Status Of The Charm Cross Section Measurement

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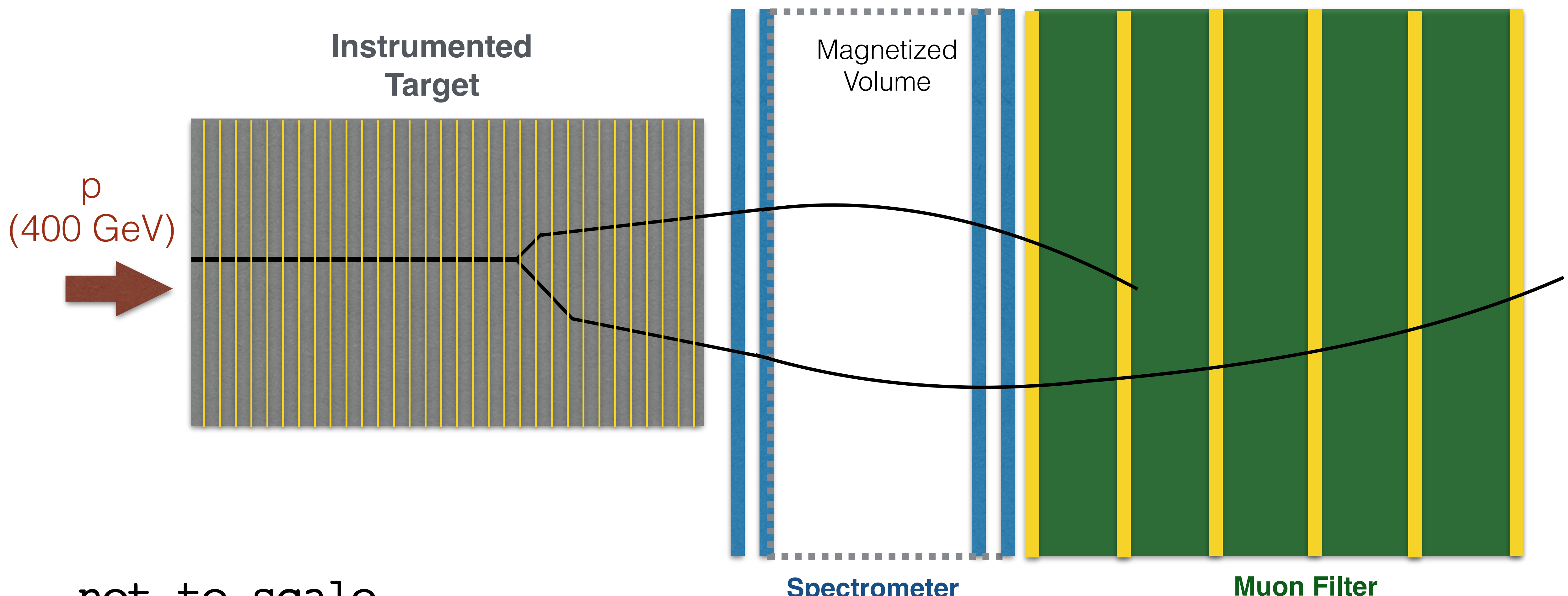
CONCEPTUAL DESIGN

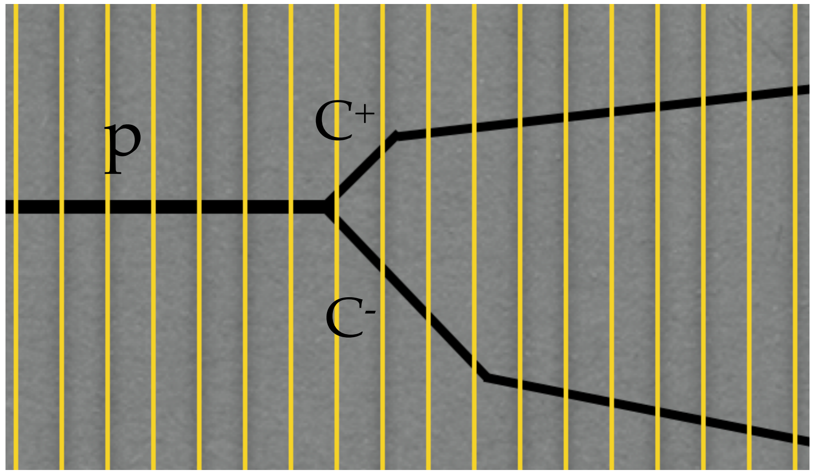
- Motivation:
  - study charm production in the SHiP target
  - measure for the first time charm production in **hadron cascades**
- **Double-differential** charm production cross-section measurement **($d^2\sigma/dEd\theta$)**
- Proton collisions in Mo target instrumented with **nuclear emulsions**
- **Nuclear emulsions** as tracking detector
- Measurement of charm daughters charge and momentum with **Spectrometer**
- Muon identification with **Muon Filter**



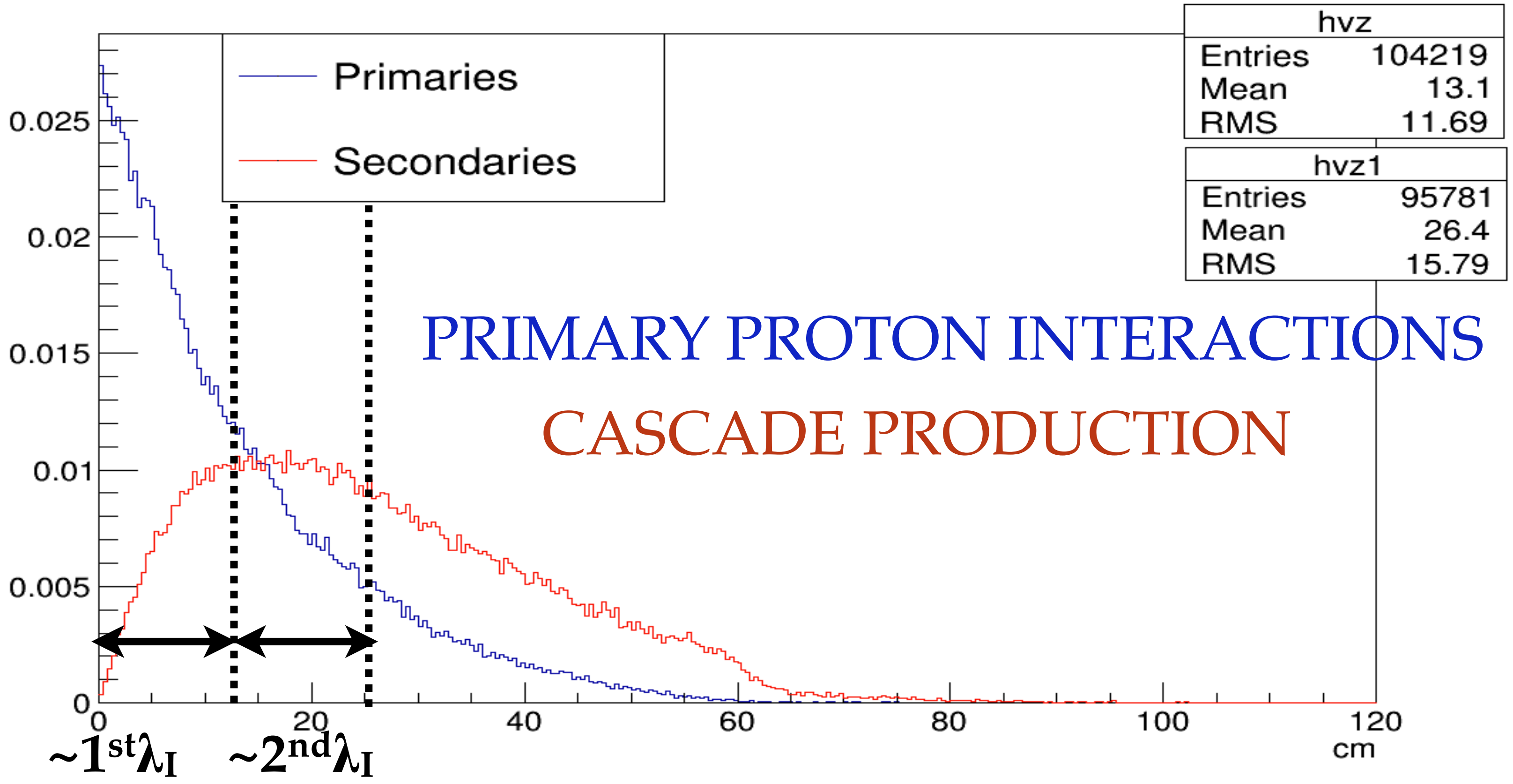
not to scale

INSTRUMENTATION OF TARGET

- Use of a replica of the SHiP target with smaller section: 10x10 cm^2
- Exactly the same TZM, W and Ta distribution
- Nuclear emulsions used as micrometric tracking device to identify charm production and decay



- Emulsion Cloud Chamber (ECC) technique employed: sampling of target material with nuclear emulsions
- Sampling of passive material: **1 mm, 2mm, 3 mm**
- Build ECC chambers to study the charm production in different sections of the target



- Position distribution along beam axis of charm production vertices in the target

- Instrumentation of first and second λ_I allows the study of a large fraction of charmed hadrons

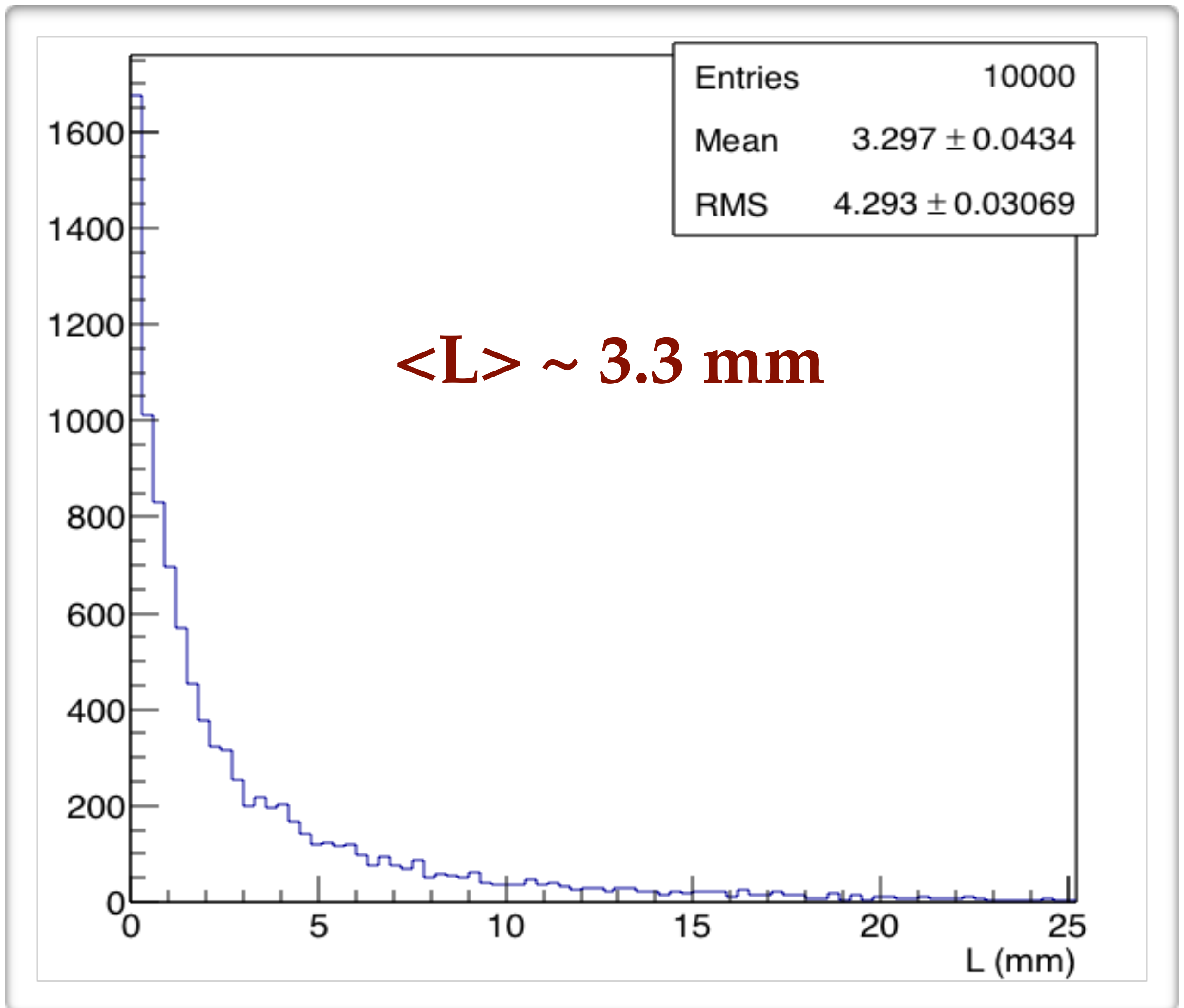
Fraction of interactions within $2\lambda_I$

- Primary 85%
- Secondary 52%

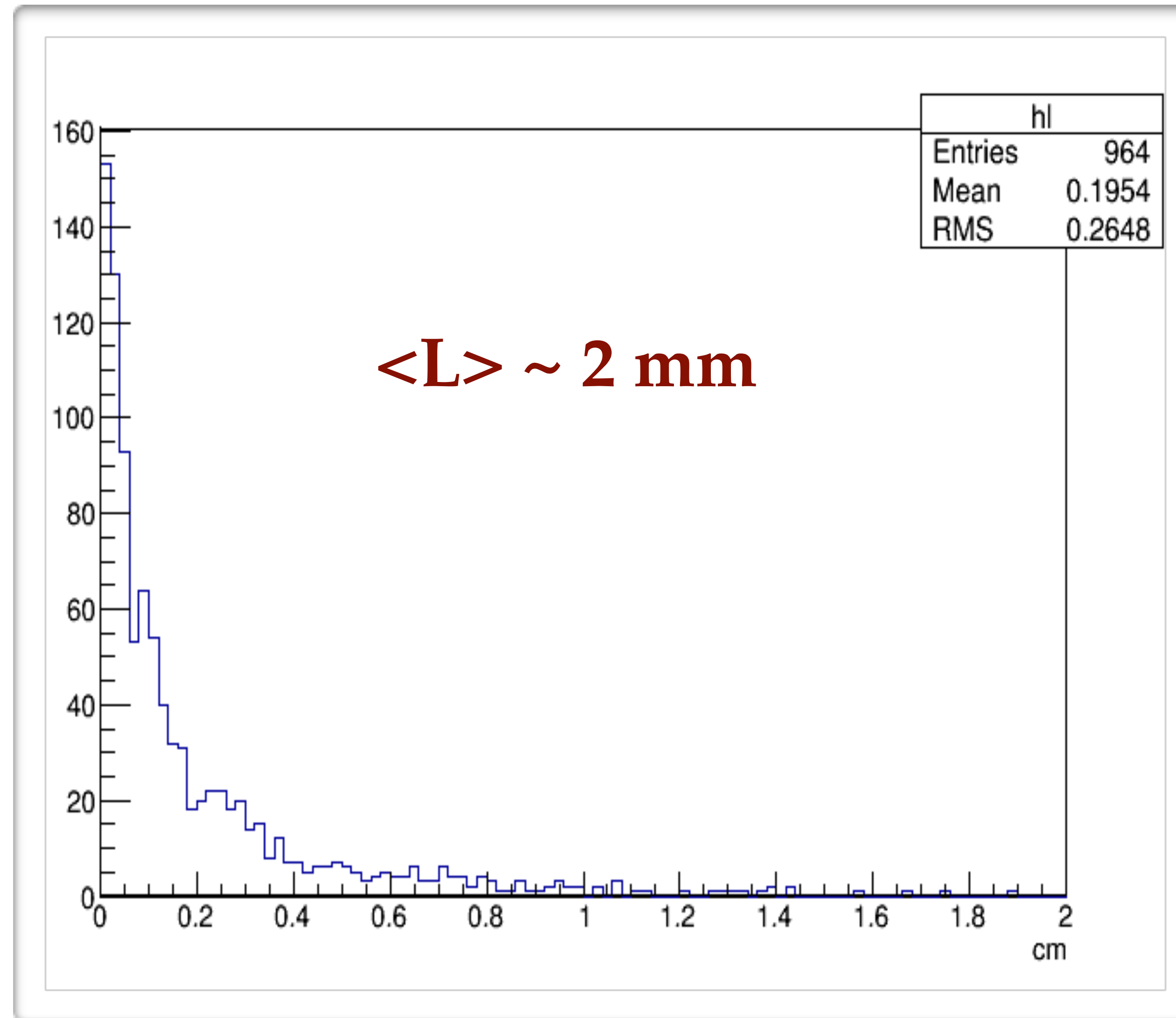
Charmed Hadrons

Charmed hadron flight length

- PRIMARY PROTONS



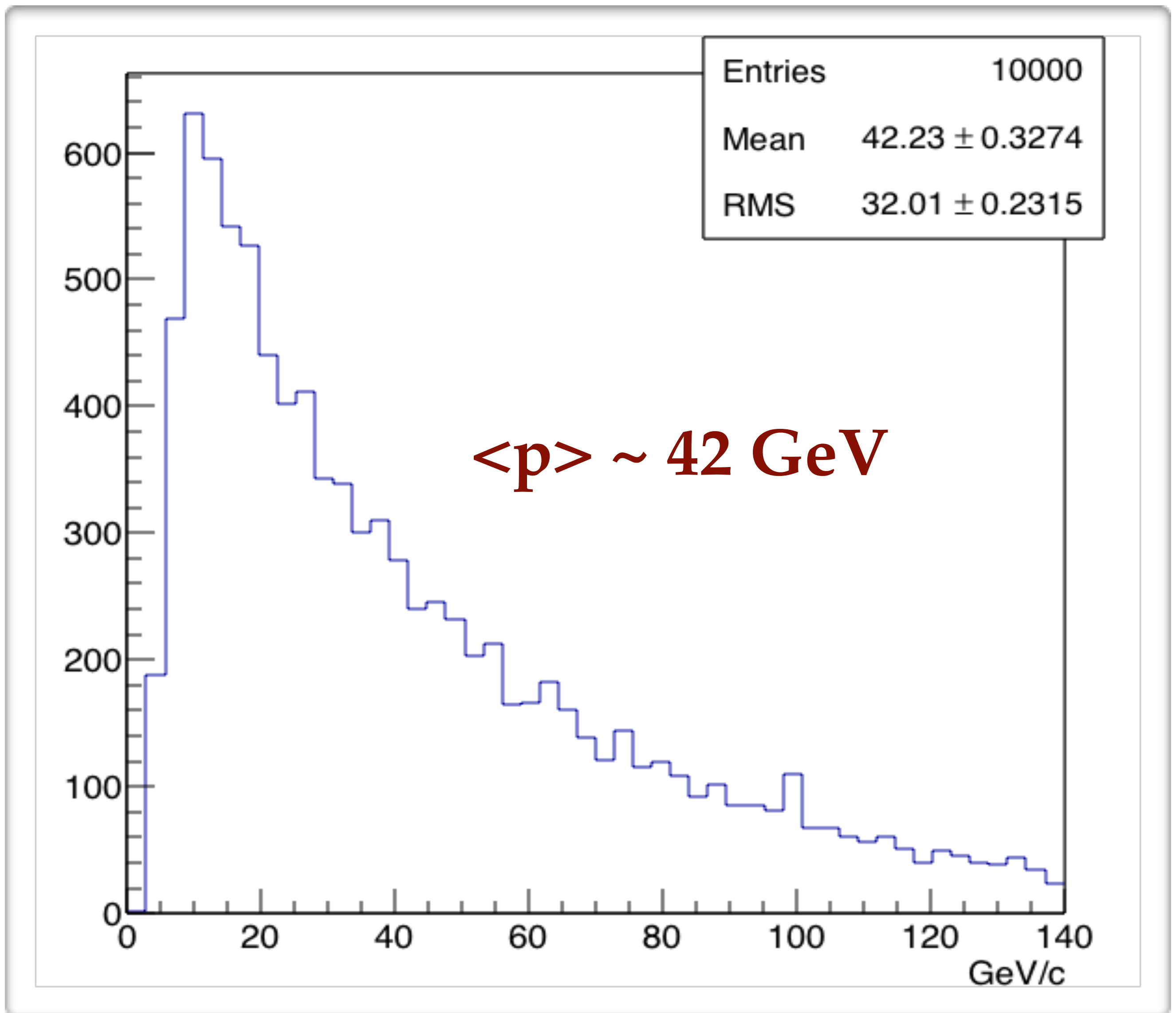
- CASCADE PRODUCTION



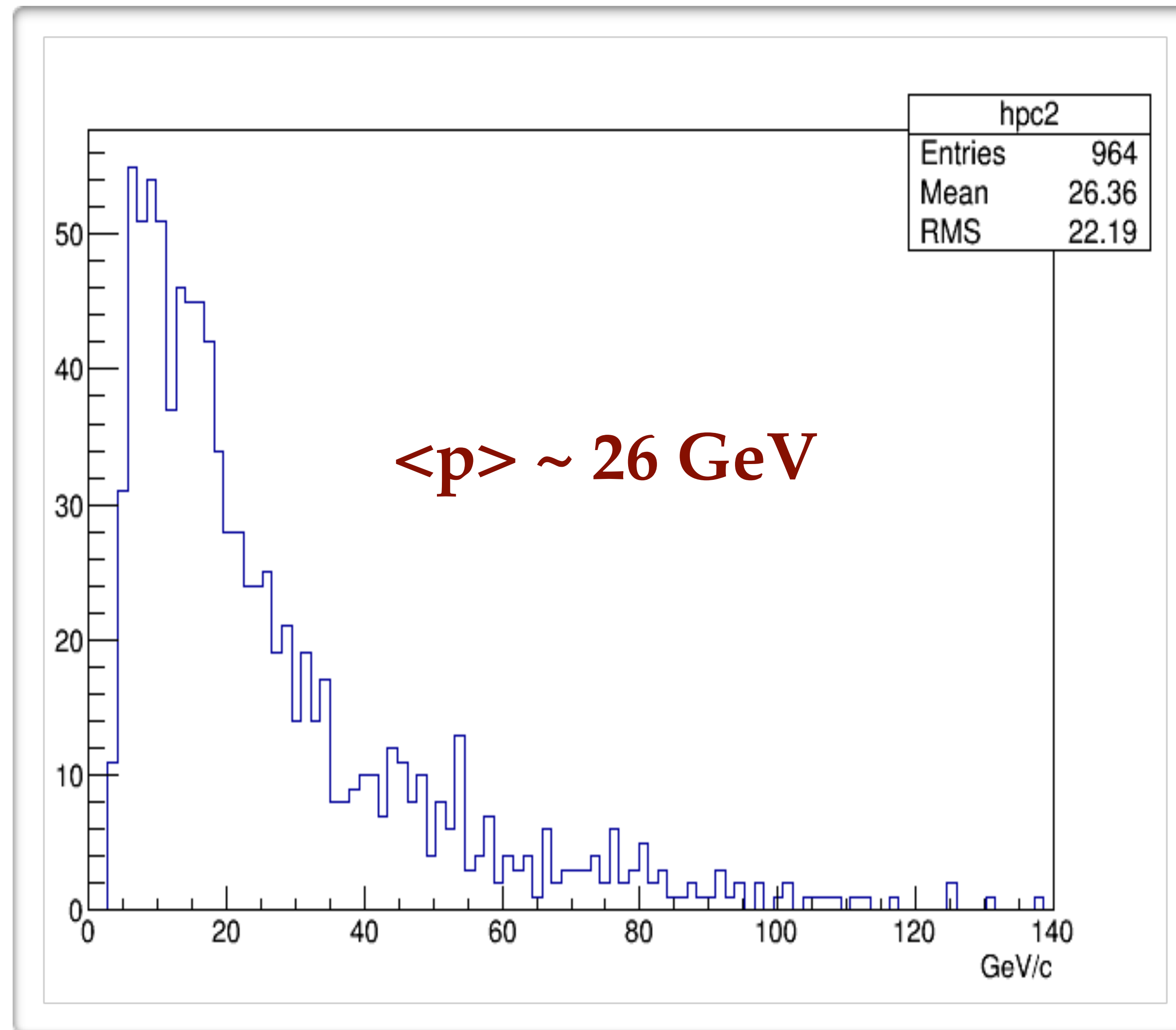
Charmed Hadrons

Charmed hadron momentum

- PRIMARY PROTONS



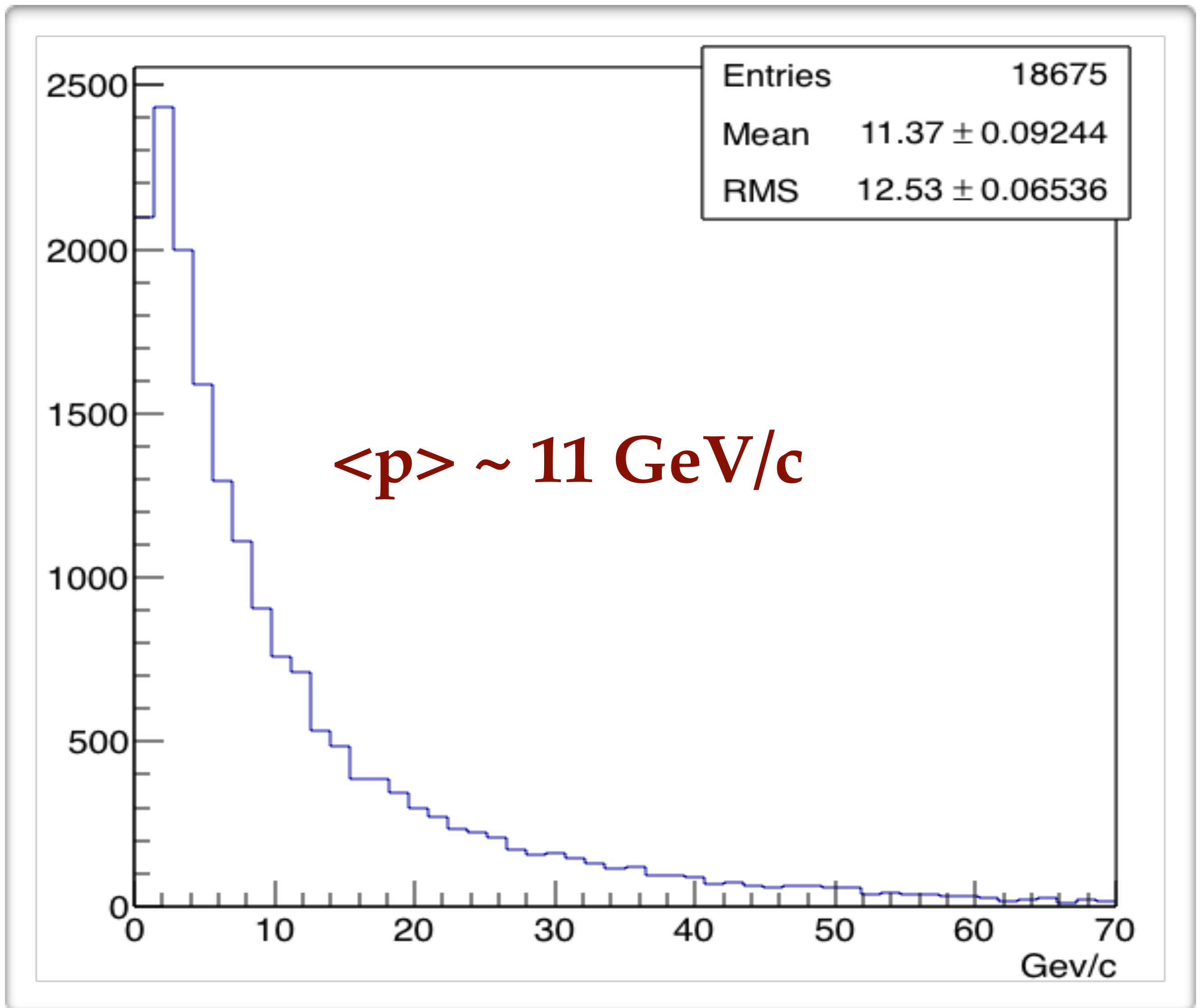
- CASCADE PRODUCTION

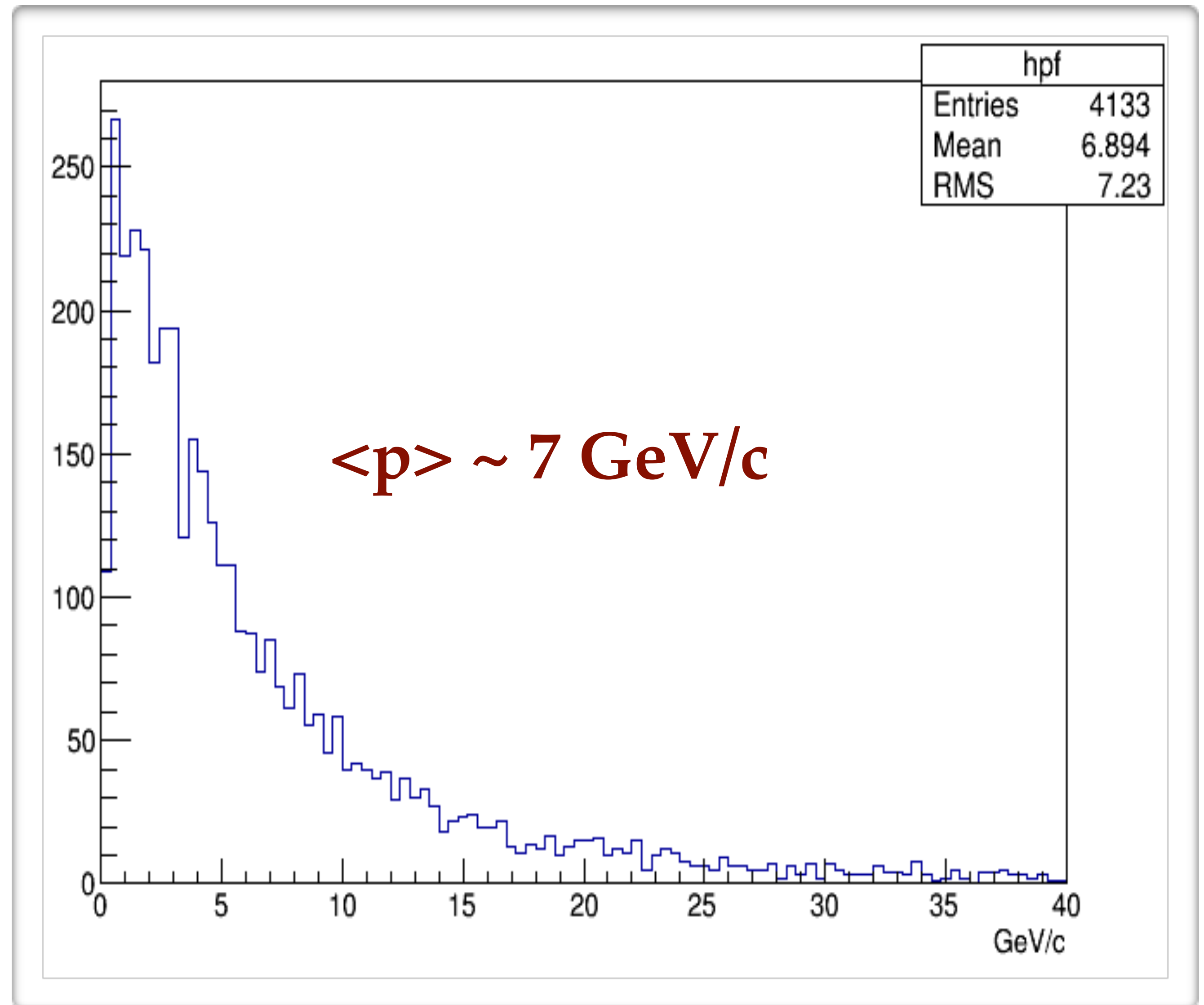


Decay Products

Charm daughters momentum

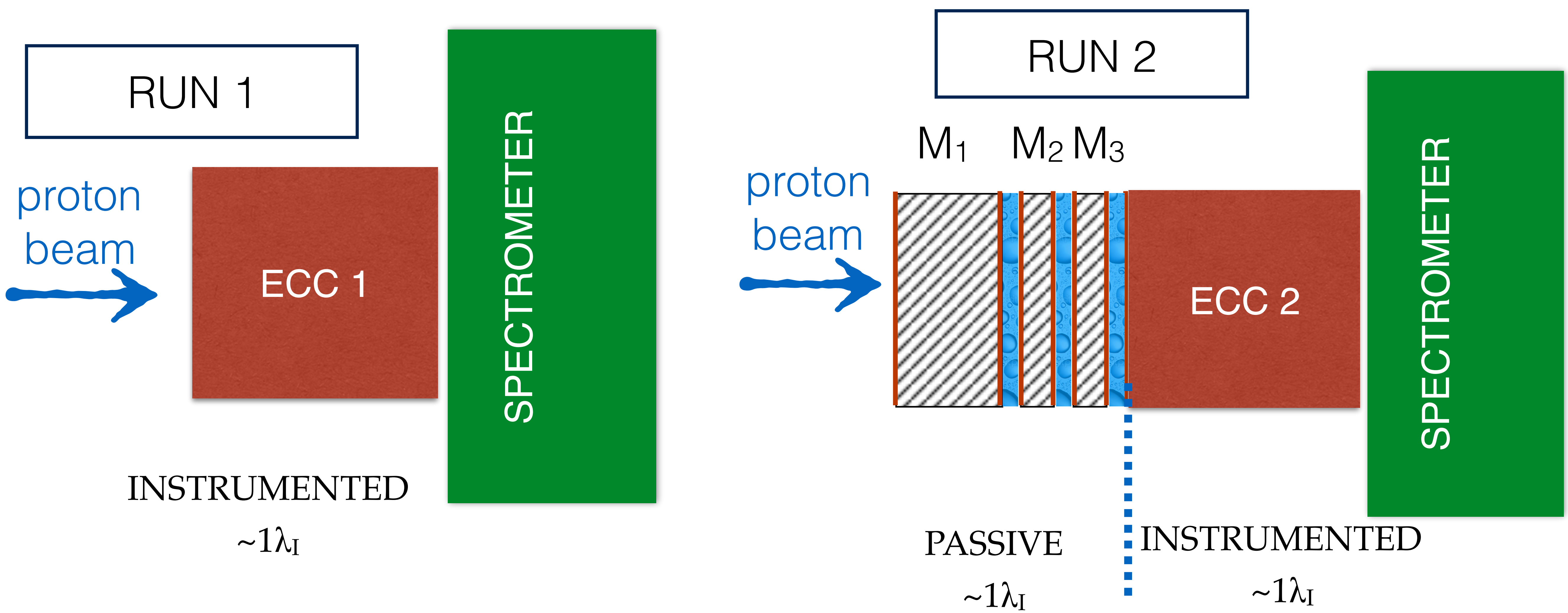
- PRIMARY PROTONS
- CASCADE PRODUCTION





RUN CONFIGURATION

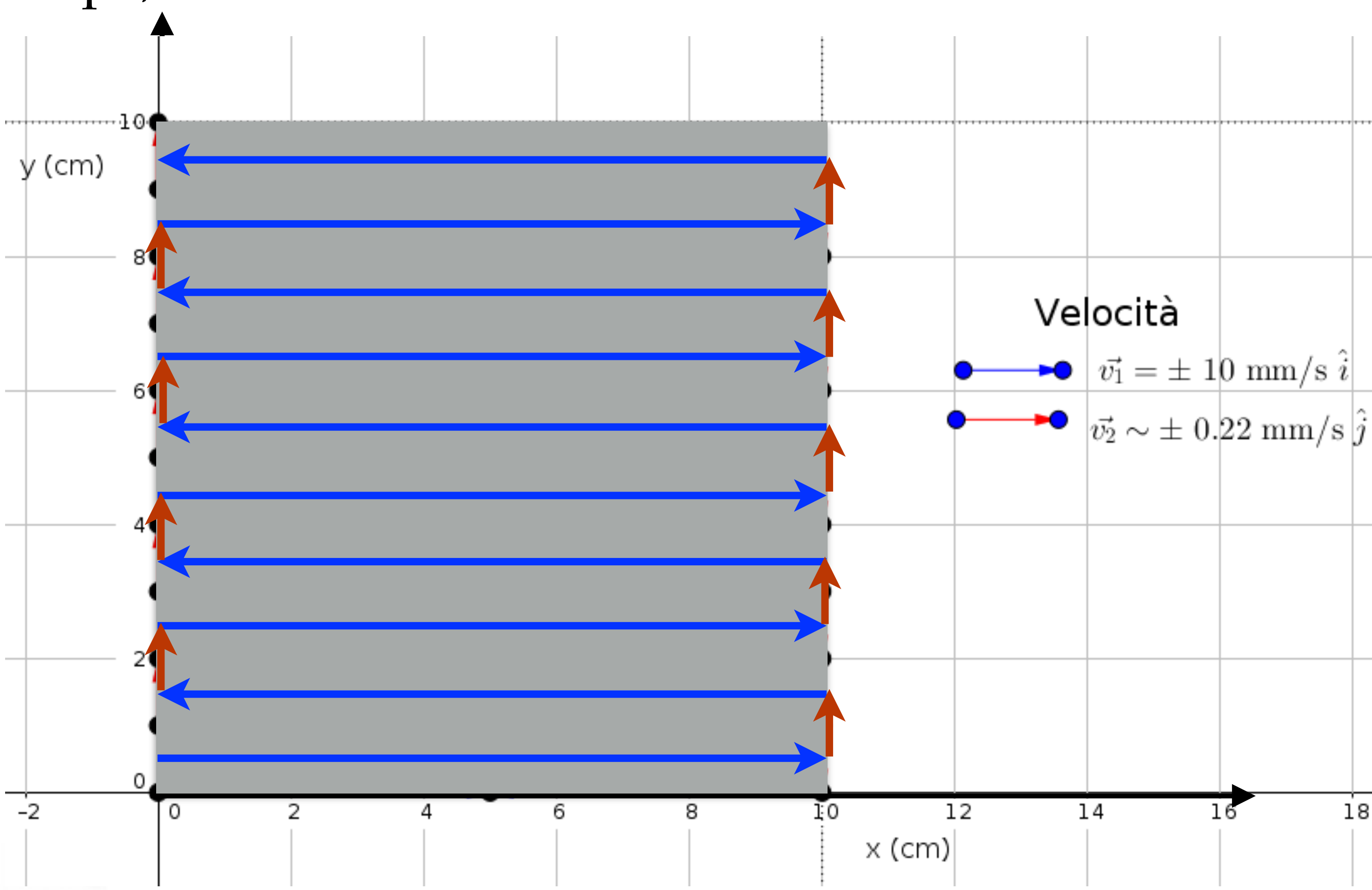
- Instrumentation of different portions of the target with emulsions
- ECC always the most downstream part of the target to let charm daughters reach the spectrometer
- Target modules are retained upstream of the ECC



MOTION OF THE TARGET

- Motion of target required to have protons uniformly distributed on a 10x10 cm² surface
- Optimization of the velocity of the table: - maximization of proton uniformity (minimization of a χ^2 function)
  - minimization of the number of spills *Ns*
- Assumption: proton beam with gaussian shape, σ=0.5 cm
- Motion of the target

- along x-axis during the spill (~5s)
- along y-axis between two spills

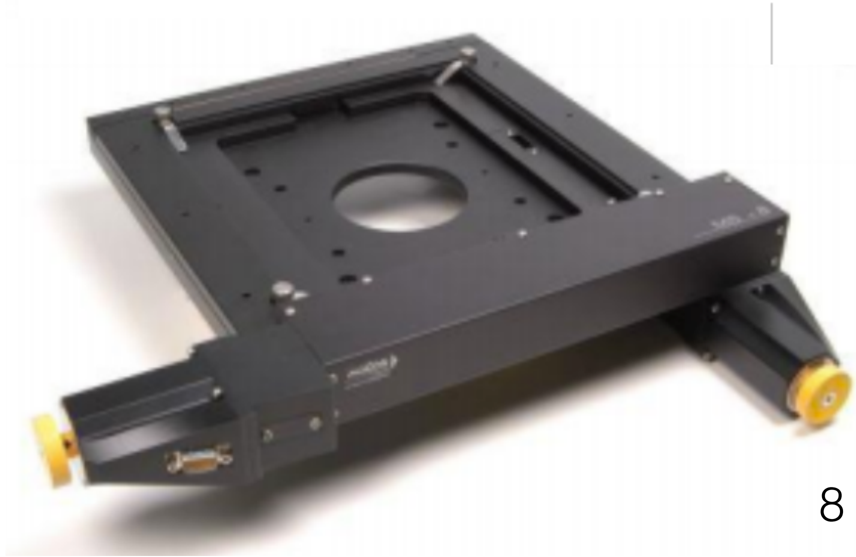


Result of optimization: $v_x = 2$ cm/s
$\Delta y = 1.0$ cm
$Ns = 10$

- Design of moving table

(N. D'Ambrosio - LNGS)

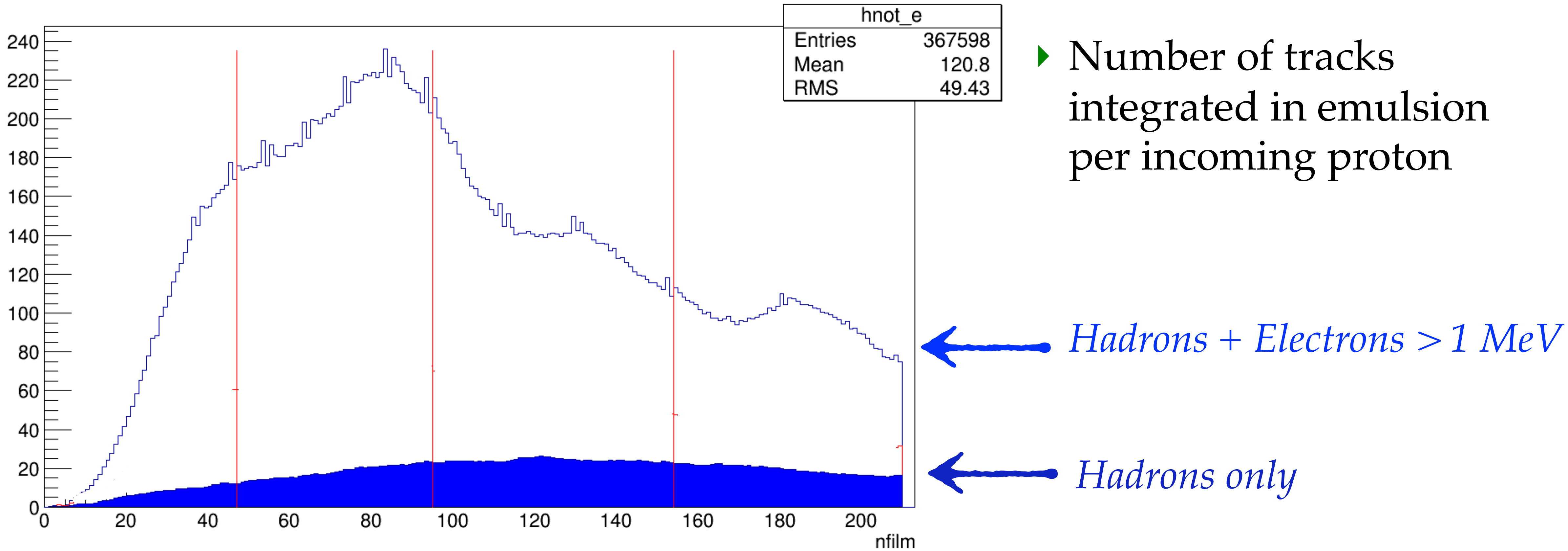
- micrometric precision
- support ~20 kg target



- First test of a prototype for light target (~1kg) will be tested in September 2017

EXPOSURE PLAN

- Number of integrated pot per run driven by the maximum number of tracks that can be integrated in emulsion films



- Number of tracks integrated in emulsion per incoming proton

Exposure needed to observe **10k** charmed pairs: ~ 8×10^7 pot

1 **Density: 10^3 tracks/mm^2**

900 x ECC1 x 5 x 10^4 pot

660 x ECC2 x 4 x 10^4 pot

Total emulsion surface (3mm sampling) ~ 750 m^2

2 **Limit density: 3×10^3 tracks/mm^2**

300 x ECC1 x 1.6 x 10^5 pot

220 x ECC2 x 1.2 x 10^5 pot

Total emulsion surface (3mm sampling) ~ 250 m^2

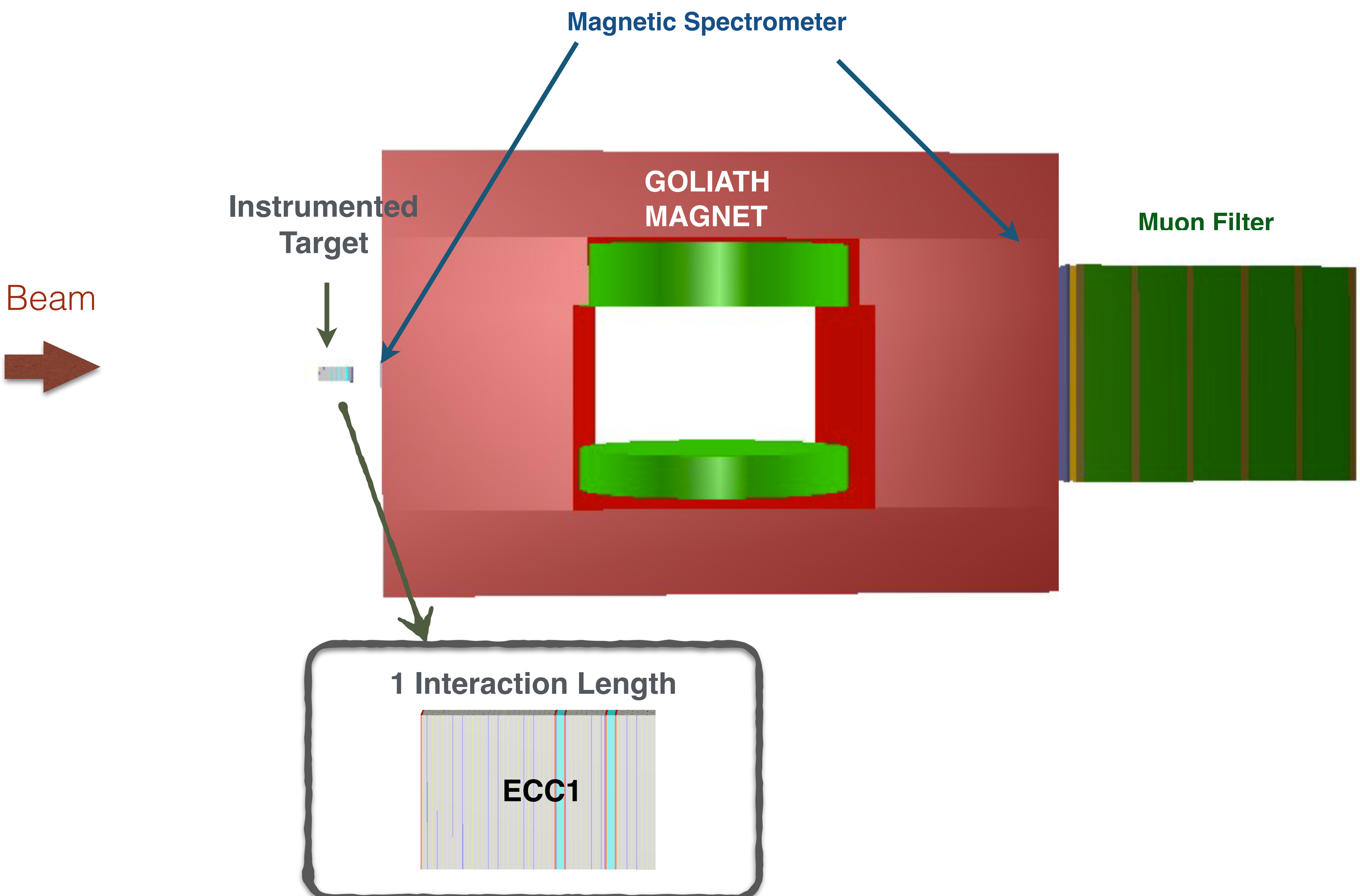
EXPOSURE PLAN

2018 EXPOSURE: OPTIMIZATION RUN

- Integrate ~10% of total statistics
- Test different samplings: 1 mm, 2mm, 3 mm
- Build 20÷40 ECC, corresponding to ~25 m^2 emulsion surface
- Exposure with different integrated density: from 10^4 to 10^5 pot
- Optimize beam parameters and exposure time
- Test moving table
- Develop and optimize of tracking/reconstruction algorithms
- First physics results

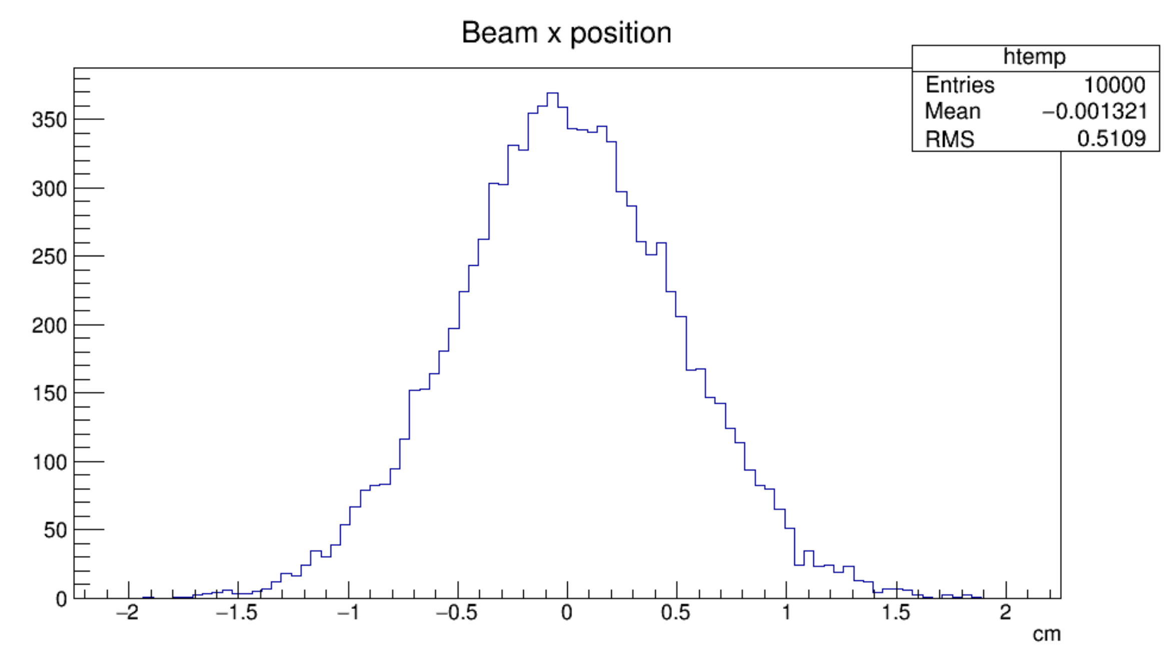
EXPERIMENTAL LAYOUT @H4

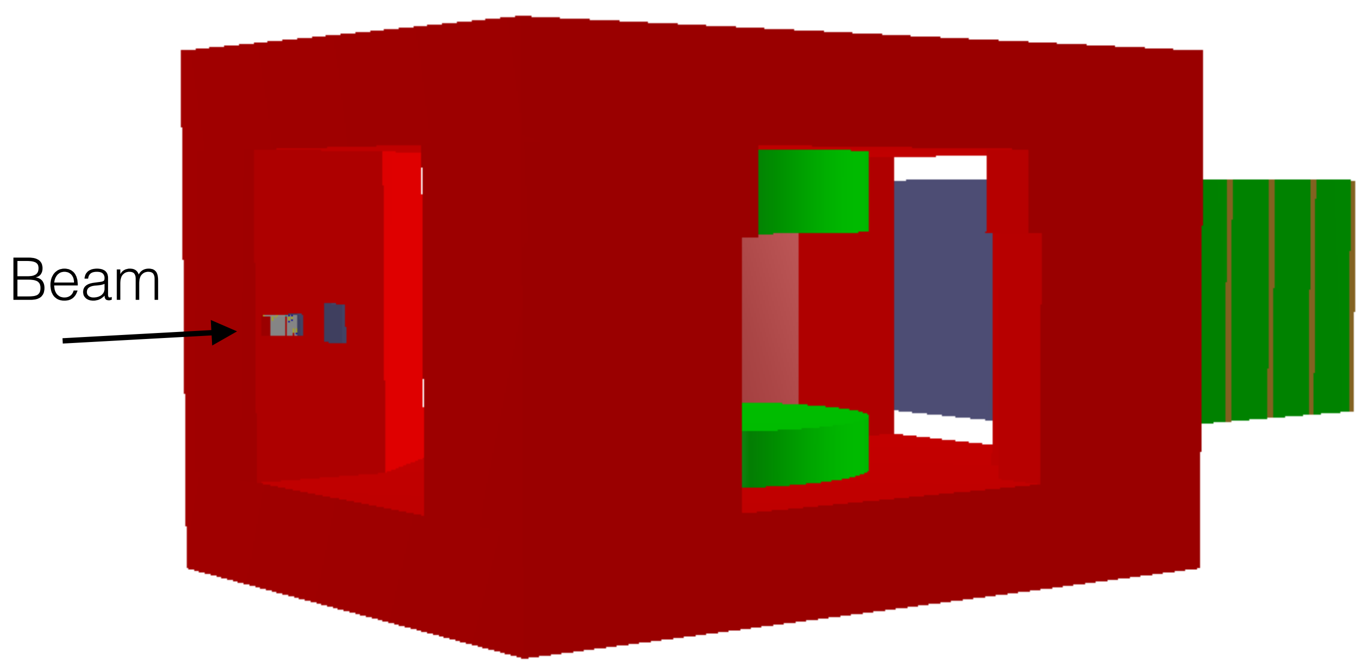
(implementation in FairShip by A. Iuliano)

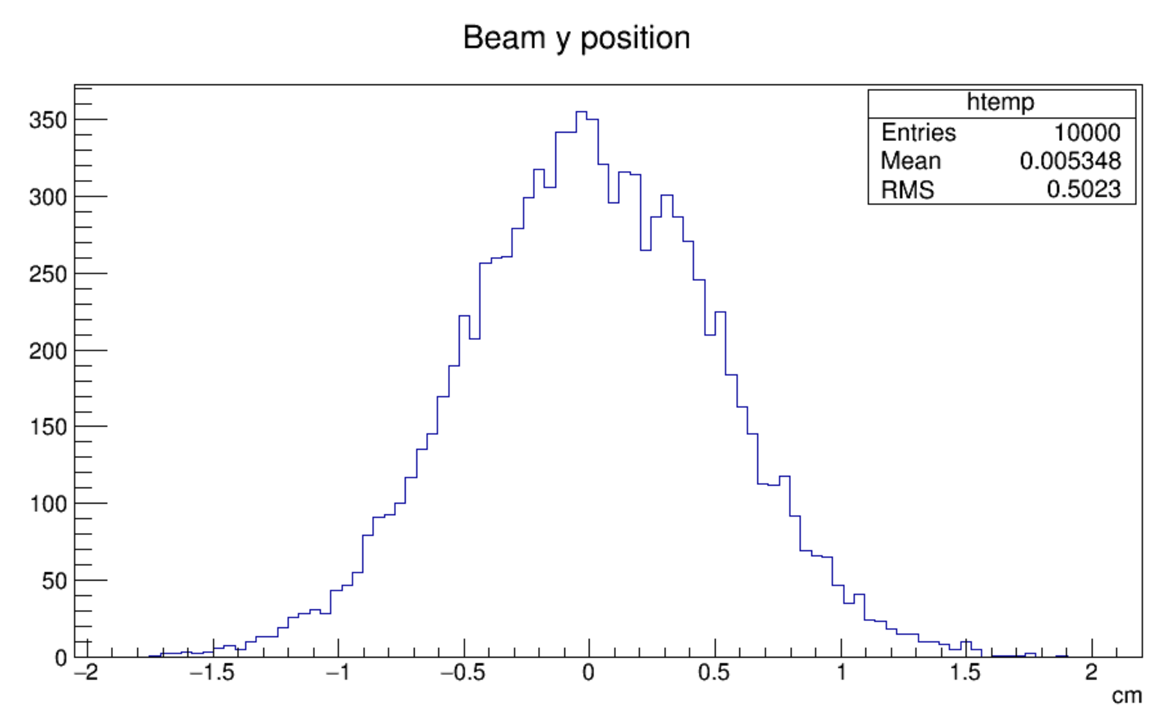


EVENT SIMULATION

- Proton beam: gaussian shape, σ=0.5cm
- Target: ECC1 (~0.8 λ_I)
- 1 spill (5s): 10^4 protons
- 2000 protons/s
- 56% interacting in the target
- 44% punch-through





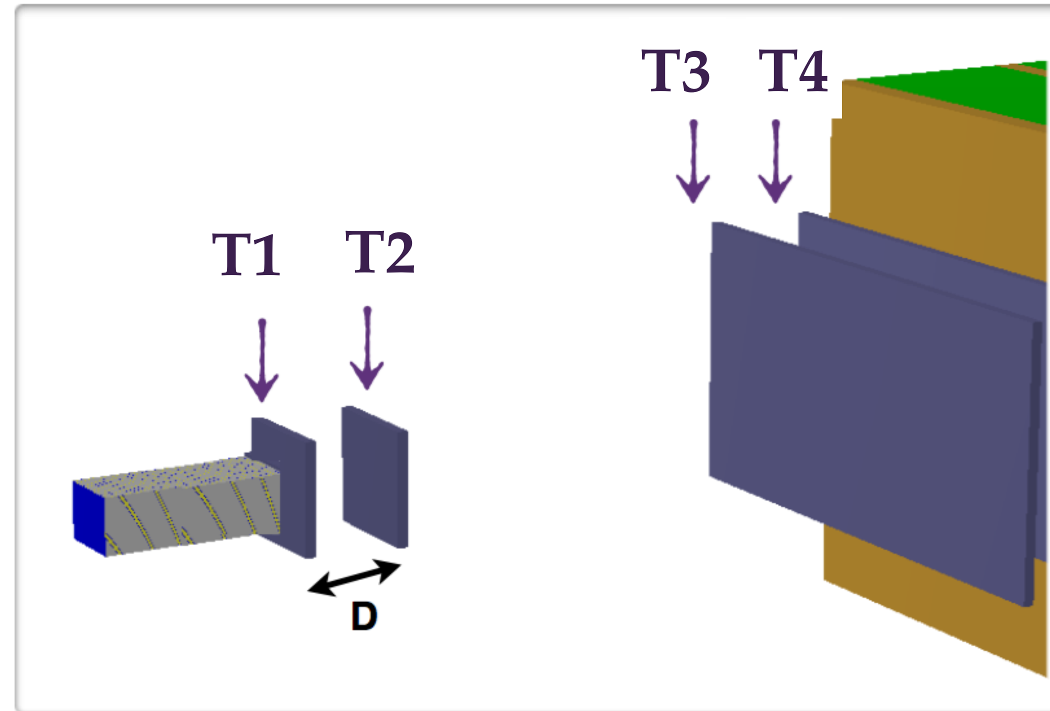


(implementation in FairShip by A. Iuliano)

EXPERIMENTAL LAYOUT

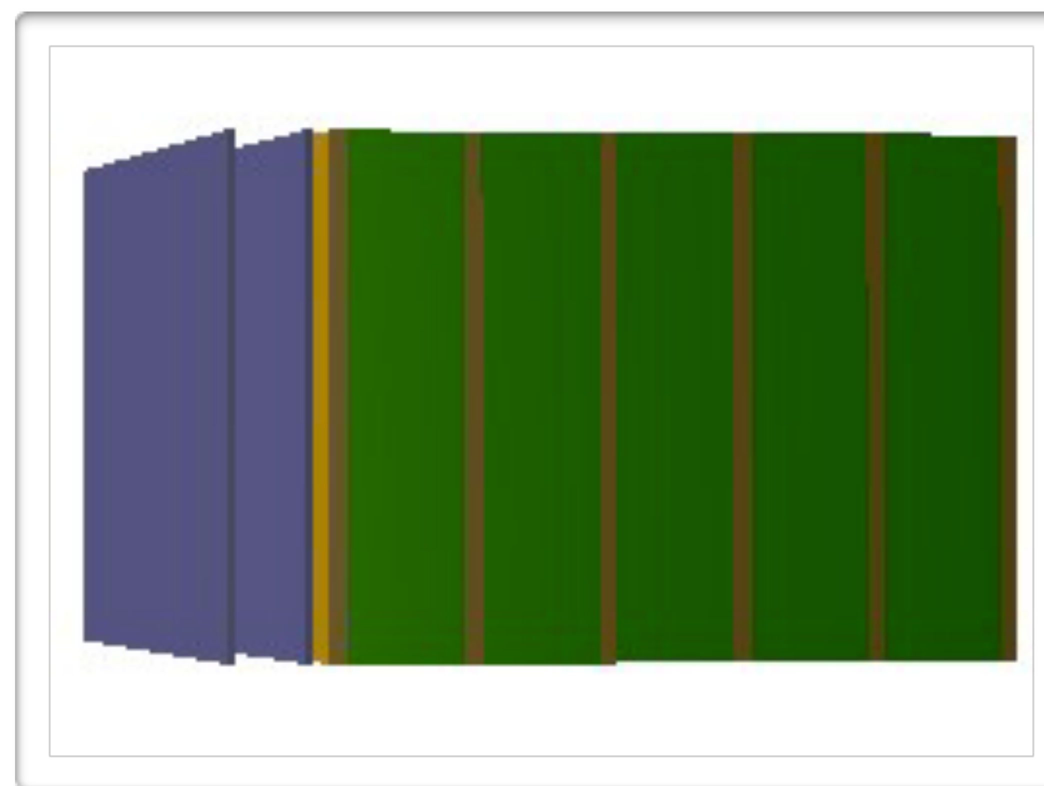
MAGNETIC SPECTROMETER:

- **Upstream** station T1: 13 x 11 cm^2
  T2: 20 x 20 cm^2
- **Downstream** station T3: 150 x 200 cm^2
  T4: 150 x 200 cm^2
- Requirements: measurement of (x,y) and (θ_x,θ_y) in both stations



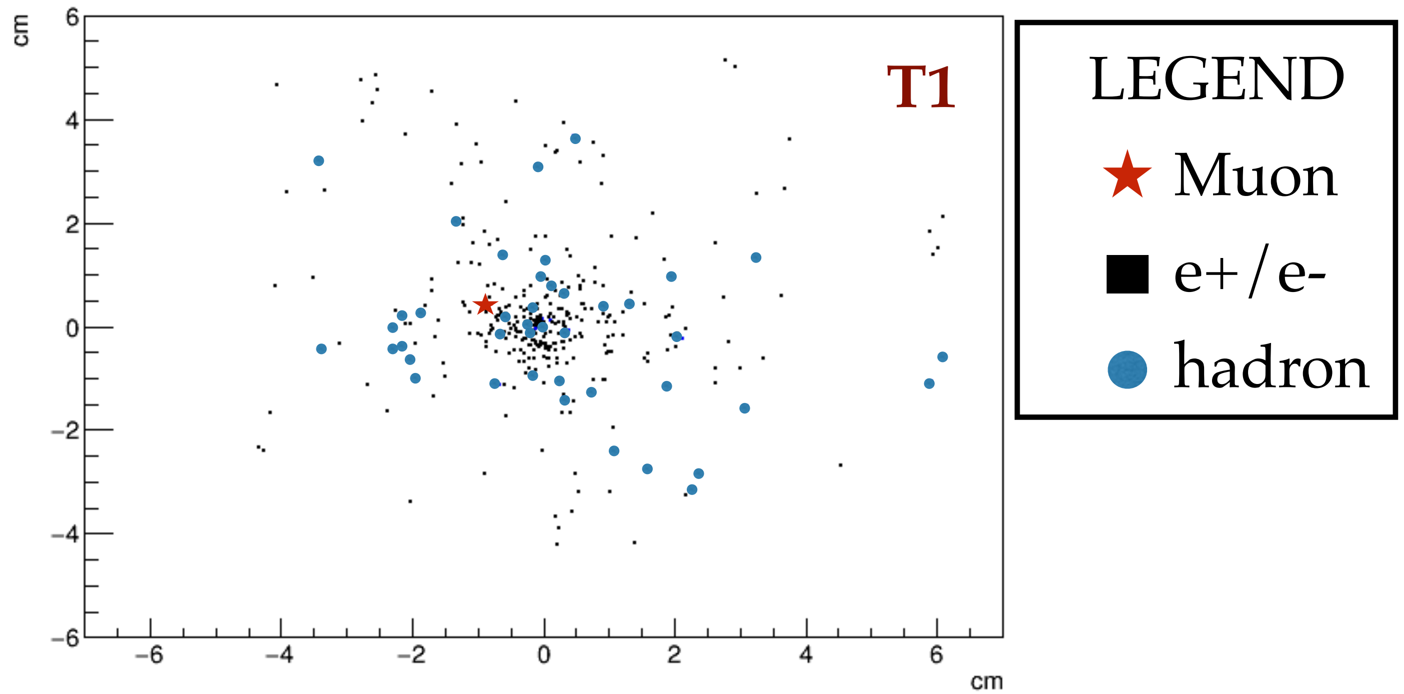
MUON FILTER:

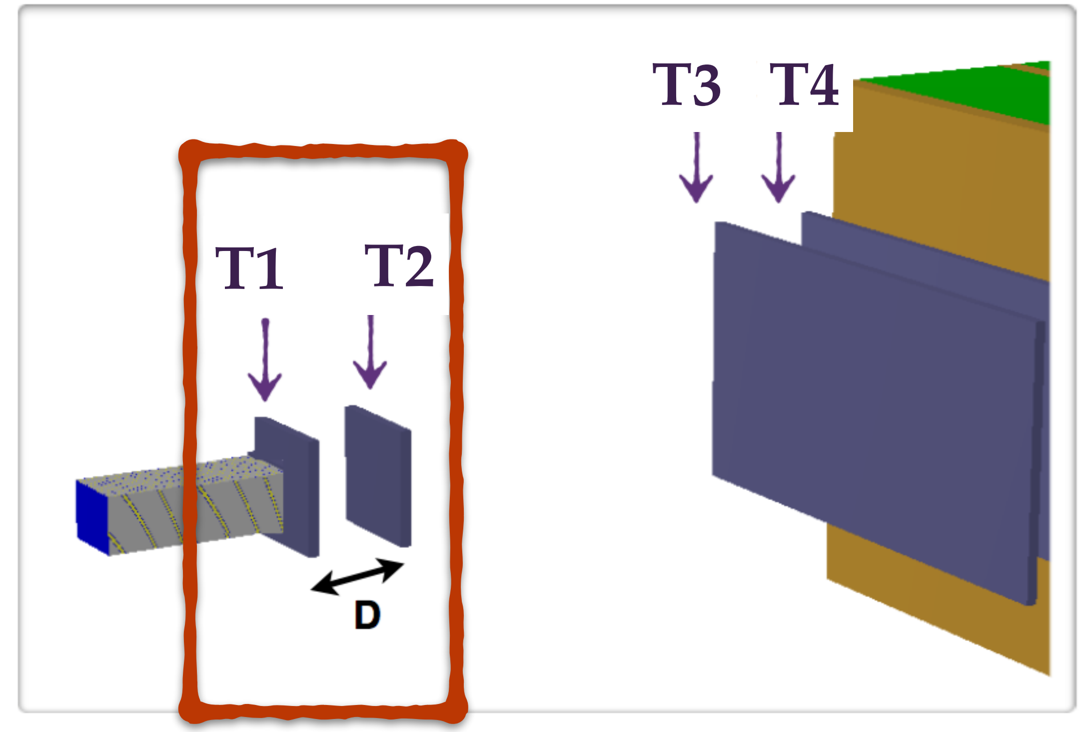
- 6 planes 200 x 200 cm^2



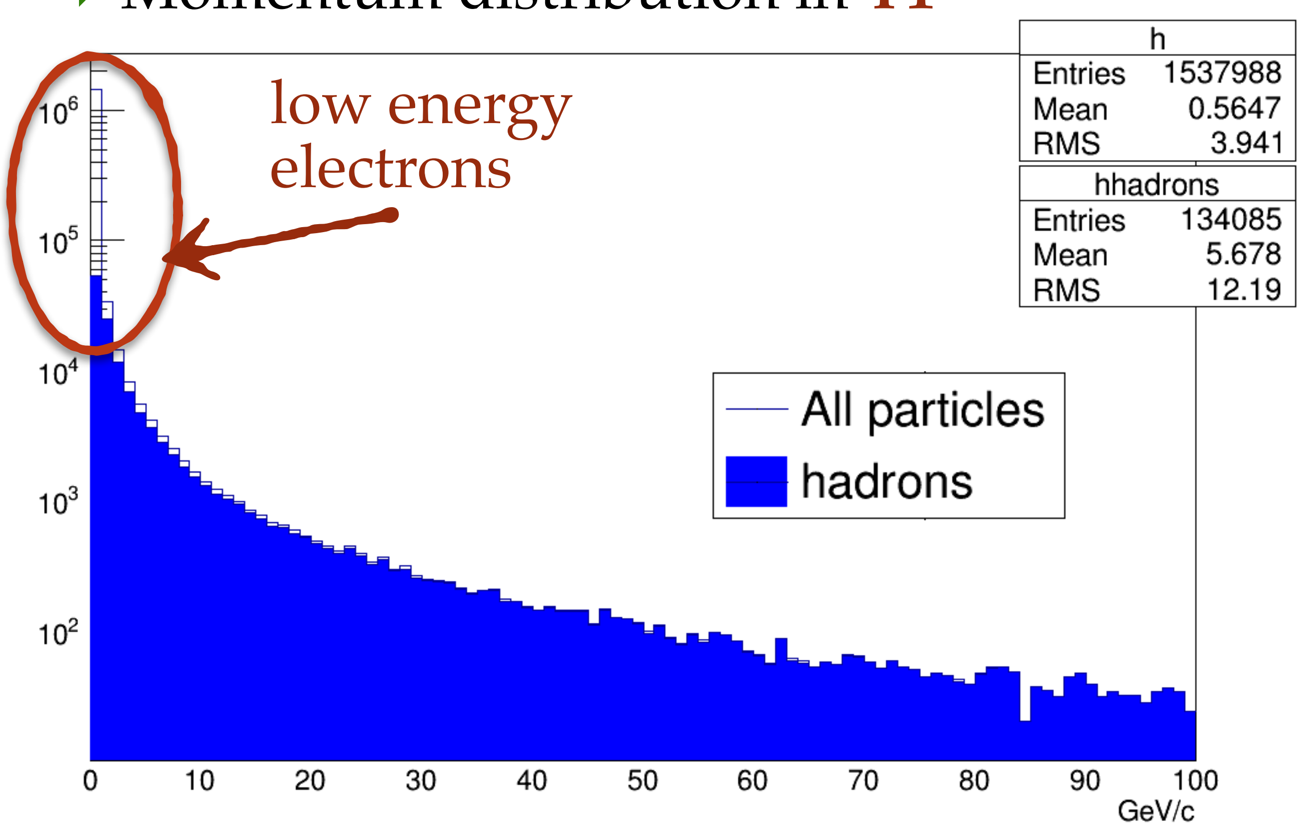
MAGNETIC SPECTRO - UPSTREAM STATION

- A “typical" charm event in T1





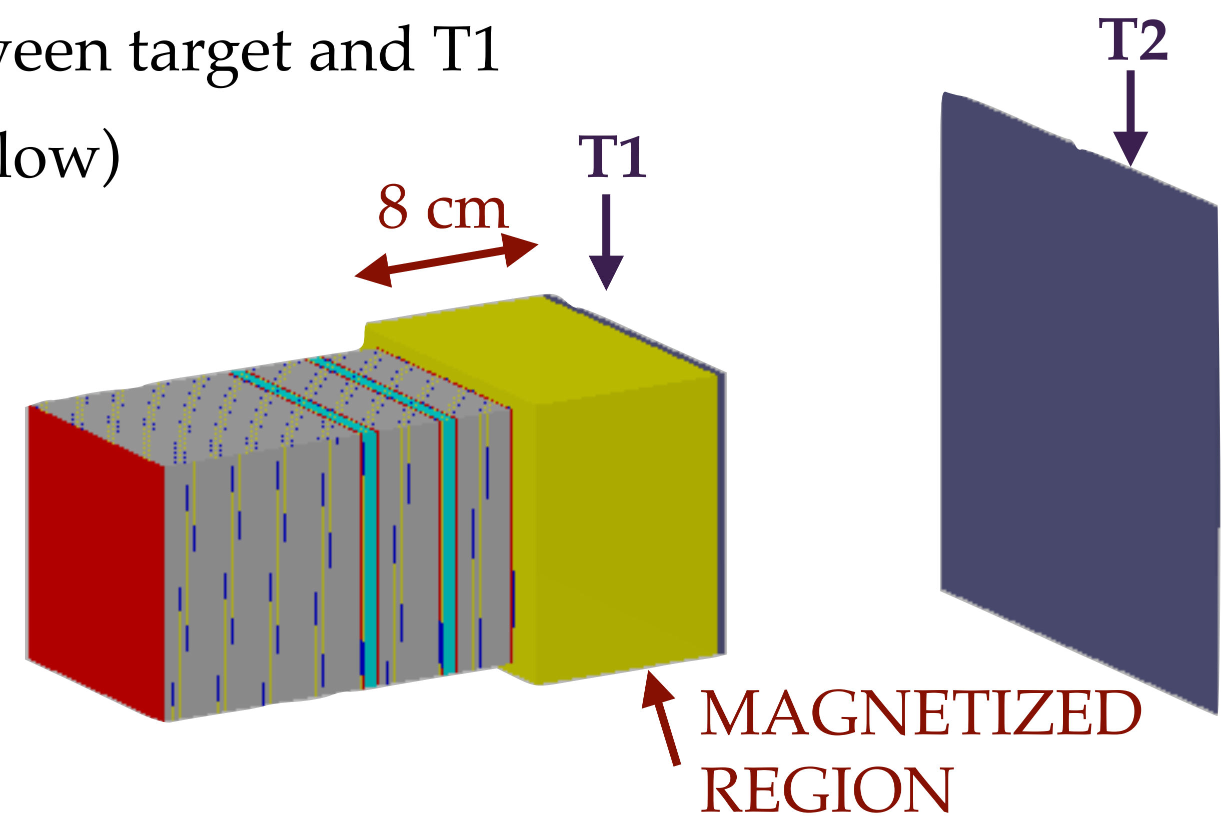
- Momentum distribution in T1



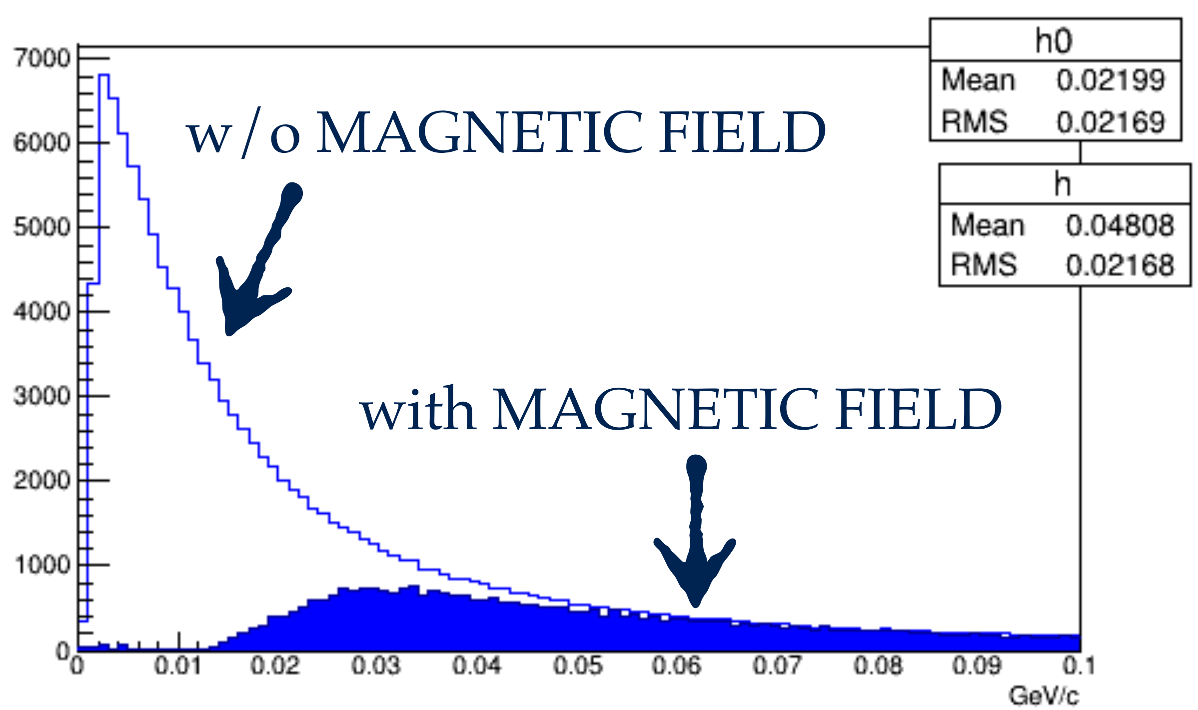
- High **occupancy** in the first spectrometer plane due to low energy electrons
- Necessary to deflect/absorb electrons before they reach T1

MAGNETIC SPECTRO - UPSTREAM STATION

- Solution under investigation: magnetic field between target and T1
- Magnetized region 8 cm-thick (highlighted in yellow)
- 1T uniform field along y-axis



- Reduction of electrons in T1: ~**factor 3x**
- Larger distance between ECC and T1 and therefore makes the pattern matching more challenging
- **MISiS** University (Moscow) is working at the magnet design



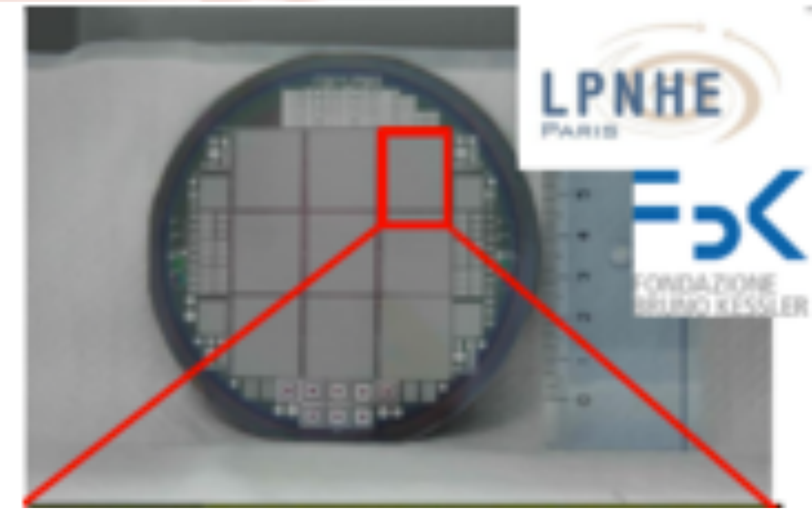
- Track density (average): 0.7 tracks/cm^2
- Track density (central region): 10 tracks/cm^2

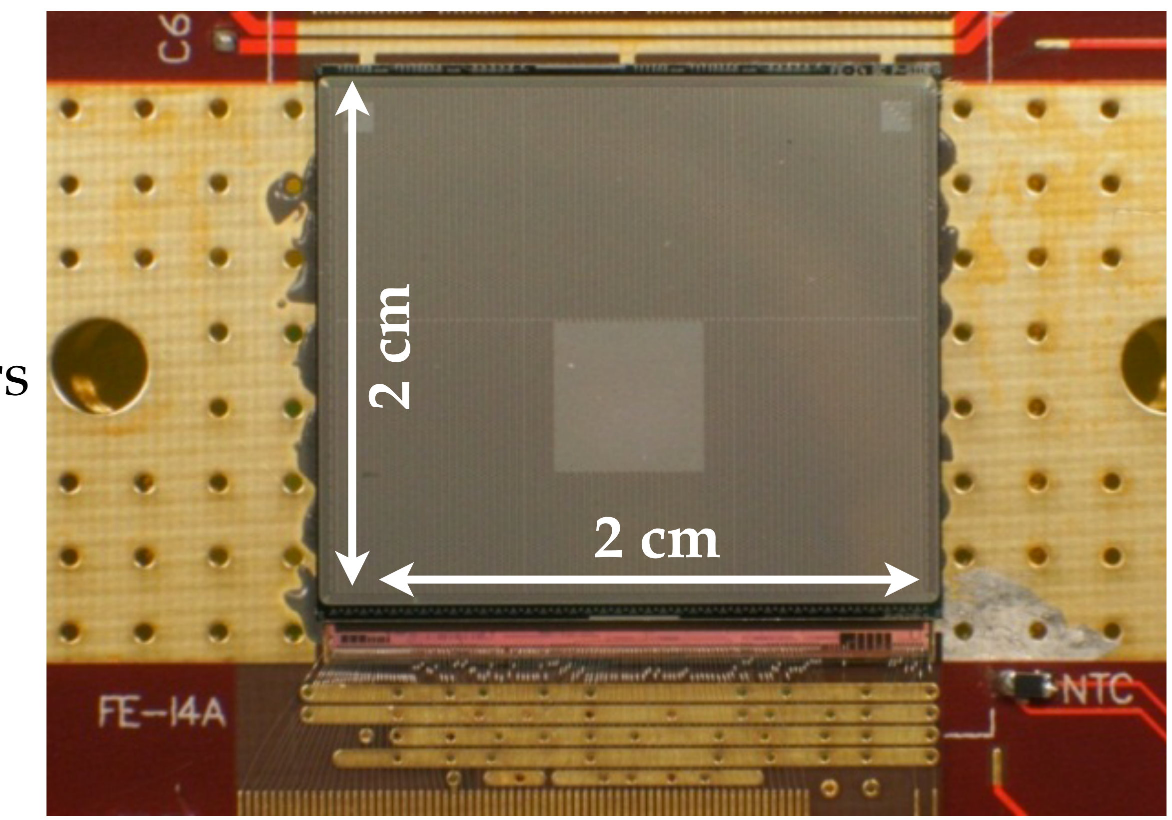
- The magnetic field would imply a larger distance between ECC and T1 and therefore makes the pattern matching more challenging

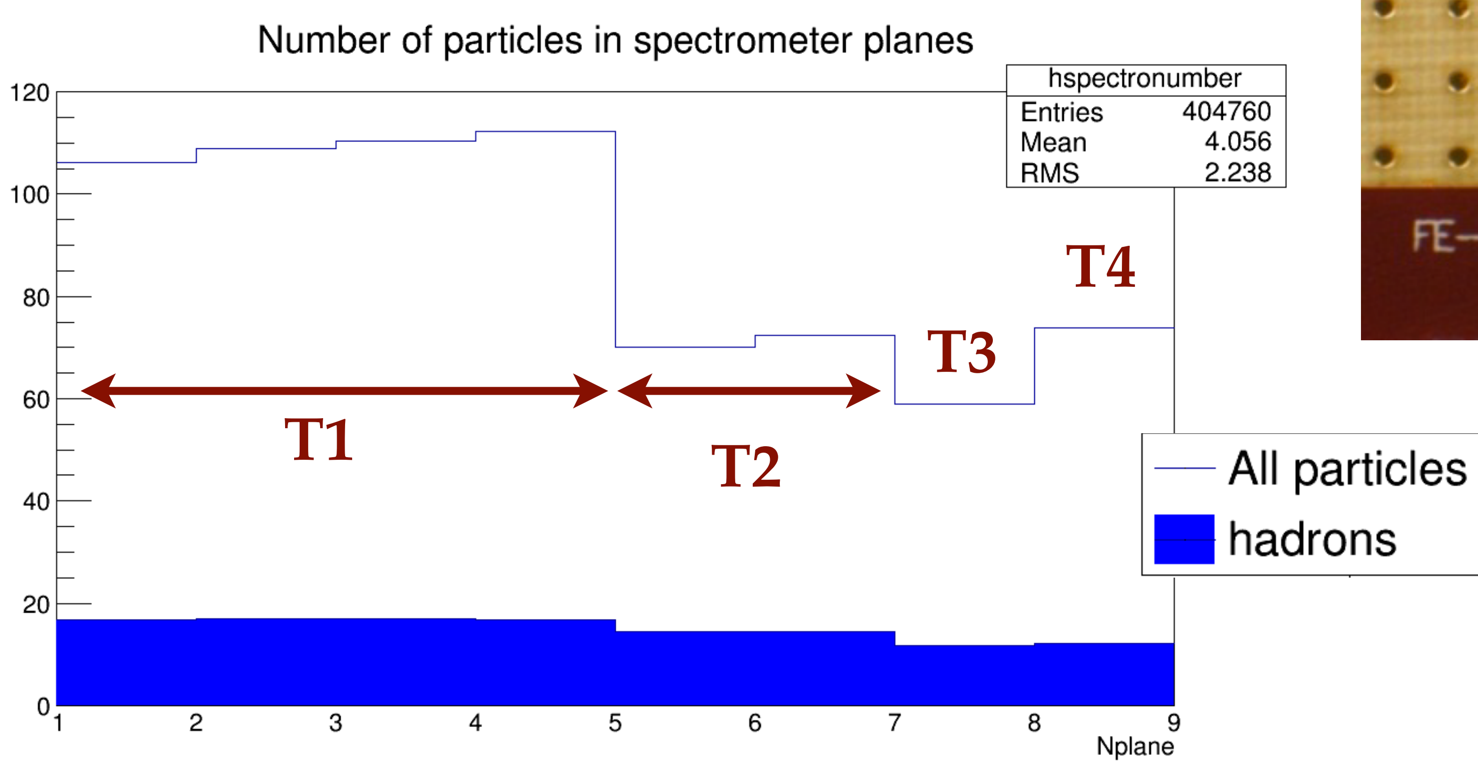
MAGNETIC SPECTRO - UPSTREAM STATION

- Detector option under investigation:

  Atlas FE-I4 silicon detectors (M. Cristinziani, Bonn University)
  - 50 μm × 250 μm pixel size
  - position resolution (2 layers): ~ 10 μm
  - total width: ~ 400 μm
  - high rate capability
  - high occupancy capability
  - sensor surface ~ 4 cm^2
  - array 3x3: 6x6 cm^2
  - possible configuration -> T1: 4 layers, T2: 2 layers

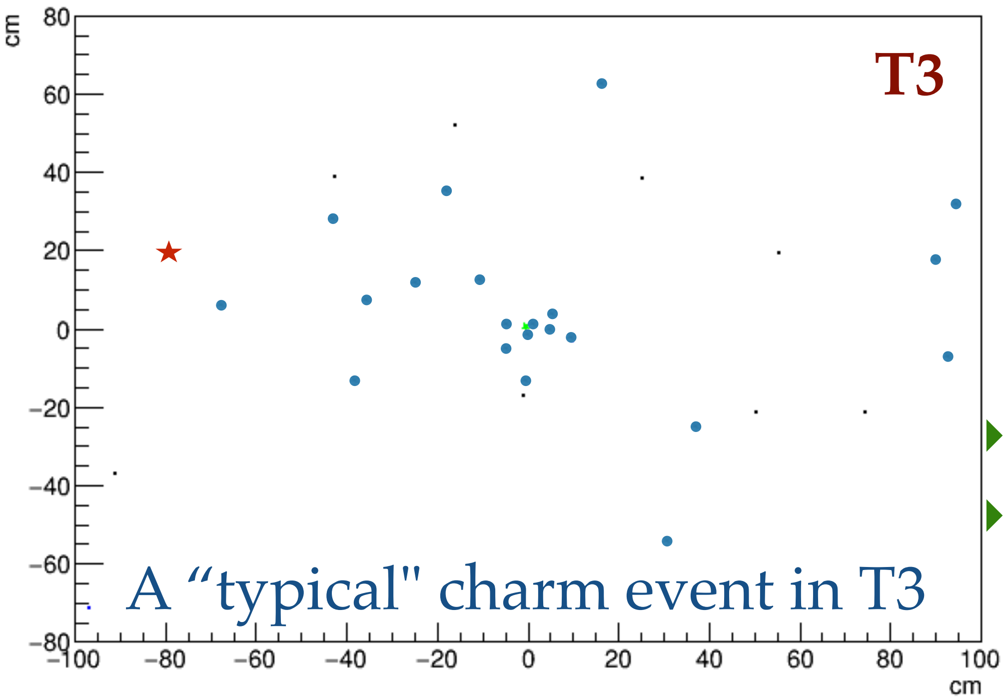




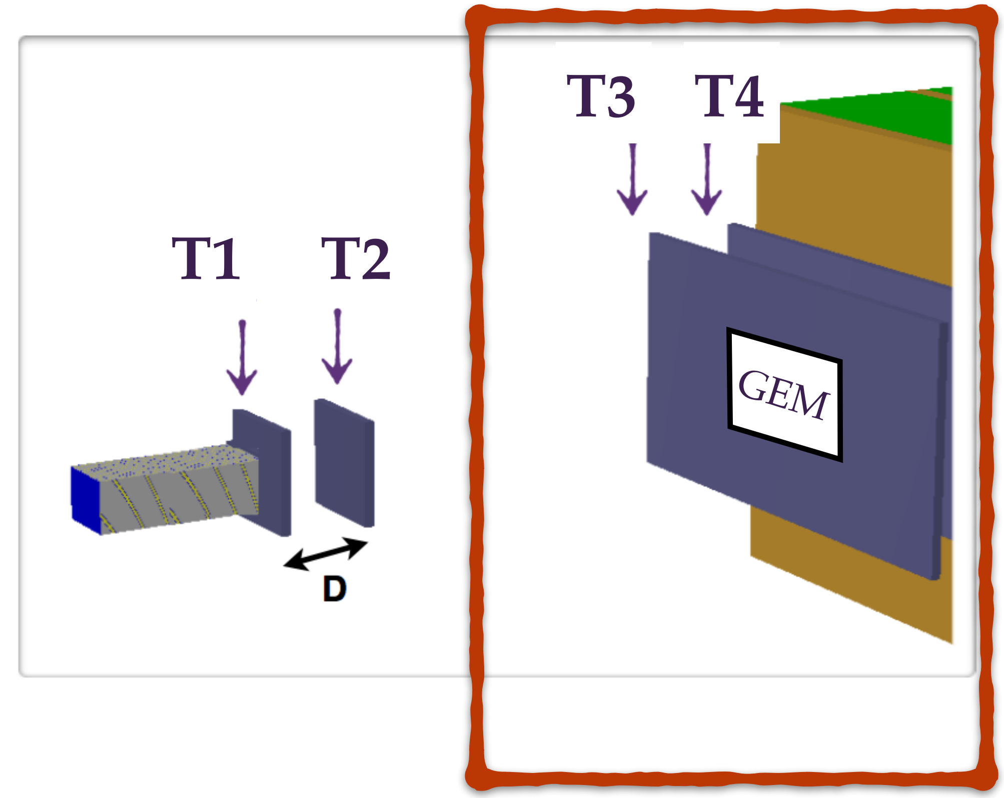


MAGNETIC SPECTRO - DOWNSTREAM STATION

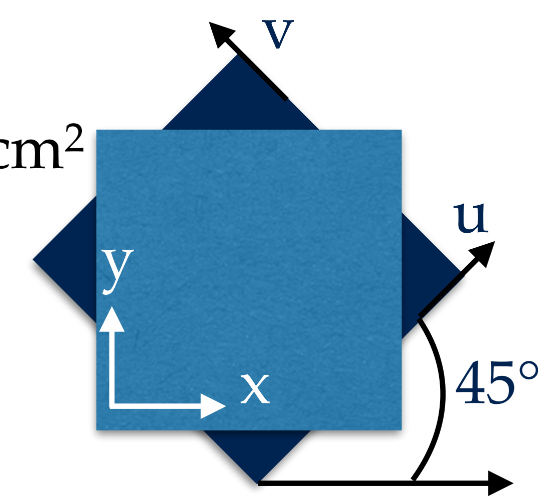
- Detector options under investigation:
  1) Scintillating fiber trackers (A. Malinin, V. Shevchenko)
  2) Drift Tubes used for muon flux measurement
     - with the addition of high granularity detector in the central high occupancy region



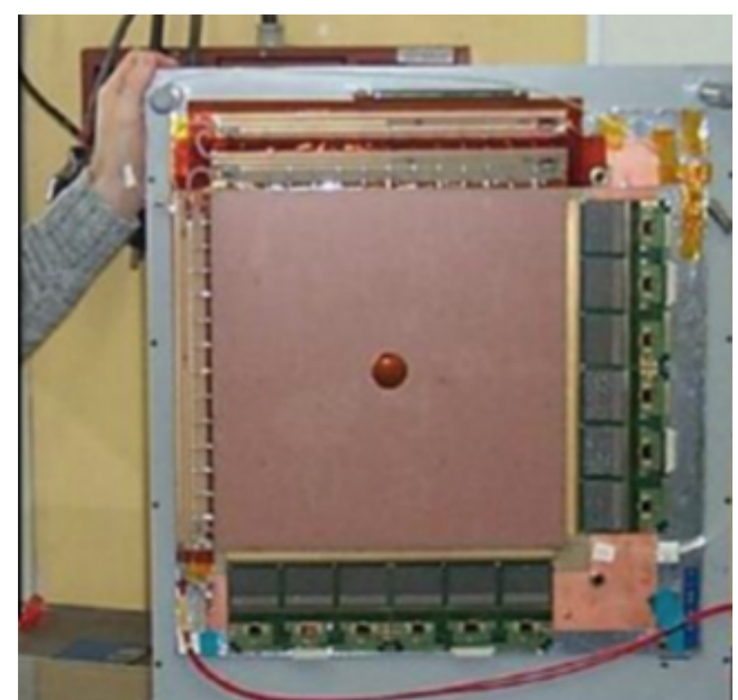
LEGEND
★ Muon
■ e+/e-
● hadron



- Track density (average): 0.002 tracks/cm^2
- Track density (central region): 0.2 tracks/cm^2

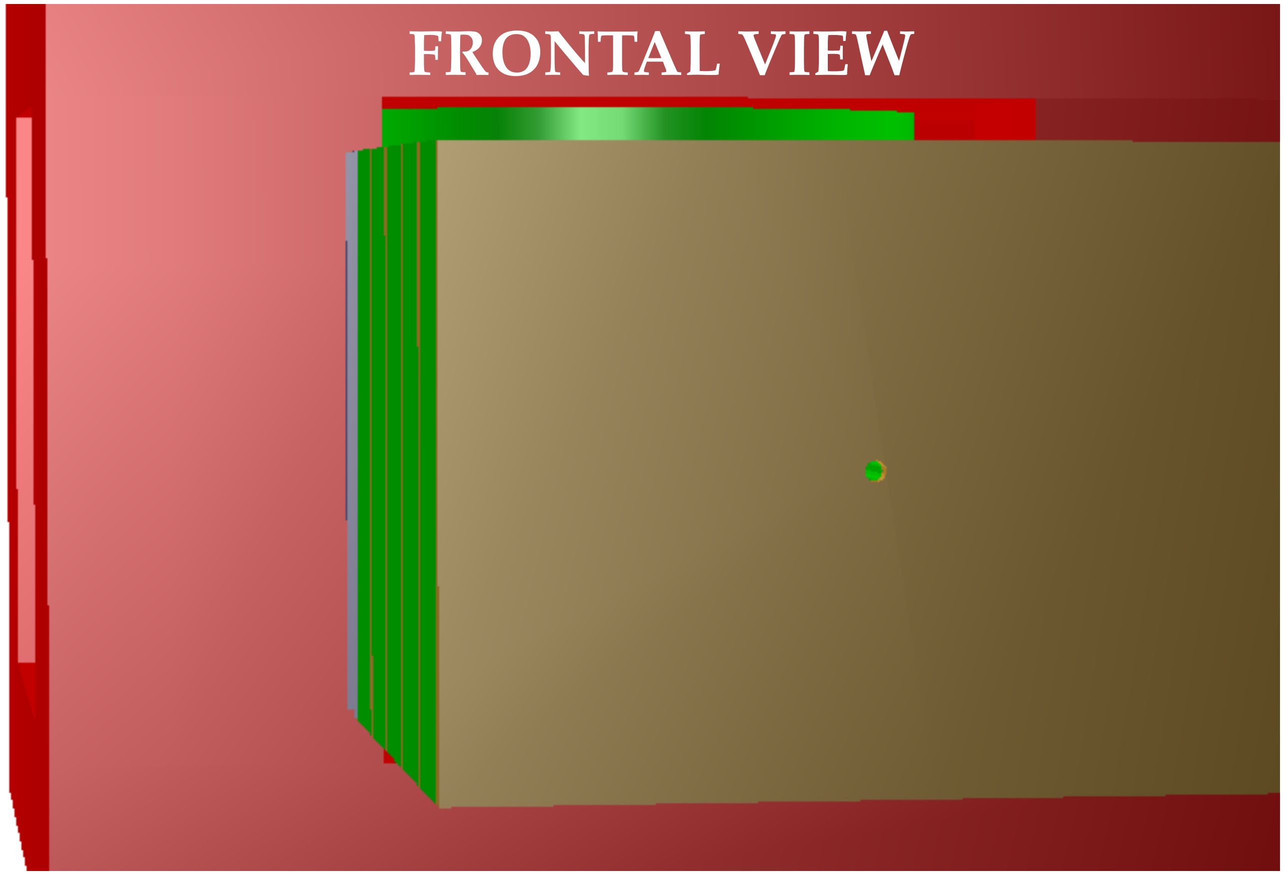


- Solution under investigation:
  - insert GEM chambers in the central region
  - COMPASS triple-GEM trackers 30x30 cm^2
  - 400 μm pitch
  - position resolution: <100 μm
  - in contact with A. Bressan for chambers availability in 2018 run



MUON FILTER

- Central hole (R=2.5 cm) foreseen in the Muon Filter slabs
  1) Rejection of proton punch-through interactions
  2) Avoid high density area in RPC planes
- 6 planes 2 x 2 m^2
- Sensitive planes: RPC
- Passive material: 34 cm-thick iron slabs

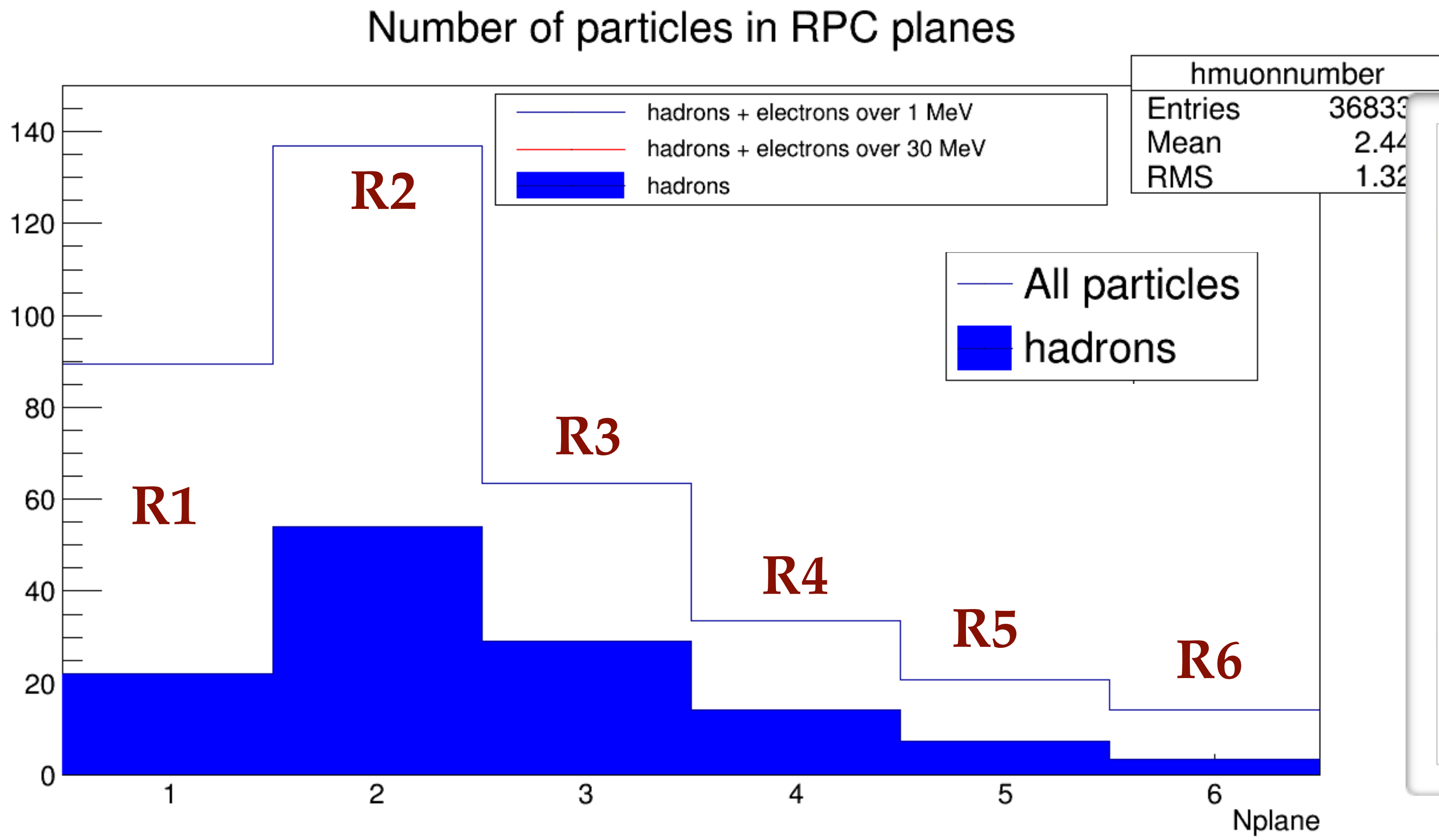


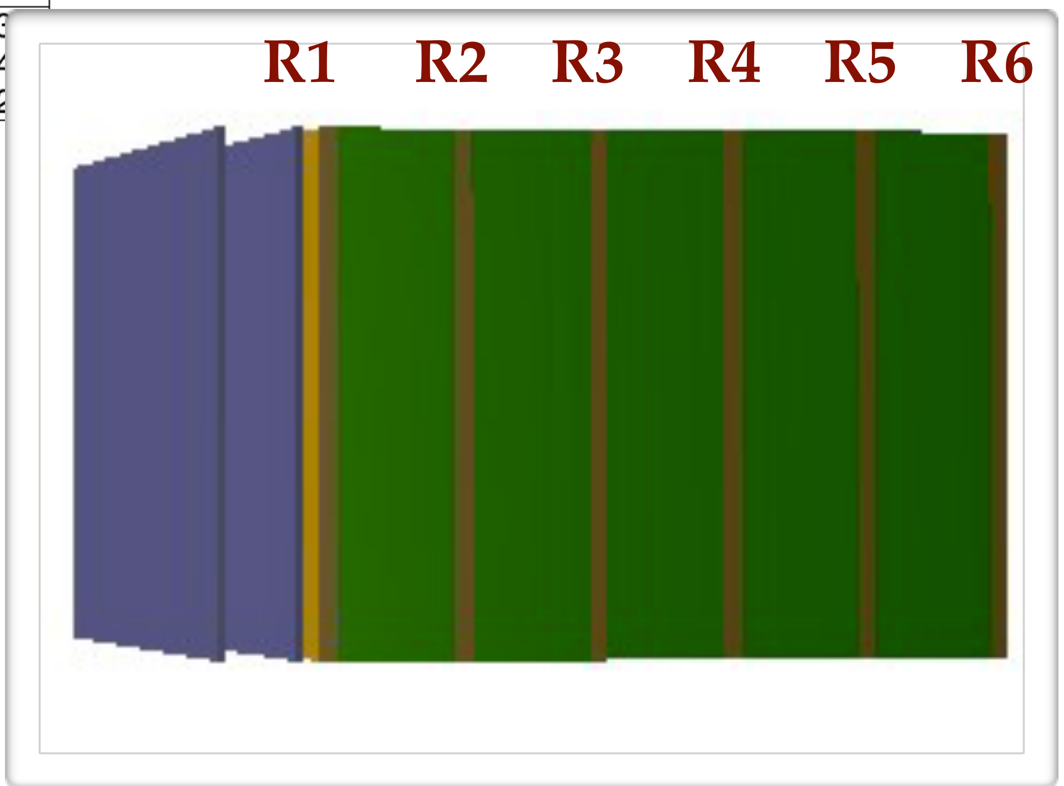
RPC CONSTRUCTION

- Joint project between INFN and KODEL from Korea University (S. Park and K.S. Lee)
- KODEL: RPC construction
- INFN (Bari and Napoli): readout electronics

MUON FILTER

- Average number of hits in RPC planes per **interacting** proton



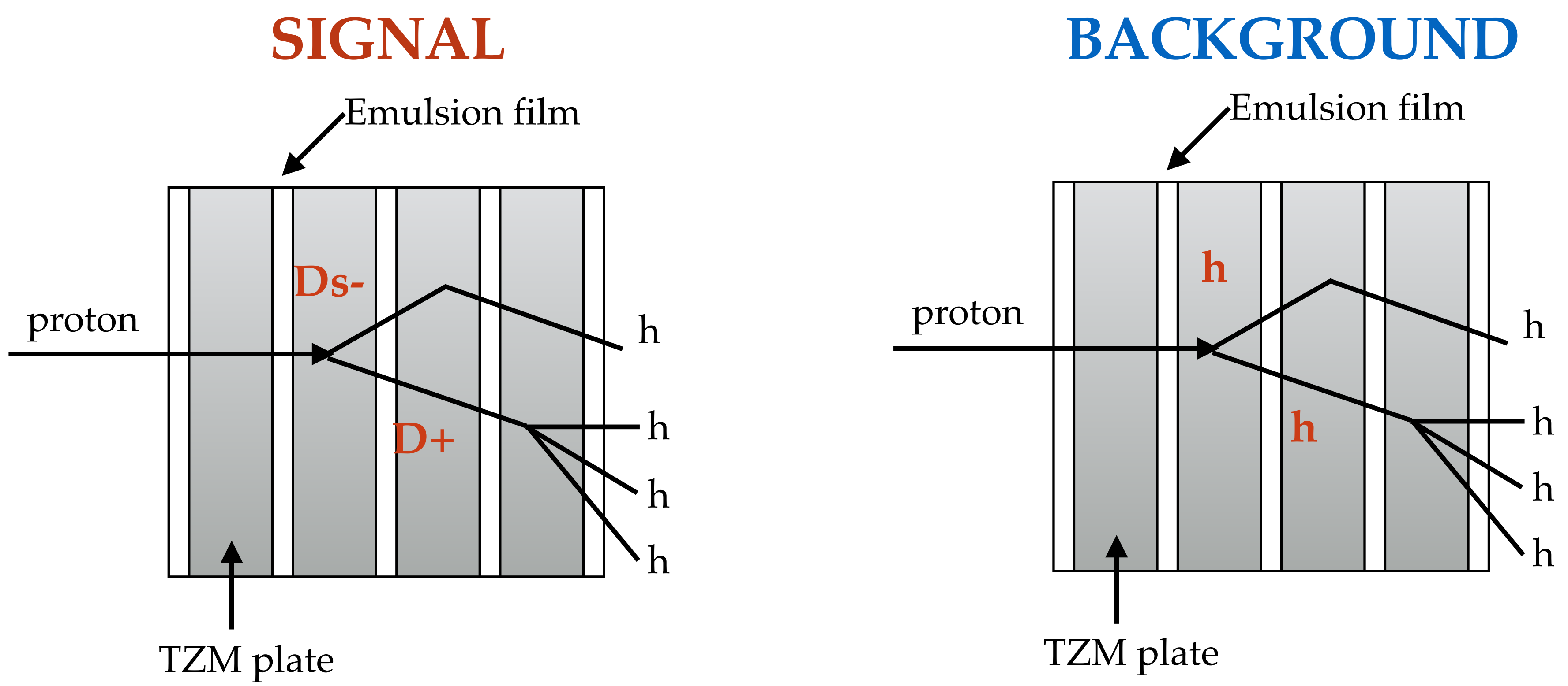


- Several charged particles per event
- em/had showers not totally absorbed in iron slabs
- Muon track non the unique in the downstream layers
- Tracking algorithm to be implemented for performances evaluation
- Detector layout in terms of passive material thickness and position of sensitive planes under optimization

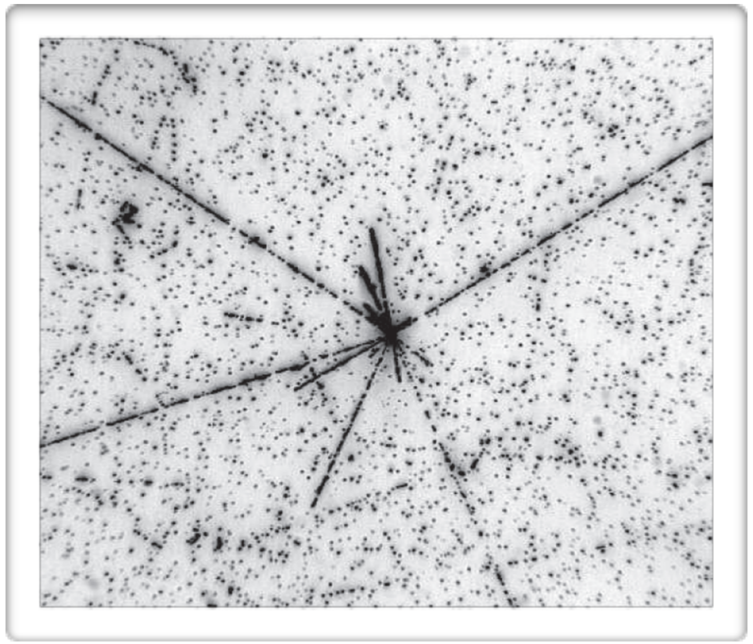
Background Studies

Background Evaluation

- Dominant background for charm search: hadronic re-interactions

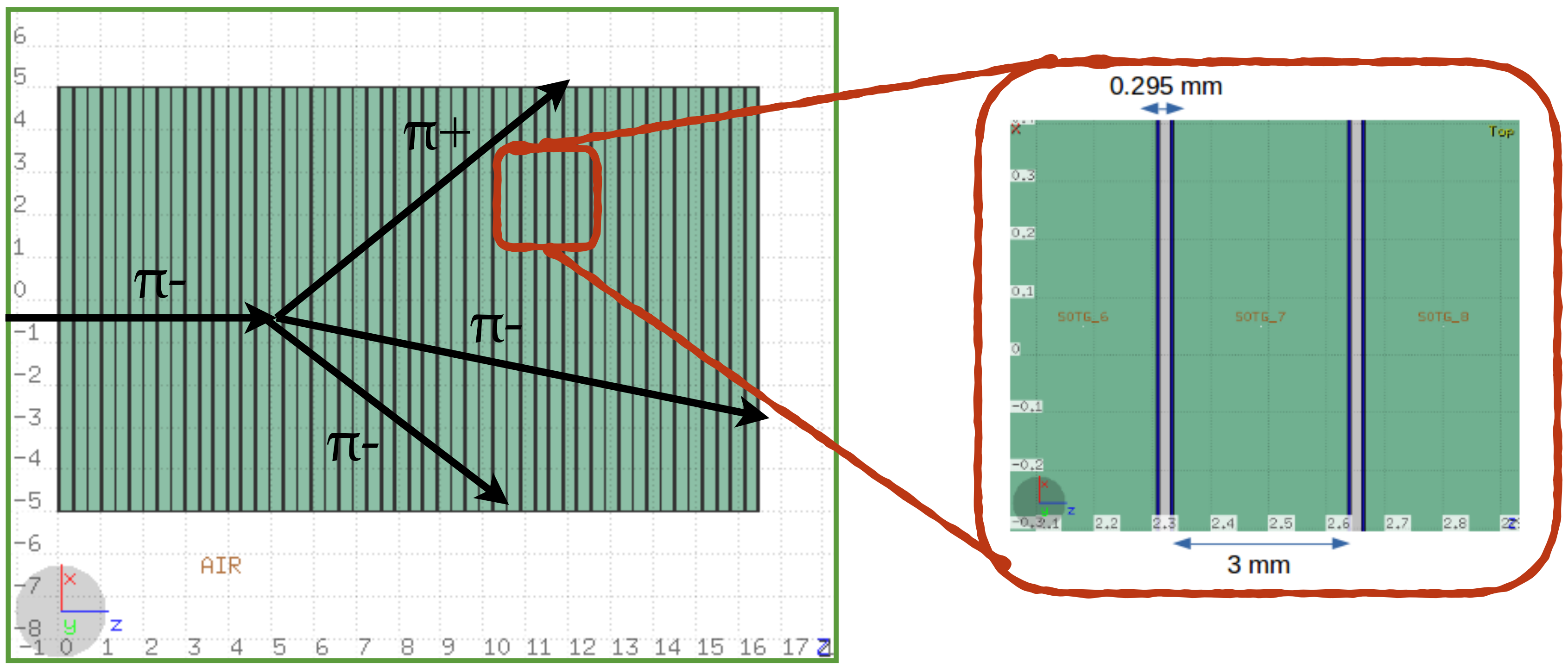


- Lever arms for signal/background discrimination:
  - observation of nuclear fragment at the hadron interaction point
  - exploit kinematical features (MVA analysis)



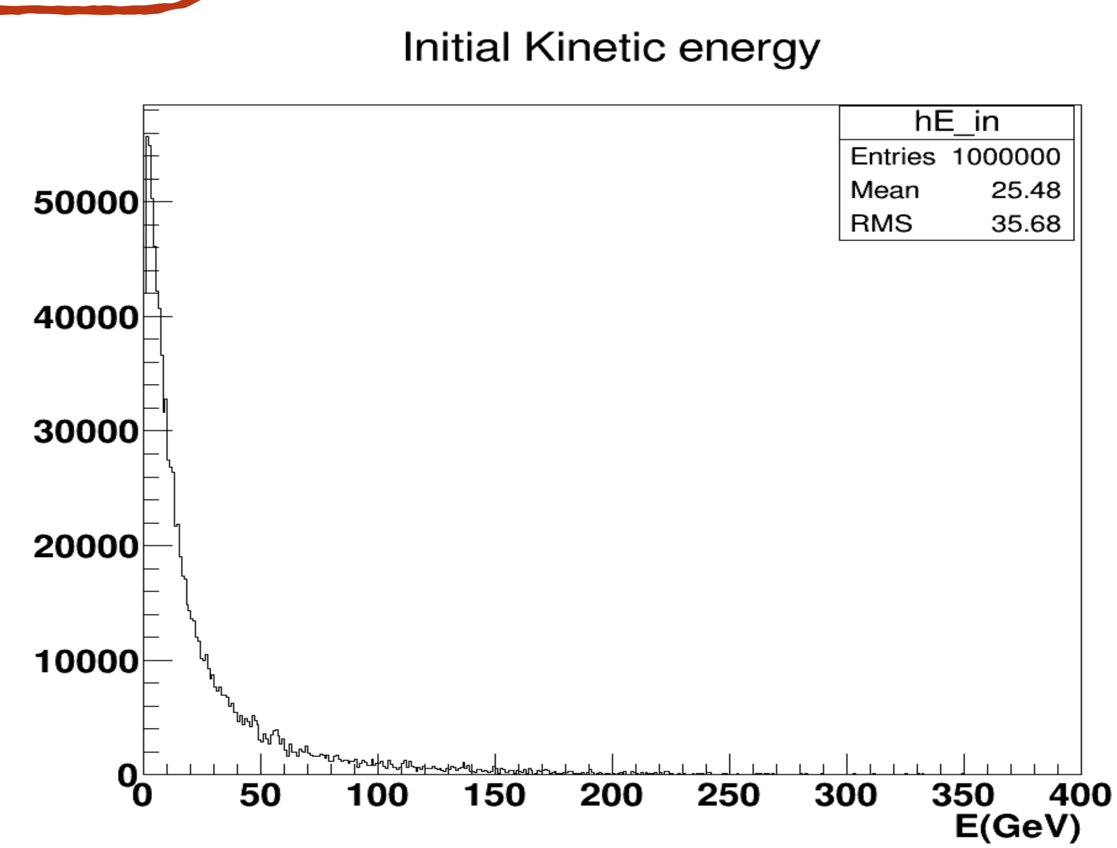
Hadronic Re-Int. Simulation

- FLUKA simulation of hadronic re-interactions in TZM/emulsion ECC chamber ***(A. Iuliano)***

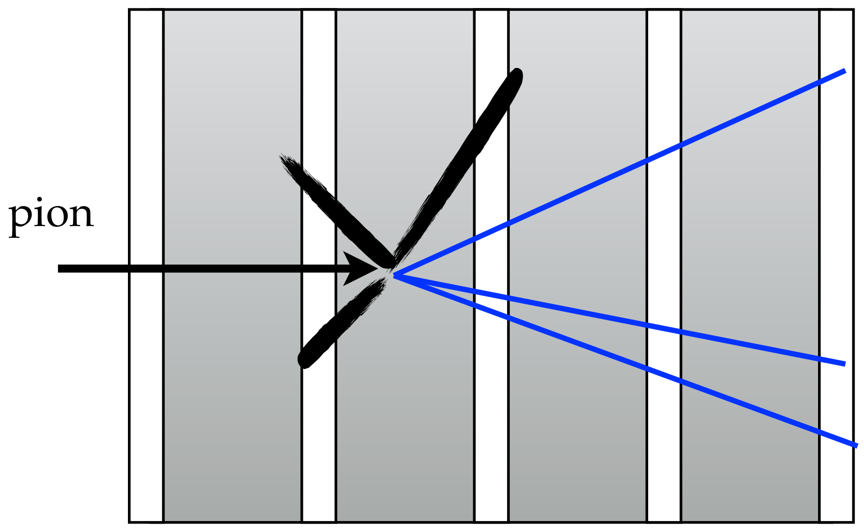


- Monte Carlo simulation used in OPERA: **FLUKA** with PEANUT model
  http://www.slac.stanford.edu/cgi-wrap/getdoc/slac-pub-10813.pdf
- Validation with test beam data: π- at 2,4,10 GeV/c in ECC brick

- Simulated beam: π-
- Energy spectrum: pions produced in proton interaction in FairShip



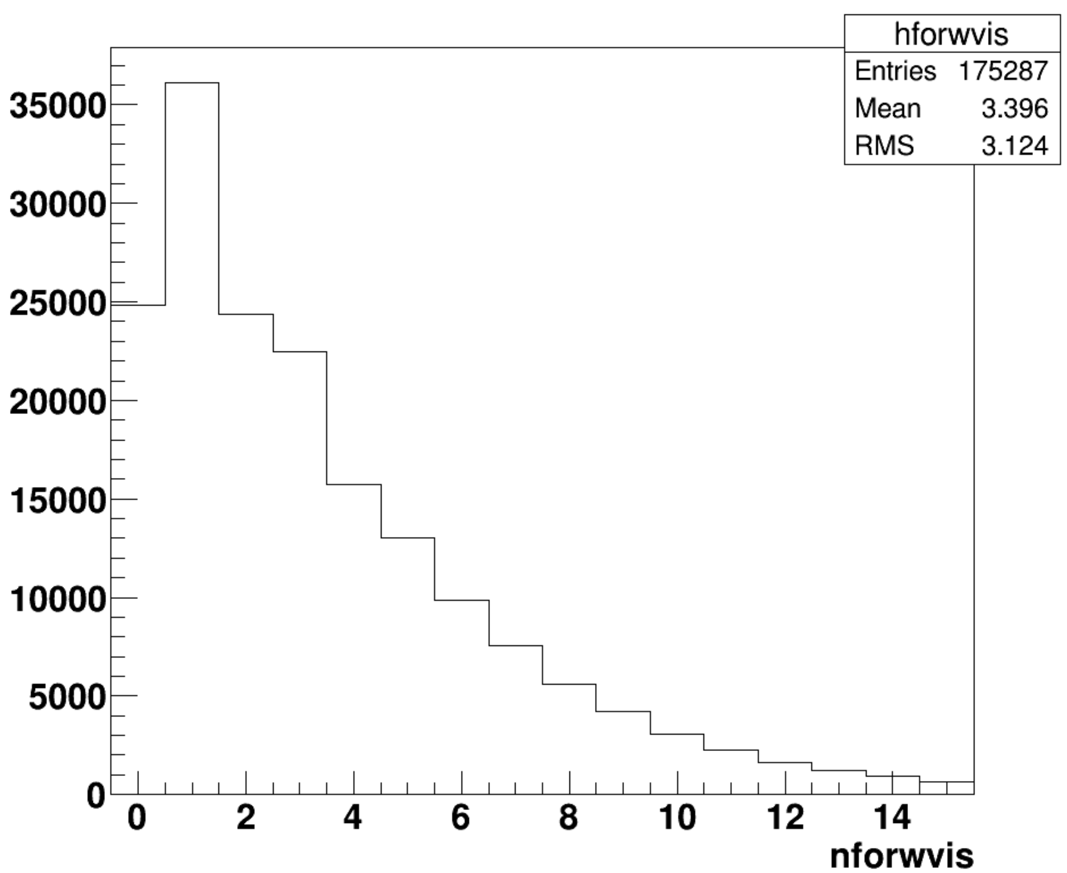
Hadronic Re-Int. Simulation



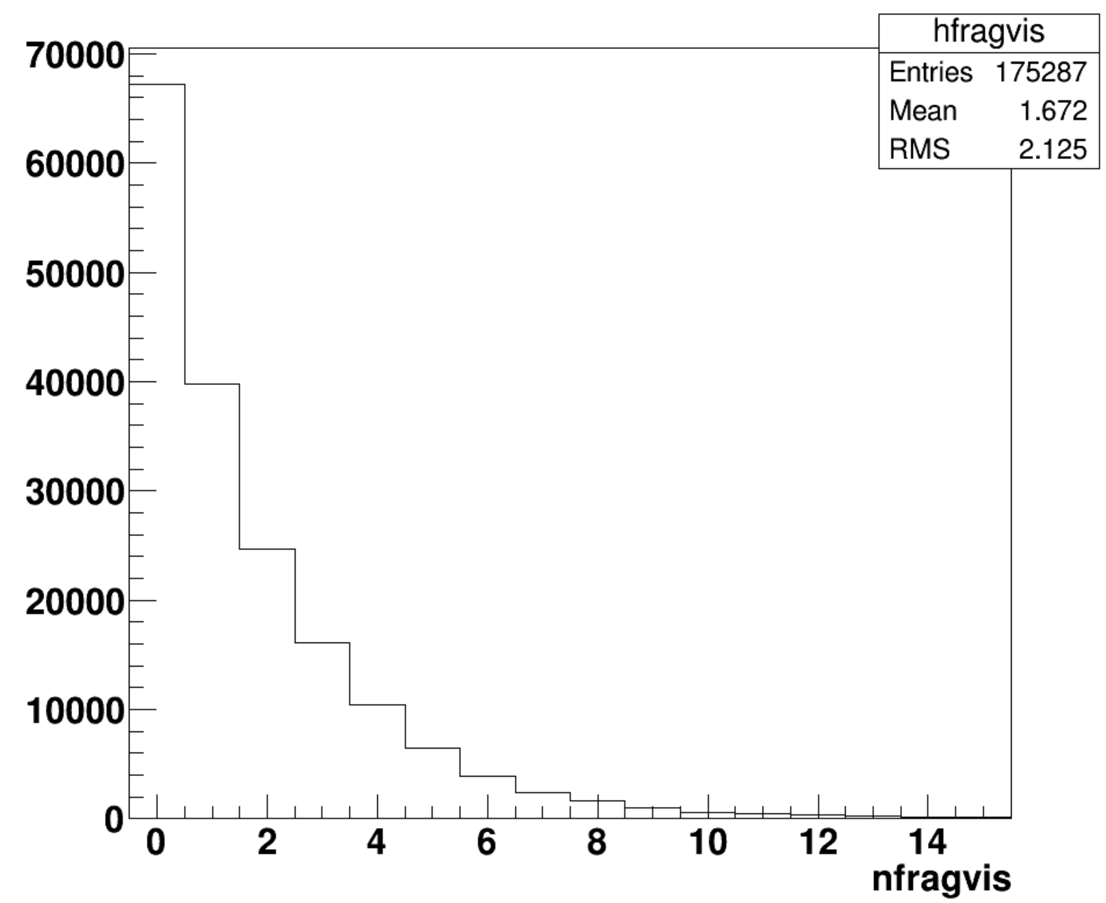
Fragment: - at least 1 emulsion film crossed
- $\tan(\theta)<3.0$
- $\beta<0.7$

Forward-going track: - at least 3 emulsion film crossed
- $\tan(\theta)<1$
- $\beta>0.7$

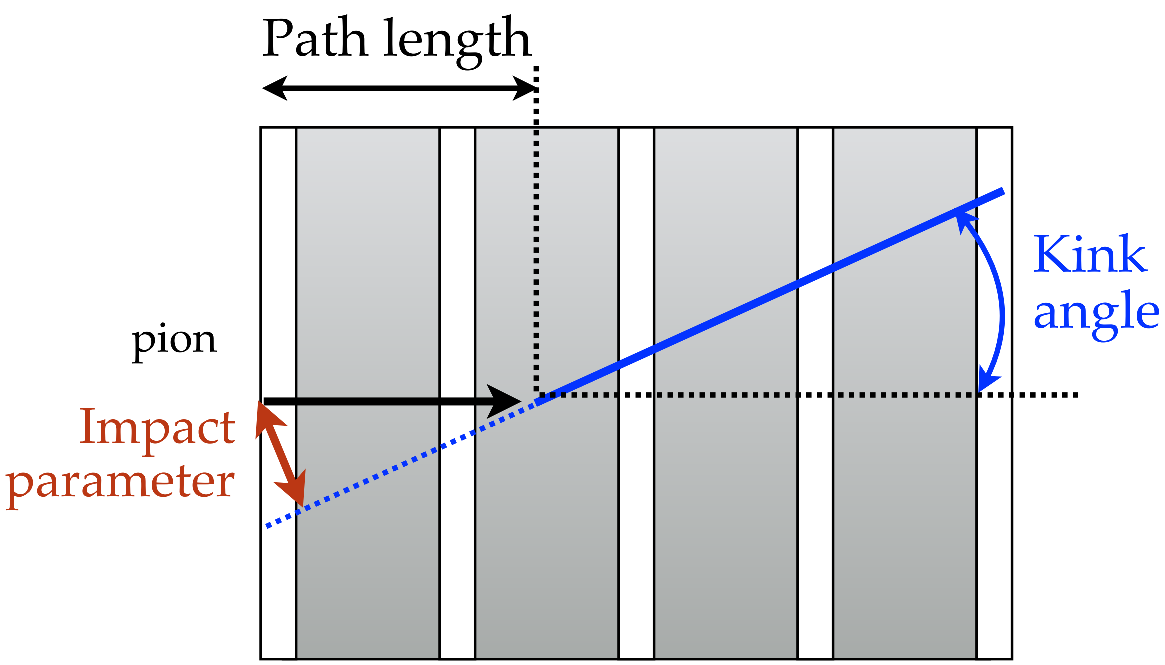
- Number of forward-going tracks



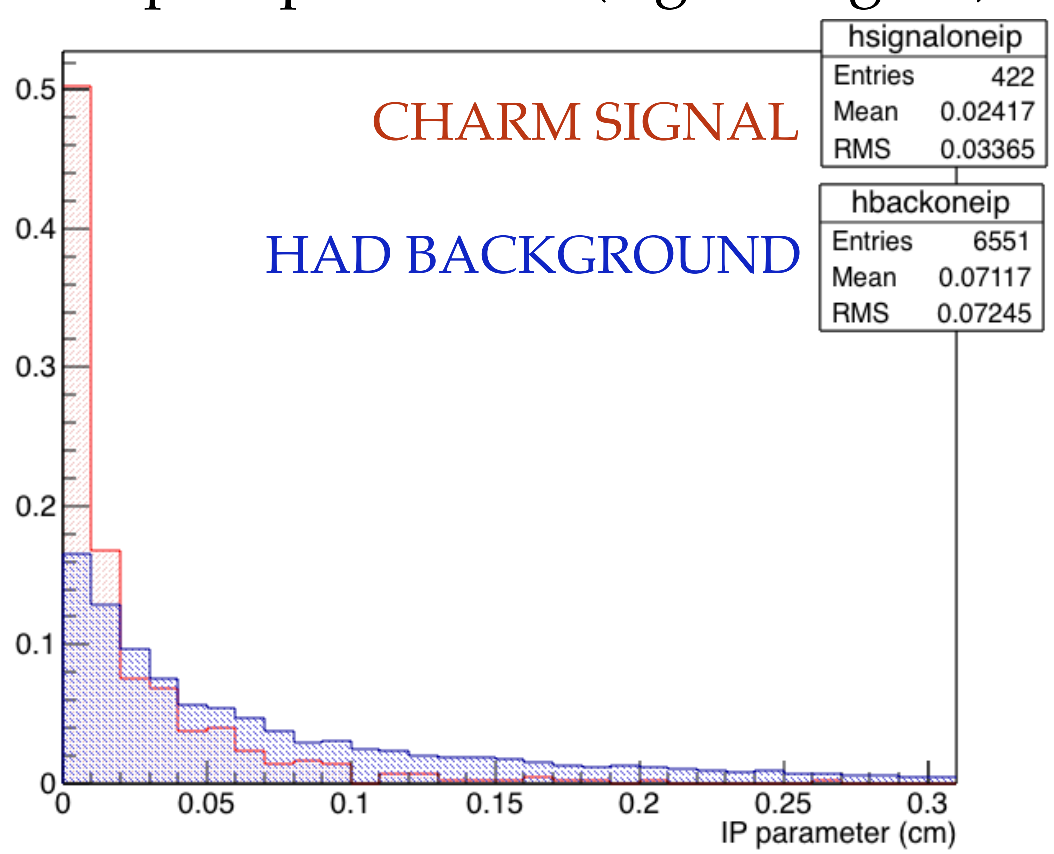
- Number of nuclear fragments



KINEMATICAL SELECTION

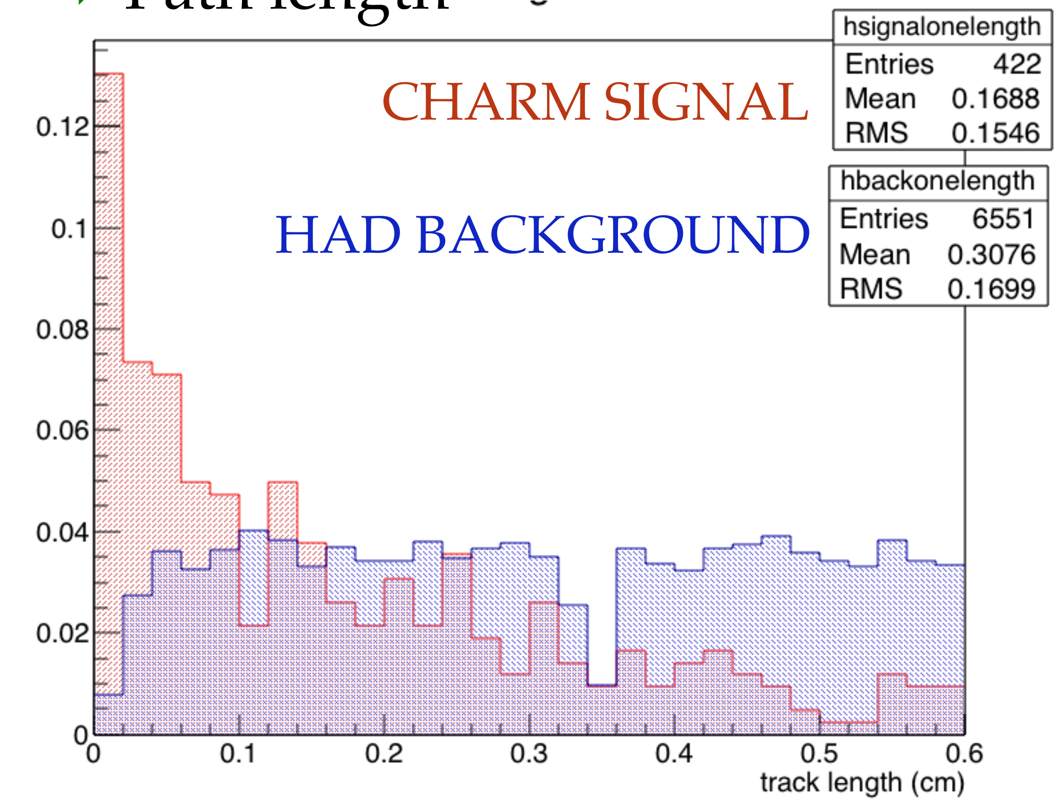


- Impact parameter (signal region)

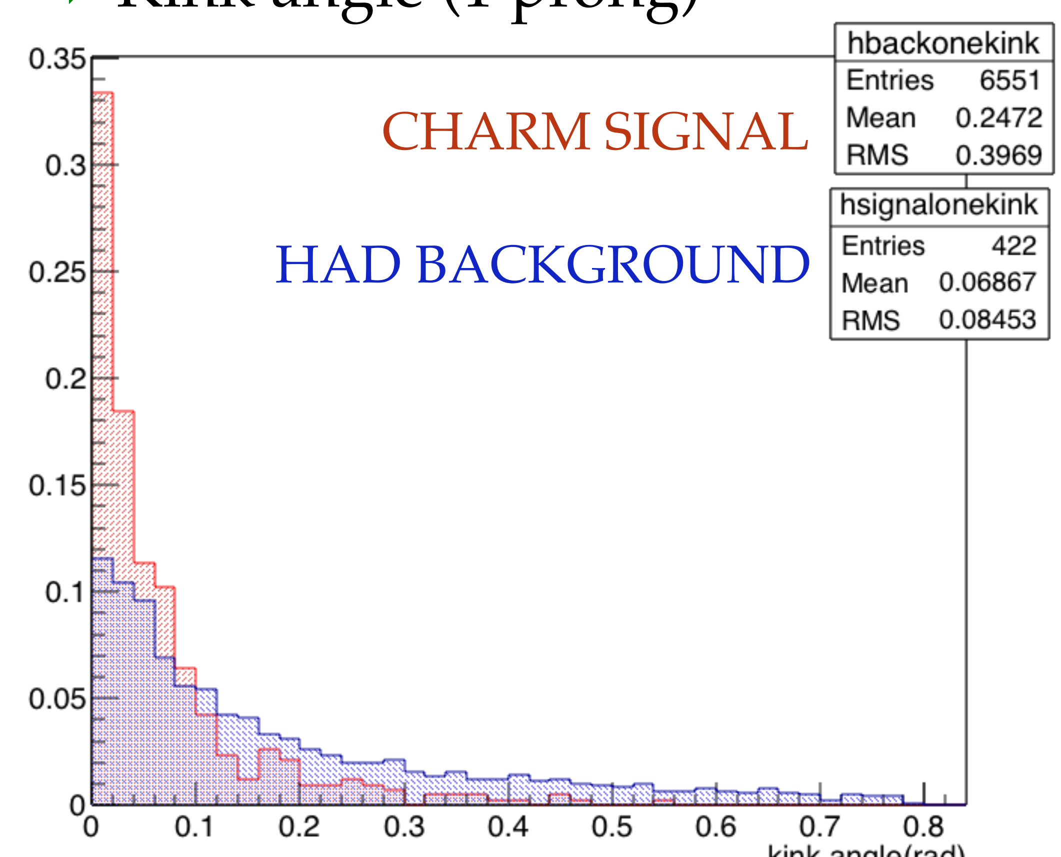


NB: signal and background distribution normalized to unity

- Path length



- Kink angle (1 prong)



Background-Yield Evaluation

- Charm decay channels: c➔1h, c➔3h

Selection Criteria	Probability
Path length<6 mm	3,4%
Impact parameter> 10 μm	2,9%
Kink angle>20 mrad	2,8%
1 or 3 forward-going tracks	1,0%
no nuclear fragments	0,45%

In progress: Kinematical selection based on total momentum, transverse momentum, invariant mass

SUMMARY

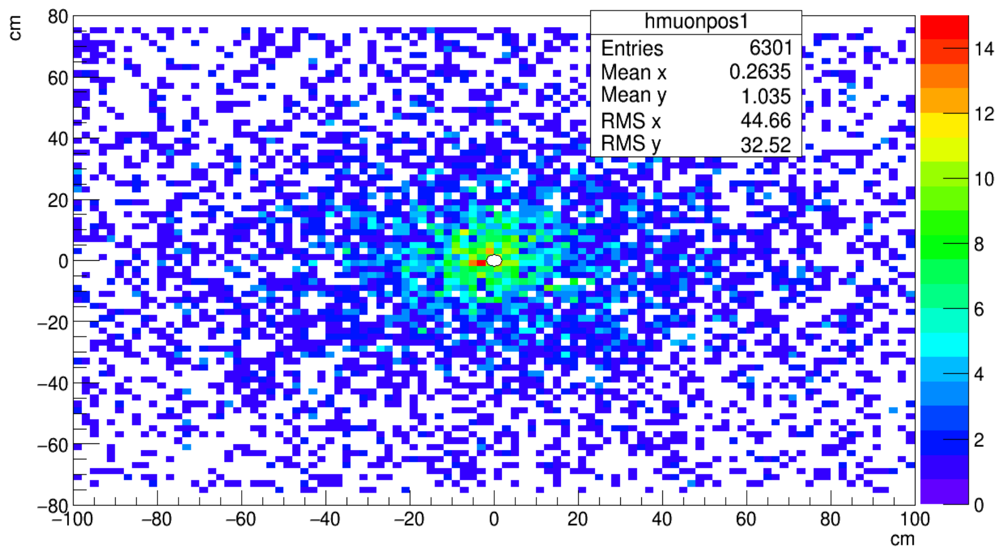
- Overall experimental layout outlined
- Magnetic field immediately downstream of the target helps reducing the electron multiplicity
- Challenge: track connection between moving target and fixed spectrometer, with a gap of a few cm
- Magnetic spectrometer: new detector options to cope with high occupancy under investigation
- Muon filter: RPC technology, sampling to be optimized
- 2018 exposure will act as "optimization run" for the charm cross-section measurement
- Hadronic background simulation performed in FLUKA. Exploit kinematical features to reduce hadronic background contamination

Back-Up Slides

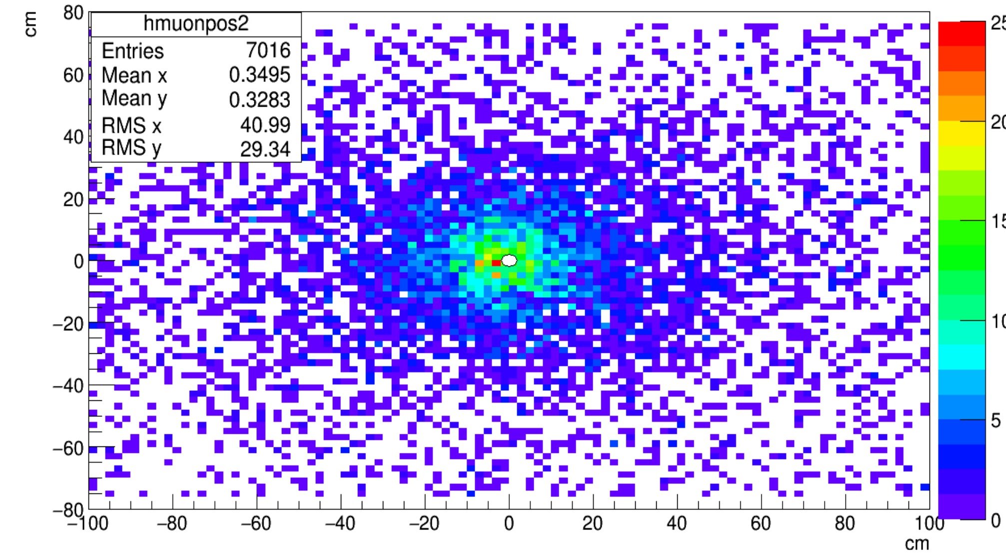
MUONS IN RPC

- Spatial distribution of muons produced by charmed hadron decay

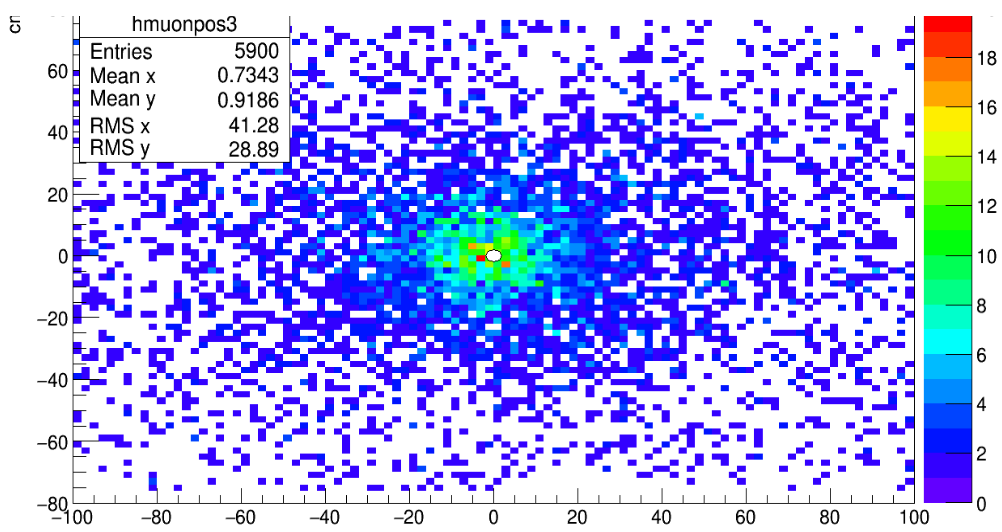
R1



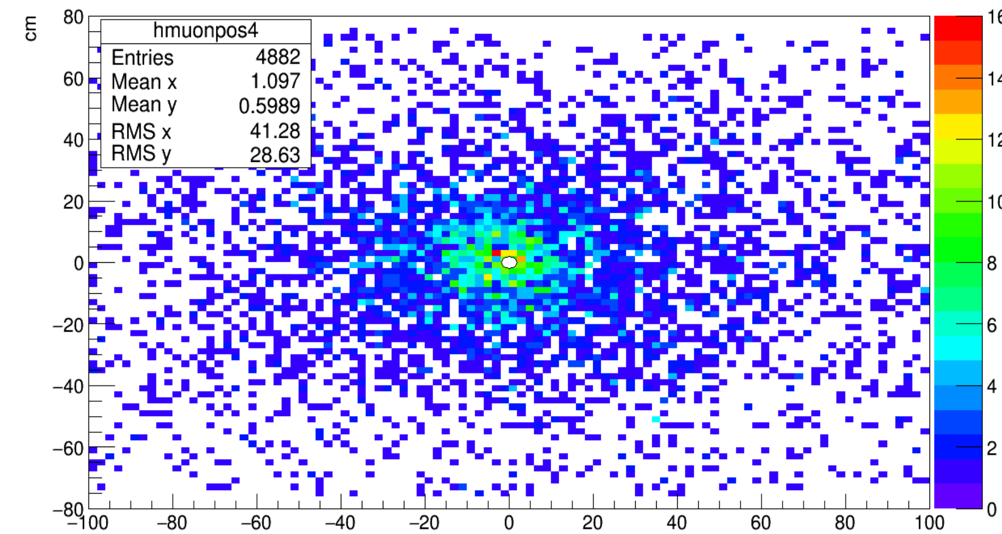
R2



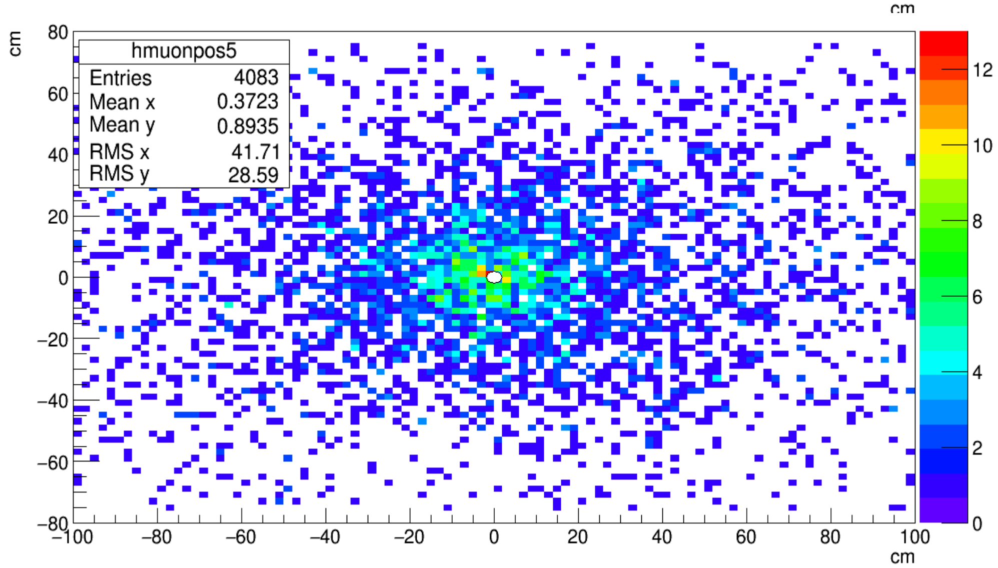
R3



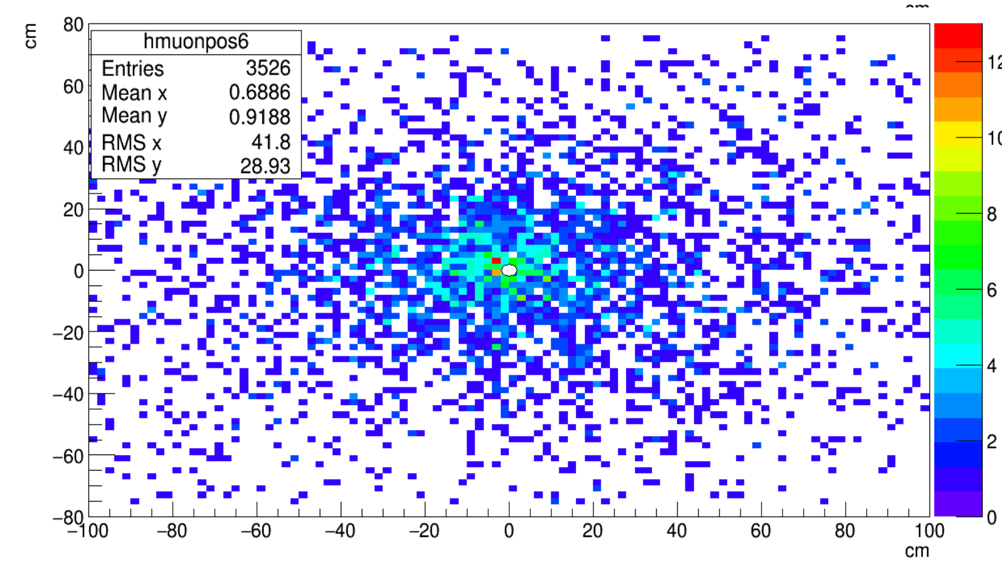
R4



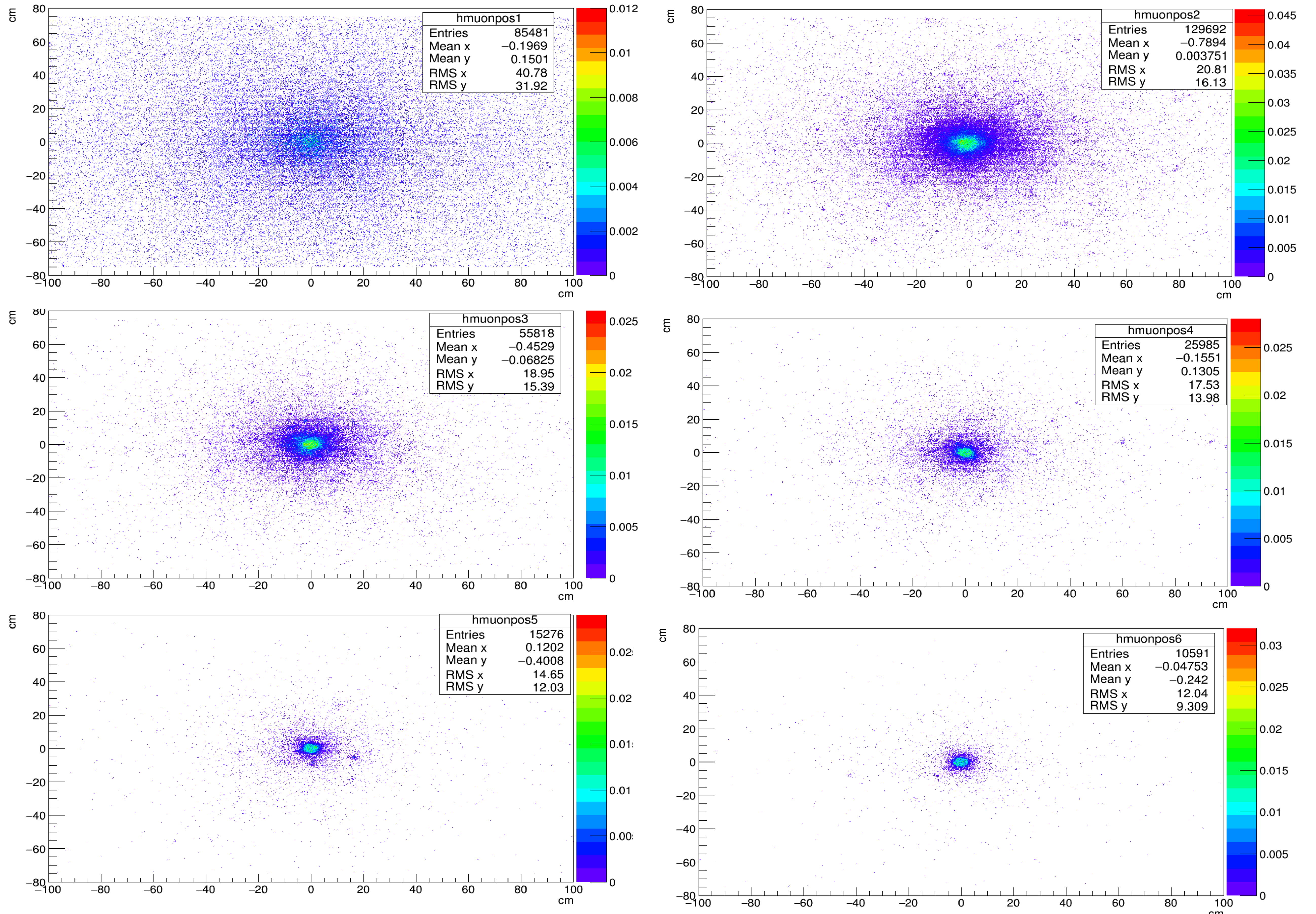
R5



R6



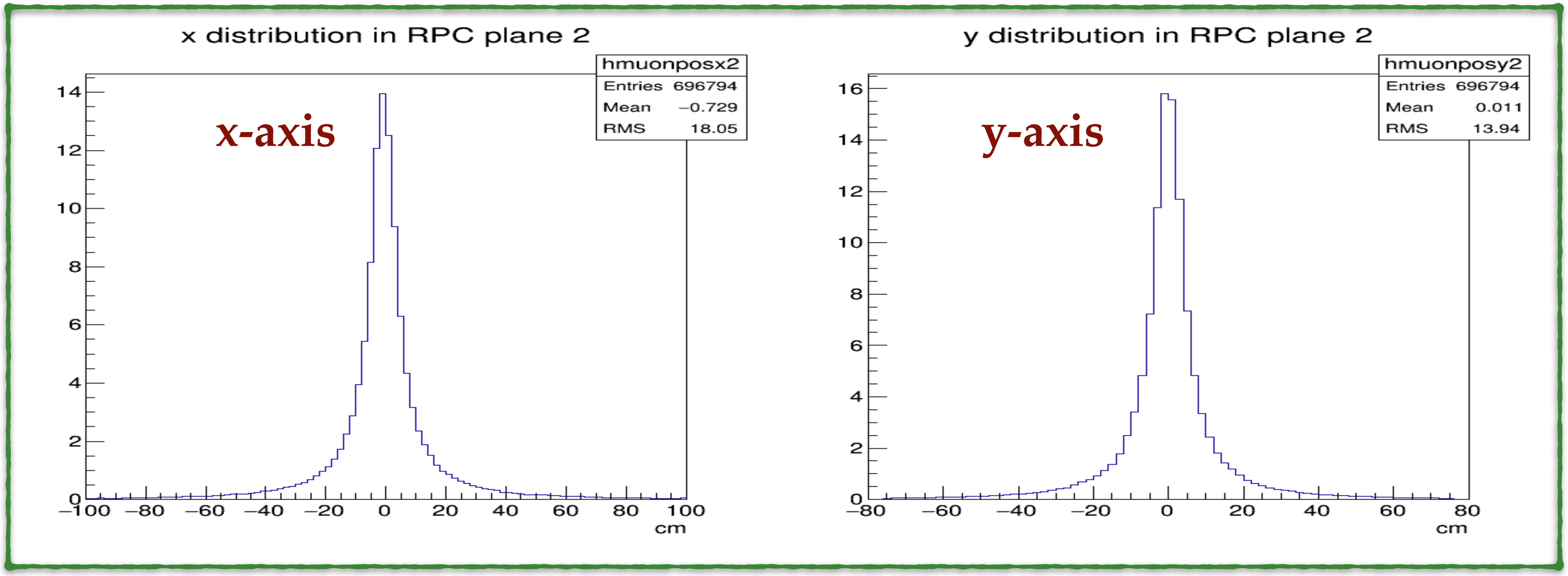
Hits In RPC cell: 2x2 mm^2



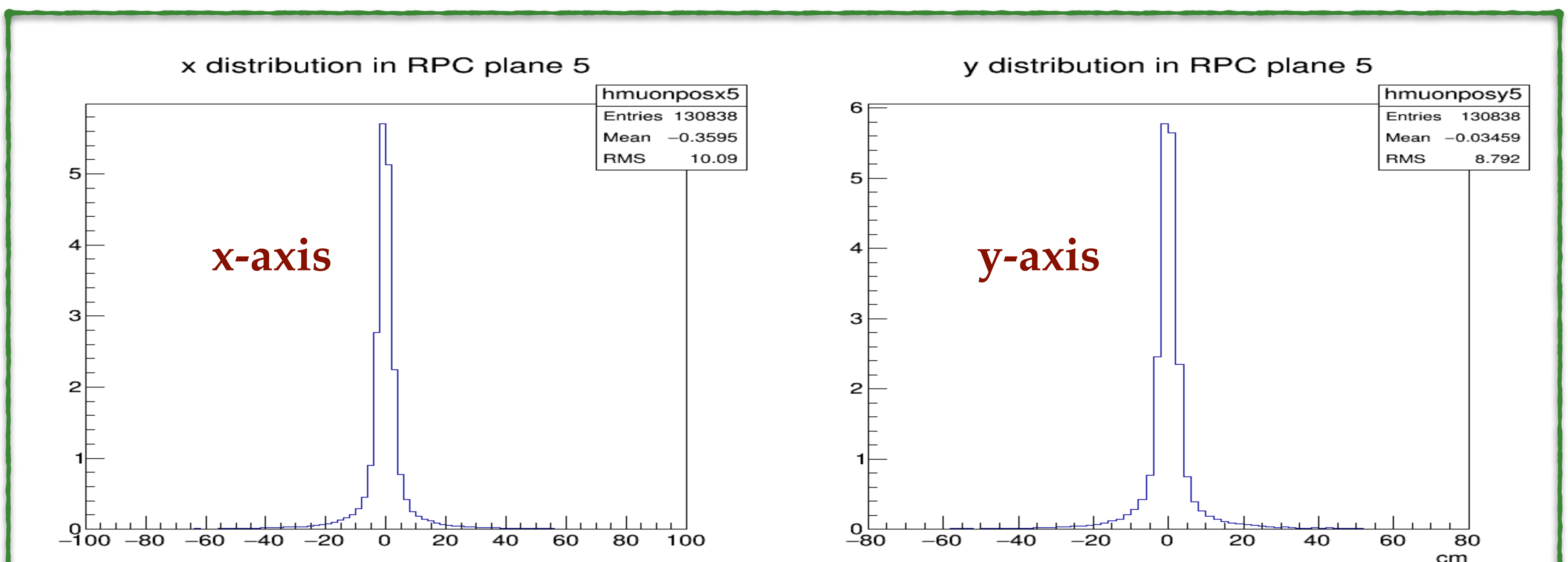
HITS IN THE RPC

- Number of hits in RPC strips (2 cm-wide) along x and y axes

R2



R5

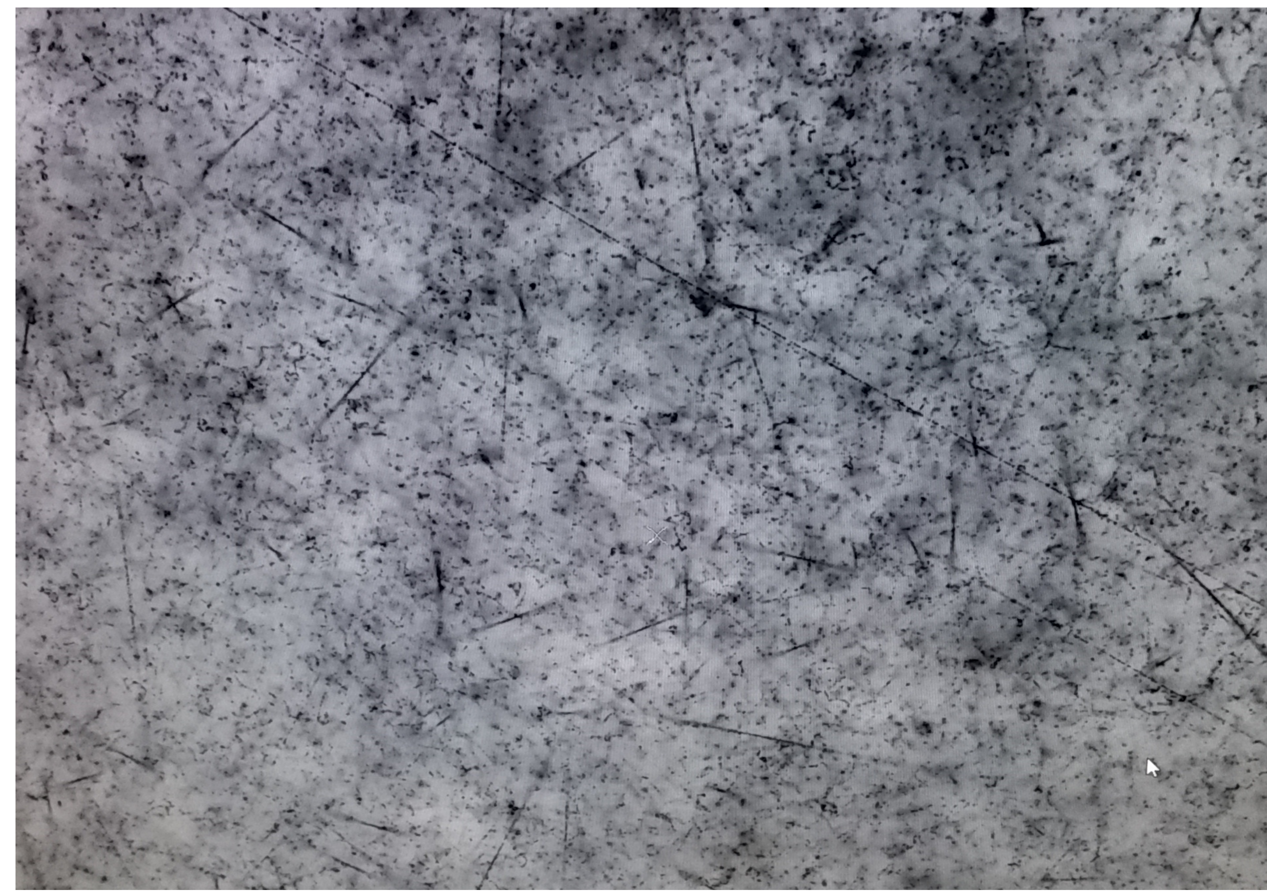


TRACKING CAPABILITY TEST

To be done: analysis of nuclear emulsions from **E653** experiment (Fermilab, '90)

- Density: 10^3 tracks/mm^2
- Limit density: $3x10^3$ tracks/mm^2

600 GeV negative pions

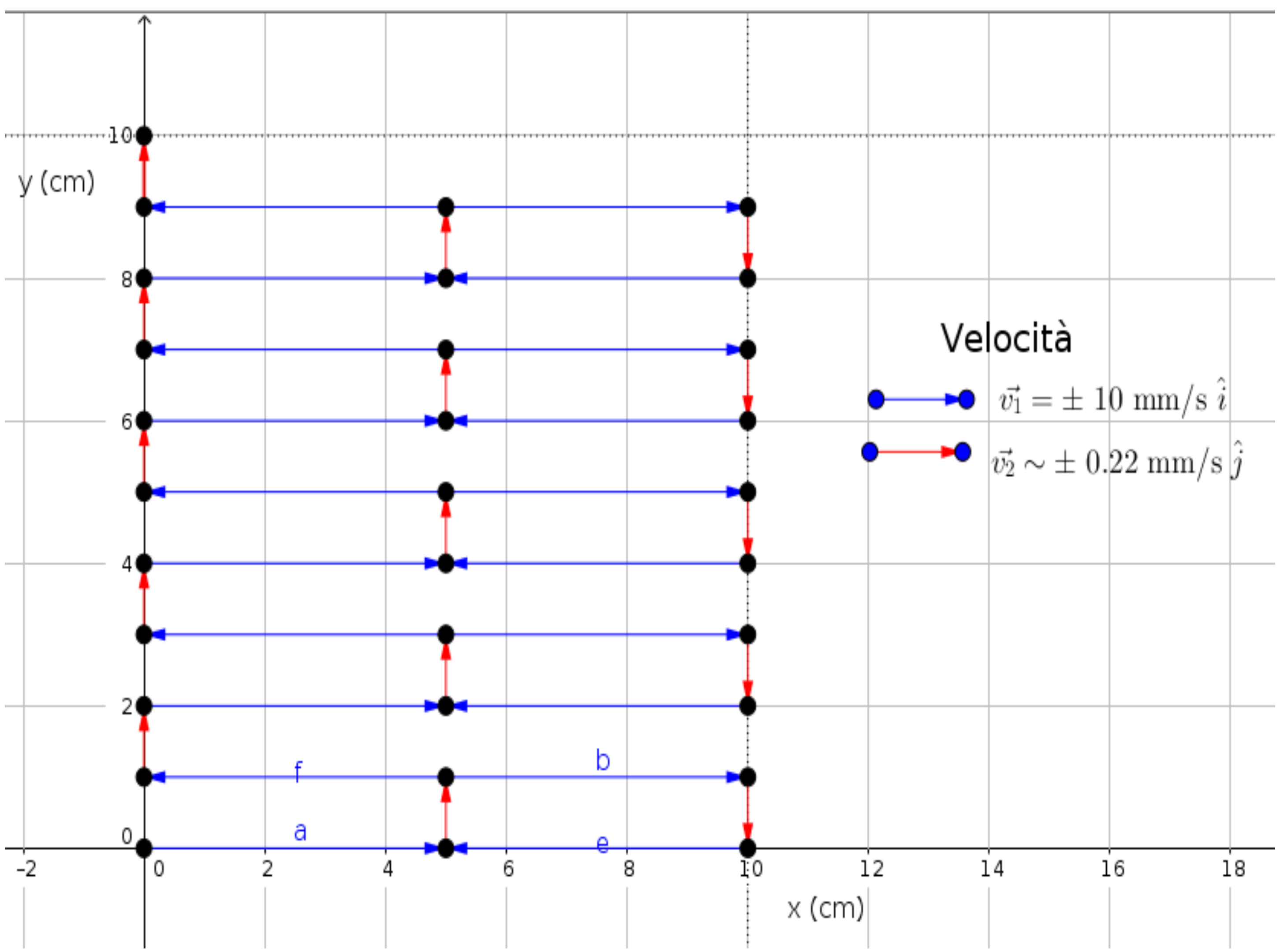


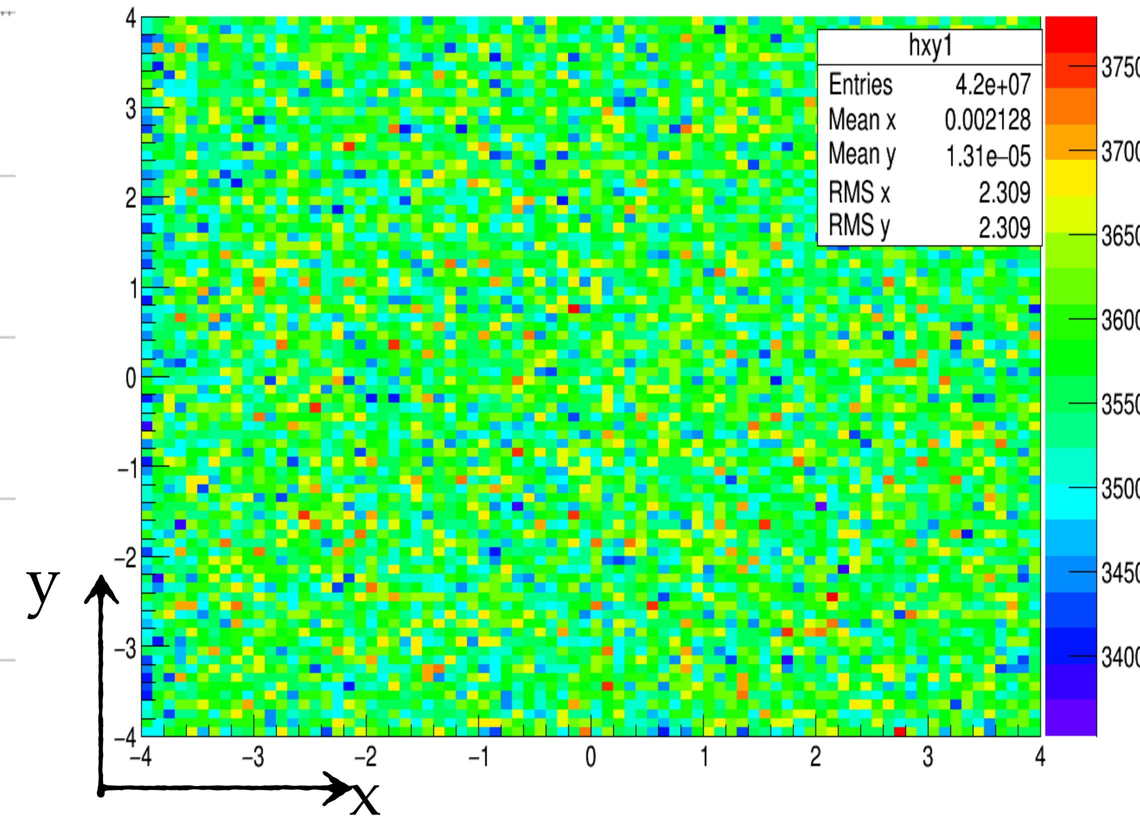
800 GeV protons

Motion Of The Target

- Motion of target required to have protons uniformly distributed on a 10x10 cm^2 surface
- Design of a moving table in progress *(details in N. D'ambrosio's talk)*

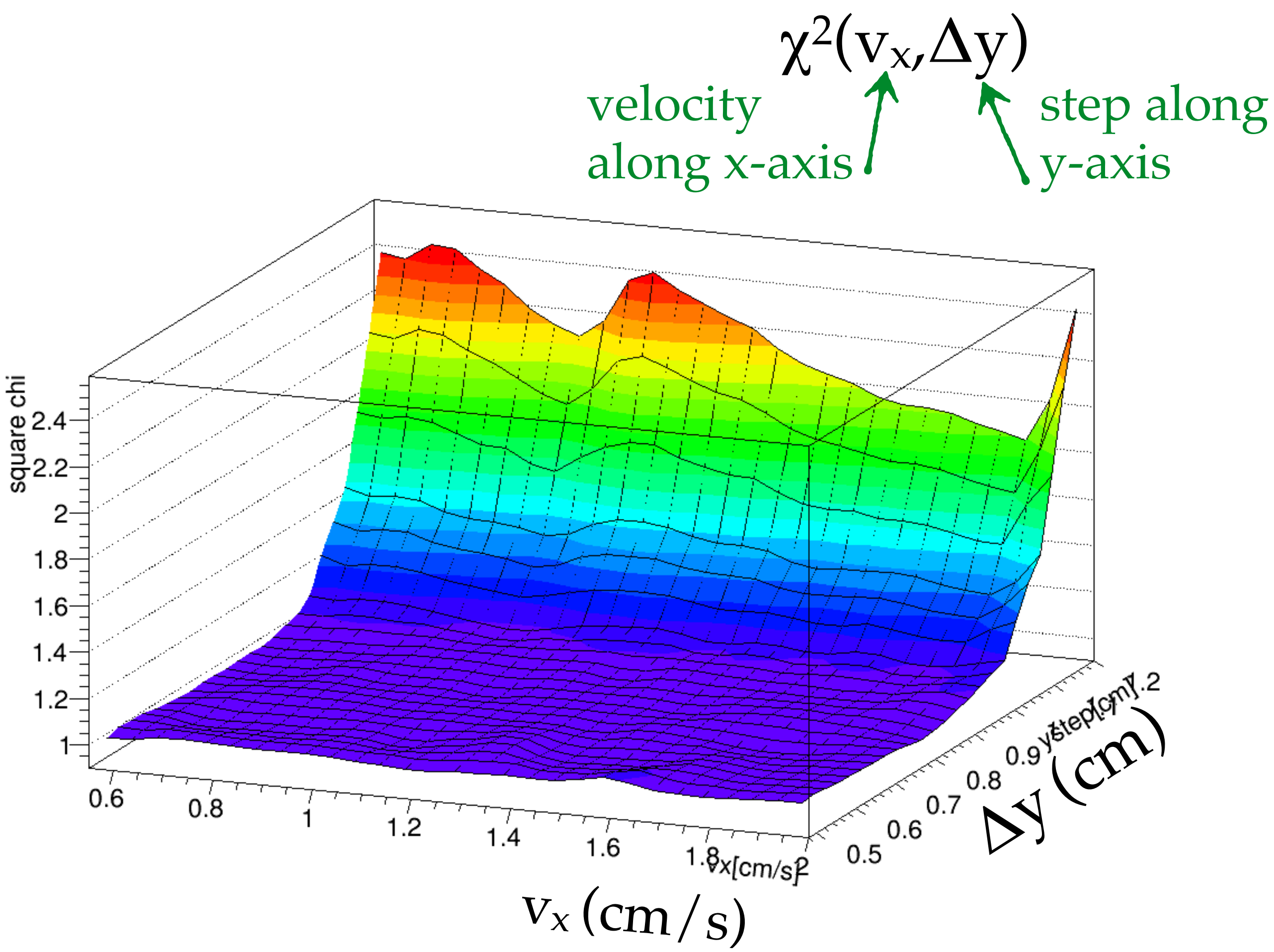
Motion of the target - along x-axis during the spill (~5s)
- along y-axis between two spills

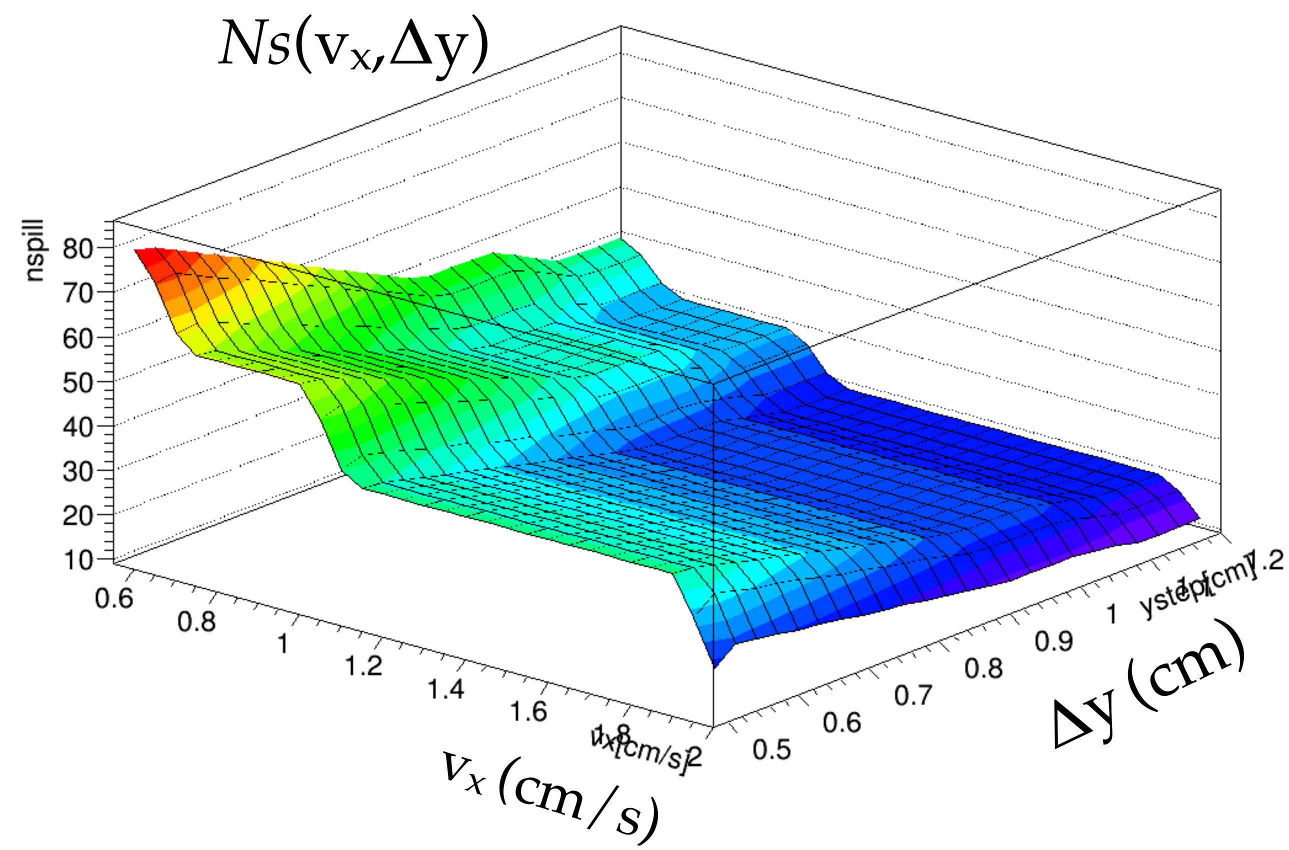




Motion Of The Target

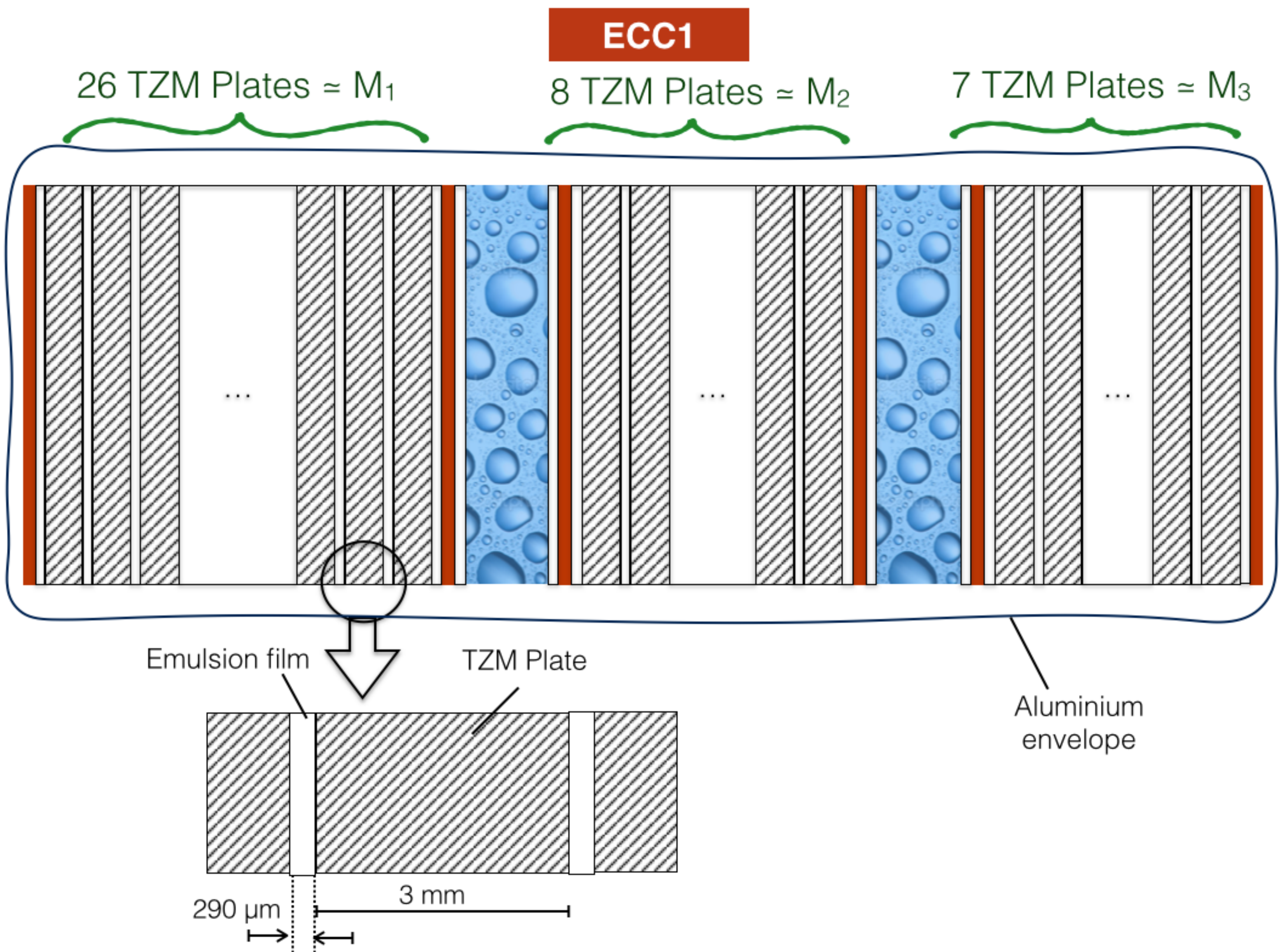
- Motion of target required to have protons uniformly distributed on a 10x10 cm^2 surface
- Design of a moving table in progress *(details in N. D'ambrosio's talk)*
- Optimization of the velocity of the table: - maximization of proton uniformity (minimization of a χ^2 function)
  - minimization of the number of spills *Ns*
- Assumption: proton beam with gaussian shape, σ=0 .5cm





Instrumentation Of Target

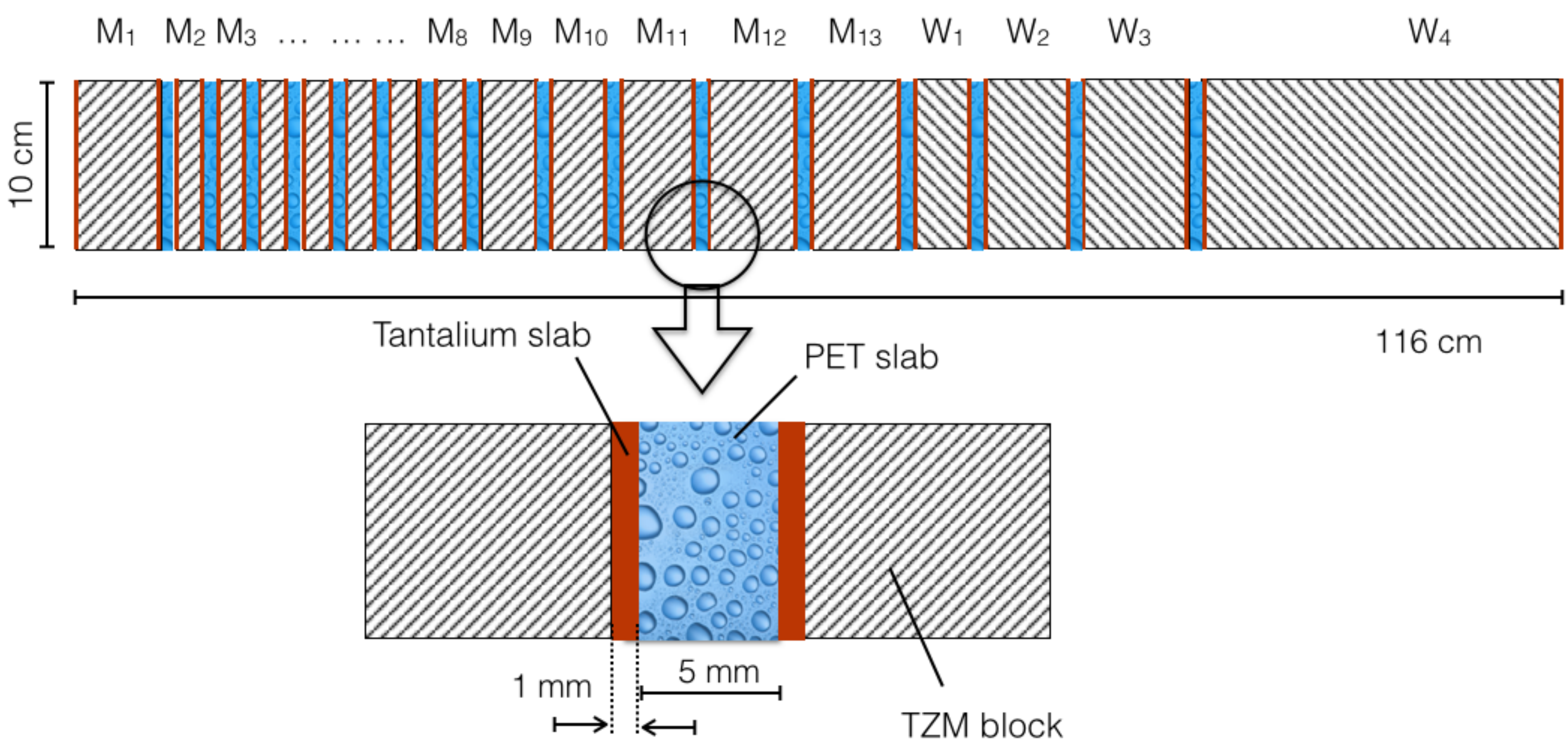
- Each ECC is made by a sequence of 3mm-thick TZM planes interleaved with 290 μm-thick nuclear emulsion films, with a total thickness of ~1λ_I
- **ECC1**: study charm production in first λ_I
- ECC2: study charm production in second λ_I



Plates	ECC1	ECC2
TZM (3mm)	41	38
λ	0,81	0,75
PET (5 mm)	2	4
Ta (1 mm)	6	10
Emulsion (0.29 mm)	47	48

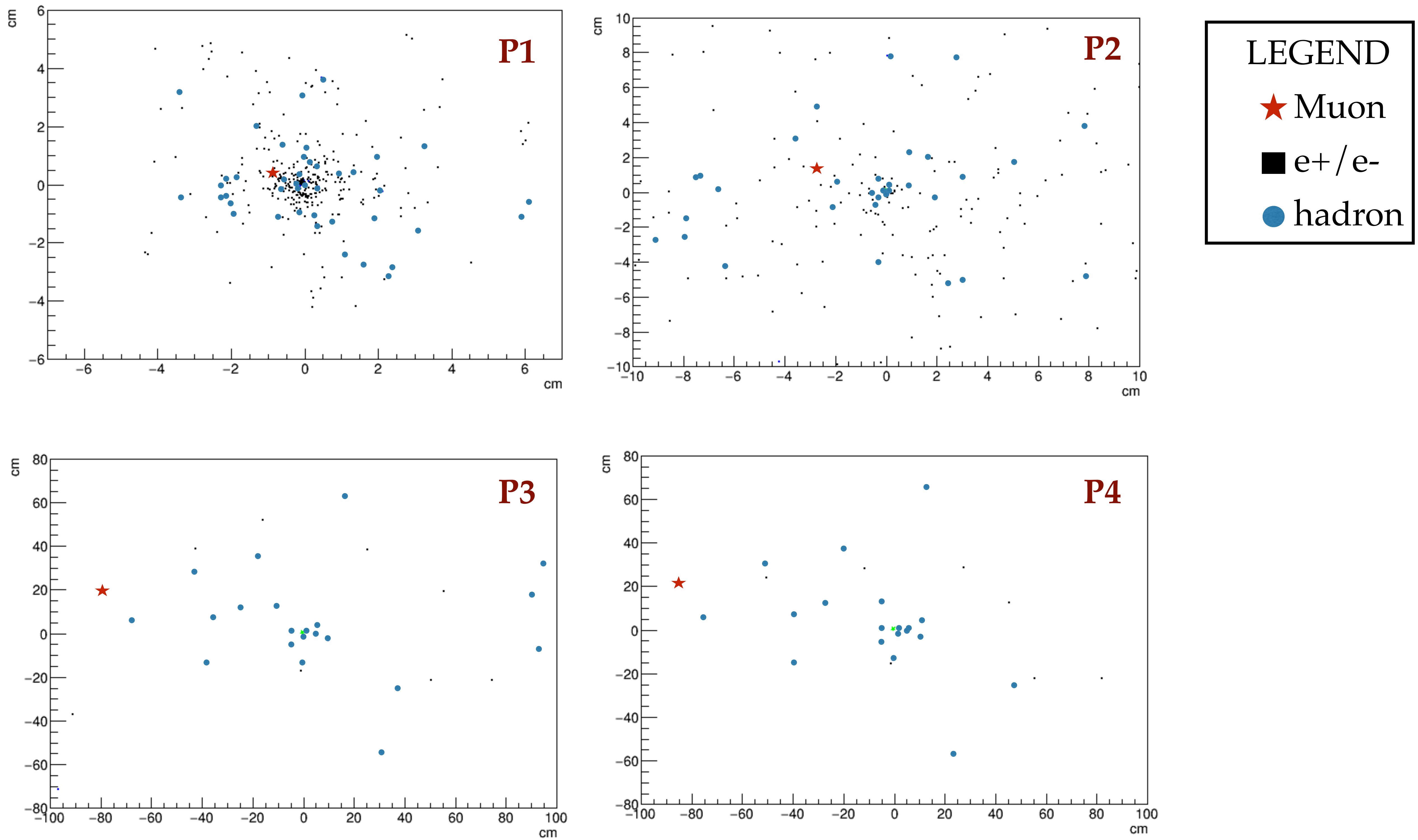
The Target Replica

- Replica of the SHiP target with smaller section: 10x10 cm^2
- Exactly the same TZM, W and Ta distribution
- Ta cladding not needed: replaced by Ta slabs to preserve number of λ_I
- Water cooling not needed: 5 mm-thick PET slabs instead of 5 mm H_20



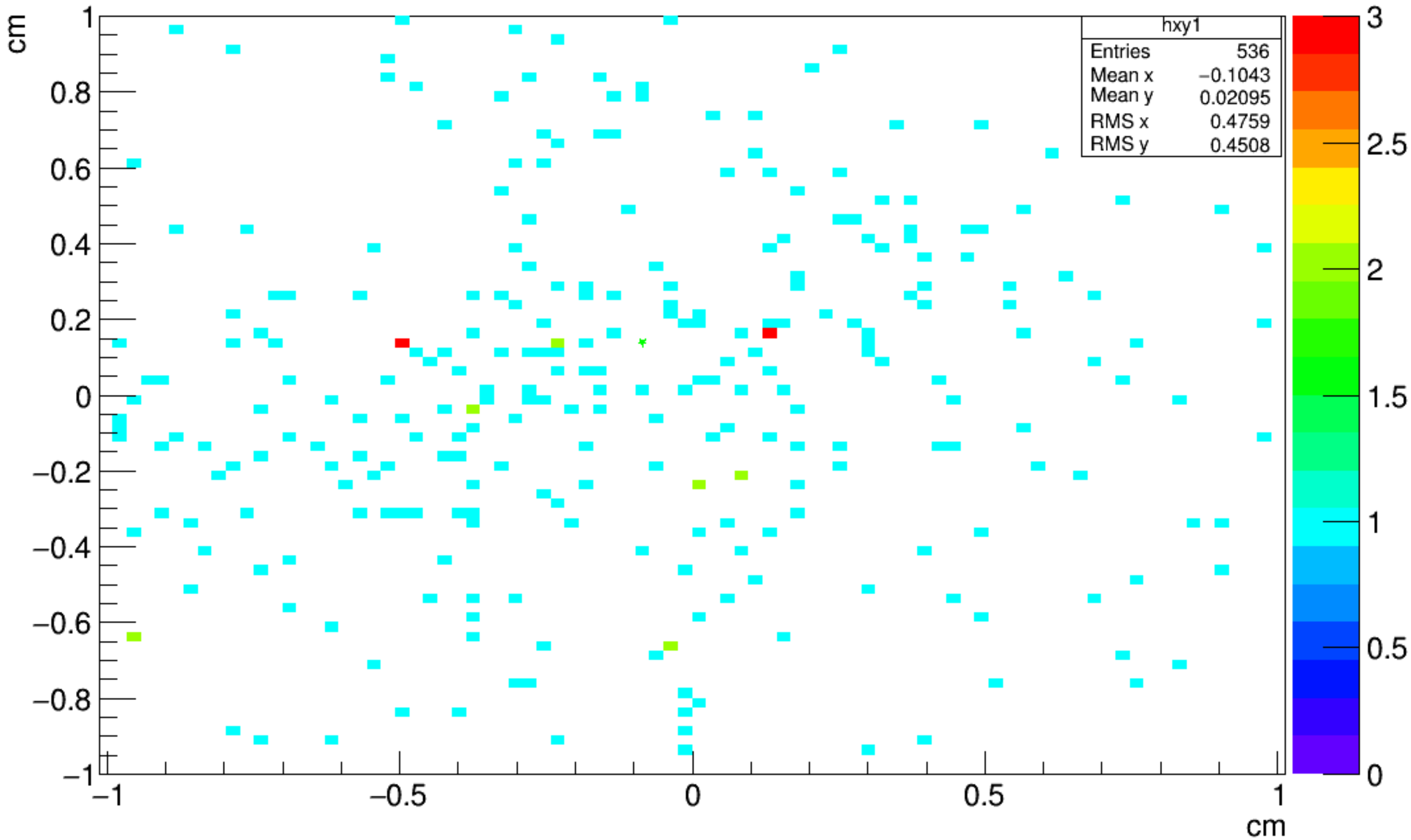
HITS IN THE SPECTROMETER

- A “typical" charm event as seen in the four spectrometer planes



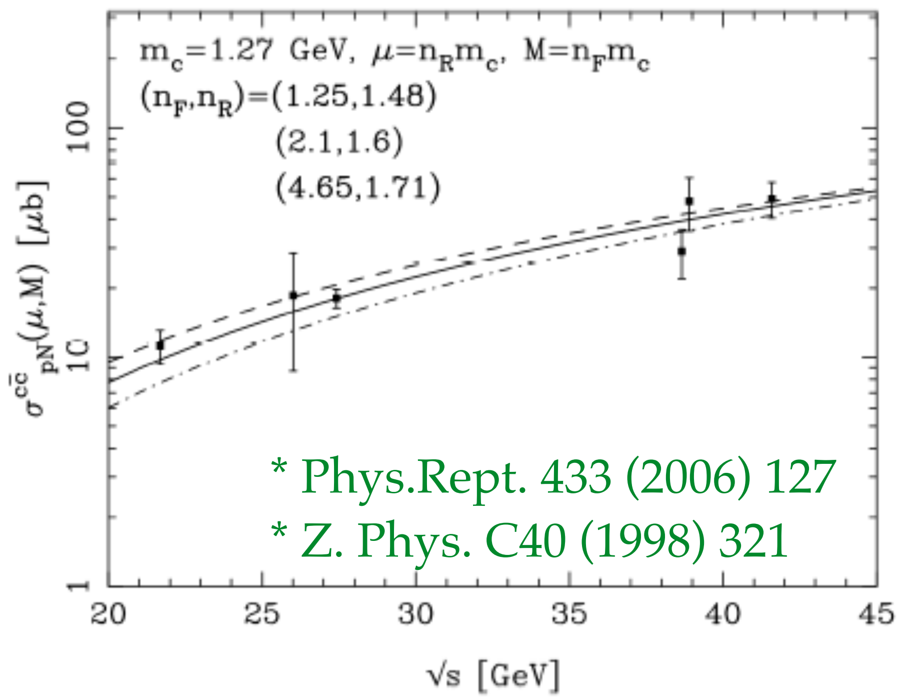
Hits In The Spectrometer

- Zoom in the most central region of the first Spectrometer plane **P1**
- Pitch: 200 x 200 μm² (size of the histogram bin)



MOTIVATION

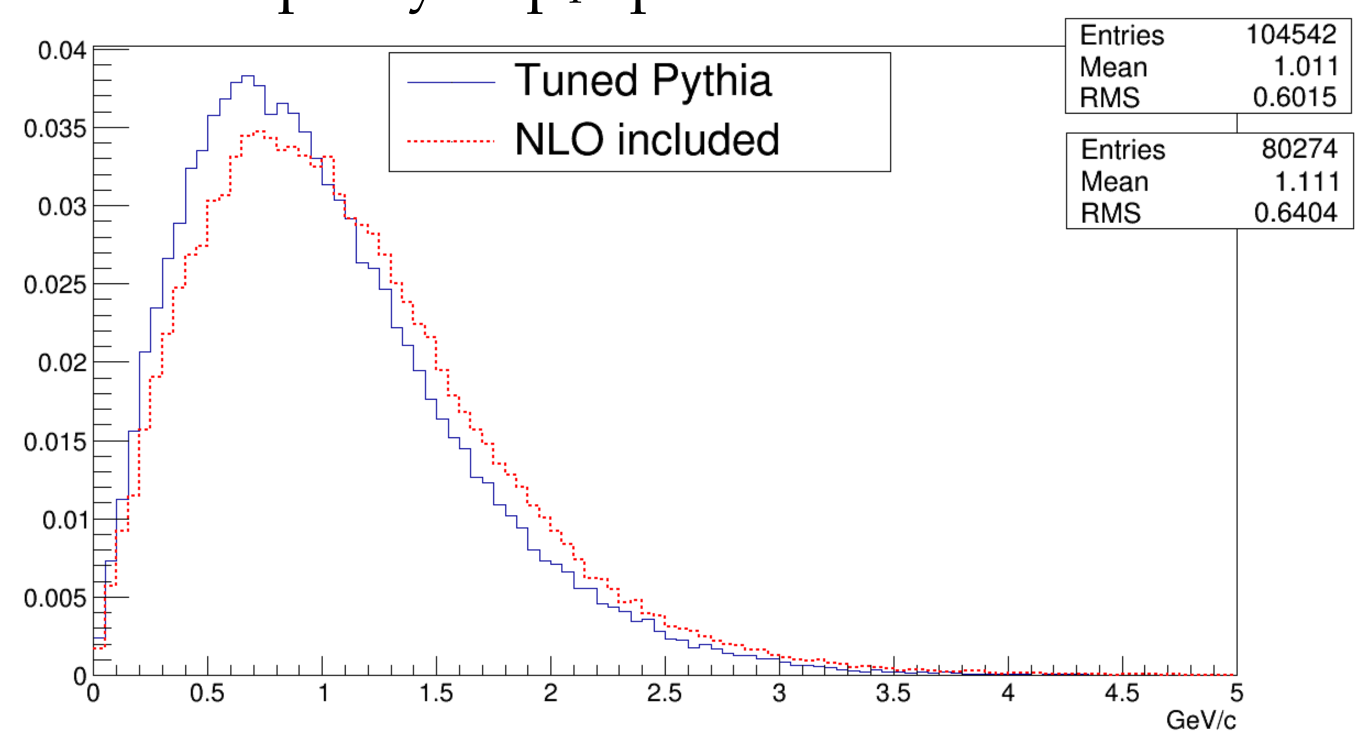
- Charm production in **proton interactions** and in **hadron cascades** in the SHiP target crucial for HNL normalization and ν_τ cross-section measurements
- Current knowledge of inclusive associated charm cross-section measurement



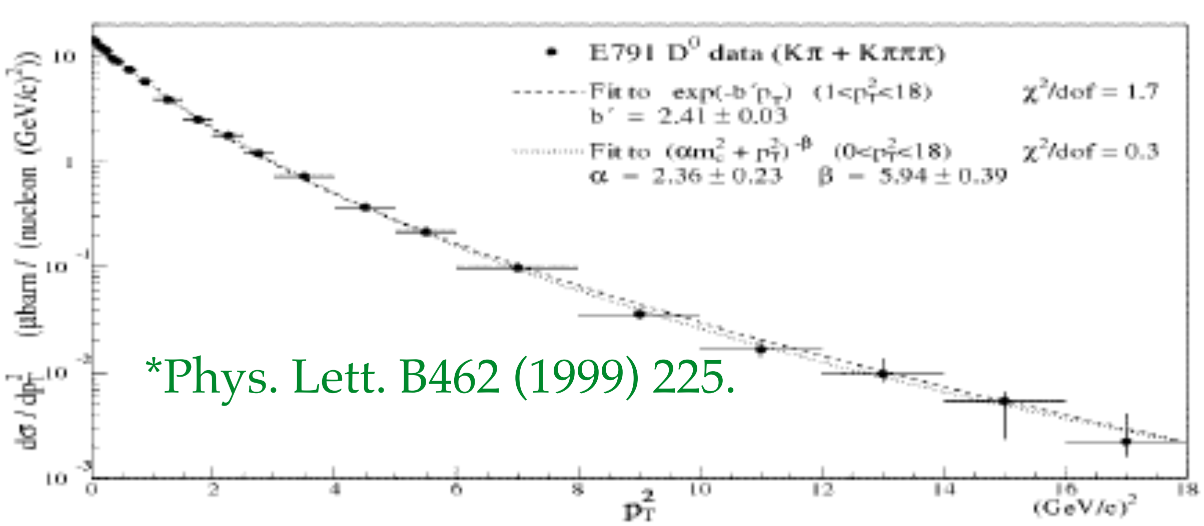
σ_{CC} = ***(18.1 ± 1.7) μbarn (NA27*)***

- Missing information: charm production in **hadron cascades** (factor>2) and charm hadron **spectra**

- Comparison between Pythia 6.4 generator and NLO calculations, ***JHEP 0709 (2007)***: discrepancy in p_T spectra



- Angular and energy spectra available only for 500 GeV pions in E791



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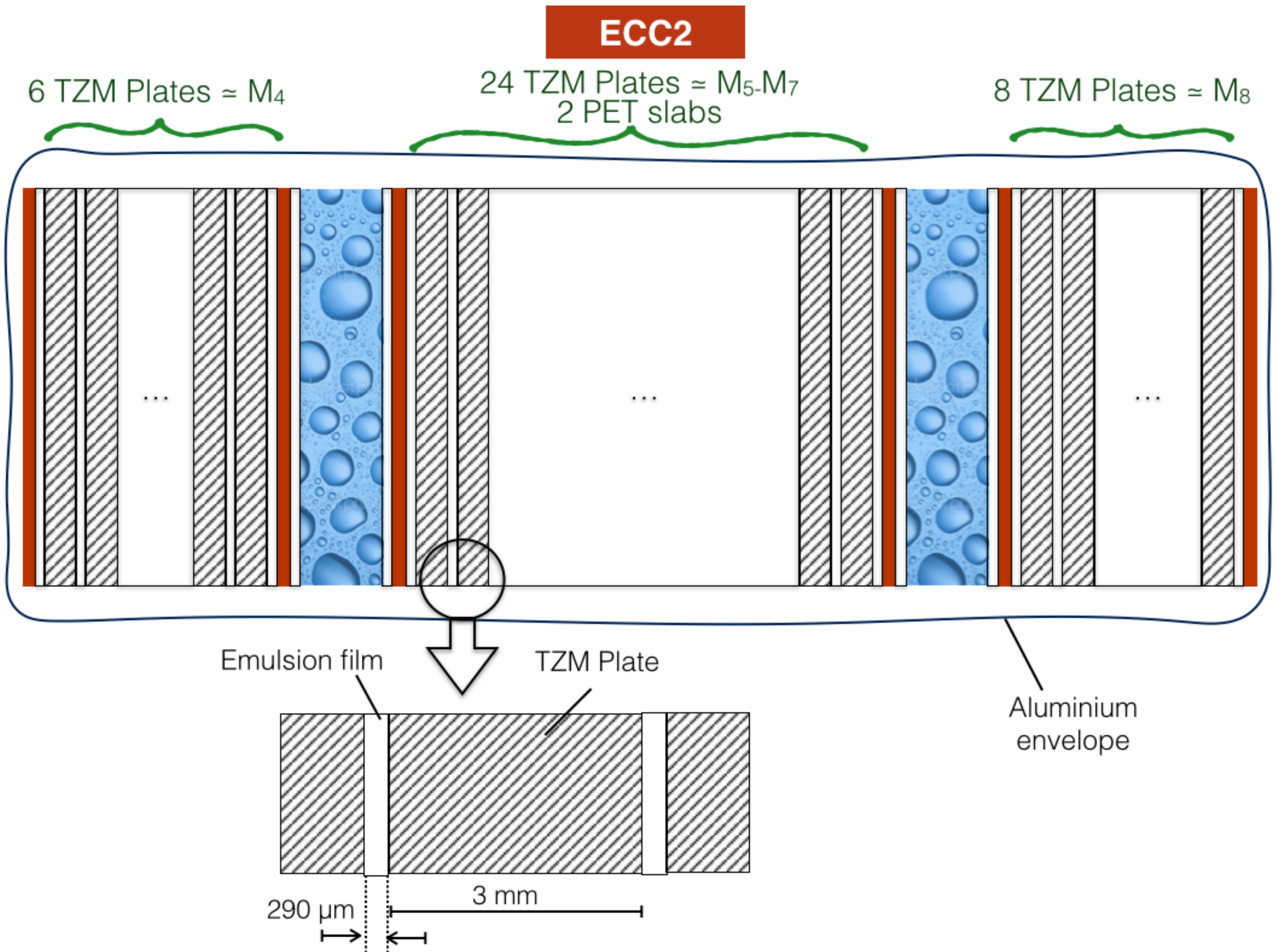

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CHARM DETECTION EFFICIENCY

ECC1

		SINGLE-CHARM	DOUBLE-CHARM
TOPOLOGICAL SELECTION	Charmed hadrons decaying in the target	91%	89%
	Charmed hadrons detected in emulsion	51%	29%
KINEMATICAL SELECTION	At least one daughter enter in the spectrometer	38%	16%
	At least one daughter cross the spectrometer	31%	11%
	Charge & momentum measurement	31%	11%
	Particle ID	30%	11%
	OVERALL EFFICIENCY (ε^{KIN})	**30%**	**11%**

MAGNETIC SPECTRO - UPSTREAM STATION

- Detector options under investigation:
  1) Scintillating fiber trackers (A. Malinin, V. Shevchenko)
  2) Atlas FE-I4 silicon detectors (M. Cristinziani, Bonn University)
     - 50 μm × 250 μm pixel size *(see M. Cristinziani's slides)*
     - position resolution (2 layers): ~ 10 μm
     - total width: ~ 400 μm
     - high rate capability
     - high occupancy capability
     - sensor surface ~ 4 cm^2
     - array 3x3: 6x6 cm^2
     - possible configuration -> T1: 4 layers, T2: 2 layers