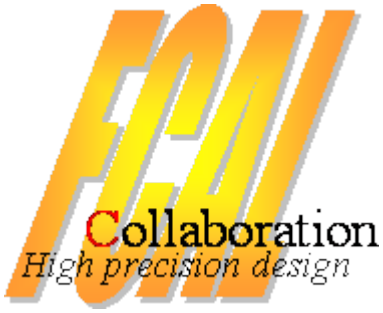

Beam Parameters Determination Using Beamstrahlung Photons and Incoherent Pairs (EUROTEV report summary)

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on behalf of FCAL collaboration

Overview:

- BeamCal and GamCal
  - geometry and purposes
- Beam diagnostics using beamstrahlung
  - method, beam parameters and observables
- Read-out structure optimization
- Single parameter mode
  - Reconstruction capabilities
  - Clusterization and layer selection
- Multi-parameter diagnostics
  - Set of the beam parameters allowing stable reconstruction
  - Correlation between the beam parameters
- Summary

BeamCal and GamCal geometry*

BeamCal:

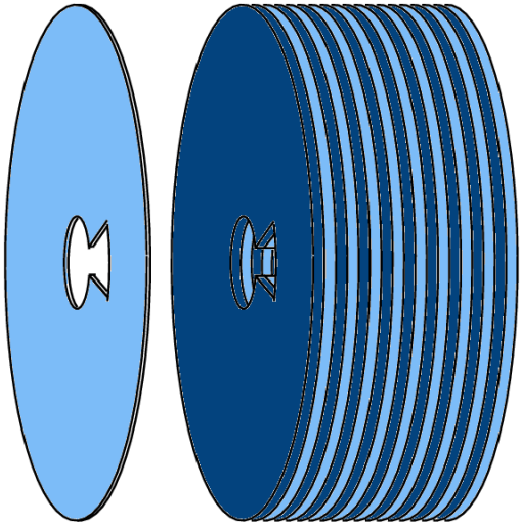
~3.5m from IP

30 tungsten-diamond(GaAs,Si) layers

R_{in} = 20mm, R_{out} = 165mm

5-45 mrad aperture (beamstr pairs)

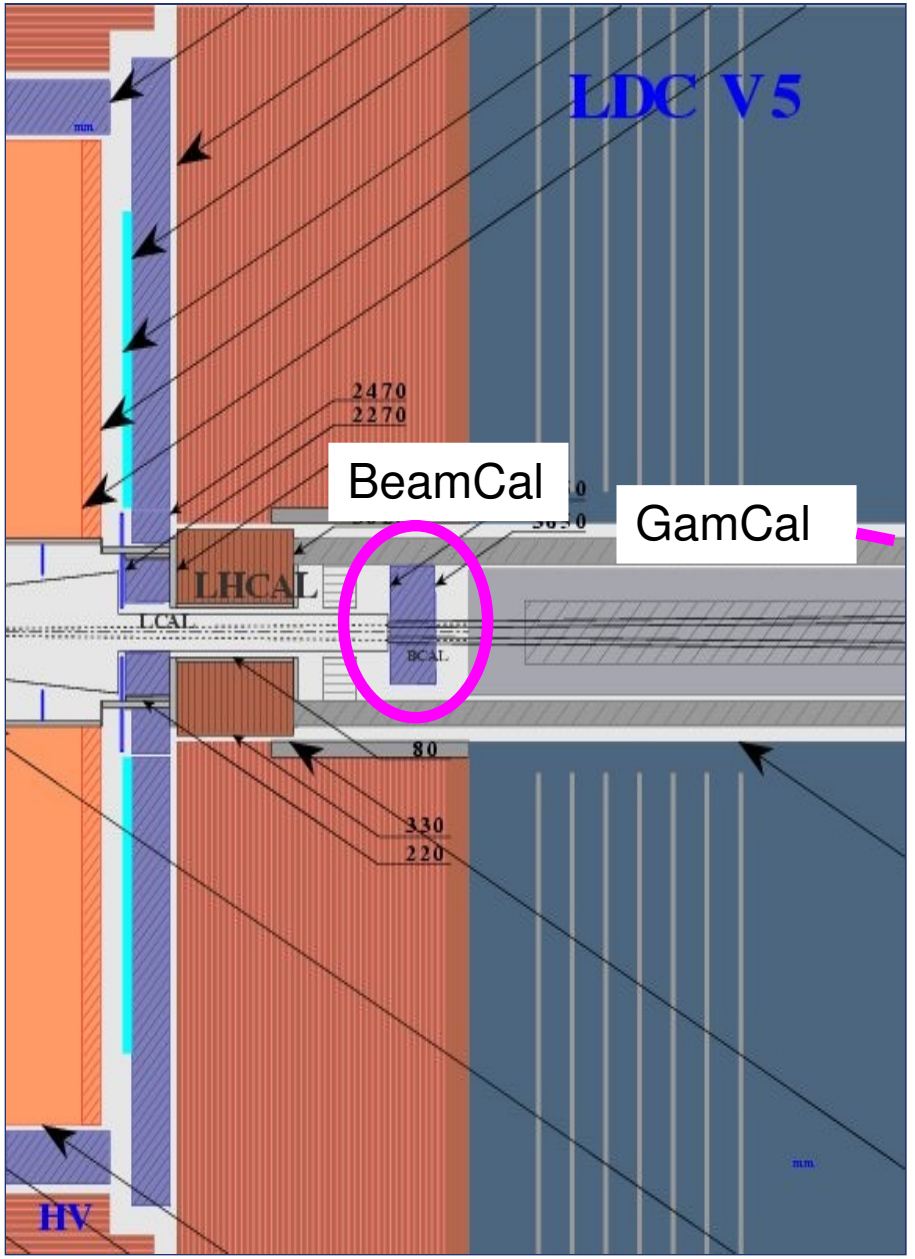
8mm segmentation



GamCal (early design stage):

~180m from IP

<5 mrad aperture (beamstr photons)



* for 14mrad crossing angle

BeamCal purposes:

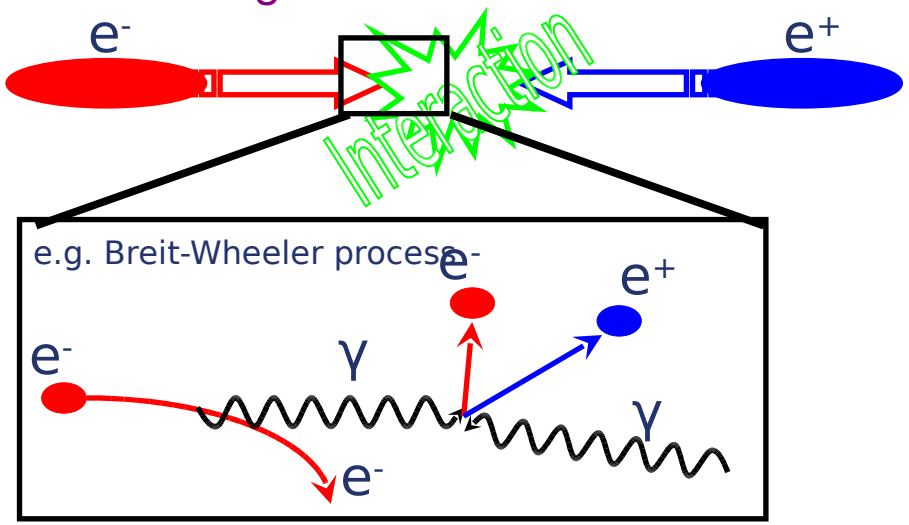
- shielding
  - inner detector – from backscattered particles
  - QD0 magnet – from beamstrahlung pairs
- physics
  - vetoing highly energetic electrons at lowest angles, hermeticity
- luminosity monitoring
  - + beam diagnostics using beamstrahlung pairs energy deposition

GamCal purposes:

- luminosity monitoring
  - determination of the beamstrahlung photons spot geometry
  - the beamstrahlung photons energy spectrum measurement
- effective at lower beam currents (down to 10% of nominal)

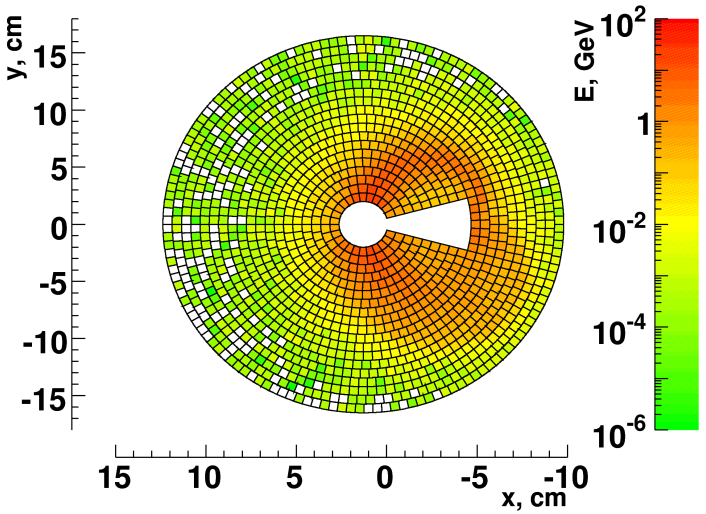
beam diagnostics: beamstrahlung

Beamstrahlung:



The shape of the energy deposition is strongly determined by bunch parameters at the collision, therefore these data can be used to reconstruct them.

15k e^+e^- per BX; 10-20TeV total en.dep:



Reading out signal from all 45k sensor cells will result in 10TBit/s data rate ->

read-out structure optimization is required to avoid need for expensive high speed links.

Input observables

- Total energy
- Radial moments
- E_γ
- Up-Down imbalance
- Right-Left imb.
- Diagonal imb.
- *N/E*
- *Phi moments*
- *Forw-Back asymm.*
- (No thrust-related) *

Beam parameters:

σ – bunch sizes

ε – emittances

$\Delta x, \Delta y$ – beam offsets

W – waist shifts

α – bunch rotations

ϕ – profile rotations

N – number of particles

* the thrust observables are not used since the shape of the energy distribution have no definite thrust direction. Also, thrust calculation is time consuming.

beam diagnostics method

Fit the simulated observables vs. beam parameters → get slopes → 1st order Taylor coefficients matrix A:

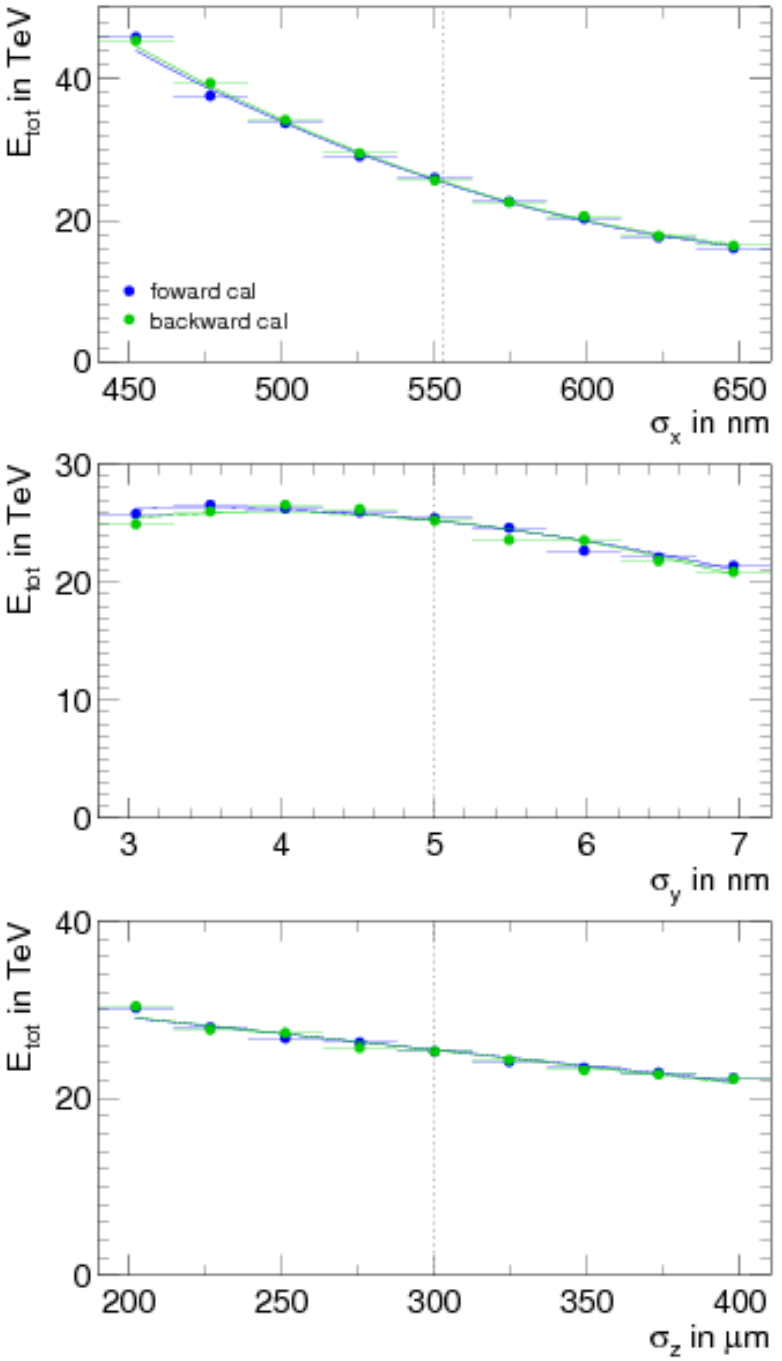
$$\begin{pmatrix}\text{Observables}\end{pmatrix} = \begin{pmatrix}\text{Observables}\end{pmatrix}_{nom} + \begin{pmatrix}\text{Taylor}\\ \text{Matrix}\end{pmatrix} * \begin{pmatrix}\Delta\,\text{BeamPar}\end{pmatrix}$$

Moore-Penrose pseudo-inverse:

$$MP_{inv} = A^T(AA^T)^{-1}$$

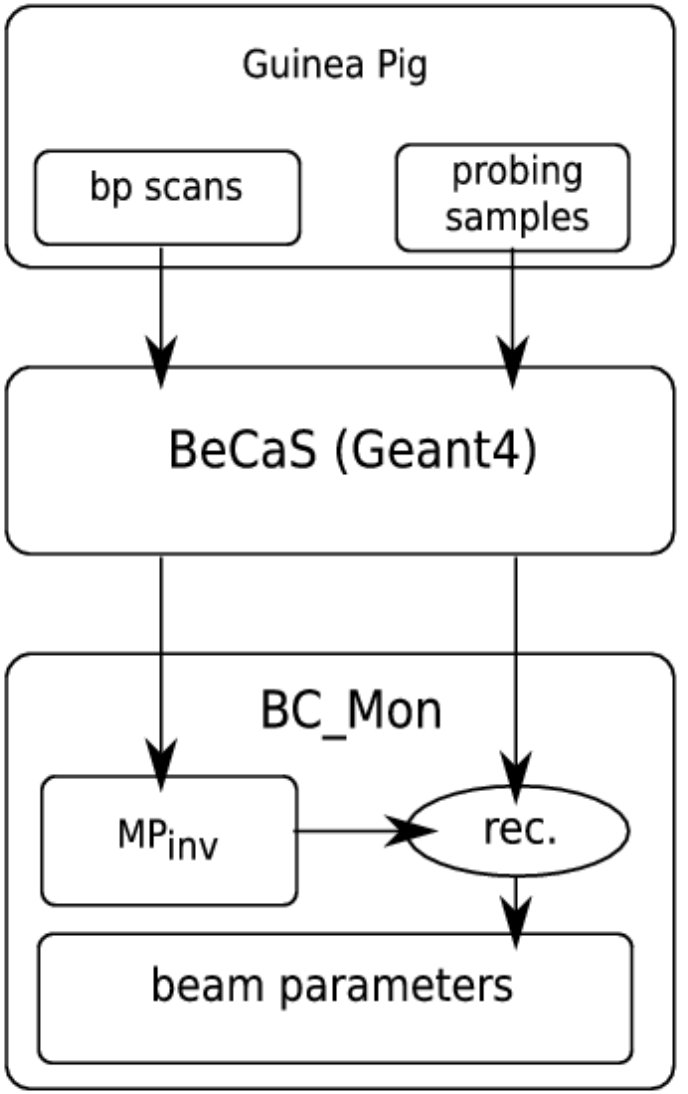
Reconstruct the beam parameters from measured observables

$$BP_{rec} = MP_{inv} \times Obs_{meas}$$



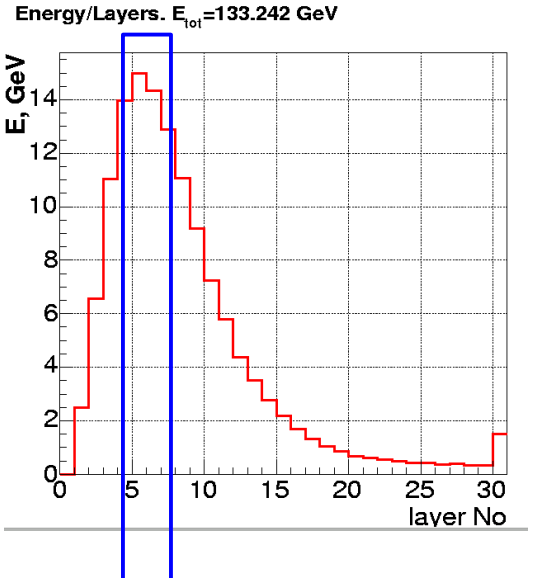
beam diagnostics simulation chain

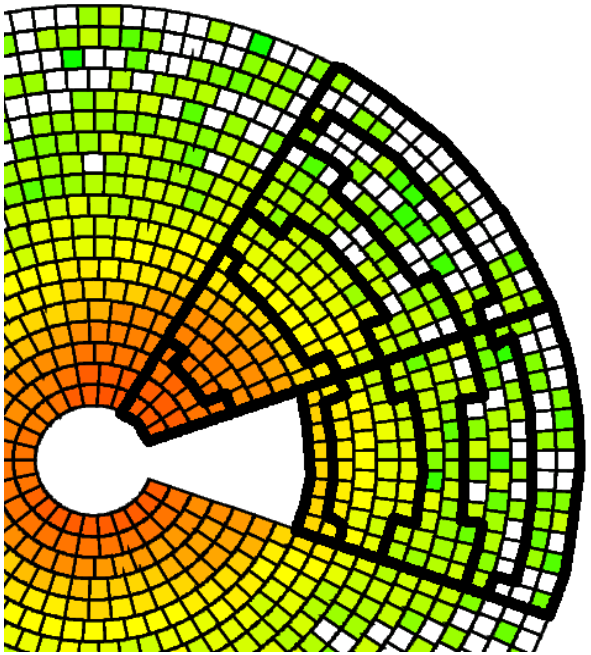
- generate the beam parameters scans and probing samples using Guinea Pig
- obtain the showered energy distributions in the Geant4 simulation
- calculate observables and construct Moore-Penrose inverse
- use the MP_{inv} to reconstruct the beam parameters
- calculate reconstruction resolution

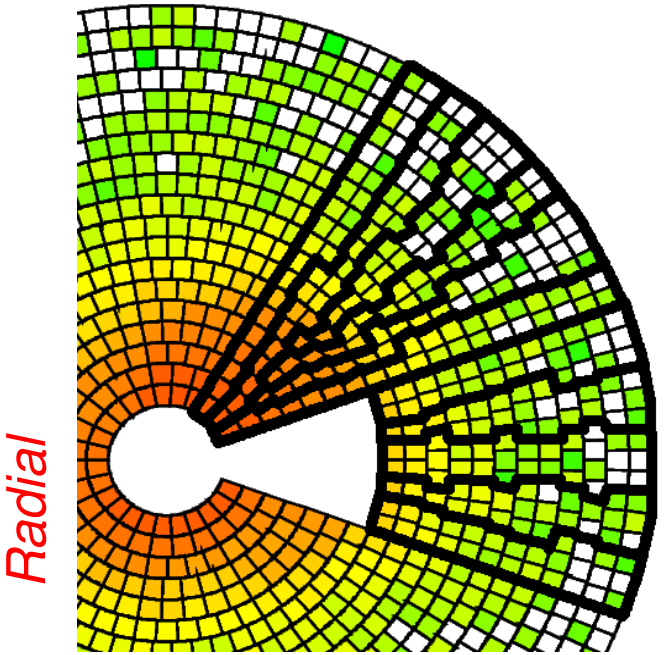


read-out structure optimization

- select signal layers
  - in the shower maximum → higher statistics
- cluster the pads
  - radial and azimuthal grouping
  - manual definition of group's radii and angles
  - 32 pads in group → one chip with 32 input channels serves one group
  - cross talk issues







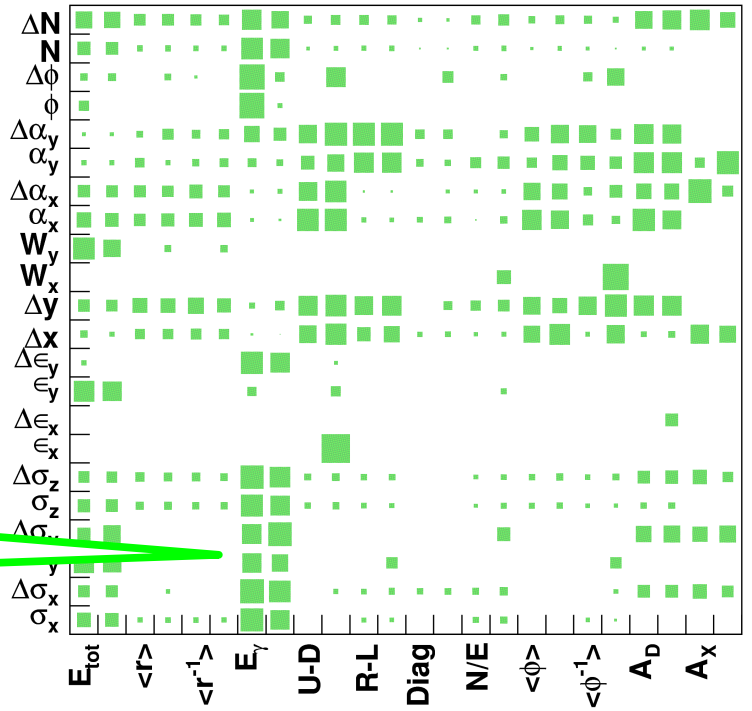
Only one BP is considered to deviate and influence the energy distribution and is reconstructed from it. The rest parameters are at their nominal values.

BP	unit	nom.	14mrad, no E_γ		14mrad, with E_γ	
			μ	σ	μ	σ
σ_x	nm	655	654.7	2.8	653.7	1.3
σ_y	nm	5.7	5.63	0.47	5.61	0.39
σ_z	μm	300	305.7	3.6	300.8	1.7
Δy	nm	0	-1.42	0.81	-0.56	0.81

10%-15% statistical error on resolution value.

qualitative representation of the observables' significance for bp reconstruction:

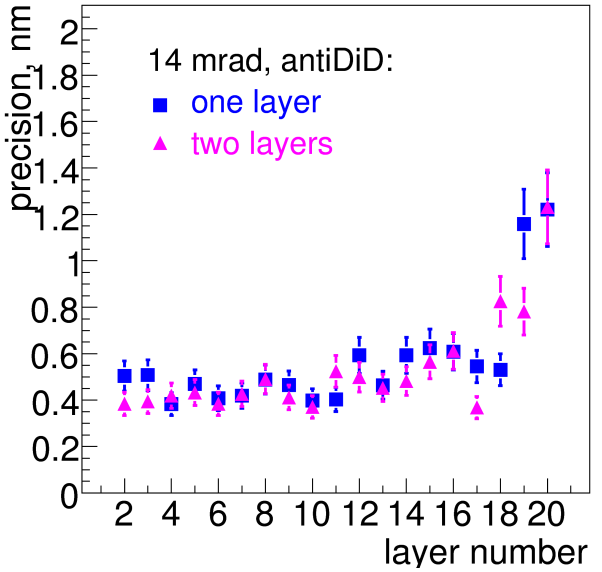
$$\text{signif.} = \frac{\text{Taylor elements}}{\text{bp resolution x obs.st.dev.}}$$



High significance of photon energy observable for bunch sizes.

Layer selection:

the resolution degrades after about 17th lr, being relatively constant before.



Pads grouping (reconstruction based on 6th layer):

BP	unit	read-out scheme			
		detailed	azim.	rad.	rad.(8bit)
σ_x	nm	3.11	3.29	3.5	3.34
σ_y	nm	0.41	0.51	0.47	0.53
σ_z	μm	4.27	5.58	4.28	3.94
Δy	nm	0.88	0.91	0.95	0.93

10%-15% statistical error on resolution value.

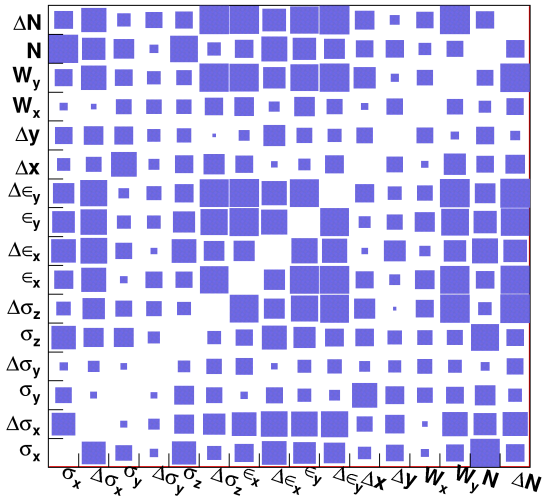
multiparameter mode

A full set of parameters cannot be reconstructed
→ we can use only part of them:

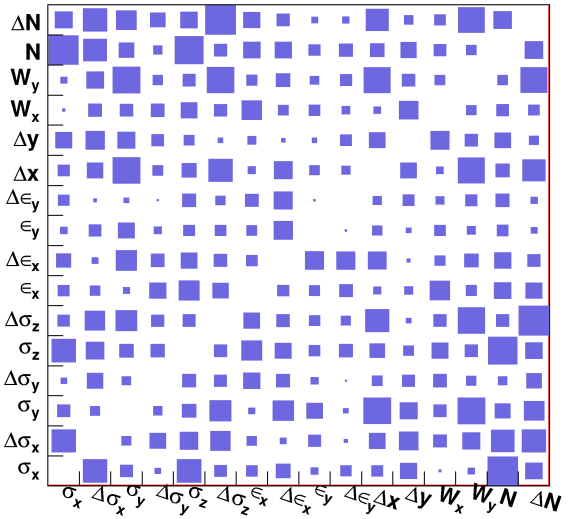
- Bunch sizes
- Emittances
- Beam offsets
- Waist shifts
- ~~Bunch rotations~~
- ~~Profile rotations~~
- Number of particles

BP	unit	nom.	14mrad, with E_γ	
			sngl.par	multi-par
σ_x	nm	655	1.3	43
σ_y	nm	5.7	0.39	2.7
σ_z	μm	300	1.7	31
Δy	nm	0	0.81	1

Quite low (!) precision for most of the beam parameters due to the correlations between them:

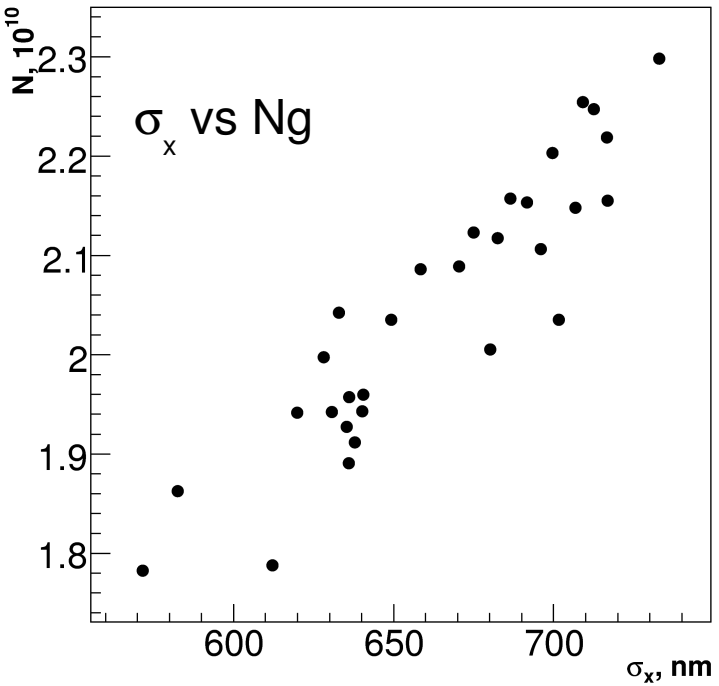


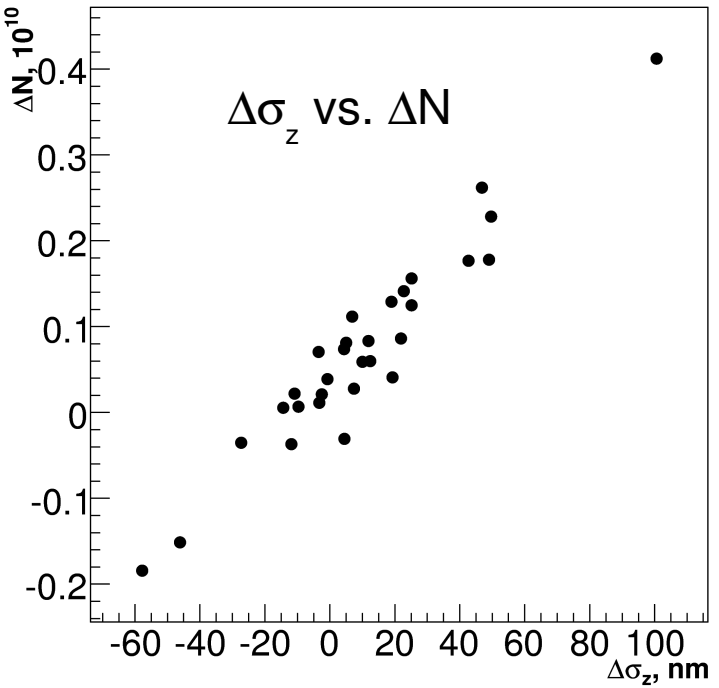
Fix emittances from external measurement tools with 10% resolution spread.



correlations in multiparameter mode

Scatter plots of correlated beam parameters from probing data samples:





One can add more observables (beamstrahlung photons energy spectrum) to reduce the correlations and/or substitute the correlated couples of parameters with their combinations (linear in these cases) and reconstruct the combinations with better precision.

summary

- The single parameter mode allows to reach sub-nm precision in measurement of vertical beam sizes σ_y
- In multi-parameter mode some of the beam parameters are highly correlated and cannot be reconstructed as precisely as in single parameter mode. They have to be substituted by their combinations.
- Inclusion of beamstrahlung photons energy measurement as an observable allows to increase measurement precision of the bunch sizes.
- Read-out optimization studies showed that method is very stable relative to the reduction input data amount and the beam parameters can be reconstructed using data from only one layer with pad clustered into 32 channels groups.
- This report summarizes the studies on beamdiagnostics possibilities which are submitted as a EUROTEV report.