Transverse beam quality along the chain for LHC beams

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Joint Accelerator Performance Workshop 05/12/23

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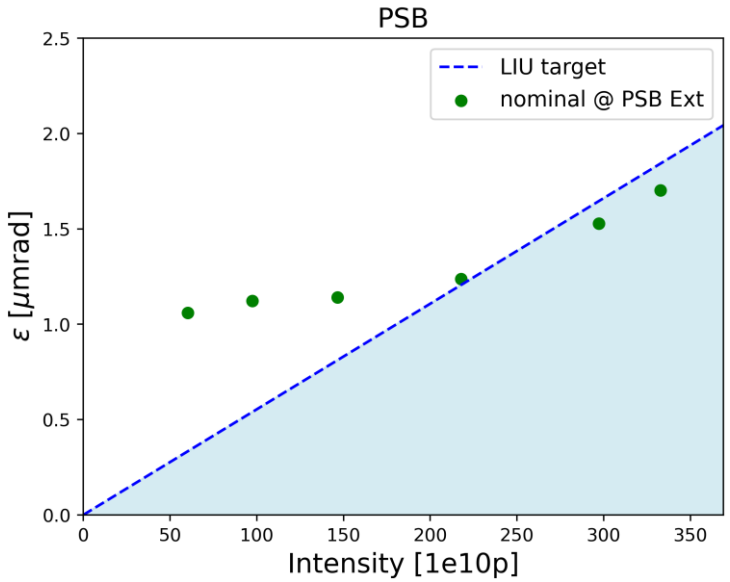
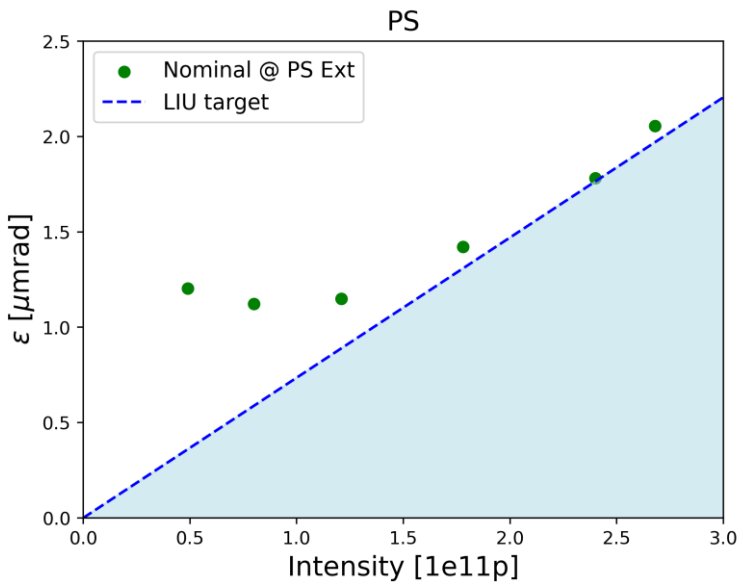
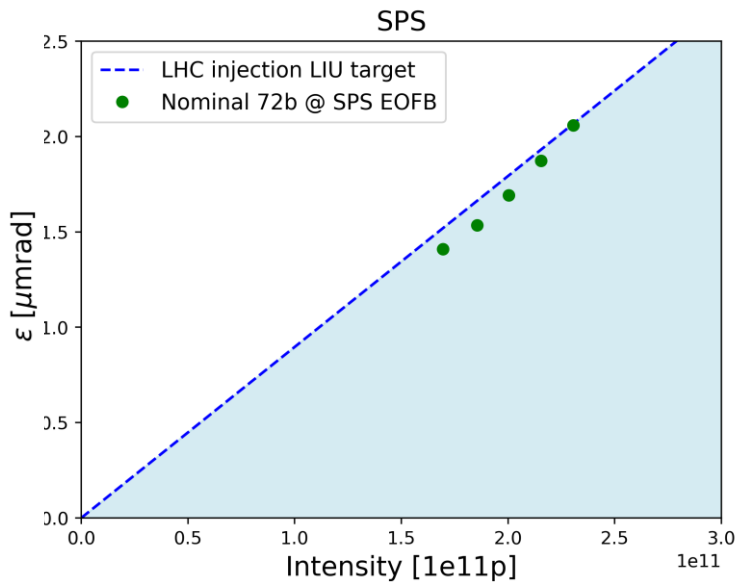
2023 observations of transverse performance

Brightness along the chain





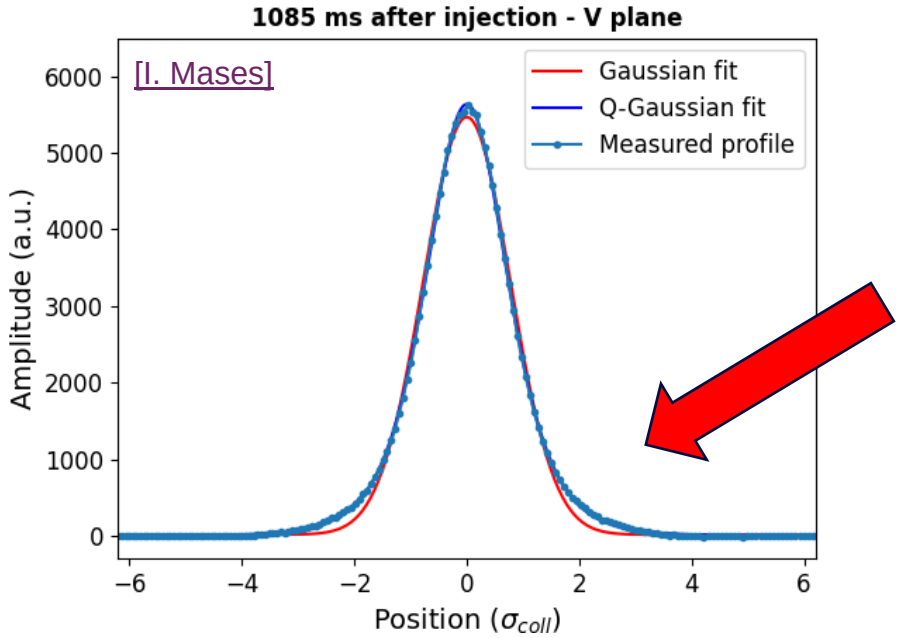


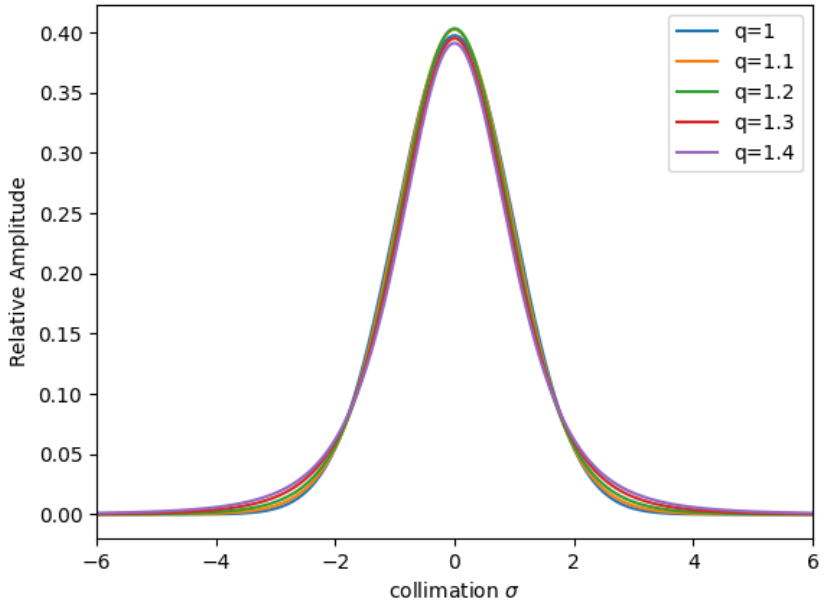
Brightness on target in all machines at high intensity for 2023 measurements

Is the brightness enough to characterize performance?

Performance of non-Gaussian beams

The emittance calculation assumes a Gaussian, but we can improve the profile **fit,** with the **q-Gaussian**.



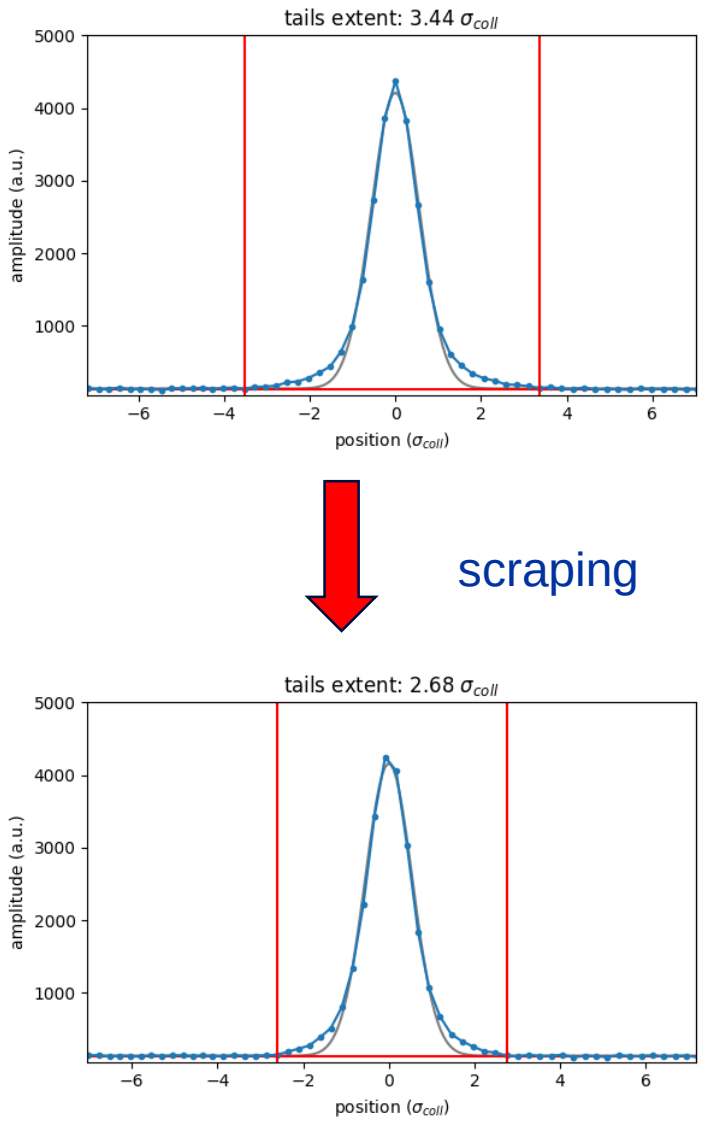


underpopulated tails ($q < 1$)
Gaussian tails ($q = 1$)
overpopulated tails ($q > 1$)

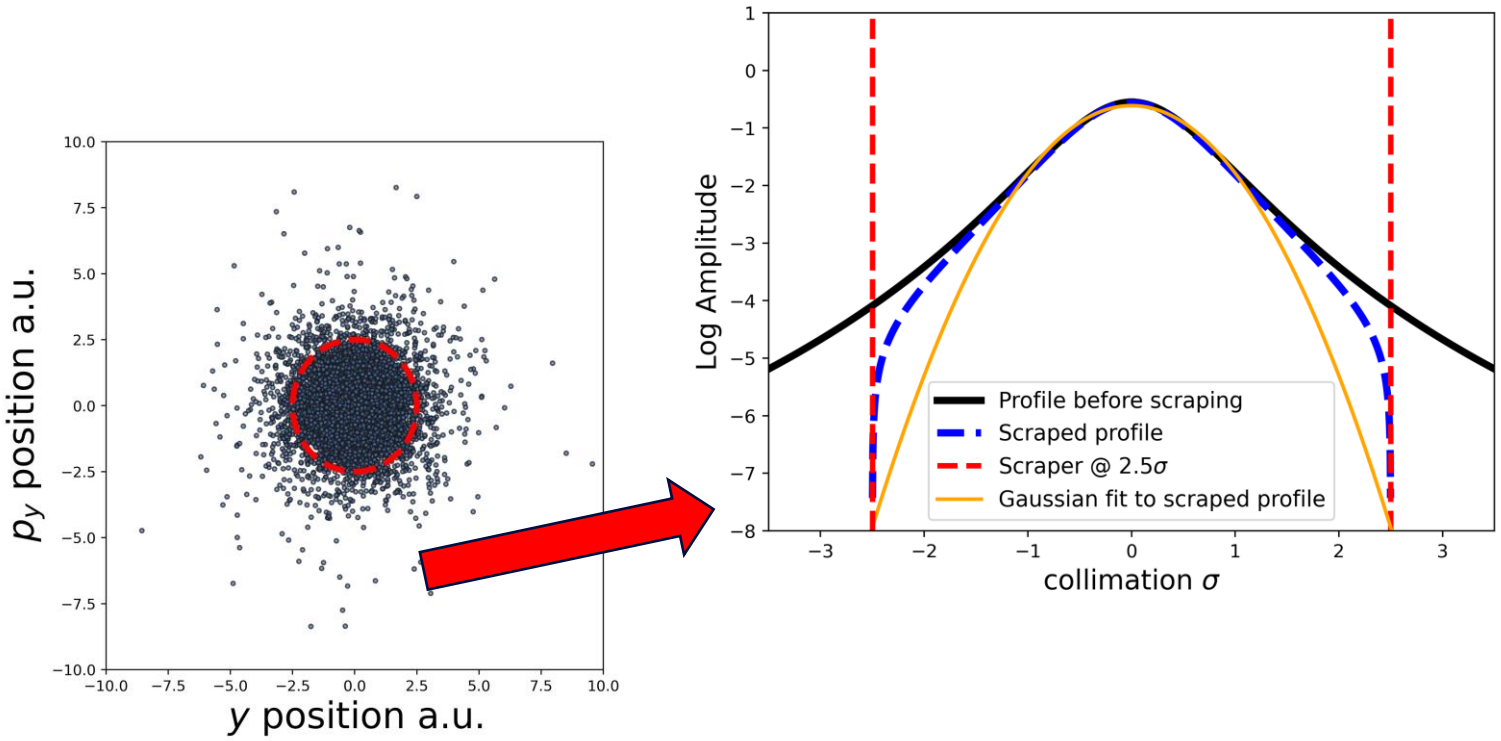
The **q** is related to the tail content.
We can use the q-Gaussian to characterise the performance in terms of **tail content** and we can see how the **luminosity varies** with respect to a Gaussian, as a complement to the brightness.

- **Luminosity depends both on the tail content and the emittance**

Tail content



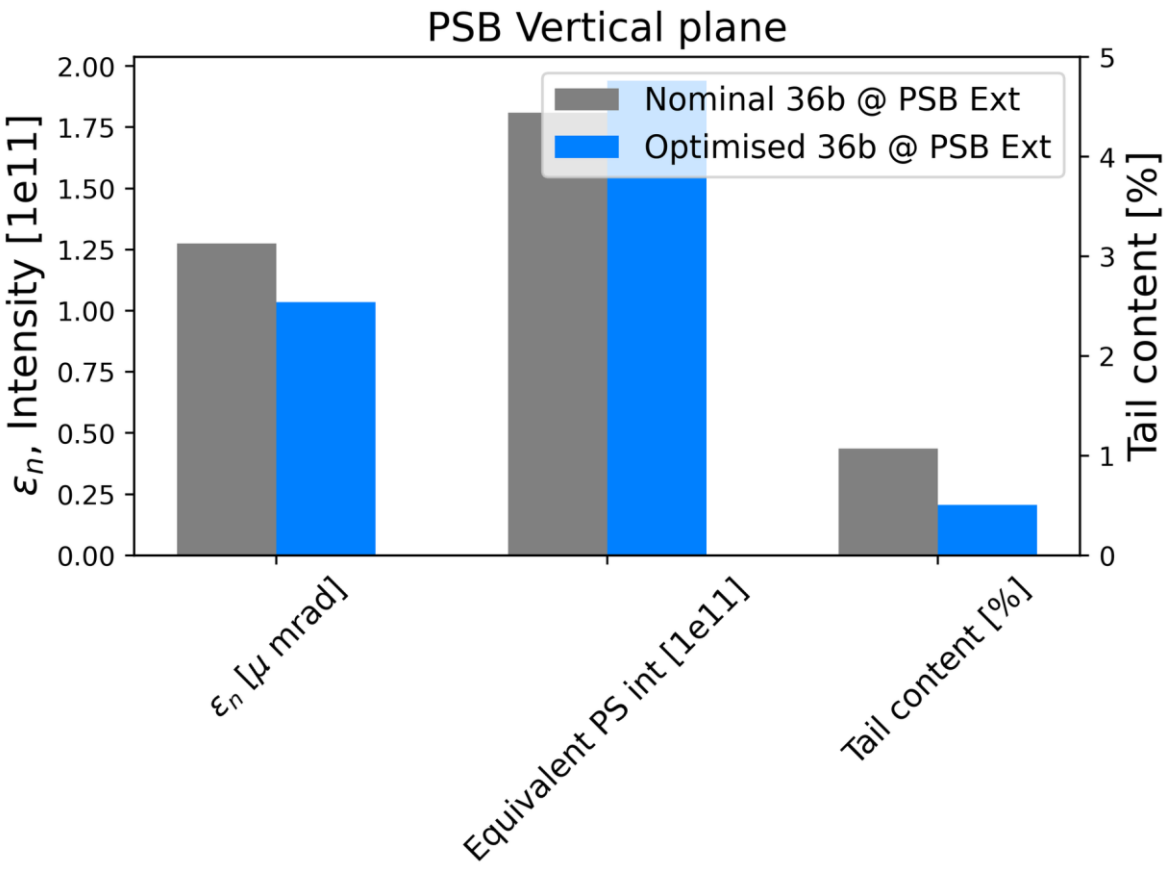
We can calculate how much beam is beyond **a set collimation position as a performance indicator.**



Heavy tailed beams do not become Gaussian unless largely scraped.

JA

PSB



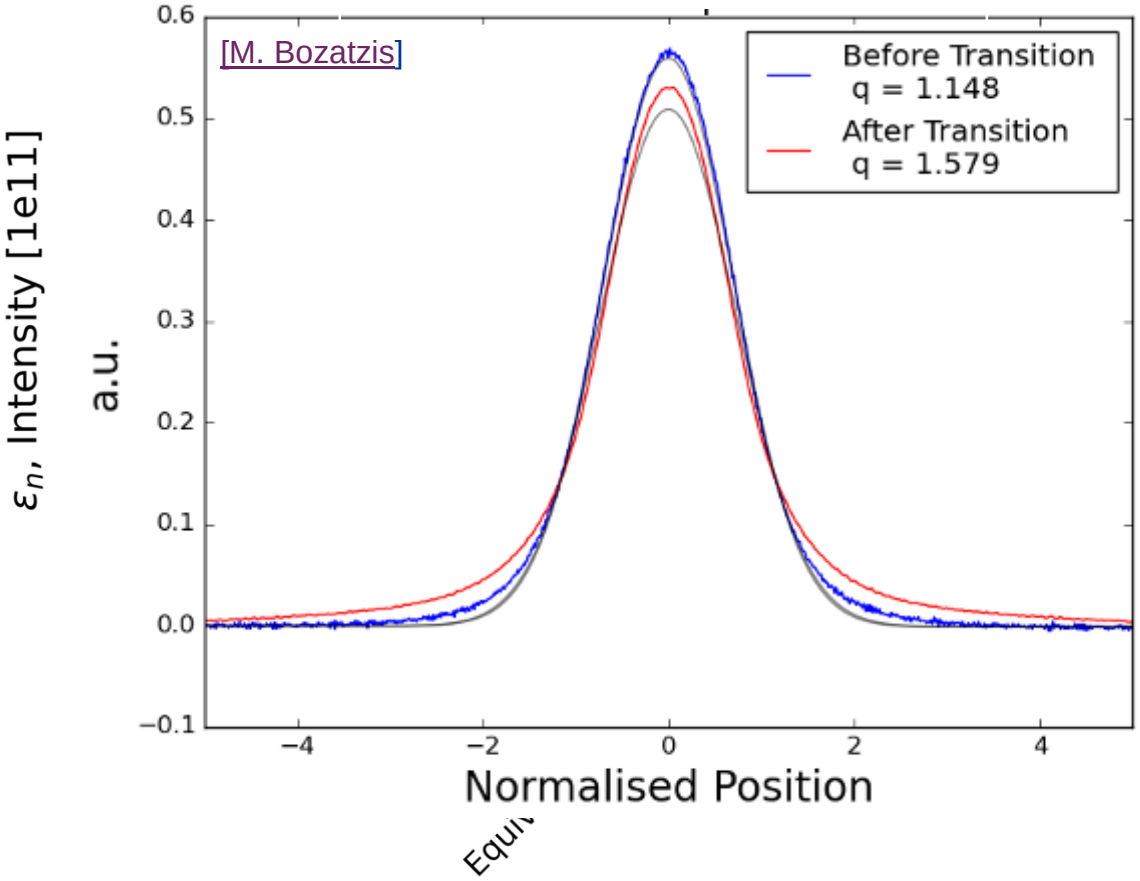
Disclaimer: Beam profiles taken in the vertical plane only due to dispersion

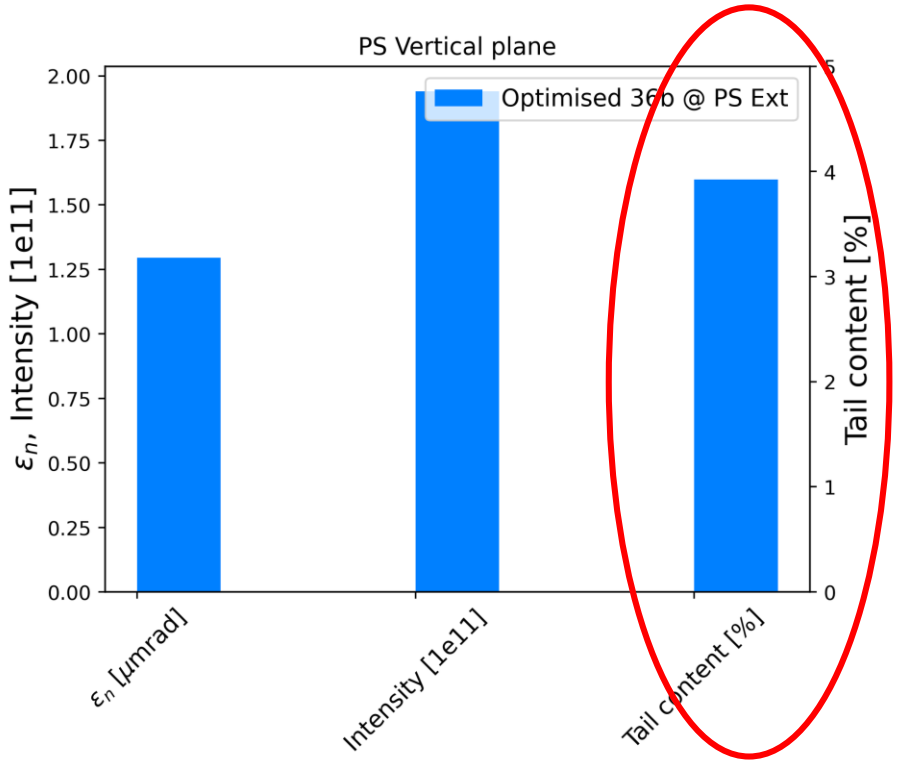
The optimised 36b gains margin from the **triple harmonic capture** used to optimize the working point and **achieve better resonance compensation**. [F. Asvesta].

Emittance and tails are reduced

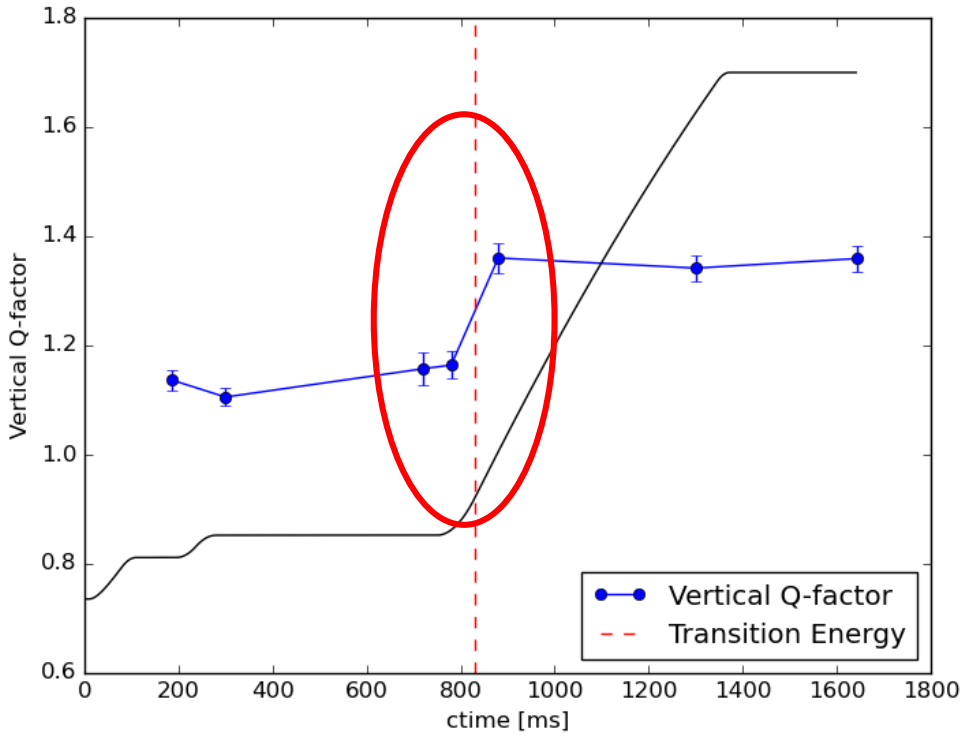
PSB-PS

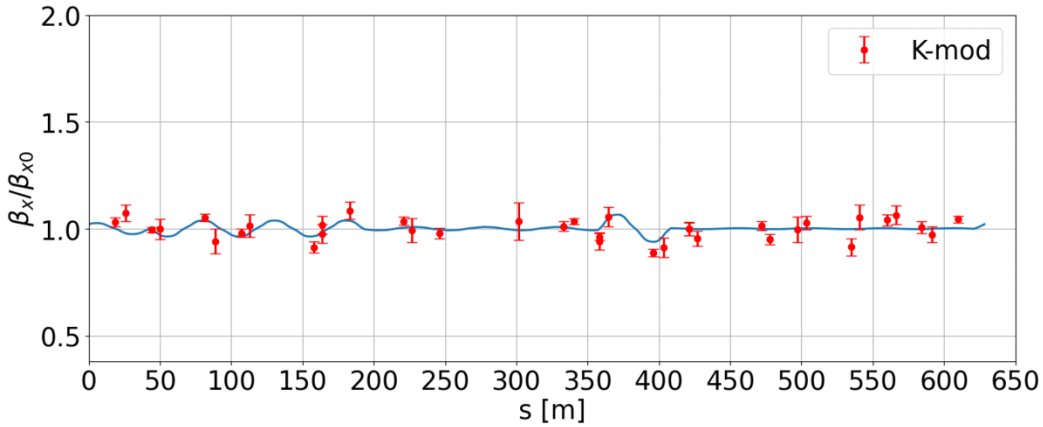
Tails created at transition crossing

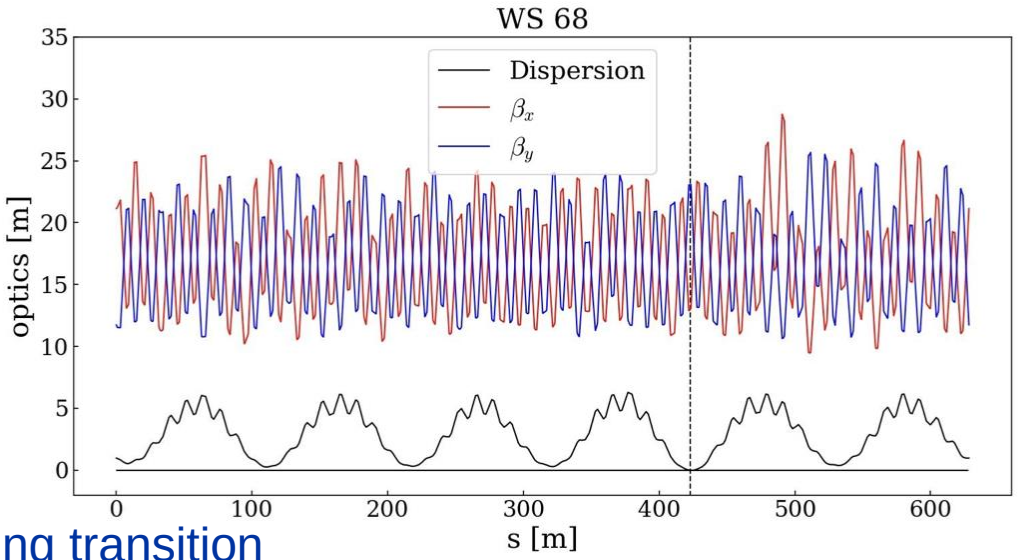




PS understanding tail formation at transition



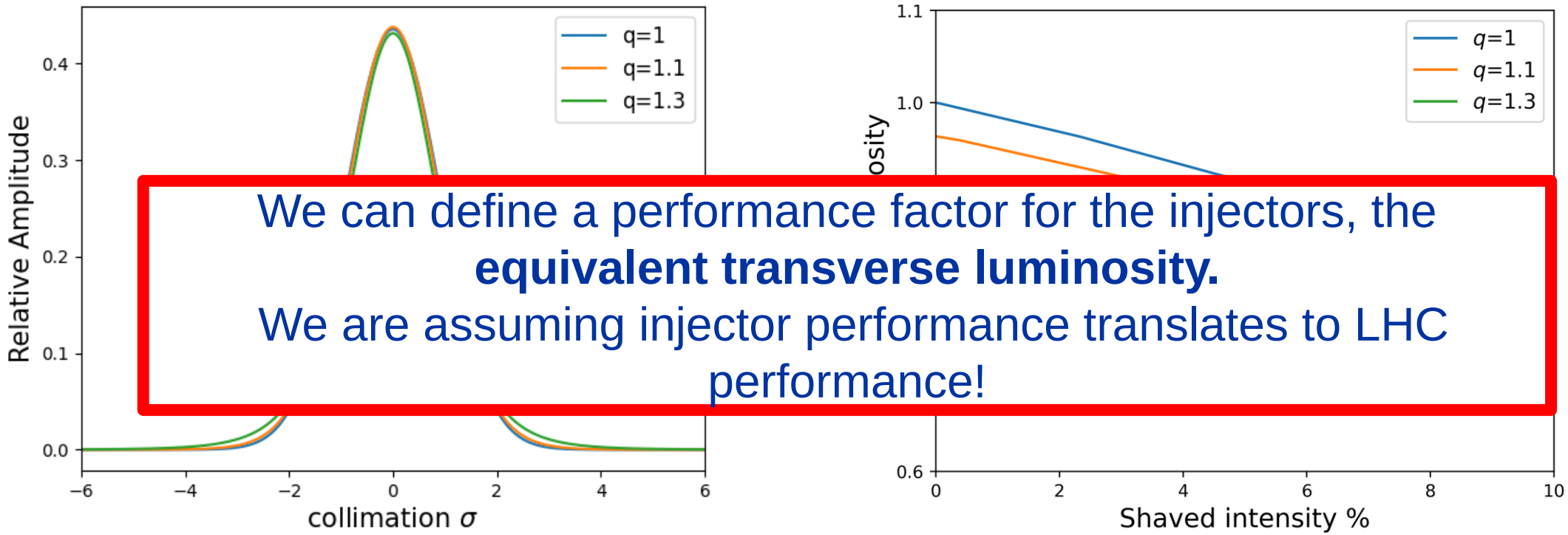




- Tails created at transition crossing
- Taken beta-beating measurements to characterise optics during transition
- Zero dispersion optics at PS Flat bottom → Possible to characterise H profiles

[M. Bozatzis], [T. Prebibaj], [W. Van Goethem]

Equivalent Luminosity



We can define a performance factor for the injectors, the **equivalent transverse luminosity.**
We are assuming injector performance translates to LHC performance!

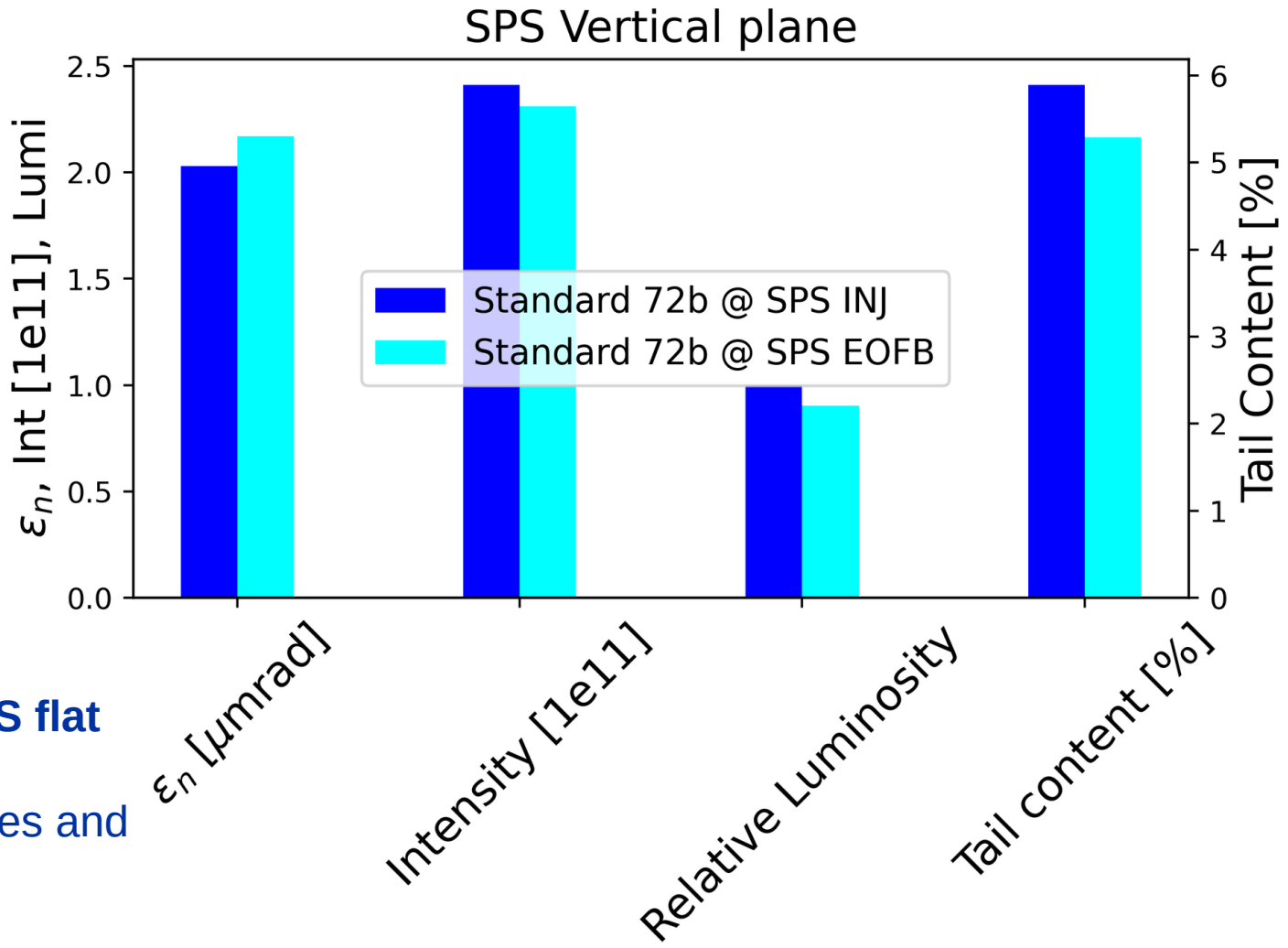
Assume

- same emittance for different q values
- same intensity as the Gaussian case
- same profiles in H and V (can measure vertical plane only due to dispersion)

$$\mathcal{L} \propto N_1 N_2 \iint \rho_1(x)\rho_1(y)\rho_2(x)\rho_2(y)$$

[S. Papadopoulou]

SPS Standard 72b along flat bottom



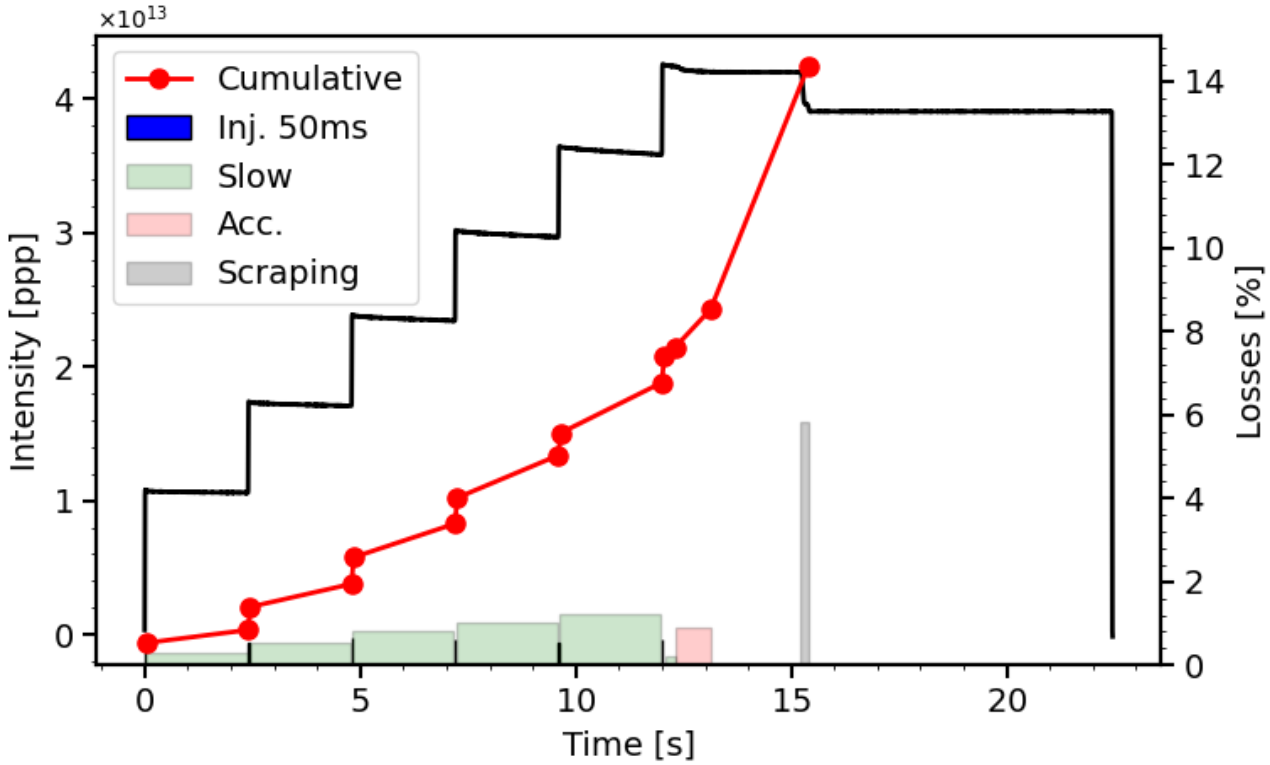
Beam quality degrades along SPS flat bottom

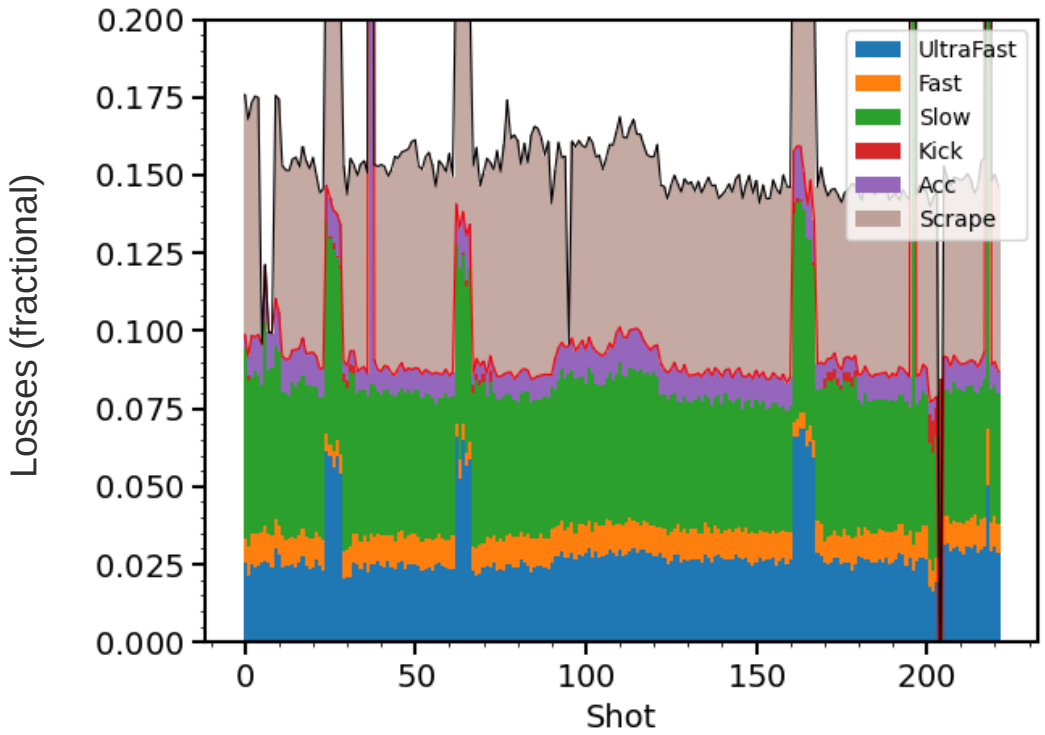
- Luminosity degrades due to losses and emittance blow up
- Tail decrease due to losses

SPS scraping

In the SPS we are **scraping** the beam for LHC injection (see presentation by Y. Dutheil)

- reduces the **intensity**
- changes the **profile**





[A. Lasheen]

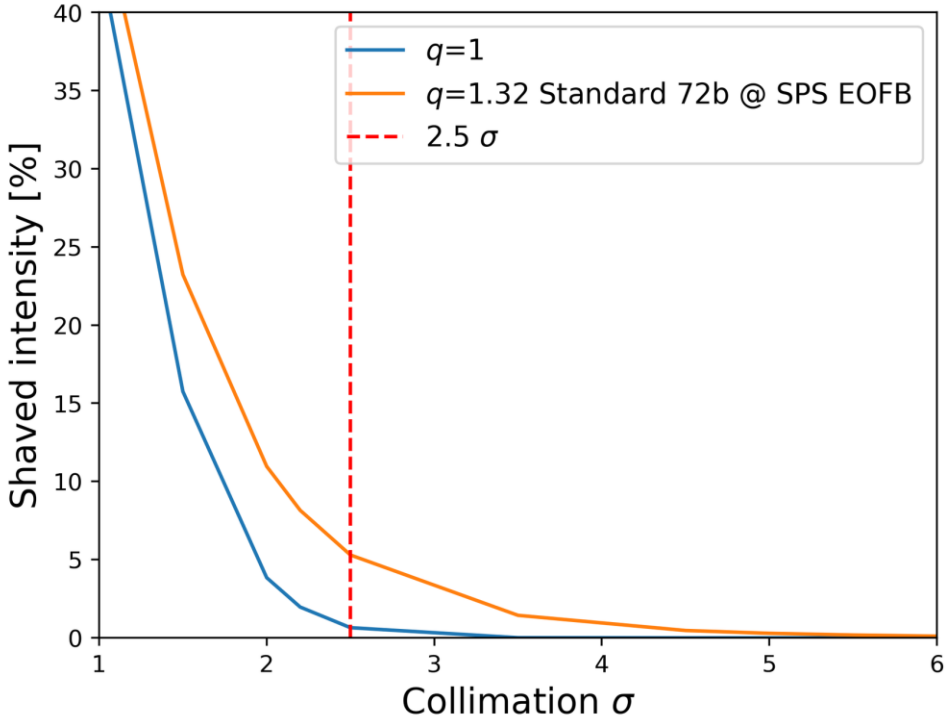
How does scraping impact luminosity?

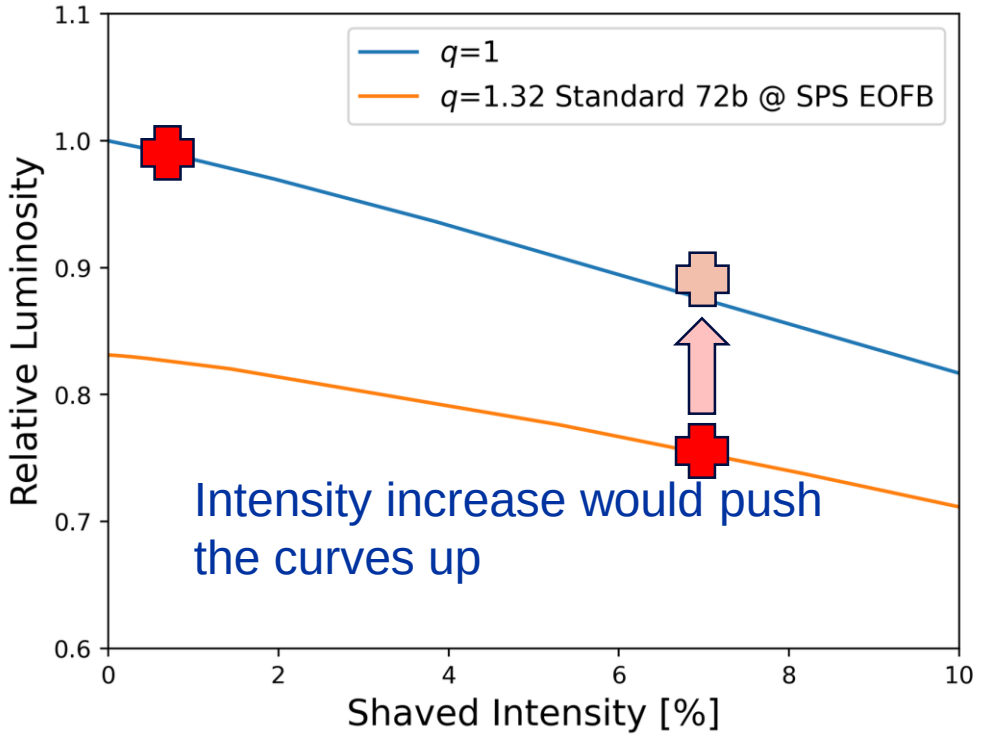
SPS scraping

We calculate **relative loss in luminosity as we scrape** the tails by numerically integrating the profile.

- Luminosity is reduced due to the tails
- Scraping further reduces luminosity
- Luminosity partially recovered by compensating intensity

Reducing tails upstream of LHC injection is important to improve performance

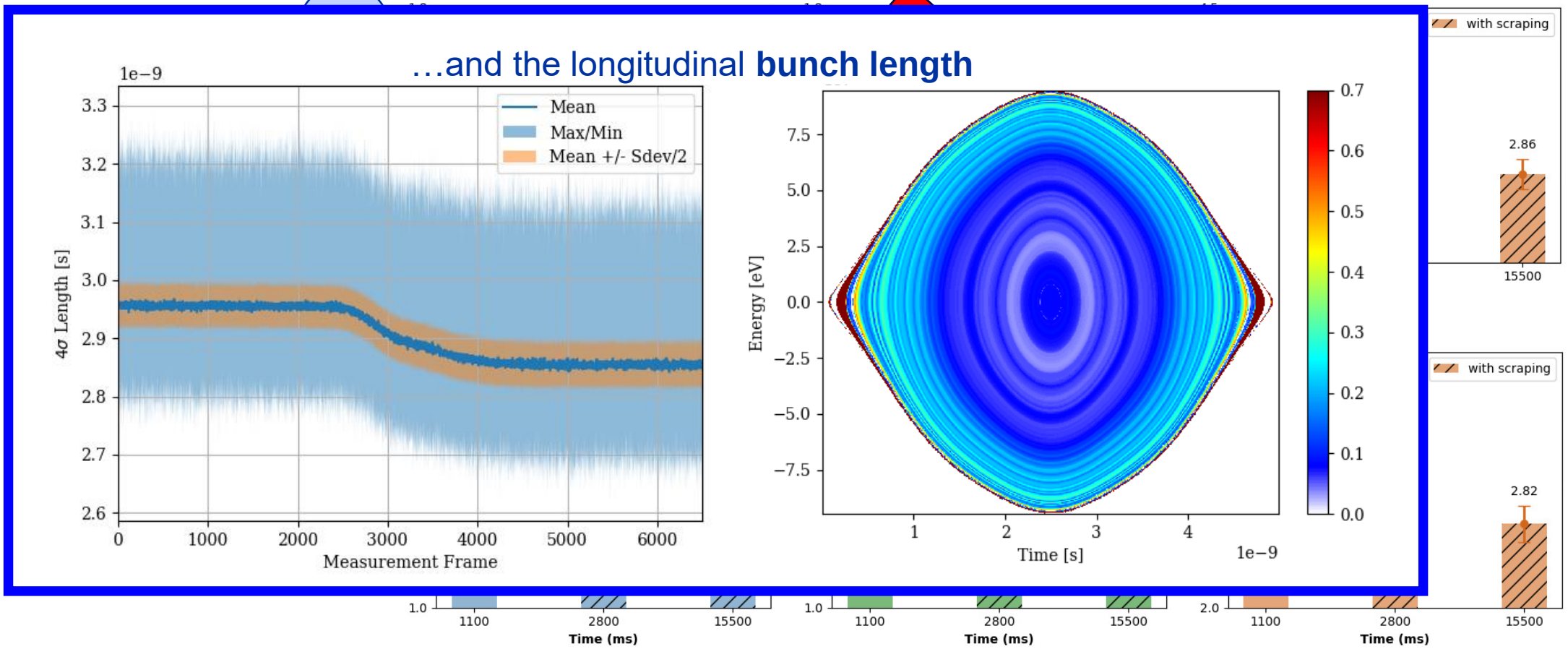




Understanding of correlations

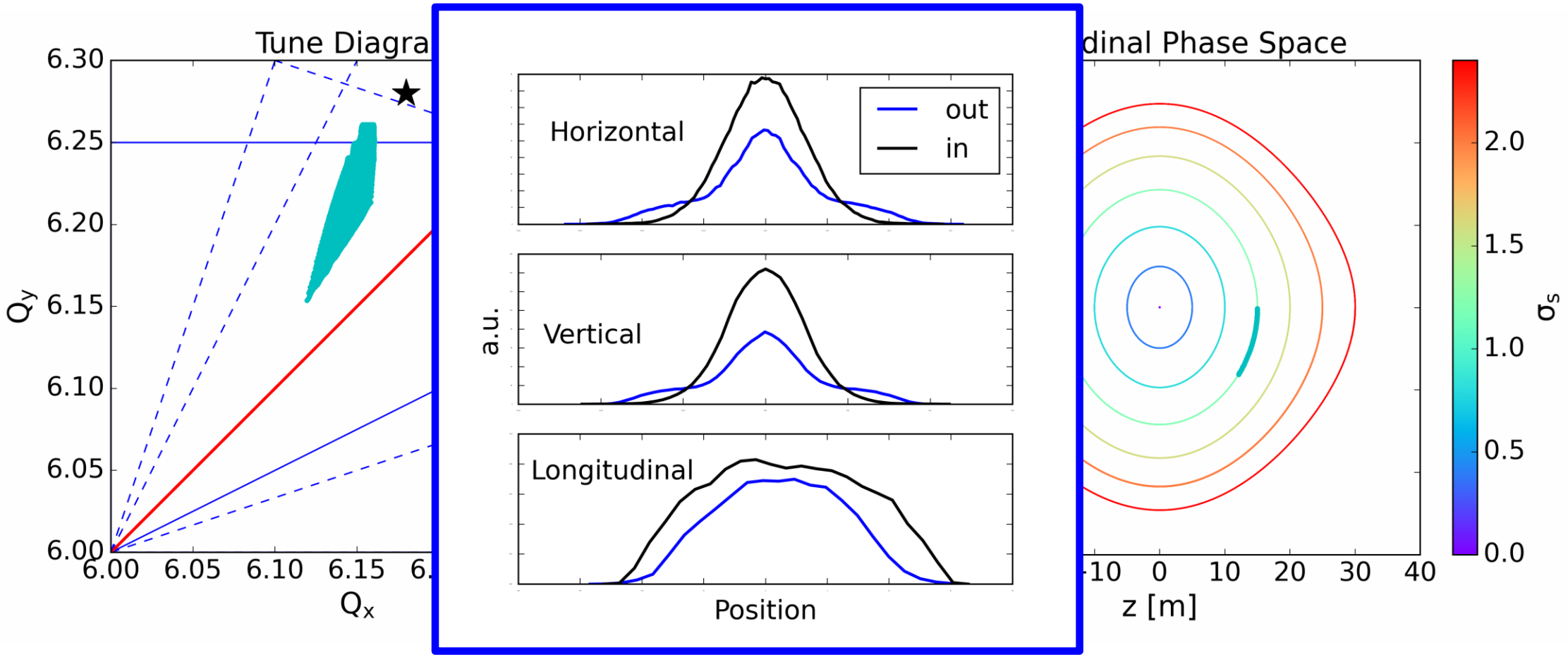
In 2022 we saw that **vertical** scraping affected **also the horizontal tails** in the SPS

…and the longitudinal **bunch length**



[E. De la Fuente, I. Mases]
[A. Lasheen]

Resonance inducing correlations

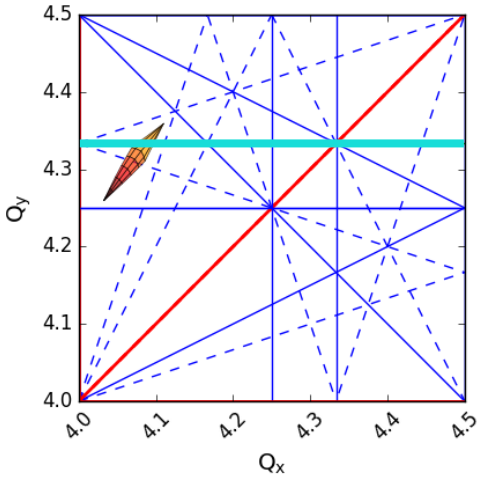


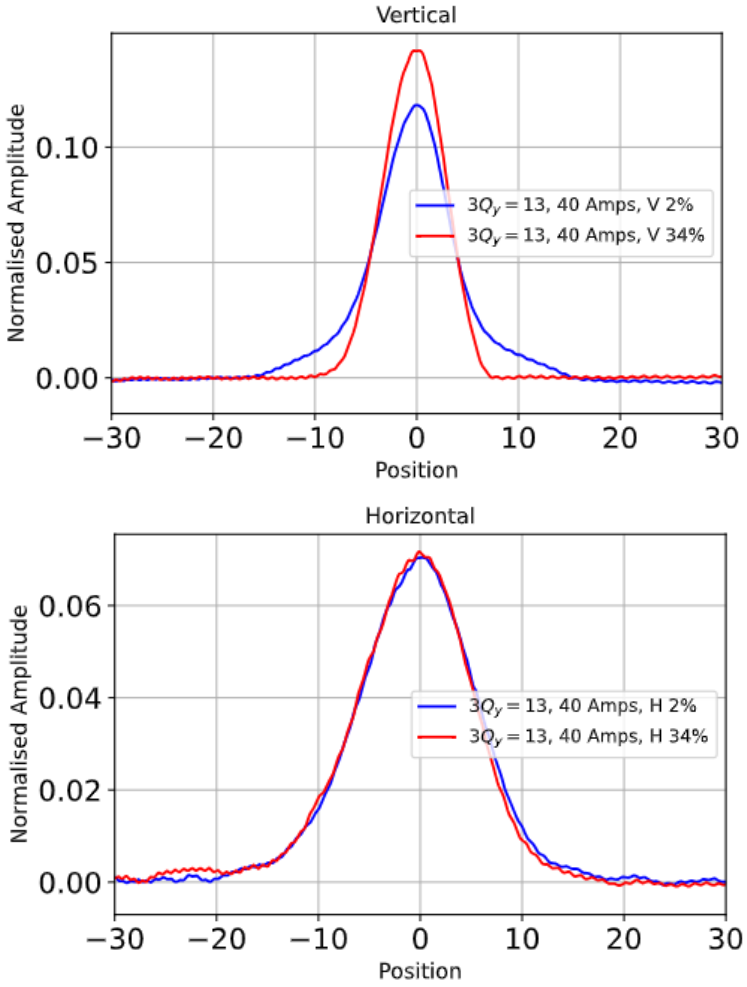
- Space charge can create **correlations in 3 planes** through the periodic resonance crossing via the synchrotron motion.
- In the presence of losses we create **tails in H and V** and **reduce the bunch length.**

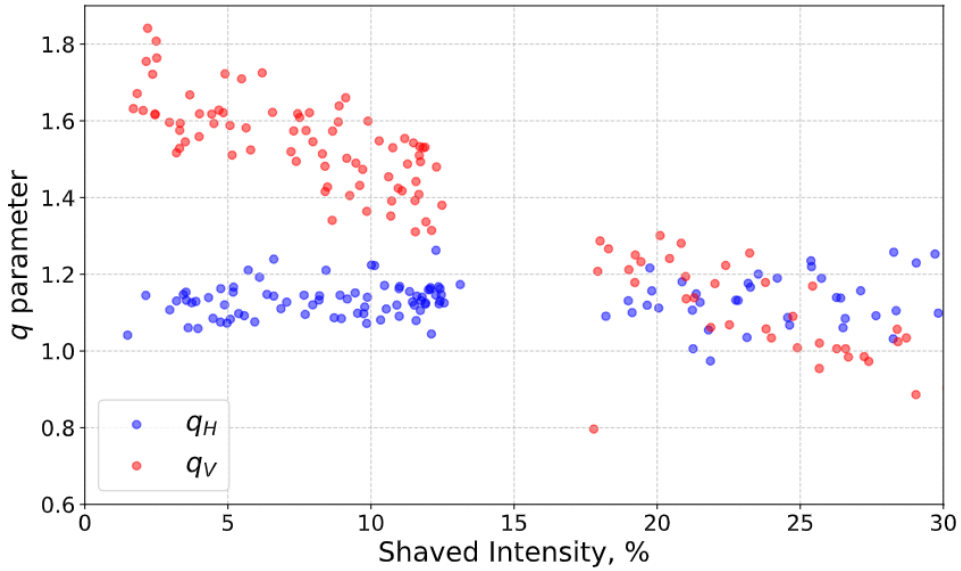
Understanding correlations in the PSB

1D resonances don't couple H and V planes.

- **Scraping in V doesn't change the profile in H.**





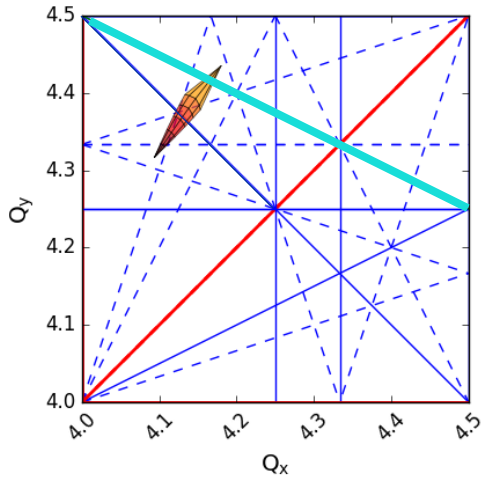


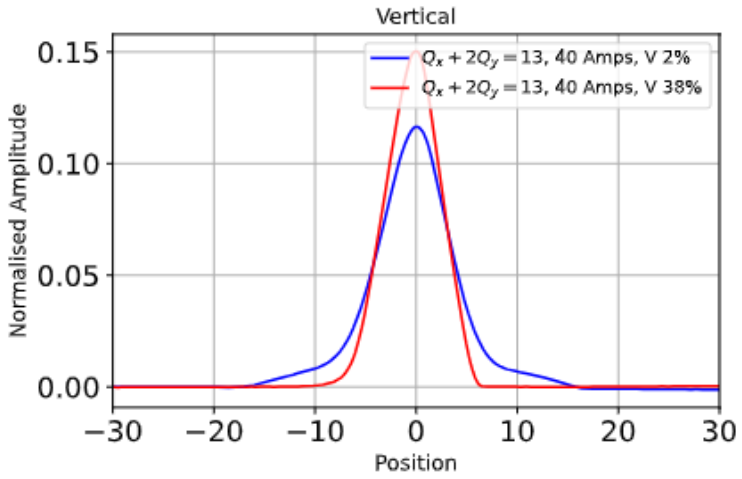
Longitudinal plane to be analysed

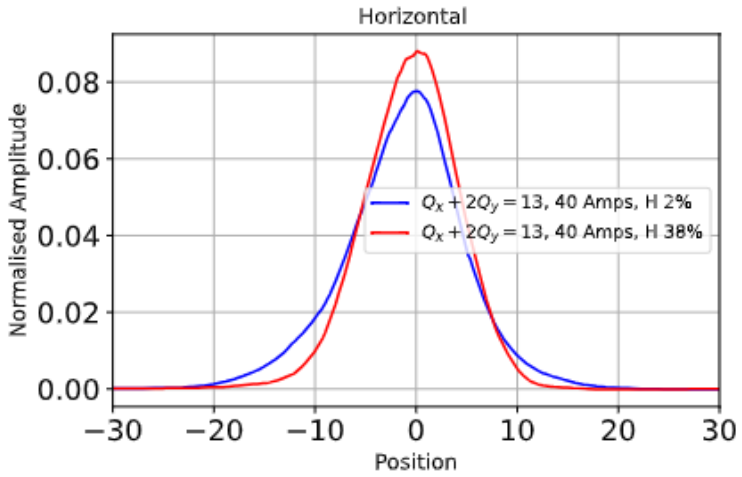
Understanding correlations in the PSB

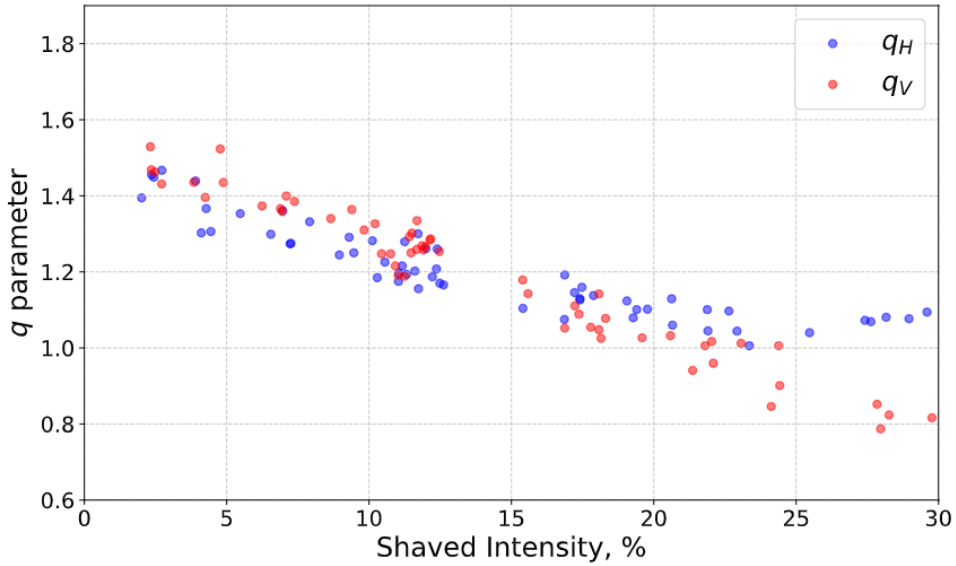
2D resonances couple the H and V planes.

- **Scraping in V changes the profile in H.**
- **Correlations last** when resonance not excited.









Longitudinal plane to be analysed

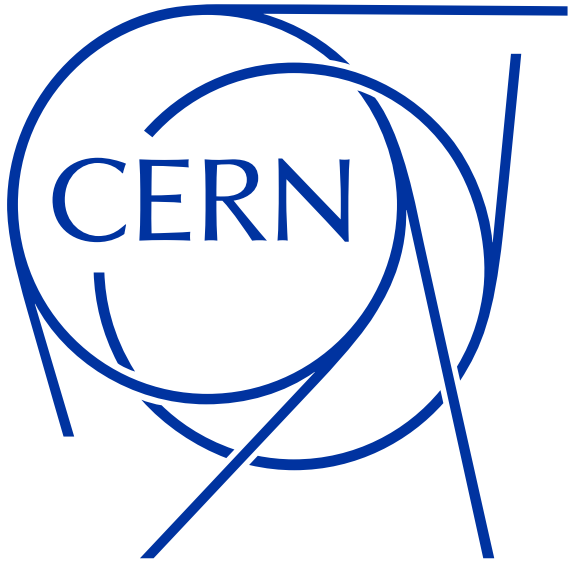
Summary and outlook ‘24

Summary

- On target for LIU brightness
  - **Heavy tails** observed and created at specific points along injector chain
  - Necessary to **scrape heavy tails in SPS**
  - **Tails reduce performance** compared to a Gaussian beam in terms of **luminosity**
- **Improved tails in the PSB** by optimization of the cycle (working point and triple harmonic)
- Identified significant **tail generation at PS transition crossing**
- Ongoing **studies** to characterize **tail generation mechanisms** in the PSB

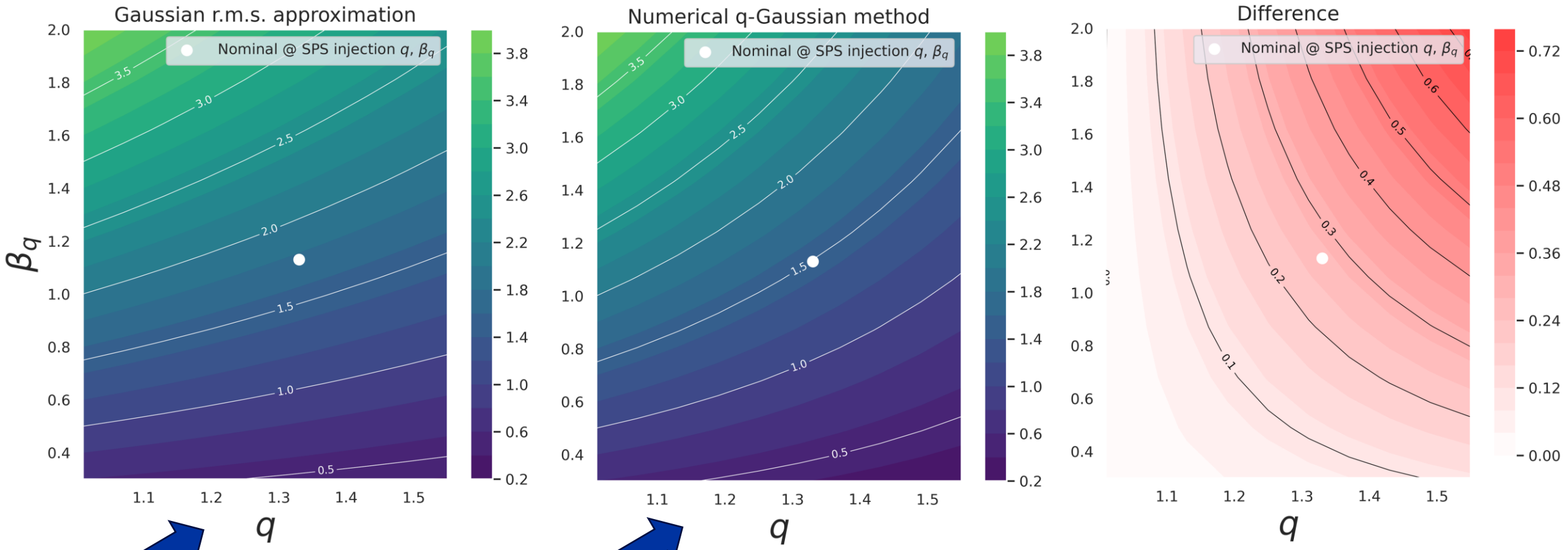
Outlook for 2024

- **Characterize profiles across beam variants along the injector chain**
- **Simulate** tail creation from **transition** crossing in the PS
- Understand how **scraping** and remaining tails **translates to luminosity performance in the LHC**
- How are the **tails transferred** along the chain up to LHC collisions


CERN

Back up

Luminosity - Gaussian or q-Gaussian



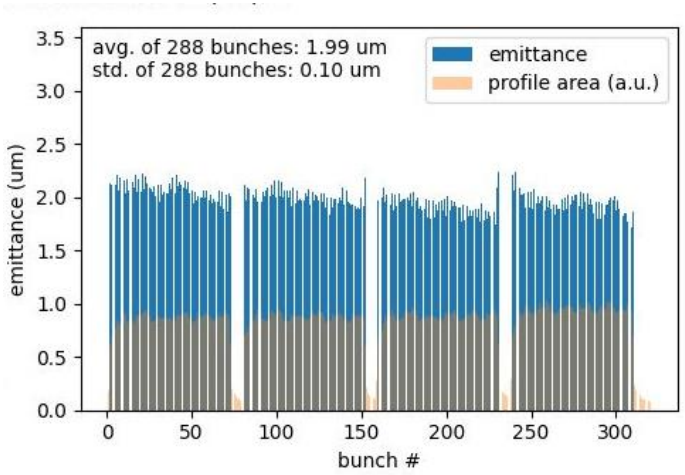
$$\mathcal{L} = \frac{N_1 N_2 f N_b}{4\pi\sigma_x\sigma_y}$$

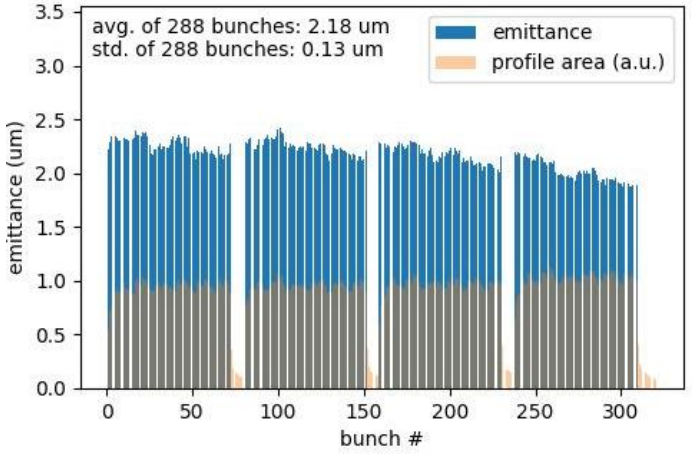
$$\mathcal{L} \propto \int\int \rho_1(x)\rho_1(y)\rho_2(x)\rho_2(y)$$

The higher the **q,** or heavier tail, the less accurate the Gaussian approximation is for Luminosity

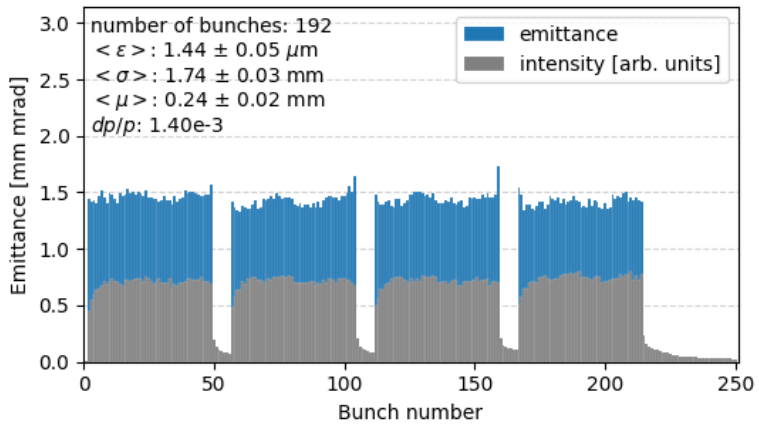
SPS bunch by bunch emittance variation

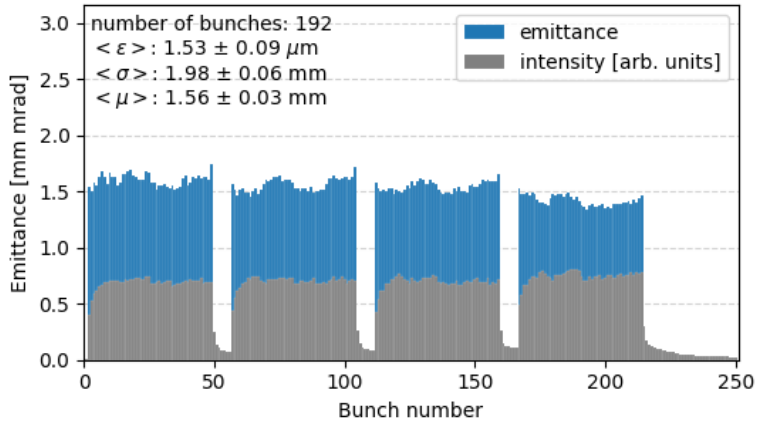
STANDARD 72b





BCMS



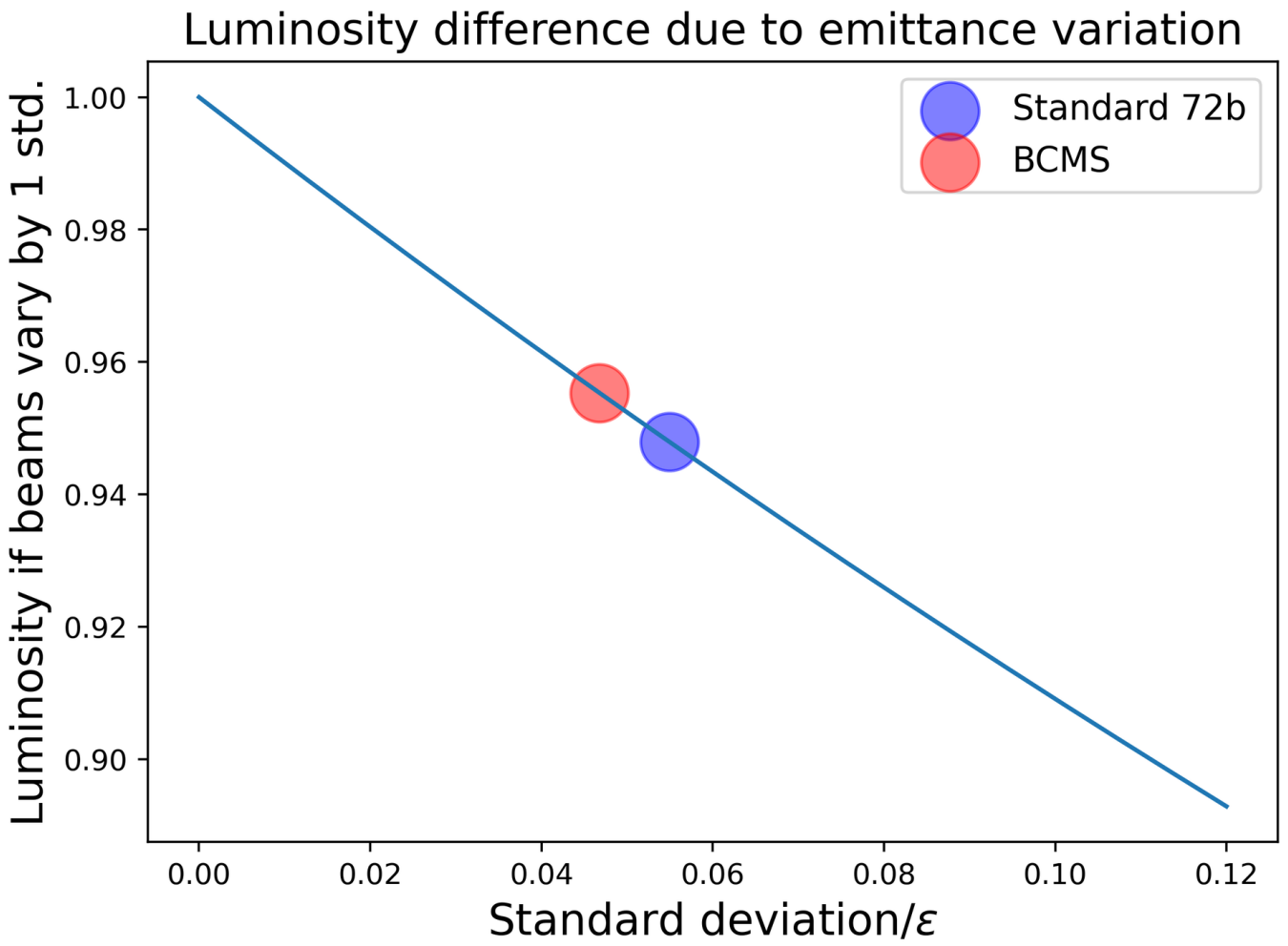


The bunch by bunch variation in emittance at the end of flat bottom in the SPS.

Both the 72b standard beam and the BCMS have a standard deviation around 5% of average emittance.

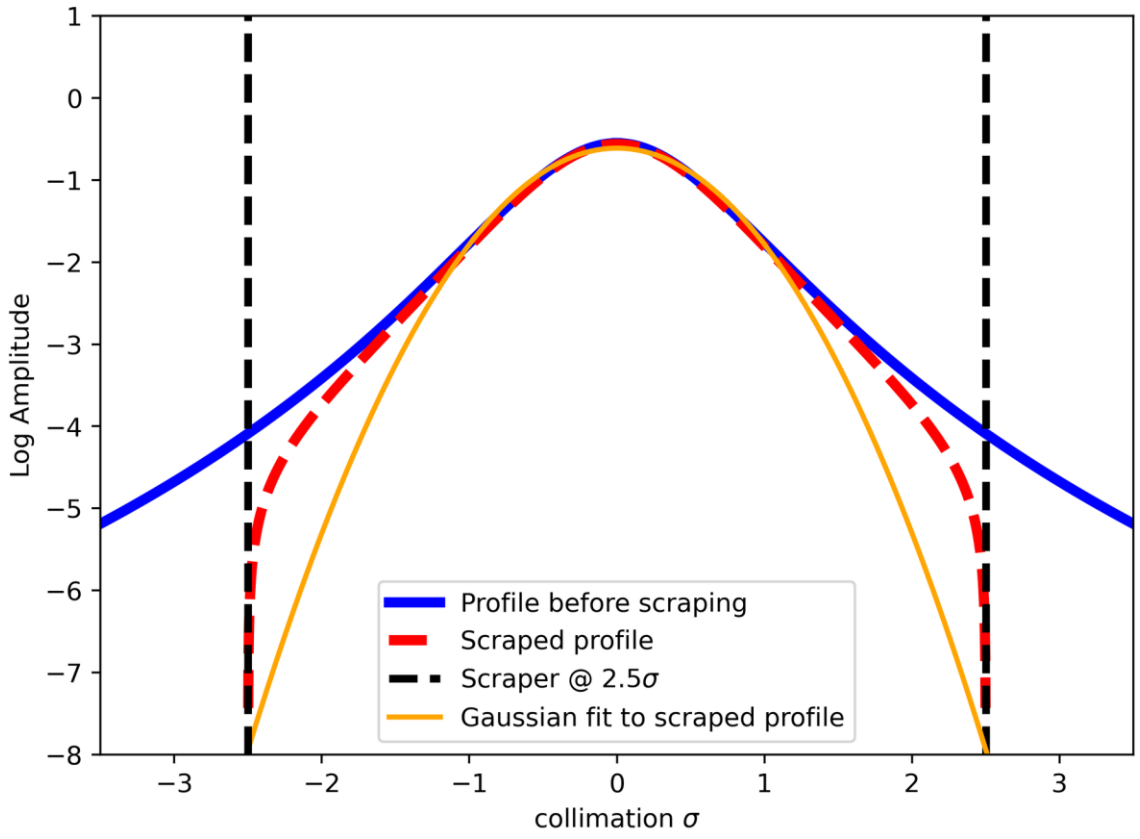
I. Mases SPS Brightness

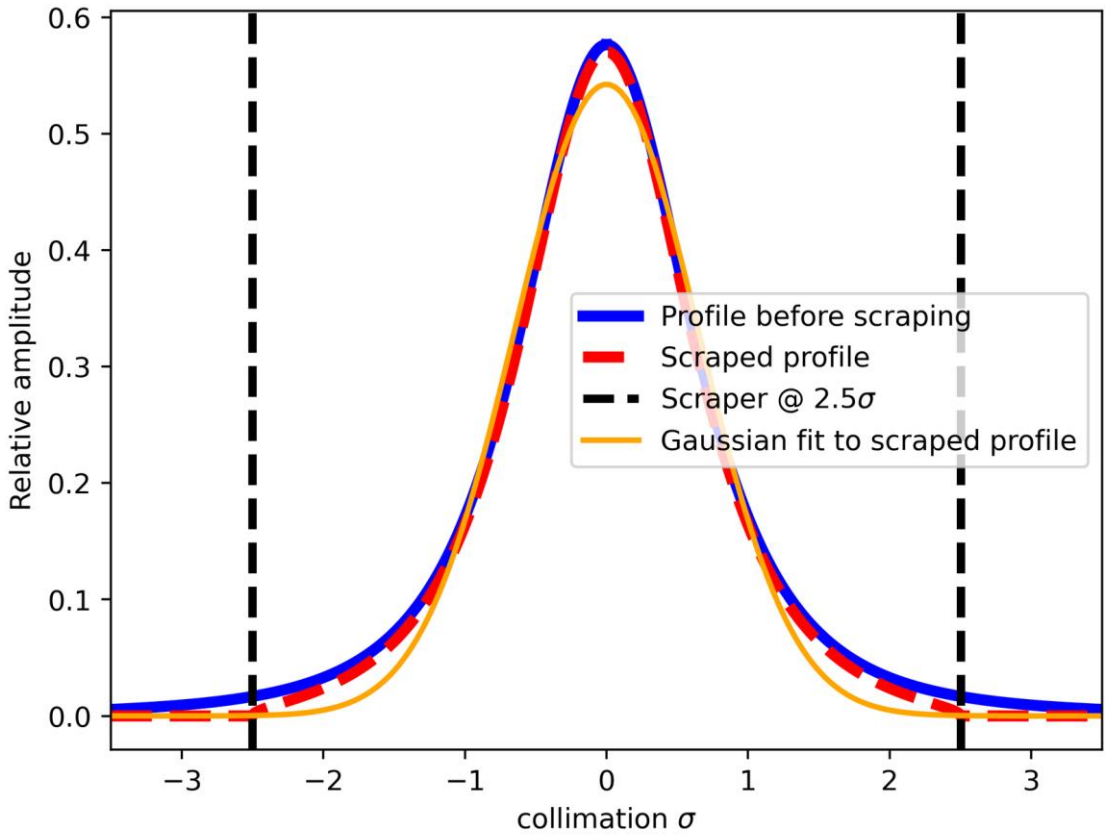
SPS bunch by bunch emittance variation



$$\mathcal{L} = \frac{N_1 N_2 f N_b}{4\pi\sigma_x\sigma_y}$$

Scraping


Log Amplitude
collimation σ
Profile before scraping
Scraped profile
Scraper @ 2.5σ
Gaussian fit to scraped profile


Relative amplitude
collimation σ
Profile before scraping
Scraped profile
Scraper @ 2.5σ
Gaussian fit to scraped profile