COMET Drift Chamber and Tracking

Yao ZHANG

Institute of High Energy Physics, Chinese Academy of Science

on behalf of the COMET Collaboration

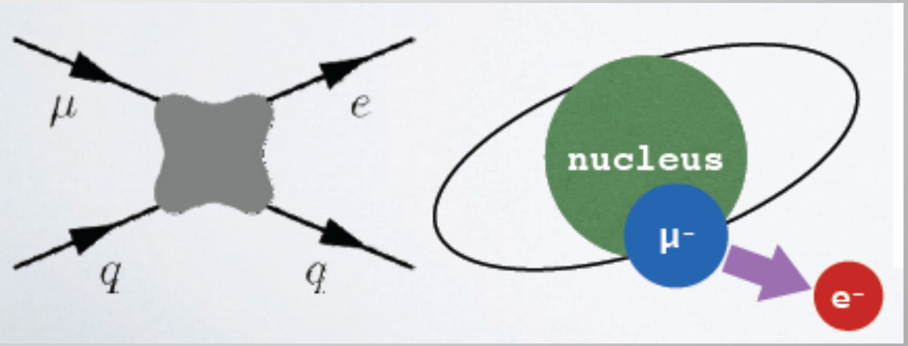
INSTR17, Novosibirsk

Outline

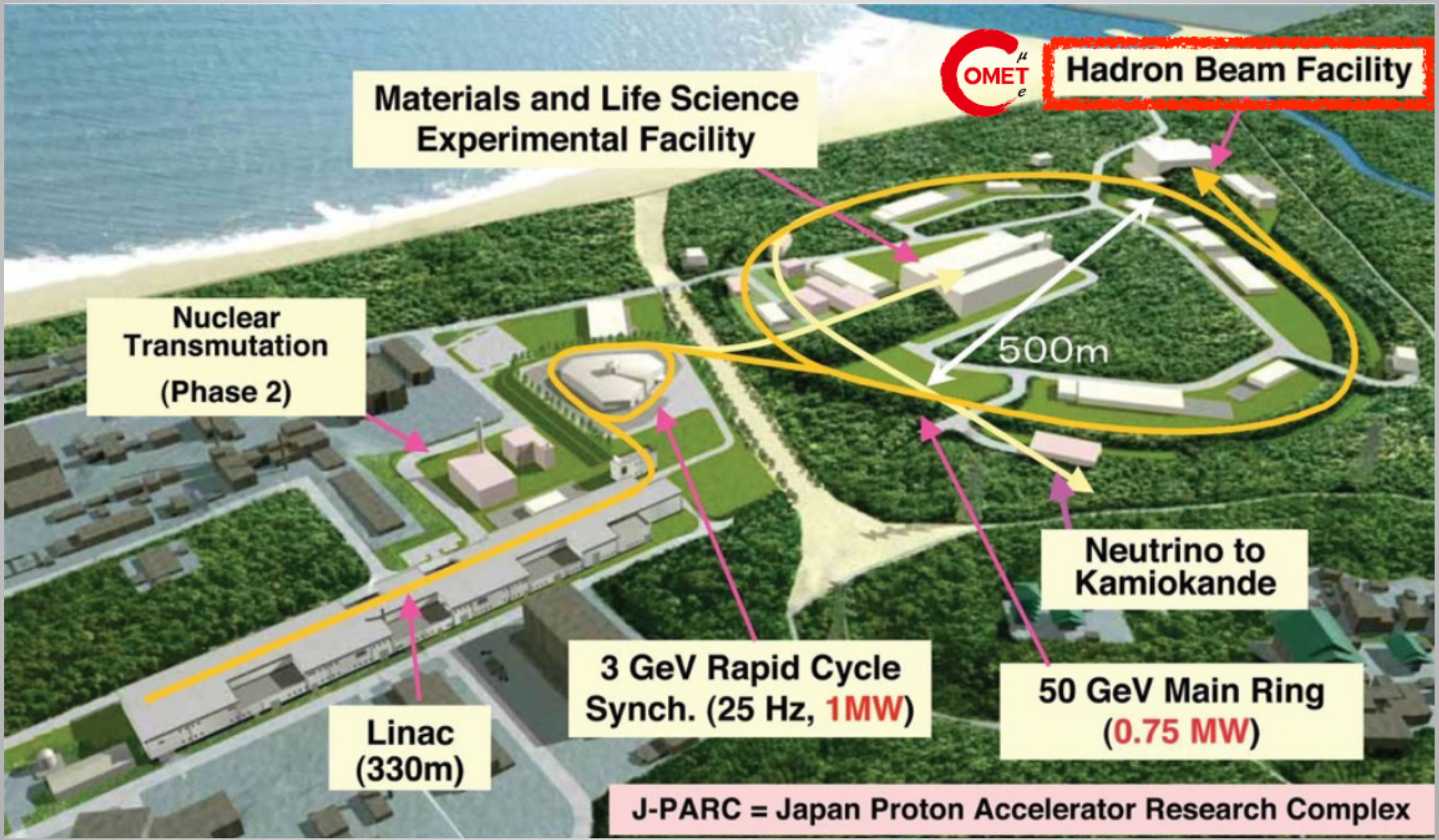
- Overview of COMET
- Cylindrical drift chamber (CDC)
  - design overview
  - construction
  - Prototype test and CDC cosmic ray test
- Offline tracking
  - tracking algorithm
  - performance

μ-e Conversion

- Charged Lepton Flavor Violation
  - Forbidden by the Standard Model
  - $B(\mu\text{->}e\gamma)\sim O(10^{-54})$ for SM + ν oscillation
- Muon to electron conversion in nuclei without neutrino emission, not observed so far
  - $\mu^- + N(A,Z) \text{->} e^- + N(A,Z)$
- Event signature: a single mono-energetic electron of ~105MeV (for Aluminum)
  - $E_{signal}=M_\mu-m_e-E_{binding}-E_{recoil}$



COherent Muon Electron Transition (COMET)



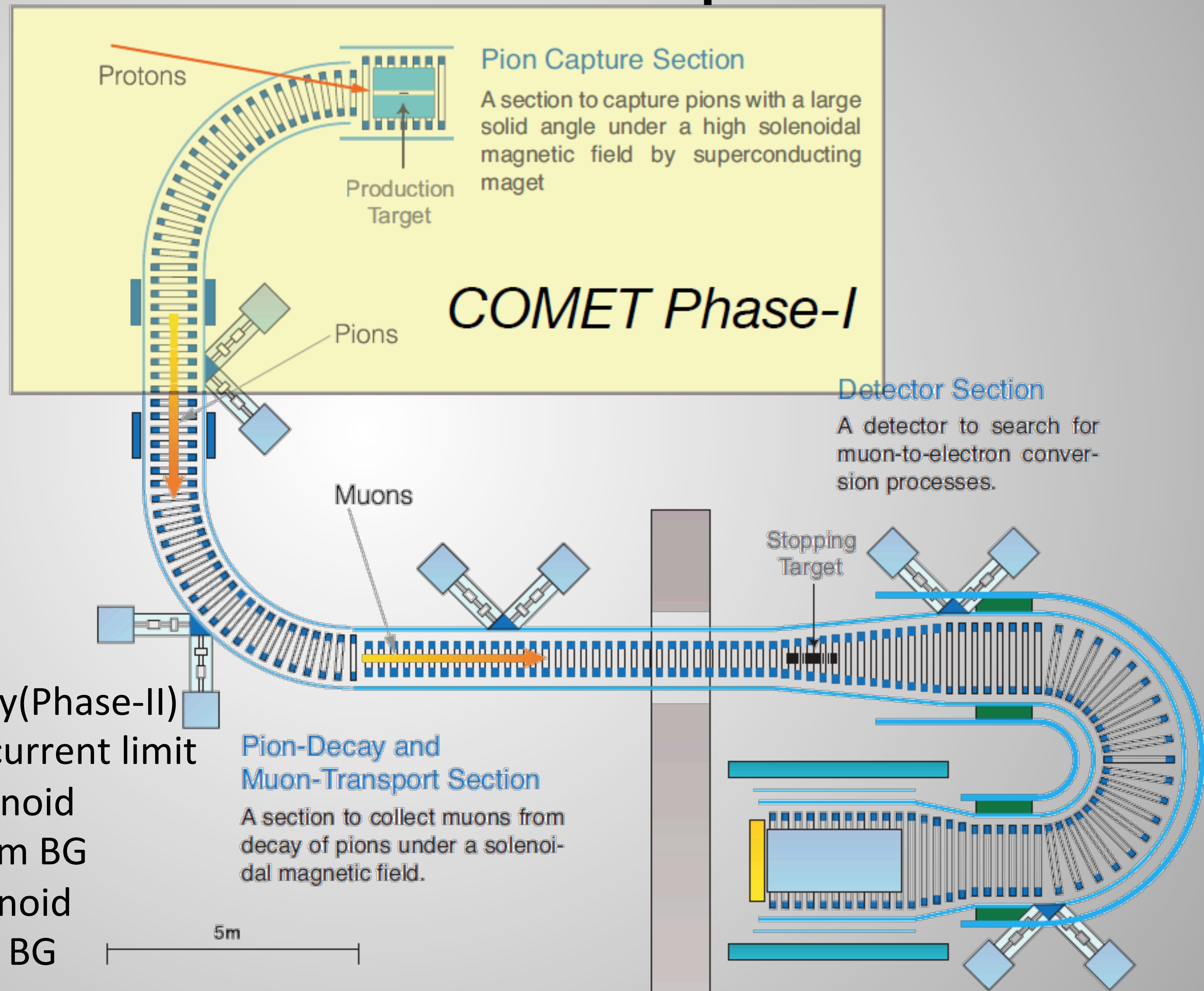
The COMET Collaboration

182+ collaborators
32 institutes, 15 countries

The COMET Collaboration

R. Abramishvili[11], G. Adamov[11], R. Akhmetshin[6,31], V. Anishchik[4], M. Aoki[32], Y. Arimoto[18], I. Bagaturia[11], Y. Ban[3], D. Bauer[14], A. Bondar[6,31], Y. Calas[7], S. Canfer[33], Y. Cardenas[7], S. Chen[28], Y. E. Cheung[28], B. Chiladze[35], D. Clarke[33], M. Danilov[15,26], P. D. Dauncey[14], W. Da Silva[23], C. Densham[33], G. Devidze[35], P. Dornan[14], A. Drutskoy[15,26], V. Duginov[16], L. Epshteyn[6,30,31], P. Evtoukhovich[16], S. Fayer[14], G. Fedotovich[6,31], M. Finger[8], M. Finger Jr[8], Y. Fujii[18], Y. Fukao[18], E. Gillies[14], D. Grigoriev[6,30,31], K. Gritsay[16], E. Hamada[18], R. Han[1], K. Hasegawa[18], I. H. Hasim[32], O. Hayashi[32], Z. A. Ibrahim[24], Y. Igarashi[18], F. Ignatov[6,31], M. Iio[18], M. Ikeno[18], K. Ishibashi[22], S. Ishimoto[18], T. Itahashi[32], S. Ito[32], T. Iwami[32], X. S. Jiang[2], P. Jonsson[14], T. Kachelhoffer[7], V. Kalinnikov[16], F. Kapusta[23], H. Katayama[32], K. Kawagoe[22], N. Kazak[5], V. Kazanin[6,31], B. Khazin[6,31], A. Khvedelidze[16,11], T. K. Ki[18], M. Koike[39], G. A. Kozlov[16], B. Krikler[14], A. Kulikov[16], E. Kulish[16], Y. Kuno[32], Y. Kuriyama[21], Y. Kurochkin[5], A. Kurup[14], B. Lagrange[14,21], M. Lancaster[38], M. J. Lee[12], H. B. Li[2], W. G. Li[2], R. P. Litchfield[14,38], T. Loan[29], D. Lomidze[11], I. Lomidze[11], P. Loveridge[33], G. Macharashvili[35], Y. Makida[18], Y. Mao[3], O. Markin[15], Y. Matsumoto[32], A. Melnik[5], T. Mibe[18], S. Mihara[18], F. Mohamad Idris[24], K. A. Mohamed Kamal Azmi[24], A. Moiseenko[16], Y. Mori[21], M. Moritsu[32], E. Motuk[38], Y. Nakai[22], T. Nakamoto[18], Y. Nakazawa[32], J. Nash[14], J. -Y. Nief[7], M. Nioradze[35], H. Nishiguchi[18], T. Numao[36], J. O'Dell[33], T. Ogitsu[18], K. Oishi[22], K. Okamoto[32], C. Omori[18], T. Ota[34], J. Pasternak[14], C. Plostinar[33], V. Ponariadov[45], A. Popov[6,31], V. Rusinov[15,26], B. Sabirov[16], N. Saito[18], H. Sakamoto[32], P. Sarin[13], K. Sasaki[18], A. Sato[32], J. Sato[34], Y. K. Semertzidis[12,17], N. Shigyo[22], D. Shoukavy[5], M. Slunecka[8], A. Straessner[37], D. Stöckinger[37], M. Sugano[18], Y. Takubo[18], M. Tanaka[18], S. Tanaka[22], C. V. Tao[29], E. Tarkovsky[15,26], Y. Tevzadze[35], T. Thanh[29], N. D. Thong[32], J. Tojo[22], M. Tomasek[10], M. Tomizawa[18], N. H. Tran[32], H. Trang[29], I. Trekov[35], N. M. Truong[32], Z. Tsamalaidze[16,11], N. Tsverava[16,35], T. Uchida[18], Y. Uchida[14,32], K. Ueno[18], E. Velicheva[16], A. Volkov[16], V. Vrba[10], W. A. T. Wan Abdullah[24], M. Warren[38], M. Wing[38], M. L. Wong[32], T. S. Wong[32], C. Wu[2,28], H. Yamaguchi[22], A. Yamamoto[18], T. Yamane[32], Y. Yang[22], W. Yao[2], B. K. Yeo[12], H. Yoshida[32], M. Yoshida[18], Y. Yoshii[18], T. Yoshioka[22], Y. Yuan[2], Yu. Yudin[6,31], J. Zhang[2], Y. Zhang[2], K. Zuber[37]

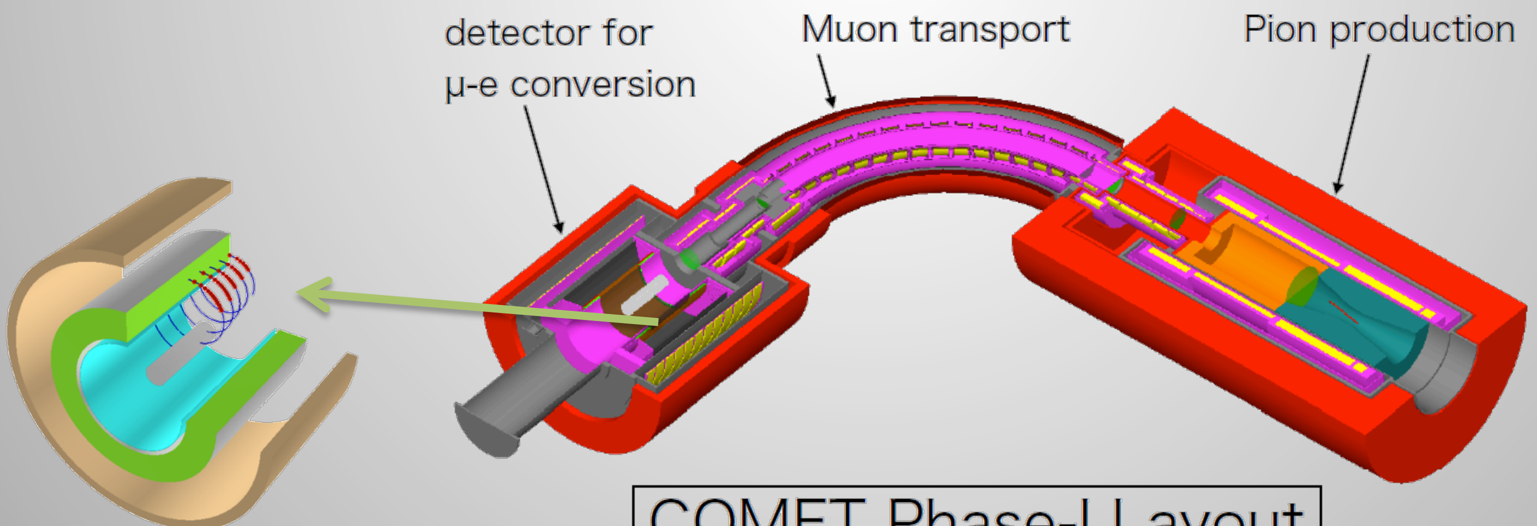
Overview of the COMET Experiment



- Aiming O(10-^{17}) sensitivity(Phase-II)
  - 10,000 better than current limit
- C-shape μ^- transport solenoid
  - Highly suppress beam BG
- C-shape e^- transport solenoid
  - suppress DIO+beam BG

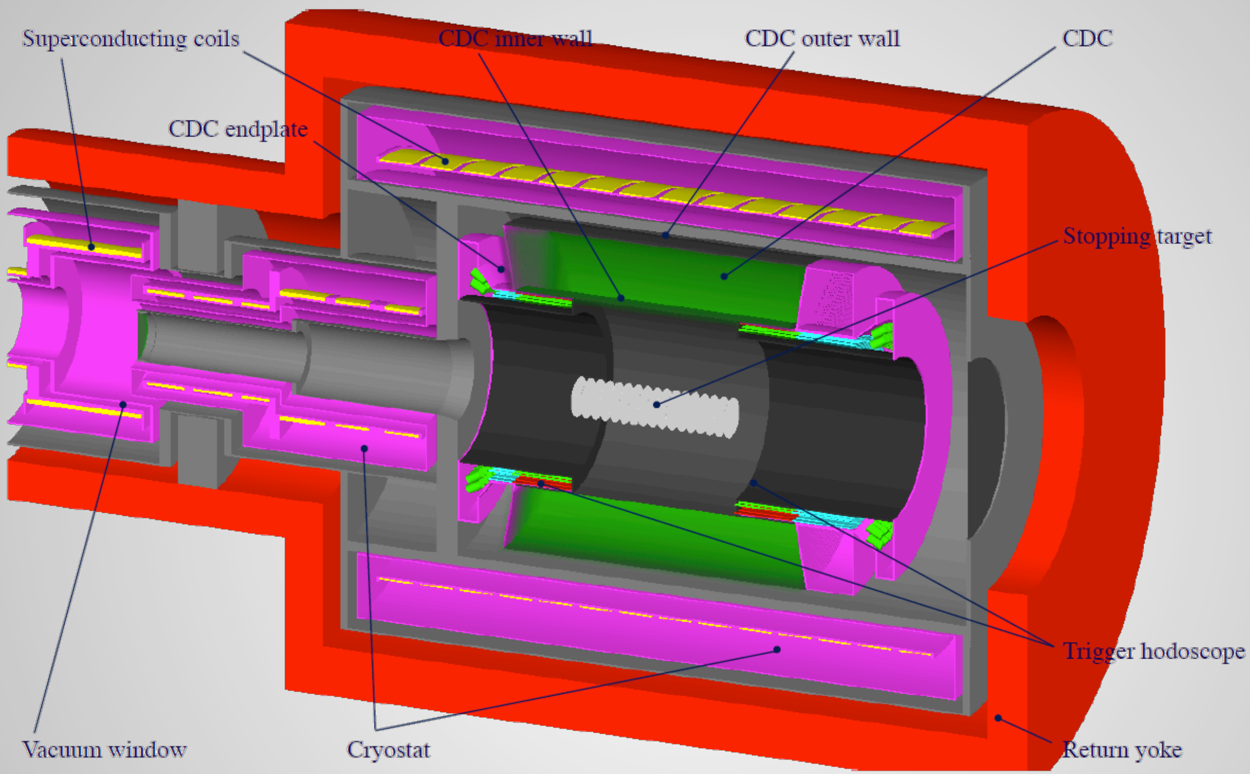
COMET Phase-I

1. search for *μ−e conversion*
   - $>10^{17}$ of stopping muons are required
   - signal sensitivity 3.1×10^{-15} (100 times better than current limit)
2. Background measurement for Phase-II
   - Intrinsic background: Muon Decay In Orbit (DIO)
     - **Excellent momentum resolution** ~200keV



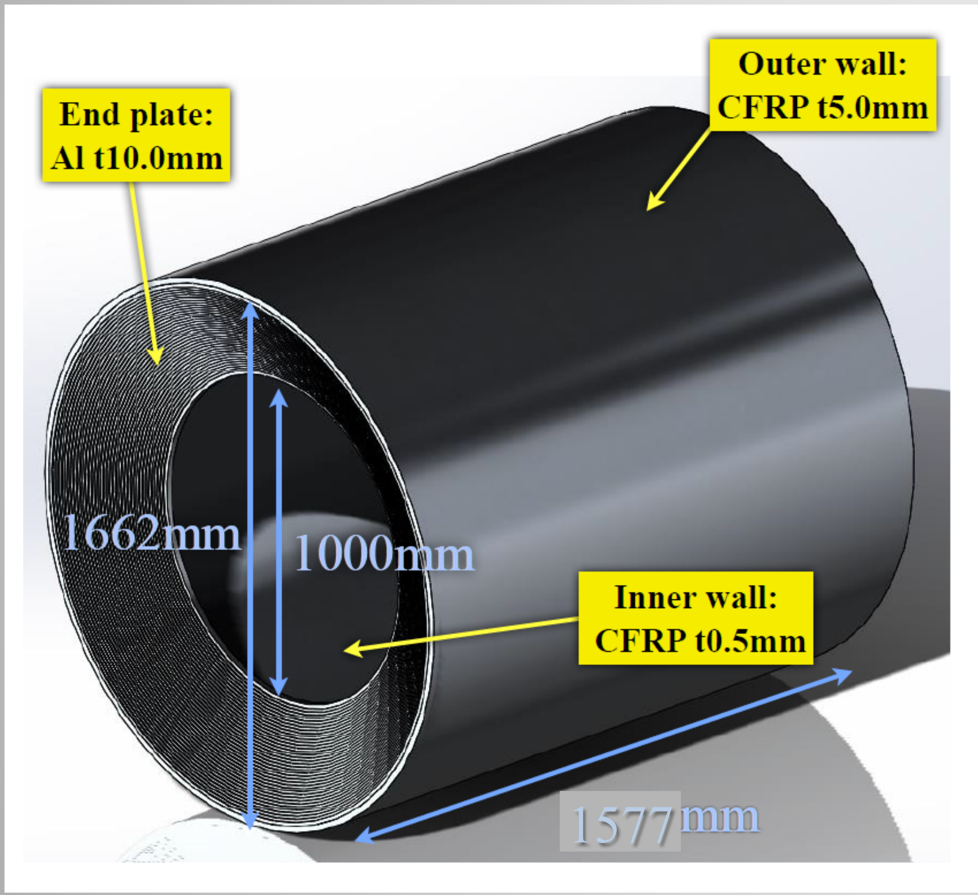
COMET Phase-I Layout

COMET Phase-I Detector -- CyDet



- A large Cylindrical drift chamber in a 1T solenoid magnet
- Trigger hodoscope (Plastic scintillator + Cherenkov)

COMET **C**ylindrical **D**rift **C**hamber(CDC)



Geometric acceptance ignores electrons with p<60 MeV/c

- 20 sense wire layers
  - including 2 guard layers
- All stereo layer
  - Stereo angle +- 4 degrees -> σ_z~3mm
- Cell size
  - ~16.8 x 16 mm^2
- Anode wire
  - Au plated W, ϕ 25um
- Field wire
  - Al, ϕ 126um
- Gas mixture
  - Helium based gas (Isobutane, Ethane or Methane)
  - Volume: 2084L
- Readout
  - 104 RECBE Boards

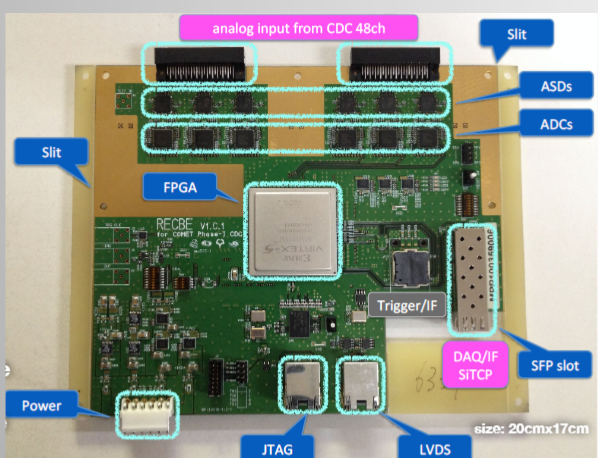
CDC Construction

- **CDC construction completed in June 2016**
  - About 20,000 wires were strung
  - Inner wall installed
  - Tension measurement and re-string finished
  - Gas leakage below safety level

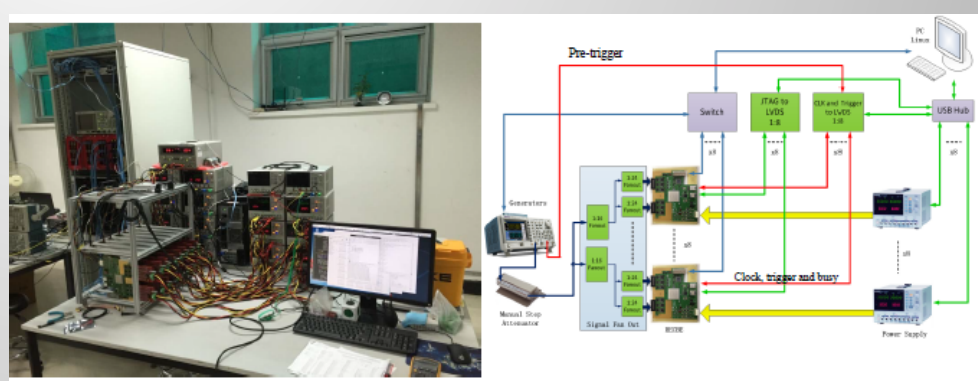
Readout electronics

- The production of 128 readout board – RECBE has finished by IHEP, China in 2015
  - TDC Time resolution: 1 nsec.
  - ADC Sampling rate : 30 MHz
- A performance test, threshold scanning and aging test have been done

128 pcs RECBE in the dry box



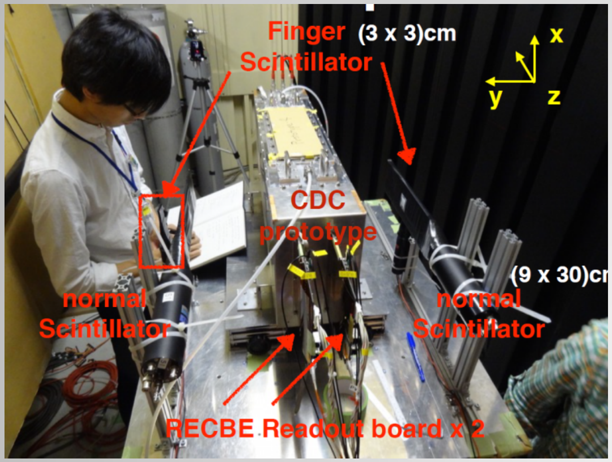
COMET-CDC readout board

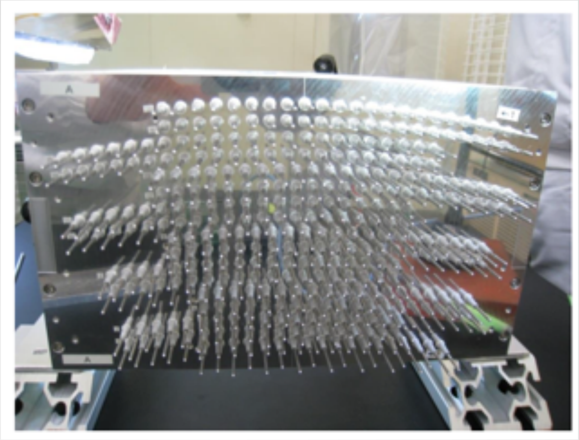


Automatic test system

CDC Prototype Test

Beam test experiment at SPring-8 without magnetic field





- 7 sense layers + 2 guard layers (1 is dummy)
- Same wire material and configuration as CDC

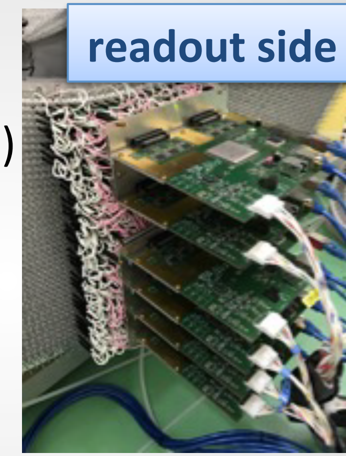
- Study different gas mixture and optimize high voltage and threshold

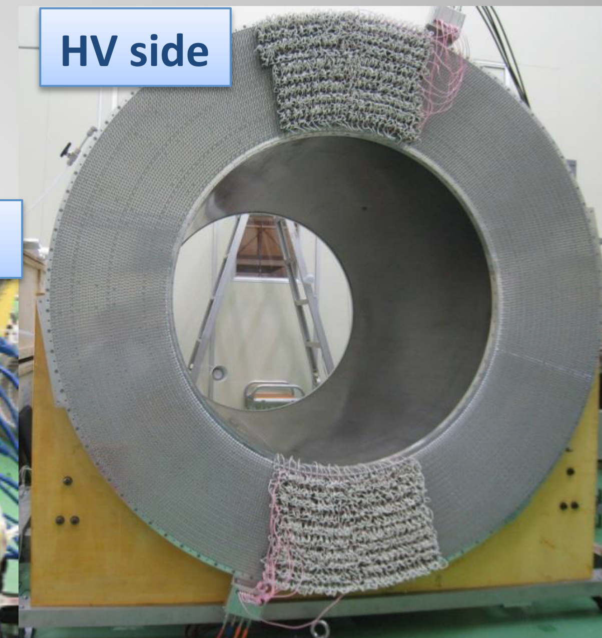
Gas	Efficiency	best Spatial resolution
He:C_2H_6 50:50	99%	140μm
He:IC_4H_{10} 90:10	97%	166μm

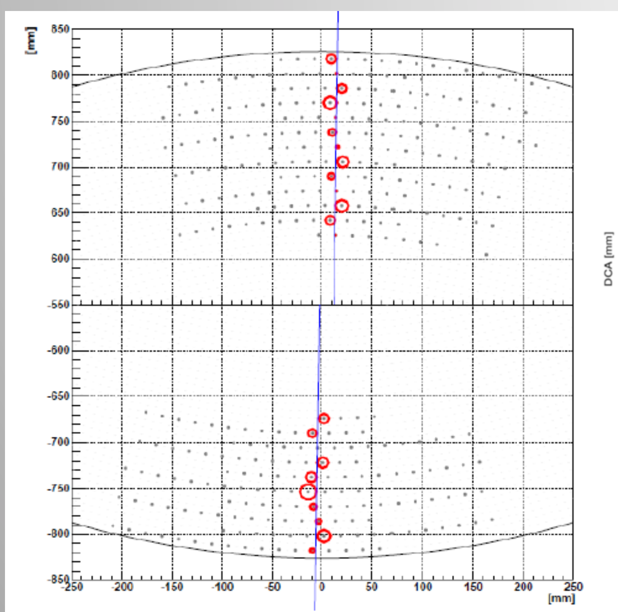
Current CDC design can reach the COMET Phase I 's requirements

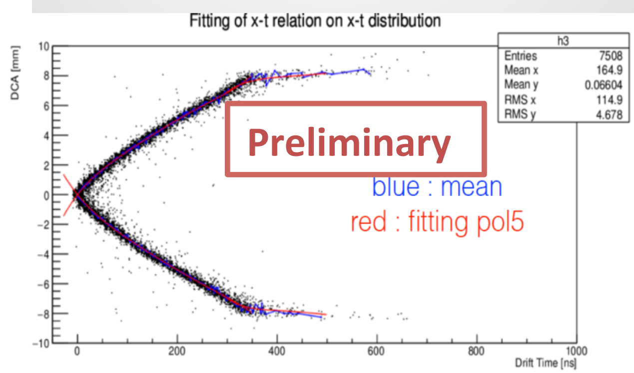
CDC Cosmic Ray Test

- Cosmic-ray test stage-1 (with 8 RECBEs)
  - Data taking started from August 2016
- 1st cosmic-ray analysis is done
  - Spatial resolution ~150μm (middle of cell)
  - Hit efficiency: 98%

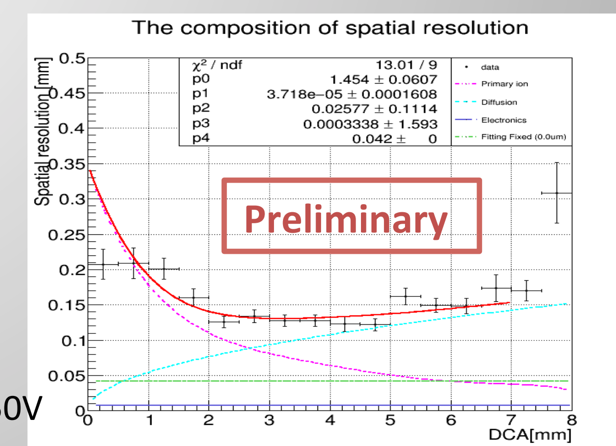






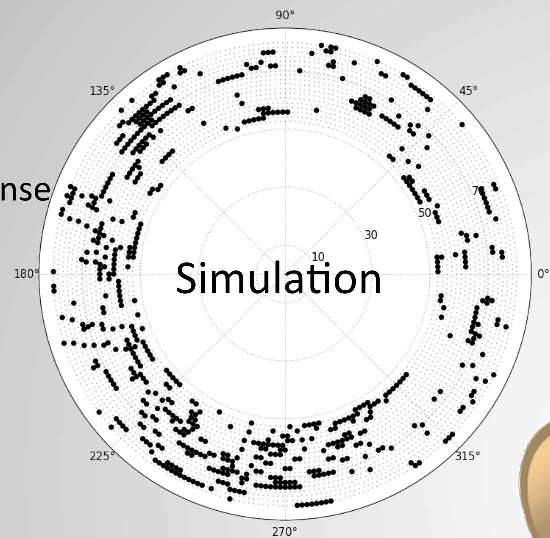


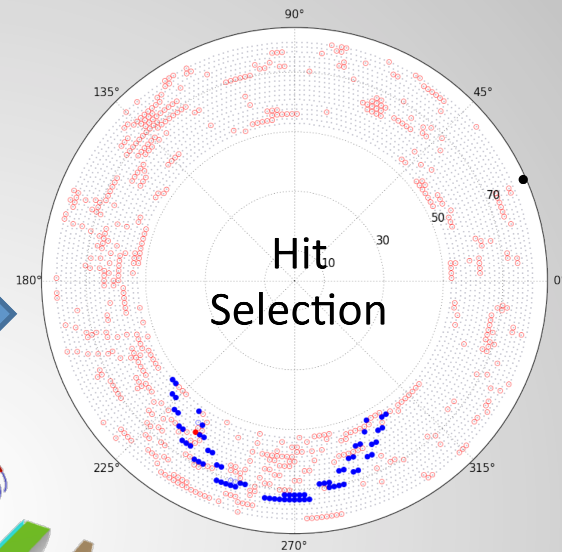
Gas mixture : He - iC4H10(90/10)@1850V



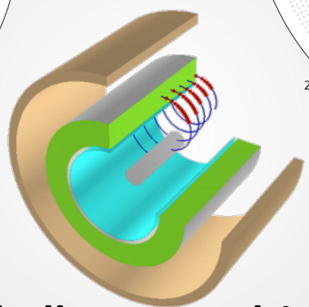
Tracking Procedure

- Signal track
- BG hit merge
- Detector response



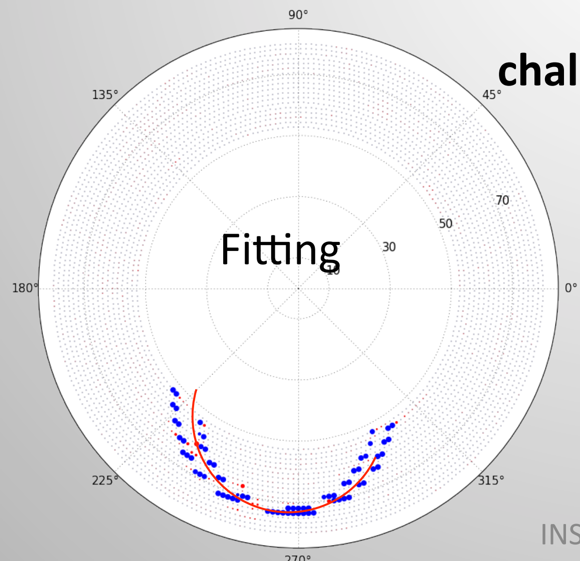


- indicate signal/noise

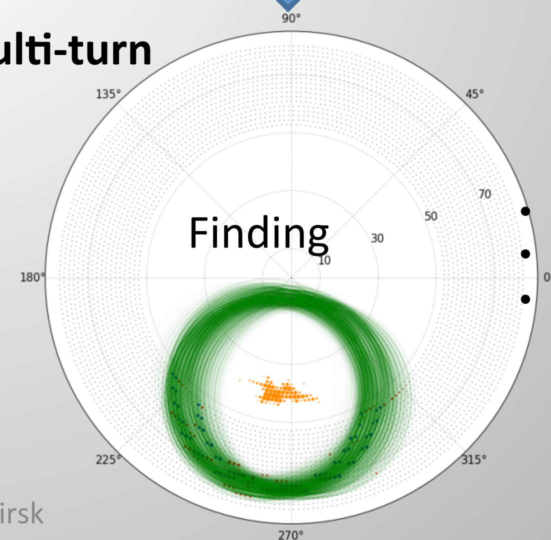


challenge: multi-turn

- Fitting with Kalman filter



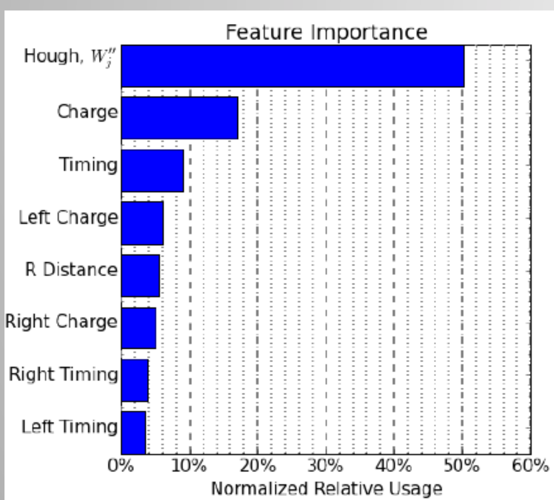
iteration

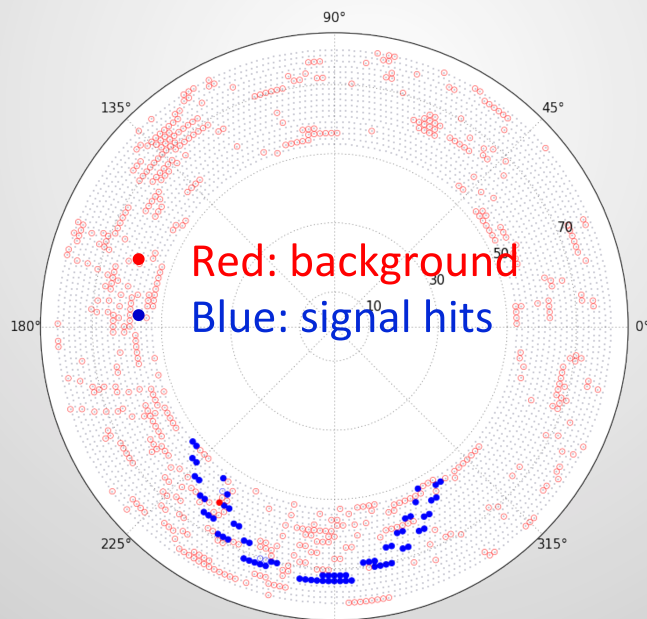


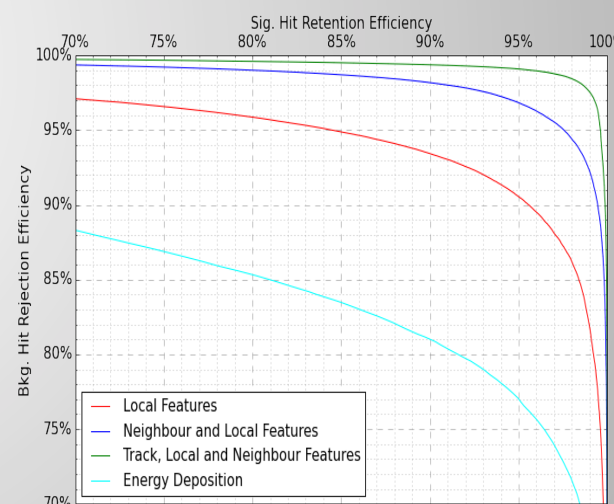
- Find tracks
- Find turns
- Decide initial track value

Hit Selection

- Hit selection using **G**radient **B**oosted **D**ecision **T**rees (GBDT) and Reweighted Inverse Hough Transform
- Classify hits using features: local, neighbor, Hough transform
- Fit track with random hit collection (RANSAC)





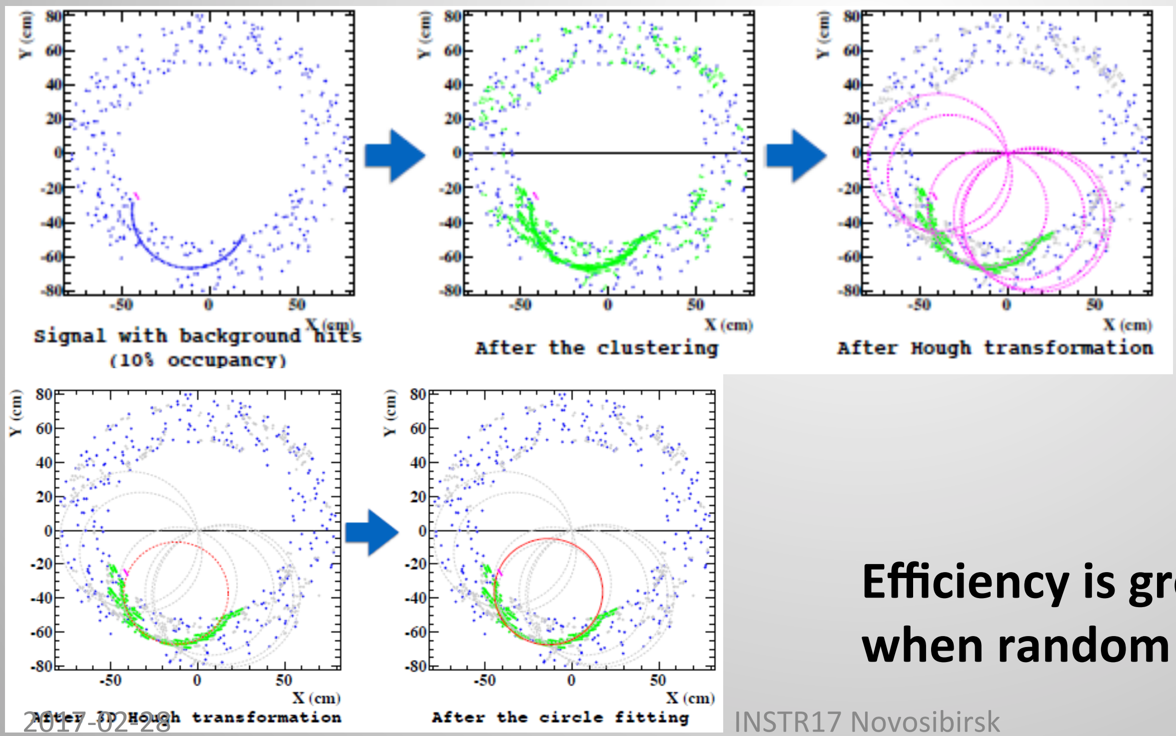


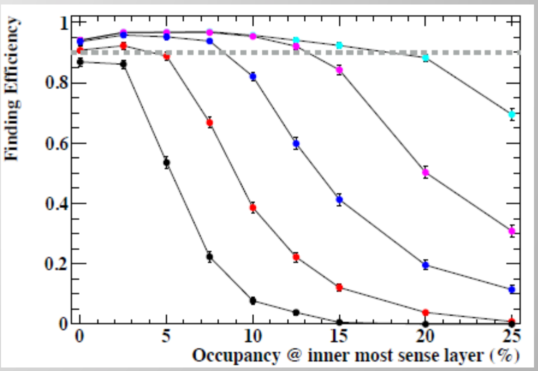
Separation between background and signal hits is clear

99 % of background can be rejected while keeping 99% of the signals

Track Finding

- Hough transformation
  - Clustering neighbor layer hits
  - Conformal mapping and Hough transform
  - 3D Hough transform
  - Circle fitting

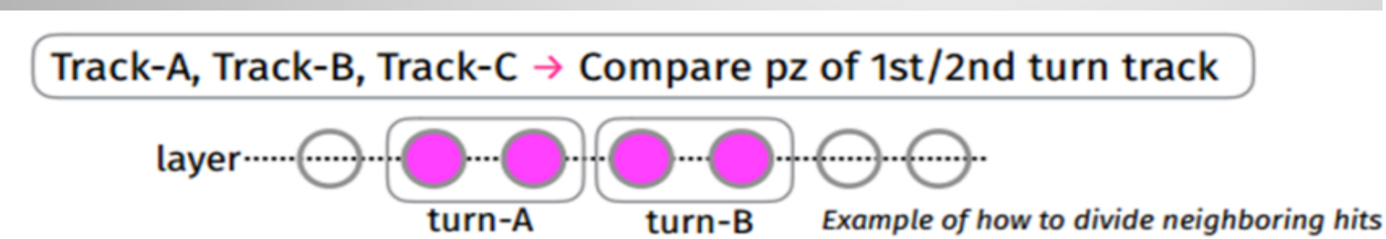


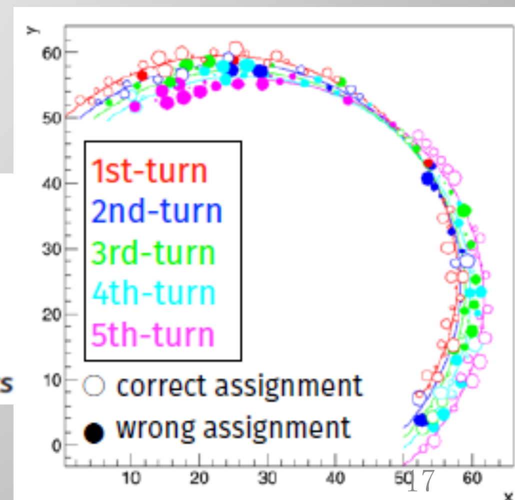


Efficiency is greater than 90%
when random occupancy @ 1st layer < 15%

Track Fitting (1)

- genfit2 based fitting using Kalman filtering(DAF)
- Multi-turn fitting based on neighboring hits pile-up pattern
  - Initial track from smeared MC truth
  - "Divide" sequential hits in same layer, odd/even, first/last 90 deg turn
  - Make ~50 different sets of hit candidates
  - Fit for each set and keep if fit result is "good" (NDF>20)
  - Using remaining hits, repeat fit procedure
  - Compare p_z of 1st and 2nd max. momentum tracks
  - If difference of p_z is smaller than 20 MeV/c, finish

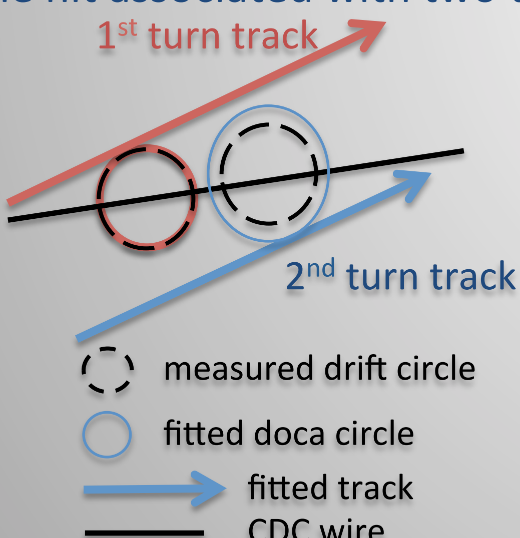




Track Fitting (2)

- Due to the importance of the reliability another fitting algorithm is developed for cross-check
- Multi-turn fitting based on hit competition
  1. Fit track with different turn hypothesis in parallel
  2. Hits associated to at least one track and calc. assignment weight to each track
  3. Hits competition using weighted mean
  4. Fit tracks iteratively with annealing scheme to avoid local minimum

one hit associated with two tracks



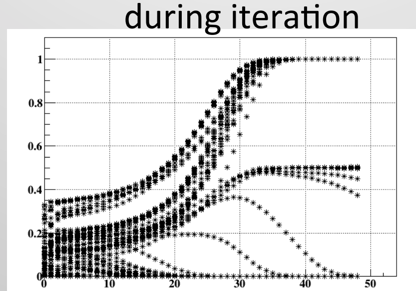
The possibility of hit *i* assigned to track *j* is defined as matrix Φ

$$(\Phi)_{ij} = \varphi_{ij} = \varphi(y_i; Hx_j, V_i),$$

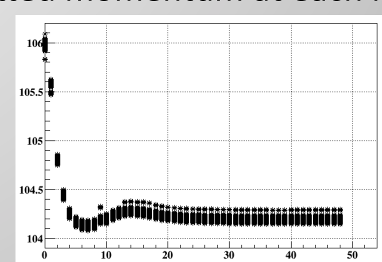
Assignment weight of hit i to track j

$$p_{i_k j} = \frac{\varphi_{i_k j}}{\sum_l \sum_\alpha \varphi_{i_\alpha l} + c}.$$

Hit assignment weight of each hit during iteration



fitted momentum at each iteration

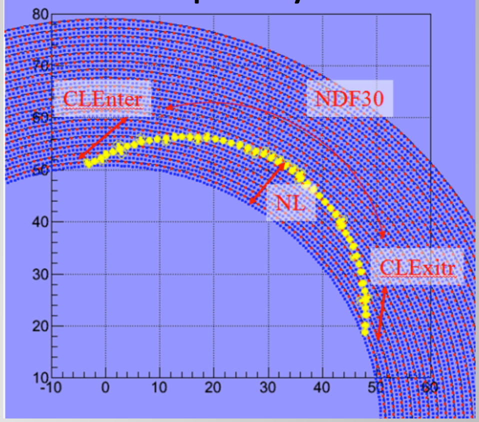


Geometrical Acceptance and Tracking Efficiency

Acceptance after geometry cuts

	Single-turn	Multi-turn
N_{CDC} hit >0	0.34	0.17
Hit 2 CTH layers	0.21	0.13
Hit CTH indirectly	0.19	0.12
2 CTH neighbor pairs	0.16	0.10

track quality cuts



Tracking efficiency

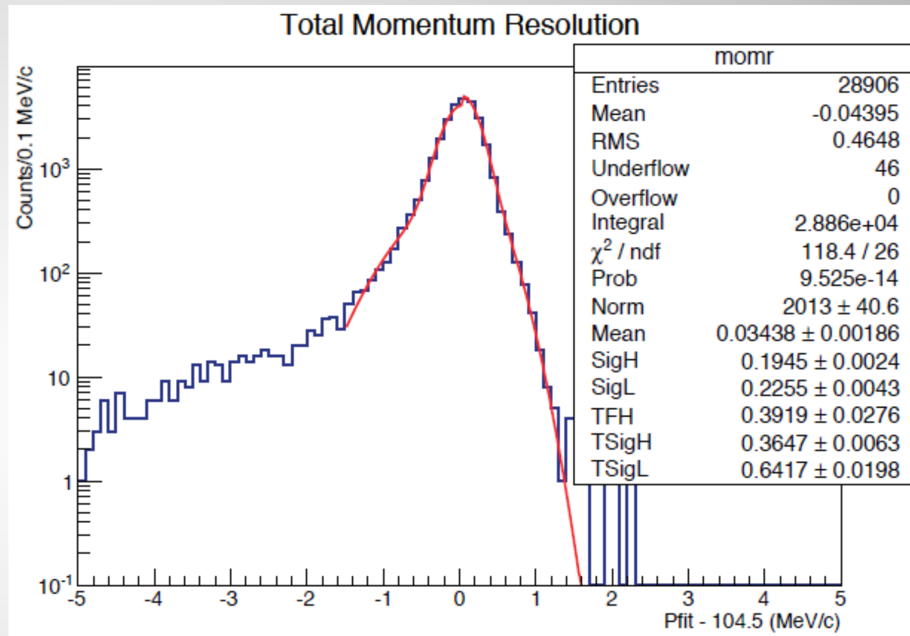
	Single-turn	Multi-turn	Total
Geometrical acceptance	0.16	0.10	0.26
Tracking efficiency after Quality cut	0.71	0.72	
Total	0.11	0.072	0.18

The total efficiency is estimated as 18%, 146 days for Phase-I

Momentum Resolution

gas mixture He:i-C4H10 (90:10)
position resolution ~200 μm

- Tail part still need study with more realistic track finding and fitting
  1. including noise
  2. fitting input from track finding



Core σ of high-momentum half-Gaussian (SigH)		195 keV/c
σ of low-momentum half-Gaussian (SigL)		226 keV/c
Fraction in tail distribution (TFH)		39%
Tail σ of high-momentum half-Gaussian (TSigH)		365 keV/c
σ of low-momentum half-Gaussian (TSigL)		642 keV/c

- The core part of resolution of the total momentum is below 200keV/c

Summary

- The construction of COMET drift chamber is accomplished
- Cosmic ray test and analysis have started
- Track finding and fitting for CDC are still in progress
- Momentum resolution can meet the requirements of COMET experiment

Thank You!