Performance Study of Pair-monitor (for ILD)

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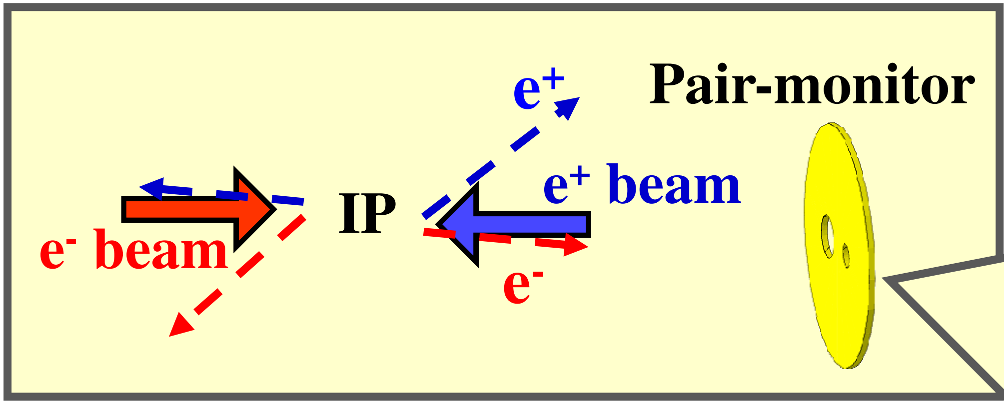
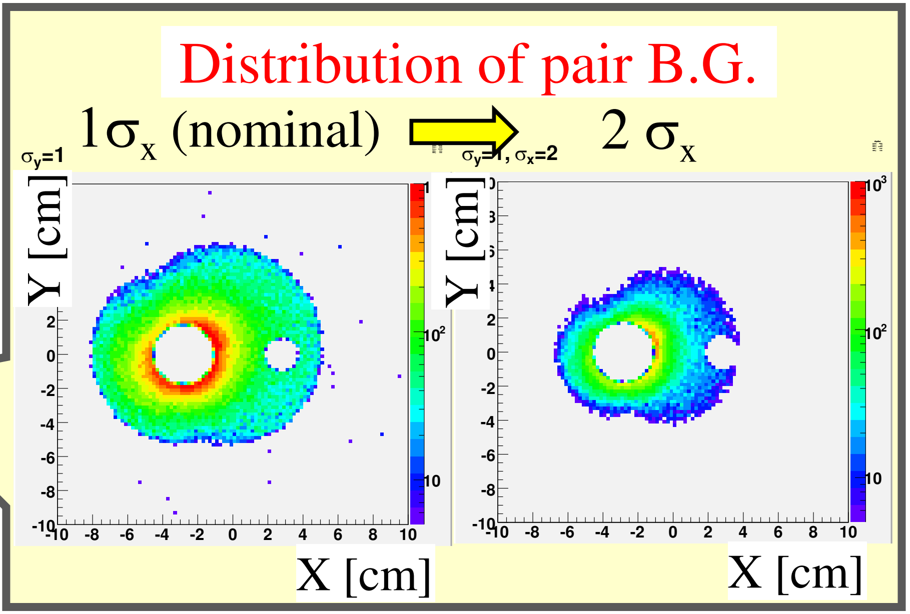
Pair-monitor

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.





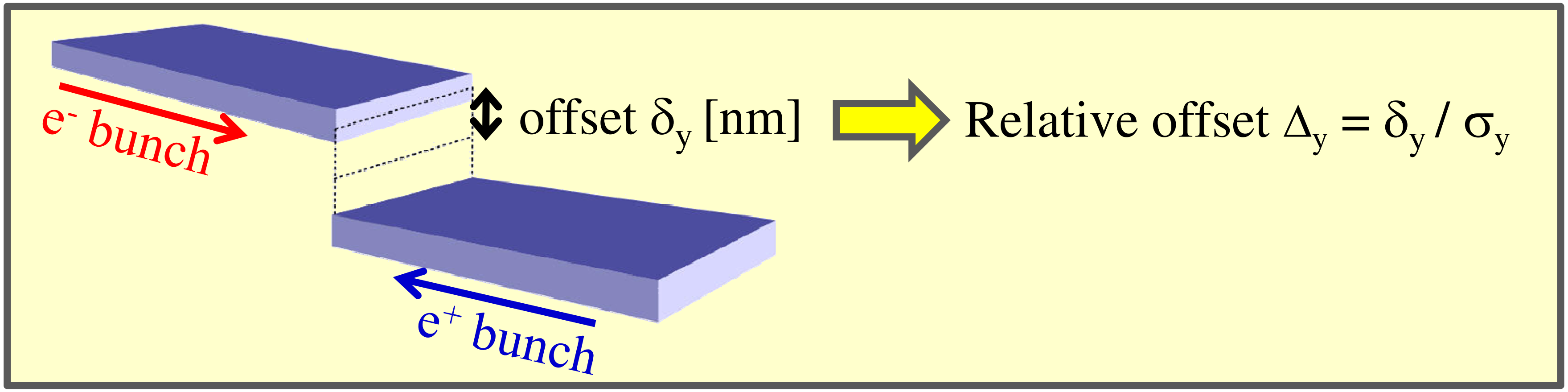
Contents

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).

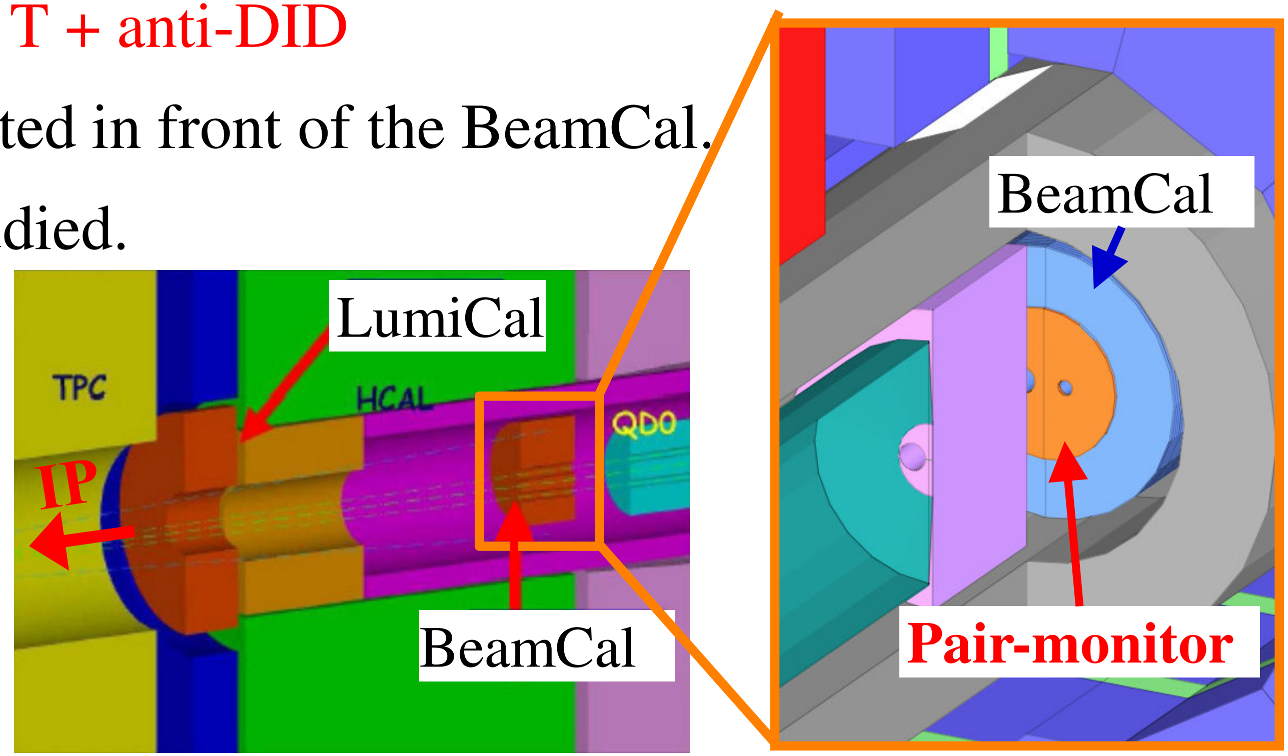


Simulation setup

Simulation setup

- CM energy : 500GeV
- Nominal beam size ($\sigma_x{}^0$, $\sigma_y{}^0$, $\sigma_z{}^0$) = (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

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

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

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

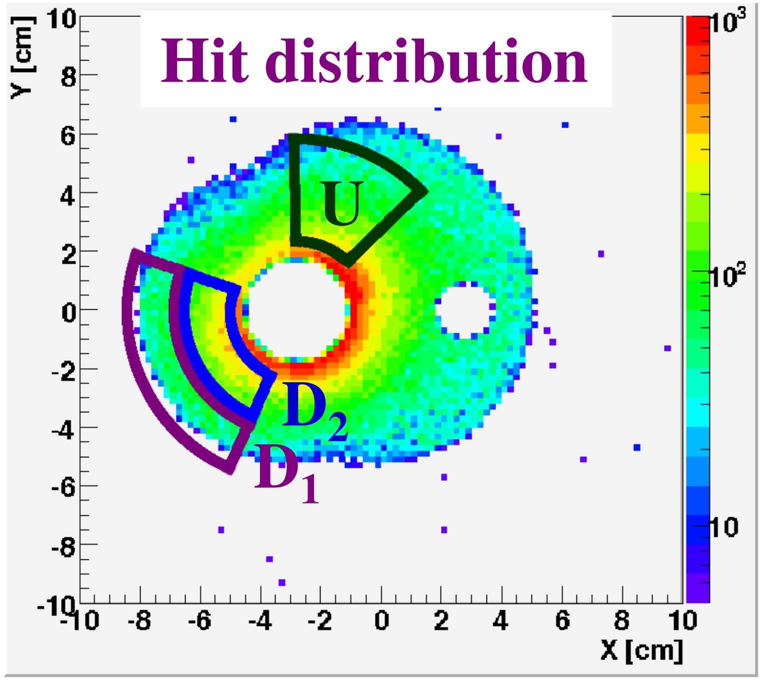
The beam parameters are reconstructed by the inverse matrix.

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

Measurement variables

8 measurement variables were defined.

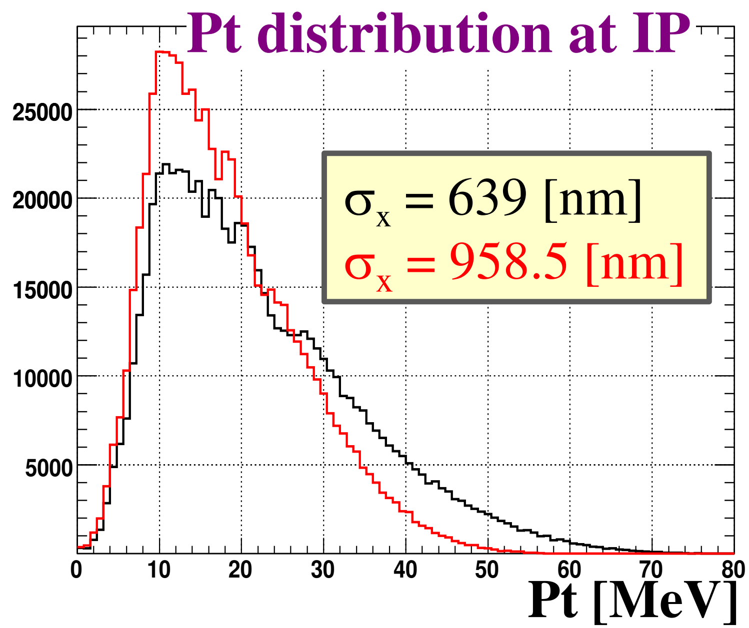
Pair-monitor	BeamCal	
R_{max}	R_{ave}	Spread
N_{D1}/N_{all}	N_D/N_{all}	Ratio of the particular region
N_U/N_{D2}	N_U/N_D	
$1/N_{all}$	$1/Edep_{all}$	Total hit or energy deposi t

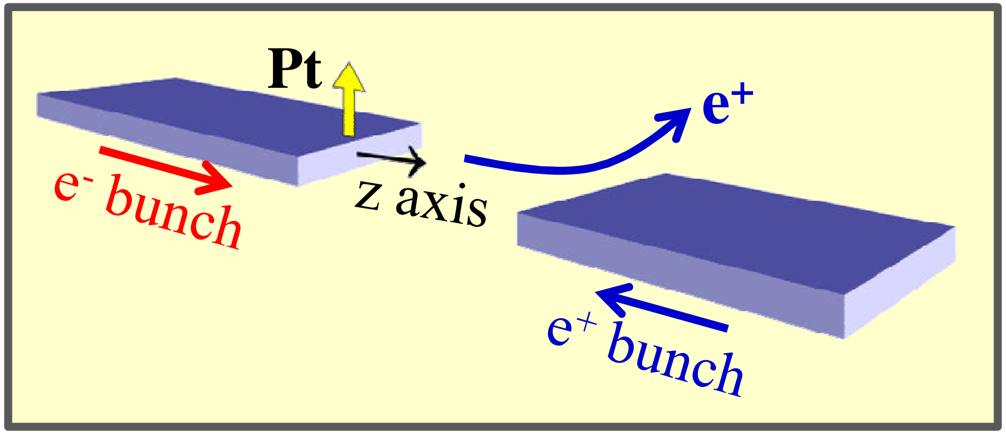


We introduce above measurement variables.

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)

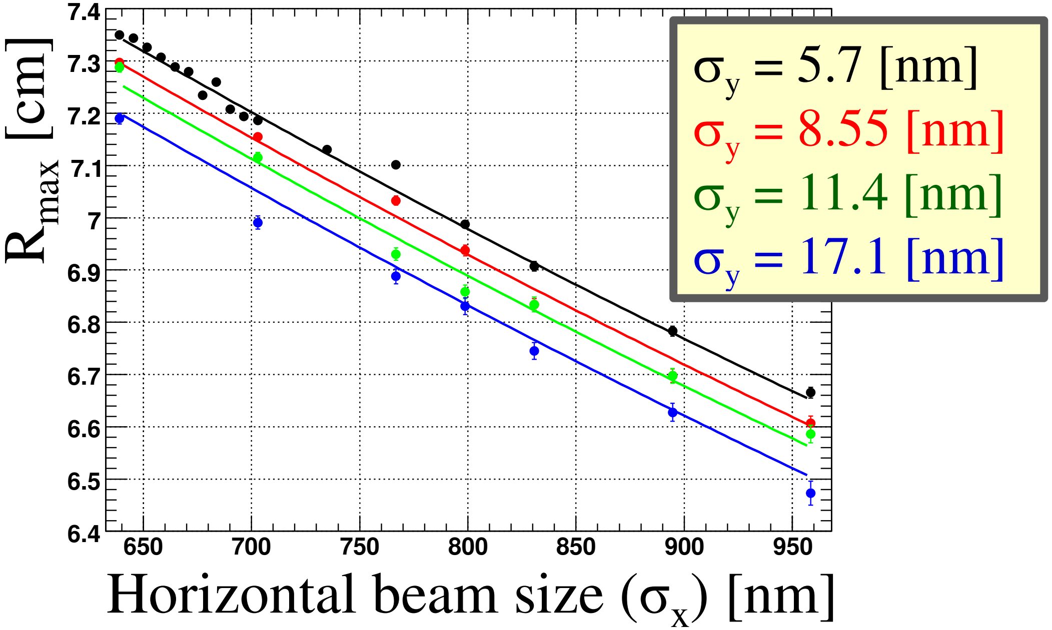
$$R_{ave} \equiv \frac{\sum R_i \times Edep_i}{\sum Edep_i}$$

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

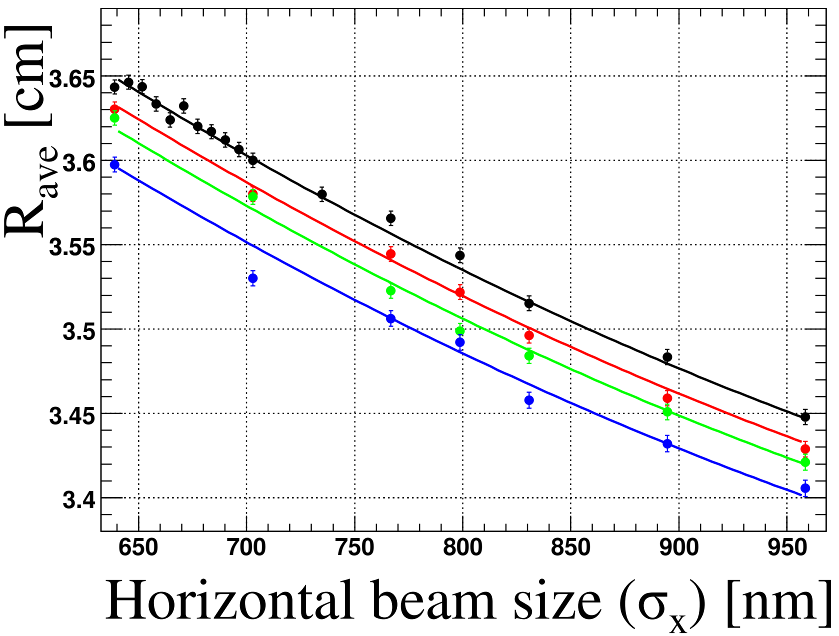
Variable : R_{max} and R_{ave}

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]

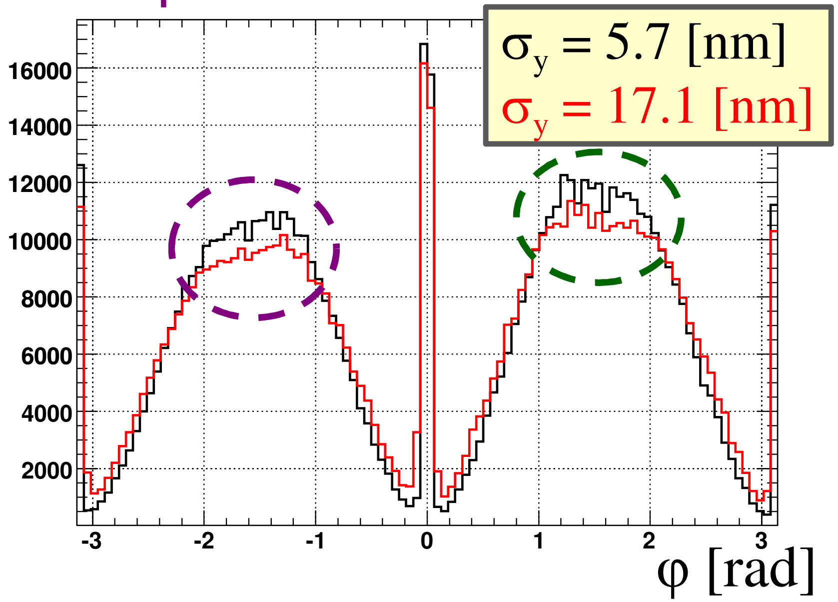


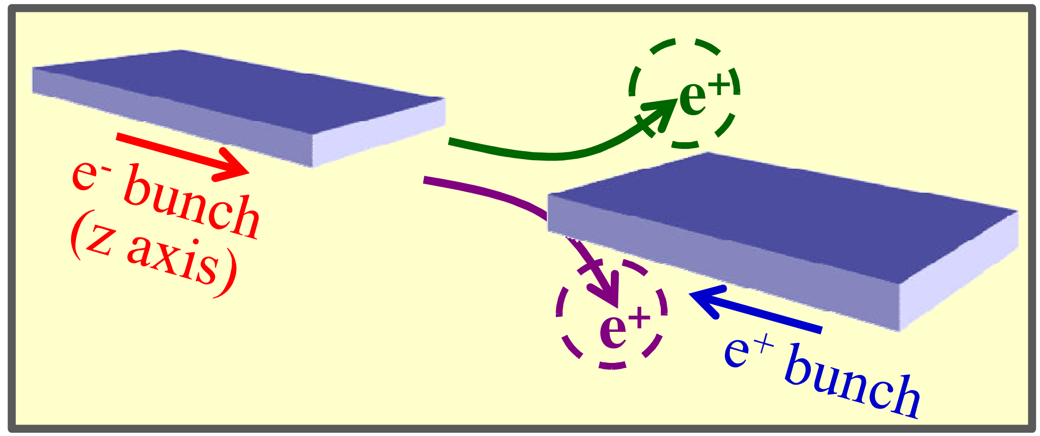
R_{max} and R_{ave} decrease for larger horizontal beam size (σ_x).

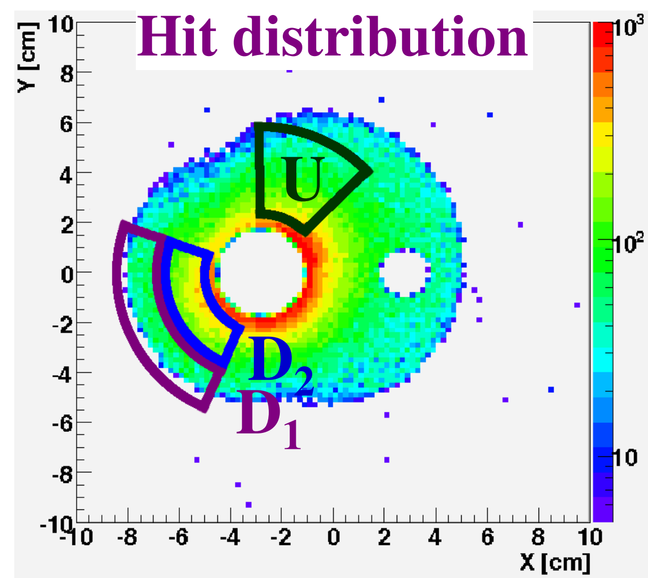
Scattered direction at IP

Scattered direction at IP changes with the beam parameters.

φ distribution at IP







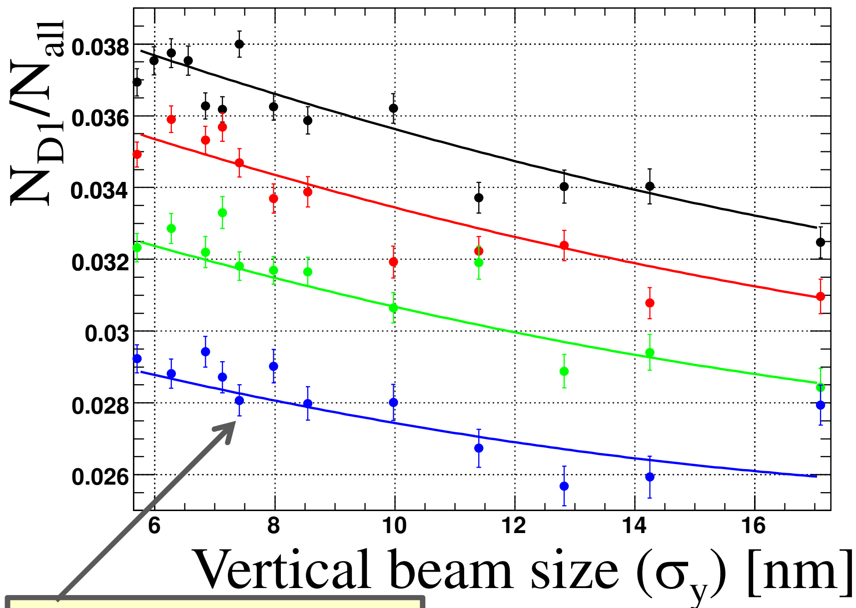
The measurement variables were defined from the pair-monitor.

- 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}

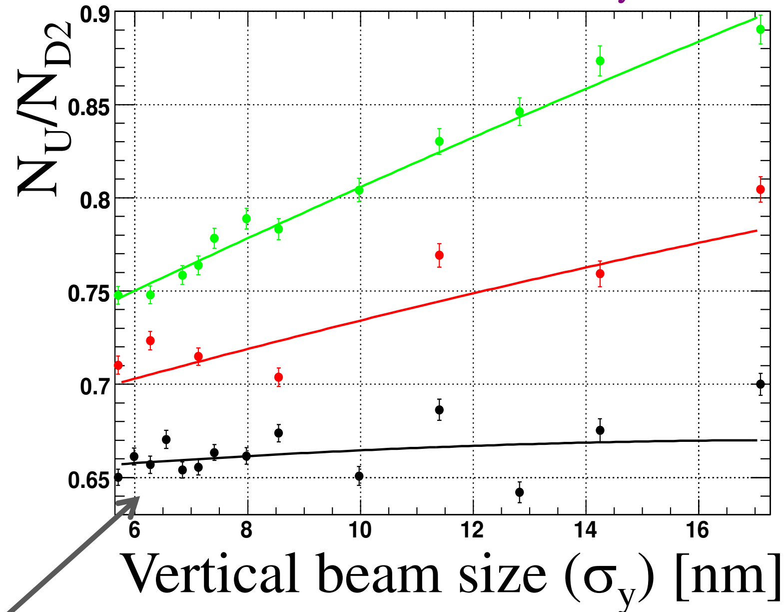
N_{D1}/N_{all} and N_U/N_{D2} were obtained with various beam parameters.

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]



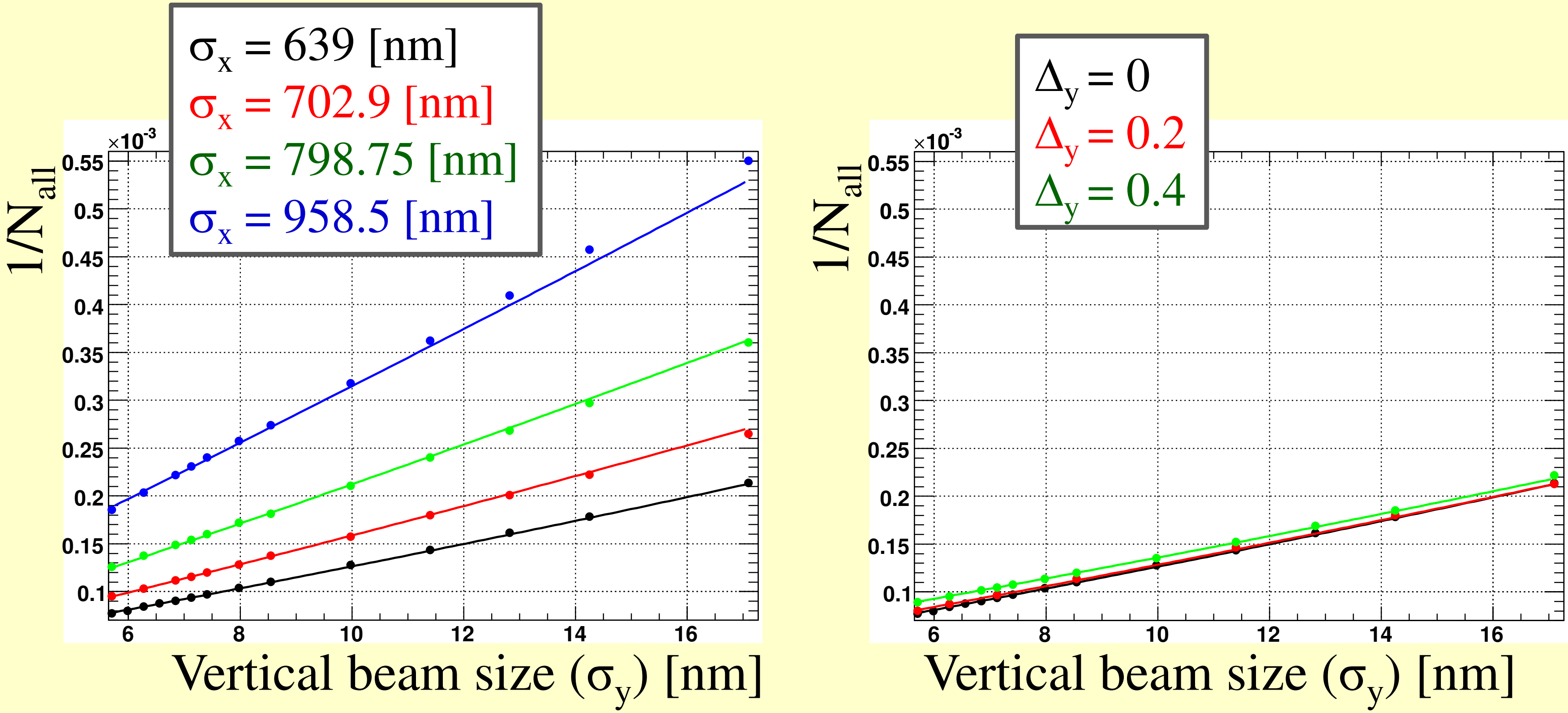
$\Delta_y = 0$
$\Delta_y = 0.2$
$\Delta_y = 0.4$

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**)

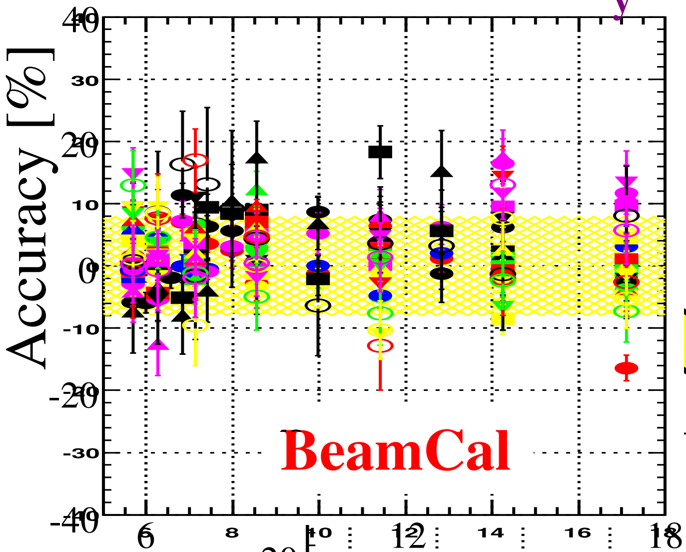
Beam parameters were reconstructed.

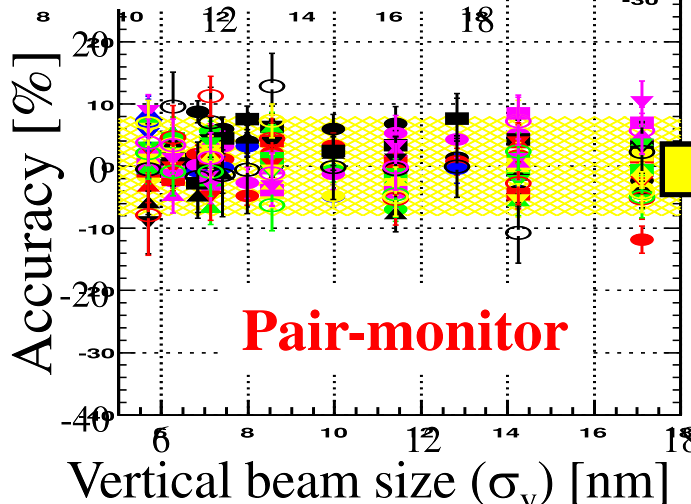
$$\mathbf{X} \equiv \begin{pmatrix} \sigma_x \\ \sigma_y \\ \Delta_y \end{pmatrix} = [\mathbf{A} + \mathbf{X}^{\mathrm{T}}\mathbf{B}]^{-1}\mathbf{M}$$

Results (σ_y)

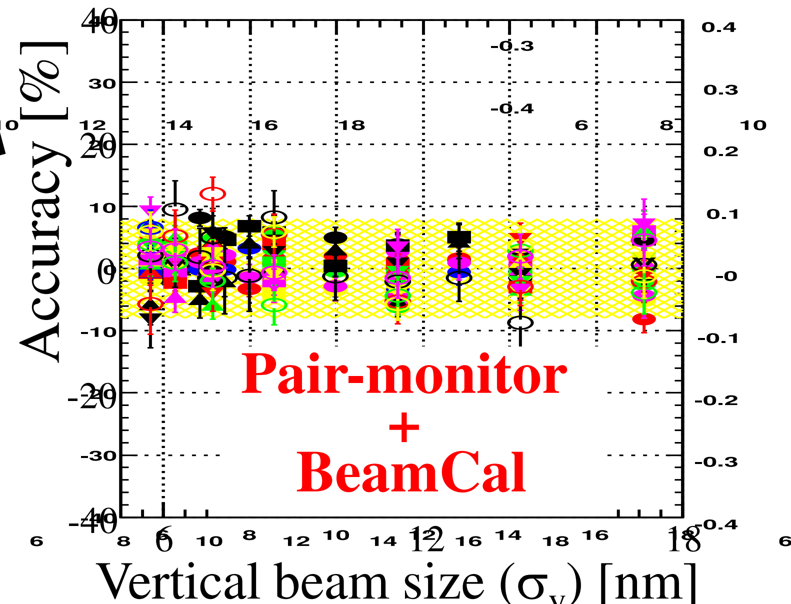
The performance was compared among three cases.

Measurement of σ_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]	



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.

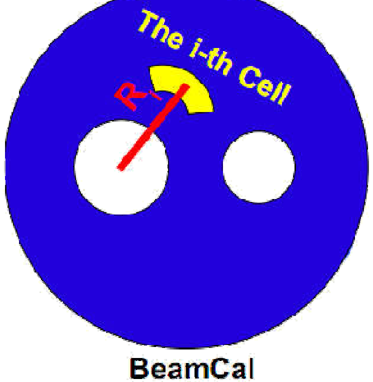
$$A^{-1} \equiv \left(A^T A\right)^{-1} A^T$$

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

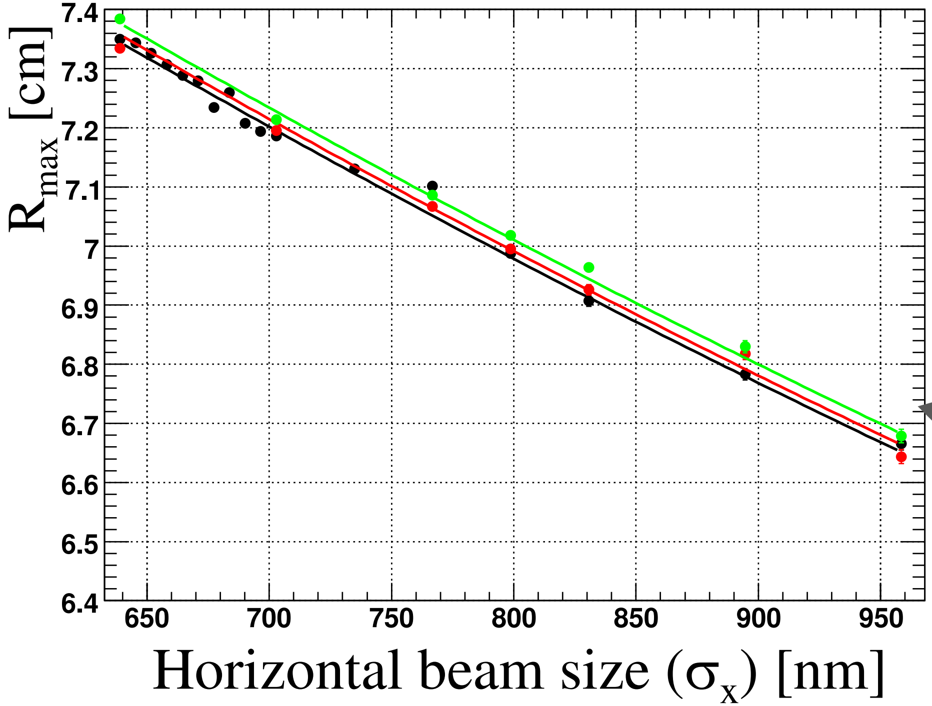
R_{max} and R_{ave}

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

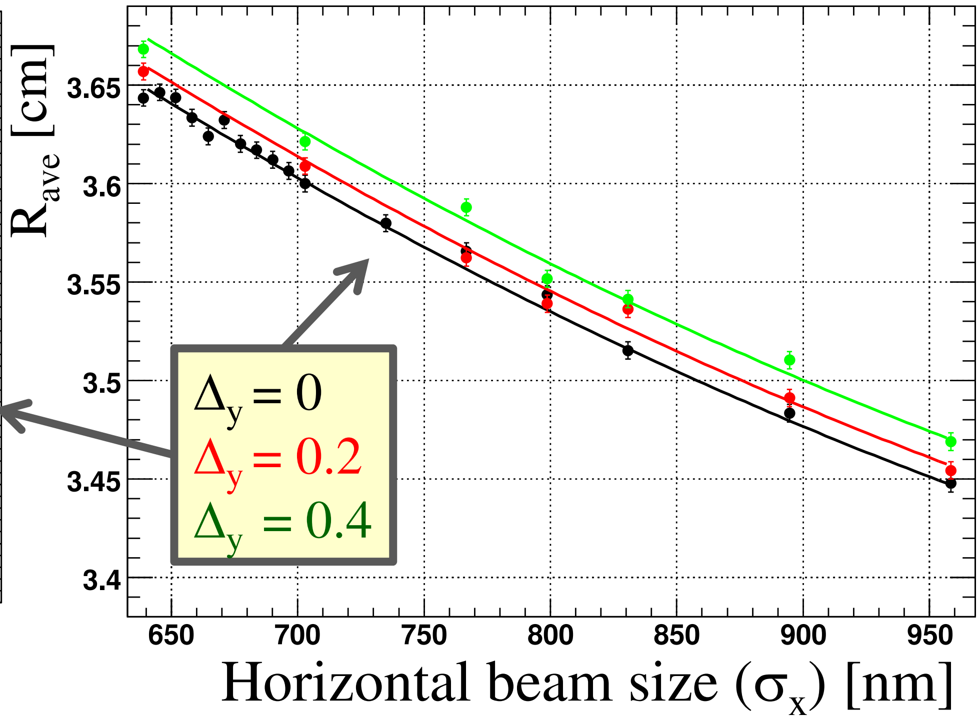
(R_i is the radius of the i-th cell)



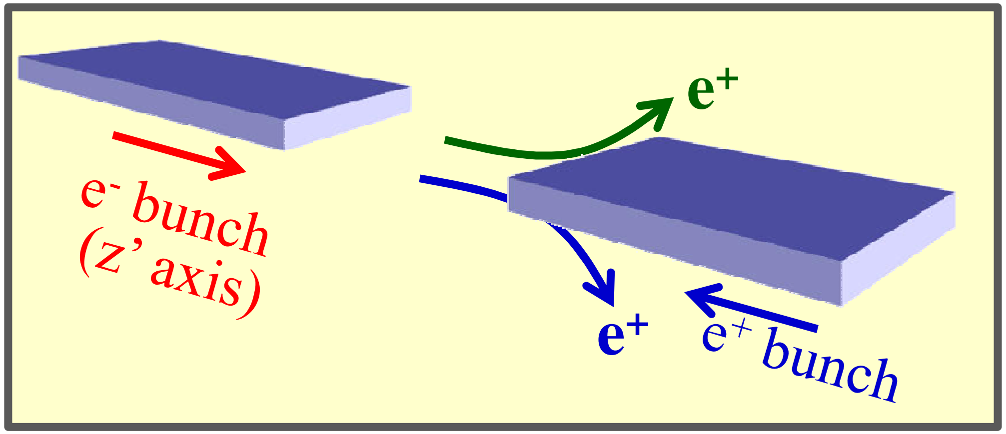
R_{max} [cm] v.s. Horizontal beam size (σ_x) [nm]

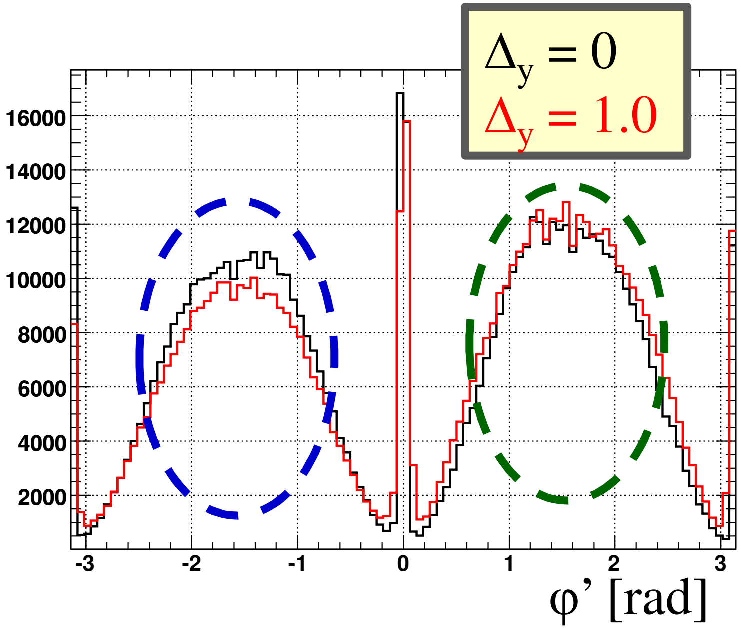


R_{ave} [cm] v.s. Horizontal beam size (σ_x) [nm]



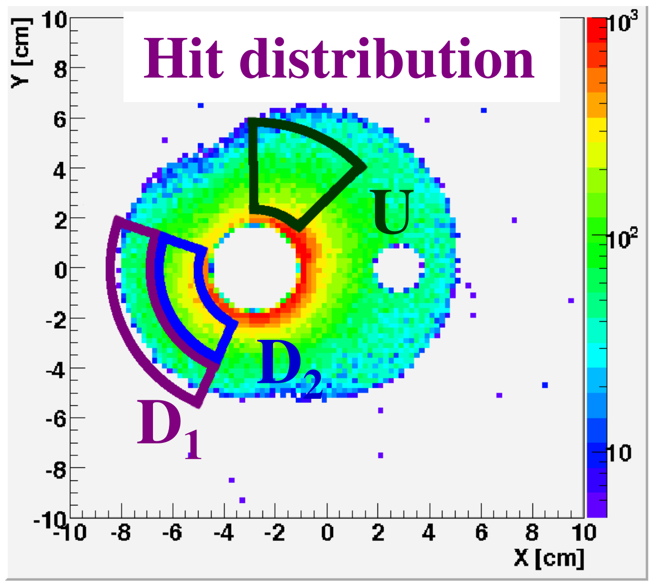
Azimuthal distribution



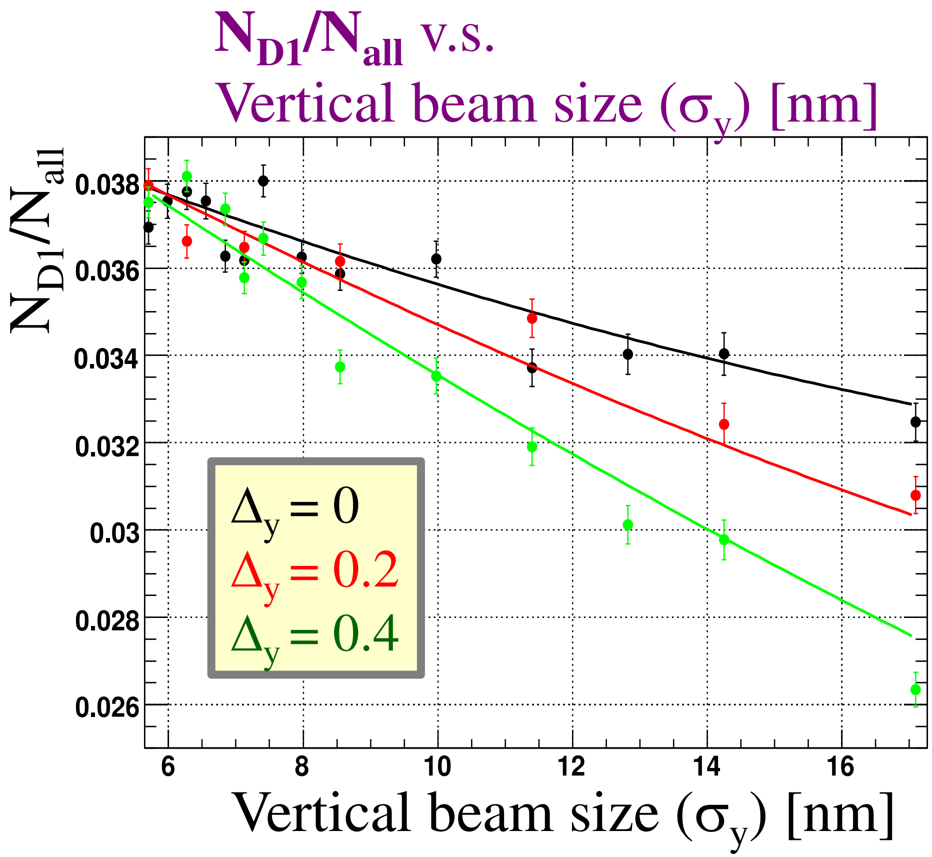


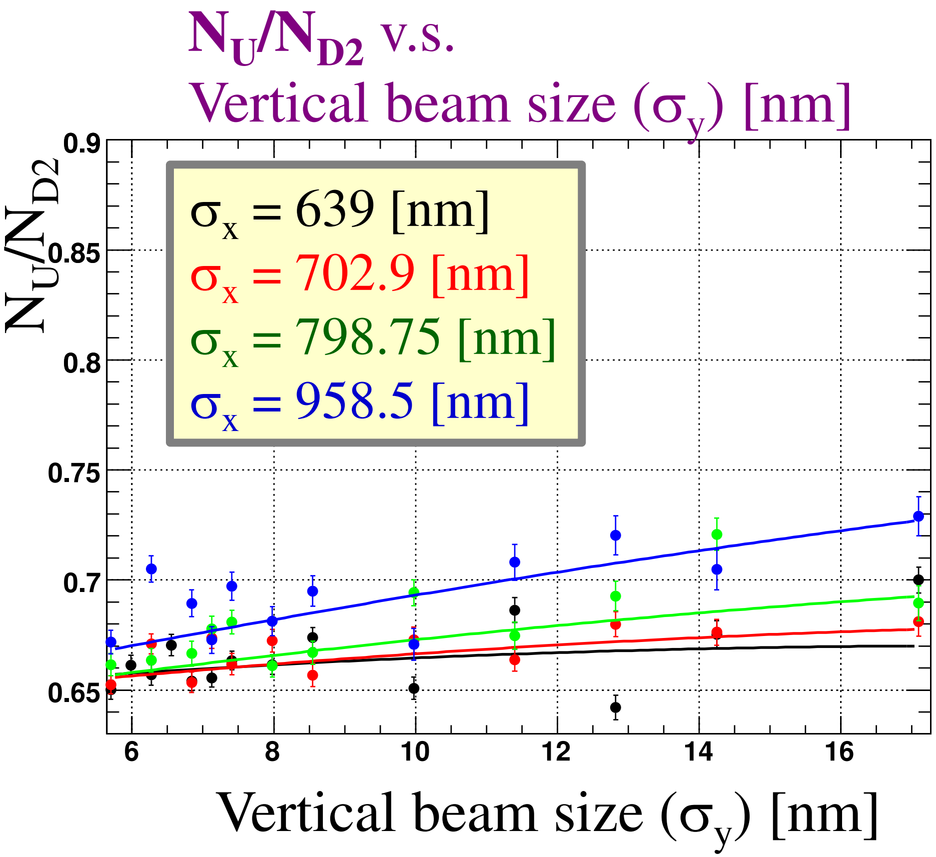
The measurement variable was defined.

$\rightarrow N_U/N_{D2}$



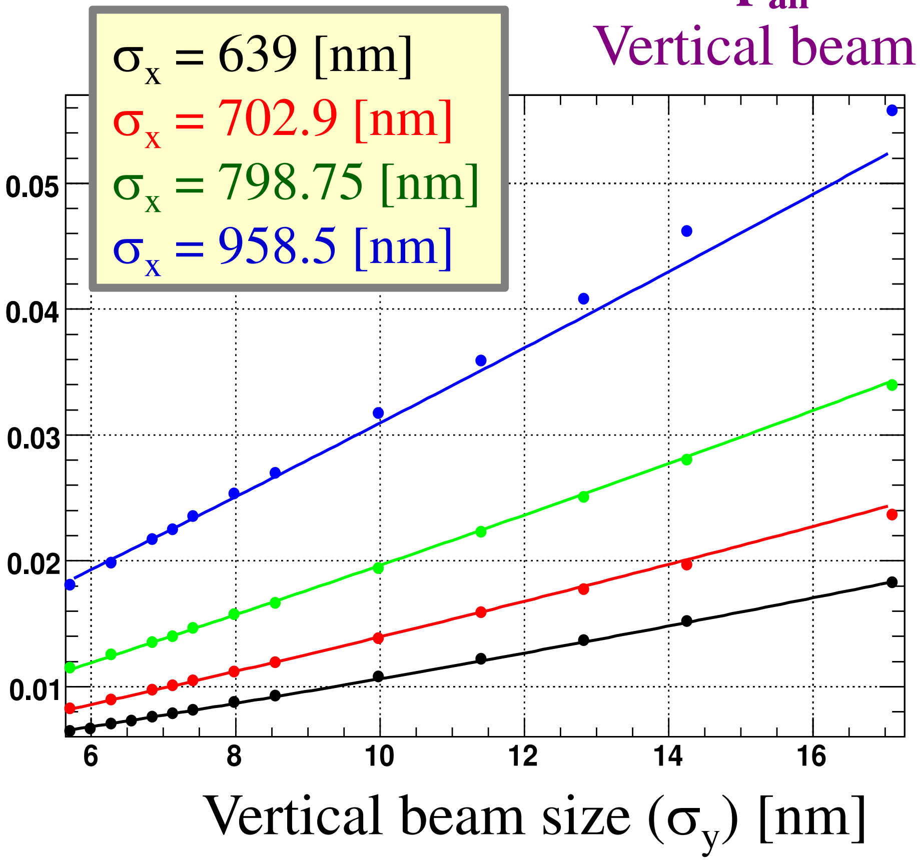
Variable : N_{D1}/N_{all}, N_U/N_{D2}

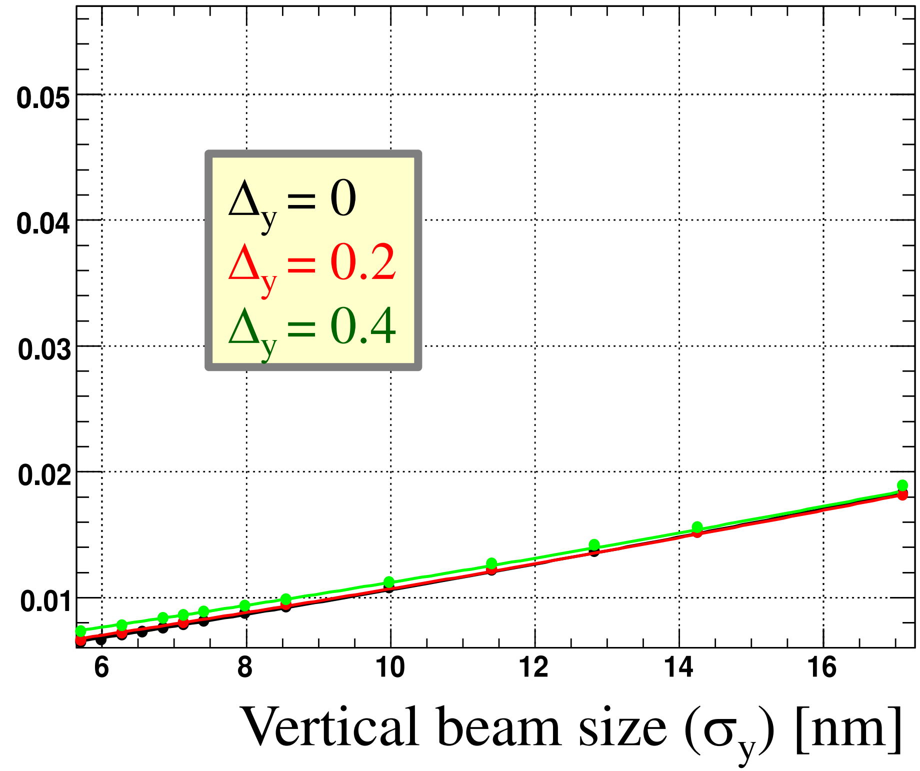




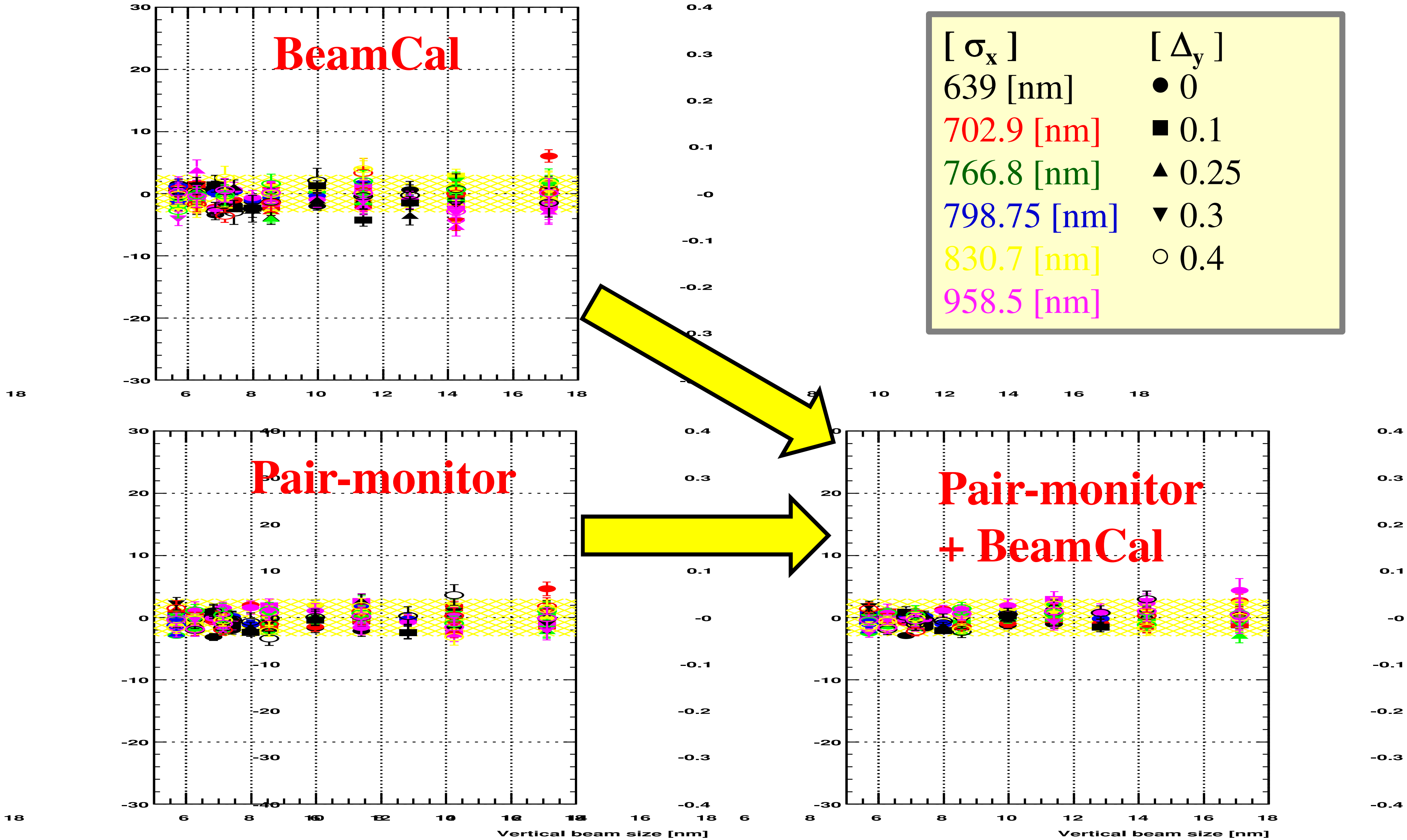
Variable : $1/N_{all}$, $1/Edep_{all}$

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

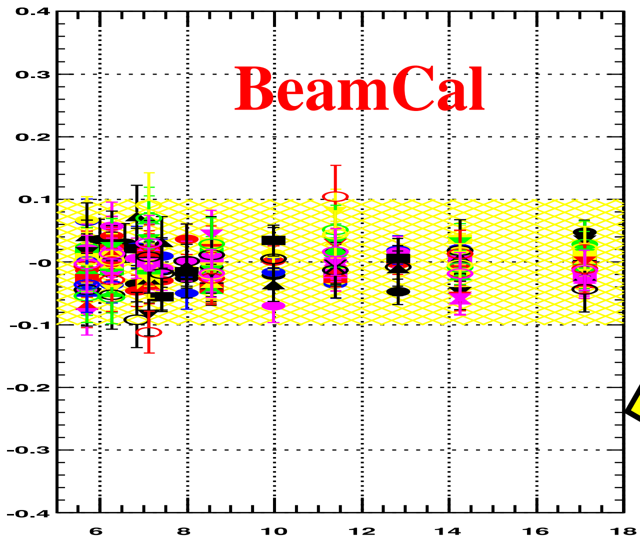




Result (σ_x)



Result (Δ_y)



$[\sigma_x]$	$[\Delta_y]$
639 [nm]	● 0
702.9 [nm]	■ 0.1
766.8 [nm]	▲ 0.25
798.75 [nm]	▼ 0.3
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958.5 [nm]