Future Circular Collider Study

Overview

Contents

- Future Circular Collider Study motivation and global context
- CERN hosted FCC study – scope and status of preparations
- Main challenges and R&D areas for machines
- Conclusions

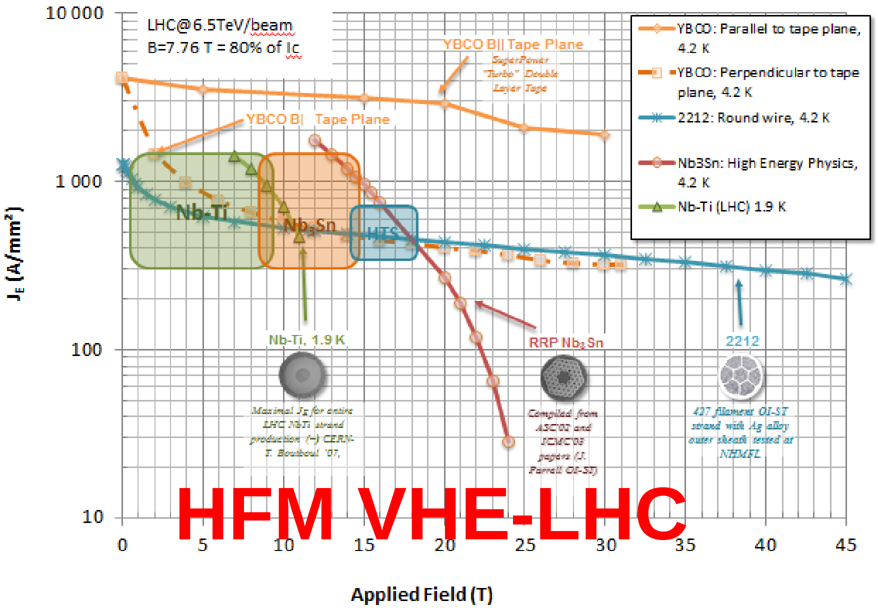
European Strategy Update on Particle Physics

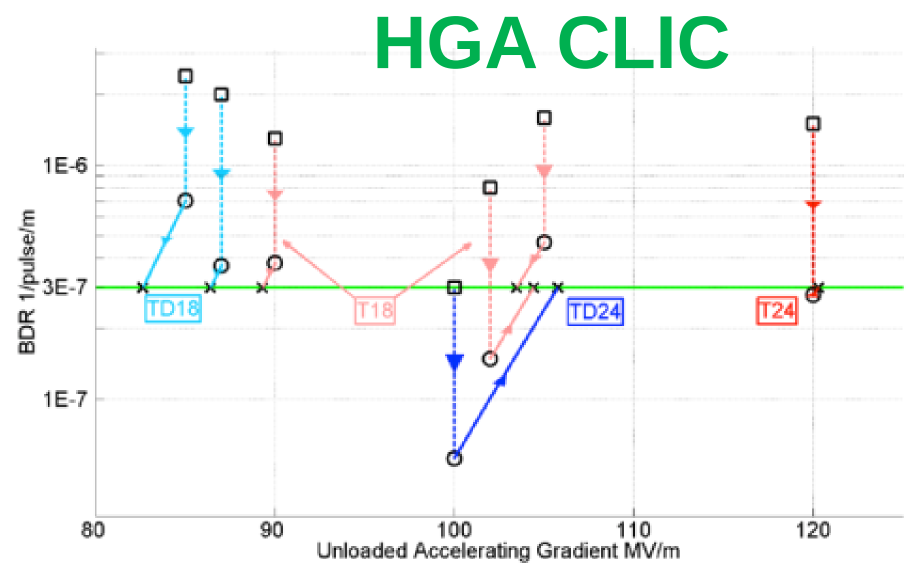
Design studies and R&D at the energy frontier

"to propose an ambitious **post-LHC accelerator project at CERN** by the time of the next Strategy update":

d) ***CERN should undertake design studies for accelerator projects in a global context,***

with emphasis on ***proton-proton and electron-positron high-energy frontier machines****. These design studies should be coupled to a vigorous accelerator* ***R&D programme****, including* ***high-field magnets*** **and** ***high-gradient accelerating structures****,* ***in collaboration with national institutes, laboratories and universities worldwide.***





Global FCC activities

- **Asia/China: studies of $C_{ircular}EPC_{collider}$ + $S_{uper}ppC_{ollider}$**
  - Focus on lepton collider, long-term potential for hadron machine.

International Workshop on Future High Energy Circular Colliders

chaired by Xinchou Lou (IHEP, Beijing)

from Monday, December 16, 2013 at **08:30** to Tuesday, December 17, 2013 at **19:20** (Asia/Shanghai)
at **IHEP (A214)**
Main Building

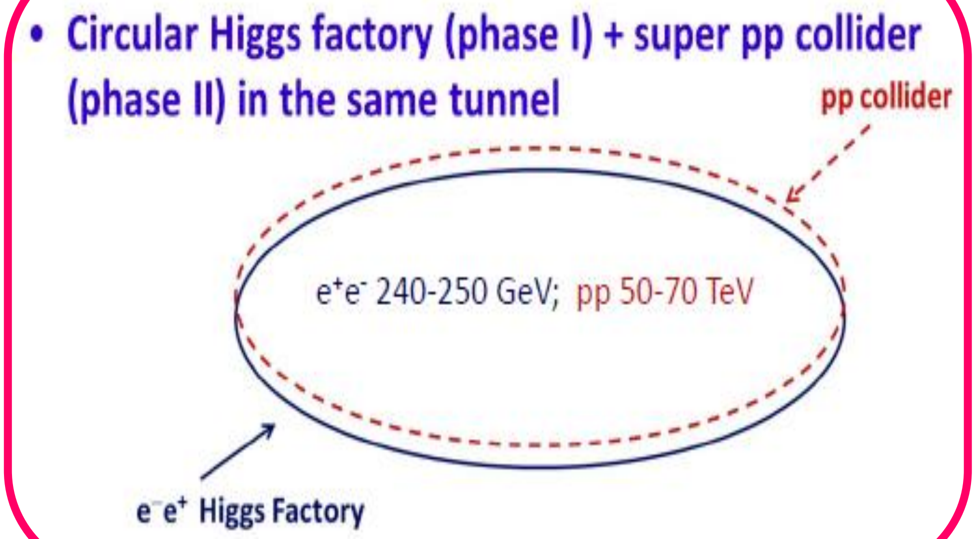
Description The workshop will bring together people interested in circular high energy e+e- colliders as a Higgs factory as well as a future circular high energy pp collider beyond the Higgs factory, and will discuss critical issues in accelerator technology, detector design and in theory on the precision measurement of the Higgs and the physics with pp collision at 50-100 TeV.

- **America/U.S: presently no initiatives for FCC projects in US.**
  - Very relevant expertise from VLHC Design Study and US DOE Labs
- **Strong arguments for common design studies since conceptual machine designs are to a large extent of non-site specific nature.**
  - Many R&D subject are of fundamental nature also relevant for other accelerator areas e.g. intensity frontier, etc.

CEPC+SppC

Slide from Y. Wang
Beijing Workshop 16.12.13

- We are looking for a machine after BEPCII
- A circular Higgs factory fits our strategic needs in terms of timing, science goal, technological & economical scale, manpower reality, etc.
- Its life can be extended to a pp collider: great for the future



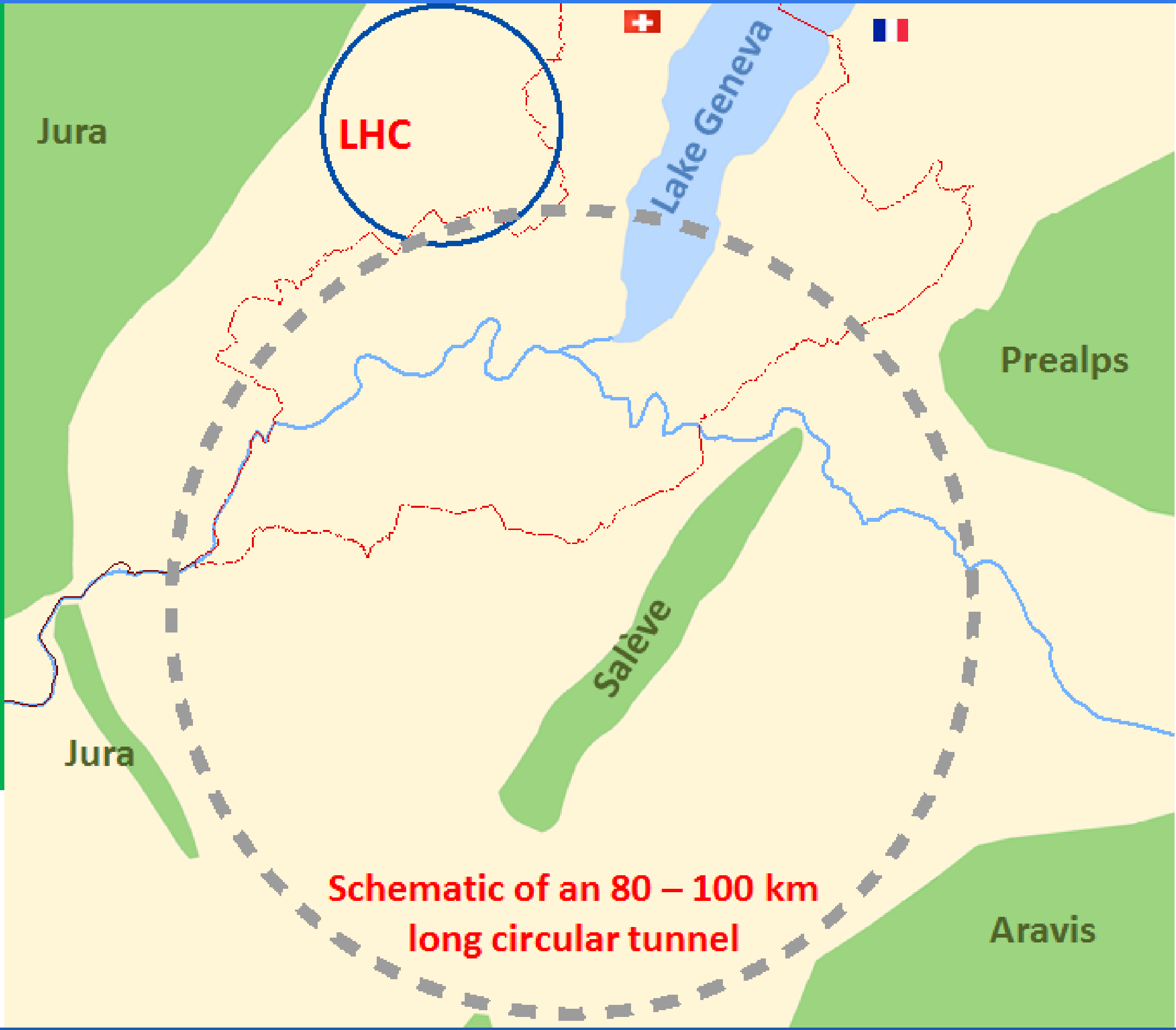
- ➢ Circular Higgs factory is complementary to ILC
  - ➢ Push-pull option
  - ➢ Low energy vs high energy

We hope to collaborate with anyone who is willing to host this machine. Even if the machine is not built in China, the process will help us to build the HEP in China

Future Circular Collider Study - SCOPE
CDR and cost review for the next ESU (2018)

- **80-100 km tunnel infrastructure in Geneva area**
- **pp-collider (VHE-LHC) defining the infrastructure requirements**
- **e+e- collider (TLEP) as potential intermed. step and p-e (VLHeC) option**
- **CERN-hosted study performed in international collaboration**

~15 T ⇒ 100 TeV in 100 km
~20 T ⇒ 100 TeV in 80 km



Study preparation – Kick-off meeting

- **Kick-off meeting will be held at Geneva University 12-15. Feb. 2014.**

- **To discuss study scope, topics, organisation**
- **To prepare for international collaborations**

- **Invitation to participate!**

Main areas for design study

Machines and infrastructure conceptual designs	Technologies R&D activities Planning	Physics experiments detectors
Infrastructure	High-field magnets	Hadron physics experiments interface, integration
Hadron collider conceptual design	Superconducting RF systems	$e^+ e^-$ coll. physics experiments interface, integration
Hadron injectors	Cryogenics	e^- - p physics, experiments, integration aspects
Lepton collider conceptual design	Specific technologies	
Safety, operation, energy management environmental aspects	Planning	

Prel. parameters for FCC – FHC *(VHE-LHC)*

PRELIMINARY

• **Energy**	**100 TeV c.m.**
• **Dipole field**	**~ 16 T (design limit) [20 T option]**
• **Circumference**	**~ 100 km**
• #IPs	2 main (tune shift) + 2
• Beam-beam tune shift	0.01 (total)
• **Bunch spacing**	**25 ns [5 ns option]**
• Bunch population (25 ns)	1×10^{11} p
• #bunches	10500
• **Stored beam energy**	**8.2 GJ/beam**
• Emittance normalised	2.15×10^{-6}m, normalised
• **Luminosity**	**5×10^{34} cm^{-2}s^{-1}**
• β^*	1.1 m
• **Synchroton radiation arc**	**26 W/m/aperture (filling fact. 78% in arc)**
• **Longit. emit damping time**	**0.5 h**

FHC - some design challenges

- **Optics and beam dynamics**
  - IR design, SC magnet field quality require., dynamic aperture studies
- **Impedances, instabilities, feedbacks**
  - Beam-beam, e-cloud, feedback simulation & system conception
- **Synchrotron radiation damping**
  - Controlled blow up, lumi levelling, etc…
- **Energy in beam & magnets, dump, collimation; quench protection**
  - **Stored beam energy and losses critical: 8 GJ/beam (0.4 GJ LHC)**
  - Collimation, losses, radiation effects
  - Synergies to intensity frontier machines (SNS, FRIB, etc.)
- **High synchrotron radiation load on beam pipe**
  - **Up to 26 W/m/aperture in arcs, total of ~5 MW for the collider**
  - (LHC has a total of 1W/m/aperture from different sources)
  - Heat extraction, cryo load, beam screen temperature,etc.

FHC high-field magnet R&D targets

- **FHC baseline is 16T Nb_3Sn technology for ~100 TeV c.m. in ~100 km**

Goal: 16T short dipole models by 2018 (America, Asia, Europe)

Develop Nb_3Sn-based 16 T dipole technology,
- with sufficient aperture (~40 mm) and
- accelerator features (field quality, protect-ability, cycled operation).
- In parallel conductor developments

- **In parallel HTS development targeting 20 T.**
- **HTS insert, generating o(5 T) additional field, in an outsert of large aperture o(100 mm)**

Goal: Demonstrate HTS/LTS 20 T dipole technology in two steps:
- a field record attempt to break the 20 T barrier (no aperture), and
- a 5 T insert, with sufficient aperture (40 mm) and accel. features

Lepton collider parameters – preliminary

- **Design choice: max. synchrotron radiation power set to 50 MW/beam**
  - Defines the max. beam current at each energy.
  - 4 Physics working points
  - Optimization at each energy (mainly bunch number).

Parameter	Z	WW	H	tt_{bar}	LEP2
E/beam (GeV)	**45**	**80**	**120**	**175**	**104**
L (10^{34} $cm^{-2}s^{-1}$)/IP	**28.0**	**12.0**	**5.9**	**1.8**	**0.012**
I (mA)	1450	152	30	6.6	3
Bunches/beam	**16700**	**4490**	**1330**	**98**	**4**
Bunch popul. [10^{11}]	1.8	0.7	0.47	1.40	4.2
Tune shift / IP	0.03	0.06	0.09	0.09	0.07

Some machine design challenges

- **Short beam lifetime from Bhabha scattering and high luminosity**
  - Top-up injection (single injector booster in collider tunnel)
- **Lifetime limits from Beamstrahlung at higher operation energies**
  - Flat beams (very small vertical emittance, β^* ~ 1 mm)
  - Final focus with large (~2%) energy acceptance
- **Machine layout for high currents, large #bunches at Z pole, WW, H.**
  - Two ring layout and size of the RF system.
- **Polarization for high precision energy calibration at Z pole and WW, where natural polarization times are ~ 15 hours.**

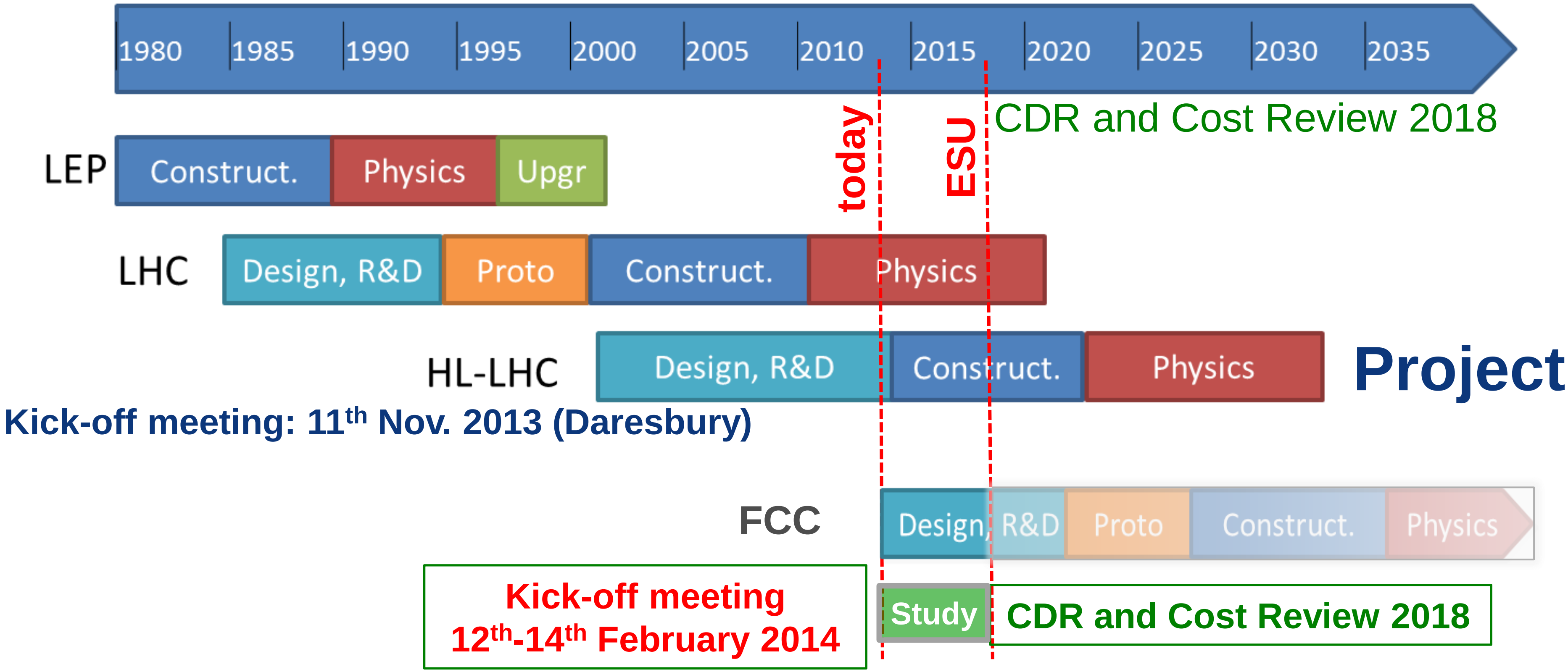
- **Important expertise available worldwide and potential synergies:**
- **IR design, experimental insertions, machine detector interface, (transverse) polarization**

⇔ CLIC, ILC, B-factories, SLAC, BNL, RHIC, SLC

RF main R&D areas

- **SC cavity R&D**
  - Large Q_0 at high gradient and acceptable cryogenic power!
  - E.g.: Recent promising results at 4 K with Nb_3Sn coating on Nb at Cornell, $800\ ℃ \div 1400\ ℃$ heat treatment at JLAB, beneficial effect of impurities observed at FNAL.
  - **Relevant for many other accelerator applications**
- **High efficiency RF power generation from grid to beam**
  - Amplifier technologies
  - Klystron efficiencies beyond 65%, alternative RF sources as Solid State Power Amplifier or multi-beam IOT, **Relevant for all high power accelerators, intensity frontier (drivers), (e.g. νstorm, LBNE, DAEδALUS, μcoll,)**
- **Overall RF system reliability**
- **R&D Goal is optimization of overall system efficiency and cost!**
  - Power source efficiency, low loss high gradient SC cavities, operation temperature vs. cryogenic load, total system cost and dimension.

FCC study milestones



Summary

- There are rising activities in energy-frontier circular colliders worldwide.
- CERN is preparing for an international study for the design of Future Circular Colliders (FCC). Collaboration in all study areas, i.e. physics, experiments and accelerators will be important to reach conceptual design level by 2018.
- Many R&D areas e.g. high-field magnets and SC RF are of general interest and relevant for many other applications e.g. intensity frontier. Significant investments have been made over the last decade(s), also in the framework of LHC and HL-LHC, and further continuation will ensure efficient use of these past investments.
- **FCC kick-off meeting 12-15 February 2014 in Geneva University**
  - *Agree on study scope, prepare and establish collaborations, Looking forward to welcoming you!*

Acknowledgements

FCC Kick-Off & Study Preparation Team

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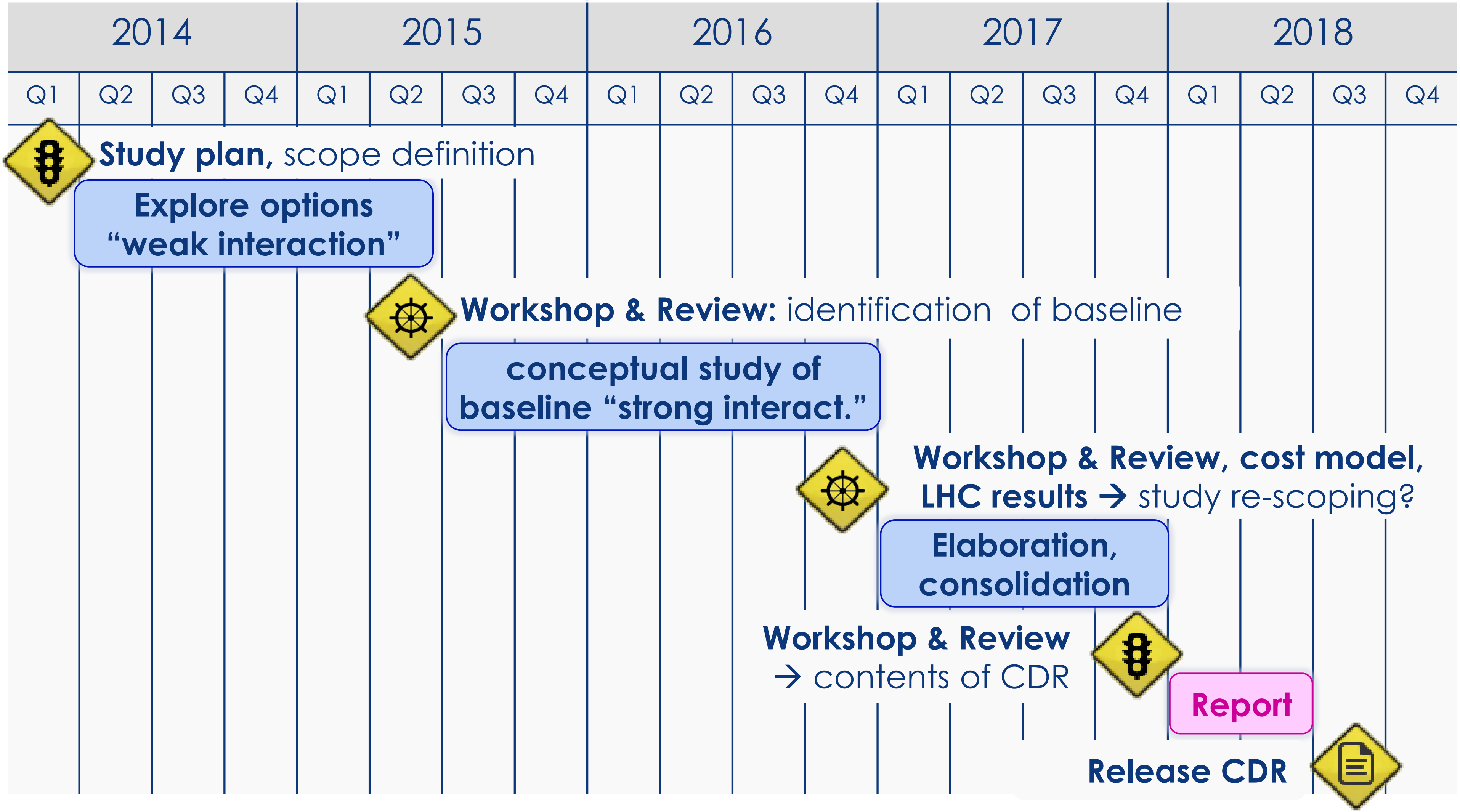
Michelangelo Mangano, Daniel Schulte,
Laurent Tavian, Jörg Wenninger,
Frank Zimmermann

Spare slides

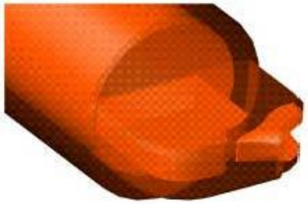
Study timeline

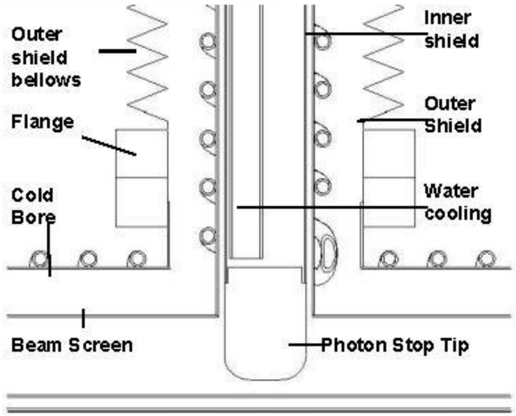


FHC - Synchrotron Radiation Heat Load

- **High synchrotron radiation load on beam pipe**
  - **Up to 26 W/m/aperture in arcs, total of ~5 MW for the collider**
  - (LHC has a total of 1W/m/aperture from different sources)

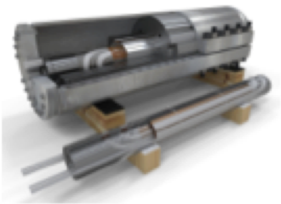
- **Three strategies to deal with this**
  - **LHC-type beam screen**
    - Cooling efficiency depends on screen temperature, higher temperature creates larger impedance → 40-60 K?
  - **Open midplane magnets**
    - Synergies with muon collider developments
  - **Photon stops**
    - dedicated warm photon stops for efficient cooling between dipoles
    - **as developed by FNAL for VLHC**





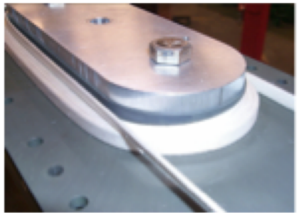
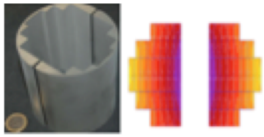
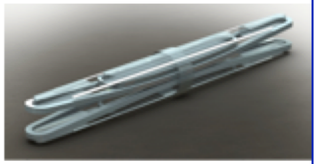
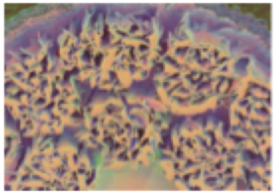
http://inspirehep.net/record/628096/files/fermilab-conf-03-244.pdf
Also P. Bauer et al., "Report on the First Cryogenic Photon Stop Experiment," FNAL TD-03-021, May 2003

The running programs – LTS (Nb_3Sn)

Program	Goals	Main partners	Status	
US-base program	High field Nb_3Sn dipoles as technology demonstrators	DOE (BNL, FNAL, LBNL)	D20 reached 13.5 T (50 mm) in 1997, HD1 reached 16 T (0 mm) in 2004. LD1 shell and conductor procured	
EuCARD FReSCa2	13 T (100 mm) Nb_3Sn dipole	EuCARD collaboration (CEA, CERN)	SMC reached 13.5 T (0 mm) in 2013, RMC in construction, FReSCa2 structure procured and tested at CERN, coils in fabrication at CEA	
US-LARP	140 T/m (150 mm) Nb_3Sn quadrupoles for the LHC IR upgrade	DOE US-LARP (BNL, FNAL, LBNL), CERN	Short HQ models (120 mm), long LQ prototype (90 mm) tested, QXF (150 mm) models in production (US-LARP and CERN)	
11 T	11 T (60 mm) Nb_3Sn dipoles for the LHC DS collimators	FNAL, CERN	2 short models tested, 1 mirror in test at FNAL, first model in production at CERN	

NOTE: program at TAMU not reported

The running programs – HTS

Program	Goals	Main partners	Status	
US-base program	High field HTS small models as technology demonstrators	DOE (BNL, FNAL, LBNL)	BSCCO racetracks produced and tested (self field) at LBNL. CCT design and prototyping work, first model (NbTi) reached 2.5 T in 2013	
EuCARD HTS insert	6 T (0 mm) HTS dipole insert for FReSCa2 (19 T)	EuCARD collaboration (INPG, CEA)	Short racetrack coils in test at INPG	
EuCARD2	5 T (40 mm) HTS short dipole (also as insert for FReSCa2 (18 T)	EuCARD2 collaboration (CERN, CEA), S-Innovation, US-BSCCo	Superconductor material studies in progress, conceptual designs	
US-BSSCo	Increase J_e of BSCCO-2212 to 600 A/mm^2 for high B physics (30 T all SC user facility)	DOE (BNL, FNAL, LBNL), NHMFL	BSCCO-2212 production restarted at OST in collaboration with CERN, OPHT furnaces, cabling R&D	
S-Innovation	HTS-based compact accelerator systems	Kyoto University, KEK	Conceptual design studies, test of a racetrack HTS at 77 K (self field) to determine field quality	

NOTE: program at Carolina University not reported

Summary on high-field magnets

- **U.S. research has been leading superconducting high-field magnet technology:**
  - **Highest field achieved in dipole configuration (LBNL, 16 T)**
  - Hosting the industrial superconductor production with highest critical current density (OST RRP, 3300 A/mm^2 at 12 T and 4.2 K)
  - Vigorous program for the industrial production of a BSCCO-2212 round wire with the characteristics required by high-field applications

- **CERN has a record of very fruitful collaborations with US-DOE Laboratories and Universities. E.g.**
  - **US-LARP collaboration for HL-LHC quadrupole production** of approximately half of the triplet magnets, as required for LHC LS3
  - **FNAL/CERN collaboration for the 11 T LHC dipole design** and demonstration of the technology required for a for the LHC
  - CERN/NHMFL collaboration agreement on the study of LTS / HTS materials.

- **These are excellent pre-requisites for a strong international collaboration on high-field magnet R&D that will be essential for FCC studies.**

Lepton collider RF - relevant parameters

Main RF parameters

- Synchrotron radiation power: 50 MW per beam
- Energy loss per turn: 7.5 GeV (at 175 GeV, t)
- Beam current up to 1.4 A (at 45 GeV, Z)
- Up to 7500 bunches of up to 4 x 10^{11} e per ring.
- CW operation with top-up operation, injectors and top-up booster pulsed

First look on basic choices and RF system dimension

- Frequency range (200 … 800) MHz with ~400 MHz as starting point
  - Initial choice based on present frequencies (harmonics of 200 MHz FHC)
  - Disadvantage lower frequency: mechanical stability, He amount for cooling, size …
  - Disadvantage higher frequency: denser HOM spectrum (multi-cell), BBU limit, larger impedance, smaller coupler dimensions
- System dimension compared to LHC:
  - **LHC 400 MHz → 2 MV and ~250 kW per cavity, (8 cavities per beam)**
  - **Lepton collider ~600 cavities 20 MV / 180 kW RF → 12 GV / 100 MW**