The ILC Detector Geometry: a Fresh Perspective

BILCW07, Beijing

Adam Para, February 6, 2007

Bottom Line

- Silicon-based tracking offers new possibilities for the optimization of the colliding-beam detector design in area of:
  - Physics capabilities
  - Detector performance
  - Cost
  - Engineering and construction

Note: in the following the angle theta will be used in an inconsistent fashion: Θ ⇔ 90^o-Θ. Substitute sinΘ ⇔ cosΘ, as necessary

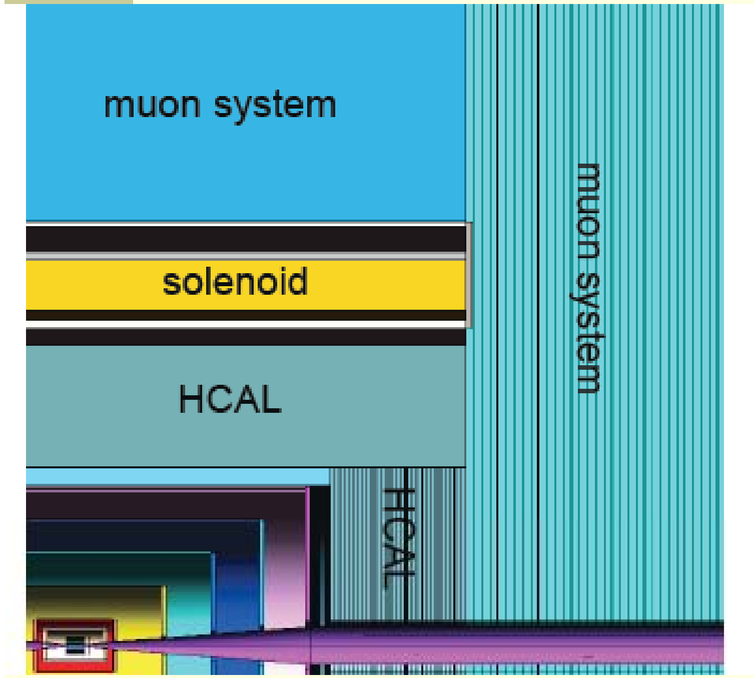
Isn’t it Too Late: Approach I?

- Colliding beam detectors are pretty standard: a modern version of a LEP detector will do just fine
- Three + one detector concepts are very advanced. Detector Outlined Documents are in preparation with detailed designs, cost estimates, construction and installation schedules aimed at the operational readiness in 2018.
- The challenge we are facing is down-selection to one or two designs, settle on the vertex detector and calorimetry technology
- We should focus our attention on engineering design, cost reduction and reliability

Isn’t it Too Late: Approach II?

- It is good to have a ‘default’ detector design as a ‘proof of concept’ and as a sensible estimate of the detector cost, but it is too early to make too far reaching decisions. We may have far more time for the detector design than we would like.
- The principal reason for the experiments at the ILC is the precision measurements. It is important that the detectors are as good as they can be to take full advantage of the huge investment in the machine construction.
- Major advances of technology (silicon, integrated electronics, computer aided design and computerized production/construction techniques) may allow, perhaps, some novel solutions in the detector design area.
- A suggestion: let’s review our thinking about detectors to identify which of ‘well known truth’ may no longer be as true as we think.

Generic Detector: Cylindrical



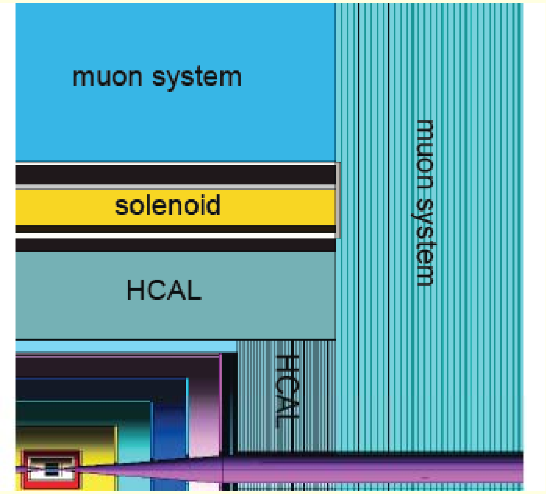
Fine example:
SiD detector

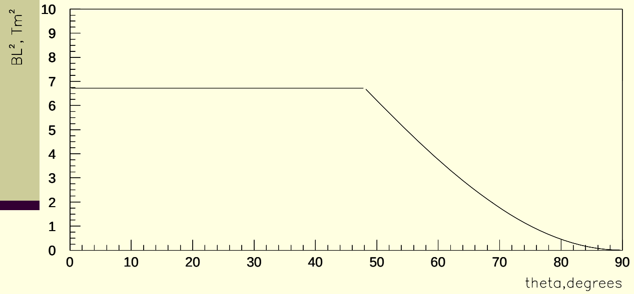
Cylindrical Detectors – Advantages:

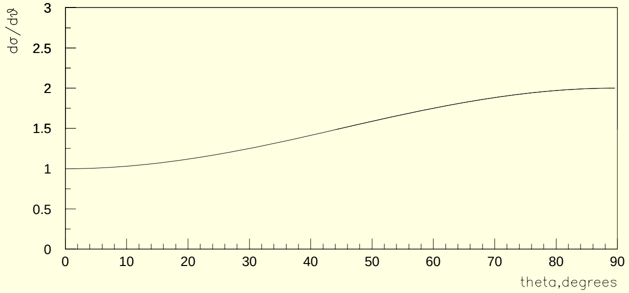
- Battle-proven, well understood design. Several existing examples: LEP, Tevatron, LHC
- uniform (axial) magnetic field, No radial field component
- Established construction techniques, support, services...
- Phi-symmetry (construction, analysis)
- significant effort in simulation, analysis, physics performance, detector optimization

An obvious candidate for the detector design.

A Cylindrical Detector: Weak Points







- Good momentum resolution in the barrel region only. It degrades rapidly at lower angles, whereas the particle density increases. For e^+e^-→ f fbar

$$\frac{d\sigma}{d\vartheta} \propto 1 + \cos^2 \vartheta$$

For other processes (like *t*-channel exchange) more forward-peaking

- Ugly corners/transitions, change of geometry (often used: this analysis for |θ>45°|, ‘forward tracking’, …)

- Calorimetric sampling/resolution degrades with 1/sinθ: too thin at θ=90°, unnecessarily thick at θ=45°.

- Albedo from large angle tracks/jets entering endcaps (at hadron collider de-weighted by sinθ, E_T)

- cost of covering the solid angle increases as 1/sinθ

Why Build a Cylindrical Detector?

- This is the way the colliding-beam detectors are usually built
- 4π gaseous tracking:
    - axial wires + (usually awkward) forward disks
    - TPC (axial drift of electrons)
    - ExB, Lorentz angle effects: need homogenous axial magnetic field => solenoid

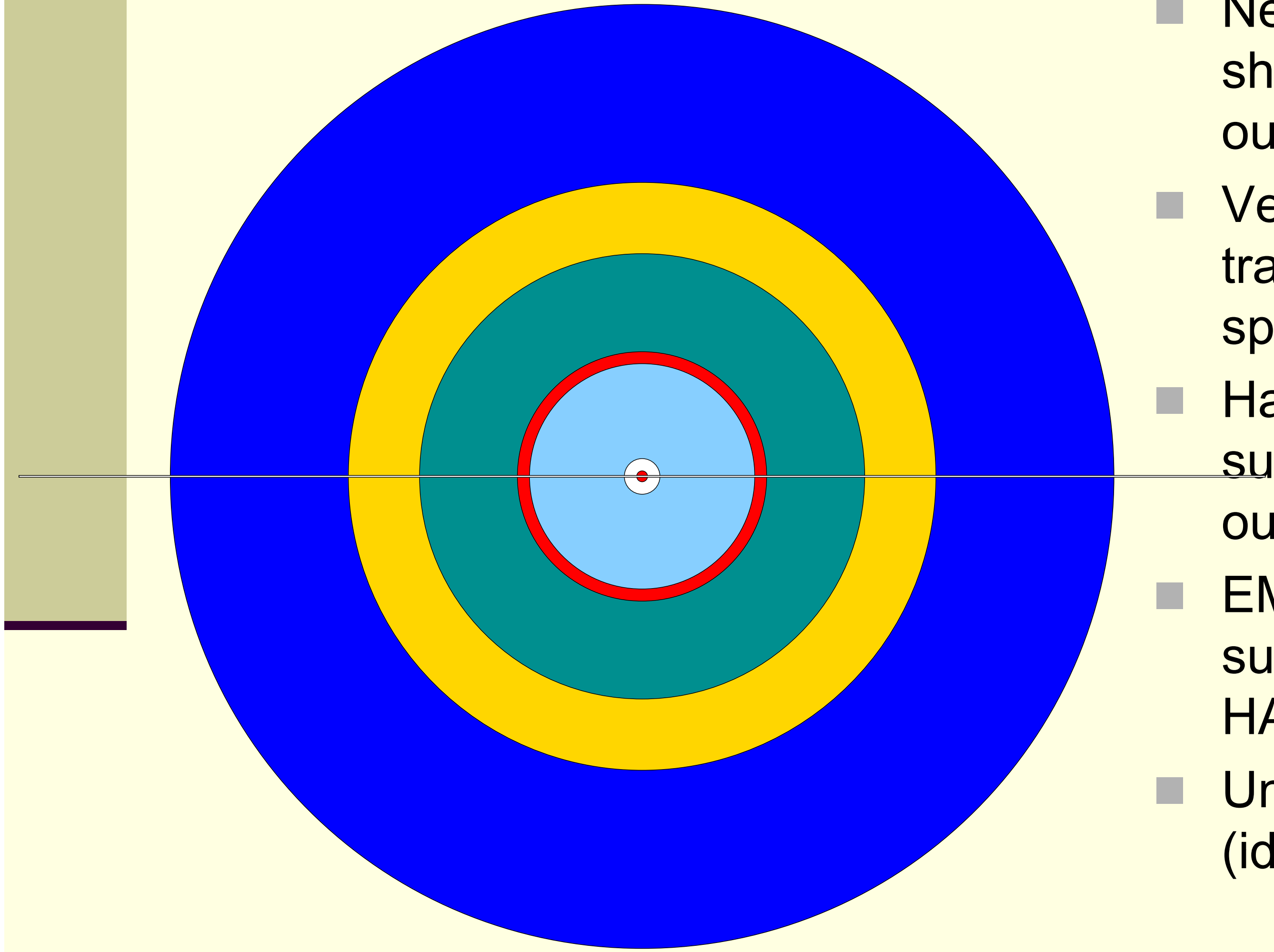
- The main (the only good?) reasons for the cylindrical geometry seem to be related to gas-based tracking detectors.

- Silicon-based tracker offers new flexibility: one may construct a traditional cylindrical detector, but other geometries are possible too.

Why not a Spherical Detector?

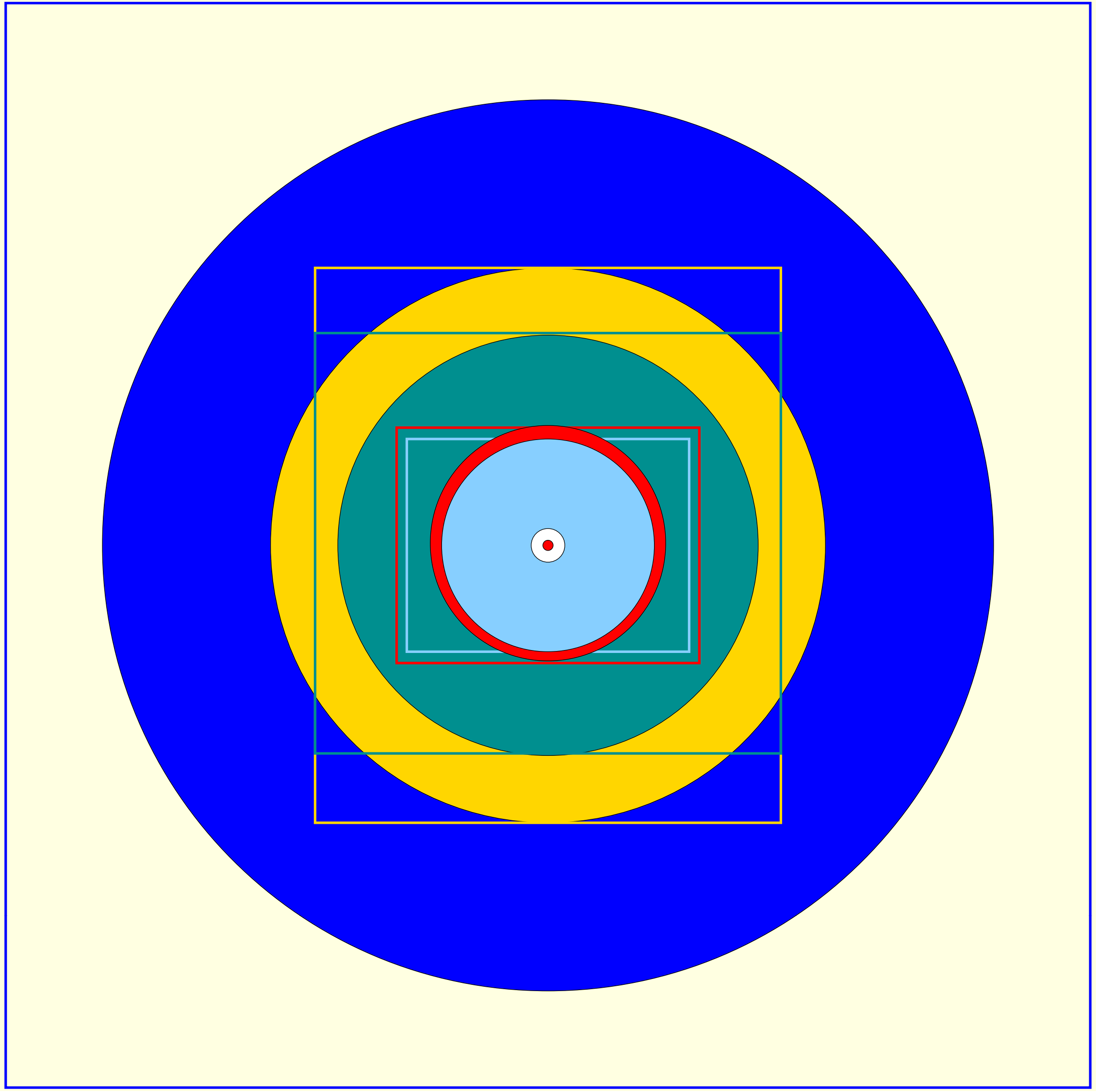
- Maximal symmetry of the detector
- Equal treatment of high and low angle regions, no corners and transition regions. Maintain good detector performance down to low angles.
- Best detector performance: detector surfaces ~orthogonal to the measured particles trajectories
- (Probably) the best use of the materials strength, the minimal need for the support structures
- Cost! Example:
    - A detector with radius R and length L=2R: area = $(4+2)\pi R^2$
    - A spherical detector with radius R: area = $4\pi R^2$
  - For the same detector radius a spherical detector is 1.5 times ‘cheaper’
  - For the ‘same cost’ the spherical detector can be 1.2 times bigger
  - For detector with L>2R the cost savings are even bigger

A Spherical Detector?



- Nested shells, inner shells supported form outer ones
- Vertex detector and tracker : spherical space frames
- Hadron calorimeter supported from an outer strong back shell
- EM Calorimeter supported from the HAD calorimeter
- Uniform calorimetry (identical ‘towers’)

Size Comparison: SiD vs a SSD (Spherical Silicon Detector)



- Postpone muons and coil discussion (coming)
- All sub-detectors of the spherical detector have 1.5-2 times smaller volumes/surfaces than those of the SiD
- The reduction of the detector volume even smaller in comparison with other detector concepts.

Construction the Spherical Detecor

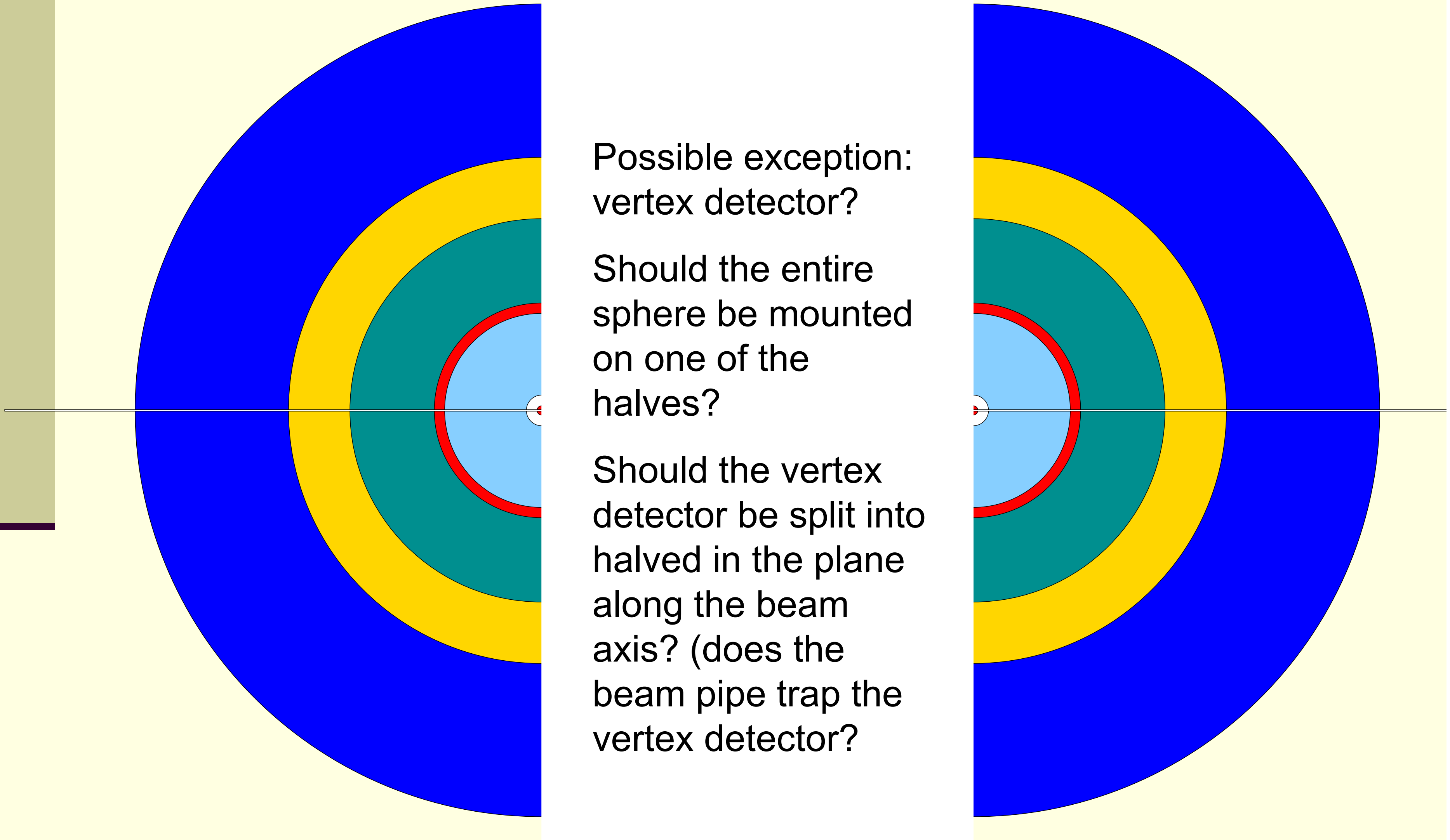
(Some of) the problems: Inner detectors are trapped inside.

- How can you build/install the detector
- Access for repairs/maintenance
- Cables/services

Solution(s):

- Split the detector in two halves at θ=90°.
- Run most of (all?) the cables out in the θ=90° 'crack'. Crack may not be projective. The particle density is at minimum and the available area is maximal there, hence the impact on physics is minimized
- Detectors can be constructed (if this is a desirable scenario) with hemispheres openings facing up (ease of access, minimize the support problems, use gravity to help the assembly of the detector) and subsequently rotated to the vertical position
- Easy access to the innermost detectors after the opening

‘Open’ Detector (for Access or before Installation)



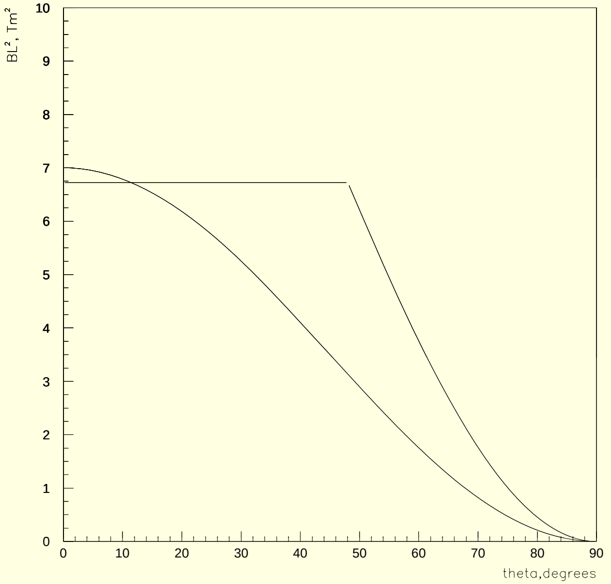
Possible exception: vertex detector?

Should the entire sphere be mounted on one of the halves?

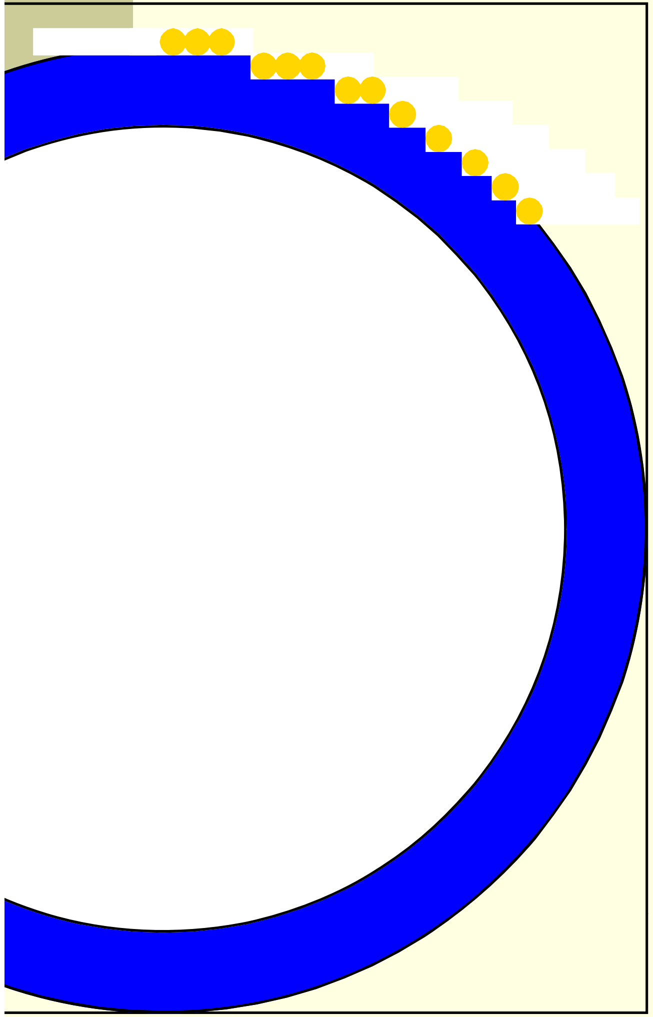
Should the vertex detector be split into halved in the plane along the beam axis? (does the beam pipe trap the vertex detector?

Tracking resolution/magnetic field

- Spherical detector may be good for calorimetric measurements, perhaps for the structural reasons. But.. If immersed in the solenoidal magnetic field, the momentum resolution is rapidly degraded with decreasing polar angle
- Two avenues for the improvement of the momentum resolution:
  - Make the detector bigger ($\Delta p/p \sim L^2$) taking advantage of the better (i.e. cheaper) coverage of the solid angle
  - ‘bend’ magnetic field to provide B_r component to magnify BxR



‘Spherical Solenoid’ ?

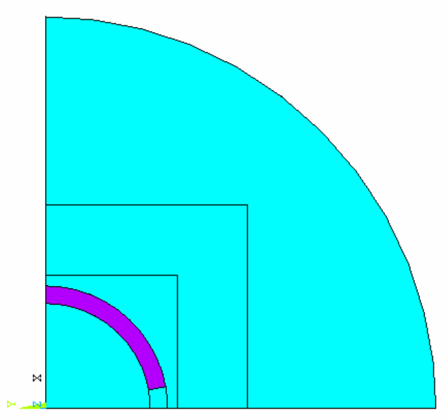


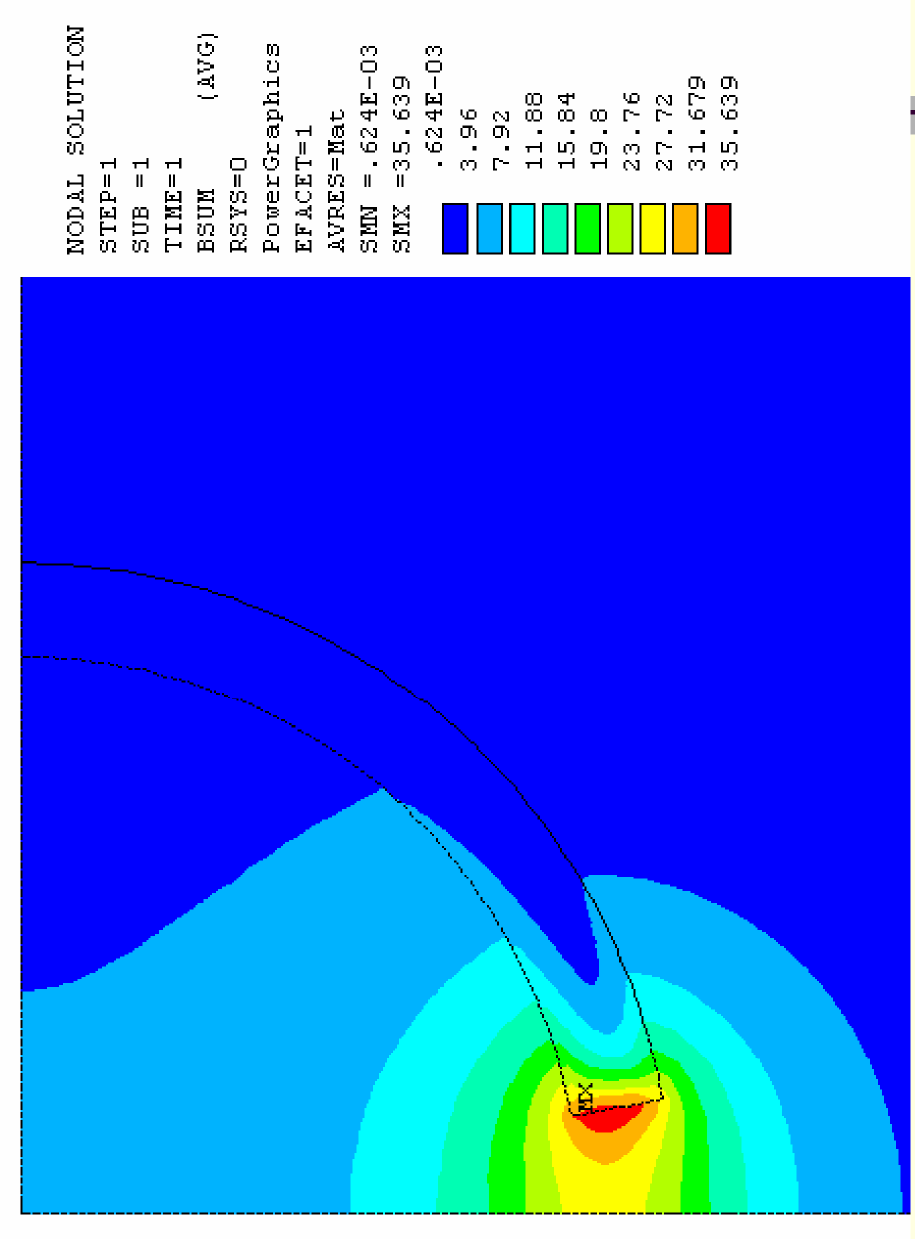
- Strong (hemi)spherical shell with notches. Outside the detector volume, no material constraints. Two separate cryostats.
- Wind the coil on the notches
- Coil radius decreasing with the polar angle:
  - Reduce the distance to the tracking volume ➔ increase the field
  - Reduce the volume of the superconductor (if the same current density) or increase the current density
- Reduce the stresses on the superconductor: most of the compressive load transferred to support shell, as opposed to the solenoid where the superconductor has to take the entire load
- Hoop stress taken by the outer spherical shell

Initial Field Calculations (B. Wands)

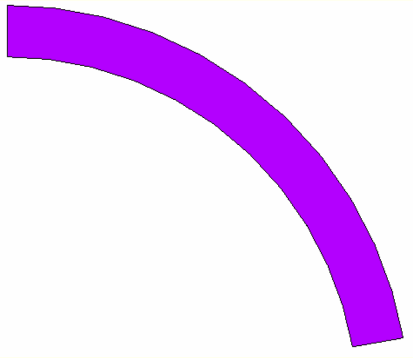
- This is NOT a design of an optimized coil, but rather some toy-examples to understand the issues:
  - Field strength and the field lines
  - Role of the iron flux return
  - BL^2 as a function of the polar angle
- Model:
  - CMS-like current density at $\theta=0°(90°)$
  - Current density ~ $1/\sin^2\theta$, down to $\theta=80°(10°, r=0.5$ m)
  - Current sheet at the radius of 3 m
  - $\int B \times R dR$ evaluated up to R=1.5 m

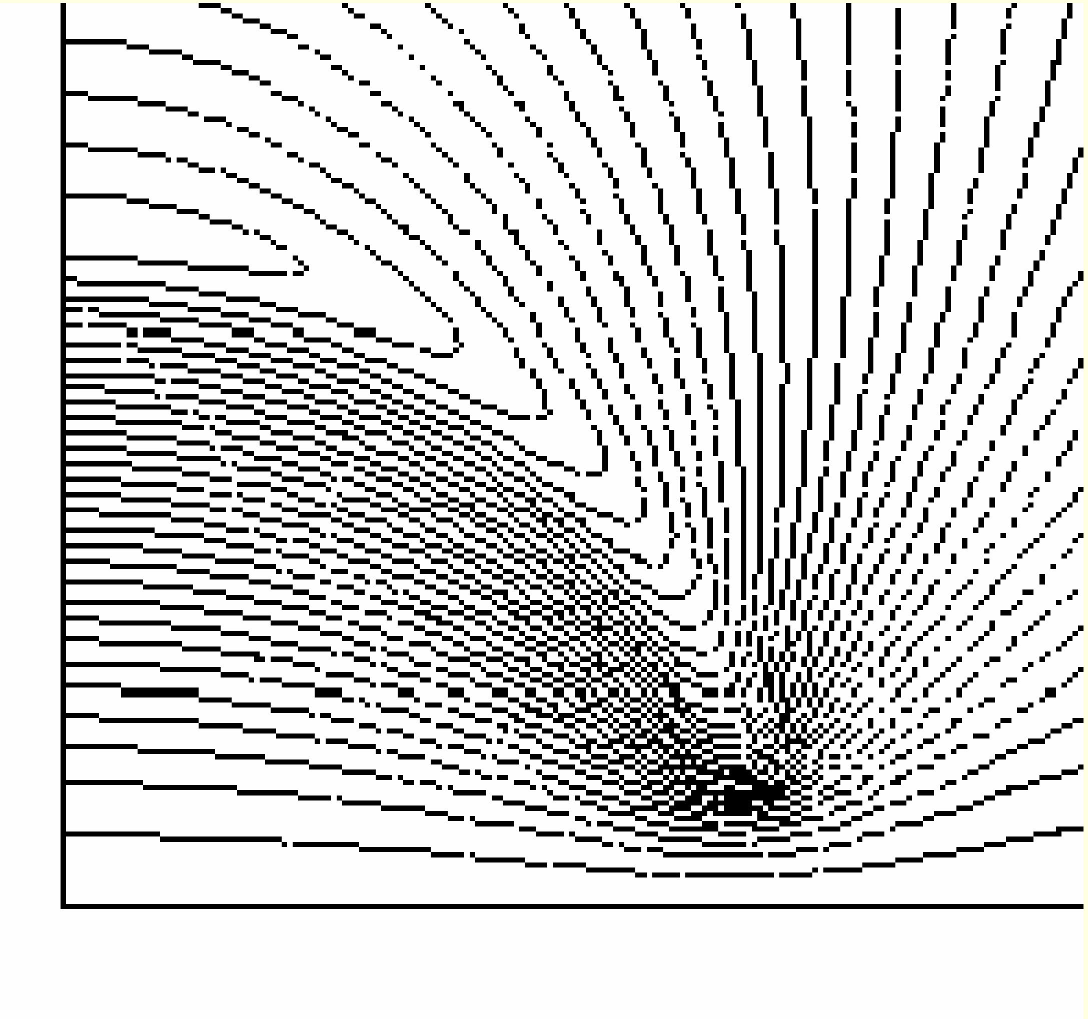
Field Strength: No Flux Return, $I(0) = 0.5I_{CMS}$



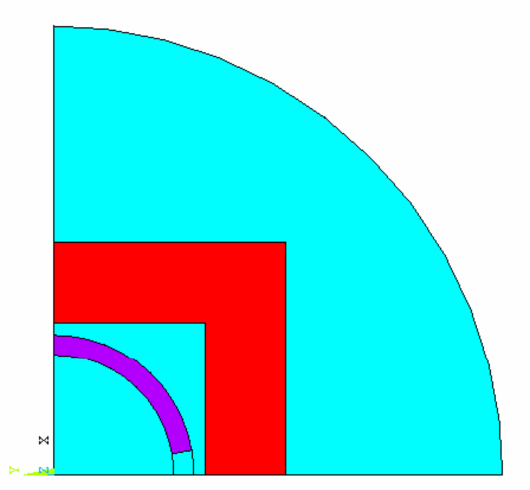


Field Lines: No Iron

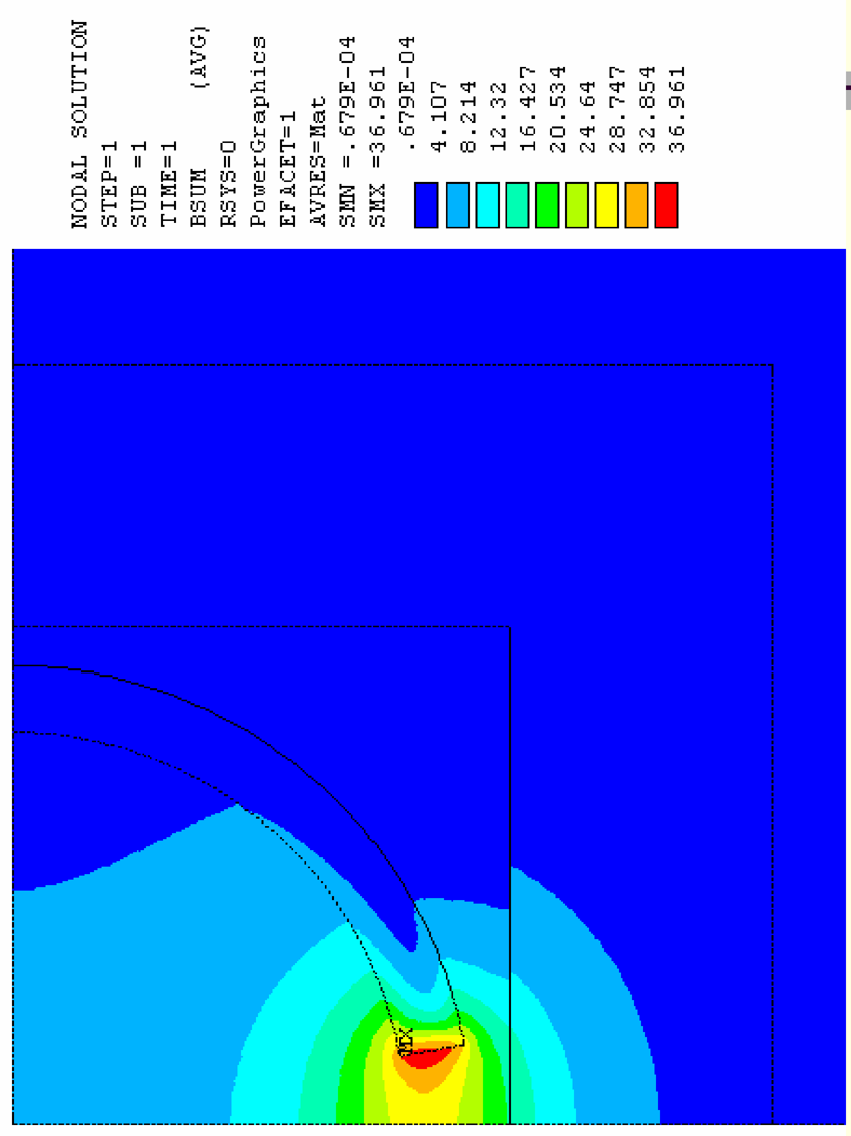




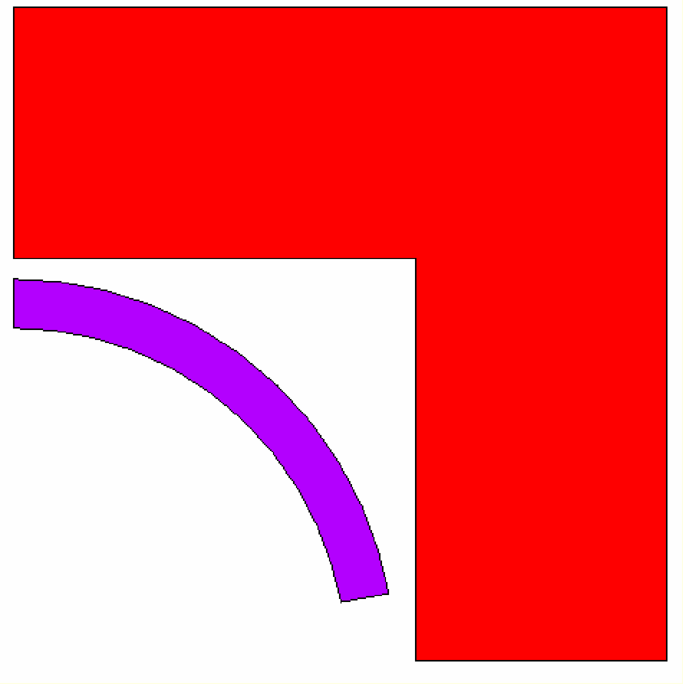
Field Strength: Flux Return, $I(0) = 0.5I_{CMS}$

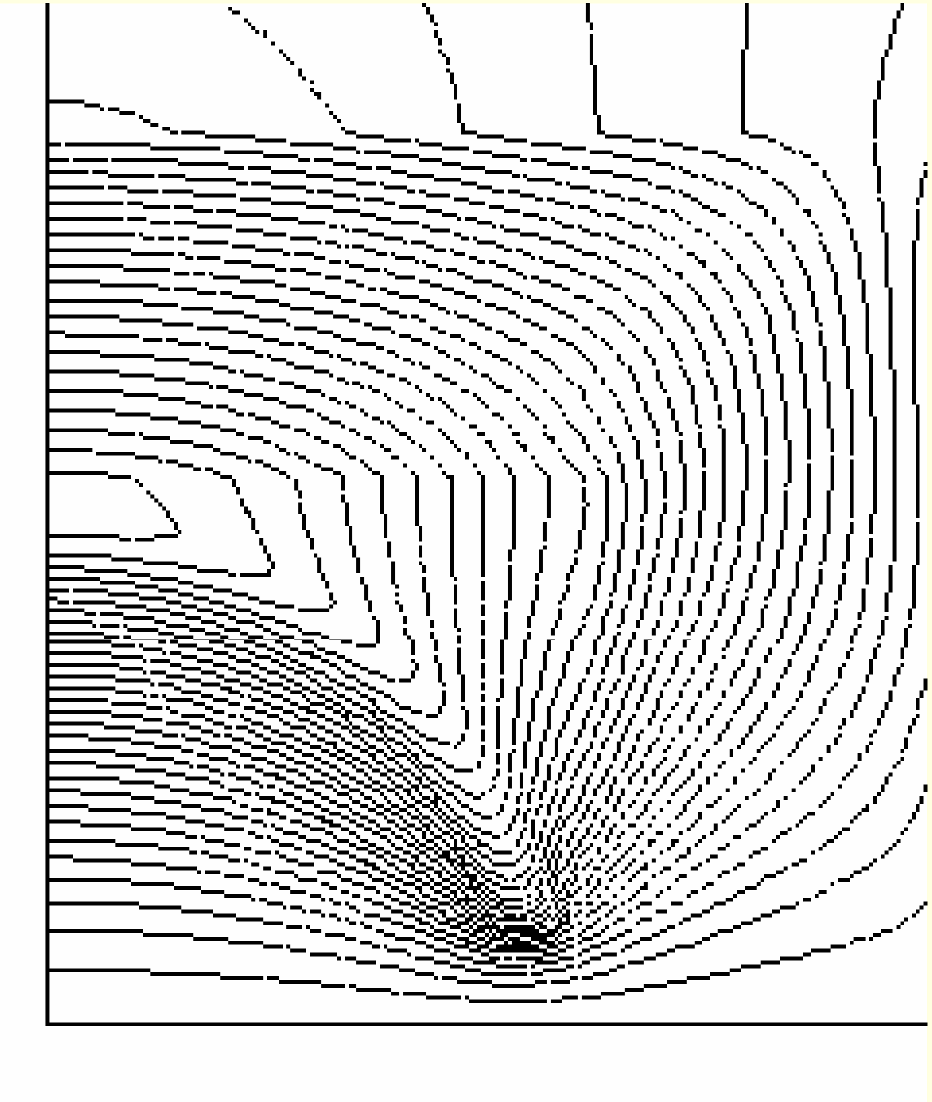


- Geometry of the flux return: naïve attempt to force the flux lines to bend more

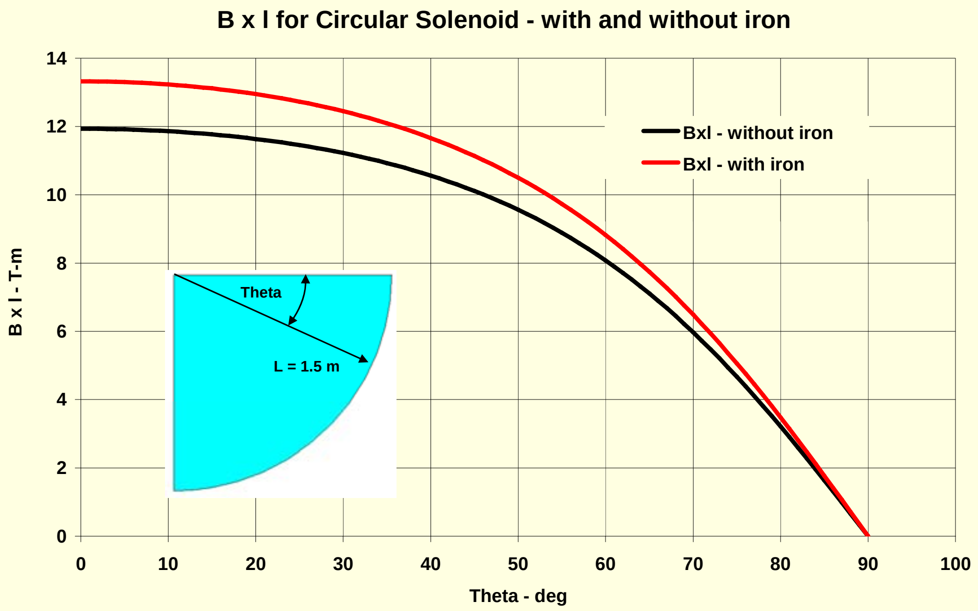


Field Lines: Iron Flux Return





$\int$BxLdL for I(0) = I_{CMS}



- Significant amount of bending down to ~10-15°. Proportional to I, of course
- Relatively small effect of the iron flux return. In retrospect: obvious. Iron saturates a values way below the actual field strength.
  ➔ Q: What is the iron for??? Muon ID? Shielding of the hall? How much is needed?

Spherical Solenoid: (Some of) the Issues

- Impact on the electron beam? The field has (nearly) axial symmetry ➔ very small radial component➔ OK??
- Non-homogenous magnetic field:
  - field mapping
  - Pattern recognition (Kalman filter-type should be OK)
  - Track fitting
- Very strong magnetic field in the detector volume
- Very, very strong magnetic field at the tip: need different superconducor (high T_c?)
- Optimize the current density as a function of a polar angle
- Optimize the angular range
- Few (3-4?) traditional solenoids of decreasing radius to restore a complete axial symmetry?
- others?