The International Linear Collider (ILC) is a proposal to construct an electron-positron collider in the energy range of 500 -> 1000 Gev/c.

- **Quick design overview**
- **Global organisation**
- **R&D plan & priorities**
  - SRF technology development
  - Cryomodule operation with beam
  - Damping Ring R&D
  - Positron production
- **Updating the baseline**

Mike Harrison

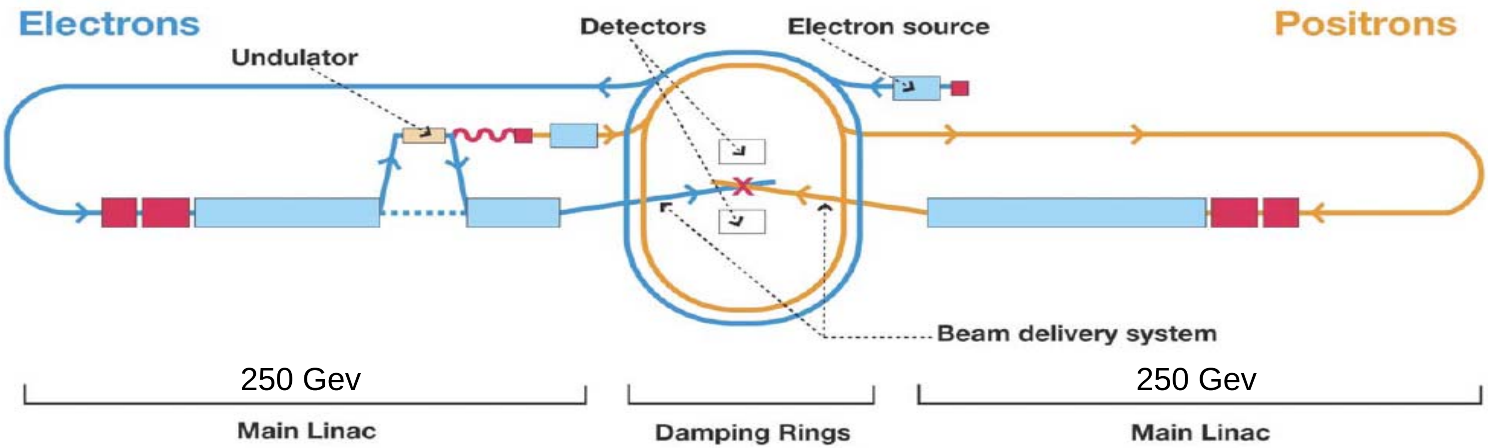
ILC/Global Design Effort - Regional Director Americas Region

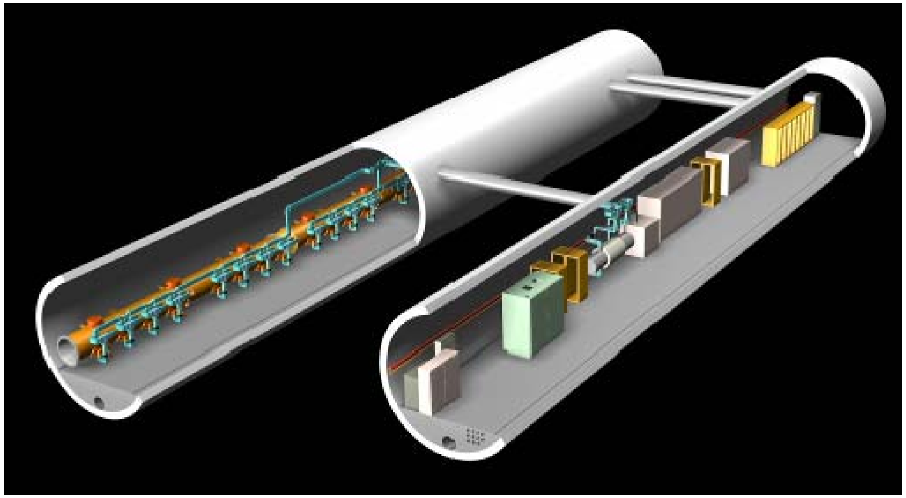
ILC Parameters - physics driven input

- Luminosity → $\int L dt$ = 500 fb^{-1} in 4 years (~2*10^{34})
- E_{cm} adjustable from 200 – 500 GeV
- Ability to scan between 200 and 500 GeV
- Energy stability and precision below 0.1%
- Electron polarization of at least 80%

- The machine must be upgradeable to 1 TeV
- Positron Polarisation desireable as an upgrade

ILC Baseline Design





e+ e- Linear Collider

Energy	250 Gev x 250 Gev
Length	11 + 11 km
# of RF units	560
# of cryomodules	1680
# of 9-cell cavities	14560

2 Detectors push-pull

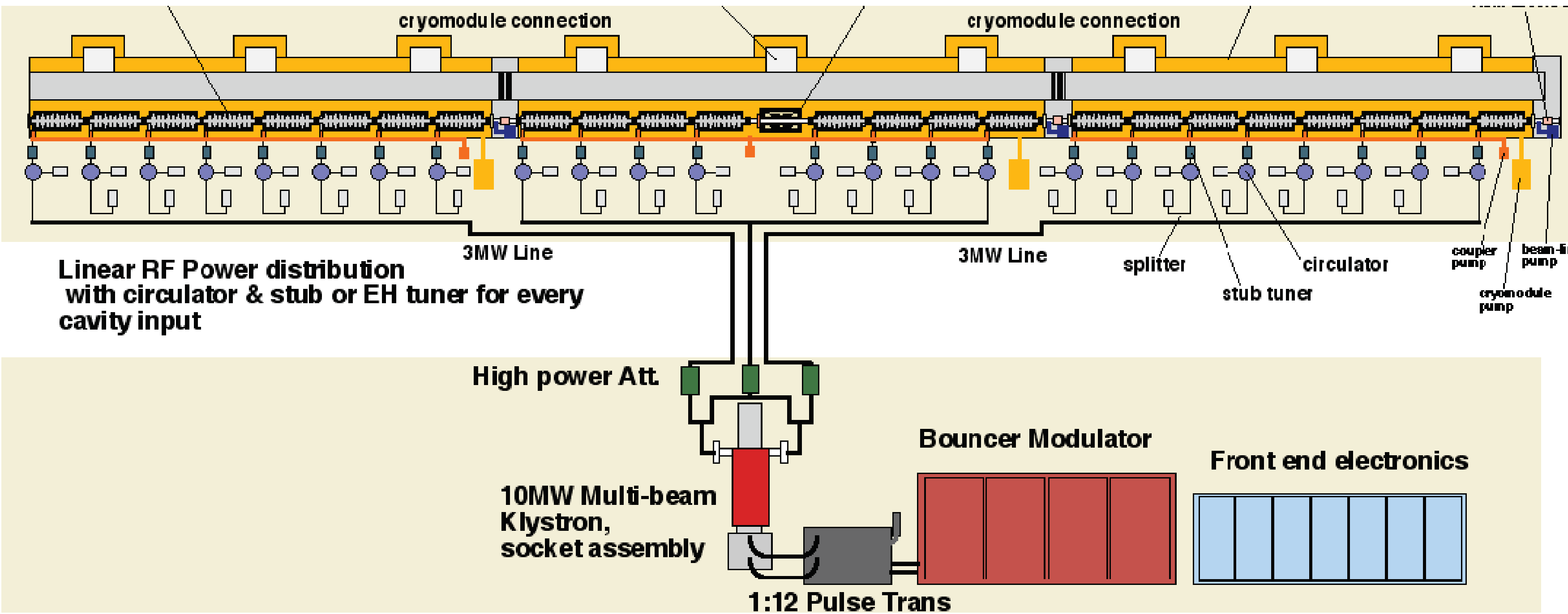
2e34 peak luminosity

5 Hz rep rate, 1000 -> 6000 bunches per cycle

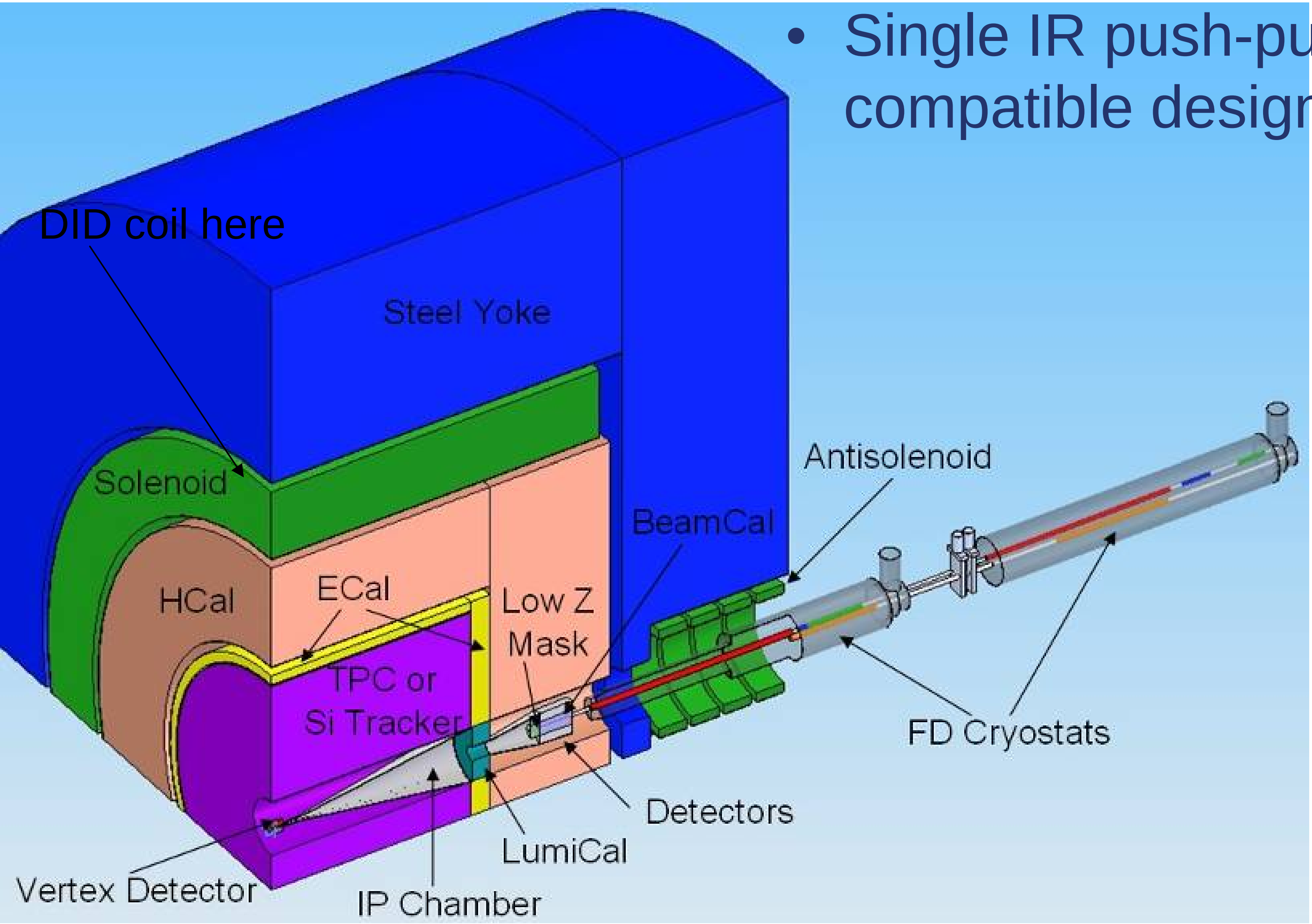
IP spots sizes: σ_x 350 – 620 nm; σ_y 3.5 – 9.0 nm

RF Unit: The Main Linac Building Block

ILC RF Unit: 3 CM, klystron, modulator, LLRF

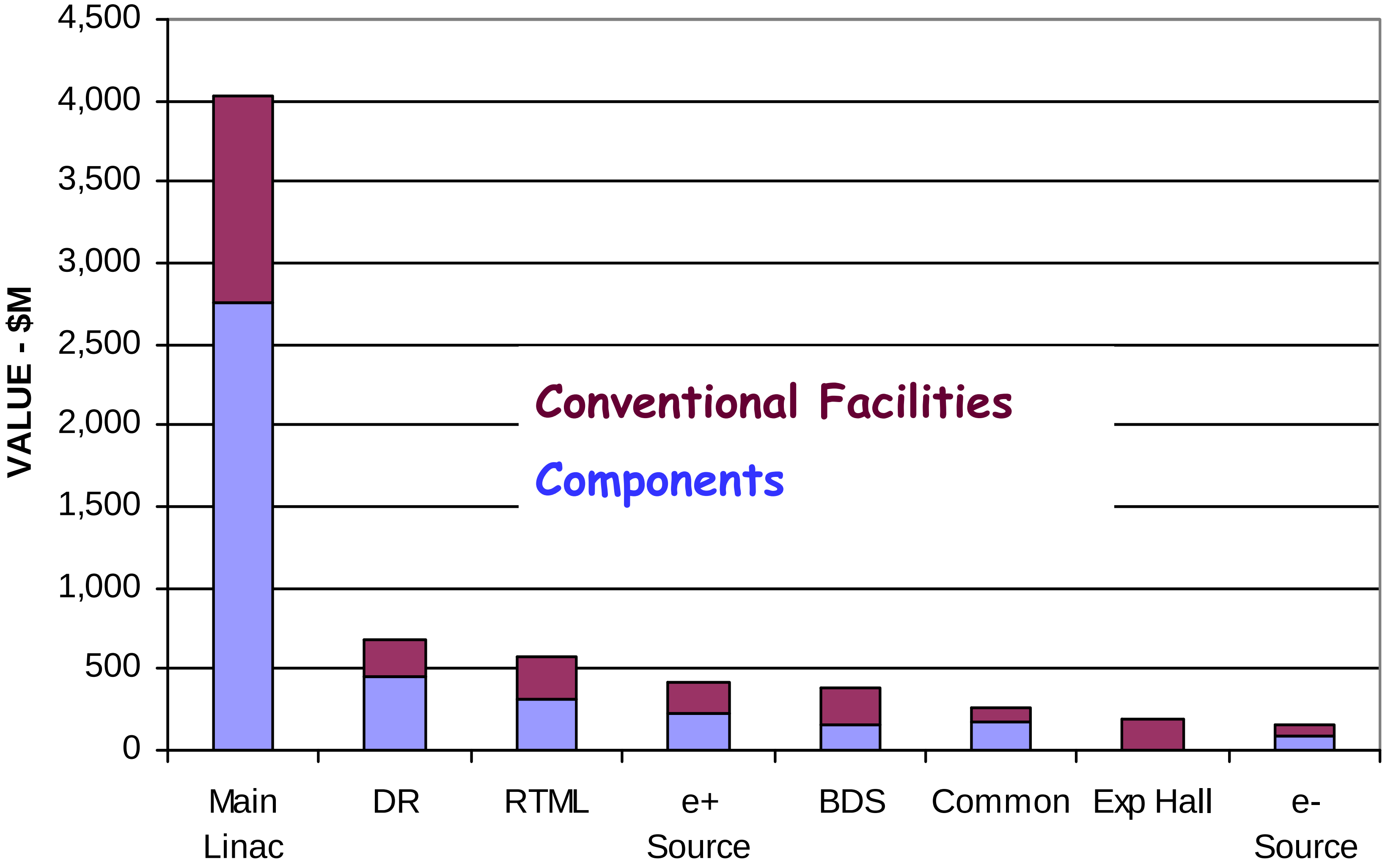


Machine-Detector Interface



- Single IR push-pull compatible design

ILC Value - by Area Systems

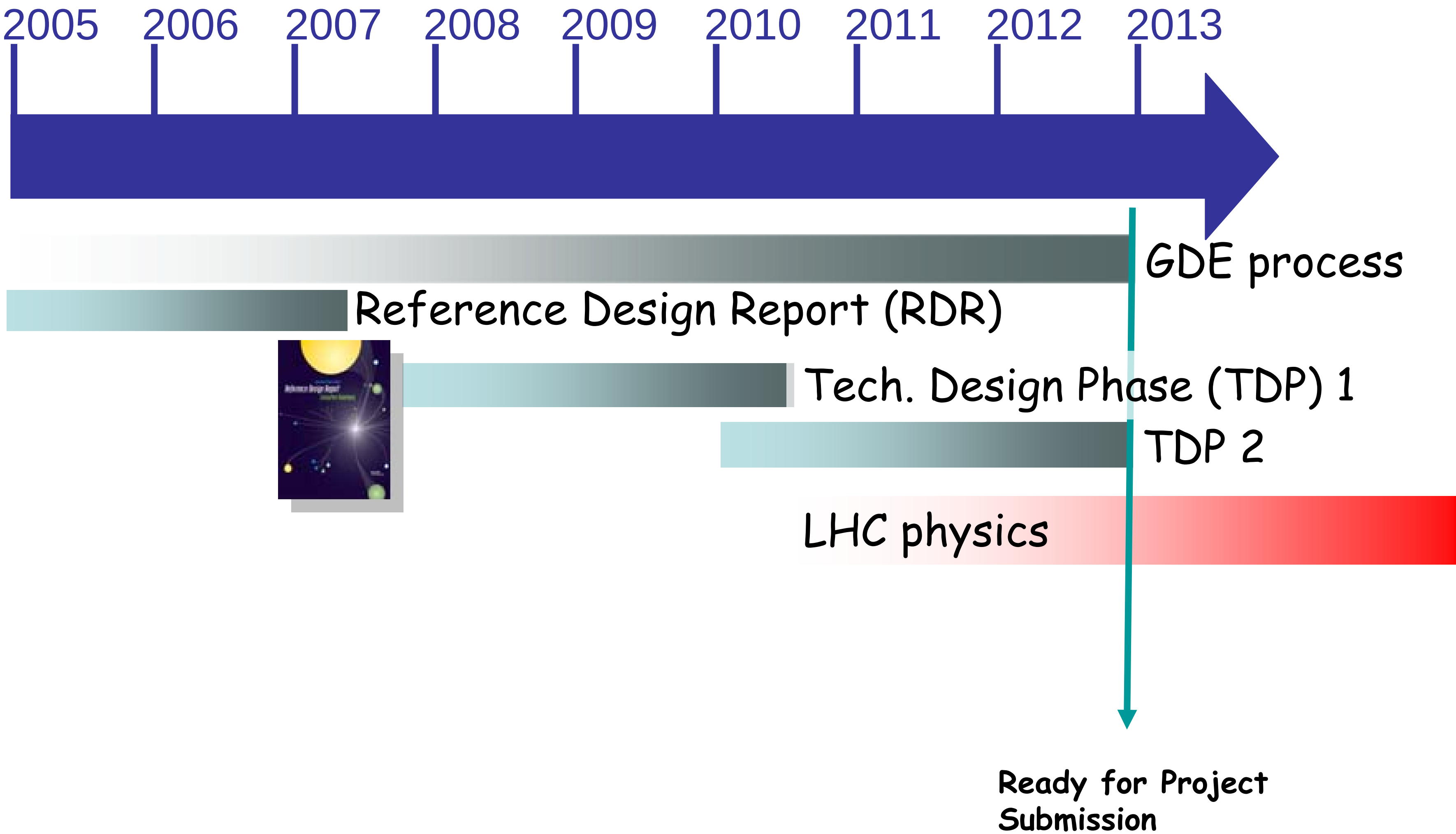


Global R&D Plan Priorities

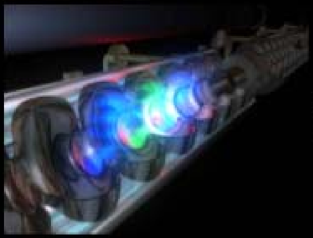
Risk Mitigating R&D	• SCRF Technology • Damping ring electron cloud • Positron production • Beam Collisions
Beam Test Facilities	• ATF / ATF 2 (KEK) • CesrTA (Cornell) • TTF/FLASH (DESY) • …
Machine Design / Cost	• CFS / Value Engineering • Accelerator Design & Integration

US program $35M/yr (globally ~$100M)

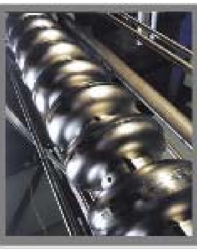
GDE ILC Timeline



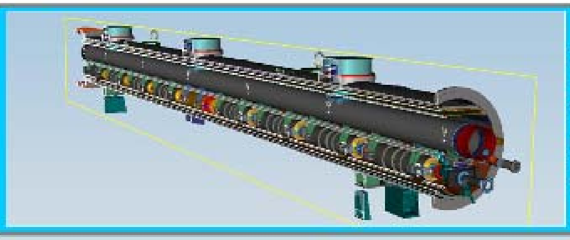
Superconducting RF Technology



Critical R&D



35 MV/m Gradient Yield in 9-cell cavities



31.5 MV/m average gradient in a cryomodule

Linac "String Test"

The ILC R&D Program – Cavity Gradient

- The baseline gradient is the (relatively) aggressive value of 35 MV/m for individual cavities in vertical test with an average of 31.5 MV/m over a cryomodule. With very similar cavities/cryomodules the XFEL has adopted 24 MV/m. We do not have any cryomodule data yet, the first one is scheduled for FY10 at Fermilab. We are starting however to amass meaningful data on single 9-cell cavities in vertical test systems.

- Typically we see two main causes of gradient limitations:

  1. Gradient limits arising from defects (bumps, pits, contamination near the e-beam welding zone i.e. fabrication defect) which cause a quench from local temperature rise. (However we also see defects in cavities that perform OK, and no defects in some cavities that don't)

  2. Gradients limited by field emission heating related to surface processing issues.

From a project perspective this reduces to the issues of yield v's gradient. We already have many cavities that make the performance spec

Global Plan for SCRF R&D

Year	07	2008	2009	2010	2011	2012
Phase	TDP-1			TDP-2		
Cavity Gradient in v. test to reach 35 MV/m	→ Yield 50%			→ Yield 90%		
Cavity-string to reach 31.5 MV/m, with one-cryomodule		Global effort for string assembly and test (DESY, FNAL, INFN, KEK)				
System Test with beam acceleration		FLASH (DESY) , NML (FNAL) STF2 (KEK, extend beyond 2012)				
Preparation for Industrialization			Mass-Production Technology R&D			

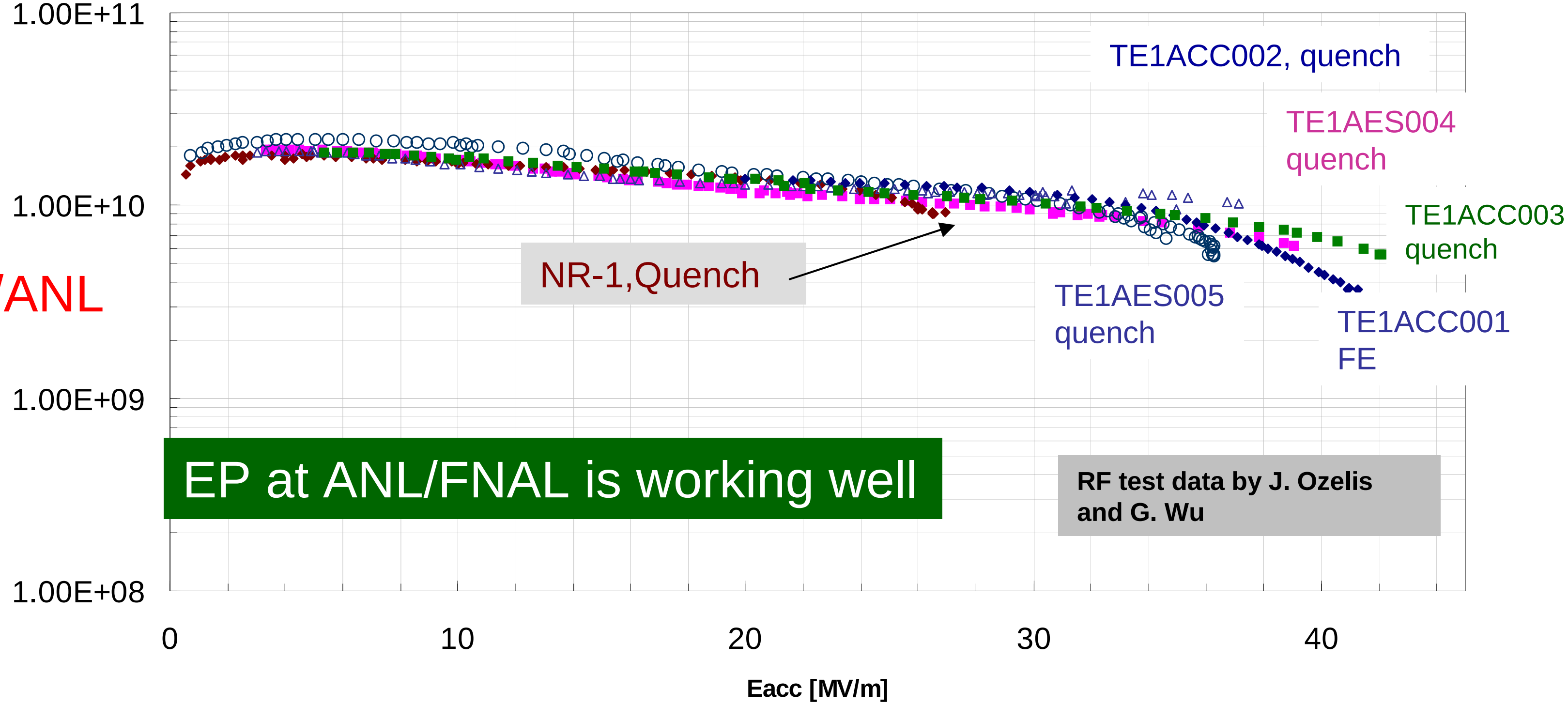
Global SCRF Technology

Existing SRF

Emerging SRF

> 40 MV/m in 1-cells @ ANL/FNAL

FNAL/ANL



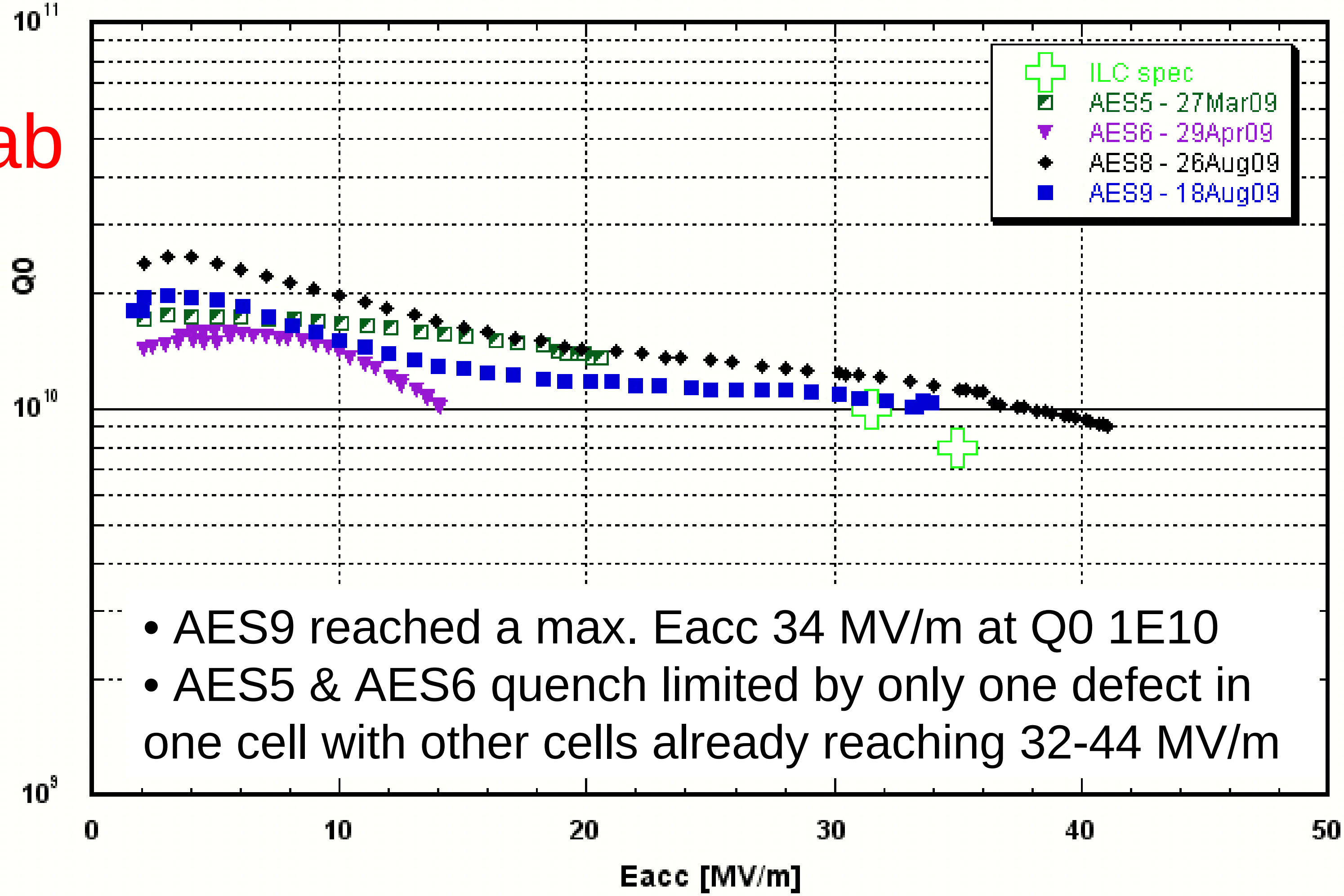
	BCP*	EP	Ethanol	Eacc [MV/m]	Notes
NR-1	150	93		26.5	No distinguishing feature
TE1AES004	107	65		39.2	Equator large pit present
TE1AES005	104	100	Yes	36.3	Oxidation by HPR water
TE1ACC001		99	Yes	41.3	FE appeared due to vacuum handling
TE1ACC002		112		37.1	No distinguishing feature
TE1ACC003		119		42.1	Pits present

* BCP done at Cornell University

Recent US cavities results

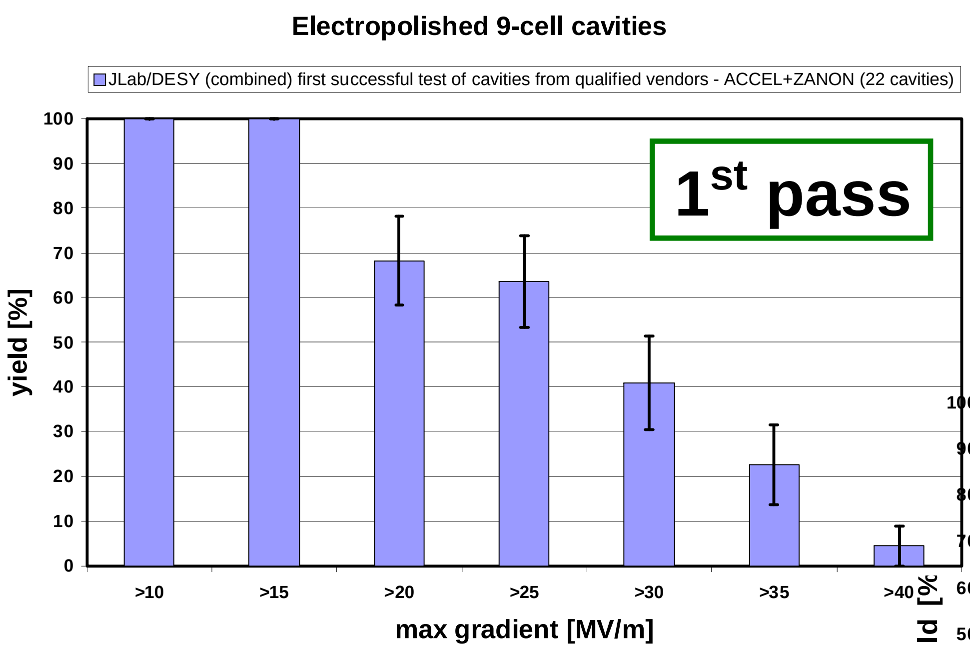
4 out of 6 second production 9-cell cavities by AES
First RF test following first light EP at JLab

JLab

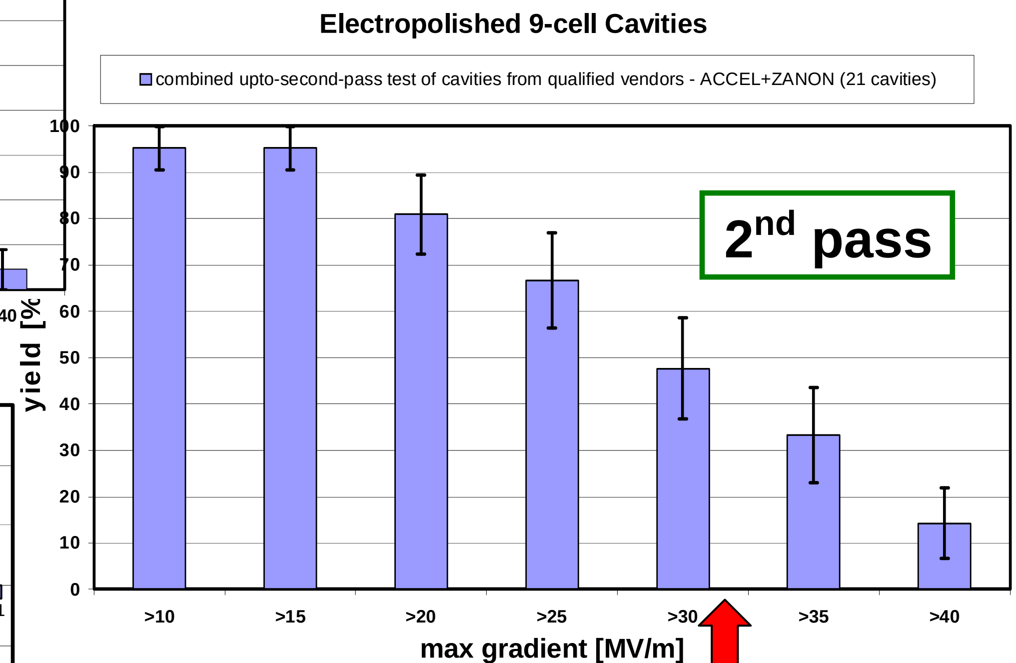


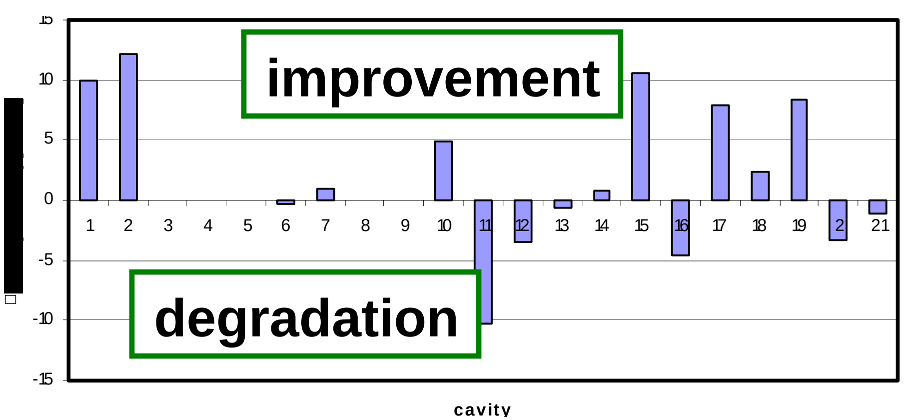
- AES9 reached a max. Eacc 34 MV/m at Q0 1E10
- AES5 & AES6 quench limited by only one defect in one cell with other cells already reaching 32-44 MV/m

New Production Yield after 1st and 2nd Pass (RF) Test



Yield at 35 MV/m:
22 % at 1st pass
33 % at up to 2nd pass

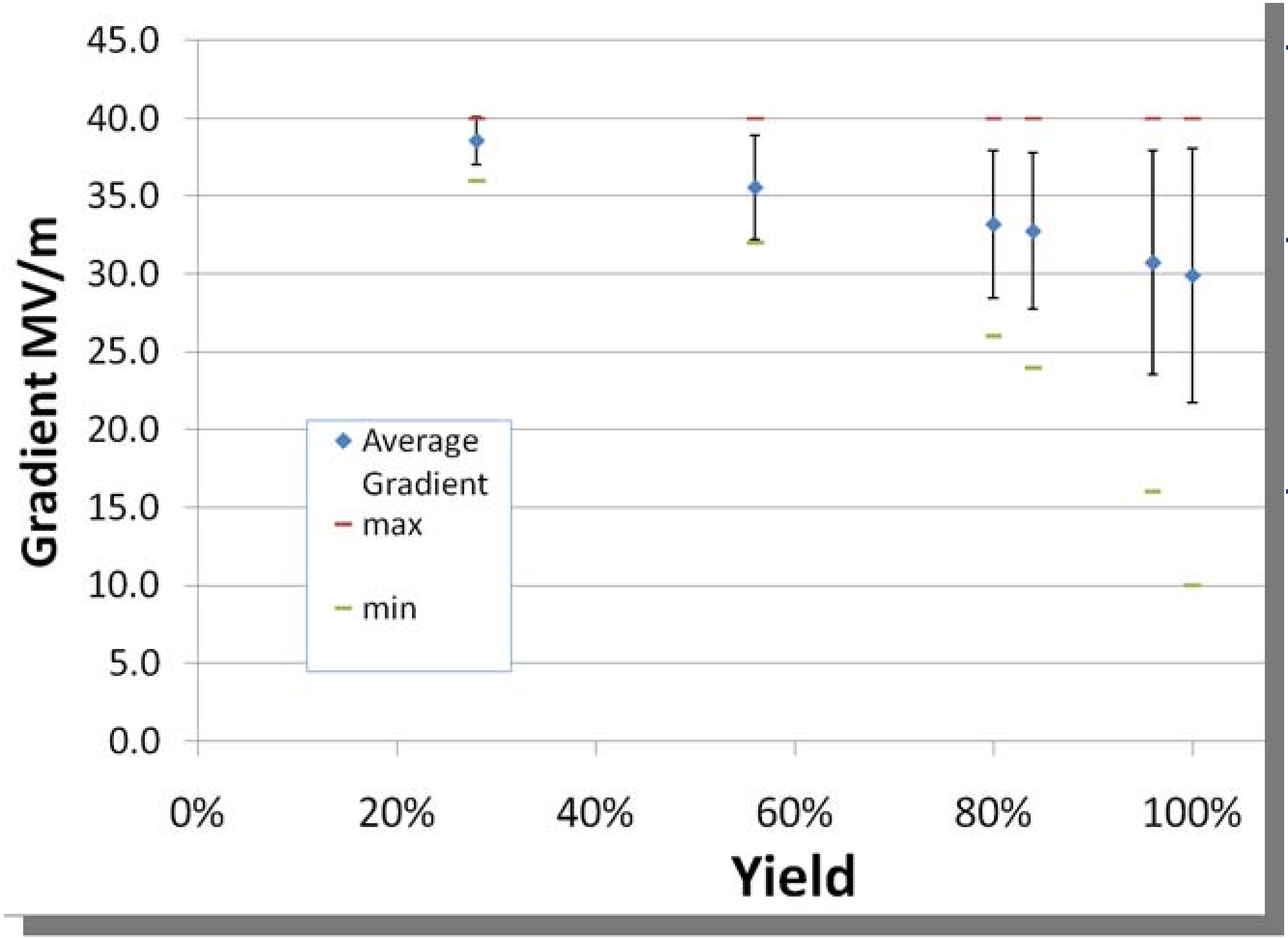




ILC Operation at <31.5 MV/>
Yield reaching ~ 40 %

Reported by C. Ginsburg and GDB team

Alternate Yield Definition: Study



- Allowing for gradient spread
- Additional RF power needed to compensate
- 20% spread seems reasonable

Standard Process Selected for Further Yield Plot

	Standard Cavity Recipe
Fabrication	Nb-sheet (Fine Grain)
	Component preparation
	Cavity assembly w/ EBW (w/ experienced venders)
Process	1st Electro-polishing (~150um)
	Ultrasonic degreasing with detergent, or ethanol rinse
	High-pressure pure-water rinsing
	Hydrogen degassing at > 600 C
	Field flatness tuning
	2nd Electro-polishing (~20um)
	Ultrasonic degreasing or ethanol
	High-pressure pure-water rinsing
	Antenna Assembly
	Baking at 120 C
Cold Test (vert. test)	Performance Test with temperature and mode measurement (1st / 2nd successful RF Test)

US Cavity Inventory and Procurement Plan thru FY11 Q1

Tesla-shape nine-cell cavities		
Description	**No. Cavities**	**Status**
AES 1-4	4	tested
AES 5-10	6	received; testing in progress
AES 11-16	6	due Dec 2009
Accel 6-9	4	tested
Accel 10-17	8	received Mar 2008; testing in progress
Accel 18-29	12	at Accel for installation of Ti rings / due late CY09
Jlab fine-grain 1-2	2	fabrication complete; testing in progress
Niowave-Roark 1-6	6	2 due Jan 2009 / 4 due May-June 2010
Stimulus Procurement	40	order in progress / expect ~12 cavities in Q1 FY11
Total	**88**	
Already Received	24	
Tesla-shape single-cell cavities		
Description	**No. Cavities**	**Status**
AES 1-6	6	tested at Cornell; further testing in progress
Accel 1-6	6	received Dec 2008; testing in progress
Niowave-Roark 1-6	6	tested at Cornell; further testing in progress
PAVAC	6	due Q2 FY10
Total	**24**	
Already Received	18	

Cavity Gradient Study - Summary

- Yield at 35 MV/m (w/ established vendors: **RI, Zanon**)
  - 22 % at 1st pass (statistics 22)
  - 33 % at 2nd pass (statistics 21, as of 2009-07))
    - Average Gradient reaching 30 MV/m
  - DESY Prod-4 data to be added, (10 more statistics)
- New statistics coming (w/ potential vendors)
  - AES: to be counted from #5 (proposed)
  - MHI: to be counted from #5 (proposed)
- Selecting statistics needed for 'Production Yield'
  - to evaluate readiness of industrialization and cost

Note: *Numbers of Cavities for 'gradient research': need to be separately counted.*

Cavity Research: Status and Prospects

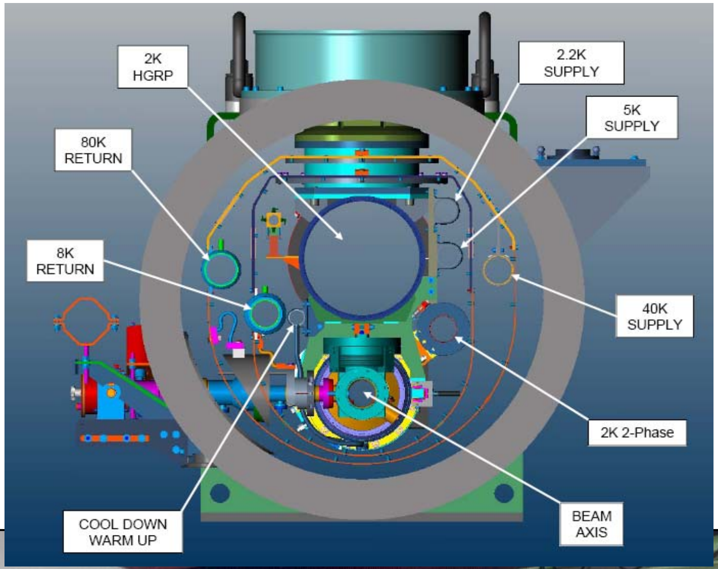
reference: R. Geng's talk at ALCPG/ILC-GDE-09

- The understanding of quench behavior is greatly improved,
- Yet some issues still remain,
  - Why some 9-cell cavities (1m^2 surface) are limited < 20 MV/m
    - by only one defect (< 1mm^2) in one cell while other cells already reaching 30-40 MV/m ?
  - Why magnetic field enhancement alone does not not sufficient
    - to explain all quench behaviors?
  - Why no observable defects in some cases of quench limit?
- Great opportunities ahead for finding answers,
  - as curious material/metallurgy researchers and eager industry partners are joining ILC SRF cavity community.
- 9-cell cavity processing and testing,
  - Significant improvement in yield statistics expected in the next ~12 months
- Complementary 1-cell cavity program
  - offers opportunities for creativity.

The ILC R&D Program– Cryomodules

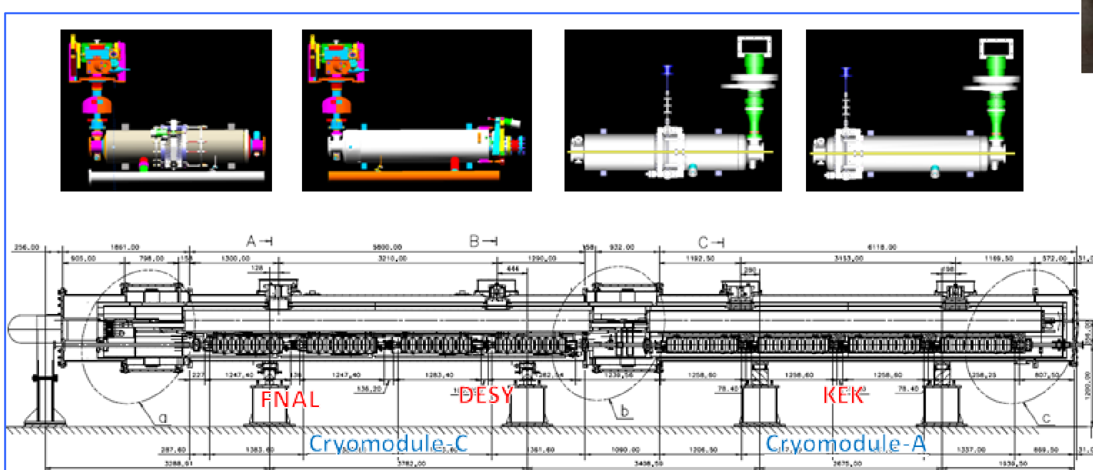
- Cryomodules are complex
  - Cavities made from pure Nb
  - Smooth & ultra clean surfaces
  - Cavity handling is crucial
  - Operate in 2K superfluid He
  - 1200 parts!

- Cryomodules are expensive
- Single most expensive component of the ILC
- Must industrialize cavities, components, and maybe assembly
- Developing the extensive infrastructure to build and test CM's
- FNAL leads an international team working to improve the TESLA CM design for ILC (DESY, INFN, KEK, CERN, SLAC, India, etc)
- Considering global plug compatibility



The First Global cryomodule is in Progress
INFN/ZANON completing Cryomodule

- Global effort for cryomodule test for ILC operational goal
  - **INFN: Cryomodule**
  - **DESY: 2 cavities**
  - **FNAL/JLab: 2 cavities**
  - **KEK: 4 cavities, Cryomodule**



Cryomodule Gradient Goal: Achieved at DESY

Reported by H. Weise, at SRF-09

NewsLine

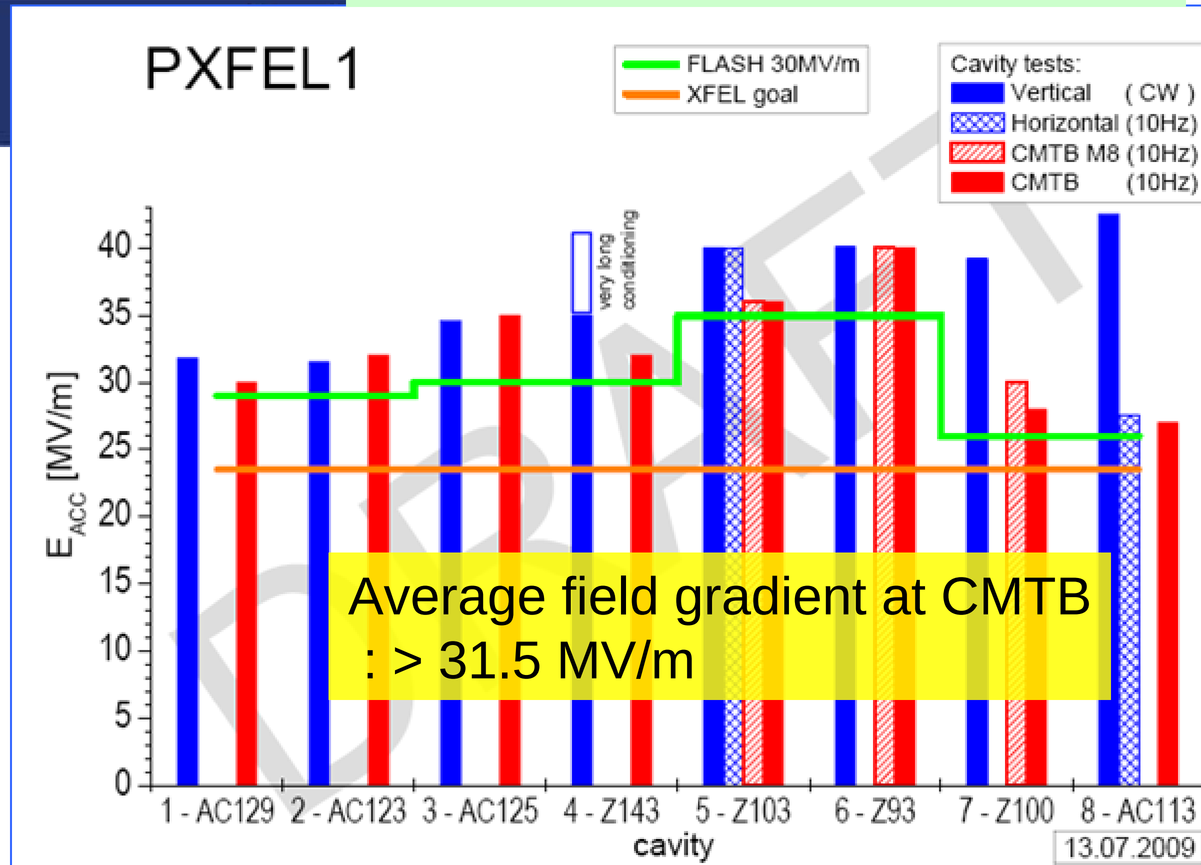
Around the World

Cryomodule surpasses ILC gradient test

European-XFEL cryomodule using SCRF technology sets new record

The cryomodule that set the world gradient record in the testbench at DESY

A cryomodule prototype for the European XFEL has set the world gradient record for cryomodules built with superconducting radiofr... technology, reaching an ave... accelerating gradient of more... megavolts per metre (MV/m)...



- First XFEL prototype module **exceeds 31.5 MV/m average**
- Module will see beam in FLASH in 2010 (av. of 30MV/m)

Cryostat ... contributed by IHEP

The challenge of industrialization

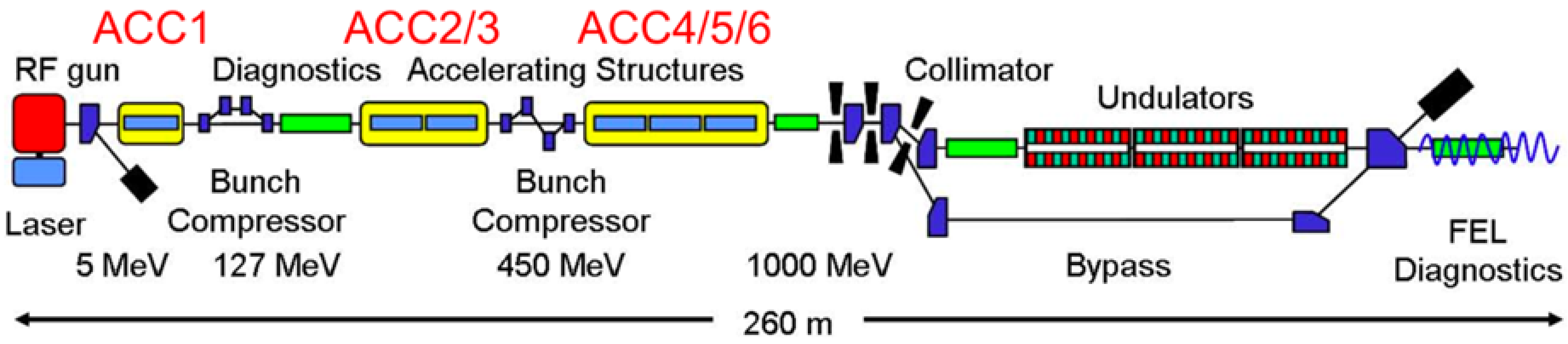
- Global status of Industries
  - **Research Instruments and Zanon in Europe**
  - **AES, Niowave, PAVAC in Americas**
  - **MHI in Asia**

Project Scope			
Euro XFEL	~800	2 years	~1 cavity / day
Project X	~400	3 years	~2 cavities/ week
ILC	~15,500	4 years	~20 cavities / day
(÷ 3 regions			~7 cavities / day)

- Industrial Capacity: status and scope
  - **No company currently has required ILC capacity**
  - **Understand what is needed (and cost) by 2012**
  - **Tech transfer only in the R&D program**

TTF/FLASH (DESY) 9mA Experiment

Full beam-loading long pulse operation → first ILC like string test



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

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

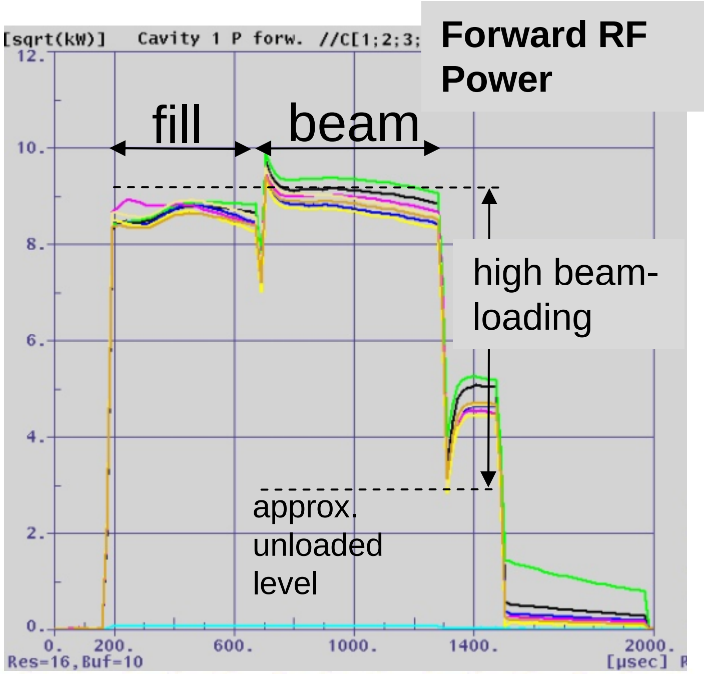
9mA Experiment Status

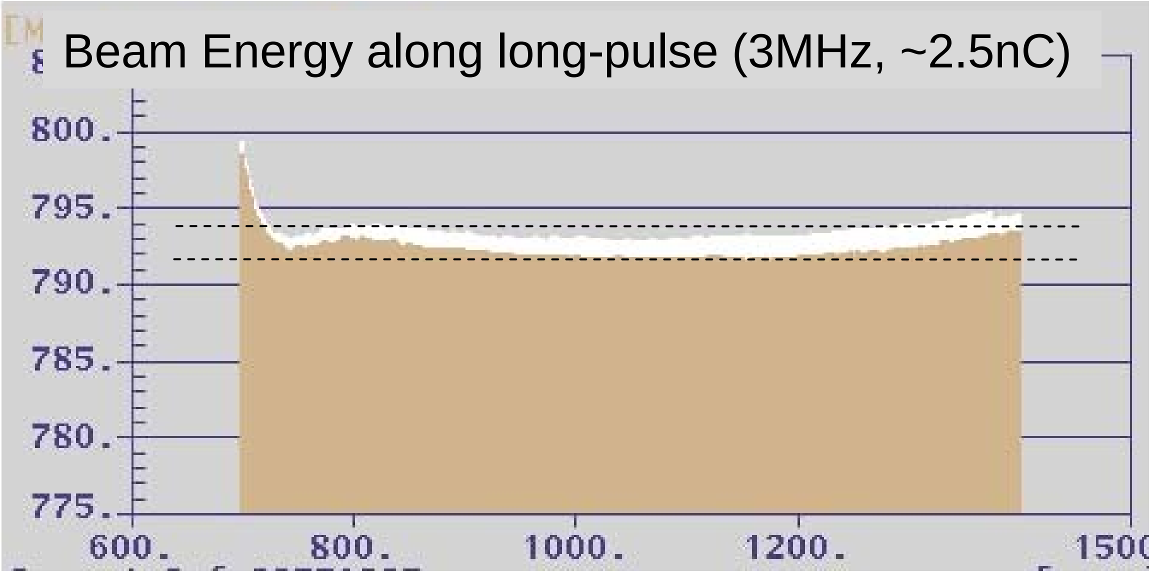
- Successfully completed 2-week dedicated experiment – Sept 09
  - **Total 5-week interruption to FLASH photon user programme when shutdown for dump-repair is included (thanks to DESY)**
- Commissioning of new hardware
  - **3MHz laser**
  - **Simcon-DSP LLRF system(s)**
  - **New instrumentation in dump line**
- Detailed data analysis now just beginning
  - **Will take some months of analysis**
- Stable operation with high beam-loading (high beam-powers) demonstrated, but
  - **Not all (original) 9mA goals were achieved**
  - **Routine operation of long bunch trains still requires work**
  - **Planning for next shifts (proposal) now underway**

9mA Example Results

Much experience gained running with high beam-loading conditions

Approx. 15 TBytes of data to be analysed (beginning)



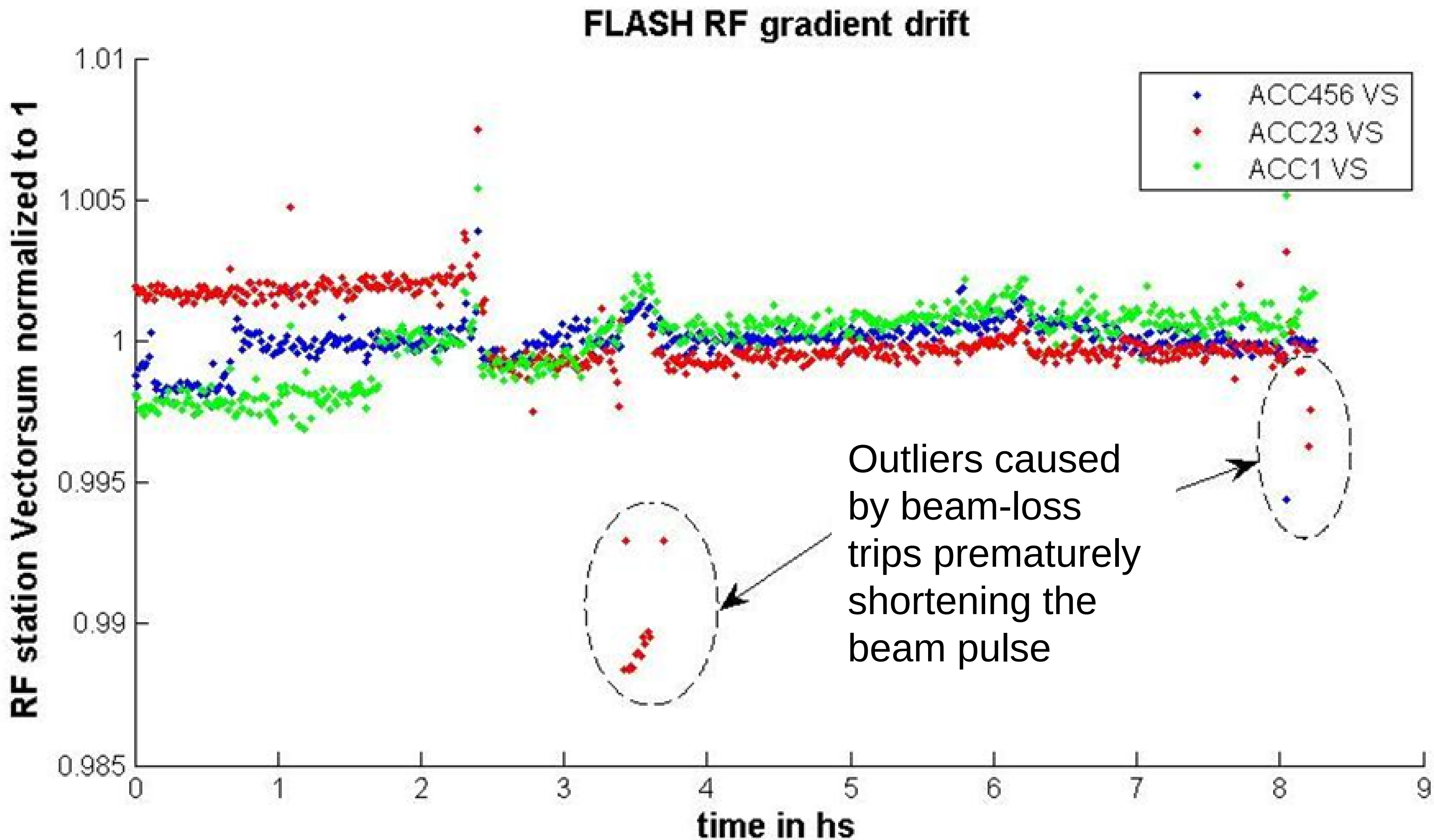


Along pulse: 0.1% RMS (0.5% pk-to-pk)
(after initial transient)
Pulse-to-pulse (5Hz): 0.13% RMS

Integrated Systems Test
- Understanding trip and trip recovery (beam loss)
- RF parameter tuning
- RF system calibration

Extrapolation to XFEL/ILC

RF Gradient Long-Term Stability



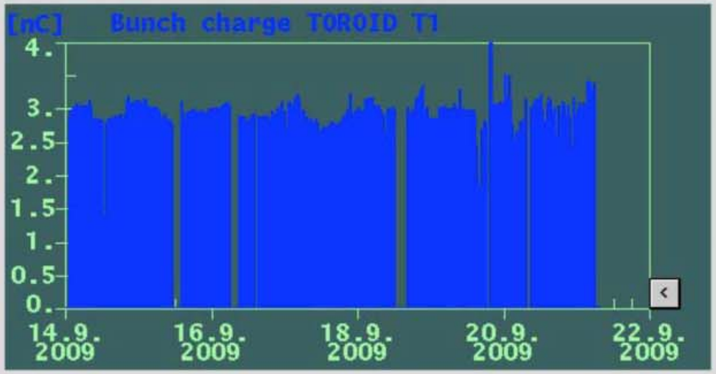
Example Result

9mA Experiment - DESY

History of bunch charge and number of bunches during Week #2

FLASH Program: 9 mA Studies
ACC studies KW37

Charge (nC)

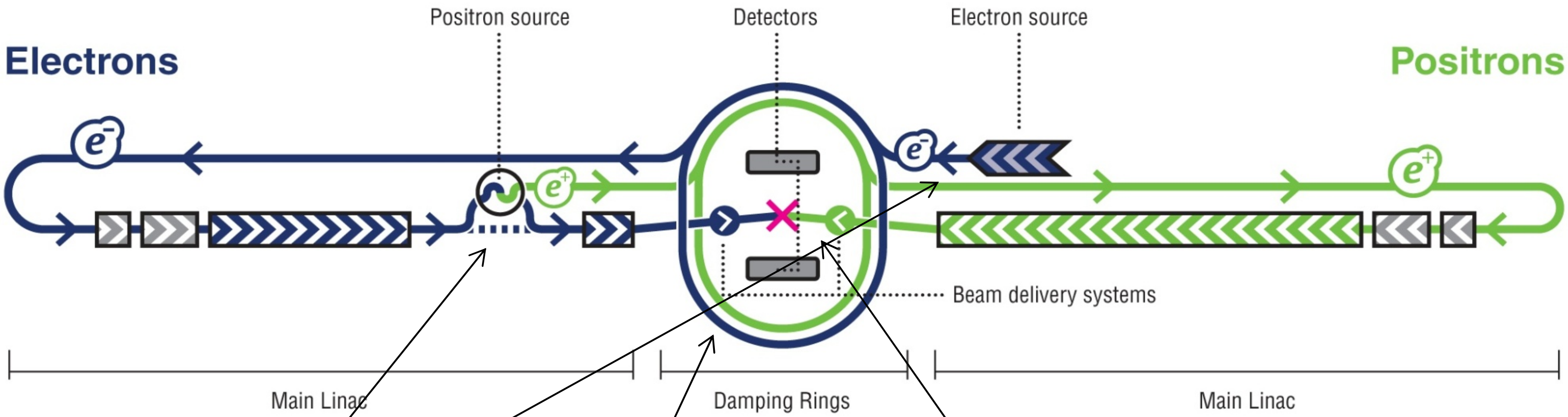


- Bunch charge was consistently between ~2.7nC and ~3nC
- Rapid progress increasing number of bunches during the last 3 days!

Number of bunches

One week Operation 14-22.09.2009

more than just SRF



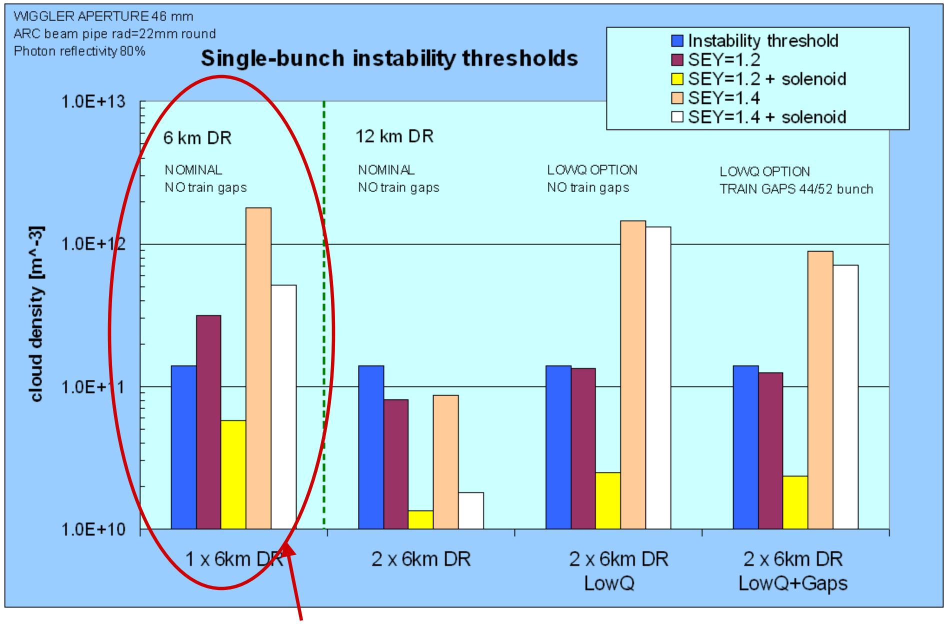
Sources
-Positron production
-Polarised electrons
-…

Damping Rings
-Electron cloud
-Fast kickers
-Low emittance tuning
-…

Beam Deliver System / MDI
-Optics / demagnification
-FD design
-Stability & feedback systems
-Detector integration
-…

Beam Test Facilities

Electron Cloud in the ILC DR



- ILCDR06 Evaluation
  - **M. Pivi, K. Ohmi, *et al.***
  - **Single ~6km positron DR**
    - Nominal ~2625 bunches with 6ns bunch spacing and $N_b=2\times10^{10}$
    - Requires SEY values of vacuum chamber surfaces with $\delta_{max}\leq1.2$ (assuming solenoid windings in drift regions) in order to operate below EC instability thresholds
    - Dipole and wiggler regions of greatest concern for EC build-up

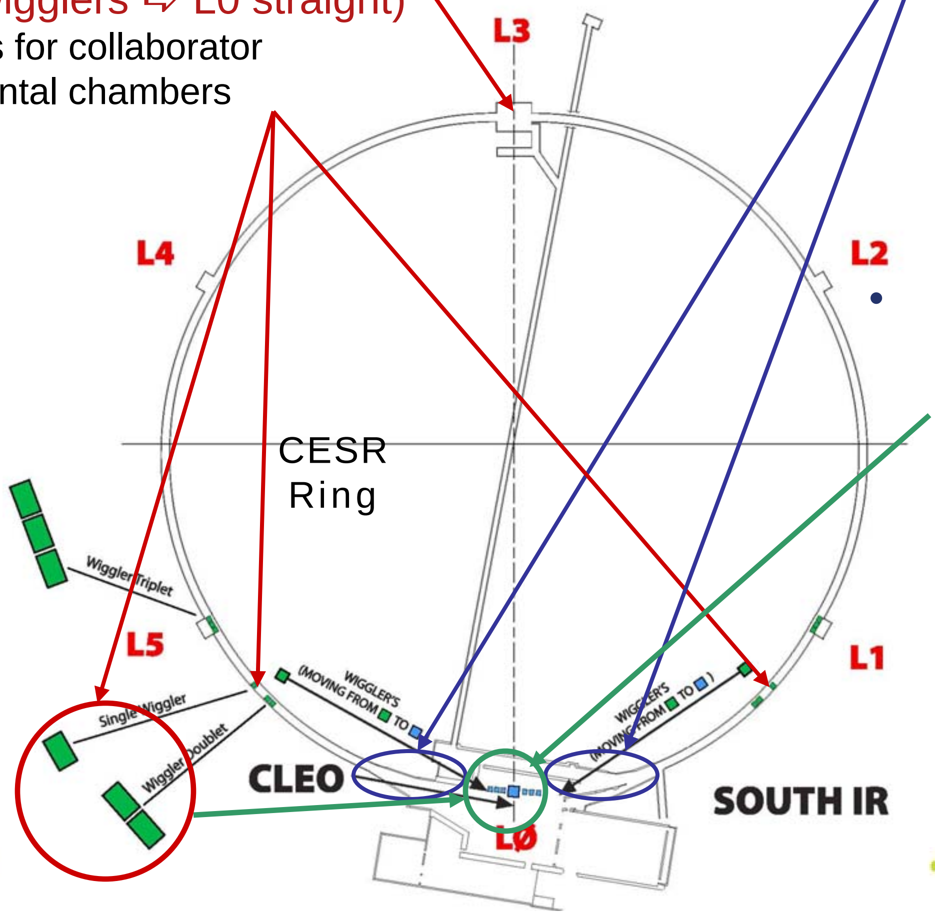
- In 2007, the ILC R&D Board's S3 Task Force identified a set of critical research tasks for the ILC DR, including:
  - **Characterize EC build-up**
  - **Develop EC suppression techniques**
  - **Develop modelling tools for EC instabilities**
  - **Determine EC instability thresholds**
- CesrTA program targets:
  - **Measurements with positron beams at ultra low emittance to validate projections to the ILC DR operating regime**
  - **Validation of EC mitigation methods that will allow safe operation of the baseline DR design and the possibility of performance improvements and/or cost reductions**

CesrTA Goals

- Key Elements of the CesrTA R&D Program:
  - **Studies of Electron Cloud Growth and Mitigation**
    - Study EC growth and methods to mitigate it, particularly in the wigglers and dipoles which are of greatest concern in the ILC DR design.
    - Use these studies to benchmark and expand existing simulation codes and to validate our projections for the ILC DR design.
  - **Studies of EC Induced Instability Thresholds and Emittance Dilution**
    - Measure instability thresholds and emittance growth due to the EC in a low emittance regime approaching that of the ILC DR.
    - Validate EC simulations in the low emittance parameter regime.
    - Confirm the projected impact of the EC on ILC DR performance.
  - **Low Emittance Operations**
    - Support EC studies with beam emittances approaching those specified for the ILC DR (CesrTA vertical emittance target: ε_v<20 pm-rad with ε_x=2.5nm @ 2GeV).
    - Implement beam instrumentation needed to achieve and characterize ultra low emittance beams
      - x-Ray Beam Size Monitor targeting bunch-by-bunch readout capability
      - Beam Position Monitor upgrade
    - Develop tuning tools to achieve and maintain ultra low emittance operation in coordination with the ILC DR LET effort
  - **Inputs for the ILC DR Technical Design**
    - Support an experimental program to provide key results on the 2010 timescale
    - Provide sufficient running time to commission hardware, carry out planned experiments, and explore surprises ⇨ ~240 running days over a 2+ year period

CESR Reconfiguration

- L3 EC experimental region
  PEP-II EC Hardware: Chicane, upgraded SEY station
  Drift and Quadrupole diagnostic chambers
- New EC experimental regions in arcs (wigglers ⇨ L0 straight)
  Locations for collaborator experimental chambers



- CHESS C-line & D-line Upgrades
  Windowless (all vacuum) x-ray line upgrade

  Dedicated optics box at start of each line

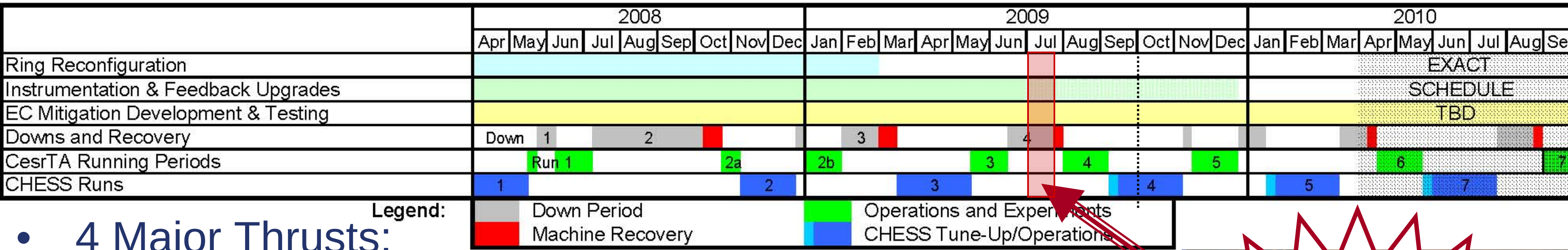
  Detectors share space in CHESS user hutches
- L0 region reconfigured as a wiggler straight
  CLEO detector sub-systems removed

  6 wigglers moved from CESR arcs to zero dispersion straight

  Region instrumented with EC diagnostics and mitigation

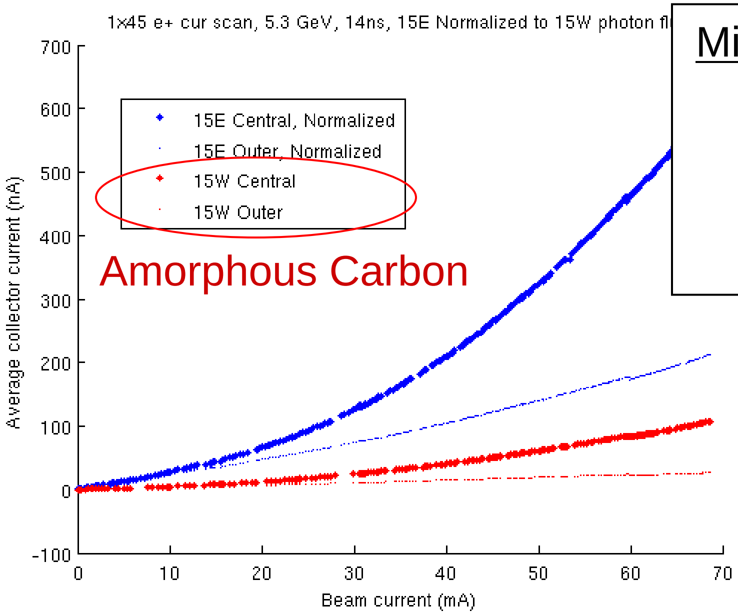
  Wiggler chambers with retarding field analyzers and various EC mitigation methods (fabricated at LBNL in CU/SLAC/KEK/LBNL collaboration)

CesrTA Program

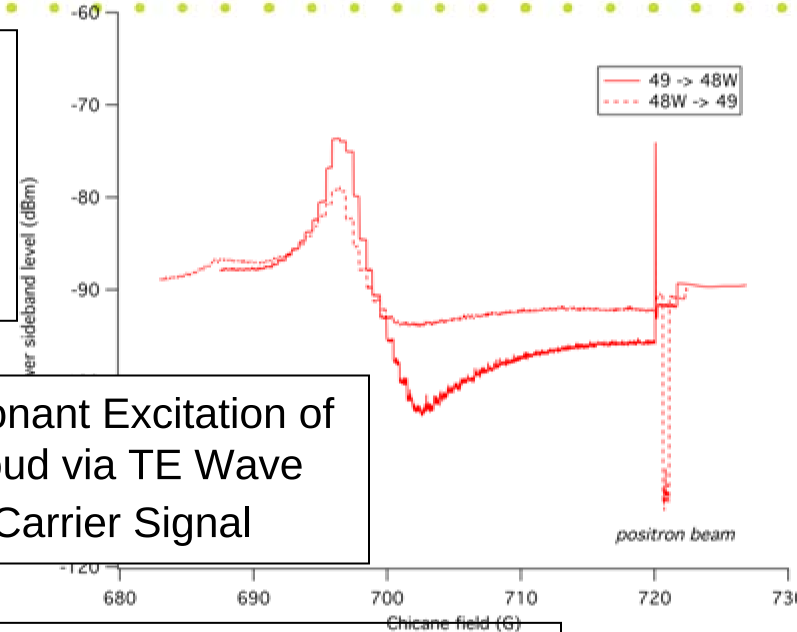


- 4 Major Thrusts:
  - **Ring Reconfiguration: Vacuum/Magnets/Controls Modifications**
  - **Low Emittance R&D Support**
    - Instrumentation: BPM system and high resolution x-ray Beam Size Monitors
    - Survey and Alignment Upgrade
  - **Electron Cloud R&D Support**
    - Local EC Measurement Capability: RFAs, TE Wave Measurements, Shielded Pickups
    - Feedback System upgrade for 4ns bunch trains
    - Photon stop for wiggler tests over a range of energies
    - Local SEY measurement capability
  - **Experimental Program**
    - Targeting 7 runs spread over a 2+ year period
    - Early results will feed into final stages of program
- Schedule coordinated with Cornell High Energy Synchrotron Source (CHESS) operations

A Few "Log Book" Snapshots

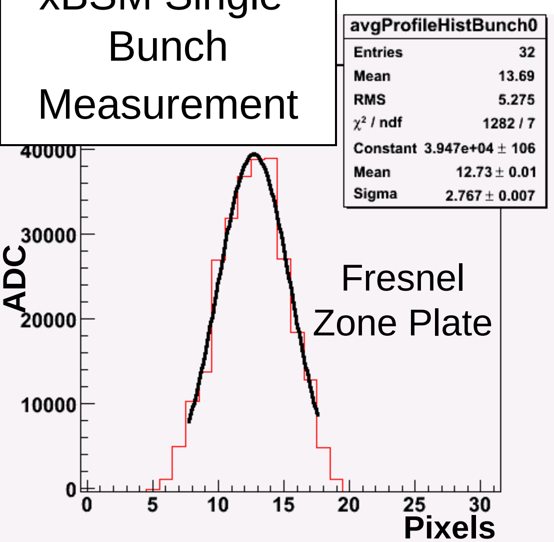


Mitigation Checks
Amorphous C-Coated VC (CERN) vs Al VC

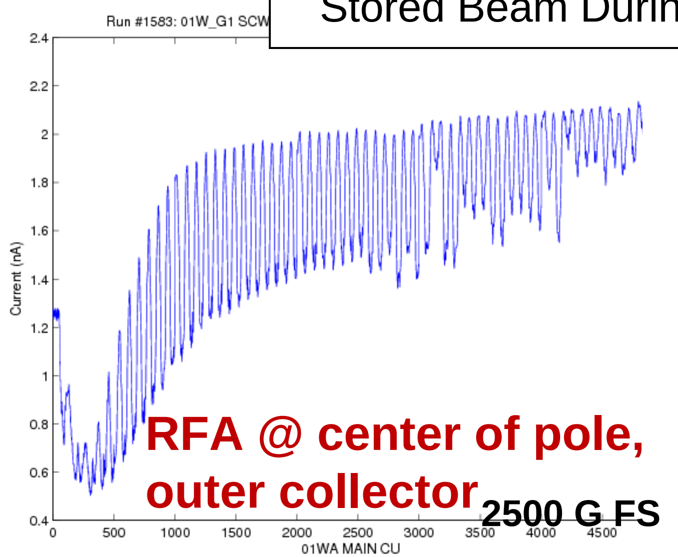


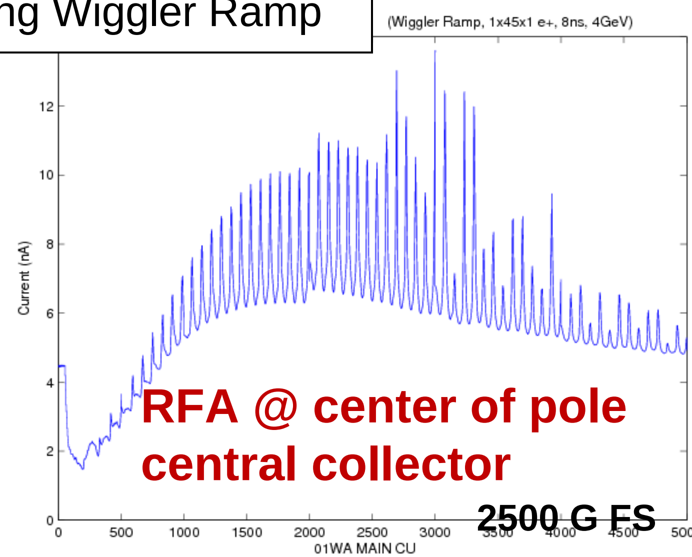
Resonant Excitation of Cloud via TE Wave Carrier Signal

xBSM Single-Bunch Measurement



Cyclotron Resonances
Stored Beam During Wiggler Ramp

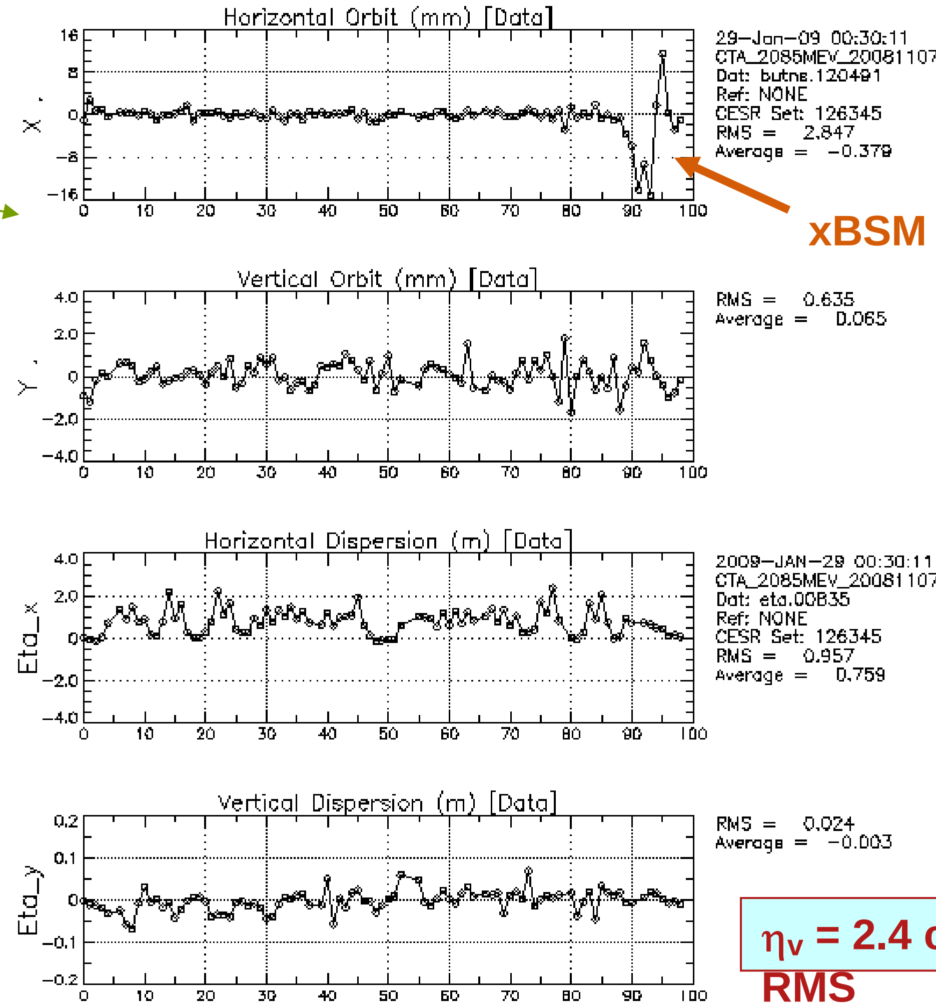




Low emittance tuning

Orbit

A feature of the orbit is the closed horizontal bump required to direct xrays onto x-ray beam size monitor



xBSM bump

-Measure and correct vertical dispersion using skew quads (14) and vertical steering magnets (~60)

Residual vertical dispersion
RMS ~ 2.4cm - Signal or systematic?
Accuracy of dispersion measurement is limited by BPM systematics

η_v = 2.4 cm RMS

Measured with older ***relay*** BPM system!!

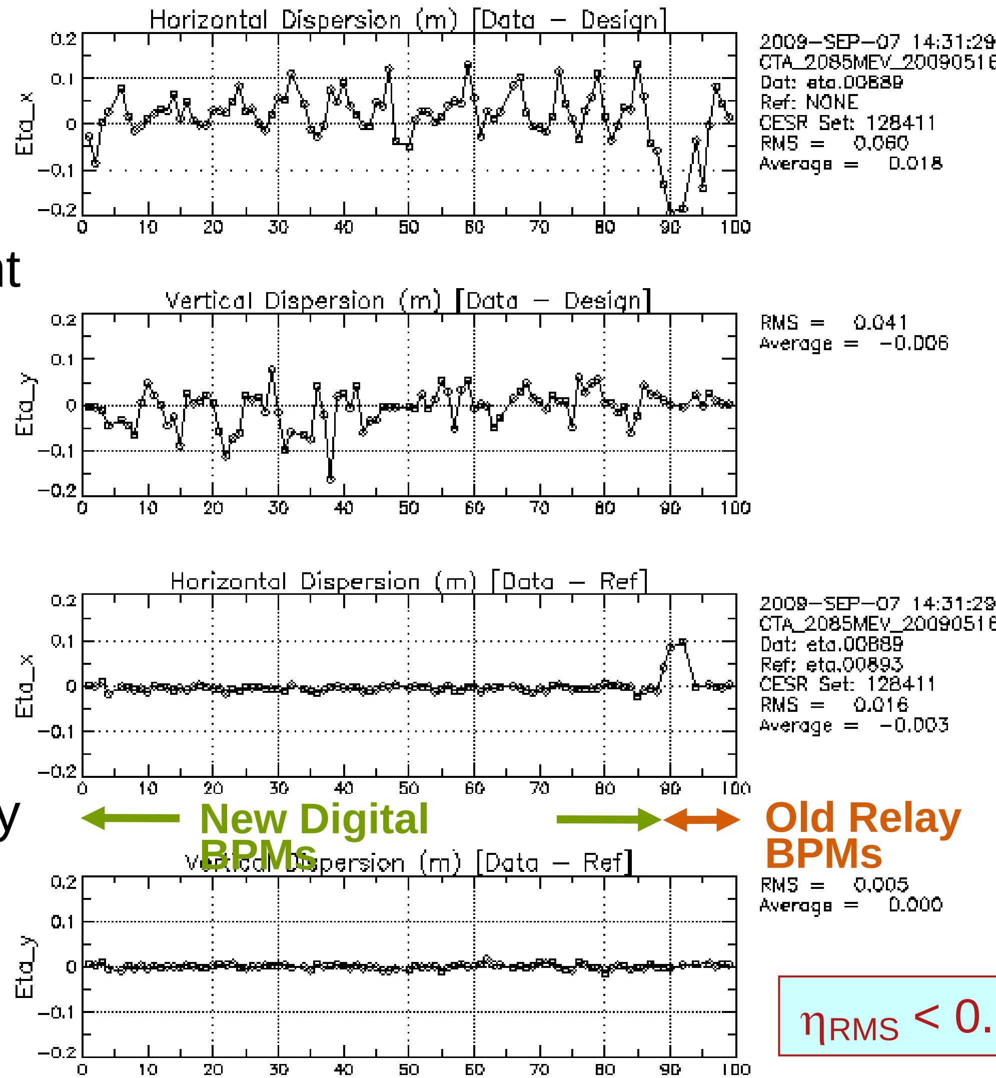
Note: Residual vertical dispersion 1 cm, corresponds to ε_v ~ 10pm

Low emittance tuning

After Installation of 80+ CBPM II modules

Dispersion Measurement

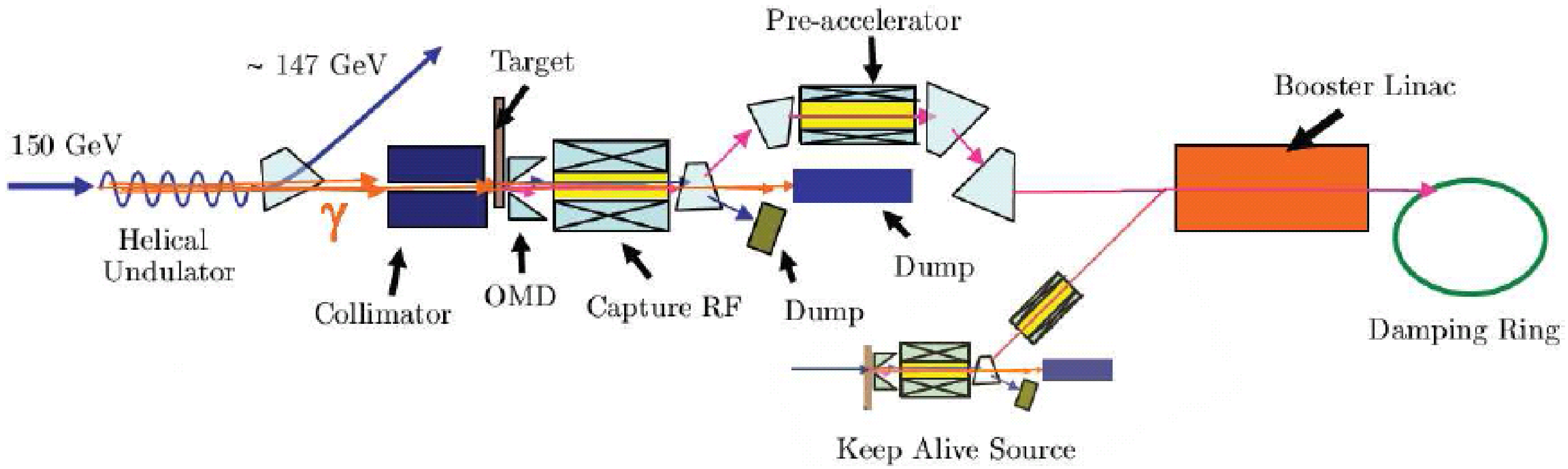
Reproducibility



Present $\varepsilon_v \leq 40$pm
Will pursue 20pm with new BPM system during Nov-Dec Experimental run

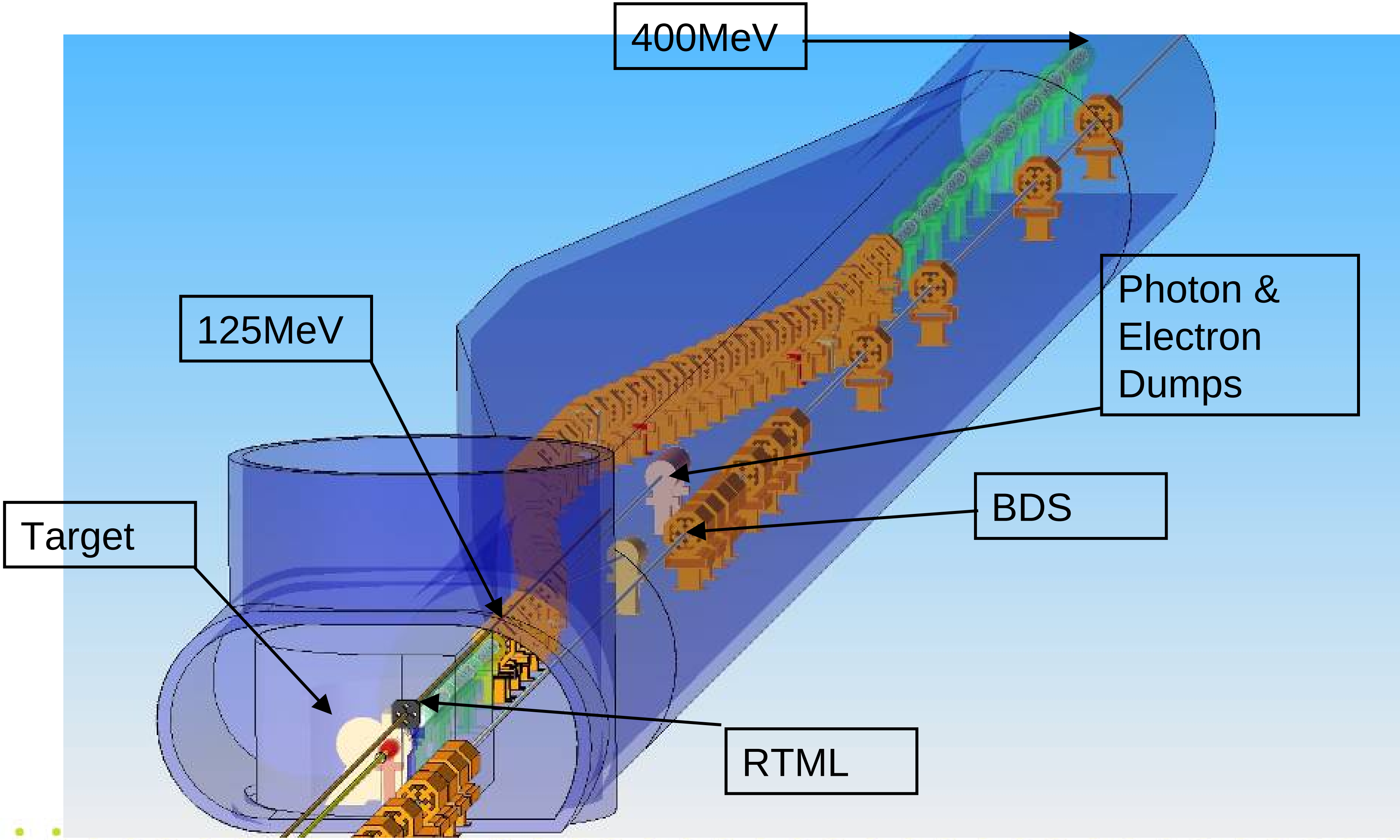
$\eta_{RMS} < 0.5$ cm

Positron production - Key Points



- Photon ‘drive beam’ generated in helical superconducting undulator at 150 GeV
- Photon beam travels ~400m beyond undulator and then impinges on Ti alloy target (0.4 rad lengths, 1.4cm)
- Positrons captured with optical matching device and accelerated by NCRF Linac with solenoidal focussing to 125 MeV
- Any electrons and remaining photons are then separated and dumped
- Positrons further accelerated by NCRF Linac with solenoidal focussing to 400 MeV
- Transported at 400 MeV for ~5km
- Accelerated to 5GeV in SCRF Linac and injected into DR

Engineering Layout



Positron production - Key Issues

- Can the undulator parameters be achieved?
- Will the undulator disrupt the electron beam?
- Will the target survive the shock from each pulse and have a sufficiently long lifetime?
- Is the capture magnet system feasible?
- Can high positron polarisation be achieved?
- Is the auxiliary source feasible?
- Can the system be modelled accurately?

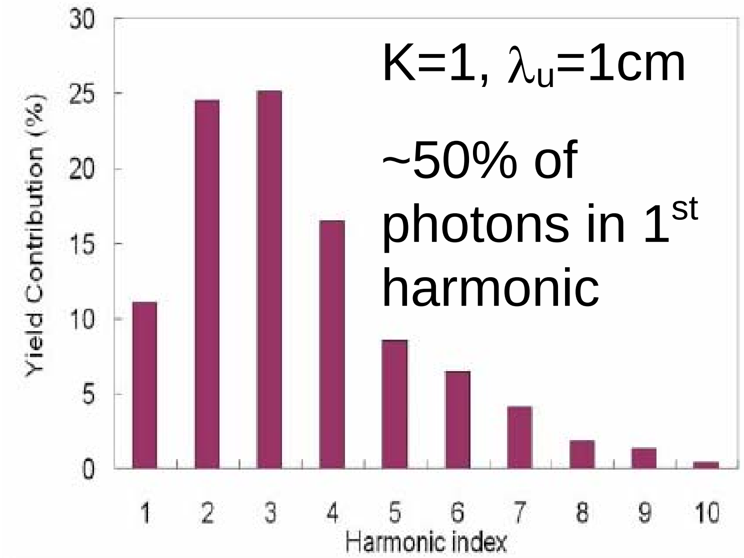
Source designed to generate 50% more positrons than specified:-
(1.5 positrons per 1.0 electron)

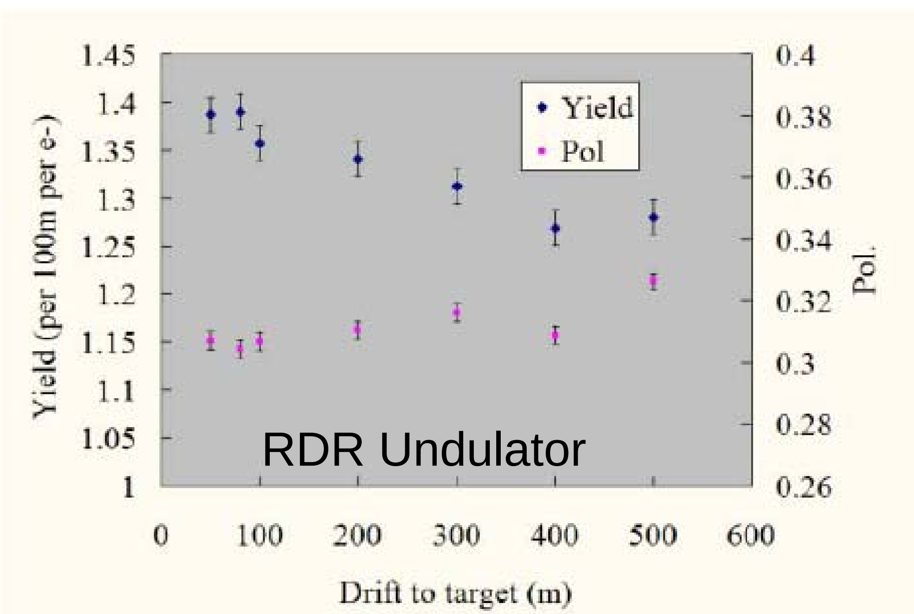
Source Modelling

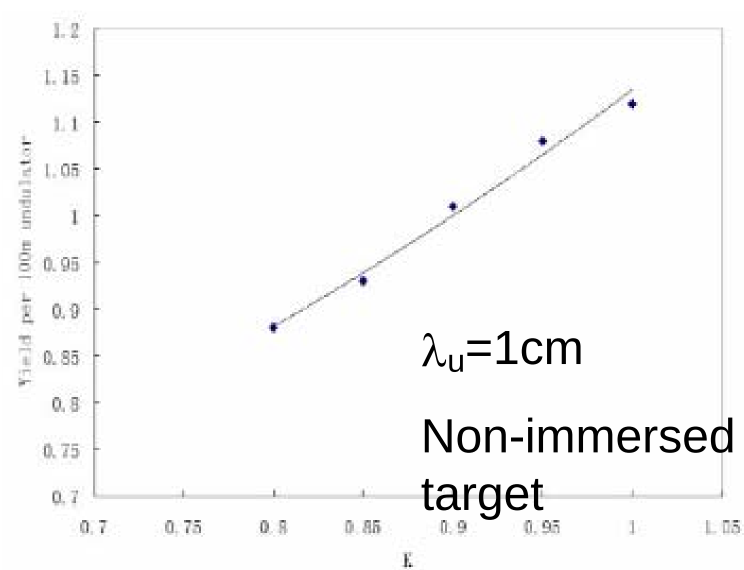
Calculations of yield vital for source design.

Simulations include undulator spectrum, collimator, target, OMD field, NC & SC Linacs.

Used to select undulator parameters after systematic study.







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Source Modelling

- Recent studies of emittance change of electron beam due to SR emission in undulator carried out by ANL group
- Simulated with Elegant for various undulator parameters (including energy spread)
- Results depend upon exact lattice and length of undulator
- Typical results show small change in emittance in both planes (few %), generally decreasing
- Results also supported by analytical work

configuration	$\Delta\varepsilon nx/\varepsilon nx$ (%)	$\Delta\varepsilon ny/\varepsilon ny$ (%)
~100m	-1.36	-1.18
~200m	-2.69	-1.27
~300m	-3.93	0.84

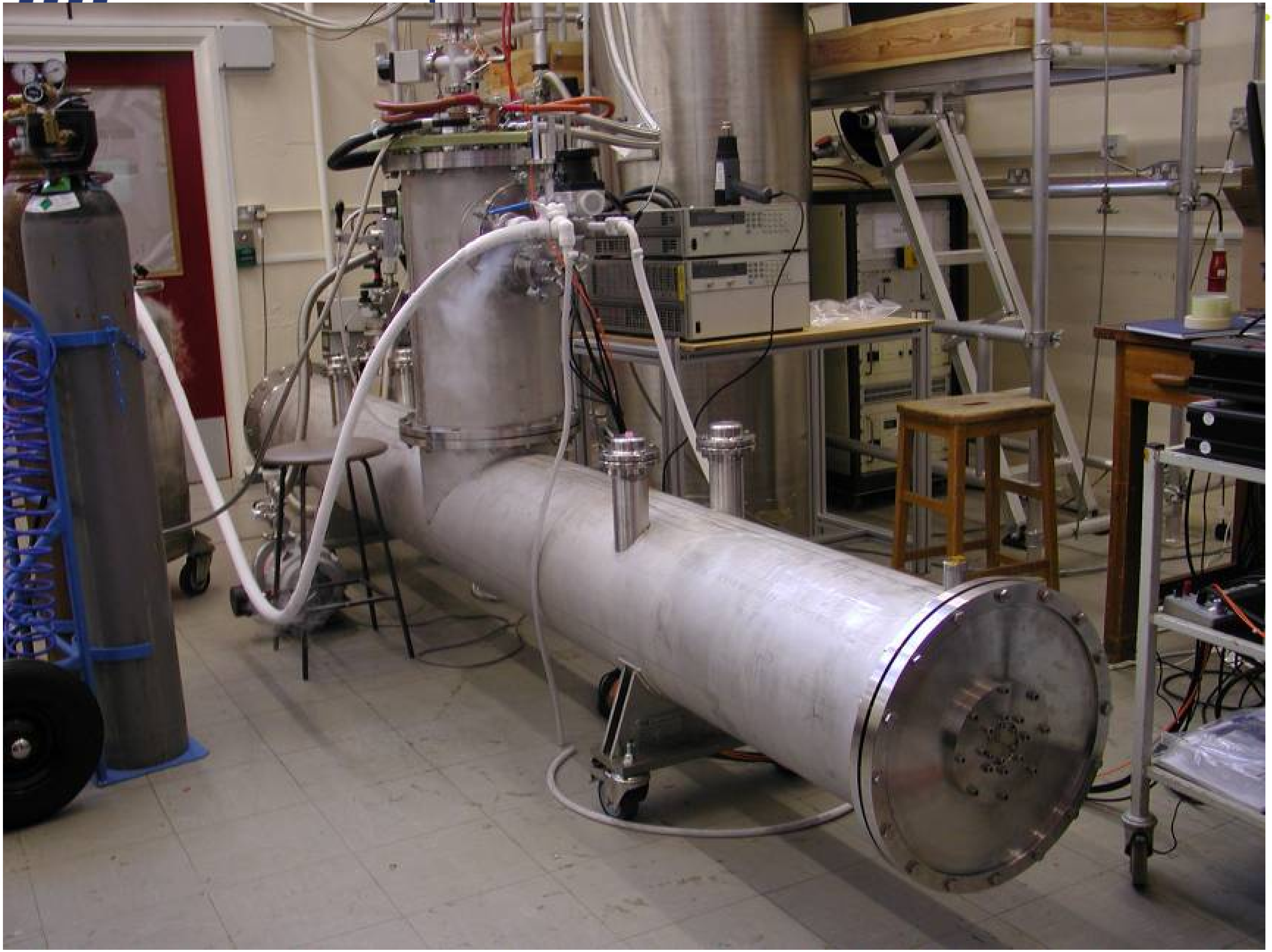
W. Gai et al, ANL

Undulator

- 42 x 4m cryomodules (42 x 3.5 = 147m active length)
- Vacuum pumps, photon collimators, quads, BPMs installed every 3 cryomodules in room

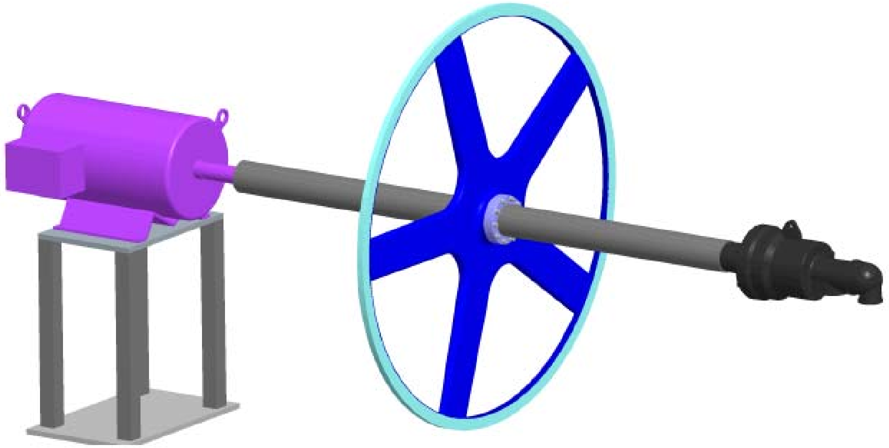
Undulator Parameters	Symbol	Value	Units
Undulator period	λ	1.15	cm
Undulator strength	K	0.92	
Undulator type		helical	
Active undulator length	L_u	147	m
Field on axis	B	0.86	T
Beam aperture		5.85	mm
Photon energy (1^{st} harmonic cutoff)	E_{c10}	10.06	MeV
Photon beam power	P_γ	131	kW

Complete Undulator at RAL



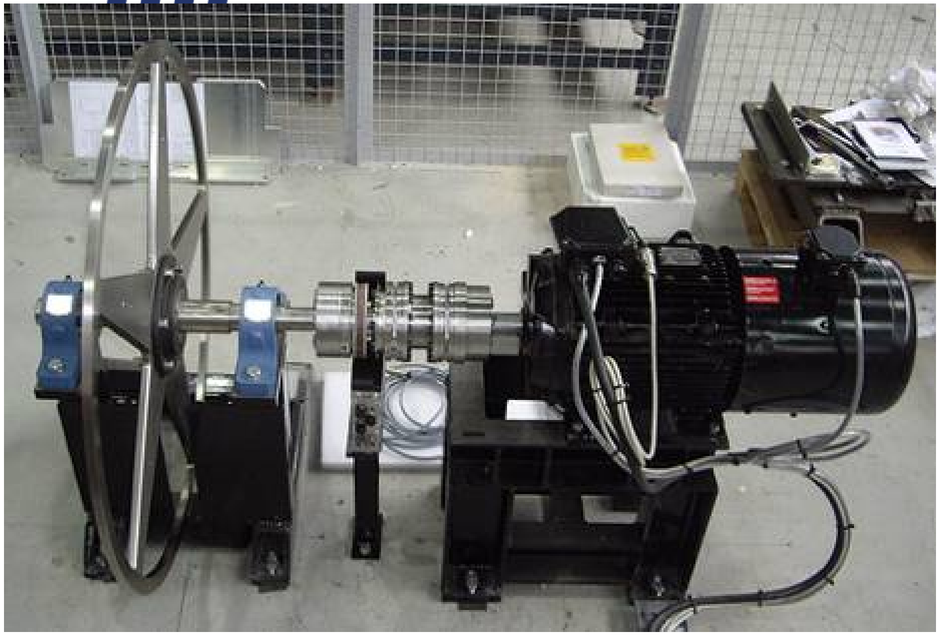
Positron production target

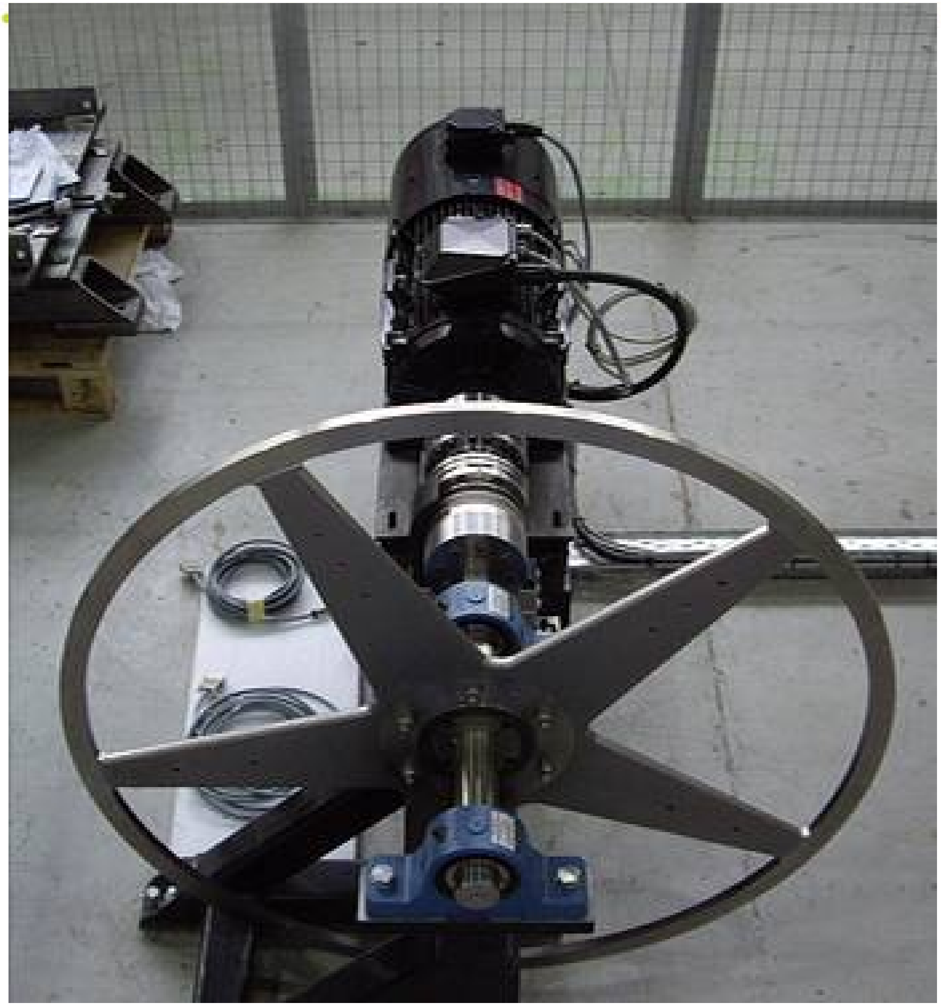
- 1m diameter spinning wheel
- Rim & spokes not solid disk to mitigate eddy current effects
- Designed for operational life of 2 years

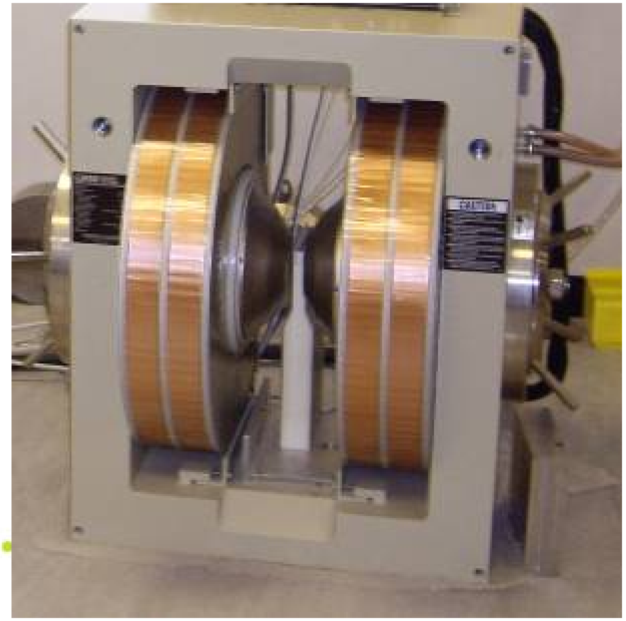


Target Parameters	Symbol	Value	Units
Target material		Ti-6%Al-4%V	
Target thickness	L_t	0.4 / 1.4	r.l. / cm
Target power adsorption		8	%
Incident spot size on target	σ_i	> 1.7	mm, rms

Cockcroft Institute Prototype







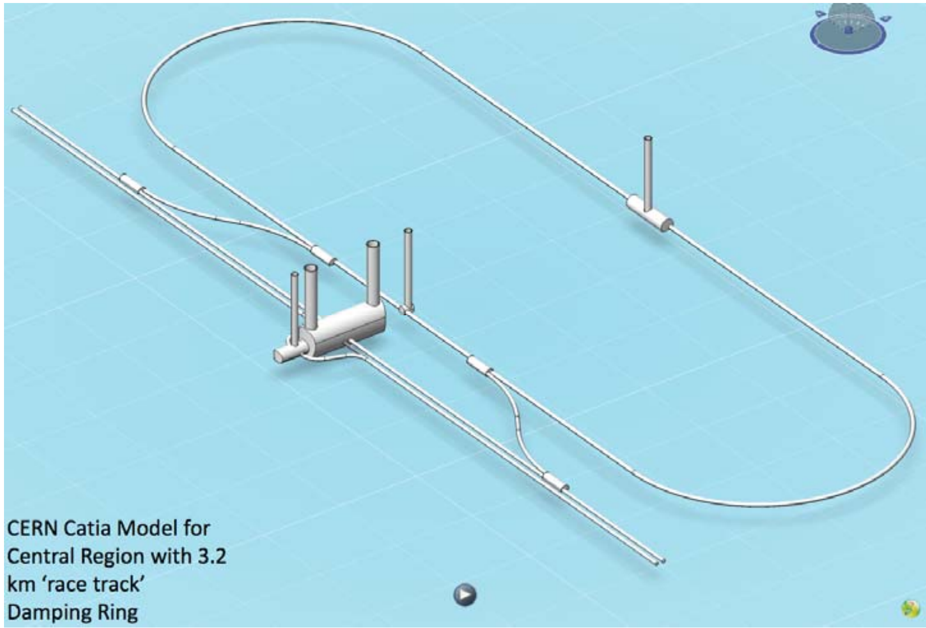
Experiment now in progress comparing models with measured torques

Positrons:Key Issues

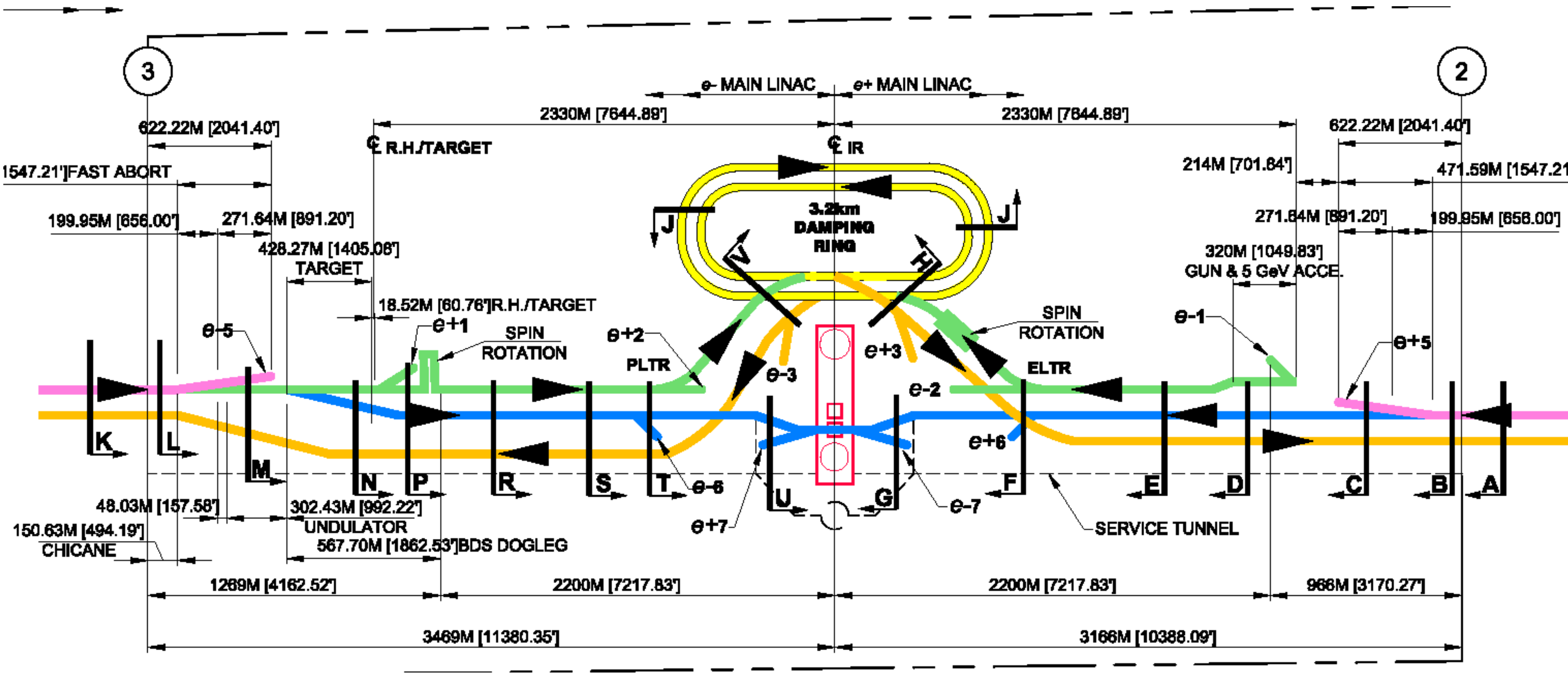
- Can the undulator parameters be achieved?
  - **Yes, they have been demonstrated in a full scale prototype**
- Will the undulator disrupt the electron beam?
  - **Not significantly (except for energy loss which must be replaced)**
- Will the target survive the shock from each pulse and have a sufficiently long lifetime?
  - **All simulations suggest a lifetime of >2 years is feasible. Replacement every year is planned.**
- Is the capture magnet system feasible?
  - **A simple solenoid is assumed at present so yes. A flux concentrator or lithium lens would enhance the positron yield. Studies are ongoing on these two options**
- Can high positron polarisation be achieved?
  - **Yes, 60% as specified.**
- Is the auxiliary source feasible?
  - **No showstoppers found so far but needs more study.**
- Can the system be modelled accurately?
  - **The successful E166 proof of principle experiment agreed very well with the simulations.**

Potential ILC baseline design changes/issues

1. Single-tunnel solution(s)
2. Klystron Cluster concept
3. Central region integration
4. Low beam power option
5. Single-stage bunch compressor
6. Quantify cost of TeV upgrade support
7. "Value engineering" The whole exercise is global value engineering!



Central Region Integration - CFS



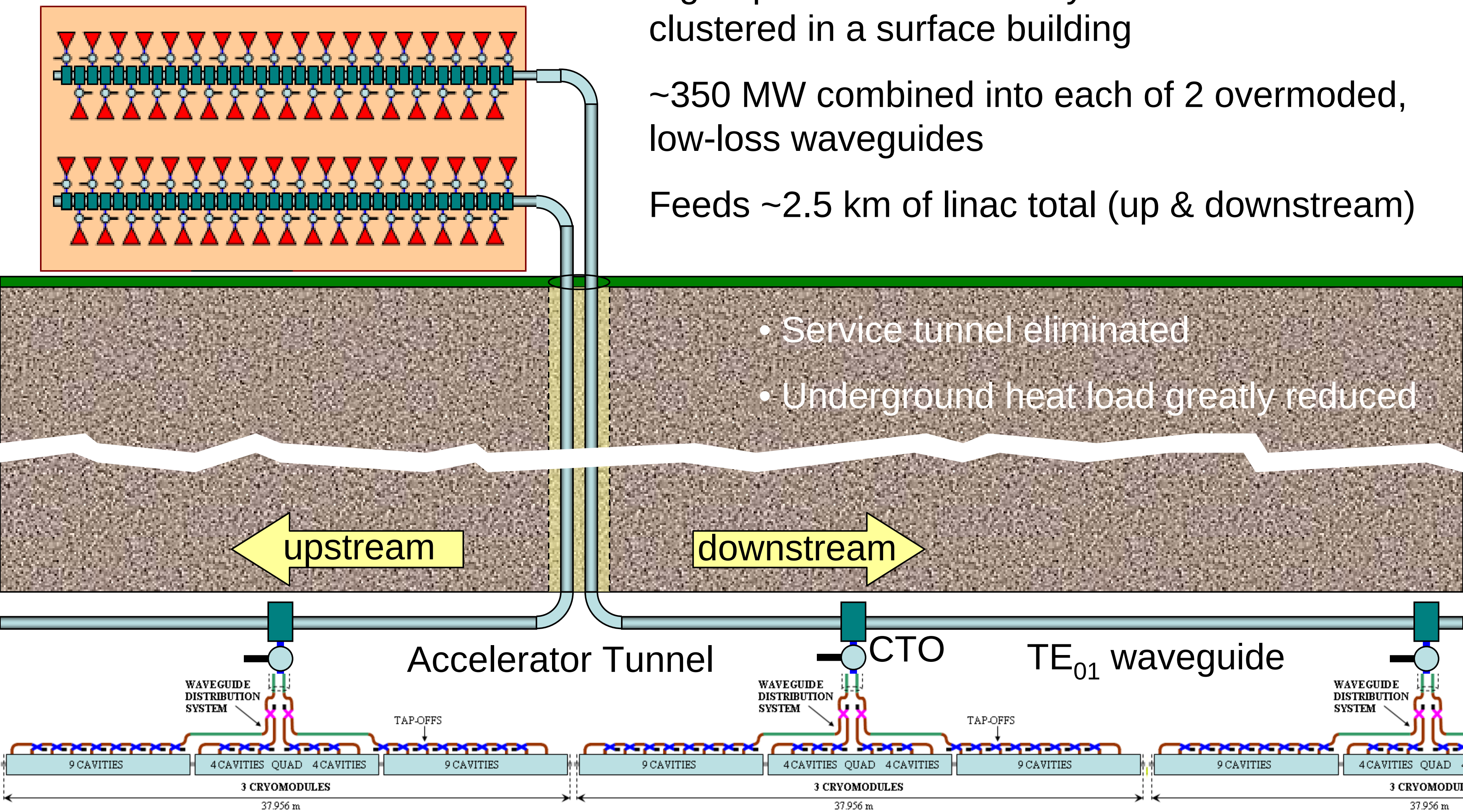
2 HLRF Schemes: 1) Klystron Cluster Layout

Surface rf power cluster building

2 groups of ~35 10 MW klystrons & modulators clustered in a surface building

~350 MW combined into each of 2 overmoded, low-loss waveguides

Feeds ~2.5 km of linac total (up & downstream)



Chris Nantista

The ILC R&D Program – Summary

- We will produce an updated conceptual design report by the end of calendar 2012. This will also have an updated cost estimate. This will be the nominal end to the R&D program.

- The R&D program should be close to completion by that time though the string tests which will have started will not be complete.

- I suspect that the 35 MV/m gradient will be retained. The cryomodule gradient degradation of 35 -> 31.5 MV/m less well known at this time.

- I suspect that positrons might prove to be the most demanding technical issue after the dust settles.

Will we move ahead into a construction project ? We need compelling physics results from the LHC in this energy range. We need an unprecedented level of international co-operation (no host lab).