BLM developments in the CLIC Test Facility (CTF3)

3rd oPAC Topical workshop on Beam diagnostics

- Motivation: BLM requirements
- Investigated BLM technologies
- Measurements at the TBL
- Diamond test at Califes

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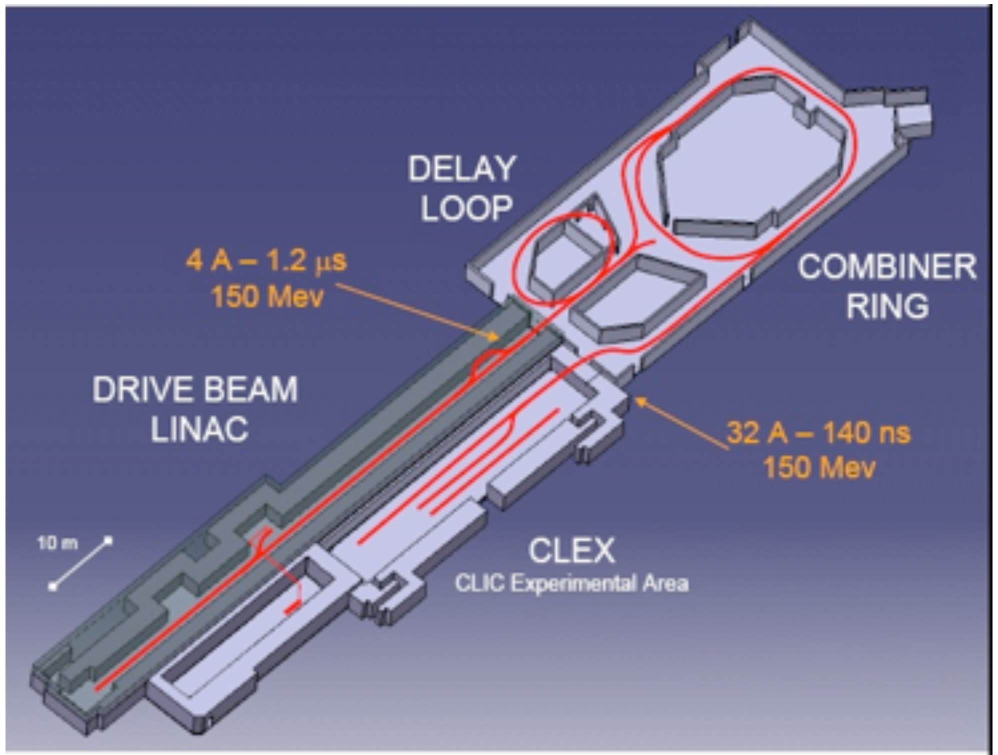
Motivation

- Design of a BLM system for CLIC
  - Two beam acceleration scheme:
    - Main Beam: Accelerating beam (9 GeV → 3 TeV) for luminosity production 4 A, 0.5ns bunch spacing, 150 ns
    - Drive Beam: Decelerating (2.4 GeV → 240 MeV) beam for RF power extraction (101 A, 250 ns, bunch spacing 0.083 ns)
    - Disentangle losses from both beams (X-talk)
  - Damping rings
    - Large amounts of synchrotron radiation (SR)
    - Continuous < 398m 2.6 GeV ring, t_{rev}=1.3μs, bunch spacing 0.5 ns, 150 ns pulse

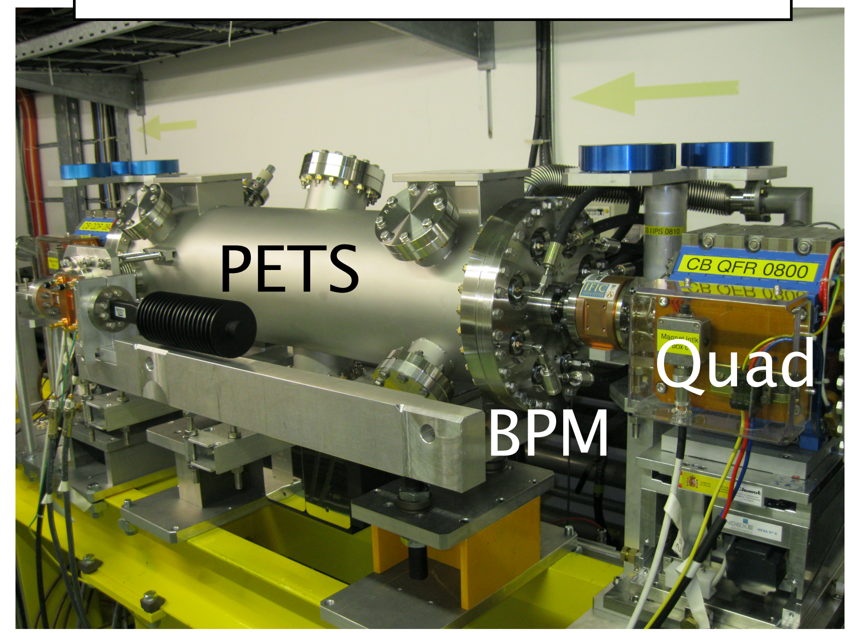
- A BLM system based on (LHC-like) ionization chambers fulfills all the requirements (for the Two Beam Module):
  - ✓ Dynamic range: 10^{+6}/ Sensitivity: 7 x 10^{-9} Gy / time response < 8 ms
  - Number of required BLMs > 40000
  - No temporal profile of the loss within the bunch train

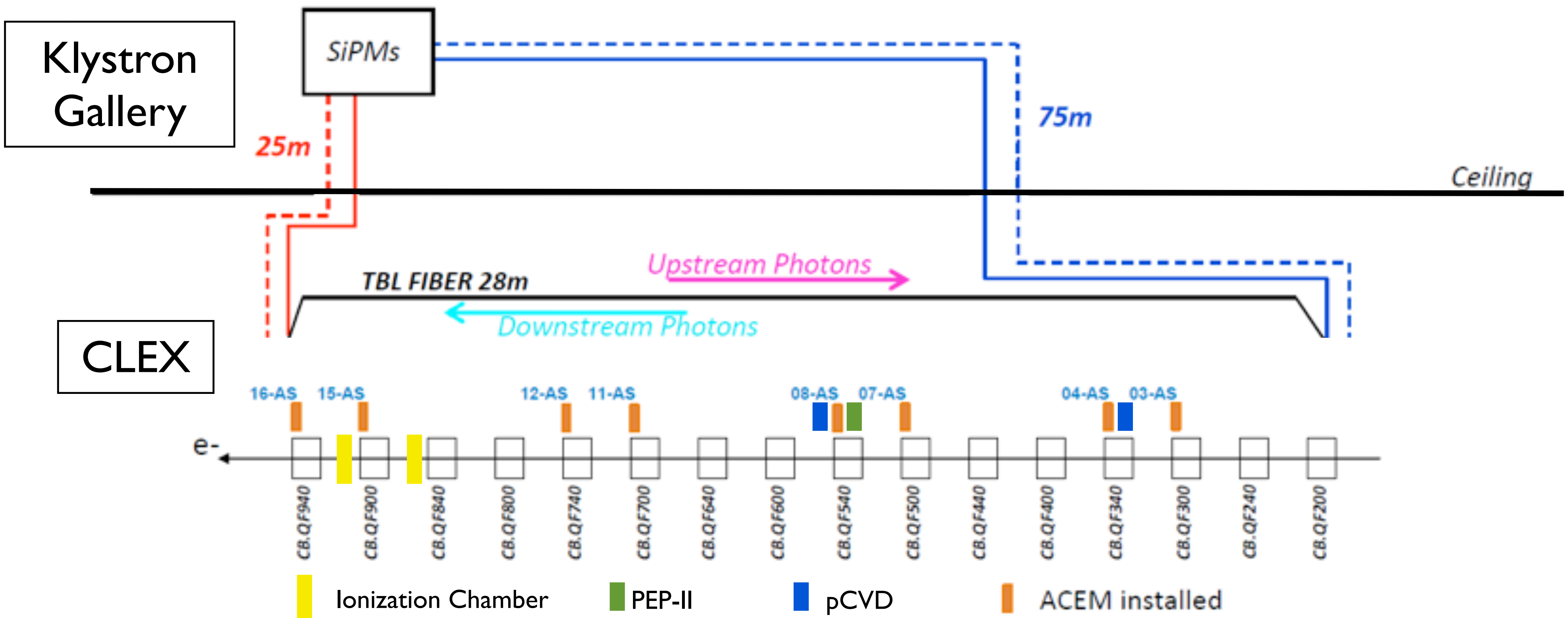
- Investigating cost effective, faster and insensitive to synchrotron radiation
  - Diamond (pCVD)
  - ACEM (Al Cathode Electron Multiplier)
  - Crystal Cherenkov radiator (PEP-II)
  - Optical fibers (Cherenkov radiator)

BLMs at the CLIC Test Facility CTF3



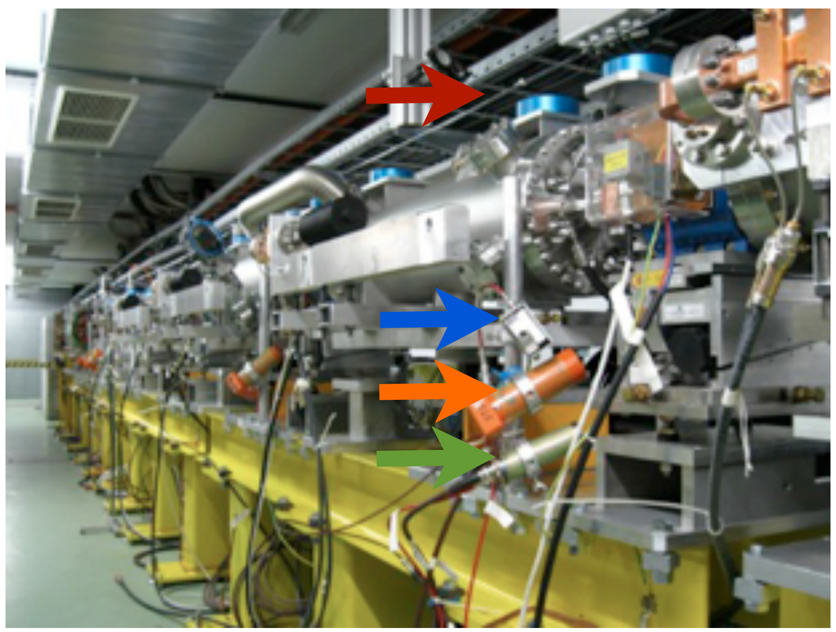
Half FODO CELL at the TBL

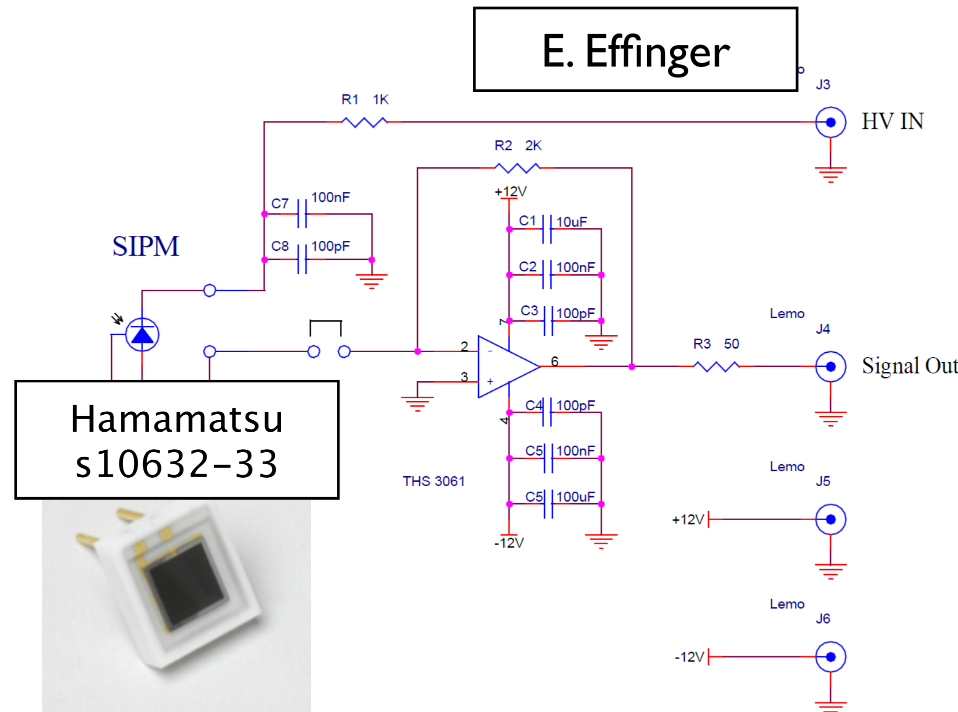




BLMs at the CLIC Test Facility CTF3

- Pure Silica 200um core multimode (NA = 0.22) optical **fiber** located 28cm on top of the beam line
- Detectors located 10cm left and 20/30/40 cm (**pCVD**/**ACEM**/**PEP-II**) below the beam line

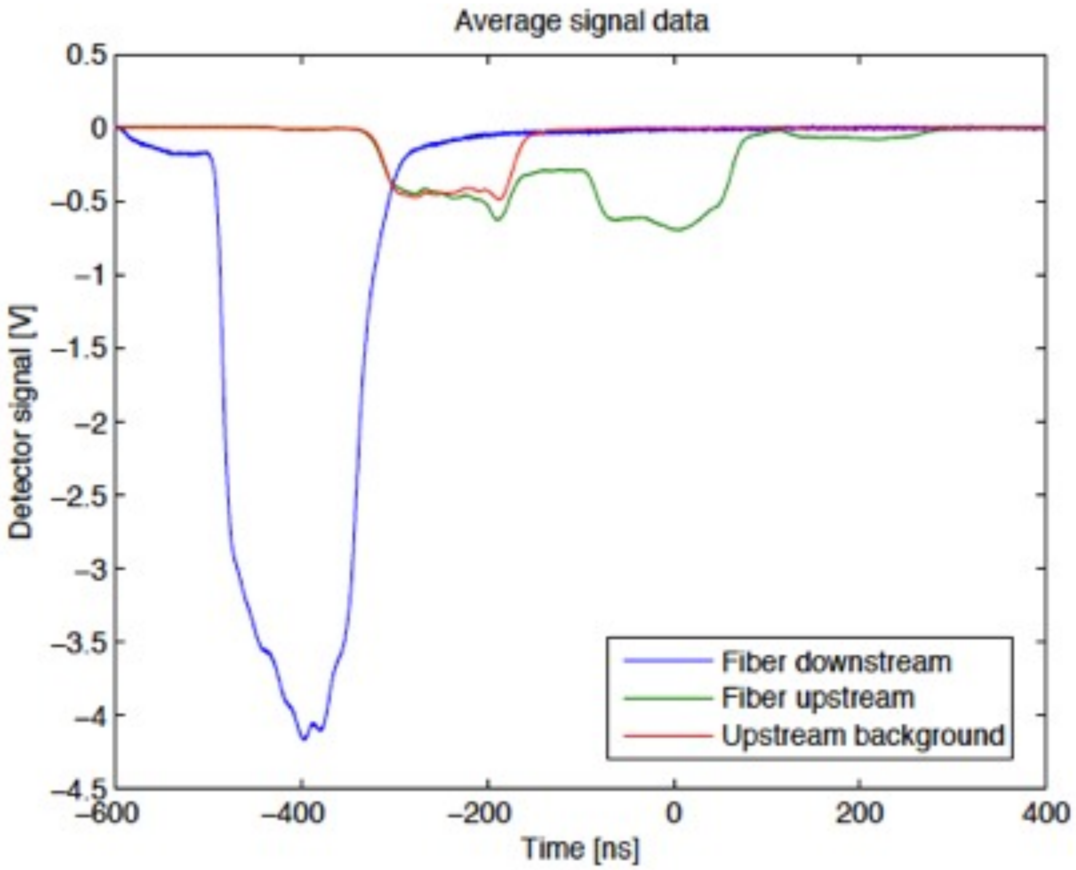


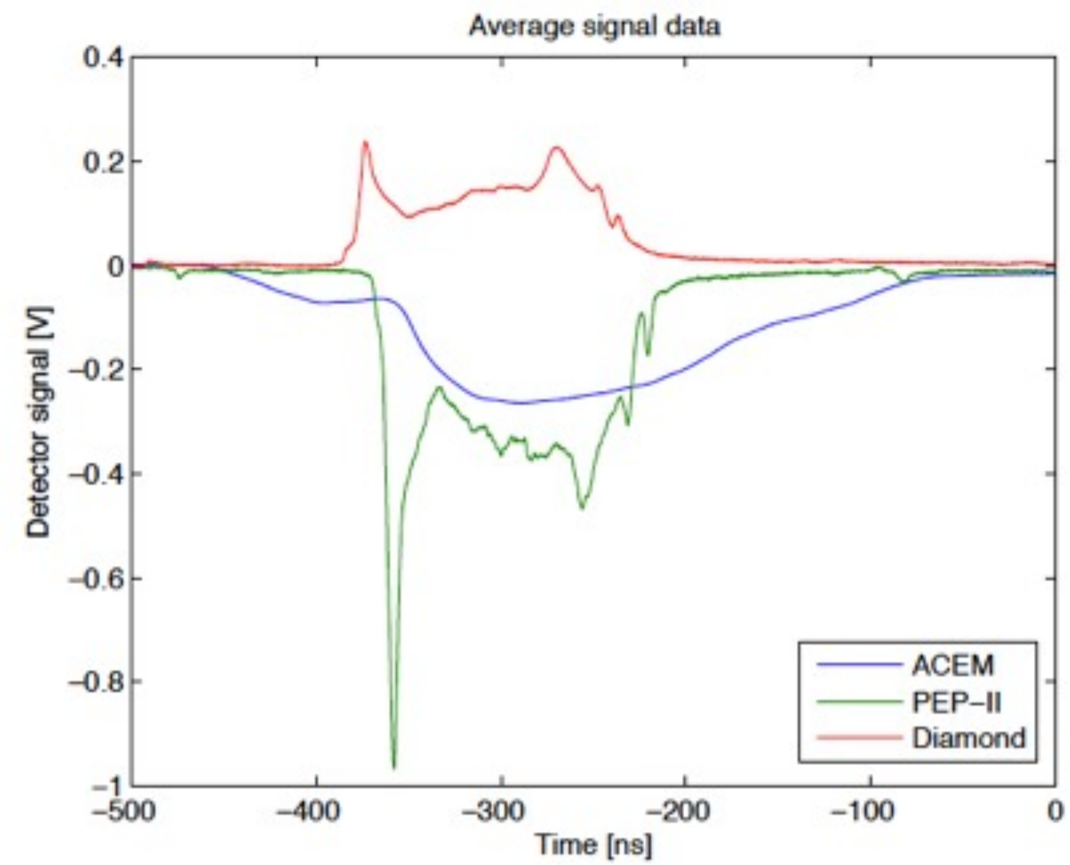


- Bias Voltages: 500 V positive for pCVD and negative for ACEM/PEP-II (10^{+4} gain) and 71.2 (MPPC gain 3.4 10^{+5} gain)
- Signals terminated on 50 Ω and read via 8 bit ADC

TBL measurements I

- Beam transmission 100% (measured by BPMs): 16A and 150 ns pulse

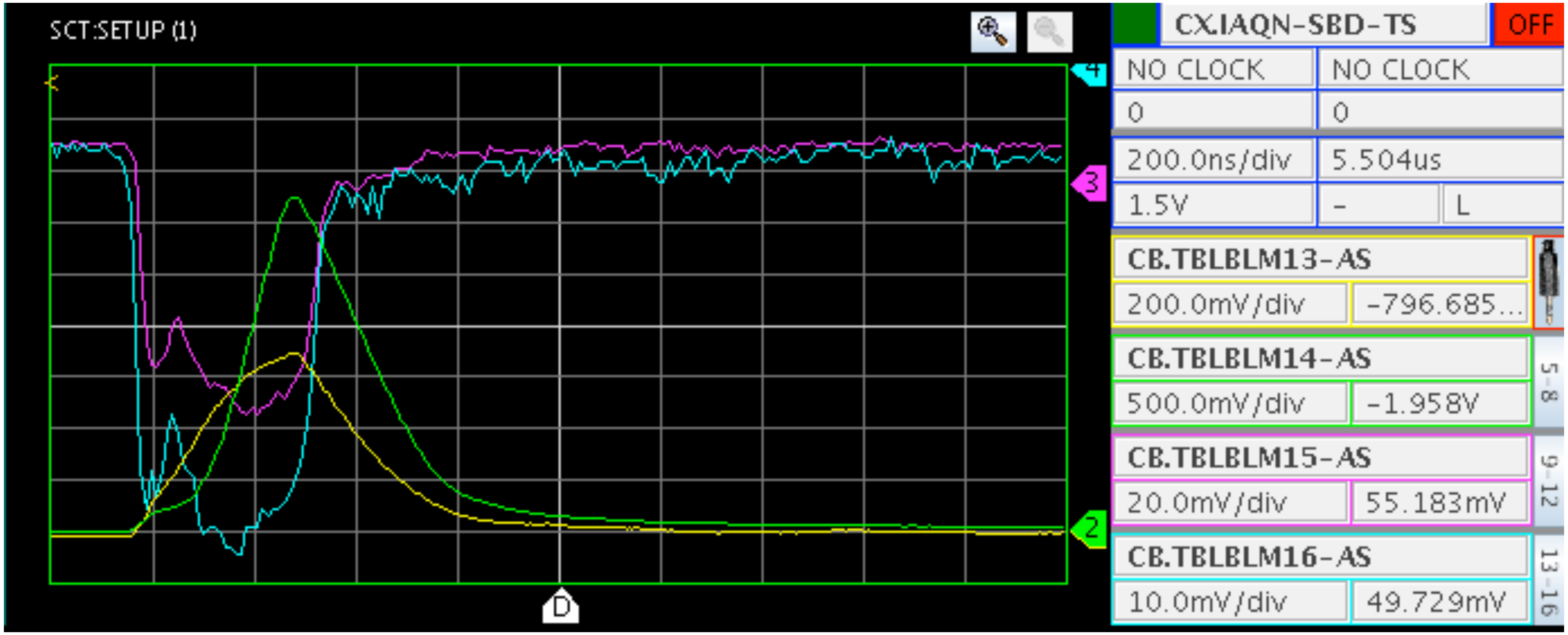




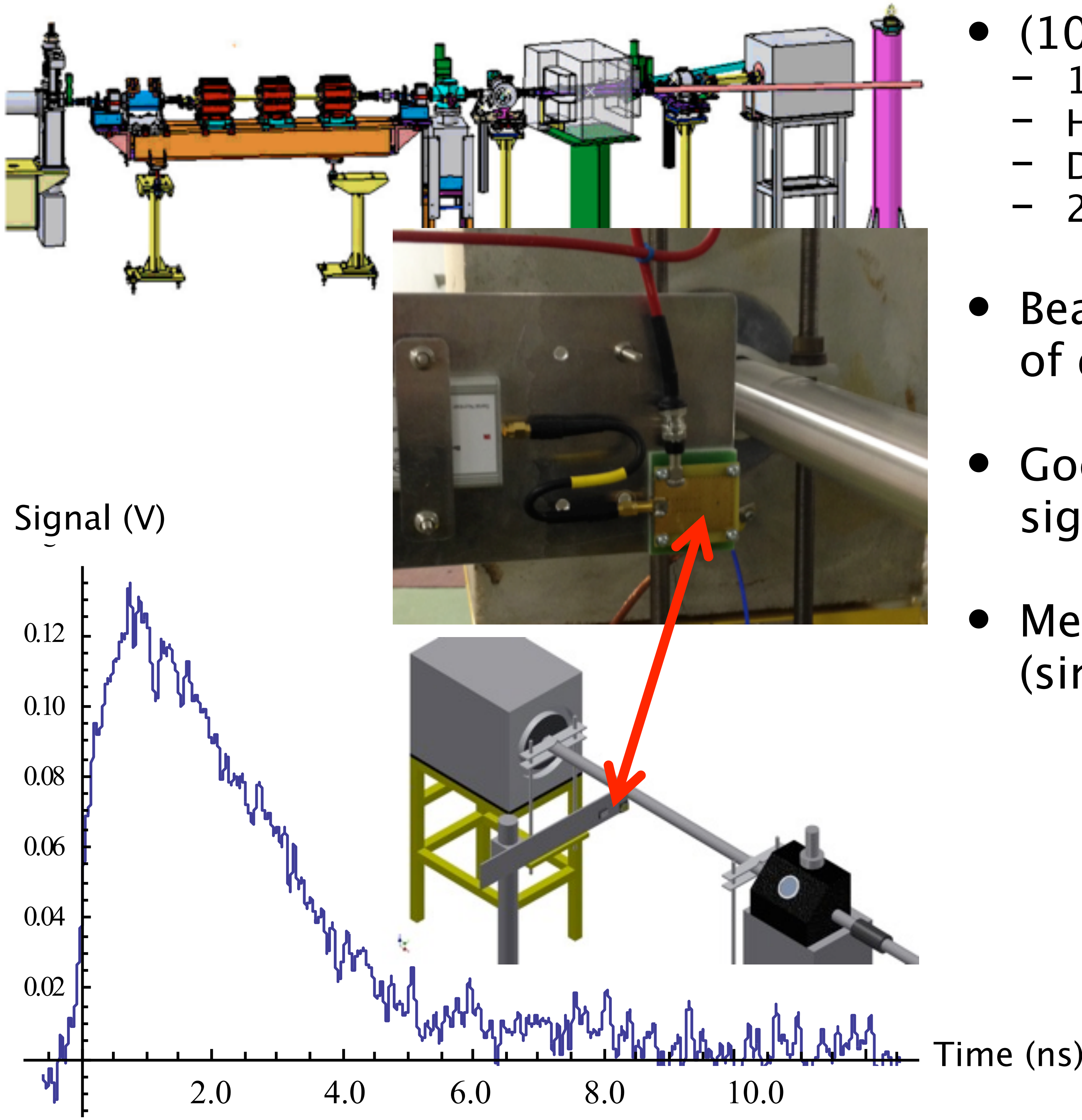
Detector	Measured Charge (nC)	Simulated min charge (10^{-21}C/e)	Simulated max charge (10^{-21}C/e)	Mean (10^{-21}C/e)	Estimated Beam Loss (mA)
ACEM	1.21± 3.9%	9.3	50.0	23.0	51
PEP-II	1.26 ± 13%	11.0	110.0	42.0	30
pCVD	4.20 ± 15%	9.7	40.0	21.0	20
Fiber (down)	2.36 ± 2.4%	2.5	19.0	9.0	260
Fiber (up)	0.514 ± 4.4%	0.037	4.4	1.4	360

TBL measurements II

- Parasitic measurement for direct comparison of ACEM and Ionization Chambers
- Sensitivity difference due to large active volume of Ionization Chamber (1.5 l N_2)
- Pulse of ~250ns not followed by IC (slow time response)



Diamond at Califes

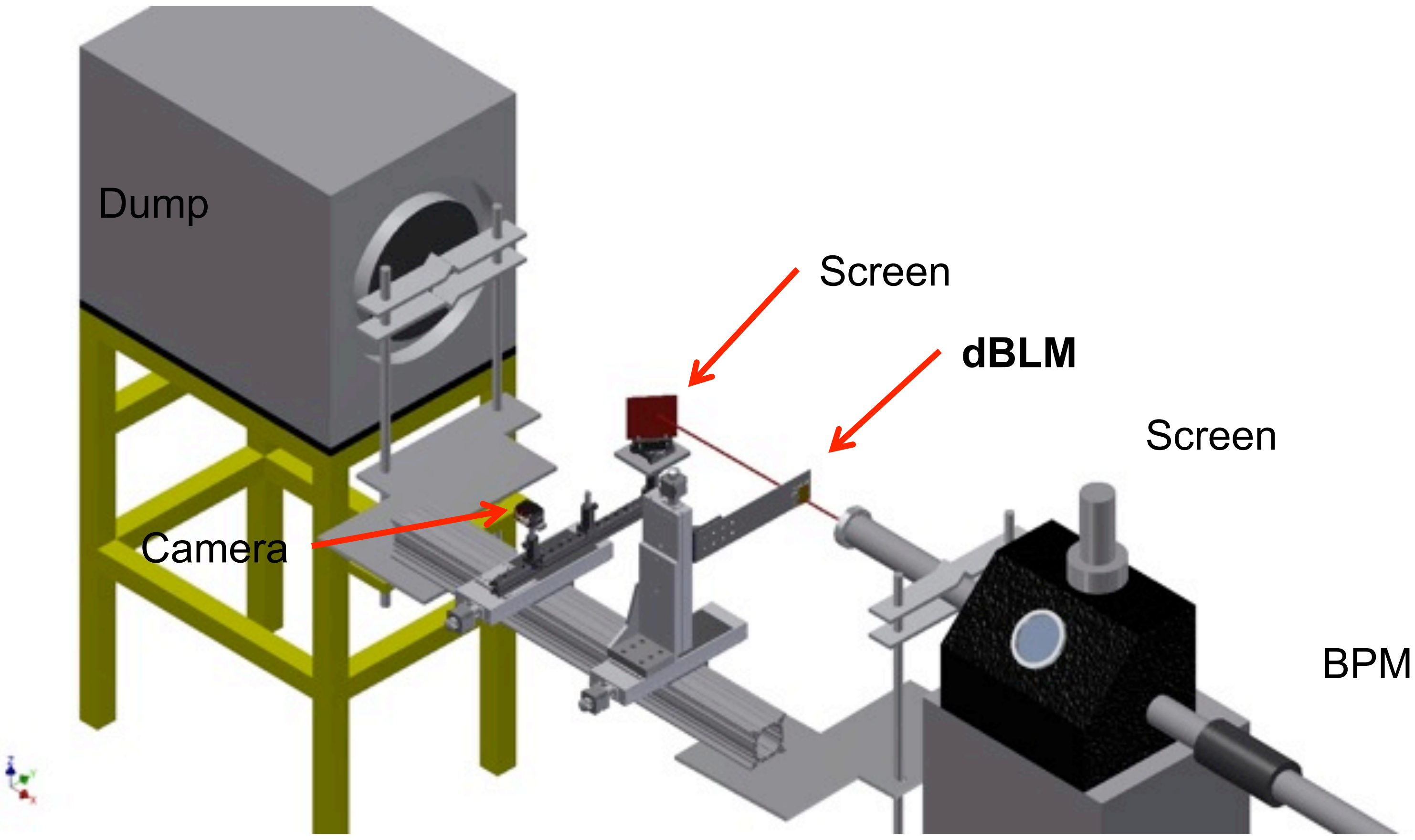


- (10 x 10 mm²) 500 µm pCVD
  - 15 cm distance from beam line
  - HV power supply in klystron gallery
  - DAQ: remote scope readout
  - 20dB amplifier
- Beam Losses at screen downstream of dipole
- Good quality and reproducibility of signals
- Measured signals for beam charges (single bunch) of 0.01-0.06 nC

Diamond at Califes

- Design and installation of beam line for particle detector test
  - Linear stages system
  - Beam window
- Characterization of diamond BLMs:
  - bunch intensities 1 x 10^{+7} – 1 x 10^{+10} electrons
  - Single bunch to 300 bunches (0.06 ns spacing)

- Cross calibration measurements with other detectors
  - e.g characterization of novel active materials (sapphire)
  - Probing internal structure of particle detectors



Summary and conclusions

- BLM system based on IC fulfills the machine protection requirements of the CLIC
  - More than 40000 BLMs to cover the 40km LINACs. Investigating Optical fiber as cost efficient technology
  - Investigating BLMs with time resolutions near bunch spacing in Main Beam: diamond and Cherenkov radiators

- Progress on quantitative estimation of beam losses at CTF3. Signals observed by BLMs consistent with BPM current measurements. Outstanding issues
  - Position resolution: Minimize the effects of modal (light collimation) and material (filtering) dispersion
  - Understanding the best choice of photo sensors (sensitivity, dynamic range and time resolution

- Development of a BLM testing table for a 200 MeV e^- beam
  - Set of rails and linear stages to move instrumentation into the beam
  - Response of diamond detectors to high frequency and small transverse size electron beams

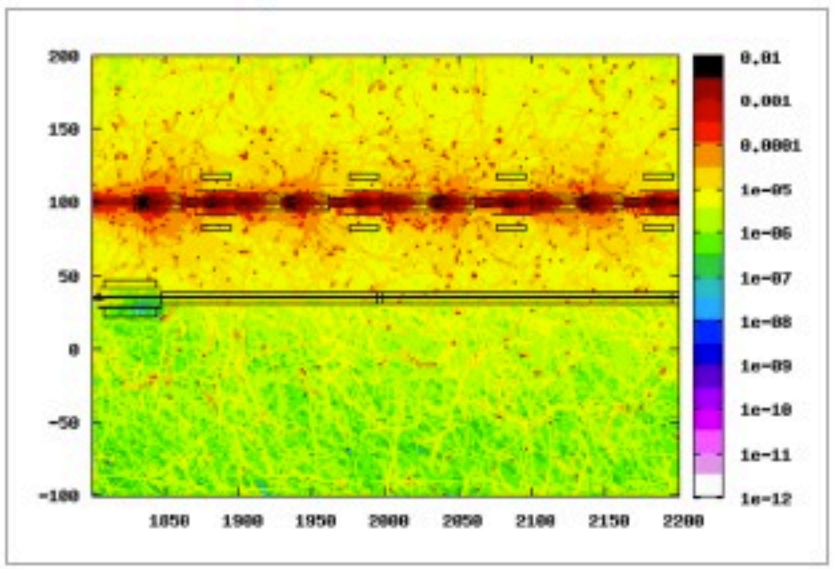
Back up Slides

Conceptual Design Report

BLM Requirements (as specified in CDR)

Sensitivity

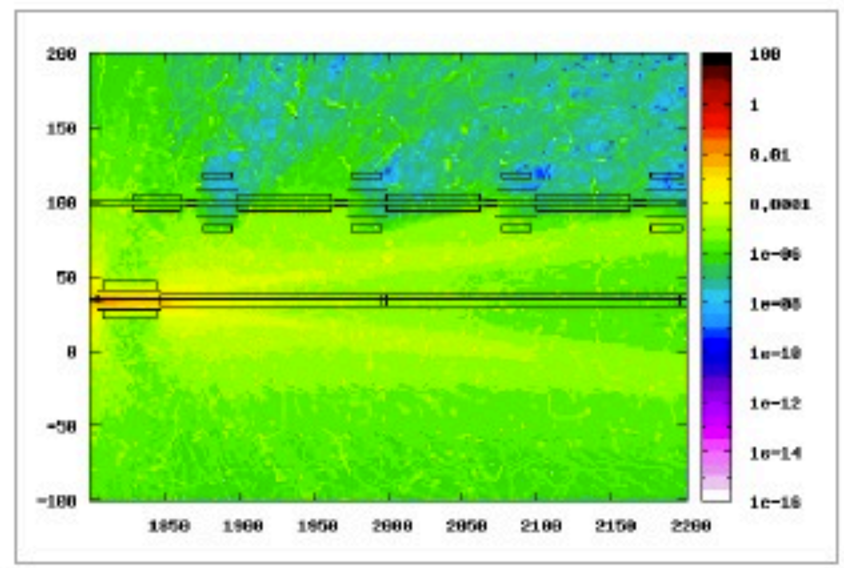
- *Standard Operational Losses*
- *FLUKA: Loss distributed longitudinally*
- ***Lower Limit of Dynamic Range**: 1% loss limit for beam dynamics requirements*
- *10^{-5} train distributed over MB linac, DB decelerator [NB! Assumed uniform losses along decelerators/linacs]*



Example: Spatial distribution of absorbed dose for maximum operational losses distributed along aperture (DB 2.4 GeV) Scaling: 10^{-3} bunch train/875m

Dynamic Range - Upper Limit

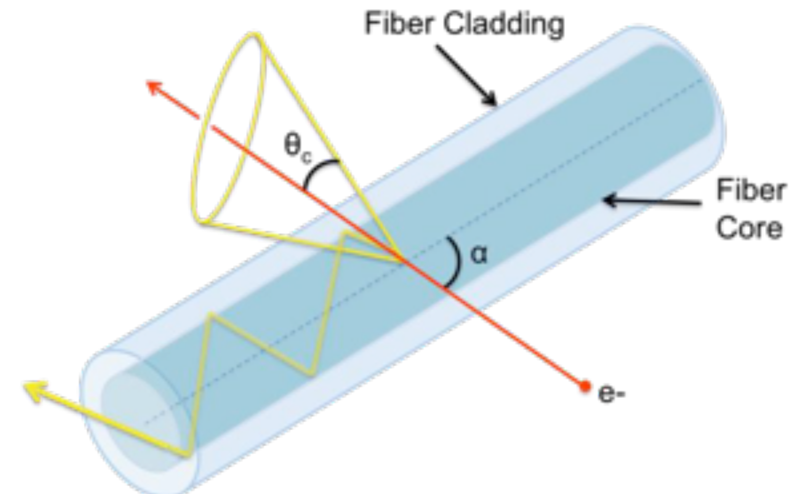
- *Detect onset of Dangerous losses*
- *FLUKA: Loss at single aperture*
- ***Upper Limit of Dynamic Range,** 10% destructive loss (desirable)*
  - *0.1% DB bunch train, 0.001% bunch train MB*



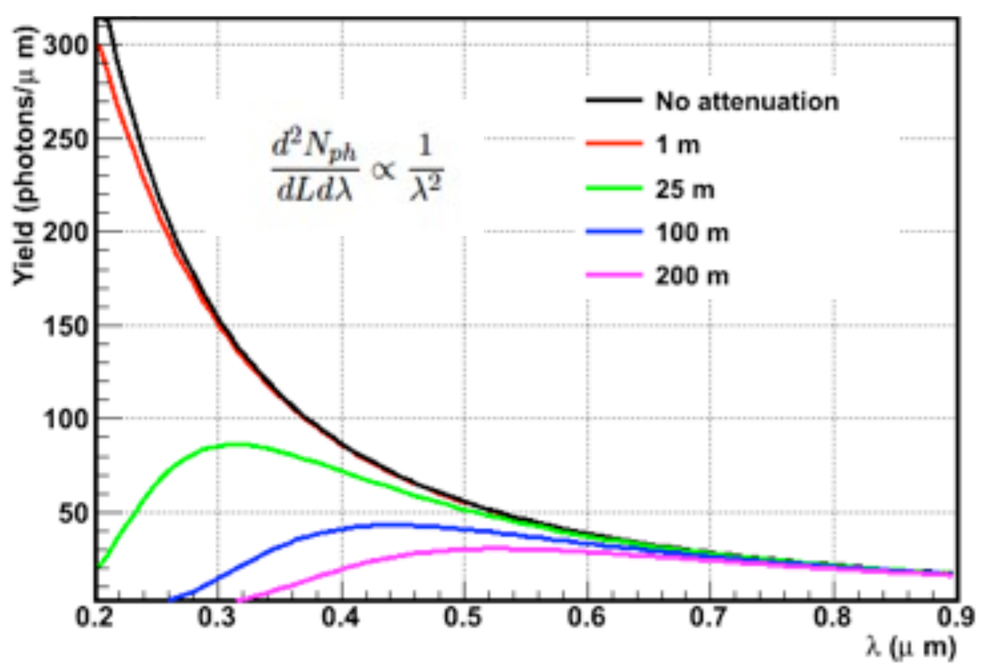
Example: Spatial distribution of absorbed dose resulting from loss of 0.01% of 9 GeV MB bunch train at a single aperture

Cherenkov–fibre based BLM systems

- When charged particles transverse an optical fibre they produce light within the Cherenkov opening cone ($\cos\theta_C = 1/\beta n$)
- A fraction of light is trapped (total reflexion core-cladding) and transported to the fiber end
- The low wavelength side of the spectrum is strongly attenuated by Rayleigh scattering



Cherenkov light spectrum and effect of fibre attenuation



J.Van Hoorne

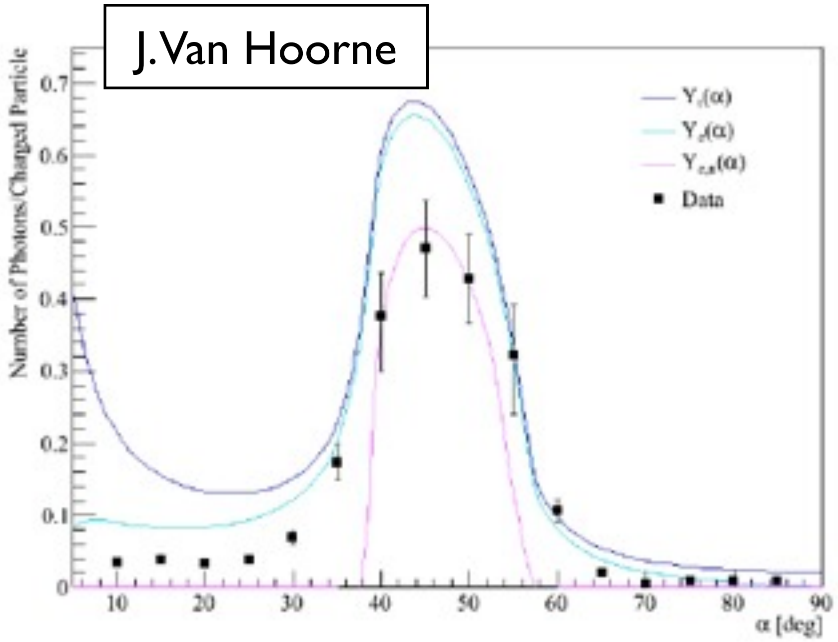
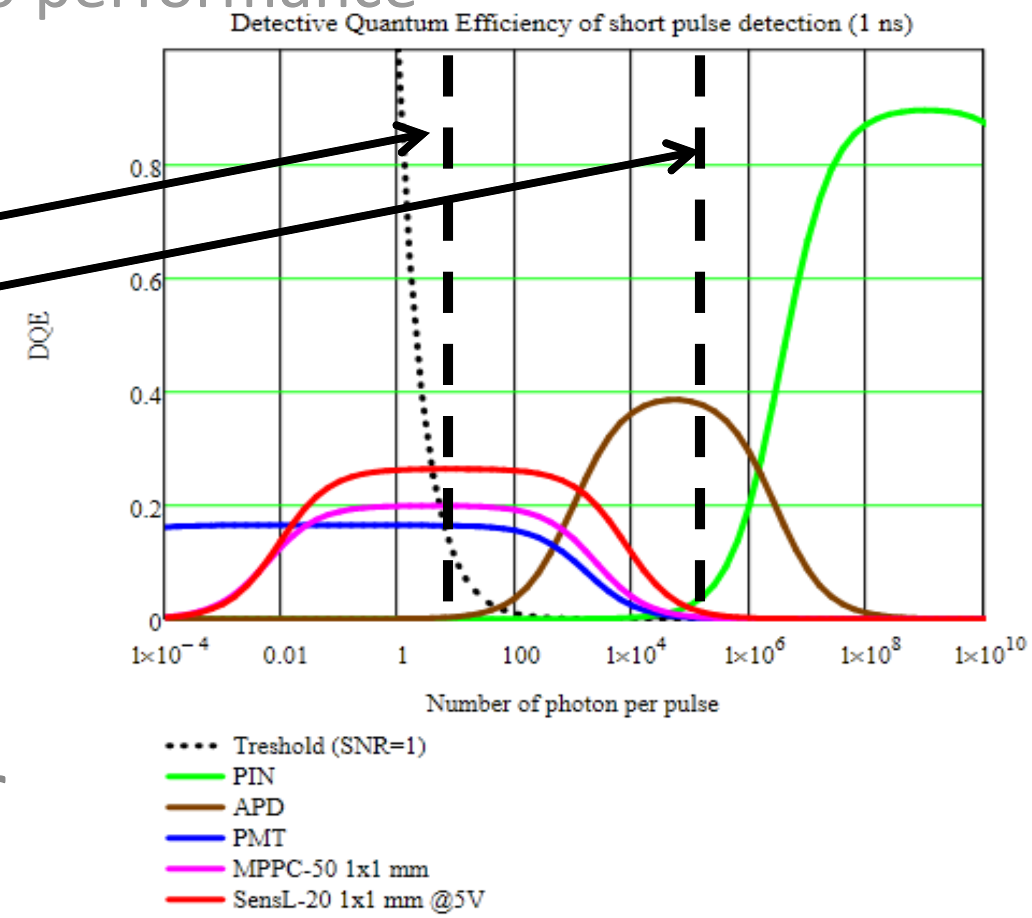


Figure 6.9: Result for the angular scan measuring the Cherenkov light yield per crossing charged particle with $\beta \approx 1$. The solid lines show the theoretical expected curves, which are computed by scaling the distribution shown in Figure 5.9a down by a factor 0.198. This factor is the result of a joint consideration of the influence of both the attenuation due to the 4 m of fiber and the PDE of the MPPC. The coupling efficiency between fiber and PD is not taken into account.

Fibre BLMs –γ detectors

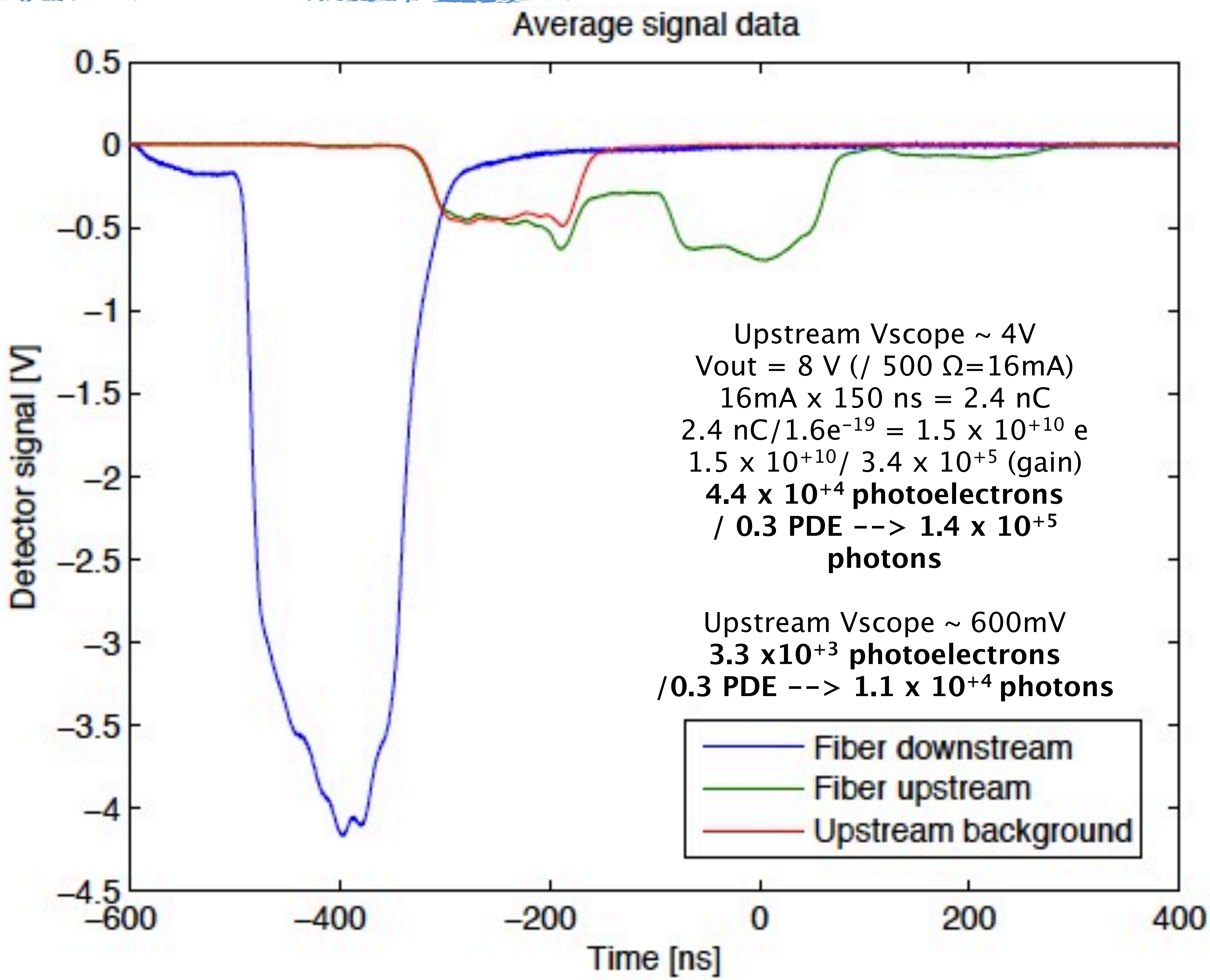
- On-going analysis for γ detector selection:
  - Are MPPCs the optimal choice
  - Take into account cost but also performance

	Sensitivity (N_{ph}/train)	Dynamic Range
DB 0.24 GeV	$2 \cdot 10^3$	$4 \cdot 10^3$
DB 2.4 GeV	$4 \cdot 10^3$	$3 \cdot 10^3$



- γ detector lab characterization planned for beginning 2014

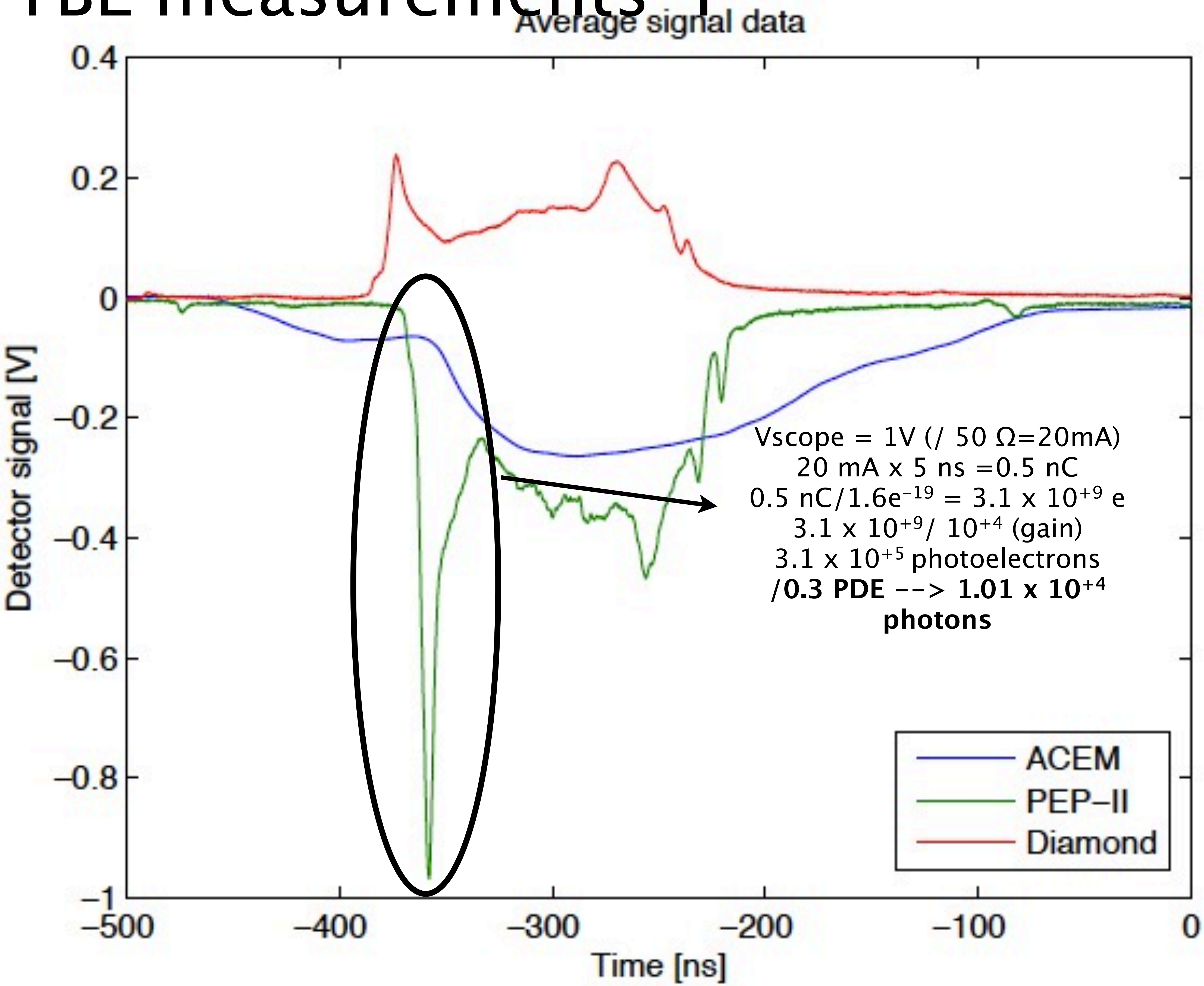
Photon Yield (optical fiber)



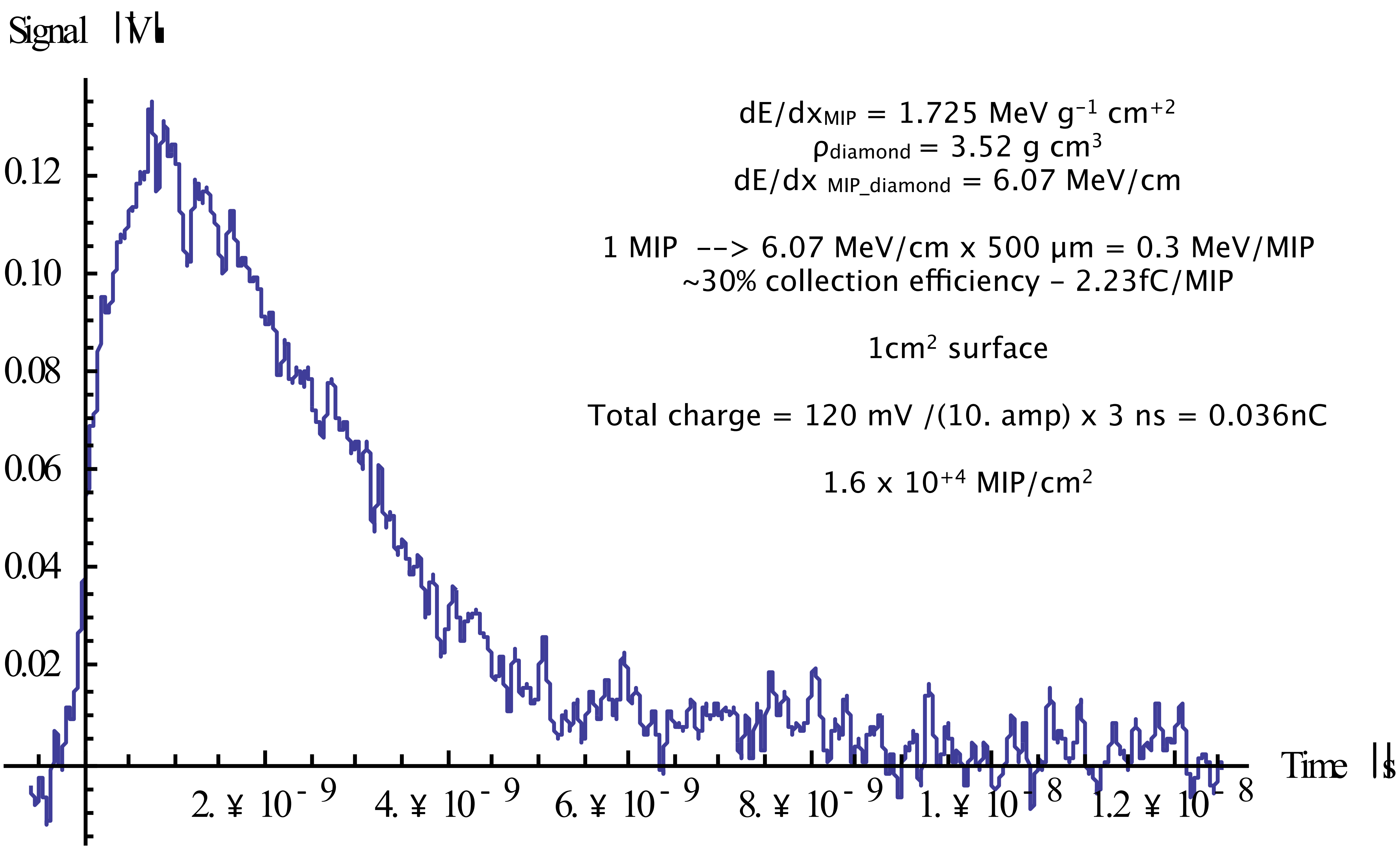
Upstream Vscope ~ 4V
Vout = 8 V (/ 500 Ω=16mA)
16mA x 150 ns = 2.4 nC
2.4 nC/1.6e^{-19} = 1.5 x 10^{+10} e
1.5 x 10^{+10}/ 3.4 x 10^{+5} (gain)
4.4 x 10^{+4} photoelectrons
/ 0.3 PDE --> 1.4 x 10^{+5} photons

Upstream Vscope ~ 600mV
3.3 x10^{+3} photoelectrons
/0.3 PDE --> 1.1 x 10^{+4} photons

TBL measurements I



Diamond (particle fluence)



dE/dx_{MIP} = 1.725 MeV g^{-1} cm^{+2}
$\rho_{diamond}$ = 3.52 g cm^3
$dE/dx_{MIP\_diamond}$ = 6.07 MeV/cm

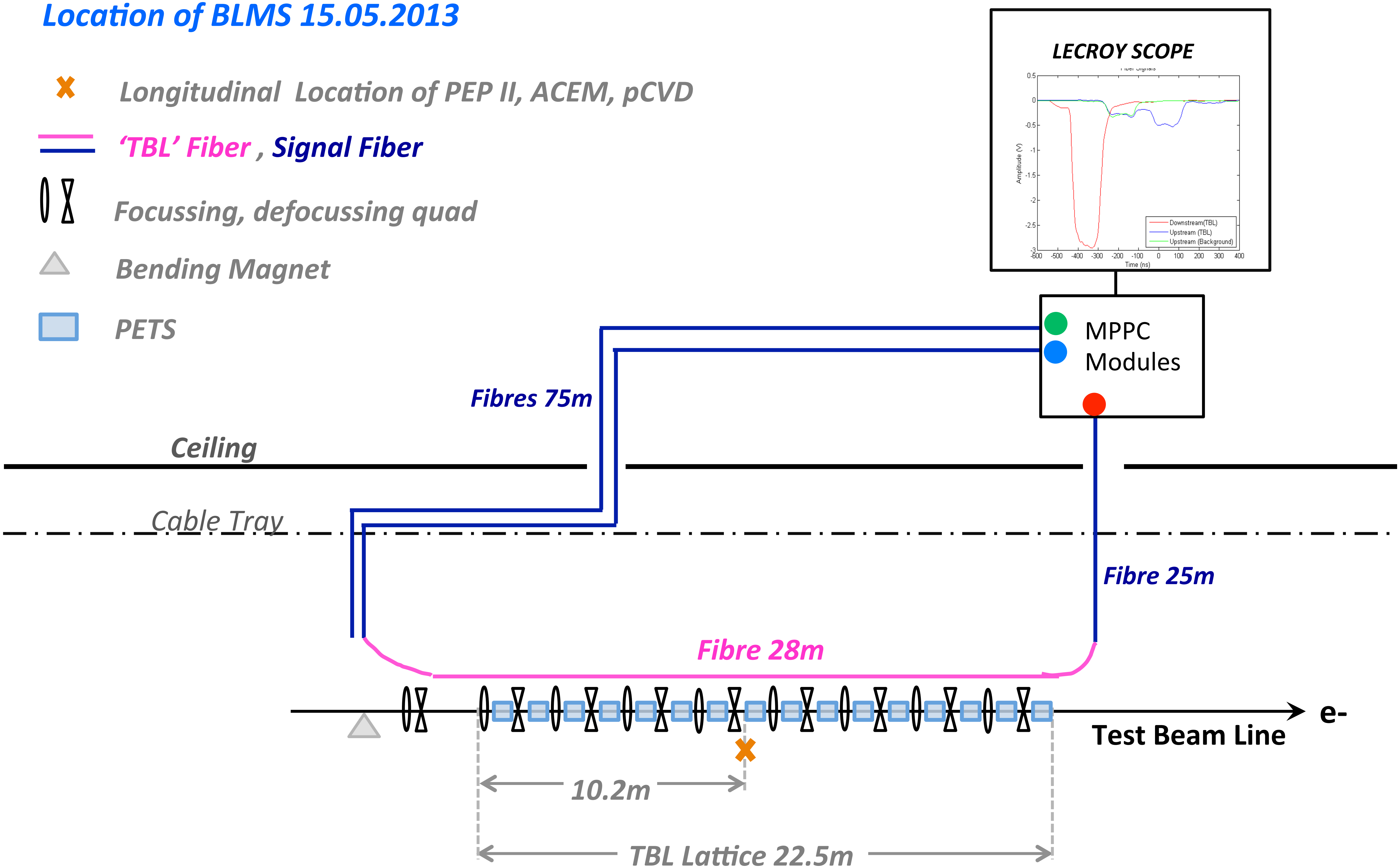
1 MIP --> 6.07 MeV/cm x 500 μm = 0.3 MeV/MIP
~30% collection efficiency – 2.23fC/MIP

1cm² surface

Total charge = 120 mV /(10. amp) x 3 ns = 0.036nC

1.6 x 10^{+4} MIP/cm²

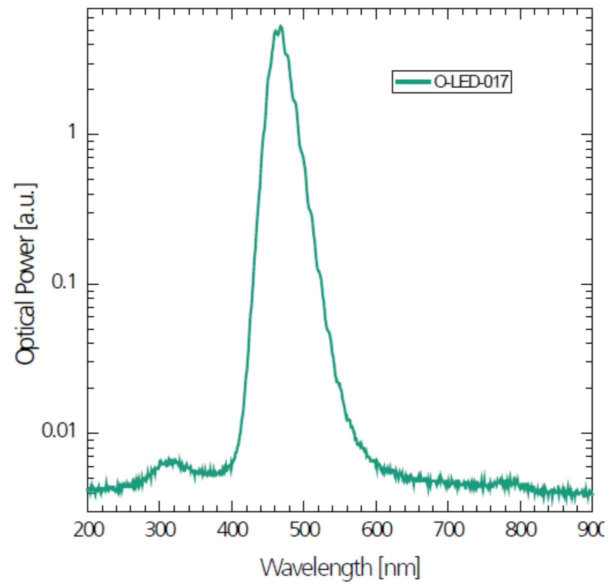
Location of BLMS 15.05.2013

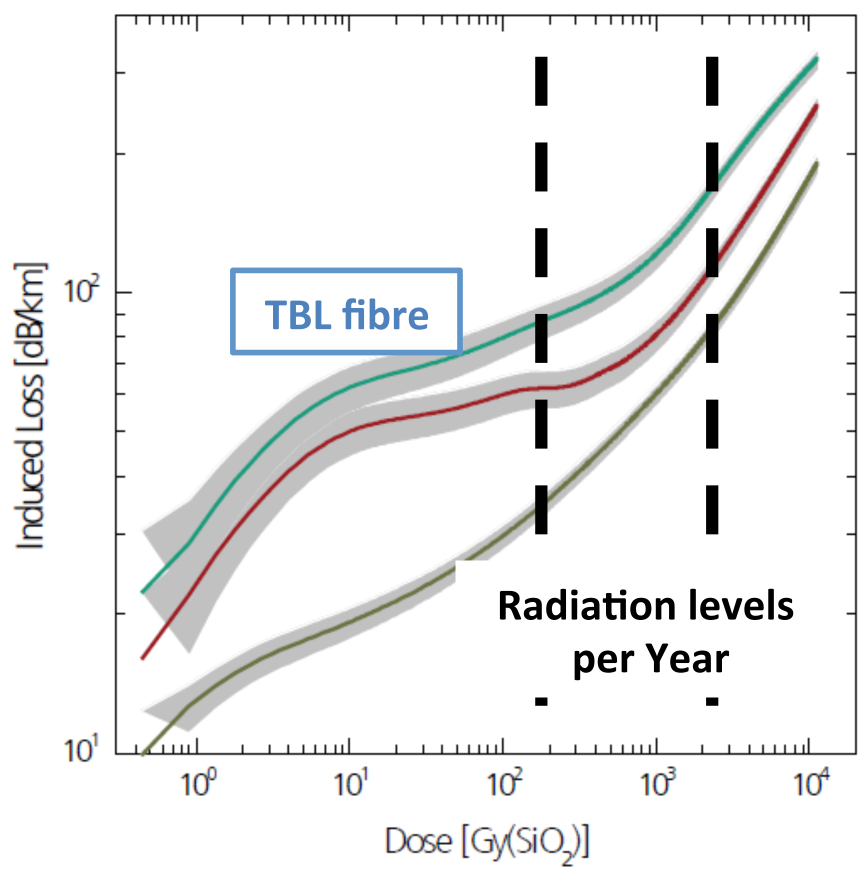


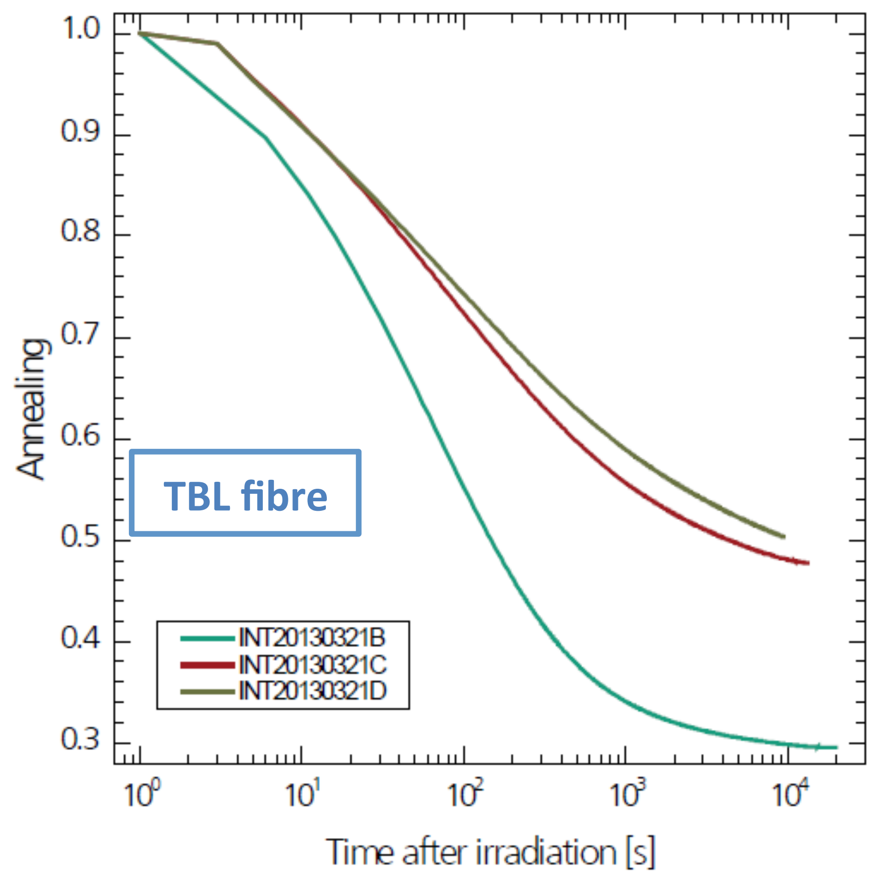
S.Mallows

Irradiation test

- Three sample fibres irradiated to study the response at 475 nm (MPPC efficiency and photon yield peak):
- Co60 (Mean E =1.25 MeV)
- 10kGy@0.22 Gy/s







$$1 \text{ MIP} = 2 \text{ MeV/(g/cm2)} = 3.2 \times 10^{-10} \text{ J/(kg/cm2)}$$

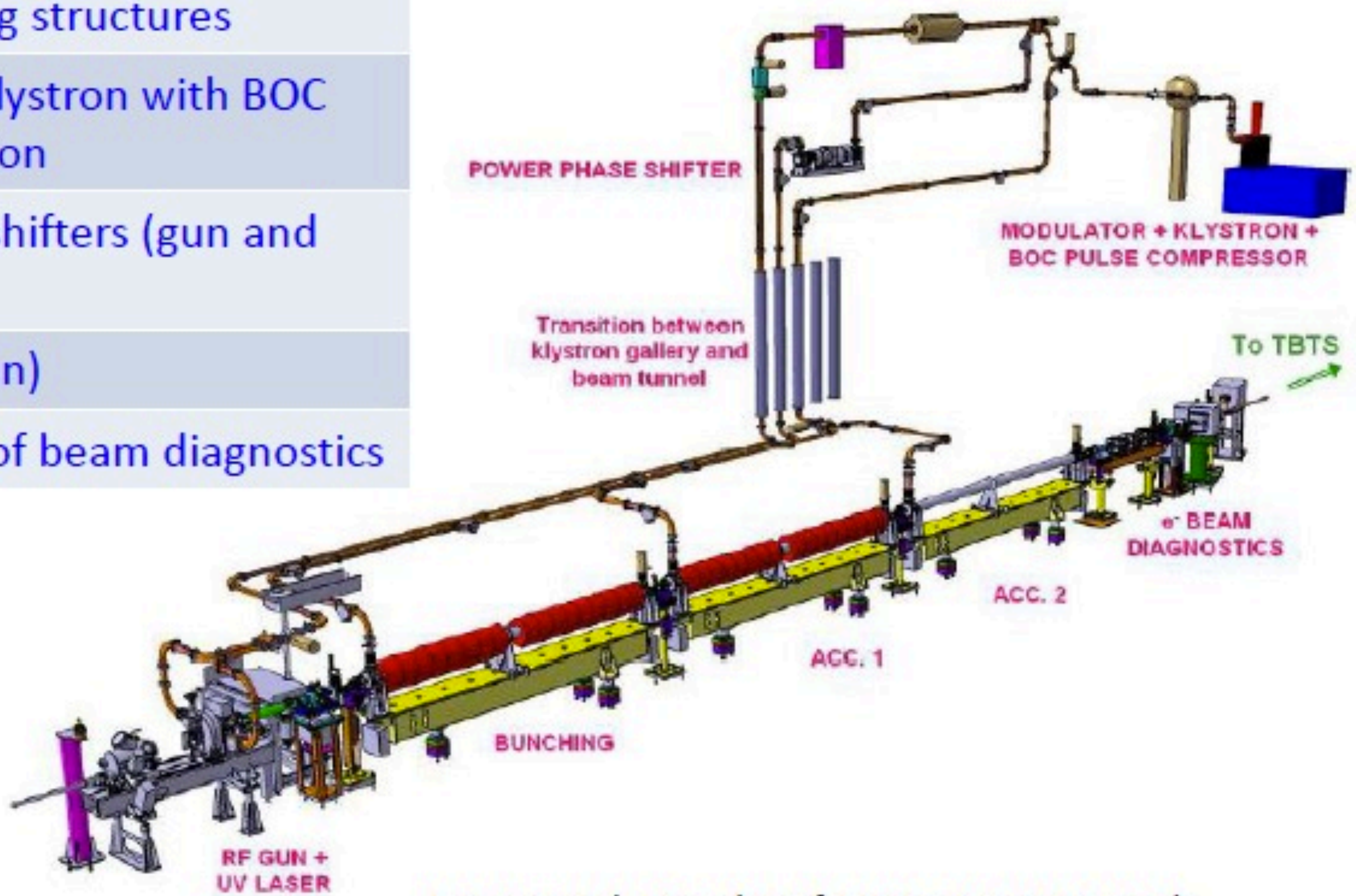
$$1\text{Gy} = 1 \text{ J /kg} \rightarrow 3.1 \times 10^{9} \text{ MIP cm}^{2}$$

Material	Density	Volume	Signal Yield	Comment
Diamond	3.52 g cm^{-3}	10mmx10mmx500um = 50mm2	13eV/pair 2.23 fC/MIP	Ionization
Al	-----	13mm2	0.05 e/MIP 0.0005 fC/MIP	Secondary emission
Quartz	---	1cm3 3.1415x$(200um)^{2}$ x 28m	100 γ $MIP^{-1}mm^{-1}$	Cherenkov light
N2	1.2 kg m^{-3}	1.5 l	34.8 eV/pair 3.39 fC/MIP	Ionization

Califes Beam line

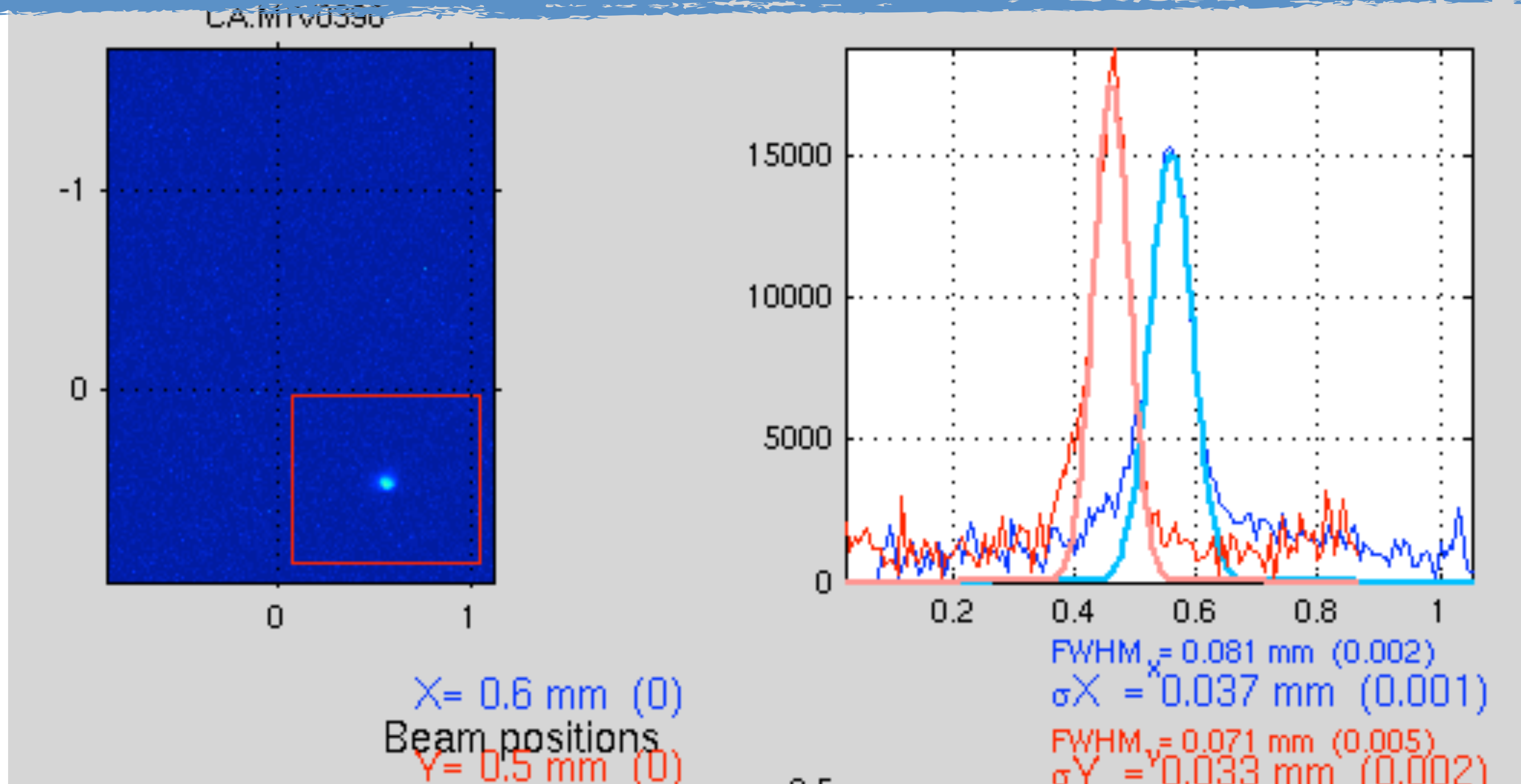
CALIFES today

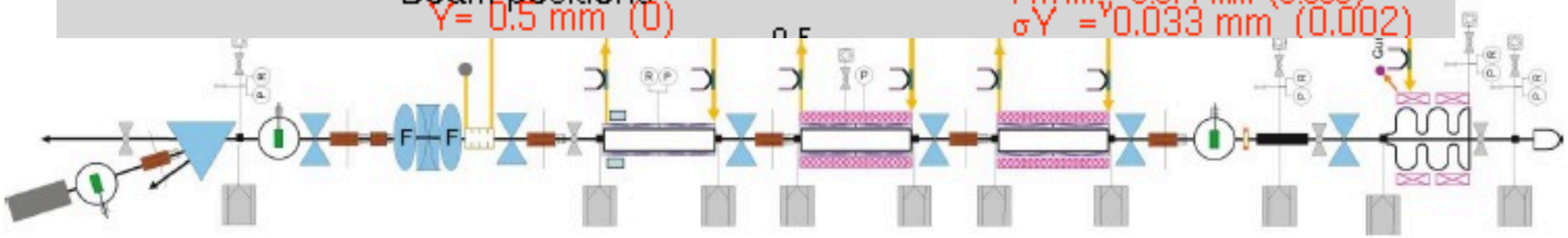
A Photo-injector
3 LIL accelerating structures
A single 3 GHz klystron with BOC pulse compression
2 power phase shifters (gun and first structure)
1 attenuator (gun)
A complete set of beam diagnostics



F. Peauger et al., Proceedings of LINAC08, Victoria, BC, Canada

Califes Beam parameters





Parameters	Specified	Tested	Comment
Energy	200 MeV	205 MeV	Without bunch compression
Norm. emittance	< 20 π mm.mrad	4 π mm.mrad	With reduced bunch charge
Energy spread	< ± 2 %	± 0.5 %	
Bunch charge	0.6 nC	0.65 nC	With new photocathode
Bunch spacing	0.667 ns	0.667 ns	Laser driven
Nb of bunches	1-32-226	from 1 to 300	Limited by RF pulse length
rms. bunch length	< 0.75 ps	1.4 ps ??	Still to be checked
Repetition rate	0.8 – 5 Hz	0.8 – 5 Hz	Upgrade possibility to 10 Hz