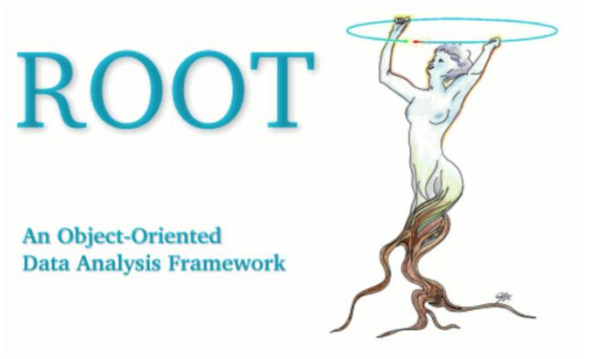
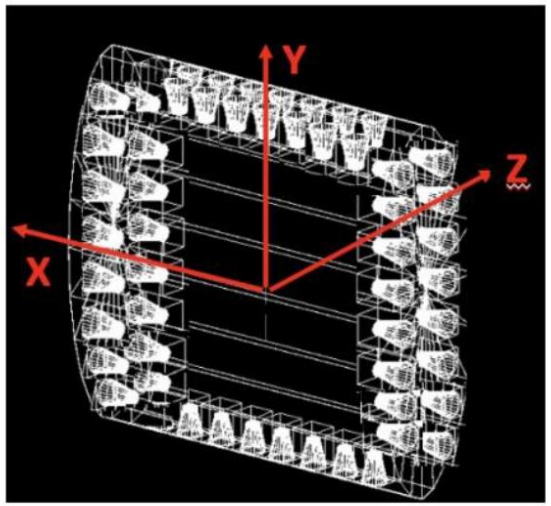
WOLFRAM MATHEMATICA



53 cameras in GRAIN



Multiple-view reconstruction in GRAIN with lenses

P. Bernardini, G. De Matteis, L. Martina, A. Surdo

DUNE Italian meeting – November 11th, 2025

UNIVERSITÀ DEL SALENTO
L'Ateneo tra i due mari

INFN
Istituto Nazionale di Fisica Nucleare

DUNE

Projective geometry based reconstruction

(from 2D images to 3D track and vice versa)

Each α camera is characterized by a 4x3 matrix: $P_\alpha[4][3]$

example

0	0	100	6000
0	-100	0	- 51200
1	0	0	649

2D track on SiPM array associated with a 3x1 matrix: $L_\alpha[3][1]$

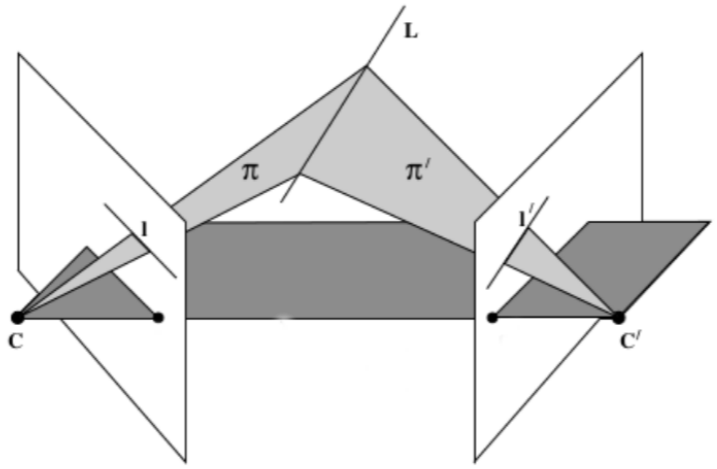
m_α -1 q_α

track parameters

The plane from the product of two matrixes: $P^T_\alpha[3][4]$ $L_\alpha[3][1] = \pi_\alpha[4][1]$

a_α b_α c_α d_α

plane parameters



Track in space found from the intersection of two planes

In this analysis only pairs of orthogonal lens-cameras

New functions

2D SiPM local reference system
3D GRAIN reference system

2Dto3D (tracks on α & β cameras) $\Rightarrow$ 3D-track

Two 2D-tracks on perpendicular cameras
(vertical & horizontal)

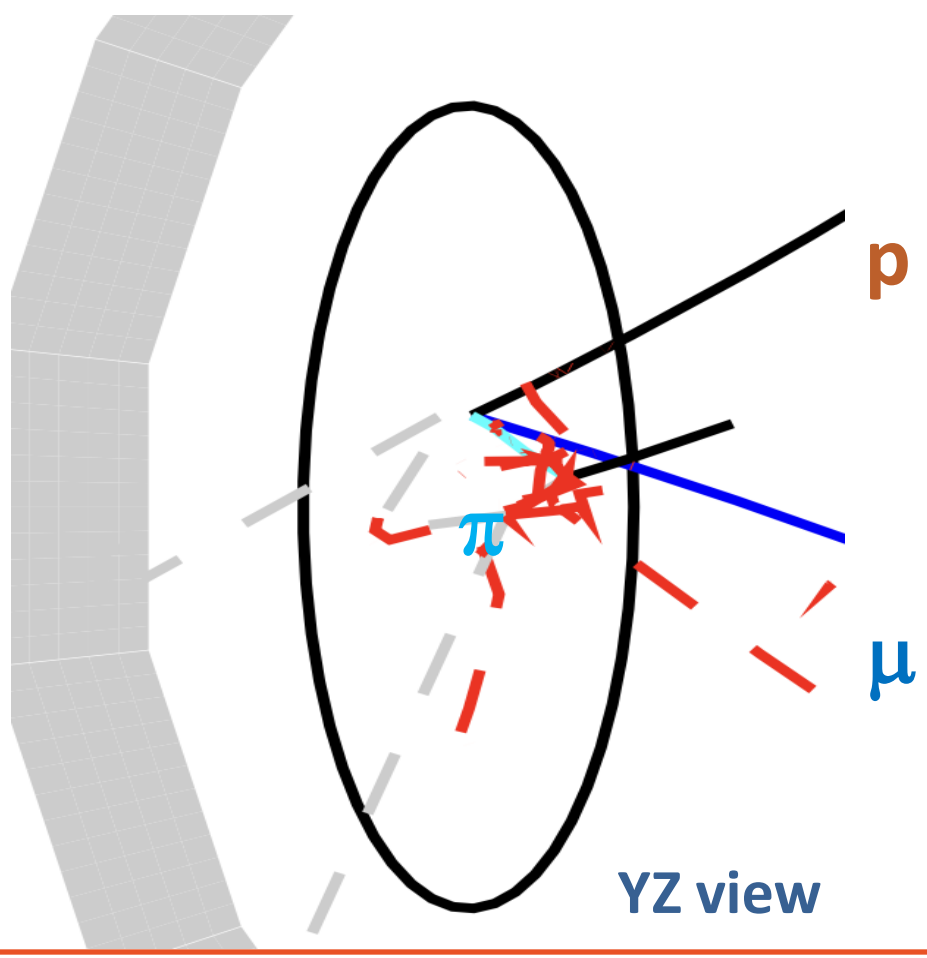
3Dto2D (3D-track) $\Rightarrow$ 2D-image on a 3rd camera (γ)

flag = 0 projection NO-visible on SiPM
1 projection visible on SiPM

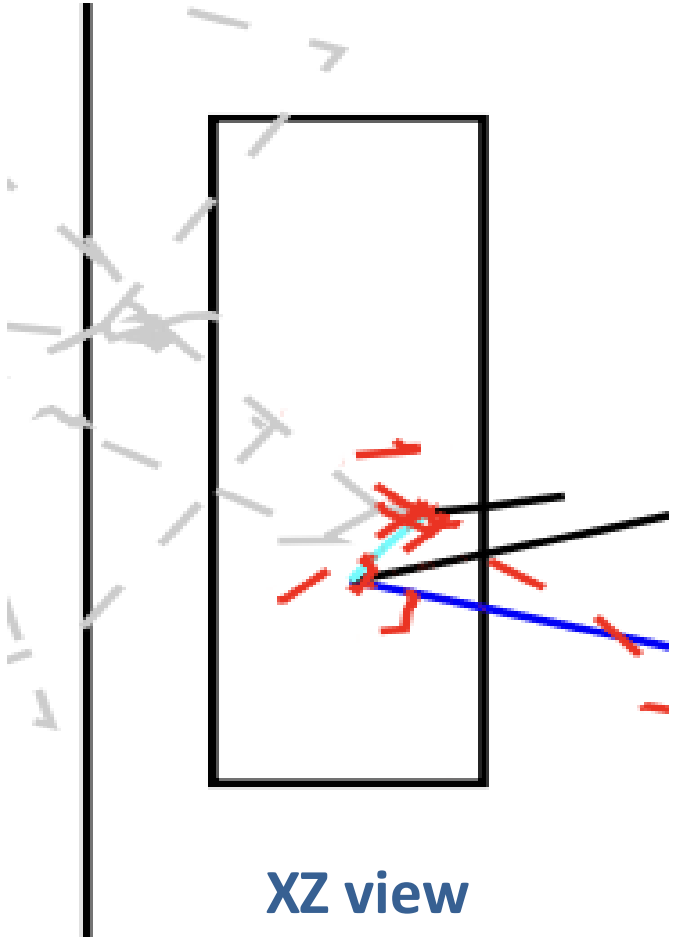
Event 158: $\nu \rightarrow p\ \pi^+\ \mu^-$

Vertex position: -292.3, +183.6, -4.3 mm

Neutrino energy: 2.97 GeV



YZ view



XZ view

Cam_1

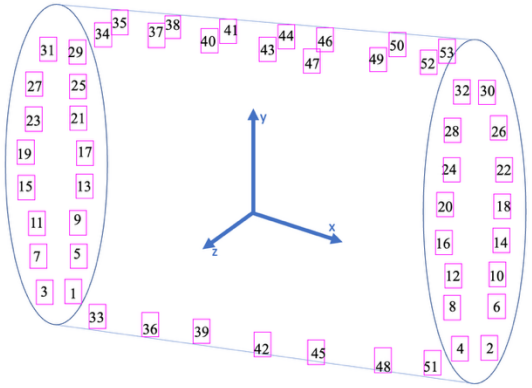
Cam_10

Cam_11

Cam_51

Shifted images with same slope in parallel cameras

Topological associations are possible



Event 158

p μ^- π^+

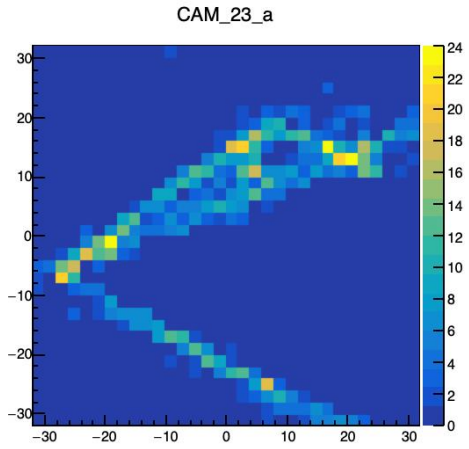
In this presentation

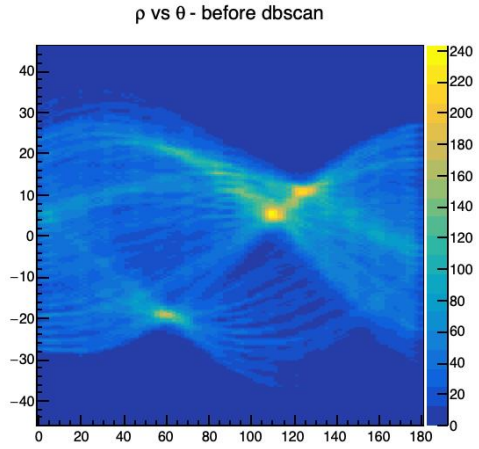
Rough algorithm to search for 2D-tracks

- dbscan + Hough transform
- no fit, just peaks in the Hough plane
- to be optimized

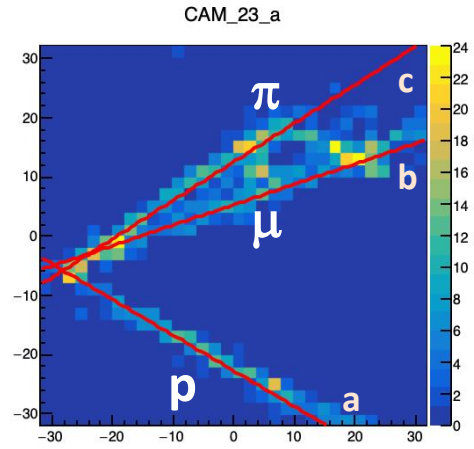
The work is focused on

- 3D reconstruction
- track association





Cam_23

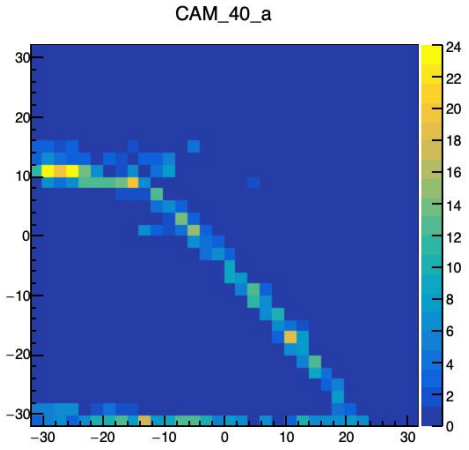


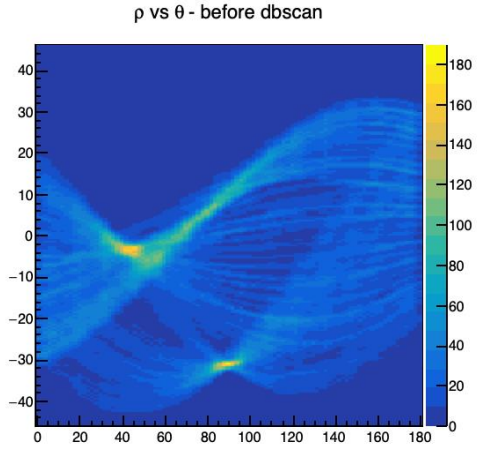
Tracks

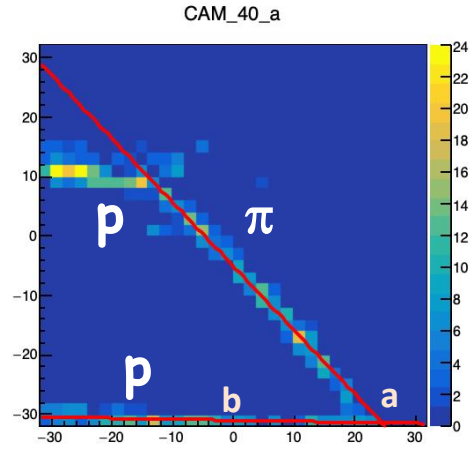
23/a
23/b
23/c

Peak choice

No track fit







Cam_40

Tracks

40/a
40/b

Event 158

p μ^- π^+

Event 158

3Dto2D

True 2D-tracks

Proton	slope	intercept
track 23/a	-0.560	-27.15
track 27	-0.645	+7.26
track 37/a	-0.454	+33.07
track 40/b	-0.036	-33.52
Muon		
track 23/b	+0.397	+2.17
track 37/b	+0.306	+12.56
Pion		
track 23/c	+0.692	+11.23
track 40/a	-1.128	-4.07

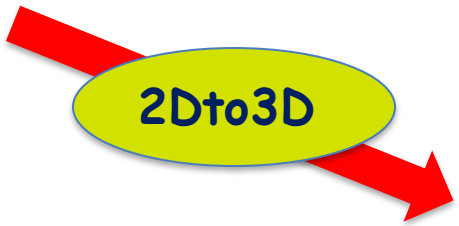
$\simeq$

Reconstructed 2D-tracks

	slope	intercept	
Track 23/a	-0.601	-22.75	vertical cameras
Track 23/b	+0.344	+5.29	
Track 23/c	+0.649	+12.52	
Track 27	-0.700	+13.43	
Track 37/a	-0.384	+29.45	horizontal cameras
Track 37/b	+0.306	+12.55	
Track 40/a	-1.072	-5.13	
Track 40/b	-0.017	-31.00	

Association of 2D tracks without MC information

2D-track on camera α
2D-track on camera β



2D SiPM local reference system
3D GRAIN reference system

3D-track

2D-image on camera γ

If a reconstructed 2D-track on camera γ is in agreement with this image,

then tracks on α , β , and γ cameras are projections of the same track. If not …

tracks: 40/b and 27 ⇒ 23
projection -0.622 -21.09

tracks: 37/a and 27 ⇒ 23
projection -0.636 -21.33

tracks: 40/a and 27 ⇒ 23
projection -0.396 -14.24

tracks: 37/b and 27 ⇒ 23
projection -0.867 -28.28

?

Reconstructed

23/a	-0.600,	-22.75
23/b	+0.344,	+5.29
23/c	+0.649,	+12.52
27	-0.700,	+13.43
37/a	-0.384,	+29.46
37/b	+0.306,	+12.55
40/a	-1.072,	-5.13
40/b	-0.017,	-31.00

Projections of the same track (proton)

40/b 27 23/a 37/a

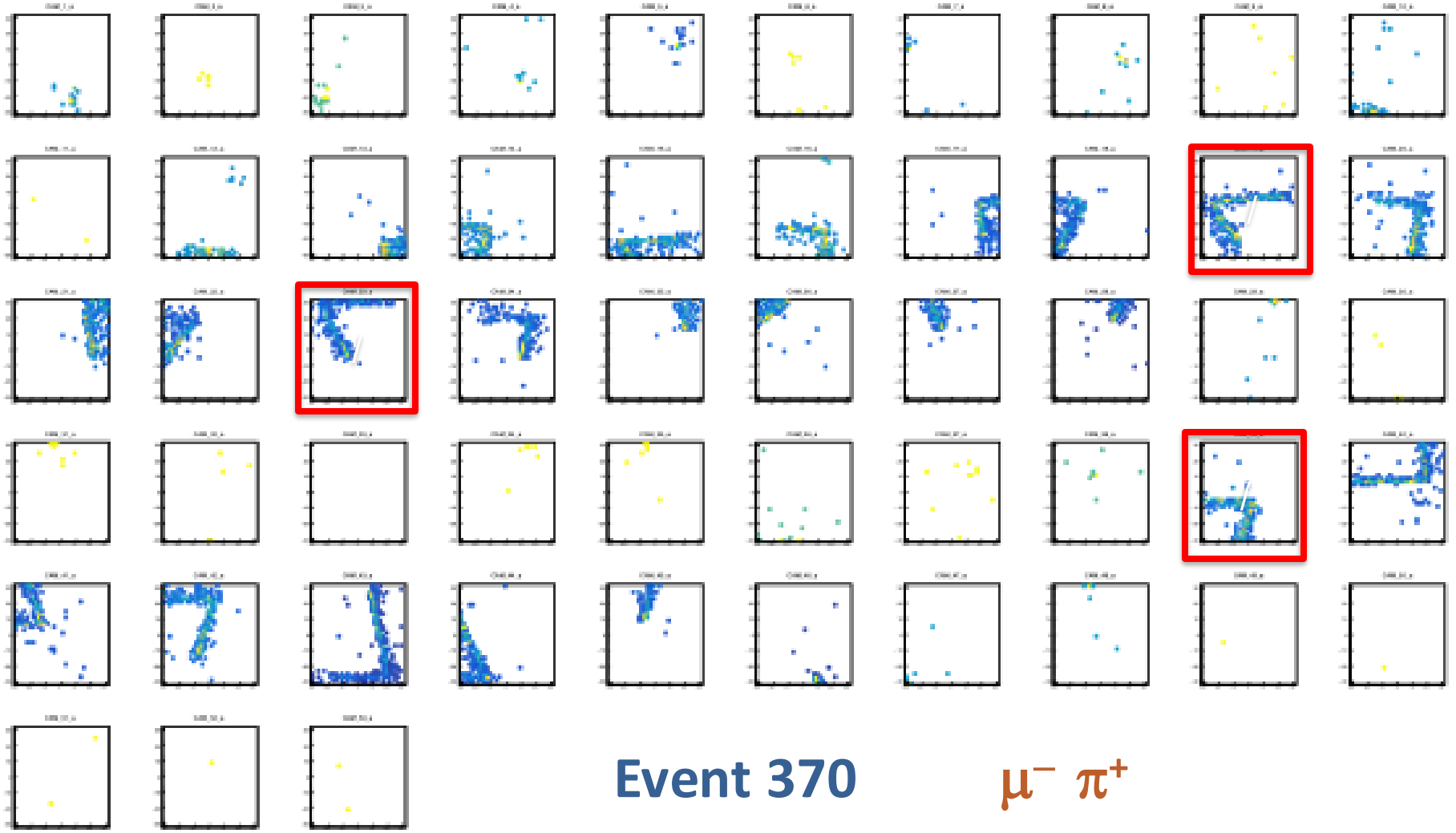
Not associated because 2 tracks are not enough

μ ⇒ 23/b 37/b
π ⇒ 23/c 40/a

(Topological association?)

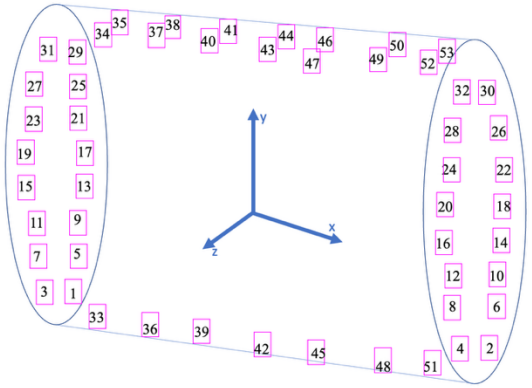
Event 158

Anyway, the 2D-track pair (α, β) allows for the projection on all chambers looking for another track in agreement with the projection



Event 370

μ^- π^+



Event 370

Reconstructed

19/a -1.235, -29.40
19/b +0.087, +5.02
22 +1, +26.16
23 -2.145, -18.93

39/a -0.123, -7.56
39/b +4.331 -13.34
40 -0.017, +7.00
42 +2.605, +9.77
43 -5.145, +73.37
44 -2.145, -56.79

tracks: 39/b and 23 ⇒ 19
projection -1.516 -32.21

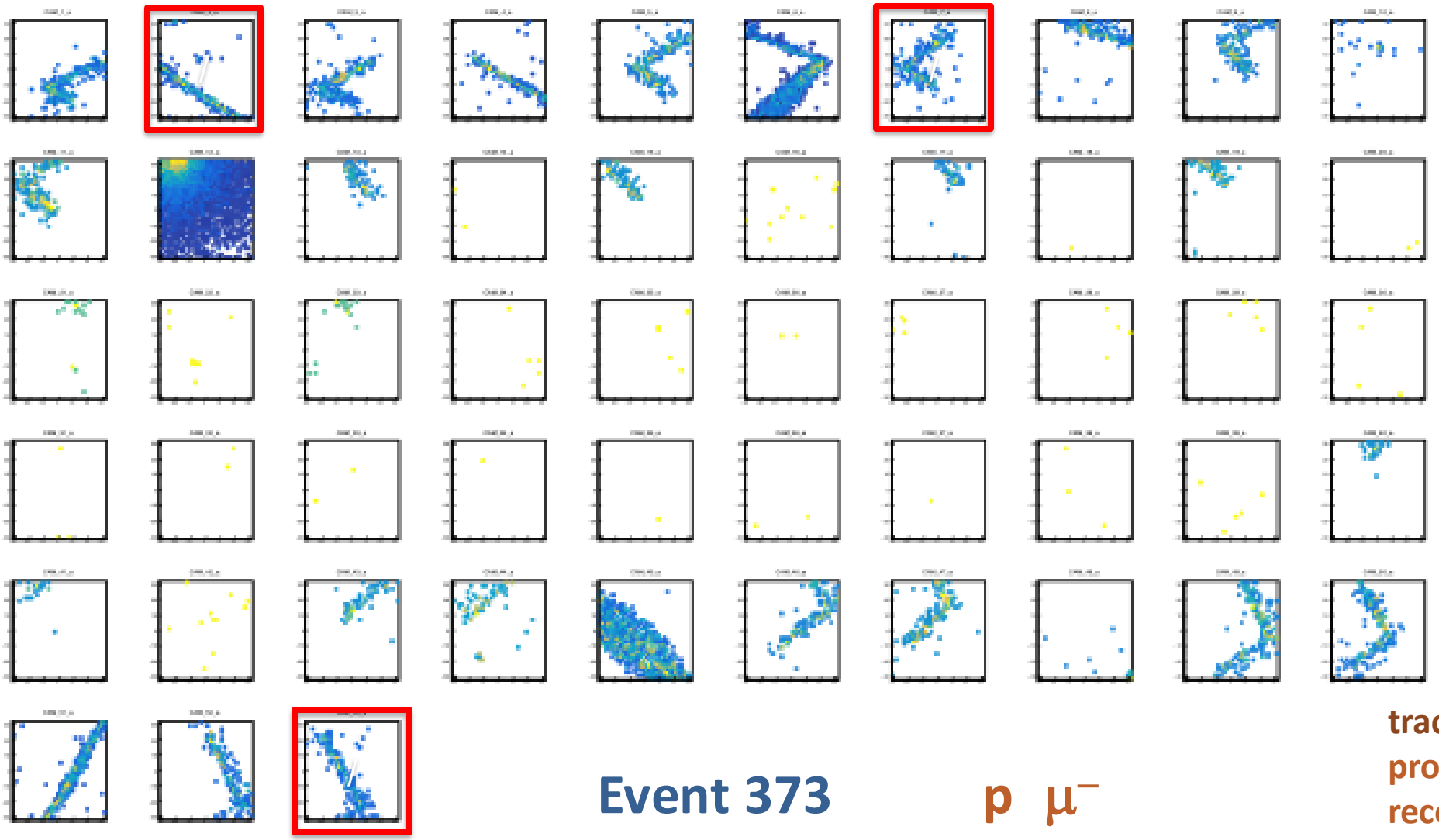
tracks: 22 and 42 ⇒ 19
projection -0.979 -27.03

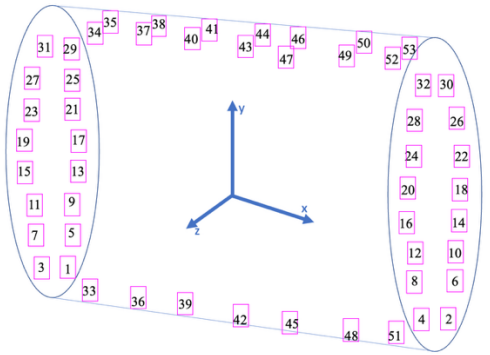
tracks: 23 and 39/b ⇒ 22
projection +1.364 +35.41

cameras: 19/b and 40 ⇒ 39
projection 0.029 -5.60

Slanted track (muon) 19/a 22 23 39/b 42 43 44

Horizontal track (pion) 19/b 39/a 40



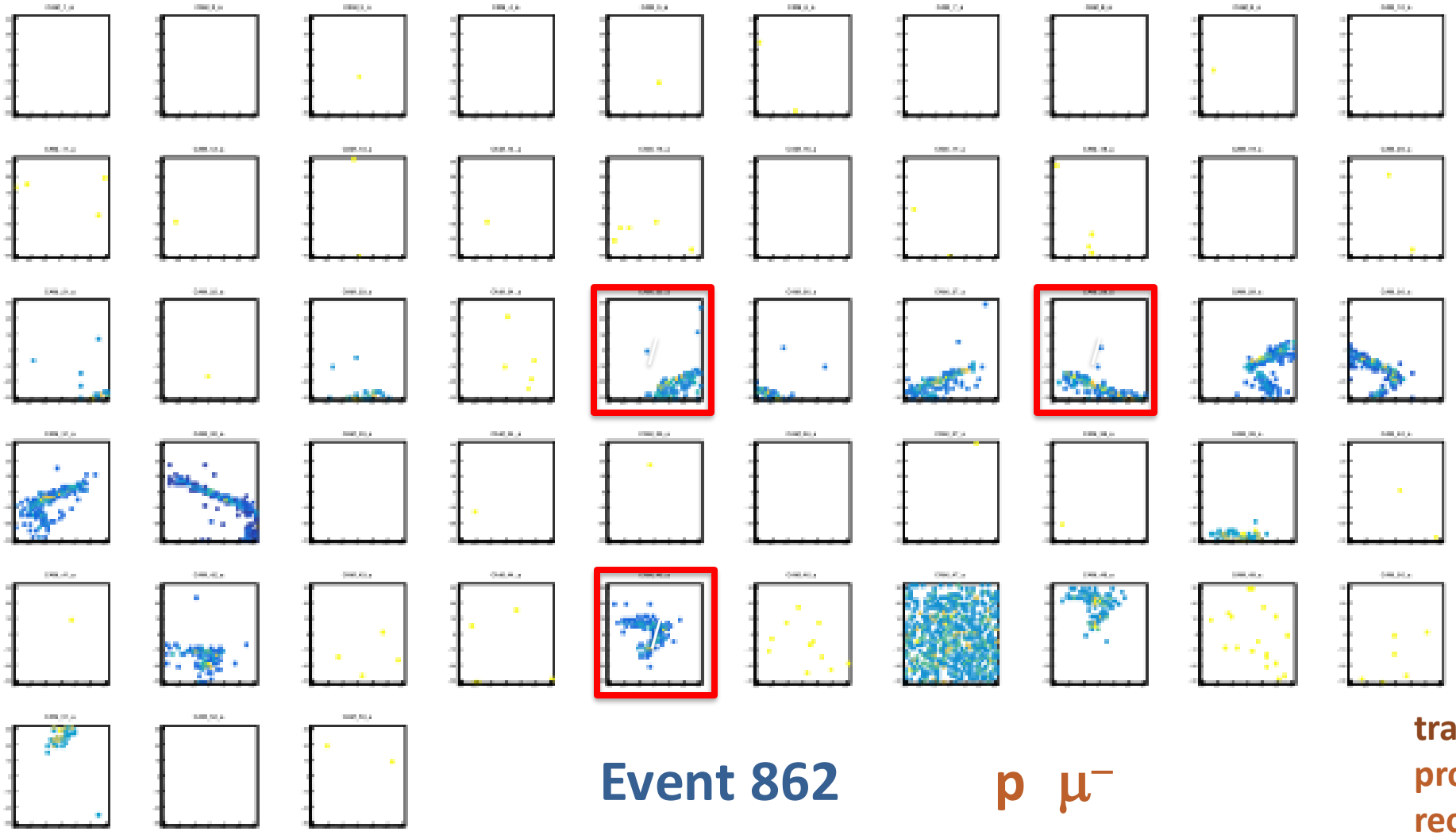


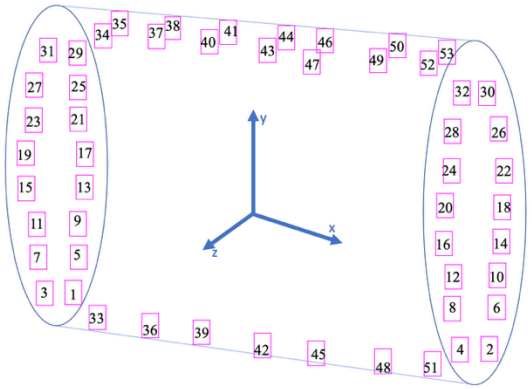
Event 373

p μ⁻

tracks: 7/b and 53 ⇒ 2

projection	-0.515	-21.83
reconstruction	-0.649	-18.48





Event 862

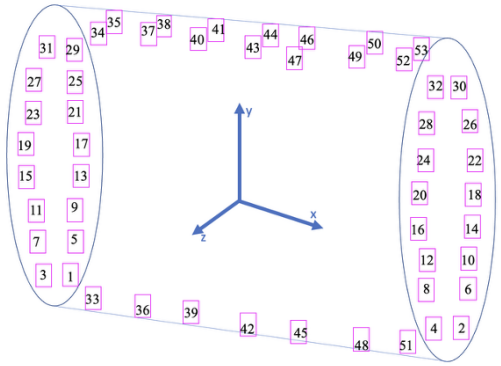
p μ^-

tracks: 28 and 45/a ⇒ 25

projection	0.881	-26.96
reconstruction	0.601	-28.58

Interaction vertex

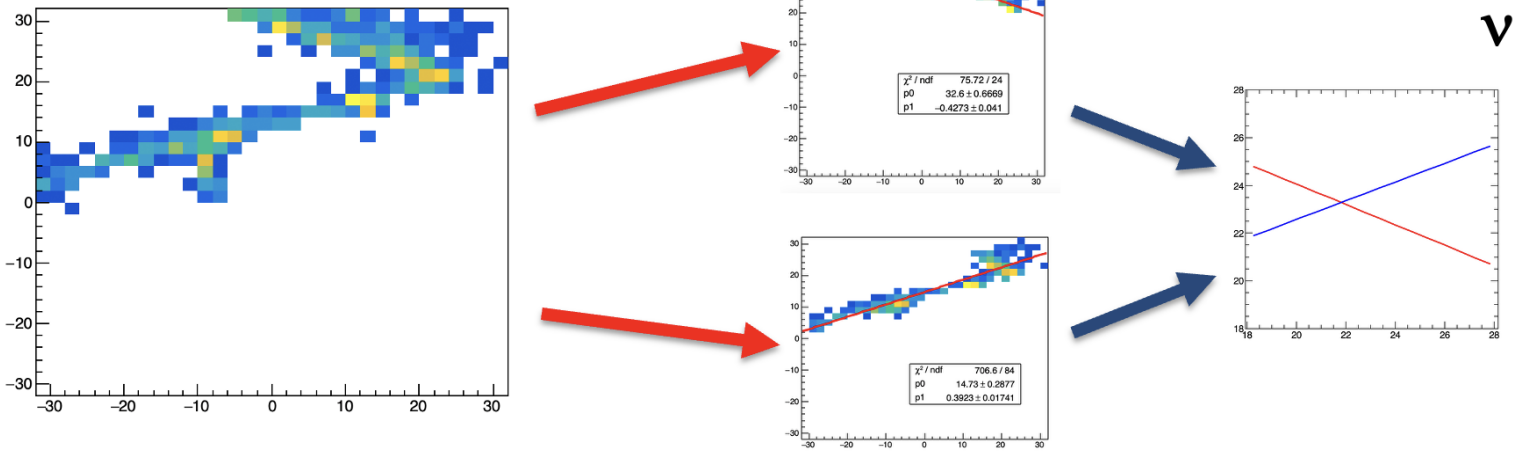
Procedure for vertex reconstruction with two-tracks neutrino events



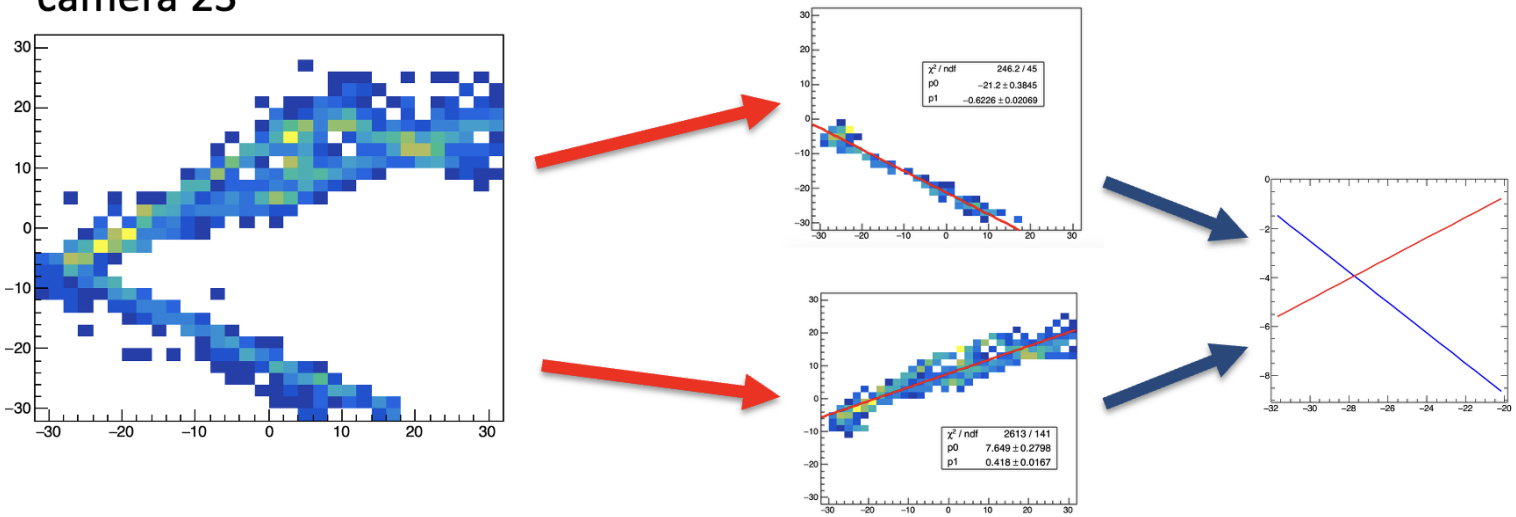
this example

$\nu \rightarrow \mu^- p \pi^+$

camera 37



camera 23



- Local 2D-vertices are obtained from tracks intersections
- 3D vertex in GRAIN frame from two local vertices on orthogonal cameras

Preliminary estimate:

few-cm uncertainty

Function 2DVto3DV

Conclusions

- Couple of 2D-tracks on orthogonal cameras
  ⇒ 3D track
  ⇒ Its projection on a third camera
  ⇒ IF a reconstructed track is in agreement with the projection
  ⇒ The 3 tracks are associated

- Two 3D-tracks ⇒ Vertex as mid point of the shortest distance

- Many reconstructed 2D-tracks on the cameras ⇒ Many associations and possible checks

- Also topological criteria can be used/investigated

Code : **tracks** - 2Dto3D – 3D track from 2 perpendicular cameras
- 3Dto2D – track image on a camera
- association - **tracks on** α, β, γ **cameras**

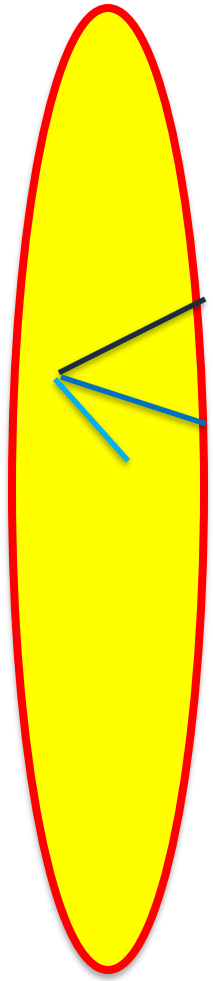
vertices - **2DVto3DV** - 3D vertex from 2 perpendicular cameras
- **check - agreement of 2D vertices** ($V_\alpha V_\beta V_\gamma$)

BUFFER

Required

centri_CAMS.txt	coordinates of the camera centers (GRAIN reference system, in mm)
P_alpha function	creates the 53-camera matrix. Based on geometry and features of the lenses

Every change in the setup must be considered



MC data: first & last coordinates

3D-tracks

3Dto2D

True 2D-tracks

Proton	slope	intercept
track 23/a	-0.560	-27.15
track 27	-0.645	+7.26
track 37/a	-0.454	+33.07
track 40/b	-0.036	-33.52
Muon		
track 23/b	+0.397	+2.17
track 37/b	+0.306	+12.56
Pion		
track 23/c	+0.692	+11.23
track 40/a	-1.128	-4.07

Association of 2D tracks without MC information

- Required 2D-tracks on 3 cameras (α, β, γ; α, β are orthogonal)

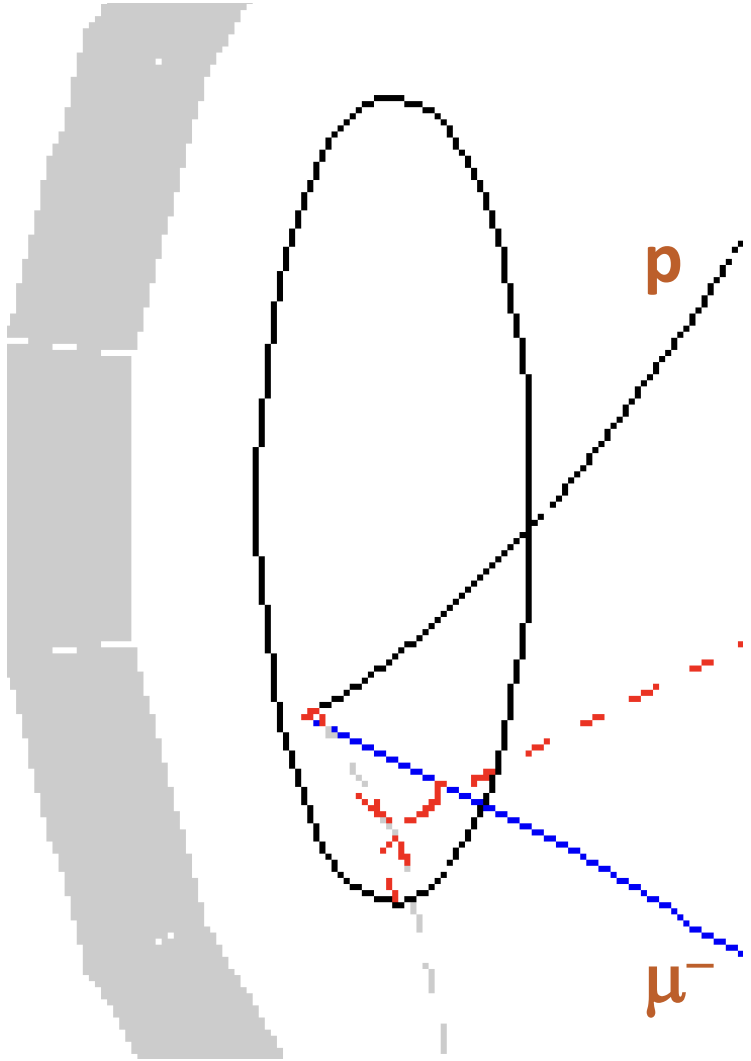
- Use of trifocal tensor TTT[53][53][53][3][3][3]

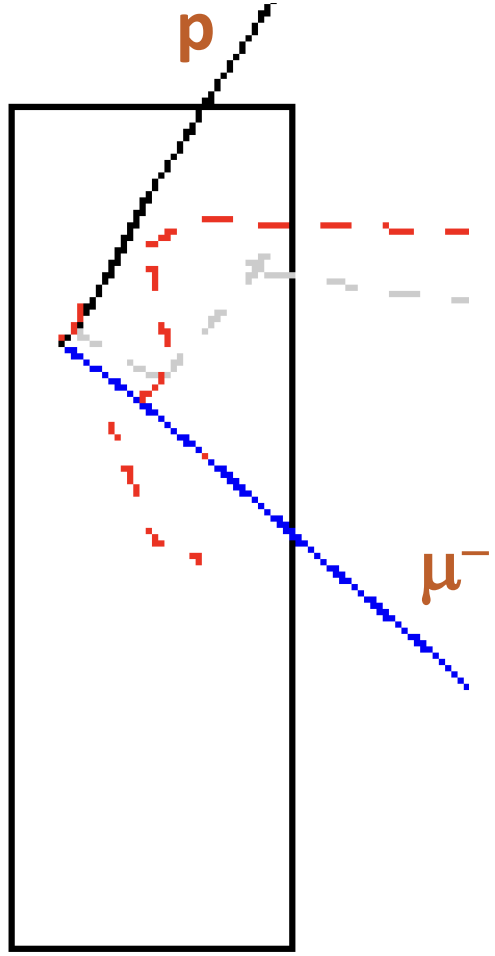
- **2Dto3D (track on α + track on β) $\Rightarrow$ 3D-track**

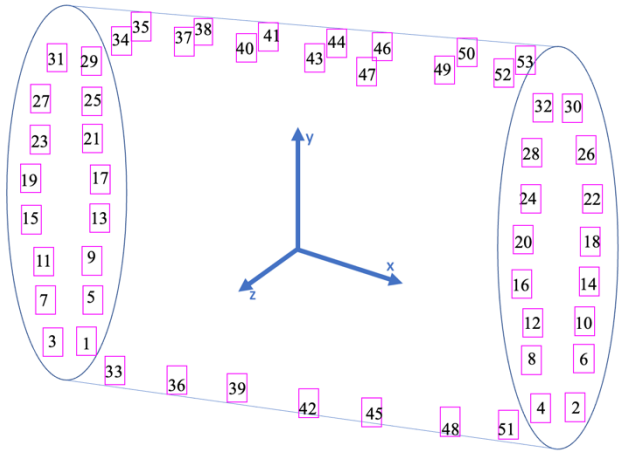
- **3Dto2D (3D track) $\Rightarrow$ 2D-track on γ camera (m_γ, q_γ, flag)**

- **If m_γ and q_γ (flag=1) are *close* to the measured values, the 3 2D-tracks are associated.** If not, repeat the procedure with other tracks

  * How much ? It depends on the analysis







Event 373 p μ⁻