Performance study of Pair Monitor

FCAL Collaboration
High precision design

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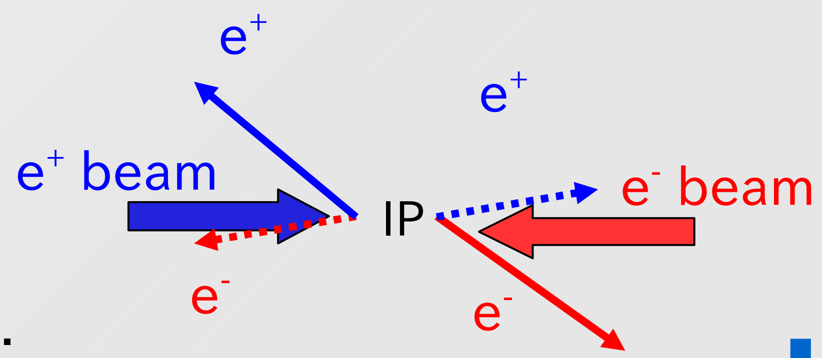
Introduction

- Pair monitor measures the beam shape at IP, using pair background.
  - The same charges with respect to the oncoming beam are scattered with large angle.
  - The potential produced by the oncoming beam is a function of beam shape.
  - The scattered particles carry the beam information.
  - Pair monitor detects the scattered particles.

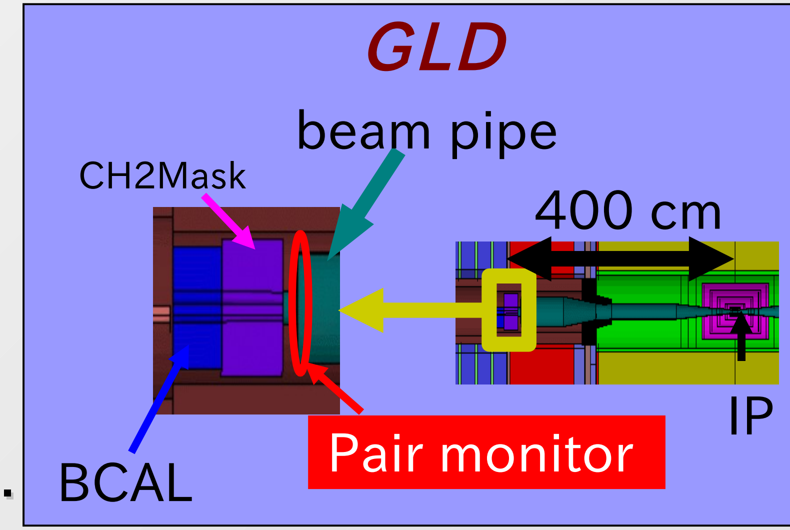


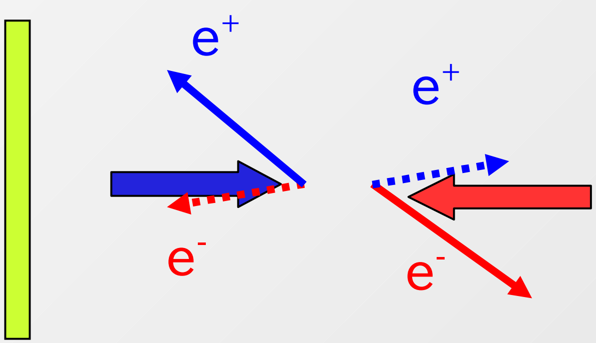
- Activity of Tohoku group.
  - Development of the readout ASIC.
  - Simulation study.

Current status of simulation study is shown.

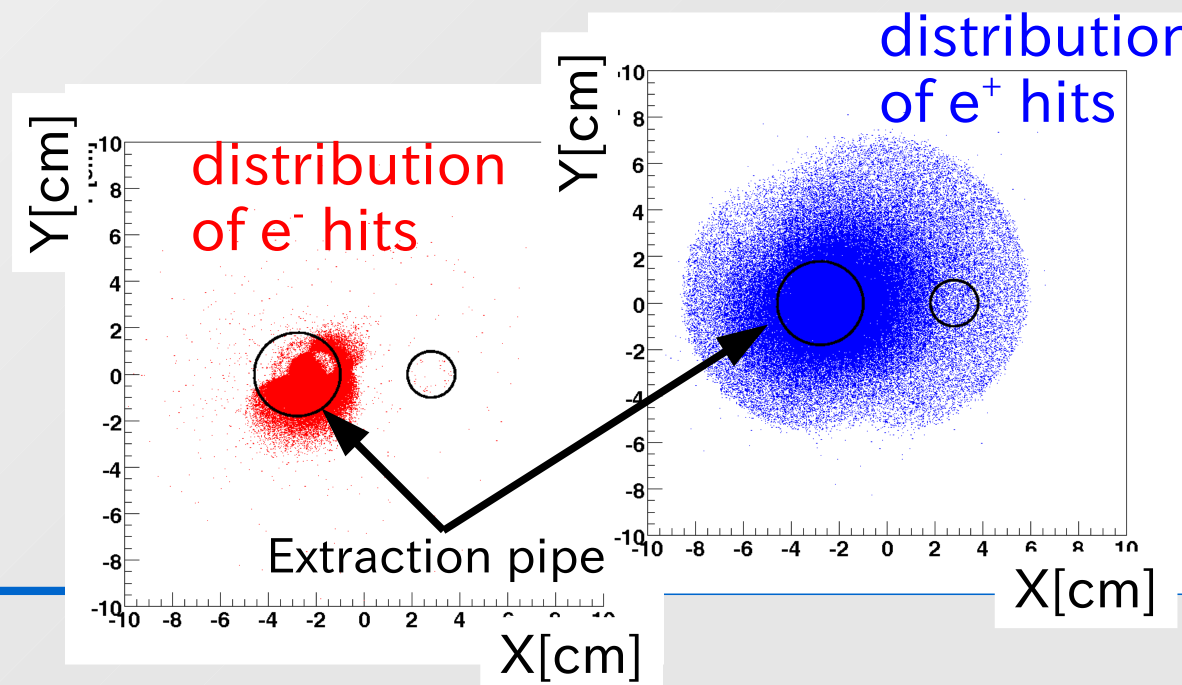
Simulation setup

- CM energy : 500GeV
- Beam size : $(\sigma_x^0, \sigma_y^0, \sigma_z^0)$
  $= (639\text{nm}, 5.7\text{nm}, 300\mu\text{m})$
- Tools : CAIN (e+e- generator)
  Jupiter (Tracking emulator)
- Magnetic field : 3T with anti-DID.
- Scattered e^+ distribution was studied.





Pair monitor



Matrix method for beam size reconstruction

- The beam size is reconstructed by the Taylor expansion.

matrix of the first order term

matrix of the second order term

Beam size (X)

$$\begin{pmatrix} m_1 \\ m_2 \\ \vdots \\ m_n \end{pmatrix} = A \begin{pmatrix} \sigma_x \\ \sigma_y \end{pmatrix} + \begin{pmatrix} \sigma_x , \sigma_y \end{pmatrix} B \begin{pmatrix} \sigma_x \\ \sigma_y \end{pmatrix} + \cdots$$

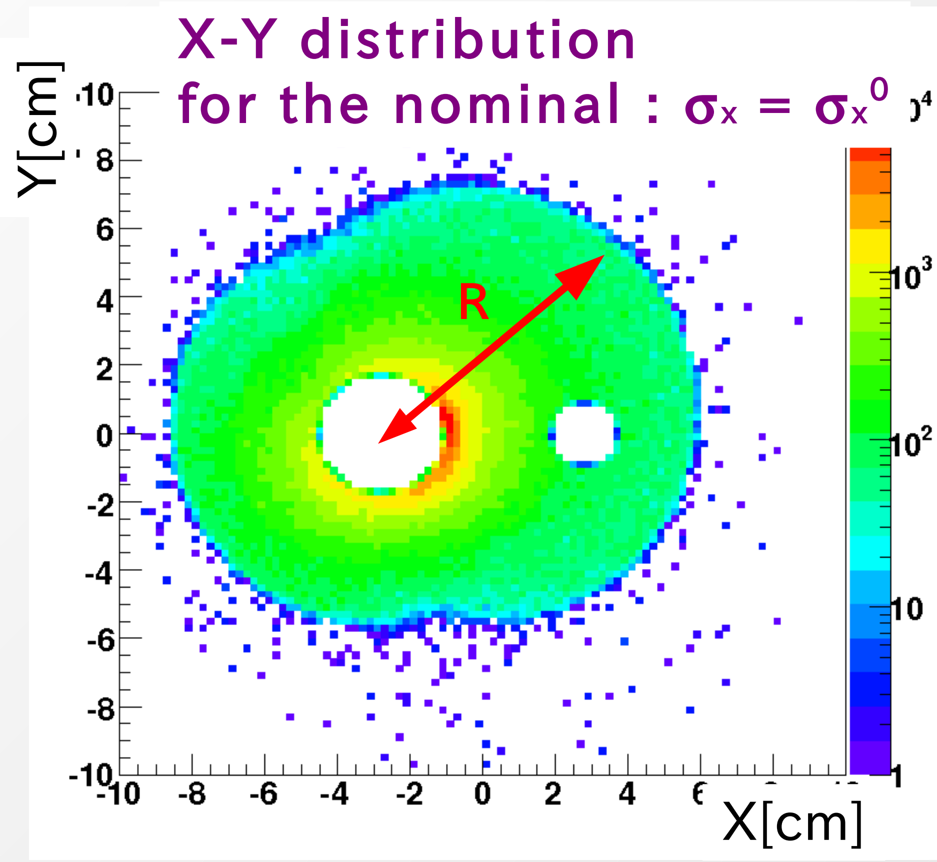
measurement variables (m)

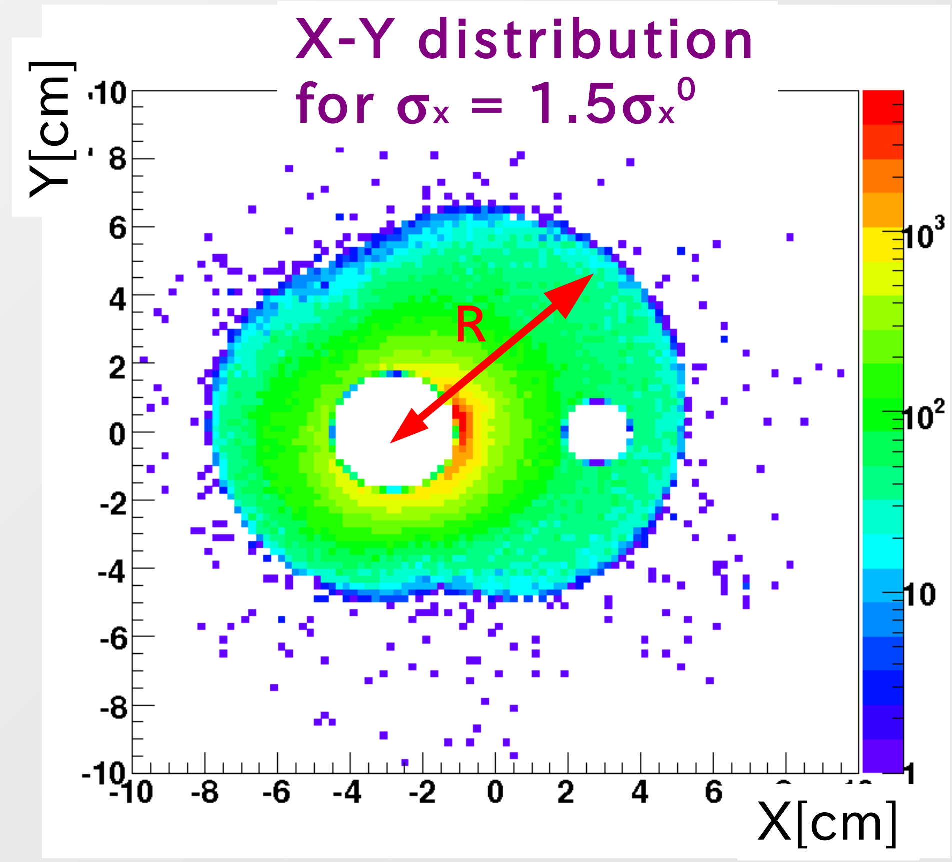
The beam size is reconstructed by the inverse matrix.

$$x \equiv \begin{pmatrix} \sigma_x \\ \sigma_y \end{pmatrix} = [\, A + x^T B + \cdots \,]^{-1} m$$

The measurement variables are studied.

Variable 1 : Rmax (sensitive to the horizontal beam size)



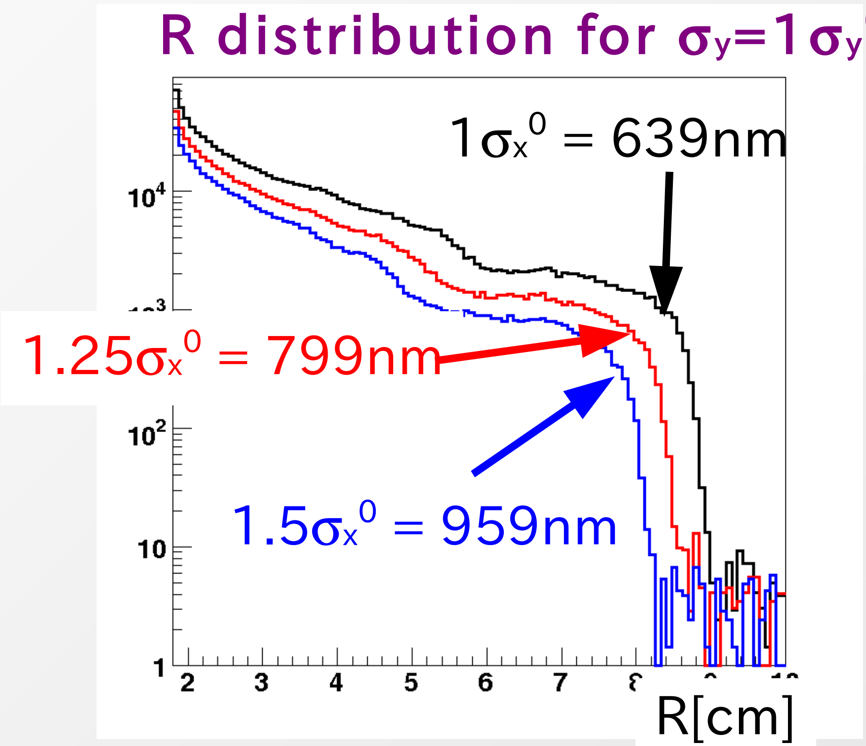


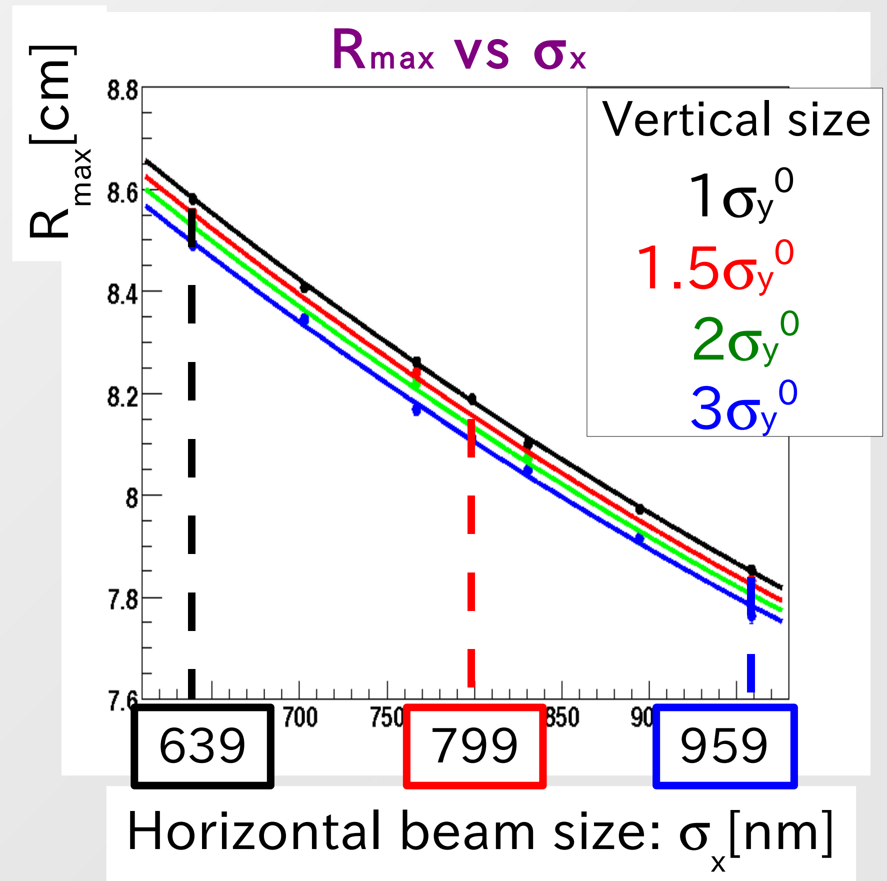
R distribution seems to depend on the horizontal beam size (σ_x).

The maximum R was investigated.

Variable 1 : Rmax

- R_{max} – Radius to contain 99.8% of all hits.

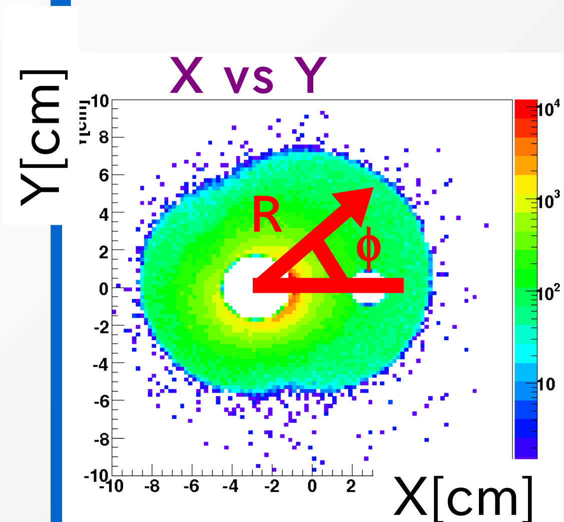




R_{max} depends on the horizontal beam size(σ_x), dose not depend on the vertical size.

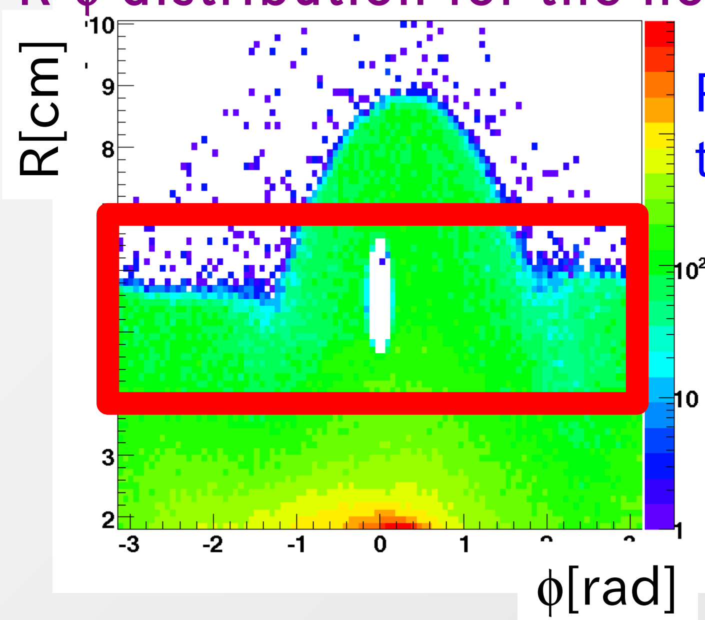
Variable 2 : Ratio (sensitive to σ_x and σ_y)

X vs Y



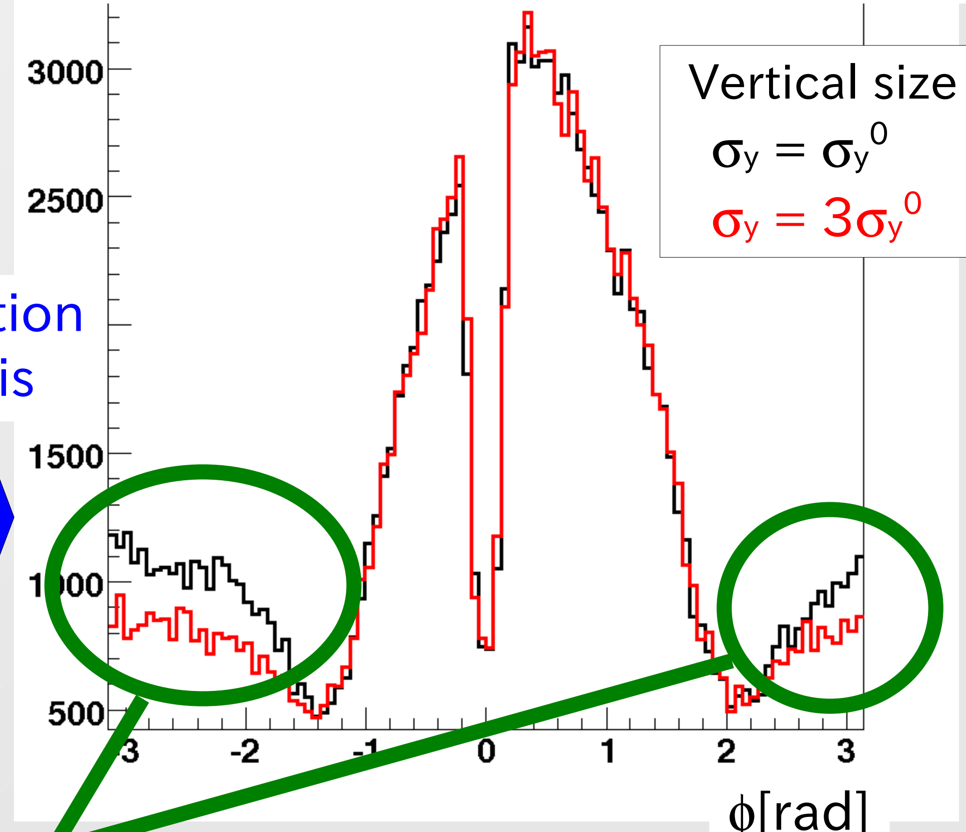
- To derive the beam information, projection to φ-axis is checked.

R-φ distribution for the nominal



Projection to φ-axis

φ distribution ($0.5 \times R_{max} < R < 0.8 \times R_{max}$)

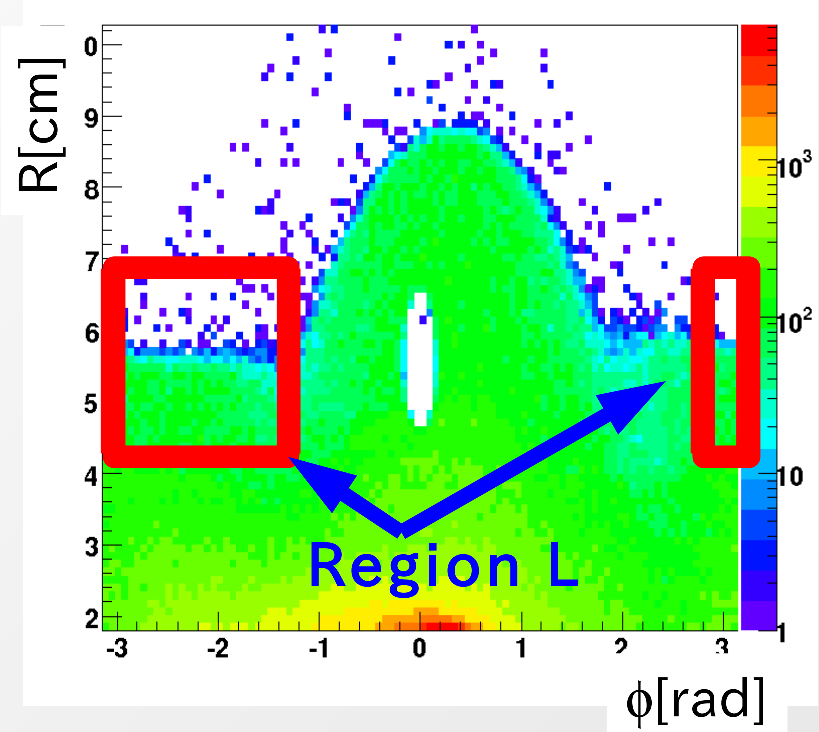


There is the information of σ_y in this region.

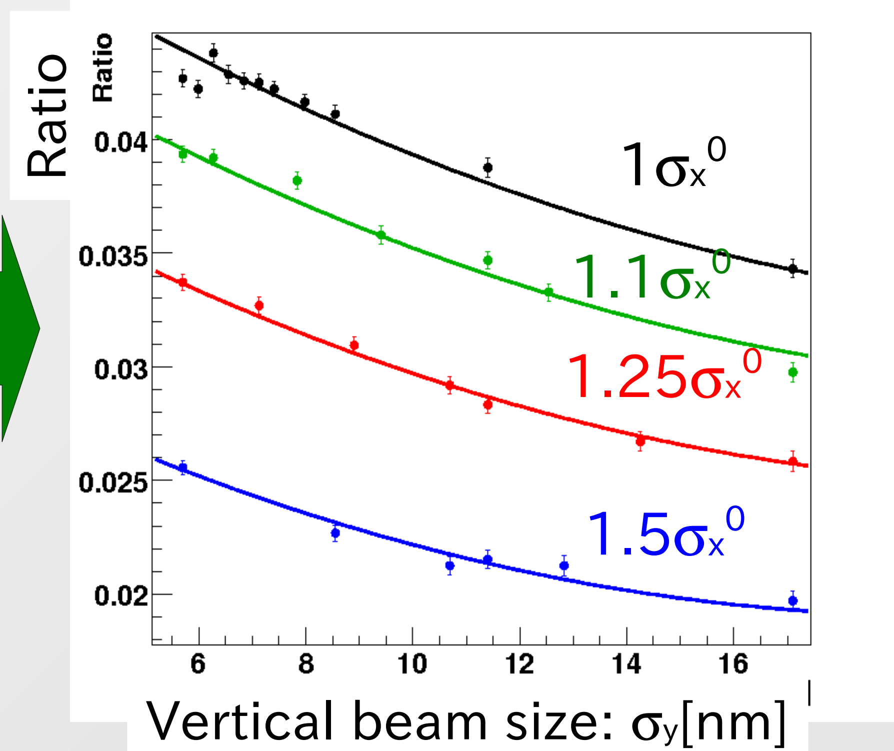
Variable 2 : Ratio

- The ratio defined N_L/N_{ALL} were obtained various beam size.

R-ϕ distribution for the nominal



Ratio = N_L / N_{ALL} (100bunches)



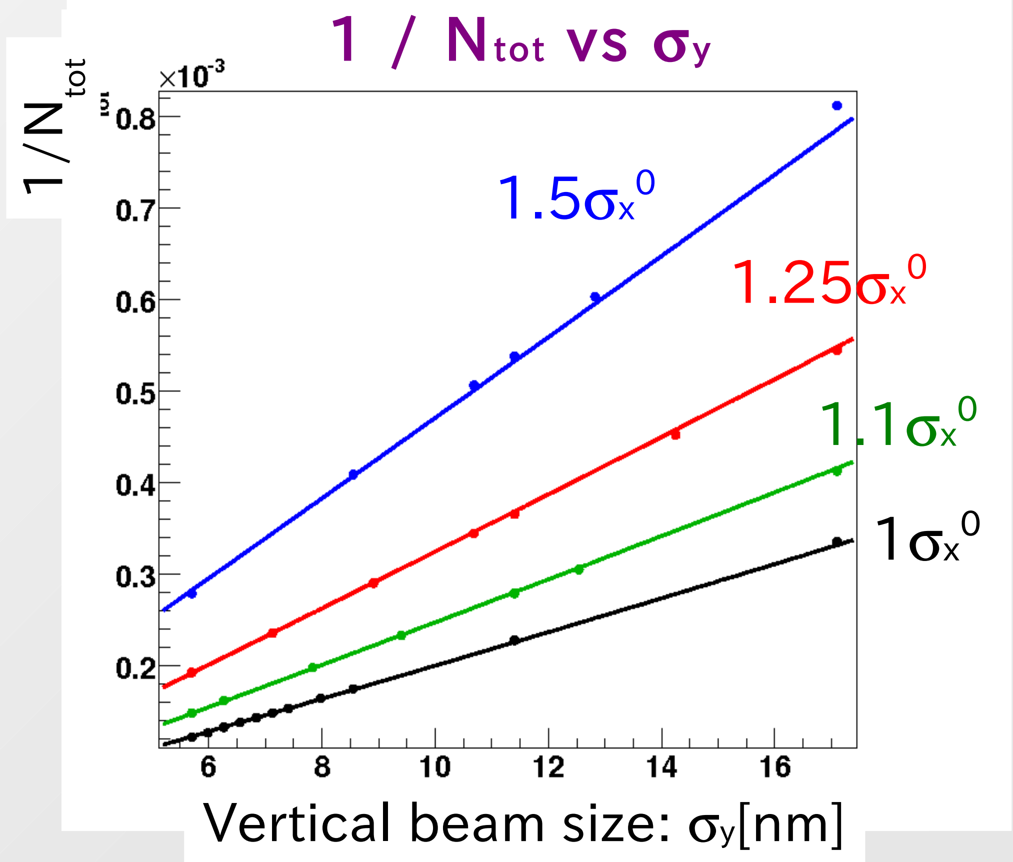
The ratio depends on the horizontal and vertical beam size(σ_x, σ_y).

Variable 3 : Total number of hits (sensitive to σ_x and σ_y)

- The number of hits also have information of beam shape.

Luminosity(L)
$L \propto 1/\sigma_x\sigma_y$

Number of hits(N_{tot})
$1/N_{tot} \propto 1/L \propto \sigma_x\sigma_y$



$1/N_{tot}$ depends on both horizontal and vertical beam size.

Reconstruction of beam size

- R_{max}, Ratio, $1/N_{tot}$ were set as the variable term (m, A and B).

$$\begin{pmatrix} R_{max} \\ Ratio \\ 1/N_{tot} \end{pmatrix} = \begin{pmatrix} \frac{\partial R_{max}}{\partial \sigma_x} & \frac{\partial R_{max}}{\partial \sigma_y} \\ \frac{\partial (Ratio)}{\partial \sigma_x} & \frac{\partial (Ratio)}{\partial \sigma_y} \\ \frac{\partial (1/N_{tot})}{\partial \sigma_x} & \frac{\partial (1/N_{tot})}{\partial \sigma_y} \end{pmatrix} \begin{pmatrix} \sigma_x \\ \sigma_y \end{pmatrix} + (\sigma_x , \sigma_y) B \begin{pmatrix} \sigma_x \\ \sigma_y \end{pmatrix}$$

measurement variables (m)

matrix of the first order term A

matrix of the second order term

$$x \equiv \begin{pmatrix} \sigma_x \\ \sigma_y \end{pmatrix} = [A + x^T B]^{-1} m$$

- Procedure of the beam size reconstruction.

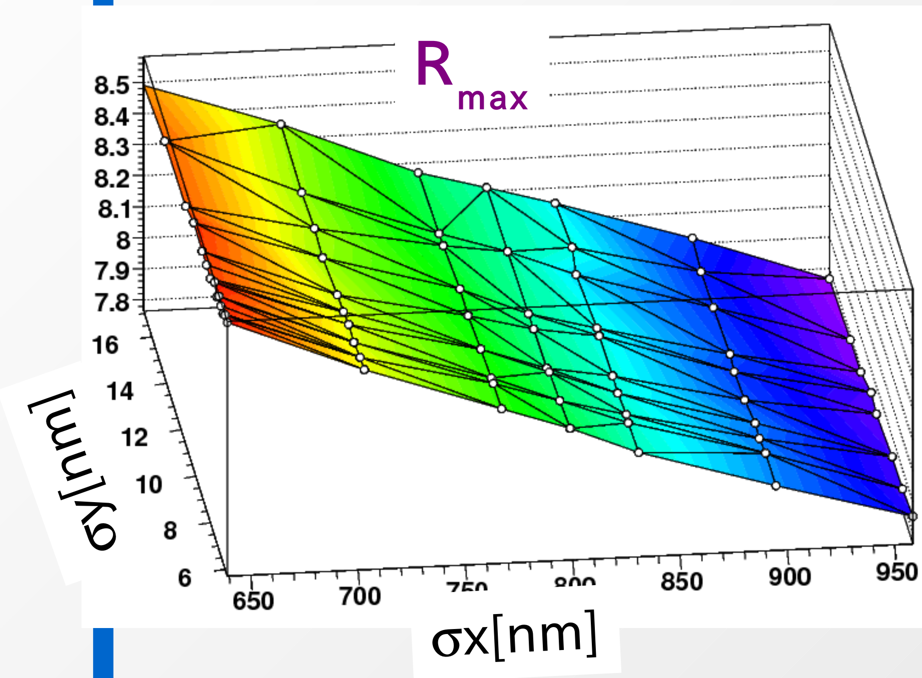
a) $x_0 = A^{-1} m$

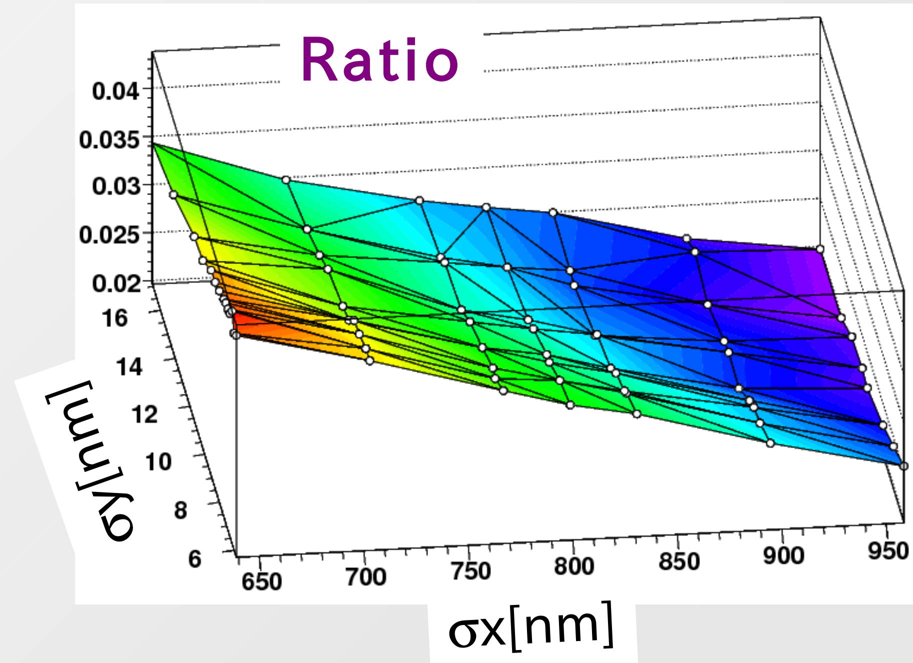
b) $x_1 = [A + x_0^T B]^{-1} m$

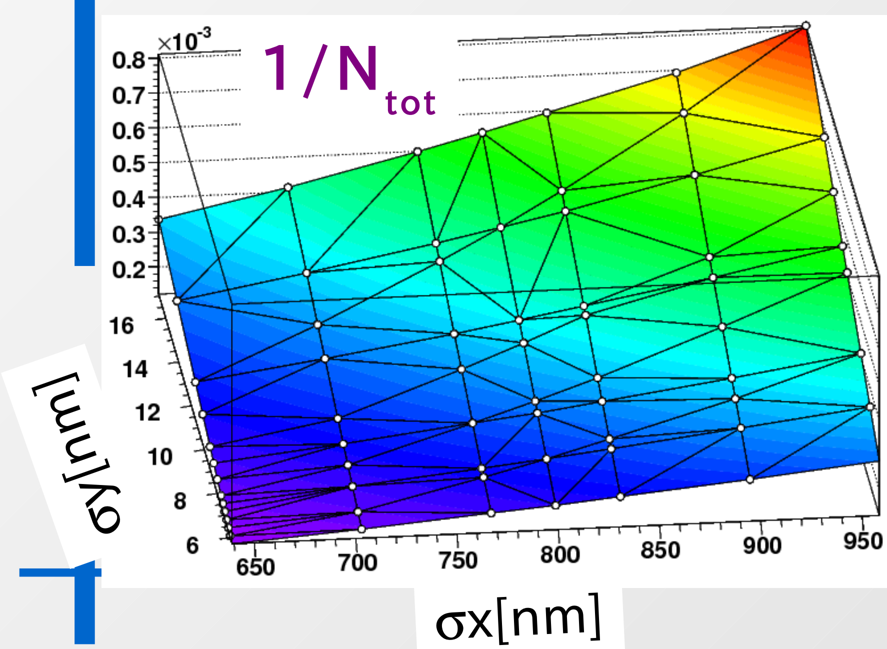
⋮

c) $x_n = [A + x_{n-1}^T B]^{-1} m$

Matrix component







Matrix components are determined by fitting.

$$\begin{pmatrix} R_{max} \\ Ratio \\ 1/N_{tot} \end{pmatrix} = \begin{pmatrix} \frac{\partial R_{max}}{\partial \sigma_x} & \frac{\partial R_{max}}{\partial \sigma_y} \\ \frac{\partial (Ratio)}{\partial \sigma_x} & \frac{\partial (Ratio)}{\partial \sigma_y} \\ \frac{\partial (1/N_{tot})}{\partial \sigma_x} & \frac{\partial (1/N_{tot})}{\partial \sigma_y} \end{pmatrix} \begin{pmatrix} \sigma_x \\ \sigma_y \end{pmatrix} + \begin{pmatrix} \sigma_x , \sigma_y \end{pmatrix} B \begin{pmatrix} \sigma_x \\ \sigma_y \end{pmatrix}$$

measurement variables (m)

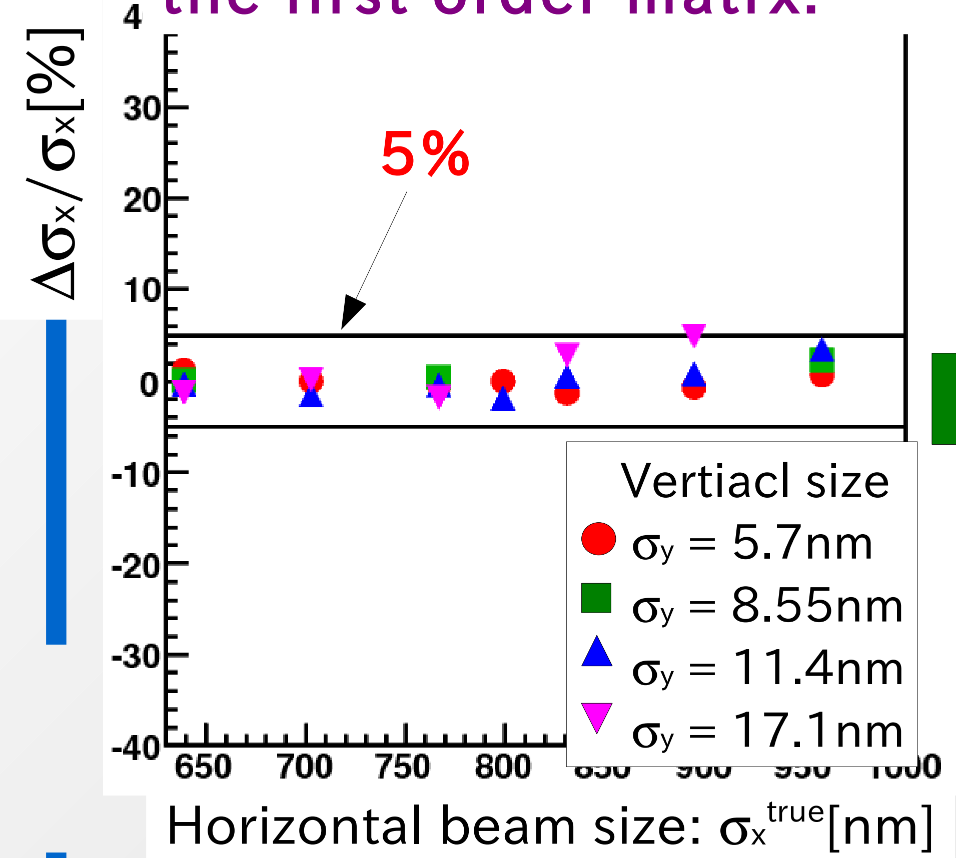
matrix of the first order term A

matrix of the second order term

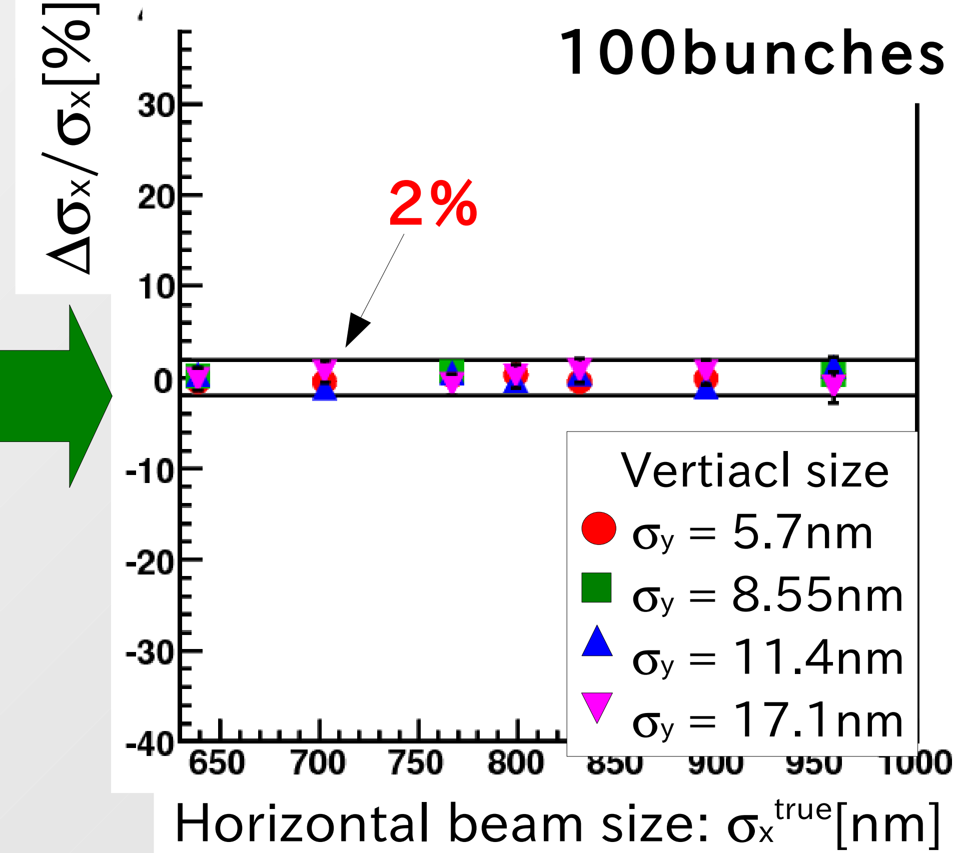
Results of the horizontal beam size reconstruction

measurement of the horizontal beam size (σ_x)

Reconstructed with only the first order matrx.



Reconstructed with the second order matrix.

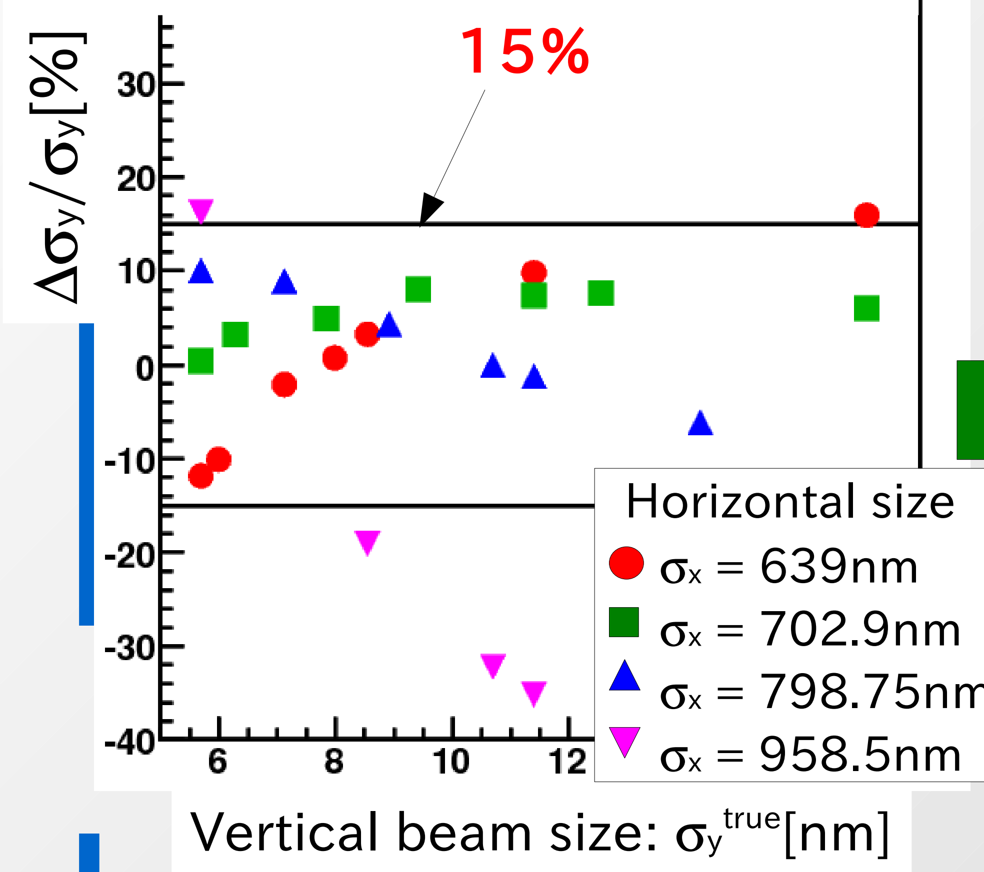


- Horizontal beam size can be measured with 2%.

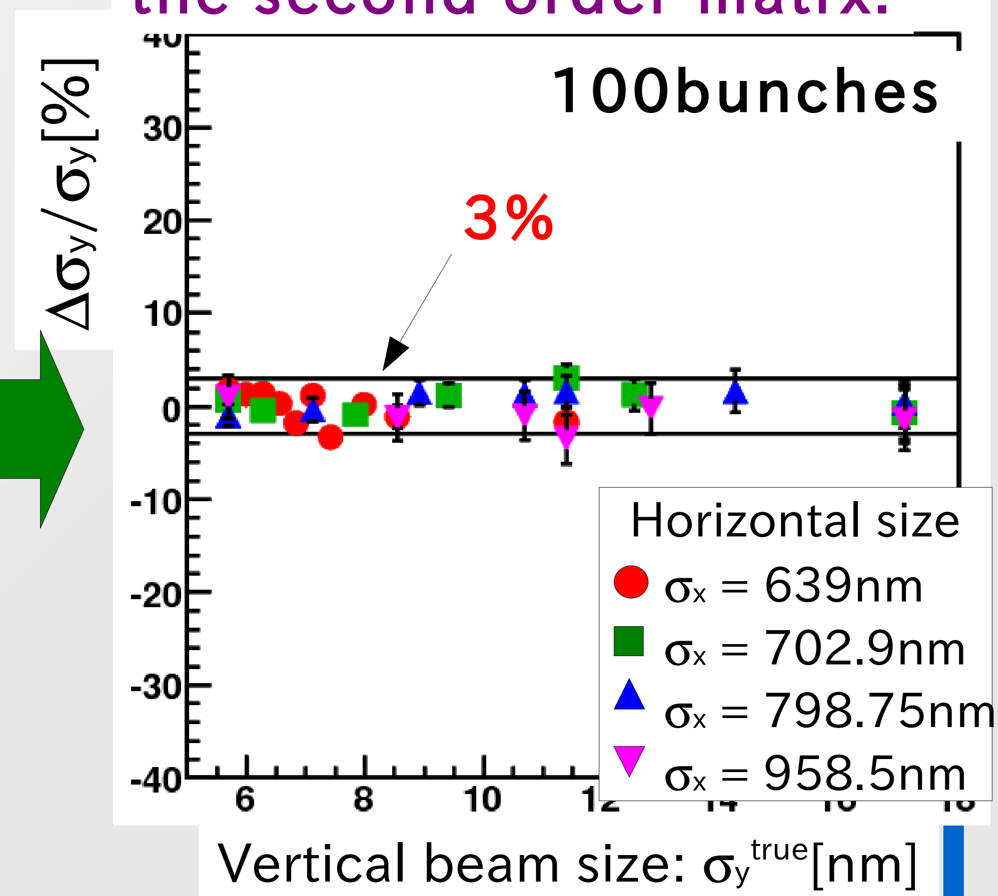
Results of the vertical beam size reconstruction

measurement of the vertical beam size (σ_y)

Reconstructed with only the first order matrx.



Reconstructed with the second order matrx.



- Vertical beam size can be measured with 3%.

Summary

- Pair monitor measures the beam shape at IP.
  - Using pair backgrounds.
- The beam size (σ_x, σ_y) were reconstructed using the matrix of the Taylor expansion (second order).
  - There are three measurement variables.
    - R_{max} – sensitive to σx.
    - Ratio – sensitive to σx and σy.
    - $1/N_{tot}$ – sensitive to σx and σy.
  - Horizontal beam size σ_x – resolution : 2% (~14nm).
  - Vertical beam size σ_y – resolution : 3% (~0.2nm).

$$m = A\,x + x^T B\,x$$

$$\Rightarrow x = [\,A + x^T B\,]^{-1}\,m$$