Charged Lepton Flavor Violation Search at COMET

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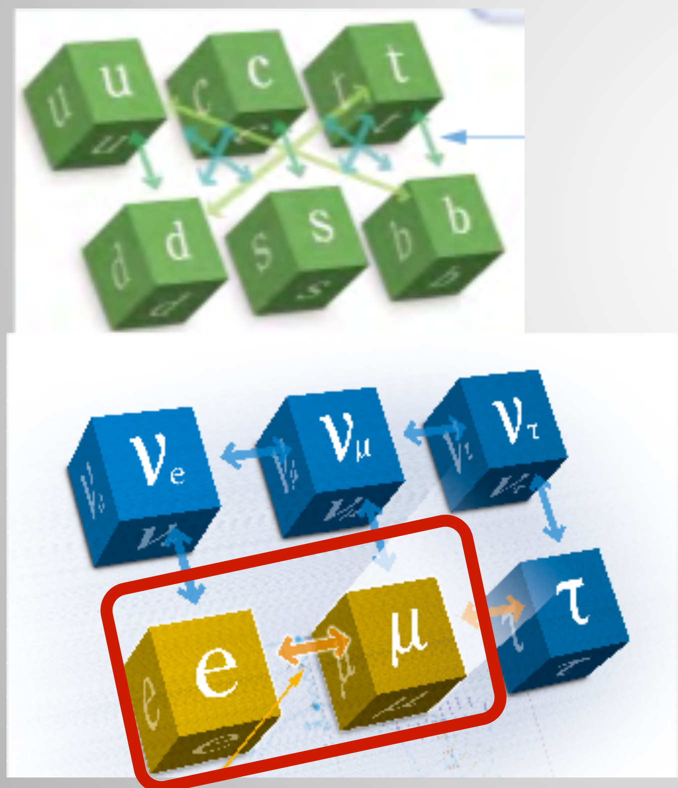
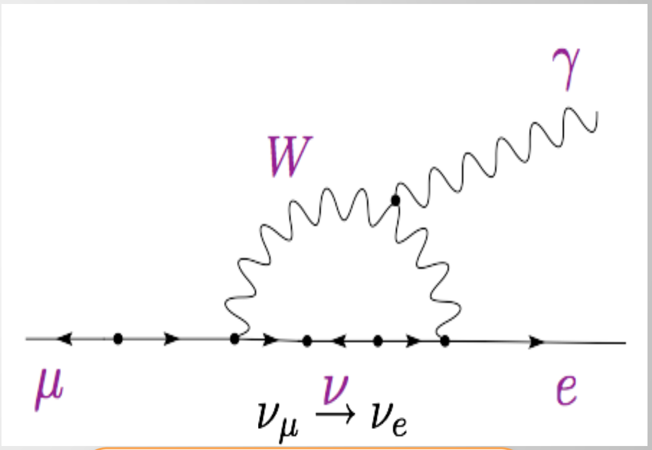
On behalf of COMET experiment group

Charged Lepton Flavor Violation

- Quark mixing and neutrino oscillation was observed
- $\mu - e$ conversion can occur in the extended SM, but it is almost not observable



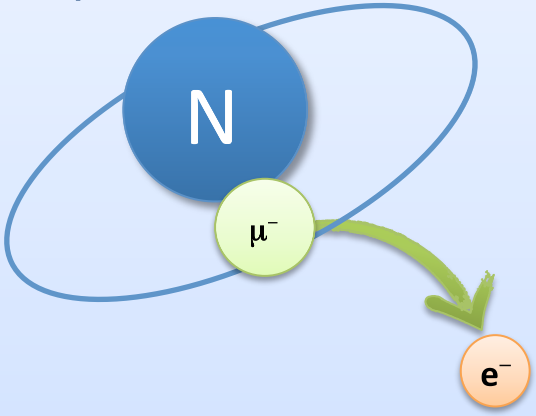


BR~O(10^{-54})

Charged LFV = new physics

Muon-e conversion

Signal $\mu - e$ conversion

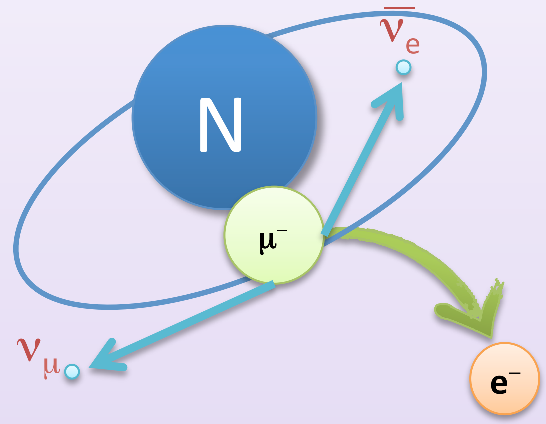


Neutrino-less Muon Nuclear Capture (clfv)

$$\mu^- + (A,Z) \rightarrow e^- + (A,Z)$$

$E_{\mu e} = m_\mu - B_\mu - E_{recoil}$ **= 104.97MeV (for Al)**
Coherent Process (Zini=Zend)

Backgrounds



- **Muon Decay in Orbit (DIO)**

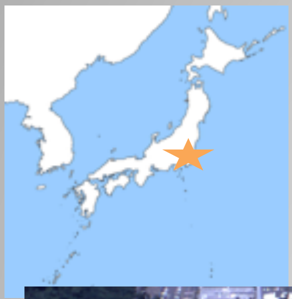
$$\mu^- \rightarrow e^- \nu_\mu \bar{\nu}_e$$

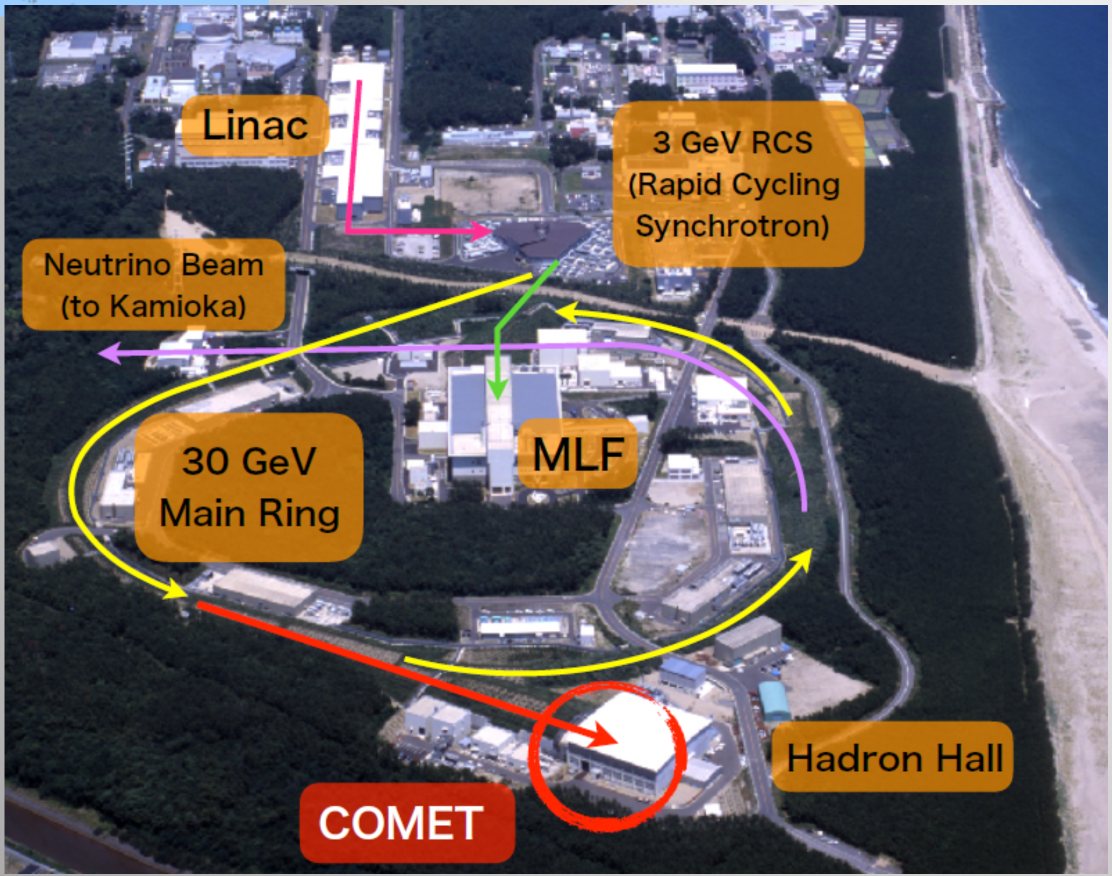
- **Nuclear Muon Capture**

$$\mu^- + (A,Z) \rightarrow \nu_\mu + (A,Z-1) + \gamma$$

- **Electrons from Muon DIF**
- **Cosmic ray,**
- **False tracking, etc**

Overview on COMET
(COherent Muon Electron Transition)



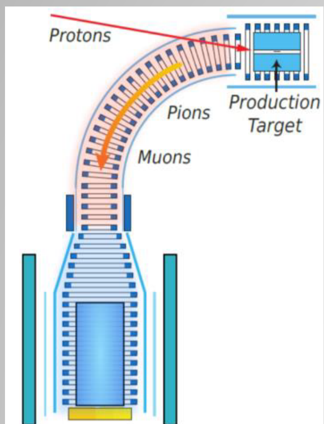


Located in the Japan Proton Accelerator Research Complex (J-PARC) in Tokai, Japan.

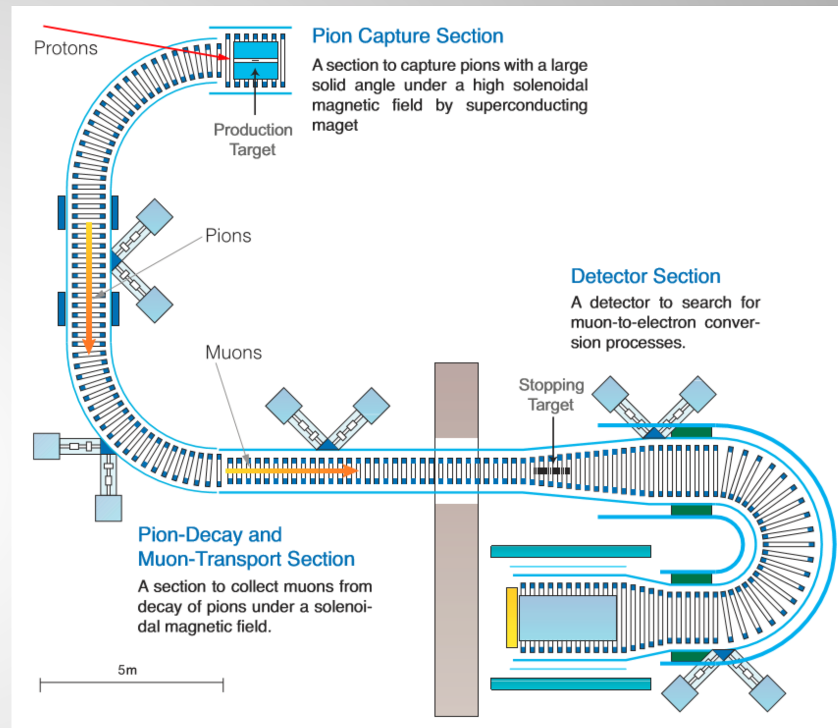
COMET Phase-I:

Search **μ- + Al → e- + Al** with **100 times** improvement of single event sensitivity (SES)

COMET Phase-I and Phase-II



Detectors:
Cylindrical drift chamber
Straw Tracker + ECAL



Detectors: Straw Tracker + ECAL

Goals of Phase- I

1. Background measurements

direct measurement of potential background sources for the full COMET experiment by using the actual COMET beam line

2. Search for μ-e conversion

a search for μ-e conversion at the intermediate sensitivity which would be 3.1×10^{-15} which is100-times better than the present limit (SINDRUM-II)

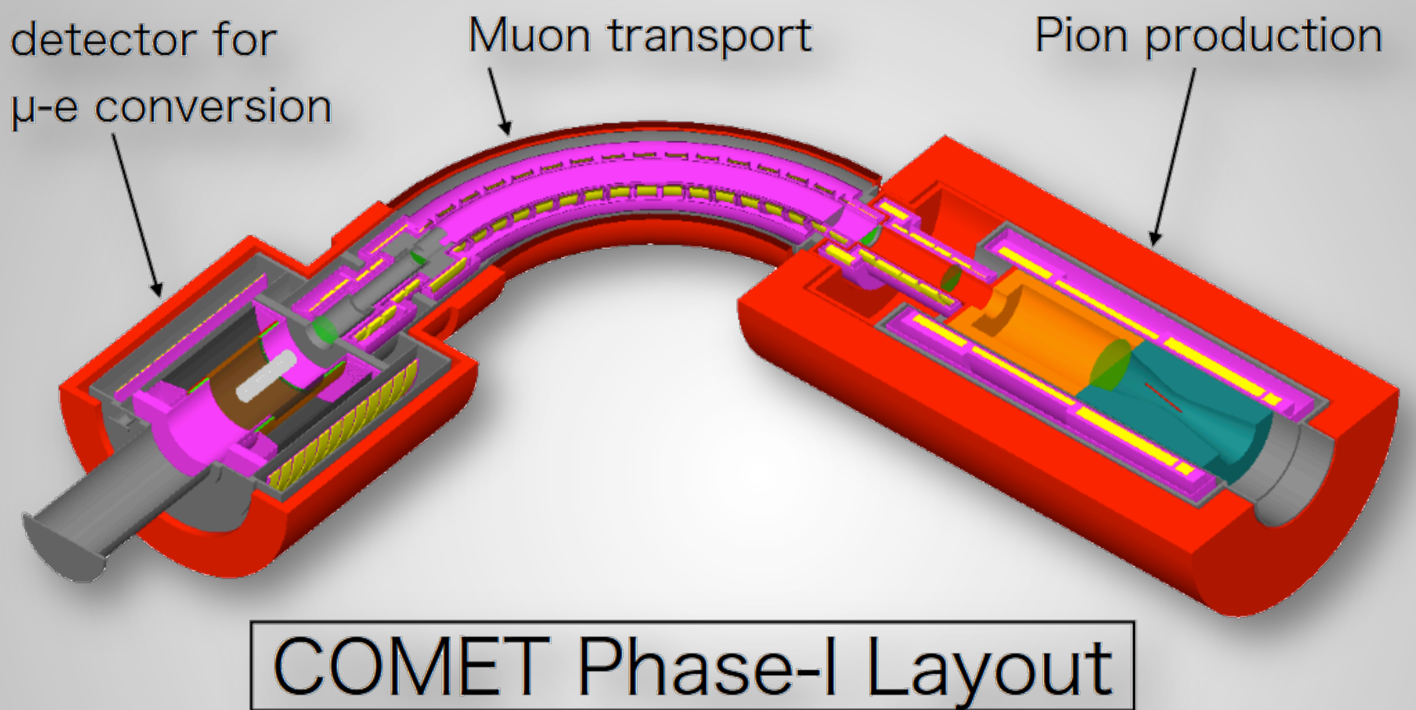
3. Beam characterization

Goal of Phase- II

- **search of μ-e conversion**

single event sensitivity: 2.7×10^{-17} which is 10,000 better than the current limit

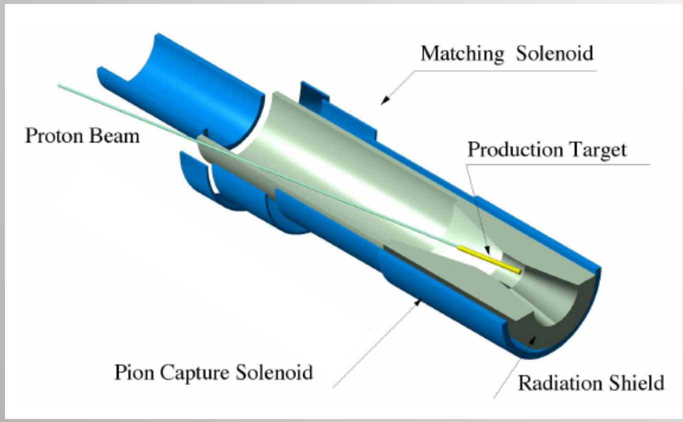
Overview of COMET Phase-I

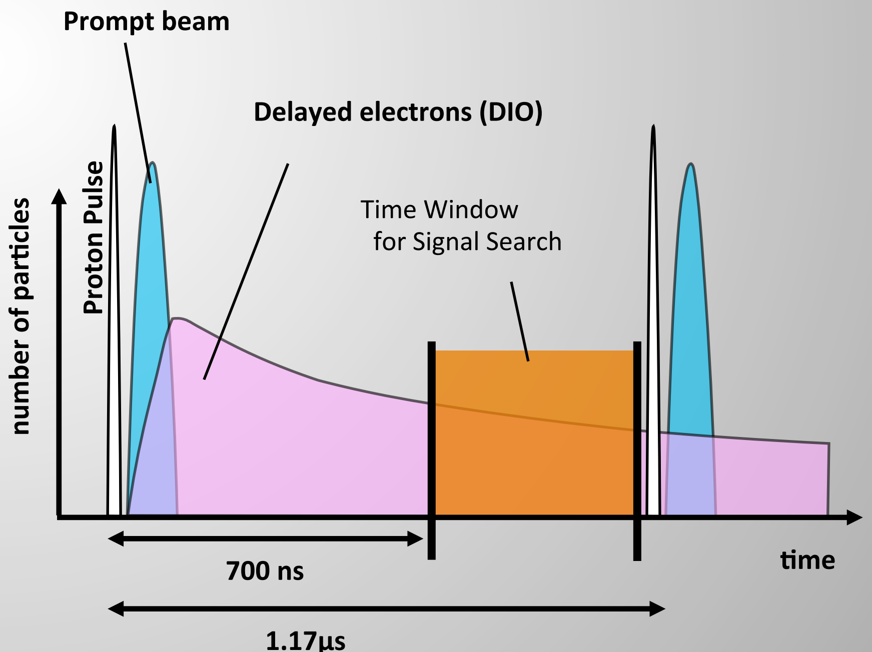


1. Proton on production targets and produce pions
2. Pions decay to muons and transported to detector sections
3. Muons stopped and decay in the stopping target

Proton Beam

- 3kW proton prompt beam:
  - ~ 10^{19} protons on proton targets (in 145 days running time)
- Bunch structure of proton beam
  - Bunch size ~ 10^7 protons on target (POT)
  - Bunch spill/width ~100ns
  - Extinction factor $3\text{x}10^{-11}$
  - Bunch separation time = 1170*ns*.

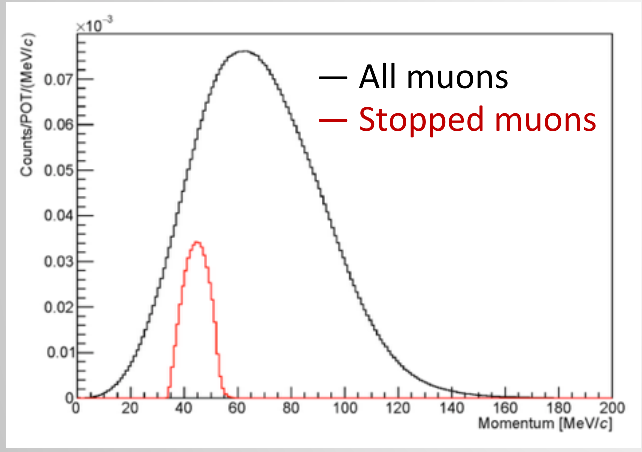




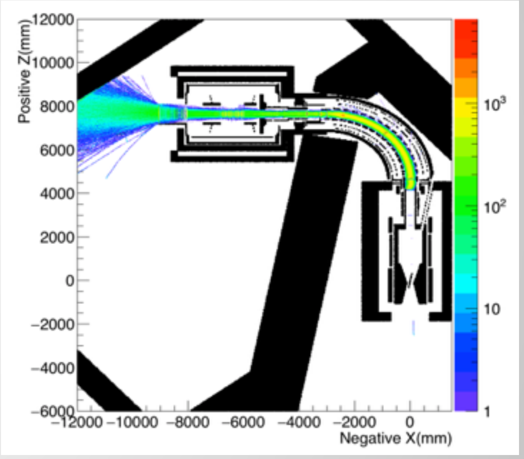
Time structure of proton beam bunch

Muon Beam

- 90 degree and long muon transport solenoid
- High efficiency and stopping rate for ~ 40 MeV/c muons
- Collimator to block high momentum muons ~ 75 MeV/c



Initial momentum of stopped muons and all muons



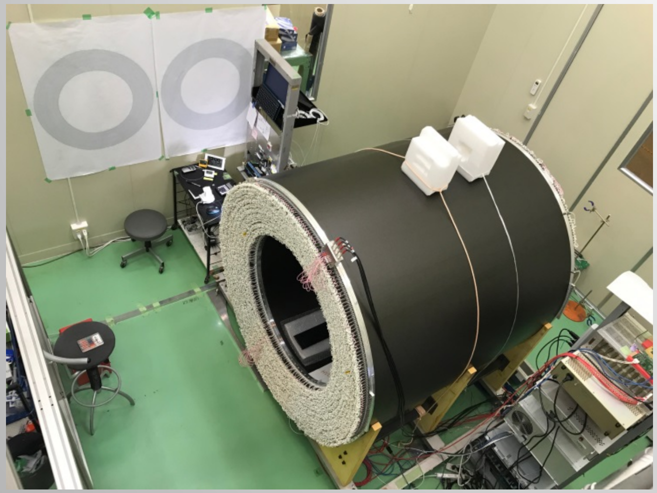
The bird view of muon beam intensity

Yield (per proton):	After muon transport section	Stopped in muon target
Muons	5.0×10^{-3}	4.7×10^{-4}
Pions	3.5×10^{-4}	3.0×10^{-6}

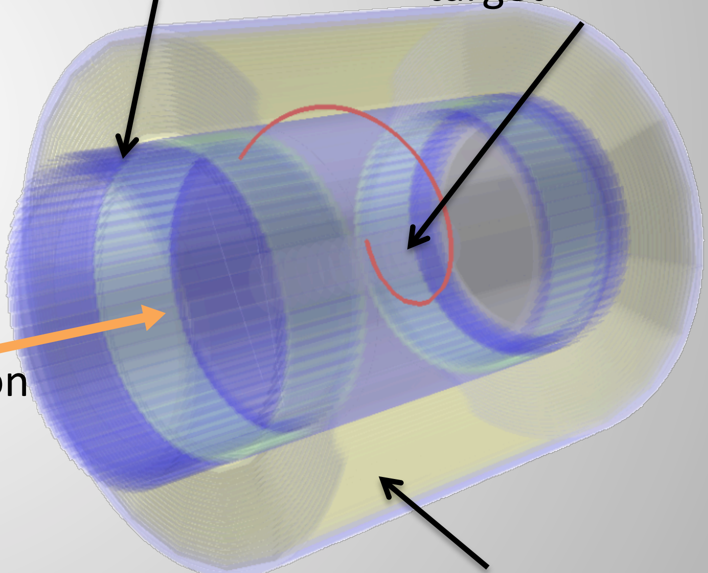
Muon and pion yields per proton at end of the muon beam line and stopped in the stopping target

Phase-I Cylindrical Detector(CyDet)

- Cylindrical Drift chamber (CDC)
  - Large inner radius : reduce beam flash
  - Low mass : Reduce multiple scattering
  - All stereo wires: Good momentum resolution
  - Spatial resolution : ~150 μm
- Trigger hodoscope
  - Cherenkov radiator + plastic scintillator
- Al muon-stopping target (17 disks)

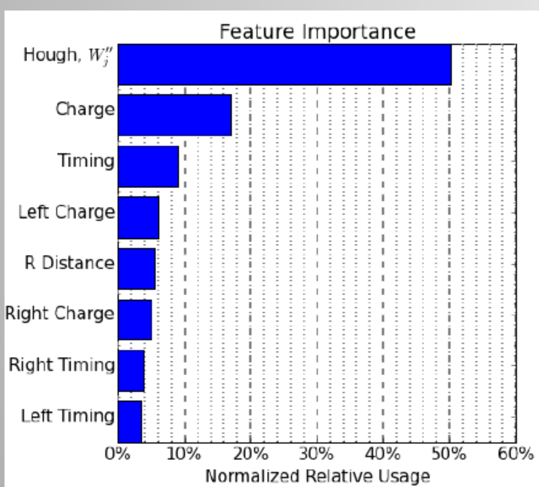


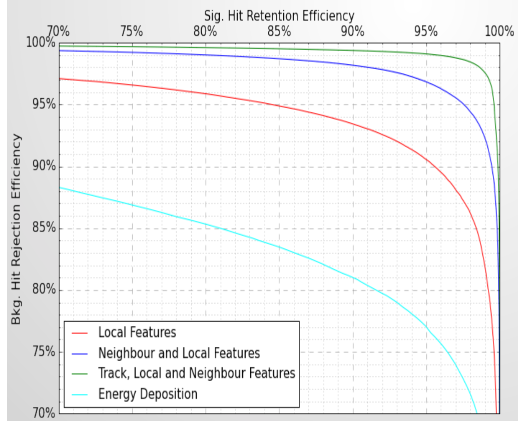
CDC under cosmic ray test

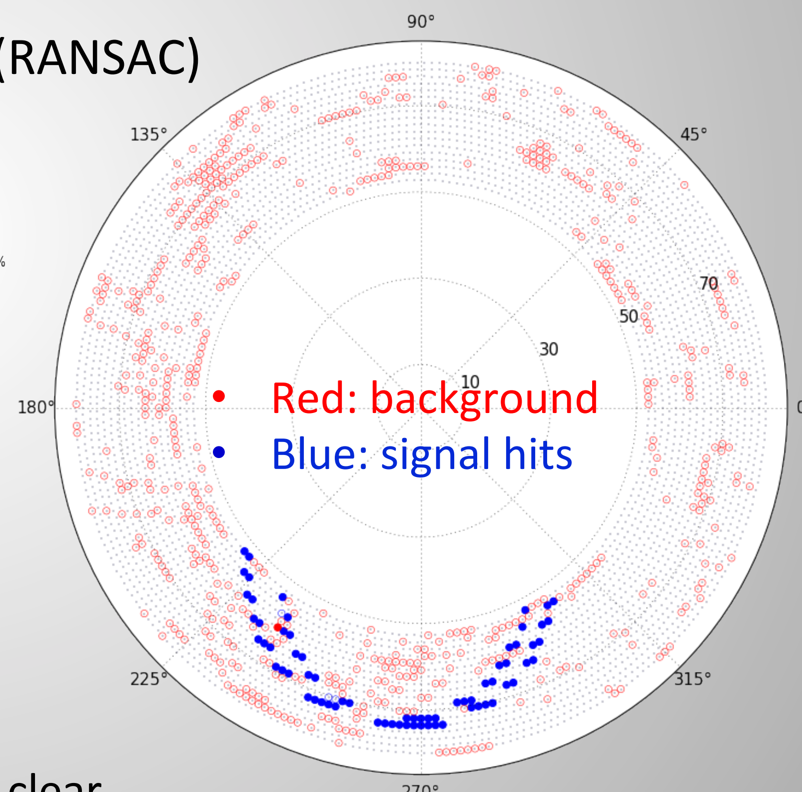


Track Hit Selection

- Hit selection using **G**radient **B**oosted **D**ecision **T**rees (GBDT) and Reweighted Inverse Hough Transform
- Classify hits using local, neighbor and shape features
- Fit initial 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

CyDet Tracking Performance

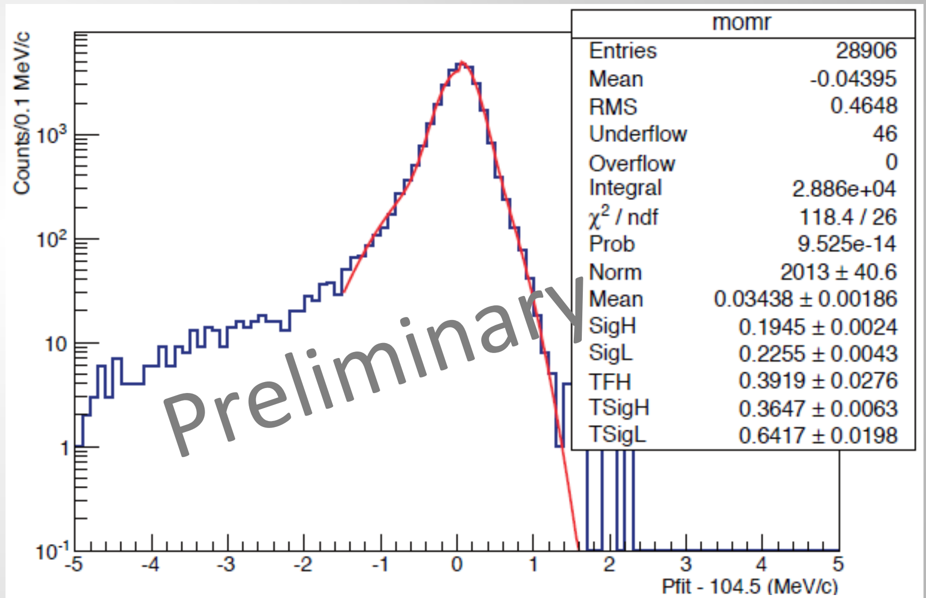
Acceptance after geometry cuts

	Single-track	Multi-track
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

Tracking Efficiency

	Single-turn	Multi-turn	Total
Geometrical acceptance	0.16	0.1	0.26
Tracking efficiency after Quality cut	0.71	0.72	
Total	0.11	0.072	0.18

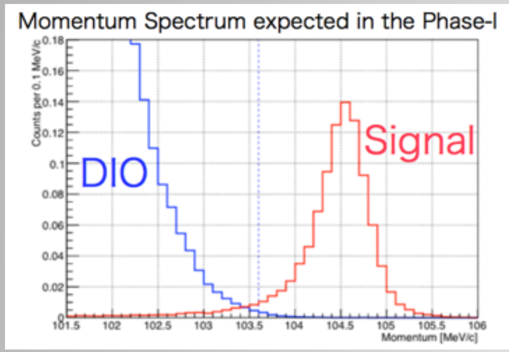
Track finding algorithms are under development
Track fitting is base on genfit



Momentum resolution of 105 MeV/c electrons

- Momentum resolution < 300 keV

Single Event Sensitivity (SES)



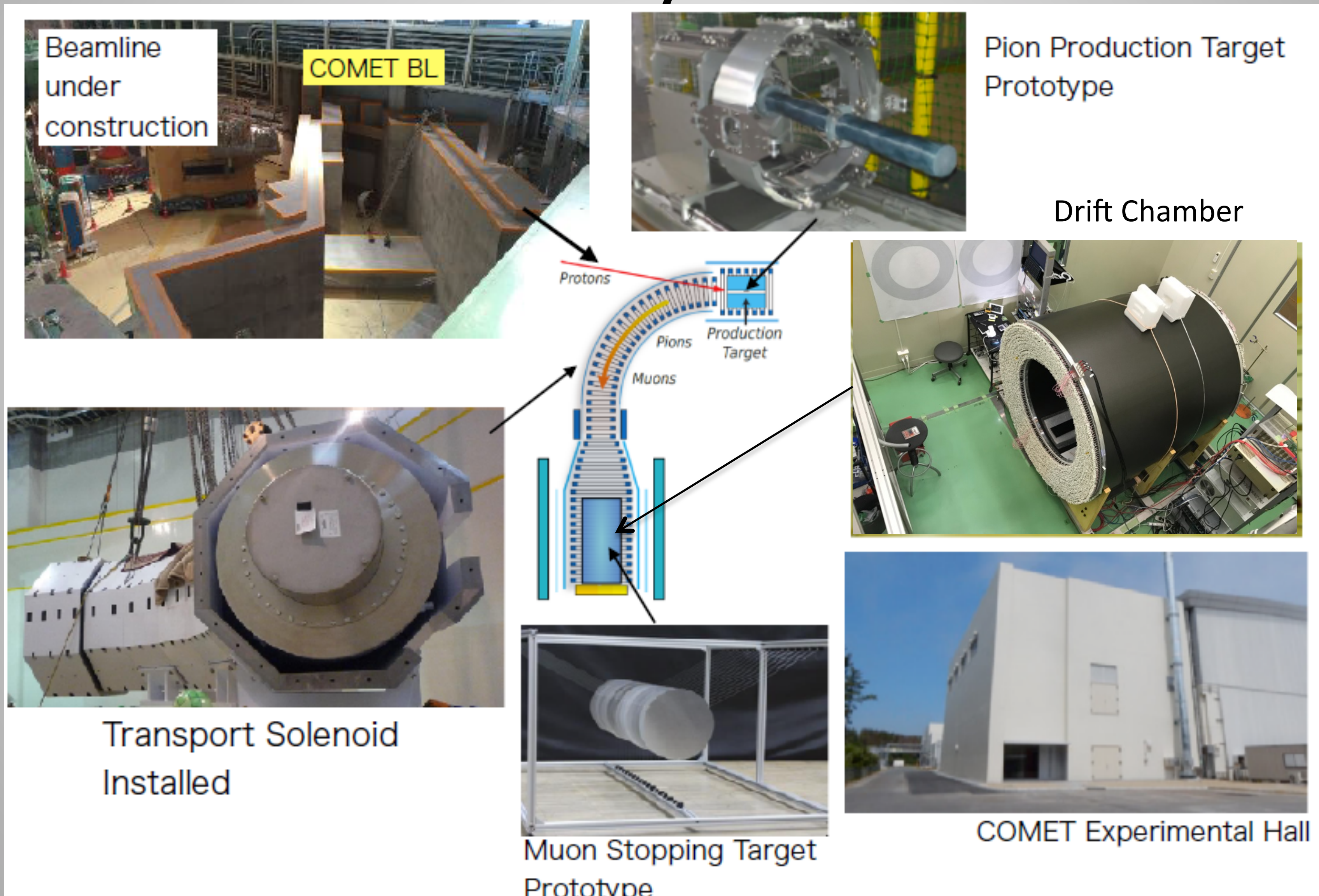
$$SES = Br(\mu^- + Al \rightarrow e^- + Al) = (N_\mu \cdot f_{cap} \cdot f_{gnd} \cdot A_{\mu\text{-}e})^{-1}$$

f_{cap}=0.61 (Al), fraction of muon capture
f_{gnd} = 0.9, the fraction of the μ-e conversion to the ground state in the final state
$A_{\mu\text{-}e}$=0.041, is the signal acceptance
N_μ is the number of muons stopping in the muon target

- With **146** days of physics measurement, the SES is calculated to be **3×10^{-15}**, which is **100 times better** than the current limit (7×10^{-15} 90% C.L. upper limit)

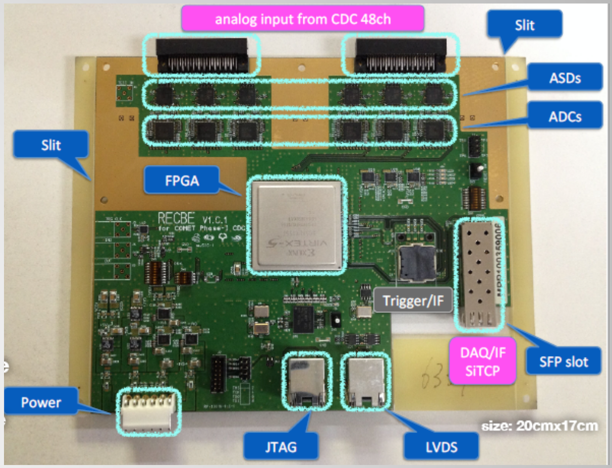
Total number of background event is 0.032 during the data taking at momentum window ($103.6 < p < 106$)

Facility Status



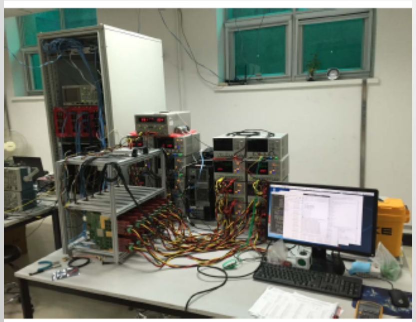
Contribution of Chinese Group
--- Development of drift chamber readout

- The production of 128 readout board (RECBE) has finished by IHEP, China in 2015
  - The design is based on BELLE-II CDC readout board
  - 48 input channels
  - TDC Time resolution: 1 nsec
  - ADC Sampling rate : 30 MHz
- The performance test, threshold scanning, aging test and irradiation test have been done
- 73 RECBEs have been send to Japan

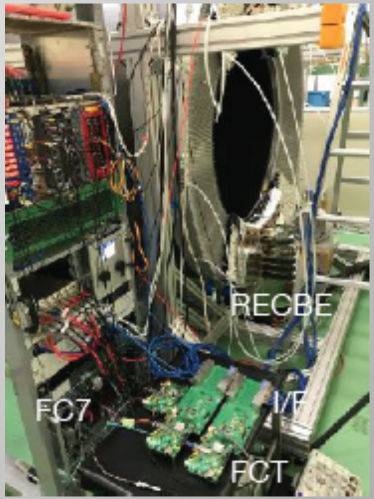


COMET-CDC readout board


128 pcs RECBE in the dry box


Automatic test system

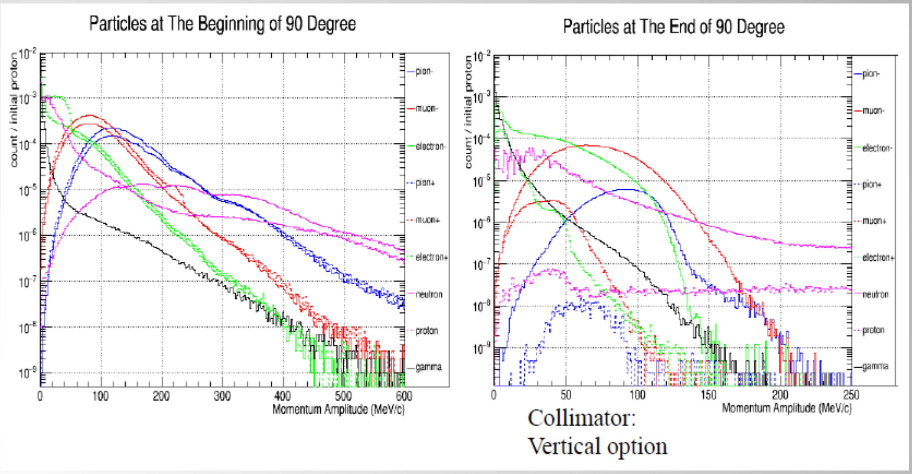

irradiation test

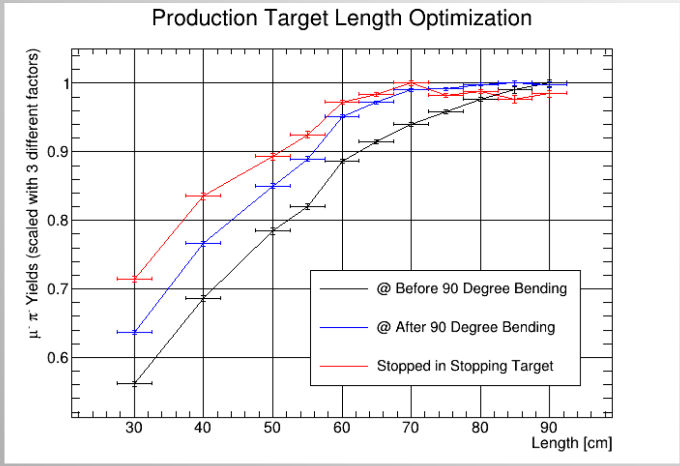


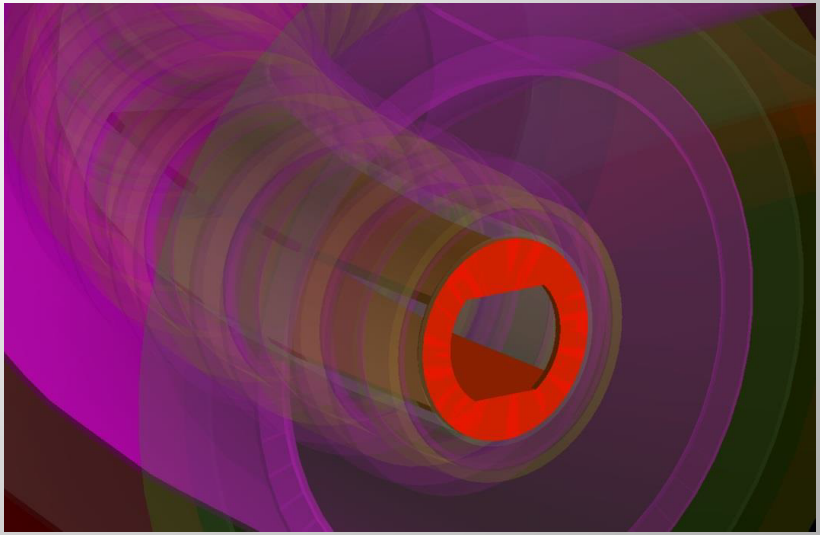
RECBE in CDC cosmic ray test

Contribution of Chinese Group
--- Phase-I design optimization

- Beam simulation
- Experiment optimization
  - Production target, Collimator ,CTH
- Sensitivity and Backgrounds
  - Muon decay in orbit (DIO)
  - Radiative muon capture (RMC)
  - Radiative pion capture (RPC)
  - anti-proton
  - Other beam related backgrounds





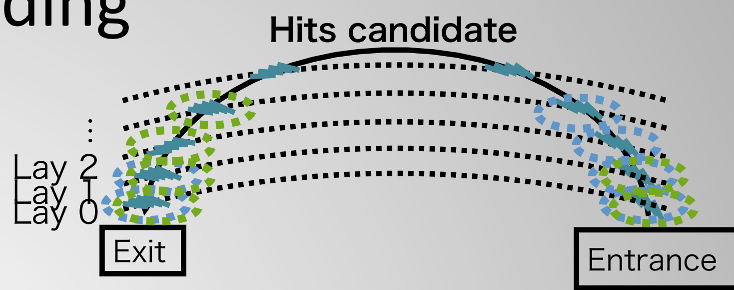


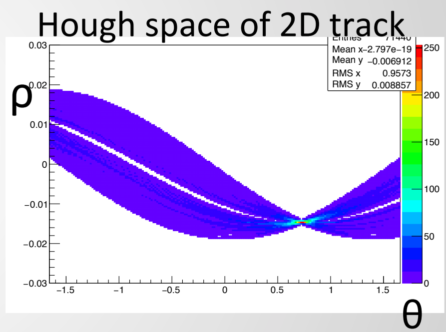
Collimator after optimization

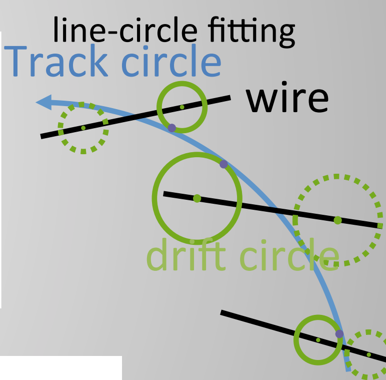
Contribution of Chinese Group

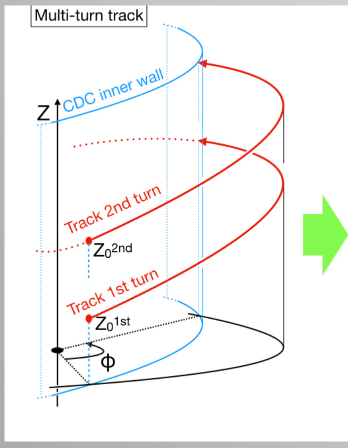
---CDC track finding

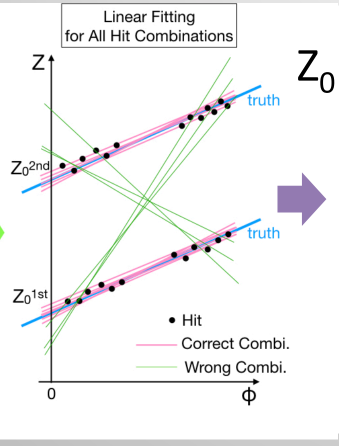
1. Create possible hit list candidates
2. Get track circle by Hough transform
3. Linear fitting on Z-Phi plane by minimize the distance between circle track and wire
4. Peak finding in the track parameter space which include all track candidates

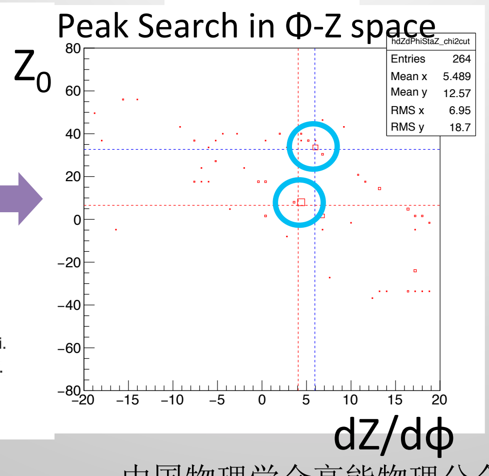


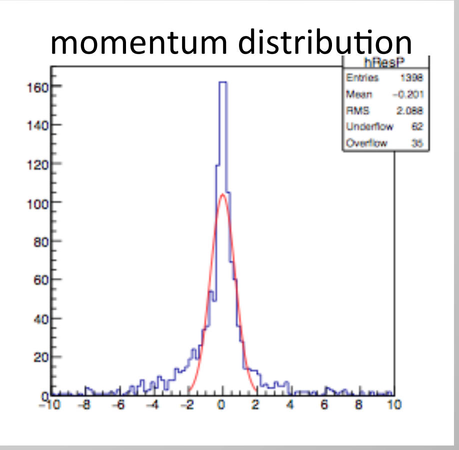












Contribution of Chinese Group
---CDC Simultaneous multi-turn track fitting

1. Based on genfit2
2. Multi track fitting: Simultaneous fit different turn hypothesis
3. Hit competition: Weighted mean assignment for each hit at same detector plane
4. Annealing: Iteratively fitting with the changing of weight to avoid local minimum

weighted measurement for multi-turn tracks

one hit associated with two tracks

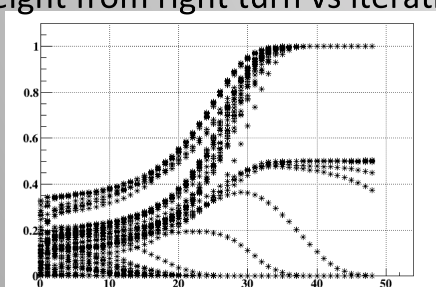
The possibility of hit *i* assigned to track *j* is defined as matrix Φ

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

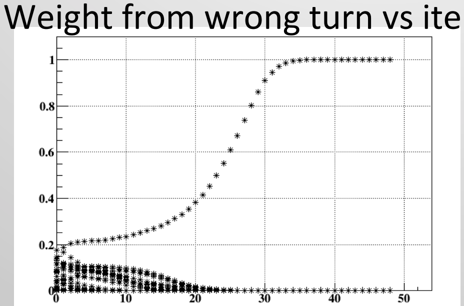
Assignment weight of hit i to track j

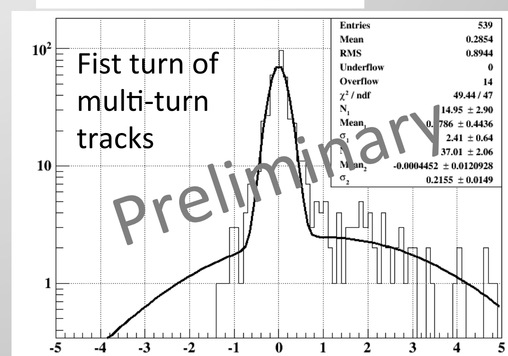
$$p_{i_k j} = \frac{\varphi_{i_k j}}{\sum_l \sum_\alpha \varphi_{i_\alpha l} + c}.$$

Weight from right turn vs iteration



Weight from wrong turn vs iteration

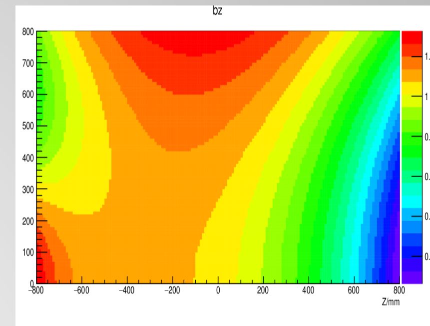




Contribution of Chinese Group

--- field map calc. and mass production on super-computer

- Magnetic filed calculation



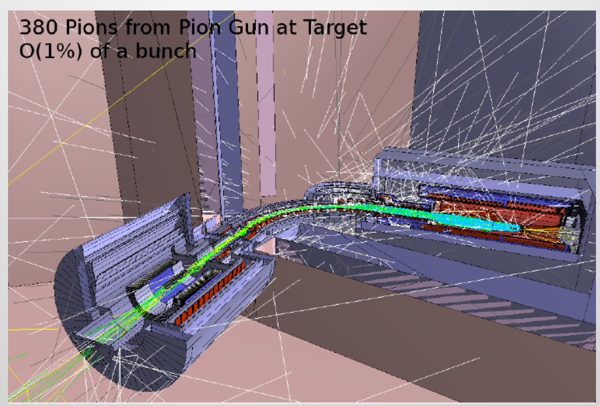
Field map(Bz) at detector region

- Super computer Tianhe2
  - Tianhe2 is the second fastest HPC in the world
  - The COMET mass production have been tested on Tianhe2 (one bunch)

中山大學 SUN YAT-SEN UNIVERSITY

国家超级计算广州中心 NATIONAL SUPERCOMPUTER CENTER IN GUANGZHOU

Super computer Tianhe2



An event display of 1% of a bunch

	# file	Proton/file	CPU time/ proton
Tianhe2	230	4e4	2.4 s
In2p3 (France)	122	8e6	2.76 s
TAURUS (Germany)	122	4e4	2.7 s

Tianhe2 is the site with largest number of cores in COMET

The COMET collaboration

16 countries, 39 University or institute,
195 collaborator

高能所，南京大学，中山大学，北京大学

The COMET Collaboration

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