Performance Study of Pair-monitor (for ILD)

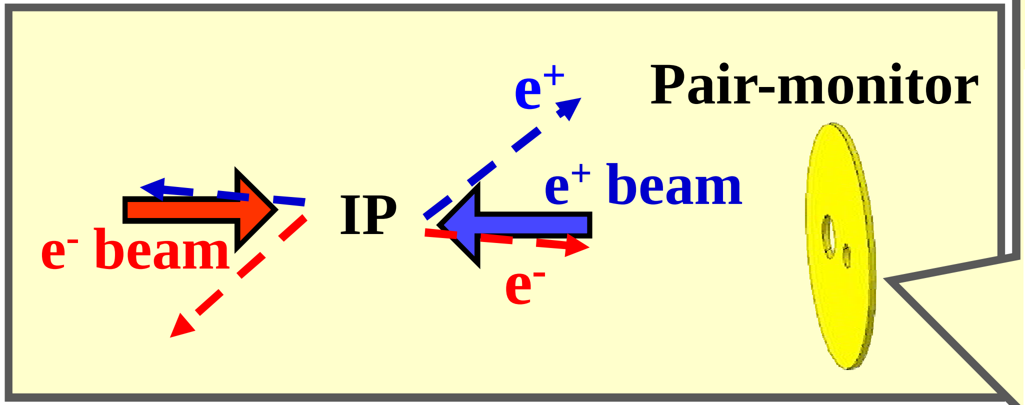
Yutaro Sato
Tohoku Univ.

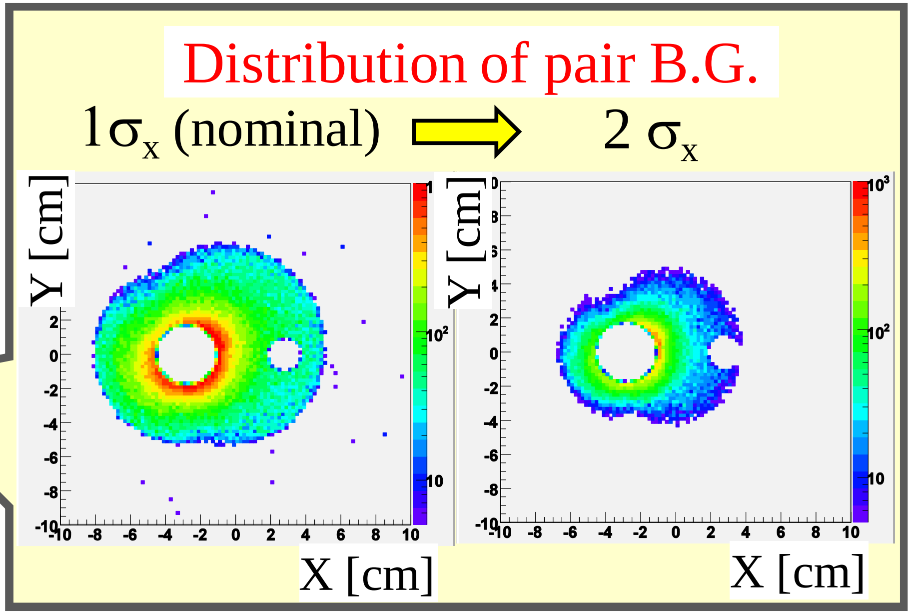
1st Oct. 2009

Pair-monitor

Pair-monitor is a silicon pixel detector to measure the beam profile at IP.

- The distribution of the pair B.G. is used.
  - The same charges with respect to the oncoming beam are scattered with large angle.
  - The scattered particles have information on beam shape.
- The pair-monitor is required to measure the beam size with 10% accuracy.





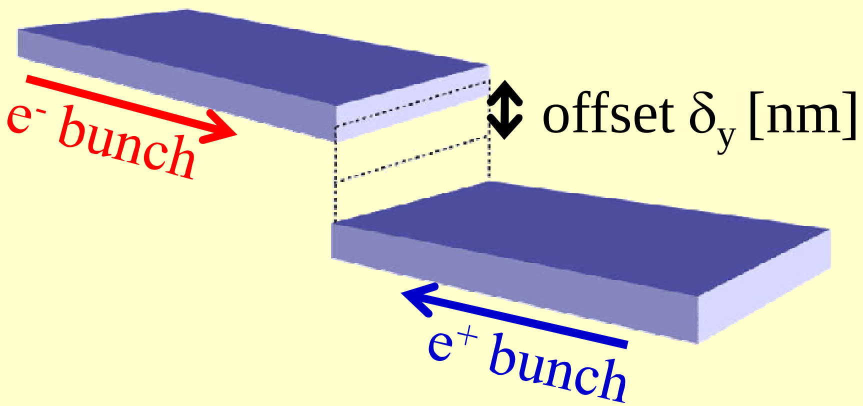
Contents

We have developed

- **performance study of the pair-monitor.**
- development of the readout ASIC for the pair-monitor.

Contents

- The combined analysis with BeamCal was performed.
  - Pair-monitor : silicon pixel detector to measure hit counts
  - BeamCal : calorimeter to measure energy deposit
- Beam parameters (σ_x, σ_y, Δ_y) were reconstructed using the Taylor matrix method (second order).



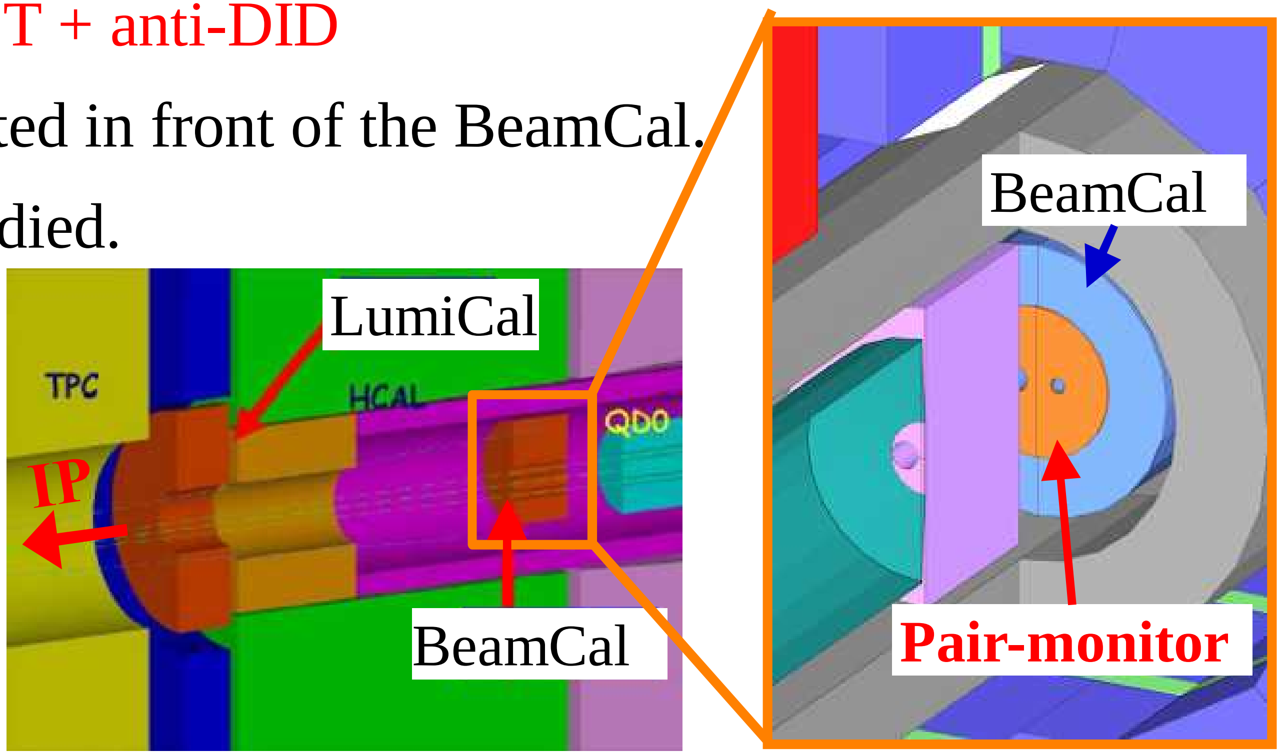
Relative offset $\Delta_y = \delta_y / \sigma_y$

Simulation setup

Simulation setup

- CM energy : 500GeV
- Nominal beam size (σ_x^0, σ_y^0, σ_z^0) = (639nm, 5.7nm, 300 μm)
- Tools : CAIN (Pair background generator)

  Jupiter (Tracking emulator)
- Magnetic field : 3.5 T + anti-DID
- Pair-monitor is located in front of the BeamCal.
- Scattered e^+ was studied.



Matrix method for reconstruction

The measurement variables are used for the reconstruction.

The measurement variables can be expanded by the Taylor expansion.

Measurement variable (**M**) Beam parameter (**X**)

Matrix of the first order term

Tensor of the second order term

$$\begin{pmatrix} m_1 \\ \vdots \\ m_n \end{pmatrix} = \mathbf{A} \begin{pmatrix} \sigma_x \\ \sigma_y \\ \Delta_y \end{pmatrix} + \begin{pmatrix} \sigma_x & \sigma_y & \Delta_y \end{pmatrix} \mathbf{B} \begin{pmatrix} \sigma_x \\ \sigma_y \\ \Delta_y \end{pmatrix} + \cdots$$

$$= \mathbf{AX} + \mathbf{X}^{\mathrm{T}}\mathbf{BX} + \cdots$$

$$\mathbf{A} = \begin{pmatrix} \frac{\partial m_1}{\partial \sigma_x} & \frac{\partial m_1}{\partial \sigma_y} & \frac{\partial m_1}{\partial \Delta_y} \\ \frac{\partial m_2}{\partial \sigma_x} & \frac{\partial m_2}{\partial \sigma_y} & \frac{\partial m_2}{\partial \Delta_y} \\ \vdots & \vdots & \vdots \end{pmatrix}$$

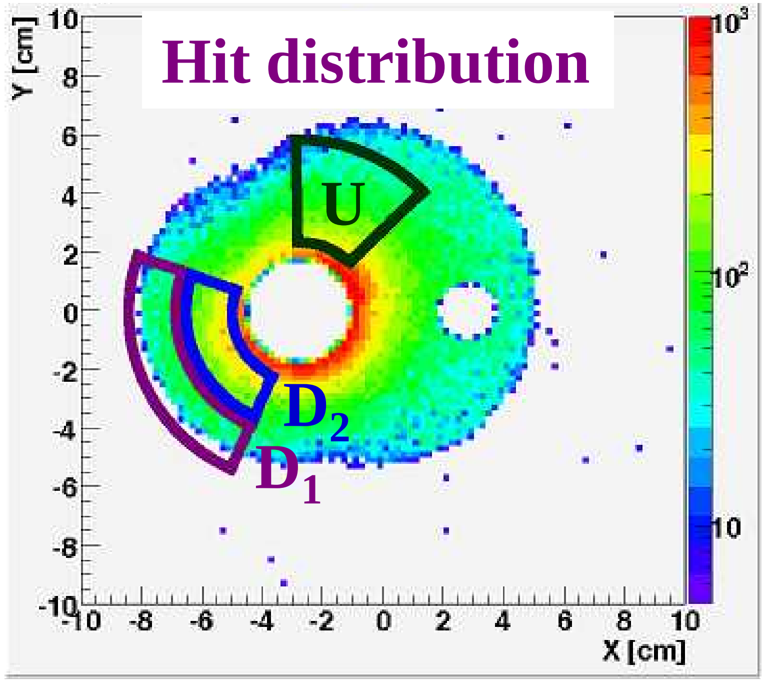
The beam parameters are reconstructed by the inverse matrix.

$$\mathbf{X} \equiv \begin{pmatrix} \sigma_x \\ \sigma_y \\ \Delta_y \end{pmatrix} = [\mathbf{A} + \mathbf{X}^{\mathrm{T}}\mathbf{B} + \cdots]^{-1}\mathbf{M}$$

Measurement variables

8 measurement variables were defined.

Pair-monitor	BeamCal	
R_{max}	R_{ave}	Spread
N_{D1}/N_{all}	N_{D}/N_{all}	Ratio of the particular region
N_{U}/N_{D2}	N_{U}/N_{D}	
$1/N_{all}$	$1/Edep_{all}$	Total hit or energy deposit

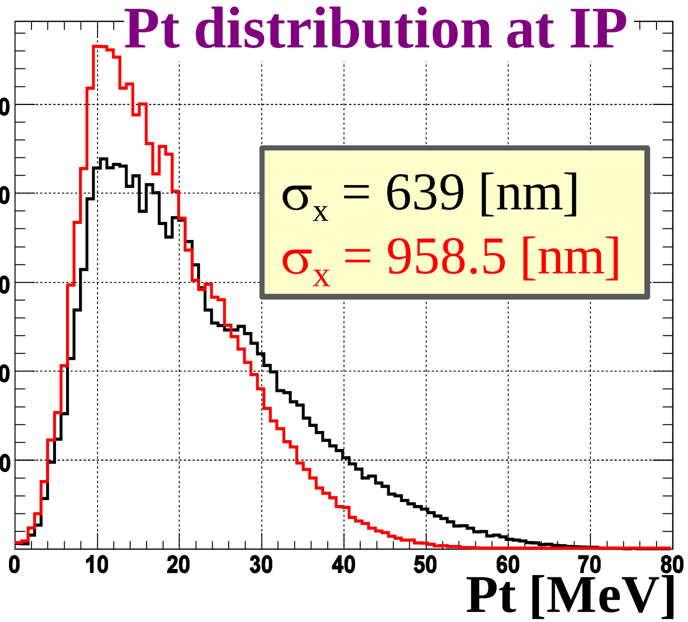


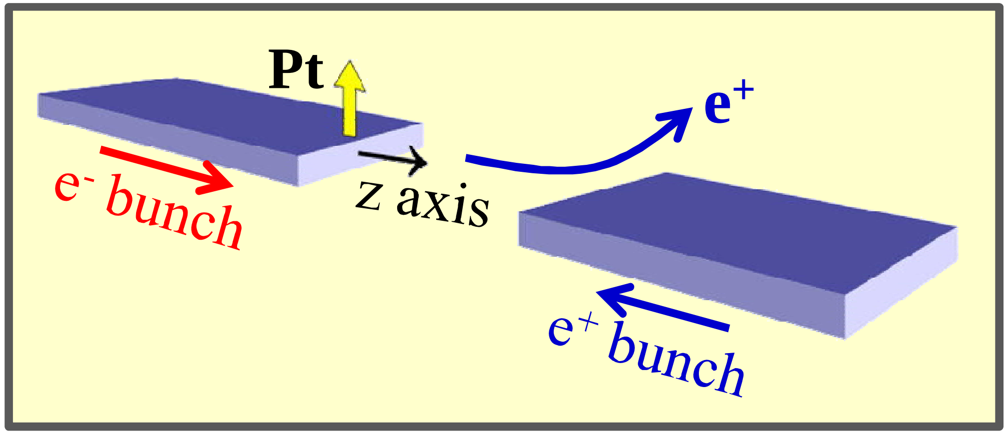
We introduce above measurement variables.

Spread of pair B.G. distribution

The spread of the pair B.G. distribution changes,

according to the transverse momentum of the pairs.





Measurement variables were defined.

R_{max} : Radius to contain 97.5% of all the hits. (Pair-monitor)

R_{ave} : Average radius weighted by energy deposit. (BeamCal)

$$R_{ave} \equiv \frac{\sum R_i \times Edep_i}{\sum Edep_i}$$

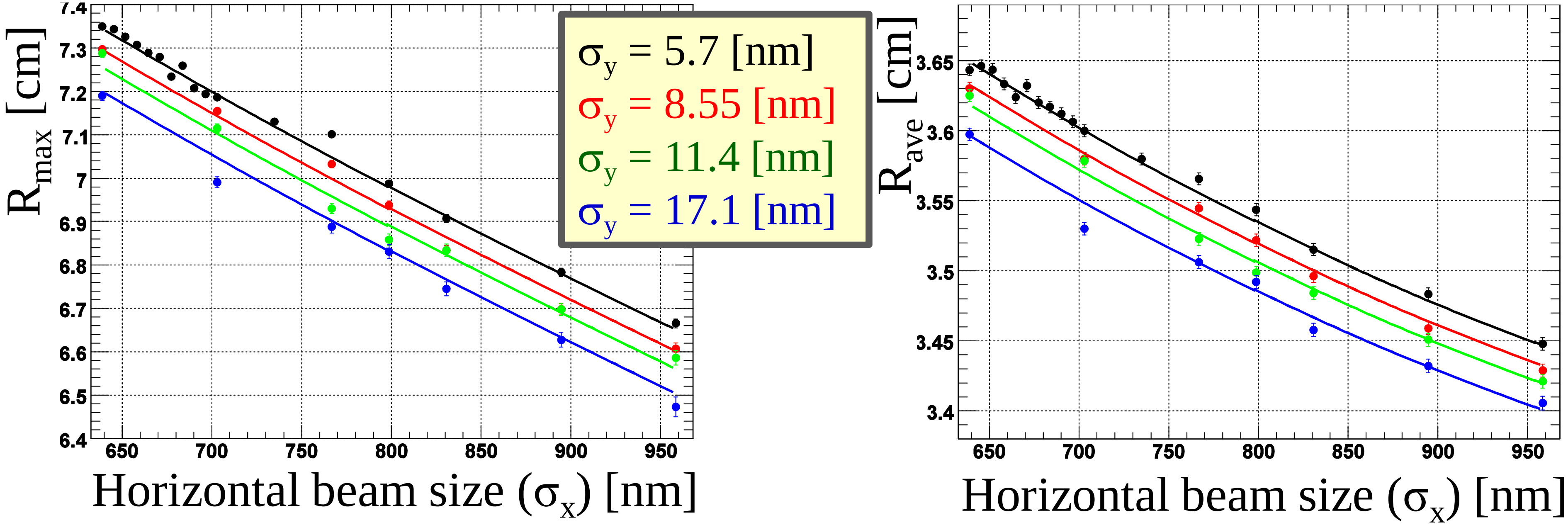
(R_i is the radius of the i-th cell)

Variable : R_{max} and R_{ave}

R_{max} and R_{ave} were obtained with various beam parameters.

R_{max} [cm] v.s. Horizontal beam size (σ_x) [nm]

R_{ave} [cm] v.s. Horizontal beam size (σ_x) [nm]

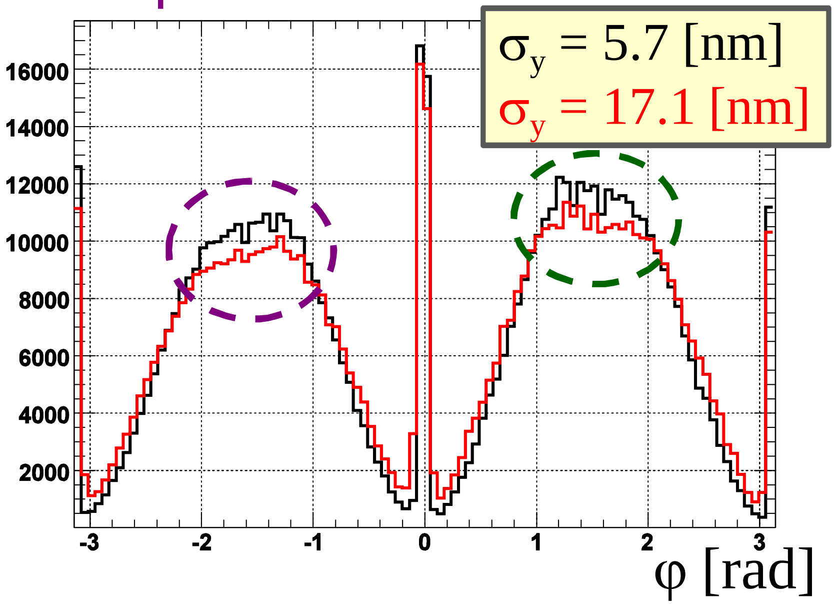


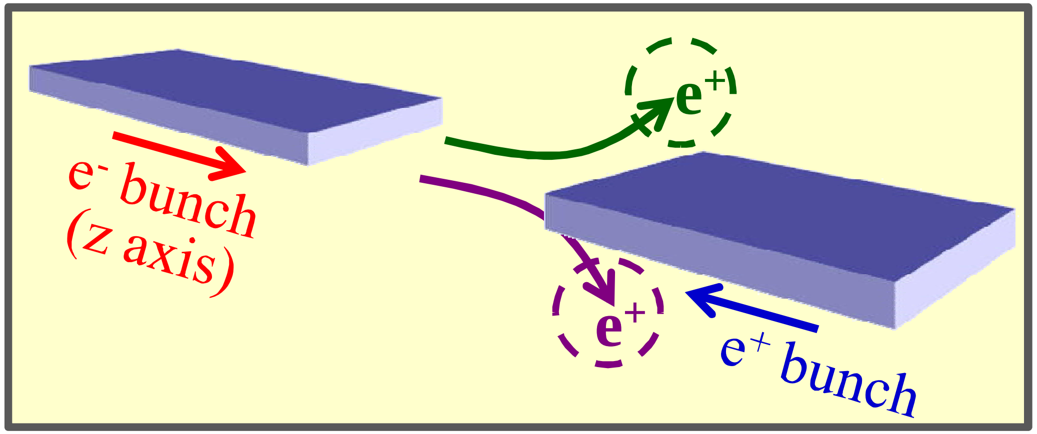
R_{max} and R_{ave} decrease for larger horizontal beam size (σ_x).

Scattered direction at IP

Scattered direction at IP changes with the beam parameters.

φ distribution at IP

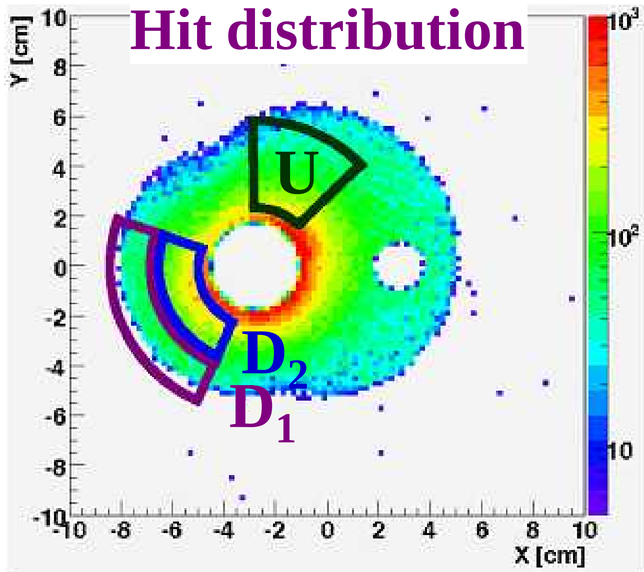




The measurement variables were defined from the pair-monitor.

N_{D1} / N_{all} for vertical beam size (σ_y)

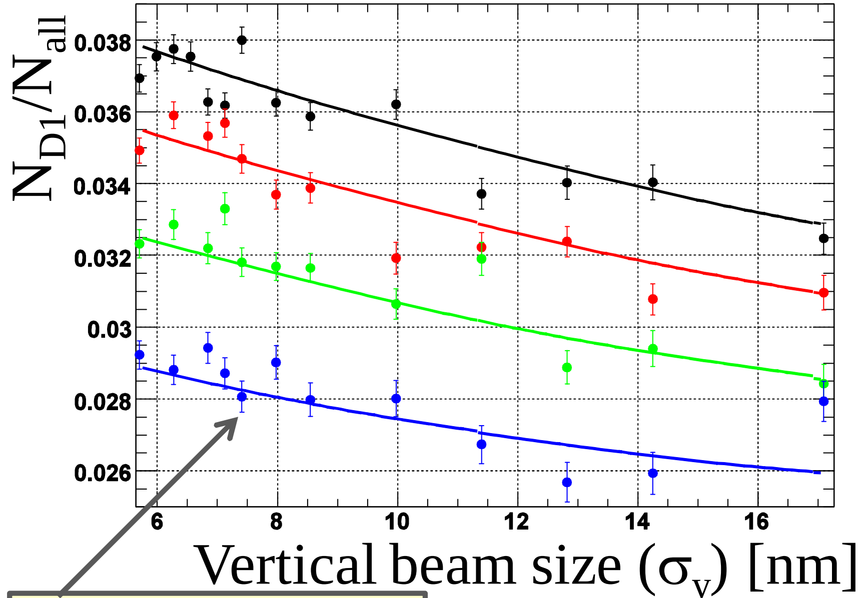
N_U / N_{D2} for relative offset (Δ_y)



Variable : N_{D1}/N_{all}, N_U/N_{D2}

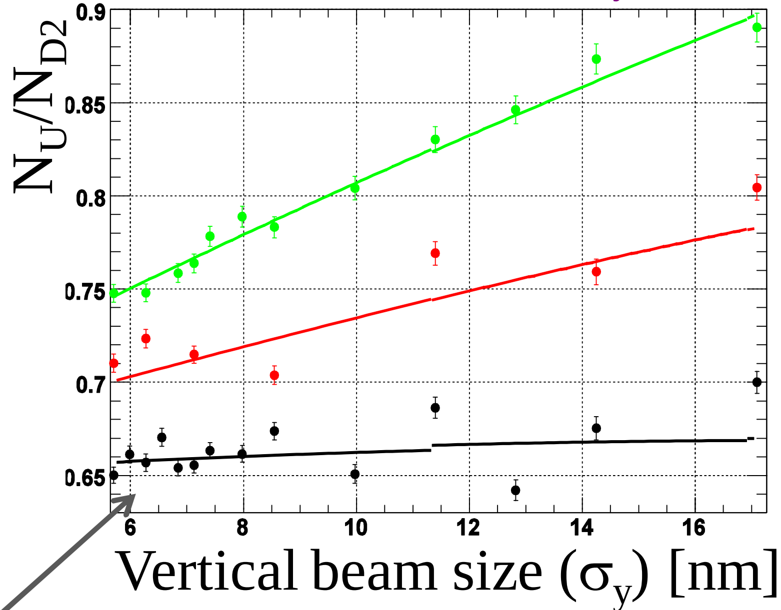
N_{D1}/N_{all} and N_U/N_{D2} were obtained with various beam parameters.

N_{D1}/N_{all} v.s. Vertical beam size (σ_y) [nm]



σ_x = 639 [nm]
σ_x = 702.9 [nm]
σ_x = 798.75 [nm]
σ_x = 958.5 [nm]

N_U/N_{D2} v.s. Vertical beam size (σ_y) [nm]



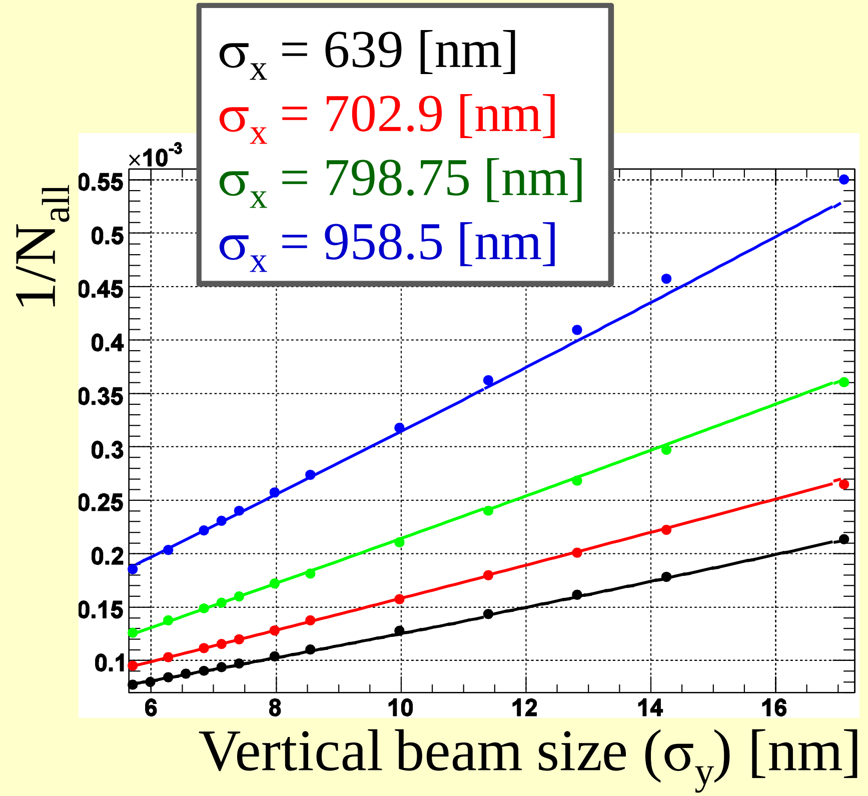
$\Delta_y = 0$
$\Delta_y = 0.2$
$\Delta_y = 0.4$

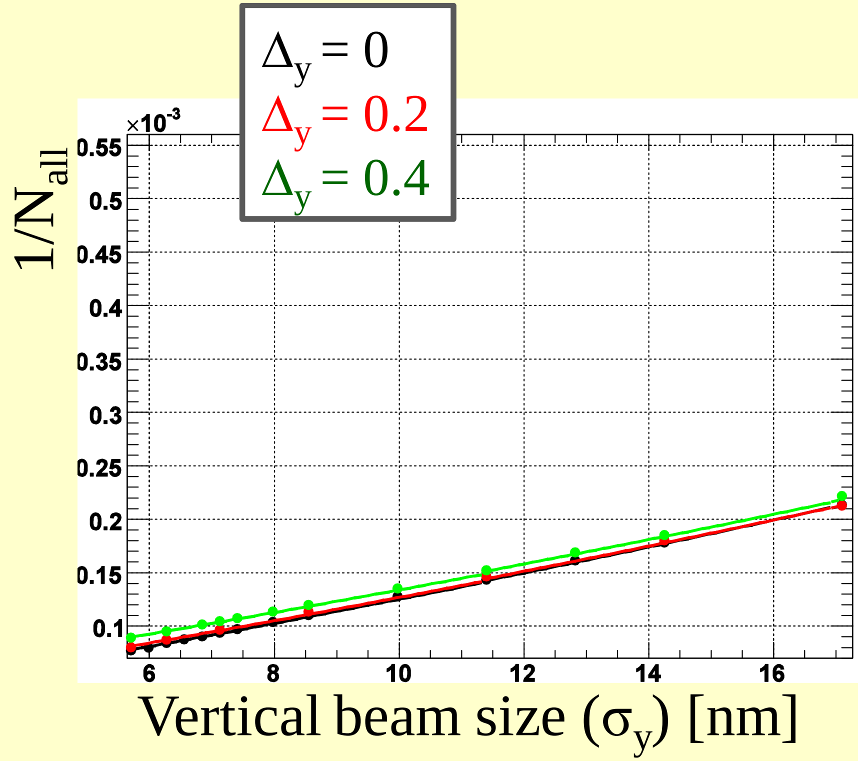
N_{D1}/N_{all} and N_U/N_{D2} change as a function of the beam parameters.

Variable : $1/N_{all}$, $1/Edep_{all}$

The total number of hits (**N_{all}**) and total energy deposit (**$Edep_{all}$**) have information on the beam parameters.

$1/N_{all}$ v.s. Vertical beam size (σ_y) [nm]





$1/N_{all}$ and $1/Edep_{all}$ change as a function of the σ_x and σ_y.

Reconstruction of beam parameters

8 measurement variables were prepared.

- **Pair-monitor** … R_{max}, N_{D1}/N_{all}, N_U/N_{D2}, $1/N_{all}$
- **BeamCal** … R_{ave}, N_D/N_{all}, N_U/N_D, $1/Edep_{all}$

Matrix components were determined by the fitting with the second order polynomials

Tensor of the second order term

Matrix of the first order term

Pair-monitor

BeamCal

$$\begin{pmatrix} R_{max} \\ \vdots \\ R_{ave} \\ \vdots \end{pmatrix} = \boxed{\mathbf{A}} \begin{pmatrix} \sigma_x \\ \sigma_y \\ \Delta_y \end{pmatrix} + \begin{pmatrix} \sigma_x & \sigma_y & \Delta_y \end{pmatrix} \boxed{\mathbf{B}} \begin{pmatrix} \sigma_x \\ \sigma_y \\ \Delta_y \end{pmatrix}$$

Beam parameter (**X**)

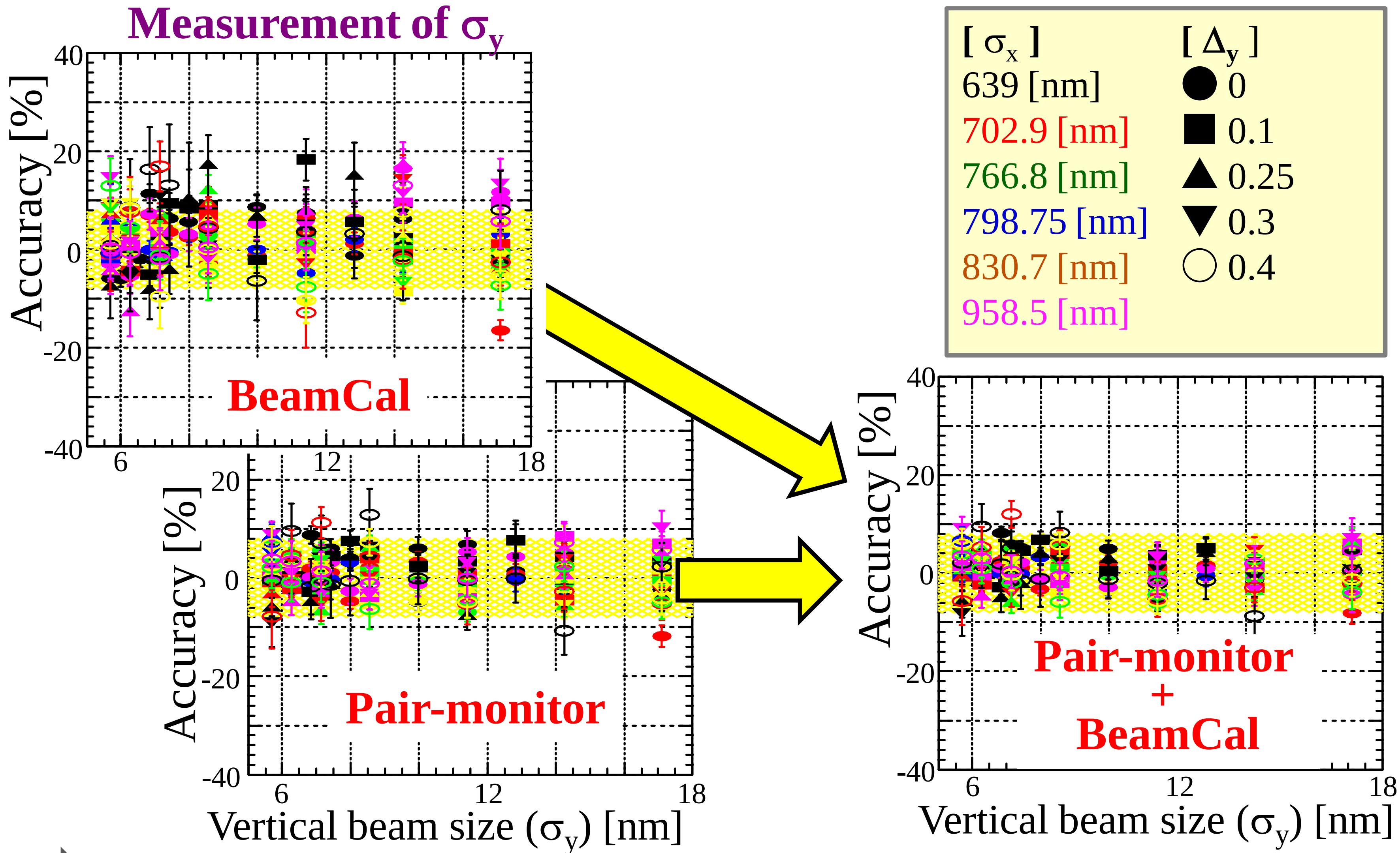
Measurement variable (**M**)

Beam parameters were reconstructed.

$$\mathbf{X} \equiv \begin{pmatrix} \sigma_x \\ \sigma_y \\ \Delta_y \end{pmatrix} = [\mathbf{A} + \mathbf{X}^{\mathrm{T}}\mathbf{B}]^{-1}\mathbf{M}$$

Results (σ_y)

The performance was compared among three cases.



The combined analysis provides more precise measurement.

Results (σ_x, σ_y, Δ_y)

The accuracy of all the beam parameters is as follows.

	Pair-monitor	BeamCal	Pair-monitor + BeamCal
σ_x	3.2 %	4.1 %	2.8 %
σ_y	10.1%	15.6 %	8.6 %
Δ_y	8.6 %	9.4 %	7.4 %

The combined analysis provides more precise measurement for all the beam parameters.

Summary

- Pair-monitor and BeamCal measure the beam profile at IP.
  - Pair-monitor : silicon pixel detector to measure the hit count.
  - BeamCal : calorimeter to measure the energy deposit.

- The combined analysis with BeamCal was performed.
- Beam parameters (σ_x, σ_y, Δ_y) are reconstructed using the Taylor matrix method (second order).

Measurement accuracy

	Pair-monitor	BeamCal	Pair-monitor + BeamCal
σ_x	3.2 %	4.1 %	2.8 %
σ_y	10.1%	15.6 %	8.6 %
Δ_y	8.6 %	9.4 %	7.4 %

The combined analysis can provides more precise measurement.

Backup

Matrix method for reconstruction

- Inverse matrix of a non-square matrix A is defined as follows.

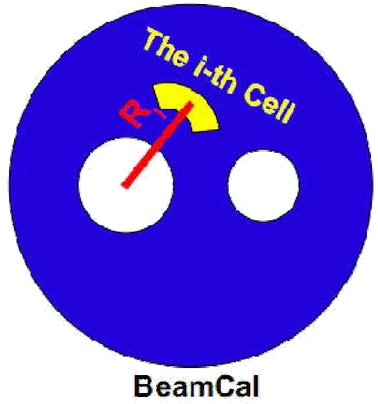
$$A^{-1} \equiv \left(A^T A\right)^{-1} A^T$$

$$\Rightarrow \underbrace{A^{-1}} A = \underbrace{\left(A^T A\right)^{-1} A^T} A = 1$$

R_{max} and R_{ave}

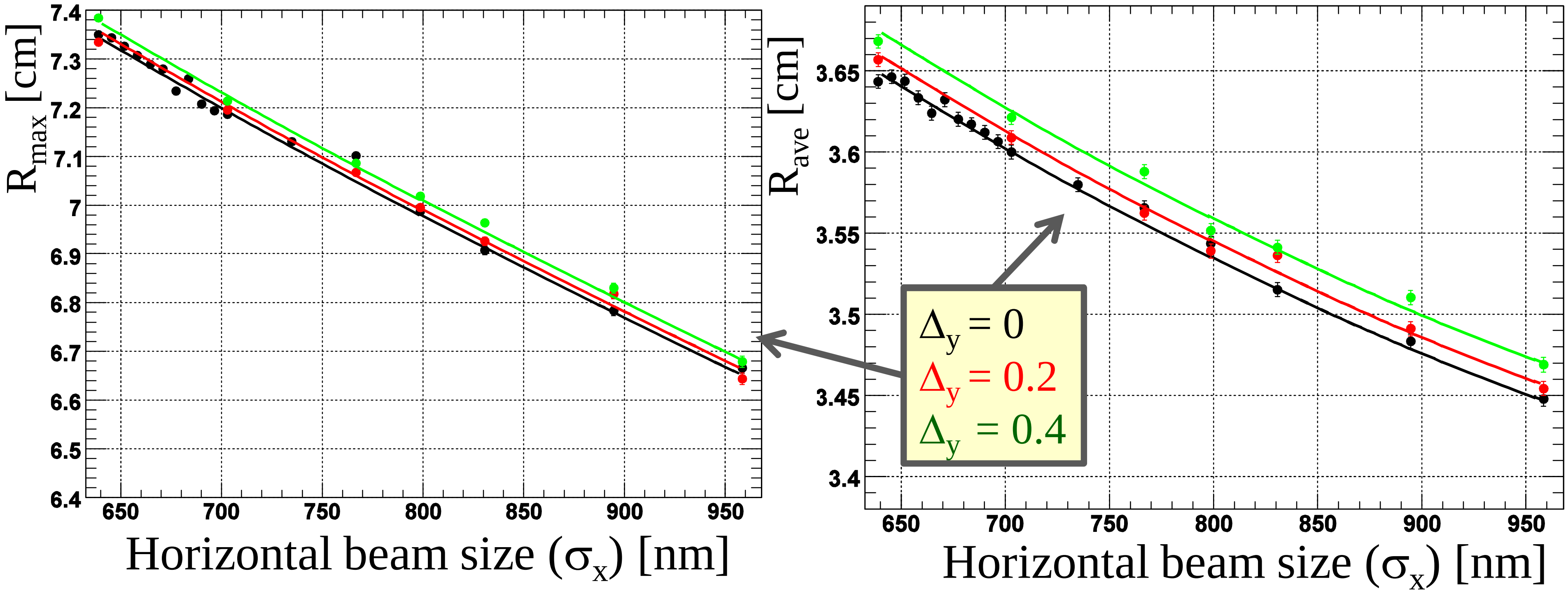
$$R_{ave} \equiv \frac{\sum R_i \times Edep_i}{\sum Edep_i}$$

(R_i is the radius of the i-th cell)

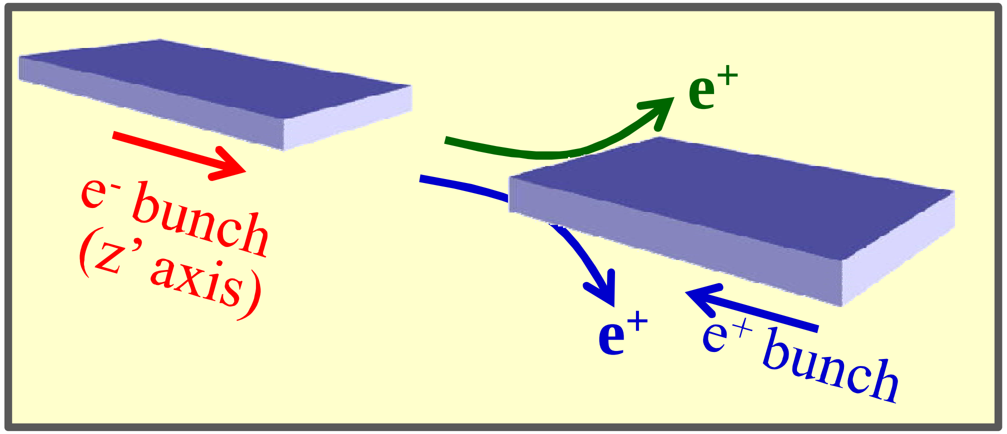


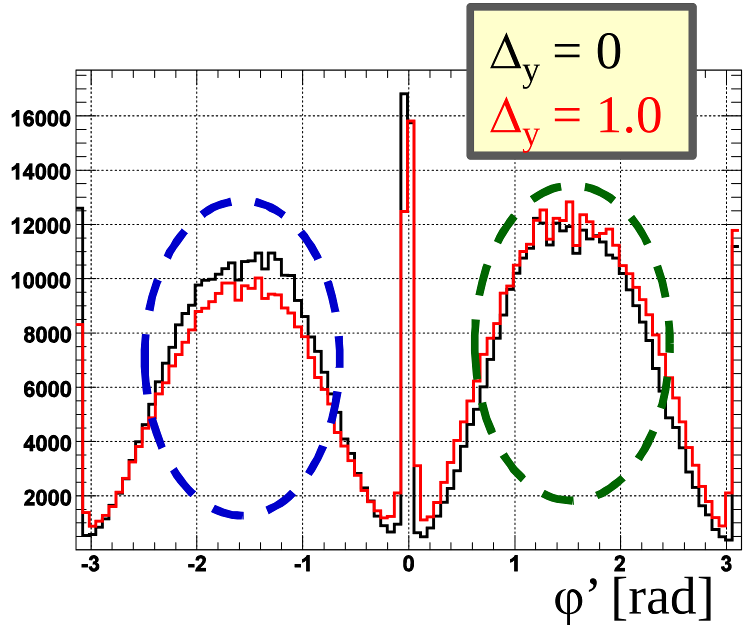
R_{max} [cm] v.s. Horizontal beam size (σ_x) [nm]

R_{ave} [cm] v.s. Horizontal beam size (σ_x) [nm]



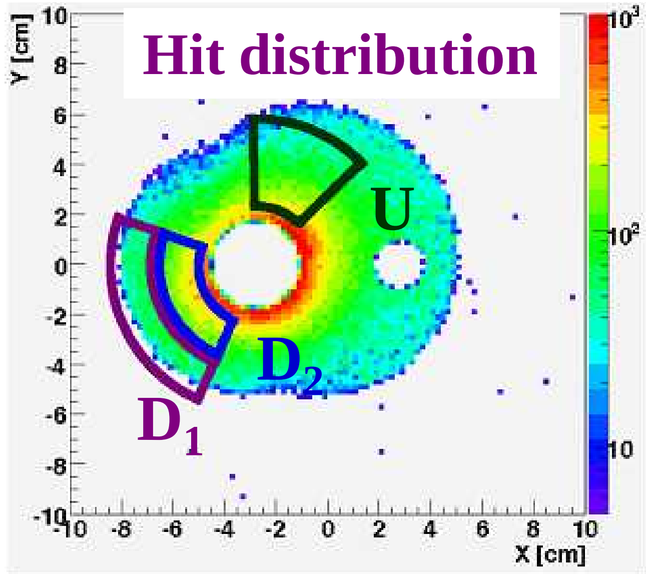
Azimuthal distribution





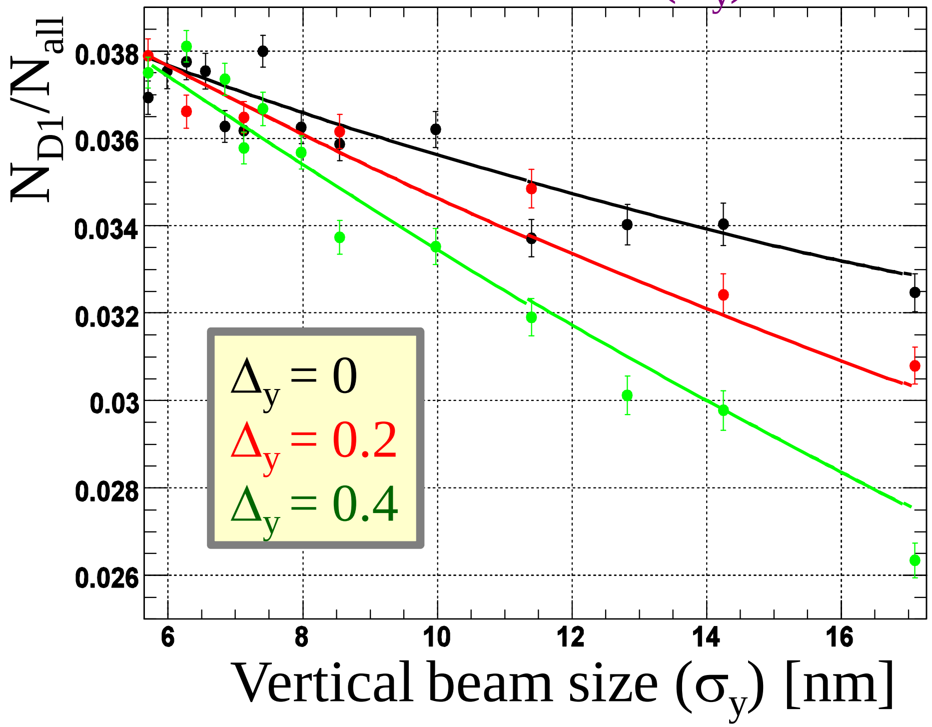
The measurement variable was defined.

→ N_U/N_{D2}

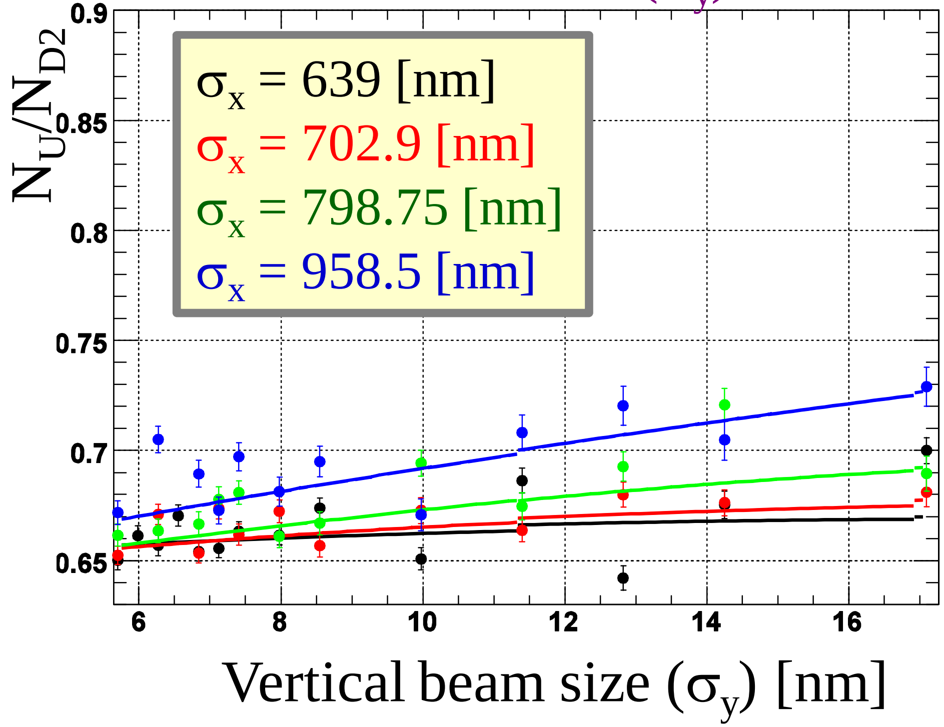


Variable : N_{D1}/N_{all}, N_U/N_{D2}

N_{D1}/N_{all} v.s.
Vertical beam size (σ_y) [nm]

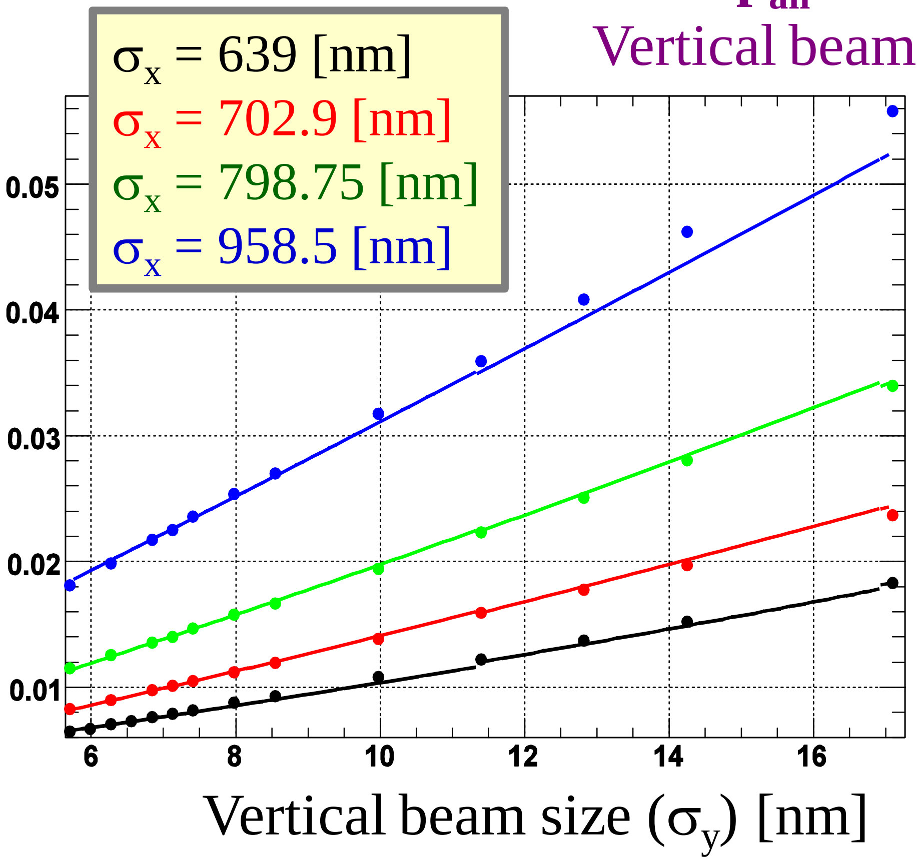


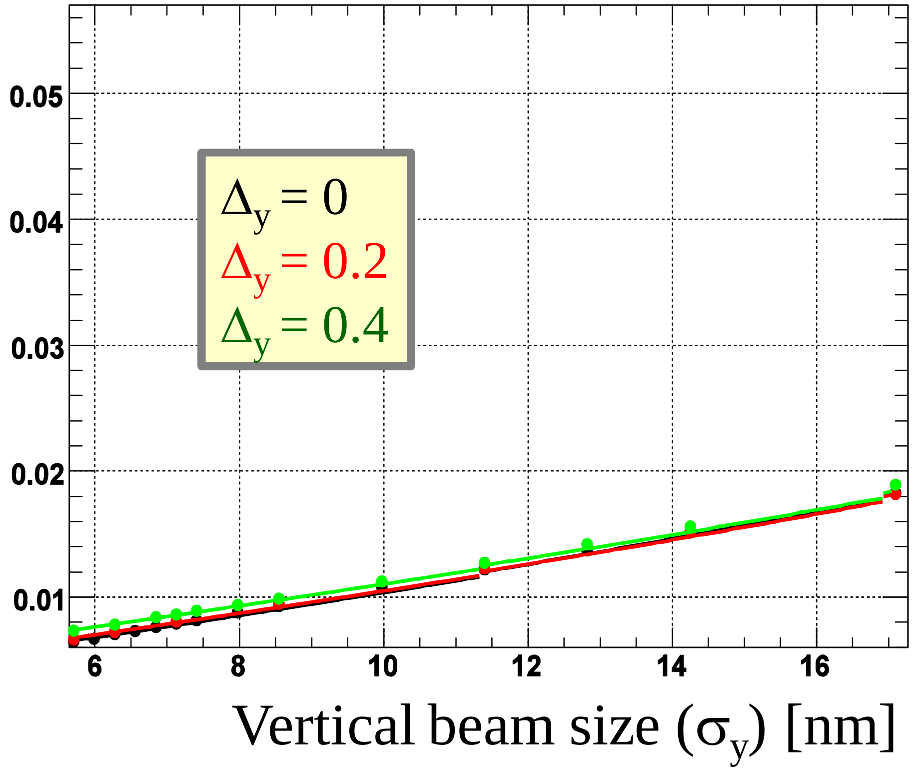
N_U/N_{D2} v.s.
Vertical beam size (σ_y) [nm]



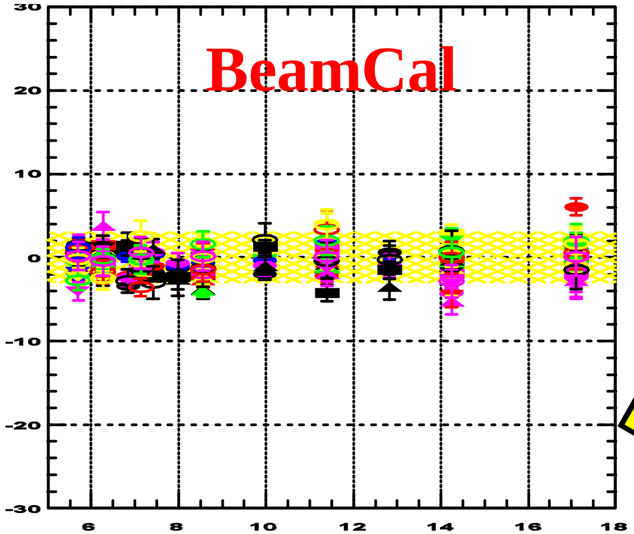
Variable : $1/N_{all}$, $1/Edep_{all}$

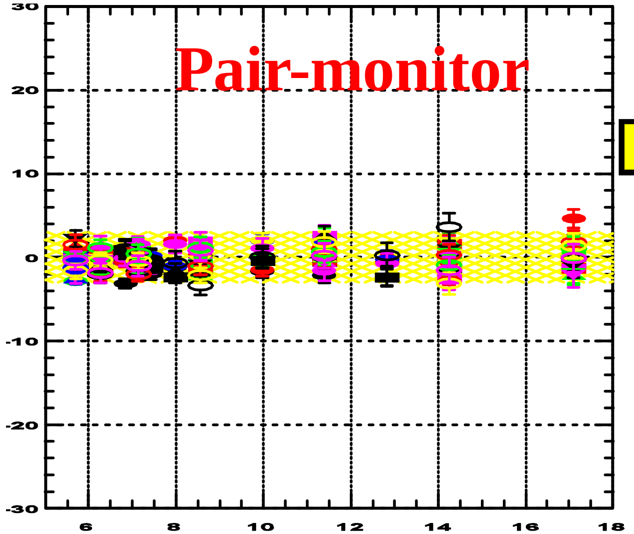
$1/Edep_{all}$ v.s.
Vertical beam size (σ_y) [nm]

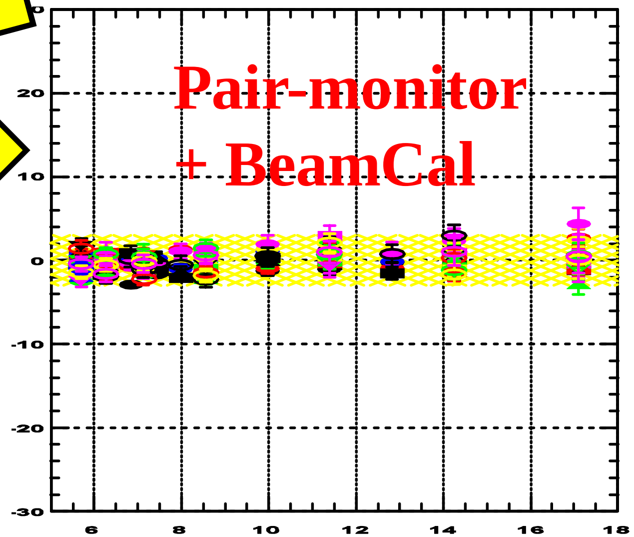




Result (σ_x)

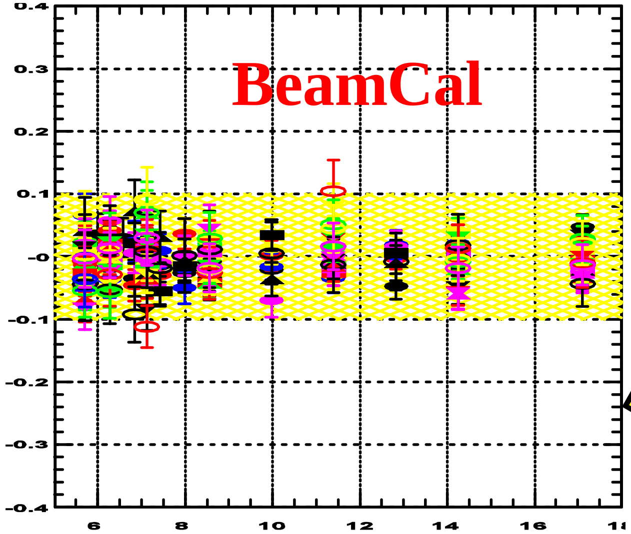


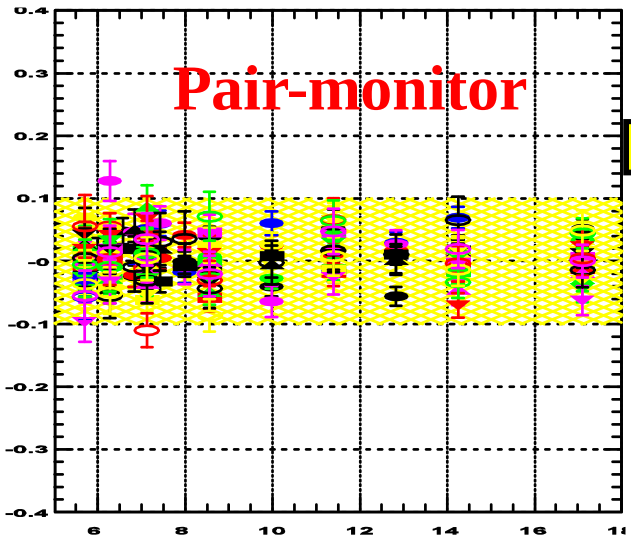




[σ_x]	[Δ_y]
639 [nm]	● 0
702.9 [nm]	■ 0.1
766.8 [nm]	▲ 0.25
798.75 [nm]	▼ 0.3
830.7 [nm]	○ 0.4
958.5 [nm]	

Result (Δ_y)





[σ_x]	[Δ_y]
639 [nm]	● 0
702.9 [nm]	■ 0.1
766.8 [nm]	▲ 0.25
798.75 [nm]	▼ 0.3
830.7 [nm]	○ 0.4
958.5 [nm]