

# Injection and Extraction System of Hadron Collider

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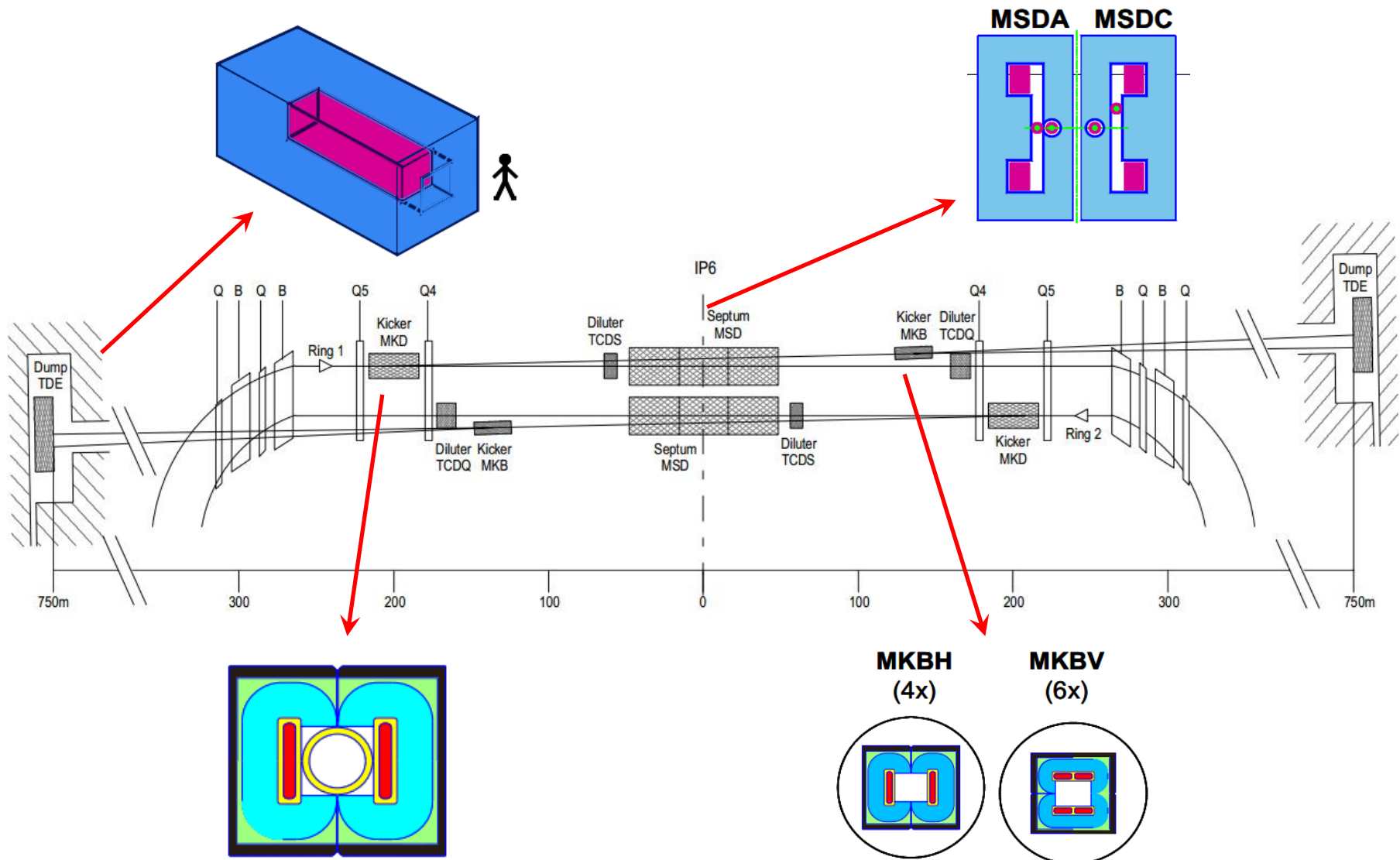
# Outline

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- ❑ Brief review of injection and extraction system of LHC
- ❑ Challenge of inj./ext. system for SppC/FCC

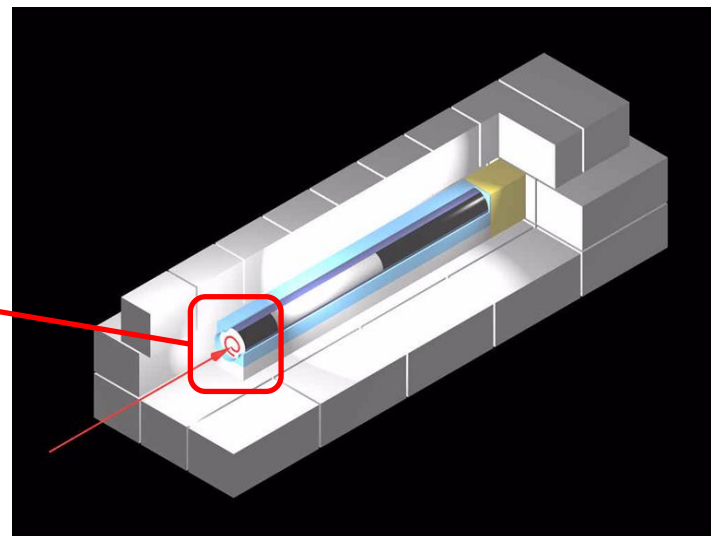
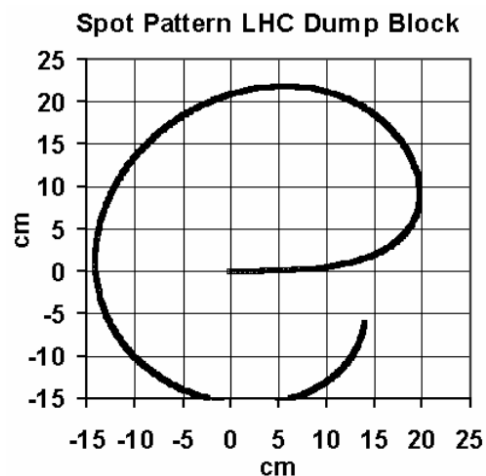
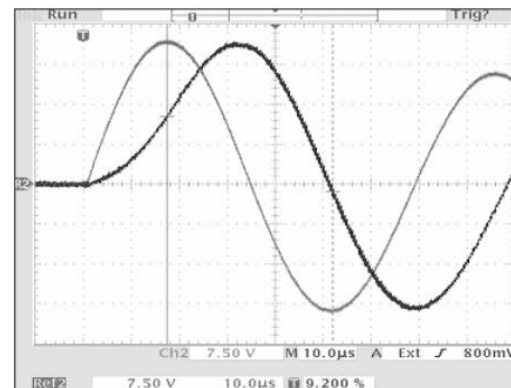
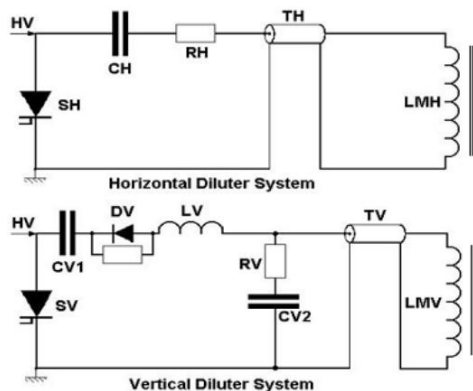


# Brief review of LHC extraction system

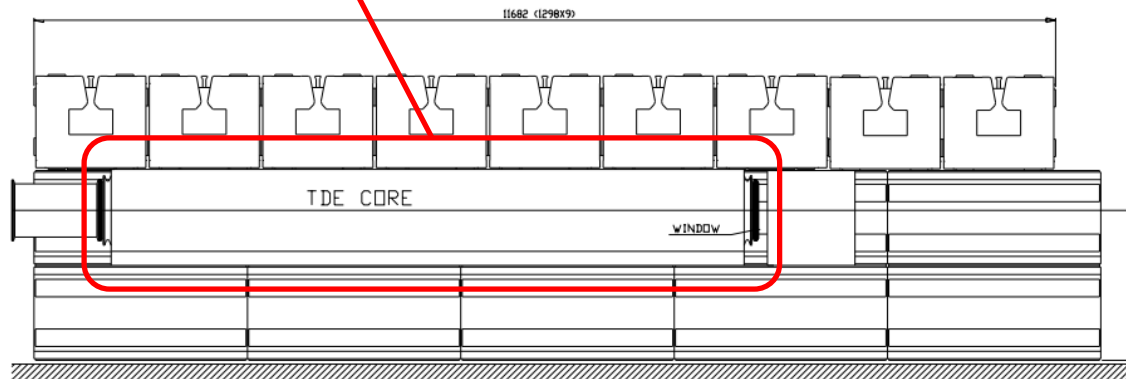


# Brief review of LHC extraction system

## □ Fast-Pulsed Dilution Magnets(MKB)



## ■ Beam Dump Absorber Block TDE



- 
- Technical drawing of a 3D structure, likely a container or storage unit. The drawing shows a top view with a central rectangular section labeled '2440' and a side view below it. The side view shows a structure with three vertical sections, each containing a smaller rectangular opening. The overall width is labeled '1290' and the height is labeled '1050'.

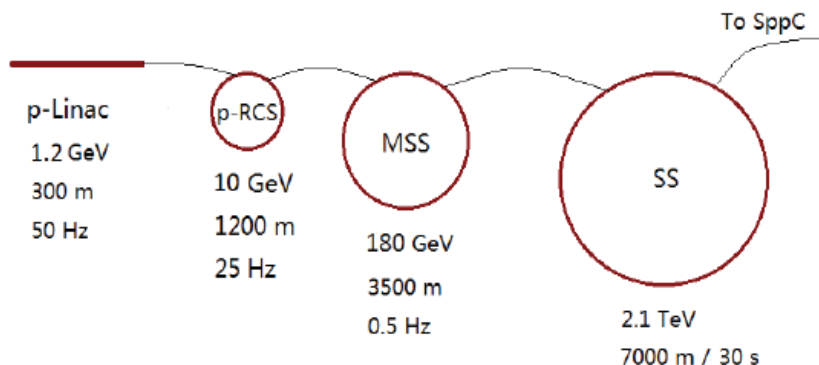
# Challenge of Inj./Ext. system for SppC/FCC

## □ Injection chain

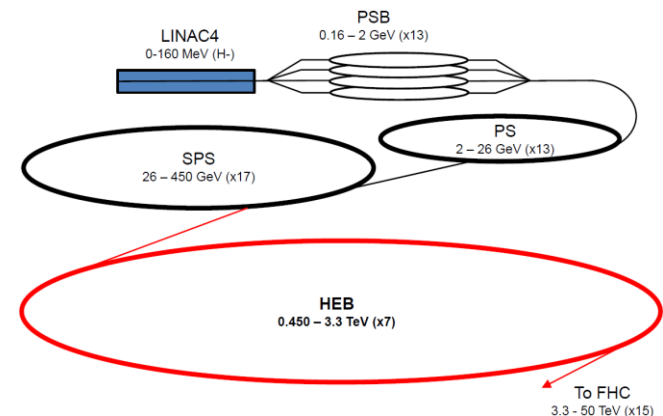
Parameter	LHC	SSC	SPPC	FCC	Unit
Injection energy	0.45	1.0	2.0	3.3	TeV
Injection rigidity	1504	3339	6674	11010	T·m
Final energy	7.0	20	35.6	50	TeV
Final rigidity	23352	66714	118556	166785	T·m
Bunches	2808	17100	5835	10600	
Bunch population	1.15e11	7.3e9	2e11	1e11	
Total beam energy	0.362	0.405	6.6	8.5	GJ

- For SppC, a new injection will be built
- For FCC, part of LHC's injection chain may be reused
- TeV level injection energy can cause serious problem for injection kicker, machine protection and safely running of injection chain

### SPPC



### FCC

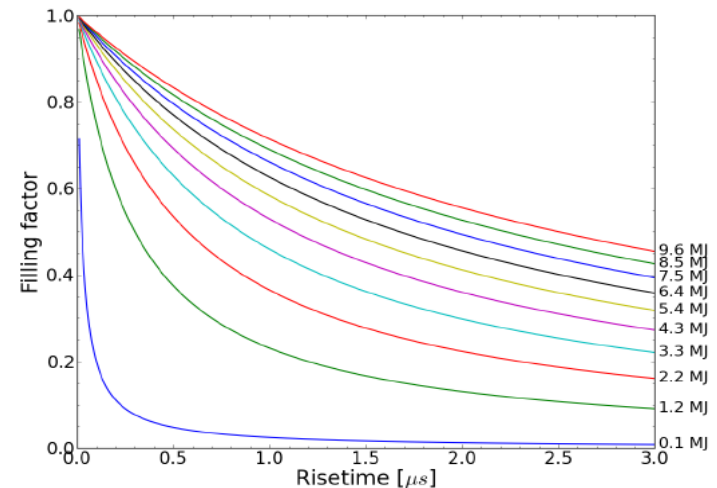
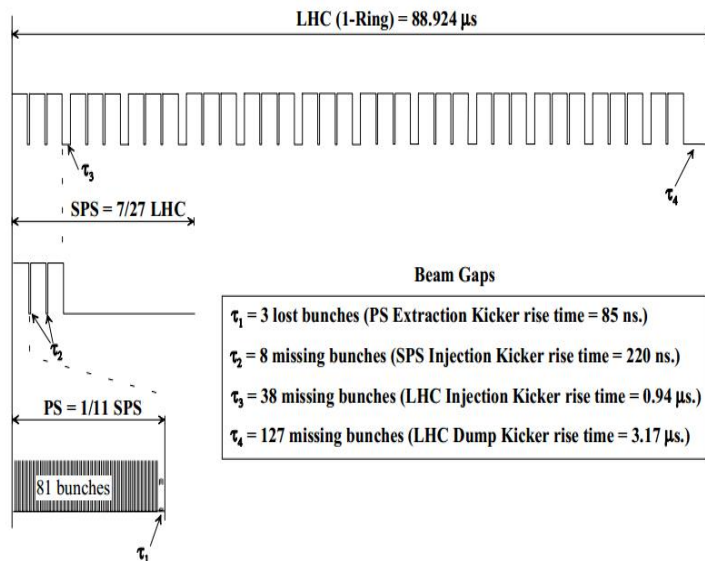


# Challenge of Inj./Ext. system for SppC/FCC

## □ Beam injection from HEB to FCC

	LHC as HEB	HEB at SPS	HEB at FCC
Magnets	Superconducting, Double aperture	Superconducting, Fast ramping, Single aperture	Superferric, Single aperture, Polarity reversal
Energy	3.3 TeV (1–6.5 TeV)	1.5 TeV	3.3 TeV (1–5.5 TeV)
FCC filling time	40 min	34 min	29 min

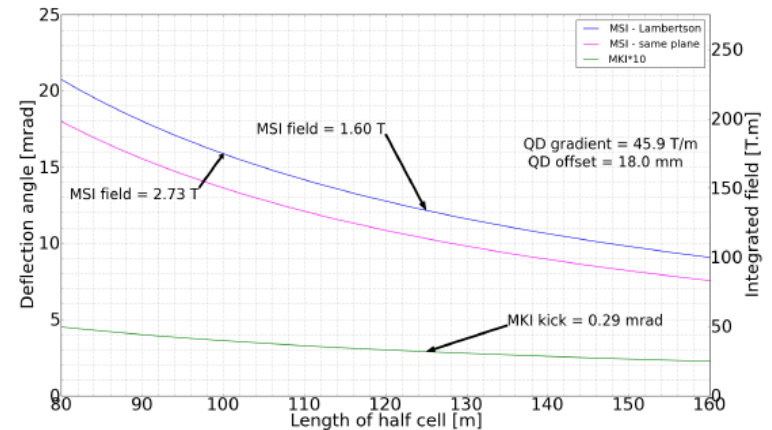
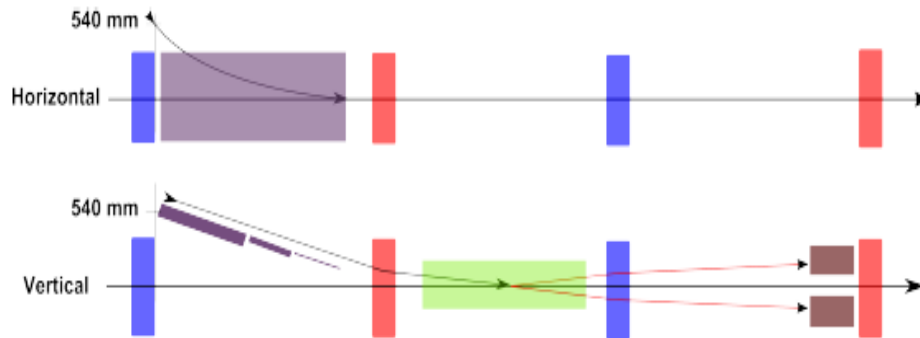
- The beam injection from HEB to FCC is mainly constrained by machine protection, staggered transfer is proposed
- Each transfer should **not exceed 5 MJ**
- The injection kicker rise time must not exceed 280 ns to reach a filling factor of 80%





# Challenge of Inj./Ext. system for SppC/FCC

## □ Beam injection from HEB to FCC

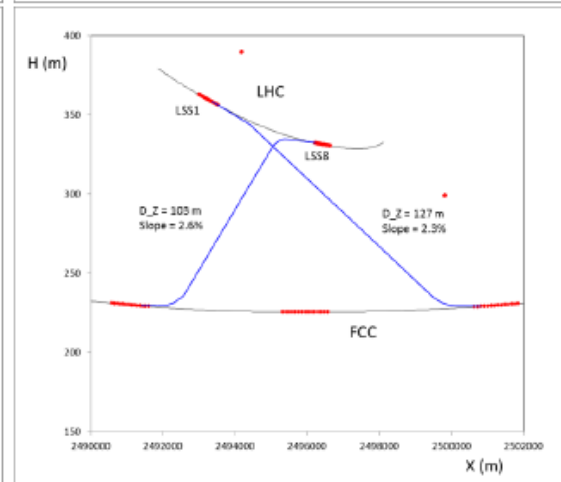
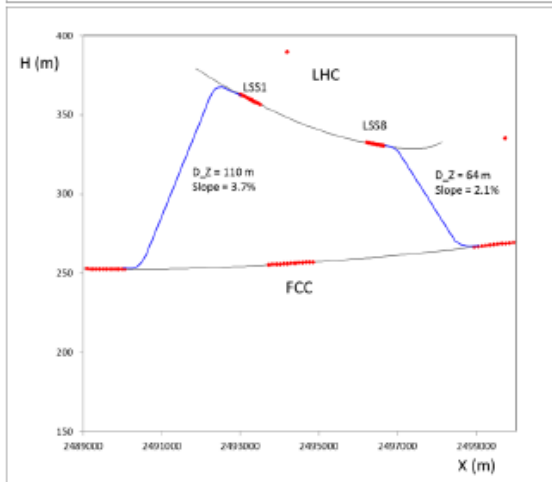
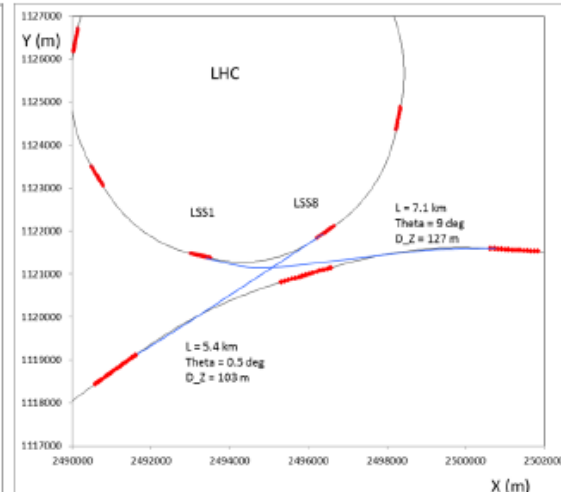
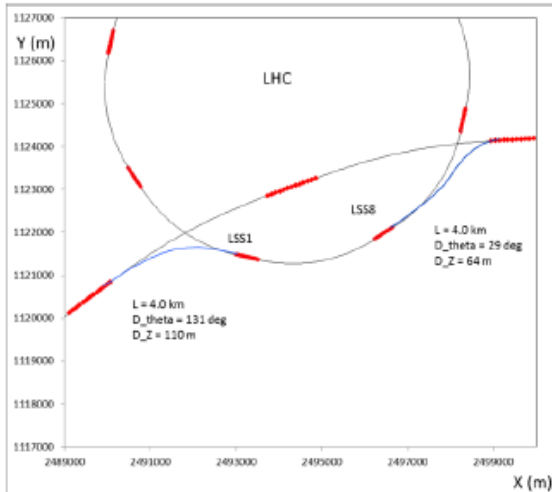


Hardware Parameters	Unit	Kicker	Septum
Deflection	mrad	0.29	12.3
Integrated field	T.m	3.2	134
Available system length	m	120	90
Rise time	$\mu$ s	0.28	-
Flat-top length	$\mu$ s	2.25	$\geq 2.25$
Flat-top stability	%	$\pm 0.5$	$\pm 0.5$
GFR h/v	mm	18/18	18/18

- The layout of injection system is similar to LHC's
- Increasing the half length to reduced the required kicker strength

# Challenge of Inj./Ext. system for SppC/FCC

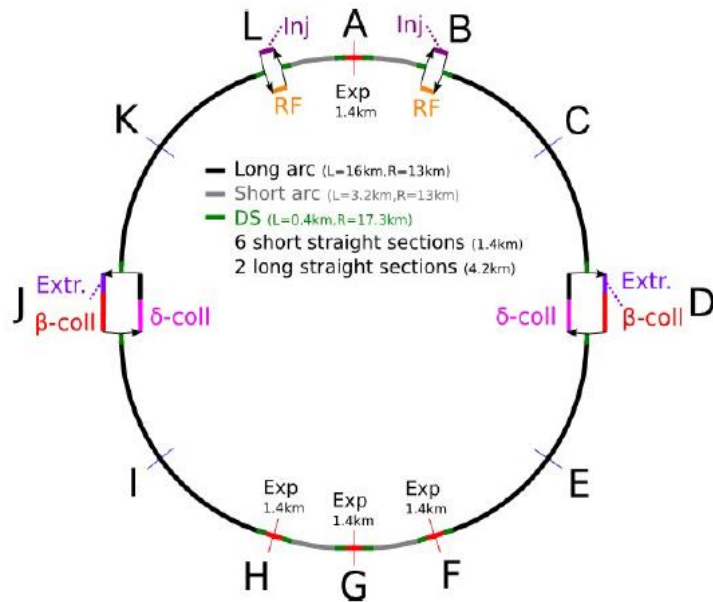
## ❑ Beam injection from HEB to FCC



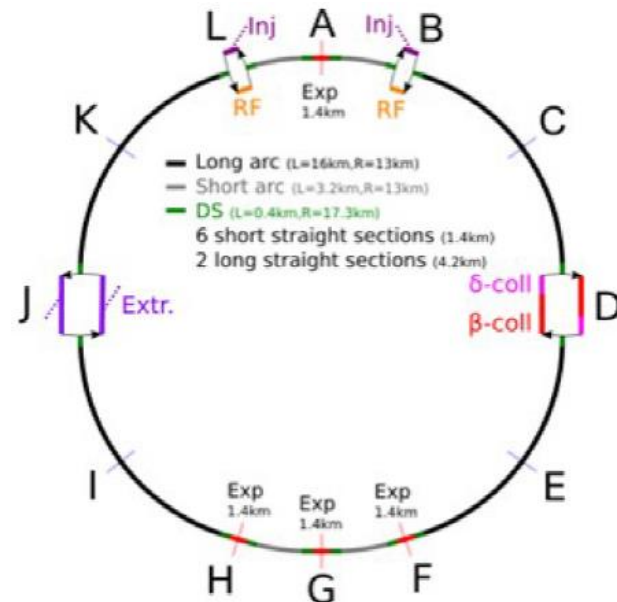
- Both transfer lines of the intersecting option measure 4 km, the transfer lines of the non-intersecting option measure 7.1 and 5.4 km
- The bending angle of intersecting option is  $150^\circ$  more than non-intersecting option, thus **require 6 km longer dipole length**

# Challenge of Inj./Ext. system for SppC/FCC

## Layout of beam extraction system of FCC



Baseline layout

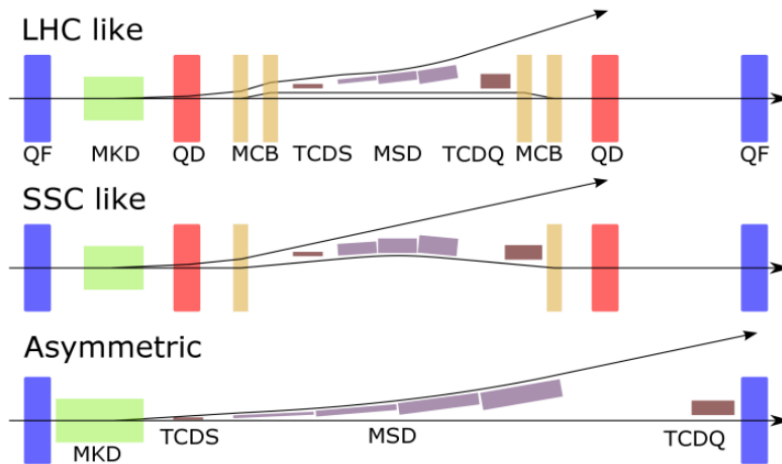


Alternative layout

- The benefit of baseline layout is that beta collimation provide complementary protection
- The disadvantage of baseline is the impact of momentum collimation showers on the sensitive kicker

# Challenge of Inj./Ext. system for SppC/FCC

## ❑ Extraction system of FCC



- Purely scaled LHC extraction system is not advantageous in hardware parameters, MCBs are added to reduce kick/septa's strength
- The SSC like option requires a very stable current and careful septa field design
- Asymmetric option can provide enough physical space to accommodate a **highly segmented kicker system**

Table 2: FCC-hh Kicker Parameters

Parameter	LHC scaled	LHC like	SSC like	Asym.
B.dl [T.m]	46	22	25	25
Available length [m]	100	100	100	125
Magnets	108	25	28	290
Magnetic length [m]	153	37	42	87
B-field [T]	0.3	0.6	0.6	0.3
Aperture (v) [mm]	56	36	36	36

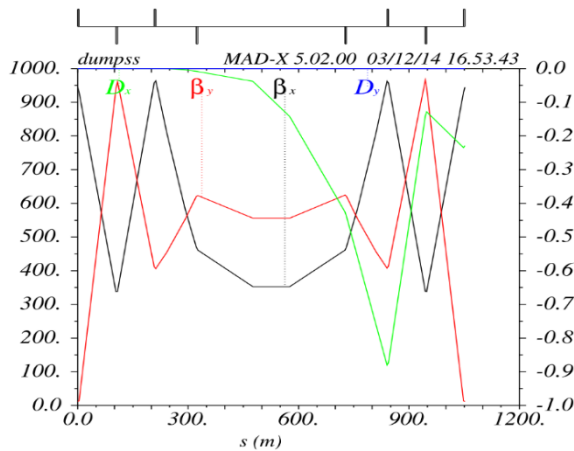
Table 3: FCC-hh Septa Parameters

Parameter	LHC scaled	LHC like	SSC like	Asym.
B.dl [T.m]	400	284	334	317
Available length [m]	200	200	300	344
Magnetic length [m]	442	<200	<300	<344
B-field [T]	1	1.4	1.2	1

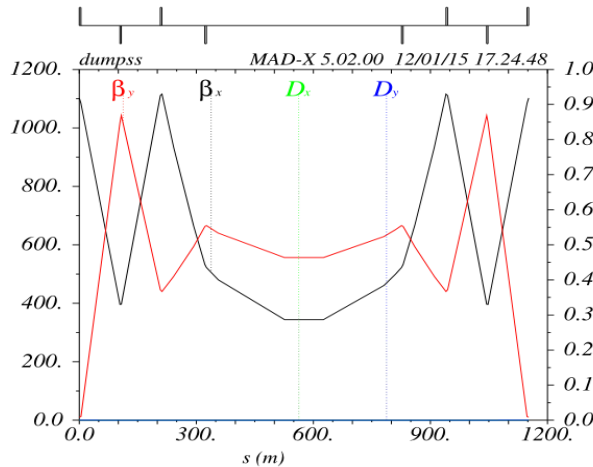
# Challenge of Inj./Ext. system for SppC/FCC

## ❑ Extraction system of FCC

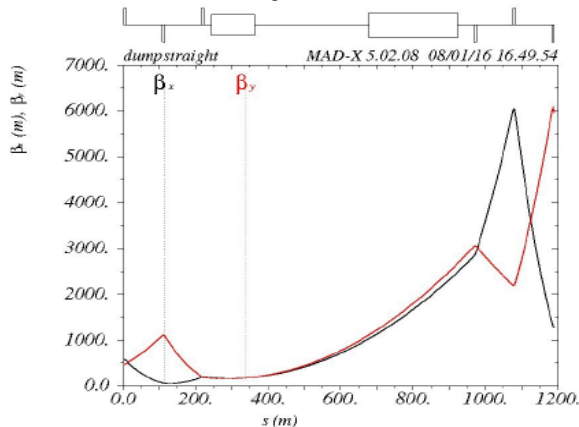
LHC like



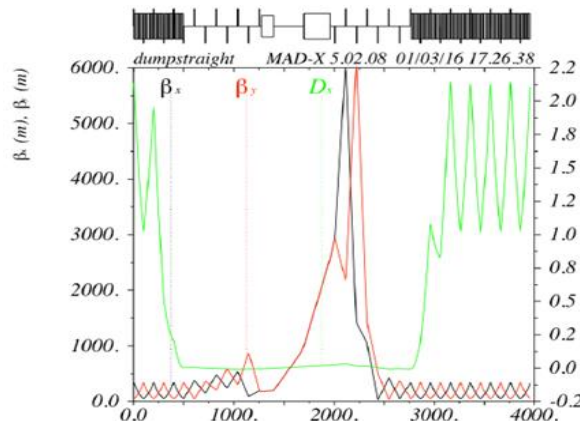
SSC like



Asymmetric



Asymmetric



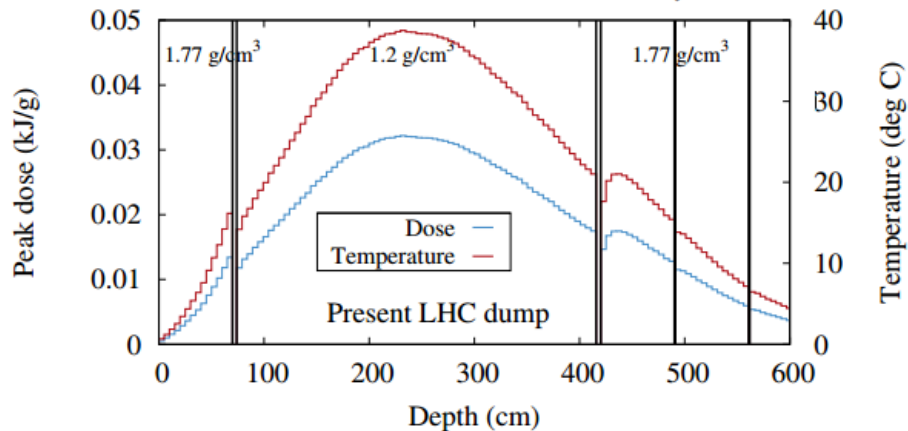
- The optics of LHC like option and SSC like option are similar
- For asymmetric option, the **small beta function at extraction kicker** opens the possibility not to retrigger the full system, the **high beta function at septum and quadrupole** protection absorbers

# Challenge of Inj./Ext. system for SppC/FCC

## ❑ Dump system consideration

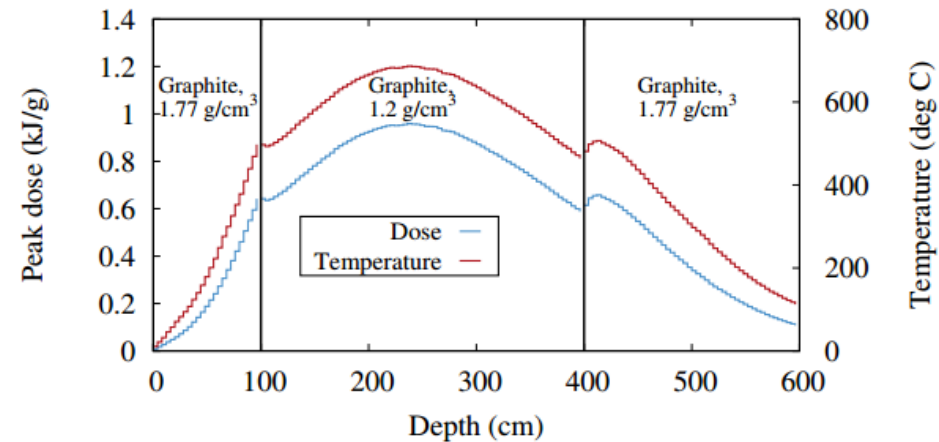
LHC

7 TeV, 1 bunch ( $1.15 \times 10^{11}$  p),  $\sigma_x = 1580 \mu\text{m}$ ,  $\sigma_y = 1410 \mu\text{m}$



FCC

50 TeV, 1 bunch ( $1.1 \times 10^{11}$  p),  $\sigma = 400 \mu\text{m}$

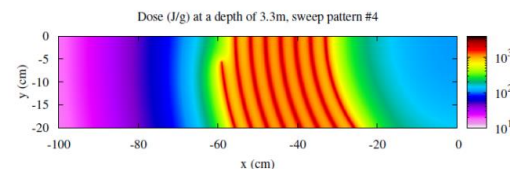
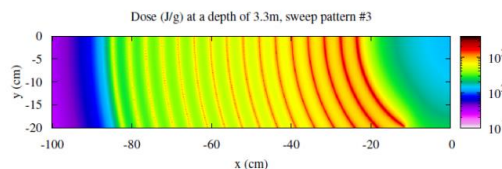
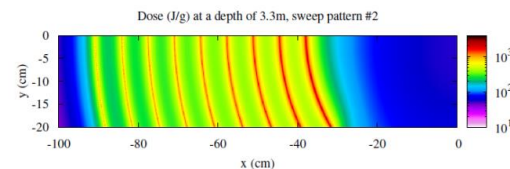
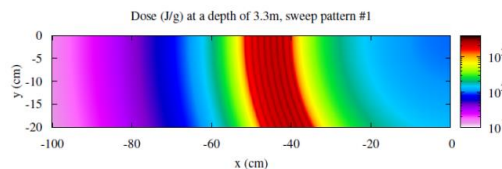
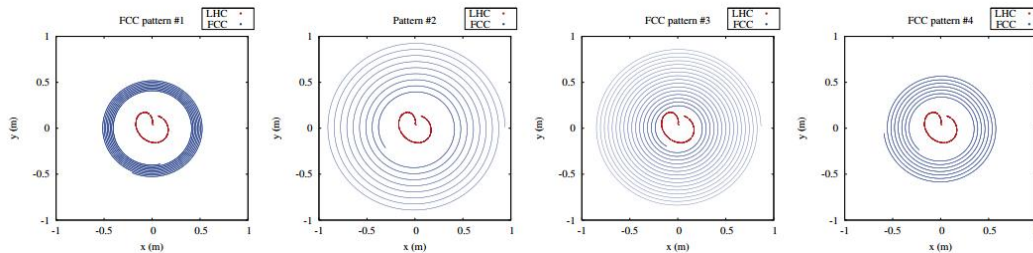


- Peak energy density increases by a factor  $\sim 30$
- Entire dump needs to be longer to sufficiently absorb showers

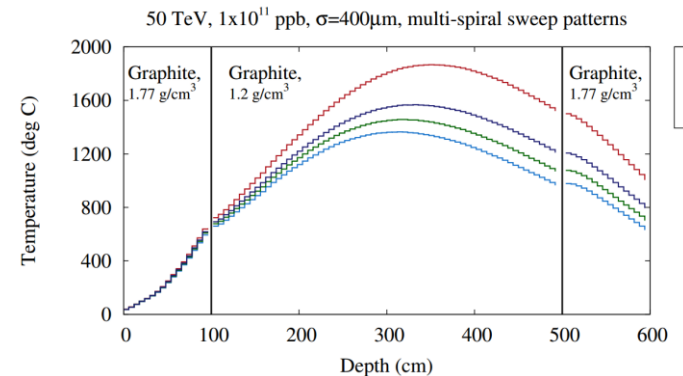
# Challenge of Inj./Ext. system for SppC/FCC

## □ Dump system consideration

	MKB frequency modulation	Frequency	B-dl <sup>a)</sup>	Distance between neighbouring bunches	Distance between neighbouring branches
#1 <sup>b)</sup>	No	32.8 kHz	34 Tm	2.00–2.64 mm	1.6 cm
#2	No	32.8 kHz	56 Tm	1.87–4.70 mm	6.5 cm
#3 <sup>c)</sup>	No	50.9 kHz	53 Tm	1.83–6.95 mm	4.0 cm
#4 <sup>c)</sup>	Yes	20–43 kHz	39 Tm	1.90 mm	3.7 cm



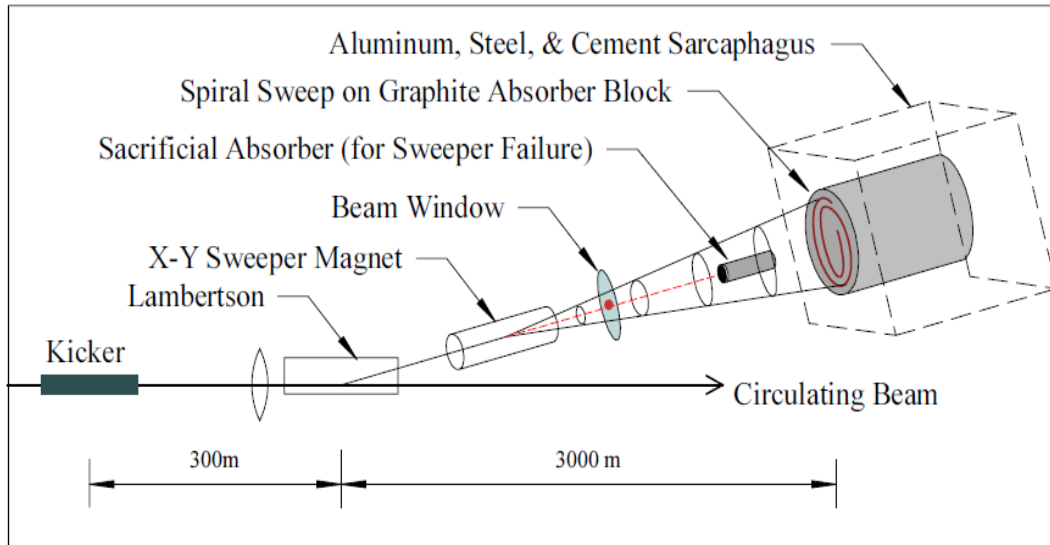
- Linear sweep to estimate peak energy density
- Distance of 2 mm between bunches should keep peak temperature below 2000 °C
- For 10600 bunches, the sweep length would be 21.2 m



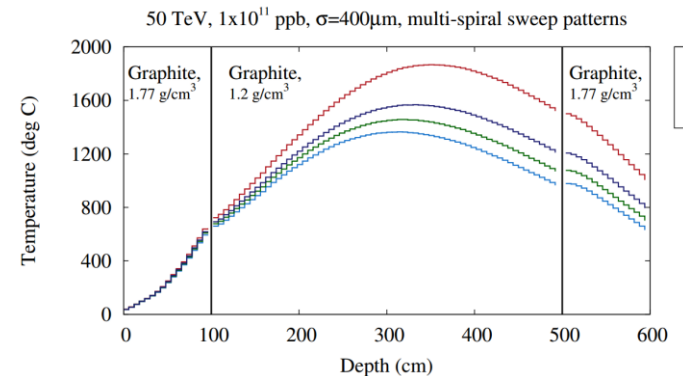
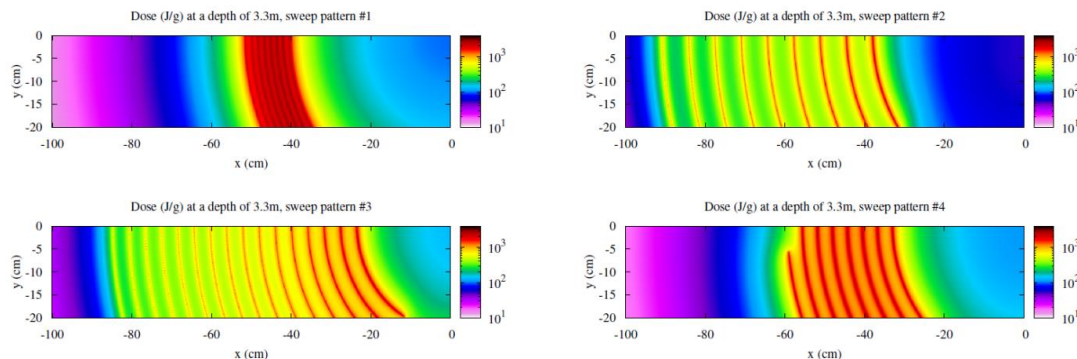


# Challenge of Inj./Ext. system for SppC/FCC

## ❑ Dump system consideration



- Linear sweep to estimate peak energy density
- Distance of 2 mm between bunches should keep peak temperature below 2000 °C
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Thank you for your attention!