Dispersion and brightness studies in the PSB

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PSB OB

Introduction

For a **single particle**, the horizontal position ***x*** is defined as:

$$x = x_b + x_d = \sqrt{\beta_x \varepsilon_x} \cos(\psi + \psi_0) + D_x \frac{\delta p}{p}$$

Betatronic position (x_b)   Dispersive contribution (x_d)

If we consider a **set of particles** and we assume**:**

- x_b and x_d are indipendent
- Both the betatronic and the dispersive distributions are Gaussian

the total variance in the horizontal plane σ_x is given by:

$$\sigma_x^2 = \sigma_b^2 + \sigma_d^2 \Rightarrow \sigma_b^2 = \sigma_x^2 - \left[D_x \left(\frac{\delta p}{p} \right)_{RMS} \right]^2$$

Horizontal emittance reconstruction

The **horizontal emittance** can be derived from the previous equation:

$$\varepsilon_{x,RMS} = \frac{\beta\gamma}{\beta_x}\left[\sigma_x^2 - \left[D_x\left(\frac{\delta p}{p}\right)_{RMS}\right]^2\right]$$

The **emittance reconstruction** relies on specific assumptions about transverse beam profiles, dispersion, and momentum spread $(\delta p/p)$. These assumptions introduce errors, leading to uncertainties in the reconstructed values.

Aim

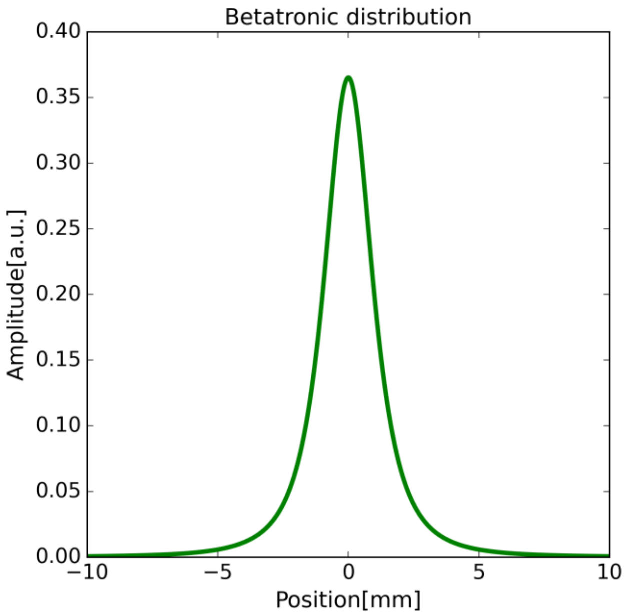
Gain deeper understanding of both the emittance and the beam's transverse shape by working to **reduce these uncertainties**.

Strategies

- **Minimize dispersion** to mitigate its impact on emittance measurements
- **Reduce** the **energy spread** $(\delta p/p)$ to improve the consistency of the beam properties
- **Improve** the **reconstruction algorithm** for more accurate beam characterization

Convolution of the measured dispersive distribution with variour q-Gaussian profiles

The measured distribution is the **convolution** of the betatronic and the dispersive components.



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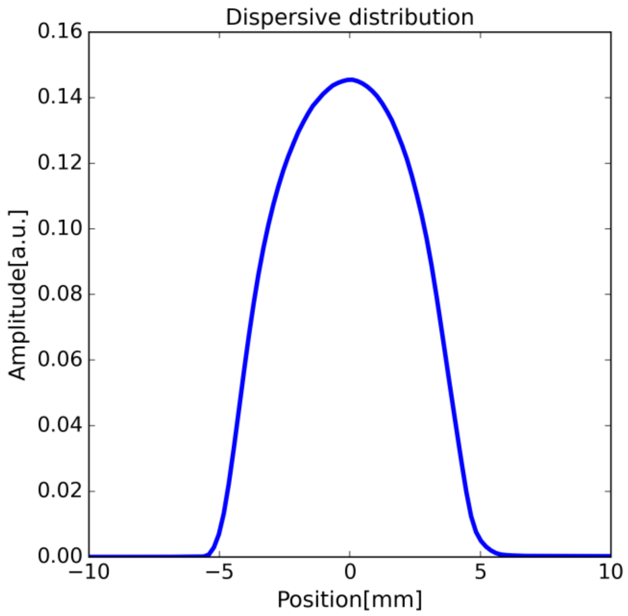

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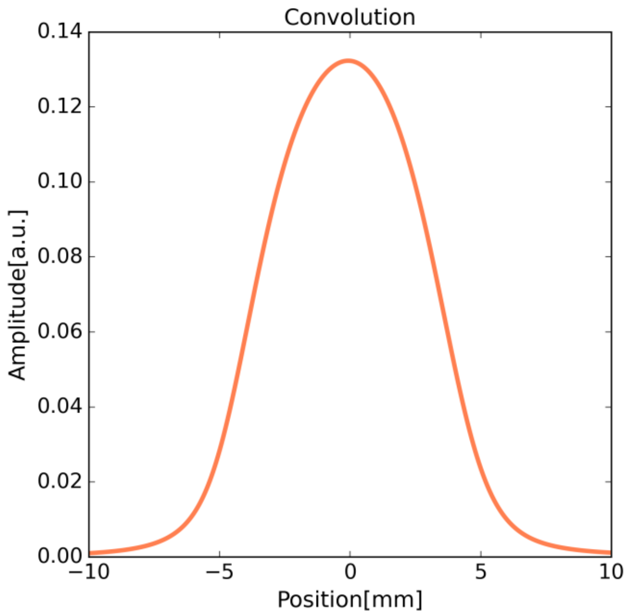


This is the **unknown** distribution in which we are interested

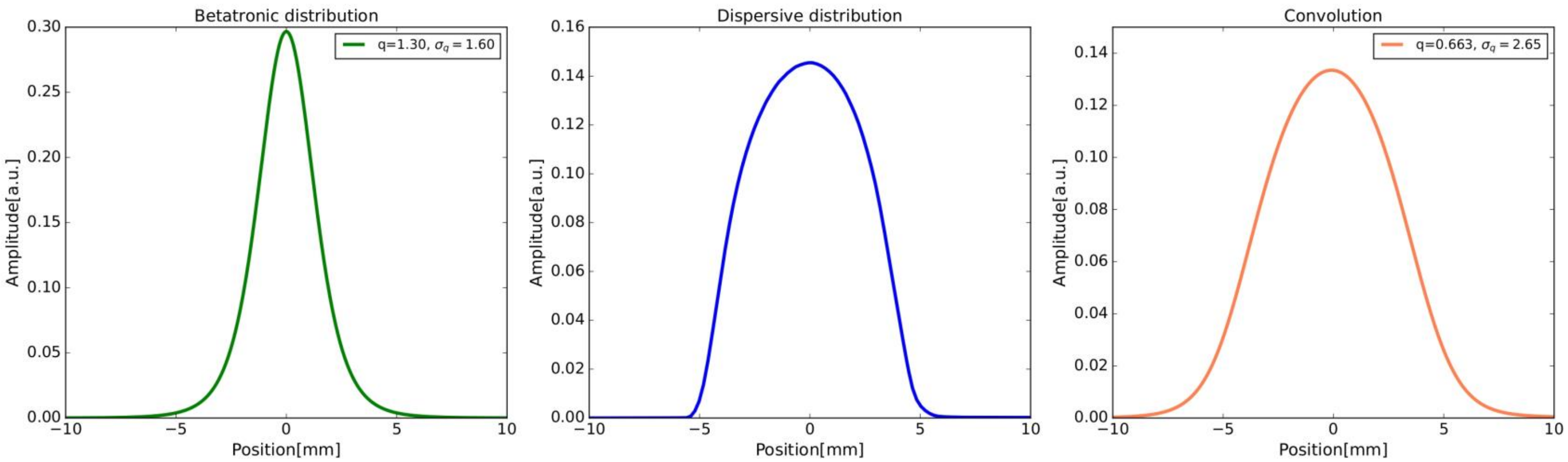
The dispersive distribution has a **parabolic** shape

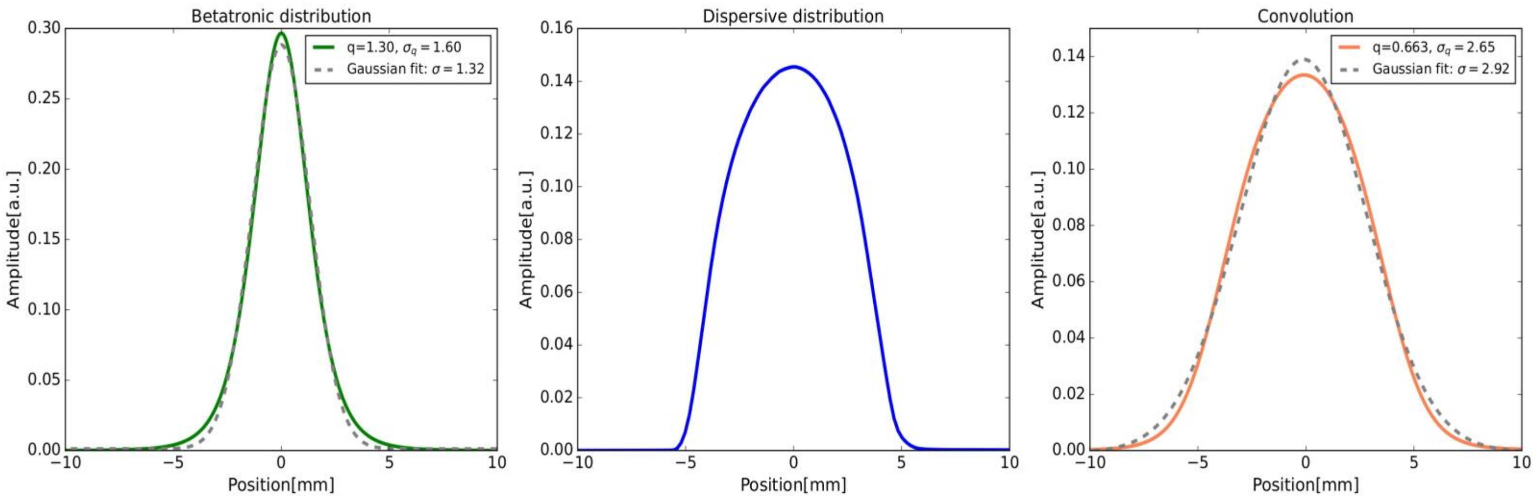
The measured profile is closer to a **q-Gaussian** distribution

Example

Betatron distribution with $q_0 = 1.3$ and $\sigma_{q,0} = 1.6$

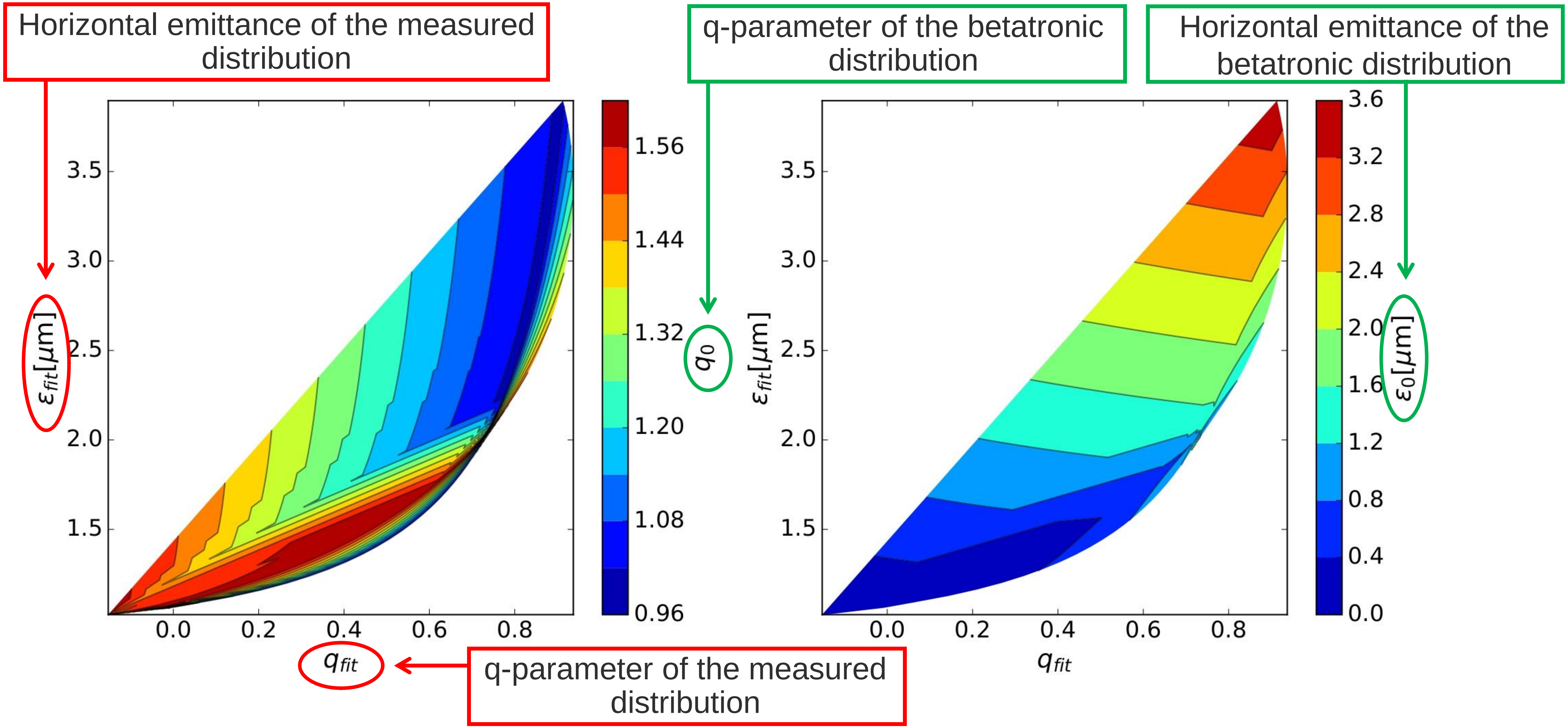
A **q-Gaussian** (with $q_0 = 1.3$ and q-Gaussian $\sigma_0 = 1.6$) was **generated** and then **convolved** with the dispersive distribution The resulting distributions were fitted using a q-Gaussian.





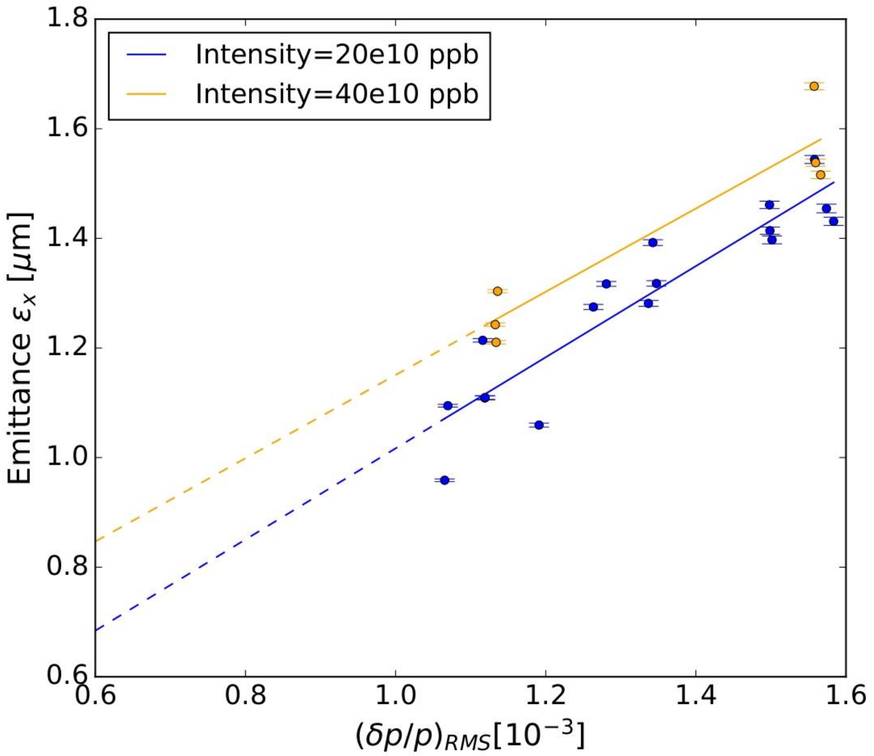
A **Gaussian fit** was then performed on both the generated betatronic distribution and the one obtained from the convolution, and the respective Gaussian sigma values were used to obtain the emittance.

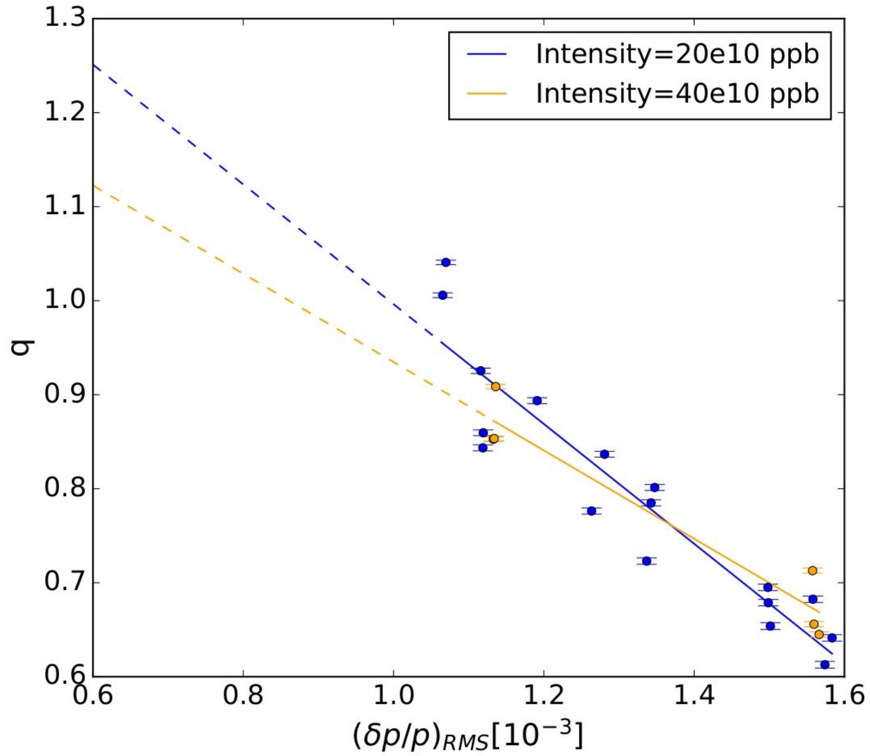
Maps for betatronic distribution extraction



Dependence of ε_x and q from $\delta p/p$

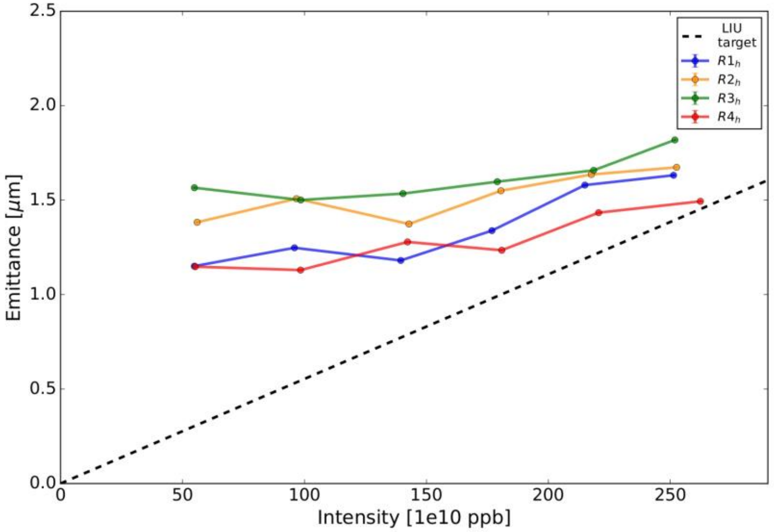
It can be observed that, with a reduced $\delta p/p$, the measured **tails** increase, while the calculated **emittance** appears smaller.

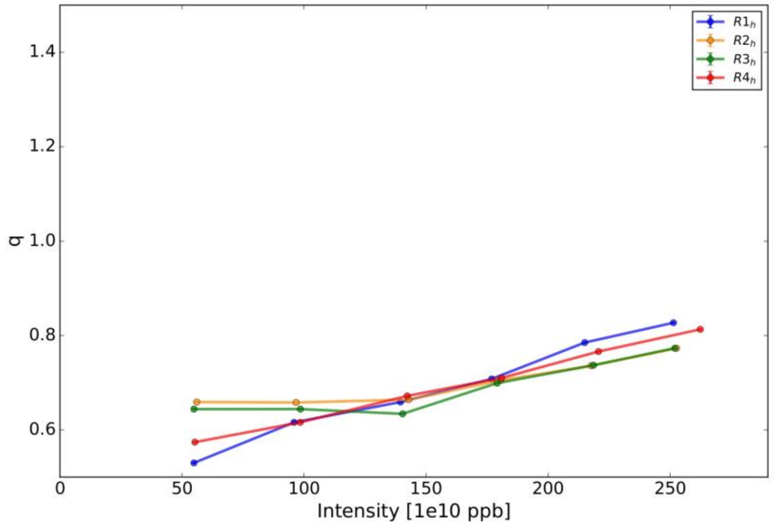




Note: dashed lines represents the projection of the fit, but no conclusions about this trend can be drawn from the data.

Impact on beam brightness

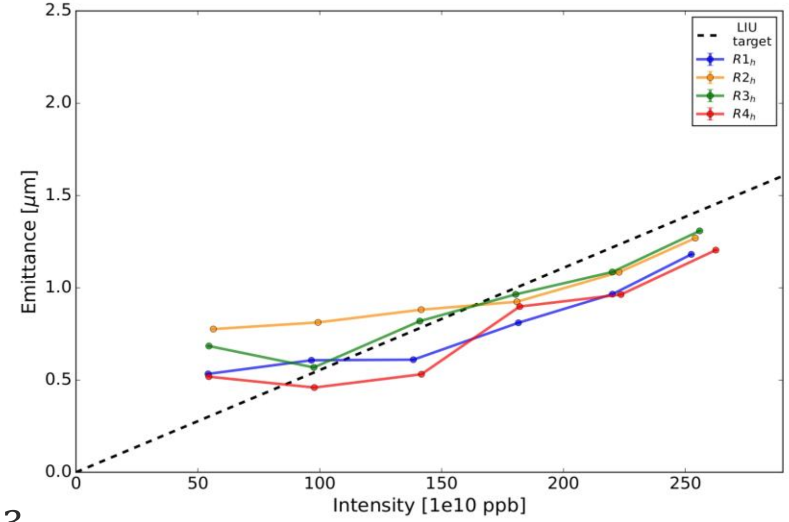


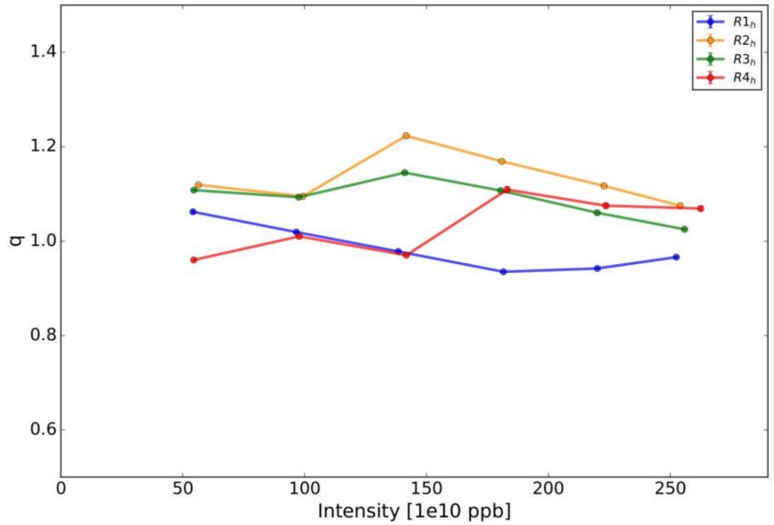


$\delta p/p$ reduction

$1.52 \cdot 10^{-3}$ ⇨ $1.05 \cdot 10^{-3}$

To achieve this reduction, the blow-up was removed and the value of the first and secoond harmonic were reduced.





Summary

- Through reduction of systematic uncertainties in the reconstruction process, we can deepen our understanding of both the emittance and transverse beam properties.
- The measured distribution, which results from the convolution of the betatronic and dispersive components, closely resembles a q-Gaussian distribution.
- A guess of the betatronic distribution can be made by modeling the convolution with q-Gaussian distributions.
- Reducing the momentum spread results in a decrease in emittance, suggesting the presence of a systematic error in the calculations using the nominal $\delta p/p$.
- The beam brightness is within the LIU target.

Thank you
for your attention!

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