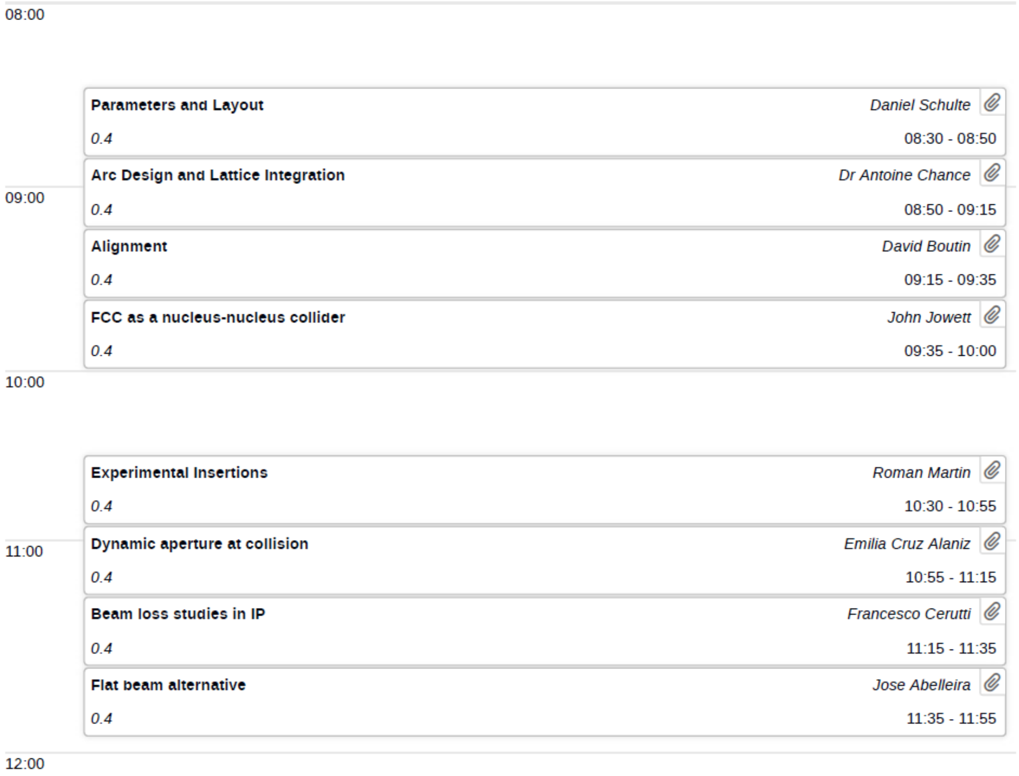
The European Circular Energy-Frontier Collider Study (EuroCirCol) project has received funding from the European Union's Horizon 2020 research and innovation programme under grant No 654305. The information herein only reflects the views of its authors and the European Commission is not responsible for any use that may be made of the information.

Summary FCC-hh machine design

B. Dalena on behalf of the FCC-hh machine design team

FCC week Amsterdam

FCC-hh machine sessions (Tue)



08:00

Parameters and Layout *Daniel Schulte*
0.4 08:30 - 08:50

Arc Design and Lattice Integration *Dr Antoine Chance*
0.4 08:50 - 09:15

09:00

Alignment *David Boutin*
0.4 09:15 - 09:35

FCC as a nucleus-nucleus collider *John Jowett*
0.4 09:35 - 10:00

10:00

Experimental Insertions *Roman Martin*
0.4 10:30 - 10:55

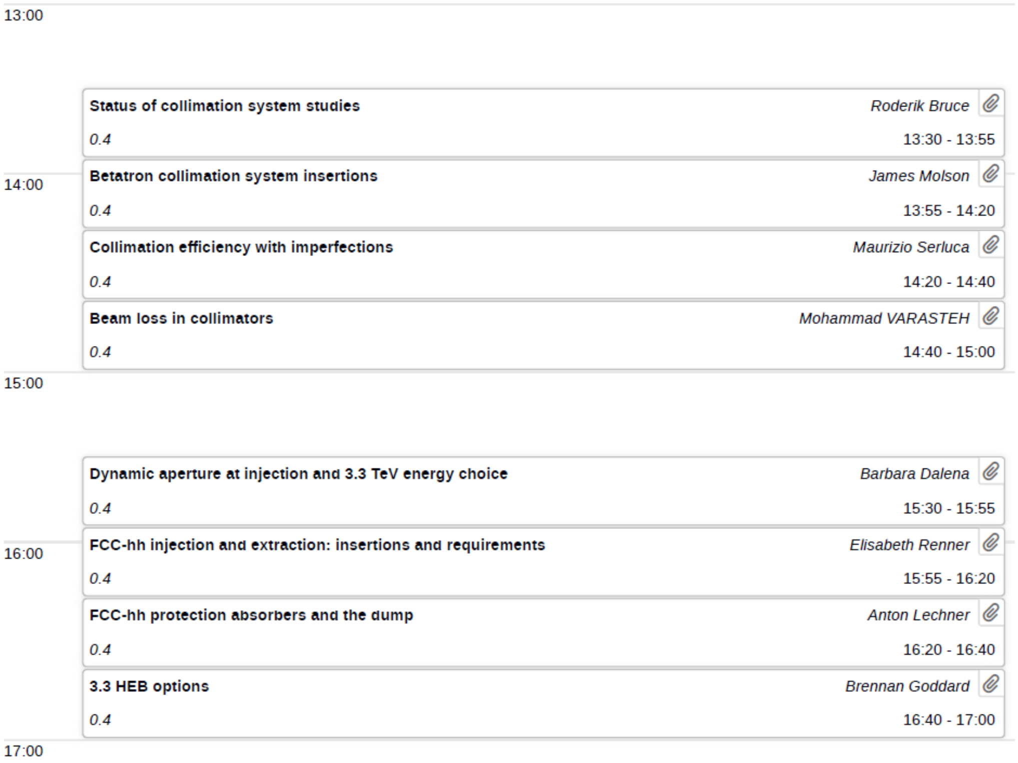
11:00

Dynamic aperture at collision *Emilia Cruz Alaniz*
0.4 10:55 - 11:15

Beam loss studies in IP *Francesco Cerutti*
0.4 11:15 - 11:35

Flat beam alternative *Jose Abelleira*
0.4 11:35 - 11:55

12:00



13:00

Status of collimation system studies *Roderik Bruce*
0.4 13:30 - 13:55

14:00

Betatron collimation system insertions *James Molson*
0.4 13:55 - 14:20

Collimation efficiency with imperfections *Maurizio Serluca*
0.4 14:20 - 14:40

Beam loss in collimators *Mohammad VARASTEH*
0.4 14:40 - 15:00

15:00

Dynamic aperture at injection and 3.3 TeV energy choice *Barbara Dalena*
0.4 15:30 - 15:55

16:00

FCC-hh injection and extraction: insertions and requirements *Elisabeth Renner*
0.4 15:55 - 16:20

FCC-hh protection absorbers and the dump *Anton Lechner*
0.4 16:20 - 16:40

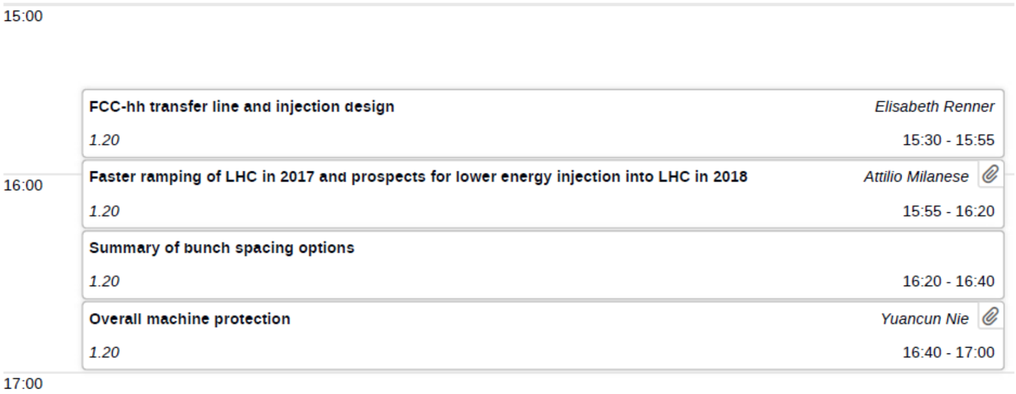
3.3 HEB options *Brennan Goddard*
0.4 16:40 - 17:00

17:00

FCC-hh accelerator

FCC-hh machine sessions (Wed & Thu)

FCC-hh injector and FCC-hh accelerator



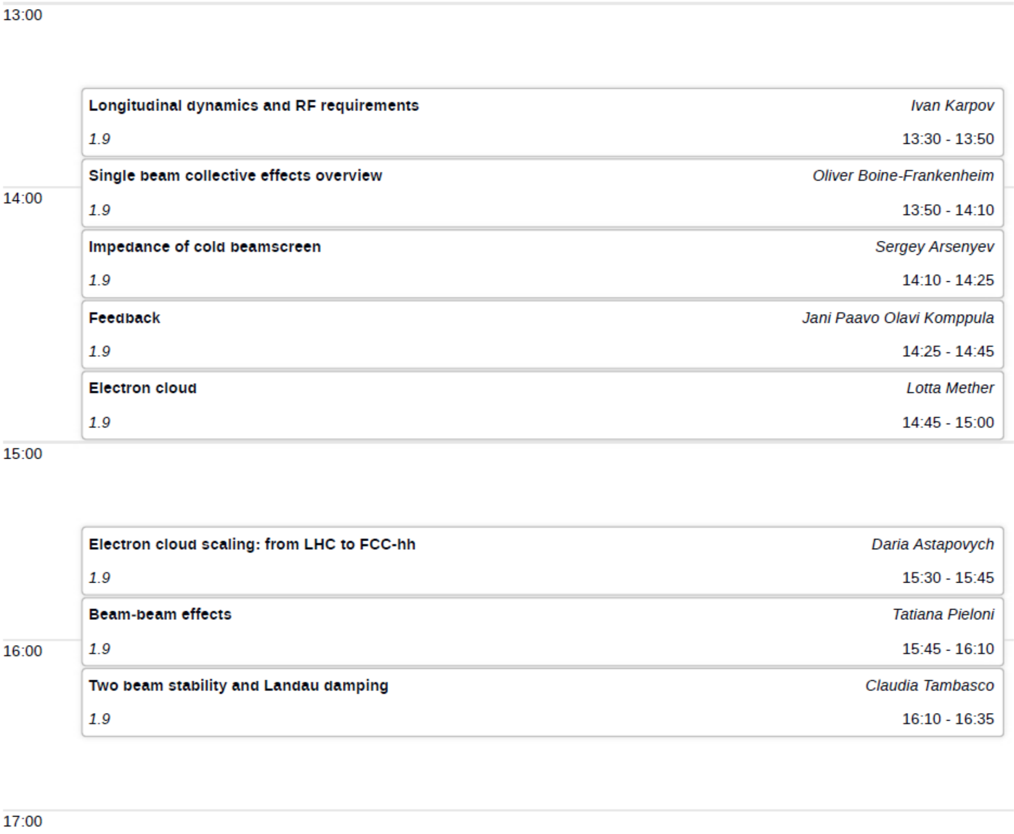
15:00

16:00

17:00

FCC-hh transfer line and injection design	*Elisabeth Renner*	*1.20*	15:30 - 15:55
Faster ramping of LHC in 2017 and prospects for lower energy injection into LHC in 2018	*Attilio Milanese*	*1.20*	15:55 - 16:20
Summary of bunch spacing options		*1.20*	16:20 - 16:40
Overall machine protection	*Yuancun Nie*	*1.20*	16:40 - 17:00

7 sessions, 24 talks



13:00

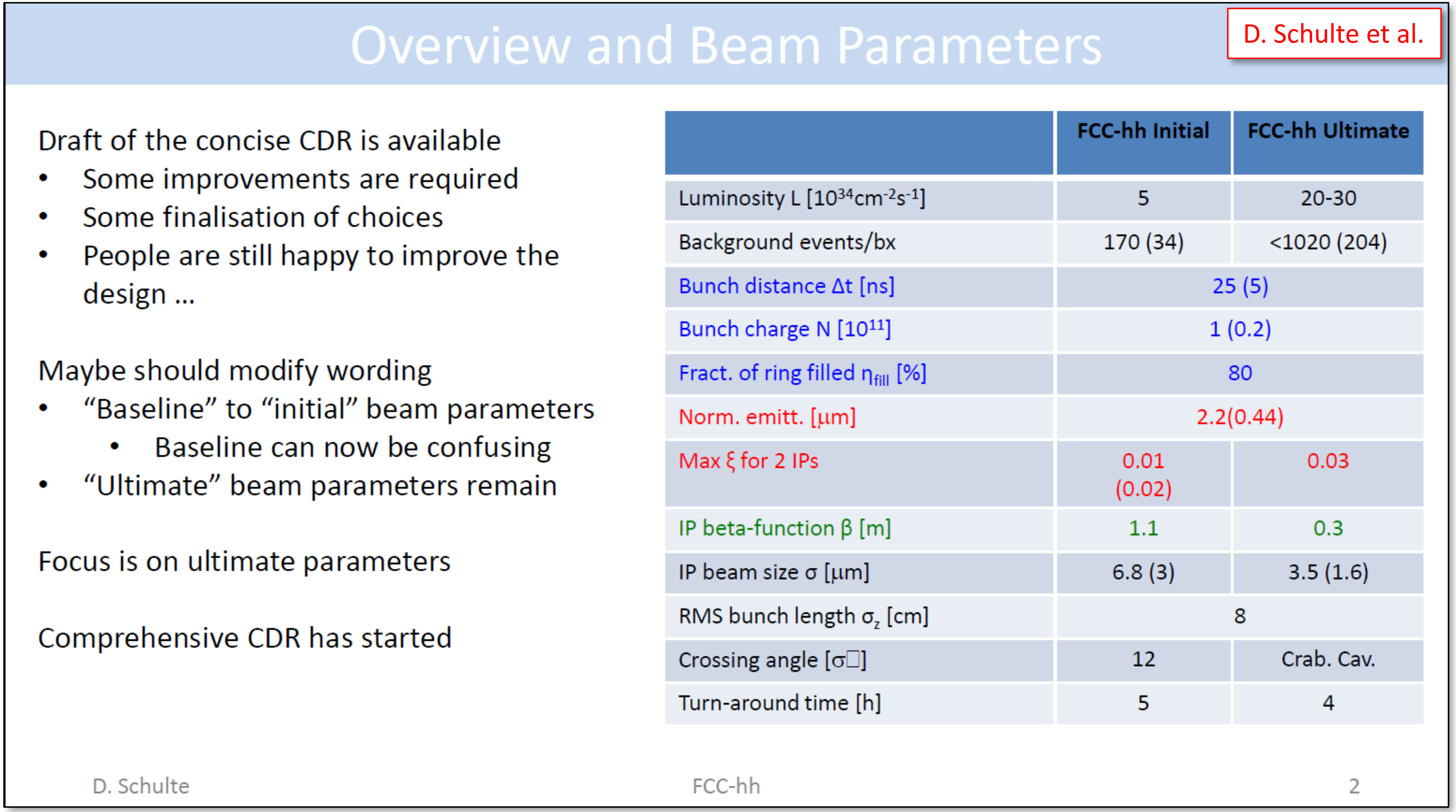
14:00

15:00

16:00

17:00

Longitudinal dynamics and RF requirements	*Ivan Karpov*	*1.9*	13:30 - 13:50
Single beam collective effects overview	*Oliver Boine-Frankenheim*	*1.9*	13:50 - 14:10
Impedance of cold beamscreen	*Sergey Arsenyev*	*1.9*	14:10 - 14:25
Feedback	*Jani Paavo Olavi Komppula*	*1.9*	14:25 - 14:45
Electron cloud	*Lotta Mether*	*1.9*	14:45 - 15:00
Electron cloud scaling: from LHC to FCC-hh	*Daria Astapovych*	*1.9*	15:30 - 15:45
Beam-beam effects	*Tatiana Pieloni*	*1.9*	15:45 - 16:10
Two beam stability and Landau damping	*Claudia Tambasco*	*1.9*	16:10 - 16:35



Overview and Beam Parameters

D. Schulte et al.

Draft of the concise CDR is available
- Some improvements are required
- Some finalisation of choices
- People are still happy to improve the design …

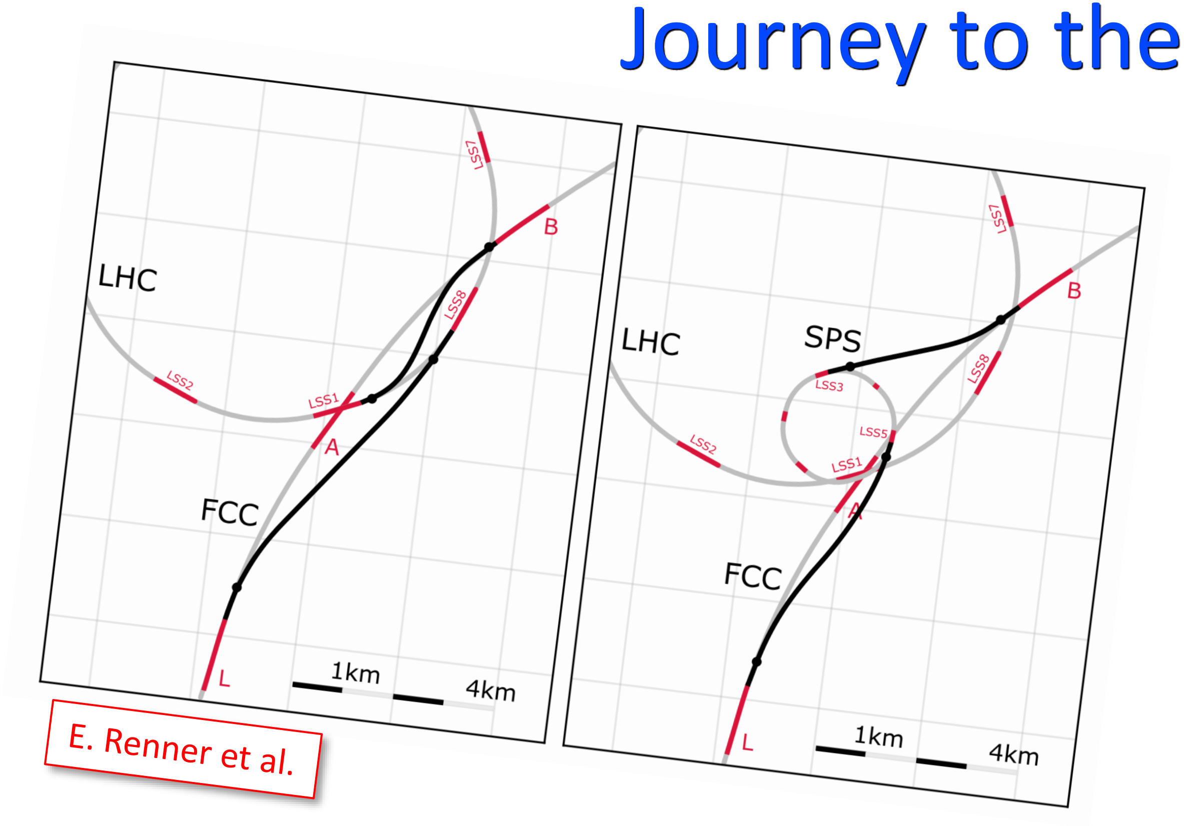
Maybe should modify wording
- “Baseline” to “initial” beam parameters
    - Baseline can now be confusing
- “Ultimate” beam parameters remain

Focus is on ultimate parameters

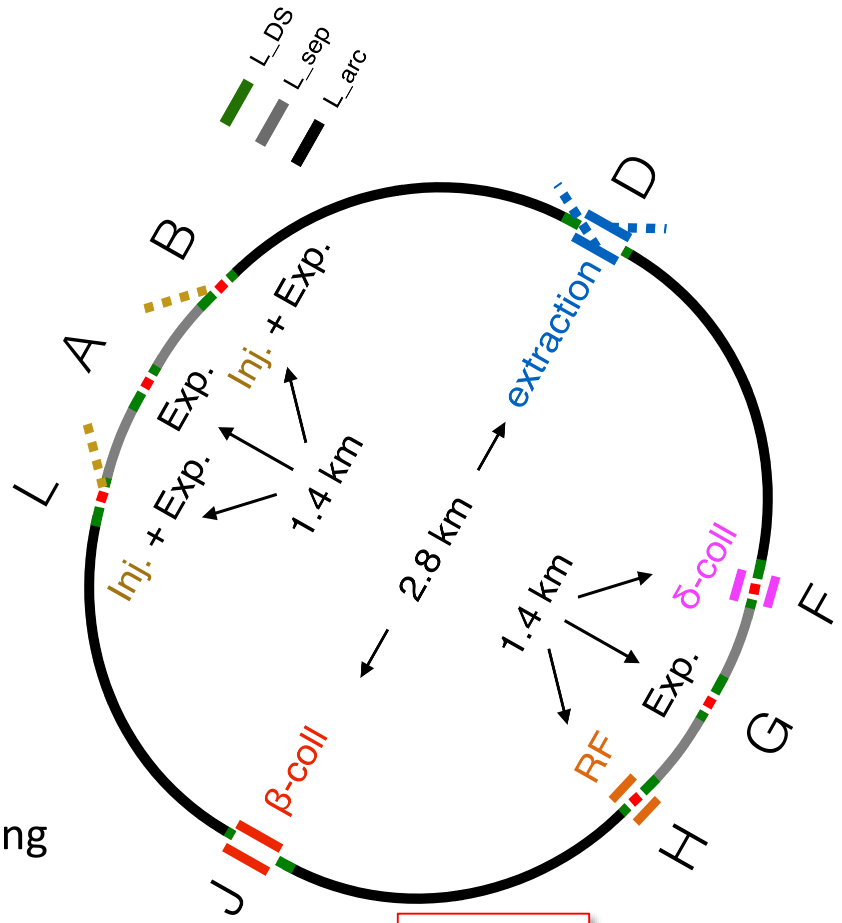
Comprehensive CDR has started

	FCC-hh Initial	FCC-hh Ultimate
Luminosity L [10^{34}cm^{-2}s^{-1}]	5	20-30
Background events/bx	170 (34)	<1020 (204)
Bunch distance Δt [ns]	25 (5)	
Bunch charge N [10^{11}]	1 (0.2)	
Fract. of ring filled η_{fill} [%]	80	
Norm. emitt. [μm]	2.2(0.44)	
Max ξ for 2 IPs	0.01 (0.02)	0.03
IP beta-function β [m]	1.1	0.3
IP beam size σ [μm]	6.8 (3)	3.5 (1.6)
RMS bunch length σ_z [cm]	8	
Crossing angle [σ□]	12	Crab. Cav.
Turn-around time [h]	5	4

Journey to the future



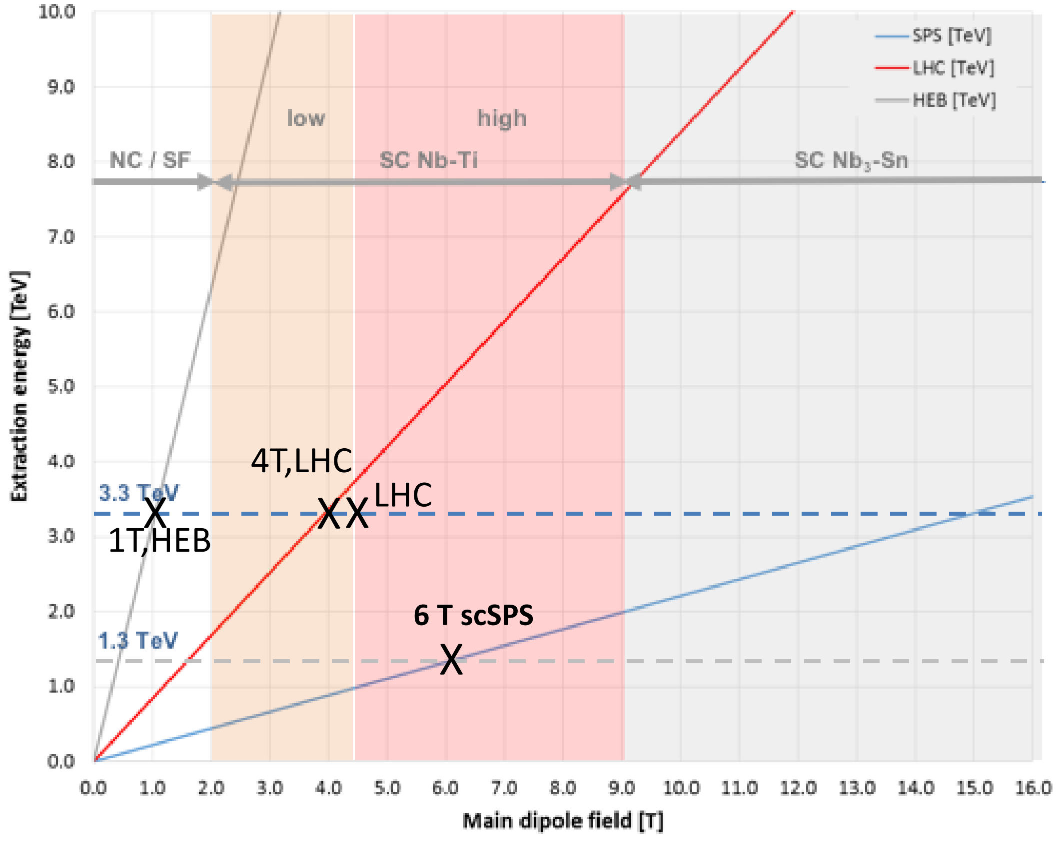
E. Renner et al.



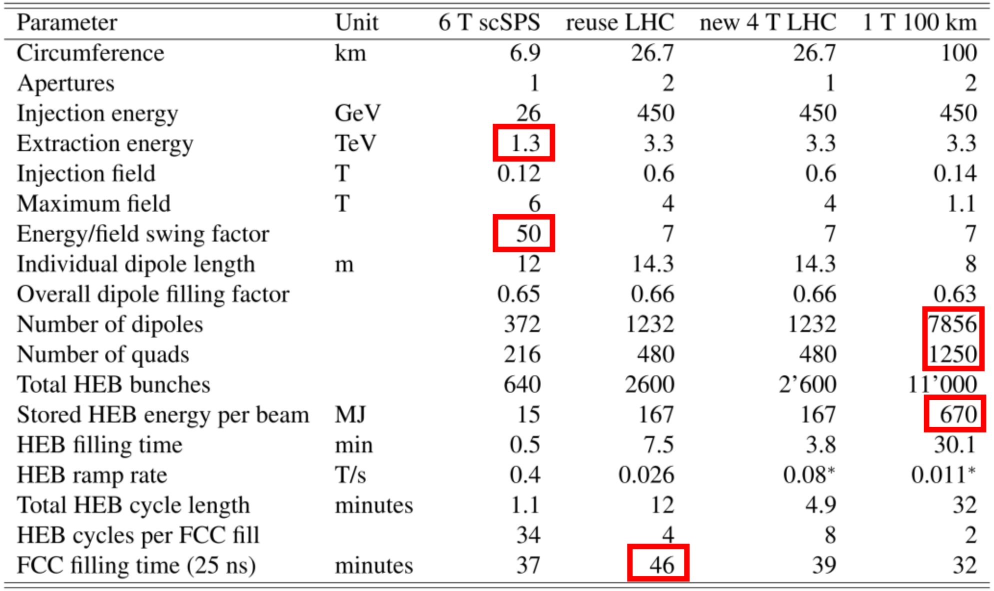
D. Schulte

From FCC-hh injectors to FCC-hh 97.75 km ring

How do will inject in the new ring ?



B. Goddard, W.Bartmann, E.Renner, A.Milanese, M.Solfaroli



Parameter	Unit	6 T scSPS	reuse LHC	new 4 T LHC	1 T 100 km
Circumference	km	6.9	26.7	26.7	100
Apertures		1	2	1	2
Injection energy	GeV	26	450	450	450
Extraction energy	TeV	1.3	3.3	3.3	3.3
Injection field	T	0.12	0.6	0.6	0.14
Maximum field	T	6	4	4	1.1
Energy/field swing factor		50	7	7	7
Individual dipole length	m	12	14.3	14.3	8
Overall dipole filling factor		0.65	0.66	0.66	0.63
Number of dipoles		372	1232	1232	7856
Number of quads		216	480	480	1250
Total HEB bunches		640	2600	2’600	11’000
Stored HEB energy per beam	MJ	15	167	167	670
HEB filling time	min	0.5	7.5	3.8	30.1
HEB ramp rate	T/s	0.4	0.026	0.08*	0.011*
Total HEB cycle length	minutes	1.1	12	4.9	32
HEB cycles per FCC fill		34	4	8	2
FCC filling time (25 ns)	minutes	37	46	39	32

For 3.3 TeV injection energy

- Reuse of existing LHC with 5x faster ramp remains FCC-hh baseline
- Two other alternative ‘simpler’ scenarios to keep as options

scSPS option only valid if 1.3 TeV FCC injection is possible

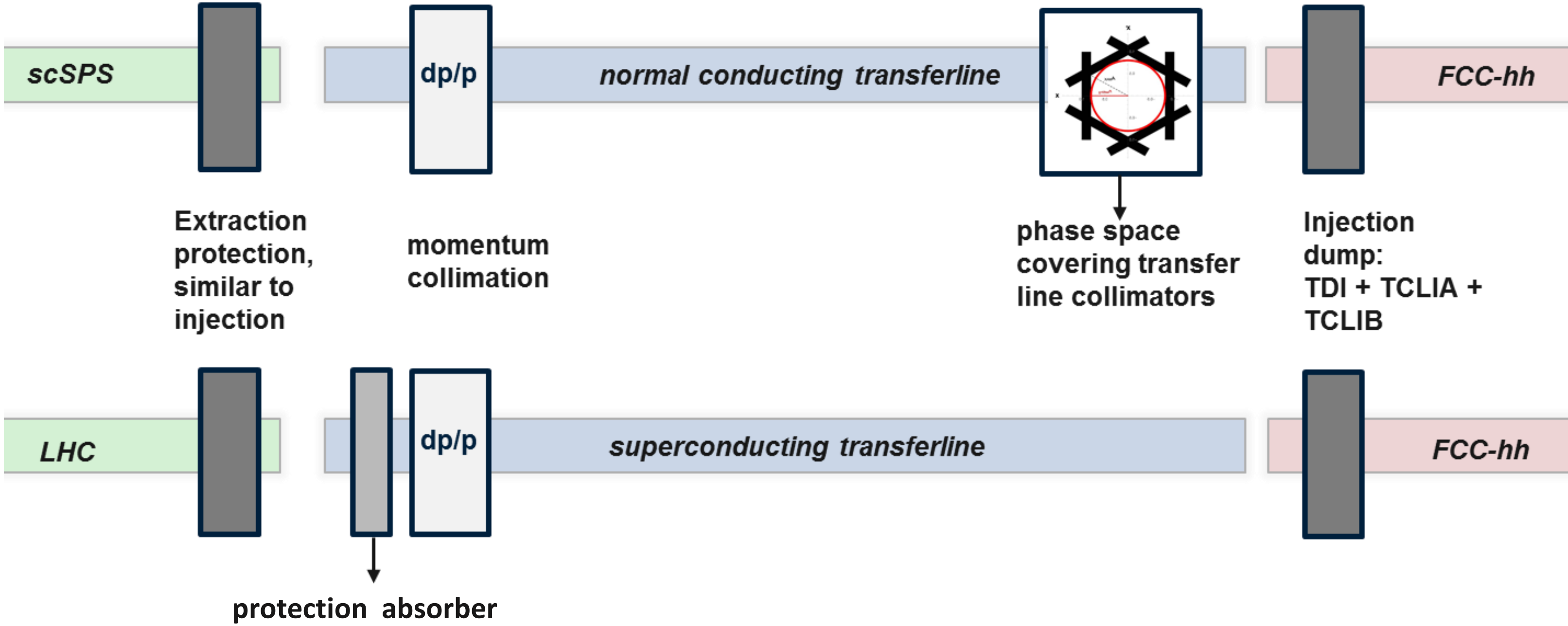
- presently excluded by collider dynamic aperture

Transfer lines design (protection)

New transferline layout

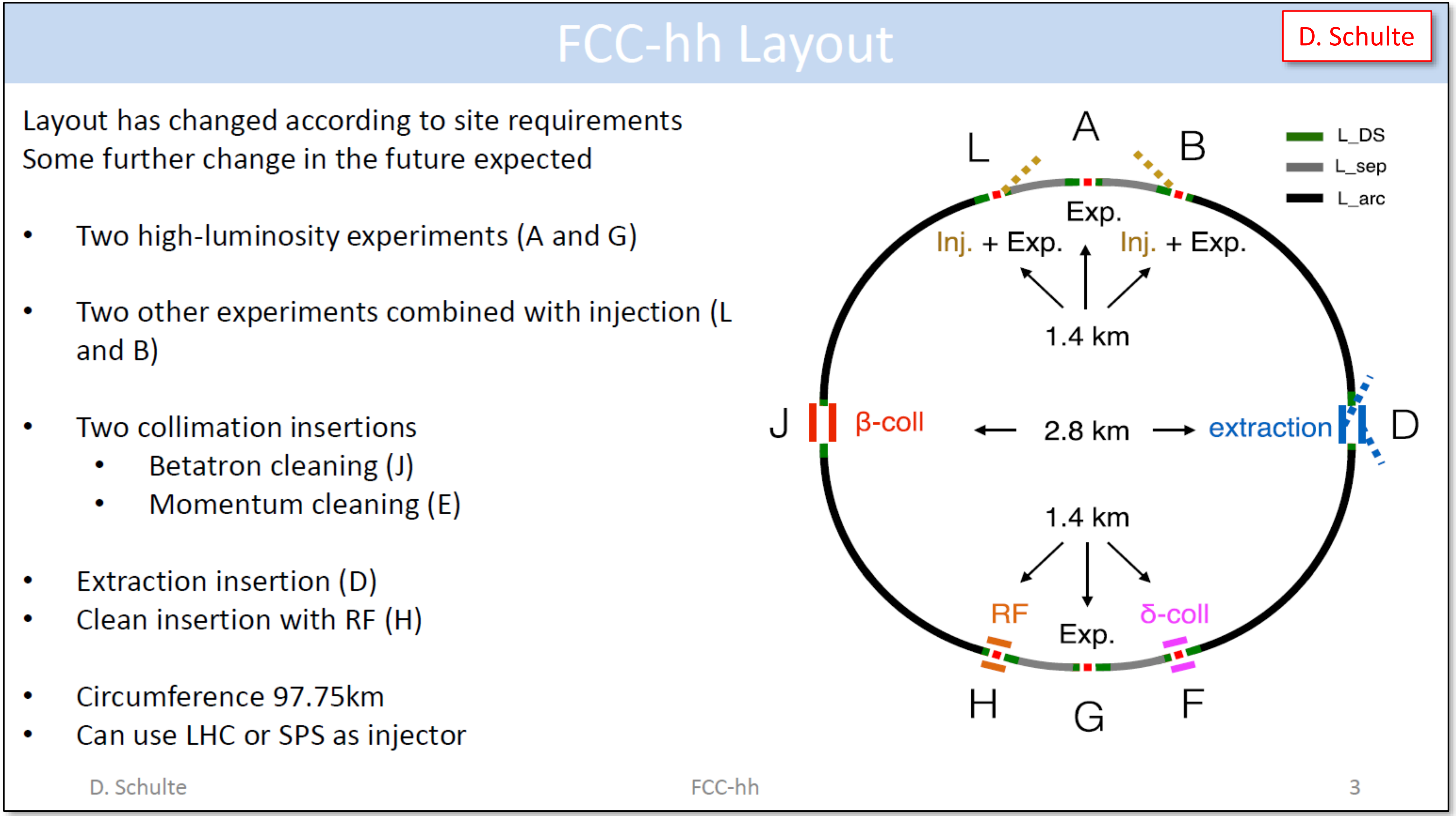
→ longer straight sections at start and end of the TL were necessary for appropriate protection from extraction / TL failures

→ Increased dipole strength (LHC-FCC: 7.2T, superconducting / scSPS-FCC: 1.8T, normal conducting)



E. Renner et al.

D. Schulte



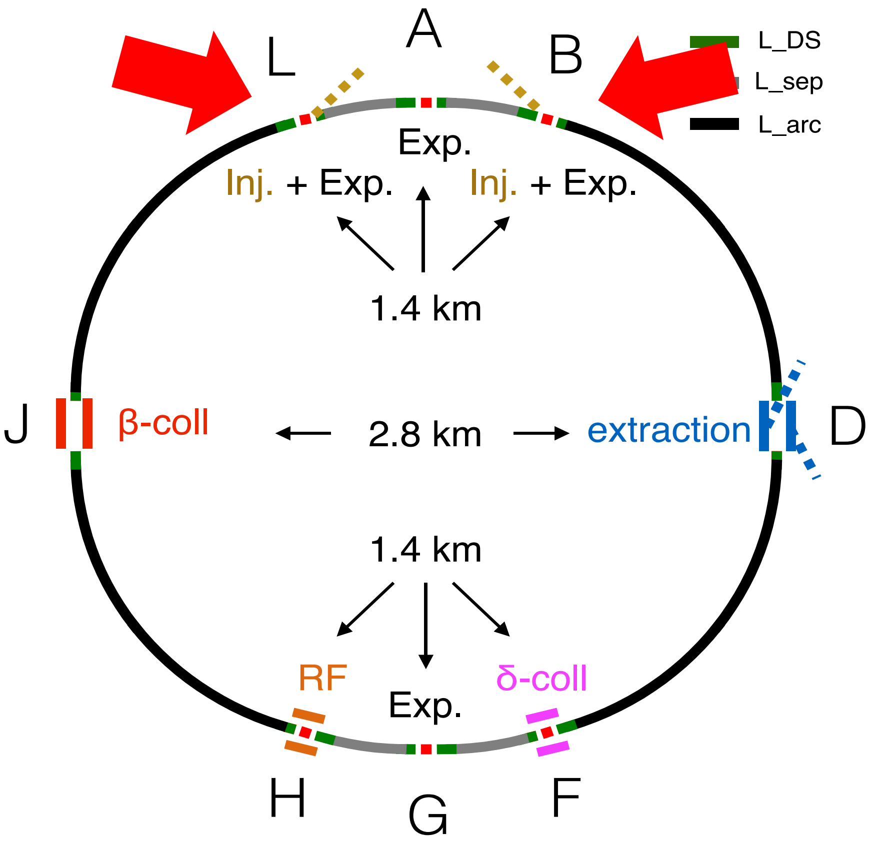
FCC-hh Layout

Layout has changed according to site requirements
Some further change in the future expected

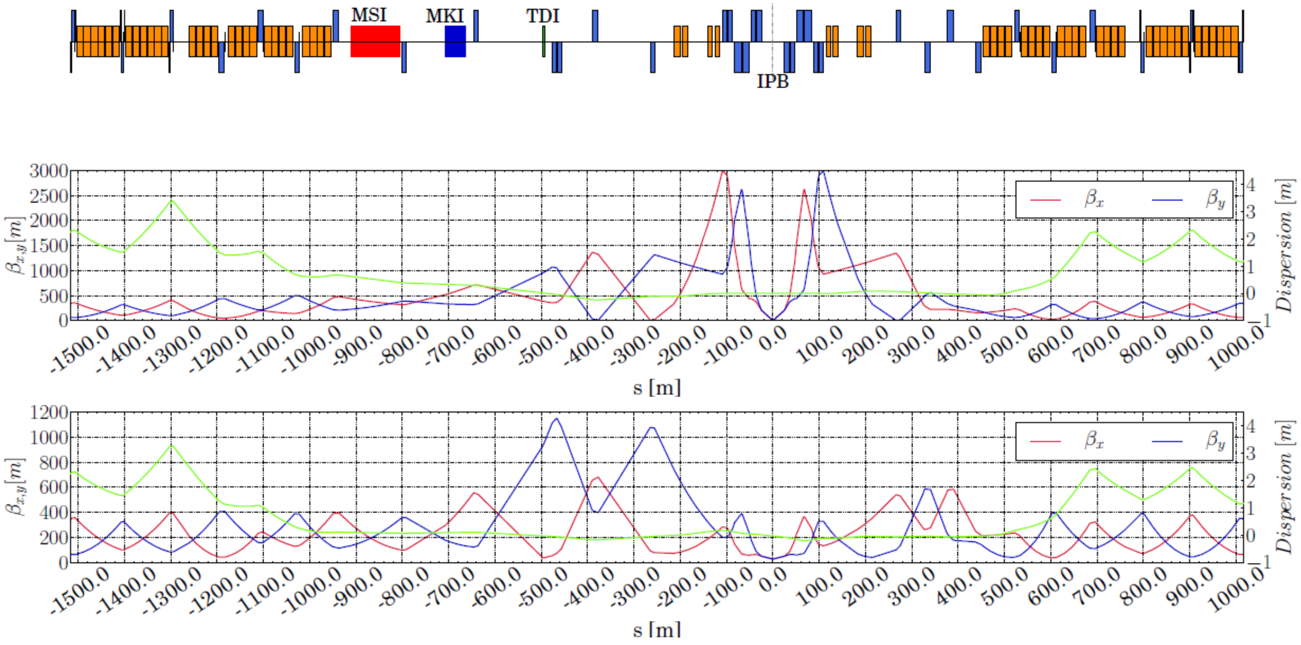
- Two high-luminosity experiments (A and G)
- Two other experiments combined with injection (L and B)
- Two collimation insertions
  - Betatron cleaning (J)
  - Momentum cleaning (E)
- Extraction insertion (D)
- Clean insertion with RF (H)
- Circumference 97.75km
- Can use LHC or SPS as injector

we arrive in L or B let’s turn clockwise…

Injection and low luminosity insertions



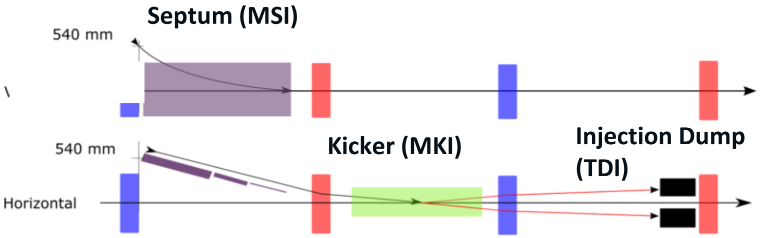
Injection and low luminosity insertions



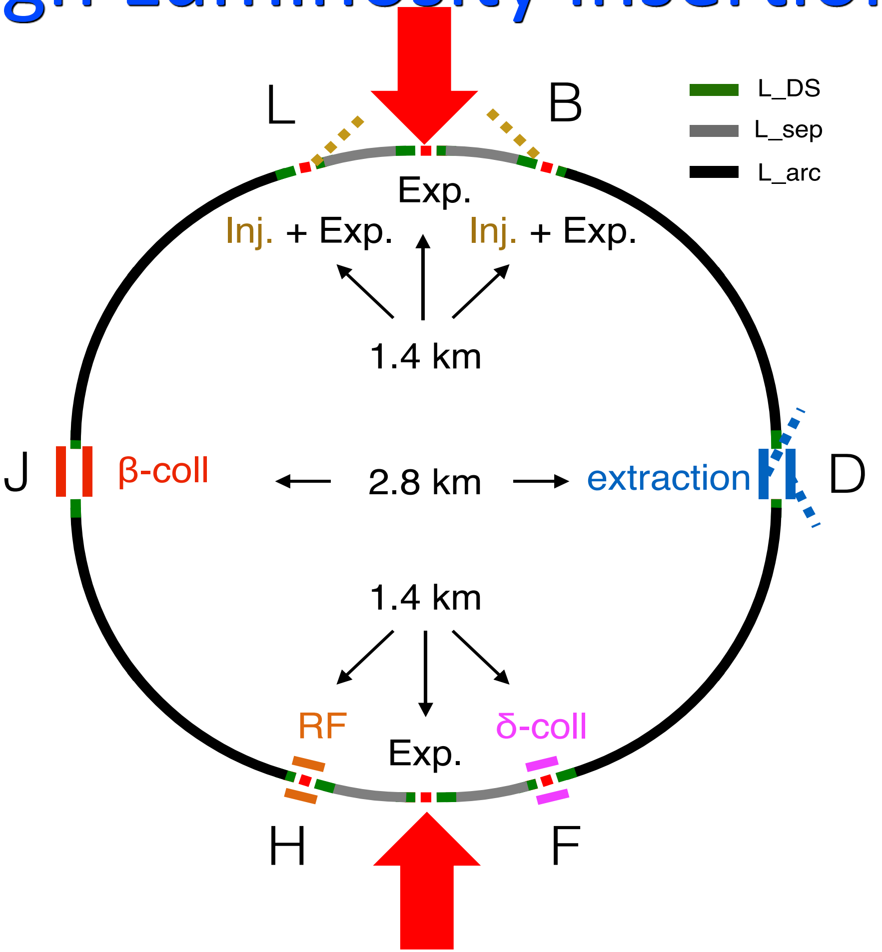
M. Hofer, F. Burkhard, E.Renner

- Low luminosity IRs provide β^*=3.0 m with L^*=25 m
- Luminosity ~ 2 10^{34} $cm^{-2}s^{-1}$
- Triplet lifetime 0.5 ab^{-1}

- 2017 → 2018: Beam size at injection dump (TDI) increased to stay below damage limit of the TDI in case of kicker failure
- Damage limit of injection dump limits injection batch length to 80 bunches

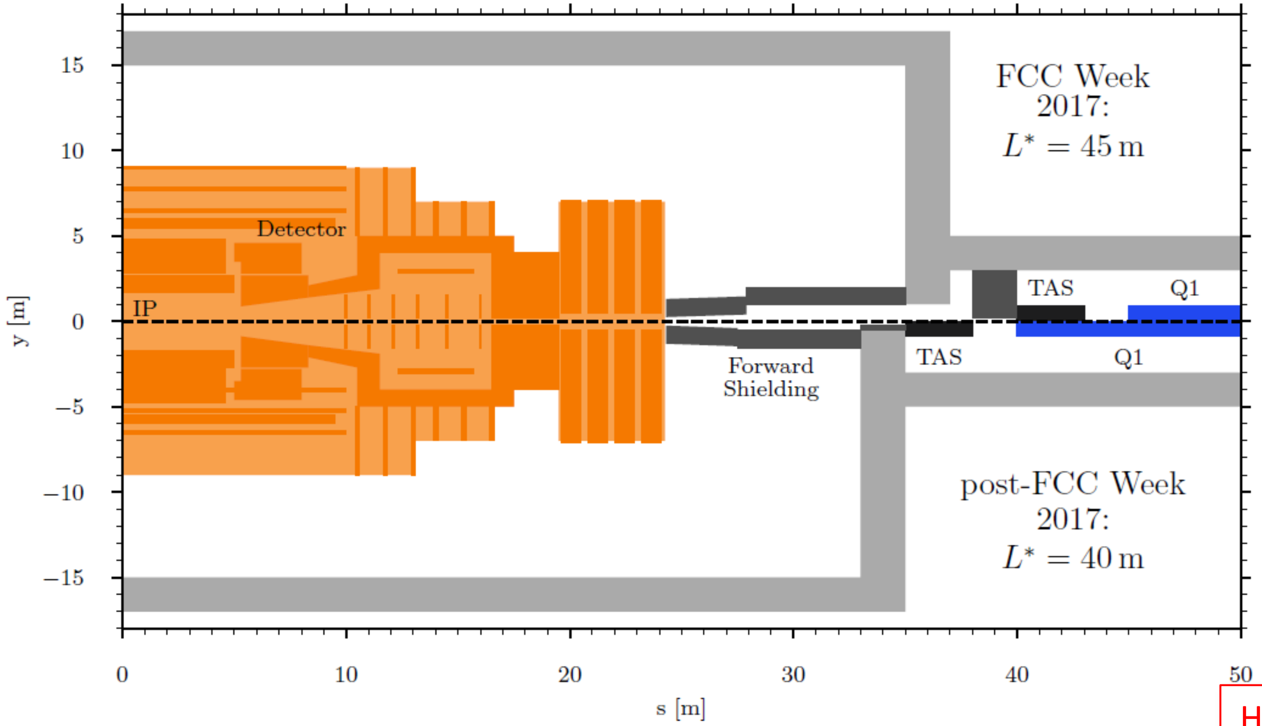


High Luminosity insertions



High Luminosity insertions: machine detector interface

- Changes to **opening scenario** and **forward shielding**



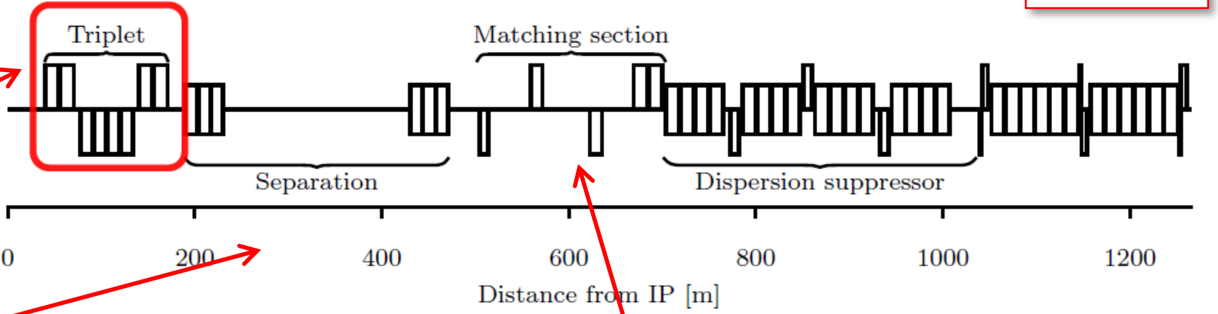
⇒ possible to
shorten L^* to 40 m

H. Da Silva, W. Riegler, R. Martin

High Luminosity insertions

R. Martin

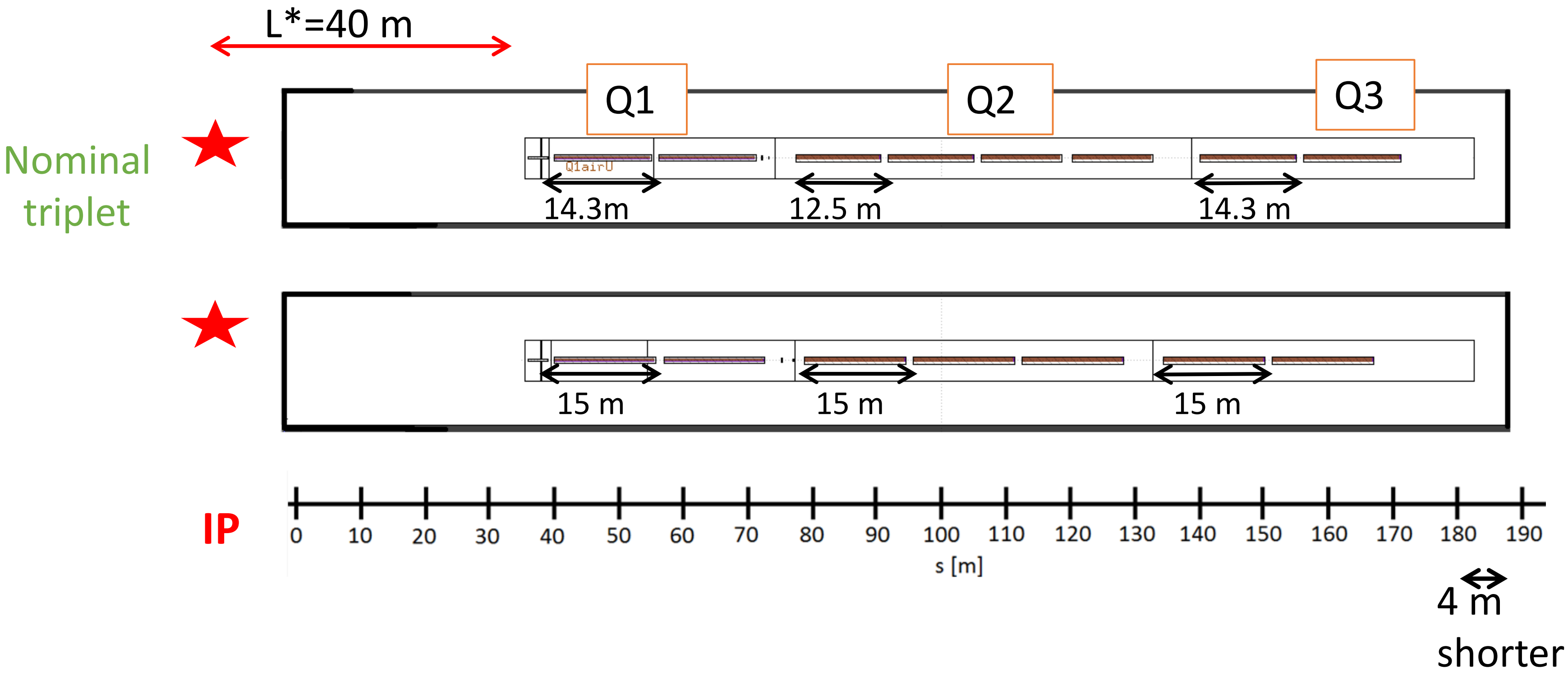
- With new L^* triplet gradients and apertures had to be adapted
- Magnet lengths reduced to fit into 15 m cryostats



- Redesigned to use normal conducting magnets
- Assuming LHC-like magnet designs
- Advantages:
  - Robustness in the highly radiative environment
  - Better field quality

- **Crab cavities** between recombination dipole and first matching quadrupole
- First studies with varying degrees of orbit leakage:
  - Full crabbing at Ultimate parameters: $V_{\text{crab}} = 12.0\,\text{MV}$
  - Full crabbing at $\beta^* = 0.15\,\text{m}$: $V_{\text{crab}} = 18.5\,\text{MV}$
  - $\approx 20\,\text{m}$ of space reserved $\Rightarrow$ expected to be compatible with **full crabbing beyond Ultimate**
- Total IR length now complies with design goal of 1.4 km
- Matched optics found for $\beta^* \geq 0.15\,\text{m}$

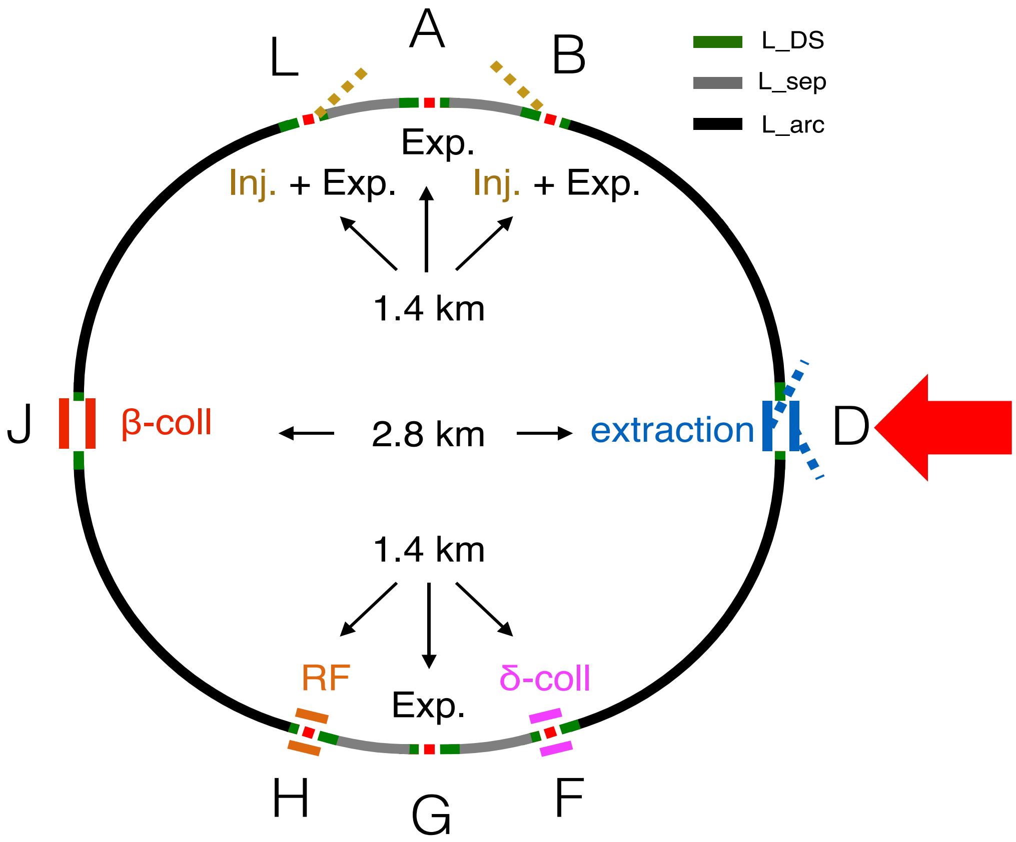
High Luminosity insertion - Alternative



The alternative triplet is used for the flat and for the round optics.

J. Abelleira, L. Van-Riesen Haupt

Extraction insertion



Extraction insertion – new baseline

(1) 150 Extraction Kicker (2017: 300)

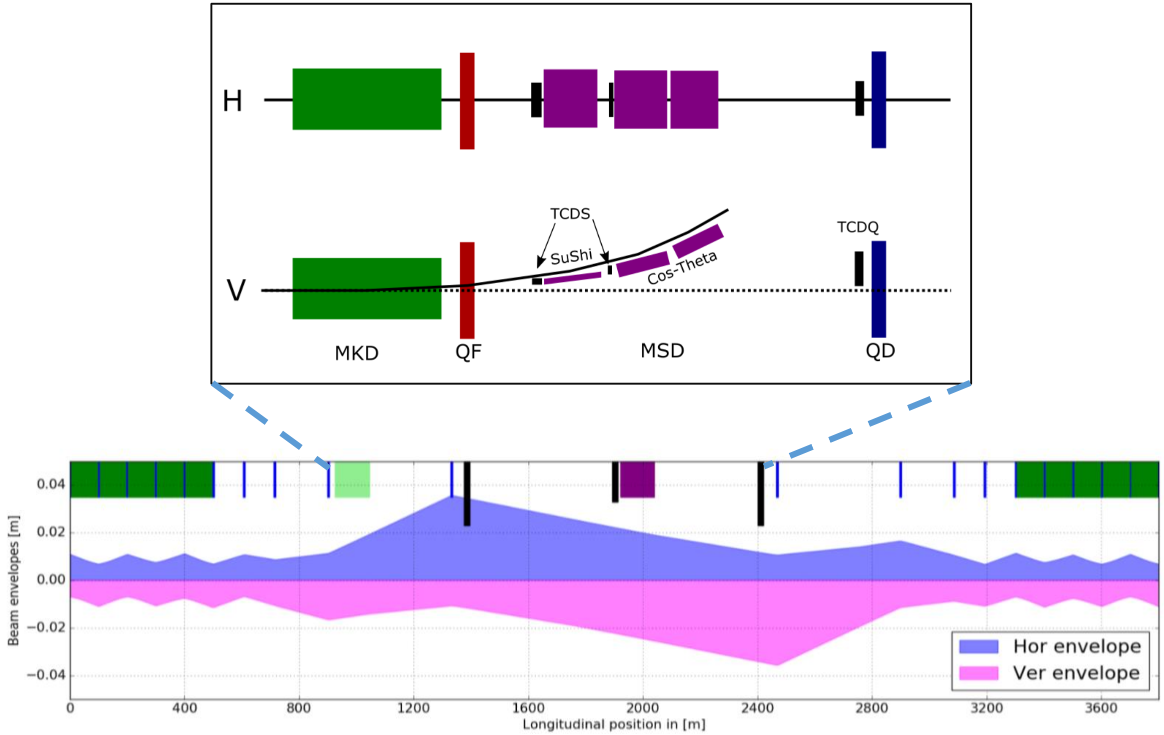
- System length 120 m
- 1 us risetime

(2) Larger beam size at protection absorber than 2017

(3) SuShi / Cos-Theta Septa instead of superferric Lambertson

- ~70m instead of 180m (2017)
- single plane extraction (vertical)

- to be integrated in the full lattice



W. Bartmann

Dumpline

2017: Dilution system envisaged kickers with <u>modulated frequency to minimize size of dumpcore (max. 50kHz)</u>

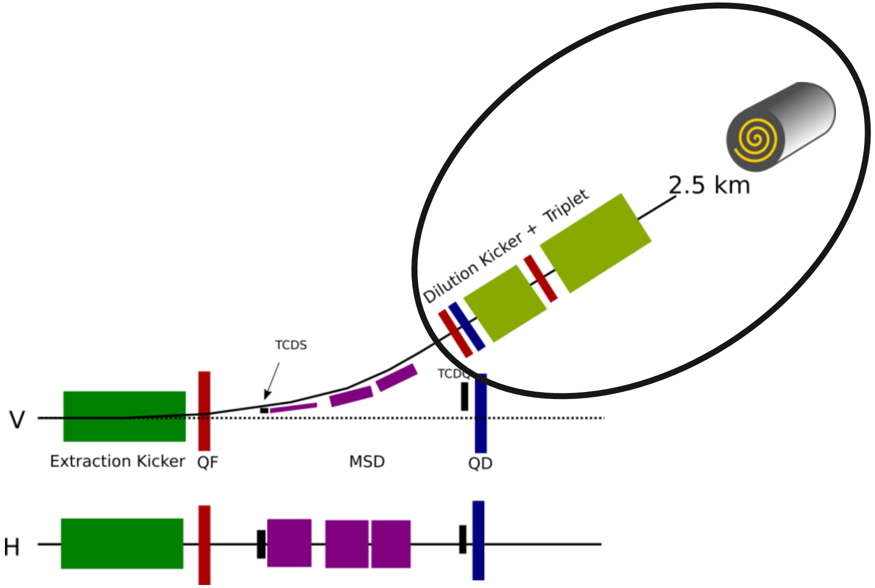
+Sweeppattern r=45 cm

-Very challenging for kicker system

-**Problematic for survival of asynchronous beam dump**

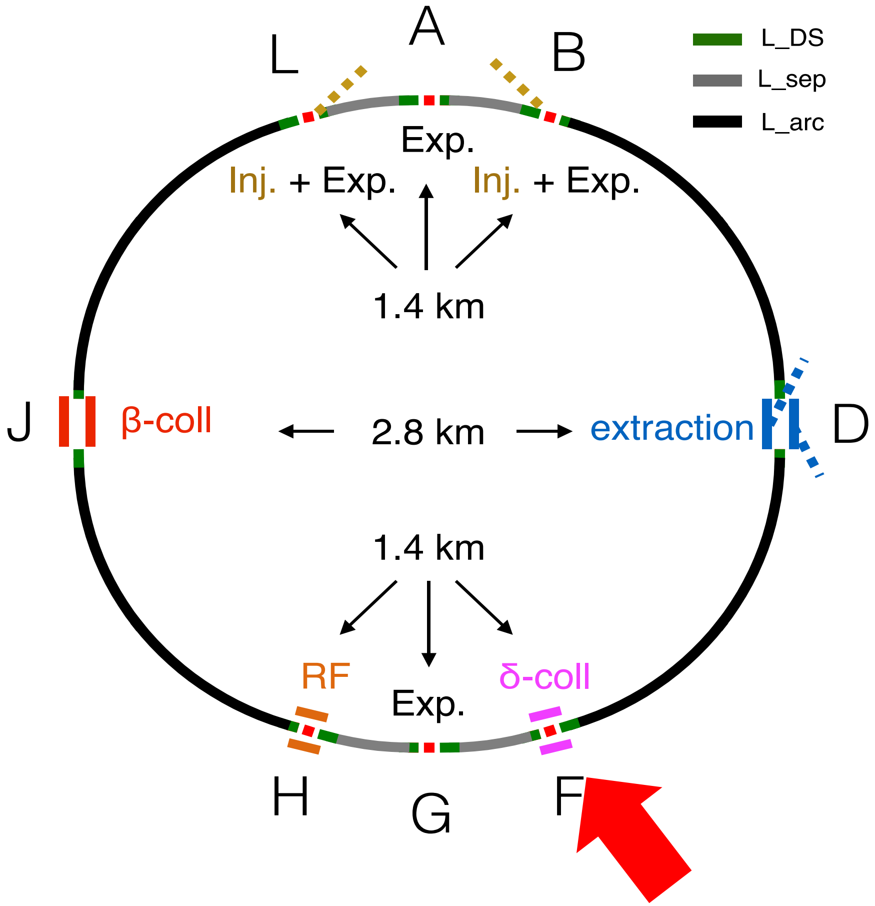
2018: <u>Constant frequency</u> of the dilution system (50kHz)

- Sweeppattern r=55 cm
- **Energy deposition in case of asynch. dump acceptable**
- Large deflection by dilution kicker necessary
  - Either increase tunnel length to 3km or increase BdL of MKBs
  - **Focusing triplet in the dumpline** helps to reduce the aperture in the dilution kickers and hence relax the hardware requirements.



E. Renner et al.

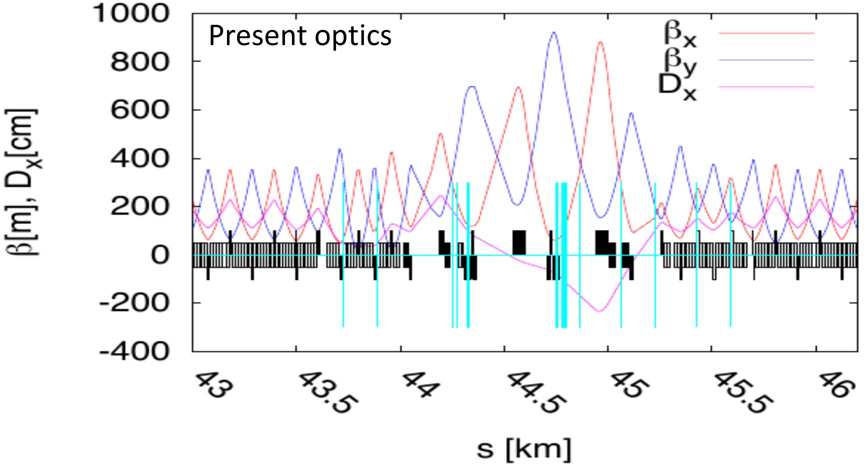
Momentum collimation insertion

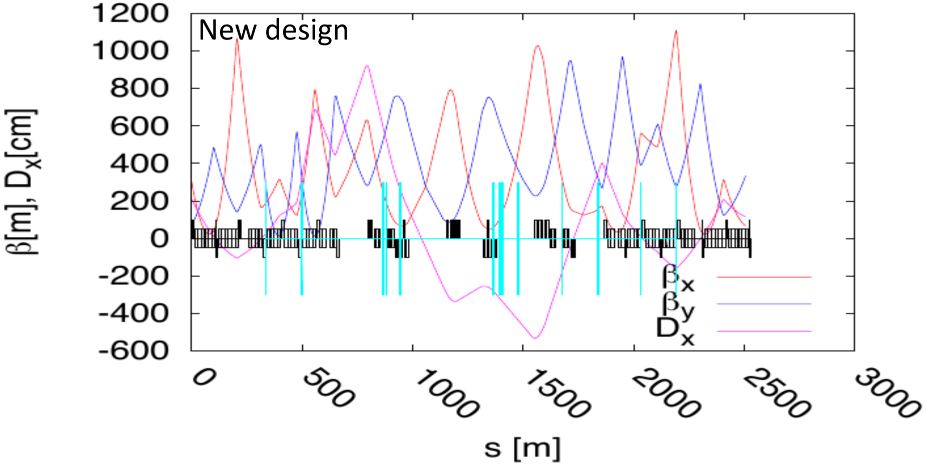


Momentum collimation insertion

New momentum collimation optics developed

FNAL (Mokhov, Alexahin, Gianfelice, Tropin), NIU (Narayanan, Syphers)



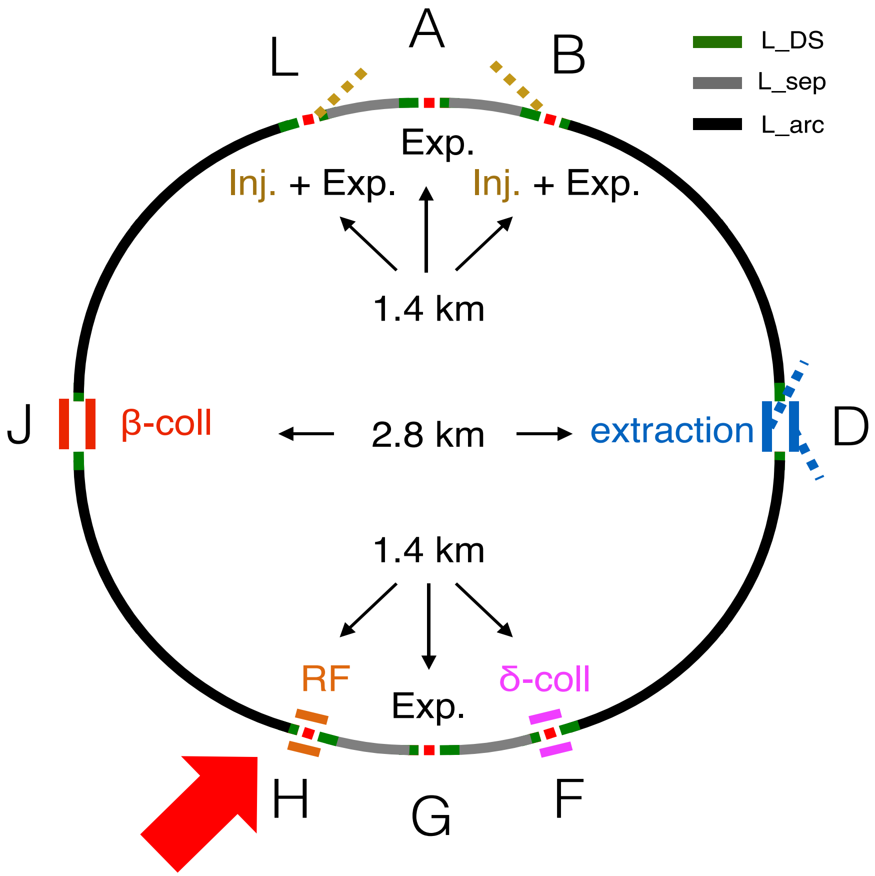


Next steps: Optimize placement of secondary collimators. Study aperture, cleaning performance, power deposition

- New MARS - MAD-X/PTC interface recently completed

R. Bruce et al.

RF insertion



RF insertion

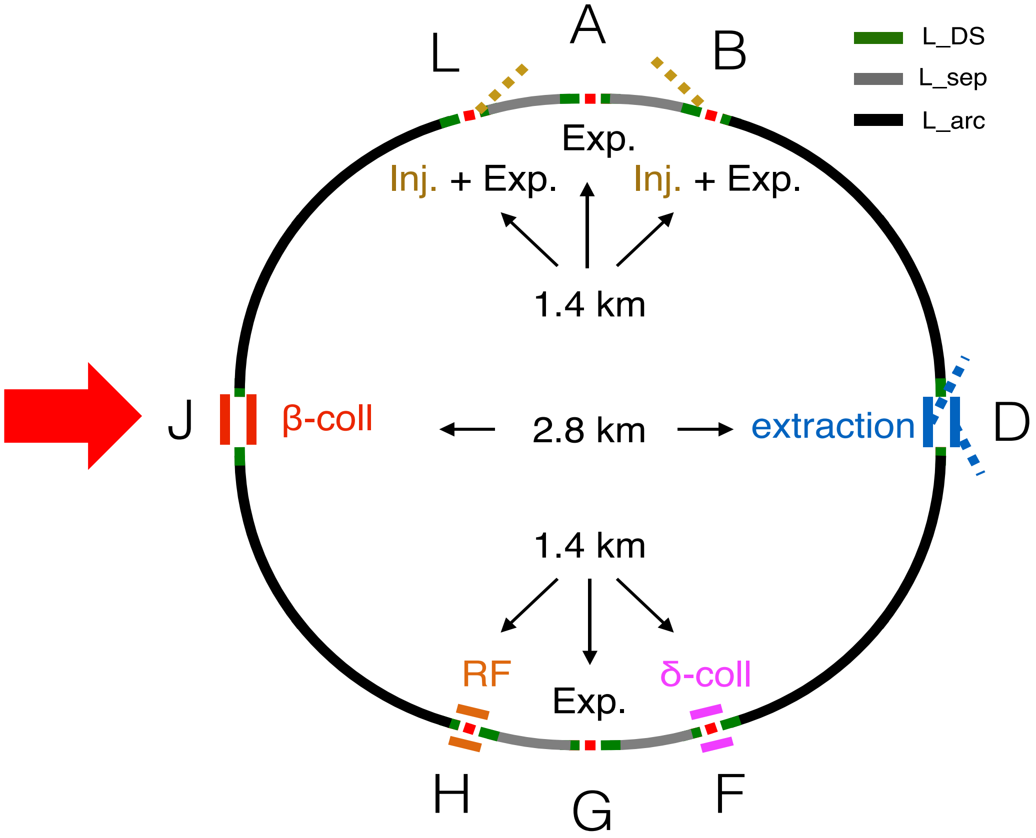
- No special requirement for the insertion optics
- Space for electron lens or RF quadrupoles foreseen

I. Karpov, E. Shaposhnikova et al.

- 400 MHz single-cell cavity (LHC-type), similar to FCC-ee Z machine
- Required voltage strongly depends on optics (for the same emittance and bunch length)
- For 20 min acceleration ramp, V=38 MV needed to accelerate bunches with emittance of 1.8 eVs at 3.3 TeV and controlled emittance blow-up to 9.0 eVs during ramp
- 20 cavities/beam with 2 MV/cavity or 40 with 1 MV/cav.
- At flat top: continuous blow-up needed in physics → additional 800 MHz RF system would give more flexibility

400 MHz(Nb-Cu)

Betatron Collimation insertion

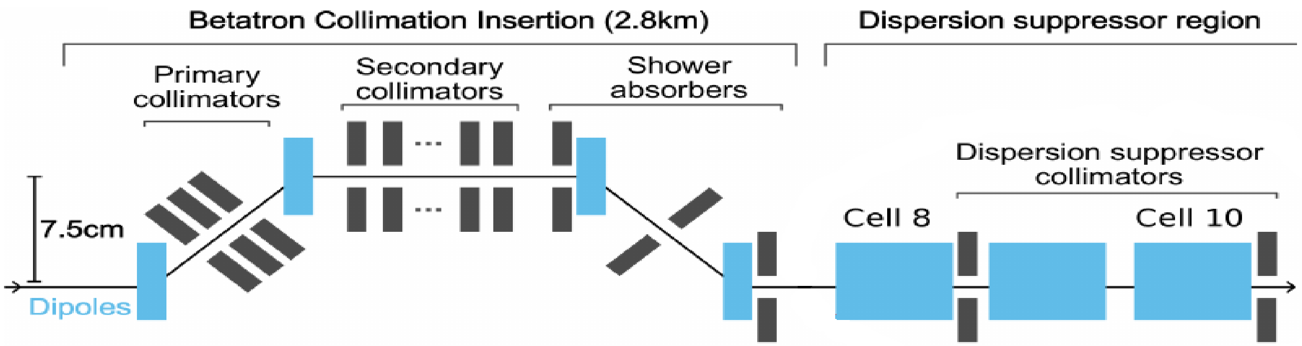


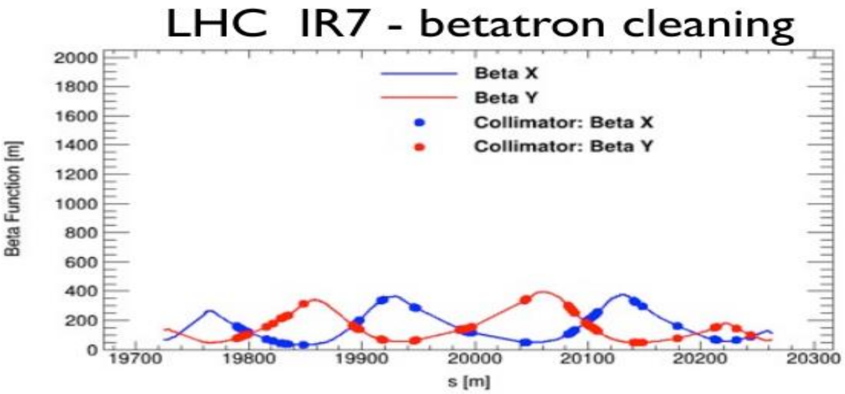
Betatron Collimation insertion

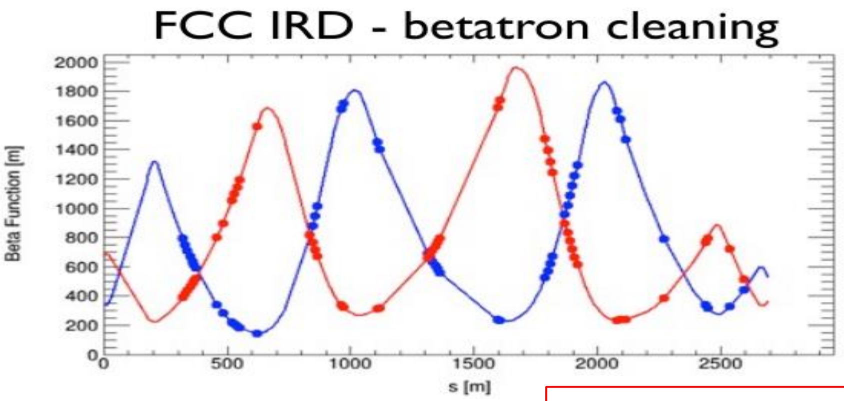
Keep layout, design and material of HL-LHC collimators

- But collimators with highest loads made of CFC

Scale β-functions and insertion length by factor 5 from the LHC




LHC IR7 - betatron cleaning


FCC IRD - betatron cleaning

M. Fiascaris, R. Tomas

Collimators energy deposition

M. Varasteh et al.

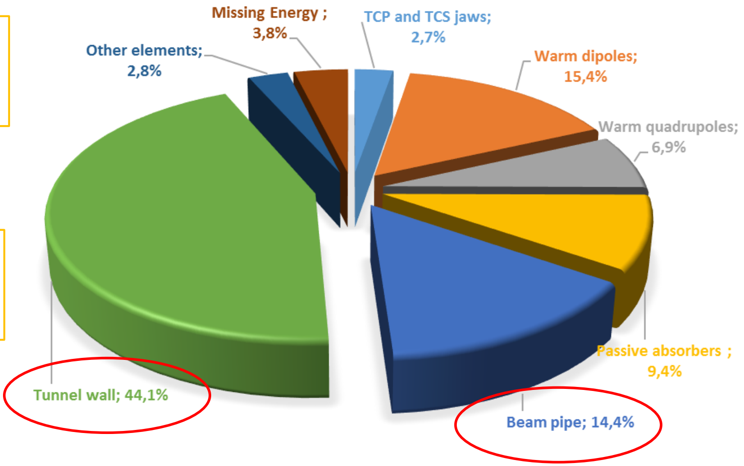
Collimator Jaws	TCP 60cm	TCP 30cm	TCP 30cm Thicker Jaw, w/o TCPB	
Primaries (kW)				
TCP.D6L	14.7	7.7	6.5	-56% ▼
TCP.C6L	158.7	99.2	79.7	-50% ▼
TCP.B6L	260.8	153.7	NA	
Secondaries (kW)				
TCSG.A6L	220.9	226.6	92.4	-58% ▼
TCSG.B5L	10.6	13.9	9.8	-8% ▼
TCSG.A5L	40.8	51.2	41.2	1% ▲
TCSG.D4L	33	43.5	32.9	0%
TCSG.B4L	8.2	11.7	6.4	-22% ▼
TCSG.A4L	10.8	14.1	11.6	7% ▲
TCSG.A4R	13.7	18.2	13.6	-1% ▼
TCSG.B5R	3.9	5	3.3	-16% ▼
TCSG.D5R	6.7	9.4	7.2	7% ▲
TCSG.E5R	10.9	14.6	12.5	14% ▲
TCSG.6R	1.8	2.4	2.3	28% ▲

- *Power on the most loaded primary collimator has been reduced from 260 kW to 80 kW by halving the primaries' active length as well as removing the skew primary.*
- *Power on the most loaded secondary decreases for 60% by making the Jaws thicker.*

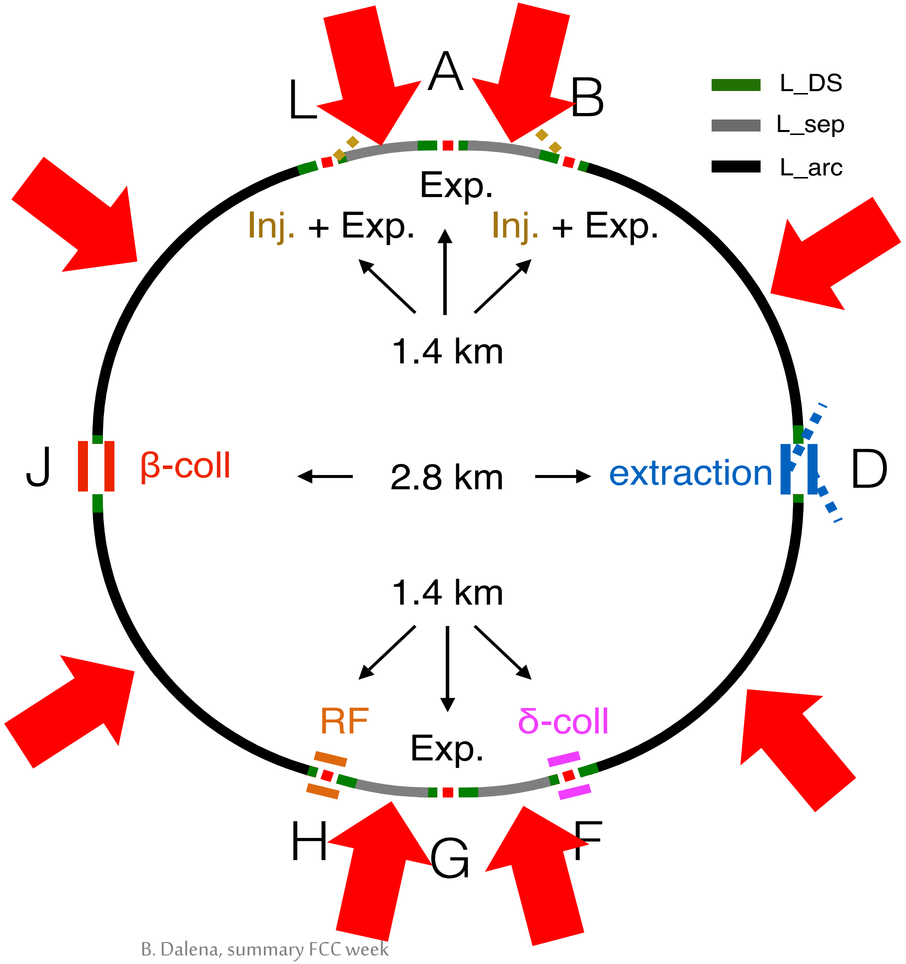
w.r.t the first design

about a factor of 15 higher than LHC

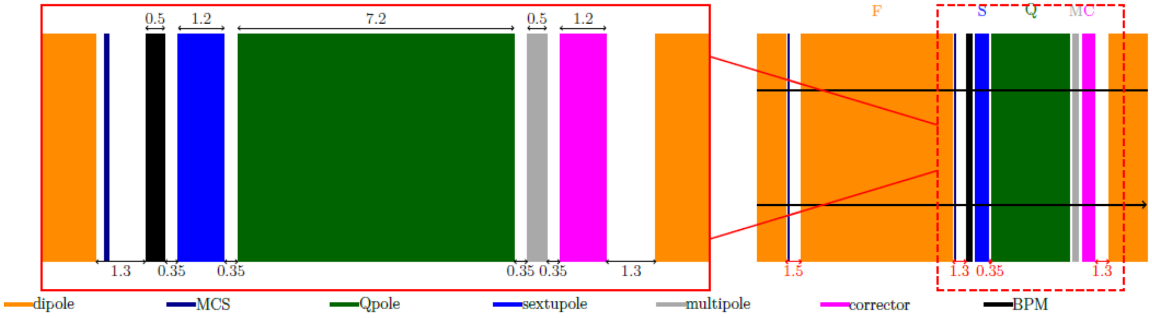
about a factor of 3 higher w.r.t. LHC



Arcs cell design and lattice design



Arcs cell design and lattice integration



A. Chancé

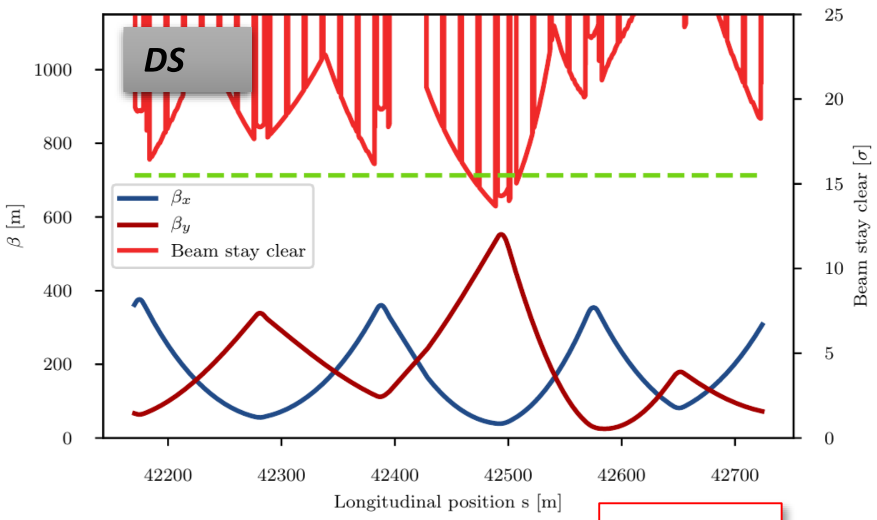
Iterated with magnet team

- Improved length estimates
- Integration of octupoles

Strategy if more space is required for correctors or quadrupole: shorten dipoles to preserve cell length

Full integrated lattice exists

- large amount of work (code, matching, tuning, …)
- some small issues remain to be solved
- specifications for magnets are almost complete
- beam separation 204mm
- alternative 60° FODO lattice under study



R. Martin

Bottleneck of aperture at injection is in DS optimization of optics and refining aperture requirements both possible

How all this will perform?

- Single beam performance in presence of imperfections or single element failure
- Machine protection
- Single beam instability: Impedance, electron cloud, feedback, Landau damping…
- Two beams performance: Landau damping, beam-beam
- After collision: beam induced debris/background

Alignment

Element	Error	Error desc.	Units	FCC	LHC	Comments
Dipole	σ(x),σ(y)		mm	0.5	0.5	no effect on observables
	σ(ψ)	roll angle	mrad	0.5	n/a	effect in vertical plane
	σ(δB/B)	random b1	%	0.1	0.08	LHC value includes σ(ψ)
	σ(δB/B)	random a2	10-4 units	1.04	1.6	
	σ(δB/B)	uncert. a2	10-4 units	1.04	0.5	
Quad	σ(x),σ(y)		mm	0.5	0.36	
	σ(ψ)	roll angle	mrad	1	0.5	
	σ(δB/B)	random b2	%	0.1	0.1	
BPM	σ(x),σ(y)		mm	0.3	0.24	value relative to quad
	σ(read)		mm	0.2	0.5	accuracy

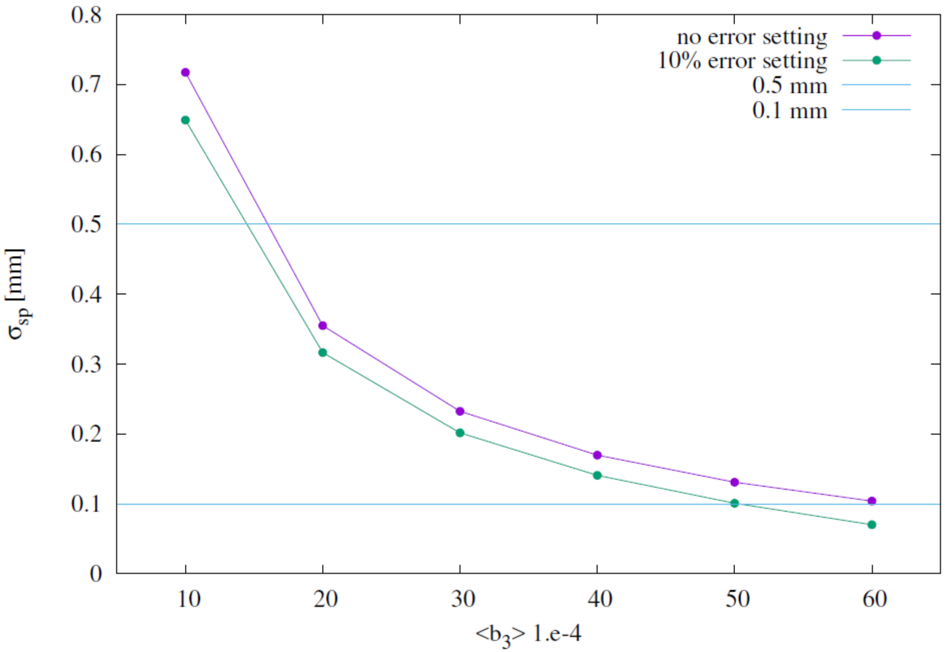
- Alignment tolerance for the main magnet of the arcs have been agreed with alignment group
- Orbit correctors in NbTi enough to keep the residual orbit and angle compatible with the aperture considered for the synchrotron radiation evacuation

- Dedicated beta-beating, dispersion and coupling correction and full integration with IR orbit correction to be further studied

D. Boutin

Dynamic Aperture at injection

- with systematic sextupole component of main dipole corrected (by MCS, feasible in NbTi technology) DA is above the target value of 12 σ at 3.3 TeV injection energy
- to limit 'β-beating' at injection to the same value as created by the random dipole b_2 component, the maximum allowed MCS alignment error should be ≤ 0.1 mm or the dipole *sextupole* field error reduced
- combination of field errors due to different magnet with phases advance between opposite points in the ring can highly reduce DA



Dynamic Aperture at collision

- Study at collision without beam-beam has been expanded to include further errors: triplet errors, dipole arc errors, separation and recombination dipoles

E. Cruz

25 σ
- β*=1.1 m *w/o non-linear correctors*

14-16 σ
- β*=0.2 and 0.3 m *with non-linear correctors*
- Expected the same for alternative design, flat beams and FCC-eh

10-13 σ
- β*=0.3 normal and alternative design
- Flat beams
- FCC-eh IR

w/o non-linear correctors

4-6 σ
- β*=0.15, 0.2 m *w/o non-linear correctors*

- With the phase scan optimization almost all studies (except for β*=0.15, 0.2 m) show good results, even without non-linear correctors.
- Check compatibility with beam-beam studies. Find best phase optimization for different stages of operation cycle.

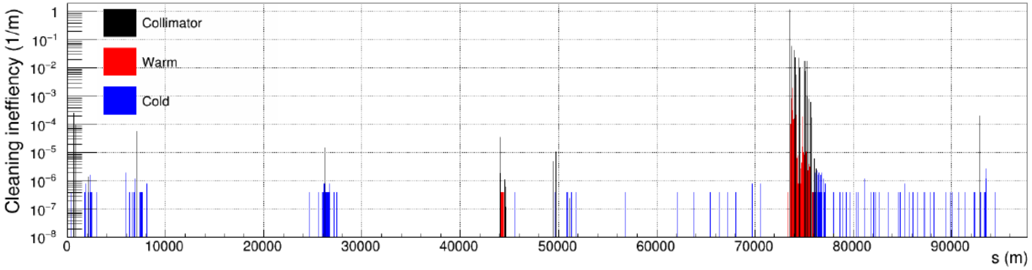
Collimation performance

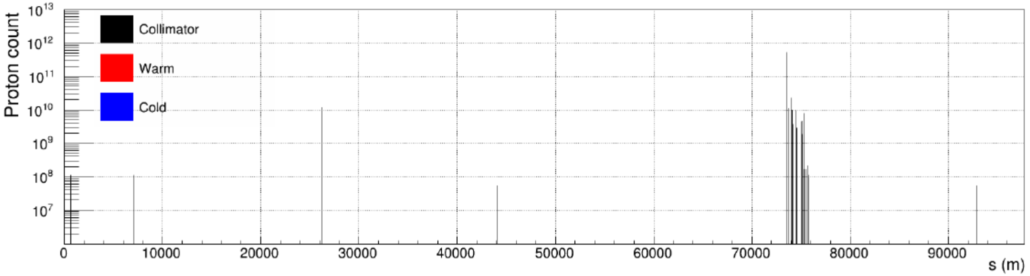
J. Molson

- Cleaning at top energy is mostly good for both the horizontal and vertical case.
- At injection due to the larger emittance and wider scattering angles the situation is not as good...
- The beam energy is lower, so there will be less energy deposited per proton. All depends on the injection quench limits.

Asynchronous dump

- The system is expected to survive 3 kickers pre-firing with 2 10^{11} proton limit on a single collimator jaw
- Including alignment, field, orbit etc errors could potentially reduce to 2 kickers pre-firing
- Phase advance between extraction kickers and collimation insertion important





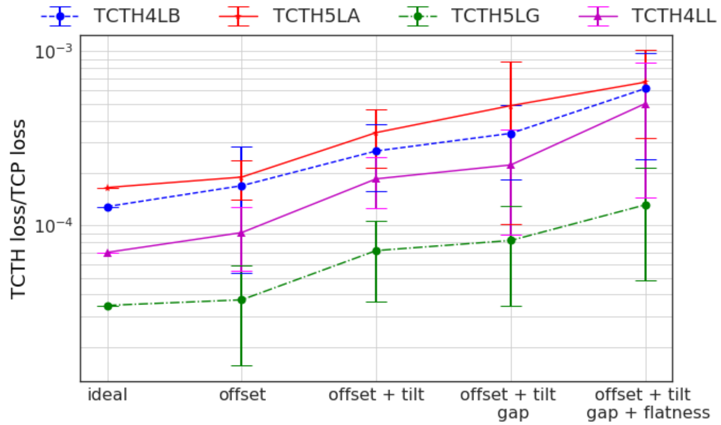
Collimation efficiency with imperfections

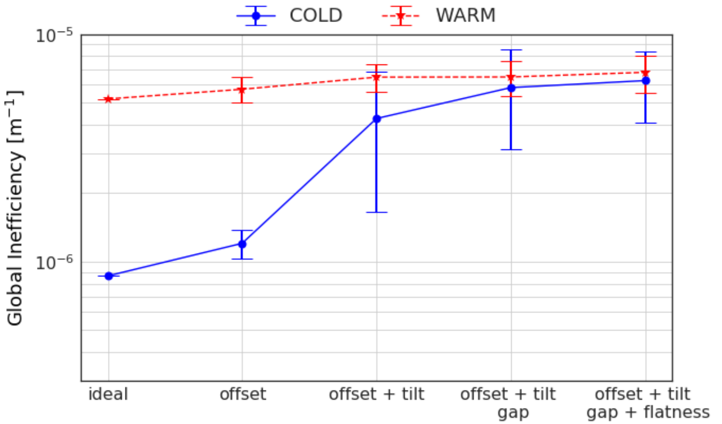
Horizontal collimation performance of FCC-hh with imperfections

- Collimator hierarchy is preserved for all imperfections
- Imperfections increase by a factor 6 the global cold losses
- Cold Losses are mostly located in A, B and dump areas
- Most affected element of cold losses is MQI.4RD

⇒ more imperfections to be added to the study

M. Serluca



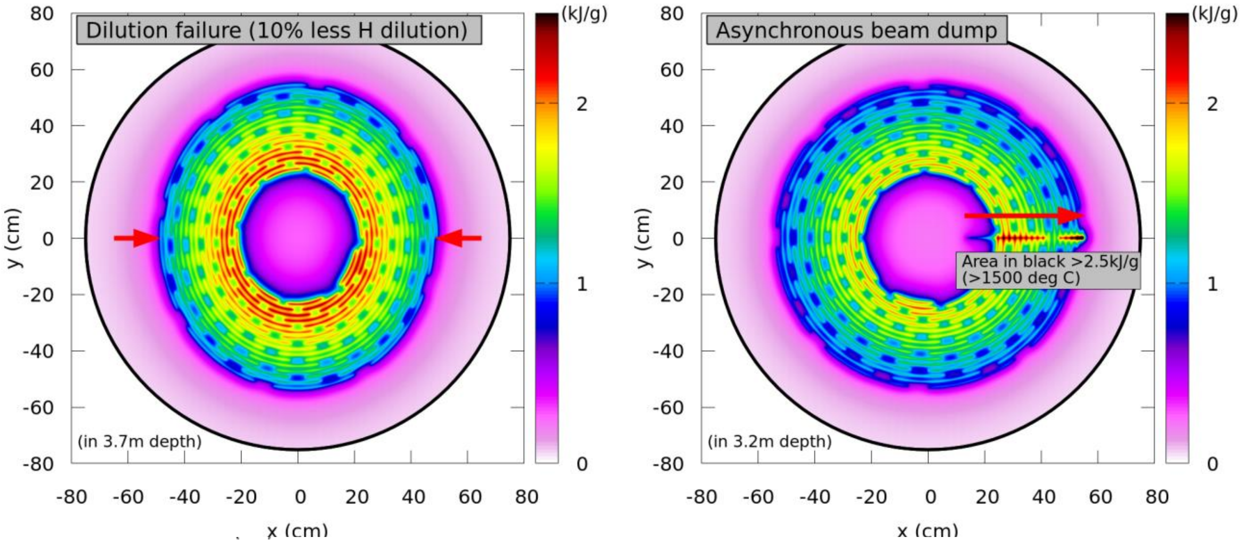


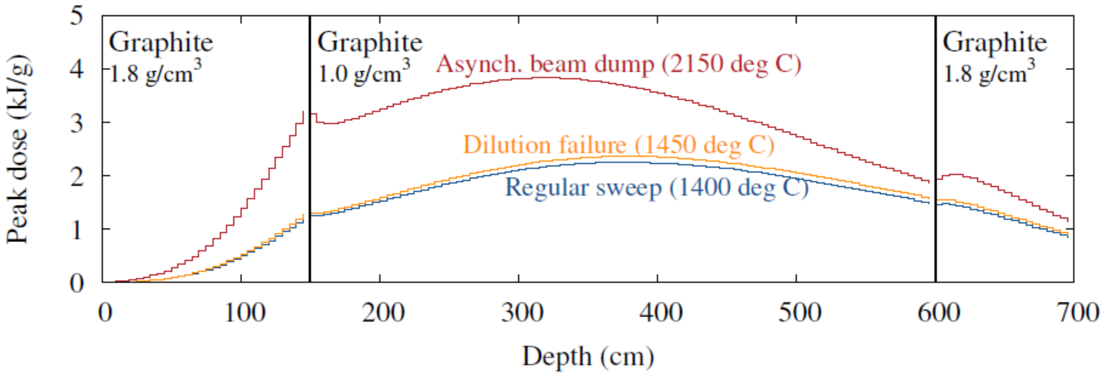
Extraction and dump performance protection

A. Lechner et al.

- New sweep pattern reduces the load on the dump, but still challenging dilution kickers required
- Dump functionality not compromised in case of asynchronous dump

- Possible directions to reduce dilution kicker requirements is to employ low density Carbon foams (to be characterize and tested)





Beam-related machine protection

Very challenging due to be energy stored in the magnets and the beam!

Parameters	LHC (nominal)	FCC-hh (baseline)
Energy of one beam (MJ)	362	**8320 (melt 10 *t* copper)**
Typical beam-energy density (GJ/mm^2)	1	**200 (potentially more destructive)**
Quench limit of dipole magnets (p/m/s)	7.8×10^6	**0.5×10^6 (protection challenge)**

- @ 50 TeV, scaling linearly from energy deposition per proton, one nominal bunch has the potential to evaporate copper at the location of the maximum energy deposition! [Y. Nie, et al., ***Physical Review Accelerators and Beams*** 2017]
- With a machine protection system similar to the LHC, the FCC would require up to three turns' to dump the beam synchronously after the detection of a failure, i.e. ~1 ms.
- Scaling from LHC, the number of elements that should be capable of triggering a beam dump for the FCC-hh is estimated to exceed 100 000!

Novel strategies proposed for specific challenges

- Requirements for magnets: the minimum time constant of field decay determined such that beam position is displaced up to 1.5 σ or tune change is up to 0.01, within 2 ms after magnet failure (>20s for separation dipoles, >140 ms for triplet)
- reducing the reaction time by using fast diamond BLMs, a shorter traveling path of the dump request and multiple abort gaps
- avoiding beam/UFO induced quenches by detecting beam losses inside the cryostat
- cleaning the beam halos by using the e-lens

Y. Nie et al.

Electron cloud

L. Mether

- The effect of beam screen geometry on e-cloud build-up evaluated

  The large slit increases multipacting threshold in drifts
- With full chamber and updated parameters an amorphous carbon coating or LASE surface should be sufficient to suppress build-up for the 25 ns beam
- For the alternative bunch spacing:
  - Full suppression needed for stability → SEY ~1 in quadrupoles
  - Coating may be necessary also in field free regions
- Photoelectrons initialized according to ray-tracing simulations

  Estimated photoelectron fluxes are within stability limits
- Photoelectrons from saw-tooth increases density in drifts → expected flux to be confirmed with WP4

25 ns, 50 TeV

Multipacting thresholds with 2017 / 2018 chamber

(highest max SEY without build-up)

	25 ns		12.5 ns		5 ns	
E [TeV]	3.3	50	3.3	50	3.3	50
Dipole	1.4 / 1.5	1.4 / 1.5	1.1	1.1	1.5	1.5
Quad	1.2 / 1.1	1.2	1.0	1.0	1.1	1.0
Drift	2.0	2.0	1.3	1.3	1.6	1.6

Electron cloud scaling from LHC to FCC

- SEY threshold depends a lot on the chosen model

D. Astapovych

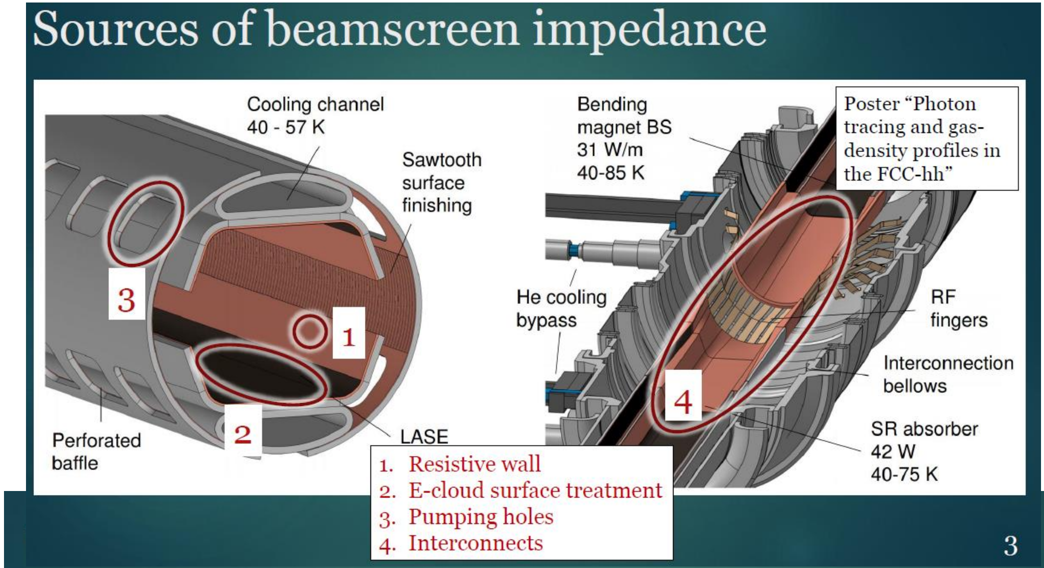
	Furman model		Simple SEY model	
	LHC	FCC-hh	LHC	FCC-hh
Drift	1.23	1.3	1.3	1.6
Injection	1.1	1.25	1.25	1.42

Take home message (by R. Cimino)

⇒ time are mature to use measured data to tune simulations

Impedance: coupled bunch instability

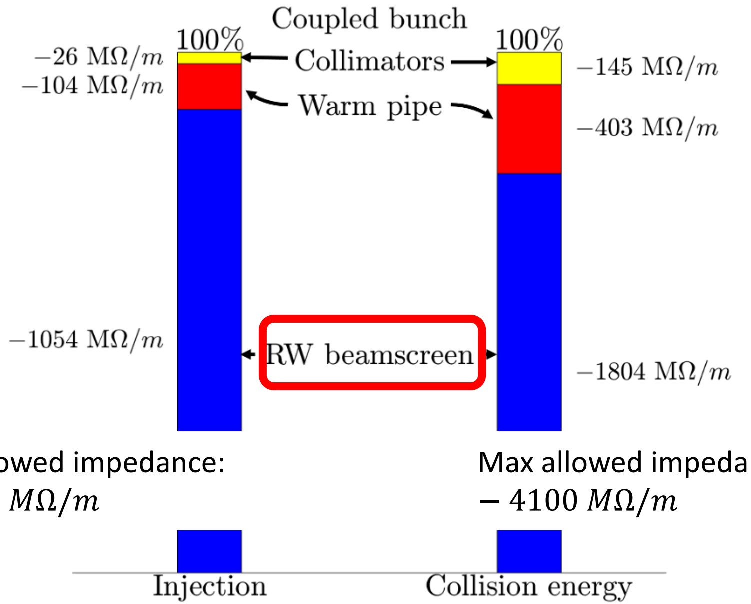
Sources of beamscreen impedance



Poster "Photon tracing and gas-density profiles in the FCC-hh"

1. Resistive wall
2. E-cloud surface treatment
3. Pumping holes
4. Interconnects

- resistive wall →
  - 🙂 OK, if aperture=13.2 mm
  - ☹ Maybe not OK, if aperture=12.22 mm due to the head-tail instability
- e-cloud surface treatment →
  - 🙂 OK, if AC or TiN coating is used
  - ☹ Unknown, if laser treatment is used (waiting for measurements at FRESCA)
- pumping holes → 🙂 OK
- interconnects → 🙂 OK, but can be better



Max allowed impedance: $-1350\ M\Omega/m$

Max allowed impedance: $-4100\ M\Omega/m$

Beamscreen-related impedance dominates coupled-bunch instability

S. Arsernyev

How do we dump instabilities ? Feedback

The LHC ADT scaled to 2.35 MHz is a solid baseline system

- Allows feasible operational margin for Q' and octupoles during the injection
- Allows gain margin for the CBI damping at injection and top energies
- The experience from the LHC and the HL-LHC directly applicable to the FCC-hh

Simulations imply that other operation schemes are feasible

- Weak additional 100 MHz system for the 5 ns bunch spacing
- 1.3 TeV injection energy feasible, but closer studies needed for the CBI damping

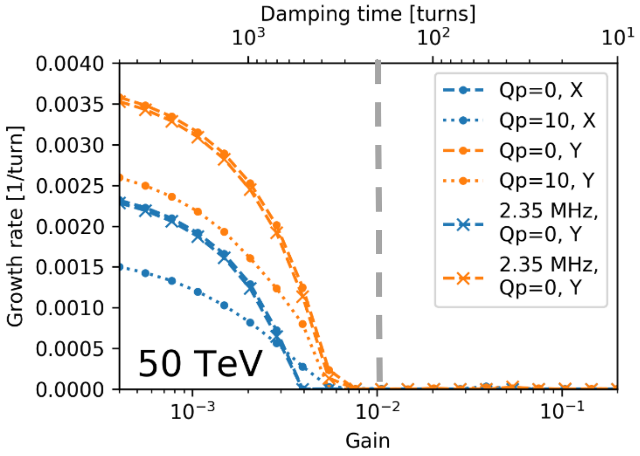
Room for future investigations

- Noise -> Distributed system and new digital filter approaches
- Future technology challenges (tetrode amplifiers) -> Feed-forward injection damping
- Extra safety margin for the single bunch instabilities -> Wideband feedback

Progress in the simulation codes

- New feedback module allows detailed feedback models to be included into beam dynamics simulations
- Multi turn wake simulations with proper feedback models are here for full FCC-hh beams

Would be good to have more experimental data for validation and verification



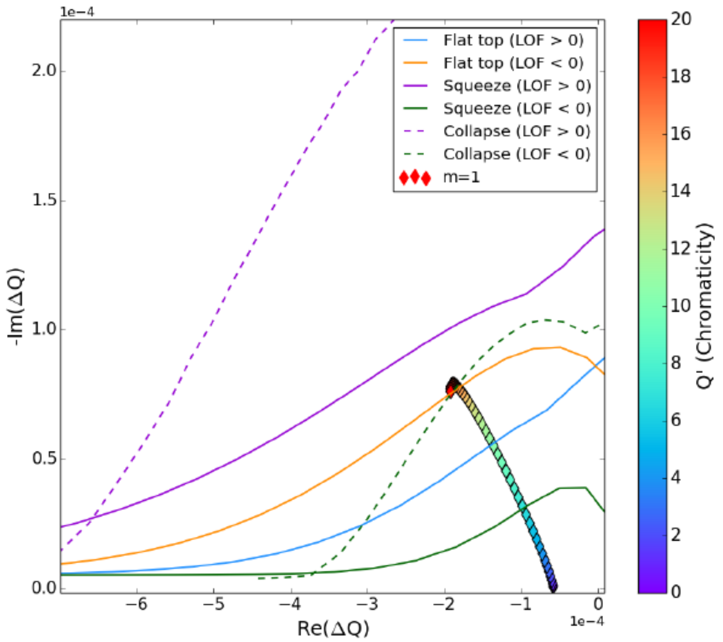
J. Komppula

Ready to future!

What about higher order mode instabilities during the operational cycle?

C. Tambasco et al.

Octupoles at their maximum strength



Flat top (single beam): larger stability with negative octupole polarity (orange line), m=1 Landau damped up to high Q' values (DA > 15 σ both polarities)

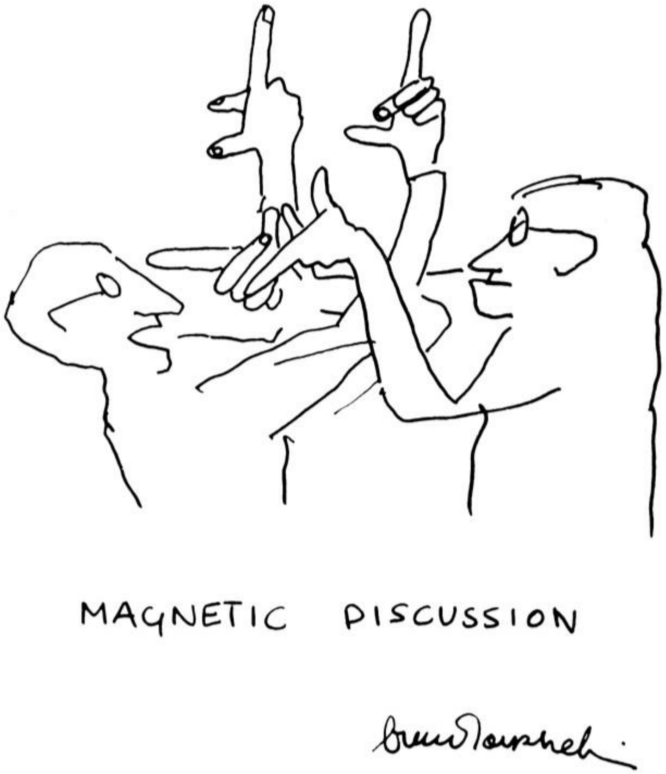
End of squeeze (beam-beam LR): strong reduction of stability with negative octupole polarity ➔ tight control on Q' values required, DA > 7.5 σ (DA < 6 σ for positive oct. polarity)

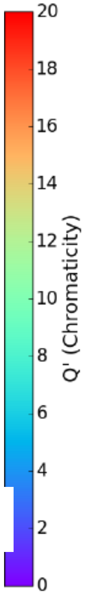
Possible solutions:
- Increase the β-function in the arcs
- Use e-lens for Landau damping
- Wide-band feedback?

Collapse of sep. bumps (LR + HO crab on): stability increases during the collapse ➔ SD is larger or equivalent compared to end of betatron squeeze

What about higher order mode instabilities during the operational cycle?

C. Tambasco et al.





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Possible solutions:

- Increase the β-function in the arcs
- Use e-lens for Landau damping
- Wide-band feedback?

It was an animated discussion…

$\Rightarrow$ additional directions that could be investigate:

- collision during squeeze (β* levelling) (S. Arsernyev)
- wire compensation (D. Schulte)

Beam-beam

Optimization of optics based on Dynamic Aperture including beam-beam

- Phase advance between IPs changes during operational cycle to have maximum Dynamic Aperture

- Crossing angle of 200 µrad at IPA and IPG allows for high chromaticity operation

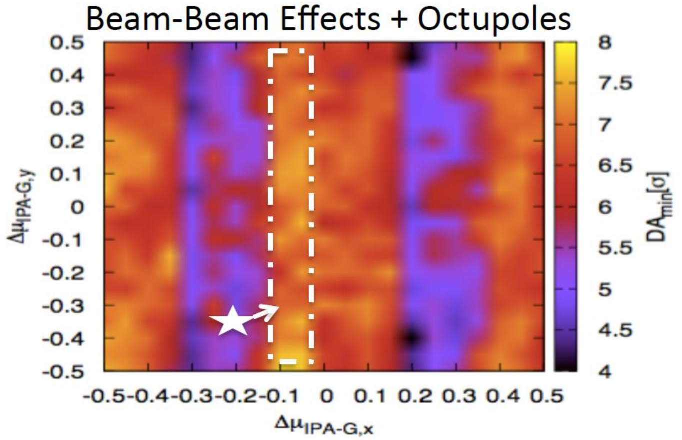
- Crossing angle of low luminosity IRs > 180 µrad to do not perturb High luminosity IR

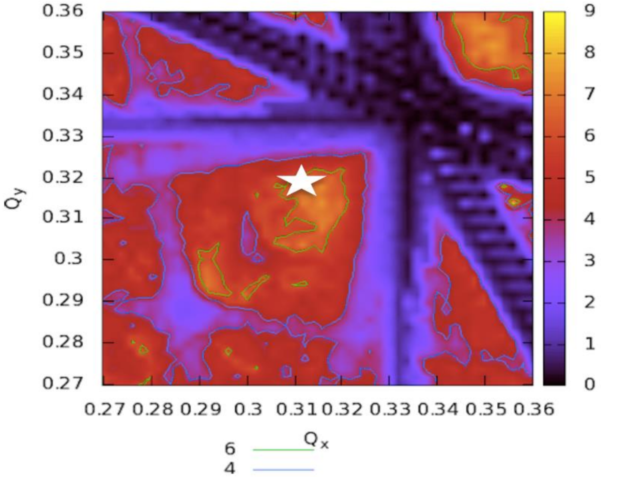
➢ Tune optimization to find the optimum and large area in tune diagram hosting low luminosity experiments and multipolar errors

➢ Explore limitations linked to head-on beam-beam: the ultimate total beam-beam tune shift 0.03 is not given

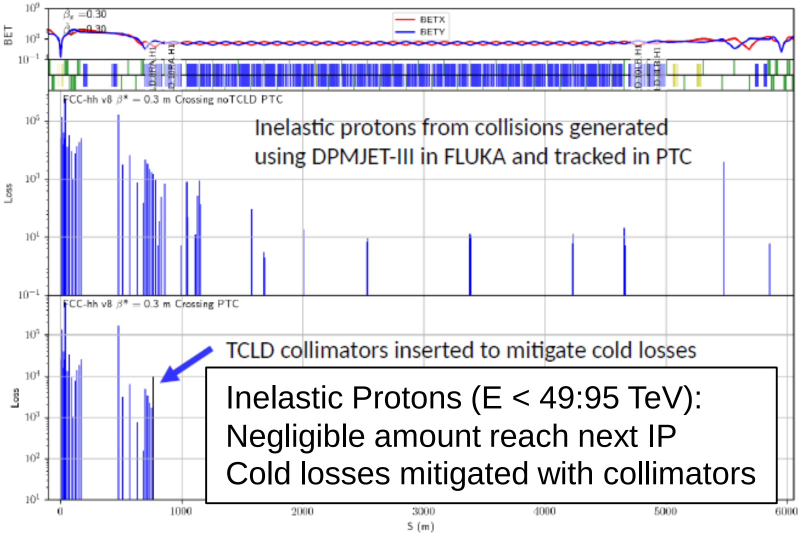
➢ LHC data benchmark is fundamental!

T. Pieloni et al.





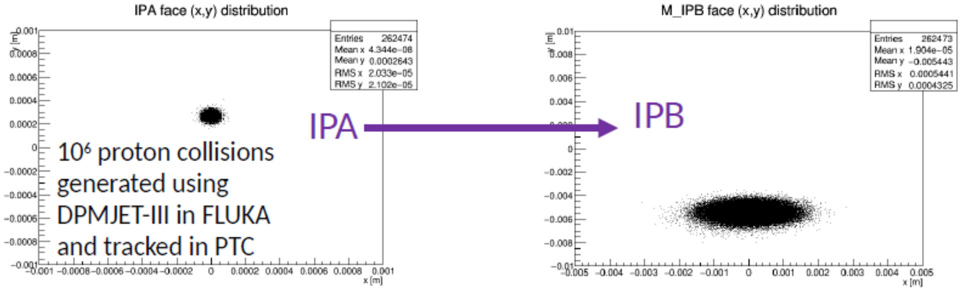
Beam induced background - detector cross talk



Inelastic protons from collisions generated using DPMJET-III in FLUKA and tracked in PTC

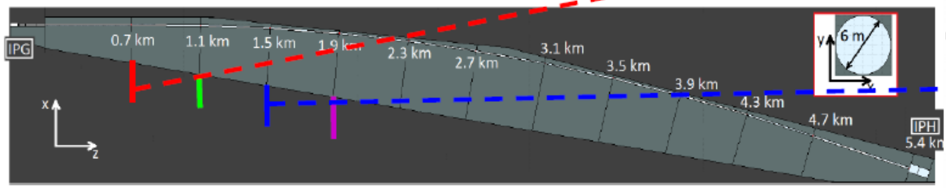
TCLD collimators inserted to mitigate cold losses

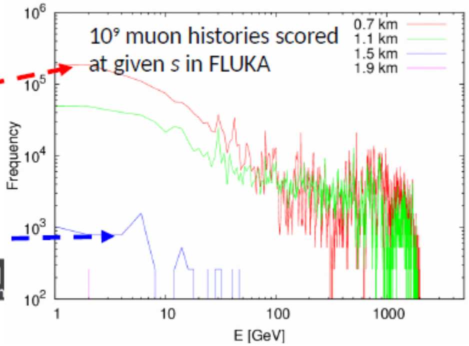
Inelastic Protons (E < 49:95 TeV):
Negligible amount reach next IP
Cold losses mitigated with collimators



10^6 proton collisions generated using DPMJET-III in FLUKA and tracked in PTC

Elastic Protons (E > 49:95 TeV): all reach next IP = small emittance growth





10^9 muon histories scored at given *s* in FLUKA

Muon do not reach next detector

The Cockcroft Institute of Accelerator Science and Technology

H. Rafique et al.

MANCHESTER 1824 The University of Manchester

Energy deposition in the triplet from collision debris

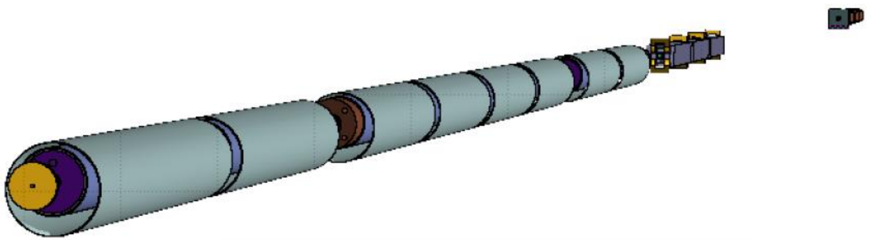
From the energy deposition point of view, ultimate luminosity goals appear to be at reach with the current material, relying on the regular crossing plane and vertical angle polarity alternation and the optimization of the Q1 splitting with an aperture step.

The cryogenics capacity should comply with a 6.5 kW dynamic load in the triplet cold mass, 30% of which in the second Q1 half (Q1b), as well as the 45 kW collected in the shielding.

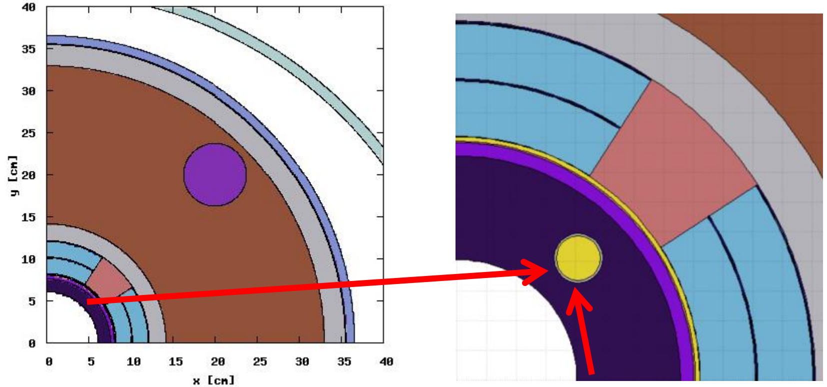
The warm D1 design appears to offer room for the required better coil protection.

The neutral absorber (TAN) is prone to take more than 100 kW.

⇒ Is there space for specific cooling system? (F. Lebrun)



F. Cerutti, A. Infantino, J.Keintzel



Cylindrical cooling capillary

Heavy Ion operation

Pb-Pb Integrated Luminosity per 1 month run

Including an overall **performance efficiency factor** of 50% for failures, start-up, etc.

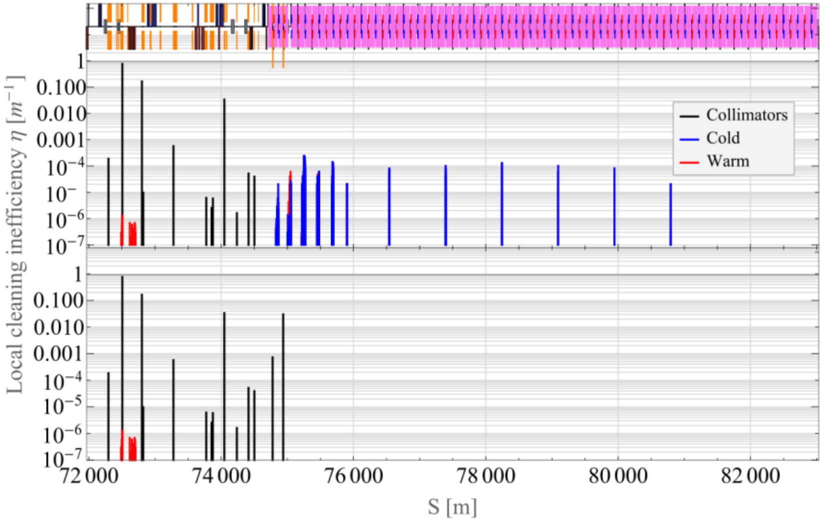
	Baseline:	Ultimate:
1 exp. L_{int}/run:	$35nb^{-1}$	$110nb^{-1}$
2 exp. L_{int}/run:	$23nb^{-1}$	$65nb^{-1}$

- Performance estimates based on 2016 injector performance for LHC kept close to p-p operation and design.

- Collisions produce secondary ions with changed rigidities that will be lost in small spots in the dispersion suppressor around the experiments → *To be studied, if these collimators can absorb the deposited power*
- Reduced collimation cleaning efficiency for ions → *More studies of collimation for ions needed*

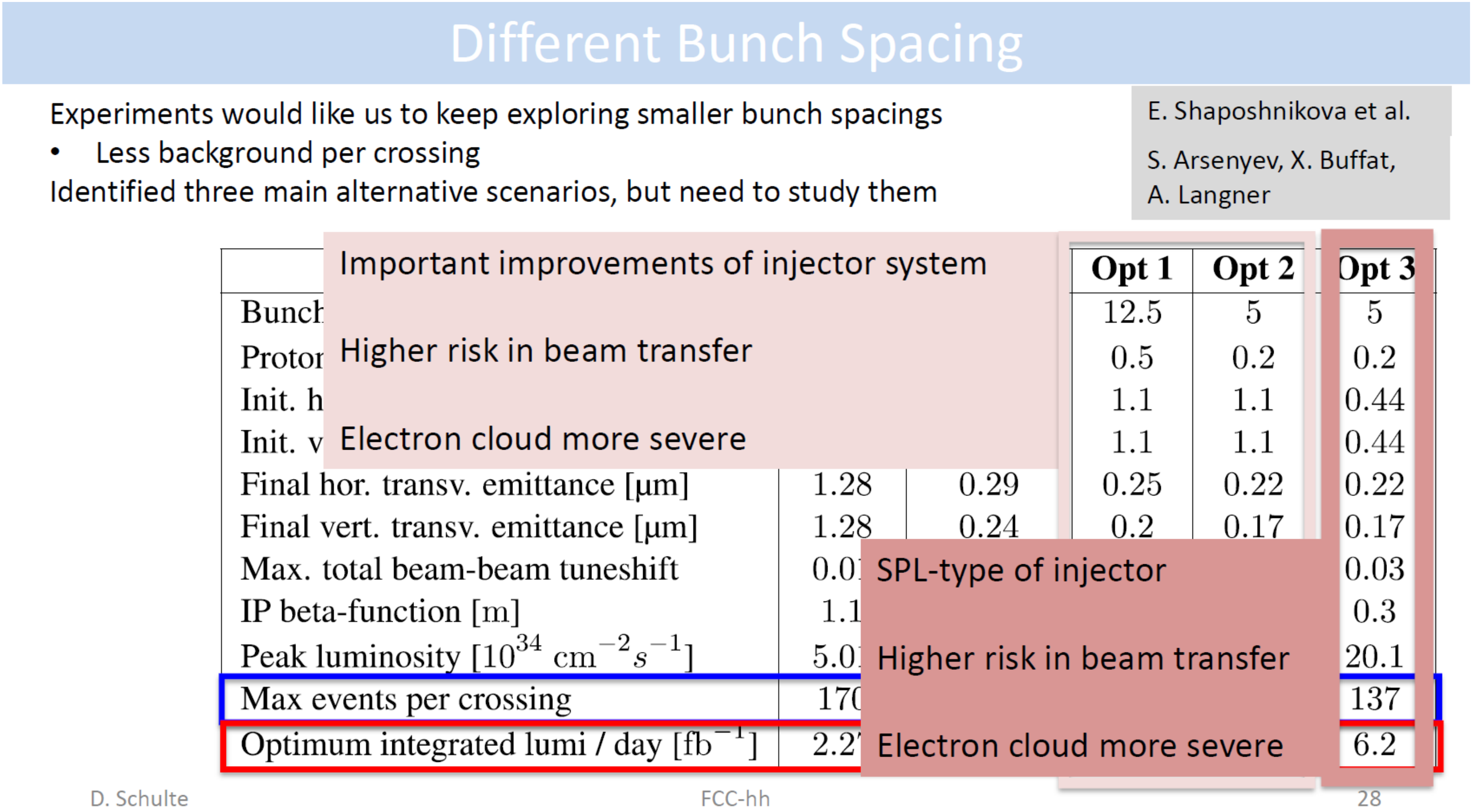
- Study future upgrades/evolution of heavy-ion injectors
- Further studies for lighter ion beams

J. Jowett, M. Schaumann, E. Logothetis Agaliotis



Many thanks to all the speakers and the great Team!

…Have a nice trip back…



Different Bunch Spacing

E. Shaposhnikova et al.

S. Arsenyev, X. Buffat,
A. Langner

Experiments would like us to keep exploring smaller bunch spacings

- Less background per crossing

Identified three main alternative scenarios, but need to study them

			Opt 1	Opt 2	Opt 3
Bunch			12.5	5	5
Proton			0.5	0.2	0.2
Init. h			1.1	1.1	0.44
Init. v			1.1	1.1	0.44
Final hor. transv. emittance [µm]	1.28	0.29	0.25	0.22	0.22
Final vert. transv. emittance [µm]	1.28	0.24	0.2	0.17	0.17
Max. total beam-beam tuneshift	0.0				0.03
IP beta-function [m]	1.1				0.3
Peak luminosity [10^{34} cm$^{-2}s^{-1}$]	5.0				20.1
Max events per crossing	17				137
Optimum integrated lumi / day [fb^{-1}]	2.2				6.2

Important improvements of injector system

Higher risk in beam transfer

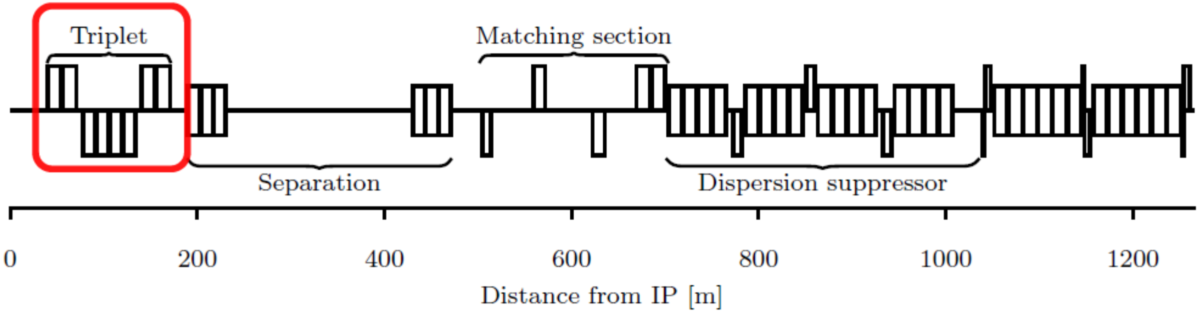
Electron cloud more severe

SPL-type of injector

Higher risk in beam transfer

Electron cloud more severe

High Luminosity insertions: Triplet

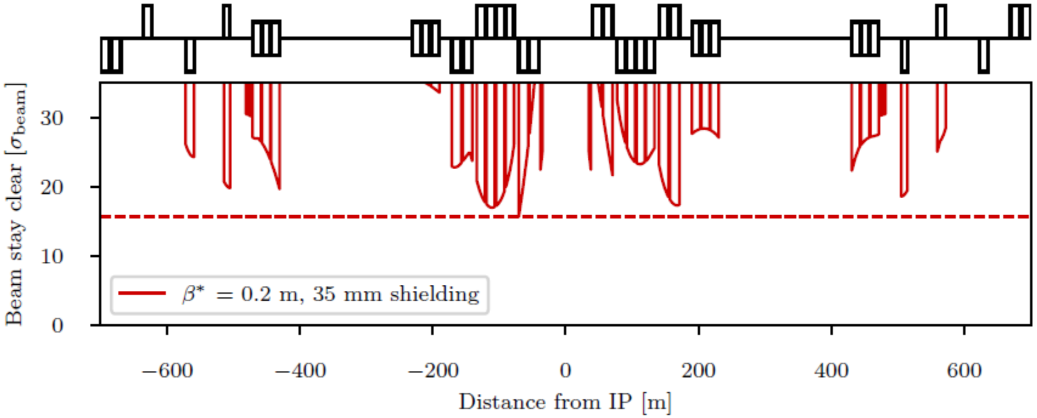


R. Martin

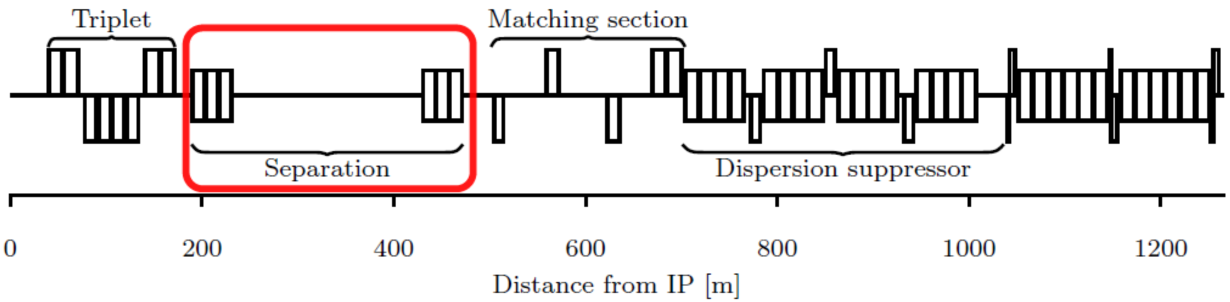
Both options can reach β^* beyond Ultimate / have comfortable margins

Currently thick shielding option is preferred

- With new L^* triplet gradients and apertures had to be adapted
- Magnet lengths reduced to fit into 15 m cryostats

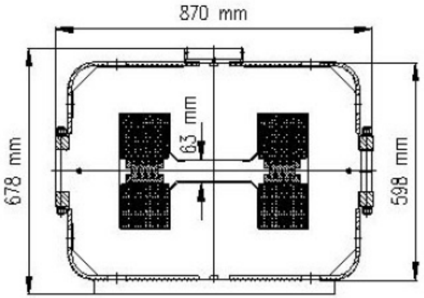


High Luminosity insertions: separation dipoles

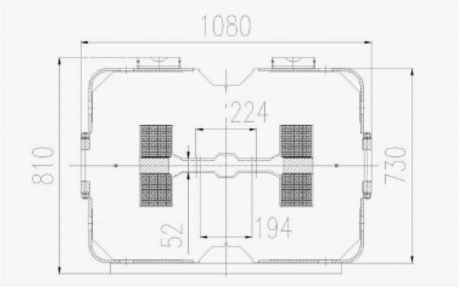


R. Martin

- Dipole strengths were close to 2 T
- Redesigned to use normal conducting magnets
- Assuming LHC-like magnet designs
- Advantages:
  - Robustness in the highly radiative environment
  - Better field quality

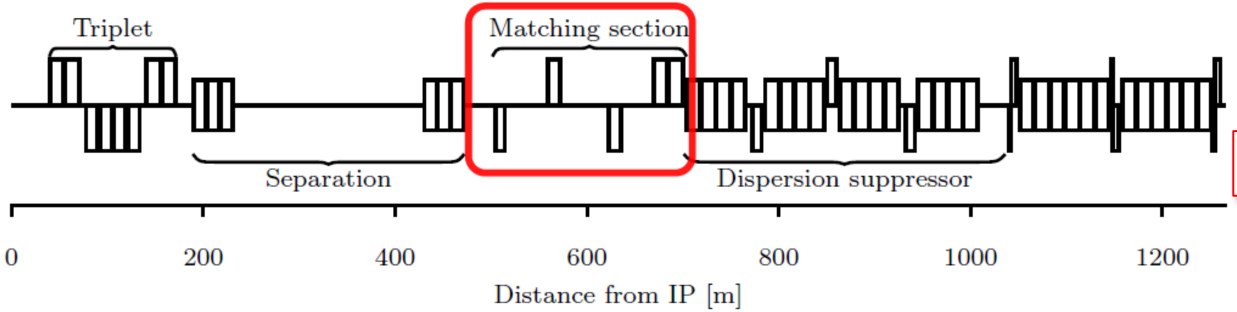


D1 (MBXW design)



D2 (MBW design)

High Luminosity insertions: matching section

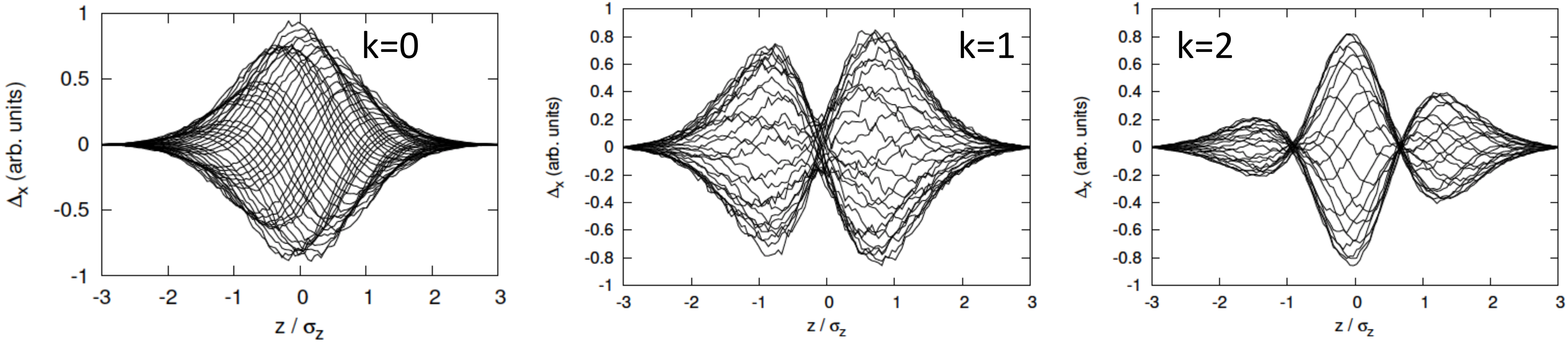


R. Martin

- **Crab cavities** between recombination dipole and first matching quadrupole
- First studies with varying degrees of orbit leakage:
  - Full crabbing at Ultimate parameters: $V_{\text{crab}} = 12.0\,\text{MV}$
  - Full crabbing at $\beta^* = 0.15\,\text{m}$: $V_{\text{crab}} = 18.5\,\text{MV}$
  - $\approx 20\,\text{m}$ of space reserved $\Rightarrow$ expected to be compatible with **full crabbing beyond Ultimate**
- Total IR length now complies with design goal of 1.4 km
- Matched optics found for $\beta^* \geq 0.15\,\text{m}$

Single bunch instability

Head-tail modes (including the k=0 mode) are not rigid-bunch modes:



- ○ Octupoles provide a similar stabilization for higher-order modes
- ○ The 2D “rigid-bunch” dispersion relation can be applied to ”non-rigid” modes
- ○ Octupoles: reliable well-understood damping mechanism
- ○ For k>0: fewer octupoles needed (lower growth rates)
- ○ The k=0 mode will be stabilized by feedback systems.

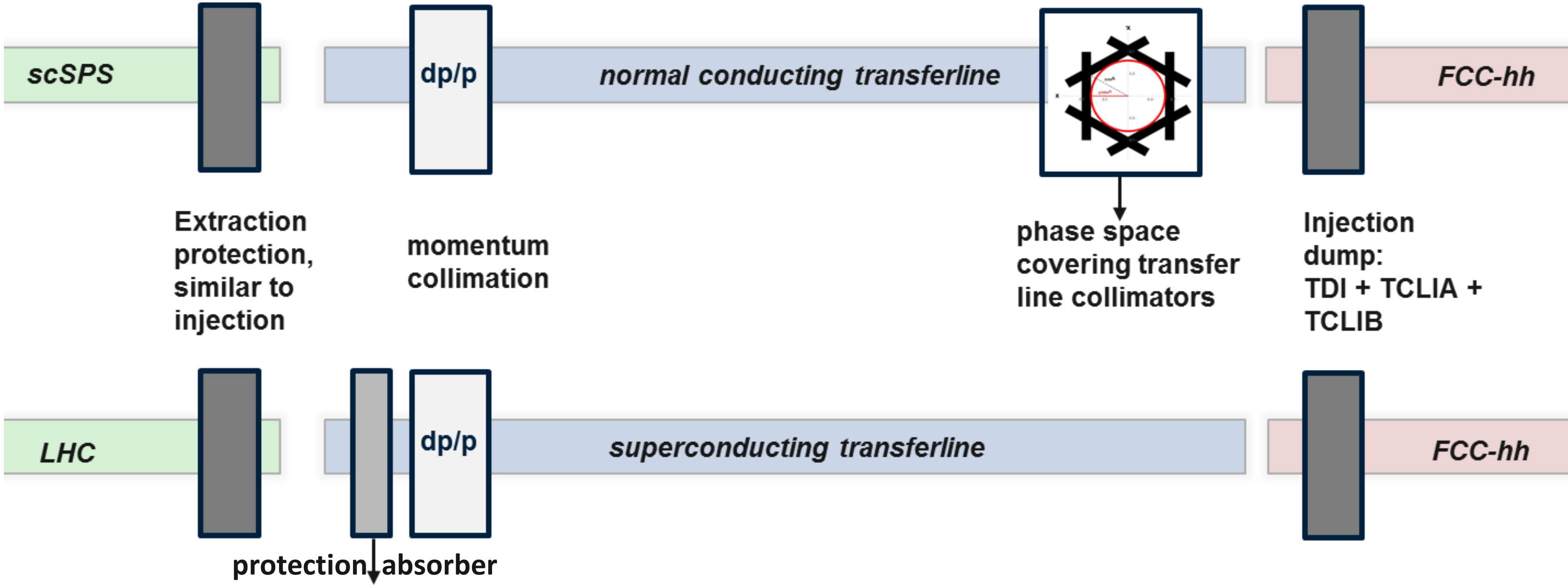
V. Kornilov, to be published

O. Boine-Frankenheim, V. Kornilov

Injection and transfer lines failure/protection

New transferline layout

- → longer straight sections at start and end of the TL were necessary for appropriate protection from extraction / TL failures
- → Increased dipole strength (LHC-FCC: 7.2T, superconducting / scSPS-FCC: 1.8T, normal conducting)



- ►Challenge: transfer 550 MJ
- ►Damage limit of injection dump limits **injection batch length to 80 bunches** (LHC: 288, different energy and intensity)
- ►Short risetime of kicker magnets (430ns) is required to enable FCC-hh filling factor (10400 bunches)
- ►**Novel pulse generator technologies** (Inductive Adder or Marx Generator) for kicker to enable **short risetime, fast recharging (10Hz)** and have **lower failure rates** due to different concept
- ►**Loss studies for injection failures are ongoing**

E. Renner et al.