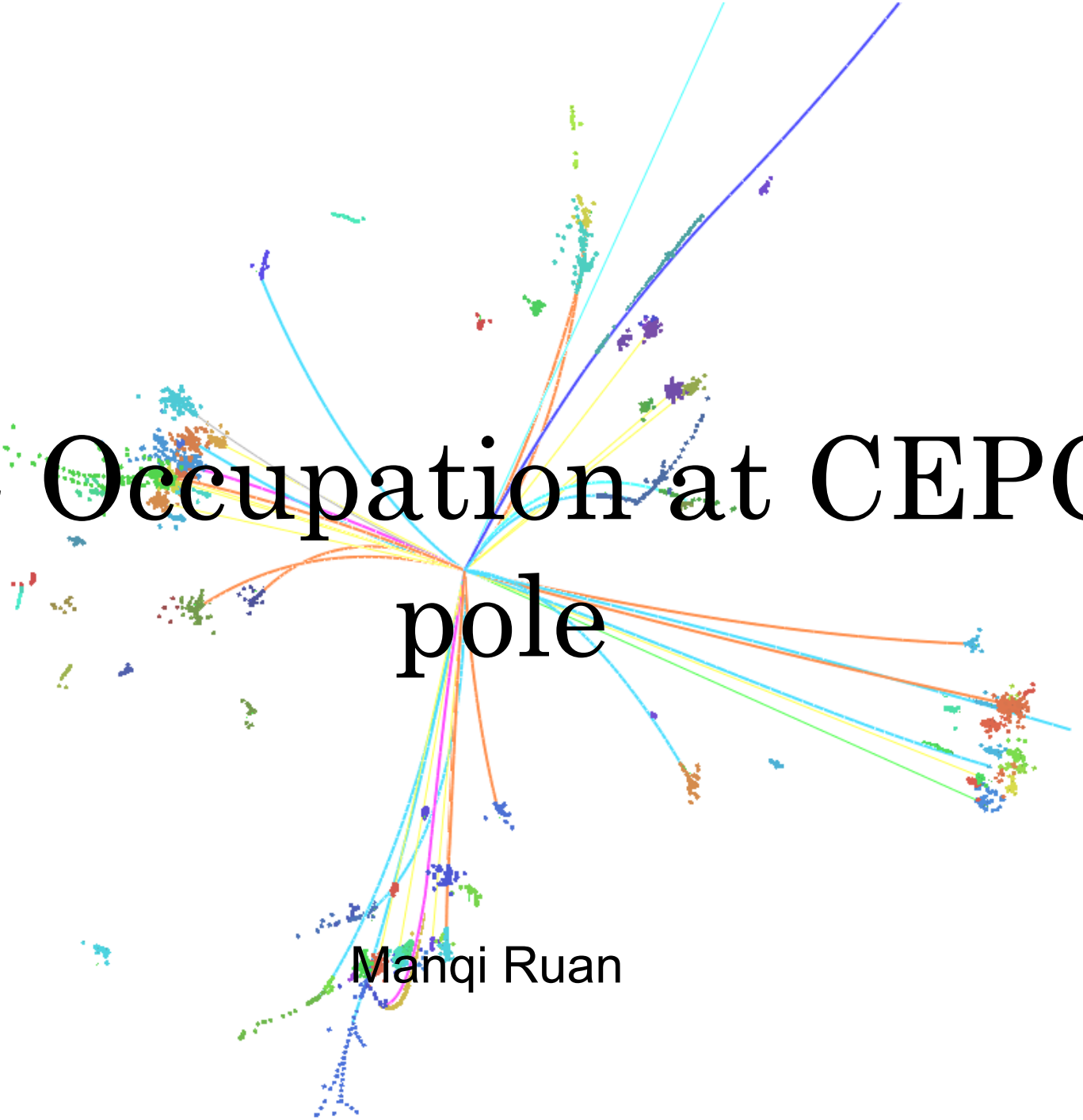
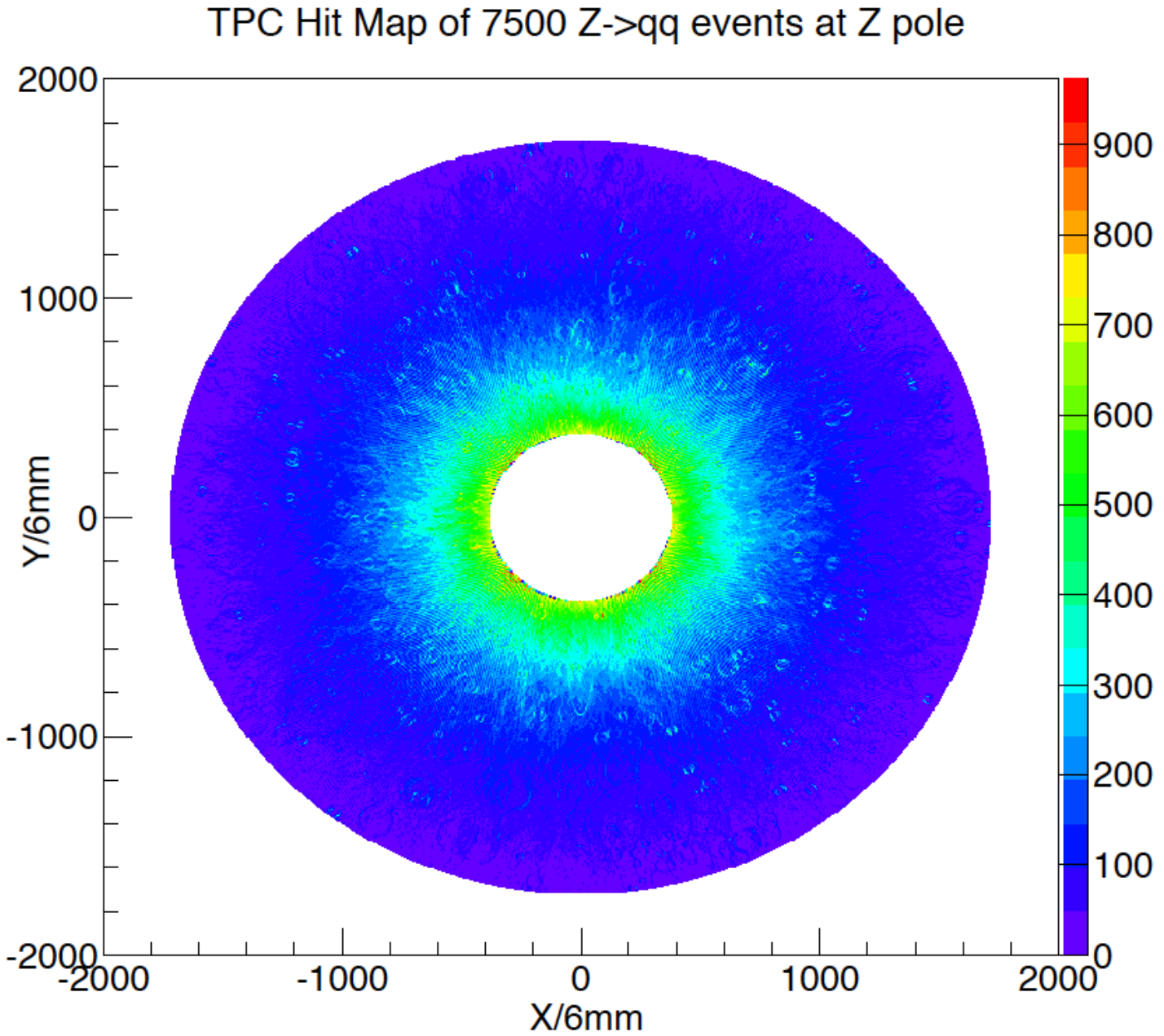
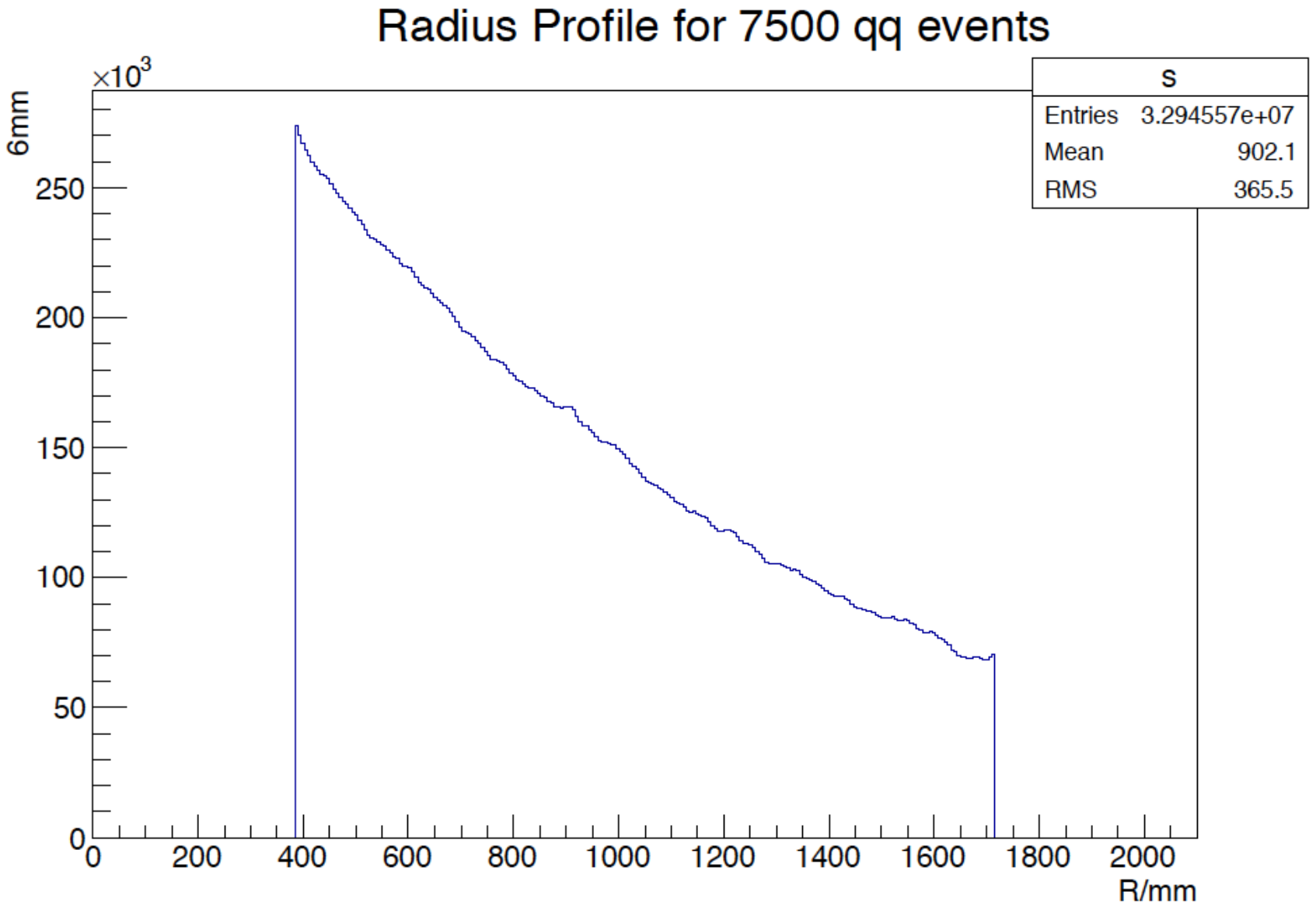
TPC Occupation at CEPC Z pole

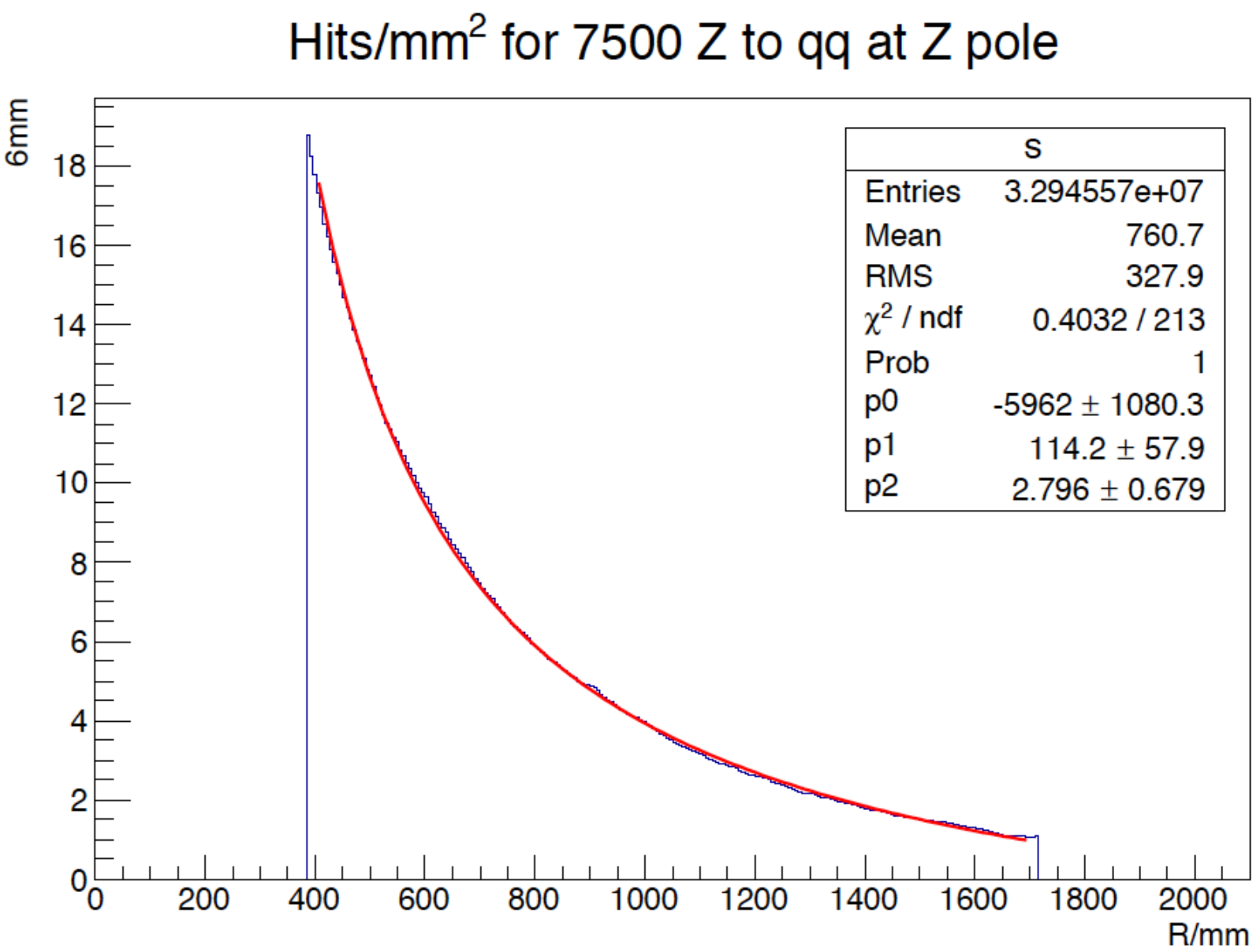


Manqi Ruan

Input: TPC Hit Profile of Fully Simulated Z->qq events


TPC Hit Map of 7500 Z->qq events at Z pole
2000
1000
0
-1000
-2000
Y/6mm
-2000
-1000
0
1000
2000
X/6mm
900
800
700
600
500
400
300
200
100
0

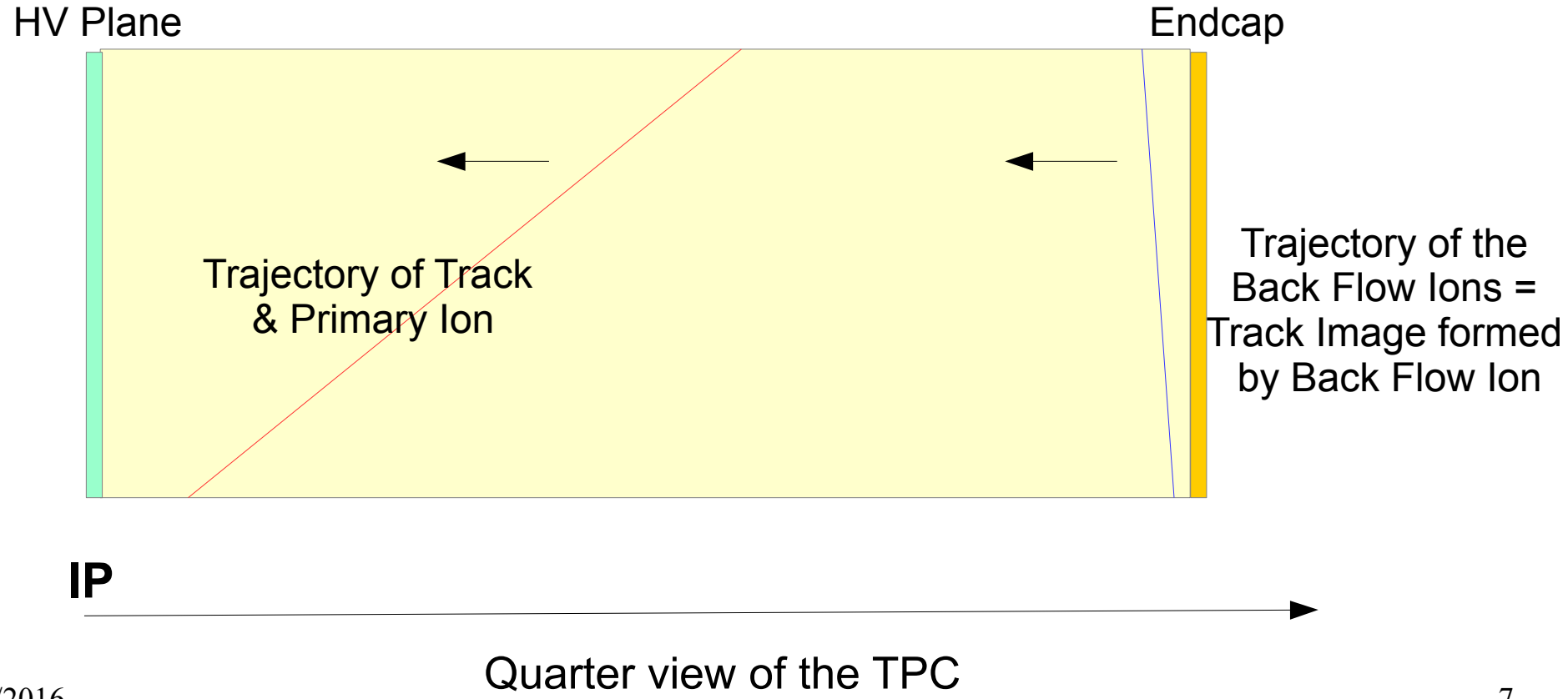

Radius Profile for 7500 qq events
×10^3
6mm
250
200
150
100
50
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
R/mm
s
Entries 3.294557e+07
Mean 902.1
RMS 365.5


Hits/mm² for 7500 Z to qq at Z pole
6mm
R/mm
s
Entries 3.294557e+07
Mean 760.7
RMS 327.9
χ² / ndf 0.4032 / 213
Prob 1
p0 -5962 ± 1080.3
p1 114.2 ± 57.9
p2 2.796 ± 0.679

Fit results

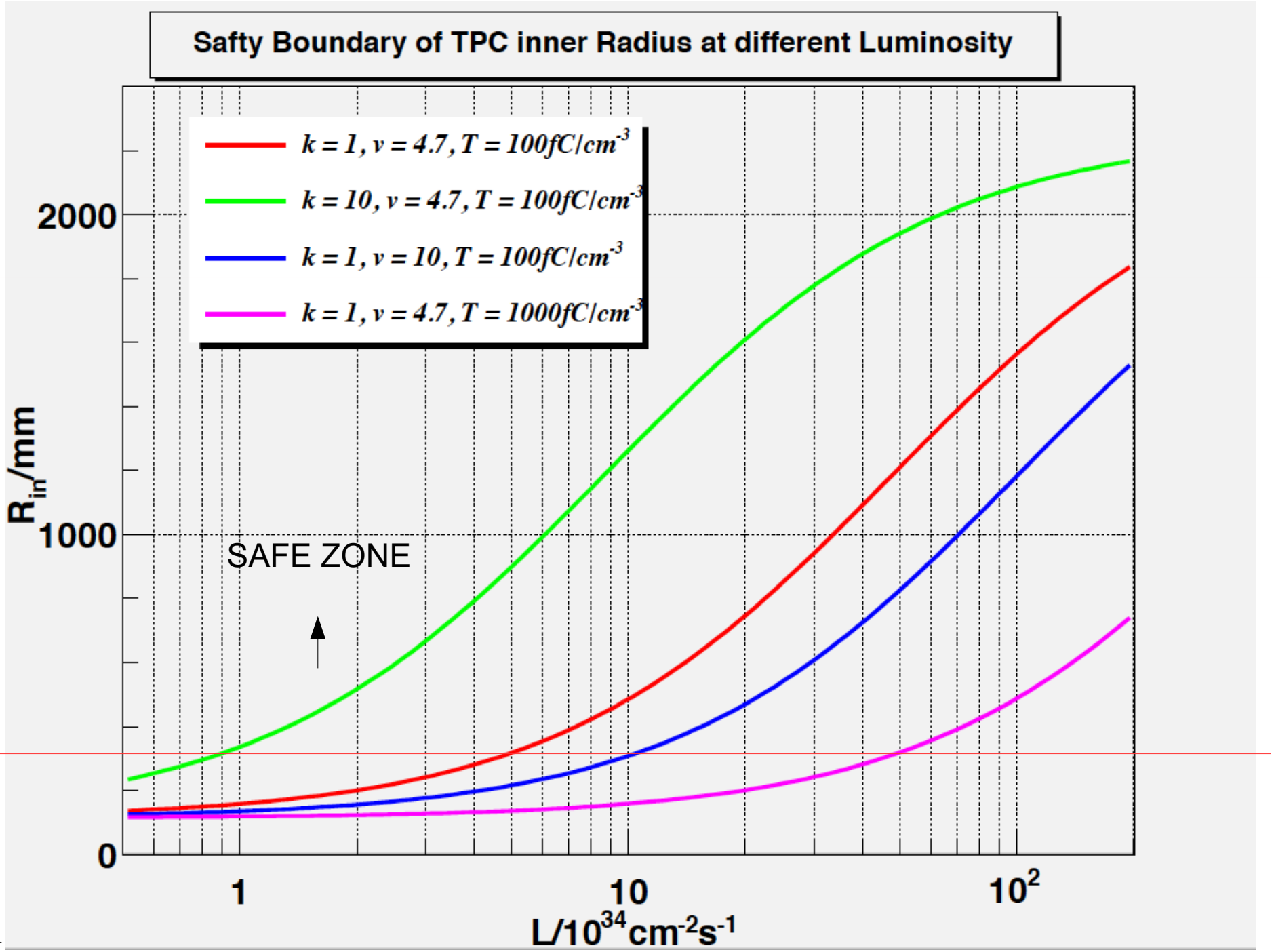
- Per 7500 events:
  - Hit Rate = 6000/(x – 114) – 2.8; (per mm^2)
- At Instant Luminosity = 2E34/IP;
  - Event Rate = 600 Hz. (30 nb * 2E-5 $fb^{-1}s^{-1}$)
  - Hit Rate = 480/(x – 114) – 0.224 (Hz/mm^2)
- At Instant Luminosity = 2E36
  - Event Rate = 60000 Hz
  - Hit Rate = 48000/(x-114) – 22.4 (Hz/mm^2);

1st limit factor: Charge Density



Charge Density

- Charge Density: ρ(r) = 22*(1+k)*L/v*(480/(r-114) - 0.224)
  - Follows the same distribution to the Hit Density
  - Assume evenly distributed along Z direction
  - Quantity & Units:
    - *ρ: charge density, unit in fQ/cm^3*
    - *k: ratio between back flow ion to the primary ionization;*
    - *L: Luminosity Unit in $10^{34}cm^{-2}s^{-1}$;*
    - *v: Drift velocity of ion, unit in $m*s^{-1}$;*
    - *r: radius of the TPC test point, for instance TPC inner radius, unit in mm*
- Define a tolerance level of Charge Density: T (fQ/cm^3)
  - From Fujii San, 100 fQ/cm^3 = 5 micrometer distortion (in X-Y plane?...)
  - TPC spatial resolution is 0.1 mm, maybe this limit can be limited to 1000 fQ/cm^3
- Then the dependence of T and R (TPC inner radius) can be resolved as:
  - R = 114 + 480/(0.224 + Tv/(22*(1+k)*L))


Safty Boundary of TPC inner Radius at different Luminosity
k = 1, v = 4.7, T = 100fC/cm-3
k = 10, v = 4.7, T = 100fC/cm-3
k = 1, v = 10, T = 100fC/cm-3
k = 1, v = 4.7, T = 1000fC/cm-3
2000
1000
0
Rin/mm
SAFE ZONE
1
10
10^2
L/10^34cm^-2s^-1

2nd limit factor: Voxel Occupancy

Beam Parameter at CEPC Z pole

- CEPC Z pole Bunch Structure
  - 40 MHz in phase with TPC readout;
  - 40 M bunches per second; 25 ns separation = 7.5 m separation
  - Luminosity:
    - $2.0 * 10^{34}$ $cm^{-2}s^{-1}$ = $2 * 10^{-5}$ $fb^{-1} * s^{-1}$
  - Per bunch
    - Integrated Luminosity $5*10^{-13}$ fb^{-1} = 0.5 mb^{-1}
    - Z->qq events: 30 nb * 0.5 mb^{-1} = $1.5*10^{-5}$
    - Even if 2E36: 1.5E-3 Z->qq Events per Bunch Xing

Voxel occupancy

- Giving 40 Mhz DAQ rate (25 ns interval) & 80 μm/ns drift velocity, the Distance difference between 2 DAQ rate is:
  - 2 mm ~ (80km/s)
  - 7.5m ~ (300000km/s)
- Therefore the Voxel Volume = 2mm * 1mm * 6mm (in the default design)
- Total N Pixel = pi*(1800**2 – 330**2)/6 = 3.3E6
- Number of Voxel in one snapshot = 3.3E6 * 1175 = 3.9E9 Voxels;
- Number of Voxel in one second = 3.3E6 * 40 M = 1.32E14 Voxels;
- Number of Hits in one second: Depends on the luminosity:
  - 2E34, 600 qq events, 2.64E6 Hits;
  - 2E35, 6000 qq events, 2.6E7 Hits;
  - 2E36, 60000 qq events, 2.6E8 Hits;
- Voxel Occupancy: of the order of 1E-8 to 1E-6...

VERY SAFE...

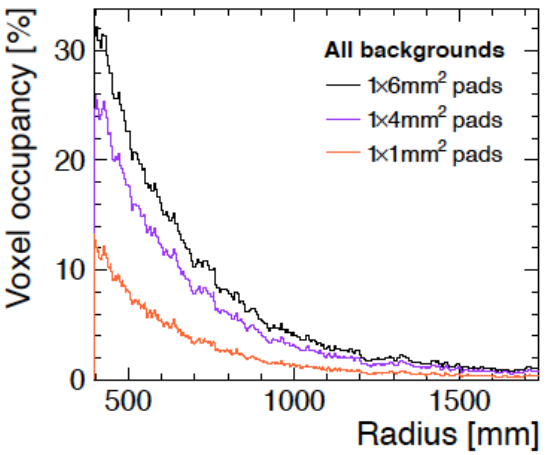
Beam Parameter at CLIC

- CLIC Bunch Structure
  - 0.5ns separation, 312-354 (3/0.5 TeV) bunches/train, 50 Hz (50 trains per second)
  - 1 train = 156 – 177 ns;
  - All trains = 7800 – 8850 ns
  - Occupancy = 1.13 – 1.28 *10^{-5}
  - Luminosity: 2.3 – 5.9 * 10^{34} $cm^{-2}s^{-1}$
  - Luminosity per sec: 2.3 – 5.9 * 10^{-5} fb^{-1}
  - Luminosity per bunch
    - Assume at Z pole: 10 μb^{-1} per bunch ~ 0.3 Z->qq per bunch
    - 0.5 TeV: 6.5*10^{-8} fb^{-1} = 65 μb^{-1}
    - 3 TeV: 1.89*10^{-7} fb^{-1} = 189 μb^{-1}

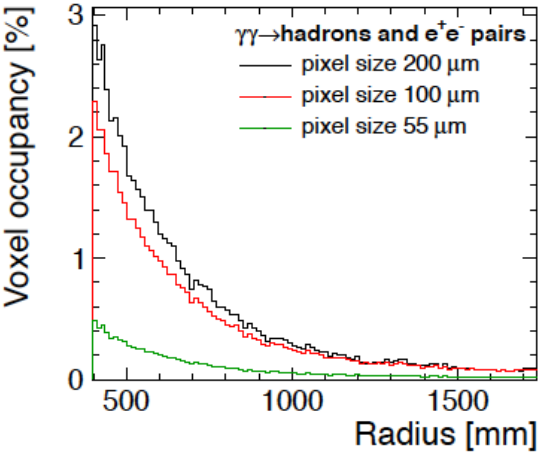
Parameter	Units	$\sqrt{s} = 500$ GeV	$\sqrt{s} = 3$ TeV
f_{rep}	Hz	50	50
n_b		354	312
Δt	ns	0.5	0.5
N		$6.8 \cdot 10^9$	$3.7 \cdot 10^9$
σ_x	nm	202	≈ 40
σ_y	nm	2.26	≈ 1
σ_z	µm	72	44
$\mathscr{L}$	$cm^{-2}s^{-1}$	$2.3 \cdot 10^{34}$	$5.9 \cdot 10^{34}$
$\mathscr{L}_{0.01}$	$cm^{-2}s^{-1}$	$1.4 \cdot 10^{34}$	$2.0 \cdot 10^{34}$
n_γ		1.3	2.1
$\Delta E/E$		0.07	0.28
N_{coh}		$2 \cdot 10^2$	$6.8 \cdot 10^8$
E_{coh}	TeV	$1.5 \cdot 10^1$	$2.1 \cdot 10^8$
N_{incoh}		$8 \cdot 10^4$	$3 \cdot 10^5$
E_{incoh}	TeV	$3.6 \cdot 10^2$	$2.3 \cdot 10^4$
n_{Had}		0.19	3.2

Voxel occupancy for CLIC: Validation

- CLIC: 3 gammagamma->Hadrons events per bunch Xing;
- For each bunch train: 1000 events;
- 1000 events -> 4000 tracks -> 800000 hits (Big Assumption), in 150 ns;
- 150 ns * 80 micrometer/ns = 12000 micrometer = 12 mm = 6 separation
- Voxel number in 150 ns:
  - 1.66E6 * 6 = 1E7
- Occupancy = 0.08;
- Inner Vs Outer:
  - Scale = 3 -> 24%.



(a) The voxel occupancy for different pad sizes [4].



(b) The voxel occupancy for different pixel sizes.

Conclusion

- Considering Z->qq sample only
  - Need to considering gammagamma background, etc.
- TPC Usage limited by
  - Local Charge Density that perturbate the Hit position, Tolerance level ~ 100fC/cm3, result in a deviation of 5 micrometer in position resolution
  - Leads to a constrain of TPC inner radius & Integrated luminosity
  - Optimized scenario: Inner Radius > 500 mm at L = 2E36
    - Tolerance = 1000 fC/cm3,
    - Ion Shift velocity: v = 4.7 m/s,
    - Ratio between back flow Ion yield to Primary ionization k = 1;
- Voxel Occupancy (NOT A Limiting Factor)
  - Orders of magnitude lower than the CLIC Case as the beam bunch time structure is much evenly distributed
  - Of the order of 1E-8 to 1E-6 at 2E34 to 2E36 Luminosity, which 40 Mhz bunch separation (25ns = 7.5 m bunch separation)