FLUM
Beam Parameters Determination and Fast Feedback Using Beamstrahlung Photons and Pairs
(EUROTEV report summary)

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- The Devices: BeamCal and GamCal
- geometry and purposes
- Beam Diagnostics Using Beamstrahlung
- Fast luminosity estimate
- beam parameters, observables and method
- Single Parameter Mode
- Reconstruction capabilities
- Pad grouping and sensitive layers selection
- Multi-parameter Mode
- Set of beam parameters allowing stable reconstruction
- Correlation between beam parameters
- FE Electronics Prototyping
- Summary

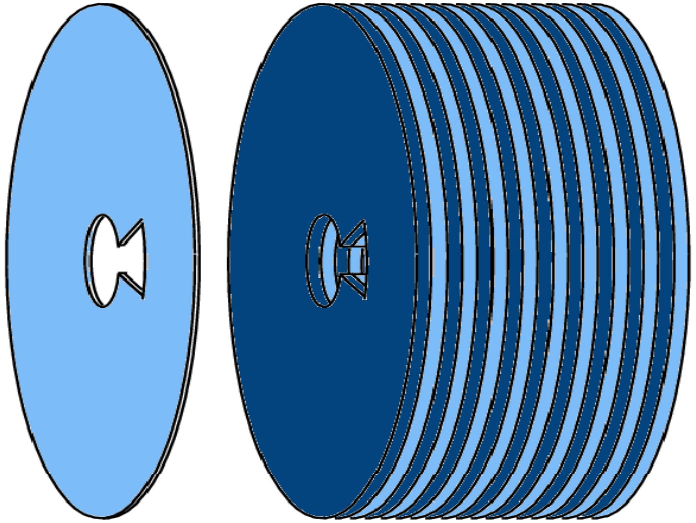
Part of FCAL:

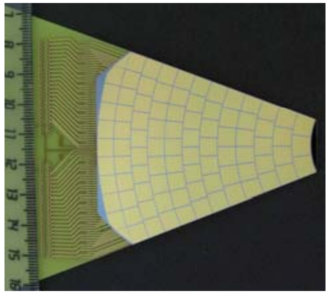
Contributions from A. Abuslemen (Stanford), B. Morse (BNL), A. Stahl (Aacheen) and M. Zeller (Yale).

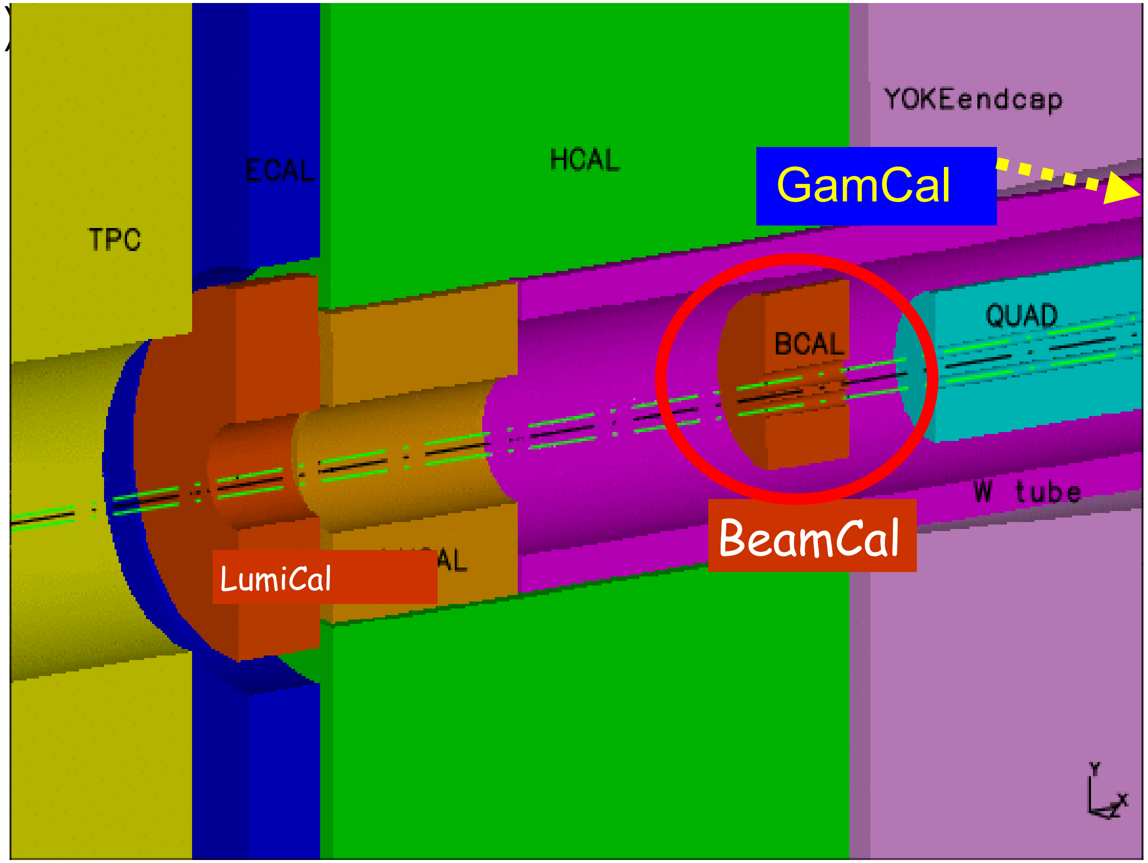
BeamCal and GamCal geometry (14 mrad crossing angle)

BeamCal:

- ~3.5m from IP
  - 30 tungsten-diamond(GaAs,Si) layers
  - R_{in} = 20mm, R_{out} = 165mm
  - 5-45 mrad aperture (beamstr pairs)
  - 8x8 mm^2 pads







BeamCal and GamCal geometry

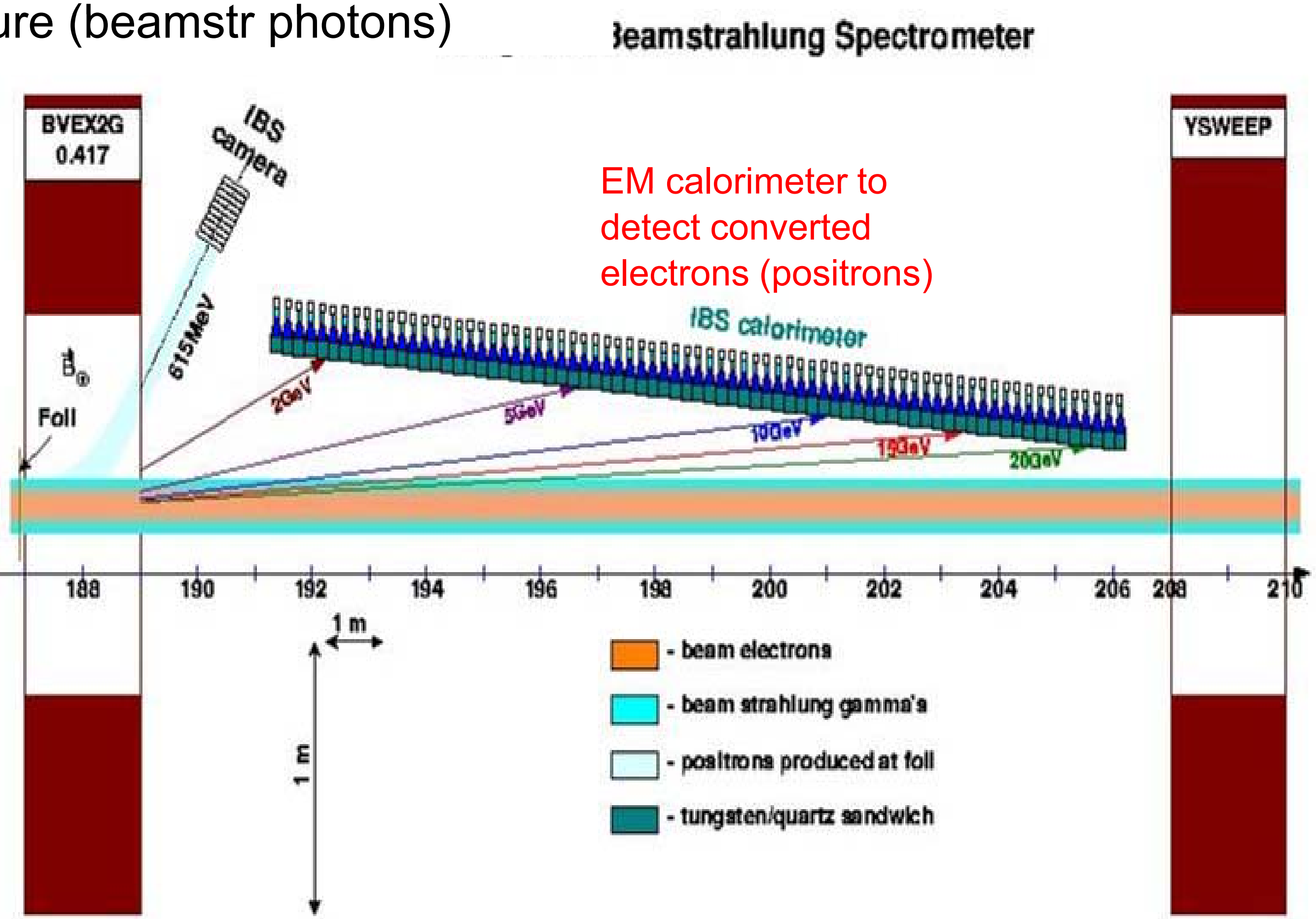
GamCal: (early design stage):

~ 180m from IP

< 5 mrad aperture (beamstr photons)

Thin foil to convert beamstrahlung photons

EM calorimeter to detect converted electrons (positrons)



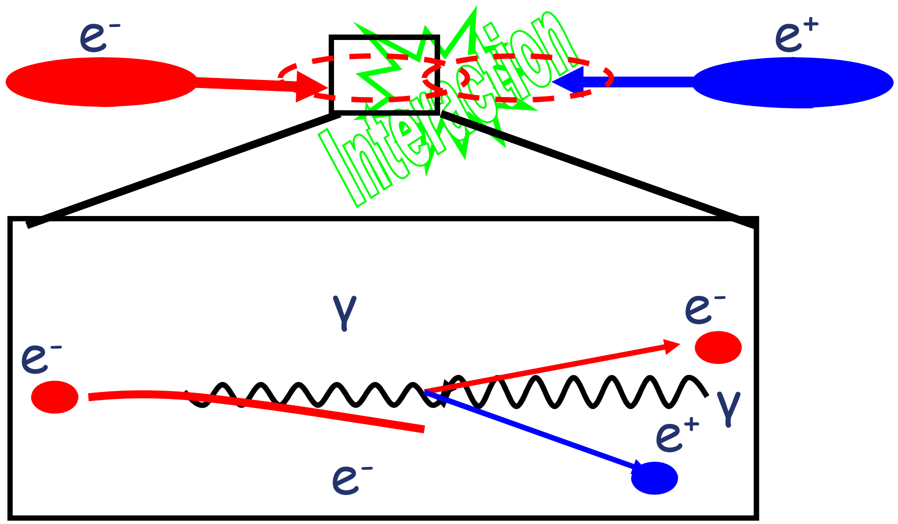
BeamCal:

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

GamCal:

- fast luminosity monitoring, extended to lower beam currents
  - determination of the beamstrahlung photons intensity and energy
- improve beam diagnostics

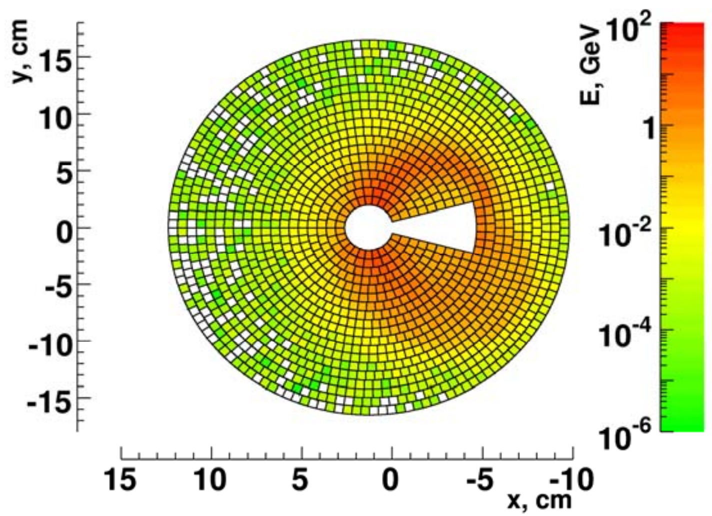
Beamstrahlung:



Pinch effect - creation of beamstrahlung
N_{phot} ~ O(1) per bunch particle
δ_{BS} ~ O(1%) energy loss (~10^8 TeV)

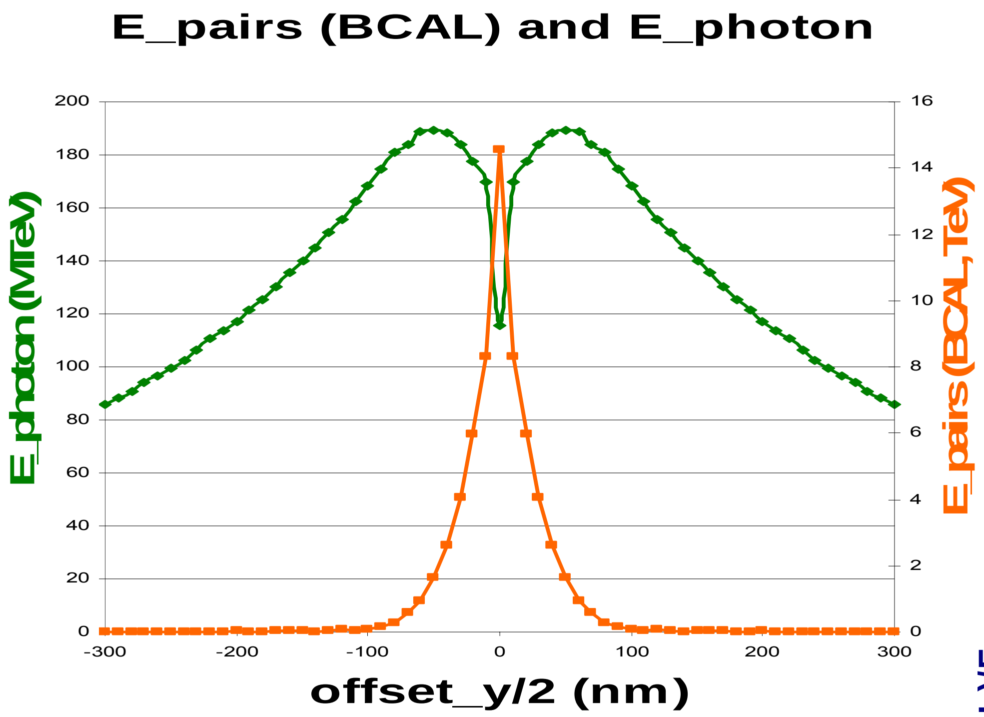
A fraction of the photons creates e^+e^- pairs, (~10^2 TeV)

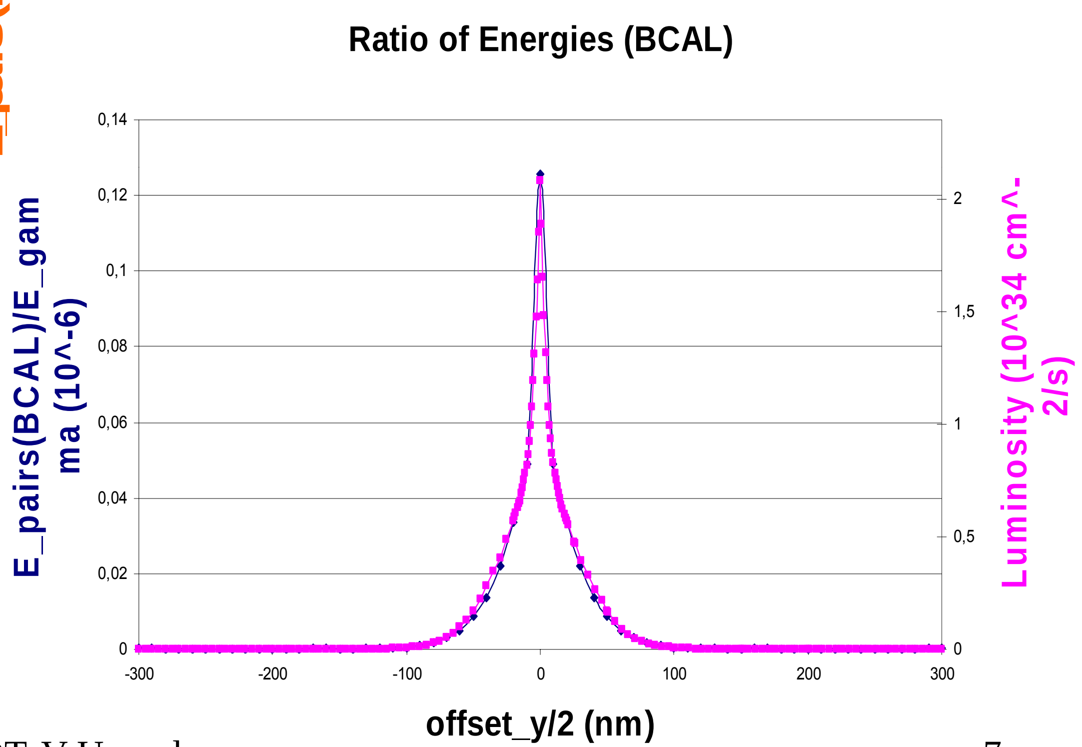
Pair depositions on BeamCal: 15k e^+e^- per BX; 10-20TeV energy



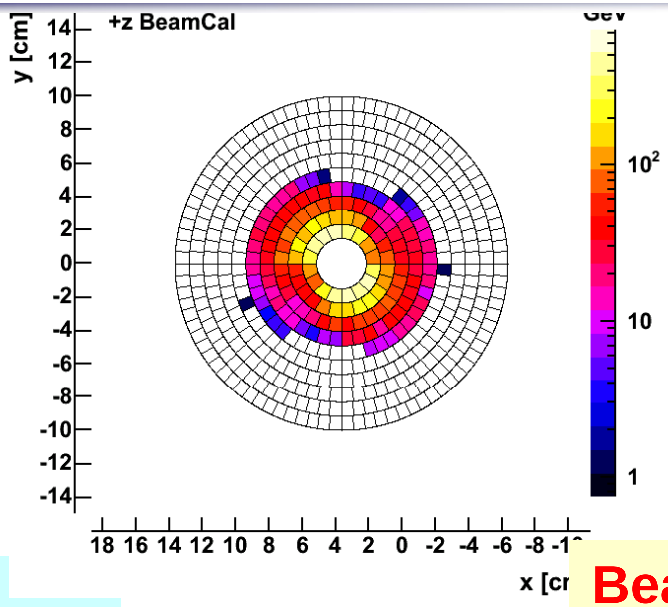
The amount and spectrum of the beamstrahlung photons and of e^+e^- pairs strongly depends on beam parameters. e.g. from the depositions on BeamCal
A bunch-by-bunch luminosity estimate and beam parameter determination is feasible

Comparing the total energies on BeamCal and GamCal a bunch-by-bunch luminosity estimate is available, e.g. offset in y:





We can do more:



Input observables

- Total energy
- Radial moments
- E_γ
- Up-Down imbalance
- Right-Left imb.
- Diagonal imb.
- N/E
- Phi moments
- Forw-Back asymm.

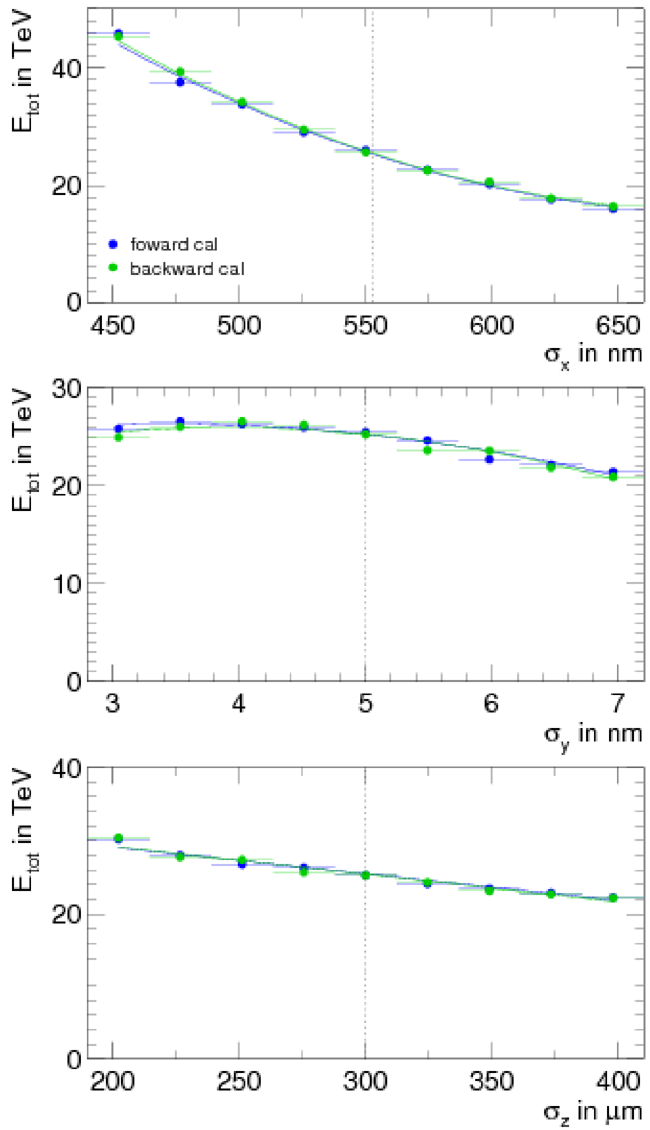
→

Beam parameters:

- σ_{xyz} - bunch sizes
- ε_{xy} - emittances
- Δx, Δy - beam offsets
- W - waist shifts
- α_{xy} - bunch rotations
- ϕ - profile rotations
- N - number of particles

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

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



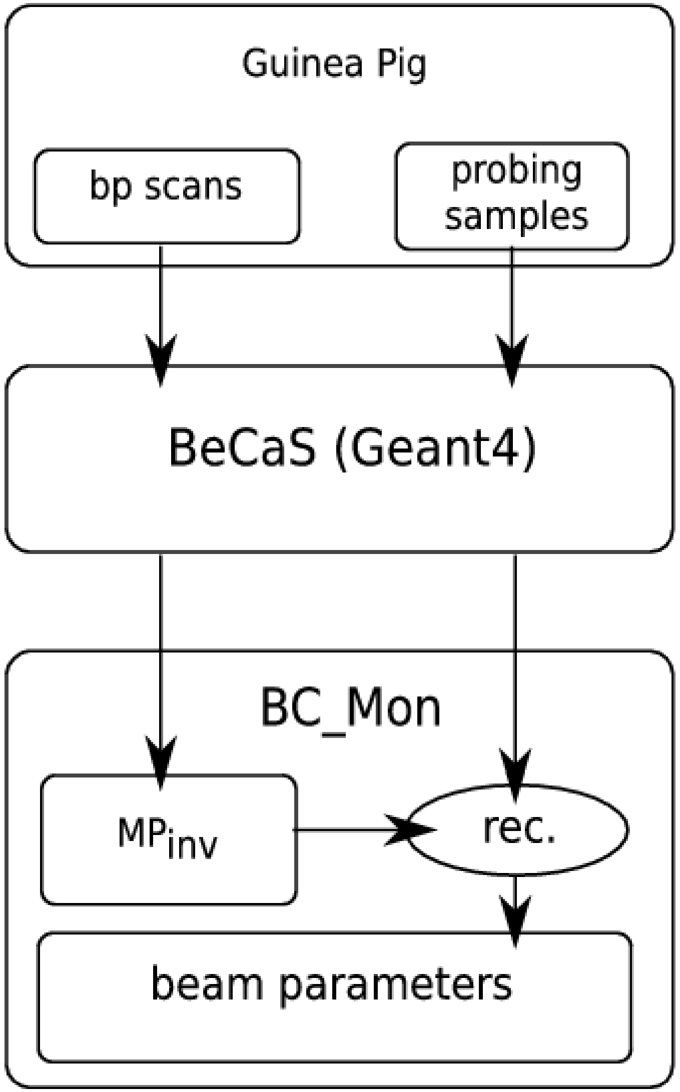
Moore-Penrose pseudo-inverse:

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

Reconstruct the beam parameters from measured observables

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

- generate beamstrahlung and pairs as a function of a certain beam parameter using the GuineaPig generator
- pass them through the Geant4 simulation of BeamCal to obtain the energy depositions on the sensors of BeamCal
- calculate observables and determine the (linear) slope of the Taylor expansion, construct the Moore-Penrose inverse
- use the MP_{inv} to reconstruct the beam parameters from the probing samples
- calculate reconstruction resolution from the spread of the results



Only one beam parameter (BP) is measured. The remaining parameters are at their nominal values.

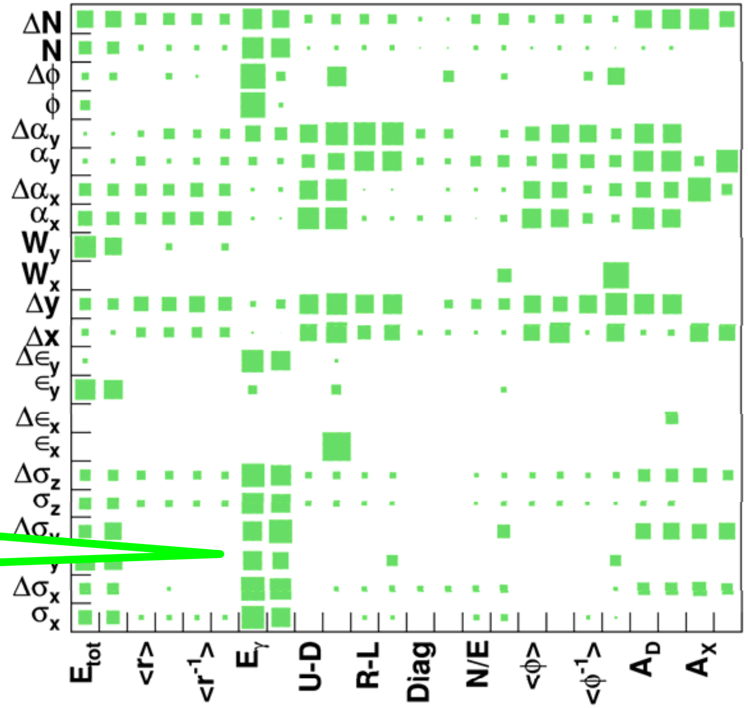
Examples:

BP	unit	nom.	14mrad, no E_γ		14mrad, with E_γ	
			mean	σ	mean	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
Δx	nm	0	-5	10	-5	10

statistical error on few % level (or below)
Sub-nm precision for σ_y

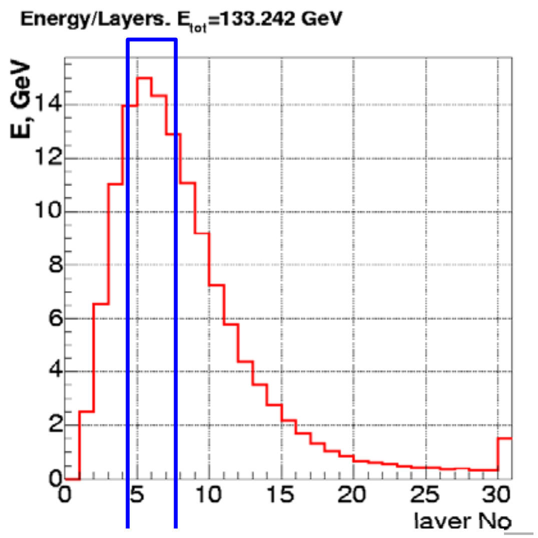
Improvement using energy measured in GamCal qualitative representation of the observables' significance for beam parameter reconstruction:

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

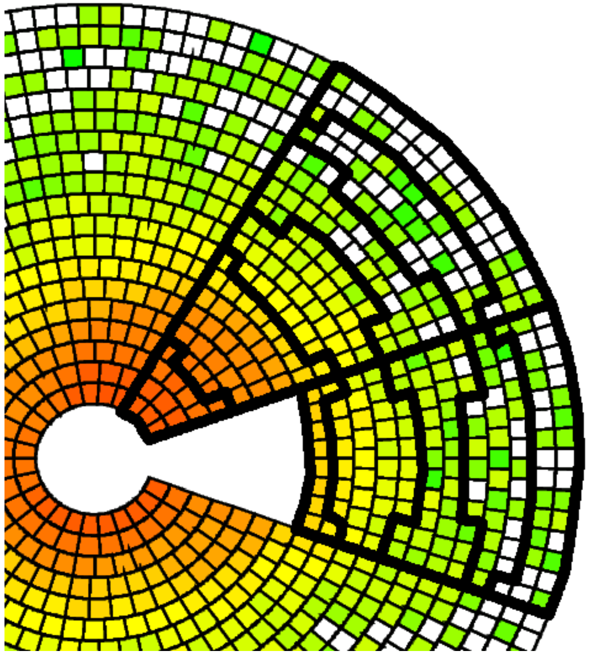


High significance of photon energy observable for bunch sizes.

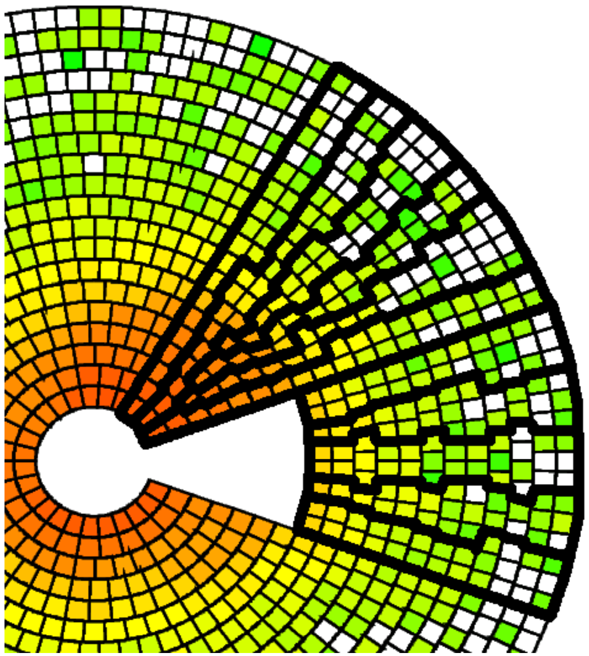
- use only a few sensor layers
  - in the shower maximum → less fluctuations
- grouping of pads
  - radial and azimuthal grouping
  - manual definition of group's radii and angles
  - 32 pads in group → one chip with 32 input channels serves one group
  - cross talk issues



Radial



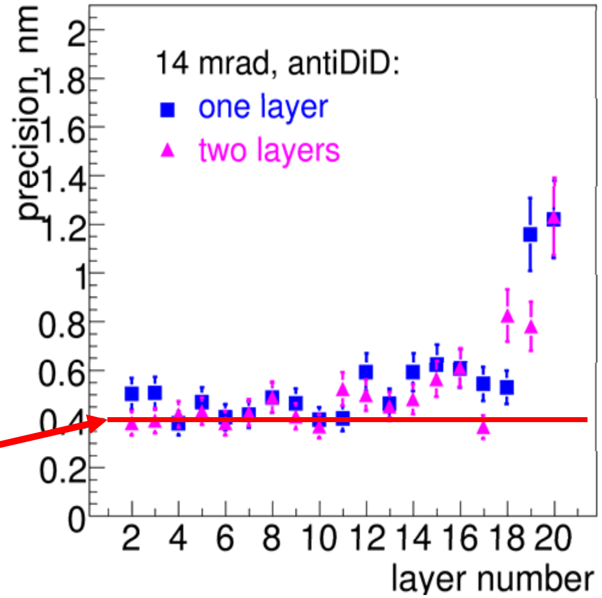
Azimuthal



Readout only of 1 or 2 sensor layers:

Using 2 layers in the 'shower maximum' range gives almost the same resolution as the full calorimeter, e.g. for σ_y

Full calorimeter readout.



Using grouped pads (reconstruction based on 6th layer):

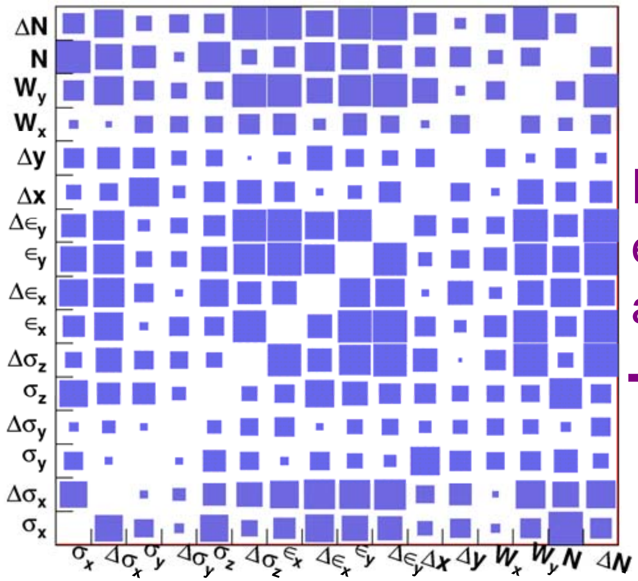
BP	unit	read-out scheme			
		detailed	radial	azimuthal	rad.(8bit)
σ_x	nm	3.11	3.29	3.5	3.34
σ_y	nm	0.41	0.51	0.47	0.53
σ_z	μm	4.27	5.58	4.28	3.94
Δy	nm	0.88	0.91	0.95	0.93

Slight deterioration of the resolution ,O(10%)

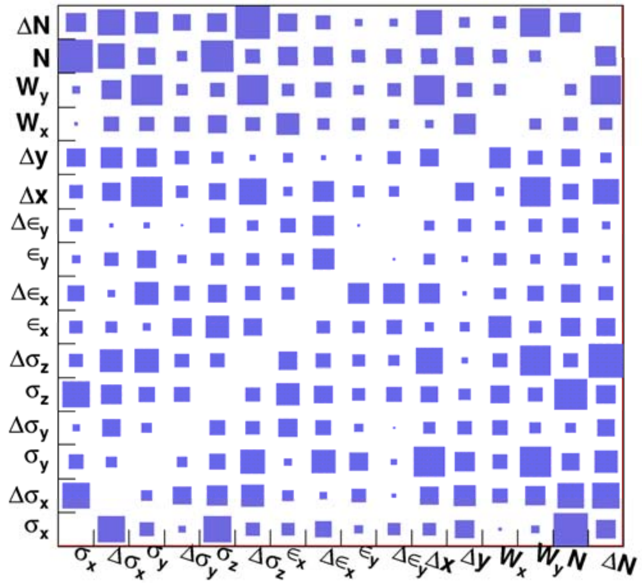
A full set of parameters cannot be reconstructed
→ we can use only part of them:

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

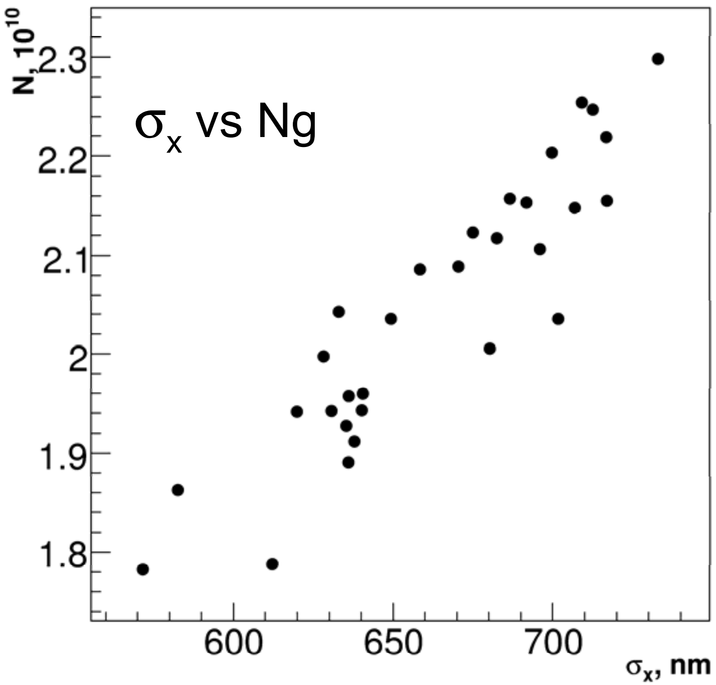
BP	unit	nom.	14mrad, with E_γ	
			sngl.par	multi-par
σ_x	nm	655	1.3	43
σ_y	nm	5.7	0.39	2.7
σ_z	µm	300	1.7	31
Δy	nm	0	0.81	1

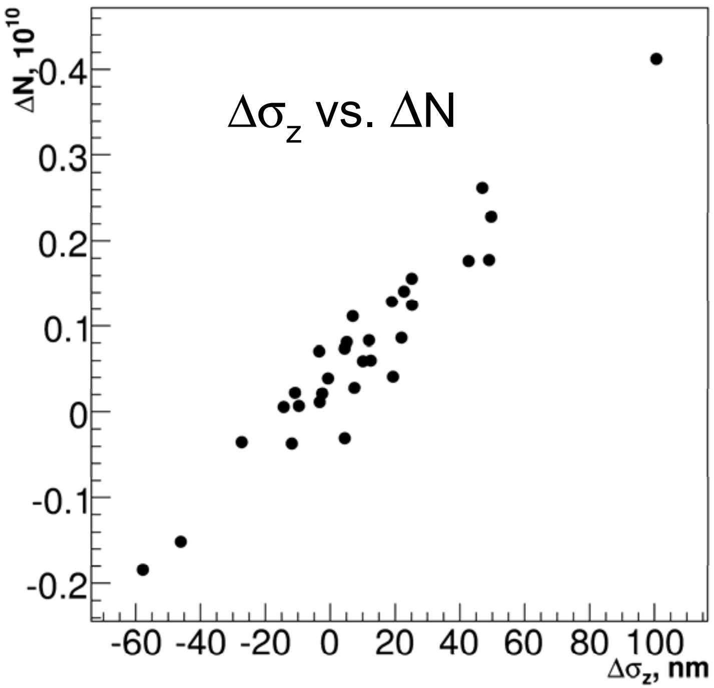


Fix e.g. emittances from external measurement; assume 10% precision



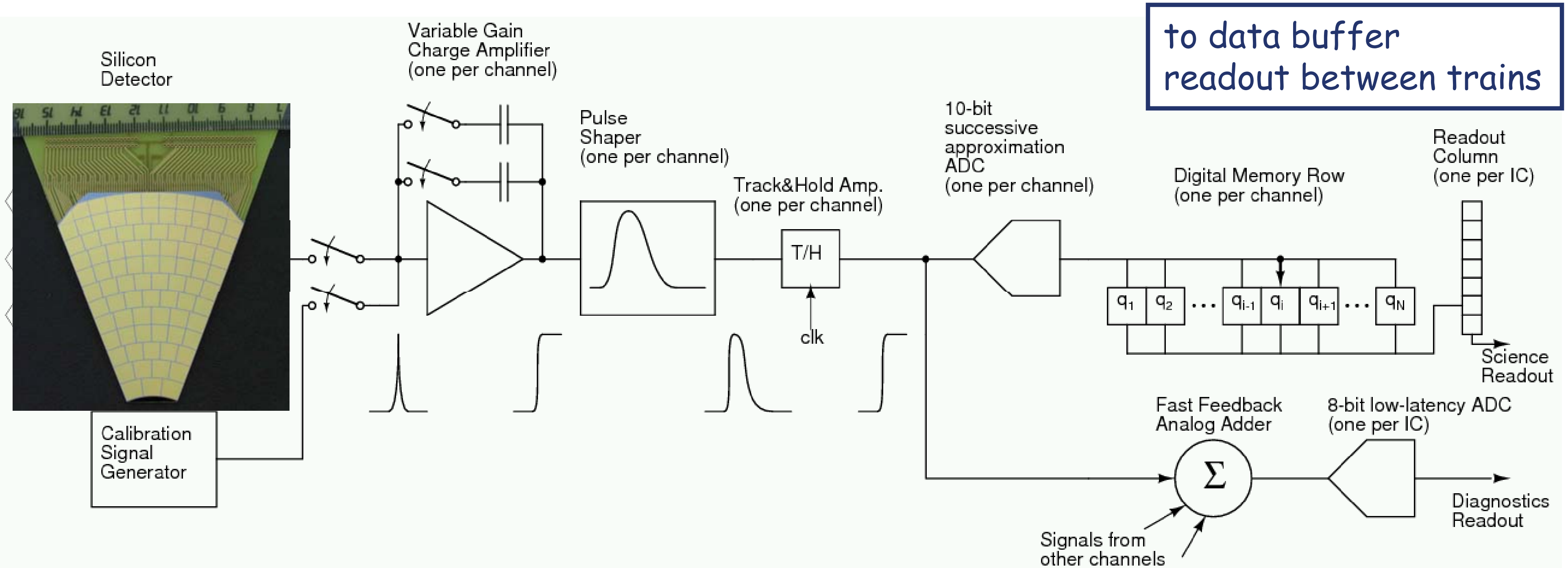
Scatter plots of correlated beam parameters from probing data samples:





One can add more observables (beamstrahlung photons energy spectrum) to reduce the correlations and/or substitute the correlated of parameters by combined quantities.

Front-end electronics design



to data buffer
readout between trains

to feedback system
(FONT)
real time + low latency!

- Dual gain front-end
- Successive approximation ADC 1/ch
- Digital memory to store information of 1 train/ch
- Analog addition of 32 ch for fast feedback, 8 bit digitisation
- First prototypes in octobre!

BeamCal and GamCal are invaluable tools for a fast luminosity estimate and for the determination of beam parameters

- The single parameter mode allows to reach precision of of a few % in in the measurement of beam parameters (per BX) using BeamCal and GamCal.
- In multi-parameter mode some of the beam parameters are highly correlated. They have to be substituted by combinations or additional information from other diagnostics systems are used.
- Read-out optimization studies have shown that only a few sensor planes are needed for beam parameter measurements.
- Grouping of pads for the fast readout leads only to a slight deterioration of the resolution.
- FE electronics to accommodate the fast readout of clustered pads is under design.

Be aware: beam parameter determination is very sensitive to the magnetic field between IP and BeamCal !