Considerations on LHC Emittance

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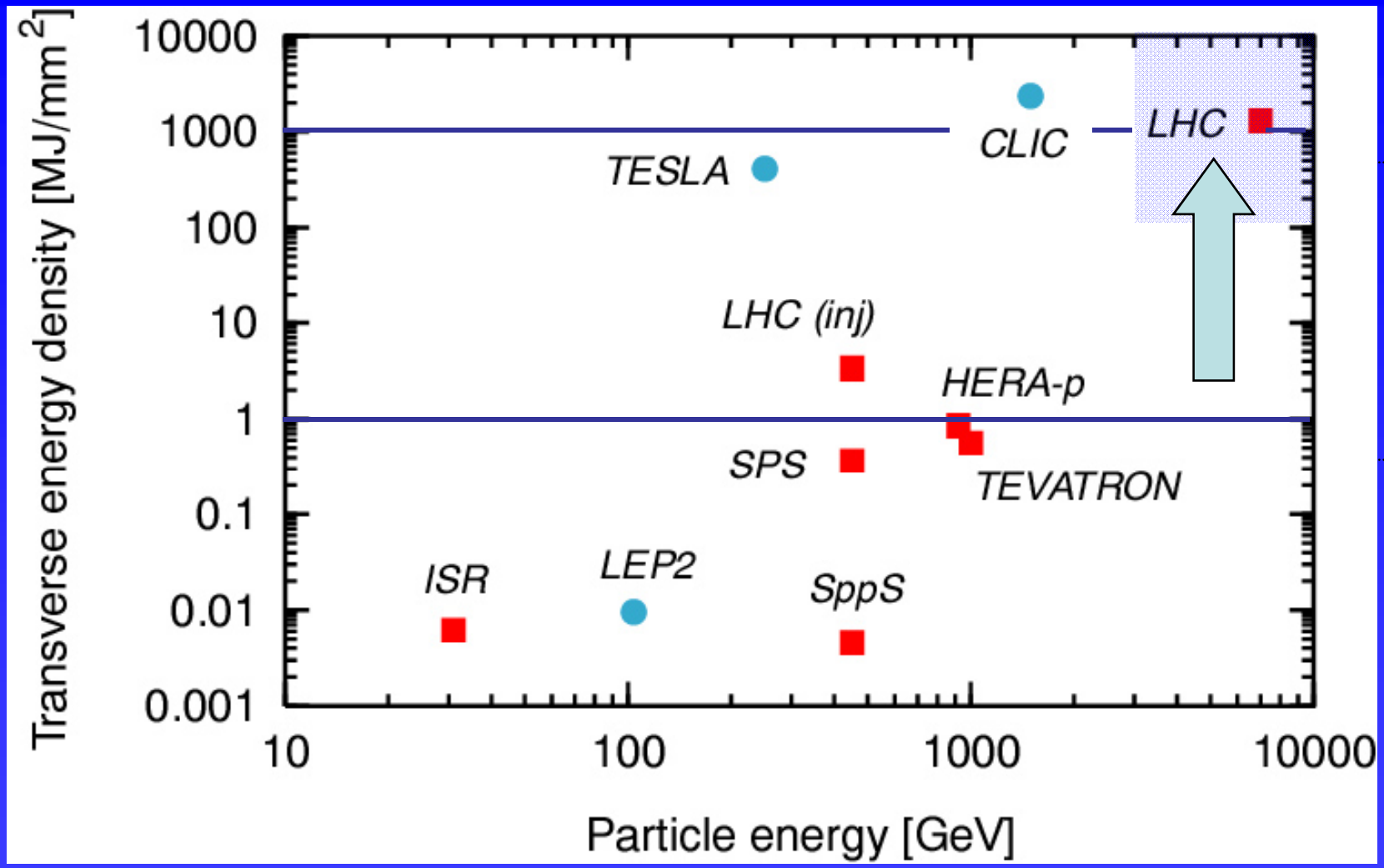
Condition on n1 (larger ε)

- Parameter n1 defines the required collimator settings to provide cleaning and protection.
- Baseline: n1 = 7 (available normalized aperture)
- For n1 = 7 primary collimators must be set to 6 σ at 7 TeV and 5.7 σ at 450 GeV.
- No margin for further reduction. Already very little margin to point where beam lifetime is usually reduced (below 5 σ). ➔ less efficiency with larger gaps.
- Larger emittance must be compensated with smaller beta to keep n1 = 7.
- Cannot set collimators for n1 < 7.

Condition on Energy Density

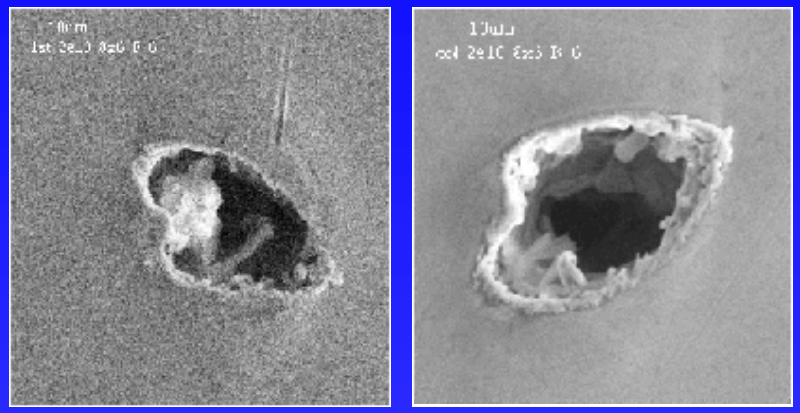
- Energy density ~ $1/\varepsilon$ (round beam)
- Small emittance makes beam more dangerous (this is why e.g. LC beams are very dangerous).



At less than 1% of nominal intensity LHC enters new territory.

There is no easy start-up for collimation!

Examples of Beam Damage



Entry and exit holes of an electron beam impacting on a spoiler

(courtesy P. Tenenbaum)

Tungsten collimator in the SPS

Lead block accidentally put into a p beam

Damage of coating of a SLC collimator

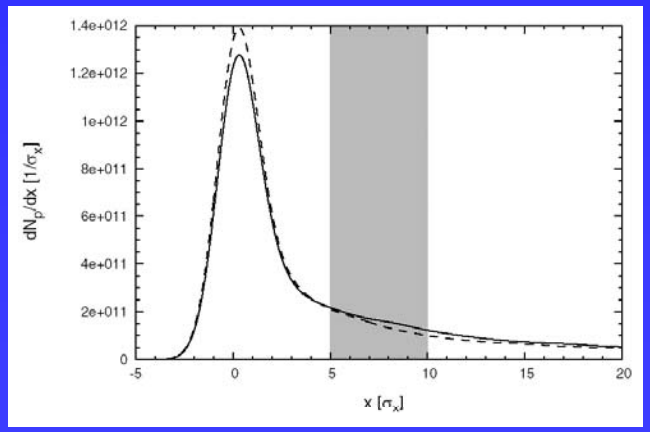
(courtesy G. Stevenson)

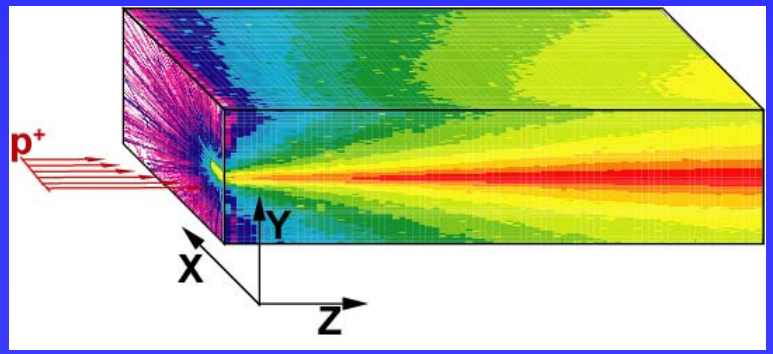
Condition on Energy Density

- Energy density ~ $1/\varepsilon$ (round beam)
- Small emittance makes beam more dangerous (this is why e.g. LC beams are very dangerous).
- LHC phase I collimators are designed to survive a number of expected beam accidents without damage.

Irregular Beam Impact

Irregular condition	Beam energy [TeV]	Intensity deposit [protons]	Energy deposit [kJ]	Transverse dimensions [mm×mm]	Impact duration [ns]	Affected plane
Injection error	0.45	2.9×10^{13}	2073	1.0×1.0	6250	H/V/S
Asynchronous beam dump	0.45	6.8×10^{11}	49	***5.0*** $\times$ 1.0	150	H
(all modules)	7.00	4.8×10^{11}	538	***1.0*** $\times$ 0.2	100	H
Asynchronous beam dump	0.45	10.2×10^{11}	74	***5.0*** $\times$ 1.0	225	H
(1 out of 15 modules)	7.00	9.1×10^{11}	1021	***1.0*** $\times$ 0.2	200	H





A. Ferrari,V. Vlachoudis

Condition on Energy Density

- Energy density ~ $1/\varepsilon$ (round beam)
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- LHC phase I collimators are designed to survive a number of expected beam accidents without damage.
- Mechanical stresses have been calculated and compared to allowed values.

Mechanical Stresses

(a) Injection

Material	Jaw length [cm]	Max. temperature [°C]	Stress σ_{equiv} [MPa]	σ_{allow} [MPa]	Suitability
Carbon-Carbon	20	335	4.4	86	yes
	100	345	12.7	86	yes
Graphite	20	335	3.1	18	yes
	100	345	6.2	18	yes
Beryllium	20	168	334	160	no
	100	200	440	160	no

(b) 7 TeV

Material	Jaw length [cm]	Max. temperature [°C]	Stress σ_{equiv} [MPa]	σ_{allow} [MPa]	Suitability
Carbon-Carbon	20	212	20.8	86	yes
	100	551	82.0	86	yes
Graphite	20	212	4.4	18	yes
	100	551	17.8	18	yes
Beryllium	20	116	584	160	no
	100	168	1248	160	no

O. Aberle, L. Bruno

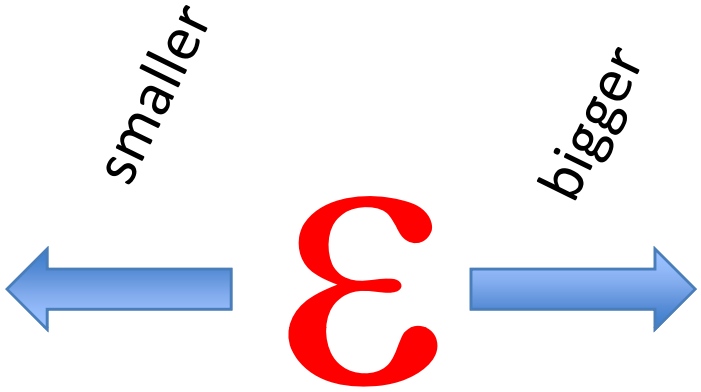
Condition on Energy Density

- Energy density ~ $1/\varepsilon$ (round beam)
- Small emittance makes beam more dangerous (this is why e.g. LC beams are very dangerous).
- LHC phase I collimators are designed to survive a number of expected beam accidents without damage.
- Mechanical stresses have been calculated and compared to allowed values.
- Essentially no margin at 7 TeV ➔ no room to reduce emittance at 7 TeV for 25 ns bunch spacing and nominal bunch intensity.
- Experiments required to evaluate in more detail!
- Operational stability lower for smaller gaps!

Summary

Higher energy density. Larger damage potential. Cannot guarantee collimator robustness. **Decrease operational stability if gaps are reduced.**

Maybe OK with phase II collimators (SLAC concept to handle collimators beyond damage threshold)



Reduced n1 must be avoided in order to keep collimator settings above 5 σ.

If gaps are opened with larger emittance, reduced cleaning efficiency. Maybe OK with phase II collimation.

Detailed experiments (HiRadMat) required to evaluate damage limits in more detail to go to final limit.