Beam size measurement with Pair monitor and BeamCal

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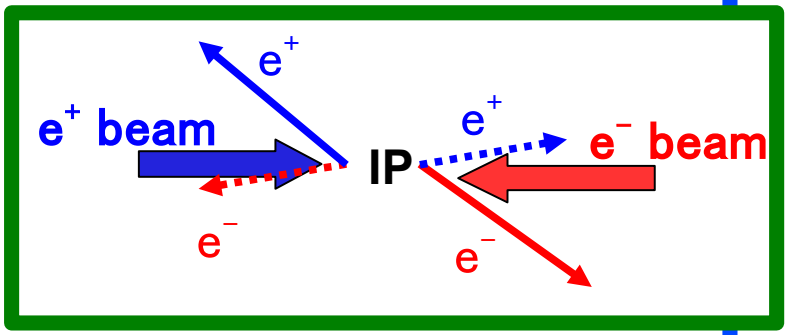
Introduction

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



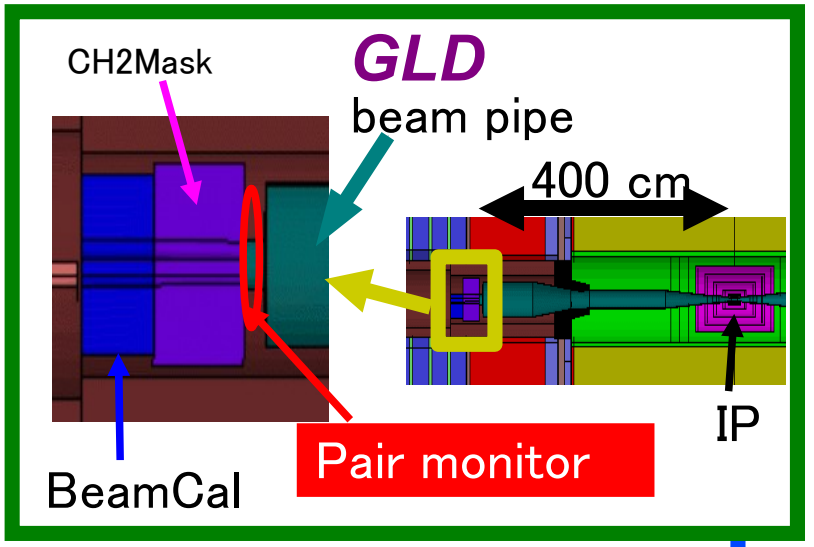
- **Activity of Tohoku group.**
  - Development of the readout ASIC.
  - Simulation study.

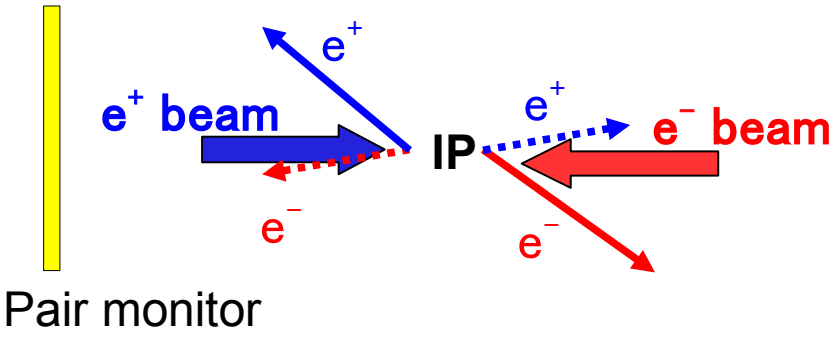
Current status of simulation study is shown.

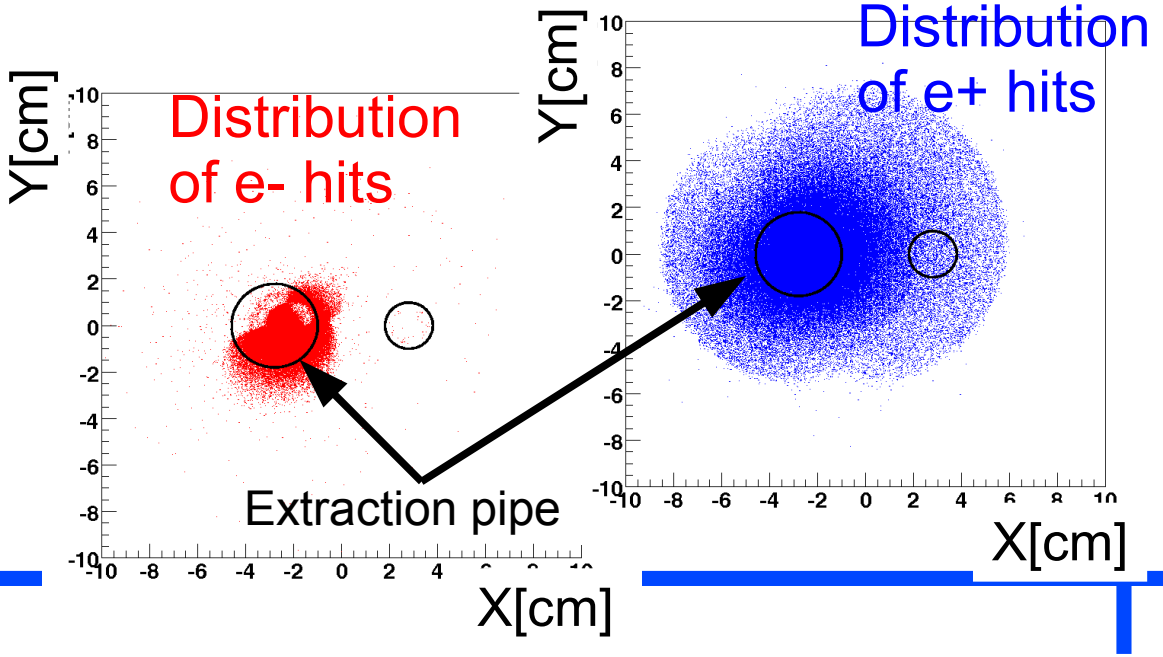
Beam size measurement with Pair monitor (GLD geometry)

Simulation setup

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

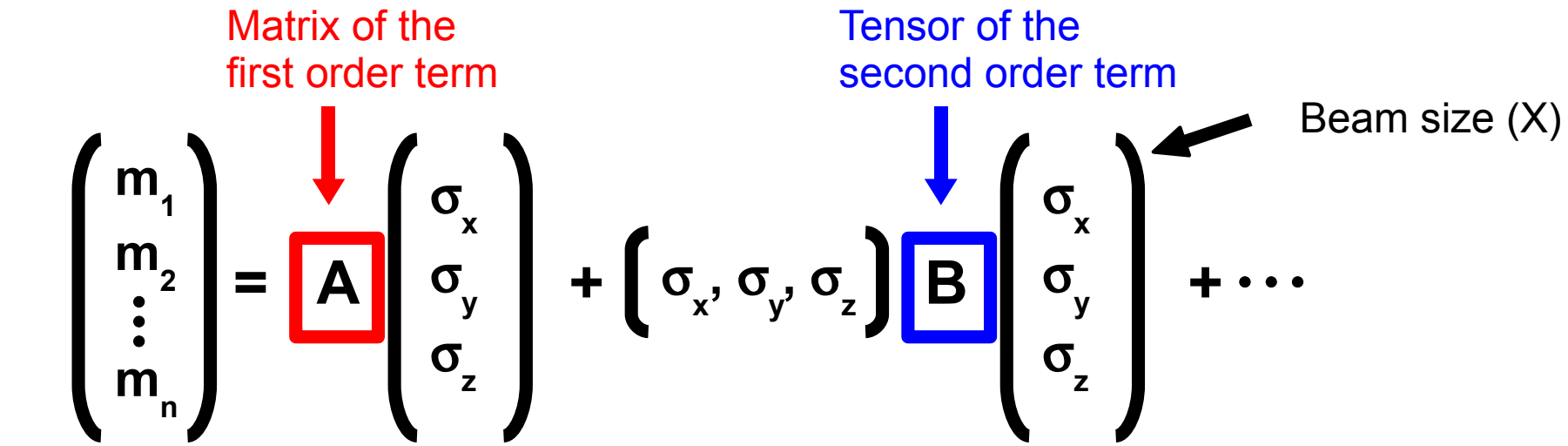






Matrix method for reconstruction

- **The beam size is reconstructed by the Taylor expansion.**



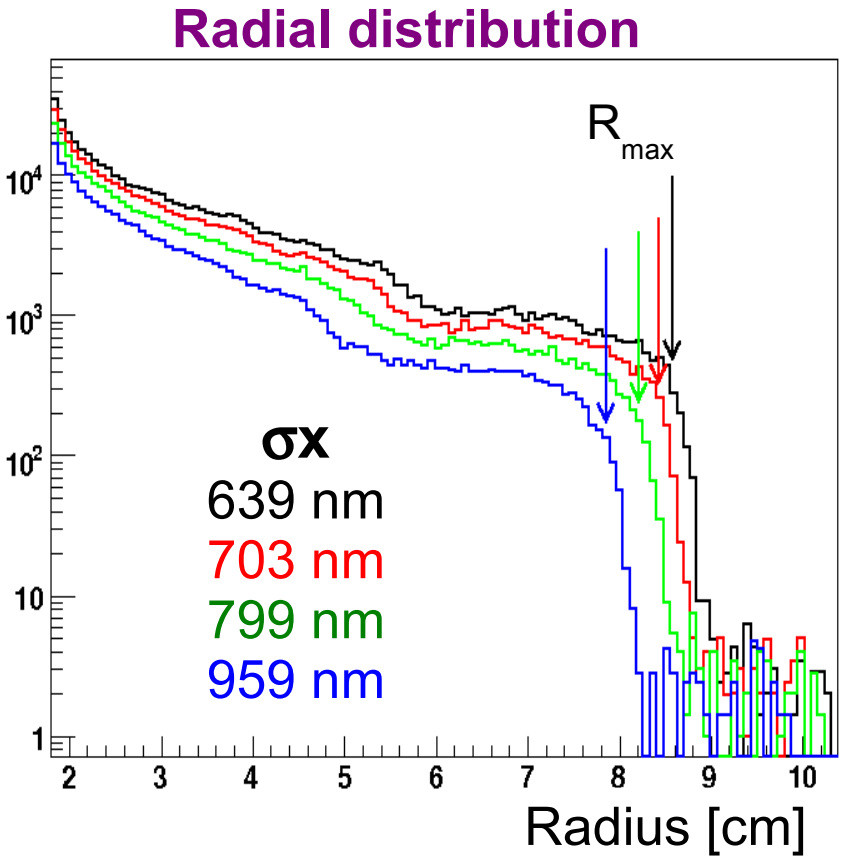
The beam size is reconstructed by the inverse matrix.

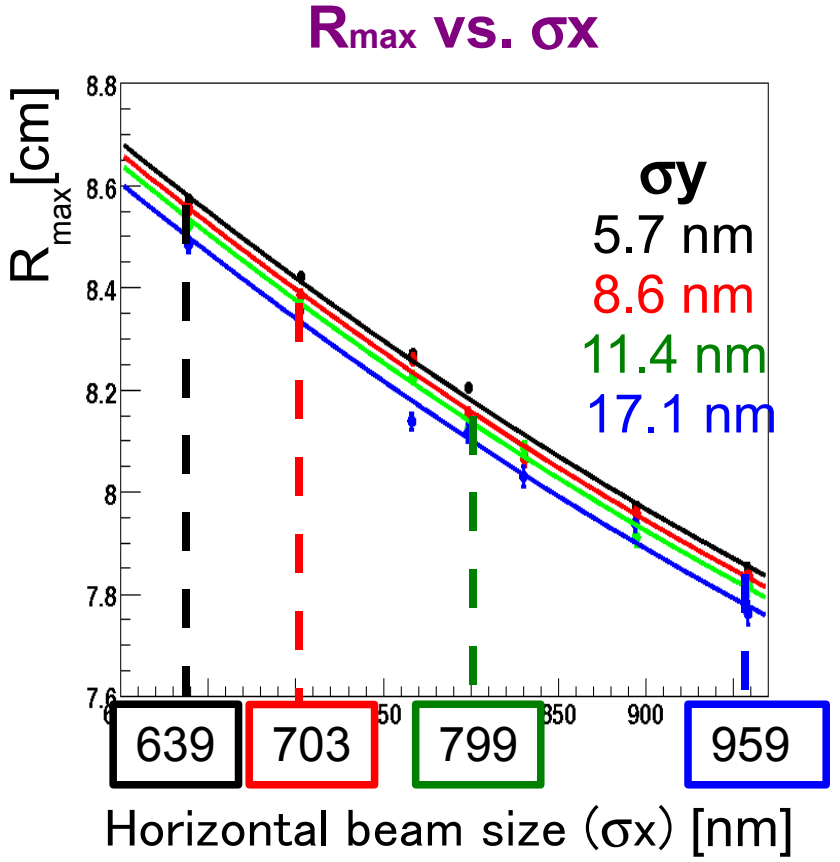
$$X \equiv \begin{pmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \end{pmatrix} = [\, A + X^T B + \cdots]^{-1} m$$

The measurement variables were studied.

Variable 1 : R_{max}

- Radial distribution changes with horizontal beam size (σx).
- R_{max} : Radius to contain 99.8% of the all hits.



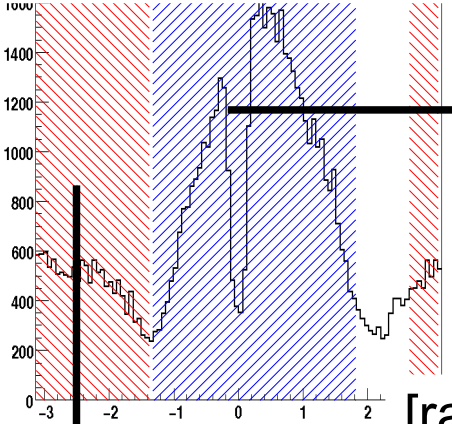


R_{max} decrease for larger horizontal beam size (σx) independent of the vertical beam size (σy).

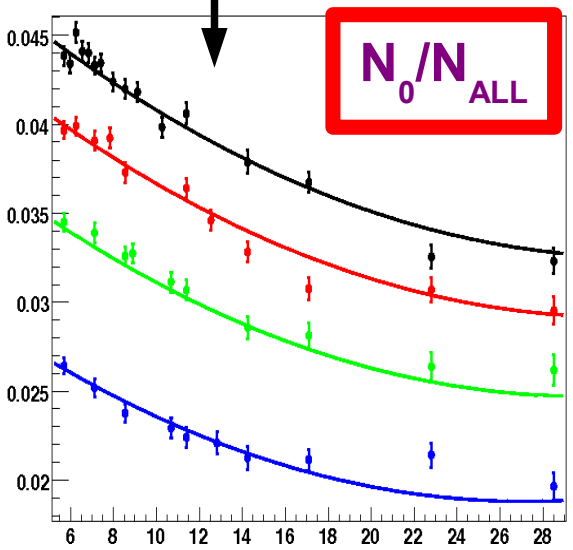
Variable 2,3 : ratio(N_0/N_{ALL}, N_1/N_{ALL})

The azimuthal distribution changes with several beam size.

Azimuthal distribution (radius > 0.5xR_{max})

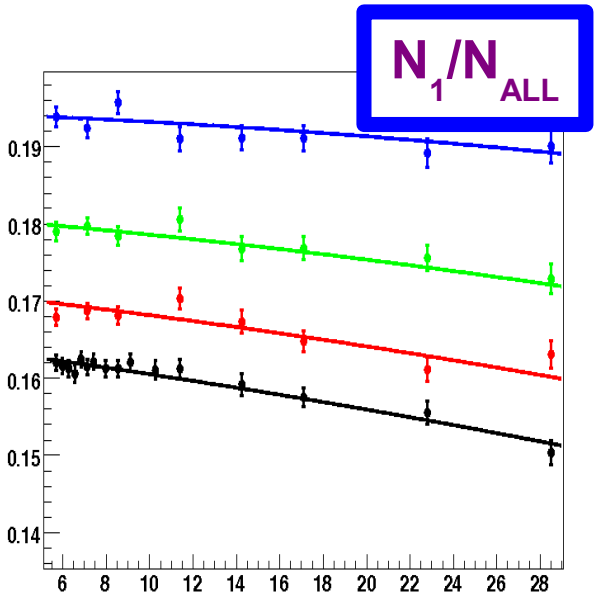


[rad]



Vertical beam size (σy) [nm]

σx
639 nm
703 nm
799 nm
959 nm



Vertical beam size (σy) [nm]

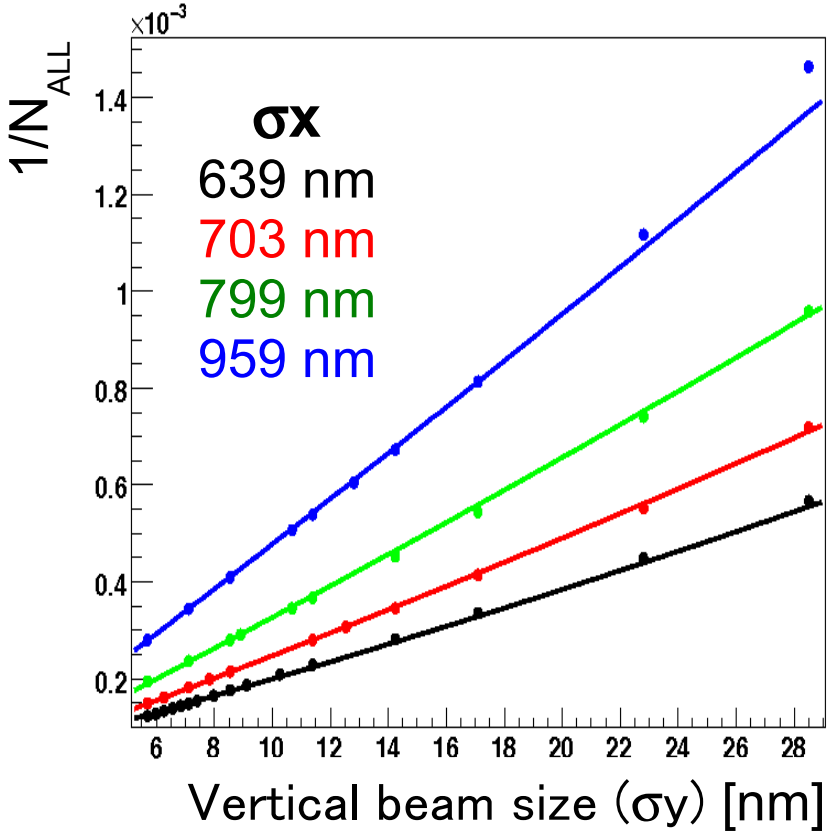
σz
300 μm
330 μm
375 μm
450 μm

N_0/N_{ALL} depends on the vertical (σy) and horizontal (σx) beam size.
N_1/N_{ALL} depends on the longitudinal beam size (σz).

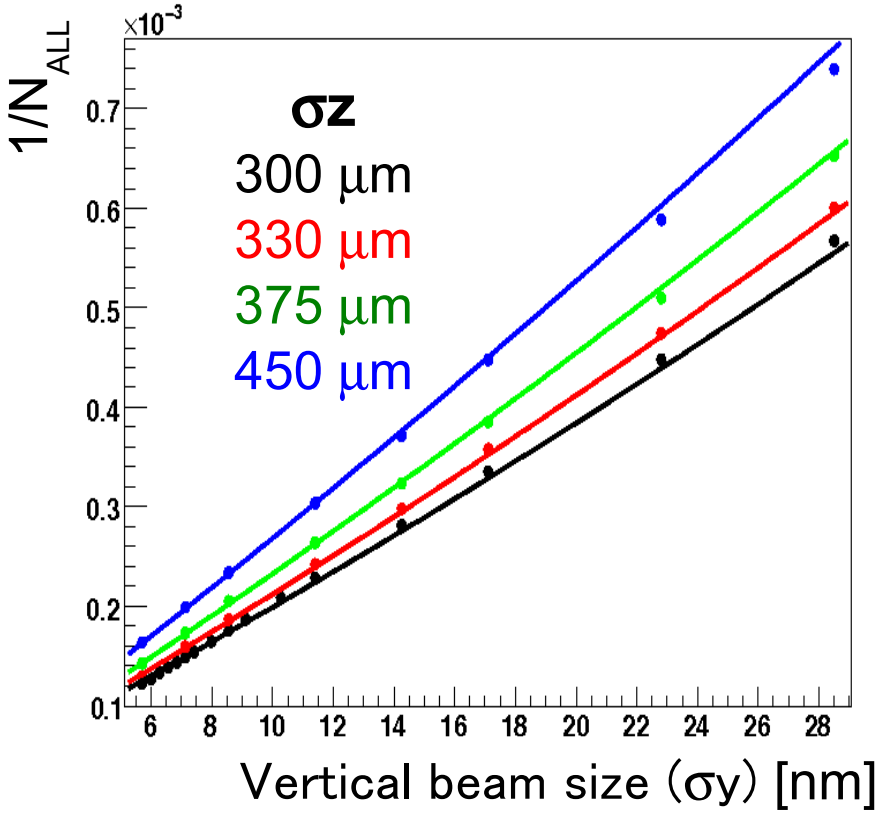
Variable 4 : $1/N_{ALL}$

- The number of hits (N_{ALL}) also has information of the beam shape.

$1 / N_{ALL}$ vs. σy for several σx.



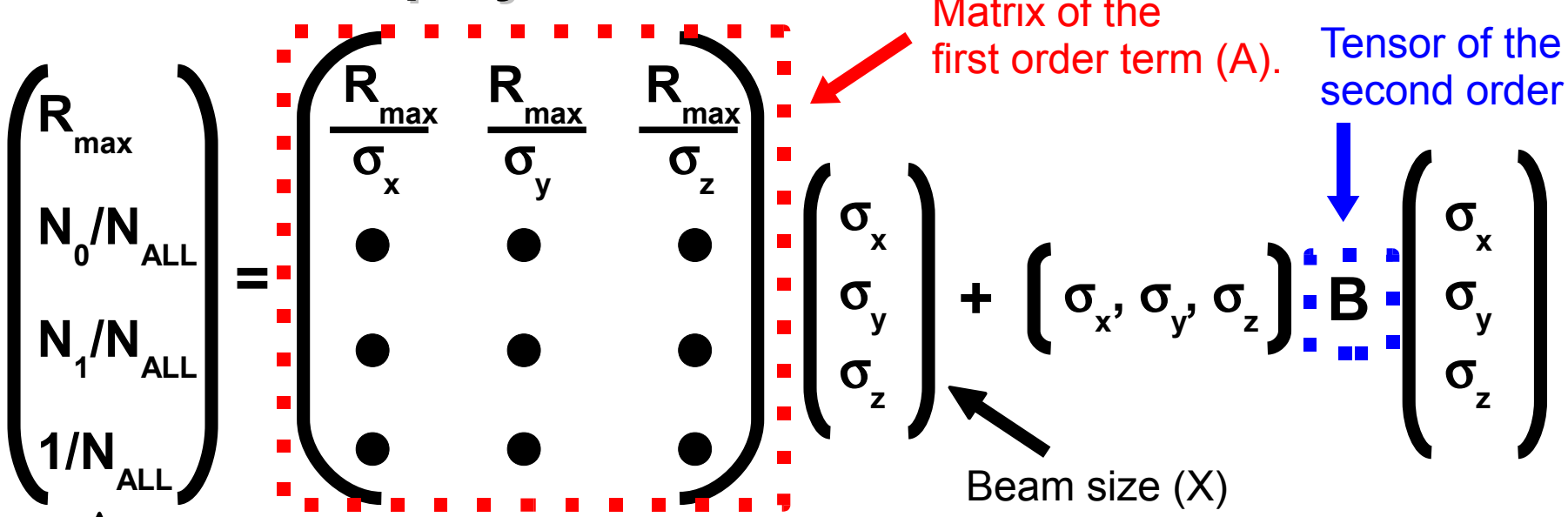
$1 / N_{ALL}$ vs. σy for several σz.



$1/N_{ALL}$ increases as a function of beam size.

Reconstruction of beam size

- R_{max}, N_0/N_{ALL}, N_1/N_{ALL} and $1/N_{ALL}$ were set as the variables.
- Matrix components were determined by fitting with the second polynomials.



$$\begin{pmatrix} R_{max} \\ N_0/N_{ALL} \\ N_1/N_{ALL} \\ 1/N_{ALL} \end{pmatrix} = \begin{pmatrix} \frac{R_{max}}{\sigma_x} & \frac{R_{max}}{\sigma_y} & \frac{R_{max}}{\sigma_z} \\ \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet \end{pmatrix} \begin{pmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \end{pmatrix} + \begin{pmatrix} \sigma_x, \sigma_y, \sigma_z \end{pmatrix} B \begin{pmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \end{pmatrix}$$

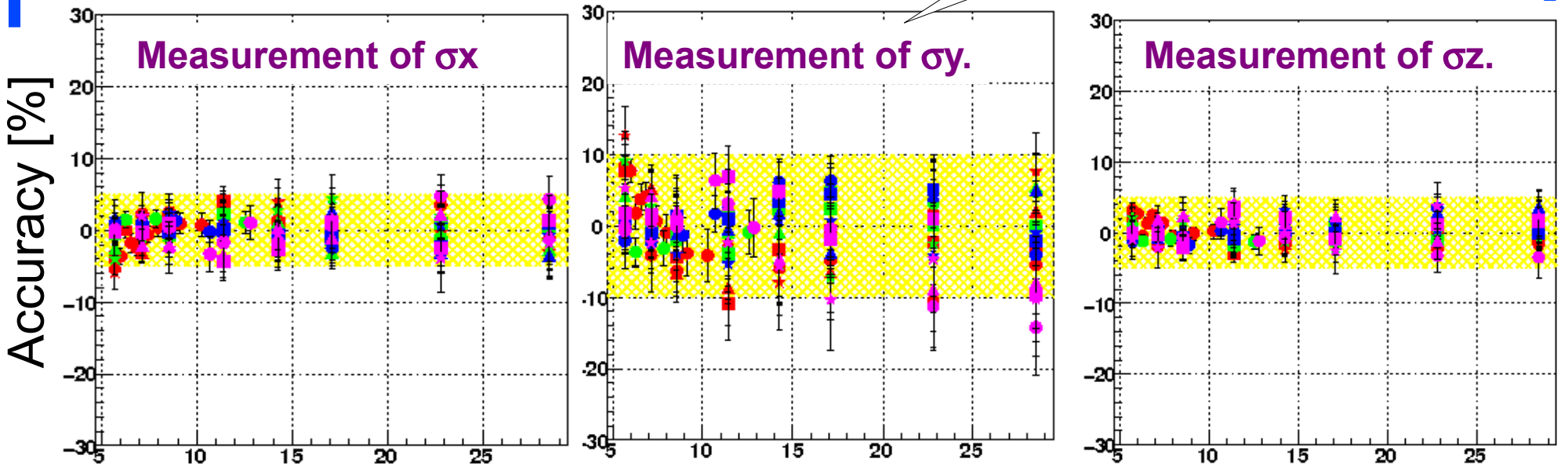
$$X \equiv \begin{pmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \end{pmatrix} = [\, A + X^T B \,]^{-1} m$$

The beam size can be reconstructed.

Results (σ_x, σ_y and σ_z)

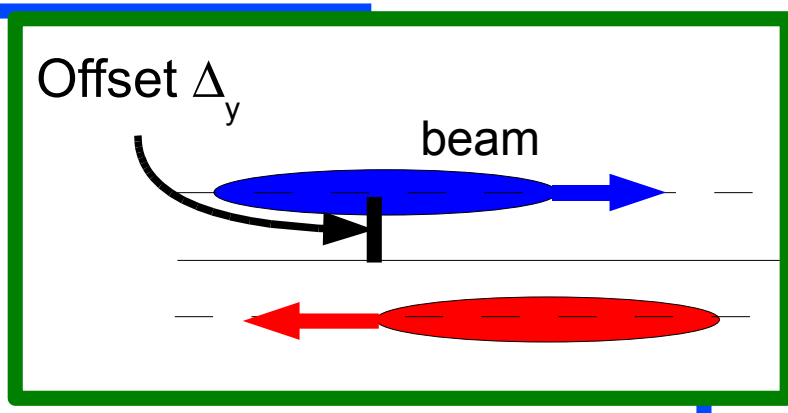
- **Beam sizes were reconstructed using the matrix.**
  - Measurement accuracies
    - 5% for the horizontal size (σx).
    - 10% for the vertical size (σy).
    - 5% for the longitudinal size (σz).

σx	σz
639 nm	● 300 μm
703 nm	■ 330 μm
799 nm	▲ 375 μm
959 nm	★ 450 μm

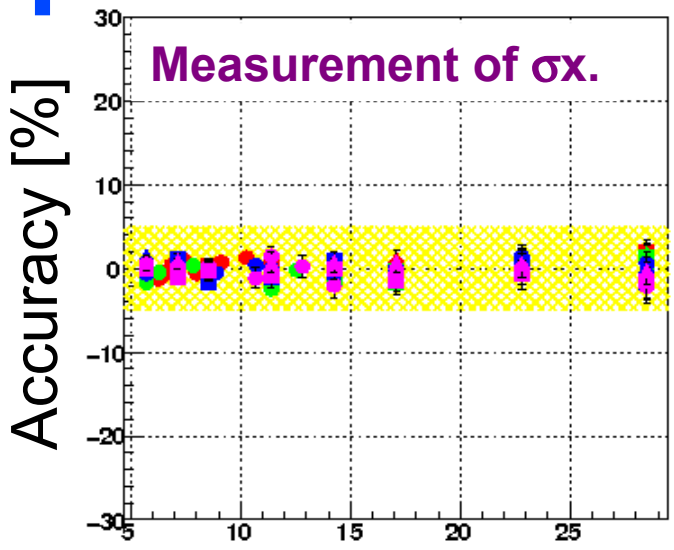


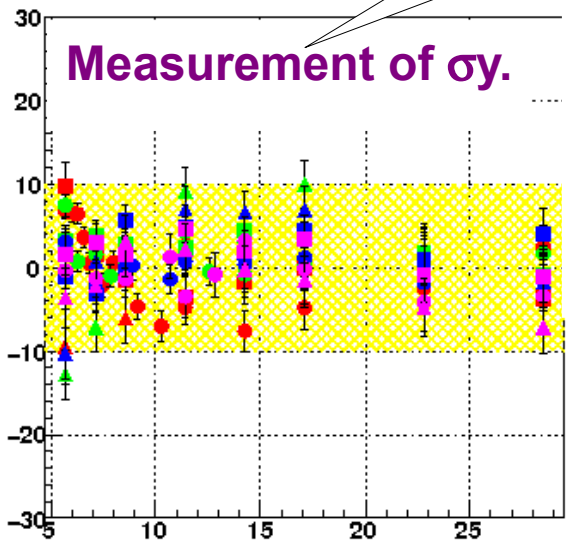
Results (σ_x, σ_y and Δ_y/σ_y)

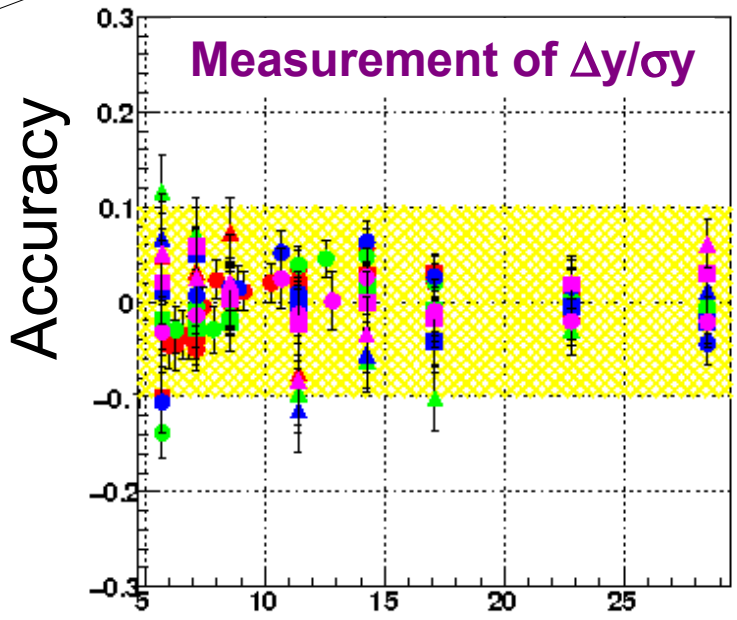
- **Beam size and relative offset (Δ_y/σ_y) were reconstructed.**
  - Measurement accuracy of the relative offset $\Delta y/\sigma y$ is 0.1. It corresponds to 0.57nm for nominal beam.



σx	Δy/σy
639 nm	● 0
703 nm	■ 0.25
799 nm	▲ 0.5
959 nm	





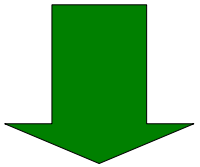


Vertical beam size (σy) [nm]

Combined analysis with BeamCal (ILD geometry)

Motivation

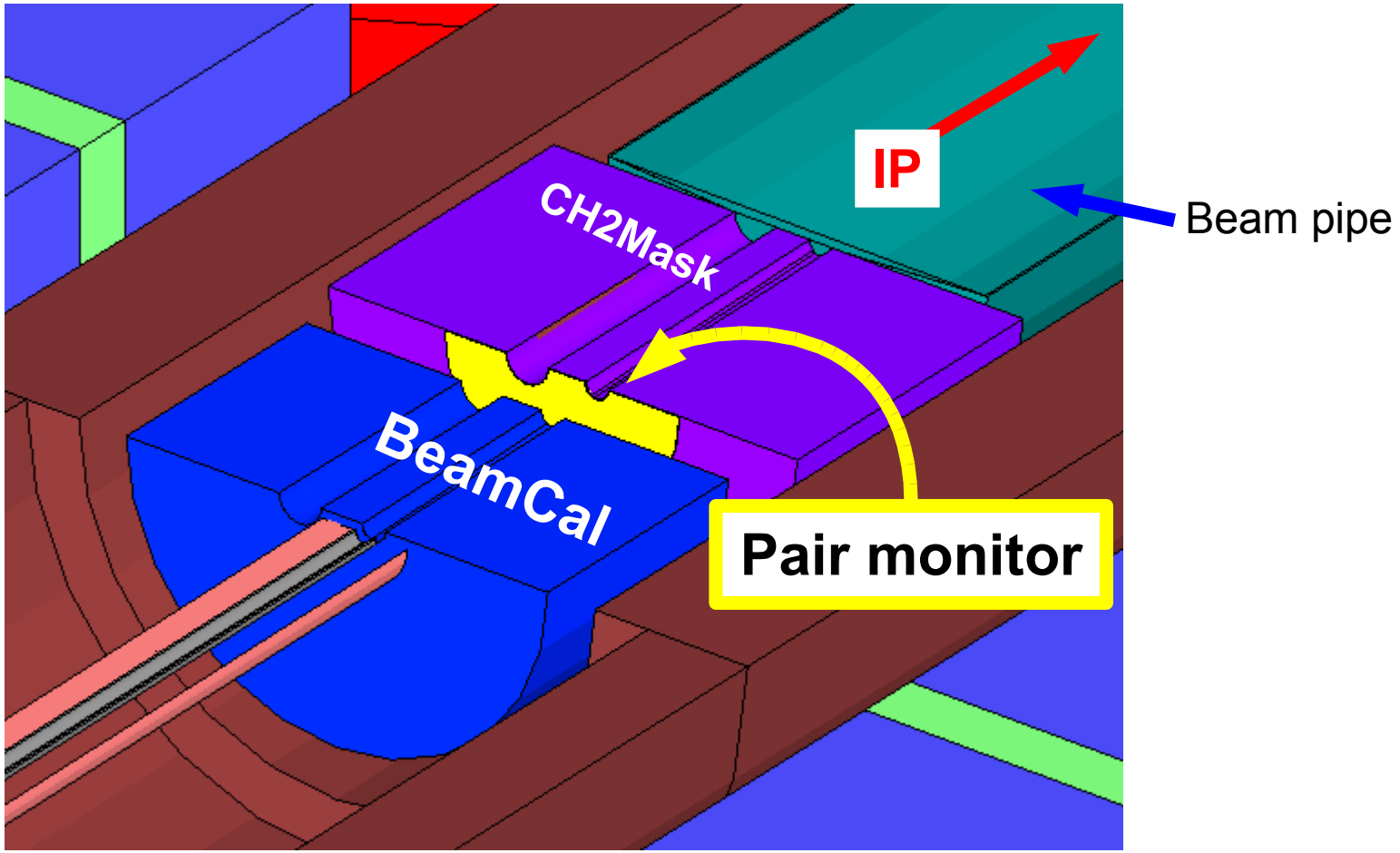
- **BeamCal also measures the beam shape at IP, and it is near to the pair monitor.**
- **It is different detector from pair monitor.**
  - Pair monitor : silicon pixel sensor, measures hit counts.
  - BeamCal : calorimeter, measures energy deposit.



- **Combined analysis will provide more precise measurement.**
- **We started combined analysis for ILD.**
  - Measurement of the horizontal (σx) and vertical (σy) beam size is reported.
    - Measurement of the longitudinal beam size (σz) has not been simulated yet. It needs more CPU-time for simulation.

Setup

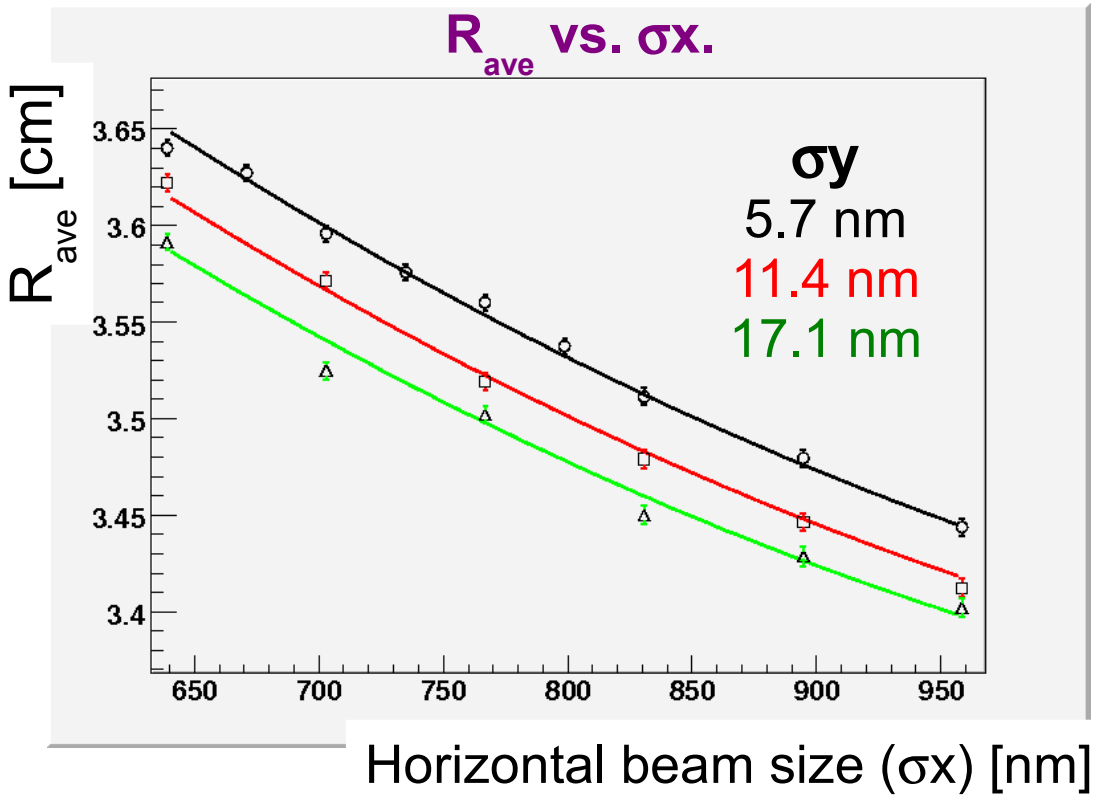
- Magnetic field : 3.5T with anti-DID.
- Pair monitor was located at in front of BeamCal.

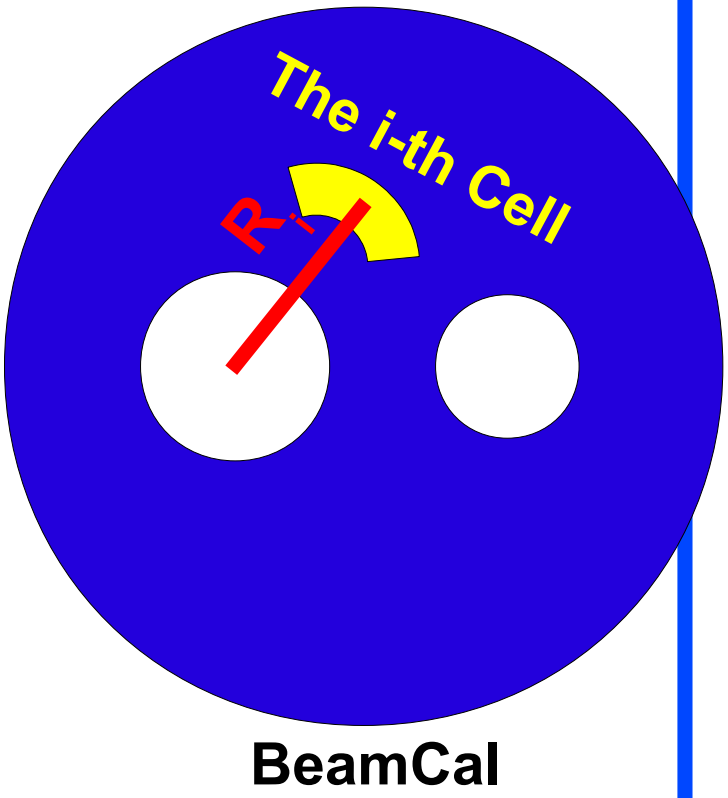


Measurement variables on BeamCal (1)

- Average radius (R_{ave}) was obtained for several beam.

$$R_{ave} \equiv \frac{\Sigma R_i \times Edep_i}{\Sigma Edep_i}$$, where R_i is the radius of the i-th Cell.

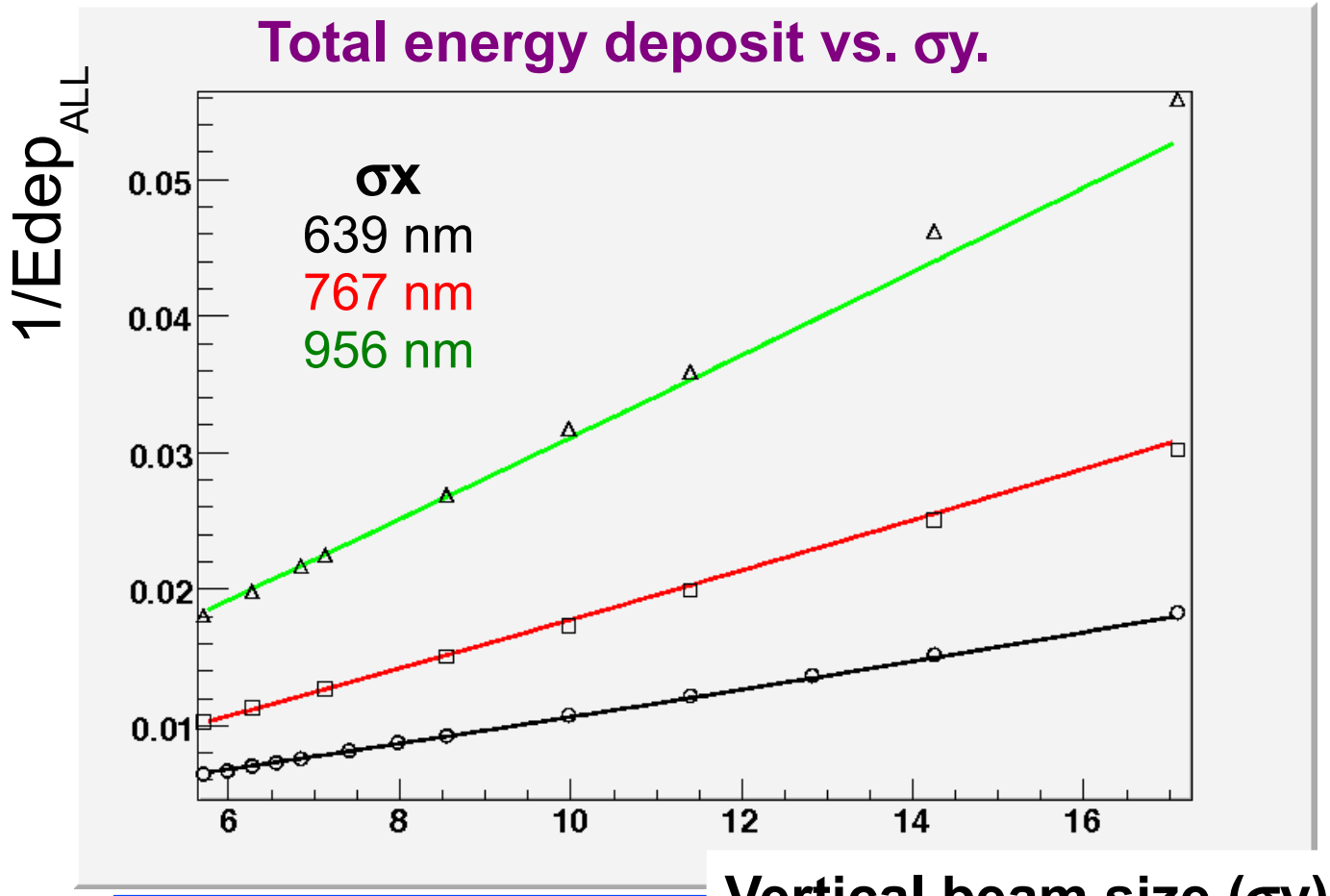




R_{ave} decreases with horizontal beam size (σx).

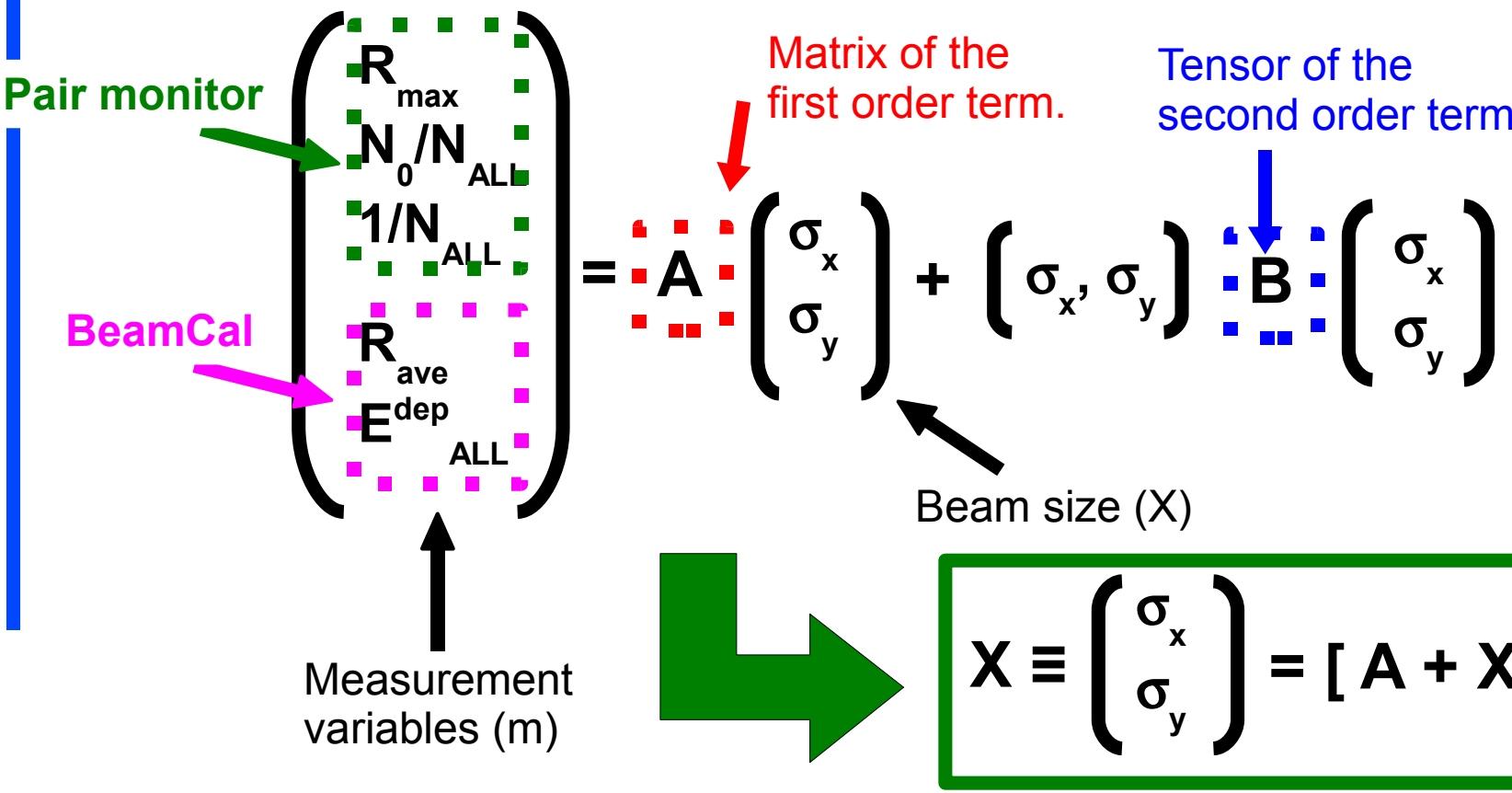
Measurement variables on BeamCal (2)

- Total energy deposit was obtained for several beam.
- $1/Edep_{ALL}$ increases with the vertical (σy) and horizontal (σx) beam size.



Matrix

- R_{max}, N_0/N_{ALL} and $1/N_{ALL}$ are measured by pair monitor.
- R_{ave} and E^{dep}_{ALL} are measured by BeamCal.



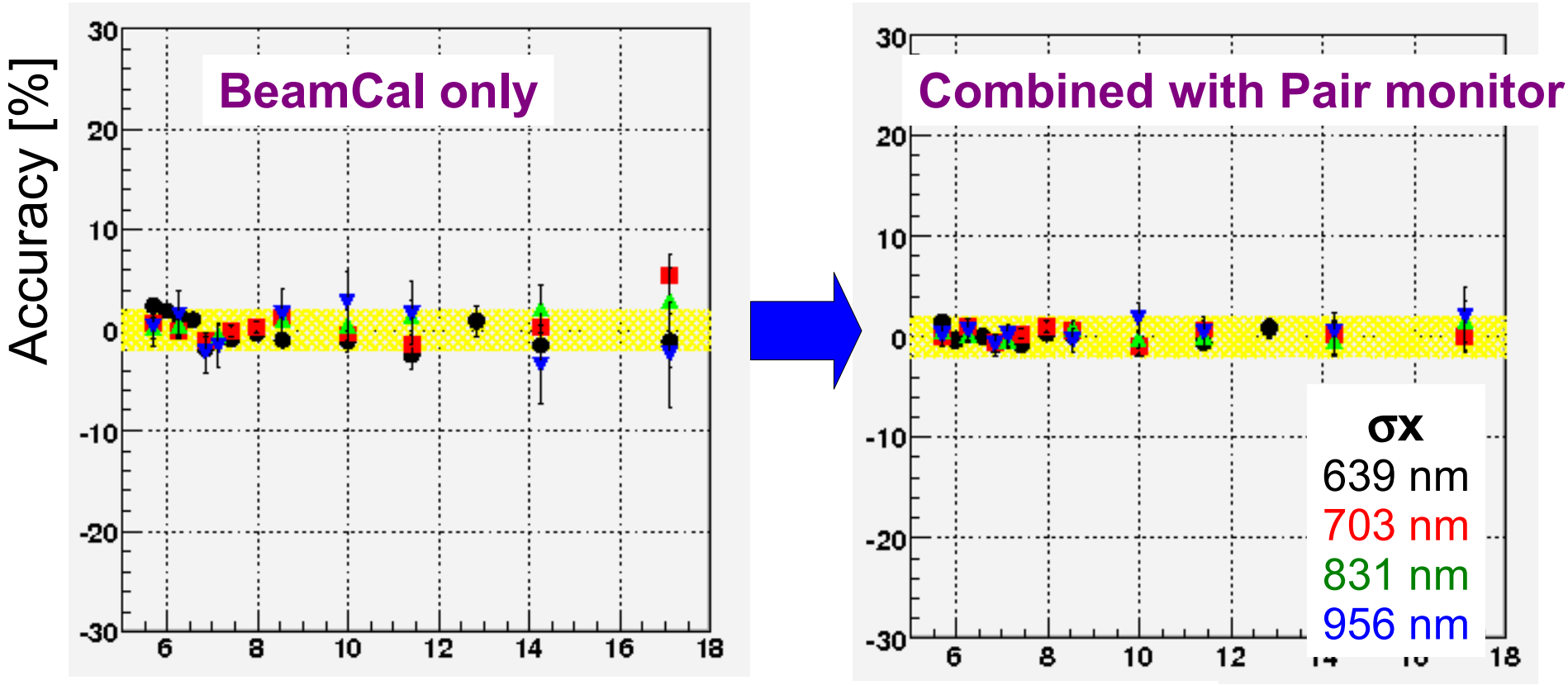
$$X \equiv \begin{pmatrix} \sigma_x \\ \sigma_y \end{pmatrix} = [\, A + X^T B \,]^{-1} m$$

The beam was reconstructed using combined matrix.

Results (1)

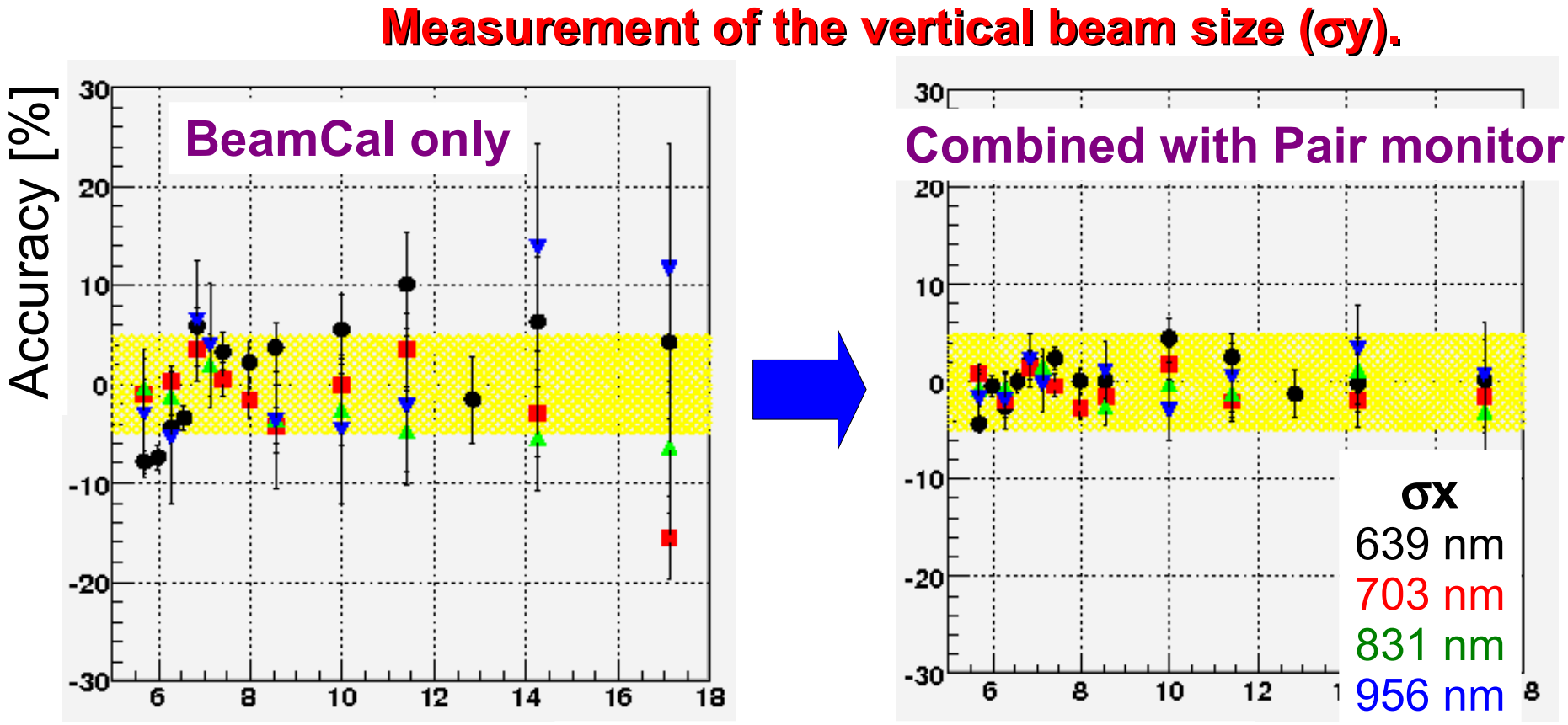
- **Measurement of the horizontal beam size (σx).**
  - Measurement accuracy seems to be improved with combined analysis for larger beam size.

Measurement of the horizontal beam size (σx).



Results (2)

- **Measurement of the vertical beam size (σy).**
  - Measurement with pair monitor will be necessary to obtain precise accuracy.



Summary

- **Pair monitor measures the beam profile at IP using the pair backgrounds.**
- **The beam size (σ_x, σ_y, σ_z) were reconstructed using the matrix of the Taylor expansion up to the second order.**
  - Measurement accuracy using 50 bunch crossings.
    - Horizontal beam size (σx) : 5%
    - Vertical beam size (σy) : 10%
    - Longitudinal beam size (σz) : 5%
    - Relative offset (Δy/σy) : 0.1
- **The combined analysis with BeamCal was started for ILD.**
  - Measurement accuracy of the beam size seems to be improved with combined analysis.