

LHC and HL-LHC DA studies with field errors at injection for proposing DA targets

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Introduction

Current Design :

- ▶ DA is used to specify field quality of magnets
- ▶ Collimation system assumes minimum beam lifetimes
- ▶ No link established between DA and beam lifetime

Obstacles :

- ▶ DA for a fixed number of turns not the whole picture
- ▶ Number of trackable turns based on available CPU-power, relevant timescales still beyond reach
- ▶ Even if CPU-power would be enough : special techniques required to keep num. errors under control (see celestial mechanics)

Introduction

- ▶ Reliable interpolation models for DA vs time available
→ Can try extrapolation to relevant timescales !
- ▶ Proven models for scaling laws of losses with DA available
→ We can try and close the loop !
- ▶ Allows to define minimum DA in terms of beam losses permitted by collimators

Introduction

Approach

- ▶ Use LHC as test bed for HL-LHC
 - ▶ Numerical simulations
 - ▶ Experimental tests
- ▶ We started with injection (see this talk) and then we will move to top energy

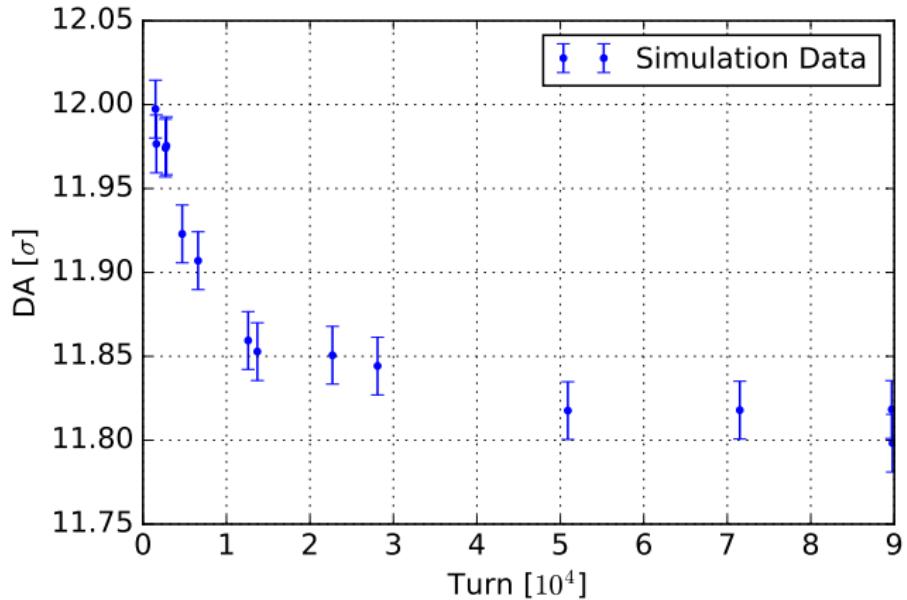
Parallel studies

- ▶ DA measurements in LHC injection (started in 2012 until now, in collaboration with Ewen)
- ▶ DA measurements in LHC at top energy (started in 2016, in collaboration with Ewen)
- ▶ Use scaling laws for simple analytical models of intensity change in collision burn-off and DA, only (started in 2012, in collaboration with Frederik)

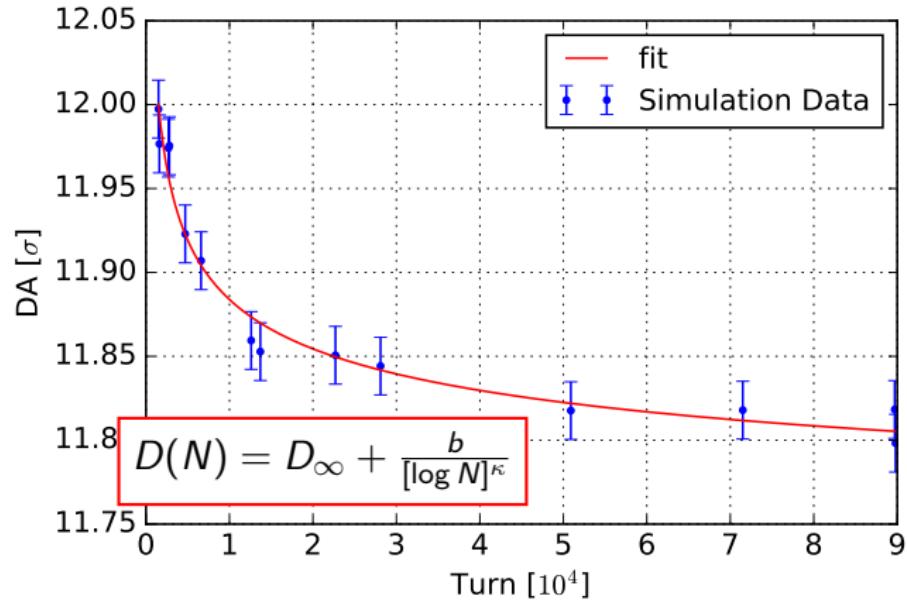
LHC Simulations

- ▶ LHC settings with different chromaticities (0 to 20) and different octupole currents (0 to 40)
- ▶ In total 121 studies for each beam \times 4620 simulations
 \approx 560000 simulations in total
- ▶ DA calculated for $\epsilon_N = 2.5 \mu\text{m}$
- ▶ Calculate the DA vs. turns (SixDeskDB)

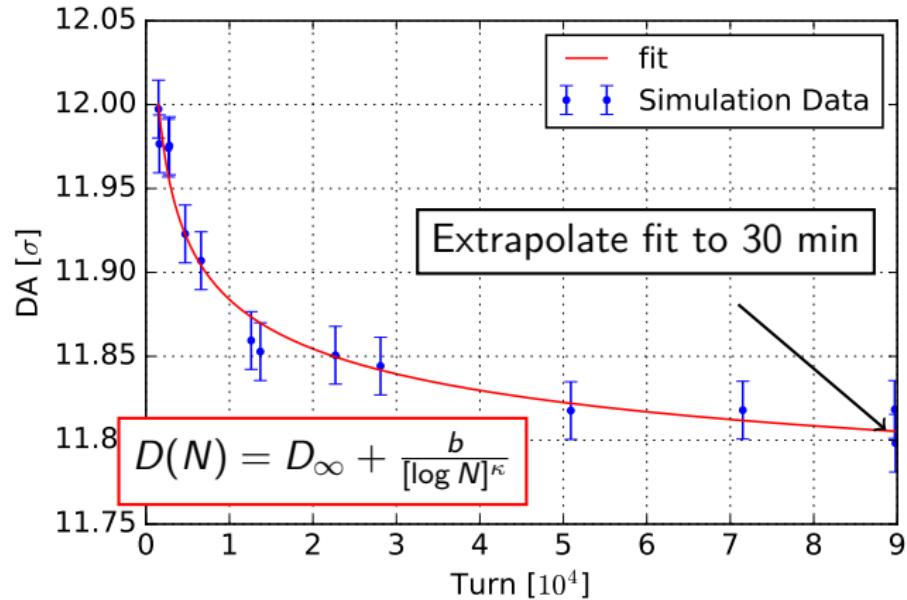
Dynamic Aperture vs. turn



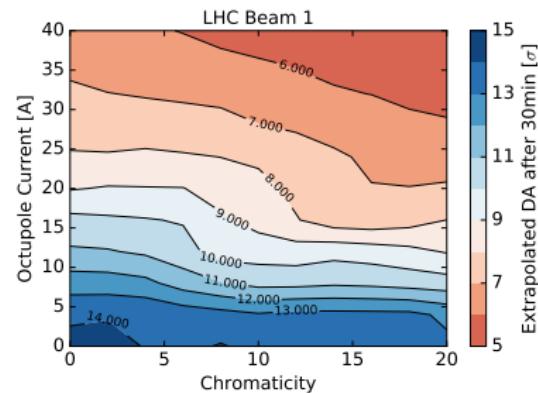
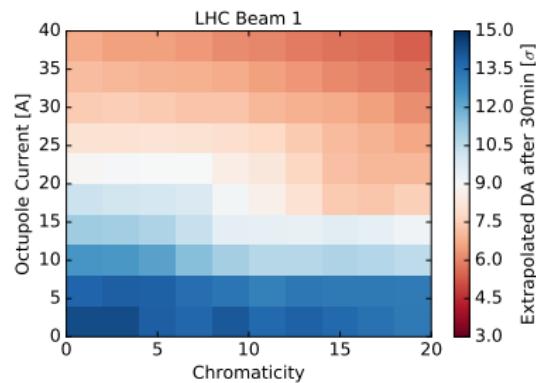
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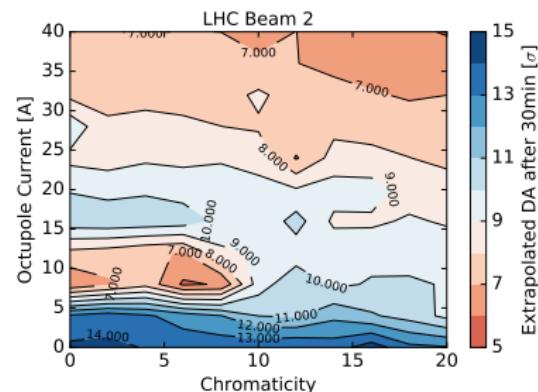
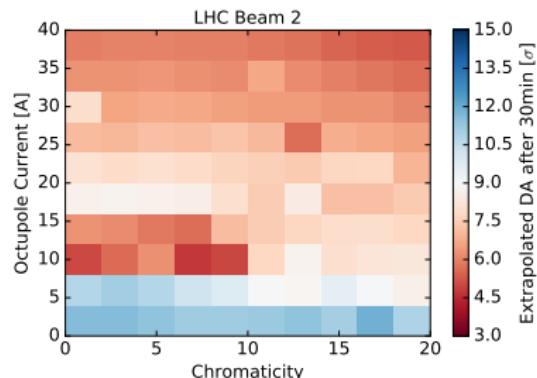
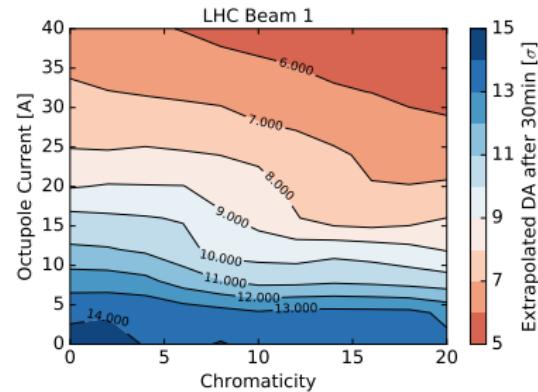
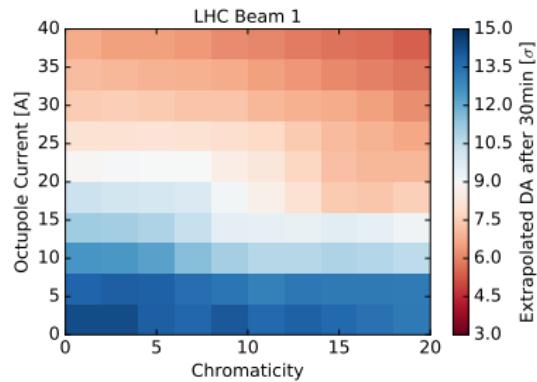
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Extrapolated DA after 30 minutes - LHC



Extrapolated DA after 30 minutes - LHC

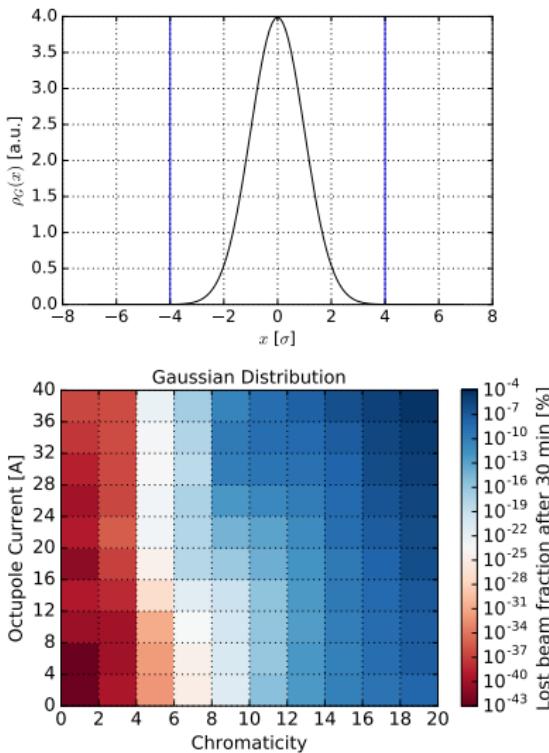


Estimating losses from DA

- ▶ Estimate the losses after N turns for a given $D(N)$
- ▶ Assuming Gaussian beam profile
- ▶ Intensity after N turns :

$$\frac{I(N)}{I_0} = \exp\left(-D^2(N)/2\right).$$

- ▶ Tails of a Gaussian are only poorly populated !
- ▶ Is this realistic ?



Estimating losses from DA

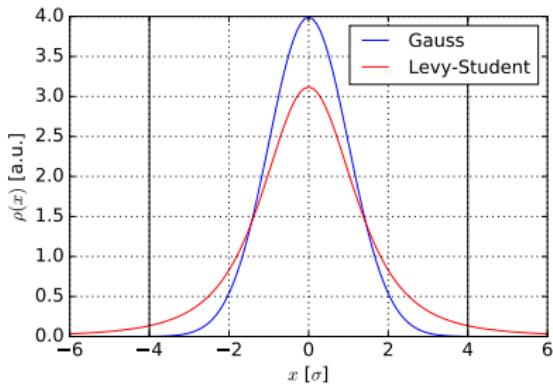
- ▶ Measured transverse beam profile¹⁾ : between 1.9% and 3.6% of the beam is at amplitudes $> 4\sigma$
- ▶ Gaussian distribution $\approx (5 \times 10^{-3})\%$ at amplitudes $> 4\sigma$
- ▶ More realistic model needed to relate DA to beam loss

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- ▶ More realistic model needed to relate DA to beam loss
- ▶ Lévy-Student Distribution²⁾

$$\rho_L(x, y) = \frac{1}{2\pi} \frac{\nu a^\nu}{[a^2 + x^2 + y^2]^{(\nu+2)/2}}$$

- ▶ Free parameters ν and a !
- ▶ Which parameters are realistic ?



1) F. Burkhardt, *Beam Loss and Beam Shape at the LHC Collimators*, CERN-THESIS-2012-046
2) M. Giovannozzi, Phys.Rev.ST Accel.Beam 15 (2012) 024001

Estimating Losses from DA

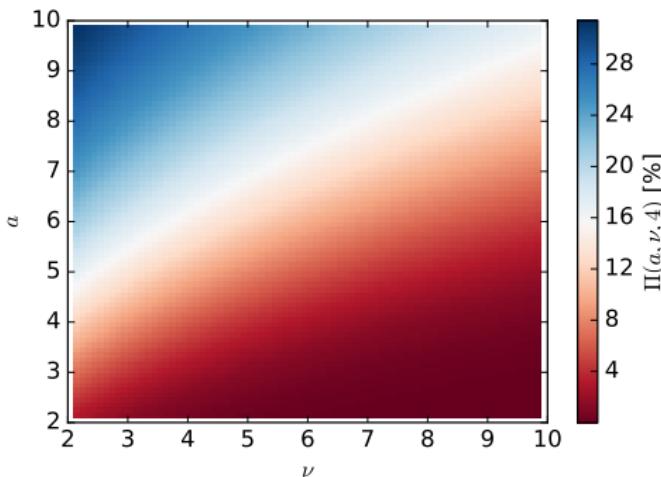
- ▶ Lévy-Student distribution requires parameters a and ν
- ▶ Define the fraction of beam above d sigma

$$\Pi(a, \nu, d) = 2 \times \frac{\int_d^{\infty} \rho_L(a, \nu, x) dx}{\int_{-\infty}^{\infty} \rho_L(a, \nu, x) dx}$$

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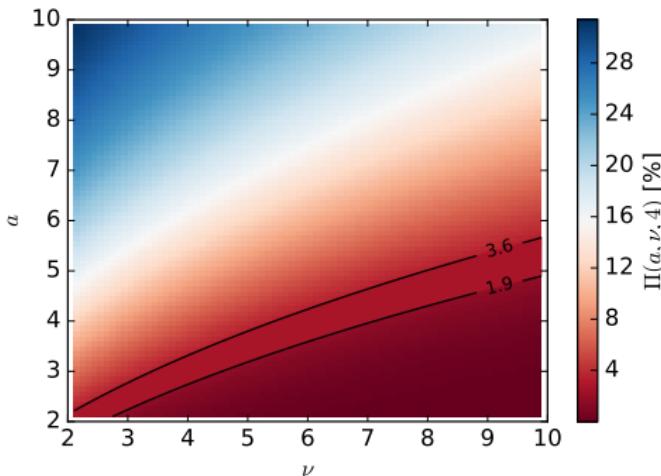
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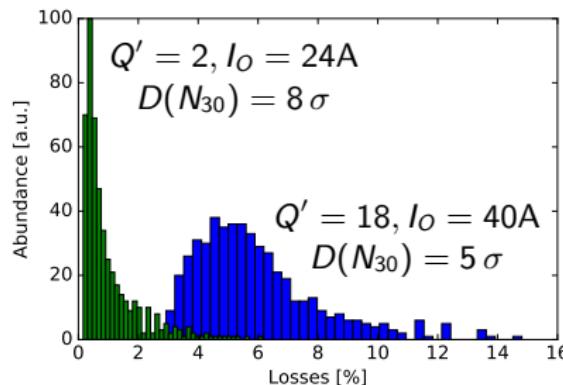


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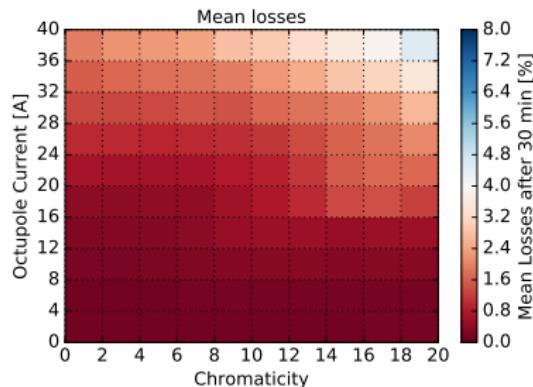
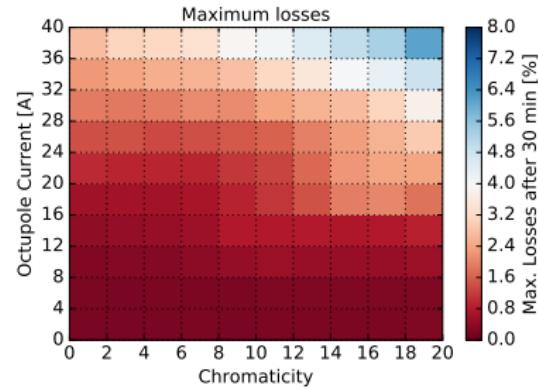
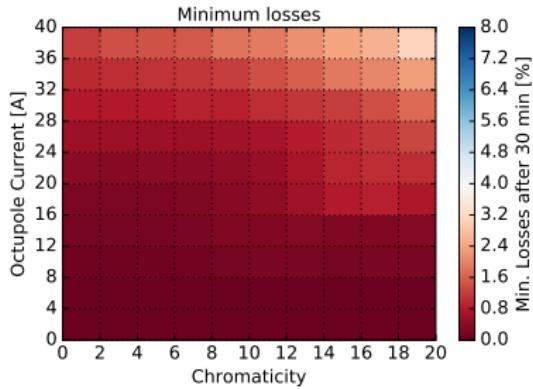
- ▶ The Lévy-Student parameters can be used to derive beam losses if the DA at turn N is known

$$\frac{I(N)}{I_0} = 1 - \frac{1}{\left[1 + \frac{D^2(N)}{a^2}\right]^{\nu/2}},$$

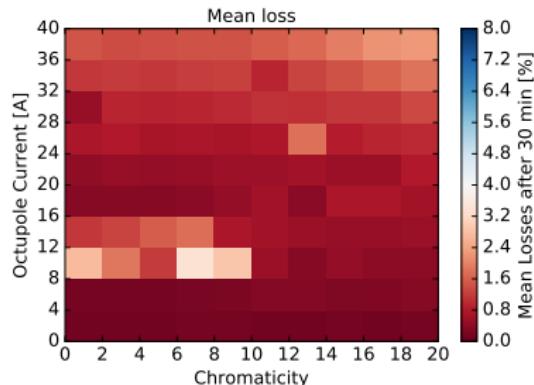
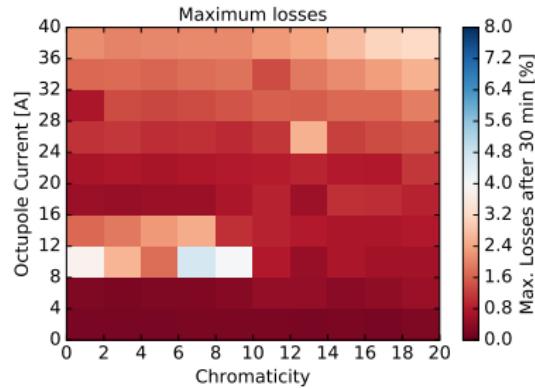
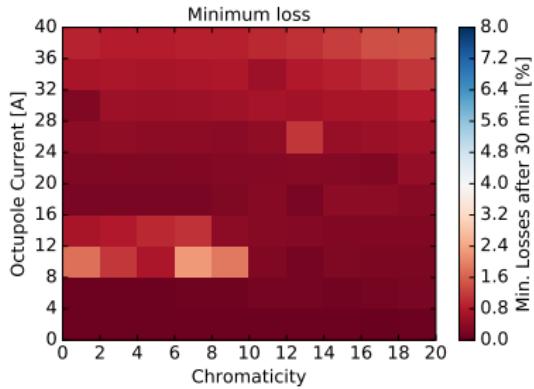
- ▶ With the different ν, a we obtain a spectrum of solutions for a given $D(N)$



Estimating losses from DA - LHC B1

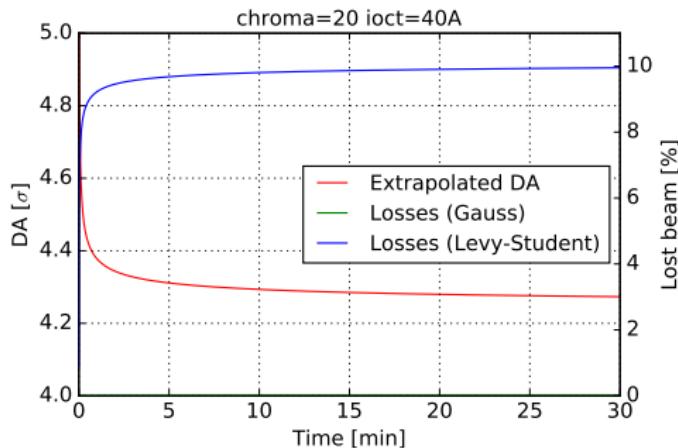


Estimating losses from DA - LHC B2



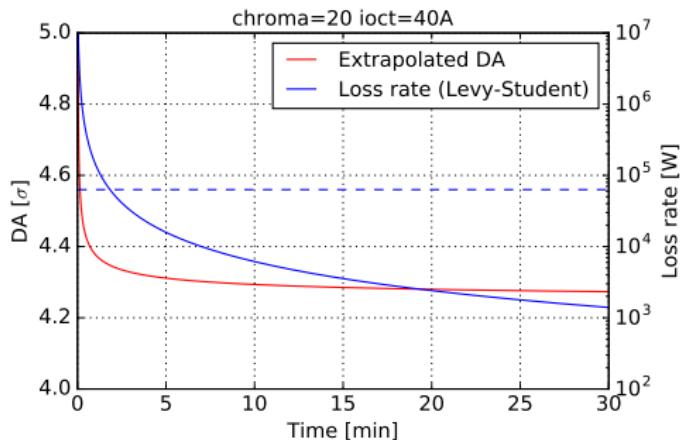
Connection to loss rate and beam lifetime

- ▶ Connection between DA and integrated beam loss
- ▶ DA vs turn data available
→ can deduce losses per time unit
- ▶ Here exemplary - thorough analysis upcoming



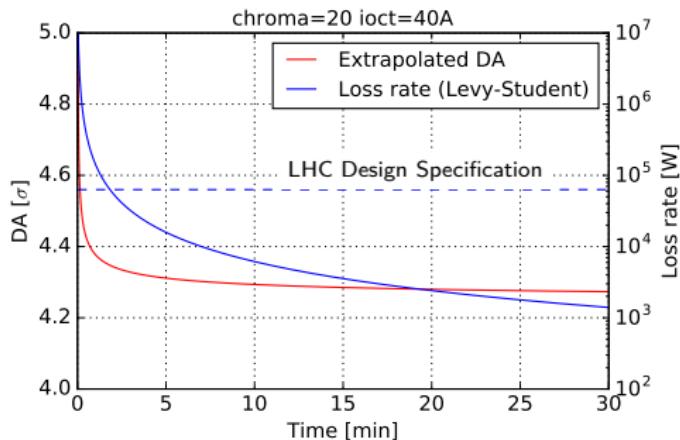
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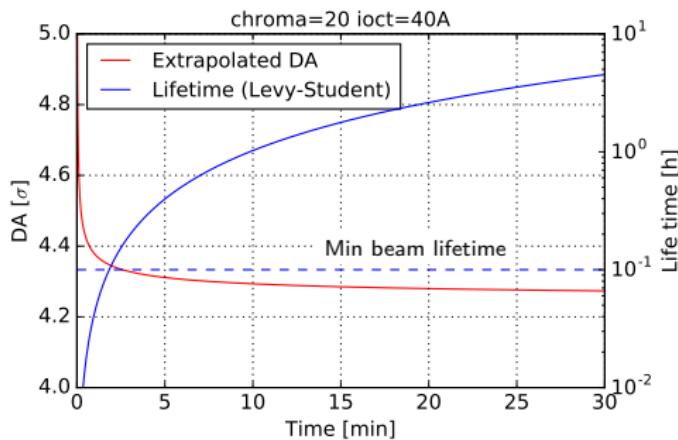
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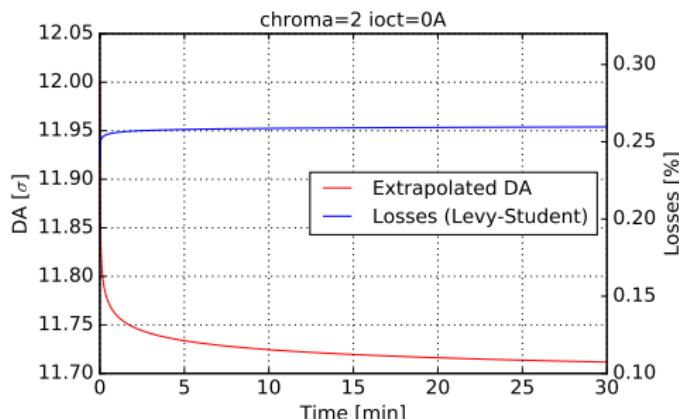
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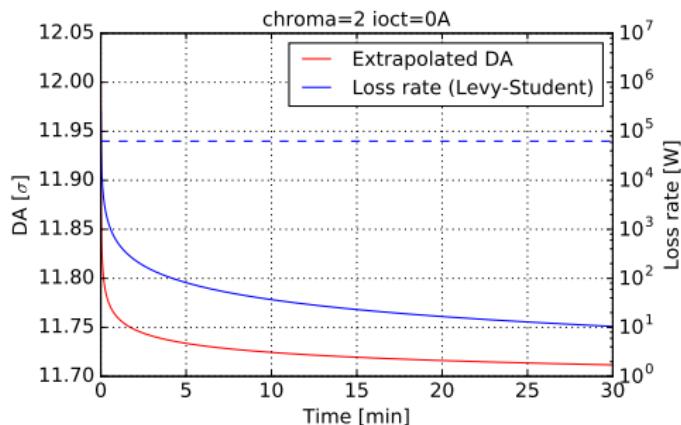
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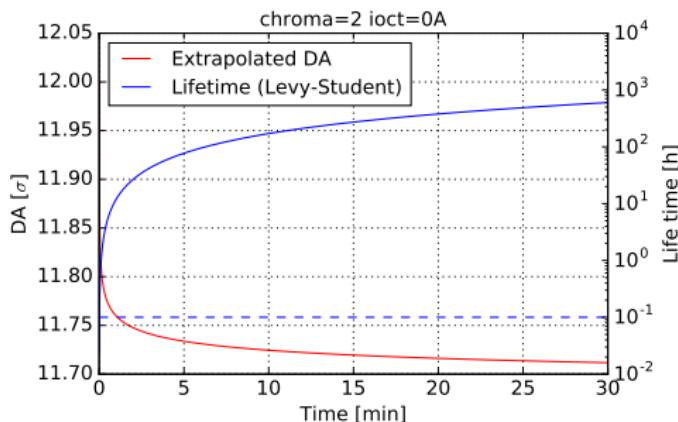
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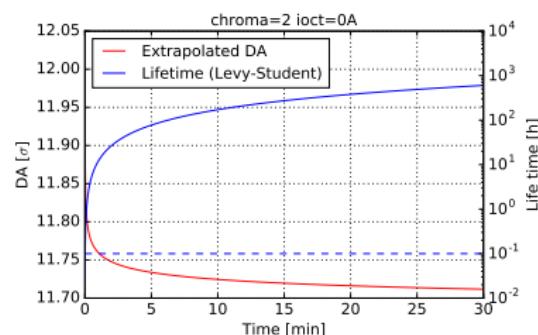
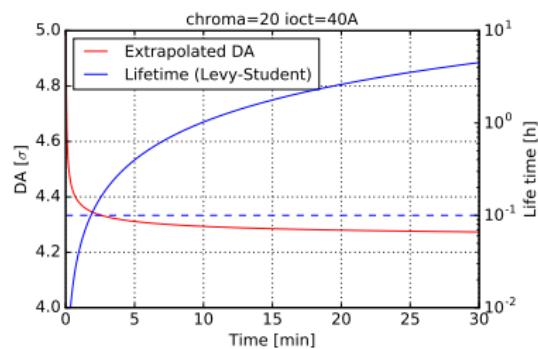
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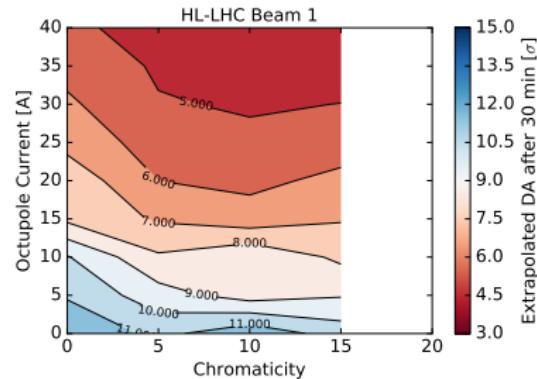
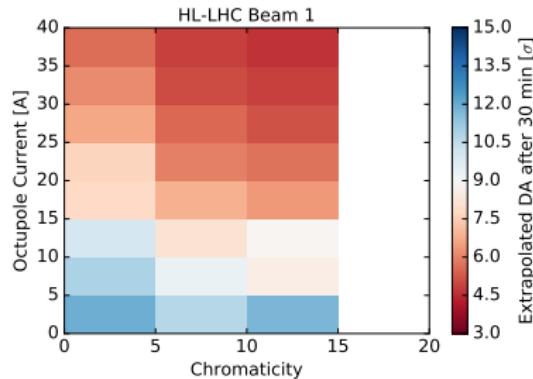


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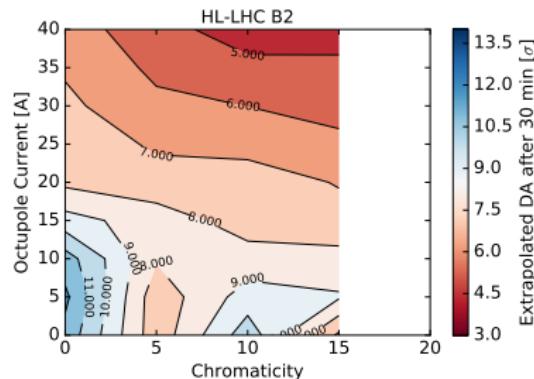
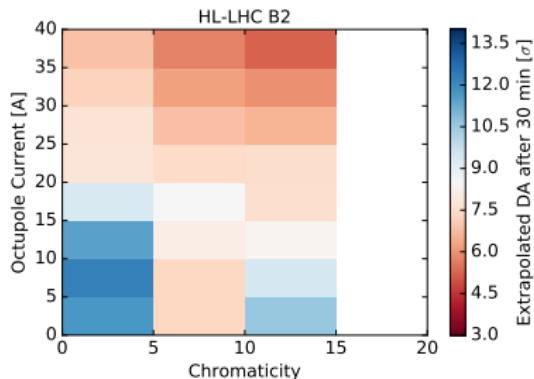
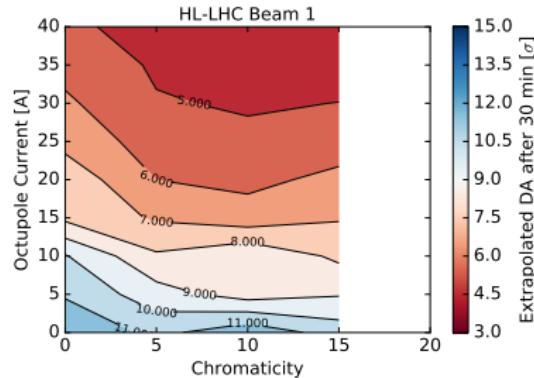
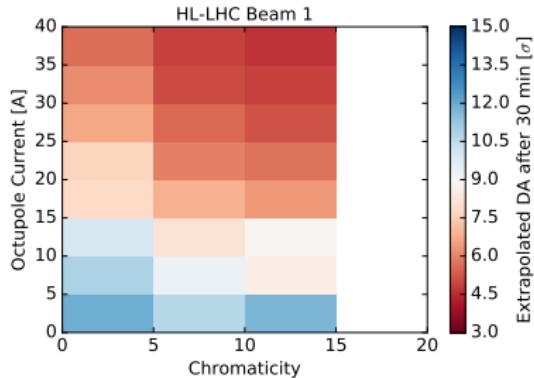
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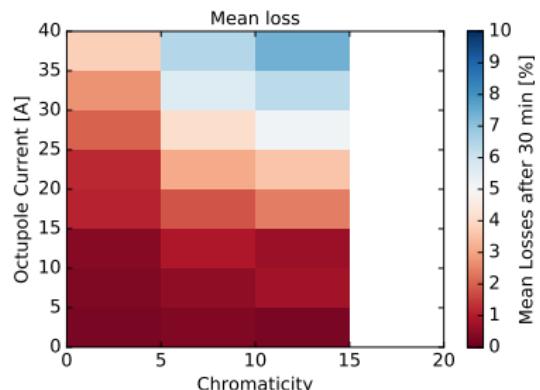
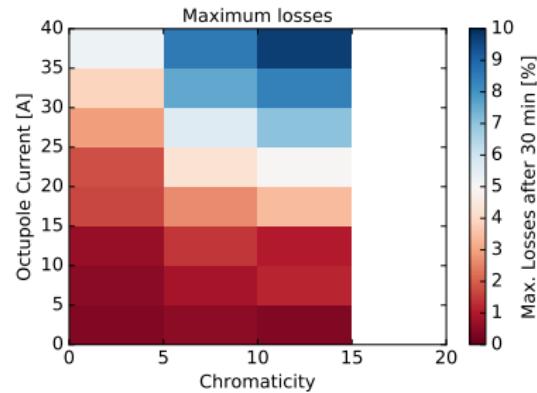
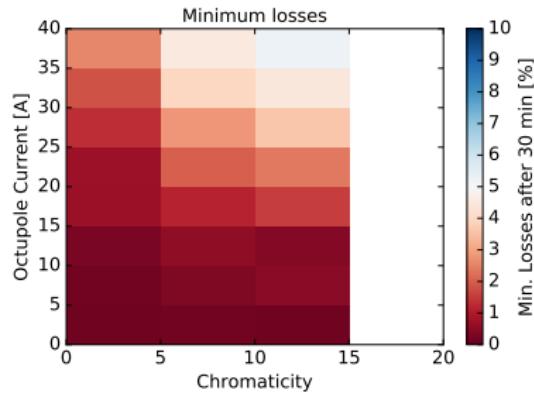
Extrapolated DA after 30 minutes - HL-LHC



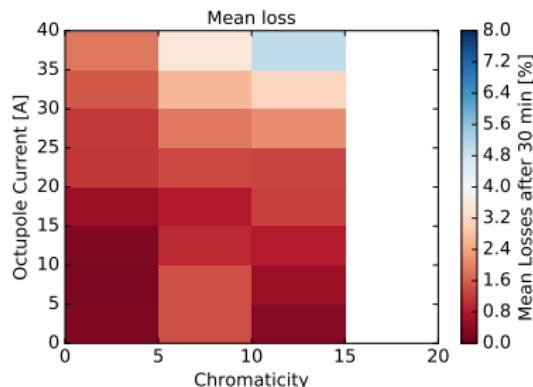
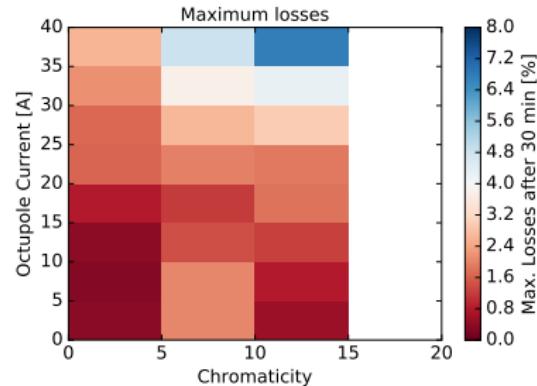
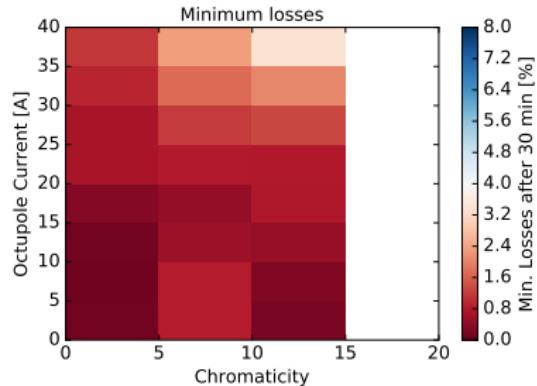
Extrapolated DA after 30 minutes - HL-LHC



Estimating losses from DA - HL-LHC B1



Estimating losses from DA - HL-LHC B2



Outlook

General

- ▶ Presented study starting point, regular updates upcoming
- ▶ Derive analytical formula for $\Pi(a, \nu, d)$
- ▶ Fix a and ν more precisely by comparing FWHM of Gauss and Lévy-Student distribution
- ▶ Calculate the emittance growth from DA
- ▶ Simulate HL-LHC for all data points

Outlook

Injection

- ▶ Check beam losses to compare with numerical simulations
- ▶ Need to disentangle contribution from emittance variation, e.g., IBS

Collision

- ▶ Repeat analysis (numerical simulations and analysis of losses)
- ▶ Transverse distributions : consider the need to repeat collimators scans

Summary and Conclusions

- ▶ Simulations of DA at injection for LHC and HL-LHC with different chromaticity and octupole setting
- ▶ Extrapolation of DA vs. turn with known functionality to obtain DA after 30 min
- ▶ Derivation of losses with Lévy-Student distribution
- ▶ Connection of beam lifetime to dynamic aperture
- ▶ First time this approach was used, several improvements upcoming + comparison to measurement
- ▶ Ultimate goal : define minimum DA for HL-LHC