# Liquid-Argon Calorimeters for High Luminosity

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DPG 16 | Hamburg
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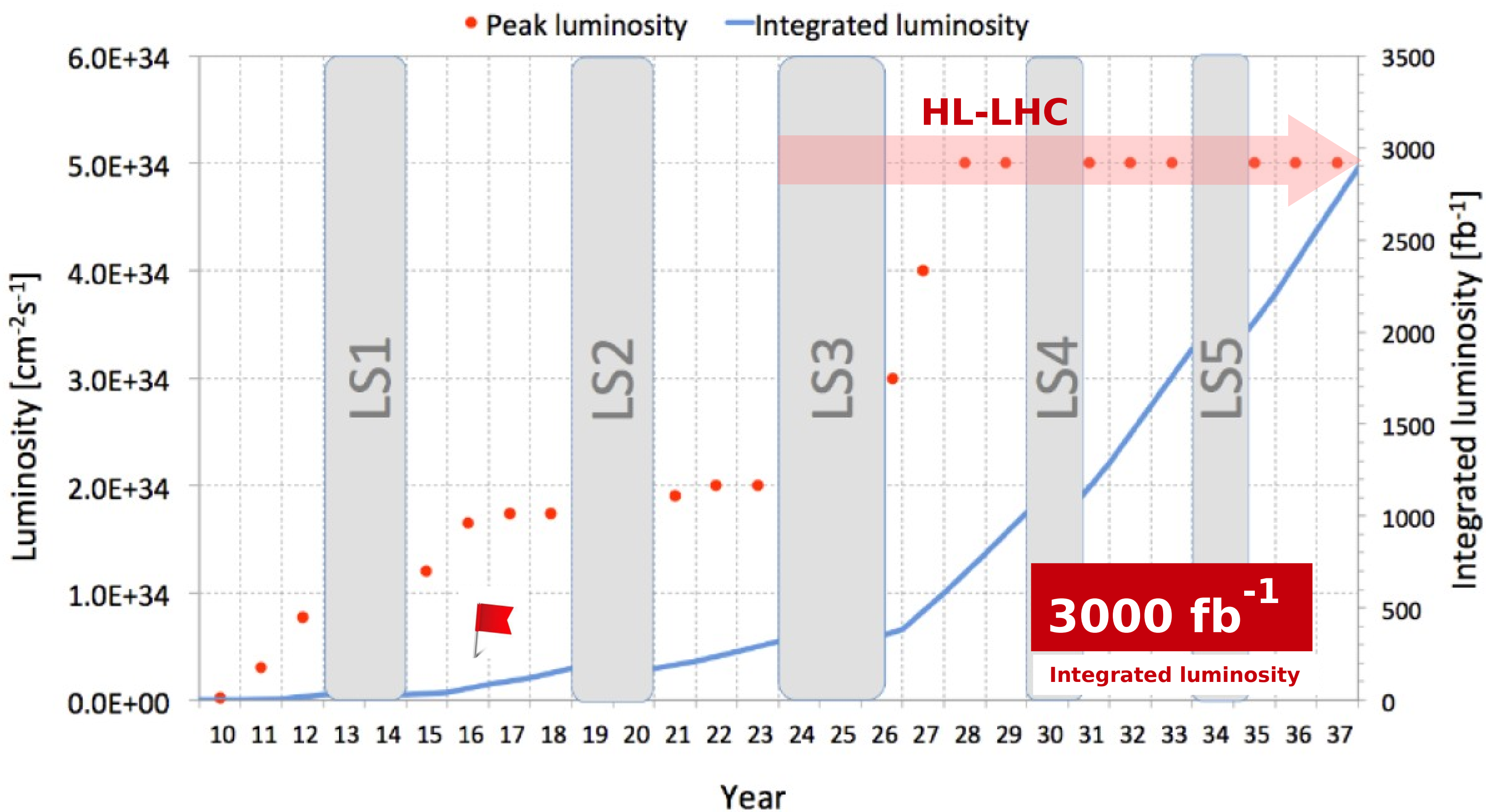
# ATLAS Detector for Phase II




Instantaneous luminosity - 5 – 7.5 x $10^{34}$ $cm^{-2}s^{-1}$

→ mean pile-up of 140-200 events

>25 years of operation instead of anticipated 10 years

**Scoping document – ATLAS Phase II Upgrade → 3 Scenarios: Reference, Middle & Low Cost**

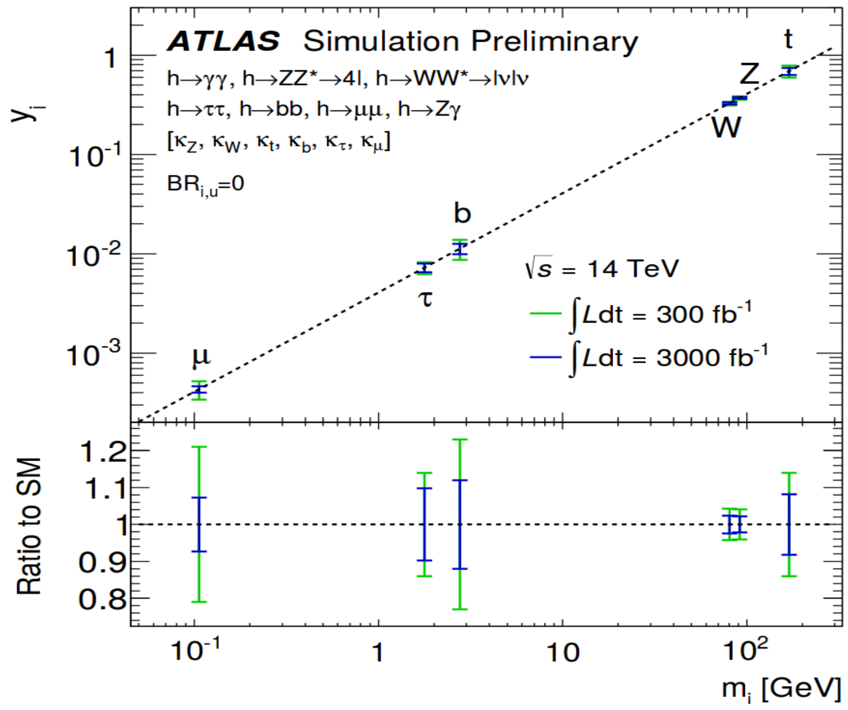
# Motivation for the HL-LHC

## to extend and improve the physics program

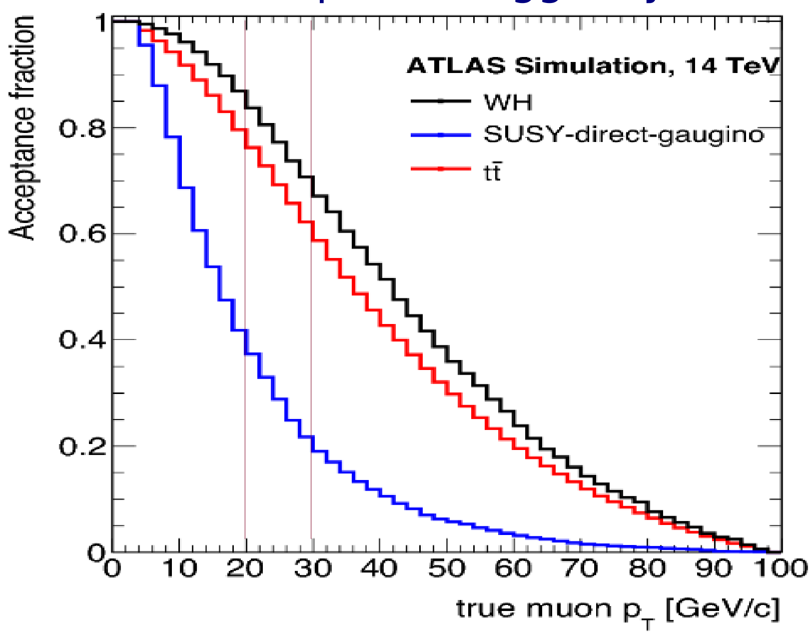
Probing the Higgs sector

- more precise coupling measurement
- rare decays
- self coupling

New physics beyond the Standard Model (SUSY and extra dimensions)




Maintain optimal trigger system




Challenges:

→ High instantaneous luminosity

→ High pile-up

→ Radiation damage

→ Higher trigger rates

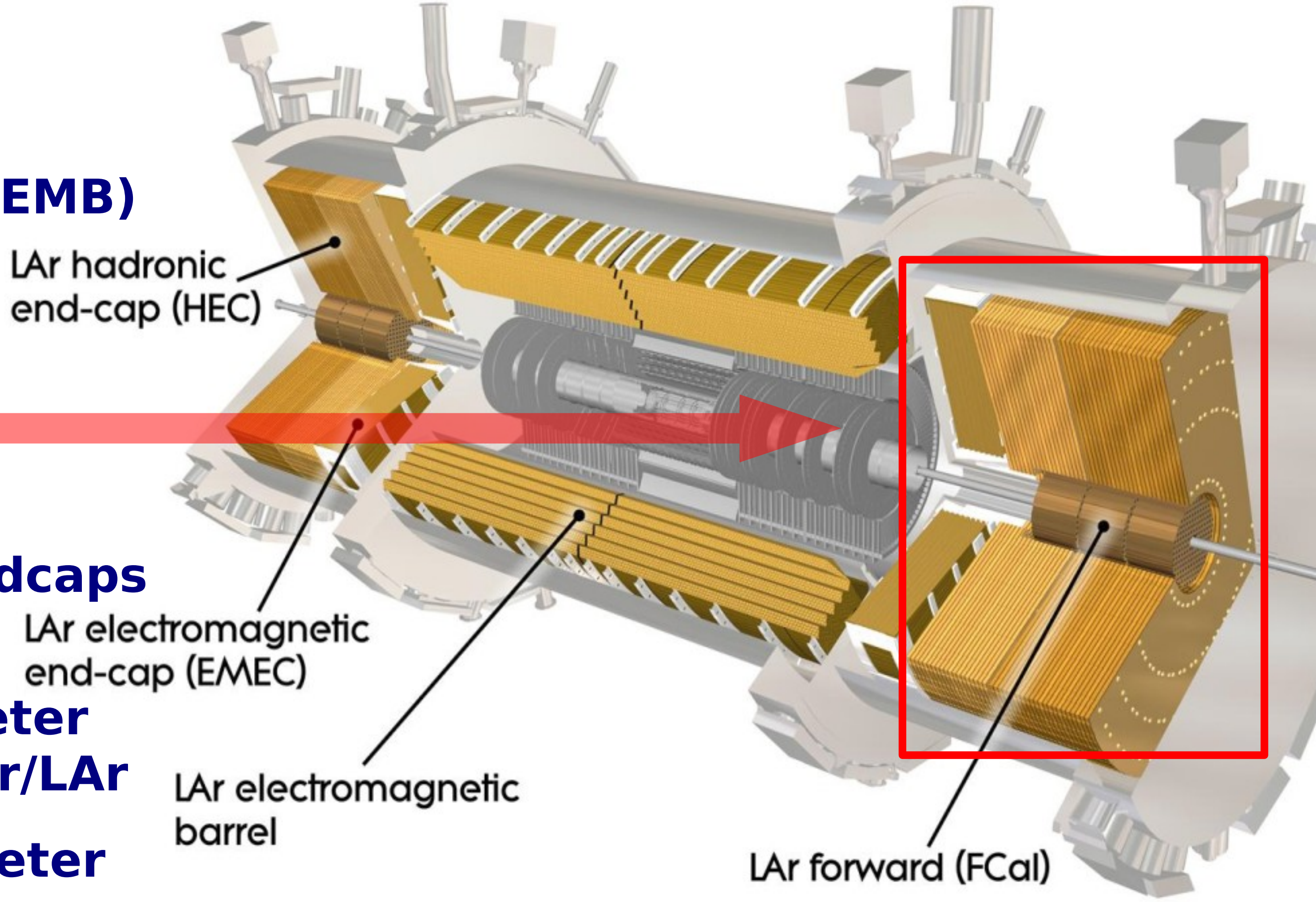
→ More complex trigger algorithms

# Liquid Argon Calorimeters

- **Active medium → Liquid Argon (LAr)**

- **The barrel cryostat**
  - **two electromagnetic (EMB) halves → lead-LAr**

- **The endcap cryostat**
  - **Electromagnetic calorimeter halves/endcaps (EMEC) → copper/LAr**
  - **Two hadronic calorimeter wheels (HEC) → copper/LAr**
  - **three forward calorimeter wheels (FCal) → copper-tungsten/LAr**



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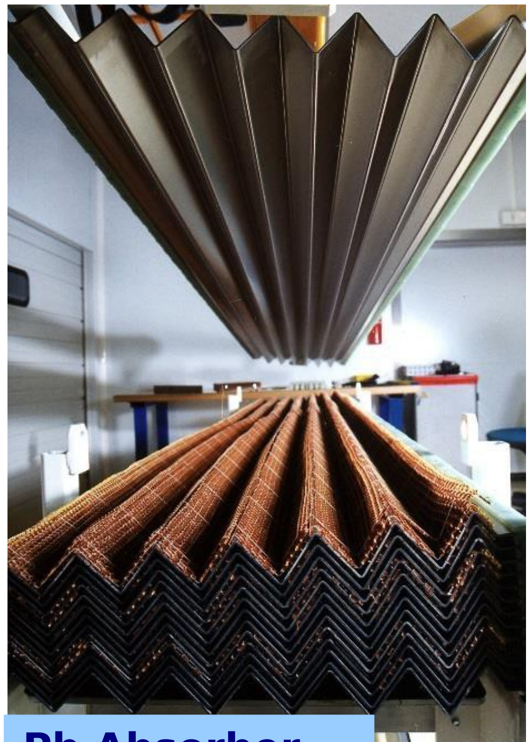
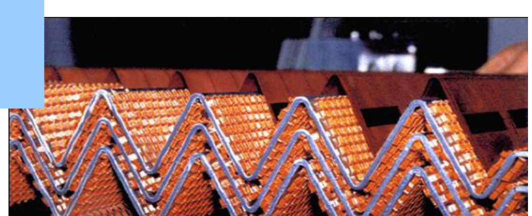
# LAr technologies

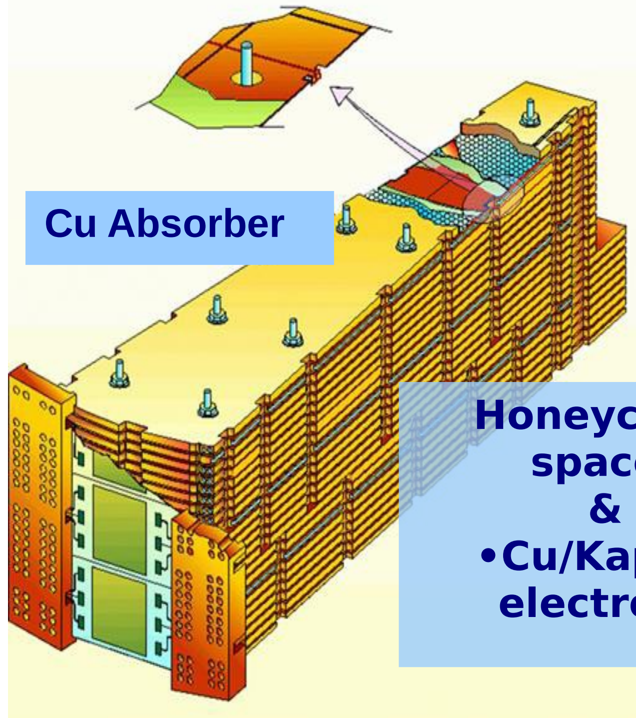
## EM Cal Structure



Pb Absorber
- Honeycomb spacer
- Cu/Kapton electrode



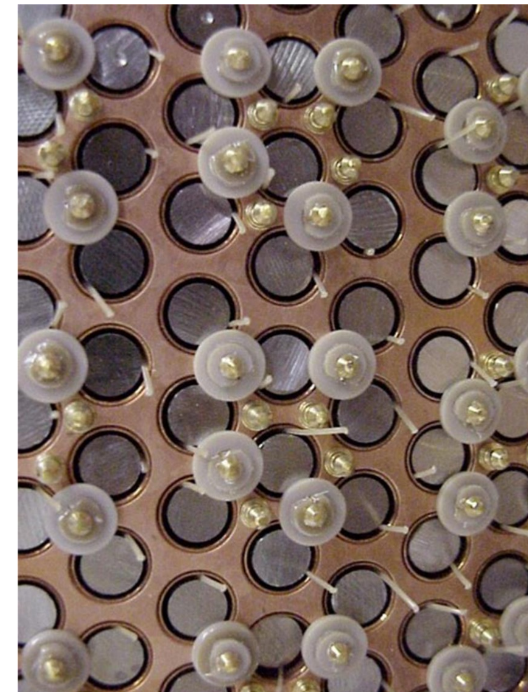
## HEC Structure

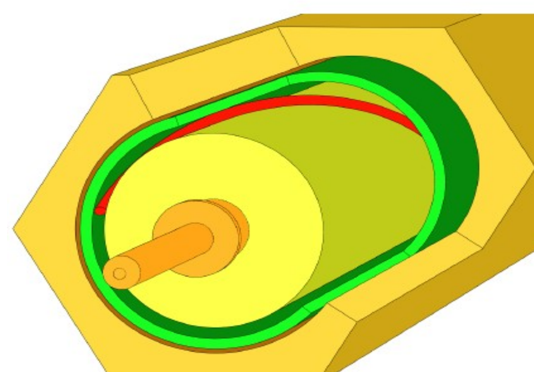


Cu Absorber

Honeycomb spacer
&
- Cu/Kapton electrode

## FCal Structure





Electrode Rods & Absorber Matrix
Cu (FCal1) + LAr 269 µm gap
W (FCal2/3) + LAr 376/508 µm gap



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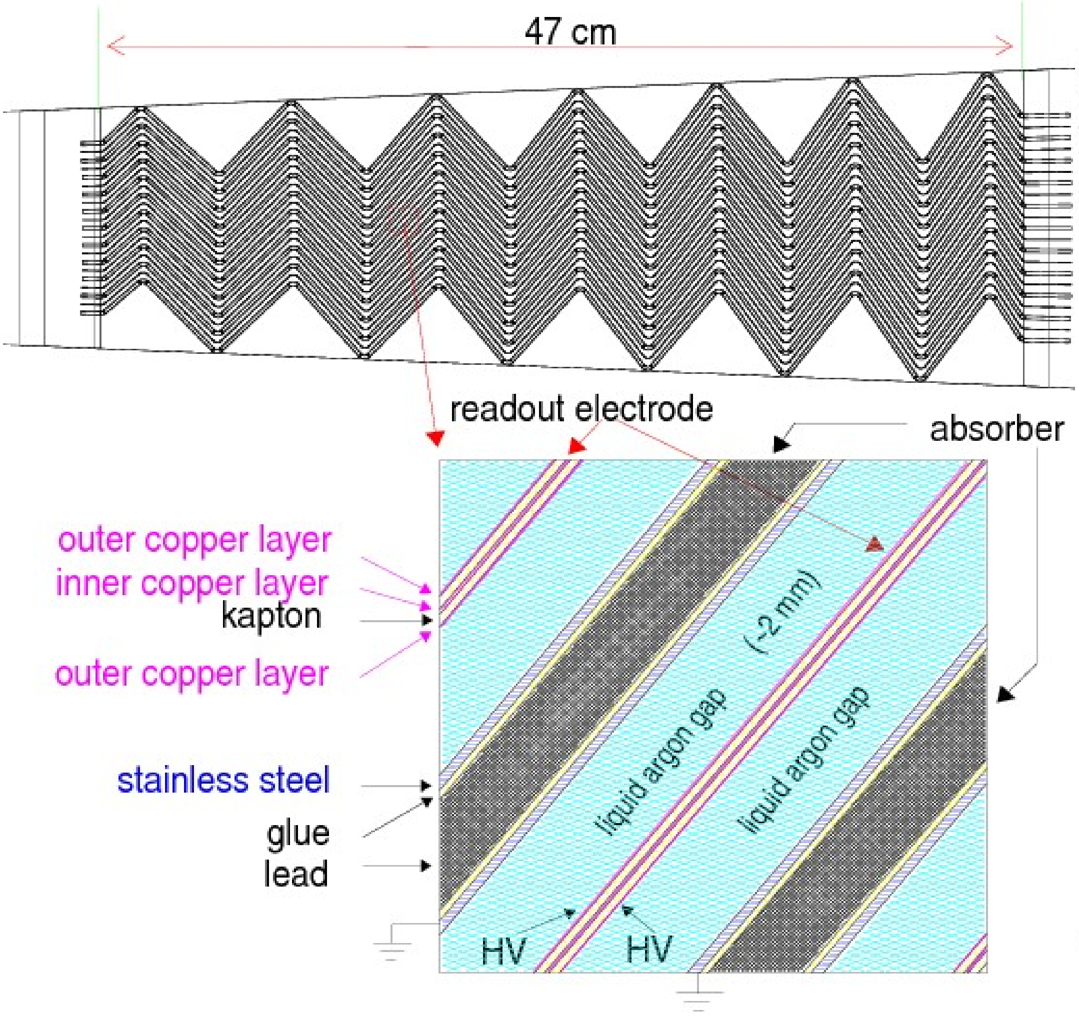
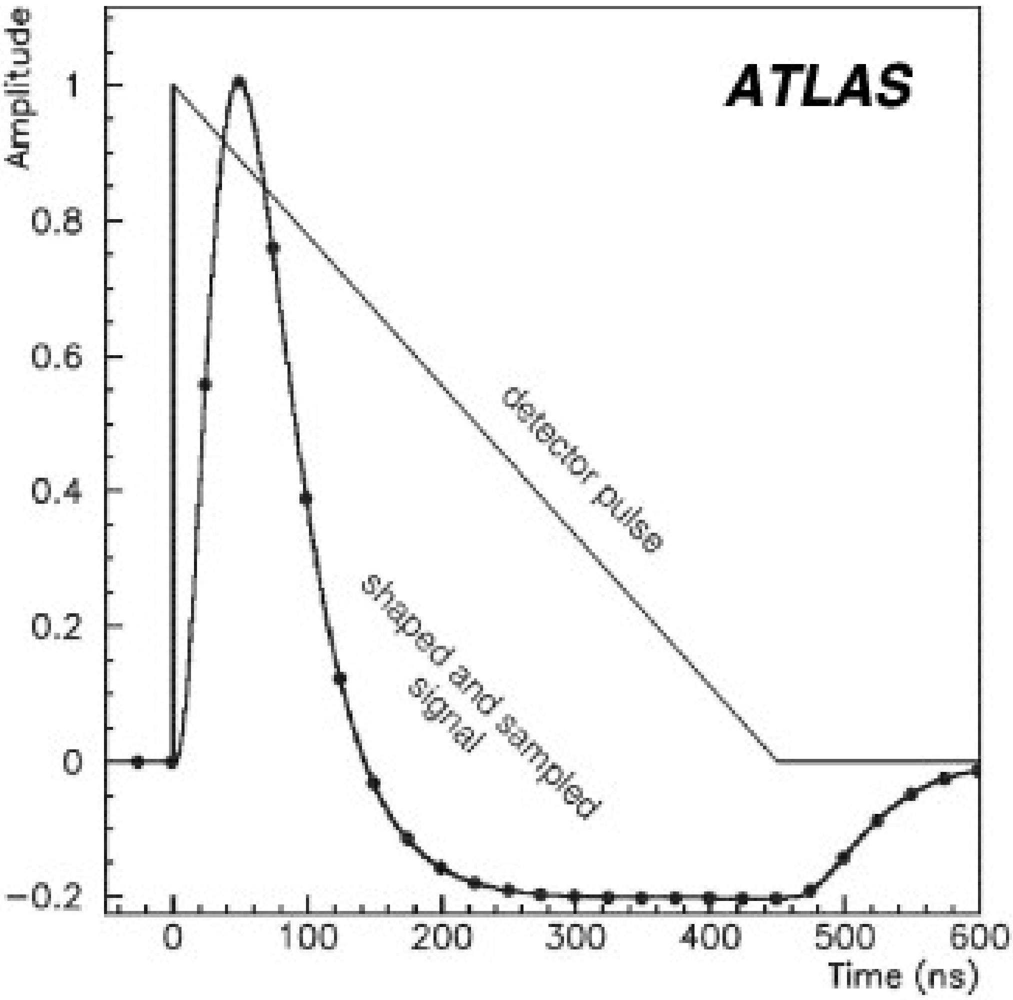
# LAr Signal Pulse Shapes



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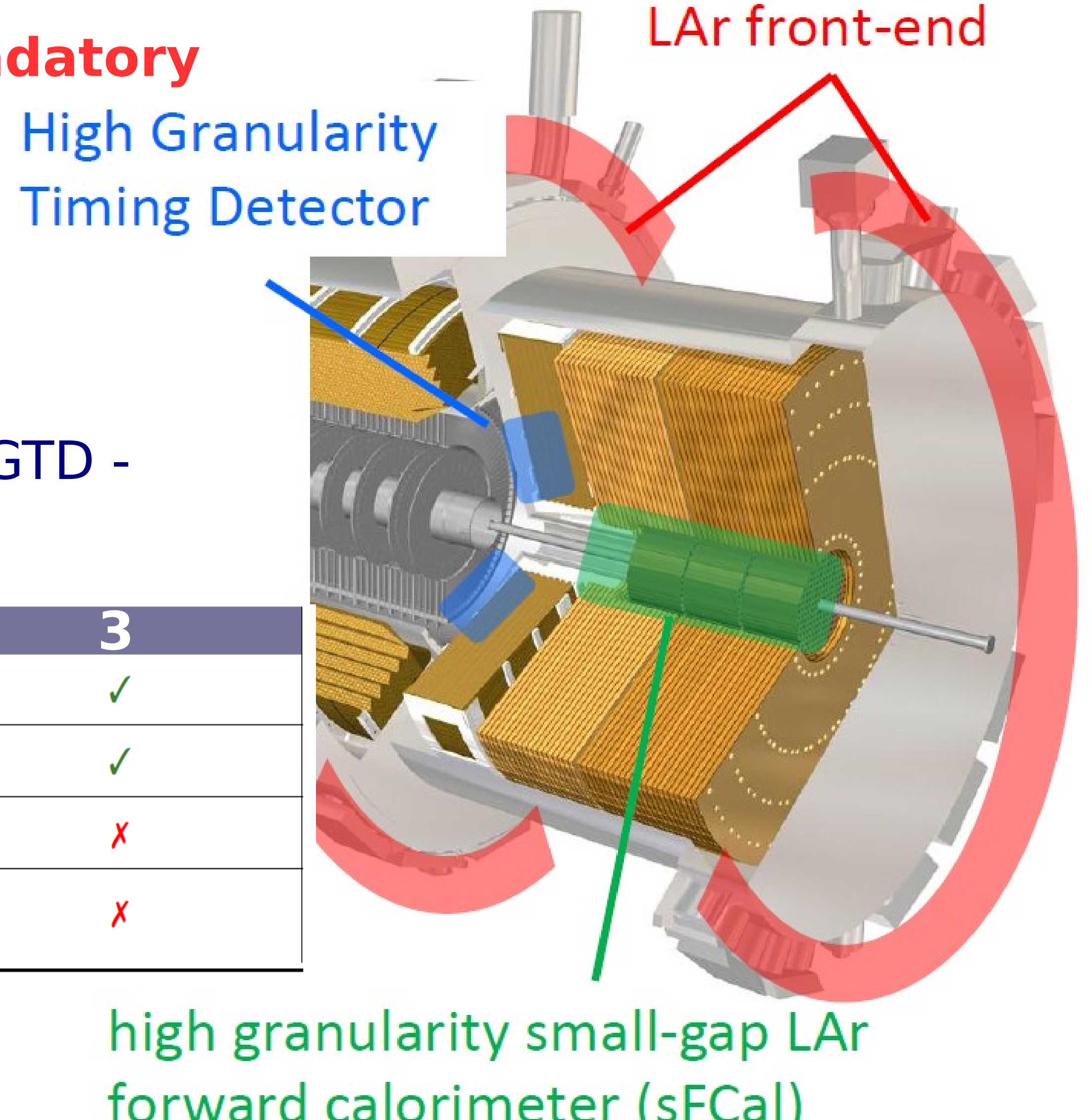
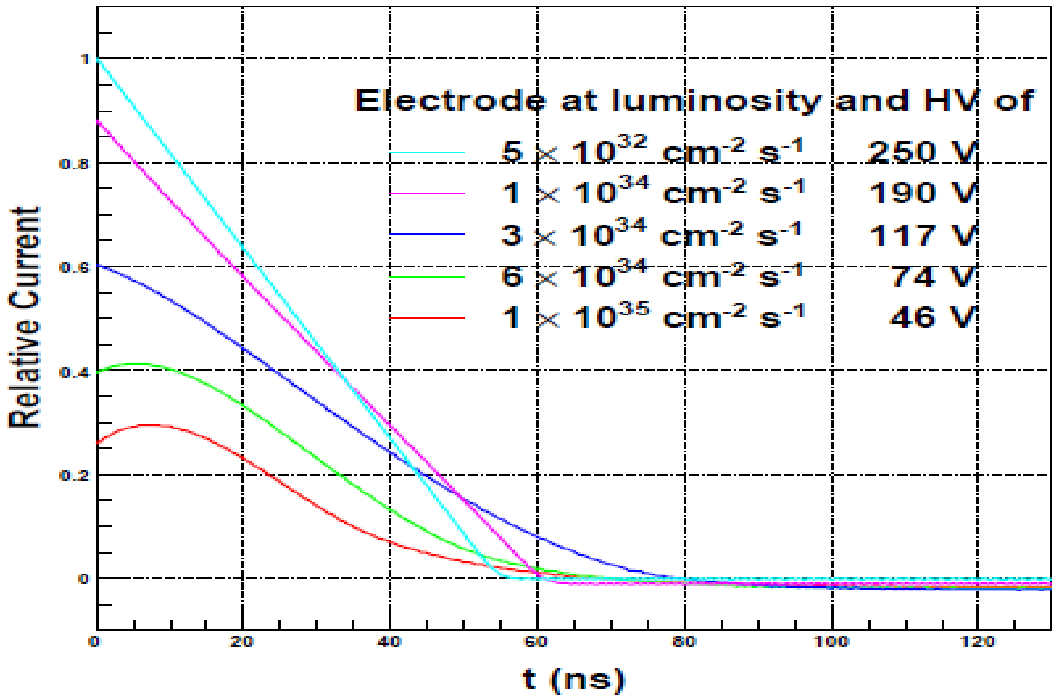
# LAr & Tile Calorimeters

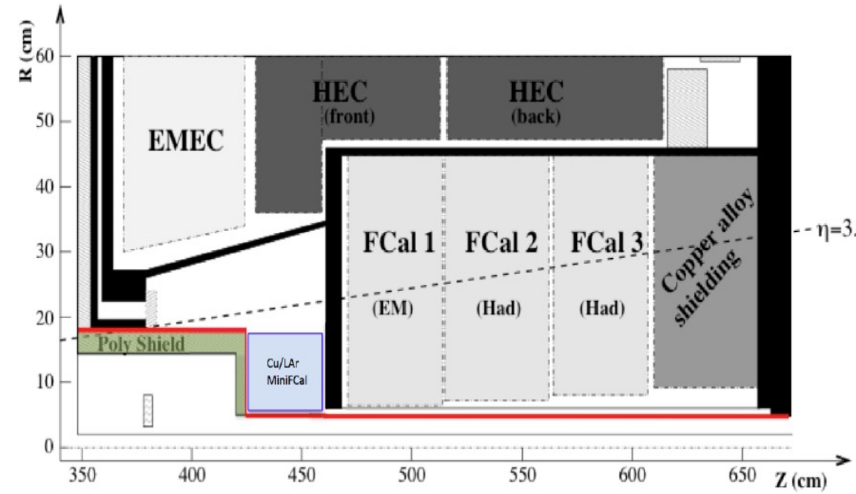
- **The LAr and Tile calorimeter electronics upgrades are mandatory → all scenarios of Phase II**
- Replacement of FCal1 with high-granularity sFCal1
  - **Boiling is almost excluded**
- New device in front of endcap: HGTD - High granularity timing detector

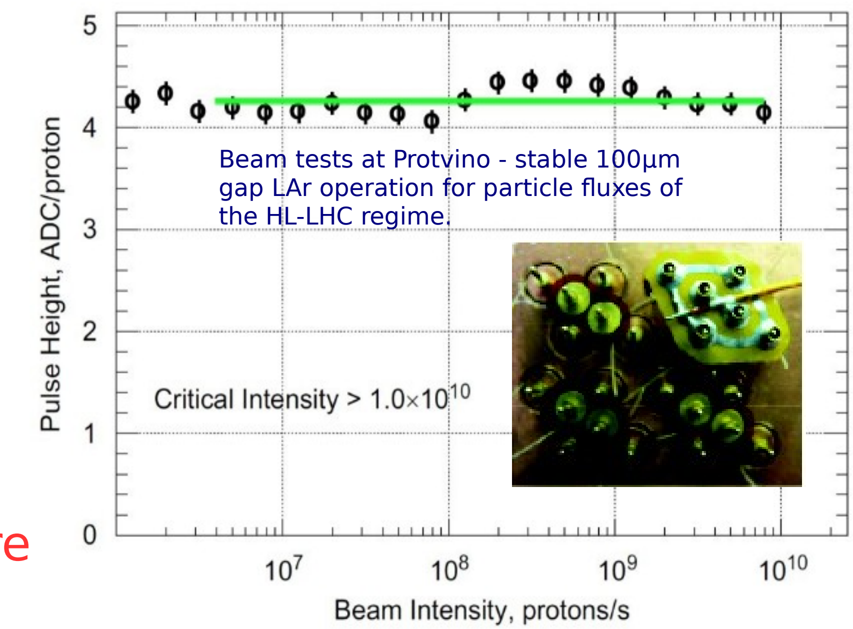
| Calorimeters | 1 | 2 | 3 |
|---|---|---|---|
| LAr Calorimeter Electronics | ✓ | ✓ | ✓ |
| Tile Calorimeter Electronics | ✓ | ✓ | ✓ |
| Forward Calorimeter | ✓ | ✗ | ✗ |
| High Granularity Precision Timing Detector | ✓ | ✗ | ✗ |



# sFCal Option




- **Degradation - most inner radius:**
  → $Ar^+$ build-up → **field & signal distortion**
  → High HV currents

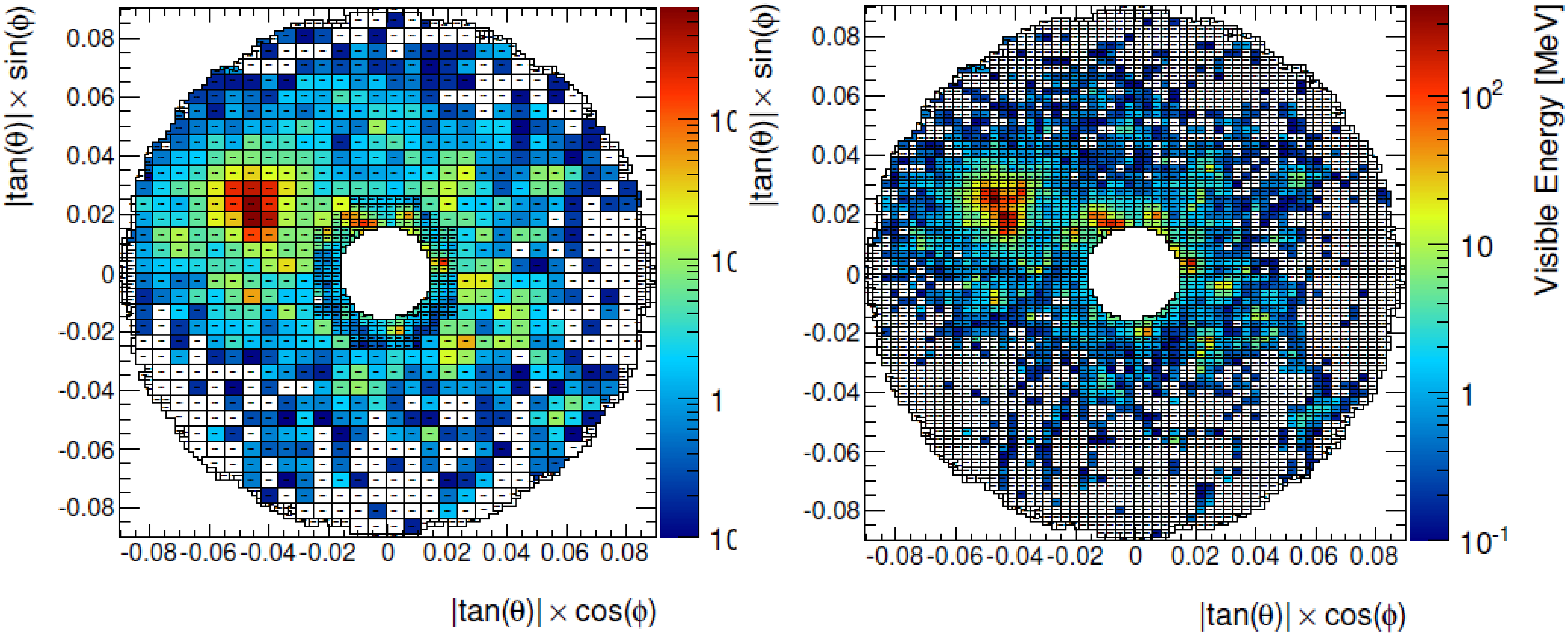
The FCal is planned to be replaced by a high-granularity sFCal in order to improve the physics performance, **if** installation and radiation risks are found to be sufficiently small.

# sFCal Option

- **sFCal - A finer granularity copy of the existing FCal1 - 100µm**
- **The only option** to improve the current performance

→ Improved granularity in (ΔηxΔφ) → by removing summing boards →will assist in pile-up reduction

→ Lower protection resistors, new cooling loops





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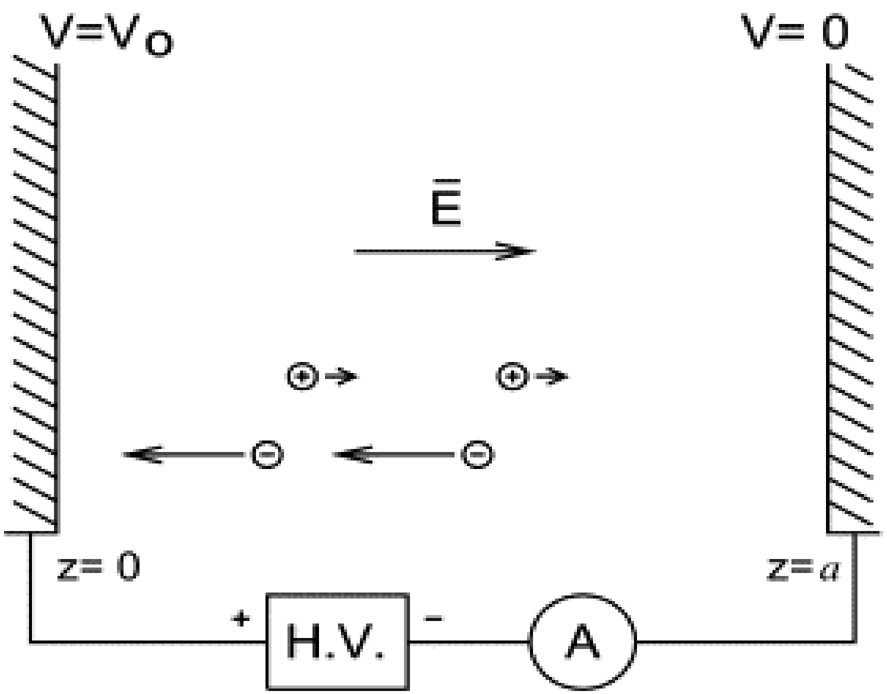
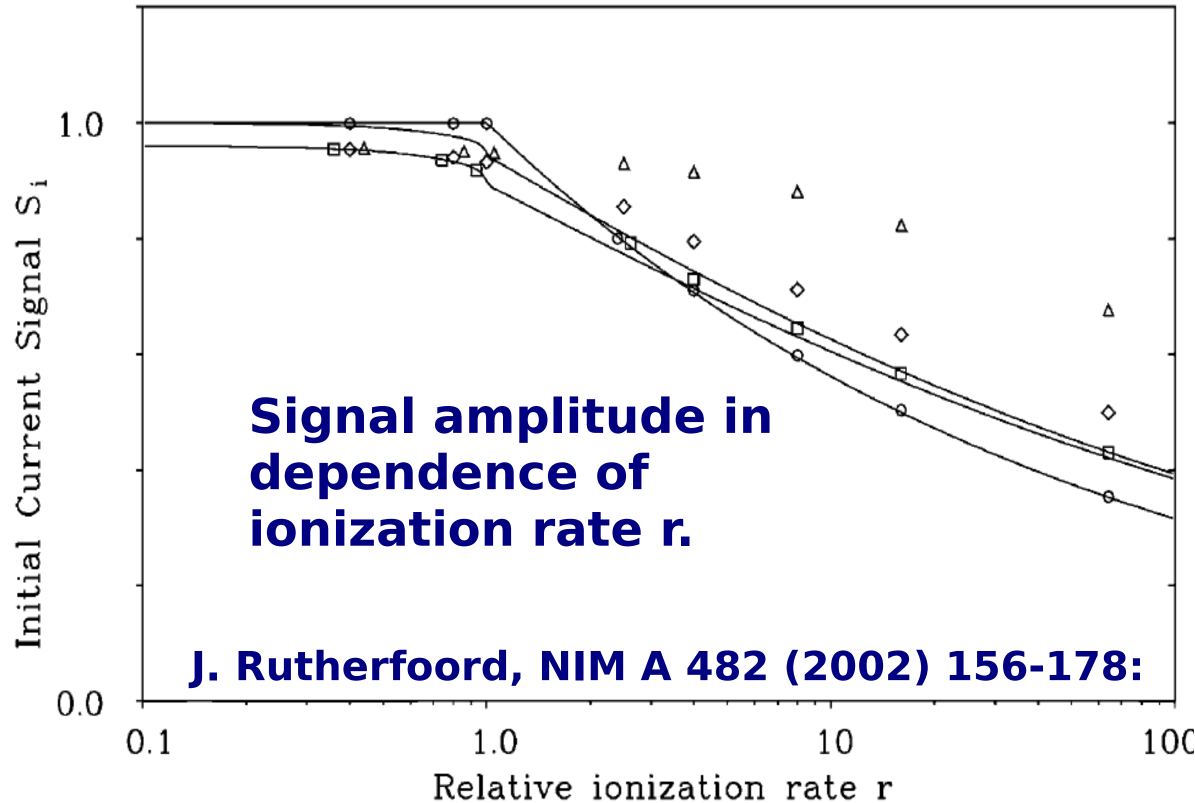
# Problem of positive ion buildup:




**Signal amplitude in dependence of ionization rate r.**

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

**D - ionization rate per volume**

**Dc** - critical ionization rate → charge buildup in gap = to charge on electrodes

Relative rate **r = D/Dc**

**Signal S:**

**1 for r≤1 and $(1/r)^{1/4}$ for r>1**

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



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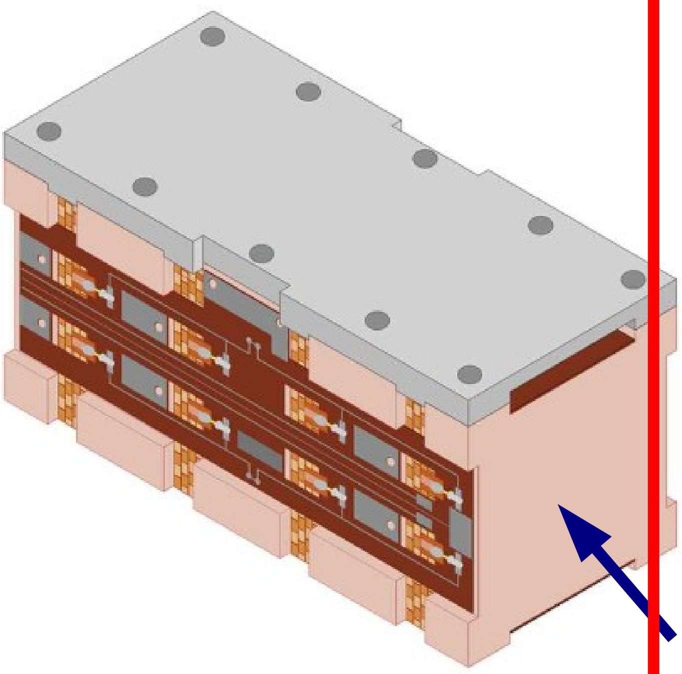
# The Calorimeter Test Modules

## HEC

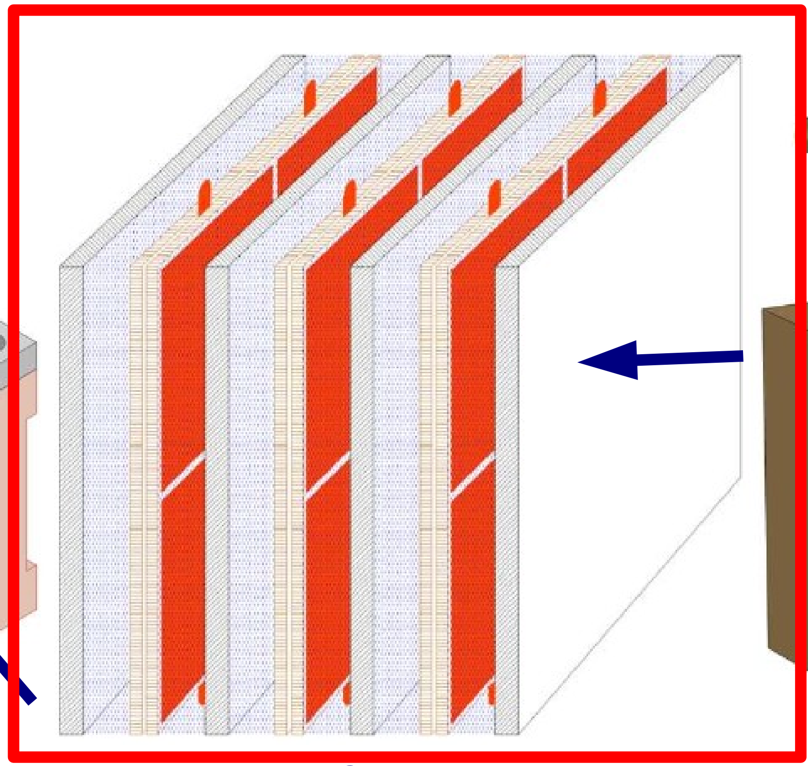


**60×60 mm²**

**4 readout channels**

**4 HV channels**

## EMEC

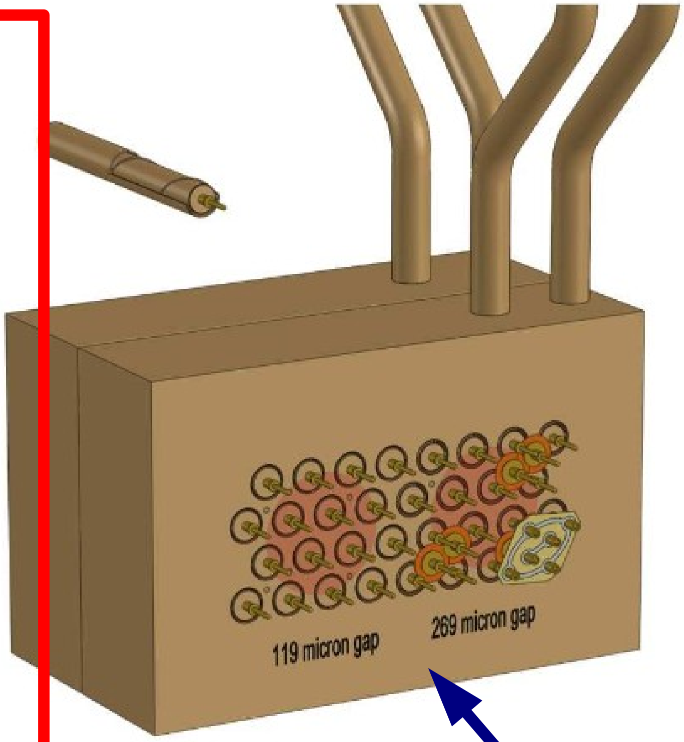


**70×70 mm²**

**4 readout channels**

**3 HV channels**

## FCal1/sFCal




**90×60 mm²**

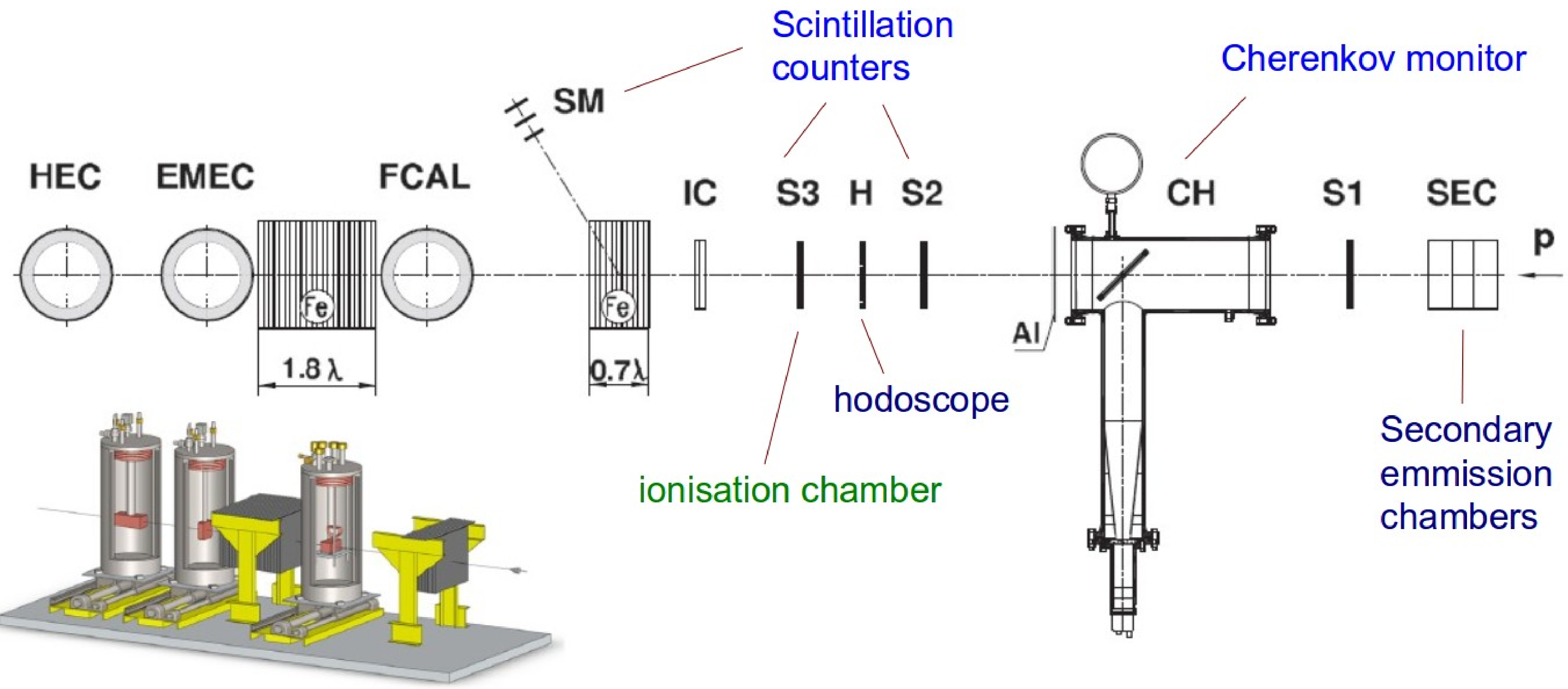
**2x4 readout channels**

**2x4 HV channels**

**Each module is housed in a separate movable cryostat.**

# Setup in experimental area

Hilum test beams in Protvino (2008, 2009, 2010, 2012, **2013**)




**Test beam setup and absorber thickness was optimized in MC**

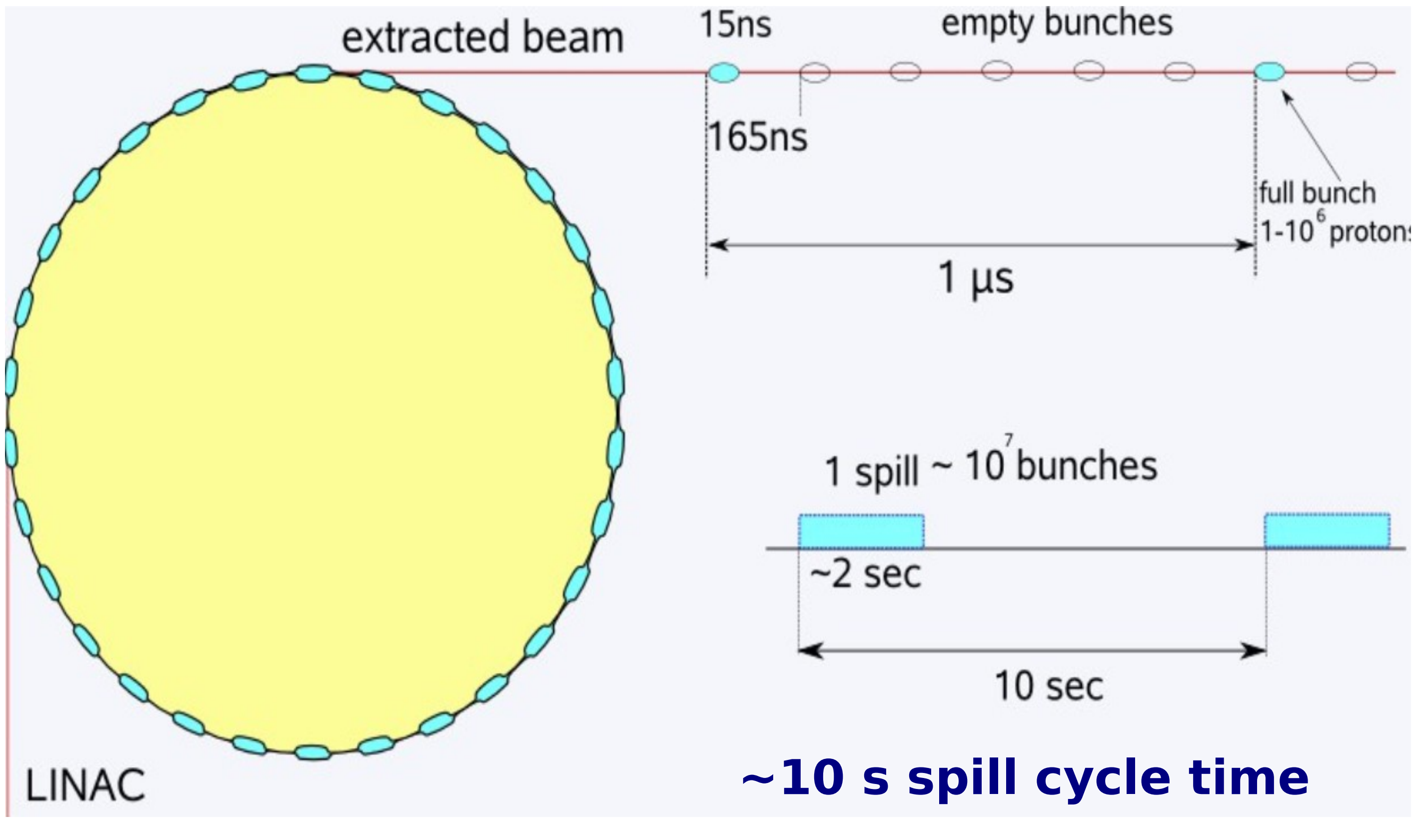
**Current talk is on the basis of 2013 Data**

# HiLum R&D Project

**IHEP/Protvino proton beam comes in bunches beam of 50 GeV**

**Bunch structure with every 6th bunch filled → ~1 μs bunch spacing**

**Studies without pileup.**

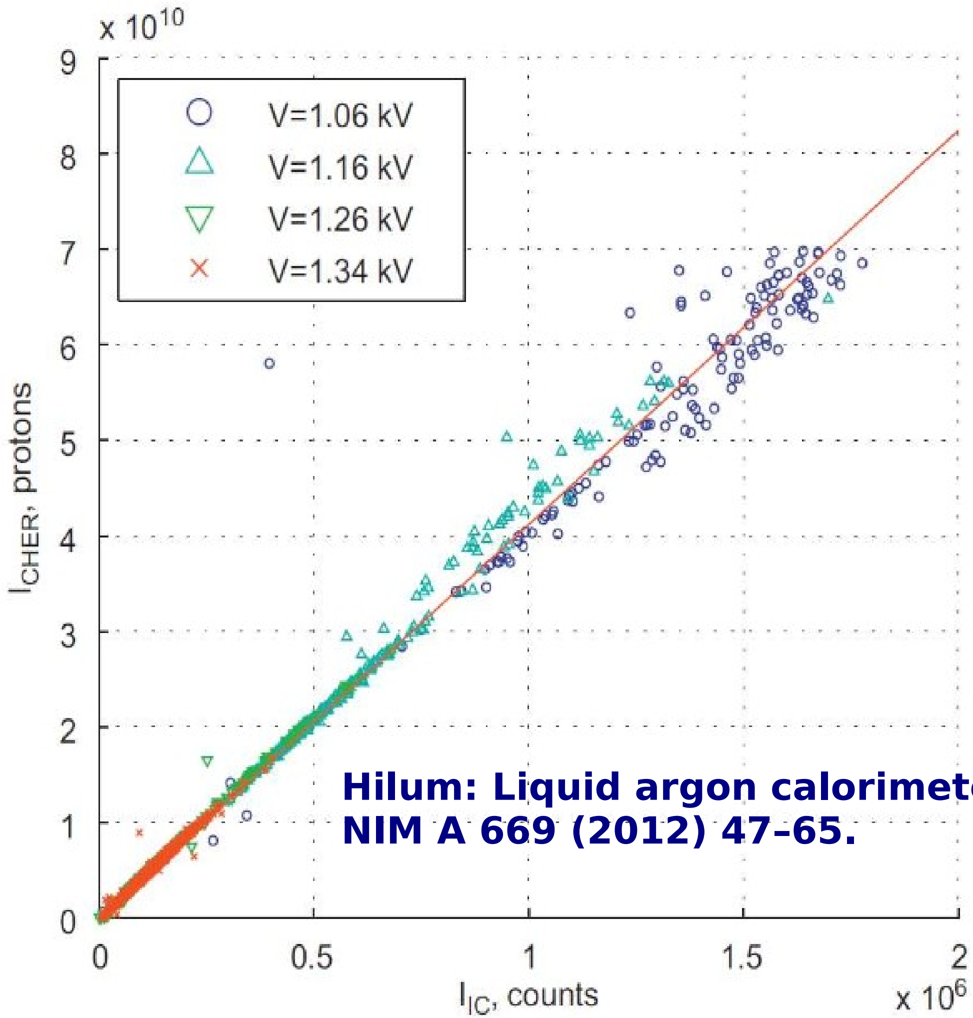


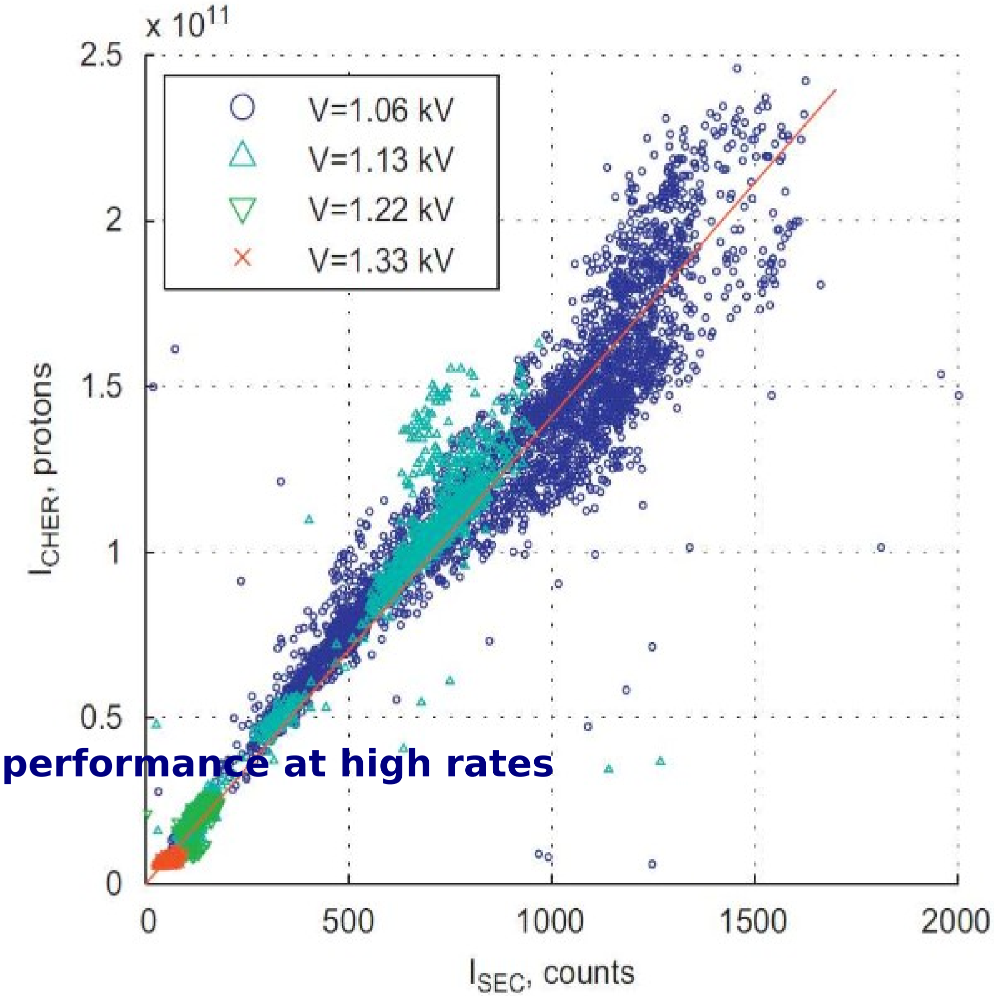

**~10 s spill cycle time**

**Extract one accelerator fill in ~1.2 s spill**

**Intensity range: $10^6$ – ~$3\times10^{11}$ p/spill**

# Intensity Measurements

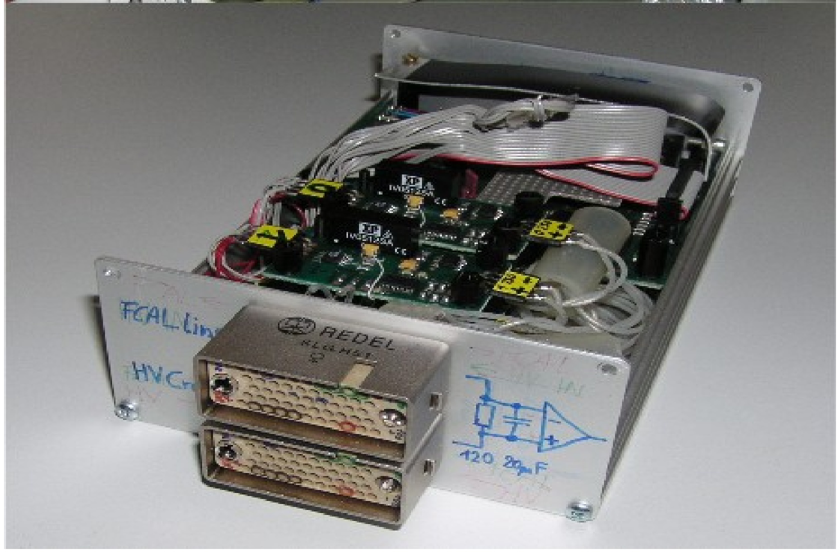



**Hilum: Liquid argon calorimeter performance at high rates**
**NIM A 669 (2012) 47–65.**

From minimum bias events at LHC we obtain for a LHC luminosity of $10^{34}$ $cm^{-2}$ $s^{-1}$ a corresponding beam intensity at Protvino of 6.7 $10^8$ p/s(8.9 $10^7$ p/s, 4.8 $10^7$ p/s) for the FCal(269) (EMEC,HEC) with ~46% MC uncertainty

# HV Current Measurement




**Device is installed between the HV power supply and the Filter Boxes of the Calorimeter modules**

**Measurement of the 3 EMEC HV channels in March 2013 run**

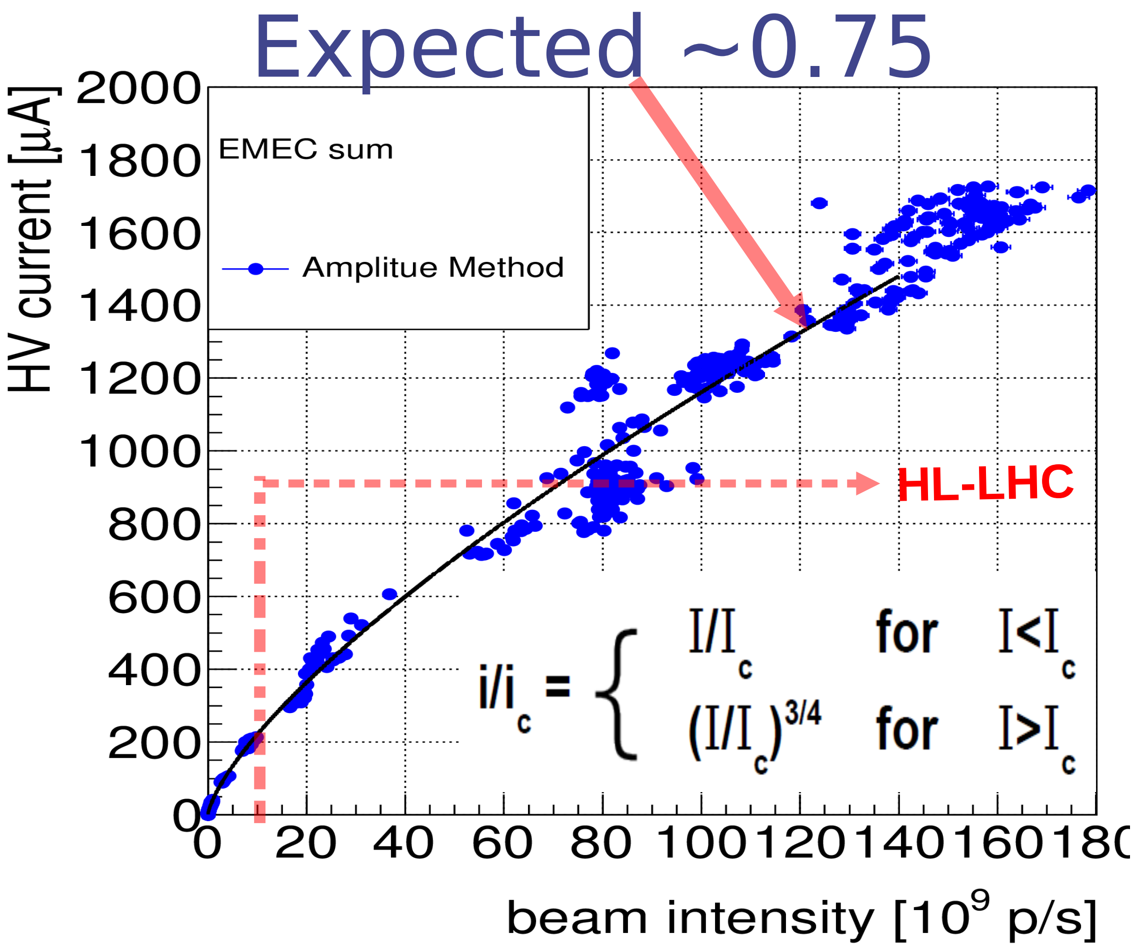
**Four 24-bit ADCs → Digital resolution of 1.2nA**

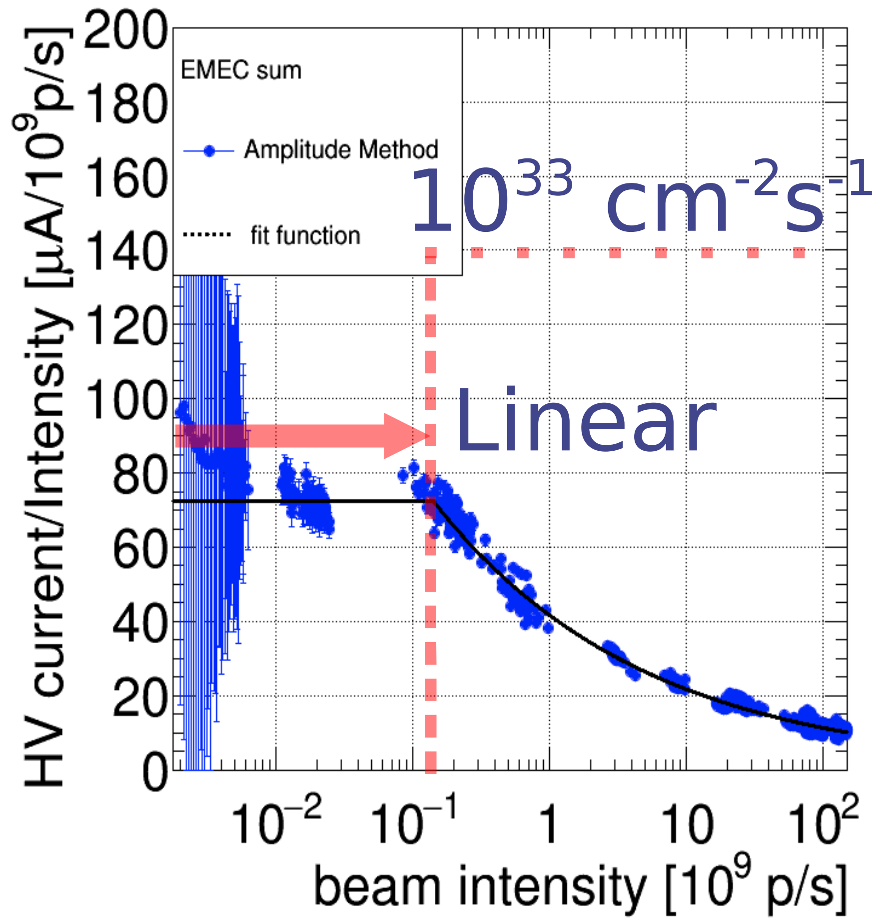
**Measurement rate: 10Hz / channel**

**Time-stamp of internal clock was synchronized with DAQ clock to ±1s**

**Stable and solid running**

# HV Current from EMEC mock-up
## over very wide range of beam intensity



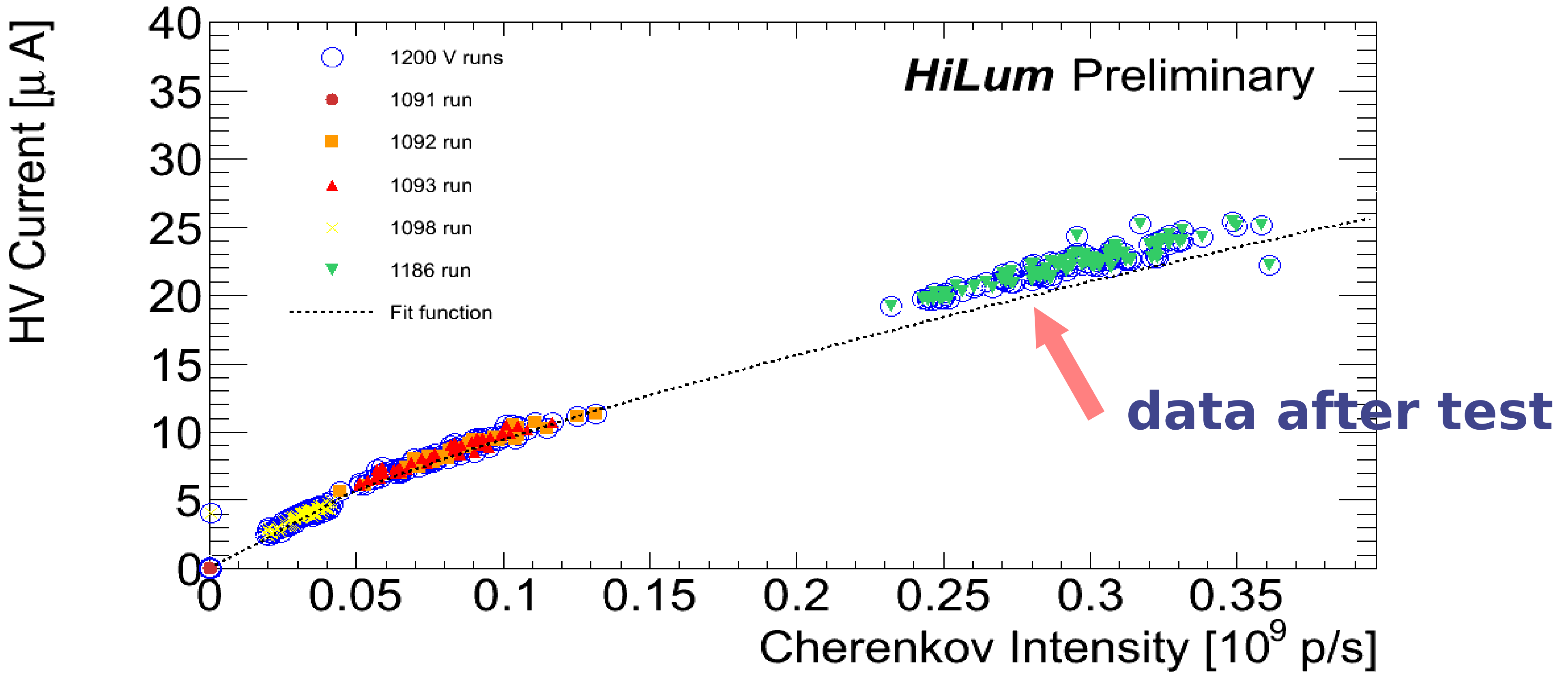

**Prediction →** **Above critical intensity $I_c$ → space charge limit.**
**Current drawn at $I_c$ is critical current $i_c$**

| | | | | | | |
|---|---|---|---|---|---|---|
| Protons/spill | $10^7$ | $10^8$ | $10^9$ | $10^{10}$ | $10^{11}$ | $10^{12}$ |
| Protons/bunch | 5 | 50 | 500 | 5000 | $5 \cdot 10^4$ | $5 \cdot 10^5$ |
| LHC lumi equal [$cm^{-2}\,s^{-1}$] | $10^{32}$ | $10^{33}$ | $10^{34}$ | $10^{35}$ | $10^{36}$ | $10^{37}$ |

Linear HL-LHC

# Test to Destruction

- **Run IHEP proton beam with highest intensity for several days**
- **Compare HV currents before and after**
- **Roughly equivalent to worst place in EMEC after about 1000 $fb^{-1}$**



# Conclusions

**Ar+ ion build-up is actually a problem for linearity for Liquid Argon Calorimetry**

- **LAr Calorimeters are intrinsically radiation tolerant (was shown after test for destruction)**

- **Critical intensity for ATLAS EMEC ~1.6 $10^8$ p/s and for FCal1 is under investigations**