Calorimeter technologies for forward region instrumentation

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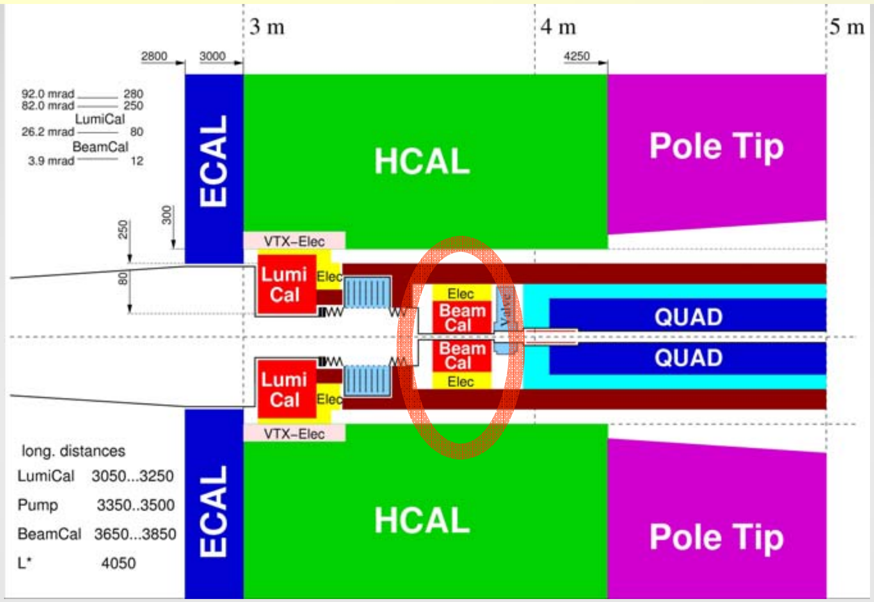
Beam Calorimeter :

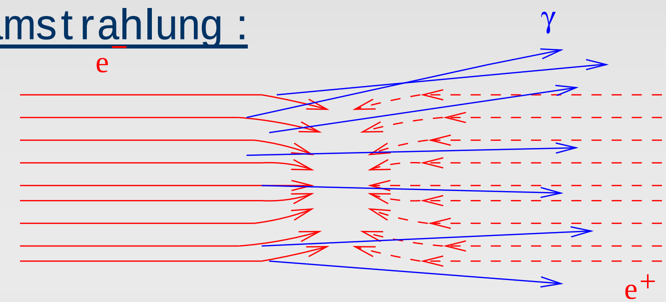
requirements and possible options



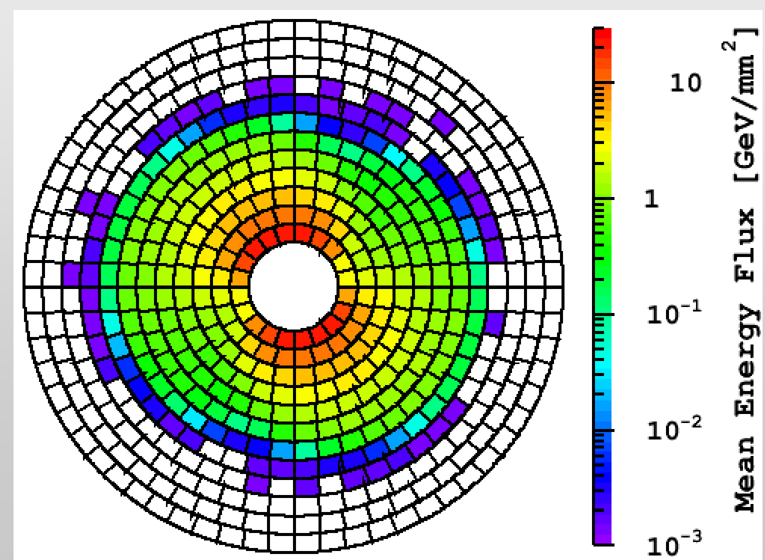
BeamCal: (4-28) mrad

- fast beam diagnostics
- detection and measurement of high energetic electrons and photons at very small angles

ILC bunch:
small size
high charge
-> beamstrahlung :



-> **high energy deposition in the BeamCal**



BeamCal:

requirement and possible options

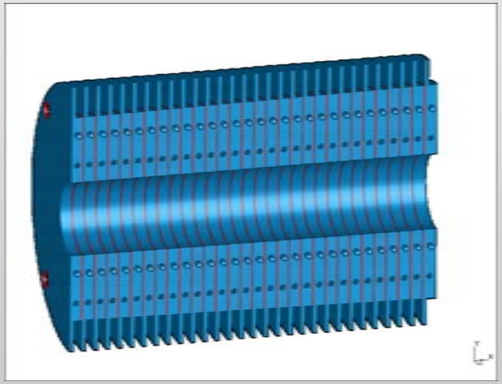
~15000 e^+e^- per BX (10 – 20 TeV)

~10 MGy / year for some area

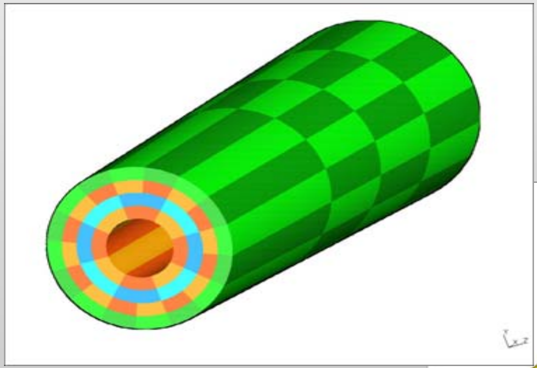
=>

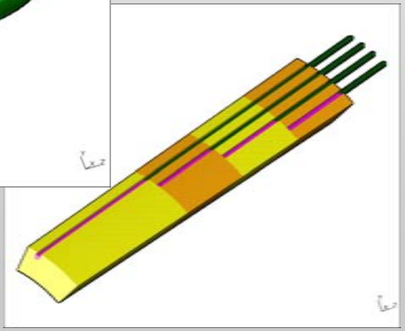
- **radiation hard material**
- **with small Moliere radius**

Diamond/Tungsten sandwich



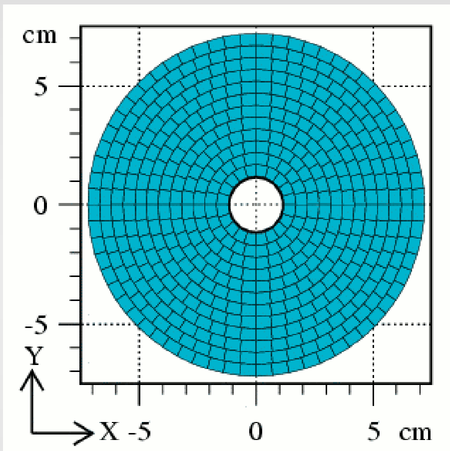
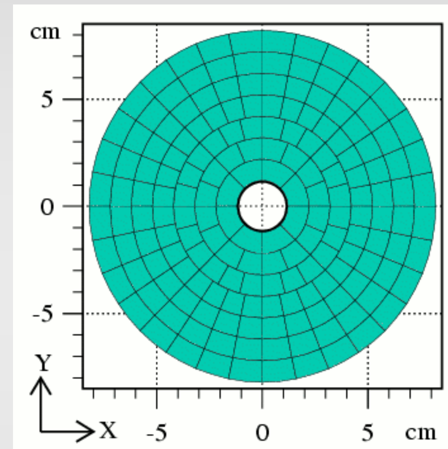
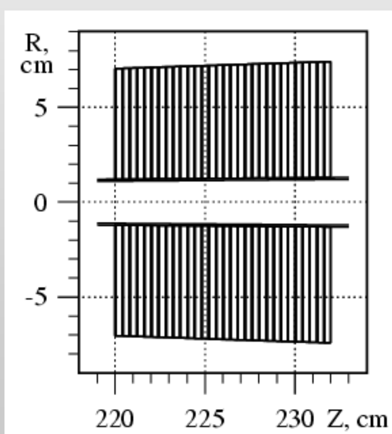
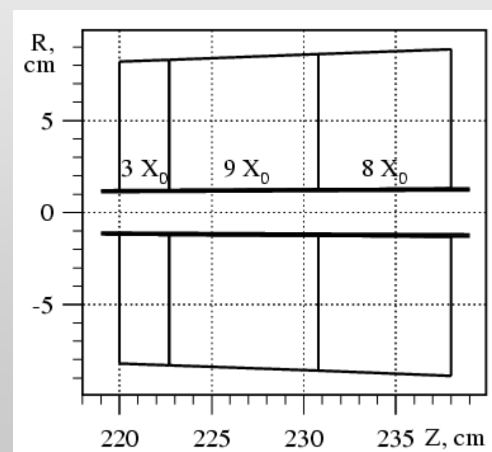
Heavy crystal





BeamCal:

performance simulations

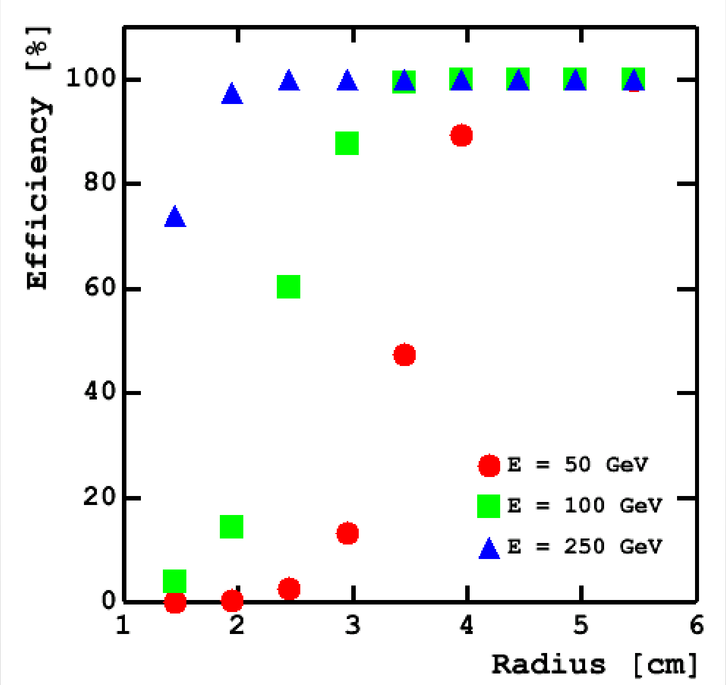
diamond/tungsten		**$PbWO_4$**
	**½ R_M**	
	**$1X_0$**	

Diamond/Tungsten BeamCal:

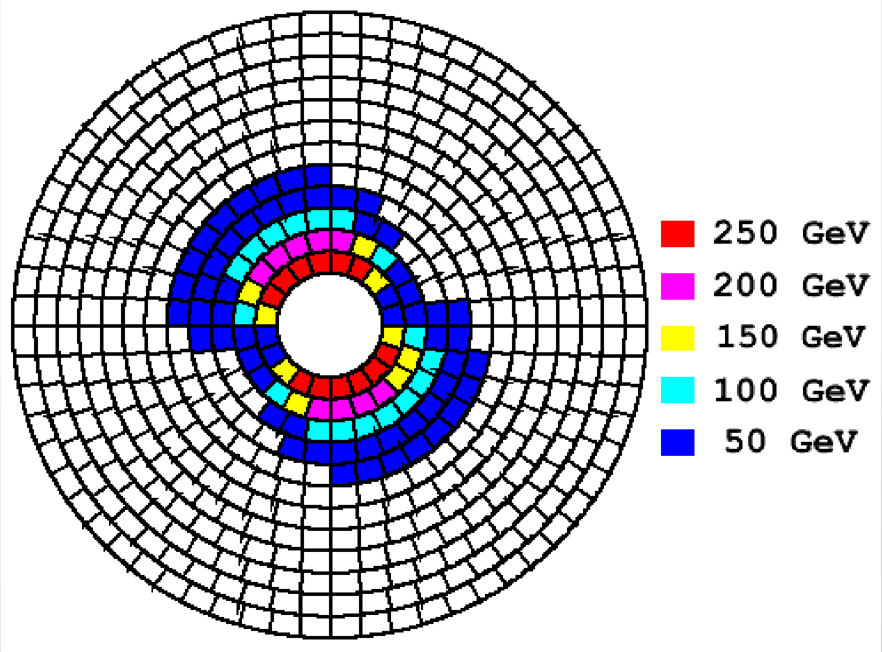
reconstruction efficiency:

Fake rate is less then 1%

chain of towers at φ = 90°
(the most affected)



Cells are colored when
the efficiency is less then 90%

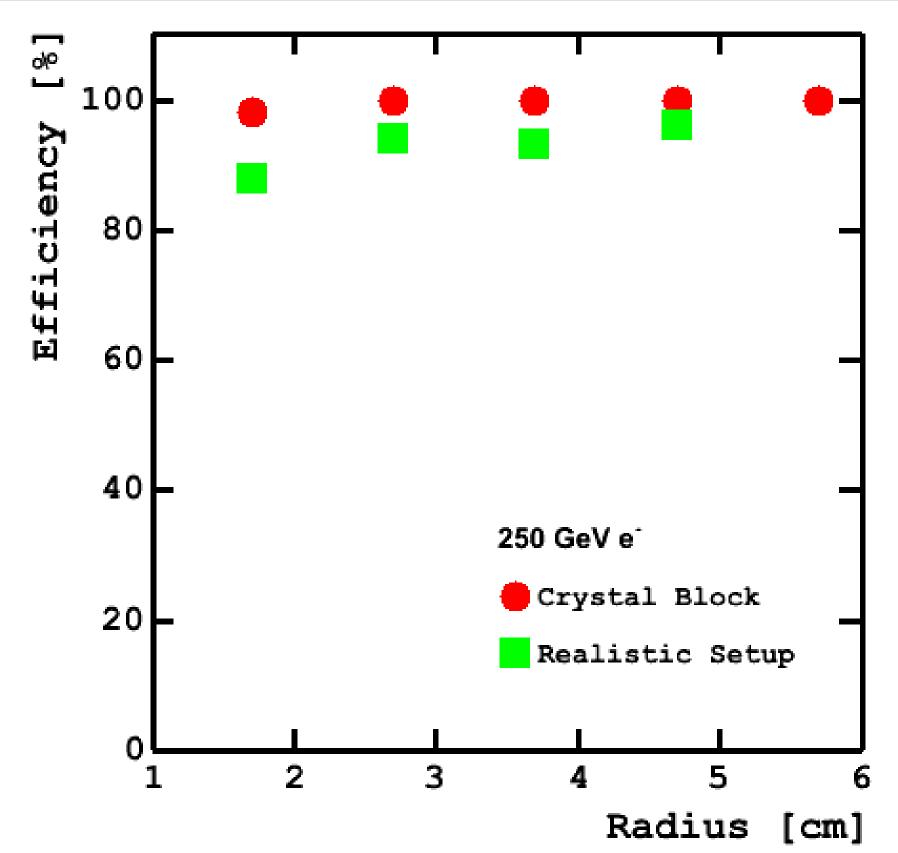


Electrons with energy more then 100 GeV are identified fairly well

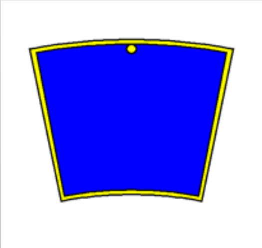
$PbWO_4$ BeamCal:

reconstruction efficiency:

Fake rate is less then 1%



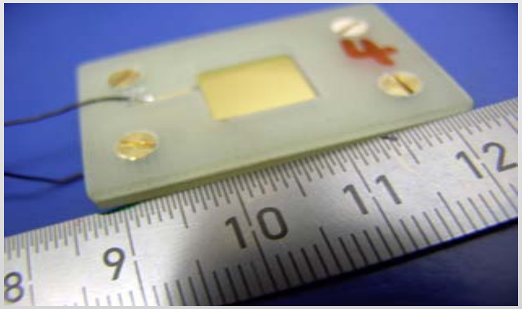
segment geometry



CVD Diamond Measurements:

Samples CVD - polycrystalline:

- Fraunhofer Institute (Freiburg)
- Element6
- GPI (Moscow)

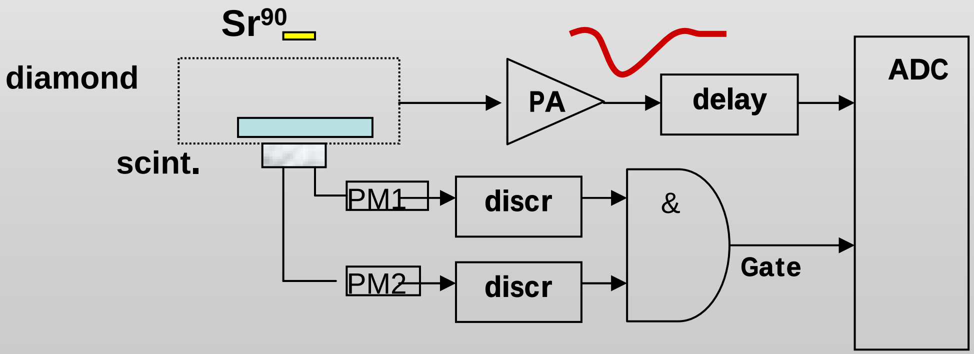


Measurements:

- Current-Voltage
- Charge Collection Efficiency
  (Charge Collection Distance)

Qmeas/Qcreated = CCD/L

Qcreated(MIP) = 36 eh/μm



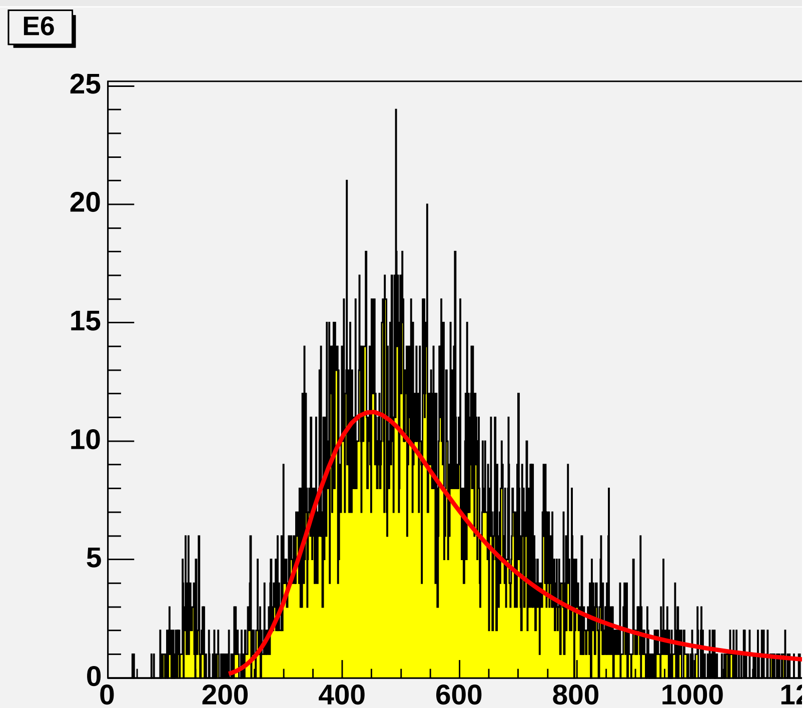
CCD vs HV, time

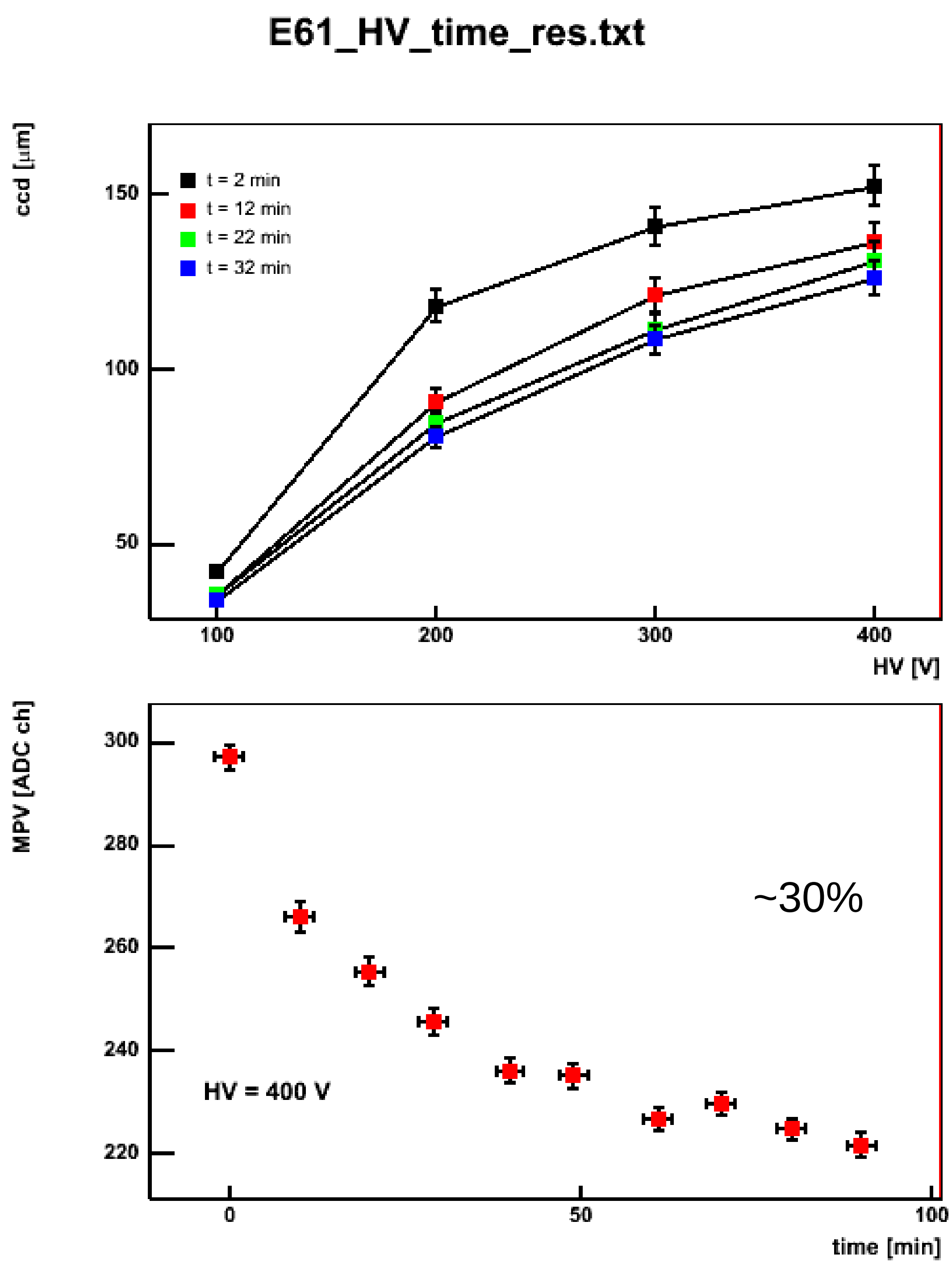
E61:

before irradiation

HV 100/200/300/400 V

Timing 30/30/30/90 min





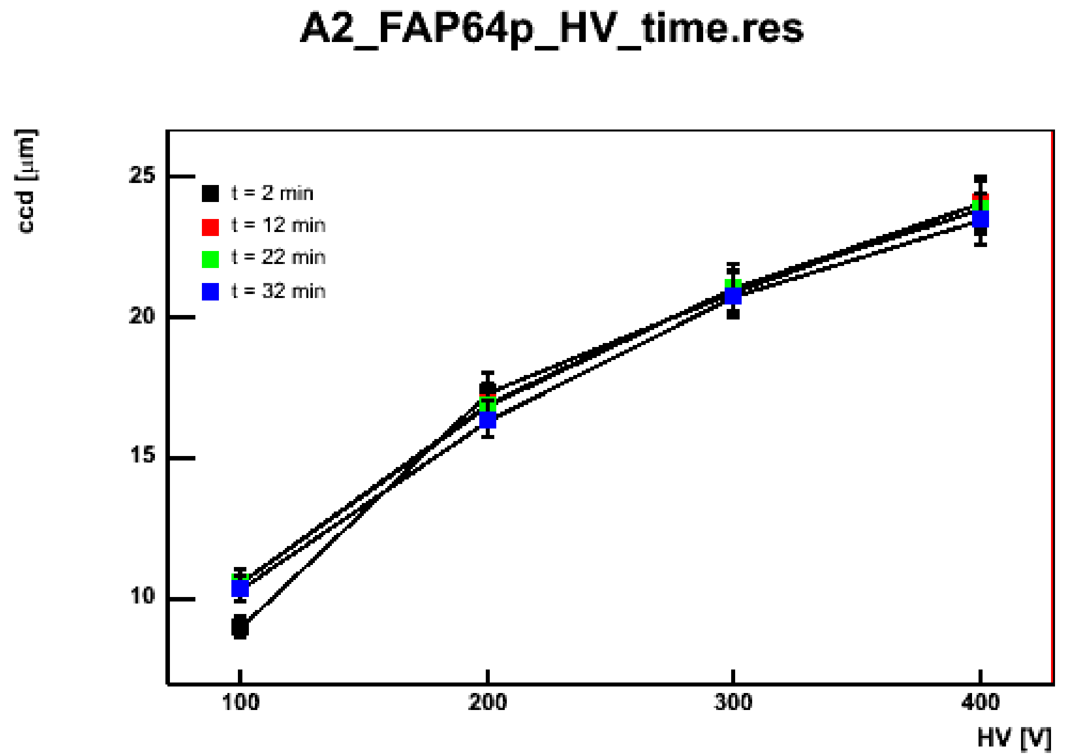
CCD vs HV, time

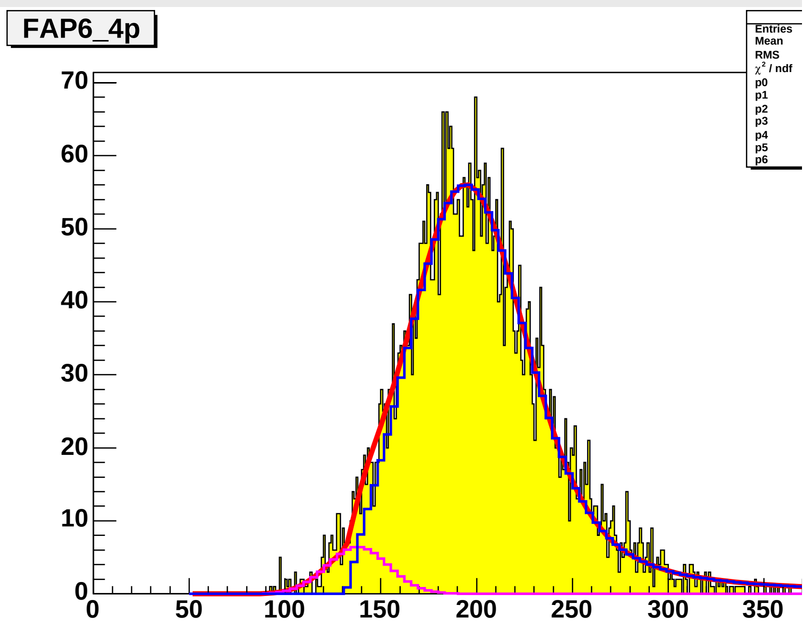
FAP6:

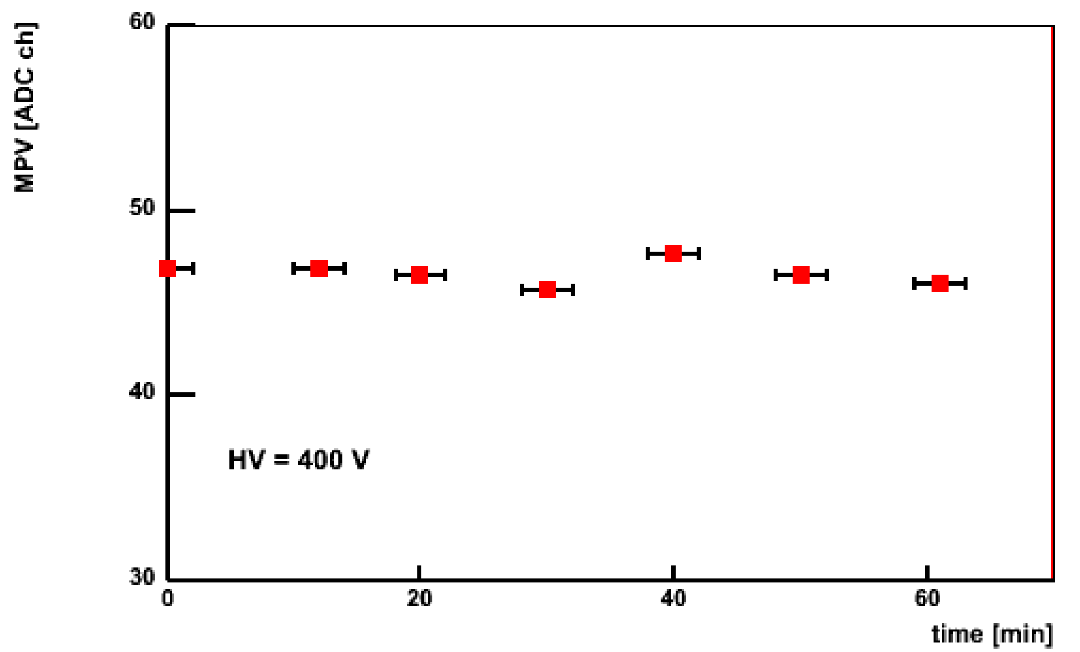
before irradiation

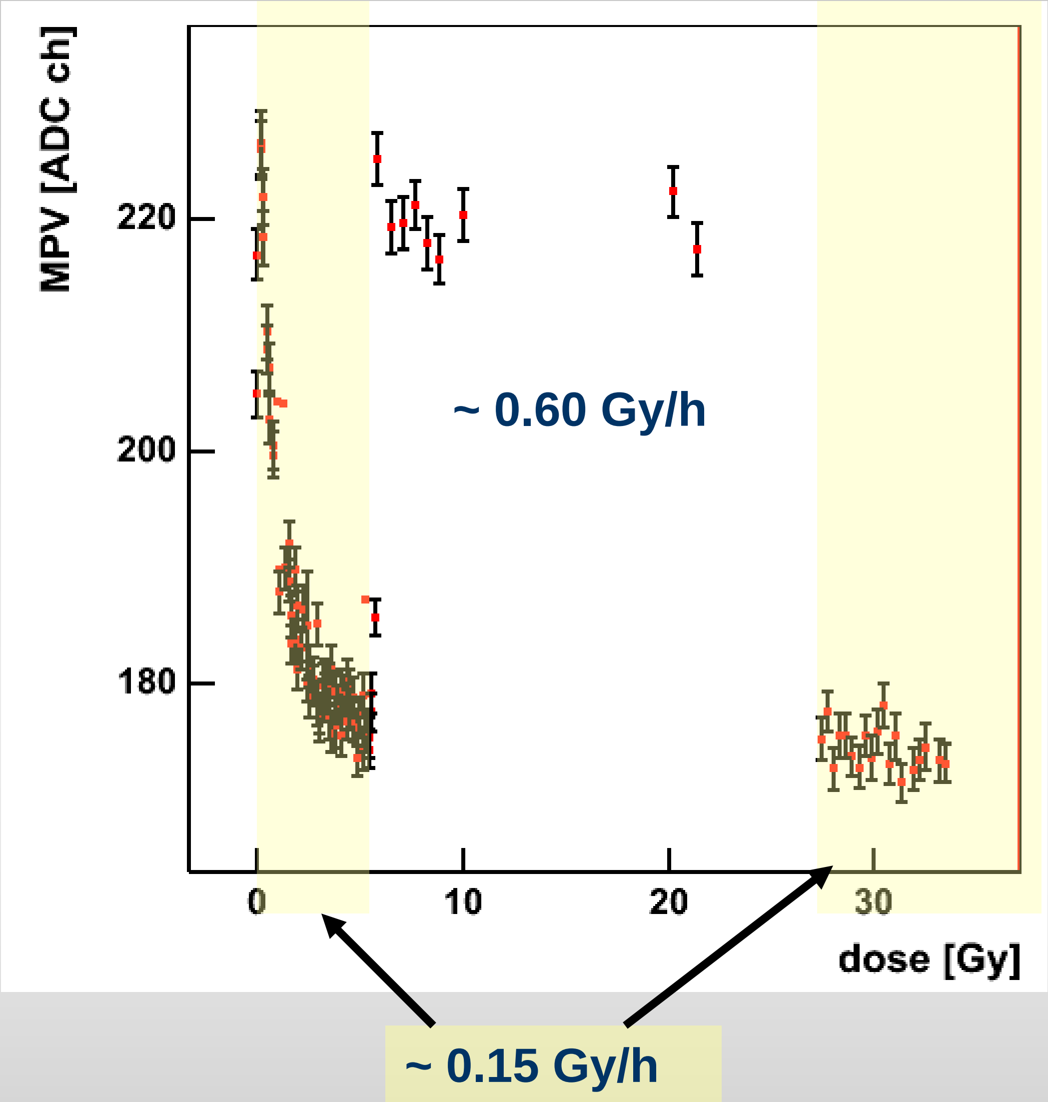
HV 100/200/300/400 V

Timing 30/30/30/60 min









~20%

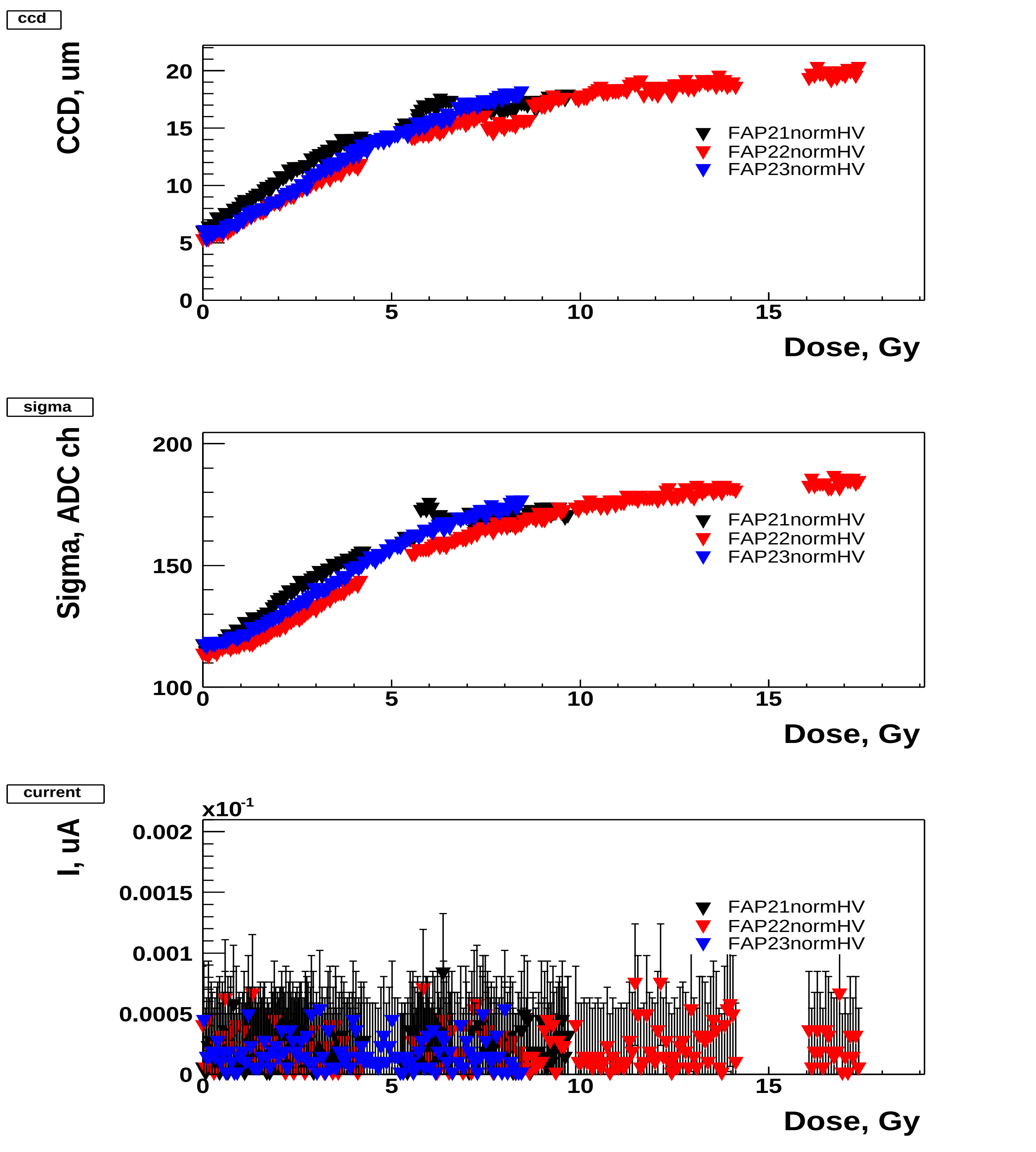
CCD vs dose:

E61:

Stable current ~0.3 nA

CCD vs dose:

FAP2:

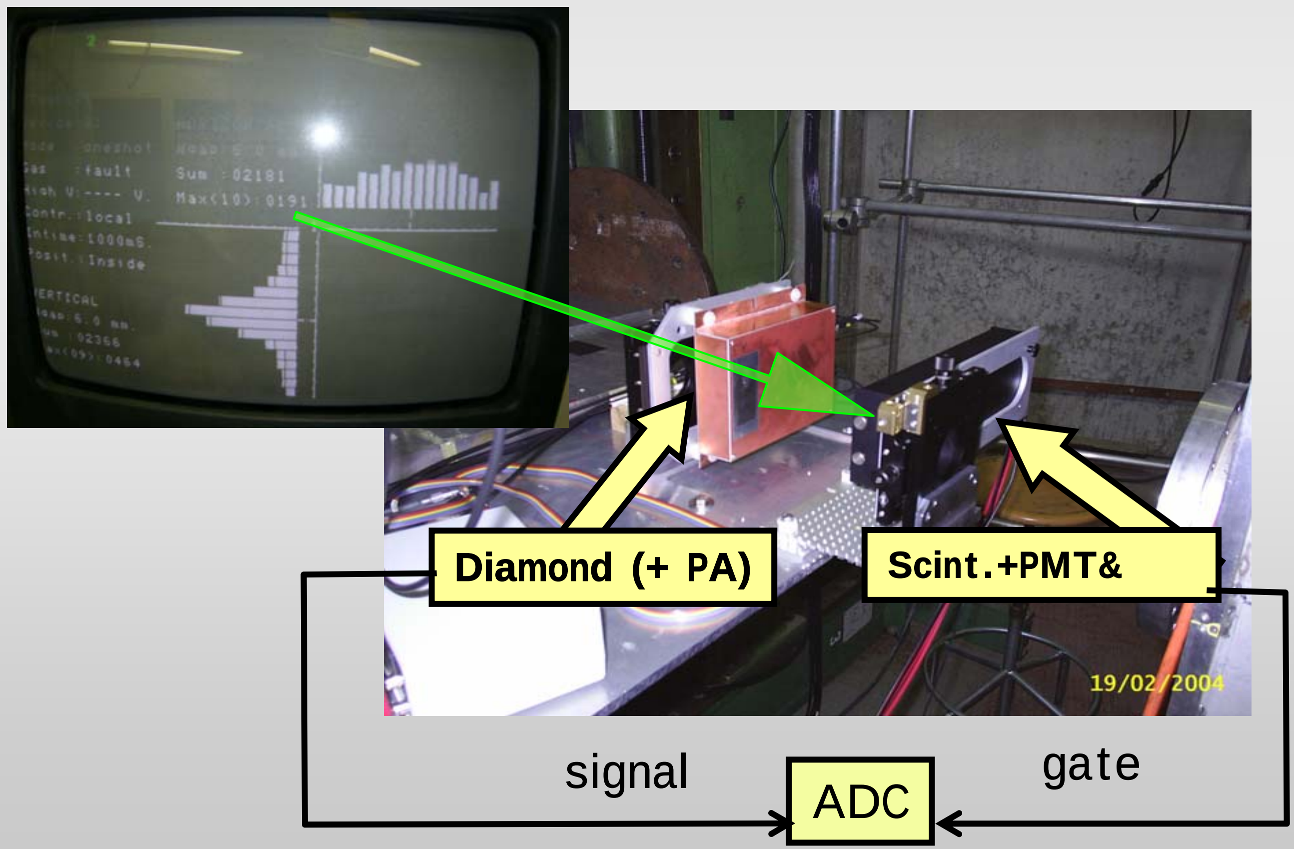


Test Beam :

Linearity measurements at High Occupancy

Hadronic beam, 3 & 5 GeV

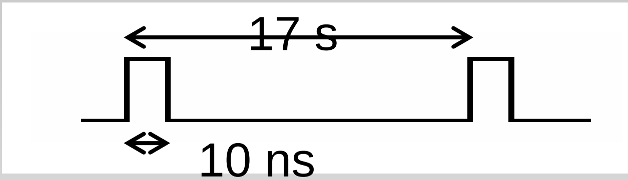
Fast extraction ~10^5-10^7 / ~10ns



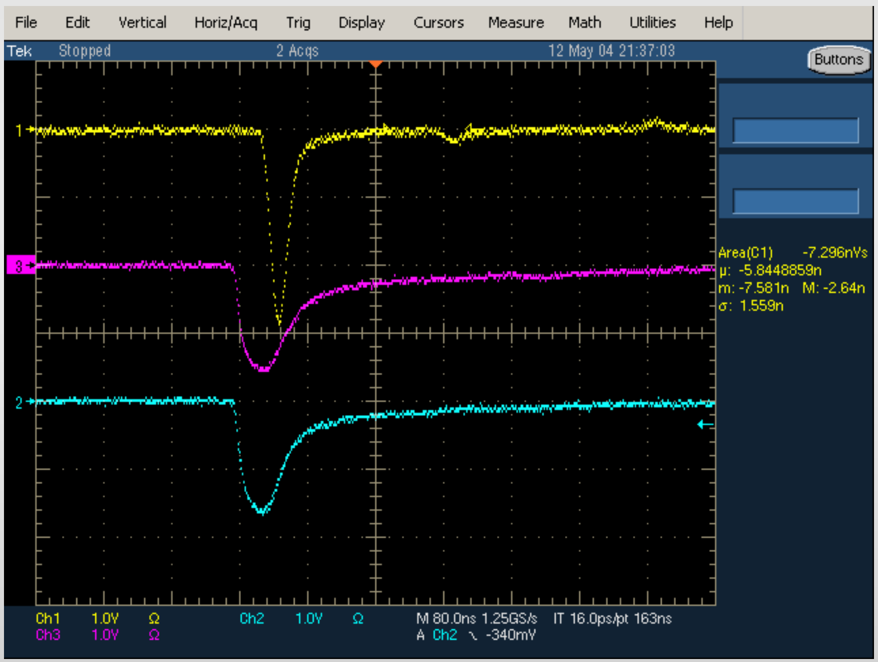
Test Beam :

Fast Extraction –

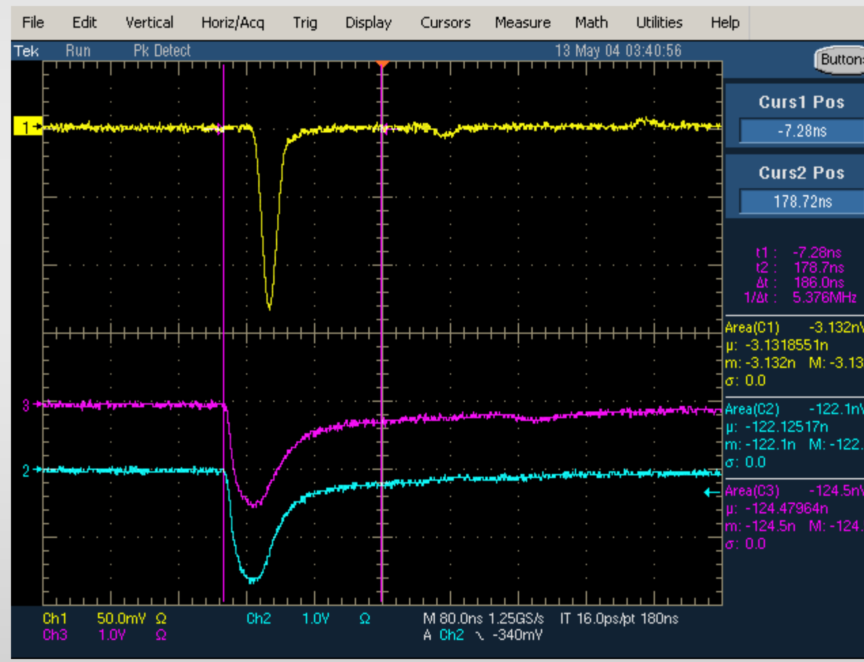
no PA is needed



E6



FAP21



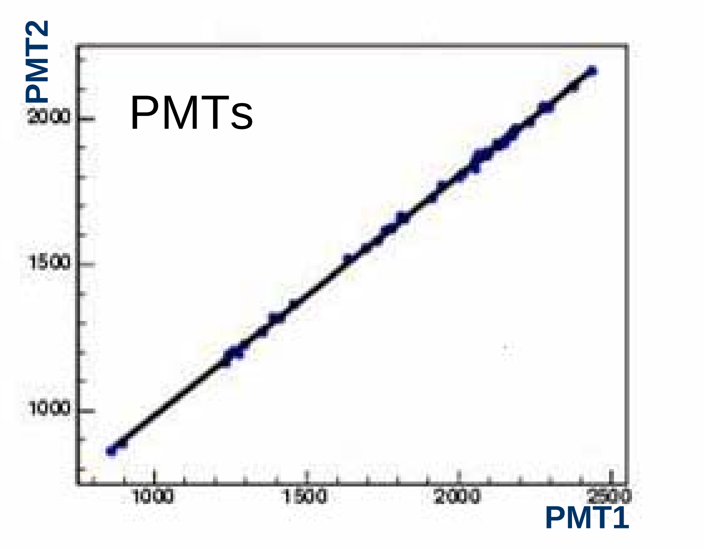
Ch1	1.0V	Ω	Ch2	1.0V	Ω
Ch3	1.0V	Ω			

Ch1	50.0mV	Ω	Ch2	1.0V	Ω
Ch3	1.0V	Ω			

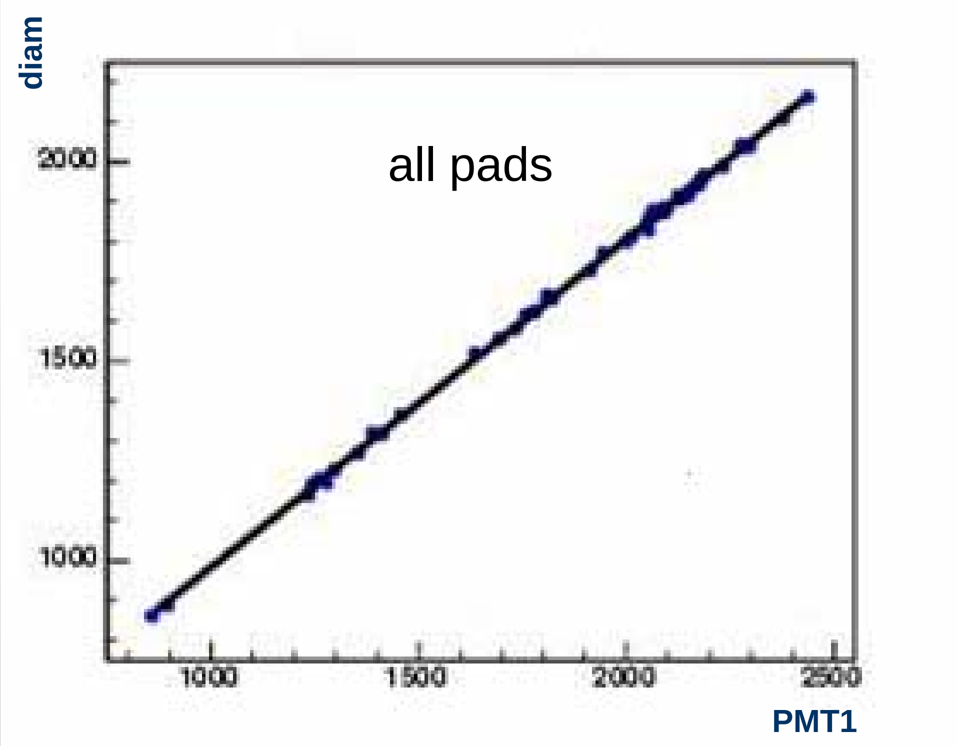
Test Beam :

Linearity - some results

PMT2 vs PMT1



diamond vs PMT1



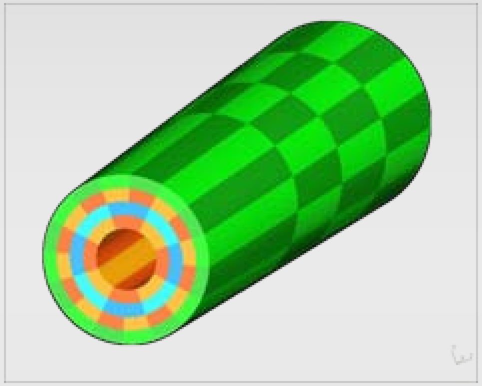
Conclusion I:

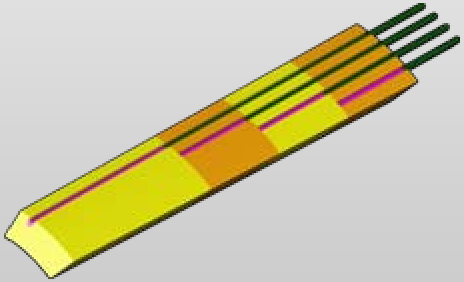
diamond/tungsten option:

- **Simulation studies shows feasibility of the diamond/tungsten option**
- **Properties of different sensors vary in a wide range**
- **The set of measurements gives information on suitability of a sensor for the BeamCal**
- **This tests together with material analysis (Raman spectrometry, Photoluminescence analysis, Thermally Stimulated Currents) should lead to an optimal choice of the BeamCal sensor material**

Heavy Crystal BeamCal with fiber readout

- crystals cut into segments in depth
- optical isolated fibers
- readout with photodetectors material
- radiation hard
- dense
- high lightyield

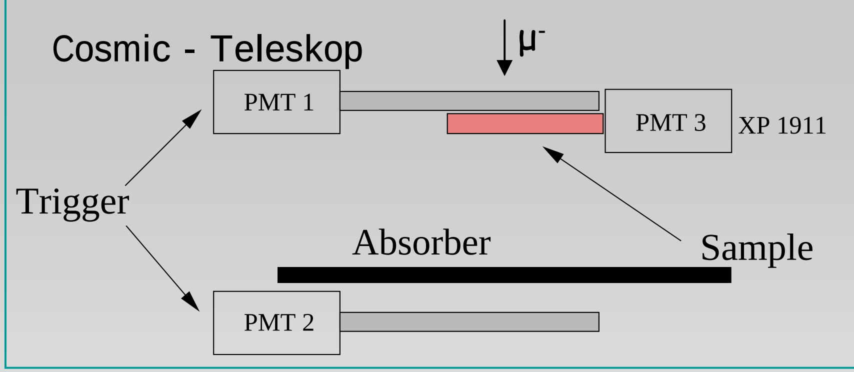


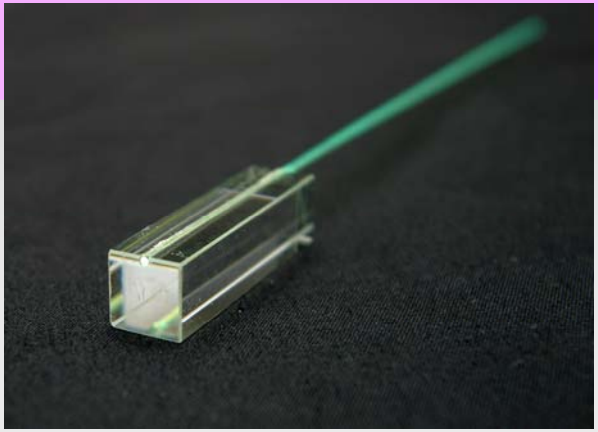


Fiber readout:

- **lightyield reduction ?**
- **crosstalk between segments ?**

SetUp





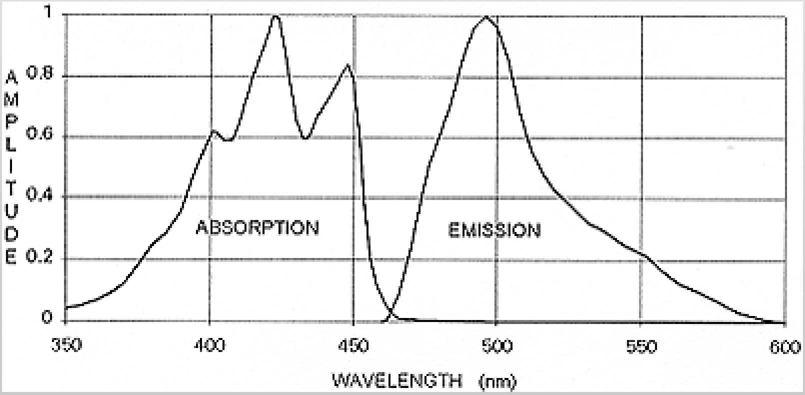
BCF-91A - Fibers:

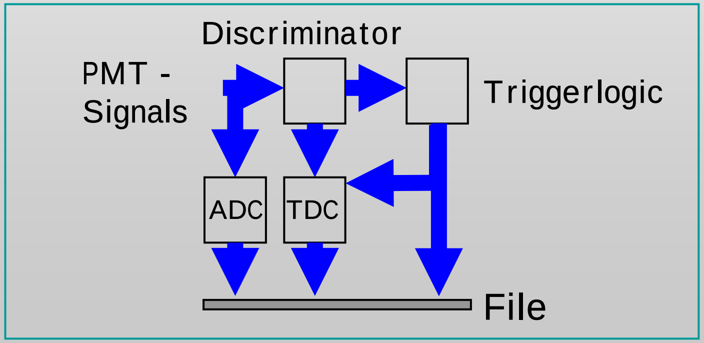
Λ(max. emission)

494 nm

-> QE(PMT-XP1911)

13 ± 2 %

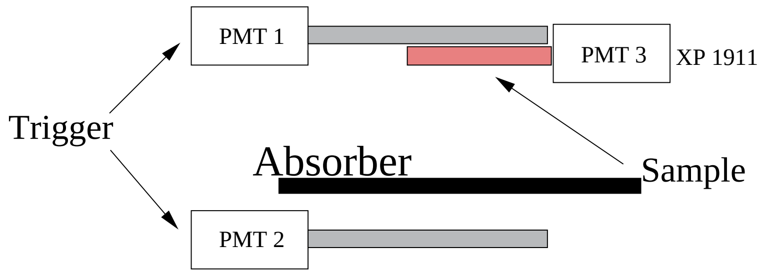




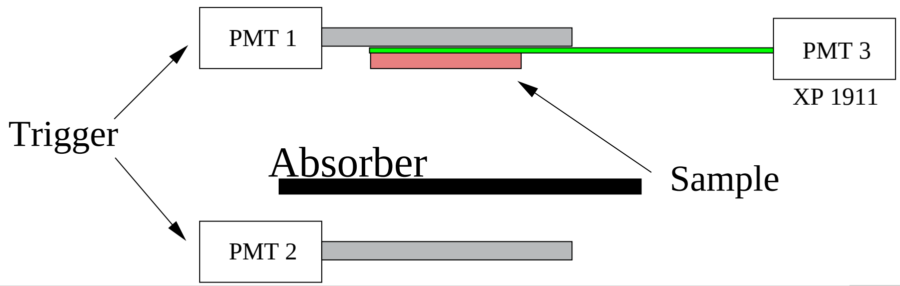
Direct vs Fiber Readout :

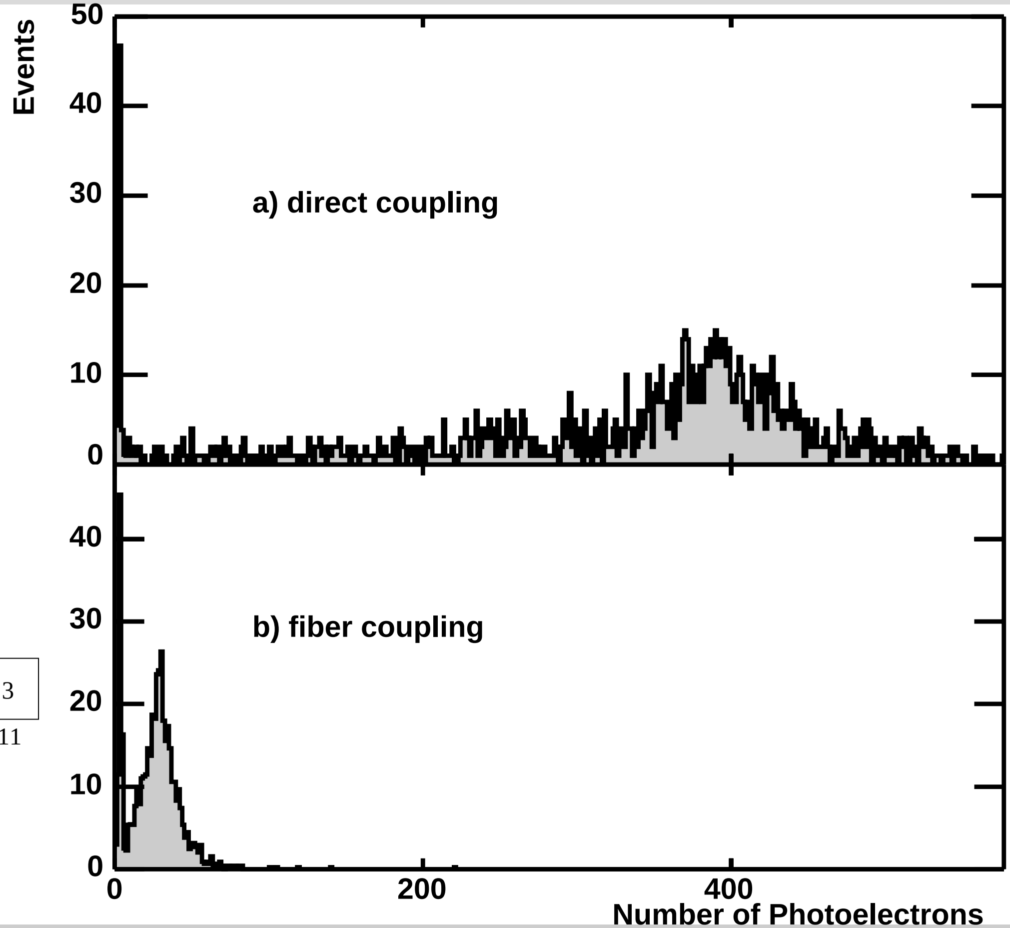
example

direct readout



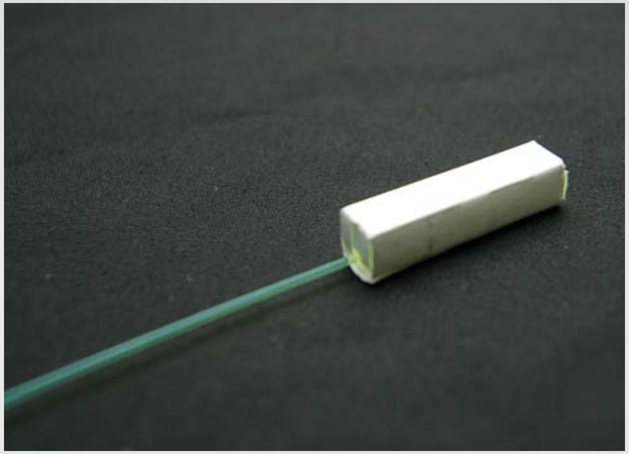
fiber readout





Direct vs Fiber Readout : results

Plastic Scintillator

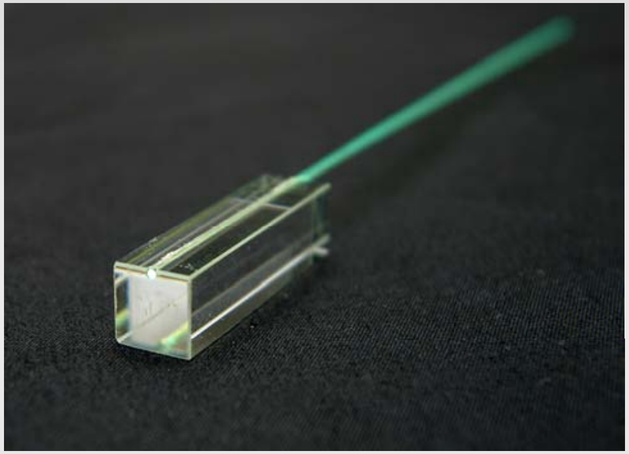


Direct readout : (QE_{PMT} 25 ± 1 %)
Photoelectrons : 390 ± 50 p.e. / μ
Lightyield : 1560 ± 260 photons / μ

Fiber readout : (QE_{PMT} 13 ± 2 %)
Photoelectrons : 27 ± 4 p.e. / μ
Lightyield : 210 ± 60 photons / μ

Lightyield reduced to 14 ± 4 %

Leadglass



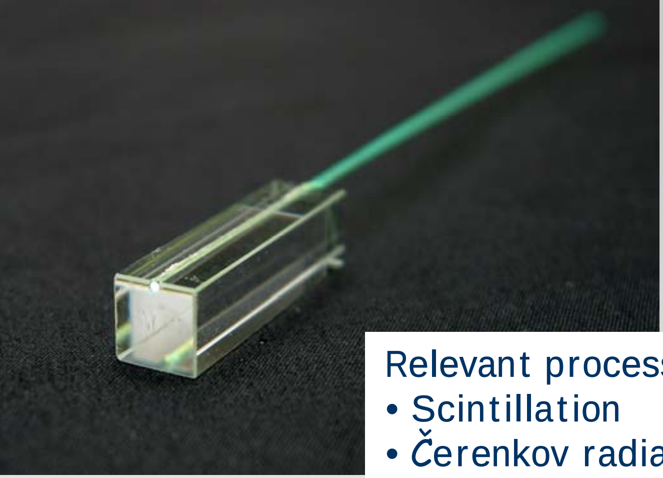
Direct readout : (QE_{PMT} 15 ± 2 %)
Photoelectrons : 18.2 ± 2.2 p.e. / μ
Lightyield : 120 ± 30 photons / μ

Fiber readout : (QE_{PMT} 13 ± 2 %)
Photoelectrons : 2.4 ± 0.5 p.e. / μ
Lightyield : 19 ± 7 photons / μ

Lightyield reduced to 16 ± 7 %

Simulation of lightyied reduction

GEANT4



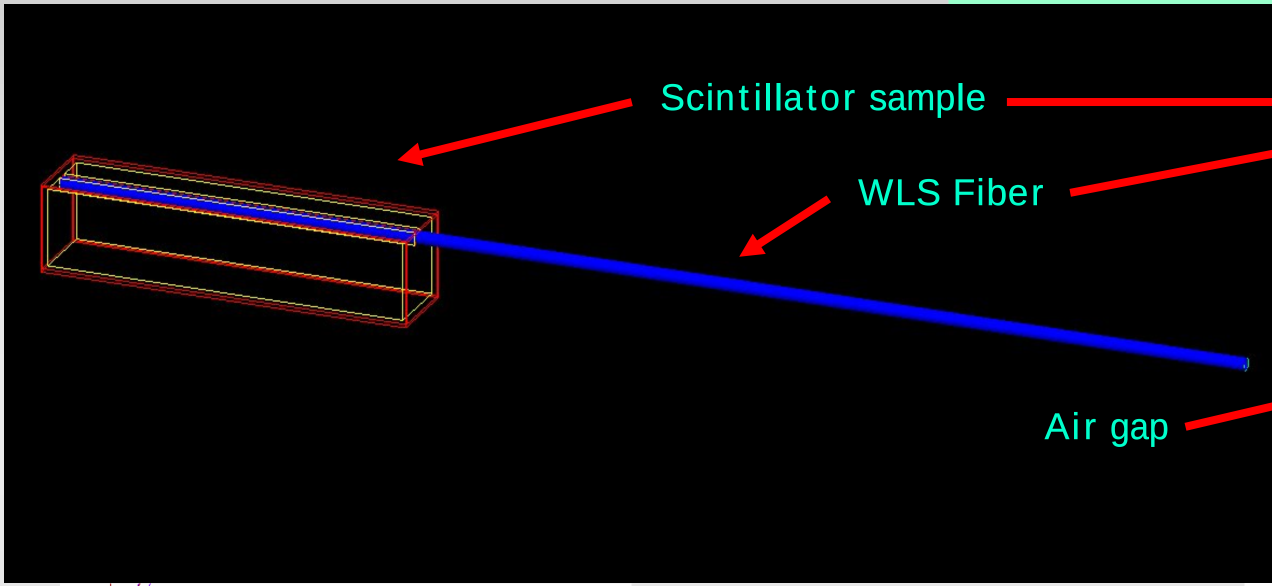
Relevant processes provided by GEANT4, that have to be understood:

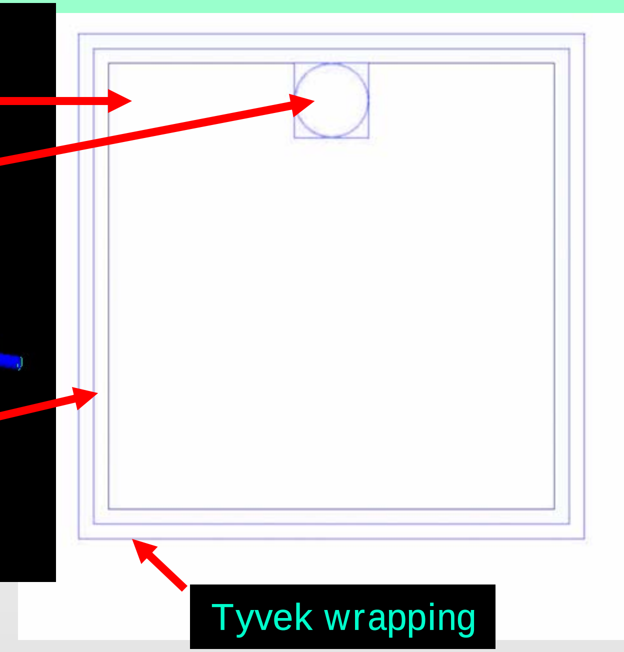
- Scintillation
- Čerenkov radiation
- Transport of optical photons in the medium
- Reflection
- Scattering
- photons at material boundaries
- Absorption
- Reemission
- wavelength shifting

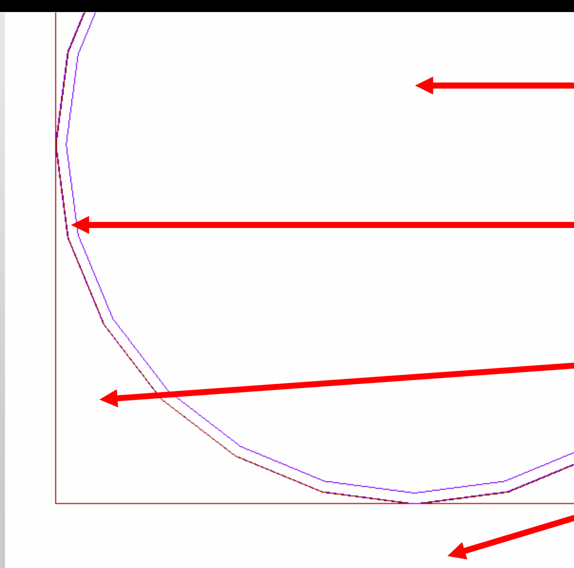
Process	**Geant4 source**	
Cerenkov	`processes/electromagnetic/xray -> G4Cerenkov`	
Scintillation	`processes/electromagnetic/xray -> G4Scintillation`	
OpBoundary	`processes/optical -> G4OpBoundary`	
OpAbsorption	`processes/optical -> G4OpAbsorption`	
OpRayleigh	`processes/optical -> G4OpRayleigh`	
OpWLS	`processes/optical -> G4OpWLS`	since GEANT4 6.0
(Transportation)		

Simulation of lightyied reduction

geometry







Fiber core:
Polystyrene, n=1.6

Fiber cladding:
Acrylic, n=1.49

Optical glue:
Epoxy, n=1.56

Scintillator:
Polyvinyltoluene, n=1.58

Fiber diameter: 1mm,

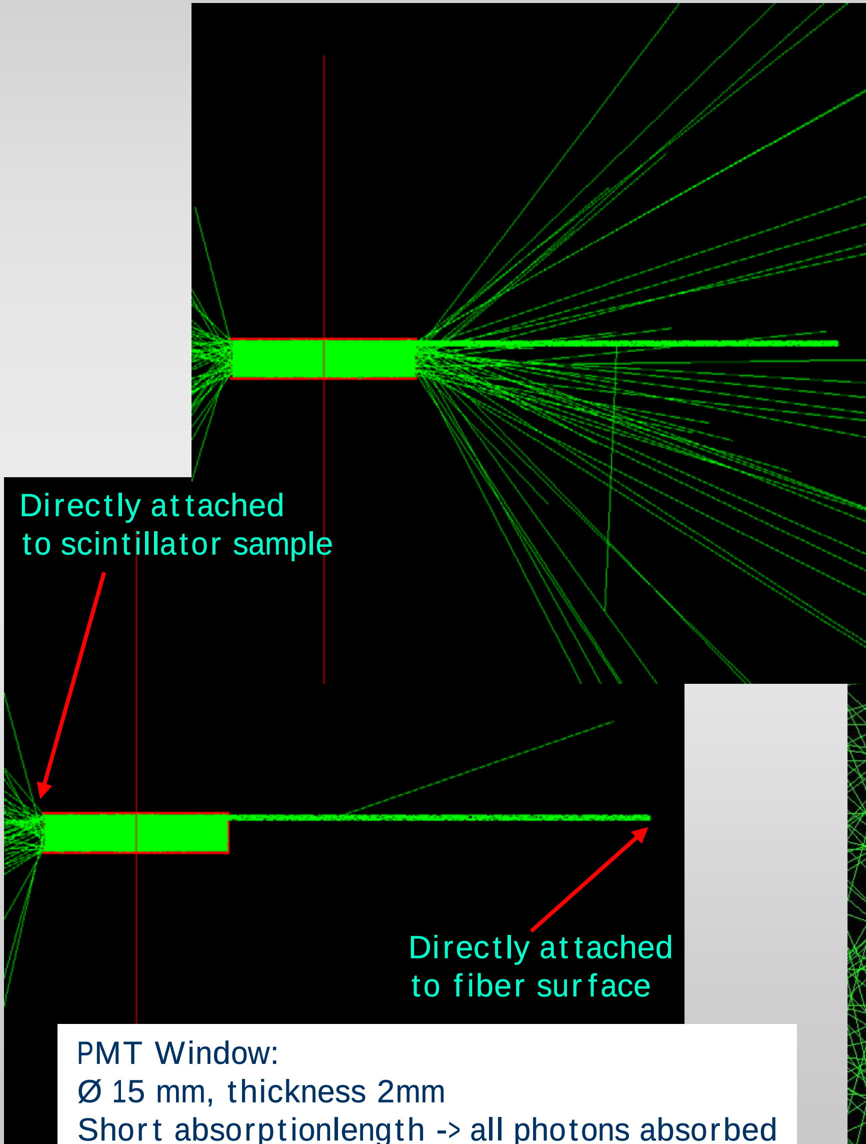
Cladding thickness:
3% of core Ø

Channel: 1mmx1mm

Simulation of lightyied reduction

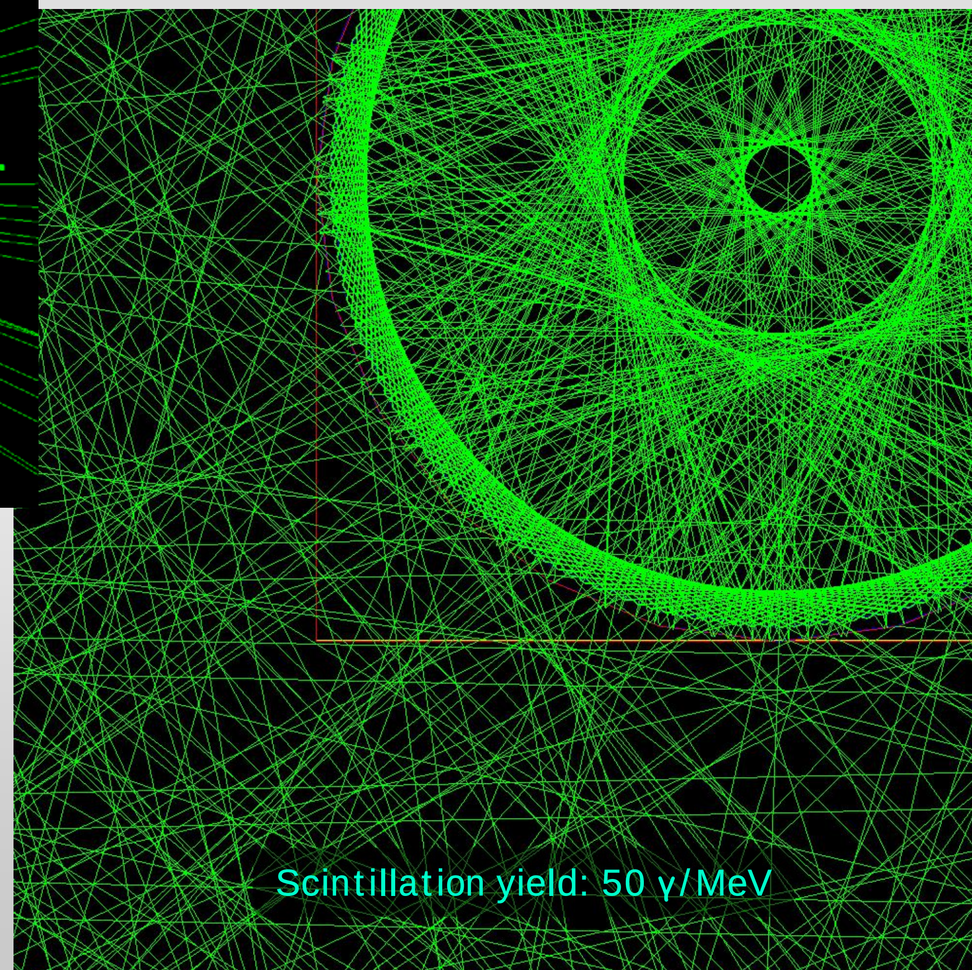
illustration

Single muon events



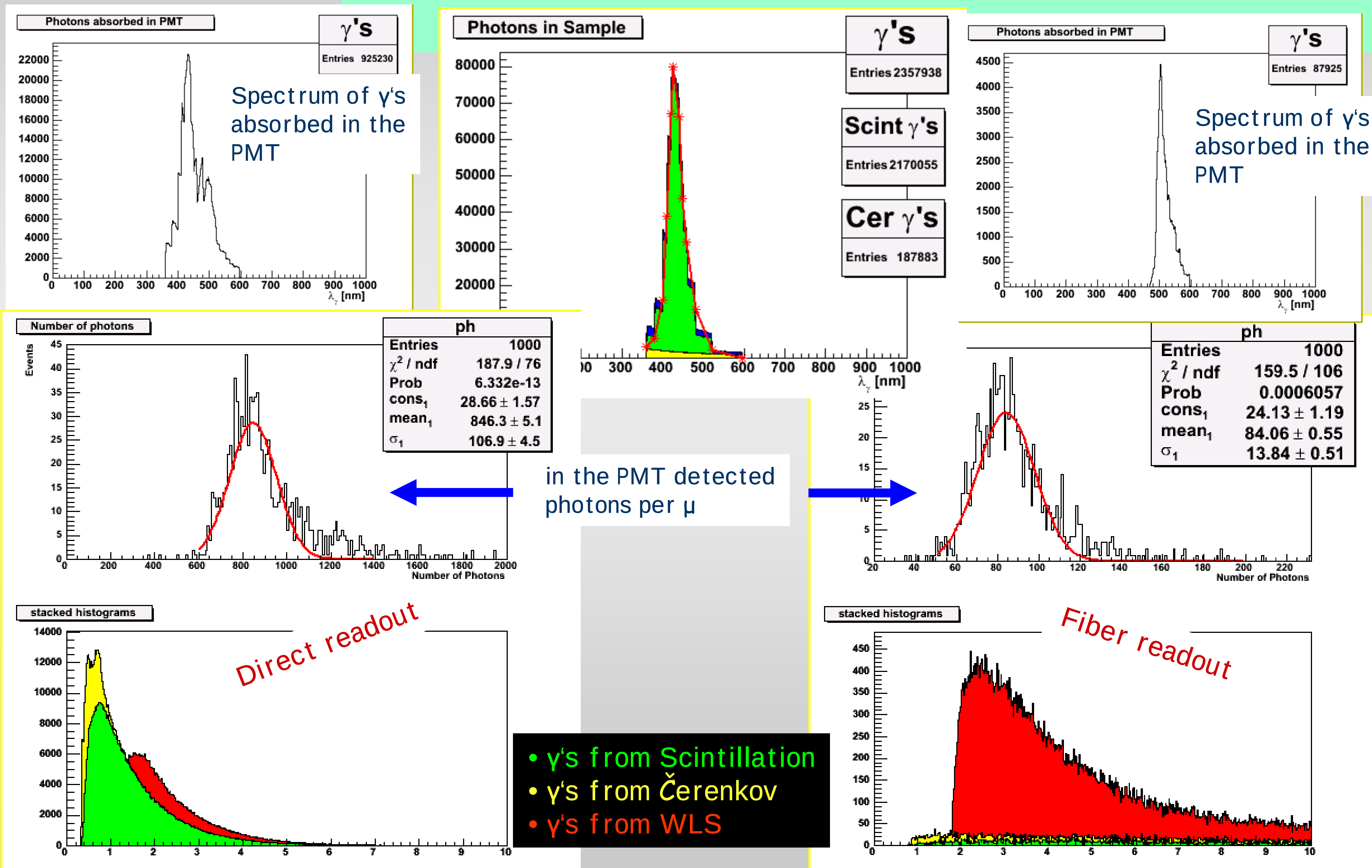
PMT Window:
Ø 15 mm, thickness 2mm
Short absorptionlength -> all photons absorbed

Optical photons coupled into the fiber



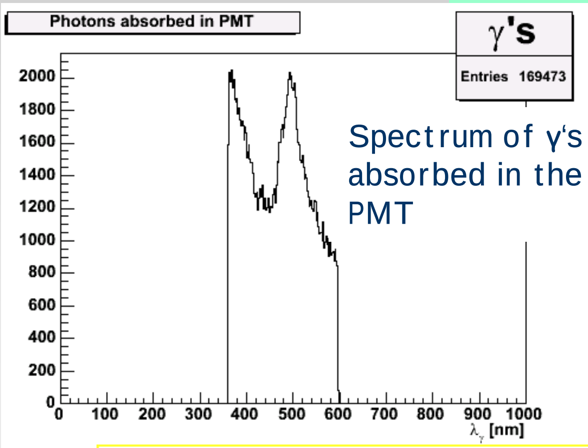
Simulation of lightyied reduction

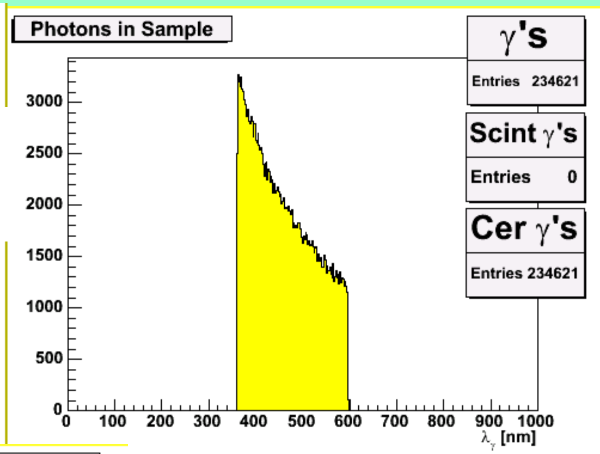
plastic scintillator – direct vs fiber readout

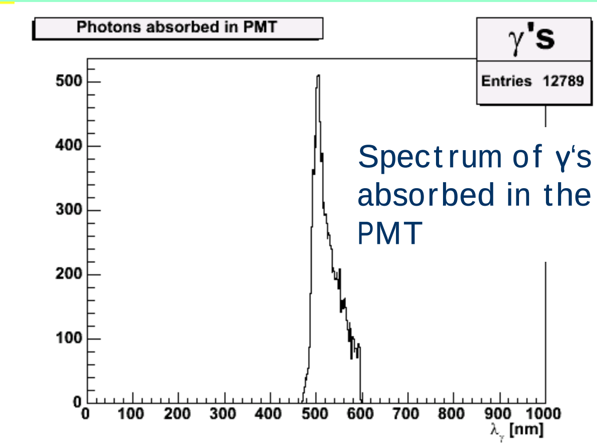


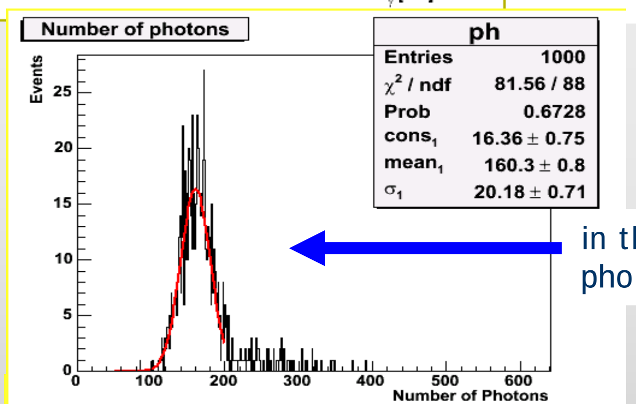
Simulation of lightyied reduction

leadglass – direct vs fiber readout

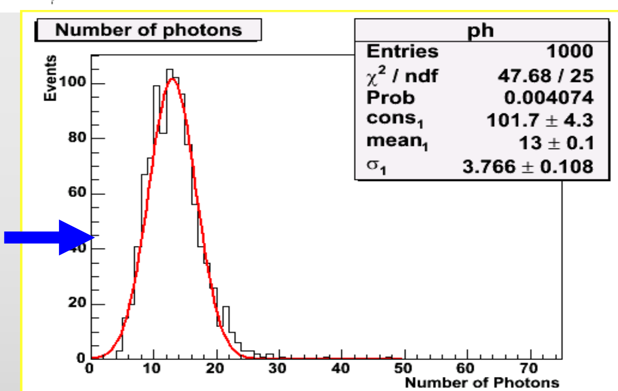


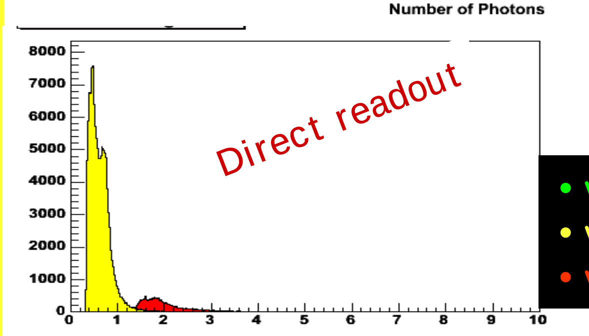




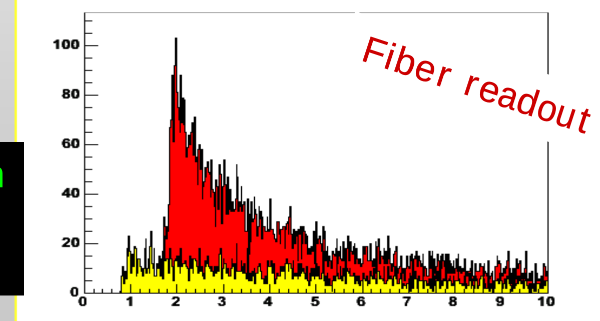


in the PMT detected photons per μ





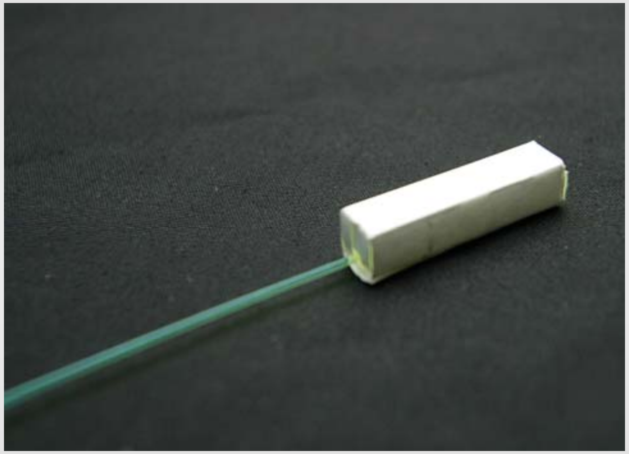
- γ's from Scintillation
- γ's from Čerenkov
- γ's from WLS



Simulation of lightyied reduction

results

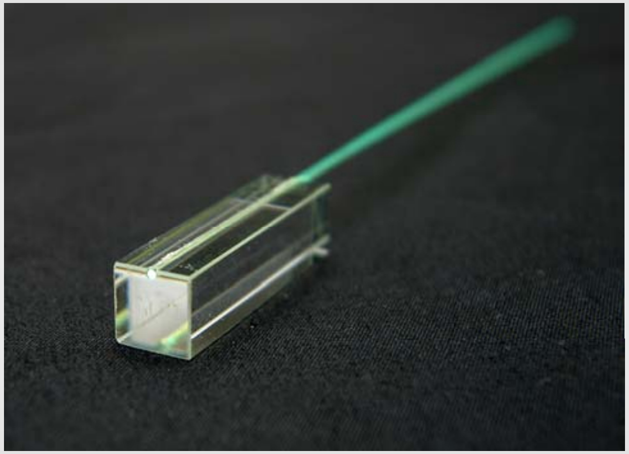
Plastic Scintillator



(exp.):
Lightyield reduced to 14 ± 4 %

(sim.):
Lightyield reduced to 9.3 – 9.8 %

Leadglass



(exp.):
Lightyield reduced to 16 ± 7 %

(sim.):
Lightyield reduced to 8.3 - 12 %

Conclusion II:

Heavy crystal option:

- **performance simulations are promising**
- **exp.: lightyield reduced to ~15 % due to fiber readout**

→ **fiber readout works**

- **first naive lightyield simulations in good agreement with experimental results**

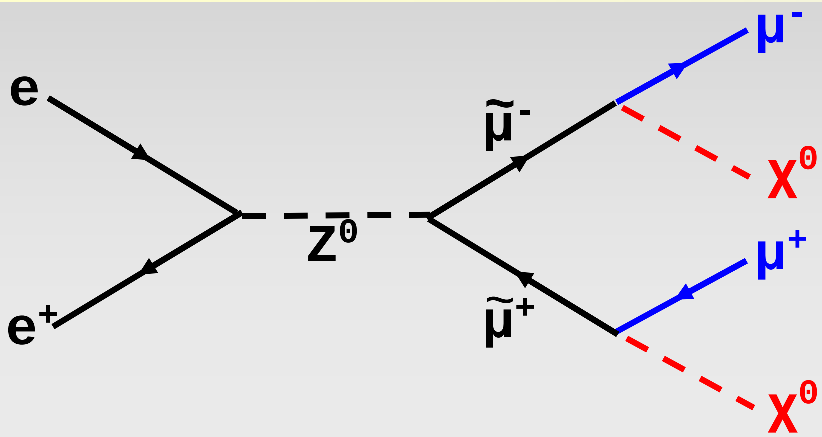
for realistic simulation:

- implementation of realistic boundary- and surface conditiond of the materials and samples
- exact WLS-absorption spectrum
- better understanding of absorption- and emissions-behaiviour of the materials
- material composition

- **next steps to include lightyield simulations in the performance simulation**

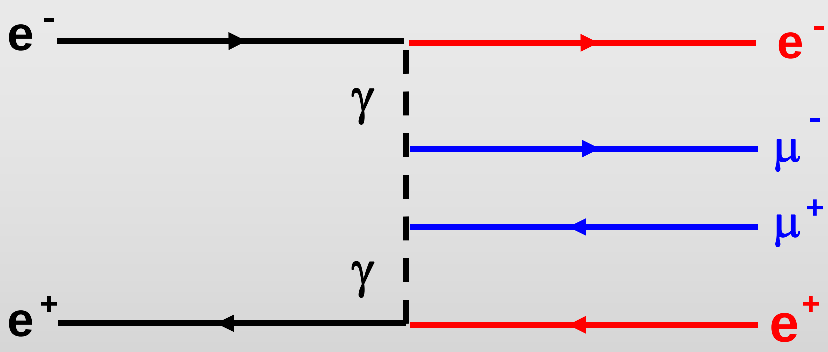
BeamCal:

new physics searches:



The Physics:
production of SUSY particles

Signature:
$\mu^+ \mu^-$ + missing energy
$\sigma \sim 10^2$ fb (SPS1a)



The Background:
two-photon events

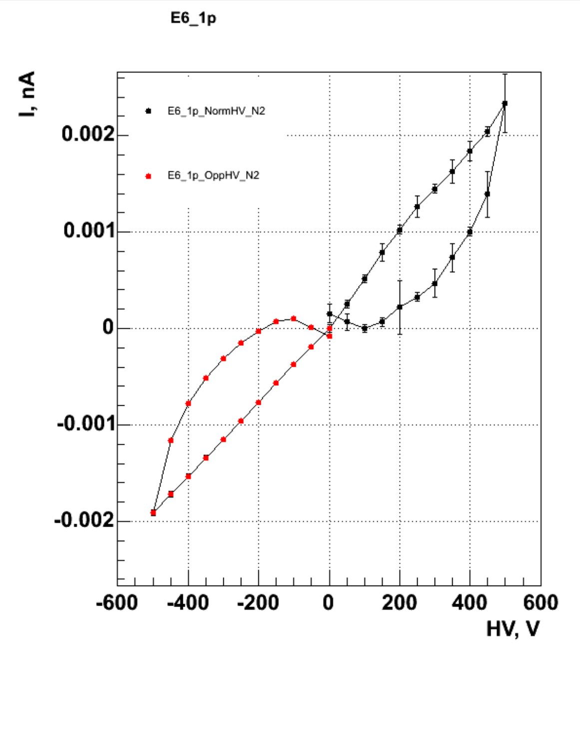
Signature:
$\mu^+ \mu^-$ + missing energy (if electrons are not tagged)
$\sigma \sim 10^6$ fb

NEED: - **Excellent electron identification efficiency**
- **Coverage down to as small angle as possible**

IV Measurements:

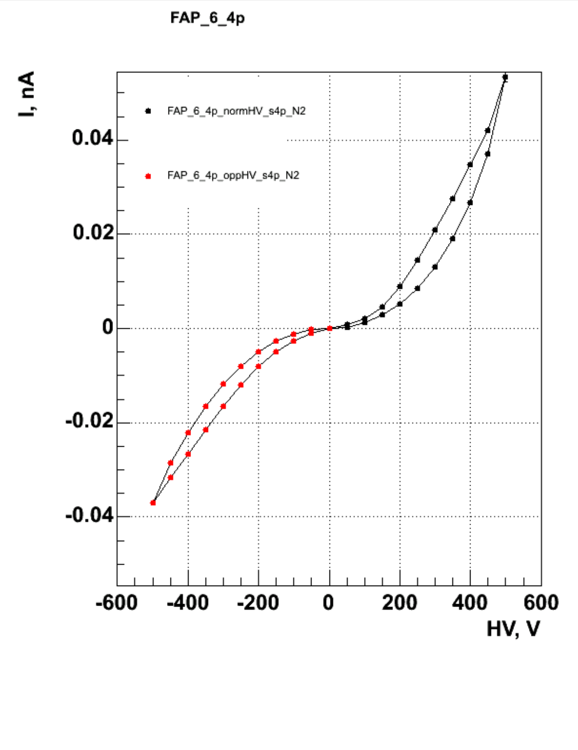
E61 – "Element6":

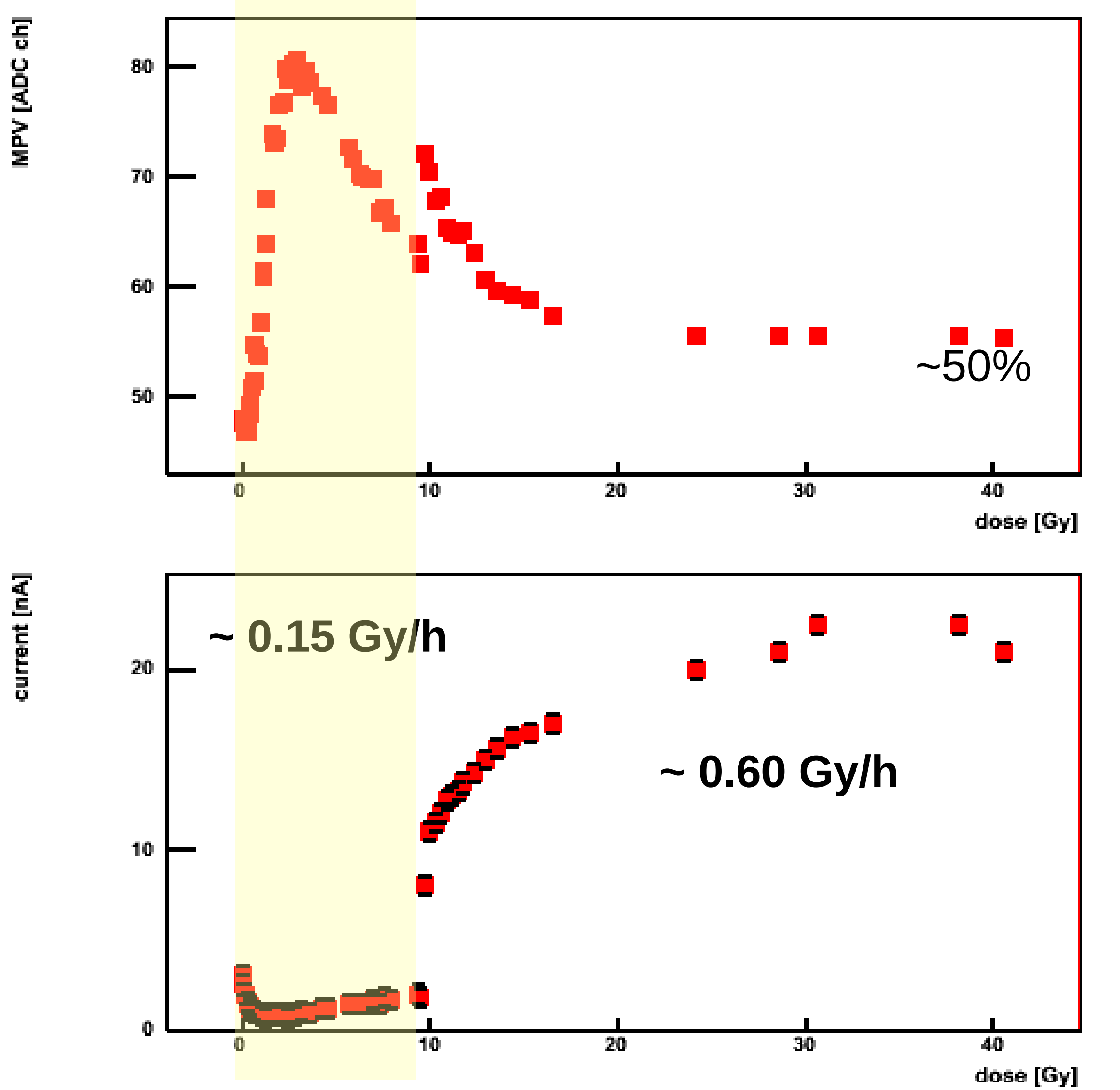
- 1X1 cm metallization
- 500 μm thickness
- C = 9.7 pF



FAP6 – Freiburg:

- 1X1 cm metallization (4 pads)
- 470 μm thickness
- C = 9.9 pF





CCD vs dose:

FAP6:

Test Beam :

Fast Extraction - some results: