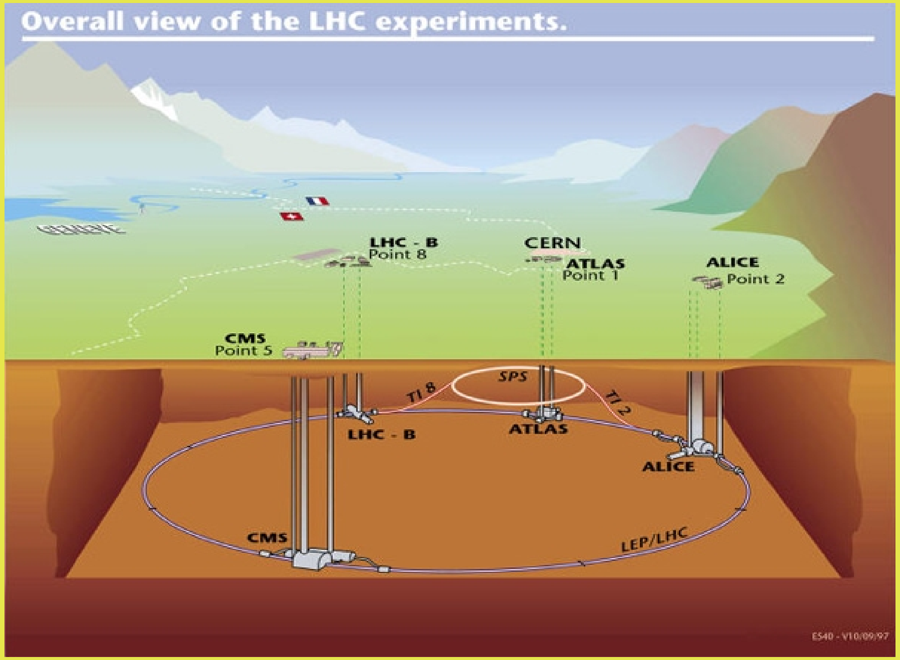
Upgrade plans for the ATLAS Calorimeters

Frank Seifert

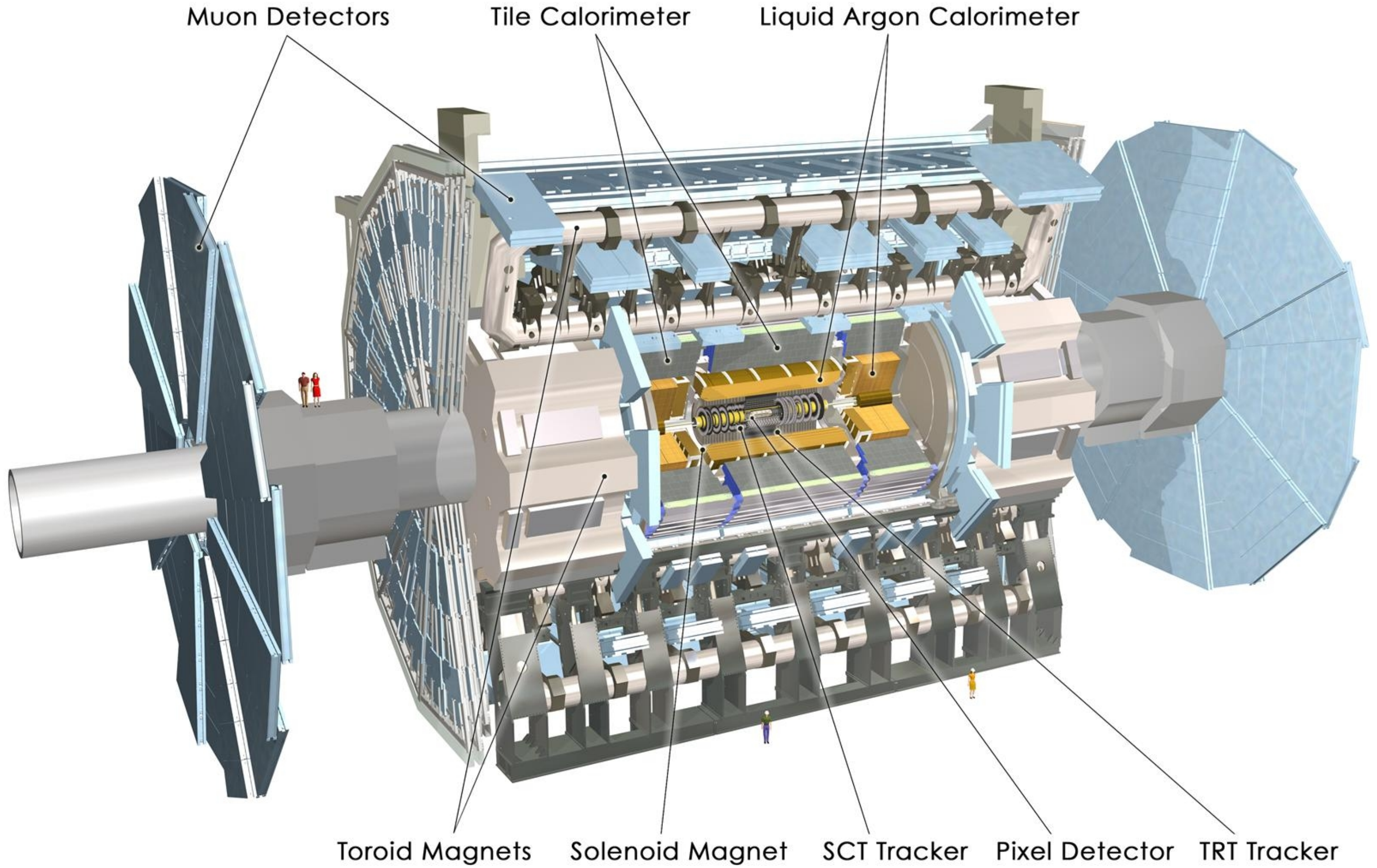
on behalf of the ATLAS calorimeter group

Contents:



12th Pisa Meeting on Advanced Detectors - 2012

1. The ATLAS experiment at the LHC



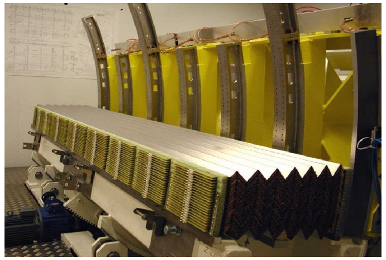
- 2011: 7 TeV, ~ 5 fb^{-1} recorded
- 2012: 8 TeV, ~ 15 fb^{-1} expected
- reached inst. luminosity: 5.5×10^{33} $cm^{-2}s^{-1}$

- Planned to be reached after shutdown 2013/2014:
  → 13 TeV, L = 1-2×10^{34} $cm^{-2}s^{-1}$ inst. luminosity (nominal design: 10^{34} $cm^{-2}s^{-1}$)

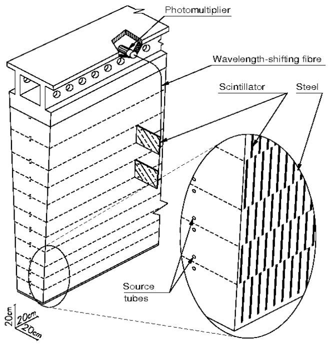
2. The Calorimeter System

2 Technologies:

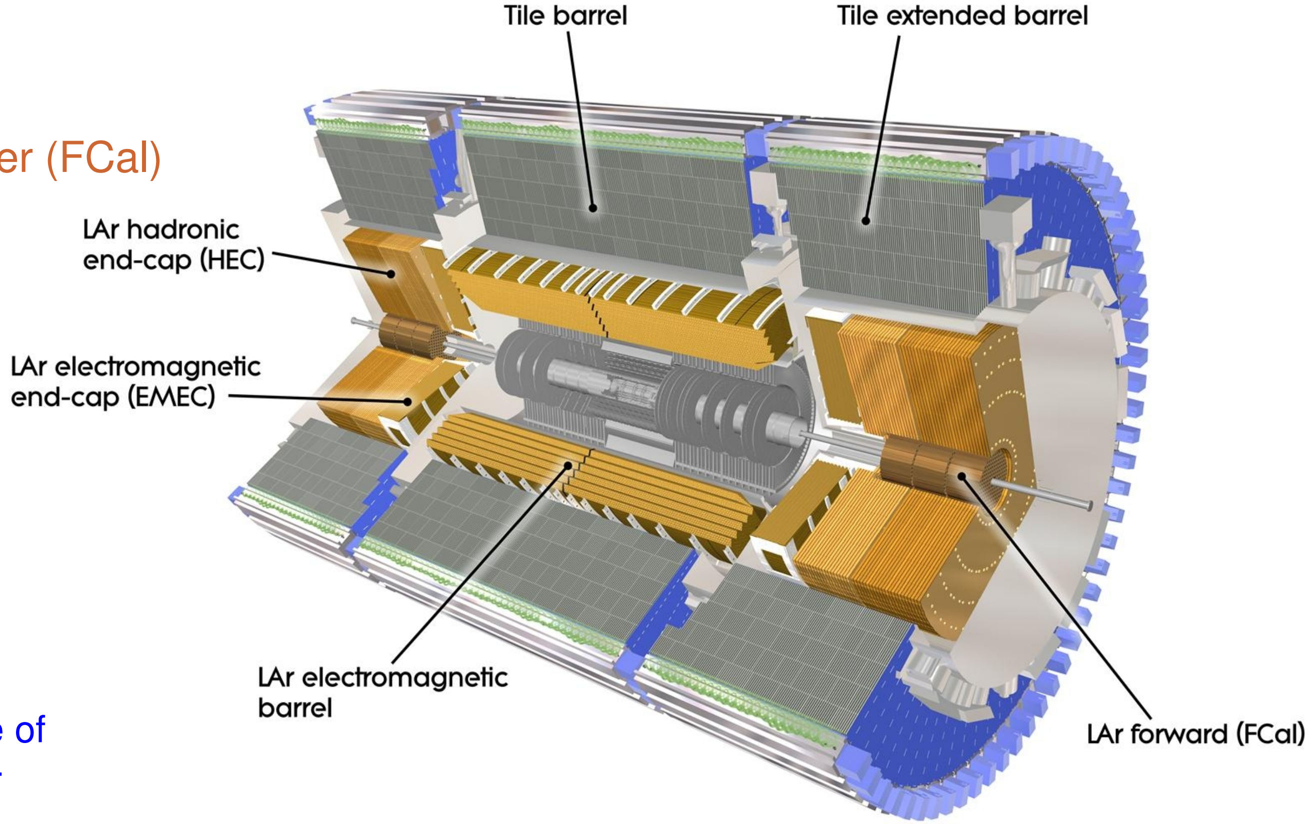
- **Copper/Tungsten - Liquid-Argon**
  → EM calorimeter + Hadronic Endcap calorimeter (HEC) + Forward calorimeter (FCal)



- **Steel – Scintillator**
  → Hadronic barrel calorimeter (Tile)

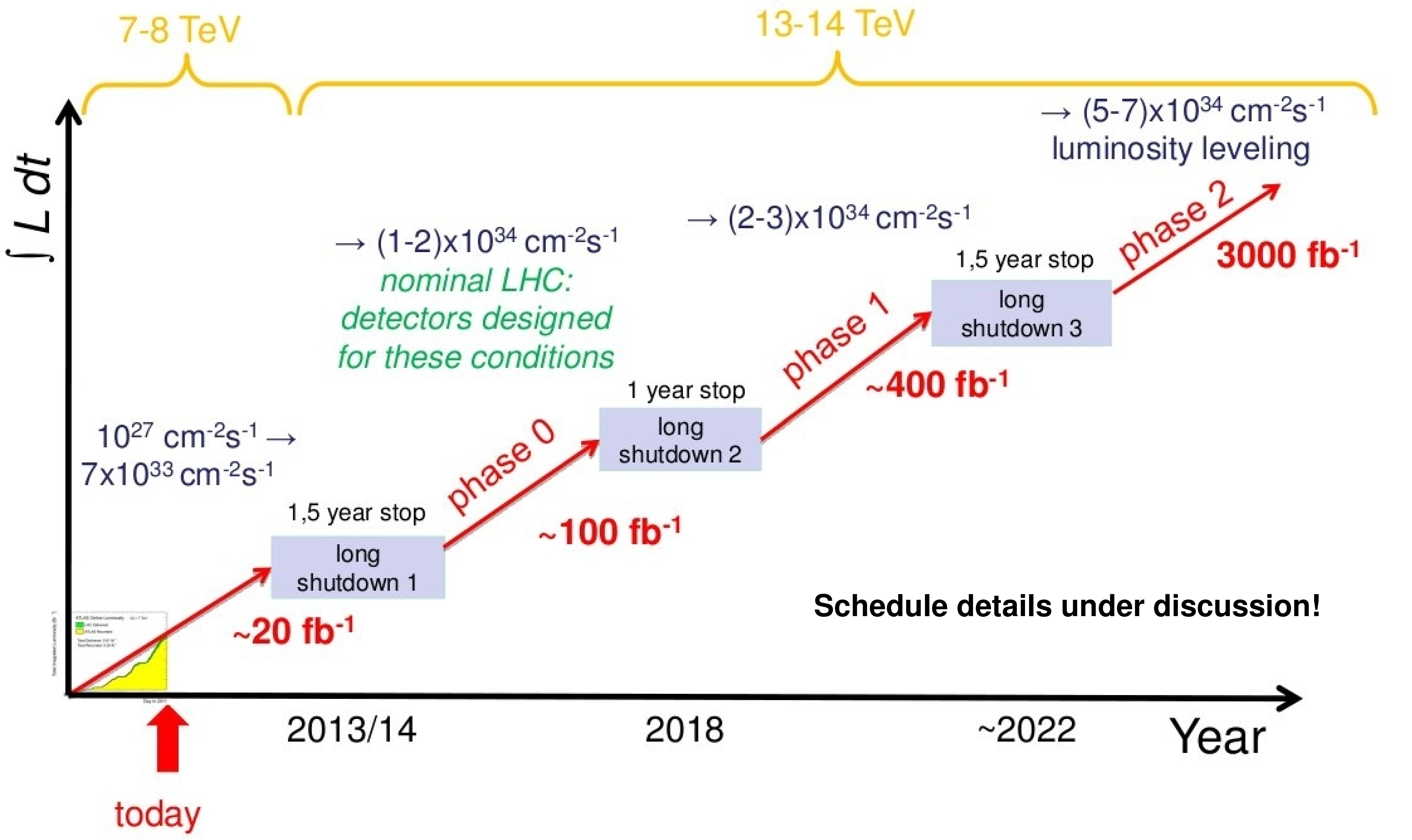


alternating structure of steel and scintillator

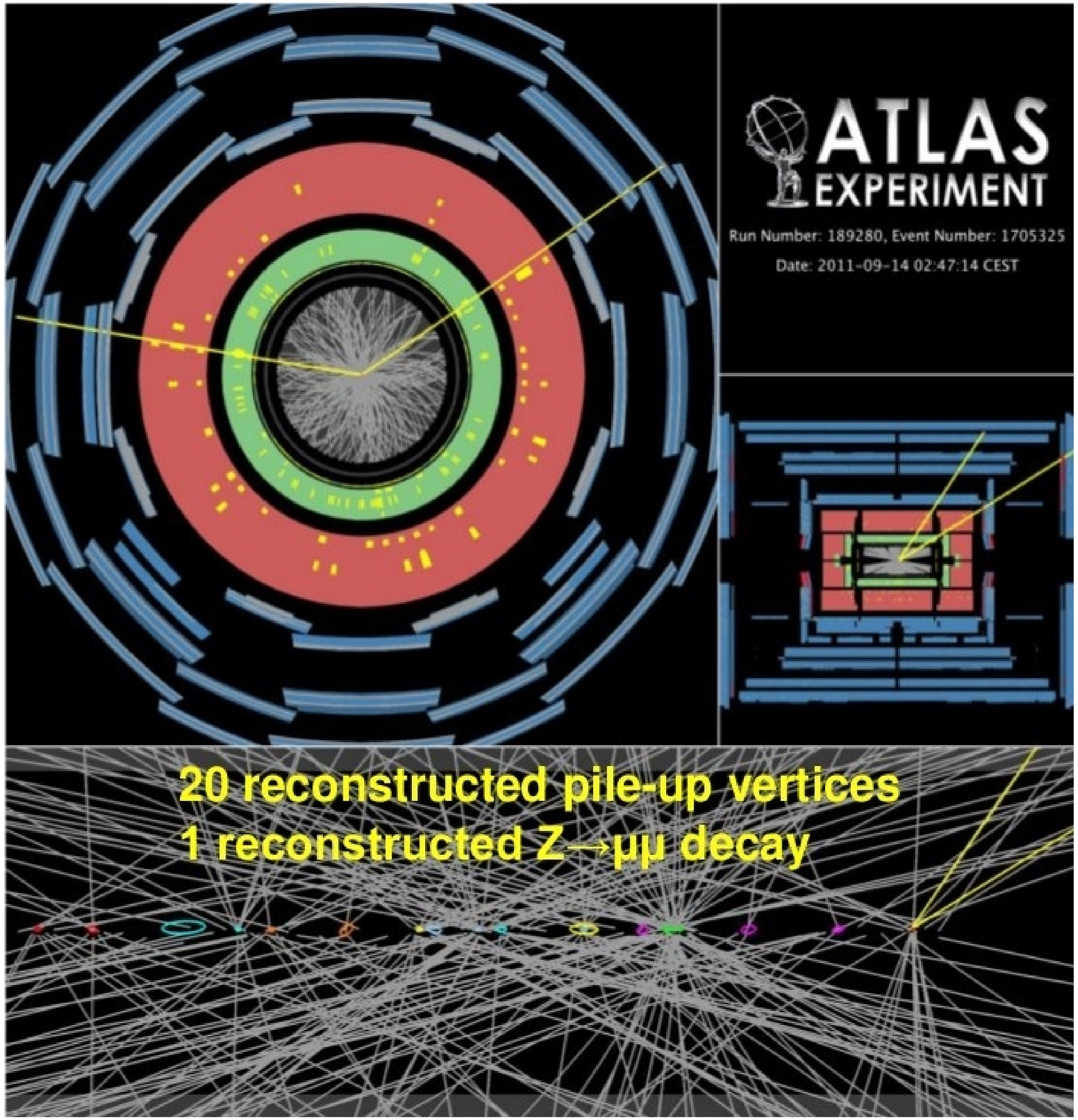


	EM barrel	EMEC	HEC	FCal1	FCal2+3	Had barrel
Thickness	22-33 X_0	24-38 X_0	~10.0 λ	27.6 X_0	~7.3 λ	9.7 λ (η=0)

Overview over upgrade plans



3. Phase I and II upgrade plans



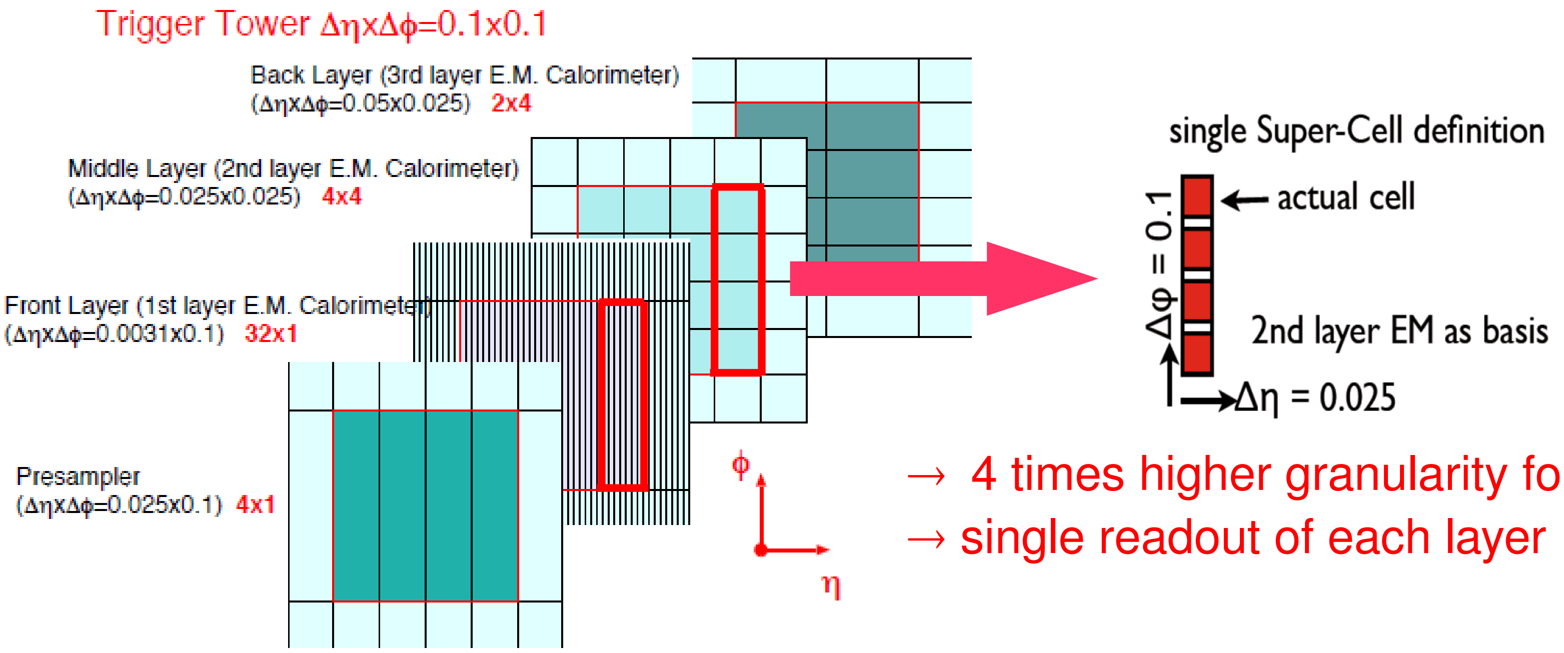
- Mean at nominal LHC: 25 p-p intercations/bunch-crossing; after Phase I: 55-80
- Trigger rates of most triggers increase linearly with instantaneous luminosity
- Level-1 trigger rate is limited in bandwidth

➔ Would need to cut away most W and Z signals to avoid trigger prescales

3. Phase I and II upgrade plans

Phase I

- Current L1 Trigger towers of $\Delta\eta\times\Delta\phi = 0.1\times0.1$ with all layers
- To reduce rates: finer granularity is planned: “Super Cells”

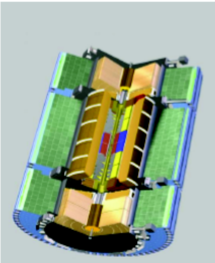


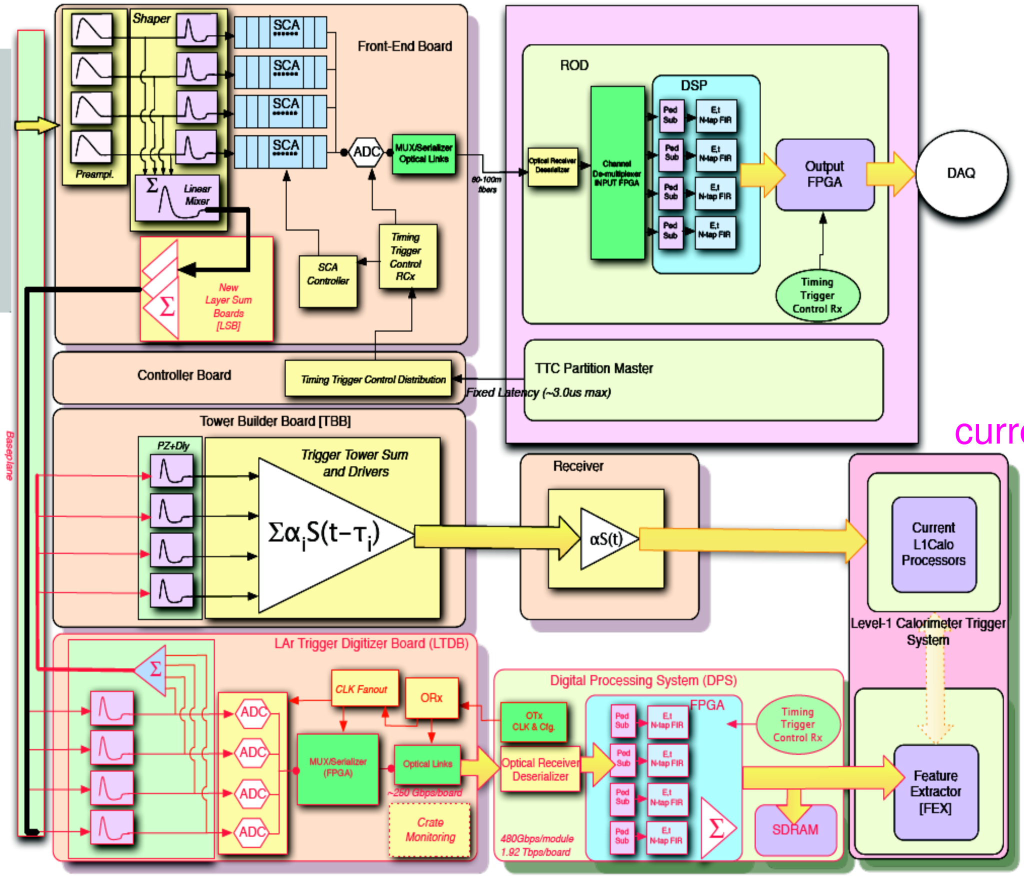
→ 4 times higher granularity for 1st and 2nd layer
→ single readout of each layer

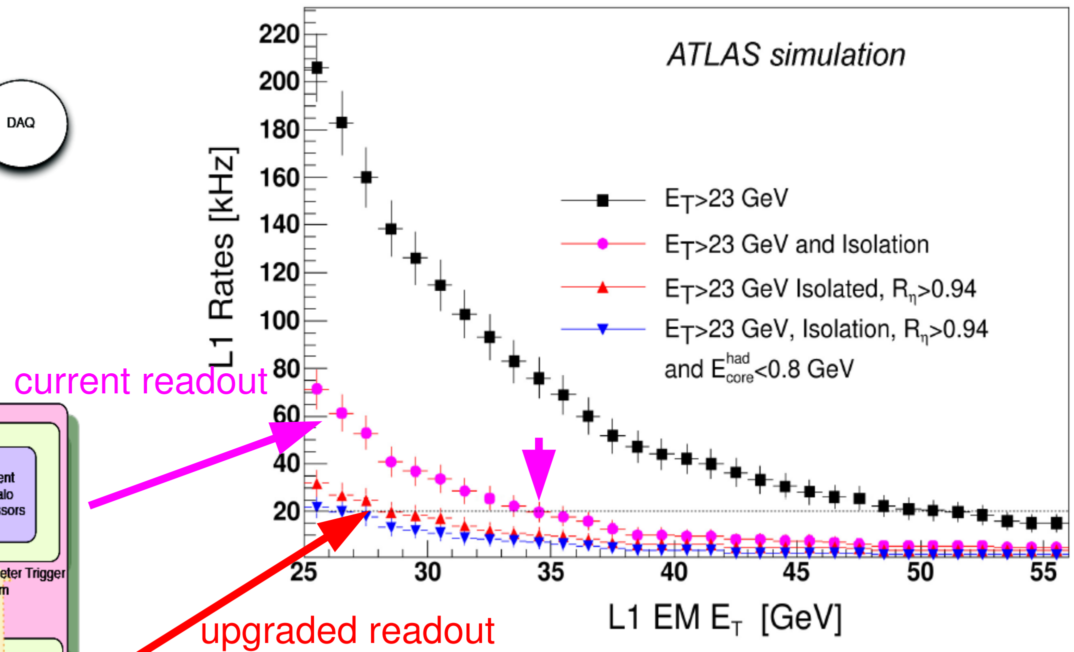
→ Will require an upgrade of the front-end readout electronics

3. Phase I and II upgrade plans

Phase I upgrade plans for LAr calorimeters







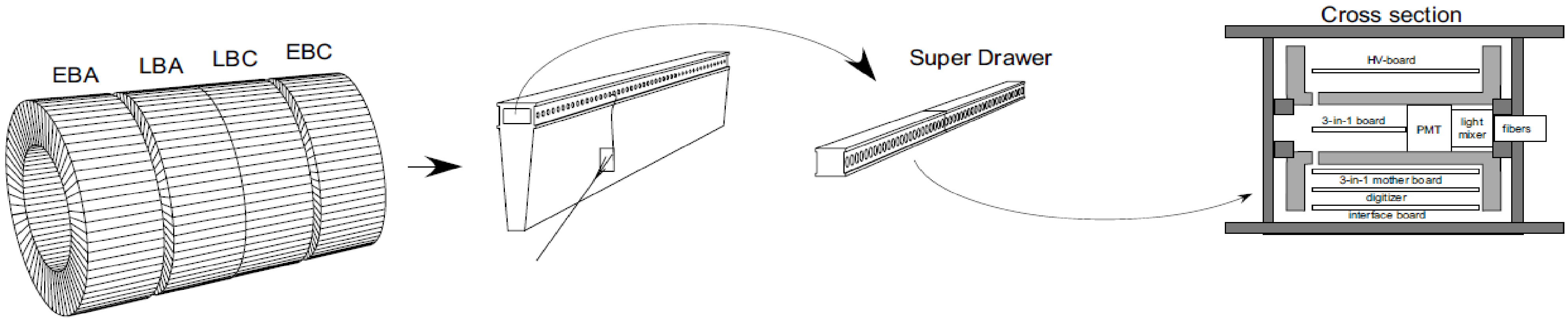
→ L1 trigger thresholds can be reduced at constant rate!

- Main read-out is unchanged, but signal forming and processing for L1 trigger will be redesigned.

More details → *See poster by Steffen Stärz*

3. Phase I and II upgrade plans

Current Readout system of Tile calorimeter



- PMT signals grouped and summed to $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ trigger towers
- Digitized and stored locally in pipeline memories
- Selected events are sent via optical fibers to the off-detector Read Out Drivers (RODs).

PhaseI upgrade plans for Tile calorimeter

➔ Considerations to use data from the outermost D-layer for muon triggers

3. Phase I and II upgrade plans

Phase II overview

Instantaneous luminosity of $5\text{-}7 \times 10^{34}\ cm^{-2}s^{-1}$, and $3000\ fb^{-1}$ integrated luminosity

Problems with rates and average energy deposits → Influence functionality of FCal itself.

↓

Ion build-up, HV drop, boiling Argon and space-charge effects.

↓

New detector design considered.

↓

Replace FCal with sFCal **or** additional mini-FCal

Problems with long-term radiation damage in the on-detector electronics.

↓

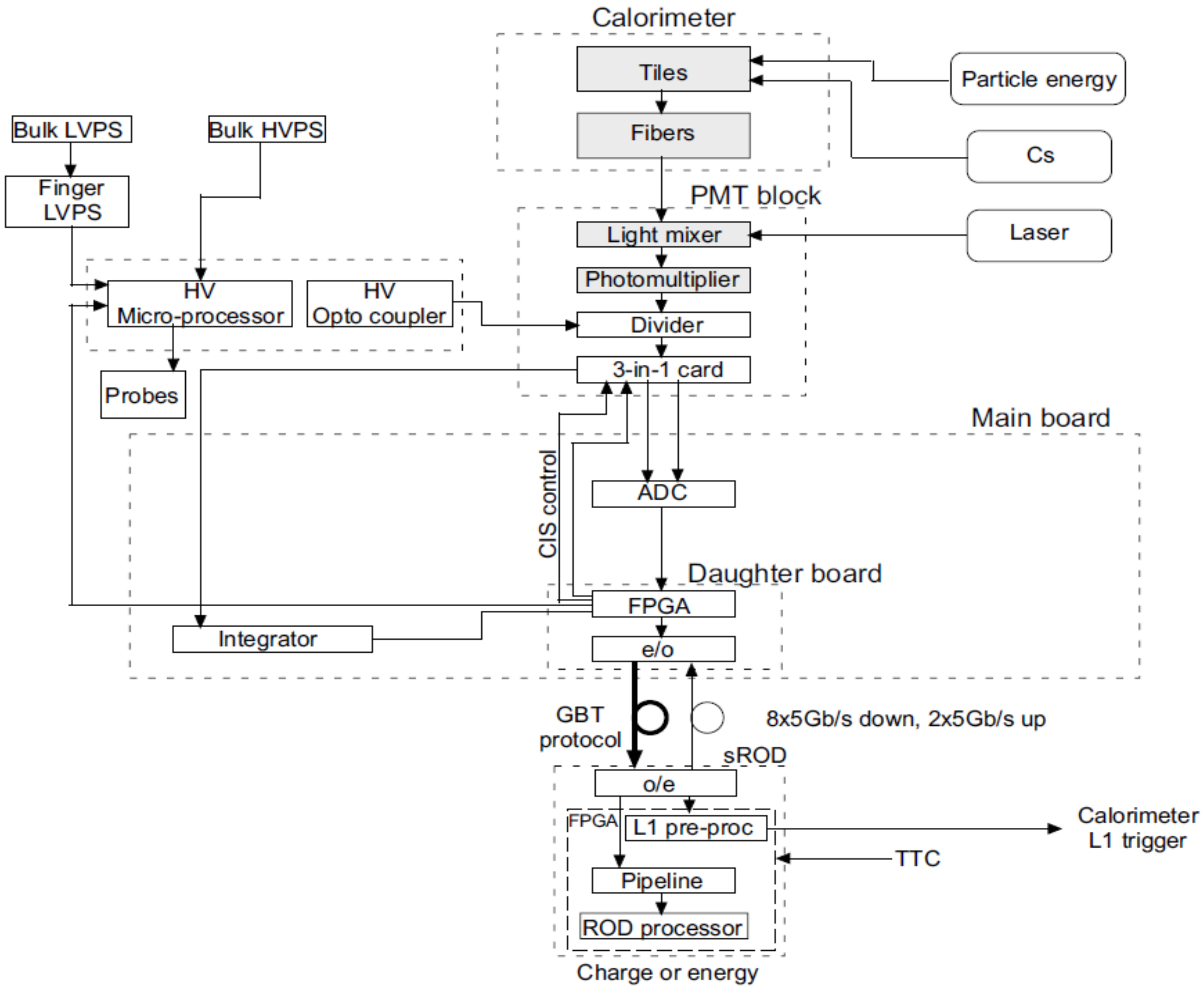
- Possible that HEC cold electronics need to be replaced.
- Upgrade of LAr FEBs is planned.
- Upgrade of Tile readout with new front-end electronics in new drawers.

3. Phase I and II upgrade plans

Phase II Tile calorimeter upgrade plans

- Only upgrade of electronics necessary (all on- and most off-detector electronics)

→ All signals are directly digitized and sent out at 40 MHz (free running mode).



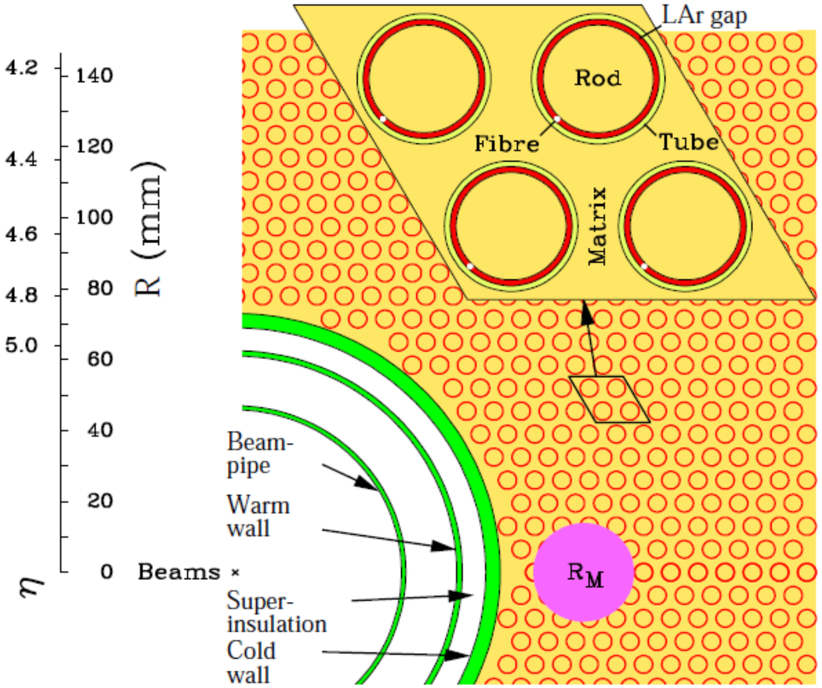
- **No analog trigger cables**
- **High speed links using the GBT protocol - then to L0/1 trigger**
- **Configuration, control and TTC information via up link**
- **Pipeline in sROD FPGA**
- **The Daughter board FPGA is the system controller**

3. Phase I and II upgrade plans

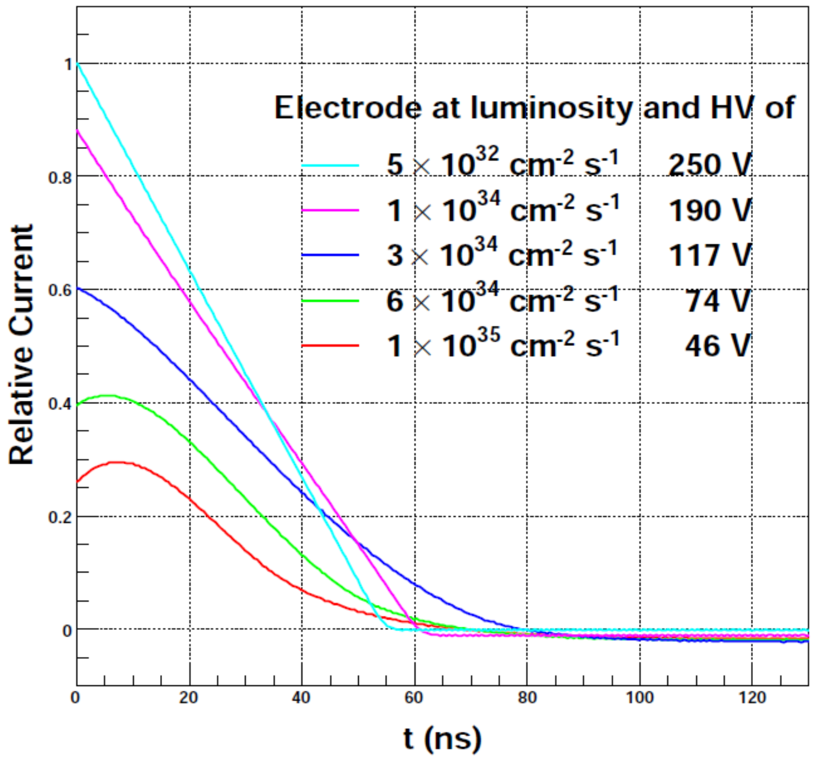
Phase II LAr calorimeter upgrade plans

- Charged particle fluxes at > 3×10^{34} $cm^{-2}s^{-1}$ are too high for current FCal with 250μm gaps.

FCal1 structure:

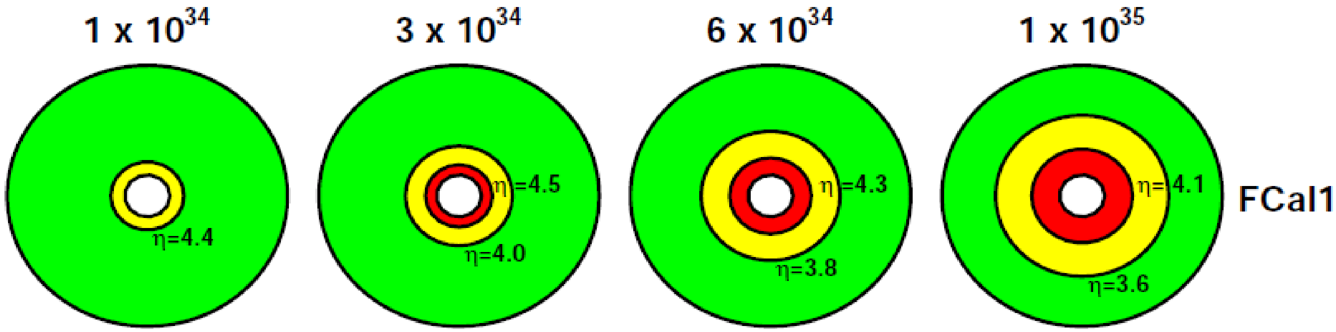


Operation performance with increased luminosity:



FCal1 transverse view:

green: acceptable performance
yellow: marginal performance
red: degraded operation



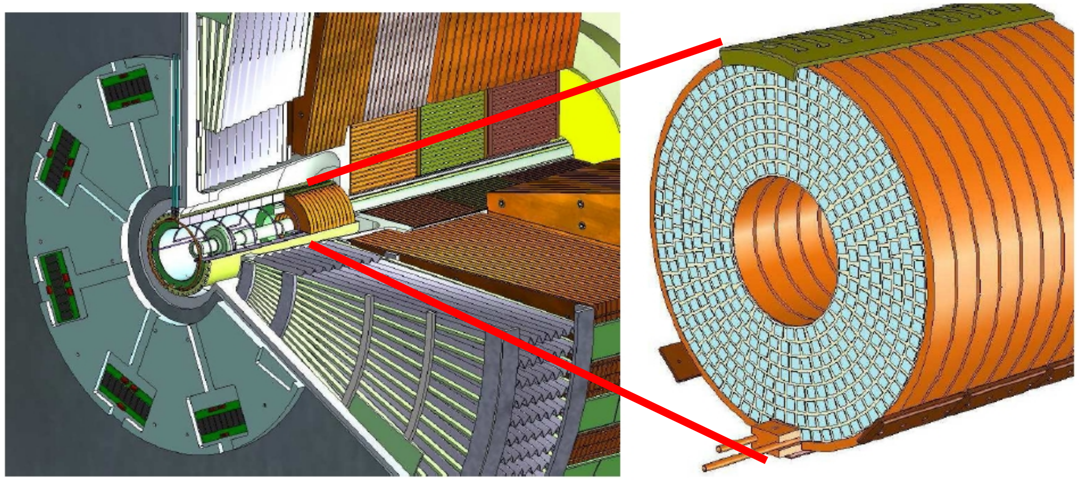
3. Phase I and II upgrade plans

Phase II LAr calorimeter upgrade plans

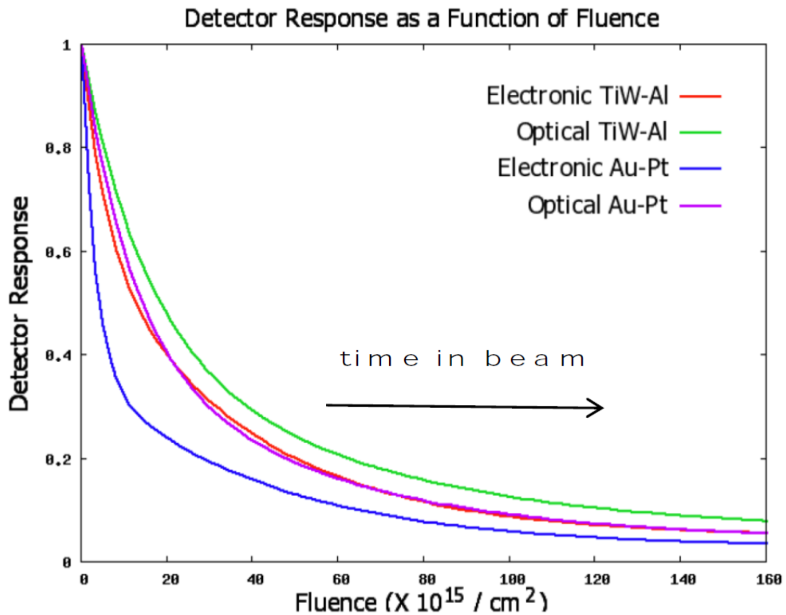
Two options:

1. Installation of Mini-FCal in front of FCal1

- Proposed design: copper – diamond calorimeter



But shows no constant response over time:



→ Alternative: LAr or high pressure Xenon design

More details → *See poster by Margret Fincke-Keeler*

2. Replacement of the FCal1 with a super-FCal (sFCal)

- 100 μm gaps instead of 250 μm ones

→ Hilum testbeam studies in Protvino

4. Hilum project in Protvino

- Hilum project at U-70 accelerator in Protvino, Russia
- Goal: Test EMEC, HEC and FCal in HL-LHC environment

INTAS Project INTAS-CERN 05-103-7555

Hilum ATLAS LAr Endcap Collaboration:

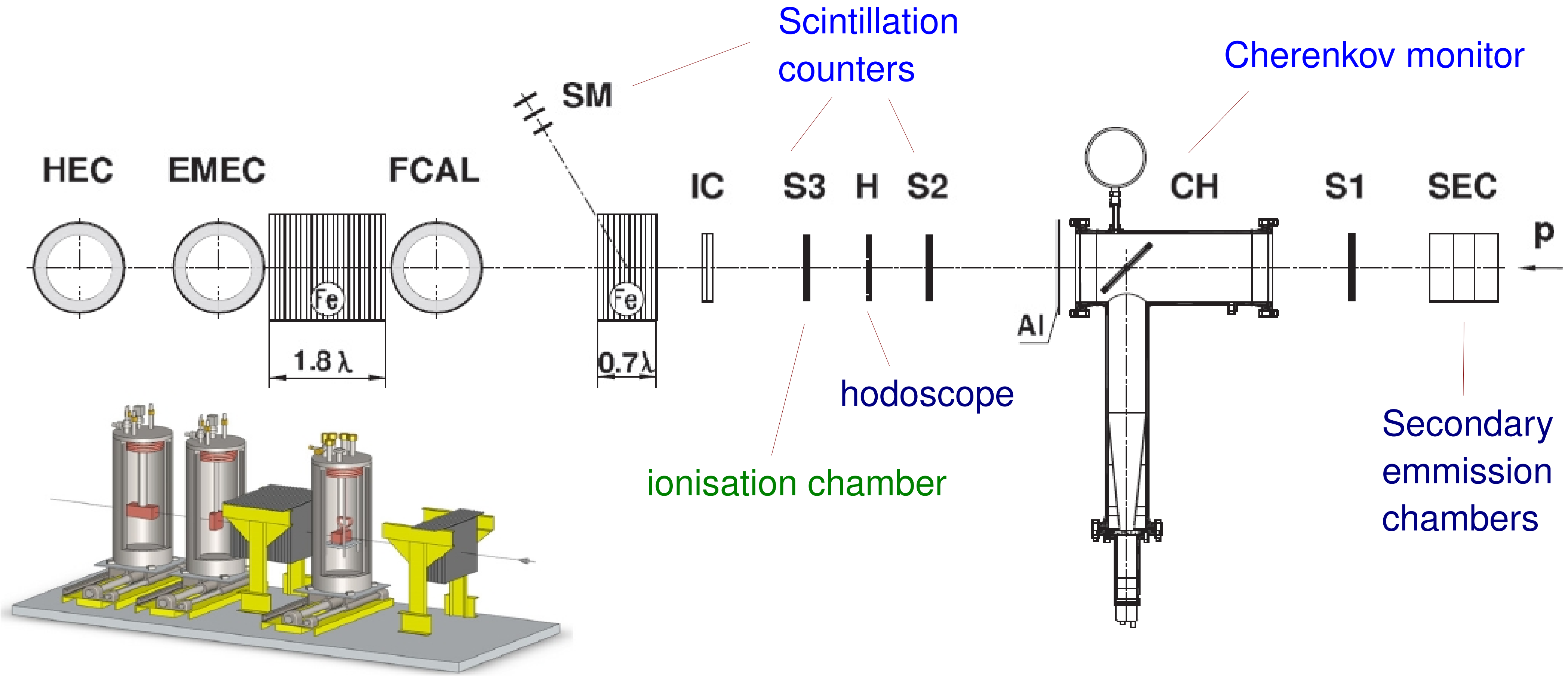
- **Univ. of Arizona**
- **Univ. of Dresden**
- **JINR Dubna**
- **IEP Košice**
- **Univ. of Mainz**
- **LPI Moscow**
- **MPI Munich**
- **BINP Novosibirsk**
- **IHEP Protvino**
- **TRIUMF Vancouver**
- **Univ. of Wuppertal**

- Proton beam of 50 GeV
- Bunched beam with Intensity range: 10^6 – ~3×10^{11} p/spill
- 1.2 s long spills every 9.5 s

4. Hilum project in Protvino

Setup in experimental area

Goal: simulate particle flux through calorimeters in dependence of η as in ATLAS

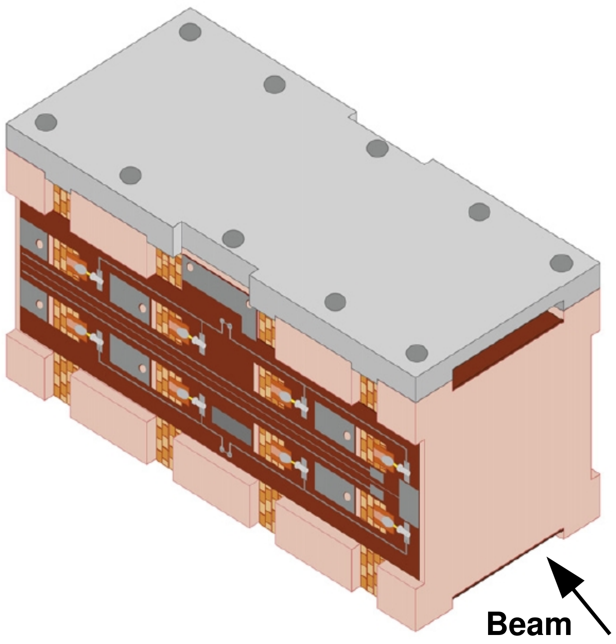


→ Testbeam setup and absorber thickness was optimized in MC simulations, using the 2D-gaussian beam size of 10mm.

4. Hilum project in Protvino

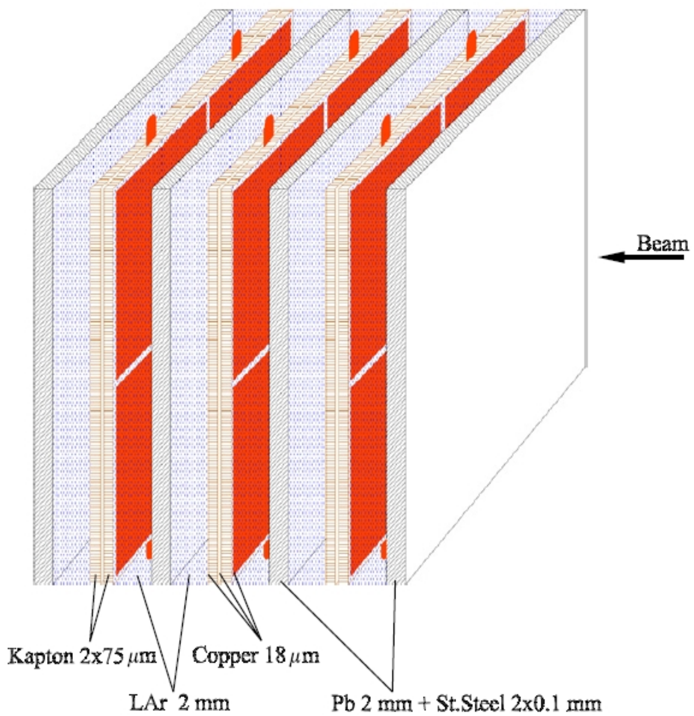
The calorimeter test modules

HEC module



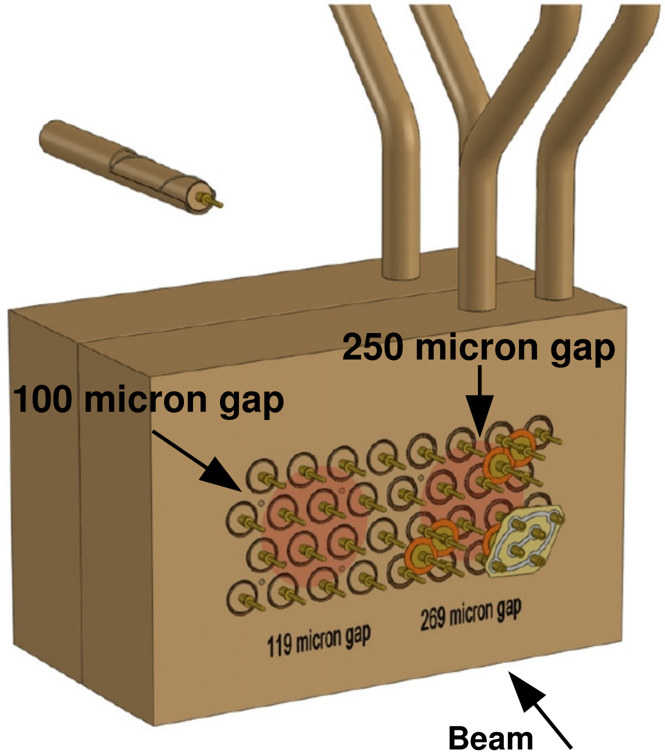
60×60 mm
4 readout channels
4 HV channels

EMEC module



70×70 mm
4 readout channels
3 HV channels

FCal1/sFCal module



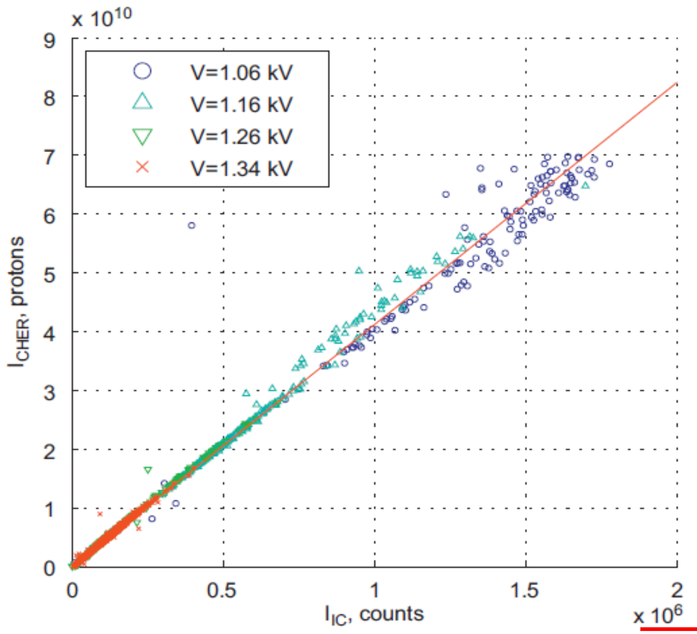
90×60 mm
2x4 readout channels
2x4 HV channels

Each module is housed in separate movable cryostat.

4. Hilum project in Protvino

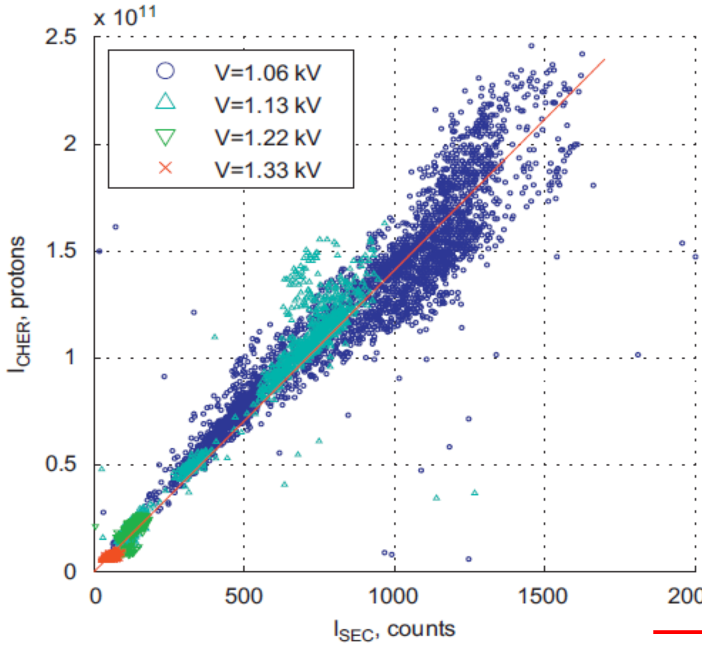
Beam intensity monitoring

Cherenkov counter



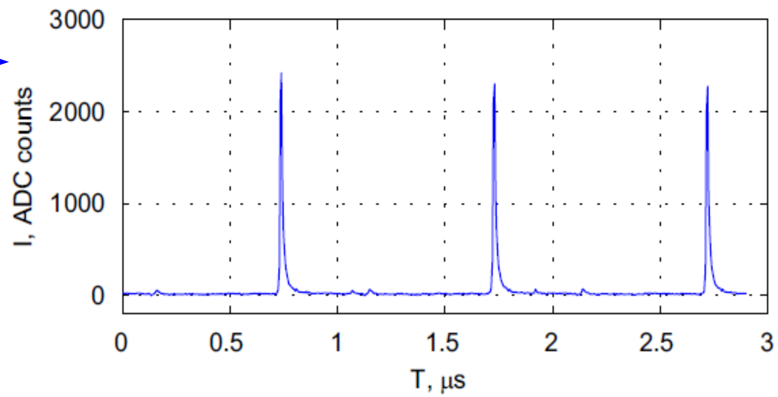
Ionisation chamber (integration over spill)

Cherenkov counter



Secondary emission chambers

- Cherenkov counter with fast ADC-readout
  - Resolution of single bunches possible



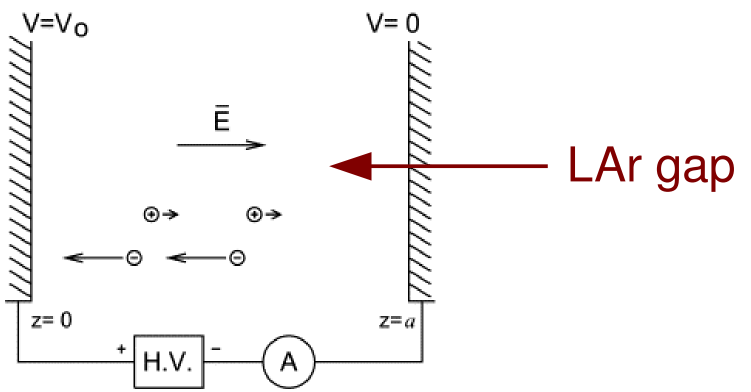
- Absolute calibration done with activation of AL foils:
  - Reaction: 27Al(p,3p3n)22Na, 22Na$\rightarrow\gamma$ (1275 keV)
  - Overall precision: 15%.

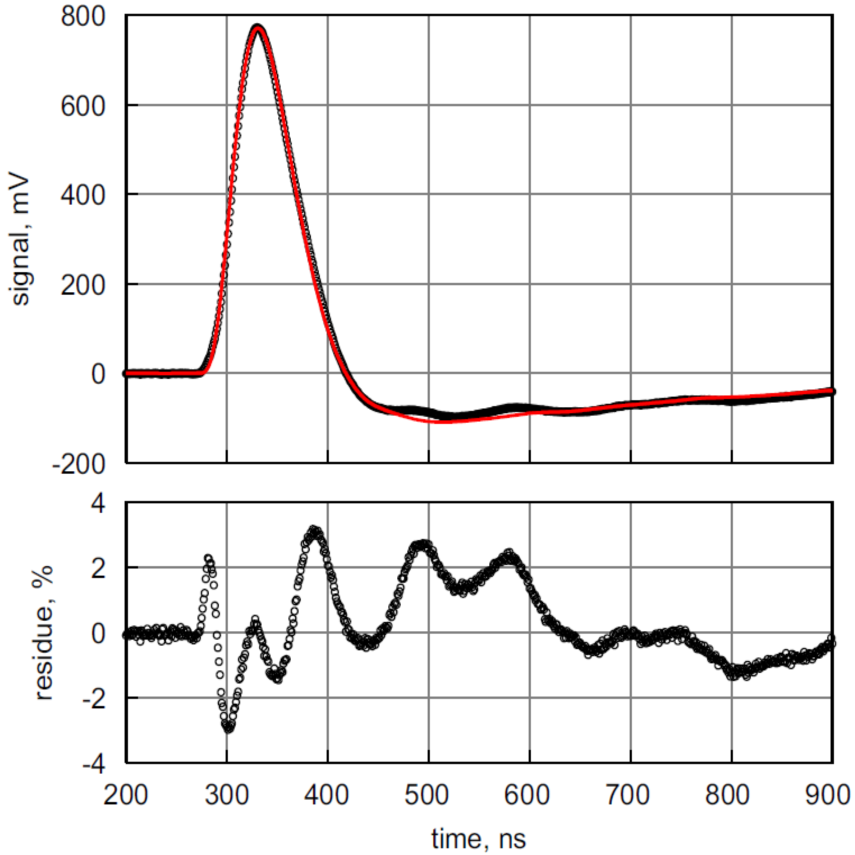
4. Hilum project in Protvino

Readout signal shapes

- Triangular pulse at the detector is shaped by the front-end electronics

- Readout done with two 25ns sampling ADCs
- Main mode+delayed mode → effective: 12.5ns
- 2 gains: low and medium gain
  - ➔ Good understanding of the whole readout chain





Response of one readout channel of the HEC to a calibration pulse (black)
Corrsponding model function (red)

- Charge flow in the gap is compensated by the HV supply system (→HV DC current).

➔ Also relevant quantity to analyse

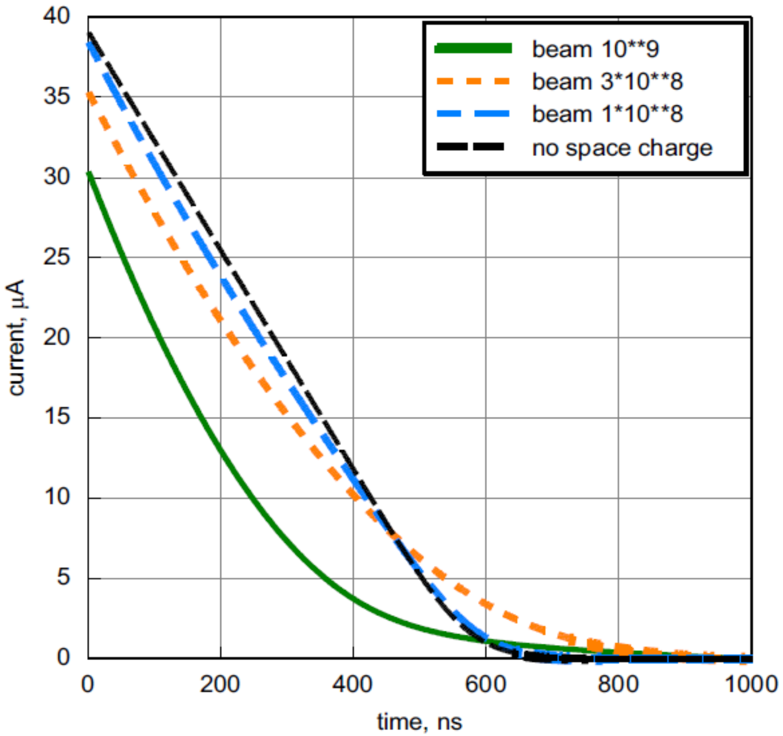
4. Hilum project in Protvino

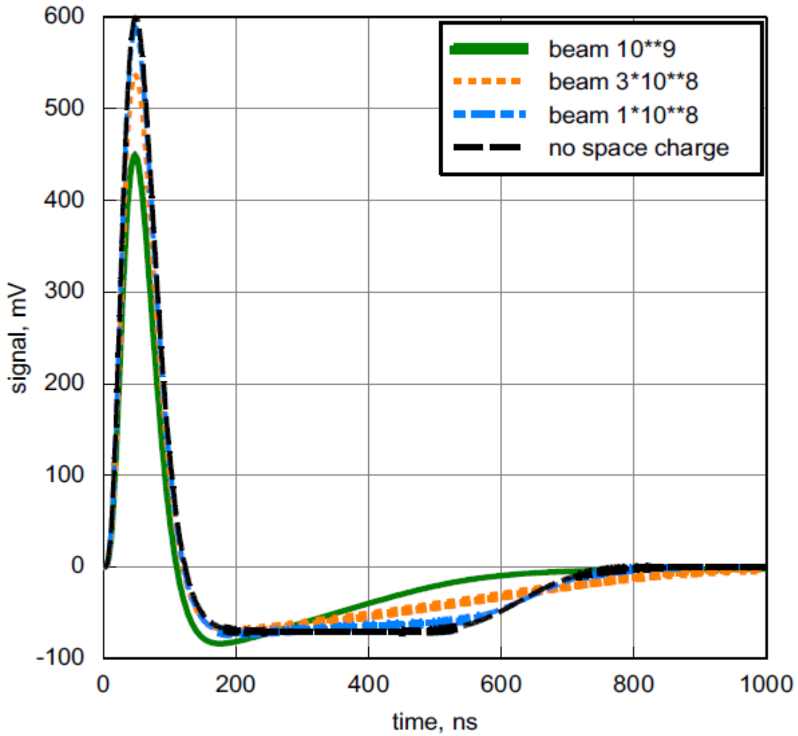
Prediction for signal behaviour with beam intensity

- Positive charge buildup in LAr gaps with increasing intensity

→ Degradation of the signal

→ Critical value if charge buildup in gap is equal to charge at electrodes





Current and Shaped pulse for 2mm LAr gap of EMEC module for different beam intensities.

Scale factors of 3.3 (10^8p/s) and 10 (3×10^8p/s) are used for better comparison of the effects.

Assumed: HV = 1.2kV

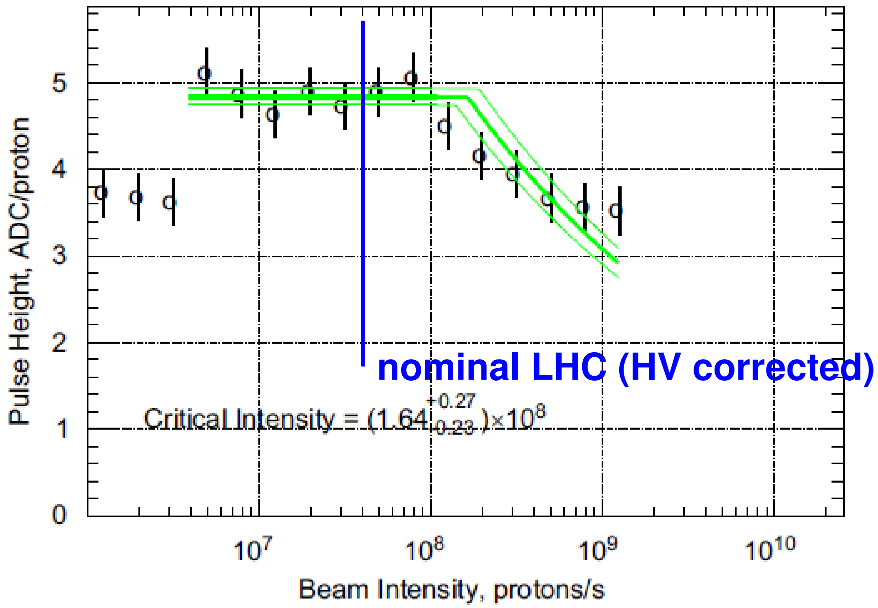
ion mobility: $\mu_+ = 10^{-3}$ cm²/Vs

reco. rate constant: $k_r = 10^{-5}$ cm³/s

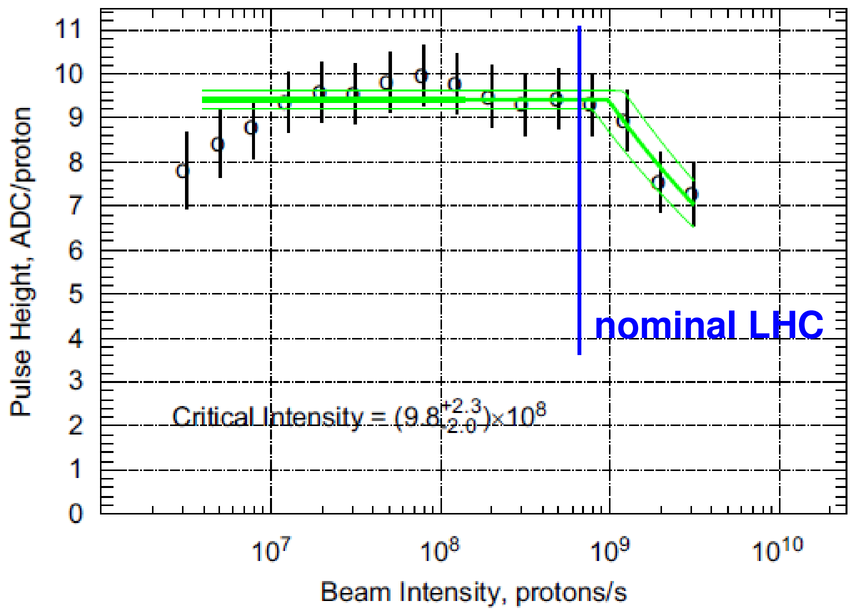
4. Hilum project in Protvino

Results – Readout signals

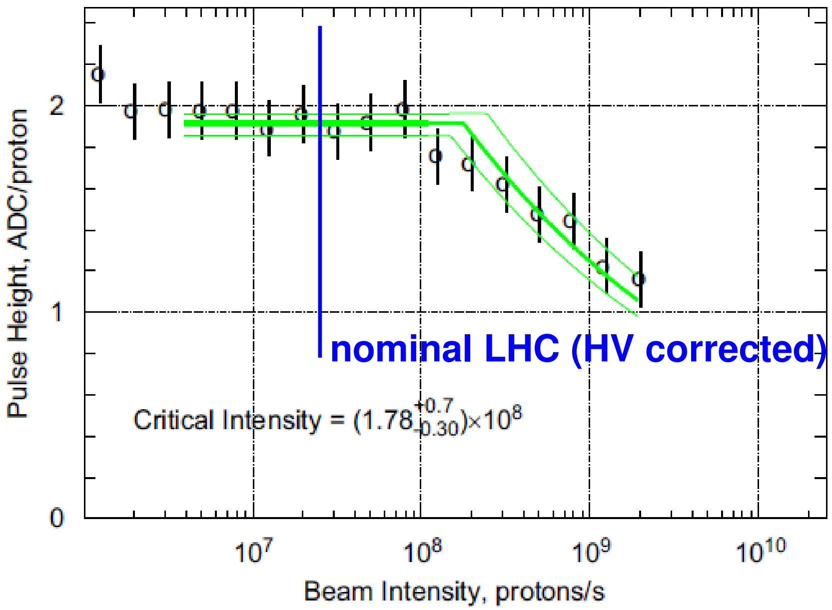
EMEC



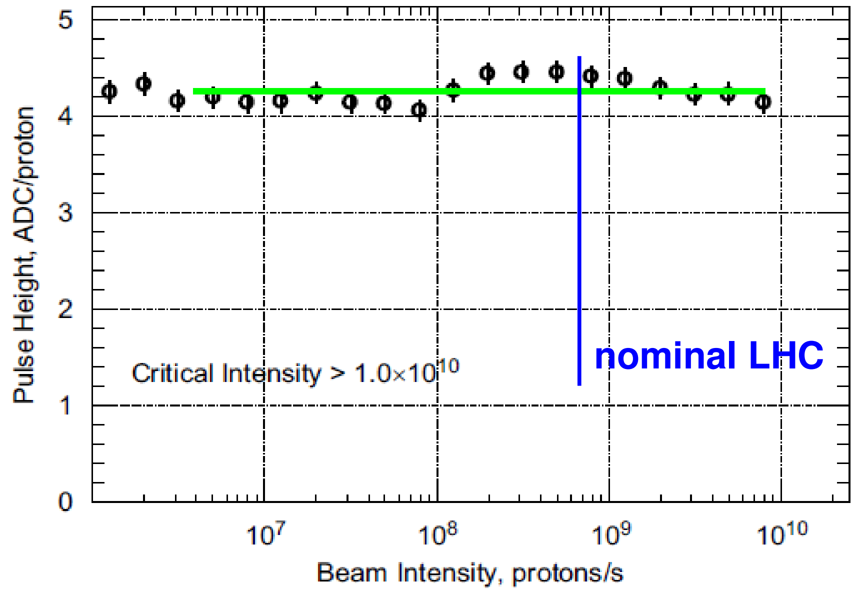
FCal 250 μm gap



HEC



FCal 100 μm gap

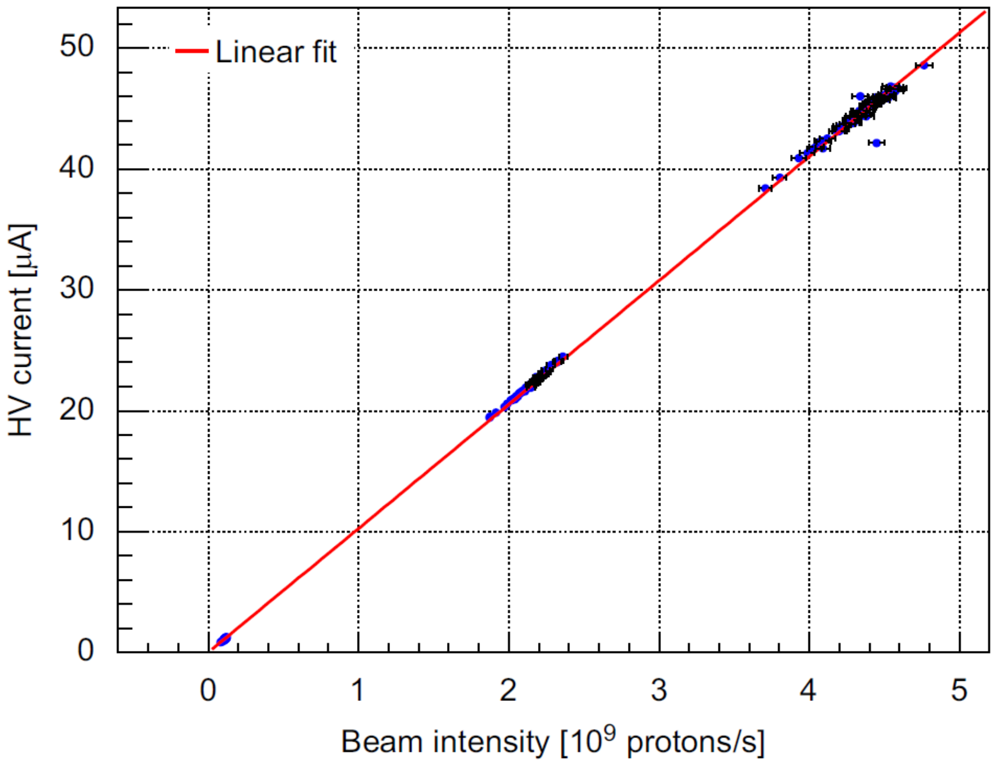


4. Hilum project in Protvino

Results – HV currents

Fcal(250μm gap)

Result from testbeam run 2008

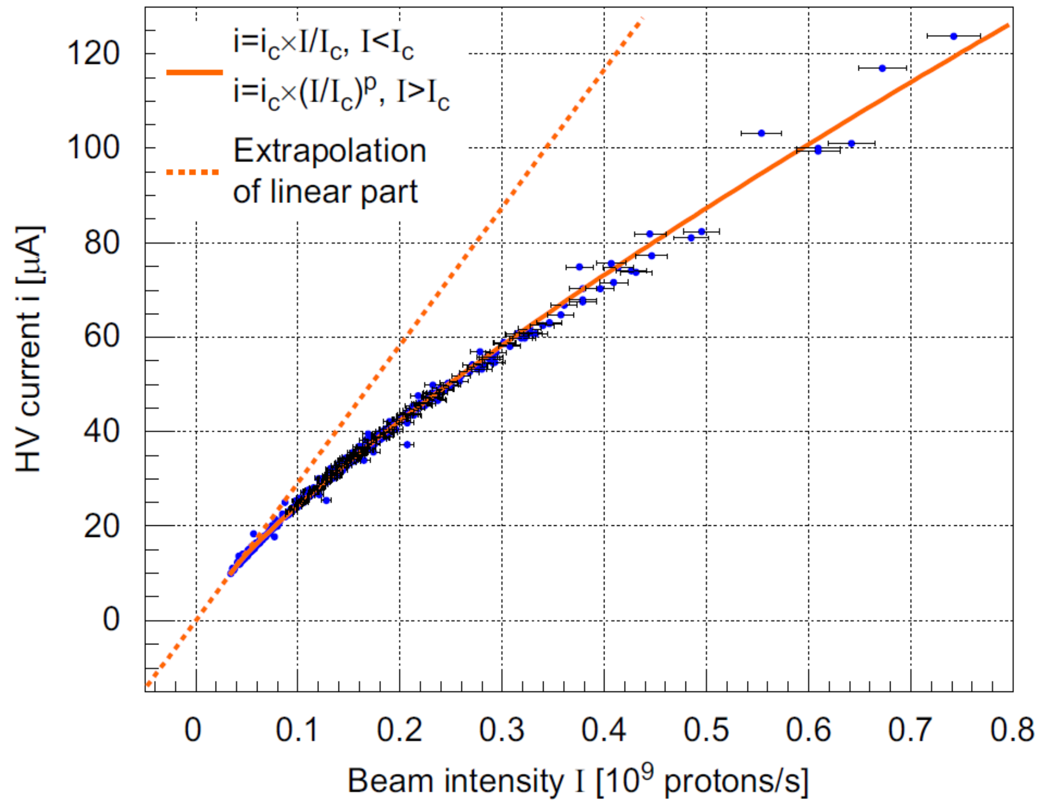


FCal currents go linear with beam intensity

→ Has become one of the standard methods for relative luminosity measurement in ATLAS

EMEC

Result from testbeam run 2010



Behaviour of EMEC currents as predicted

Prediction: $i = i_c \times (I/I_c)^{0.75}$ for I>Ic

→Fit: Exponent $p = 0.76 \pm 0.03$

5. Summary and Conclusion

• **With increased instantaneous and integrated luminosity of the LHC, the Lar- and Tile calorimeters need to be upgraded and some components may need to be replaced.**

• **Phase I:** Upgrades planned for triggers, electronics and readout;
No detector upgrades needed

• **Phase II:** Upgrade of detector front-end electronics for Tile and LAr calorimeters
FCal may need to be replaced/upgraded

• **Hilum testbeams in Protvino (2008, 2009, 2010) have been performed successfully.**

- Results are overall in agreement with the expectations
- Signals of EMEC, HEC are flat up to ~ 5 x nominal LHC luminosity (within present systematics).
- FCal(250 μm) amplitudes drop already slightly above nominal LHC intensity.
- Proposed Fcal(100 μm) test module shows stable behaviour until 10 x nominal LHC luminosity
- HV currents of EMEC behave well as predicted in dependence of intensity.
- Recent run in 2012 (analysis ongoing) allows to reduce the systematic errors at both low and high intensities

References

[1] The ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, JINST 3 (2008) S08003, 2008.

[2] The ATLAS Collaboration, *Letter of Intent for the Phase-I Upgrade of the ATLAS Experiment*, CERN-LHCC-2011-12, 2011.

[3] J. Rutherfoord, *Signal degradation due to charge buildup in noble liquid ionization calorimeters*, NIM A 482 (2002) 156-178, 2002.

[4] Hilum ATLAS Liquid Argon Endcap Collaboration, *Liquid argon calorimeter performance at high rates*, Nuclear Instruments and Methods in Physics Research A 669 (2012) 47-65, 2011.

Backup

3. Phase I upgrade

Current Readout system of LAr calorimeters

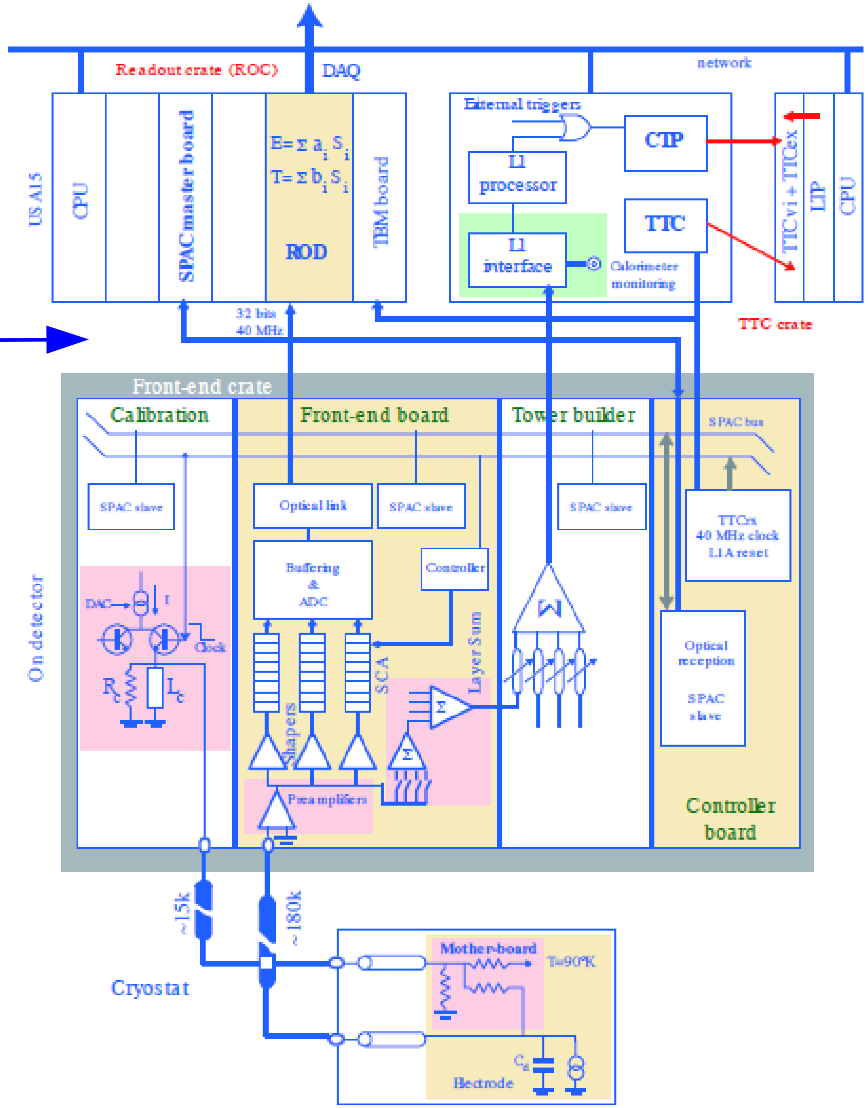
Readout, L1 Trigger Processor [warm]

128 channels/FEB,
40MHz sampling rate

Front-end board (FEB)
[warm]

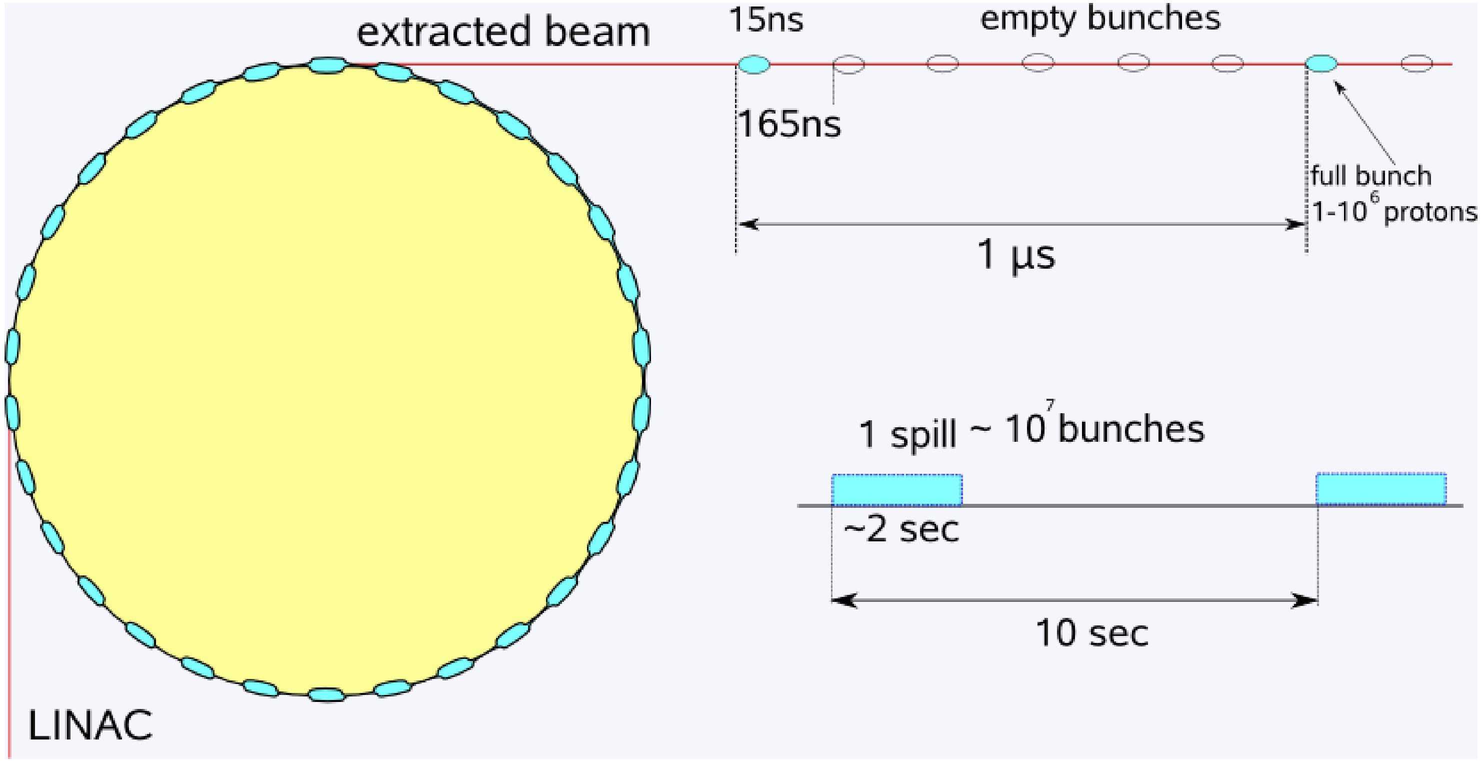
Radiation tolerance for total 700fb^{-1}

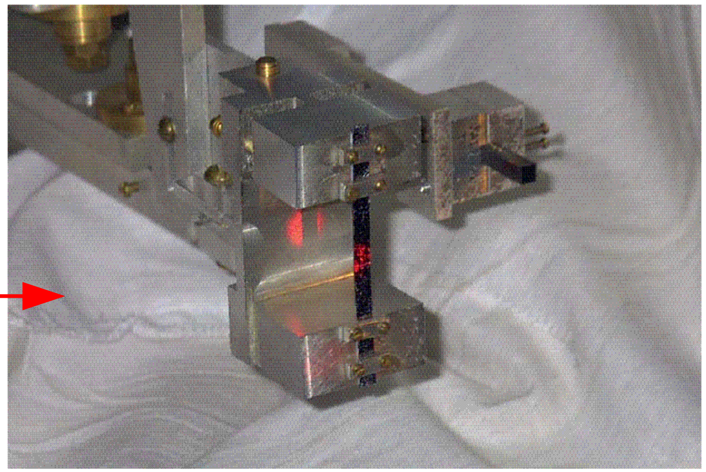
Calorimeter [cold]



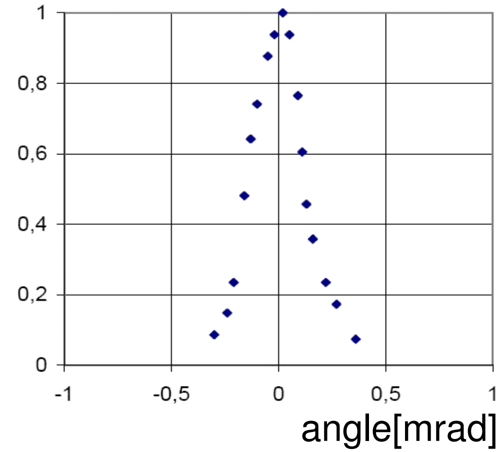
4. Hilum project in Protvino

- Proton beam of 50 GeV
- Bunch structure with every 6th bunch filled
  → ~1μs bunch spacing
- Extract one accelerator fill in ~1.2 s ⟶ **spill**
- ~9.5 s spill cycle time
- Intensity range:
  10^6 – ~3×10^{11} p/spill
- Beam extraction with bent crystal technique →



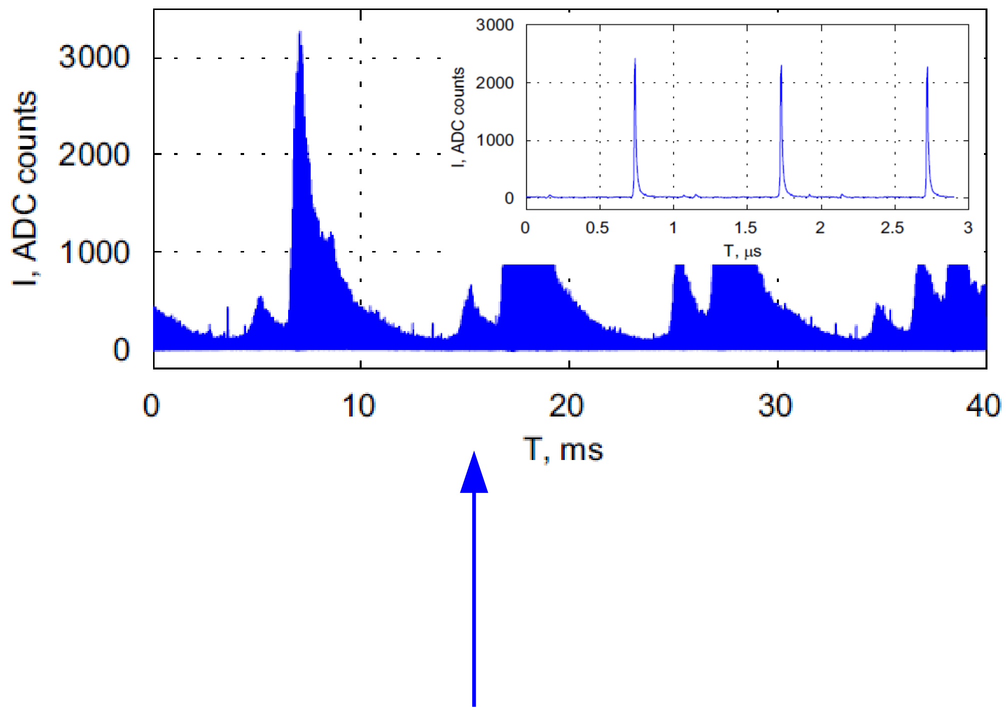


Beam intensity vs crystal orientation:



4. Hilum project in Protvino

Beam intensity monitoring



- Bunch based: Cherenkov counter with fast ADC-readout
  - → Resolution of single bunches possible
  - → Important due to bunch-to-bunch variations

5. Hilum project in Protvino

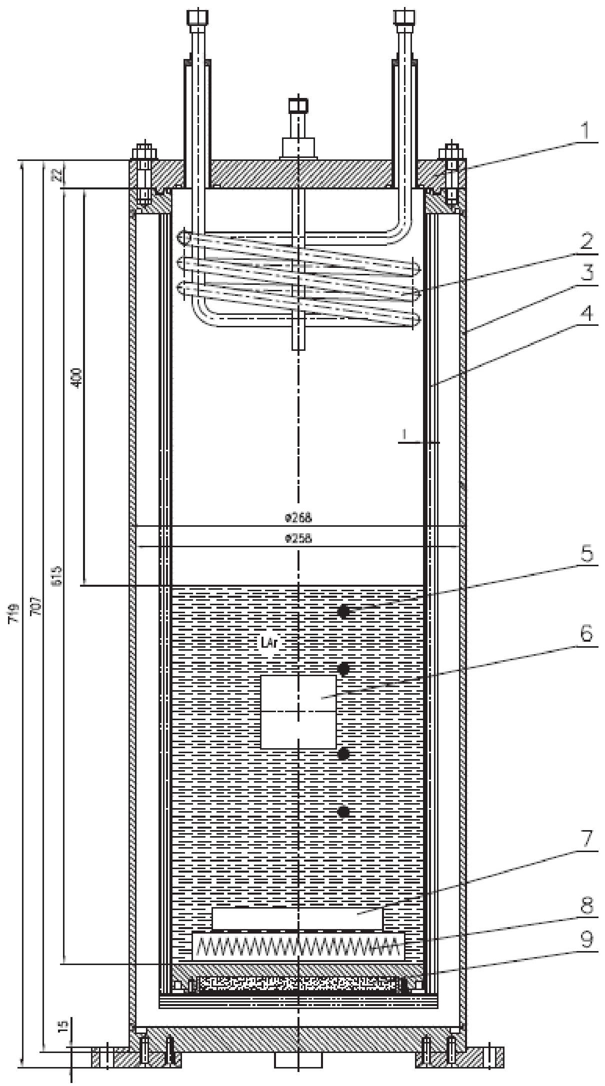
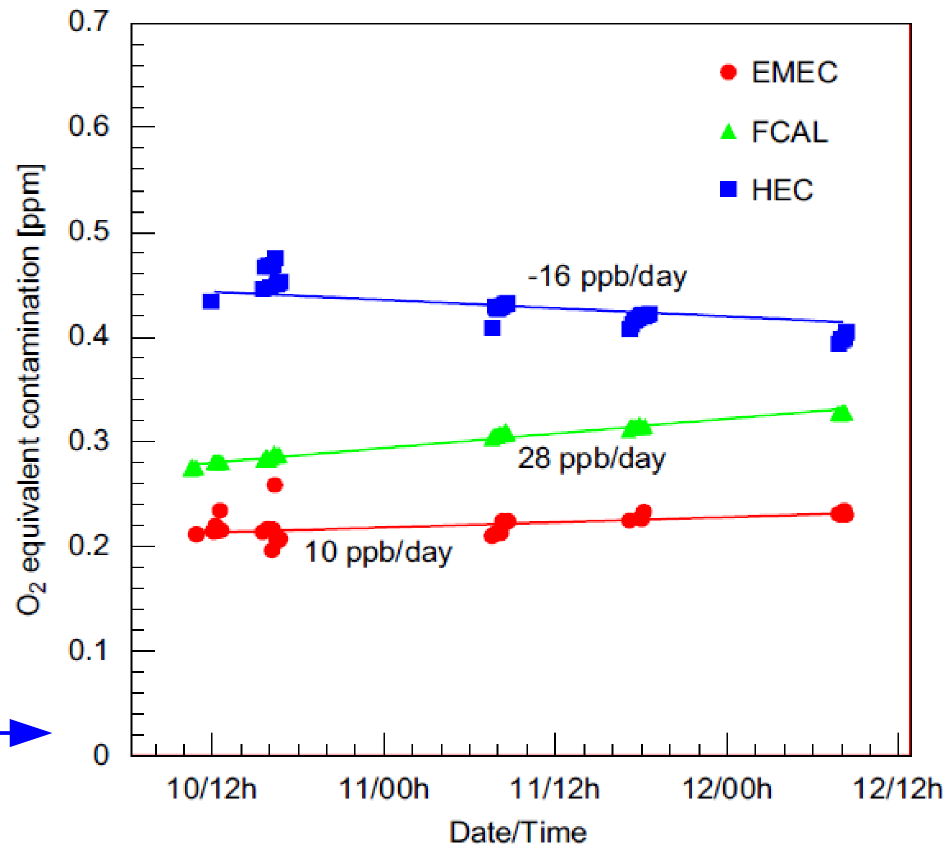


Fig. 13. Schematics of a single cryostat. The cooling loop (2) is supported from the top flange (1). The cryostat with stainless steel walls (3) and (4) is vacuum isolated. Four PT-100 temperature probes (5) monitor the temperature at different levels resp. at the module (6). The purity probe (7) monitors the argon purity. The heater (8) is operated for the warm-up phase of the cryostat. A carbon absorber plate (9) is located at the bottom of the cryostat.

Cryogenic and LAr purity monitoring

- Temperature, pressure and level of LAr was monitored
- Purity has to be < 1ppm O_2 equivalent to prevent signal bias due to space charge effects

→ sufficient and stable enough over the time

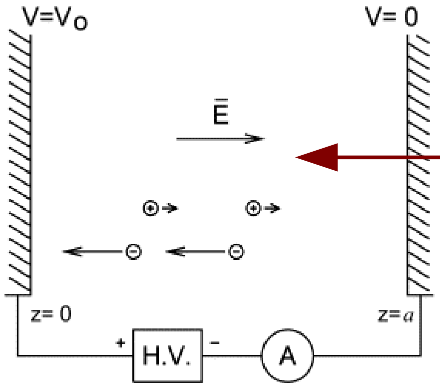


4. Hilum project in Protvino

Prediction for signal behaviour

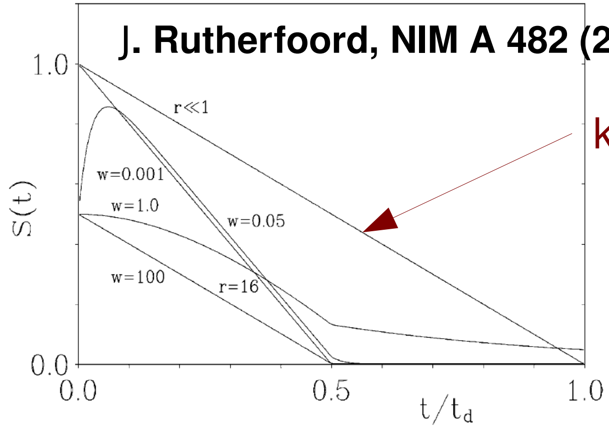
Problem of positive ion buildup:

- **D is ionization rate per volume**
- **D_c is critical ionization rate → charge build-up in gap is equal to charge on electrodes**
- **Relative rate $r=D/D_c$**
- **w: recombination rate**
- **Signal S: 1 for $r \le 1$ and $1/r^{1/4}$ for $r>1$**

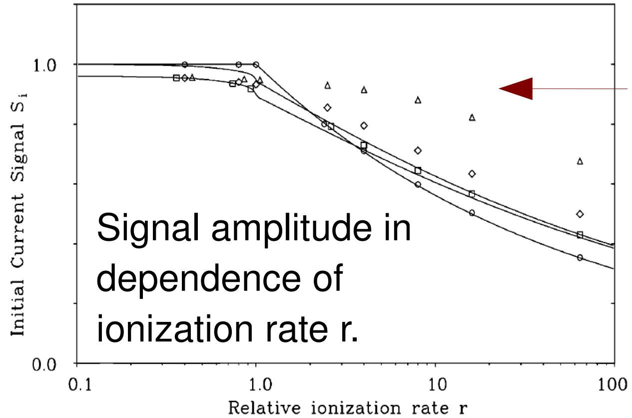


LAr gap

J. Rutherfoord, NIM A 482 (2002) 156-178:



known triangular pulse



Signal amplitude in dependence of ionization rate r.

Analytic calculations (curves) and simulations (dots) for different recombination rates w

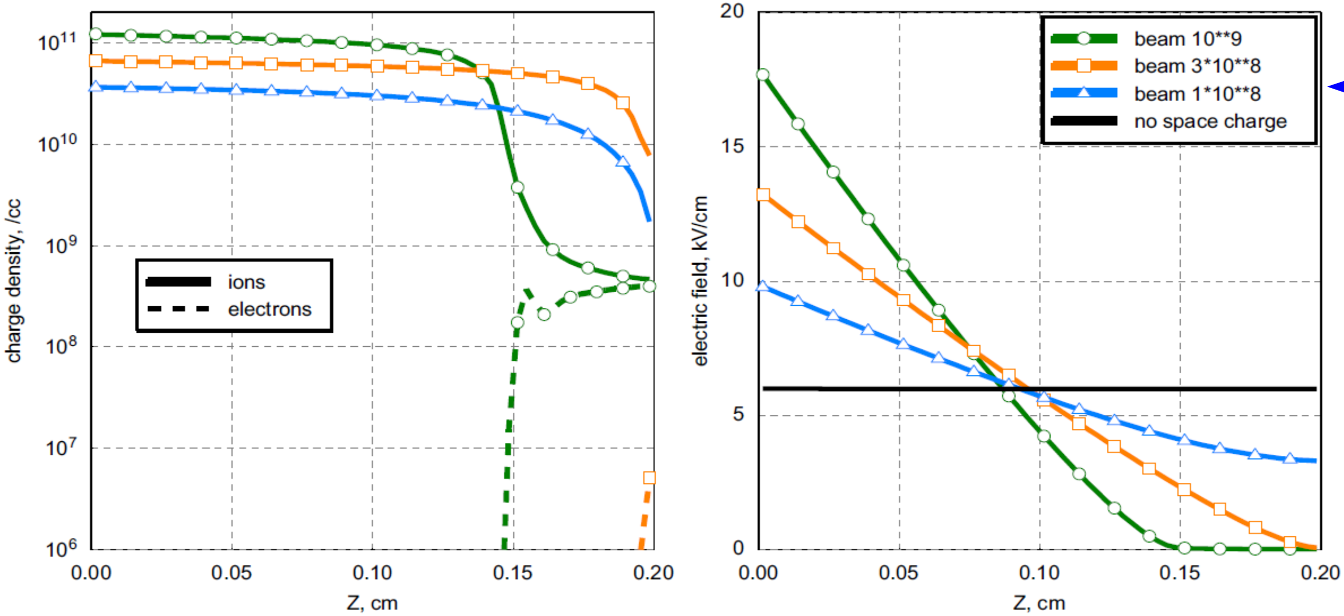
Prediction of HV currents:

Above critical intensity I_c → space charge limit. Current drawn at I_c is critical current i_c

$$i/i_c = \begin{cases} I/I_c & \text{for} \quad I<I_c \\ (I/I_c)^{3/4} & \text{for} \quad I>I_c \end{cases}$$

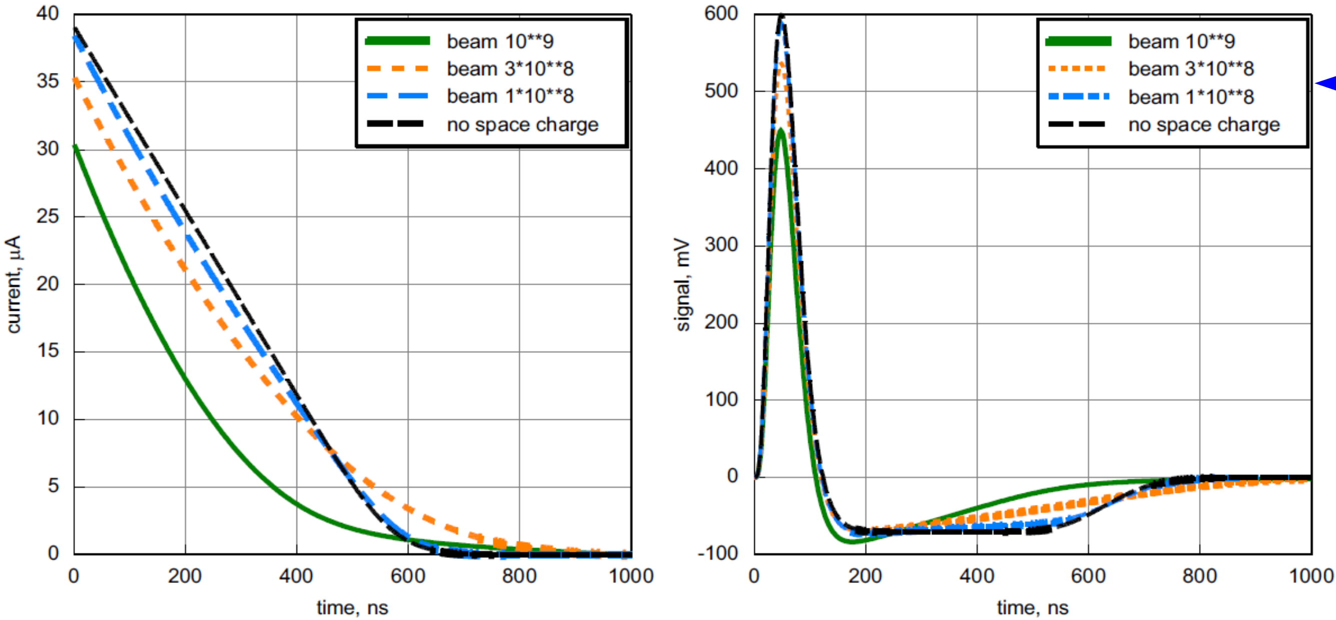
4. Hilum project in Protvino

Prediction for signal behaviour (2)



Simulations of charge density and electric field over 2mm LAr gap of EMEC module for different beam intensities.

Assumed: HV = 1.2kV
ion mobility: $\mu_+ = 10^{-3}$ cm^2/Vs
reco. rate constant: $k_r = 10^{-5}$ cm^3/s



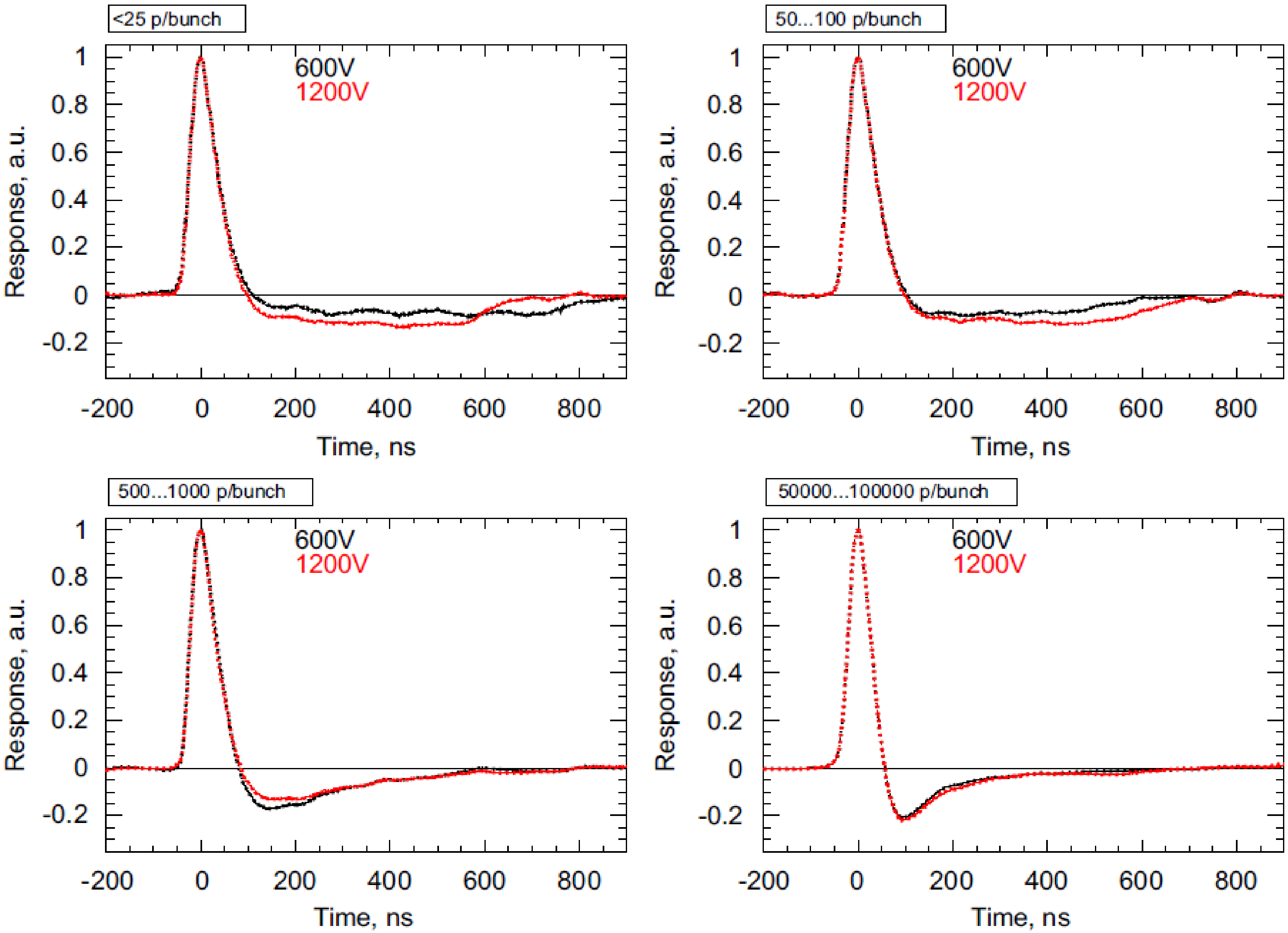
Current and Shaped pulse for 2mm LAr gap of EMEC module for different beam intensities.

Scale factors of 3.3 (10^8p/s) and 10 (3×10^8p/s) are used for better comparison of the effects.

tors

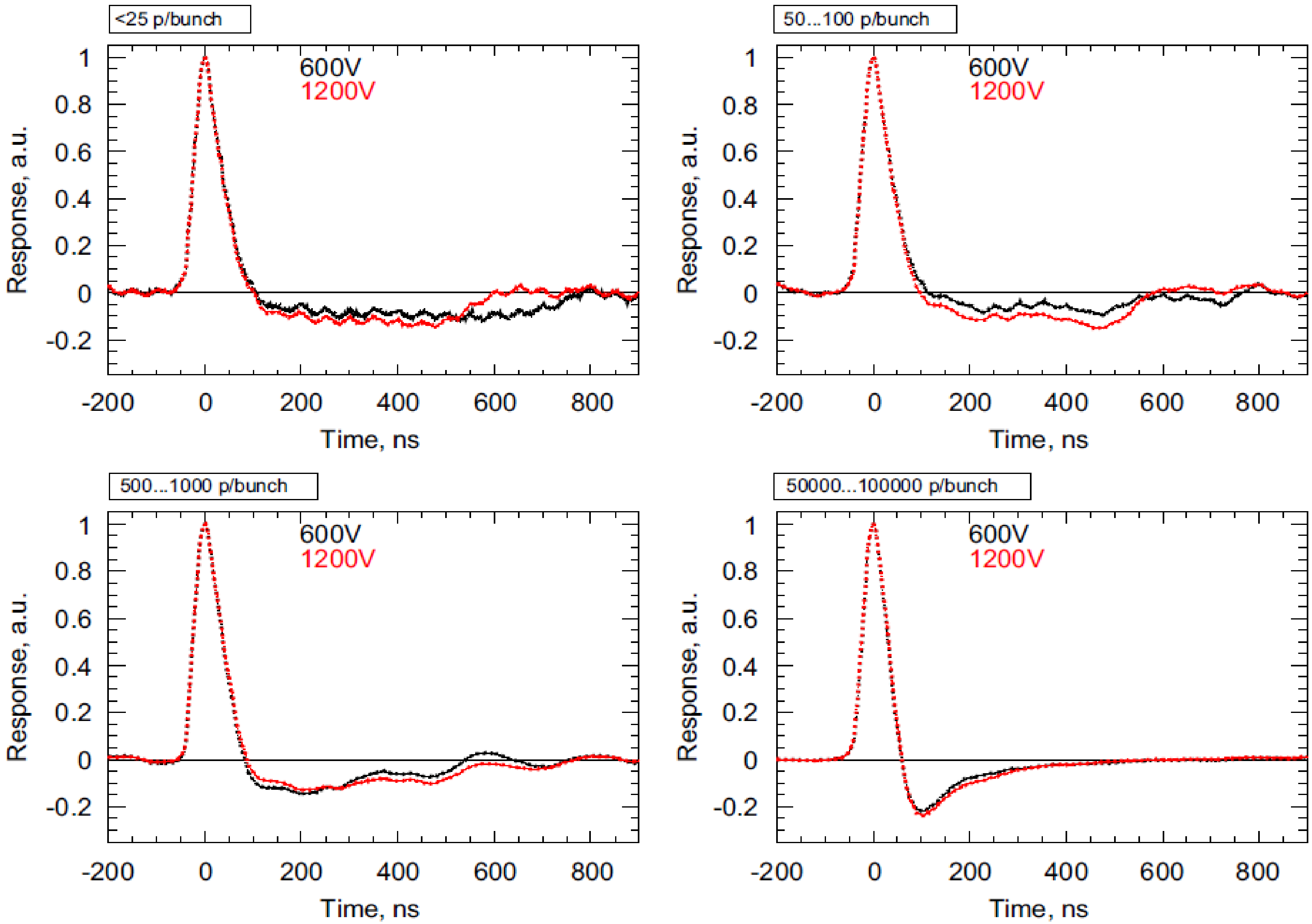
4. Hilum project in Protvino

Results – Readout signal shapes EMEC



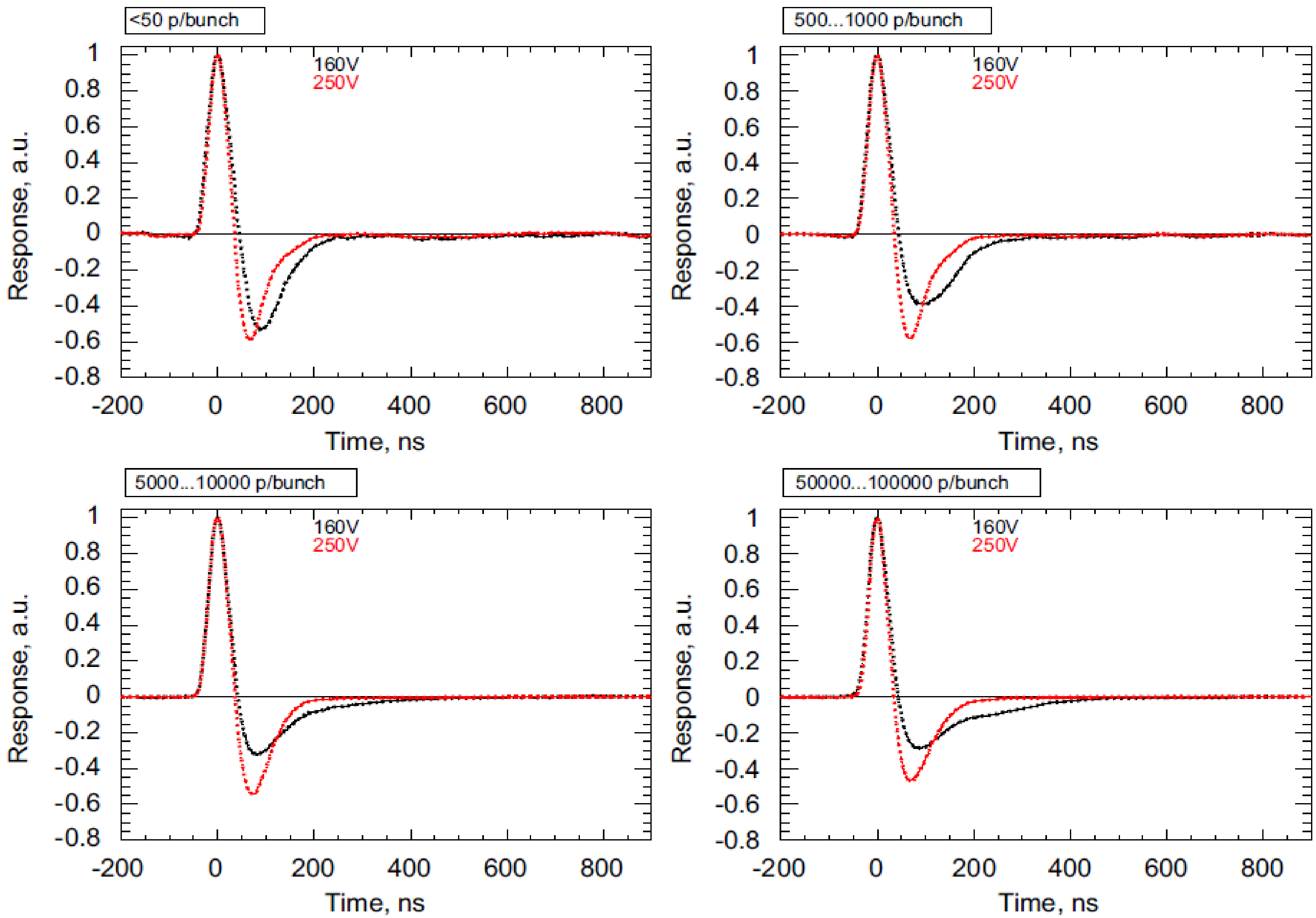
4. Hilum project in Protvino

Results – Readout signal shapes HEC



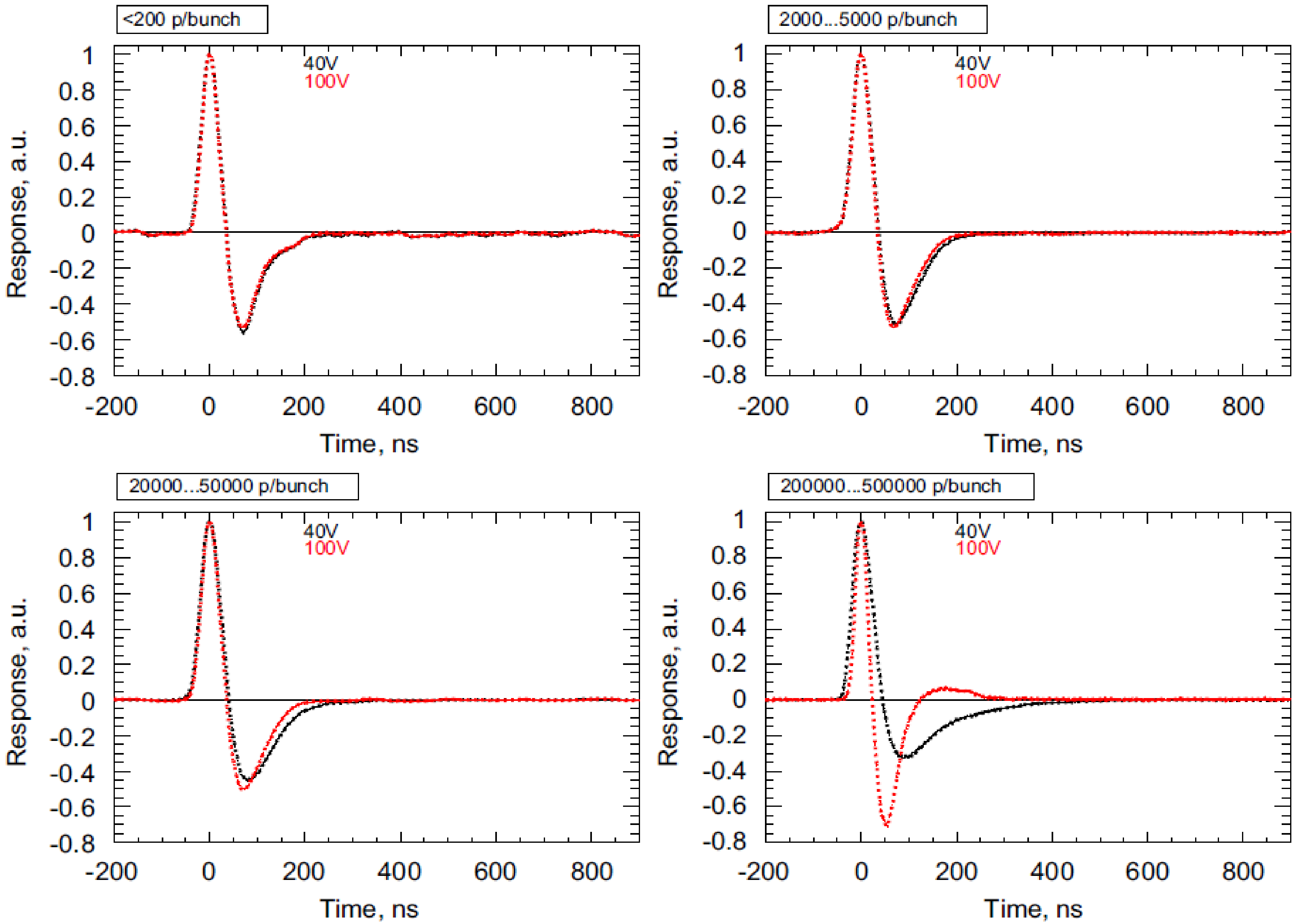
4. Hilum project in Protvino

Results – Readout signal shapes FCal(269)



4. Hilum project in Protvino

Results – Readout signal shapes FCal(119)



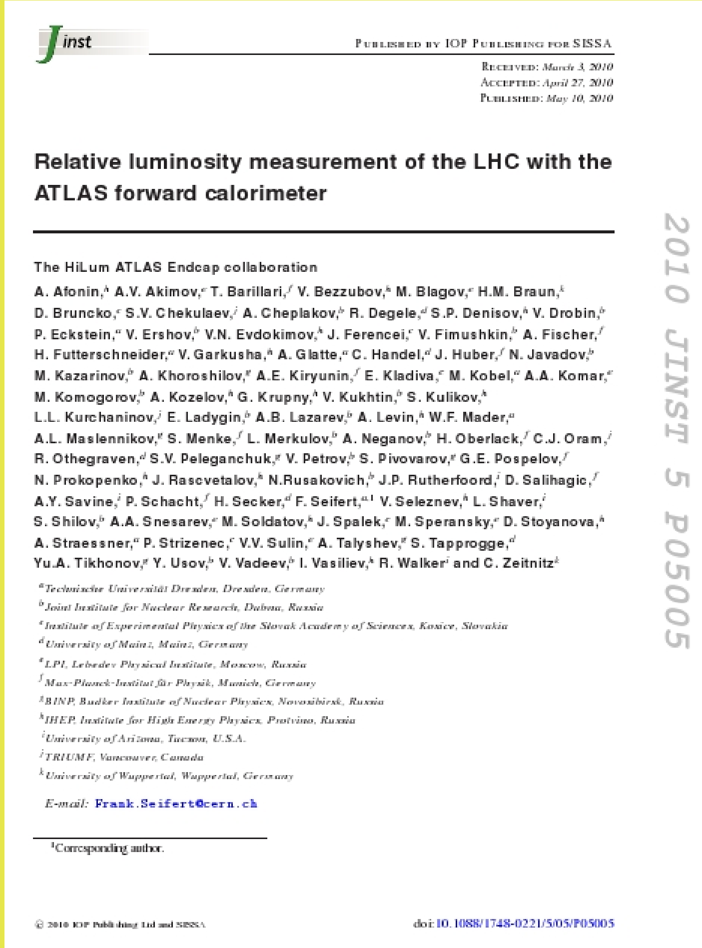
Lumi monitoring with HV currents

- Was possible to show, that FCalchick HV current depends linear on beam intensity with non-linear part < 0.36% (95% CL) at 10^9 p/spill $\approx$ 10^{34} LHC Lumi.

- Results are published in JINST: http://iopscience.iop.org/1748-0221/5/05/P05005

→ including systematic uncertainties a precission of ~0.5% might be possible in ATLAS at nominal luminosity

- Relative luminosity in ATLAS is measured using HV currents with < 1% precision.



JINST

PUBLISHED BY IOP PUBLISHING FOR SISSA

RECEIVED: *March 3, 2010*
ACCEPTED: *April 27, 2010*
PUBLISHED: *May 10, 2010*

Relative luminosity measurement of the LHC with the ATLAS forward calorimeter

The HiLum ATLAS Endcap collaboration

A. Afonin,[h] A.V. Akimov,[e] T. Barillari,[f] V. Bezzubov,[h] M. Blagov,[e] H.M. Braun,[k] D. Bruncko,[c] S.V. Chekulaev,[j] A. Cheplakov,[b] R. Degele,[d] S.P. Denisov,[h] V. Drobin,[b] P. Eckstein,[a] V. Ershov,[b] V.N. Evdokimov,[h] J. Ferencei,[c] V. Fimushkin,[b] A. Fischer,[f] H. Futterschneider,[a] V. Garkusha,[h] A. Glatte,[a] C. Handel,[d] J. Huber,[f] N. Javadov,[b] M. Kazarinov,[b] A. Khoroshilov,[g] A.E. Kiryunin,[f] E. Kladiva,[c] M. Kobel,[a] A.A. Komar,[e] M. Komogorov,[b] A. Kozelov,[h] G. Krupny,[h] V. Kukhtin,[b] S. Kulikov,[h] L.L. Kurchaninov,[j] E. Ladygin,[b] A.B. Lazarev,[b] A. Levin,[h] W.F. Mader,[a] A.L. Maslennikov,[g] S. Menke,[f] L. Merkulov,[b] A. Neganov,[b] H. Oberlack,[f] C.J. Oram,[j] R. Othegraven,[d] S.V. Peleganchuk,[g] V. Petrov,[b] S. Pivovarov,[g] G.E. Pospelov,[f] N. Prokopenko,[h] J. Rascvetalov,[h] N.Rusakovich,[b] J.P. Rutherfoord,[i] D. Salihagic,[f] A.Y. Savine,[i] P. Schacht,[f] H. Secker,[d] F. Seifert,[a,1] V. Seleznev,[h] L. Shaver,[i] S. Shilov,[b] A.A. Snesarev,[e] M. Soldatov,[h] J. Spalek,[c] M. Speransky,[e] D. Stoyanova,[h] A. Straessner,[a] P. Strizenec,[c] V.V. Sulin,[e] A. Talyshev,[g] S. Tapprogge,[d] Yu.A. Tikhonov,[g] Y. Usov,[b] V. Vadeev,[b] I. Vasiliev,[h] R. Walker[i] and C. Zeitnitz[k]

[a] *Technische Universität Dresden, Dresden, Germany*
[b] *Joint Institute for Nuclear Research, Dubna, Russia*
[c] *Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovakia*
[d] *University of Mainz, Mainz, Germany*
[e] *LPI, Lebedev Physical Institute, Moscow, Russia*
[f] *Max-Planck-Institut für Physik, Munich, Germany*
[g] *BINP, Budker Institute of Nuclear Physics, Novosibirsk, Russia*
[h] *IHEP, Institute for High Energy Physics, Protvino, Russia*
[i] *University of Arizona, Tucson, U.S.A.*
[j] *TRIUMF, Vancouver, Canada*
[k] *University of Wuppertal, Wuppertal, Germany*

E-mail: Frank.Seifert@cern.ch

[1] Corresponding author.

doi:10.1088/1748-0221/5/05/P05005

2010 JINST 5 P05005