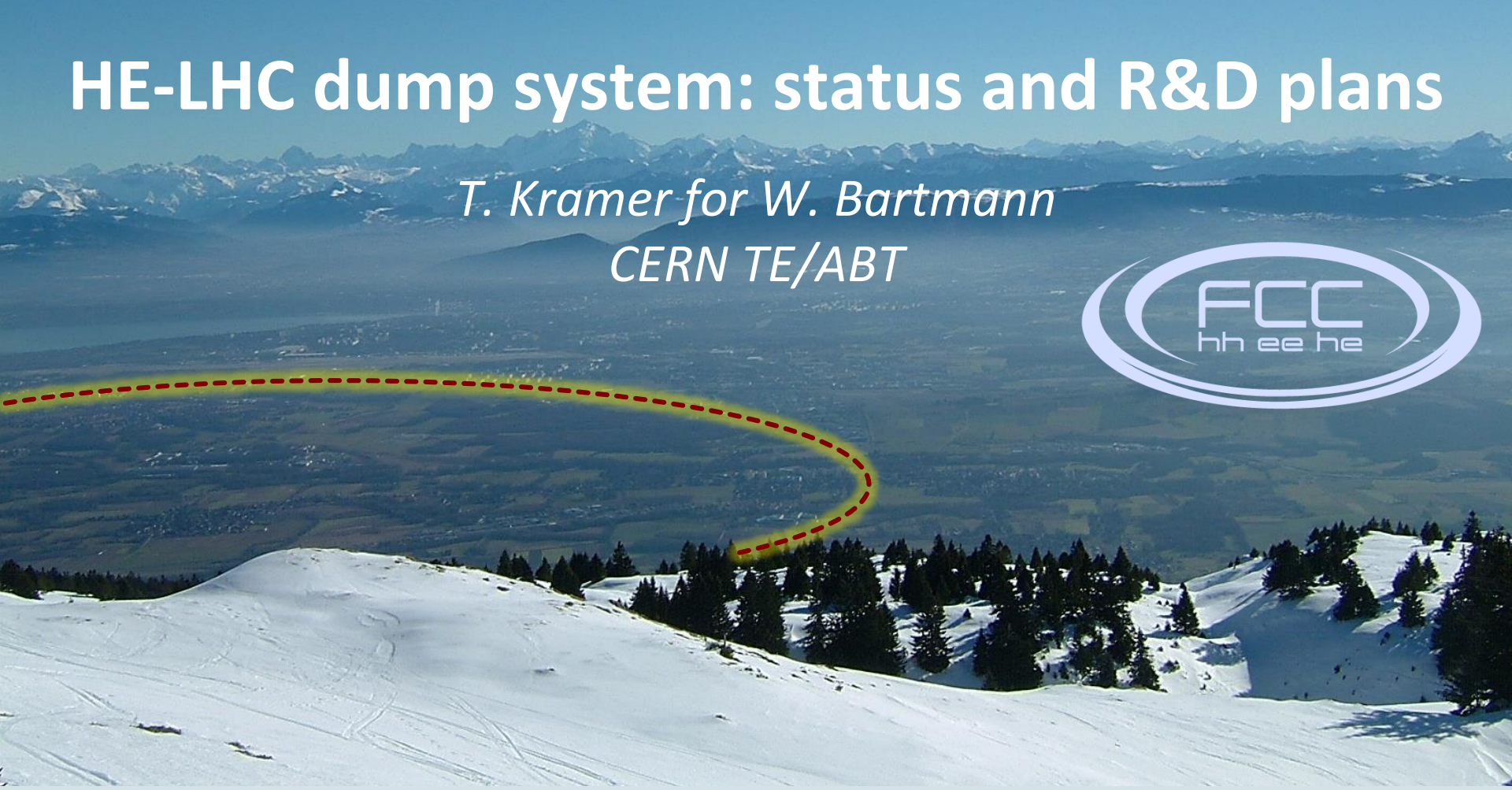
HE-LHC dump system: status and R&D plans

T. Kramer for W. Bartmann
CERN TE/ABT



B. Goddard, M.Hofer, A. Lechner, E.Renner

Overview

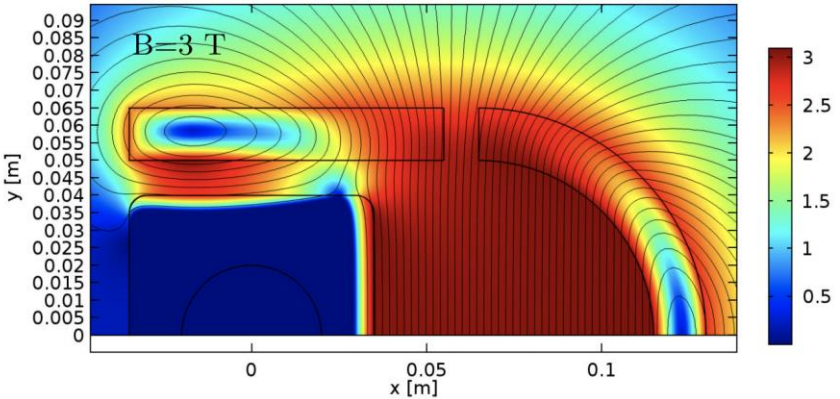
- Introduction and requirements
- 13.5 TeV dump system
  - Extraction kickers and septa
  - Dilution system
- Conclusions & Outlook

Introduction and requirements

- 450, 900 or 1300 GeV injection energy (HE-LHC design choice)
- 13.5 TeV extraction to beam dump
- HL-LHC 25 ns beam parameters
  - 2.2 x 10^{11} pb in 2.5 μm
  - No. of injected bunches at 1.3 TeV limited by absorbers to 100 – 150
- Aim for design with robust (i.e. non-sacrificial) absorbers
  - Layouts, optics and designs constrained by need for absorber survival in the event of kicker failures

Injection

- 450 GeV – straight forward (HL-LHC design)
- For 1300 GeV, rigidity increases by 2.9 for septa and kickers
  - New inj. hardware needed but extraction design profits from reduced aperture
- Several solutions possible
  - **Increase proportionally insertion space** for septa and kicker and limit beta* of experiment: this option will work and therefore no showstopper to inject higher energy beams
  - **Introduce new HW concepts**: superconducting septum, short circuit mode for kickers, higher dI/dt
- Even for short-circuit kicker need more space in lattice (+40 m) to keep same rise time (filling pattern)
  - Impact on experiments and beta* reach
  - Can devise intermediate solution to trade-off space for rise-time (1.5 μs = 20 m)

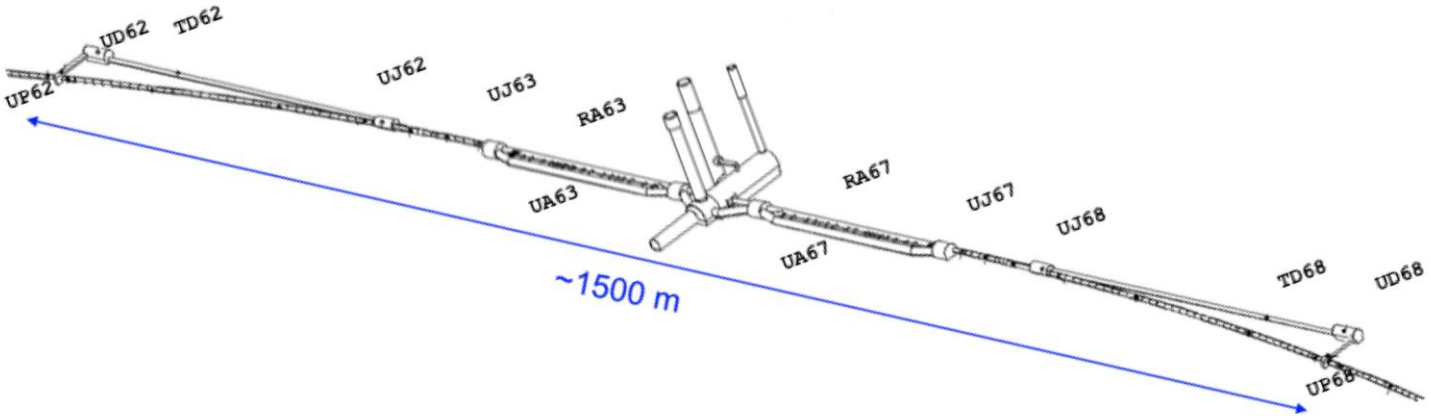


Dump system design assumptions

- Reuse existing tunnel and caverns
  - Similar extraction trajectories in H & V
  - Can assume similar kicker and septum angles
- Maximum **~300 mm** dilution sweep radius
  - Similar quadrupole layout and optics
- 2 matching quads in LSS per side of IP (Q4, Q5)
  - Space available in LSS remains similar to LHC
- Beam parameters
  - 450 / 1300 GeV at injection
  - 13.5 TeV at extraction
  - 2.5e11 p/b at 25 ns bunch spacing, 2800b
  - Stored beam energy **1.4 GJ**

Extraction and beam dump

- Available straight section LSS6 and dump channels TD62/68
  - **Geometry given** – stick to kicker and septa locations similar to existing LHC ones
- LHC Lambertson septa have challenging back-to-back design
  - **Can't compensate** with **higher field/current** for higher beam rigidity
- Assume **superconducting septa** (as studied for FCC-hh)
  - Gain space for additional absorber length
  - Also consider **cryostat passage** through downstream quadrupole, ~1/3 deflection reduction



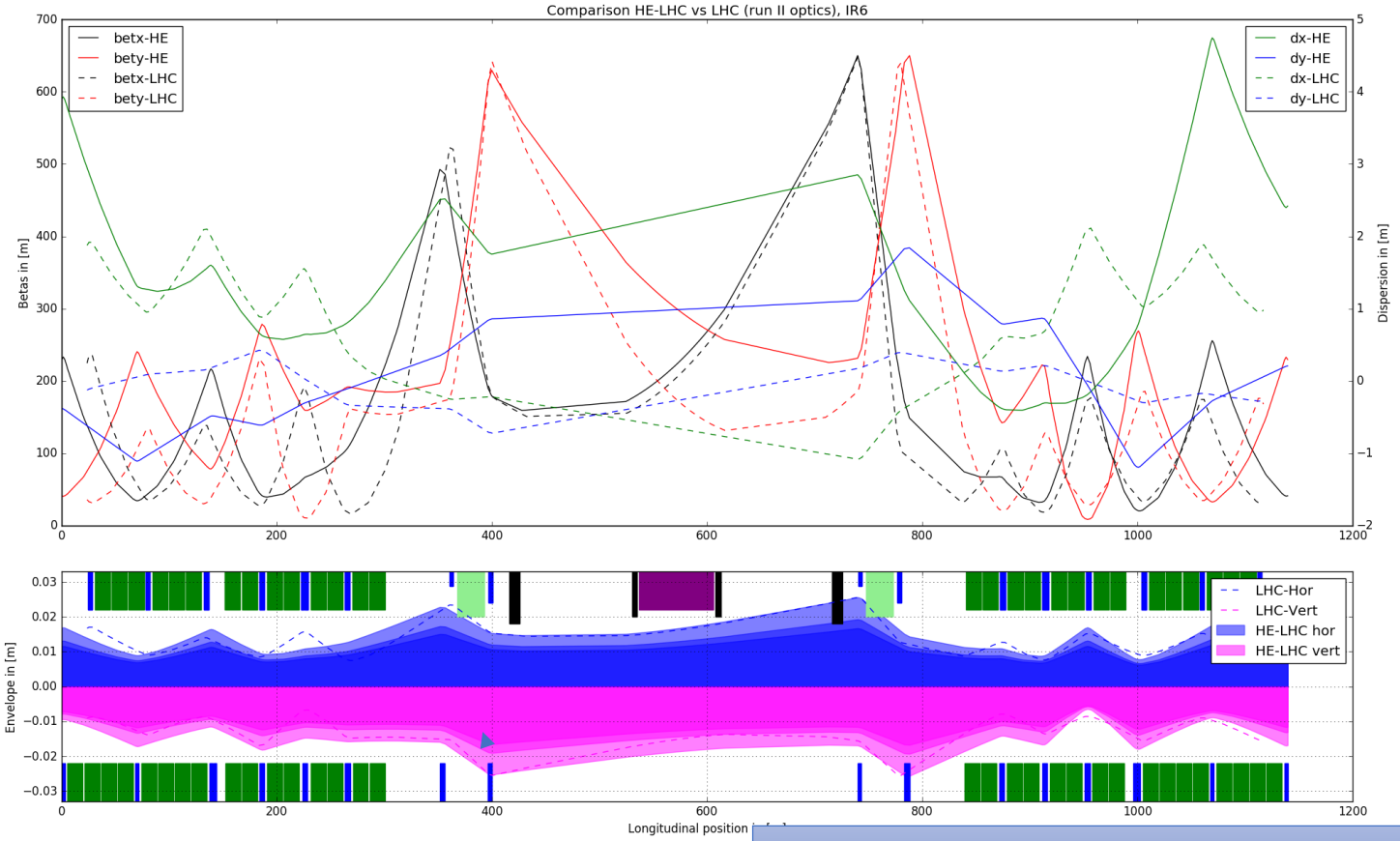
Extraction and beam dump

- For **extraction kickers** assume same required deflection to clear the first thin normal conducting septum blade
  - Compensate with **more magnets, higher current** and dI/dt
  - Profit from the **smaller gap** for the higher injection energy cases (900 and 1300 GeV)
- **Absorbers**
  - Assume same protection functionality as for LHC: Septum protection (fixed) and downstream machine protection absorber (movable, transverse position follows the energy)
- **Optics**
  - Initial optics from HE-LHC repository had beta functions up to 1200 m in IR6 (c.f. 600 m present LHC): larger gaps detrimental for required kicker current

Extraction and beam dump

- LSS6 optics
  - **Can be matched** down to present LHC functions including matching quads in dispersion suppressor
  - **Beta functions** at kicker and septum **fit** with deflection angle and quad kick & aperture
  - **Phase advance** kicker-absorber 90^{o}
  - **Dispersion** to be matched globally
  - Opened the **space between Q4 and Q5** to generate more space for the kickers – limit given by **trade-off with maximum beta functions**
  - Shifting Q5 has the drawback of also shifting the dilution kickers for the other beam further downstream

LSS6 optics for HE-LHC



LHC

HE-LHC

450, 900 and 1300 GeV envelopes; dashed line is present LHC

Extraction kicker parameters

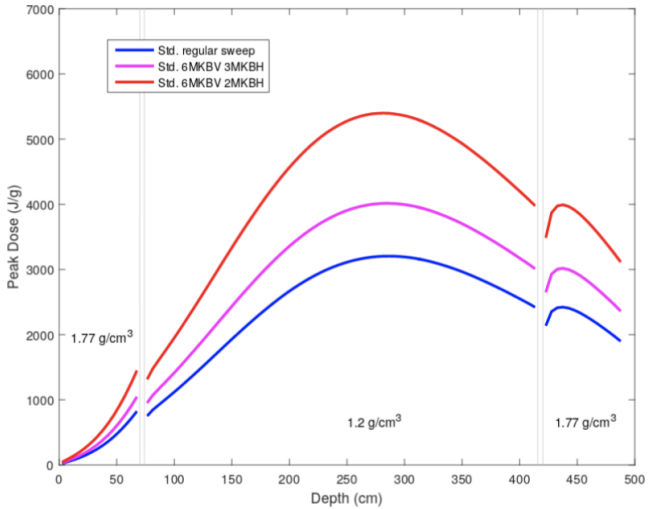
		LHC now	HE-LHC 1300 GeV inj	HE_LHC 450 GeV inj
Deflection angle	mrad	0.27	0.27	0.27
Rigidity	T.m	23337	45034	45034
Required Bdl	T.m	6.30	12.16	12.16
Rise time	s	3.00E-06	3.00E-06	3.00E-06
Aperture width	m	0.072	0.072	0.072
Aperture height	m	0.072	**0.054**	0.072
Magnet length	m	1.42	**0.75**	**0.75**
Gap field	T	0.323	0.49	0.49
Permeability	H/m	1.26E-06	1.26E-06	1.26E-06
Inductance	mH	1.78	1.26	0.94
Corr. factor stray inductance		1.35	1.35	1.35
dI/dt	kA/us	6.2	7.0	**9.4**
Current	kA	18.5	21.1	**28.1**
Impedance	Ohm	0.80	0.57	0.42
Voltage	kV	29.7	23.8	23.8
# magnets		13.7	**33.1**	**33.1**
Total magnetic length	m	19.5	24.8	24.8
Filling factor		0.76	0.76	0.76
Total installed length	m	25.6	32.6	32.6

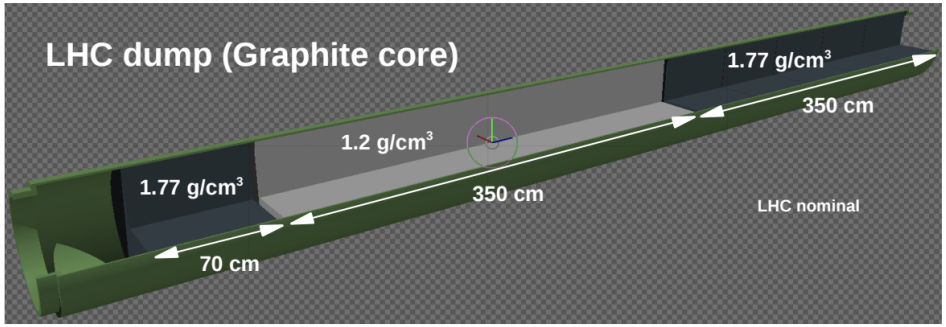
Optics vs extraction kicker parameters

- **Stay quite conservative with gap** compared to earlier solutions – pure scaling with energy is too optimistic from engineering point of view
- Creating **more space in lattice** for kickers **brings current below 30 kA** and dI/dt below 10 kA/us **for 450 GeV** injection energy (still **challenging**)
- **Higher injection energies clearly better** (smaller gap) – 1.3 TeV case compares quite well to present system parameters
- Optics functions at **diluters** similar to present LHC – calculations by A.Lechner show a factor 2-3 above damage limit
  - **Absorber limits** constrain the design: need to get energy density down
  - Increasing spot size of limited help, **separation of bunches more** effective
  - **Faster rise time** helps: however for 2 μs, need 14 kA/s and voltage of 36 kV
  - But higher dI/dt means more **difficult switch design**, and higher voltage gives higher probability for **erratics**

Dilution system

Already a challenge for HL-LHC at 7 TeV



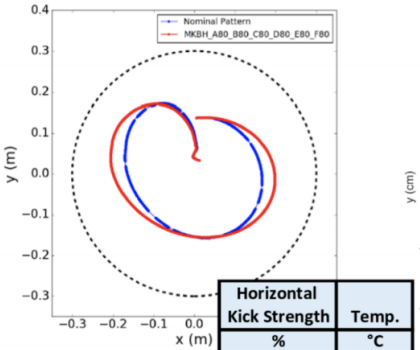


- Regular sweep → peak dose ~ **3 kJ/g**
- 1 MKBH missing → peak dose rising to ~ **4 kJ/g**
- 2 MKBH missing → peak dose rising to > **5 kJ/g**

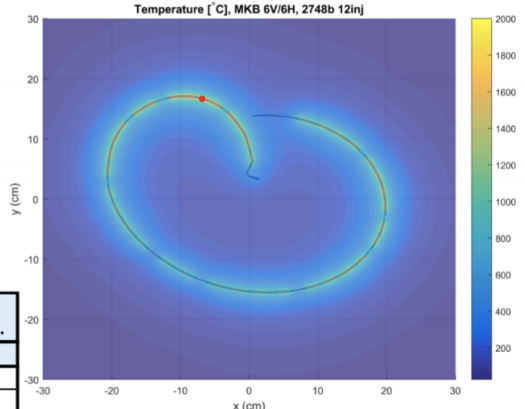
A.Lechner, FCC Design Meeting Dec 7th, 2017

→ **Additional dilution kickers under study:**

120 %

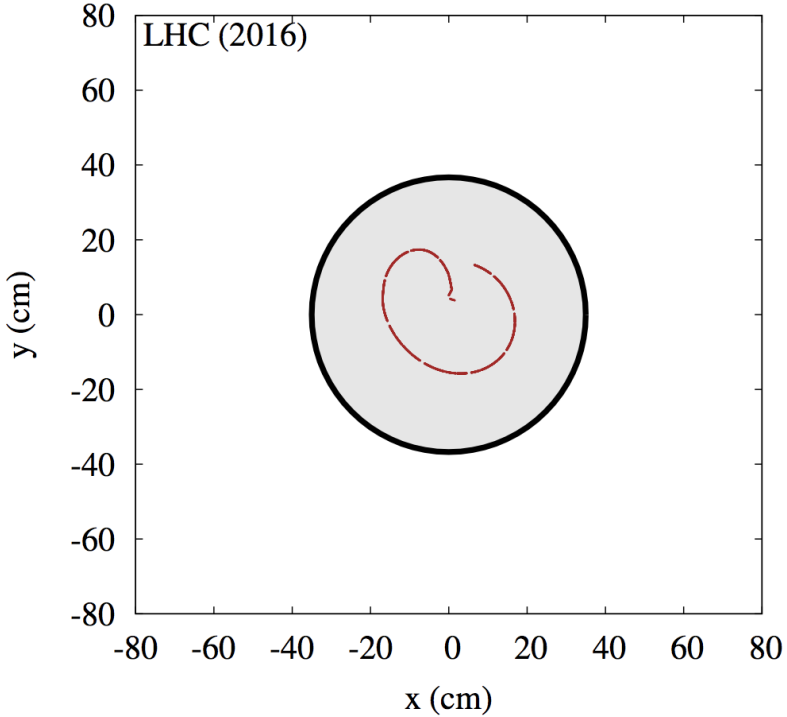


Horizontal Kick Strength	Temp.
%	°C
100	1860
110	1760

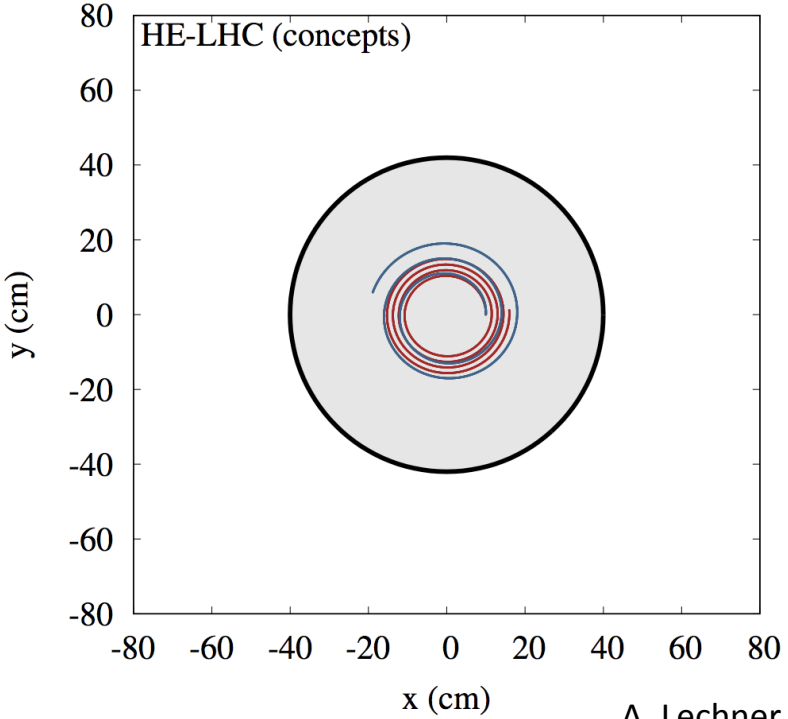


Optimising dilution sweep

- **LHC (core radius = 35 cm):**



- **HE-LHC (core radius ∼ sim to LHC):**



A. Lechner

→ **Started first preliminary (generic) studies with multi-spiral patterns for a LHC-like dump core**

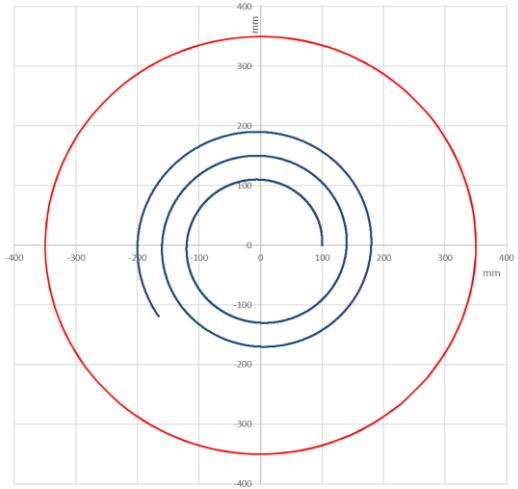
→ **Need a minimum sweep path length which is 2–3 times longer than for LHC (2.5-3.5 m vs 1.2 m)**

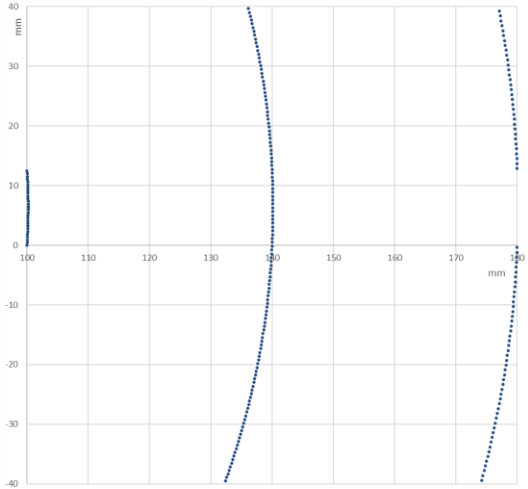
Dilution kicker optimisation

- Aim for **1 g cm^{-3} solid graphite core**
  - Fixes target of ~**2.5m sweep length**
- Optimized dilution sweep kicker characteristics
  - Assumed present kicker dimensions and inductance per unit length
  - Limited magnet current to **25 kA**
  - Limited switch voltage to **30 kV**
  - Varied **module length** and **numbers** to reach target kick, sweep length, voltage and current

Possible dilution kicker parameters

- 2.6 turn spiral
- 38 modules (14h/24v) (vs. 10 for LHC)
- Requires 42 m installed length (vs. 20 m for LHC)
- 44 kHz frequency
- Tight aperture at V dilution kicker exit





		MKBV	MKBH
Module length	m	700	1000
inter magnet gap	mm	300	300
turns		2	1
frequncy	kHz	44.40	44.40
rmax	mm	204	204
H gap width	mm	66	58
V gap height	mm	36	32
num modules		24	14
spacing	mm	200	200
system length	m	23.7	17.9
magnetic length	m	16.8	14
centre	m	30.35	8.95
drift to TDE	m	619.65	641.05
kick needed	mrad	0.329	0.318
rigidity	Tm	45005	45005
Bdl needed	Tm	14.82	14.32
field needed	T	0.88	1.02
mu0	H	1.26E-06	1.26E-06
current needed	kA	23.16	26.05
Inductrance	uH	2.21	3.98
voltage needed	kV	28.6	28.9
H offset at exit	mm	10.6	2.4
V offset at exit	mm	4.1	0

Summary

- HE-LHC injection
  - Still 2 choices: Whilst 450 GeV inj. is available, dump system design would profit from 1.3 TeV
- Dump extraction for 13.5 TeV is feasible
  - **More space** for extraction kickers, and **advances in technology** assumed
  - Need to work out solution for (protection) **absorber limits vs. rise time**
  - Trade-off between **failure probability** and **consequences**
  - **Septa** require **SC technology** and/or cryostat passage
- Dump **dilution** system most **challenging**
  - Failure scenarios also to consider in design

Outlook

- Status is only **initial conceptual design**, need to go in first HW design to iterate within ABT
- Assuming there is only one FCC machine for TDR design (HE-LHC would replace FCC-hh)

- Resources to progress towards TDR:
  - Beam physics: Comparable to FCC-hh ~1 FELL
  - Estimates for hardware
    - Injection strongly depending on energy - for 1.3 TeV R&D needs similar to FCC-hh (1 PhD)
    - Extraction, dilution & protection elements: more detailed conceptual design needed; big design challenge due to space constraints (1 FELL kickers, 1 FELL septa)