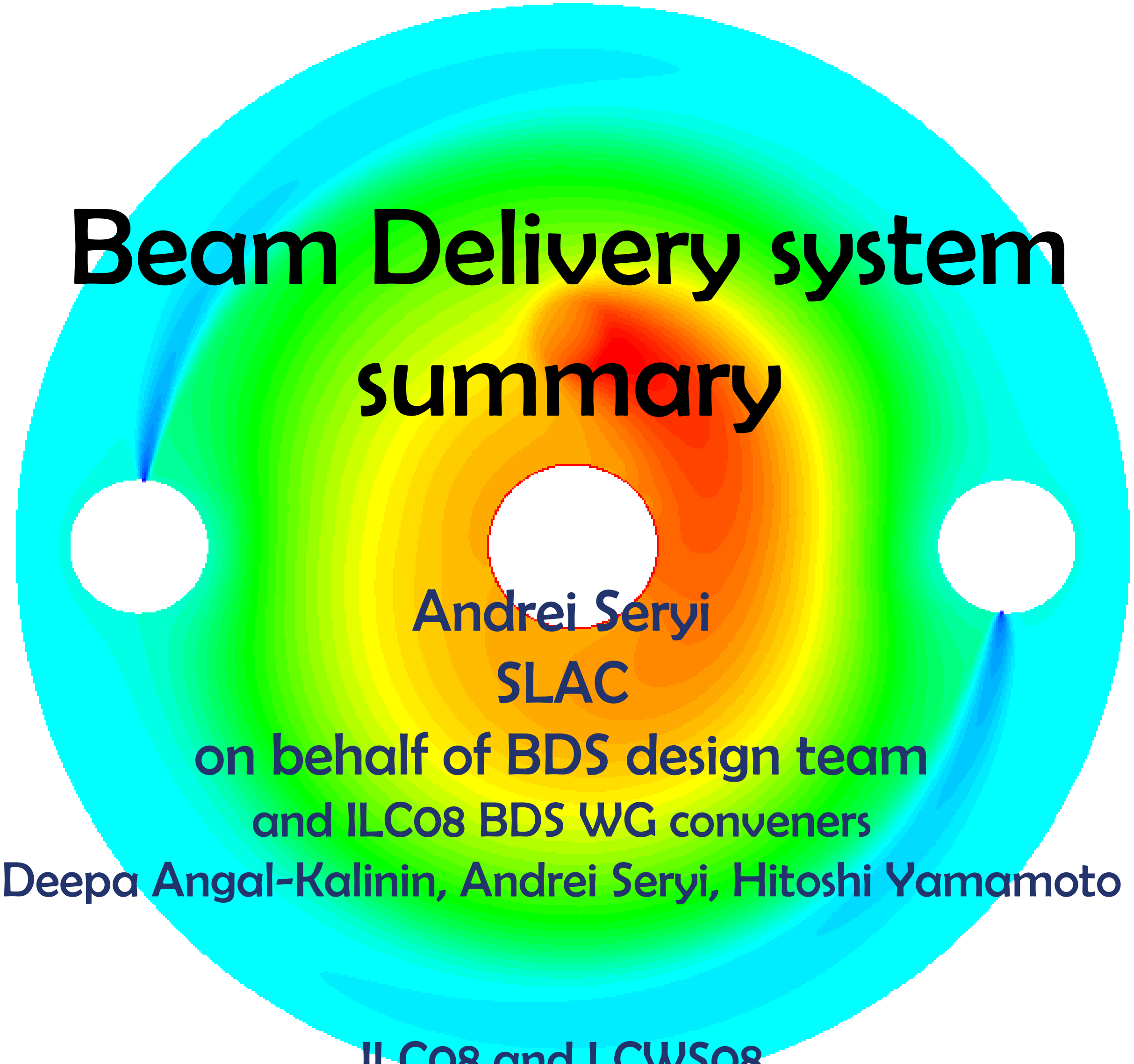
Beam Delivery system summary



Andrei Seryi

SLAC

on behalf of BDS design team

and ILC08 BDS WG conveners

Deepa Angal-Kalinin, Andrei Seryi, Hitoshi Yamamoto

ILC08 and LCWS08

20 November 2008

Illustration of beam dump with double header is from Satyamurthy Polepalle et al (BARC-SLAC)

Agenda…

- Status and plans
- BDS design and plans
  - Andrei Seryi (SLAC)
- Project manager's view
  - Marc Ross (FNAL)
- BDS optics and minimal machine study
  - Deepa Angal-Kalinin (STFC Daresbury)
- Collimation system status and plans
  - Nigel Watson (Birmingham HEP)
- Vacuum science status and plans
  - Oleg Malyshev (STFC) , Michael Sullivan (SLAC)

- Joint with Beam Dynamics
- Discussion about common issues for CLIC and ILC BDS design
  - Daniel Schulte (CERN)
- MDI, FF Magnets, Anti-Solenoid, Anti-DID & ATF2 Tests
  - Brett Parker (BNL)
- ILC and CLIC luminosity performance w. intra-train feedback
  - Javier Resta Lopez (JAI, Oxford University)
- Latest beam test results of FONT4 ILC intra-train feedback
  - Philip Burrows (Oxford University)

...Agenda...

- Joint BDS and MDI
- Status of ILD Detector MDI work
  - Toshiaki Tauchi (KEK)
- Status of SiD Detector MDI work
  - Marco Oriunno (SLAC)
- Status of 4th Detector Concept MDI work
  - Alexander Mikhailichenko (Cornell University)
- Final Doblet stability and in-detector interferometry (monalisa)
  - David Urner (University of Oxford)
- IR Interface Document updates and discussion
  - Thomas Markiewicz (SLAC) , Brett Parker (BNL)
- New low power parameter set
  - Andrei Seryi (SLAC)
- Beam test facilities, ESA
  - John Jaros (SLAC)
- Instrumentation in ILC, requirements and R&D plans
  - Philip Burrows (Oxford University)

…Agenda…

- Joint with ATF technical board meeting
- Report on ATF International Collaboration
  - Junji Urakawa (KEK)
- Report of 5th and 6th Meetings of the ATF Technical Board
  - Andrzej Wolski (Cockcroft Institute)
- Present Status of ATF/ATF2
  - Nobuhiro Terunuma (KEK)
- ATF2 Commissioning Plan
  - Toshiaki Tauchi (KEK)

- Joint Gamma-Gamma, BDS and MDI
- Laser cavity R&D status
  - Tohru Takahashi (Hiroshima University)
- Photon collider before e+e-, has it sense
  - Valery Telnov (Budker INP)
- GG status and R&D plans in LLNL
  - Jeff Gronberg (LLNL)
- Discussion of BDS deisgn and GG-plans

...Agenda

- Join with MDI and Detectors
- Support system of final quadrupole magnets in ILD
  - Hiroshi Yamaoka (KEK)
- Development of Pair Monitor
  - Yosuke Takubo (Tohoku University)
- Beam Size Measurement with Pair Monitor and BeamCal
  - Kazutoshi Ito (Tohoku university)
- Permanent final quadrupole magnet option and prototype at ATF2
  - Yoshihisa Iwashita (Kyoto Univ.)
- Interim summary of discussion of IR Integration plans and IR Interface Document
  - Thomas Markiewicz (SLAC) , Brett Parker (BNL)
- View from Research Director
  - Sakue Yamada (KEK)
- Upstream polarimeter
  - Jenny List (DESY)
- Compton Cherenkov detector development
  - Daniela Kaefer (DESY - FLC)
- Depolarization from the upstream to the downstream polarimeter
  - Anthony Hartin (John Adams Institute)
- Beam dump design progress
  - Raymond Arnold, John Amann, Dieter Walz (SLAC) , Satyamurthy Polepalle (BARC, India)
- Crab Cavity and LLRF tests
  - Peter McIntosh (STFC)

Beam Delivery Systems strategy in TDP

In TDP I & II plan, the scope of work changed, and the focus is shifted →

- Focus on a few critical directions. Selection criteria:
  - –Critical impact on performance versus cost;
  - –Advanced ideas promising breakthrough in performance;
  - –Broad impact and synergy with other worldwide projects

→

- Three critical directions:
  - –General BDS design
    - beam dump
    - photon collider
    - crystal collimation
    - crab cavity
    - MDI diagnostics …
  - –Test facilities, ATF2
    - ATF2 commissioning & operation
    - Develop methods to achieve small beam size
    - Diagnostics, Laser Wires, Feedbacks …
  - –Interaction Region optimization
    - IR interface document & design
    - SC FD prototyping and vibration test
    - ILC-like FD for ATF2 …

BDS five year plan

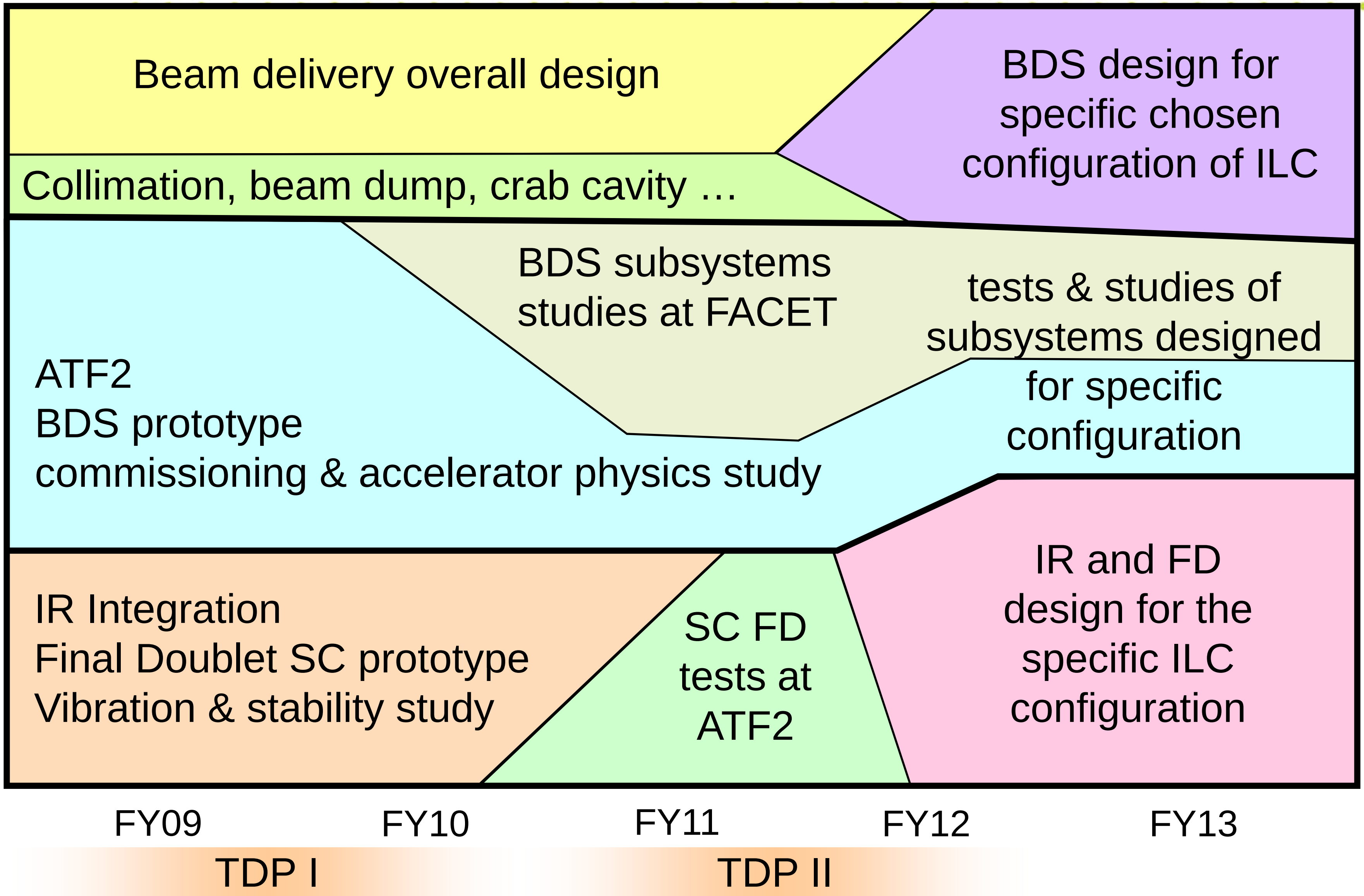


Table 3.4: TD Phase Beam Test Facilities Deliverables and Schedule.

Test Facility	Deliverable	Date
Optics and stabilisation demonstrations:		
ATF	Generation of 1 pm-rad low emittance beam	2009
ATF-2	Demonstration of compact Final Focus optics (design demagnification, resulting in a nominal 35 nm beam size at focal point).	2010
	Demonstration of prototype SC and PM final doublet magnets	2012
	Stabilisation of 35 nm beam over various time scales.	2012

BDS in GDE Technical Design Phase plan

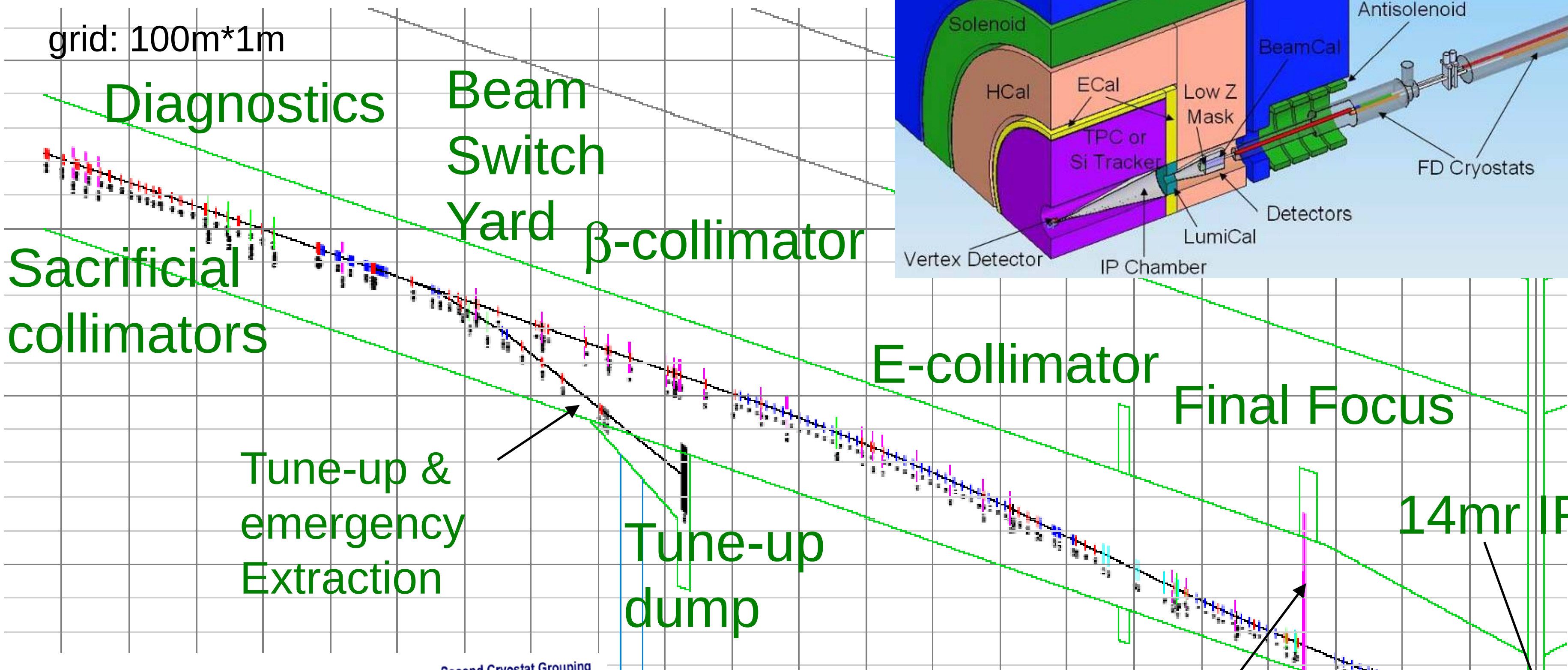
3.3.5 Beam Delivery System

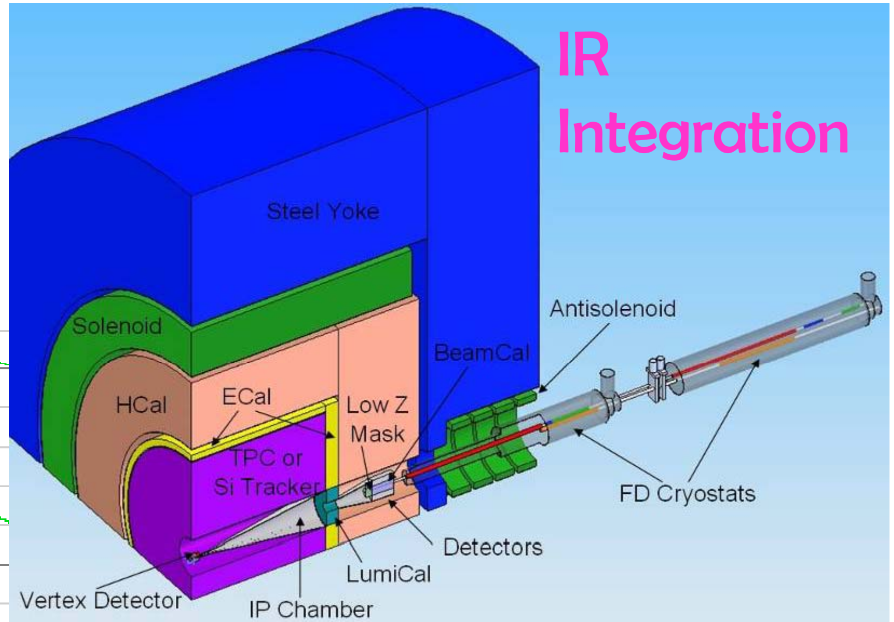
The main R&D focus for the BDS is the ATF-2 programme at KEK which will allow demonstrations of many of the key BDS components and design concepts, the Machine-Detector activity for optimization of the Interaction Region, and design for those BDS subsystems which are critical for system performance or which may expand the physics capabilities of the collider. Examples of R&D are:

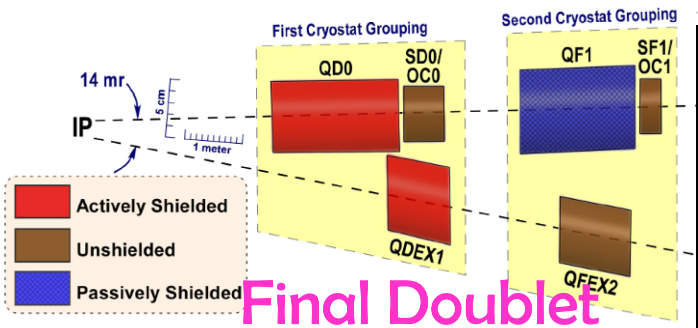
- Development of instrumentation (e.g. laser-wires), algorithmic control software, beam-based feedback systems and emittance-preservation techniques to achieve the small beam-size goals (2010)
- Developing of IR Interface Document defining MDI specifications and responsibilities (2010) and design or optimised IR (2012)
- Development of the prototype of the Interaction Region SC Final Doublet (2012)
- Development of Interferometer system for FD stability monitoring (2012)
- Design of the beam dump system (2012)
- Tests of SC and PM Final doublet at second stage of ATF2 (2012)
- Design studies for the photon collider option (2012)
- Collimation and dump window damage tests at ATF2 (2010)
- Development and demonstration of the SCRF crab-cavity system (2010)

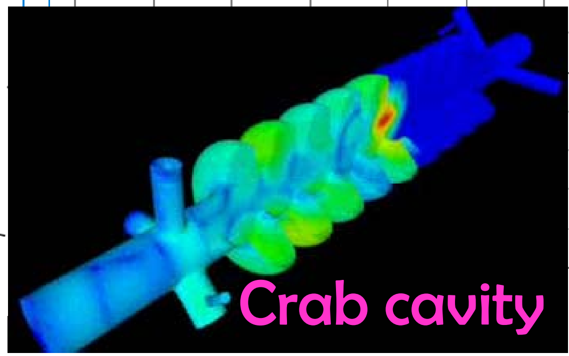
BDS RDR design

1TeV CM, single IR, two detectors, push-pull

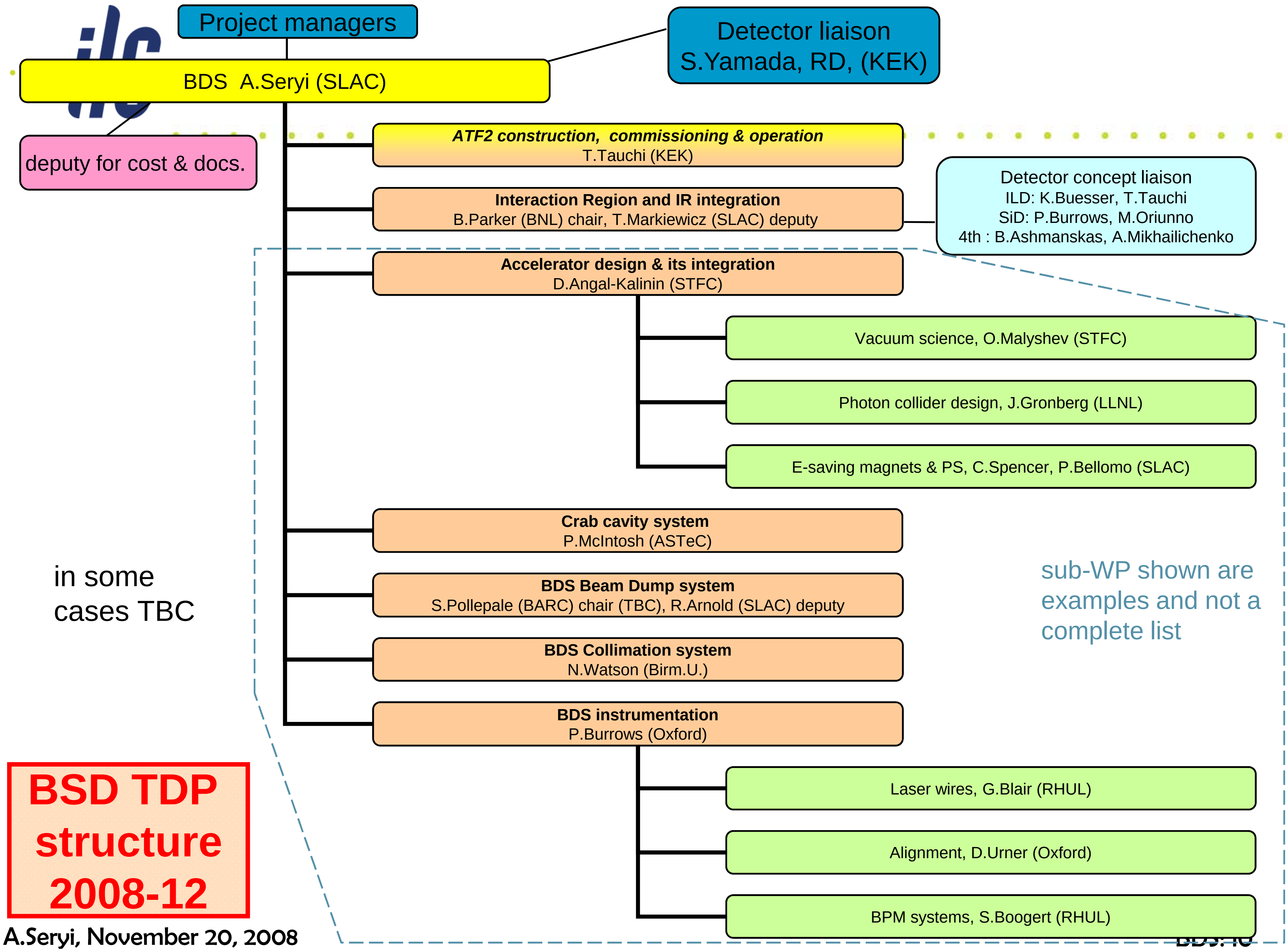




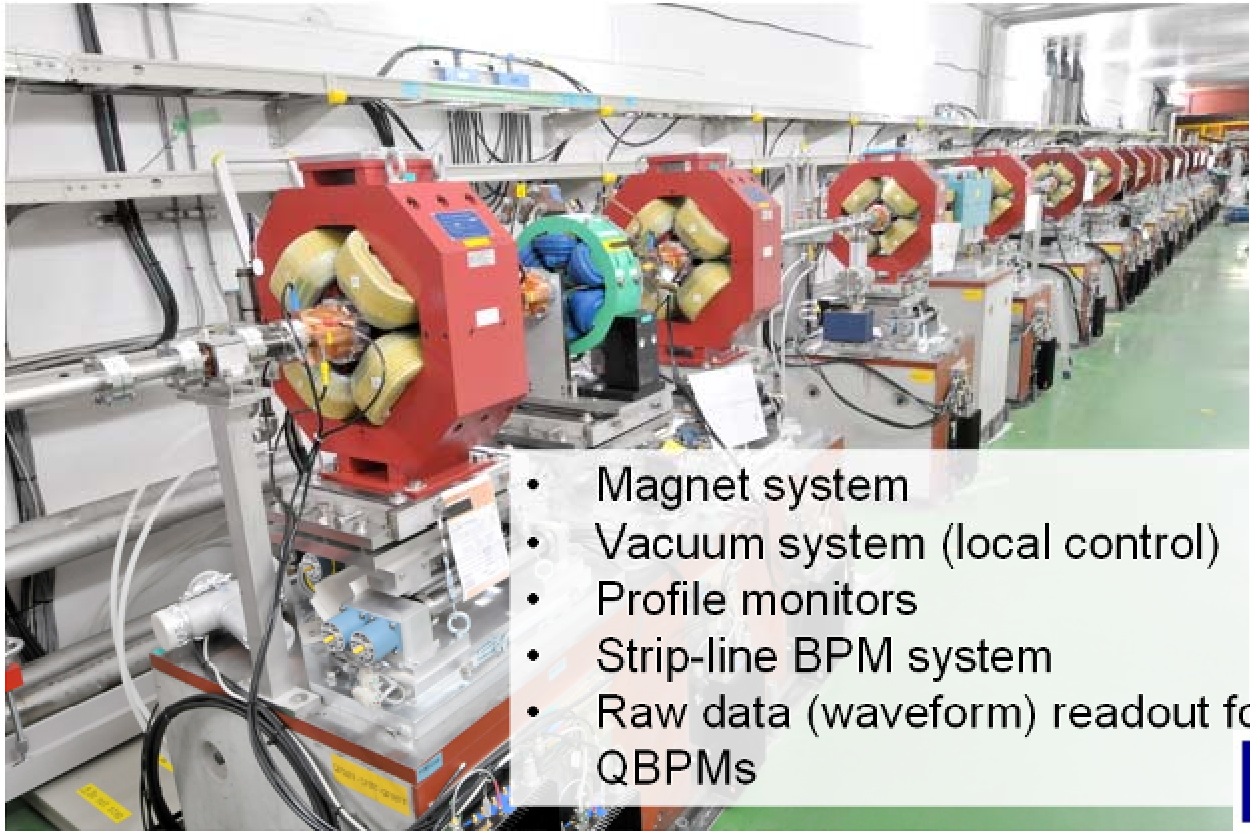




BSD TDP structure 2008-12



Finished works for ATF2 beamline



- Magnet system
- Vacuum system (local control)
- Profile monitors
- Strip-line BPM system
- Raw data (waveform) readout for QBPMs

ATF/ATF2 Status

N. Terunuma (KEK)

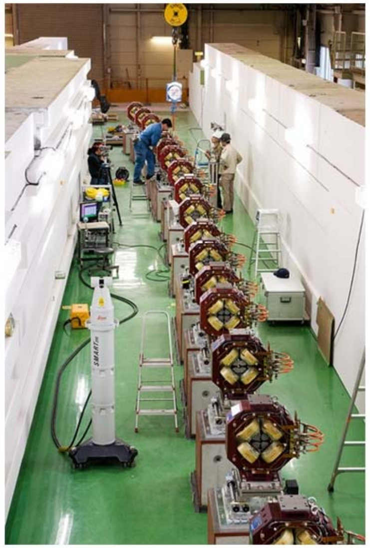
Status after last ICB meeting at DESY.

- New RF gun installation
- Alignment of DR magnets
- **ATF2 construction**

Summary

- We expect the better injection efficiency by newly installed RF gun.
- DR emittance recovery is higher priority.
- We have a lot of remaining works for ATF2 and they should be finished soon.
- Commissioning of ATF2 will be started soon.

ATF2 construction


2008/2

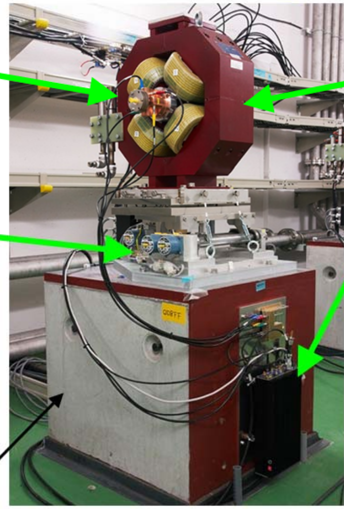

2008/5


2008/9: new EXT

International Contribution (1)
ATF2 Q-magnet Setup

QBPM
(Cavity BPM)
(KEK,PAL)

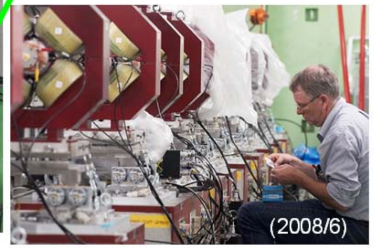
FFTB mover
(SLAC)



Q magnet
(KEK,SLAC,IHEP)

QBPM electronics
(SLAC)

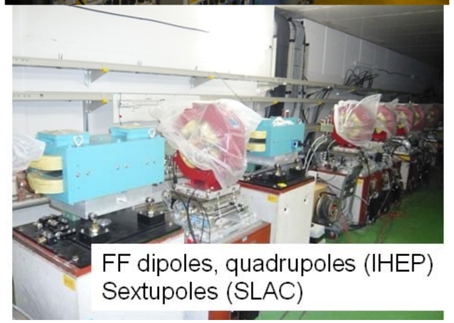
Concrete Base Stand (KEK)

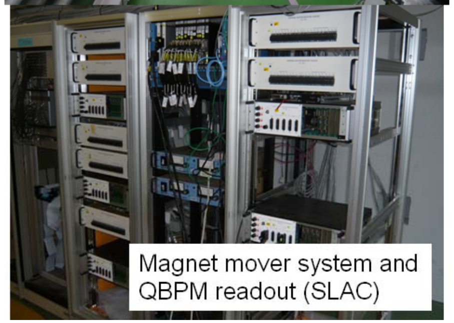

(2008/6)

International contribution (2)


High Availability PS (SLAC)

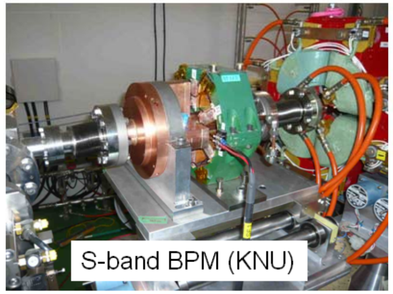

Infrastructures, Cables (KEK)


FF dipoles, quadrupoles (IHEP)
Sextupoles (SLAC)


Magnet mover system and
QBPM readout (SLAC)

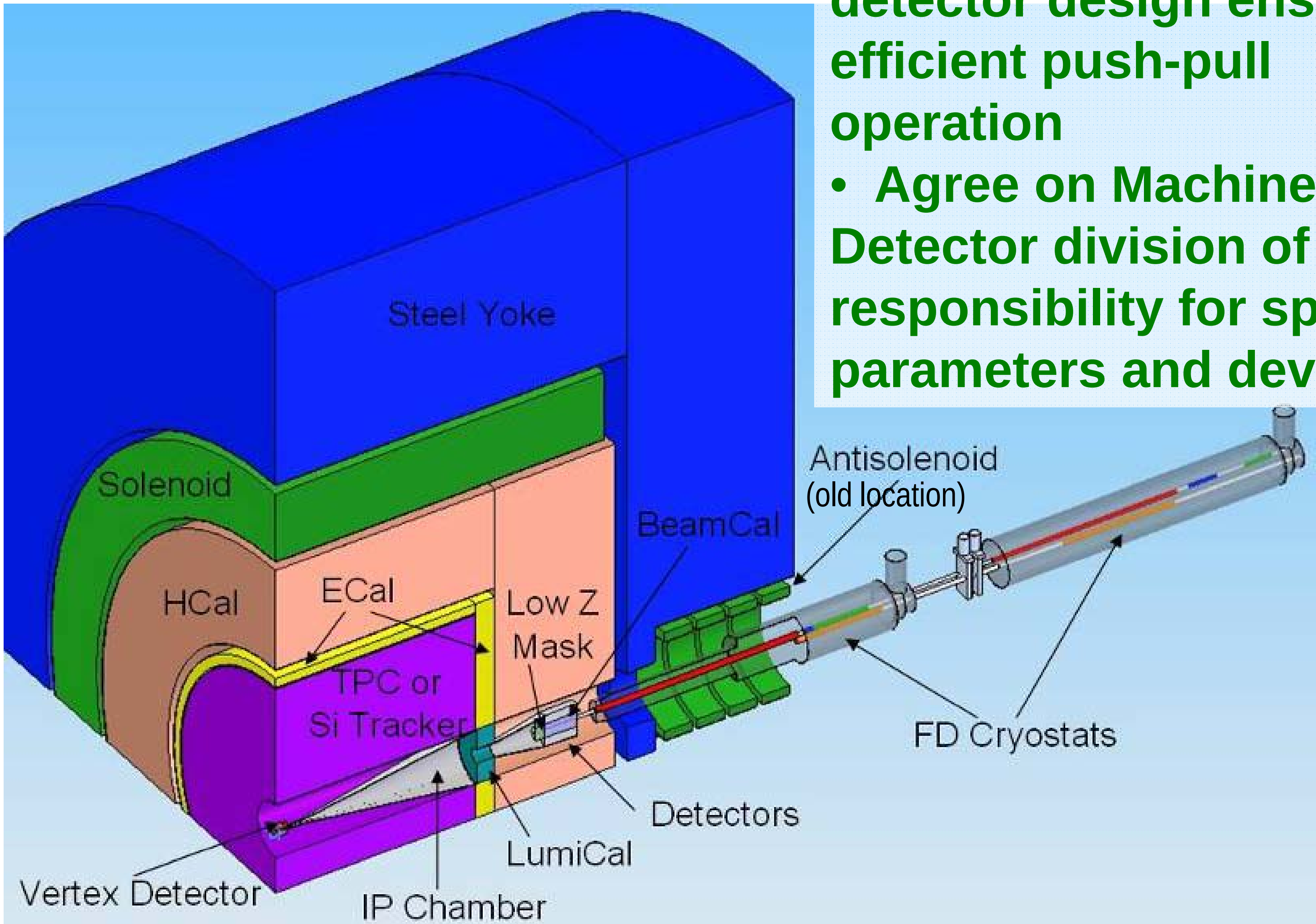
International contribution (3)

Final Doublet system
Magnets and Movers(SLAC)
Supports and Table (LAPP)


S-band BPM (KNU)


IP-BSM (Tokyo Univ.)

IR integration

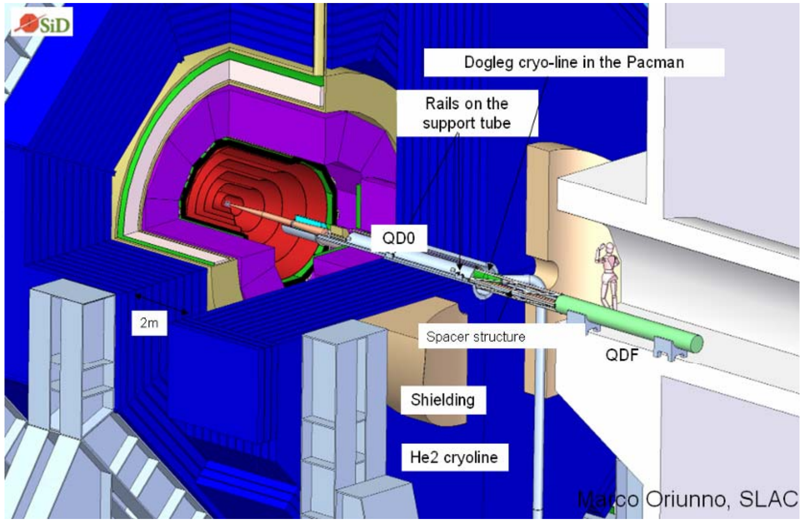


Challenges:

- **Optimize IR and detector design ensuring efficient push-pull operation**
- **Agree on Machine-Detector division of responsibility for space, parameters and devices**

IR integration

- Machine – Detector work on Interface issues and integration design is a critical area and a focus of efforts
- IR integration timescale
  - EPAC08 & Warsaw-08
    - Interface document, draft
  - LCWS 2008
    - Interface doc., updated draft
  - LOI, April 2009
    - Interface document, completed
  - Apr.2009 to ~May 2010
    - design according to Interface doc.
  - ~May 2010: LHC & start of TDP-II
    - design according to Interf. doc and adjust to specific configuration of ILC



EPAC08

CHALLENGES AND CONCEPTS FOR DESIGN OF AN INTERACTION REGION WITH PUSH-PULL ARRANGEMENT OF DETECTORS – AN INTERFACE DOCUMENT*

B.Parker (BNL), A.Herve, J.Osborne (CERN), A.Mikhailichenko (Cornell Univ.), K.Buesser (DESY), B.Ashmanskas, V.Kuchler, N.Mokhov (Fermilab), A.Enomoto, Y.Sugimoto, T.Tauchi, K.Tsuchiya (KEK), J.Weisend (NSF), P.Burrows (Oxford Univ.), T.Markiewicz, M.Oriunno, A.Seryi, M.Sullivan (SLAC), D.Angal-Kalinin (STFC), T.Sanuki, H.Yamamoto (Tohoku Univ.)

Abstract

Two experimental detectors working in a push-pull mode has been considered for the Interaction Region of the International Linear Collider [1]. The push-pull mode of operation sets specific requirements and challenges for many systems of detector and machine, in particular for

The speed of push-pull operation is the first defining assumption. We set as the goal that hardware design should allow the moving operation, reconnections and possible rearrangements of shielding to be performed in a few days, or less than a week.

The range of detector sizes considered in the design

ILC-Note-2008-nnn
December 2008
Version 0, 2008-11-16

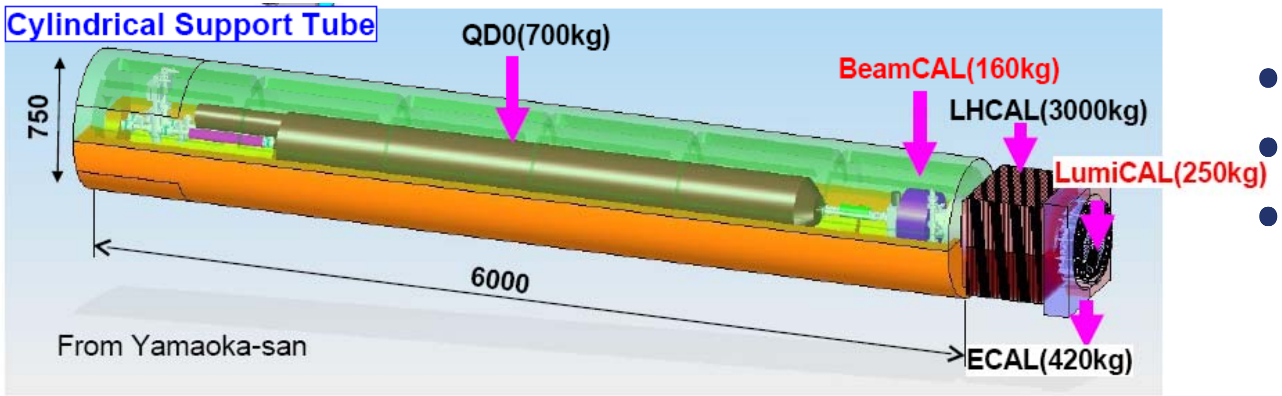
Functional Requirements on the Design of the Detectors and the Interaction Region of an e^+e^- Linear Collider with a Push-Pull Arrangement of Detectors

B.Parker (BNL), A.Mikhailichenko (Cornell Univ.), K.Buesser (DESY), B.Ashmanskas (Fermilab), T.Tauchi (KEK), P.Burrows (Oxford Univ.), T.Markiewicz, M.Oriunno, A.Seryi (SLAC)

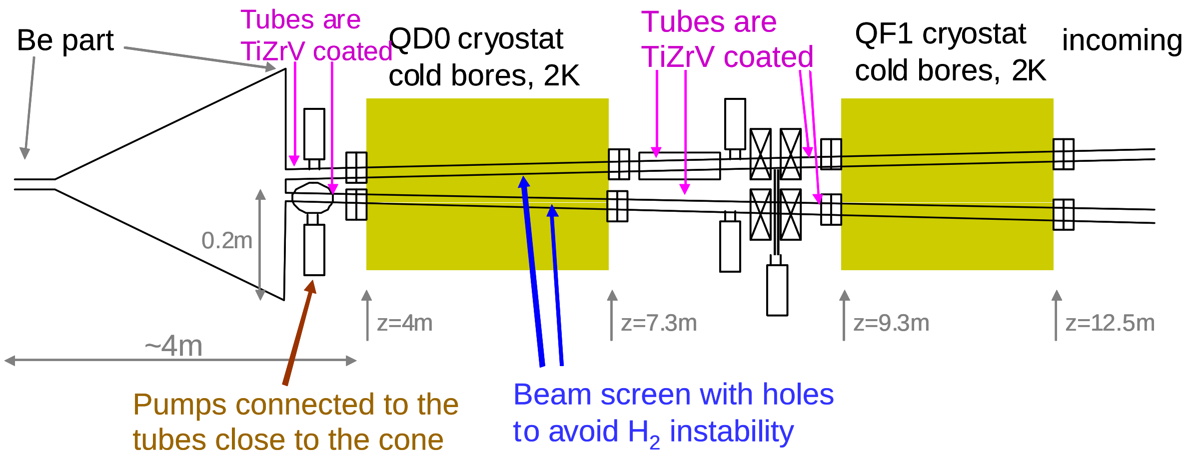
Abstract

The Interaction Region of the International Linear Collider [1] is based on two experimental detectors working in a push-pull mode. A time efficient implementation of this model sets specific requirements and challenges for many detector and machine systems, in particular the IR magnets, the cryogenics and the alignment system, the beamline shielding, the detector design and the overall integration. This paper attempts to separate the functional requirements of a push pull interaction region and machine detector interface from the conceptual and technical solutions being proposed by the ILC Beam Delivery Group and

Hot MDI issues, examples



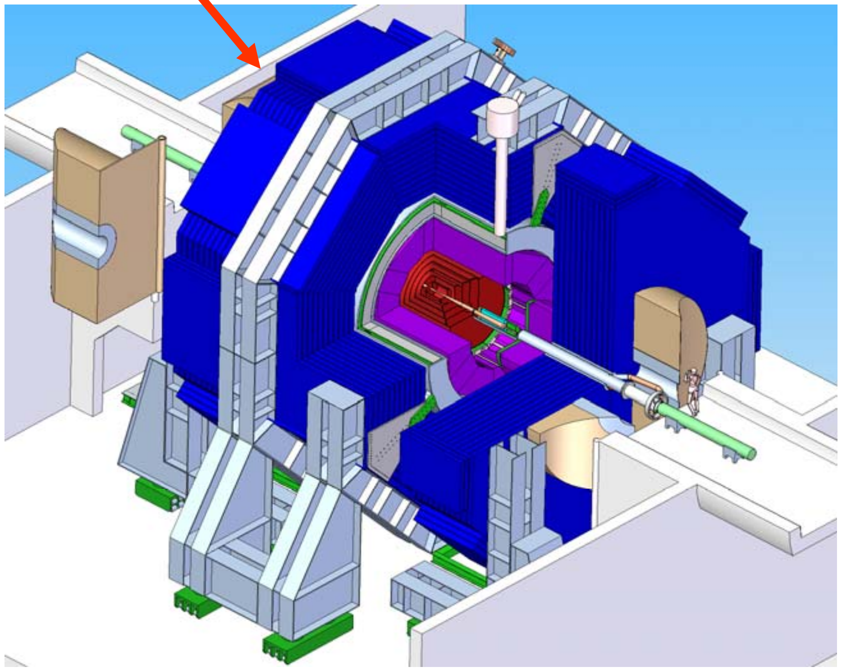
- < 50nm for QD0 stability
- compact movers for QD0
- support ~3t LHCAL mass such that it does not adversely affect the QD0 dynamics

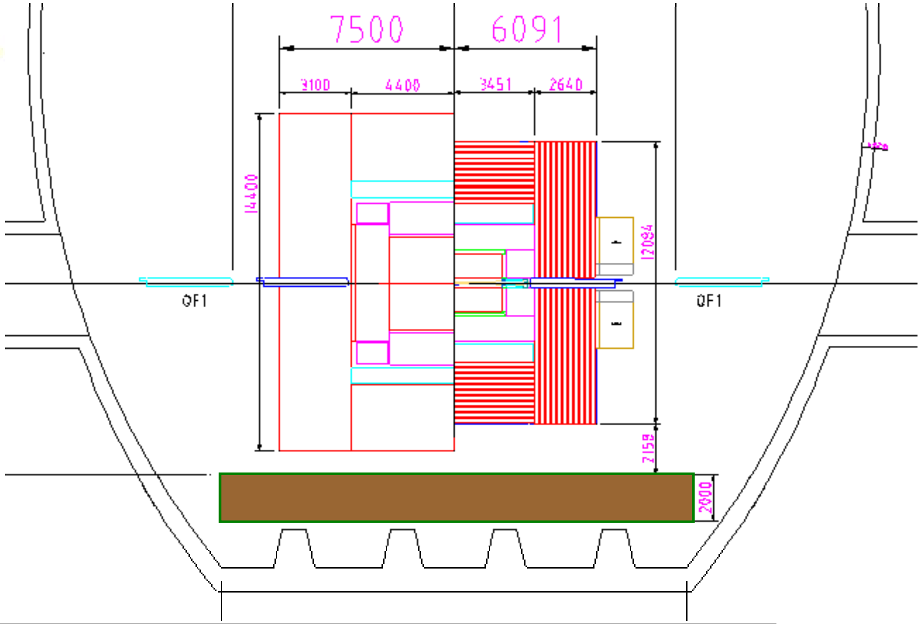


- May need pump close to IP
- Do not rely on QD0 cold bore cryo-pumping
- High Order Modes
- Support and alignment of IR chamber and VX
- Assembly, flanges...

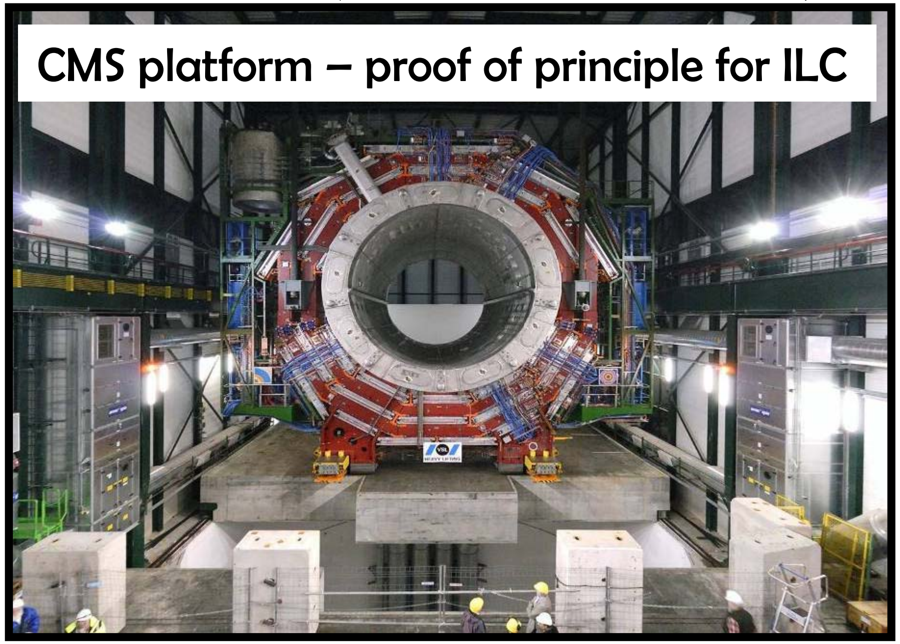
Hot MDI issues, examples

Detector motion system with
or without an intermediate platform



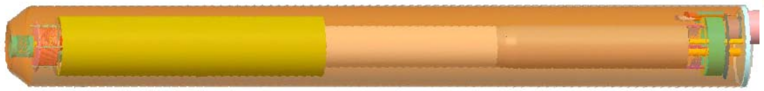


• Working assumption: use platform
• As detector design develops, a feasible and cost effective solution without a platform might be found

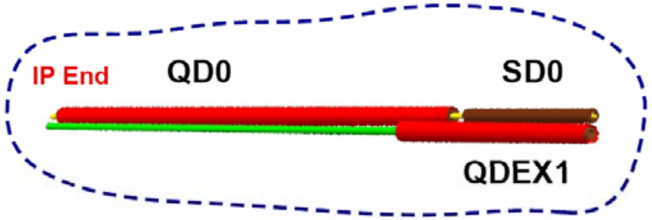


CMS platform – proof of principle for ILC

SC FD modified plans and ATF2 tests

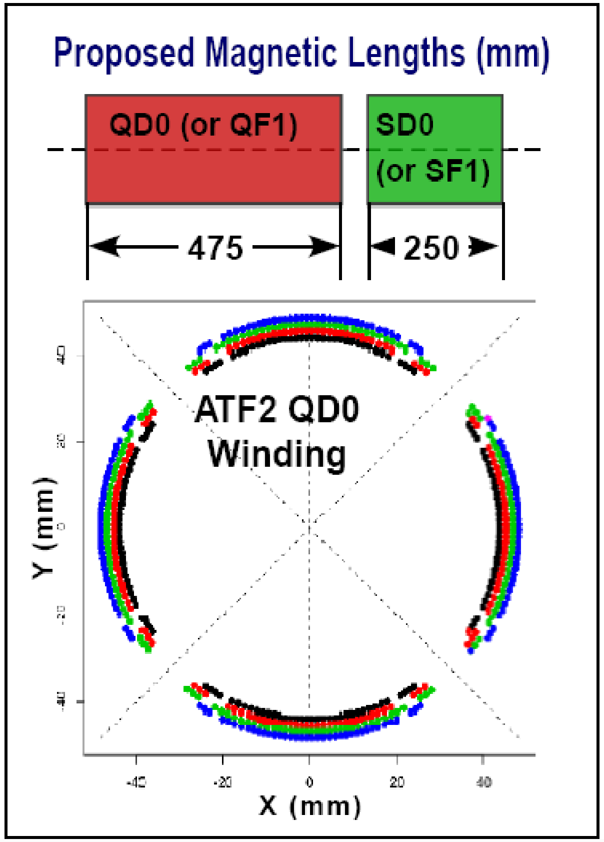


QD0 Cryostat Design for L* = 4.5 m.



Earlier plan was to prototype ILC-like QD0 magnet with cryostat & study its stability

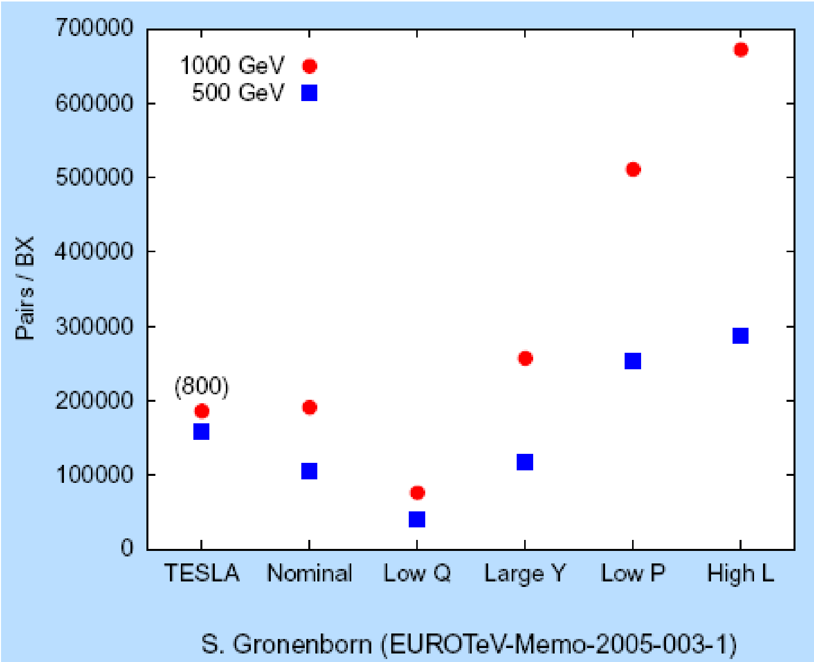
- In TDP, has adjusted the plans for SC FD prototype at BNL
  - reduce efforts on ILC-like FD prototype; make only long cold mass and perform its field & stability tests
  - enhance efforts on ILC-technology-like SC Final Doublet for ATF2 upgrade

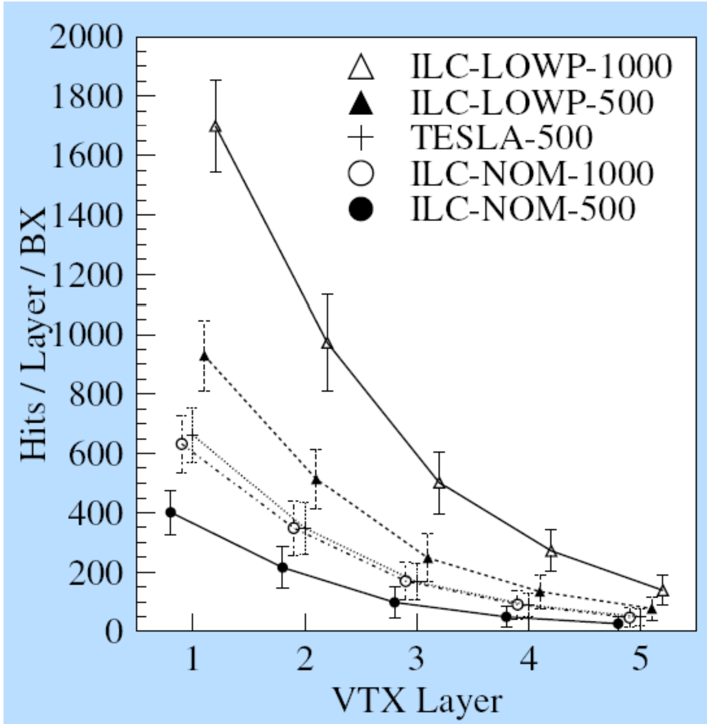


- Only produce one quadrupole/sextupole magnet combination (in common cryostat).
- No self-shielding or anti-solenoid (simple).
- KEK Cryogenic system (major challenge).
- 50 mm aperture but with a warm bore (i.e. optimize to limit cold mass heat leak).
- Minimum degrees of freedom (correctors).
- Found it easy to match corrector coils and main coil magnetic lengths.

Support search for optimal IP parameters for min machine

- The "low power" option may be a **machine** "cost saving" set
- The RDR "Low P" is not a favorite set for detectors:

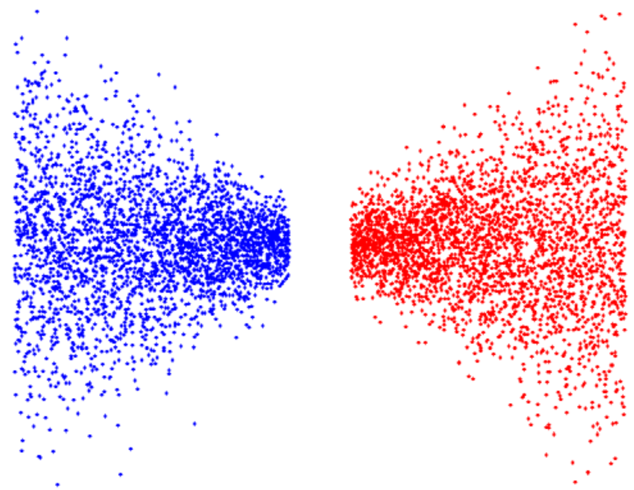


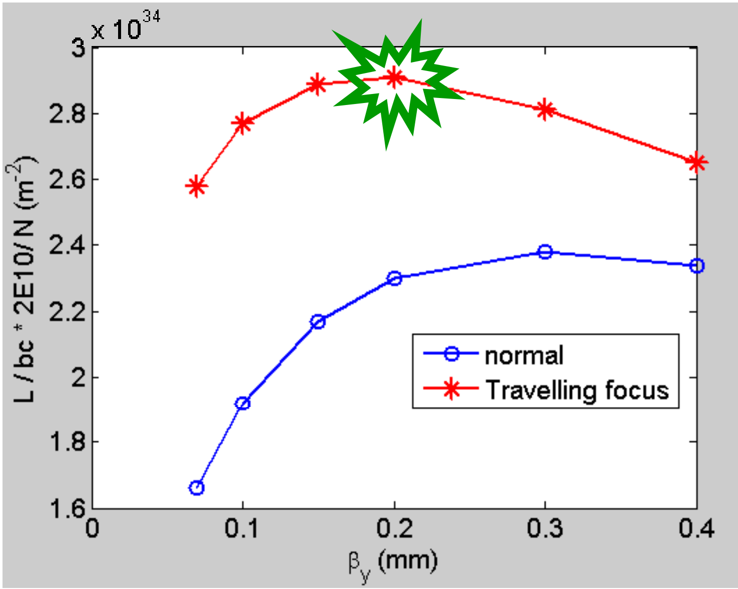


- Improved version of Low Power may require tighter IP focusing, and use of "travelling focus" [V.Balakin, 1990]

New low P parameters

	Nom. RDR	Low P RDR	new Low P
E CM (GeV)	500	500	500
N	2.0E+10	2.0E+10	2.0E+10
n_b	2625	1320	1320
F (Hz)	5	5	5
P_b (MW)	**10.5**	**5.3**	**5.3**
$\gamma\varepsilon_X$ (m)	1.0E-05	1.0E-05	1.0E-05
$\gamma\varepsilon_Y$ (m)	4.0E-08	3.6E-08	3.6E-08
βx (m)	2.0E-02	1.1E-02	1.1E-02
βy (m)	4.0E-04	2.0E-04	2.0E-04
Travelling focus	No	No	**Yes**
Z-distribution *	Gauss	Gauss	Gauss
σ_x (m)	6.39E-07	4.74E-07	4.74E-07
σ_y (m)	5.7E-09	3.8E-09	3.8E-09
σ_z (m)	3.0E-04	2.0E-04	**3.0E-04**
Guinea-Pig δE/E	**0.023**	**0.045**	**0.036**
Guinea-Pig L ($cm^{-2}s^{-1}$)	**2.02E+34**	**1.86E+34**	**1.92E+34**
Guinea-Pig Lumi in 1%	1.50E+34	1.09E+34	1.18E+34





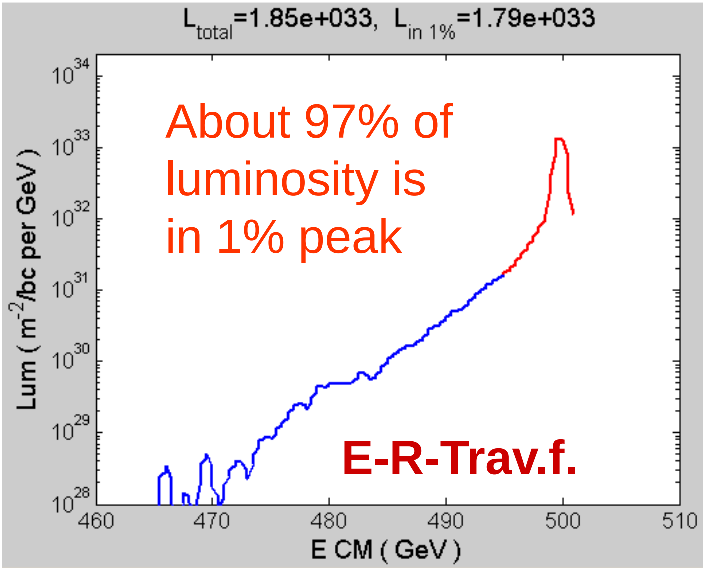
A.Seryi, November 20, 2008

	Nominal RDR	E-R-Trav.f.
E CM (GeV)	500	500
N	2.0E+10	**5.0E+09**
n_b	2625	**11000**
Tsep (ns)	369.2	90.0
Iave in train (A)	0.0087	0.0089
f_{rep}(Hz)	5	5
P_b (MW)	**10.5**	**11.0**
$\gamma\varepsilon_x$ (m)	1.0E-05	4.0E-06
$\gamma\varepsilon_y$ (m)	4.0E-08	2.0E-08
βx (m)	2.0E-02	2.0E-02
βy (m)	4.0E-04	4.0E-04
σ_x (m)	6.39E-07	4.04E-07
σ_y (m)	5.7E-09	4.0E-09
σ_z (m)	3.0E-04	6.0E-04
Dy	19.0	21.2
δ_B	**0.023**	**0.002**
P_Beamstrahlung (MW)	0.24	0.024
ngamma	1.29	0.53
Hd	1.70	**1.53**
Luminosity (cm-2 s-1)	**1.95E+34**	**1.02E+34**

reduced 10 times

Parameter study spin-off

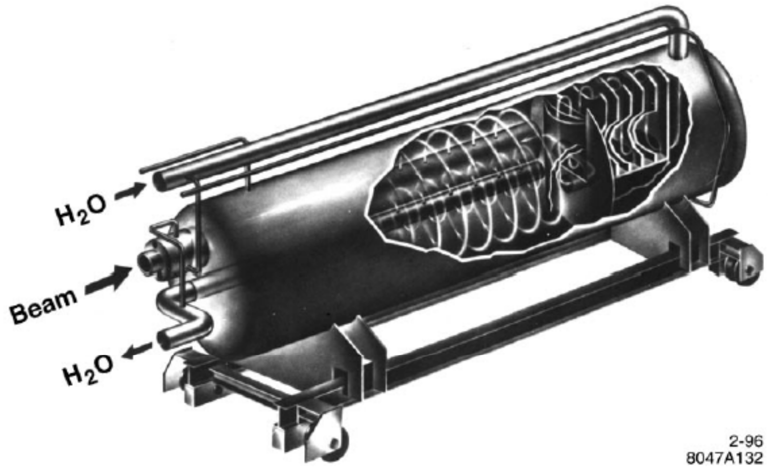
- Parameters with L~1E34, and 10 times lower beamstrahlung dE/E



- Such beams can be decelerated back to ~5-10GeV
  - Beam & energy recycling?
- Approach may be applied to TeV CM set to improve luminosity spectrum

Beam dump design

Beam dump is MDI issue via neutrons coming back to IP which affect lifetime of VX detector



New collaboration with BARC, India, on 18MW beam dump design

SLAC/BARC critical expertise for beam dump project:

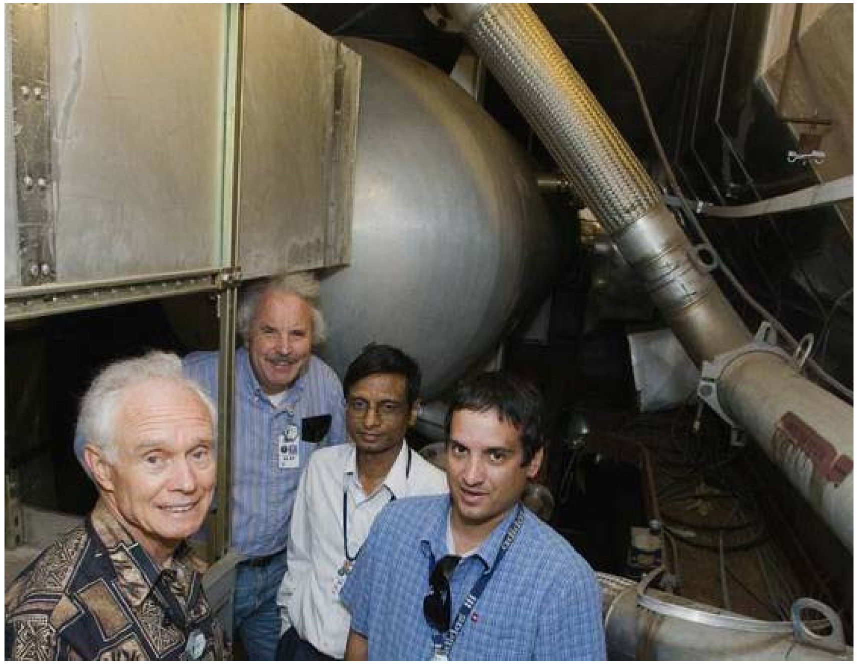
Satyamurthy Polepalle - expert in CFD and thermal hydraulic analysis with numerous successful projects in nuclear physics and power; large technical resources at BARC.

Dieter Walz - expert in beam dump design, materials performance and engineering for particle accelerator applications.

SLAC-BARC Dump Group

J. Amann, R. Arnold, D. Walz
Stanford Linear Accelerator Center
Stanford CA

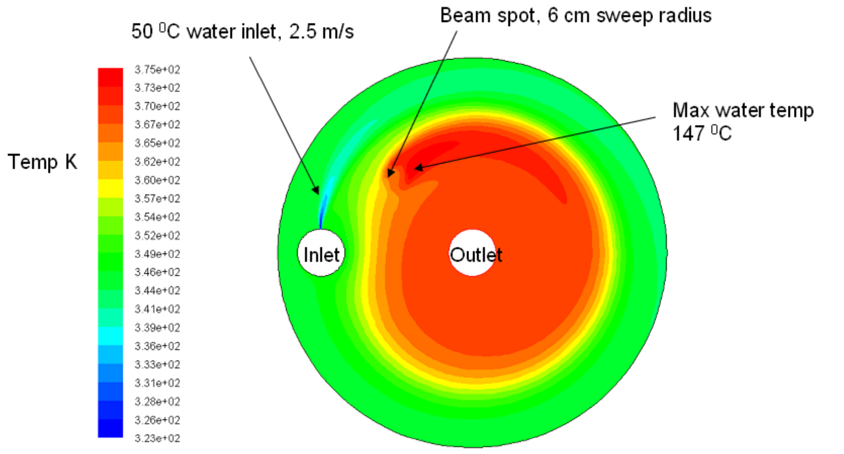
P. Satyamurthy, S.Pal, P. Rai, V. Tiwari
Bhabha Atomic Research Centre
Mumbai, India



Dieter Walz, Ray Arnold, Satyamurthy Polepalle (BARC, India), John Amann, at SLAC beam dump area (February 2008)

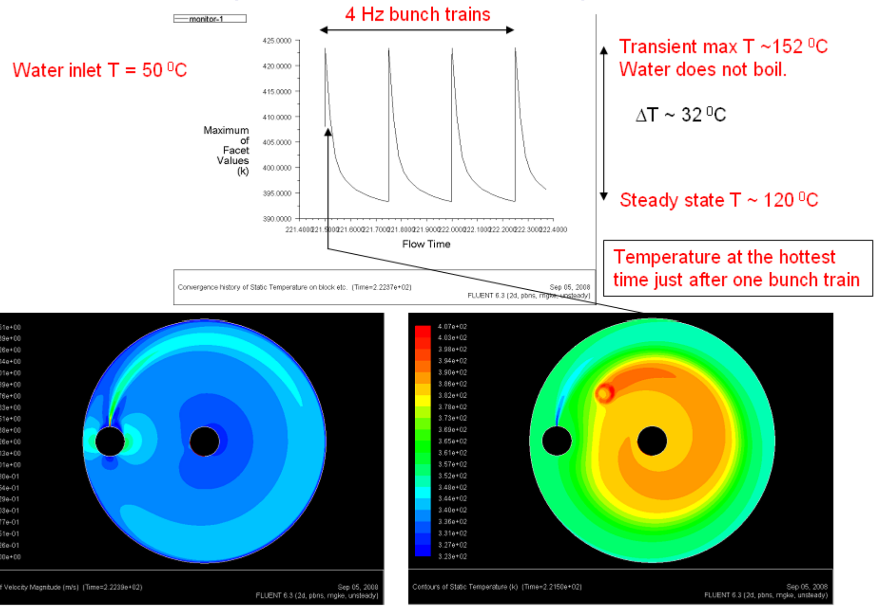
Space Distribution of Steady State Water Temperature

Use 2-D FLUENT models to study water velocity, header size, beam spot location, sweep radius.



Temperature contours for CASE 5b (At location of Z=1.82 m for 2.50 m/s nozzle velocity without blocking outlet)

Time Dependence of Water Temperature

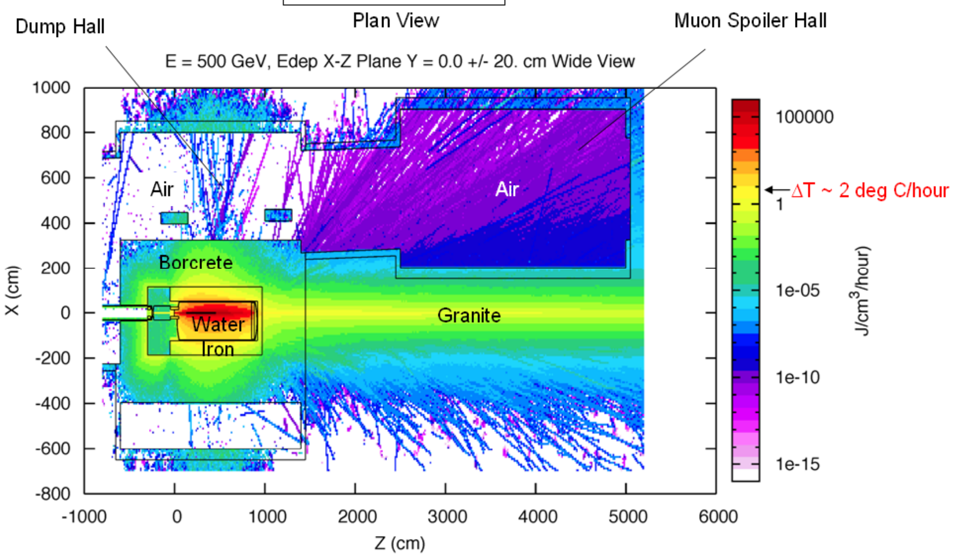


Velocity distribution at 222.3 seconds

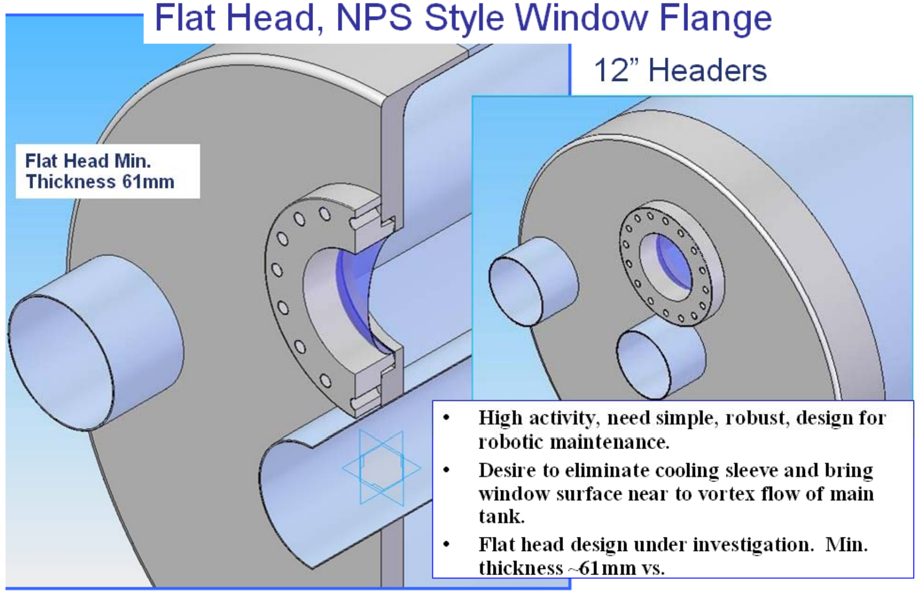
Temperature Distrubution at 221.5 seconds

Prompt Energy Deposition - J/cm^3/hour - Geometry V2

Even the rocks get hot!



Variation of Baseline Design
Flat Head, NPS Style Window Flange



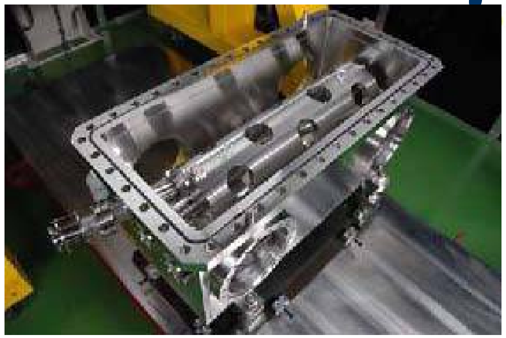
- High activity, need simple, robust, design for robotic maintenance.
- Desire to eliminate cooling sleeve and bring window surface near to vortex flow of main tank.
- Flat head design under investigation. Min. thickness ~61mm vs.

R&D plan for γγ

Public Note / ACCDT / BDS LLNL-TR-403955 ILC-NOTE-2008-043

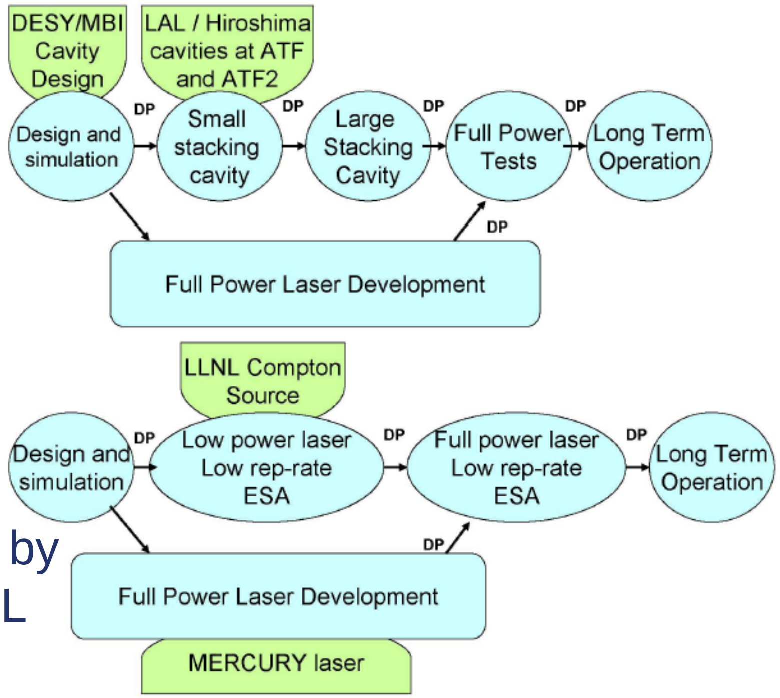
Photon Collider Technology Readiness and Near Term Plans

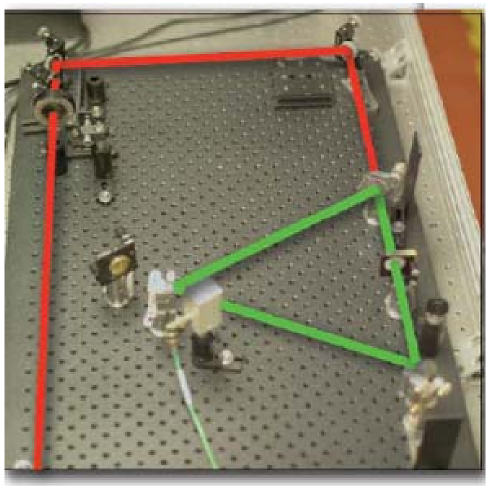
Gronberg, J. ; Omori, T. ; Seryi, A. ; Takahashi, T. ; Telnov, V. ; Urakawa, J. ; Variola, A. ; Woods, M. ; Zomer, F.



Pulse Stacking Cavity
(R&D for Positron source KEK-LAL-Hiroshima-Waseda-Kyoto-IHEP)
enhancement: 300-1000,
tight motion tolerances

- Developed R&D plan based on step-wise approach and large natural synergies with e+ laser cavities R&D





I. Jovanovic, LLNL

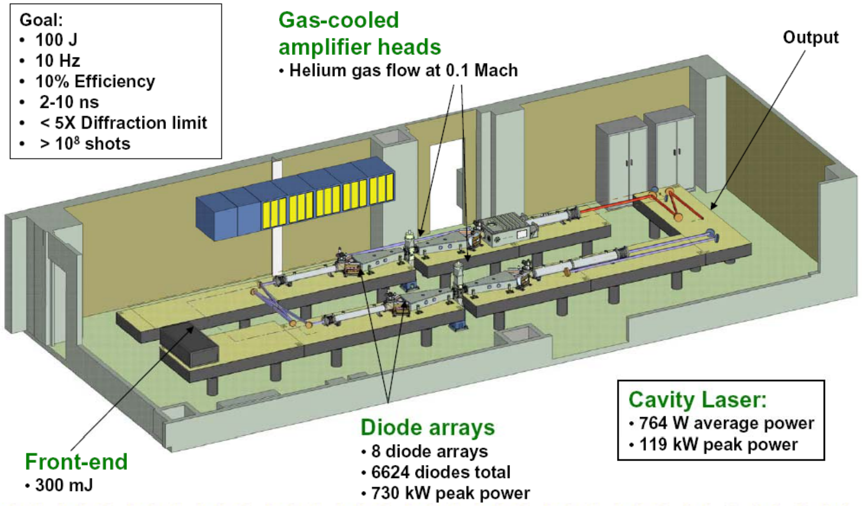
RING (Recirculation Injection by Nonlinear Gating) Cavity LLNL
recirculation of a pulse ~50 times
compensation of circulated pulse decay

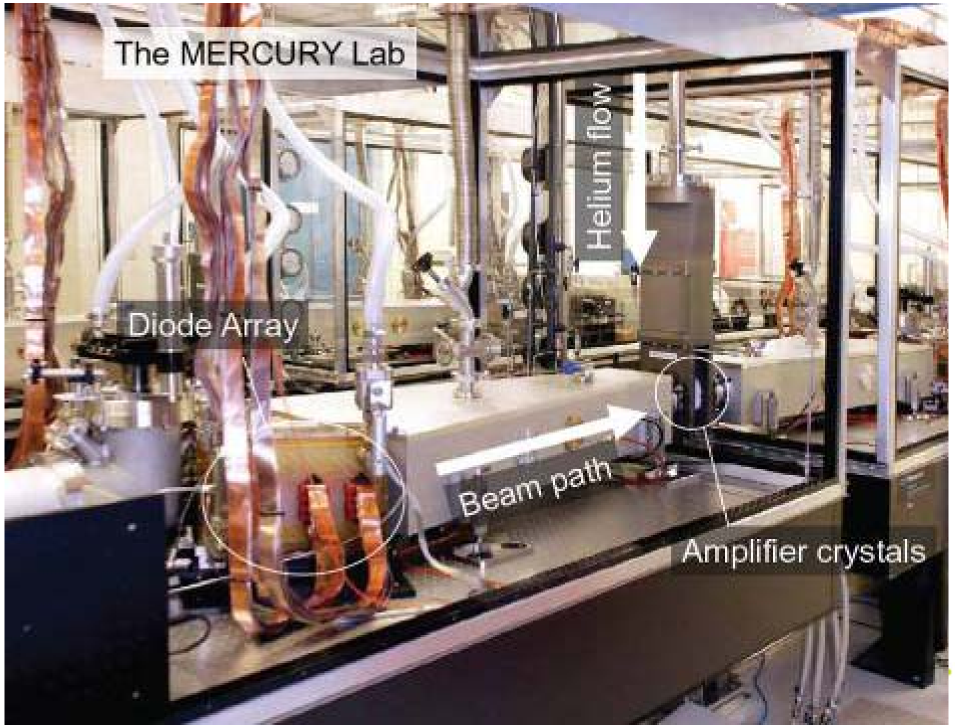
Gamma-gamma laser development at LLNL

Jeff Gronberg / LLNL
November 18, 2008
LCWS08
UIC, Chicago

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

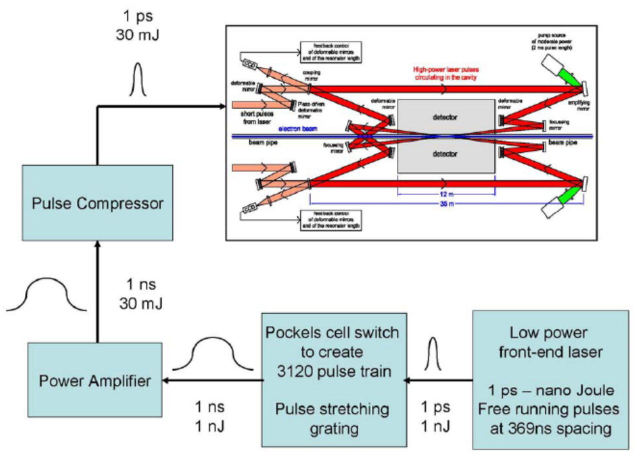
The MERCURY laser is an attempt to create high average power with good efficiency





It is time to develop a conceptual design for a photon collider laser

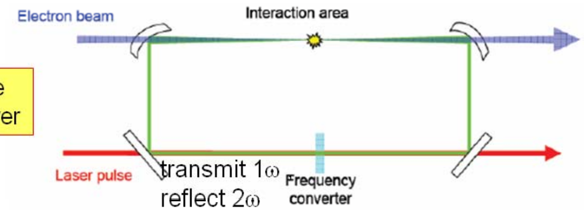
- Average power of ~500W
  - **Been done before**
  - **But not with**
    - ps pulse
    - Good wavefront quality
    - Time formatting
- In 2009 we will create a conceptual design for the laser system
  - **Identify any technology limitations**
  - **Understand the R&D path to demonstrating a workable system**



Ideas to reduce laser power

- RING (Recirculation Injection by Nonlinear Gating) Cavity (Gronberg LEI2007)

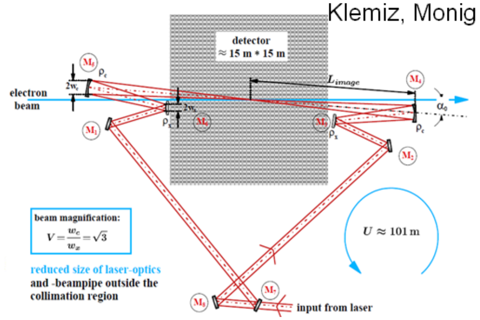
Recirculation of a laser pulse to reduce average laser power



- Pulse Stacking Cavity

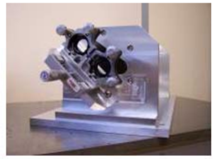
Stack laser pulses on phase to reduce peak as well as average power

Klemiz, Monig



T.Takahashi Hiroshima

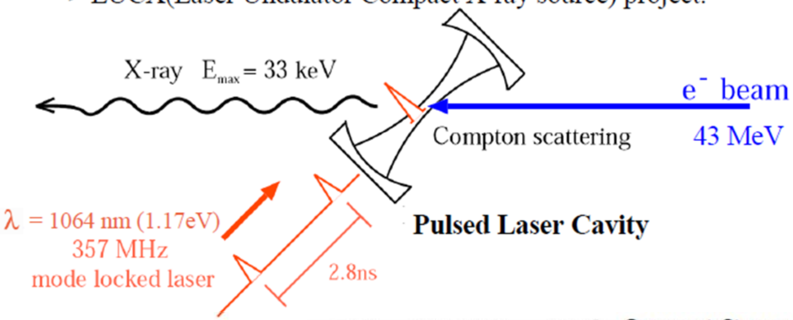
Next plan: 4 mirror ring cavity

	KEK 	LAL 
type	2 mirrors FP	4 mirrors ring
enhancement	1000	10000
Laser spot size	30μm	15μm
Feed back	Analog PID	digital
e-	at ATF, to get experiences with e- beam	stand alone (new w/ e- beam being designed. to be at ATF 2009)

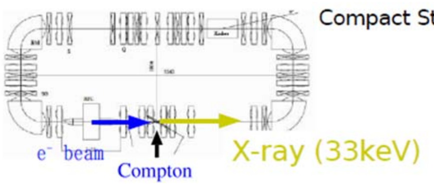
Introduction

Fukuda
PosiPol2008

We have developed an X-ray source based on Inverse Compton Scattering with the pulsed laser-wire Cavity.
=> LUCX(Laser Undulator Compact X-ray source) project.

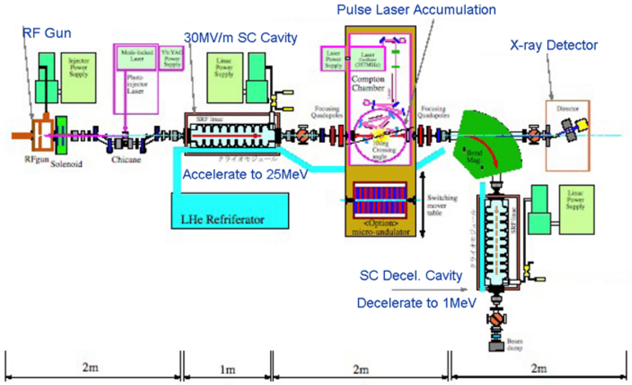


Final layout of high intensity X-ray source



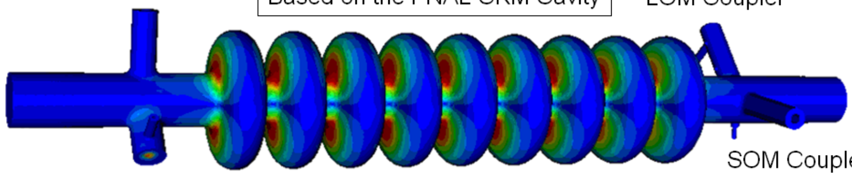
量子ビーム (Ryoushi Biimu, Quantum Beam) Project

High-Intensity Compact X-ray Source

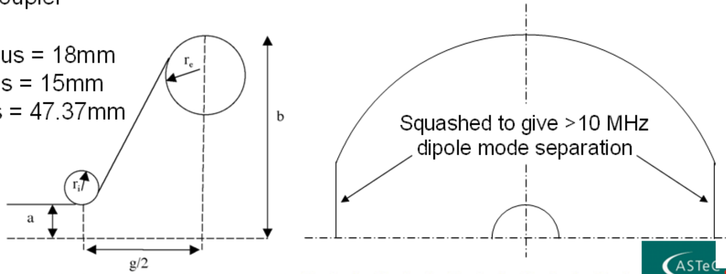


- Must be demonstrated by JFY2012
- Includes 25 MV SC acceleration and deceleration (but perhaps, deceleration can be omitted)
- Beam current (9mA) and pulse length (1ms) same as ILC, but bunch spacing 6.15nsec

ILC-CC Design

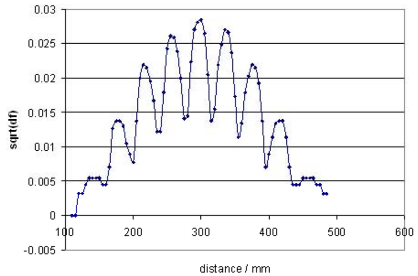


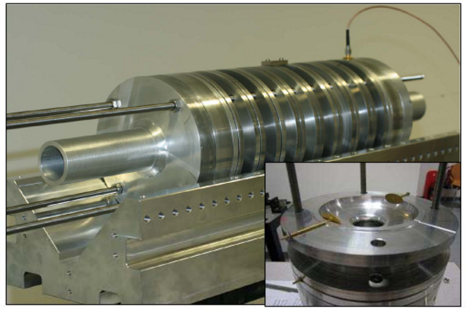
Beam-pipe radius = 18mm
Cavity iris radius = 15mm
Equator Radius = 47.37mm



Structure Characterisation

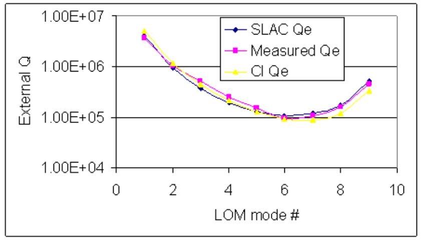
- Model fabricated at DL and used to evaluate:
  - **Mode frequencies**
  - **Cavity coupling**
  - **HOM, LOM and SOM Qe and R/Q**

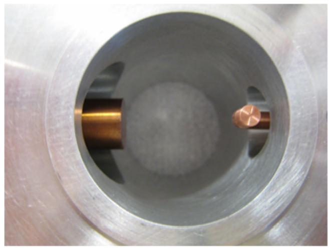




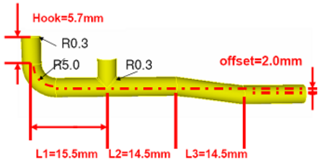
- Modular design allows evaluation of:
  - **Up to 13 cells.**
  - **Including all mode couplers.**

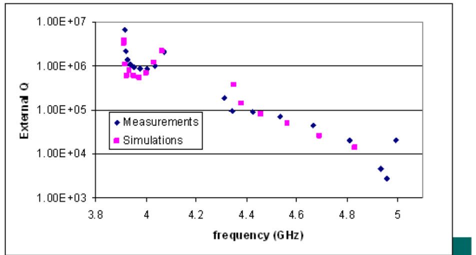
Prototype LOM Qe Measurements





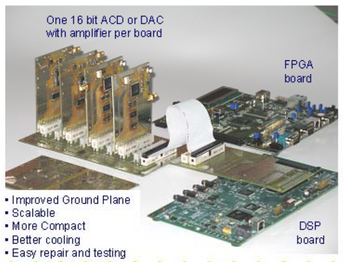
The LOM coupler was found to give good agreement with both MWS and Omega3P simulations.

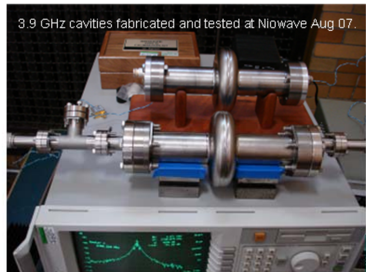




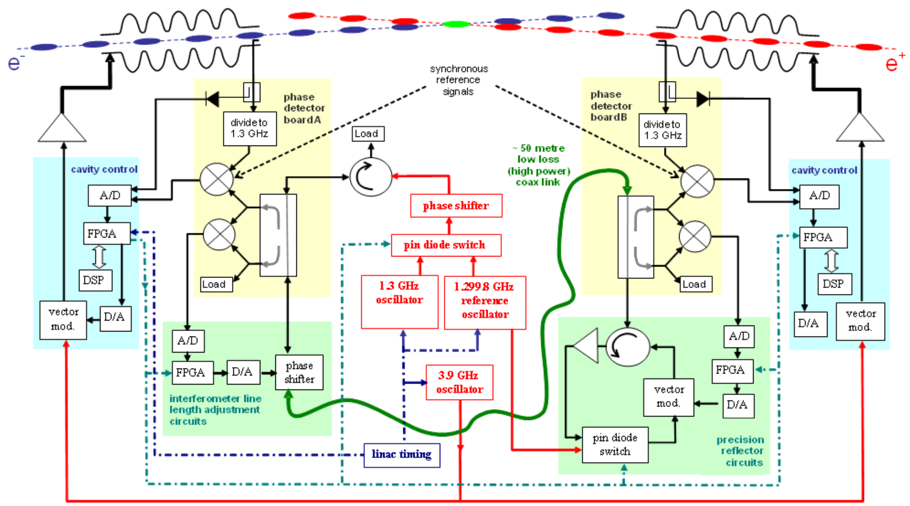
ILC-CC System Verification

- The phase of the field in each cavity is sampled, compared to the timing reference and the error sent to a digital signal processor (DSP) to determine how the input signal must be varied to eliminate the error.
- Provide an RF interferometer between each crab cavity so that the same cavity clock signal is available at both systems.
- 16-bit DAC/ADC architecture (high resolution)



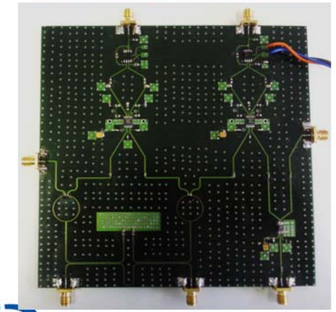


LLRF/Synchronisation Scheme (Final)

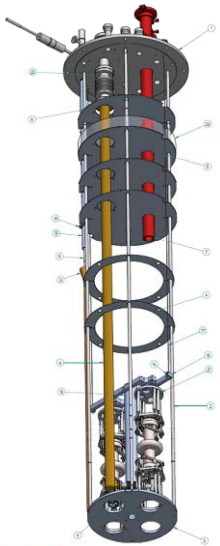


RF Interferometer Controls

Integrated interferometer termination



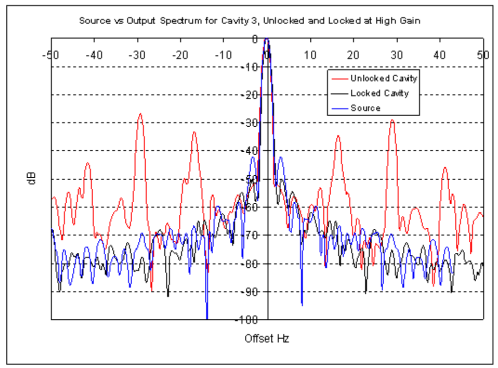
ILC-CC Testing Hardware



Cavities limited in gradient to 1 MV/m (~40kV/cell) – shielding implications.

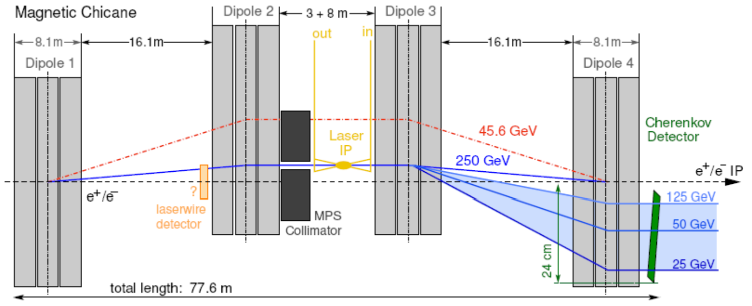
Preliminary Measurement Results

- Independent phase lock achieved for both cavities:
  - Unlocked ⇒ 10° r.m.s.
  - Locked ⇒ 0.135° r.m.s.
- Performance limited by:
  - Source noise (dominant)
  - ADC noise
  - Measurement noise
  - Cavity frequency drift
  - Microphonics
- Improvements being made.
- Next tests scheduled for December 08.



Conflicts with Collimator / Laser Wire

- first remark: scenario completly changed if positron source undulator moved into BDS?!
- but: what happens on the positron side?
- let's still look at the issues...



Recommendations

1. Separate the functions of the upstream polarimeter chicane. Do not include an MPS energy collimator or laser-wire emittance diagnostics; use instead a separate setup for these two.
2. Modify the extraction line polarimeter chicane from a 4-magnet chicane to a 6-magnet chicane to allow the Compton electrons to be deflected further from the disrupted beam line.
3. Include precise polarisation and beam energy measurements for **Z**-pole calibration runs into the baseline configuration.
4. Keep the initial positron polarisation of 30-45% for physics (baseline).
5. Implement parallel spin rotator beamlines with a kicker system before the damping ring to provide rapid helicity flipping of the positron spin.
6. Move the pre-DR positron spin rotator system from 5 GeV to 400 MeV. This eliminates expensive superconducting magnets and reduces costs.
7. Move the pre-DR electron spin rotator system to the source area. This eliminates expensive superconducting magnets and reduces costs.

A.Seryi, November 20, 2008

Summary: BDS progress

- ATF2
  - constructed, hardware mostly commissioned
  - Next: beam commissioning
  - Developing long-terms plans for AFT2
    - SC FD
    - squeezed beta* tests, etc
- IR integration
  - have a new version of "IR Interface Document"
  - the document is focused on functional requirements
  - MDI and DDI (Detector-Detector Interface)
  - Also a lot of progress on detailed Detector and MDI design

Summary: BDS progress

- Minimal machine studies
  - developing new low P set
  - will study optics, layout & interferences in MM
- Reviewed great progress & discussed further plans in
  - Crab cavity work
    - demonstrated 0.13deg phase stability, only x2 from ILC reqs, and know how to improve further
  - Beam dump work
    - Collaboration BARC-SLAC makes great progress
  - Collimation
    - Focus on beam damage tests in near future
  - Instrumentation
    - focus on ATF2 and selected critical instrumentation

Summary: BDS progress

- With gg WG
  - reviewed gg r&d progress
  - outlined next steps for
    - studies of extraction lines
    - lasers and FEL configuration
    - Upstream and IR layout
- Polarization discussion
  - Discussed the list of interferences of existing design
  - Will be looking for design adjustments to minimize interference in most efficient way

Conclusion

- The BDS group, in TDP phase, will focus on several key areas
- Planned work expected to make significant contribution to TDP efforts on reduction of cost, risk and increase of machine performance