EMULSION CLOUD CHAMBER STATUS

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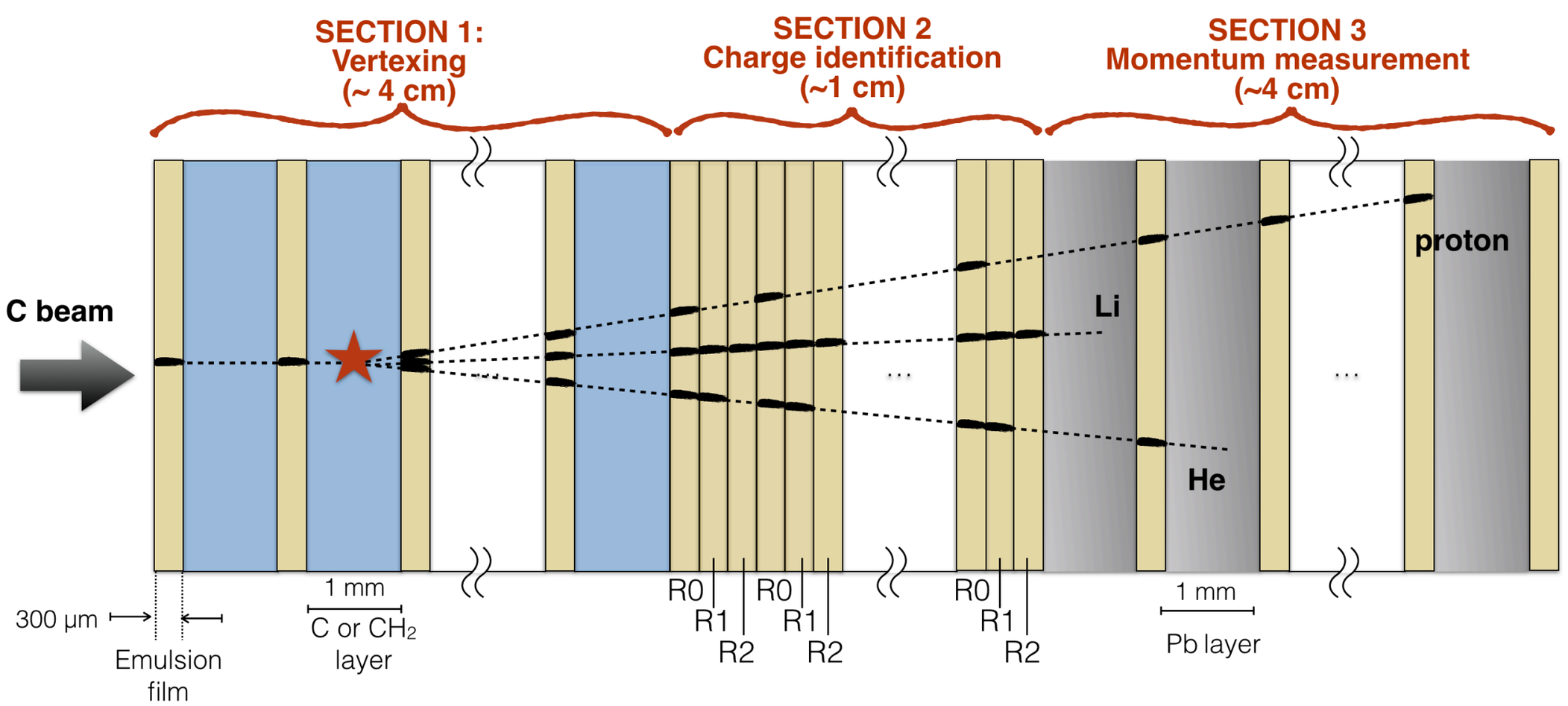
Napoli University and INFN

FOOT General Meeting
Bologna, 4th-5th December 2017

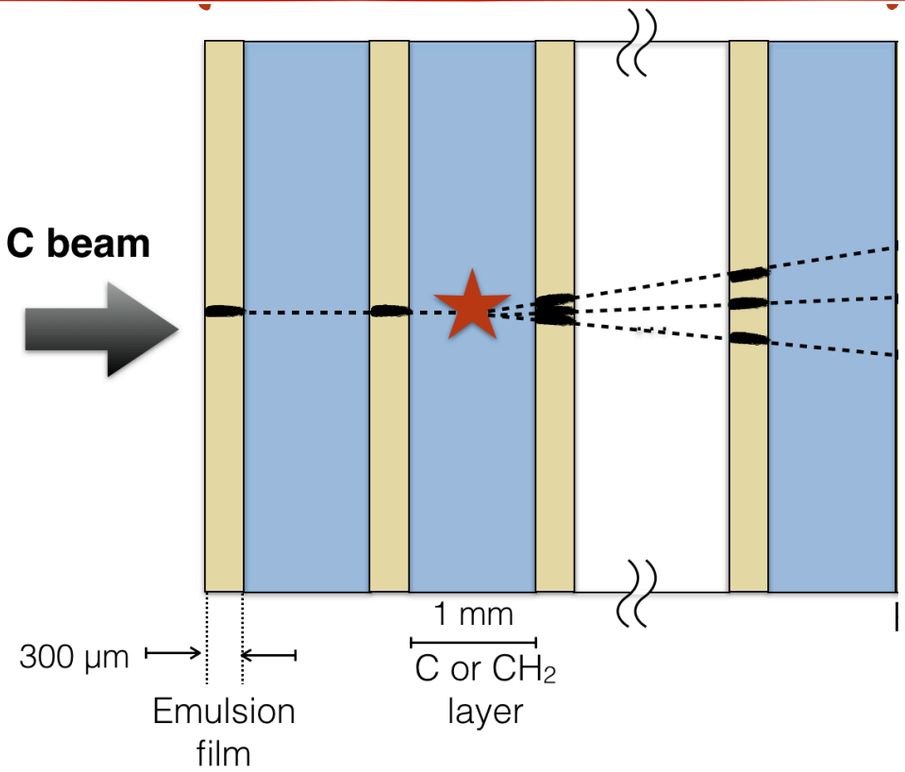
DETECTOR STRUCTURE

The Emulsion Cloud Chamber detector is made of three sections

- **SECTION 1**: alternated layers of emulsion films and target (C/C_2H_4)
  - Vertex detector
  - Tracking of all charged particles
- **SECTION 2**: emulsion films only
  - Charge identification for low Z fragments
- **SECTION 3**: alternated layers of emulsion films and passive material (Lead/Steel)
  - Momentum measurement by range and Multiple Coulomb Scattering (MCS)
  - Isotopic identification



SECTION 1: Vertex



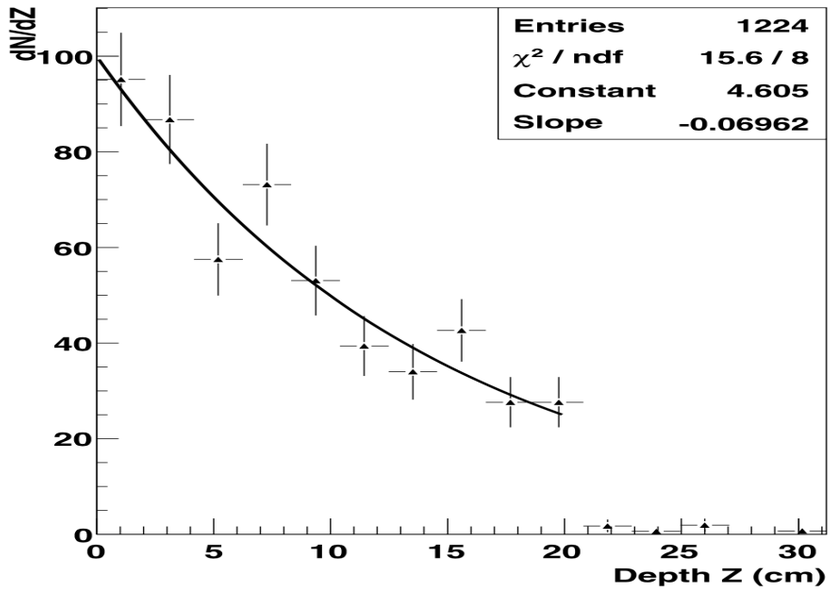
- Alternate target layers of C or C_2H_4(1 mm) and emulsion films (300 µm)
- Vertex detector and particle tracking
- Chamber thickness defined by the interaction length to obtain a sufficiently high number of interactions
- Current layout
  - 30 cells (30 emulsion films)
  - 39 mm

ACTIVITIES IN 2017:

1) Order of 25 Carbon plates
   - Dimensions: (12.5 x 9.9 cm^2)
   - Thickness: 1mm
   - Company: Goodfellow
   - Purity: 99.95 %
2) Order of 25 High Density C_2H_4 plates
   - Dimensions: (12.5 x 9.9 cm^2)
   - Thickness: 1mm
   - Company: Goodfellow

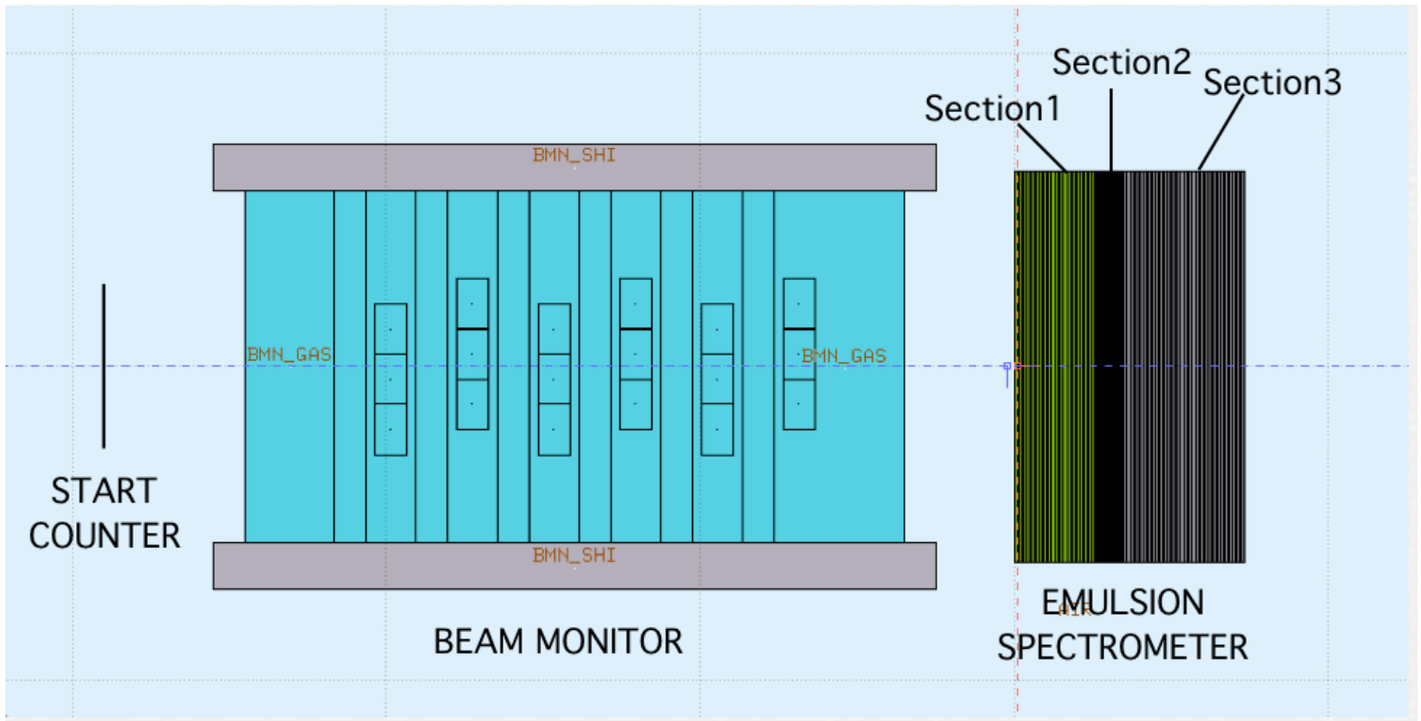
SHORT TERM PLAN:

1) Optimization of the layout with simulations



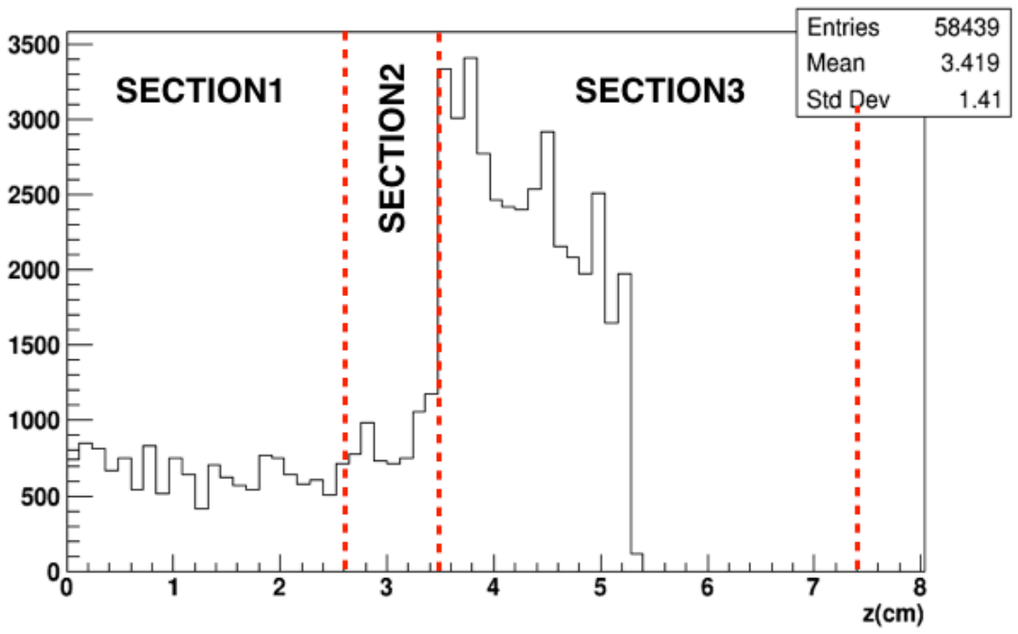
- 20% of 400 MeV/n Carbon ions interacting in 3 cm Lexan
- *G. De Lellis et al. Nucl. Phys. A 853 (2011) 124-134*

FLUKA SIMULATION

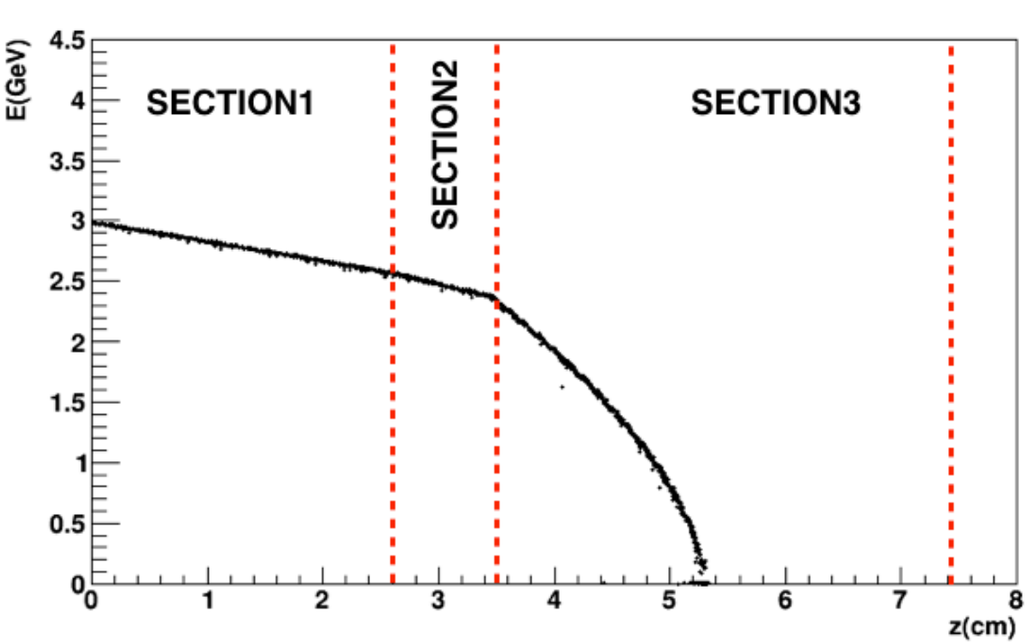


- ECC structure implemented by S.M. Valle and G. Battistoni
- Preliminary results in CDR using ^{12}C beam (250 MeV/u) with FWHM = 1 cm

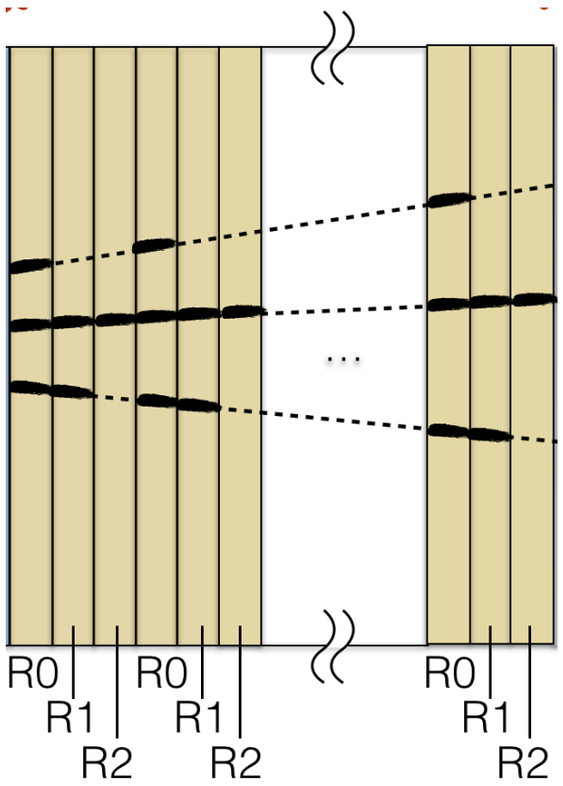
- Position of C interaction vertex along beam axis



- Final kinetic energy of C as a function of the depth



SECTION 2: Charge



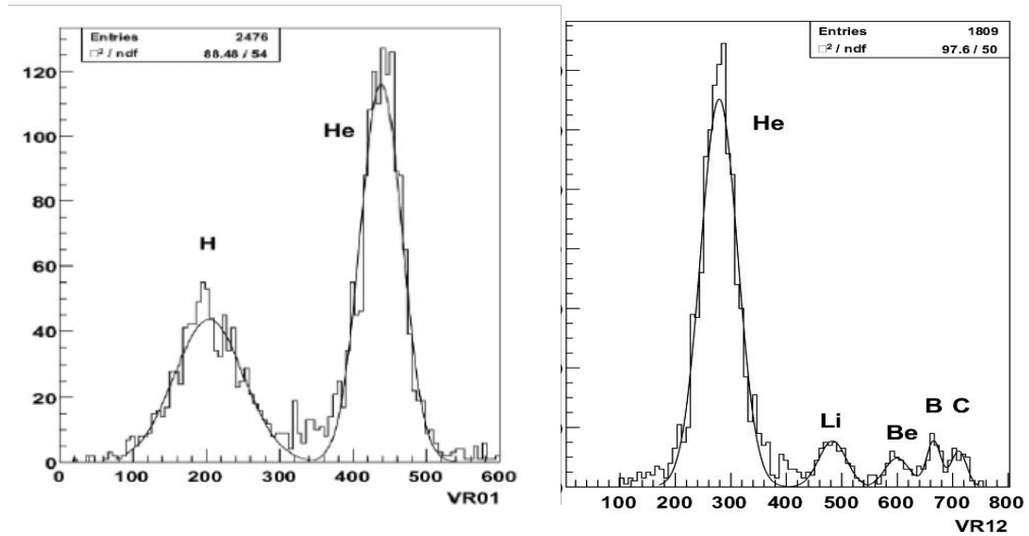
- Charge identification for low Z fragments (H, He, Li)
- Emulsions will have a different thermal treatment (refreshing) according to the position in the elementary cell
- **R0:** not refreshed
  - ➔Sensitive to m.i.p. and Z>=1
- **R1**: appropriate refreshing for protons
  - ➔Sensitive to Z>=2
- **R2**: appropriate refreshing for He
  - ➔Sensitive to Z>=3
- Current layout: 9 cells (27 emulsion films)

ACTIVITIES IN 2017:

1) Installation and commissioning of refreshing machine @LNGS
2) Test beam @LNS
3) Refreshing and chemical treatment of exposed samples
4) Scanning and preliminary analysis of exposed samples

SHORT TERM PLAN:

1) Finalize the analysis of data from LNS test beam
2) Test beam @Trento in December 2017
3) Refreshing and chemical treatment of exposed samples
4) Scanning and analysis of exposed samples

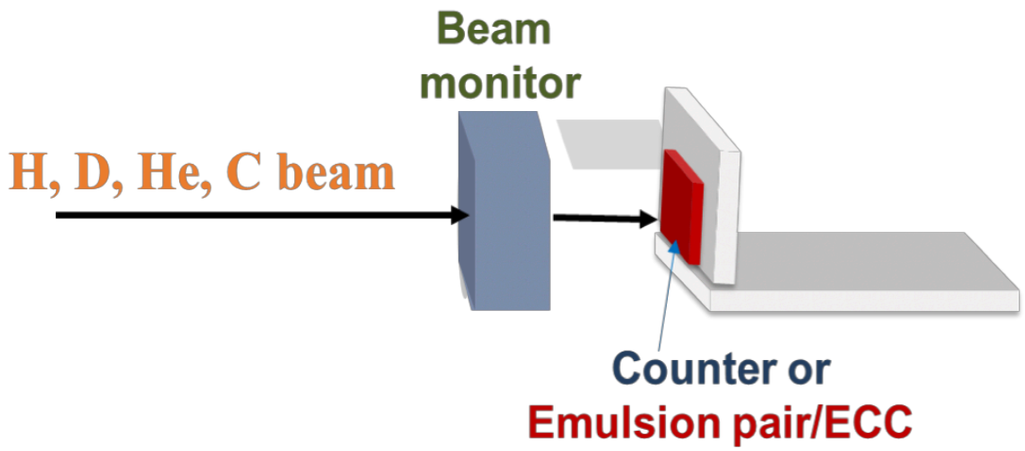


- Identification of the secondary nuclei produced by fragments on of 400 MeV/n ^{12}C achieved with high significance
- *G. De Lellis et al. JINST 2, 2007, P06004*

SECTION 2: Test beam @LNS

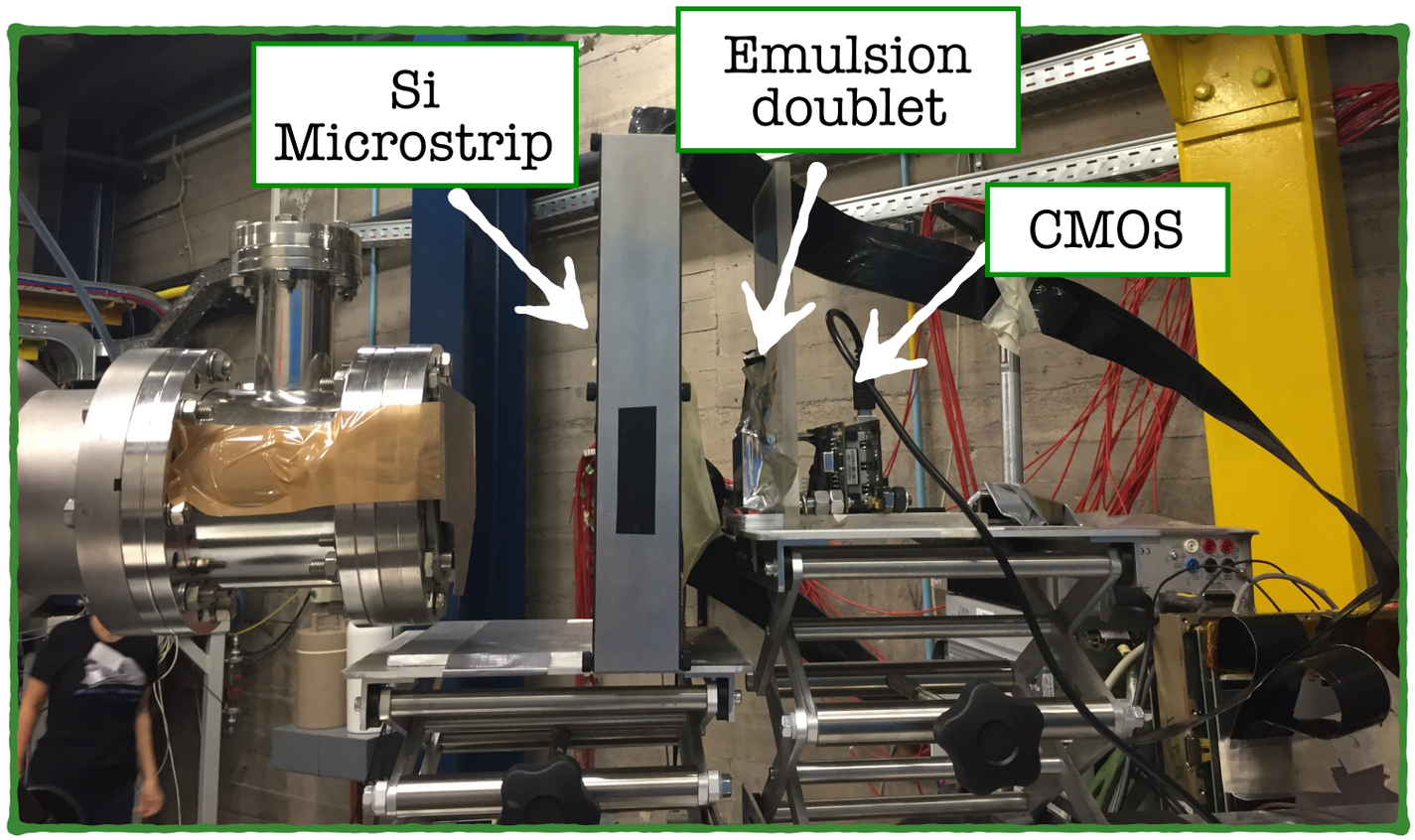
Motivation:

- New nuclear emulsions (Nagoya production) will be used in the FOOT experiment, never used for particle identification
- Test of different refreshing procedures to define the working point for particle identification



Beam Monitor by the Perugia group: silicon microstrip detector (strip pitch 250 μm, thickness 350 μm, total area 8x8cm^2)

Counter by the Perugia group: beam intensity registered by a CMOS detector (up to 3 MHz)



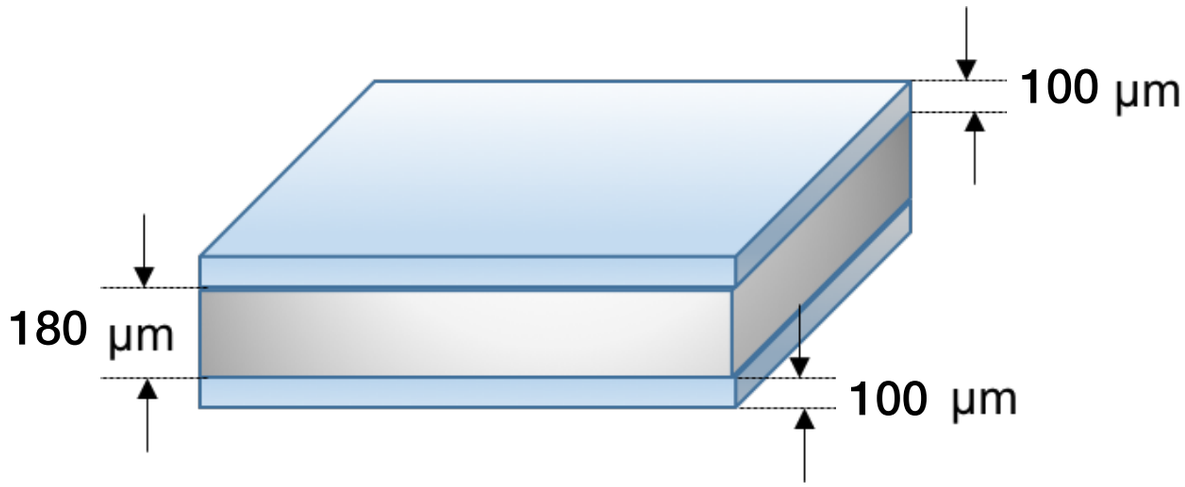
Main difficulties coped with:

- Make the beam uniform over the emulsion surface
- Reduce the beam intensity down to 10 particles cm^2
- No online monitoring, needed for normalization

EMULSION FILMS: Production & Exposure

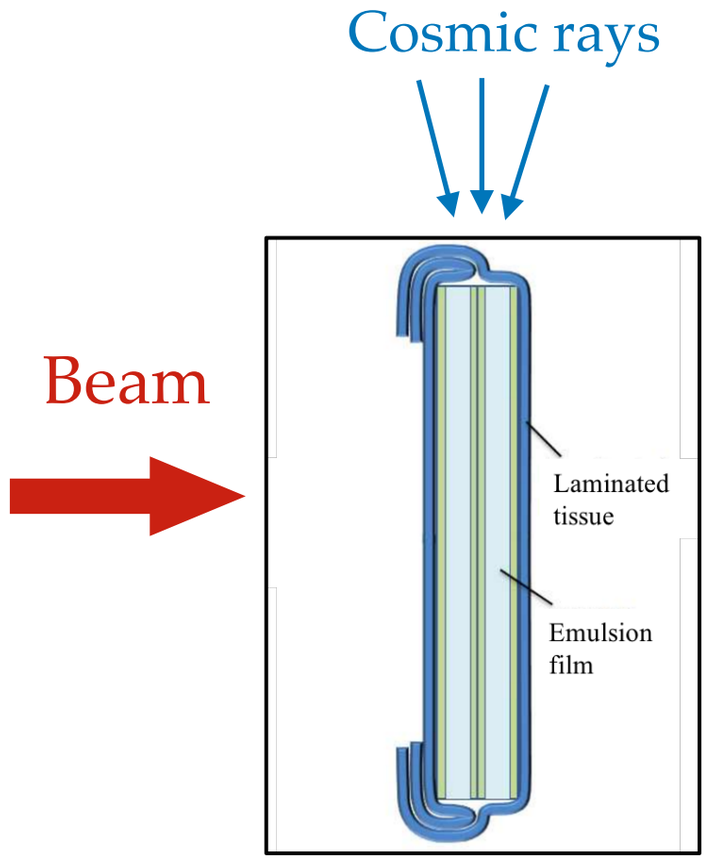
1) Production @Nagoya University

- Emulsion films produced in **Nagoya University** in May 2017
- Film dimensions:
  - Surface: 125 mm x 100 mm
  - Total thickness: 380 μm
    - Emulsion Layers: 2x100 μm
    - Plastic Base: polystyrene : 180 μm



2) Exposure @LNS

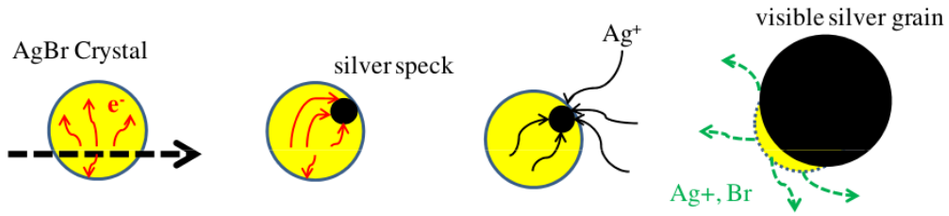
- Surface of exposed emulsion samples: 5x4 cm^2 (1/4 of emulsion film)
- One sample made of 2 consecutive emulsions enveloped in laminated tissue under vacuum
- Beam particles orthogonal to emulsion surface
- Four particle beams (H, D, He, C) @80 MeV/u
- Five exposures per beam, each treated with different refreshing procedure

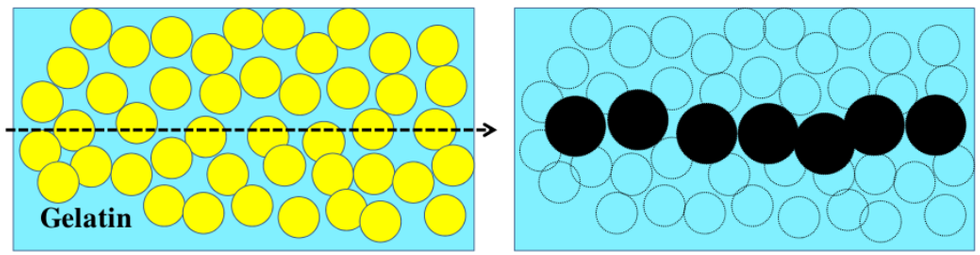


EMULSION FILMS: Treatment

3) Refreshing and chemical treatment @LNGS

- Treatments performed in the Emulsion Facility in Underground Gran Sasso Laboratories
- Climatic chamber GENVIRO 120L used for refreshing procedure





Sensitivity:

50 grains / 100 μm

	No refreshing	28°C	34°C	36°C	38°C
H (80 MeV/u)	✓	✓	✓	✓	✓
D (80 MeV/u)	✓	✓	✓	✓	✓
He (80 MeV/u)	✓	✓	✓	✓	✓
C (80 MeV/u)	✓	✓	✓	✓	✓

- Refreshing conditions used:
  - Temperatures from 28°C to 38°C
  - Relative humidity: 98%
  - Refreshing time: 24h

*same ionization as Li (200 MeV / u)

✓ Analysed

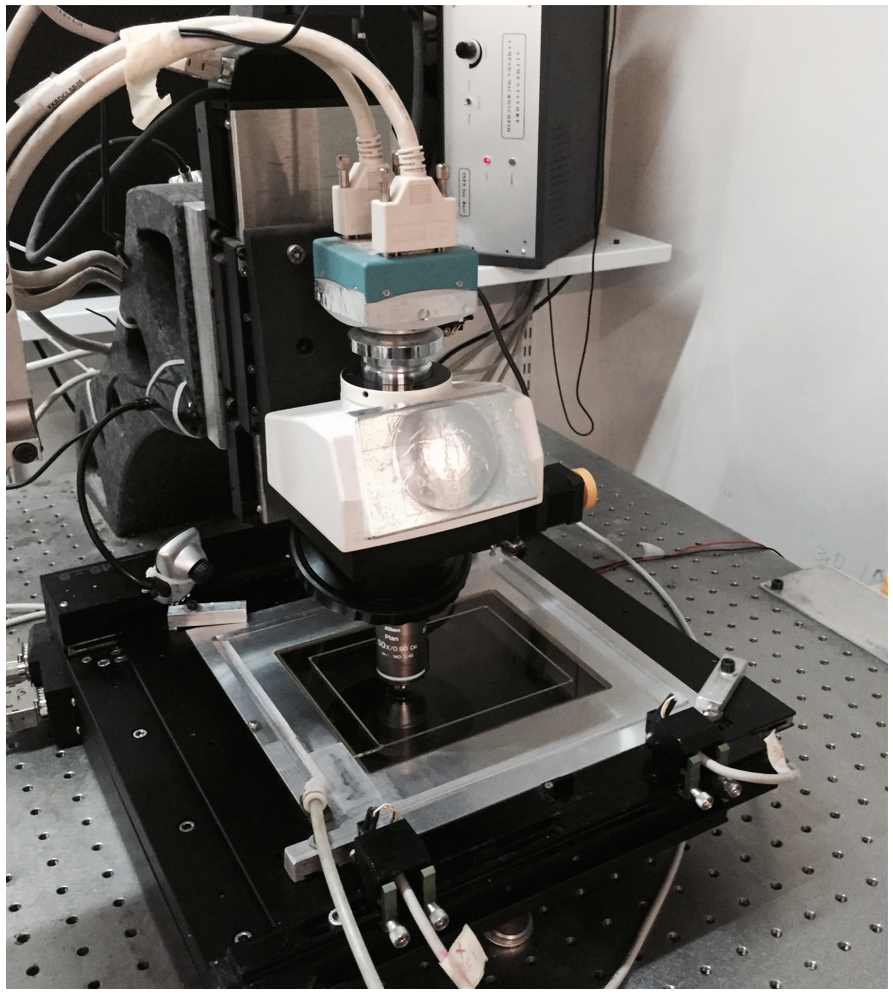
EMULSION FILMS: Data acquisition

4) Scanning with optical microscope @Napoli

- Data acquisition performed with fully automated optical microscopes

SCANNING SYSTEM CHARACTERISTICS

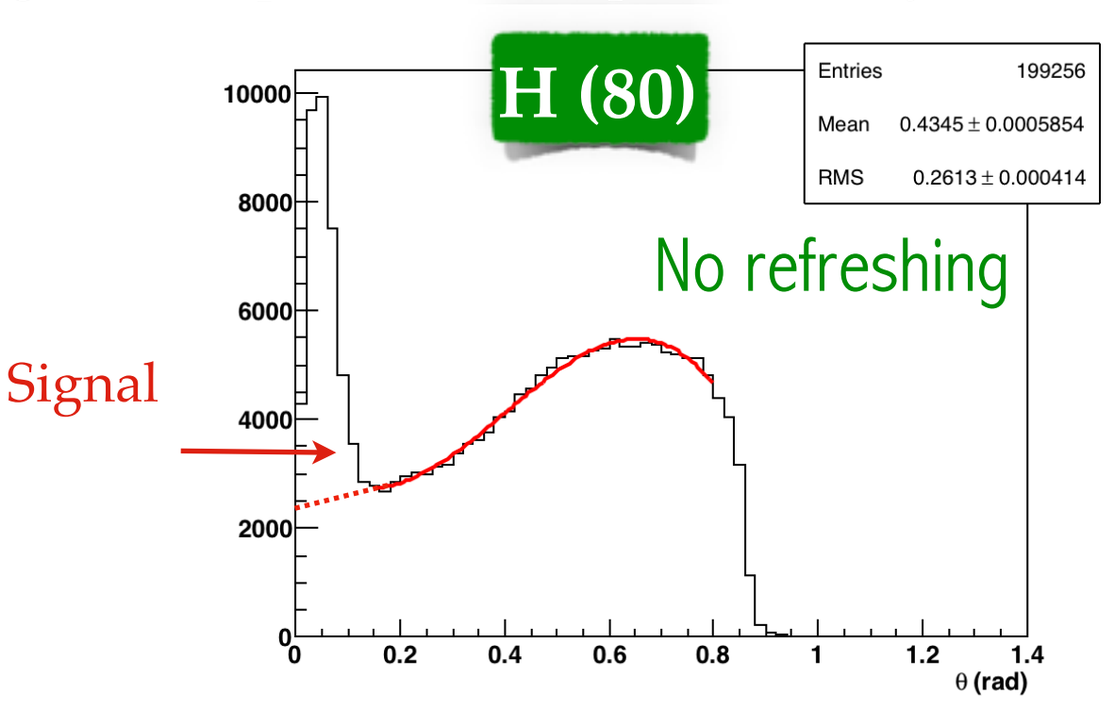
- New reconstruction software to extend track recognition angular acceptance from $\theta = 30°$ to $\theta = 72°$
- Software: LASSO in Continuous Motion mode
- Development a new generation Scanning System with new hardware. Extension of the scanning speed from 20 cm^2/h to 190 cm^2/h

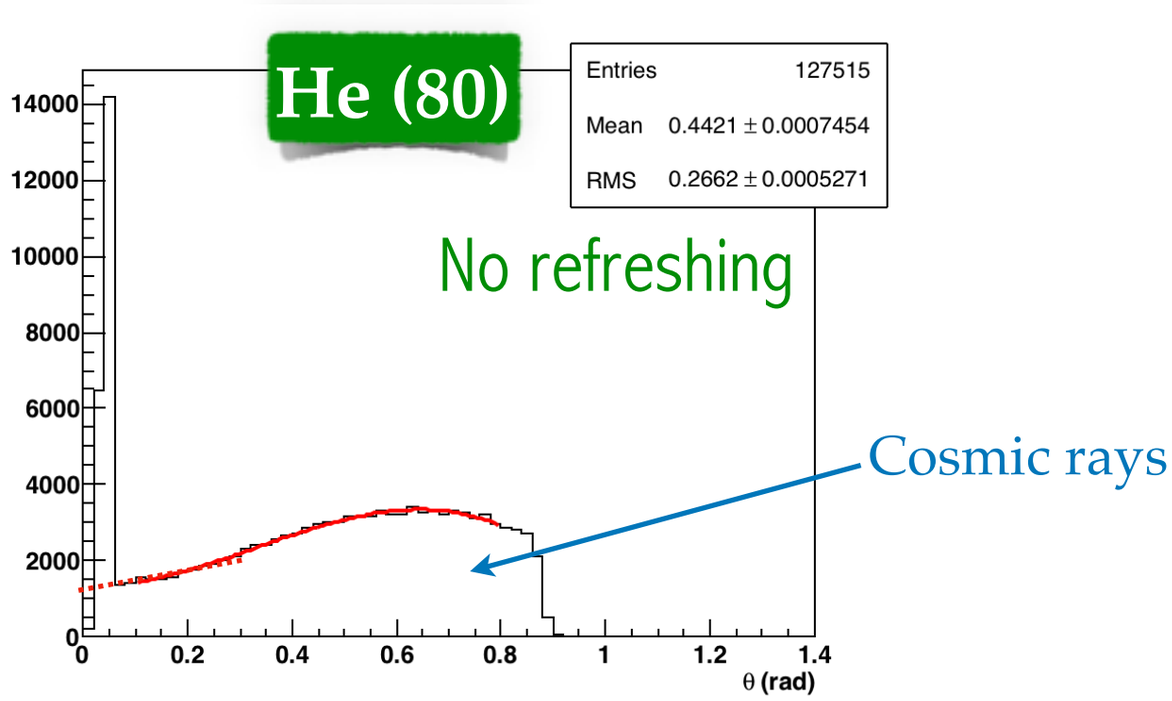


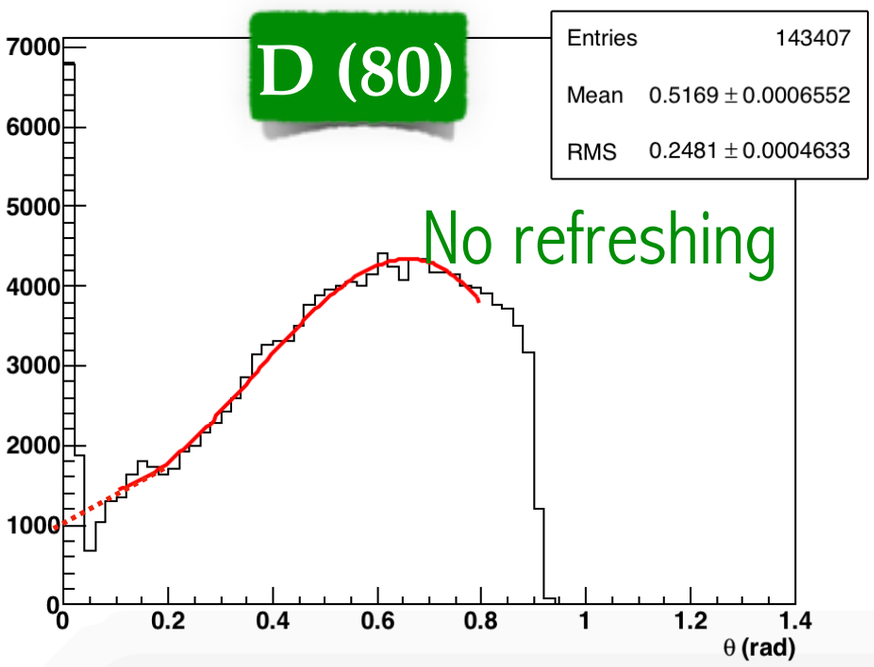
- [1] A. Alexandrov et al., JINST 10 (2015) no.11 P1100
- [2] A. Alexandrov et al., Nature Scientific Reports **7** (2017) 7310

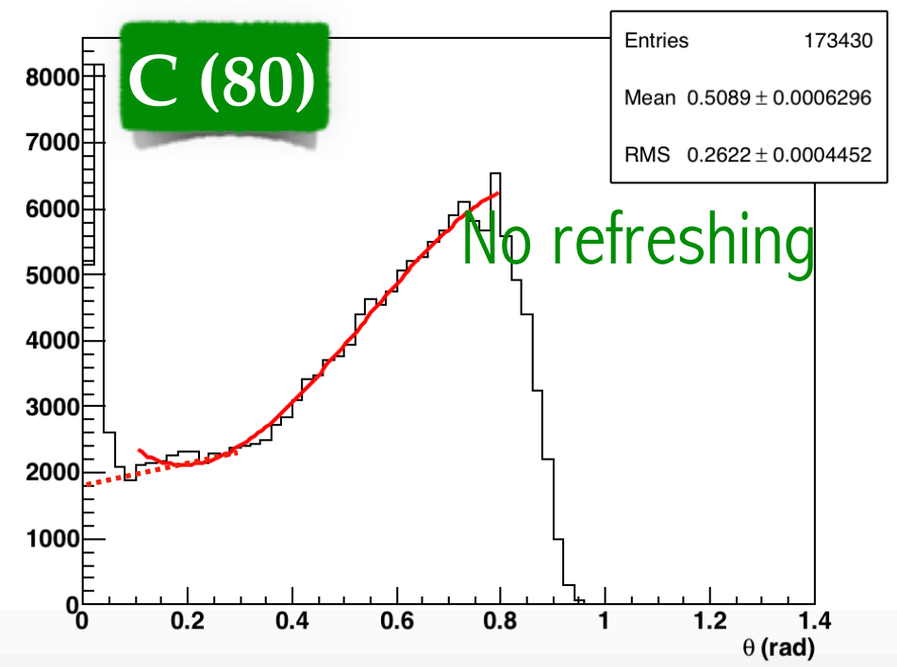
EMULSION ANALYSIS: Signal selection

- Emulsion films integrates cosmic rays passing through them from production to development (~2 months)
- Signal tracks perpendicular to emulsion films (θ<0.1 rad)
- Angular acceptance for the present analysis: θ<1 rad





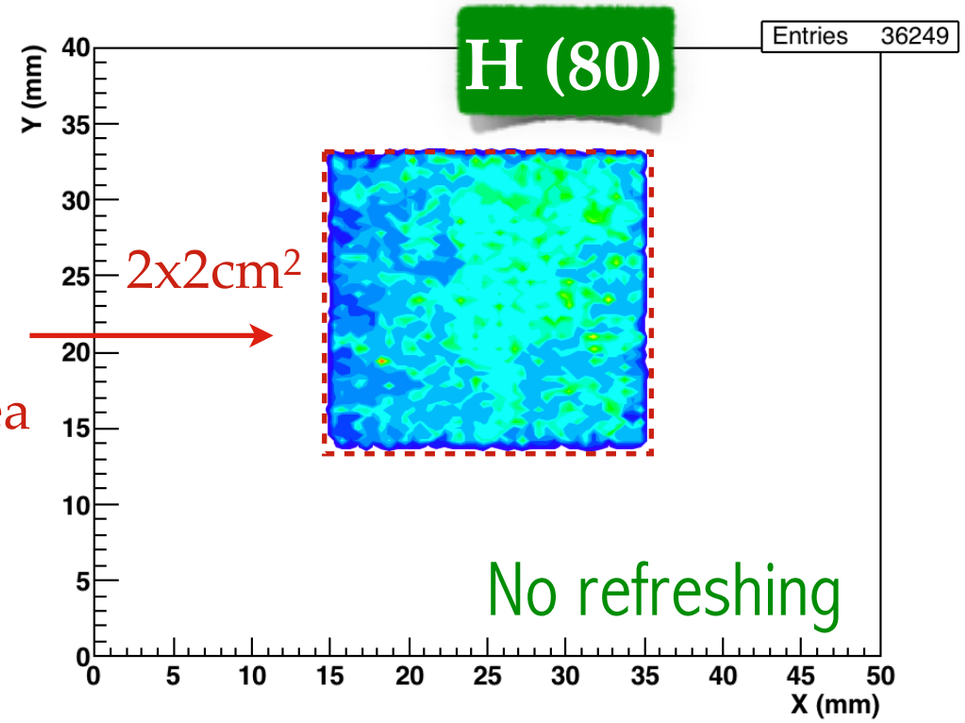


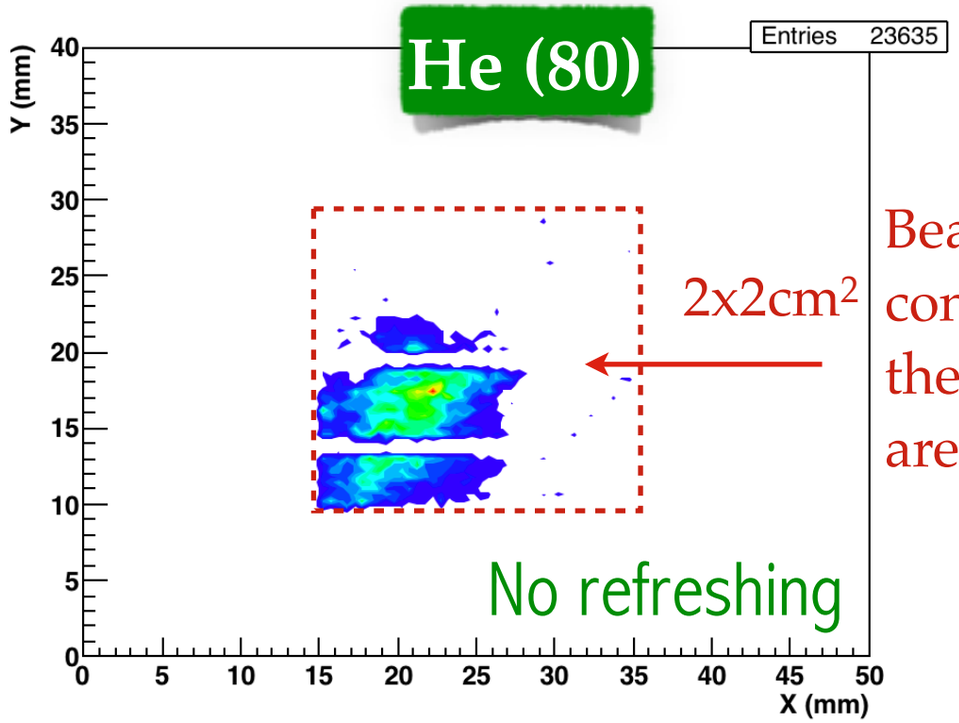


EMULSION ANALYSIS: Scanned area

- Signal selection: θ<0.1 rad

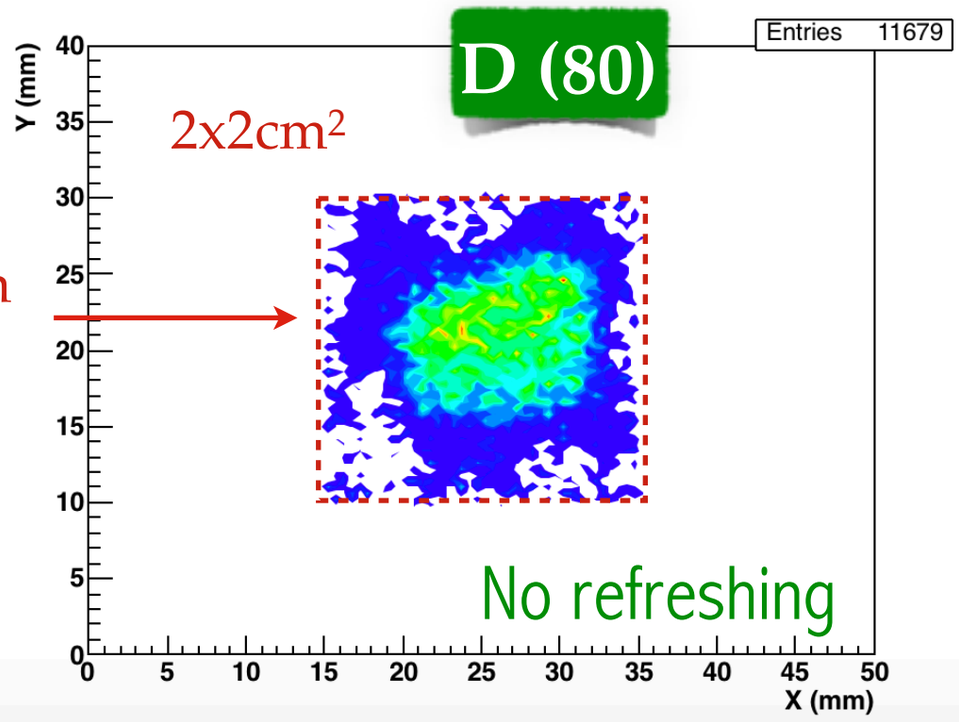
Beam size wider than scanned area

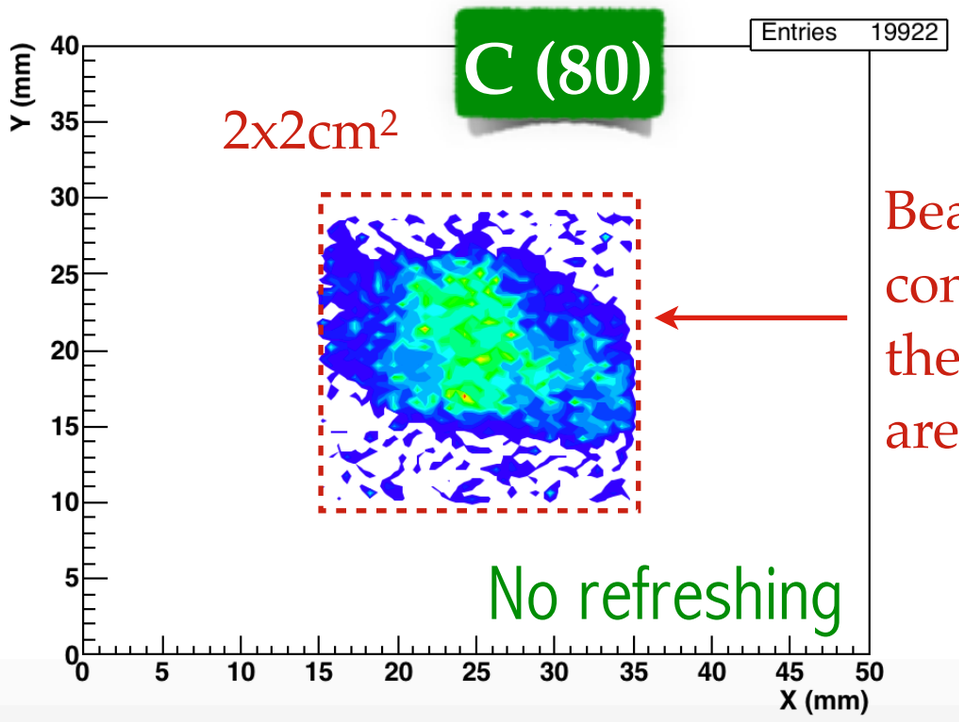




Beam spot contained in the scanned area

Beam spot contained in the scanned area



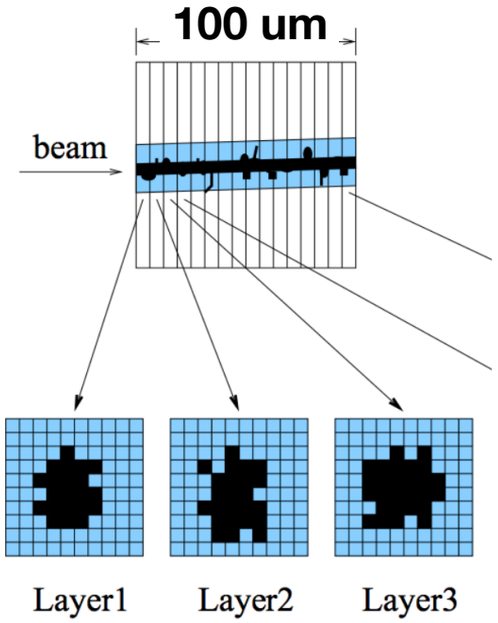


EMULSION ANALYSIS: Signal selection

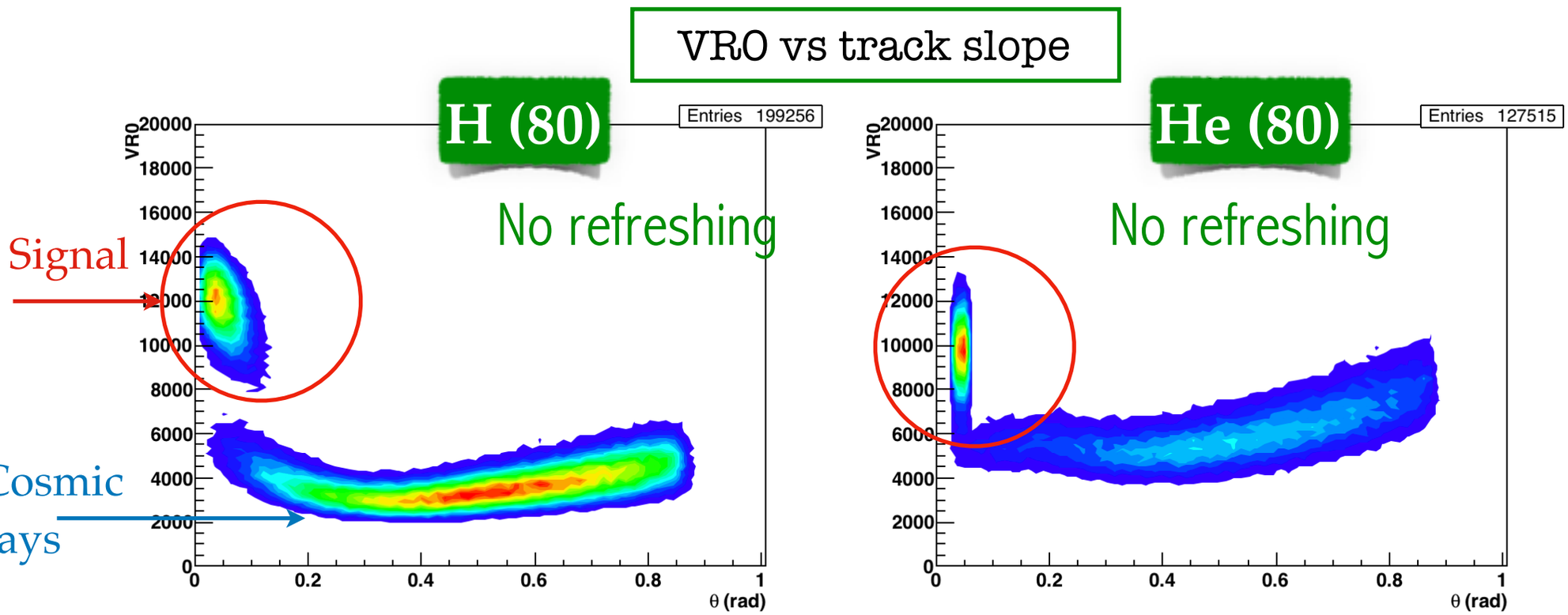
- Signal tracks from H, He and D show ionization (VR0) larger than cosmic rays
- **Unexpected** behavior for Carbon: same response of cosmic rays

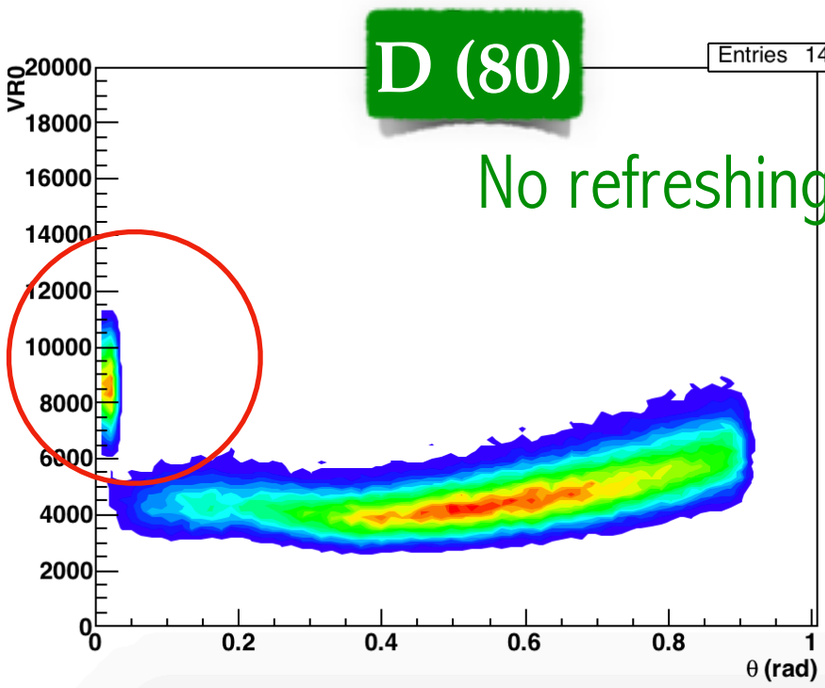
VR0

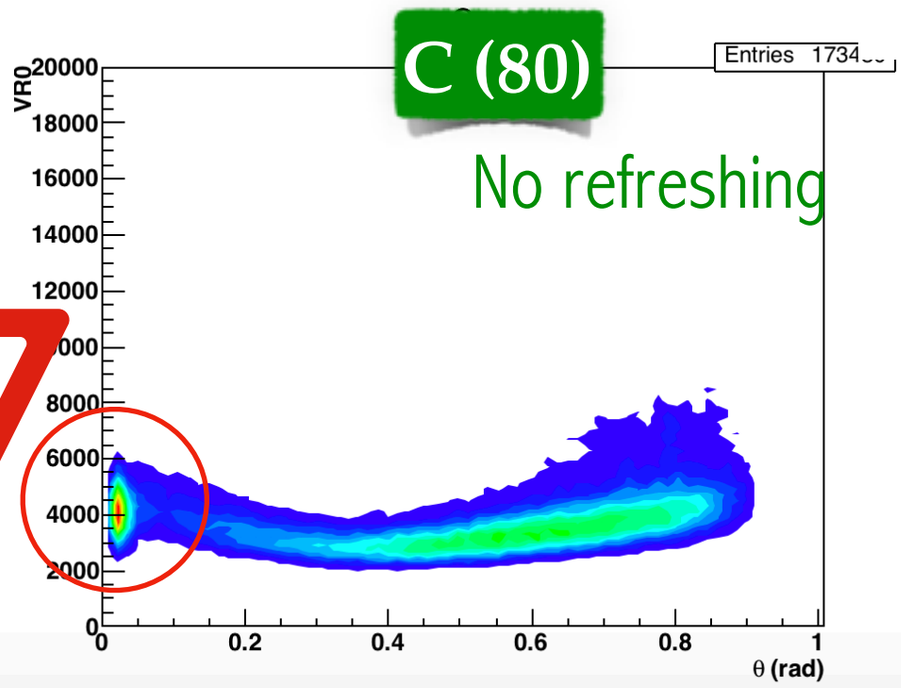
Sum of the number of pixels associated with each recognized tracks



VR0 vs track slope



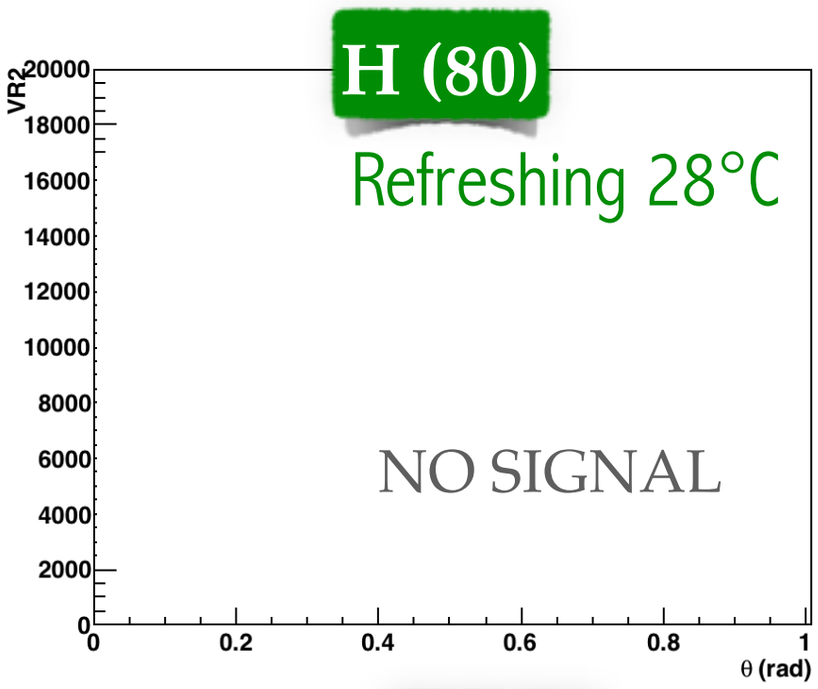


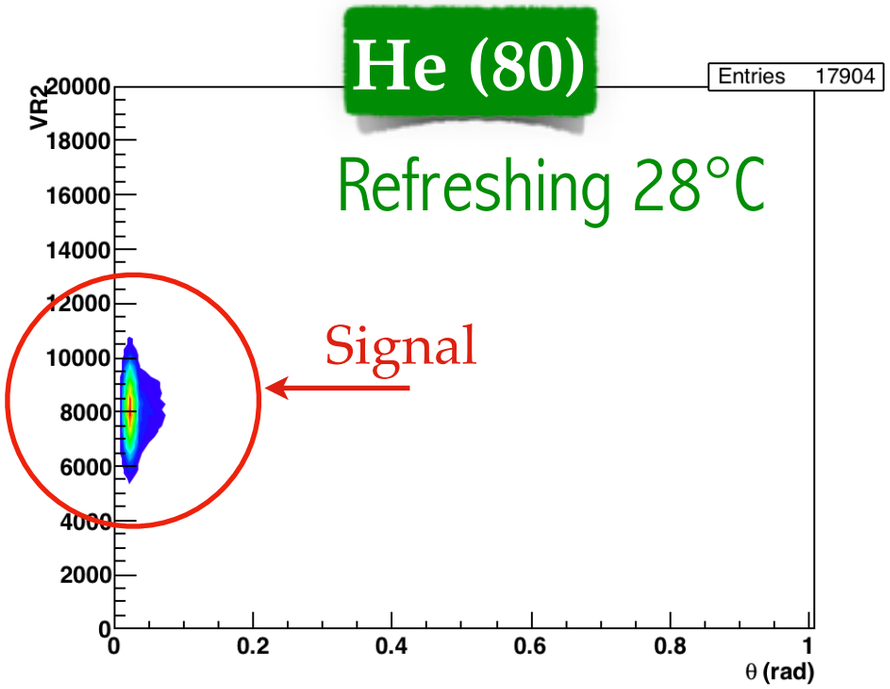


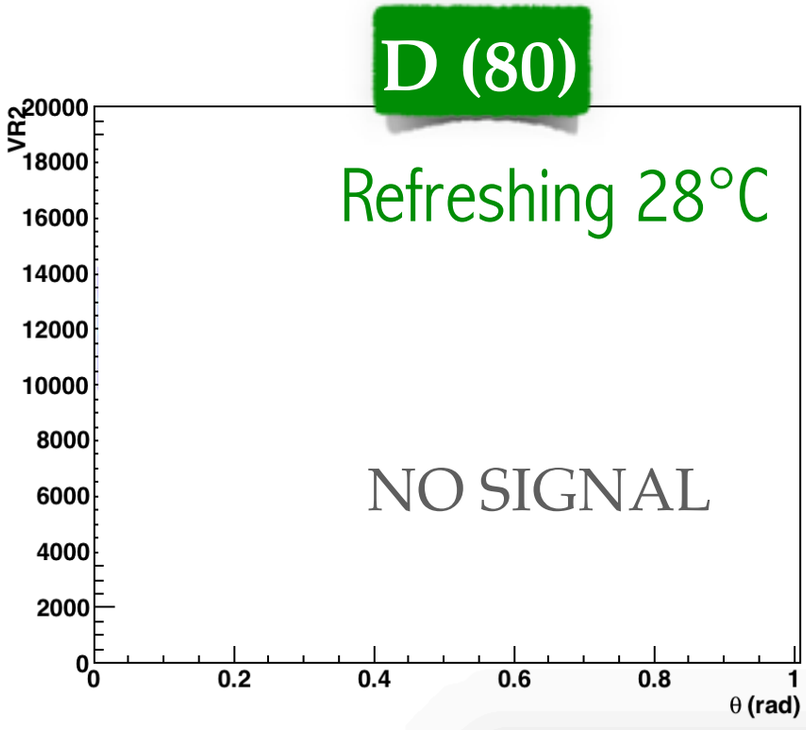
EMULSION ANALYSIS: Refreshing at 28°C

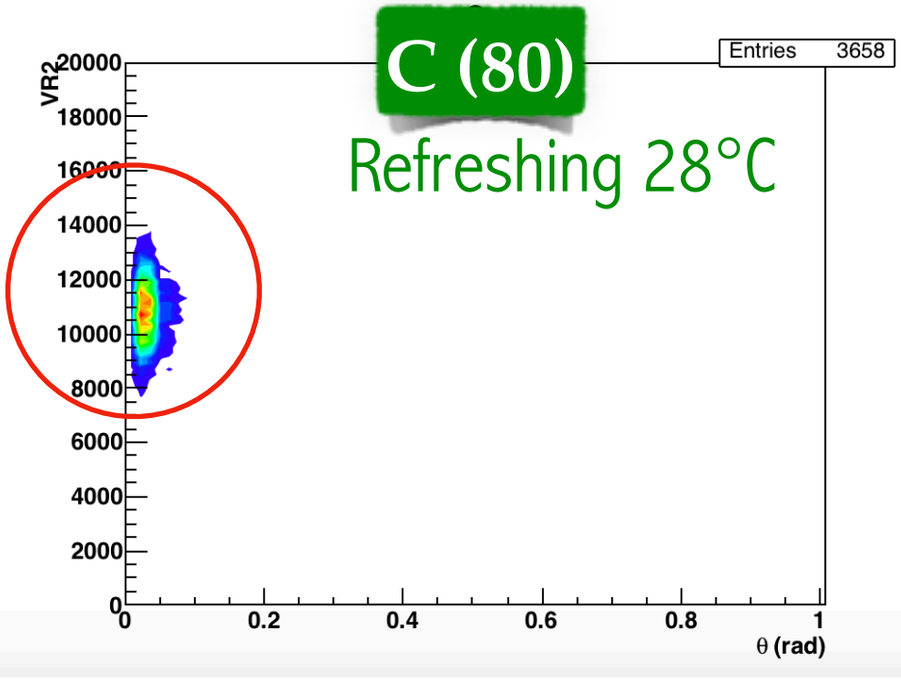
- Cosmic rays cancelled
- H and D tracks cancelled
- Degradation of ionization for He tracks
- High ionization for C tracks (as expected)

VR0 vs track slope



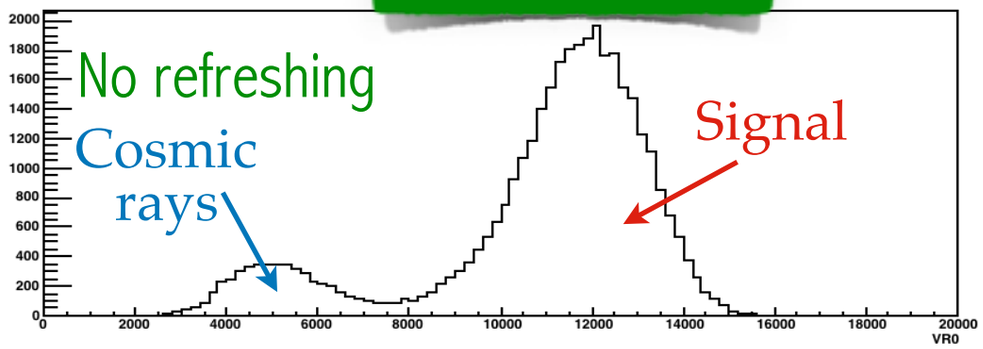


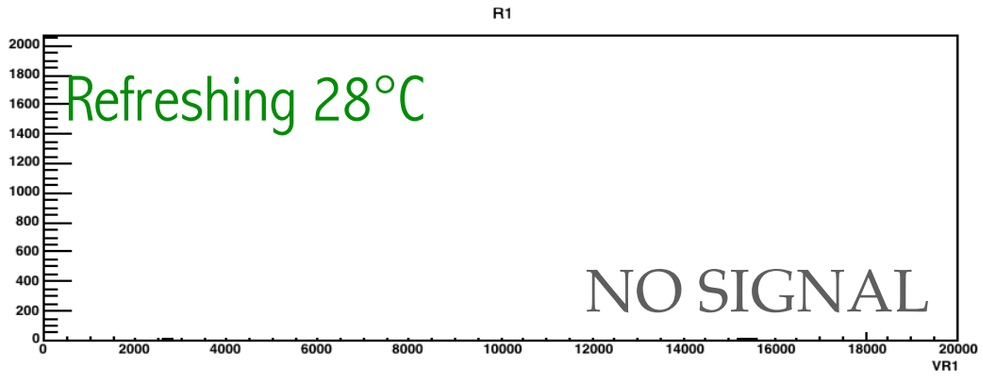


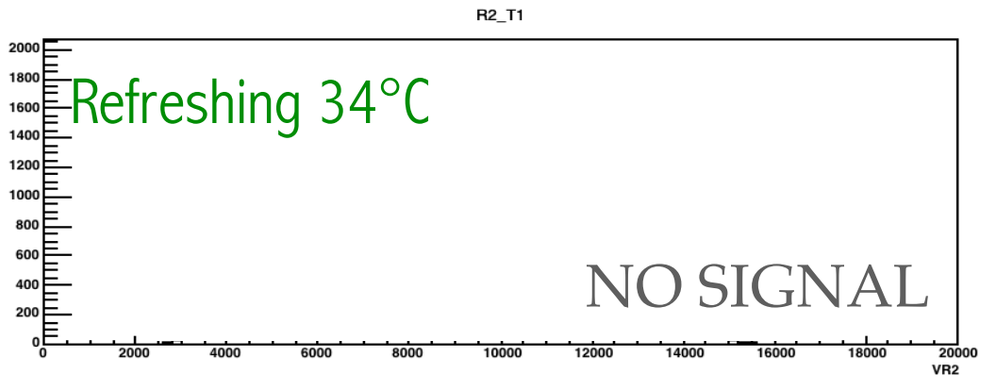


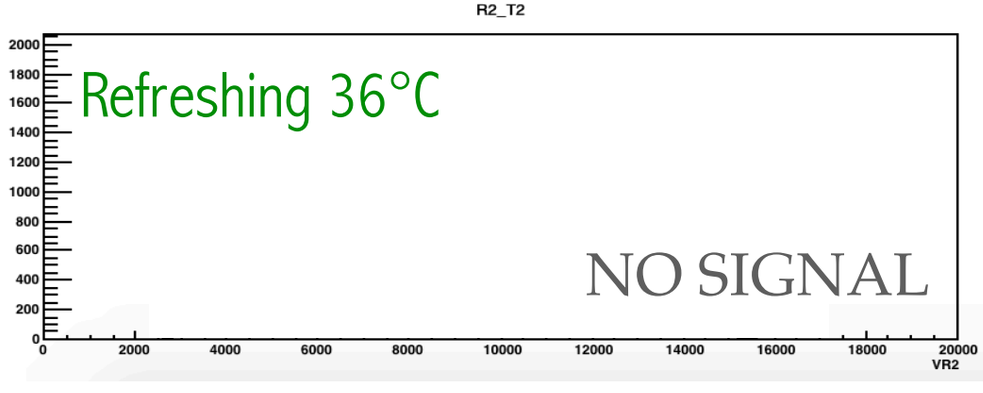
EMULSION ANALYSIS: Results

H (80 MeV)

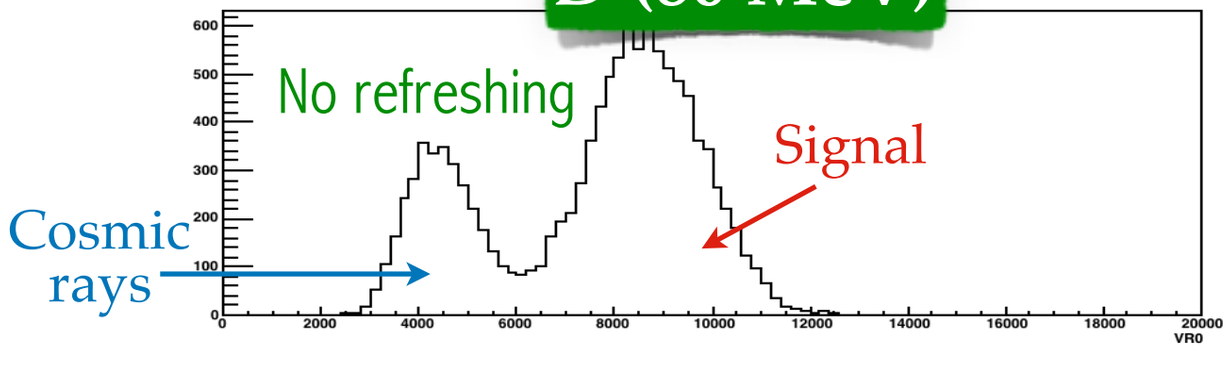


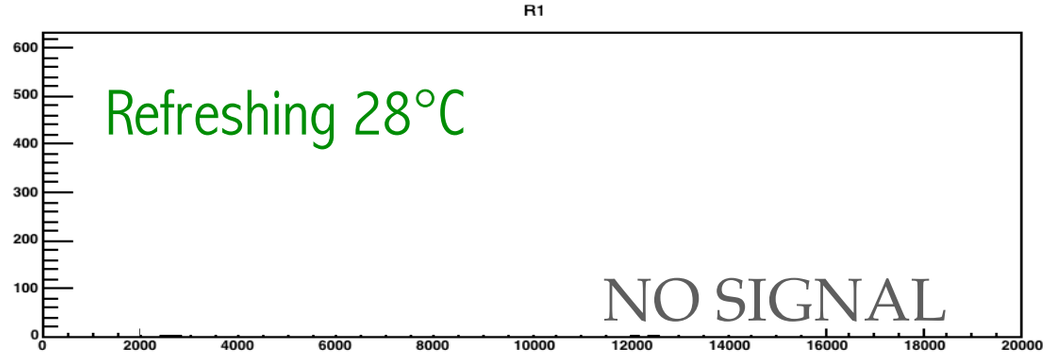


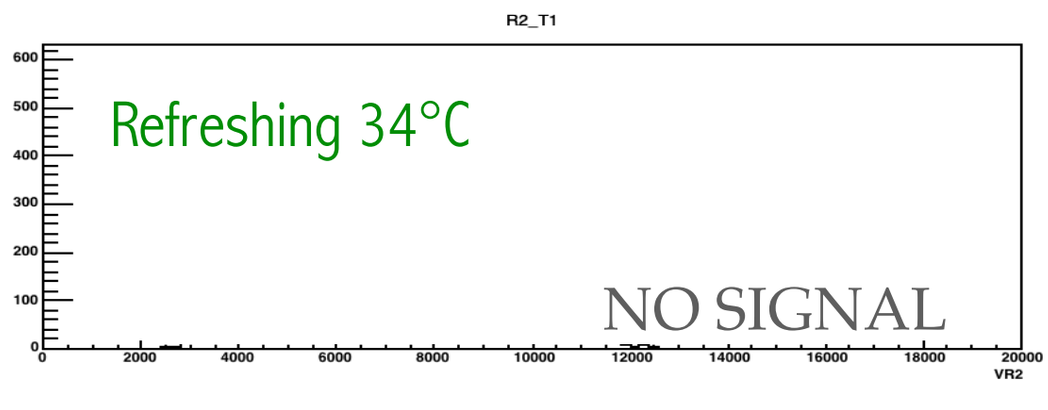


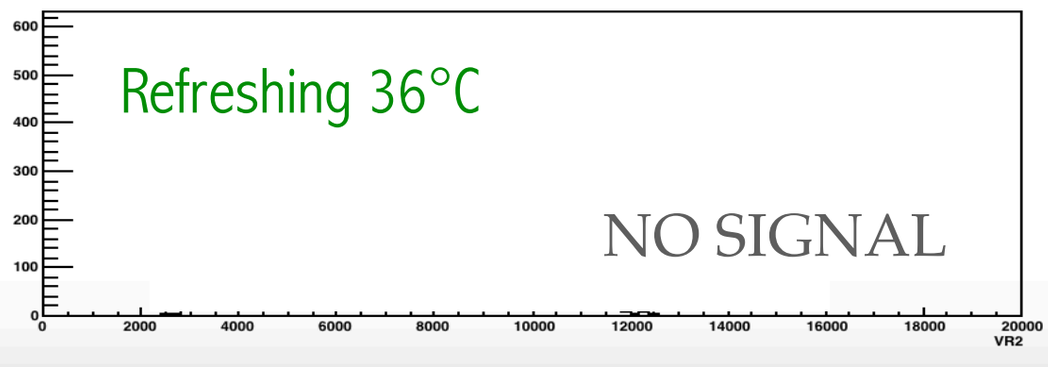


D (80 MeV)

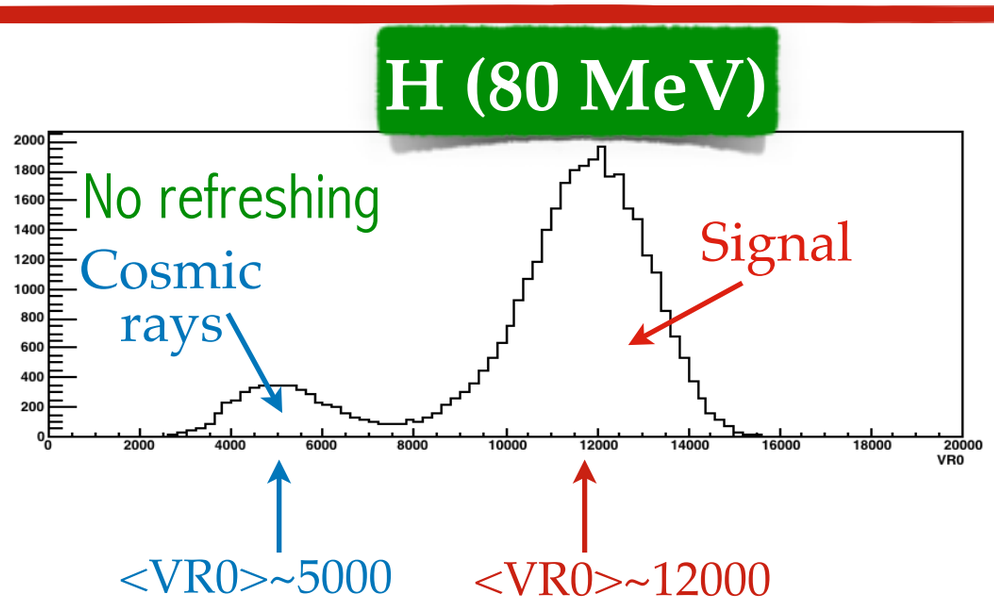


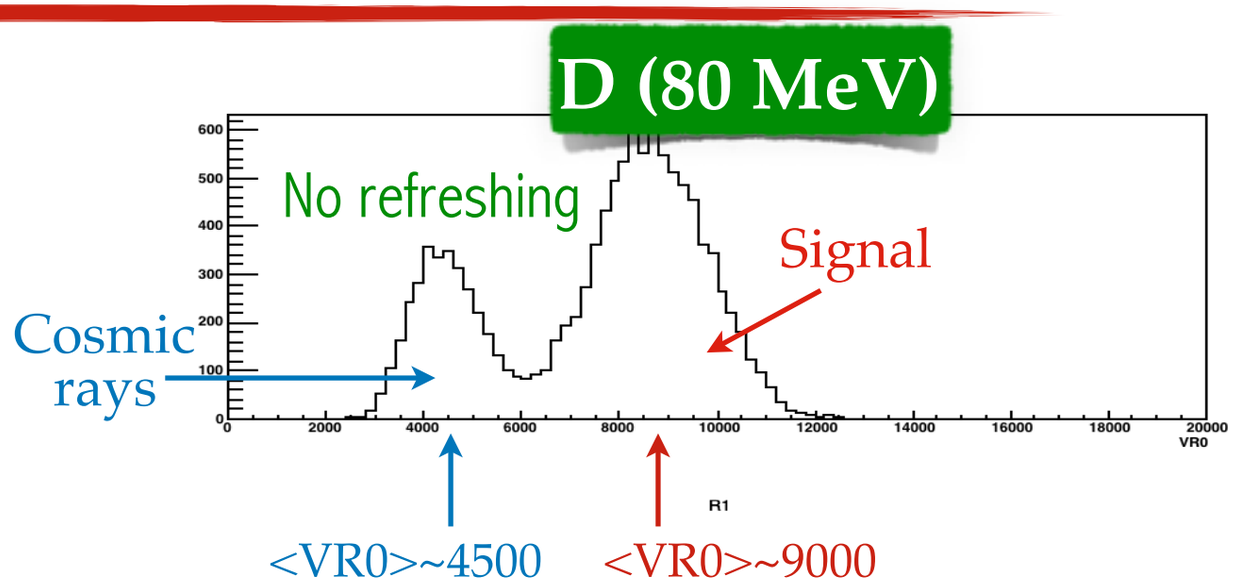






EMULSION ANALYSIS: Results





Comments

- Response to ionization not uniform in different samples
- Manual pouring of emulsion gelatin can cause fluctuations in the emulsion thickness

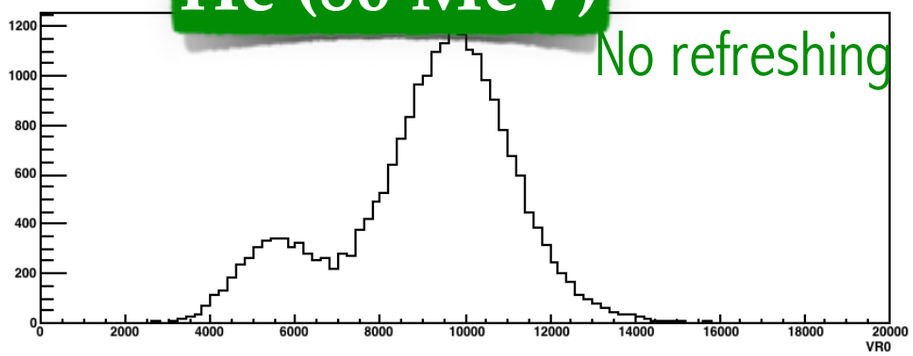
SOLUTIONS UNDER INVESTIGATION

- Local corrections via software
- Production of machine coated films with gelatine produced in Nagoya, in contact with companies

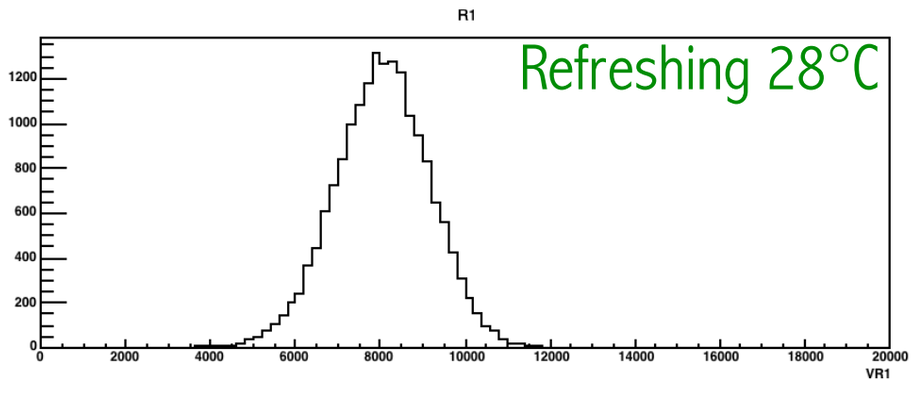
EMULSION ANALYSIS: Results

He (80 MeV)

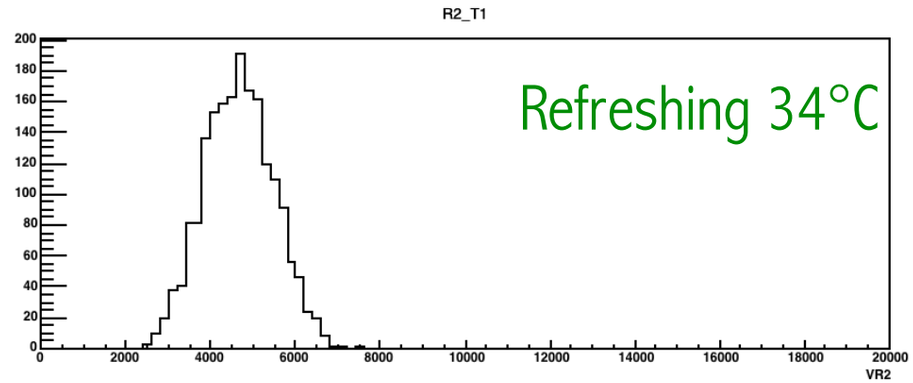
No refreshing



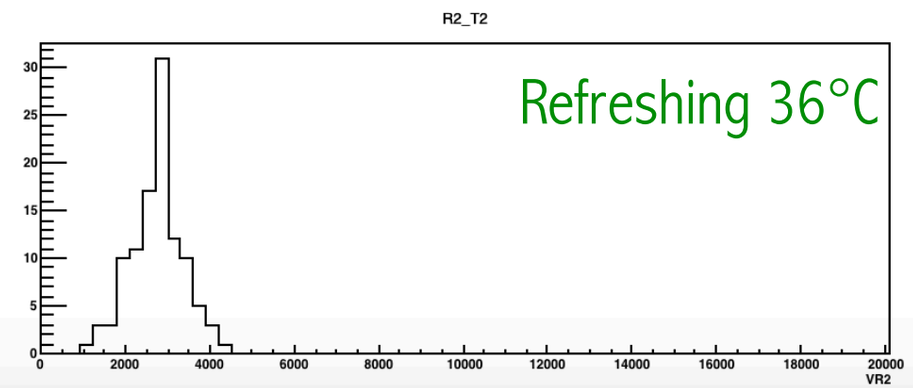
Refreshing 28°C



Refreshing 34°C



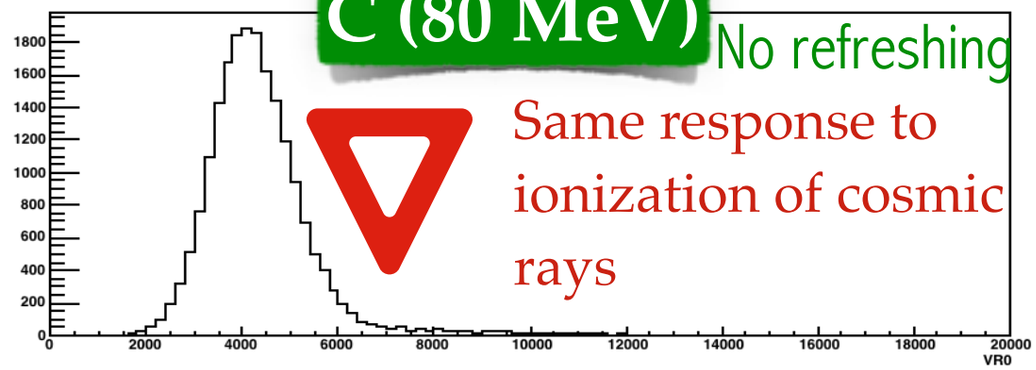
Refreshing 36°C



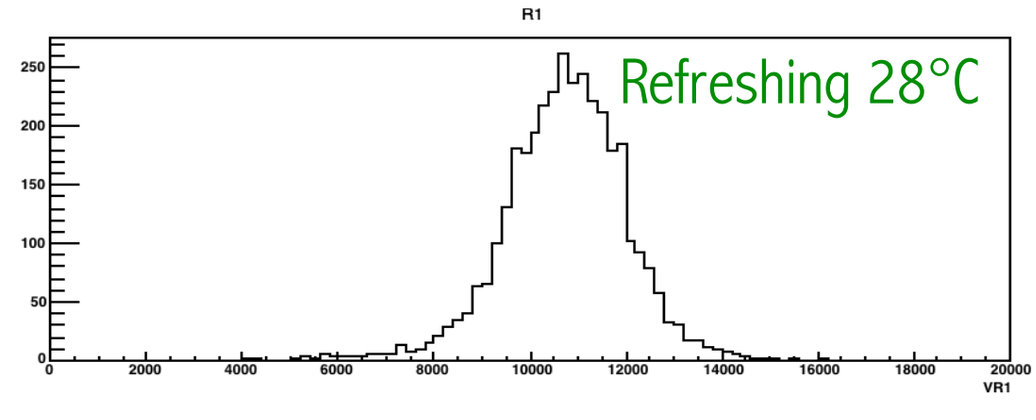
C (80 MeV)

No refreshing

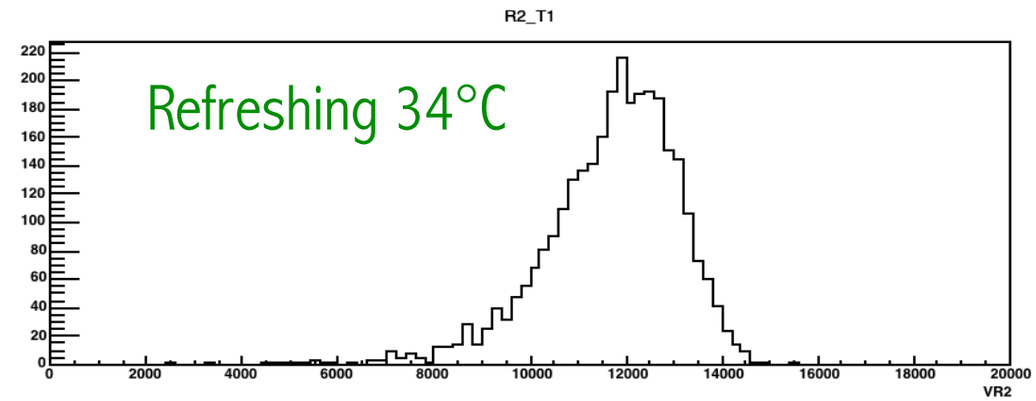
Same response to ionization of cosmic rays



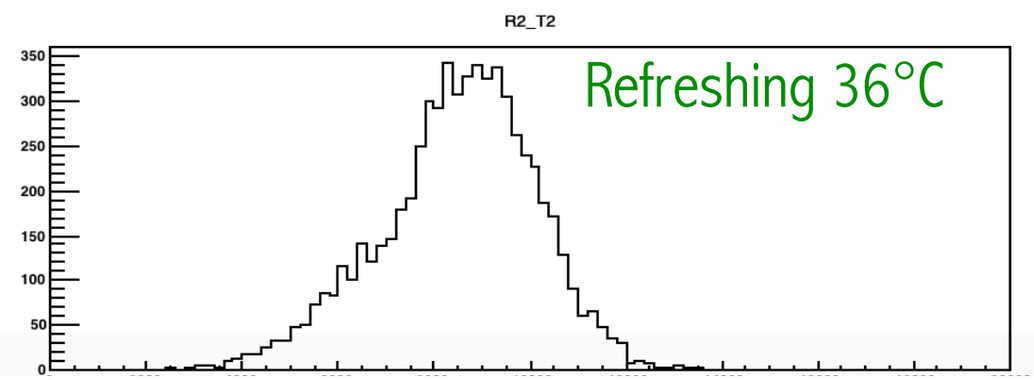
Refreshing 28°C



Refreshing 34°C



Refreshing 36°C



TEST BEAM@LNS: Summary

DELIVERED	H (80 MeV/u)	H (200 MeV/u)	H (47 MeV/u)	He (80 MeV/u)	C (80 MeV/u)
EQUIVALENT TO	H (80 MeV/u)	H (200 MeV/u)	He (200 MeV/u)	Li (200 MeV/u)	C (80 MeV/u)
R0	✓	✓ ?	?	✓	✓
R1 28°C	✗	✗	?	✓	✓
R2 34°C	✗	✗	?	✓	✓

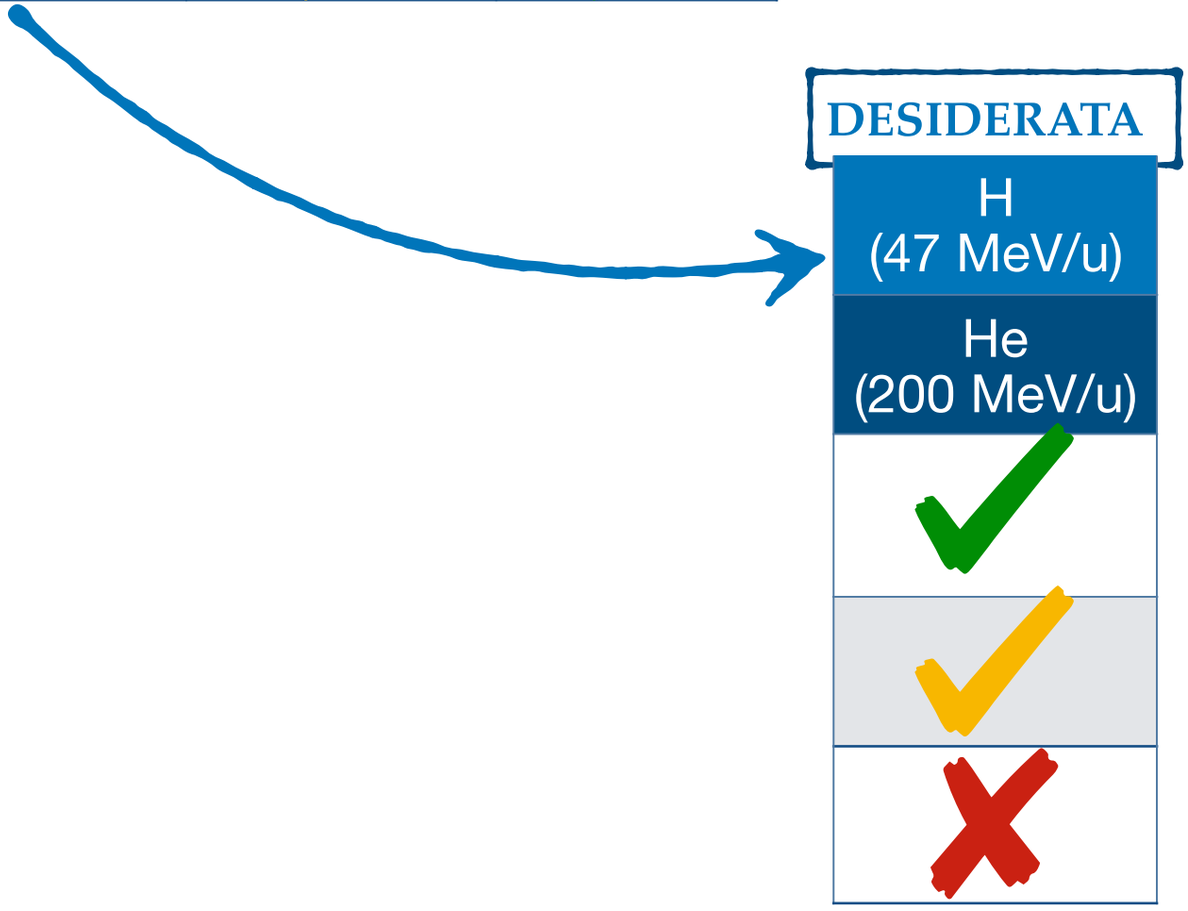
✓ VISIBLE

✓ VISIBLE partial degradation

✗ NOT VISIBLE

? To be tested

- Definition of working point for R1: 28°C, 98% relative humidity, 24 h
- Definition of working point for R2: 34°C, 98% relative humidity, 24 h



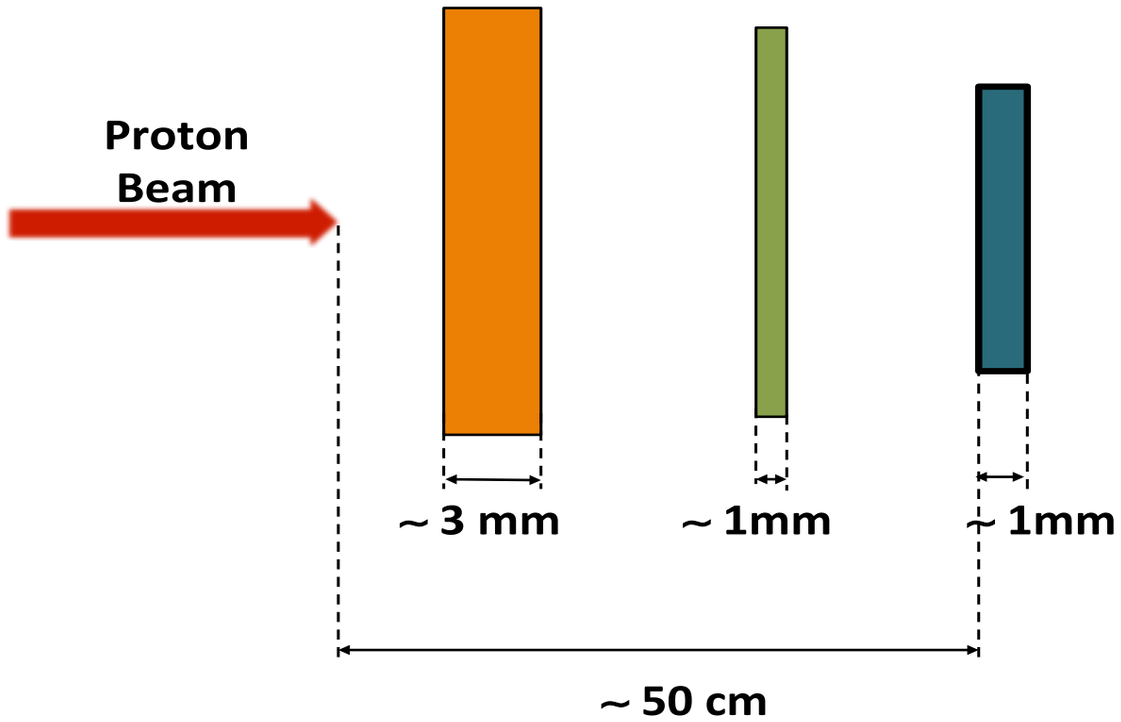
TEST BEAM@TRENTO: 11-15 Dec 2017

- Groups involved: Napoli, Perugia, Milano, Trento

Plastic scintillator:
- To count impinging particles
- Time resolution: ~ns

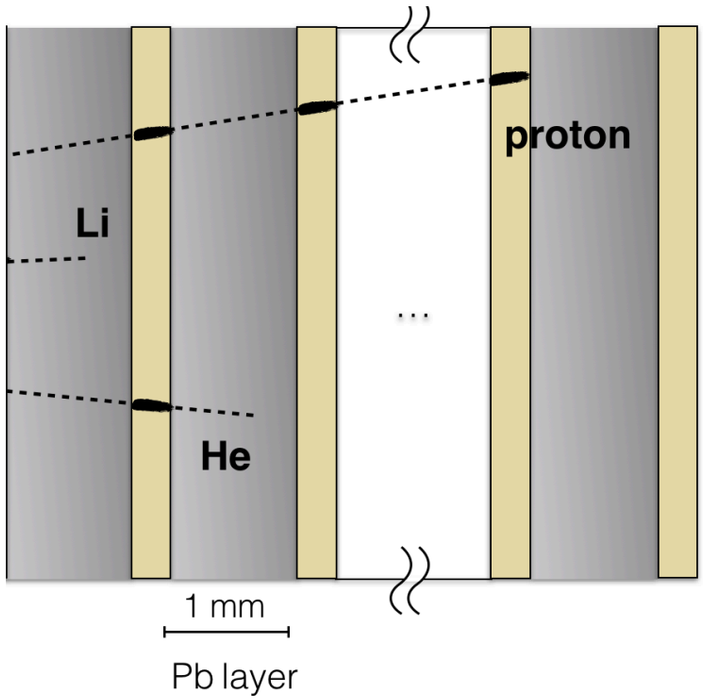
Beam profile Monitoring:
Spatial resolution < 1mm
Si Microstrip Detector

Emulsion doublets



- Exposures:
  - **H(200 MeV/u)**
  - H(50 MeV/u) simulating **He(200 MeV/u)** - not delivered @LNS
  - H(80 MeV/u) for comparison with LNS measurements

SECTION 3: Momentum



- Emulsion films interleaved with passive layers (lead / stainless steel)
- Momentum by range: from the track length
- Momentum by MCS: from angular deflections
- Isotopic identification: combine range and MCS measurements to retrieve the mass
- Current layout
  - 30 cells (30 emulsion films)
  - 39 mm

ACTIVITIES IN 2017:

1) Test beam @LNS
2) Chemical treatment of exposed samples
3) Scanning and preliminary analysis of exposed samples

} Details in next slides

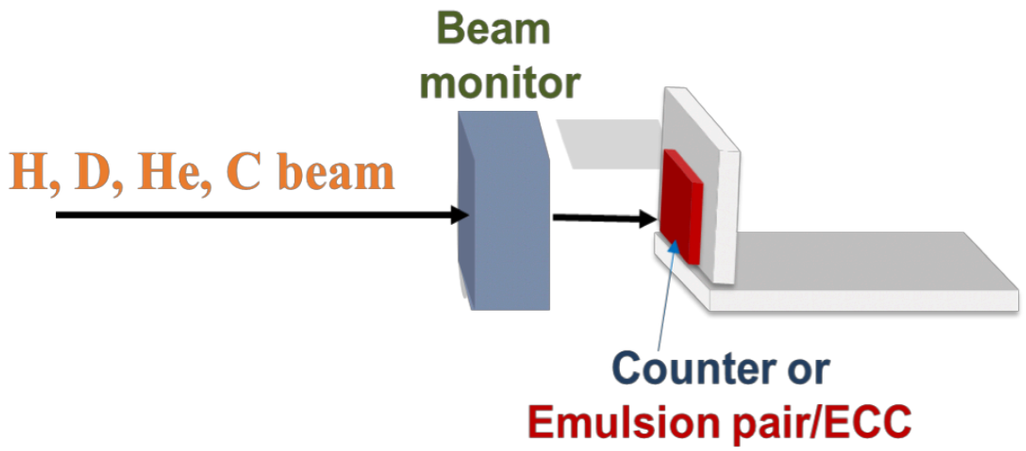
SHORT TERM PLAN:

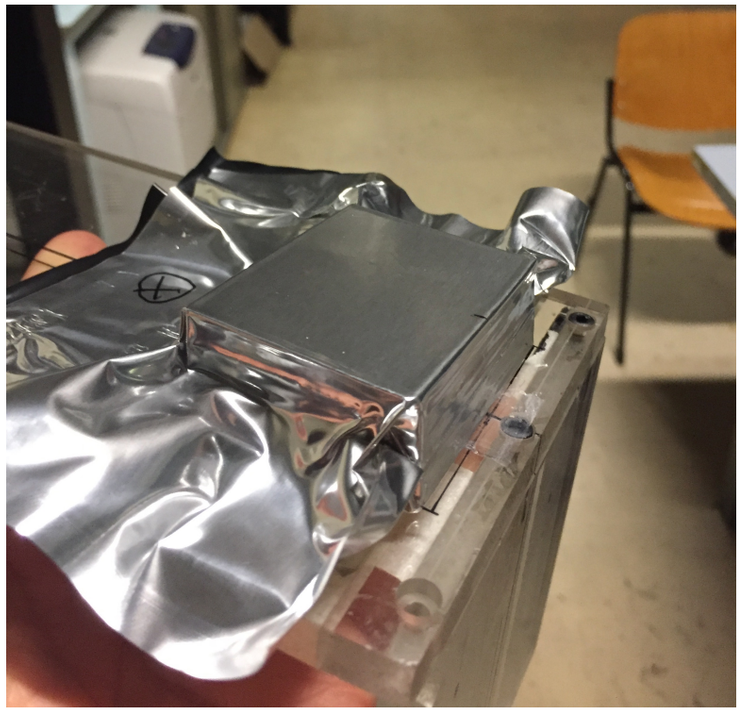
1) Finalize the analysis of data from LNS test beam
2) Develop of an algorithm for the momentum measurement with MCS and isotopic identification
3) Optimization of the layout with simulations

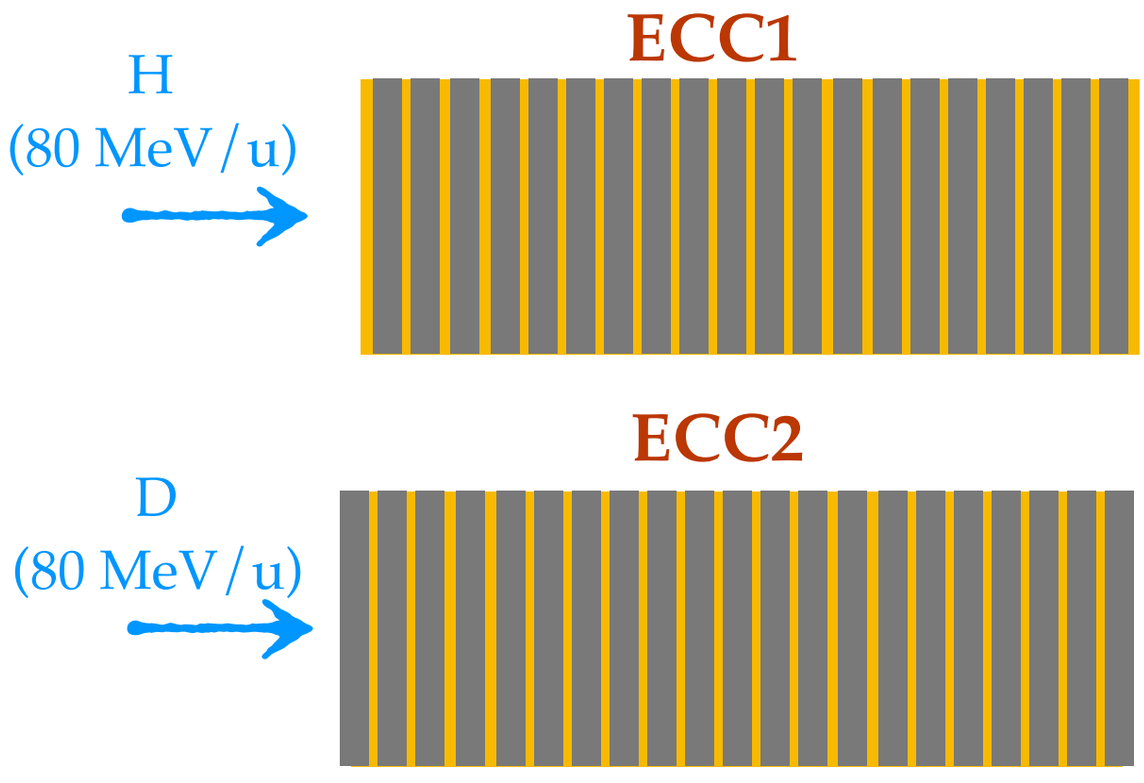
SECTION 3: Test beam @LNS

Motivation:

- Develop and test with data an algorithm for isotopic identification
- Exposure of two ECC chambers to H and D at the same energy





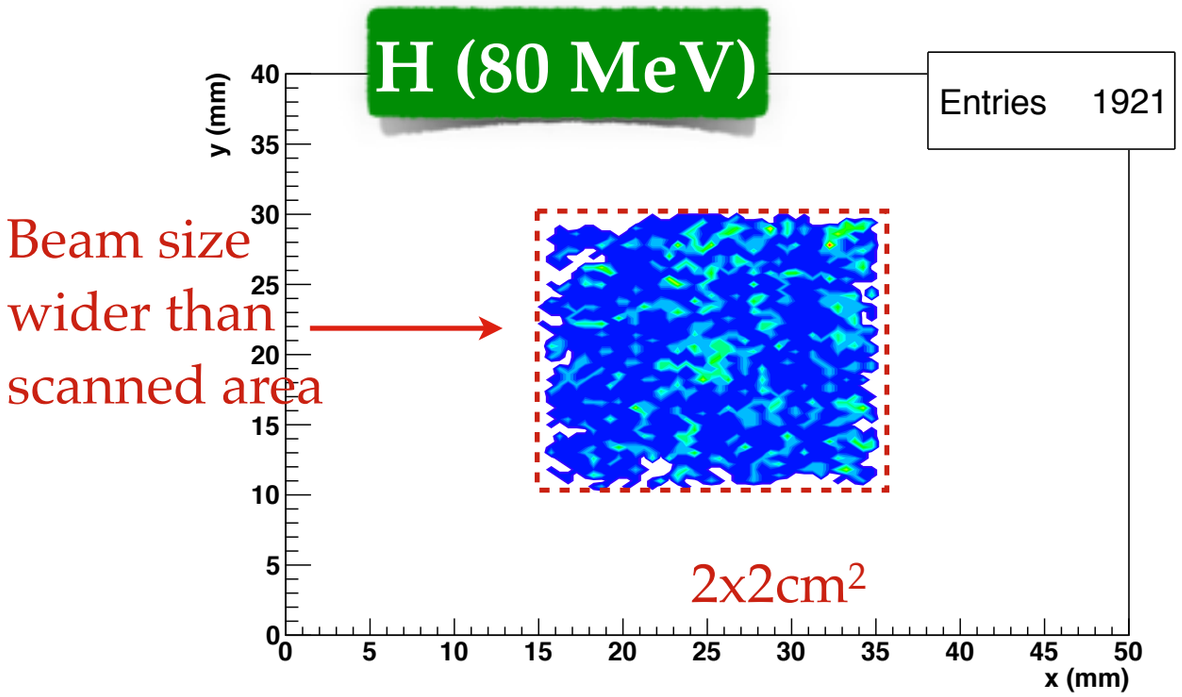


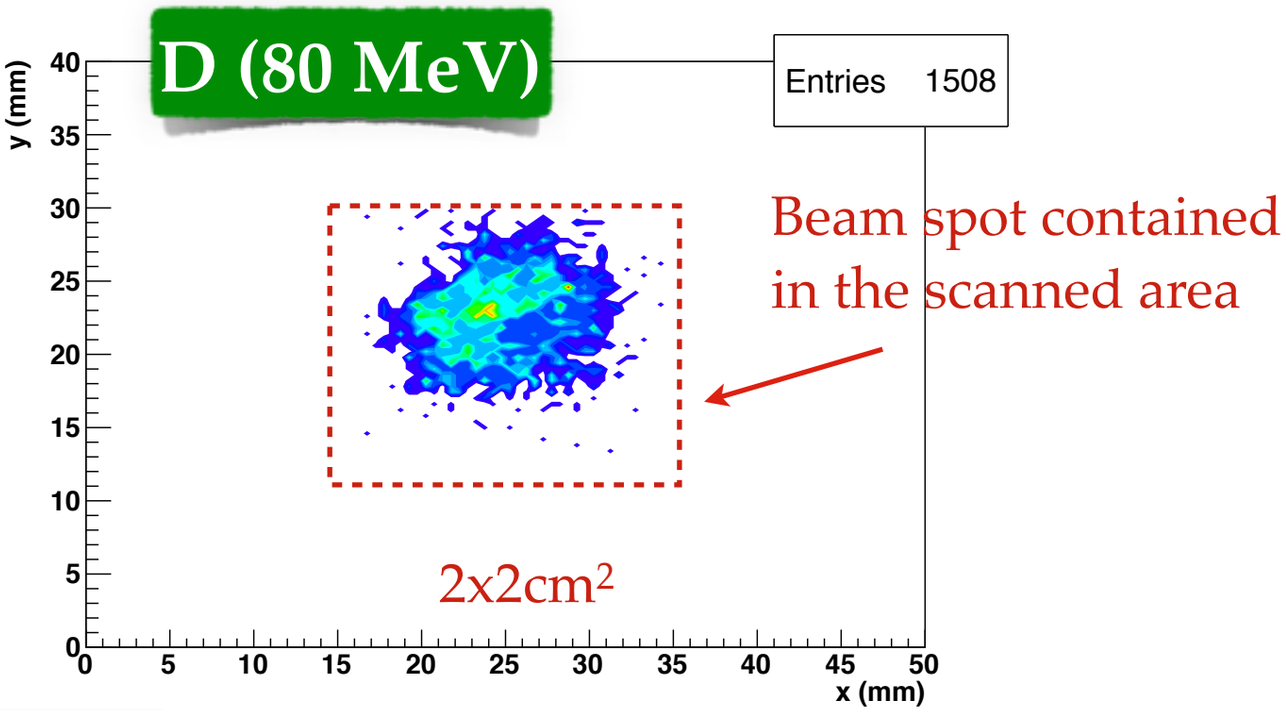
- 21 nuclear emulsion films
- 20 stainless steel planes 0.5 mm-thick (X0 = 1.76 cm)
- Surface: 5x4 cm^2

- ECC1 exposed to H (80 MeV/u)
- ECC2 exposed to He (80 MeV/u)

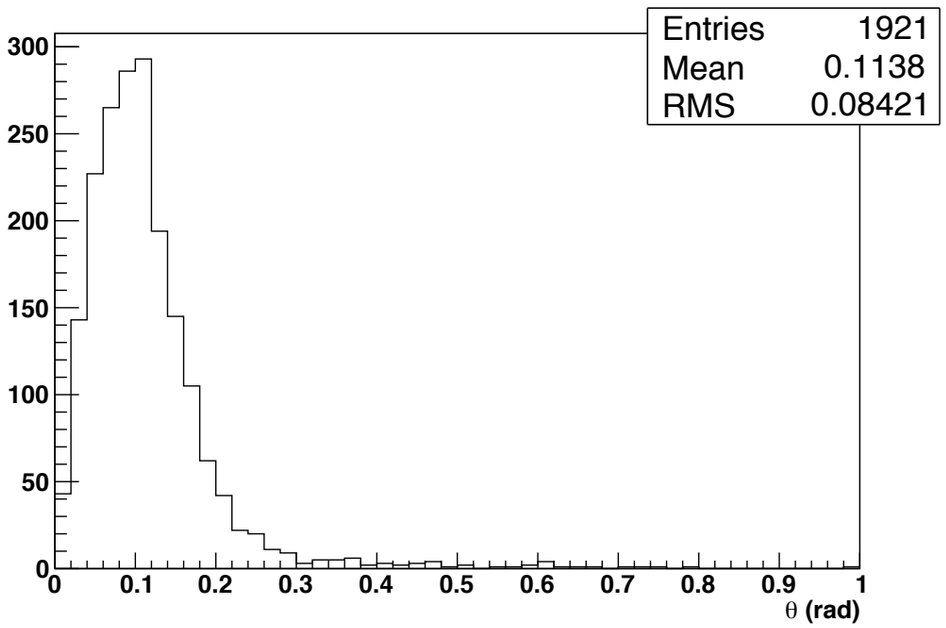
EMULSION ANALYSIS: Scanned area

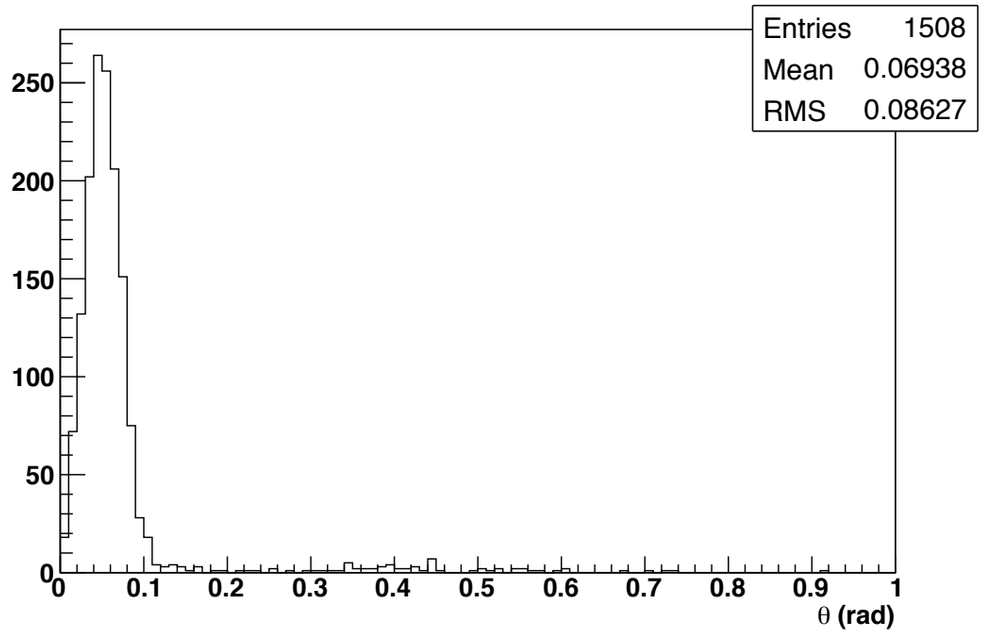
- Preliminary results based on the tracks reconstructed in the first **10 emulsion films** of both ECCs
- Requirement: number of segments>=6





Track slope



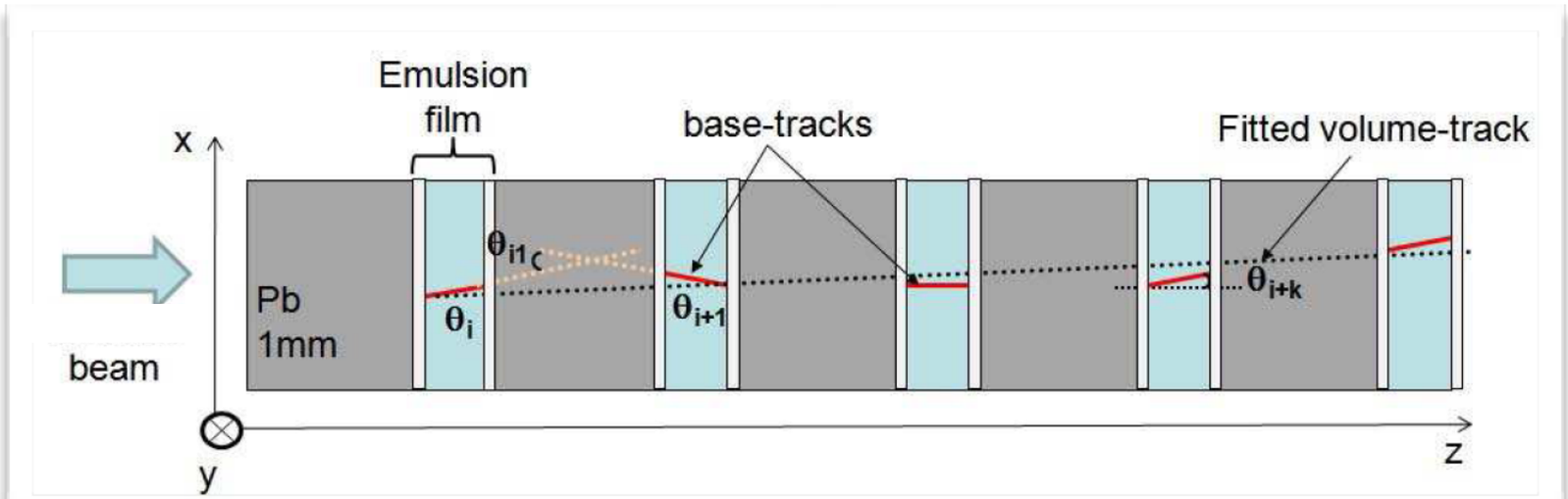


EMULSION ANALYSIS: P measurement

- Angular deflections in passive layers due to Multiple Coulomb Scattering show a gaussian distribution centered in zero with a sigma

$$\theta_0 = \frac{13.6}{p\beta}\sqrt{\frac{x}{X_0}}\left[1 + 0.038\ln\left(\frac{x}{X_0}\right)\right]$$

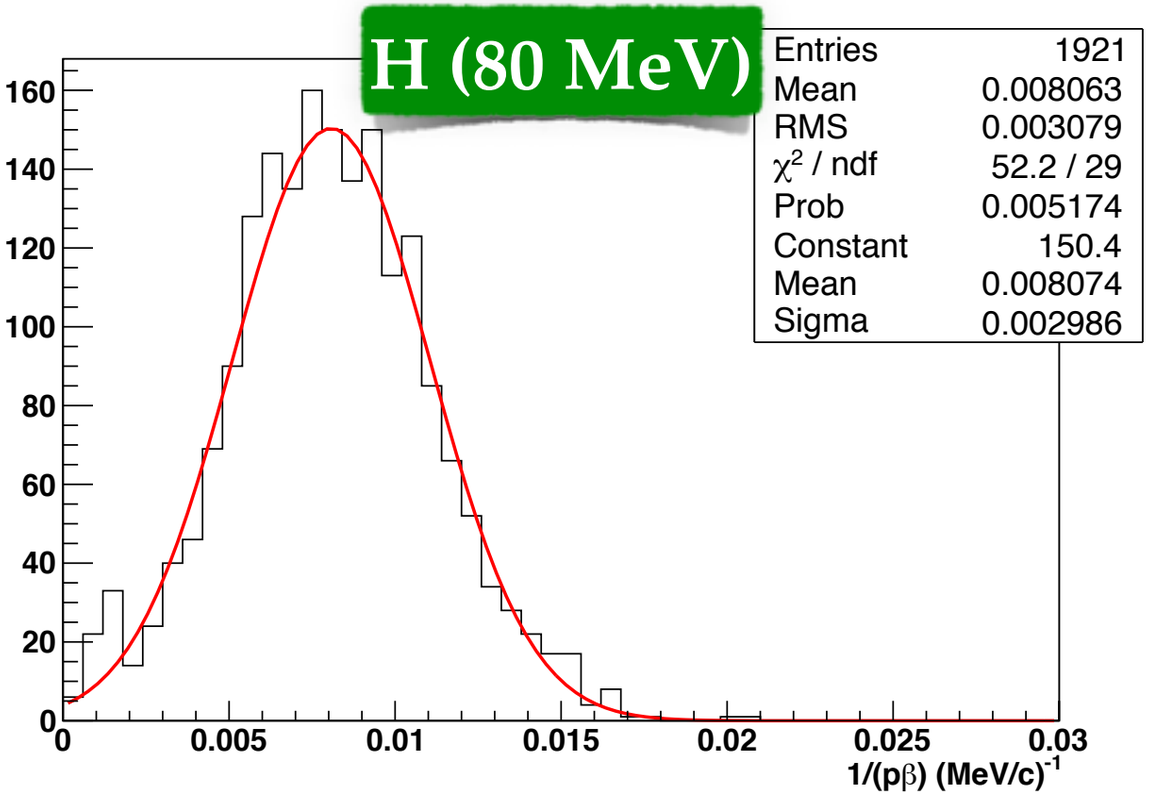
Proportional to **1/pβ**



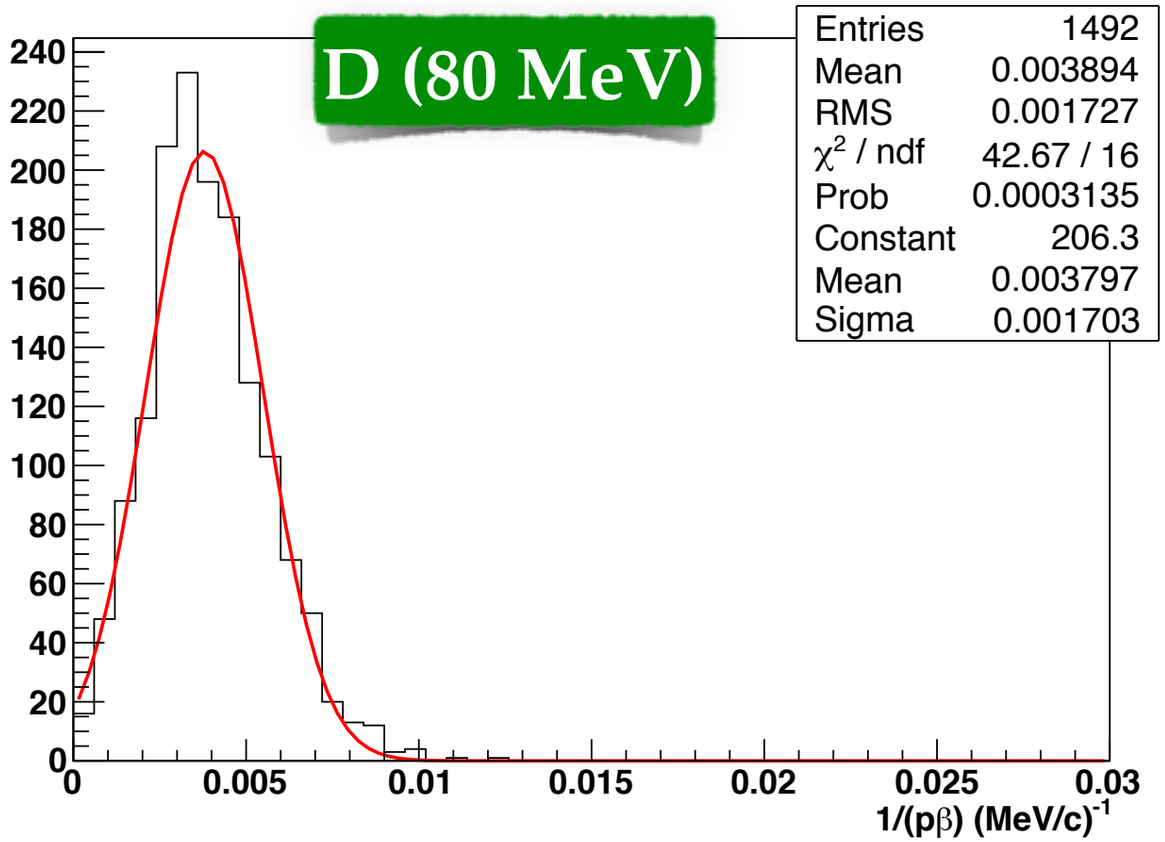
EMULSION ANALYSIS: P measurement

- Preliminary estimation of **pβ** from "standard" OPERA algorithm [1] that assumes the fitted track not to lose energy during its path

- **Expected 1/pβ: 0.0068 MeV^{-1}**
- **Measured 1/pβ: 0.008±0.003 MeV^{-1}**



- **Expected 1/pβ: 0.0034 MeV^{-1}**
- **Measured 1/pβ: 0.004±0.002 MeV^{-1}**



- Combination of momentum measurement by range and MCS (both dependent on the mass of the particle) could provide **isotope identification**

[1] N. Agafonova et al. Momentum measurement by the Multiple Coulomb Scattering method in the OPERA lead emulsion target. New J. Phys., 14:013026, 2012

CONCLUSIONS

The optimization of the layout of the Emulsion Cloud Chamber layout relies on:

1) Results from test beam exposures
   - Test beam @LNS in July 2017 for the optimization of Section2 and Section3
     - Preliminary results obtained
     - Analysis in progress
     - Definition of working points for R1 and R2 refreshing conditions
     - Momentum measurement by MCS compatible with expectations
     - New algorithms for isotope identification to be developed
   - Test beam @Trento in December 2017

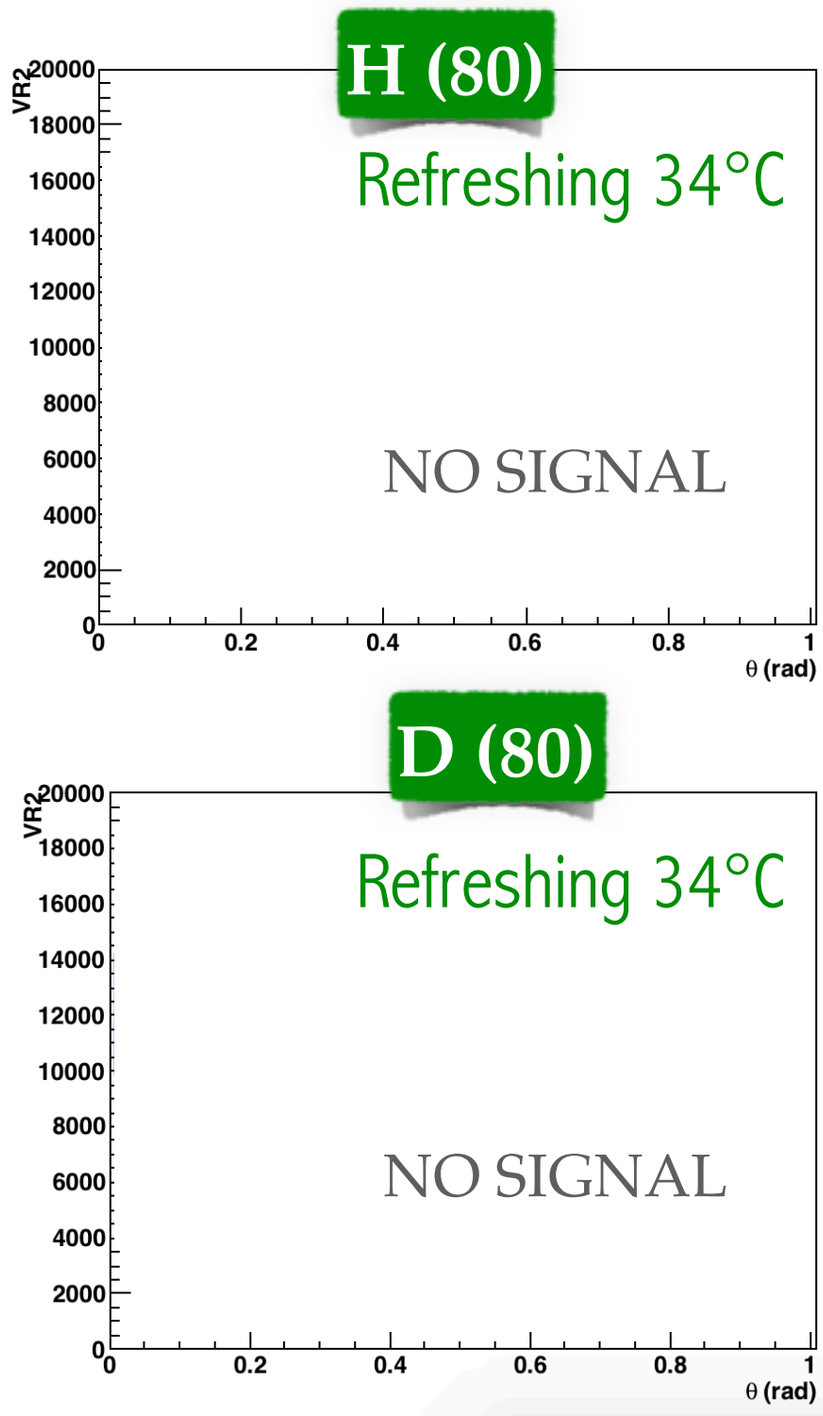
2) Simulation
   - Overall thickness of Section1
   - Overall thickness of Section3
   - Thickness of passive layers in Section3

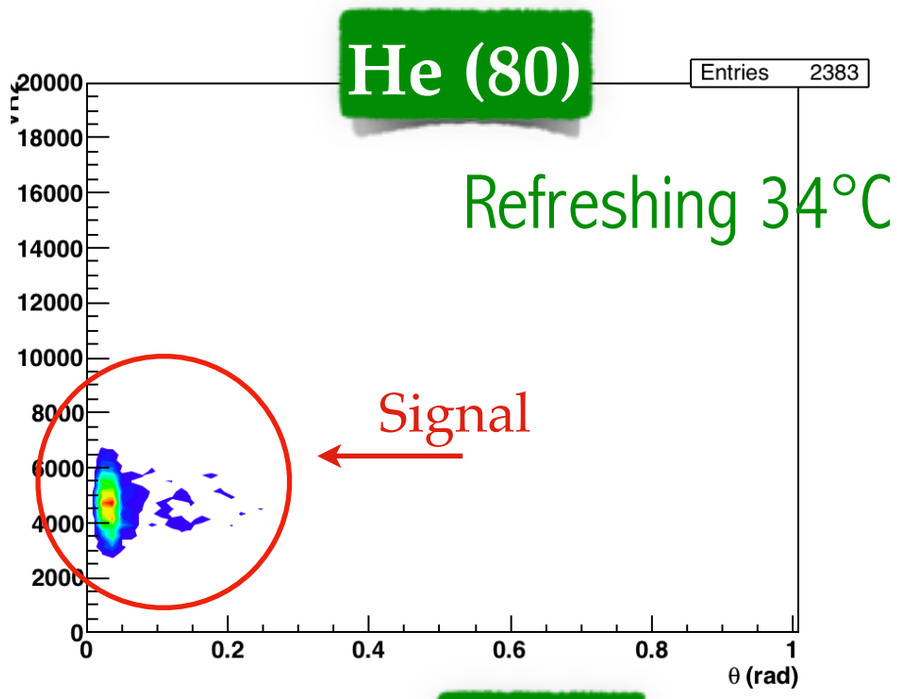
Backup Slides

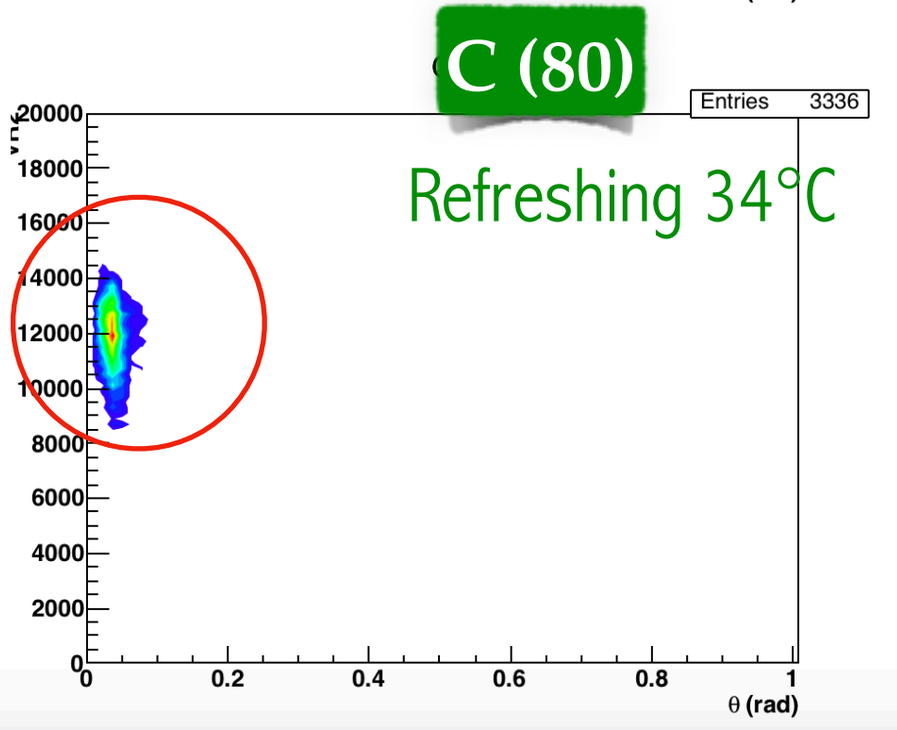
EMULSION ANALYSIS: Refreshing at 34°C

- Cosmic rays cancelled
- H and D tracks cancelled
- Further degradation of ionization for He tracks
- No degradation of C ionization

VR0 vs track slope







EMULSION ANALYSIS: Refreshing at 36°C

- Cosmic rays cancelled
- H and D tracks cancelled
- Further degradation of ionization for He tracks
- Degradation of C ionization

VR0 vs track slope