EUDET/AIDA pixel beam telescope for detector R&D

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DESY
on behalf of AIDA consortium

Test beam telescope as an R&D tracker
- Telescope development overview
- Testbeam lines at DESY, CERN, SLAC

From EUDET to AIDA telescope

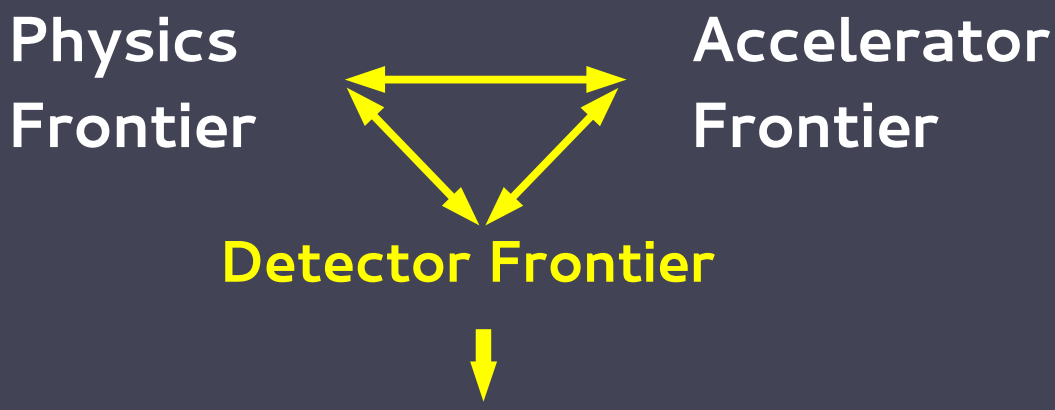
International Conference on Technology and Instrumentation in Particle Physics

TIPP'14
2-6 June 2014
Amsterdam, The Netherlands

AIDA

DESY

In the context of European Strategy for Particle Physics and the detector R&D



the detector concepts are continuously evolving
Prototyping and intensive testing in the labs and at test beam

EU FP6 (2006-2010) - **EUDET (European Detectors)**
aimed at detector R&D infrastructure towards ILC

EU FP7 (2011-2014) - **AIDA (Advanced Infrastructures for Detectors at Accelerators)**
aimed to "upgrade, improve and integrate key European research infrastructures and develop advanced detector technologies for future particle accelerators … in line with the European Strategy for Particle Physics"

In this talk we overview the **test beam telescope** developed as European **Detector R&D Infrastructure** within **EUDET and AIDA** projects

EUDET/AIDA pixel beam telescope = HEP community effort

EU FP6 EUDET JRA1 "DESY Testbeam and Pixel Telescope"

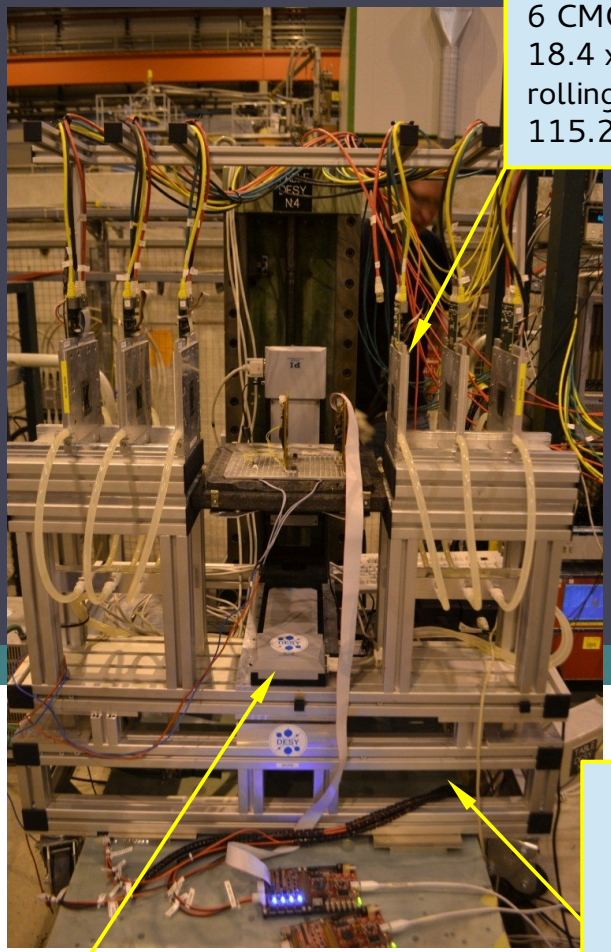
DESY (coordination)
CEA, France
Bristol University, UK
CERN
CNRS-IReS, Strasbourg, France
CNRS-LPSC, Grenoble, France
Max-Planck-Society for the Advancement of Science
Max-Planck-Institut für Physik, Munich, Germany
Universität Bonn, Germany
University College London, UK
Universität Mannheim, Germany
Université de Genève, Switzerland
Universität Heidelberg,Germany
INFN Milano, Milano, Italy
INFN Ferrara, Ferrara, Italy
INFN Roma III, Roma, Italy
INFN Pavia, Pavia, Italy

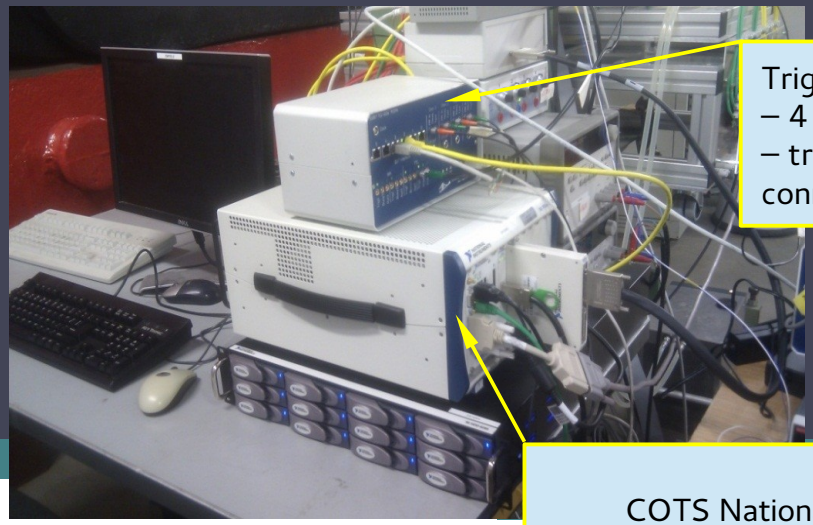
EU FP7 AIDA WP9.3 “Precision Pixel Detector Infrastructure”

DESY (coordination)
Bristol University, UK
CERN
CNRS-IReS, Strasbourg, France
IFAE, Barcelona, Spain
LPNHE, Paris, France
NIKHEF, Amsterdam, Netherlands
Oxford, UK
Universität Bonn, Germany
University of Santiago de Compostela, Spain
Wuppertal University, Germany

EUDET pixel beam telescope ≡ high resolution R&D Tracker

6 CMOS pixel detectors (IPHC Strasbourg): Mimosa26 thinned to **50 µm thickness**
18.4 x 18.4 µm^2 → 1152 columns x 576 rows (2x1 cm^2)
rolling shutter = continuous readout = deadtime free
115.2 µs integration time/frame → 8.68 kFrames in 1 second for "always sensitive" telescope





Trigger Logic Unit (TLU):
– 4 inputs from PMTs
– trigger/busy handshake to connect up to 6 DAQ systems

COTS National Instruments Flex RIO (Vertex-5 FPGA) based solution for Mimosa26=1x2 cm2 (<20 MB/s)

Immediate writing on RAID

Mechanical support
based on rigid Al profiles
~1 µm precision rotation
in horizontal plane (µ- screw)

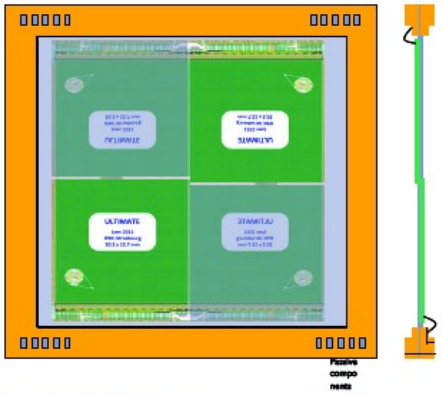
Device Under Test (DUT)
with precise XY/rotation stage

The DAQ components interact via Hard & Soft layers → TLU and **EUDAQ**
Data reconstruction within ILCSoft/Marlin/ **EUTelescope**

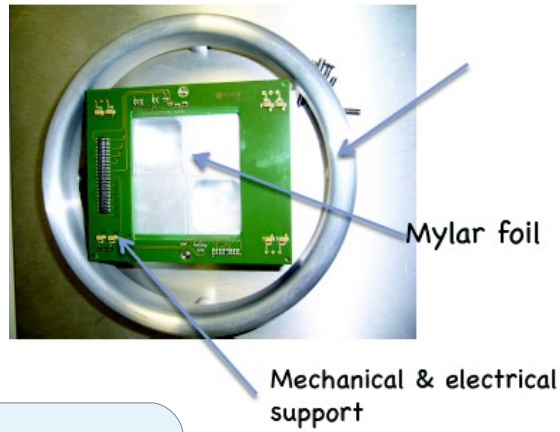
an evolving beam telescope within AIDA project

focusing more on the LHC experiments upgrade

For the LHC detectors R&D
– from 4.34 kHz to ~1 MHz tracks per cm^2 (Mimosa26 capable)
→ **improve: triggering (TLU ↔ DUT),**
DAQ architecture,
Offline: pattern recognition/ tracking



For large detector prototypes need larger tracking acceptance:
→ **from single to quad Mimosa planes (quad-Mimosa28)**

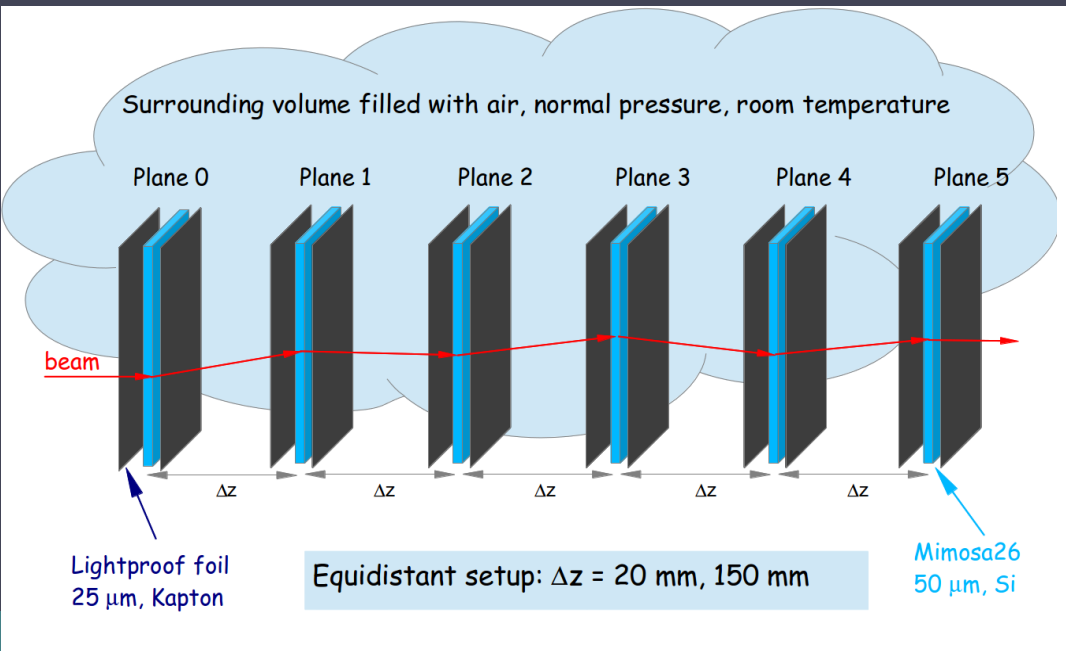


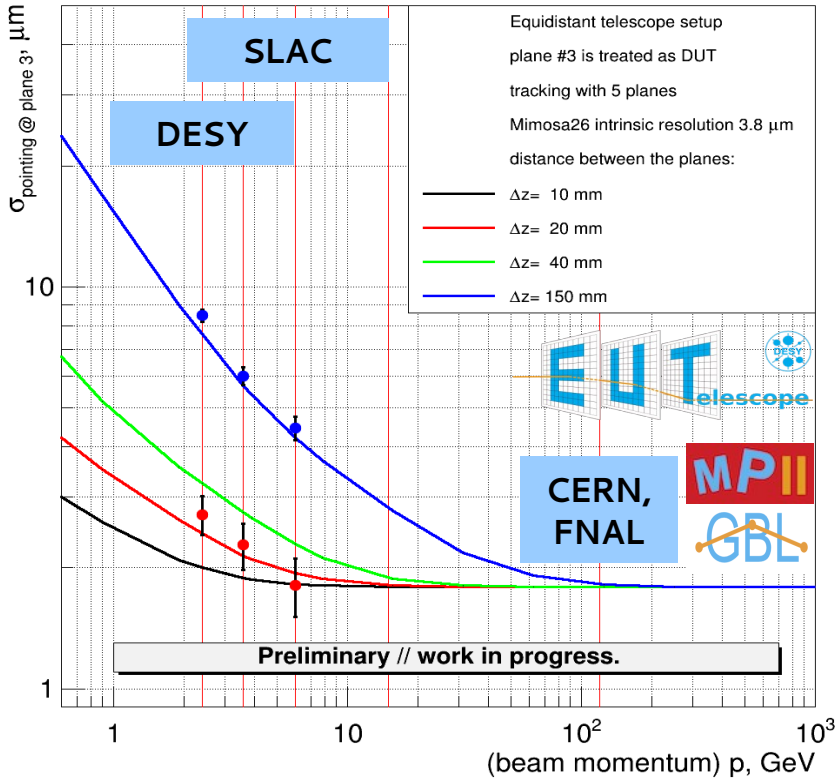
Adjustable trigger window for small DUT prototypes (~ mm^2)
→ **Region of Interest Trigger by ATLAS FEI4**

Track timestamping
→ **with FEI4 + TLU we can also say when a track entered the DUT (~ns)**
(also at the very high track rate)

at the end **"Test beam Tracker with 1 MHz/cm^2 x 1 µm x 1 ns track resolution"**

EUDET/AIDA pixel beam telescope, tracking precision





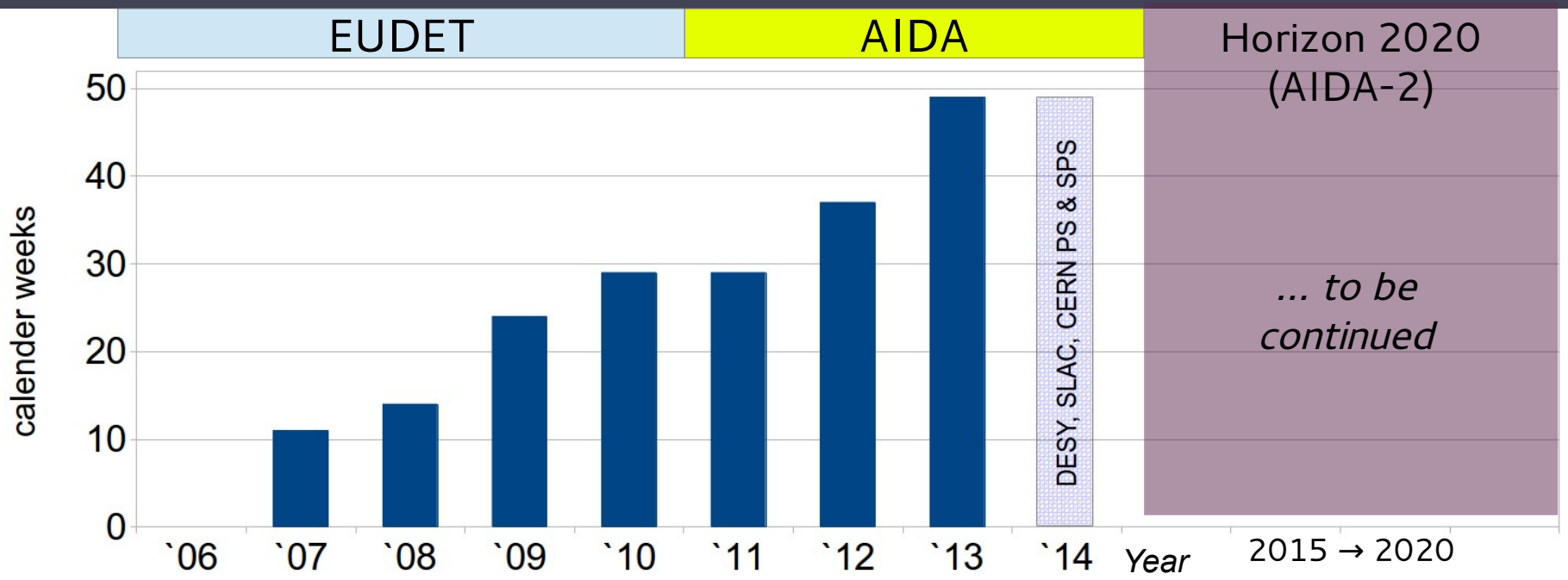
The interplay between
- the telescope detector resolution,
- multiple scattering,
- distance between telescope planes
- distance to the DUT (track fit "passive" plane)

and their impact on alignment and tracking are well understood.

There are more low energy beam facilities not mentioned on this plot

In many cases the R&D groups revise their DUT mechanics to get optimal track pointing precision on the DUT

EUDET/AIDA telescope demand over the years



The EUDET telescope

– Mimosa26 sensors

CDS, ZS, binary, 18.4 µm square pitch

– the NI COTS readout system

introduced to replace VMEx64
and custom made electronics
to solve scalability issues

AIDA Single Arm Large Area Telescope

AIDA upgrades to EUDET telescopes
Trigger, DAQ integration, offline reco
→ *TLU, EUDAQ, EUTelescope*

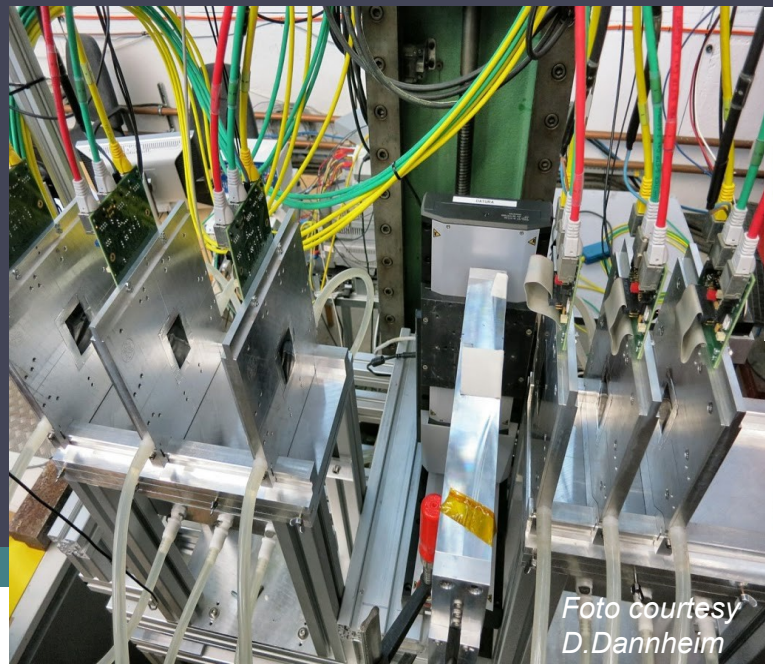
CALADIUM (for Carlton, Canada) (at FNAL)

ACONITE (for ATLAS)

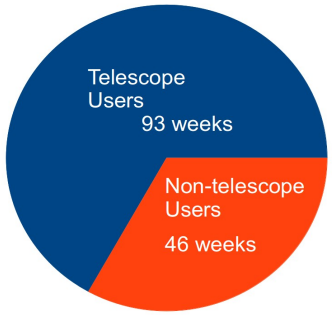
DATURA (for DESY)

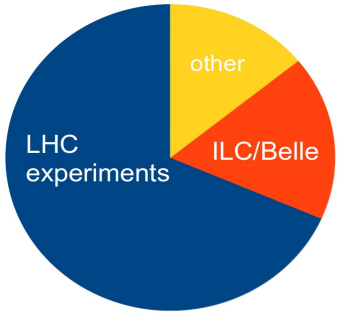
ANEMONE (for Bonn) (at ELSA)

2013 – a good year at DESY TB
(up to 3 telescopes simultaniously)



Top to bottom view on the EUDET telescope sensor fixtures with a DUT box mounted in between





In 2013
- 49 Calendar weeks
- 123 User weeks in total
- 7100 test beam hours
- 400 Users in total

DESY-II primary beam at 6.3 GeV
- high availability time (>99%)
- secondary e+/e- at 1-6 GeV
- rates 0.1-10 kHz

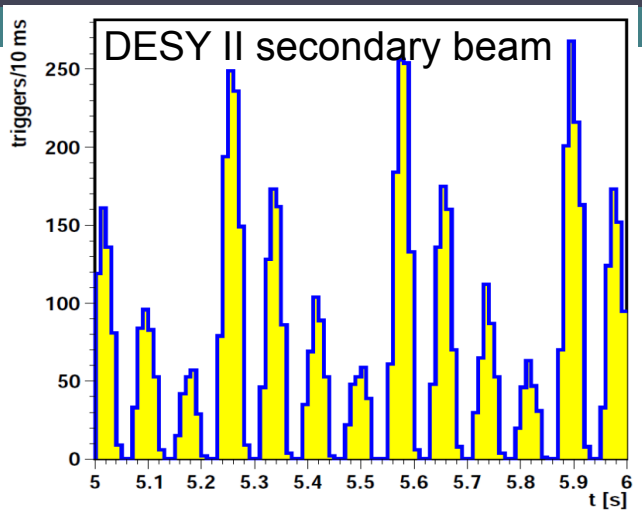
Test beam in 1 Tesla Solenoid
- new telescope & DUT mechanics
- new DUT colling system
- over 20 weeks in B-field

Many of results obtained at this test beam shown on this conference

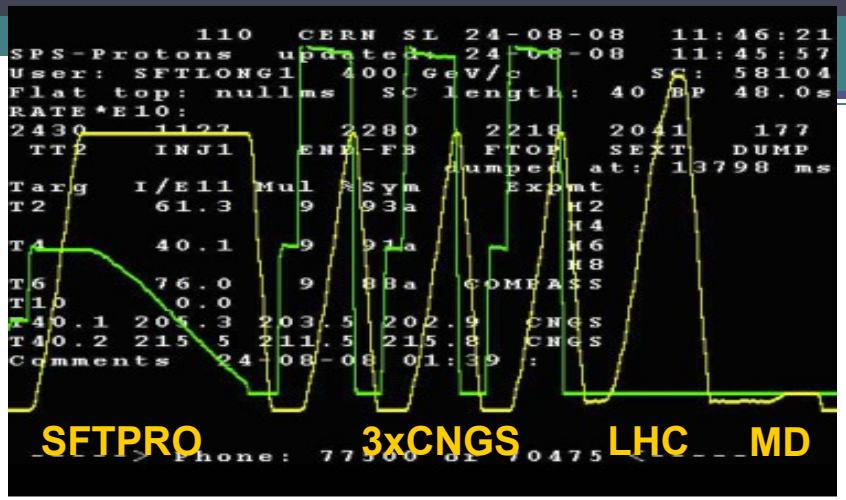
Test Beams @ DESY, CERN, SLAC → the beam rate challenge

		Particle type	Energy, GeV	N particles per pulse	length, seconds	next pulse/bunch/spill
DESY II	LINAC primary secondaries	e (prim.) e+/e−	6.3 1 – 6	$< 10^{10}$ $< 10^{3}$	eff~0.040 instant	0.080 (12.5 Hz) > 1 µs
CERN	PS East (T9) SPS North (H6)	e/hadrons/µ e/hadrons/µ	1 – 15 5 – 205	$< 10^{6}$ $< 10^{8}$	0.400 4.9 – 9.6	33.6 14 - 48
SLAC	End Station A	e (prim.)	1 – 15	$1 \div 10^{10}$	instant	0.2 (5 to 10 Hz)

25 kHz
Instant.



Beam structure only on [ms] scale



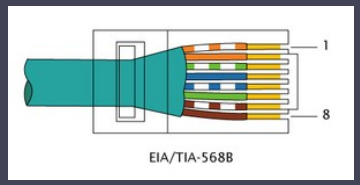
CERN SPS: Complex timing structure on [s] scale

EUDET Trigger Logic Unit (TLU)

tells the DAQ systems that there was
a particle passing through the detector active volume and issues a TRIGGER

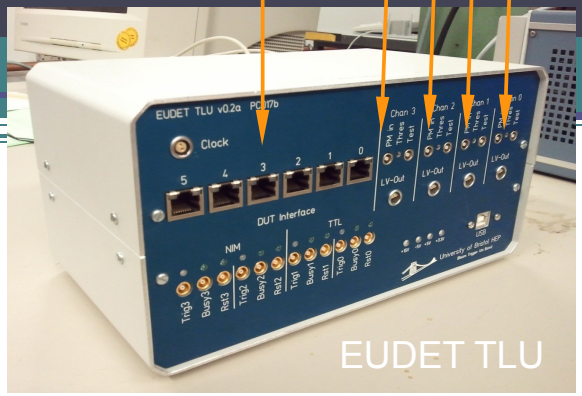
To ensure that no triggers are lost by the DAQ systems the EUDET TLU provides a handshake mechanism
- every trigger is followed by a hardware 16 bit counter.

Defined by design
TLU-DUT protocol signals:
Trigger, BUSY, CLOCK, RESET



up to 6 DUT DAQ via RJ45

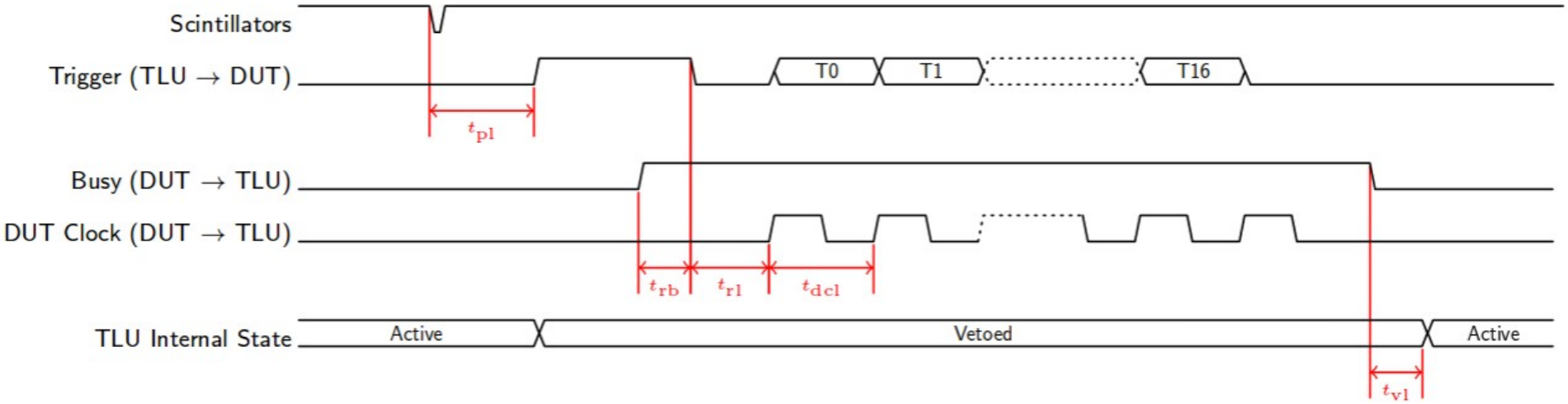
PMT 1-4



The EUDET TLU trigger interface has been performing well....
but we have reached the limits already,

so we come to AIDA TLU.

EUDET Trigger Logic Unit (TLU) – Trigger/BUSY handshake



Signal processing limitations:

– discriminator board ~ 800 ns [and the PMT pile-up looks like a very long pulse]

– TLU ↔ DUT full handshake >~ 1.6 µs

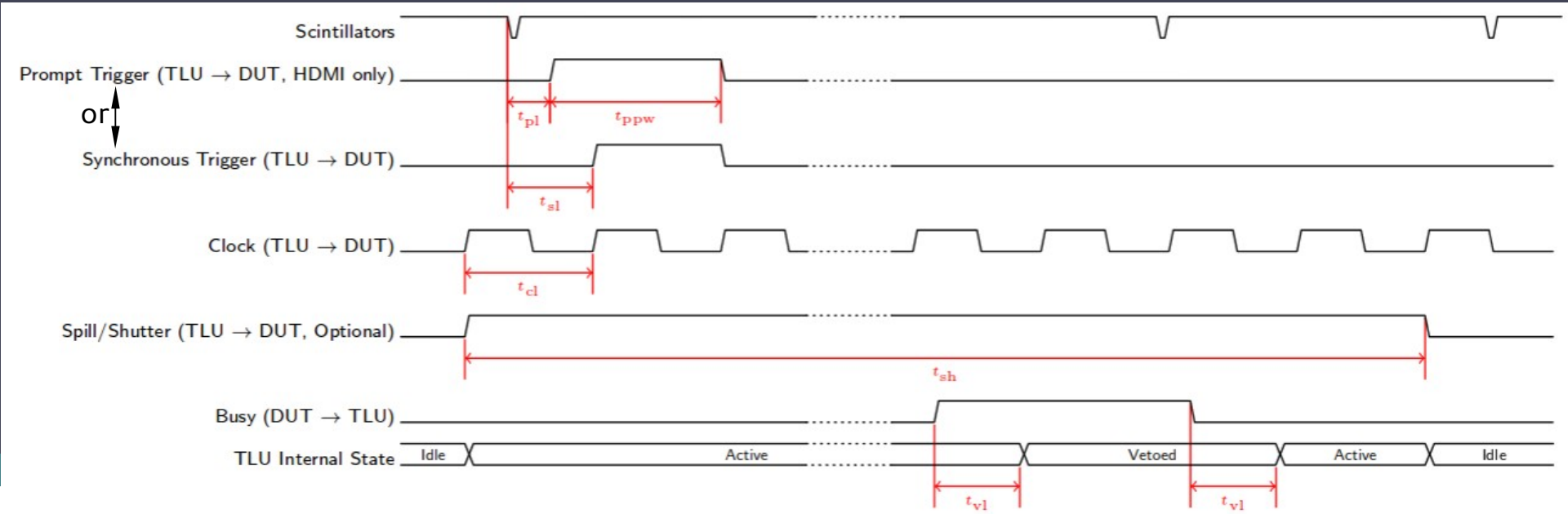
Overall in the final telescope setup → < 100 kHz track rate [pulse generator tests]

System design limitations:

– the DAQ system which keeps **BUSY** longest → becomes the telescope bottleneck [compared to LHC DAQ has to wait till the Mimosa DAQ becomes **READY**]

AIDA Trigger Logic Unit (TLU) – no handshake

more handles to test DUT DAQ efficiency as well



Different w.r.t. EUDET TLU:

Synchronous (shared clocks) interface → Allows higher trigger rate

Higher rate discriminators (~ MHz count rate) → Threshold and constant-fraction

→ Thresholds remotely controllable.

Timestamps on each scintillator input → More accurate timing.

→ Timestamp granularity increased 3.2 → 0.8 ns

Sofware: DAQ and Offline reconstruction

Changes to the triggering scheme inevitably brings changes to

1) DAQ Software Architecture → EUDAQ 2.0
   - decentralized data storage (multiple files)
   - a list of trigger timestamps for every DAQ readout block

2) Track reconstruction → EUTelescope 1.0
   - merging of data streams late → at the level of Pattern recognition
   - fundamental changes to the reco: TGeo navigation between planes, General Broken Line tracking library (benefiting also from the built-in Millepede II interface for alignment)

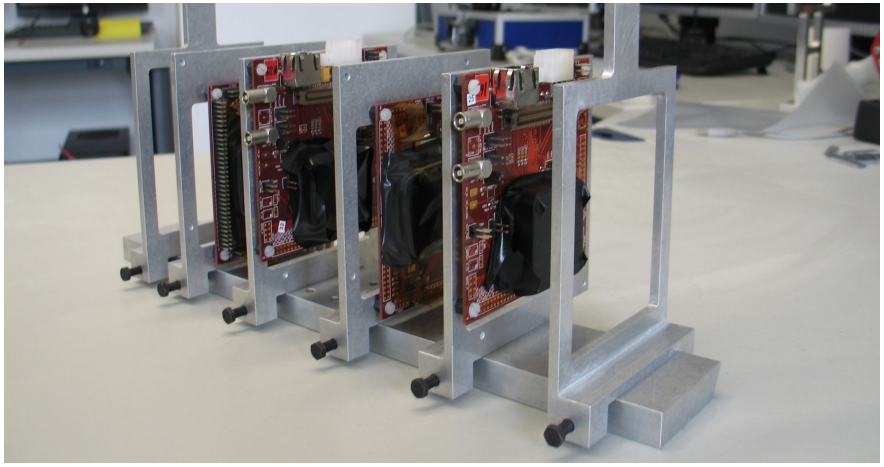
more details in the backup slides and on the poster
by Hanno Perrey "EUDAQ and EUTelescope: Software Frameworks for Test Beam Data Acquisition and Analysis"
Section: Experiments: 2a) Experiments & Upgrade

AIDA telescope extention: ATLAS FEI4 module and readout

ATLAS FEI4 telescope arm (1-4 planes) provides

– flexible triggering → Region Of Interest (next slides)
active area 16 x 20 μm^2

– every pixel contains timing information @25 ns resolution
FEI4 pixel size 50 X 250 μm^2



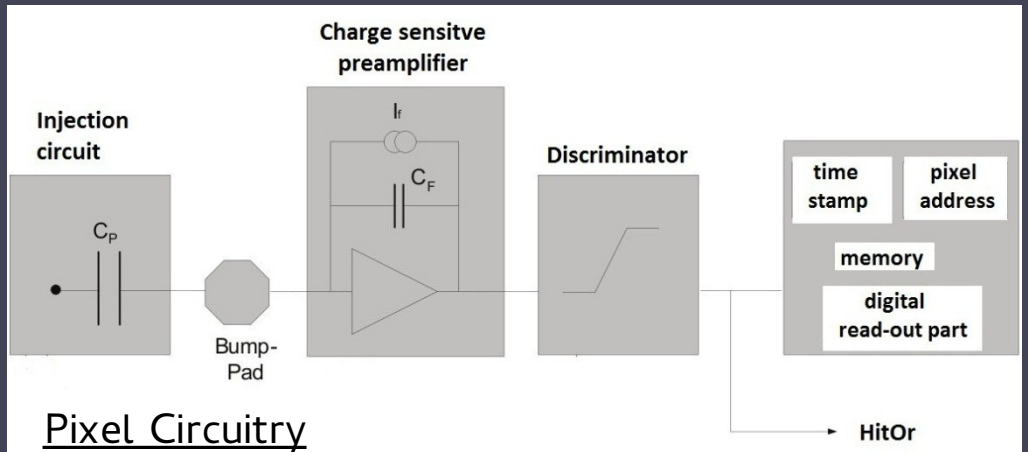
A standalone FEI4 arm was tested as well

see T.Obermann Thesis BONN-IB-2012-14
“Development of a test beam telescope based on the ATLAS front end ASIC FE-I4”

universitätbonn

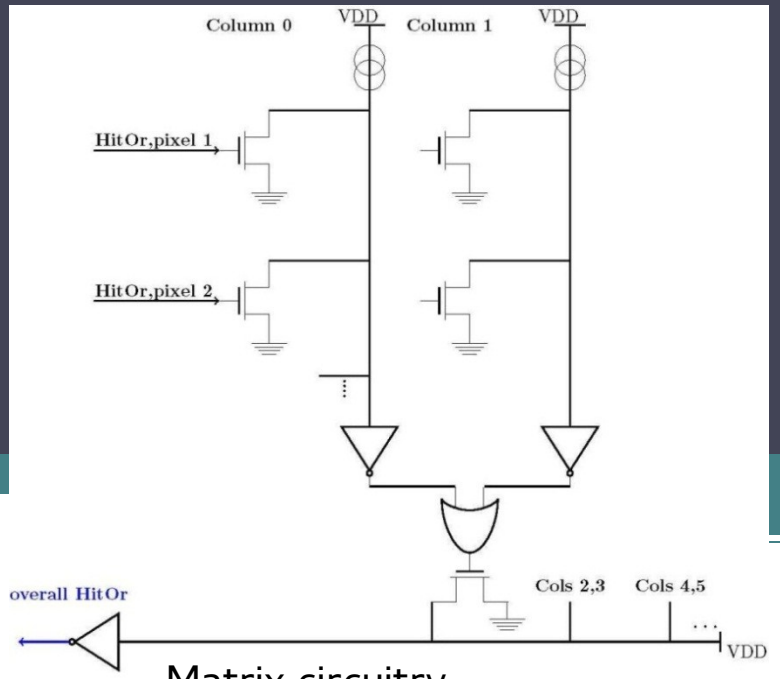
ATLAS FEI4 based modules can be built into a telescope (arm) of it's own type as any other type of HEP detector: pixel or strip or other.

What extra functionality can FEI4 chip provide in test beam infrastructure?



Pixel Circuitry

- Constant (adjustable) current feedback pre-amp
- Discriminator with adjustable threshold
- Circuitry to measure Time over Threshold
- Analog and digital injection points for calibration



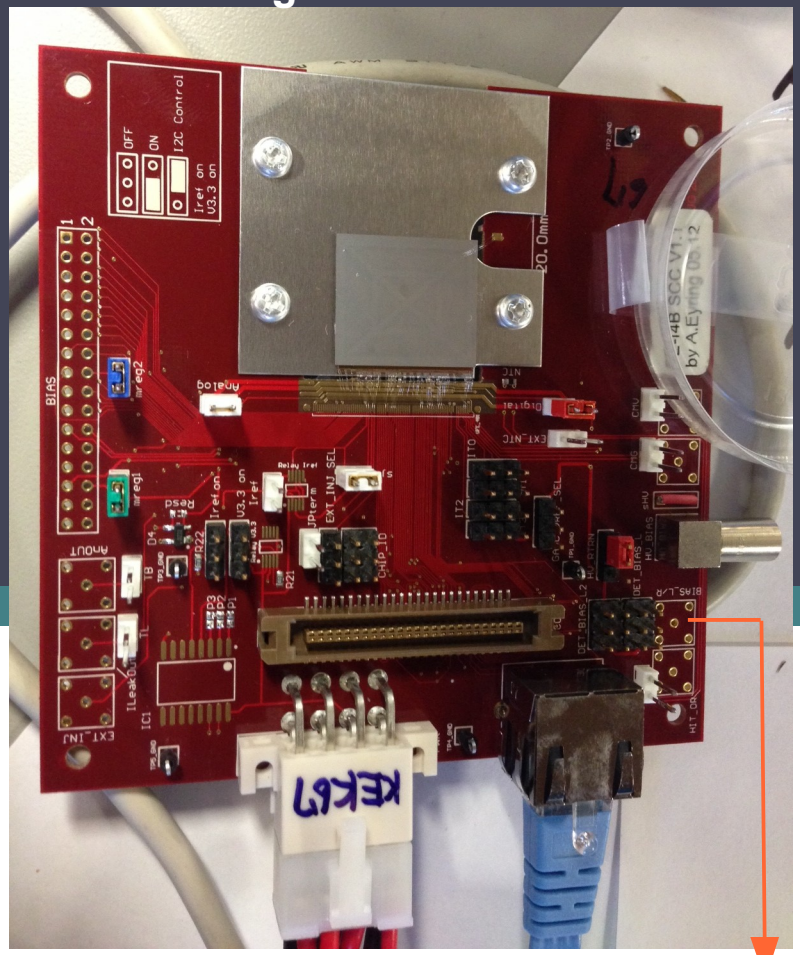
Matrix circuitry

Each pixels discrimator output is or-ed together

HitOr: **Is high if one of the activated pixels sees a hit** (low otherwise)
Length adjustable with threshold and feedback current

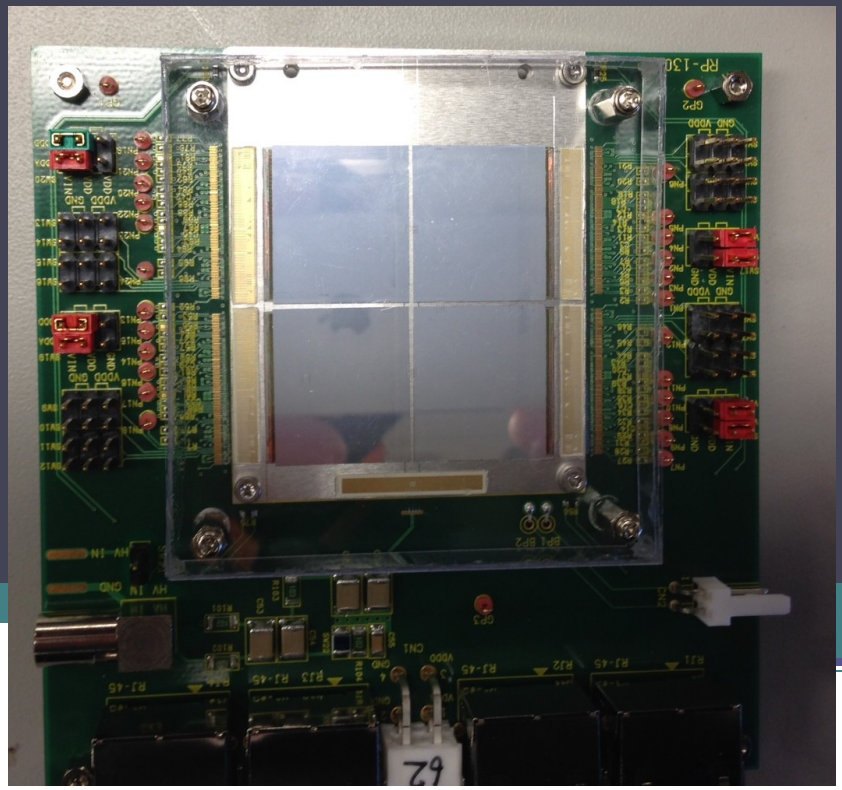
EUDET/AIDA pixel beam telescope, FEI4 modules [SelfTriggered]

Single FEI4 Module



LEMO HitOr signal (SelfTrigger) – if any pixel in the predefined mask is above threshold. Active area: **16.8x20 mm²**

Quad FEI4 Module



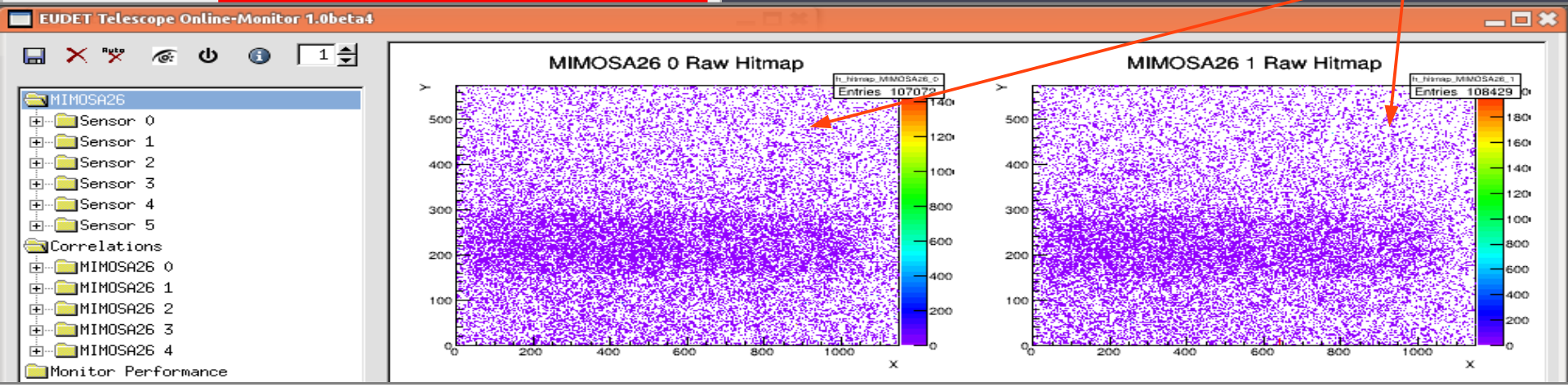
Single sensor (4x size) + 4 FE-I4 on it
→ all DATA cables x4
The default PCB layout missing HitOr LEMO
→ **redesign and production (IFAE, Bonn)**
Active area: 33.6x40 mm²

Foto by Andy Blue from recent ATLAS PPS Testbeam @ SLAC

FEI4 as Region of Interest plane – Configurable Trigger window

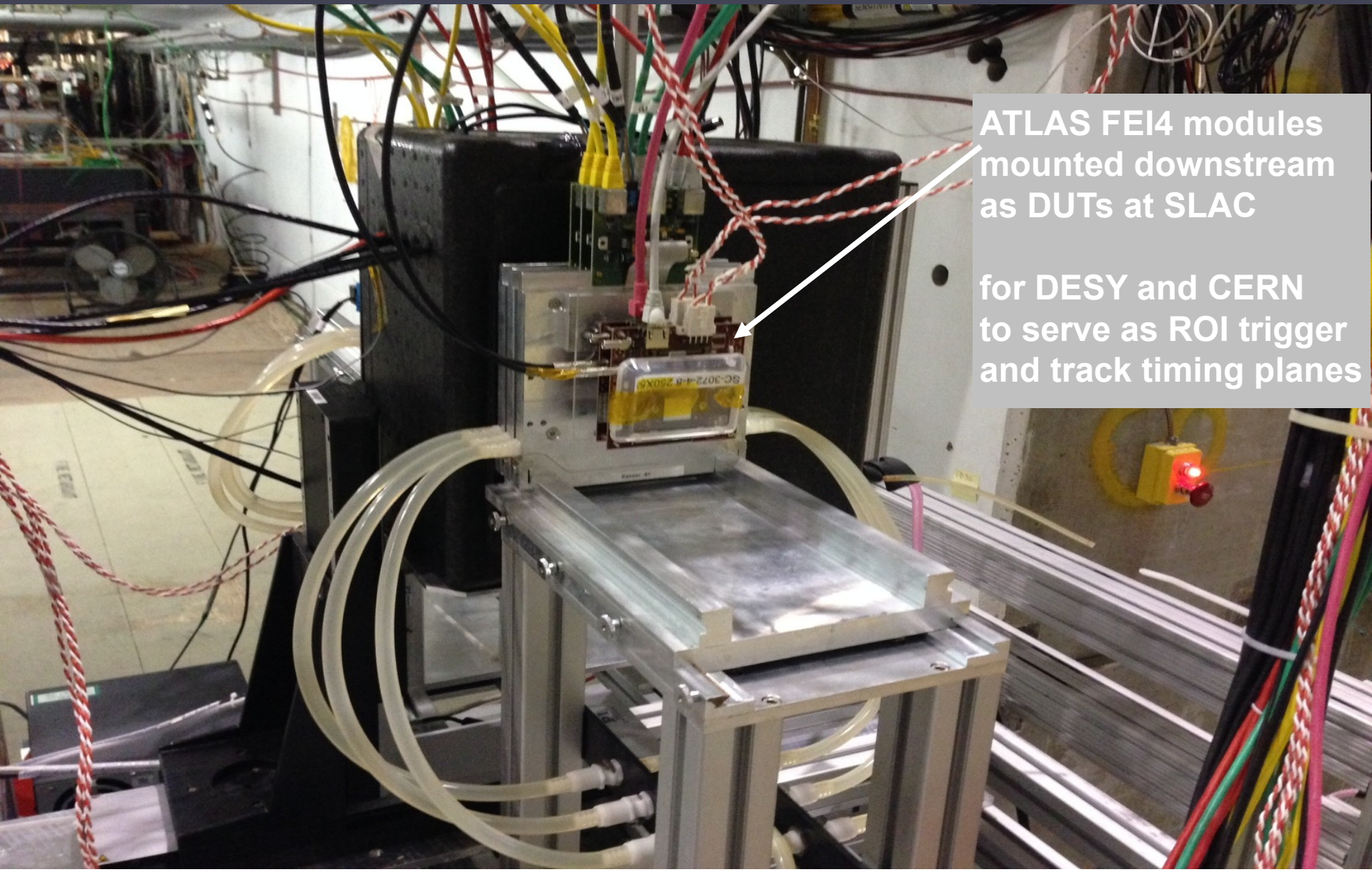
FEI4 module pixel mask
– black area is SelfTrigger Enabled
– the FEI4 SCC connected to the TLU replacing one of the PMTs,
Software tunable Trigger area
→ Region Of Interest (ROI)

Mimosa26 .vs. FEI4 overlap and hitmaps



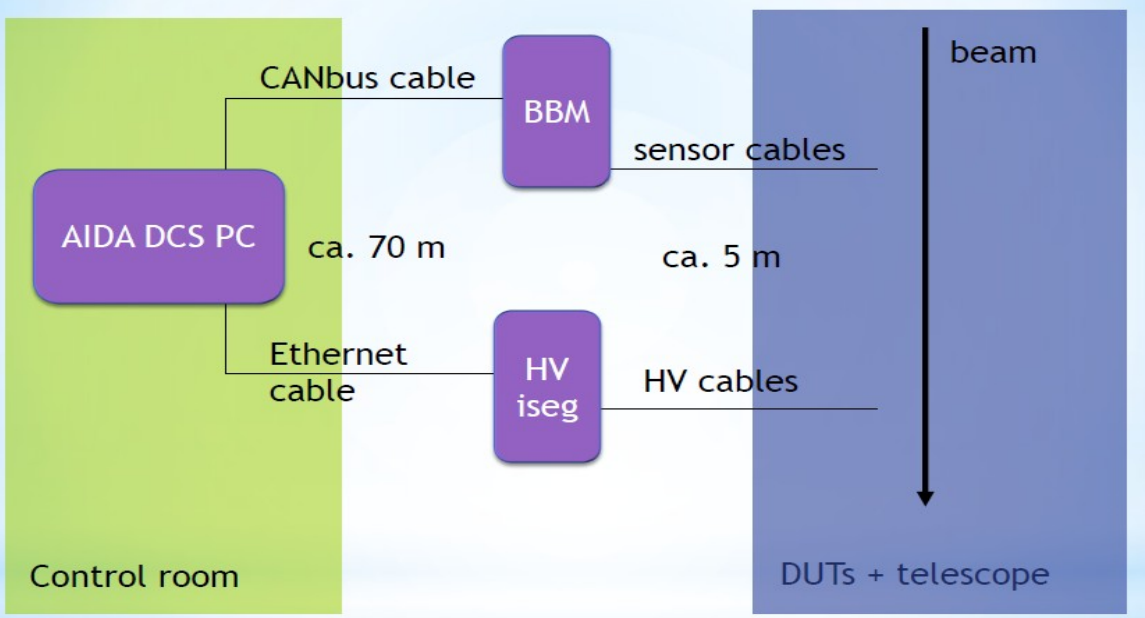
Turned out to be a very useful feature for small prototypes (few mm^2) beam tests

EUDET/AIDA pixel beam telescope, FEI4 modules



Non-tracking AIDA telescope infrastructure

Additional AIDA Test beam infrastructure, DCS and CO2 cooling plant



AIDA DCS (by Wuppertal Uni):

– HV ISEG crate
→ Software control
→ up to 16 HV channels
– (new option HV & LV Wiener)

– BBM
→ temperature, humidity

readout and logging with 10 second intervals [tunable]

commissioned

Development goal
(lead by NIKHEF, CERN):
portable laboratory cooling unit

- Cooling power 100 to 250 W
- Temperature range -40 to +20 C
- Turn key
- Very simple to operate "fridge like"

Traci-1 (ATLAS SR1 & R&D, LHCb R&D)
Traci-2 (Uni Ge, CMS R&D, KEK for ILC-TPC R&D) → Foto
Traci-3 (AIDA) – commissioning in the next months

Nov. 2014

The AIDA telescope to be commissioned in November 2014 (end of AIDA in January 2015)

- quad planes with Mimosa28 and FEI4
- TLU and EUDAQ coping with 1 MHz track rate

What next?

Looking forward to Horizon-2020 (AIDA-2)

AIDA-2 Transnational Access (TA) package

Work related to the CERN and DESY test beams.

Maintenance of the infrastructure that has been developed for test beam needs within EUDET/AIDA projects.

The AIDA telescope completion has been scheduled late in the AIDA project, there is no usage experience to identify the upgrade objectives (mainly for LAT sensitive planes, likely to be funded by other means)

Proposal being submitted ... now

Final remarks

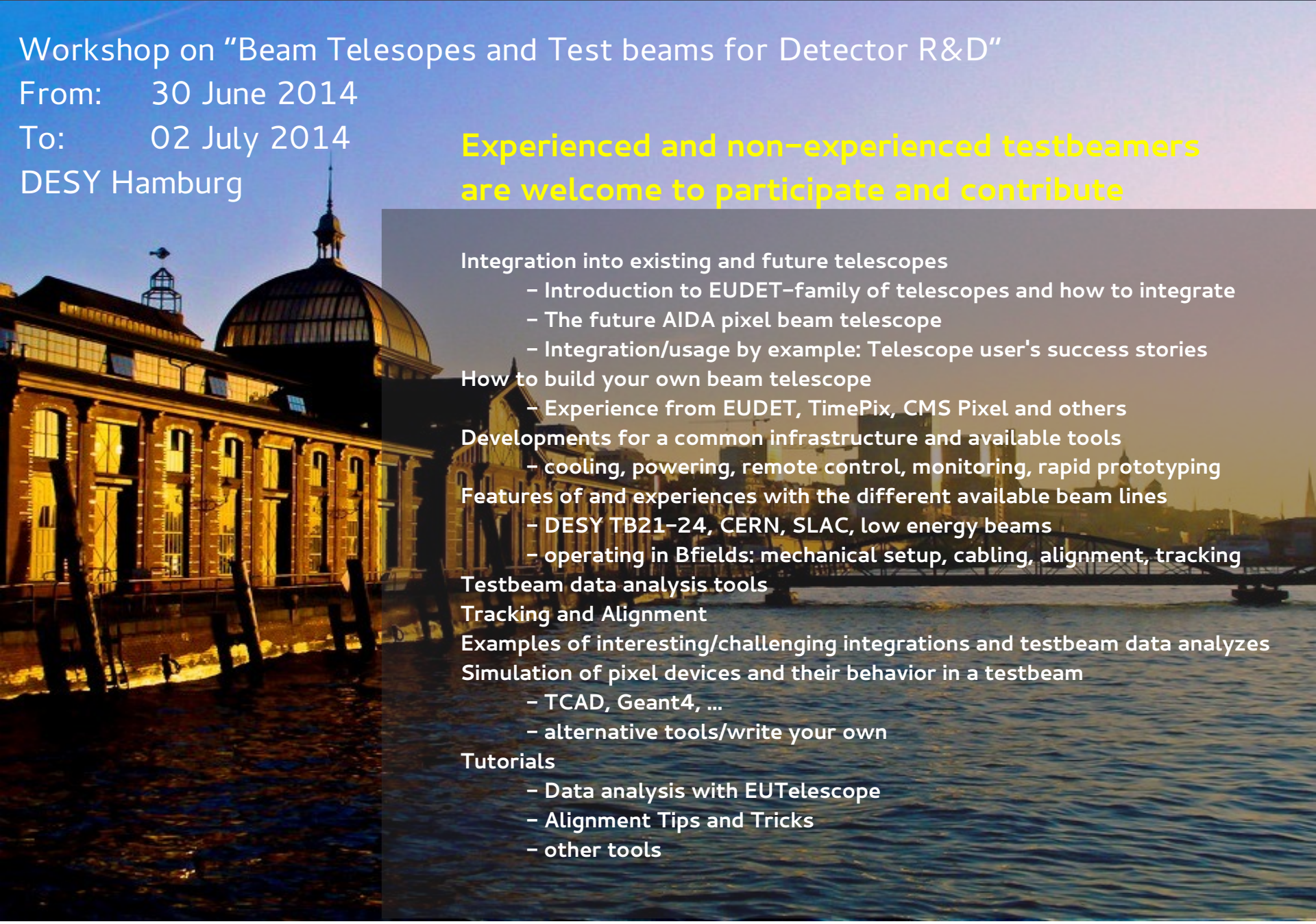
The EUDET/AIDA telescope is in growing demand from the HEP community. The upgrades are driven by the community demands and efforts equally.

The EUDET telescope(s) will be upgraded to be capable of managing up to 1 MHz tracks / cm^2 (1 μm & 1 ns) which will make it into the AIDA telescope → tests at PS & SPS CERN from July to November 2014.

The Large Area Telescope arms (Mimosa28 and FEI4) are scheduled for November test beam at CERN SPS.

For more information please visit

– **http://beam-telescopes.desy.de** get updated on the hard- and software status
– poster session “EUDAQ and EUTelescope software” by H.Perrey
– workshop at DESY (next slide)



Workshop on "Beam Telesopes and Test beams for Detector R&D"

From: 30 June 2014

To: 02 July 2014

DESY Hamburg

Experienced and non-experienced testbeamers are welcome to participate and contribute

Integration into existing and future telescopes
- Introduction to EUDET-family of telescopes and how to integrate
- The future AIDA pixel beam telescope
- Integration/usage by example: Telescope user's success stories

How to build your own beam telescope
- Experience from EUDET, TimePix, CMS Pixel and others

Developments for a common infrastructure and available tools
- cooling, powering, remote control, monitoring, rapid prototyping

Features of and experiences with the different available beam lines
- DESY TB21-24, CERN, SLAC, low energy beams
- operating in Bfields: mechanical setup, cabling, alignment, tracking

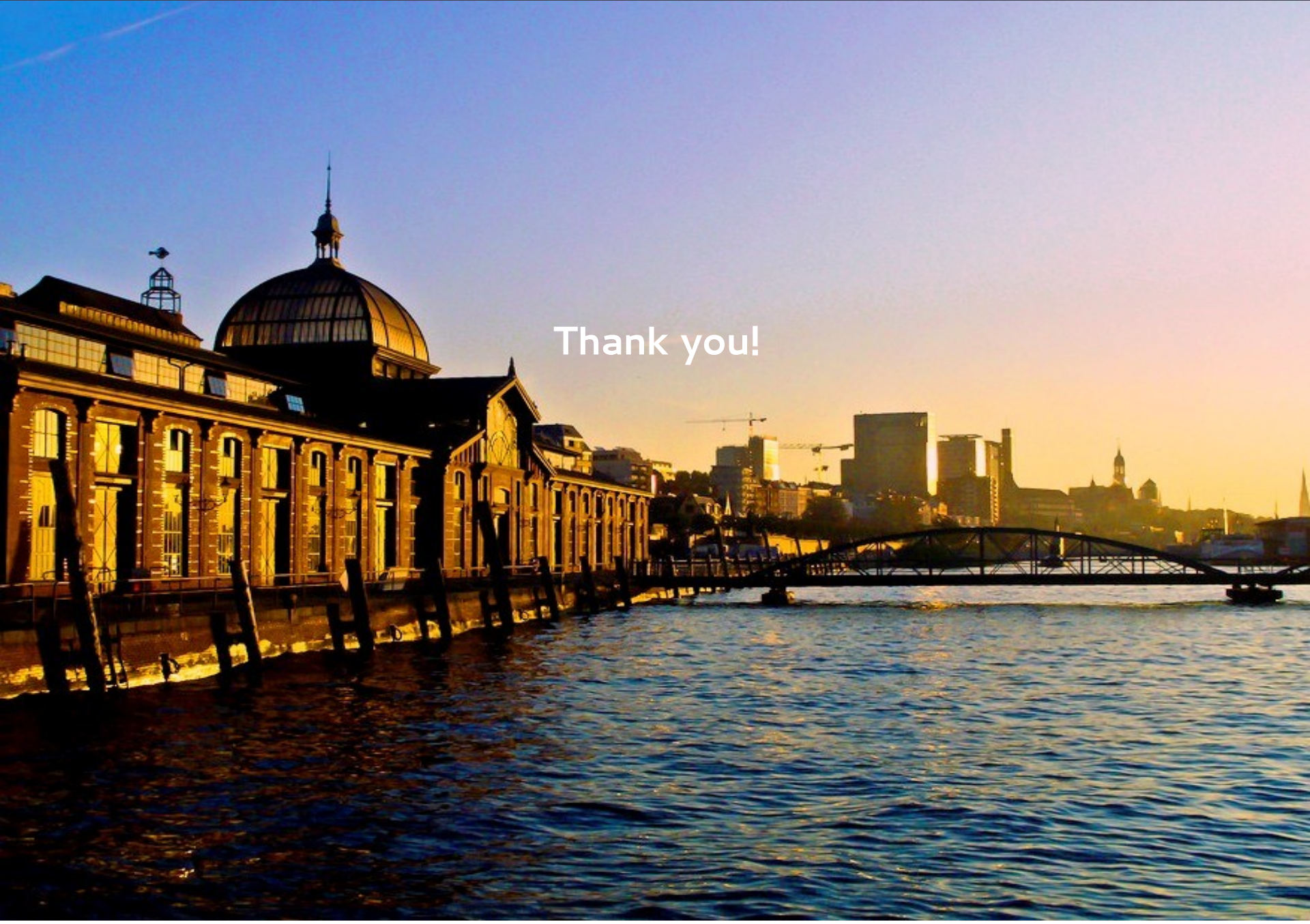
Testbeam data analysis tools

Tracking and Alignment

Examples of interesting/challenging integrations and testbeam data analyzes

Simulation of pixel devices and their behavior in a testbeam
- TCAD, Geant4, ...
- alternative tools/write your own

Tutorials
- Data analysis with EUTelescope
- Alignment Tips and Tricks
- other tools


Thank you!

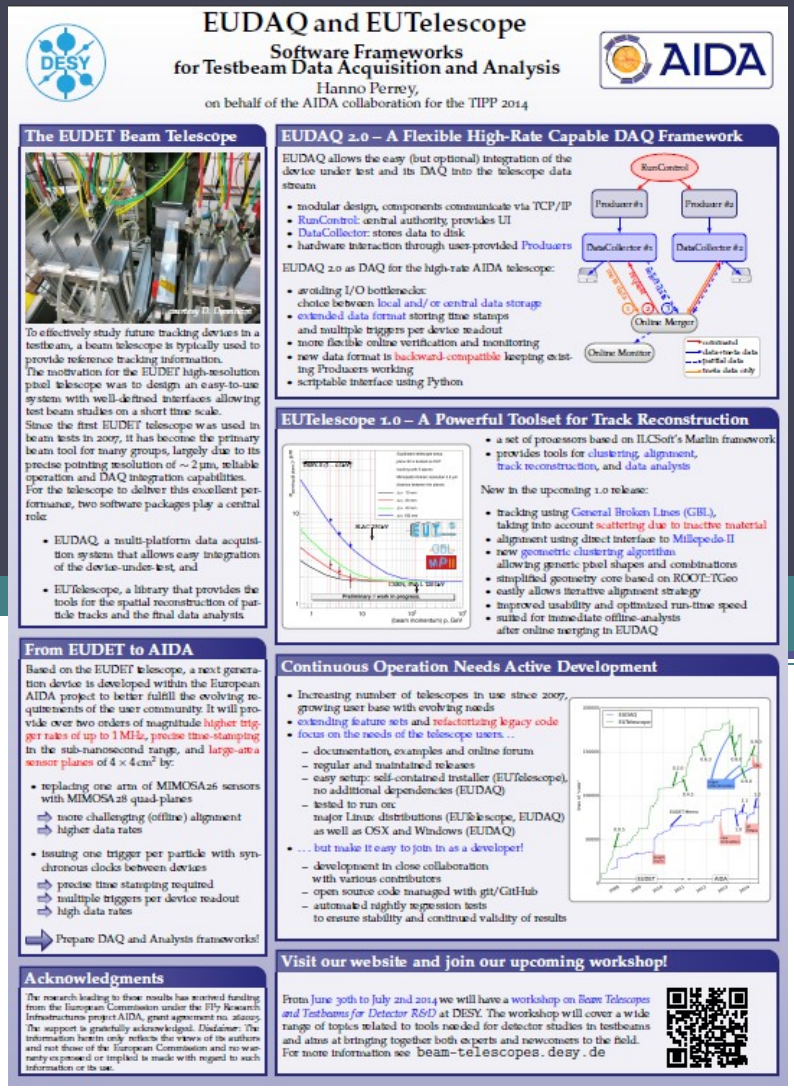
Backup

TIPP`14 poster session

EUDET/AIDA software overview

more details are given on the poster
by Hanno Perrey
“EUDAQ and EUTelescope:
Software Frameworks for Test Beam
Data Acquisition and Analysis”

Section:
Experiments: 2a) Experiments & Upgrade



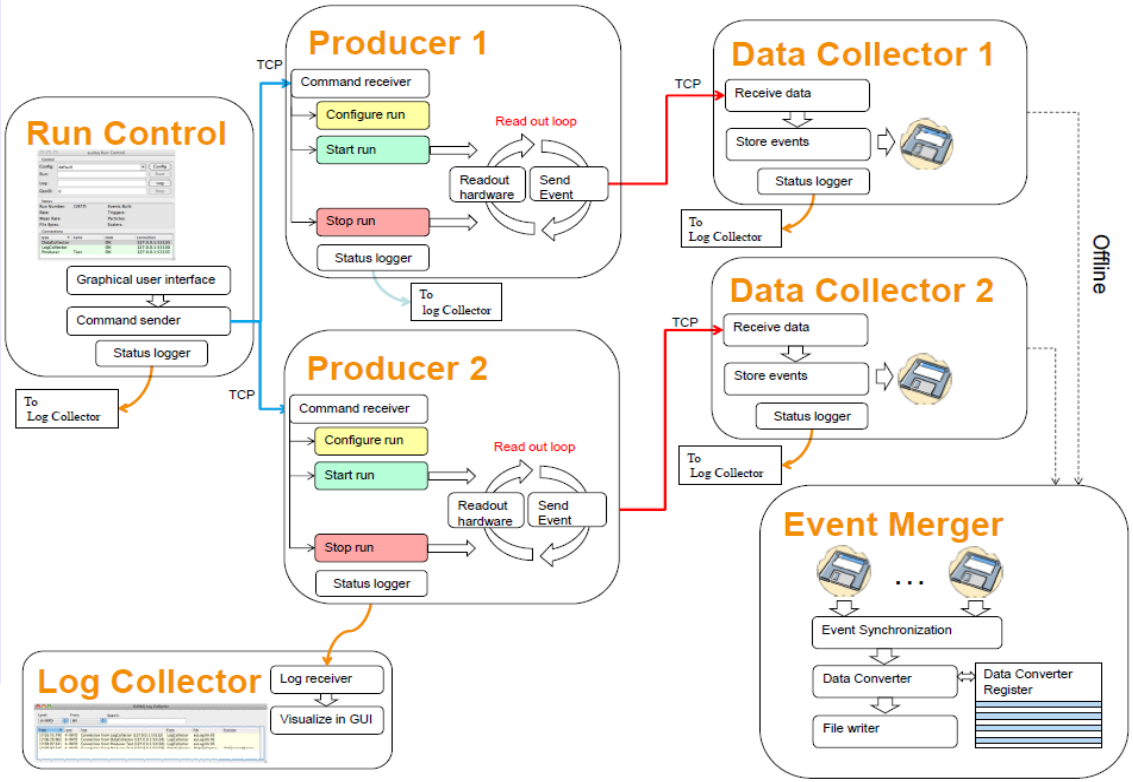
more on the transition
from EUDET to AIDA
on next few slides

… pixel beam telescope ≡ R&D Tracker, DAQ

https://twiki.cern.ch/twiki/pub/MimosaTelescope/EUDAQ/EUDET-Memo-2010-01.pdf

EUDET 1.0 DAQ shared library and binaries
- Windows 7 (MSVS, default), Linux, MacOS
- an integration layer for other DAQ systems
- Modular design, communication over TCP/IP
  - RunControl: central authority, provides UI
  - DataCollector: stores data to disk
  - Producers engage DUT DAQ
- bottlenecks:
  - single central data collector (DC)
  - One Trigger by definition is
    → one Producer Event → DC Event
  - Online Monitoring for every event

EUDAQ 1.0



EUDAQ 2.0

DAQ for the high-rate AIDA telescope:
bottlenecks being sorted out:
- optionality → local and/or central data storage
- extended data format storing time stamps [DUT DAQ]
- backward-compatible to EUDAQ 1.0
- multiple triggers per device readout [AIDA TLU]
- more flexible online verification and monitoring

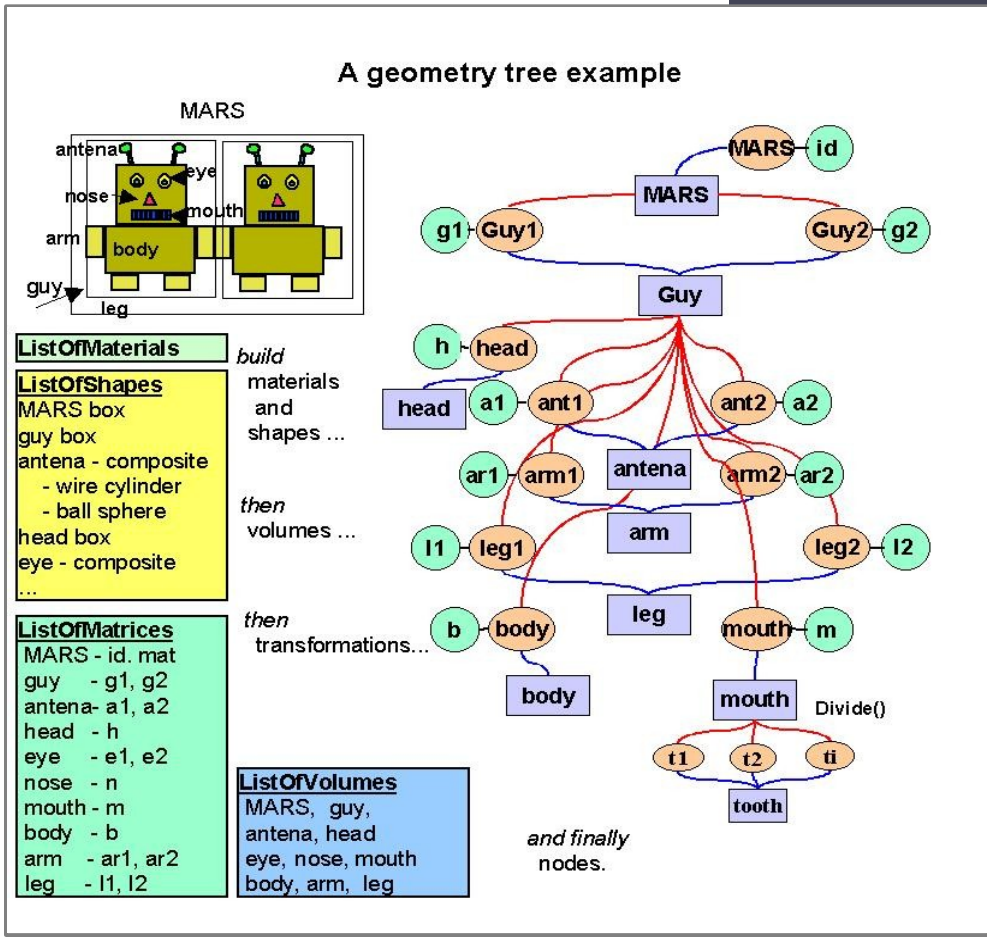
New Producer Interface (scriptable, Python)

… pixel beam telescope ≡ R&D Tracker, Offline Software 1/2

Reconstruction Software EUTelescope highlights

– based on ILCSoft/Marlin framework and LCIO data format
– generic implementation of data processing: clustering, alignment, tracking
– new implementation of the telescope geometry
  – relies on ROOT::TGeo as major construction block and benefits from built-in methods:

– new generic clustering algorithm
  • (TGeo neighbor search)
  • allowing generic pixel shapes
– navigation from one volume to next one:
  • fetch next volume ID by global 3D point coordinate
  • Track incidence with next volume surface,
  • Track direction tilt to the volume surface
– coordinate system transformation
  • Global frame ↔ Local Measurement



… pixel beam telescope ≡ R&D Tracker, Offline Software 2/2

Reconstruction Software highlights (continues)

- General Broken Lines (GBL) for tracking and alignment via Millepede-II
  - implementation benefits a lot from new Geometry model
  - with new Geometry accurate description of all inactive material
    - more realistic Chi2 of the tracks for low energy beam
    - X0 map of the DUT

The result of the track fit now is a collection of track points (hits) on every scattering plane. Every track point contains X,Y (local, module frame) and incidence angle to the volume surface normal

→ basically this is all we want to know about a track at DUT surface to match Cluster info.

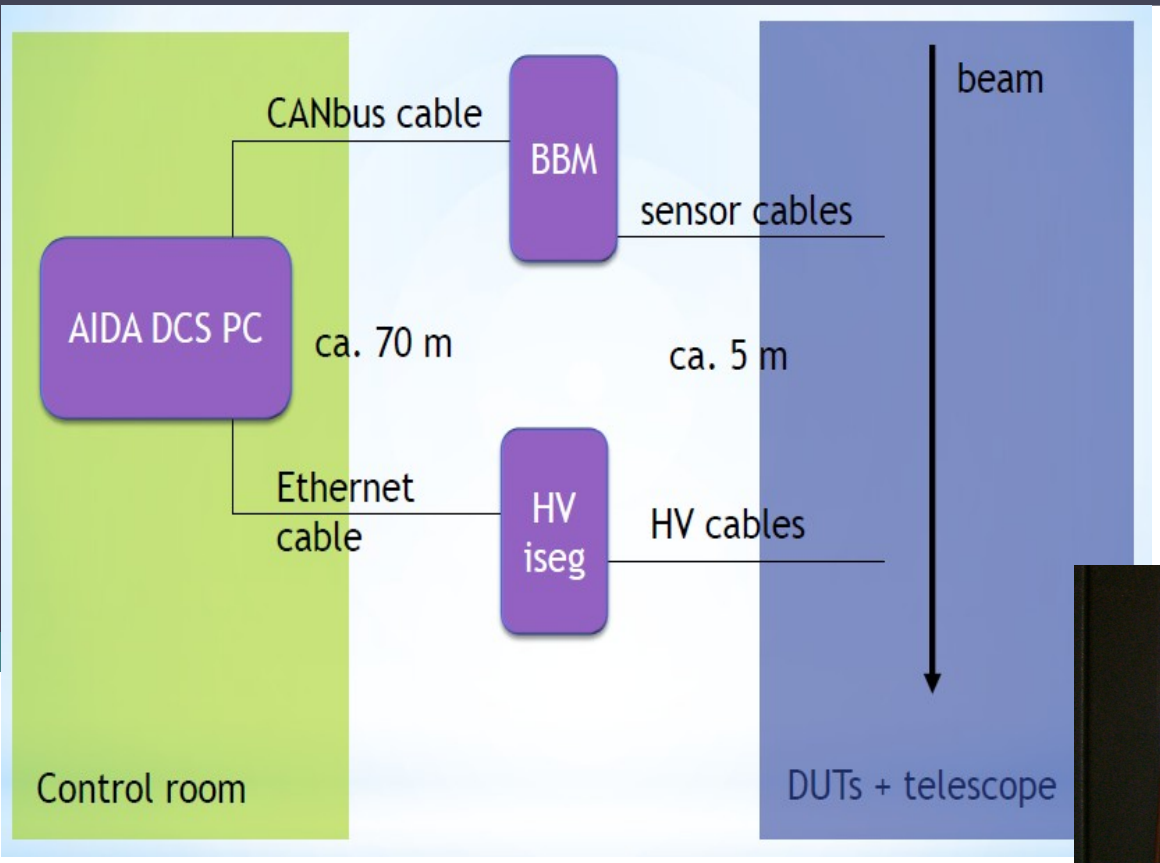
Free way towards grazing angle test beams (high interest from RD50, ATLAS)

Couple more items on the test beam infrastructure:

Common DCS (Power, Climate control)

CO2 Cooling plant

EUDET/AIDA pixel beam telescope, AIDA DCS system



AIDA DCS:

– HV ISEG crate

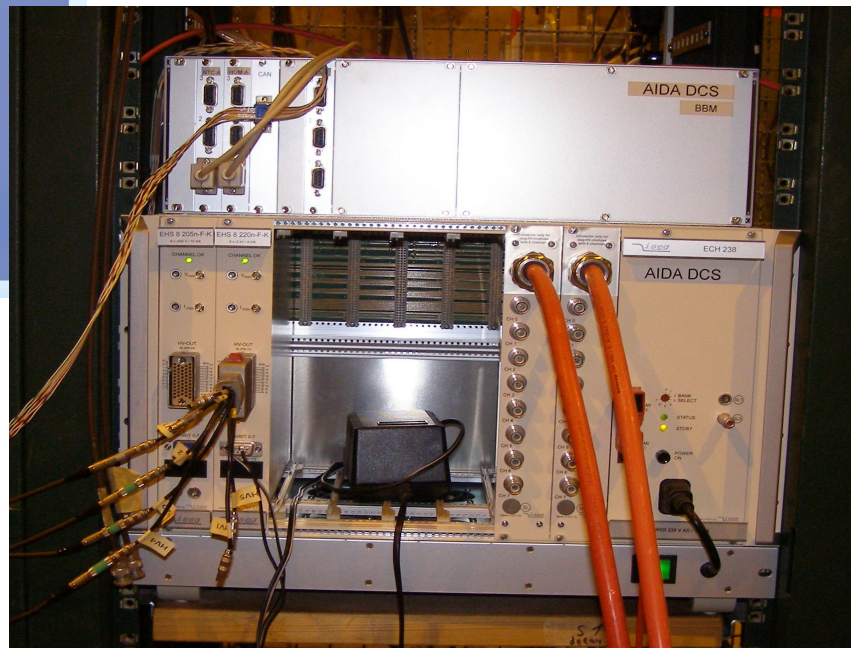
→ Software control

→ up to 16 HV channels

– BBM (by Wuppertal Uni)

→ temperature, humidity

readout and logging with 10 second intervals [tunable]



A copy of the system prepared for ATLAS with both HV and LV powering modules and DIM Software Module for Remote Control (operational at SLAC)

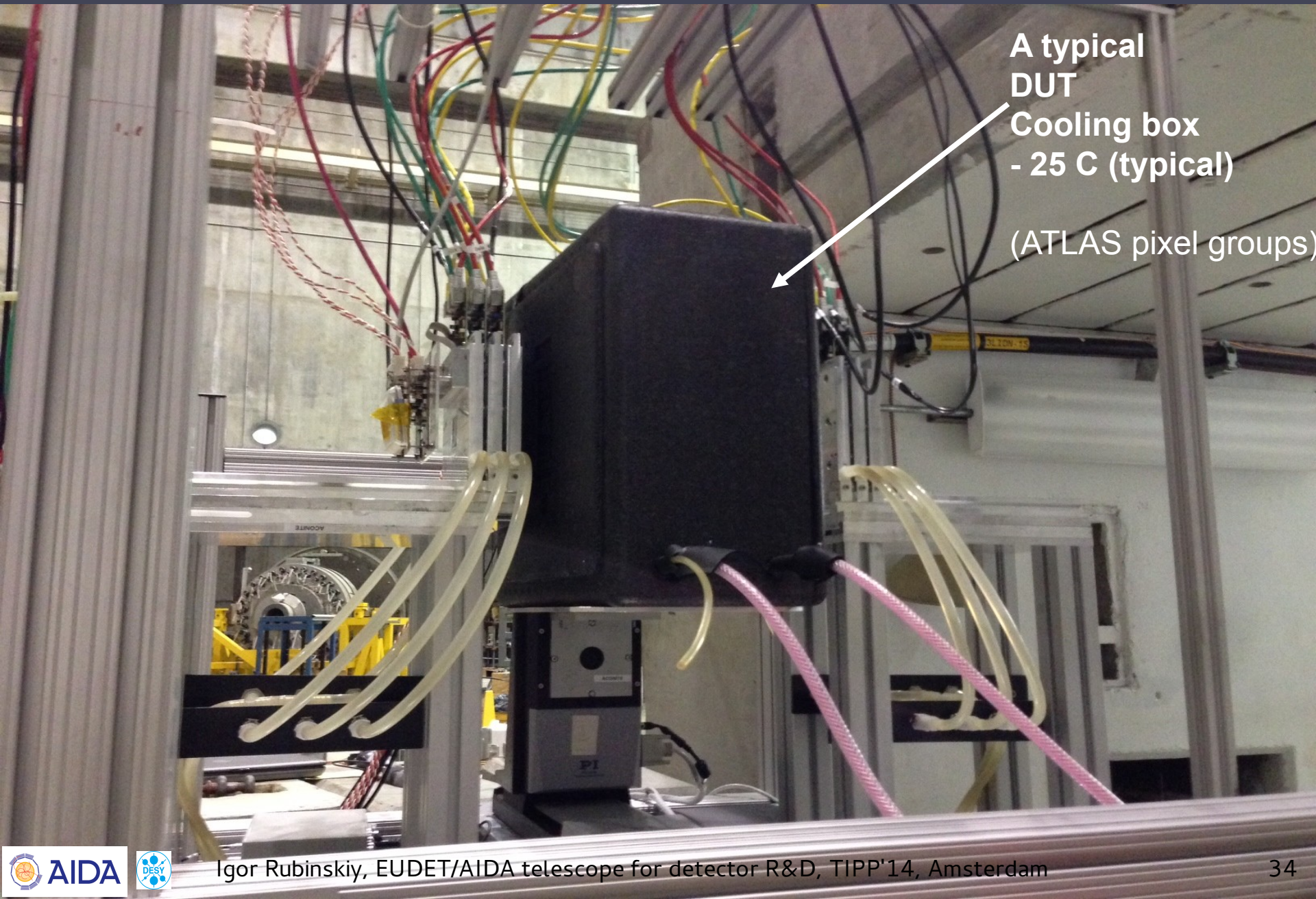
→ can control and readout via a script(!)

Couple more items on the test beam infrastructure:

Common DCS (Power, Climate control)

CO2 Cooling plant

AIDA cooling plant as test beam infrastructure



AIDA cooling plant as test beam infrastructure

Development goal:

Portable laboratory cooling unit

- Cooling power 100 to 250 W
- Temperature range -40 to +20 C
- Turn key
- Very simple to operate "fridge like"

Lead: PK, CERN, NIKHEF

New partners: The University Of Sheffield., INFN Istituto Nazionale di Fisica Nucleare SEZIONE DI MILANO, UNIVERSITY OF OXFORD, UNIVERSITY OF LIVERPOOL

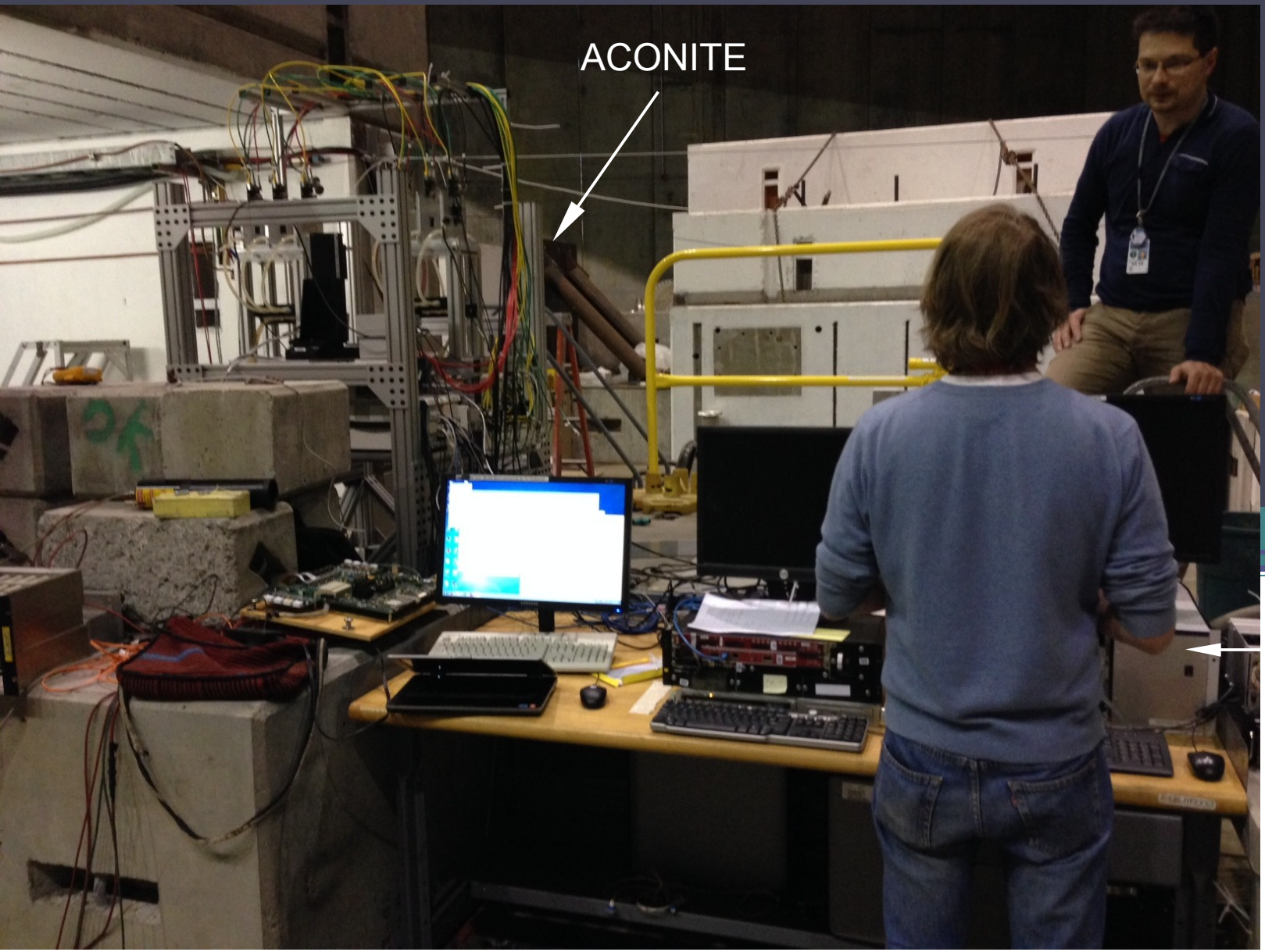
Traci overview (cooling with CO_2)

Traci-1 (ATLAS SR1 & R&D, LHCb R&D)
Traci-2 (Uni Ge, CMS R&D, KEK for ILC-TPC R&D) → Foto

Traci-3 (AIDA) – commissioning in the next months

- prototyping prototype, improved control system
- Improvements will be made towards serial production
- Focus on improved pumping concept (also smaller)

Setting up in the End Station A hall (test beam area)

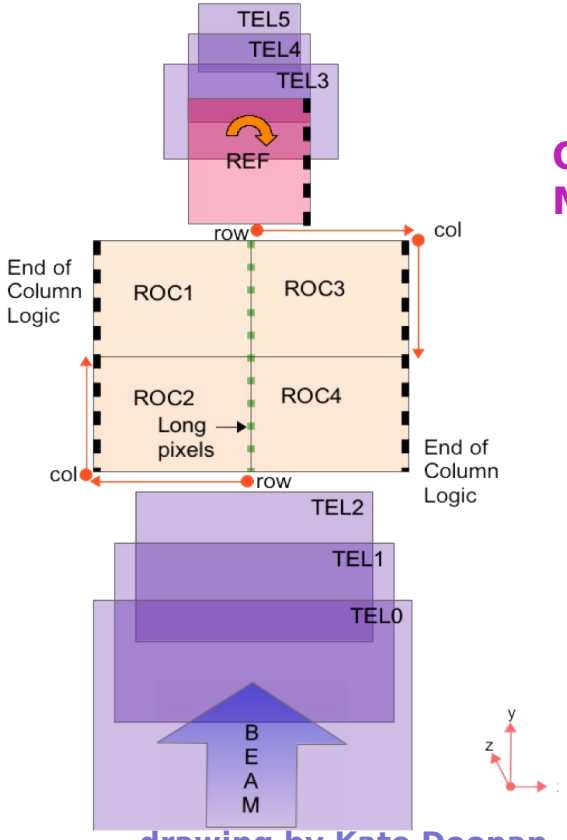


ACONITE copy of the AIDA DCS system:
– HV, LV
– temp,
– humidity

DESY testbeam

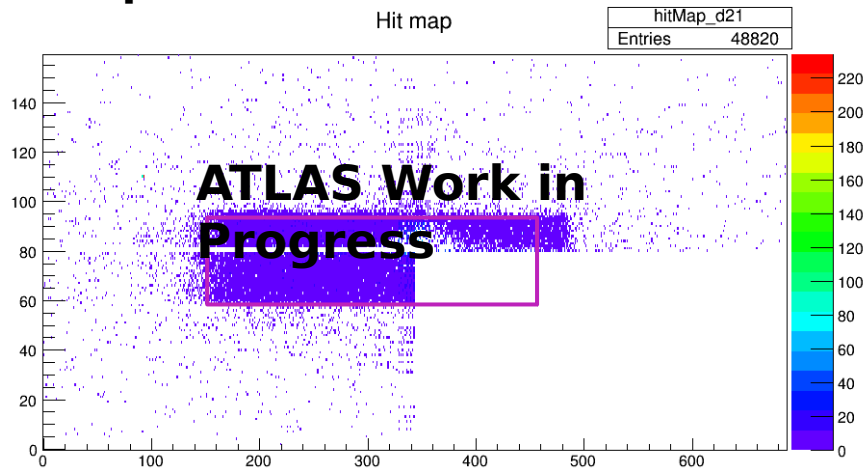
Glasgow
By
Andy Blue

Trigger is from a scintillator attached to 1st telescope plane
- **Only a fraction of coverage of 1 CMOS chip**

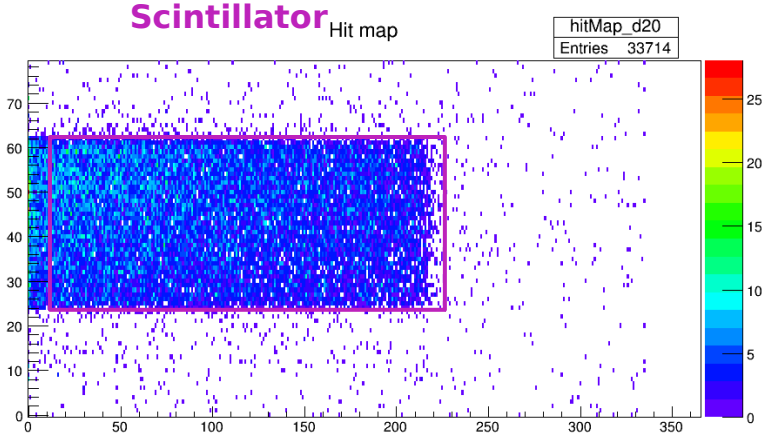


drawing by Kate Doonan

Quad Module



Scintillator



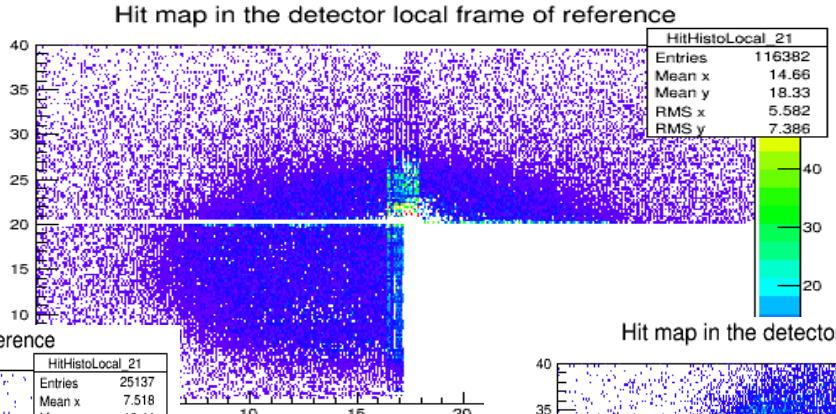
Reference sensor

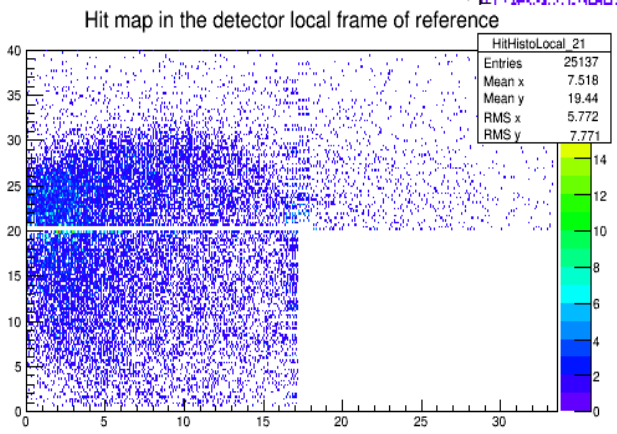
SLAC QuadFEI4 test beam

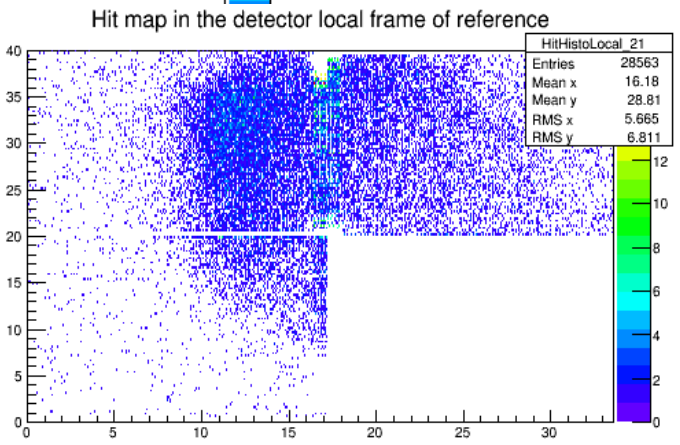
Glasgow
By
Andy Blue

3 different positions of interest

- **Use automated stage to change position of beam**
- **Beam size of ~2x2cm (Perfect size!)**







However, due to beam pulse structure – no clear telescope print is seen in the DUT alone plots