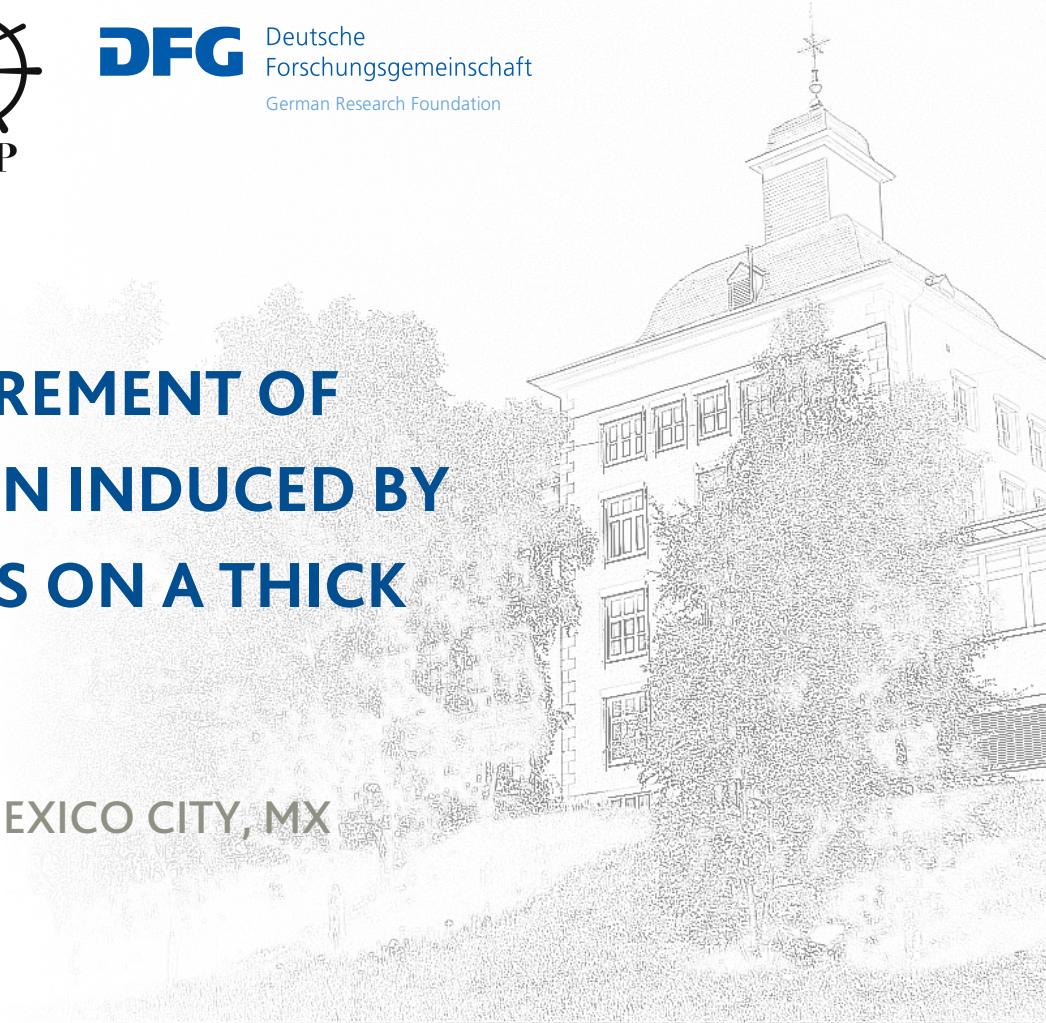


NIKOLAUS OWTSCHARENKO

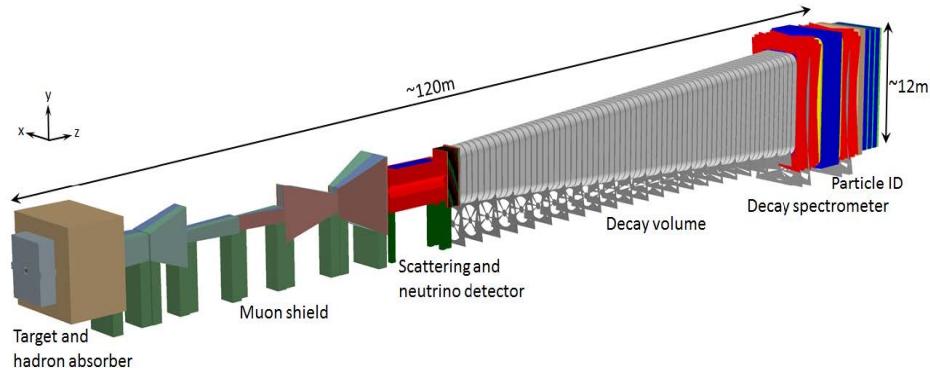
# **TOWARDS A MEASUREMENT OF CHARM PRODUCTION INDUCED BY 400 GEV/C PROTONS ON A THICK TARGET**

CHARM 2020 – 03/06/2021, MEXICO CITY, MX



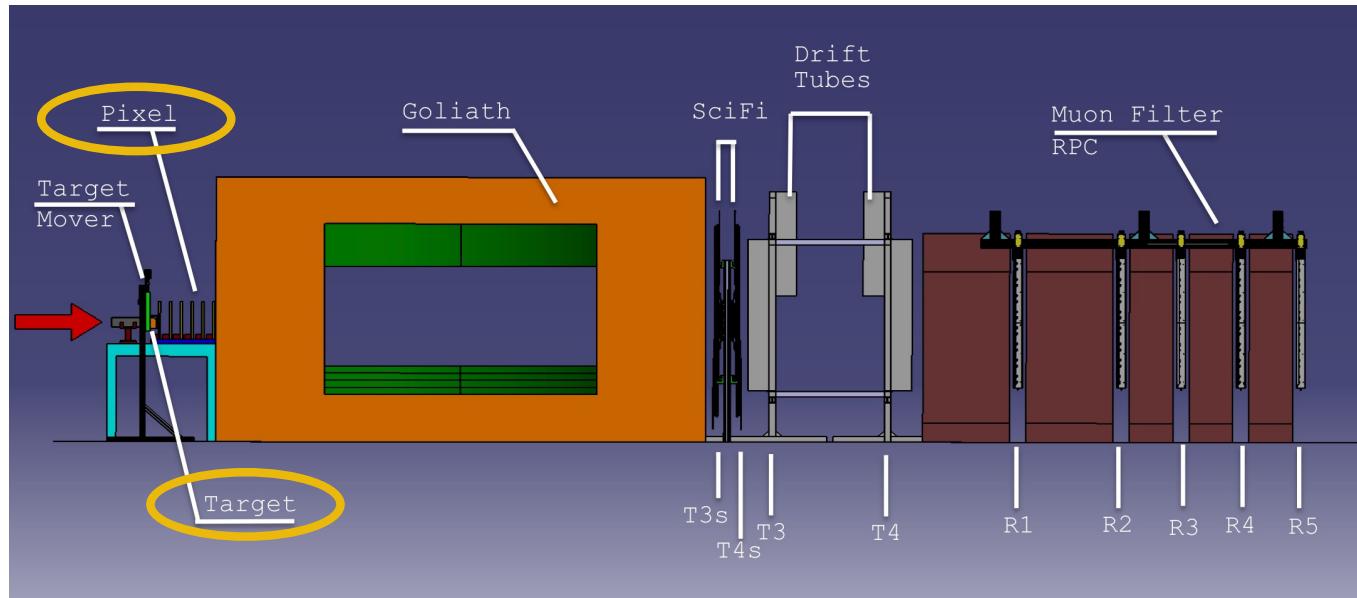
# THE SHIP EXPERIMENT

- Proposed beam dump experiment at BDF at CERN
  - SPS beam at 400 GeV,  $2 \times 10^{20}$  protons on target
- Search new physics in hidden sector
  - Sensitivity depends on number of produced charmed hadrons
  - Secondary charm decays dominate by factor 2
- Need measurement of charm cross section in thick target
  - Including angular and energy spectrum



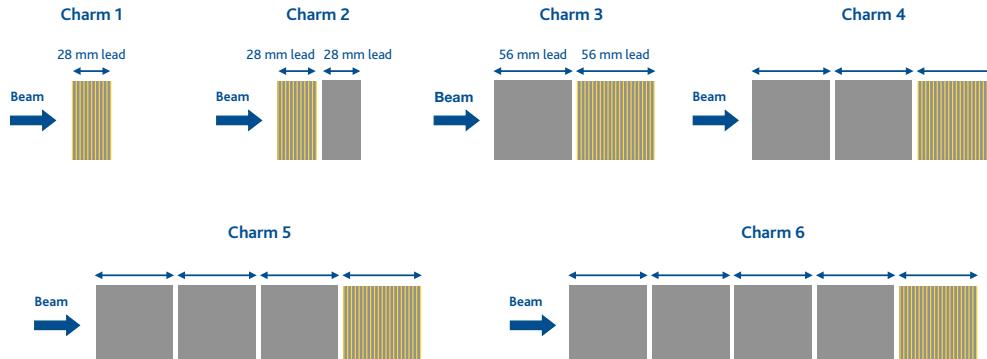
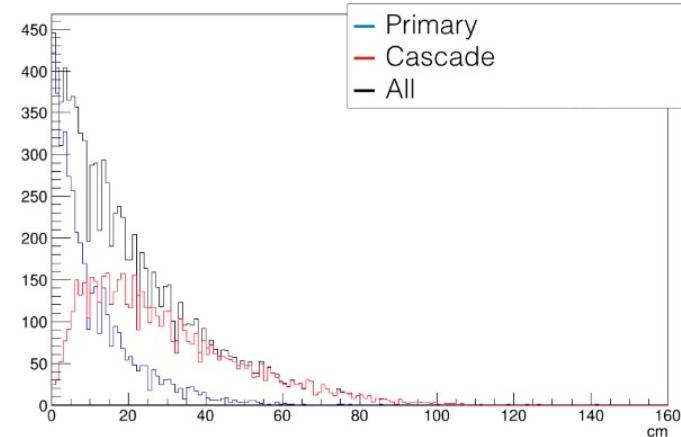
# CHARM CROSS SECTION MEASUREMENT

- 400 GeV protons
- 5 sub systems
- Emulsion with density limit
  - > Moving target
- Pixel detector
  - High timing and spatial resolution
- Test run to integrate detectors and develop reconstruction tools



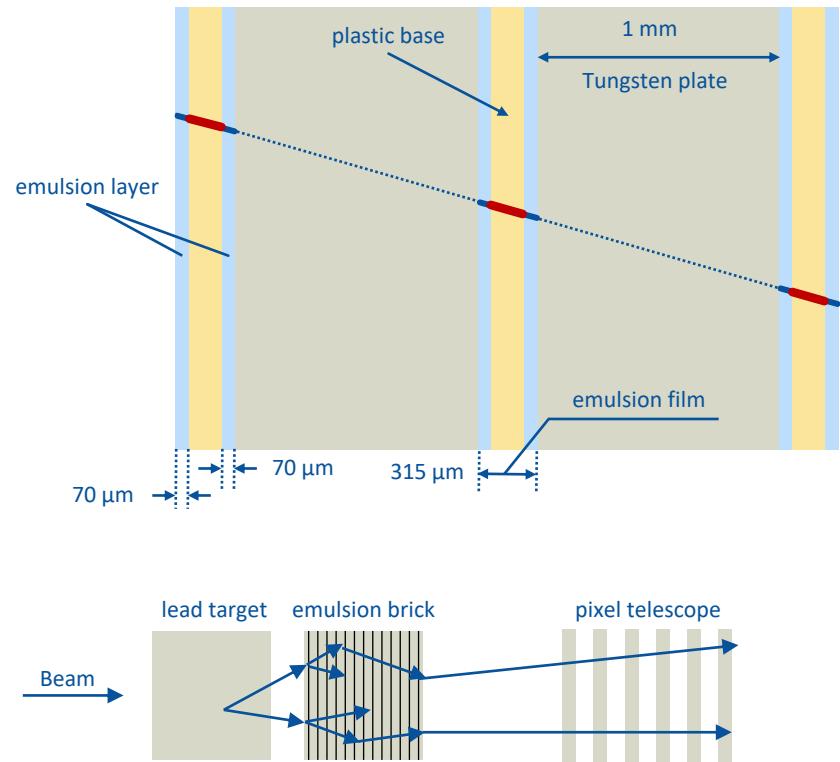
# TARGET REPLICA

- Simulation of charmed hadroproduction for full SHiP target
  - First 2 interaction lengths cover 80% of primary and 52% of cascade production
- Target replica most effective in first interaction length
  - 6 configurations: 0.16 - 1.6 interaction lengths
  - 29 or 57 active layers in last segment



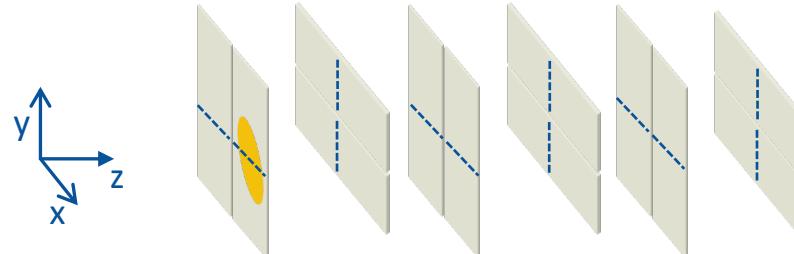
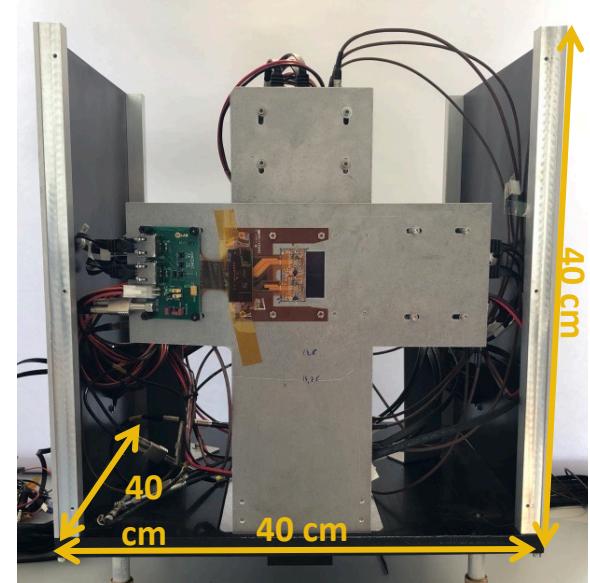
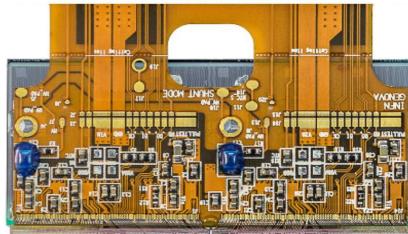
# EMULSION CLOUD CHAMBER - ECC

- Nuclear emulsions similar to OPERA experiment
- Active :  $2 \times 70 \mu\text{m}$ , thickness:  $315 \mu\text{m}$
- Scanned surface:  $11 \times 9 \text{ cm}^2$
- 29 films in one brick, forming emulsion cloud chamber
- Permanent 3D tracks
  - no time information
- Tracks reconstructed by INFN Napoli
  - $3 \mu\text{m}$  resolution



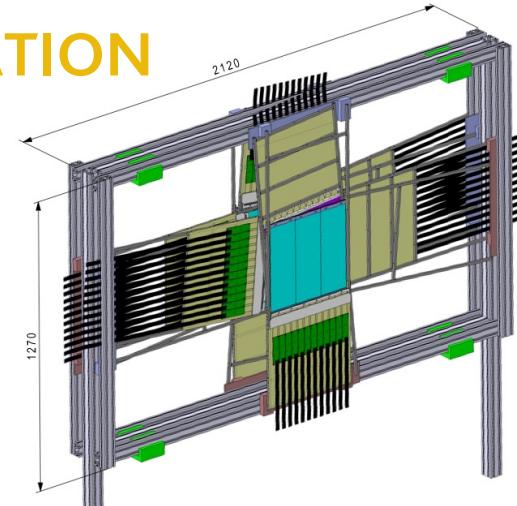
# PIXEL TRACKER

- 12 ATLAS IBL modules,  $250 \times 50 \mu\text{m}^2$  pixel pitch
- 650k channels
  - $33.6 \times 40 \text{ mm}^2$  active area per plane
- 6 planes, pairwise orthogonal to each other
  - x/y resolution is similar
- Tracker length ca. 14 cm
- Distance 1<sup>st</sup> plane <-> emulsion detector 1.8 cm



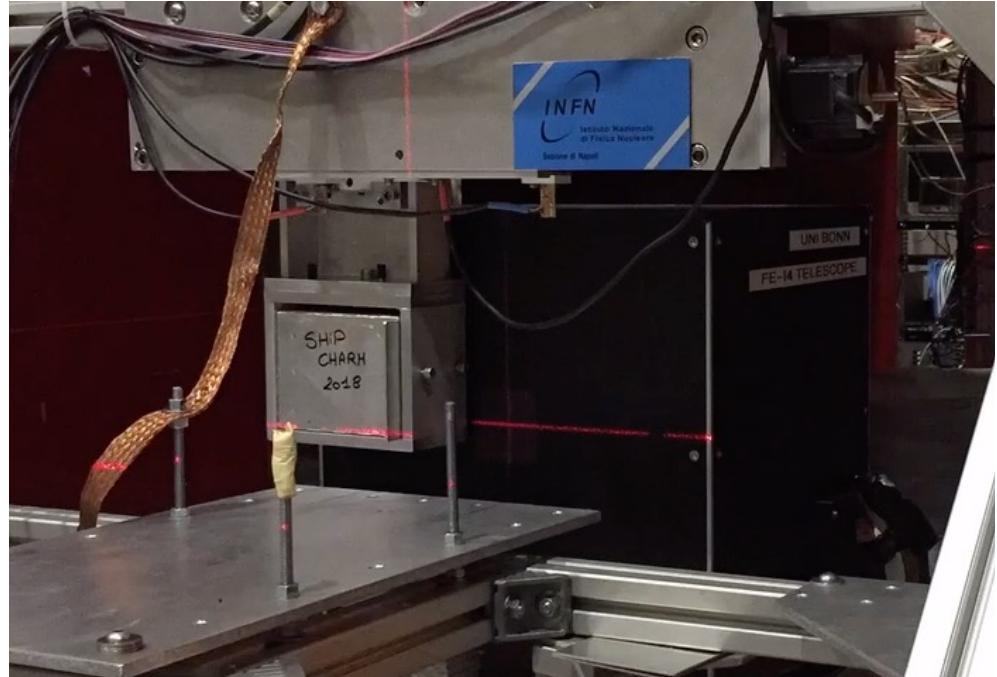
## DOWNSTREAM TRACKING STATION

- Acceptance of 200 mrad, large area needed
- Scintillating fiber in center for high occupancy
  - 8 planes, 4 straight and 4 stereo planes at  $2.5^\circ$
  - $36 \times 40 \text{ cm}^2$  active area per plane
  - $270 \mu\text{m}$  fiber pitch
- Drift Tube detector for outer low occupancy region
  - $160 \times 50 \text{ cm}^2$  modules, 2 layers
  - 36 mm tubes,  $300\mu\text{m}$  resolution



## MOVING EMULSION SEQUENCE

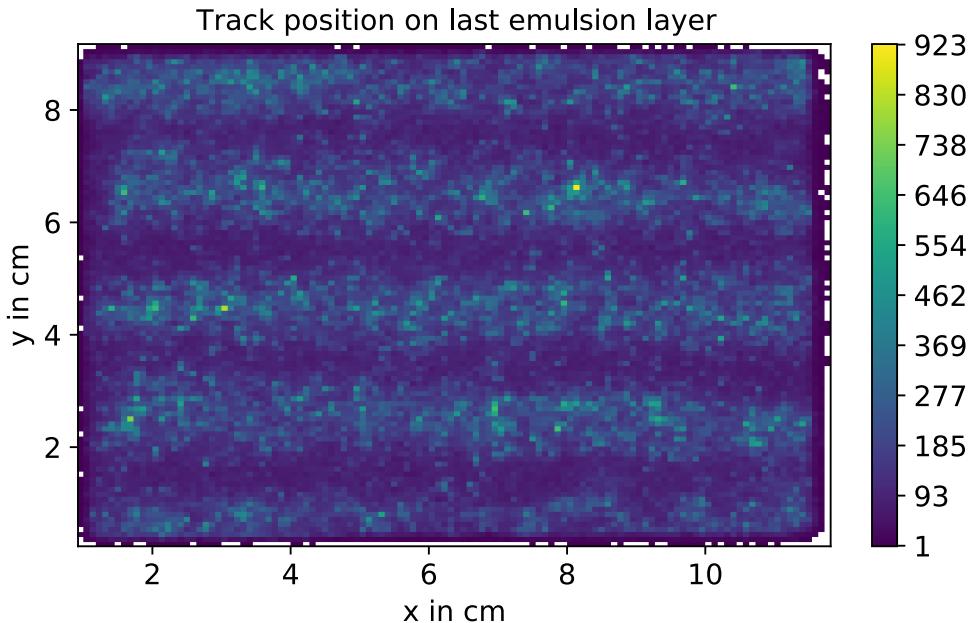
- Limit occupancy to 3000 / mm<sup>2</sup>
- 5 spills on one brick
- 2 cm step size in y in between spills
- 2.6 cm/s in x during spill
- 14 cm/spill in total



Video : A. Di Crescenzo, Università e INFN, Napoli

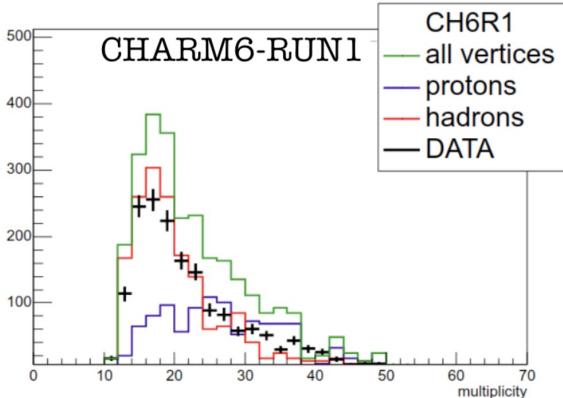
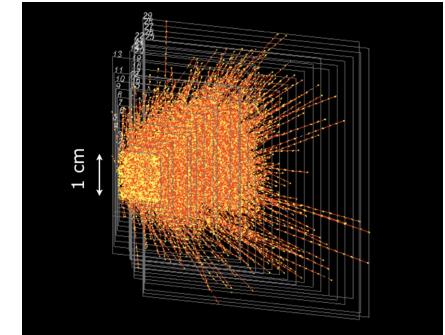
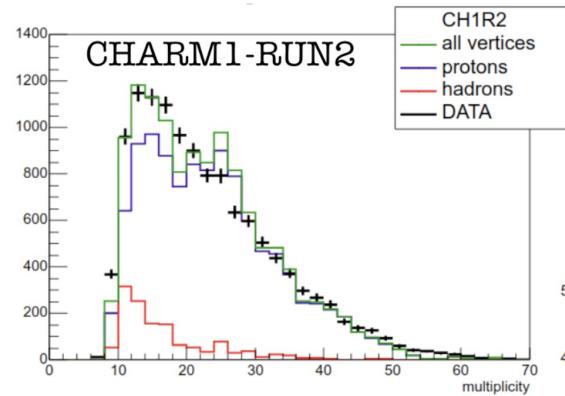
# MOVING EMULSION SEQUENCE

- Limit occupancy to 3000 / mm<sup>2</sup>
- 5 spills on one brick
- 2 cm step size in y in between spills
- 2.6 cm/s in x during spill
  - 14 cm/spill in total
- Match with timestamped tracks from pixel detector



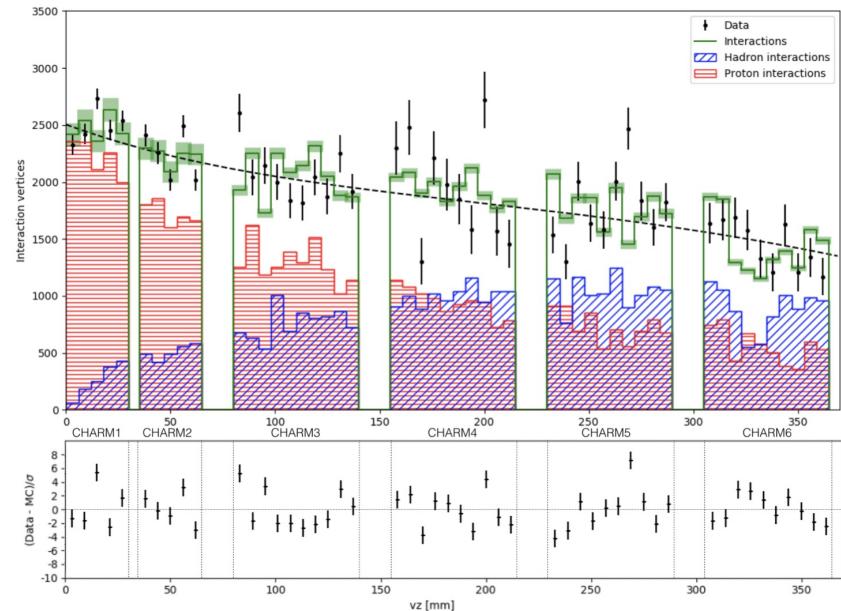
# INTERACTION VERTEX IDENTIFICATION

- High density environment, up to 35000 tracks/cm<sup>2</sup>
- Employ BDT based on
  - Vertex probability
  - Angular distance within vertex
  - Impact parameter
  - Fill factor of tracks
- Fraction for secondary interaction from 11% to 59% for high material budget



# PROTON INTERACTION LENGTH

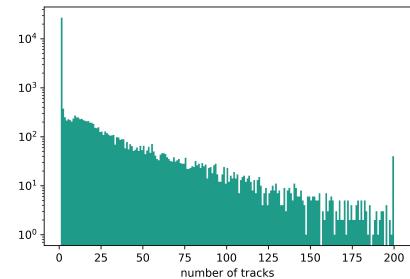
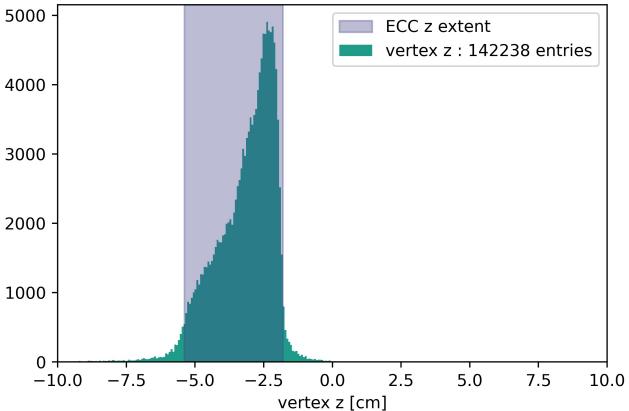
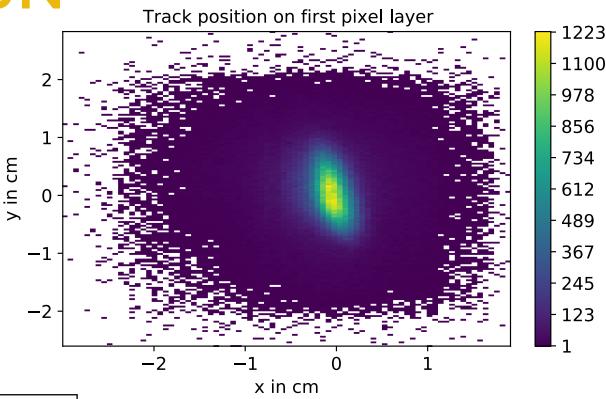
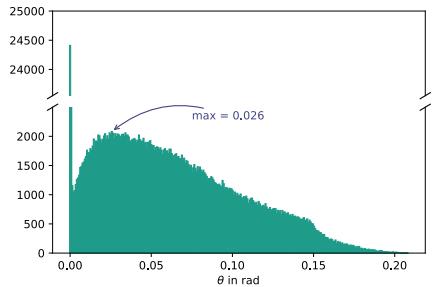
- Prove capability of reconstruction and BDT classification
- Data from 6 different target configurations
  - Primaries : exponential
  - Secondaries: 2nd order polynomial
- 58% primary and 42% secondary interaction
- Proton interaction length  $\lambda = (182^{+19}_{-16}) \text{ mm}$



Ahdida et al., CERN-SHiP-NOTE-2020-002

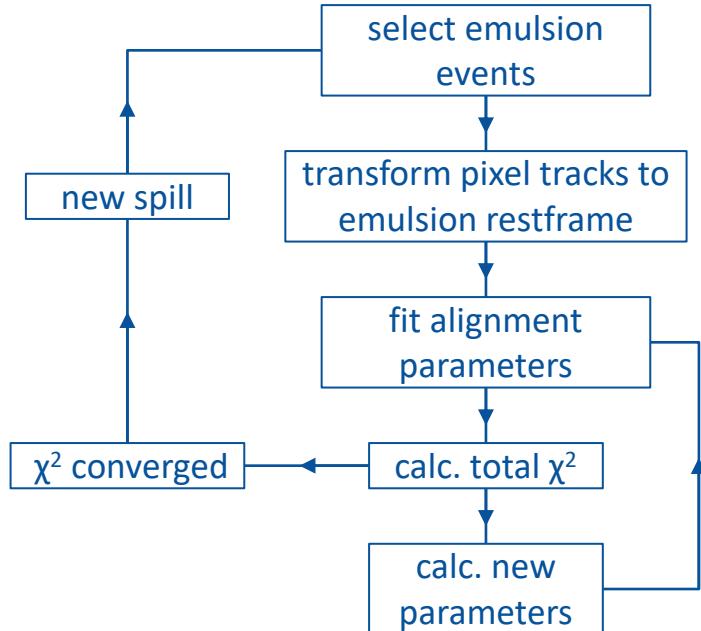
# PIXEL TRACKS – EXAMPLE RUN

- Different rest frame
- Reconstruction limit at 200 mrad
- 24% of protons interact
- Avg. 33 tracks per event
- 2-track vertices reconstructed in target



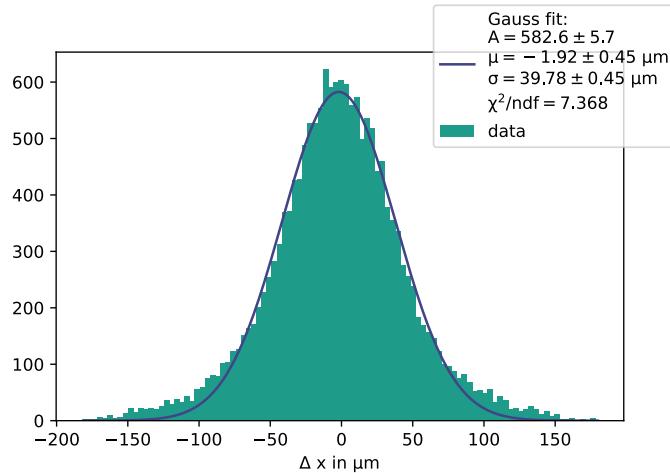
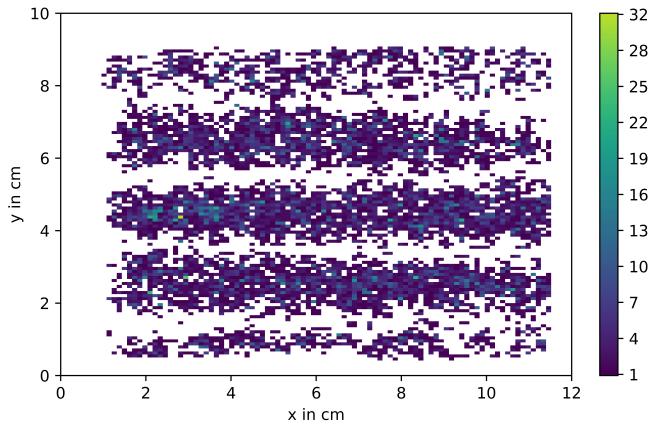
# MATCHING PROCEDURE

- Selection:
  - Min. 6 tracks per emulsion vertex
  - Tracks must leave emulsion detector
  - Track must not leave spectrometer
    - $\theta < 200$  mrad
- Newton-Raphson alignment independent per spill
  - Simultaneous iterative optimization of 8 parameters



# MATCHED TRACKS

- 72% of selected emulsion tracks matched
- Distinct spill structure found in matched track distribution
- Uniform residual distribution
- $\text{res} = x_{j,pix} - x_{j,emu}$  for  $j = (x, y, \theta_{xz}, \theta_{yz})$



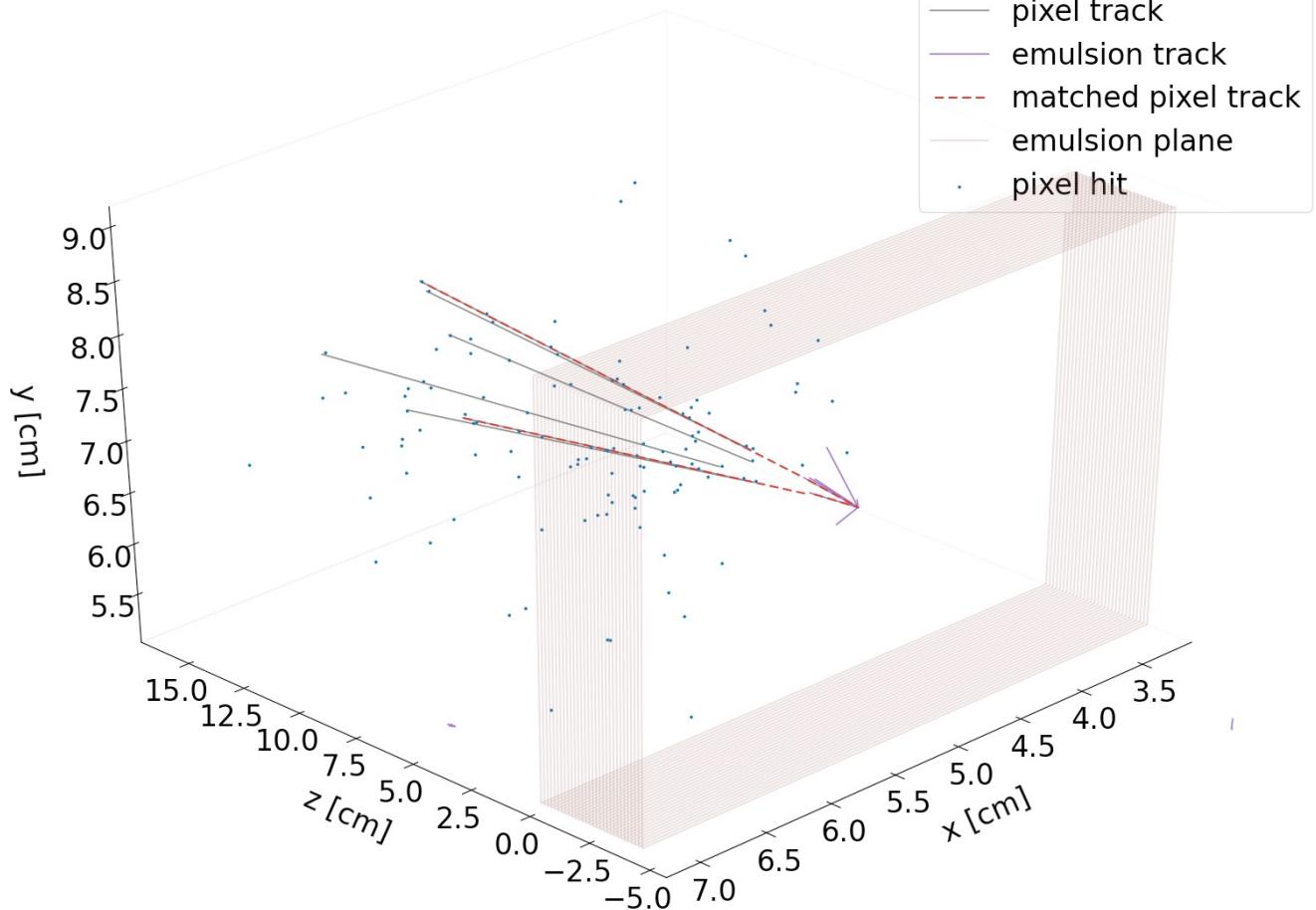

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**matching resolutions**

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$\sigma_x$	$40 \mu\text{m}$
$\sigma_y$	$72 \mu\text{m}$
$\sigma_{\theta_{xz}}$	$3.5 \text{ mrad}$
$\sigma_{\theta_{yz}}$	$3 \text{ mrad}$

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## SUMMARY

- Successful operation of pixel tracker and emulsion system
- Vertex reconstruction in the emulsion target
- Successful matching of pixel and emulsion tracks
  - Resolutions of 40 µm, 72 µm, 3.5 mrad and 3 mrad in x, y,  $\theta_{xz}$  and  $\theta_{yz}$
  - Estimate for mean free path length of protons in target
  - Perform measurement in long run after LS2

Acknowledgements:

Emulsion data: **Antonio Iuliano, Antonia Di Crescenzo**, INFN Napoli; Pixel modules and R/O software: **Fabian Hügging, David-Leon Pohl**, SiLab, Universität Bonn; Alignment and matching: **Christopher Betancourt**, Universität Zürich; Pixel tracking: **Vadim Kostyukhin**, University of Sheffield; Project: **Markus Cristinziani**, CPPS, Universität Siegen

This research project is partially funded by the Deutsche Forschungsgemeinschaft (DFG – German Research Foundation) under Grant Agreement no. 415102982

Thank you

Nikolaus Owtscharenko

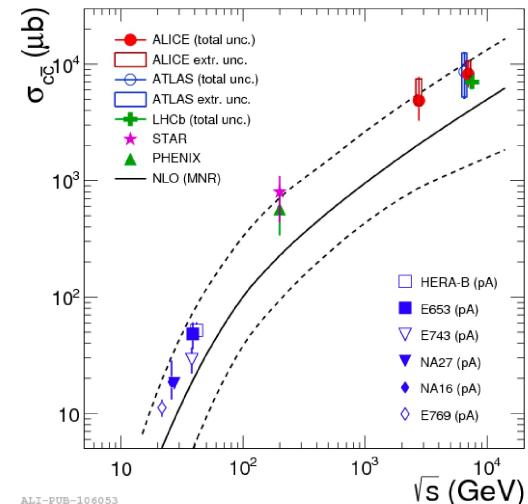
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Teilchenphysik

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# CHARM CROSS SECTION

- Experimental cross section from NA27, closest to SHiP configuration
- Expect large NLO contribution
- No data on angular and energy spectra
- Inclusive cc does not account for cascade production

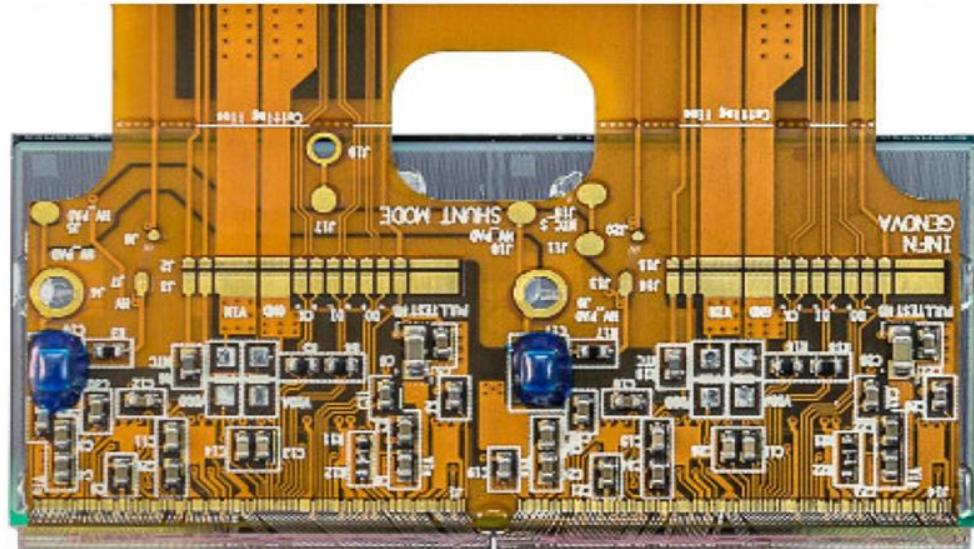
	exp NA27	th NLO (mc = 1.3)	th NLO (mc = 1.5)	th NLO (mc = 1.8)
$\sigma$ [ $\mu\text{b}$ ]	$18.1 \pm 1.7$	$24.3^{+80.1}_{-12.4}$	$10.1^{+22.6}_{-4.8}$	$3.12^{+4.86}_{-1.36}$



ALI-PUB-106053

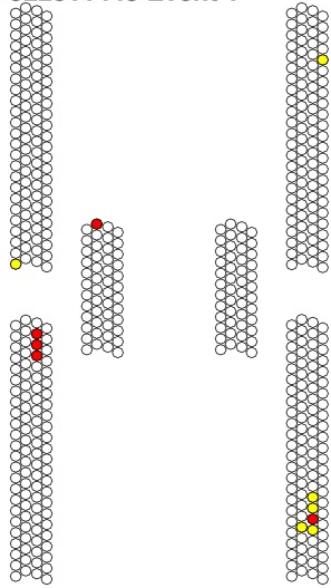
# ATLAS PIXEL DOUBLE CHIP MODULES

- FE-I4B read out chip
  - $250 \times 50 \mu\text{m}$  pixels
  - $80 \times 336$  pixel/FE
- One sensor bump bonded to 2 FE
- Timing resolution of 25 ns
- Flex on top for connectivity
  - Power, commands, data out, sensor HV
- $500 \mu\text{m}$  material budget

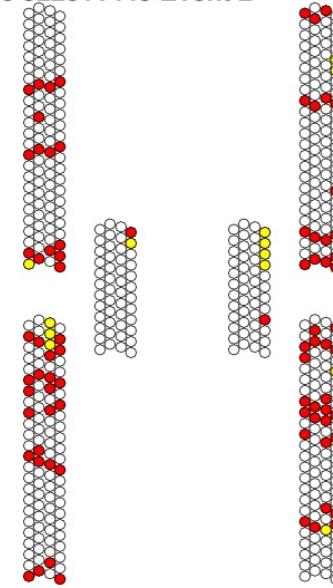


# DRIFT TUBE OCCUPANCY

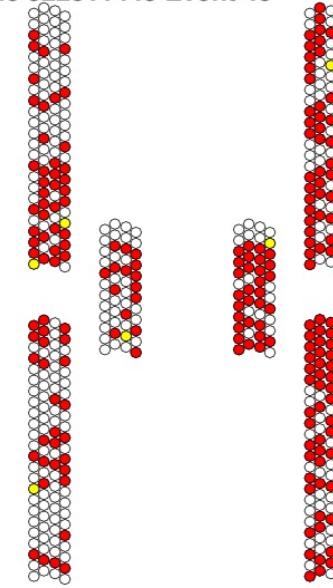
Cycle 522311445 Event 1



Cycle 522311445 Event 2



Cycle 522311445 Event 43



# NEWTON-RAPHSON METHOD

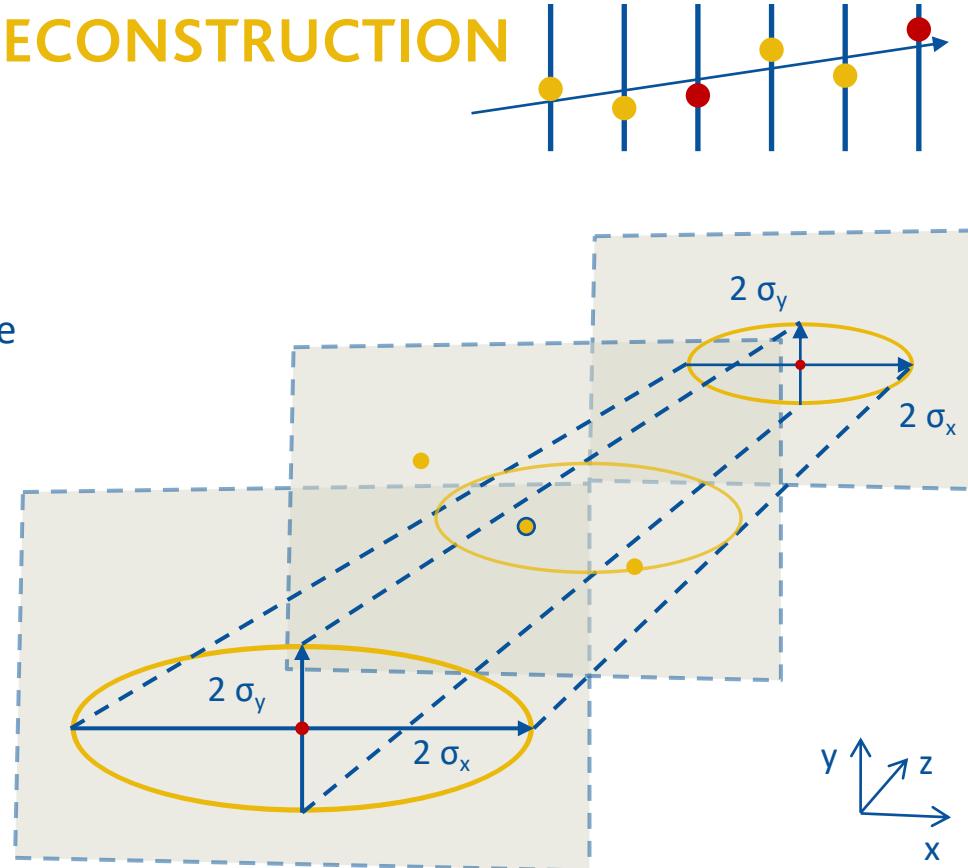
- Alignment parameters:  $\vec{\alpha} = (x_0, y_0, z_0, \theta_{xz}, \theta_{yz}, \theta_{xy}, v_x, v_y)$
- $\chi^2_{track} = \vec{r}^T \mathbf{V}^{-1} \vec{r}$ 
  - Residual vector :  $\vec{r} = \vec{x}^{pix} - \vec{x}^{emu} = (\Delta x, \Delta y, \Delta \theta_{xz}, \Delta \theta_{yz})$
  - Covariance matrix :  $\mathbf{V} = \mathbf{V}^{pix} + \mathbf{V}^{emu}$
- Minimization criterion:  $0 \equiv \frac{d\chi^2}{d\alpha} = 2 \sum_j \frac{d\vec{r}^T}{d\alpha} \mathbf{V}^{-1} \vec{r}$
- $\alpha_1 = \alpha_0 - \left( \frac{d^2\chi^2}{d\alpha^2} \right)^{-1} \Big|_{\alpha_0} \cdot \left( \frac{d\chi^2}{d\alpha} \right) \Big|_{\alpha_0}$

# PIXEL TRACK RECONSTRUCTION

- 2 planes for track seed

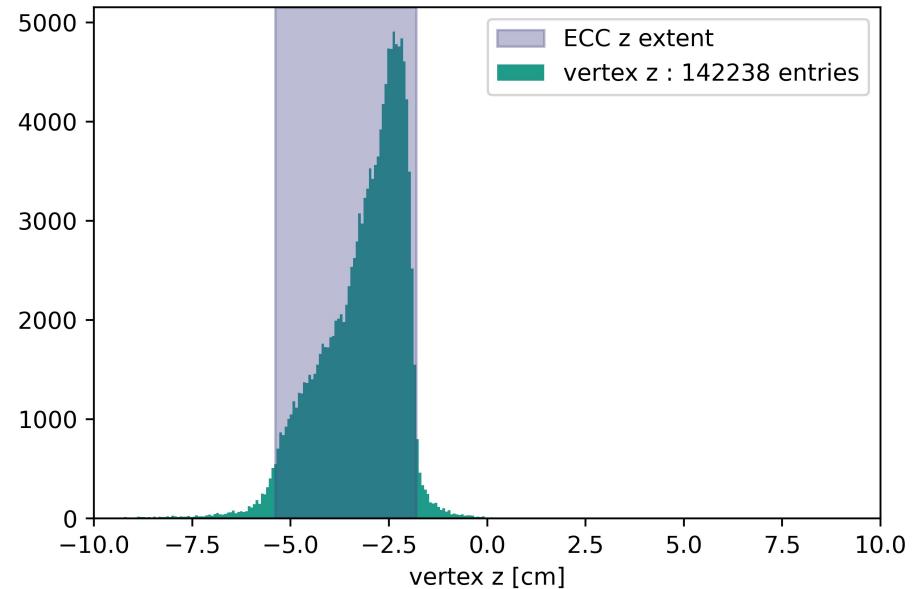
For each hit pair in seed planes:

- Build volume of  $2\sigma$  around hit in last seed plane
  - Project cylinder to first seed plane
  - Take hits closest to track projection on all other planes
- Fit track, cut on fit quality  $\chi^2/\text{ndf} < 5$



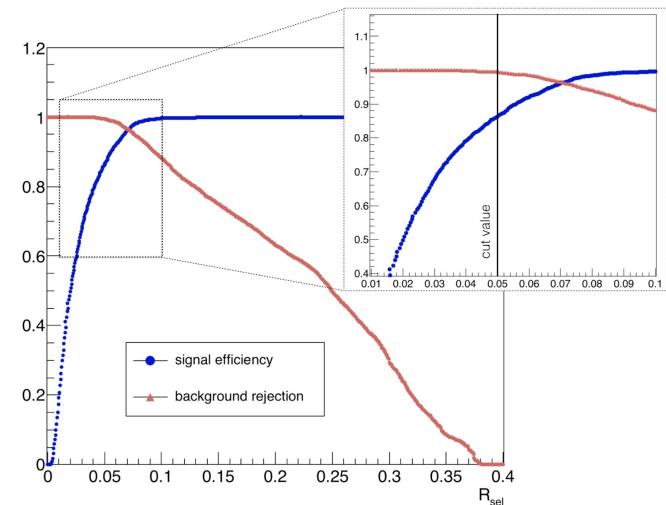
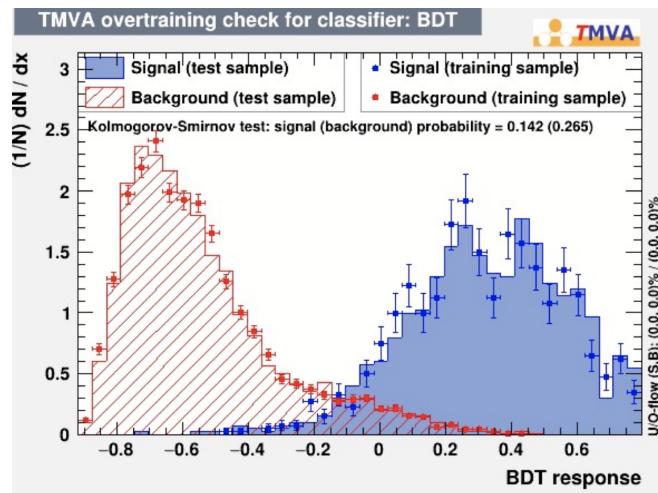
## PIXEL 2-TRACK VERTICES

- Max euclidian distance 50  $\mu\text{m}$
- Track seeds in plane 5 and 11
- Allow hit sharing on plane 1
- Vertices clearly in target
  - No vertex possible on seed planes



# VERTEX IDENTIFICATION - BDT

- Signal : interaction vertex
- Background : random association of low-momentum tracks / EM showers



# BDT VARIABLES

- Fill factor (per track):  $\frac{\# \text{ of tracklets in track}}{\# \text{ of planes downstream}}$
- Mean and maximum Impact parameter
- Vertex prob. from vertex fit
- Aperture: angular distance between tracks in vertex

