Activities for LHC Upgrade at Texas A&M University

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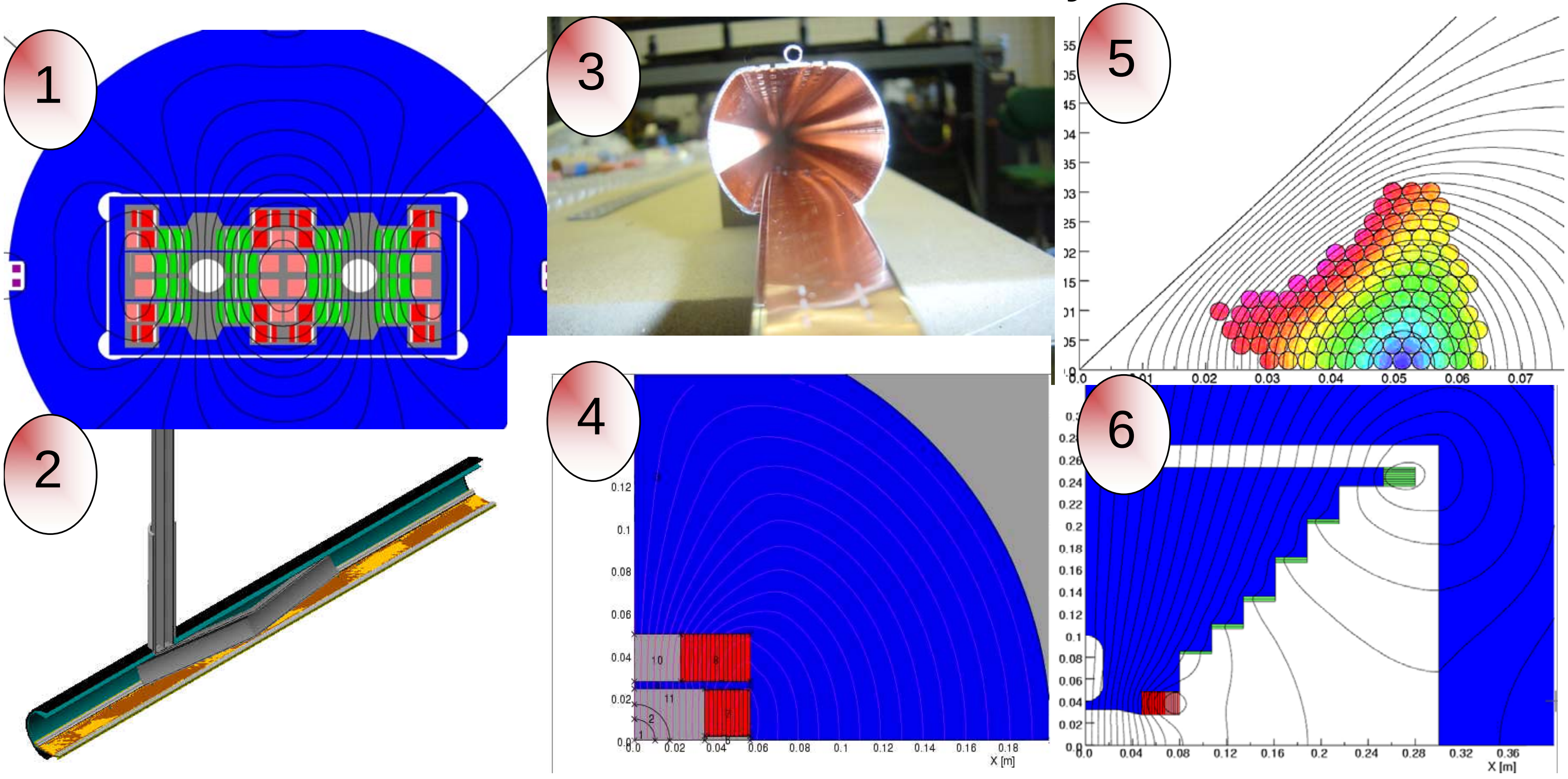
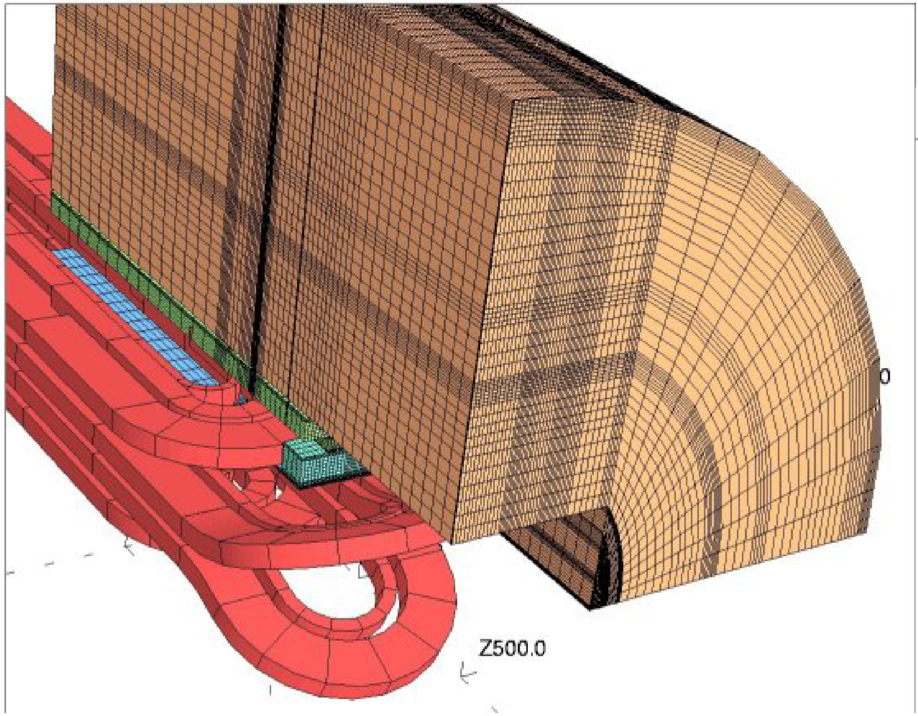
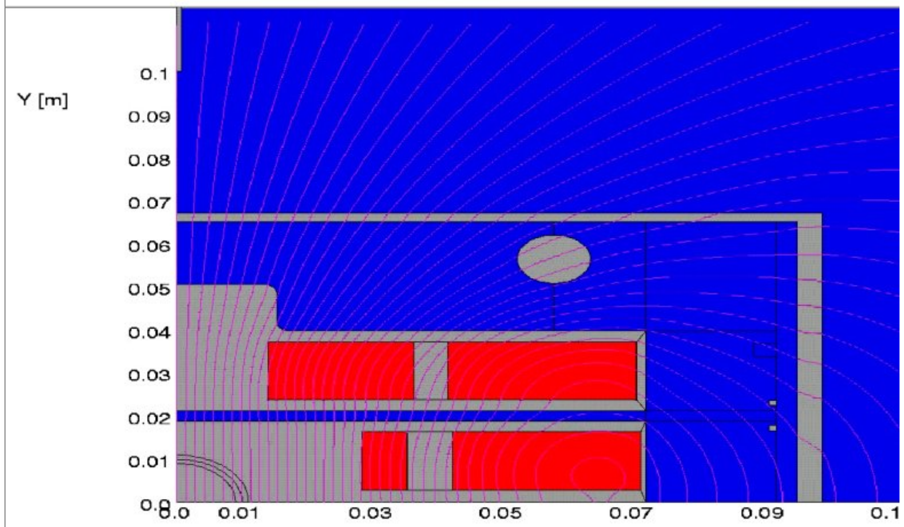


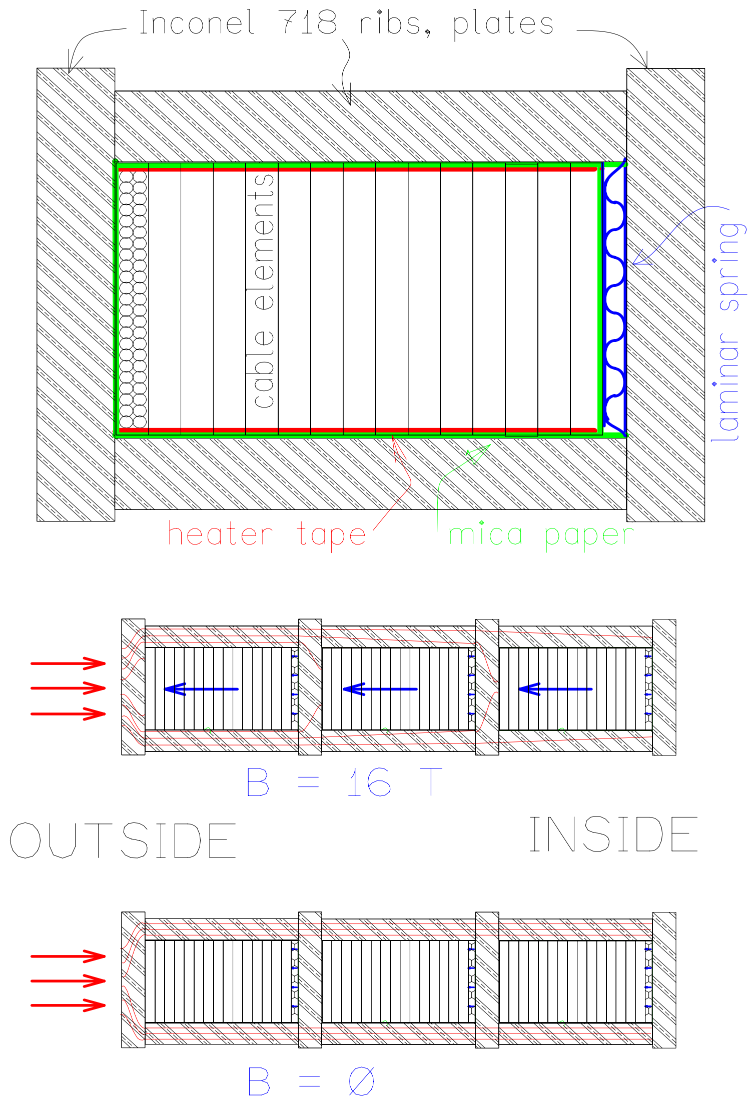
Our base program:
Block-coil dipoles with Nb_3Sn



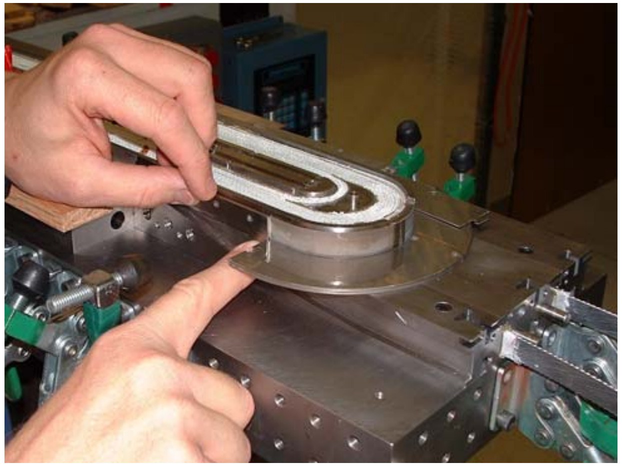


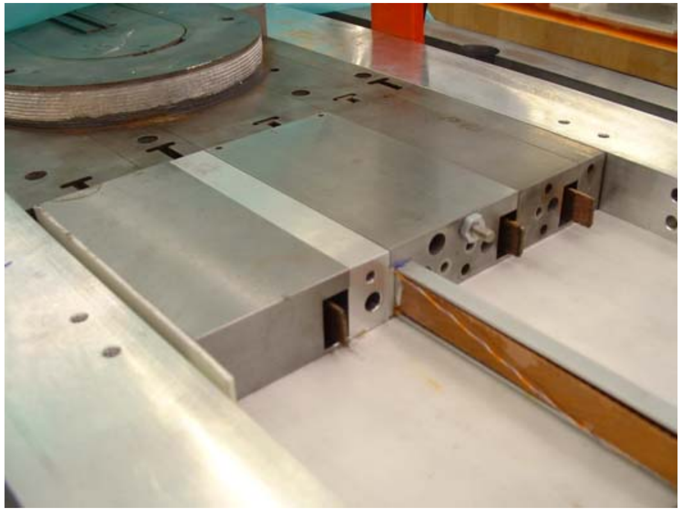
- **Bore field** **14.1 T**
- **Current** **12.6 kA**
- **Maximum Coil Stress** **120 MPa**
- **Superconductor cross section** **29 cm^2**

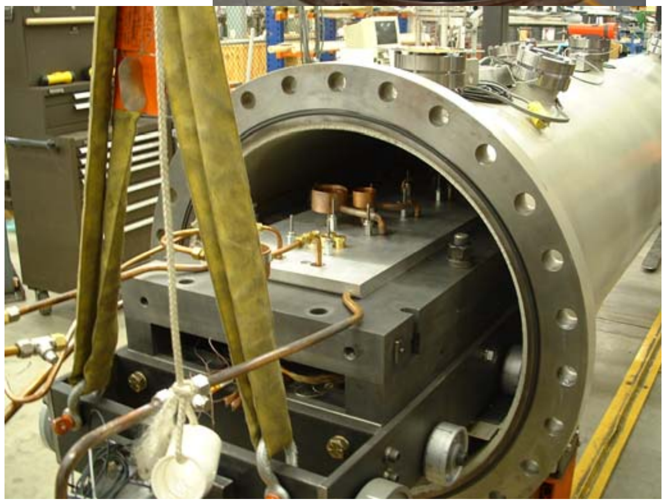
Use high-field superconductor, limit coil stress



Nb_3Sn dipole technology at Texas A&M:
stress management, flux plate, bladder preload







1 Hybrid dipole for an LHC Tripler: Bi-2212 in inner (high field) windings, Nb_3Sn in outer (low field) windings

Dual dipole (ala LHC)

Bore field **24 Tesla**

Max stress in superconductor **130 MPa**

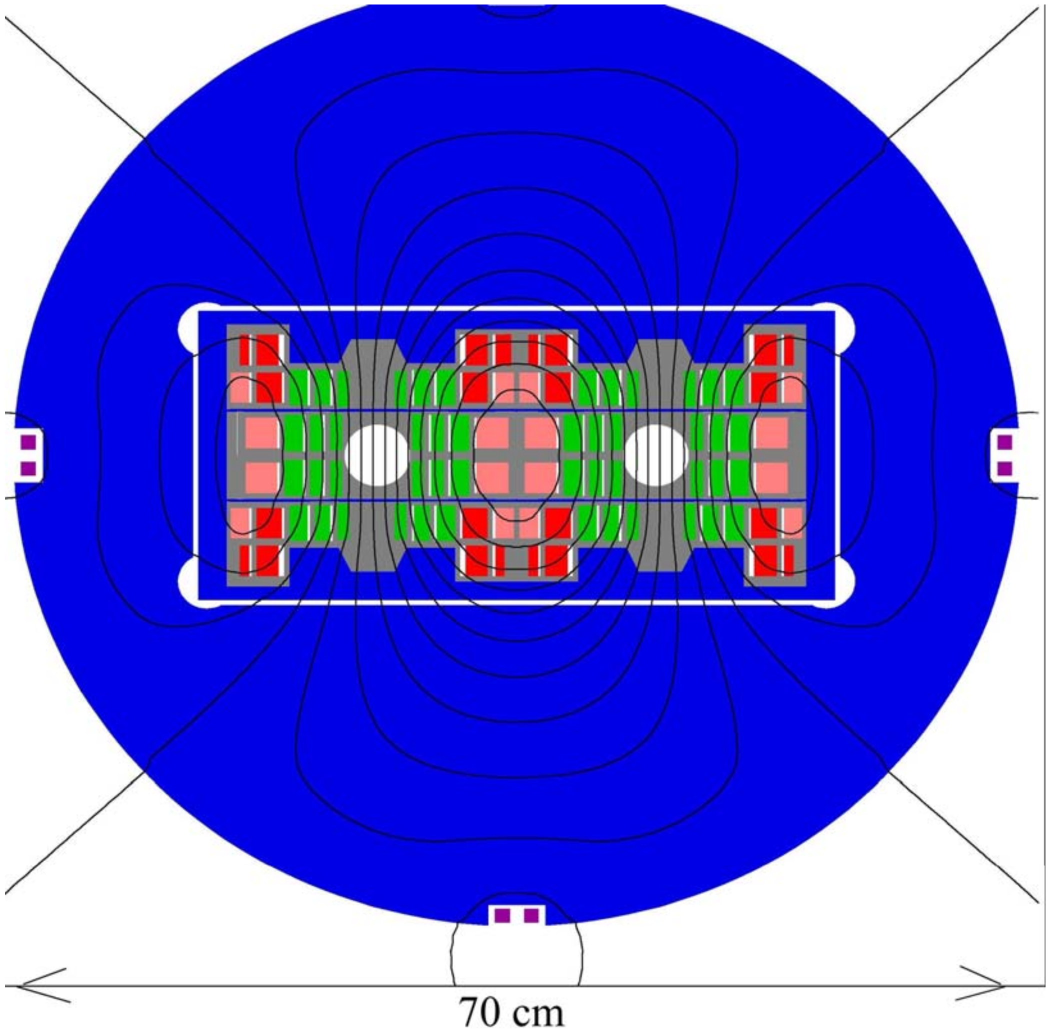
Superconductor x-section:

Nb_3Sn	**26 cm^2**
Bi-2212	**47 cm^2**

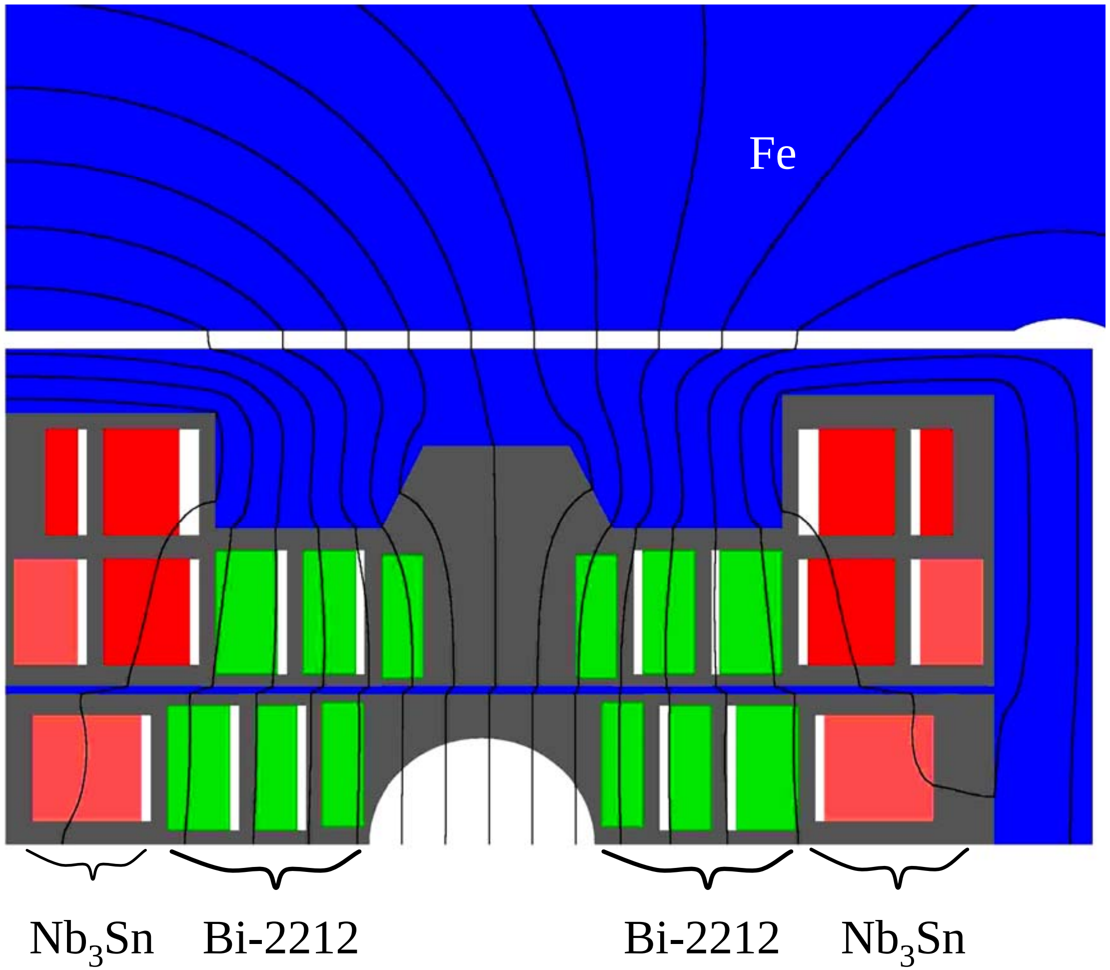
Cable current **25 kA**

Beam tube dia. **50 mm**

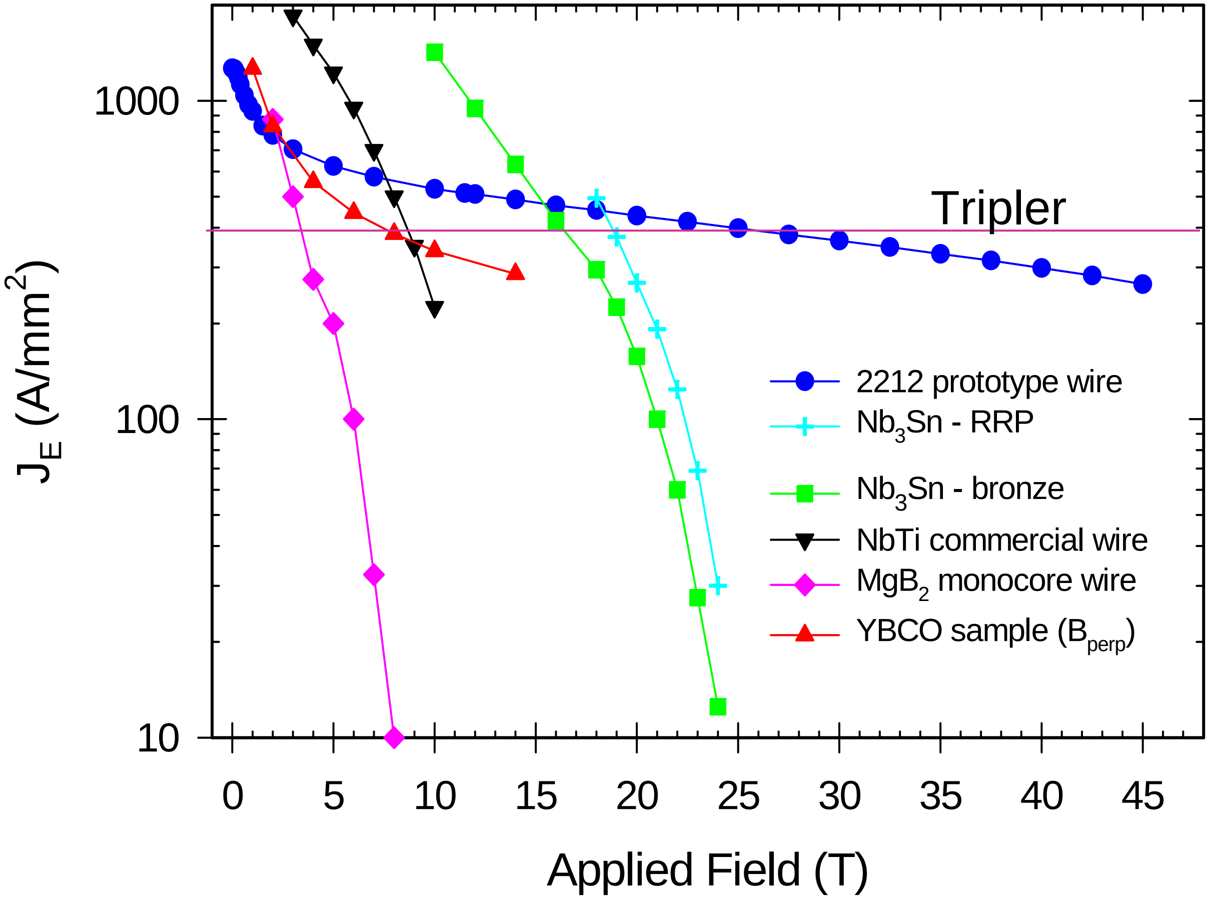
Beam separation 194 mm



Flux plate suppresses multipoles from persistent currents, snap-back

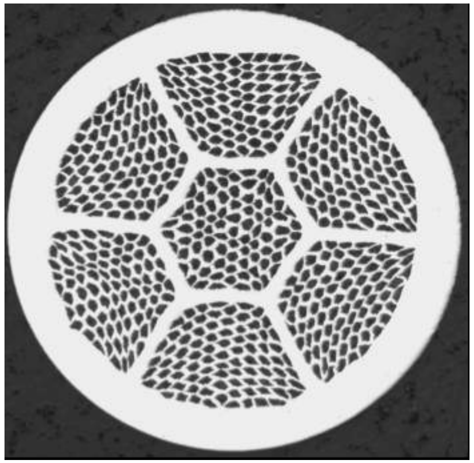


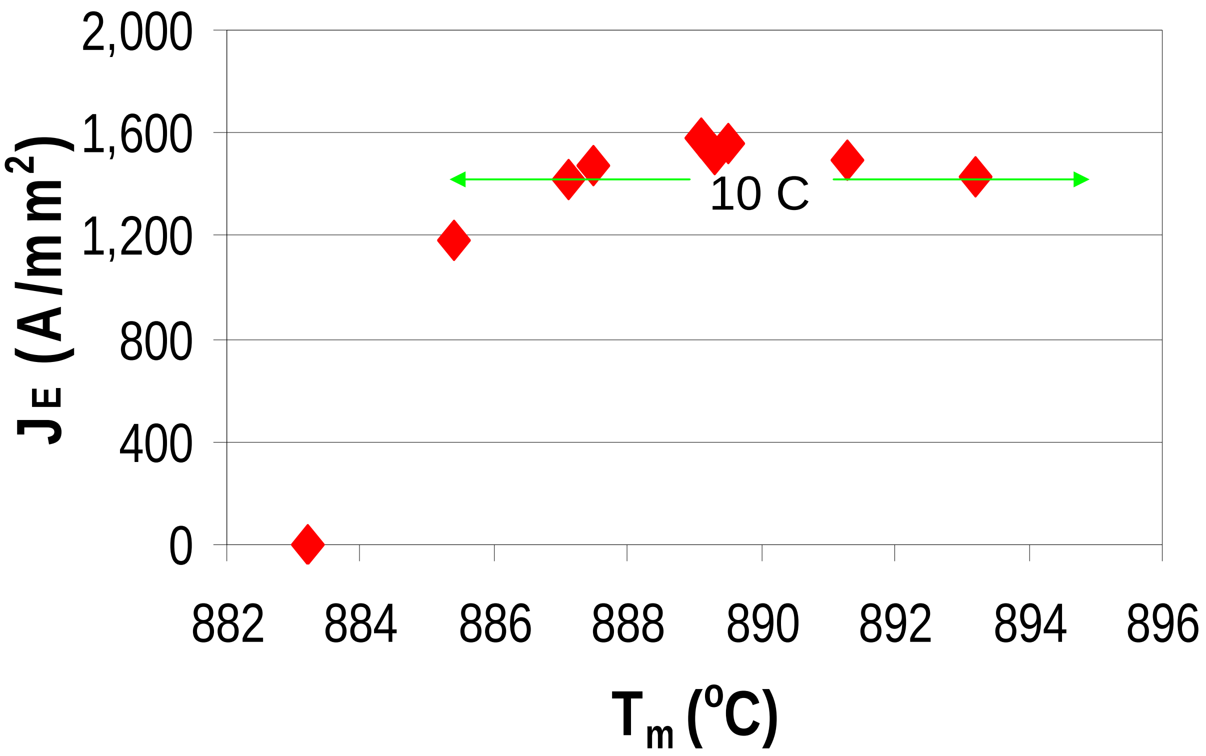
2005: Breakthrough in Bi-2212 enables the hybrid dipole - OST



At the last HHH-CARE I presented the LHC Tripler concept and said it needed Bi-2212 wire with 400 A in a 0.8 mm wire at high field – 40% more than existed. ***OST has done it!***

OST reduces filament size (15 μm), widens T plateau for partial melt



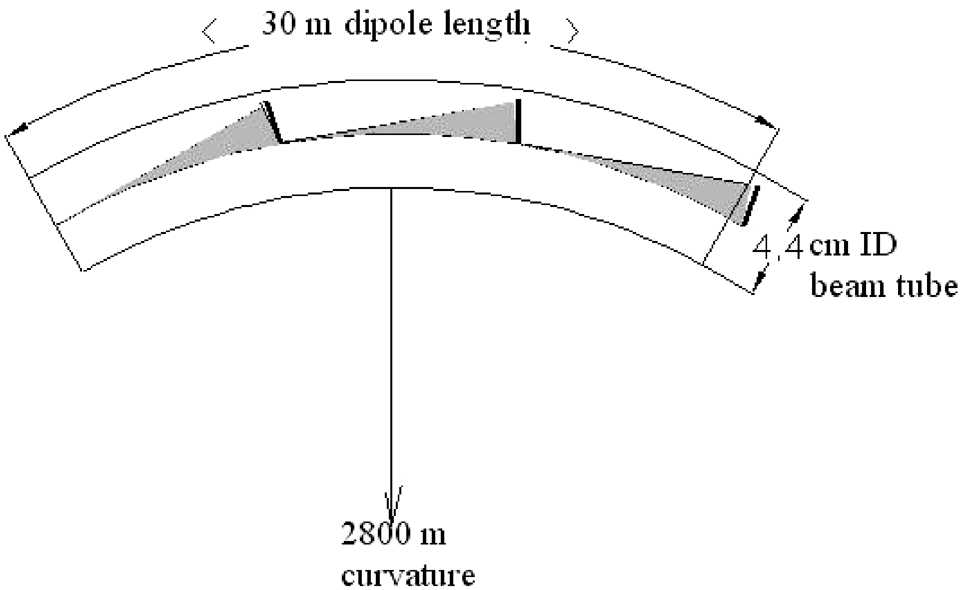


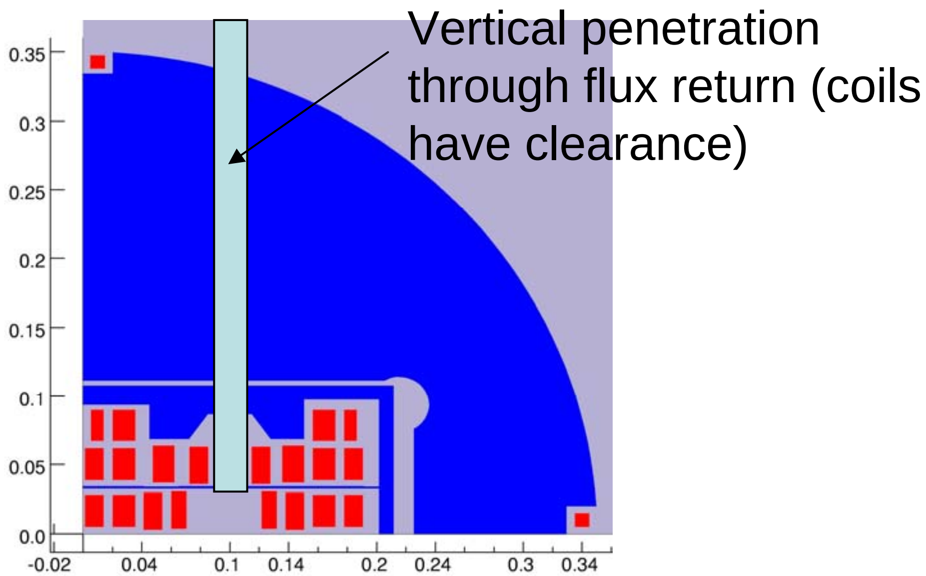
2

Photon stop: absorb synchrotron radiation @ 160 K – same refrigeration for Tripler as LHC

- power/length $\tilde{P} \propto E^4 I / \rho^2$
- critical energy $E_c \propto E^3 / \rho$

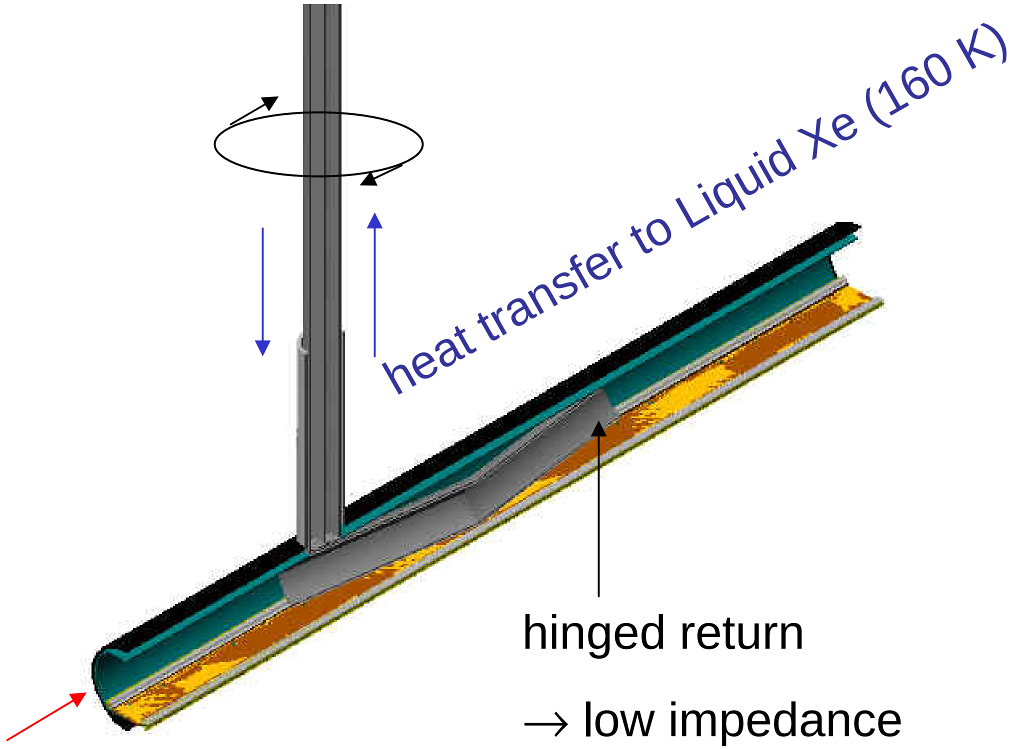
LHC:	E = 7 TeV	P = 0.22 W/m	E_c = 44 eV (hard UV) scatters, desorbs
Tripler:	E = 20 TeV	P = 14 W/m	E_c = 1.2 keV (soft X-ray) absorbs!

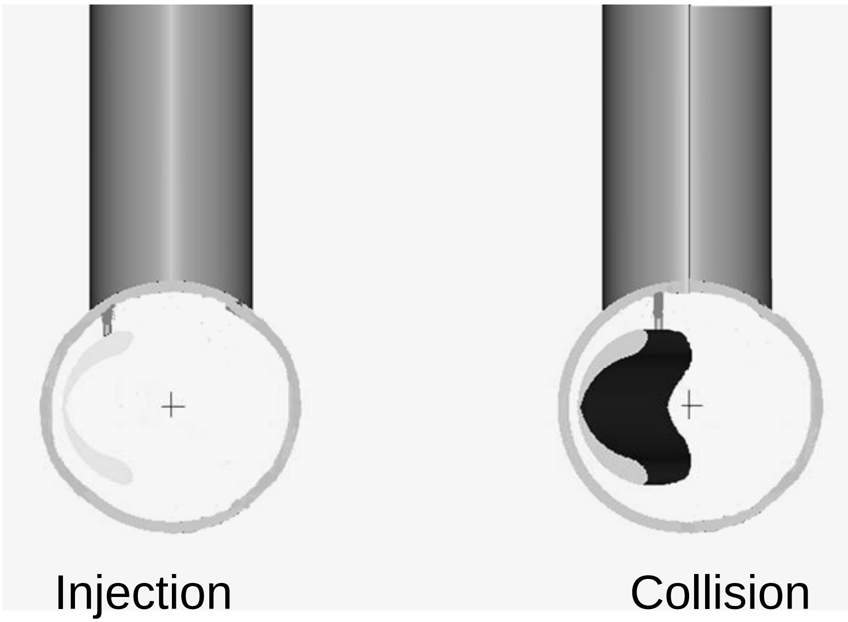




Effect on $\langle b_3 \rangle \sim 10^{-5}$ cm^{-2}

Photon stop rotates:
clears aperture at injection energy,
collects light at collision energy





160 W/stop collected @ 1 W/cm^2

Same refrigeration power for Tripler as for LHC

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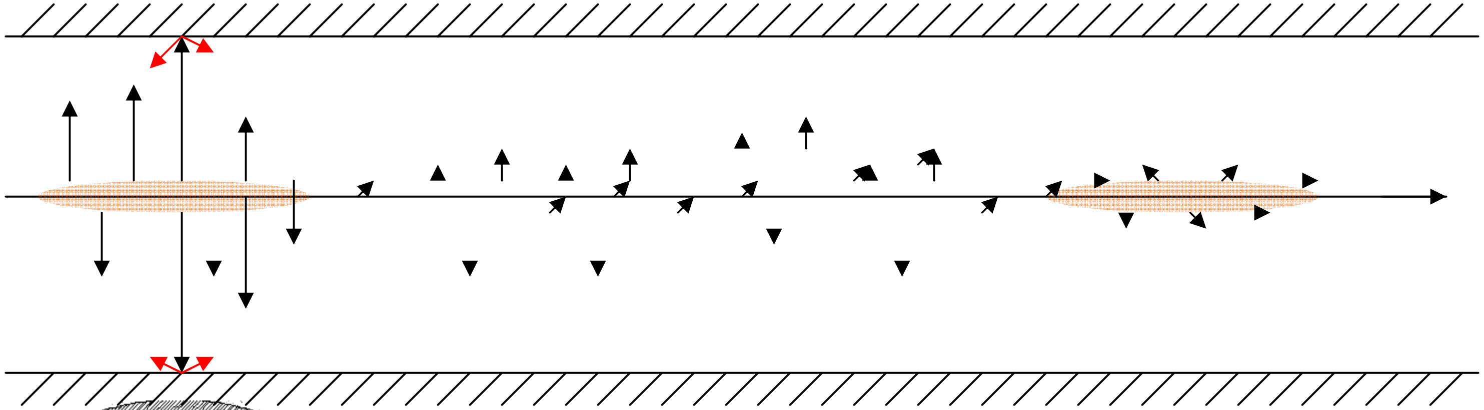
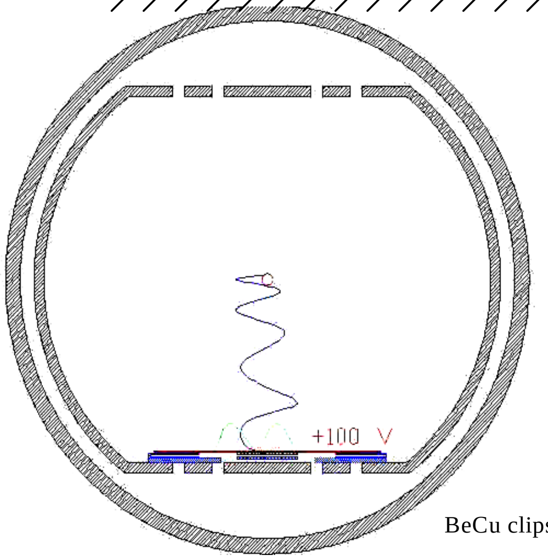
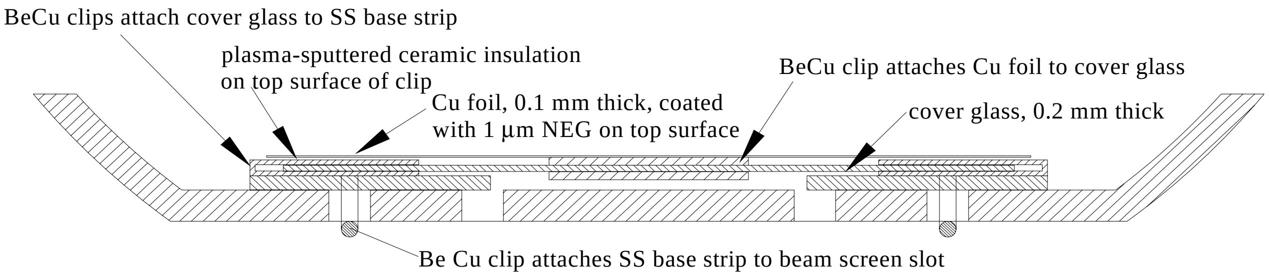
Electron cloud effect



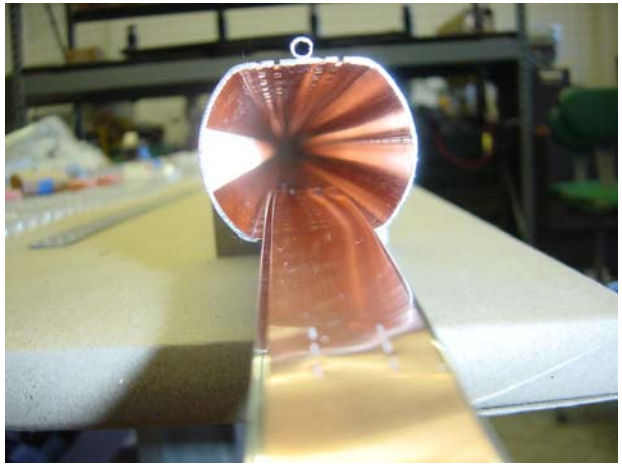


- Suppress electron multipacting by locating an electrode on bottom of beam screen.(1 mm thick).
- Bias electrode +100 V, suppress all secondary electrons, kill electron cloud effect.
- ECE could - limit bunch spacing to 75 ns,

  - dominate heat load ~2 W/m



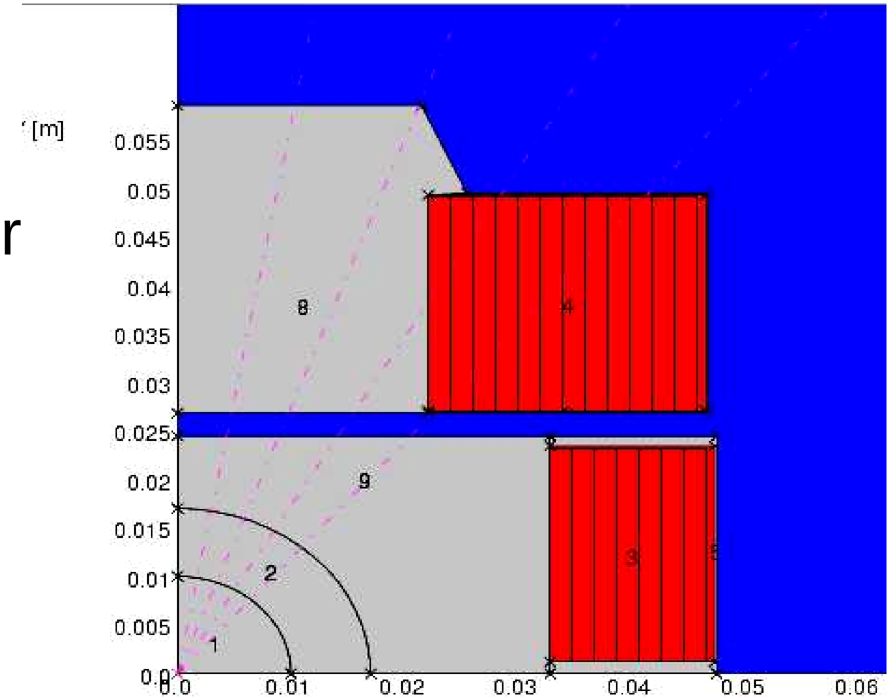
We are here at CERN to install a full-length prototype of the ECE killer



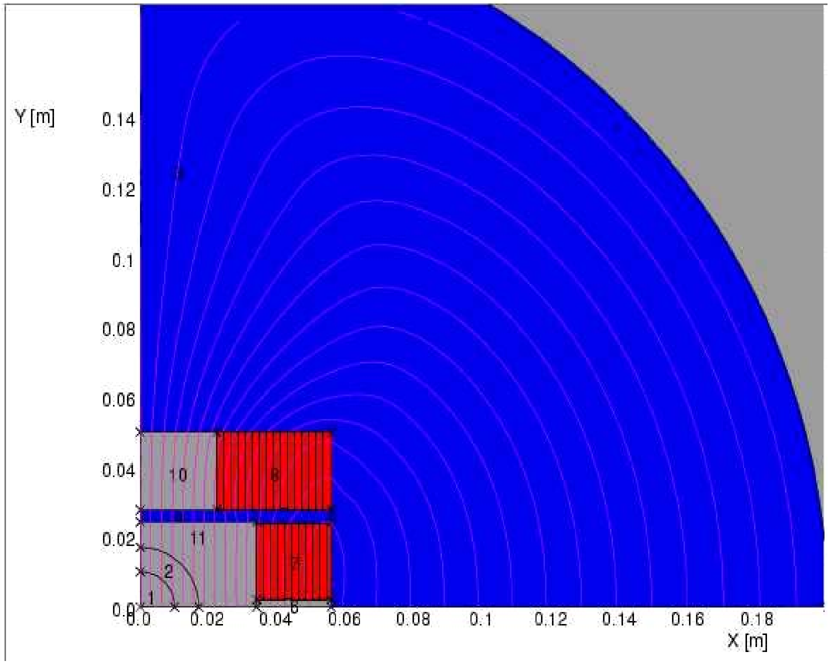
4

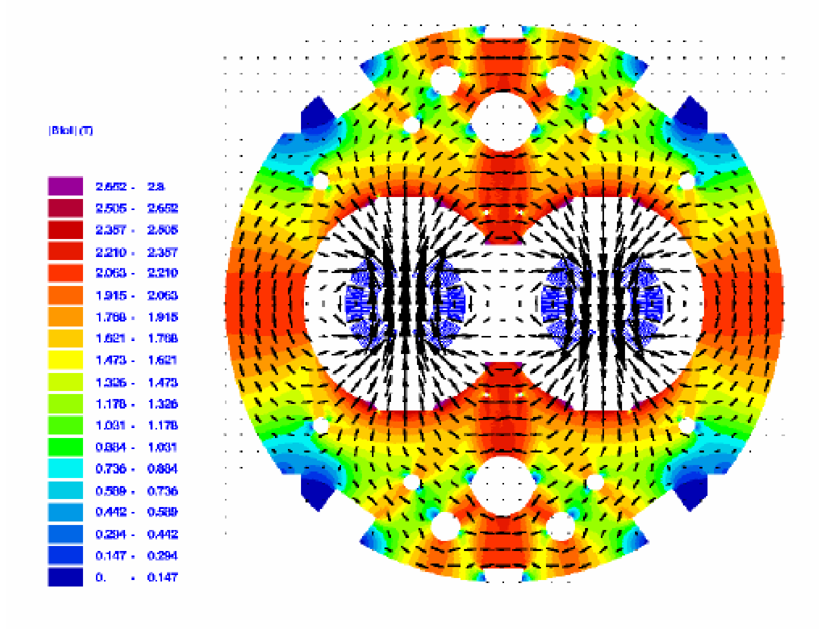
Inject to Tripler from Super-SPS

- For luminosity upgrade of LHC, one option is to replace the SPS, PS with a rapid-cycling superconducting injector chain.
- 1 TeV in SPS tunnel → 1.25 T in hybrid dipole: flux plate is unsaturated, x5 suppression of snap-back multipoles at injection.
- SuperSPS needs 6 T field,
- ~10 s cycle time for filling Tripler
- → > 1 T/s ramp rate



Again block-coil geometry is optimum





In block-coil dipole, cables are oriented vertically:

$$\vec{B} \parallel \hat{n}$$

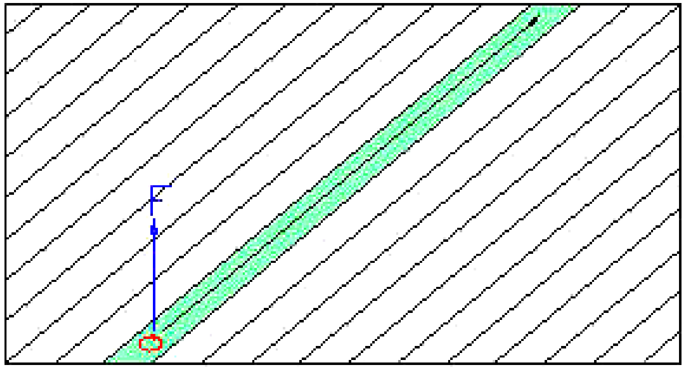
Result: minimum induced current loop, minimum AC losses

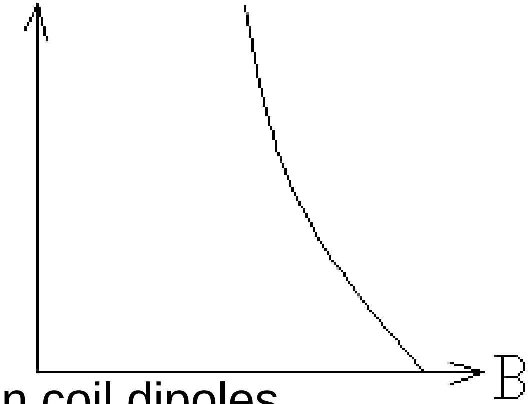
In cos θ dipole, cables are oriented on an azimuthal arch:

$$\vec{B} \perp \hat{n}$$

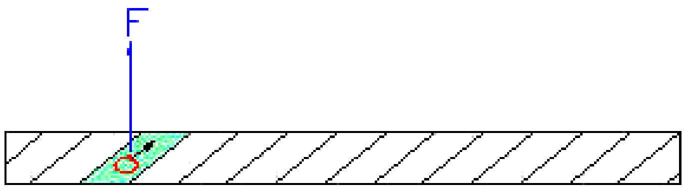
Result: maximum induced current loop, maximum AC losses

Block-coil geometry strongly suppresses the re-distribution of magnetization by boundary-induced currents





Field face-on to cable: cos θ, common coil dipoles

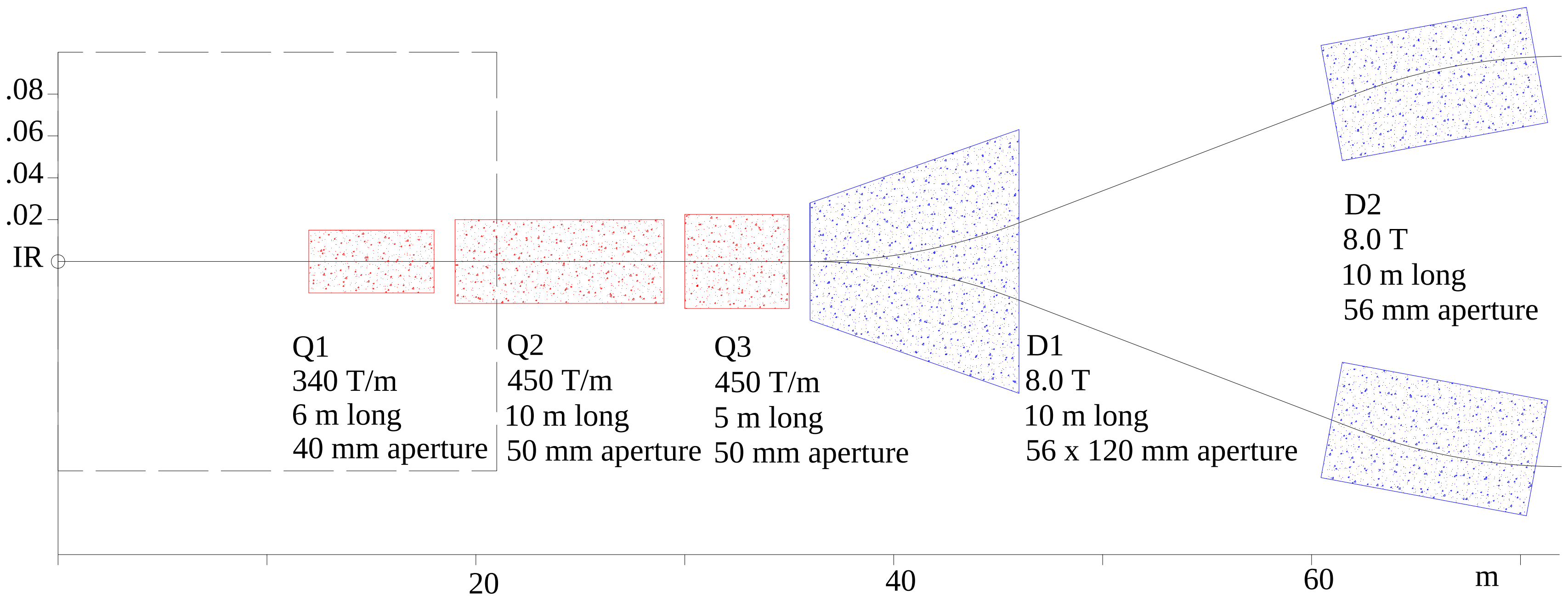


$$\vec{F} = \left(\vec{\mu} \cdot \vec{\nabla}\right)\vec{B}$$

Field edge-on to cable: block-coil dipole

- Ramp field hi→lo, induce magnetization current loops in subelements
- Cycle dipole at injection to reduce magnetization, set on charging side of hysteresis
- Dwell at fixed field for injection – magnetization loops migrate under gradient force
- Begin ramp – sudden return to charging curve – snap-back

Optimizing IR for Luminosity Upgrade

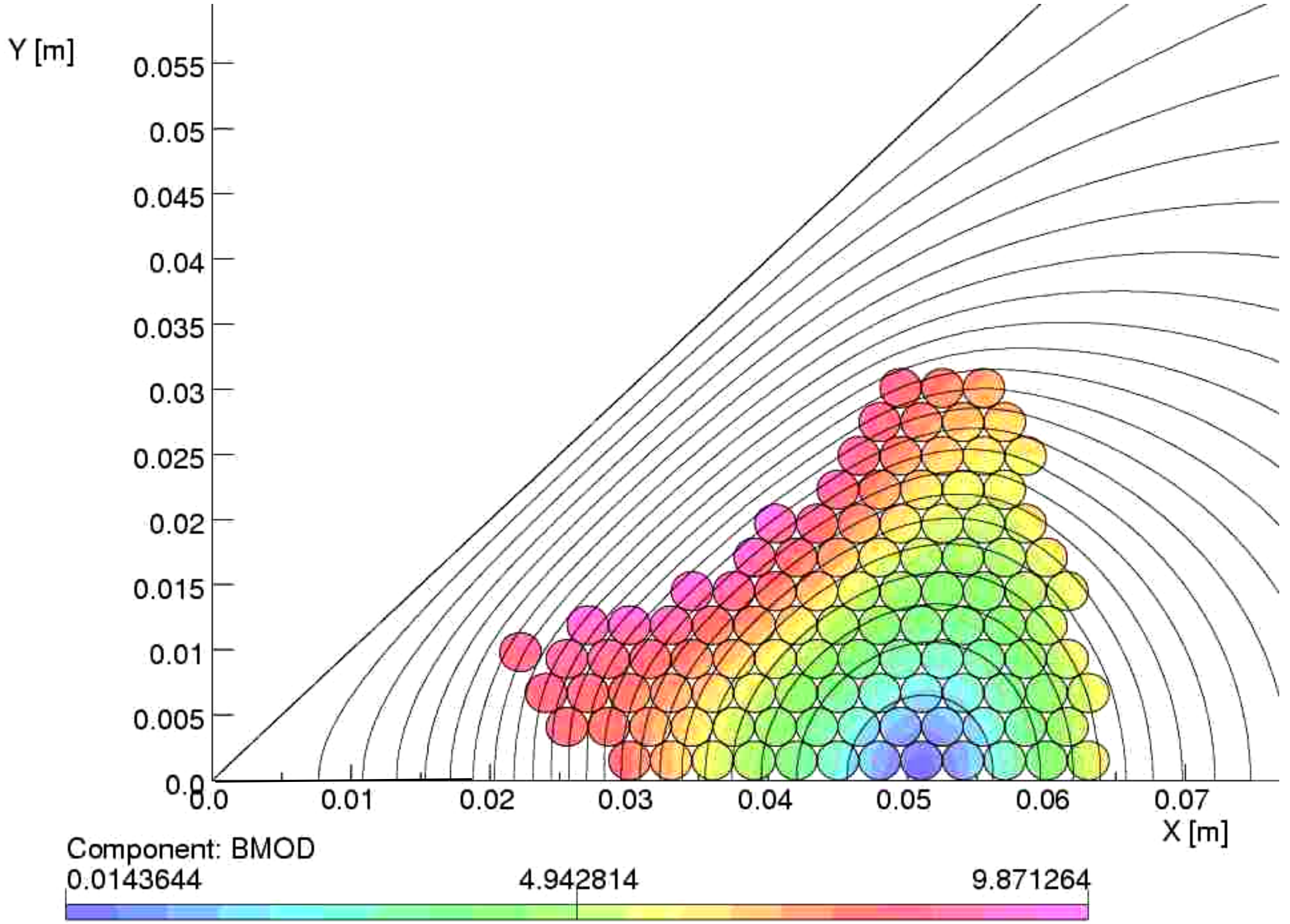


- Move triplet in to 12 m – miminize effects of chromaticity, placement/multipole errors
- *Challenges*: - Q1 must take high load from particle heat, radiation

  - D1 has intense flux of forward secondaries swept into the midplane

5

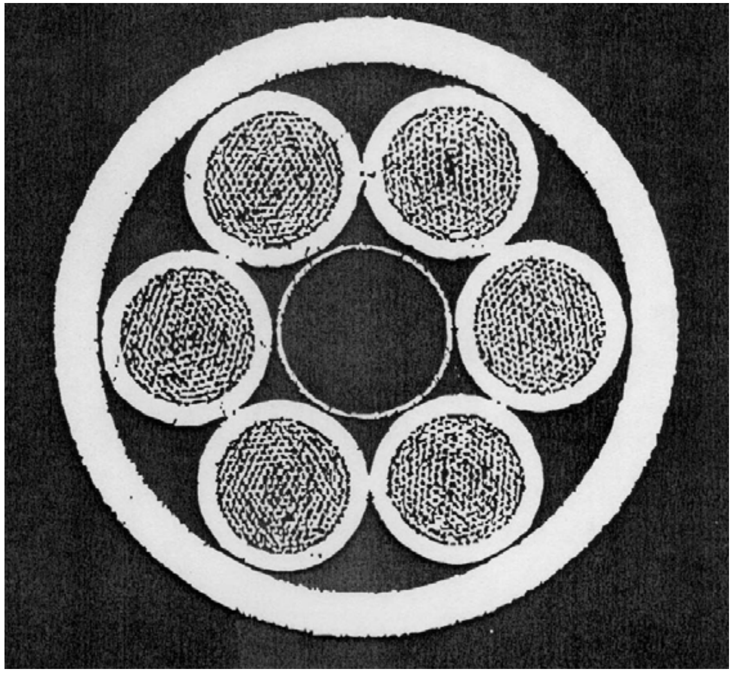
Ironless Quadrupole for Q_1 using structured cable of Nb_3Sn



340 T/m **48 mm aperture**

4.5-6 K supercritical cooling

Design Q_1 using structured cable



6-on-1 cabling of Nb_3Sn strand around thin-wall Inconel X750 spring tube

Pull cable into a thicker Inconel 718 sheath, then draw down to gently compress strands

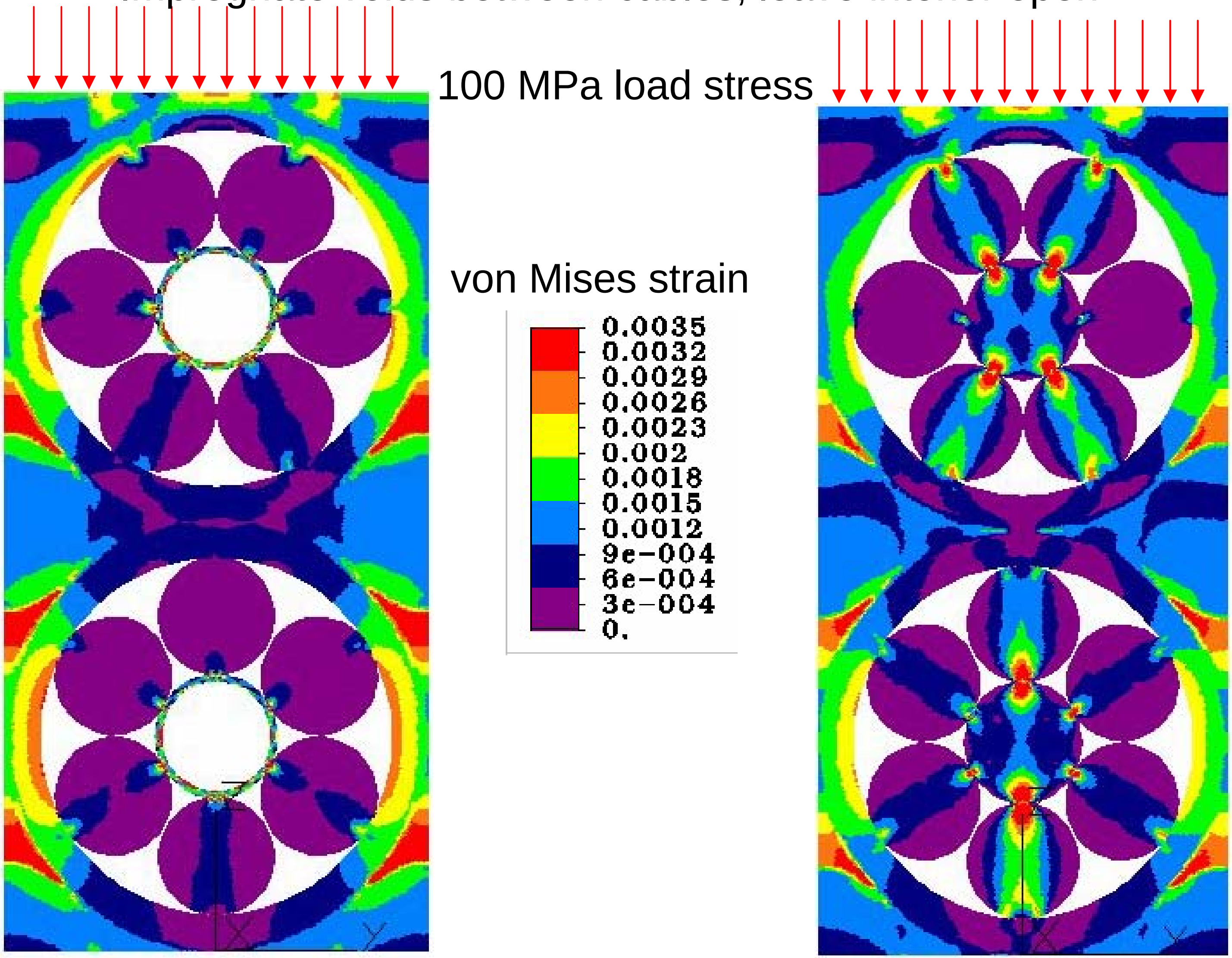
Load strands against sheath so they are immobilized without need of impregnation

Interior is not impregnated – only region between cables in winding

Volumetric cooling to handle volumetric heating from particle losses

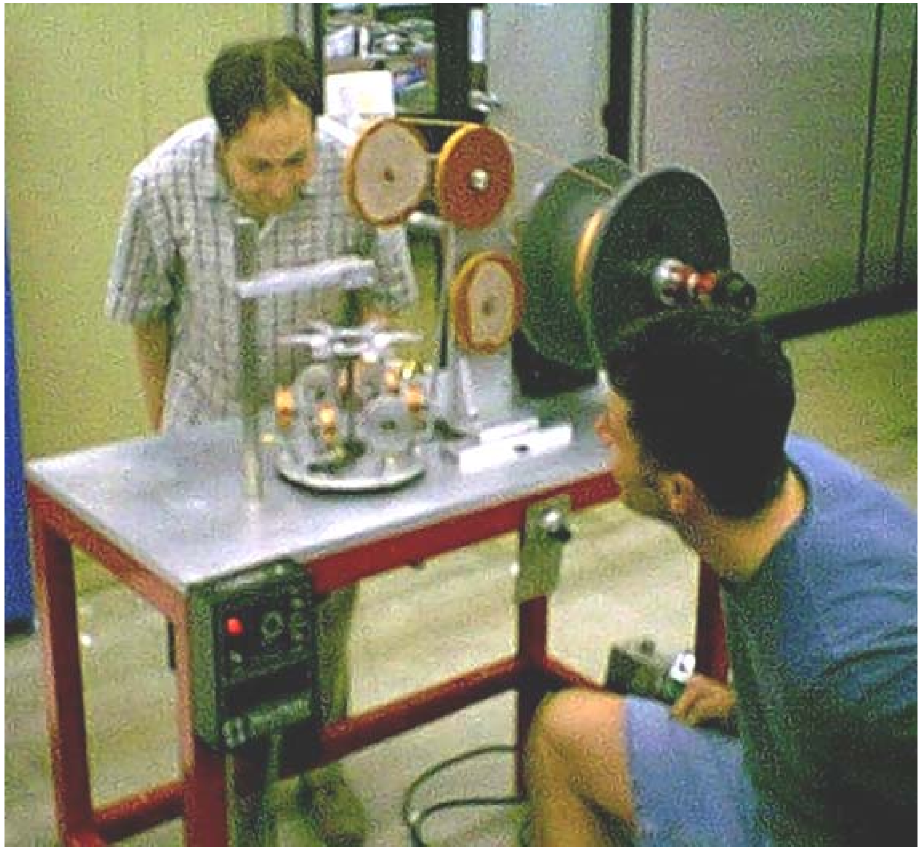
Structured Cable → Stress Management

Impregnate voids between cables, leave interior open



With spring core – no strain degradation   *Without spring core* – strain degradation

Fabricating the cable

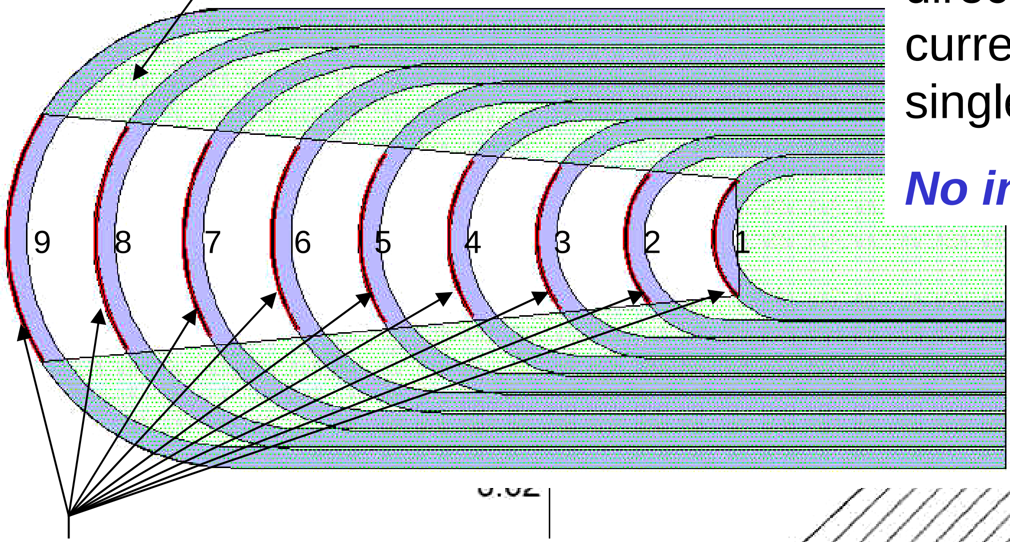


Cabling 6-on-1 cable onto spring tube

Drawing outer shell onto cable

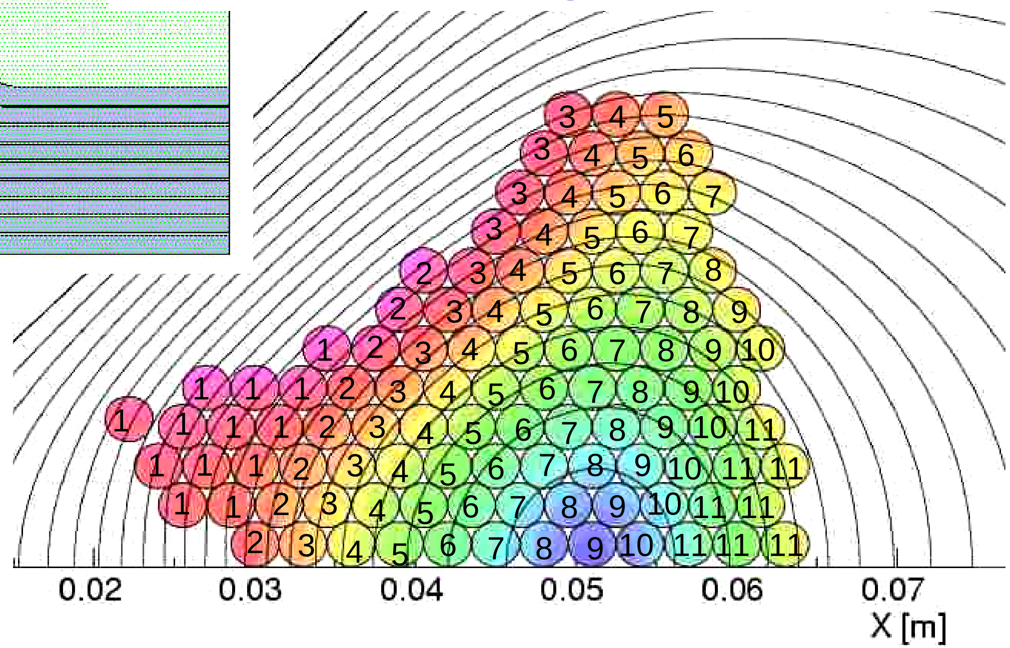
Supercritical cooling, No insulation between turns

Epoxy impregnation of voids between cables



Adjacent turns have the Inconel sheaths in direct contact. Resistance channels currents in normal operation, becomes single-turn during quench

No insulation to degrade from radiation

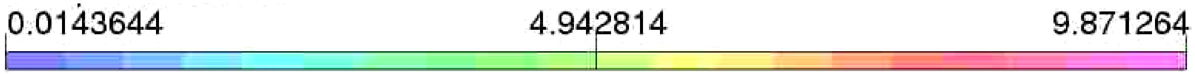


Slit end arc of each turn:

Manifold gas during reaction bake,

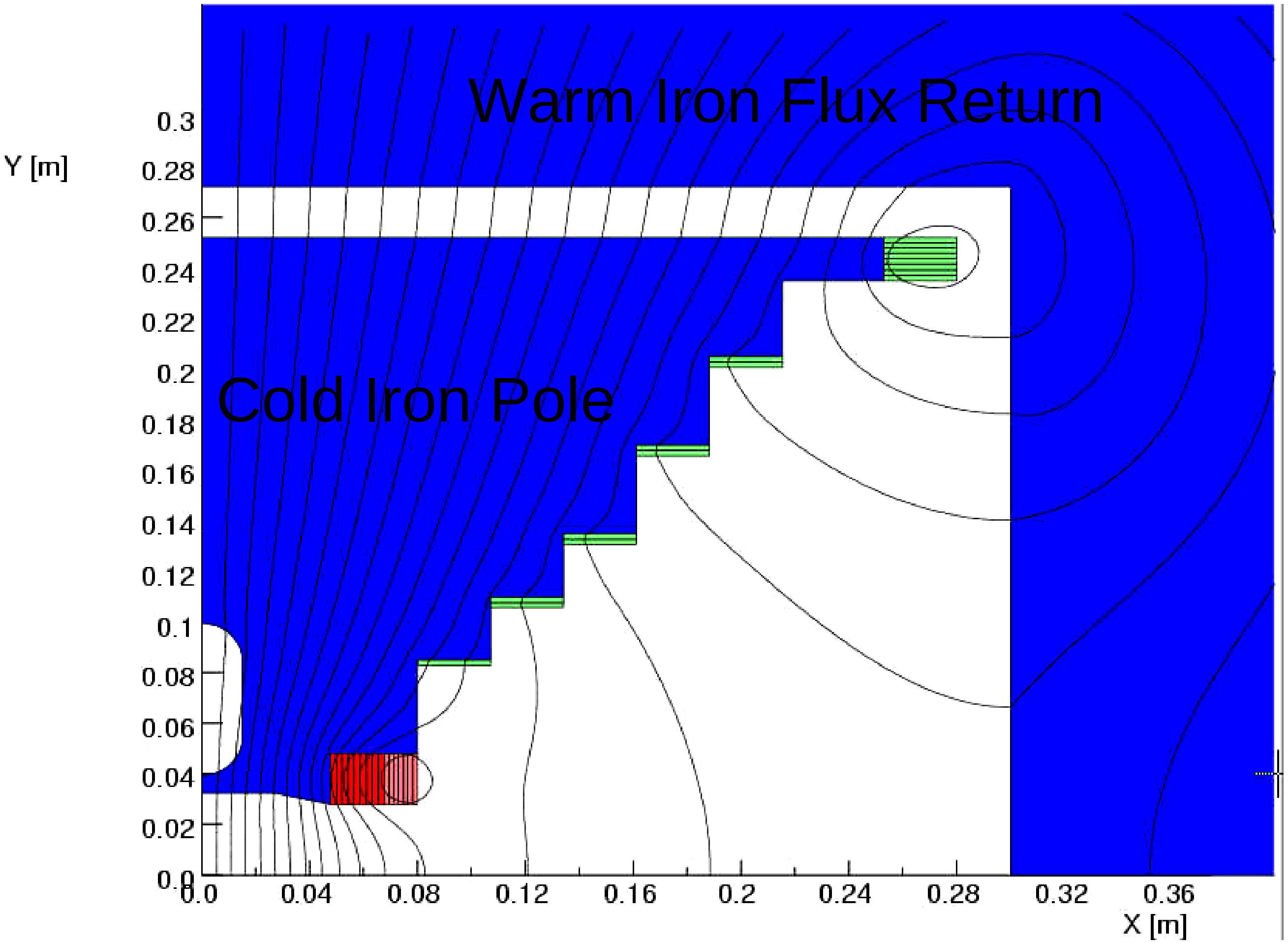
Supercritical He for cooling

Heat loads to ~ 0.2 W/cc



6

Levitated-pole Dipole for D1



9T @ 6 K

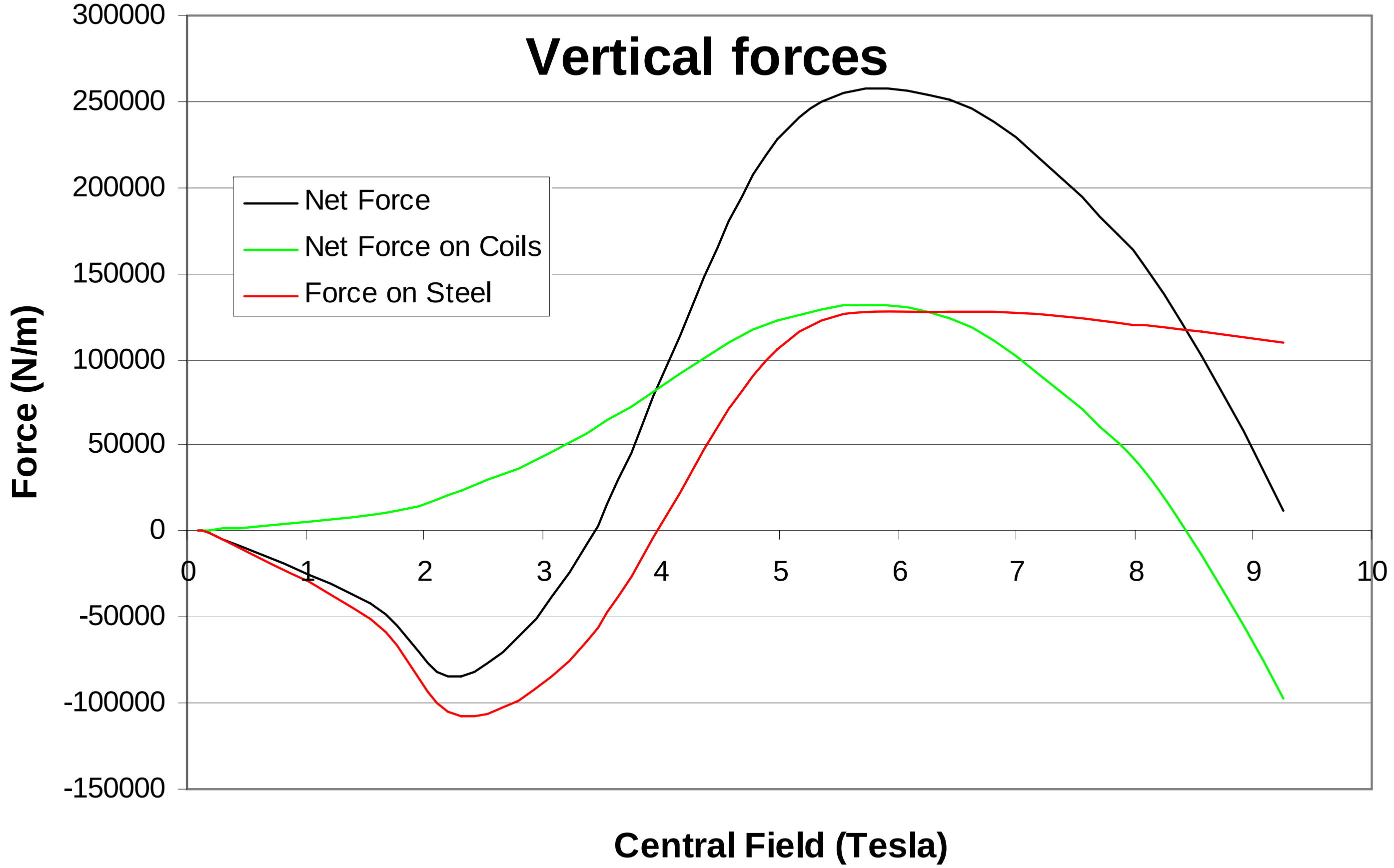
Only pole tip winding is Nb_3Sn.

All others are NbTi.

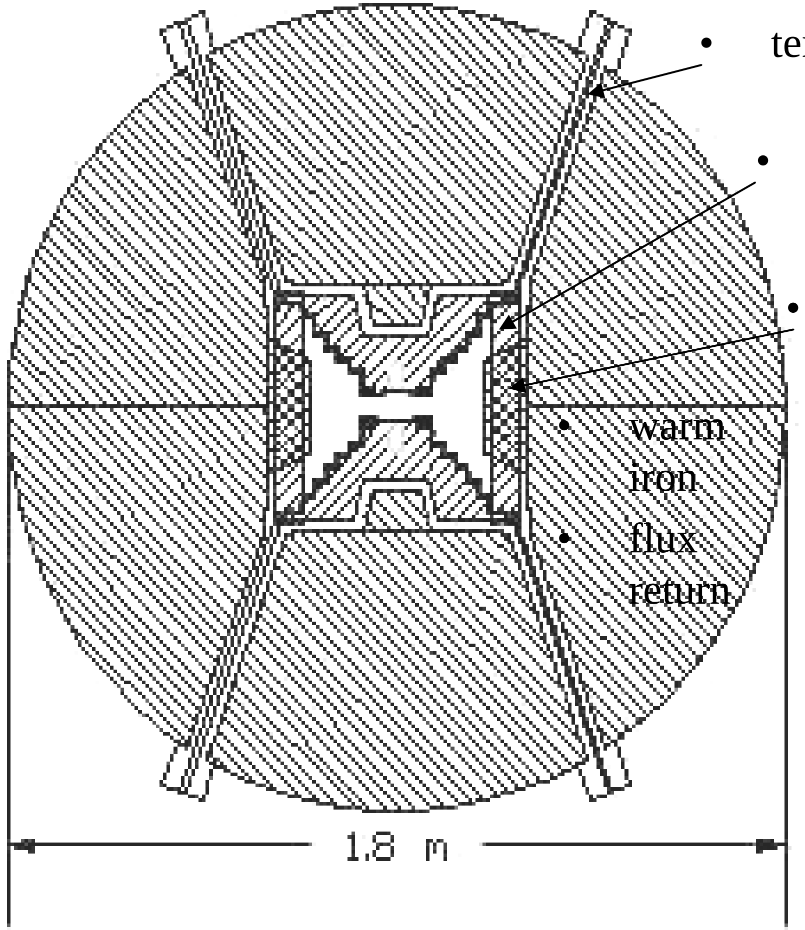
Support each pole piece using tension struts (low heat load).

56 mm clear aperture

Levitation works over dynamic range needed for LHC

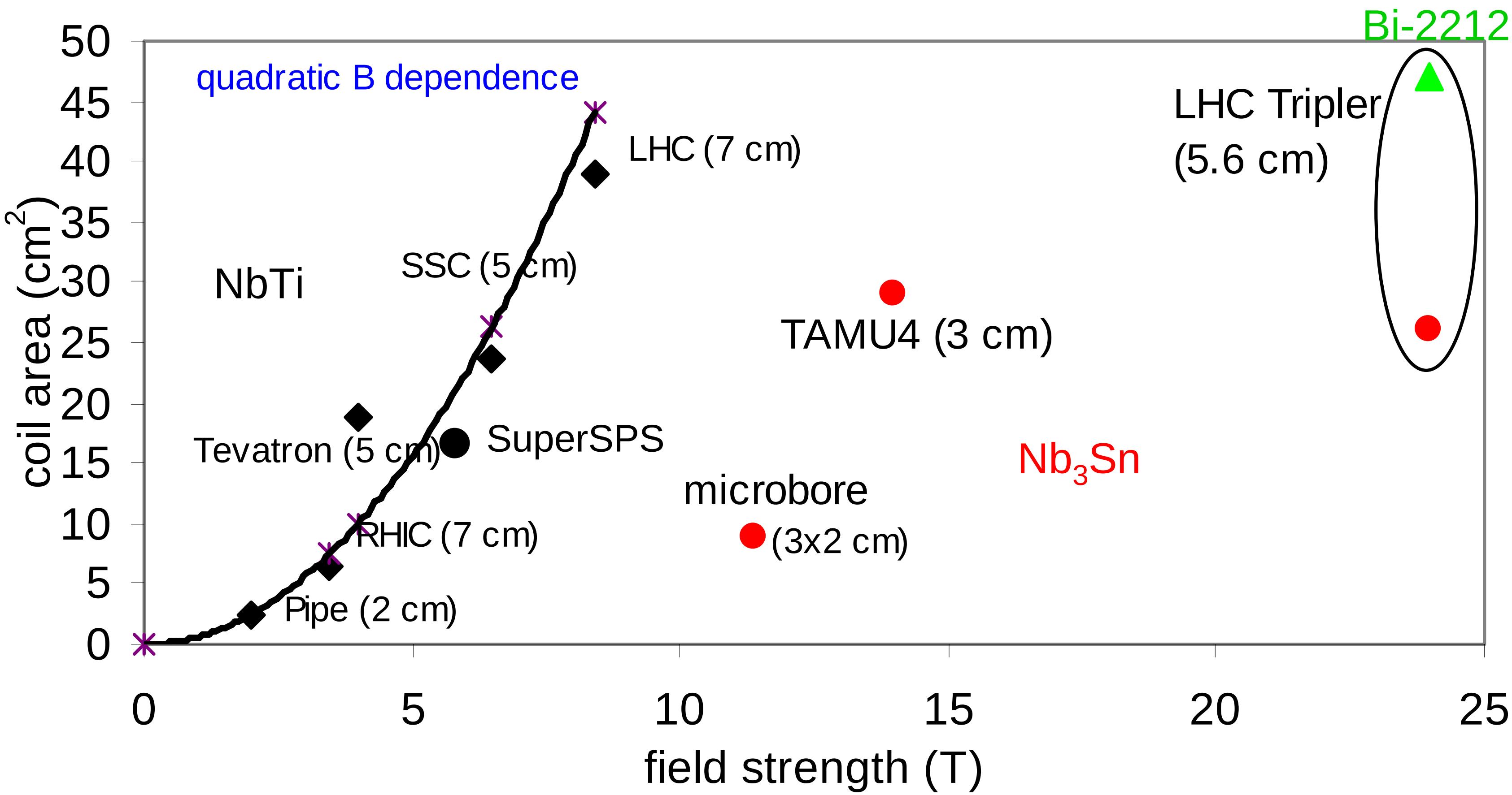


Mechanical Support



- tension supports
- cold SS struts
- warm Cu shields
- warm iron
- flux return

Magnets are getting more efficient!



Conclusions

- Stress management can facilitate the fabrication of Bi-2212 windings and Nb_3Sn windings in the same coil.
- With photon stops it should be possible to collect synchrotron light at high reservoir temperature so that refrigeration is not a dominant expense.
- There is no obvious limit to how high a magnetic field can be used for future hadron colliders.
- We hope to demonstrate feasibility to kill electron cloud effect using electrode assembly in beam screen
- New cable design can enable quad operation with very high radiation damage, heat load
- Levitated-pole dipole offers solution to the D1 problem