FCC – hh

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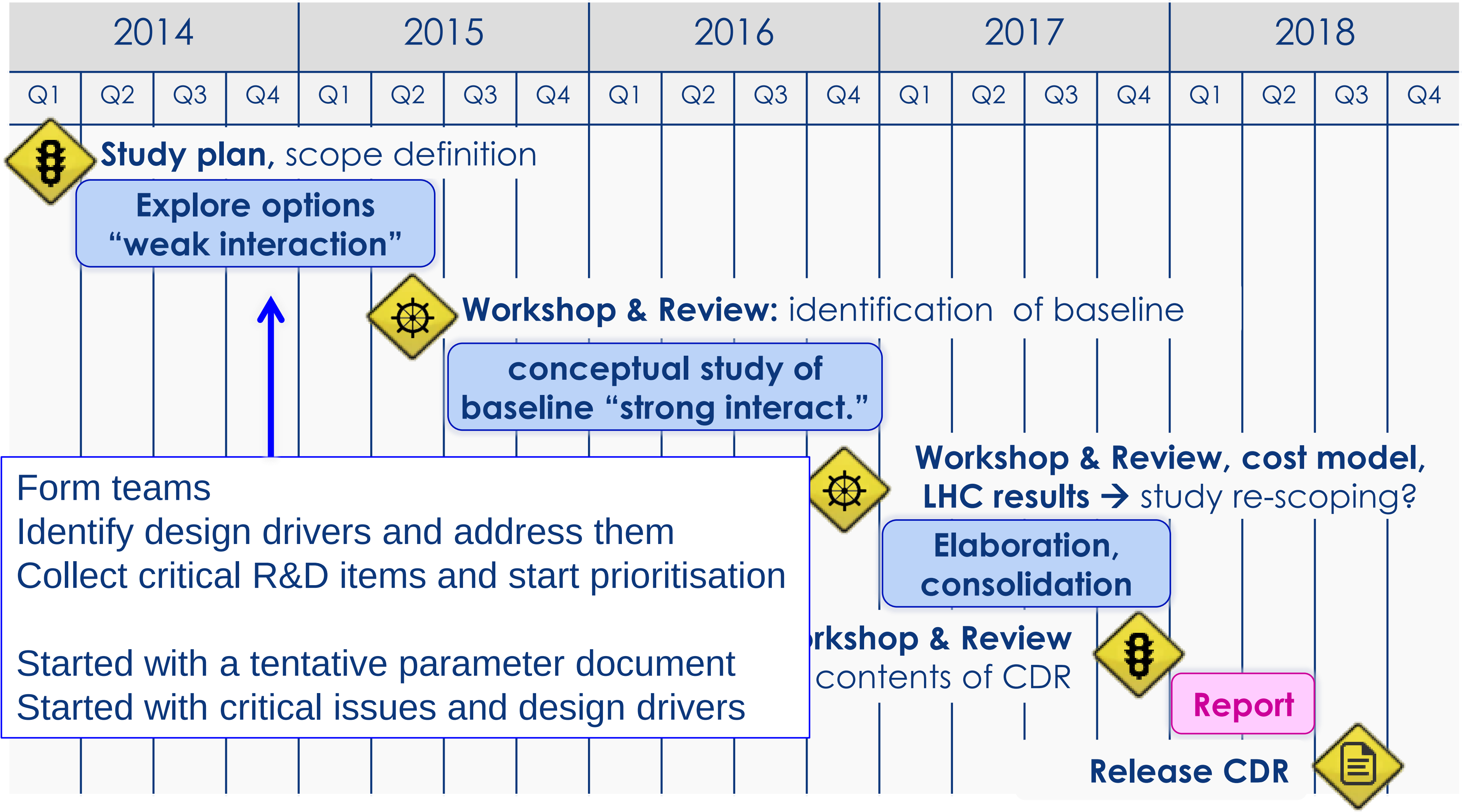
FCC-hh kick-off meeting – March 2014

FCC-hh Study Scope



Form teams
Identify design drivers and address them
Collect critical R&D items and start prioritisation

Started with a tentative parameter document
Started with critical issues and design drivers

Goal for First Phase

- Goal is to have a baseline by early 2015
  - Try to have input end of 2014 to have time for discussions

- Should aim for:
  - Baseline
    - Forward-looking but reasonable risk
    - Required R&D for CDR identified
  - Specific alternatives
    - e.g. cost reduction/performance improvement, but higher risks require additional R&D
    - E.g. lower risk but less performance/higher cost, fallback solution
    - Identified specific R&D

Workplan for First Phase

- FCC will be a global collaboration

- It will need some time to form this collaboration
  - Non-committing letters of interest end of May
  - Formal agreements in September
  - EU design study submission in September

- But need to work on the baseline already now
  - Preparation of baseline
  - Identification of R&D needs for CDR
  - Preparation of technical scope of the collaboration

- In particular senior experts required

- Will use this series of meetings for this goal

Note on Organisation

- Will start with this meeting (FCC-hh-design)
  - Covers all aspects of the hadron collider ring

- Will start other meetings
  - When this meeting becomes too loaded
  - When a critical mass is available for specific topics
  - When a subject requires detailed interaction of experts

- Examples
  - Beampipe meeting (already exists)

- Like to maintain mixture of different expertises
  - Interfaces and integration are critical
  - Link between technical experts and FCC-hh should be done here

Baseline Design

- Physics requirements
  - Have some first requirements, iterations will be needed
- Baseline parameters
  - First document exists, further improvement needed
- Baseline layout
- Injection requirements / injector system design
- Baseline parameters for HE-LHC
- Staging scenarios

Rational for Parameter Choice

- Put together something that is reasonable
  - Somewhat conservative
  - With some aggressive choices to avoid excessive cost
  - To criticise and improve
  - To guide the design work and identify challenges
  - Seed of the baseline

- More aggressive choices will be considered as alternatives
  - When more R&D is required
  - When they involve a performance/cost trade-off

  - http://indico.cern.ch/event/282344/material/3/

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Physics Parameters

	LHC	HL-LHC	HE-LHC	FCC-hh
Cms energy [TeV]	14		33	100
Luminosity [$10^{34}cm^{-2}s^{-1}$]	1	5	5	5
Bunch distance [ns]	25			25 (5)
Background events/bx	27	135	147	170 (34)
Bunch length [cm]	7.5	7.5	7.5	8

- Two main experiments sharing the beam-beam tuneshift
  - Two reserve experimental areas not contributing to tuneshift
- Currently assume 25ns as baseline
  - May be able to reduce bunch spacing and background
- Might be able to increase bunch length
  - Will explore this if experiments find it useful
- 80% of circumference filled with bunches

Basic Machine Parameters

	LHC	HL-LHC	HE-LHC	FCC-hh
Dipole field [T]	8.33		20	16 (20)
Magn. Aperture [mm]	56		40	40
Arc fill factor [%]	79		79	79
Straight section	8x0.5km			16.8km
Total length	26.7km			100(83)km

- Need to determine overall layout
  - LHC-type with 12 insertions (1.4km average, pairwise same length)
  - Racetrack-type with two almost straight sections (each 8.4km)

- Fill factors include dispersion suppressors (80.5% in the cell)
- Ambitious magnet strength goal 16T (Ni_3Sn) or 20T (with high temperature superconductor)
- Ambitious aperture goal

Beam Parameters

	LHC	HL-LHC	HE-LHC	FCC-hh
Bunch charge [10^{11}]	1.15	2.2	1	1 (0.2)
Norm. emitt. [μm]	3.75	2.5	1.38	2.2(0.44)
IP beta-function [m]	0.55	0.15	0.35	1.1
IP beam size [μm]	16.7	7.1	5.2	6.8 (3)
RMS bunch length [cm]	7.55	7.55	7.55	8

- Values in brackets for 5ns spacing
- Same values for 16T and 20T design

- Beam-beam tuneshift for two IP 0.01
- Beta-function at IP scaled with sqrt(E) from one LHC insertion line design with 0.4m (some safety margin)
  - Beam current
  - Bunch charge
  - Emittance as function of bunch charge

Synchrotron Radiation

	LHC	HL-LHC	HE-LHC	FCC-hh
Dipole field [T]	8.33	8.33	20	16 (20)
Synchr. Rad. in arcs [W/m/aperture]	0.17	0.33	4.35	28 (44)
Eng. Loss p. turn [MeV]	0.007		0.2	4.6 (5.9)
Crit. eng. [keV]	0.044		0.575	4.3 (5.5)
Total synr. Power [MW]	0.0072	0.0146	0.2	4.8 (5.8)
Long. Damp. Time [h]	12.9		1.0	0.54 (0.32)
Transv. Damp. Time [h]	25.8		2.0	1.08 (0.64)

- Values in brackets for 20T magnet field

- Radiation given by beam energy and dipole field
- Leads to damping of the longitudinal and transverse emittance
- Leads to significant power load on the beam screen

Operation

	FCC-hh
Luminosity lifetime [h]	19.1 (15.9)
Turn-around time [h]	5
Optimum run time [h]	12.1 (10.7)
Int. lumi / day [fb^{-1}]	2.2 (2.1)

- Values in brackets for 20T magnet field

- Beam lifetime due to burn-off considered
- Assume to keep transverse emittance proportional to charge
- Assume longitudinal emittance is kept constant
- Average luminosity is about 50% of maximum

Physics Requirements Topics for 2014

- Review the specifications for completeness and identify potential issues, if any
  - E.g. space requirements, L*

- Alternative parameter sets need to be investigated
  - E.g. 5ns spacing (other spacings may be possible)
    - Less background per crossing, but time resolution required in detectors
  - Ultimate luminosity limit
    - Requires detector development
  - Optimisation of average/maximum luminosity
    - Currently about 50%
    - E.g. follow beam burn-off with emittance and beta-function (i.e. constant luminosity)

Baseline Parameters Topics for 2014

- Explore whether additional design drivers and critical issues exist that need to be integrated into the baseline parameter definition.

- Verify that the target parameters appear achievable based on the existing studies, e.g.:
  - Which beam pipe radius is required and what is the magnet aperture?
  - Can 80% of the ring be filled with bunches?
  - Turn-around time

- Define several parameters, e.g.:
  - Which beam-beam separation and mitigation techniques are necessary?
  - RF voltage

Baseline Parameters Topics for 2014

- Explore the possibility to improve the design parameters to reduce the risk, power consumption or cost or to increase the performance. E.g.:
  - Can the beam charge be reduced to minimize synchrotron radiation load and machine protection/ radiation issues?
    - This requires a reduction of the beta-functions at the collision point or an increase in beam-beam tuneshift
    - A fast turn-round is also important to maintain high average luminosity
    - Alternative parameter sets planned
      - e.g. β^*=0.55m, N=0.5x10^{11}, ε=1.1μm

$$P_{synrad} \,\mu\, I \,\mu\, b^* / x \,´\, L \,\mu\, t_{lumi} \,´\, L$$

Baseline Layout Topics for 2014

- What is the overall layout of the tunnel, e.g. racetrack vs. LHC-type or something in between?
- Do we need one or two beam dumps/extractions?
- How does the injection layout look like? In particular, how does it constrain the collider layout and integration into the site?
- Do we need short cuts between different parts of the tunnel for feedback or other purposes?
- Is a single tunnel or a double tunnel better?
- Which is the tunnel diameter(s)?
- Where are shafts located?
- The maximum acceptable sector length and design of the connection between sectors (cryogenics, magnets, …)

Baseline Layout Topics for 2014

- For the layout definition an evaluation of the design requirements and a first lattice design is essential for all relevant parts of the machine. In particular:
  - Arcs
  - Collimation
  - Experiment insertions
  - Extraction and injection
  - Other lines (RF, reserve experiments, short straight section bends for racetrack)
  - Integration of the lattices and verification of the performance of the combined system including intensity and loss related limitations

Arc Fill Factor and Beta-function

- Current first assumptions:
  - Same arc fill factor as in LHC
    - 80.5% in the regular arc cell
    - 79% including the dispersion suppressors
  - Can use the same cell layout and phase advance
    - Scaling all lengths in a cell one finds

More in Bernhardt's talk

$$\frac{Ea}{b^2 B_{poletip}} = const \ \text{Þ} \ \ b \, \mu \sqrt{\frac{Ea}{B_{poletip}}}$$

- Cell length (and beta-function) about 1.6 times longer than in LHC
  - Magnet aperture is important

Insertions

- Two main experiments
- Two additional experiments
- Injection insertion
- Extraction insertion
  - Do we need two?
- Two collimation insertions
  - Is this a good number?
- RF insertion
  - Can this be combined with some other line?

- Total 9
  - But some uncertainty

Racetrack vs. LHC-type layout

- For LHC-type layout can adjust length of insertions pairwise
  - Assumed an average of 1.4 km for insertions
- Can combine more than one insertion into a single straight section
  - SSC had racetrack with 4 experiment/utility lines per side
    - Separated by small arcs
    - Local compensation of experimental insertion chromaticity
- We need to review the length requirements for our insertions
  - SSC assumed 4x2.4km per side (at 40 TeV cms)
  - We need first order design
- We need to then put them together
  - Check which is the best way

Insertion Length

- Current first assumption:

$$b \mu L_{whatever} \mu \sqrt{E}$$

- In this case the same technology can be used
- Optics design is simply scaled but with same difficulty
  - Second order differential equation
  - Example: transverse separation by kickers

$$\mathrm{D}x_1 = \tfrac{1}{2} const \frac{B}{E_1} L_1^2 = \tfrac{1}{2} const \frac{B}{(E_1 / E_0) E_0} \left(\sqrt{E_1 / E_0} \right)^2 L_0^2 = \tfrac{1}{2} const \frac{B}{E_0} L_0^2 = \mathrm{D}x_0$$

- Smaller bams make some difference
- Using LHC insertions of a bit more than 500m, one finds 1400m
  - But different technologies
  - Collimation scales different

Baseline Injection Topics for 2014

- From where and in which sequence will the beam be injected?
  - LHC, 100km ring, SPS, …

- What are the beam energy, emittance and other key parameters?

This requires addressing:

- The lowest energy accessible with the magnets (and power supply). With first consideration of potential field quality, dynamic aperture, mitigation techniques, speed of the ramp.
- The beam stability at injection (collective effects and their mitigation, in particular impedance and feedback)
- Injection sequence, how many bunches can be injected at once

Conclusion

- Let us start the technical discussion with the lattices today
- Other subjects will be discussed in subsequent meetings
  - Try to focus on one subject at a time
- Aim for a meeting every other week
- Need to review the time slot
  - Conflict with LHC meetings
  - Choose another day, same time?