Differential Charm Cross-Section Measurement In Proton Collisions

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INTRODUCTION

MOTIVATION

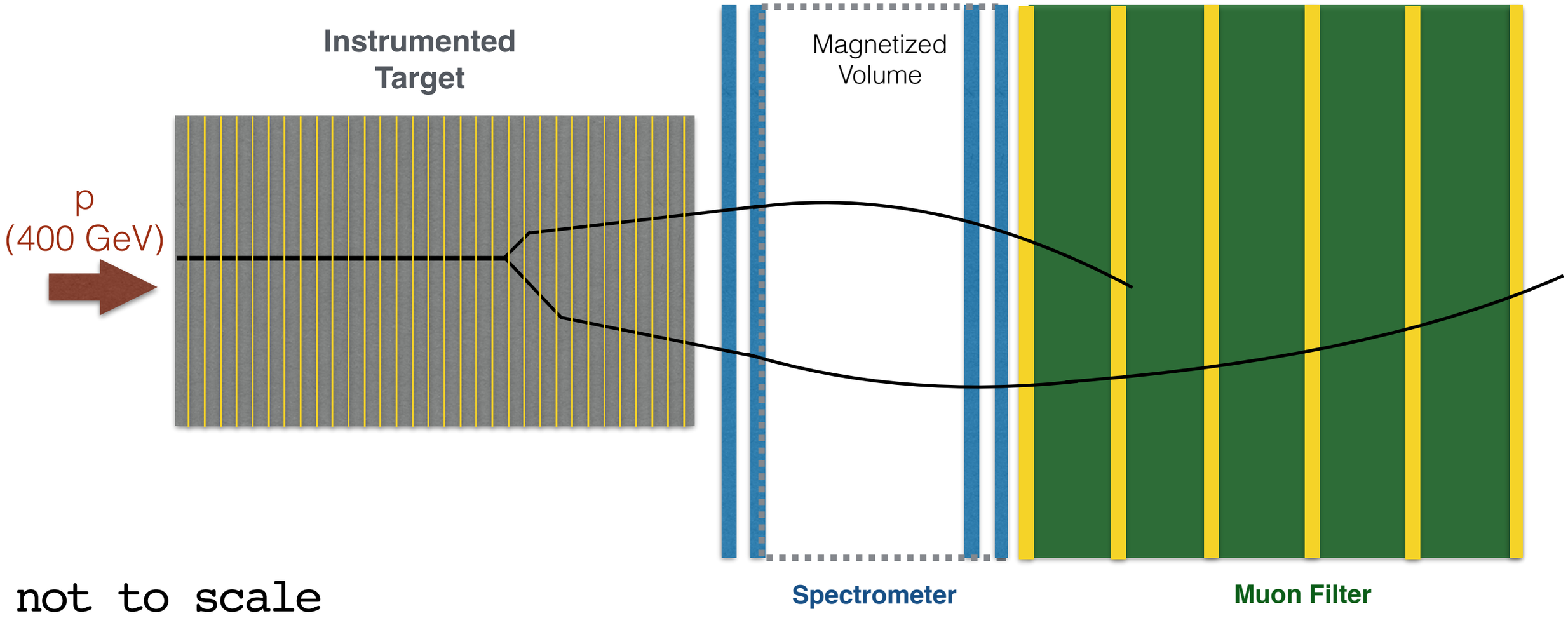
- Charm production in **proton interactions** and in **hadron cascades** in the SHiP target crucial for HNL normalization and ν_τ cross-section measurements
- Encouragement from SPSC to perform this measurement

OUTILINE

- Design of a hybrid detector for **double-differential** cross-section measurement **($d^2\sigma/dEd\theta$)**
- Use of **nuclear emulsions** as tracking detector
  - identification of hadronic and leptonic charm decay modes
  - volume of sensitive layers << target volume
- Momentum and charge measurement by electronic detectors
- FairShip simulation:
  - detector geometry
  - charm production in primary proton interactions and in hadron cascades
- From simulation to detector layout and **run configuration**

Conceptual Design

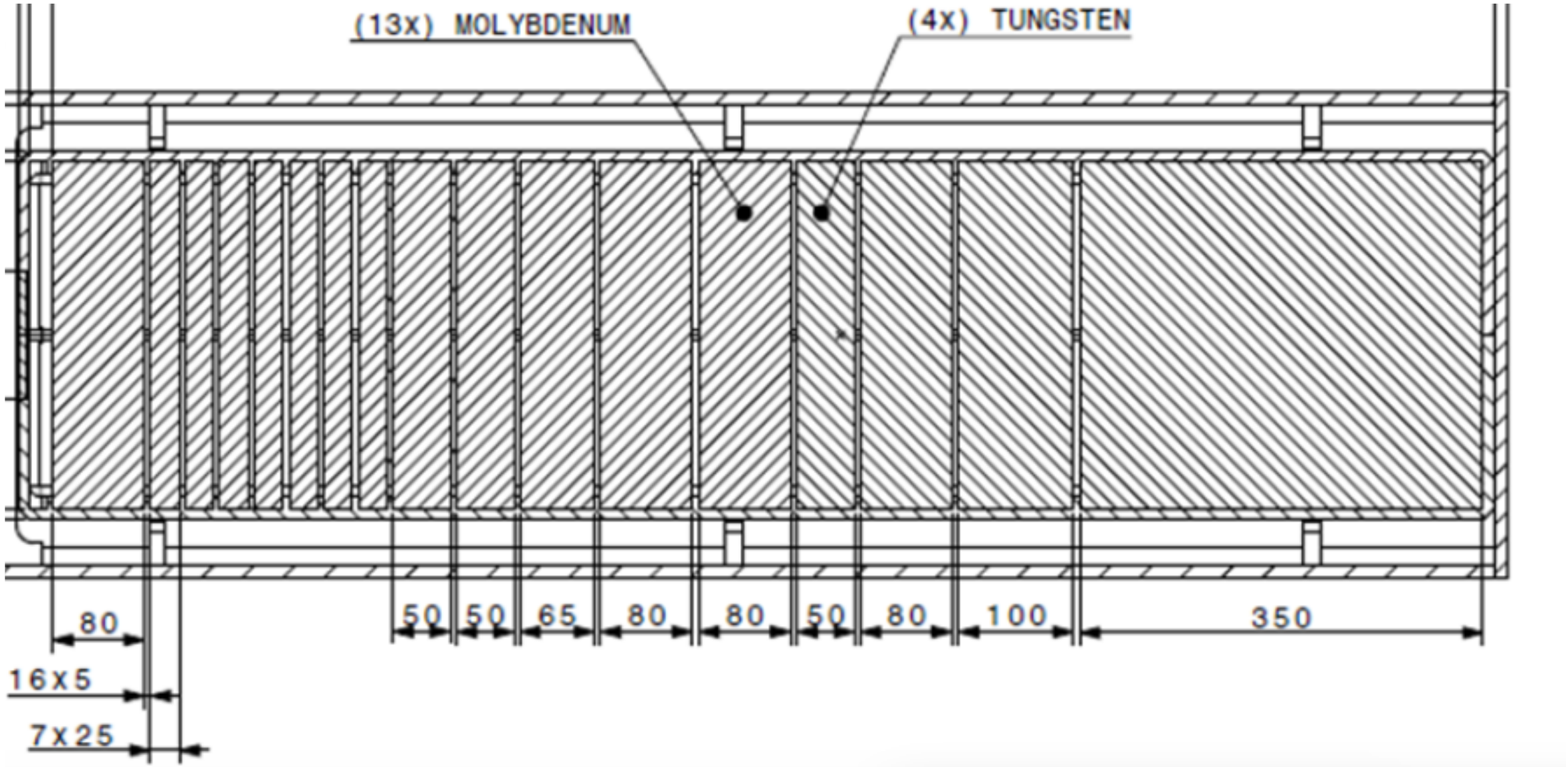
- Proton collisions in Mo/W target instrumented with **nuclear emulsions**
- Identification of charm production and decay vertices
- Measurement of charm daughters charge and momentum with **Spectrometer**
- Muon identification with **Muon Filter**



not to scale

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



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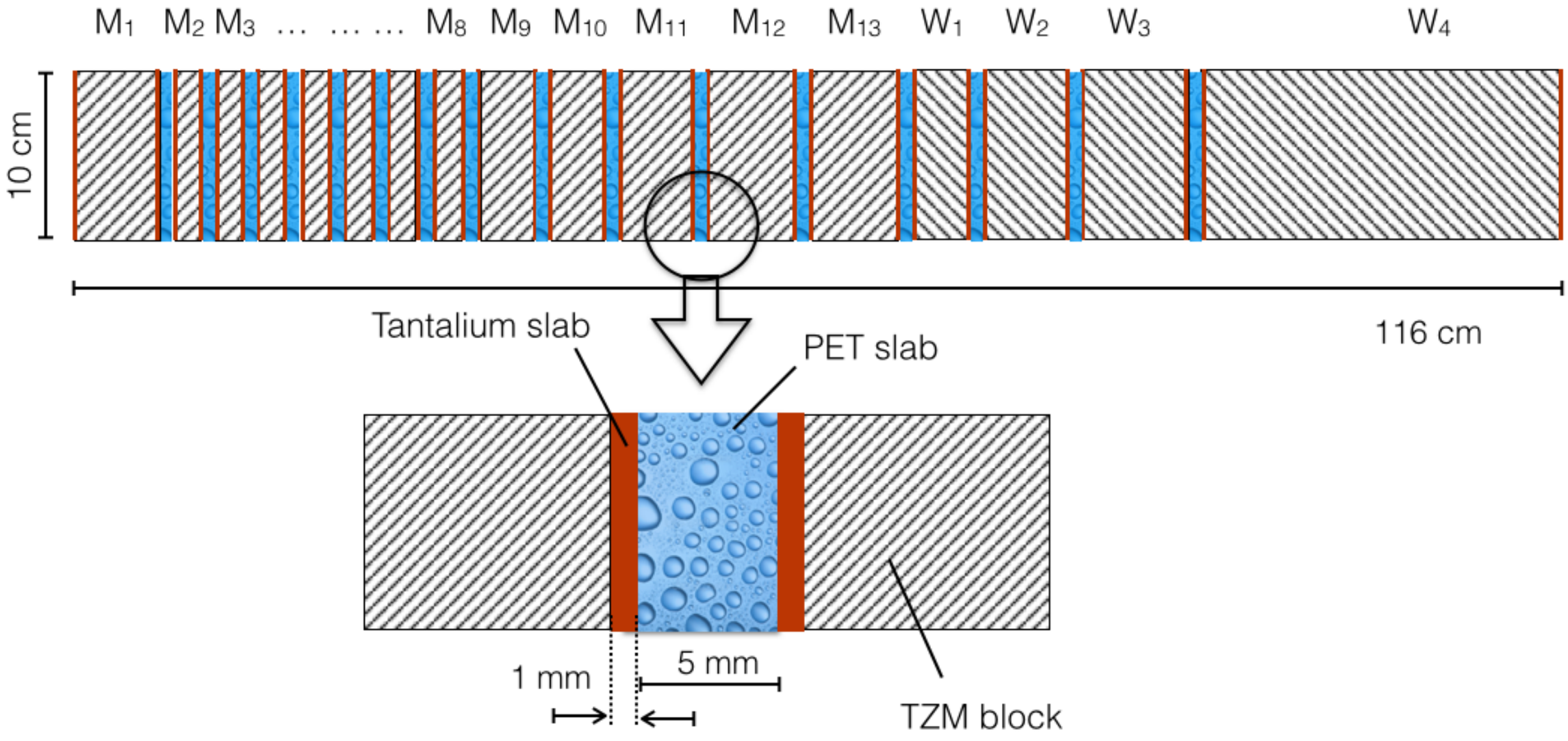
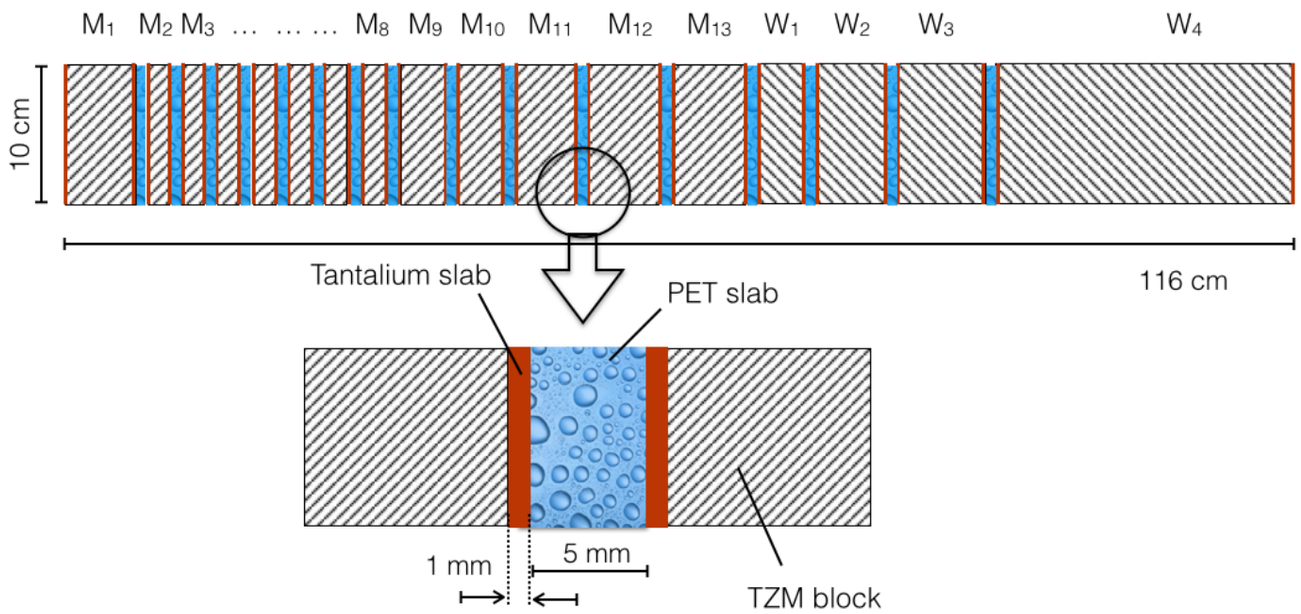


The Target Replica

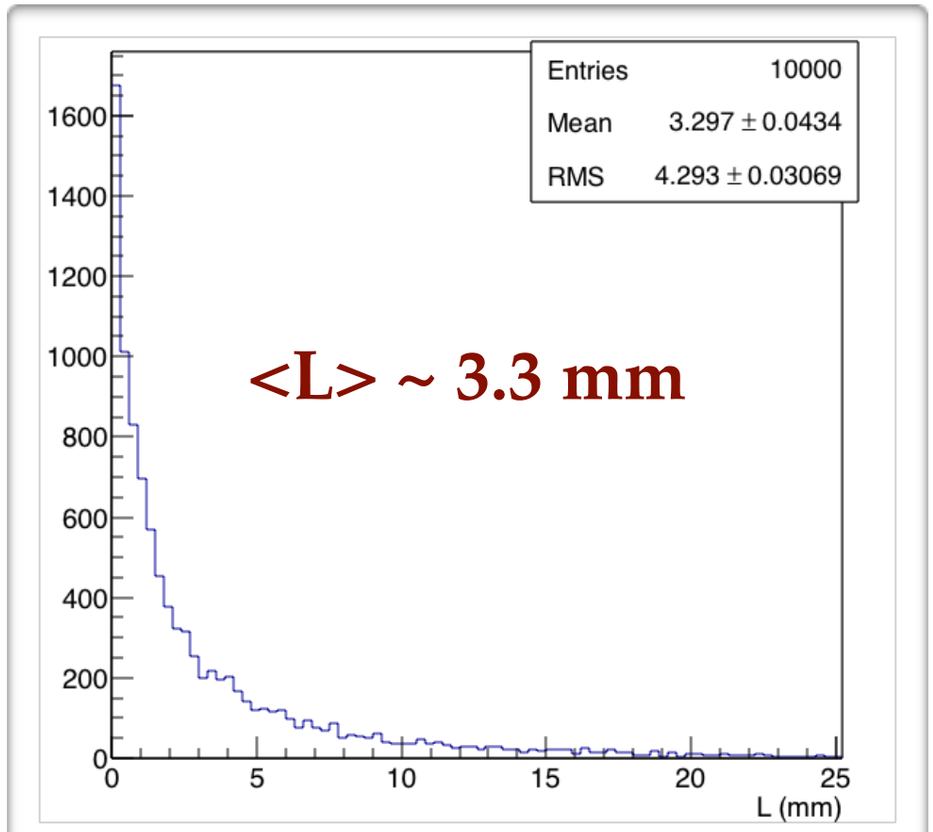
- Characterization of the target blocks



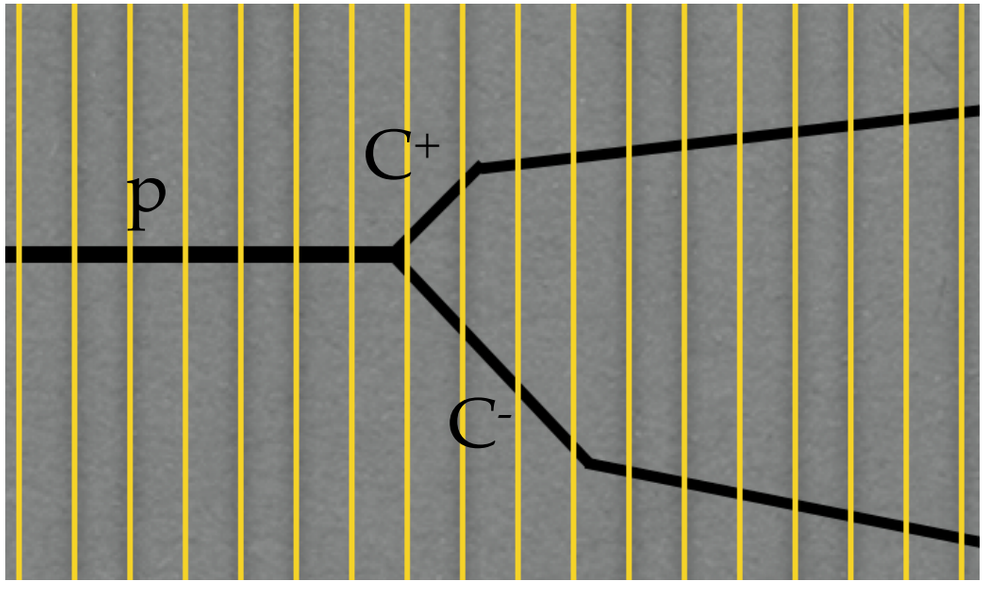
Block	Material	Thickness	λ
M_1	TZM	78 mm	0,51
M_2	TZM	23 mm	0,15
M_3	TZM	23 mm	0,15
M_4	TZM	23 mm	0,15
M_5	TZM	23 mm	0,15
M_6	TZM	23 mm	0,15
M_7	TZM	23 mm	0,15
M_8	TZM	23 mm	0,15
M_9	TZM	48 mm	0,31
M_{10}	TZM	48 mm	0,31
M_{11}	TZM	63 mm	0,41
M_{12}	TZM	78 mm	0,51
M_{13}	TZM	78 mm	0,51
W_1	W	48 mm	0,48
W_2	W	78 mm	0,78
W_3	W	98 mm	0,98
W_4	W	348 mm	3,50

Instrumentation Of Target

- Nuclear emulsions used as micrometric tracking device to identify charm production and decay
- Charm average decay length ~ 3.3 mm

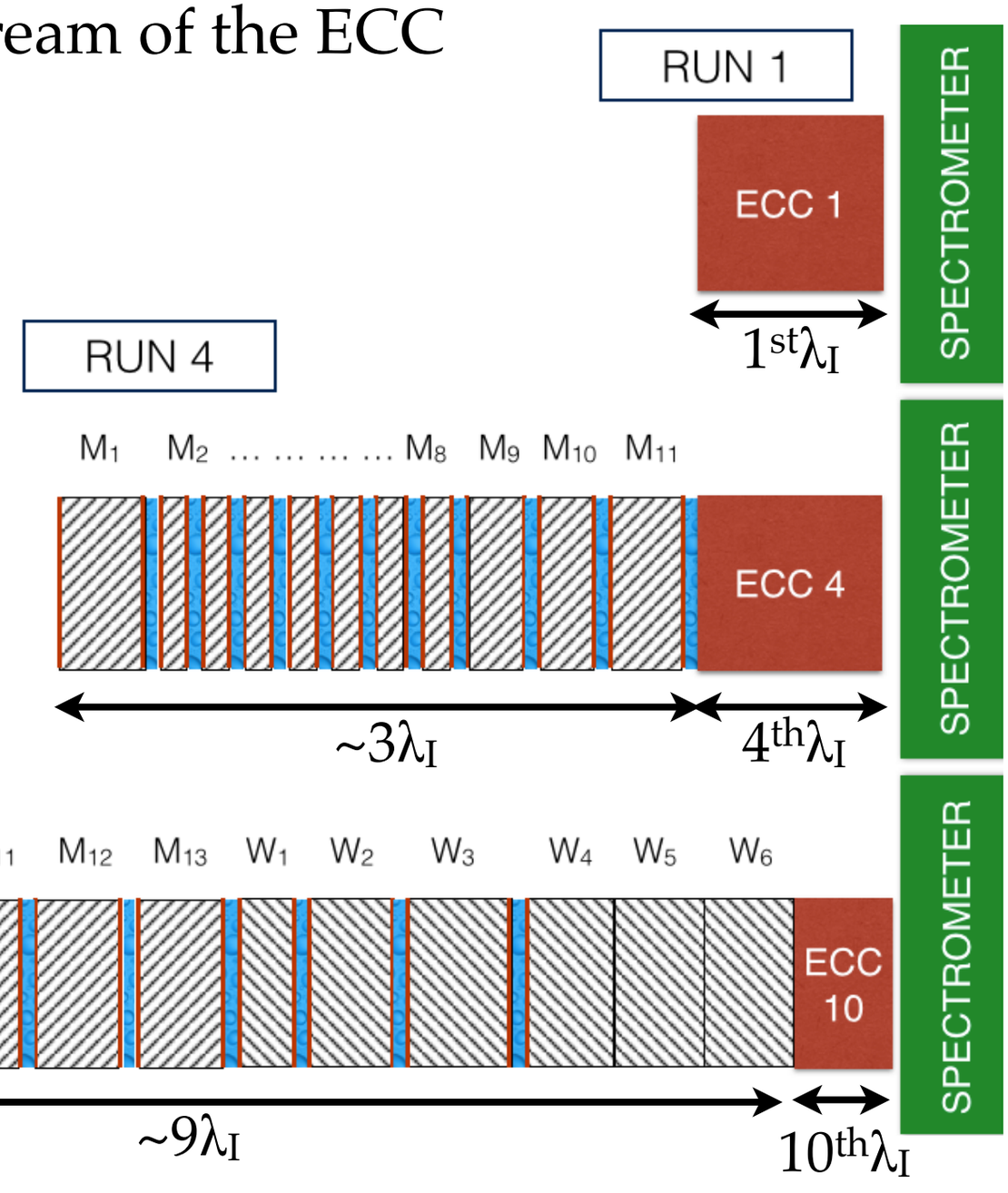


- Emulsion Cloud Chamber (ECC) technique employed: sampling of target material (TZM/W) every 3 mm
- Build ECC chambers to study the charm production in different sections of the target



INSTRUMENTATION OF TARGET

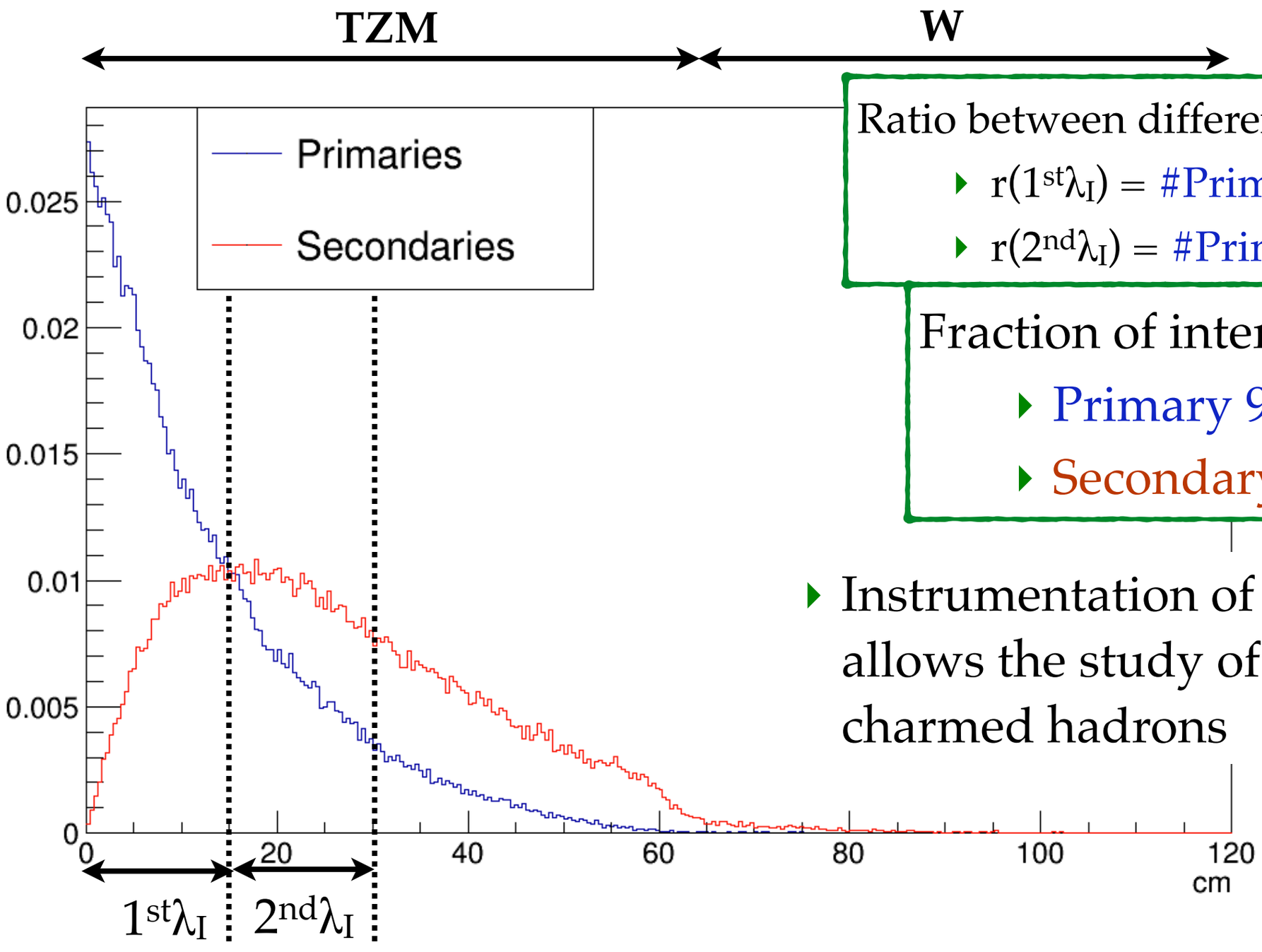
- Instrumentation of different portions (~1λ_I) of the target with emulsions
- ECC always the most downstream part of the target to let charm daughters reach the spectrometer
- Target modules are retained upstream of the ECC



CHARMED HADRON PRODUCTION

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

PRIMARY PROTON INTERACTIONS
CASCADE PRODUCTION



Ratio between different production modes

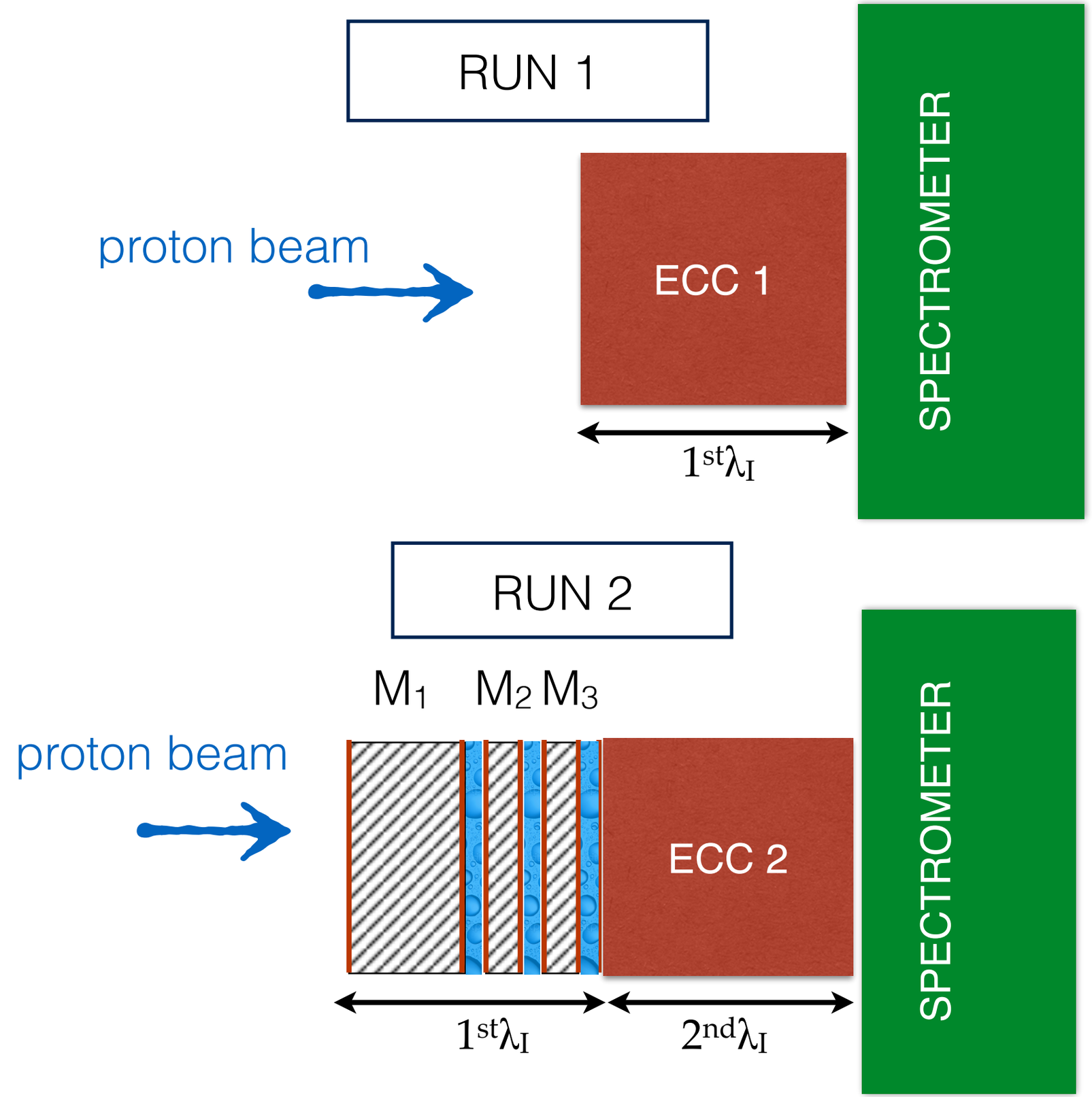
- $r(1^{st}\lambda_I)$ = #Primary / #Secondary = 2.7
- $r(2^{nd}\lambda_I)$ = #Primary / #Secondary = 0.8

Fraction of interactions within $2\lambda_I$

- Primary 92%
- Secondary 66%

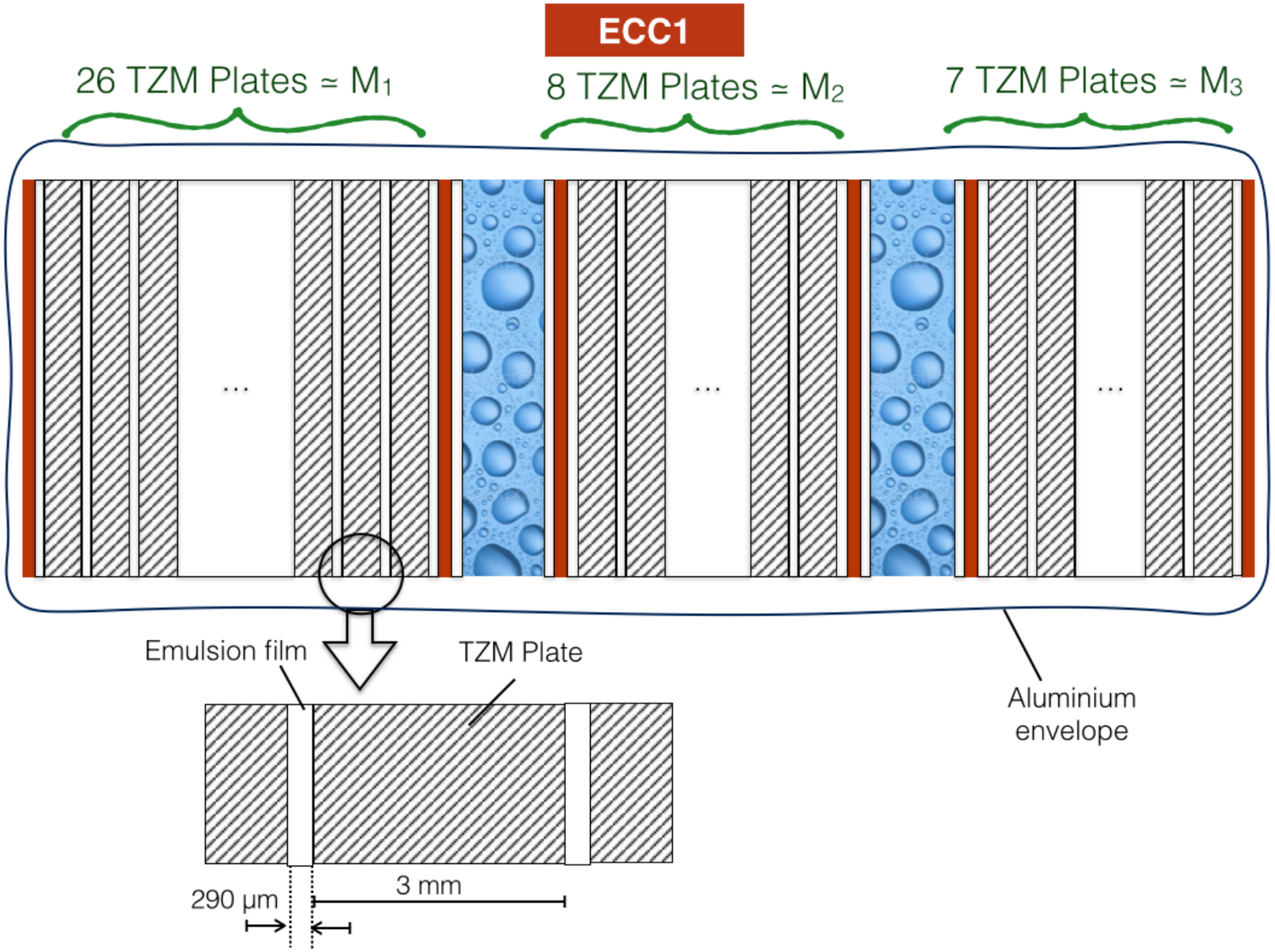
- Instrumentation of first and second λ_I allows the study of a large fraction of charmed hadrons

RUN CONFIGURATION



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

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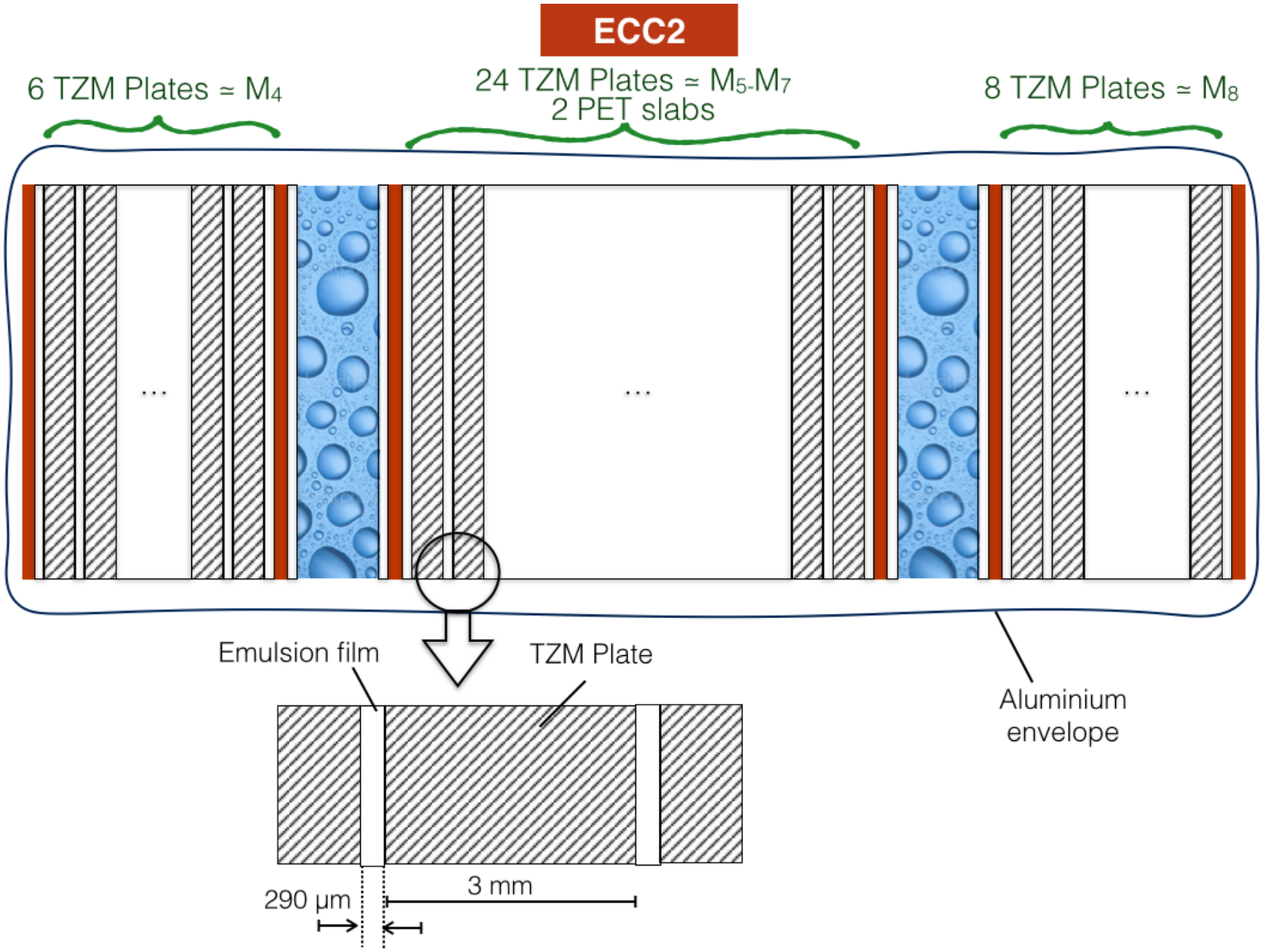

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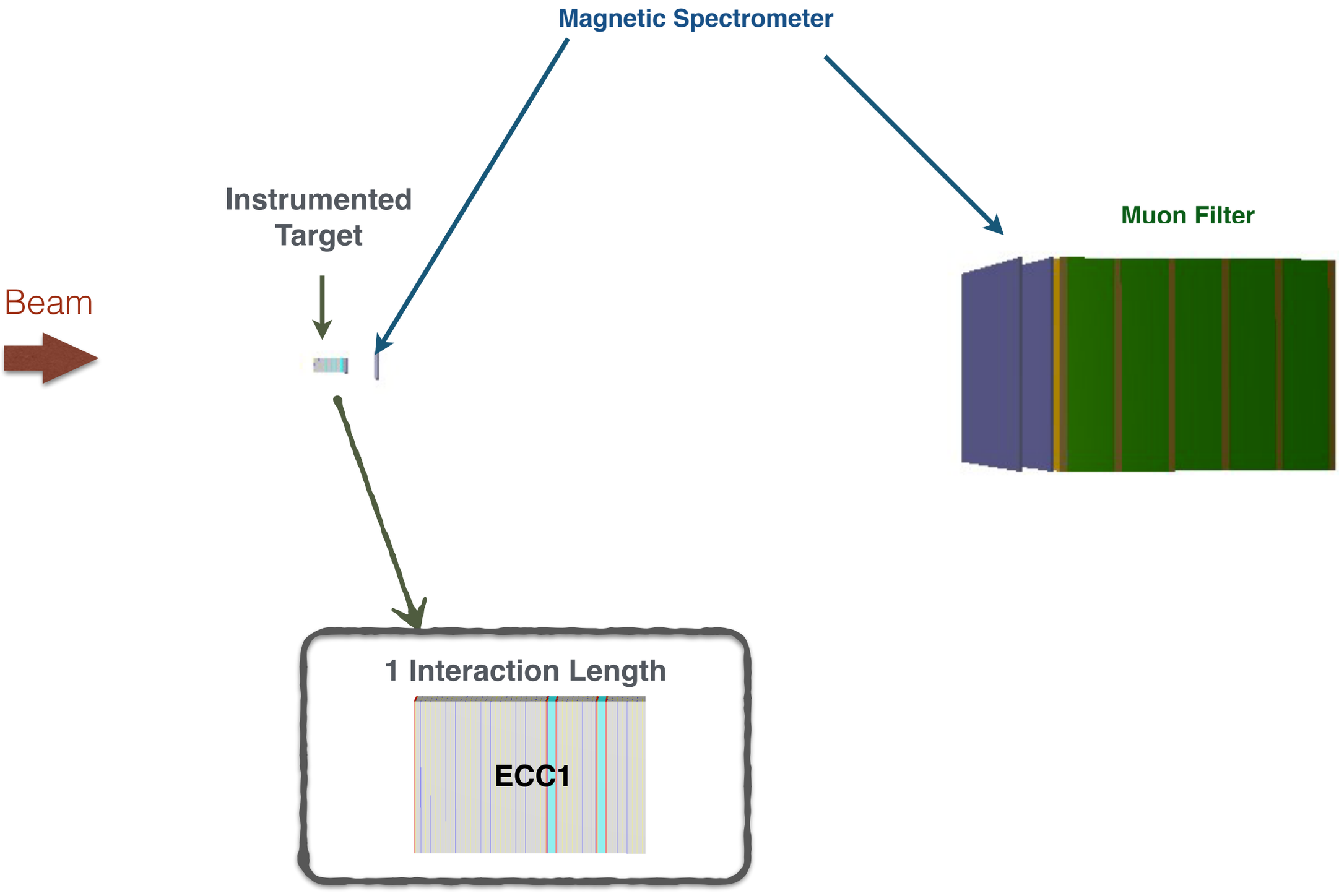
Implementation In FairSHiP



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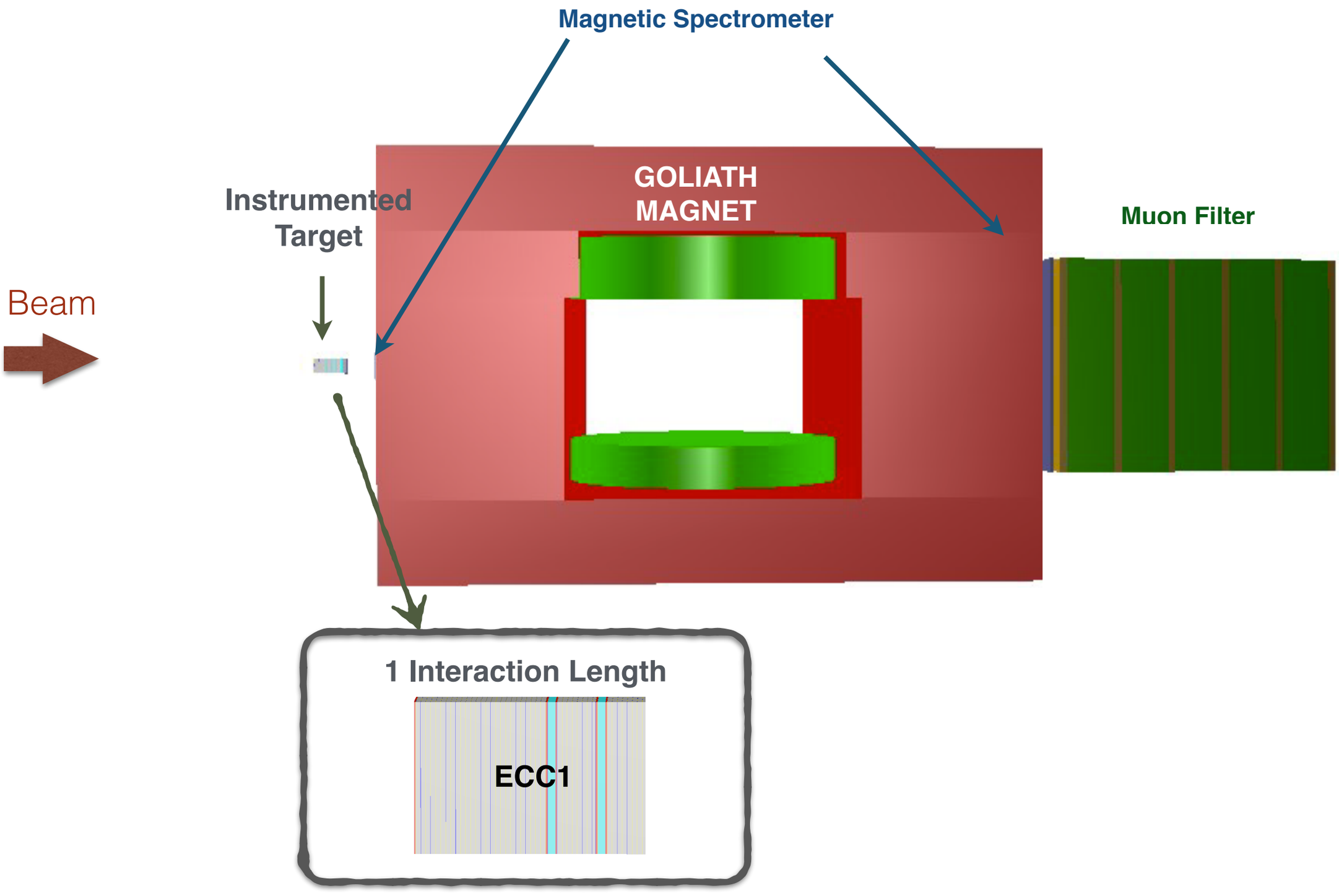
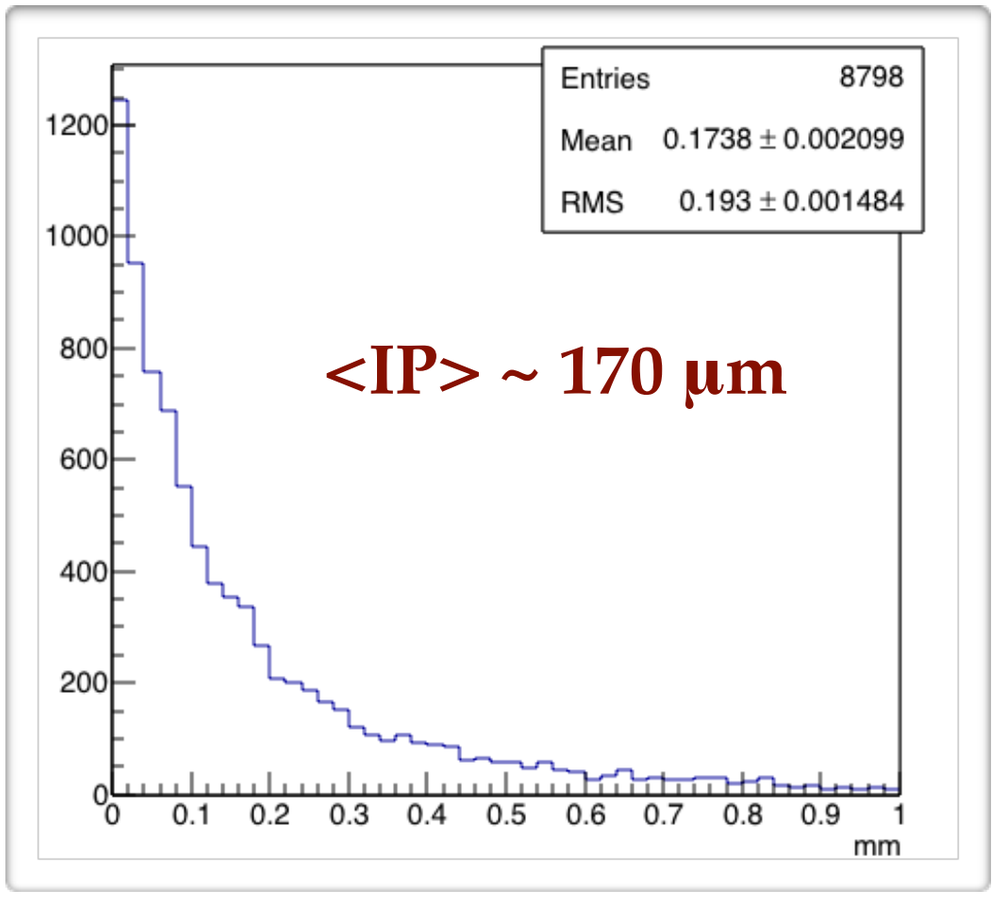
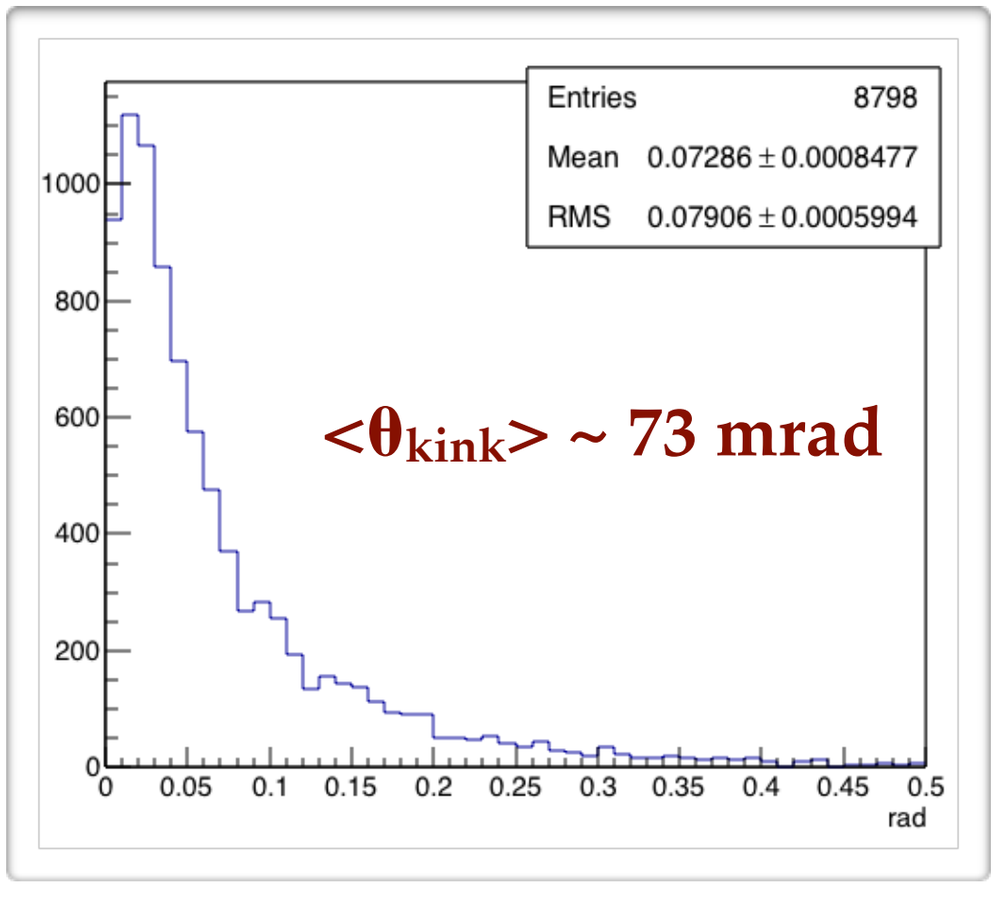


DECAY SEARCH

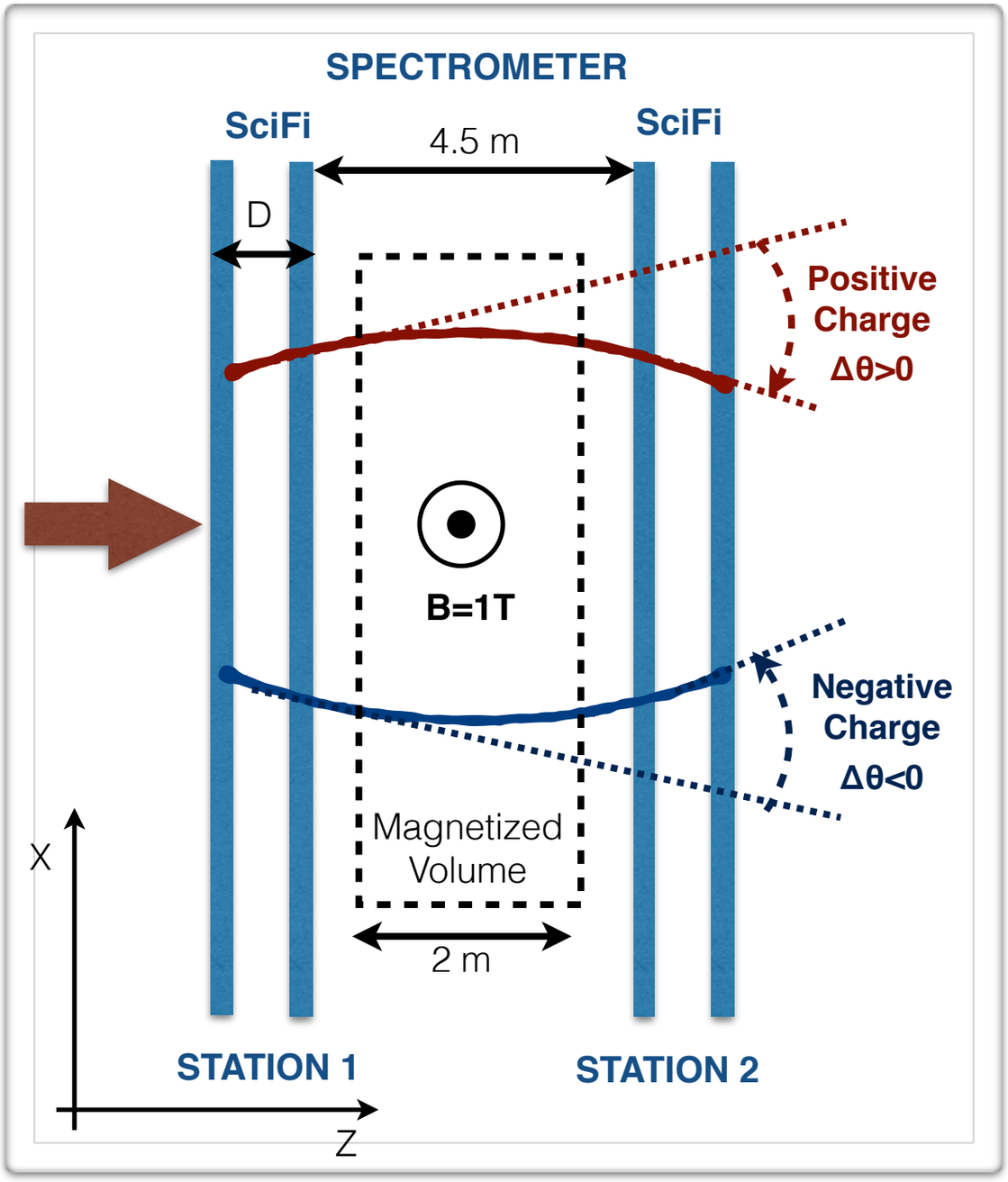
- Charm decay vertex identification:
  - Impact parameter of daughter track w.r.t. primary vertex >10 μm
  - 1-prong topology: kink angle>20 mrad
  - at least one track with >1 GeV/c
  - Fight length <6 mm

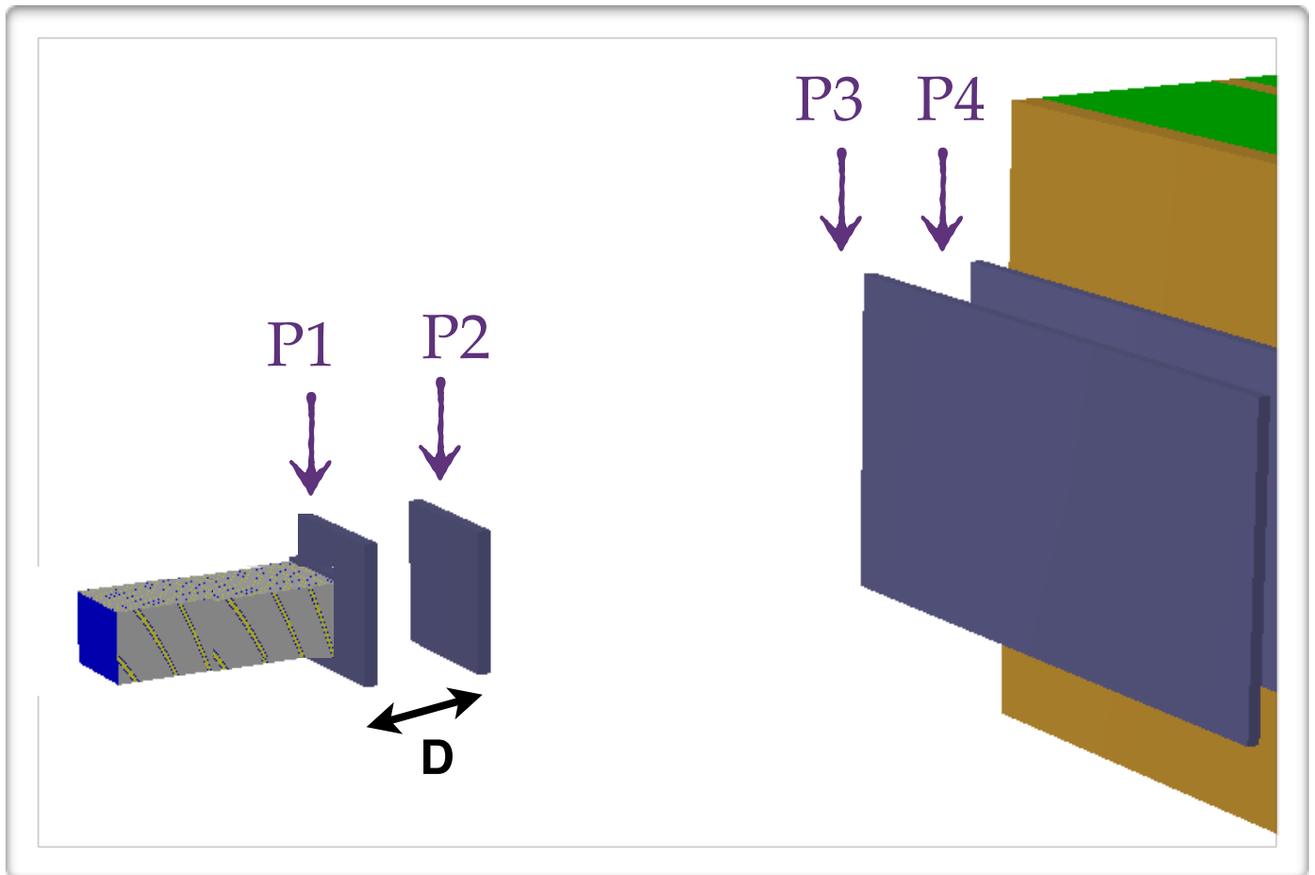




SPECTROMETER

- Stations: 2
- Planes: 4 (two per station)

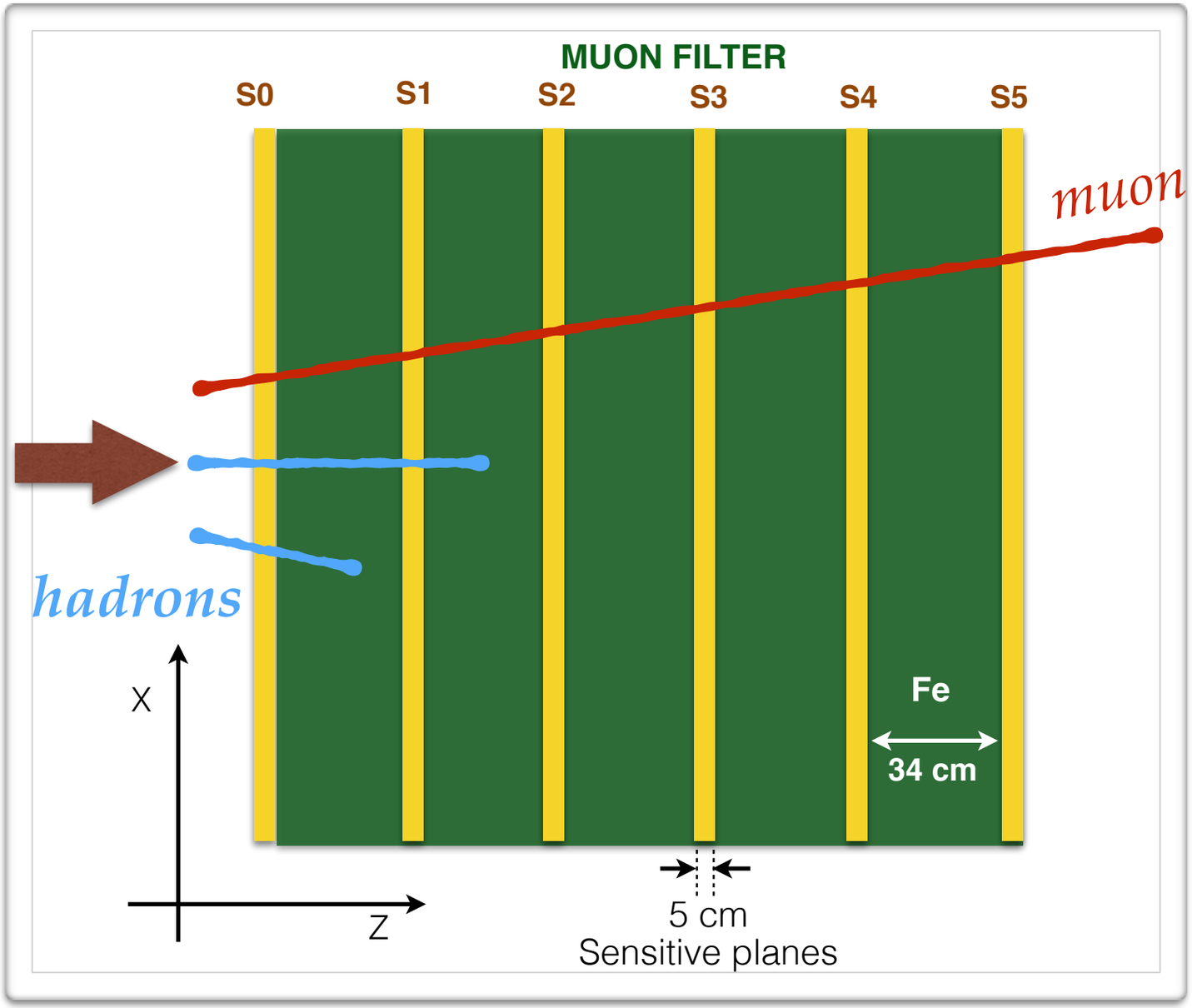




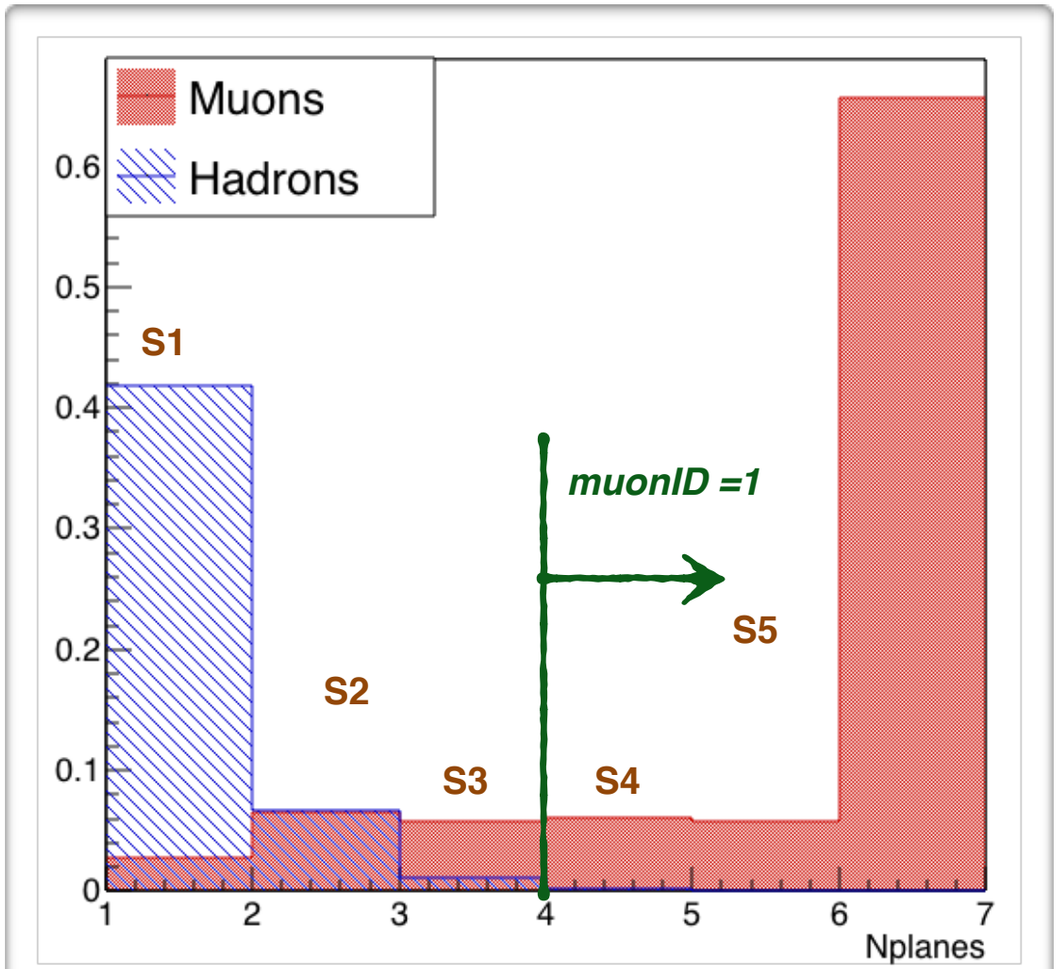
- Smaller dimensions for most upstream planes

P1&P2	20 x 20 cm^2
P3 &P4	200 x 150 cm^2

Muon Identification



MuonID criterium
number of crossed layers > 3



MuonID efficiency

87 %

MuonID purity

99 %

Possible improvements using momentum/range correlation

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%**

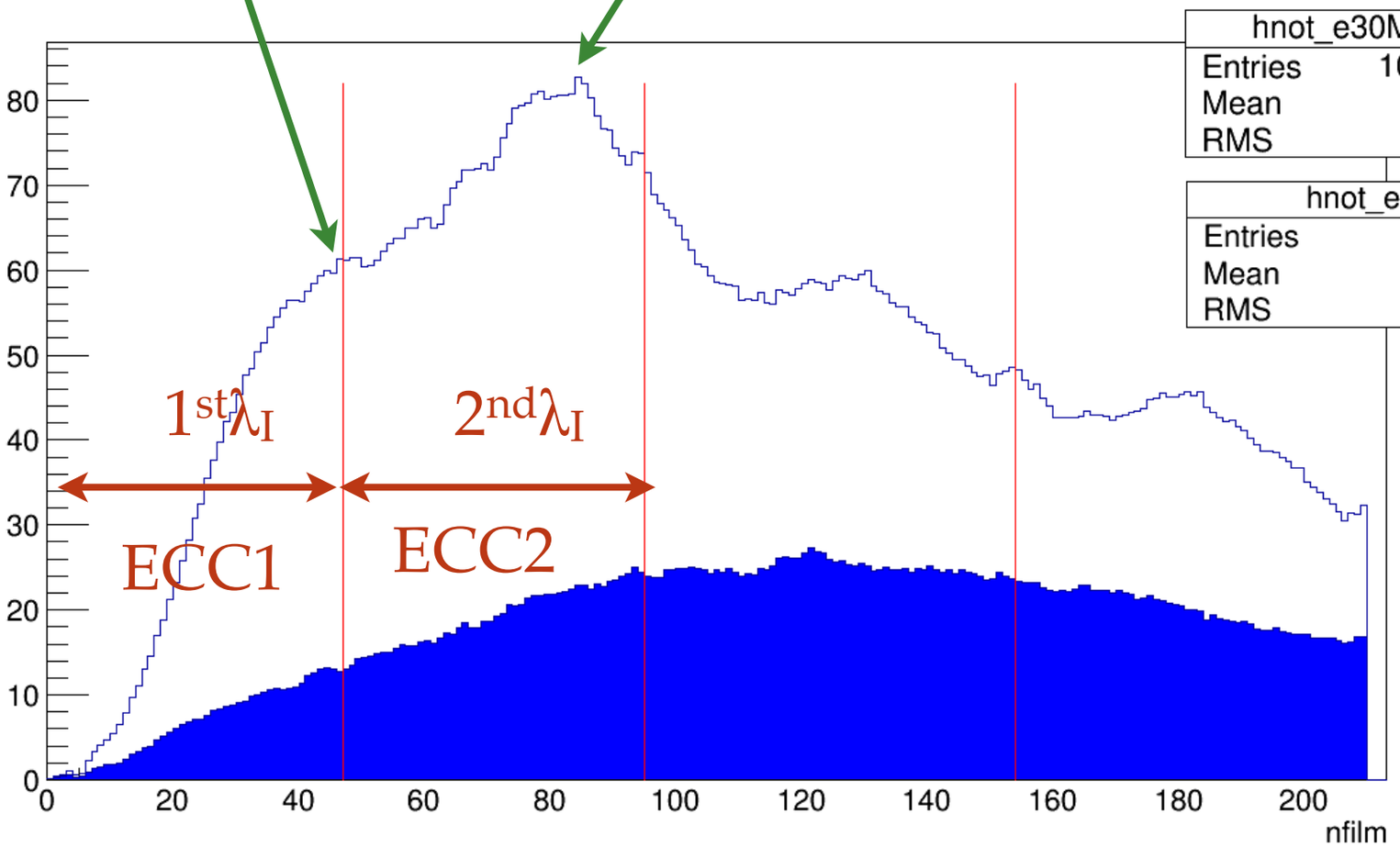
EXPOSURE PLAN

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

ASSUMPTION: protons uniformly distributed in 10x10 cm^2

Maximum density of tracks in

$1^{st}\lambda_I \Rightarrow 6.1\times10^{-3}/mm^2$ $2^{nd}\lambda_I \Rightarrow 8.3\times10^{-3}/mm^2$



- Number of tracks integrated in emulsion per incoming proton

Electrons <30MeV discarded

All electrons discarded

EXPOSURE PLAN

- Maximum allowed track density in emulsion: 1000 tr/mm^2
- Maximum number of pot/ECC1 = 1.63 x 10^5 pot

  ECC2 = 1.21 x 10^5 pot
- Number of charm pairs detected/ECC1 = 24.2

  ECC2 = 12.6

Exposure needed to observe **1000** charmed pairs

30 x ECC1 x 1.63 x 10^5 pot

22 x ECC2 x 1.21 x 10^5 pot

Total number of integrated pot = 7.6 x 10^6

Total number of emulsion films = 2466 films

Total emulsion surface = 24.7 m^2

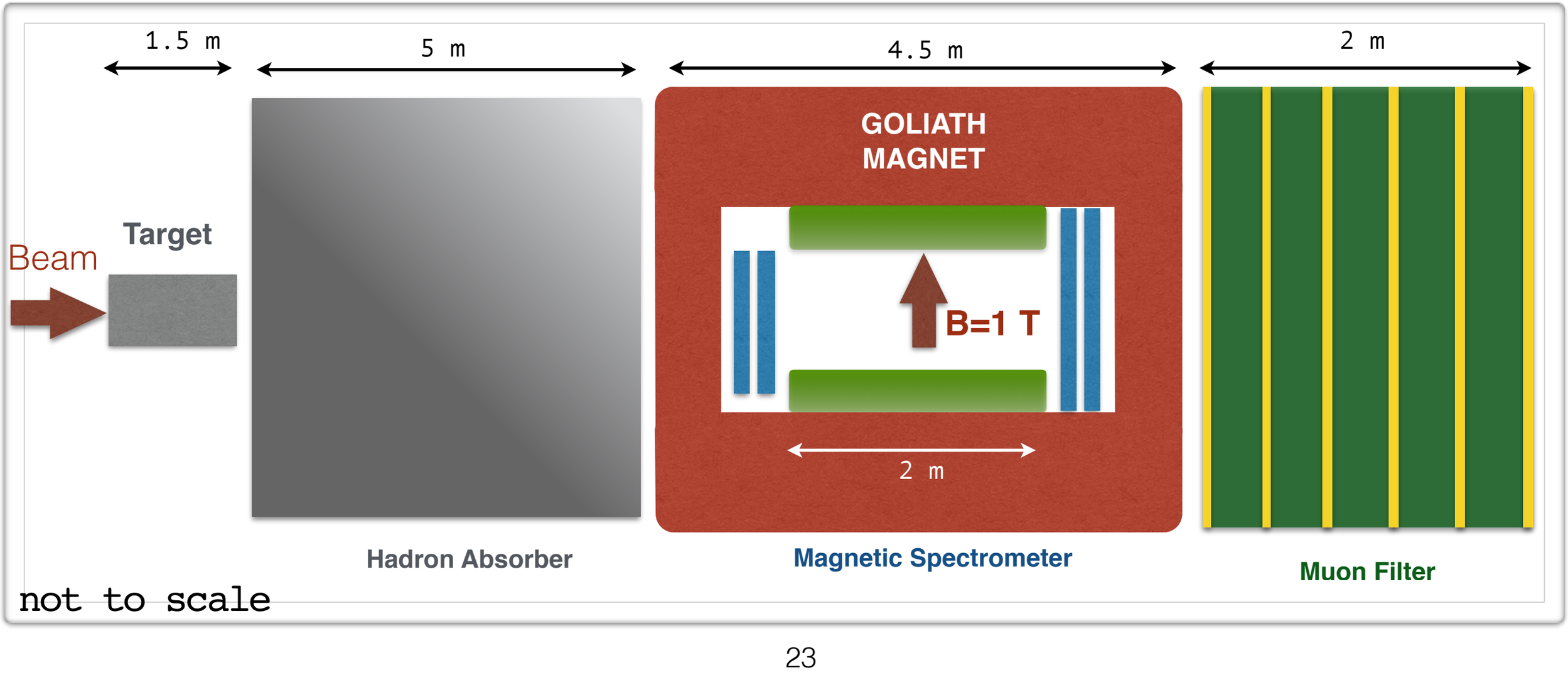
SUMMARY

- Design of a detector for the measurement of charm differential cross-section in proton interactions and in hadron cascades
- Description of run configuration and exposure plan
- Instrumentation of first two target interaction lengths with nuclear emulsions
- 1000 charm pairs expected with 7.6 x10^6 pot and 25 m^2 emulsion surface
- Challenge: uniform proton beam on 10 x 10 cm^2 for runs of ~10^5 pot
- Next step: evaluation of the hadronic background contamination

BACK-UP SLIDES

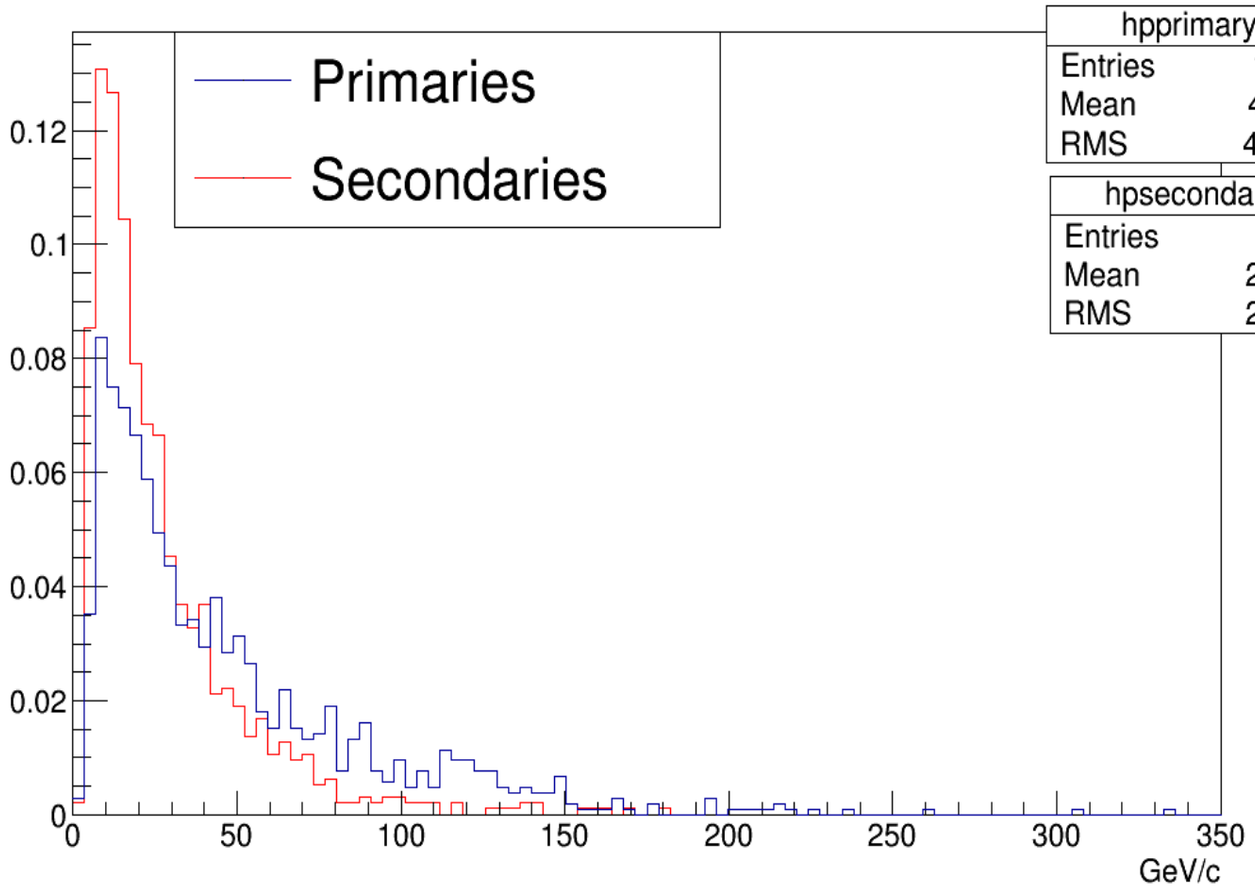
Possible Layout Including Muon Measurement

- Add hadron absorber upstream of the magnet



CHARMED HADRON PRODUCTION

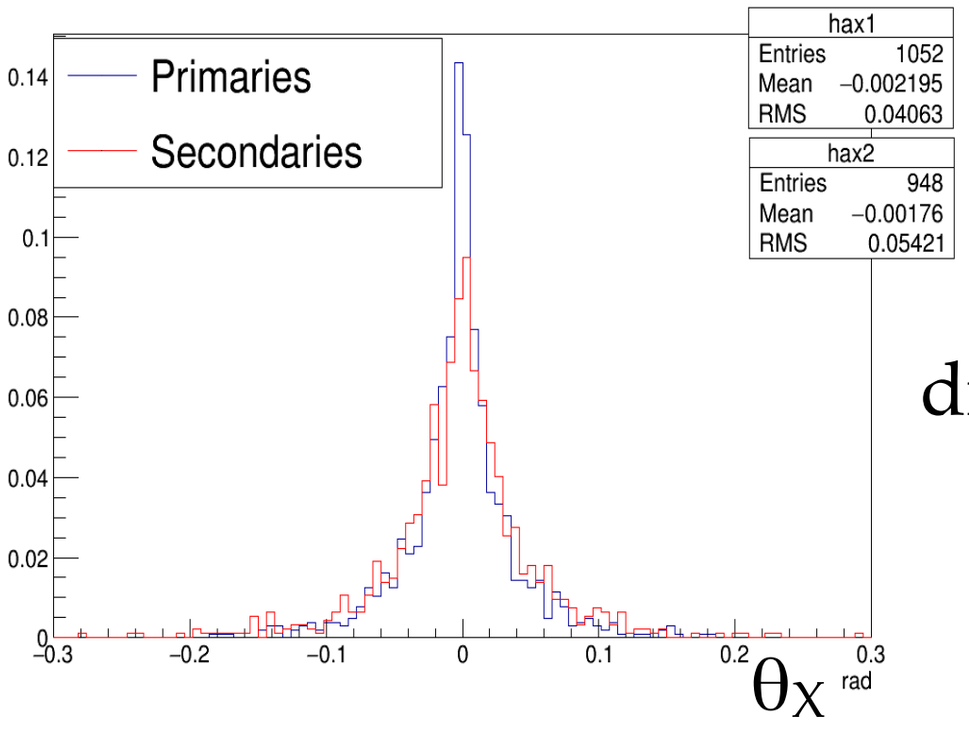
Charm momentum

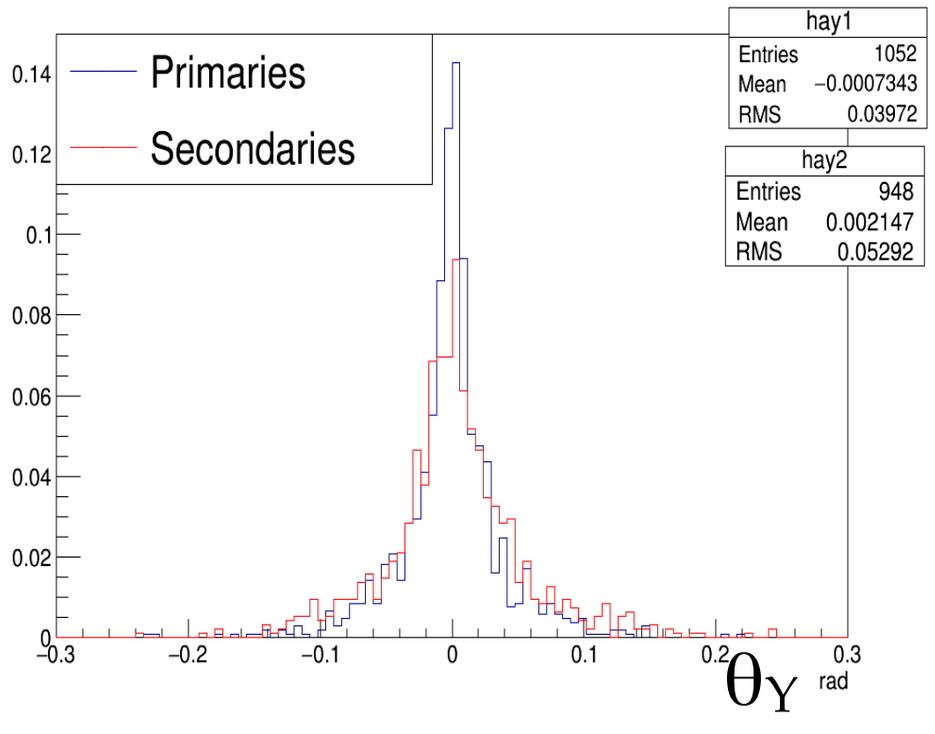


CASCADE PRODUCTION

PRIMARY PROTON INTERACTIONS

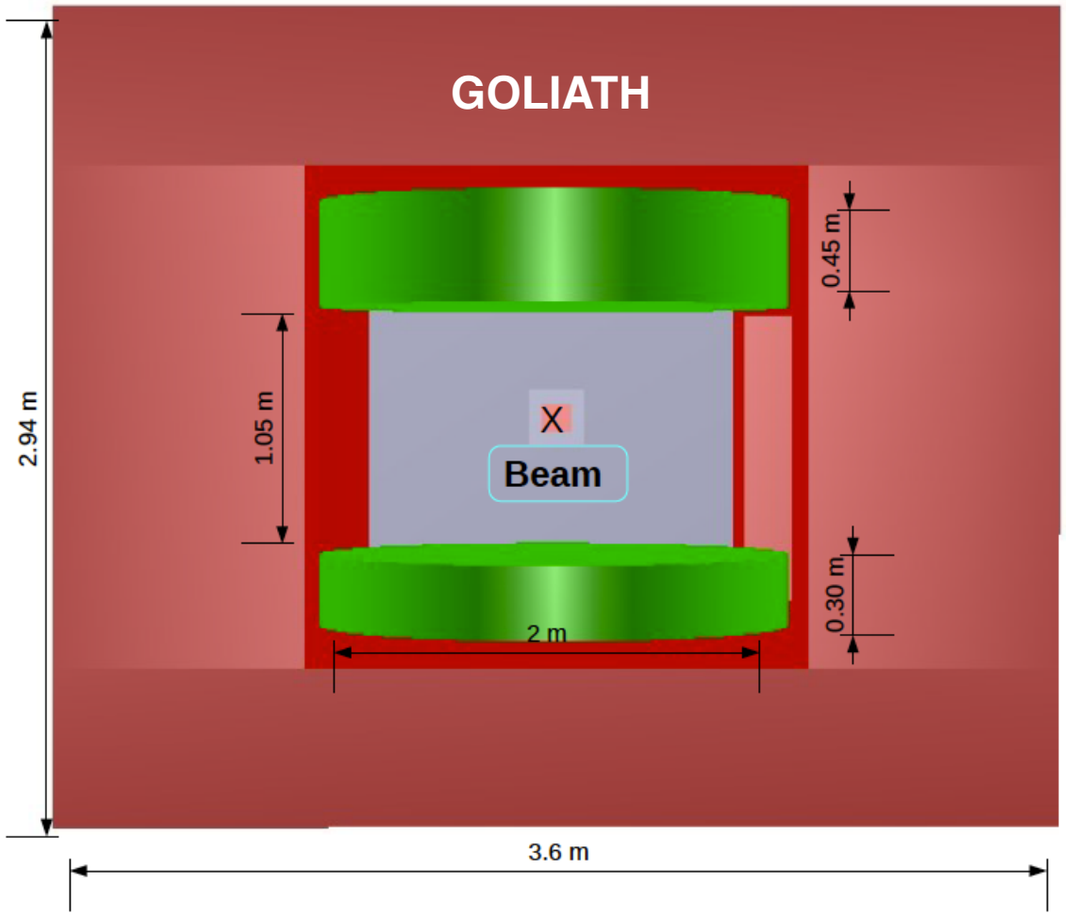
Angular distribution



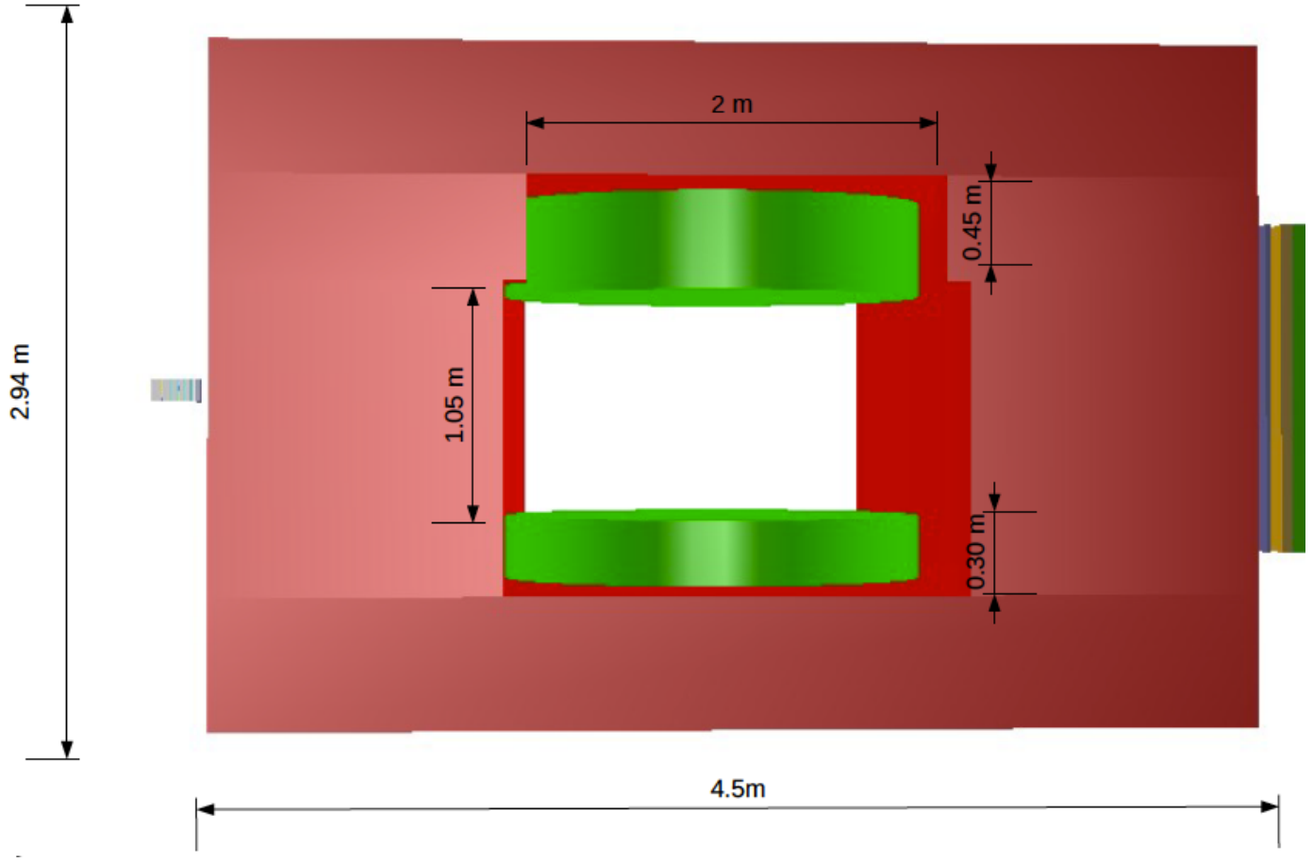


GOLIATH DIMENSIONS

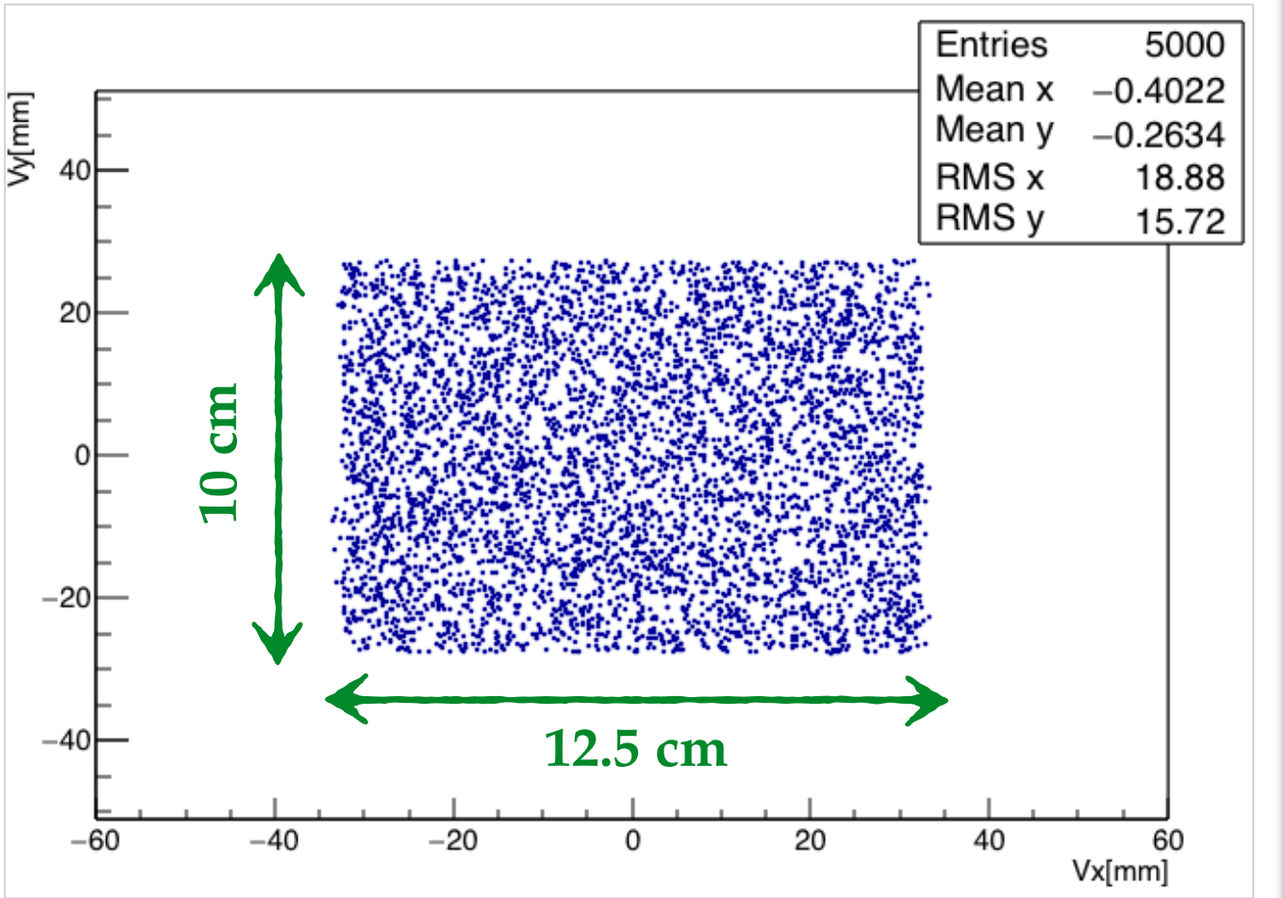
FRONT VIEW



Beam



Charmed Hadron Production

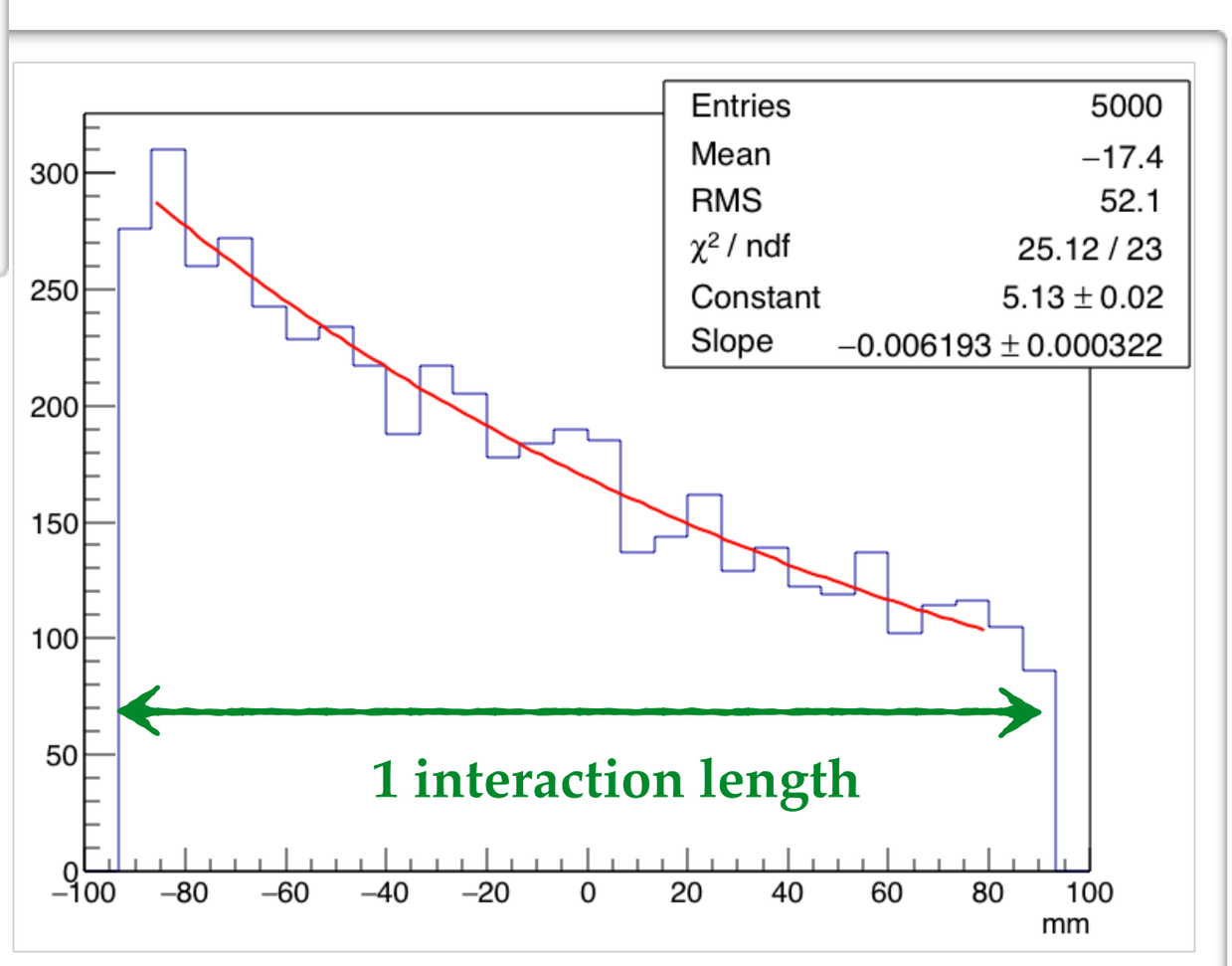


- Charm production vertex uniformly distributed in (x,y) target plane

p
(400 GeV)

- Charm production along the beam axis follows exponential distribution

λ=1/0.006193 ~ 160 mm



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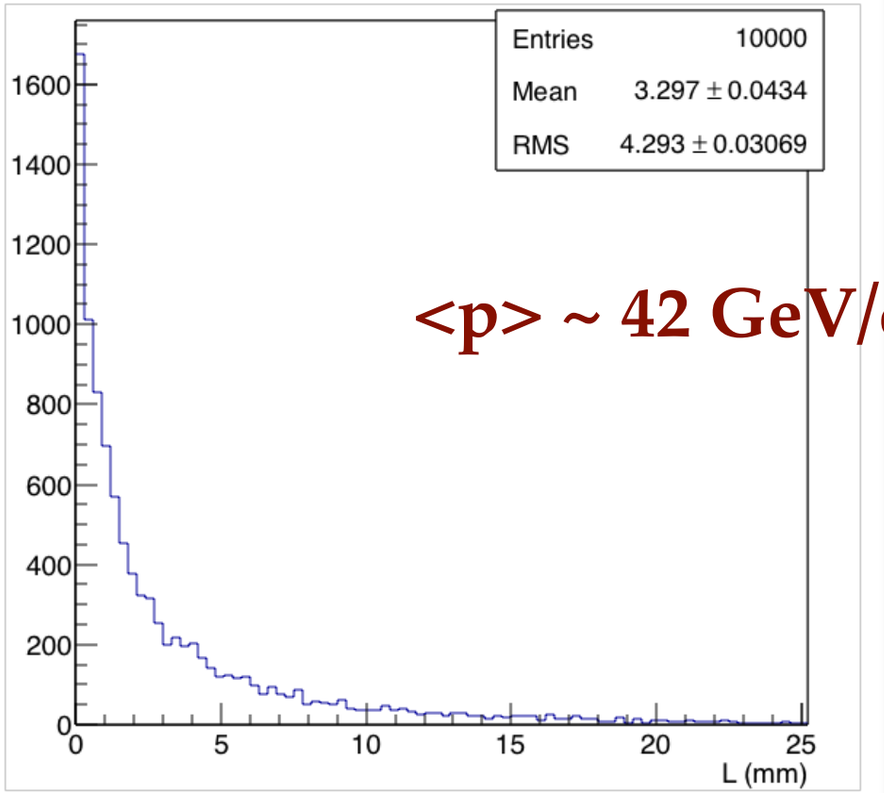
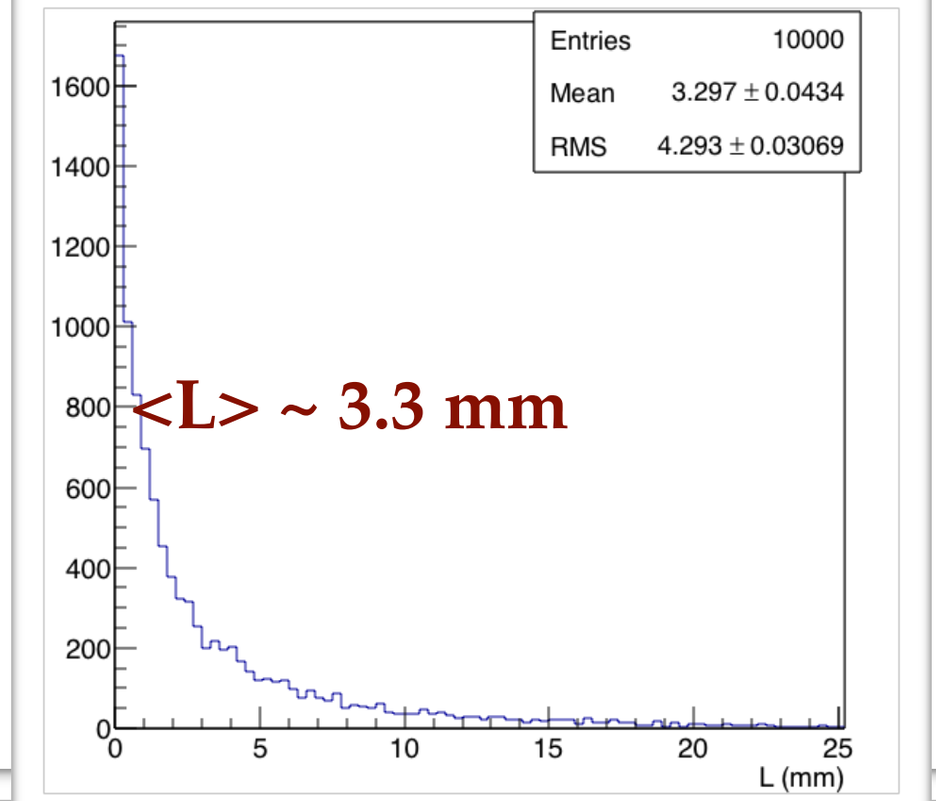
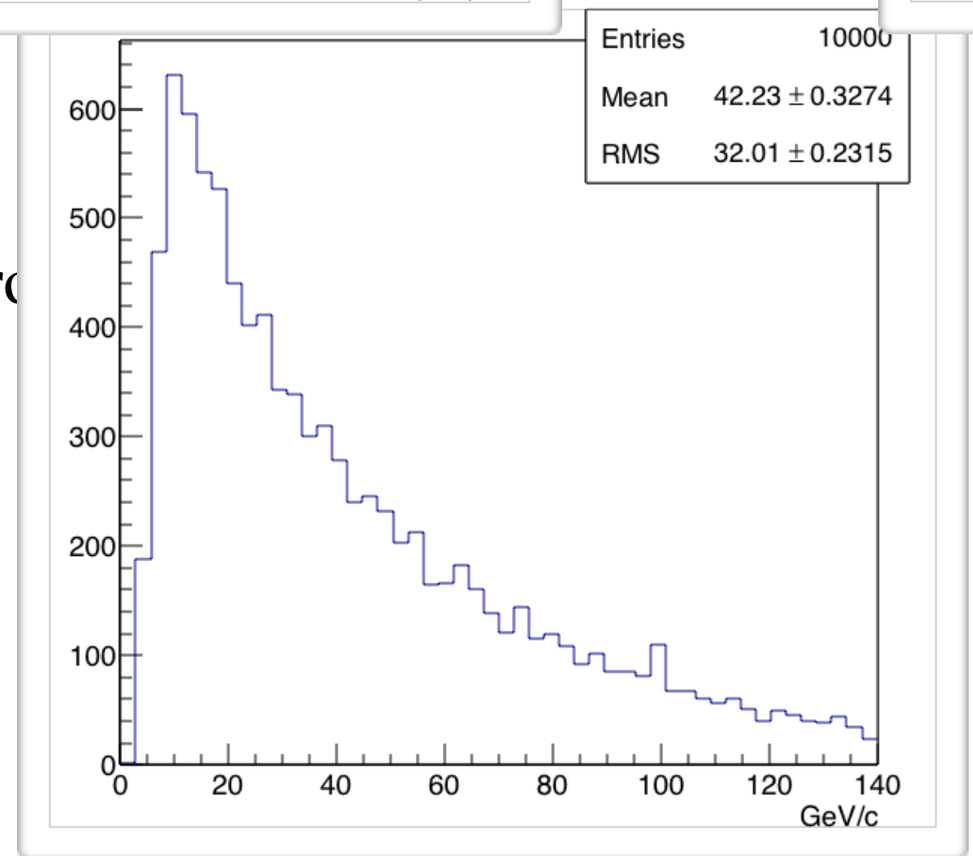


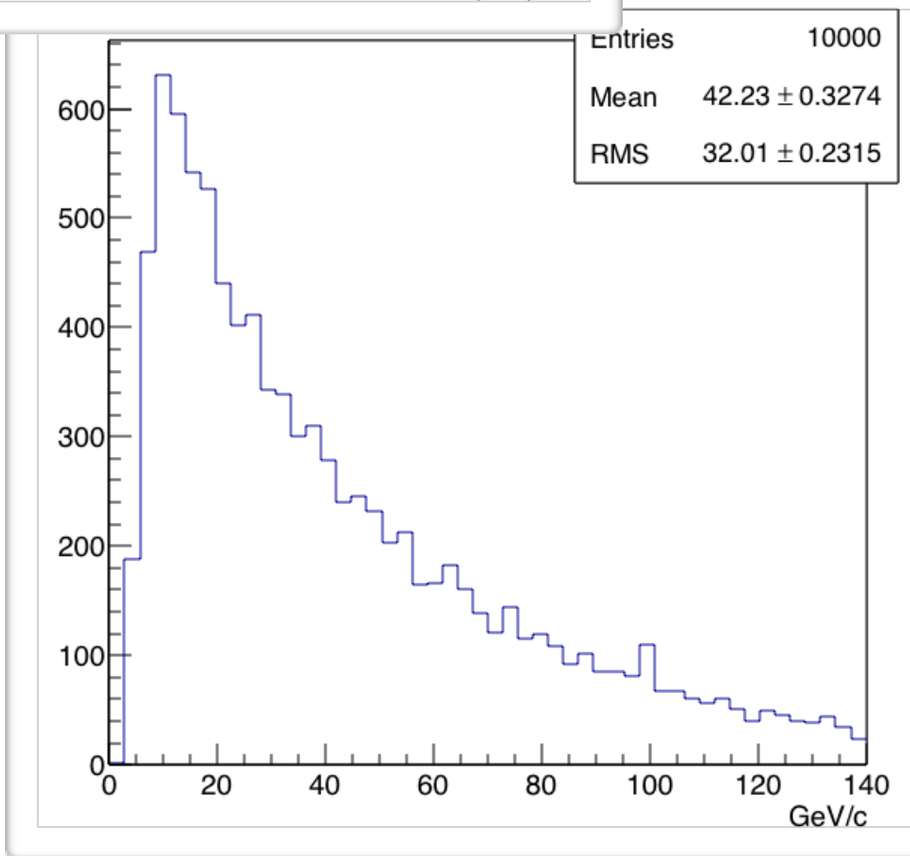
<p> ~ 42 GeV/c



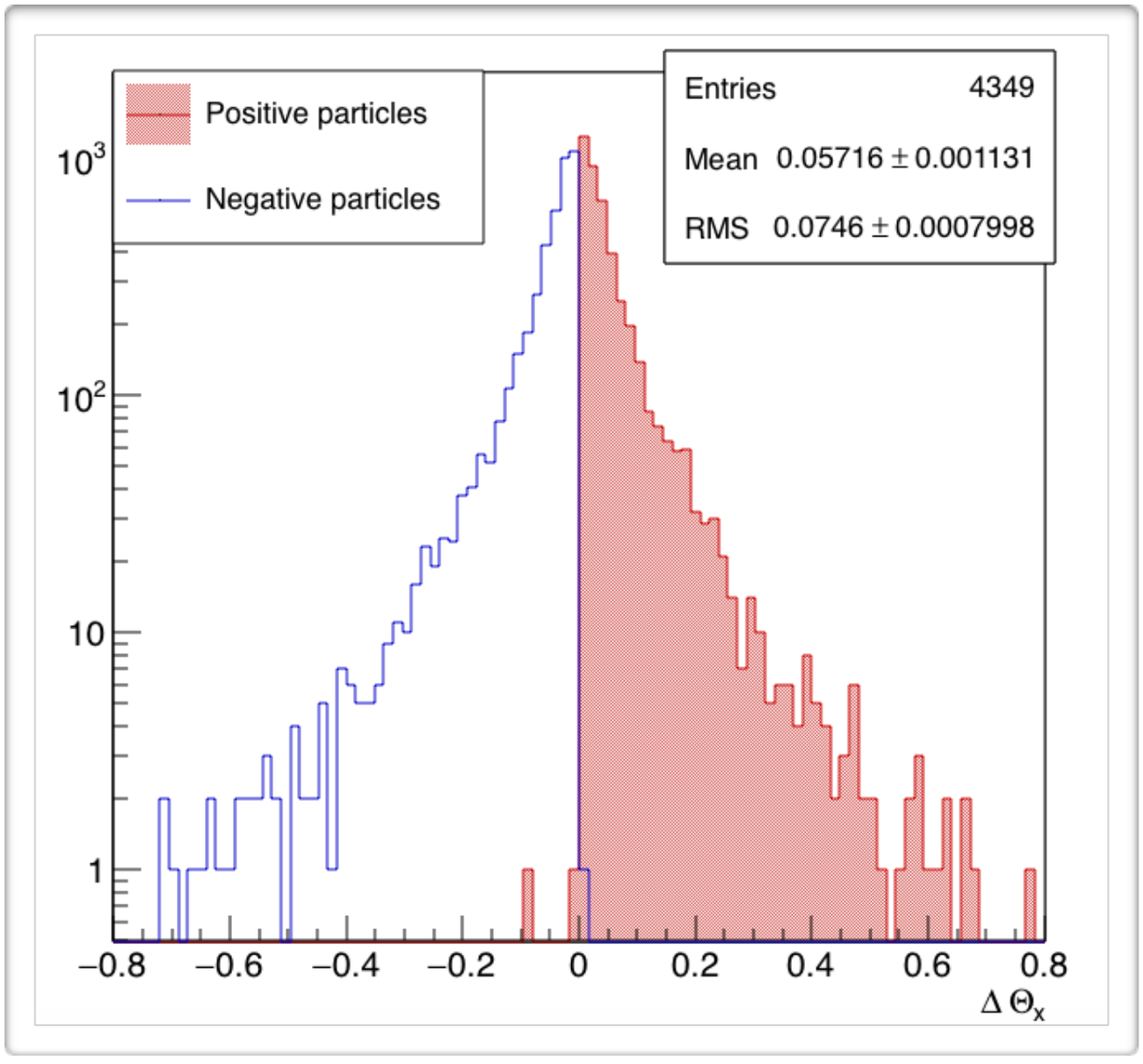
<L> ~ 3.3 mm

- Charmed hadr
  flight length





Charge Measurement



Charge measurement criteria

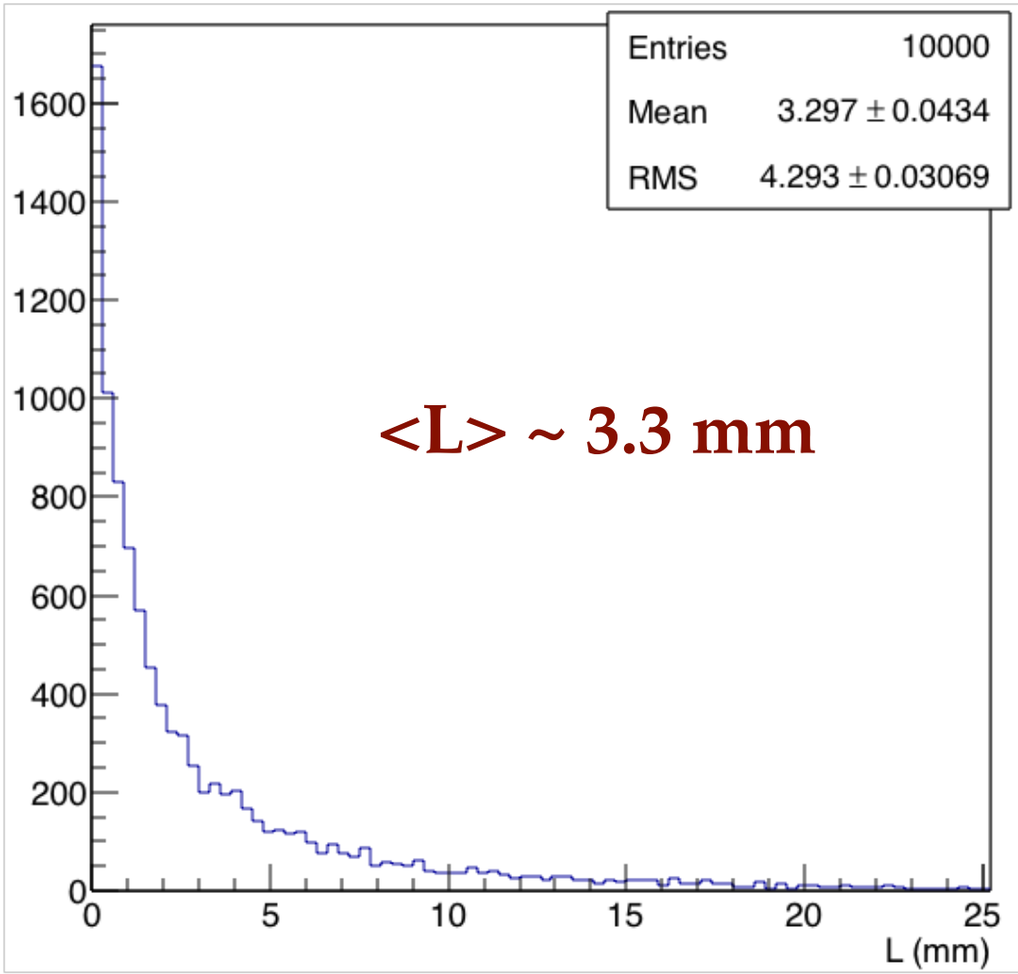
$\Delta\theta_X > 3^*\sigma_{\Delta\theta}$

Charge measurement efficiency 98%
(single track)

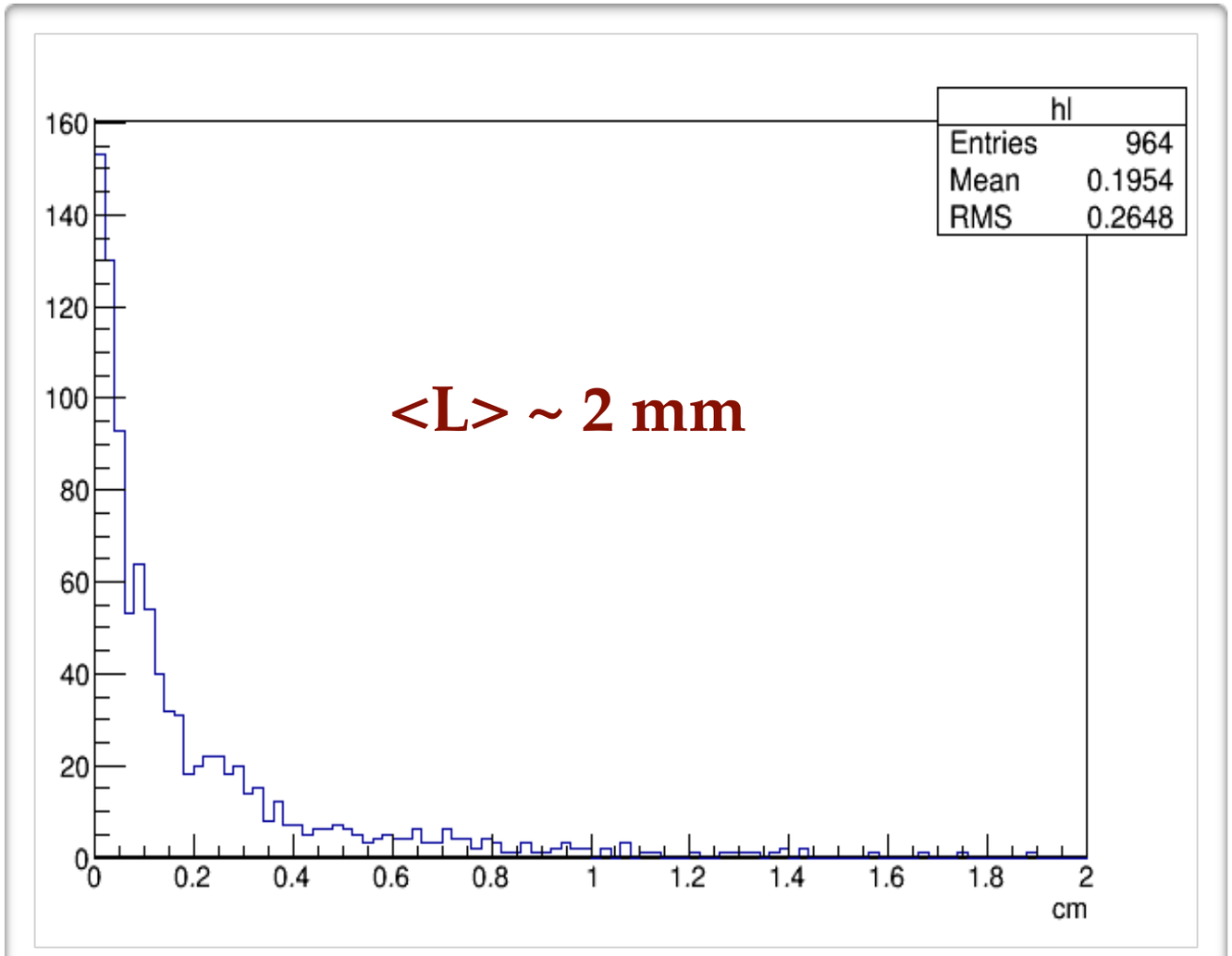
CHARMED HADRON PRODUCTION

Charmed hadron flight length

- PRIMARY PROTONS



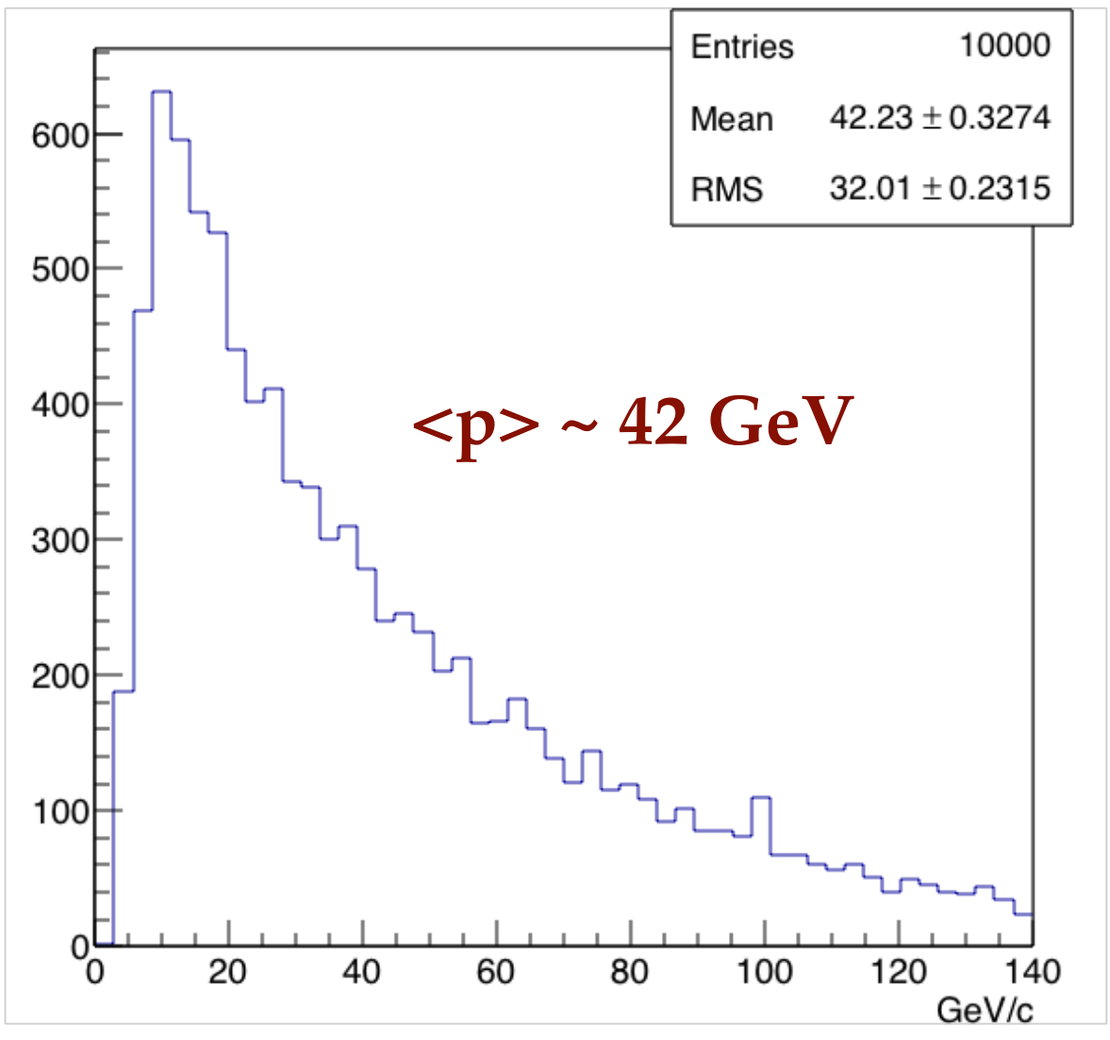
- CASCADE PRODUCTION



Charmed Hadron Production

Charmed hadron momentum

- PRIMARY PROTONS



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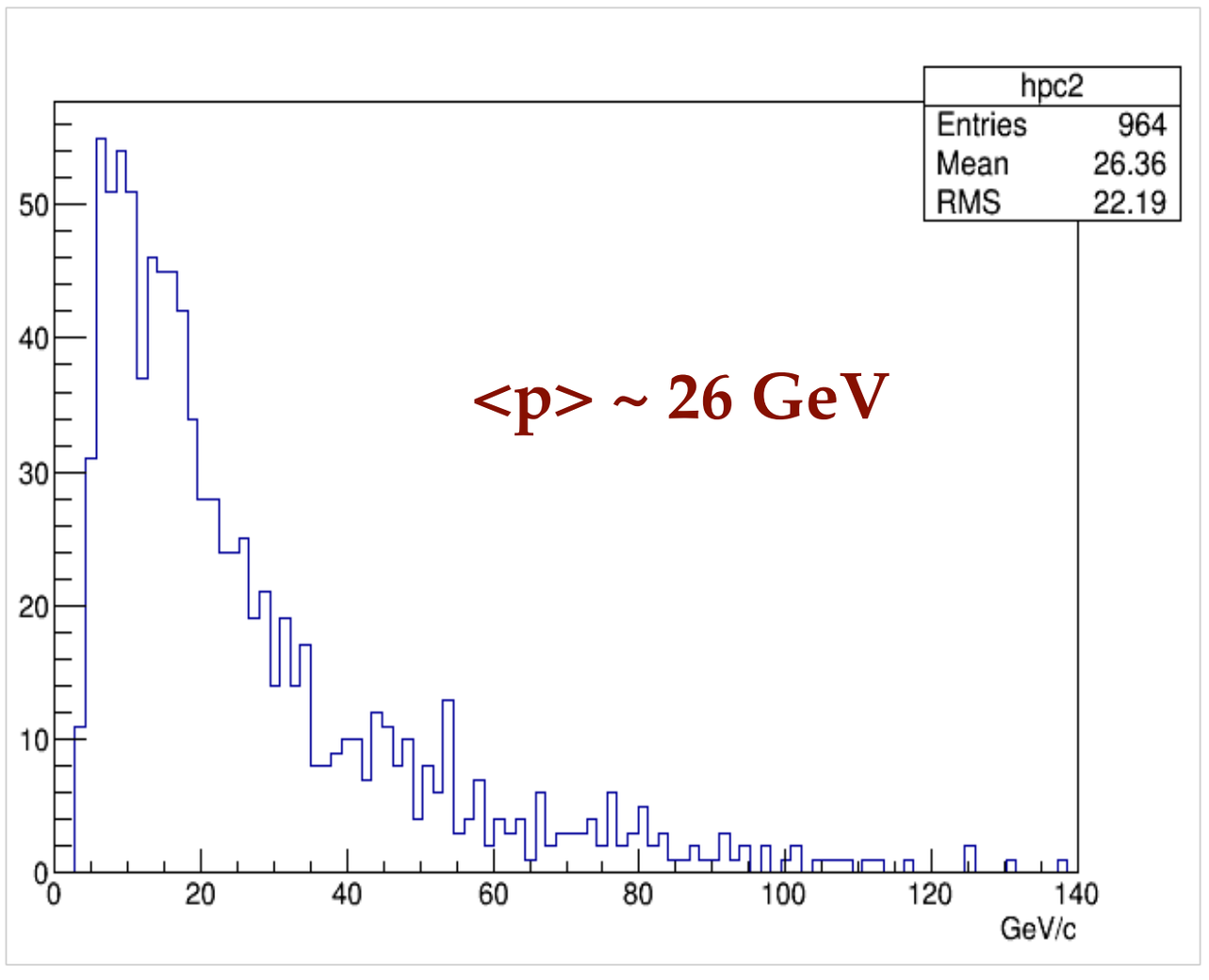
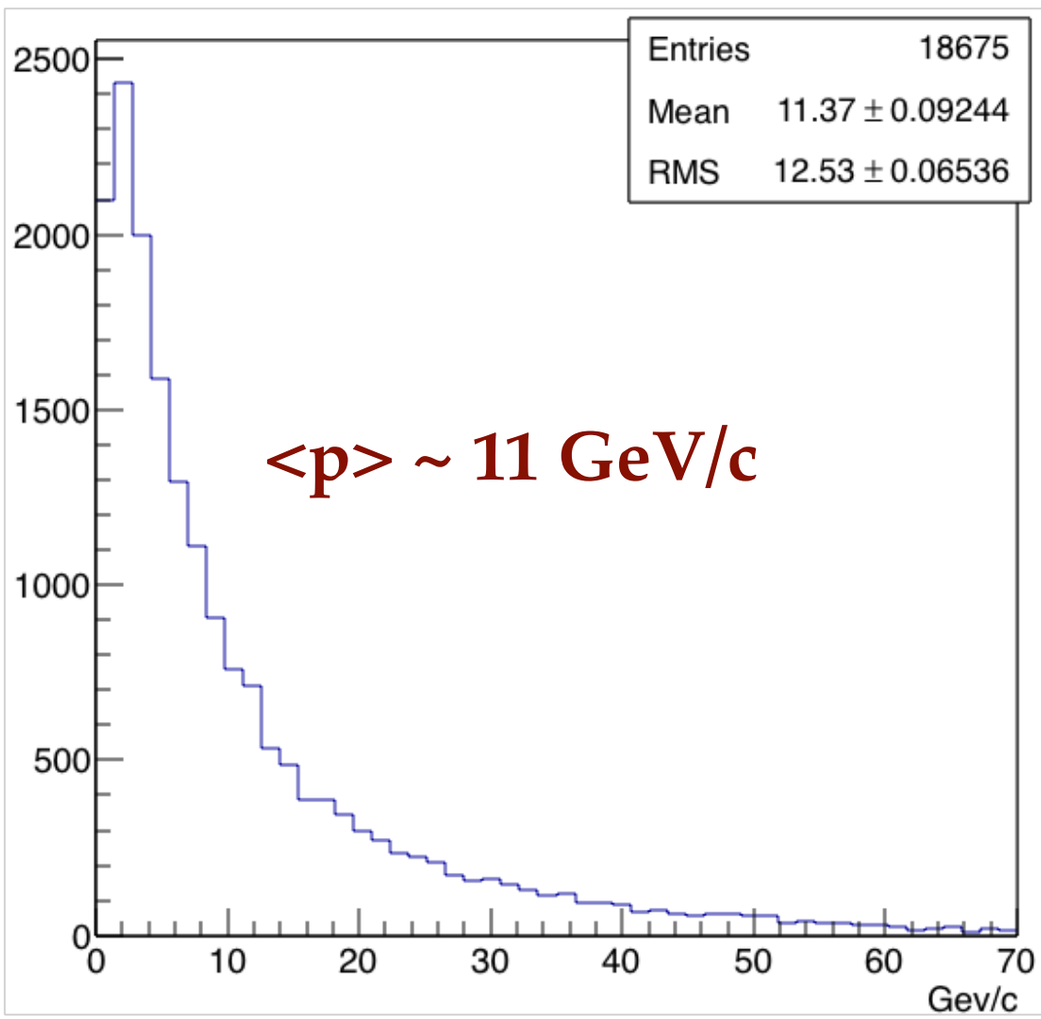


DECAY PRODUCTS

Charm daughters momentum

- PRIMARY PROTONS



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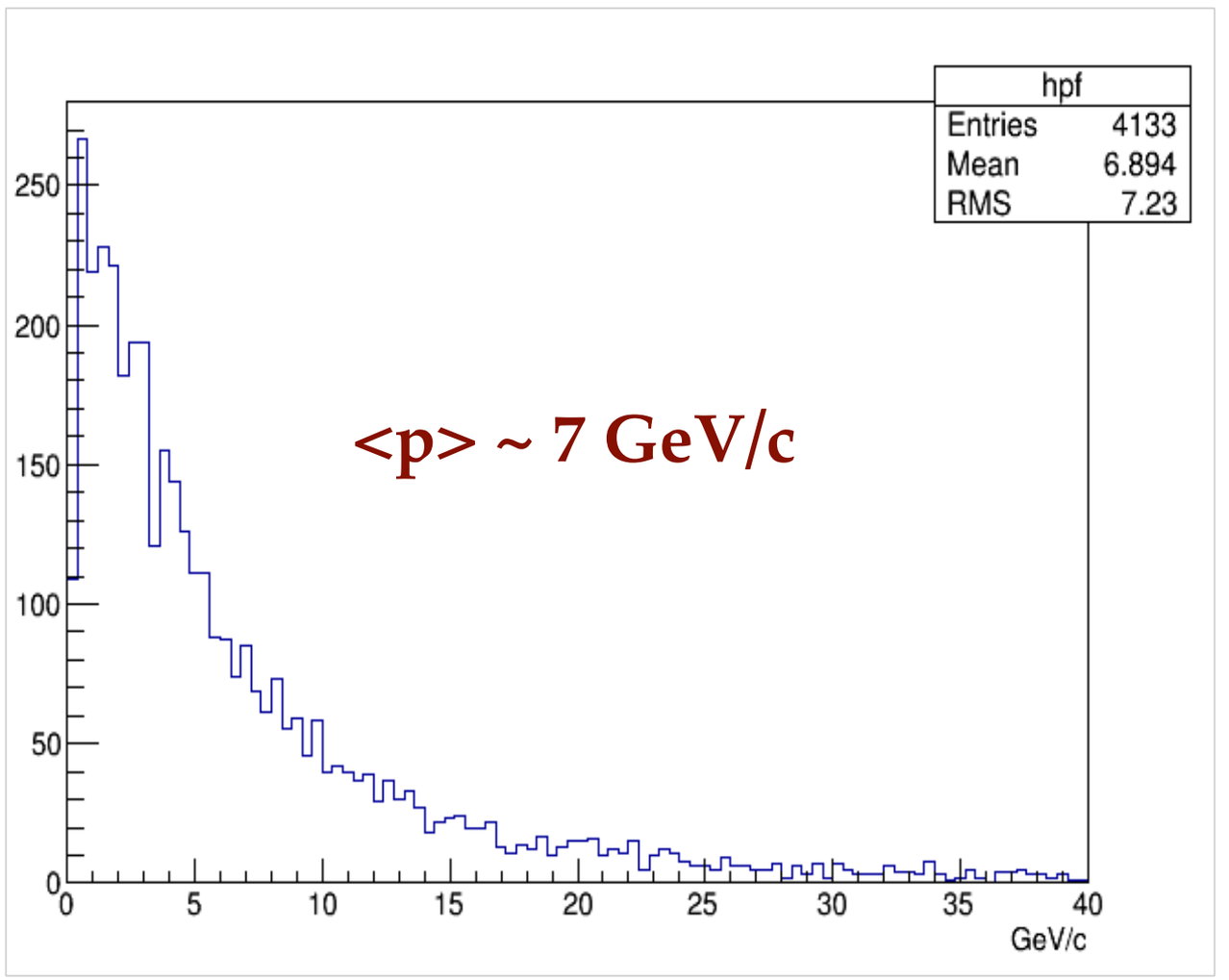
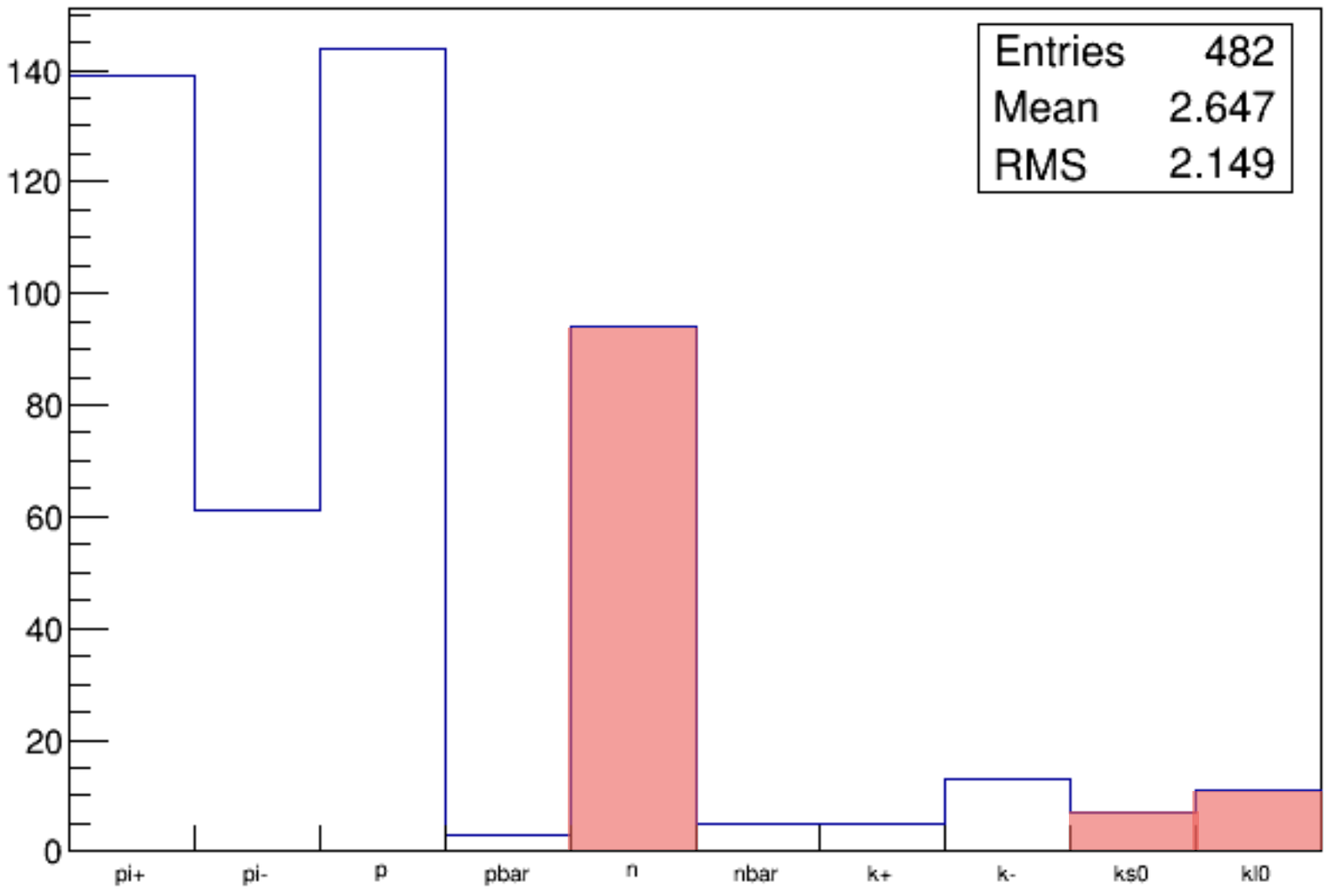


Cascade Production

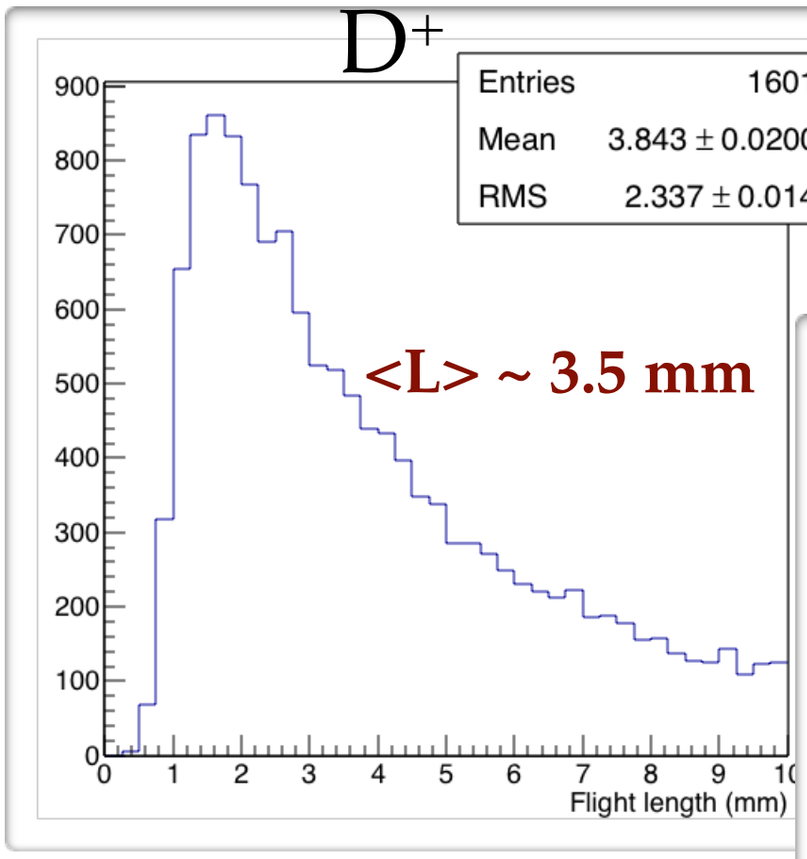
Mother particles of charm in cascade production

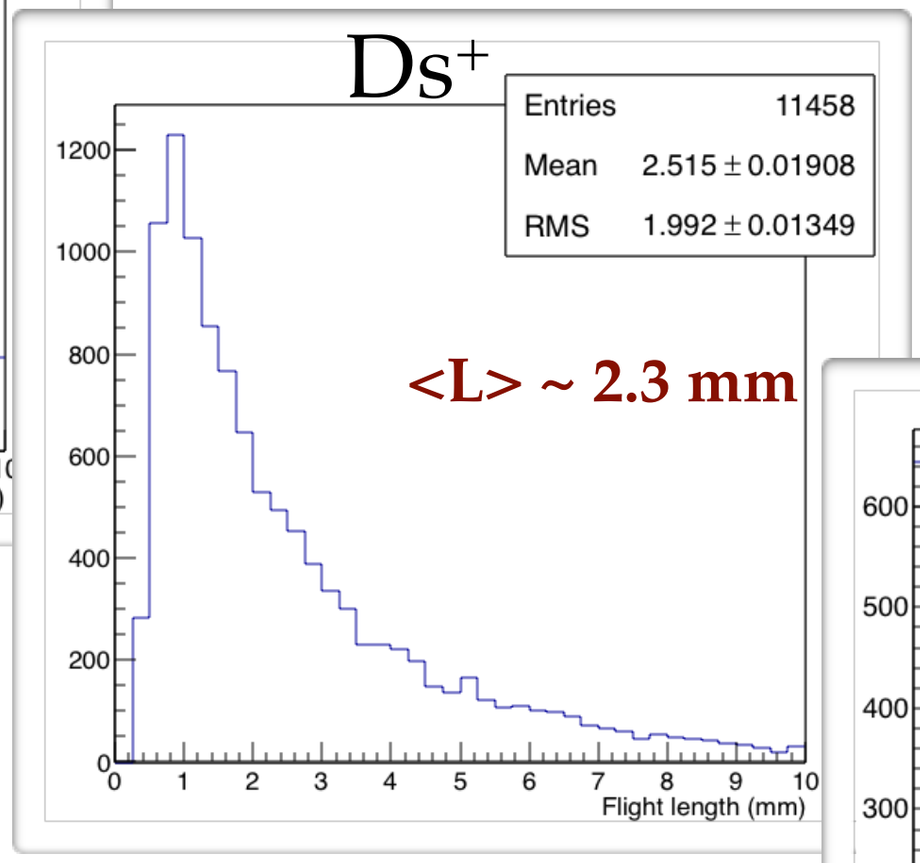


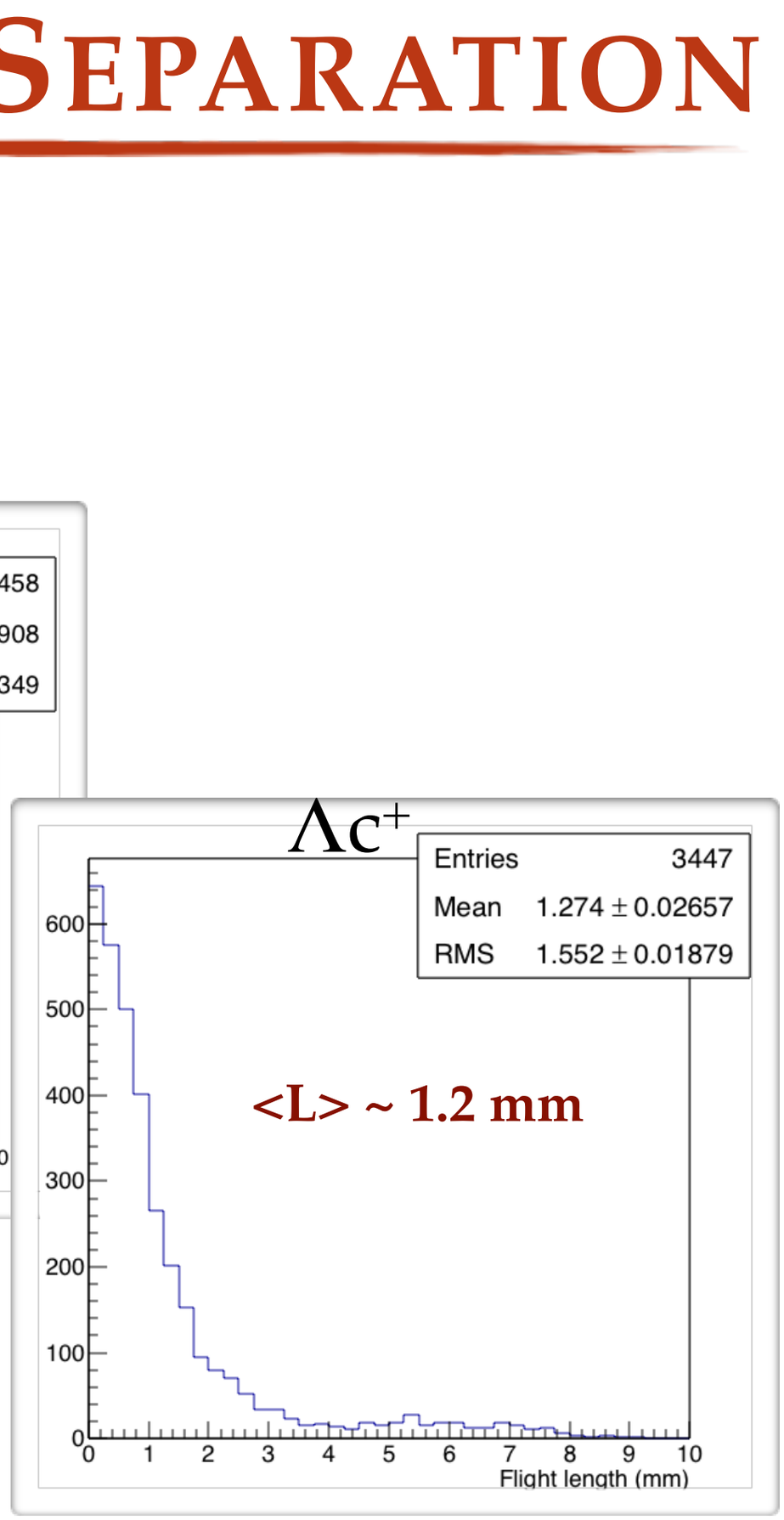
23% neutral particles

77% charged particles

Charmed Hadron Separation

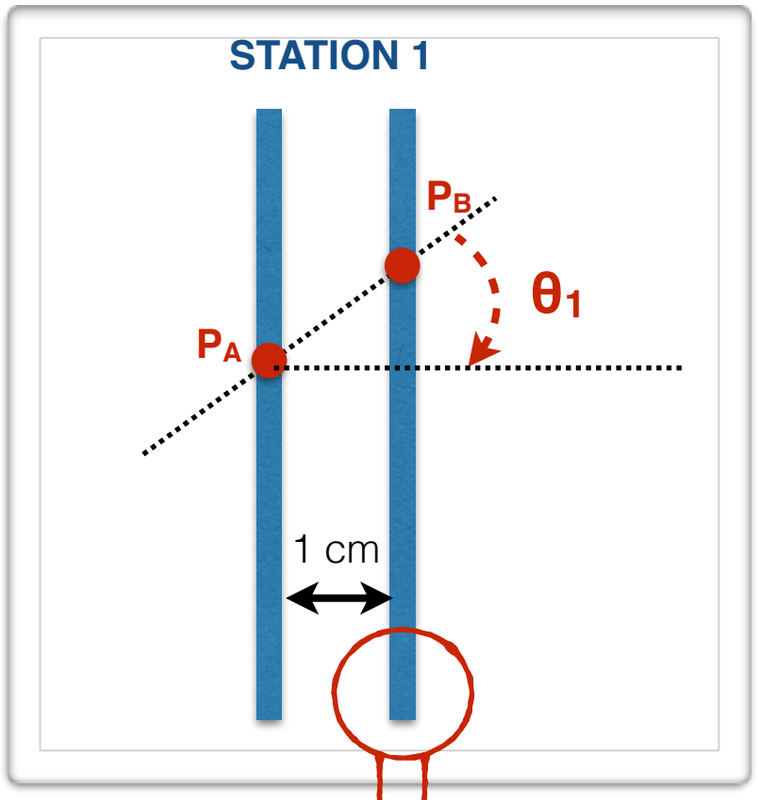






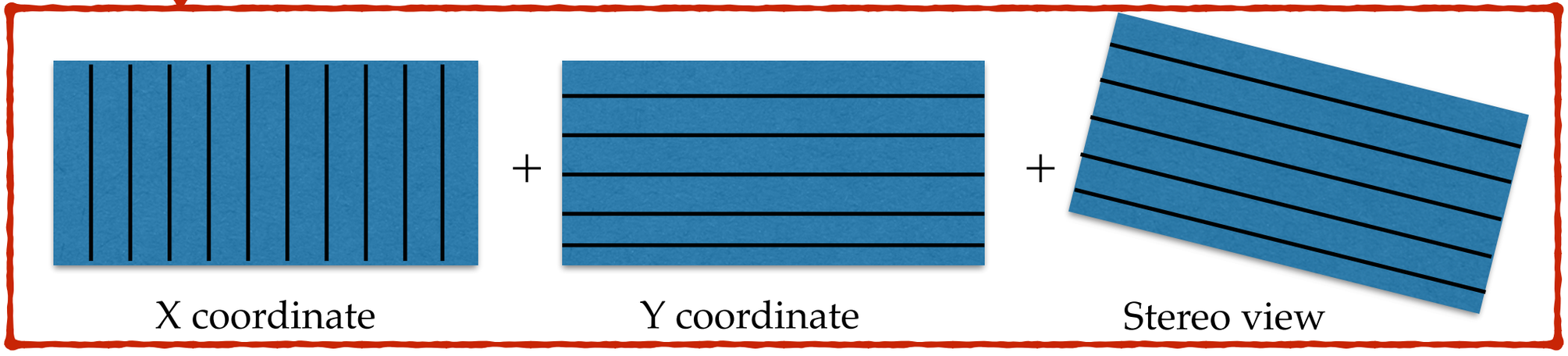
SPECTROMETER: REQUIREMENTS

- Requirement: 10 mrad angular resolution at each station
- Angle measured from the track position in two layers (P_A and P_B)

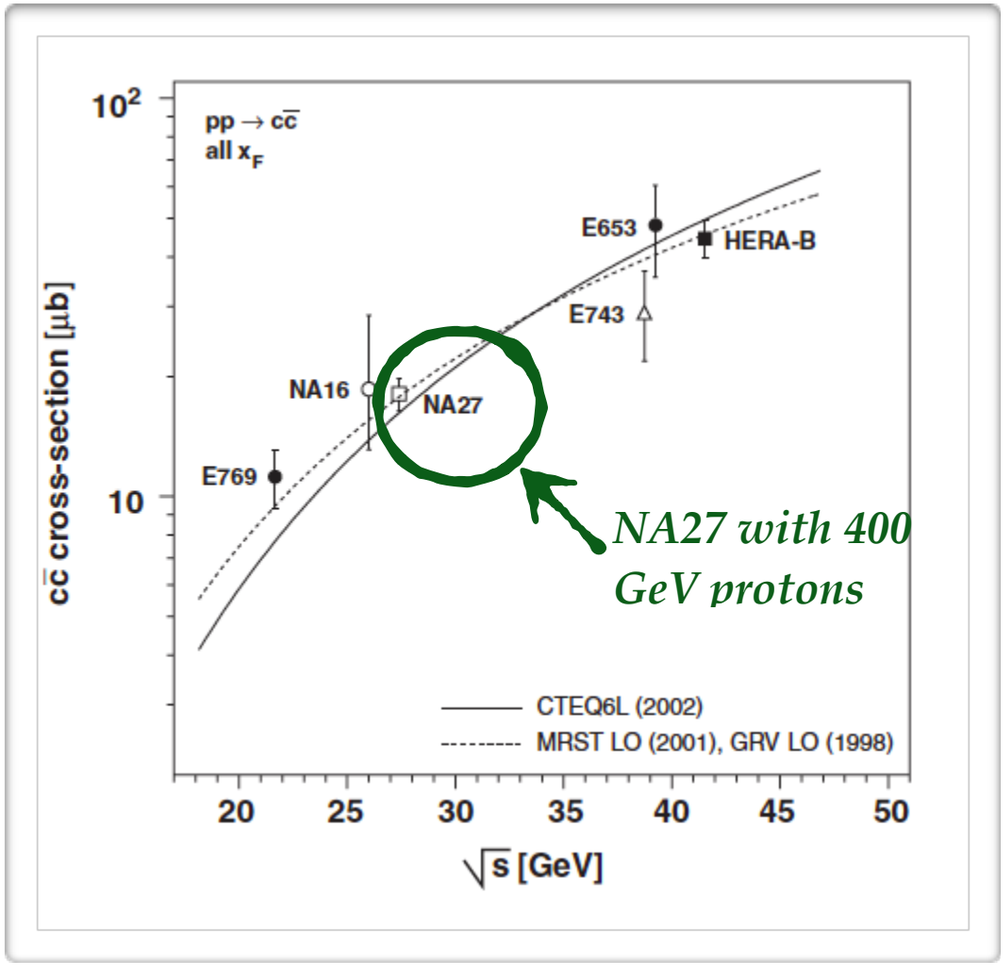


- If the distance between the two layers is 1 cm

Required position resolution at each layer = **100 μm**



Charm Production Cross-Section



- Impact on ν_τ yield

$$N_{\nu_\tau+\bar{\nu}_\tau} = 4N_p \frac{\sigma_{c\bar{c}}}{\sigma_{pN}} f_{D_s} Br(D_s \to \tau) = 2.85 \cdot 10^{-5} N_p$$

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$$Br(D_s \to \tau) = (5.54 \pm 0.24)\%$$

$$\sigma_{c\bar{c}} = 18.1 \pm 1.7 \ \mu\text{barn}$$

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$$f_{D_s} = (7.7 \pm 0.6^{+0.5}_{-0.4})\%$$

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