Operation of the ATLAS end-cap calorimeters at sLHC luminosities, an experimental study

Jozef Ferencei

Institute of Experimental Physics

Slovak Academy of Sciences

Košice, Slovakia

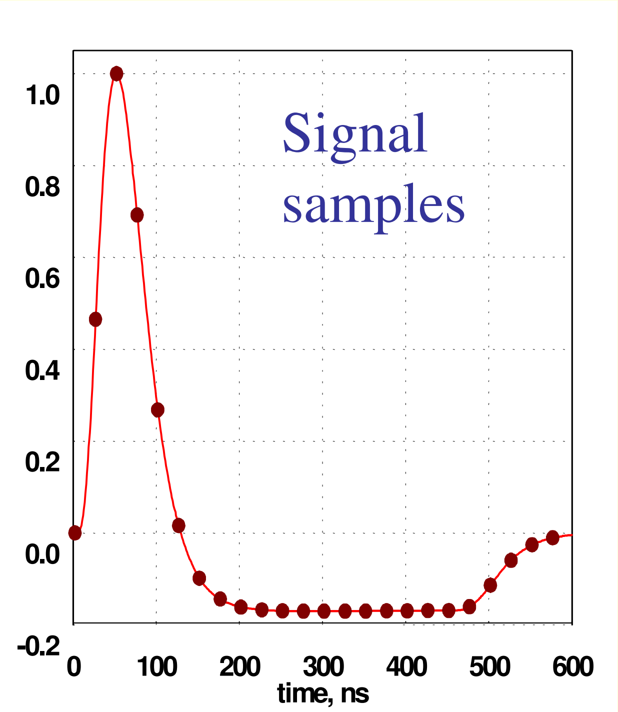
For the Atlas Liquid Argon End-cap HiLum Collaboration

View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by CERN Document Server

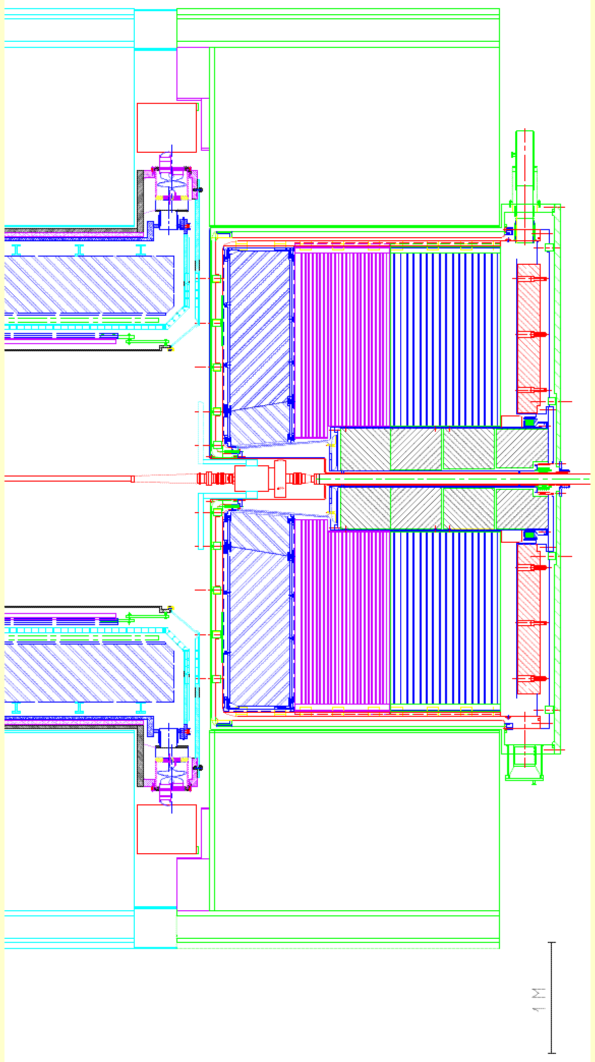
Outline

- ATLAS end-cap calorimetry
- Calorimeter mini-modules
- Beam set-up
- Data and preliminary results
- Conclusions

ATLAS end-cap calorimetry @ LHC



- electromagnetic (EMEC), hadronic (HEC) and forward (FCAL) calorimeters
- electrode geometry: FCAL → tube, EMEC → accordion, HEC → planar with electrostatic transformer
- rapidity range: $1.5 < \eta < 4.9$



- designed to work at LHC luminosities of ~10^{34} $cm^{-2}s^{-1}$ → charged particle flux density: for FCAL ~10^{7} (η=5.0) and EMEC/HEC ~10^{6} (η=3.2) → in $\Delta\eta \times \Delta\varphi$ = 0.1 x 0.1 to 10^{15} particles for 10 years of LHC → integrated energy of 6 x 10^{15} GeV (η=3.2) and 28 x 10^{15} GeV (η=5.0).
- neutrals expected 10-20% higher

ATLAS end-cap calorimetry @ sLHC

- expected increase of luminosity by a factor of 10
- particle flux densities in the range $10^7 – 10^8$ particle/s.cm^2 for luminosity of 10^{35} cm^{-2}s^{-1}

→ to investigate possible operating limits of ATLAS end-cap calorimeters @ sLHC -> **HiLum ATLAS end-cap project**: a) study of ion build-up, b) heat impact, c) HV issues and d) radiation hardness for the three end-cap calorimeter technologies in the range from LHC luminosity to higher luminosities.

Collaboration of Arizona, Dresden, JINR Dubna, IEP Košice, Mainz, LPI Moscow, MPI Munich, BINP Novosibirsk, IHEP Protvino, TRIUMF, Wuppertal (INTAS Project 05-103-7555)

Ion build up

- potential **V**
- **D_c** is critical ionization rate where charge build up in gap is equal to charge on electrodes
- **D** is actual ionization rate
- **$r=D/D_c$**
- for r > 1 the effective gap starts to shrink

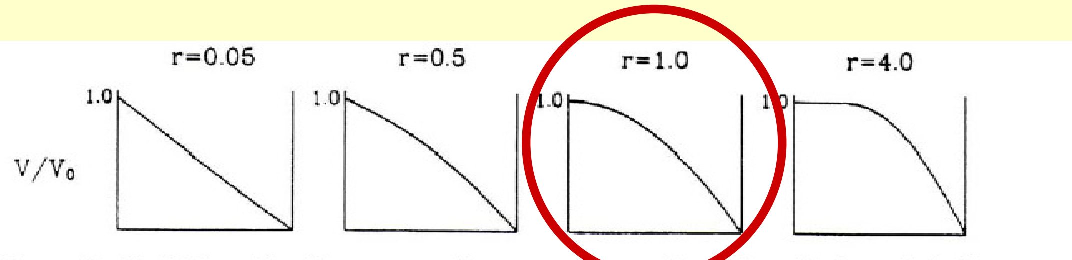
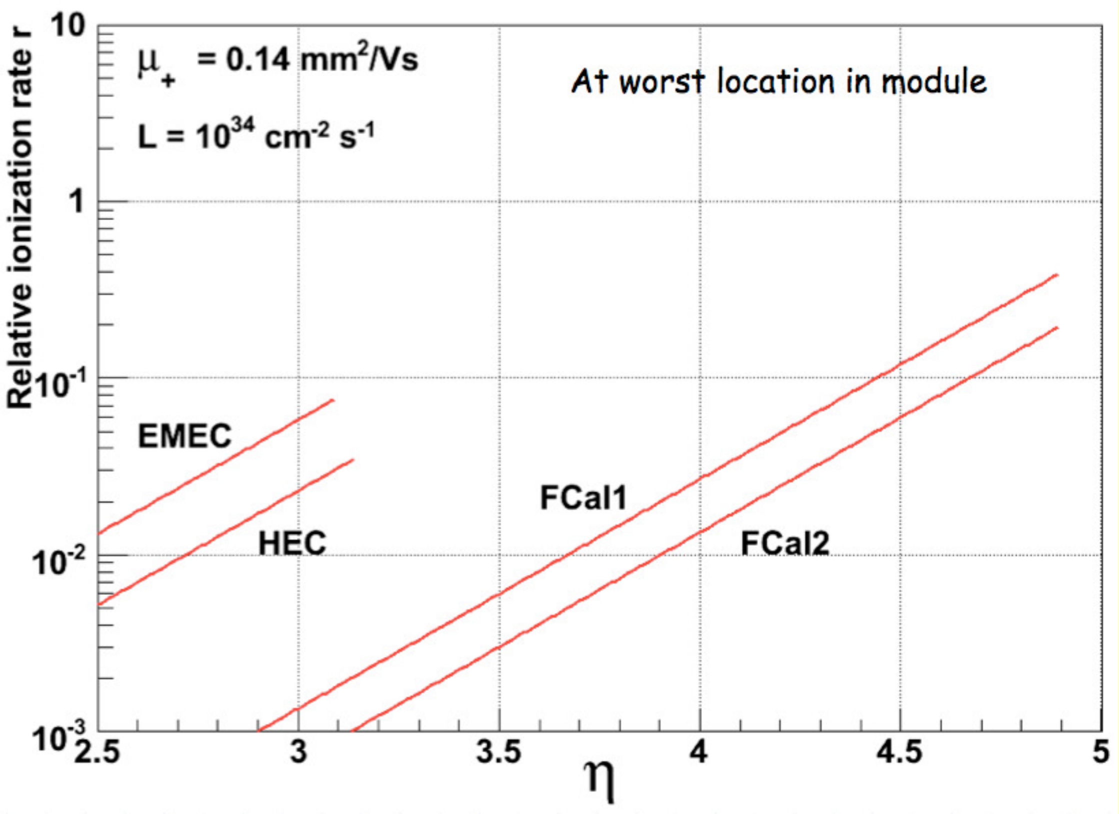


Figure 3: Variation of voltage across the argon gap as the value of r is varied. The vertical axis is voltage, and the horizontal the position across the gap. In all cases the voltage is V_0 at one copper plate and zero at the other plate.

J. Rutherfoord, NIM A 482 (2002) 156

- HEC / EMEC look OK at 10 x design luminosity
- FCal2 may become problematic at highest η
- FCal1 definitely problematic at highest η → reduce gap (→ ion build up) from 250 μ to 100 μ



Magnitude of problems not well known
→ need to do system test in beam

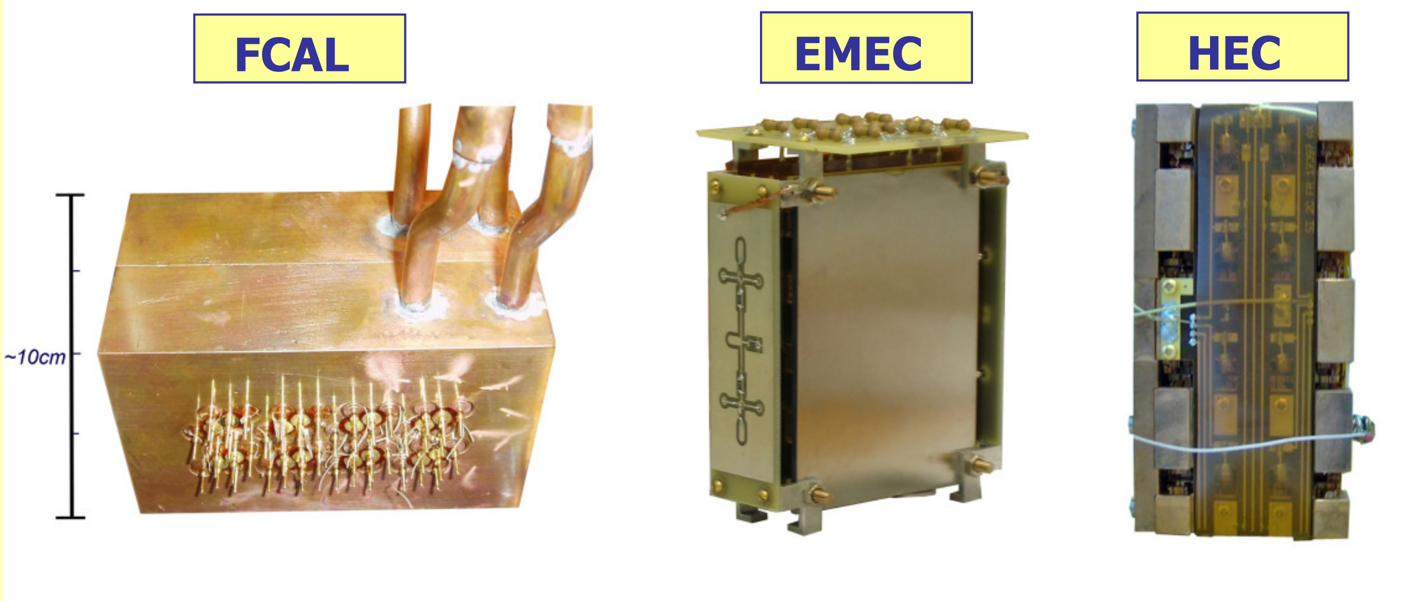
High Luminosity Tests @ U70 Proton Synchrotron

IHEP Protvino beam line # 23:

- extraction via channeling in bent crystal → widest available rate variation from 10^7 up to 10^{12} p/spill
- energy 50 GeV
- bunch width: ~30 ns at 5%, ~15 ns FWHM
- RMS width up to 35 mm (homogeneous coverage of module front face)
- spill: 1.2 s, spill cycle time: 10 s
- full RF bunch structure (debunching off mode)
- nominal bucket spacing Δt=165 ns
- 5 empty buckets between 5 filled bunches (30 in total) → filled bunch spacing 990 ns

Protons/spill	**10^7**	**10^{12}**
Protons/bunch	**8**	**8×10^5**
Protons/s [pps]	**7.7×10^6**	**7.7×10^{11}**
Rate rel. to sLHC for FCAL	**7.7×10^{-4}**	**77**
Rate rel. to sLHC for EMEC	**0.0132**	**1324**
Rate rel. to sLHC for HEC	**0.033**	**3340**

R&D FCAL, EMEC and HEC mini-modules



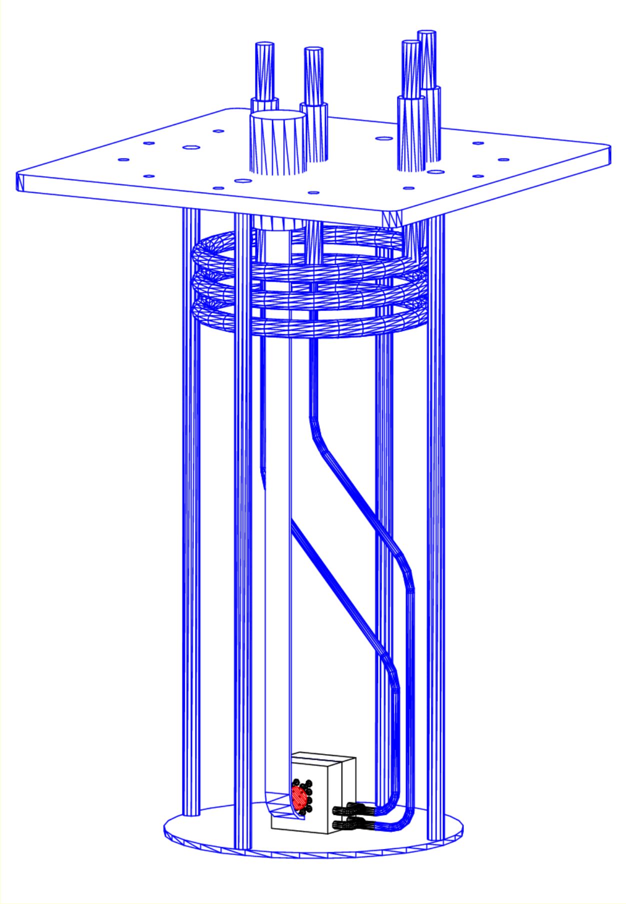
- each module in separate cryostat (~6 liters of liquid argon) on movable platform
- each cryostat equipped with α and β (a là ATLAS) purity probes (Am-241 and Bi-207) to monitor possible pollution due to high beam intensity
- 4 temperature probes of PT-100 in each cryostat
- HV modules: EMEC/HEC (V_{max}=2 500 V) up to I_{max}=200 μA; FCAL (V_{max}=600 V) up to I_{max}=10 mA

Read-out:

- 0T preamplifier and RC2-CR shaper with 15 ns time constant
- ATLAS test FEB board with 3 x 32-channel 40 MHz FADC boards
- 2 outputs per driver, shifted by 12.5 ns → effective sampling 80 MHz
- medium and high gain used with gain ratio about 10
- read-out up to 252 time slices

FCAL module

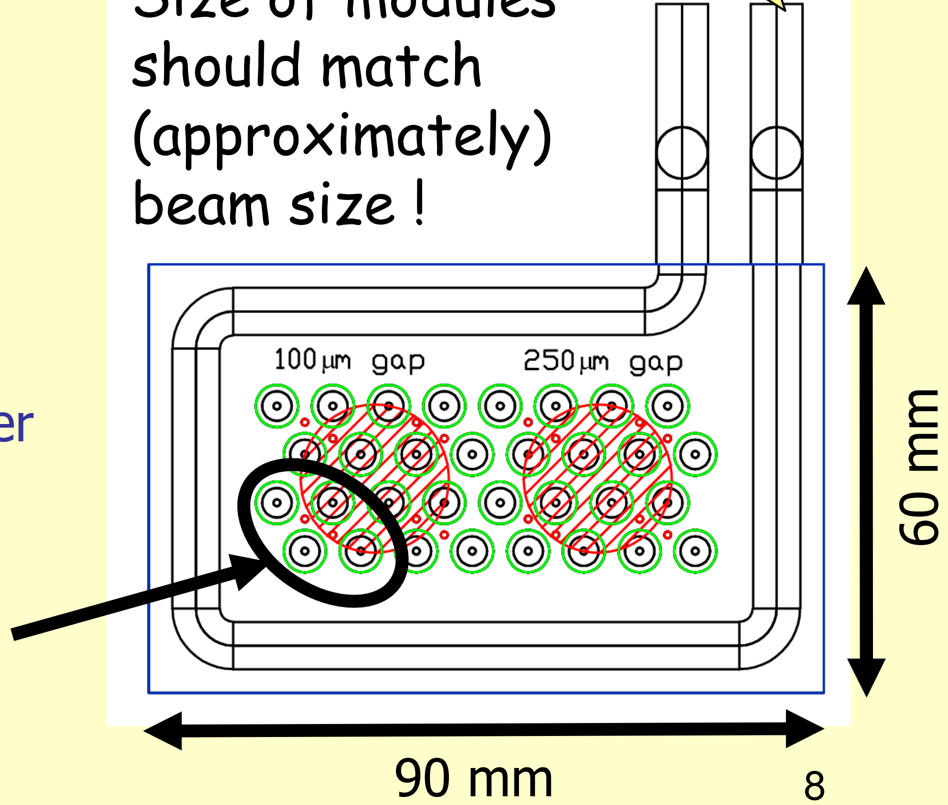
- electrodes: copper rods (anodes) within thin-walled copper tubes (cathodes)
- internal nitrogen cooling loops near the periphery to remove heat generated by intense proton beam



FCal test module has two sets of electrodes:

- one with the nominal LAr gap size of 250 µm
- another with 100 µm gaps (proposed for replacement FCal1 module)

- 4 readout channels per side → 8 channels in total

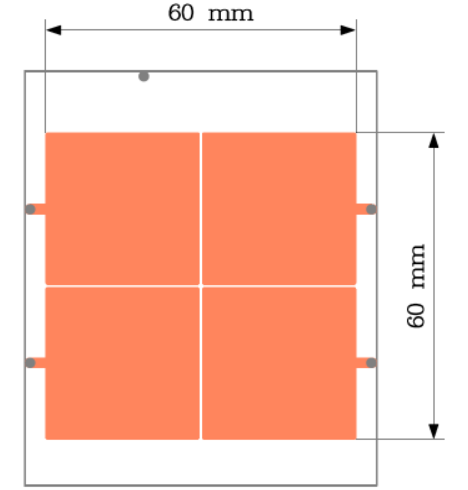


2nd cooling loop

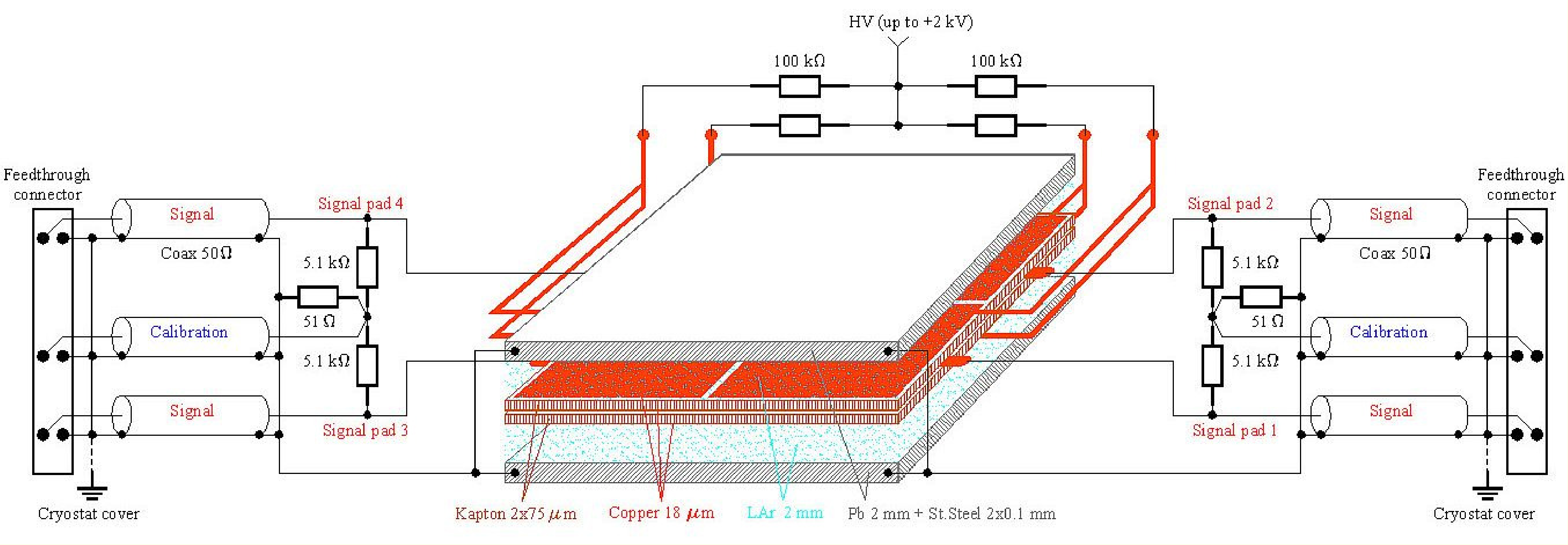
Size of modules should match (approximately) beam size !

Tube Group

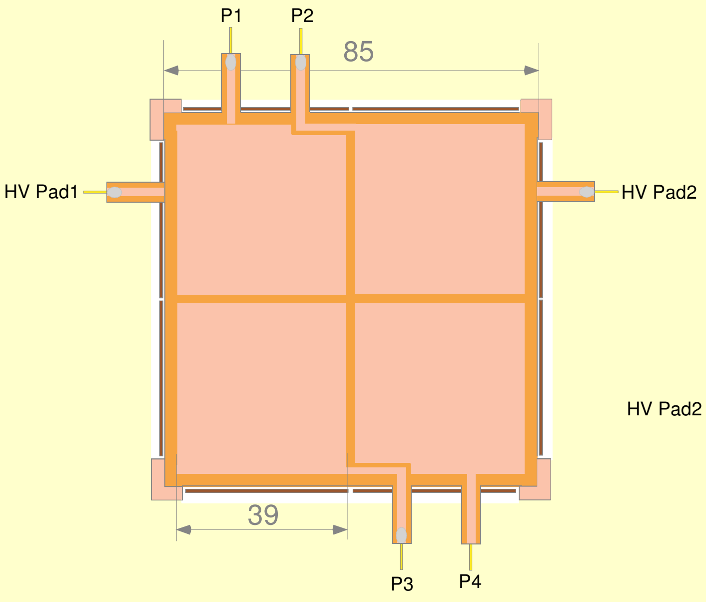
EMEC module



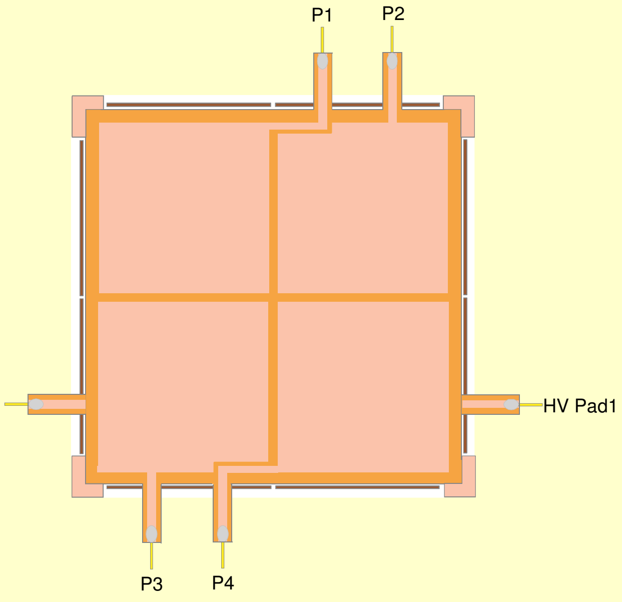
- 4 lead absorbers (2 mm Pb + 2 x 0.1 mm stainless steel) and 3 thin polyimide electrodes with 2 mm gaps between electrodes and absorbers
- electrodes have 3 conductive layers
- positive HV (2 kV) is applied to the two outer layers, signal is read out from the middle layer
- signal electrode is structured in 4 pads yielding 4 read-out channels in total



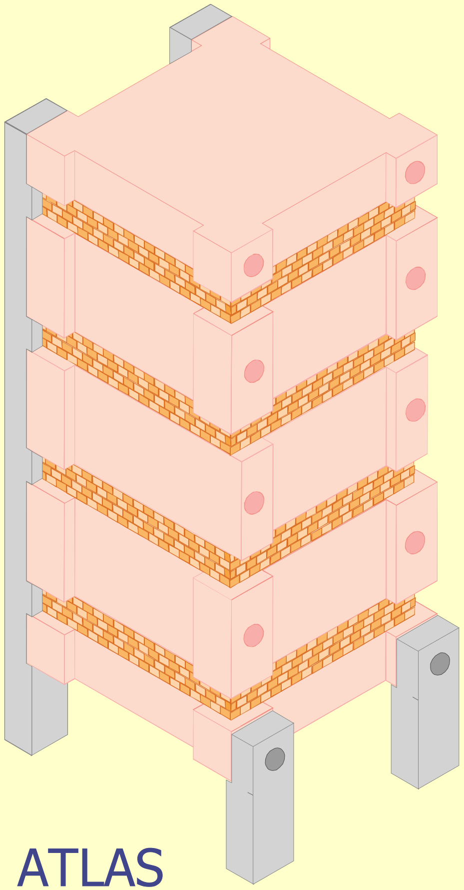
HEC module



Odd gaps



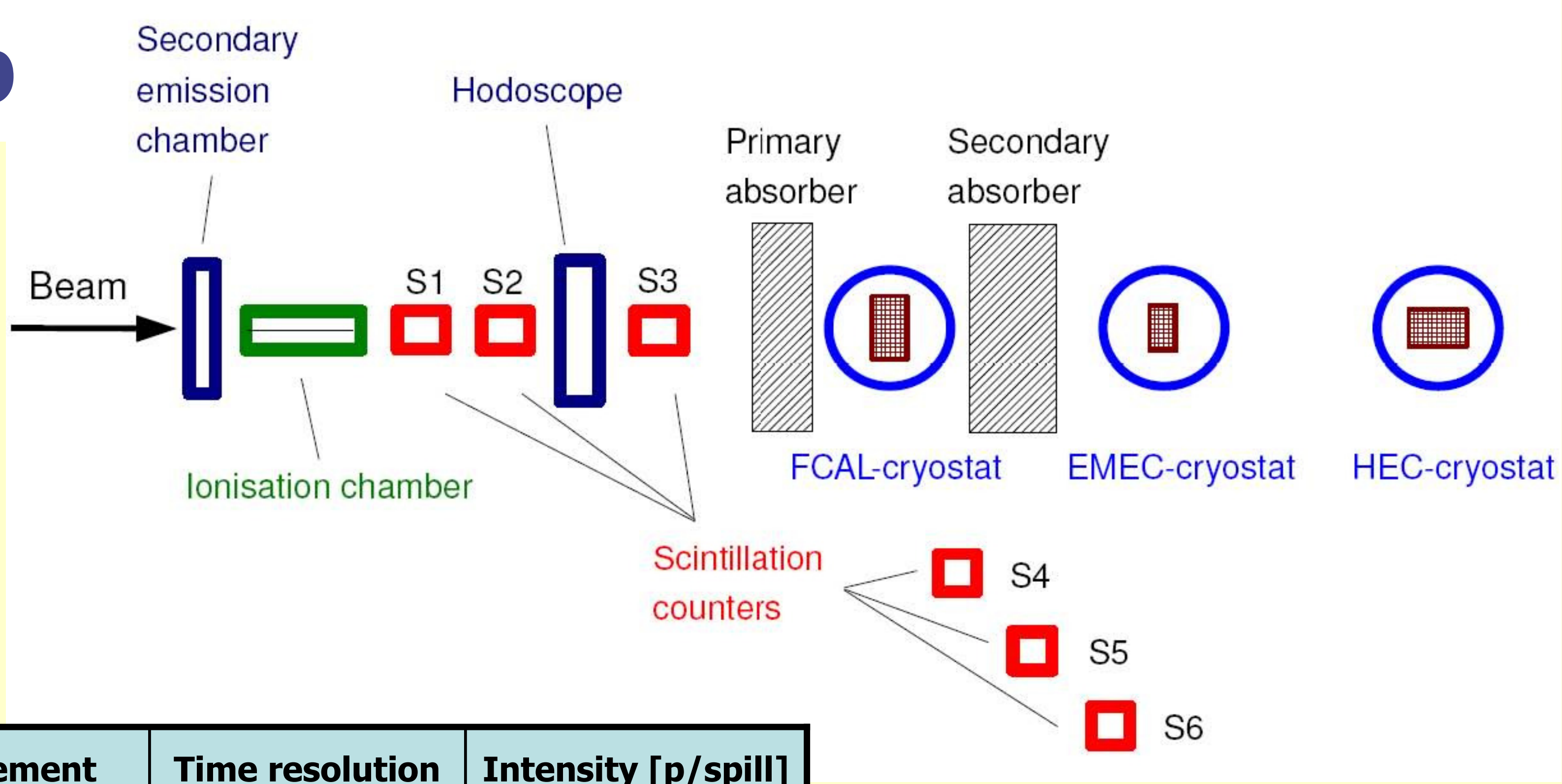
Even gaps



Design follows closely ATLAS HEC1 calorimeter:

- copper absorber: 25 mm with front plate 12.5 mm only
- 5 absorber plates → 4 Ar gaps ↔ half of the first long. section in ATLAS
- lateral size: 60 mm x 60 mm
- spacers define 8.5 mm gap between the absorber plates
- the read-out structure follows the principle of an electrostatic transformer (EST)
- EST and PAD electrodes correspond exactly to the ATLAS design
- 4 read-out channels and 4 HV lines (one per subgap) via strip-line polyimide connectors

Beam Setup



Since November 2008 Cherenkov counter has been installed downstream S1 counter to monitor / record individual bunch intensity (→ prehistory of ion build up)

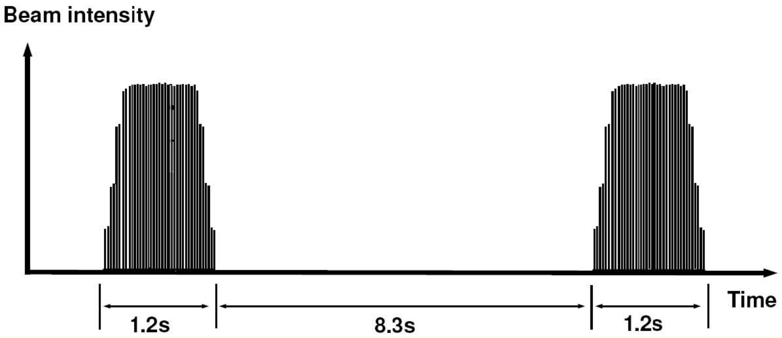
Device	Measurement	Time resolution	Intensity [p/spill]
Secondary emission chamber	**Beam position**	**spill**	**> 5 x 10^9**
Ionization chamber	**Beam intensity**	**spill**	**2 x 10^7 ÷ 2 x 10^{11}**
Counters S1, S2, S3	**Beam intensity**	**~10 ns**	**< 5 x 10^7**
Counters S4, S5, S6	**Beam intensity**	**~10 ns**	**< 5 x 10^{10}**
Cherenkov	**Beam intensity**	**bunch**	**full range**
Hodoscope	**Beam position/profile**	**bunch**	**< 5 x 10^7**

MC optimization of setup with aim to have all 3 modules simultaneously in beam with ratio of energy flows close to ATLAS

→ steel absorbers: 0.7 λ in front (primary) and 1.8 λ behind (secondary) FCAL

Extracted Beam Intensity

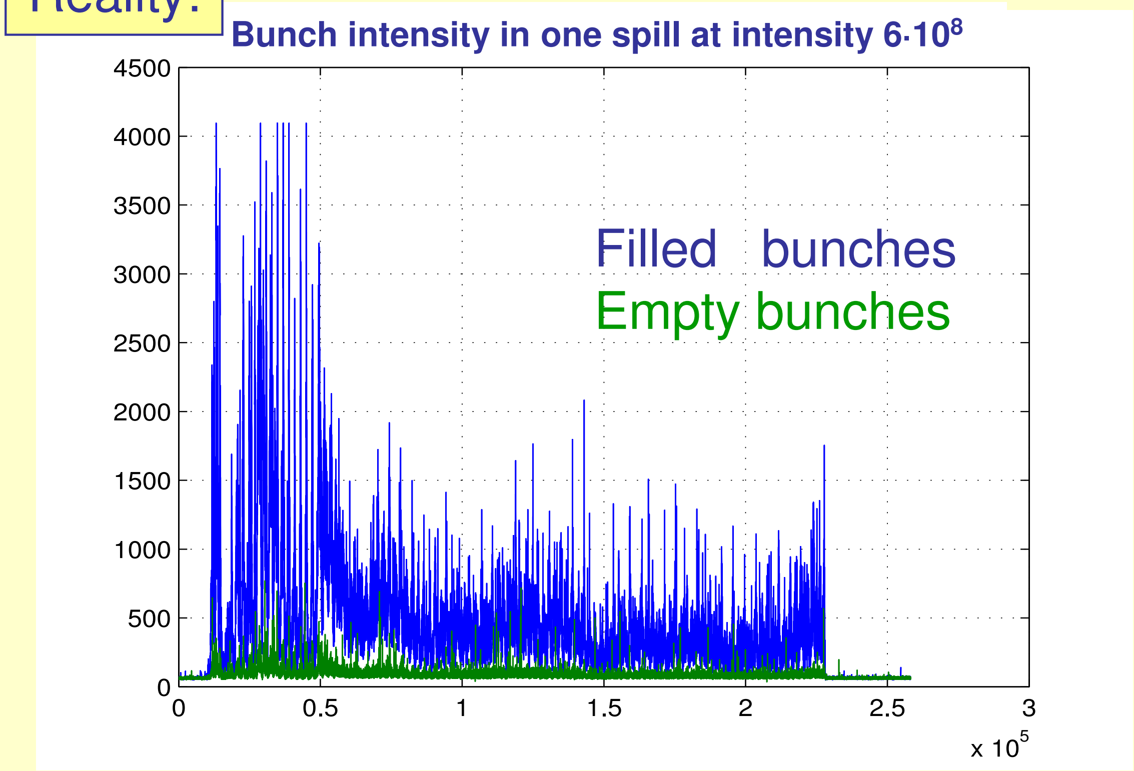
Nominal spill structure:



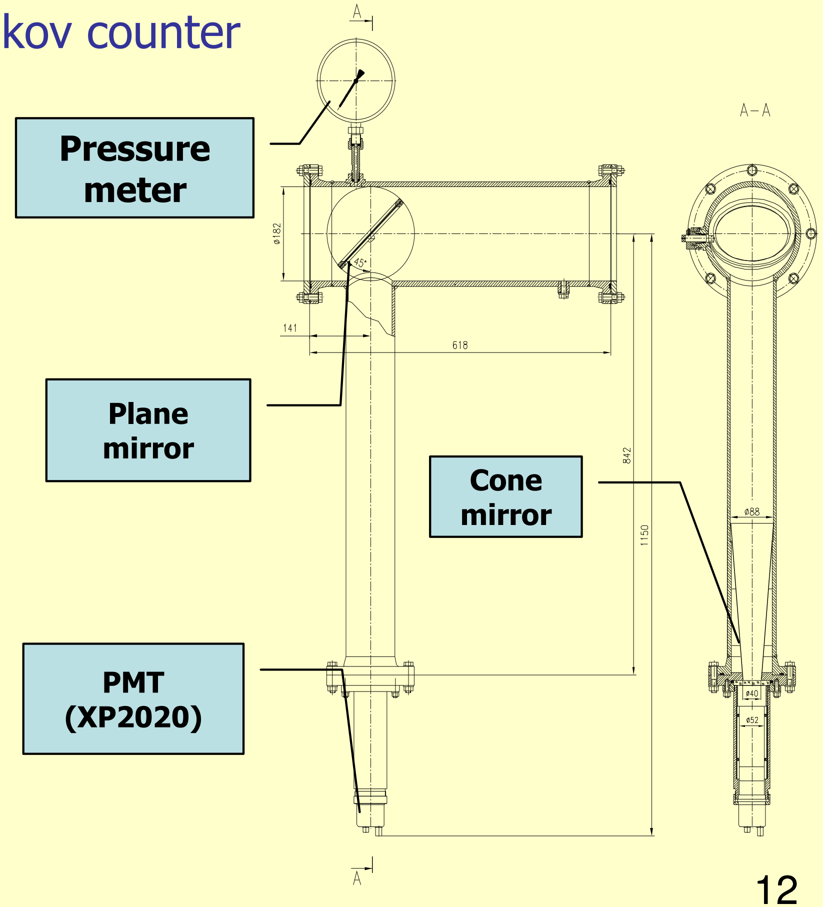
Unexpected large beam intensity variations up to ~2 orders of magnitude:

- Fourier spectrum → several low frequency (50 Hz) harmonics clearly seen
- intensity variations caused by beam extraction system → on going discussions with accelerator group

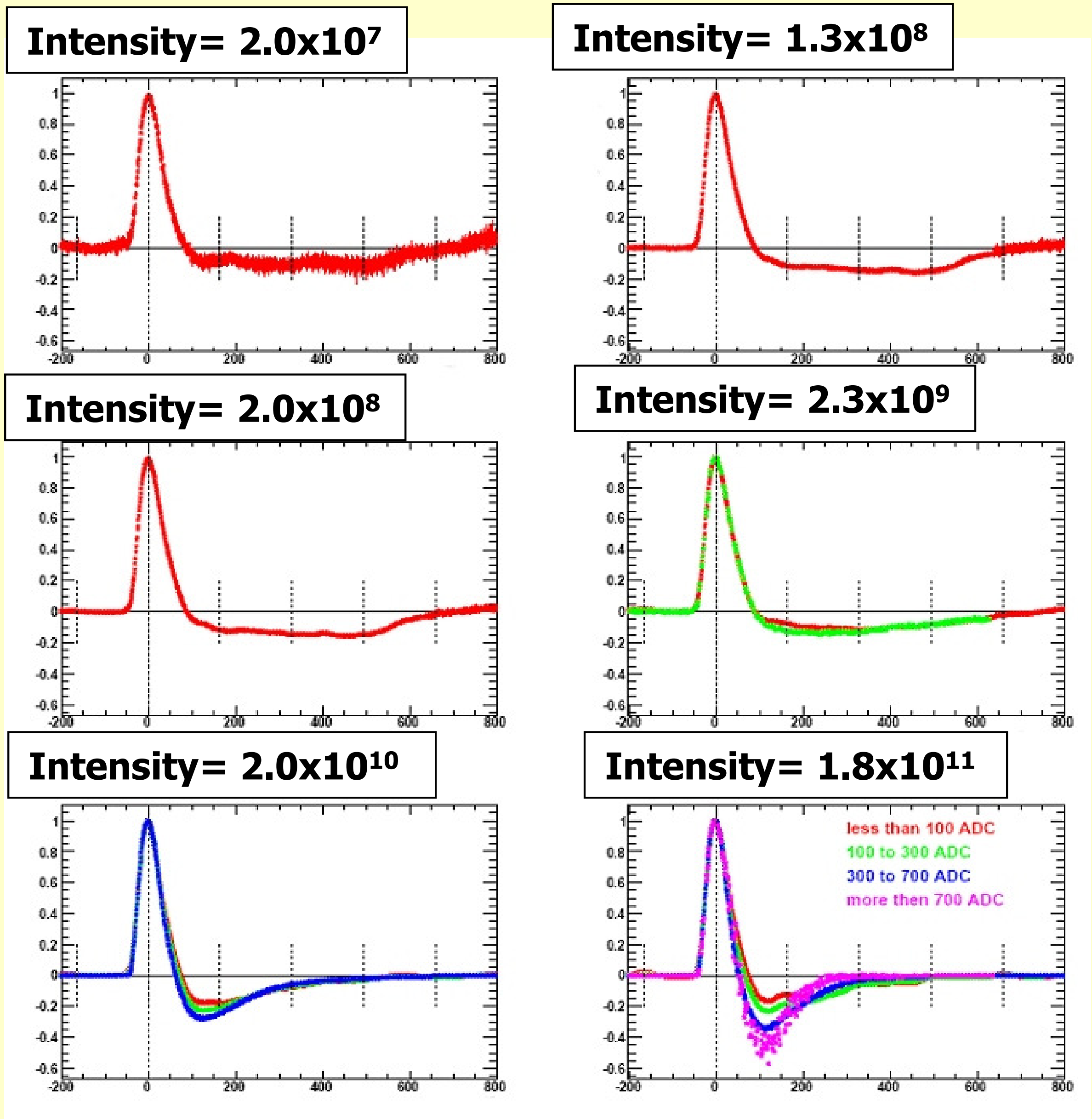
Reality:


Bunch intensity in one spill at intensity $6{\cdot}10^8$

Cherenkov counter design:

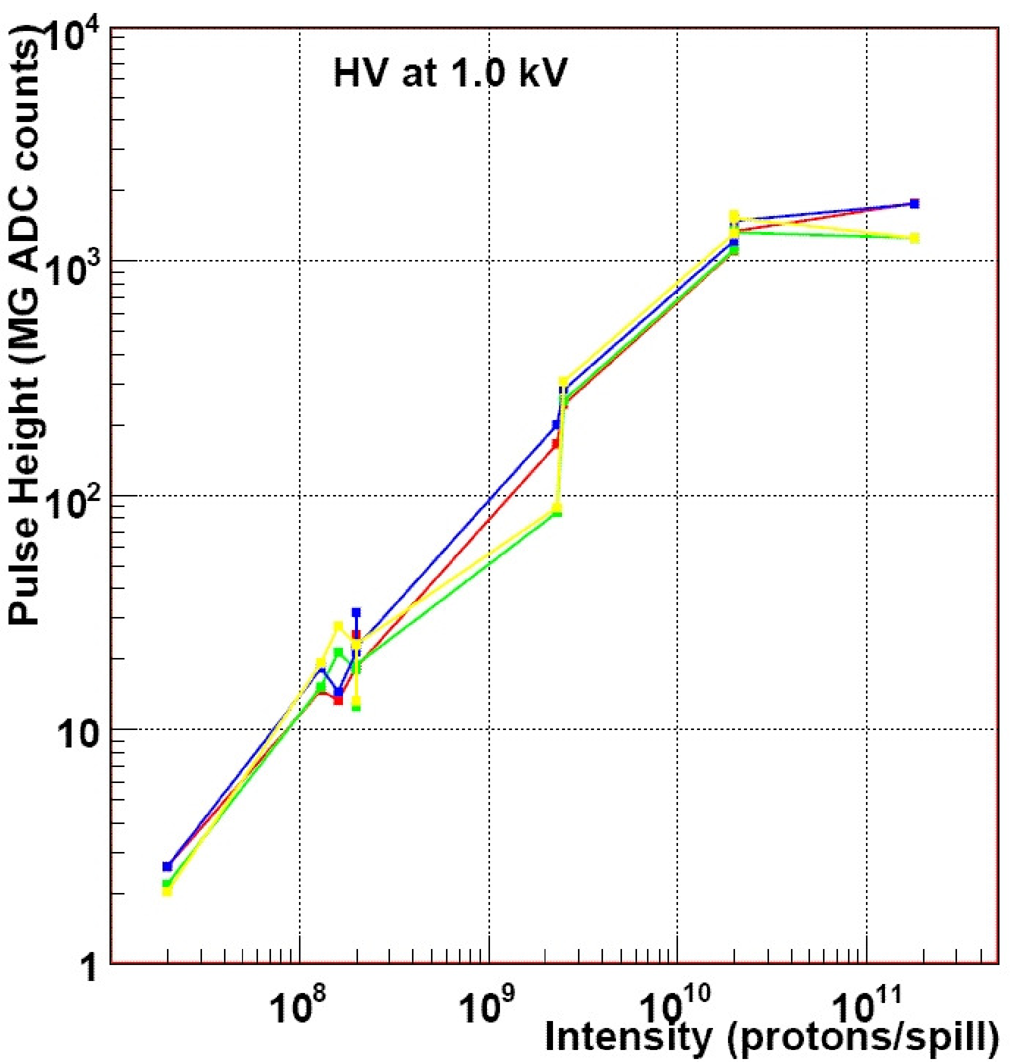


Mean normalized HEC signal



- sum of 4 channels for intensities from 2 x 10^7 pps up to 1.8 x 10^{11} pps
- low intensity: effects of ion build up negligible
- due to high beam intensity variations for higher fluxes → normalized signals shown (different colors) for different amplitudes
- $3\text{x}10^8$ pps corresponds to the sLHC luminosity 10^{35} $\text{cm}^{-2}\text{s}^{-1}$
- with increasing intensity pulse changing: falling edge shorter and sags → shorter and deeper negative signal after shaping

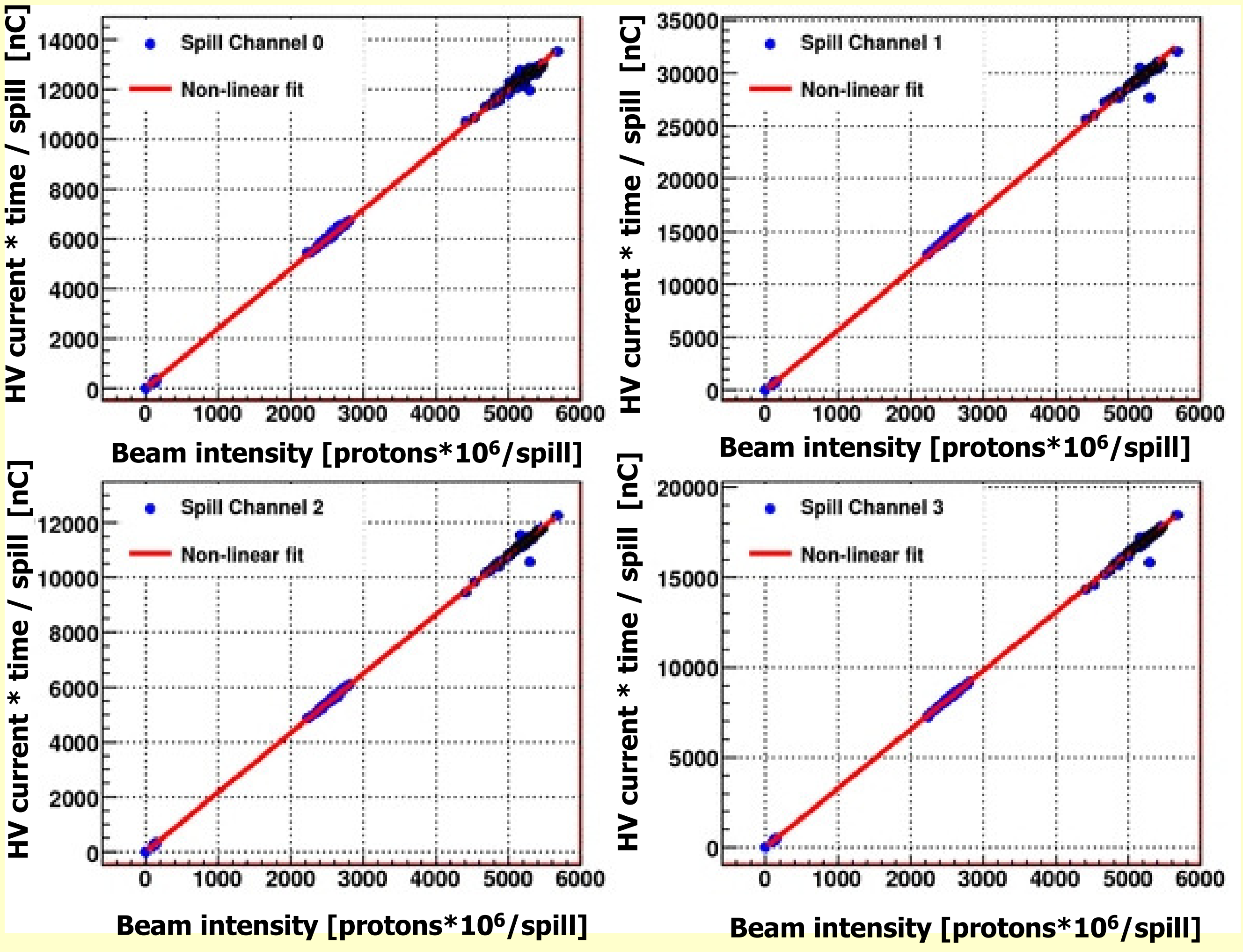
HEC Amplitude vs Beam Intensity



- mean signal amplitude in ADC counts in medium gain for four HEC channels
- intensities from 2 x 10^7 pps up to 1.8 x 10^{11} pps
- above the beam intensity ~10^{10} pps the nonlinearity of the response starts to get visible
- 3×10^8 pps corresponds to the sLHC luminosity 10^{35} $cm^{-2}s^{-1}$

Integrated FCAL HV Currents vs. Beam Intensity

Channel 0 current with polynom.fit **Channel 1 current with polynom.fit**



- currents integrated over one spill for 4 different FCAL 250 μm gap HV channels compared with beam intensity as measured by ionization chamber
- intensities: $10^8 \div 10^{11}$ pps ↔ $10^{33} \div 10^{36}$ $cm^{-2}s^{-1}$ luminosity at LHC
- constant beam position relative to cryostat
- non-linearity < 0.36% at 95% CL for 2nd order polynomial fit for nominal LHC luminosity of 10^{34} $cm^{-2}s^{-1}$ ↔ 10^9 pps
- precision for relative luminosity measurement in ATLAS of 0.5 % can be expected

Conclusions

- change of the signal shape was observed at high intensities
- correlation between beam intensity and read-out signal has been studied
- dependence of HV currents and calorimeter module temperature on the beam intensity has been measured
- effort to monitor / get under control large beam intensity variations

Analysis of the collected data and the data of two scheduled beam runs (November 2009 / spring 2010) → to establish operating limits of the ATLAS LAr end-cap calorimeters at luminosity of 10^{35} $cm^{-2}s^{-1}$ based on the detailed studies of:

- calorimeter cell response as a function of beam intensity and applied HV,
- measurement of radioactive pollution of LAr, calorimeter components and materials as a function of integrated particle flux,
- measurement of argon purity versus integrated particle flux,
- analysis of the signal shapes as function of integrated particle flux.

Many thanks to all members of the HiLum ATLAS End-cap Collaboration!