Preliminary studies on SPPC collimation

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Outline

- Why SPPC needs collimation
- Introduction about LHC collimation system
- Upgrades of collimation system for HL-LHC
- Consideration about new collimation optics for SPPC
- Preliminary studies about collimation materials
- Advanced collimation concepts
- Conclusions and plans

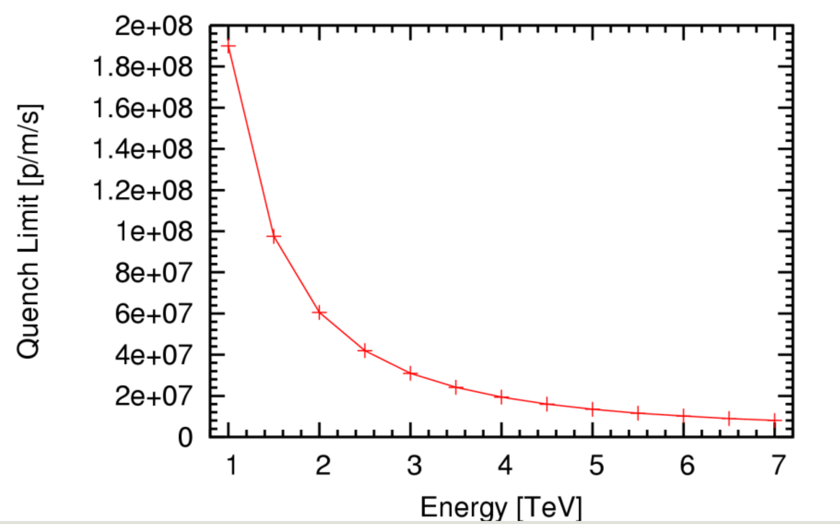
Why SPPC needs collimation system

- Beam loss: Touschek effect, beam-beam interactions, transverse and longitudinal diffusion, residual gas scattering, instabilities and so on
- Quench prevented: for SC machines
- Machine protection: prevent damaging radiation-sensitive devices
- Reduction of total doses: hands-on Maintenance
- Cleaning of physics debris: collision products
- Optimize background: in the experiments

$$N^{q}_{\mathrm{tot}} = \frac{\tau_{min} R_q}{\tilde{\eta}_c}$$

minimum beam lifetime

cleaning inefficiency at limiting cold location



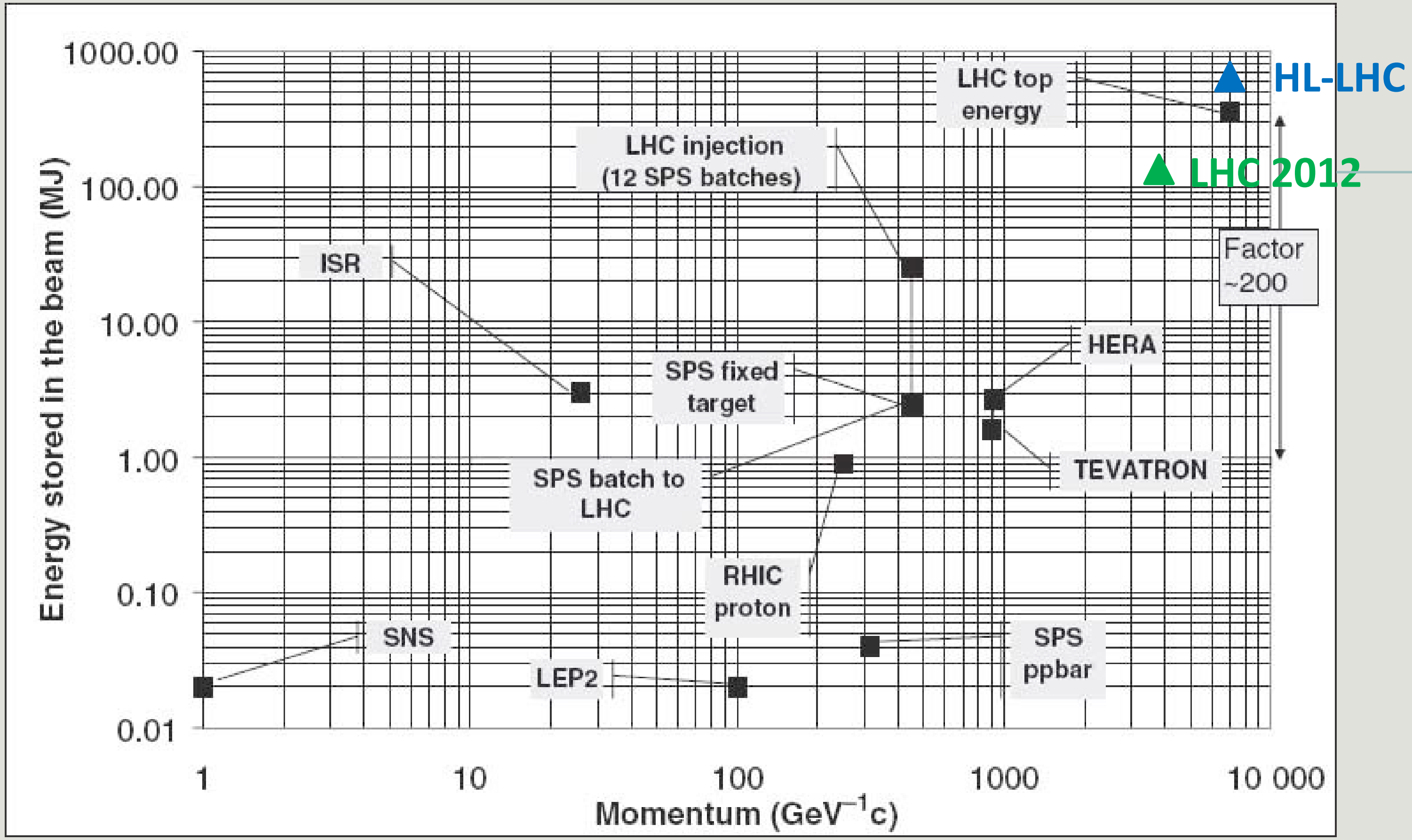
Collimation system is very important for SPPC!

FCC 8.5 GJ

SPPC 6.6 GJ

Large stored energy, very difficult for collimation

Factor~18



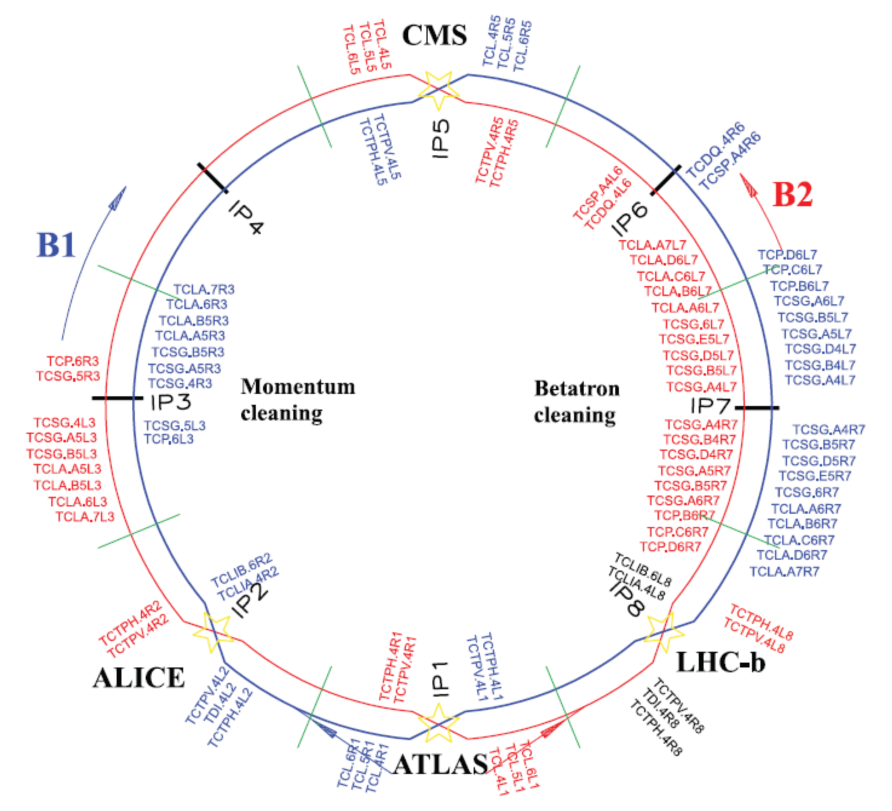
What is Energy of 1 SPPC beam equivalent to?

Airbus A380

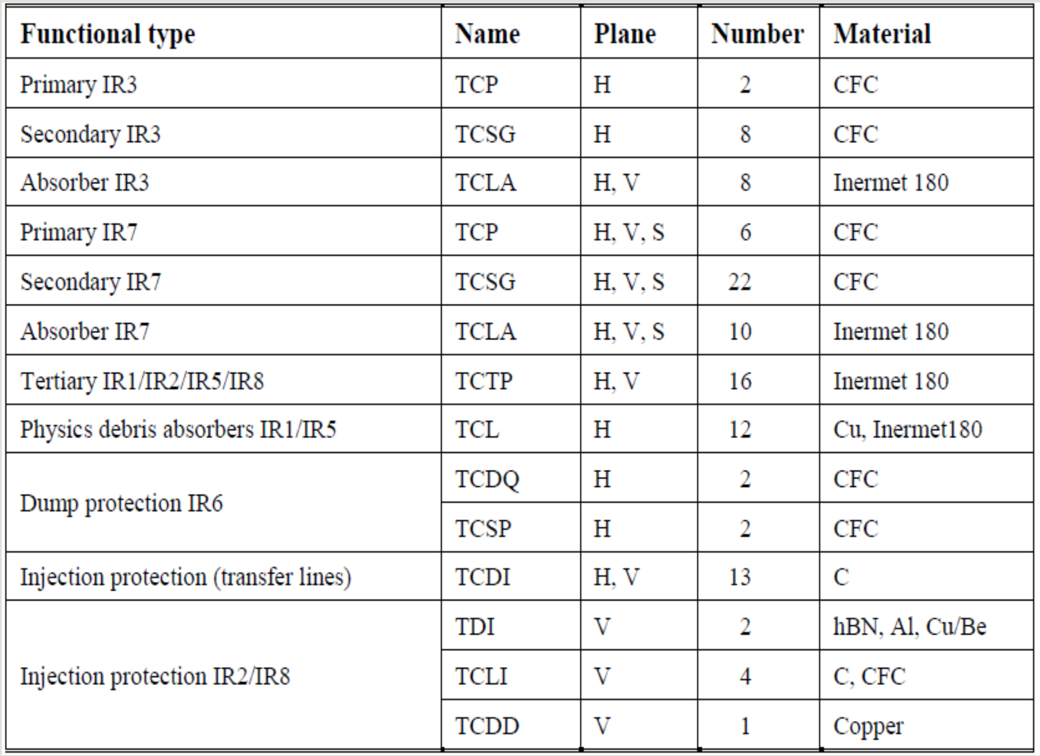
1576kg TNT

Introduction about LHC collimation system

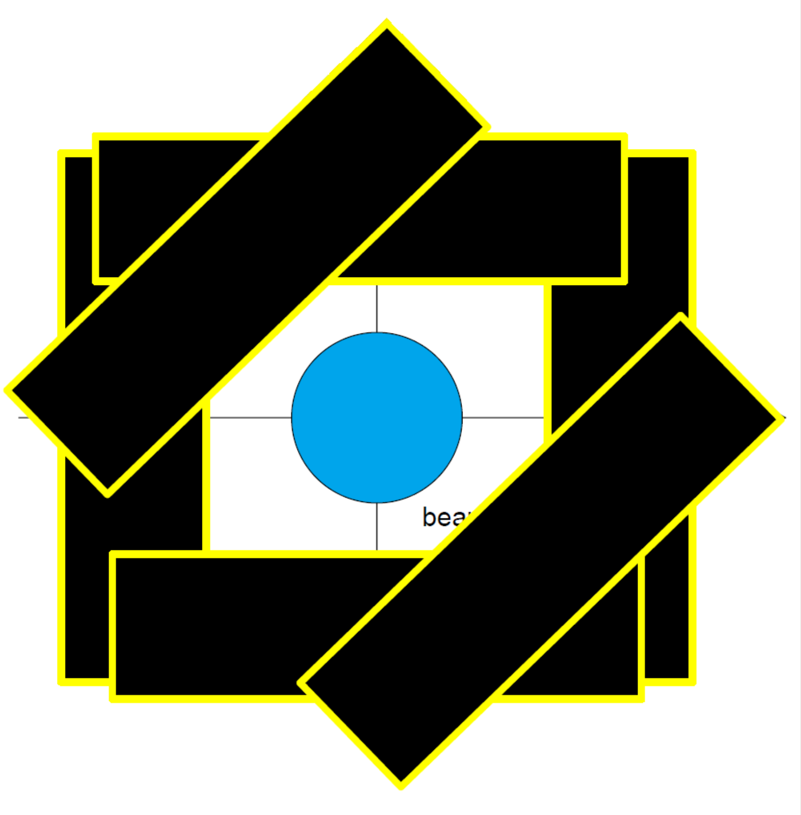
- Very good performance of collimation system so far
- The cleaning inefficiency ~ $\mathbf{10^{-5}}$
- IR3 for momentum collimation and IR7 for betatron collimation
- 108 movable collimators (TCP, TCSG, TCT, TCLA..)
- Dogleg lattice



Introduction about LHC collimation system

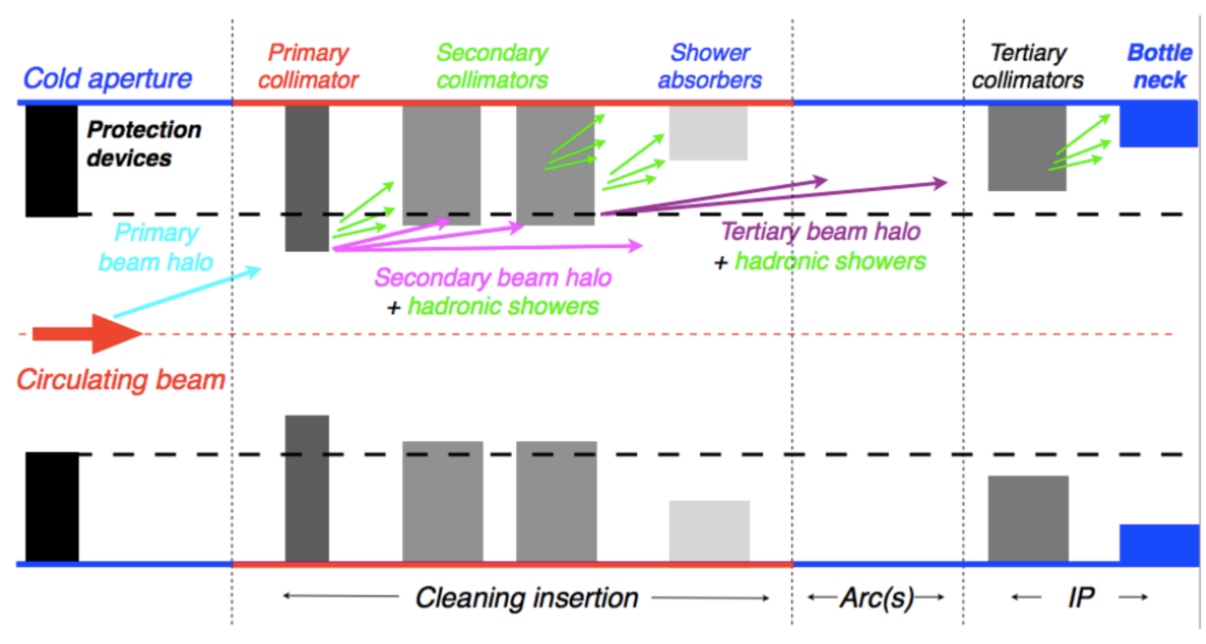


Functional type	Name	Plane	Number	Material
Primary IR3	TCP	H	2	CFC
Secondary IR3	TCSG	H	8	CFC
Absorber IR3	TCLA	H, V	8	Inermet 180
Primary IR7	TCP	H, V, S	6	CFC
Secondary IR7	TCSG	H, V, S	22	CFC
Absorber IR7	TCLA	H, V, S	10	Inermet 180
Tertiary IR1/IR2/IR5/IR8	TCTP	H, V	16	Inermet 180
Physics debris absorbers IR1/IR5	TCL	H	12	Cu, Inermet180
Dump protection IR6	TCDQ	H	2	CFC
	TCSP	H	2	CFC
Injection protection (transfer lines)	TCDI	H, V	13	C
Injection protection IR2/IR8	TDI	V	2	hBN, Al, Cu/Be
	TCLI	V	4	C, CFC
	TCDD	V	1	Copper



Introduction about LHC collimation system

- The primary collimators (TCPs) are the closest to the beam in transverse normalized space, cutting the primary halo
- The secondary collimators (TCSGs) cut the particles scattered by the primaries (secondary halo)
- The absorbers (TCLAs) stop the showers from upstream collimators
- The tertiary collimators (TCT) protect directly the triplets at the colliding IRs

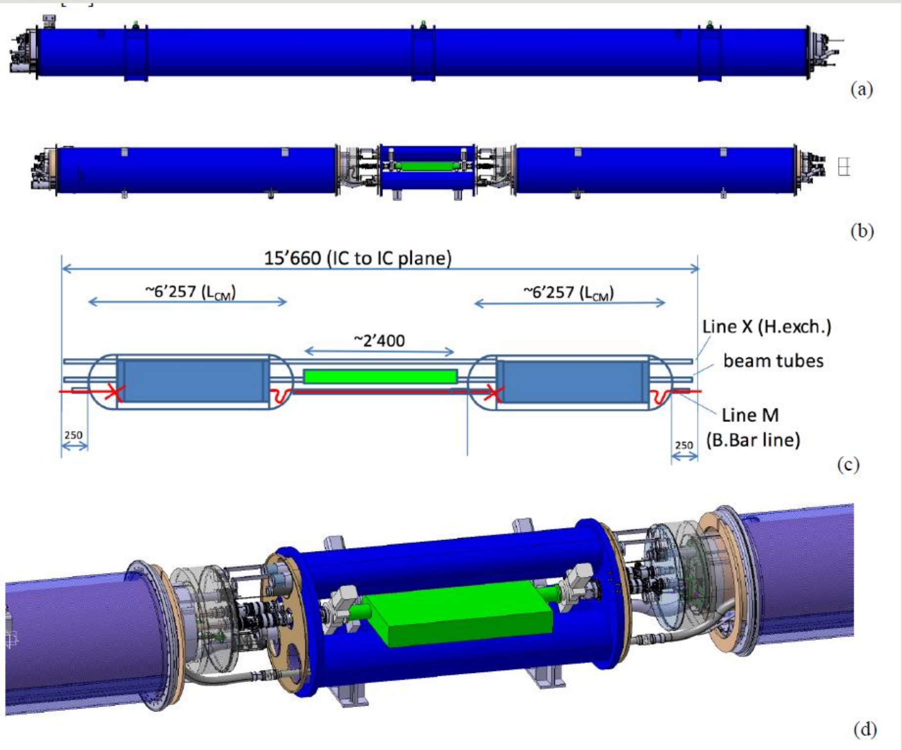


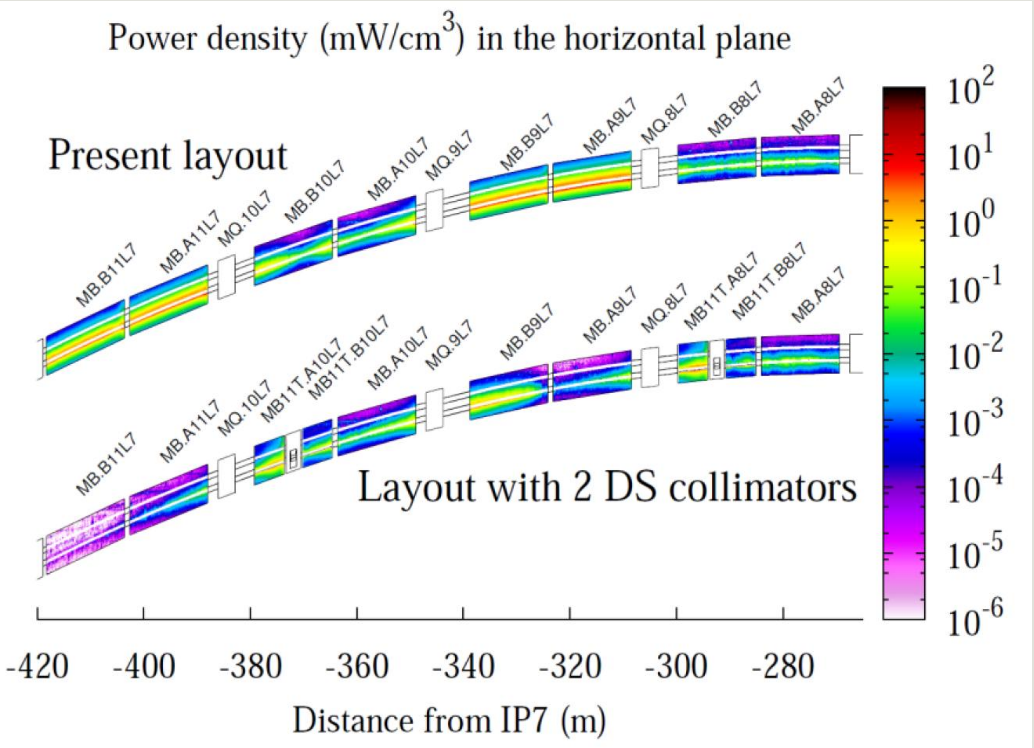
Upgrades of collimation system for HL-LHC

- The collimation system could not satisfy the magnet quenching requirement when doubling the bunch intensity
- The main cold loss around the ring is in the dispersion suppressor (DS) downstream of IR7, which has the risk of quenching the cold magnets
- The cold loss mainly caused by Single-diffractive (SD) effect with an energy loss
- The local collimators are added to eliminate the risk of quenching

	LHC (design)	**HL-LHC**	**FCC-hh**	**SPPC**
Beam energy	7 TeV	7 TeV	50 TeV	**35.6 TeV**
Beam intensity	3×10^{14}	6×10^{14}	1×10^{15}	$\mathbf{1.2 \times 10^{15}}$
Stored energy	360 MJ	690 MJ	8500 MJ	**6600 MJ**
Power load (τ=0.2h)	~500 kW	~960 kW	~11800 kW	**~9200 kW**

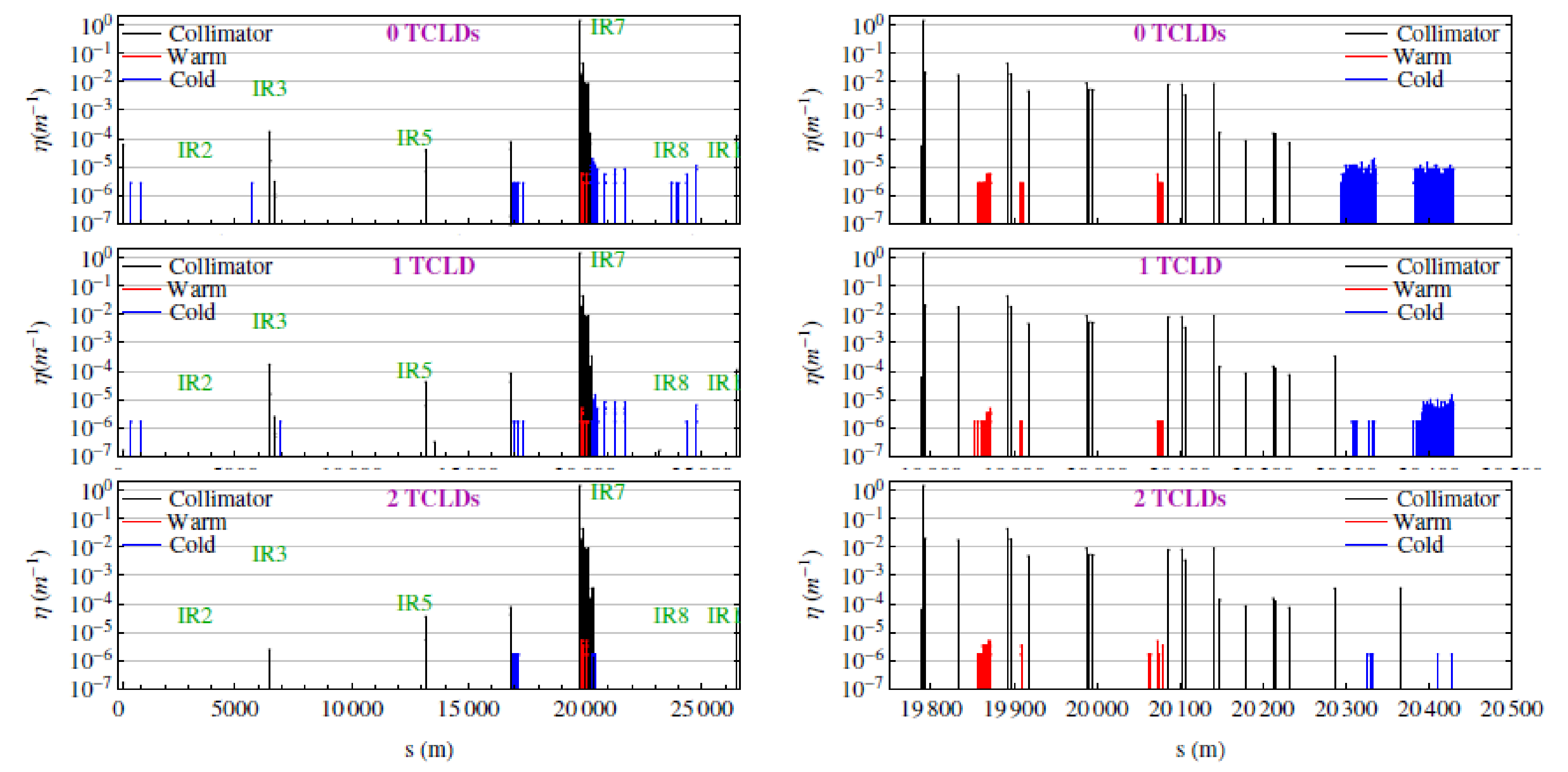
Upgrades of collimation system for HL-LHC





In order to make space for the new collimators, it is envisaged to replace, for each TCLD, an existing main dipole with two shorter 11 T dipoles with the TCLD in between

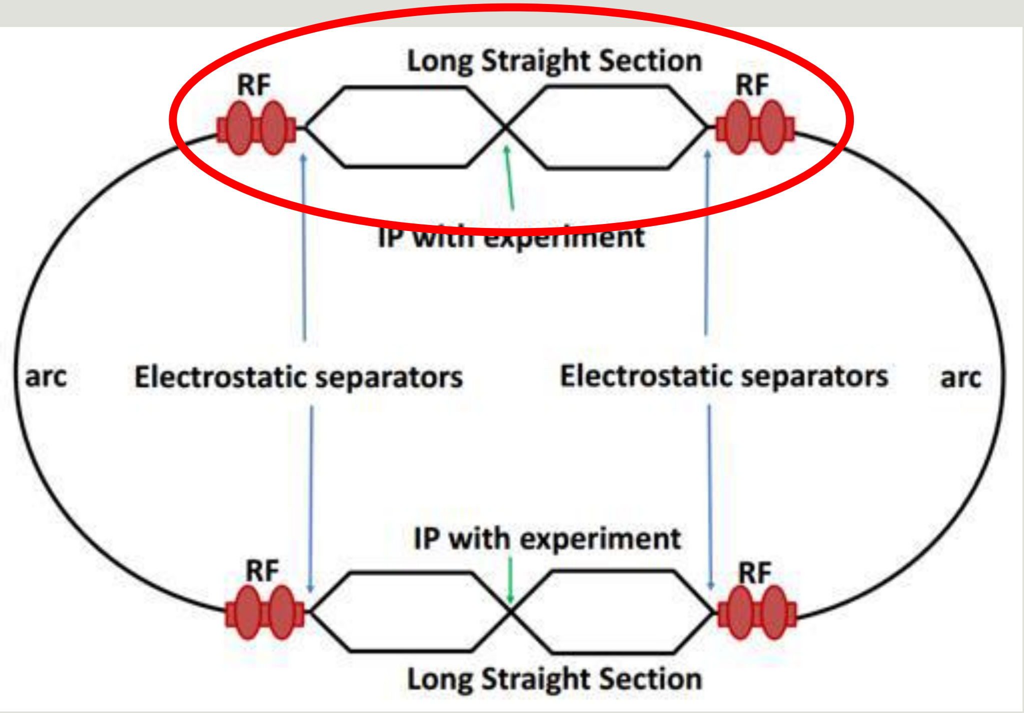
Local cleaning inefficiency with or without collimators at DS



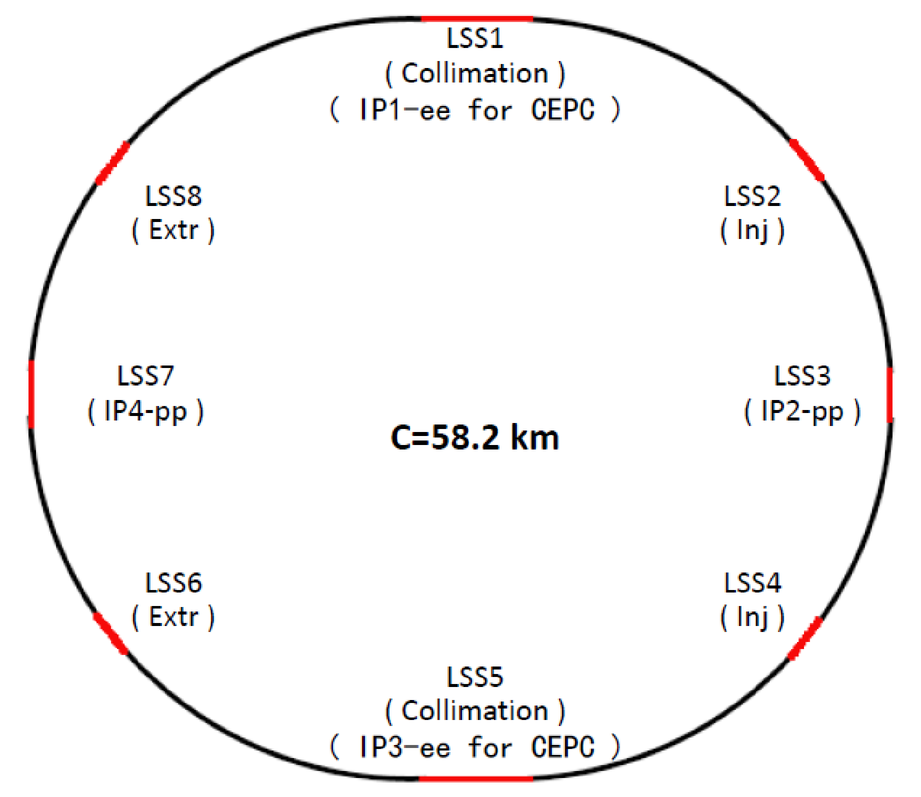
Consideration about new collimation optics for SPPC

- Particles with energy loss would be lost in DS downstream the LSS, where the dispersion starts to increase
- Local collimators had to be added to remove the particles with energy loss
- If one puts the whole momentum collimation system in the same long straight section after betatron collimation system, one can also remove these particles
- A very long straight section is needed…

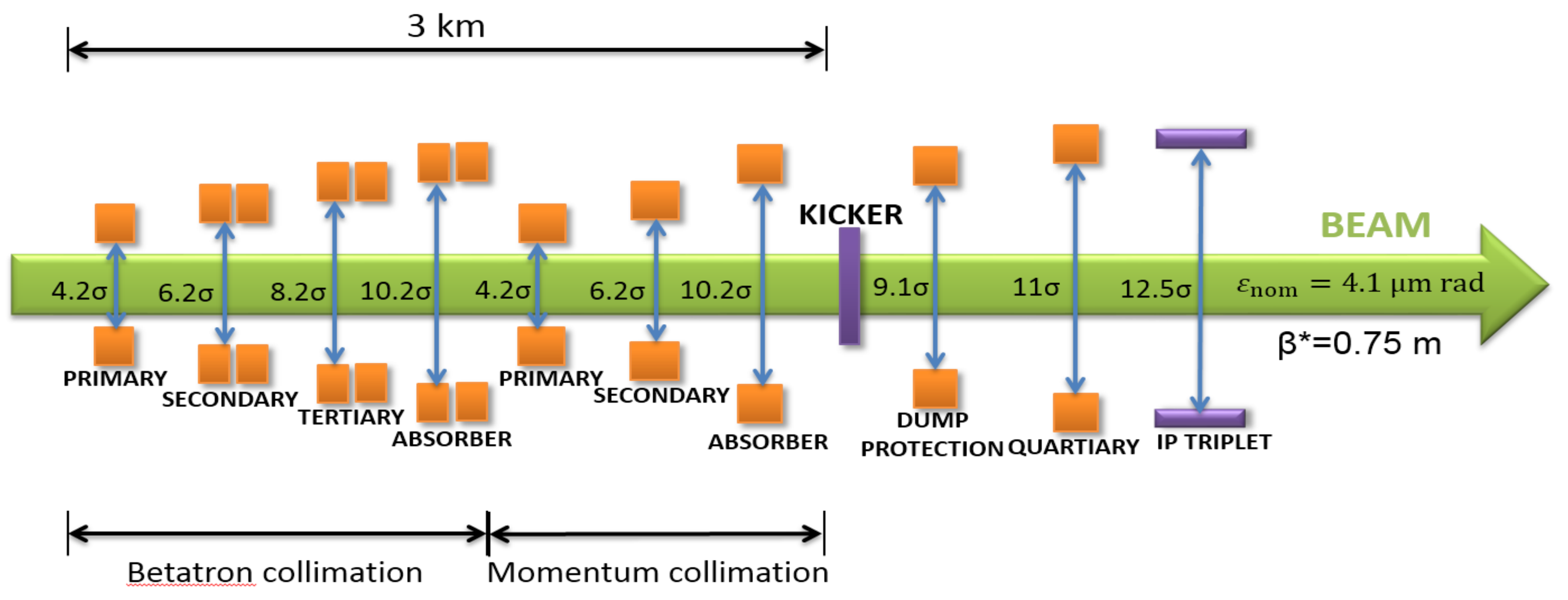
Consideration about new collimation optics for SPPC



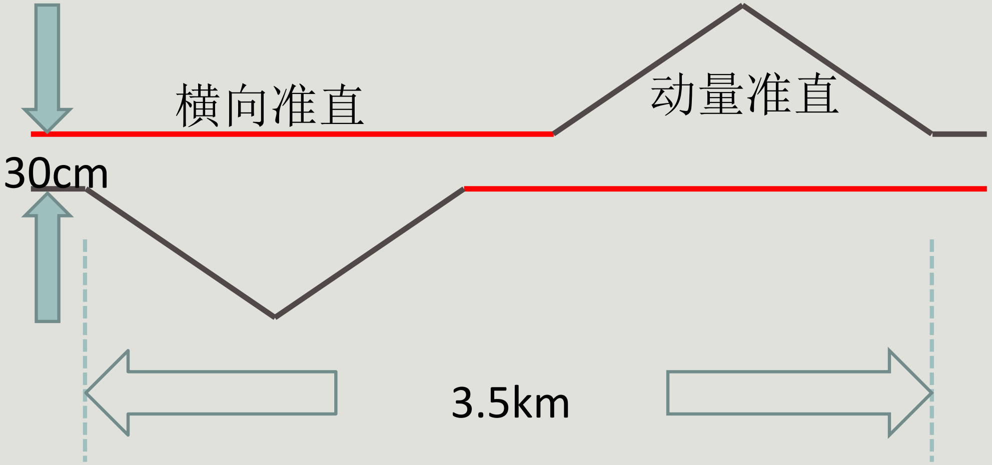
Two 3.5 km long straight section for CEPC

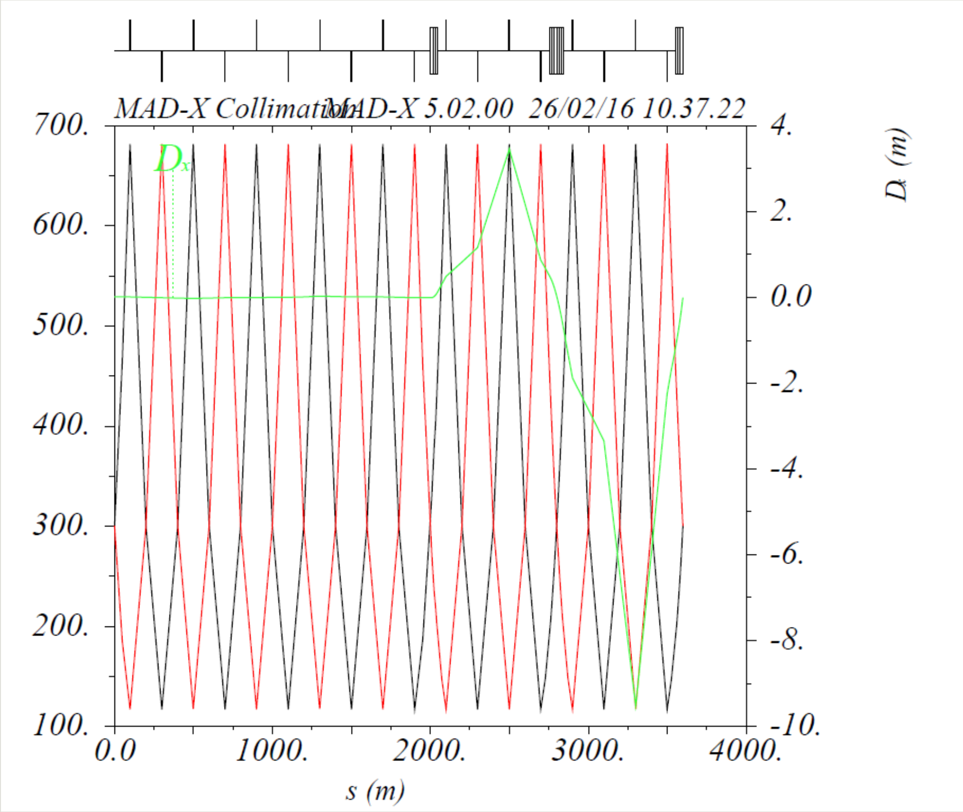


Consideration about new collimation optics for SPPC



Consideration about new collimation optics for SPPC





-Yang Jianquan

Preliminary studies about collimation materials

Materials performance:

- Thermomechanical Robustness Index (TRI)

  Related to the ability of a material to withstand the impact of a short particle pulse

- Thermal Stability Index (TSI)

  Index of the ability to maintain dimensional stability under beam slow losses

- RF Impedance Index (RFI)

  Index of the ability to minimize the contributions to RF impedance

Materials for collimators

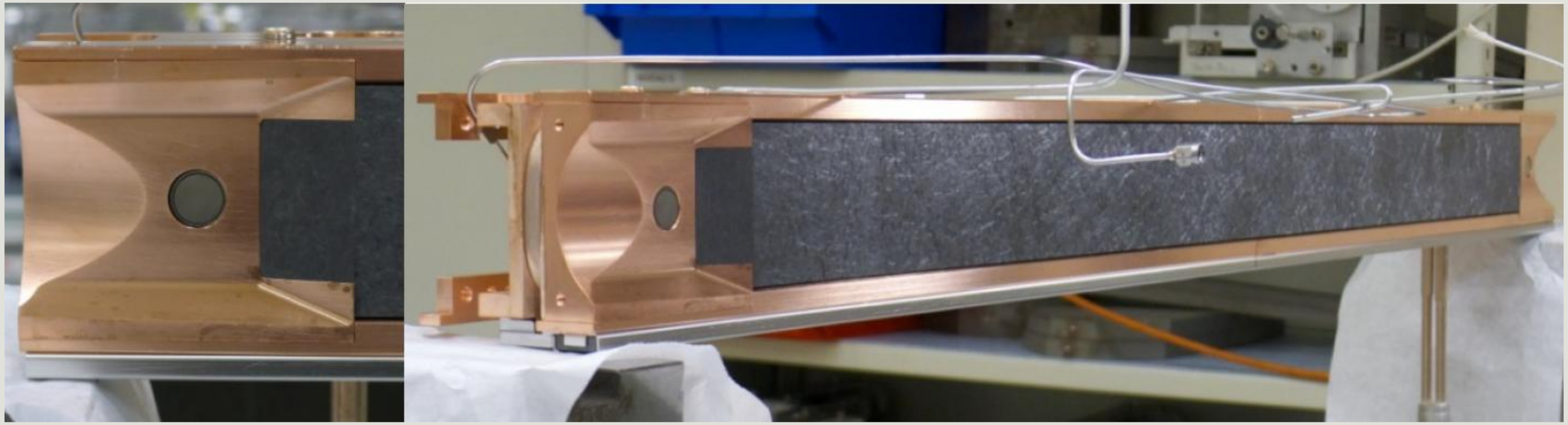
	FOM for BIDs existing materials						Indicative Required FOM for LHC Secondary Collimators	
	Be	Carbon-Carbon	Graphite	Cu (Glidcop)	Mo	W Alloy (IT180)	LHC (Nominal)	HL-LHC
	1273	3650	3650	1083	2623	~1400		
TRI	800	800-1200	800-1100	5	6	0.5	300-500	600-1000
TSI	17	45	10	0.8	0.7	0.1	~20	~40
RFI	4.83	~0.38	~0.27	7.33	4.38	2.93	0.4 (?)	~1 (?)

- Carbon-based materials feature excellent TRI and TSI (to low-Z, low CTE, low density, high degradation temperature, high conductivity), but are penalized by low RFI (low electrical conductivity) ….
- Beryllium is outstanding under many points of view … unfortunately its use is severely limited by its toxicity
- Metal-based materials feature excellent RFI, but are penalized by low TRI and TSI

Materials for Phase I LHC collimators

Primary and secondary collimators: closest to the beam, robustness (withstand beam impacts without significant permanent damage from the worst failure cases), carbon- fiber-carbon composite (CFC)

- Absorbers and tertiary collimators: not so close to the beam, higher particle stopping potential, less impedance effect, metal-based jaws

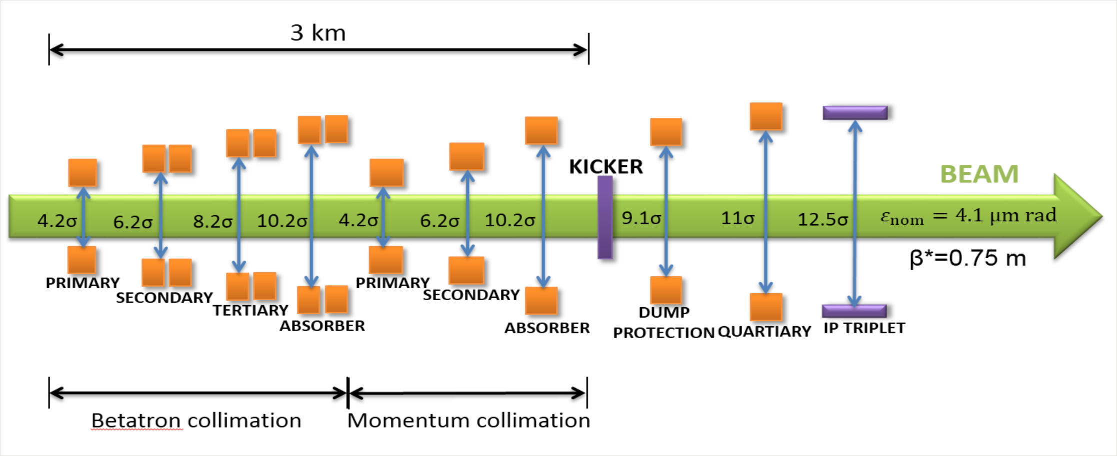


Materials for phase II LHC collimators

- The LHC performance may be limited by collimator material-related concerns, such as the contribution from the present carbon-based secondary collimators to the machine impedance
- Novel materials for new collimator jaws are explored to replace the CFC of the secondary collimator material (combine the excellent thermal properties of graphite or diamond with those of metals and metal-based ceramics of high mechanical strength and, good electrical conductivity)
- Molybdenum Carbide - Graphite (MoGr) composite (碳化钼石墨复合材料) and Copper-Diamond (CuCD) composite (铜金刚石（CuCd）复合材料)

Materials for preliminary SPPC collimators

- Very high stored energy (6.6 GJ)
- CFC is not suitable for the collimator material with its low electrical conductivity
- Good thermal stability, high robustness, good electrical conductivity
- Novel composite materials might be suitable as the TCP, and TCSG materials, like MoGr, CuCD, or other composite materials

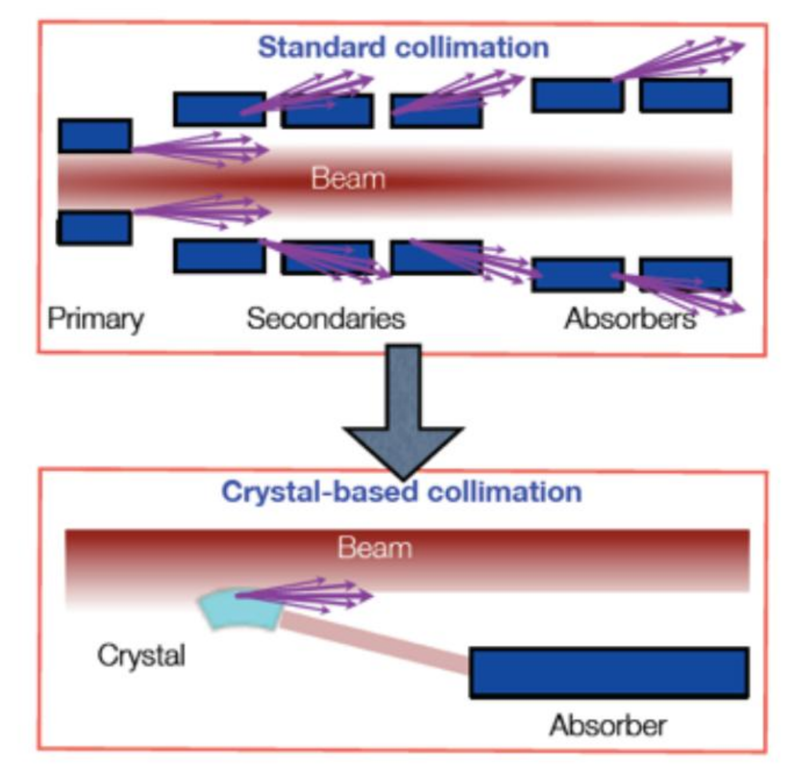


Advanced collimation concepts - bent crystal

Bent crystal can be used for channeling and extracting the beam halo in a controlled way

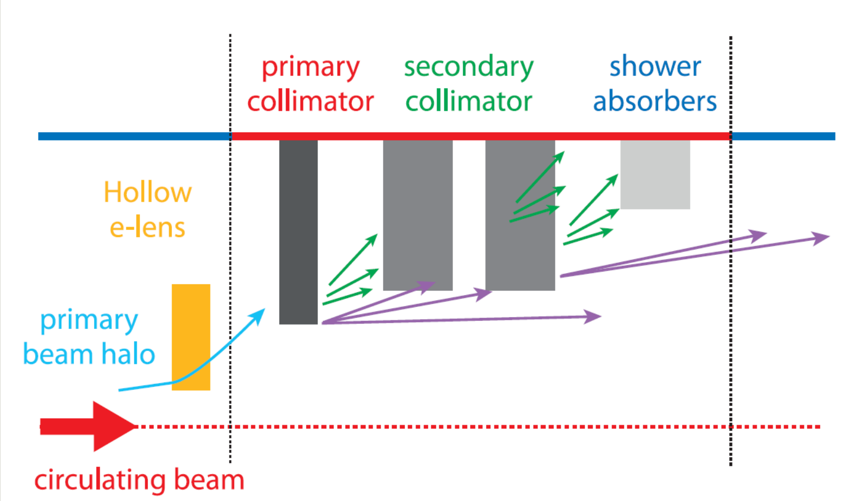
- ◆ Can improve cleaning efficiency
- ◆ Reduce impedance: less secondary collimators, larger gaps

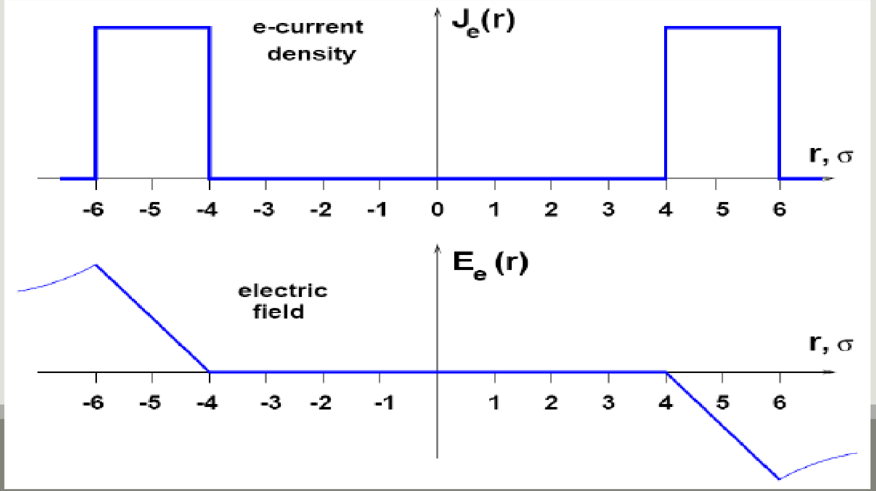
- ➢ Low intensity beam tests at the LHC in 2015
- ➢ Promising for the SPPC, but large uncertainties on extrapolations to high energies and several operational challenges

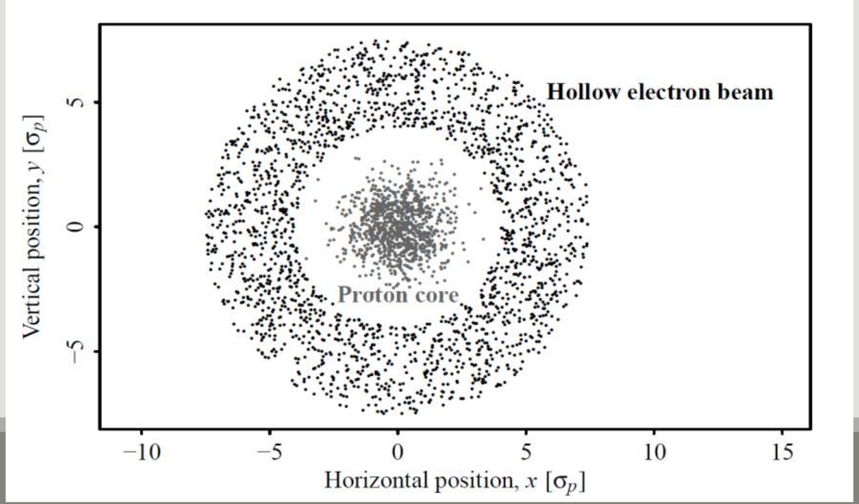


Advanced collimation concepts– Hollow e-lenses collimation

- Hollow electron beam collimation is a novel technique for beam collimation and halo scraping
- In the case of high-power proton beams, scraping is smooth, controllable, and the issues of material damage are mitigated
- The concept was tested experimentally at the Fermilab Tevatron collider using a hollow electron gun installed in one of the Tevatron electron lenses
- Expected to be used in HL-LHC

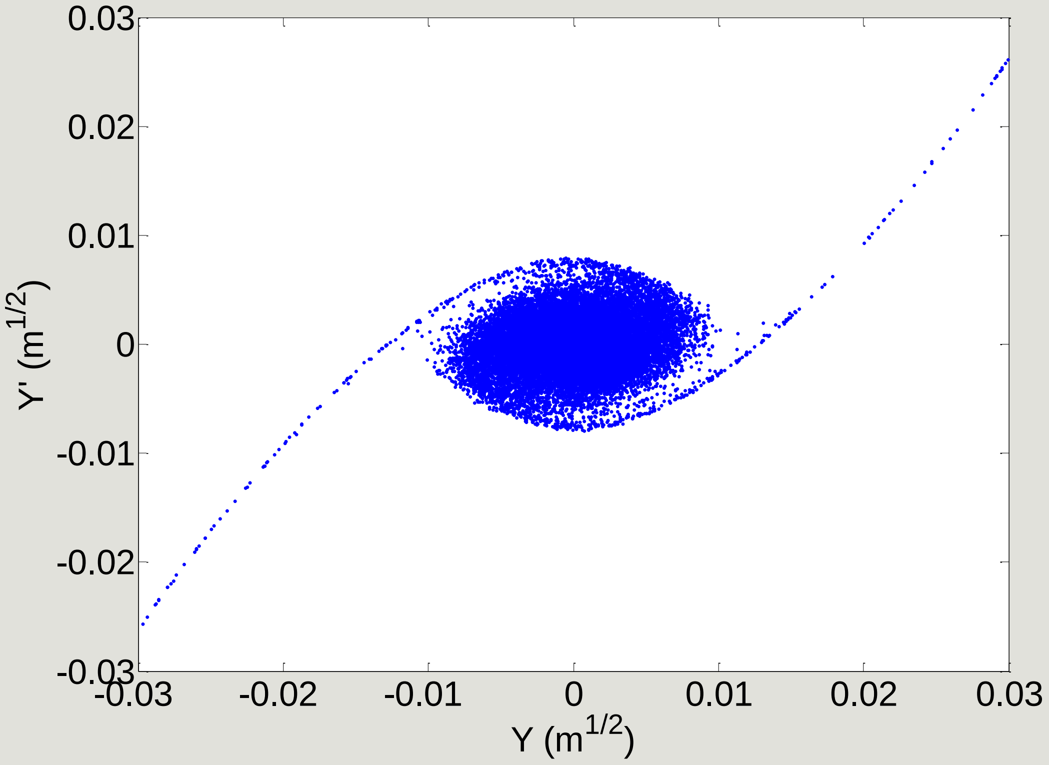






Advanced collimation concepts – nonlinear collimation

- Anti-symmetric sextupole could cause resonance to extract beam halo particles in two directions
- It could replace the primary collimators to scatter the beam halo particles which could be removed by secondary collimators
- Expectation advantages: no touch with particles-suitable for very high energy, very high collimation efficiency, reduce impedance, and so on
- Will be done in the next step…



Conclusions and plans

Conclusions:

- Collimation system at high energy colliers is very complex
- Extremely high cleaning efficiency is needed
- A new collimation optics for SPPC has been considered preliminarily
- Novel composite materials might be suitable as the collimator materials
- Some advanced collimation concepts have been studied for the future colliders

Plans:

- Do the collimation system simulations with SixTrack code
- Study one of the advanced collimation concepts – nonlinear collimation

Thanks for everyone

EXTRAS

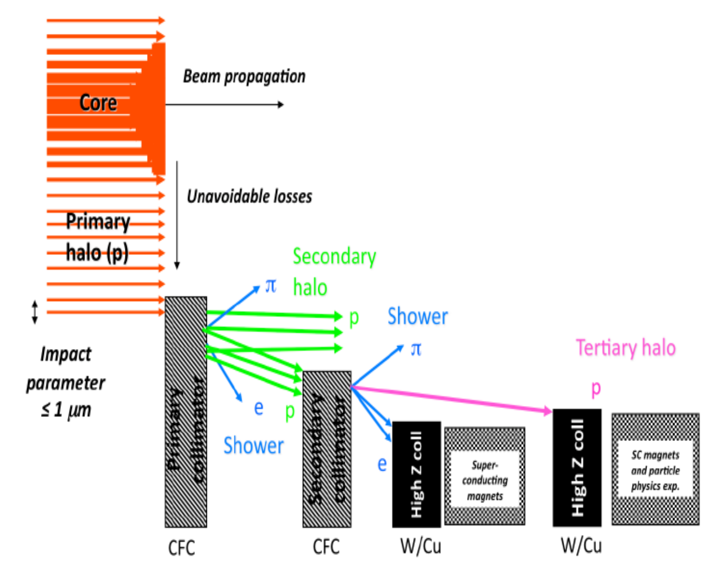
高能情况下（E>20 GeV）能量损失主要是非弹性核散射

当强子能量足够高时，它们和原子核发生强作用的截面增大，且多重产生成为主要过程，即一个高能强子与原子核碰撞产生许多次级强子（粒子数第一代增殖），次级强子能量足够高将继续与介质中的原子核发生第二代增殖，一代一代，粒子数不断增加，但平均能量不断减小，有些强子由于电离损失就会逐渐消失在介质中，称为强子簇射（Hadronic shower）

描述强子簇射主要参数：介质的平均核作用长度λ_0

$$\lambda_0 = (N\sigma_a)^{-1}$$

其中σ_a为原子核对强子的非弹性碰撞截面，N单位体积内原子核数



Hadronic shower