Luminosity detector software

Background studies summary and Software alignment

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September 11, 2012

Outline

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Background studies with DPM

Strategy

- Generation of background with DPM:
  $0.0018 < \theta < 2\pi$ rad, $2 \cdot 10^7$ events
  P_{beam} 1.5, 4.06, 8.9, 11.91, 15 GeV/c
- Track reconstruction in the luminosity detector:
  $\bar{p}$ assumption
- Comparison reconstructed and MC information
  (for scattered $\bar{p}$ and bkg signal)

Without HIMster it wouldn't be possible!

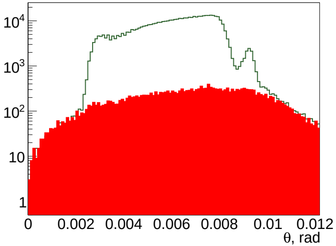
Background channels and particles

15 GeV/c

channel	ratio to $\bar{p}^{el}$, %
$p\bar{p}$	100
$p\bar{p}\pi^0$	0.8
$p\bar{p}\pi^-\pi^+$	0.63
$p\bar{p}\pi^-\pi^+\pi^0$	0.55
$n\bar{p}\pi^+\pi^0$	0.46
$n\bar{p}2\pi^+\pi^-\pi^0$	0.19
$n\bar{p}\pi^+2\pi^0$	0.12
$p\bar{p}\pi^-\pi^+\gamma$	0.06
$p\bar{p}\pi^-\pi^0 2\gamma$	0.05
$p\bar{p}\pi^-\pi^+3\pi^0$	0.04
...	
Total	3.72

particle	% of tracks
$\bar{p}$	103.4
π^-	0.17
e^+	0.11
e^-	0.1
π^+	0.01
K^-	0.008
p	0.007
K^+	0.0002

90.4% of bkg = $\bar{p}$ tracks



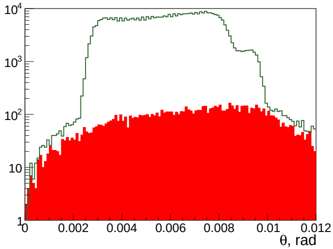
Background channels and particles

11.91 GeV/c

channel	ratio to $\bar{p}^{el}_{rec}$, %
$p\bar{p}$	100
$p\bar{p}\pi^0$	0.66
$p\bar{p}\pi^-\pi^+$	0.44
$n\bar{p}\pi^0\pi^+$	0.31
$p\bar{p}\pi^0\pi^-\pi^+$	0.29
$n\bar{p}\pi^0\pi^-2\pi^+$	0.08
$n\bar{p}2\pi^0\pi^+$	0.07
$p\bar{p}\pi^0 2\gamma$	0.03
$p\bar{p}\pi^+\pi^-\gamma$	0.02
$p\bar{p}\Lambda K^+\gamma$	0.02
...	
Total	2.36

particle	% of tracks
$\bar{p}$	102.12
π^-	0.13
e^-	0.07
e^+	0.06
π^+	0.01
p	0.008
K^-	0.003
K^+	0.0004
Σ^+	0.0001

89.6% of bkg = $\bar{p}$ tracks



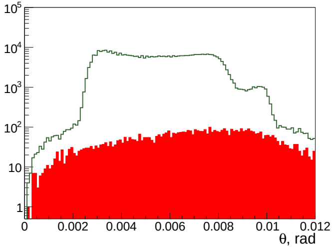
Background channels and particles

8.9 GeV/c

channel	ratio to $\bar{p}^{el}_{rec}$, %
$p\bar{p}$	100
$p\bar{p}\pi^0$	0.59
$p\bar{p}\pi^-\pi^+$	0.29
$n\bar{p}\pi^0\pi^+$	0.21
$p\bar{p}\pi^0\pi^-\pi^+$	0.12
$n\bar{p}2\pi^0\pi^+$	0.03
$n\bar{p}\pi^0\pi^-2\pi^+$	0.02
$\bar{p}\Lambda K^+$	0.02
$\bar{p}\Lambda K^+\gamma$	0.02
$p\bar{p}2\gamma$	0.01
$p\bar{p}\pi^0 K_L$	0.01
...	
Total	1.57

particle	% of tracks
$\bar{p}$	101.38
π^-	0.12
e^-	0.05
e^+	0.04
p	0.005
π^+	0.005
K^-	0.002

87.7% of bkg = $\bar{p}$ tracks



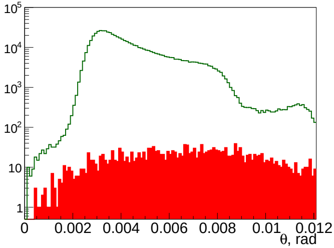
Background channels and particles

4.06 GeV/c

channel	ratio to $\bar{p}^{el}_{rec}$, %
$p\bar{p}$	100
$p\bar{p}\pi^0$	0.14
$2\pi^-2\pi^+$	0.04
$2\pi^-2\pi^+\pi^0$	0.03
$\pi^-\pi^+2\pi^0$	0.03
$\pi^-\pi^+\pi^0$	0.02
$2\pi^-2\pi^+2\pi^0$	0.02
$p\bar{p}\pi^-\pi^+$	0.01
$n\bar{p}\pi^0\pi^+$	0.009
$\pi^-\pi^+\pi^0 2\gamma$	0.005
$\pi^-\pi^+3\pi^0$	0.005
$2\pi^-2\pi^+\gamma$	0.005
$\pi^-\pi^+$	0.004
...	
Total	0.35

particle	% of tracks
$\bar{p}$	100.17
π^-	0.17
e^-	0.007
e^+	0.005
π^+	0.002
p	0.002
K^-	0.0002

49.8% of bkg = $\bar{p}$ tracks

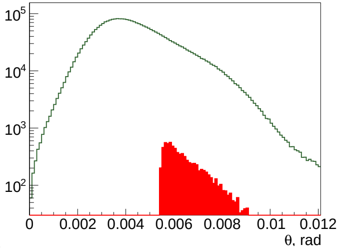


Background channels and particles
1.5 GeV/c

channel	ratio to $\bar{p}^{el}$,%
$p\bar{p}$	100
$\pi^+\pi^-\pi^0$	0.005
$\pi^+\pi^-2\pi^0$	0.003
$2\pi^+2\pi^-\pi^0$	0.003
$2\pi^+2\pi^-$	0.002
$\pi^+\pi^-$	0.001
$p\bar{p}\pi^0$	0.001
$p\bar{p}\pi^+\pi^-$	0.001
$2p\bar{p}\pi^-$	0.001
...	
Total	0.025

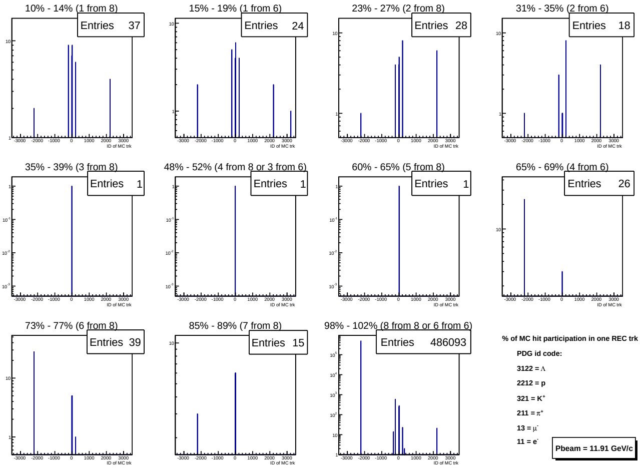
particle	% of tracks
$\bar{p}$	100.01
π^-	0.02
e^+	0.0002
e^-	0.0003
π^+	0.04
p	0.002

58.6% of bkg = $\bar{p}$ tracks



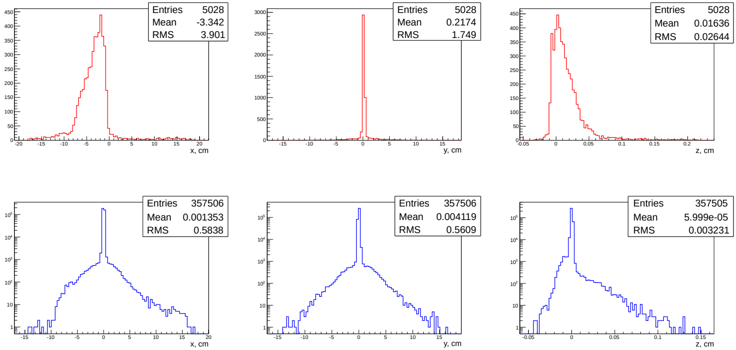
Bkg hits contribution to tracks

How background gives contribution to tracks?



Background suppression

How to distinguish background from signal?



Any cut for background cuts part of signal (and only ∼85% of bkg). Situation even worse for small P_{beam}

Possible solution: fit signal and bkg together

Kernel Density Estimation

Estimating a Signal In the Presence of an Unknown Background, W. Rolke and A. Lopez (Jan 2012)

"Non-parametric" density estimation

- $X_1, .., X_n$ – observations from some unknown density f.
- K – continuous, non-negative and symmetric function with $K(x) \rightarrow 0$ as $x \rightarrow \pm\infty$
  (Often K is chosen to be p.d. itself: Gaussian density)

$$\hat{f}_h(x) = \frac{1}{nh} \sum_{i=1}^{n} K\left(\frac{x - X_i}{h}\right)$$

- h – tuning parameter called bandwidth.
  (in regions where true density changes slowly h should be large than in regions where f changes rapidly)
  $\rightarrow$ adaptive bandwidth h_x

Semi-parametric fitting

Function for maximum likelihood

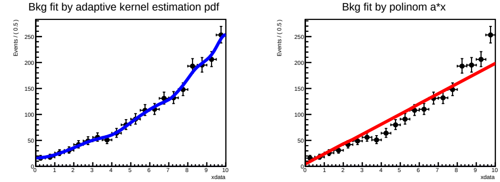
$f(x;\alpha,\theta) = (1-\alpha)f_B(x) + \alpha f_S(x;\theta)$

for $f_B(x)$ (estimation of bandwidth and density) one need pure sample of background events
:(

RooFit contains RooKeysPdf class:

A one-dimensional kernel estimation p.d.f which model the distribution of an arbitrary input dataset as a superposition of Gaussian kernels
:)

Example



Sig(x) = Landay(3.5, 1)⊗Gaus(0,0.1)

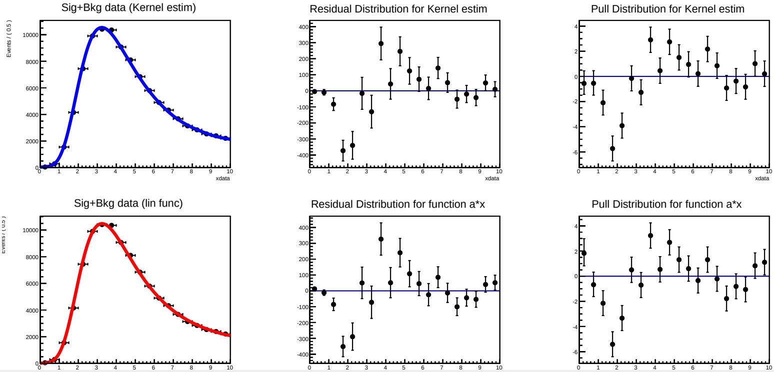
Bkg(x) = x+0.001x^2+0.01x^3

Data(x)= Sig(x) + Bkg(x)

sig/(sig+bkg)=0.95

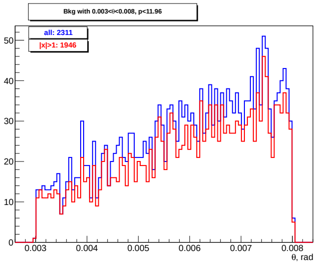
Kernel: 9.4966e-01± 2.35e-03 (<σ)

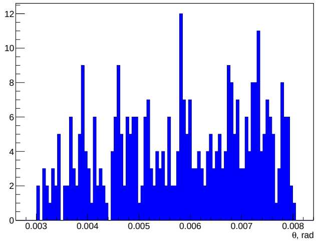
Lin:9.3780e-01± 2.84e-03 (4σ)



Sample of "pure" background

- Shape of background is not fixed (important for us, because it could differ for different P_{beam})
- But to fit it background sample is needed.





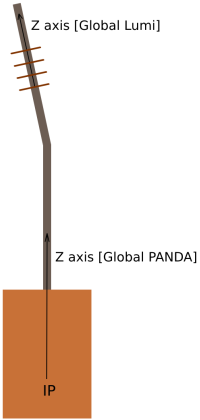
Seems small addition signal fraction to bkg sample doesn't change shape too much

Outline

Hit reconstruction

change in lmd hit reconstruction

Hits position (x,y,z) reconstruction from digital information

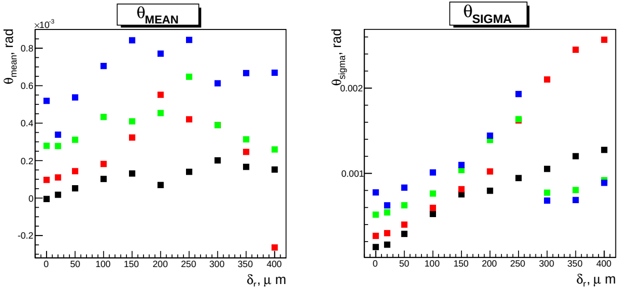


- sensor & strip number
- (x,y,z) local sensor frame
- Global PANDA frame
- Global Lumi frame

result of sensor alignment will be applied at this stage

Impact of sensors misalignment
on θ resolution

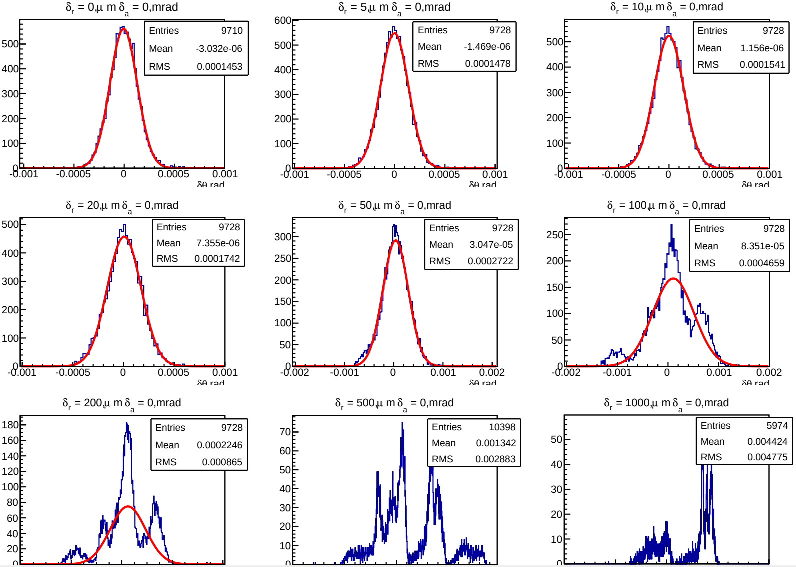
Each sensors has 6 d.o.f: 3 translation (δ_r) and 3 rotation (δ_α)
δ_r=0, 20, 50, 100, 150, 200, 250, 300, 350, 400 μm
δ_α=0, 3, 6, 9 mrad



P_{beam}=11.91 GeV/c: for $\delta_r \sim 100\ \mu m$ ($\delta_\alpha = 0$ mrad) θ resolution become 5 times worse!

Impact of misalignment

on θ resolution



Software alignment based

Minimizing the residuals (Iterative alignment)

- Fit a large number of tracks and plot the residuals for each sub-detector
- The mean value of each residual distribution should then be centered on the misalignment value
- Correct the sub-detector coordinates from this value
- Fit the track again, plot the residuals,...
  And so on until the residuals central values are stabilized at 0.

Iterations are based on biased track fit results
Then, even if the method converges, it could leads to biased misalignment values

Software alignment

Fitting the residuals (Alignment in one step)

two different types of fitted parameters:

- Related to the track properties determined by a fit. different for each tracks → LOCAL parameters
- Parameters which are depending on the detector position. Alignment parameters → GLOBAL parameters

To get a good accuracy significant number of tracks is needed
Size of the system equation: $n_{tot} = n_{loc} \cdot n_{tracks} + n_{gl}$

Example

10000 tracks with 4 parameters → 40000 equations!

Software alignment

How to deal with large matrix equation?

Millepede algorithm

- Matrix is divided on sub-matrices of dimensions $n_{loc} * n_{loc}$
- C++ implementation is done for LHCb VELO (Knossos)

Track parametrization

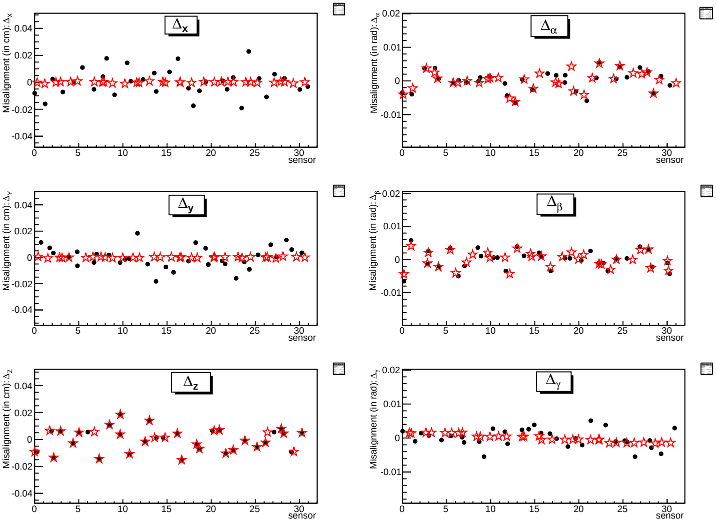
$$\begin{cases} x & = a \cdot z + b \\ y & = c \cdot z + d \end{cases}$$

Residuals parametrization

$$\begin{cases} \epsilon_x & = -\Delta_x + y_{hit} \cdot \Delta_\gamma + a \cdot (\Delta_z + x_{hit} \cdot \Delta_\beta + y_{hit} \cdot \Delta_\alpha) \\ \epsilon_y & = -\Delta_y - x_{hit} \cdot \Delta_\gamma + c \cdot (\Delta_z + x_{hit} \cdot \Delta_\beta + y_{hit} \cdot \Delta_\alpha) \end{cases}$$

3 translations (Δ_x,Δ_y,Δ_z) and 3 rotation (Δ_α,Δ_β,Δ_γ) around x, y, z

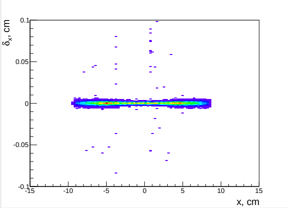
Alignment constants

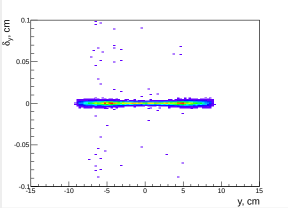


Alignment Results

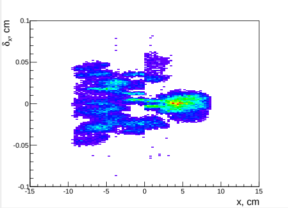
Residuals between reconstructed hit and track

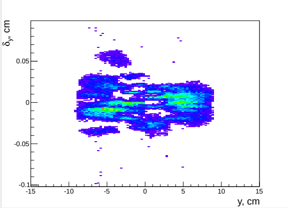
Ideal case





Misaligned sensors

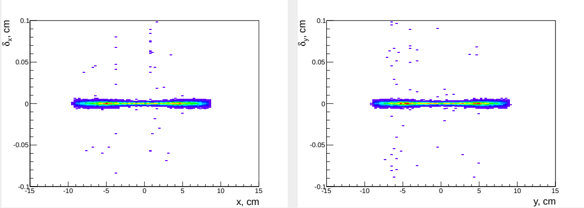




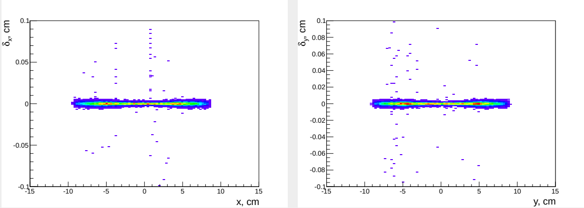
Alignment Results

Residuals between reconstructed hit and track

Ideal case

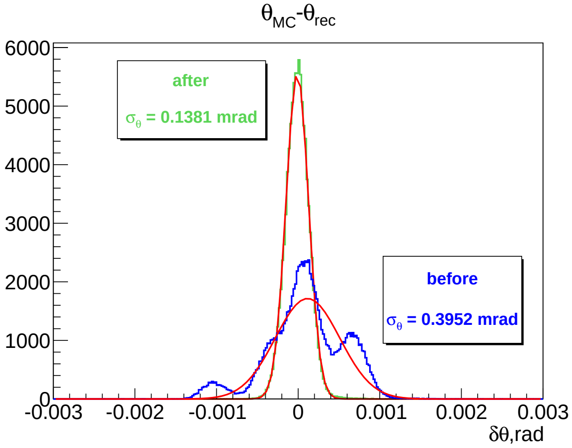


Misaligned sensors



Sensors alignment for translation

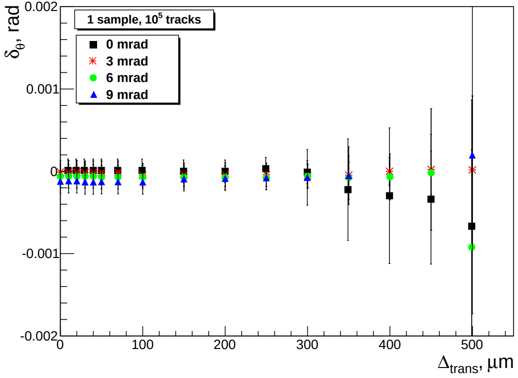
misalignment $\sim 100\mu m$



Without sensors misalignment resolution 0.1361 mrad

Sensors alignment

sensitivity to misalignment scale (11.91 GeV/c)



Limits

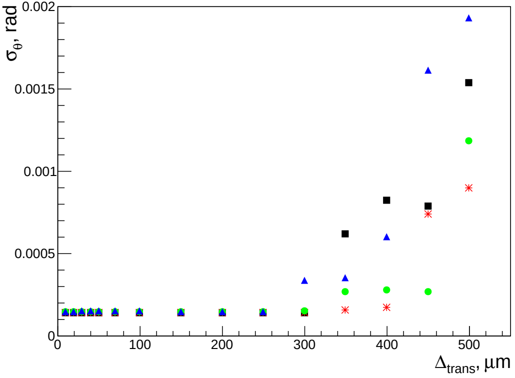
translation 300 μm
rotation 6 mrad

Expectation from mechanical point

translation 200 μm
rotation 3 mrad

Sensors alignment

sensitivity to misalignment scale (11.91 GeV/c)



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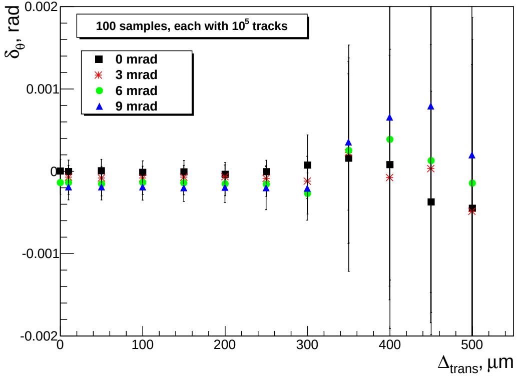
Sensors alignment

sensitivity to misalignment scale (11.91 GeV/c)



Limits

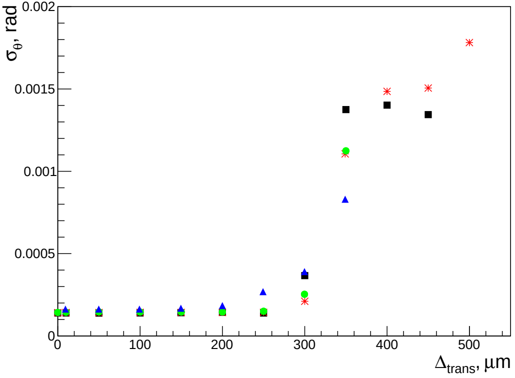
translation 300 μm
rotation 6 mrad

Expectation from mechanical point

translation 200 μm
rotation 3 mrad

Sensors alignment

sensitivity to misalignment scale (11.91 GeV/c)



Limits

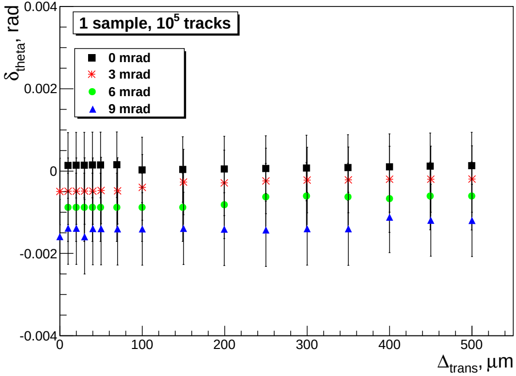
translation 300 μm
rotation 6 mrad

Expectation from mechanical point

translation 200 μm
rotation 3 mrad

Sensors alignment

sensitivity to misalignment scale (1.5 GeV/c)



Limits

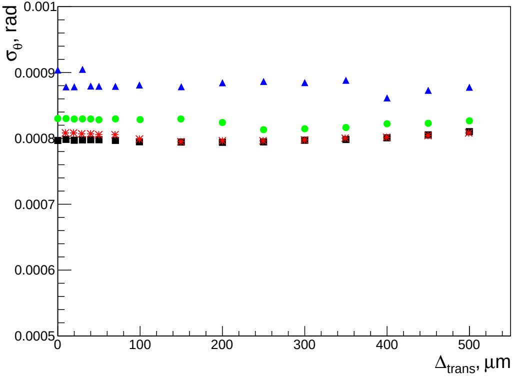
translation $\geq 500\ \mu m$
rotation 3 mrad

Expectation from mechanical point

translation $200\ \mu m$
rotation 3 mrad

Sensors alignment

sensitivity to misalignment scale (1.5 GeV/c)



Limits

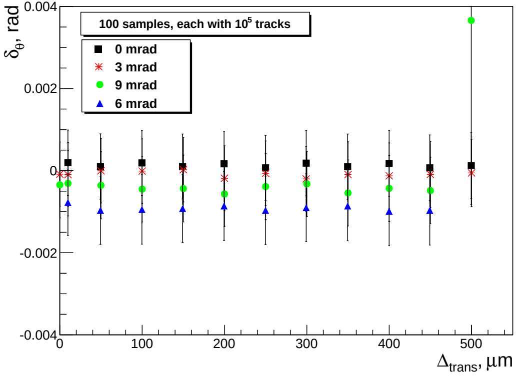
translation $\geq$ 500 μm
rotation 3 mrad

Expectation from mechanical point

translation 200 μm
rotation 3 mrad

Sensors alignment

sensitivity to misalignment scale (1.5 GeV/c)



Limits

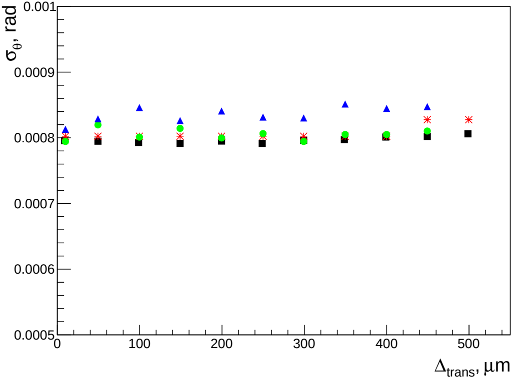
translation $\geq 500\ \mu m$
rotation 3 mrad

Expectation from mechanical point

translation $200\ \mu m$
rotation 3 mrad

Sensors alignment

sensitivity to misalignment scale (1.5 GeV/c)



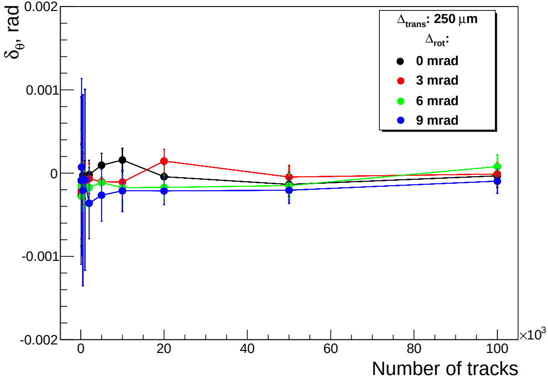
Limits

translation $\geq$ 500 μm
rotation 3 mrad

Expectation from mechanical point

translation 200 μm
rotation 3 mrad

Effect of track statistics



Number of required tracks strongly depends on mechanical precision

Results

- Simulation on HIMster: DPM (θ_{min}=0.1), $2 \cdot 10^7$ events, lumi + beam pipe,full reconstruction
  P_{beam}=15, 11.91, 8.9 GeV/c, 4.06 and 1.5 GeV/c
- Main background particle for high energy is $\bar{p}$ from different channels!
- Amount of background is less then 5%
- Kernel Density Estimation = future background description?
- Preliminary results for software alignment based on fitting the residuals:
  works up to 300 μm for translation, 6 mrad for rotation. (11.91 GeV/c)

Background channels and particles

15 GeV/c

channel $p\bar{p}$	# of tracks 511285	ratio to $\bar{p}^{rec}$, % 100	particles $\bar{p}(511285)$
$p\bar{p}\pi^0$	4080	0.8	$\bar{p}(3949)$, $\pi^-(131)$
$p\bar{p}\pi^-\pi^+$	3234	0.63	$\bar{p}(3073)$, $\pi^-(152)$, $\pi^+(9)$
$p\bar{p}\pi^-\pi^+\pi^0$	2804	0.55	$\bar{p}(2708)$, $\pi^-(96)$
$n\bar{p}\pi^+\pi^0$	2359	0.46	$\bar{p}(2216)$, $\pi^-(140)$, $\pi^+(3)$
$n\bar{p}2\pi^+\pi^-\pi^0$	982	0.19	$\bar{p}(958)$, $\pi^-(23)$, $\pi^+(1)$
$n\bar{p}\pi^+2\pi^0$	613	0.12	$\bar{p}(581)$, $\pi^-(31)$, $\pi^+(1)$
$p\bar{p}\pi^-\pi^+\gamma$	289	0.06	$\bar{p}(280)$, $\pi^-(8)$, $\pi^+(1)$
$p\bar{p}\pi^-\pi^0 2\gamma$	232	0.05	$\bar{p}(215)$, $\pi^-(2)$, $e^+(8)$, $e^-(6)$
$p\bar{p}\pi^-\pi^+3\pi^0$	205	0.04	$\bar{p}(200)$, $\pi^-(4)$, $e^-(1)$
$p\bar{p}2\pi^-2\pi^+\pi^0$	182	0.04	$\bar{p}(178)$, $\pi^-(4)$
...			
Total	19000	3.72	

particle	# of tracks
$\bar{p}$	528452
π^-	864
e^+	569
e^-	524
π^+	72
K^-	40
p	37
K^+	1

17167 $\bar{p}$ come from bkg channels (90.4% of bkg)

Background channels and particles

11.91 GeV/c

channel	# of tracks	ratio to $\bar{p}^{rec}$, %	particles
$p\bar{p}$	474902	100	$\bar{p}$(474902)
$p\bar{p}\pi^0$	3155	0.66	$\bar{p}$(3058), π^-(93)
$p\bar{p}\pi^-\pi^+$	2084	0.44	$\bar{p}$(1987), π^-(87)
$n\bar{p}\pi^0\pi^+$	1462	0.31	$\bar{p}$(1386), π^-(72)
$p\bar{p}\pi^0\pi^-\pi^+$	1392	0.29	$\bar{p}$(1351), π^-(41)
$n\bar{p}\pi^0\pi^-2\pi^+$	358	0.08	$\bar{p}$(343), π^-(15)
$n\bar{p}2\pi^0\pi^+$	311	0.07	$\bar{p}$(295), π^-(16)
$p\bar{p}\pi^0 2\gamma$	119	0.03	$\bar{p}$(107), e^-(7), e^+(5)
$p\bar{p}\pi^+\pi^-\gamma$	116	0.02	$\bar{p}$(113), π^-(3)
$p\bar{p}\Lambda K^+\gamma$	112	0.02	$\bar{p}$(110), K^-(2)
$p\bar{p}2\gamma$	111	0.02	$\bar{p}$(111)
Total	11191	2.36	

particle	# of tracks
$\bar{p}$	484978
π^-	609
e^-	317
e^+	280
π^+	50
p	37
K^-	14
K^+	2
Σ^+	1

10022 $\bar{p}$ come from bkg channels (89.6% of bkg)

Background channels and particles

8.9 GeV/c

channel $p\bar{p}$	# of tracks 384225	ratio to $\bar{p}^{rec}$, % 100	particles $\bar{p}(384225)$
$p\bar{p}\pi^0$	2281	0.59	$\bar{p}(2205)$, $\pi^-(75)$, $\pi^+(1)$
$p\bar{p}\pi^-\pi^+$	1097	0.29	$\bar{p}(1066)$, $\pi^-(30)$, $\pi^+(1)$
$n\bar{p}\pi^0\pi^+$	806	0.21	$\bar{p}(775)$, $\pi^-(29)$, $\pi^+(2)$
$p\bar{p}\pi^0\pi^-\pi^+$	465	0.12	$\bar{p}(456)$, $\pi^-(9)$
$n\bar{p}2\pi^0\pi^+$	126	0.03	$\bar{p}(126)$, $\pi^-(5)$
$n\bar{p}\pi^0\pi^-2\pi^+$	96	0.02	$\bar{p}(95)$, $\pi^-(1)$
$\bar{p}\Lambda K^+$	65	0.02	$\bar{p}(64)$, $K^-(1)$
$\bar{p}\Lambda K^+\gamma$	63	0.02	$\bar{p}(62)$, $K^-(1)$
$p\bar{p}2\gamma$	48	0.01	$\bar{p}(48)$
$p\bar{p}\pi^0 K_L$	48	0.01	$\bar{p}(48)$
Total	6046	1.57	

particle	# of tracks
$\bar{p}$	389526
π^-	466
e^-	197
e^+	153
p	20
π^+	19
K^-	8

5301 $\bar{p}$ come from bkg channels (87.7% of bkg)

Background channels and particles

4.06 GeV/c

channel	# of tracks	ratio to $\bar{p}^{rec}$, %	particles
$p\bar{p}$	615808	100	$\bar{p}(615808)$
$p\bar{p}\pi^0$	847	0.14	$\bar{p}(838)$, $\pi^-(8)$, $p(1)$
$2\pi^-2\pi^+$	230	0.04	$\pi^-(230)$
$2\pi^-2\pi^+\pi^0$	180	0.03	$\pi^-(179)$, $\pi^+(1)$
$\pi^-\pi^+2\pi^0$	171	0.03	$\pi^-(171)$
$\pi^-\pi^+\pi^0$	130	0.02	$\pi^-(127)$, $\pi^+(3)$
$2\pi^-2\pi^+2\pi^0$	87	0.02	$\pi^-(86)$, $\pi^+(1)$
$p\bar{p}\pi^-\pi^+$	79	0.01	$\bar{p}(76)$, $p(1)$, $\pi^-(1)$, $\pi^+(1)$
$n\bar{p}\pi^0\pi^+$	58	0.009	$\bar{p}(58)$
$\pi^-\pi^+\pi^02\gamma$	32	0.005	$\pi^-(31)$, $\pi^+(1)$
$\pi^-\pi^+3\pi^0$	29	0.005	$\pi^-(29)$
$2\pi^-2\pi^+\gamma$	29	0.005	$\pi^-(29)$
$\pi^-\pi^+$	22	0.004	$\pi^-(22)$
...			
Total	2158	0.35	

1075 $\bar{p}$ come from bkg channels (49.8% of bkg)

particle	# of tracks
$\bar{p}$	616883
π^-	1059
e^-	42
e^+	33
π^+	14
p	12

HEY!

What's going on with data stat (pbarp number of tracks should increase with decreasing of energy!)

Background channels and particles

1.5 GeV/c

channel	# of tracks	ratio to $\bar{p}^{rec}$, %	particles
$p\bar{p}$	2.86707e+06	100	$\bar{p}$(2.86707e+06)
$\pi^+\pi^-$	31	0.001	π^-(29), π^+(2)
$\pi^+\pi^-\pi^0$	141	0.005	π^-(137), π^+(4)
$\pi^+\pi^-2\pi^0$	81	0.003	π^-(78), π^+(3)
$2\pi^+2\pi^-$	53	0.002	π^-(53)
$2\pi^+2\pi^-\pi^0$	73	0.003	π^-(68), π^+(5)
$p\bar{p}\pi^0$	31	0.001	$\bar{p}$(30), π^+(1)
$p\bar{p}\pi^+\pi^-$	35	0.001	$\bar{p}$(6), π^-(15), π^+(14)
$2p\bar{p}\pi^-$	81	0.001	$\bar{p}$(15), p(42), π^-(24)
...			
Total	717	0.025	

particle	# of tracks
$\bar{p}$	2.86749e+06
π^-	522
e^+	5
e^-	9
π^+	53
p	81

420 $\bar{p}$ come from bkg channels (58.6% of bkg)