DE LA RECHERCHE À L'INDUSTRIE

Aging effects in the COMPASS hybrid Micromegas+GEM pixelized detectors

Damien Neyret

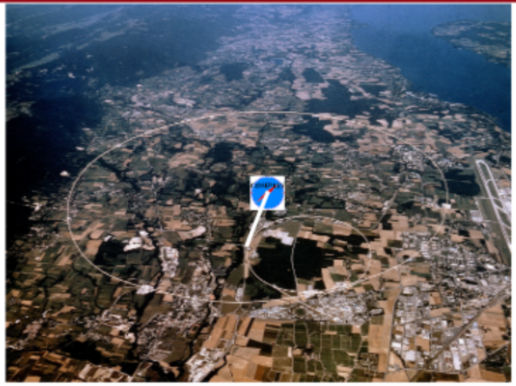
3rd International Conference on Detector Stability and Aging Phenomena in Gaseous Detectors
6-10/11/2023

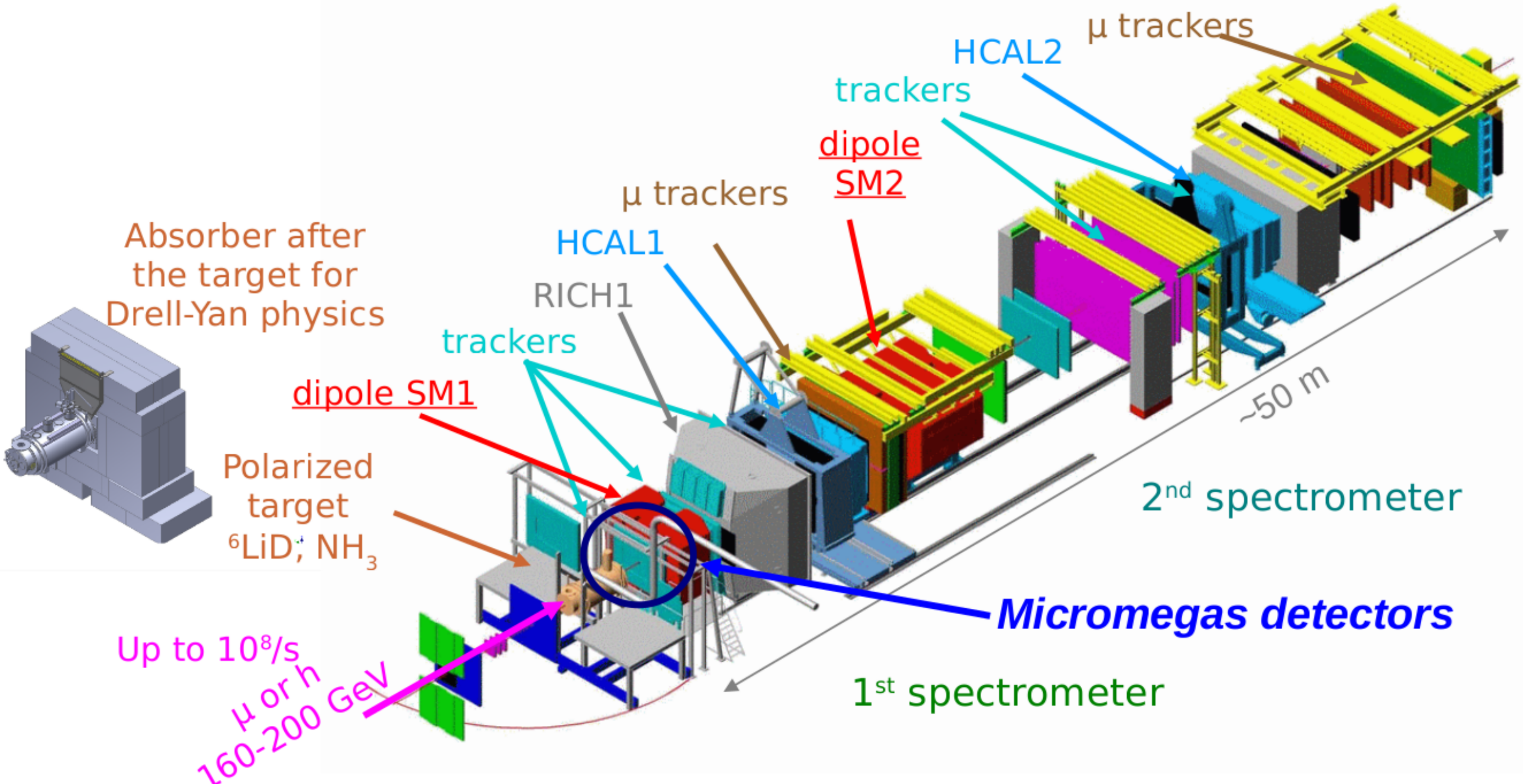
COMPASS

The COMPASS experiment
The hybrid Micromegas
Beam conditions 2015-2022
Detector performances
Conclusions

www.cea.fr

- **Fixed target experiment for hadron structure studies**
  - Muon and hadron beams up to 200 GeV
  - 2 spectrometers
  - Taking data 2002-2022
  - High statistic experiment (> 30 kHz trigger rate)
  - High intensities in 2015-2018 (μ and π)

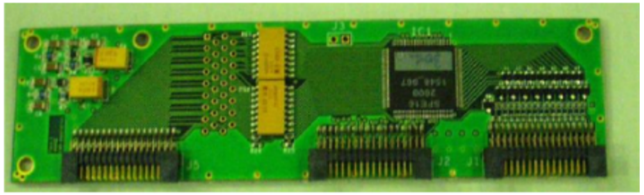


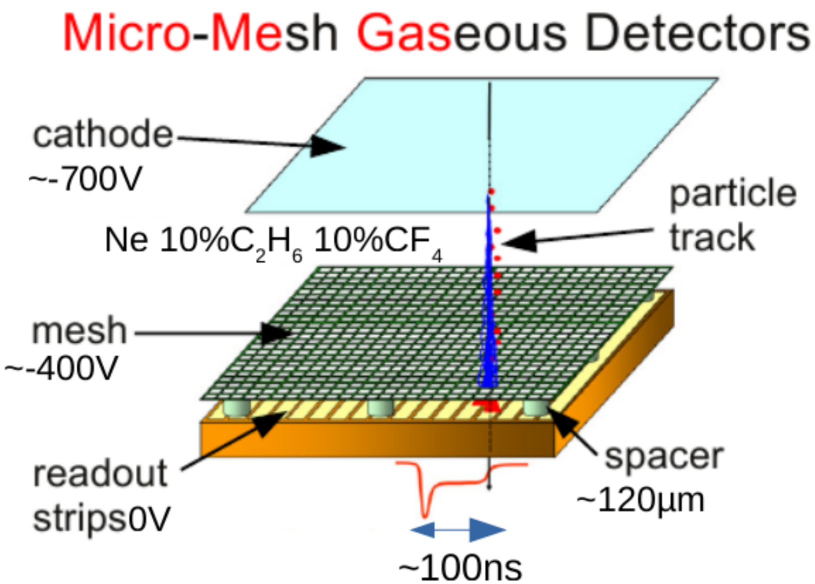


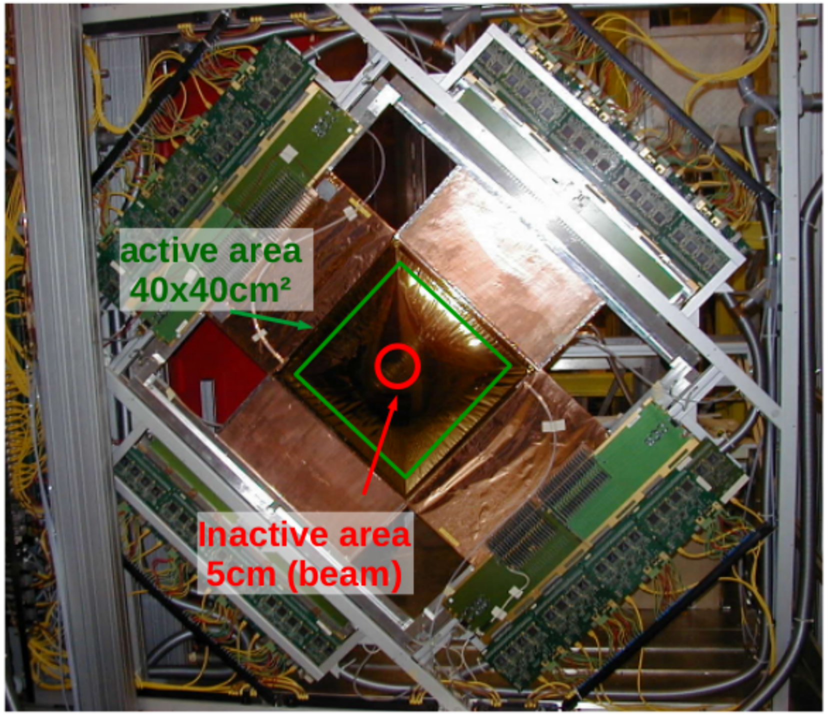
HISTORICAL COMPASS MICROMEGAS DETECTORS

First COMPASS Micromegas (2001-2014)

- First Micromegas detectors installed in a particle physics experiment (installed 2001-2002)
- 40x40 cm^2 area on light board sandwich
- Good resolutions: 70-100 µm, 10 ns
- Light gas mixture Ne + 10% C_2H_6 + 10% CF_4, to keep discharge rate low
- Blind center to reduce electronics occupation
- Low noise electronics based on SFE16 (threshold ~ 4000 e^-)
- 12 planes on X, Y, U, V (45°) orientations in 3 stations
- Lasted more than 10 years (2001-2012) with a few refurbishing: drift gap increased to 5mm, mesh from Ni to Cu
- Stable performance with up to 10^{13} p/cm^2 integrated







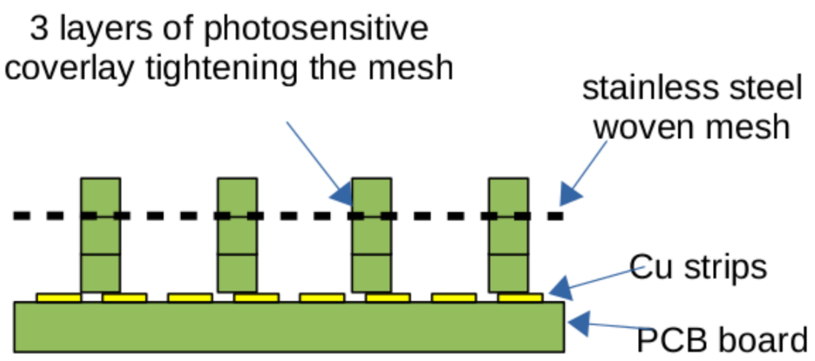
NEW PIXELIZED MICROMEGAS DETECTORS

Motivations

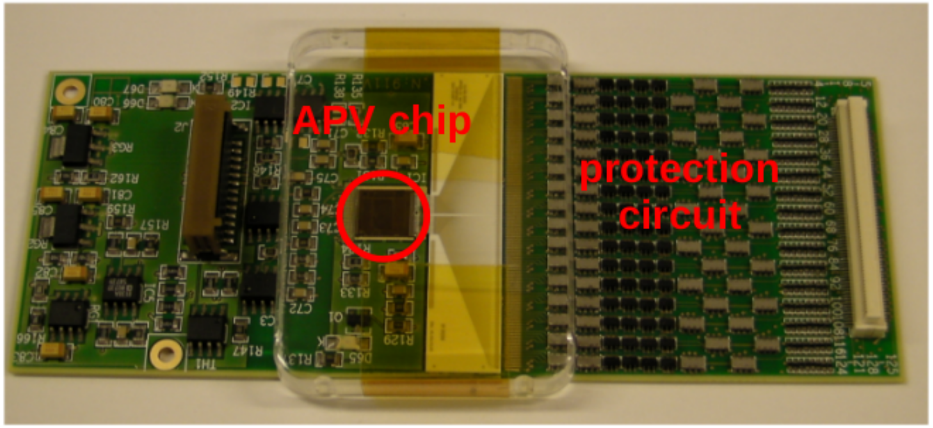
- Tracking at very small angle with same material budget as old Micromegas
- Reduction of discharge rate required for Drell-Yan program (high intensity pion beam)
- Improve robustness

Project

- R&D and development in 2008-2013, installed in 2014-2015
- Discharge reduction based on hybrid Micromegas, with an additional GEM foil
- Detector center readout with pixels, same active area 40x40 cm²
- Robustness with bulk Micromegas technology
- Highly integrated APV-25 readout electronics (1024 → 2560 channels / plane)
- Same gas mixture Ne + 10 C_2H_6 + 10% CF_4

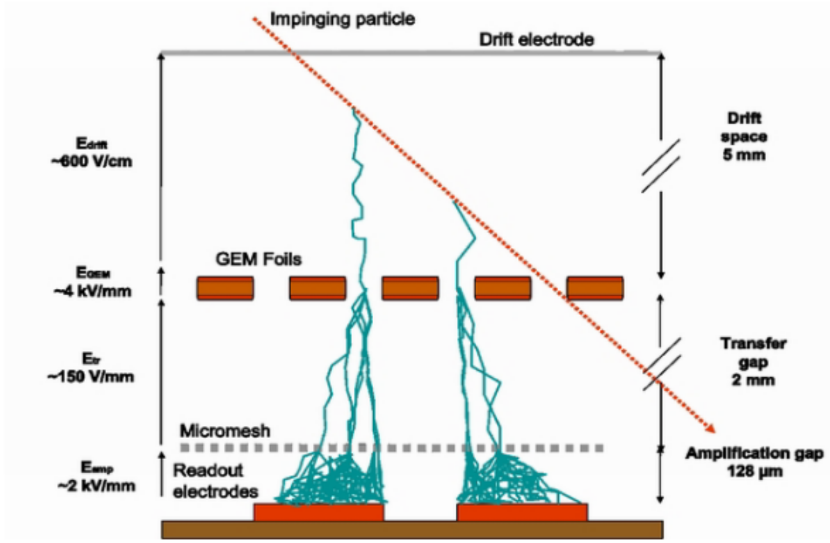


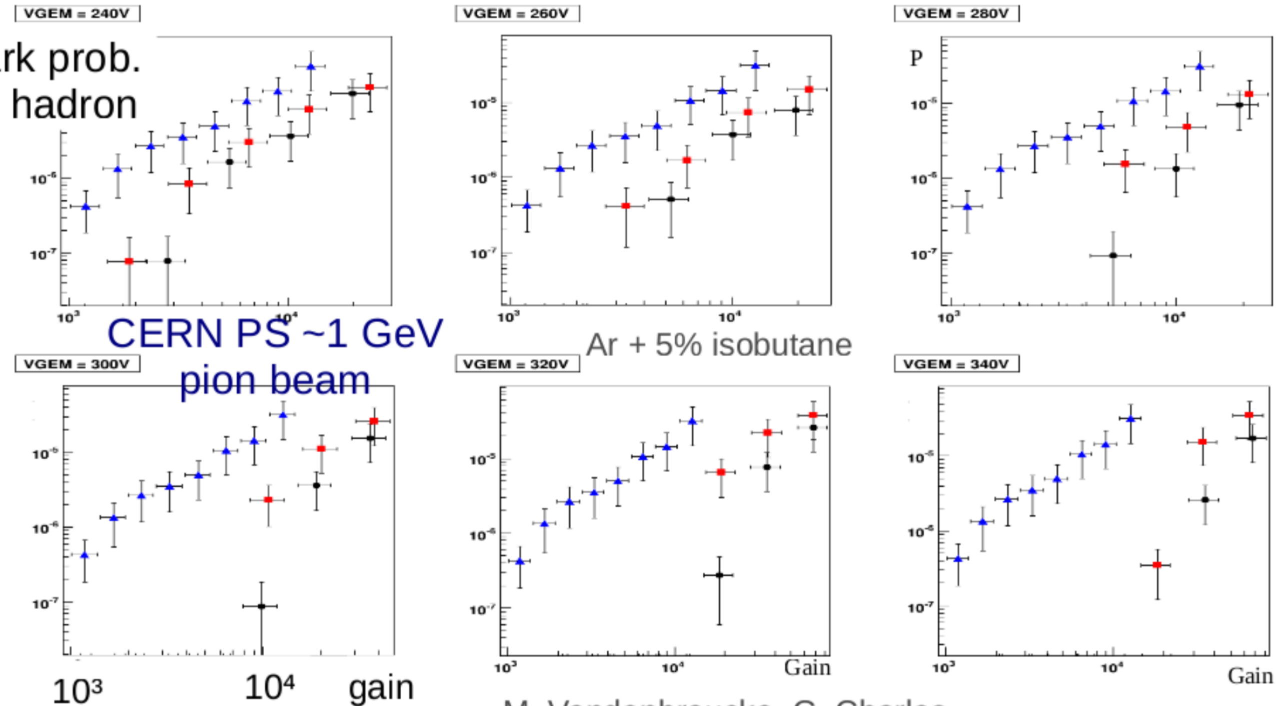
bulk technology

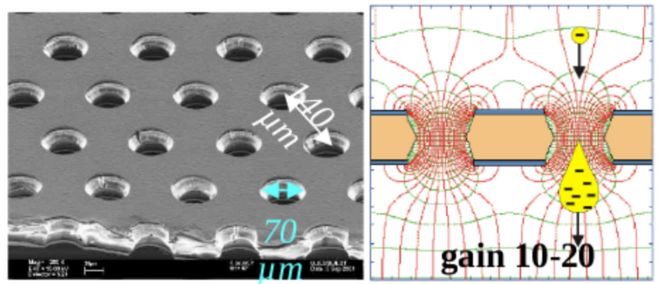


DISCHARGE REDUCTION WITH HYBRID STRUCTURE

- **Hybrid MM with 1 GEM foil**
  - GEM foil for preamplification (gain 10-20)
  - Micromegas stage at lower gain → fewer discharge
- **Studied with muon and pion beams**
  - Tests at PS (low energy pions) and SPS in association with Saclay CLAS12 group
  - Spark rates decreased by factor 10 to >100





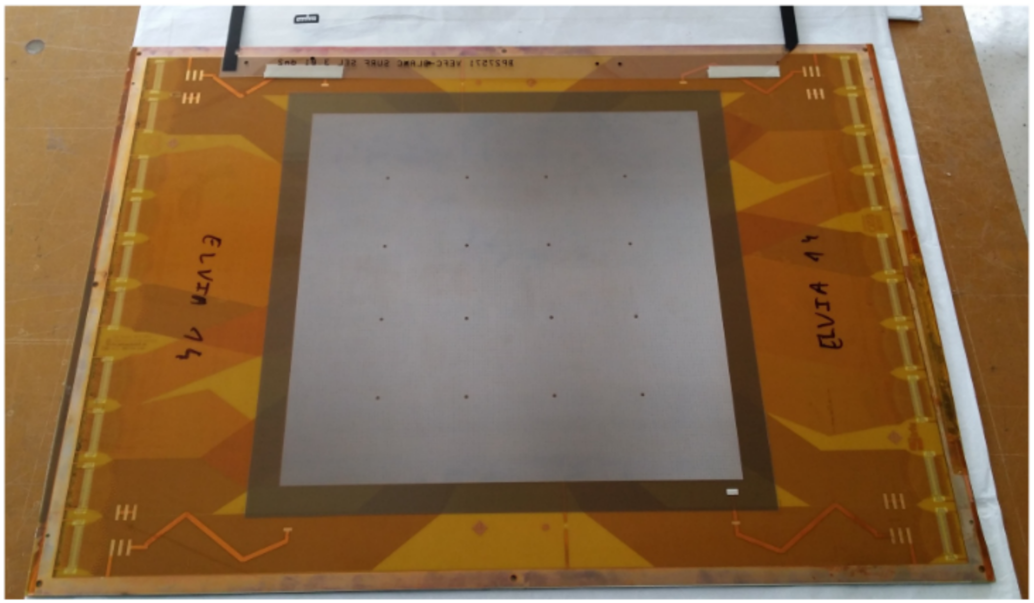


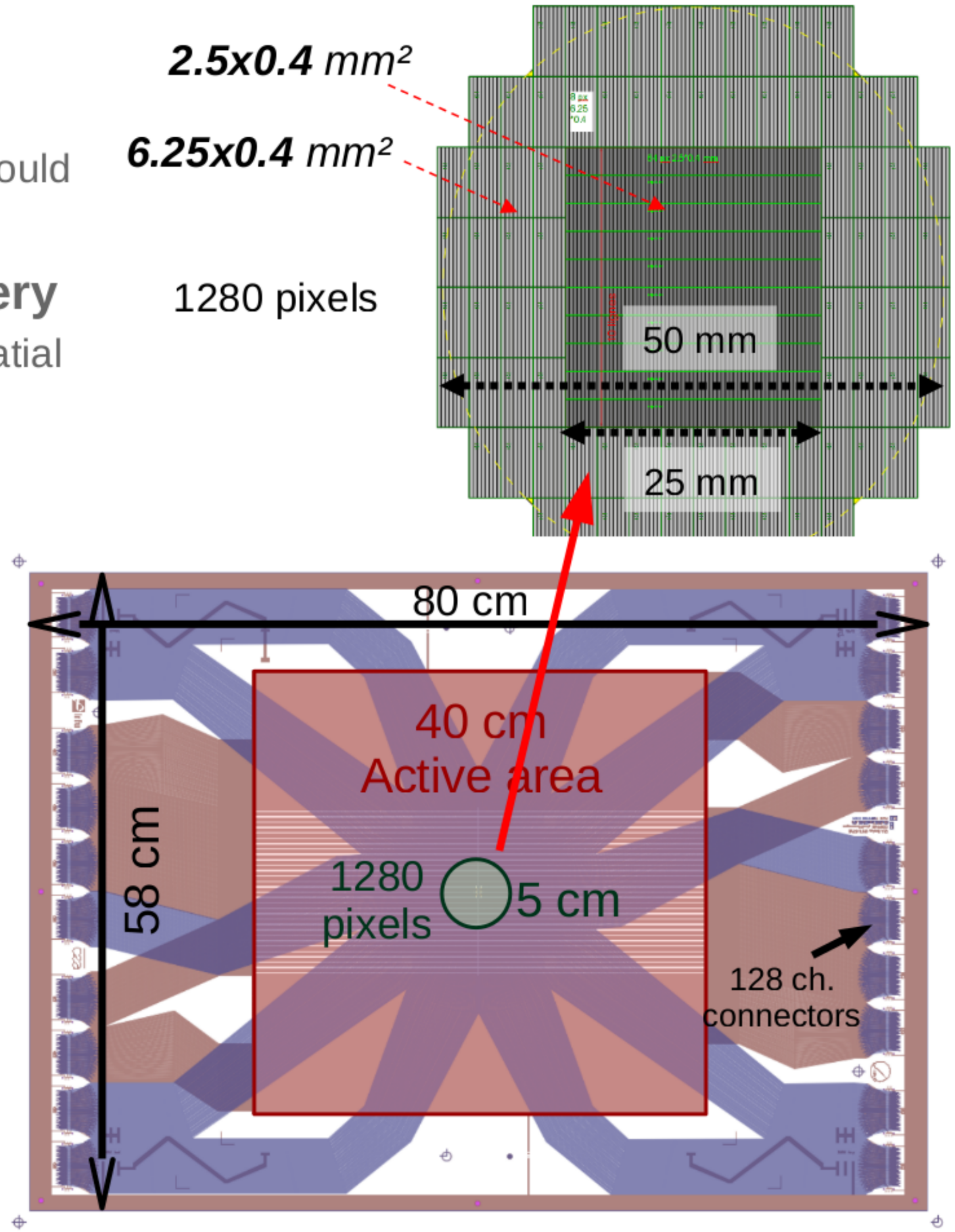
- ▲ MM
- ■ MM+GEM 1 mm
- ■ MM+GEM 2 mm

M. Vandenbroucke, G. Charles

PIXEL READOUT IN THE DETECTOR CENTER

- **Too high flux for strips in center**
  - Expected particle flux > 100 kHz/mm²
  - > 500 kHz/channel with strip read-out → would lead to 10% electronics inefficiency
- **Rectangular pixels + strips in periphery**
  - 400 µm pitch pixels, like strips → same spatial resolution
  - 1280 pixels + 1280 strips
  - 40x40 cm² total active area
  - Material budget ~0.38% X_0 per plane

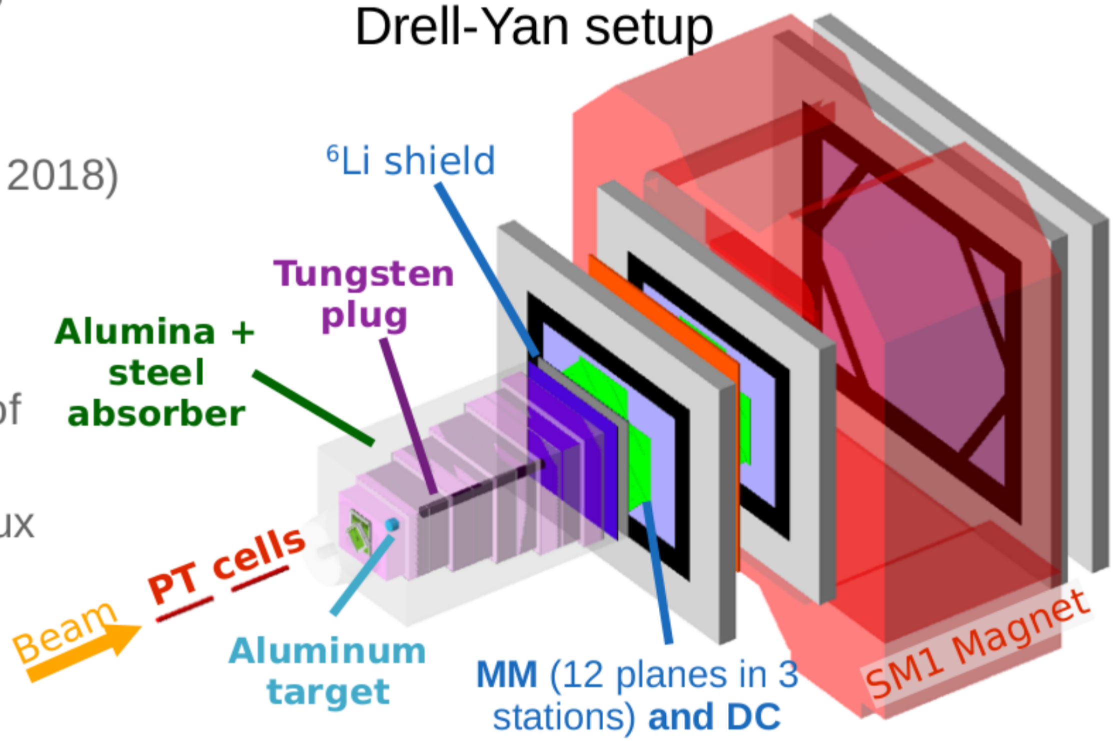




COMPASS ACTIVITIES IN PERIOD 2014-2022

Drell-Yan runs 2014-2015 and 2018

- High flux 190 GeV **pion** beam
- ~3.5x10^{8} pions per 5s spill
- ~23x10^{13} pions in total (9 in 2015, 14 in 2018)
- Several thick targets in beam
  - 110 cm polarized ammonia
  - 7 cm aluminum
  - 150 cm tungsten plug + absorber
- Beam stopped in tungsten plug but lot of secondaries and low energy particles
- Detectors just after absorber → large flux
- Additional Lithium shield before MM added in 2018



DVCS runs 2016-2017

- Medium intensity 160 GeV **μ⁺ and μ⁻** beam on 2.5m-long hydrogen target
- ~6x10^{7} muons per 5s spill
- 3x10^{13} muons delivered in total

Transversity run 2021 and 2022

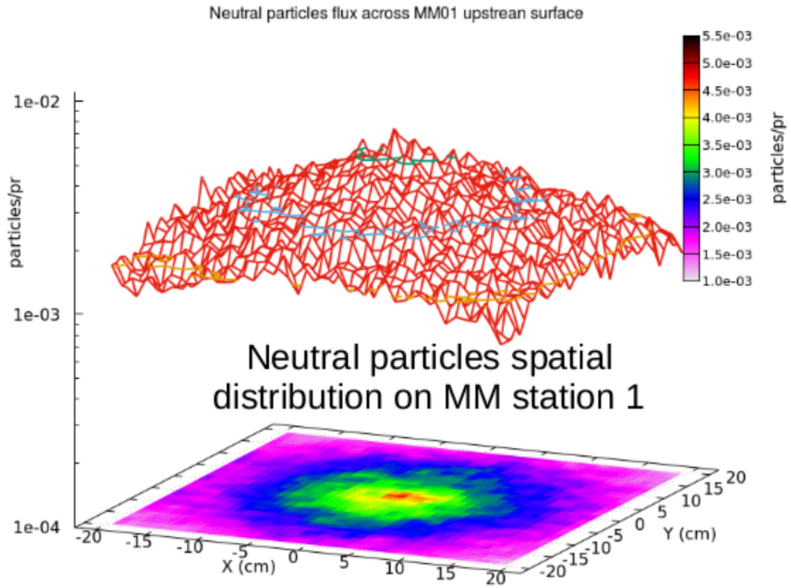
- High flux 160 GeV **muon** beam
- 1.2m-long polarized ^{6}LiD target
- 2.5x10^{8} muons per 5s spill
- 1.3x10^{13} muons in total

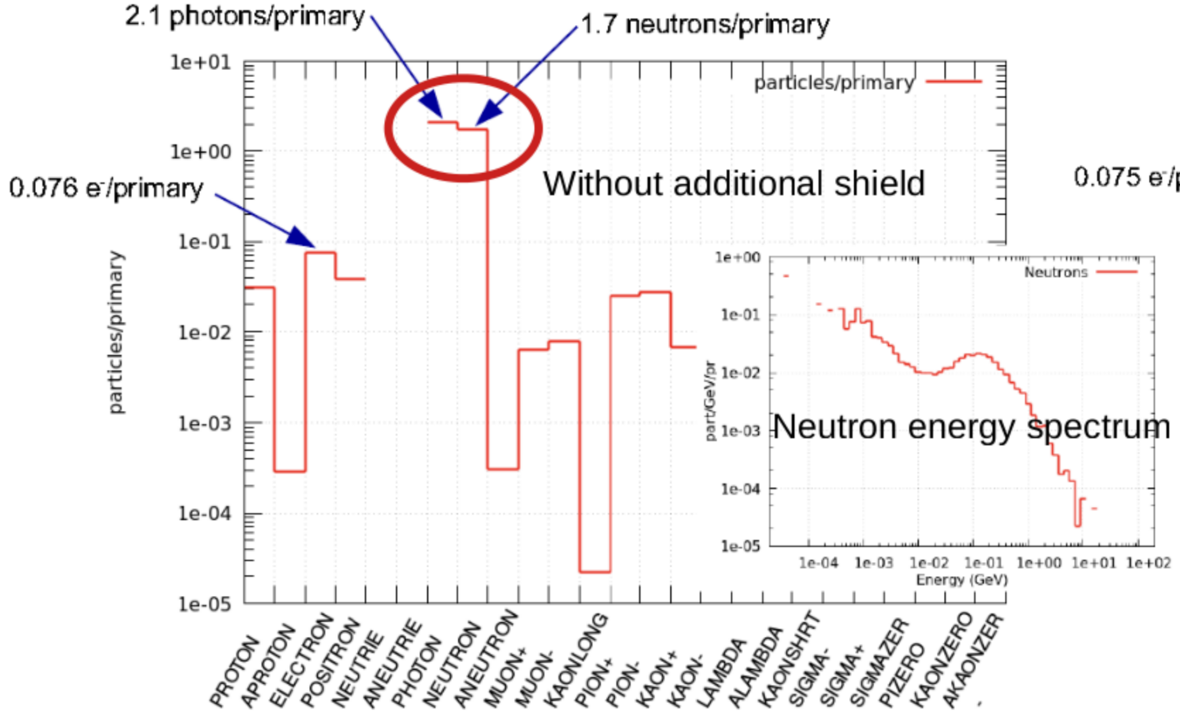
Flux estimations by N. d'Hose, C. Quintans and J. Matousek

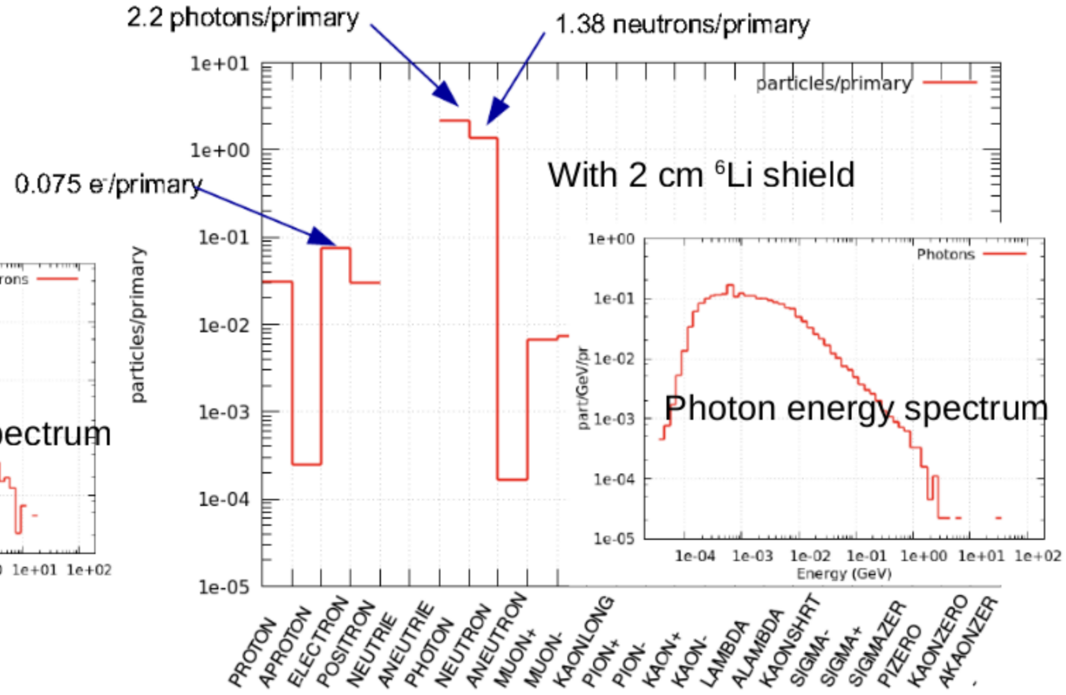
RADIATION LEVELS IN MM DURING DRELL-YAN RUNS

Estimations based on simulations

- FLUKA MC with realistic absorber geometry
- Done by Angelo Maggiora (INFN Torino) 2011-2015
- Radiation at 1st MM station
- With and without additional Li layer before MM
- Total irradiation of first MM station in 2015 + 2018 estimated to
  - 3.4×10^{14} neutrons
  - 5×10^{14} photons



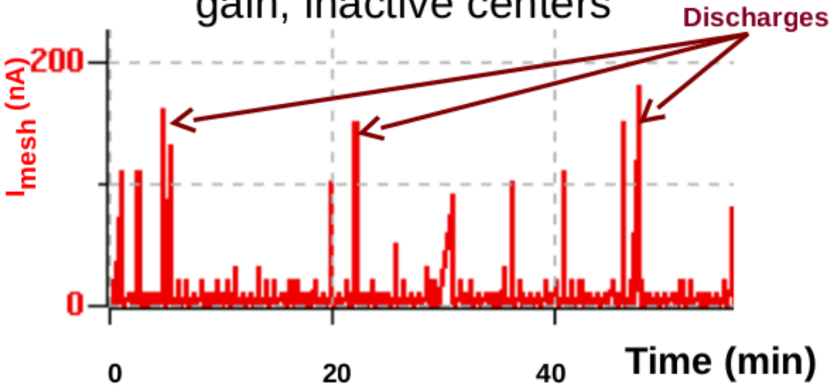




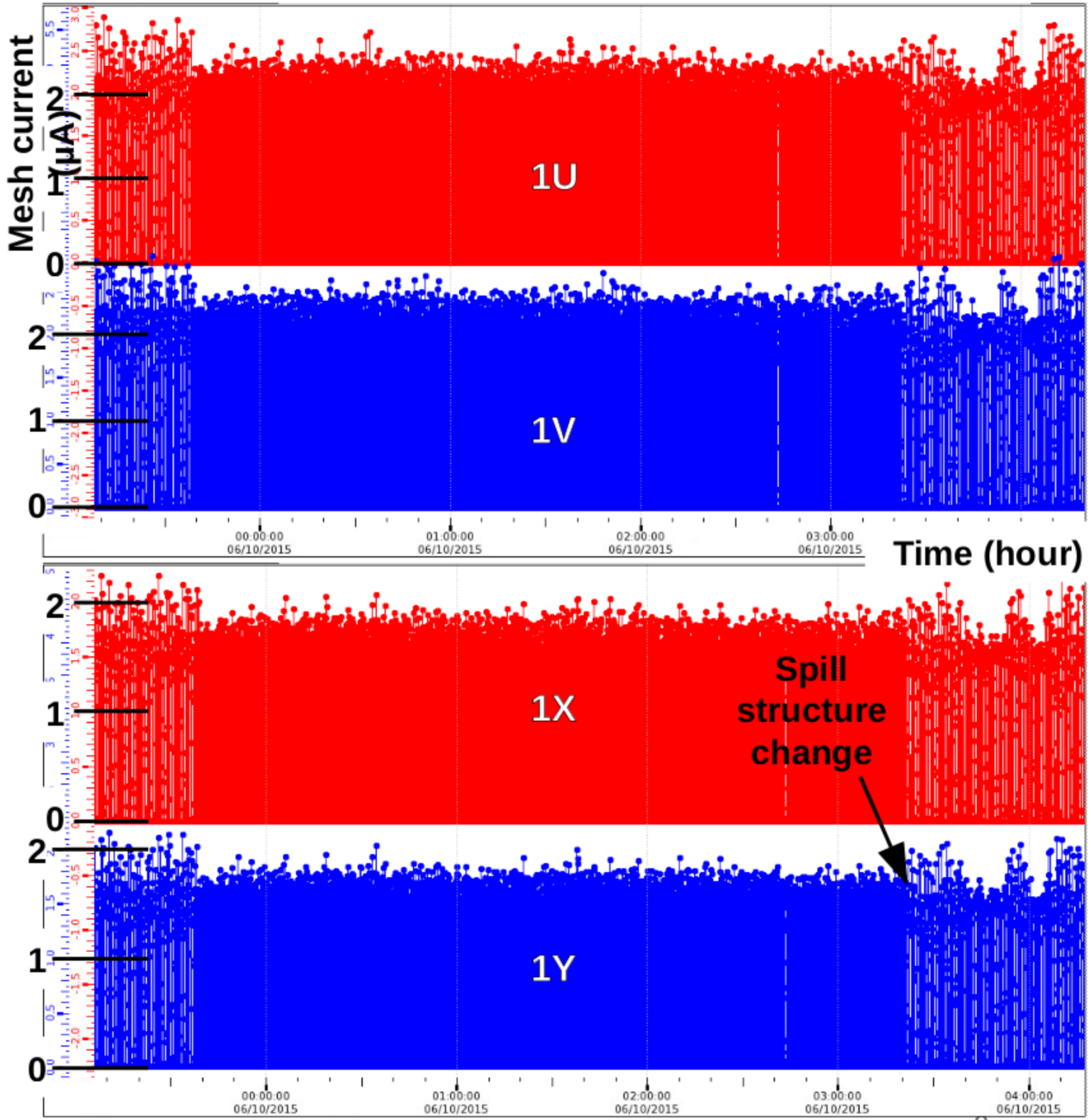
MM station 1

- High flux pion beam (2015 Drell-Yan run)
- Large current due to low momentum particles in detectors, spill structure very visible
- Discharges barely visible as amplification currents much larger

Standard MM with reduced gain, inactive centers



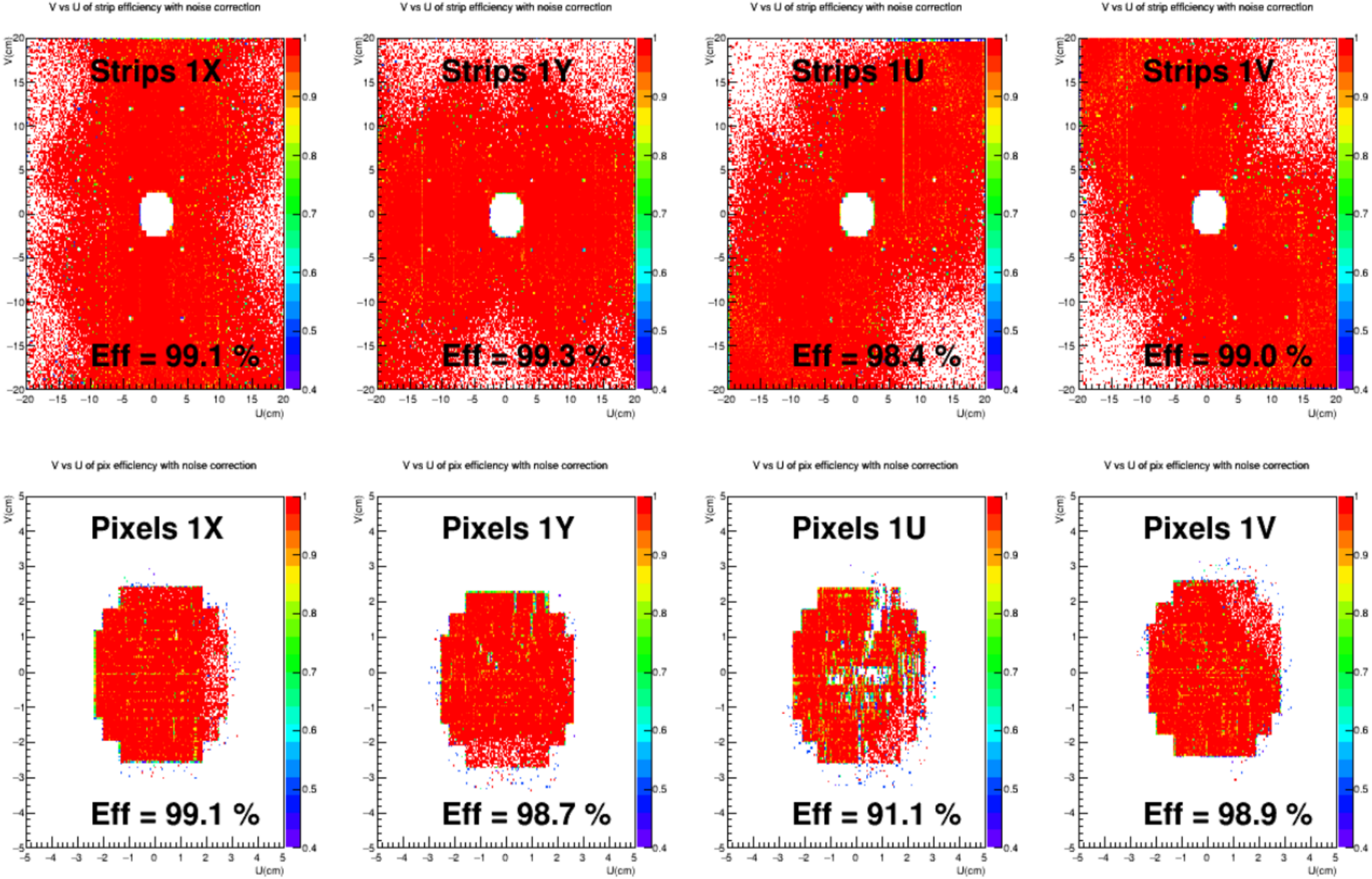
Low intensity pion beam



EFFICIENCY WITH LOW FLUX MUON BEAM

Station 1

Efficiencies corrected from pile-up contributions

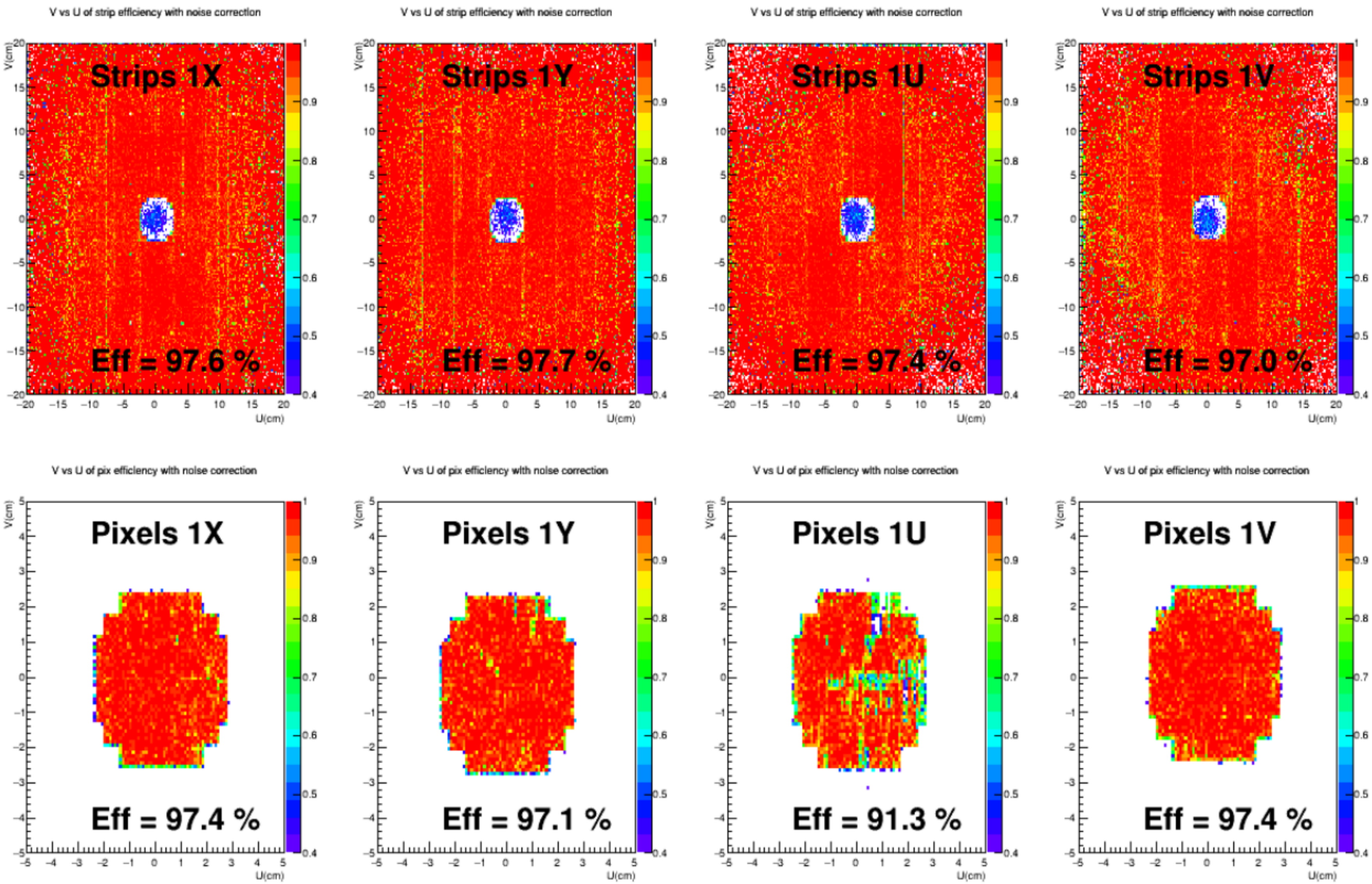


Low intensity muon beam, Drell-Yan run 2015

Nominal efficiency

EFFICIENCY WITH HIGH FLUX HADRON BEAM

Station 1, close to absorber

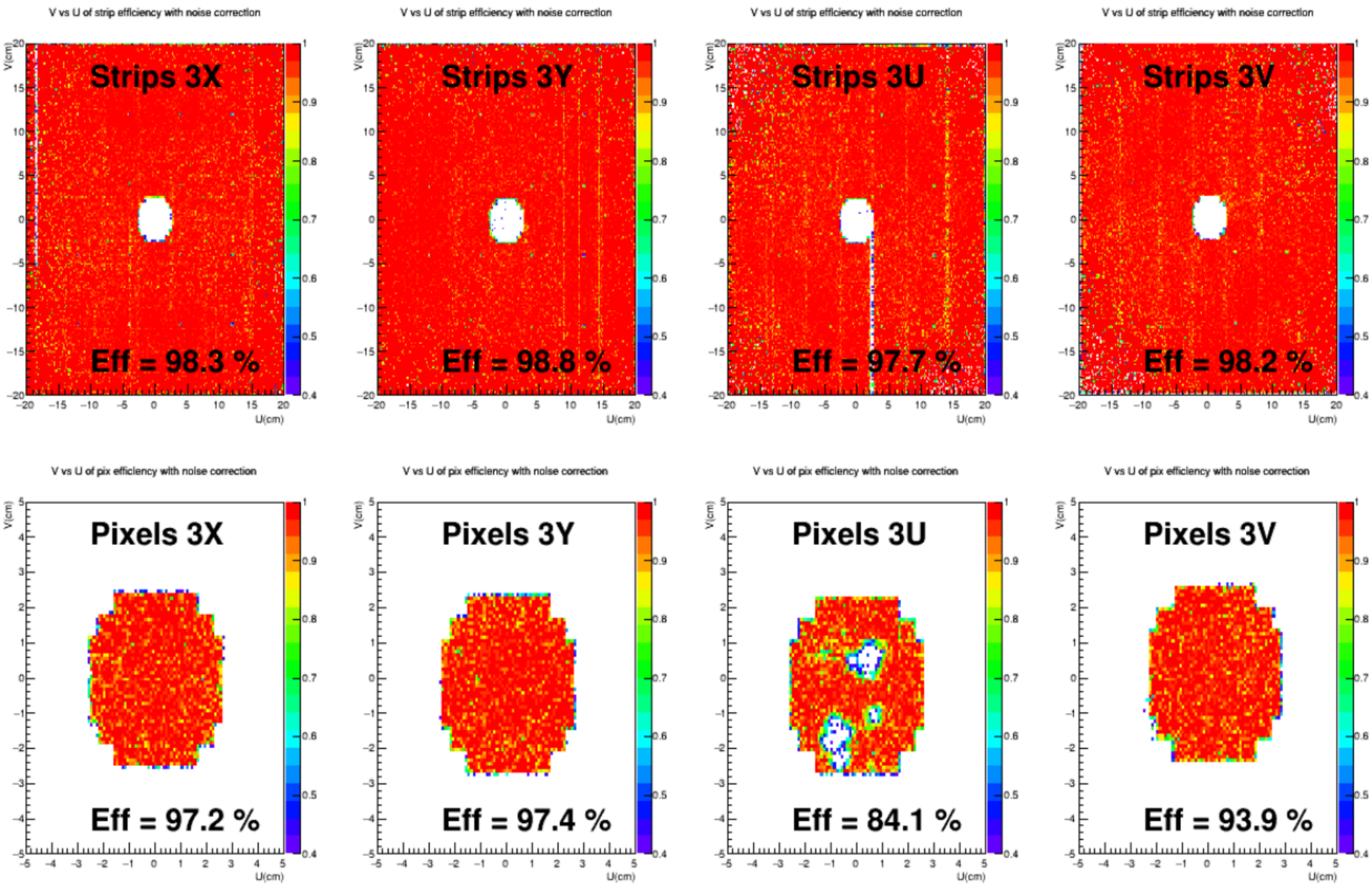


High intensity pion beam, Drell-Yan run 2015

Lower efficiency due to large particle flux

EFFICIENCY WITH HIGH FLUX HADRON BEAM

- Station 3, 1.5 m from absorber

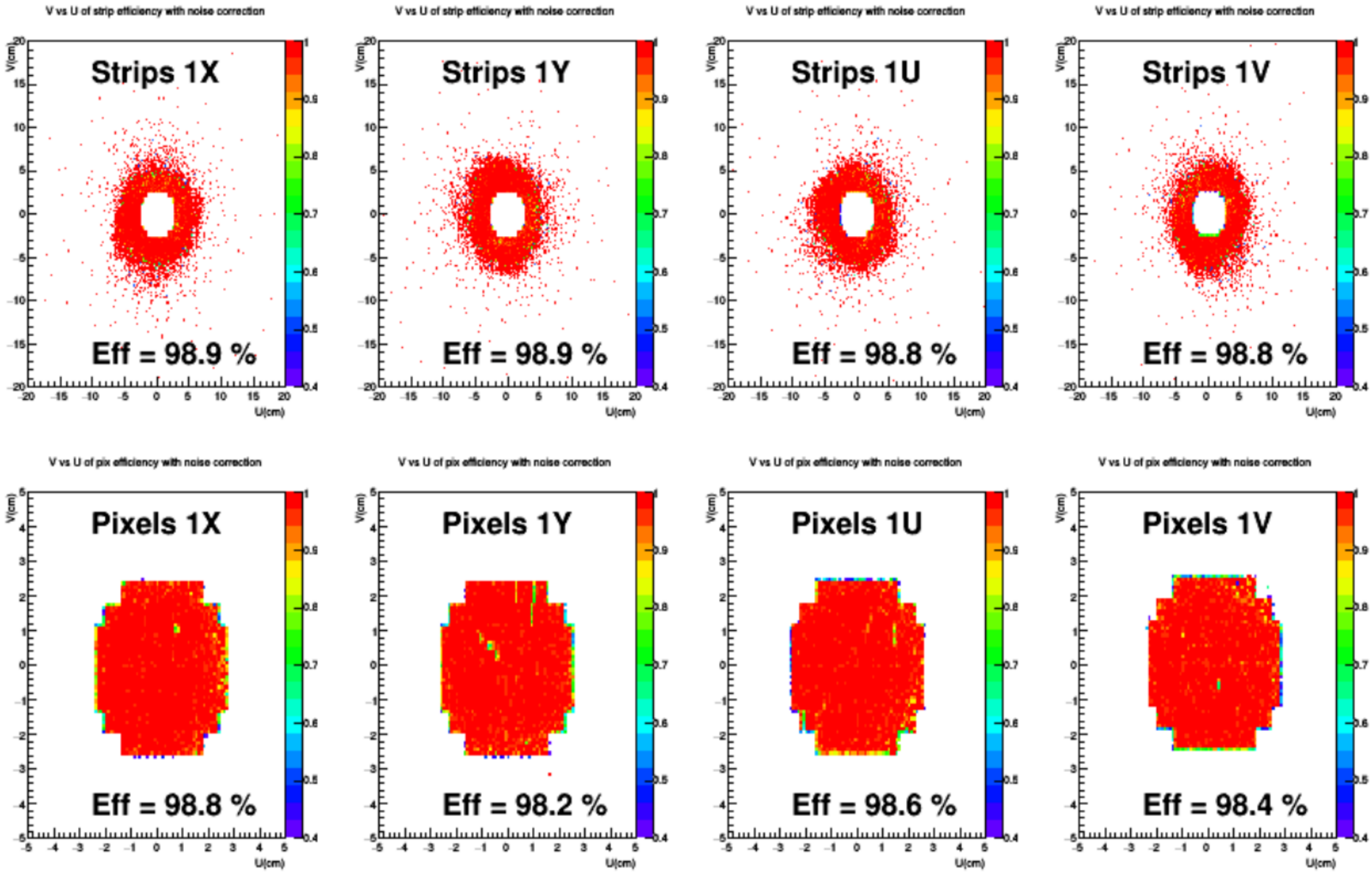


High intensity pion beam, Drell-Yan run 2015

Lower efficiency due to high particle flux

EFFICIENCY WITH MEDIUM FLUX MUON BEAM

- ## Station 1, close to hydrogen target

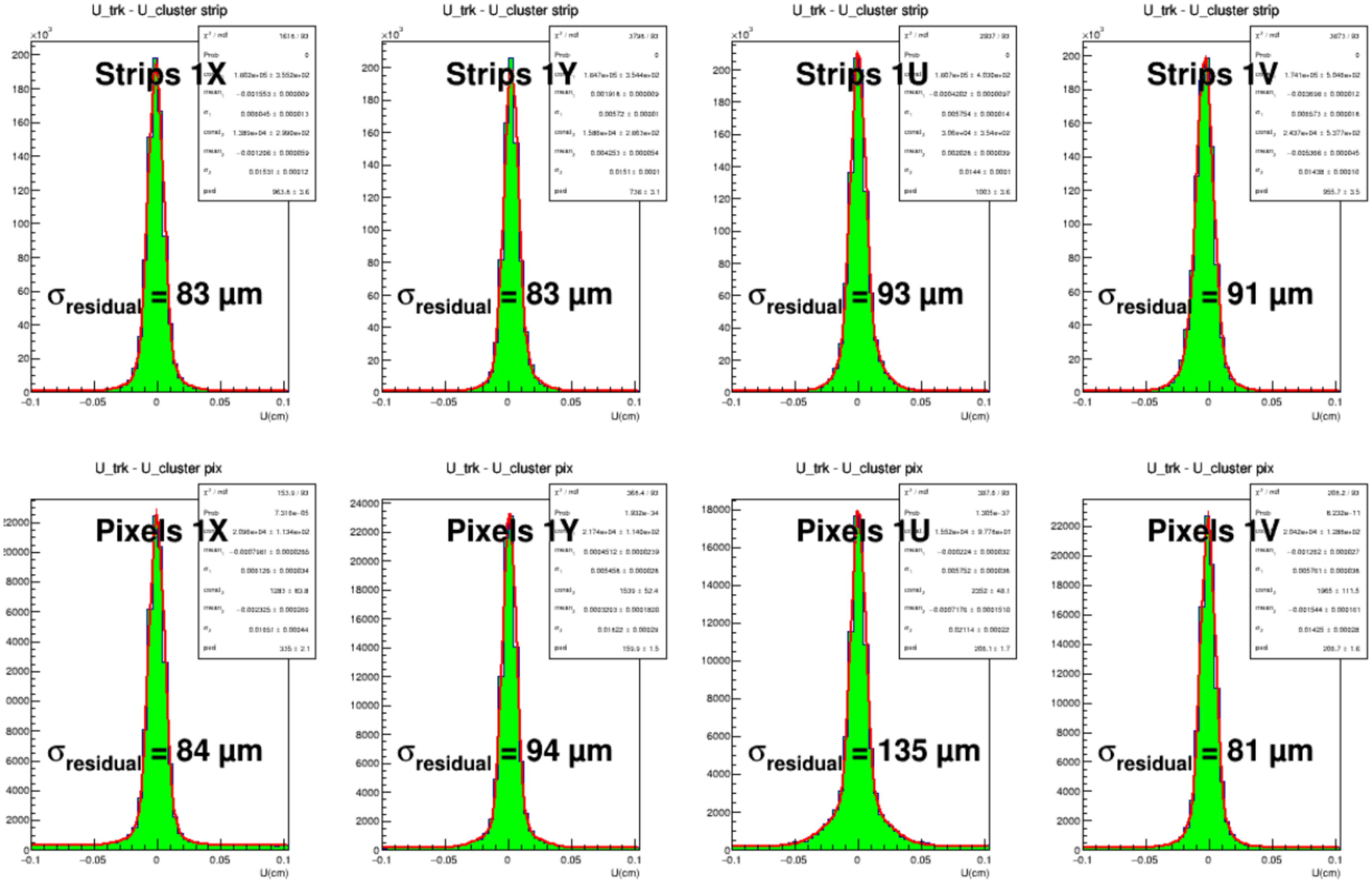


Medium intensity muon beam, DVCS run 2016

High efficiency despite large particle flux

SPATIAL RESOLUTION WITH LOW FLUX MUON BEAM

Station 1

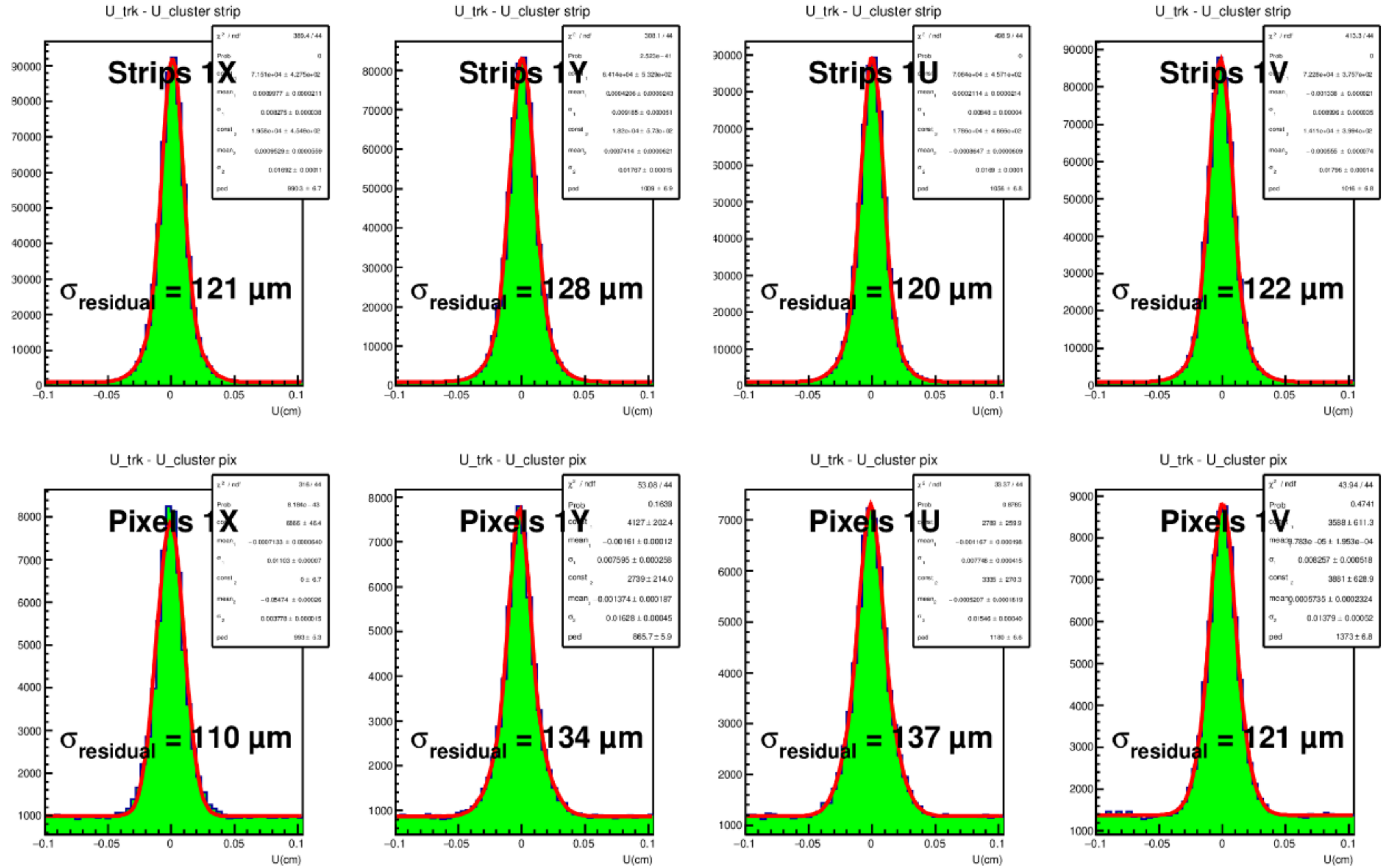


Low intensity muon beam, Drell-Yan run 2015

Residuals 85-95 µm

SPATIAL RESOLUTIONS WITH HIGH FLUX HADRON BEAM

Station 1, close to absorber

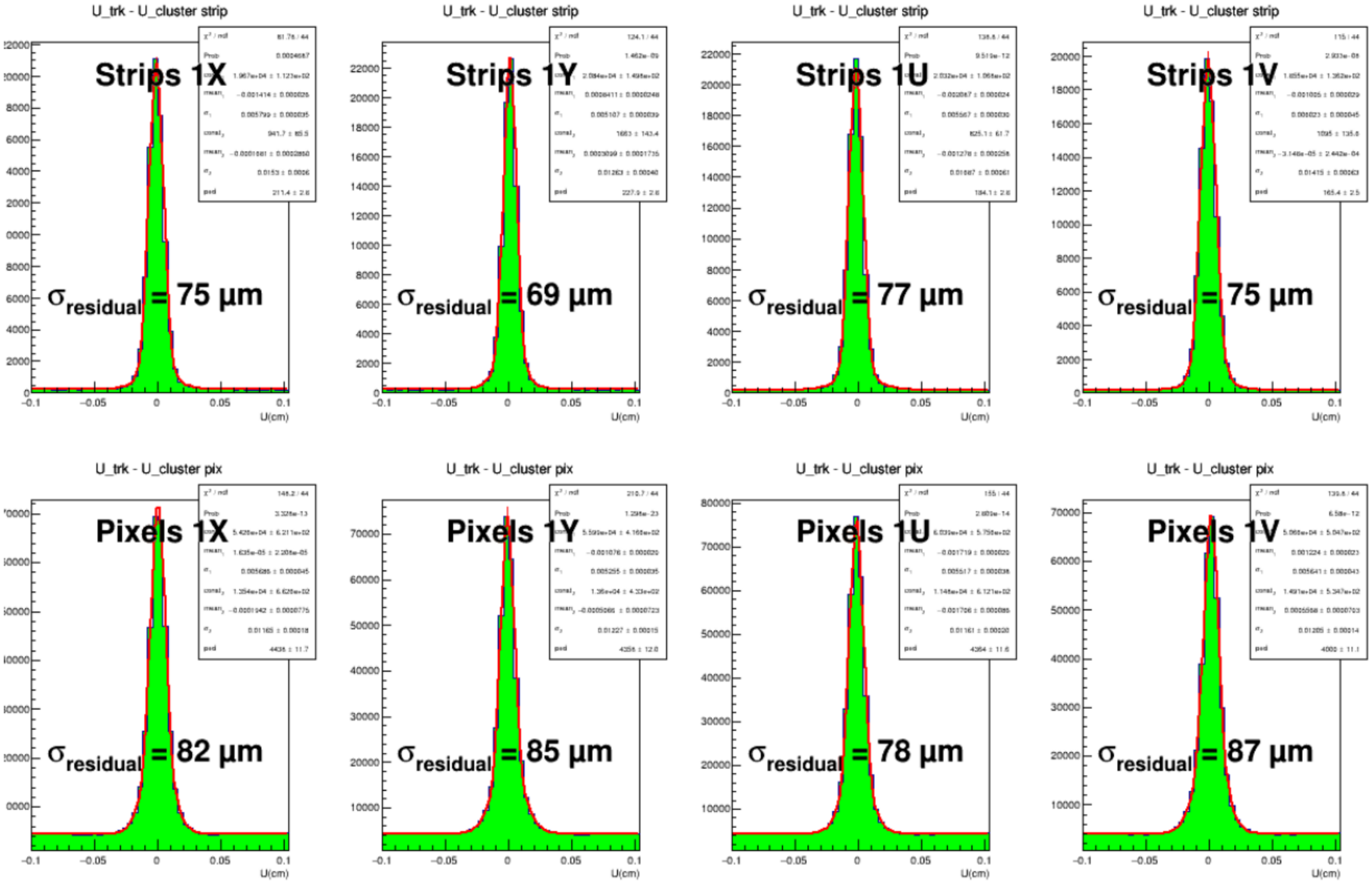


High intensity pion beam, Drell-Yan run 2015

Degraded resolutions due to high particle flux

SPATIAL RESOLUTION WITH MEDIUM FLUX MUON BEAM

Station 1

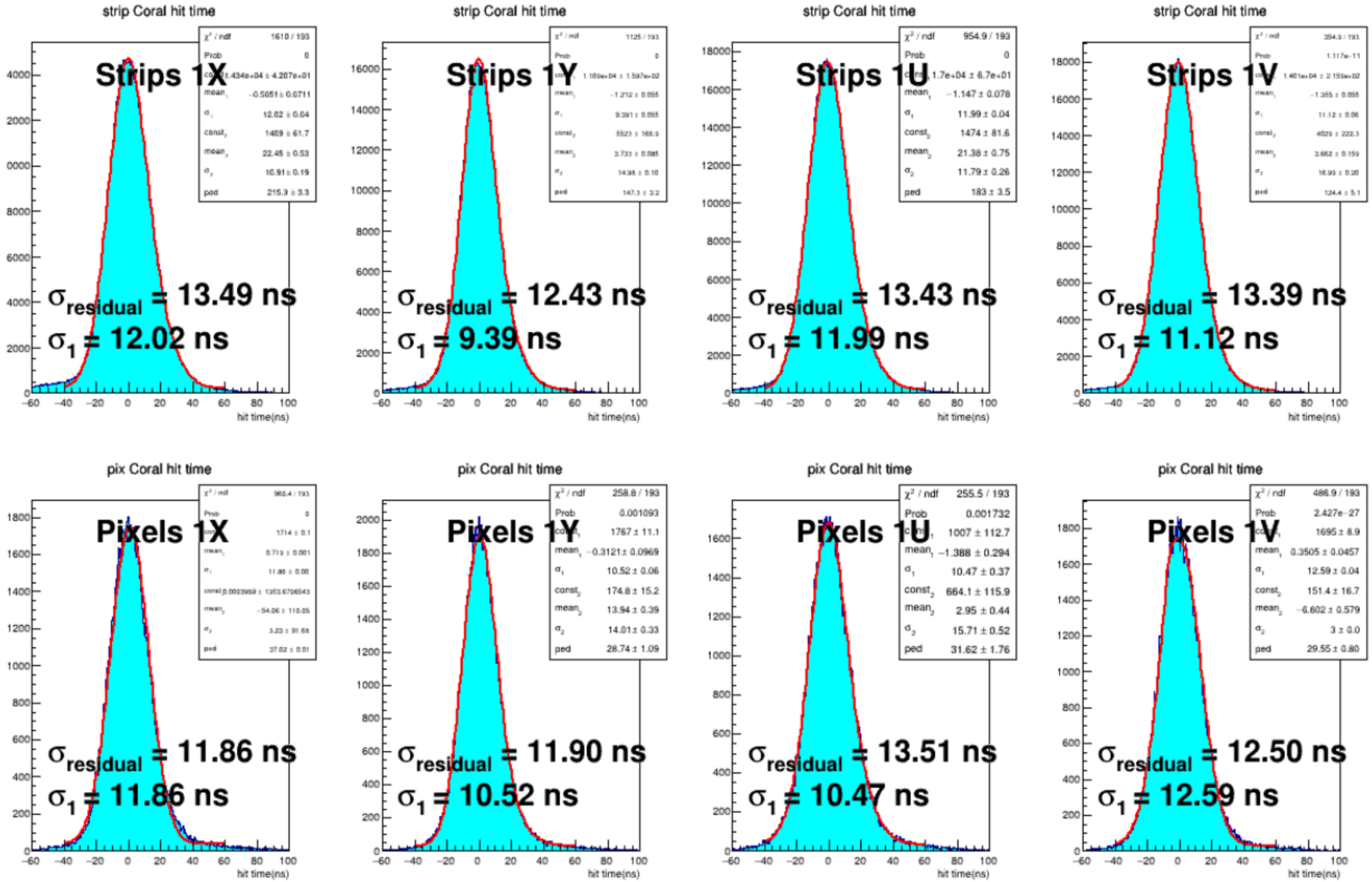


Medium intensity muon beam, DVCS run 2016

Residuals 70-85 µm

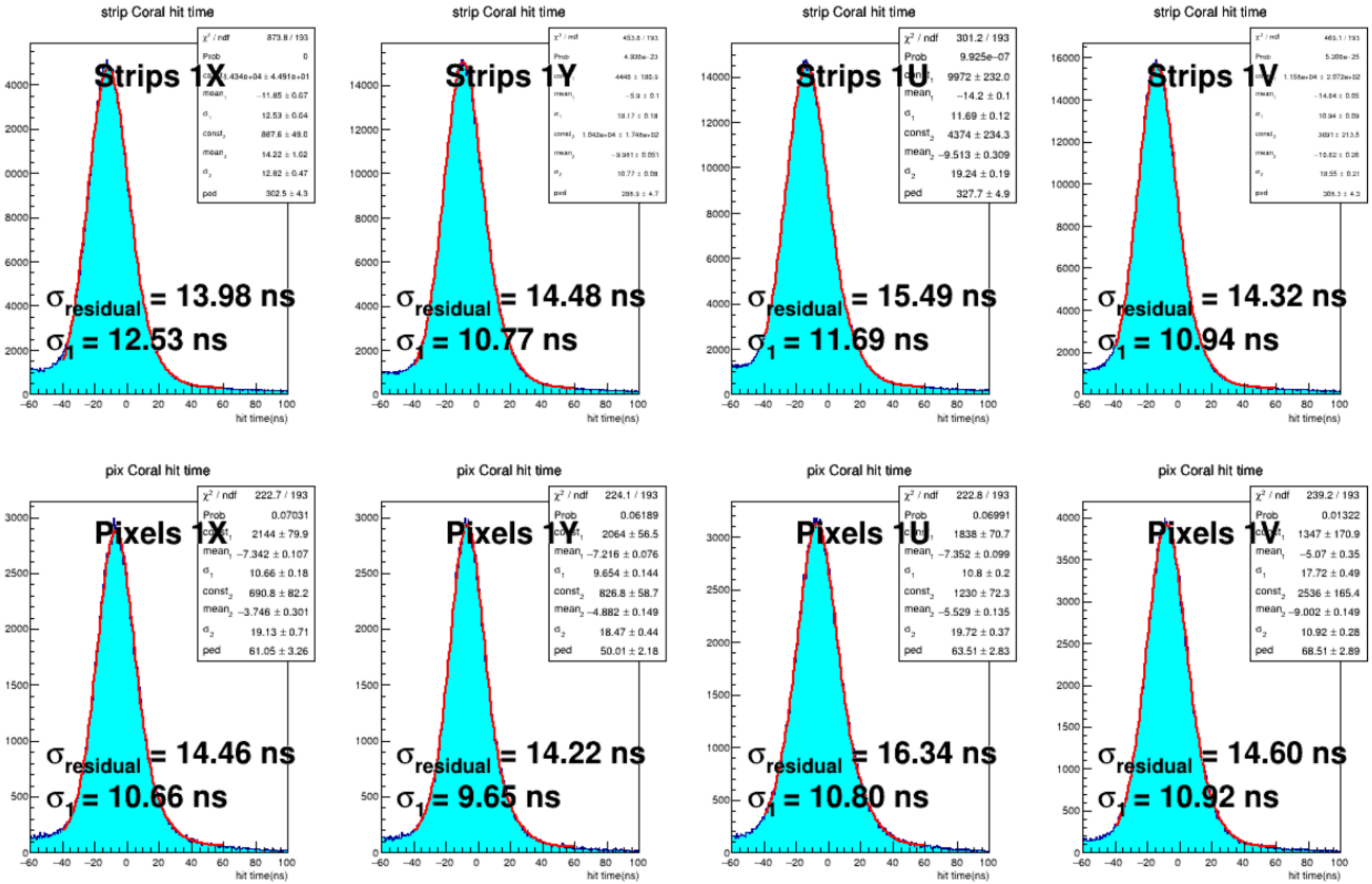
TIME RESOLUTION WITH LOW FLUX MUON BEAM

Station 1



Low intensity muon beam, Drell-Yan run 2015 Time resolution ~12-13 ns

Station 1, close to absorber

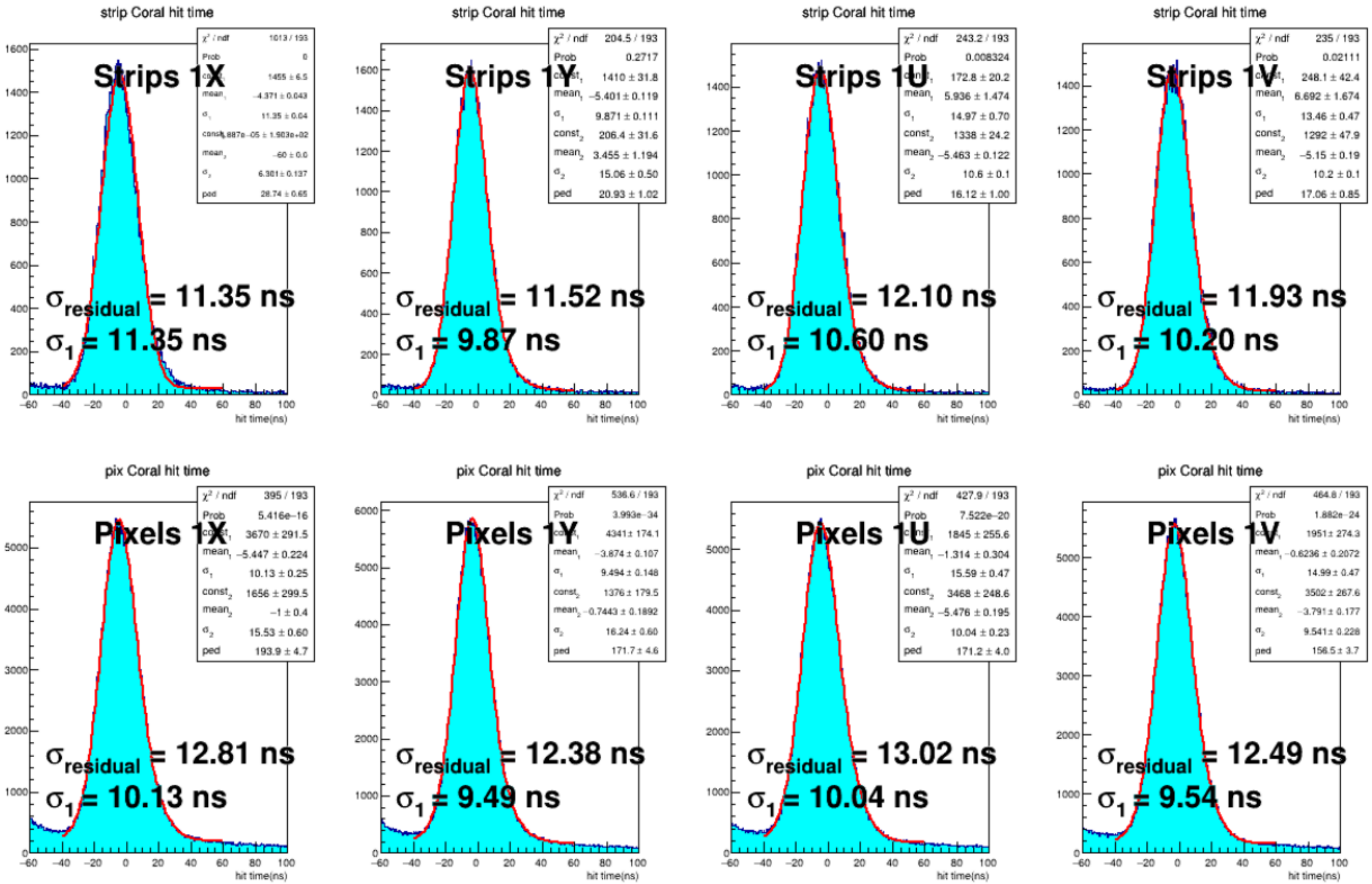


High intensity pion beam, Drell-Yan run 2015

Time resolution 14-16 ns

TIME RESOLUTION WITH LARGE FLUX MUON BEAM

Station 1

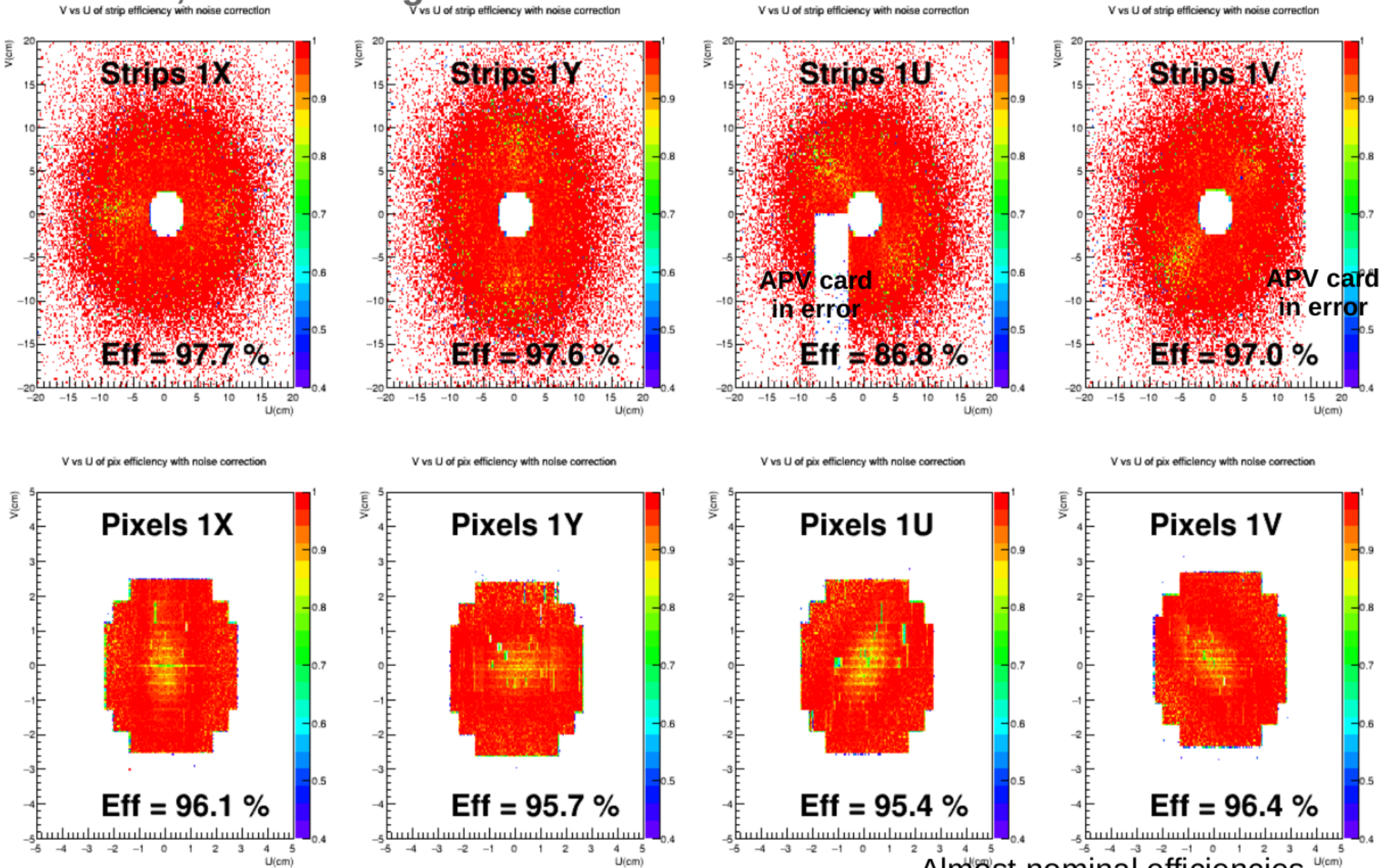


Medium intensity muon beam,DVCS 2016

Time resolution ~11-13 ns

EFFICIENCY WITH HIGH FLUX MUON BEAM, 7 YEARS AFTER

- Station 1, close to target

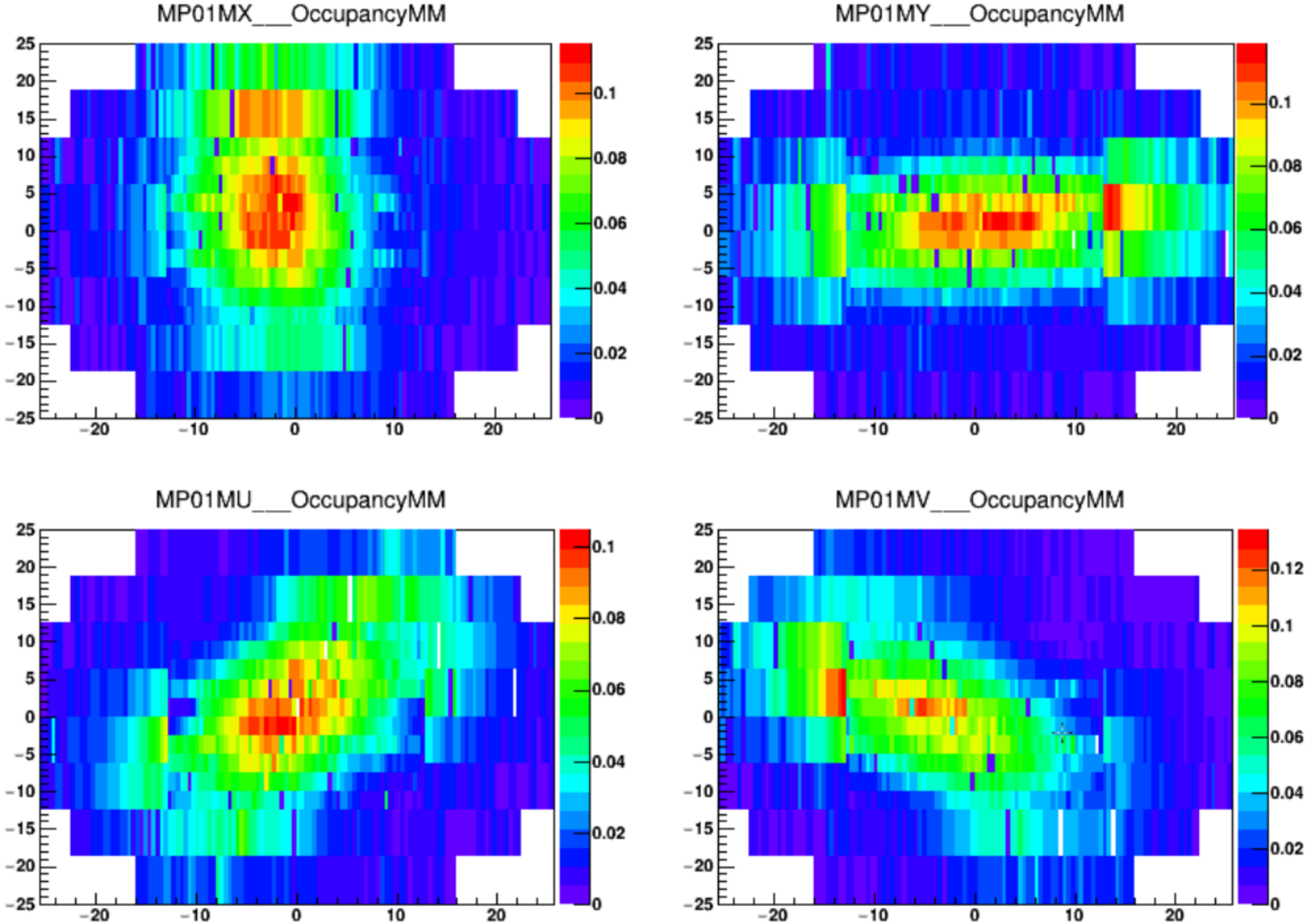


High intensity muon beam, transversity run 2022

Almost nominal efficiencies but in pixel centers

EFFICIENCY WITH HIGH FLUX MUON BEAM, 7 YEARS AFTER

Occupancy of pixel channels, station 1



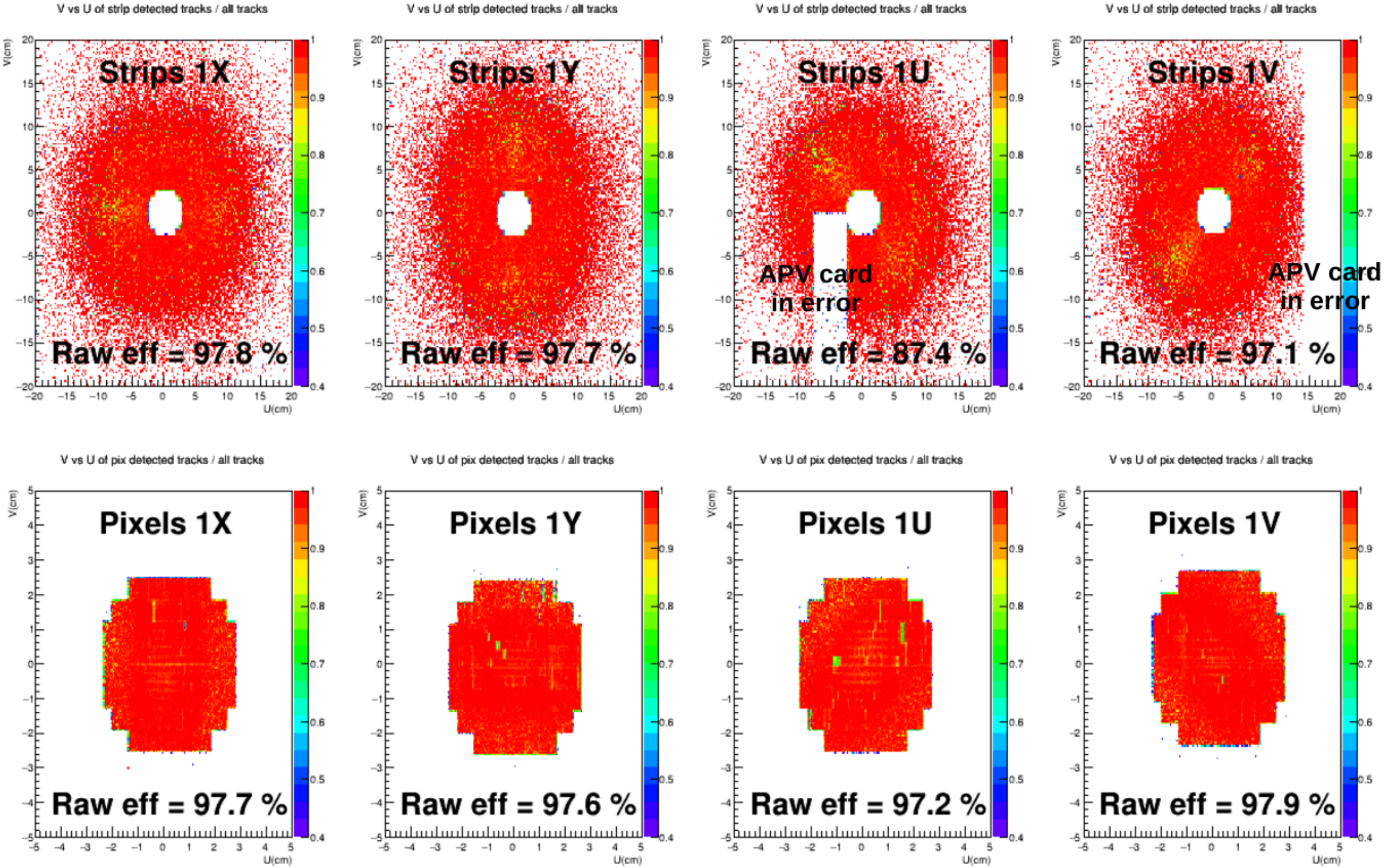
High intensity muon beam, transversity run 2022

Almost nominal efficiencies

EFFICIENCY WITH HIGH FLUX MUON BEAM, 7 YEARS AFTER

Station 1, close to target

Without correction from pile-up contributions

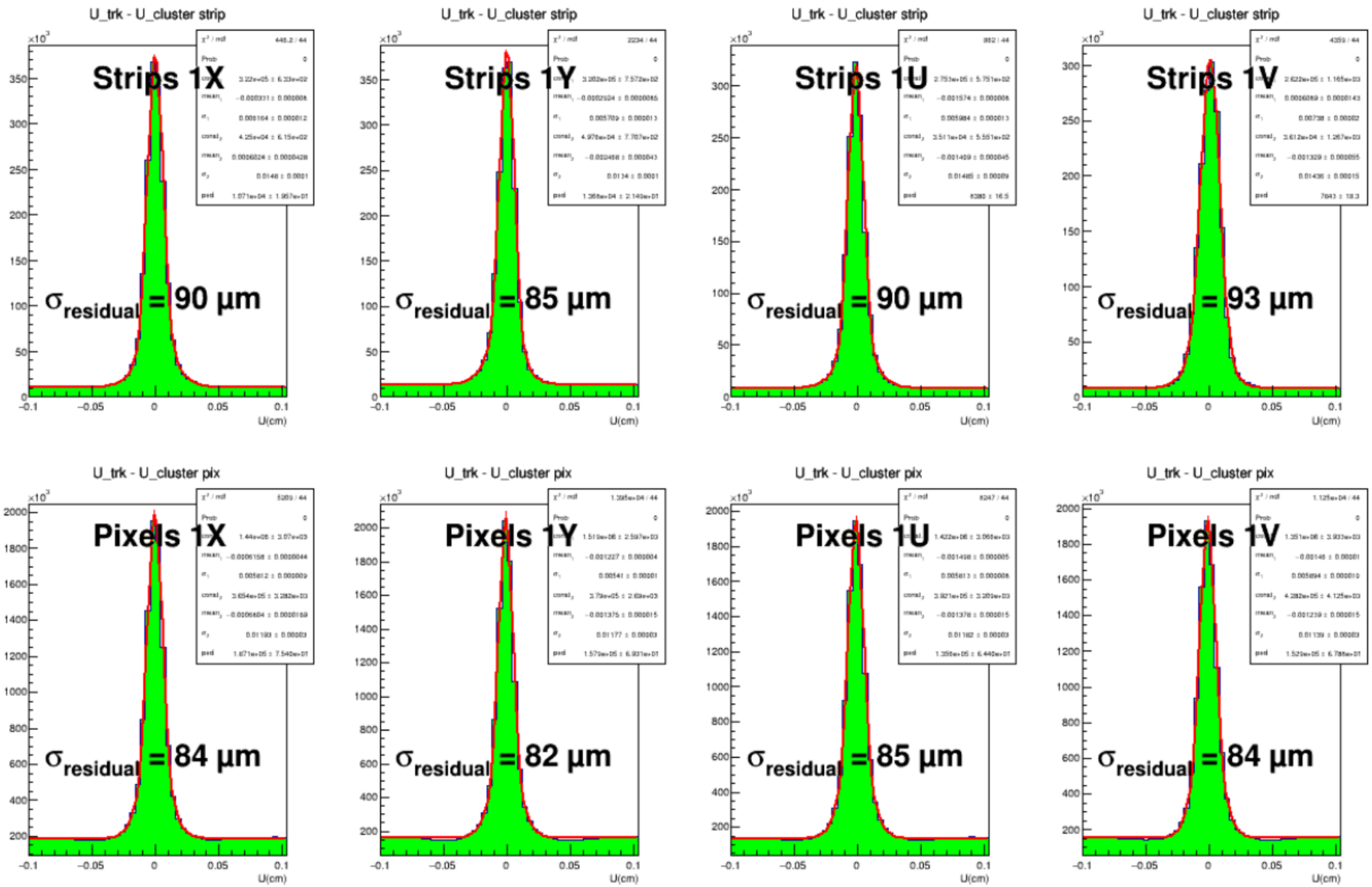


High intensity muon beam, transversity run 2022

Efficiencies 97-98%

SPATIAL RESOLUTIONS WITH HIGH FLUX MUON BEAM, 7 YEARS AFTER

Station 1, close to target

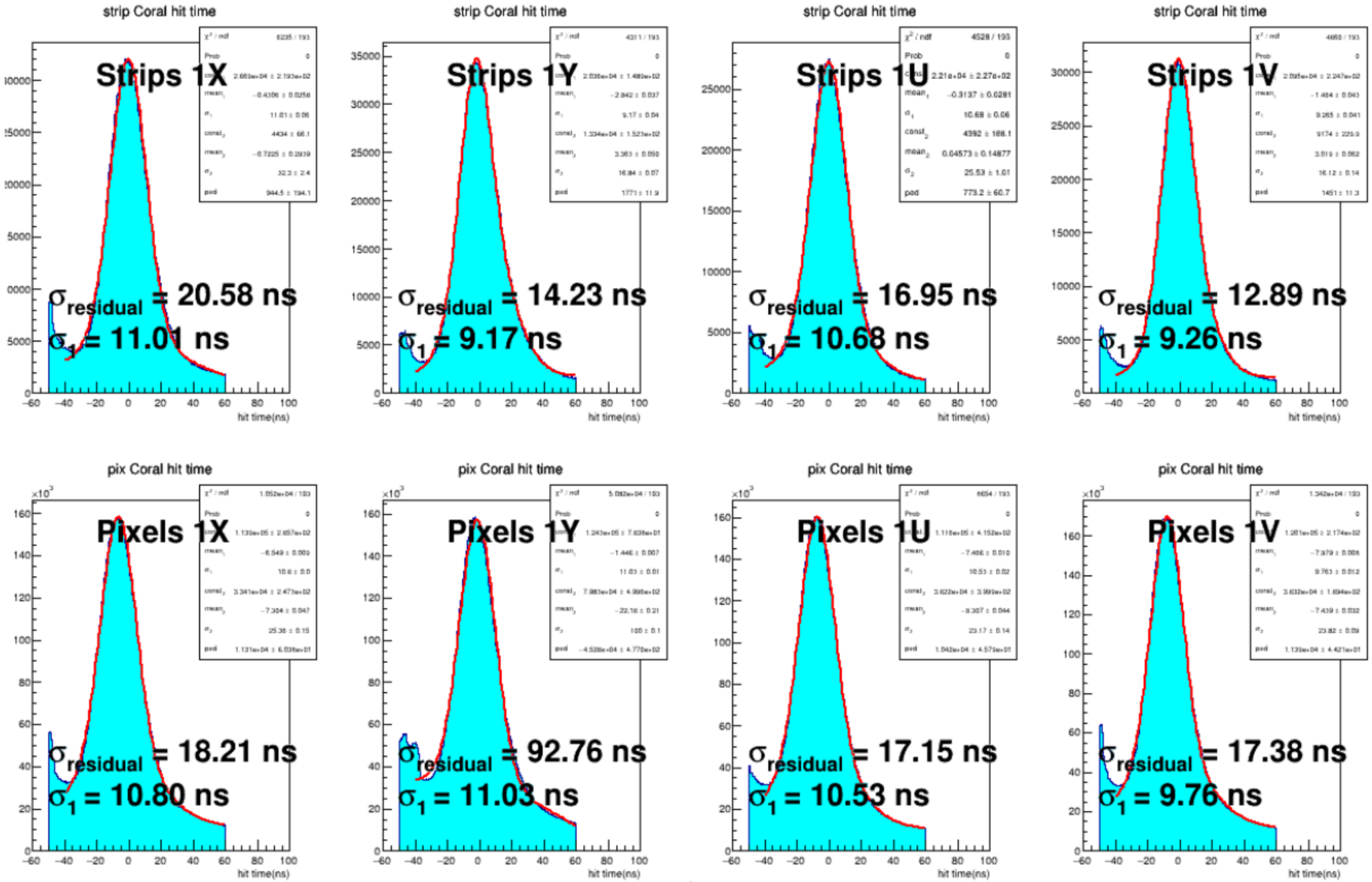


High intensity muon beam, transversity run 2022

Residuals 85-90 µm

TIME RESOLUTIONS WITH HIGH FLUX MUON BEAM, 7 YEARS AFTER

Station 1, close to target



High intensity muon beam, transversity run 2022

Time resolution 13-18 ns

CONCLUSIONS

Pixelized hybrid Micromegas detectors

- Discharge rates reduced by factor >100 with hybrid GEM + Micromegas structure
- Pixel readout in center with same spatial resolution
- Installed in 2014-2015, COMPAS data taking 2015-2022
- Used since 2023 in AMBER experiment in same beam line, with different phases foreseen, including Drell-Yan measurements

Irradiation impact

- Muon beams in 2016-2017 and 2021-2022, significant irradiation only around detector centers
- Pion beams on very thick target in 2014-2015 and 2018, low energy photons and neutrons on whole detector surface
- Detector performance sensitive to beam conditions, impact of channel occupancies
- But almost no degradation with the time
- Best performances: efficiencies around 98%, spatial resolutions around 80 µm, time resolutions around 12 ns

Hybrid Micromegas structure with 1 GEM foil interesting to get MM-like performance in high muon and hadron flux conditions