Review of *FCC-hh* injection energy

CERN, 16 October 2015

Review Charge & Introduction

Michael Benedikt and Frank Zimmermann

Review Motivation

FCC Baseline: 3.3 TeV using LHC with 5x ramp rate

A lower injection energy may degrade the magnet field quality (persistent currents), will imply a larger beam size (aperture), and also result in enhanced sensitivity to the beam-pipe impedance (res.-wall instability).

On the other hand, **a higher injection energy** will further aggravate machine protection issues (5MJ → limiting the beam transfer to fewer bunches).

A lower injection energy, of ~1.5 TeV, would allow injecting from a faster cycling SC accelerator in the SPS tunnel, or from a super-ferric ring in the LHC tunnel.

Review Goals

- **Determine the minimum reasonable injection energy and impact on collider design**
- **Determine the maximum useful injection energy and impact on collider design**
- **Confirm/define injector/collider scenarios** (taking into account existing infrastructure) **to be studied in detail**

Review Members:

Ralph Assmann, Oliver Brüning, Yunhai Cai,

Antoine Daël, Lyn Evans, Wolfram Fischer (Chair),

Valeri Lebedev, Akira Yamamoto

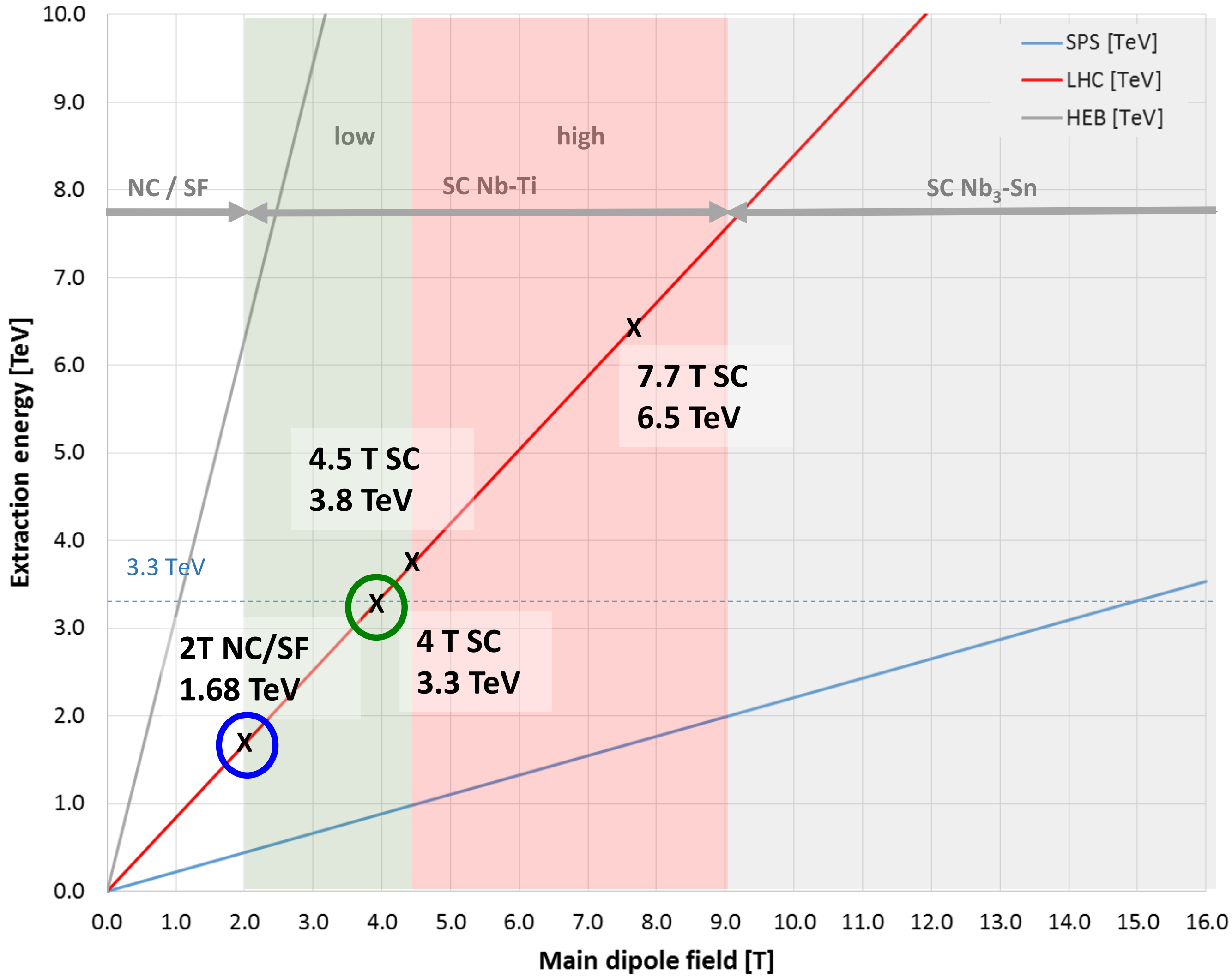
➔ 9 technical presentations in one day meeting

Indico: https://indico.cern.ch/event/449449/other-view?view=standard

Review Agenda

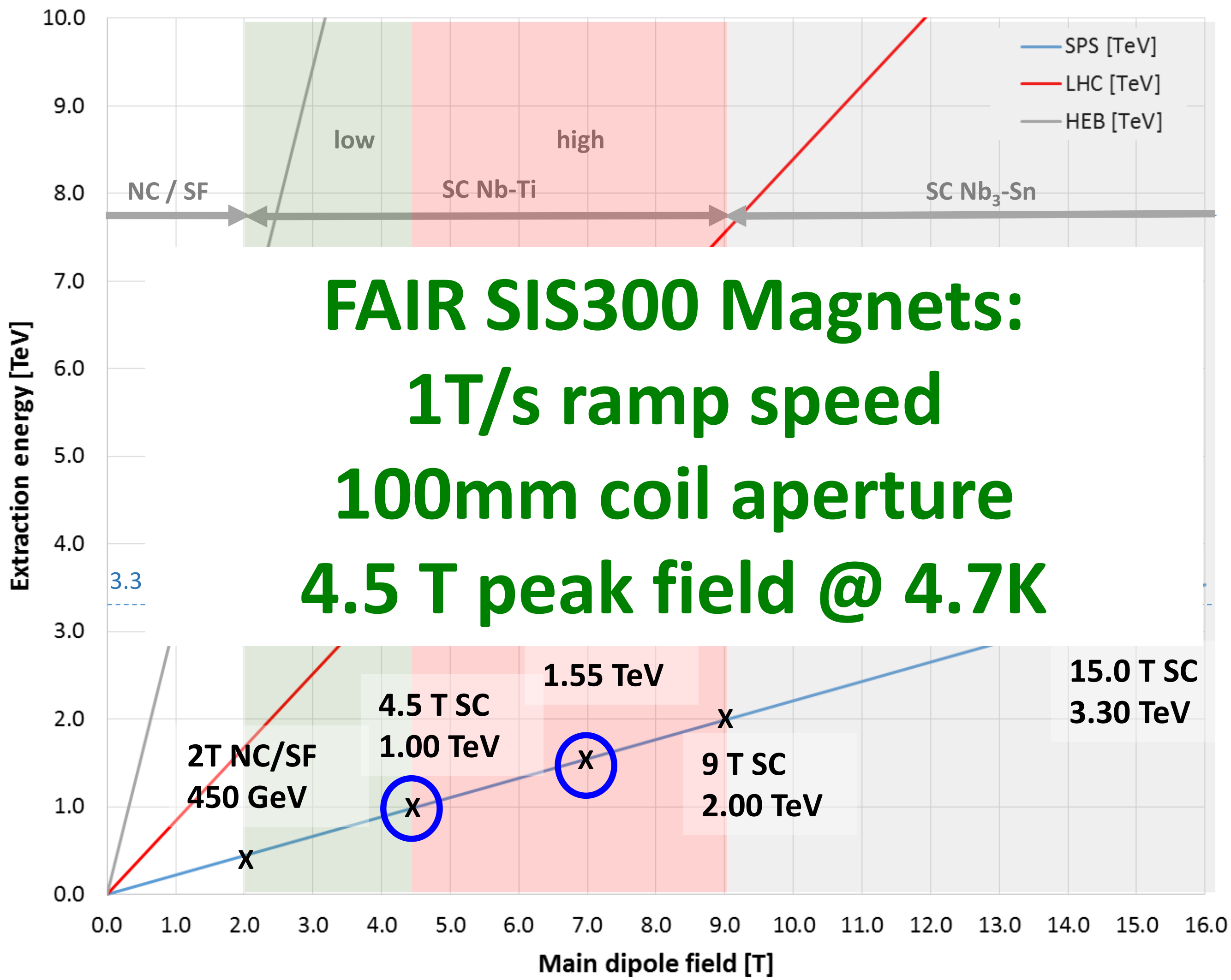
time	length	title	speaker(s)
08:30-08:40	10 min.	Goals of the review	Michael Benedikt and Frank Zimmermann
08:40-09:10	30 min.	Injector options, transfer energies, filling times	Brennan Goddard
09:10-09:40	30 min.	Overview of options, relative merits, parameters, criteria	Daniel Schulte
09:40-10:00	20 min.	Previous studies (SCC, VLHC,..)	Uli Wienands
10:00-10:30	30 min.	Discussion	
10:00-10:45	15 min.	*Coffee break*	
10:45-11:05	20 min.	Transfer & injection process,…	Wolfgang Bartmann
11:05-11:25	20 min.	Beam screen & cooling, vacuum	Paolo Chiggiato
11:25-11:45	20 min.	Impedance budget & limitations	Oliver Boine-Frankenheim
11:45-12:05	20 min.	Feedback systems	Wolfgang Höfle
12:05-12:30	25 min.	Discussion	
12:30-13:45	75 min.	*Lunch break*	
13:45-14:15	30 min.	Injection energy in FCC magnets	Davide Tommasini
14:15-14:35	20 min.	Lattice, dynamic aperture, etc.	Antoine Chancé
14:35-15:00	25 min.	Discussion	
15:00-17:30	150 min.	Executive session	

HEB options in LHC tunnel



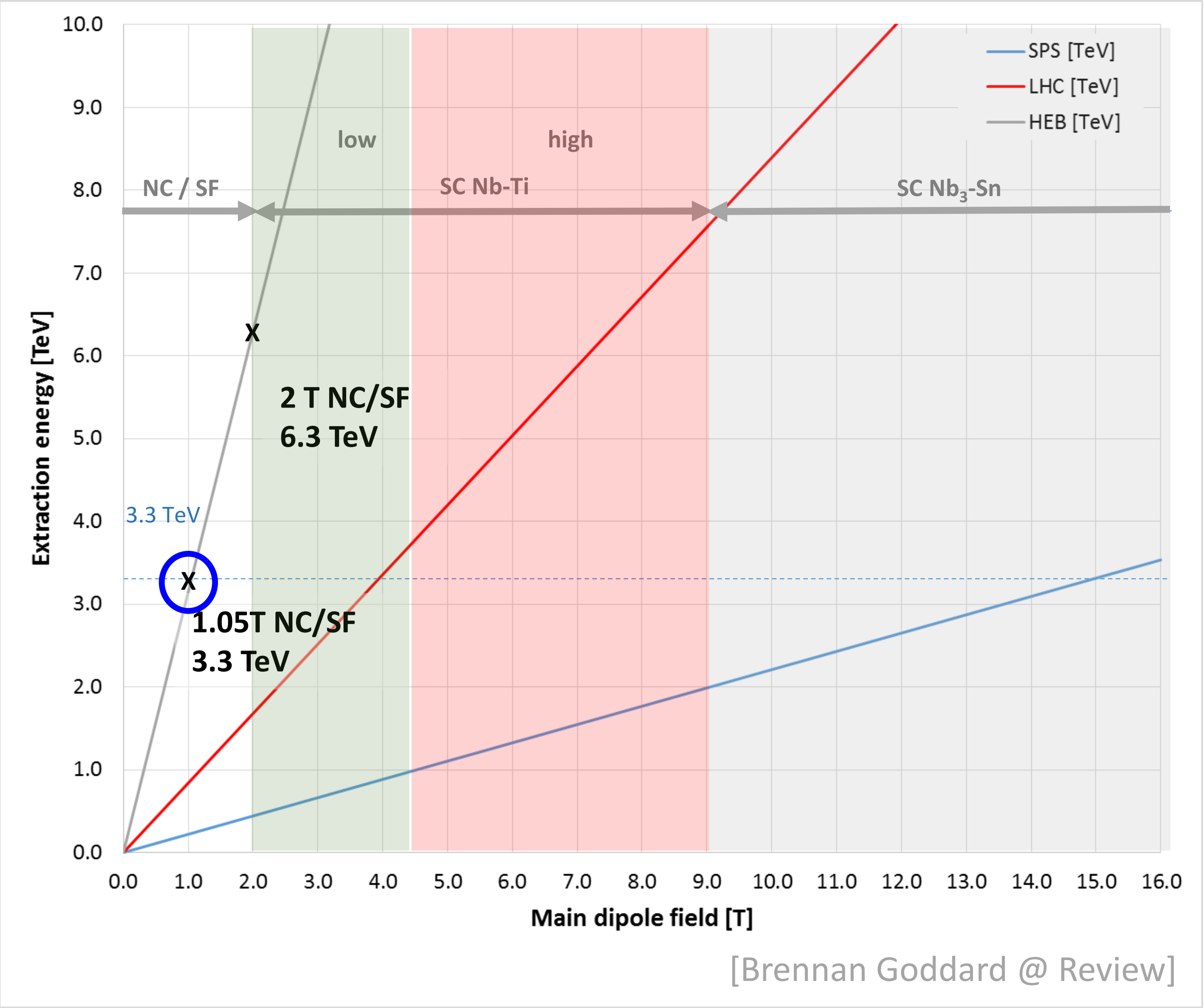
[Brennan Goddard @ Review]

HEB options in SPS tunnel

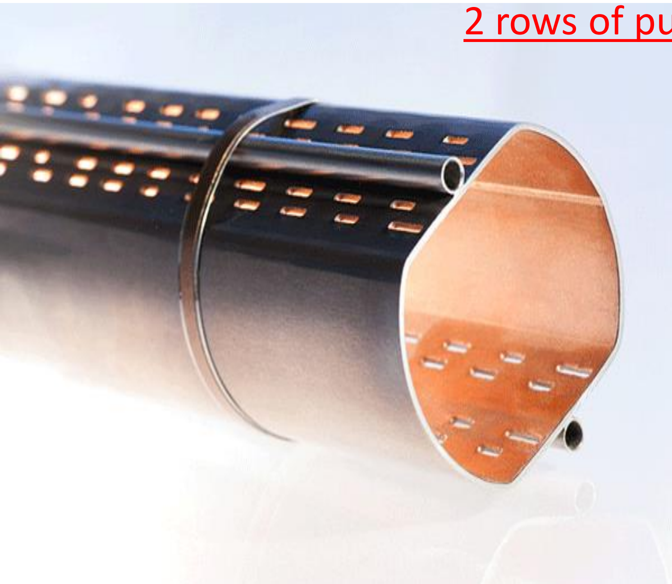


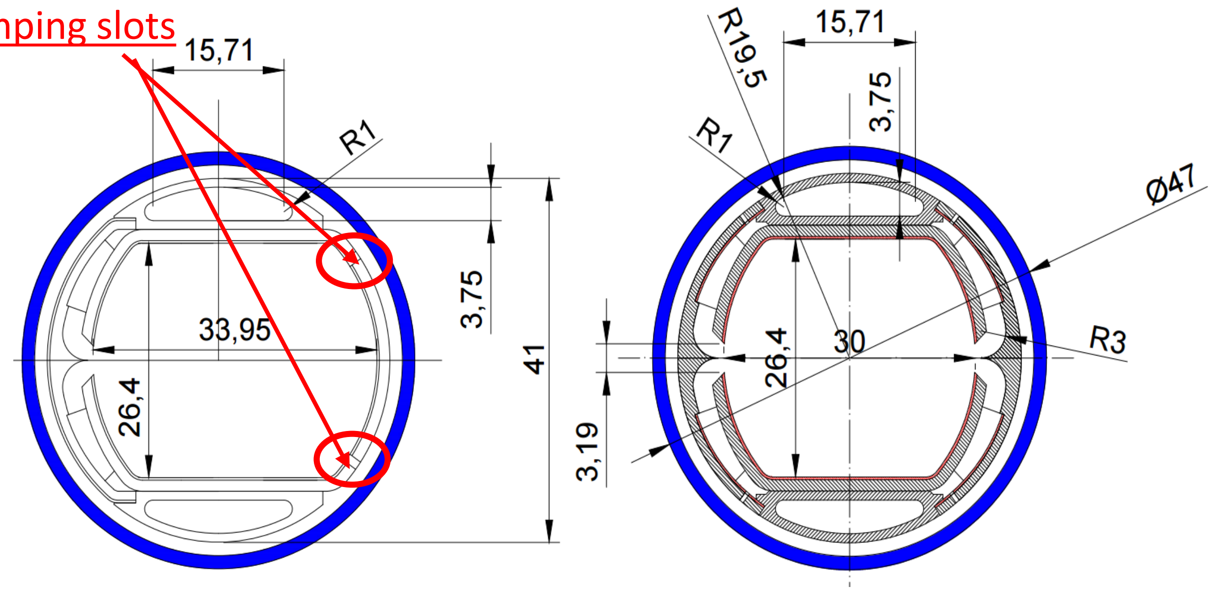
[Brennan Goddard @ Review]

SF HEB options in FCC tunnel

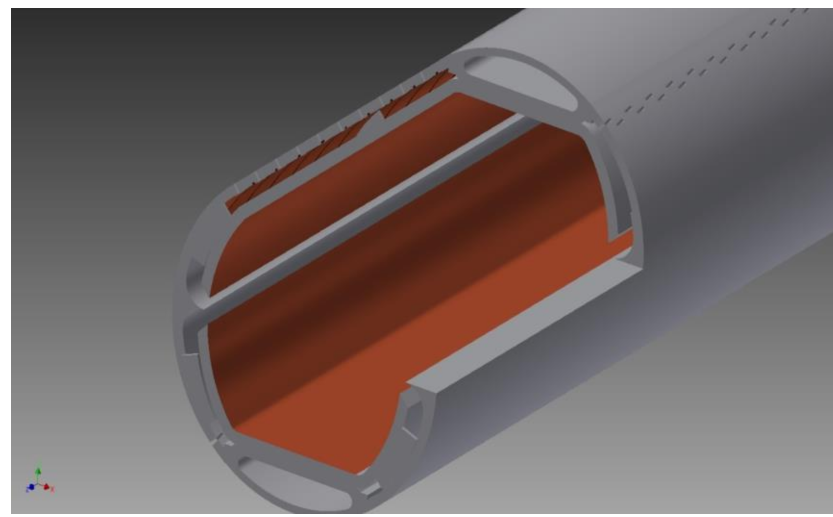


Beam Screen Design Evolution:





1. The 1-slot concept originally presented at the FCC Week in Washington has moved to a more practical version (C. Garion, CERN-TE-VSC, shown here **above**)
2. During an FCC-hh meeting at CERN, it has been noticed that from the **impedance point of view** a symmetric **double slot** would be beneficial
3. We have therefore designed and analysed such a configuration (**above right**)
4. The second slot would also allow the removal of the 2 rows of pumping slots in the beam area required by the 1-slot version, thus **decreasing further the impedance contribution**



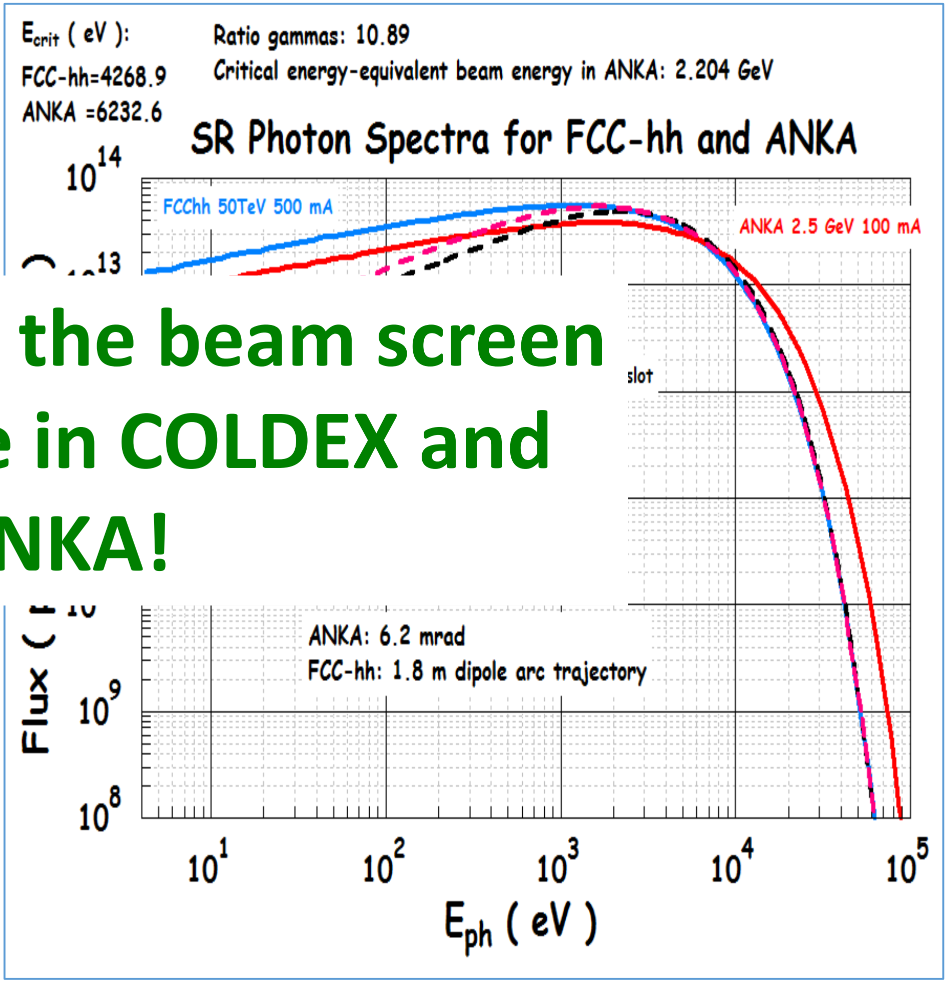
[Roberto Kersevan @ Review]

SR Flux and Power Spectrum:

SR photon flux:

F (ph/s/mA) = $\alpha/2\pi \cdot \gamma \cdot$ 4.1289E+14 $\cdot$ K_F

- Contrary to the LHC, where the SR flux and power are marginal, the FCC-hh is a **powerful light source**; Its SR flux spectrum at 50 TeV is compar
generation lig
- A 1.8 m long a
magnet trajec
on average, to 2 m of BS length in the arc sections of FCC-hh (filling factor), giving the correct 31.5 W/m average SR linear power density



Allows testing the beam screen performance in COLDEX and ANKA!

[Roberto Kersevan @ Review]

Field Quality and Q'

- The FCC doubles the cell length, so the number of cells increases only by a factor 2 w.r.t LHC

  - tune is ~120 → natural chromaticity is ~120
  - 1 unit of b_3 in the dipoles is ~80 units of chromaticity

→ 1/10 units of b_3 corresponds to 8 chromaticity

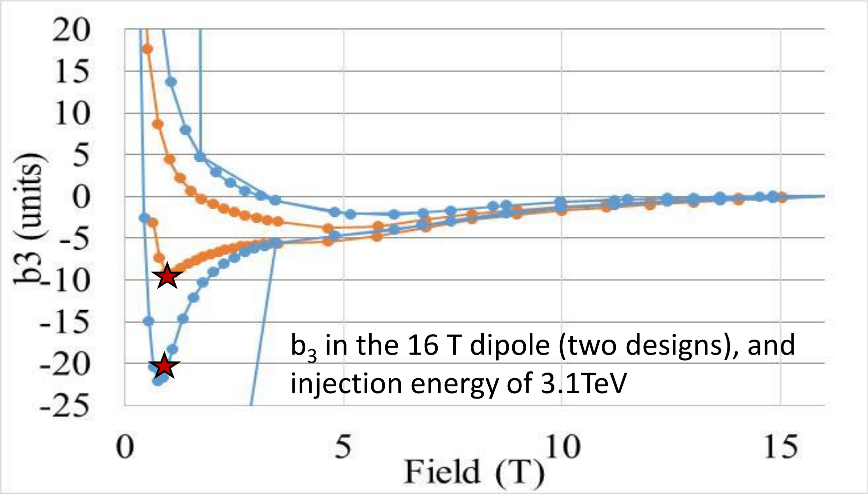
1) **can we really be reproducible at 1/10 units of B_3 (Injection field)?**
2) **do we need it ?**

[D. Tommasini @ Review]

Field Quality and Q’

- Two designs of 16 T, 50 micron filament, if we inject at 1 T we are at penetration field ☺
- From 10 to 20 units of persistent current
  - Chroma swing of 800 to 1600 units, but stable working point for injection
  - Compensation schemes or smaller filament or design can reduce this

[D. Tommasini @ Review]



➔Injection energy of 1.5TeV might be feasible!

Field Quality and Q'

- In the LHC dipoles we have 1-0.5 units of b_3 snapback, giving a chroma swing of 20-40 units in ~10 s
- In FCC twice the sensitivity, and more persistent currents
  - Decay and snapback in Nb_3Sn magnets to be investigated, could be critical
  - Lower energy would give larger decay and snapback?
- Intense program measurement on 11 T, QXF, and 16 T when available, is needed
- More measurements at lower energy on a LHC dipole desirable
- It would be interesting to have an MD in the LHC injecting at 230 and 340 GeV
  - Very complex , to be checked with operation, injection and transfer
  - Would allow to check many issues
  - Just before LS2?

[D. Tommasini @ Review]

Observations from other presentations:

- **Impedance: No minimum injection energy identified based on impedance related aspects and beam stability considerations**
- **Beam Transfer: SPS to FCC → more design freedom and lower rigidity → can avoid SC lines → 1.55TeV within reach**
- **Optics: RMS beam size and thus the required magnet aperture requirements scale with $1/\gamma^{1/2}$ but injection energy above 1.5 TeV still looks OK.**
- **Optics: For a given triplet design, the β* at the IP needs to be increases if the injection energy is lowered below 3.3 TeV. But, should be possible to have optics with enlarged β***
- **Optics: Field Quality, required correction circuits and DA might be a concern and need to be analysed in more detail**
- **Feedback: probably need several system, low injection energy OK**

Review Conclusions: Charge replies

- **Maintain 3.3 TeV as the baseline injection energy.**

  With this baseline:
  - **The dynamic energy range in FCC-hh is 15x (Tev: 7, HERAp: 23, RHIC: 10, LHC = 16).**
  - **The LHC is usable as injector.**
  - **Transfer is possible.**
  - **A design for a beam screen exists with acceptable impedance.**
  - **Instabilities at FCC-hh injection can be controlled with a damper.**
  - **The dynamic aperture is probably sufficient (limited knowledge of field errors).**
- **Determine the minimum reasonable injection energy and its impact on collider design:** The minimum injection energy considered should be 450 GeV, allowing injection directly from the SPS.
- **Determine the maximum useful injection energy and its impact on collider design:** The maximum useful injection energy is approximately 6.5 TeV, allowing injection from the existing LHC.

Review Conclusions:

- **Confirm or define injector/collider scenarios to be studied in detail, taking into account existing infrastructure:**
  The main scenarios to be studies should be:
  - The present baseline scenario with 3.3 TeV beam energy
  - Injection from the SPS at 450 GeV beam energy
  - Injection from a new injector in the SPS tunnel at 1.2 TeV beam energy
  - Injection from the LHC at 6.5 TeV beam energy.

- **Recommendations (sub-selection):**
  - The 5 MJ limit on the injected beam energy should be complemented by considerations on power absorption in case of failures and survival of components.
  - Test the new beam screen in existing machines, like ANKA and the LHC.
  - Review the DA criterion of 12 s light of the LHC experience.
  - Measure LHC magnetic field errors for a cycle needed for low energy injection (i.e. ≤ 450 GeV) and fast ramps and etermine experimentally the lowest possible injection energy in the LHC .
  - Study electron clouds with 5 ns bunch spacing for the ultimate FCC-hh parameters

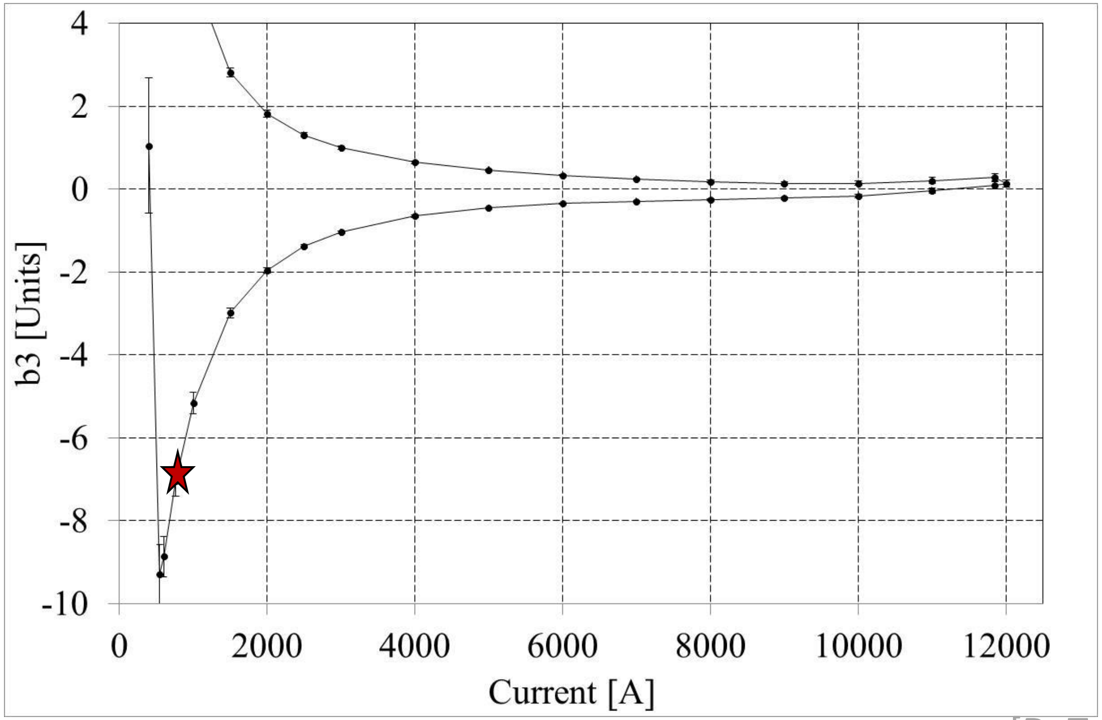
Review Conclusions:

- **Keep 3.3 TeV injection energy as baseline**
- **1.5 TeV injection energy very interesting:**
  - Compatible with all three injector options (SPS, LHC and FCC booster)
  - Can profit from the LHC to make real measurements on the possible larger energy swing by injection at lower energy than 450 GeV

Reserve Transparencies

Field Quality and Q'

In LHC we inject with 7 units of persistent current, above penetration field



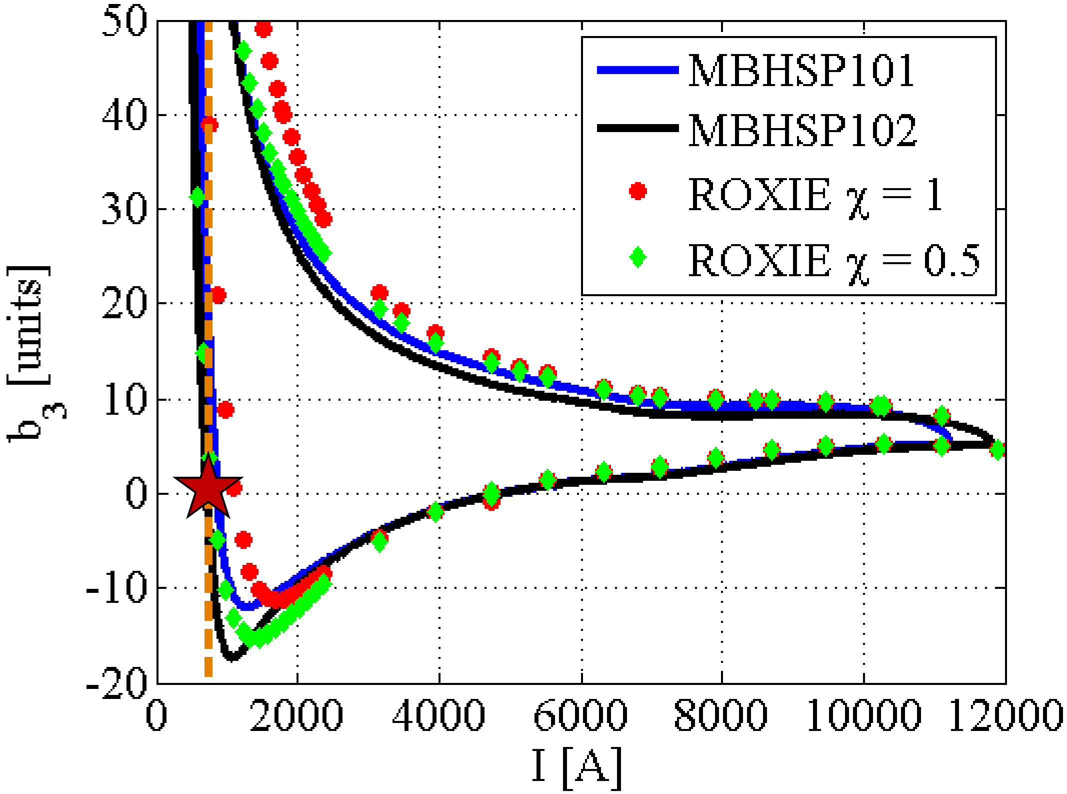
[D. Tommasini @ Review]

b_3 in the main LHC dipoles, and injection energy at 450 GeV

Field Quality and Q’

If we were using the 11 T for the whole LHC, we would have 10-15 units of persistent current but we would inject below penetration field

[D. Tommasini @ Review]



b_3 in the 11 T dipole, and injection energy at 450 GeV