CGEM offline Software

***I. Garzia*, S. Spataro, L.L. Wang, P. Weidenkaff**
(on behalf of CGEM-software group)

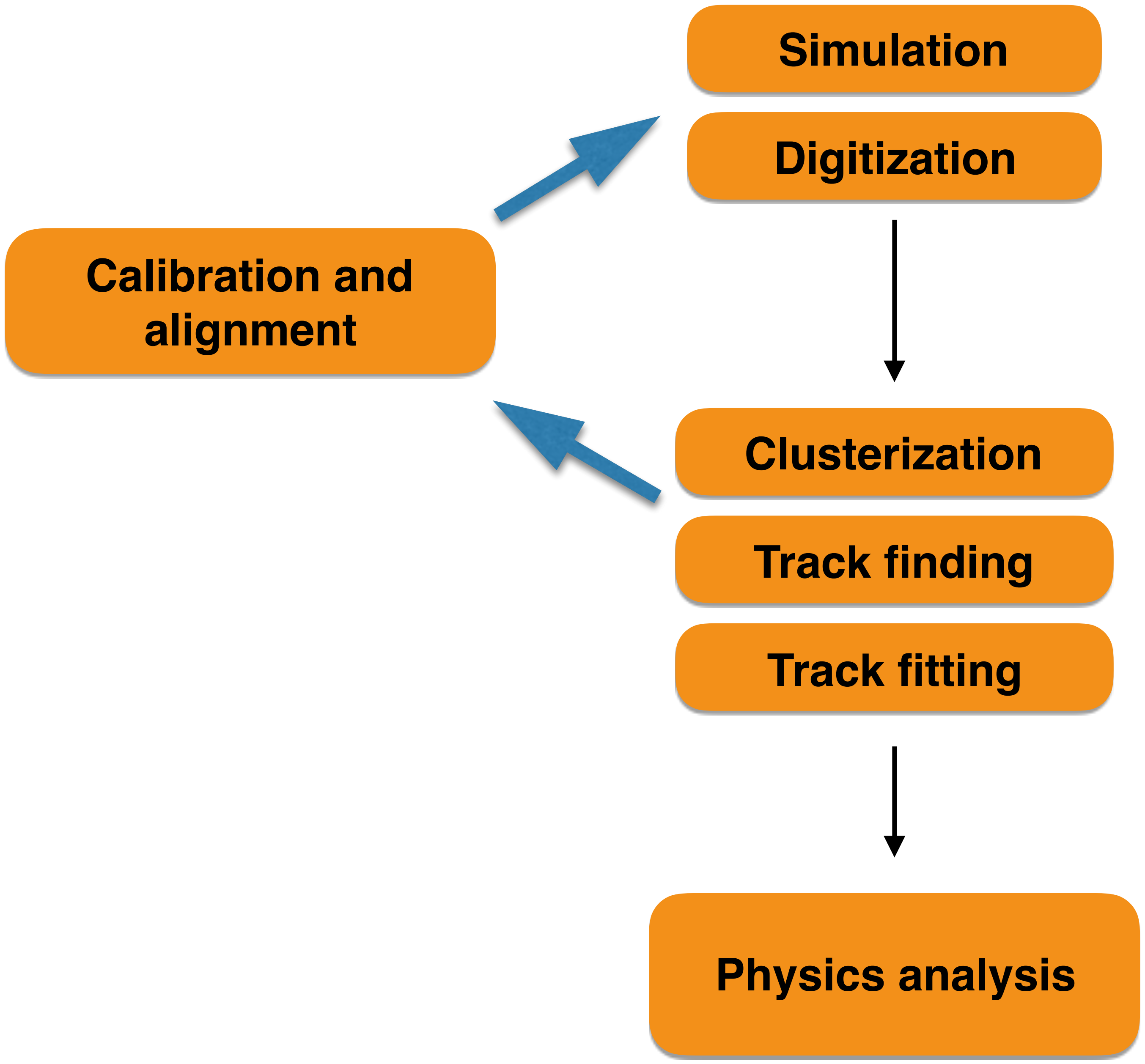
IRC meeting - July 15, 2019

Outline

- **Introduction**
  - **software milestones and status**
- **Implementation of the CGEM-IT in the BESIII software**
- **Calibration and alignment**
- **Releases, tests and conclusions**

Software overview

Cgem BESIII Offline Software System (CgemBoss)



OFFICIAL RELEASE (April 2017):

- **CgemBoss v. 665b** developed for benchmark channel studies
  - CGEM+ODC segment matching

INTERNAL RELASE (July 2018):

- Test Release: **CgemBoss v. 665c** developed to test and debug the Hough tracking code

CGEM software milestones

- **Understand triple-GEMs behavior using test beam data**
  - Detector simulation of planar setup (digitization): comparison of simulated and experimental results
  - Resolution optimization, merging between CC and μTPC methods
- **Implementation of the CGEM-IT in the BESIII software**
  - Full geometry (including also passive elements)
  - Full digitization
  - Global reconstruction (CGEM cluster and ODC hit combination)
  - Alignment and calibration
  - Event display
  - …
- **Check physics performances**
  - Single track and multi track event simulation, benchmark physics channel, …

CGEM software milestones

- **Understand triple-GEMs behavior using test beam data**
  - Detector simulation of planar setup (digitization): comparison of simulated and experimental results
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Milestones 4 and 5

- **Implementation of the CGEM-IT in the BESIII software**
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  - Full digitization
  - Global reconstruction (CGEM cluster and ODC hit combination)
  - Alignment and calibration
  - Event display
  - …

Milestones 6

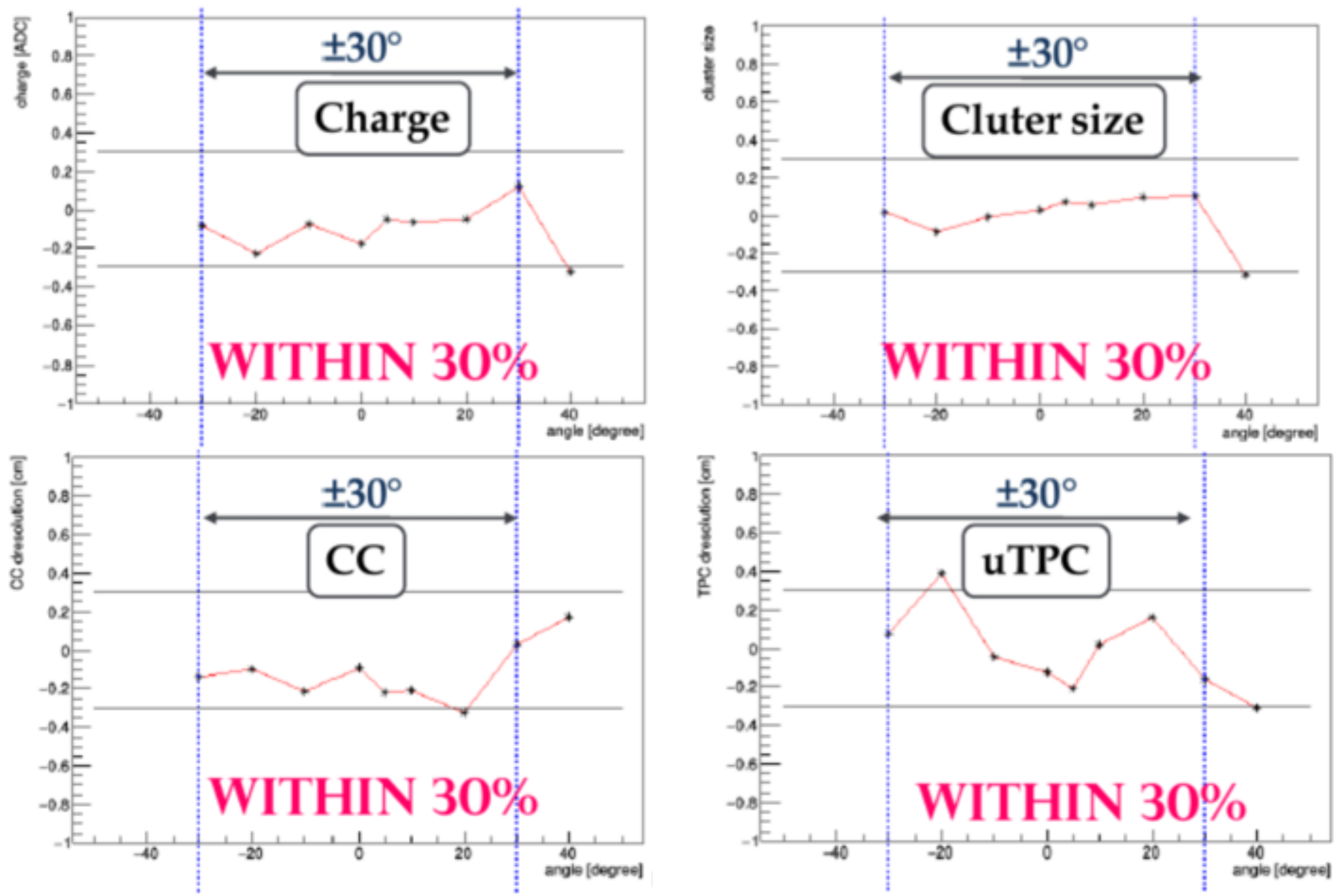
- **Check physics performances**
  - Single track and multi track event simulation, benchmark physics channel, …

Milestone 5: digitization for the test beam setup

R. Farinelli, L. Lavezzi

- Planar GEM instrumented with APV25
- Data from test beam (April 2018)
- B = 1T

$$\frac{MC - exp}{exp}$$



Agreement within 30% as required by IRC milestone #5

Milestone 5: digitization for the test beam setup

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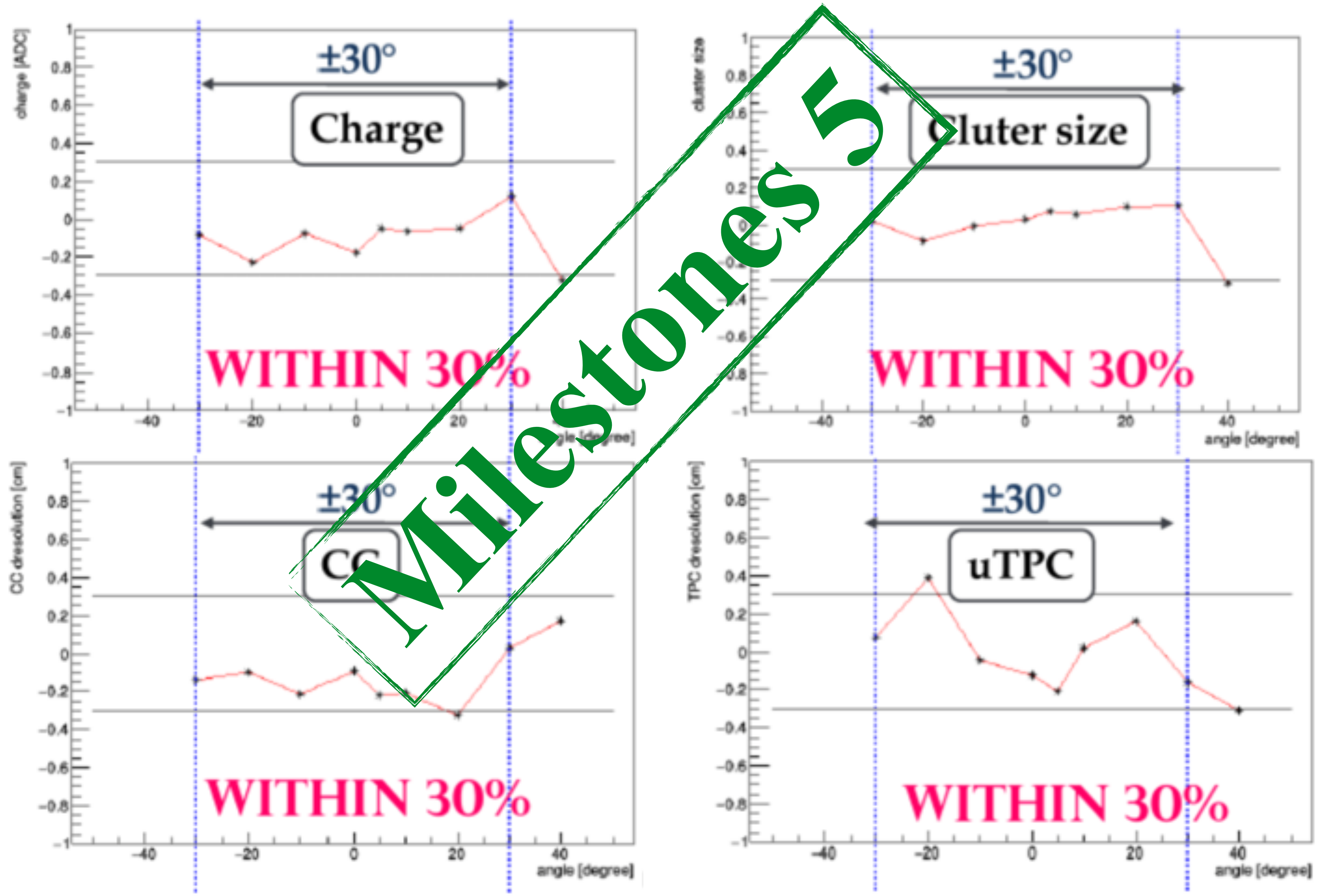

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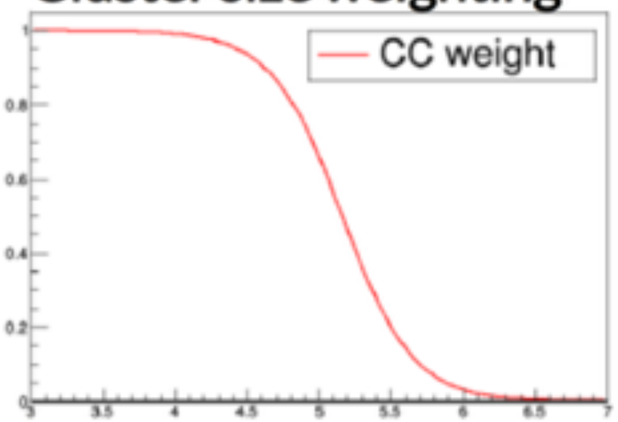
Milestone 4: CC and μTPC merging algorithm

R. Farinelli

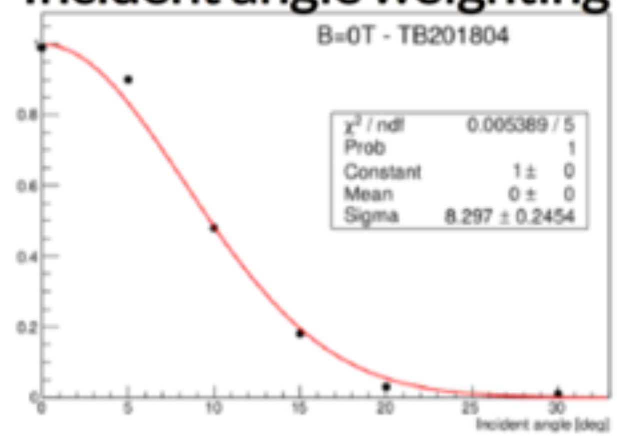
$$x_{\text{merge}} = \frac{x_{cc} \cdot w_{cc} + x_{\mu tpc} \cdot w_{\mu tpc}}{w_{cc} + w_{\mu tpc}}$$

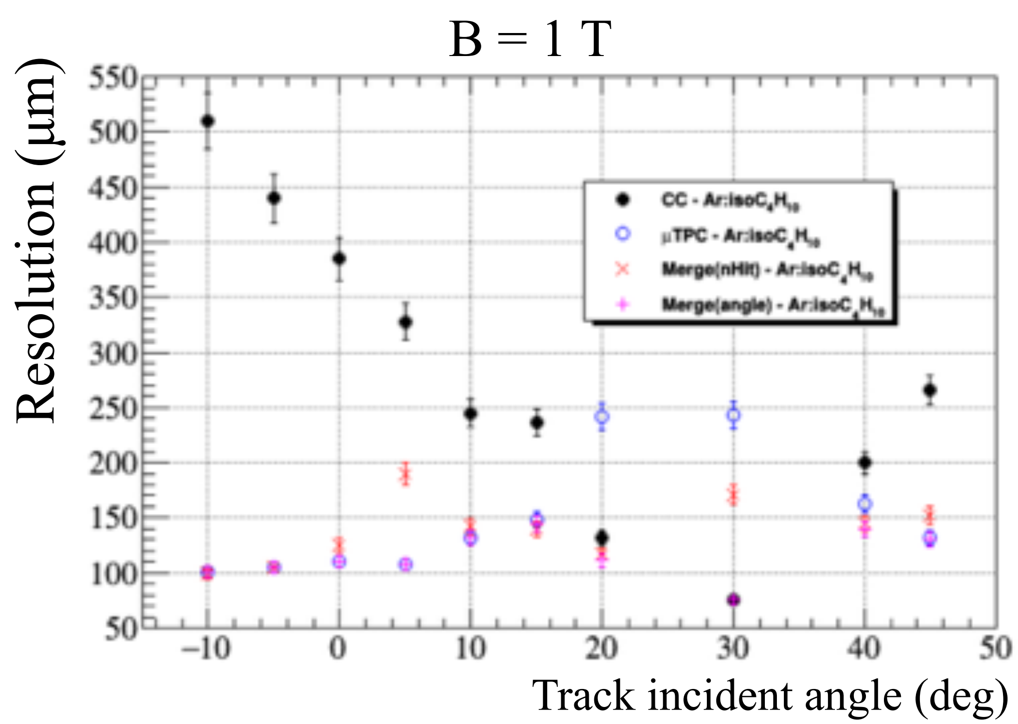
- CC and μTPC must be combined
- Iterative combination of cluster size weighting and incident angle weighting in order to achieve the expected resolution

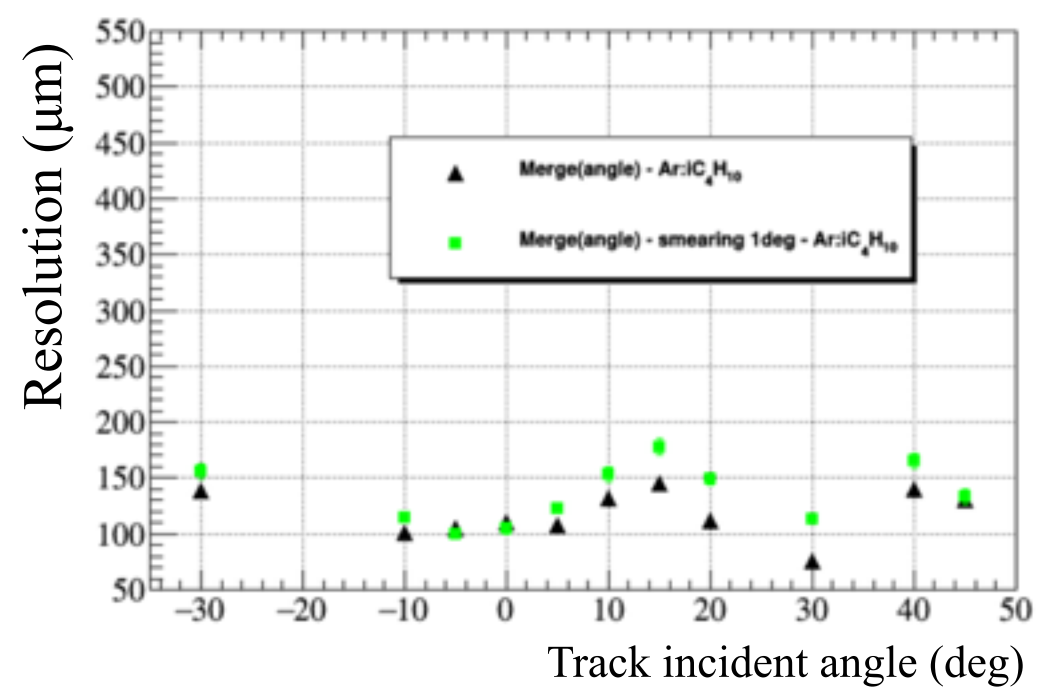
Cluster size weighting



Incident angle weighting







- **Resolution < 140 μm**
- Efficiency between 95%-98%

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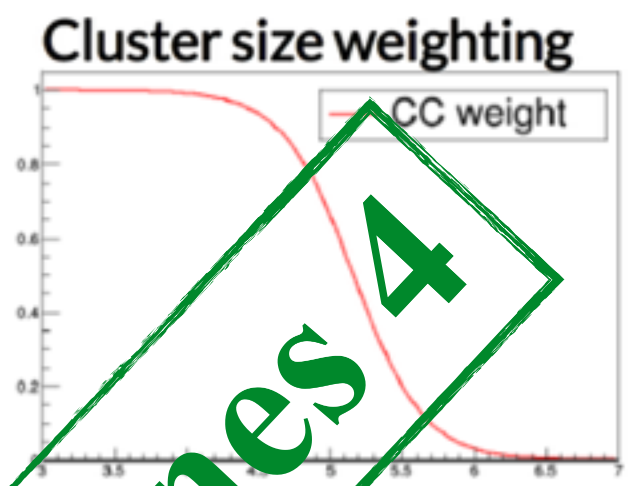

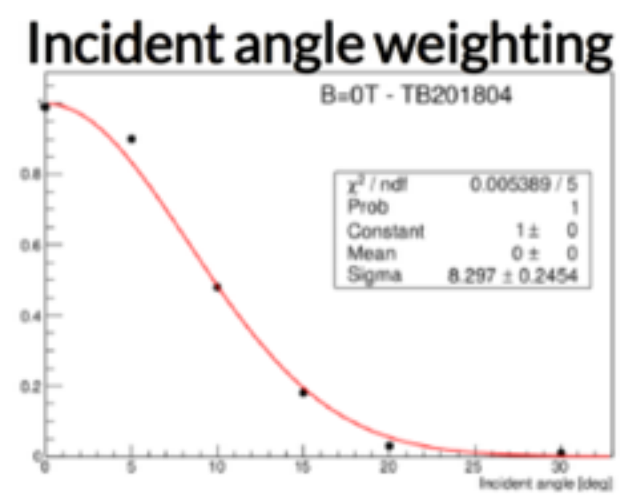

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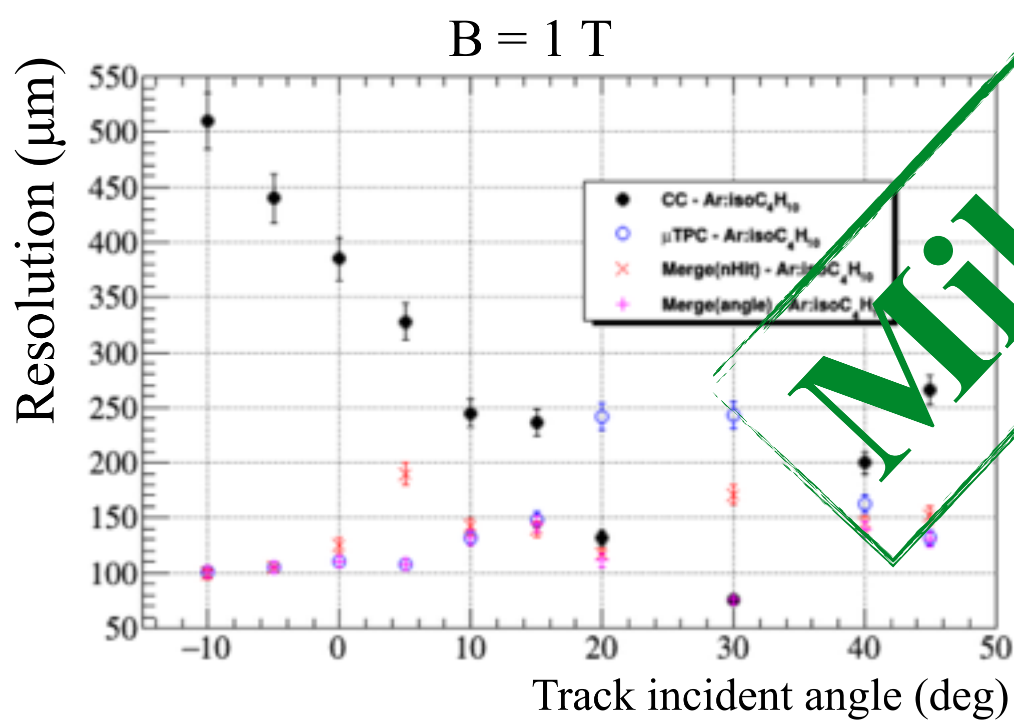
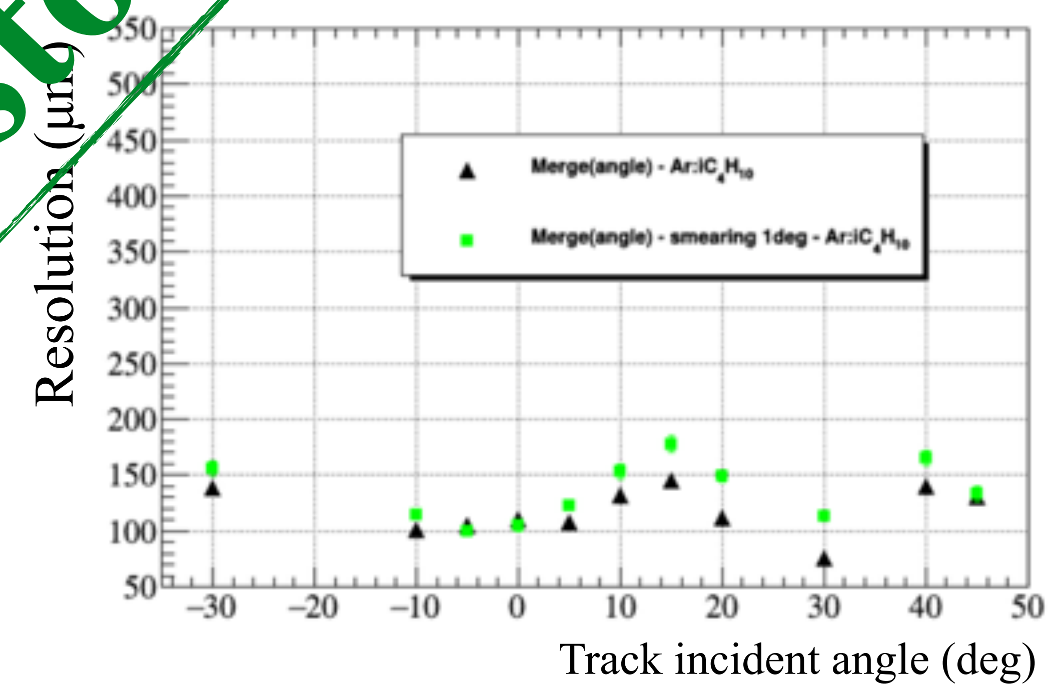




- **Resolution < 140 μm**
- Efficiency between 95%-98%

Cluster reconstruction with Machine Learning

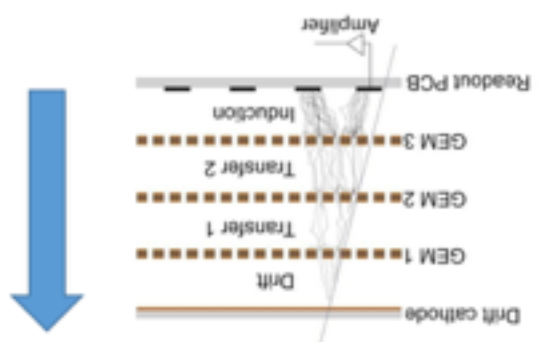
Preliminary studies by means of machine learning (ML) technique

shown @ CHEP2018

Beijiang Liu, Xian Xiong

Cluster reconstruction of CGEM-IT with ML

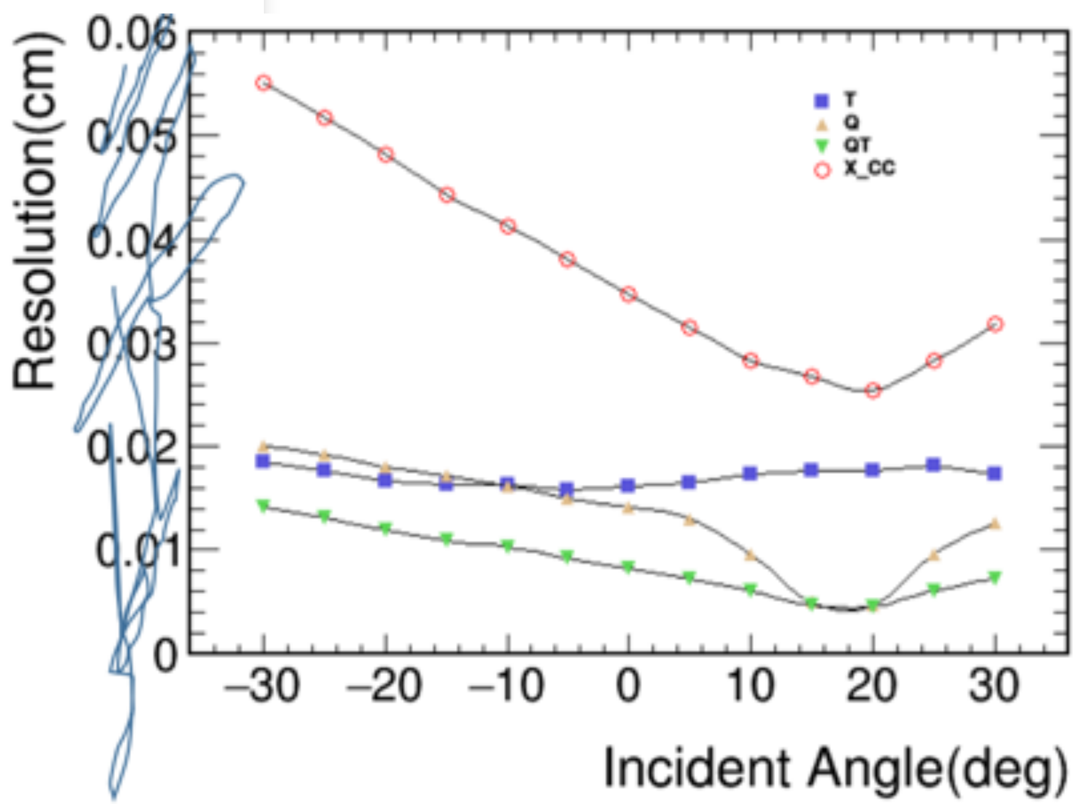
- Use Q and T of the fired strips to measure the initial ionizing particle position X



- A regression problem
  - i.e. X= f(Q,T)

Set up

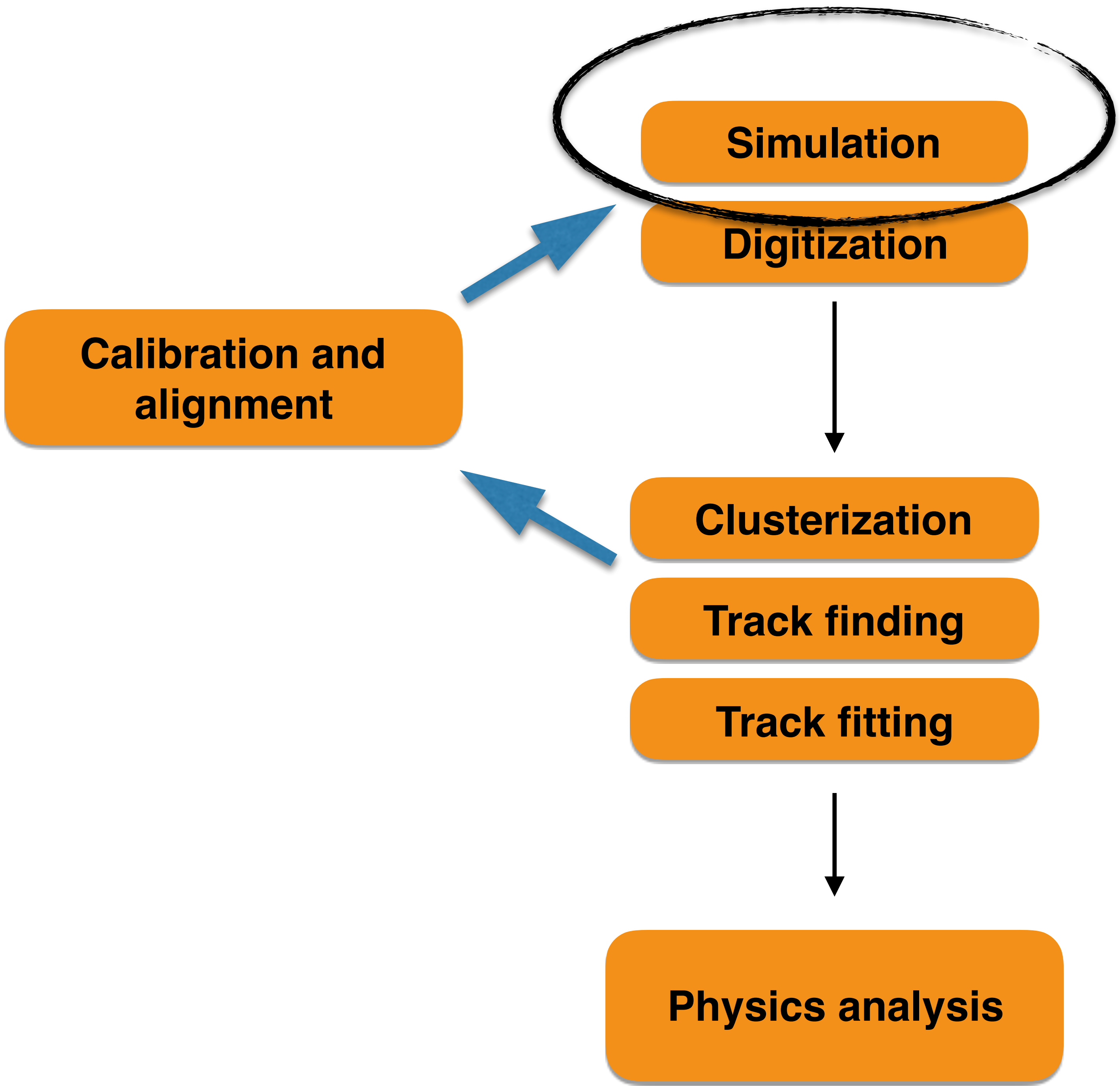
- Simulation with a standalone digitization code, based on GARFIELD results [R.Farinelli, L.Lavezzi, etc. arXiv:1807.01210]
  - B=1T
  - Incident angle [-30 °, 30 °]
  - 1 layer of planar Triple-GEM
- XGBoost regressor



- Resolution from **QT** combined output better than resolutions from **Q** or **T** only
- Resolution from **ML** technique better than charge centroid
- ***Promising results …. but more studies based on more realistic simulation/digitization***

Implementation of CGEM-IT in the BESIII software

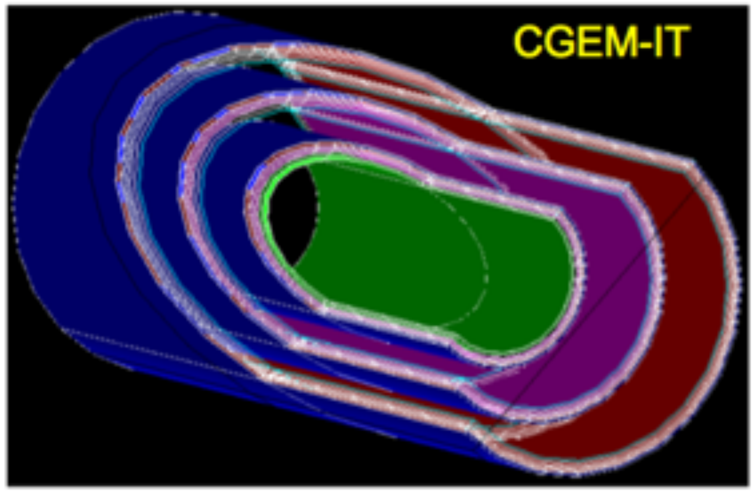
R. Farinelli, L. Lavezzi, N.N. Miao, L.H. Wu, J.Y. Zhao, L.L. Wang



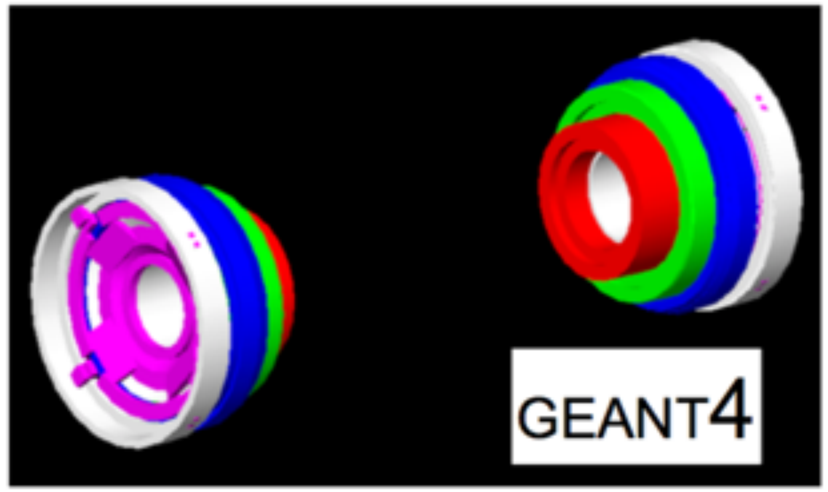
Full geometry implementation in CgemBoss

Geant4 description of CGEM

✓ CGEM-IT (sensitive part)



✓ passive elements



✓ Inner barrel of Outer-Drift-Chamber

✓ CGEM geometry service package (CgemGeomSvc)

- manage geometry parameters
- provide geometry information and calculation
- Same for simulation, reconstruction, calibration, and aligi

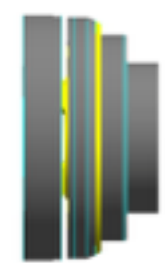
Updates in geometry (passive part)

✓ Simplified Geometry (Michele)

✓ Implementation in Geant4 (Lia)

✓ Cables (recent update) New

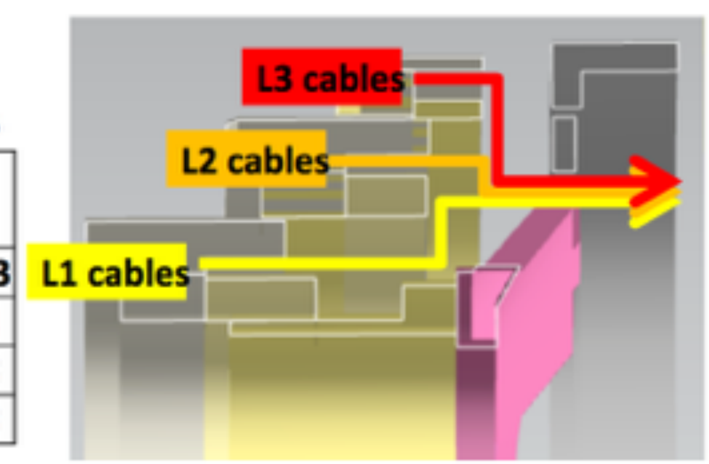
- Types: HV/LV/signal
- Density measured (Ilaria)
- Average density set in free volumes to considering cables



- Flanges
- Rings
- Cables

east #cables from each layer			
	n L1	n L2	n L3
HV	6	12	12
LV	8	14	18
signal	8	18	18

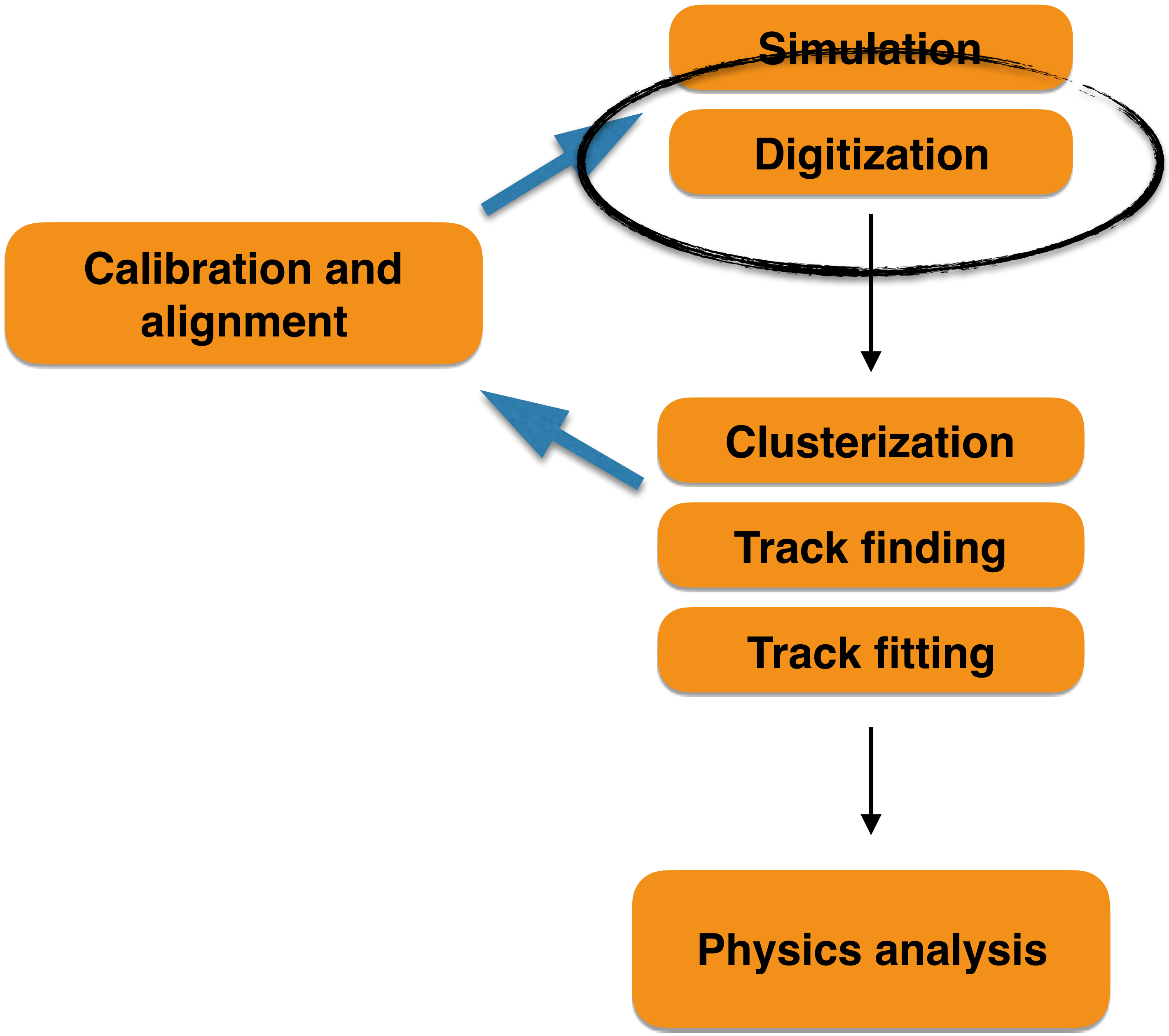
west #cables from each layer			
	n L1	n L2	n L3
HV	7	14	14
LV	8	14	18
signal	8	14	18



The passive element geometry is completed and available now

Implementation of CGEM-IT in the BESIII software

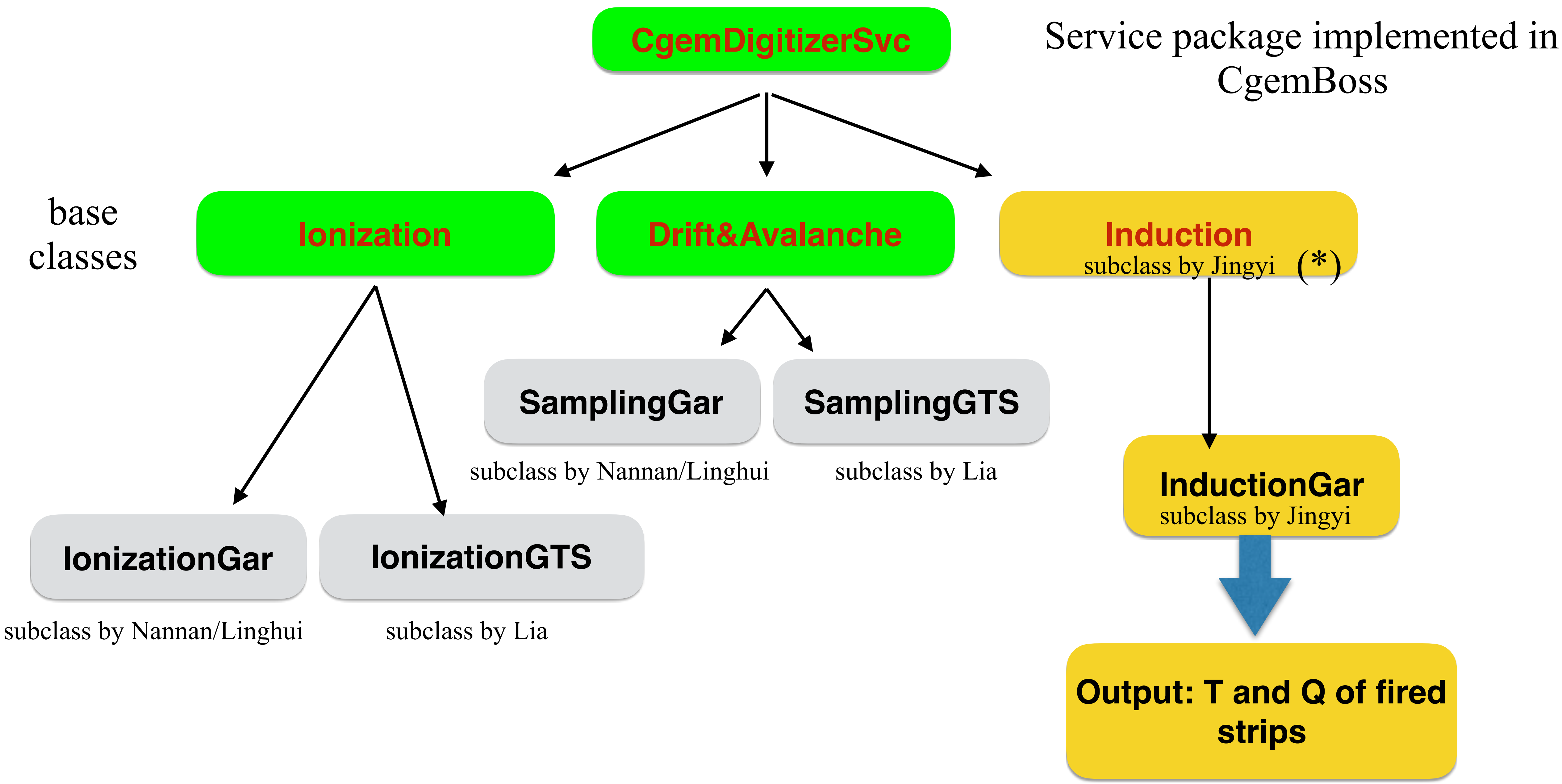
R. Farinelli, L. Lavezzi, N.N. Miao, L.H. Wu, J.Y. Zhao, L.L. Wang



Full digitization implementation in CgemBoss almost complete

Digitization

R. Farinelli, L. Lavezzi, N.N. Miao, L.H. Wu, J.Y. Zhao, L.L. Wang

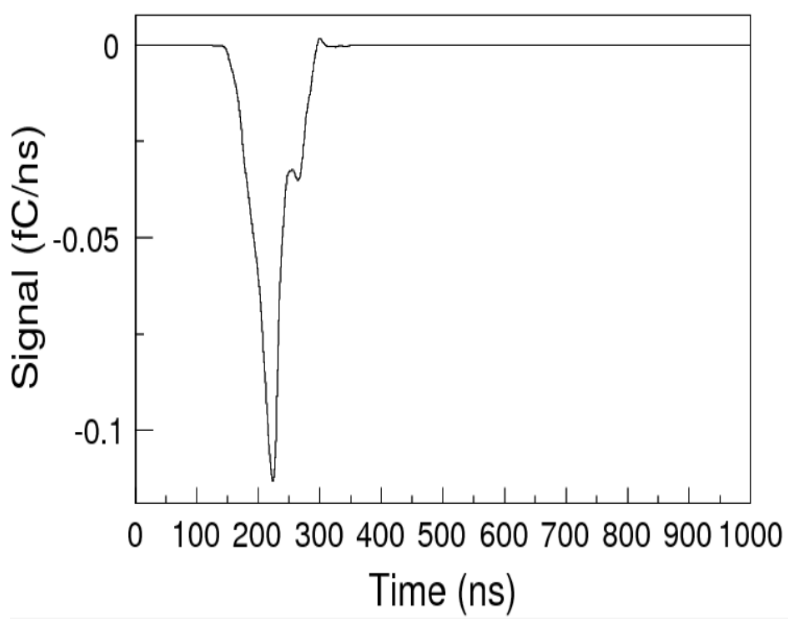


(*) subclass InductionGTS by Lia ready soon

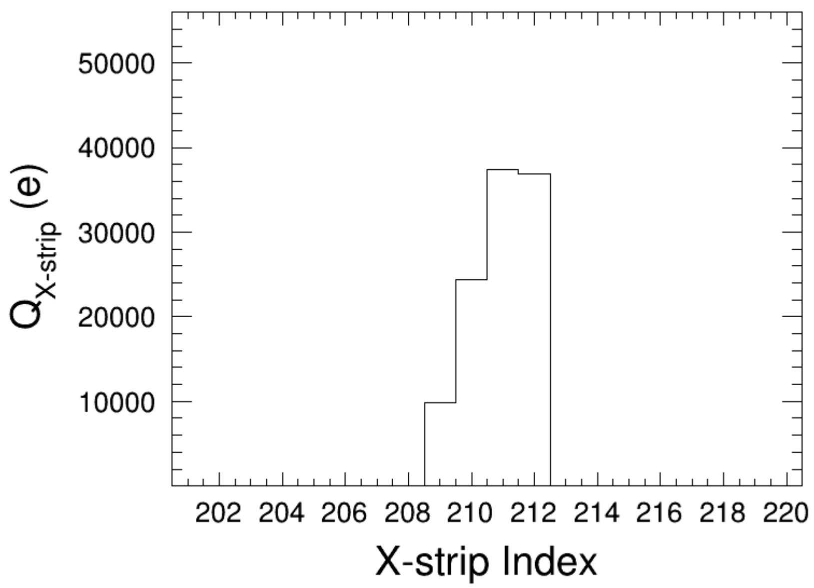
Digitization: Induction

- Induction with 2D weighting field
  - ANSYS/Elmer (primary/secondary ionization)
  - Garfield++ (sampling model for drift, diffusion and multiplication)
  - updated with current strip design

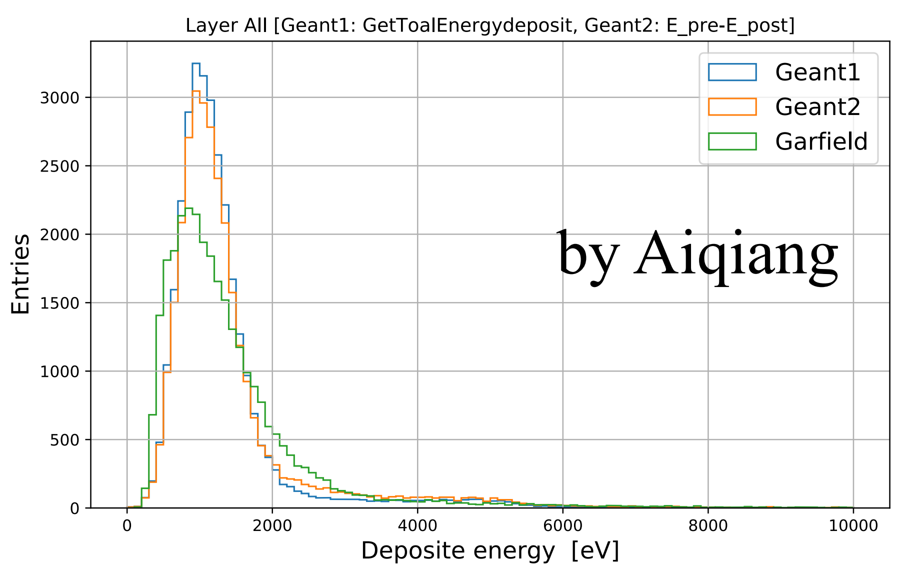
Induced ***current*** on the X strip



Induced ***charge*** on the X strip

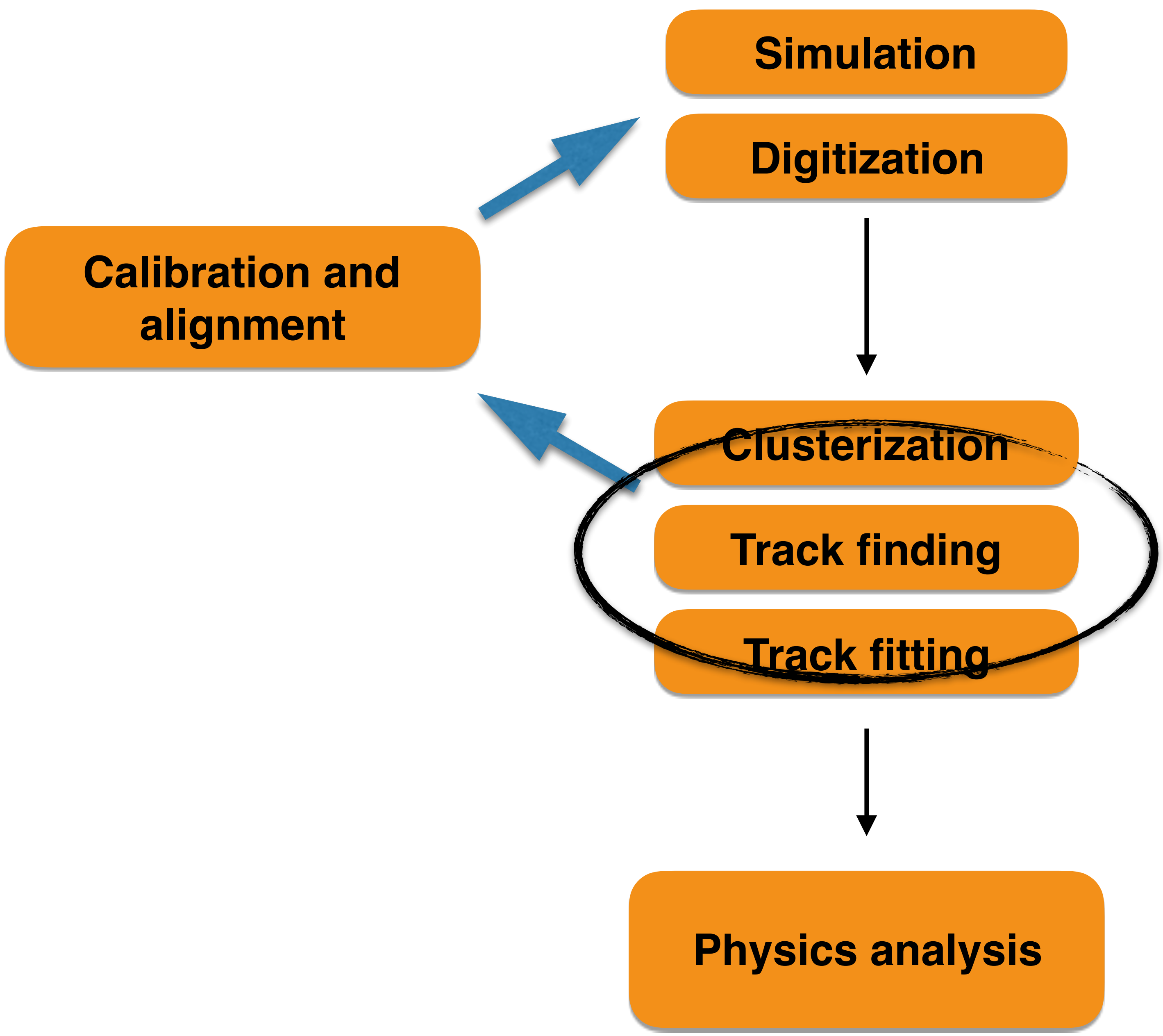


- Digitization process validated by comparing the deposit energy in Geant4 and Garfield
- Cluster size from beam test data is bigger than the cluster size from digitization algorithm: tuning with CGEM data needed
- Readout electronic (sum and signal conversion) ***TIGER***: *work in progress*



by Aiqiang

Reconstruction



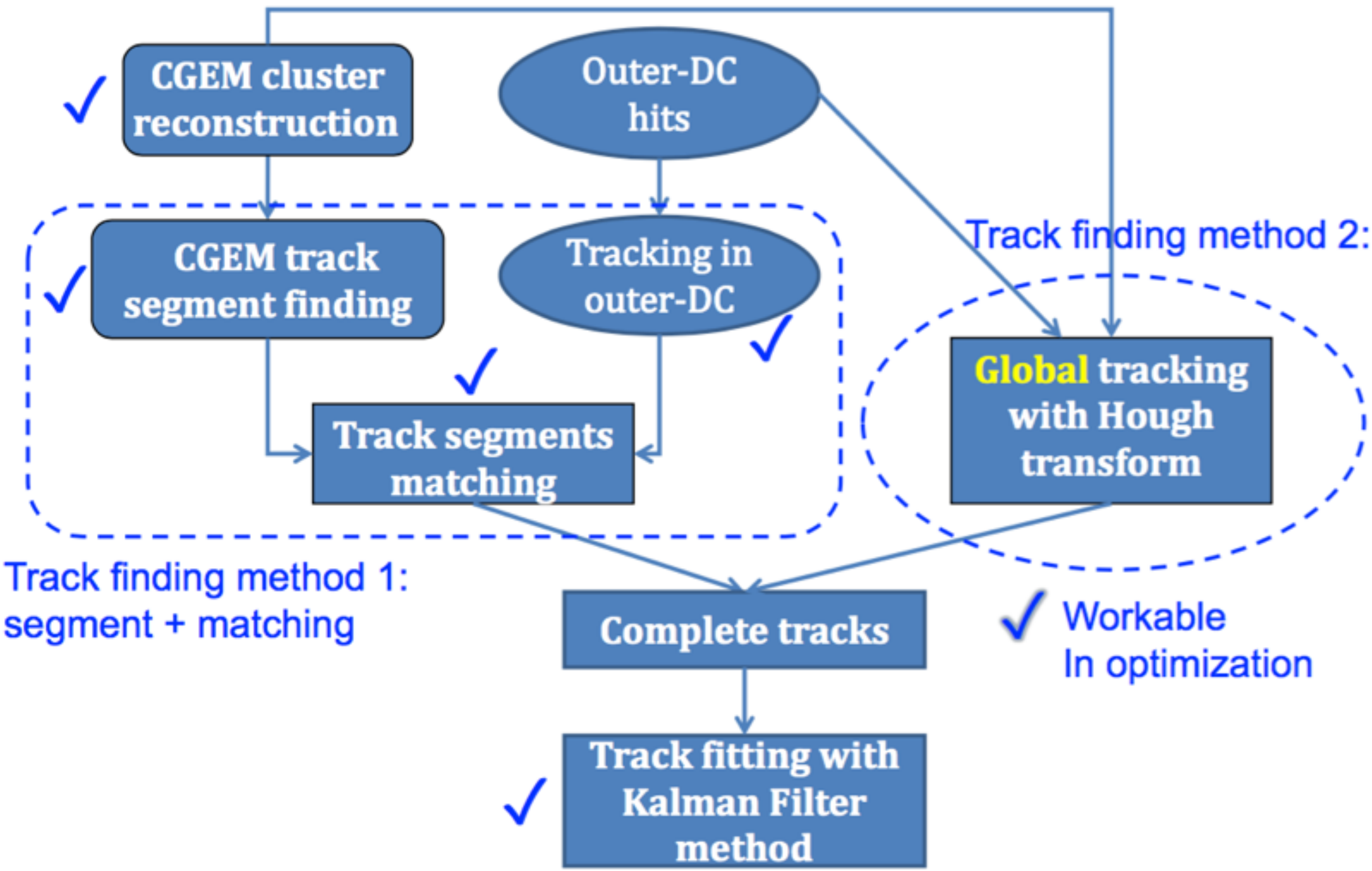
- ***CemBoss665b:*** Segment finder in Cgem and ODC + matching
  - Low efficiency for low track momenta

- ***CgemBoss665c:***
  - Global track finding: Hough transform v.12 (Cgem clusters + ODC hits)
  - Global track fitting: least square method

- ***Next CgemBoss release:*** updated Hough packages

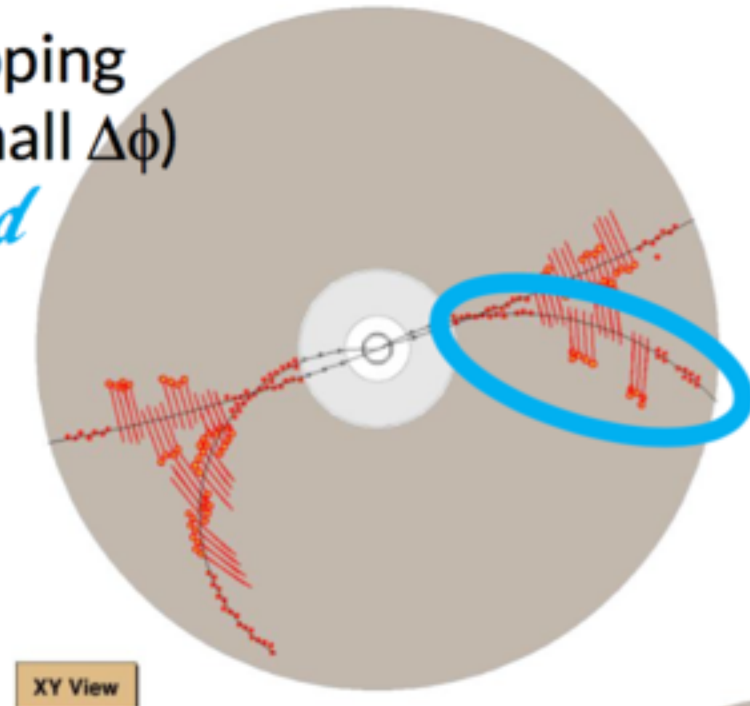
Milestones 6

CGEM+ODC reconstruction



Global Reconstruction: Improvements

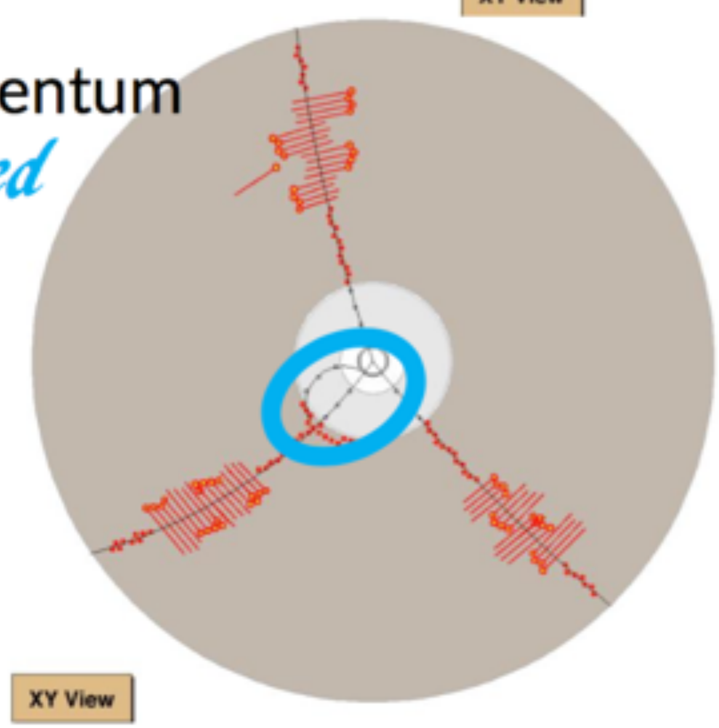
Overlapping tracks (small $\Delta\phi$)
fixed



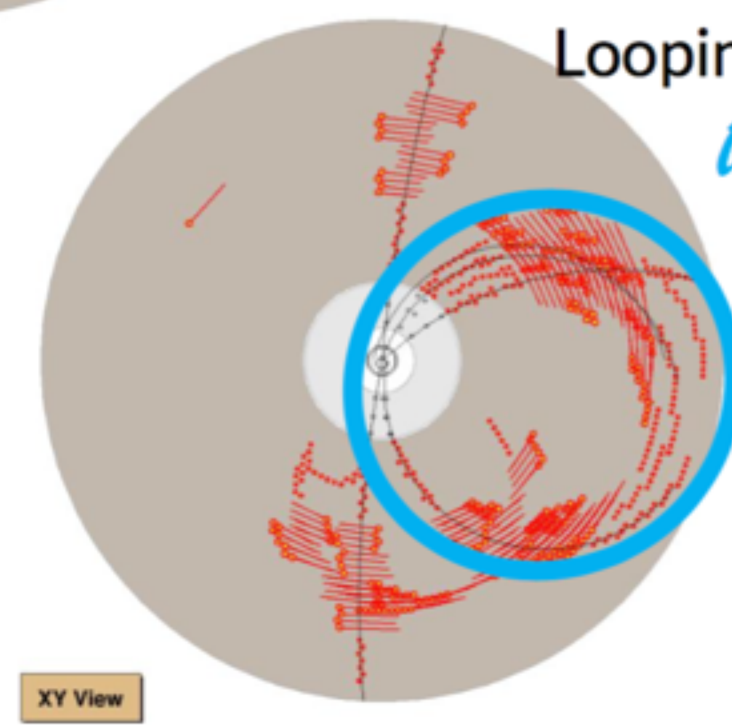
Improvements that will be included in the new CgemBoss release

Optimization and update of the V-hit association in progress

Low momentum
fixed

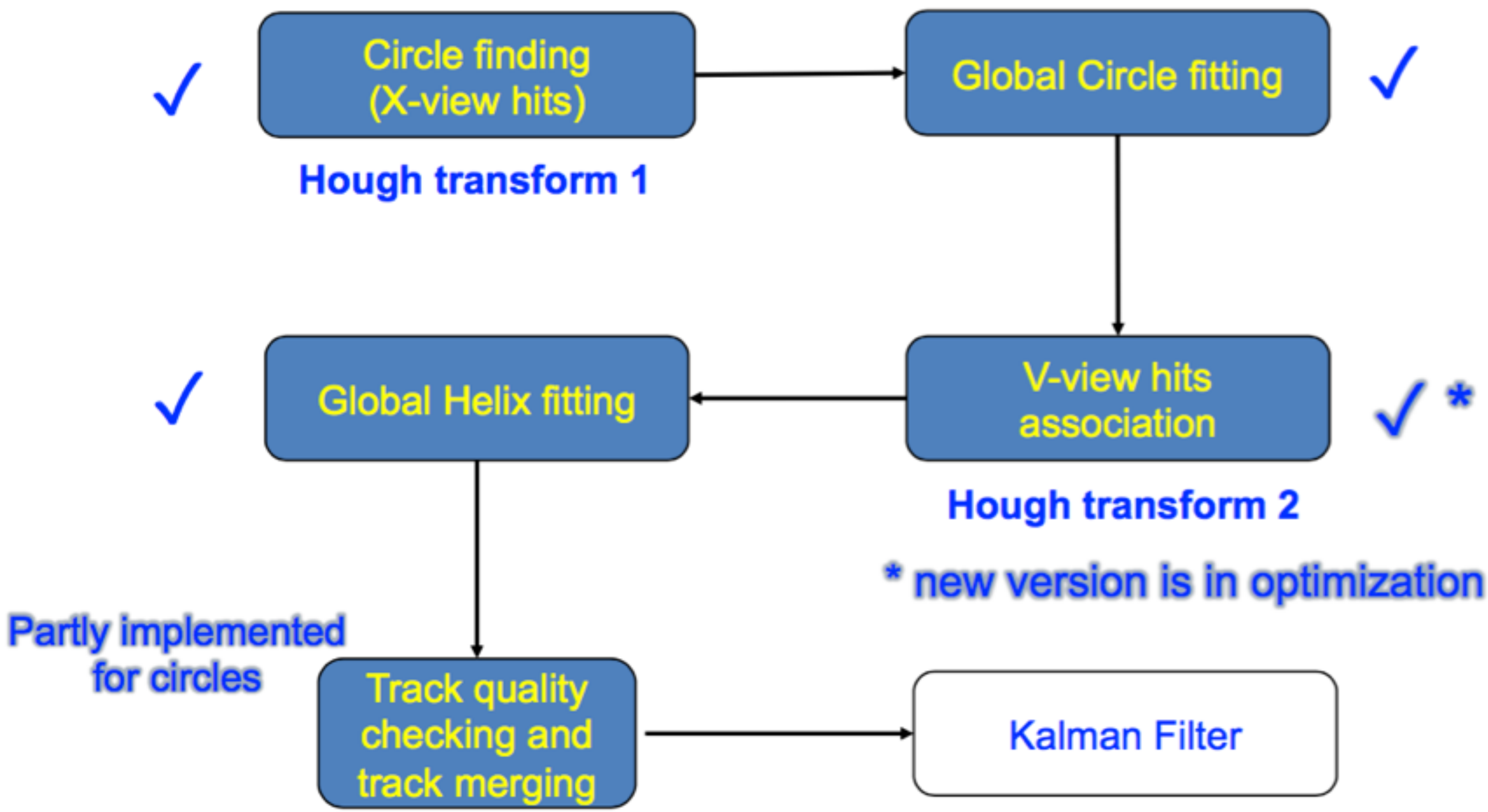


Looping tracks
fixed



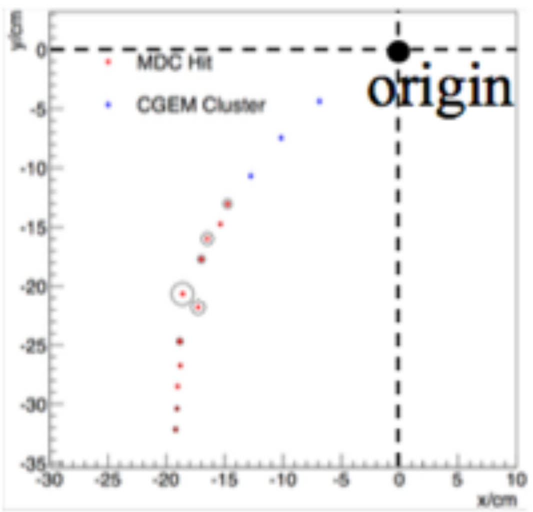
Global track finding with Hough transform for CGEM+ODC

Basic procedure



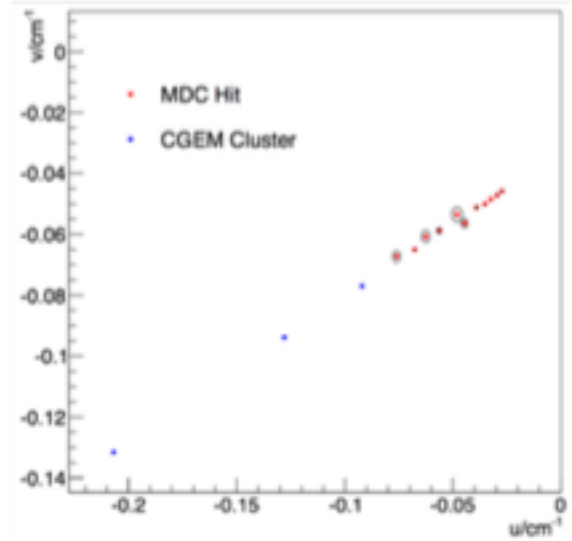
Global circle finding

y



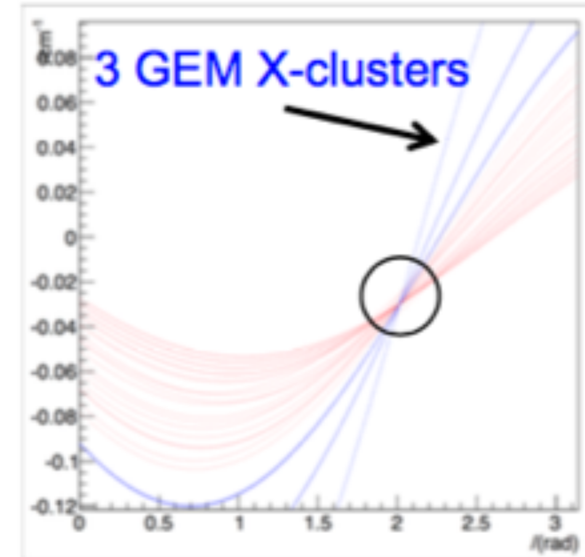
x

Y



X

ρ



β

circle pattern (real space) ~ **from origin (IP)**

$X=2x/(x^2+y^2)$

$Y=2y/(x^2+y^2)$

conformal transform

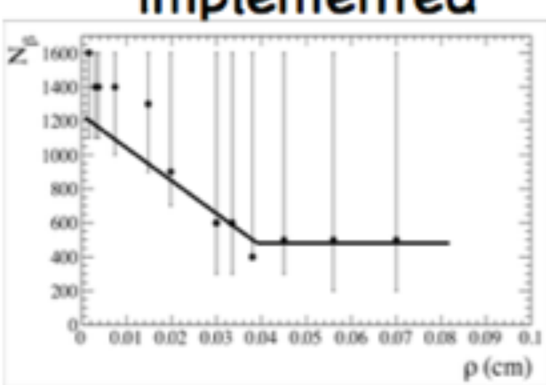
line pattern (image space)

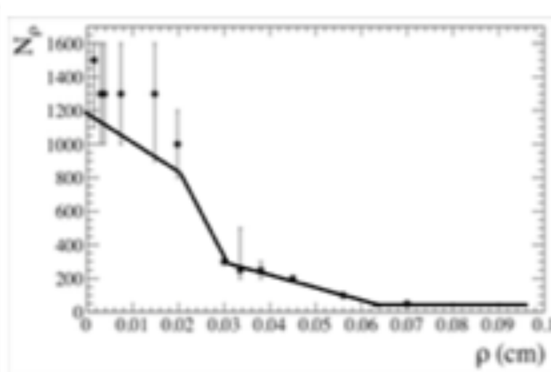
$\rho = X\cos\beta + Y\sin\beta$

Hough transform 1

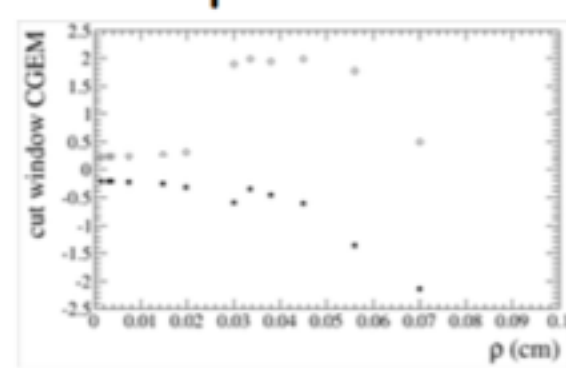
sinusoids (parameter space)

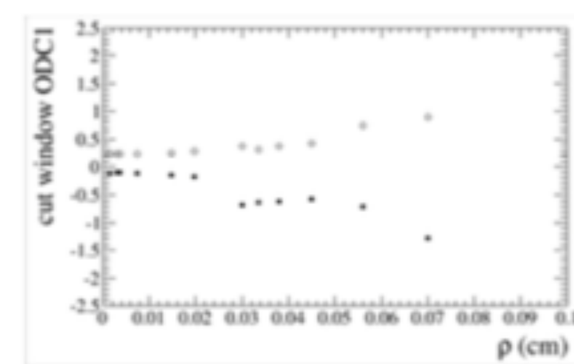
- ✓ Optimal binning of ρ–β map as a function of p_T investigated & implemented





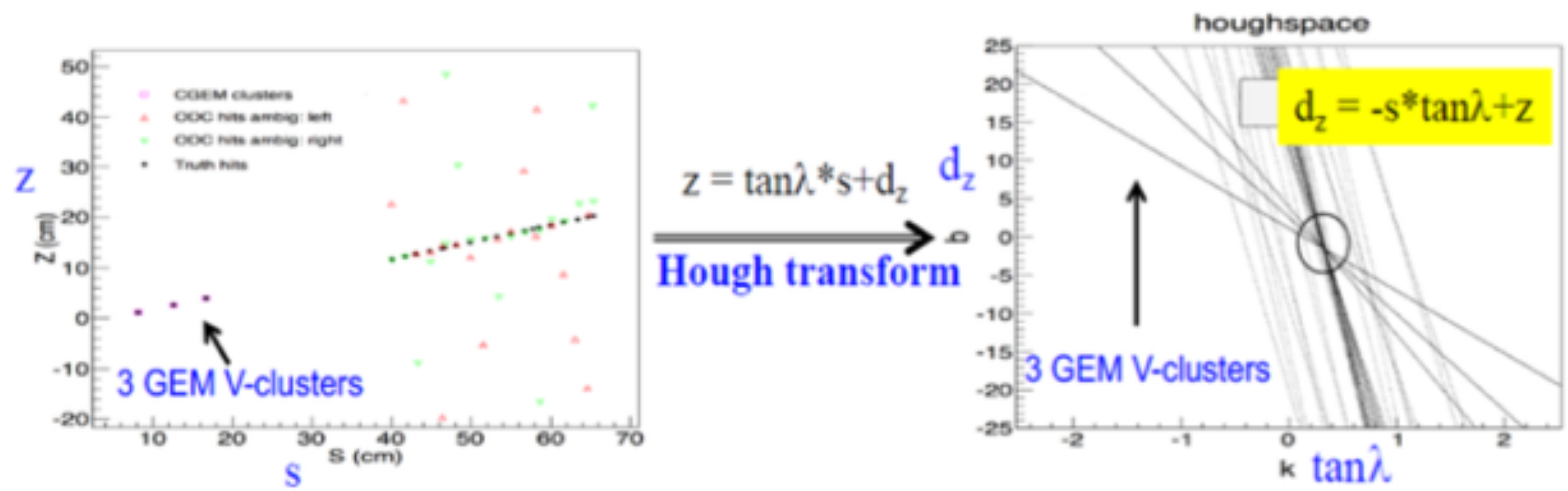
- ✓ X-view hit association windows as a function of p_T investigated & implemented

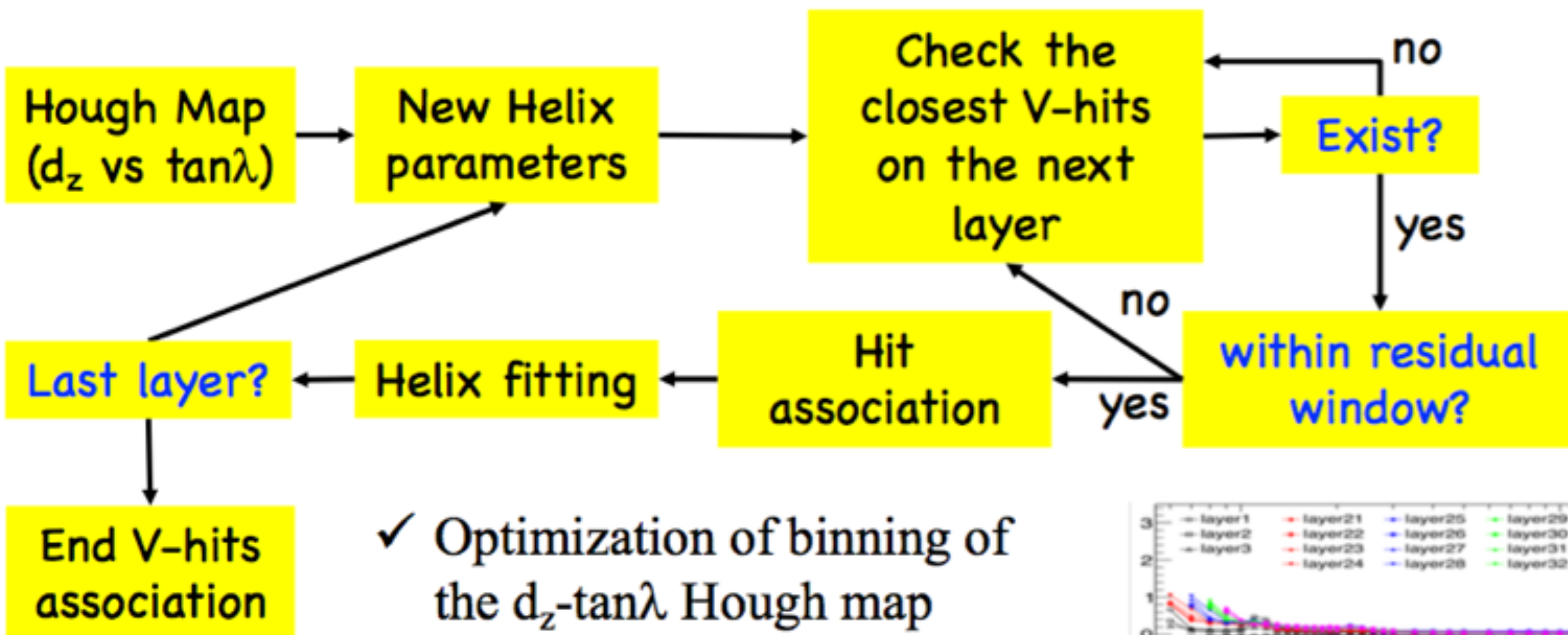




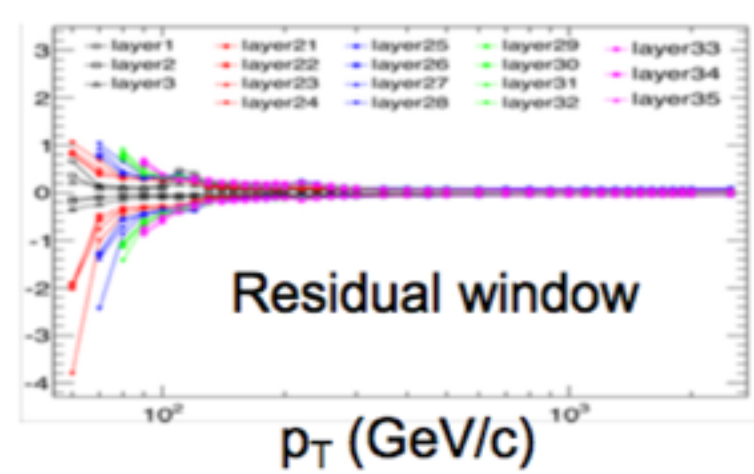
V-view hits association

s: trajectory length in the transverse plane calculated with circle parameters



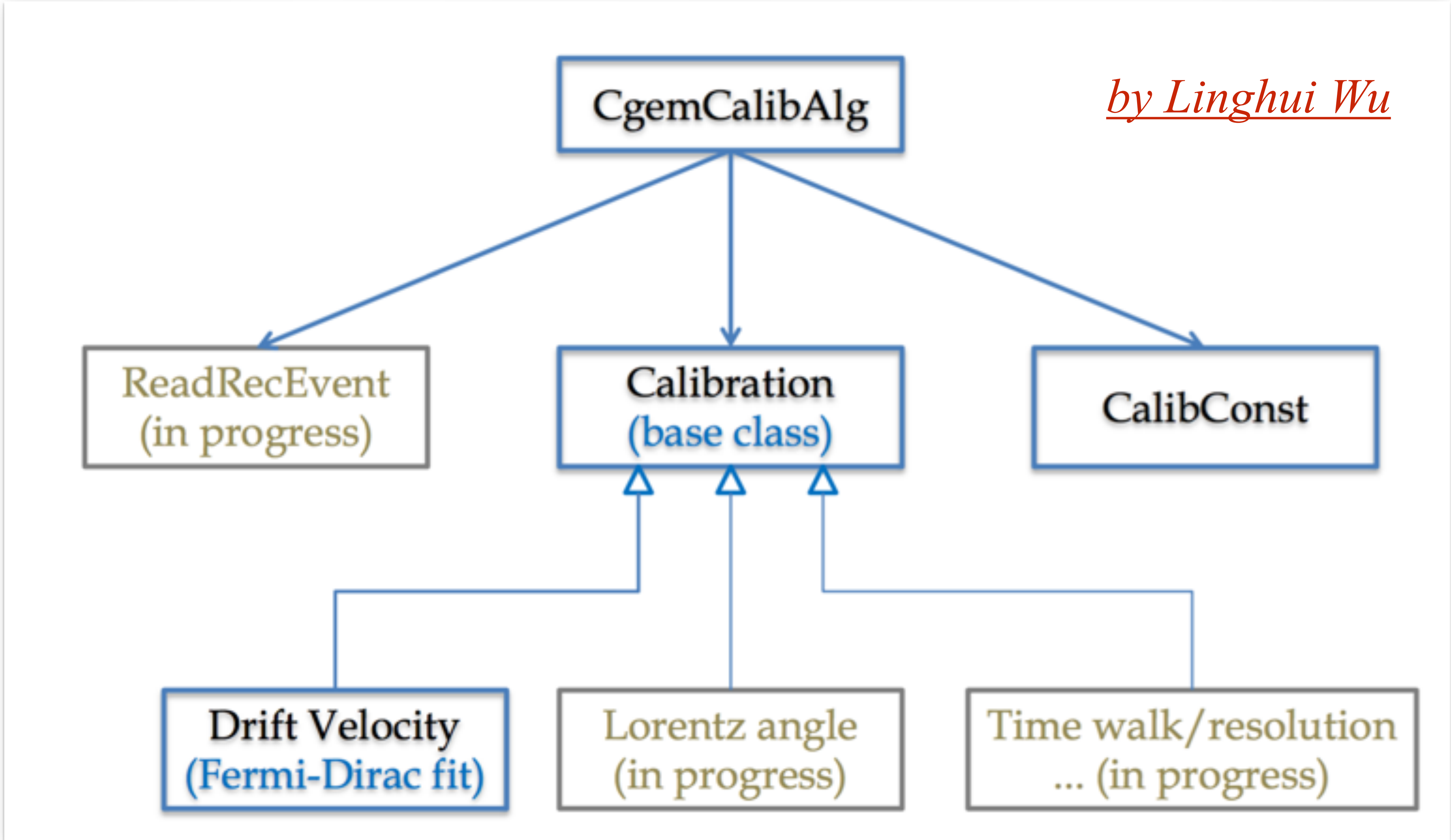


- ✓ Optimization of binning of the d_z-$\tan\lambda$ Hough map
- ✓ Recursive association procedure with global fitting
- ➢ Validation in progress



Calibration and Alignment

Calibration



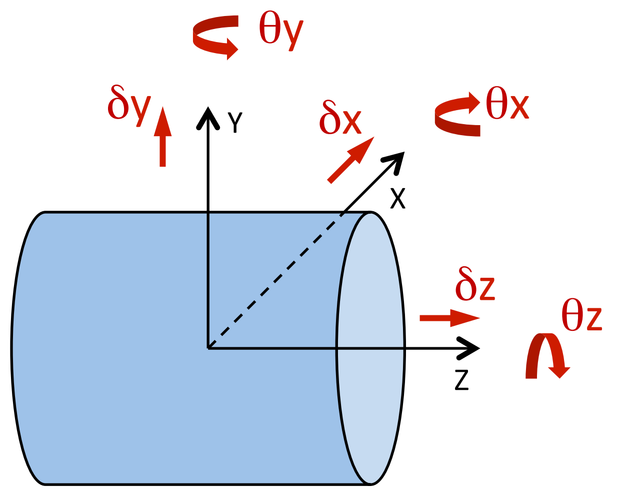
- Framework ready
- Real data needed to complete and test the package

Alignment

Aiqiang Guo, Jingyi Zhao, Hongpeng Wang,
Tong Sun, Kang Zhao, Linghui Wu,
Liangliang Wang, Ryan Mitchell, Xi'an Xiong

Aim: correct the relative displacement (ODC as reference)

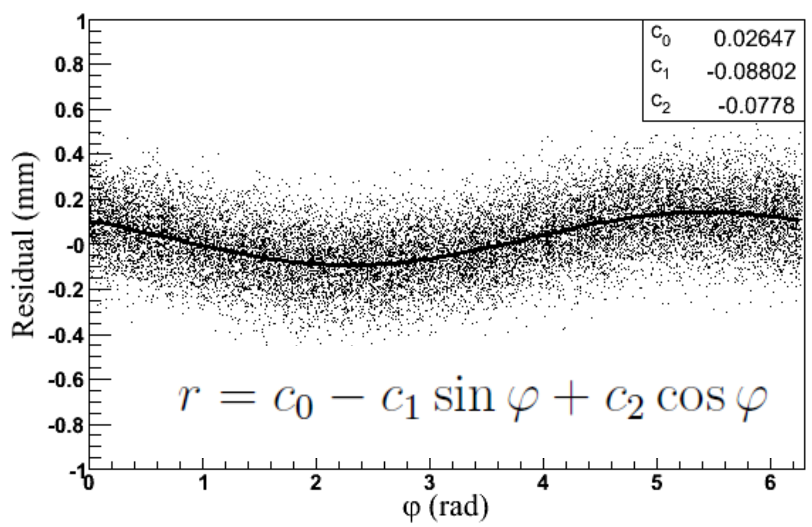
- among the different CGEM layers
- between CGEM and ODC
- consider rotations, translations, concentricity



- 6 parameters for each CGEM layer
- Two methods:
    1. Residual fit: suitable for large displacement
    2. Millepede matrix method: for refinement

$$\chi^2 = \Sigma_{data\ sets}\left(\Sigma_{events}\left(\Sigma_{tracks}\left(\Sigma_{hits}\frac{\Delta_i^2}{\sigma_i^2}\right)\right)\right);$$

$$\Delta = u_{measurement} - u_{prediction}(q_{track}, p_{alignment})$$



- Validation of alignment package:
    - cosmic ray events (single muon, no B field) with mis-aligned geometry

Releases and code tests

Benchmark physics channel

Single tracks (e, m, p, K)
(Isabella Garzia, Zhen Huang, L.L. Wang)

$\psi(3686) \to \pi^+\pi^- J/\psi$
(Zhen Huang, L.L. Wang)

$e^+e^- \to p\bar{p}$
(Christoph Rosner)

$e^+e^- \to \pi^+\pi^-\gamma_{ISR}$
(Yasemin Schelhaas)

$e^+e^- \to \pi^+ D^0 D^{*-}$
(Andreas Pitka)

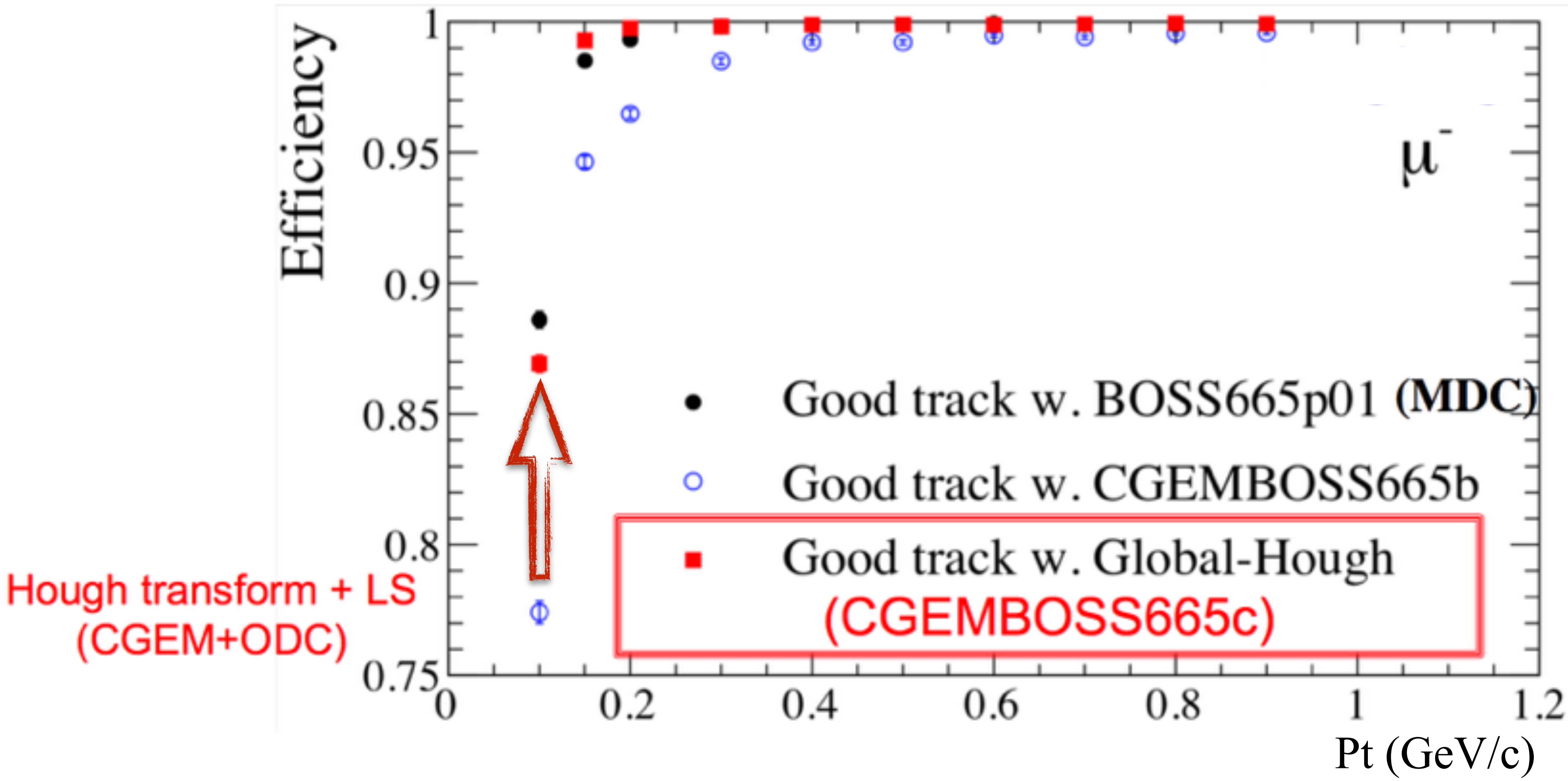
$e^+e^- \to \Lambda\bar{\Lambda}$
(Viktor Thorén)

$D^0 \to K_S^0 K^- K^+$
(Peter Weidenkaff)

- Studies completed in CgemBoss665b
  - first workable version
  - Simulation:
    - Detector sensitive part only
    - basic digitization
  - Reconstruction
    - charge centroid
    - CGEM track segment reco
    - Recursive track fitting with Kalman filter method
- Check performances in CgemBoss665c test release
  - Hough transform
  - Global track fitting with least square method

Test release improvements

Z. Huang, Y. Zhang, LL. Wang



- ***CgemBoss665c:*** strong improvement in the efficiency for single track simulation

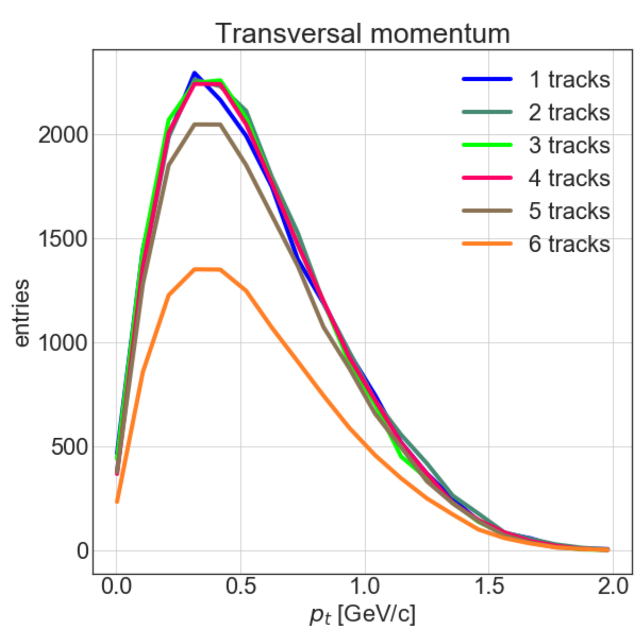
Beam Background simulation

by Peter Weidenkaff

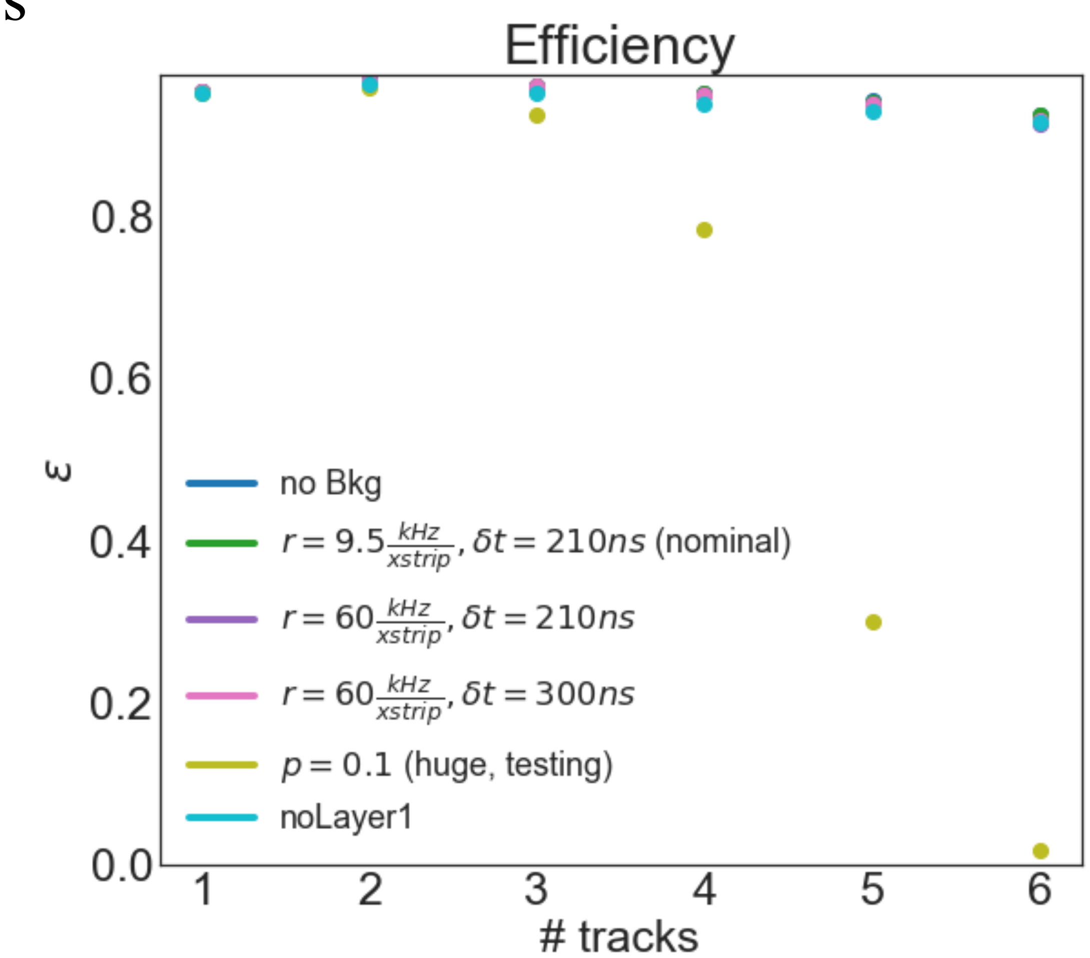
- New algorithm implemented: CgemBeamBkg
- Simulate additional (random) background clusters
- Probability of background clusters per event
  - P = (***background rate***) × (***time window***)

1-2 additional clusters on the first layer

- Simulation: $e^+e^- \to n(\pi^\pm)$
- n = {1,…,6} @ $\sqrt{s}$ = 4.6 GeV
- same momentum distribution:

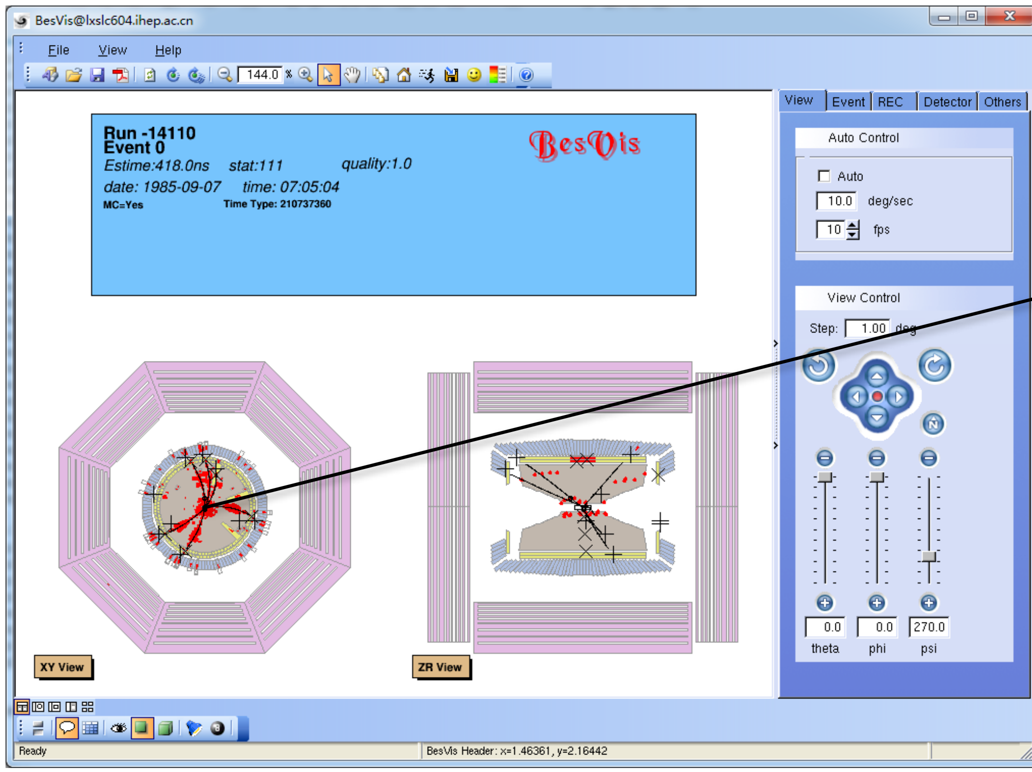


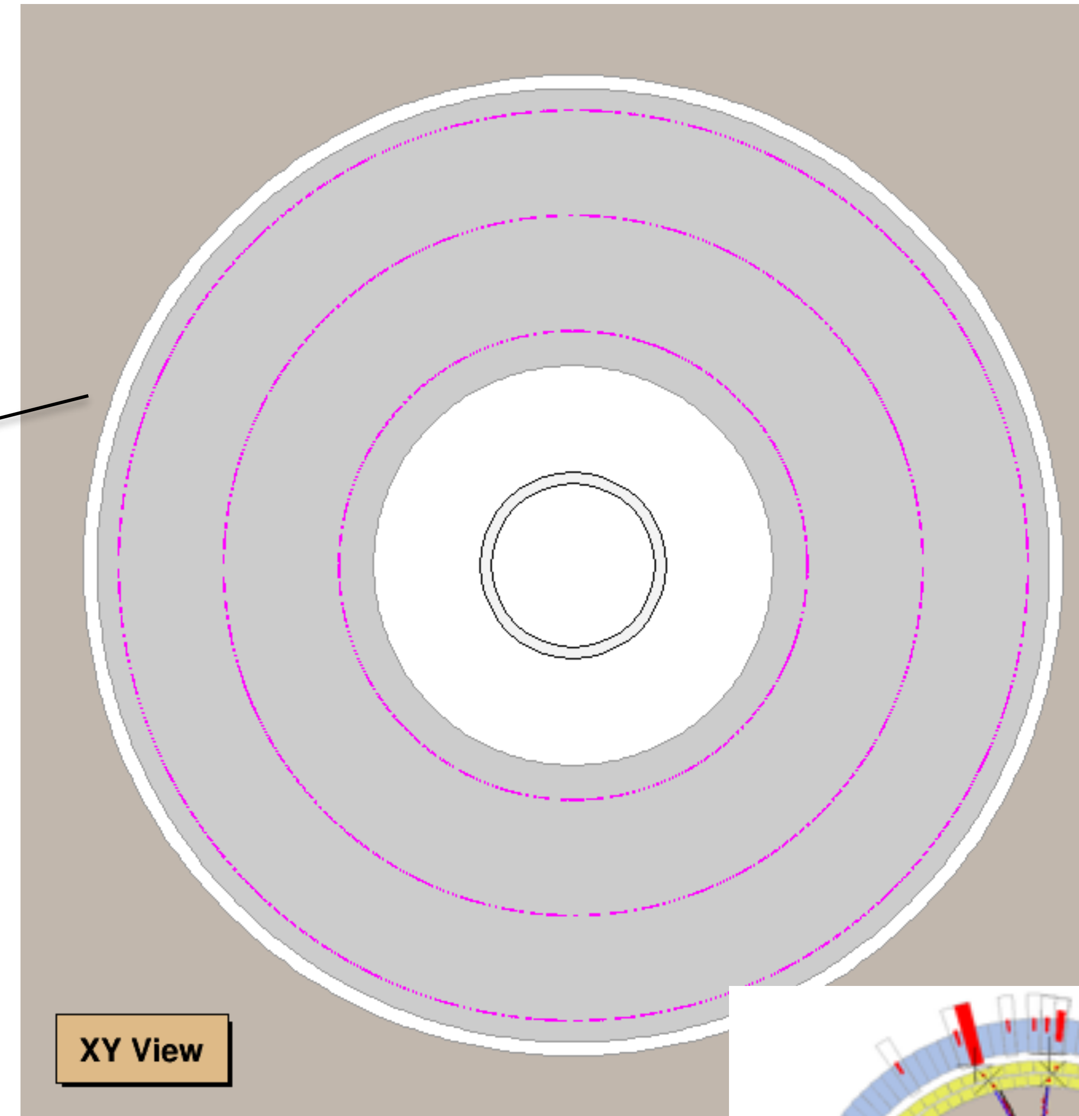
- Tested on CgemBoss665c
- Negligible effect in most cases

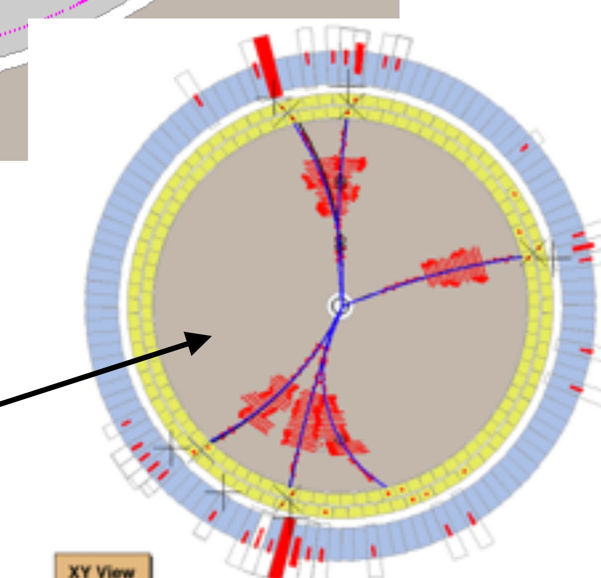


nTrk	noBkg	Nominal	Consv.	Consv2
1	0.954	0.954	0.955	0.955
2	0.969	0.969	0.969	0.969
3	0.962	0.961	0.961	0.96
4	0.953	0.953	0.951	0.95
5	0.943	0.943	0.94	0.939
6	0.926	0.925	0.92	0.915

Event display







- Update with the latest CgemGeomSvc
- *Recent update: MC truth track added*

Summary

- Milestones 4 and 5 accomplished successfully
- Milestone 6 not yet finished but ready to be completed

- Implementation of the CGEM-IT in the BESIII software
  - Debug studies
  - New release will be ready soon
  - Check physics performances

- Calibration and alignment packages ready
- Software for cosmic ray data ready

Thanks for your attention

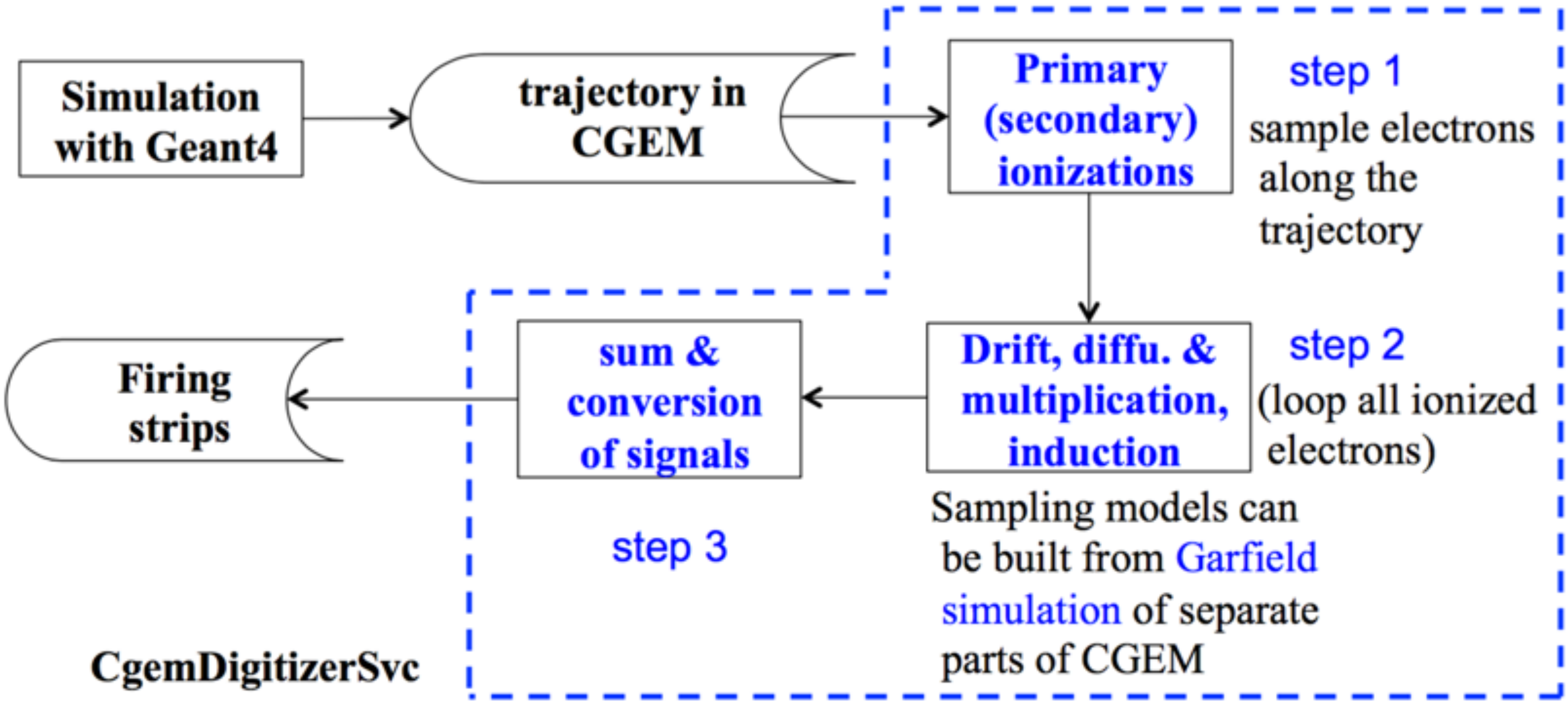
spares

Full Digitization

By Lia Lavezzi, Riccardo Farinelli, Nannan Miao, Linghui Wu, Liangliang Wang

Final Digitazione model following the physics processes in CGEM is ongoing:

- reproduce the CGEM performances
- based on the results from separate simulation of different parts of CGEM with Garfield++ in order to reduce the time consuming



Beam Background simulation (I)

by Peter Weidenkaff

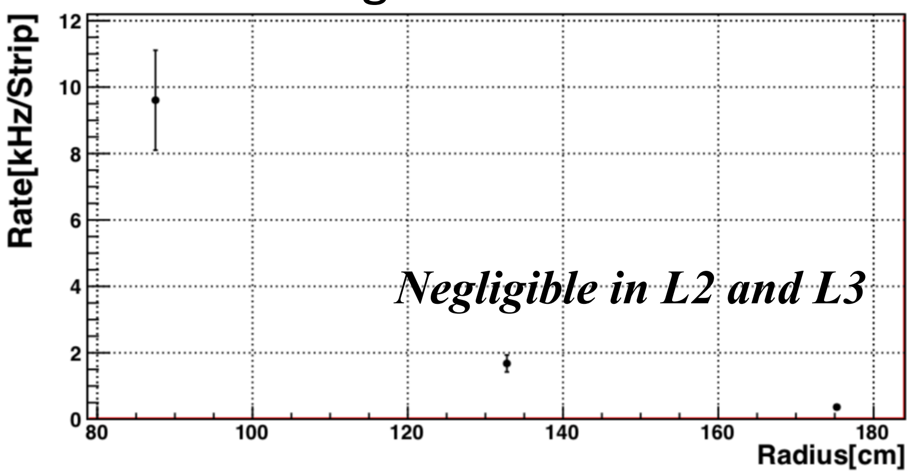
- New algorithm implemented in CgemBoss: CgemBeamBkg
- Simulate additional (random) background clusters
- Probability of background clusters per event
  - P = (***background rate***) × (***time window***)

- Beam background rate per layer:
  - from CDR
  - based on beam background estimate with MDC
  - ***Nominal*** (1th layer): 9.5 kHz/x-strip
  - ***Conservative*** (1th layer): 60 kHz/x-strip

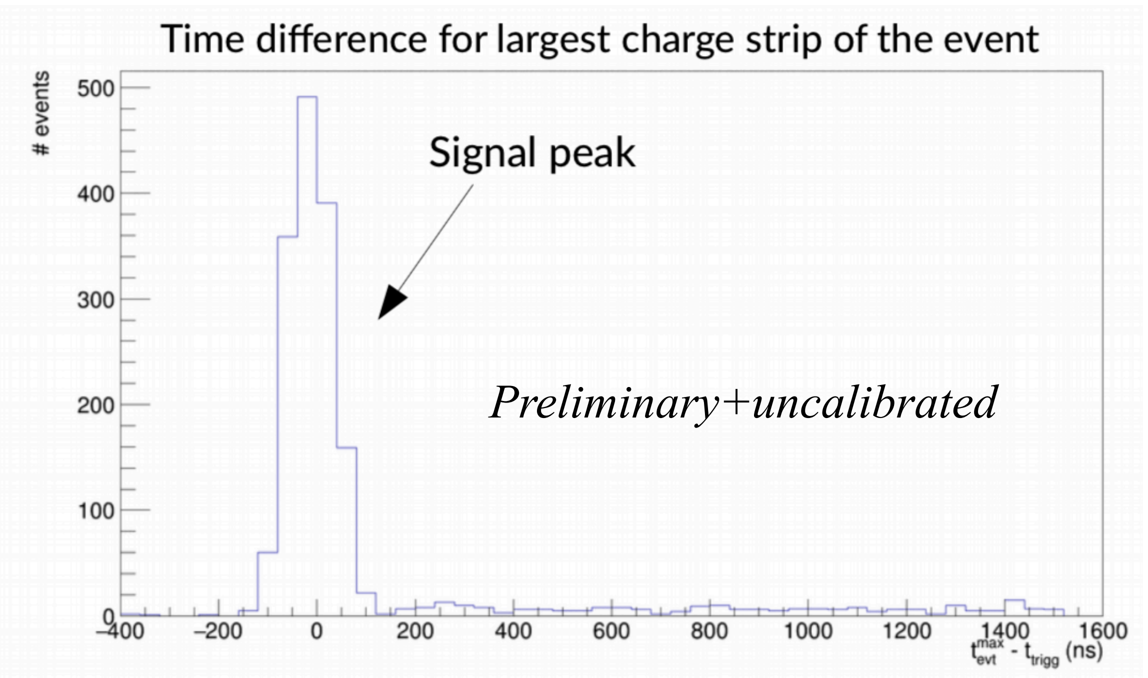
- Time window:
  - Time resolution of Cgem
  - Intrinsic time spread of primary ionization
  - ***Nominal***: 210 ns
  - ***Conservative***: 300 ns

1-2 additional clusters on the first layer

Beam background rate estimate

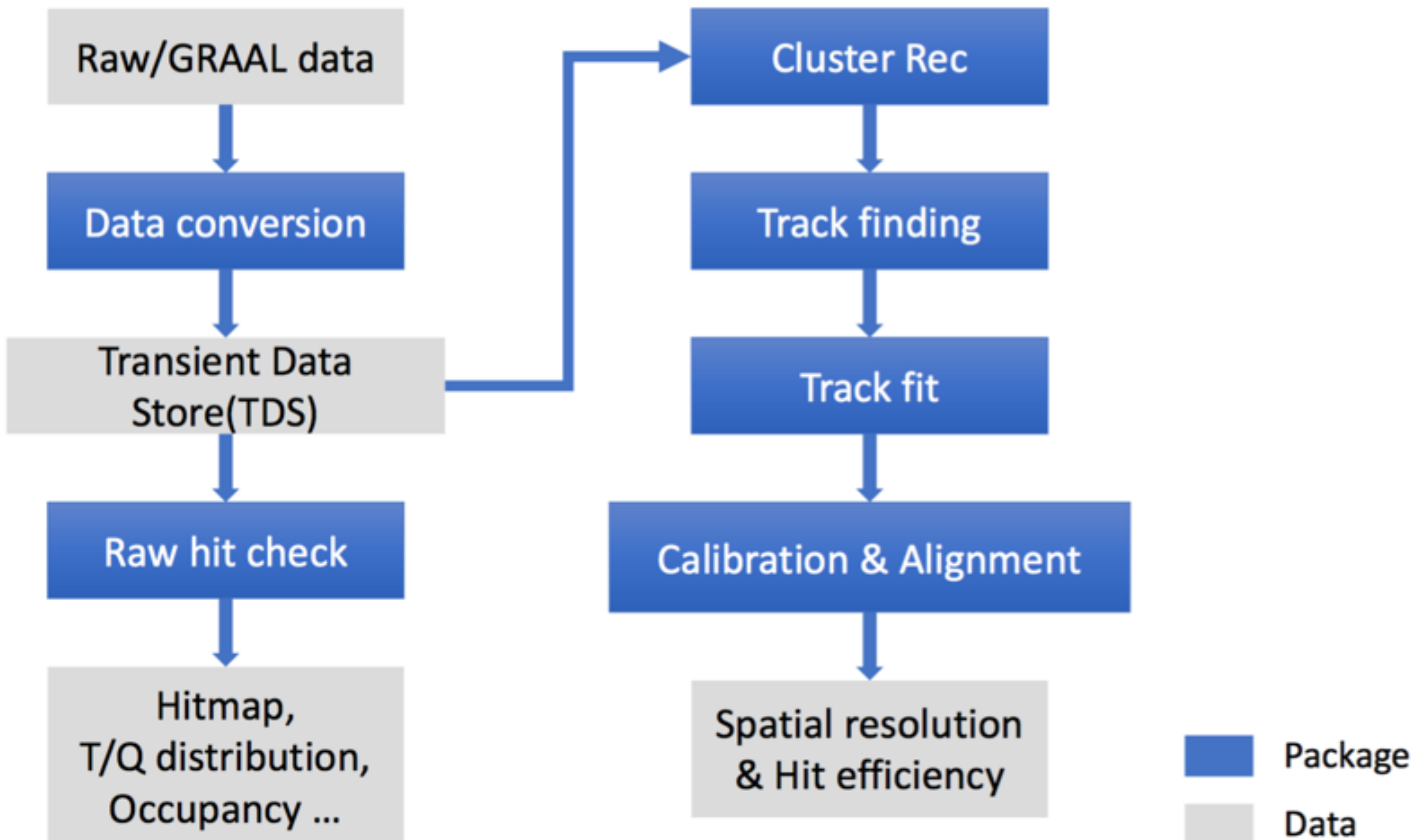


From Giulio's studies:



Data analysis for cosmic ray test

By Linghui



Data from Cosmic ray test can be used to study calibration and alignment

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