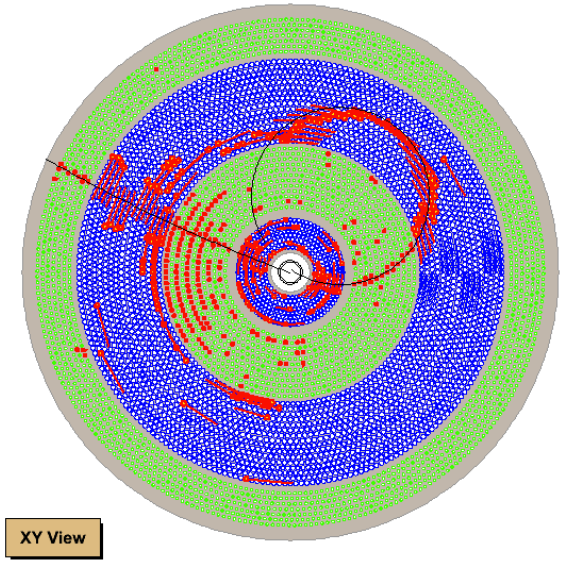
Hough Transform Based Track Finding for BESIII

Zhang Yao

June 5 2017

BESIII Drift Chamber (MDC)

- Design of MDC
  - **Axial** and **stereo** wires in grouped to super layers
  - Continuous axial/stereo layers
  - Big “gap” between axial & stereo layers
  - Max solid angle coverage is 0.93%

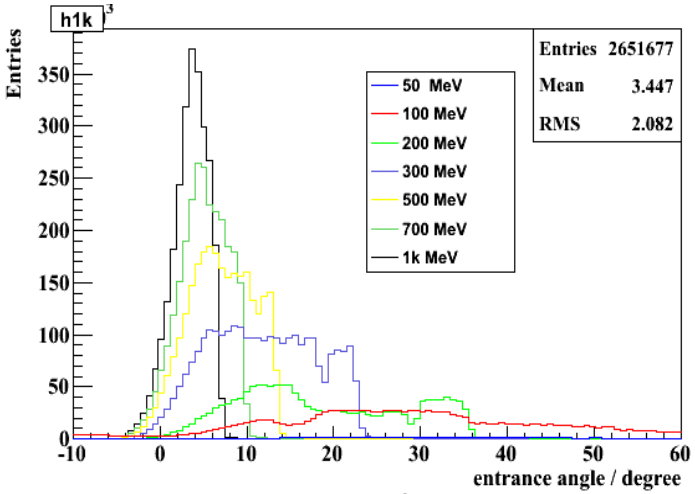


- MDC track finding algorithms
  - High pt tracks: Segment based finders
  - Curled tracks: Road hit searching method

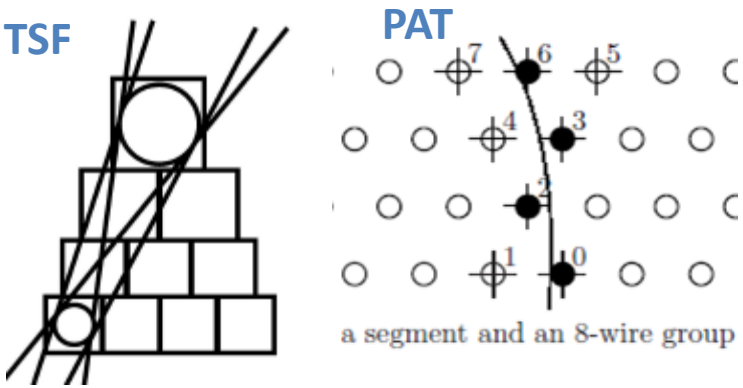
- Requirement for a new tracking algorithm
  - Tracking efficiency can be improved for low Pt
  - Inner drift chamber will be replaced with a Cylindrical GEM detector

Why need a new tracking algorithm(1) ----Improve curling track efficiency

1. BESIII tracking Segment based finders :PAT & TSF
   - Find **segment in super-layers** by template matching or hit searching in window area
   - **group** segment to track



Entrance angle of track in cells



Track segment design in super layers

Angle coverage is limited by segment design

Sensitive to detector design, track Pt, hit inefficient and noise

Why need a new tracking algorithm(1) ----Improve curling track efficiency

2. Road method for curled track: CurlFinder
   - **Select continuous hits** in same axial layer
   - Pick up hits on road by hit neighbors
   - **Effect by noise or background on the road**

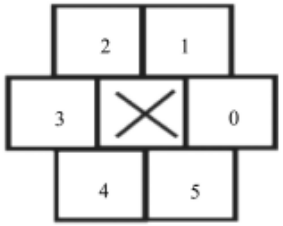
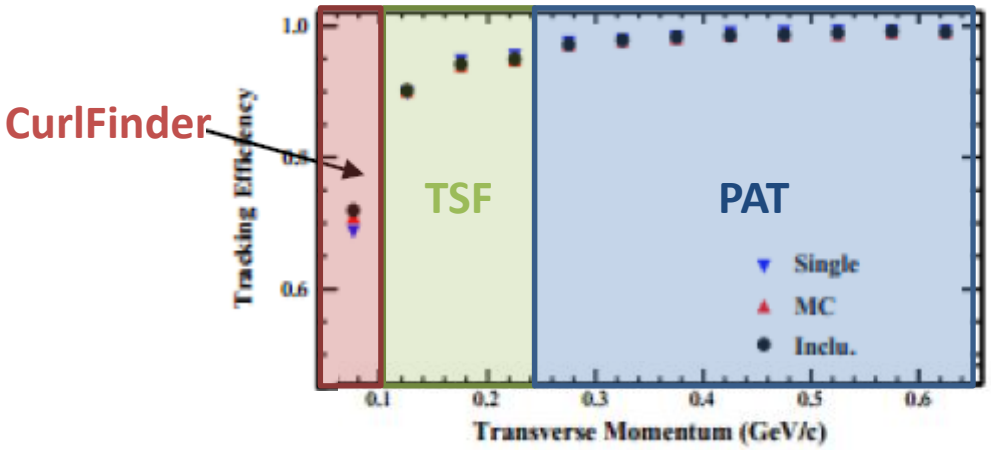


Fig. 2. The definition of neighbor: x represents one fired wire and 0–5 represent the sequentially numbered neighbor wires.

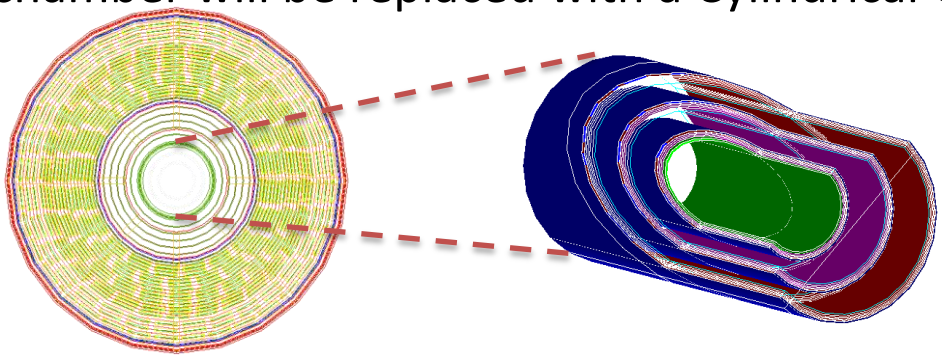


Tracking efficiency of π^- with P_T

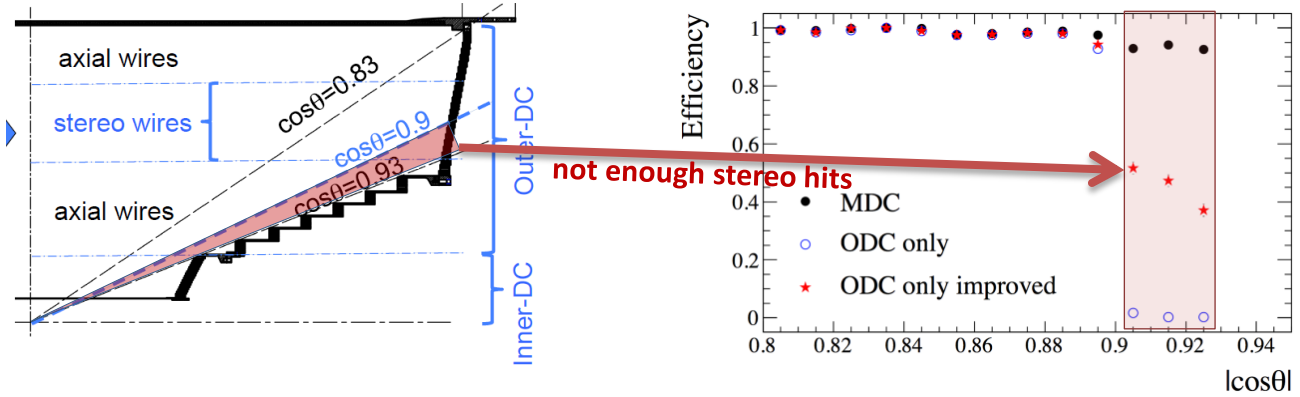
Low p_T tracking can be improved

Why need a new tracking algorithm(2) ----Inner chamber upgrade

- Inner drift chamber will be replaced with a Cylindrical GEM detector



- Current tracking algorithms are limited by the geometrical acceptance
  - w/o inner chamber, **not enough stereo hits** for tracking when |cosθ|>0.9



The combine tracking of CGEM and ODC is needed

Introduction to Hough transform

- Global method
  - All hits are treated equally
- Mathematical
  - Transform of real space hits into a mathematical space in which the track candidates can be found more conveniently and insensitive to detecor design
- Voting schemes
  - Let each feature vote for all the models that are compatible with it

Advantages

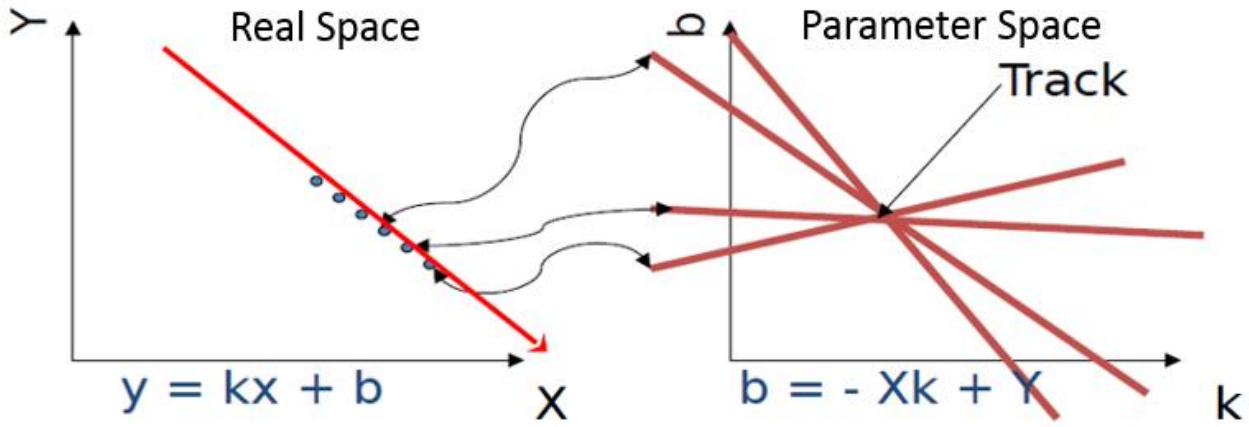
- More hits can be included at first step
  - Find track using all axial/stereo layers or with axial and stereo layer simultaneously
- Noise resistant
  - Hopefully the noise features will not vote consistently for any single model
- Hit inefficient resistant
  - Missing data doesn't matter as long as there are enough features remaining to agree on a good model
- Quick

Introduction to Hough transform

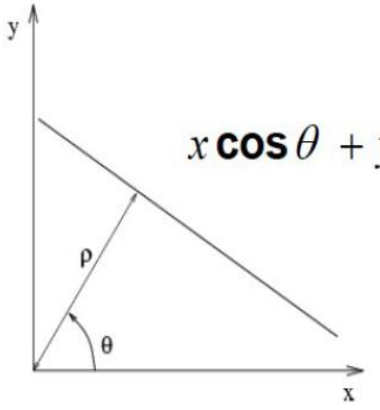
Hough transform : a mathematical transformation

•Transform a point in real space to a line or a curve in parameter space

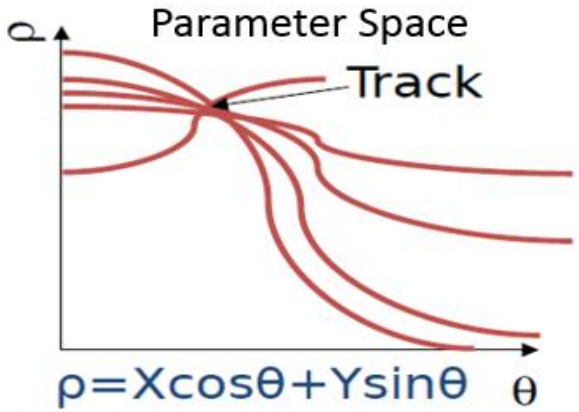
•Points rest on a line in real space ← → lines or curves focus in Hough space



- ρ=xcos(ϑ)+vsin(ϑ) hits becomes sinusoidal curves



$$x\cos\theta + y\sin\theta = \rho$$

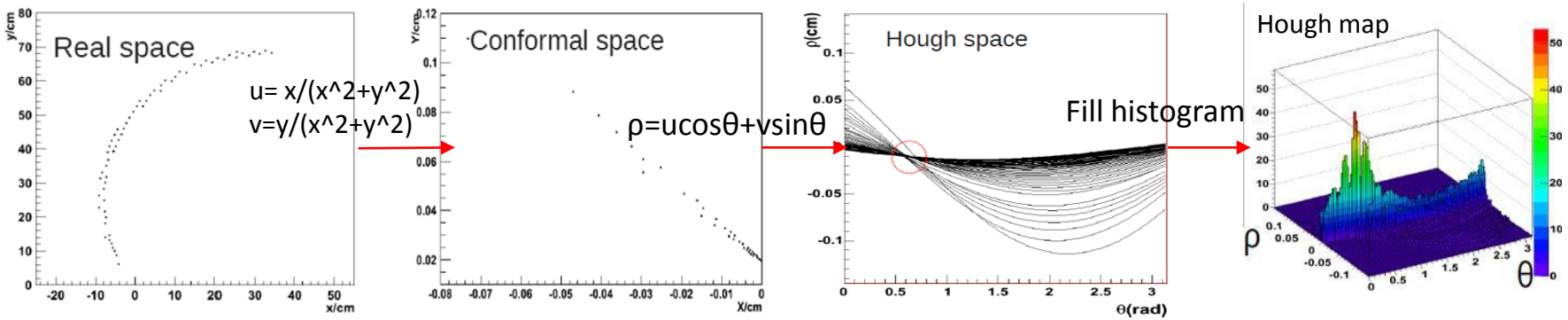


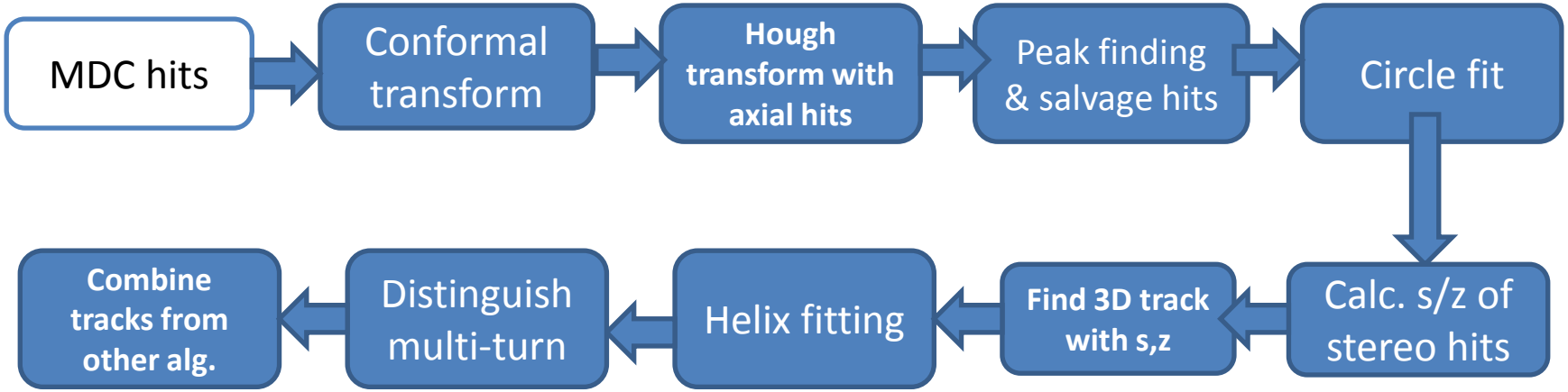
Overview of Hough tracking Development

- Manpower
  - Zhang Jin, Zhang Yao, Liu Huaimin (IHEP)
  - Zhang Xueyao (Shandong University)
  - Huang Zhen is work on CGEM-ODC tracking

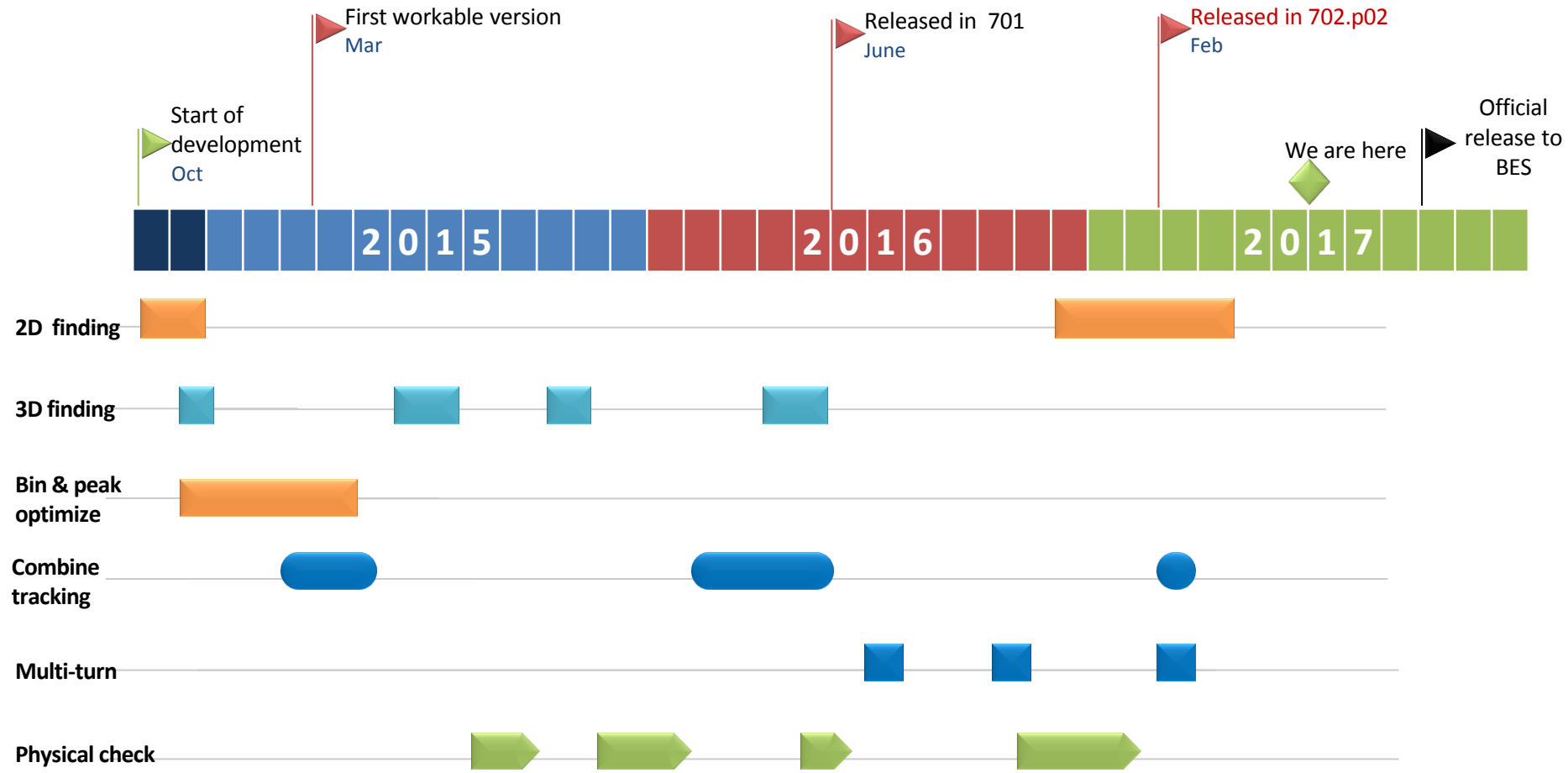
- History and status
  - Coding all by ourselves, start from Oct. 2014
  - Now as a supplementary to PAT&TSF
  - Have been released for physical use @ BOSS 702.p02
  - CGEM-ODC tracking using Hough is under development

Implementation of Hough method



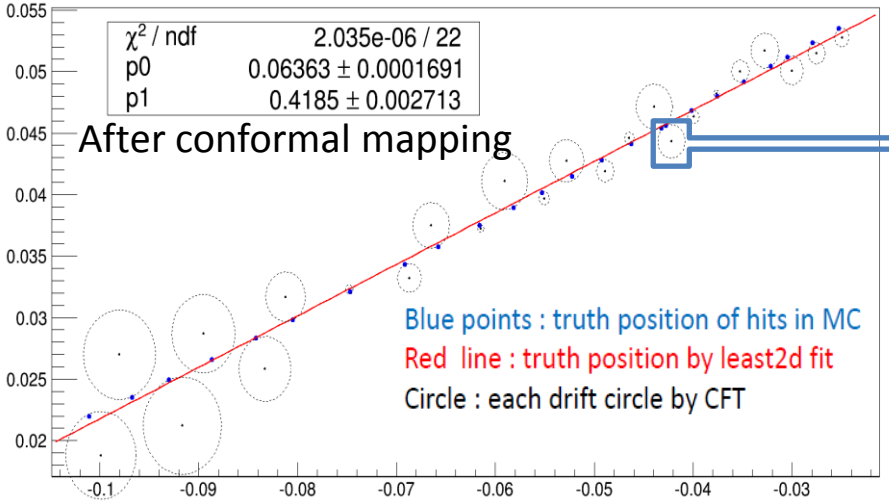


Timeline

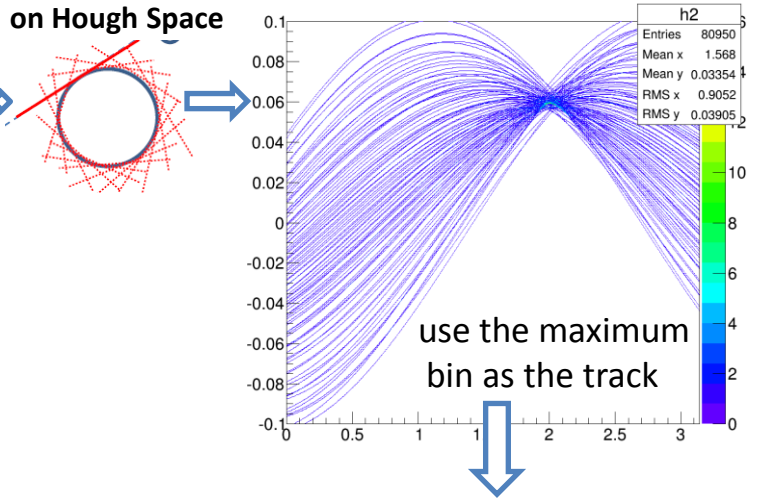

First workable version
Mar
Released in 701
June
Released in 702.p02
Feb
Start of development
Oct
We are here
Official release to BES
2015
2016
2017
2D finding
3D finding
Bin & peak optimize
Combine tracking
Multi-turn
Physical check

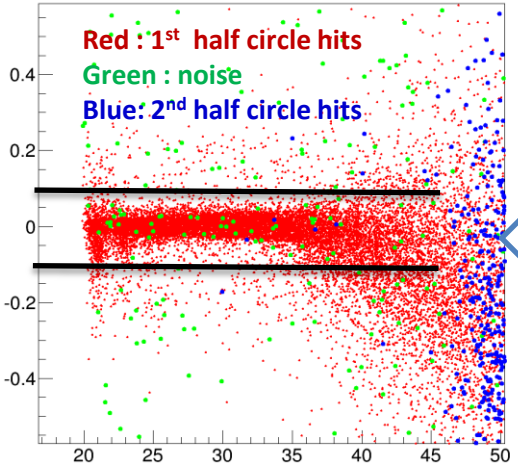
2D finding

- From mapping wire position to use hit drift distance



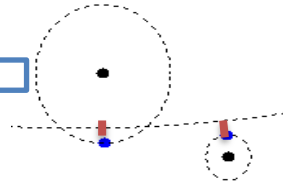
map drift circles on Hough Space

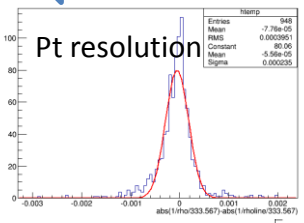


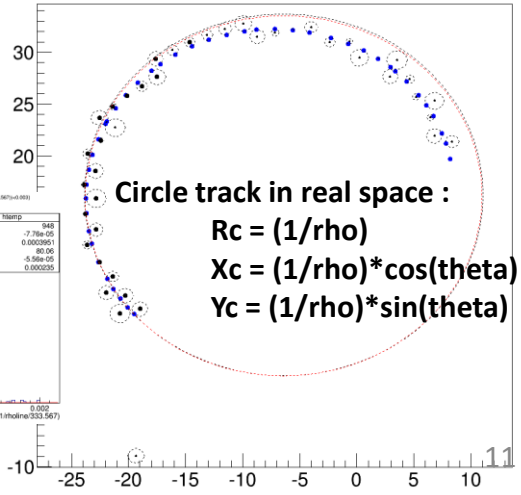


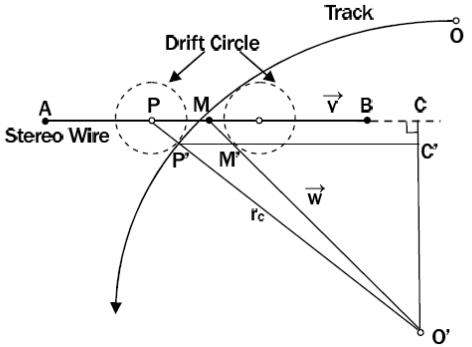
Use hits within cut

Calc. distance between candidate track and drift circle



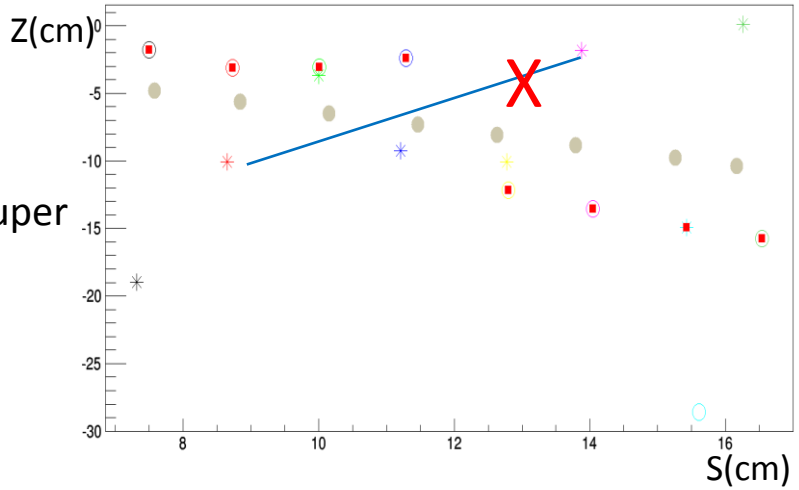




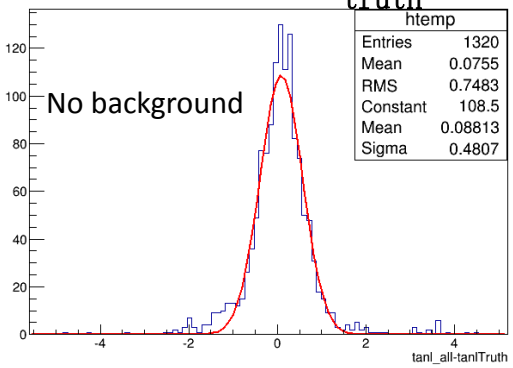


3D finding

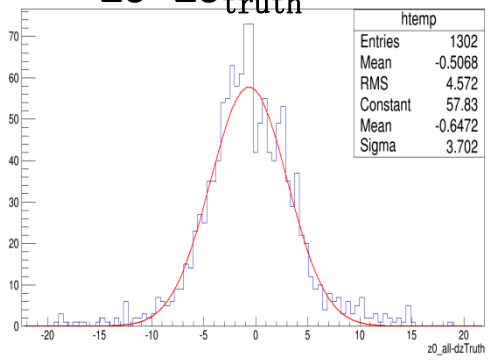
- Calculate z and flight length alone track (S) by circle track and drift distance
- In S/Z plane calculate every line of points in same super layers
- Each two points add (0,0) to fit a straight line
- Chi2 cut && z0cut && tanl cut ->candidate line
- Fill candidate line in (tanl,z0) Hough space



tanλ–tanλ$_{truth}$

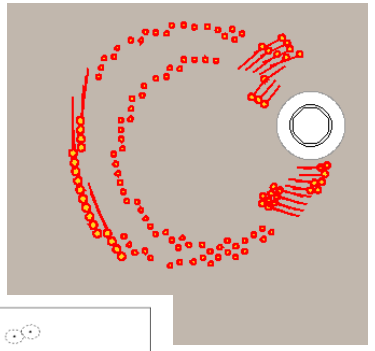


Z0–Z0$_{truth}$

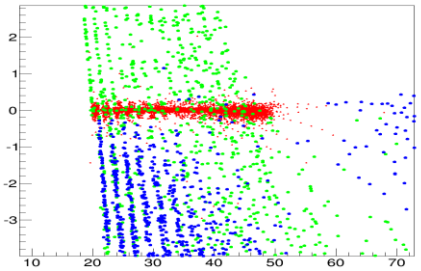


Resolution of tanλ and z0 by s/z Hough transform is good

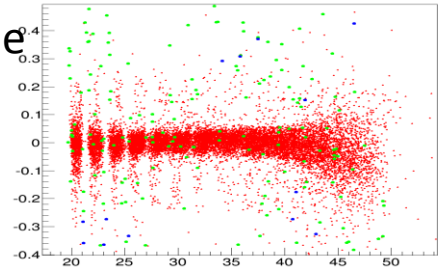
Multi turn tracks

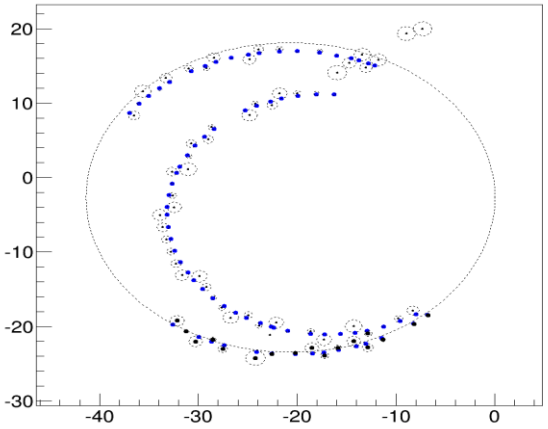


70MeV : begin to make multi turn tracks



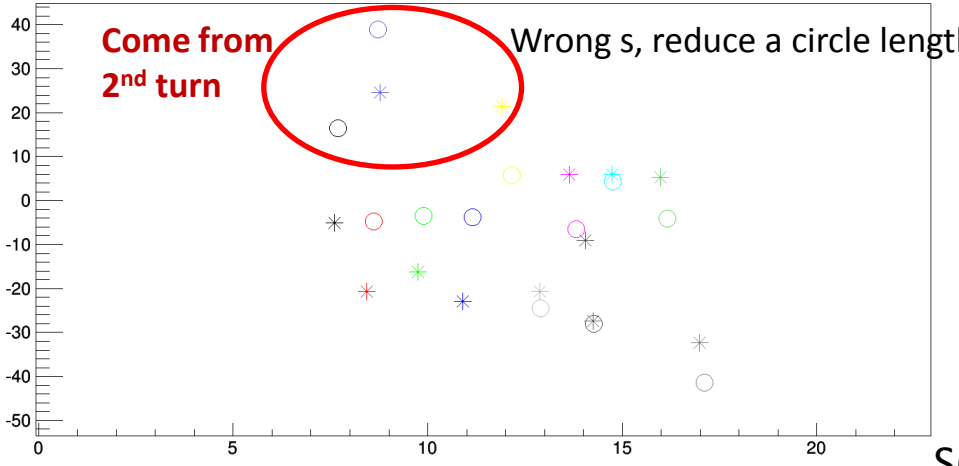
Large scale





Hits can be tell from different turns in 70MeV

Z(cm)



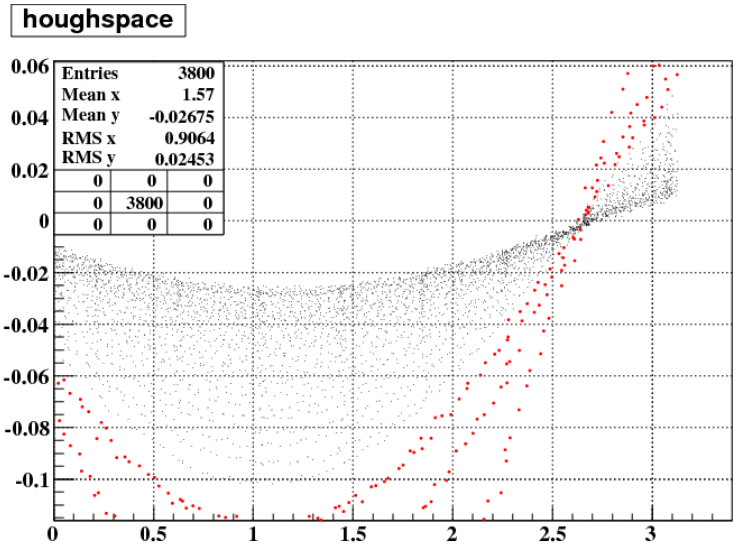
Wrong s, reduce a circle length

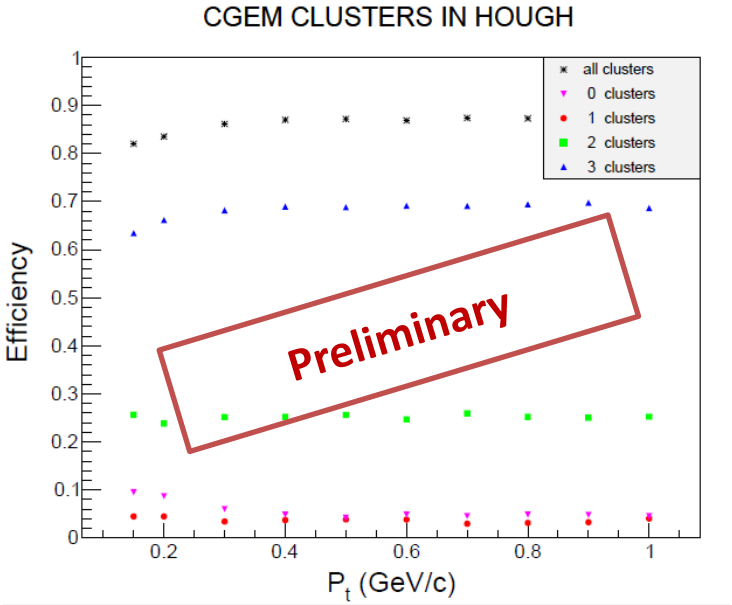
S(cm)

By S/Z Hough transform as first step , noise & hits from other turn may be reduced

CGEM+ODC tracking

- A preliminary CGEM+ODC tracking have been realized
  - CGEM cluster have been used for 2D track finding





HOUGH tracking release

- Validation before release
  - Increments of computing time and memory are acceptable
  - No effect on original tracking
  - Improvement is consistent with previous study

- **HOUGH method have been released in BOSS 7.0.2.p02**
- **But not used in official release**
  - Won't influence the official tracking by default

- To use this package , modify the reconstruction job option file:

  replace

  #include "$MDCXRECOROOT/share/jobOptions_MdcPatTsfRec.txt"

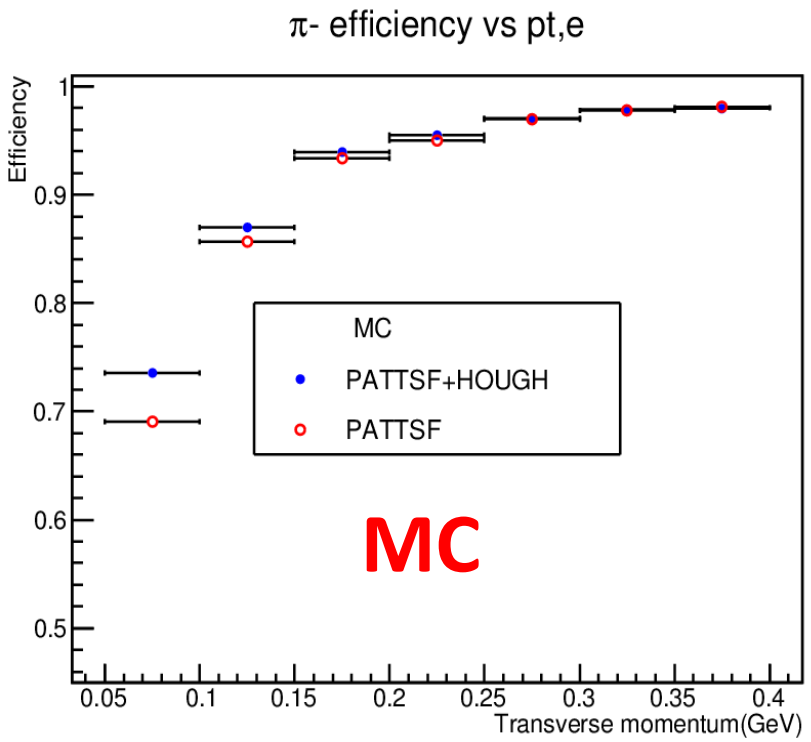
  with

  #include "$MDCHOUGHFINDERROOT/share/jobOptions_MdcPatTsfHoughRec.txt

Tracking efficiency check with MC

$\Psi(2s) \rightarrow \pi^+\pi^- J/\Psi$, $J/\Psi \rightarrow l^+l^-$

Signal MC with background mixing, 500k events

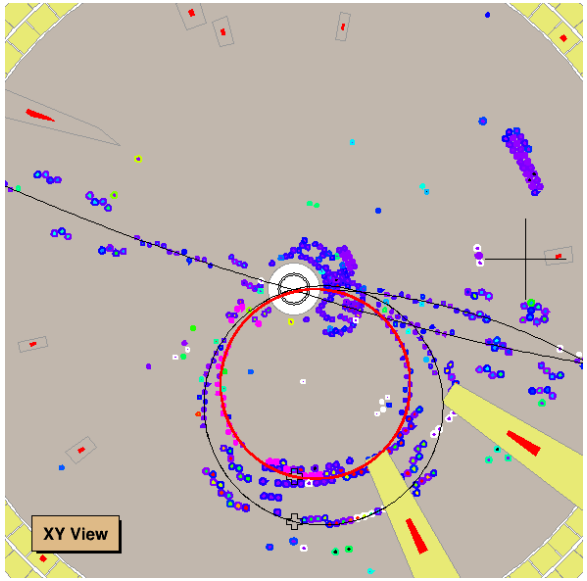


Tracking efficiency increased ~4.5% for 50MeV<pt<100MeV , relative increased ~6.5%

Clone Track Rate

$\Psi(2s) \to \pi^+\pi^- J/\Psi$, $J/\Psi \to l^+l^-$

find 5 tracks passed tracking selection : a ghost track in this event



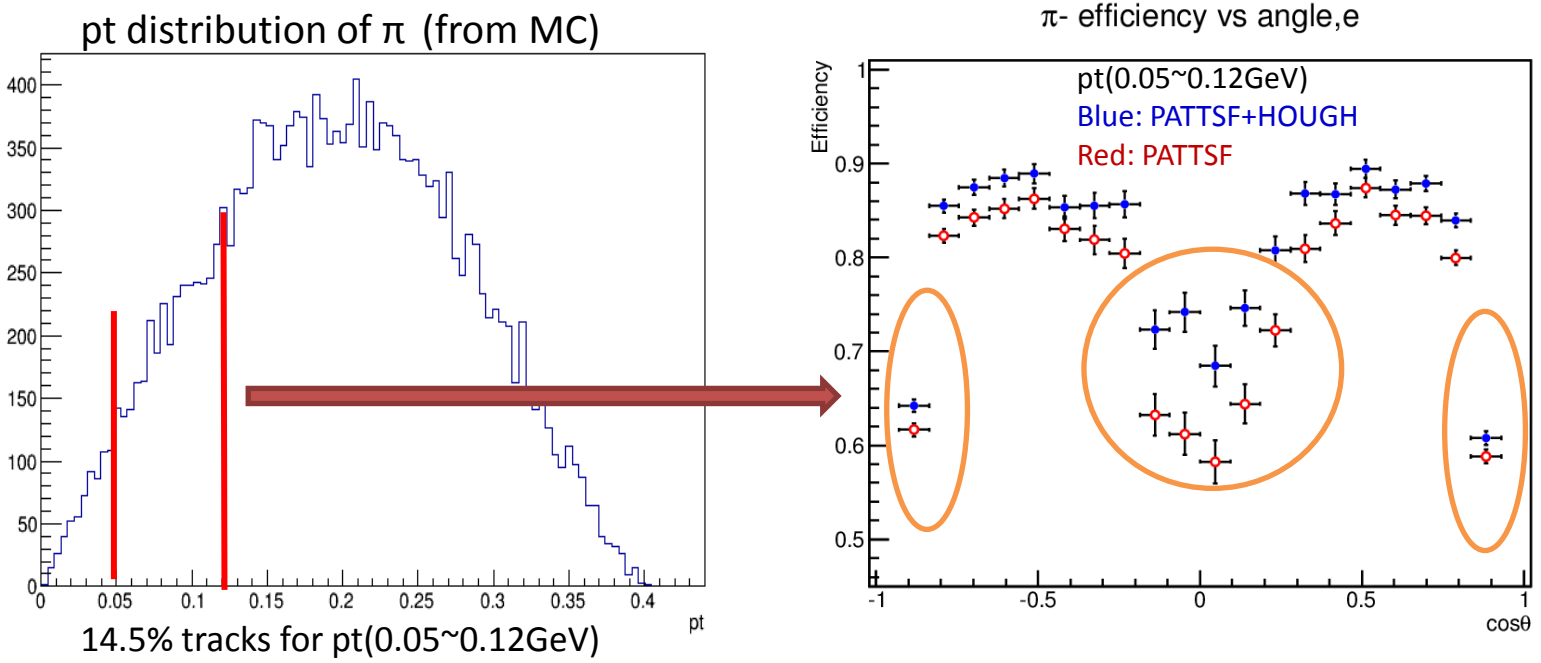
Most ghost tracks are from multi turn tracks

	N=3,4,5	N=4	N=5	N5/N(3,4,5)
PATTSF	207338	189847	240	1.16%
PATTSF+HOUGH	209211	193313	336	1.60%

clone track rate is acceptable

Tracking efficiency vs cosθ

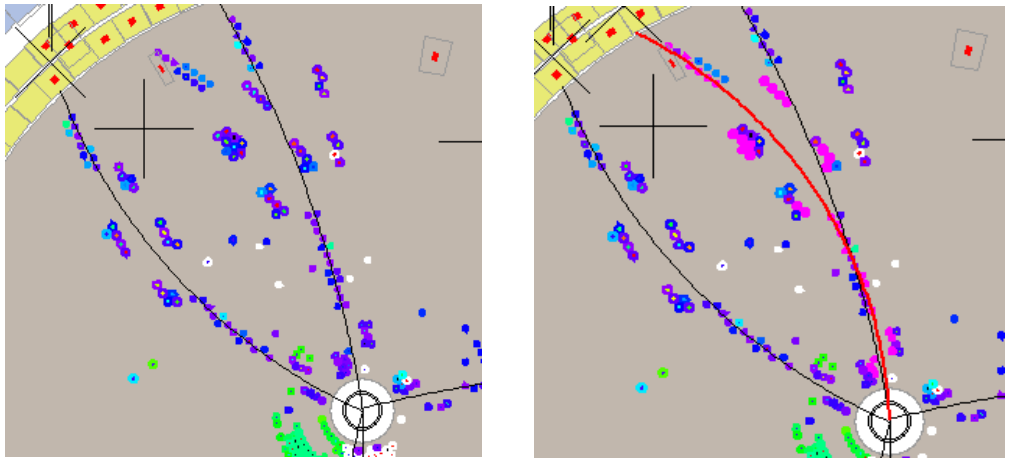
Ψ(2s)-> $\pi^+\pi^-$J/Ψ , J/Ψ -> l^+l^-



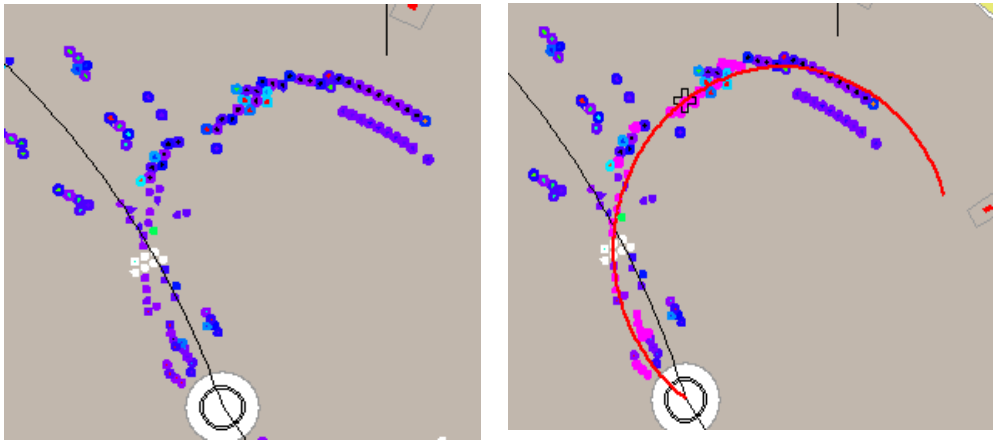
- Reason of low efficiency
  - small dip angle(|cos θ |<0.2): bad vertex , hit overlap
  - large dip angle (|cos θ |>0.83): hit overlap, noise, insufficient hits

Examples of salvaged tracks with HOUGH

Salvage high p_T track



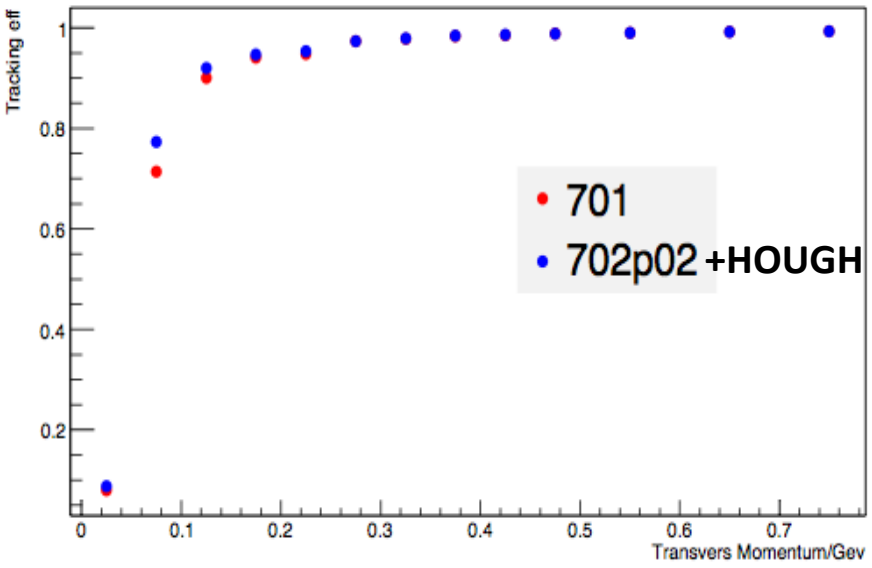
Salvage low p_T track



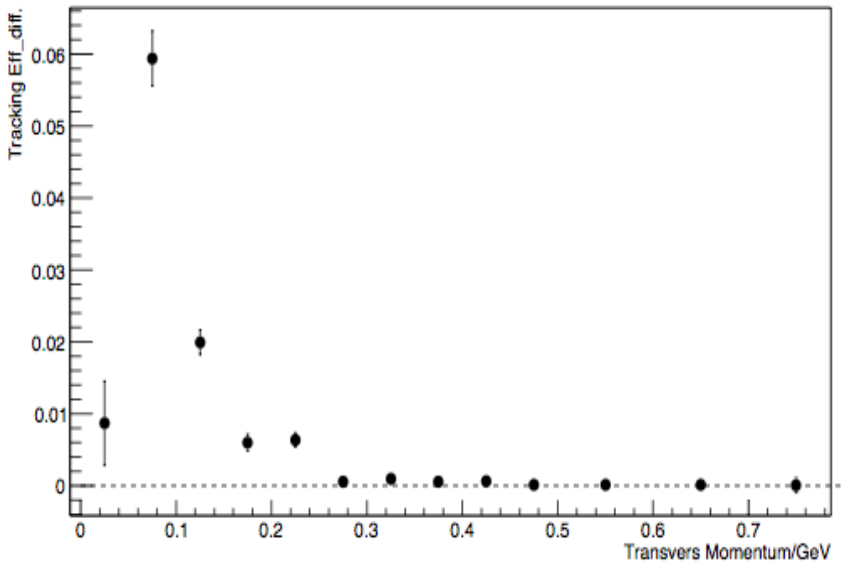
Tracking performance check with $J/\psi \to p\bar{p}\pi^+\pi^-$

Signal MC with 100,000 events

Tracking efficiency of π



Tracking efficiency difference after using HOUGH



Tracking efficiency increased for barrel pion at 50MeV<pt<100MeV

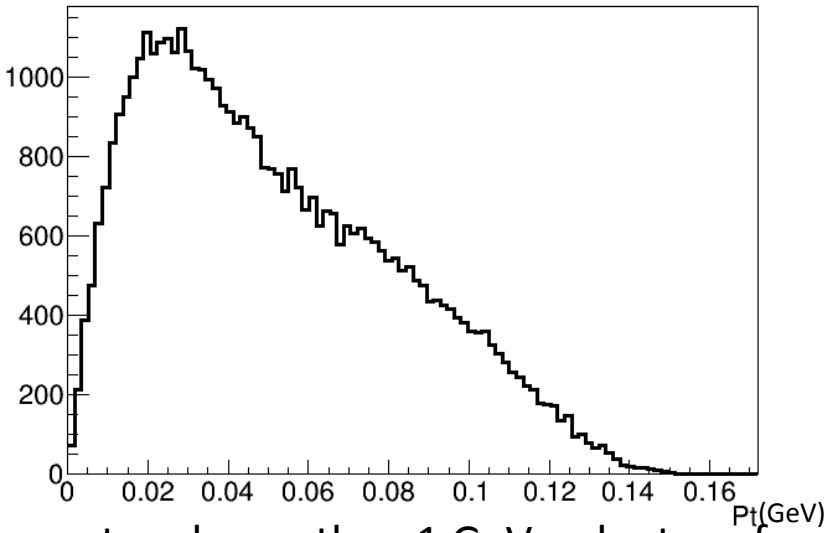
Detailed study is on going

Preliminary performance check by

$\Psi' \to e^+ e^- \chi_{cJ}, \chi_{cJ} \to \Upsilon J/\Psi, J/\Psi \to l^+ l^-$

Thanks to Zhang Jielei's help

Pt distribution of e (from MC)



Event Selection :

- 3 or 4 tracks
- define tracks with a momentum larger than 1 GeV as leptons from J/ Ψ
- one good photon
- 1C kinematic fit
  - chi2<5
  - m($l^+ l^-$)>3.06GeV && m($l^+ l^-$
  - m(ϒJ/ Ψ)>3.49GeV

$$\epsilon = \frac{n(nGood = 4)}{N(nGood = 3or4)}$$

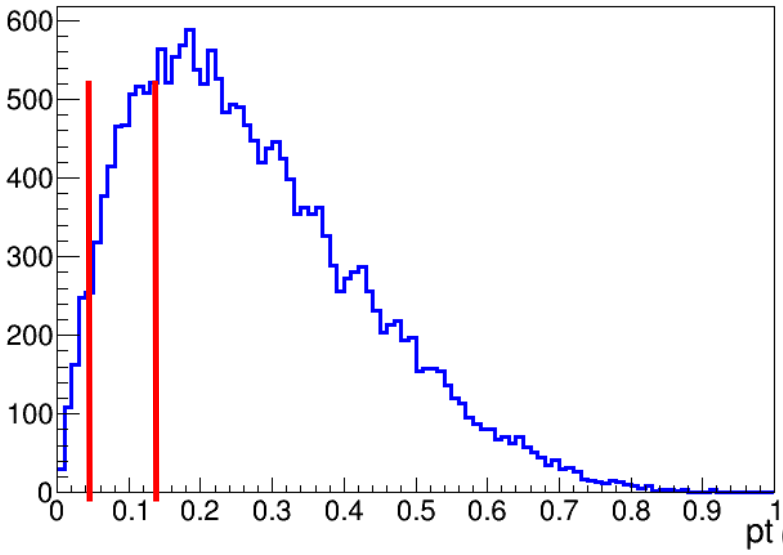
Tracking efficiency ↑ 2.6% relatively ↑ 5% with HOUGH

Preliminary performance check by

Thanks to Luyu's help

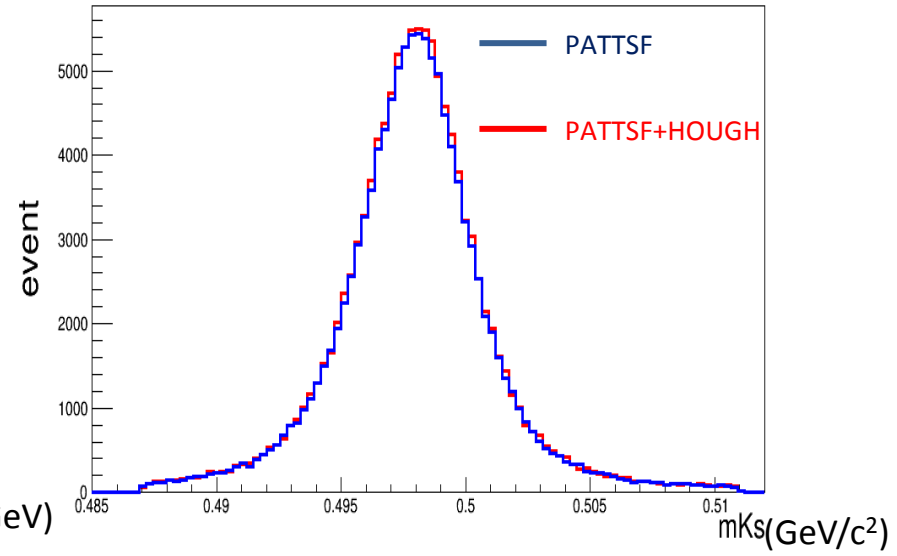
$Ds^- \rightarrow K^-Ks\,\pi^0$, $Ks \rightarrow \pi^+\pi^-$

pt distribution of π (from MC)



14 % tracks for pt(0.05~0.12)GeV

mass distribution of taged Ds



number of taged Ds ↑ 1.87% after HOUGH in preliminary result

Ds Signal Yields

By H.L. Ma and S.F. Zhang

Check the Ds yields using 4180 data at run 45427 ~ 45855

- Version 702p01 : w/o HOUGH
- Version 702p02 + HOUGH

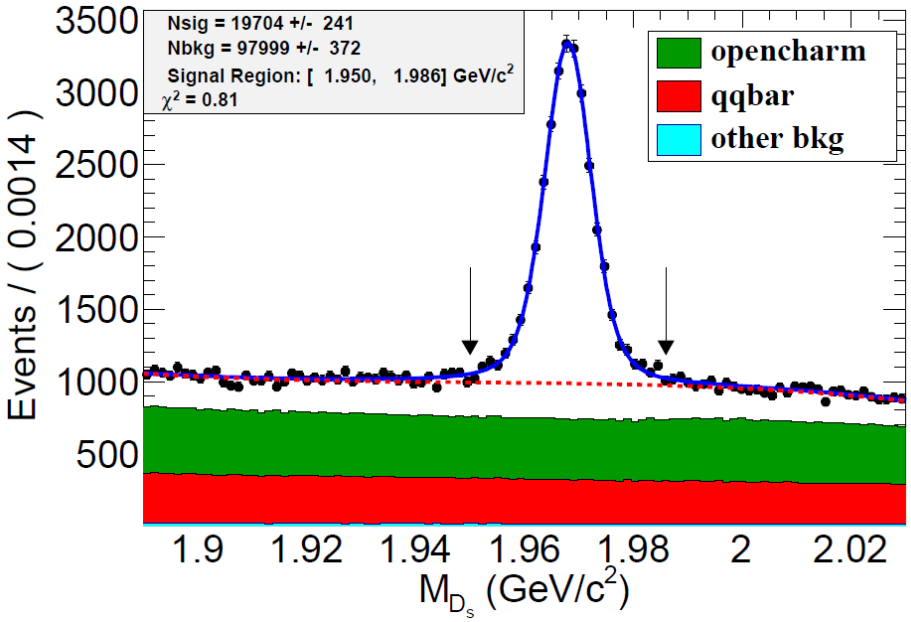
Tag Mode	$M_{D_s^+}$ window ($\mathrm{GeV/c^2}$)	yields(702p01)	N_{bkg}(702p01)	yields(702p02)	N_{bkg}(702p02)
$K^+K^-\pi^+$	[1.950,1.986]	19704 ± 241	25336 ± 189	19746 ± 240	25132 ± 188
$K^+K^-\pi^+\pi^0$	[1.947,1.982]	5897 ± 438	32187 ± 290	5828 ± 267	32419 ± 226
$\pi^+\pi^+\pi^-$	[1.952,1.984]	5147 ± 353	44397 ± 271	5120 ± 354	45569 ± 274
$K_S^0K^+$	[1.948,1.991]	4706 ± 116	2700 ± 166	4701 ± 109	2638 ± 138
$K_S^0K^+\pi^0$	[1.946,1.987]	1670 ± 348	7836 ± 217	1725 ± 219	7780 ± 151
$K^+\pi^+\pi^-$	[1.953,1.983]	2384 ± 337	36090 ± 246	2415 ± 339	36473 ± 250
$K_S^0K_S^0\pi^+$	[1.951,1.986]	769 ± 62	1577 ± 49	815 ± 64	1635 ± 50
$K_S^0K^-\pi^+\pi^+$	[1.953,1.983]	1911 ± 92	3875 ± 74	1970 ± 95	3978 ± 75
$K_S^0K^+\pi^+\pi^-$	[1.958,1.980]	1002 ± 96	5344 ± 83	1055 ± 104	5486 ± 85
$\eta_{\gamma\gamma}\pi^+$	[1.930,2.000]	2768 ± 173	8203 ± 149	2810 ± 175	8285 ± 151
$\eta_{\pi^+\pi^-\pi^0}\pi^+$	[1.941,1.990]	795 ± 62	1633 ± 52	820 ± 87	1689 ± 64
$\eta'_{\pi^+\pi^-\eta_{\gamma\gamma}}\pi^+$	[1.940,1.996]	1380 ± 59	700 ± 39	1416 ± 60	766 ± 41
Total		48133 ± 825	169878 ± 608	48421 ± 703	171850 ± 557

Ds –> $K^+K^-\pi^+$

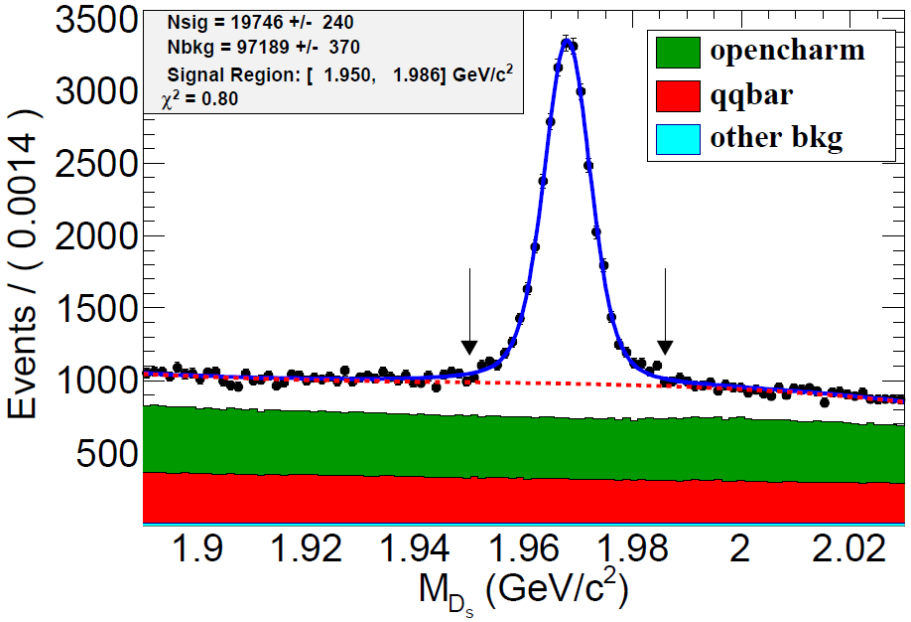
Ds mass window : [1.950,1.986]

Tag Mode	$M_{D_s^+}$ window (GeV/c^2)	yields(702p01)	N_{bkg}(702p01)	yields(702p02)	N_{bkg}(702p02)
$K^+K^-\pi^+$	[1.950,1.986]	19704 ± 241	25336 ± 189	19746 ± 240	25132 ± 188

Version 702p01



Version 702p02 + HOUGH



Improvement can be seen after using HOUGH tracking

Summary and Outlook

- Hough tracking is released for physical test in BOSS 7.0.2.p02
  - Not yet been included in the default reconstruction flow
- Improvement can be seen at low p_T from physical channels
  - Efficiency have **3~4%** improvement in 50-120MeV
- More validations will be done using low p_T channels

- Outlook
  - Used for official data reconstruction at next released
  - Can be used on outer drift chamber + CGEM tracking