TESLA Forward Calorimeters
Recent Developments

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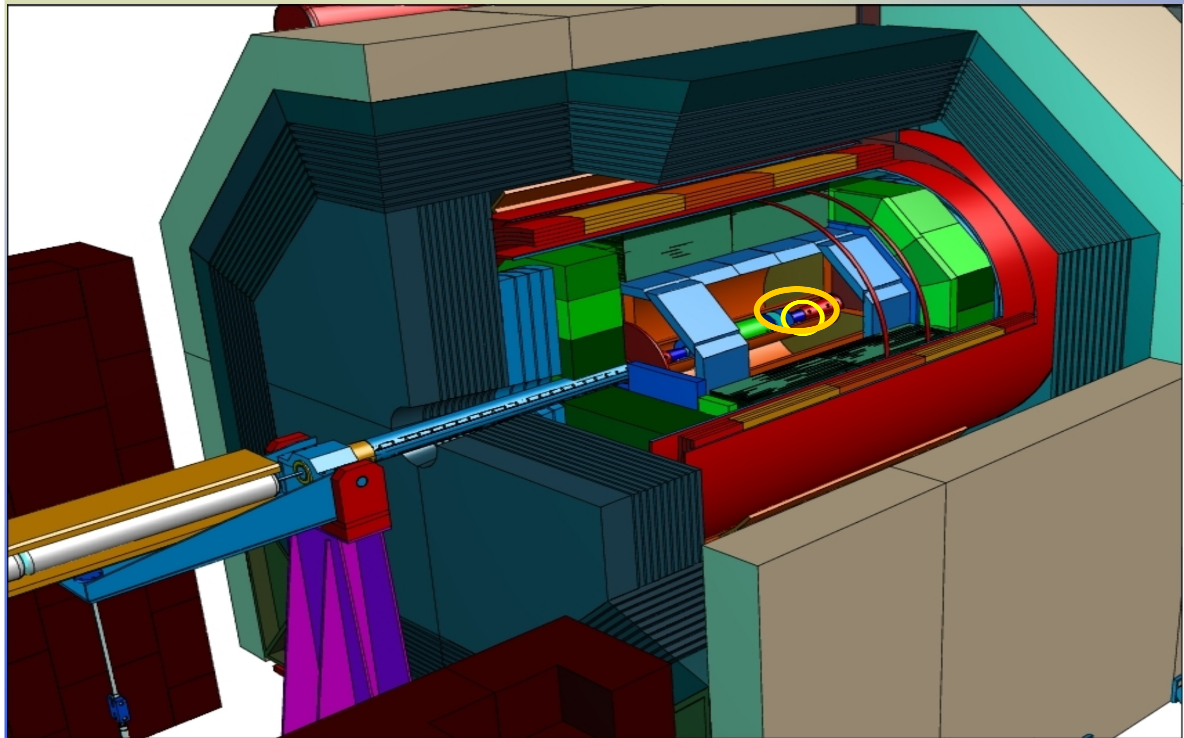


Colorado
Cracow
Dubna
London
Minsk
Moscow
Prague
Protvino
Tel-Aviv

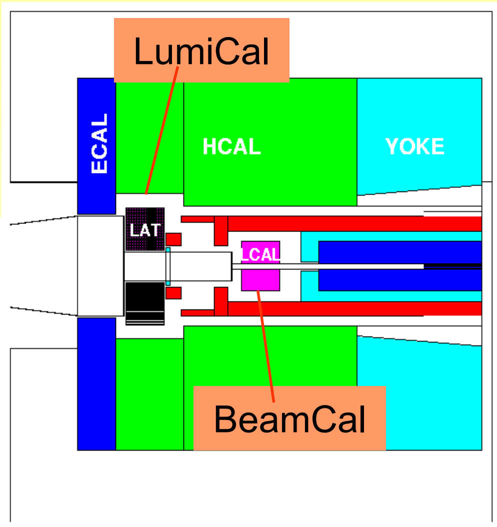
Forward Region – LumiCal (LAT) and BeamCal (LCAL) Calorimeters

The main functions:

- Precision luminosity measurements (LumiCal) : $\Delta L / L \approx 10^{-4}$
- Fast beam diagnostic + physics (BeamCal)
- Detection of electrons and photons at very small angles
- Shield of inner (tracking) detector
- Supplied maximum hermiticity

for Bhabha process $e^+e^- \rightarrow e^+e^- (\gamma)$

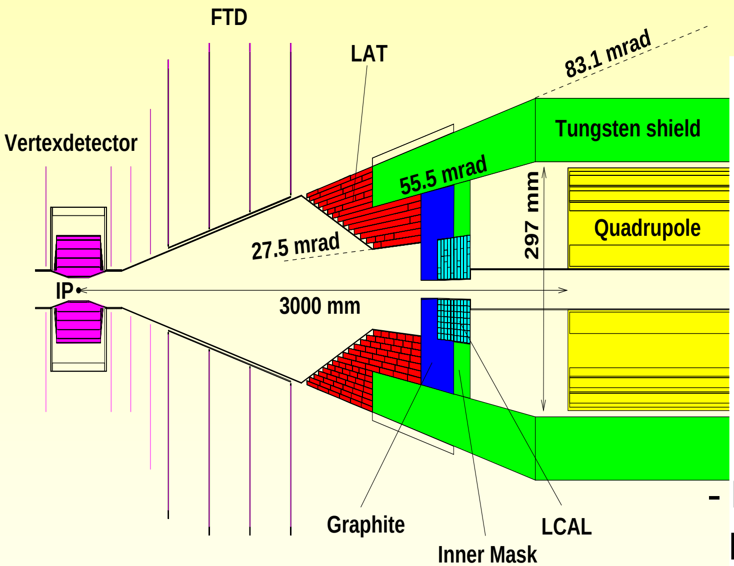
New mask design



$L^* \approx 4$ m optics

LumiCal
- z = 305-325 cm
- r= 8-28 cm
- $26.2<\theta< 82$ mrad
- $0<\varphi<360$ deg

BeamCal
- z = 365-385 cm
- R = 1.2-8 cm
- $3.9<\theta<26.2$ mrad
- $0<\varphi<360$ deg



Advantages:
- Reduce the leackage particles from LumiCal – help to achieve required precision in LUMI
- less fakes can scatter from mask into ECAL
- more space for electronics
- outer CAL better separated from beamstrahlung
- Shintake monitor can be used

TDR design:
$\Delta L/L$: 10^{-4} impossible
0.2 – 0.3 mrad accuracy

$\Delta\theta \sim$ a few μrad : $\Delta L/L$ 10^{-4} possible

LumiCal - Luminosity Measurement

Monte Carlo Simulation - Cracow

Optimisation of shape and structure are studied to reach $\Delta L / L \sim 10^{-4}$. Need laser alignment system

Si (sensor) / W calorimeter
concentric cylinders (in r), sectors in (φ) and rings in (z)
Si : pads or strips

Realistic Monte Carlo

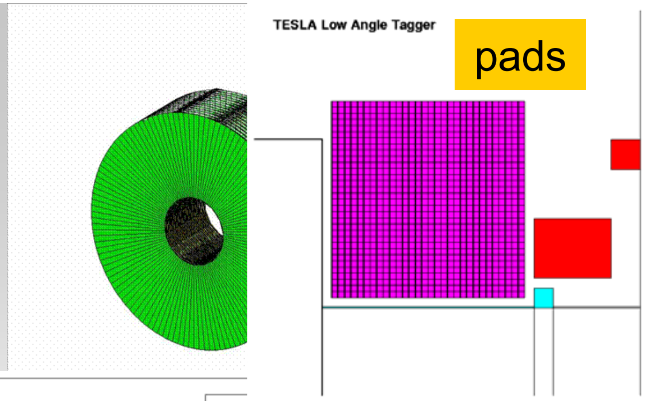
- rad. corrections (BHLUMI / BHWIDE) - Bhabha MC program
- beamstrahlung (CIRCE, Guinea-Pig $\rightarrow e^- e^+$ pairs background)
- full detector simulation
- reconstruction of events

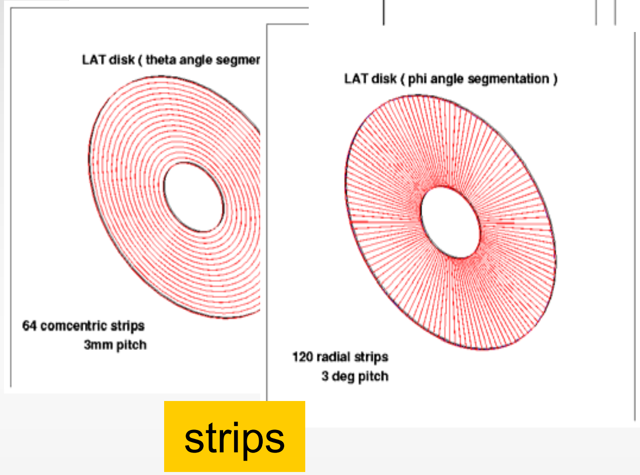
Possible LumiCal segmentation :

15 - 32 cylinders in r
24 - 48 sectors in φ
30 rings in z (readout from every 2nd)
$\sim$ 11500 channels

Resolution: $\sigma(\theta) \sim 70 - 90\ \mu\text{rad}$ feasible
possible improvement - reconstruction algorithm

Energy resolution: $\sim 40\% \sqrt{E}$





rings – 30 , every second ring –
120 radial or 64 concentric strips
$\sim$ 3000 readout channels

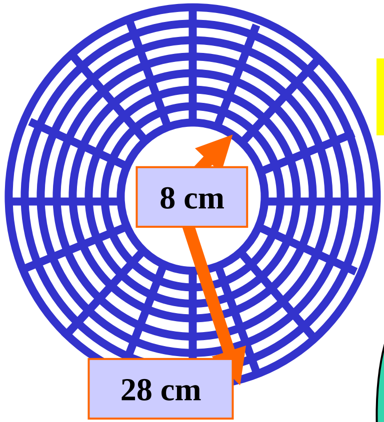
Resolution: $\sigma(\theta) \sim 50 - 90\ \mu\text{rad}$

Energy resolution: $\sim 31 - 43\ \% \sqrt{E}$

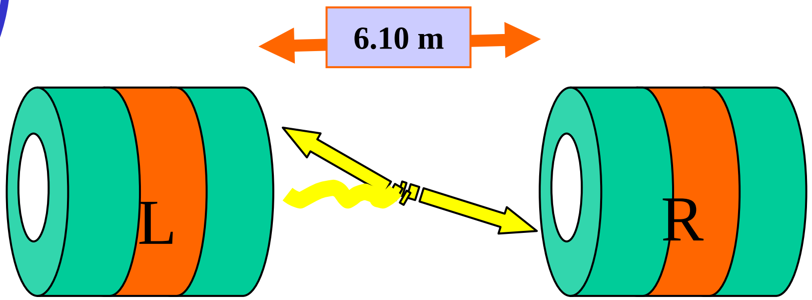
LumiCal - Simulation

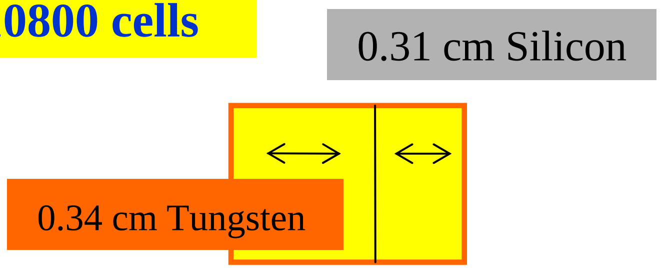
Tel-Aviv

Detector Design



15 cylinders * 24 sectors * 30 rings = 10800 cells



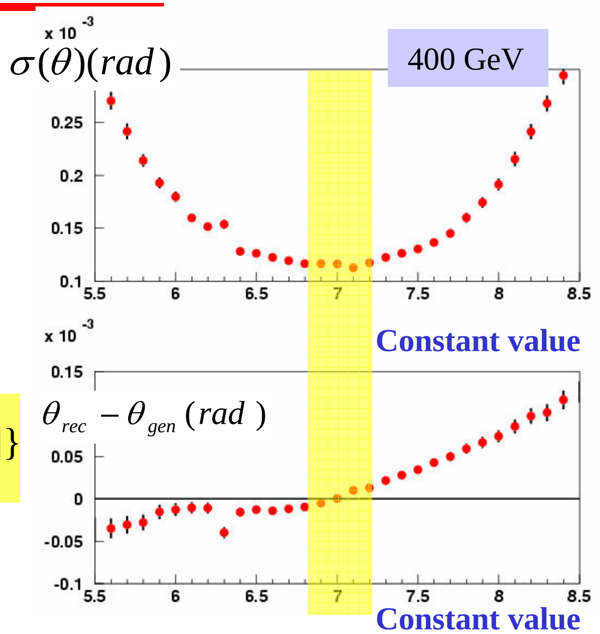


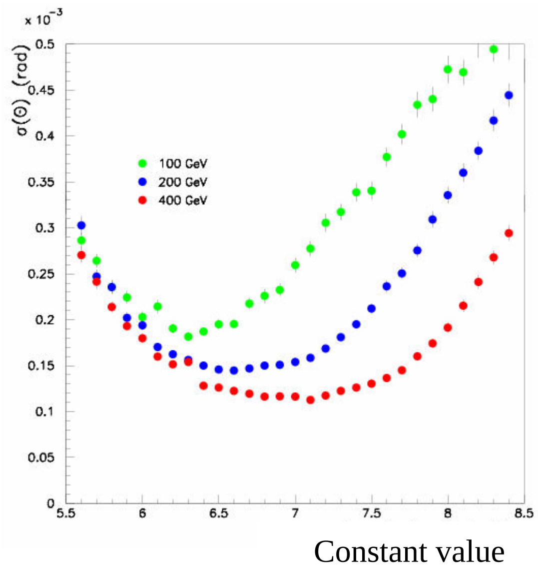
Reconstruction Algorithm

$$< X > = \frac{\sum X_i E_i}{\sum E_i}$$

$$< X > = \frac{\sum X_i W_i}{\sum W_i}$$

$$W_i = \max\{0, [const(E_{beam}) + \ln(\frac{E_i}{E_T})]\}$$

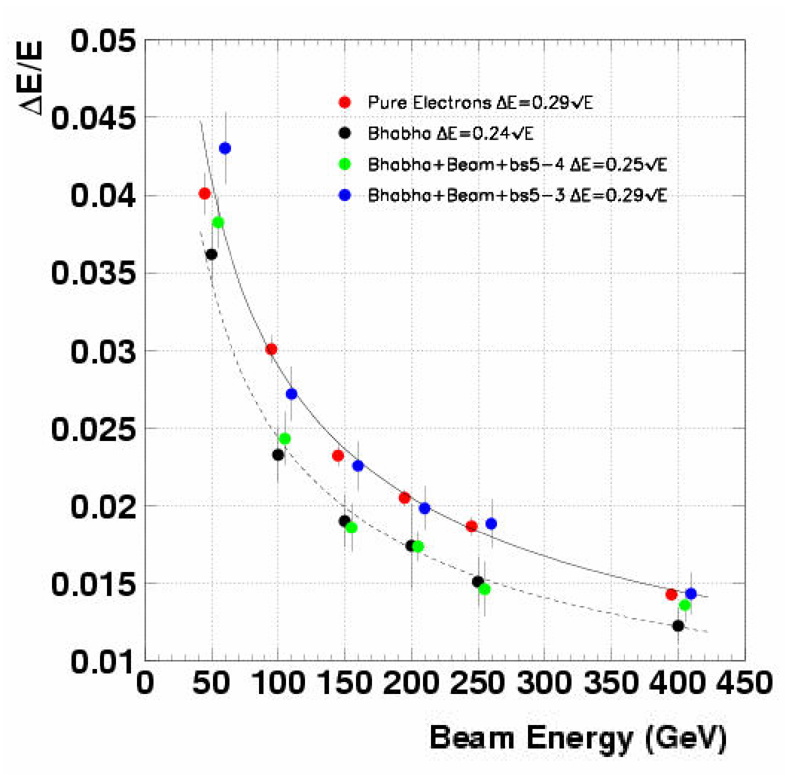


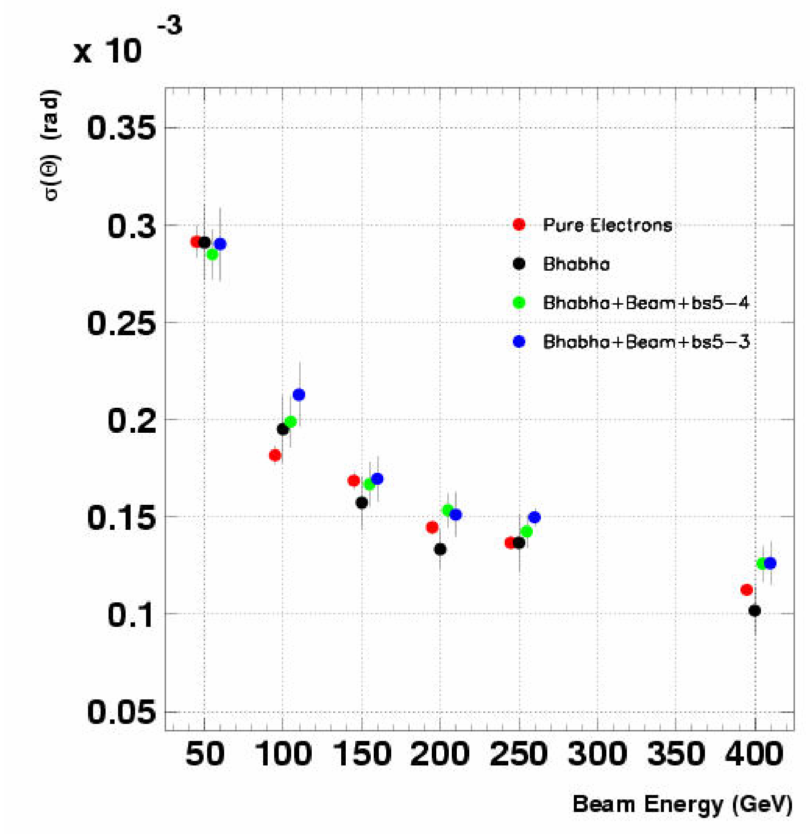


Energy and Angular resolution

Simulation: BHWIDE (Bhabha)+CIRCE (Beamstrahlung)+beamspred

Events selection: acceptance, energy balance, azimuthal and angular symmetry.



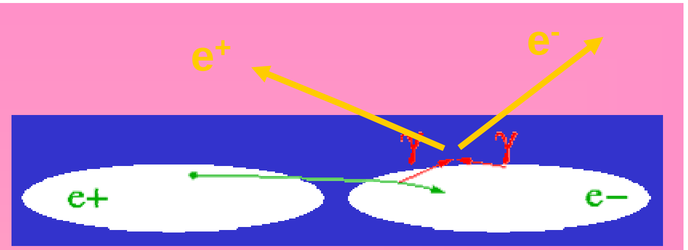


Final choice of LumiCal sensor geometry ?

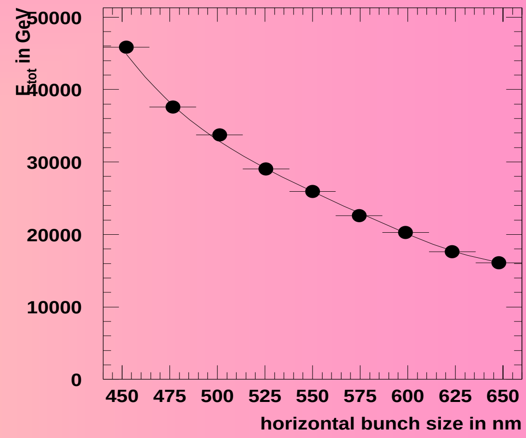
BeamCal - Beam Monitoring

Beam monitoring - observation e^-e^+ pairs from beamstrahlung which is sensitive to the machine parameters.

- pairs in BeamCal
- photons downstream



Deposited energy over r and ϕ contains information about beam parameters



Severe conditions for work:

thousands pairs (~15000 hits) per BX

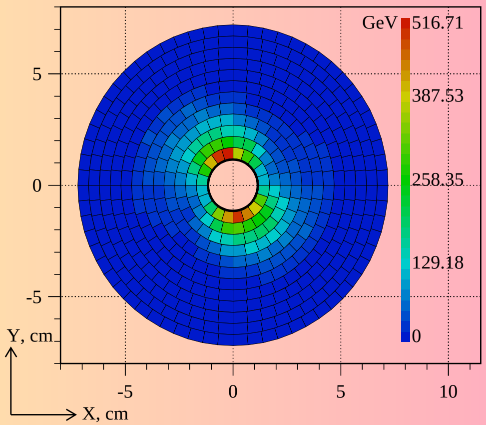
- large energy deposition 10 – 20 TeV

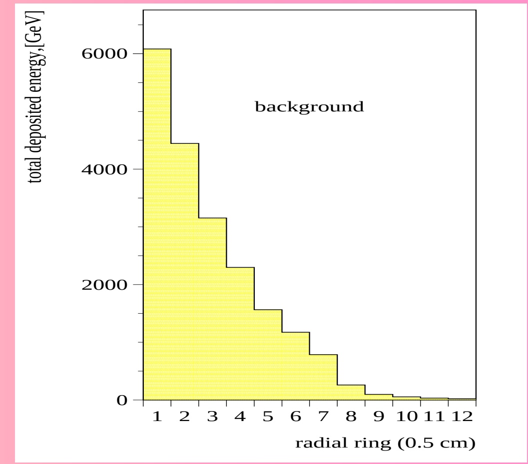
hard radiation

- 10 MGy per year. Required rad. hard sensors

In cold technology:

large bunch spacing
information can be used for feedback





Considered technologies :

- **Diamond-W Sandwich**
- **Gas ionisation chamber**
- **Scintillator crystals**

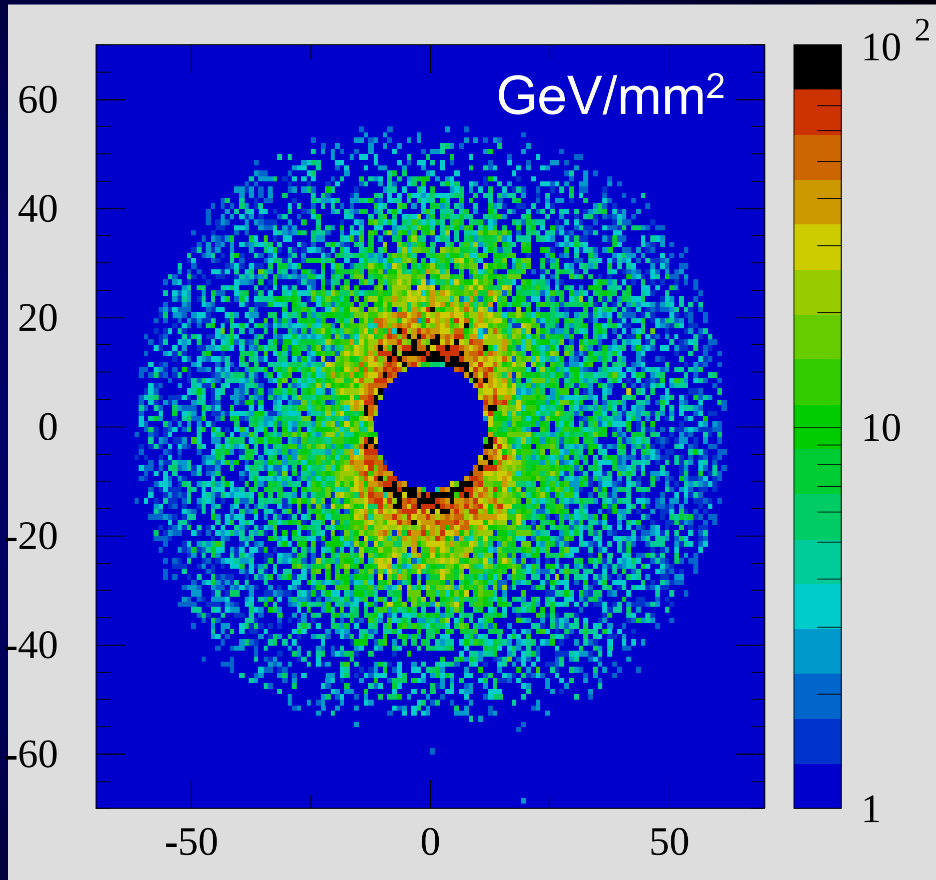
Beam Strahlung

Diagnostics of bunches at IP

3 potential sources of information
- energy-distribution of pairs
- number-distribution of pairs
- distribution of photons

Over-simplified detector simulation
- detectors subdivided into cells
- sum energy impact on cells

main source of uncertainty
→ stat. fluctuations of beam-str.



Linear approximation

BeamCal – Monte Carlo Studies

Zeuthen

Beam Monitoring -

Current Analysis Concept

Beam Parameters

- determine collision
- creation of beamstr.
- creation of e^+e^- pairs

guinea-pig

1st order Taylor-Exp. →

Observables

- characterize energy distributions in detectors

analysis program

$$\left(\text{Observables} \right) = \left(\text{Observables} \right)_{nom} + \left(\text{Taylor Matrix} \right) * \left(\Delta \text{BeamPar} \right)$$

Solve by matrix inversion
(Moore-Penrose Inverse)

Beam Monitoring

Single parameter analysis (one free parameter)

	nominal	old	new	norm.	Beam Diag.
Bunch width x Ave. Diff.	553 nm	1.2 2.8	2.0 3.6	1.5 2.1	~ 10 % ~ 10 %
Bunch width y Ave. Diff.	5.0 nm	0.1 0.1	0.2 0.5	0.2 0.5	Shintake Monitor
Bunch length z Ave. Diff.	300 μm	4.3 2.6	7.5 3.5	4.3 2.7	~ 10 % ~ 10 %
Emittance in x Ave. Diff.	10.0 mm mrad	1.0 0.4	--- 0.7	--- 0.7	? ?
Emittance in y Ave. Diff.	0.03 mm mrad	0.001 0.001	0.001 0.004	0.001 0.002	? ?
Beam offset in x Beam offset in y	0 0	7 0.2	30 0.6	6 0.4	5 nm 0.1 nm
Horizontal waist shift Vertical waist shift	0 μm 360 μm	80 20	--- 23	--- 24	None None

Good precision - determination of beam parameters look optimistic

Beam Monitoring

Multi parameter analysis

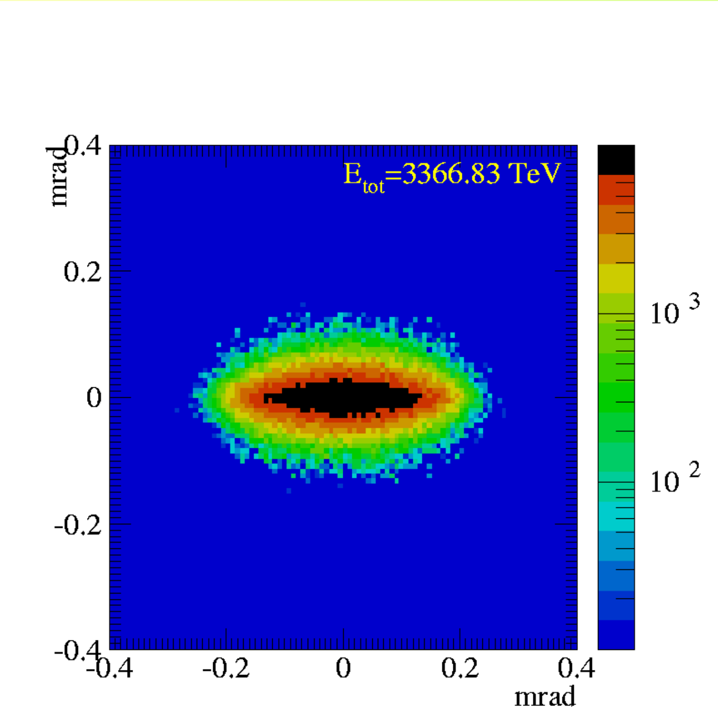
Expected resolutions when 1, 2, 4 or 6 parameters are running.

σ_x	$\Delta\sigma_x$	σ_y	$\Delta\sigma_y$	σ_z	$\Delta\sigma_z$
0.3 %	0.4 %	3.4 %	9.5 %	1.4 %	0.8 %
0.3 %	0.4 %	3.5 %	11 %	1.5 %	0.9 %
0.9 %	1.0 %	11 %	24 %		
		5.7 %	24 %	1.6 %	1.9 %
1.8 %	1.1 %	16 %	27 %	3.2 %	2.1 %

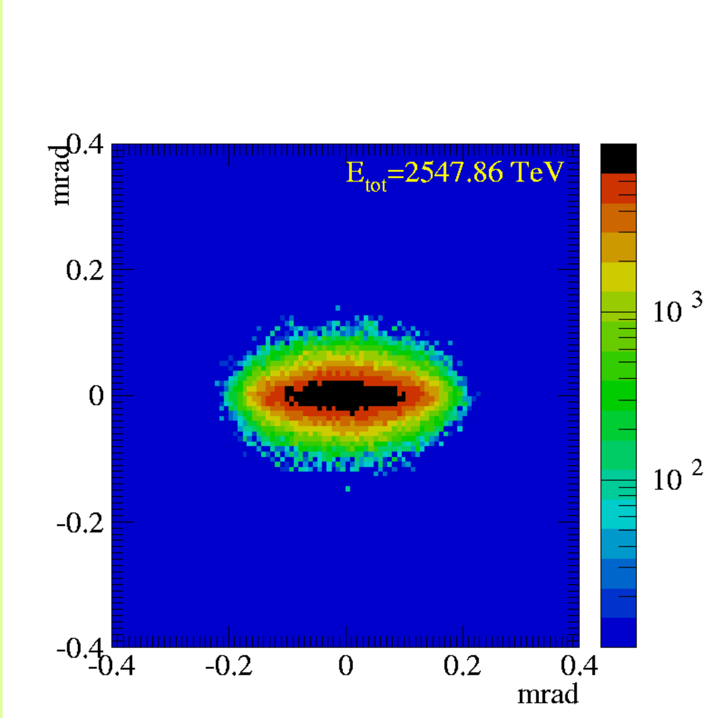
Current analysis $\rightarrow$ we can measure 6 (more ?) beam parameters simultaniously with reasonably accuracy

First Look at Photons

Zeuthen



nominal setting
(550 nm x 5 nm)



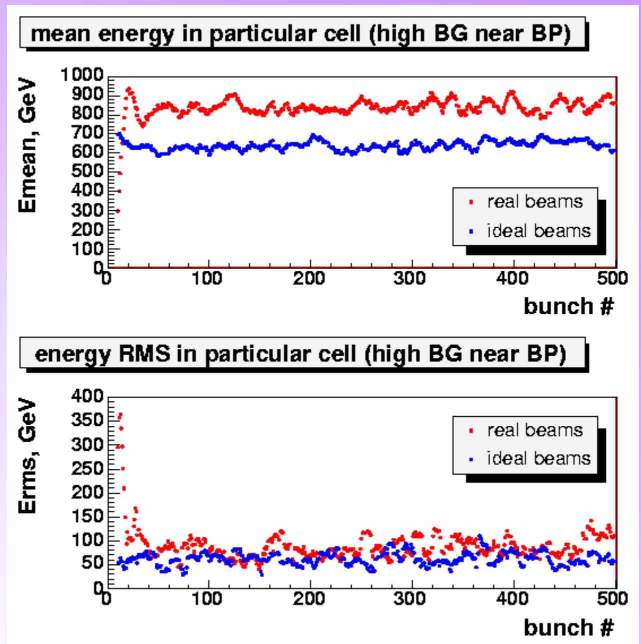
σ_x = 650 nm

σ_y = 3 nm

MC BeamCal - Real Beam simulation

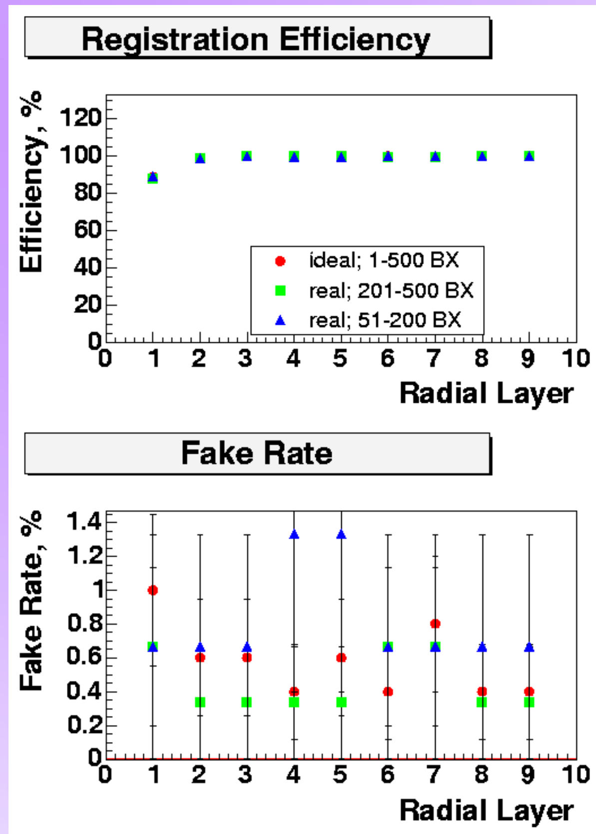
Minsk / Zeuthen

Included in the simulation:
ground motion,
feedback system delay,
emittance growth,
lumi optimisation



Total energy deposited in one pad of BeamCal near the beampipe is larger for real beam
Resolution of energy deposition rms is similar

The efficiency to identify a 100 GeV electrons close to the beam is nearly the same for RB and IB



Fake rate resulting from BG fluctuation is on the same level

LumiCal / BeamCal - Potential Technologies

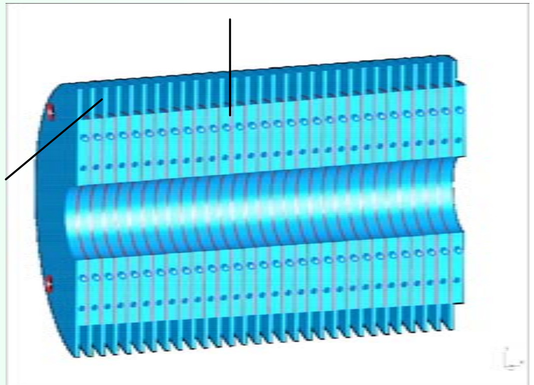
Challenge for detectors:

- high precise luminosity measurements
- fast ,online, beam diagnostic and identification high energy electrons and photons
- radiation hard sensors

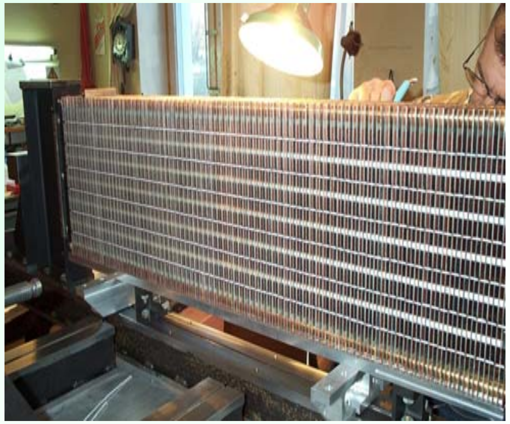
Calorimeters R&D →

Sensor: Diamond/Silicon

Space for electronics



- Diamond/Silicon – Tungsten (sandwich cal.)



One module

- Gas Ionisation Chamber – Tungsten (sandwich cal.)

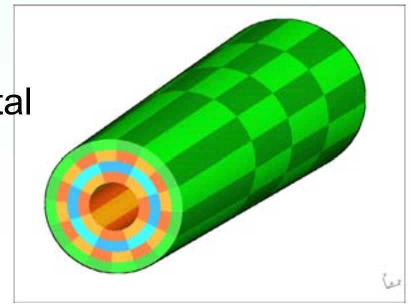
  Instead sensor → heavy gas C_3F_8
  to measure energy deposit

- *Heavy Crystal Calorimeter*

  option with scintillating fibres

  option with ultra-thin photo-tiodes

Segments of heavy crystal



Silicon Facilities:

- Prague
- Cracow
- Zeuthen

Design consideration

Prague

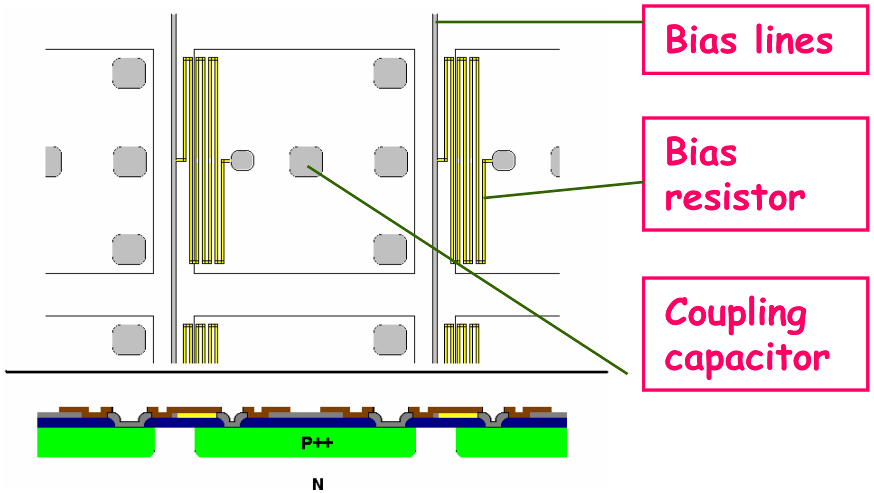
a) polysilicon resistors:

- should not be a problem to have resistors ≈ 10 MΩ;
- capacitors ≈ 1-10 nF.

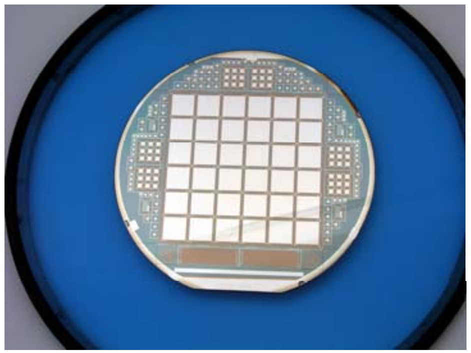
b) punch through resistors:

- resistors to be tested; if acceptable then it is a simple solution;
- capacitors as *a)*.

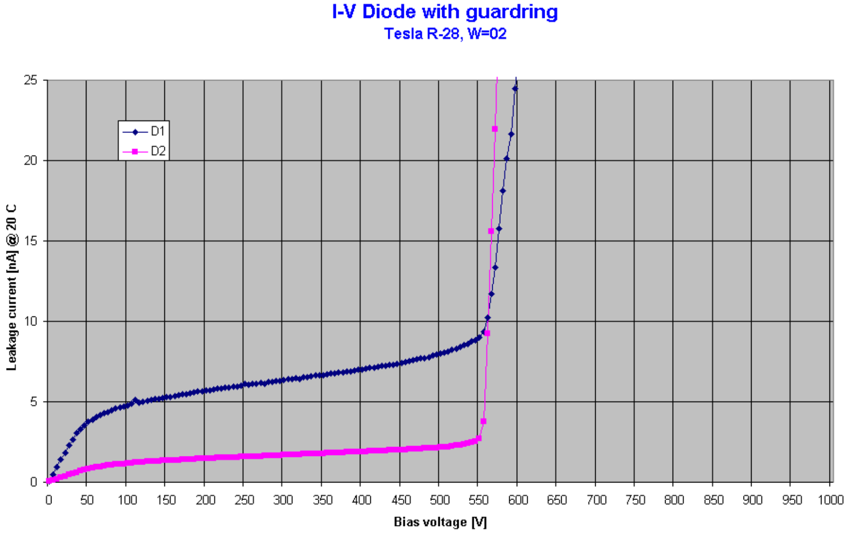
Compatibility of process for variants *a)* and *b)* on one wafer? Option *a)* as a *baseline* for main sensor tile?

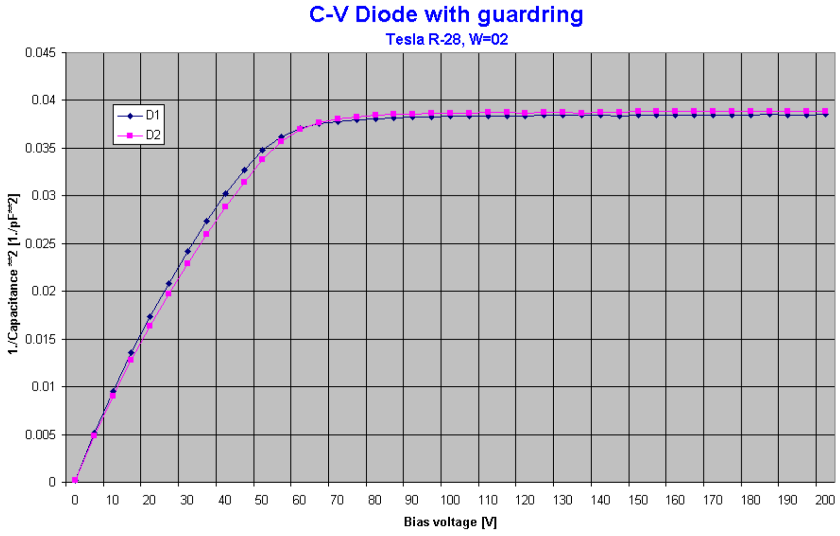


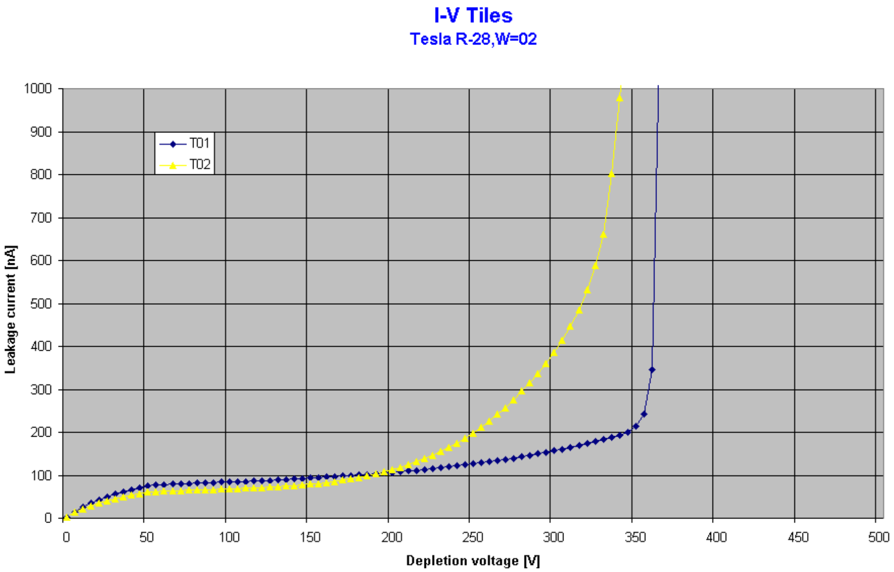
Pre-prototype

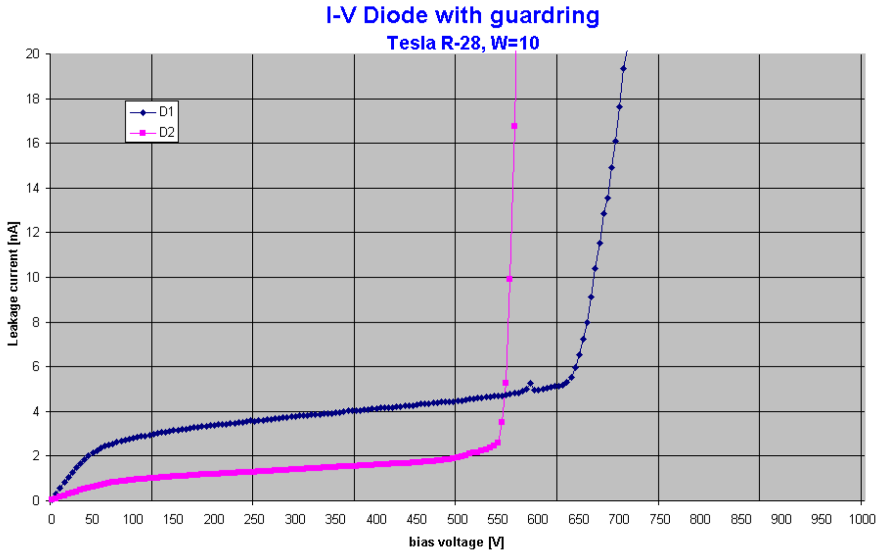


Electric characterization





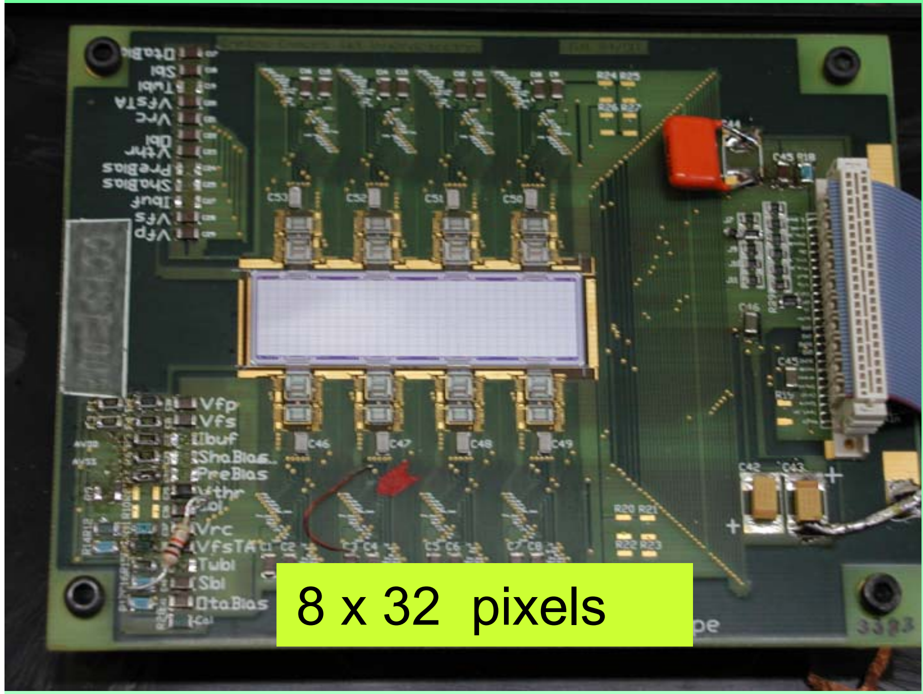




Silicon sensors

Cracow

- Preamplifier based on Minsk „Tetrode”
- Bonding of silicon samples from Prague
- Testing of the pixel detector
- New preamplifiers ordered



Next steps:

- Tests of the pixel detector with source
- Tests of the silicon diode samples
- Preamplifiers based on AmpTek chips

At **DESY Zeuthen** we are able to perform (class 10k clean room):

- Ultrasonic wire bonding (Au, Al, down to 17.5 µm wires)
- Glueing with high mechanical precision and/or special hardening procedures (silver epoxies)
- Measurements of single and double sided sensors on different probe stations
- long term measurements (darkness, special atmosphere: N_2 or similar)
- chip testing (delivered probe cards can be adapted)

additional: electronics workshop with automatic SMD placement and soldering tools
mechanical workshop with NC machining/milling
at **DESY Hamburg** a 'state of the art' programmable wire bonder

Companies / Institutions we are used to work with:

- Sensors: CiS Erfurt (D), Micron Ltd. (UK), SINTEF Oslo (N), Hamamatsu (J)
- chip design: IDE AS, Oslo (N) and ASIC Laboratory of University of Heidelberg (D)
- probe cards: Wentworth Deutschland GmbH, München (D)
- high precision printed circuit boards: Würth GmbH, Roth am See (D), Optiprint (CH)
- thick film hybrids: Elbau GmbH, Berlin (D)

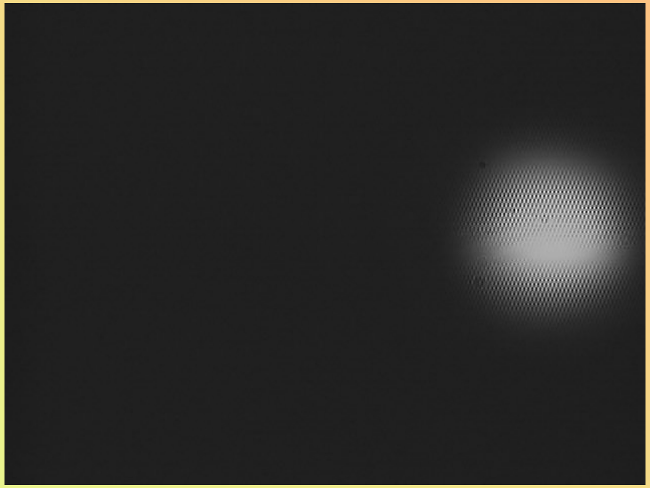
Position Measurement with Laser and CCD Camera

Cracow

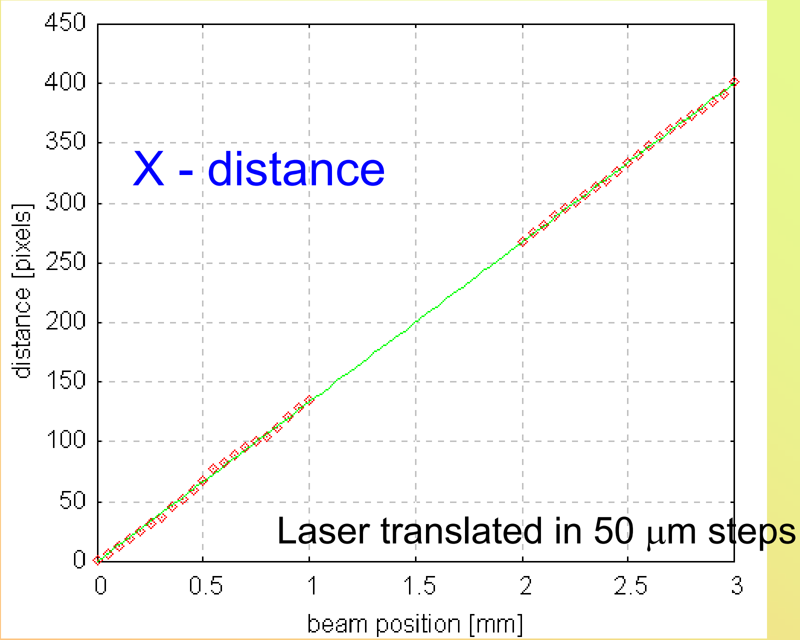
Requirements on alignment:

Inner Radius of LumiCal < 1 µm

Axial LumiCal position < 60 µm



Reconstruction of He-Ne red laser spot on CCD camera



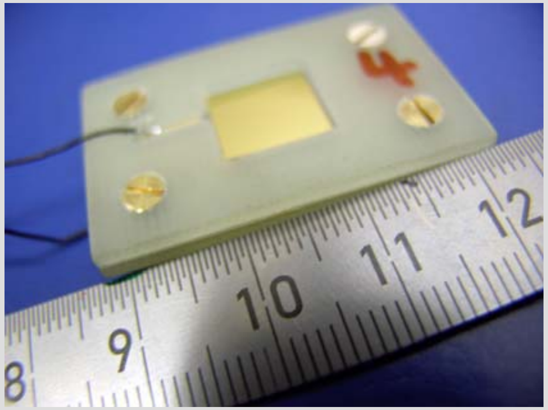
Next steps:

- Small-pixel camera, CCD technical data,
- Manually controlled sensitivity, BW camera,
- Micro pointing stability of lasers,
- Semiconductor laser,
- Piezzoelectric movement of camera,
- More statistics.

possible resolution of ~1µm if the center of the light spot is determined with accuracy better than 0.1 pixel

Diamond Sensors

Zeuthen



CVD diamonds from
Frauenhofer Inst. Freiburg
12 samples (12 x 12 mm)
300 and 200 μm
different surface treatments:
#1 – substrate side polished; 300 um
#2 – substrate removed; 200 um
#3 – growth side polished; 300 um
#4 – both sides polished; 300 um
metallisation: 10 nm Ti + 400 nm Au

Measured:

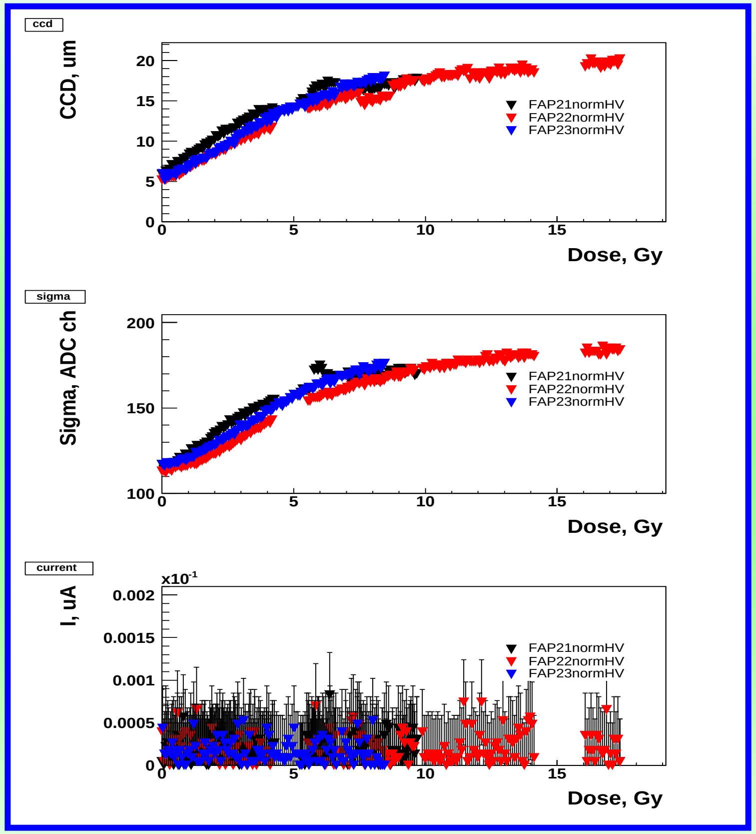
- I-V characteristics
- Charge collection distance (CCD) – not irradiated samples
- CCD – irradiation studies

CCD – irradiation, purities studies and beam tests

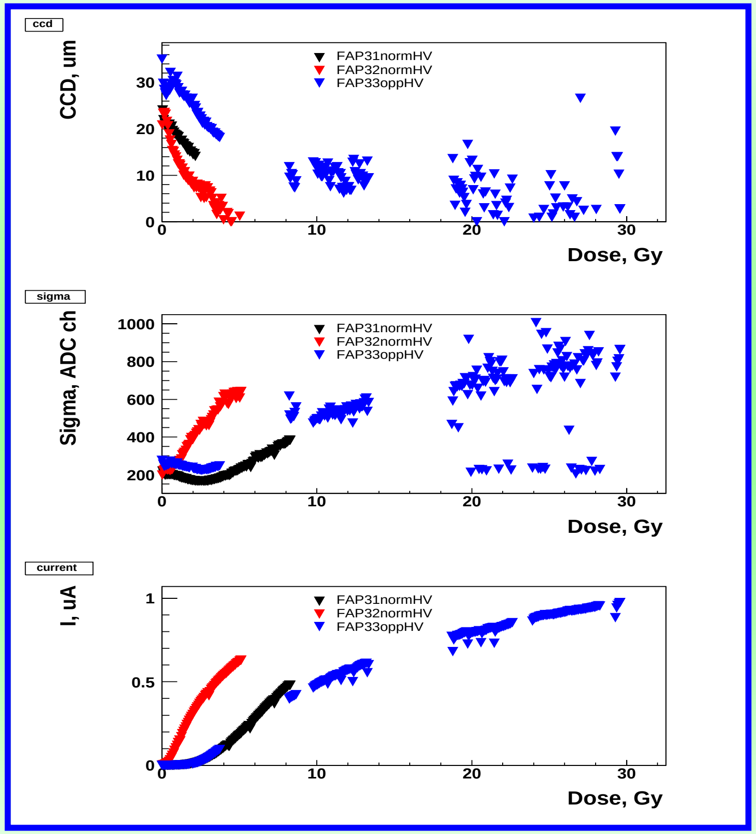
- ✓ The samples were irradiated with Sr-source with estimated dose-rate of about 0.45 Gray per hour
- ✓ The total absorbed dose for all the samples was at least 5 Gy.
- ✓ Parameters monitored during the irradiation:
  - Sr-spectrum peak position
  - width of the peak (->noise)
  - current in HV-circuit
  - test pulse from a generator (-> electronics stability)
- ✓ Raman spectroscopy and photoluminescence analysis
  - no nitrogen, no silicon found
- ✓ Tests on electron beam prepared for May

CCD – irradiation studies

Examples



Group #2 (substrate side removed).
HV = 200V



Group #3 (growth side polished).
HV = 300V

In general Group #2 can work as detector

Diamonds

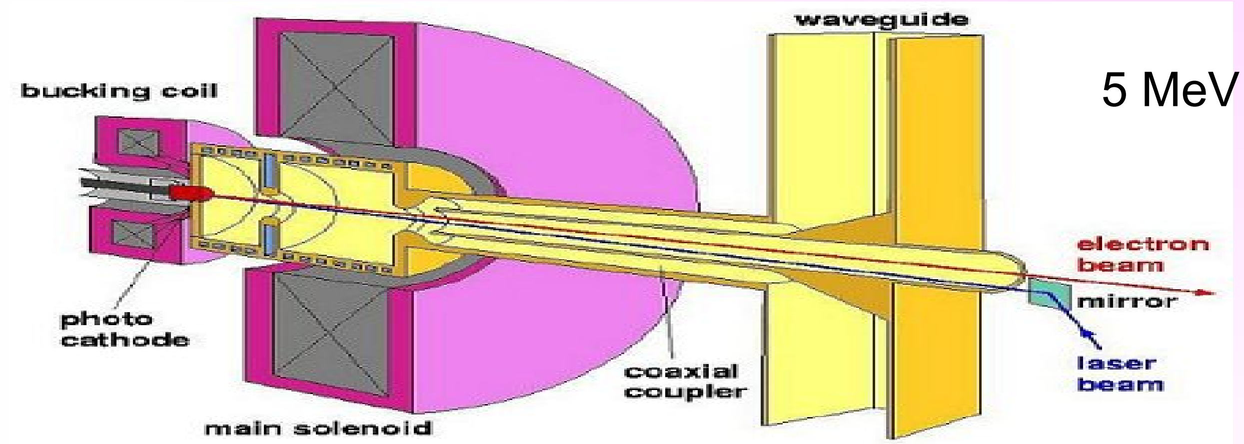
Minsk

Current step : Laboratory tests with ^{90}Sr: Charge collection efficiency of 20%

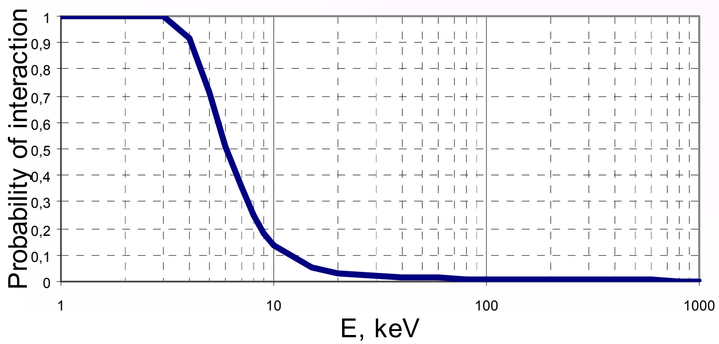
Readout electronics ready for beam tests

Next step: First prototype for beam tests

Beam tests planned: PITZ / Zeuthen, CERN, HERA, TTF2



5 MeV gamma energy



Probability of photon interaction within 300 μm of diamond sensor

CVD Diamonds

NSC GPI – Moscow / Dubna

Diamonds disks: 57 mm diameter, 250 and 350 μm thickness , laser cut, polished both sides, metallized Cr/Au electrodes deposited to grownth and substrate side sides to compare their quality

The purity and optical properties

Inpurities content → measur. the optical transmision spectra - UV visible and IR range

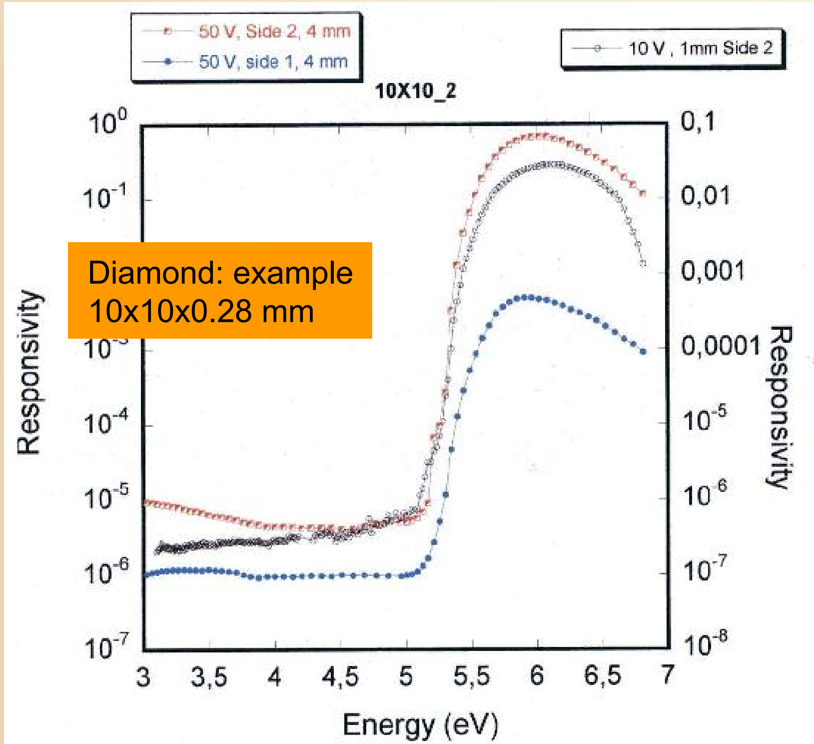
The diamond quality → measur. of the spectral photoresponse in UV-visible (200-225 nm) range.

Ratio of photoresponse (UV to visible range) says about diamond quality –higher when this ratio increasing

MPCVD device for diamond deposition

Spectral photoresponse measured separately for growth and substrate side side

The spectral discrimination ~six orders of magnitude for growth side
Two order of magnitude lower for substrate side → more defective structure



Preparation for ionization radiation tests (Dubna)
(alpha and beta spectra)

5 new diamond samples are available now (thickness: 110, 280,290 380, 380 microns)
The measur. of optical properties, purity, I-V characteristics and irradiation tests are under the work

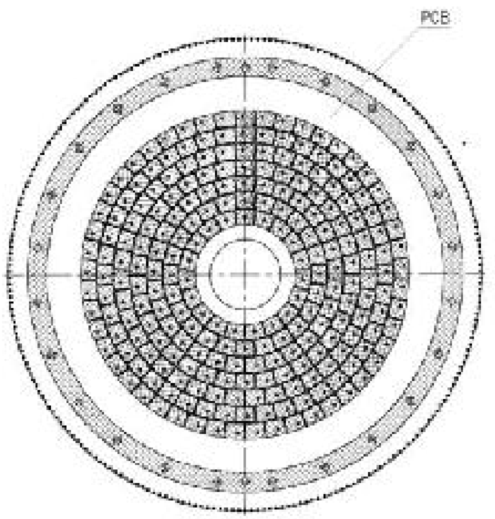
Gas Ionization Calorimeter W / C_3F_8

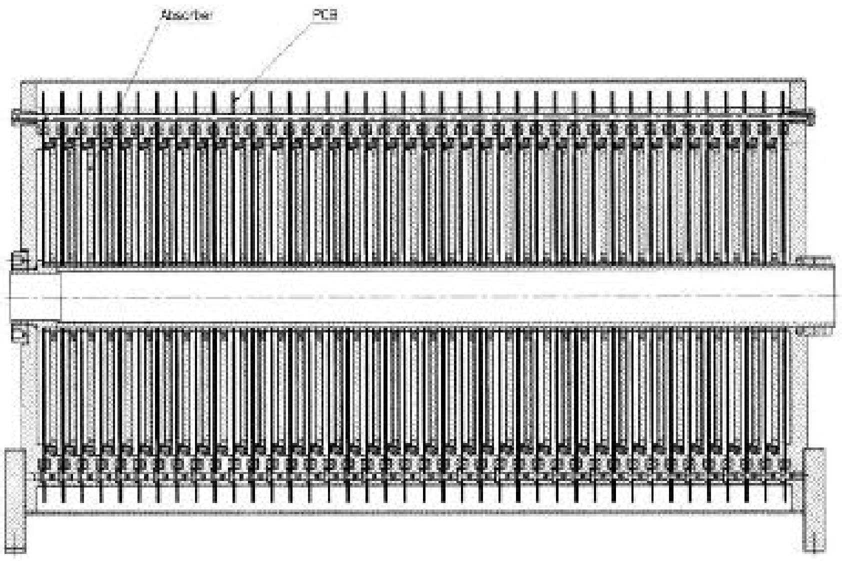
Protvino

W / C_3F_8 Cal. $\rightarrow$
- good energy resolution
- high uniformity and stability
- simple calibration
- high radiation hardness
- low equivalent noise energy also at atm. pressure
- low cost

C_3F_8 (octa fluoro propane) measurements:
density 0.0075 g/cm^3
molecular weight 188
drift velocity v = 0.07mm / ns
at ~ 800 V / atm

The volumes between absorber plates (W) are filled with gas **C_3F_8** at 0.5 and higer atm pressure

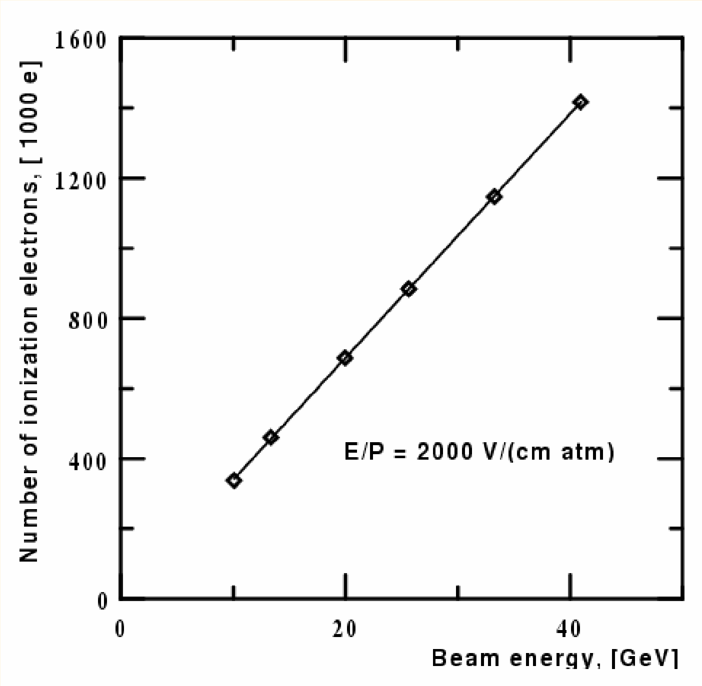




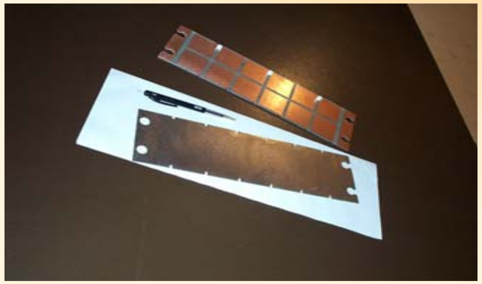
Pressure vessel with the readout connectors

Gas Ionization Calorimeter W / C_3F_8

- Beam tests of prototypes with electrons up to 70 GeV (IHEP Protvino) at pressure up to 1.8 atm , lead absorber - 1.5 and 3 mm , 10mm gas bigap

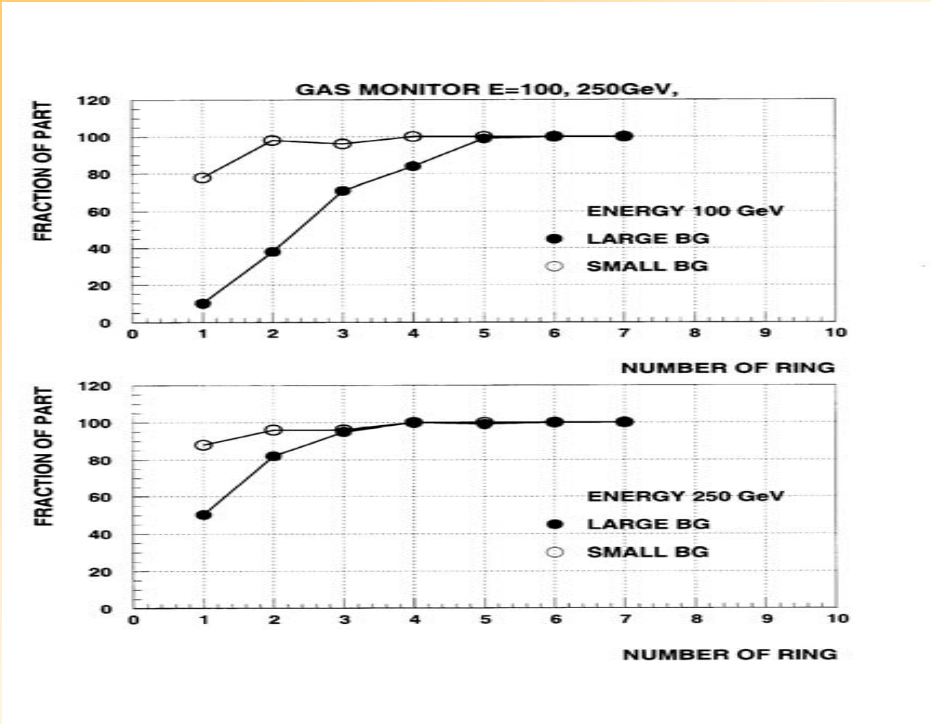


PCB with redout pads
to collect the ionization electrons



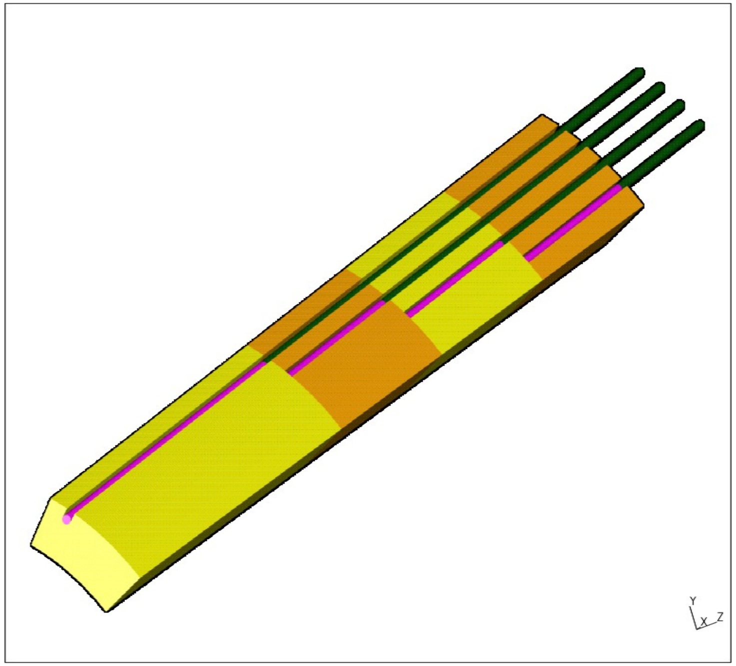
- MC simulation – Tungsten as absorber

Efficiency to identify high energy electron
- small and large background



Crystal Calorimeter Option for BeamCal

Expectation : homogeneous crystal calorimeter –
better energy and time resolution than a sandwich calorimeter



Individual fiber readout for every crystal segment

Example : $PbWO_4$ –
Moliere radius ~ 2.3 cm

Readout via fibers reduces light yield to 14 %

Conclusions

The recent developments indicate on essential progress in most areas