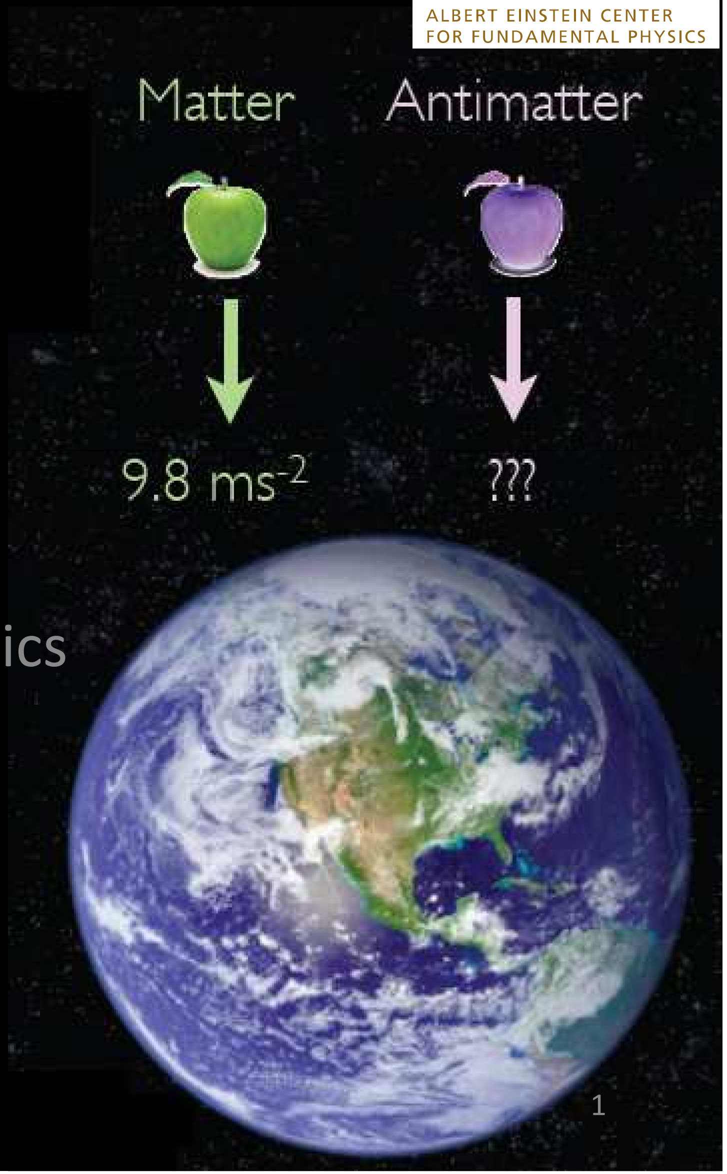
The AEgIS experiment



Akitaka Ariga

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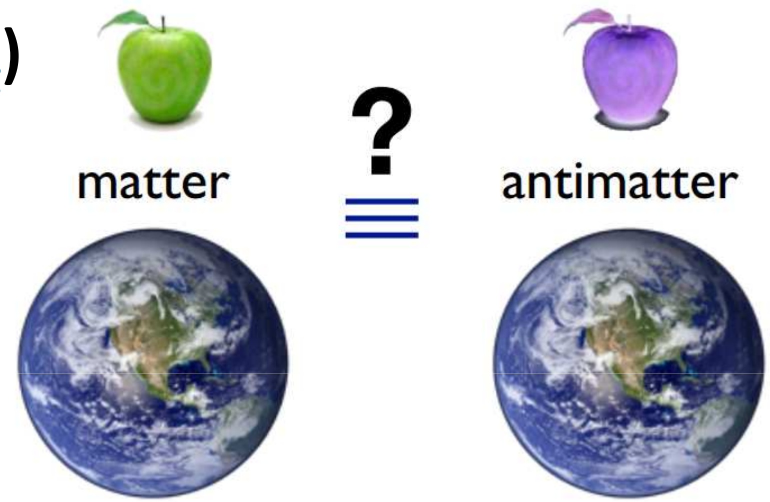
Laboratory for High Energy Physics
University of Bern, Switzerland
for the AEgIS collaboration

Motivation:
Why study gravity with antimatter?

- **Principal of equivalence between gravitational and inertial mass ($m_i = m_g$) is a foundation of General Relativity.**



- **General relativity: classical theory that makes no distinction between matter and antimatter.**

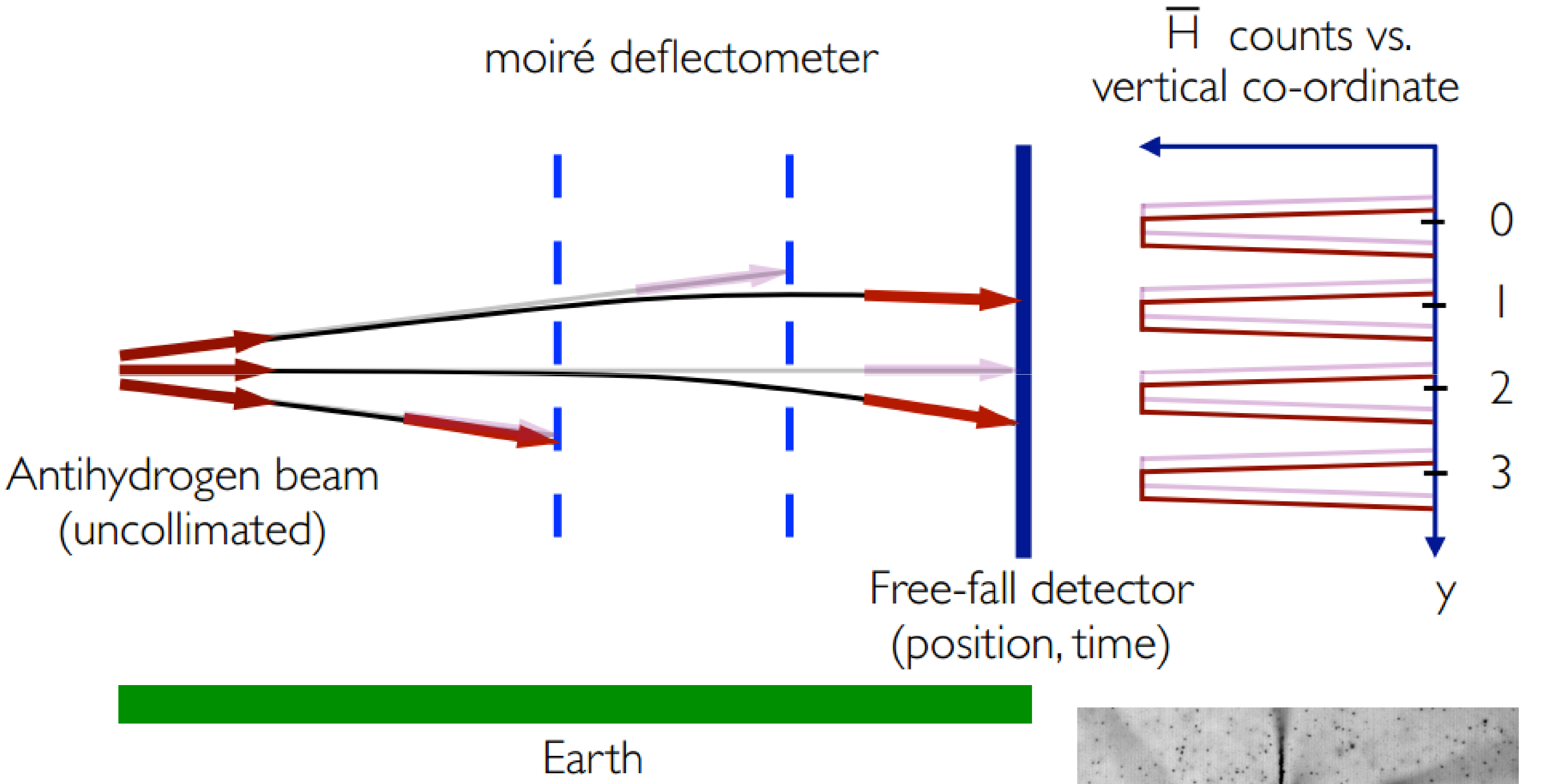
- **Universality of Free-Fall tested directly to 10^{-12}, but only with matter based experiments.**

AEgIS Antimatter Experiment gravity Interferometry Spectroscopy
Test the Universality of Free-Fall with antimatter by measuring the Earth's gravitational acceleration (g) on a beam of antihydrogen.

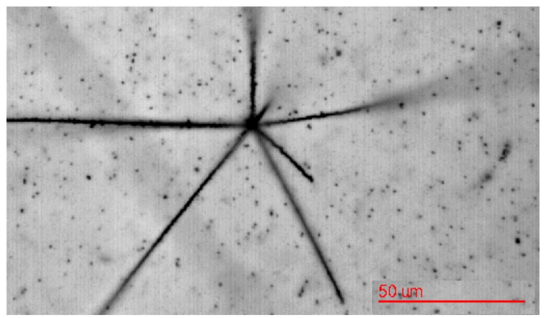
The AEgIS Collaboration at CERN

- CERN, Switzerland
- INFN Genova, Italy
  INFN Bologna, Italy
- Kirchhoff Institute of Physics, Heidelberg, Germany
- Max-Planck-Insitut für Kernphysik Heidelberg, Germany
- INFN, Università degli Studi and Politecnico Milano, Italy
- INFN Pavia-Brescia, Italy
- INR Moscow, Russia
- Université Claude Bernard, Lyon, France
- University of Oslo and University of Bergen, Norway
- Czech Technical University, Prague, Czech Republic
- INFN Padova-Trento, Italy
- ETH Zurich, Switzerland
- Laboratoire Aimé Cotton, Orsay, France
- University College, London, United Kingdom
- Stefan Meyer Institut, Vienna, Austria
- University of Bern, Switzerland

Principle of the AEgIS experiment

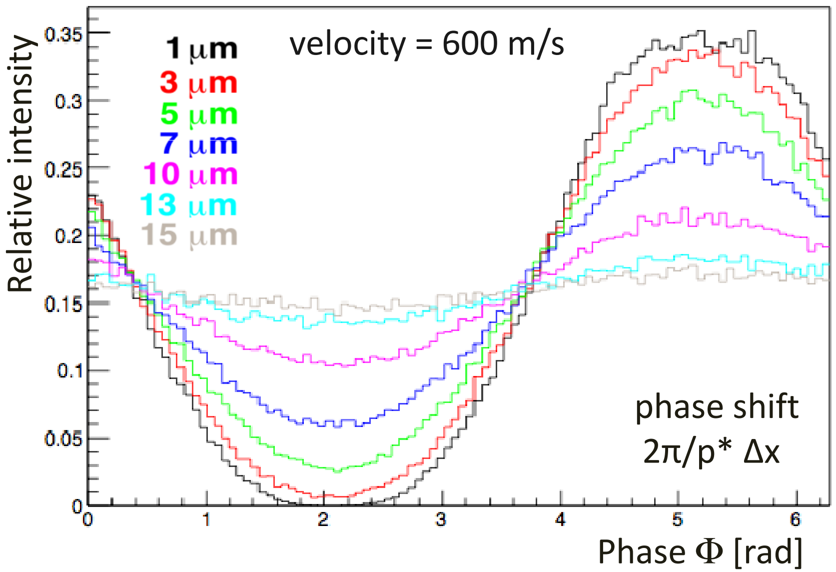


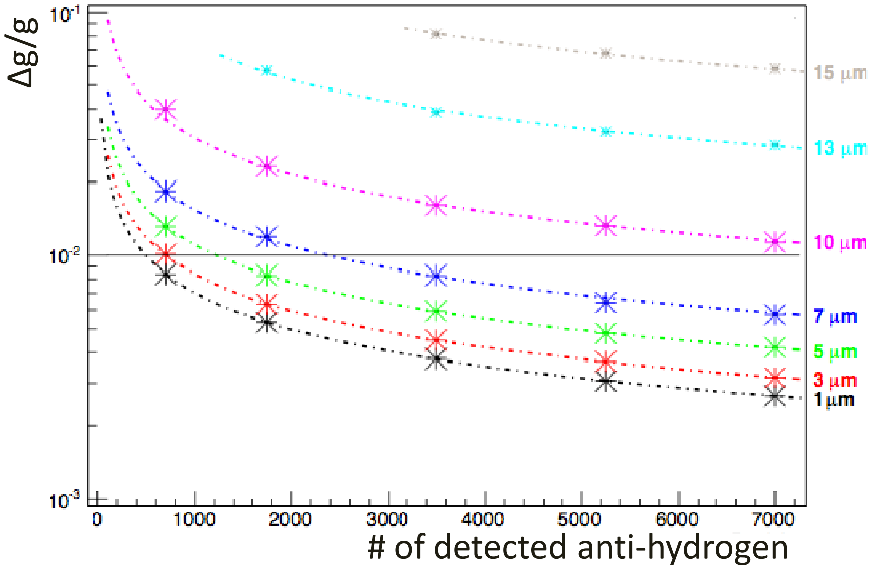
The free-fall is of the order of 10 microns
→ Nuclear emulsion



Resolution requirements for a position detector in AEgIS

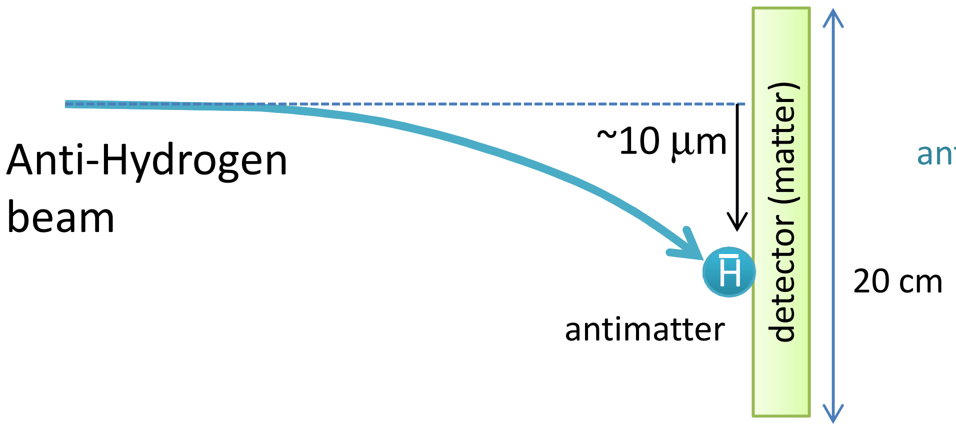
- AEgIS goal: 1% resolution for $\Delta g/g$
- **Emulsion detectors**: ~1 µm resolution

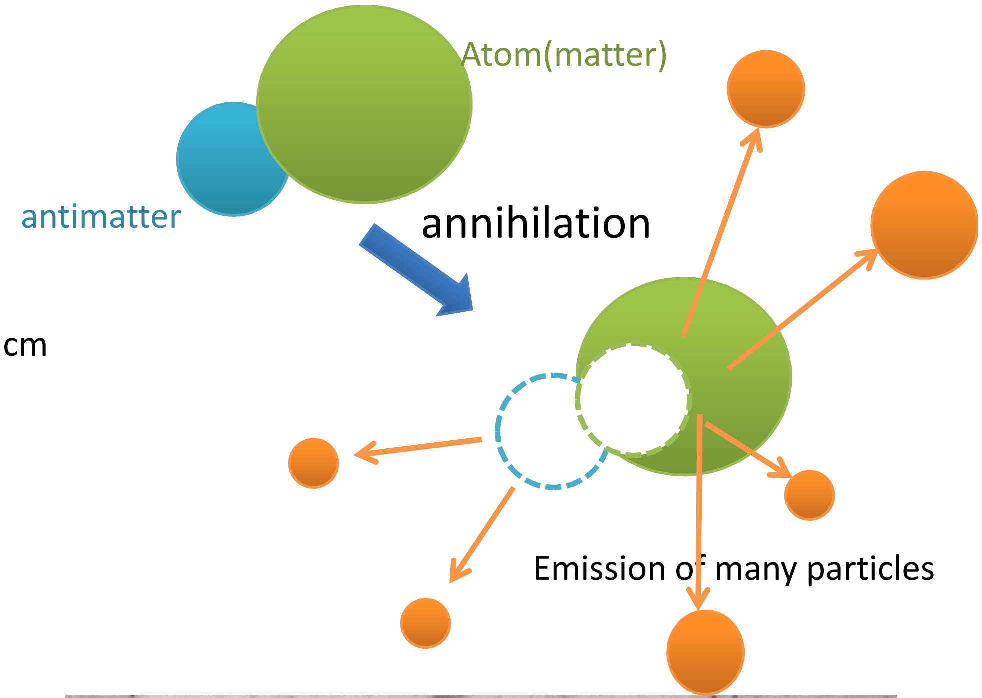




Emulsions allow to achieve the experiment goal with less than 1000 detected anti-hydrogen atoms

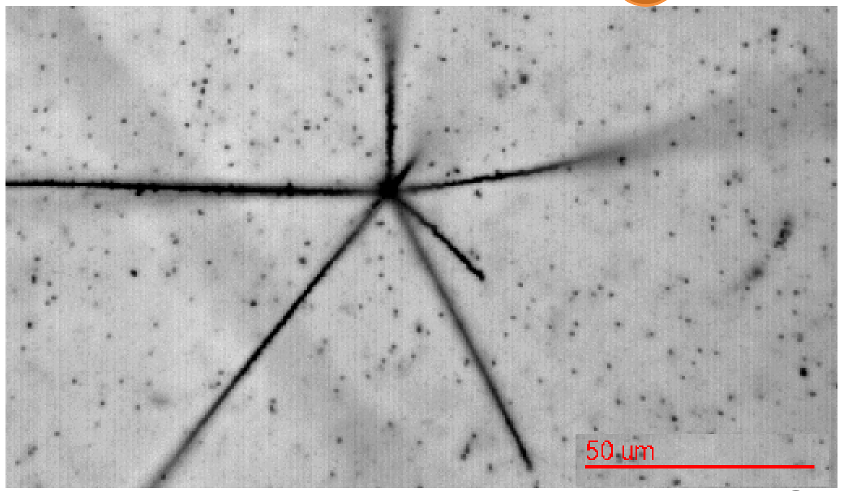
Detection of antimatter annihilation



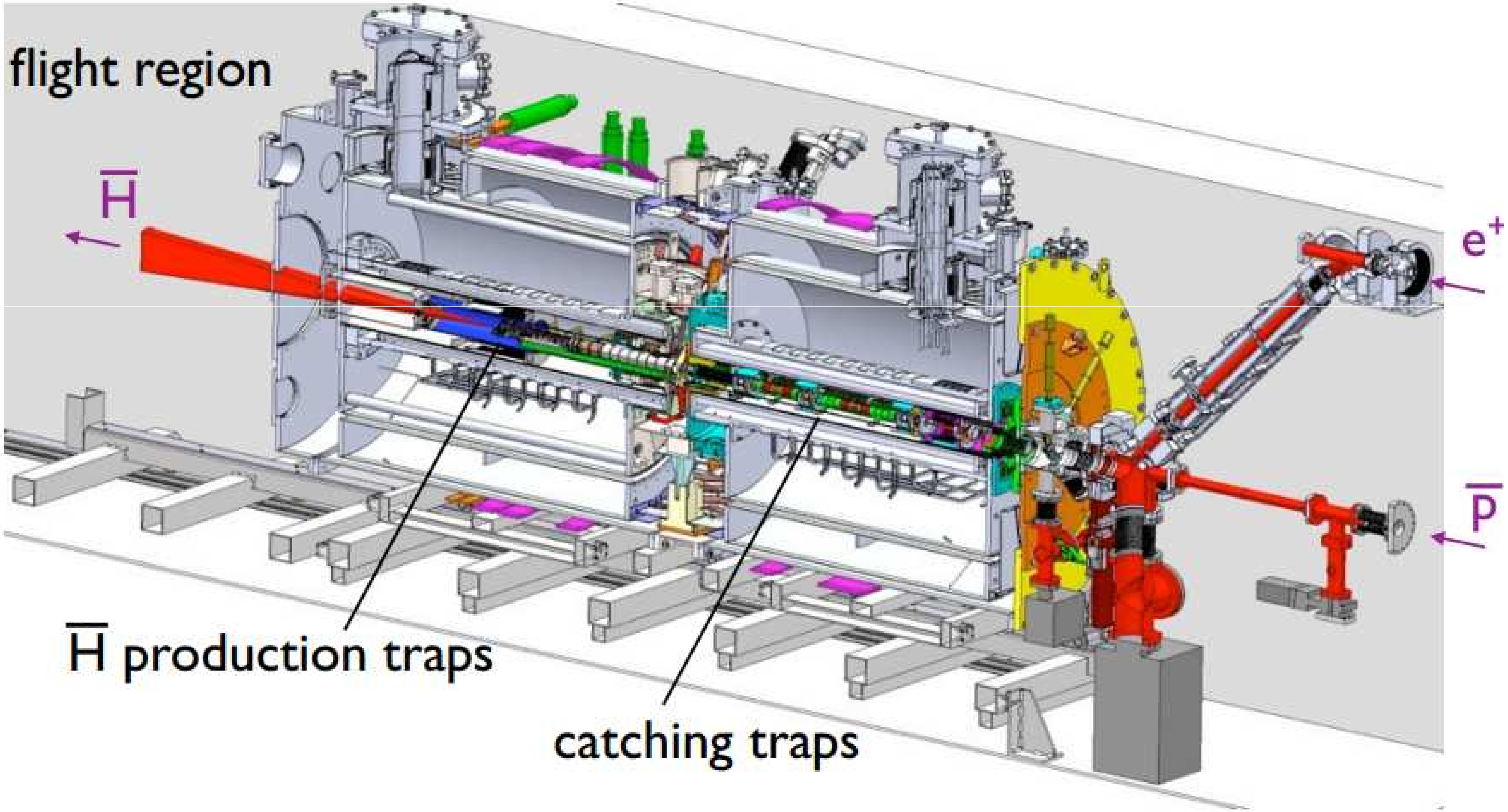


Photographic emulsion detectors

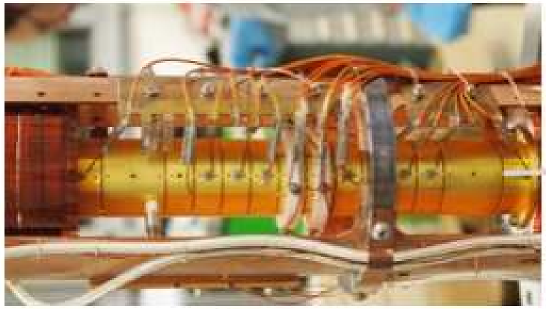
- 3D tracking of particles
- High position resolution (50 nm)



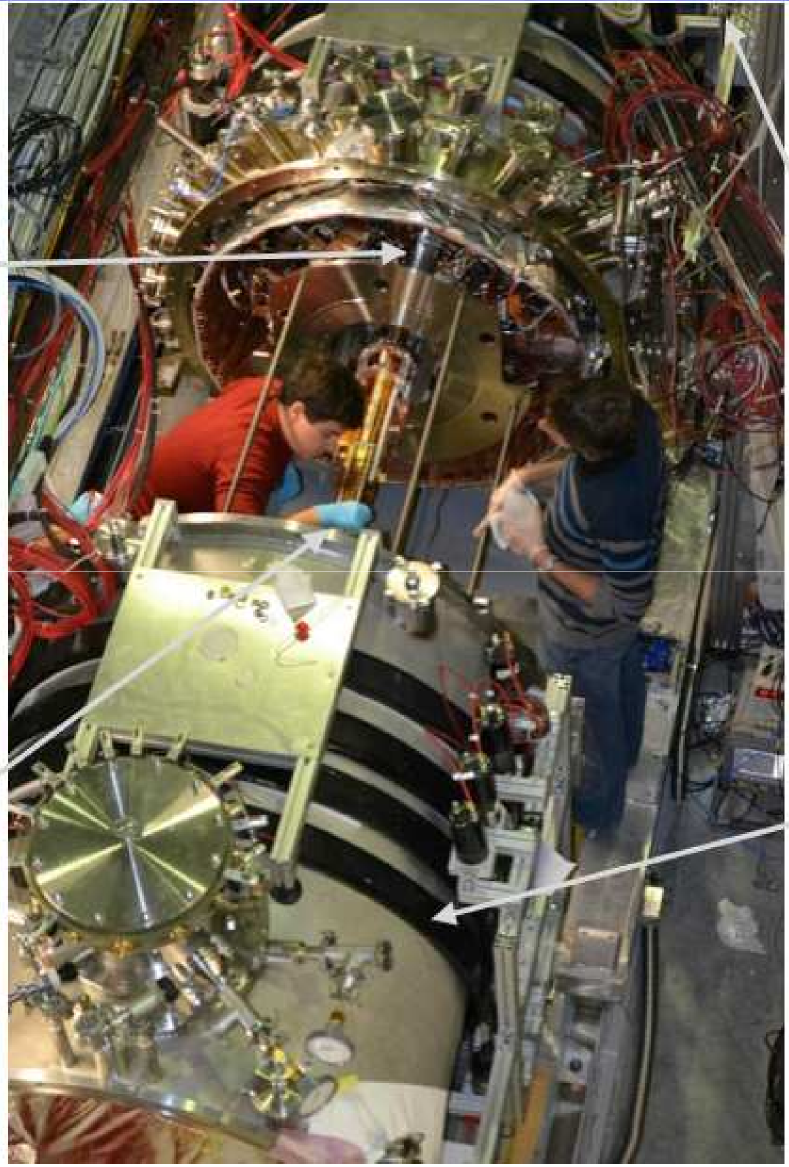
The AEgIS apparatus

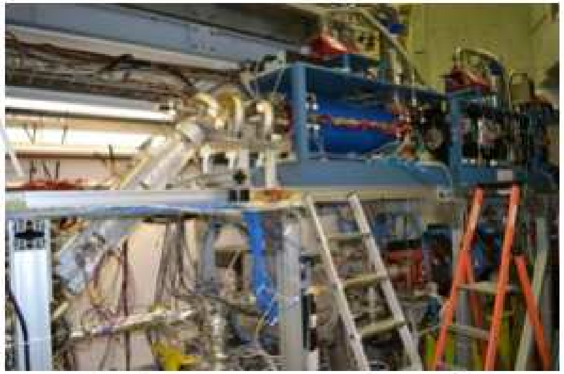


Current status

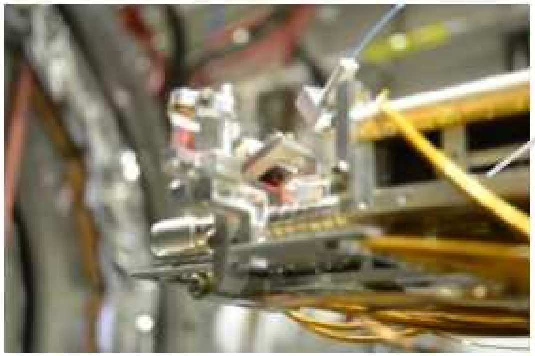


catching traps

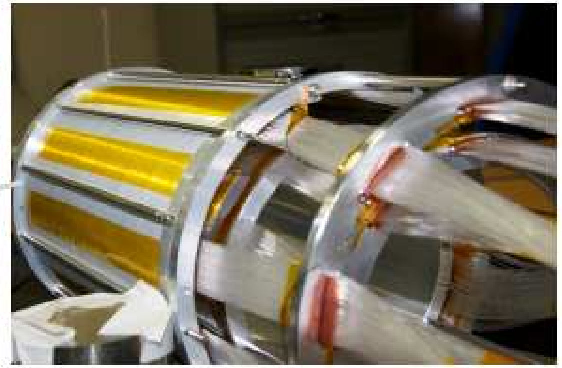




positron accumulator & transfer line



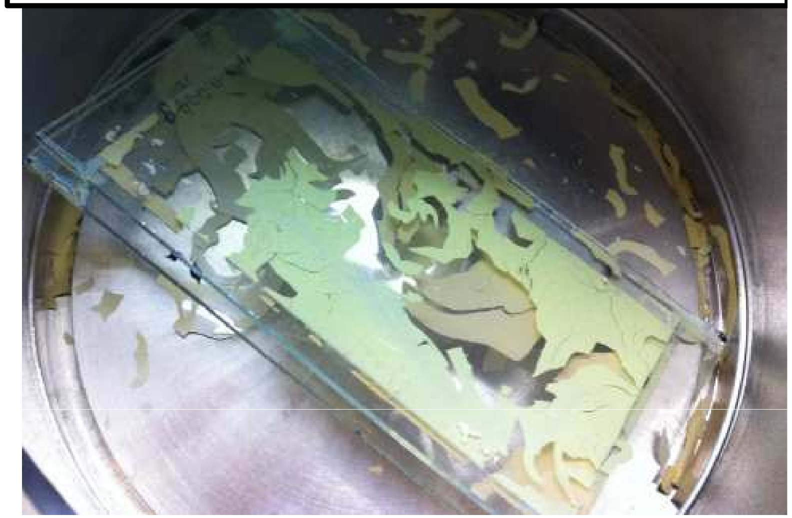
Ps production target, fiber for laser excitation, & antihydrogen production traps



annihilation detector

Technical challenges

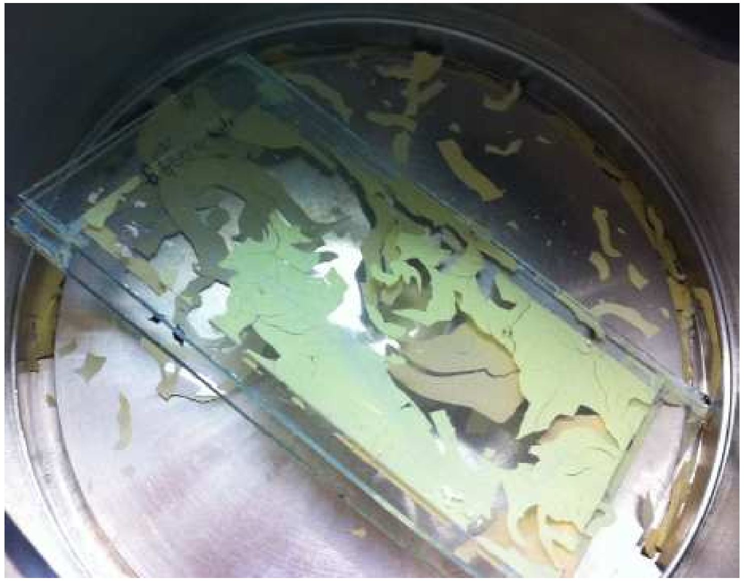
First test in vacuum → emulsion layer on glass was completely destroyed in vacuum after2 days.

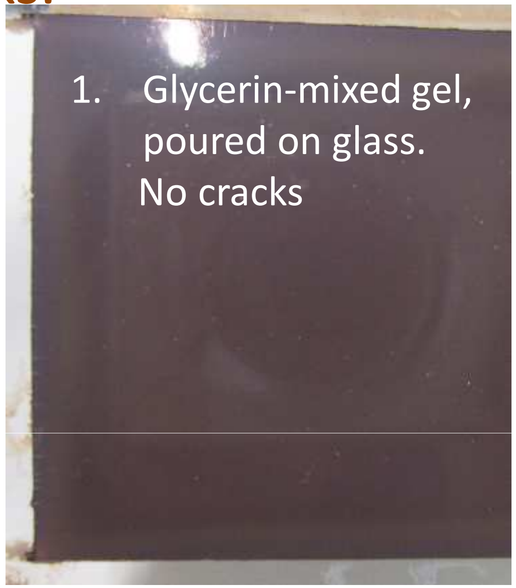


- Emulsion in vacuum
  - Little previous experience
  - Vacuum can damage the emulsion surface
  - Increase random noise
  - →R&D on vacuum tolerant emulsions
- Emulsion in low temperature of 77K
  - Little previous experience
- Scanning of tracks
  - Tracks from antihydrogen -> Low energy, 4π steradian
  - Need to develop a dedicated scanning algorithm → see my another talk later

Actions on vacuum problem

- Water loss by vacuum leads to emulsion cracks.
- Two ways to avoid cracks established
  - Mix glycerin with emulsion gel →baseline
    - Replace water by glycerin
  - Put gas barrier films on emulsions
    - Keep water in the films

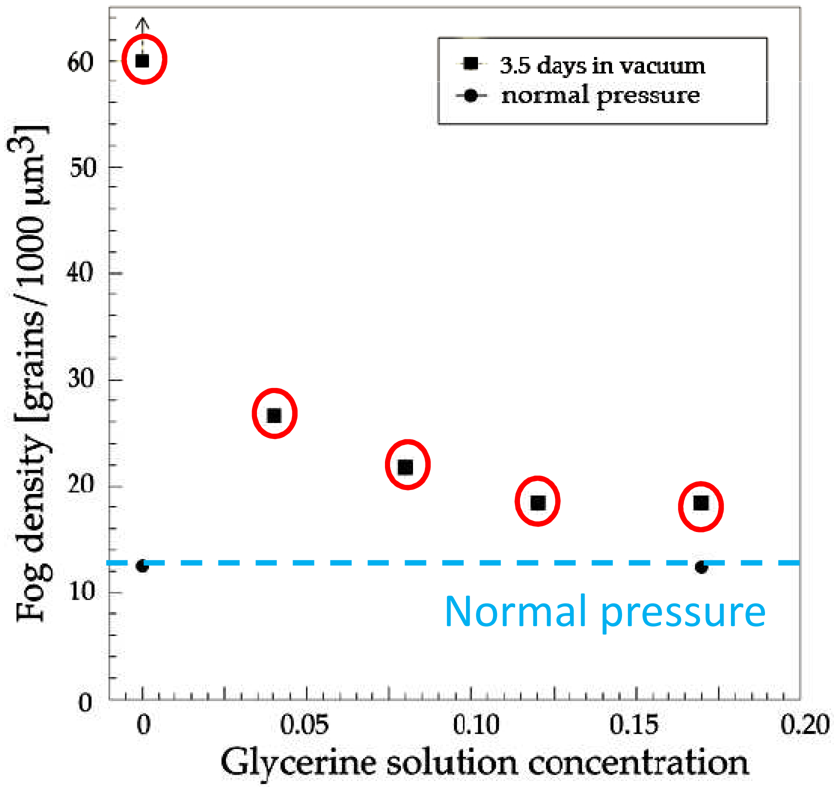




2. "Aluminum vapor deposition tape"

Noise increases in vacuum

- Mechanical stress by drying increases random BG (fog)
- Fog density measured in films dipped in glycerin solution (normal and vacuum)
- Fog density is reduced by adding glycerin



<u>Sample</u>

- OPERA film
- Dipping emulsion for 60 min in glycerin solution with various densities (water, 4, 8, 12, 17 %). After drying, films are kept in vacuum for 3.5 days.

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※Fog density is the number of background grains per 1000 μm^3

Sensitivity of glycerin-treated films

- Sensitivity of glycerin treated films in vacuum by MIP (π^- 6 GeV/c, CERN PS/T-10 in Aug 2012).
- Films in vacuum for 1 day (down to 10^{-5} mbar) or 3 days (10^{-6}mbar).
- Detection efficiency per crystal measured for MIP.
  - About 230 crystals along 100 μm in emulsion
- No degradation by glycerin content

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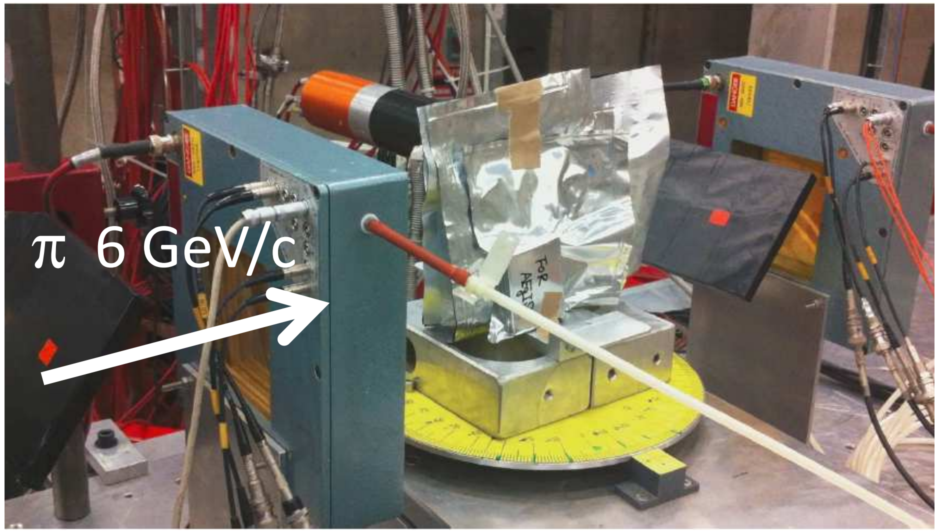
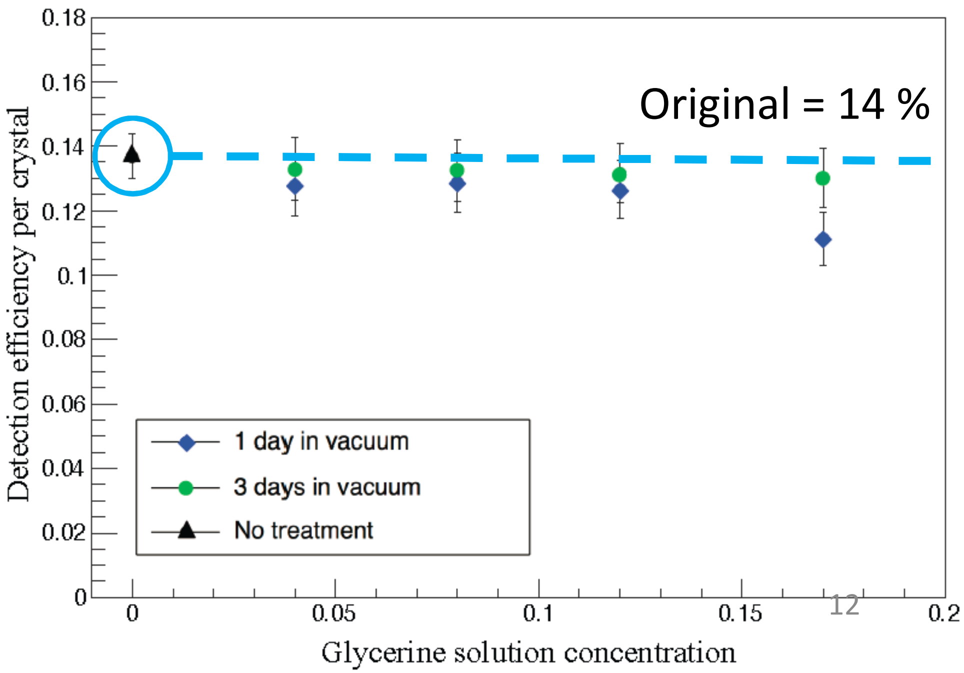
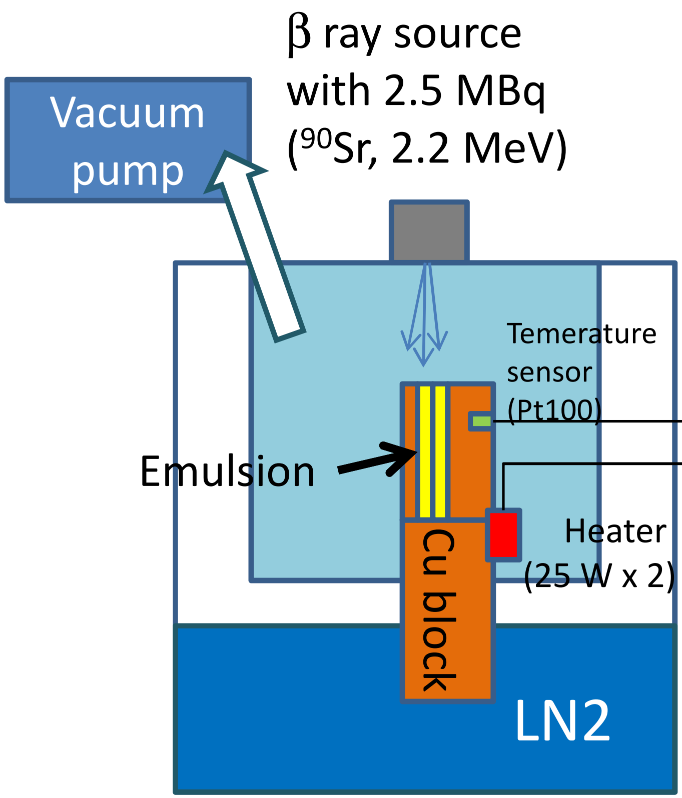


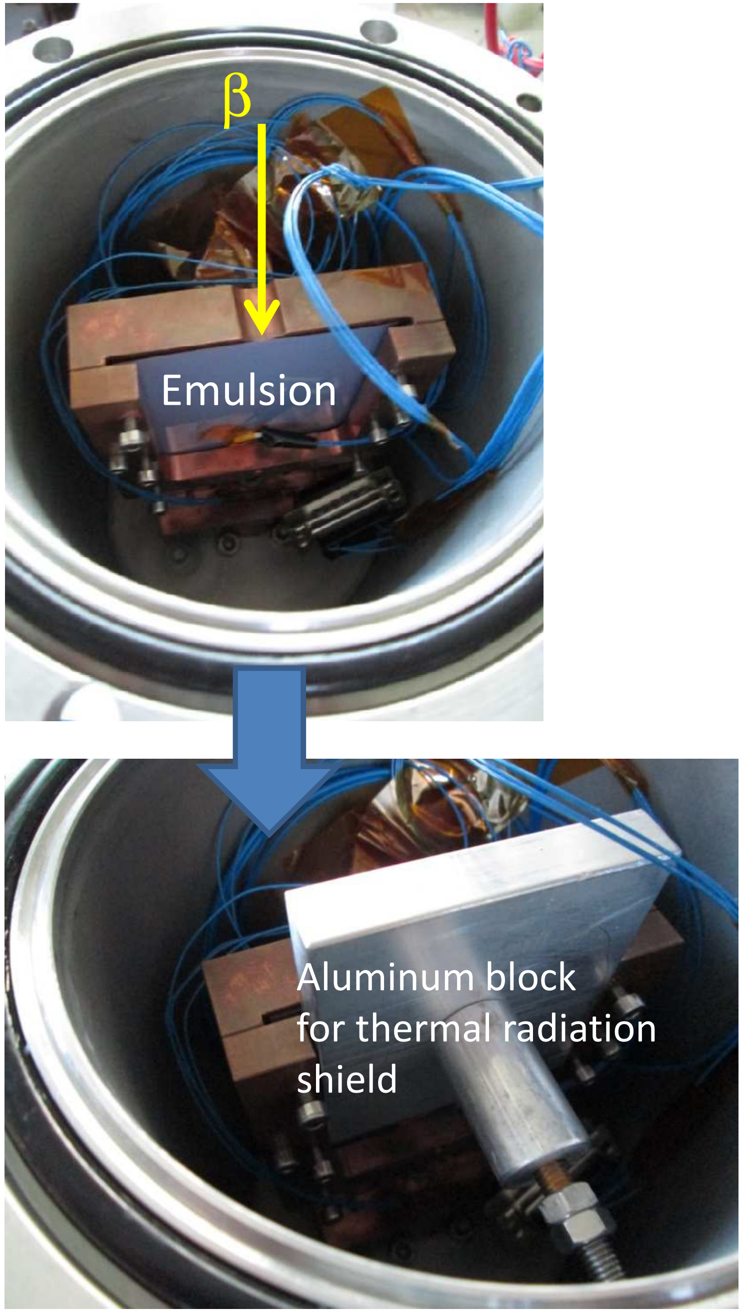


Low temperature test setup

•a new variable temperature cryostat is constructed to measure the sensitivity as function of temperature.

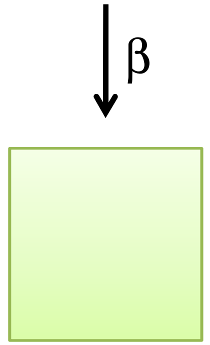
- ``Sensitivity” = number of grains along MIPs

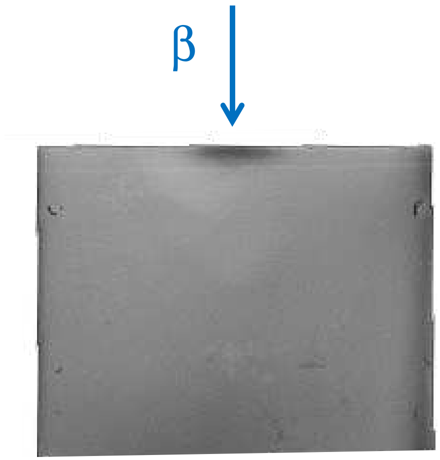


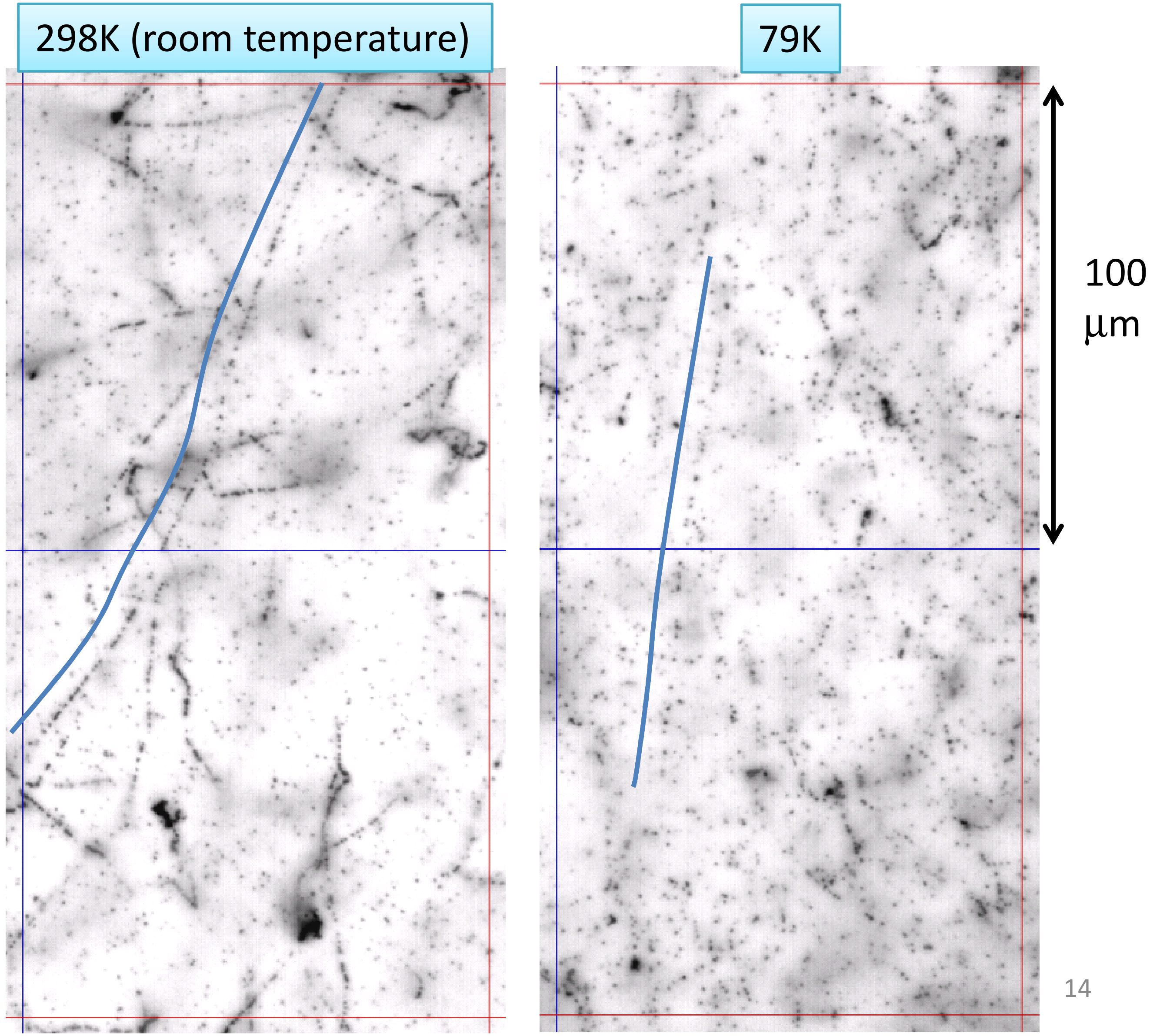


Cryostat inside

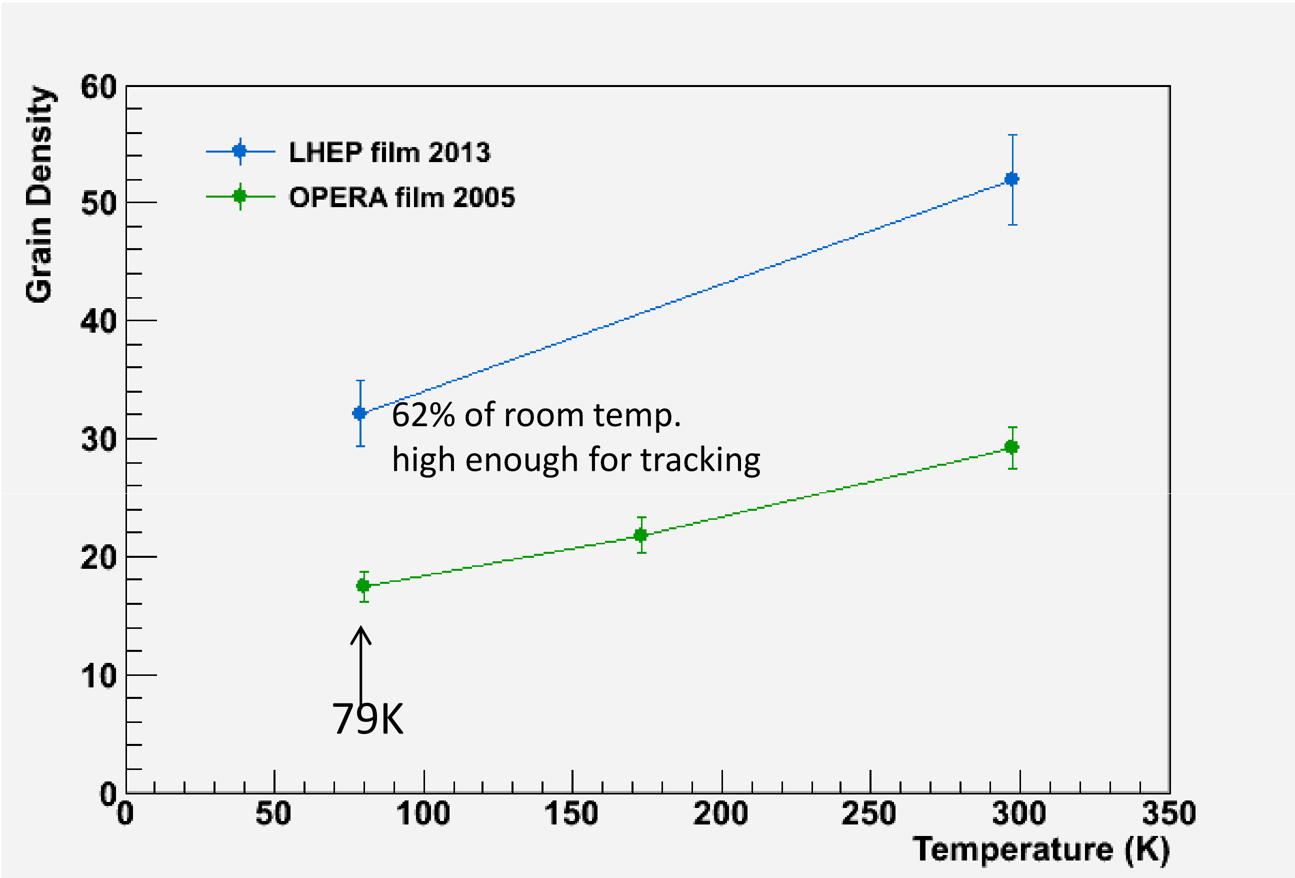
β-ray tracks







Sensitivity at low temperature



	Ratio 298K/79K
LHEP	62%
OPERA	60%

More or less linear correlation has been observed.

Sensitivity of LHEP film at 79K is 32 grains/100micron, which is 62% of that at room temperature.

Nevertheless, it is still higher than that of OPERA films at room temperature → reconstruction of MIP particles will be OK.

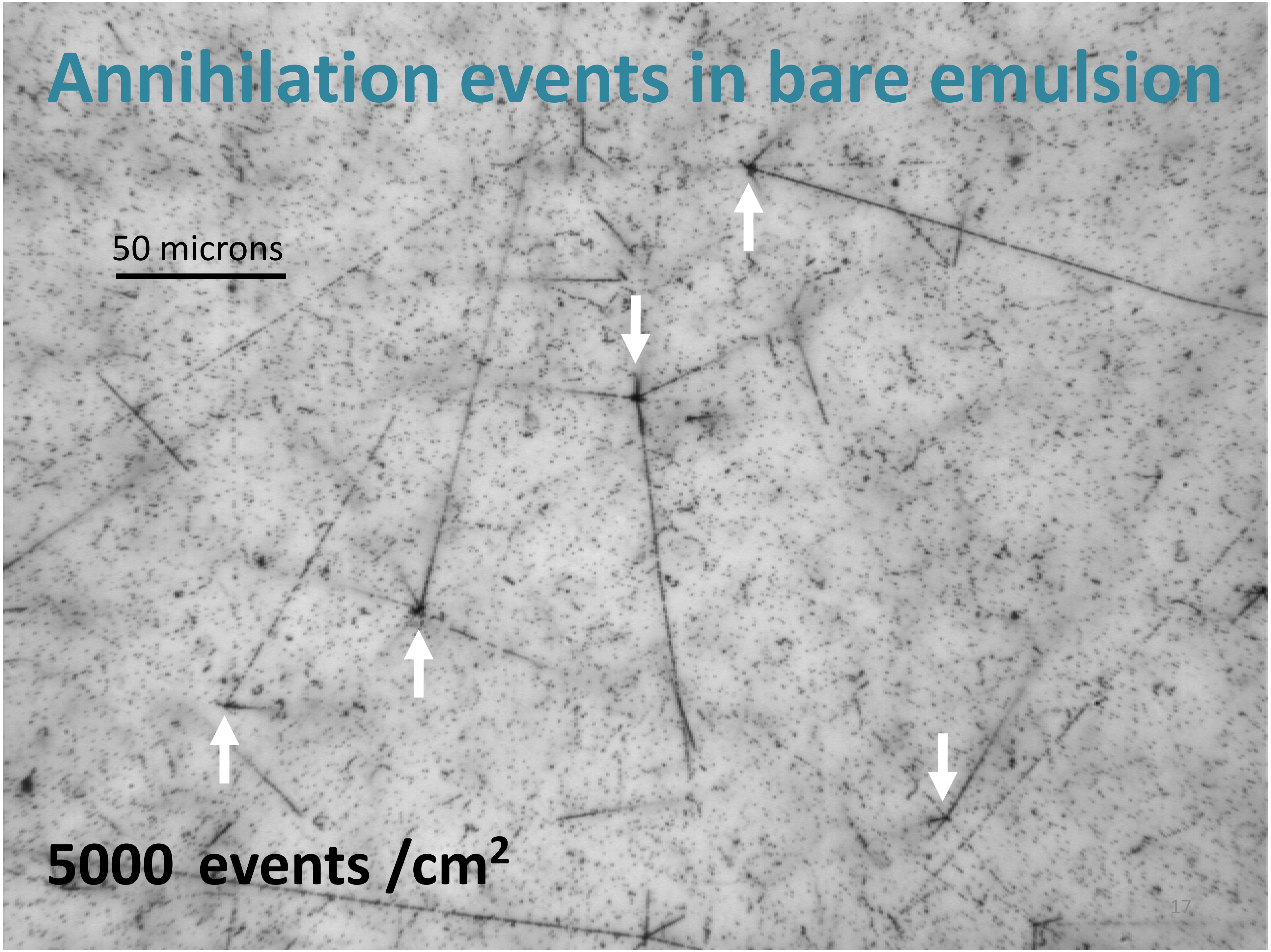
Commissioning in 2012

Exposure procedure

Assemble module in darkroom in CERN → Setting in AD6 (0.5h) → Pumping (2h) → Exposure (2h) → Removal from AD6 (0.5h) → Disassemble in darkroom

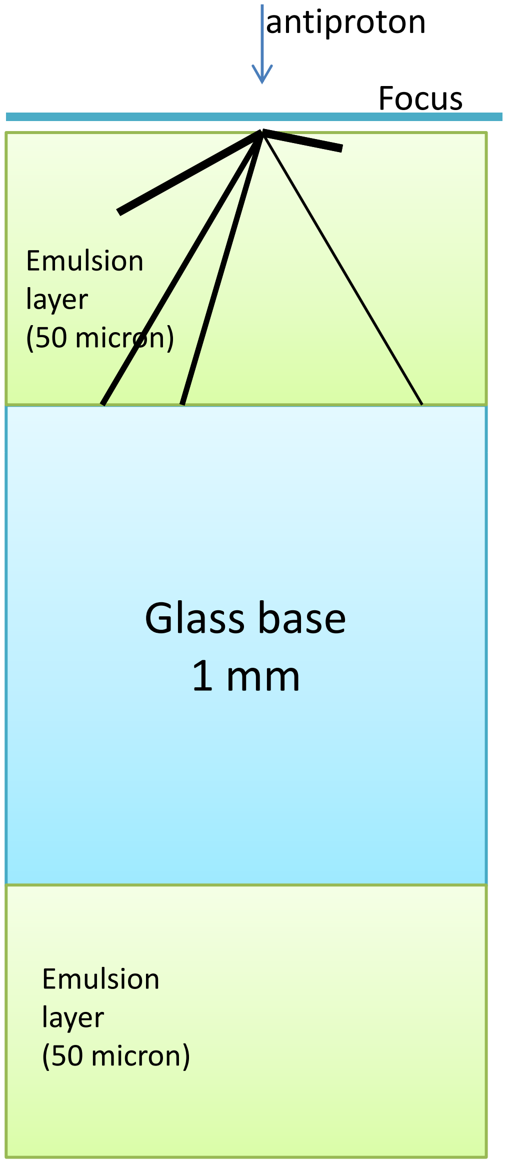
Thanks to reduction of pumping time, 2 exposures became possible in one shift

Annihilation events in bare emulsion

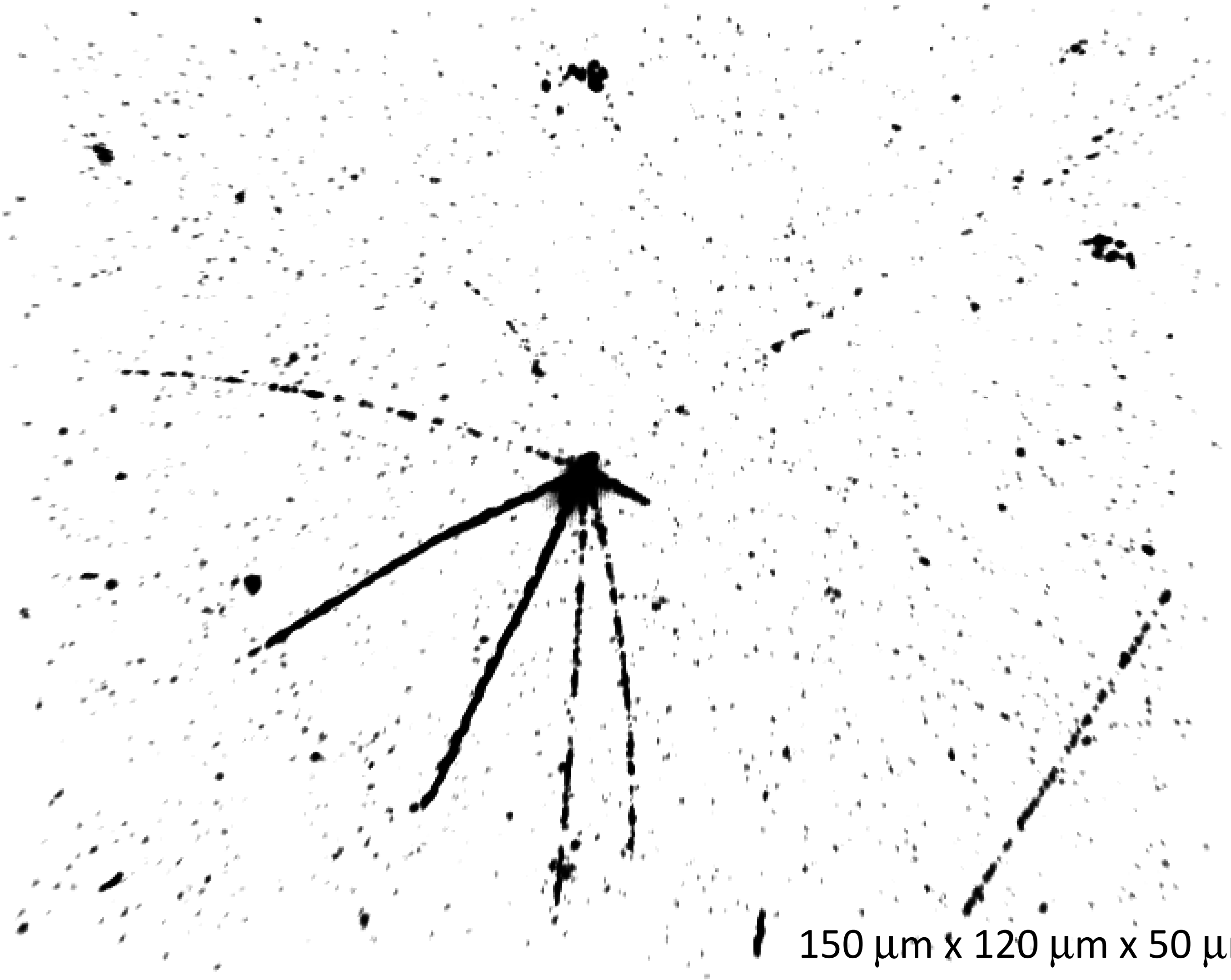


5000 events /cm^2

Emulsion view in new gel on glass base

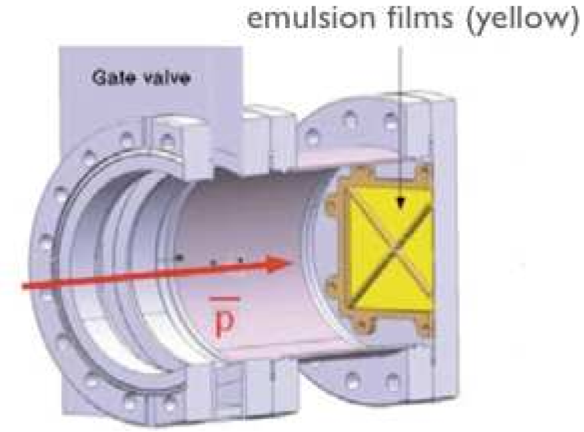


3D view of new gel on glass

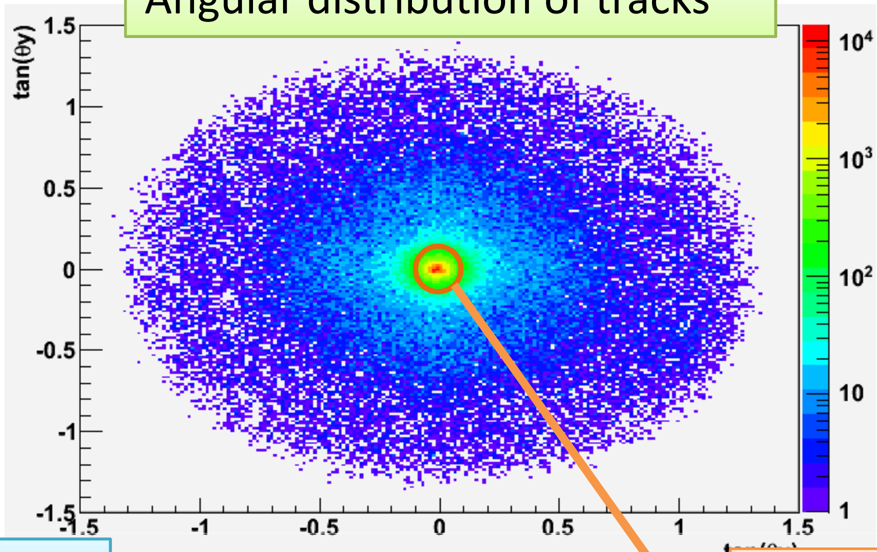


150 μm x 120 μm x 50 μm

Scanned data



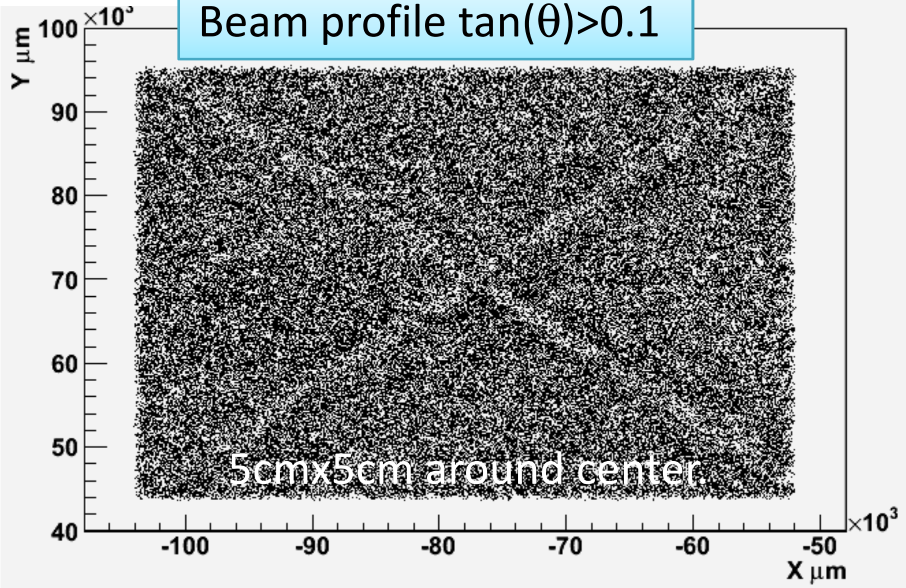
Angular distribution of tracks



OPERA film
(5cm x 5cm)

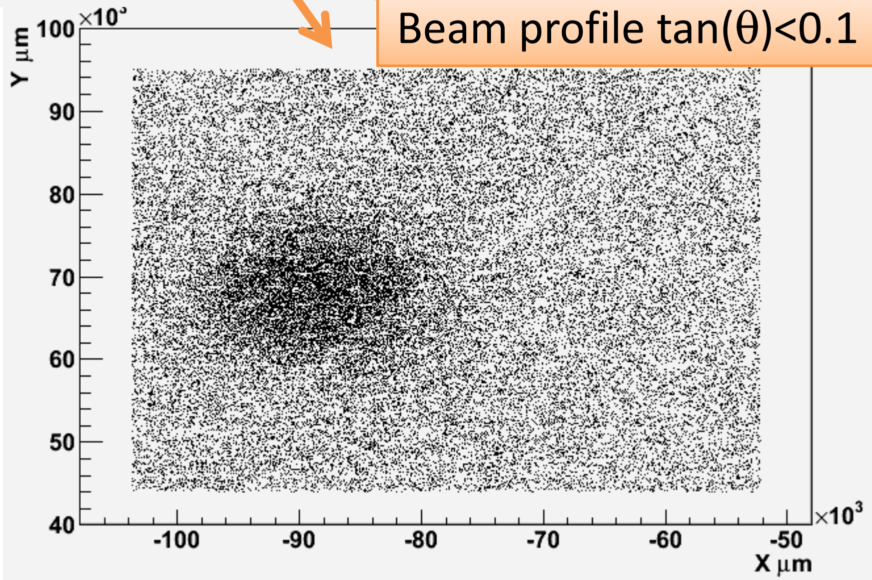
Peak at angular center

Beam profile tan(θ)>0.1



Mechanical support clearly seen

Beam profile tan(θ)<0.1



Beam profile for low angle BG tracks

Multiplicity distribution of antiproton annihilation products

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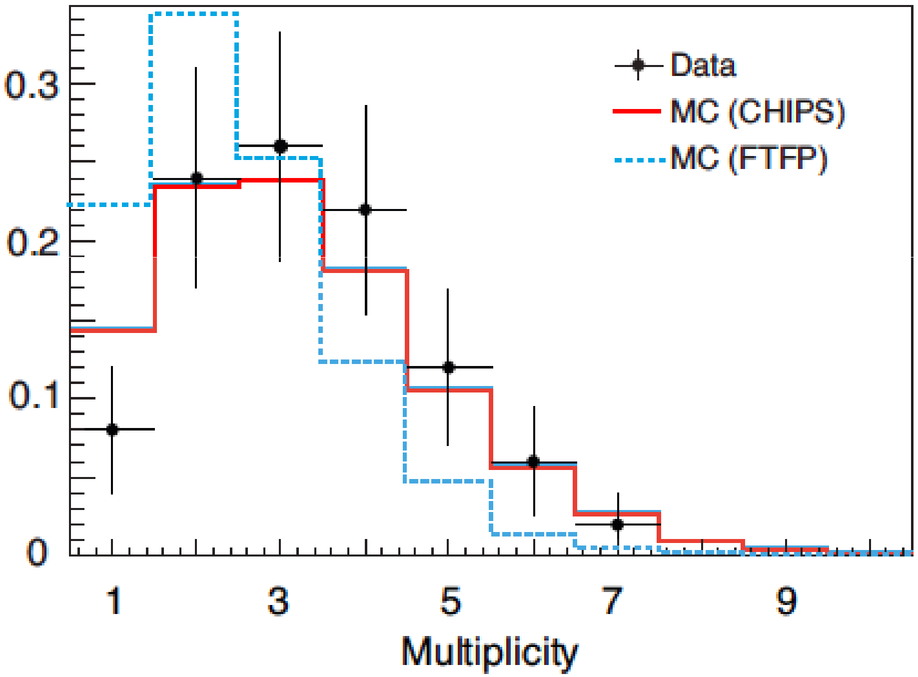
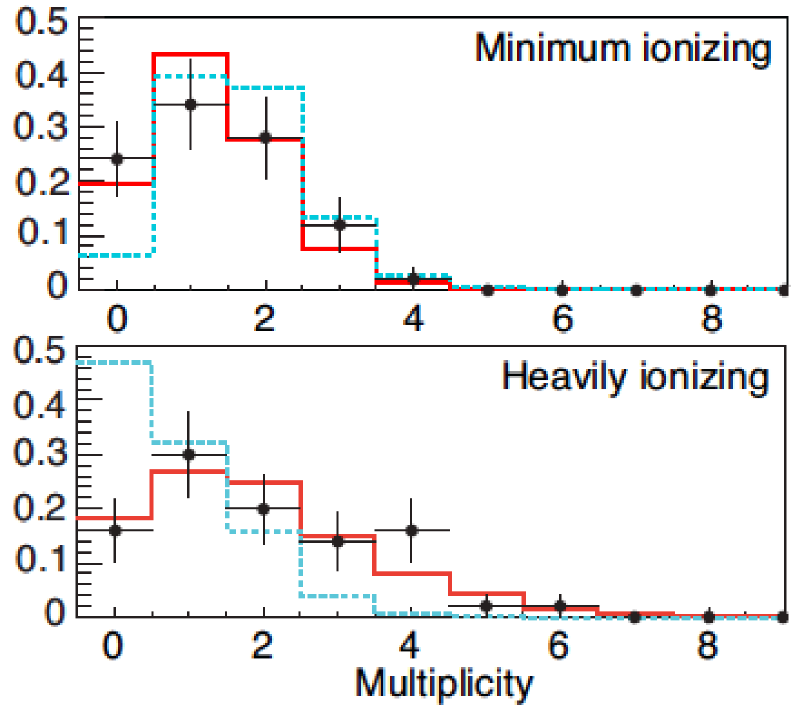
Data – Monte Carlo comparison





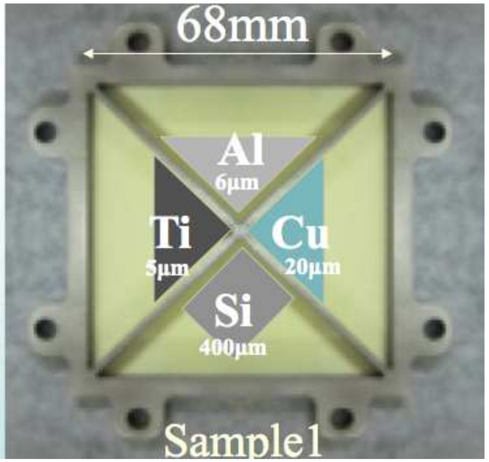
The detection of heavily ionizing tracks allows to discriminate among nuclear models

Nuclear fragments in antiproton annihilations

Nuclear fragmentation production in antiproton annihilation is poorly known.

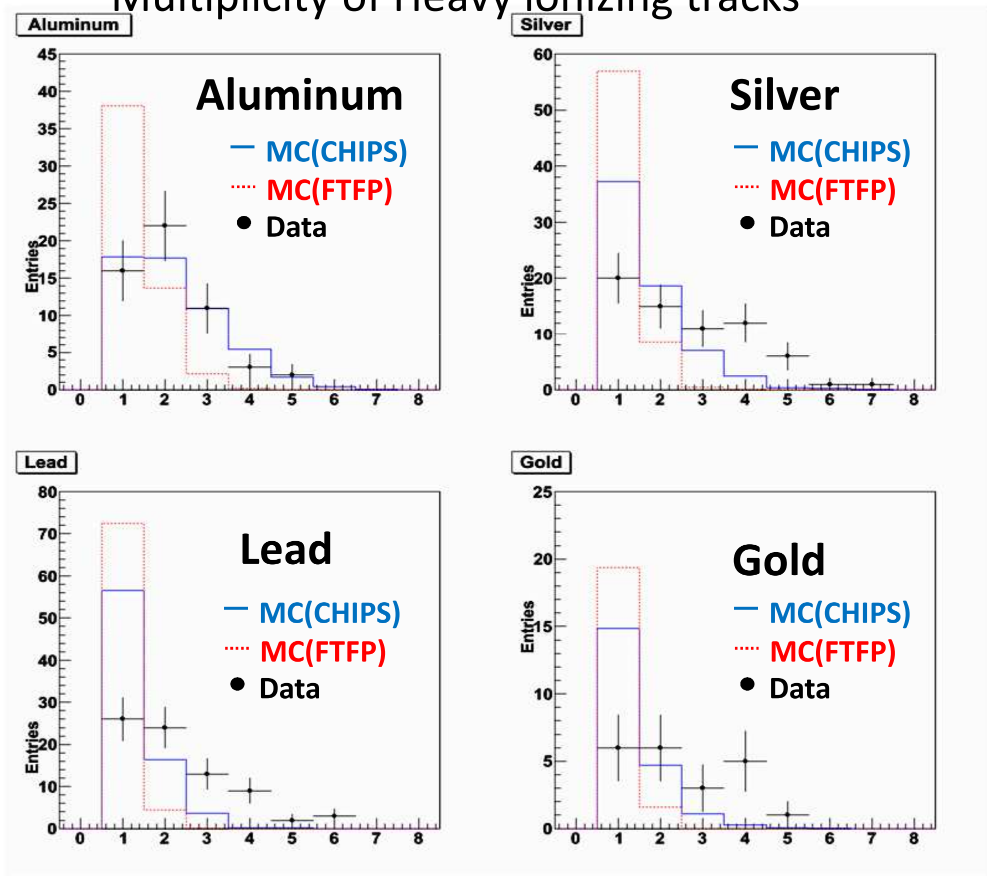
Emulsion films provide a unique possibility to study in detail:

- Fragment multiplicity
- Dependence on the mass number



Preliminary

Multiplicity of Heavy ionizing tracks



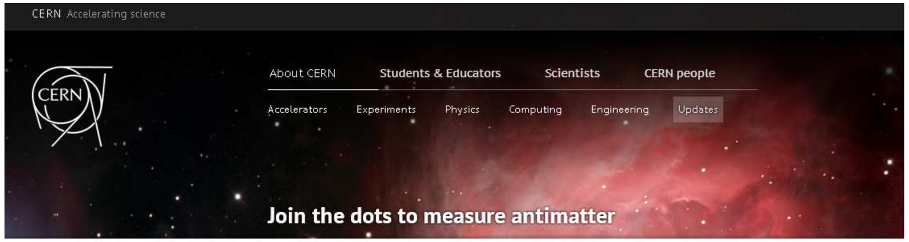
- Normalized to number of events(data)
- Slope acceptance 0.1 < tanθ < 3.0

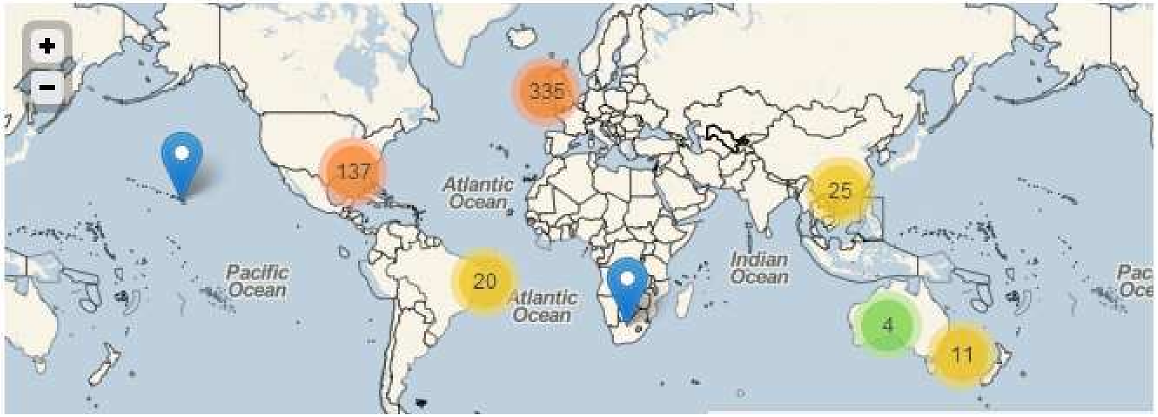
AEgIS for general public

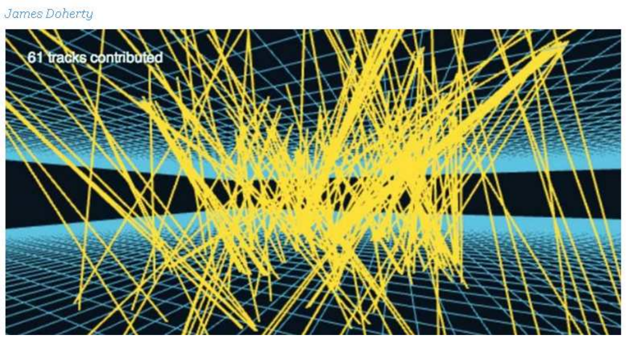
- Open opportunity for general public to analyze emulsion data
  - amateur physicists with PC and internet can join analysis
- Prototype in Aug 2013 for 2 days
  - Manual track measurement of 100 views
- 726 participants from all over the world joined!
  - All views were completed in a few hours
- Need a lot of manual check?

  → Crowdsourcing!

http://home.web.cern.ch/about/updates/2013/08/join-dots-measure-antimatter







Summary

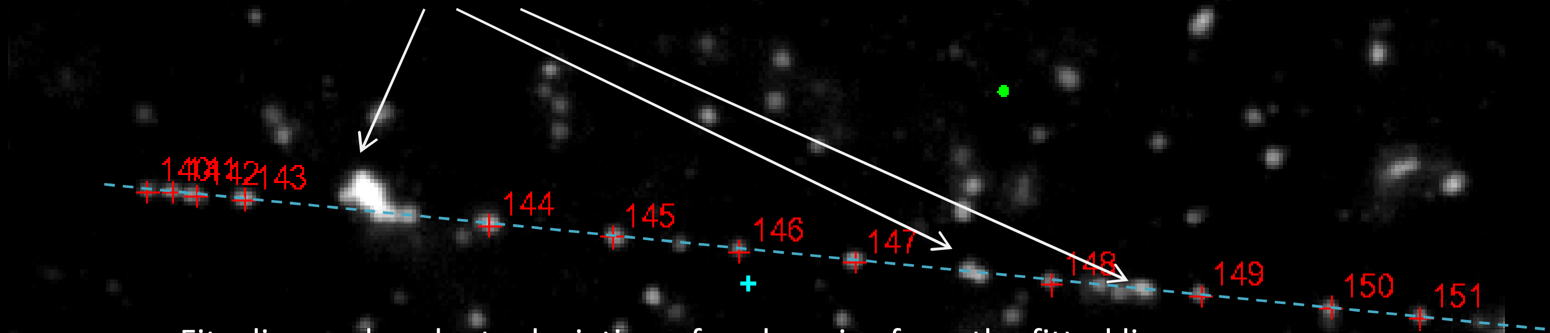
- The gravitational force on antimater is a fundamental question in understanding of our universe
- The AEgIS experiment is going to measure it for the first time.
- Emulsion is employed as the free-fall detector for the high position resolution
  - Rich physics byproducts
- Many technical challenges
  - Emulsion in vacuum OK.
  - Emulsion in low temperature OK.
- Successful commissioning in 2012
- R&D on emulsion is ongoing in 2013, 2014
- Physics run in 2015

Some publications

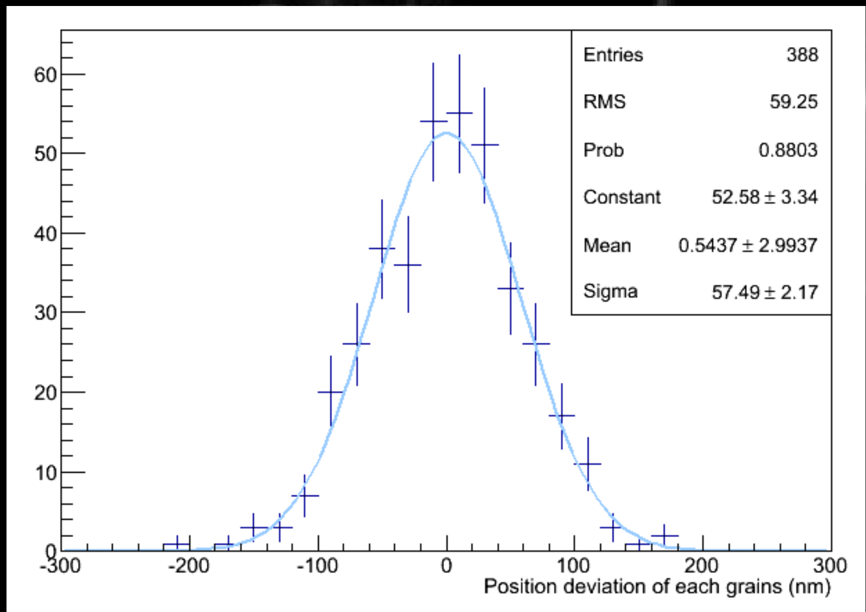
- JINST 8 (2013) P02015
- JINST 8 (2013) P08013

Measurement of intrinsic resolution

- Find straight MIP tracks on the display
- Click the grains → center of gravity calculation
- (Use only grains near to the center of view ← to minimize optical distortion)
- (Reject overlapping grains)



- Fit a line and evaluate deviation of each grains from the fitted line

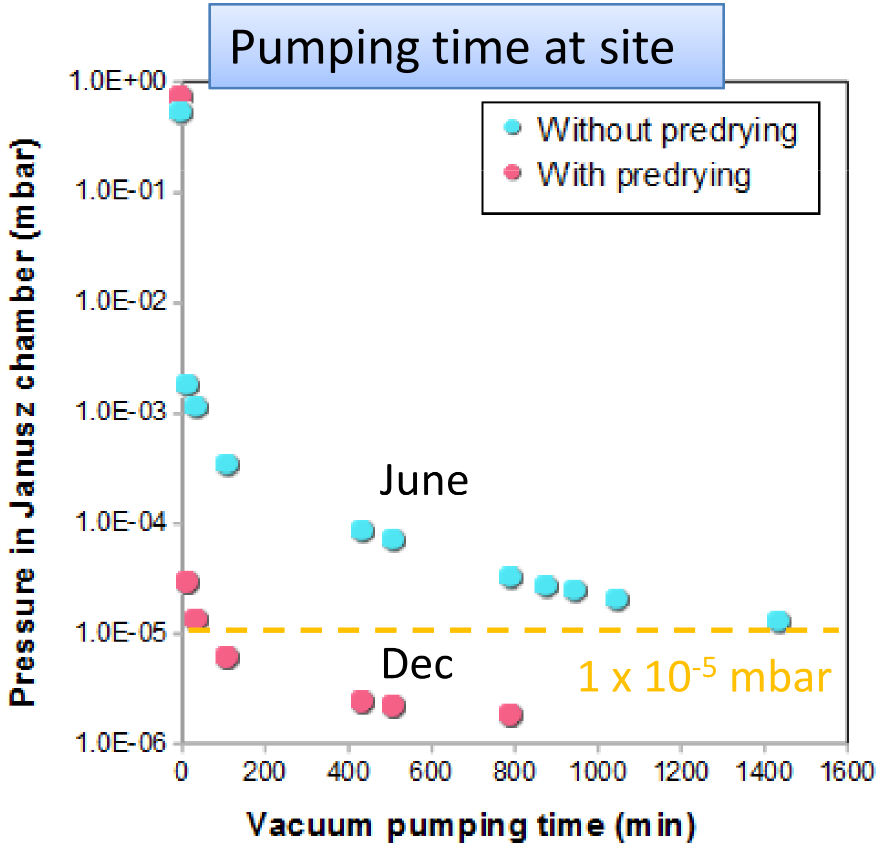


Resulting intrinsic resolution = 58nm

- This is good, similar to standard film (50nm)
- There may be possible contributions
  - Measurement error (5nm by x100 objective, 10nm by x50 objective)
  - Optical distortion
  - Contamination of very short delta-rays (single grain)
  - Scattering of the track itself (~ 300 MeV pions)
  - Due to glycerin. After glycerin washed away, there might be bigger rooms that silver filaments can grow more freely in the development process

Improvement of evacuation speed by pre-drying

- Film pre-dried in vacuum in Bern
  - improve detection efficiency by controlling dry level
  - shorter vacuum pumping time in Janusz chamber



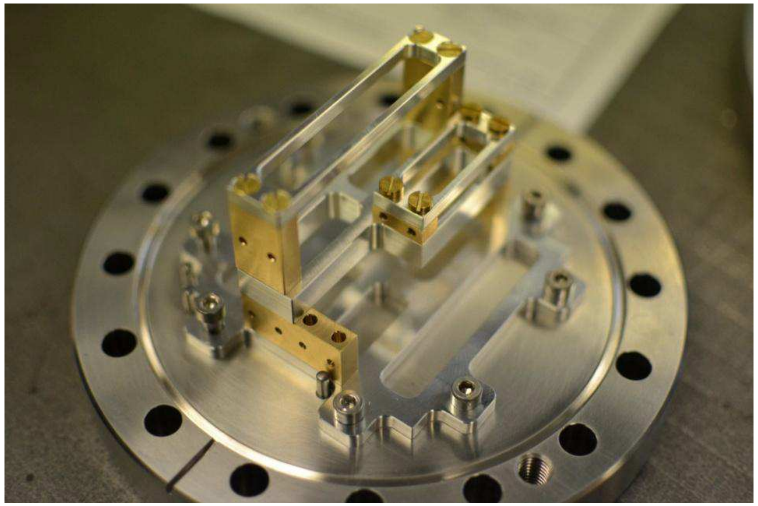
Sample

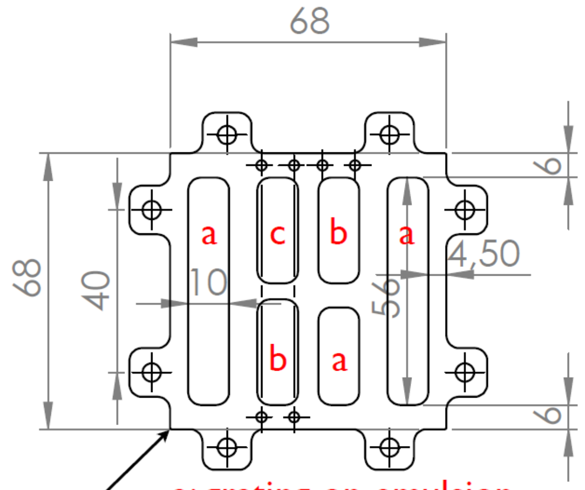
68 x 68 mm^2 x 5 films

- Without pre-drying
  - glycerine density: 17 %
  - dipping for 60 min
- With pre-drying
  - glycerine density: 12 %
  - soaking emulsion for 60 min
  - predrying time: 2 day

Data taking in mini-moiré sample

- Proof of principle
- Automatic measurement not used (due to chemical induced BG)
- Eye measurement
  - In (b) region with 2 moiré gratings
  - **47** vertices detected in 3 hours within 0.16 cm^2





Emulsion on glass base

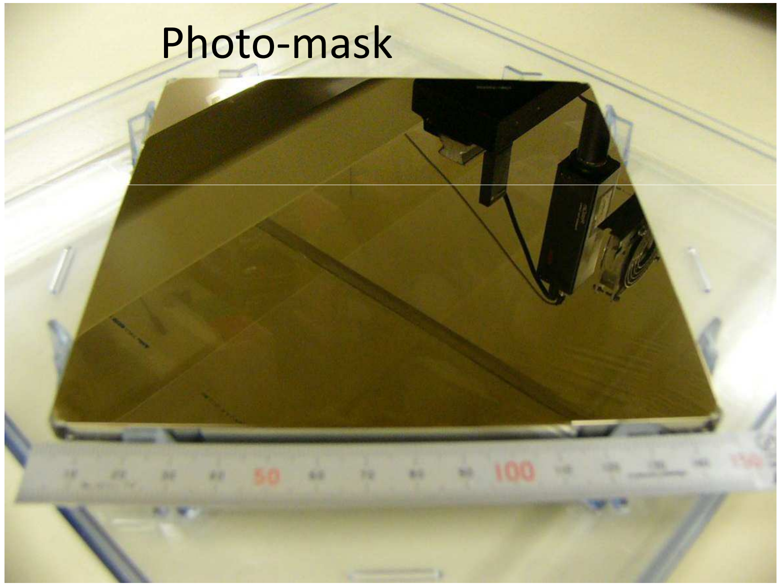
- Minimize systematics from expansion of emulsions
- Smaller expansion factor (measured)
  - Plastic base: 11 μm/cm
  - Glass base: less/equal 0.4 μm/cm
- Smaller thermal expansion

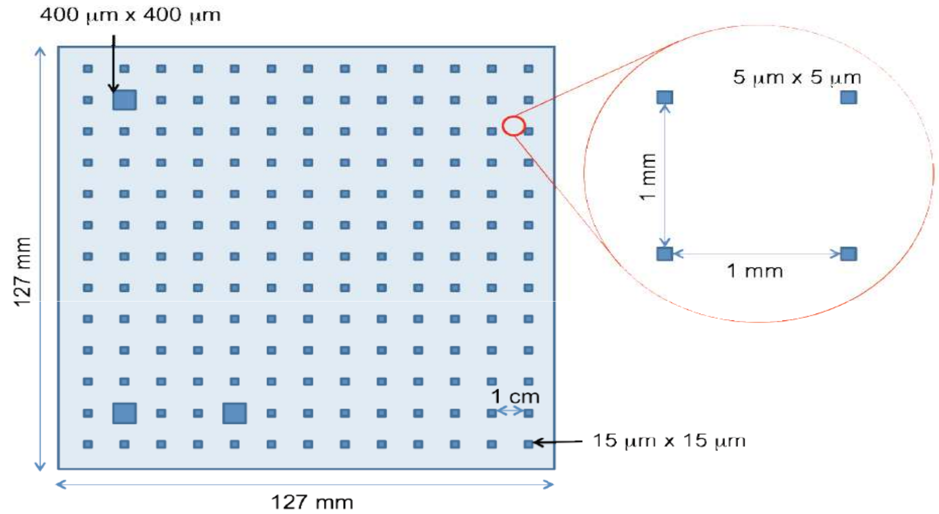
	Thermal expansion coefficient (/K)
Acrylic	**~ 10^{-4}**
Glass	**~ 5×10^{-6}**

- Production and test of emulsions on glass ongoing

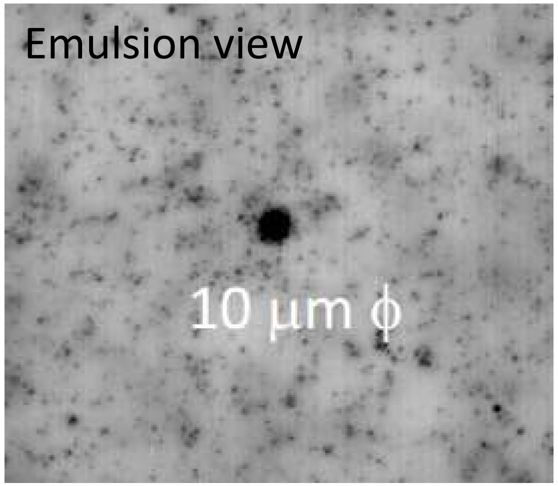
Study of film expansion

- Emulsion film can change its size after photo-development
- Pattern of marks printed on OPERA films by photo-mask



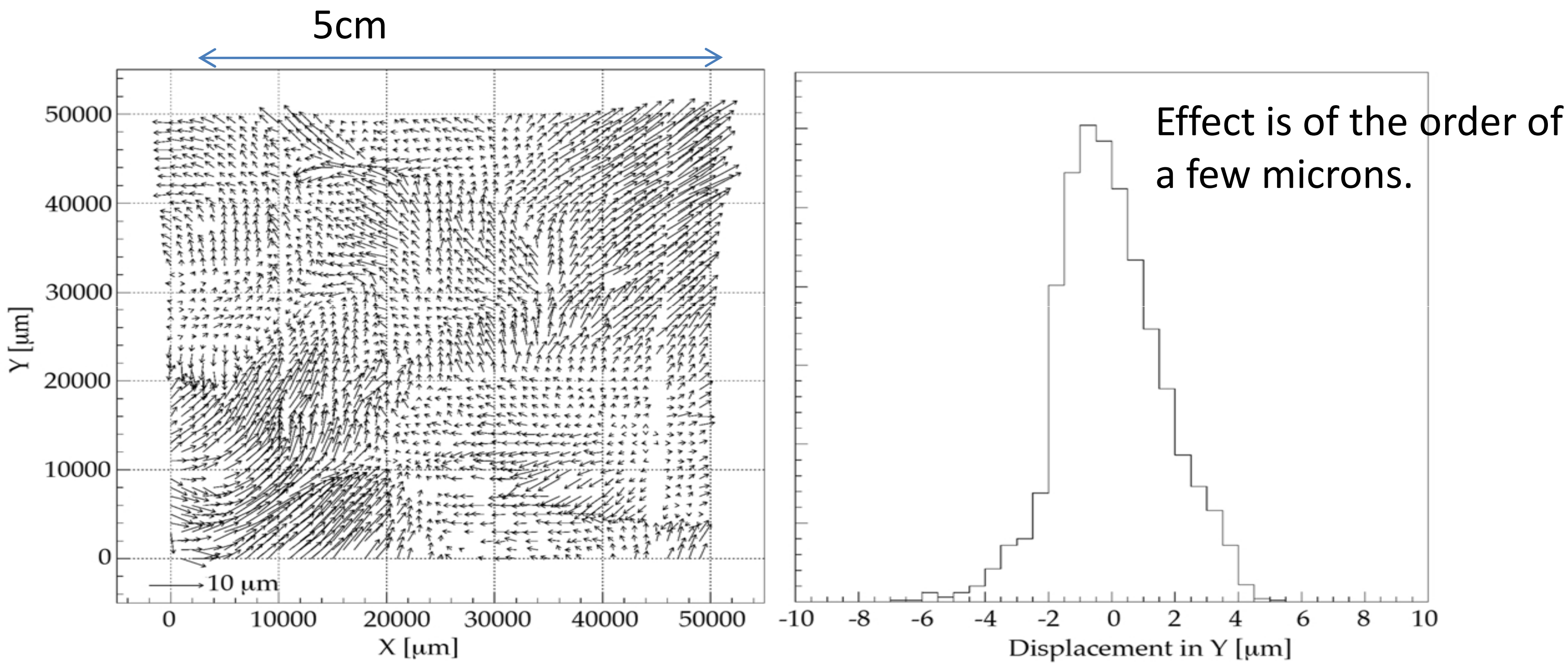


A dot is printed every 1 mm.



Measured expansion pattern

- Measured expansion factor is 11 μm/cm
- Local displacement from photo mask and emulsion shown as arrows

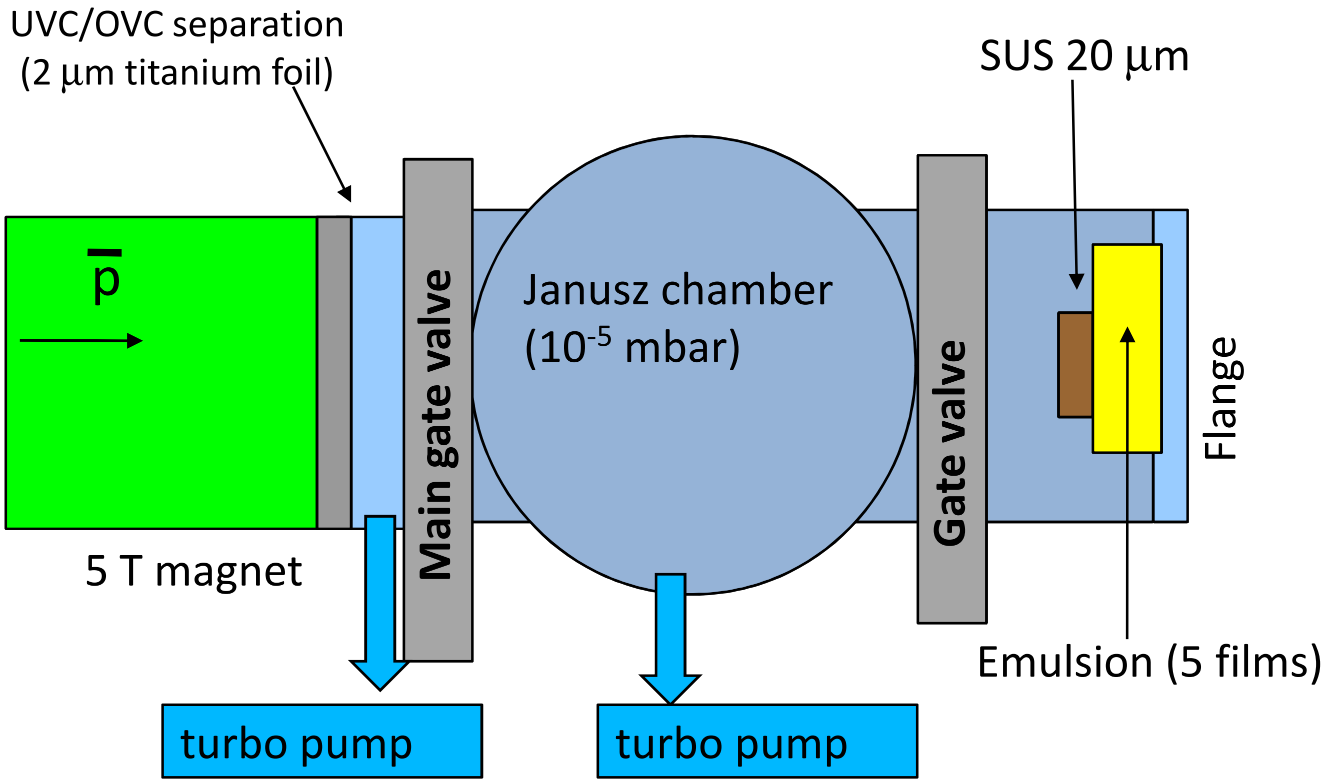


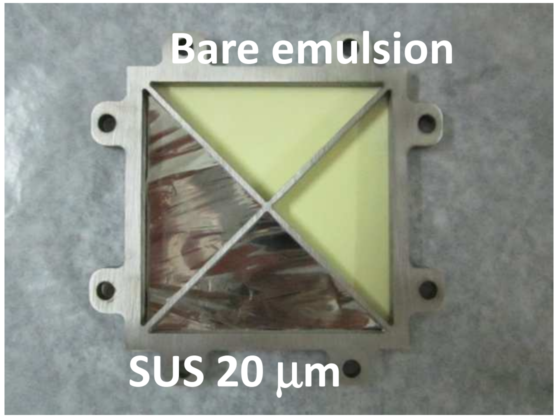
- Local displacement under control (1 μm) by photo-mask patterns
- More rigid base (glass) instead of plastic base

Detector setup

(also in December)

- Emulsion : (68 mm x 68 mm x 0.3 mm) x 5 films
- Target : stainless steel (SUS) 20 μm thick / bare emulsion.

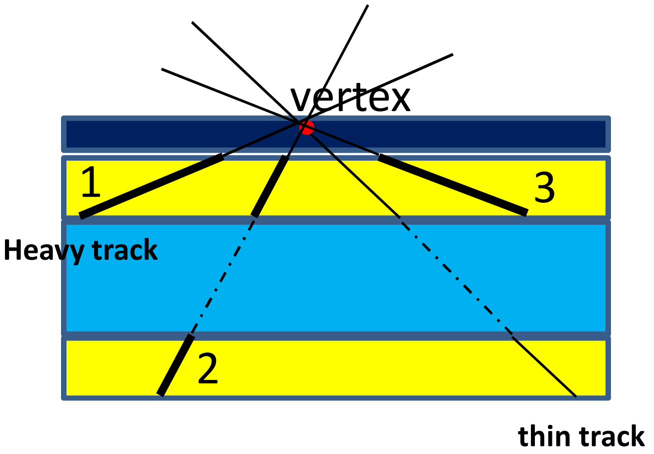




Heavy ionizing tracks multiplicity

MC(CHIPS model) comparison

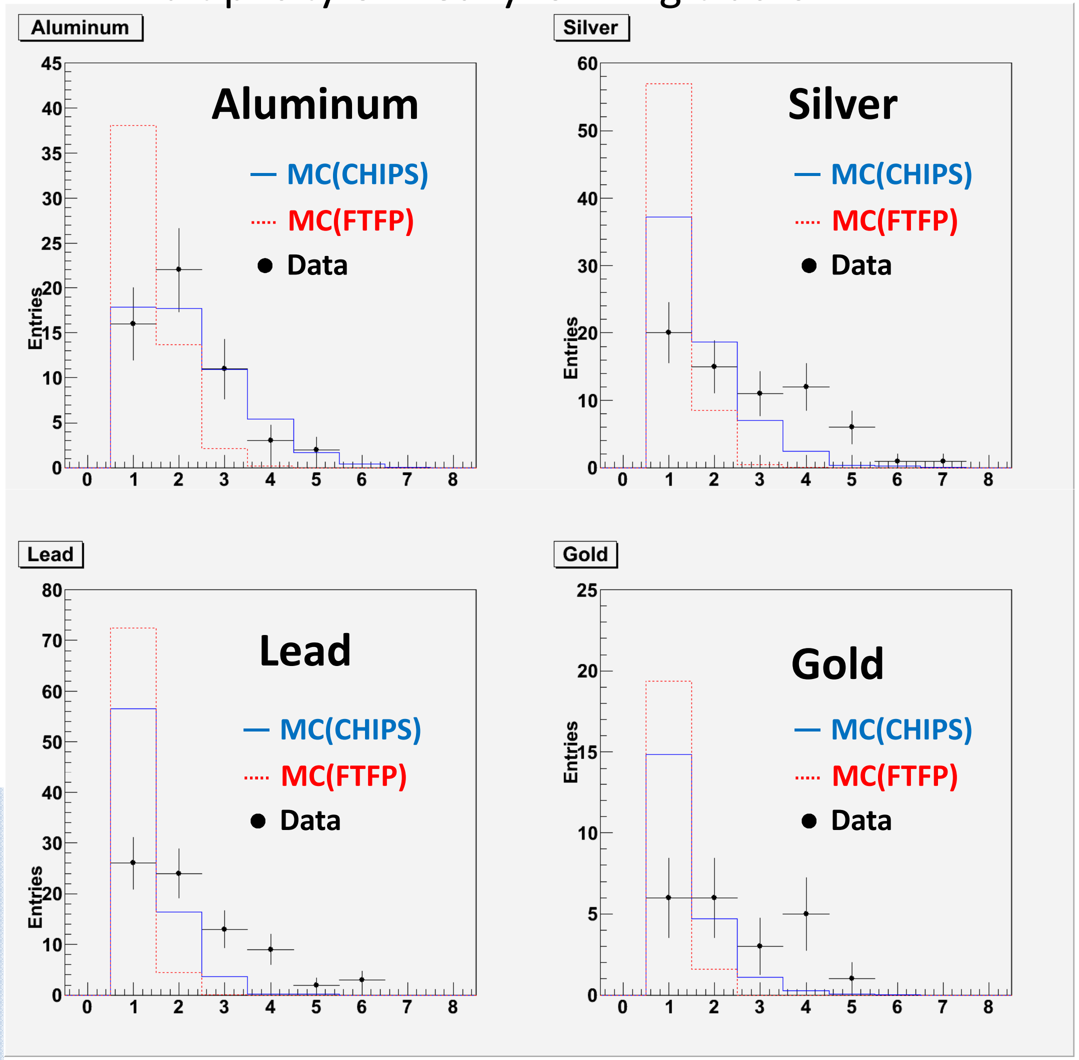
- Require at least 1 thin track, and 1 heavy track



Vertex location is done by 1 thin track and 1 heavy track.
→ Then, all heavy tracks were counted.

Here in **MC** simulation,
-100% efficiency for heavy ionizing tracks is assumed.
-Heavy ionizing means **dE/dX>2.0MeV/[g/cm²]**

Multiplicity of Heavy ionizing tracks

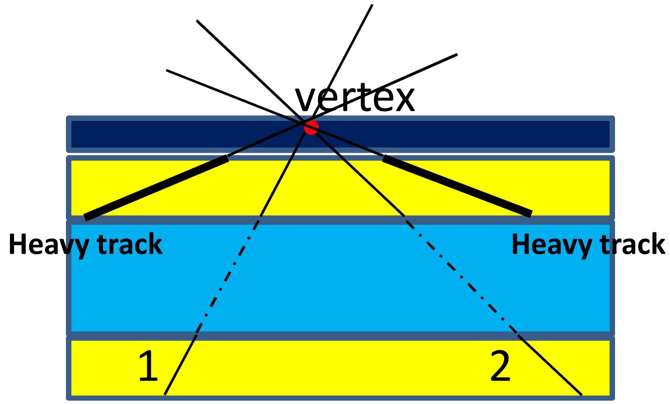


- Normalized to number of events(data)
- Slope acceptance 0.1 < tanθ < 3.0

Minimum ionizing tracks multiplicity

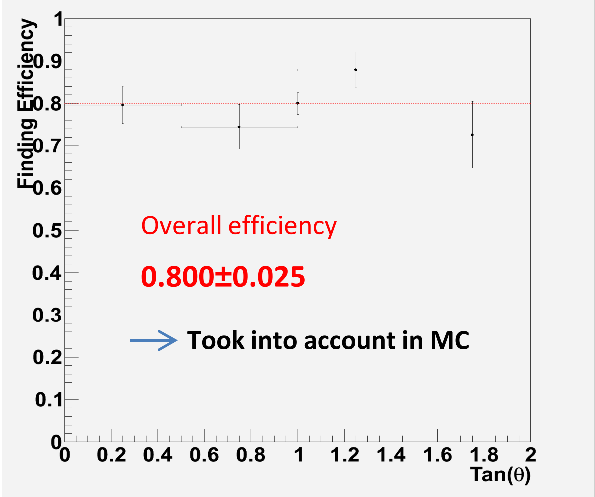
MC(CHIPS model) comparison

- Require at least 2 heavy track

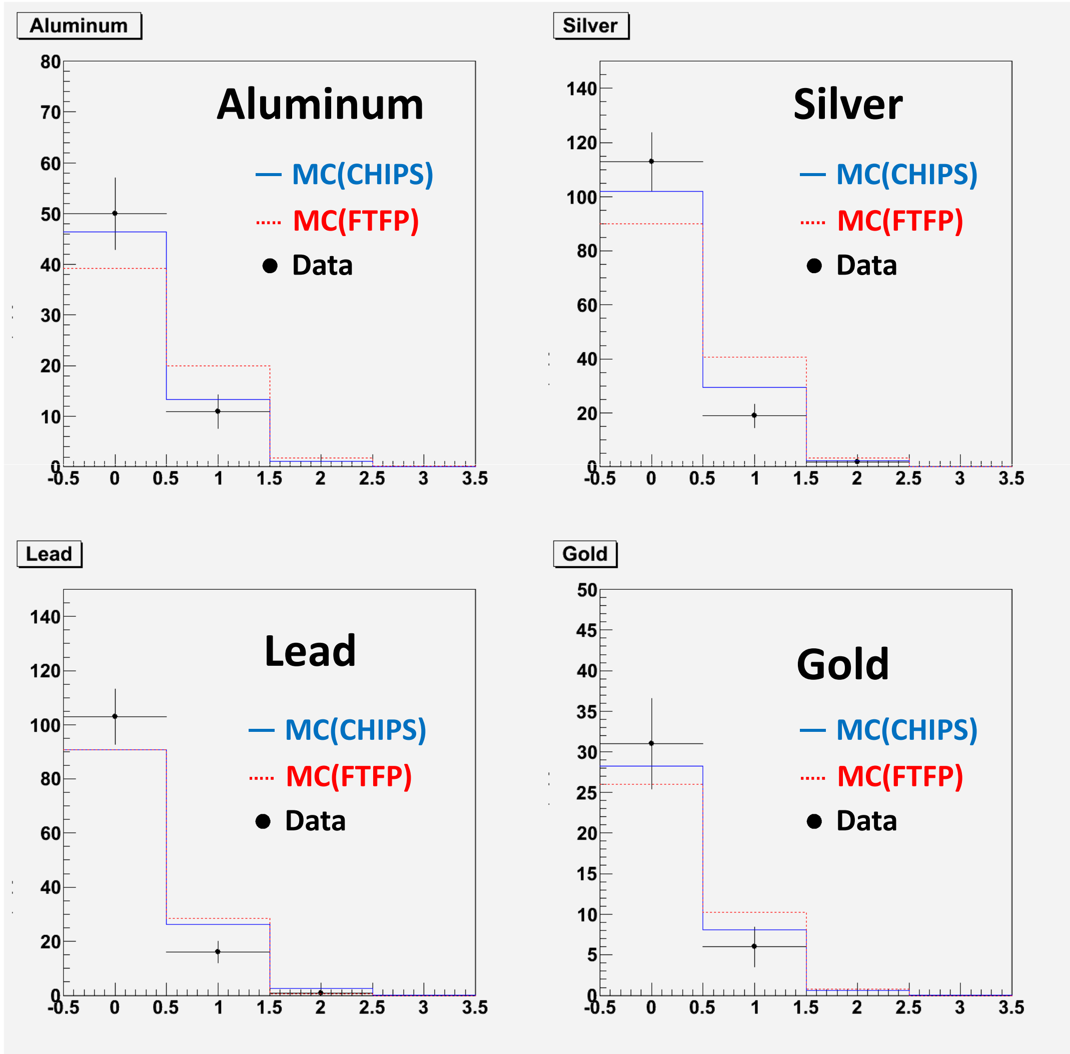


Vertex location is done by heavy tracks.
→ Then, all MIP tracks were counted.

MIP track finding efficiency

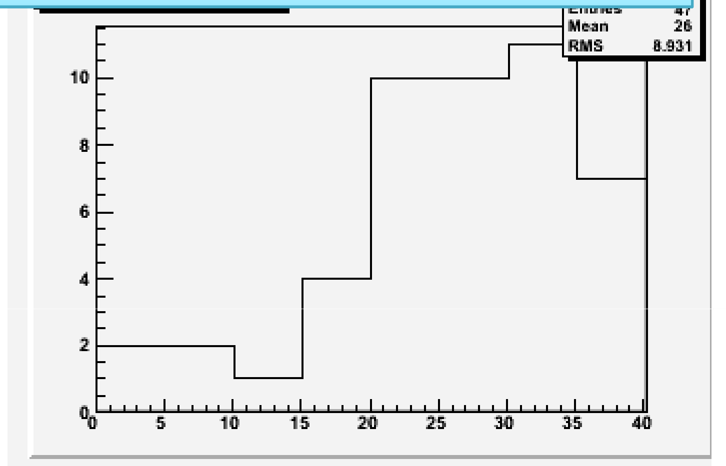


Multiplicity of Minimum ionizing tracks



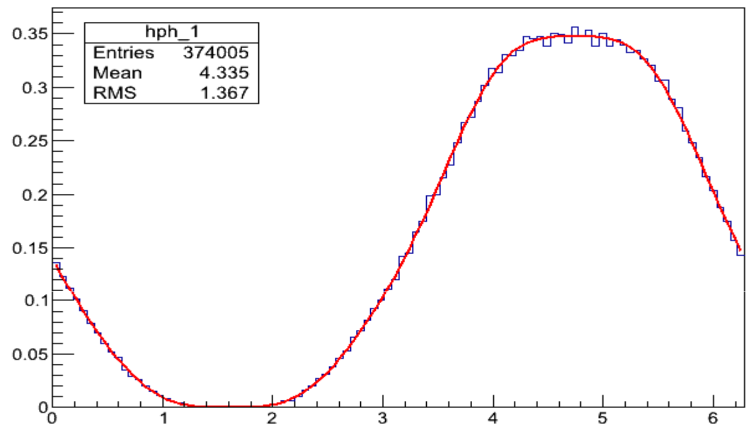
- Normalized to number of events(data)
- Slope acceptance 0.1 < tanθ < 3.0

Data folded in period
(after rotation and expansion correction)



Y folded in a pitch (μm)

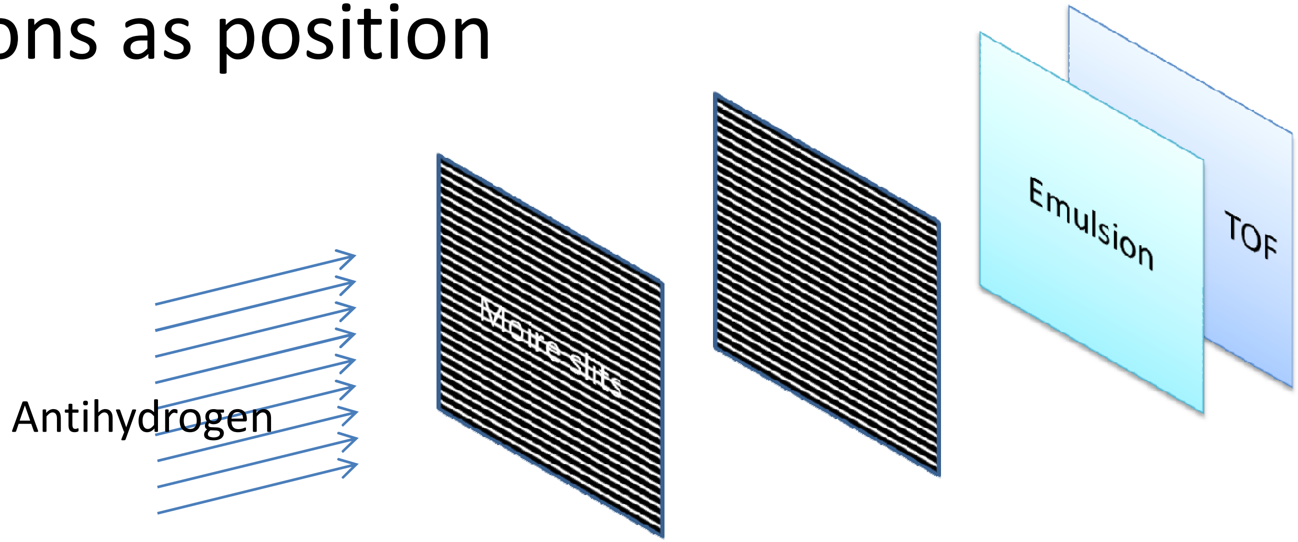
MC (from C. Pistillo)



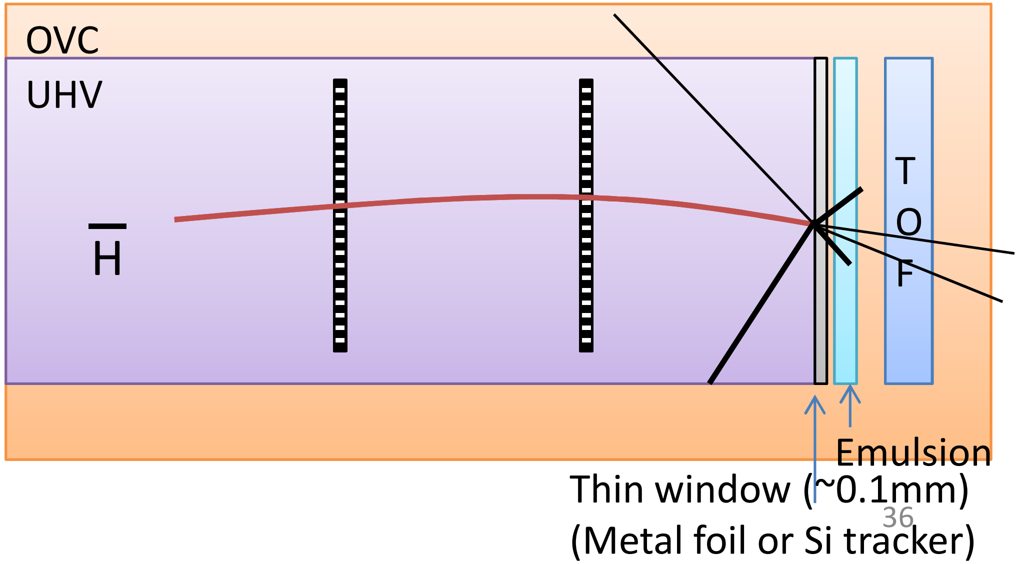
period (rad)

Emulsion for in the AEgIS

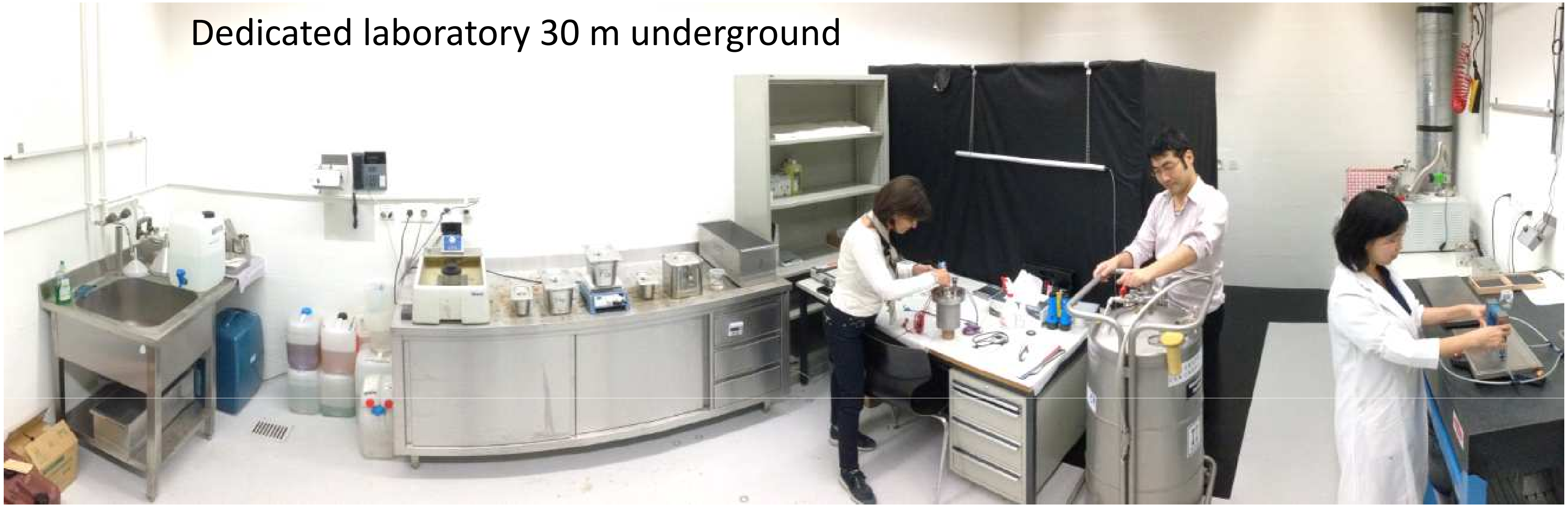
- Use emulsions as position detector



•Ideal position resolution down to a few microns.
•Emulsion to be placed in OVC



Setup at LHEP, Bern

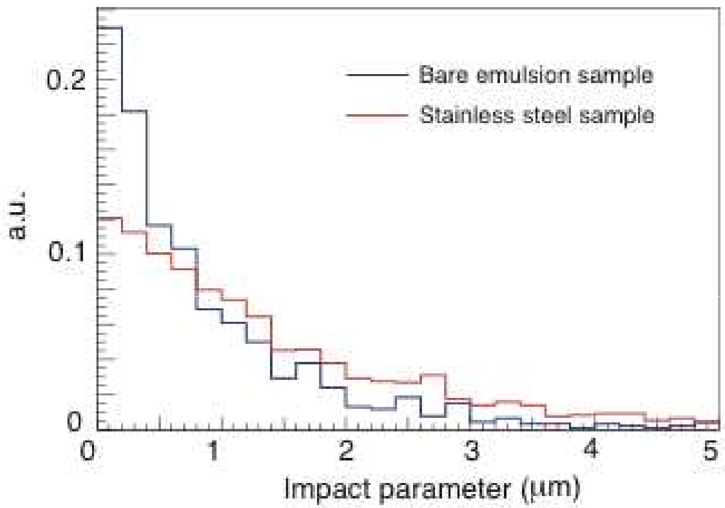


Dedicated laboratory 30 m underground

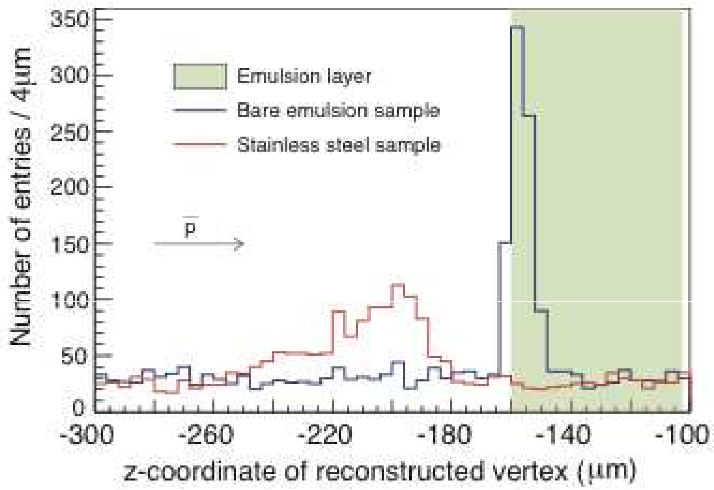
Low temperature tests for emulsion is now continued in Bern

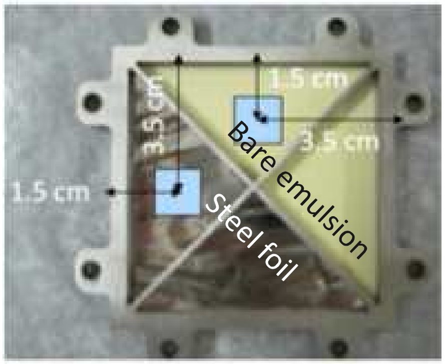
Annihilations vertex resolution

Vertex resolution



Vertex resolution perpendicular to the emulsion surface

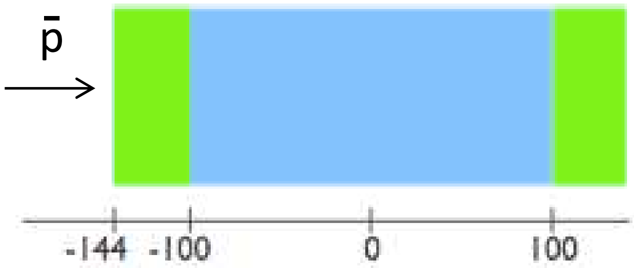


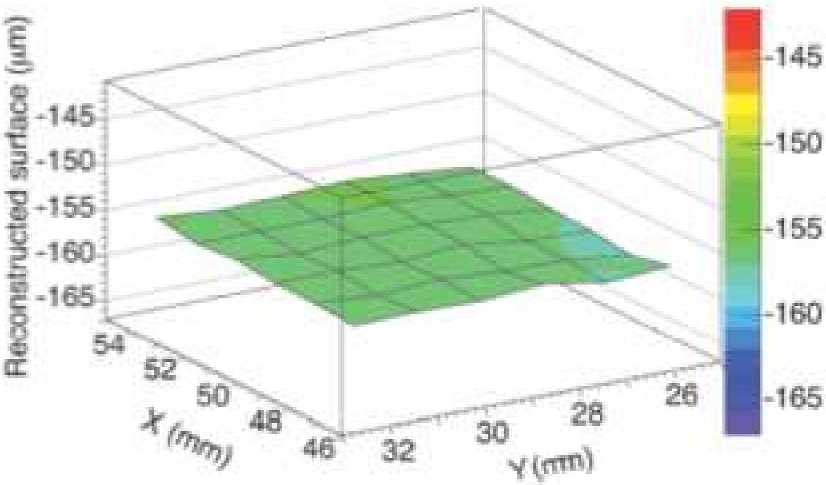


1 μm rms resolution on the vertical position of the annihilation vertex is achievable

Topography of the emulsion and stainless steel foil

Bare emulsions





Emulsions + stainless foil