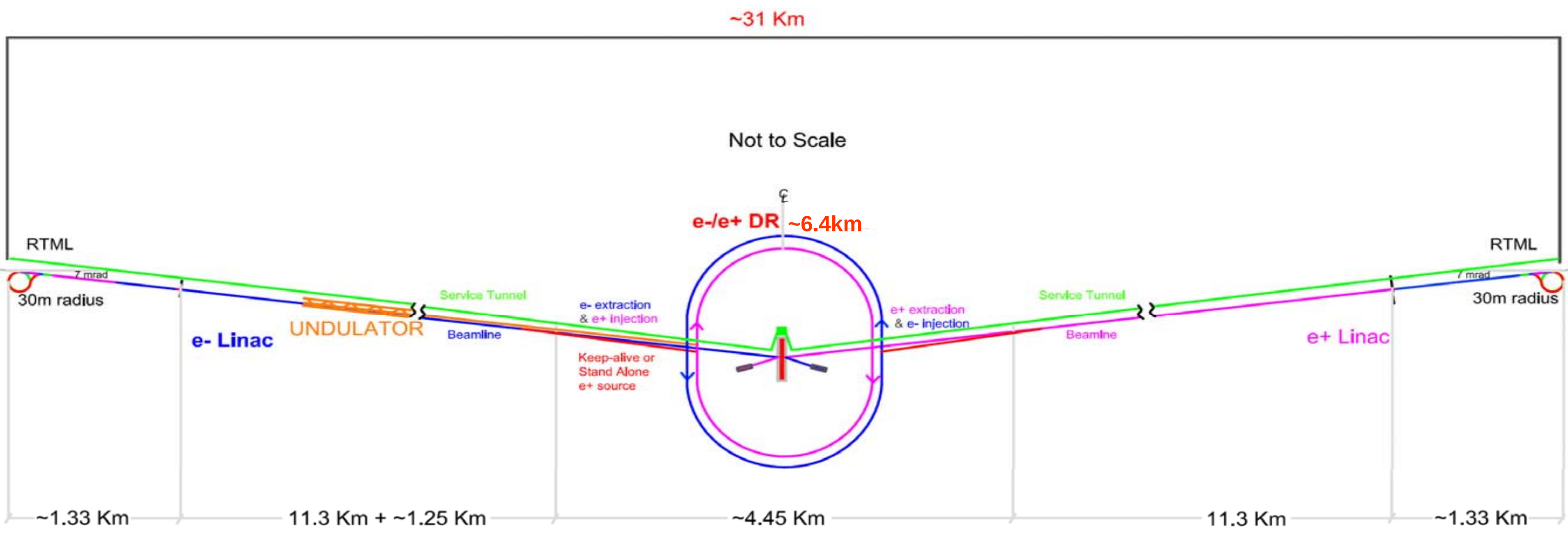
ILC Reference Design



Reference Design in a Nutshell

- ECM = 500GeV max within a site footprint of ~31km.
- Main Linacs: superconducting cavities
- Eacc = 31.5MV/m (16000 x 9-cell cavities → 2 x ~12km)
- Injectors: Polarized (P~80%) e- source
- 2 damping rings (e- and e+) around interaction region.

- Injectors : Undulator e+ source within e- main linac
- Interaction region: Single IR with 14mrad beam crossing
- Lumi = 2×10^{34} $cm^{-2}s^{-1}$, f_rep = 5Hz



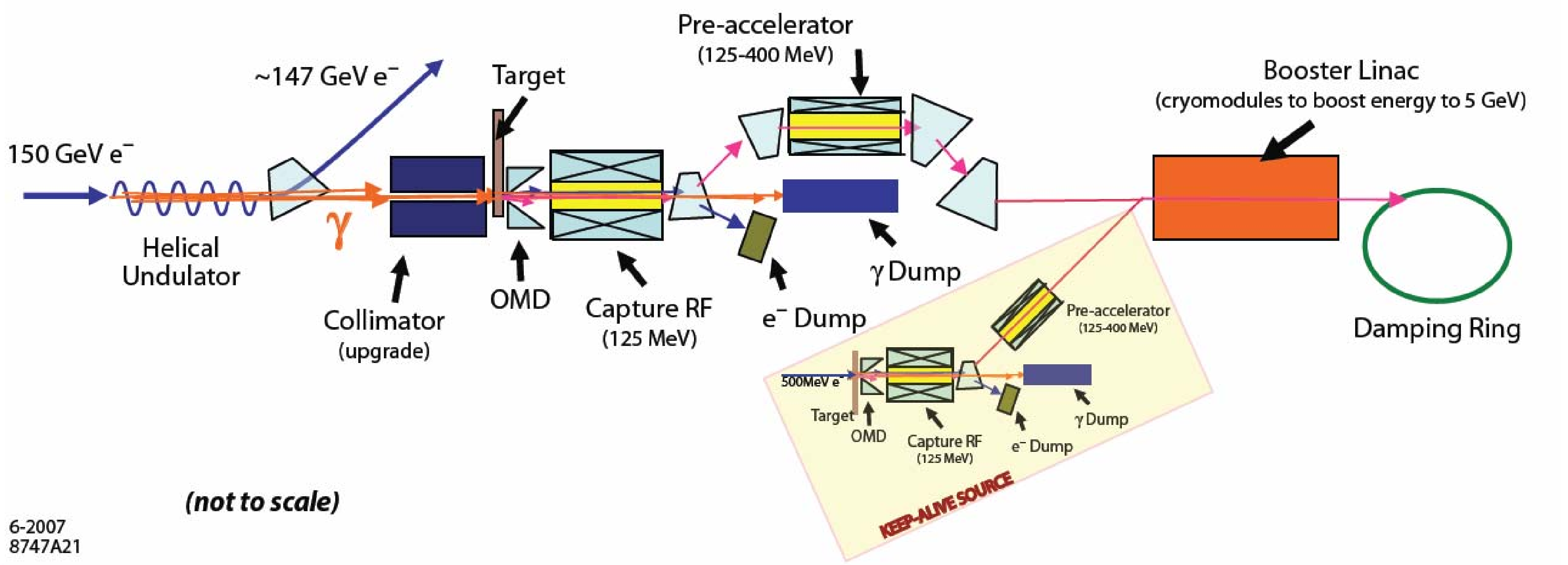
Schematic Layout of the 500 GeV Machine

ILC R&D Test Facilities Deliverables

Test Facility	Deliverable	Date
Optics and stabilisation demonstrations:		
ATF	Generation of 1 pm-rad low emittance beam	2009
ATF-2	Demo. of compact Final Focus optics (design demagnification, resulting in a nominal 35 nm beam size at focal point).	2010
	Demo. of prototype SC and PM final doublet magnets	2012
	Stabilisation of 35 nm beam over various time scales.	2012
Linac high-gradient operation and system demonstrations:		
TTF/FLASH	Full 9 mA, 1 GeV, high-repetition rate operation	2009
STF & ILCTA-NML	Cavity-string test within one cryomodule (S1 and S1-global)	2010
	Cryomodule-string test with one RF Unit with beam (S2)	2012
Electron cloud mitigation studies:		
CESR-TA	Re-config. (re-build) of CESR as low-emittance e-cloud test facility. First meas. of e-cloud build-up using instrumented sections in dipoles and drifts sections (large emittance).	2008
	Achieve lower emittance beams. Meas. of e-cloud build up in wiggler chambers.	2009
	Characterisation of e-cloud build-up and instability thresholds as a func. of low vertical emittance ($\leq$20 pm)	2010

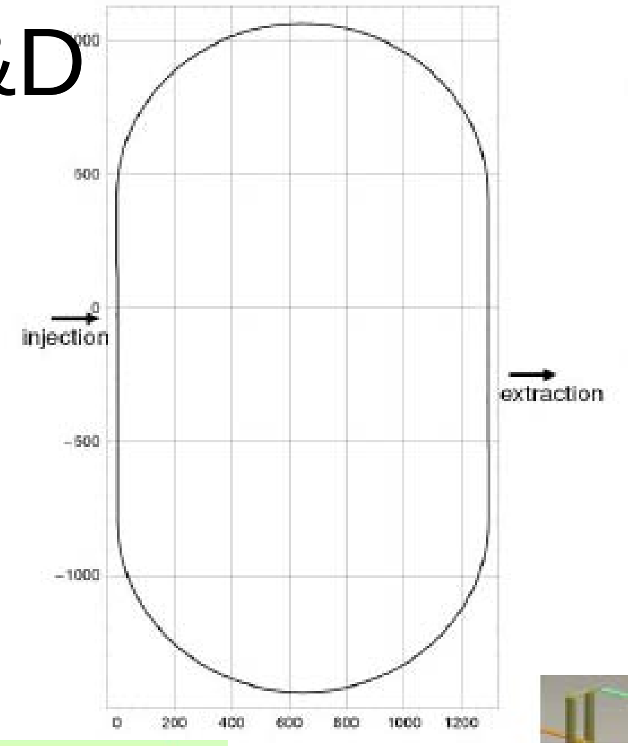
Baseline Features – Positron Source

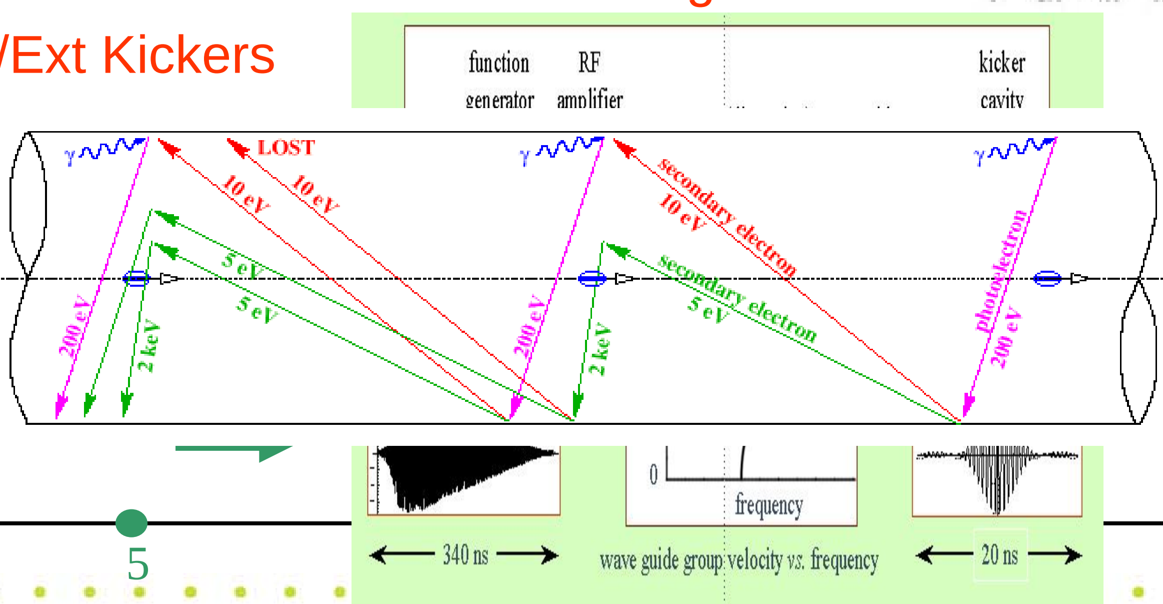
- Positron Source – Helical Undulator with Polarized beams
  - 150 Gev electron beam goes through a 200m undulator making photons that hit a 0.5 rl titanium alloy target to produce positrons.
  - The positrons are accelerated to 5-GeV accelerator before injecting into positron damping ring.

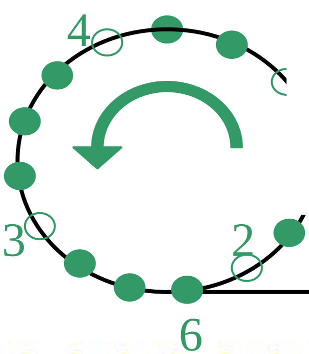


Damping Ring R&D

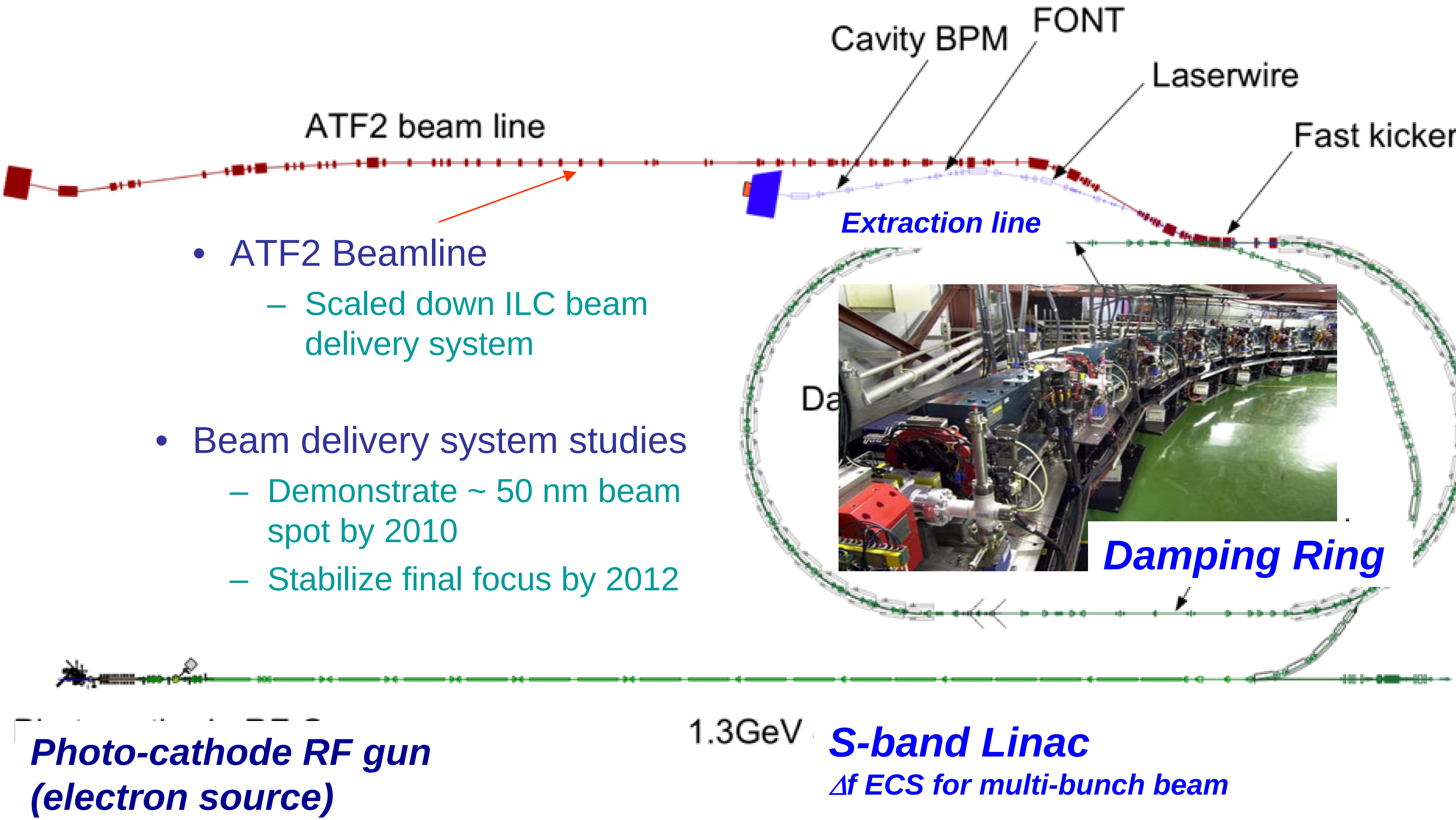
- DR - flexible race track design
  - 6.4 km Circumference with >1 km straights, which contain, RF, Wigglers, Chicanes, Injection/ Extraction Systems
- There are two critical components
  - Suppression of e- Cloud in the e+ ring
  - Fast Inj/Ext Kickers





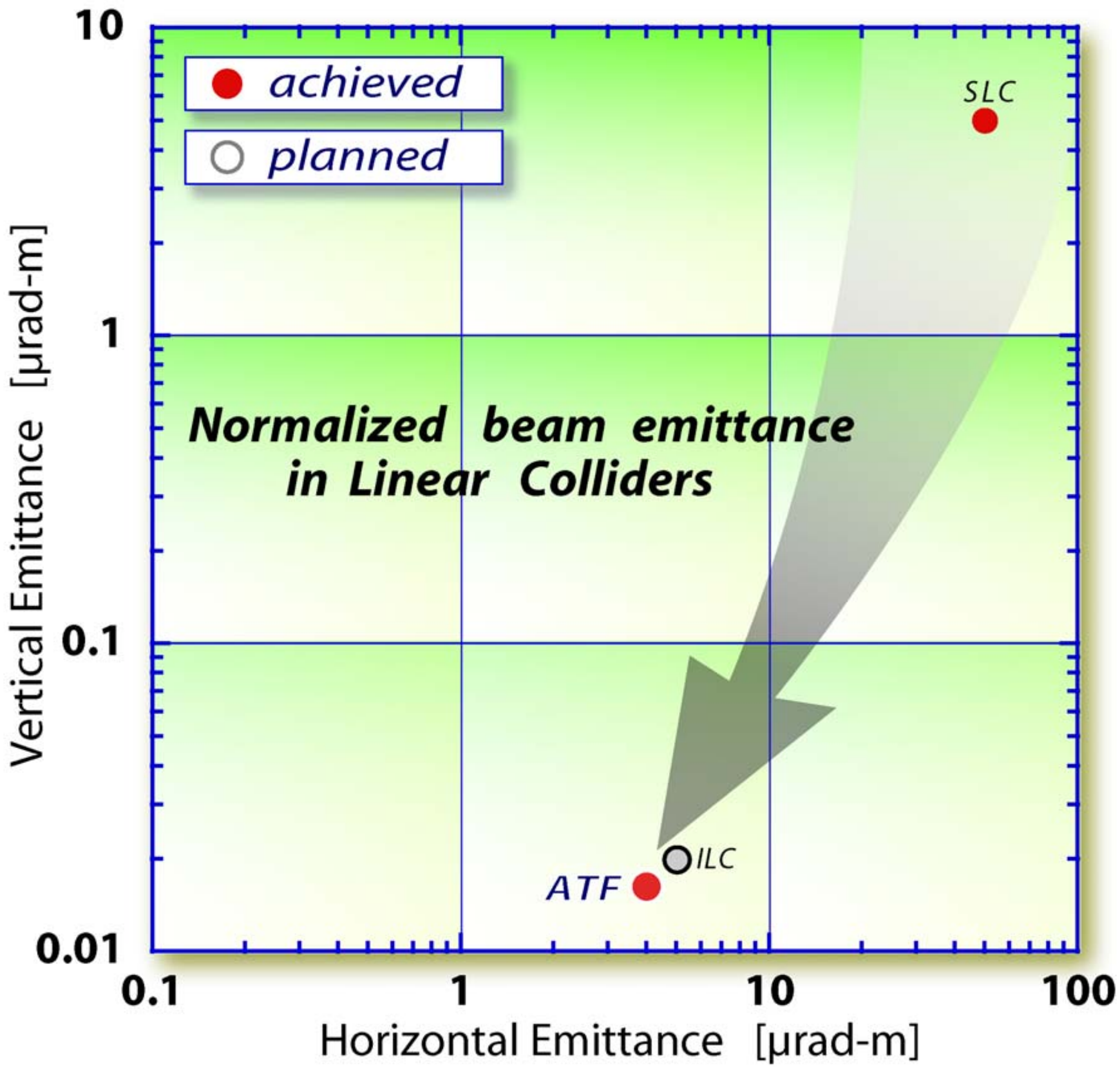


KEK – ATF/ATF2



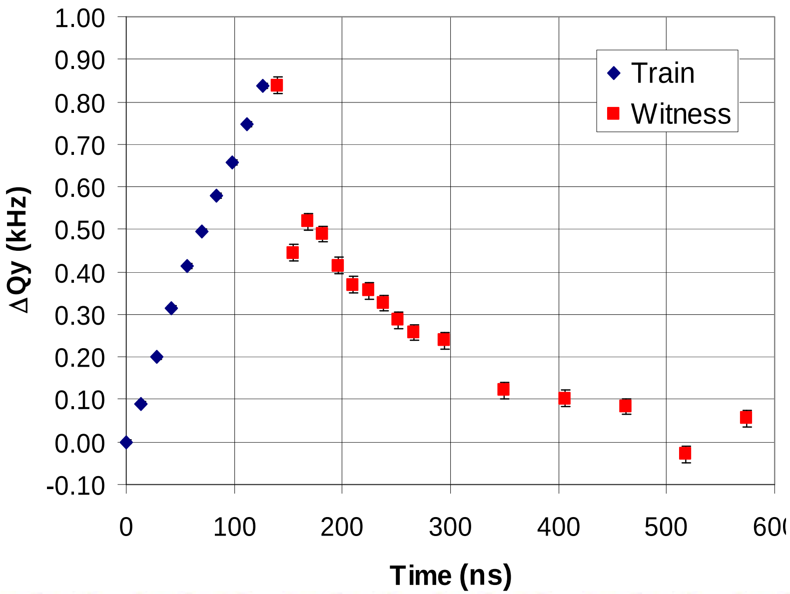
- ATF2 Beamline
  - Scaled down ILC beam delivery system
- Beam delivery system studies
  - Demonstrate ~ 50 nm beam spot by 2010
  - Stabilize final focus by 2012

Damping Ring Emittance



CesrTA @ Cornell

- "Electron Cloud" Issue at Positron Damping Rings (e+ DR)
  - Synchrotron radiation → Inner wall of vacuum chamber → secondary electrons → "Electron cloud" → Beam instabilities / Emittance growth
- A series of beam experiments in 2008-2010.
  - Growth of Electron Cloud and Mitigation Studies
    - Probe bunch configurations similar to ILC DR
    - Tune shift characterizes global effect on DR



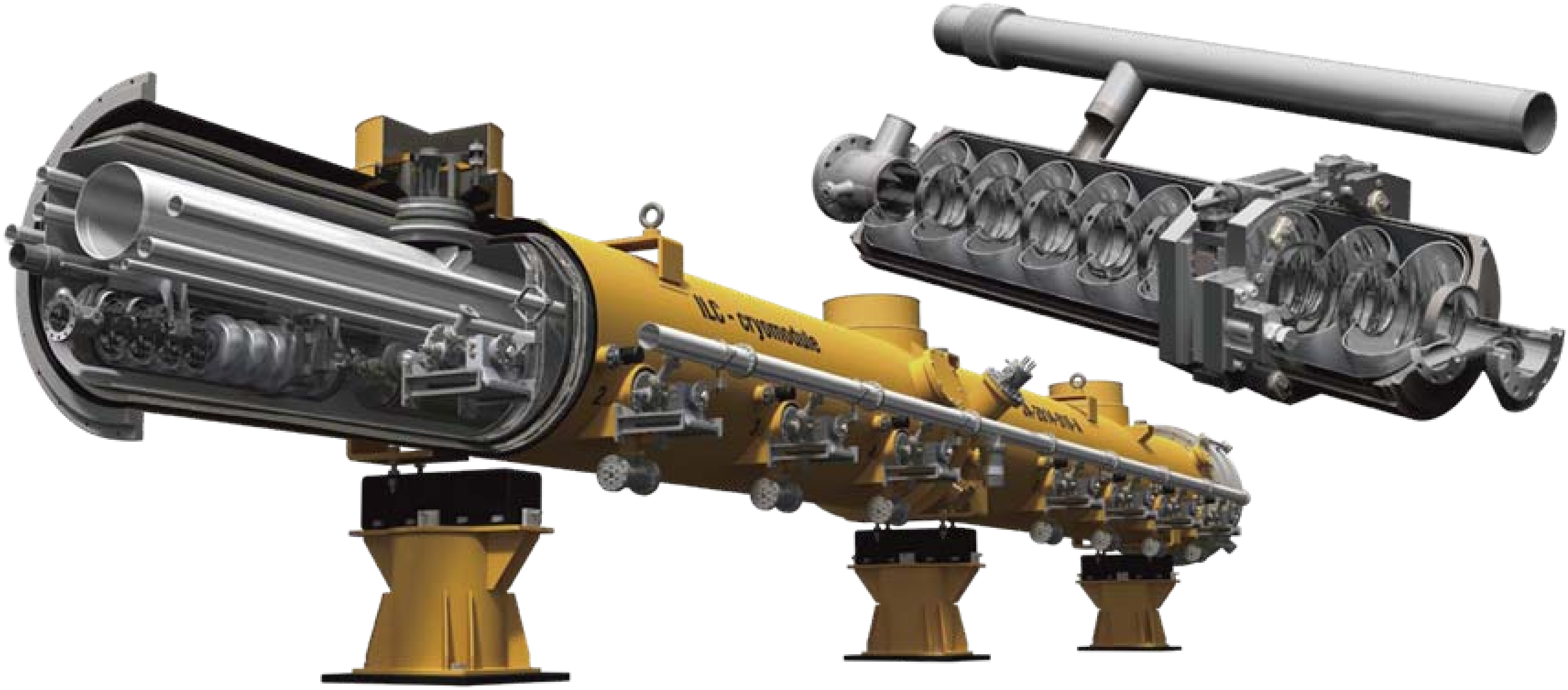
0.75mA/bunch e+@1.9 GeV

Bunch-by-bunch, Turn-by-turn BPM

Witness Bunch Measurements – E.C. Tune Shift

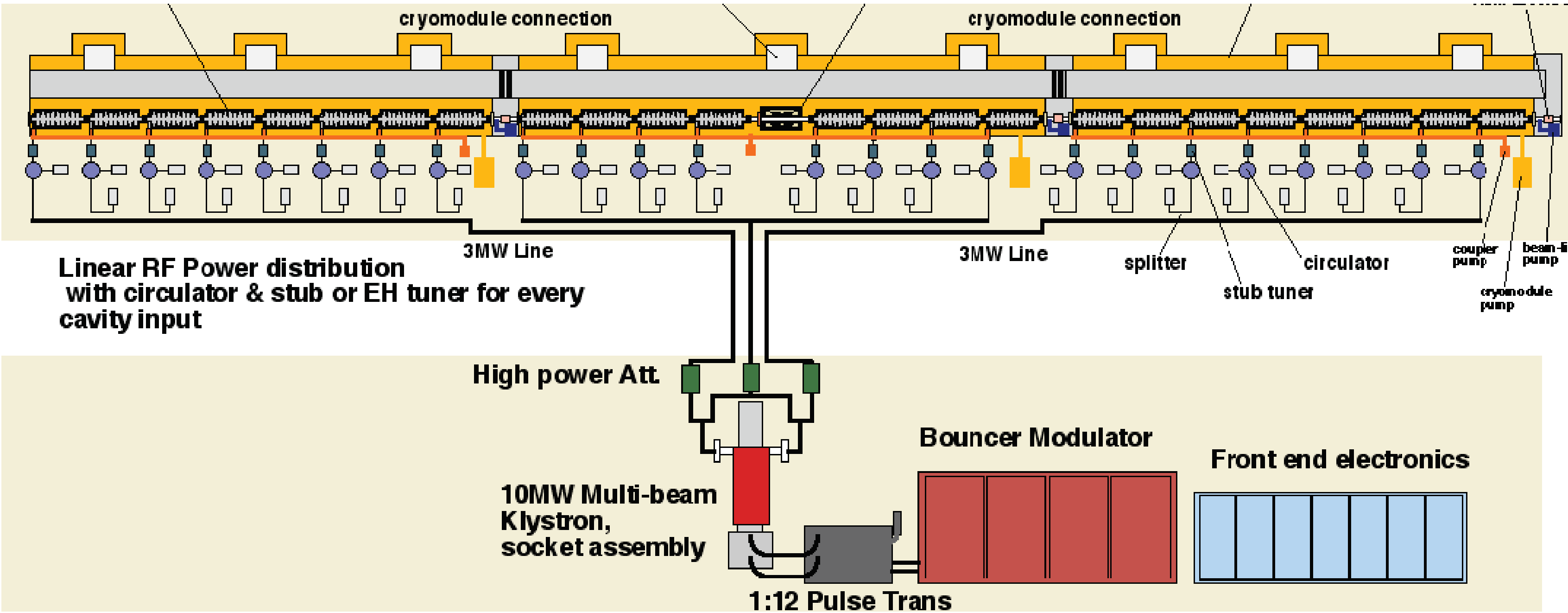
ILC Cryostats and Cavities for Main linacs

- 1 cryomodule contains 8 cavities + 1 magnet or 9 cavities (Eacc = 31.5MV/m on average, each having a length ~ 1m)



- Total ~1700 cryostats, ~16000 cavities.
- 3 cryostats to be driven by one 10MW L-band klystron
- Total 560 RF units in e+/e- main linacs

One RF unit of ILC main linac

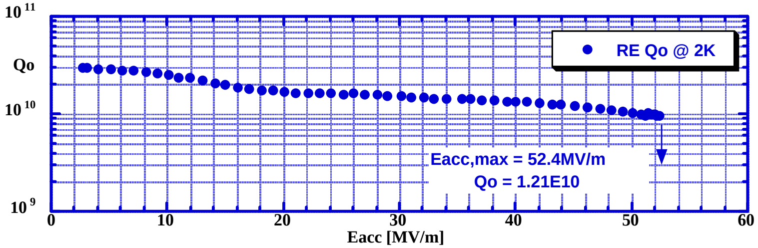


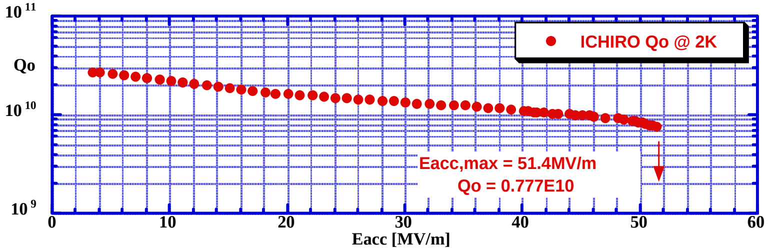
- Current baseline configuration of a unit RF system
  - 3 units of cryomodules
  - 10MW multibeam klystron driven by a bouncer modulator

- Total 560 RF units in main linacs (e+ and e-)

Superconducting Test Facility @ KEK

Single-cell cavities that recorded Eacc > 50MV/m

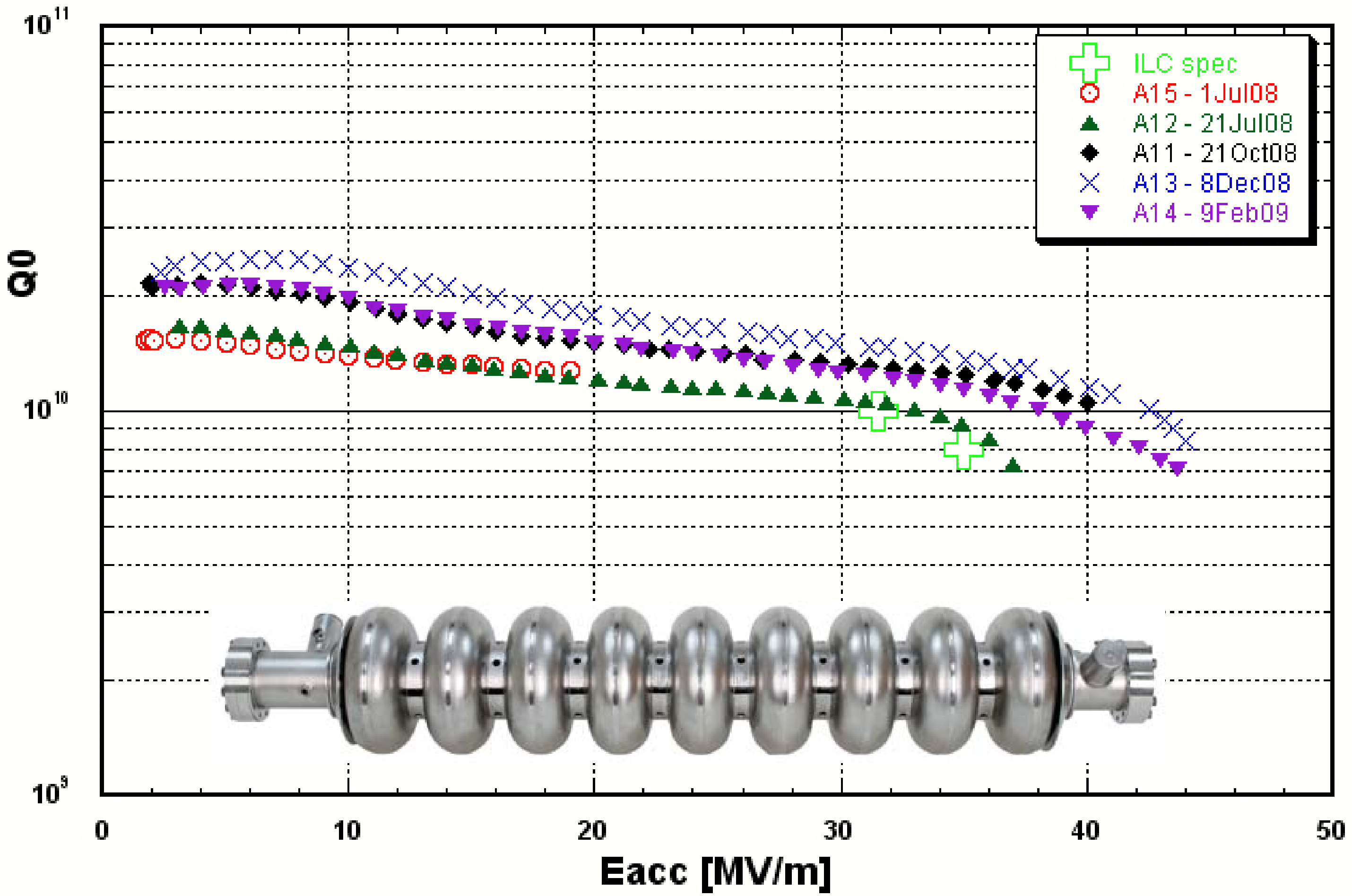




Horiz. Cryostat with 4 units of 9-cell cavities

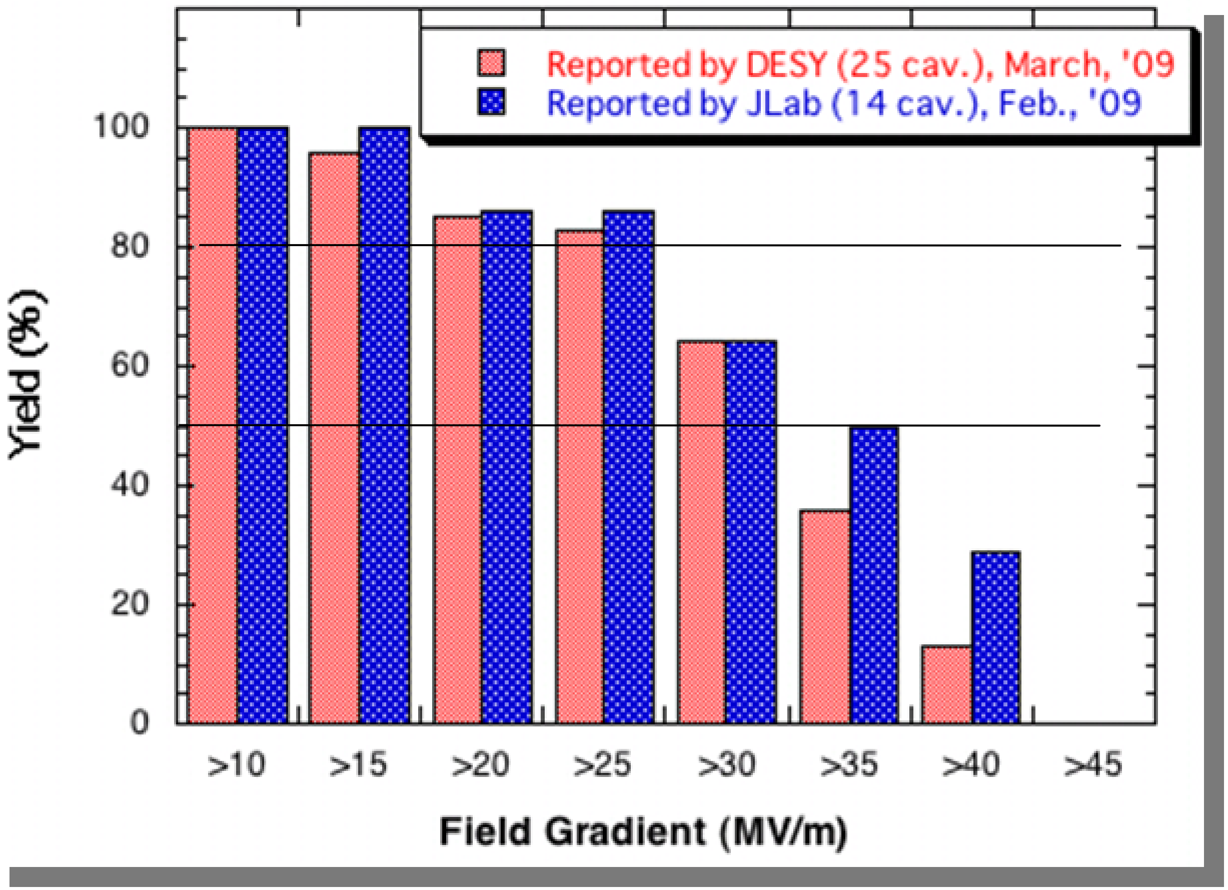
Most Recent Results from Jlab

as of Feb. 18, 2009



- Five 9-cell cavities: built by ACCEL, and processed/tested at Jlab.

Progress Towards High-Gradient Yield



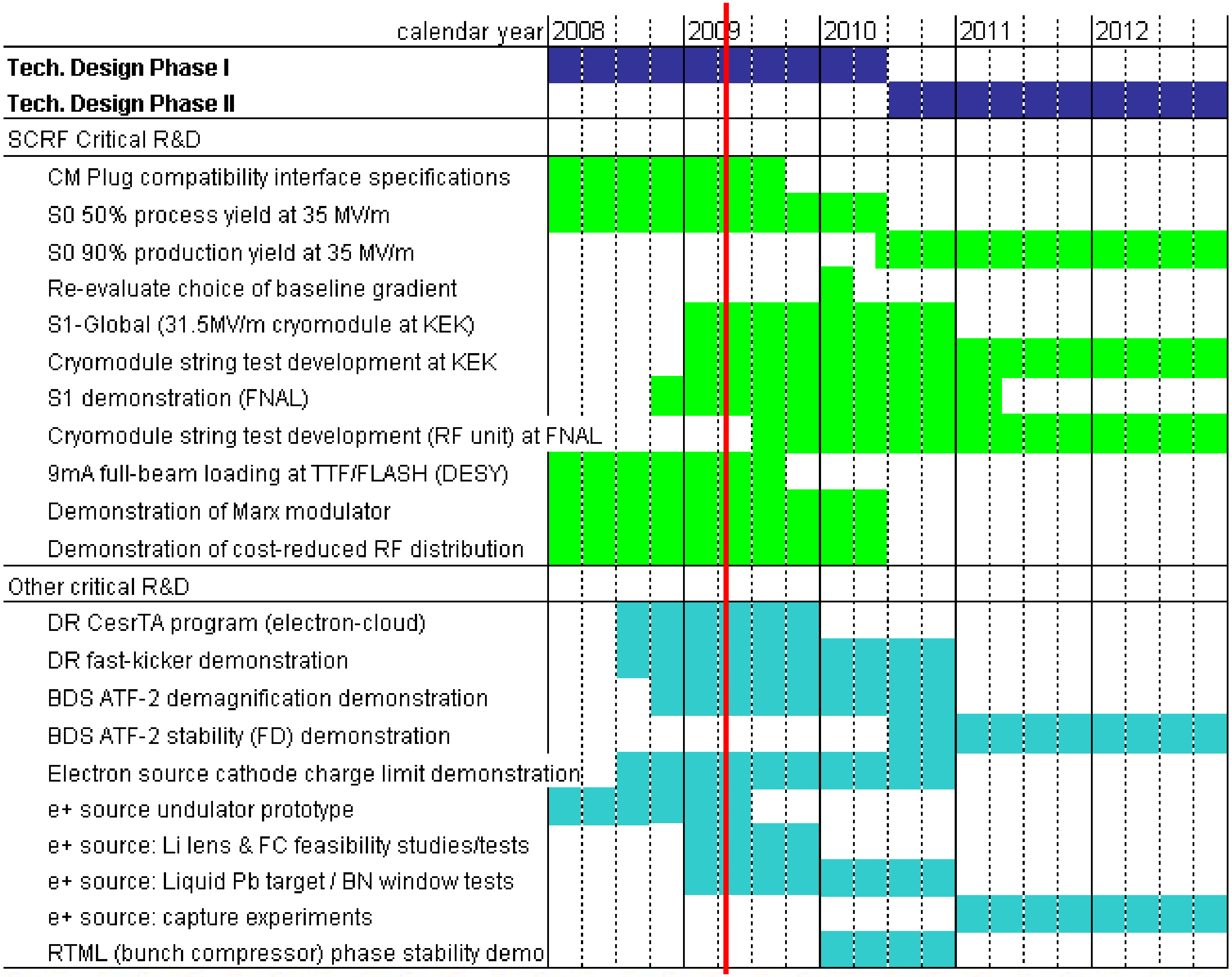
Recent DESY/JLab "production" series.

Total 39 cavities (08/09)

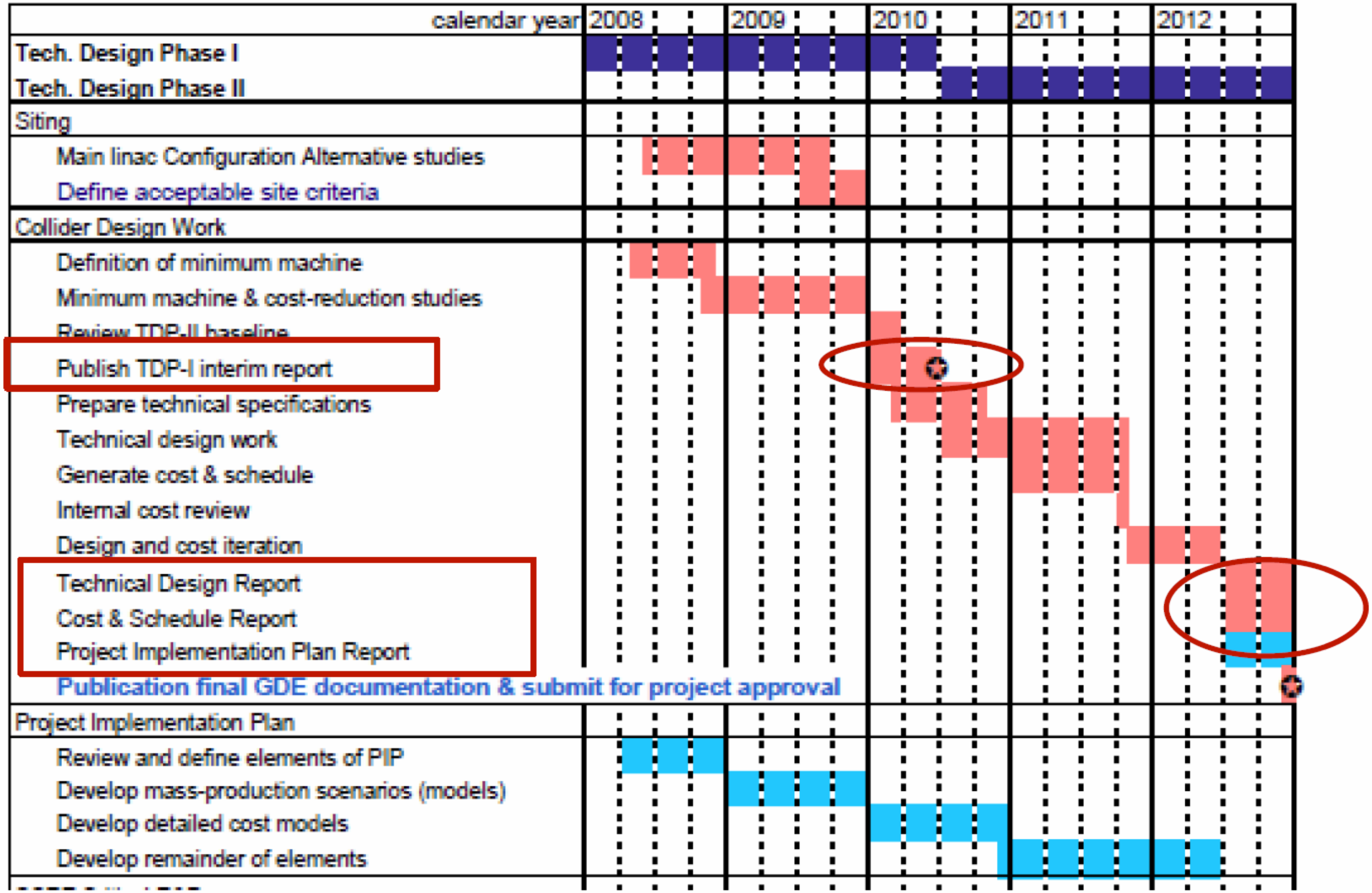
Baseline gradient re-evaluation (TDP1) expected to be based on sample of >60 cavities

Current status:
50% yield at ~ 33 MV/m;
(80% >25MV/m)

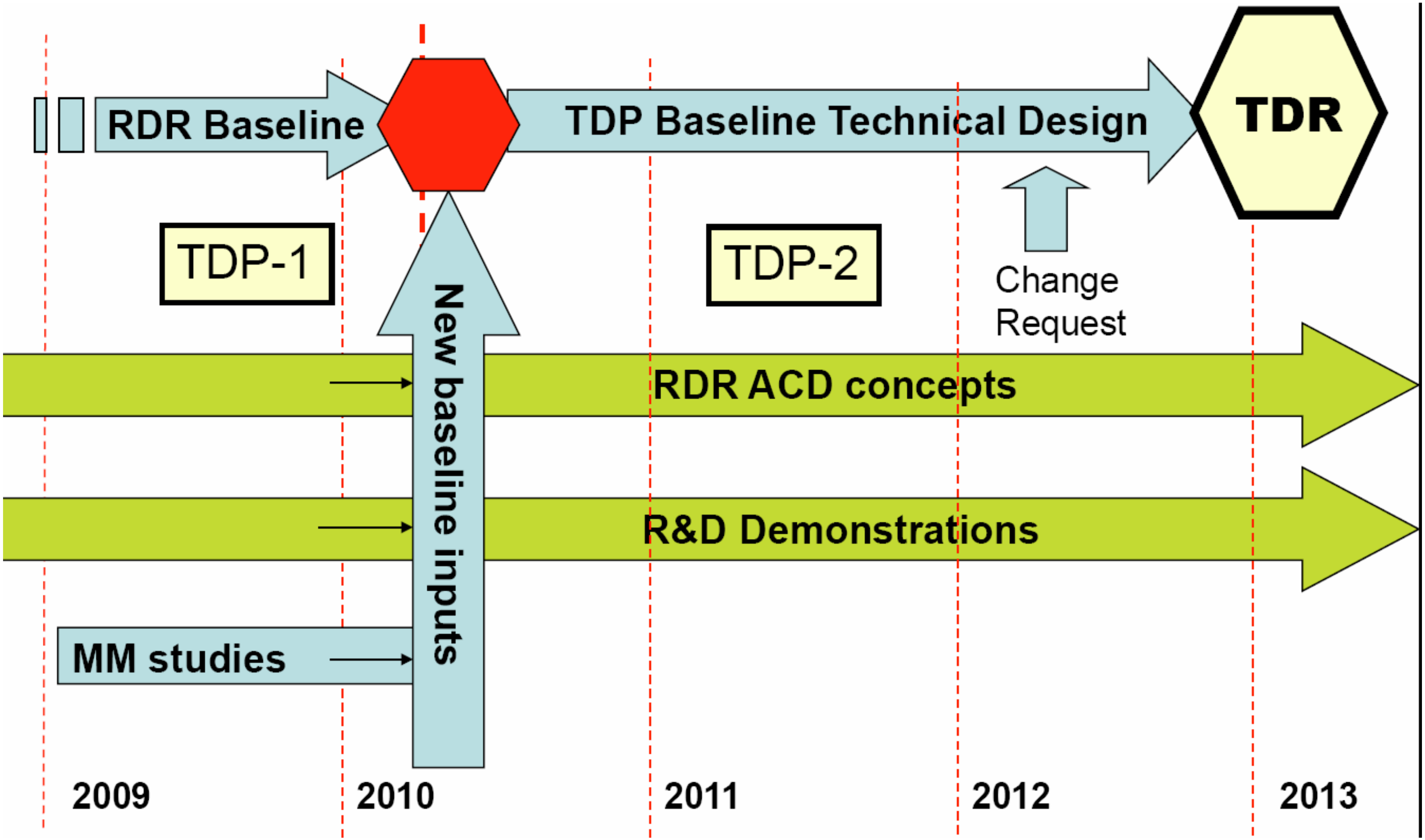
TDP R&D Plan Milestones



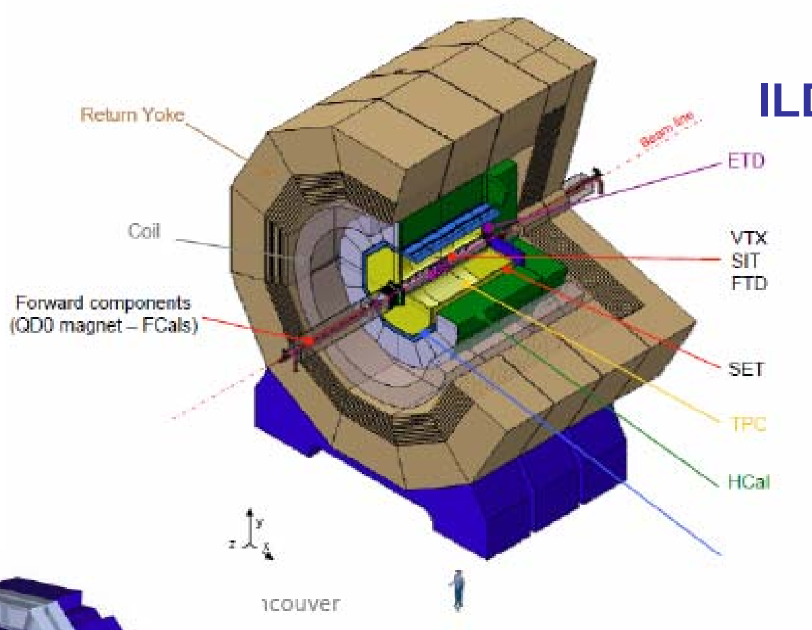
Technical Design Phase Milestones



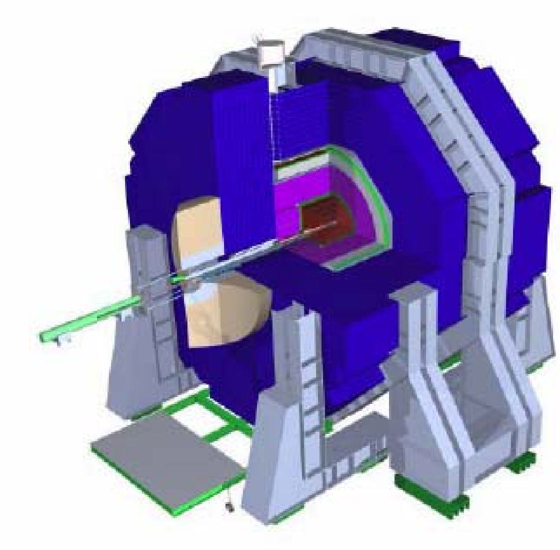
Technical Design Phase & Beyond



Detector Concepts



ILD



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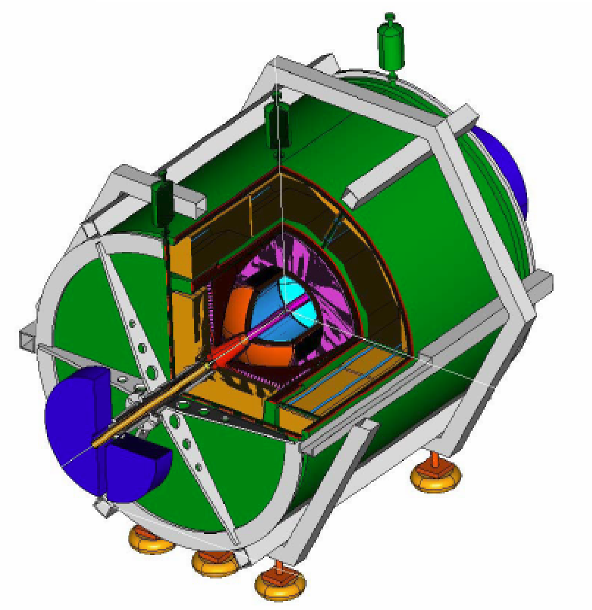
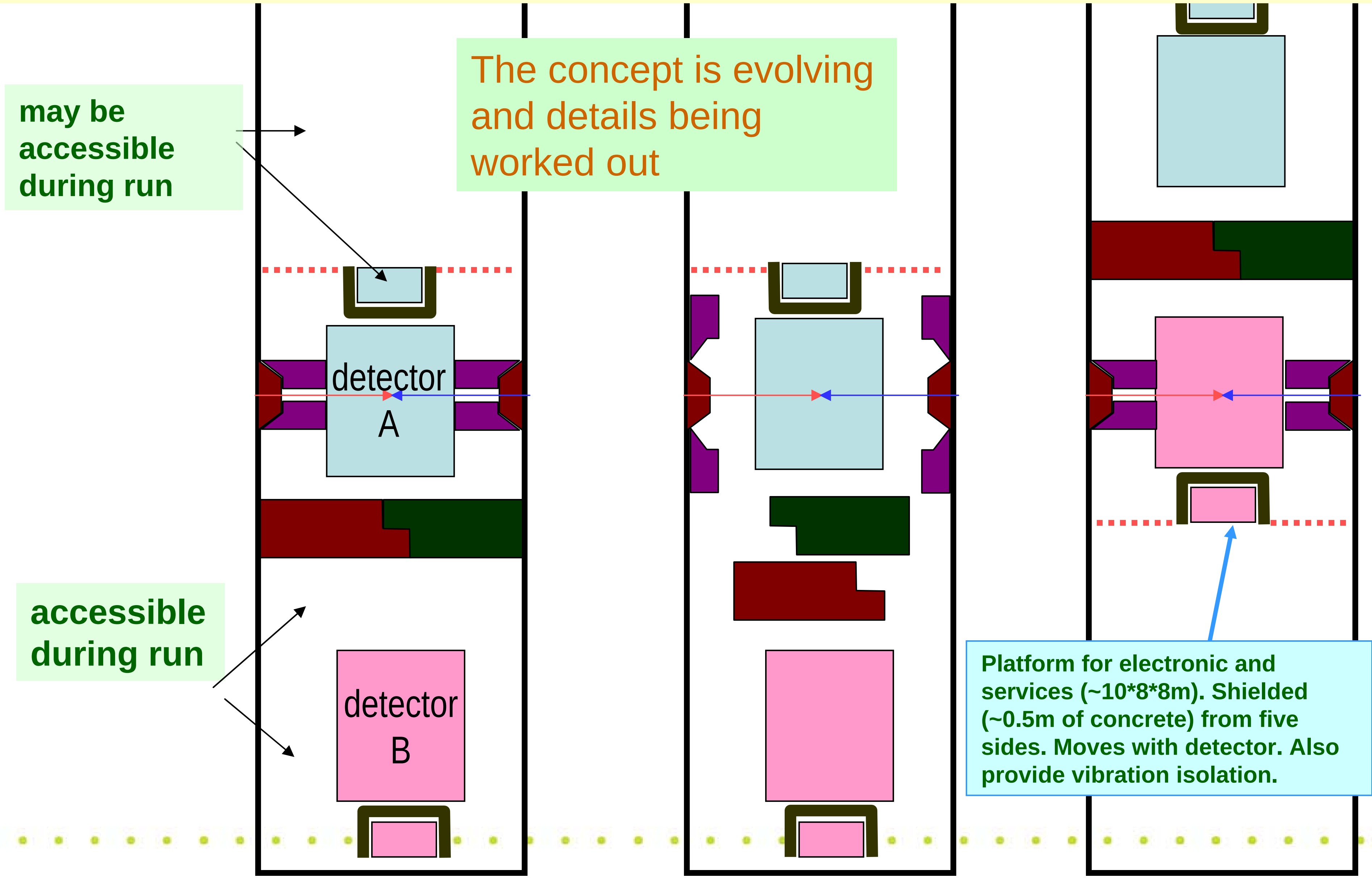


4th

Push-Pull Concept for two detectors



Responding to LHC

- Systematic studies needed
  - When are we likely to know what from LHC?
    - Possible LHC discovery scenarios
  - For each scenario
    - What physics modes to study at ILC
    - What kind of machine to build
    - What kind of detector to build
    - Priorities and timescale
  - Cost and political realities to be included
- Rethinking of the machine parameter will be needed.
  - Energy (250 GeV, 360 GeV, 500 GeV, 800 GeV…)
  - Luminosity
  - Upgrade path

終

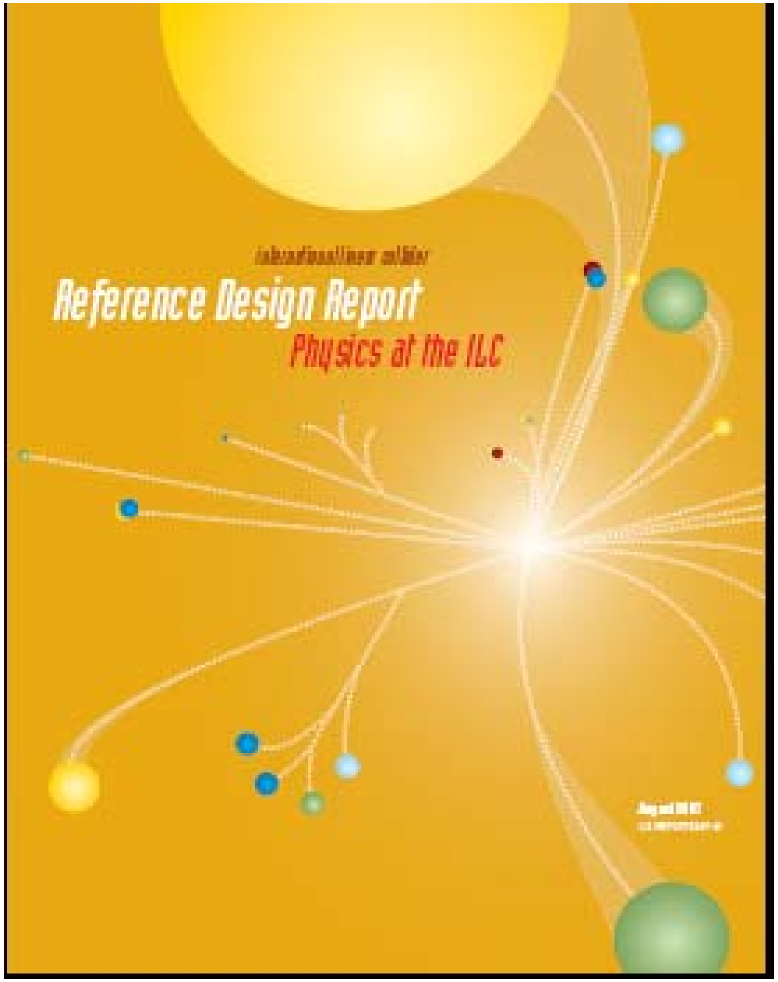
Removed from Talk

In this talk…

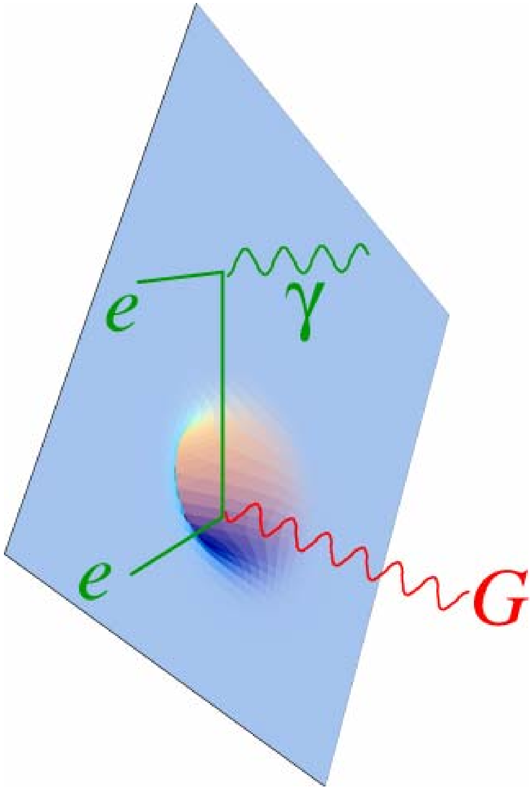
- Up date on -
  - Global efforts for ILC (International Linear Collider): Status and near-future plans.
    - Accelerator - GDE (Global Design Effort)
    - Detector-related - RD (Research Director's Org.)
- To put the conclusions first –
  - There is a large, coordinated, global efforts on ILC,
    - Aiming at developing a project proposal with integrated accelerator and detectors designs, together with
    - A project execution plan,
    - Which can be handed to governments.
    - In the form of a document completed in 2012.

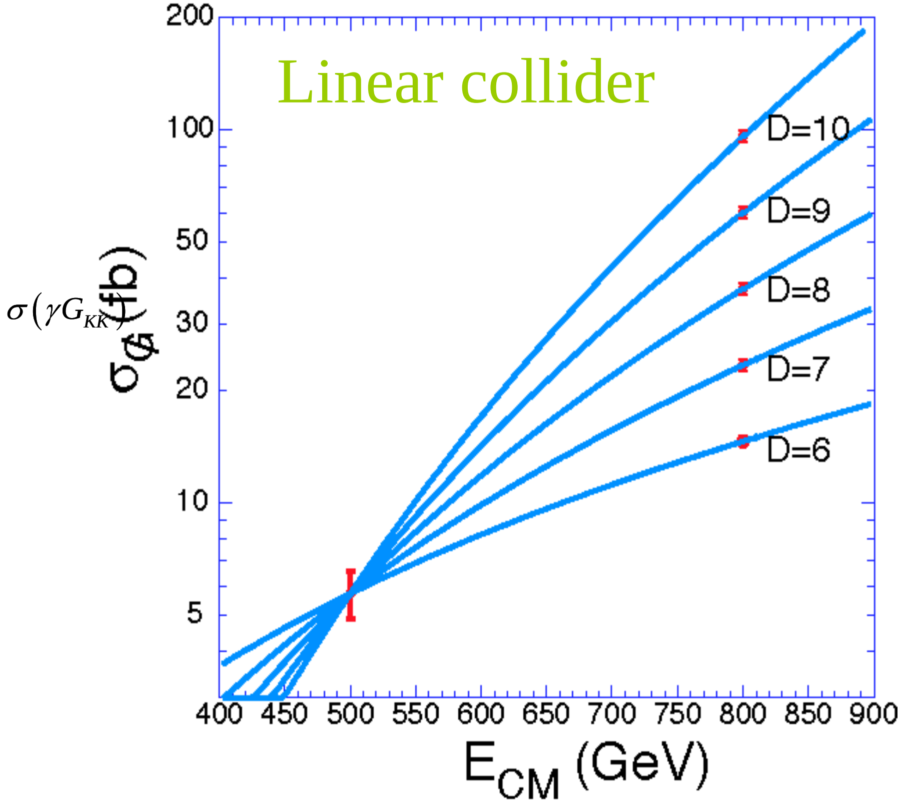
Physics at ILC

- **Higgs-strahlung**
  - Detection + Decays
  - Coupling
  - Properties
- **SUSY**
  - Detection
  - Smuon mass, spin
  - Parameters
  - SUSY dark matter
- **Top quark**
  - Mass, width, decay mode
- **Signatures beyond SM**
  - If there are some

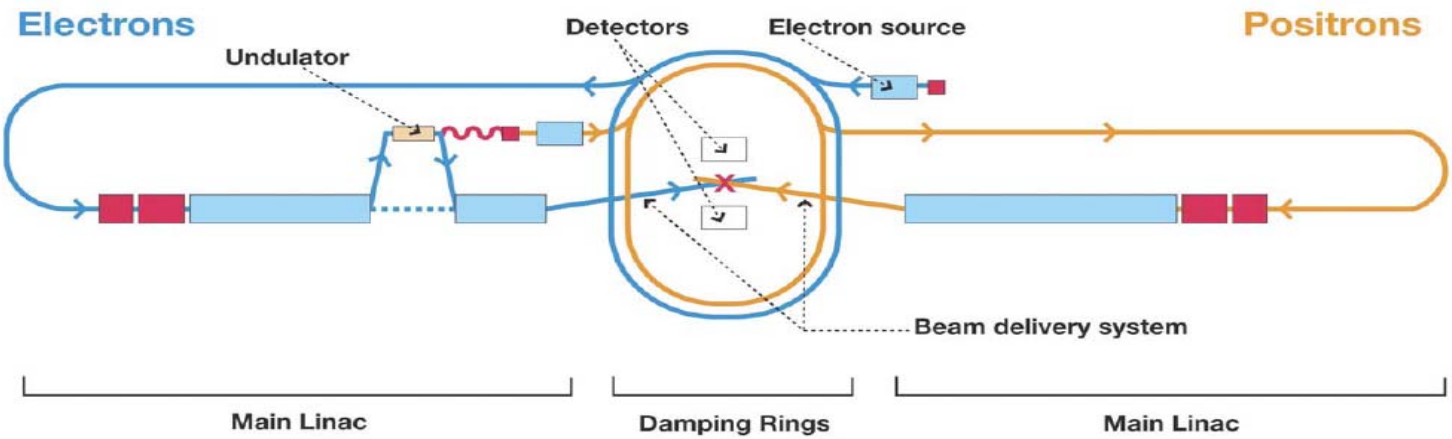


G_{KK} production from extra dimensions ?



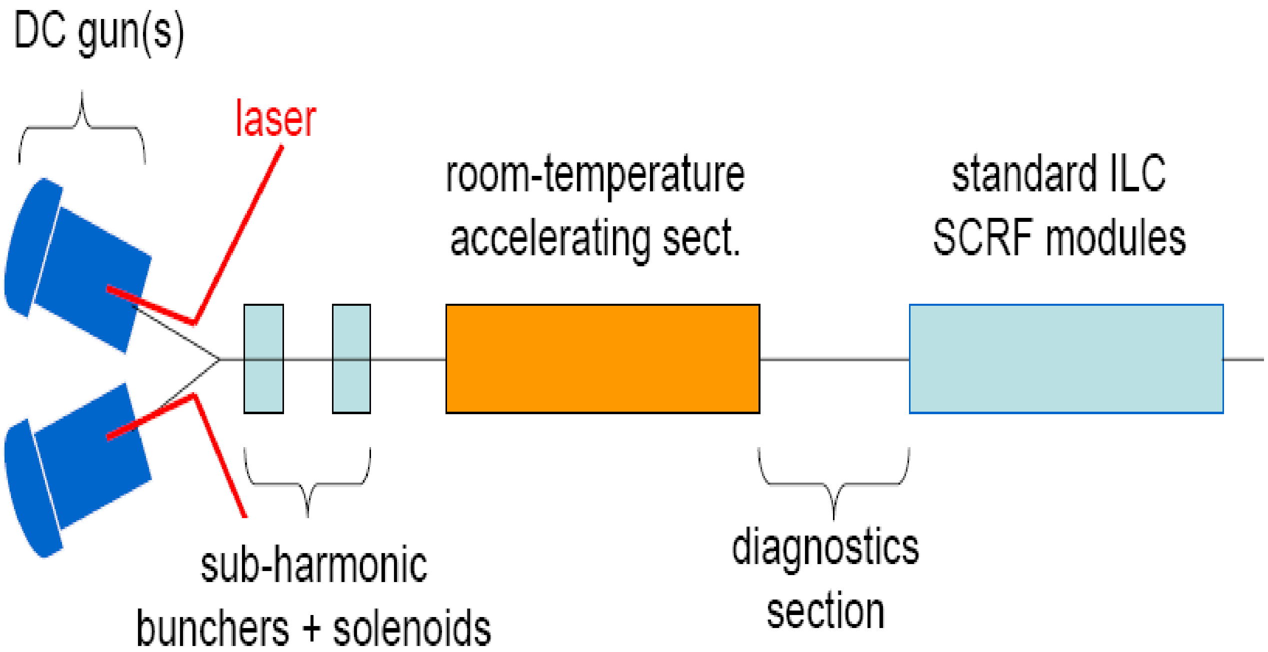


$\sigma(\gamma G_{KK})$ at two CM energies

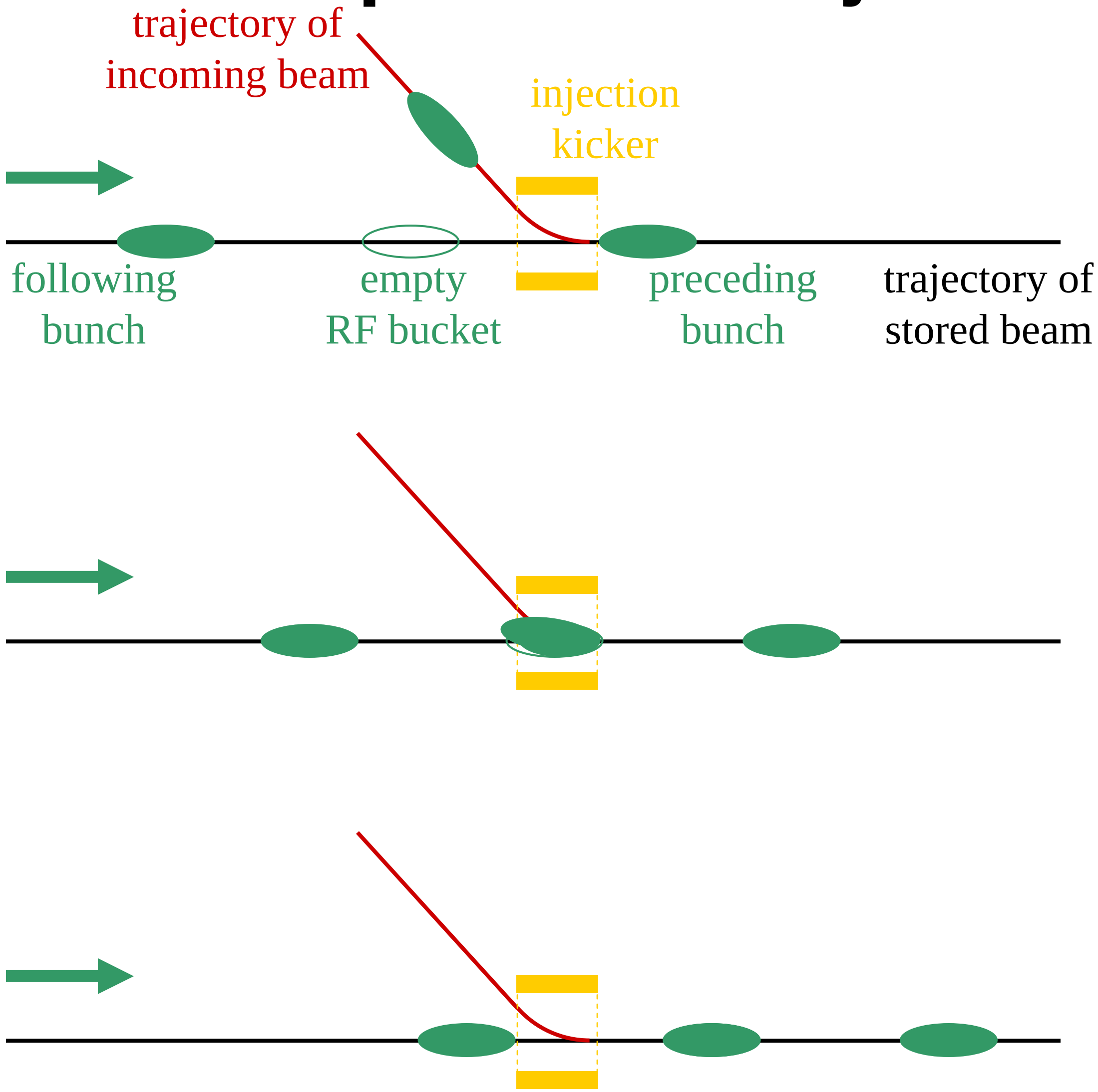

Electrons
Undulator
Detectors
Electron source
Positrons
Beam delivery system
Main Linac
Damping Rings
Main Linac

Baseline Features – Electron Source

- Electron Source –
  - Conventional Source using a DC Titanium-sapphire laser
  - Emits 2-ns pulses that knock out electrons
  - Electric field focuses each bunch into a 250-meter-long 5 GeV linear accelerator



Introduction: Basic Principles of Operation - Injection/Extraction

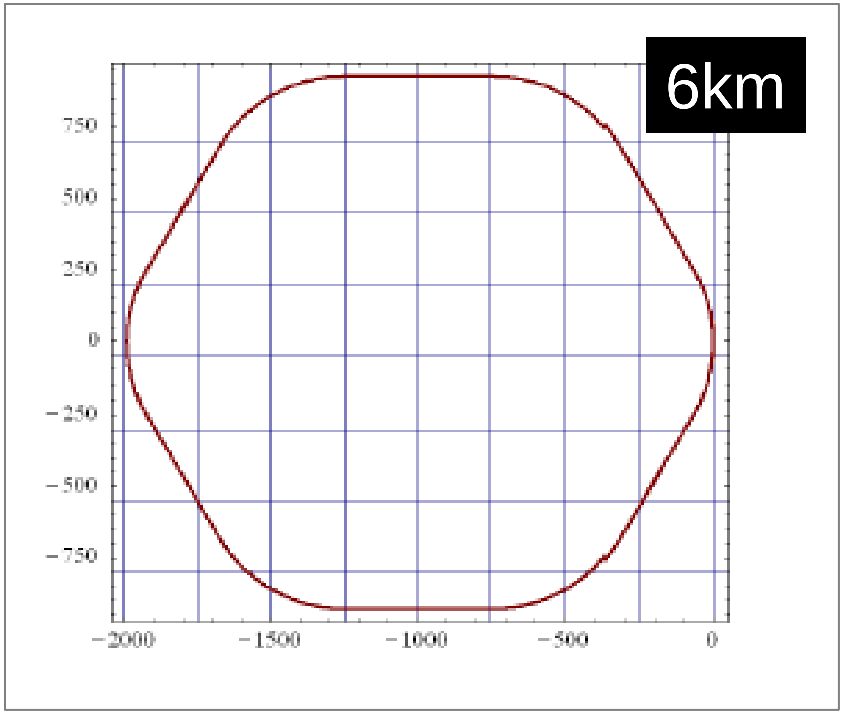


1. Kicker is OFF.
   "Preceding" bunch exits kicker electrodes.
   Kicker starts to turn ON.

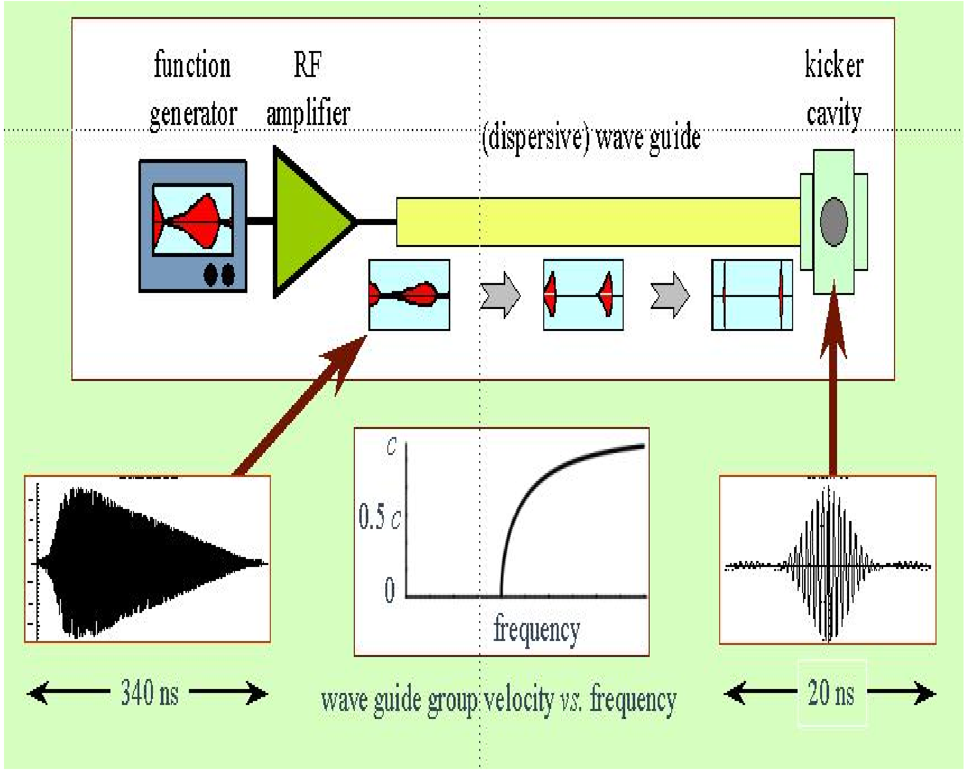
2. Kicker is ON.
   "Incoming" bunch is deflected by kicker.
   Kicker starts to turn OFF.

3. Kicker is OFF by the time the following bunch reaches the kicker.

6 Km Damping Ring

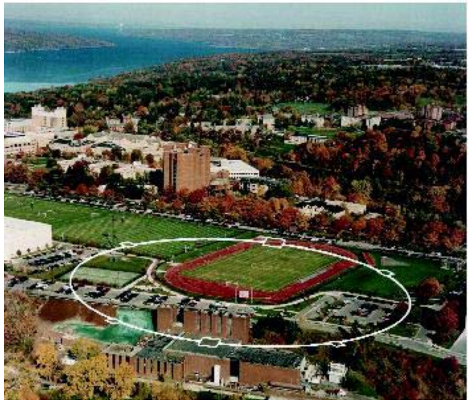


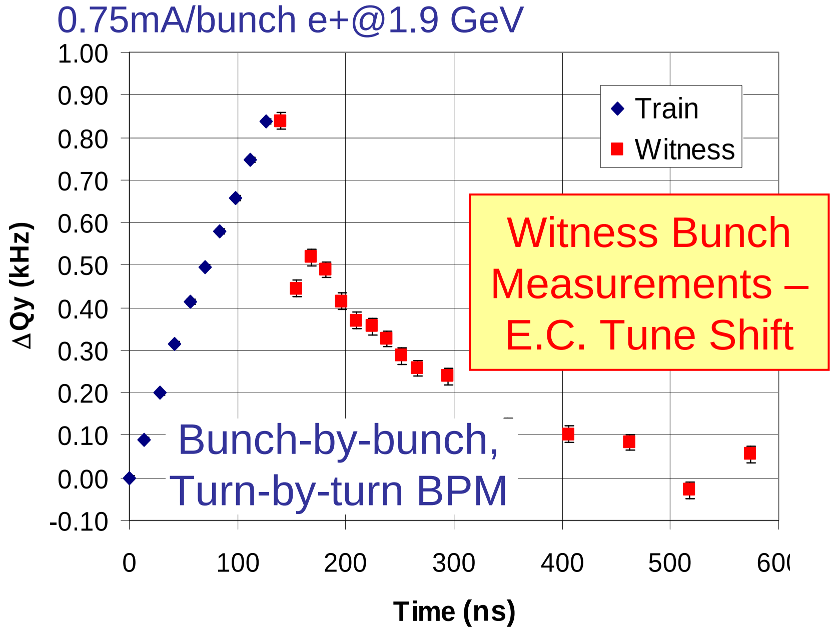
Requires Fast Kicker 5 nsec rise and 30 nsec fall time



The damping rings have more accelerator physics than the rest of the collider

CesrTA @ Cornell - Program





Baseline Lattice

Parameter	Value
No. of Wigglers	12
Wiggler Field	2.1 T
Beam Energy	2.0 GeV*
$\Delta E/E$	8.6×10^{-4}
ε_v (geo) target	<20 pm
ε_h (geo)	2.3 nm
Damping Time	47 ms
Bunch Spacing	4 ns
Bunch Length	9 mm

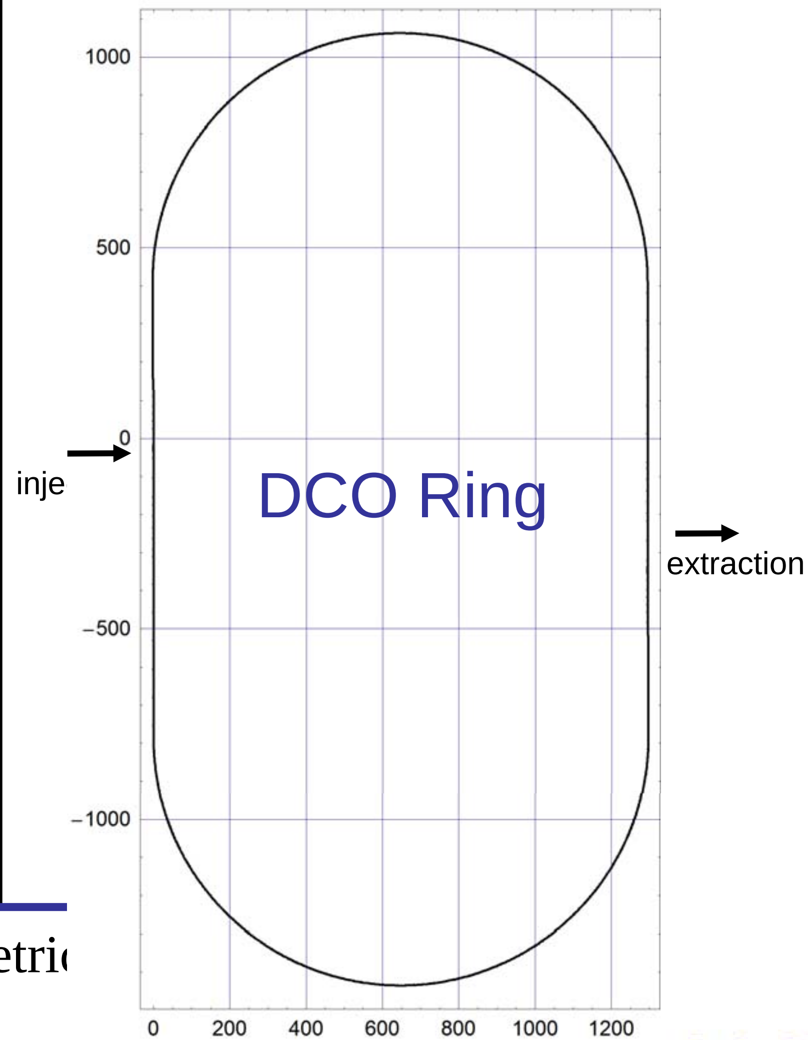
*CESR operating range is 1.5-5.5 GeV

The ILC Damping Rings

Beam energy	5 GeV
Circumference	6476.44 m
RF frequency	650 MHz
Harmonic number	14042
Injected (normalised) positron emittance – $\gamma\varepsilon_{x,y}$	0.01 m
Extracted (normalised) emittance $\gamma\varepsilon_x \times \gamma\varepsilon_y$	8 μm $\times$ 20 nm
Extracted energy spread	<0.15%
Average current	400 mA
Maximum particles per bunch	2×10^{10}
Bunch length (rms)	6 mm
Minimum bunch separation	3.08 ns

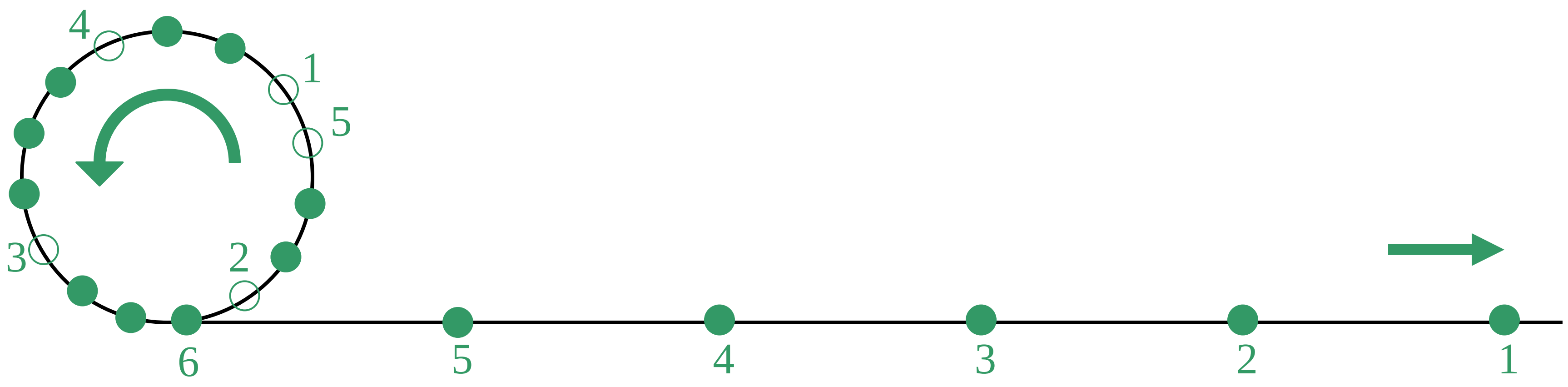
2 pm-rad geometric emittance

Present Baseline Design



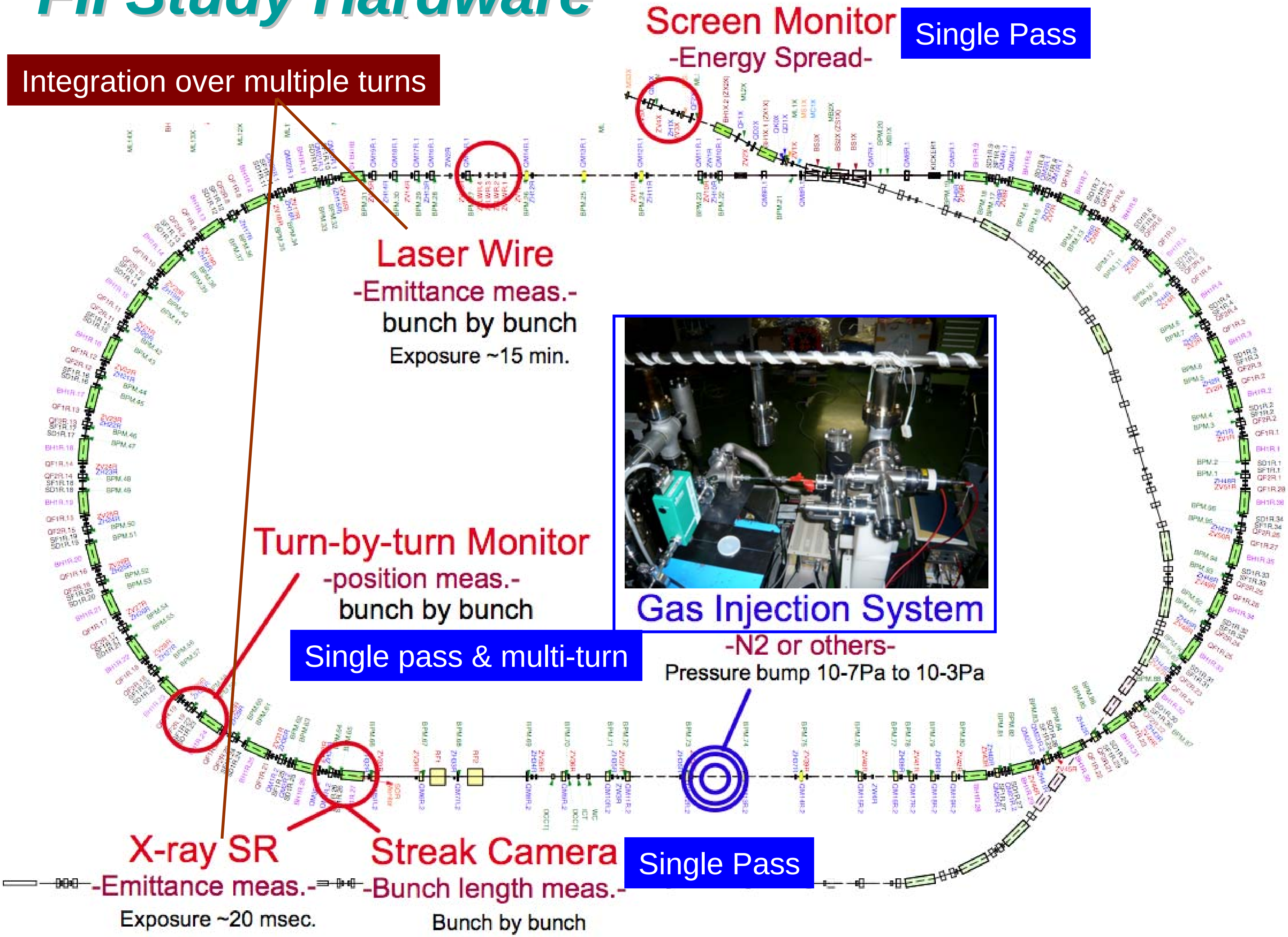
Train (De)compression

- *h* stored bunches, bunch separation Δt.
- extract every *n*th bunch, where *n* is *not* a factor of *h*, then we extract a continuous train of *h* bunches, with bunch spacing $n \times \Delta t$.



- An added complication is that we want to have regular gaps in the fill in the damping ring, for ion clearing.

FII Study Hardware



ATF / ATF2 R&D Program and Goals

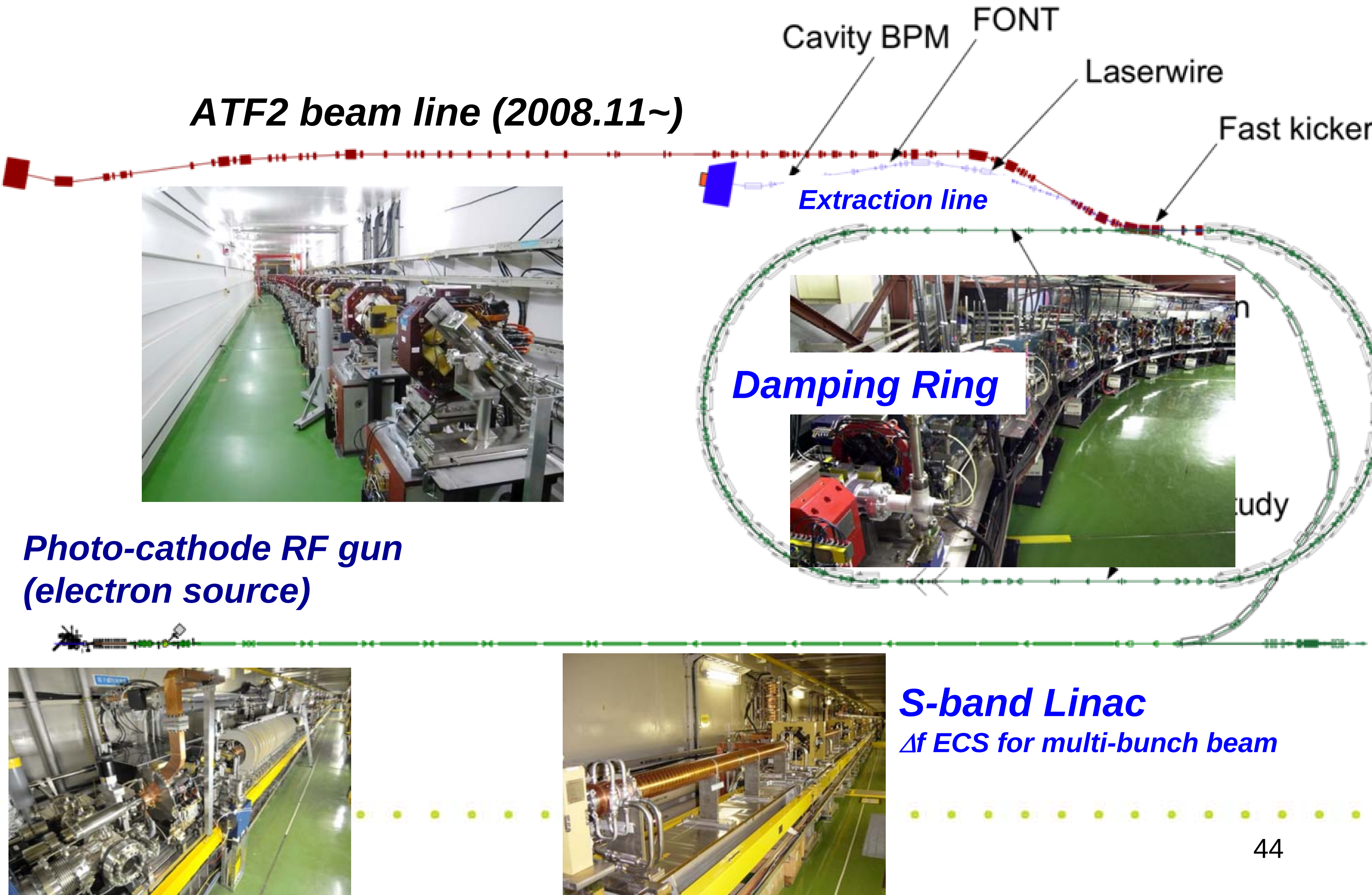
- Beam delivery system studies
  - Demonstrate ~ 50 nm beam spot by 2010
  - Stabilize final focus by 2012

- ATF2 Beamline
  - Scaled down ILC beam delivery system

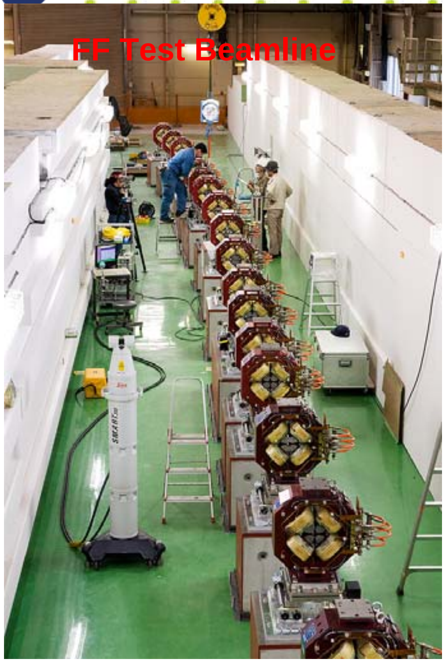
ATF2 Beam Line vacuum pipe connected in October

Commissioning this fall

Accelerator Test Facility

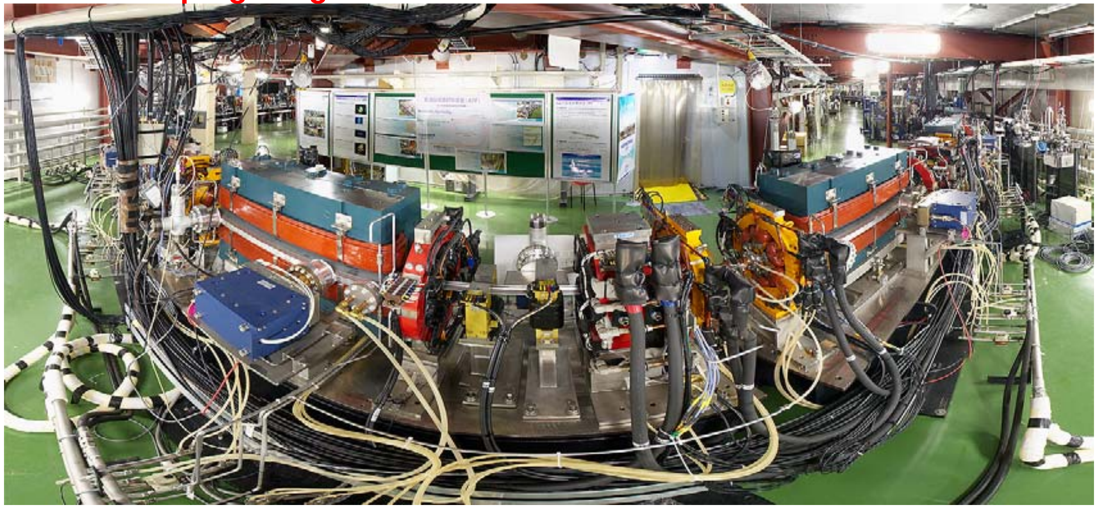


ATF and ATF2 @KEK

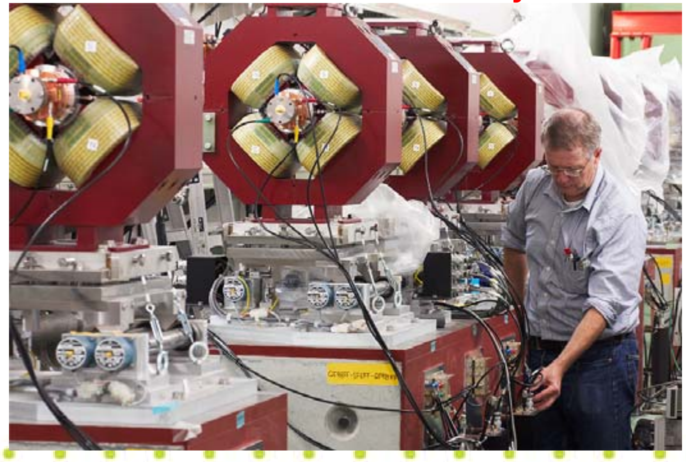


FF Test Beamline

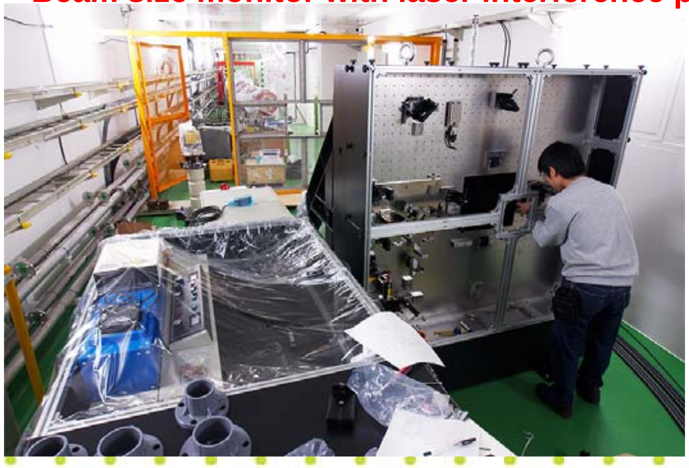
ATF Damping Ring



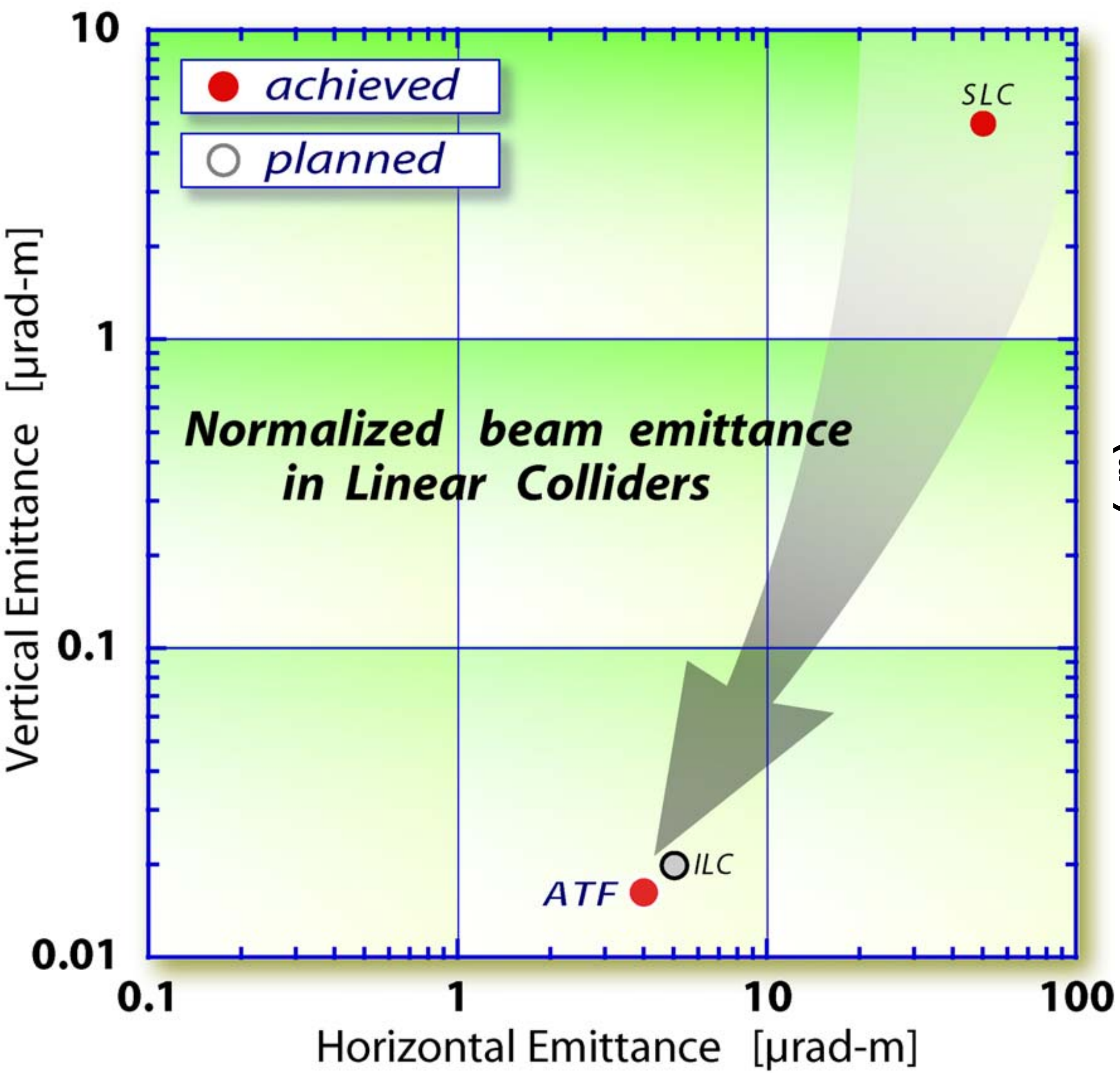
Check-out electronics for cavity BPMs



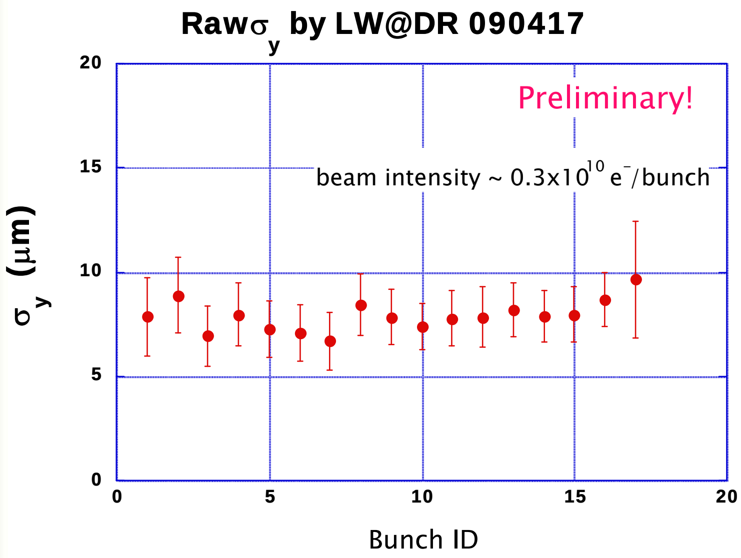
Beam size monitor with laser interference pattern



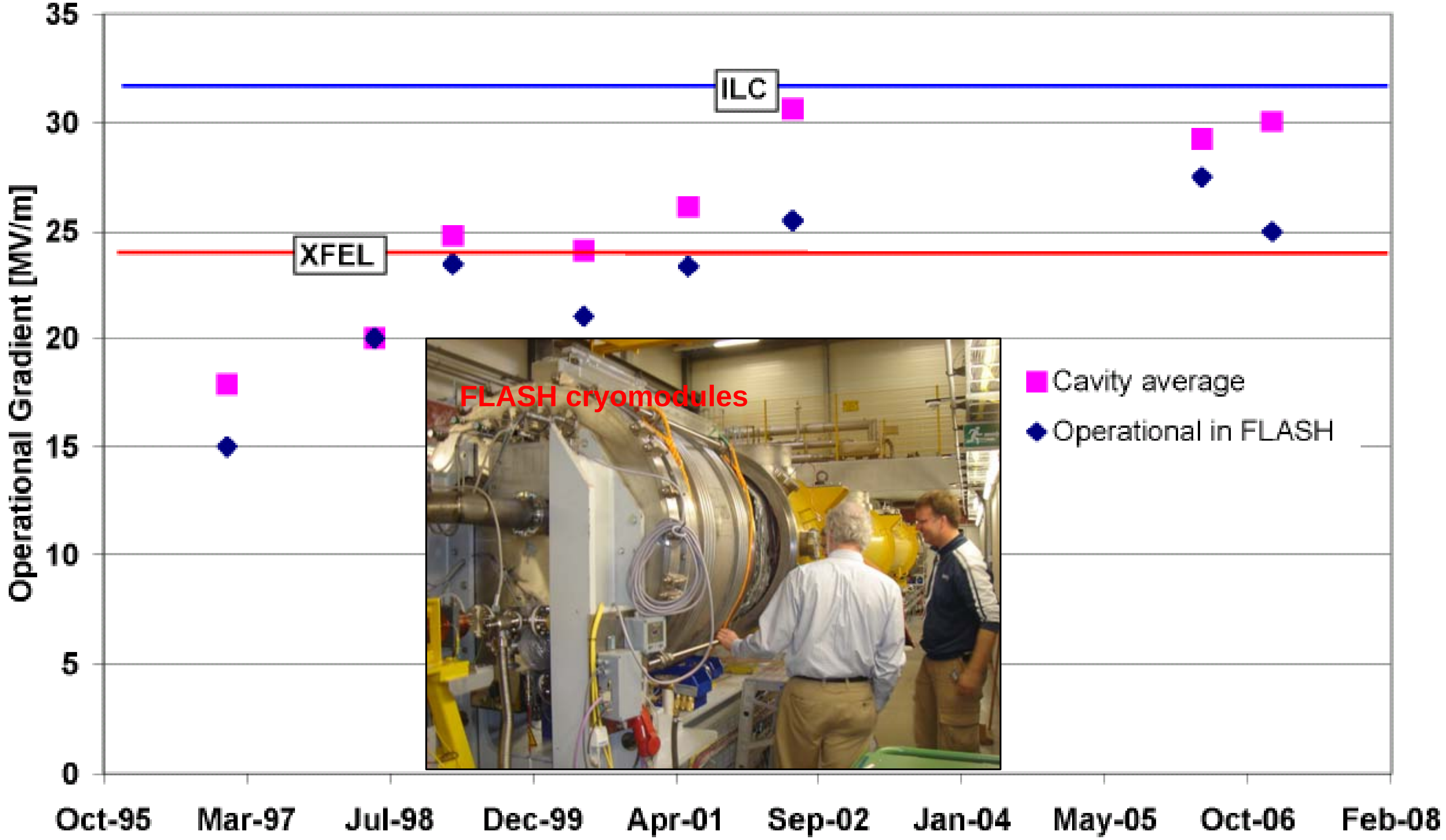
Nanobeam



2009, April



DESY Activities



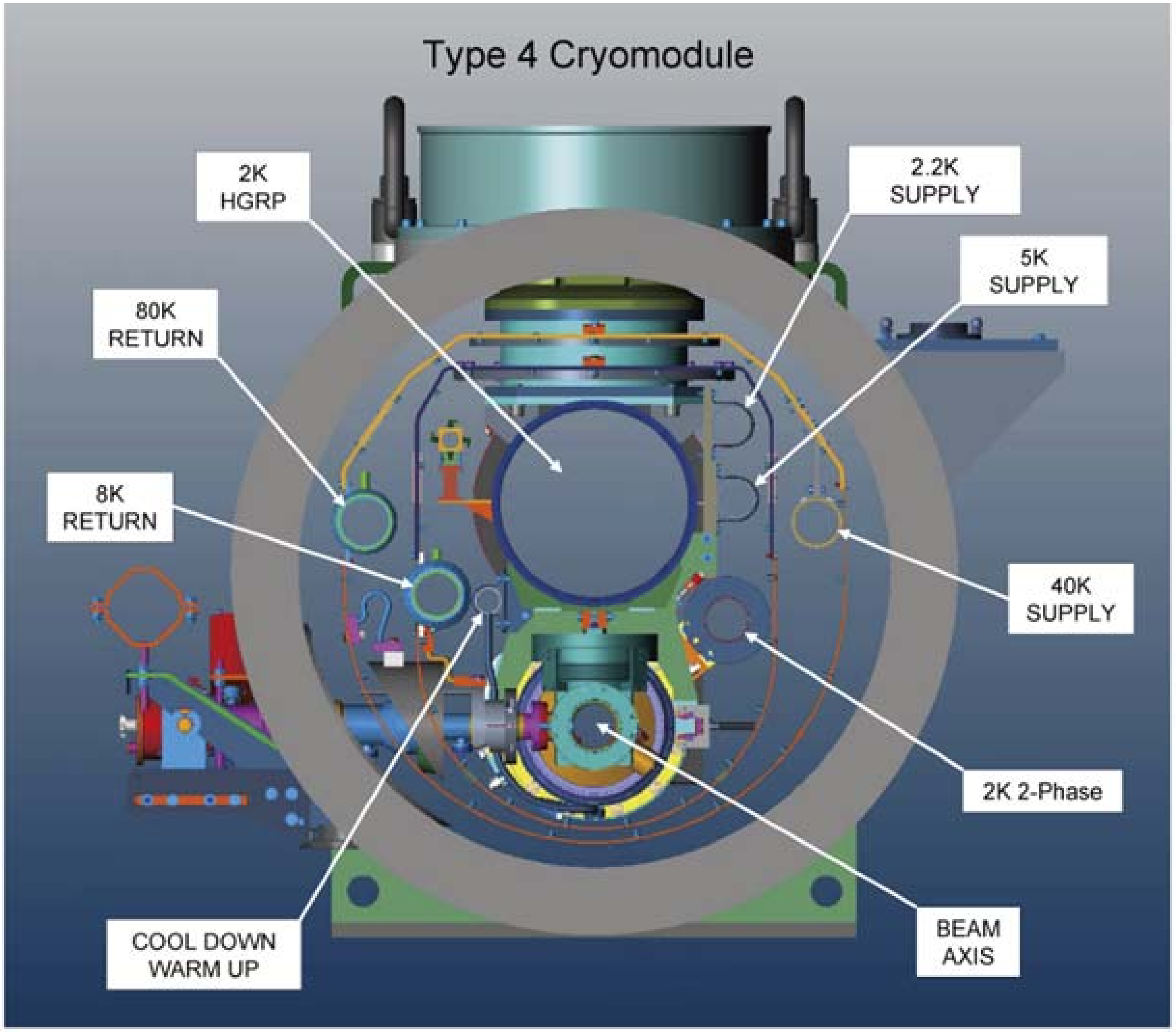
Experiences being gained from FLASH and EuroXFEL construction are critical inputs for ILC:

SCRF tech; HW implementation in tunnels; multinat'l mgmnt

ILC High-Gradient Cavity R&D

- A certain number of 9-cell cavities started satisfying ILC performance spec in vertical testing.
- Basic infrastructure has been built up and put in place for cavity manufacturing and testing, at US and Asian labs, besides Europeans.
- "Reference procedure" for cavity fab. and tests has been formulated:
  - For repeated studies.
  - For identifying issues and varying practices across the world
- New (or renewed) diagnostic techniques and studies are put into lab test cycles.

Cross section of a cryomodule

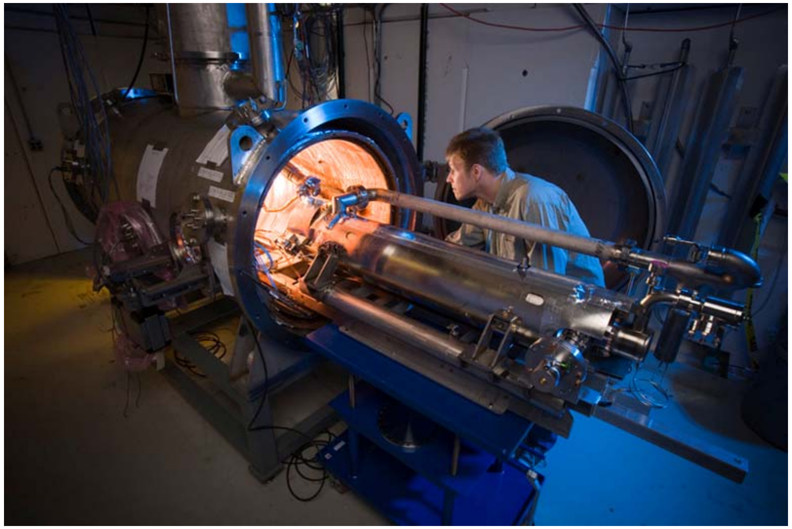


FNAL-ANL

New electro-polishing facility built at ANL

ILCTA-NML @ FNAL

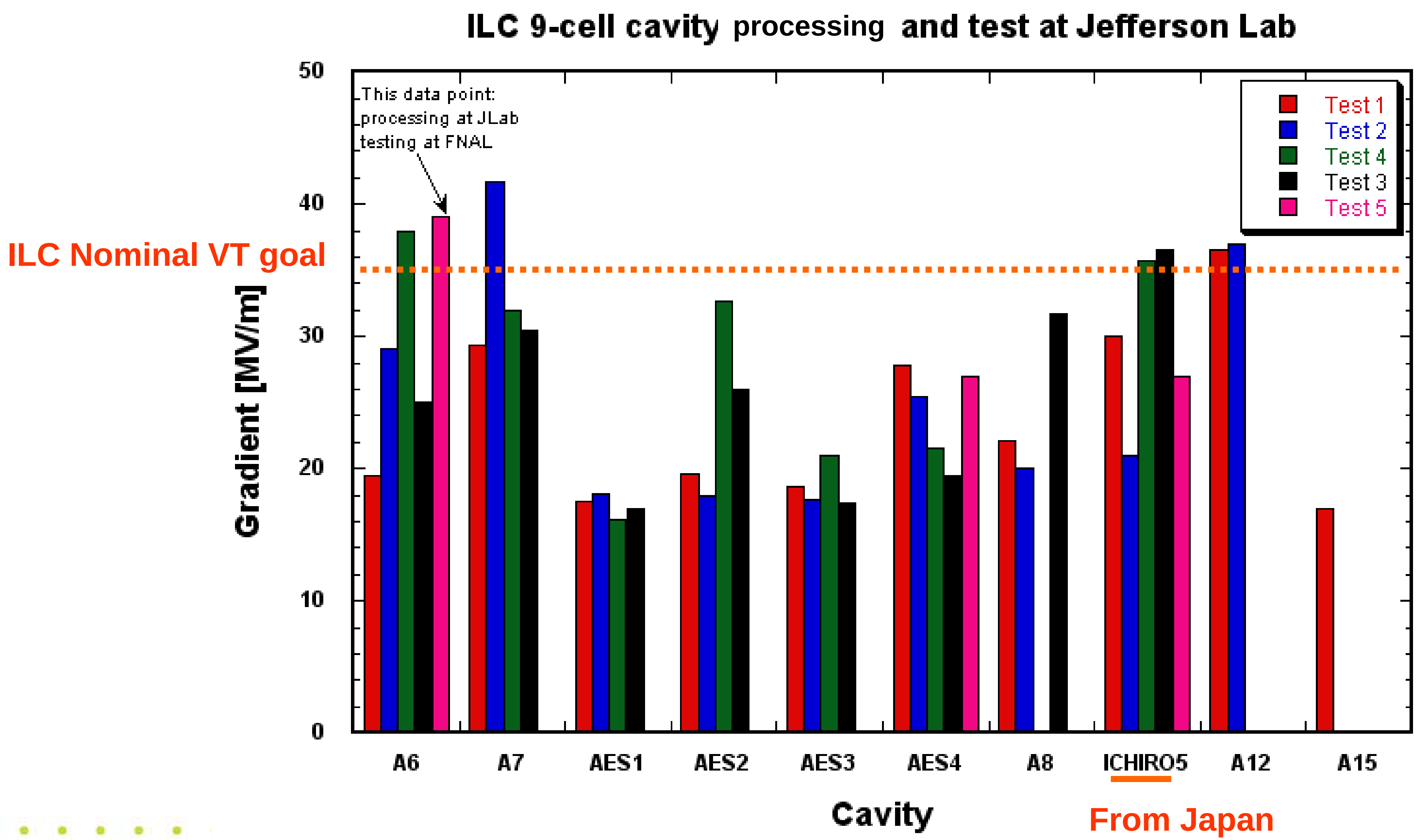
Horizontal test stand for cavities



9-cell cavity near vertical test stand

Cryomodule built at FNAL with DESY cooperation

Data from Jefferson Lab
US Cavity Test Program (FNAL-Cornell-Jlab)



R&D on Superconducting RF System

Calender Year		2008	2009	2010	2011	2012
Technical Design	**TDP1**				**TDP-II**	
S0: Cavity Gradient (MV/m)	**30**	**35** (> 50%)				**35** (>90%)
KEK-STF-0.5a: 1 Tesla-like/LL						
KEK-STF1: 4 cavities						
S1-Global (AS-US-EU) 1 CM (4+2+2 cavities)			**CM ($4_{AS}+2_{US}+2_{EU}$)** <31.5 MV/m>			
S1(2) -ILC-NML-Fermilab CM1- 4 with beam				**CM2**	**CM3** **CM4**	
S2:STF2/KEK: 1 RF-unit with beam			**Fabrication in industries**		**STF2 (3 CMs)** Assemble & test	

TD 1 Phase Resources – SCRF Facilities

		FTE-Years						total M&S						
		Cavities	Cryomodule	HLRF	Cryogenics	ML Integ.	**total FTE-Years**	Cavities	Cryomodule	HLRF	Cryogenics	ML Integ.	**total M&S**	
Americas	**Canada**	18					**18**	1050					**1050**	k$
	USA	73	24	68	5	14	**183**	9169	3960	5909	134	362	**19535**	k$
Asia	**China**	12	8	8	4	1	**33**	10000	10000	10000	5000	1000	**36000**	kRMB
	India	24	12				**36**	1560	900				**2460**	k$
	Japan	45	6	11	4	5	**72**	2225	462	452	180	1119	**4438**	M JY
	Korea	13		5			**18**	1500		245			**1745**	M KRW
Europe	**EU (CERN)**				1	4	**5**					129	**129**	kEUR
	France	94					**94**	10058					**10058**	kEUR
	Germany	51	10	7	7	9	**83**	1705	361			23.5	**2089**	kEUR
	Italy	38	8		1	1	**48**	1182	160				**1342**	kEUR
	Poland													kEUR
	Russia	2	20				**22**	20					**20**	k$
	Spain		3				**3**		9				**9**	kEUR
	Sweden													kEUR
	Switzerland													kEUR
	UK													kGBP
		370	**90**	**99**	**21**	**34**	**615**							

Global Efforts – Now what?

Technical Design Phase 1 -- till mid-2010

- Demo. "Technical Feasibility"
- High-priority, risk-mitigating R&D
- Value engineering (cost vs performance analysis) in selected areas.
- Re-baseline of the design as found appropriate and necessary.

Detector Design Phase 1 -- till mid-2010

- Validation of detector concepts, to examine as integral parts of accelerator TDP.
- Focus R&D on critical elements; MDI design details.
- Update of physics performance
- Start-up of technical design work

Technical Design Phase 2 -- till 2012

- Demo. "Technical Credibility"
- Refine the design
- Continued R&D
- Cost roll-up
- Development of a project implementation plan.

Detector Design Phase 2 -- till 2012

- Refine the design
- Continued R&D
- Cost roll-up.
- Development of a project implementation plan.
- Actions in response to LHC results

Intention is to produce a report which can be handed to governments for evaluation in ~2012.