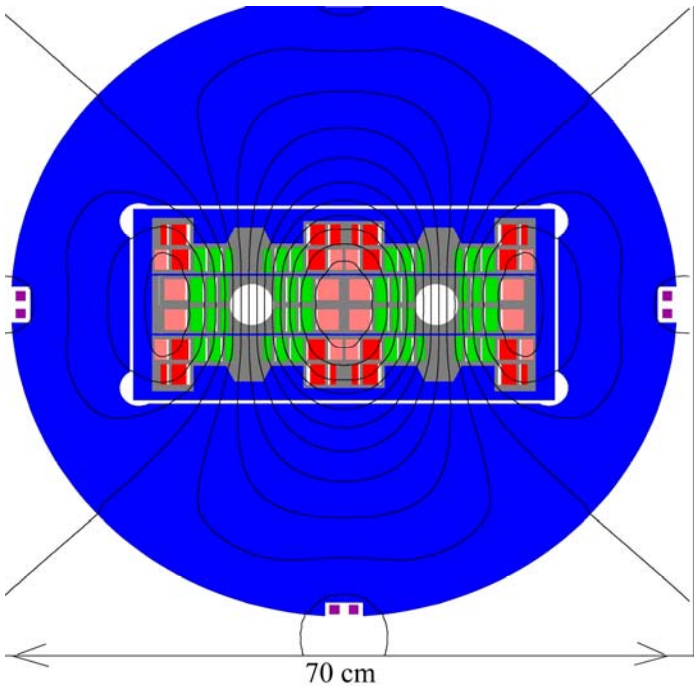
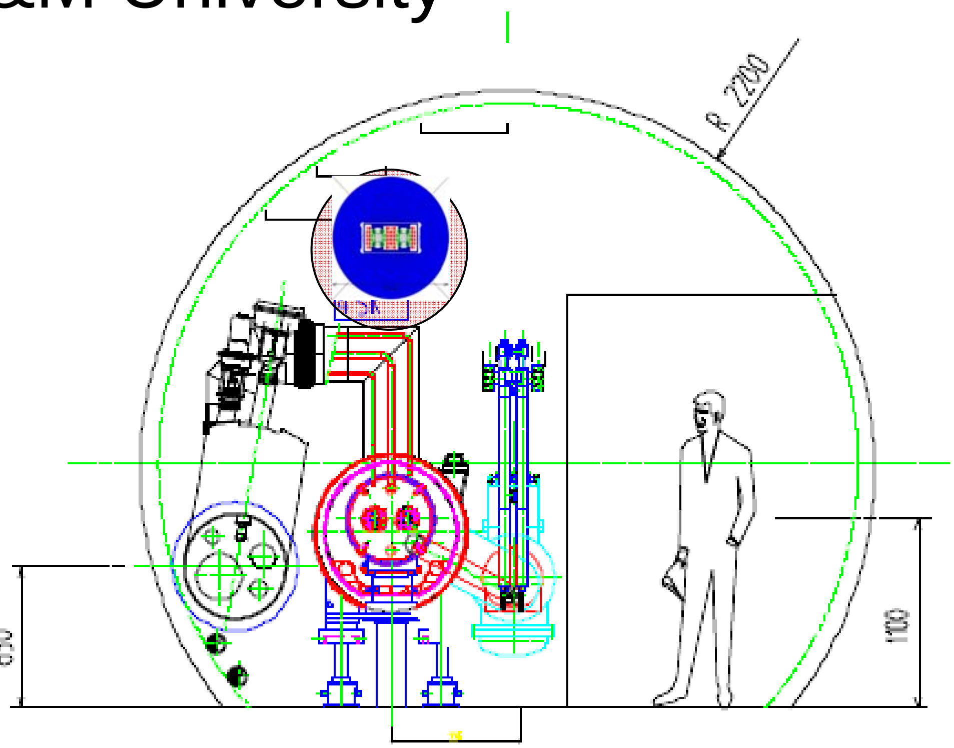
Hybrid Dipoles how to triple the energy of LHC

Peter McIntyre, Akhdiyor Sattarov

Texas A&M University





Presentation to ***CERN LHC Seminar***

14/3/2005

p-mcintyre@physics.tamu.edu

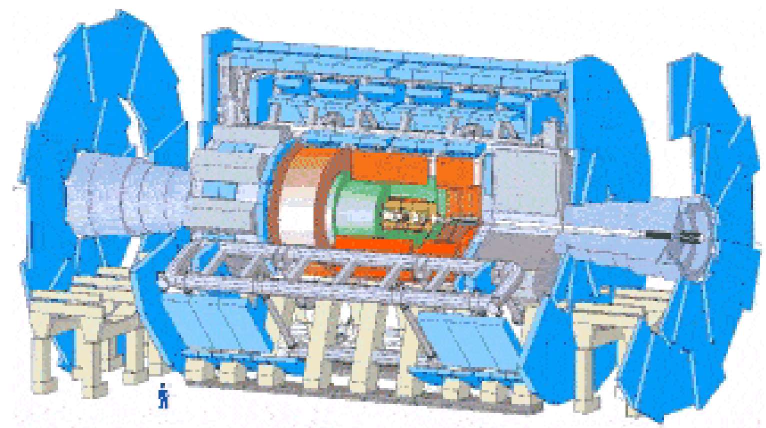
Large Hadron Collider

proton - proton colliding beams

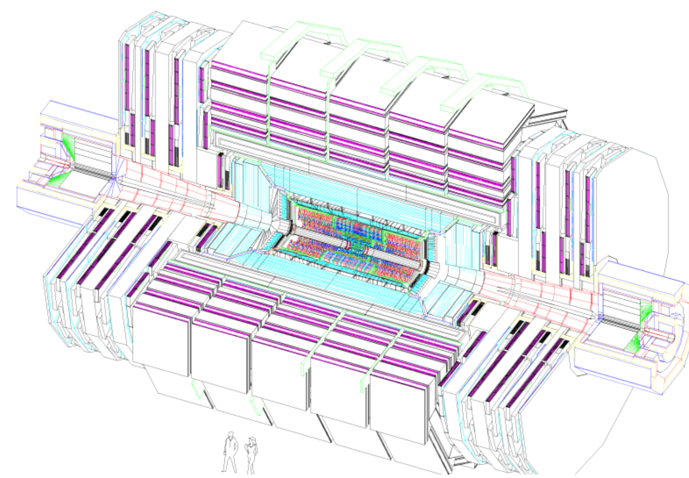
$$\sqrt{s} = 14\, TeV$$

$$\Im = 10^{34}\ cm^{-2} s^{-1}$$

27 km circumference tunnel at CERN



ATLAS detector



CMS detector

LHC is a tool for discovery in high energy physics

- Higgs sector
- Supersymmetry / Supergravity
- New gauge couplings

The Higgs boson and the spectrum of sparticles should be discovered at LHC, unless…

The flood of precise data from astrophysics suggests that the gauge fields of nature may be far more complex than the picture of the Standard Model + Supergravity

Can we extend the energy reach for direct discovery of new gauge fields?

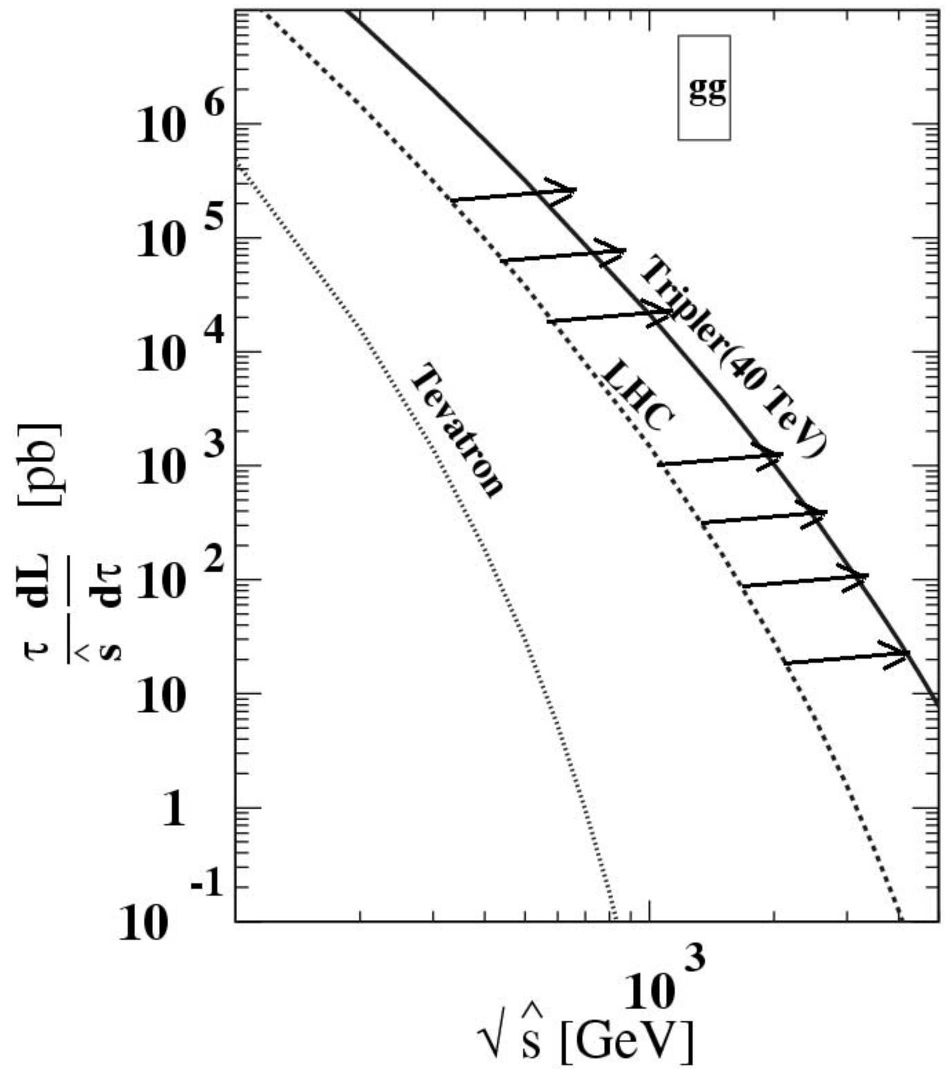
Hadron colliders are the only tools that can directly discover gauge particles beyond TeV

- Predicting the energy for discovery is perilous.
- Example: for a decade after discovery of the b quark, we 'knew' there should be a companion t quark. But we couldn't predict its mass. Predictions over that decade grew (with the limits) $20 \rightarrow 40 \rightarrow 80 \rightarrow 120$ GeV
- 4 colliders were built with top discovery as a goal.
- Finally top was discovered at Fermilab – 175 GeV!
- In the search for Higgs and SUSY, will history repeat?

Evolution of the gluon spectrum

Assumptions:

- Luminosity grows x3 with adiabatic damping
- Luminosity needed to produce a given number of particles of mass m (assuming gauge couplings constant) scales with m^2
- So twice the mass scale requires 4/3 the luminosity.



Triple the energy – double the mass reach

Dutta 2004

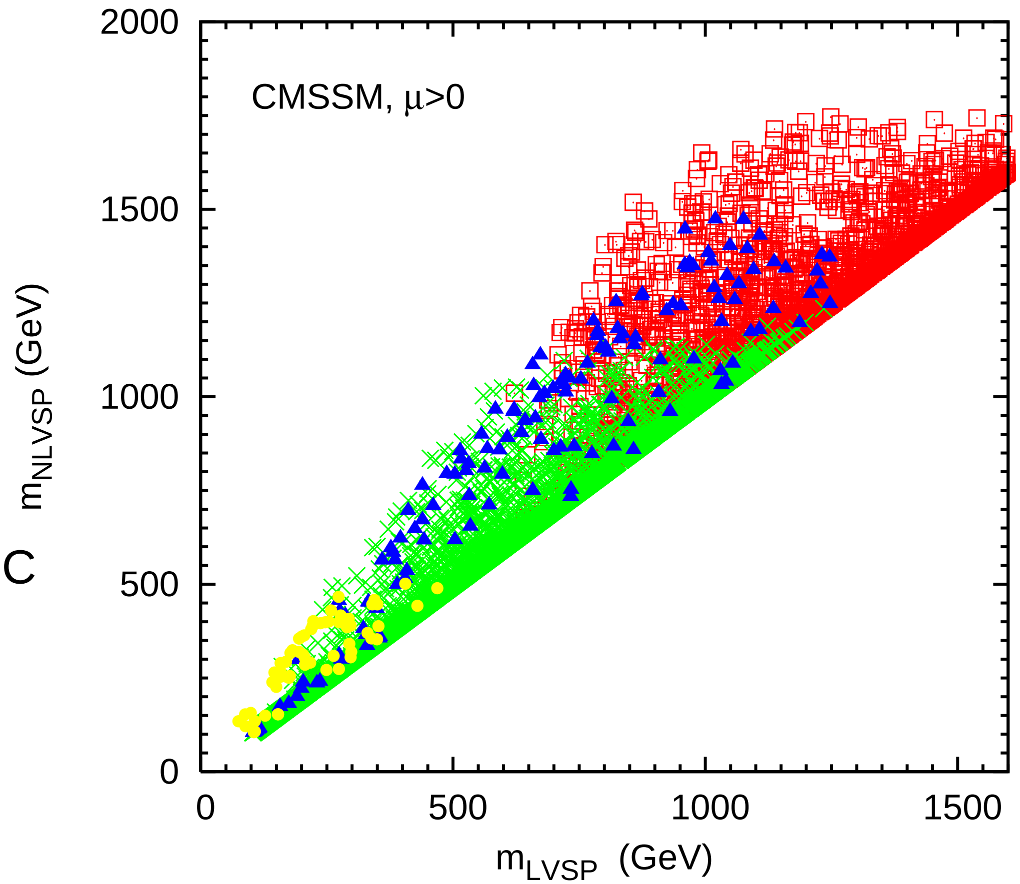
Discovery of sparticles

- Ellis *et al* have calculated the masses of the lightest 2 visible sparticles in minimum supersymmetric extension of the Standard Model (MSSM), constrained by the new results from astrophysics and cosmology.

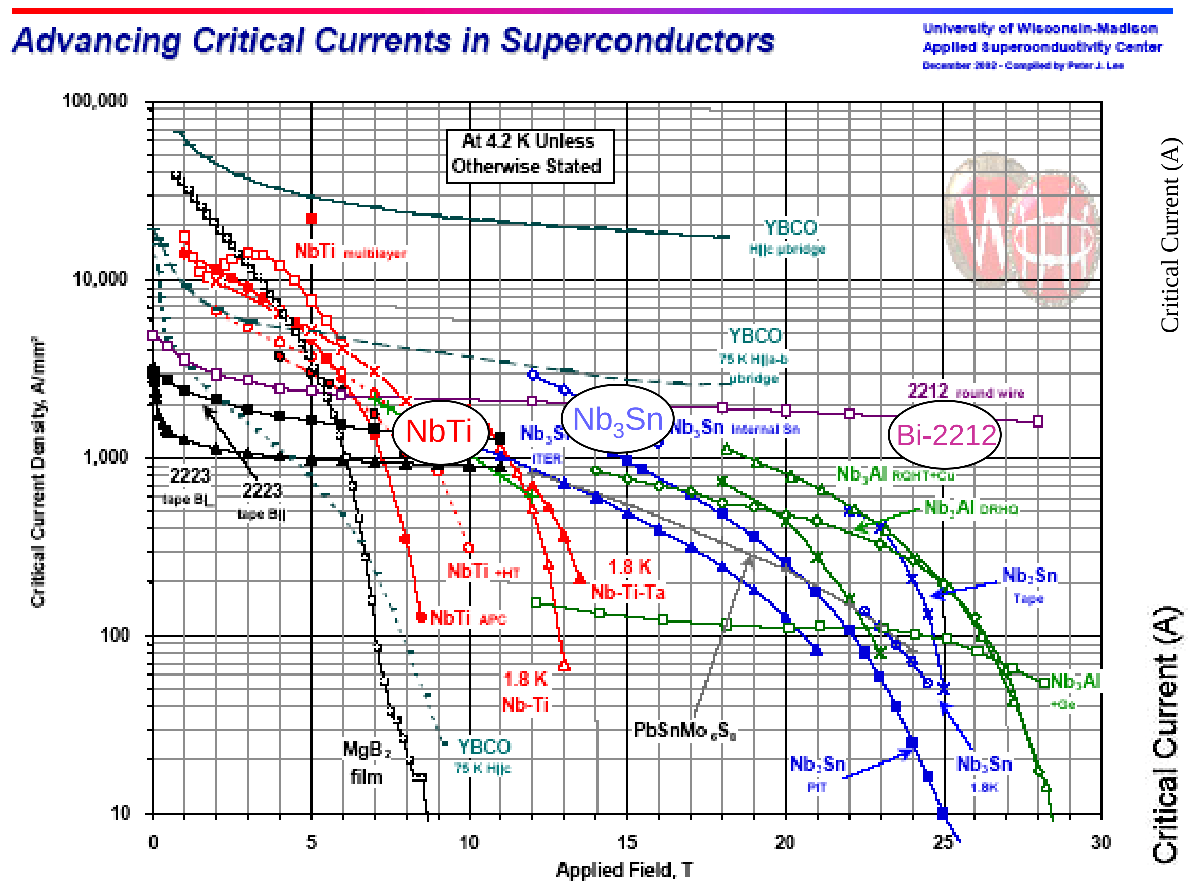
● = observable in WIMP searches ($\sigma > 10^{-8}$ pb)

X = observable at LHC

■ = only observable at LHC Tripler

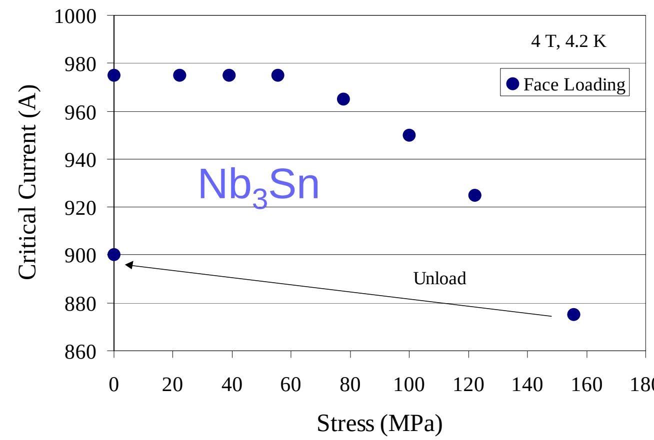


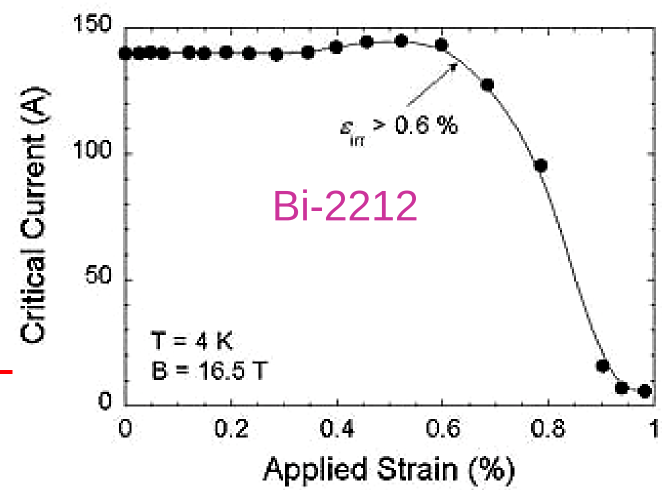
Higher field requires new superconductor, handling immense stress loads



Cost today:

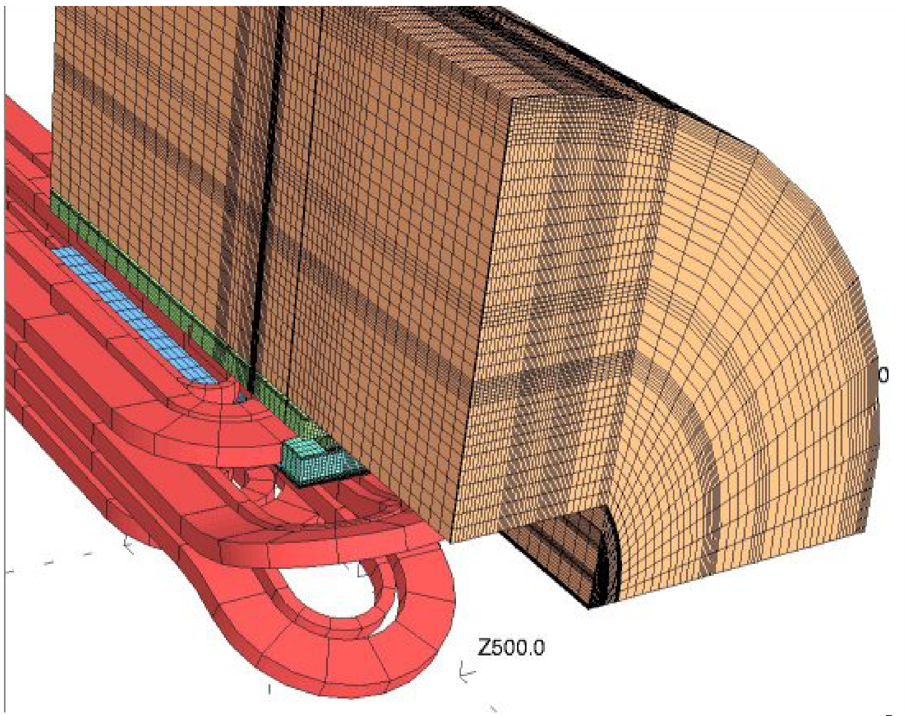
NbTi	\$100/kg
Nb_3Sn	\$1,000/kg
Bi-2212	\$2,000/kg

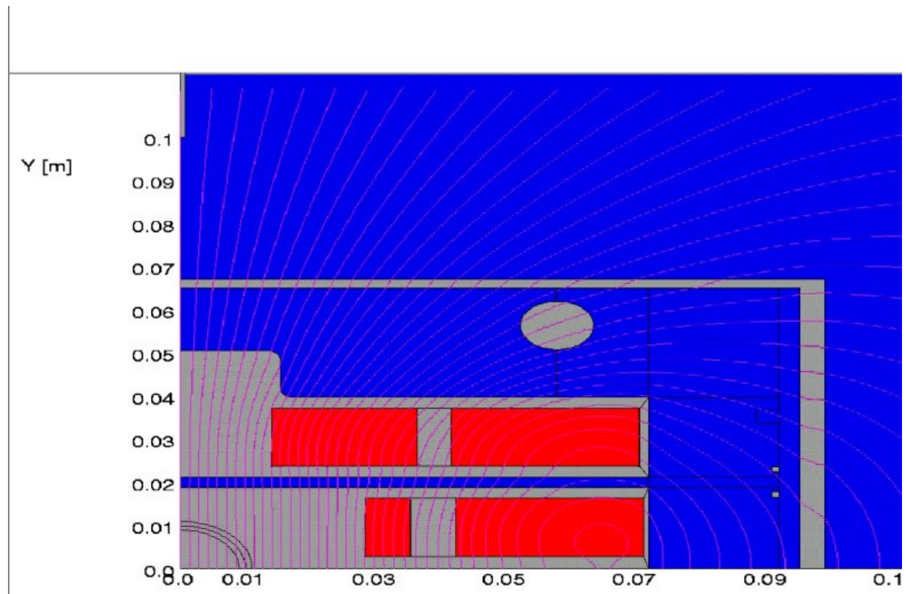




To push to higher field: use high-field superconductor, limit coil stress

- Nb_3Sn: 14 Tesla dipole

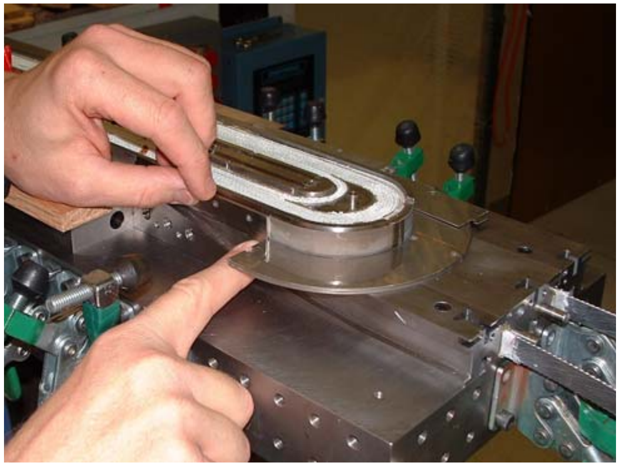


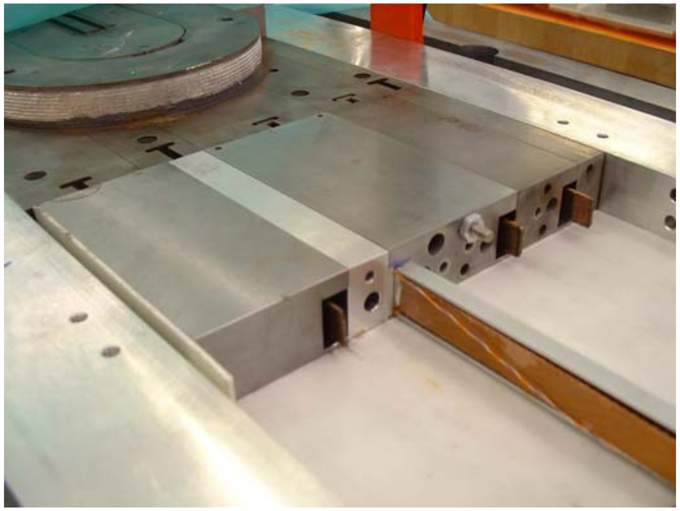


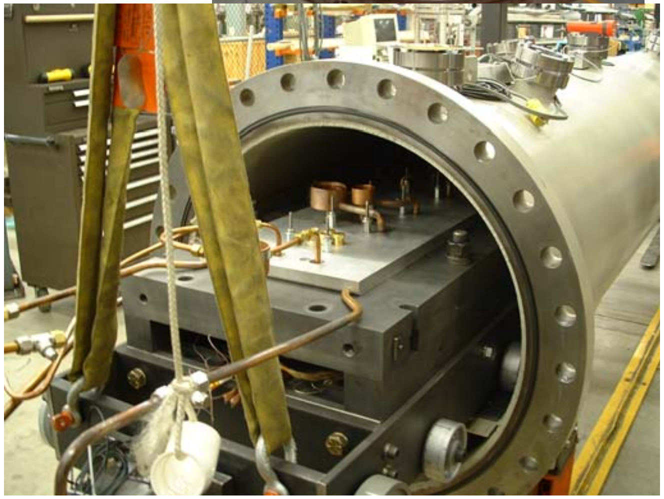
- **Bore field** **14.1 T**
- **Current** **12.6 kA**

- **Maximum Coil Stress** **120 MPa**
- **Superconductor cross section** **29 cm^2**

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



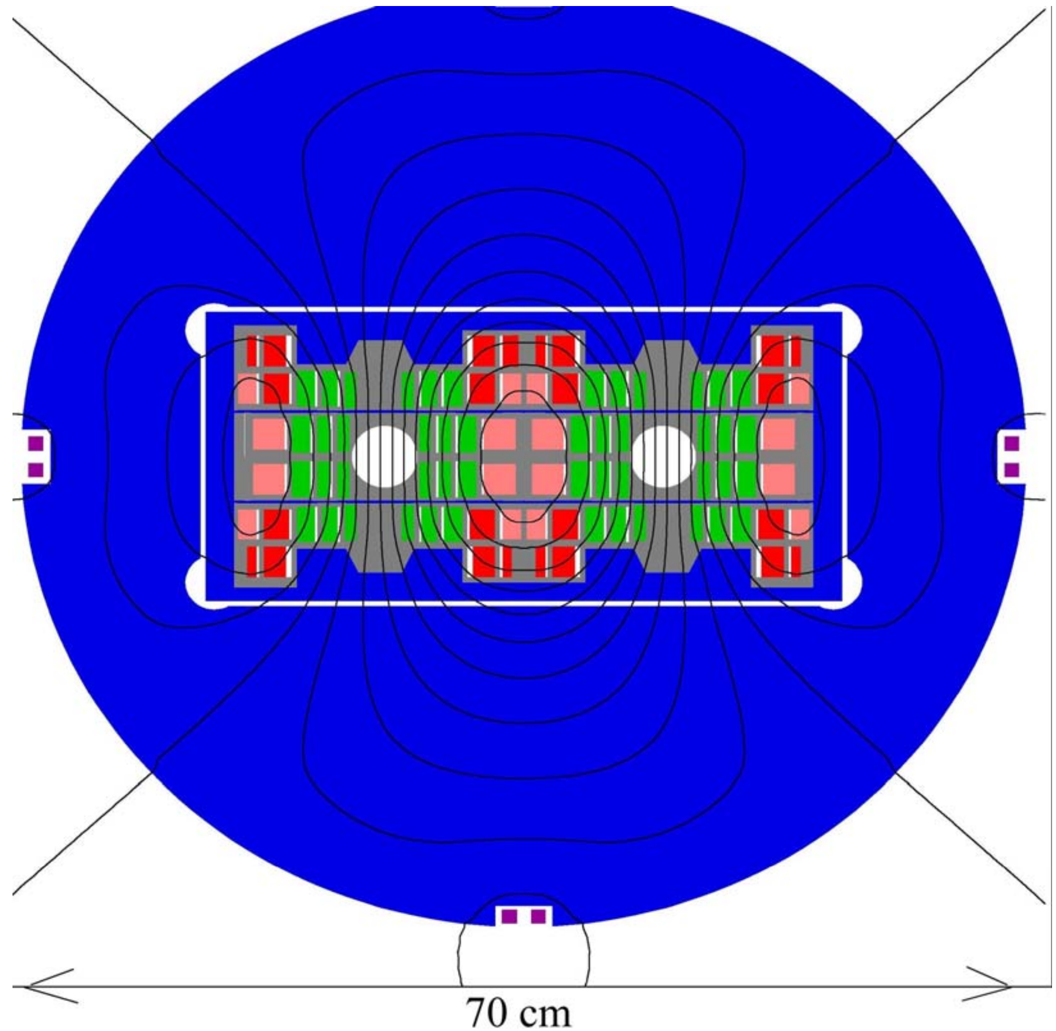




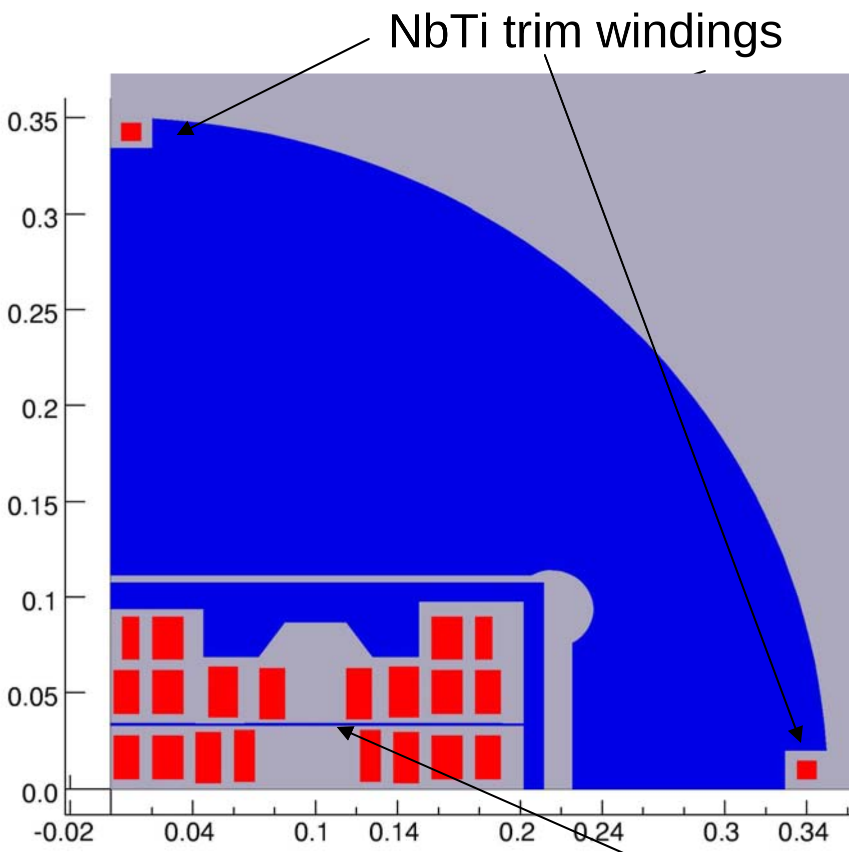
Extend to 24 Tesla: Bi-2212 in inner (high field) windings, Nb_3Sn in outer (low field) windings

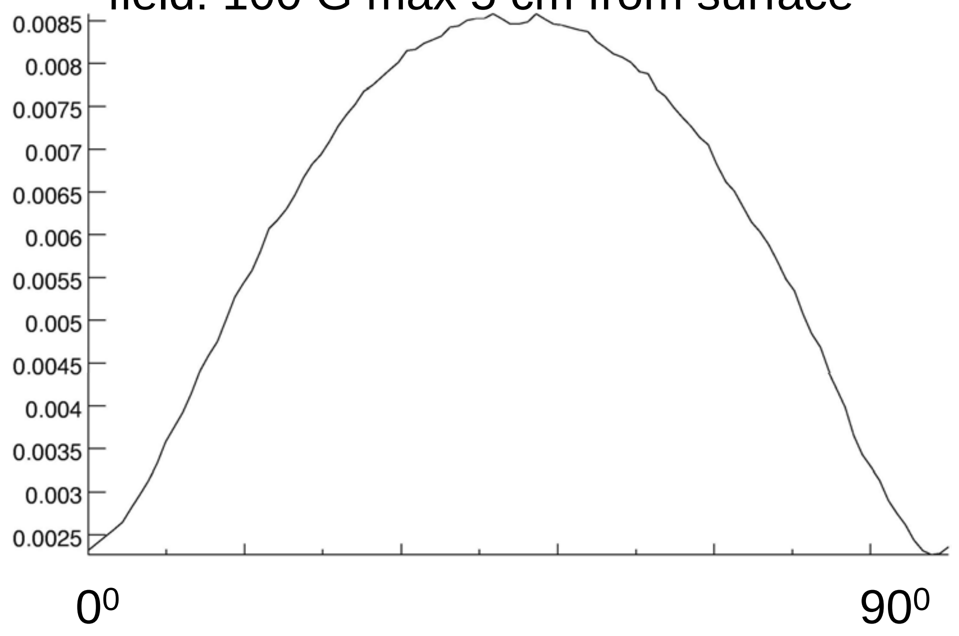
Dual dipole (ala LHC)

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



Control flux return size using NbTi trim





Magnet issues

- Nb_3Sn windings must be reacted at 650 C in argon atmosphere for a week to form the superconducting phase.
- Bi-2212 windings must be reacted at 850 C in O_2 atmosphere, ~10 minute excursion to partial melt, ΔT ~2 C
- How to do both on one coil???
  - Wind Bi-2212 inner windings, do heat treat.
  - Control fast excursion to partial melt using ohmic heating in coil itself and/or modulation of pp O_2.
  - Then wind Nb_3Sn outer windings, stress management structure isolates the ventilation of the two regions
  - React the Nb_3Sn with Ar purge, hold O_2purge on Bi-2212.
- Quench protection - Bi-2212 highly stable, very different quench strategy from that with all-Nb_3Sn dipoles.

Accelerator Issues

- Synchrotron radiation: power/length $\tilde{P} \propto E^4 I / \rho^2$

  critical energy $E_c \propto E^3 / \rho$

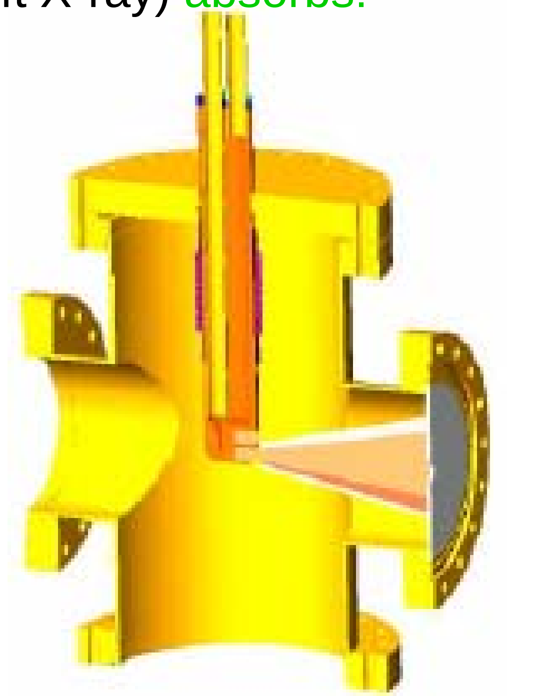
LHC: E = 7 TeV P = 0.22 W/m E_c = 44 eV (hard UV) scatters, desorbs

LHC Tripler: E = 20 TeV P = 14 W/m E_c = 1.2 keV (soft X-ray) absorbs!

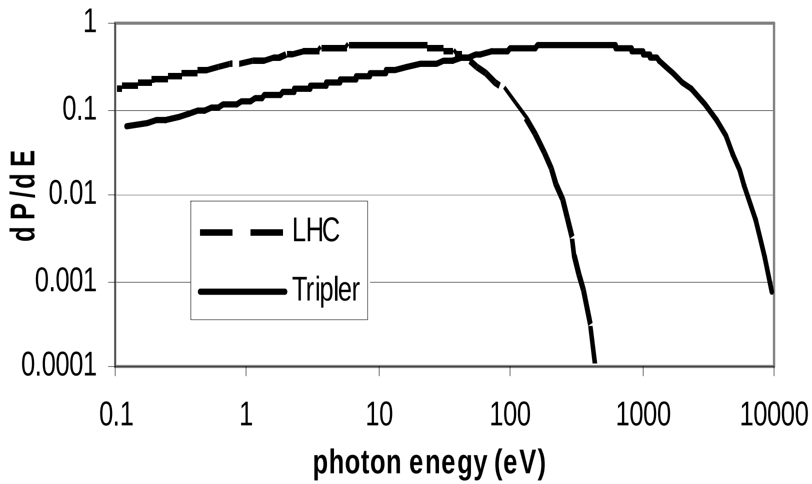
  – Use photon stop:

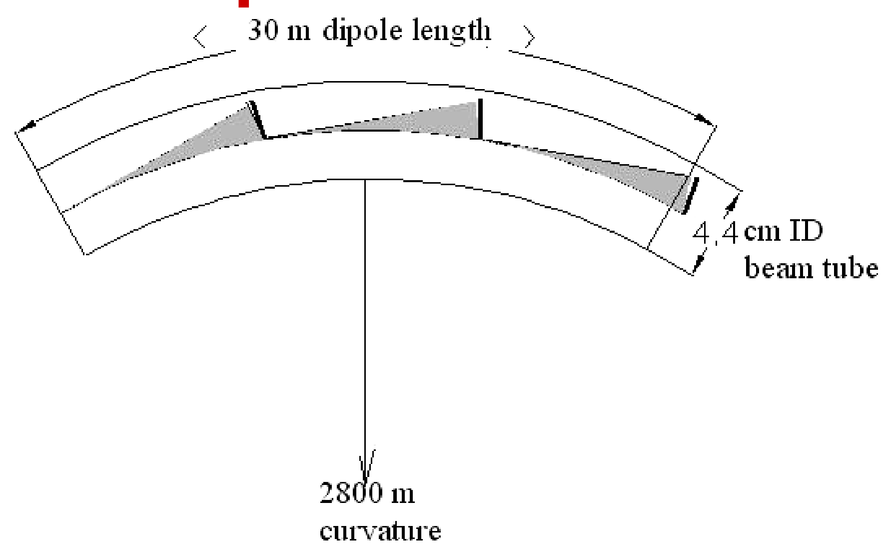
    Instead of intercepting photons at ~10 K along dipole beam tube, intercept between dipoles on room-temperature finger.

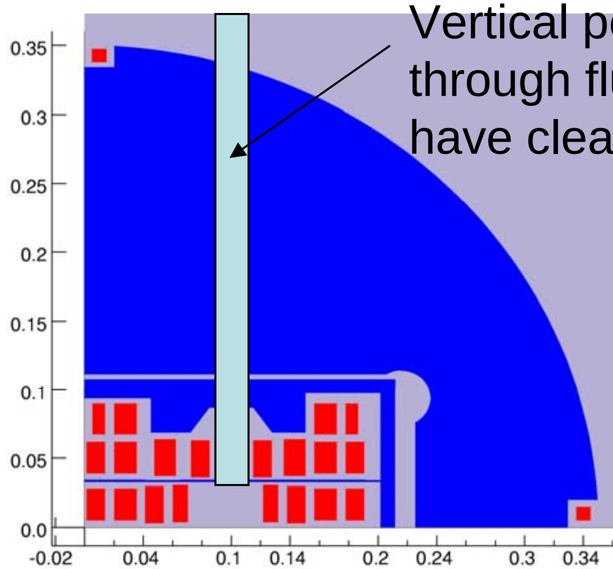
  – Soft X-rays actually easier to trap that hard UV



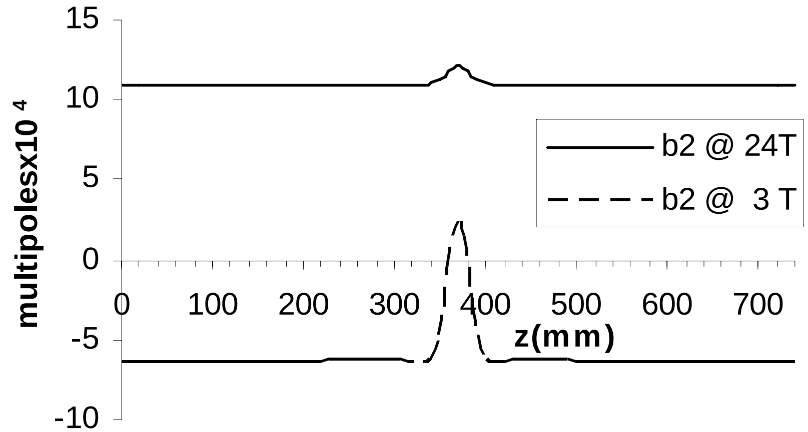
Photon Stop





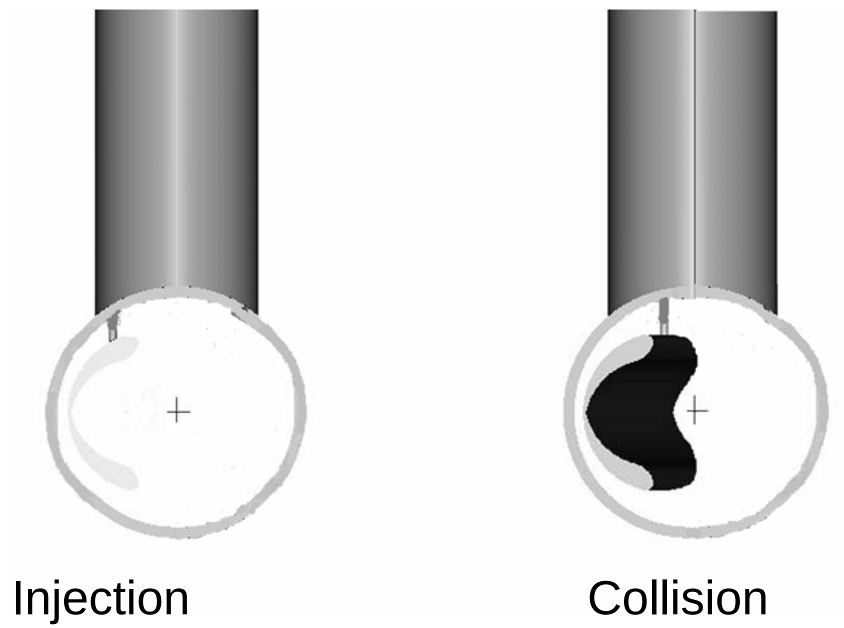


Vertical penetration through flux return (coils have clearance)



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

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



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

heat transfer to Liquid Xe (160 K)

Same refrigeration power for Tripler as for LHC!

- Synchrotron damping

$$\tau = \frac{16644h}{J_n E[TeV] B[T]^2} \left(\frac{C}{2\pi\rho} \right)$$

J_n = damping partition: $J_x \sim J_y \sim 1$, $J_E \sim 2$

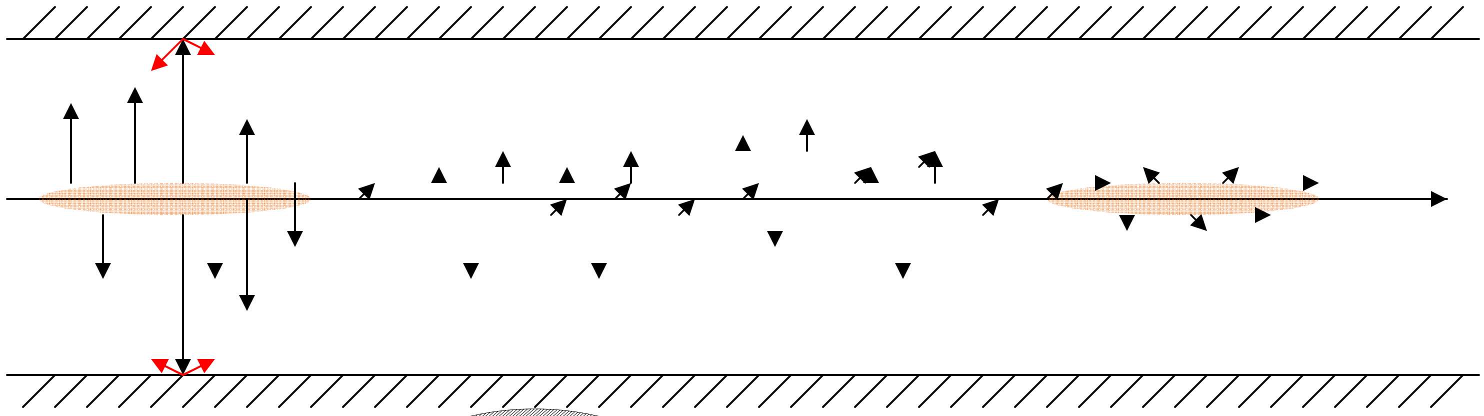
LHC: τJ_n = 53 hours, $\tau_E = \tau_\varepsilon \sim 26$ h

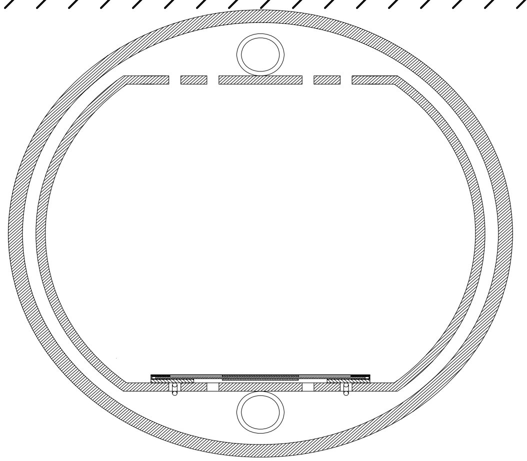
LHC Tripler: τJ_n = 2.2 hours, $\tau_E = \tau_\varepsilon \sim 1$ h!

This may be enough damping to help push luminosity.

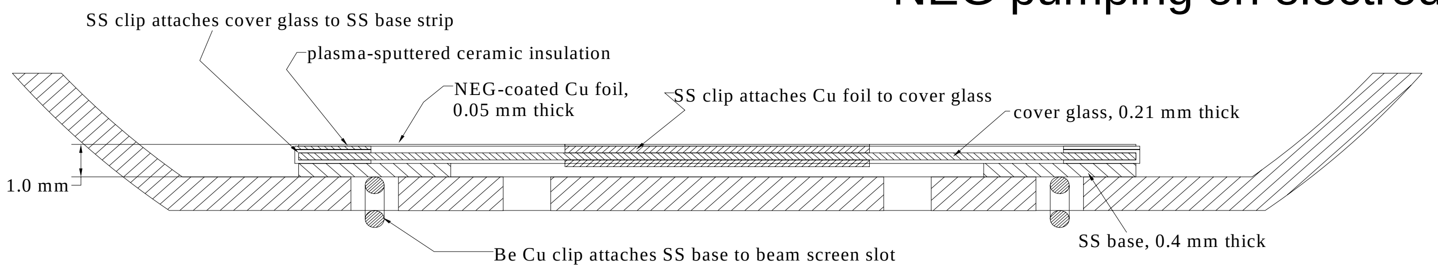
Stacking of new beam on old every few hours?

Electron cloud effect

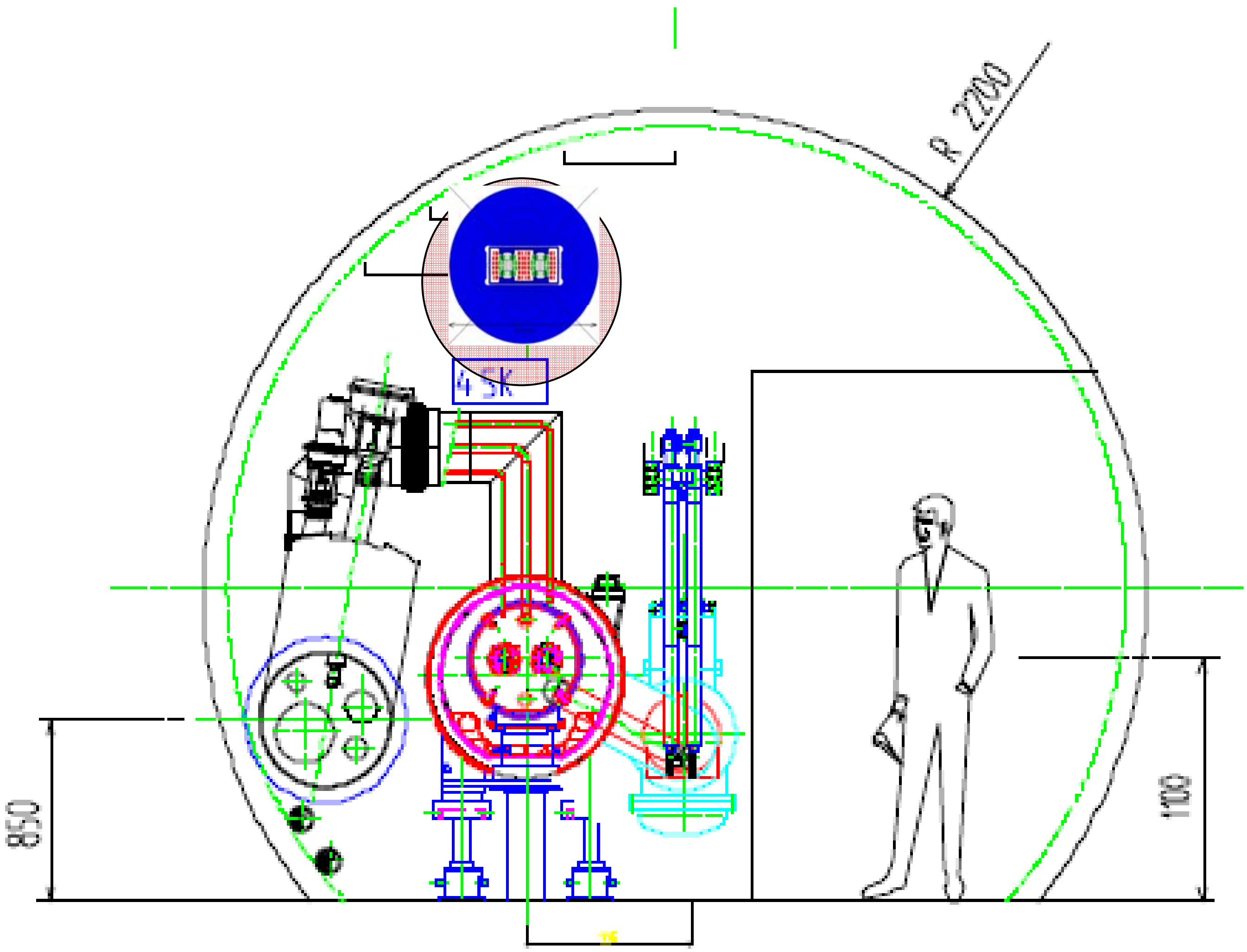




- •Suppress electron multipacting by locating an electrode on bottom of beam screen.
- •Bias +100 V, suppresses all secondary electrons , kills ECE
- •NEG pumping on electrode surface



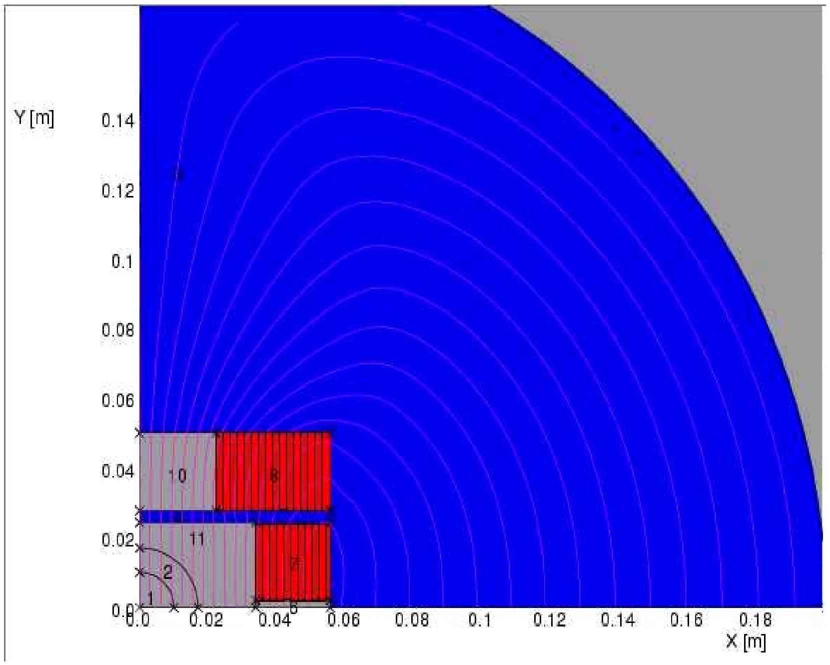
Locate Tripler over LHC

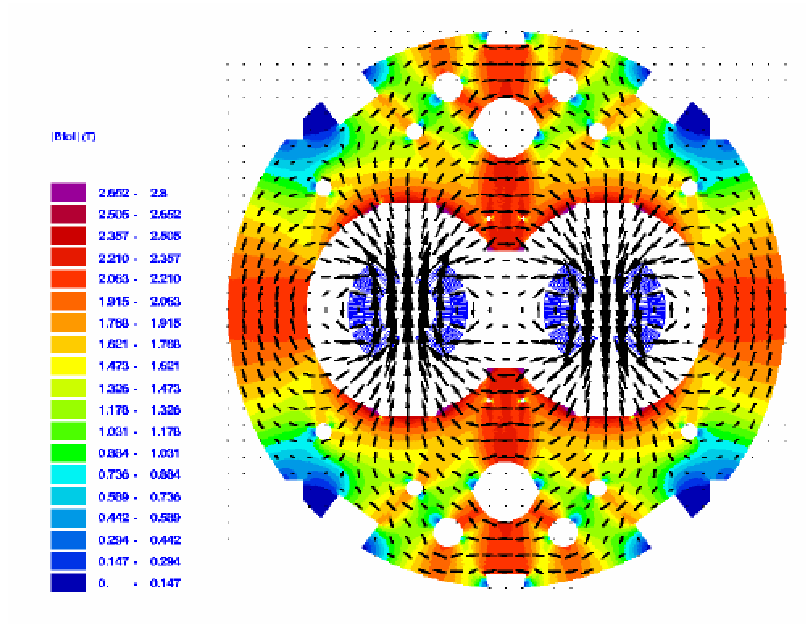


Inject from Super-SPS

- For luminosity upgrade of LHC, one option is to replace the SPS and PS with a rapid-cycling superconducting injector chain.
- 1 TeV in SPS tunnel → 1.25 T in hybrid dipole: flux plate is unsaturated, suppression of snap-back multipoles at injection.
- SuperSPS needs 5 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:

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

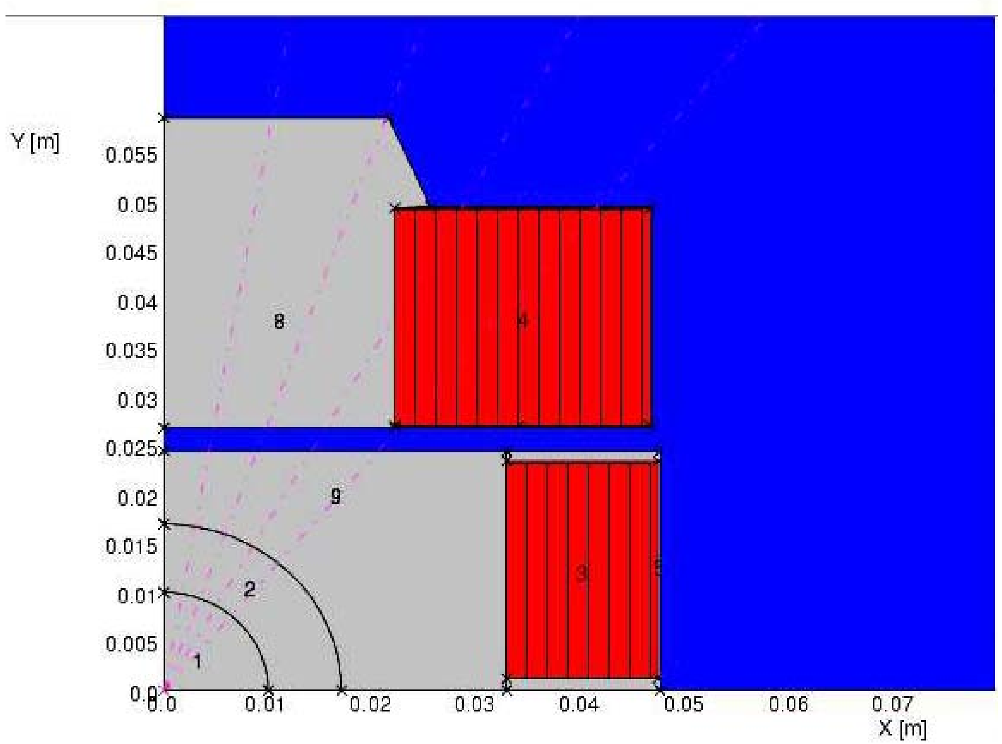
Result: minimum induced current loop, minimum AC losses

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

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

Result: maximum induced current loop, maximum AC losses

Preliminary design for Super-SPS dipole



6 T short-sample field (to allow for AC loss degradation)

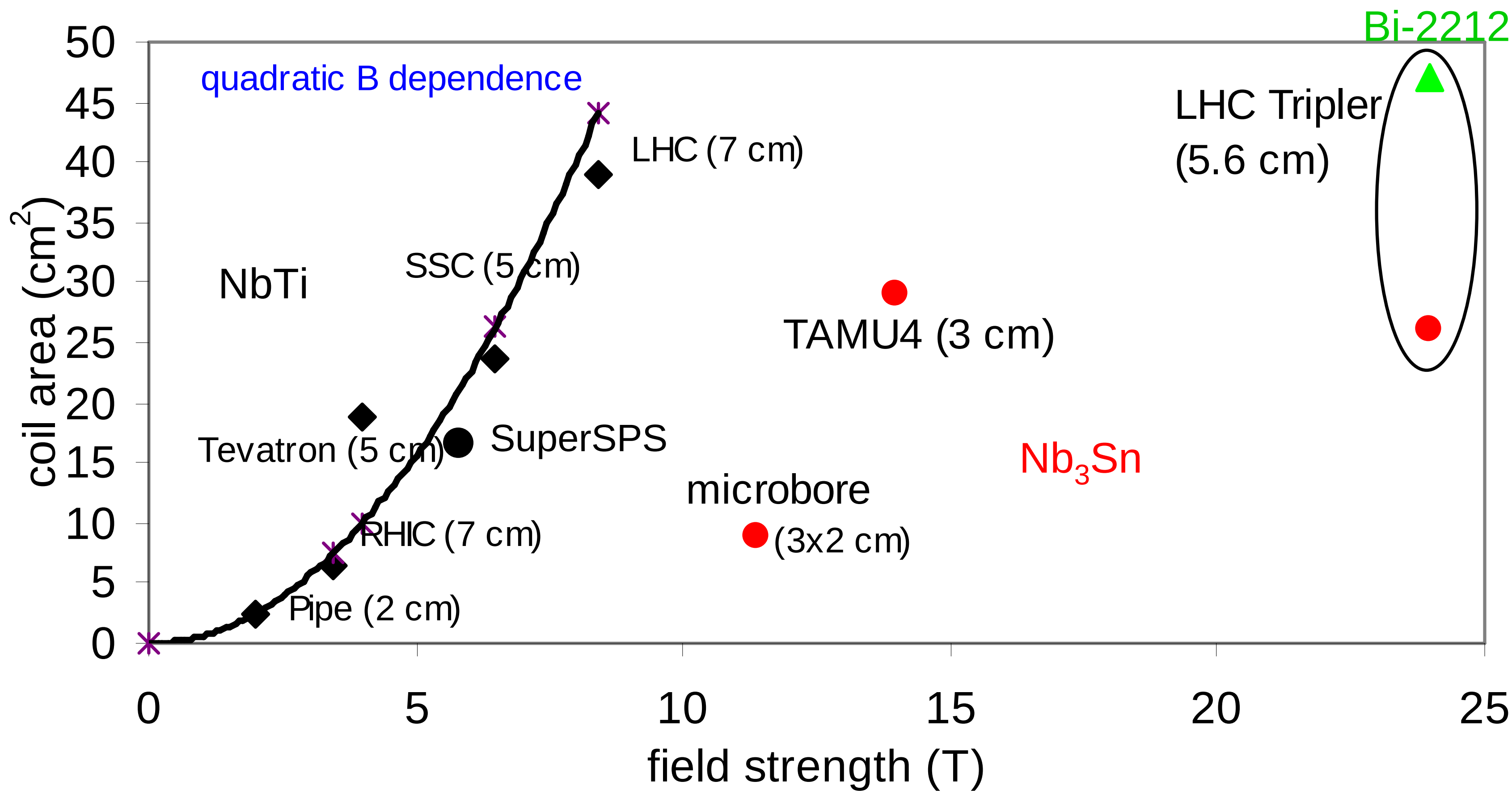
LHC NbTi strand (wider cable to optimize geometry, minimize inductance)

We are modeling AC losses, expect to be low.

Flux plate suppresses multipoles from persistent currents, AC-induced currents

(flux plate must be laminated)

Magnets are getting more efficient!



LHC Tripler Cost?

- Cost of high-field magnets:

  $ ~ half superconductor, half structure
- Neither Nb_3Sn nor Bi-2212 have ever been produced in large-scale manufacture
- Nb_3Sn today ~$1,000/kg. Tripler needs 400 tons
  - Nb_3Sn will soon be manufactured for ITER
  - Goal of DOE HEP conductor development program ~ $300/kg - projected Nb_3Sn cost = $120 M
- Bi-2212 today ~$2,000/kg. Tripler needs 1000 tons
  - 2 Bi-2212 manufacturers project large-volume price ~$700/kg - projected Bi-2212 cost = $700 M

No show-stoppers to date

- Idea presented at CARE-HHH-AMT meeting at CERN
- Suggestions for first uses of hybrid dipoles at LHC:
- We are building a collaboration to begin the developments needed for hybrid coil technology