US LHC
Accelerator Research Program

US LHC Users Organization Annual Meeting
September 25-26, 2009

GianLuca Sabbi, LBNL

LARP Program Goals

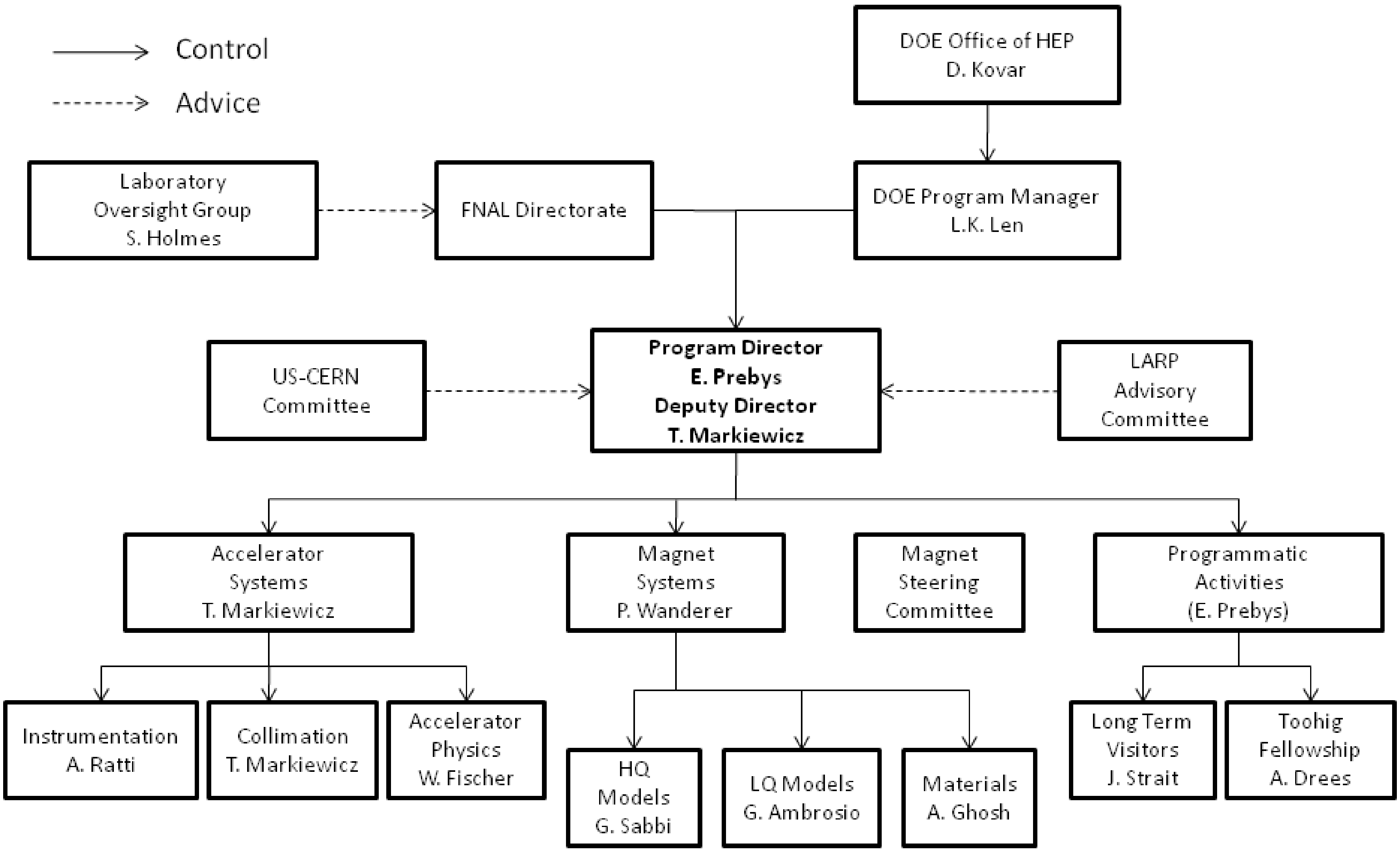
Coordinate US LHC Accelerator Research:

- Started in 2004, expected to be completed around 2014
- Progression from the US LHC Accelerator Research Project
- Collaboration of four national Labs: BNL, FNAL, LBNL, SLAC
- Funding level: $12-13M/year (FY06-FY10)

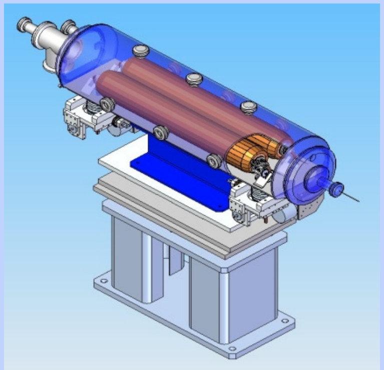
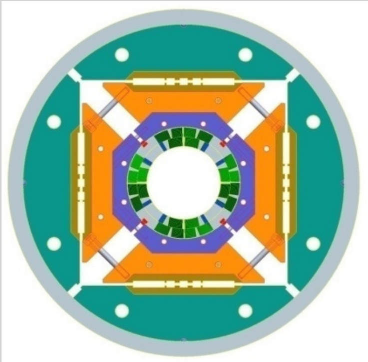
Goals:

- Extend and improve the performance of LHC
  - *Maximize scientific output in support of the experiments*
- Maintain and develop US Labs capabilities
  - *Prepare for a leadership role in future projects*
- Research and training for US accelerator physicists and engineers
- Advance international collaboration on large accelerator projects

Organization Chart

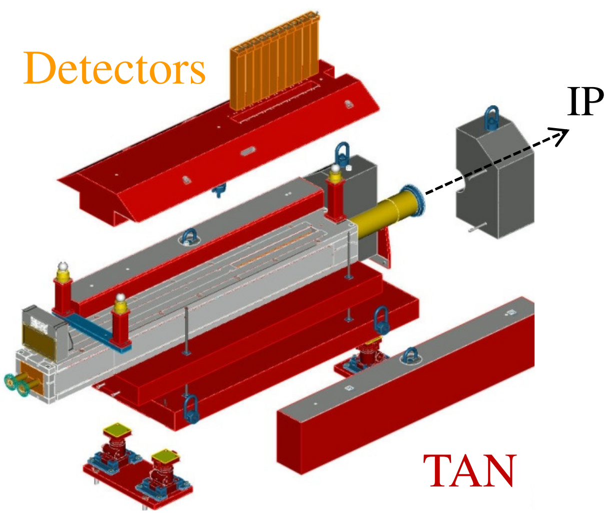


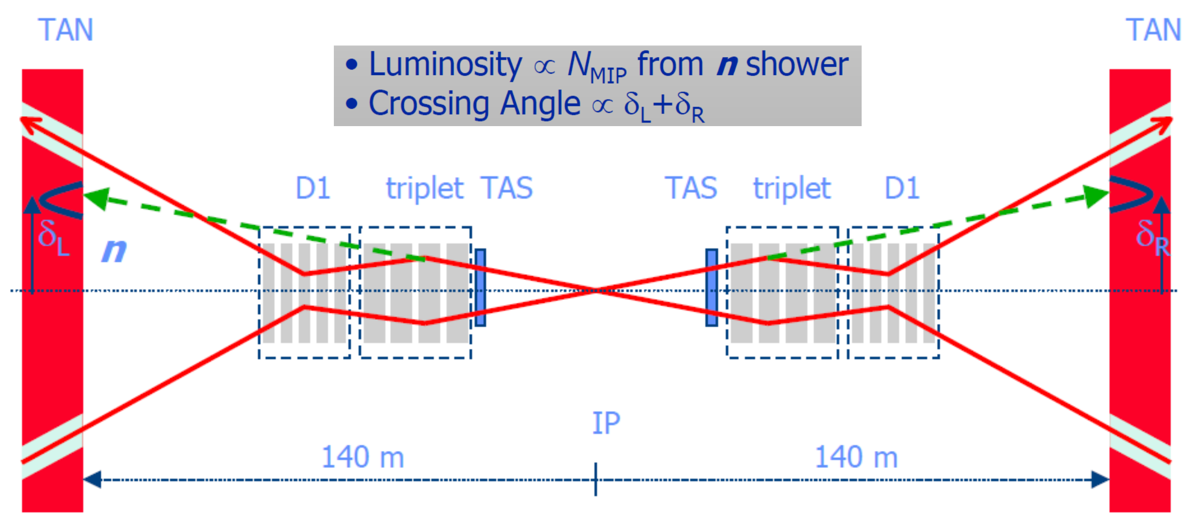
Overview of LARP Activities

Accelerator Systems 	Instrumentation	• Luminosity monitor • Tune tracker, AC dipole • Schottky monitor
	Accelerator Physics	• Electron cloud instability • Beam-beam studies • Crab crossing
	Collimation	• Rotatable collimators
Magnet Systems 	Materials	• Strand characterization • Cable development
	Model Quadrupoles	• Technology Quadrupoles • High-field Quadrupoles
	Long Quadrupoles	• Coil fabrication • Structure and assembly • Instrumentation and Test
Program Management	Programmatic Activities	• Toohig Fellowship • Long Term Visitors

Luminosity Monitor

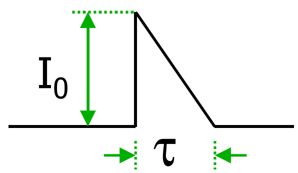
- Goal: measure/optimize the luminosity of colliding bunch pairs
- Approach: instrument TAN to measure forward shower from IP
- Performance requirements:
  - 40 MHz bandwidth to resolve 25 ns bunch spacing
  - High sensitivity to variations in IP position and crossing angle
- Very high radiation environment:
  - 25 MGy/yr, 10^{18} N/cm^2 & 10^{16} p/cm^2 over lifetime (20 years)
  - ~100 times worse than any previous accelerator instruments



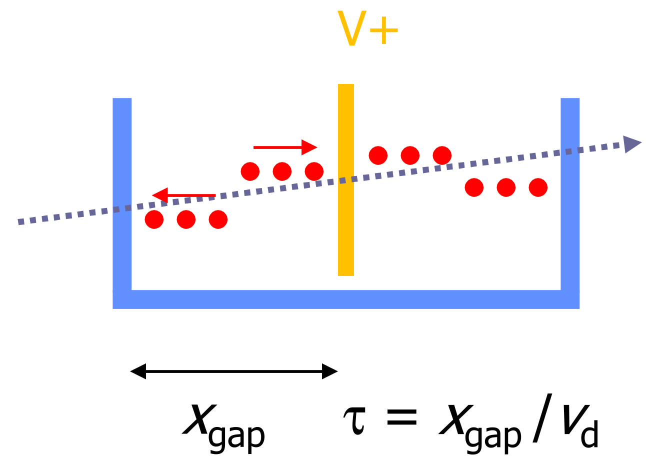


Design and Fabrication

- Concept (W. Turner, LBNL) : flowing gas (Argon) Ionization Chamber
- $Q = \int_0^{\tau} I(t)dt = \frac{1}{2} I_0 \tau$

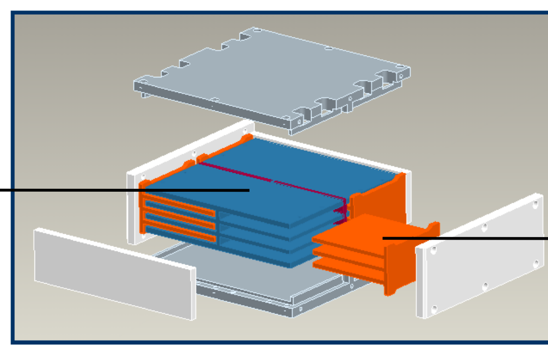


- Optimized for 6 parallel gaps:
  - ☺ Signal increases with N_{gap}
  - ☹ Capacitance increases with N_{gap}
- High precision machining and assembly

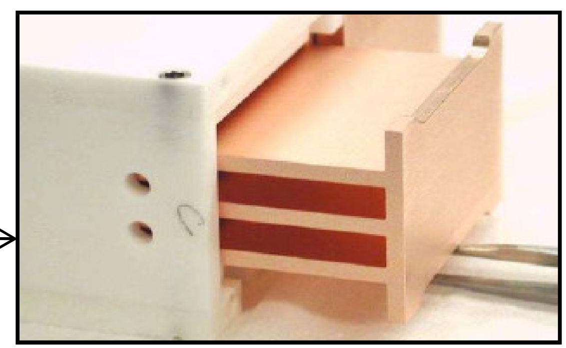


Ground Plane (OFHC copper)

Chamber assembly

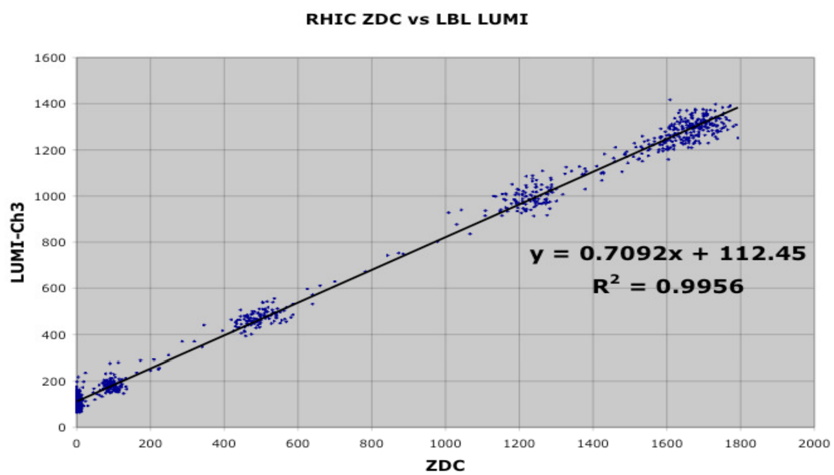


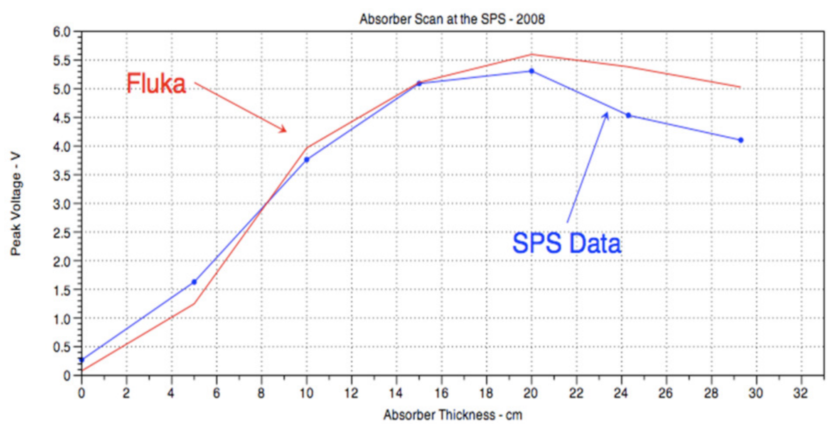
Electrode, 1/4 (OFHC copper)



Prototype Testing

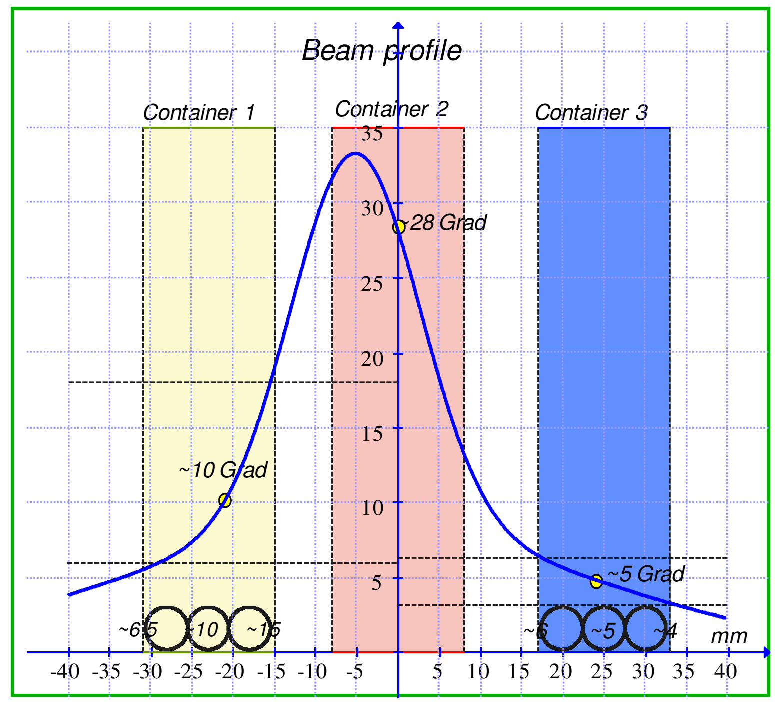
In-beam testing at RHIC and SPS





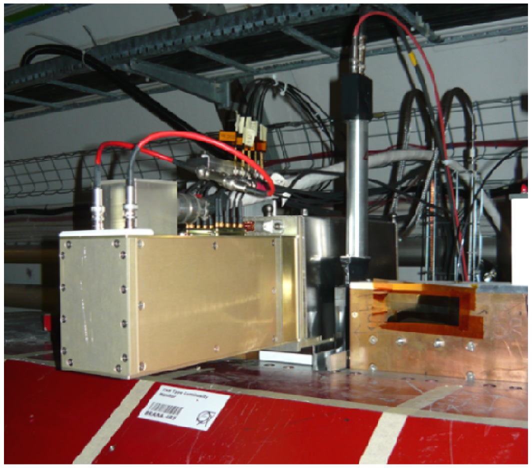
Irradiation at BNL Isotope Facility

- Protons and/or neutrons
- Up to 350 MGy total dose
- No observable problem

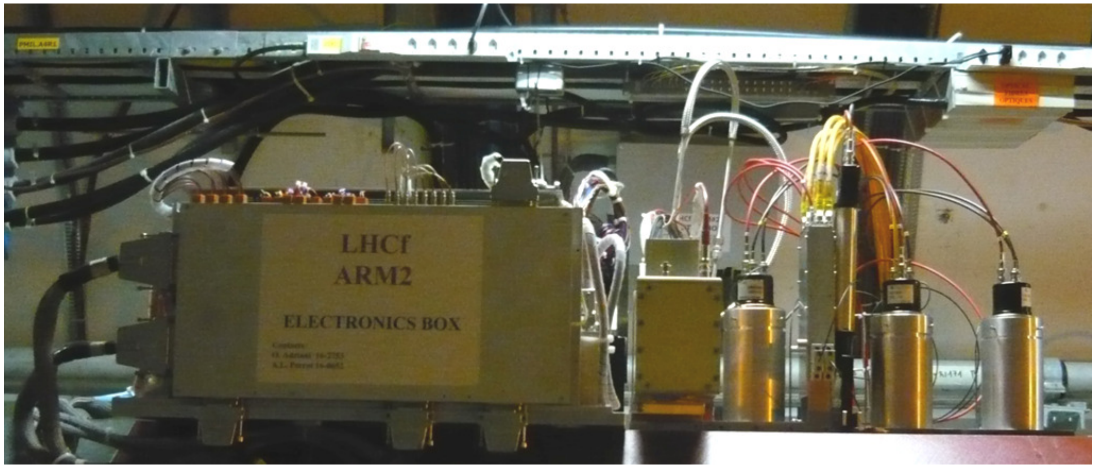


Installation and Commissioning

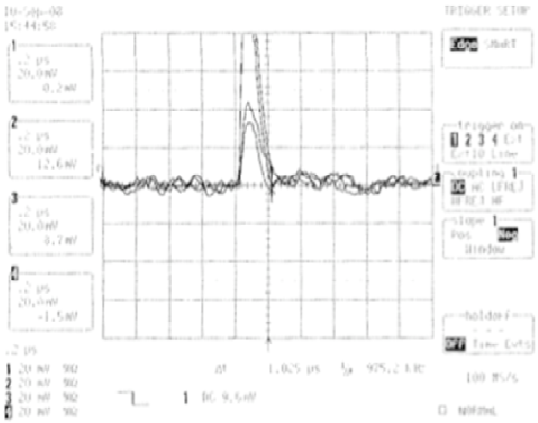
CMS



ATLAS



First LHC data (9/10/08)



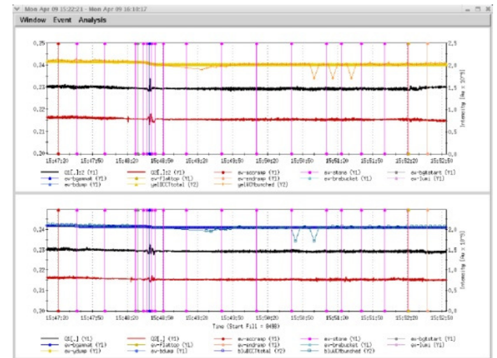
Beam commissioning plan

Mode	Bunches	Bunch Spacing	Luminosity [$cm^{-2}\,s^{-1}$]	Interactions/ Xsing	Mean pulse height/ occupied bunch Xsing - mV
A–Collision studies with single pilot bunch beam - no crossing angle	1	N/A	2.5×10^{26} - 3.7×10^{27}	0.0006-0.092	0.04-0.53
B–Collision studies with single higher intensity bunch - no crossing angle	1	N/A	1.1×10^{29} - 4.3×10^{30}	0.27-10.71	16-611
C–Early p-p luminosity	43	2.025 μs	4.8×10^{30} - 8.4×10^{31}	0.28-4.86	15-277
	2808	25 ns	6.5×10^{32}	0.58	33
	936	75 ns	1.8×10^{33}	4.79	273
D–Nominal p-p luminosity	2808	25 ns	1.0×10^{34}	8.87	506
E–Ultimate p-p luminosity	2808	25 ns	2.3×10^{34}	20.39	1163

Other Beam Instrumentation

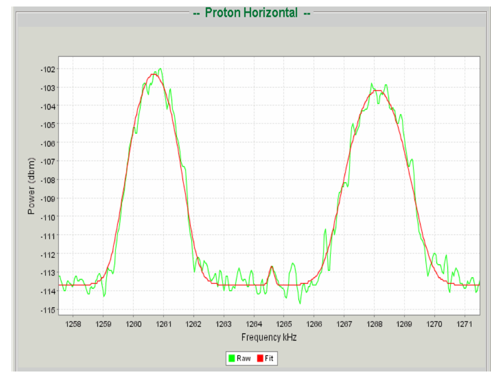
Tune and Chromaticity tracking / feedback:

- Goal: control effect of persistent current snapback
- Fast measurements of betatron tunes and chromaticity
- Feedback to correction quadrupoles and sextupoles



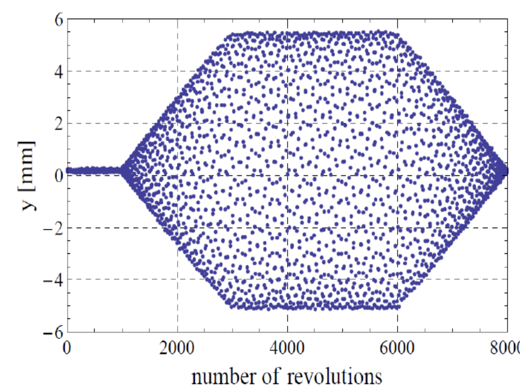
High sensitivity pickups (Schottky monitors):

- Traveling wave structure operating at 4.8 GHz
- Tune measurement from peak positions
- Chromaticity measurements from differential width
- Momentum spread from average width
- Emittance from average band power

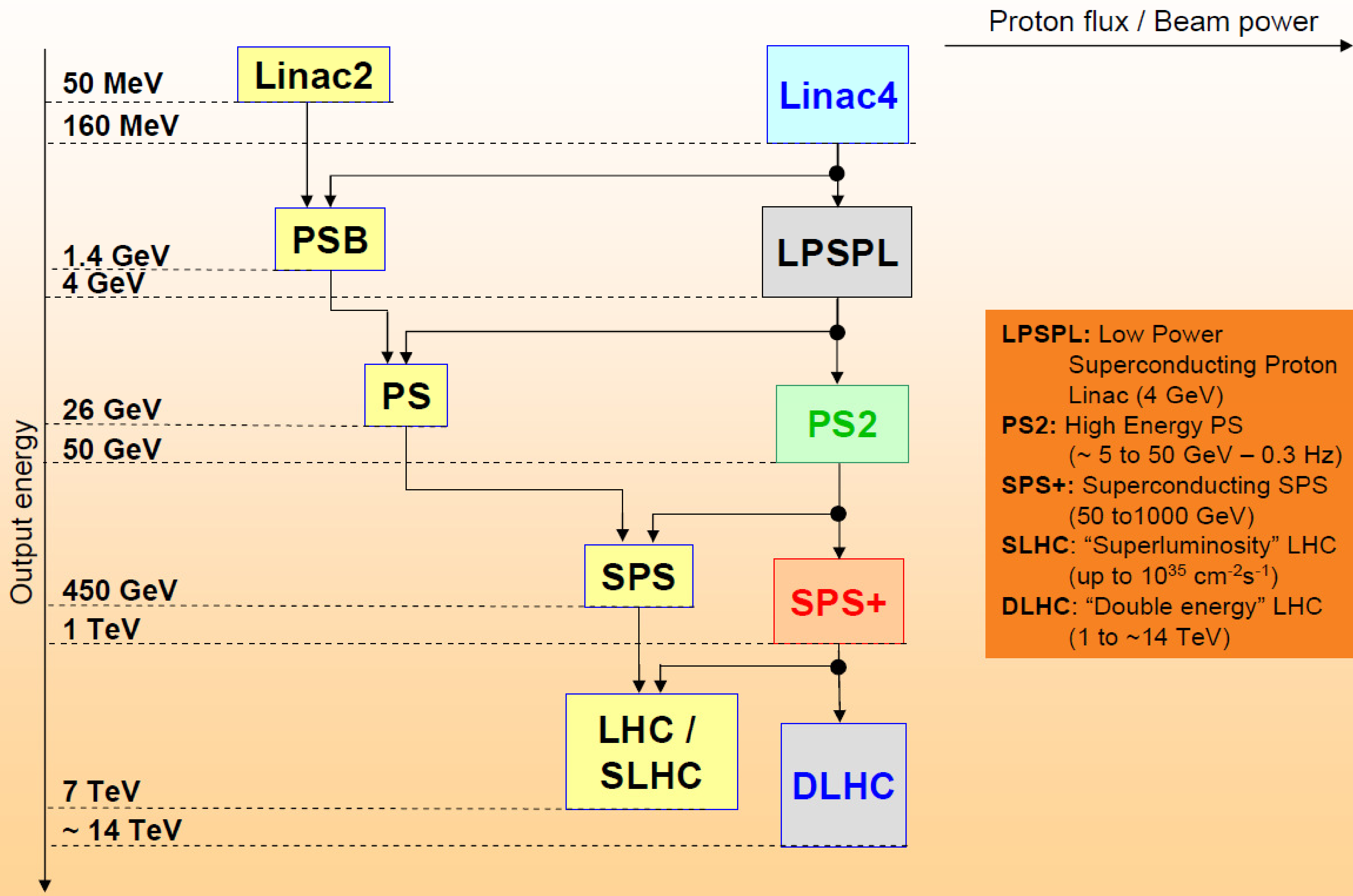


Beam Optics measurements (AC Dipole):

- Approach: oscillating field drives the beam
- Safe oscillation, preserves emittance
- Three systems built at BNL, FNAL, CERN
- β functions, phase advance, dynamic aperture



Upgrade components



LPSPL: Low Power Superconducting Proton Linac (4 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to1000 GeV)
SLHC: "Superluminosity" LHC (up to 10^{35} $cm^{-2}s^{-1}$)
DLHC: "Double energy" LHC (1 to ~14 TeV)

Accelerator Physics Studies

Electron cloud instability:

- Simulation tools (3D analysis)
- SPS, PS2 studies and machine experiments
- Development of feedback systems

PS2 design:

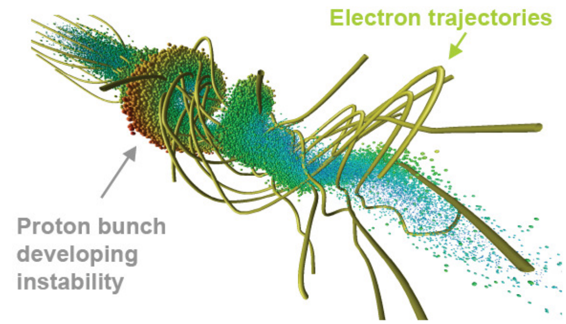
- Space-charge simulations
- Impedance, instabilities, feedback systems
- Laser stripping, Ionization monitor

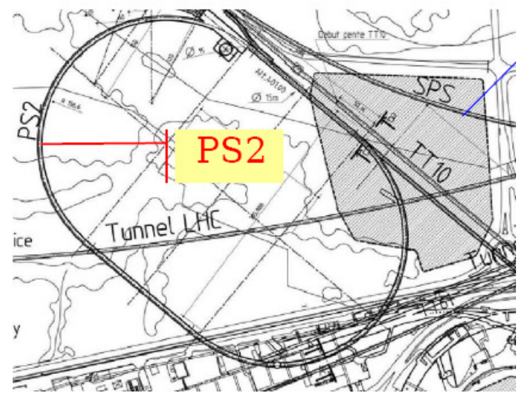
Beam-beam effect:

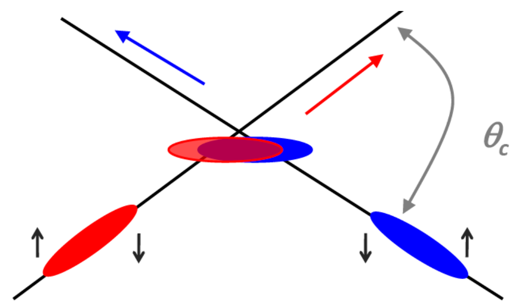
- Wire compensation experiments in RHIC
- Electron lens experiments at Tevatron

Crab crossing:

- Deflect bunch at IP to collide head-on
- Restore luminosity loss due to crossing angle
- Requires special superconducting cavities
- Large collaboration (beyond LHC)







Collimation System

- A baseline collimation system has been installed for initial machine operation
- A "Phase 2" collimation system with 10x better efficiency is under development
- LARP has been developing a prototype "Rotatable Collimator" for Phase 2
- R&D issues: mechanical tolerances, thermal effects, impedance, robustness

<u>Next steps</u>:

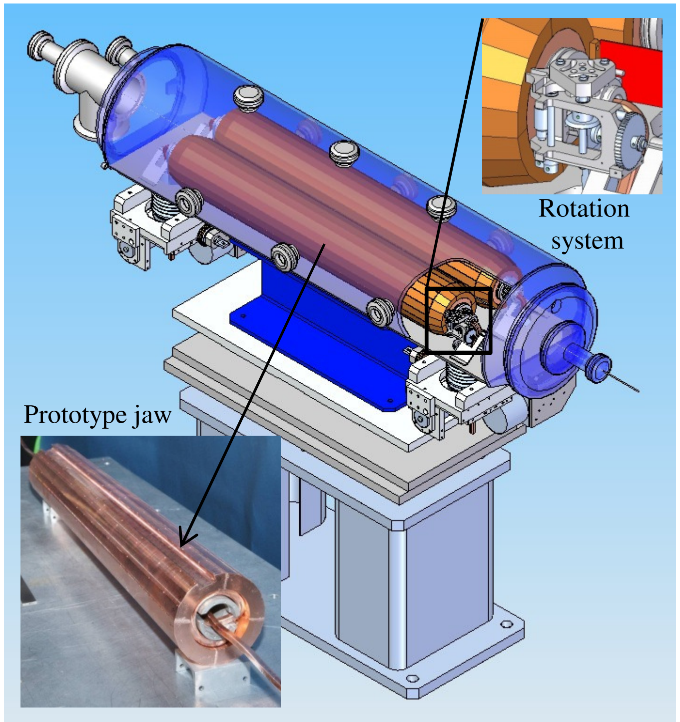
2009 Build fully functional prototype
- *Vacuum & mechanical tests at SLAC*

2010 Ship to CERN
- *Vacuum & mechanical tests at CERN*
- *S PS Tests of impedance and BPMs*

2012 Diagnostics for damage assessment

2013 In-beam test, technology decision

2014 Apply lessons learned to production



Luminosity Upgrade (SLHC)

Physics goals:

- *Improve measurements of new phenomena seen at the LHC*
- *Detect/search low rate phenomena inaccessible at nominal LHC*
- *Increase mass range for limits/discovery by ~30%*

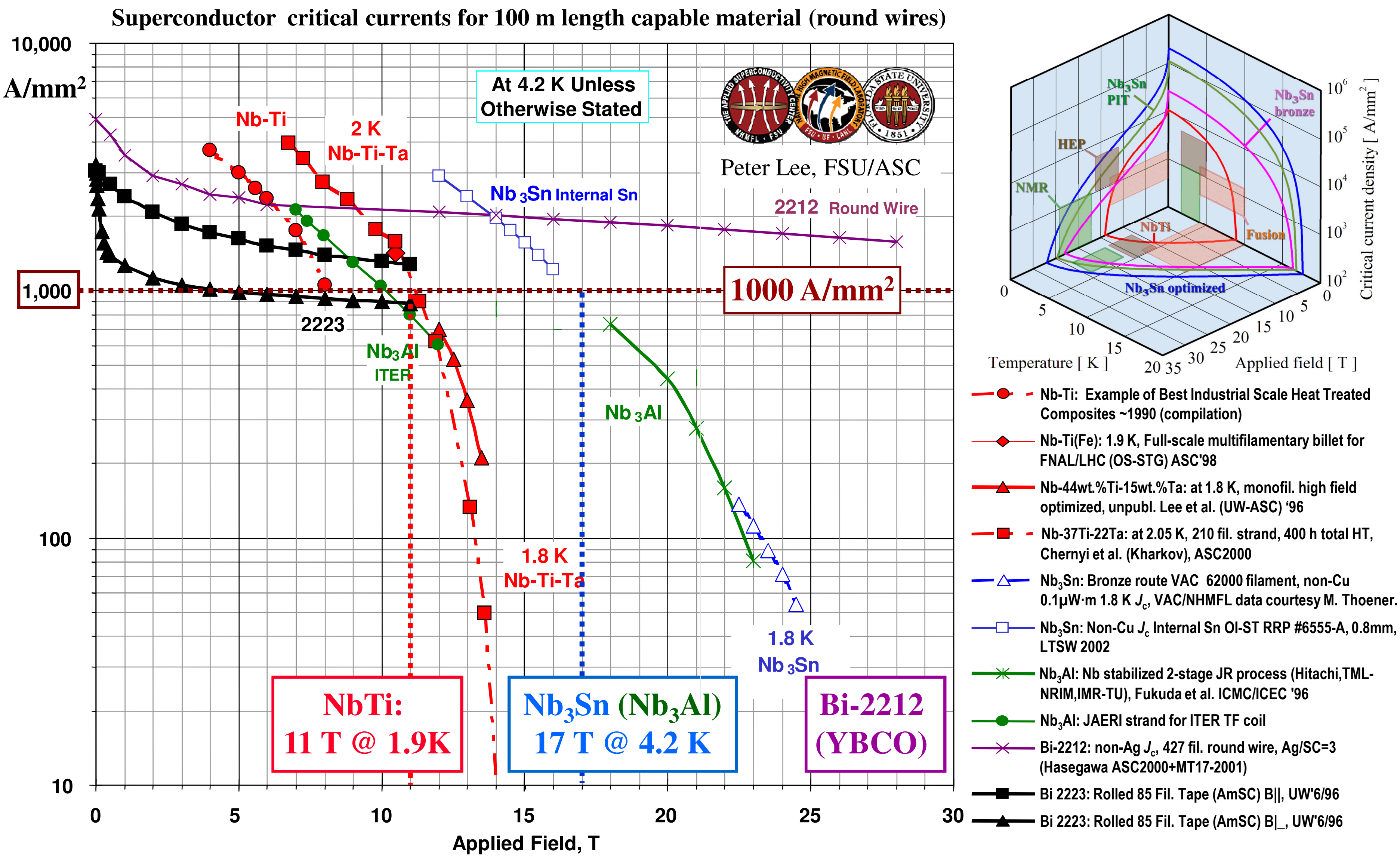
Implementation in 2 phases:

- *Phase 1* ($L= 2\cdot10^{34}$ $cm^{-2}sec^{-1}$)*: ~2014*
- *Phase 2* ($L=10\cdot10^{34}$ $cm^{-2}sec^{-1}$)*: ~2020*

Required accelerator upgrades include new IR magnets:

- *Directly increase luminosity through stronger focusing*
  $\Rightarrow$ *decrease* β^*
- *Provide design options for overall system optimization/integration*
  $\Rightarrow$ *collimation, optics, vacuum, cryogenics*
- *Be compatible with high luminosity operation*
  $\Rightarrow$ *Radiation lifetime, thermal margins*

Conductor Options



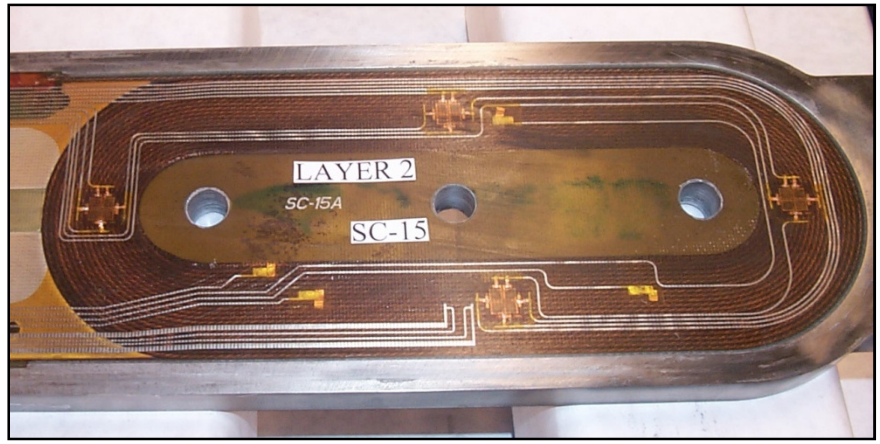
Nb_3Sn Challenges

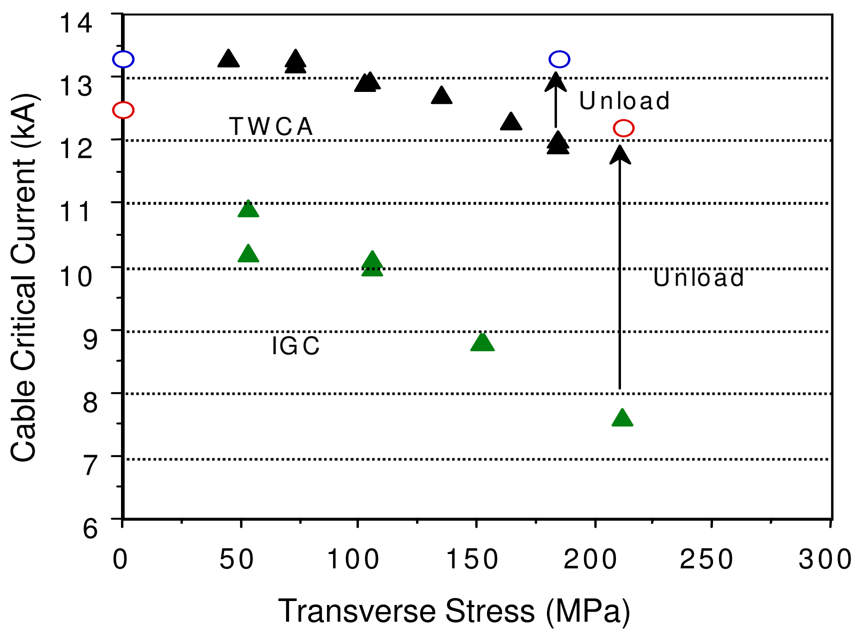
Brittleness:

- React coils after winding
- Epoxy impregnation

Strain sensitivity:

- Mechanical design and analysis to prevent degradation under high stress





Material	NbTi	Nb_3Sn
Dipole Limit	10-11 T	16-17 T
Reaction	Ductile	~675^{0}C
Insulation	Polymide	S/E Glass
Coil parts	G-10	Stainless
Axial Strain	N/A	< 0.1 %
Transverse stress	N/A	< 200 MPa

Magnet R&D Program

1. Nb_3Sn Technology

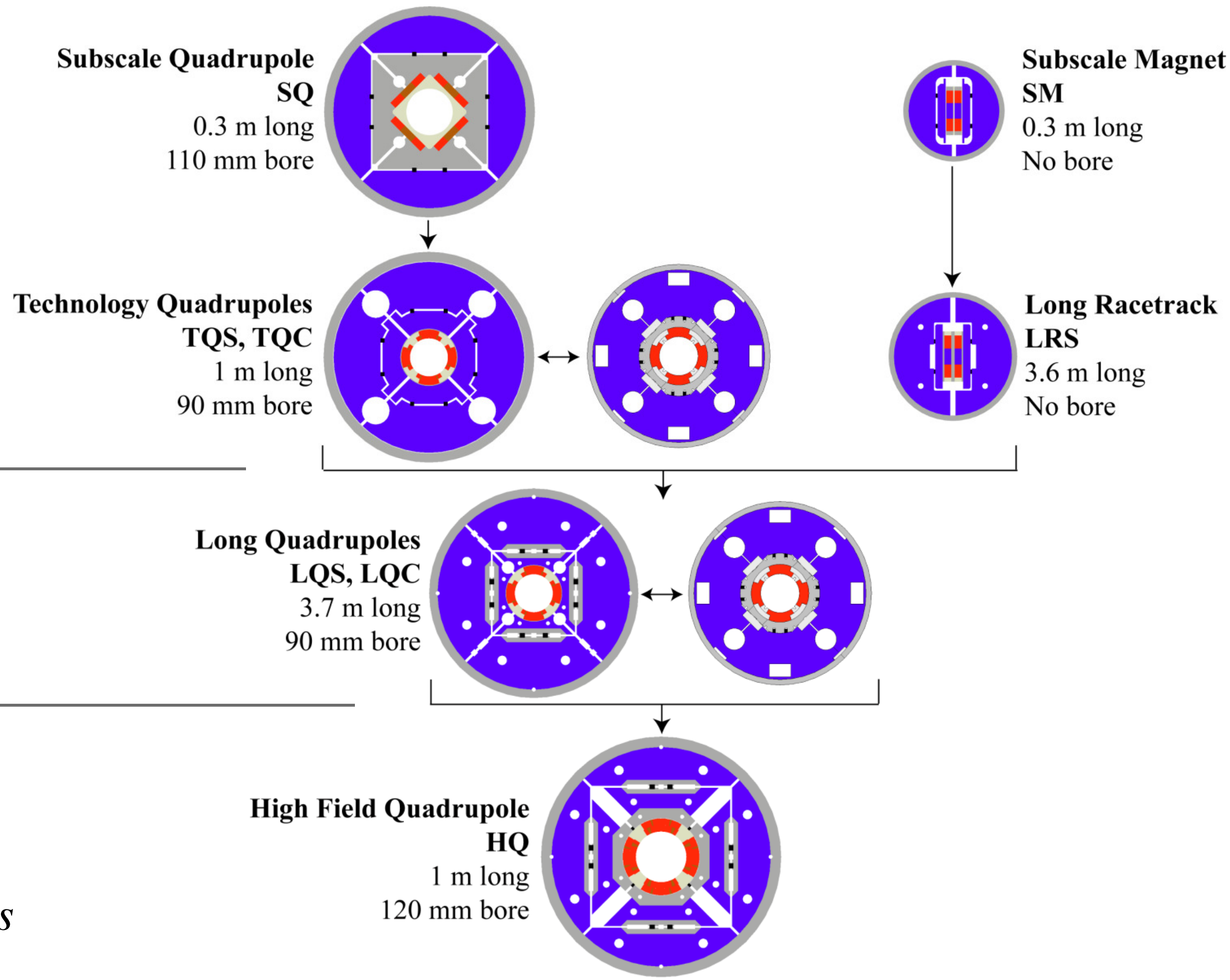
- *Conductor studies*
- *Coil fabrication*
- *Mechanical support*
- *Modeling tools*
- *Quench protection*

2. Length scale-up

- *Coil technology*
- *Quench protection*

3. Design optimization

- *Larger aperture*
- *higher energy and forces*
- *Accelerator quality*



Technology Quadrupole Shell

- A new strand design (RRP 108/127) was incorporated in TQS03 coils
- TQS03a achieved the best results to date: 238 T/m
- Exploring the stress limits in TQS03b: 160 MPa, only 2% degradation
- Next reassembly and test scheduled at CERN for December-January

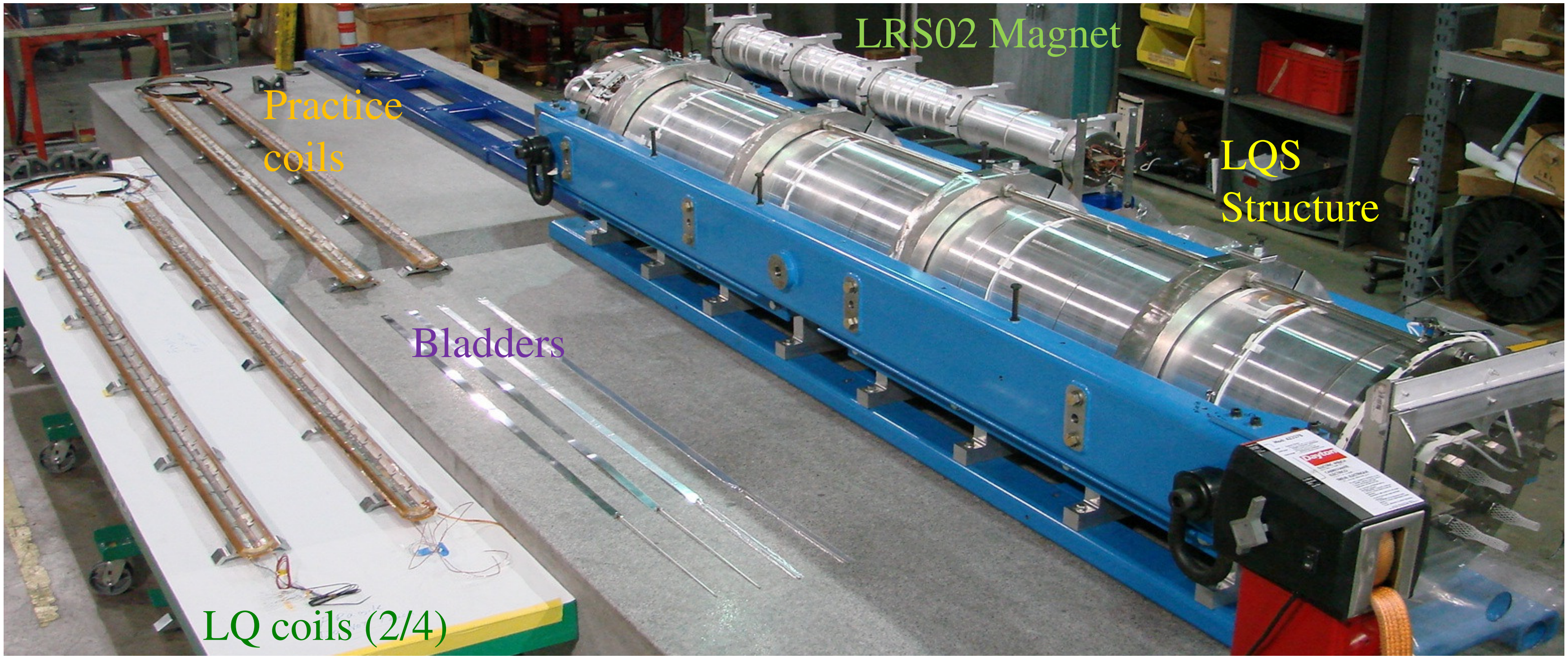
TQS Test Results

TQS Model	Test Location	G_{Max} (T/m)	G_{Max} quench Temperature
TQS01a	LBNL	200	*3.2K*
TQS01b	LBNL	182	4.4K
TQS01c	FNAL	191	1.9K
TQS02a	FNAL	222	*2.2K*
TQS02b	CERN	205	1.9K
TQS02c	CERN	231	2.7K
TQS03a	CERN	238	1.9K
TQS03b	CERN	233	1.9K

TQS assembly at CERN

Long Quadrupole

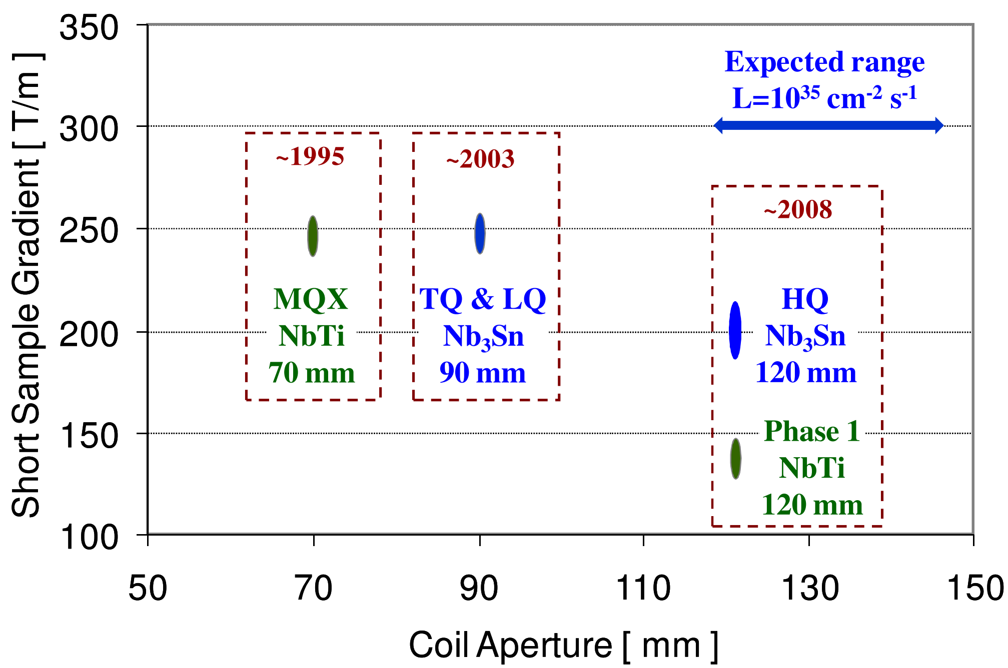
- Length scale-up of the Technology Quadrupole, from 1 m to 4 m
- Coil fabrication: BNL+FNAL; Support structure and assembly: LBNL
- LQS01 model assembled in August and shipped to FNAL for testing
- *Additional coil fabrication and magnet tests are planned for FY10*



Next Phase: 120 mm Quadrupoles

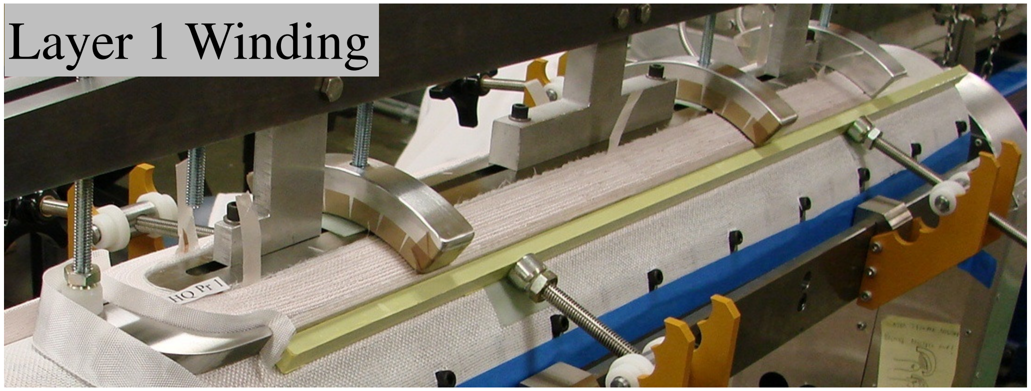
- IR Studies show *large aperture quads are required* for L=10^{35} cm^{-2} sec^{-1}
- Phase 1 (L=2 10^{34} $cm^{-2}sec^{-1}$) will use NbTi Quads with *120 mm aperture*
- The *same aperture* was chosen for the next series of Nb_3Sn models (HQ)

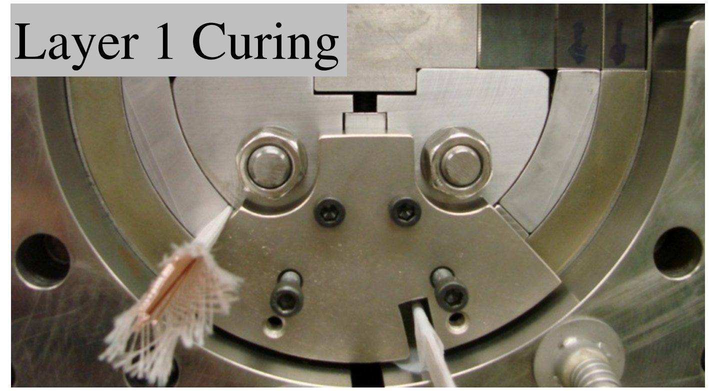
Aiming at:
- Full qualification based on Phase 1 luminosity requirements
- Providing performance reference for Phase 2 upgrade design



LARP

HQ Coil Fabrication


Layer 1 Winding


Layer 1 Curing


Layer 2 Winding

Energy Upgrade (DLHC)

Motivation for a 14 TeV → 28 TeV upgrade:

- *Direct enhancement of physics reach by a factor of two in mass*
- *No major detector upgrades required*

The better upgrade path depends on where and what the new physics is:

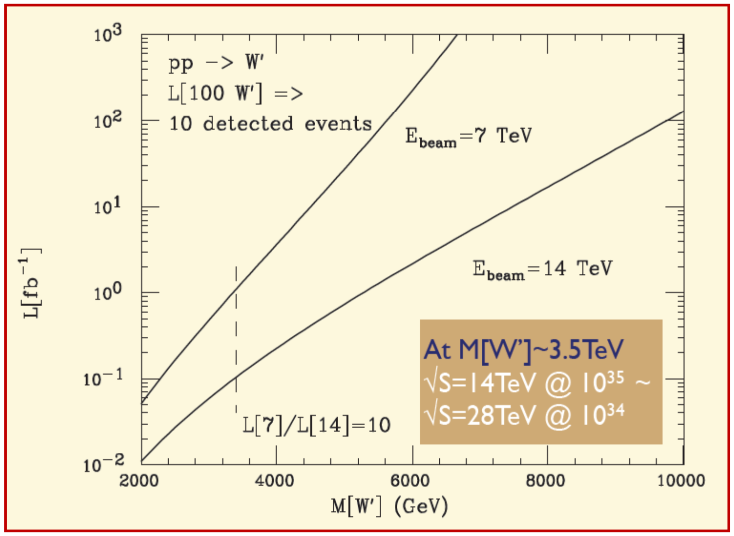
- *Low mass: 10xLum better that 2xE_{beam}*
- *High mass: increase of E_{beam} is essential*

Strong physics interest in energy upgrade:

"14→28 TeV is great, 14→42 is even better"

(M. Mangano, SLHC kick-off meeting)

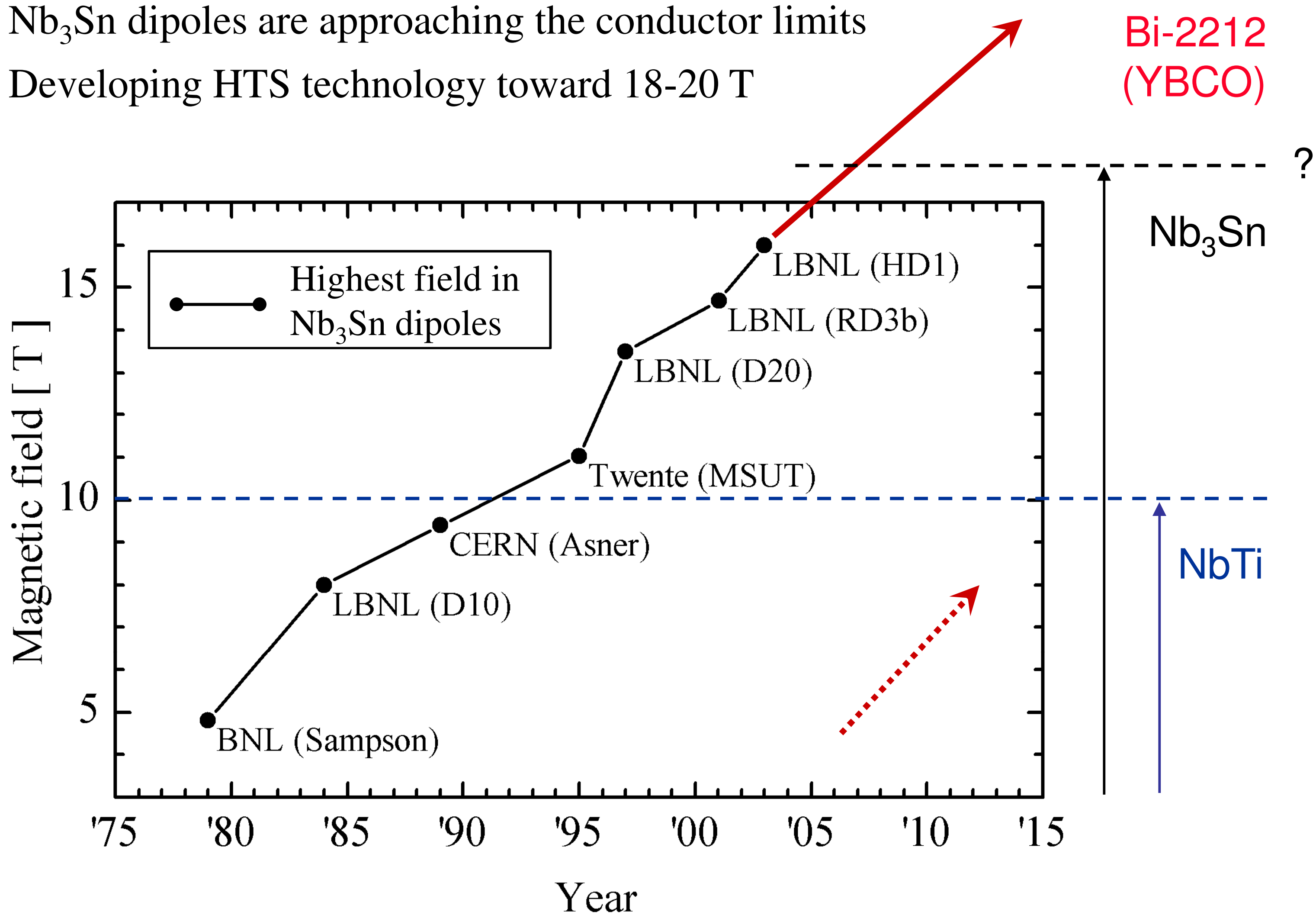
M. Mangano, HHH Workshop, Arcidosso



Key R&D challenge is developing the high field dipoles

Progress in Maximum Dipole Field

- Nb_3Sn dipoles are approaching the conductor limits
- Developing HTS technology toward 18-20 T



Summary

Strong US involvement in support of the LHC Accelerator

- USLHC Project (1996-2005)
  - IR magnets, absorbers, cryogenic feedboxes
- LARP Program (2004-2014)
  - LHC Baseline: Commissioning, instrumentation
  - LHC Upgrades: IR magnets, collimation, AP studies

New Construction Project: Accelerator Project for the LHC (APUL)

- Phase 1 upgrade (CD0-approved):
  - Separation dipoles (BNL) and cryogenic feeds (FNAL)
- Expected to expand toward Phase 2 upgrade:
  - Nb_3Sn IR Magnets, Collimation, Injector Systems