# MDI and magnetic configuration of the 4th detector

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***For 4th Collaboration***

TLC09, April 17-21, 2009 –Tsukuba, Japan

Document reflecting MDI statements prepared by MDI team; ILC Note-2009-050

"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 "

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–The speed of push-pull operation less than a week.

– Radiation shielding is essential with two detectors occupying the same Interaction Region hall.

– Requirement for the magnetic field outside of detector is an important factor which defines the amount of iron in the detector (or degree of compensation for iron-free design).

– Vibration stability requirements about 50nm.

– Dimensions of the cavern and beam height above the floor of IR cavern.

– For reference, the detector has its own internal alignment requirements, which typically involve measuring vertex position with respect to tracker on micron level, and measuring tracker to calorimeter on mm level.

# BASIC PRINCIPLES OF 4$^{TH}$ AFFECTING MDI

- The dual solenoids plus end wall current coils allow:

  1) Strict confinement of magnetic field inside limited region; second solenoid closes the flux (minimal configuration).
  2) Spectroscopy of muons in magnetic field between solenoids
  3) Incorporate FF optics for better stability
  4) Modular design which helps in modifications and re-installations
  5) lightweight detector having flexible functionality and remarkable accuracy
  6) Easiest incorporation of laser optical system for gamma-gamma collisions

- Active alignment-mechanical and electric (tested at FFTB). Vibration of frame and quads could be reduced to the level required by passive and active systems;

- Final lenses incorporated in detector; stability of Final Doublets (from each side) stabilization could be arranged easier as they are installed on the same frame;

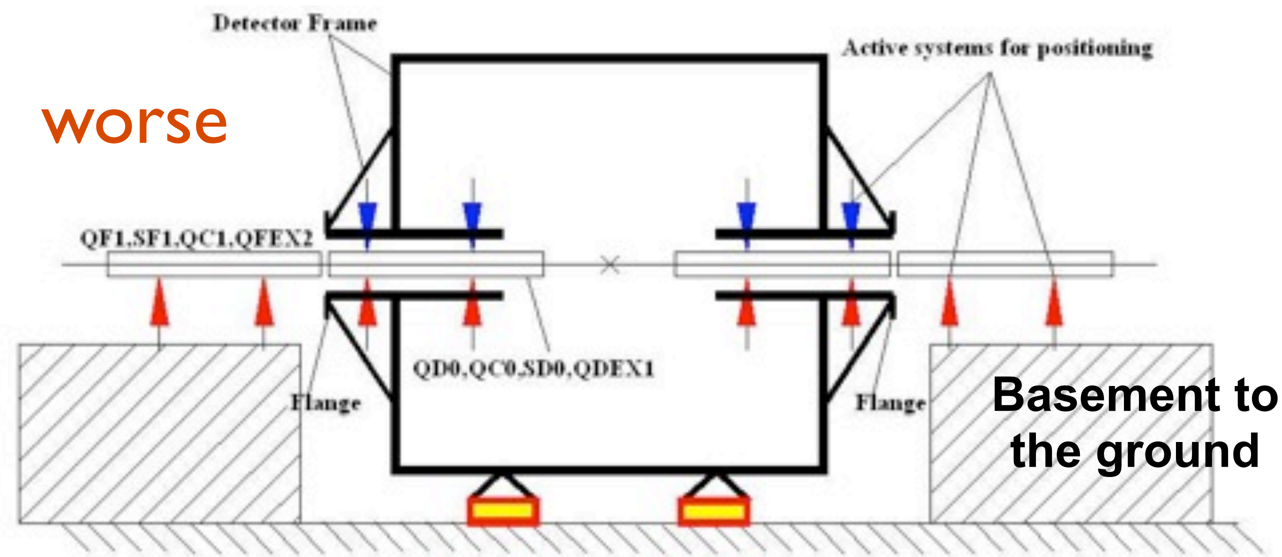
- Iron is absent; protection arranged by surrounding (Borated) concrete blocks;

- Light weight detector allows easy transportation and re-alignment;

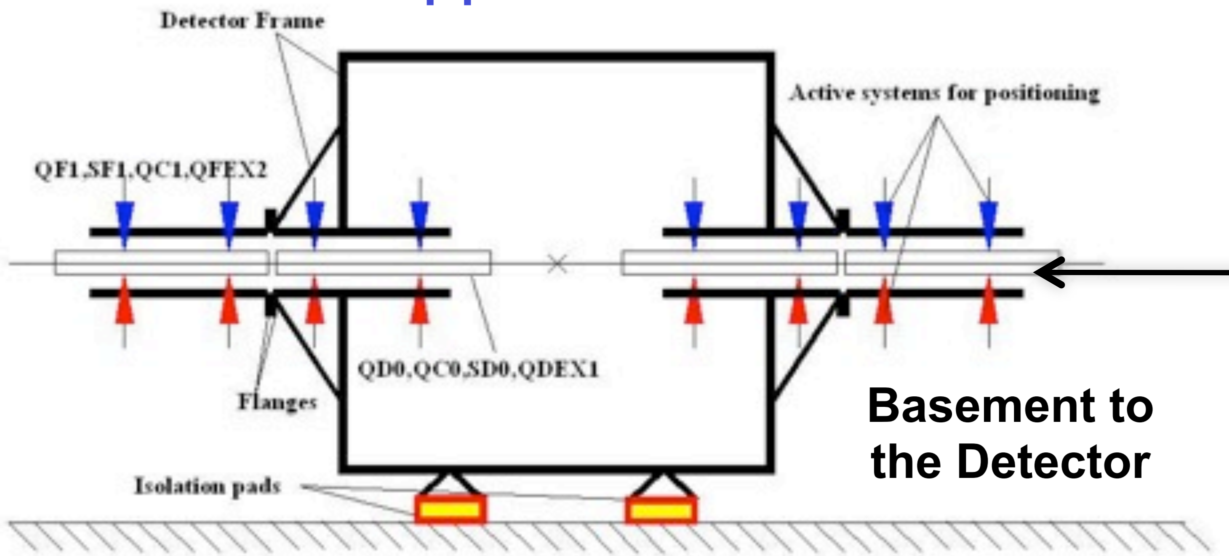
- Push-pull concept satisfied easily; platform allows even quicker motion;

# CONCEPTS OF FF OPTICS INSTALLATION

worse




better – 4th approach

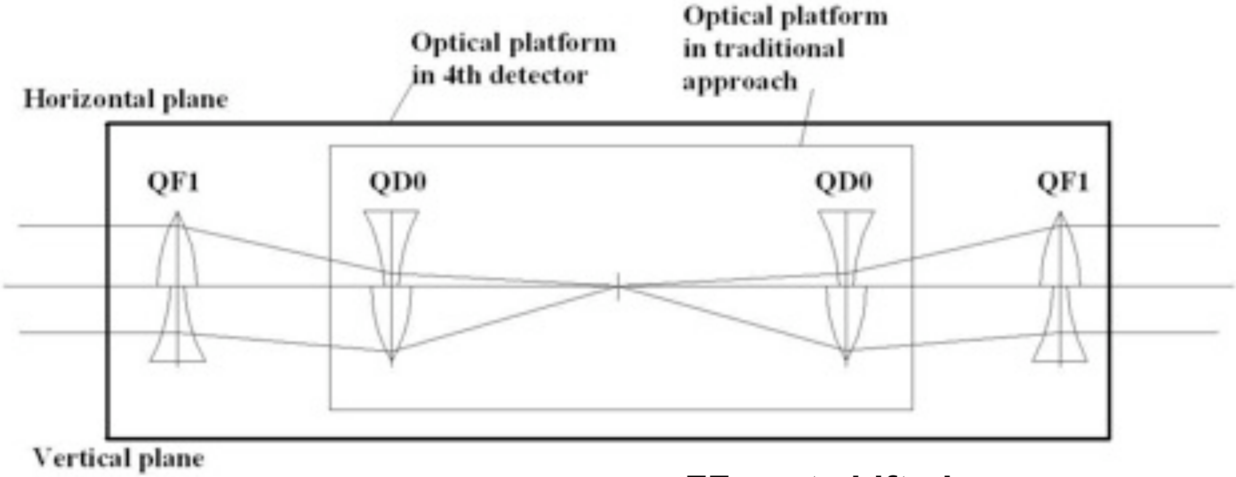


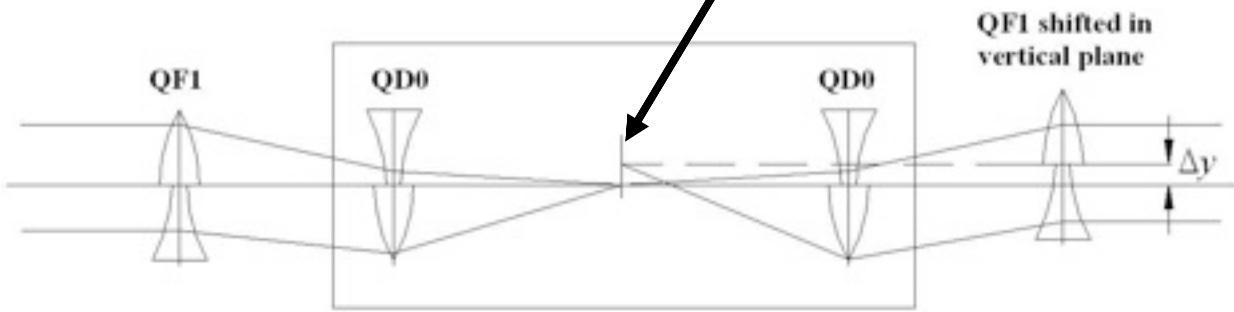

Active systems for positioning include:

- Stepping motor-driven micro-positioning movers (tested at FFTB);
- Piezoelectric fast movers with active feedback;
- Dipole windings in each quadrupole for equivalent shift of quadrupole axis in both transverse directions (tested at FFTB).

Attachment of cryostat with QF1 to the detector frame could be done after positioning detector in place

# Analog with ordinary optics-all elements must be at the same platform




Displacement of lens and displacement at IP linked by equation

$$\delta y(s_1) = \frac{\Delta y G l}{(HR)} \sqrt{\beta_x(s_1)\beta_x(s_0)} Sin(\Delta\Phi) \cong \frac{\Delta y G l}{(HR)} \sqrt{\beta_x(s_1)\beta_x(s_0)}$$

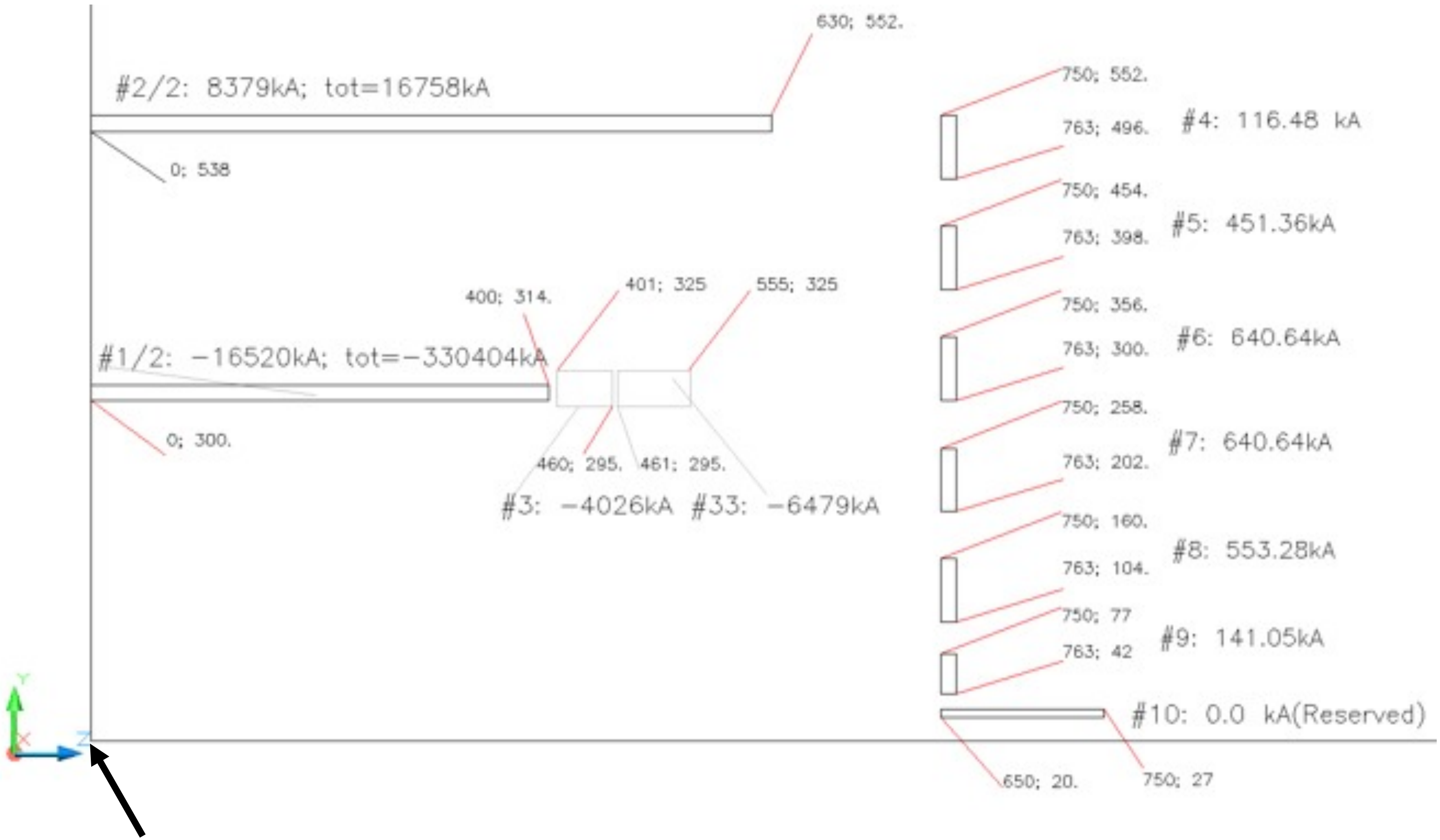
←**Must be much less, than the beam size**

Where Dy is lens displacement, b($s_1$) –beta function at IP, b($s_0$)-beta function at lens location, G-lens gradient, l –length of lens, (HR)=pc/300 –magnetic rigidity



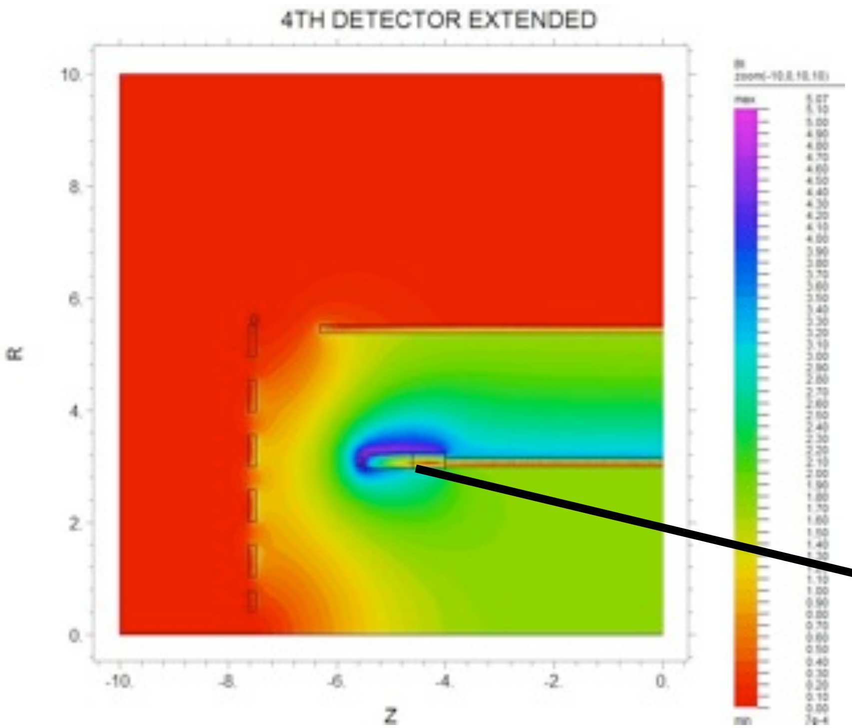
It yields Dy <1.3nm ; with $4^{th}$ approach this effect is not manifest

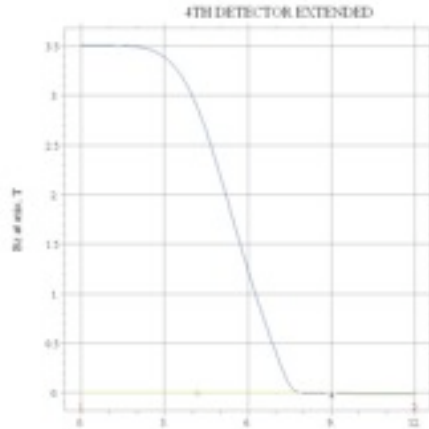
# COIL DIMENSIONS USED FOR PRELIMINARY MODELING



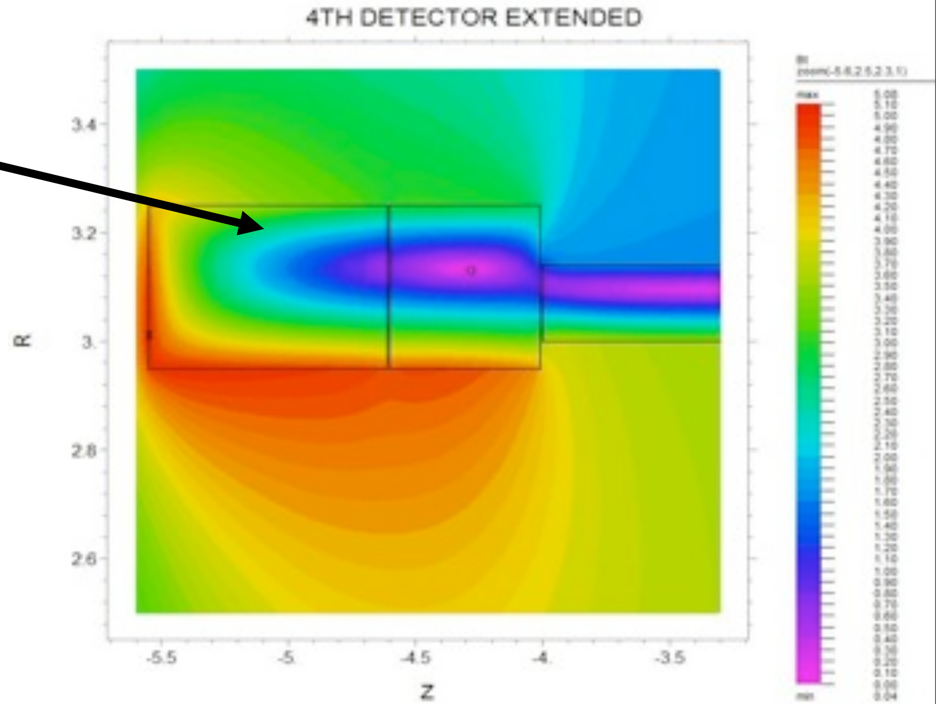

Center of Detector

# Field around end coil with simplest configuration



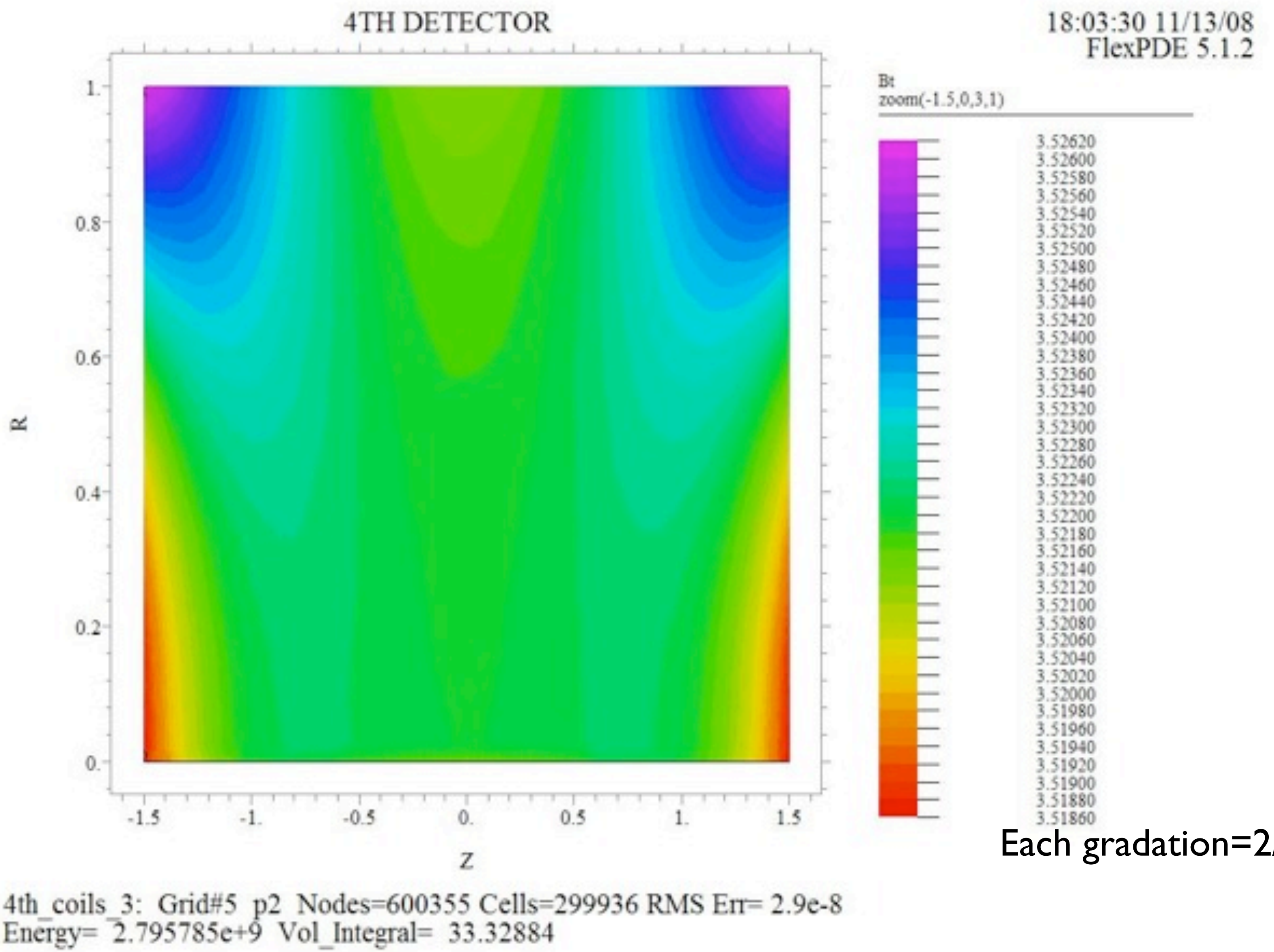




Longitudinal field distribution



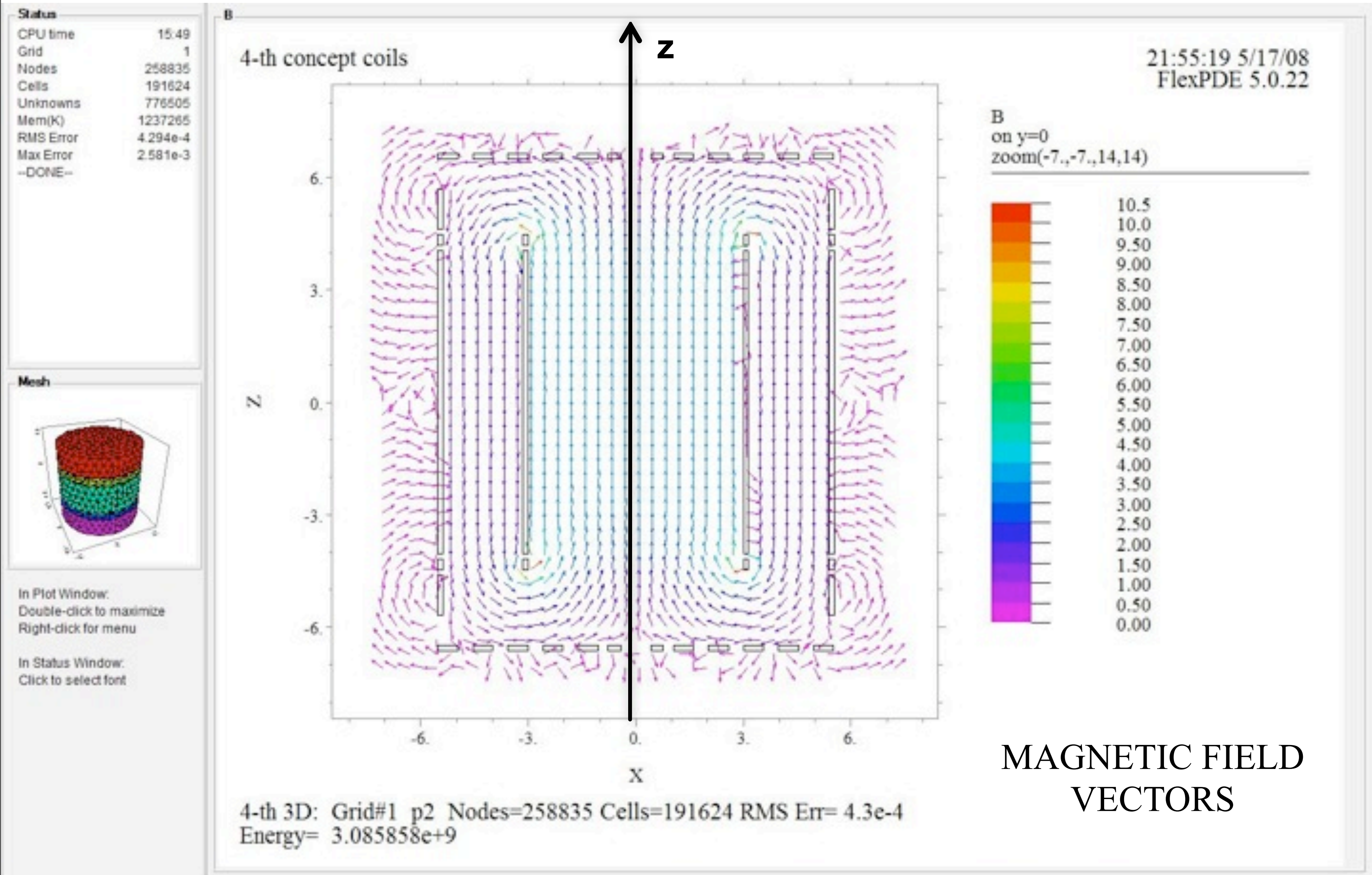

Field does not exceed 5.1 T;
Could be made less, if necessary

# Field homogeneity in central tracking region



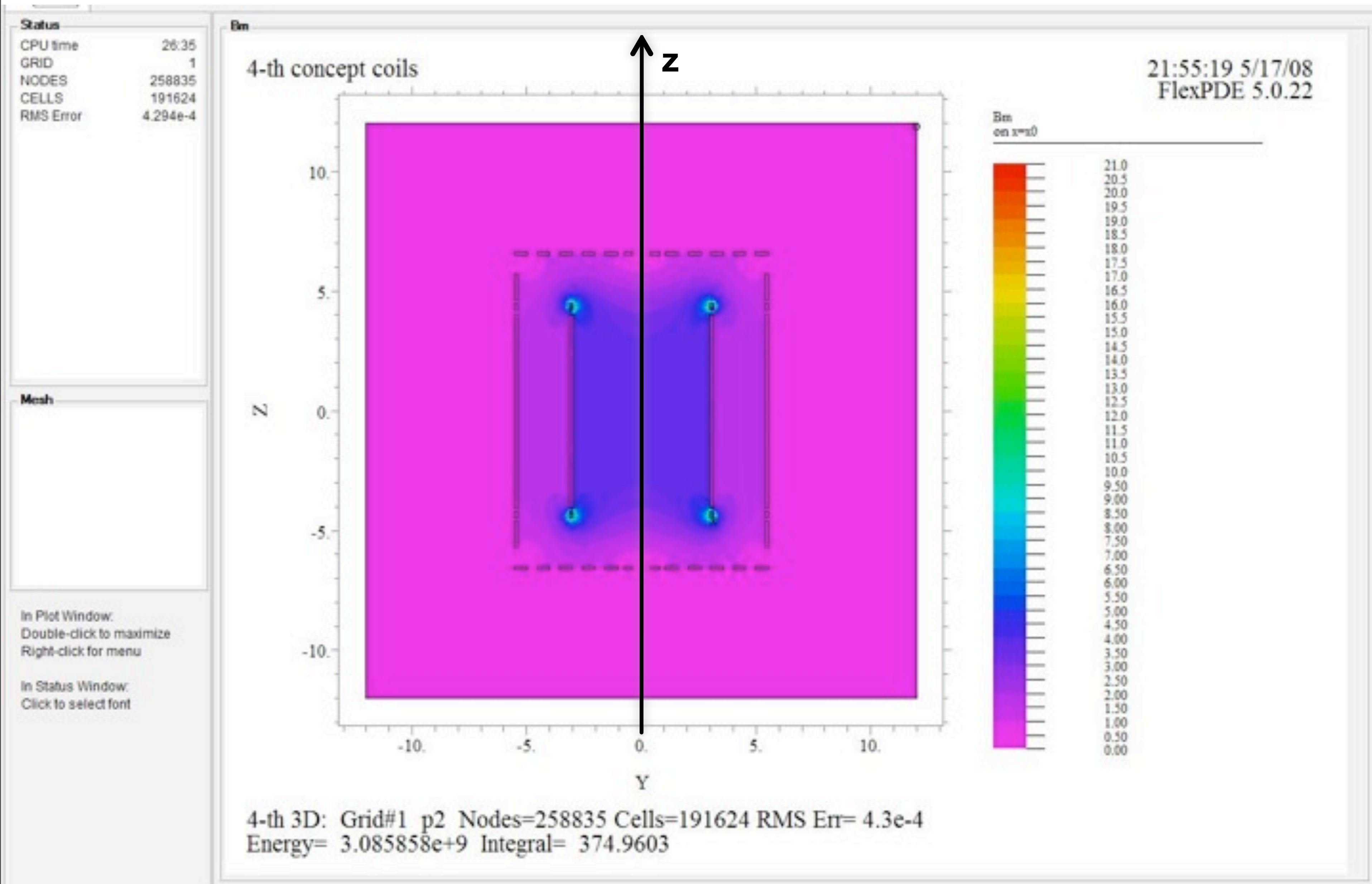

Each gradation=2/35200

# 3D MODEL ERECTED FOR INVESTIGATION OF TOLERANCES




MAGNETIC FIELD VECTORS

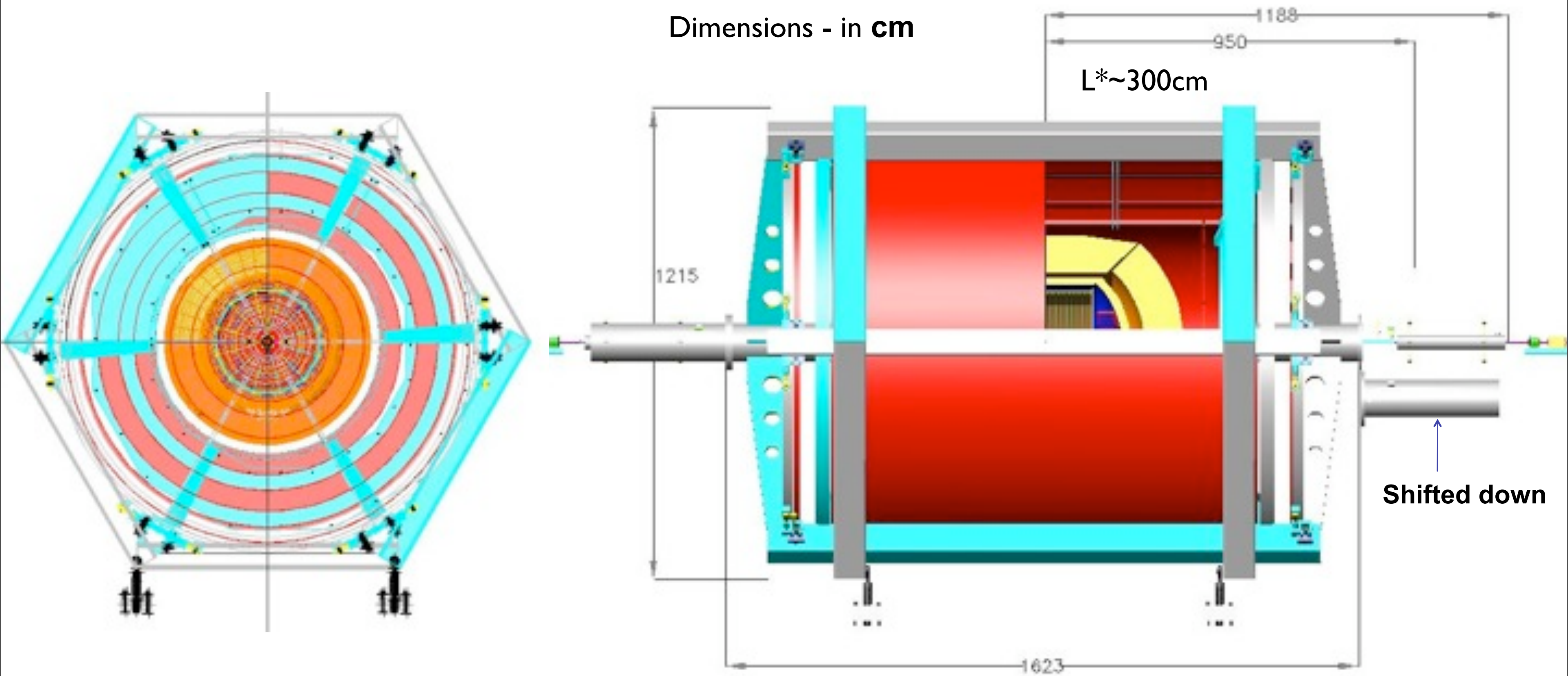
# FIELD HOMOGENEITY MAP



# DETECTOR CARRIES FINAL FOCUS OPTICS. MORE DETAILED VIEW

## Total stored energy~2.77 GJ

FF optics has trimming possibilities-mechanical and magnetic

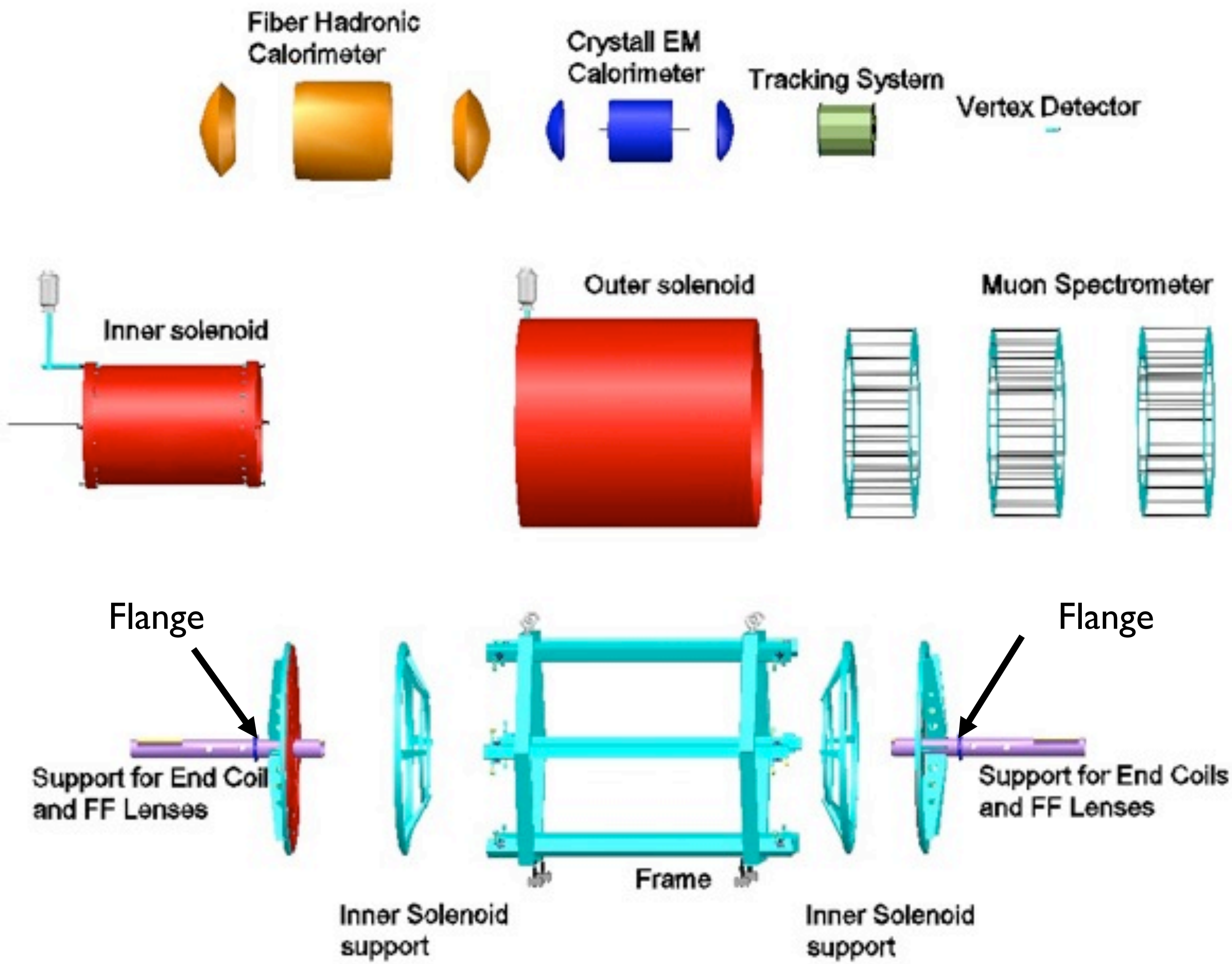



Thanks to the absence of iron all elements are visible from single point.

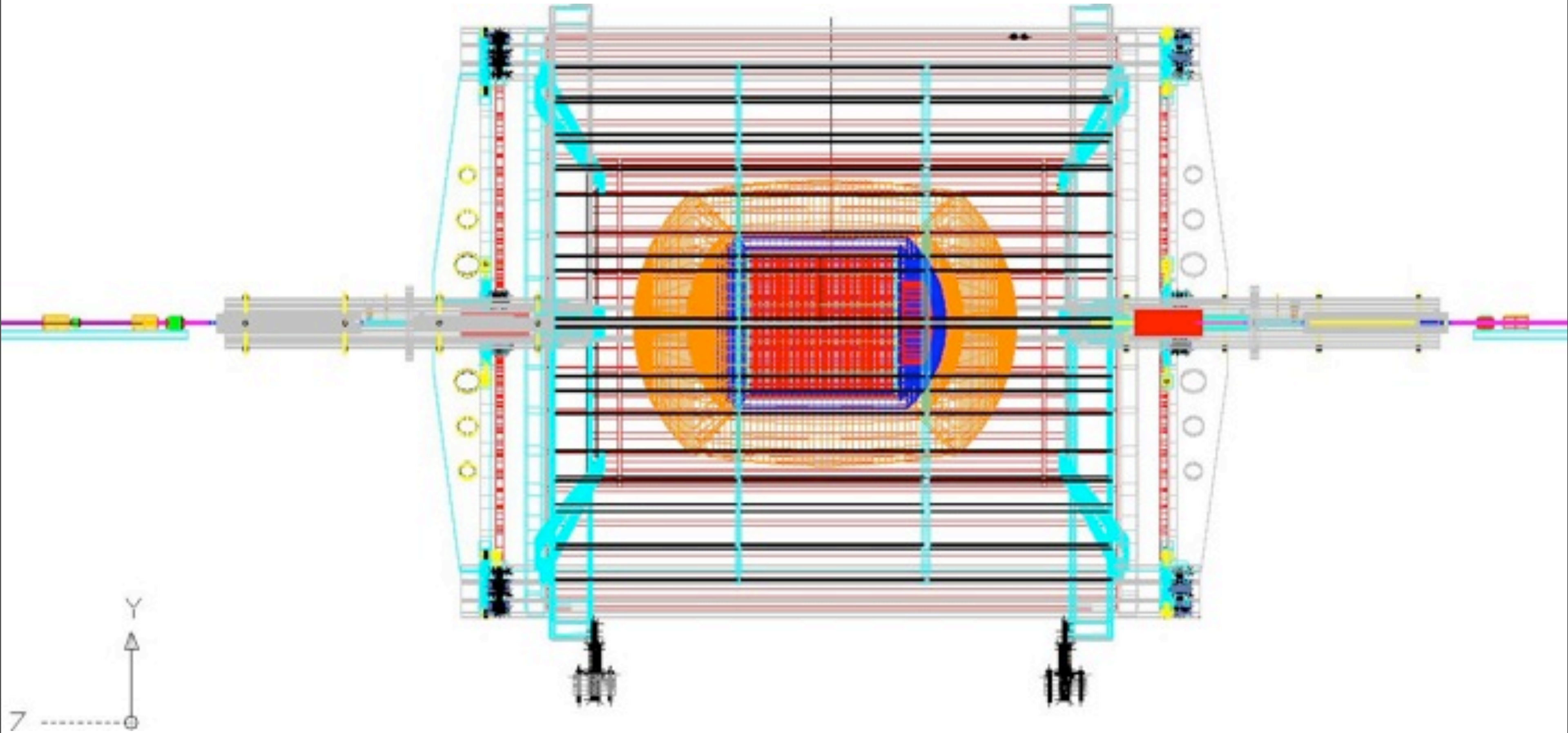
Total weight at most 300 tons in optimistic estimation, so E/M ratio ~10kJ/kg;

1000 T in conservative estimation (traditional coil design)

# DETECTOR IS WELL STRUCTURED & MODULAR



# TRANSPARENT VIEW OVER DETECTOR




Latest developments associated with fabrication of solenoids:

1) Reduction of current density in end coils of main solenoid.
2) Engineering of solenoids
3) Vibrations

# WE ARE AT ENGINEERING STAGE IN COIL DESIGN

Coil design: two approaches under consideration:

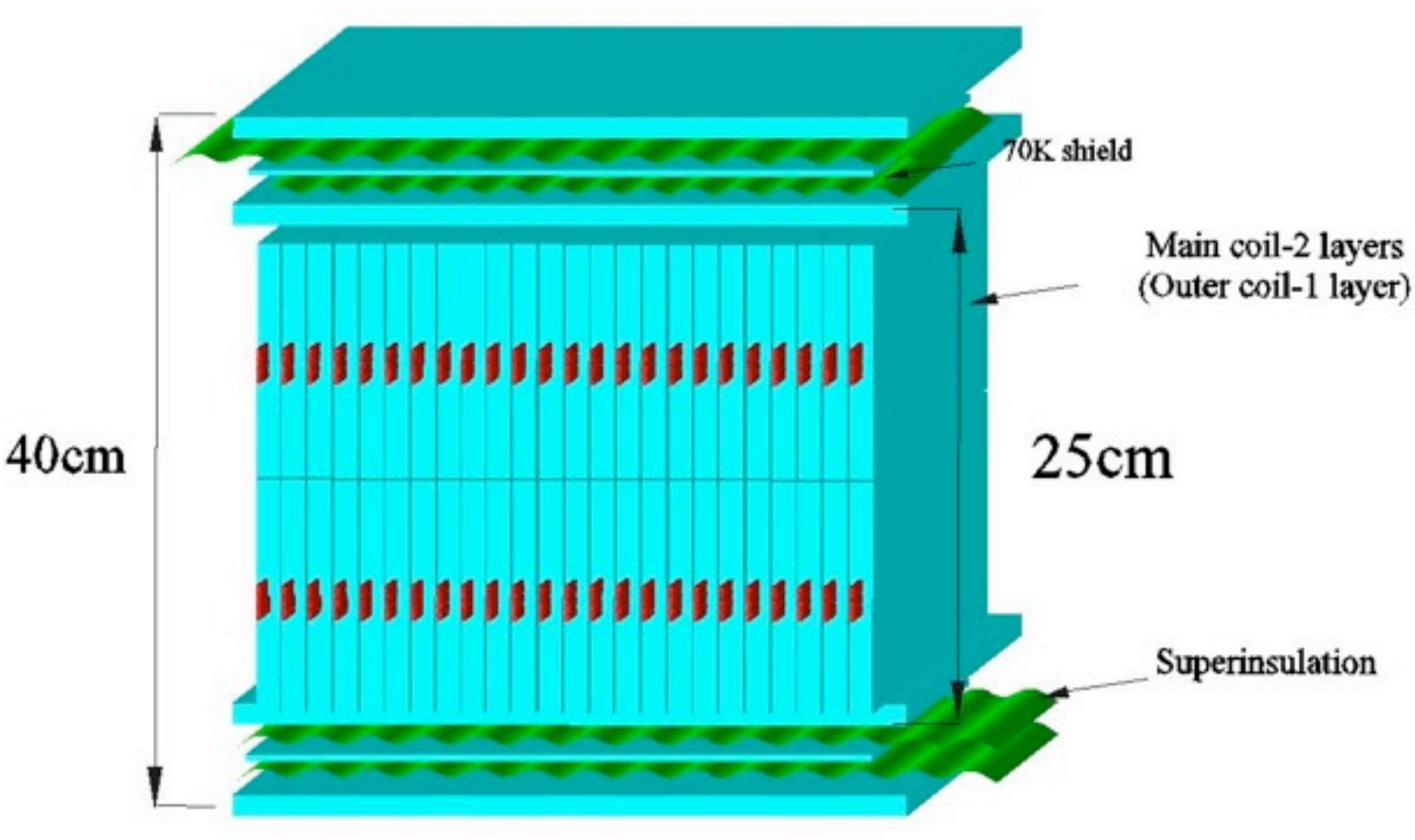
(a) Al stabilized Rutherford-type cable (traditional way)
(b) BINP technology with soldered SC cable (new approach)

All approaches include studies:

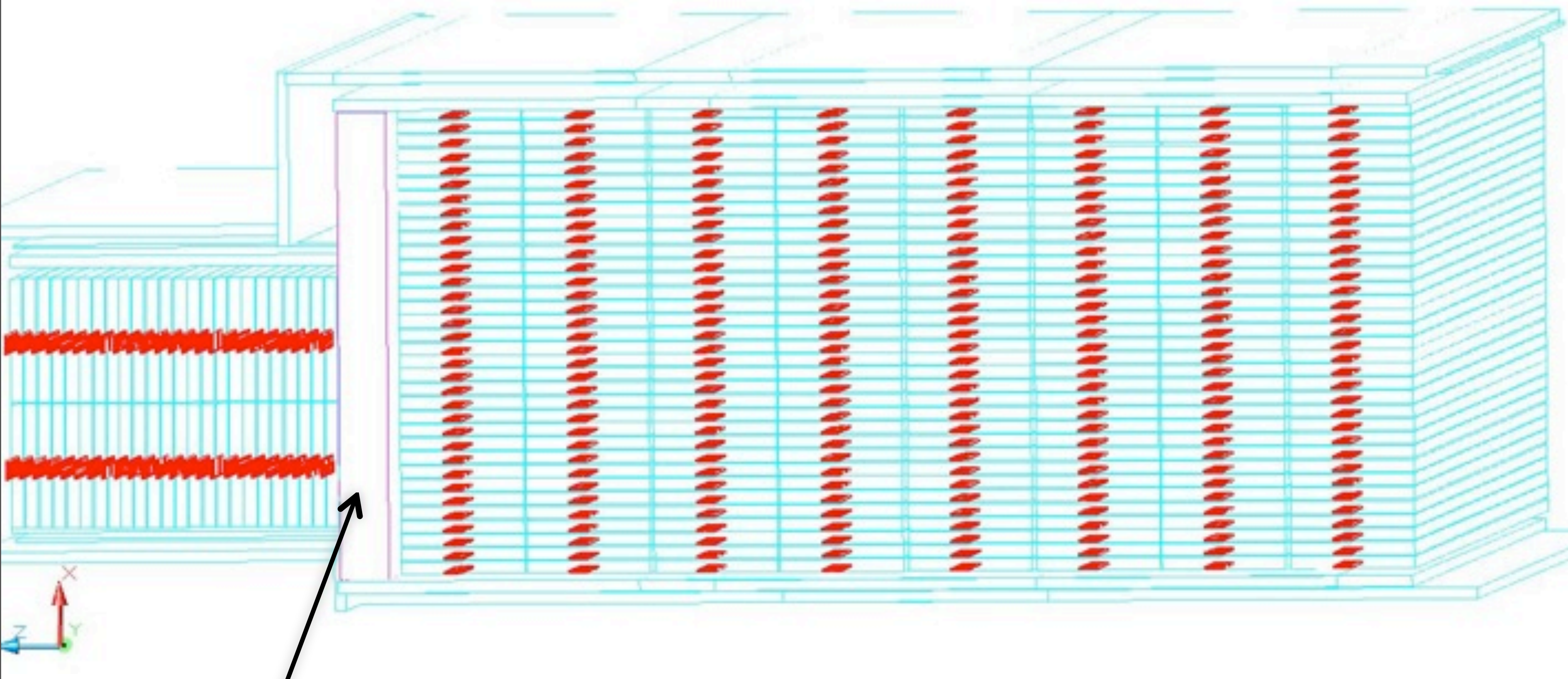
1. Type of cable, wire;
2. Tests need to be carried;
3. Technologies need to be revisited;
4. Structural composition of solenoids;
5. Mechanical stability;
6. Quench protection (coils, electronics and all inner systems)
7. Wall coils (room temperature); adjustment of current density and shape.

# Approach (a)

MAIN SC COIL WITH AL STABILIZER (TRADITIONAL APPROACH)



# Packaging of main solenoid around Helmholtz coils schematics

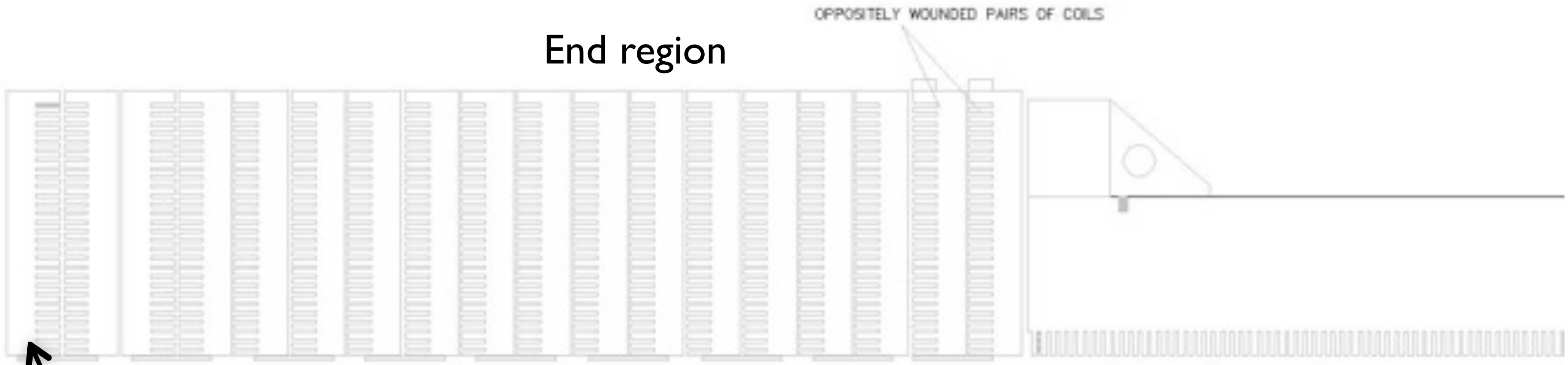



Reinforcement plate

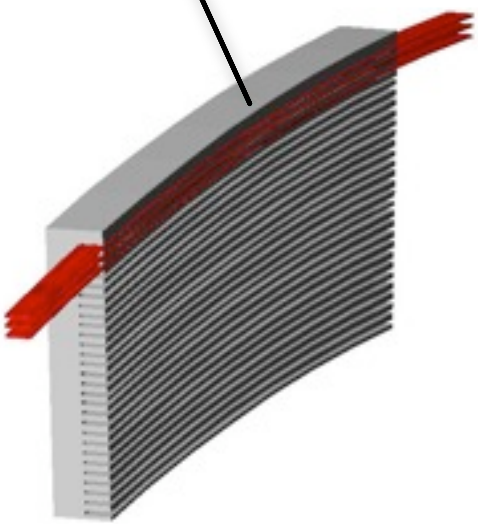
No needs for $Nb_3Sn$

# Approach (b)

## MAIN SC COIL WITH BINP TECHNOLOGY SCHEMATICS





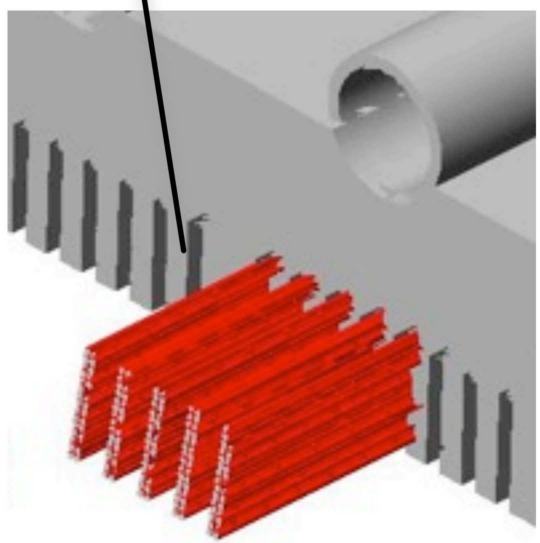


Used indirect cooling

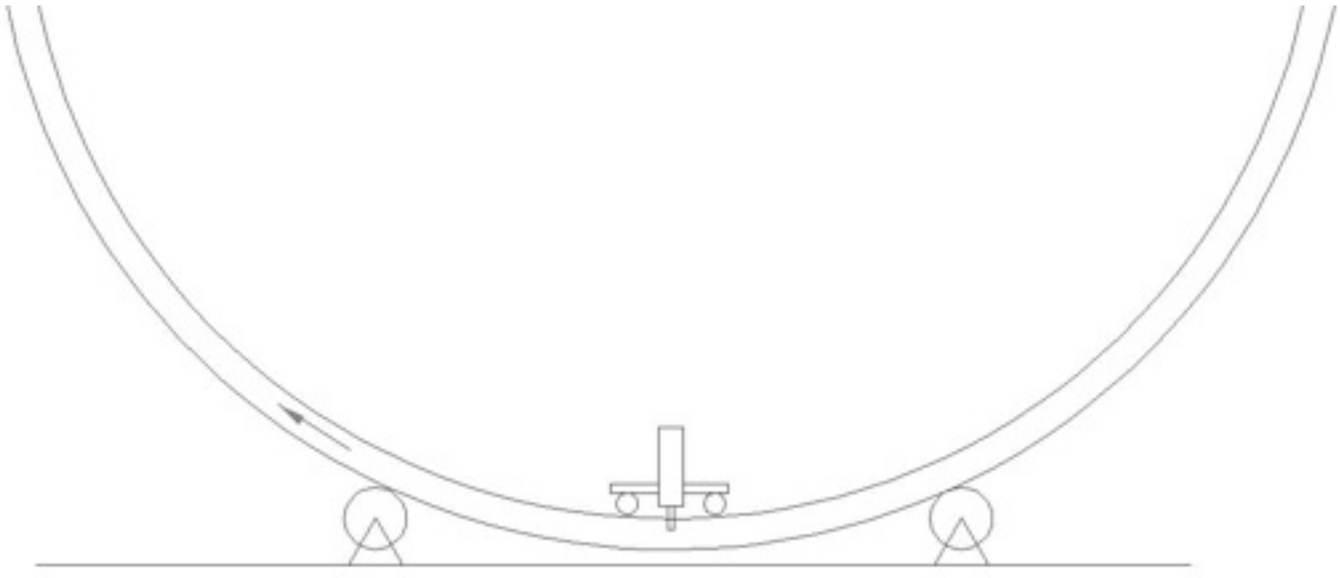
SC cable embedded into grooves made in Al cylinders (discs)

Coil is sectioned

Cable 20x2 - Ø1mm NbTi wires

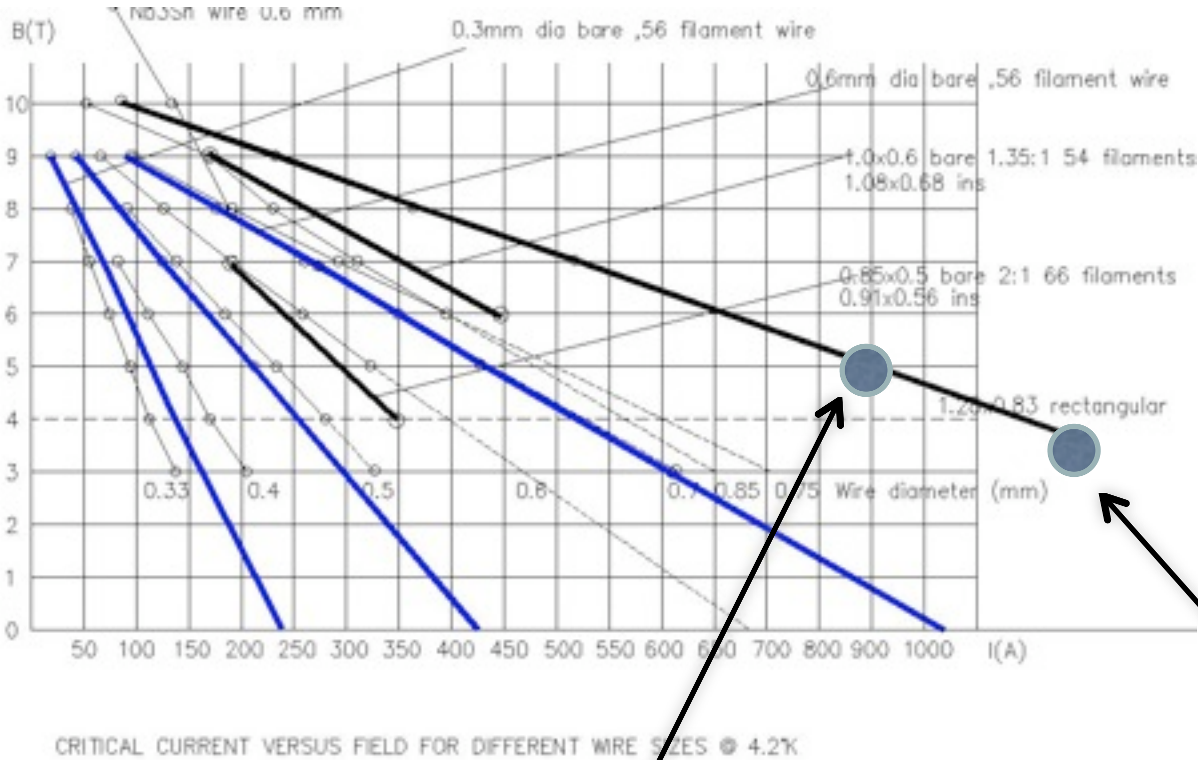


# Less expensive technology will be chosen



Making grooves in a modular coil;
Tinning at the same time;
Cartridge based to the neighboring grooves and edge

NbTi is possible;




{total current, kA }

I1=-29500*kA_per_$m^2$ { -33040}

I2= 9500.*kA_per_$m^2$ { 16758.}

{end coils}

I3=-22750*kA_per_$m^2$ {-4026.}

I33=I3*1.01, {-6479 }

{wall of coils}

I4=1600*kA_per_$m^2$ { 116.48}

I5=6200*kA_per_$m^2$ { 451.36}

I6=8800*kA_per_$m^2$ { 640.14}

I7=8800*kA_per_$m^2$ { 640.14}

I8= 7600*kA_per_$m^2$ { 553.28}

I9= 3100*kA_per_$m^2$ { 141.05}

End coils 900x30=27kA/cable

In regular part 1300x30=39kA/cable

The work continues towards:

1) Reduction of density by increasing the length of end package

2) Possible introduction of varying current distribution in main solenoid –this solution is guaranteed.

# QUENCH PROTECTION SYSTEM

Based on experience of CMS and other large systems;

Stored energy in magnetic field of $4^{th}$ is 2.78 GJ - the same as in CMS solenoid;

External resistor;

Shunts across windings (BINP technology);

Use of cryostat case for inductive coupling with main coil; the same for end wall coils;

Room temperature wall-coils make support system and energy extraction much easier;

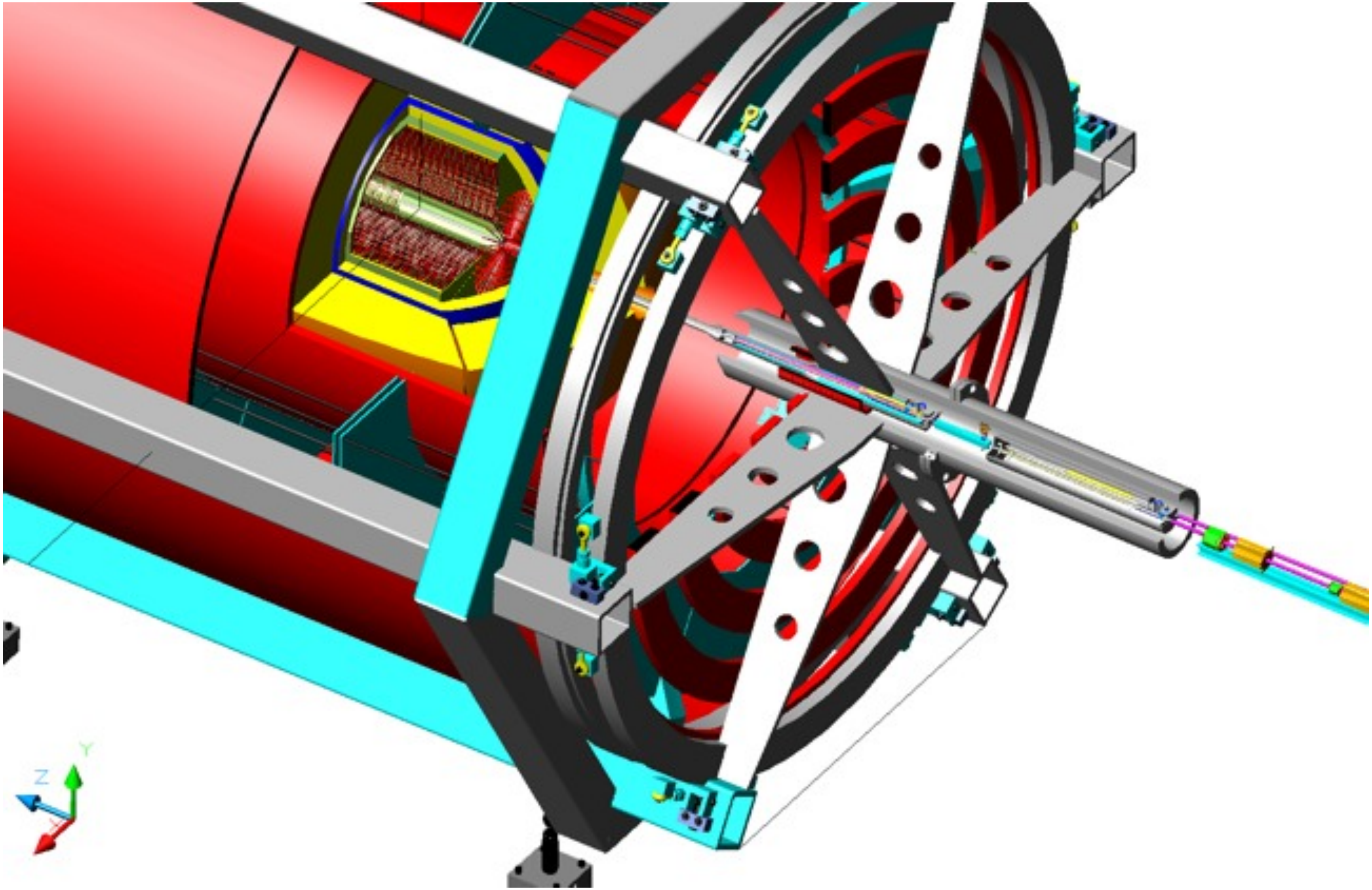
Outer solenoid is under more relaxed conditions, easier than the inner one;

Detailed quench model for different scenarios is under development;

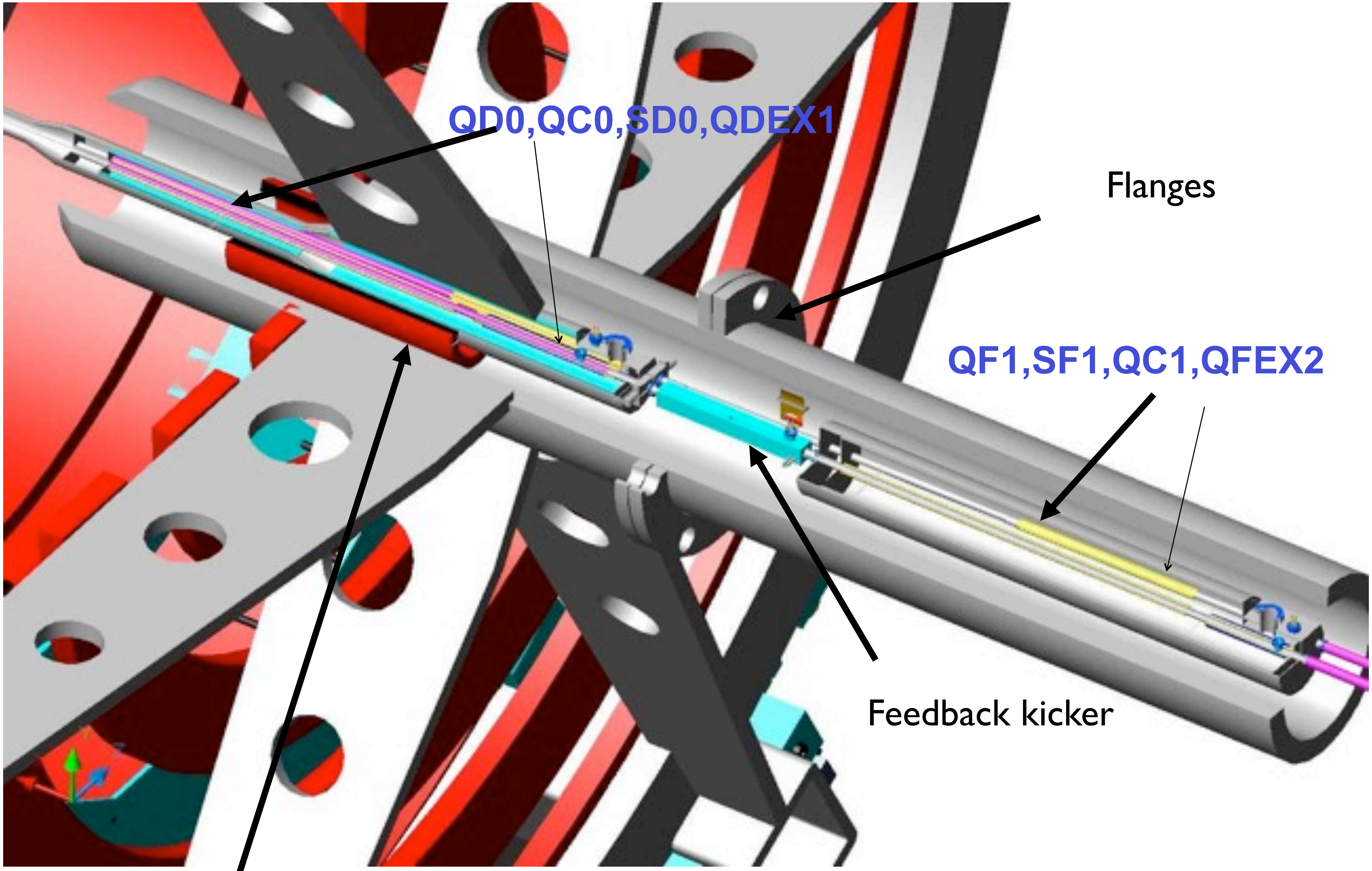
Without current in outer solenoid, the field in central region would rise to 5T with a rapid drop outside detector;

Optimization of current density profile is in progress.

# 14 mrad CROSSING ANGLE (BASELINE)

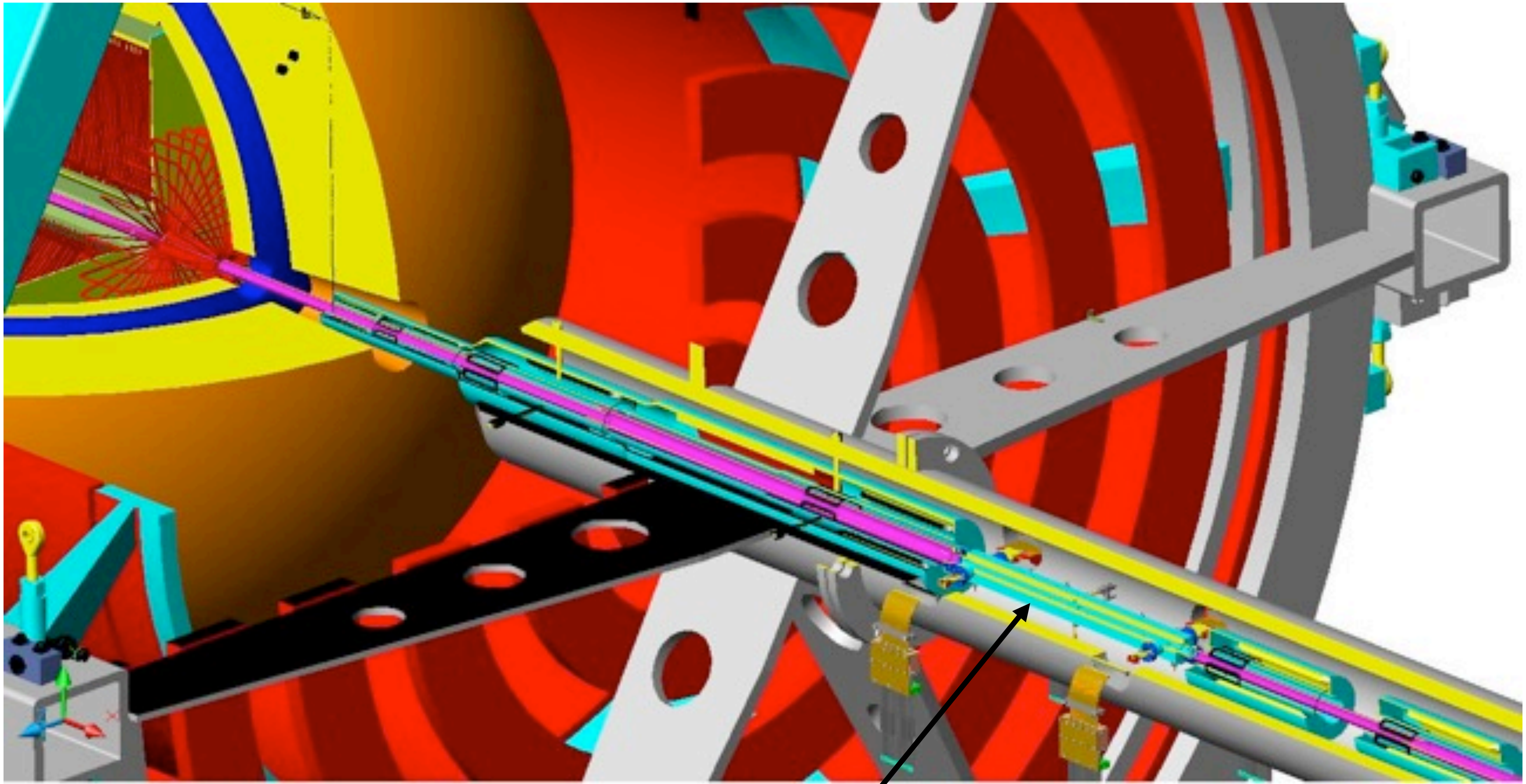


# 14 mrad crossing angle optics fragment



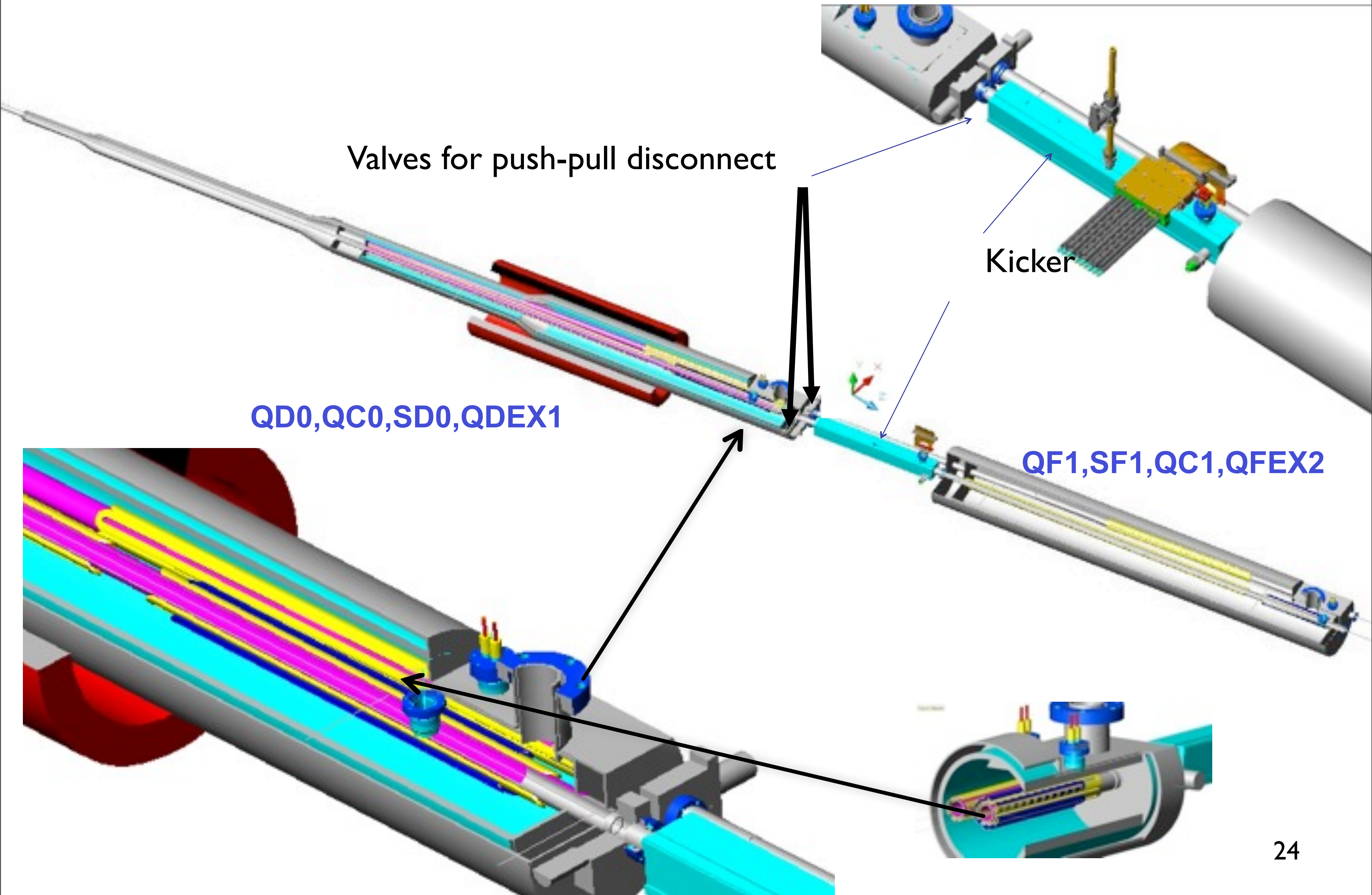

Each quad could be moved mechanically + trim coils

# OPTICS WITH ZERO CROSSING ANGLE (NO PROBLEM)

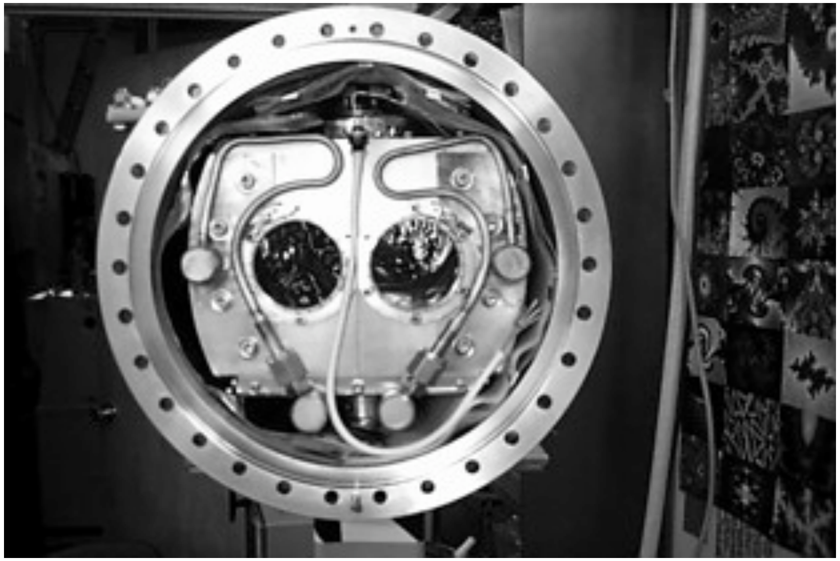


Directional kicker with TEM wave

# FINAL DOUBLET ( IN/OUT), SEXTUPOLES FOR 14 mrad CROSSING ANGLE



- Active systems move the lens centroids in transverse plane using dipole mechanical movers +windings in lenses;
- Windings used for generation of Skew-quadrupole fields;
- Cancellation of  influence of deformations induced by ponderomotive forces;
- Cancellation of  influence of ground motion;
- Cancellation of influence of detector field on beam and spin dynamics



Dual bore SC quadrupole developed and tested at Cornell as an example.
Distance between room temperature walls ~25mm

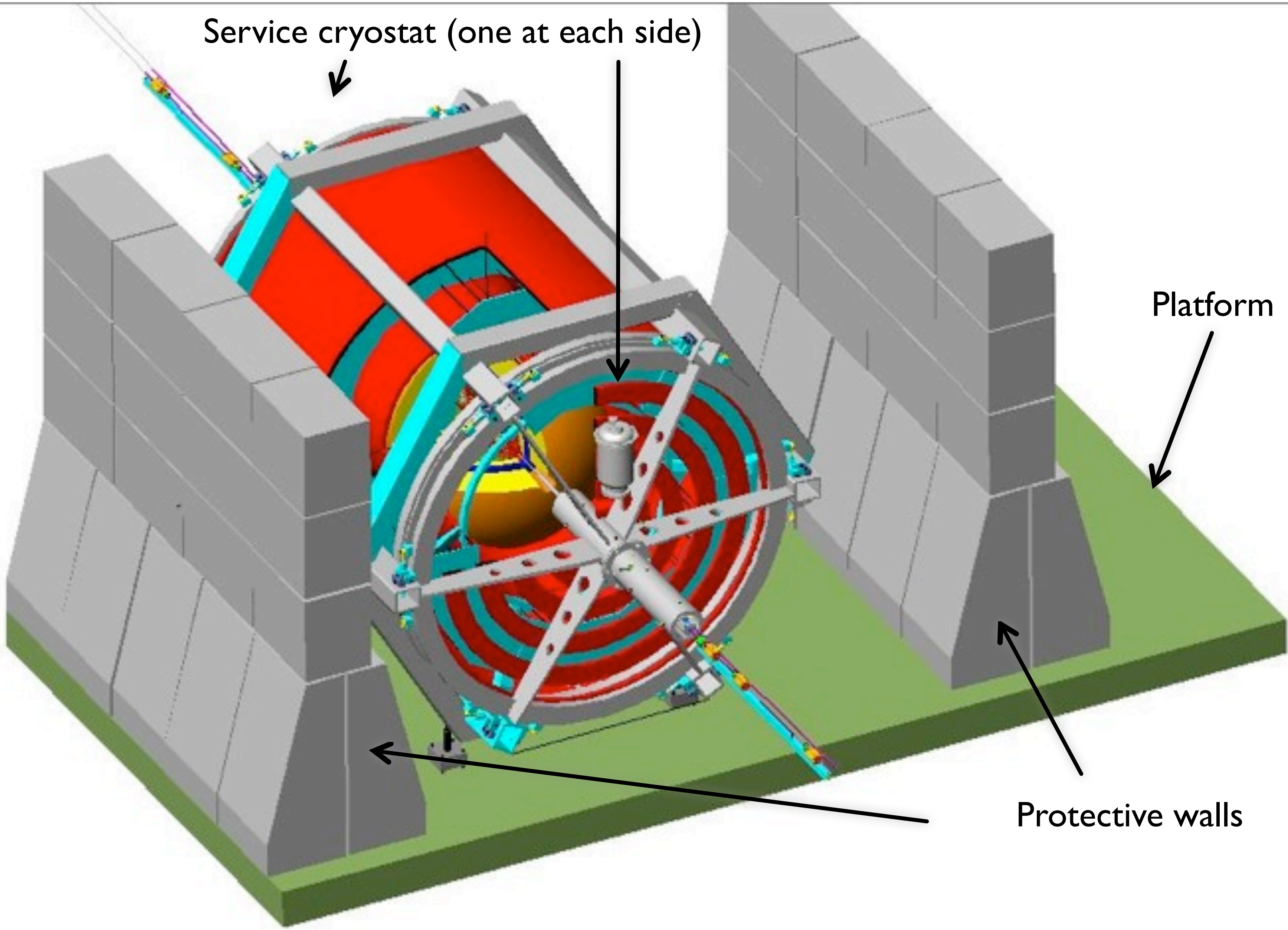
Septum between SC apertures~5 mm

Warm inner chamber

We are ready for possible modification of FF optics (if any occurrs):  use of multiplet of lenses, rather than a doublet with local compensation of chromaticity and residual dispersion at IP.

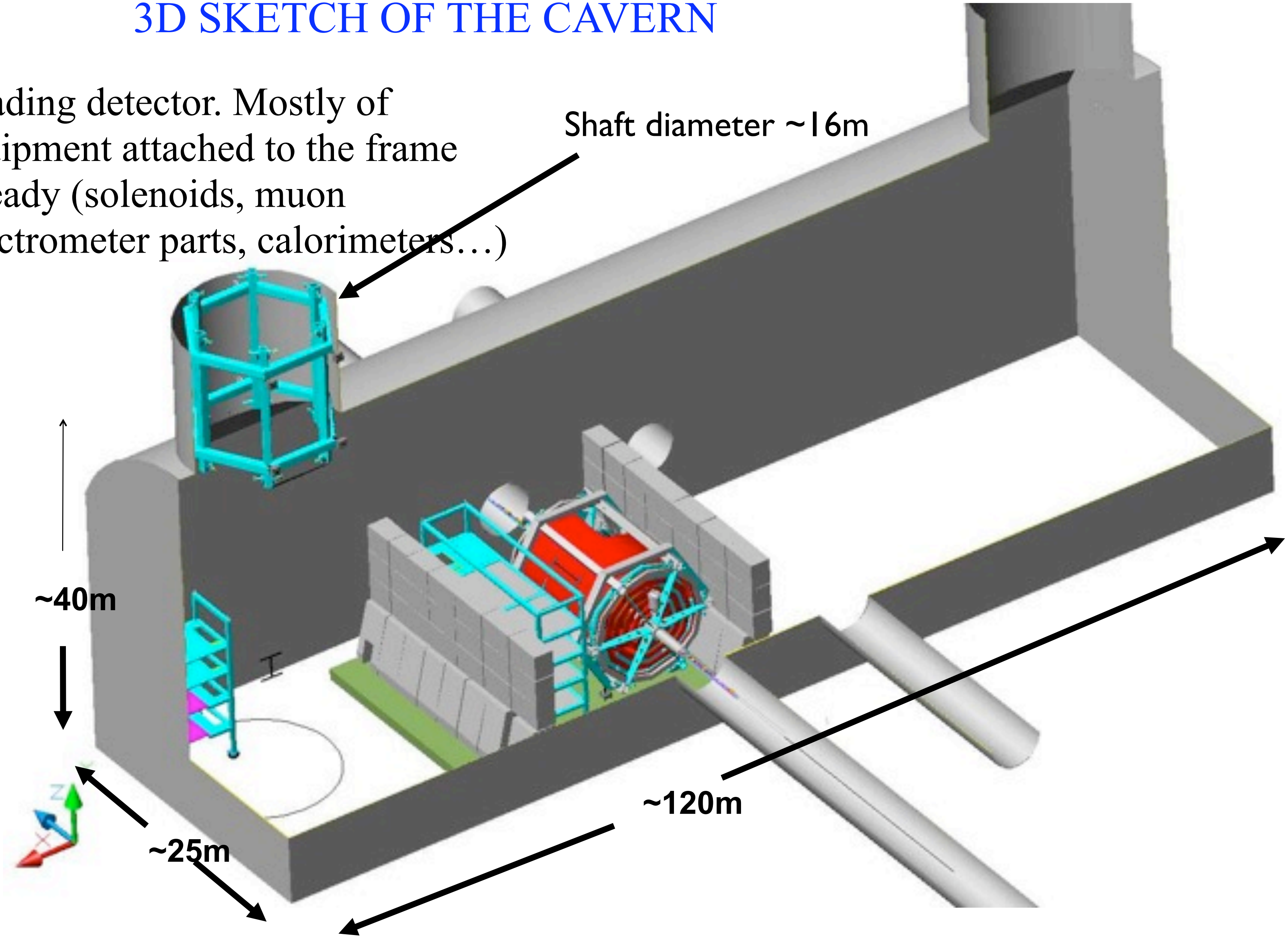
Potentially this might drastically reduce the length of Beam Delivery System

# INSTALLATION ON A PLATFORM WILL SPEED UP PUSH-PULL ACTION

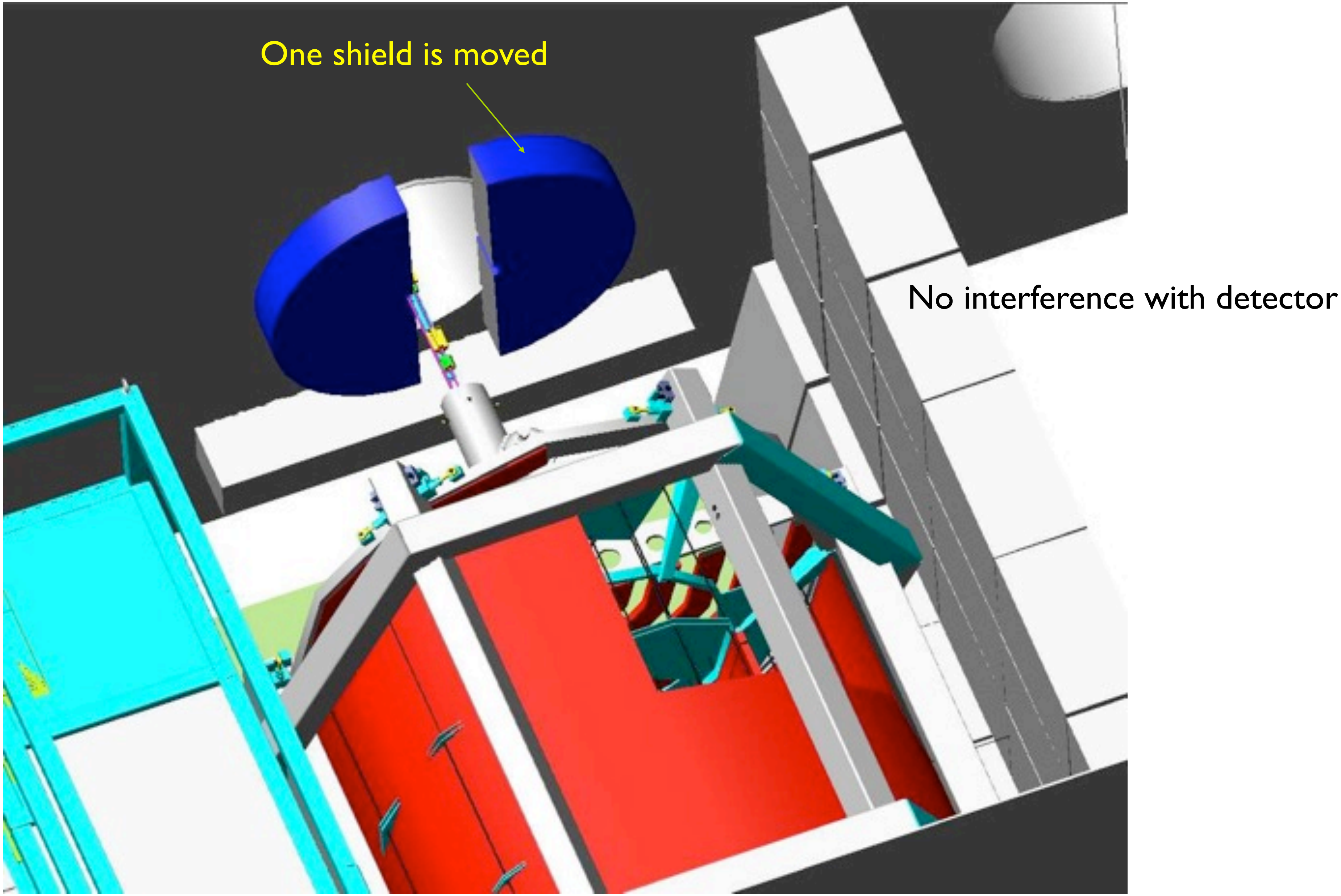


# 3D SKETCH OF THE CAVERN

Loading detector. Mostly of equipment attached to the frame already (solenoids, muon spectrometer parts, calorimeters…)

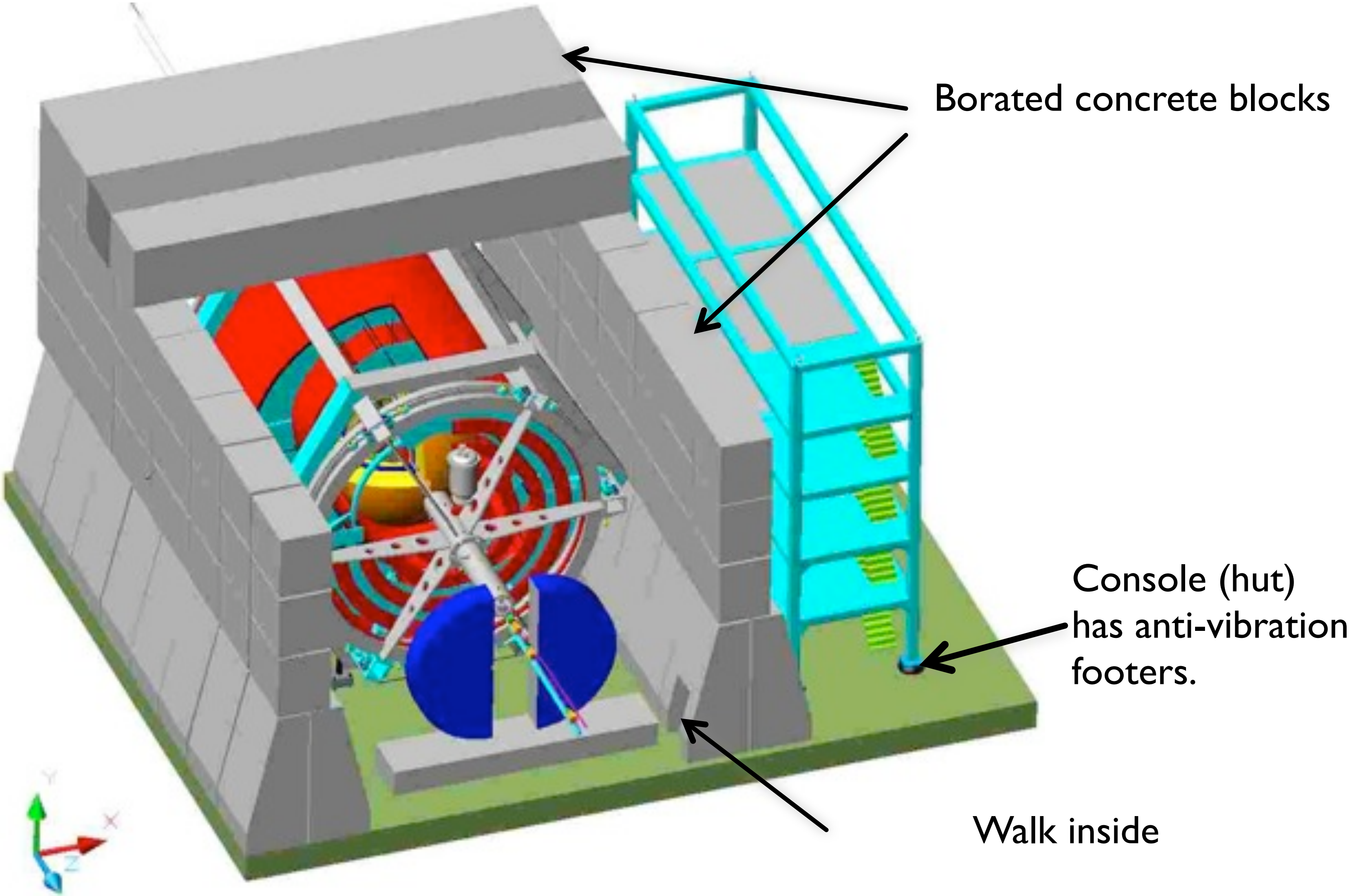



Tunnel shields at the cave entrances (Pacmans) not shown (next slide)




So called PACMAN-type cover (shields on hinges) require more space and limit freedom of movement.

# The hut with electronics could be installed behind the wall




Detector protected by inexpensive shield;  Boron Carbide interlace for protection against slow neutrons could be incorporated into protective wall.

SLAC RADIATION PHYSICS NOTE RP-09-08
March 30, 2009

# IR hall dose rate estimates with detector concepts

T.Sanami[1) 2)], A.Fasso[2)], M.Santana[2)], L.Keller[2)], A.Seryi[2)], S.Rokni[2)], S.Ban[1)]

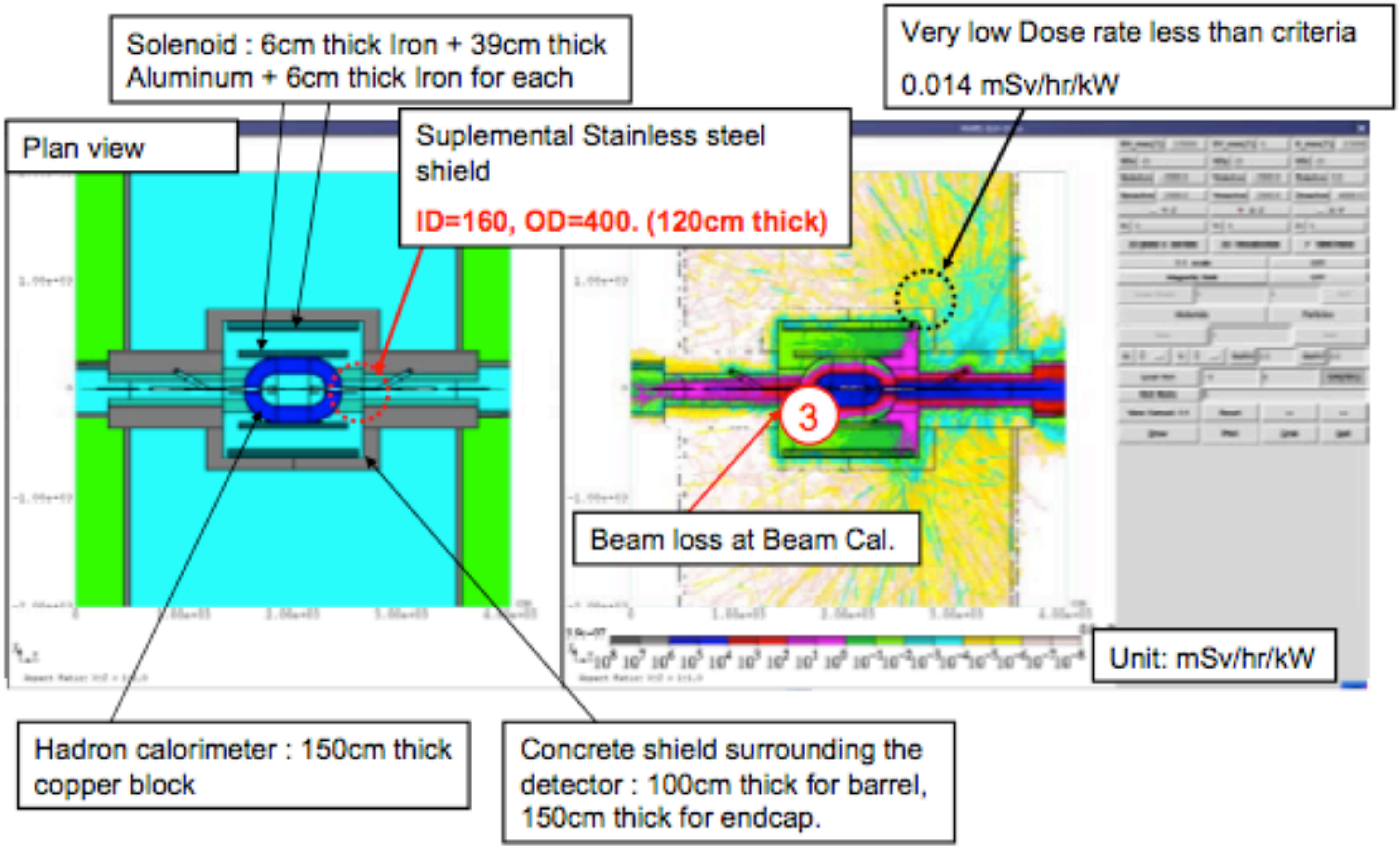



Fig 3-12-2 Plan view and dose rate distribution in experimental hall for 4[th] concept detector with supplemental stainless steel shield. The shield thickness is 120 cm.

# CONCLUSIONS

- All MDI questions can be answered;
- 4th detector can easily accommodate any beam optics;
- It can be easily installed in detector cavern as it has no heavy Iron;
- 4th allows easy motion in cavern for push-pull operation;
- Elements of FF optics mounted on detector frame allow better protection against ground motion; active system against vibrations;
- Field can be made homogeneous to satisfy tracking system request; measured accurately as there is no interference from iron ($10^{-4}$);
- Easy upgrade for gamma-gamma if necessary ;
- Modular concept of 4th detector allows easy exchange of different equipment, such as tracking chamber, vertex detector, sections of calorimeter, gamma-gamma hardware, and detectors beyond the calorimeter;
- Current density could be reduced by sectioning to allow NbTi wire by end coil sectioning;
- Engineering stage for coil design must be continued toward practical tests of concept.

# Backup slides

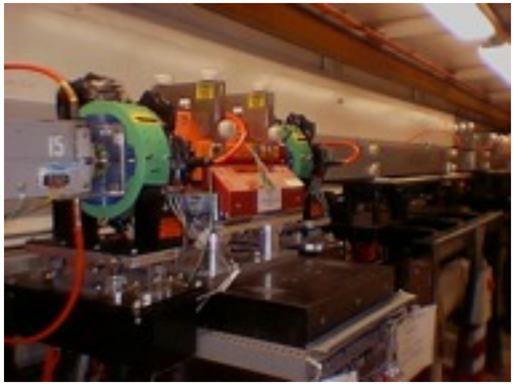
# PREVIOUS ACHIEVEMENTS OF FINAL FOCUS DESIGN USED IN 4th DESIGN

Beam delivery system –Final Focus Test Beam Facility- FFTB- was constructed to test FF optics concepts, stabilization, beam size measurements, magnet technology, 1993.

International project with participation of France, Germany, Japan, Russia, USA.

Located at the end of SLAC linac in a specially build extension housing. Total length ~200m; compensation of chromaticity of FF doublet done by sextupoles.

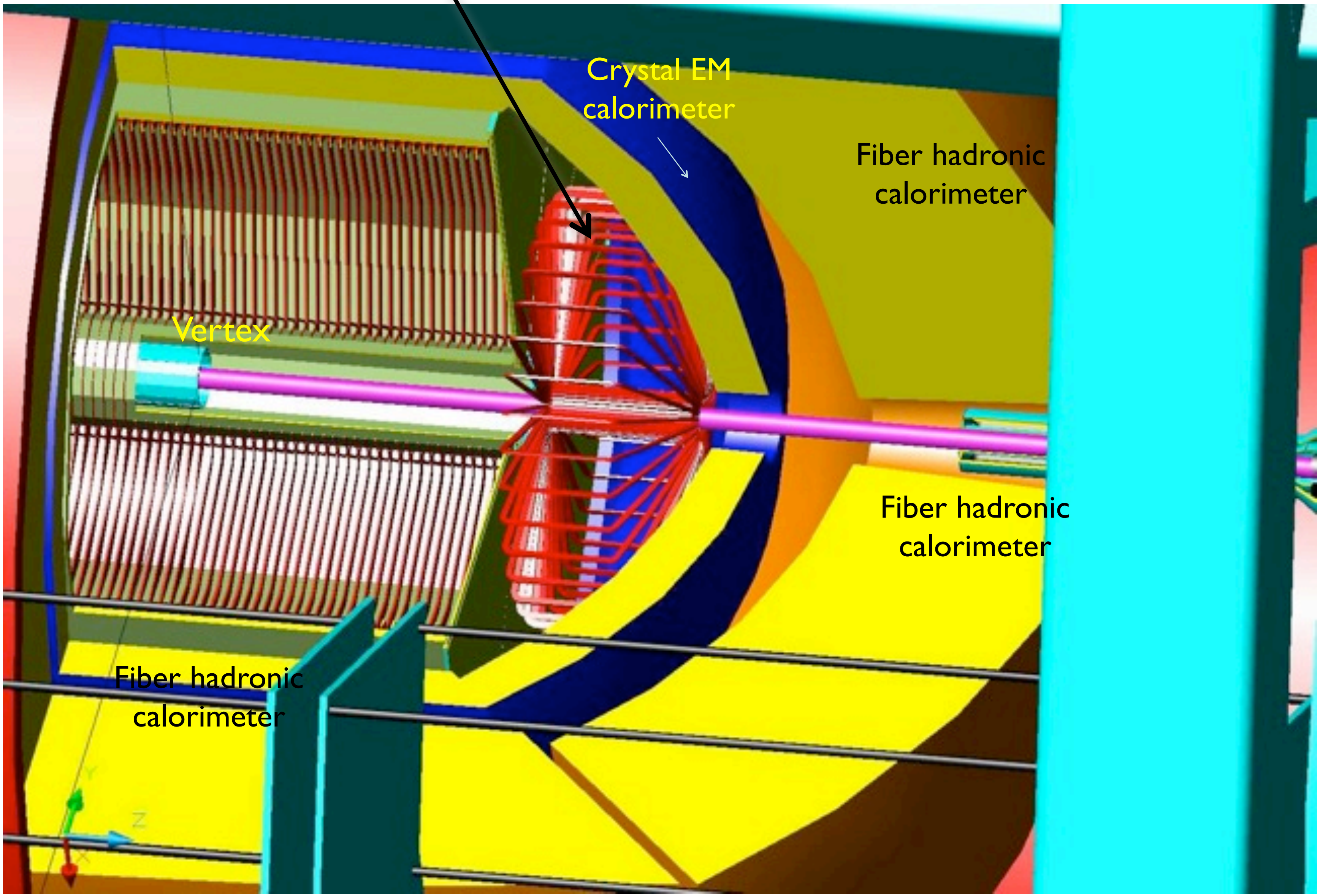
Vertical beam size ~70nm was measured at IP – Phys.Rev.Lett.74:2479-2482,1995
Obtained substantial experience in Final Focus design

In particular,

- Tested stabilization of few long strings of magnets, representing functional electro-optical blocks (such as final telescope etc) with stretched wire.
- Tested active magnet alignment.
- Introduced and tested ballistic method for FF alignment • Tested new-type of beam size monitor for nm scale

Being studied – toroid between tracker and calorimeter to improve momentum resolution for particles at small angle. Tracker will come to r=20cm radially and extend to z=1.7m axially including the readout end plates. Concept not finished yet



*Different energy of colliding beams.* It is natural to keep such possibility for ILC. Here all background products generated off-center in contrast with asymmetric B-factory.

ILC accelerating structure is a standing wave type; it allows acceleration in *both* directions. One can consider the possibility to work at *double energy with a stationary target.* For this action, the beam accelerated in the first linac is redirected through IP into another one. The phasing could be arranged; the optics needs to be tuned.

*Zero crossing angle.* Nonzero angle initiated by NLC/JLC type machines. Crossing angle vas not required for TESLA, VLEPP. Zero angles give advantages in optics, preventing from SR in magnetic field of detector and degradation of luminosity. So we think, that this option must be kept in detector design as alternative.

*Monochromatization* –the ability to arrange collision at IP in such a way, that low energy particles from the first beam collide with the higher energy ones in the opposing beam. This idea was considered for circular machines a long time ago. For a single pass system, as the ILC is, realization of such program becomes much easier procedure. Despite significant SR energy spread generated during collision, this might be important for measurements at narrow resonances, including low energy option (Giga-Z).

*Work with nonzero dispersion at IP.* This might be useful for monochromatization and to simplify the FF optics.

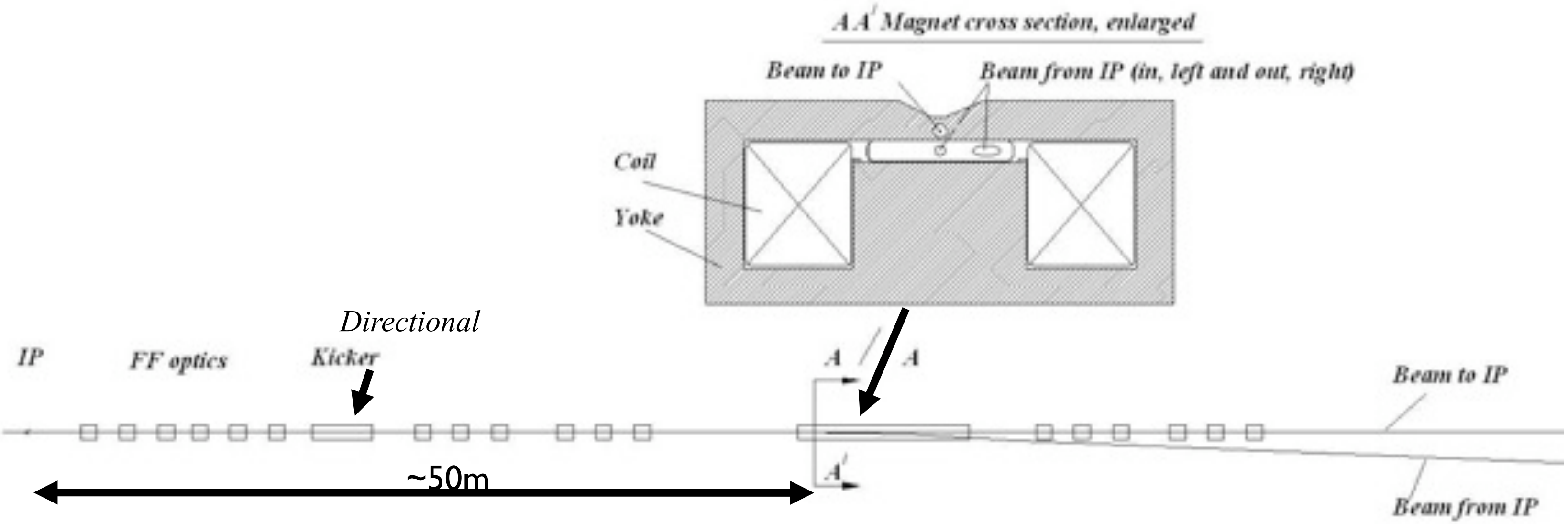
*Adiabatic focusing at IP.* Focusing arranged with *multiplet* of quadrupoles, rather than a doublet so that the strength of the lenses changes slowly from lens to lens.

Peculiarity for registering of collisions with *both polarized beams.* Registration of back-forward asymmetries of secondary products is the main task for operation with polarized particles. This question requires special attention. 4-th magnet allows easy swap polarity.

## WE ALSO CONSIDERING ALTERNATIVE HEAD ON COLLISION SCHEME

Directional kicker used for separation of beams
Kicker is TEM type, kicked by electrical and magnetic fields;
So the kicker hits the counter-propagating beam only

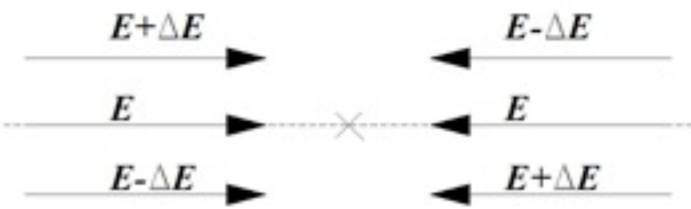
Magnetic field between wide current sheets does not depend on distance between them  This opens a possibility for relatively long pulse, ~1msec scale

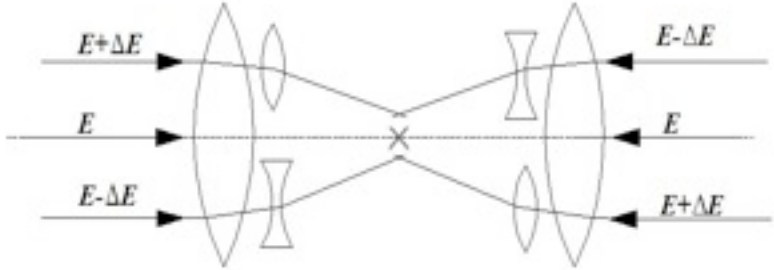



Zero crossing angle scheme, top view. Kicker operates in vertical direction (out from the view to the plane of Figure). Distance between kicker and the Lambertson/Picconi  magnet ~40m. Scaled cross section of this magnet is represented in upper part of Figure.

This promises drastic reduction of BDS length (down ~ten times)

# Monochromatization



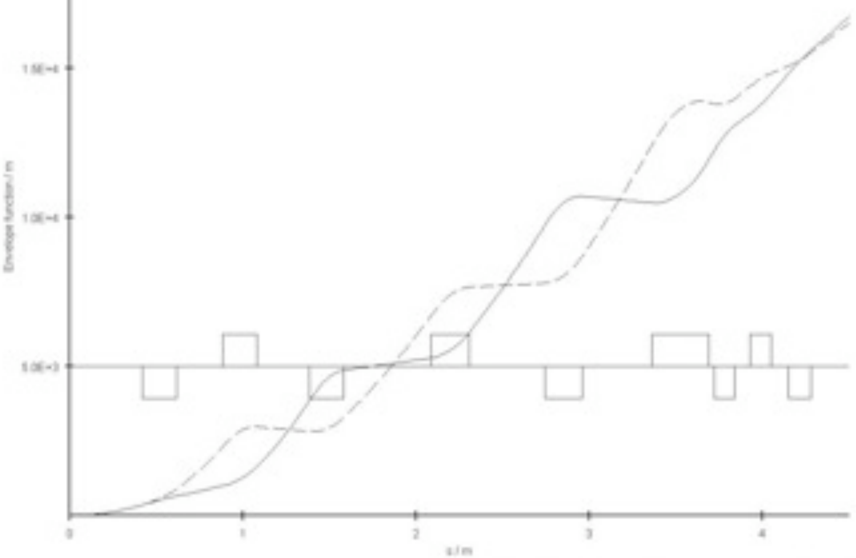

Residual chromaticity at IP is a positive factor for monochromatization

# Adiabatic focusing

Strength of the lenses deceasing from the strongest -near IP to the weakest

Local compensation of chromaticity and residual dispersion at IP for wider energy acceptance

Example of Adiabatic Focusing of 1 TeV beam

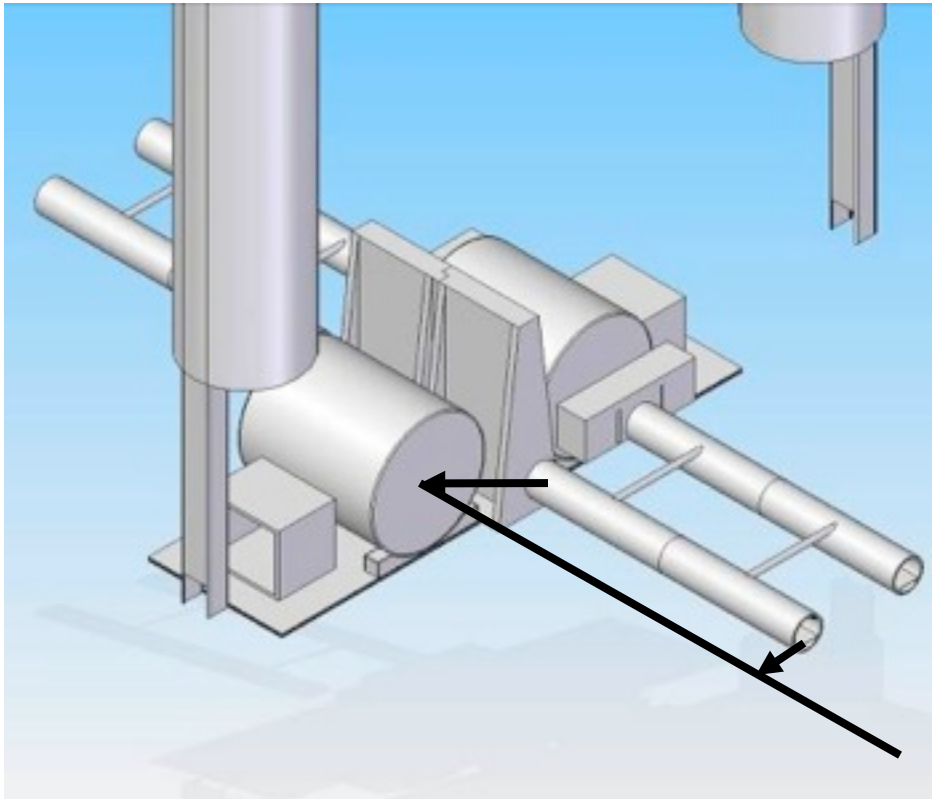


Envelope function behavior for the multiplet of lenses around IP. IP supposed to be at *s*=0, left point at abscise axis. Beta-functions for x and y directions at IP in this example is chosen equal the same with values 0.05cm.

Chromaticity $\cong -\dfrac{1}{4\pi(HR)}\int G(s)\beta(s)ds$

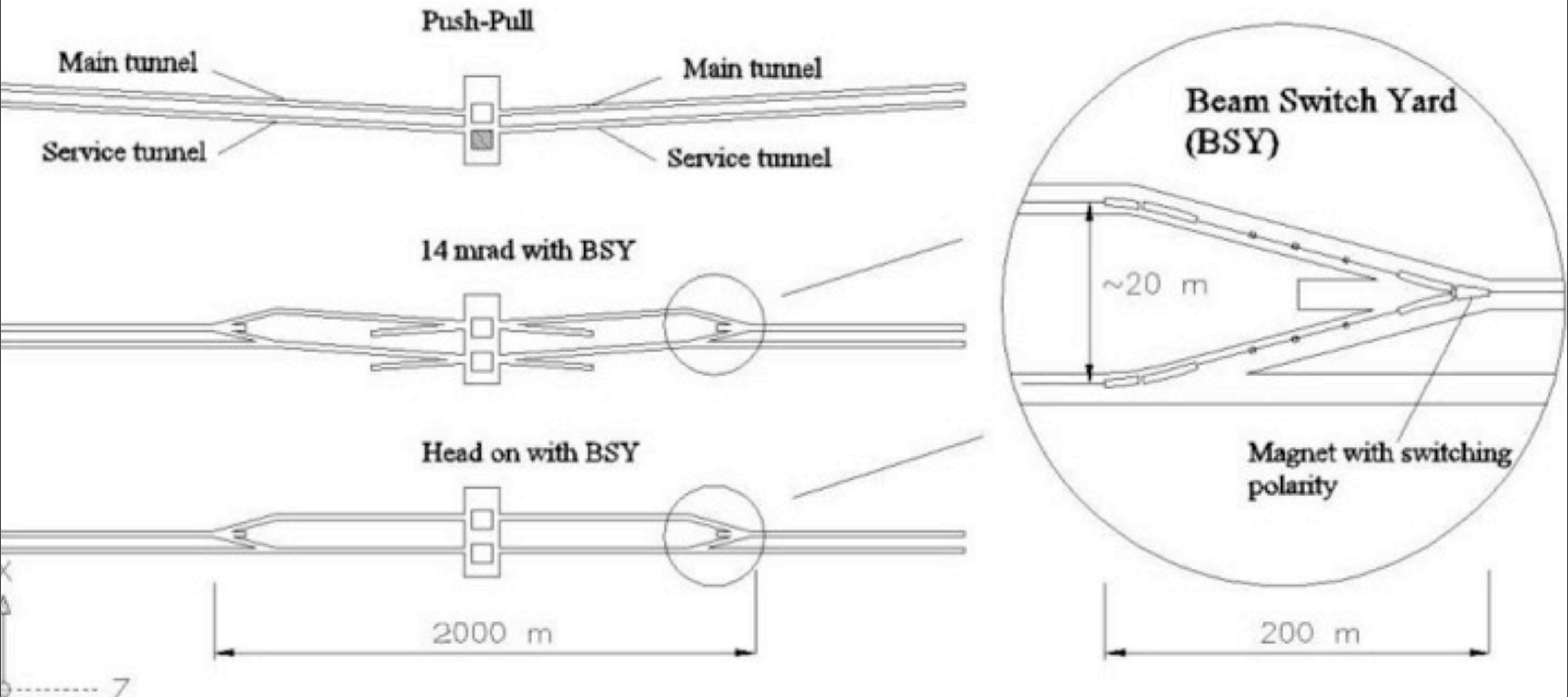
gradient changes, $\beta$ *~const,* so chromaticity might be lowered significantly by neighboring lens

# One recommendation…



The service tunnel must be shifted so its axis runs through the center of second detector even the only one detector will be in operation at the beginning.

# 4th FITS INTO ANY SCENARIO OF FF ARRANGEMENTS




Scenario with Beam Switch Yard allows independent operation of detectors

Cost of additional optics is comparable with all push-pull complications

FF lenses are mostly expensive and every detector has these lenses already

4th CD can be easily fit into this scenario