Multi-vertex fiTQun for pion scattering measurements in WCTE
Processes

Institut de Física d'Altes Energies

Introduction to fiTQun
oo

Strategy
o

Scattering angle and track length study
oooooooooooooooooooo

Statistics
o

Display
oooooo

Conclusion
oo

Table of Contents

1 Introduction to fiTQun

2 Strategy

3 Scattering angle and track length study

**4** Statistics

5 Display

6 Conclusion

fiTQun

- FiTQun is a maximum likelihood estimation event reconstruction algorithm for WC experiments,

- FiTQun steps:
  1. Vertex pre-fitting,
  2. Hit clustering,
  3. Single-ring reconstruction,
  4. Multi-ring reconstruction.

- likelihood, function of the particle parameters specifying initial condition:
  - vertex position x, y, z, time t,
  - zenith angle and azimuth of the direction θ, ϕ,
  - momentum p,
  - Eloss (visible energy), only for pion.

$$L(\mathbf{x}) = \prod_{j}^{unhit} P_j\left(unhit|\mathbf{x}\right) \prod_{i}^{hit} P_i\left(hit|\mathbf{x}\right) f_q\left(q_i|\mathbf{x}\right) f_t\left(t_i|\mathbf{x}\right)$$

Likelihood to maximise — Candidate track hypothesis — Probability of no hit at PMT — Probability of hit at PMT — Hit charge probability density — Hit time probability density

Preparation for Multi-Vertex fiTQun

- Normal fiTQun only find the pion upstream track →
- Multi-Vertex needed to find pion scattering vertex ↘
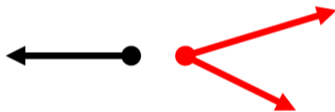
1. Reconstruct the first ring

2. Search the second ring assuming the primary vertex.

3. Search the third ring assuming the primary vertex.

1. Reconstruct the first ring
2. Search second vertex
3. Search the second ring assuming the second vertex.
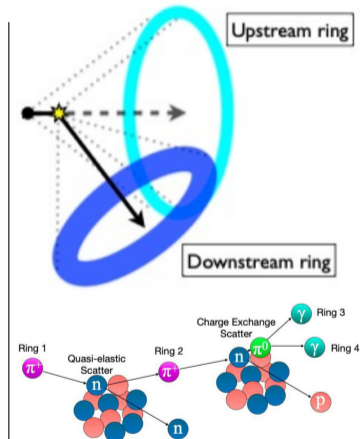4. Search the third ring assuming the second vertex.

Figure: Pion scattering processes in WCTE

Strategy

1. Single Vertex fit ✓
2. Multi-ring Separation ✓
3. Implementation of Multi-Vertex fit ✓
4. Scattering angle and track length study
5. Multi-Vertex fit with constraint
6. e^-/π Multi-ring study (background)

Interaction processes

- Interactions of π^+ seen through WCSim track list to consider:
  1. π^+ scattering,
  2. Charge Exchange π^0,
  3. Double Charge Exchange π^-,
  4. Δ Resonance with one π^+,
  5. Δ Resonance with two $\pi^\pm$,
  6. Δ Resonance with three $\pi^\pm$,
  7. Decay $\mu^\pm$,
  8. Other ($e^\pm$).

Figure: created from
`https://www.aidansean.com/feynman/`
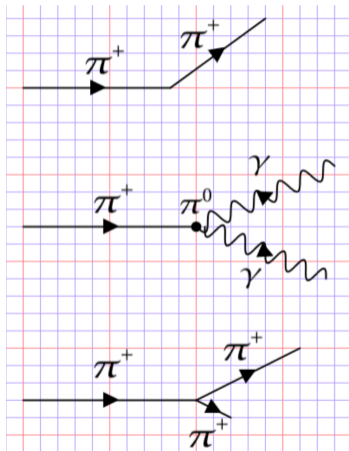
Interaction processes

π^+ scattering
- $\pi^+ + X \to \pi^+ + X$

Decay μ^+
- $\pi^+ \to \mu^+ + \nu_\mu$

Charge Exchange π^0
- $\pi^+ + n \to \pi^0 + p \to \gamma + \gamma + p$

Double Charge Exchange π^-
- $\pi^+ + 2n \to \pi^- + 2p$

Δ Resonance with one π^+
- $\pi^+ + p \to \pi^+ + \pi^0 + p$
- $\pi^+ + n \to \Delta^+ \to \pi^+ + \pi^0 + n$
- $\pi^+ + p \to \Delta^{++} \to \pi^+ + \pi^0 + p$

Δ Resonance with two $\pi^\pm$
- $\pi^+ + p \to \pi^+ + \pi^+ + n$
- $\pi^+ + n \to \pi^+ + \pi^- + p$
- $\pi^+ + {}^{16}O \to \pi^+ + \pi^- + \pi^0 + fragments$
- $\pi^+ + p \to \Delta^{++} \to \pi^+ + \pi^+ + n$

Δ Resonance with three $\pi^\pm$
- $\pi^+ + {}^{16}O \to \pi^+ + \pi^- + \pi^+ + fragments$

Other
- $\pi^+ \to e^+ + \nu_e$
- $\pi^+ + {}^{16}O \to 2p + 2n + {}^{12}C$
- $\pi^+ + n \to p + \gamma$

Length and scattering angle for pions of 200 MeV momentum
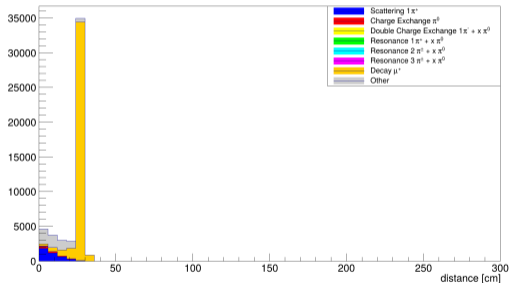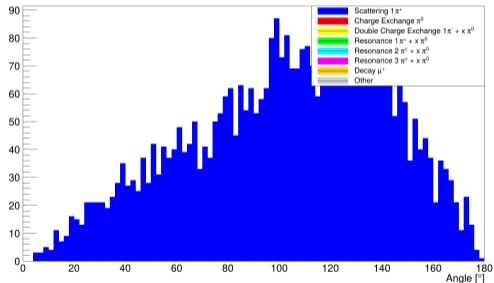
Length and scattering angle for pions of 250 MeV momentum

Introduction to fiTQun

Strategy

Scattering angle and track length study

Statistics

Display

Conclusion
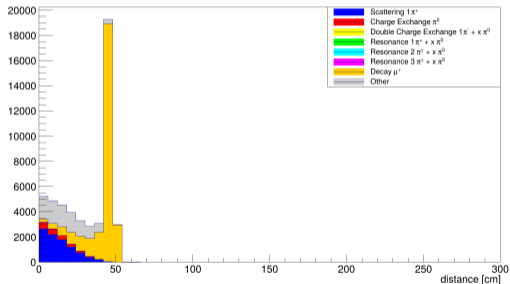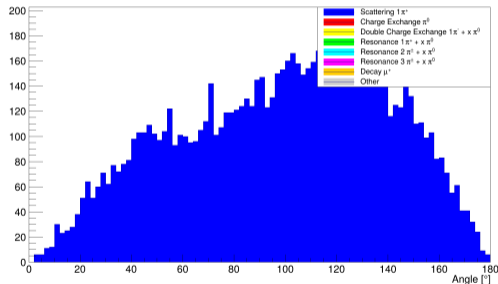
Length and scattering angle for pions of 300 MeV momentum
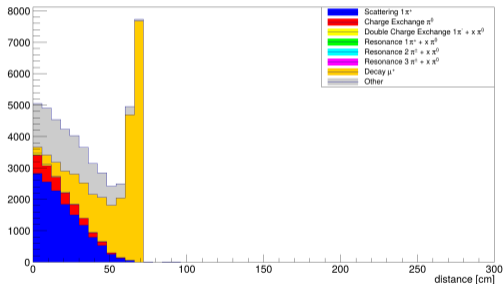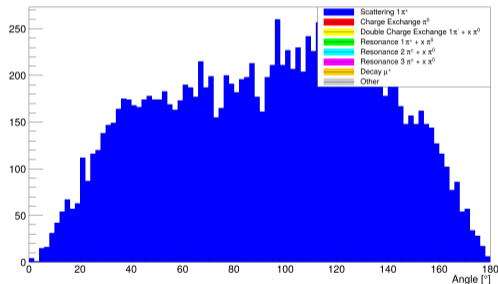
Length and scattering angle for pions of 350 MeV momentum

Length of 1st π^+ for 350 MeV
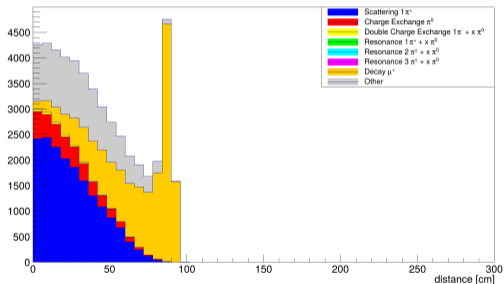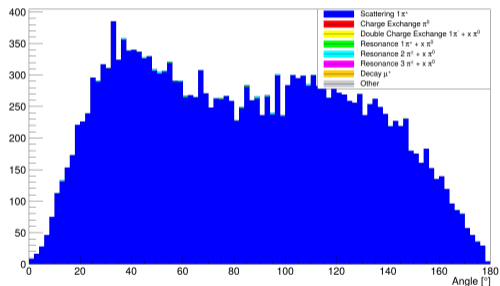

Angle between 1st π^+ track WCSim and 2^{nds} π^+ for 350 MeV
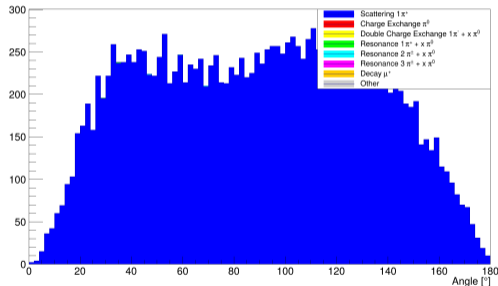
Length and scattering angle for pions of 400 MeV momentum

Length of 1st π^+ for 400 MeV
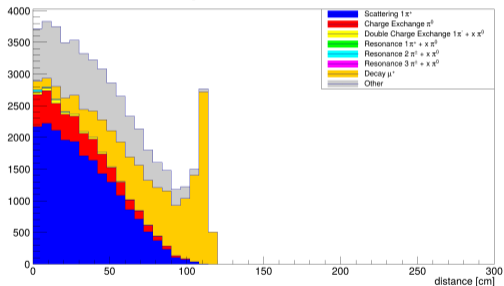
Angle between 1st π^+ track WCSim and 2^{nds} π^+ for 400 MeV

Length and scattering angle for pions of 450 MeV momentum
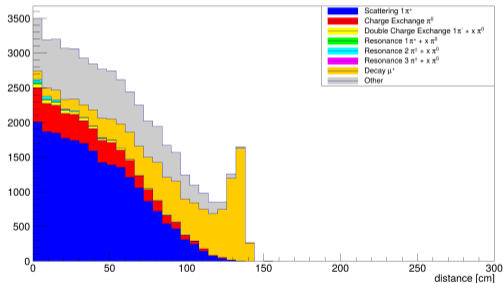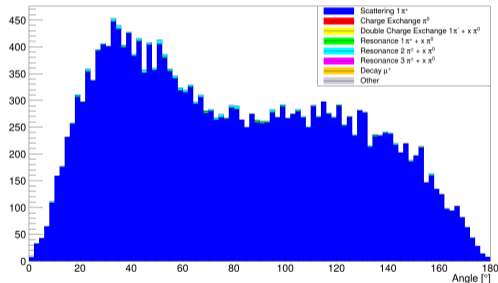
Length and scattering angle for pions of 500 MeV momentum
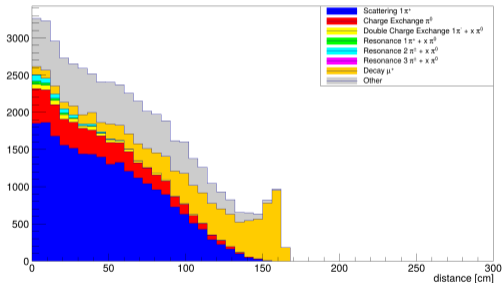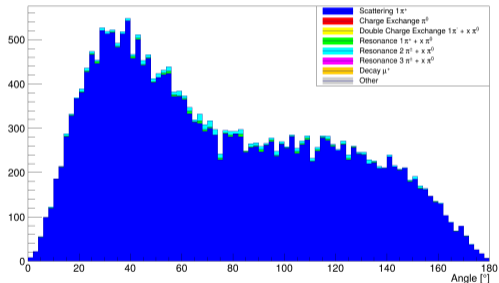
Length and scattering angle for pions of 550 MeV momentum

Length of 1st π^+ for 550 MeV
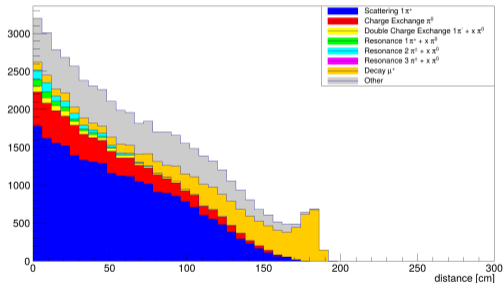
Angle between 1st π^+ track WCSim and 2^{nds} π^+ for 550 MeV
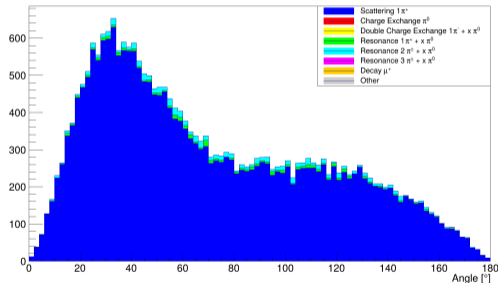
Length and scattering angle for pions of 600 MeV momentum
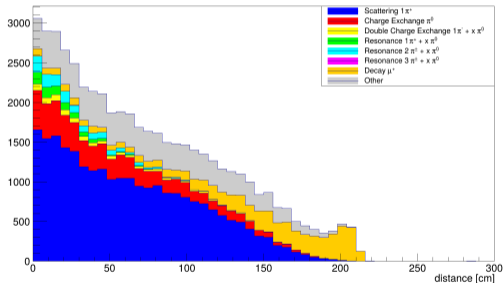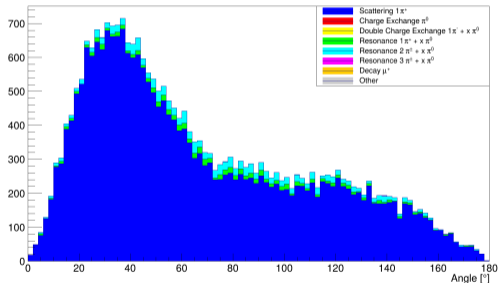
Length and scattering angle for pions of 650 MeV momentum
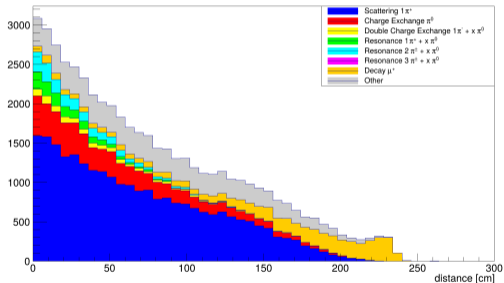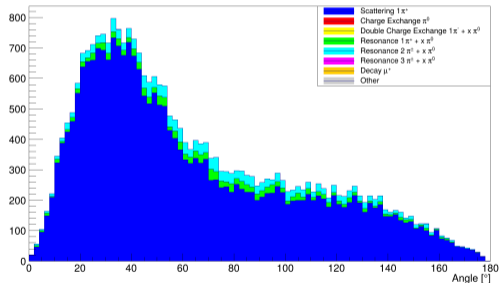
Length and scattering angle for pions of 700 MeV momentum

Length of 1st π^+ for 700 MeV
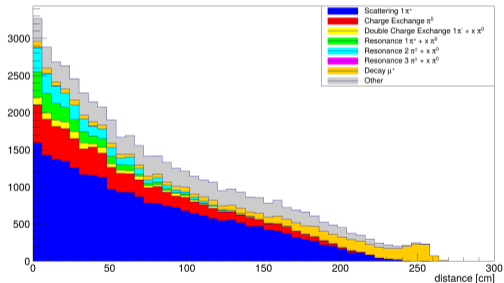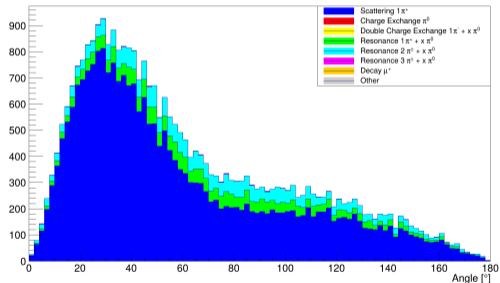

Angle between 1st π^+ track WCSim and 2^{nds} π^+ for 700 MeV
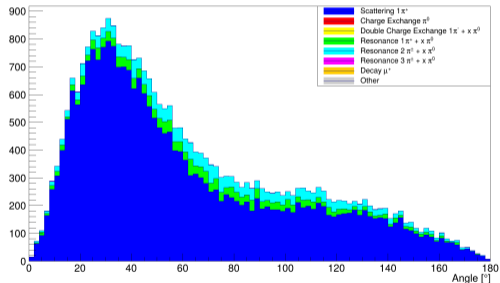
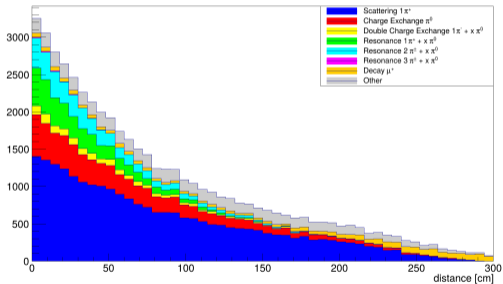# Length and scattering angle for pions of 750 MeV momentum

Length of 1st π^+ for 750 MeV
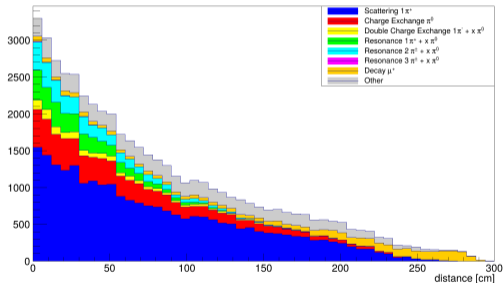
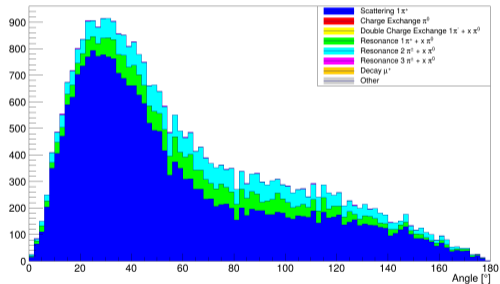Angle between 1st π^+ track WCSim and 2^{nds} π^+ for 750 MeV

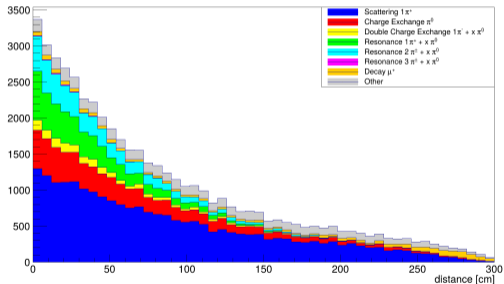# Length and scattering angle for pions of 800 MeV momentum

Length of 1st π^+ for 800 MeV

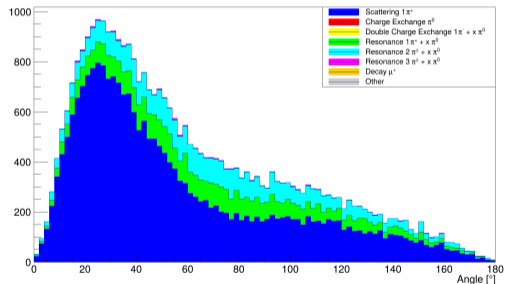Angle between 1st π^+ track WCSim and 2^{nds} π^+ for 800 MeV

Length and scattering angle for pions of 850 MeV momentum

Length and scattering angle for pions of 900 MeV momentum
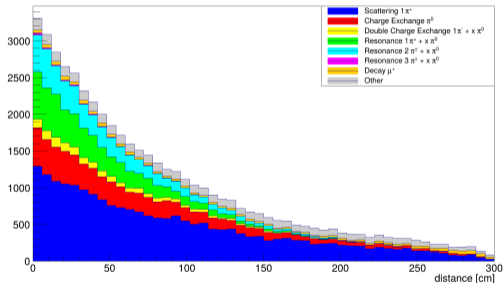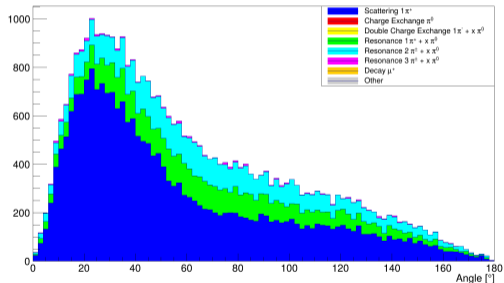
Length and scattering angle for pions of 950 MeV momentum

Length of 1st π^+ for 950 MeV
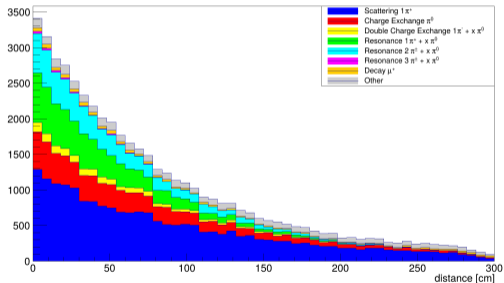
Angle between 1st π^+ track WCSim and 2^{nds} π^+ for 950 MeV
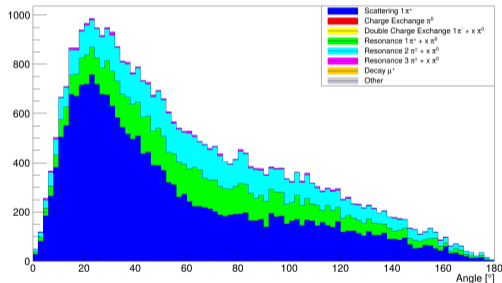
Length and scattering angle for pions of 1000 MeV momentum

Length of 1st π^+ for 1000 MeV
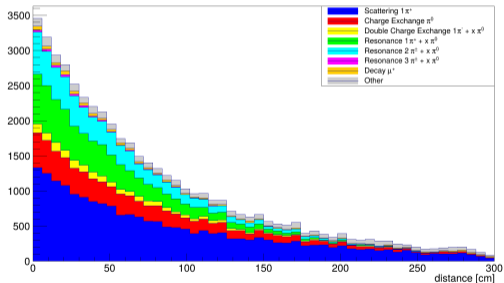
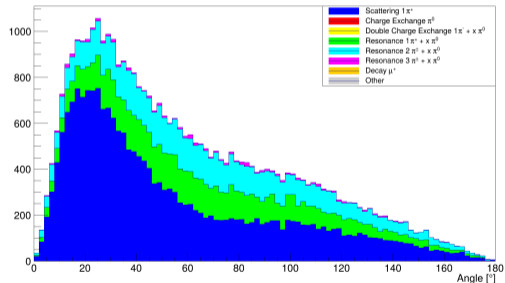Angle between 1st π^+ track WCSim and 2^{nds} π^+ for 1000 MeV
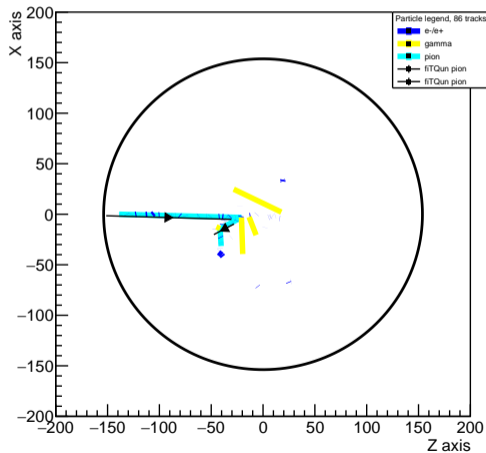
Interaction process statistics

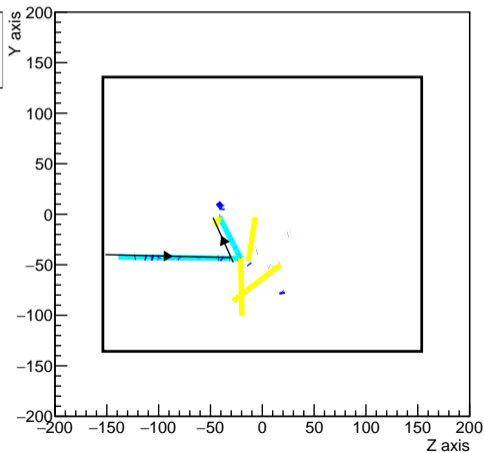| Momentum MeV	Scattering	Charge Exchange pi0	Double CE pi-	resonance 1pi	resonance 2pi	resonance 3pi	decay mu+	Other	total
200	3885	781	0	26	0	0	38447	6861	50000
250	9123	1777	0	69	0	0	28893	10138	50000
300	13892	2801	0	155	1	0	22083	11068	50000
350	17341	3550	2	257	4	0	17284	11562	50000
400	20427	4244	16	357	49	0	13509	11398	50000
450	22340	4696	61	458	157	0	10973	11315	50000
500	23731	5250	169	586	379	0	8804	11081	50000
550	24368	5796	394	748	673	0	7321	10700	50000
600	24924	6172	762	810	1193	2	6003	10134	50000
650	25263	6504	1267	946	1669	1	5120	9230	50000
700	25219	6975	1997	1155	2312	12	4117	8213	50000
750	24766	7162	2999	1332	3048	26	3397	7270	50000
800	24427	7437	3884	1464	3684	54	2805	6245	50000
850	23186	7518	5173	1608	4567	83	2443	5422	50000
900	22198	7757	6137	1656	5361	149	2003	4739	50000
950	21421	7765	7179	1698	5962	201	1706	4068	50000
1000	21188	7504	7851	1744	6461	273	1476	3503	50000

Process pi+Inelastic : 430357

Track display, good event

Track display, presence of π^0

Introduction to fiTQun
Strategy
Scattering angle and track length study
Statistics
Display
Conclusion
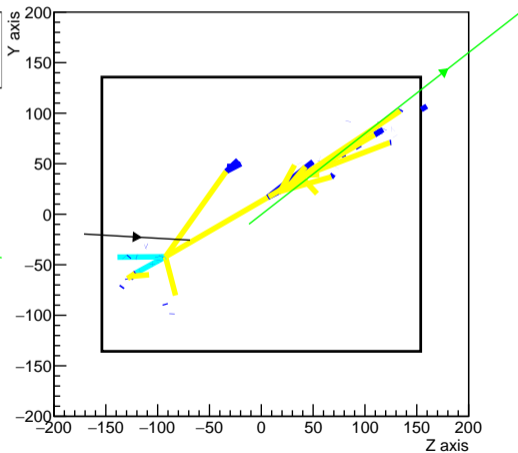
Track display, WCSim lack of information

WC detector, ev #6 from pi+ (1000.00 MeV)
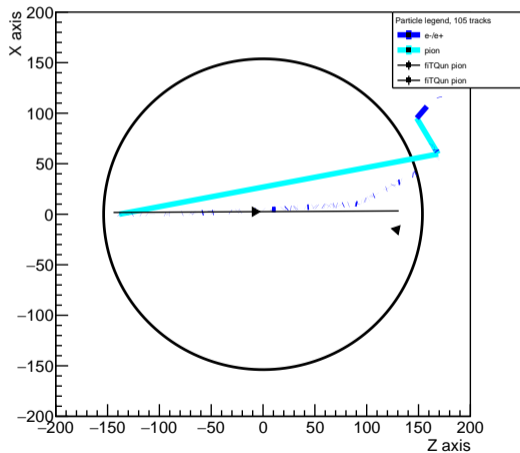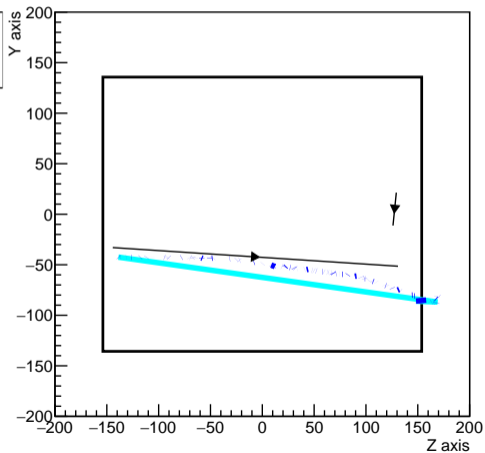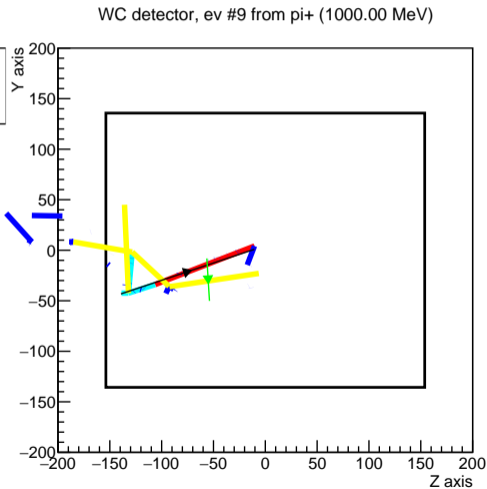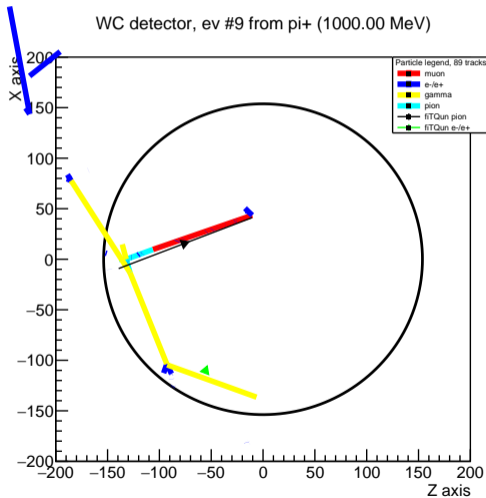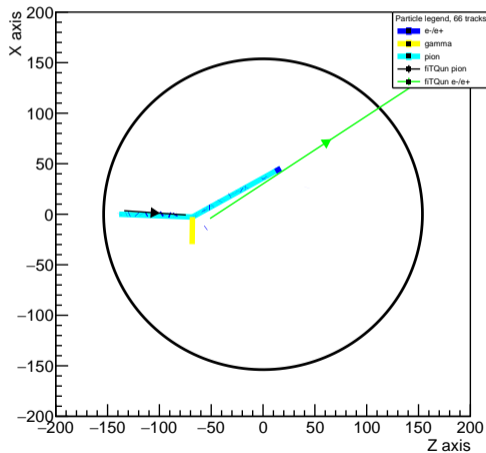
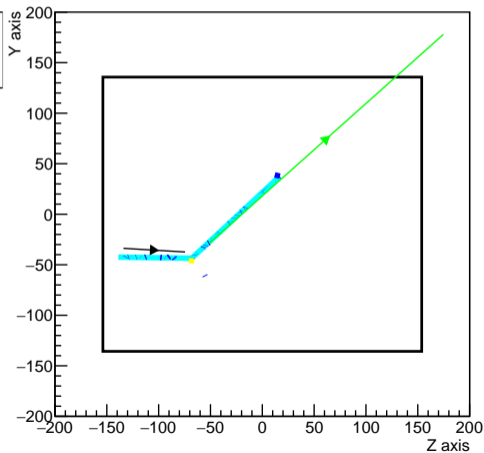WC detector, ev #6 from pi+ (1000.00 MeV)

Track display, in-flight decay

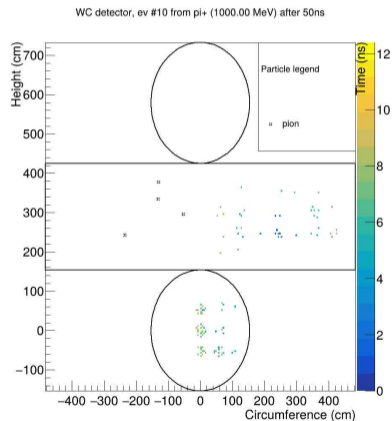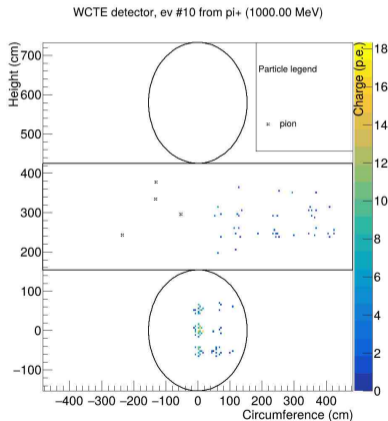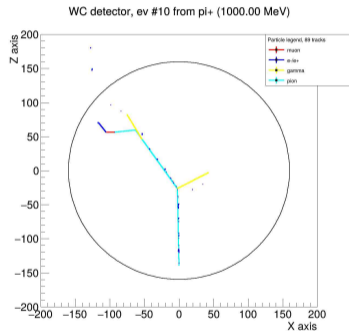# Track display, needs better MR tuning

Track display, only few PMT hits

WC detector, ev #10 from pi+ (1000.00 MeV)

WCTE detector, ev #10 from pi+ (1000.00 MeV)

WC detector, ev #10 from pi+ (1000.00 MeV) after 50ns
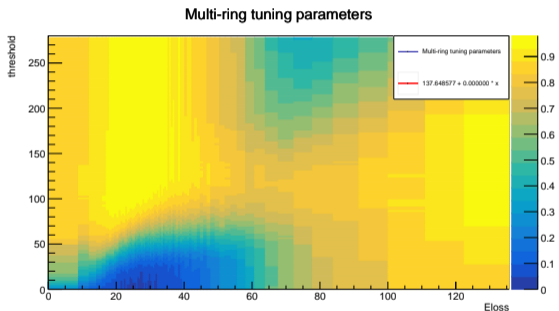
Multi-ring tuning with Multi-Vertex
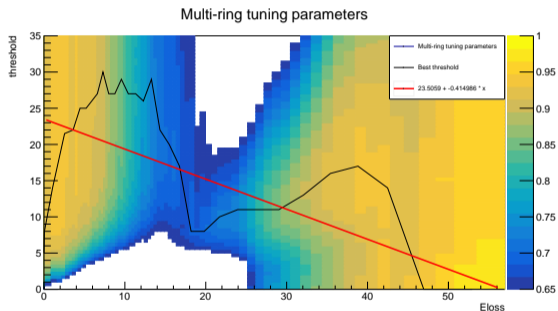
- Muon at center, all directions
- 88.7% separation

- One muon at beam position, second 1m away
- 92.5% separation

Conclusion

- A lot of unexpected interactions with π^+,
- Couldn't find yet a good relation between fiTQun reconstruction and the length or angle of WCSim tracks,
- It looks like fiTQun try to perfect the reconstruction by using small electron track at times,
- CherenkovDigiHit sometimes does not go beyond few ns,
- I will add constraints on fiTQun first track (position and direction),
- I am redoing the MR tuning with Multi-Vertex (new threshold found for 1/2 rings), with exponential distribution for second muon position.