Progress on the online tracking algorithm

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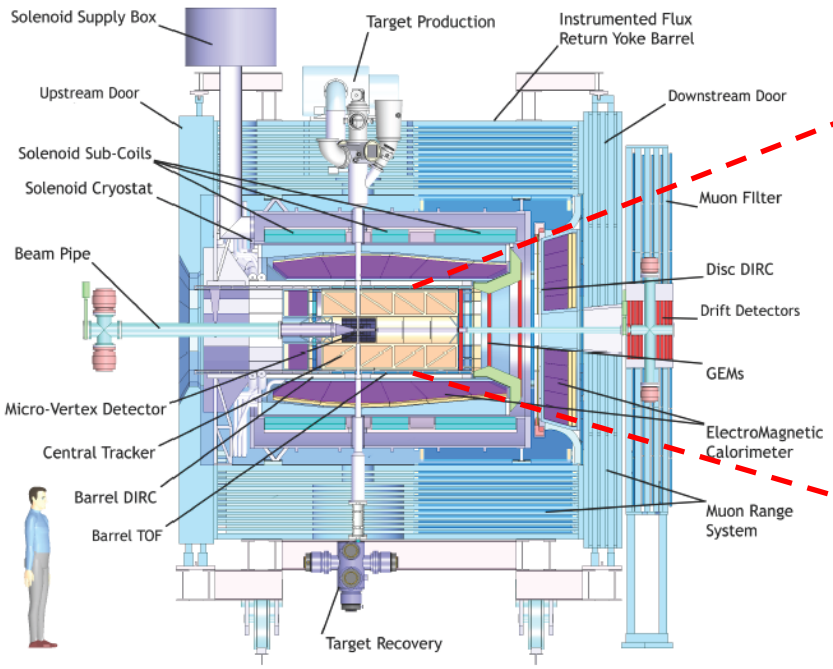
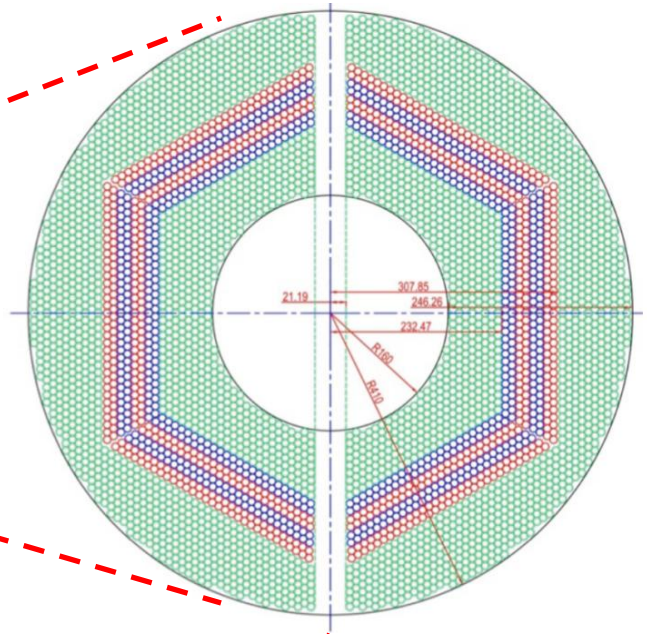
Dec. 10 2013

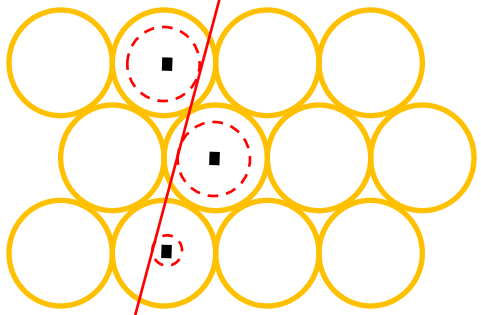
Outline

1. Introduction
2. Road finding and momentum calculation
3. Performance studies
   - Single/multi-track events
   - Dpm (event-based)
   - Dpm (time-based)
4. VHDL implementation
5. Summary and outlook

Straw Tube Tracker(STT)



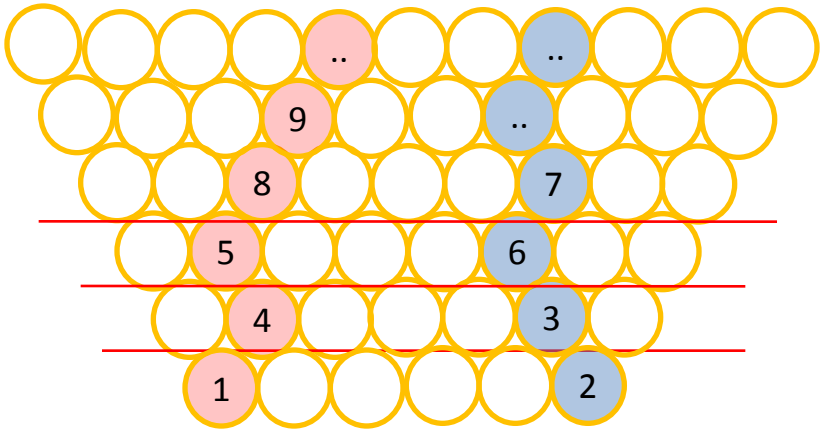




- ➢4636 Straw tubes
- ➢23-27 planar layers
- 15-19 axial layers(green) in beam direction
- 4 stereo double-layers for 3D reconstruction, with ±2.89 skew angle(blue/red)

From STT : Wire position + drift time

Road finding



1: Sort hits, and fill into array
array_layer_0 <= (1, 2)
array_layer_1 <= (3, 4)
array_layer_2 <= (5, 6)

2: Combine hits of two adjacent layers,
keep effective combinations (in red color)

Layer 0 & 1: 1->3 || 2->3 || 1->4 || 2->4
Layer 1 & 2: 3->5 || 4->5 || 3->6 || 4->6
Easy to parallel design.

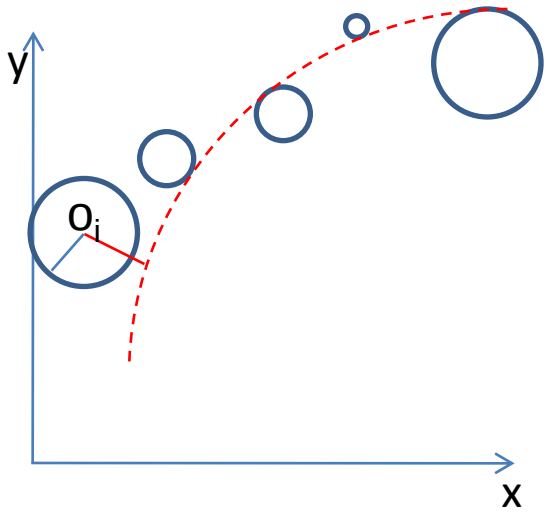
3: Connect these combinations and form tracklets

1->4 + 4->5 … = 1->4->5->8->9
2->3 + 3->6 … = 2->3->6->7…..

If somewhere broken, a further step to connect them…

4: Calculate momentum for each tracklet.

Calculation of circle parameters



Known : x_i , y_i ,d_i

Question: To determine a circle,

$x^2 + y^2 + ax + by + c = 0$

Method: Minimize the equation

$E^2 = \sum(x_i^2 + y_i^2 + a\,x_i + b\,y_i + c)^2\,(1/d_i)^2$

1) Circle para.

$$\begin{pmatrix} S_{xx} & S_{xy} & S_x \\ S_{xy} & S_{yy} & S_y \\ S_x & S_y & N \end{pmatrix} \begin{pmatrix} a \\ b \\ c \end{pmatrix} = \begin{pmatrix} -S_{xxx} - S_{xyy} \\ -S_{xxy} - S_{yyy} \\ -S_{xx} - S_{yy} \end{pmatrix}$$

$S_x = \sum x_i$ …
$S_{xx} = \sum x_i x_i$ …
$S_{xxx} = \sum x_i x_i x_i$ …

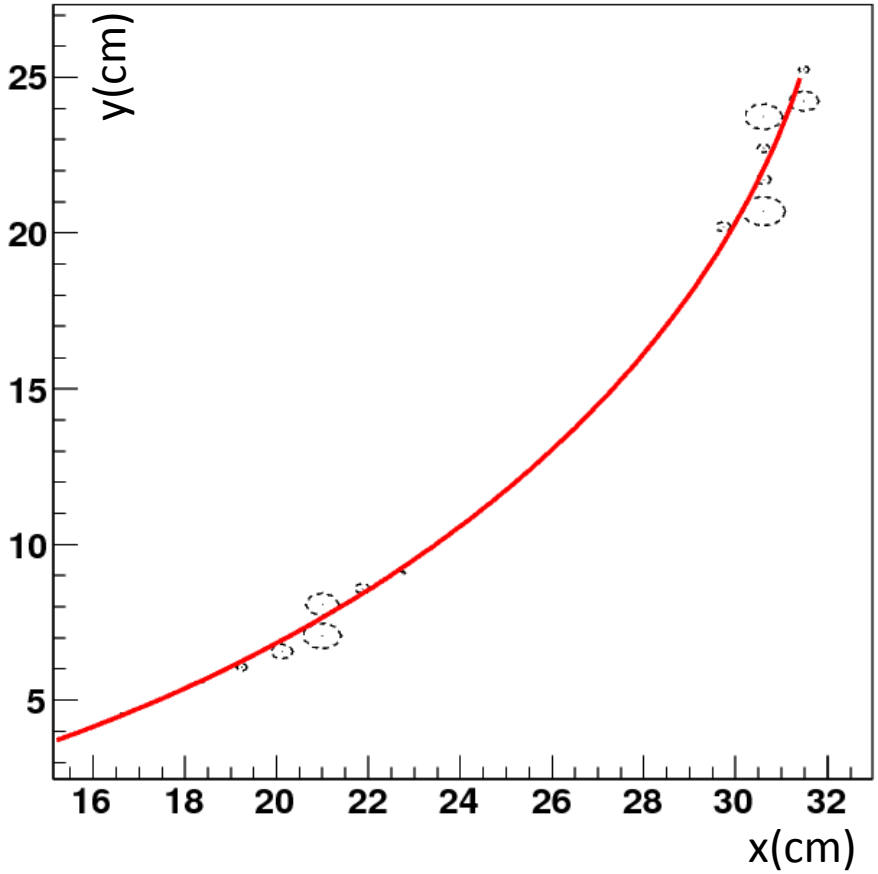
2) Track quality.

$$\chi^2 = 1/n \times \sum_i \frac{(x_i^2 + a x_i + y_i^2 + b y_i)/2r^2}{d_i^2}$$

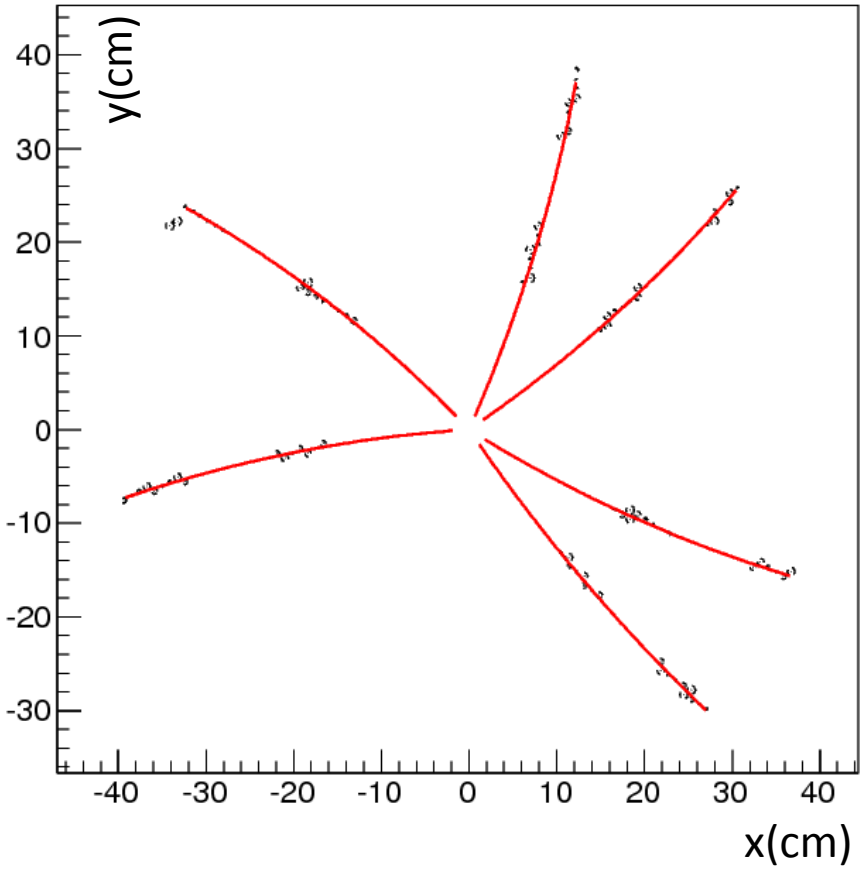
$$= (S_{xxxxdd} + S_{yyyydd} + 2S_{xxyydd} + 2aS_{xxxdd} + 2bS_{yyydd} + 2bS_{xxydd} + 2aS_{xyydd} + a^2 S_{xxdd} + b^2 S_{yydd} + 2abS_{xydd})/2r$$

Performance study -- single/multi-track event

Single track, 0.2GeV

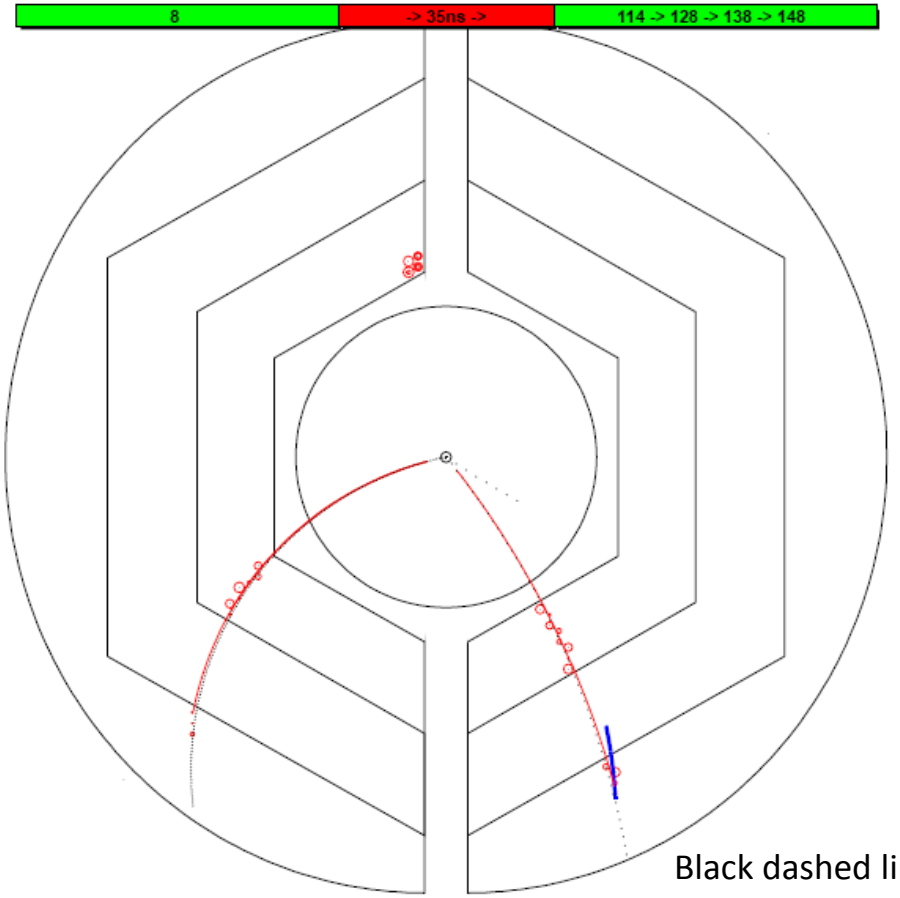


Multi-track

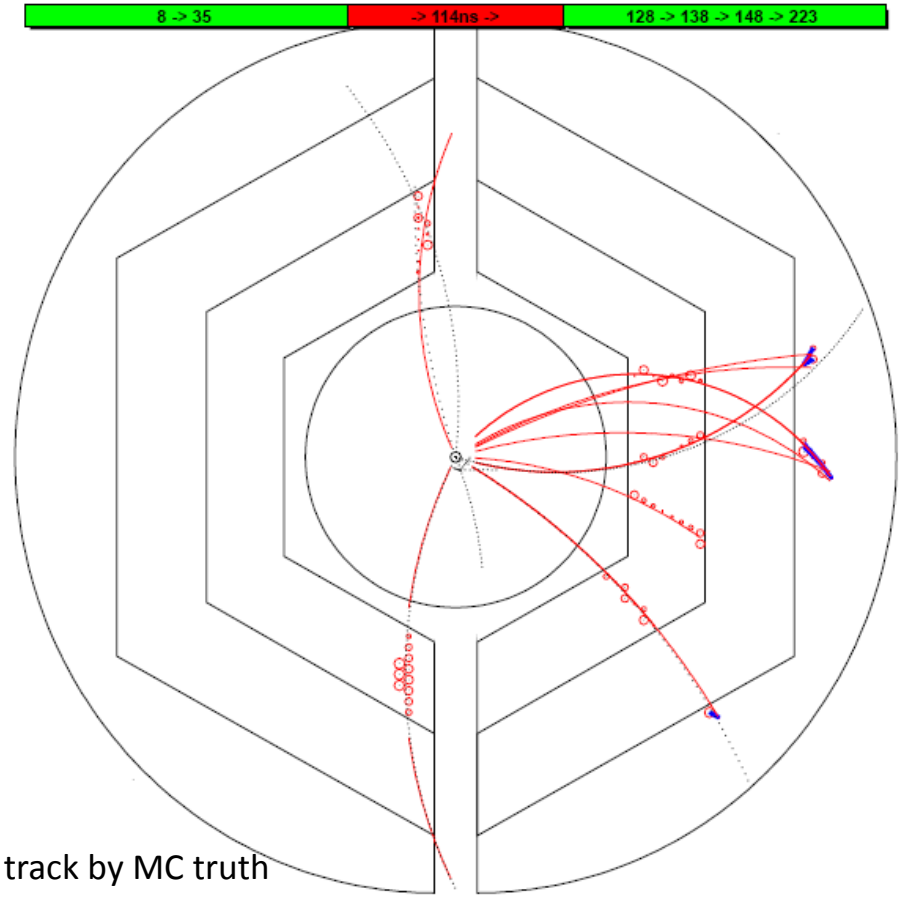


Performance study -- Dpm events

T_0 information: current event(Red) or other events(Green)



Event #1

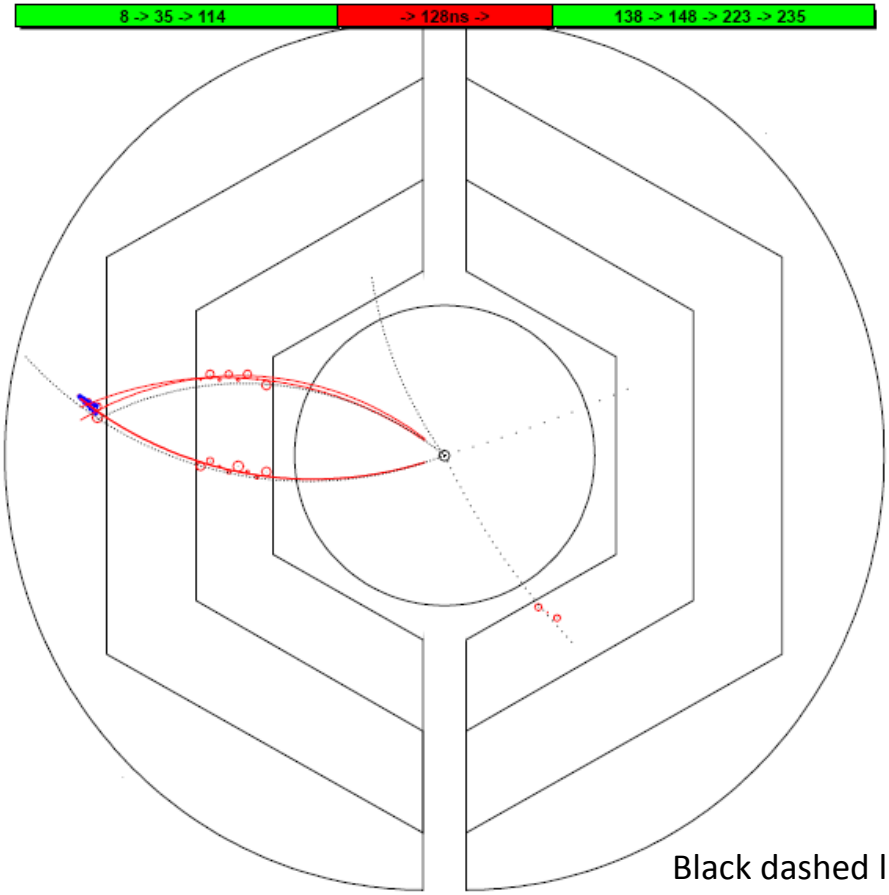


Event #2

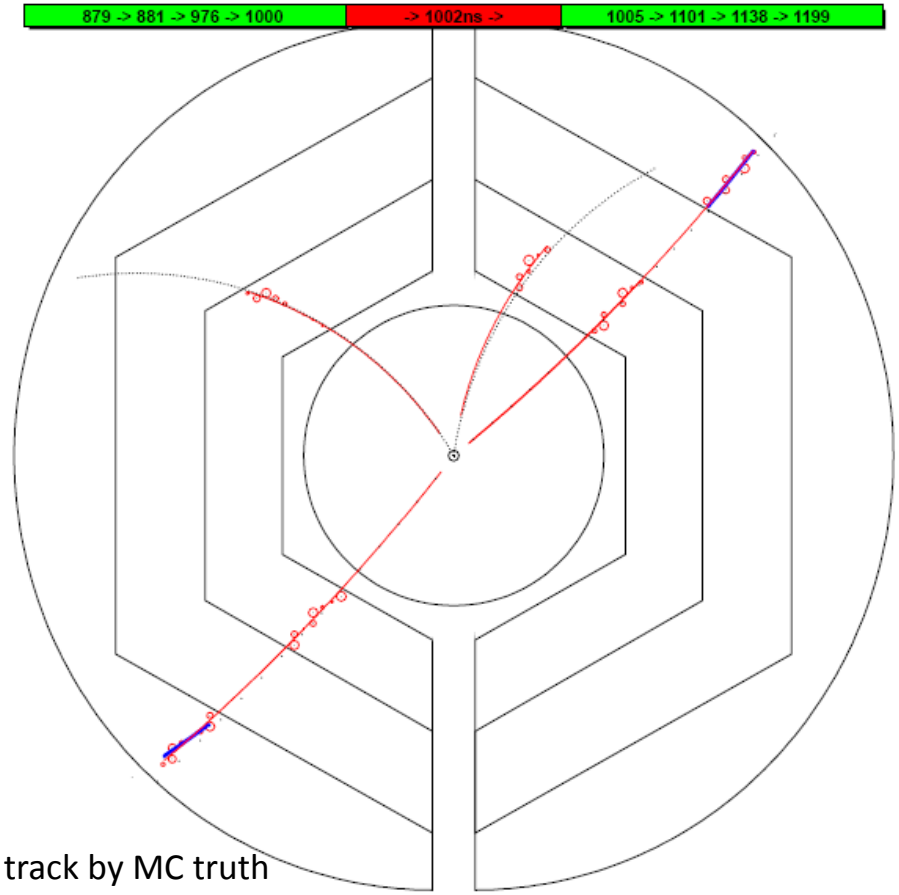
Black dashed line: track by MC truth
Red line: recon. track
Blue: recon. using outer layers
drift circles belong to current event (Red) or other events (Green)

Performance study -- Dpm events

T_0 information: current event(Red) or other events(Green)



Event #3

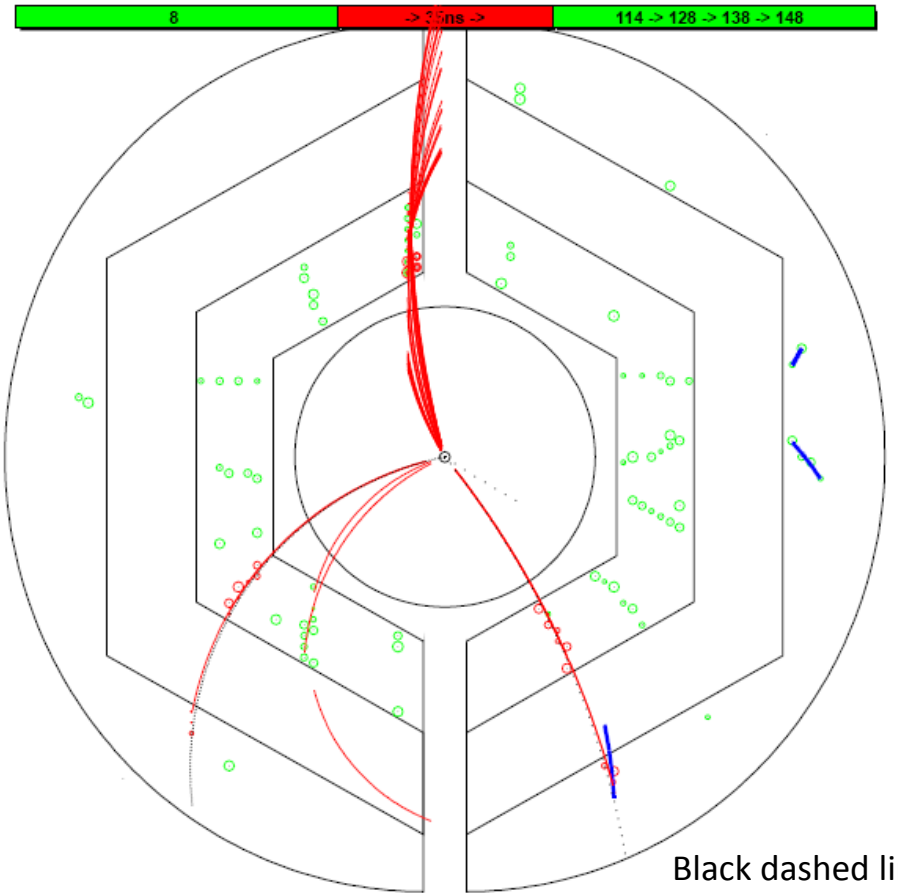


Event #4

Black dashed line: track by MC truth
Red line: recon. track
Blue: recon. using outer layers
drift circles belong to current event (Red) or other events (Green)

Performance study -- Dpm events, time-based

T_0 information: current event(Red) or other events(Green)



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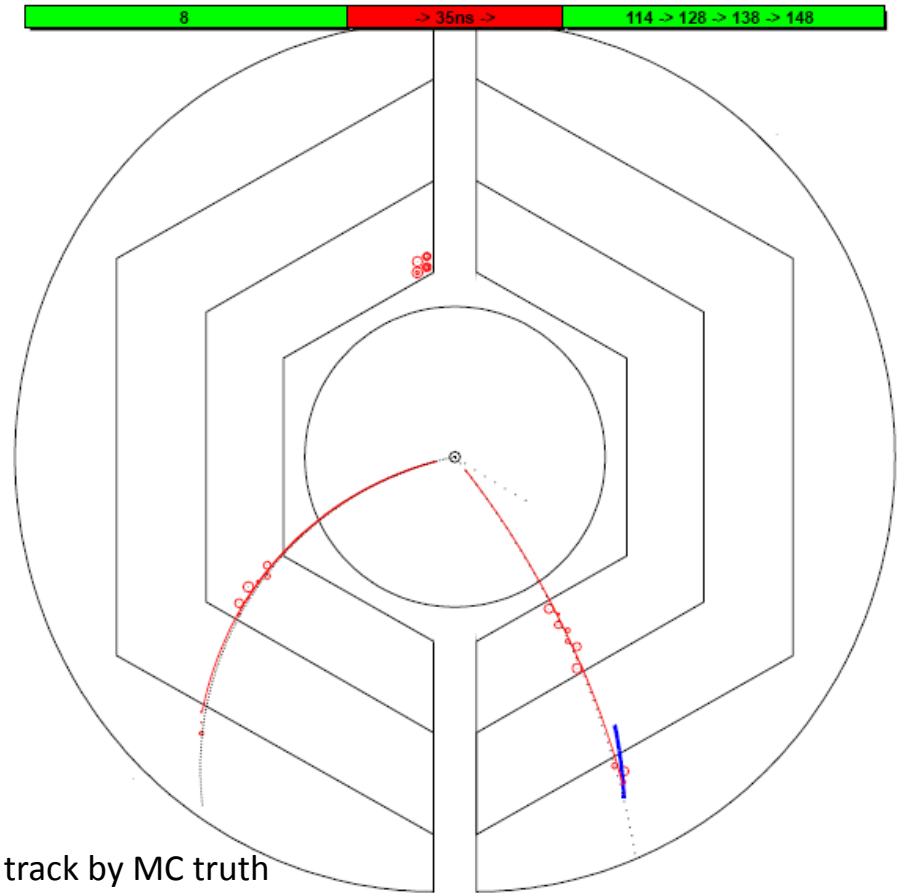

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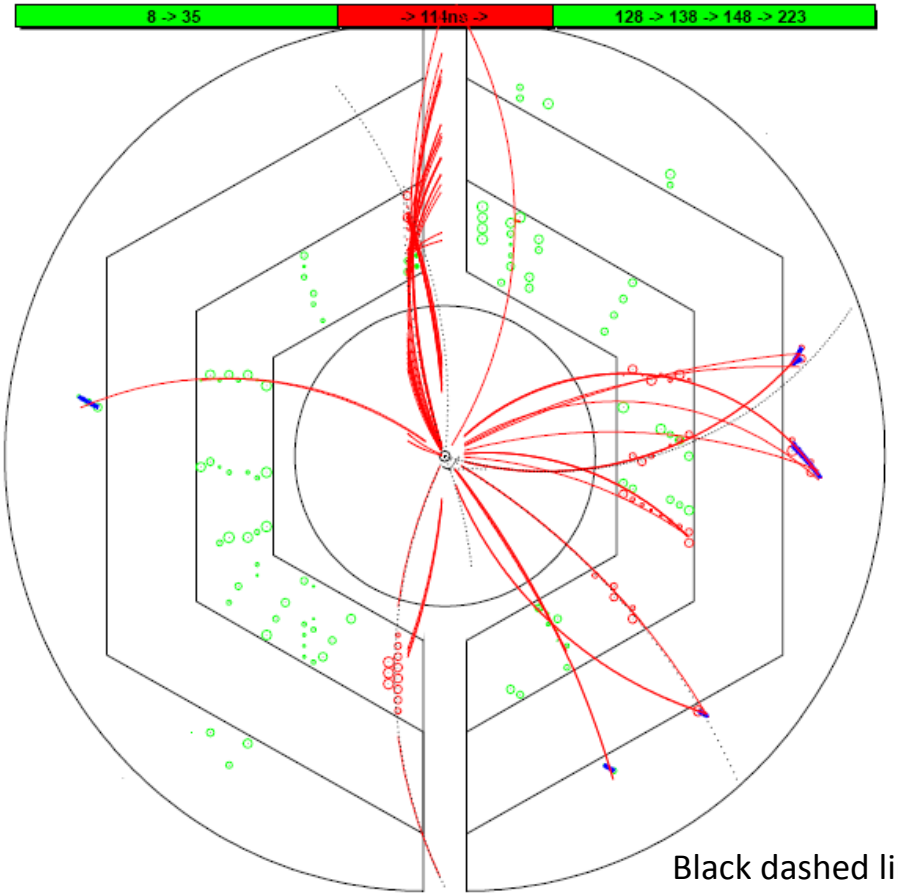

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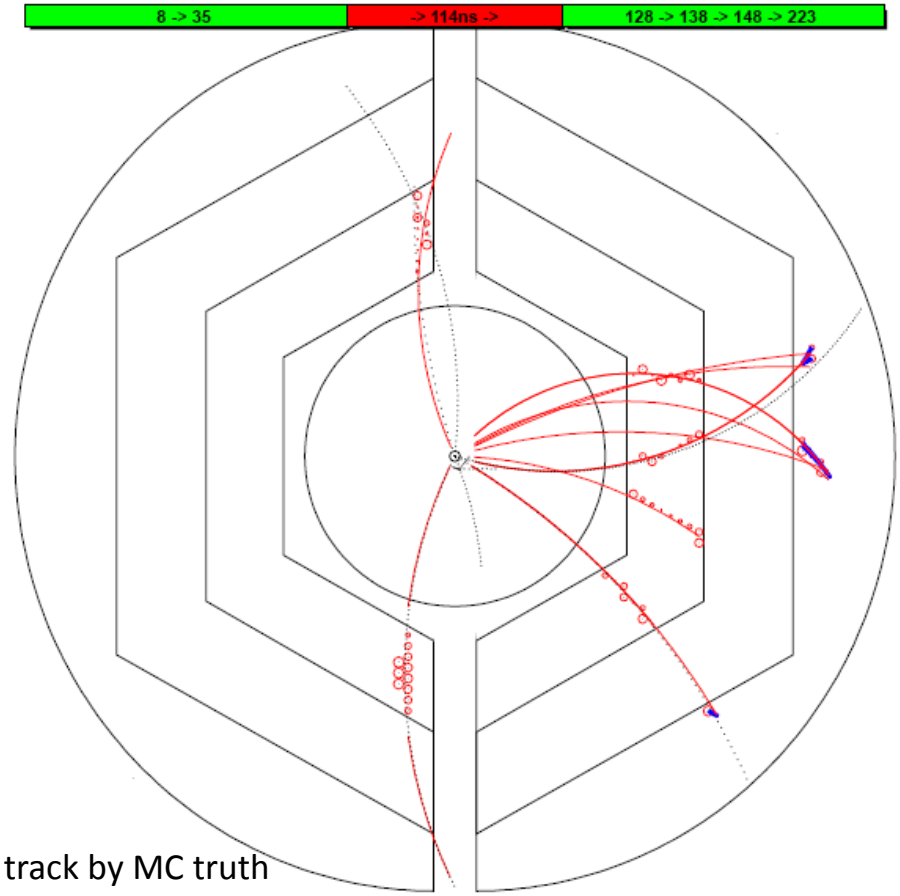

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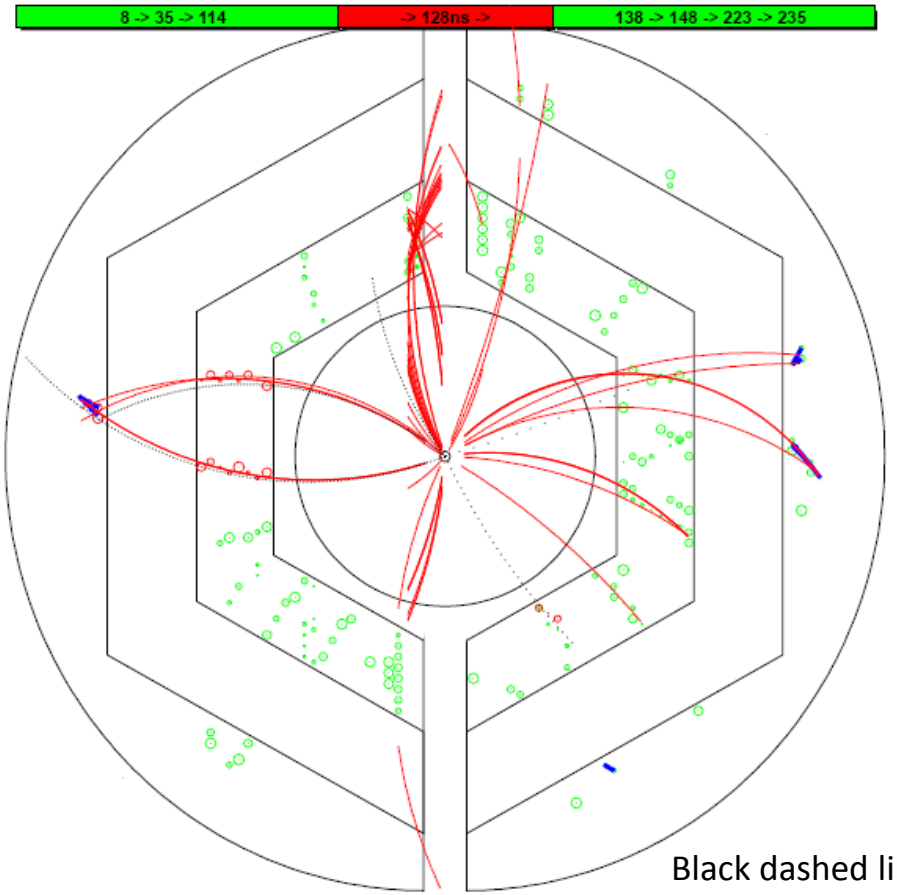
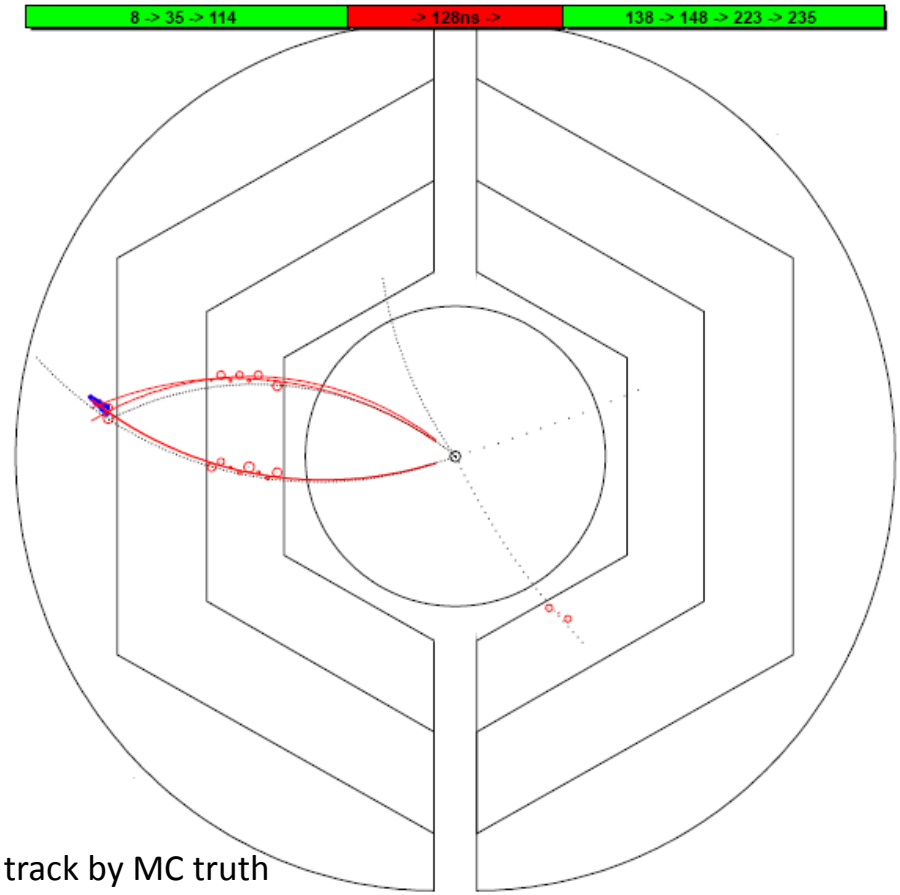
Performance study -- Dpm events, time-based

T_0 information: current event(Red) or other events(Green)



Event #3



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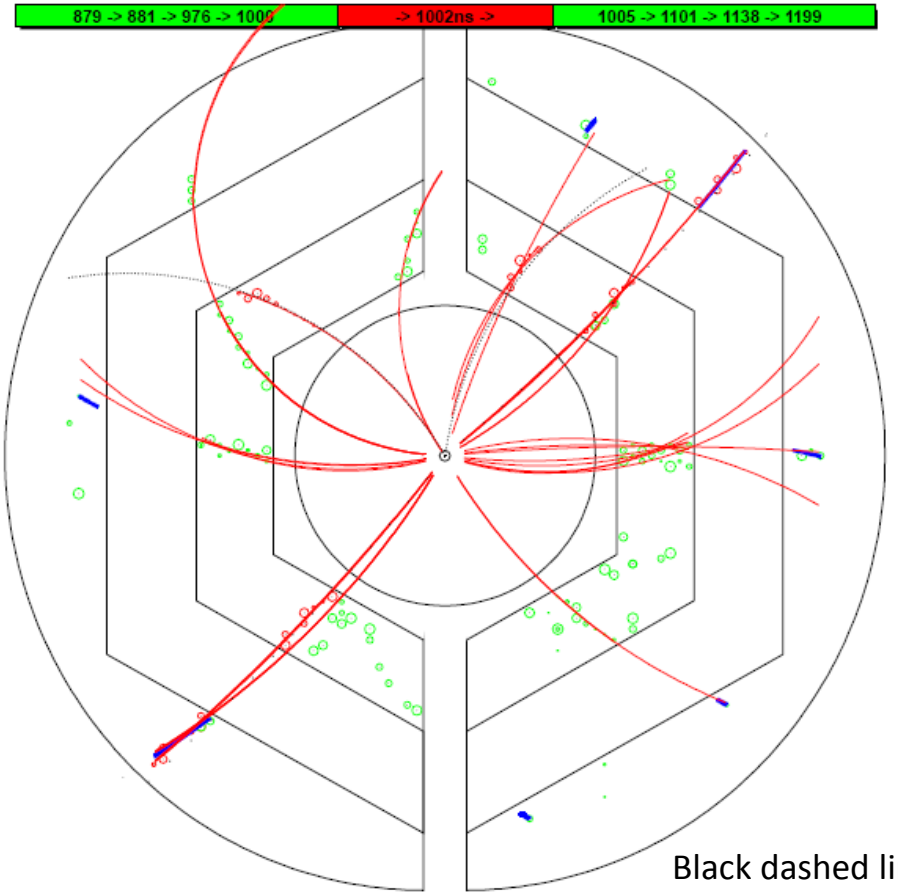

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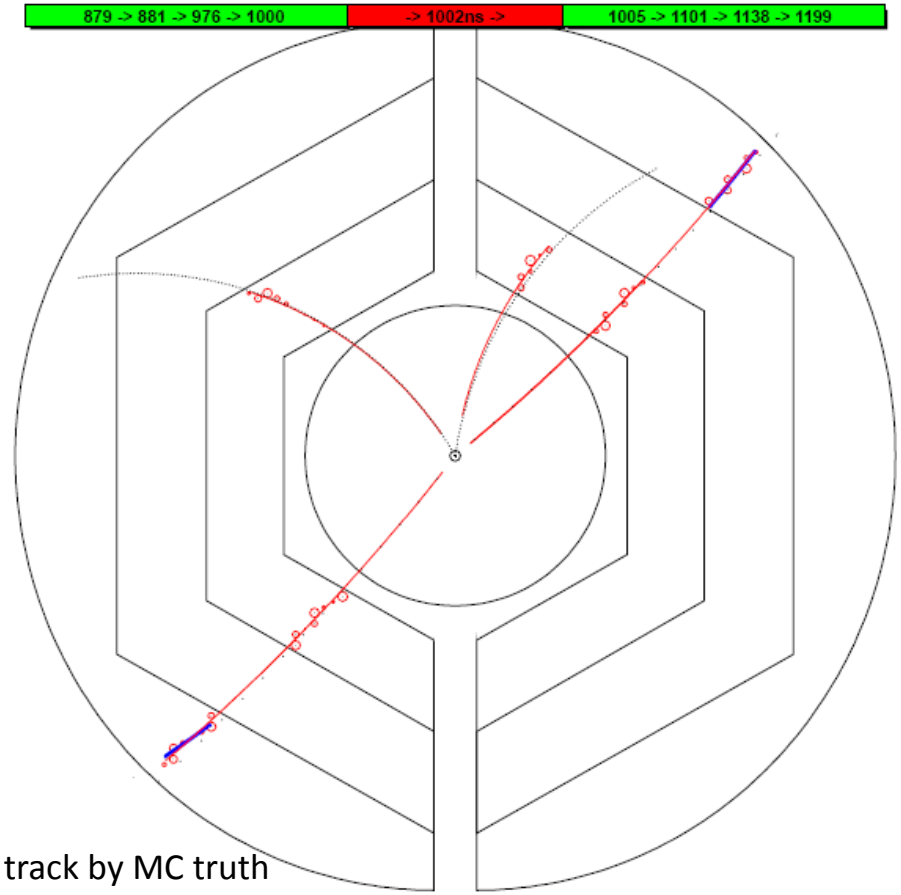
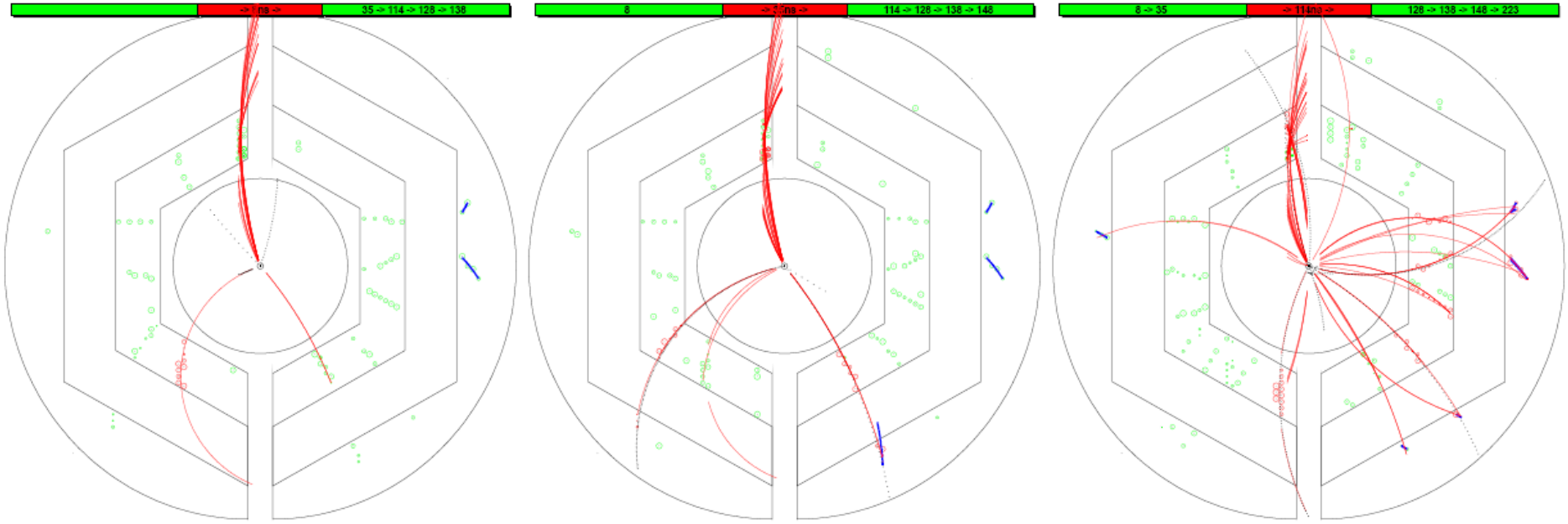


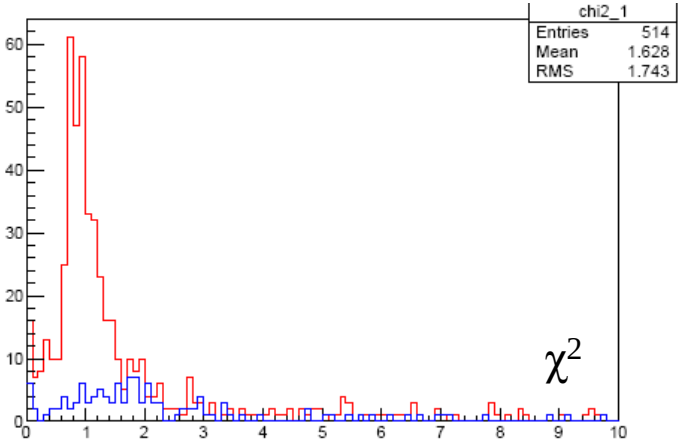
Event #4

Assign a track to the correct event



1: Number of hits in the track

2: χ^2 of the track



Assign a track to the correct event

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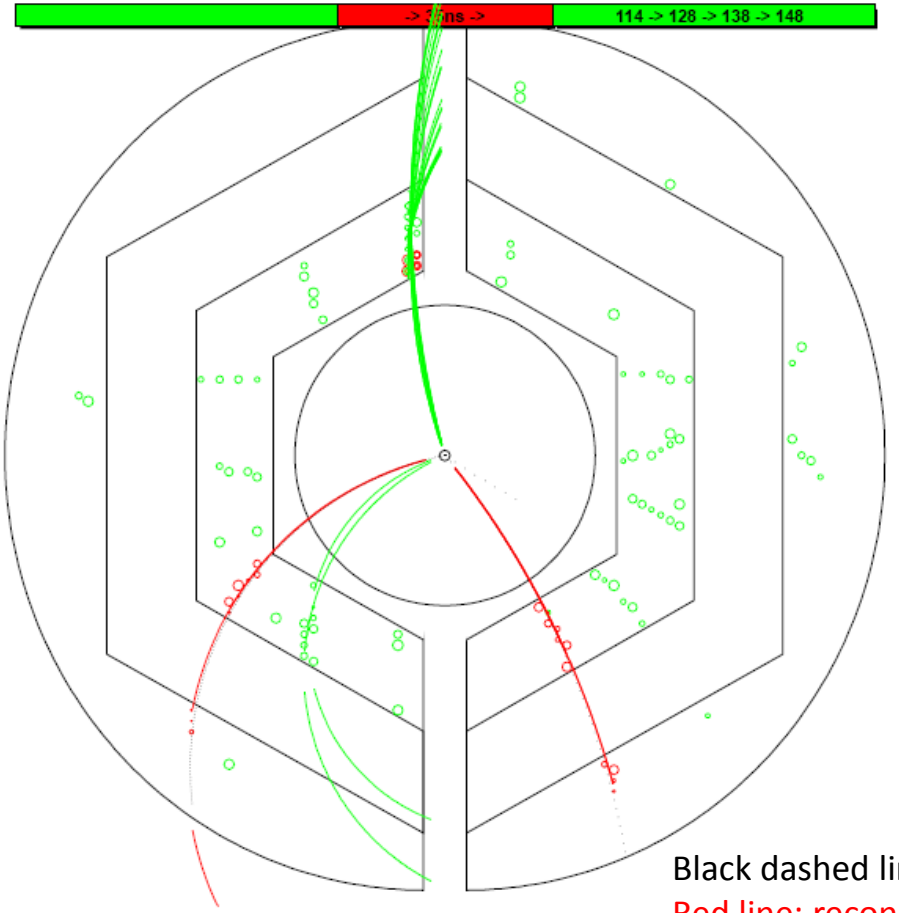

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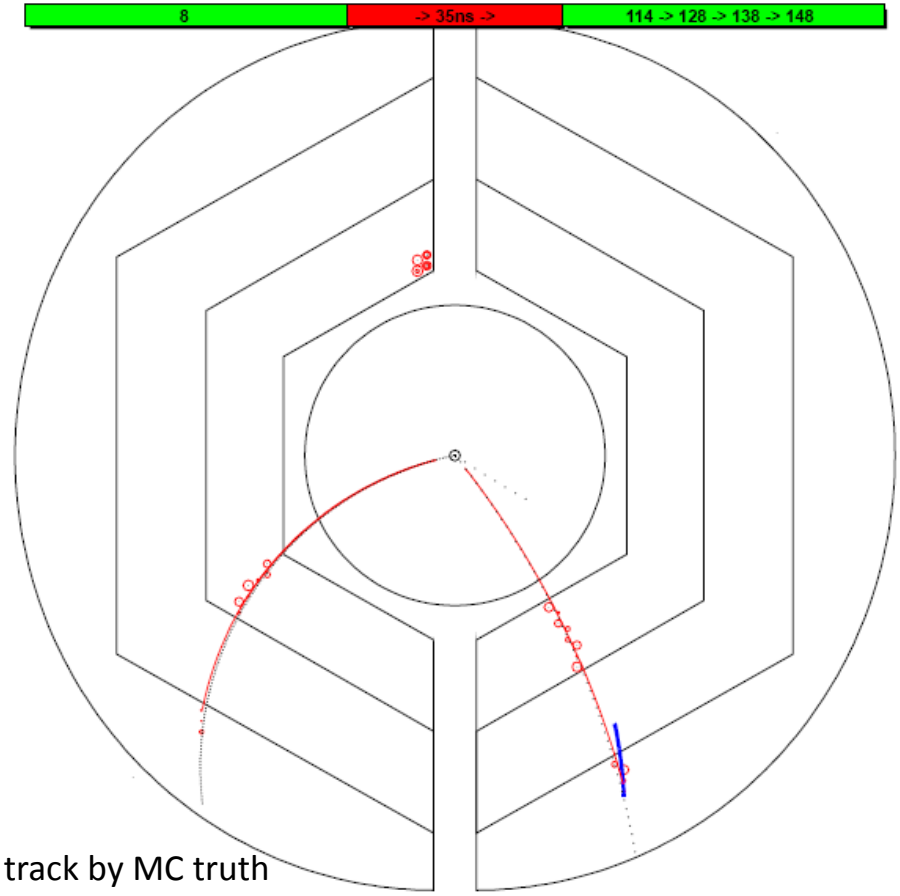

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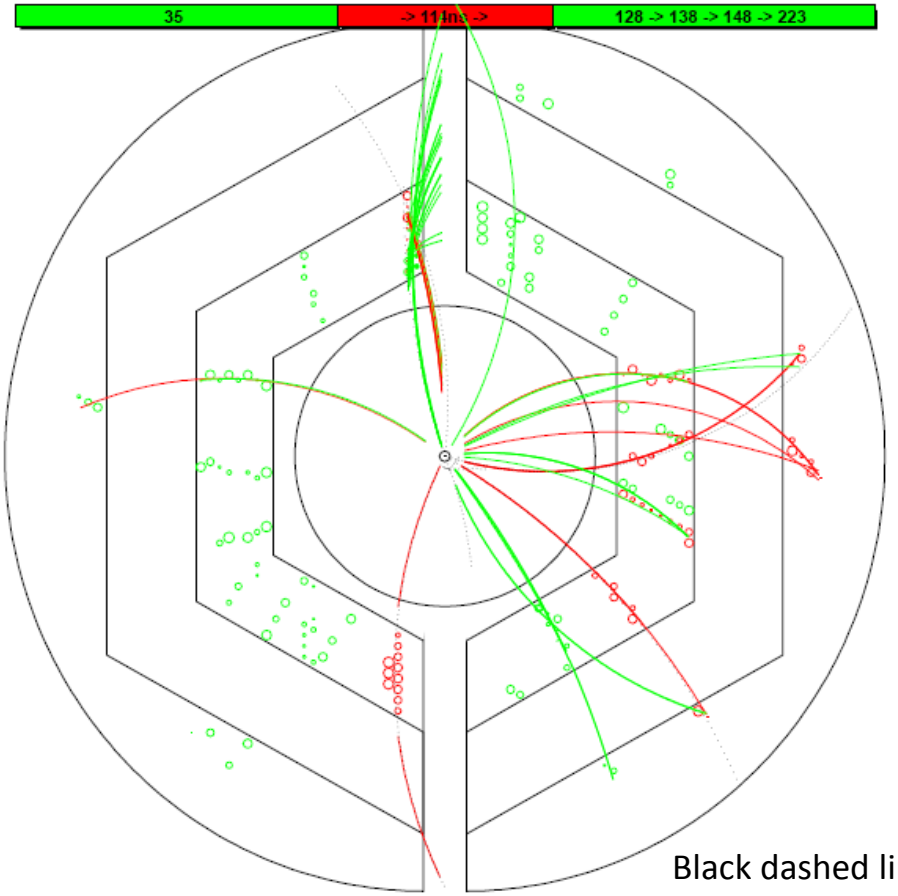

Event #2

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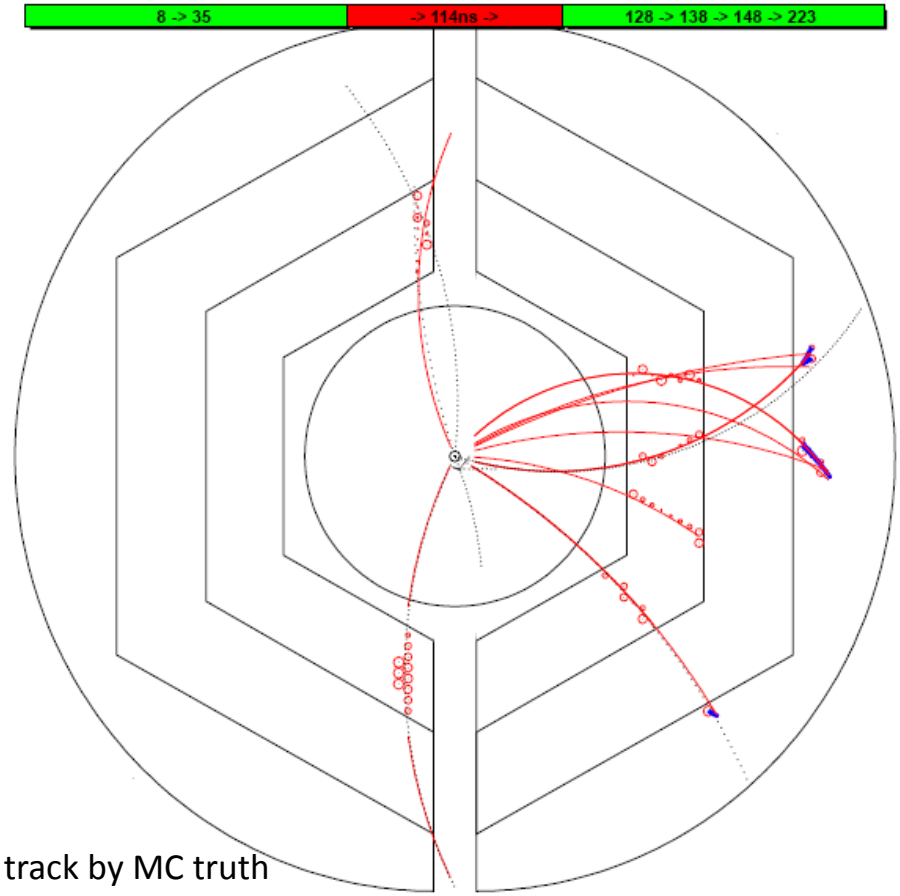

Event #2

Assign a track to the correct event

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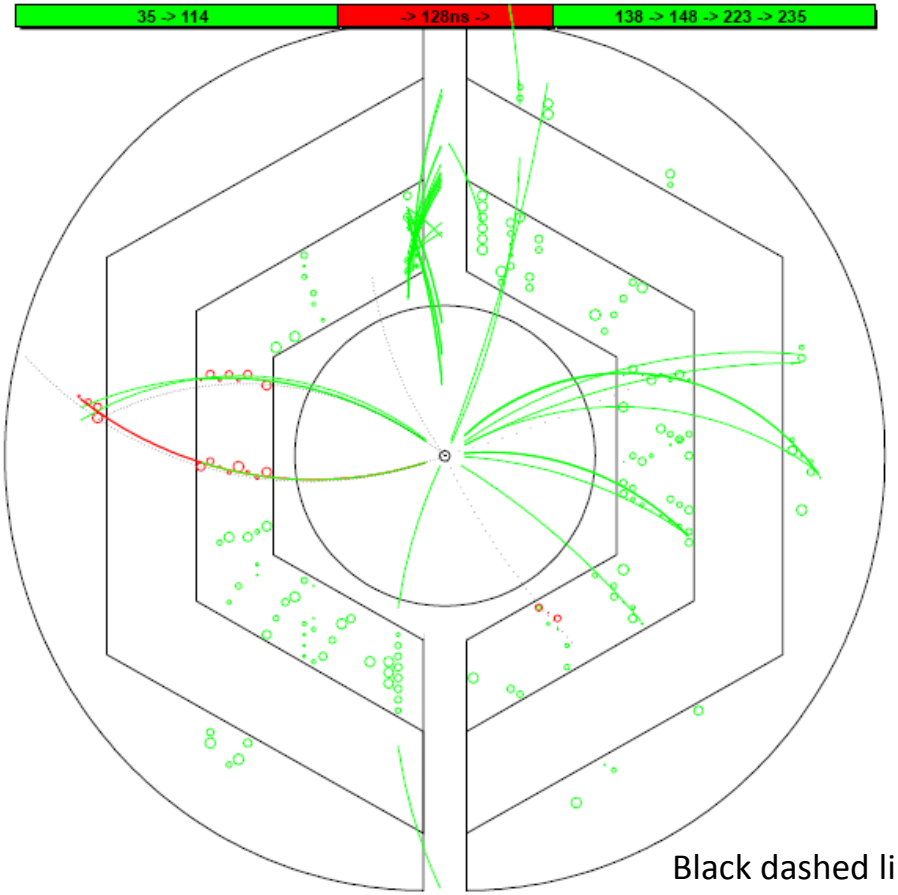
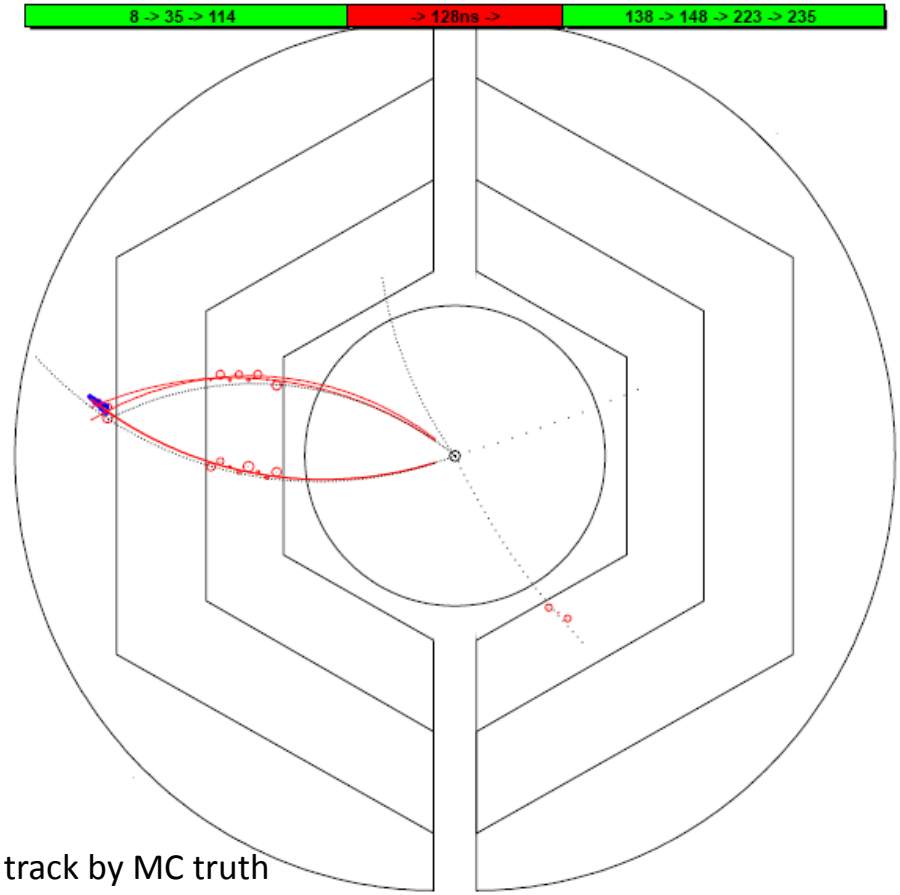


Event #3



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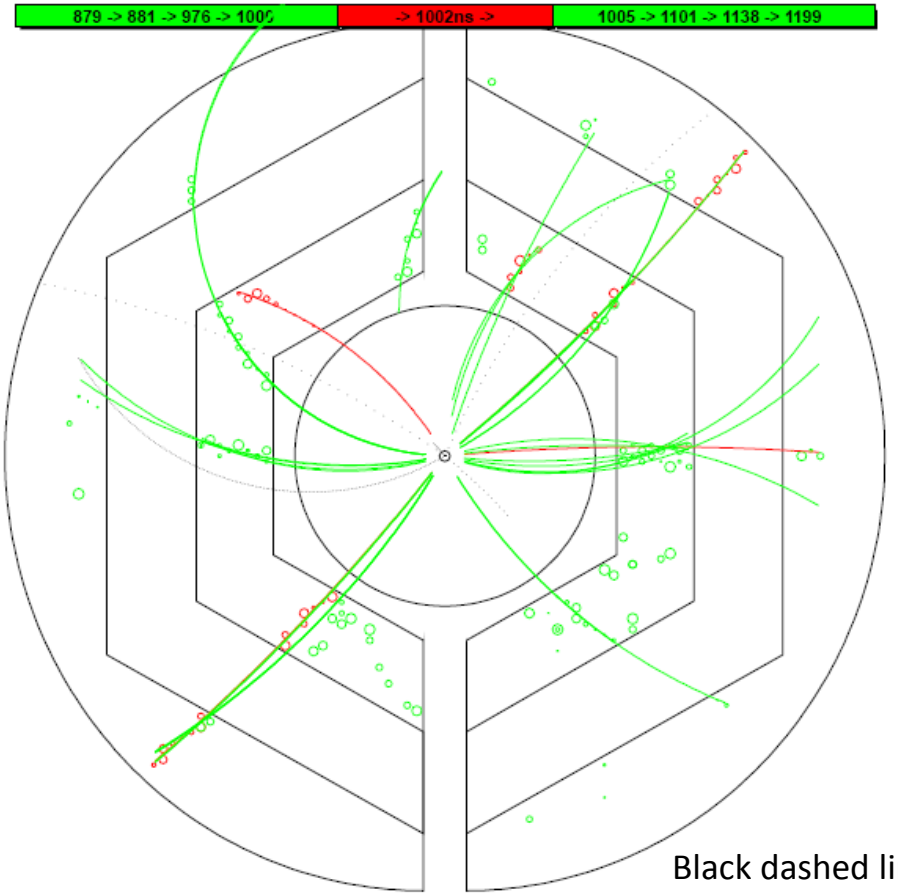

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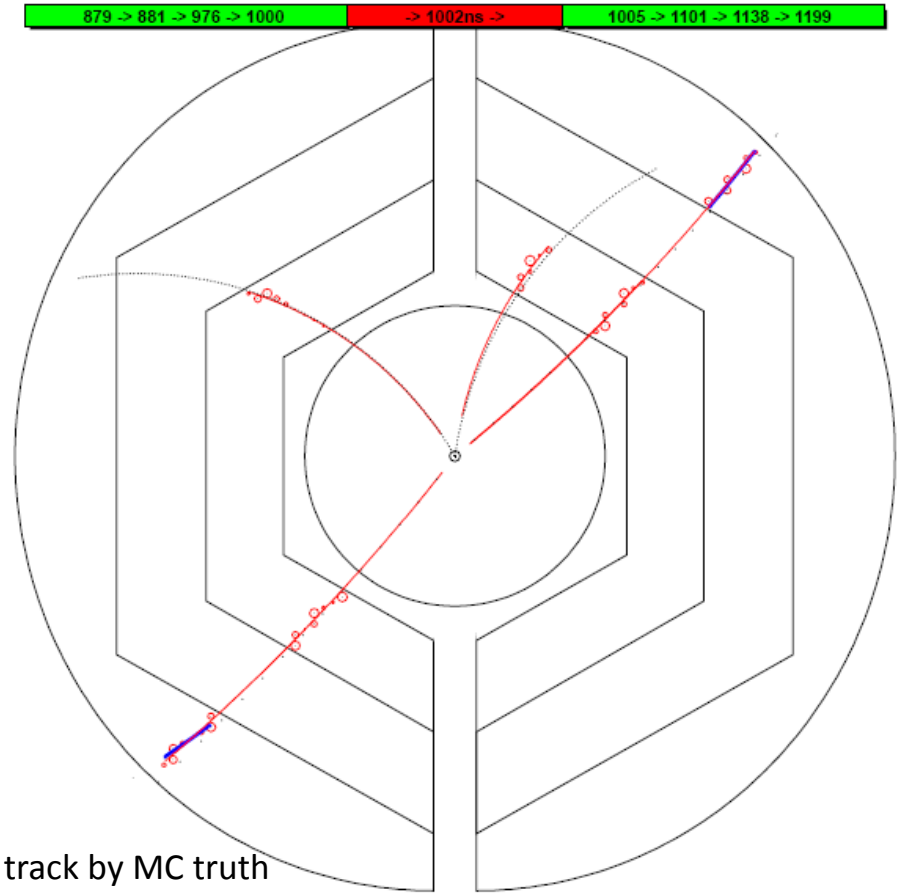


Event #4

VHDL implementation

1: Road finding: Using status machine to control the following procedures.

1) Hit sorting: fill hit into array_layer_id according to layer ID

2) Combine hits from two adjacent layers

3) Form a tracklet by attaching hit layer by layer
   tracklet_inner : layer 0-7
   tracklet_outer: layer 8-15

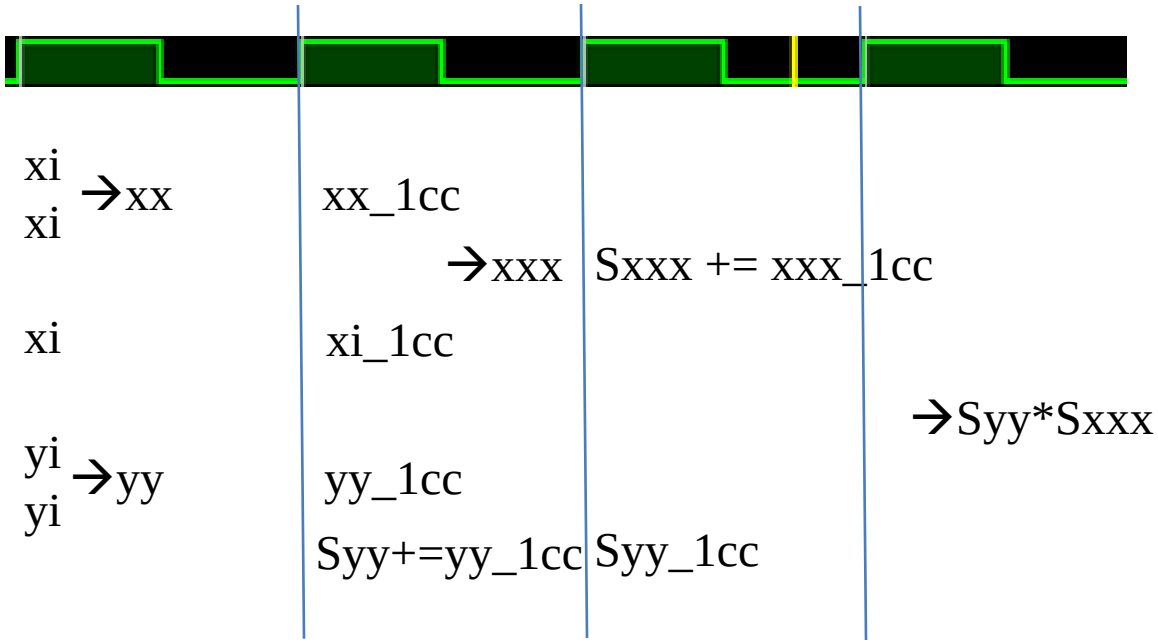
4) Combine tracklet_inner and tracklet_outer.

For one event with 100 hits (6 tracks): 1) 100 clock cycles (cc) 2) ~ 300-600cc 3) ~200cc → several us (if FPGA running at 100MHz)

VHDL implementation

2: Momentum calculation

a = Syy*(-Sxxx-Sxyy) - Sxy*(-Sxxy-Syyy);



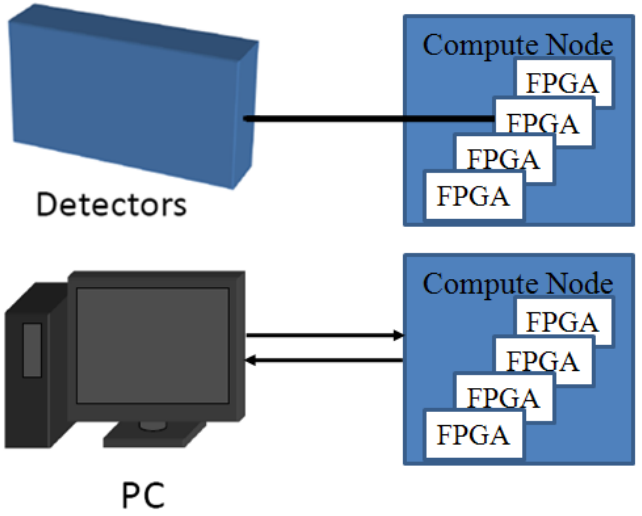
3: χ^2 calculation

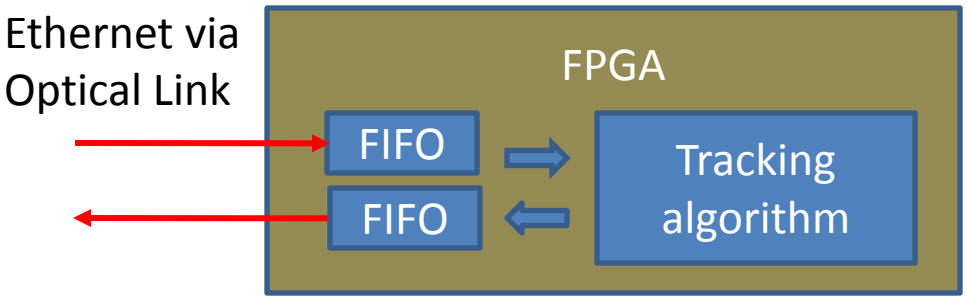
24X24 bit not precise enough → 32X32 bit

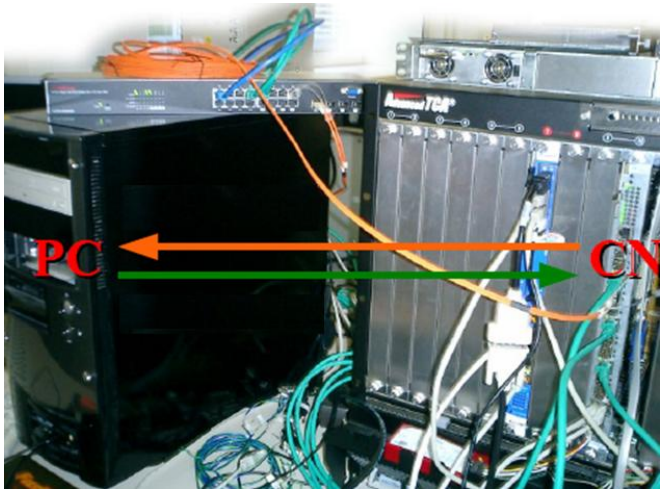
Setup and test

PC as data source and receiver.

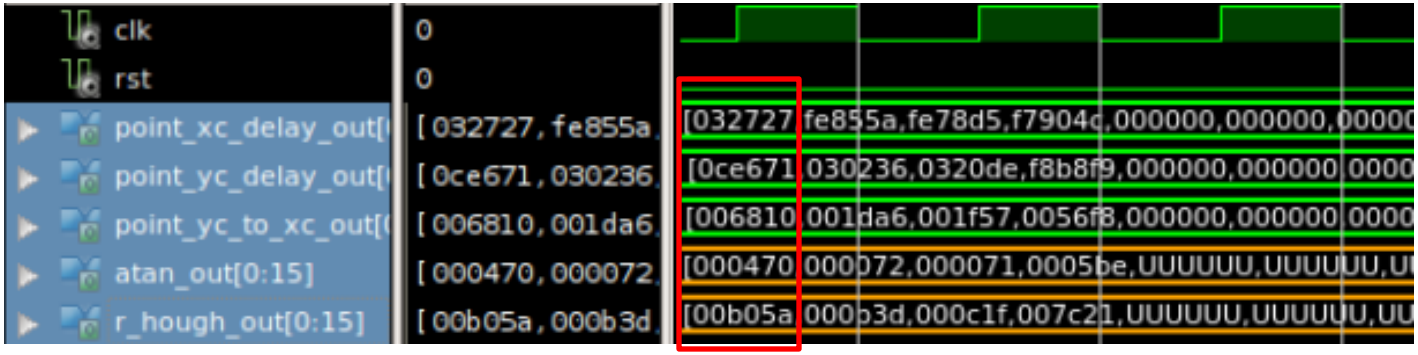
- Ethernet.
- Optical link (UDP by Grzegorz Korcyl) (not integrated yet)



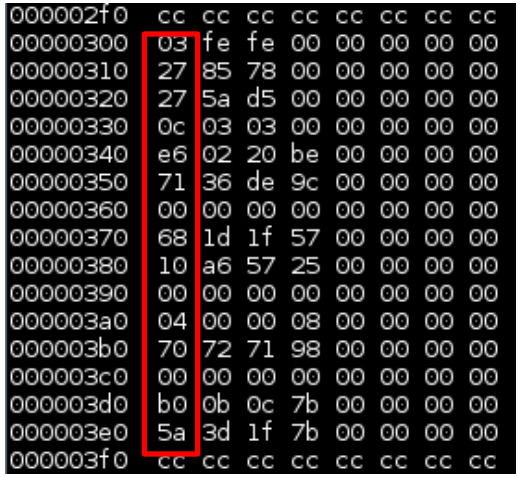




Simulation with ISim and test at FPGA



Track	#1	#2	#3	#4
Xr (cm):	-38.8	63.9	62.4	124.2
Yr (cm):	-158.7	-129.9	-127.8	107.1
R(cm):	163.3	144.7	142.2	164.0
χ^2 :	0.40	0.63	0.58	0.74



Timing Expectation(4 tracks per event): 200cc+300cc → 300~500cc
→ 3~5 us/event, agrees to the test with 1M events.

Device utilization Summary

Device Utilization Summary				
Logic Utilization	**Used**	**Available**	**Utilization**	**Note(s)**
Number of Slice Flip Flops	18,301	50,560	36%	
DCM autocalibration logic	14	18,301	1%	
Number of 4 input LUTs	22,934	50,560	45%	
DCM autocalibration logic	8	22,934	1%	
Number of occupied Slices	17,997	25,280	71%	

.....

Number of DSP48s	124	128	96%	
Number of DCM_ADVs	2	12	16%	
Average Fanout of Non-Clock Nets	2.98			

31 multiplications take too much resource.

Multiplication(32 X 32 bit): 4 DSPs or 1088 LUTs

Need a smarter way to calculate χ^2

Summary and Outlook

- In the road finding module, the match of inner and outer layer is done.
- In momentum calculation module, the χ^2 is calculated.
- One more module is necessary to assign one recon. track to the correct event.

Next to do:

The road finding module is being optimized.

The module to calculate χ^2 need to be improved.

Thank you

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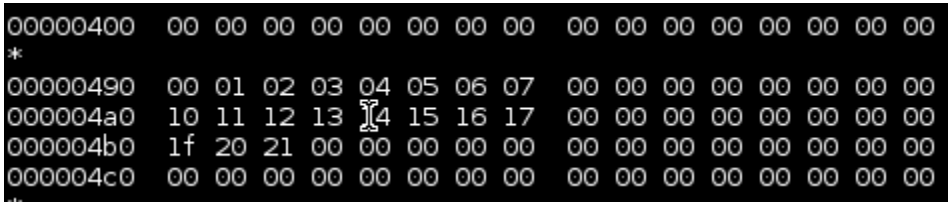
Number of 4 input LUTs	22,934	50,560	45%	
DCM autocalibration logic	8	22,934	1%	
Number of occupied Slices	17,997	25,280	71%	
Number of Slices containing only related logic	17,997	17,997	100%	
Number of Slices containing unrelated logic	0	17,997	0%	
Total Number of 4 input LUTs	23,331	50,560	46%	
Number used as logic	19,002			
Number used as a route-thru	397			
Number used as 16x1 RAMs	8			
Number used for Dual Port RAMs	2,448			
Number used as Shift registers	1,476			
Number of bonded IOBs	36	576	6%	
IOB Flip Flops	3			
IOB Dual-Data Rate Flops	1			
Number of BUFG/BUFGCTRLs	6	32	18%	
Number used as BUFGs	5			
Number used as BUFGCTRLs	1			
Number of FIFO16/RAMB16s	102	232	43%	
Number used as RAMB16s	102			
Number of DSP48s	124	128	96%	
Number of DCM_ADVs	2	12	16%	
Average Fanout of Non-Clock Nets	2.98			

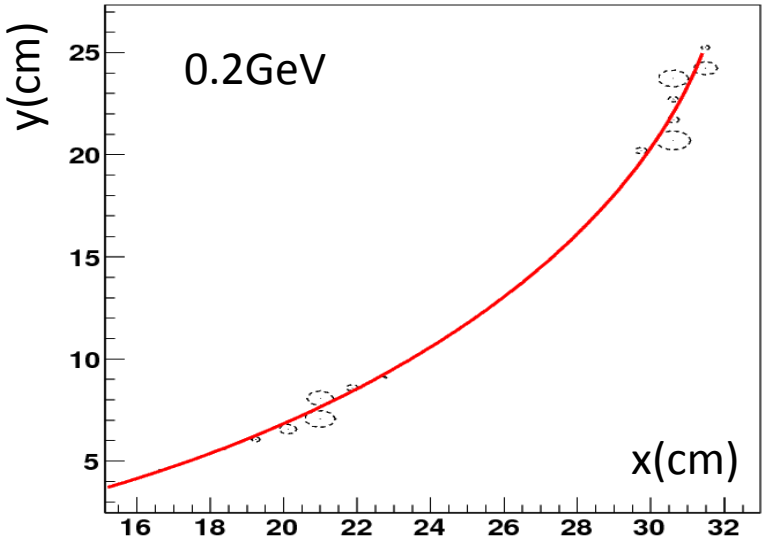


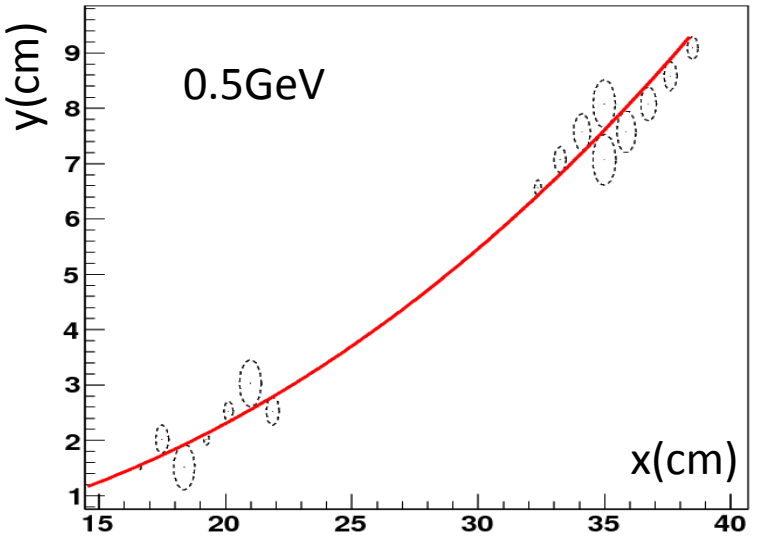
PANDA@20MHz. $2*10^7$ events/second
1 event: ~3 tracks/event * ~16 hits/track * ~ 2 (overlap factor) → ~100 hits/event

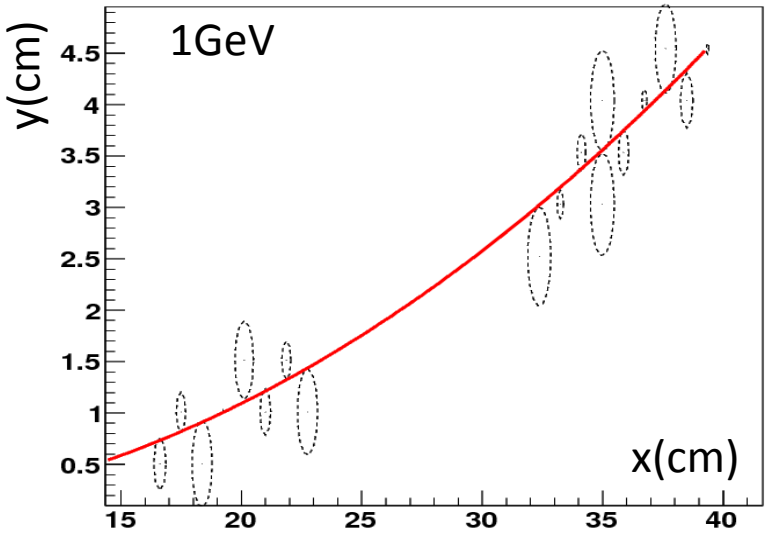
When dividing STT into 16 layers, ~6 hits/layers. 6*6*15 = 540 combinations
~1~2 clock cycles/combination. → 500~1000 clock cycles/event

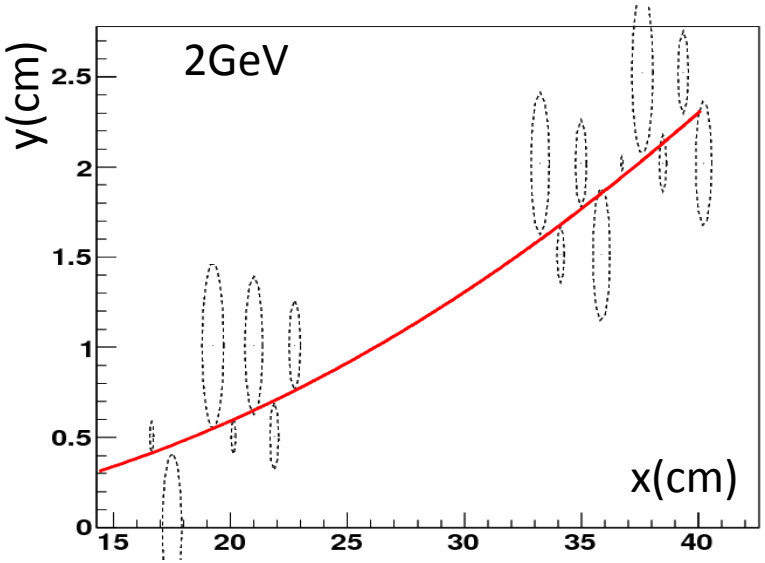
If FPGA running at 100MHz, (500~1000)*10ns/ 50ns → 100~200 FPGA → 25~50 CN

Performance study – single track

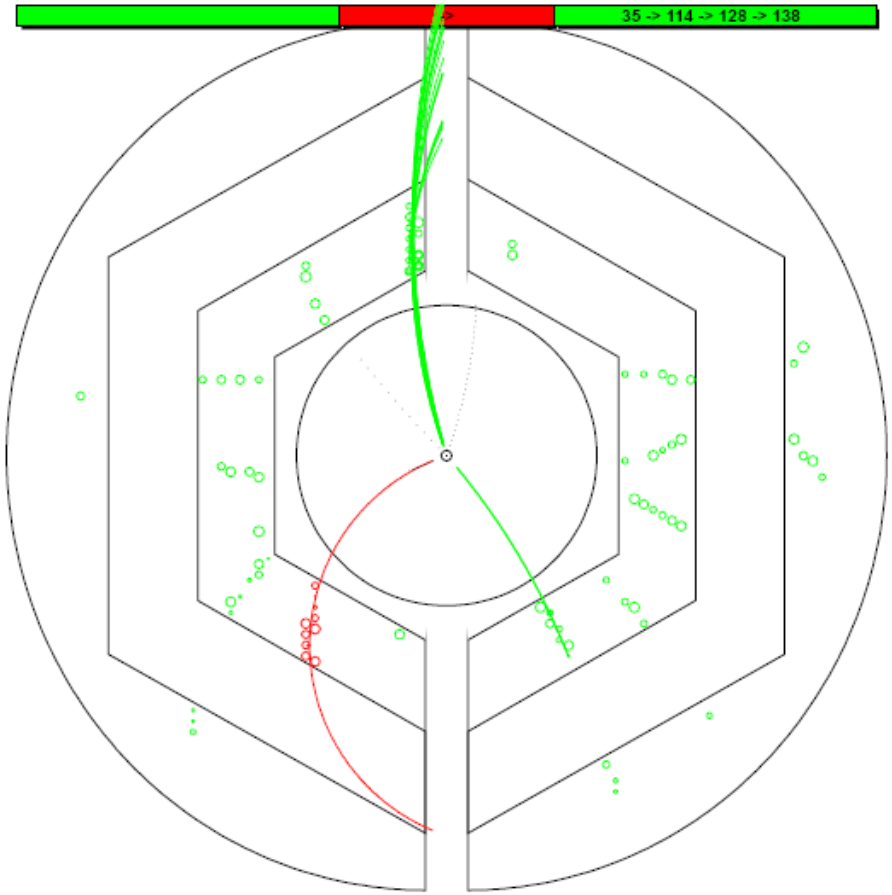


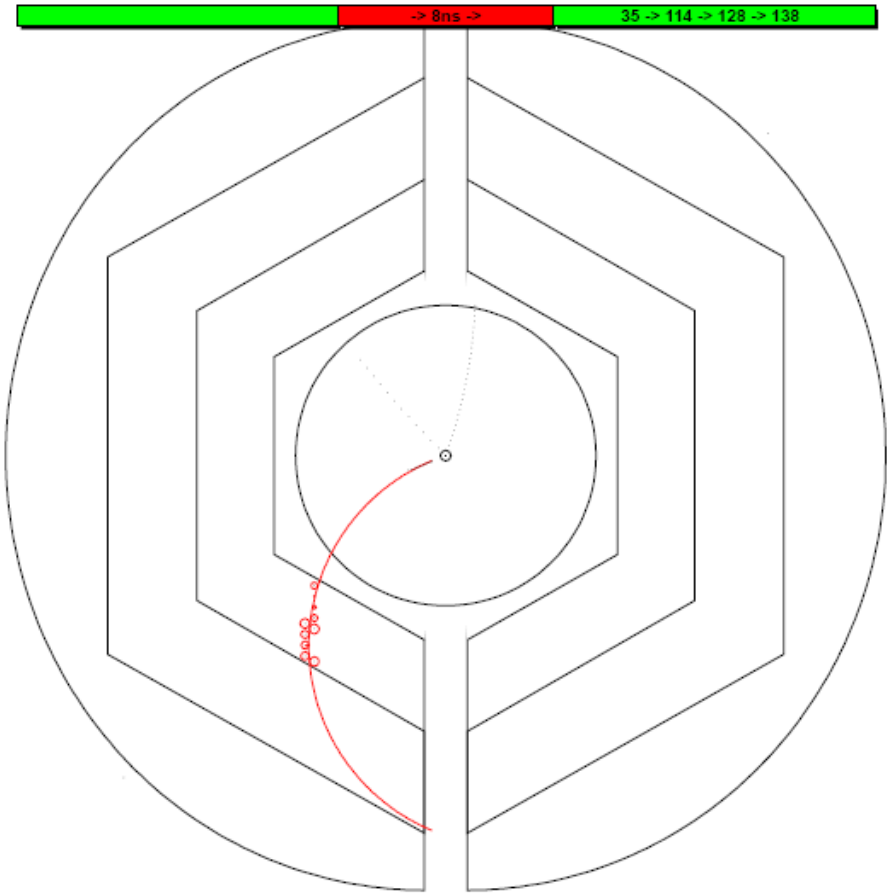




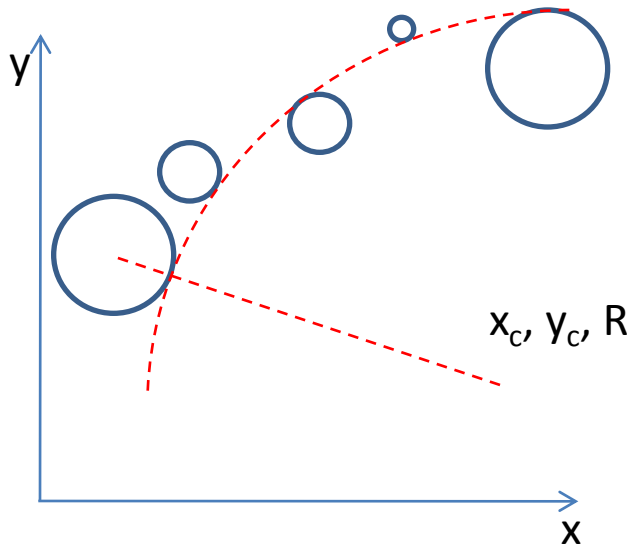


DPM background – Event # 1

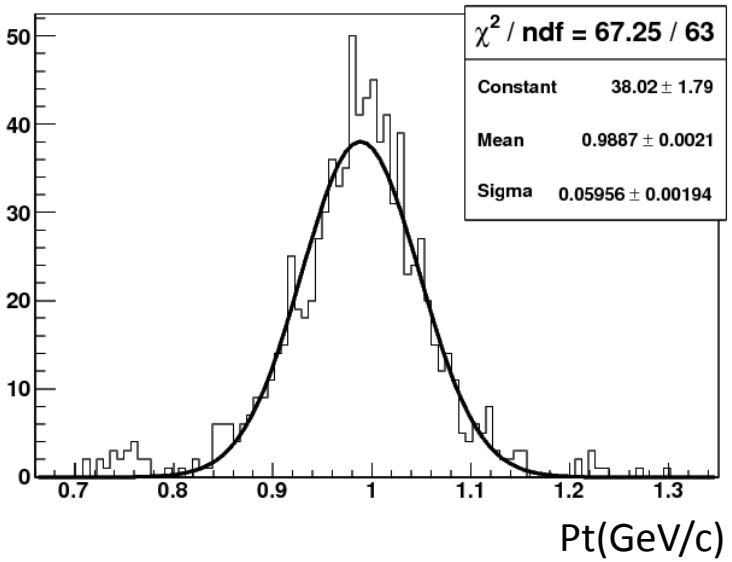


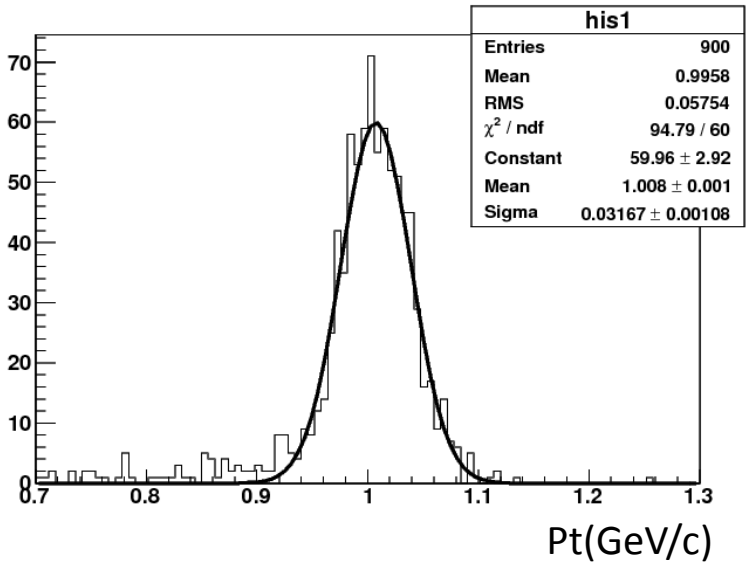


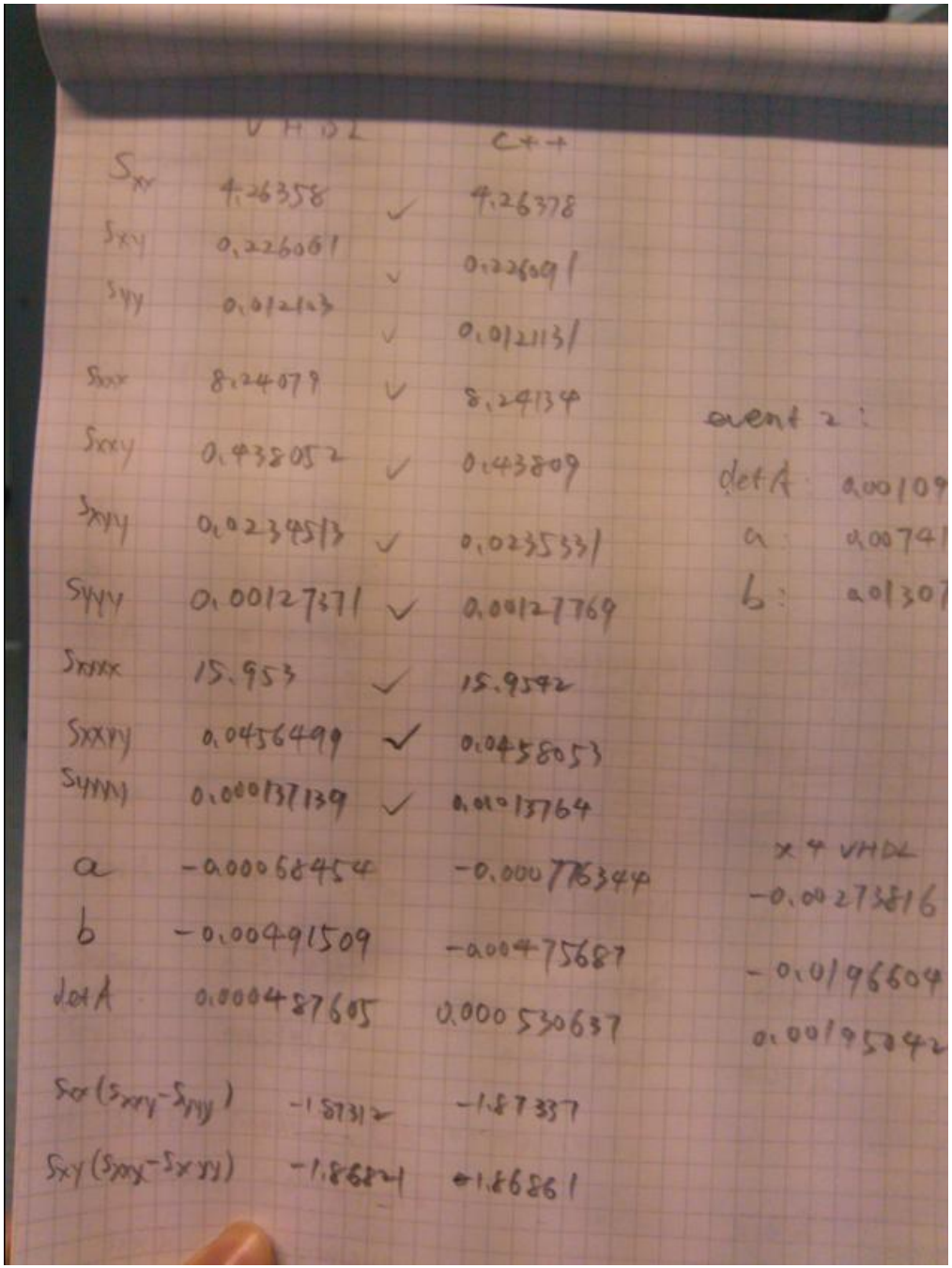
To improve the momentum resolution



0.2GeV/c :	0.195	±0.0068	0.195	±0.0068
0.5GeV/c :	0.5	±0.0212	0.5	± 0.0164
1.0GeV/c :	0.99	±0.0595	1.0	± 0.0317
2.0GeV/c :	1.85	±0.213	2.0	± 0.073







	VHDL		C++
S_{xx}	4.26358	✓	4.26378
S_{xy}	0.226061	✓	0.226091
S_{yy}	0.012103	✓	0.012113
S_{xxx}	8.24079	✓	8.24134
S_{xxy}	0.143852	✓	0.143809
S_{xyy}	0.0234513	✓	0.0235331
S_{yyy}	0.00127371	✓	0.00127769
S_{xxxx}	15.953	✓	15.9542
S_{xxxy}	0.0456499	✓	0.0458053
S_{xyyy}	0.000137139	✓	0.000137764
a	-0.00068454		-0.000776344
b	-0.00491509		-0.00475687
detA	0.000487605		0.000530637
$S_{xy}(S_{xxy}-S_{xyy})$	-1.87312		-1.87337
$S_{xy}(S_{xxx}-S_{xxy})$	-1.86824		-1.86861

event 2:

detA: 0.00109

a: 0.00741

b: 0.01307

x4 VHDL

-0.0027381

-0.0196604

0.0019542

2**(-16) = 0.00001526