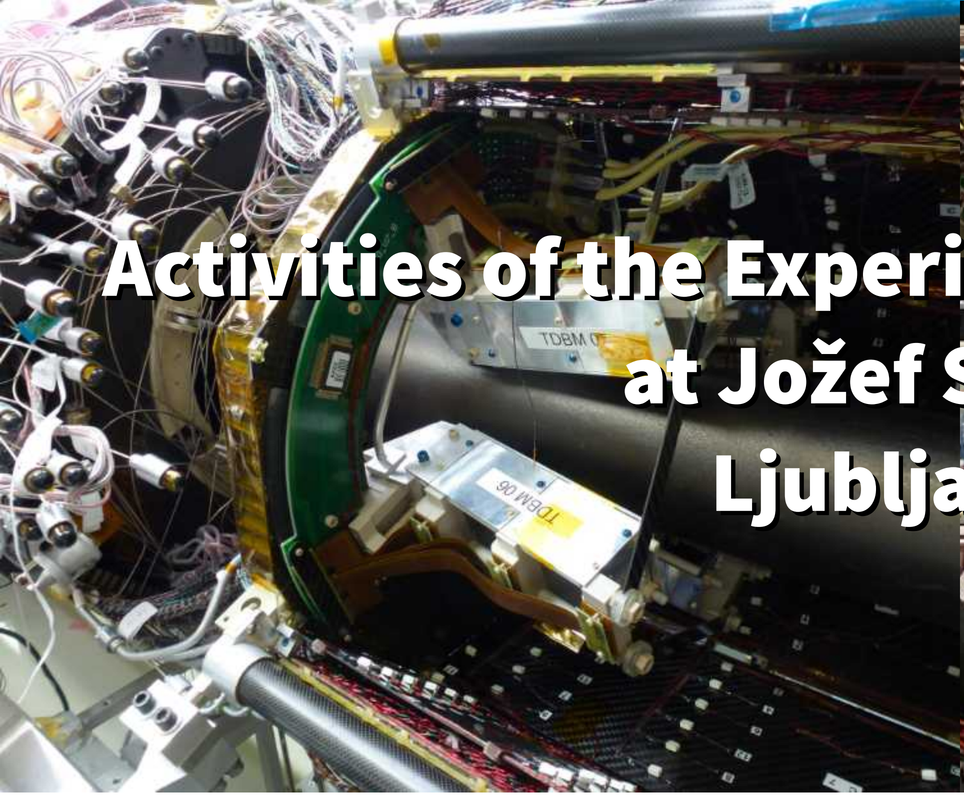
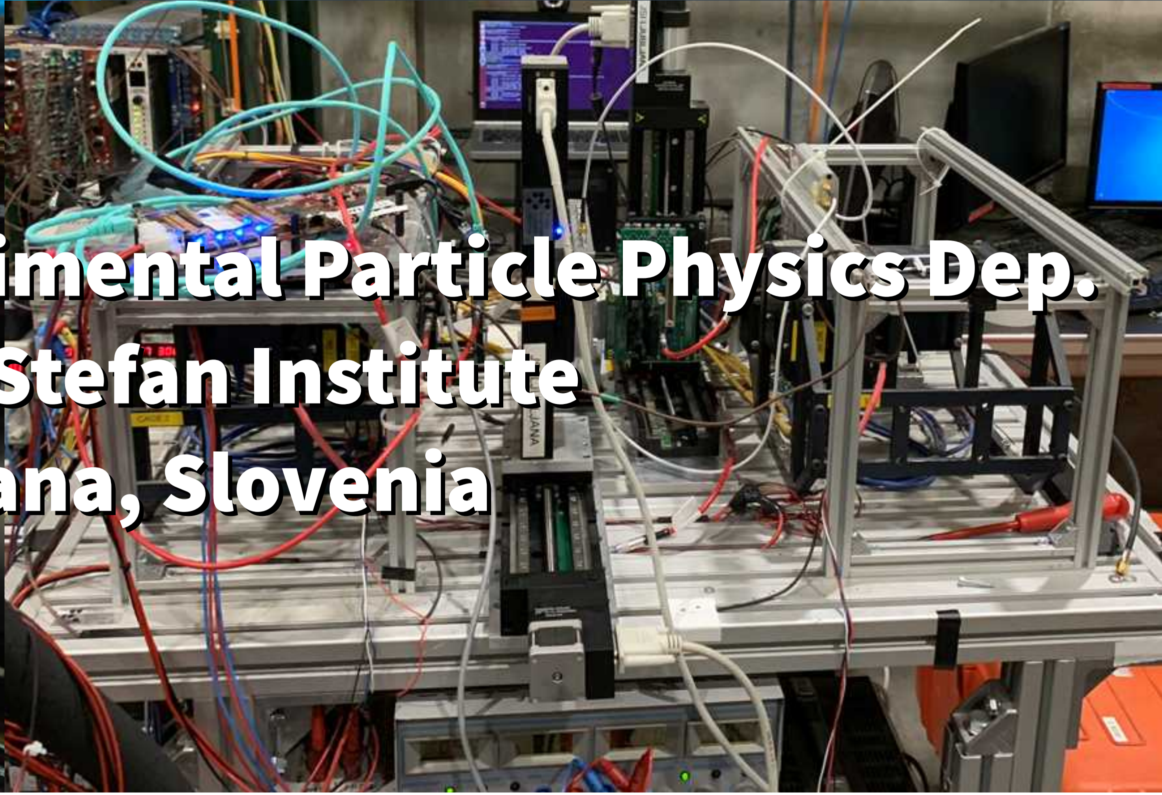




Activities of the Experimental Particle Physics Dep. at Jožef Stefan Institute Ljubljana, Slovenia

Marko Zavrtanik

J. Stefan Institute and University of Nova Gorica

UNIVERZA V NOVI GORICI
SCIENTIA 1995 VINCES

Outline

- **Jožef Stefan Institute**
- **Experimental particle physics**
  - Bell 2 group / photonic devices
  - Atlas group / Si detectors
  - Pierre Auger Observatory
  - Lab
- **Conclusions**

Ballpark

- **SLOVENIA in a nut shell**
  - Population 2 million
  - GDP 55 GUSD, 26 kUSD per capita
    - ~ order of magnitude smaller than Germany
    - Appropriate scaling is advised when talking about budgets
  - ~0,5 % GDP goes to basic research

Jozef Stefan Institute

- **Established in 1946**

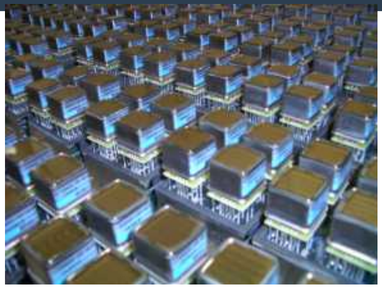
first by Slovenian Academy of Sciences and then Federal government ("peaceful" use of atomic energy)

- **The biggest research institute in Slovenia**
- **Fields:**
  - Physics
  - Biochemistry
  - Electronics and IT
  - Reactor techniques
- **1050 employees (510 PhD, 420 M. Sc/B. Sc.)**
- **Budget 55 M EUR (of which 15 M EUR market)**

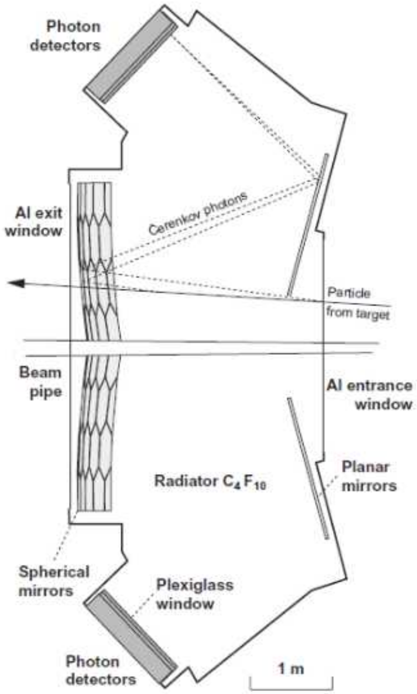
Experimental Particle Physics Department F-9

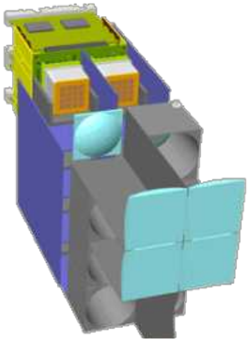
- Staff ~ 40
- Main activities:
  - Bell (KEK)
  - Atlas (CERN)
  - P. Auger observatory
  - Detector R&D

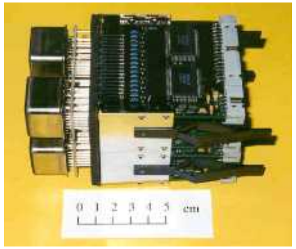
F9 – Bell 2 ARICH / Hera-B



- First major hardware project of Bell 2 group was Hera-B rich





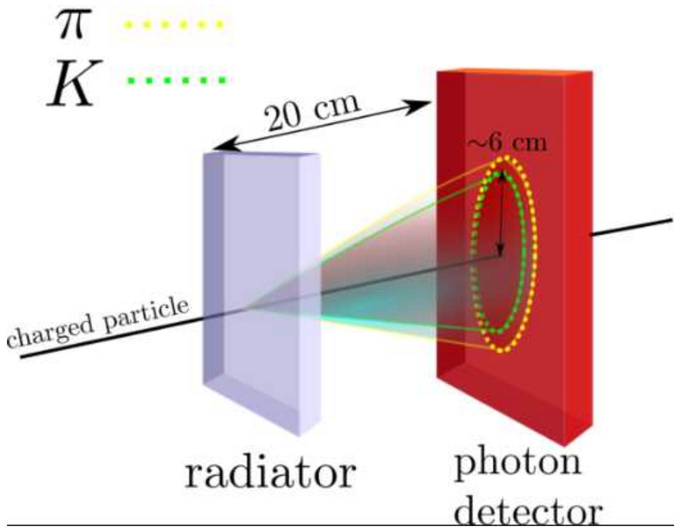


- Main challenge for photodetectors –high occupancy
  ≈5 MHz/cm^2
- spherical + planar mirrors – move photon detector
  away from magnet and particle tracs
- optical demagnification – telescope
- use of multi-anode PMTs
- first large deployment of multi-anode PMTs
  produced by Hamamatsu
- characterization of MA-PMTs: single photon detection
  efficiency, aging tests, base board development ...

F9 – Bell 2 ARICH

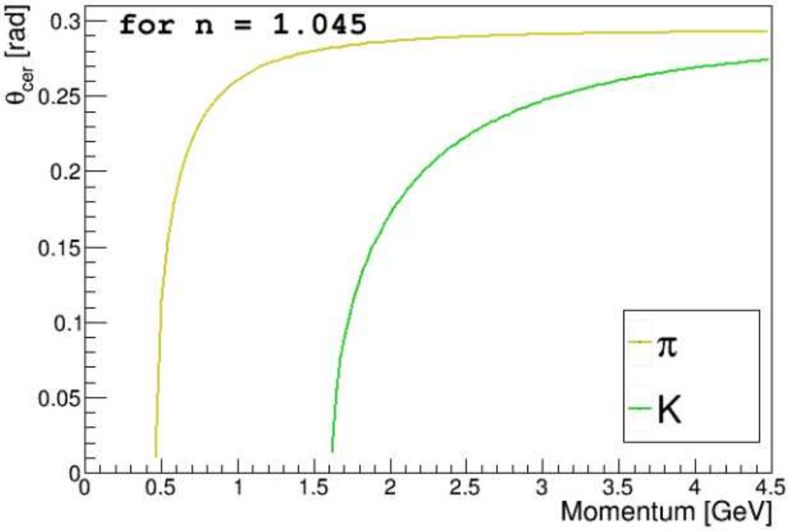
Endcap Aerogel RICH detector for particle ID

It's main objective is to provide good separation between kaons and pions

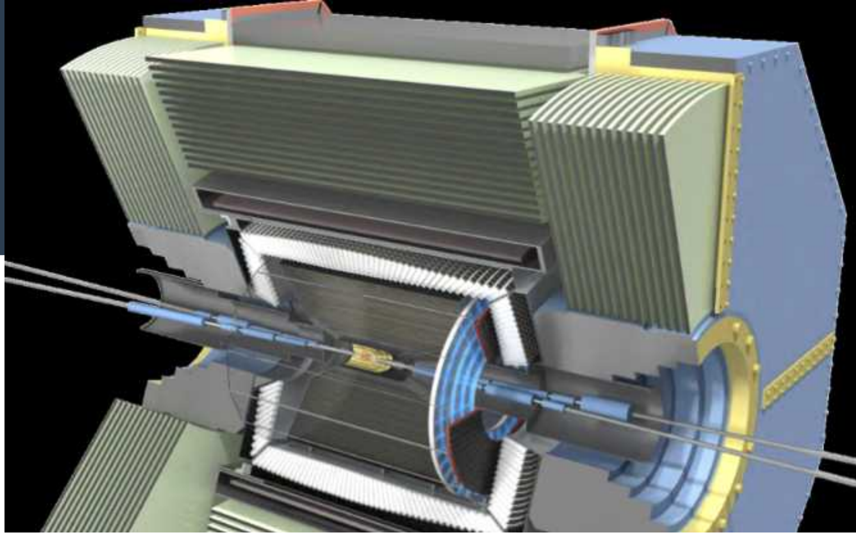


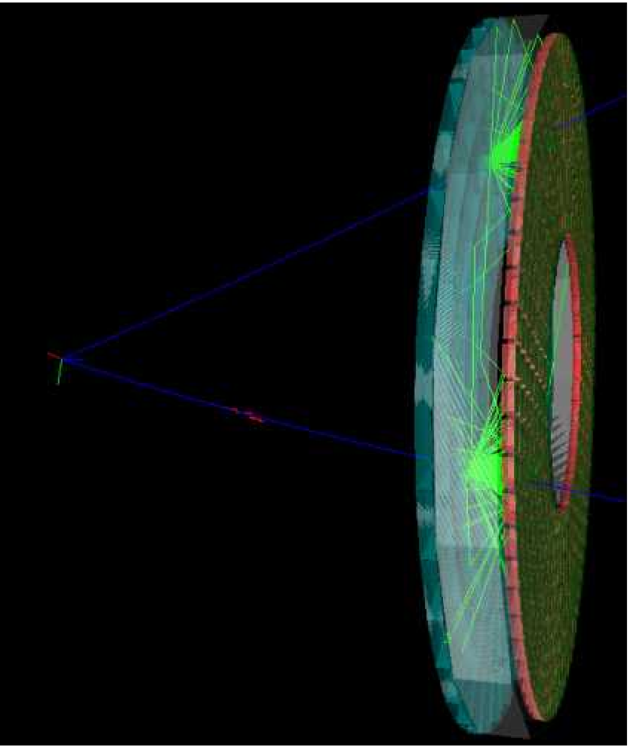
$$\cos \Theta = 1/n\beta$$

$$\beta = v_p/c$$

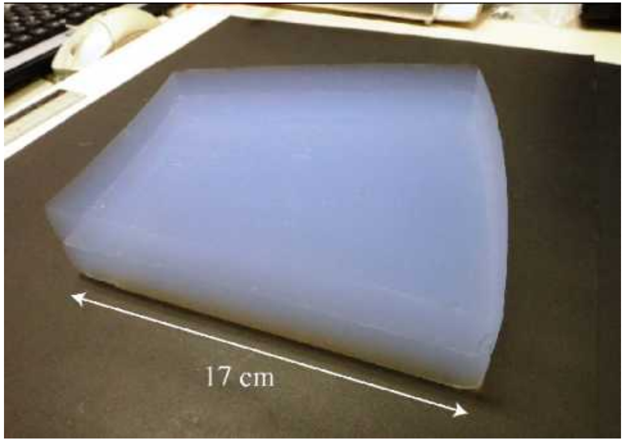


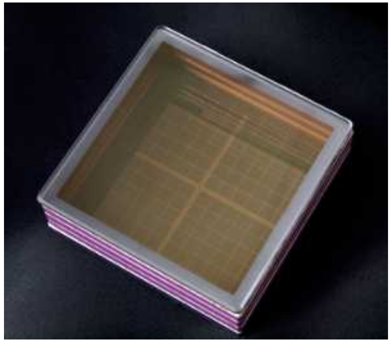
F9 – Bell 2 ARICH





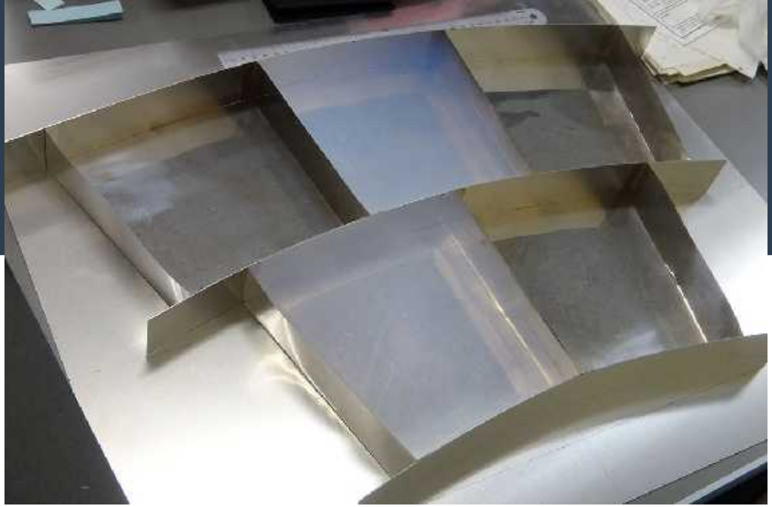
Radiator: double layer aerogel (n_1=1.045, n_2=1.055)





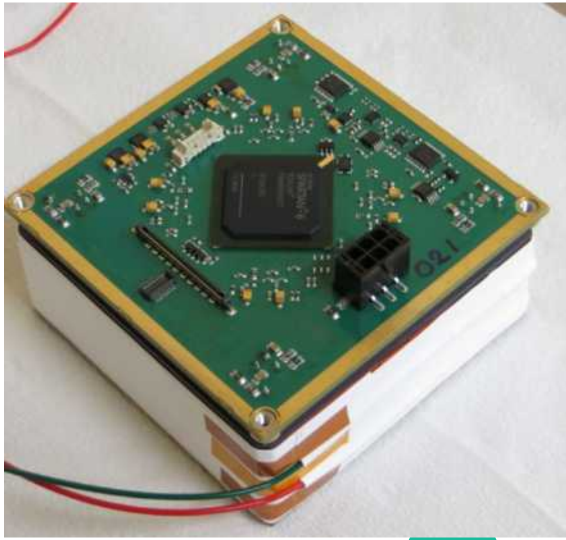
Photodetector: HAPD

F9 – Bell 2 ARICH



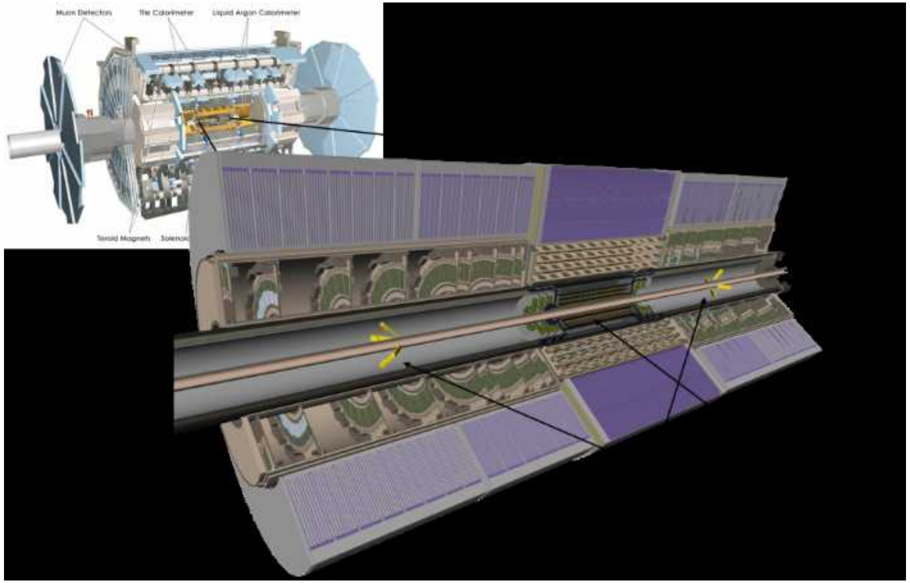
In total ARICH consists of 420 HAPD modules arranged in seven concentric rings (r_in = 56cm, r_out = 114 cm) and of 2 × 124 aerogel tiles of wedge shape.

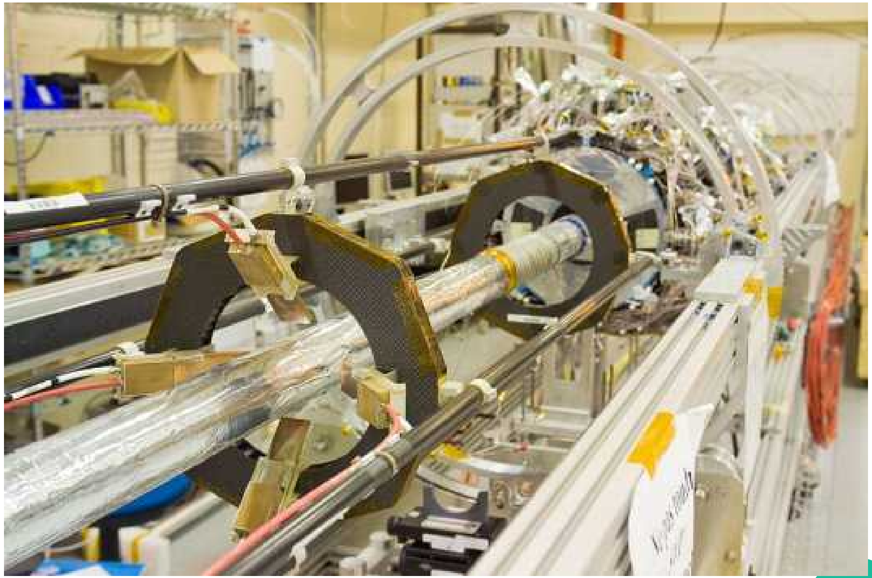
- ARICH front-end board was design @JSI and produced at local company KENS
- radiation hardness of the board was tested at the JSI reactor including the tests of SEU in FPGA



F9 – ATLAS Hardware

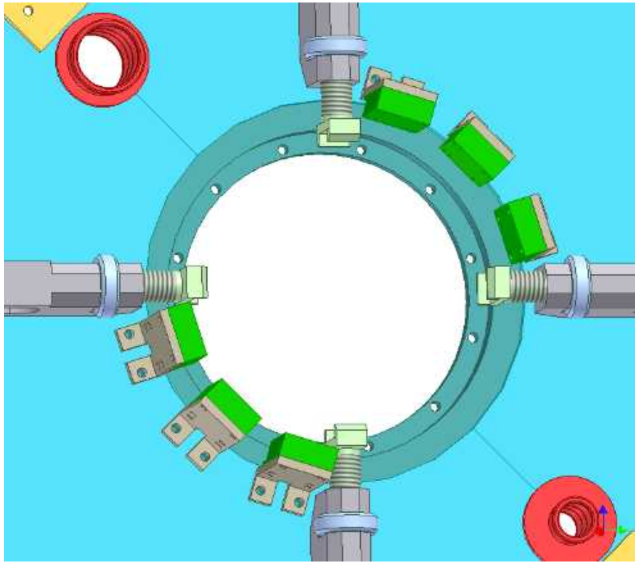
BCM (Beam Condition Monitor) : Bunch by bunch safety device with MIP sensitivity and sub-ns timing. Installed in ID volume at r=55 mm and z=1.9 m. Used for beam diagnostics. Can abort the beam upon anomalous conditions. Was used as primary on-line luminometer during Run 1. *Lead institute for production, commissioning and operation.*

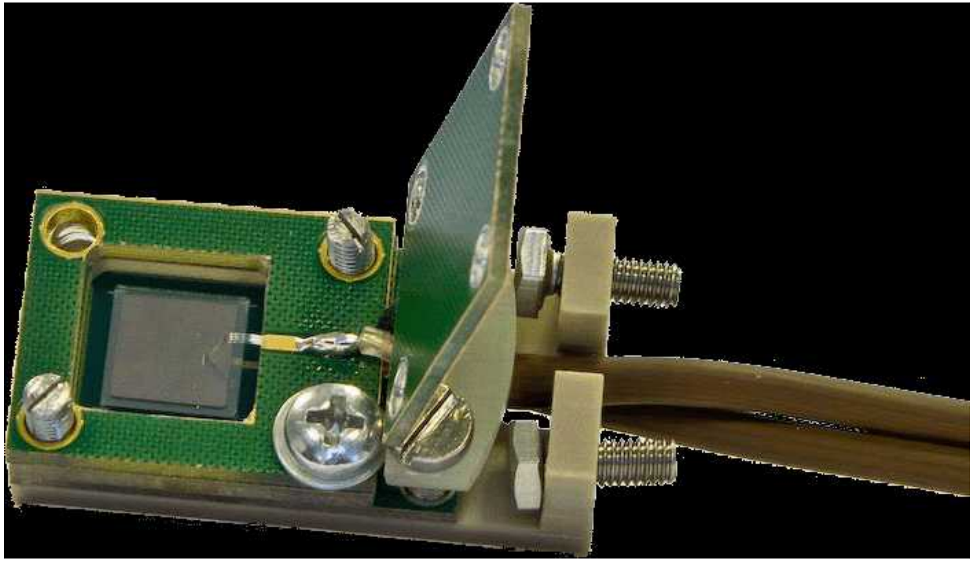




F9 – ATLAS Hardware

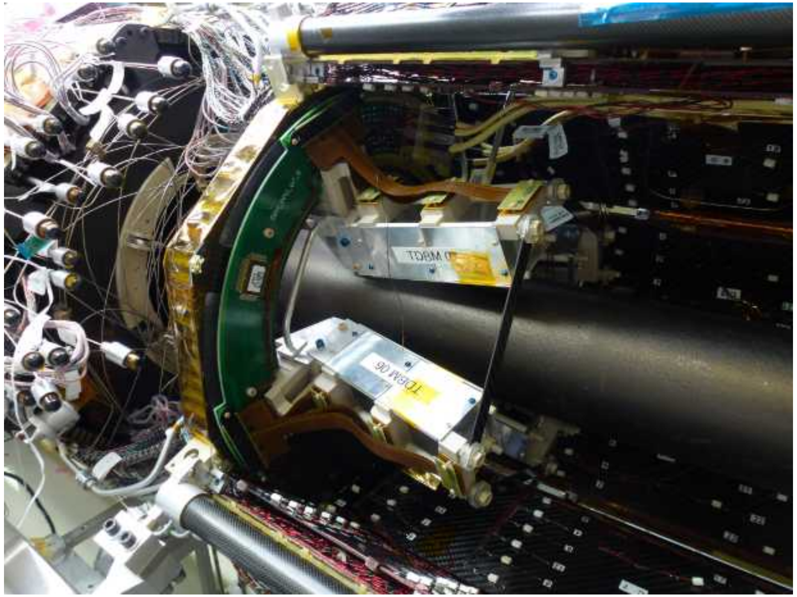
BLM (Beam Loss Monitor): LHC machine beam protection system with 6 diamond sensors replacing ionization chambers. Installed around the beam pipe at ID end plate (z~3450mm, r=65mm). Integrates ionization current for 40 us (and repetitive factors of 2 longer). Connected to the LHC beam abort system. *Production, commissioning and operation in collaboration with CERN-BE (R/O electronics) and OSU (sensor supply)*.

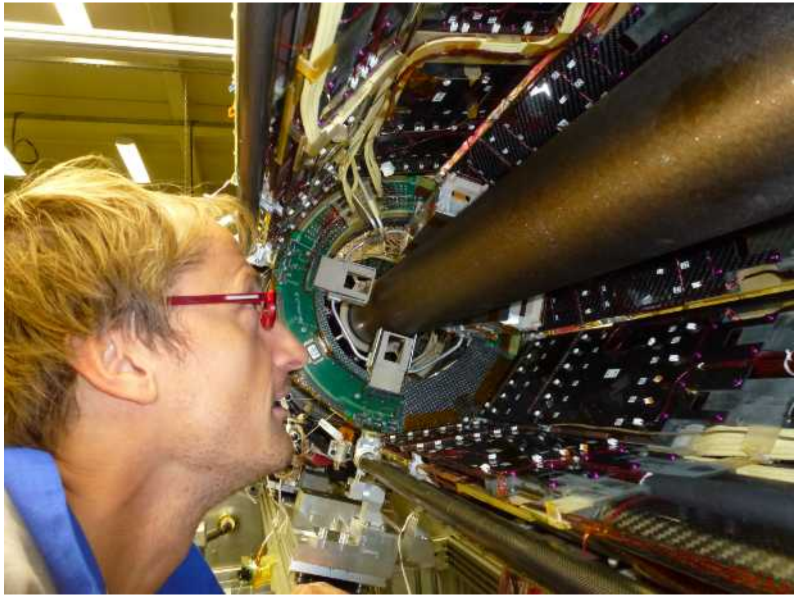




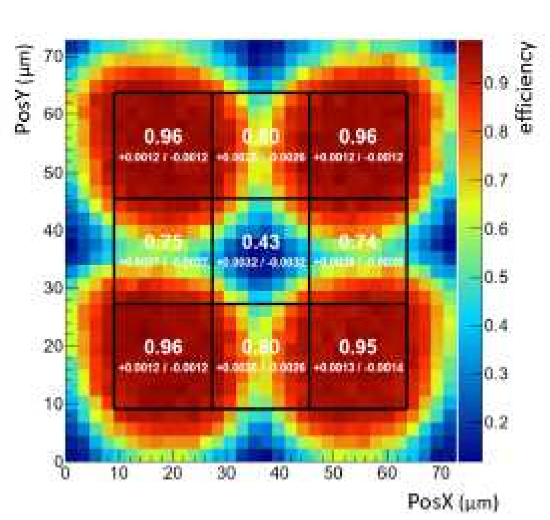
F9 – ATLAS Hardware

DBM (Diamond Beam Monitor): Luminosity telescopes with pixelated diamond sensors using single FE-I4 pixel chip. Installed with IBL. Construction deficiencies rendered several modules non-operational. Foreseen usage as bunch-by-bunch luminometer with single planes and adaptive fiducial region. ***Production,commissioning and operation in collaboration with Bonn, CERN, OSU and Toronto.***





F9 – ATLAS Hardware



Specific development and testing of sub-system components SCT:

- **irradiation studies of SCT front end readout chips (ABCD3T),**
- **radiation quality assurance during ABCD3T chip production,**

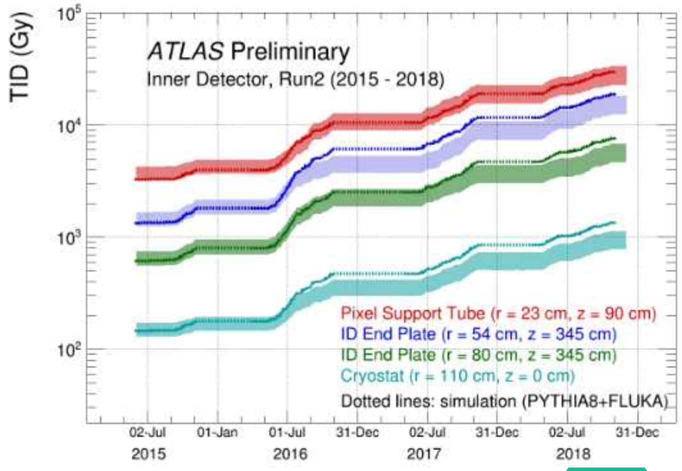
Radiation hardness study of n-p silicon detectors:

- **irradiation studies and QA for ITk strip sensors for ATLAS upgrades,**
- **charge collection studies of CMOS pixel detectors for ATLAS upgrade.**

Radiation monitors:

- Radiation monitoring is useful to cross check radiation background simulation and to understand radiation damage in sensors and readout electronics.

  Development, production installation and maintenance of online radiation monitoring system in ATLAS.



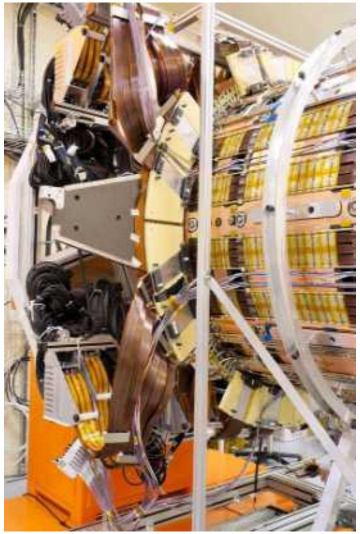
F9 – ATLAS Hardware

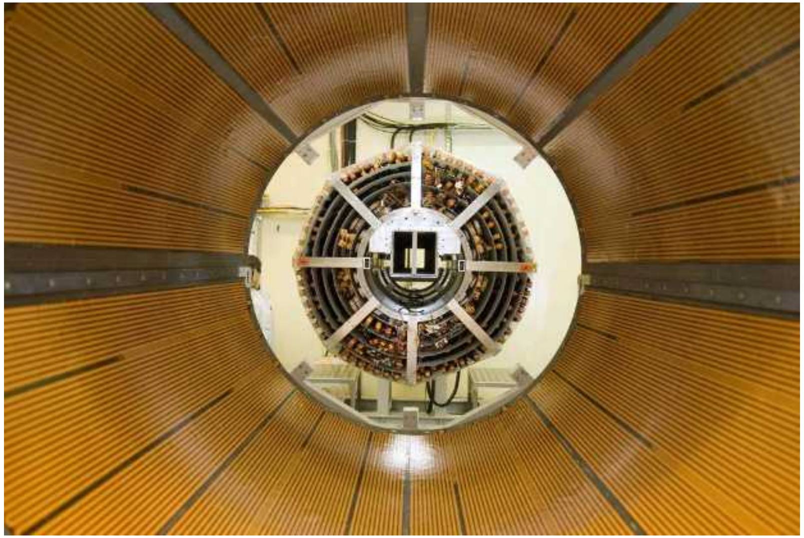
- Low mass tapes for SCT: development of industrial process in collaboration with ELGOLINE.

  About 4000 flexible tapes with a length up to 4 meters. 2 layers, Al and Cu conductors, radiation hard,

- Flexible heaters for ATLAS, voltage controllers, cable testers…

Successful collaboration with the Slovenian industry!





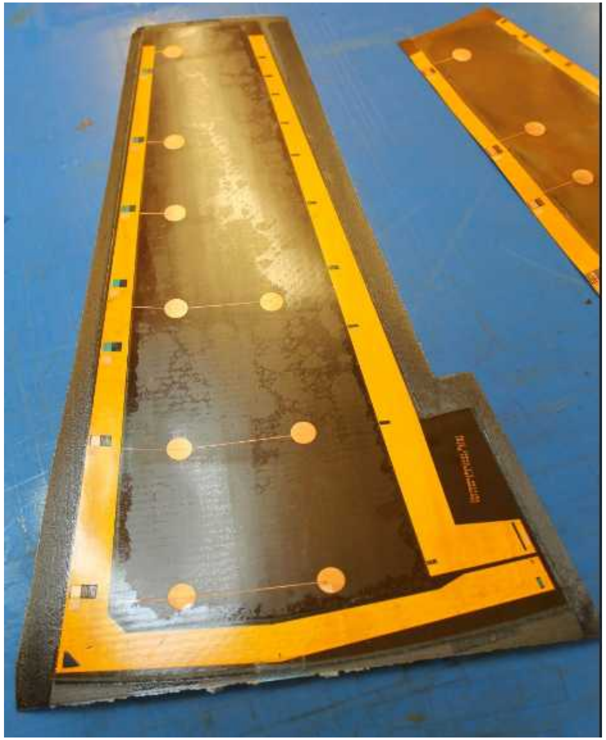
F9 – ATLAS Hardware - upgrade

- **BCM prime: Fast beam monitoring device (sub-ns timing) with two monitoring levels: MIP and “very large” signals. Diamond sensors and custom CMOS FE tailored to the two signal levels. Installed in inner end-cap pixels of ITk. MIP can be used for luminosity and beam background monitoring, “very large” aims at beam anomalies dangerous for ATLAS. Slow, integrating BLM system integrated in installation package.**

- **Irradiation tests: Charge collection studies of ATLASI ITk strip sensors, irradiations of sensors, electronics and materials at the TRIGA research reactor.**

- **HV CMOS: Studies (and explanation of radiation dependence of) charge collection mechanisms in various HV-CMOS prototypes, Edge-TCT measurements, test beam with Ljubljana beam telescope.**

- **Flexible circuits for endcap ITk: flexible multilayer circuits assembled with carbon corres and used as local support for silicon modules, distribution of electrical signals, control levels at transmission of digital signals with frequencies up to 650 MHz**



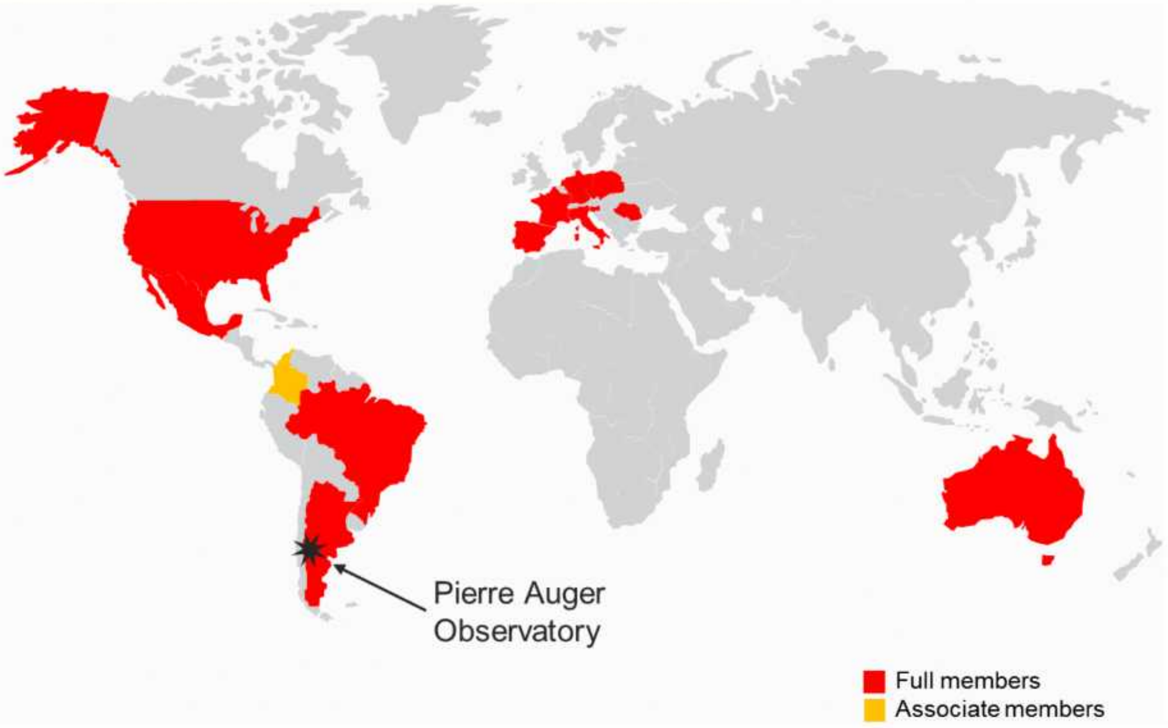
F9 – Pierre Auger observatory *(trip to astroparticle physics)*

PIERRE AUGER OBSERVATORY

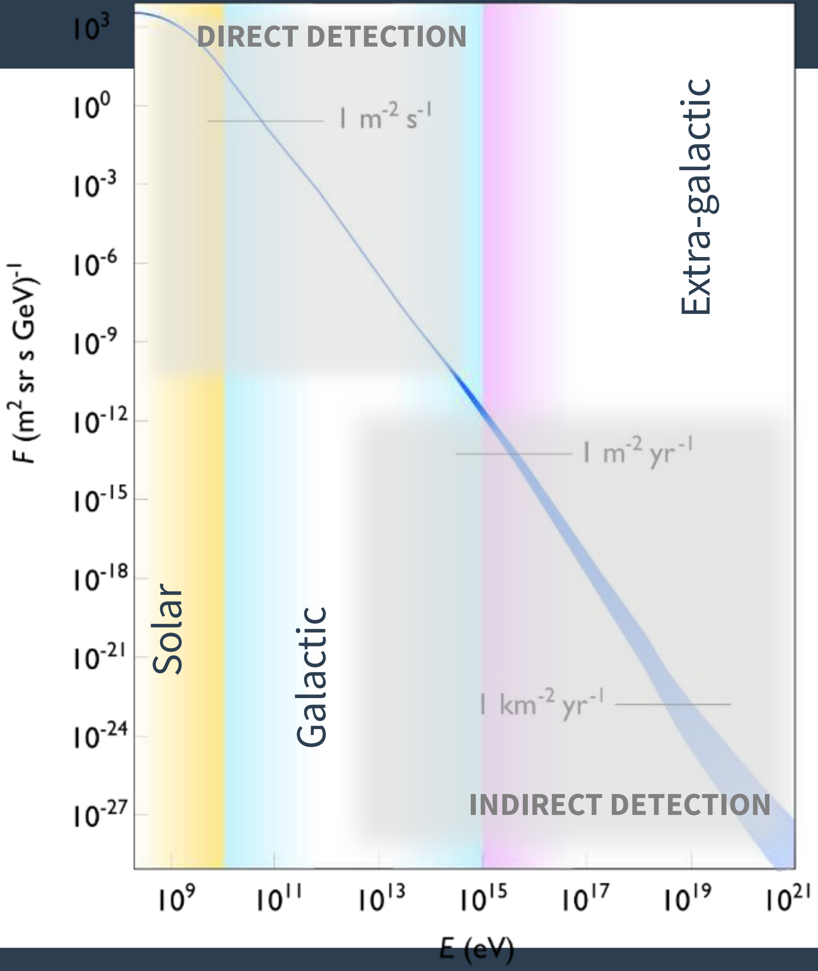
About 400 members from 90 institutions in 16 countries

Argentina
Australia
Brasil
Colombia*
Czech Republic
France
Germany
Italy
Mexico
Netherlands
Poland
Portugal
Romania
Slovenia
Spain
USA

*associated



F9 – Pierre Auger observatory *(trip to astroparticle physics)*



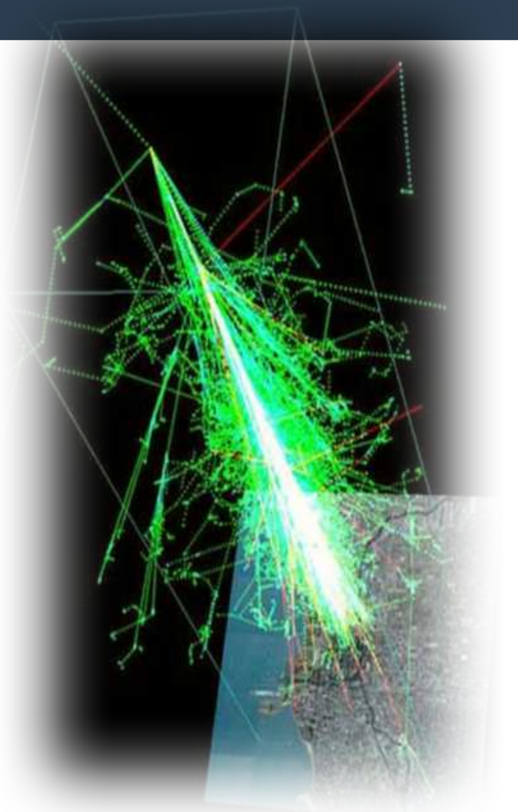
UHECR >10^{18} eV

EECR > 5×10^{19} eV

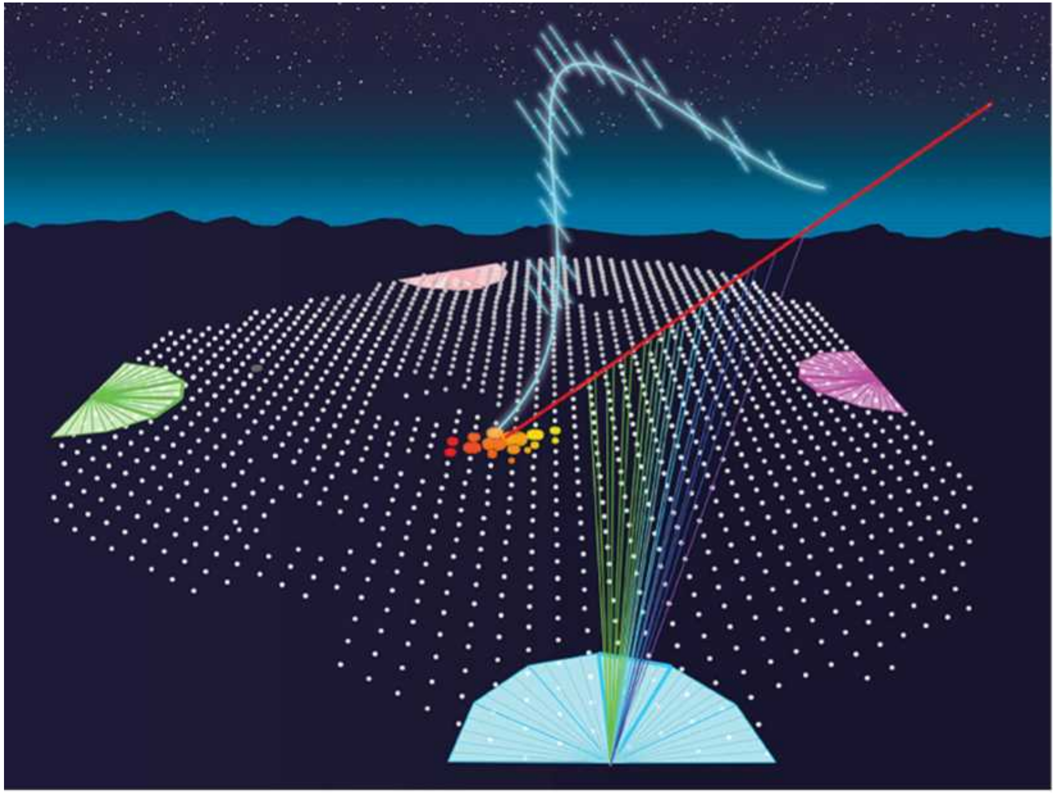
Flux to low for direct detection.

⇩

Atmosphere as calorimetric medium.



F9 – Pierre Auger observatory – hybrid design



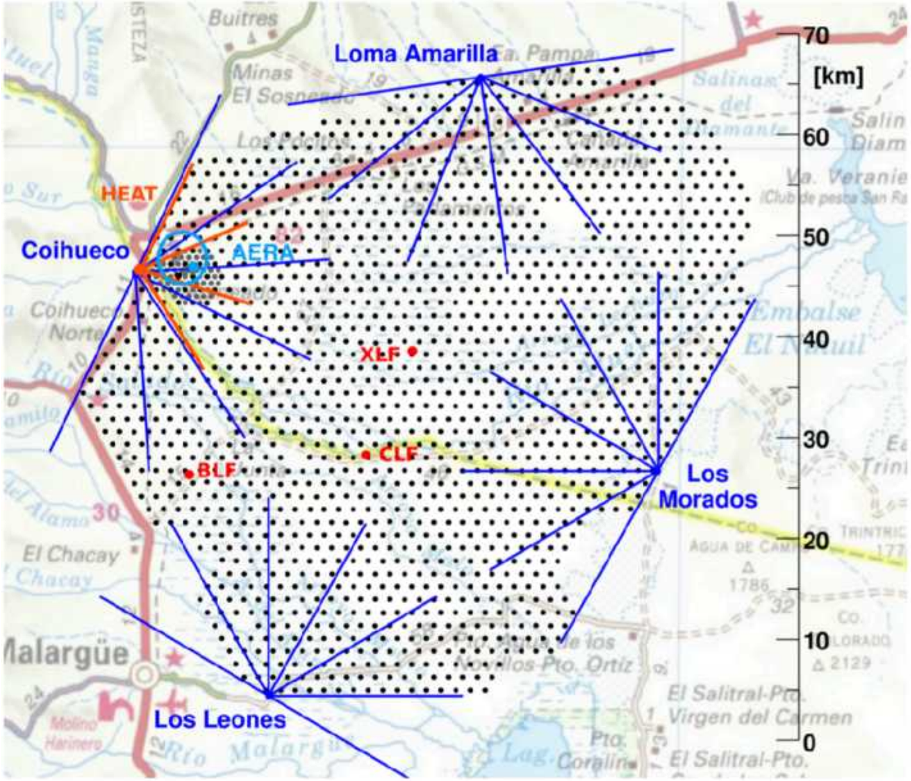
Ground detector

Number of particles that hit ground detector
↓
Shower profile at the ground level

Fluorescence detector

Fluorescence light along the shower path
↓
Longitudinal shower profile

F9 – Pierre Auger observatory – hybrid design



Hybrid design

- **Ground detector**

  Array of 1660 Čerenkov detectors, triangular mesh, distance 1.5 km, area 3000 km^2, sensitivity>2x10^{18} eV)

  "Infill" array (71 detectors, distance 750 m, area 23.5 km2, sensitivity >2x10^{17} eV)

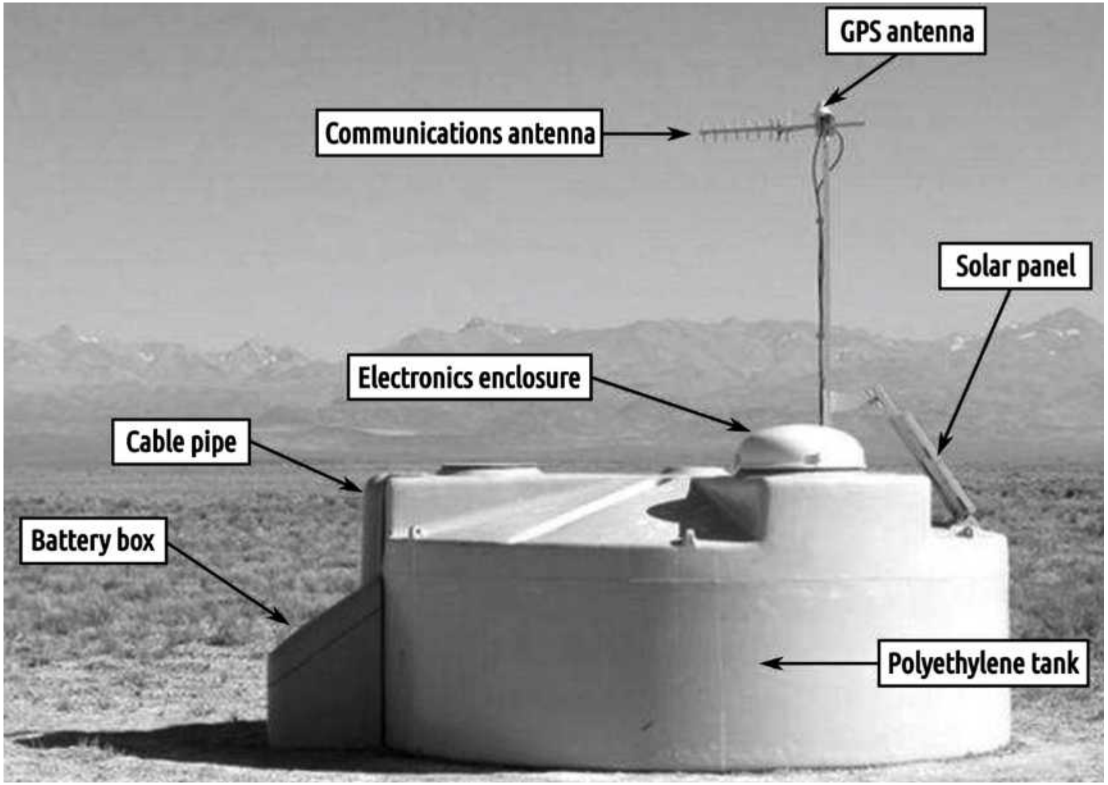
- **Fluorescence detector**

  24 telescopes in 4 buildings (FOV 30^o)
  + 3 telescopes in HEAT (FOV 30^o - 60^o)

- **Radio detectors (AERA)**

  153 antenas, area 17km^2

F9 – Pierre Auger observatory – ground detector



Detection medium:

height 1.6 m, diameter 3.6 m , 12 t deionised water

Power:

Solar cells 55W, 12V 105Ah bateries

Detection:

3 x 9 inch Photonis XP1805 PM-s, ADC Analog Device AD9203 10bit 100MHz flash ADC

Timing (time stamp):

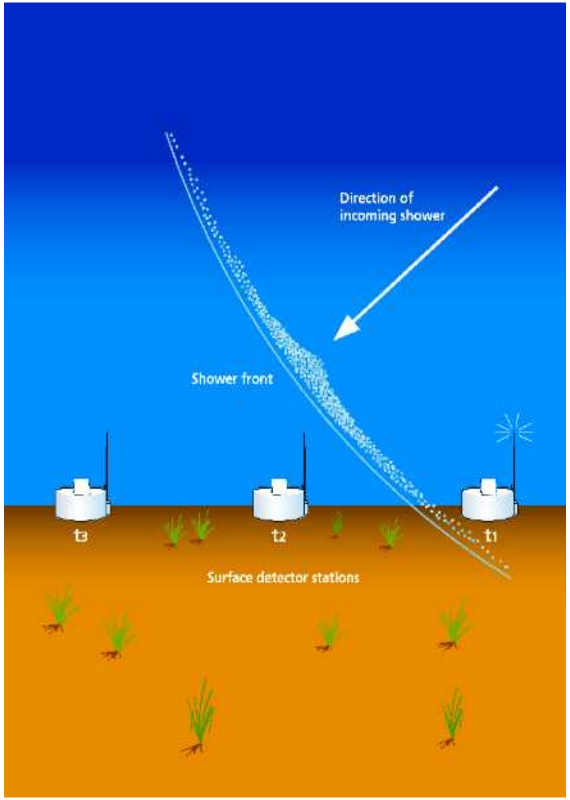
Motorola Oncore UT+ GPS deferentially corrected, PPS, 100MHz clock (10 ns RMS)

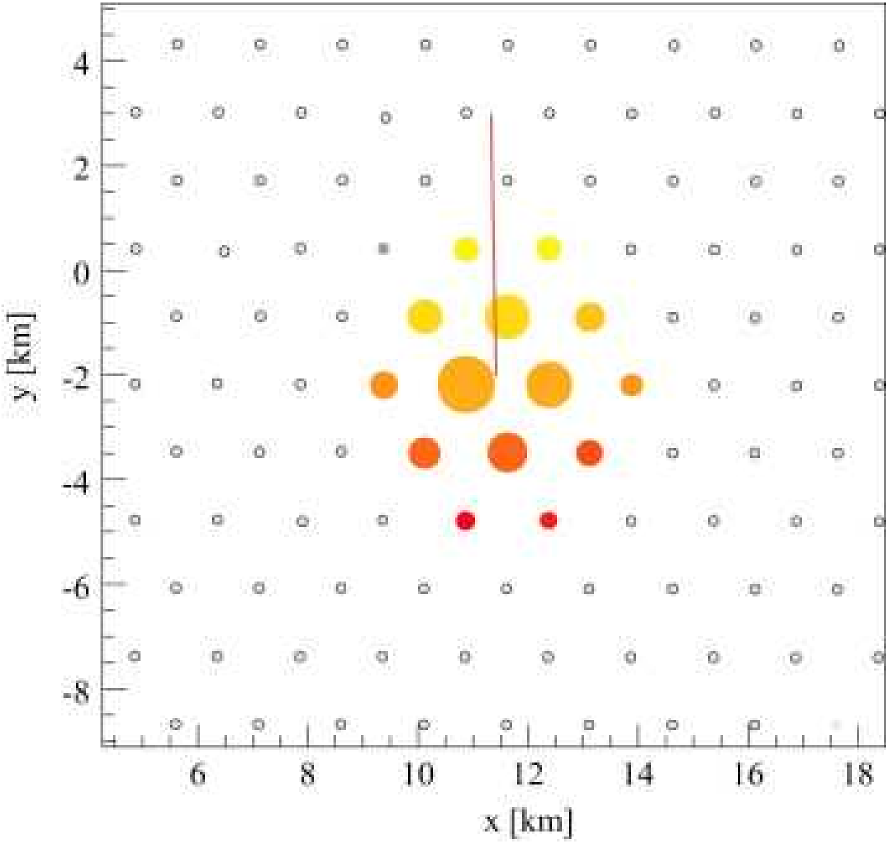
Coms:

Extended WLAN 902-928 MHz ISM band (TDMA)

F9 – Pierre Auger – ground detector

F9 – Pierre Auger observatory – ground detector





E ~ 10^{20} eV

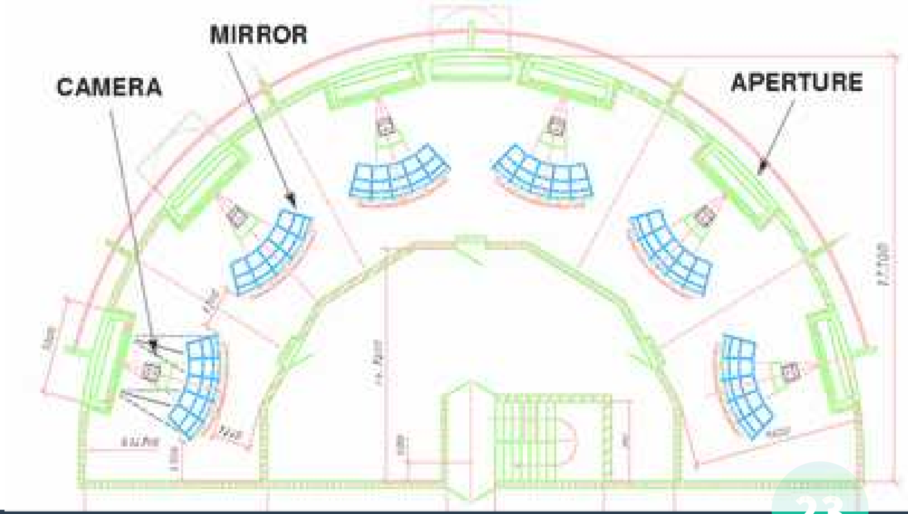
Size → measured signal→ **Energy**

Colour → Timming → **Direction**

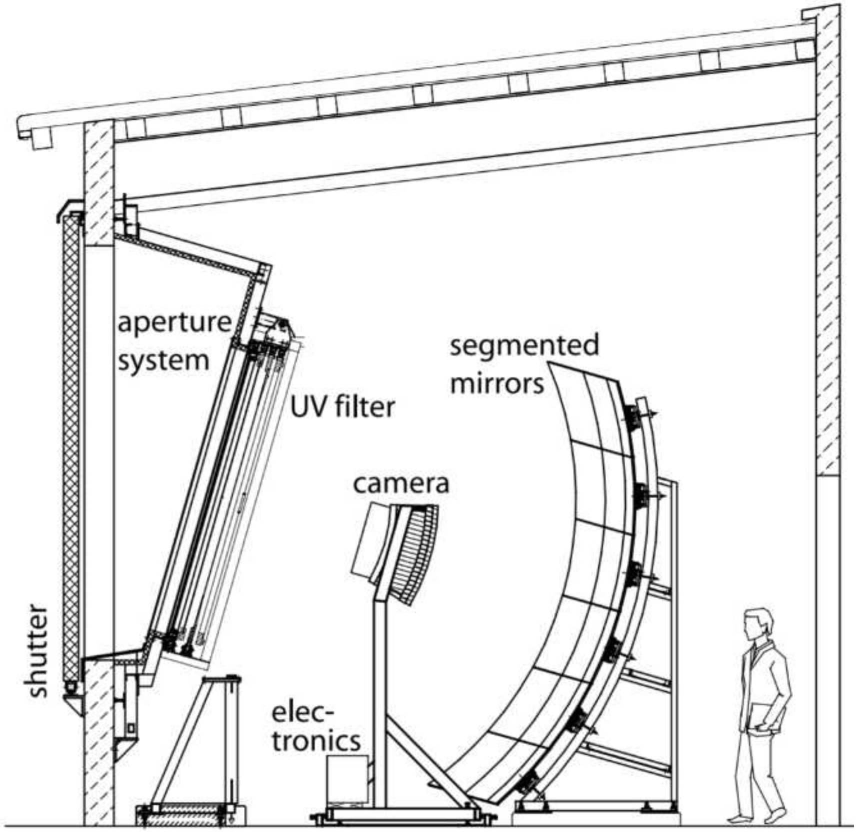
(yelow → fast, red→ slow)

F9 – Pierre Auger observatory – fluorescence detector

Each fluorescence detector (4) has 6 sectors. Each sector contains a telescope/camera with (30x30)^{o}FOW



F9 – Pierre Auger – fluorescence detector

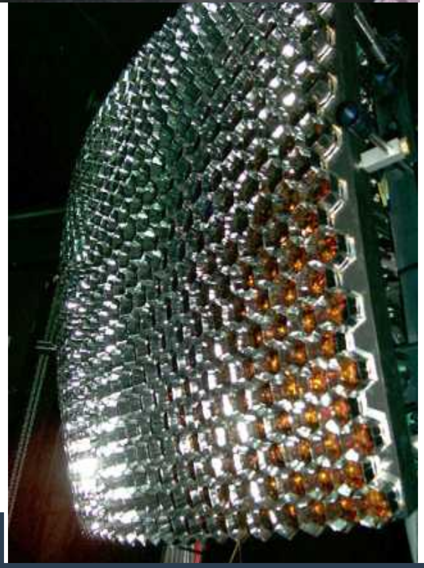


Reflector:

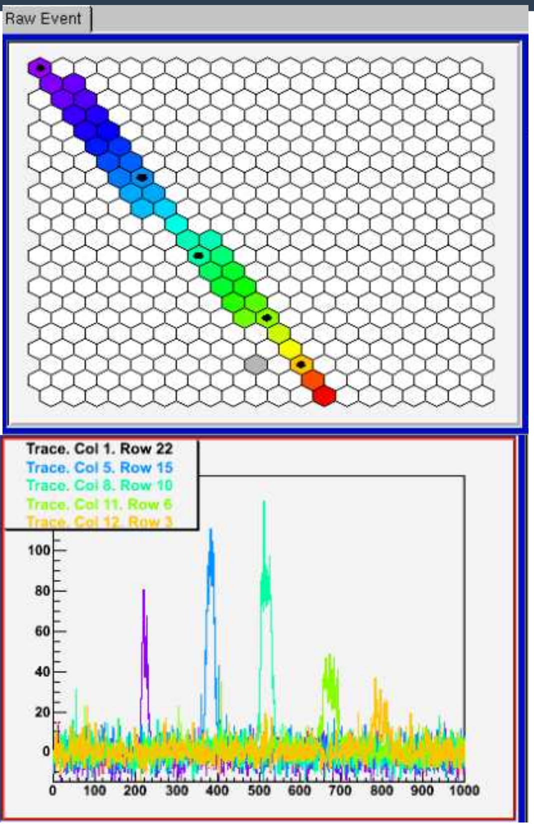
Segmented spherical mirror
r=3.4 m, area 13 m^2

Camera:

440 hex PMT-s
Photonis XP3062
r=1.7m

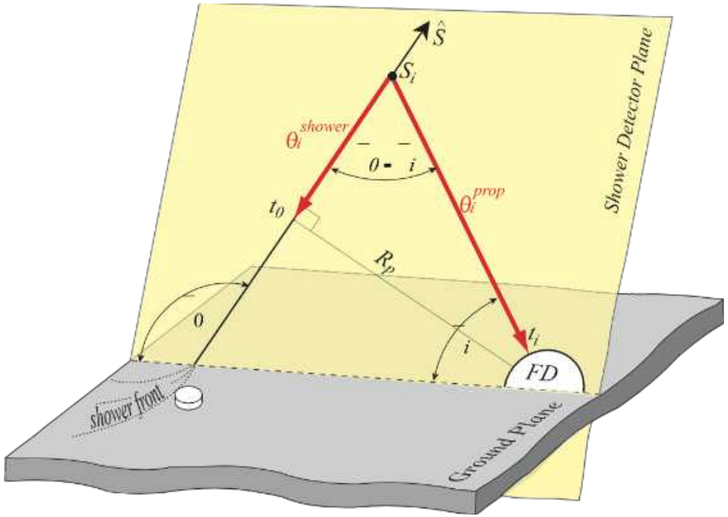


F9 – Pierre Auger observatory – fluorescence detector



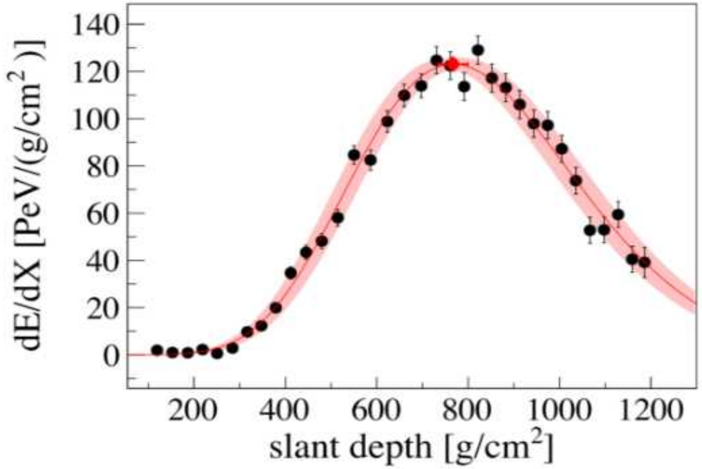
DIRECTION

Path geometry from detection pattern and timing.



COMPOSITION

Atmospheric depth at wich shower reaches maximum X_{max}



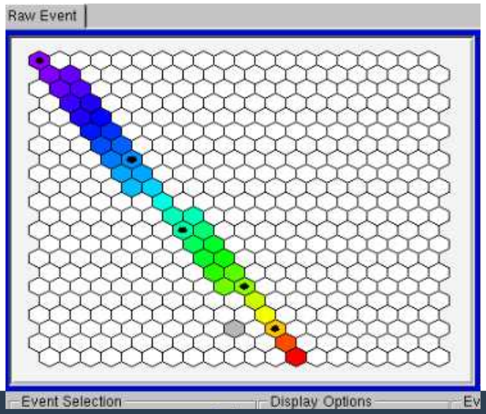
F9 – Pierre Auger observatory – fluorescence detector

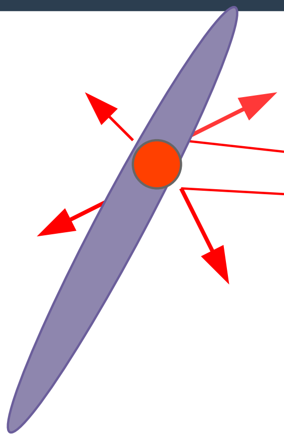
ENERGY

$$E_{FD} = \int_0^{\infty} dE/dX\, dX$$

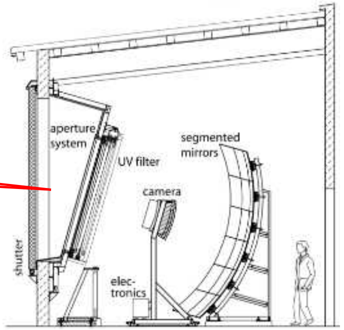
$$dE/dx \propto N_{ph}$$

Proportional to the number of detected photons.
Resolution 10% @ 10^{19} eV





Atmospheric transmisiom



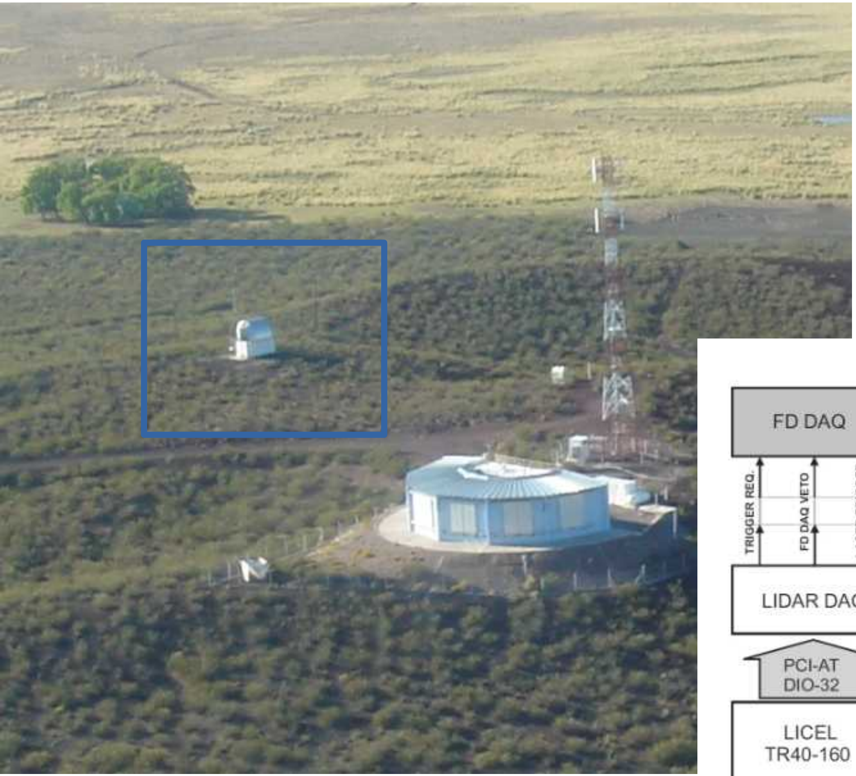
$N_{em} \rightarrow N_{ph}$

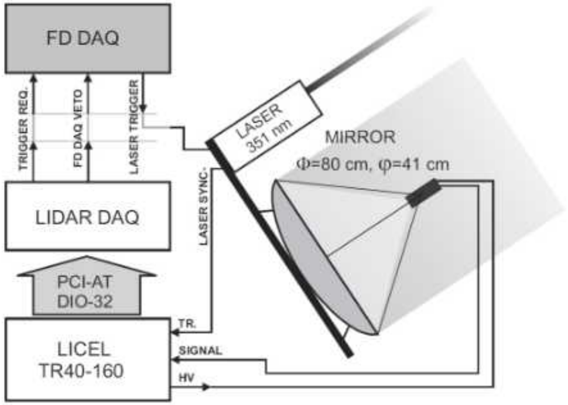
$N_{em}(x) \propto N_{ph}\, r^2(x)/T(x)$

T(x) – atmospheric transmision

Lidar stations!!

F9 – Pierre Auger – Lidar

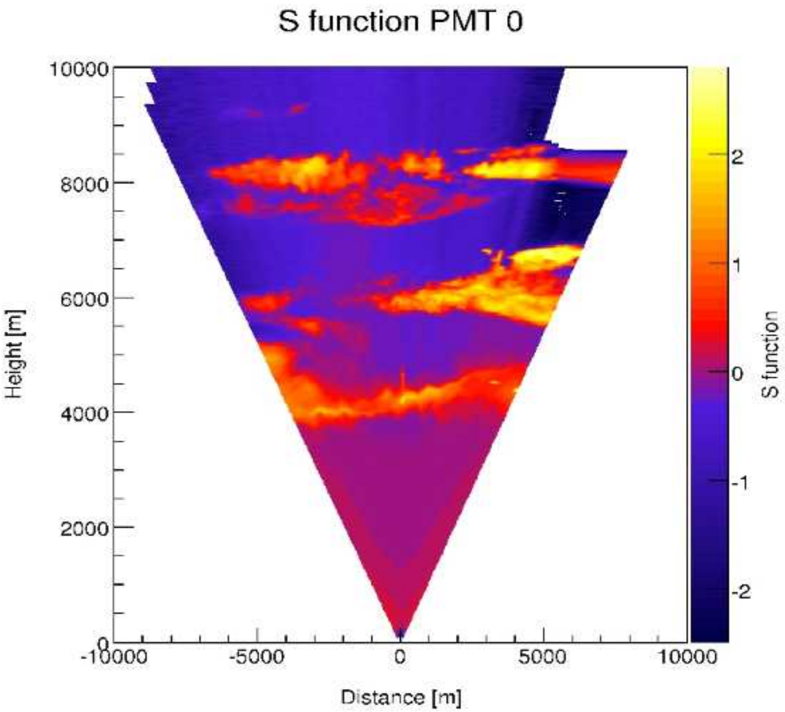




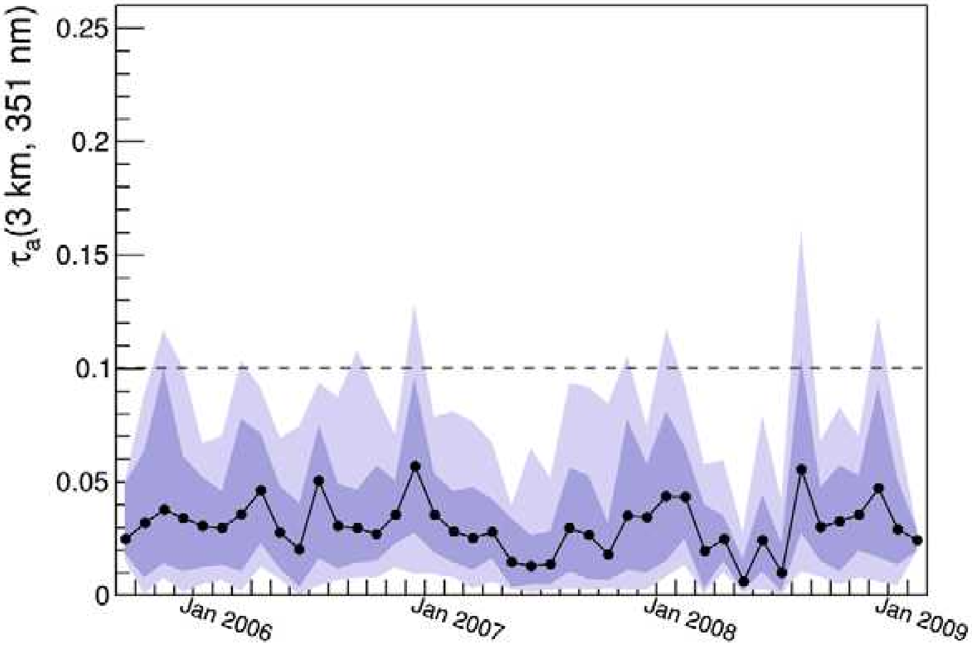
4 stations
3 x 80cm mirrors, 351nm laser
autonomous
remotely operated
FD DAQ master

F9 – Pierre Auger – Lidar

Cloud coverage database

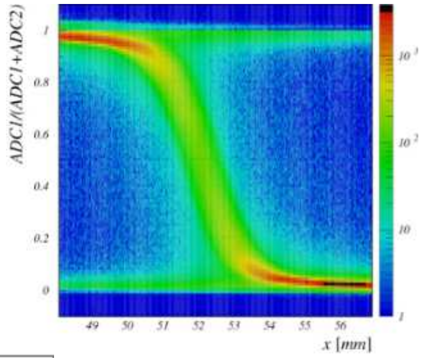


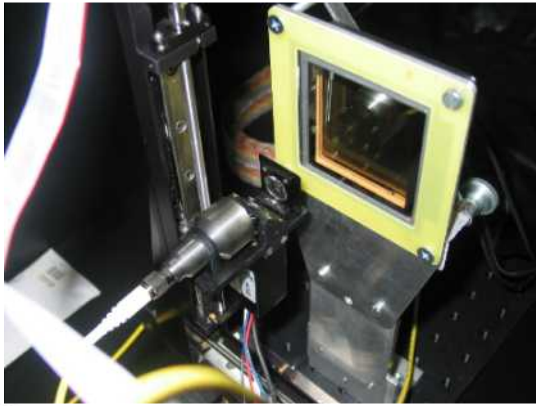
Database of vertical aerosol optical depth

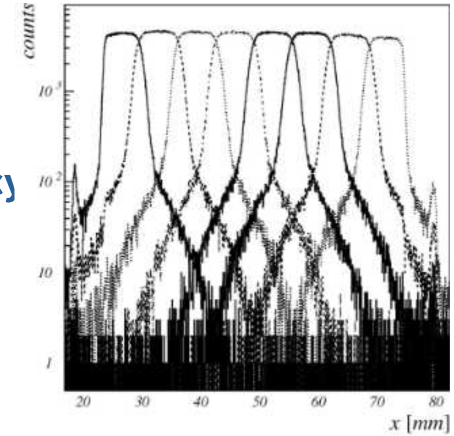


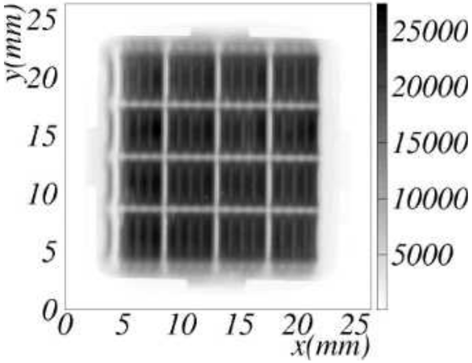
F9 – detector characterization - photodetectors

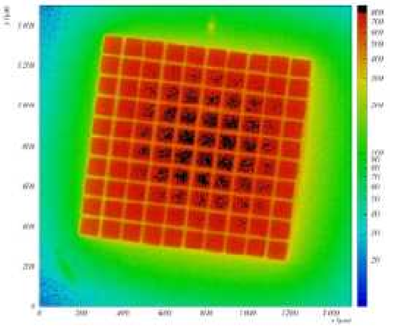
- several setups for photodetector characterization:
- 2D, 3D stages for position dependent characterization
- library of modular electronics (VME, CAMAC) for pulse height and timing measurements
- different types of light sources:
  - pico-second lasers
  - LED sources
  - spectrometers
- climate chamber for tests to $-70C^{o}$
- study of position dependent efficienc timing, charge sharing, cross-talk, photoelectron backscattering ...





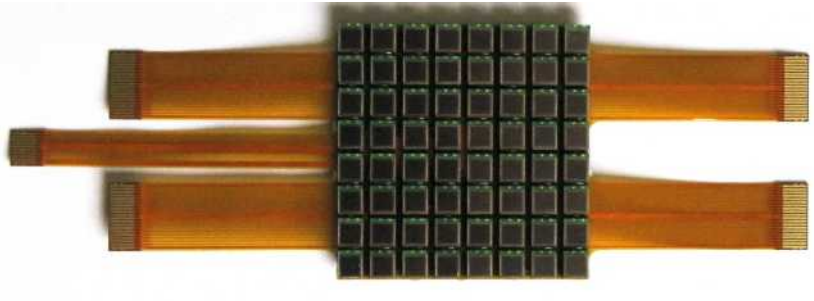


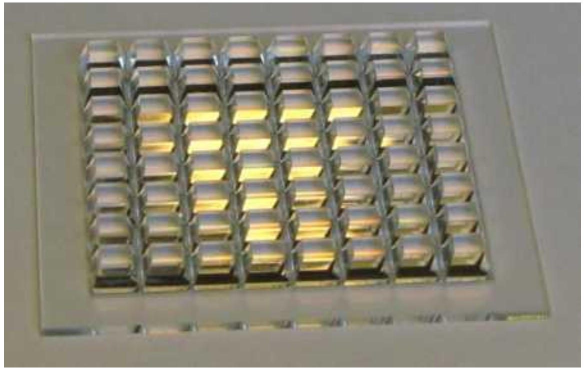


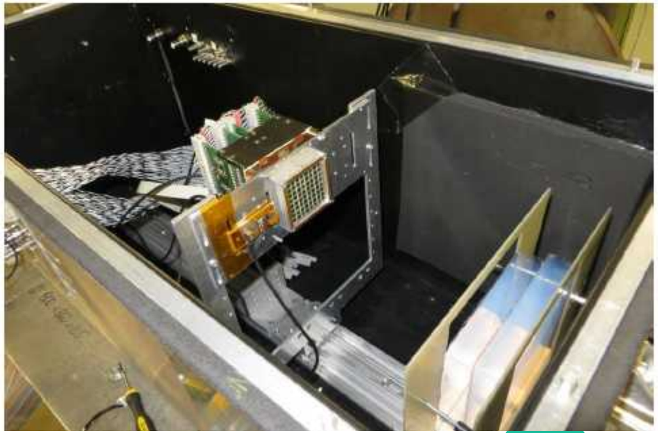


F9 – detector characterization – photodetectors

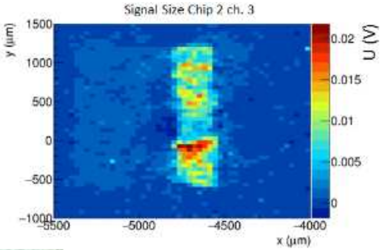
- continuation of development of SiPM photodetector for future experiments
- tests new type of SiPM arrays + light concentrators
- compact module designs
- study of photon detection efficiencies after neutron irradiation
- integration with available electronics
- evaluation in the beam tests





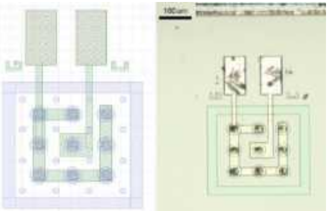


F9 – detector characterization – Si detectors - ACTIVITIES



Research in semiconductor particle detectors and dosimetry sensors

ATLAS upgrade

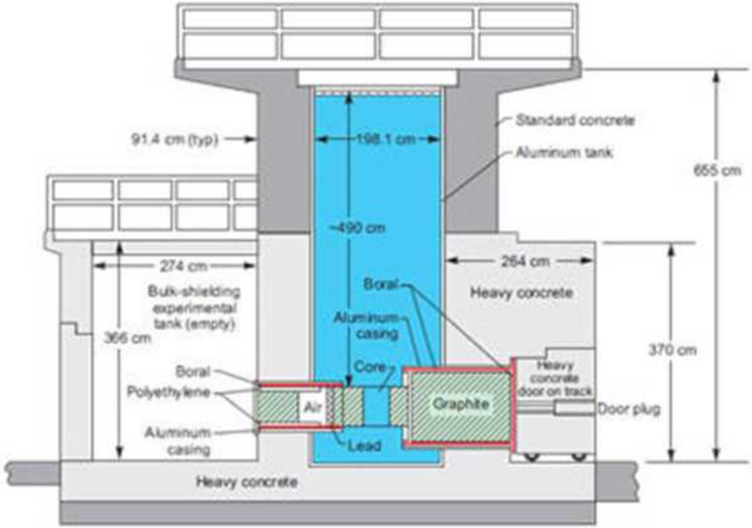


- Beam Condition Monitor (diamond detectors)
- Radiation monitoring (dosimeters)
- High Granularity Timing Detector (LGADs)
- ITk (strip sensors, depleted CMOS)

R&D Collaborations for HEP (upgrade of LHC, Future Circular Collider) and Nuclear physics

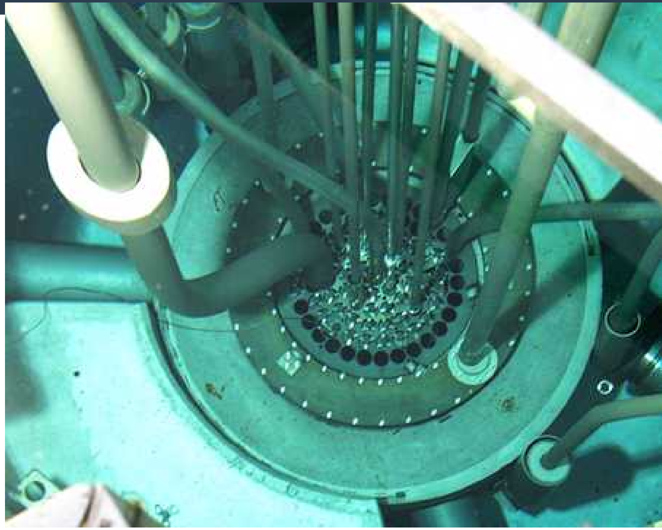
- RD50 - Radiation hard semiconductor devices for very high luminosity colliders (previously in RD39, RD48)
- RD42 - CVD Diamond Radiation Detector Development
- Dosimetry (PIN, MOS-FET and diamond)

F9 – detector characterization – Si detectors - Infrastructre



TRIGA Mk. 2 type

- Built 1961
- 250 kW max
- TID at 250 kW ~1 kGy /10^{14} $n_{eq}cm^{-2}$
- <10% accuracy



Reference irradiation facility for HEP – similar spectrum of neutrons than those at LHC

(well known spectrum, regulary calibration checks, known conditions, established procedures)

Different irradiation channels which allow irradiations to extremenly high fluences up to *10^{18} neq/cm^2*s

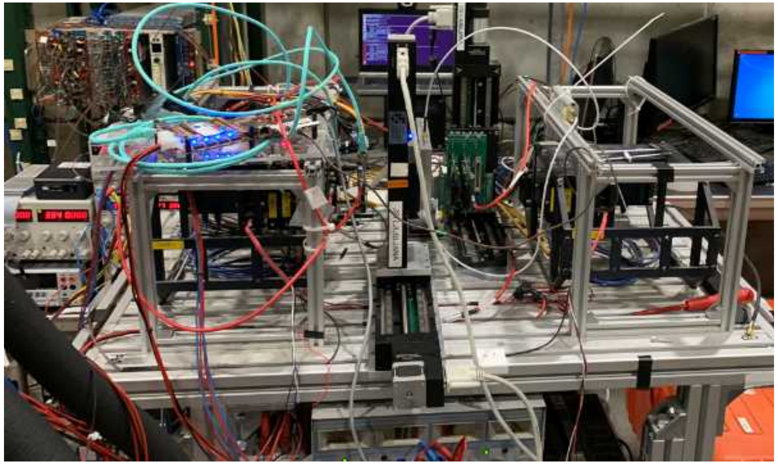
- 3 vertical for samples up to 6 cm in diameter with fluxes: *1.54, 3.57, 6 ·10^{12} neq/cm^{2}s*
- tangentional channel (*130×200 mm^2*) - *4 ·10^{11} neq/cm^{2}s*

AIDA 2020 facility – widely exploited by all LHC experiments : 514.5 units delivered in 98 projects, approx 580 irradiations (ALICE 1%,LHCB 2%,CMS 18%, ATLAS 26%, RD 49%, 4% others)

F9 – detector characterization – Si detectors - Infrastructre

- **Lab Techniques (probe stations, wire-bonders, CAD/CAM workshop clean room Cryo-TCT, Timing resolution Setup, Multi-Ch. charge collection …**

KARTEL Beam Telescope



6 Mimosa planes with FEI4 for anchoring tracks used by RD42, ATLAS (HVCMOS)

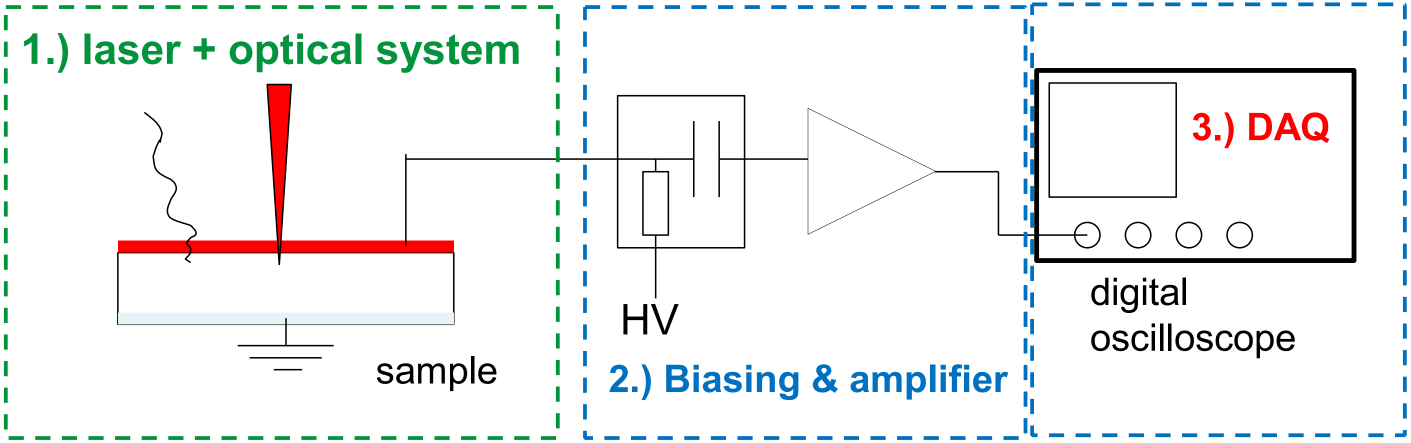
Scanning-Transient Current Technique (pioneers)

Used by many laboratories around the world
Commercialization through Particulars Ltd.

F9 spin-out: Particulars

- Particulars d.o.o is a F9/IJS spin-out that produces scanning TCT systems.
- Established 2016
- Founders: M. Mikuz, A. Gorisek, V. Cindro, G. Kramberger, I. Mandic and M. Zavrtanik
- Amazingly (and contrary to our own believe) we are still in business

F9 spin-out: Particulars - TCT basics

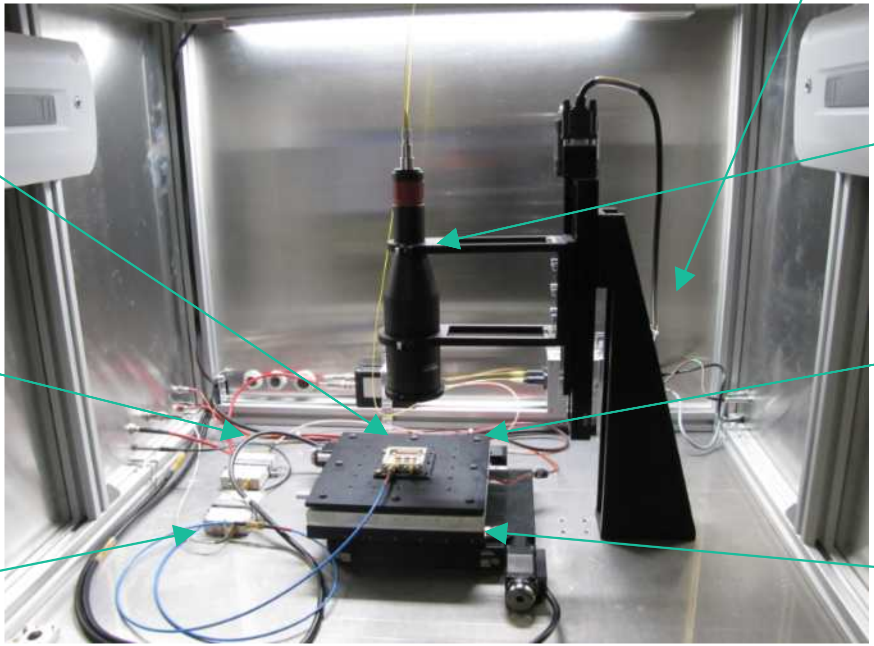


Inject carriers into sample
Red light for surface injection
(electron hole separation)
IR light for sample penetration
(MIP like signal)

Bias the sample with bias-T
Amplify the signal
Digitize the signal
Analyze the data

Optional:
Cool down the sample
Focus the laser beam
Scan over the sample

F9 spin-out: Particulars



Laser

Sample mount

Focusing optics

Bias-t

Cooling table

Amplifier

Translator

F9 spin-out: Particulars -bits and parts

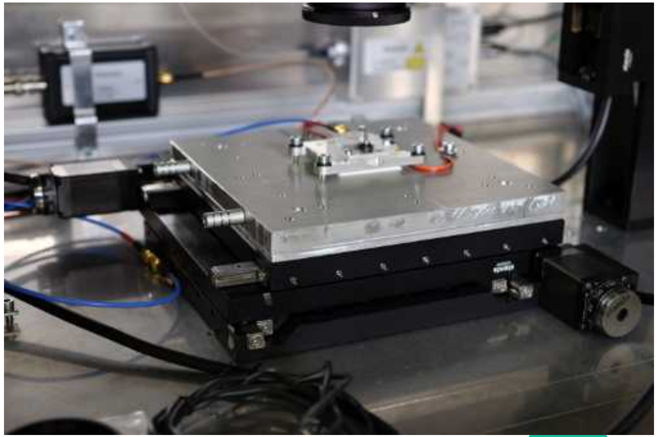
Parallel logic devices (74AC family)
as current generator!

- Wavelengths (380nm, 420nm, 640nm, 980nm, 1060nm)
- pulse duration from 400 ps to 4000 ps with no bleeding
- pulse frequency from 50 Hz to 1 MHz
- program a desired sequence of pulses (1024 bit) (pump and probe measurements)

AM-01 amp is a RF amplifier with a (0.01-. 2000) MHz bandwidth.
The amplification can be set to 35 dBm and 55 dBm.

BT-.-01 is a standard three-port network used for setting DC bias point of device under test while not disturbing the rest of the RF read-out chain. But goes up to 2000 V.

Large area cooling block
(180 x 180) mm² cooling surface
4 x 80W Peltier, range -20° C to 100° C



F9 spin-out: Particulars -references

Over 60 TCT systems

Over 180 lasers

Close to 200 amps/bias-Ts

Conclusions

- Detector R&D for experimental particle physics has a strong tradition.
- At JSI we have set up an infrastructure for R&D of photosensors, semiconductor detectors and neutron irradiation studies
- Contribution to detectors at the energy (ATLAS) and luminosity frontier (Belle II)
- R+D efforts in collaboration with the Slovenian industry, successful transfer of technology
- Applications in medical and environmental physics