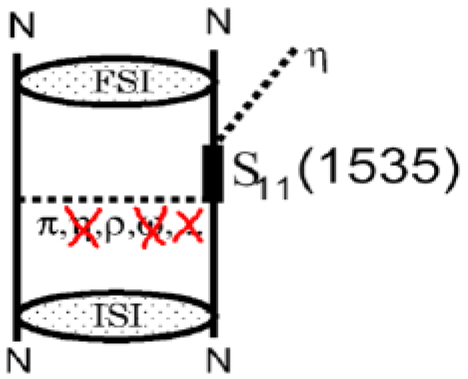
Study of the η meson production with the polarized proton beam

Iryna Schätti-Ozerianska
Institute of Physics, Jagiellonian University
Krakow, Poland

Motivation

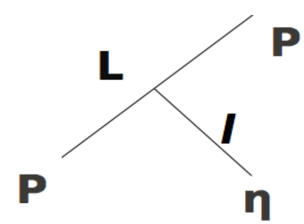
dynamics of the η meson production in pp->ppη



CELSIUS
COSY
SATURNE

interaction of the η meson with nucleons

- analyzing power:
  - $A_y \sim \mathrm{Im}\{A_{Ss}A_{Sd}^*\}\sin\theta_\eta\cos\theta_\eta$
  - $A_y \sim \mathrm{Im}\{A_{ps}A_{Pp}^*\}\sin\theta_\eta$

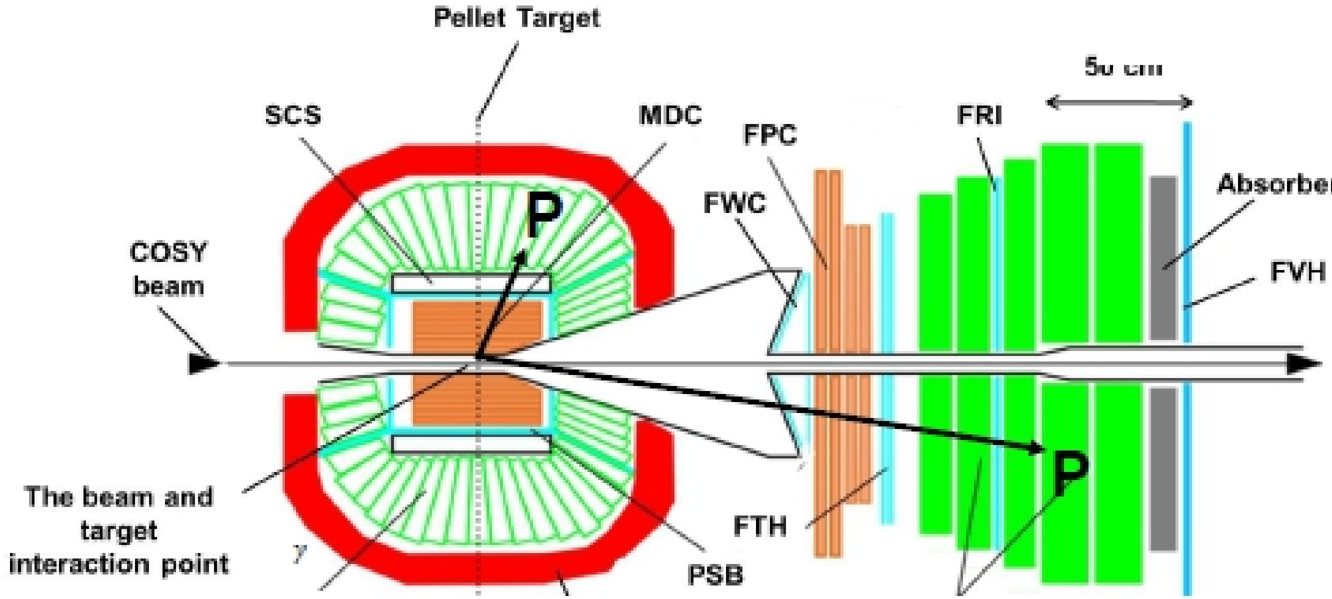


L:	0	1	2	...
Wave:	S	P	D	...
l:	0	1	2	...
Wave:	s	p	d	...

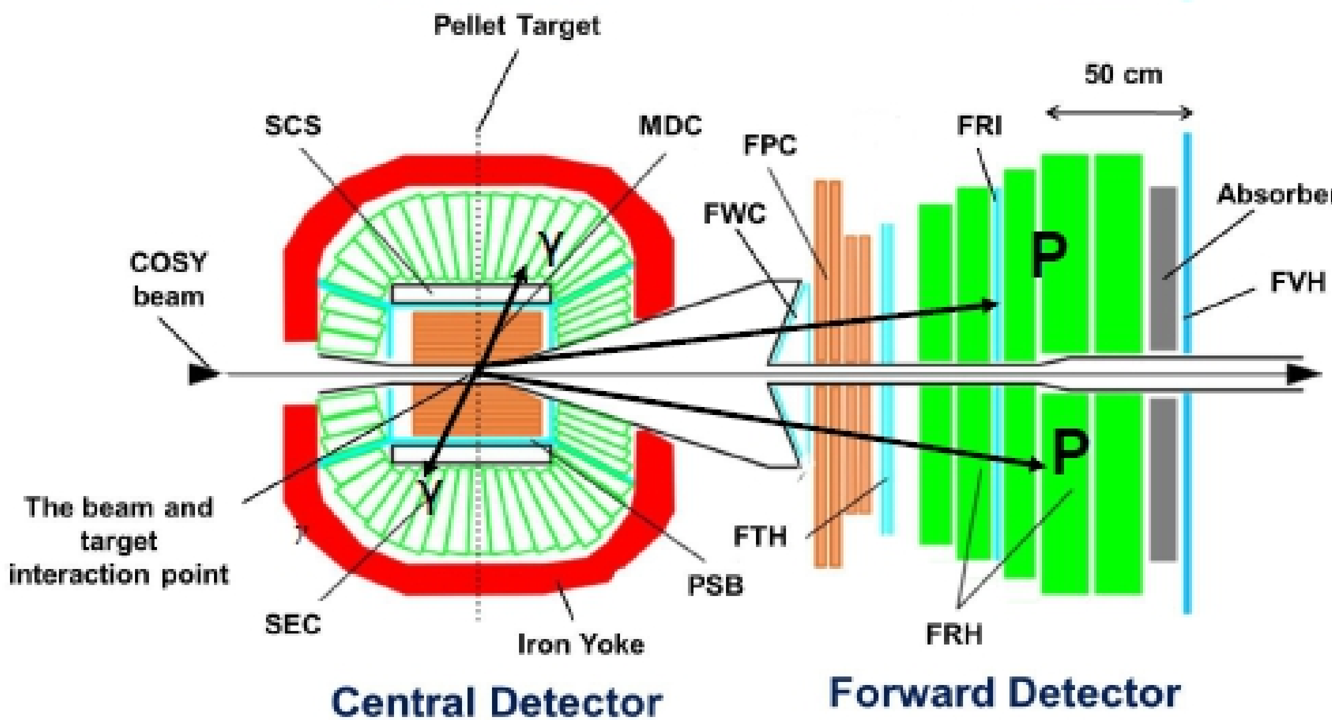
Our aim is to measure angular dependence of the analyzing power

$$\sigma(\theta,\varphi) = \sigma_0(\theta,\varphi)\left(1 + \sum_{i=1}^{3} P_i A_i(\theta,\varphi)\right)$$

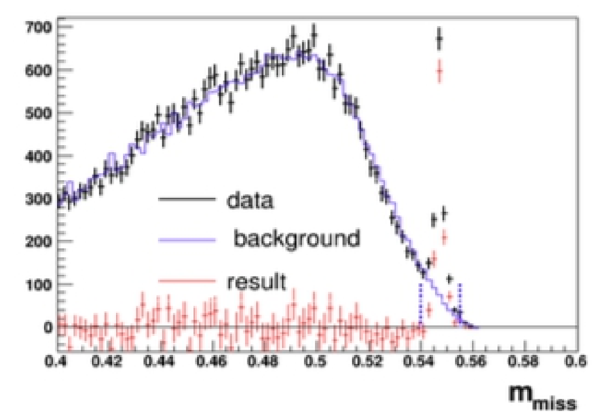
WASA Detector

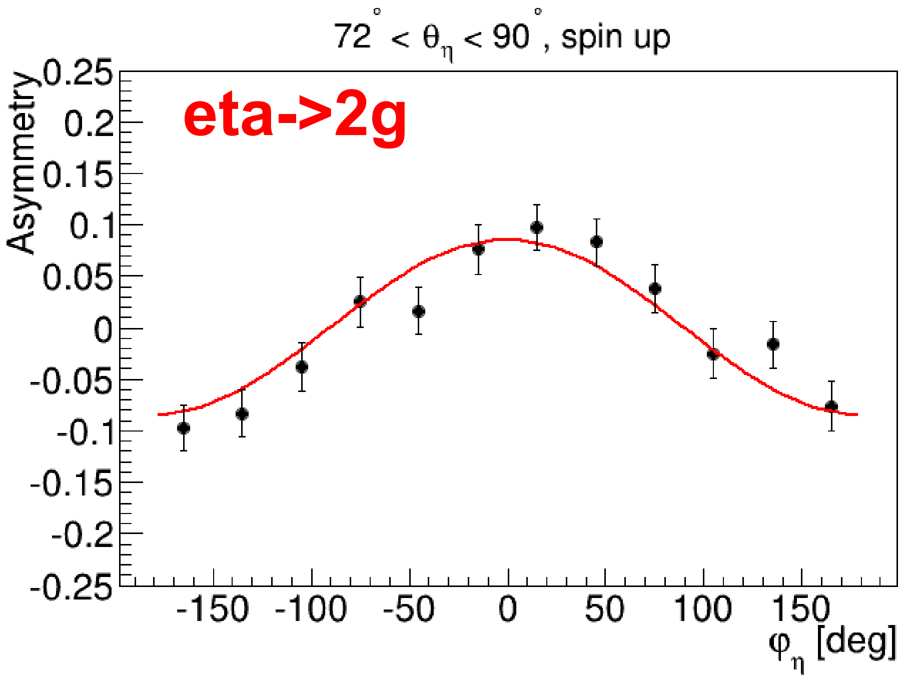


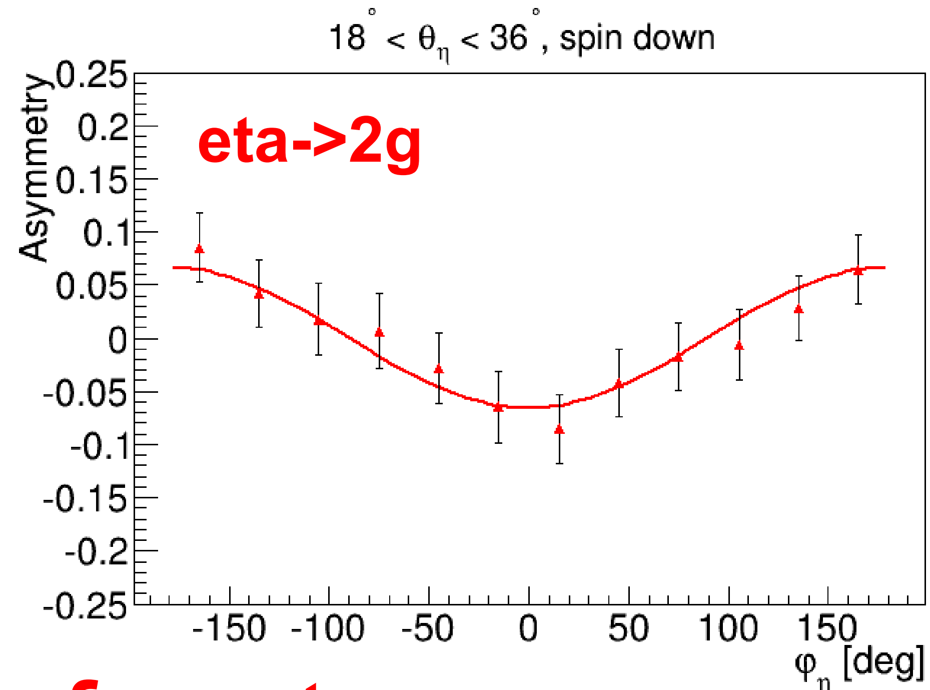
Based on the pp->pp reaction, polarization were defined



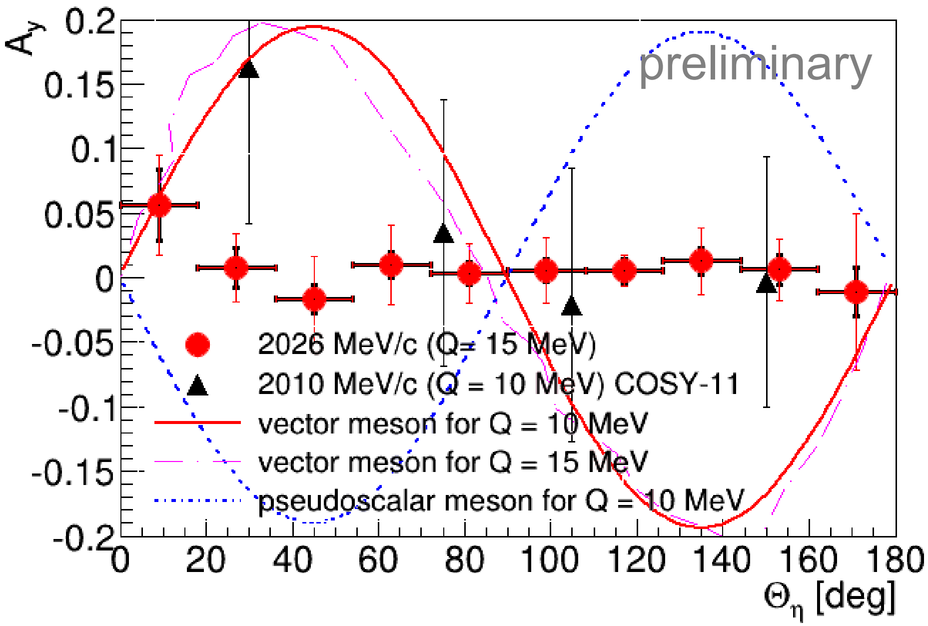
Analyzing power for the eta meson

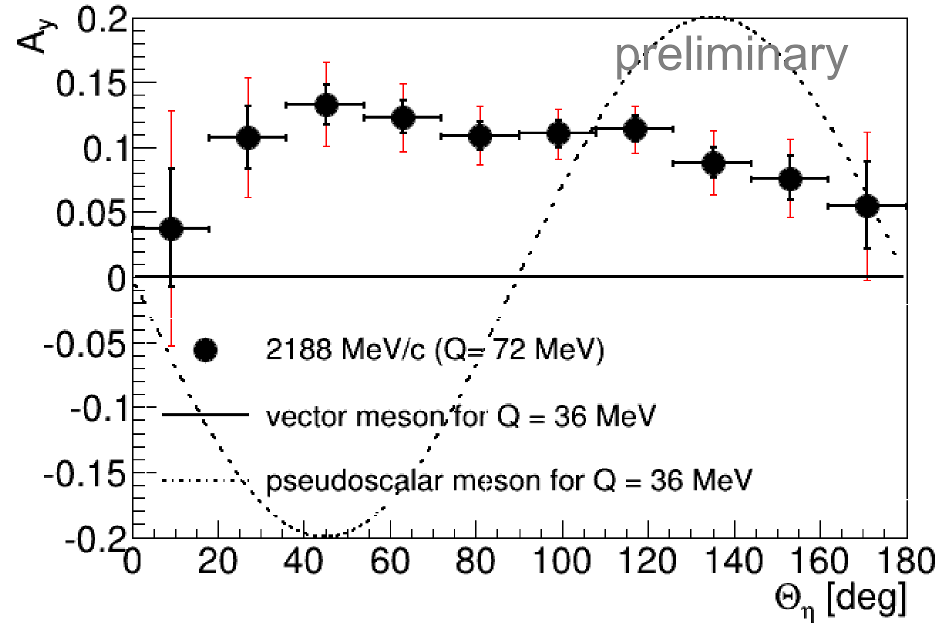






Analyzing power for eta meson



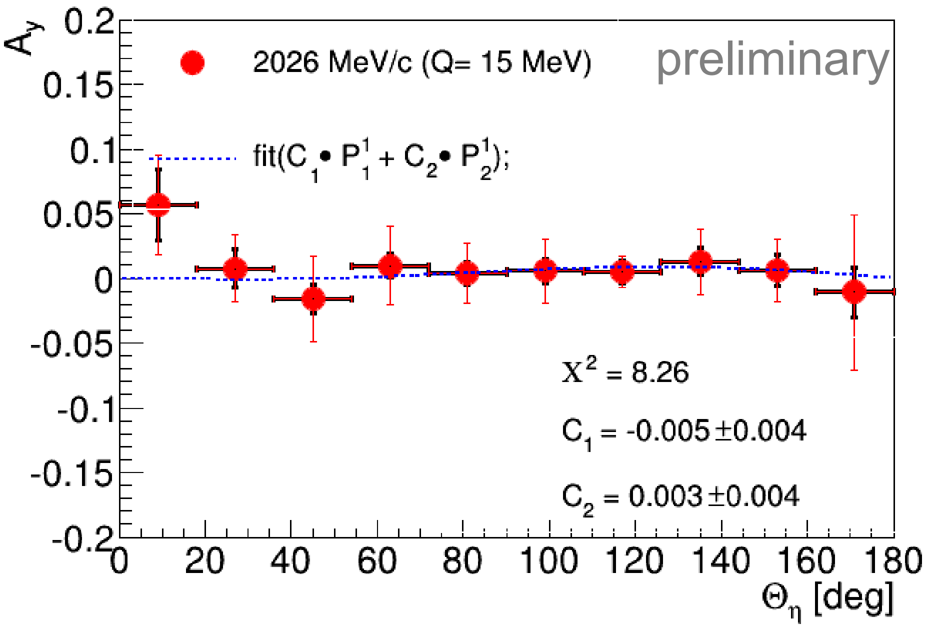


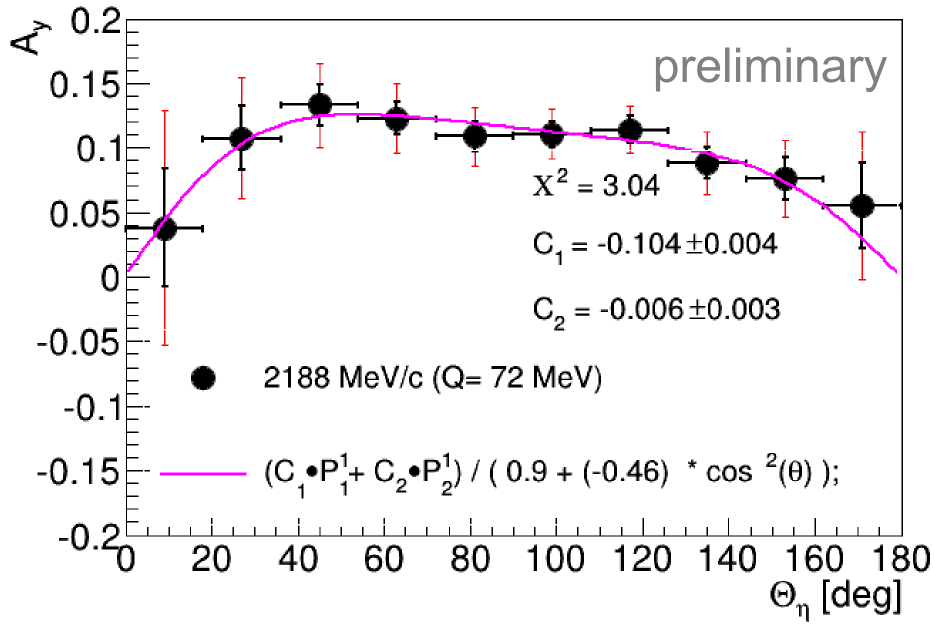
K. Nakayama et al. Phys. Rev., C65:045210, 2002.
G. Fäldt and C. Wilkin. Phys. Scripta, 64:427, 2001.
K. Nakayama et al. Phys. Rev., C68:045201, 2003.

Associated Legendre polynomials

$$A_N = \frac{\Im(A_{Ps}A_{Pp})sin\theta + \Im(A_{Ss}A_{Sd})3cos\theta_\eta \sin\theta_\eta}{\frac{d\sigma}{d\Omega}}$$

- analyzing power:
  - $A_y \sim$ Im $\{A_{ss}A_{Sd}{}^*\}$ $\sin\theta_\eta\cos\theta_\eta$ → C2
  - $A_y \sim$ Im $\{A_{ps}A_{Pp}{}^*\}$ $\sin\theta_\eta$ → C1





The analyzing power is zero for the beam momentum 2026 MeV/c.

For the beam momentum 2188 MeV/c there is enough excess energy available to produce not only s waves but also p waves, and indeed a strong interference between Ps and Pp partial waves was observed.

Thank You for Attention:)

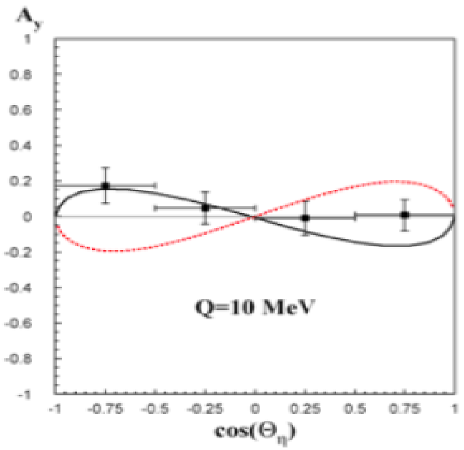
η meson production in pp collisions

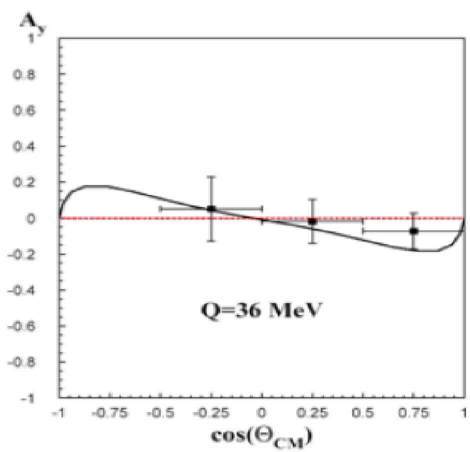
dynamics of the η meson production in pp->ppη

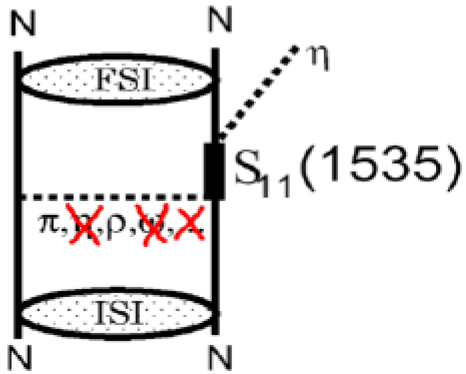
CELSIUS
COSY
SATURNE

COSY-11

R.Czyżykiewicz et al., Phys.Rev.Lett. **98**, 122003 (2007)





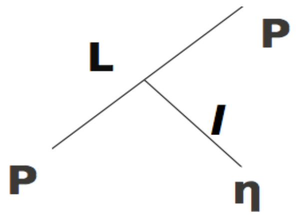


Compare with previous Experiment (reconstructed Eta=2000 events)

K. Nakayama et al., Phys. Rev. C 65 (2002) 045210 pseudoscala

G. F¨aldt and C. Wilkin, Phys. Scripta 64 (2001) 427 vector meso

Partial Wave Analysis



L:	0	1	2	...
Wave:	S	P	D	...

l:	0	1	2	...
Wave:	s	p	d	...

interaction of the η meson with nucleons

- the lowest partial wave decomposition (S,P and s,p waves)

- few possibilities: Ss, Ps, Sp, Pp, Sd, ...

- two groups:
    - odd angular momentum (Pp, Ps,...)
    - even angular momentum (Ss, Sd, ..)

- analyzing power:
    - $A_y \sim \mathrm{Im}\,\{A_{Ss}A_{Sd}^*\}\sin\theta_\eta\cos\theta_\eta$
    - $A_y \sim \mathrm{Im}\,\{A_{ps}A_{Pp}^*\}\sin\theta_\eta$

Our aim is to measure angular dependence of the analyzing power

Analyzing Power

$$\sigma(\theta,\varphi) = \sigma_0(\theta,\varphi)(1 + \sum_{i=1}^{3} P_i A_i(\theta,\varphi))$$ ⟸ **$P \neq 0$**

$\sigma(\theta,\varphi)$ Differential cross section with polarisation
$\sigma_0(\theta,\varphi)$ Differential cross section without polarisation

$$\sigma(\theta,\varphi) = \sigma_0(\theta,\varphi)$$ ⟸ **$P = 0$**

- Vector A_y analyzing power may be understood as a measure of the relative deviation between the differential cross section for the experiments with and without polarized beam.

Analysis steps (WASA@COSY)

1 For $\vec{p}p$ -> pp: we know A_y (EDDA)

we calculate Polarization P

2 For $\vec{p}p$ ->ppη:

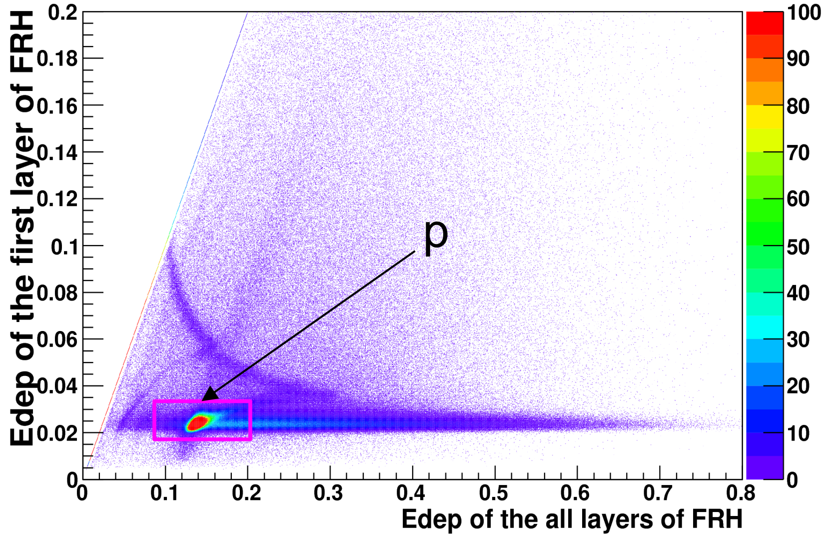
we calculate A_y

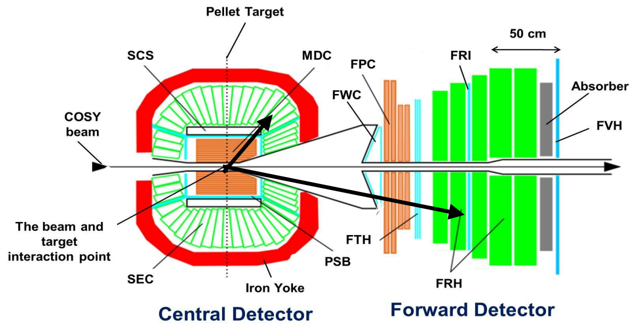
Q [MeV/c]	P [MeV/c]
15	2026
72	2188

$$A_y(\theta) \equiv \frac{1}{P cos\varphi} \cdot \frac{N(\theta,\varphi) - N(\theta,\varphi+\pi)}{N(\theta,\varphi) + N(\theta,\varphi+\pi)}.$$

Determination of the Elastic scattering

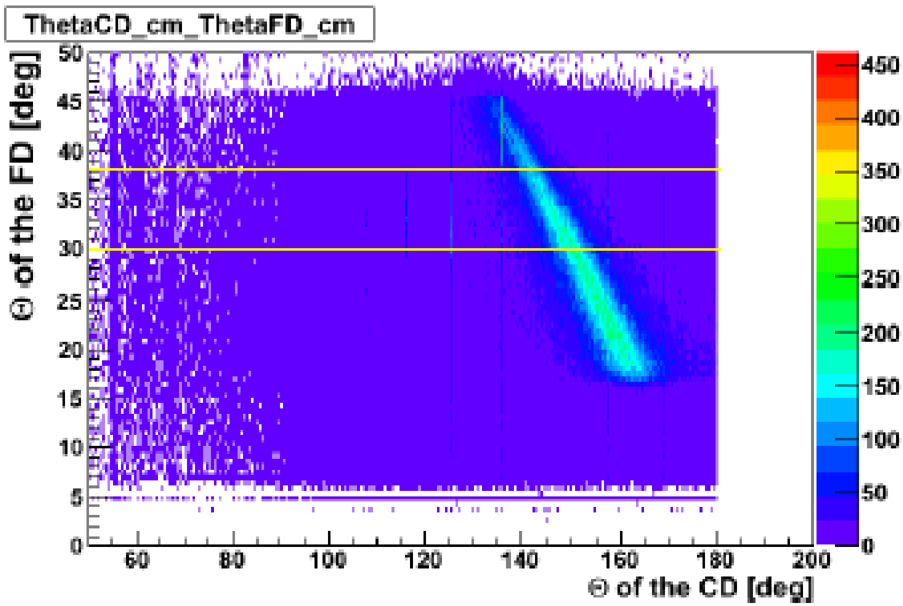
FD: - one charge particle

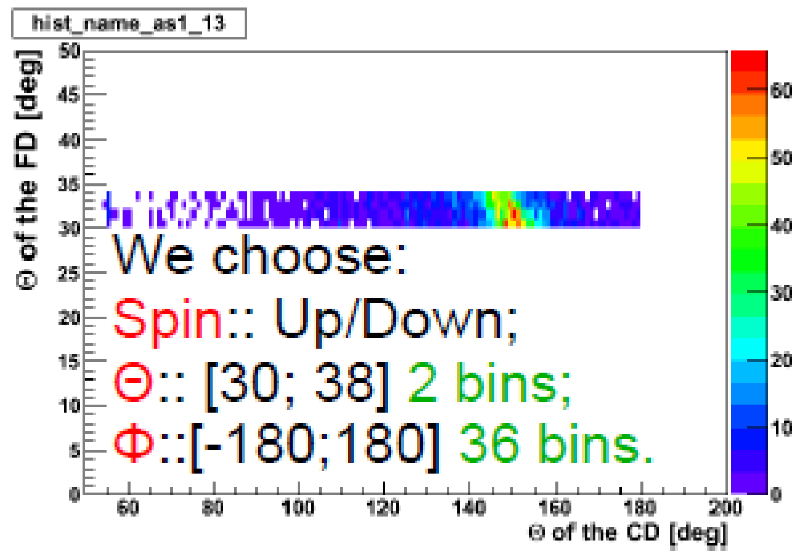




CD: - one charge particle

Determination of the *pp* elastic scattering



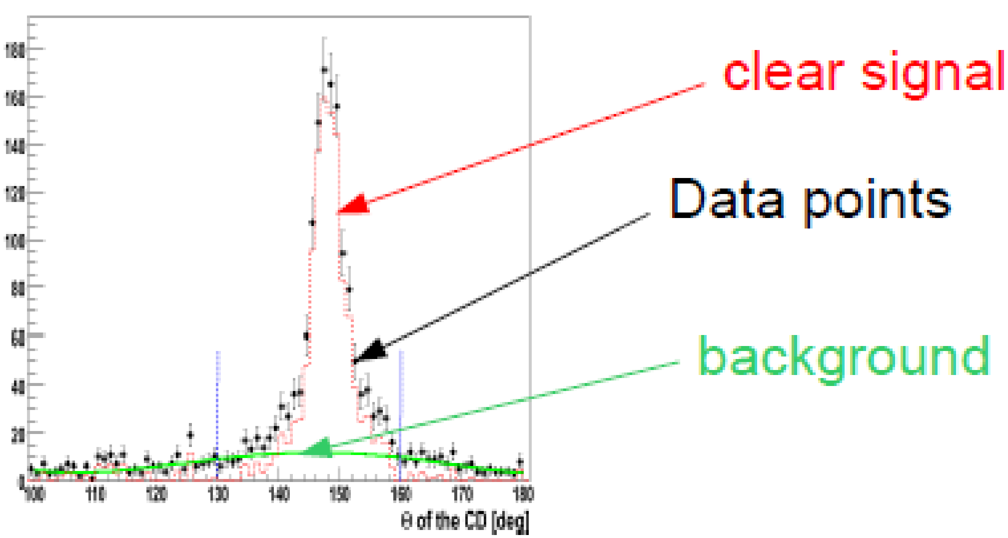


We choose:

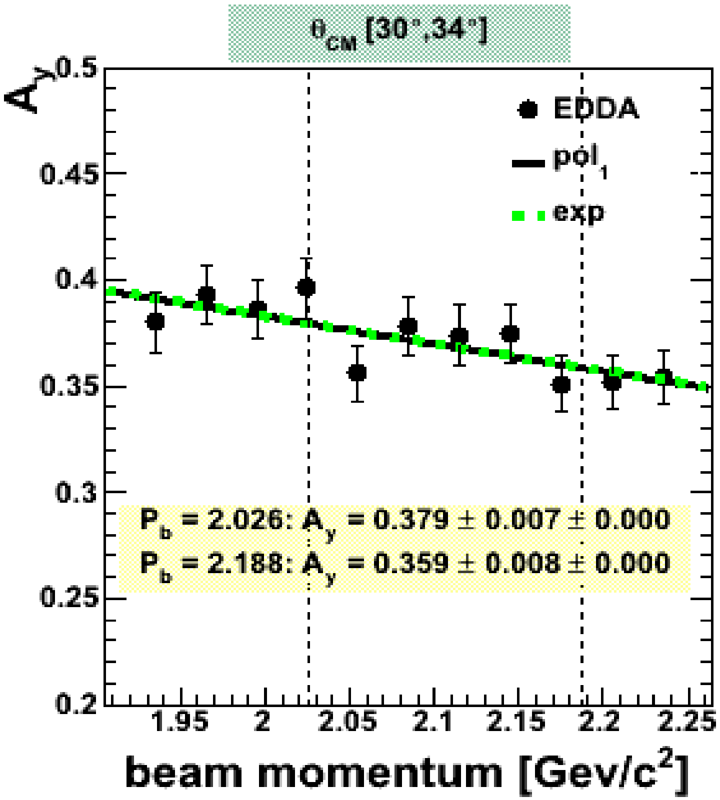
Spin:: Up/Down;

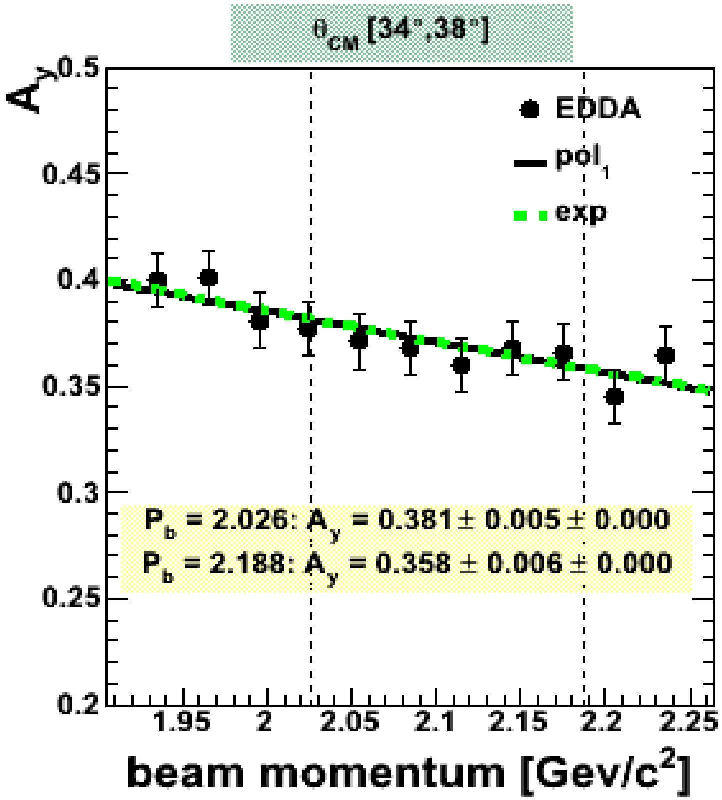
Θ:: [30; 38] 2 bins;

Φ::[-180;180] 36 bins.



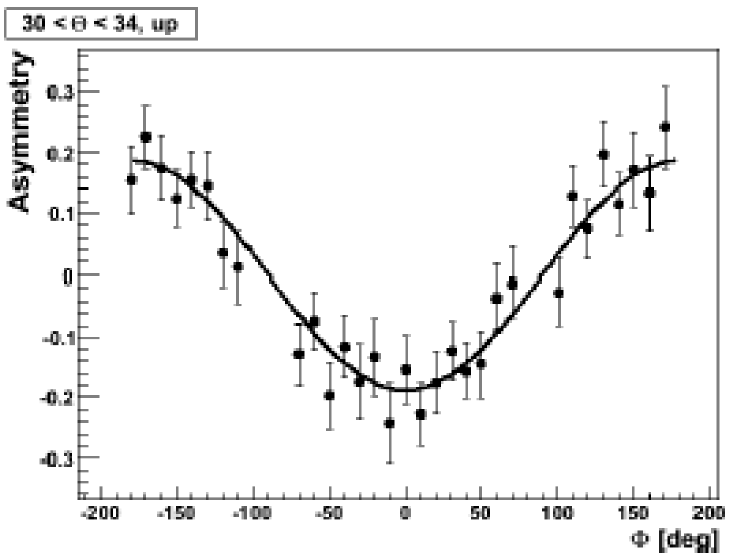
A_y from EDDA

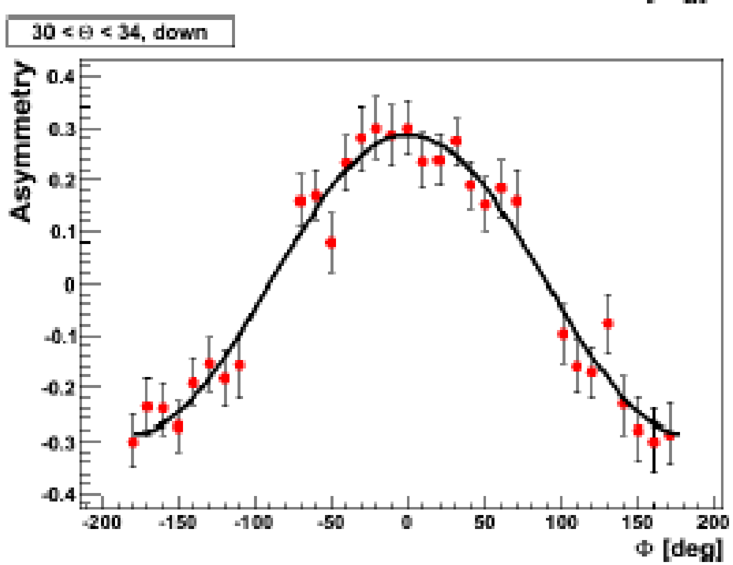




$\theta_{CM}[°]$	A_y	
	$p_{beam} = 2.026\,\mathrm{GeV}/c^2$	$p_{beam} = 2.188\,\mathrm{GeV}/c^2$
[30,34]	$0.380 \pm 0.007_{stat} \pm 0.002_{syst}$	$0.358 \pm 0.007_{stat} \pm 0.001_{syst}$
(34,38]	$0.382 \pm 0.004_{stat} \pm 0.001_{syst}$	$0.358 \pm 0.005_{stat} \pm 0.002_{syst}$
(38,42]	$0.376 \pm 0.005_{stat} \pm 0.001_{syst}$	$0.356 \pm 0.006_{stat} \pm 0.002_{syst}$
(42,46]	$0.366 \pm 0.006_{stat} \pm 0.002_{syst}$	$0.344 \pm 0.008_{stat} \pm 0.002_{syst}$

Asymmetry





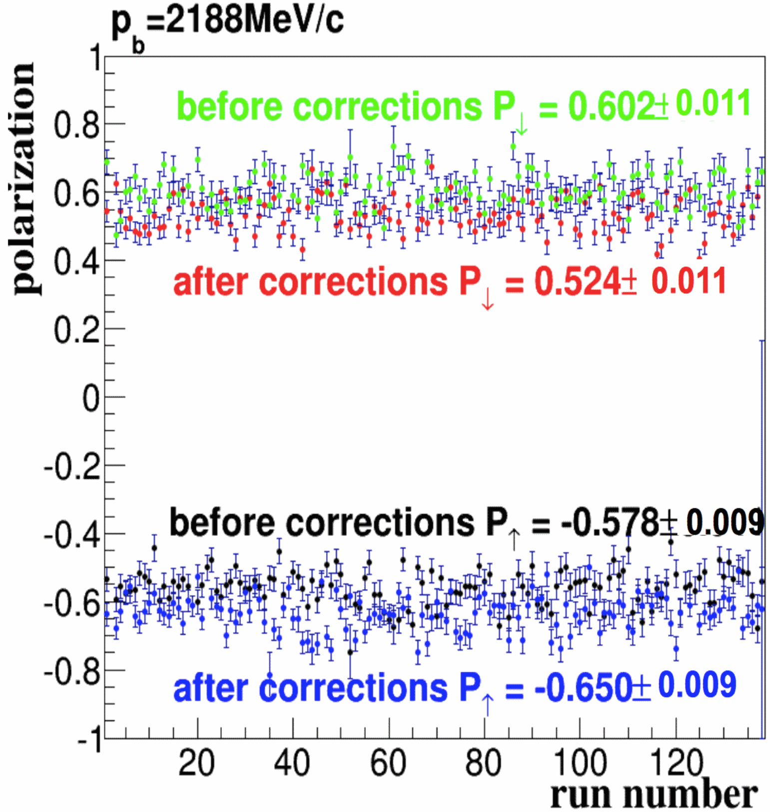
$$\frac{N(\theta,\varphi)-N(\theta,\varphi+\pi)}{N(\theta,\varphi)+N(\theta,\varphi+\pi)} \equiv \epsilon(N(\theta,\varphi),N(\theta,\varphi+\pi))$$

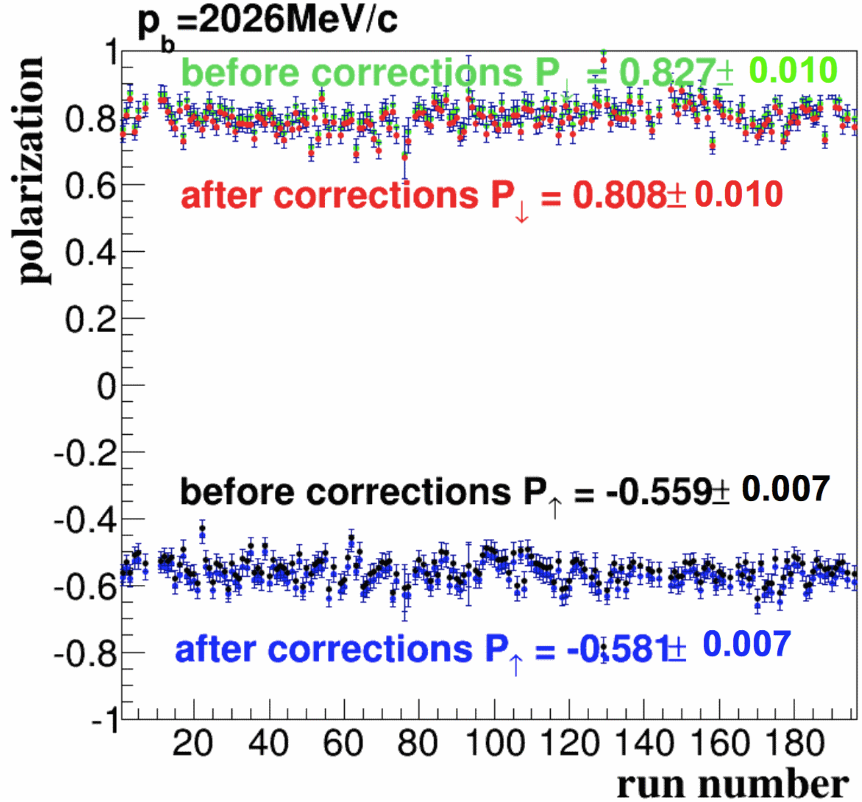
$$Asymmetry \equiv P \cdot \cos\varphi \cdot A_y$$

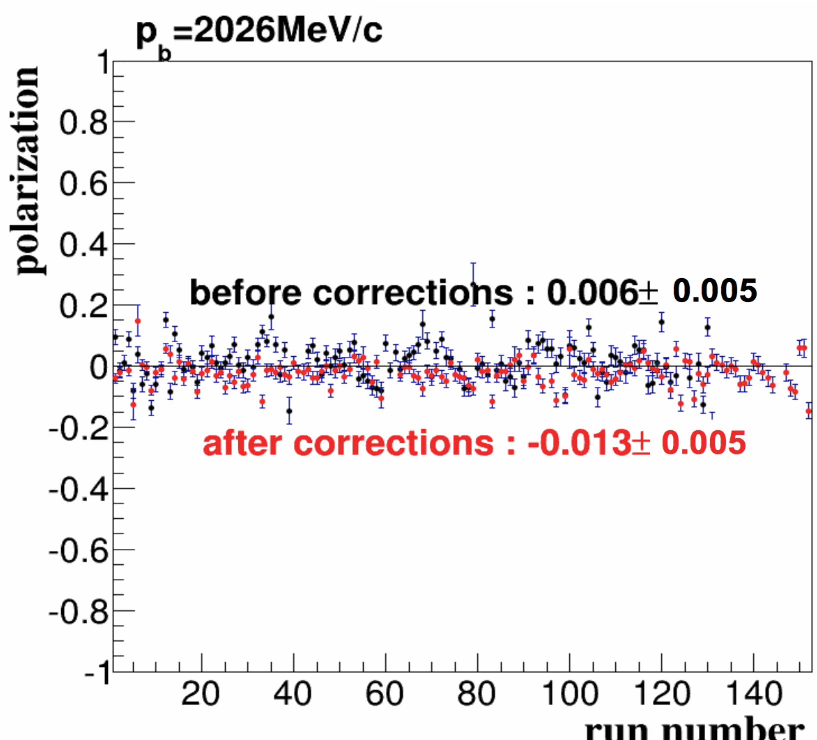
$$Asymmetry \equiv a \cdot \cos\varphi + b$$

$$a \equiv A_y \cdot P$$

$$P \equiv \frac{a}{A_y}$$







UJ Krakow & IKP1 Jue
lich

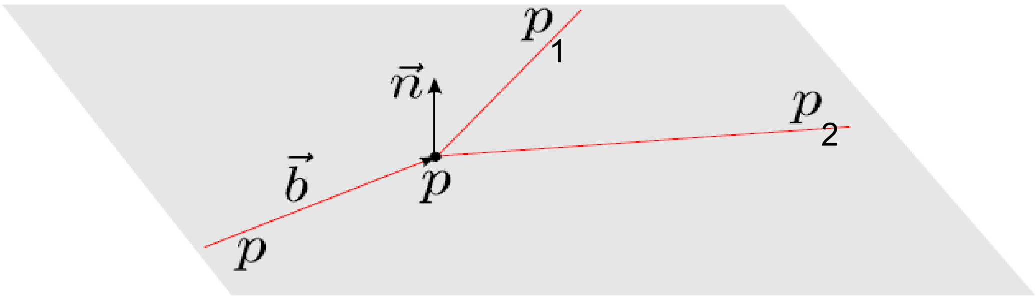
Vertex position (Systematics studies)

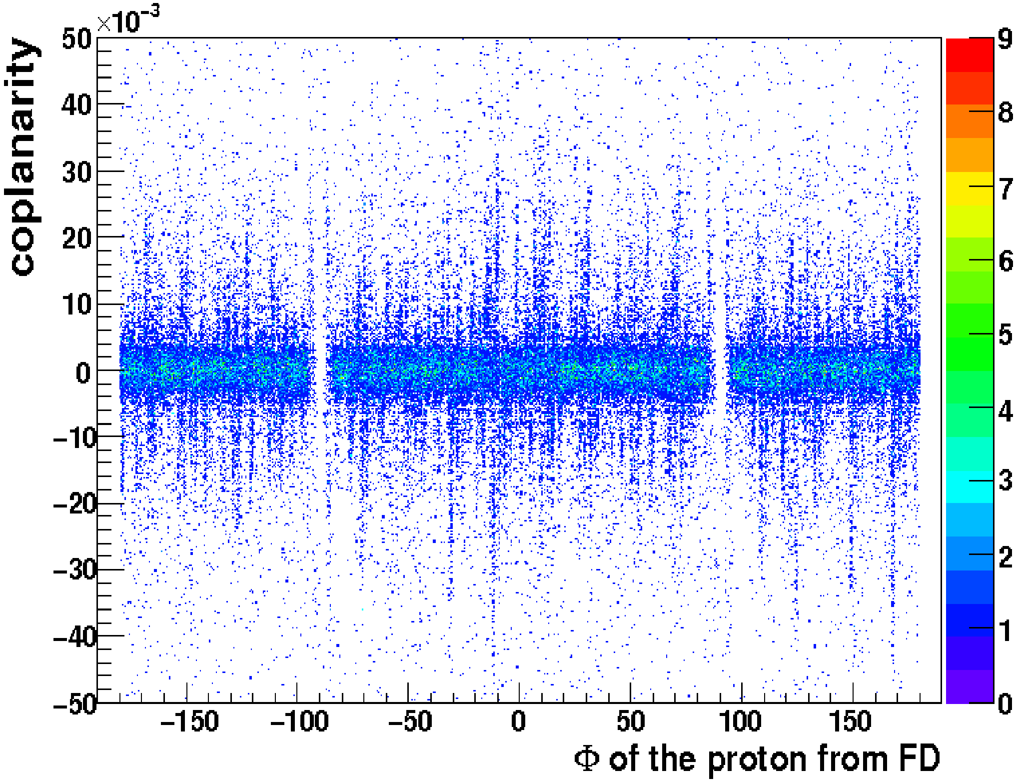
Coplanarity method

$d(\phi_d)$ method

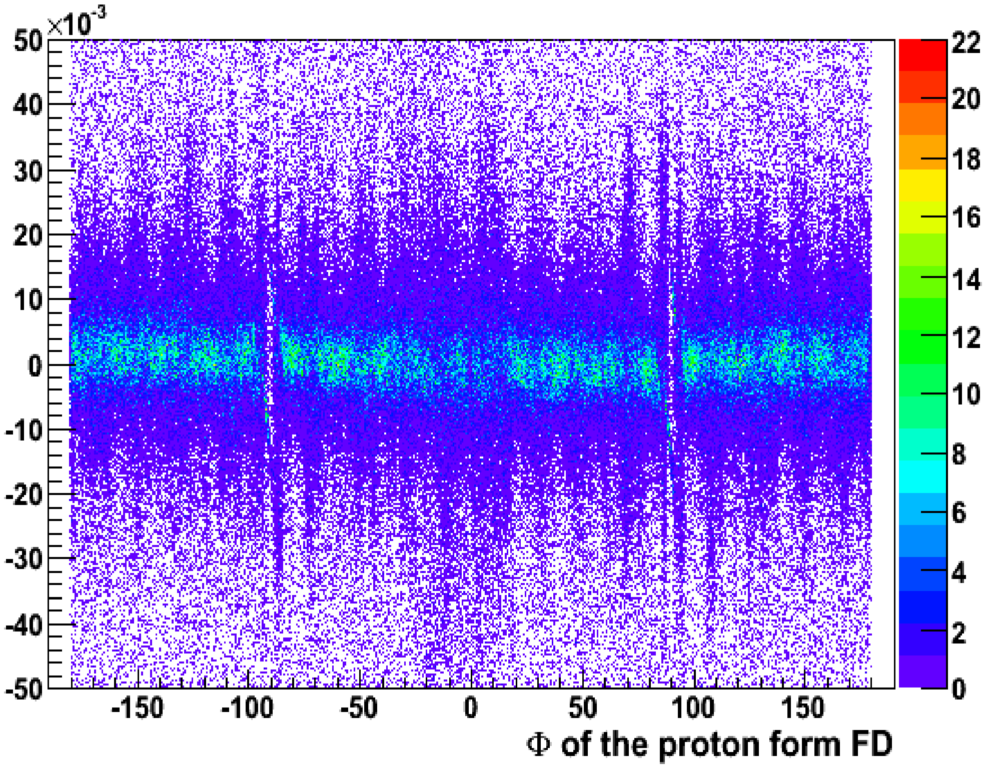
Vertex position determination:
coplanarity

Coplanarity: $C = \frac{(\vec{p}_1 \times \vec{p}_2) \cdot \vec{p}_{beam}}{|\vec{p}_1 \times \vec{p}_2| \cdot |\vec{p}_{beam}|}$,





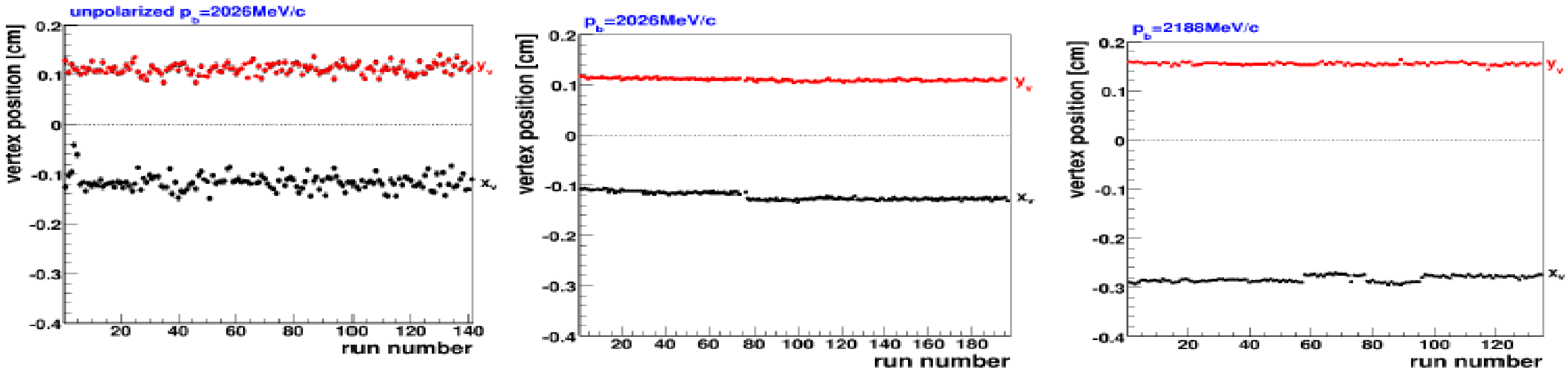
MC



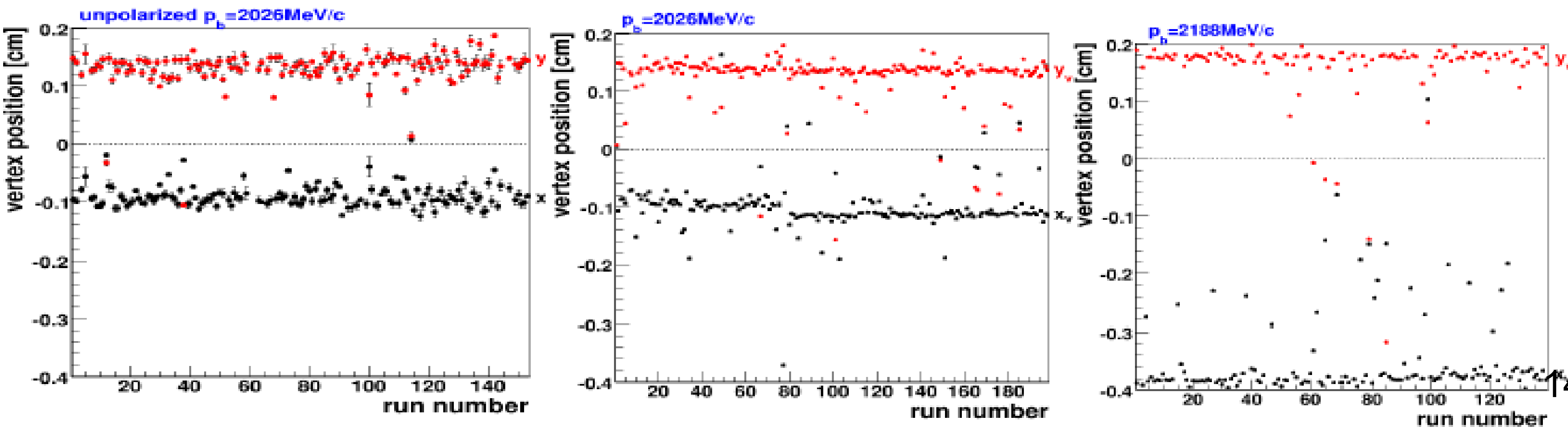
DATA

M. Hodana, P. Moskal, I. Ozerianska, Acta Phys. Polon. Supp. 6 (2013) 1041

Result for the coplanarity method

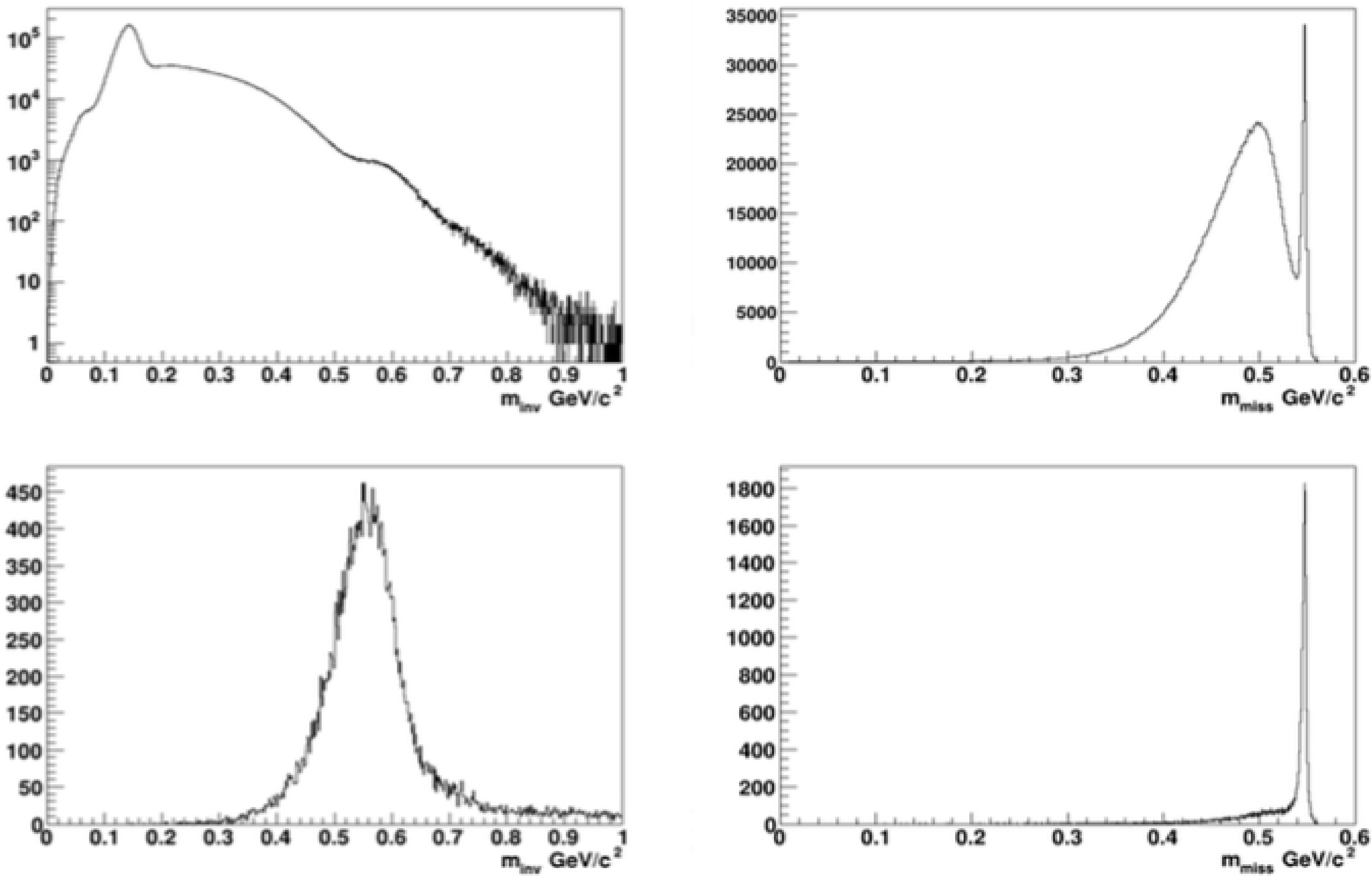


Result for the distance method



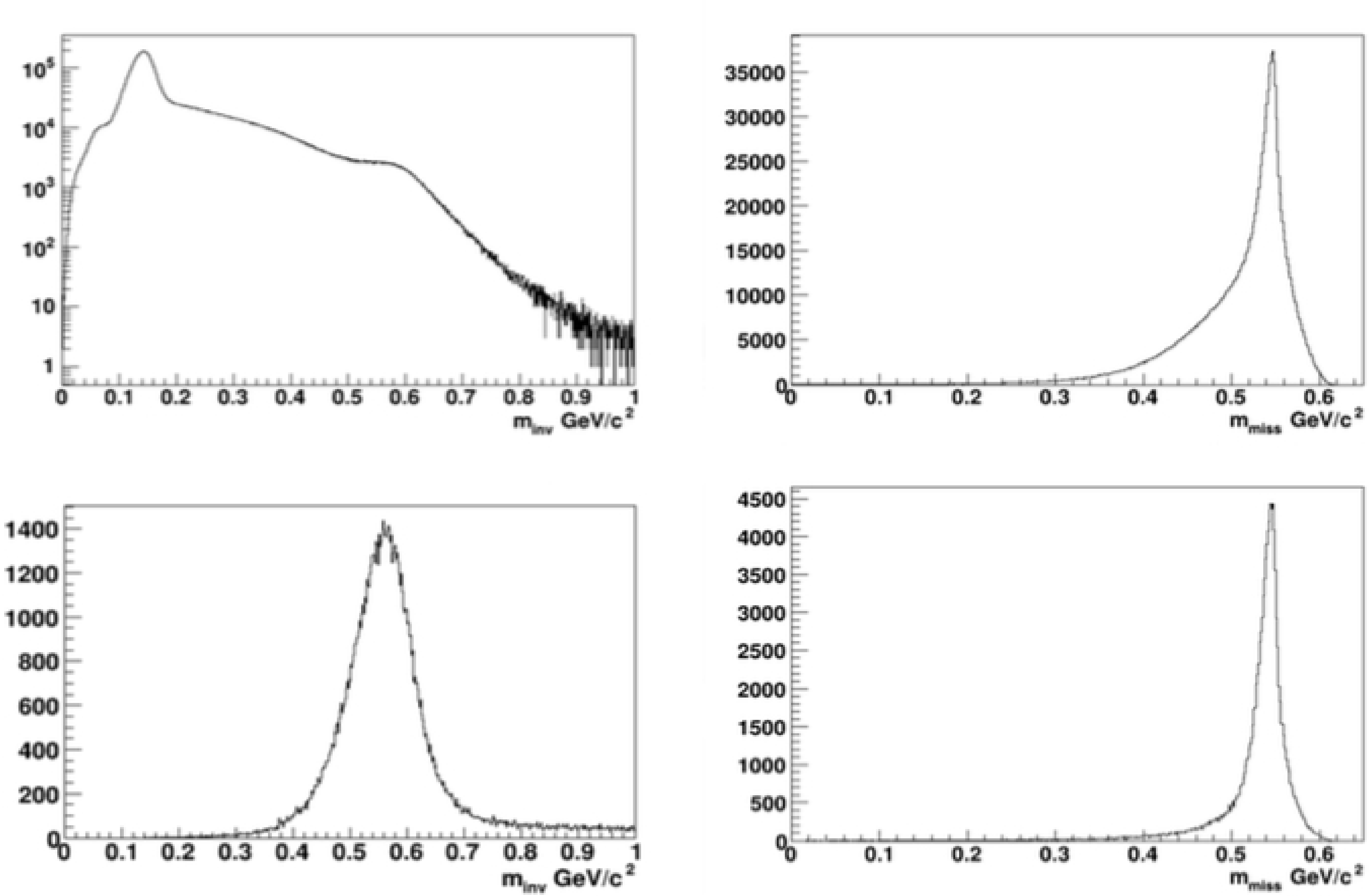
Eta meson

2026 MeV/c



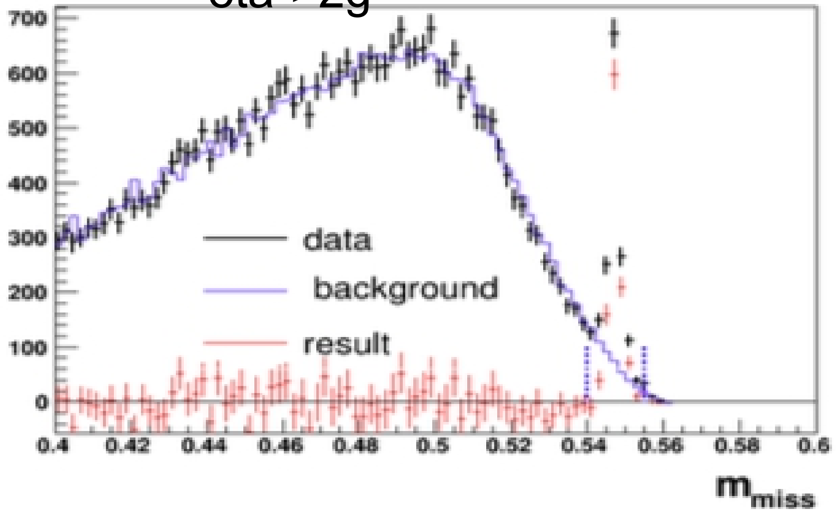
Eta meson

2188 MeV/c

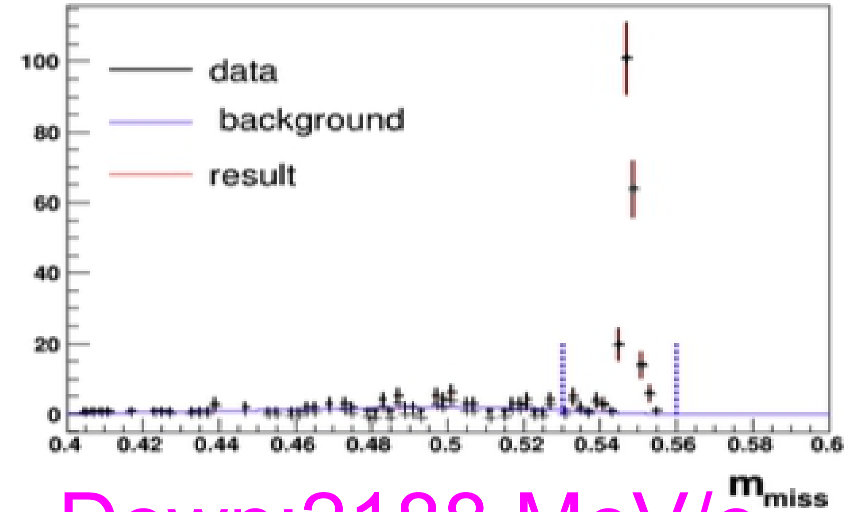


Missing Mass distribution for the Up:2026 MeV/c

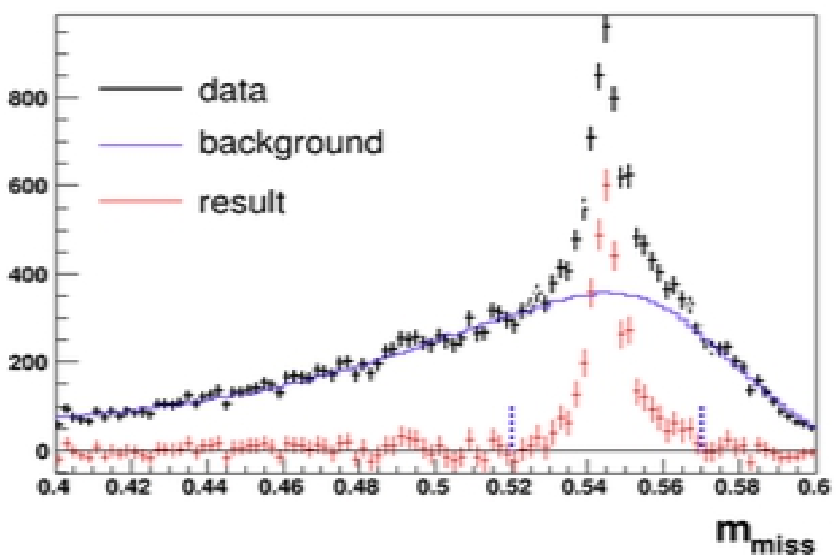
eta->2g

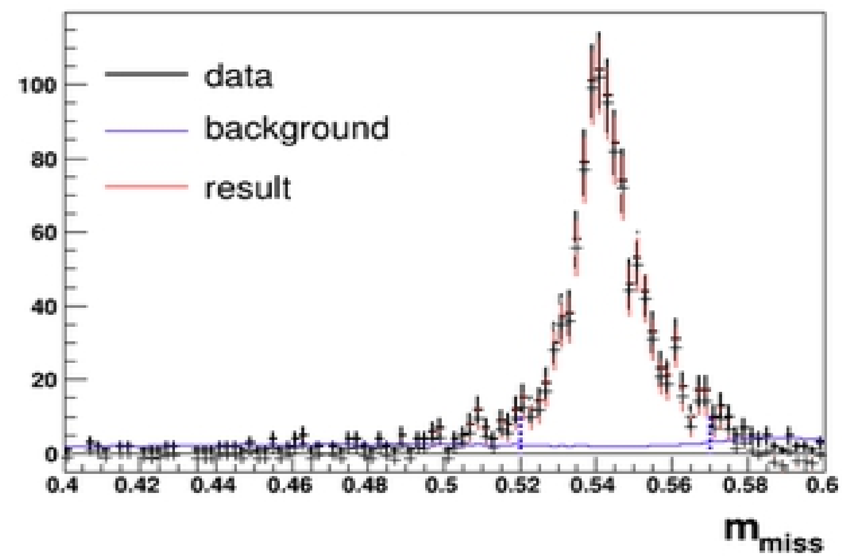


eta->3pi0

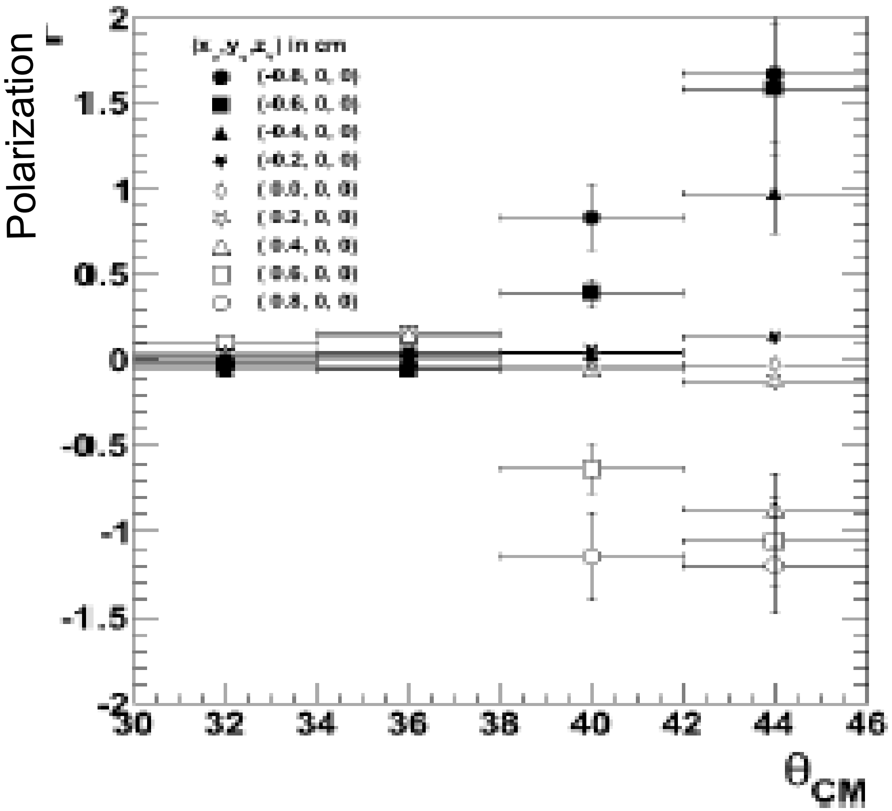


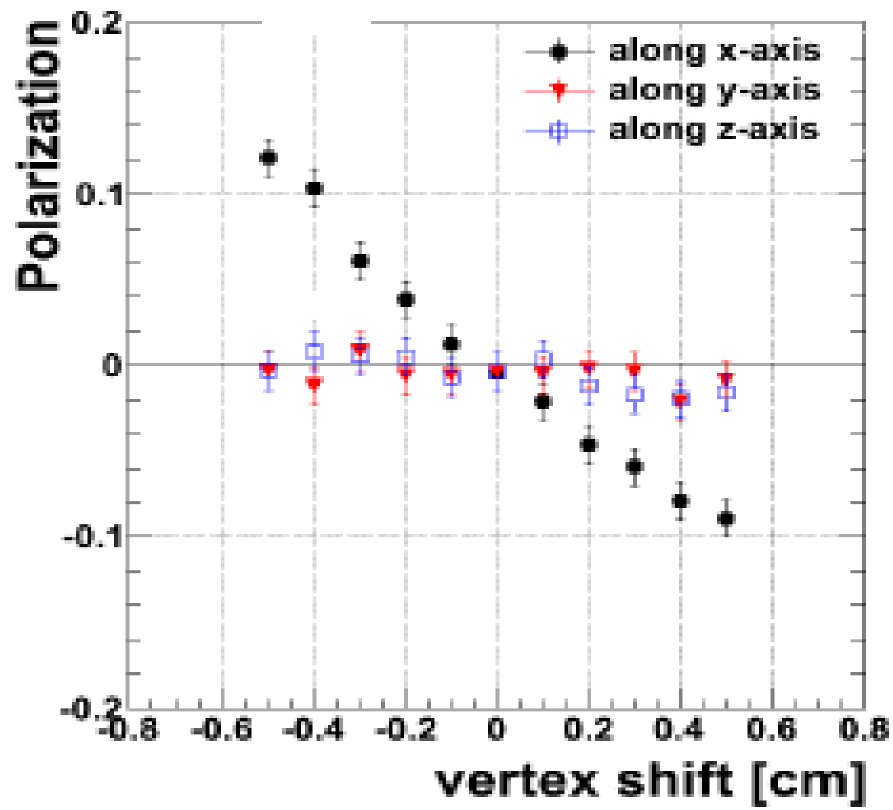
Down:2188 MeV/c





Study of the influence of the position of the interaction point for the polarization



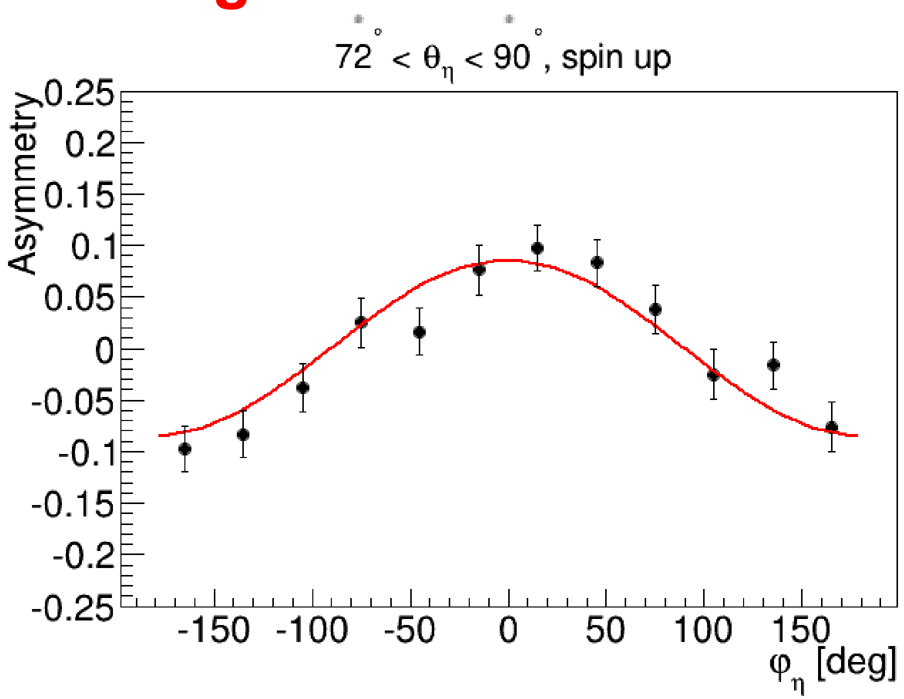


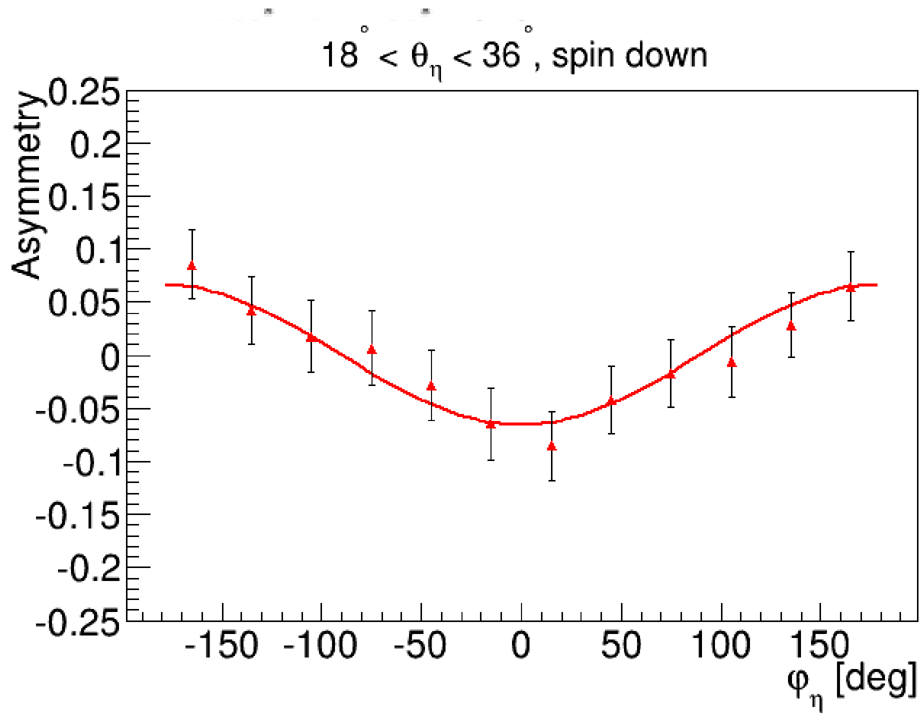
Example of asymmetry vs θ_η distribution for the $p_b = 2026$ Mev/c.

$$\epsilon_\eta^\uparrow(N(\theta_\eta,\varphi_\eta),N(\theta_\eta,\varphi_\eta+\pi)) \equiv \frac{N_\eta^\uparrow(\theta_\eta,\varphi_\eta) - N_\eta^\uparrow(\theta_\eta,\varphi_\eta+\pi)}{N_\eta^\uparrow(\theta_\eta,\varphi_\eta) + N_\eta^\uparrow(\theta_\eta,\varphi_\eta+\pi)}$$

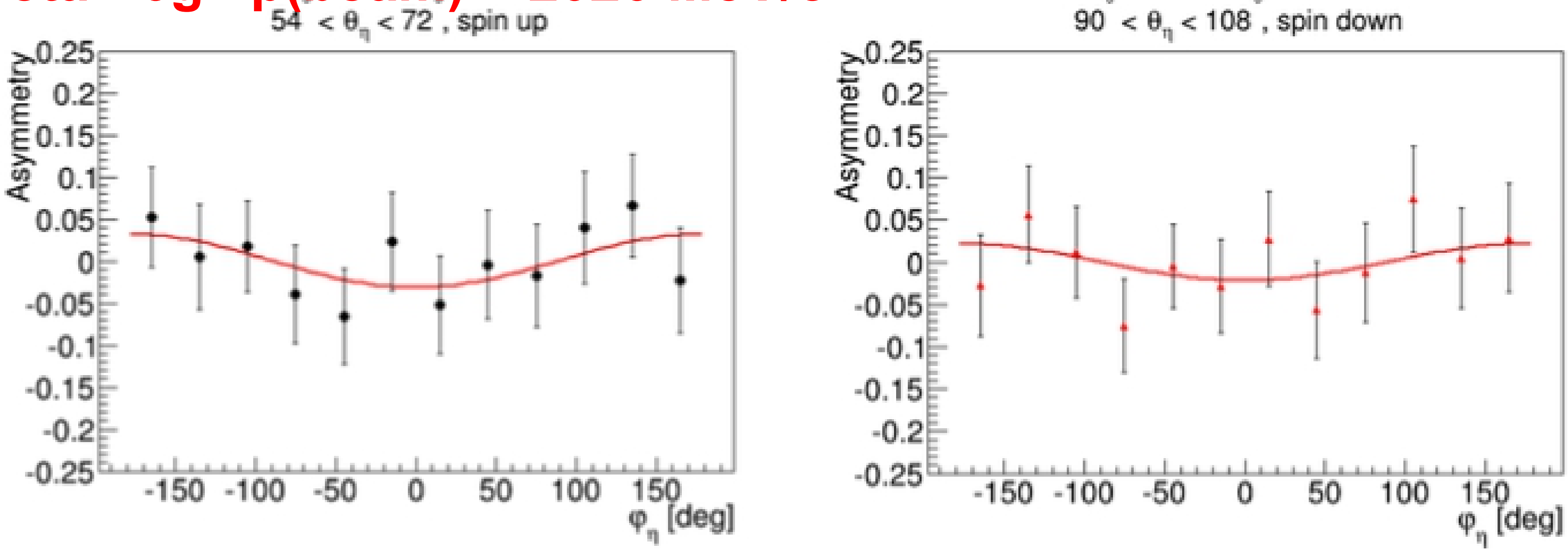
$$\epsilon_\eta^\downarrow(N(\theta_\eta,\varphi_\eta),N(\theta_\eta,\varphi_\eta+\pi)) \equiv \frac{N_\eta^\downarrow(\theta_\eta,\varphi_\eta+\pi) - N_\eta^\downarrow(\theta_\eta,\varphi_\eta)}{N_\eta^\downarrow(\theta_\eta,\varphi_\eta+\pi) + N_\eta^\downarrow(\theta_\eta,\varphi_\eta)}$$

eta->2g

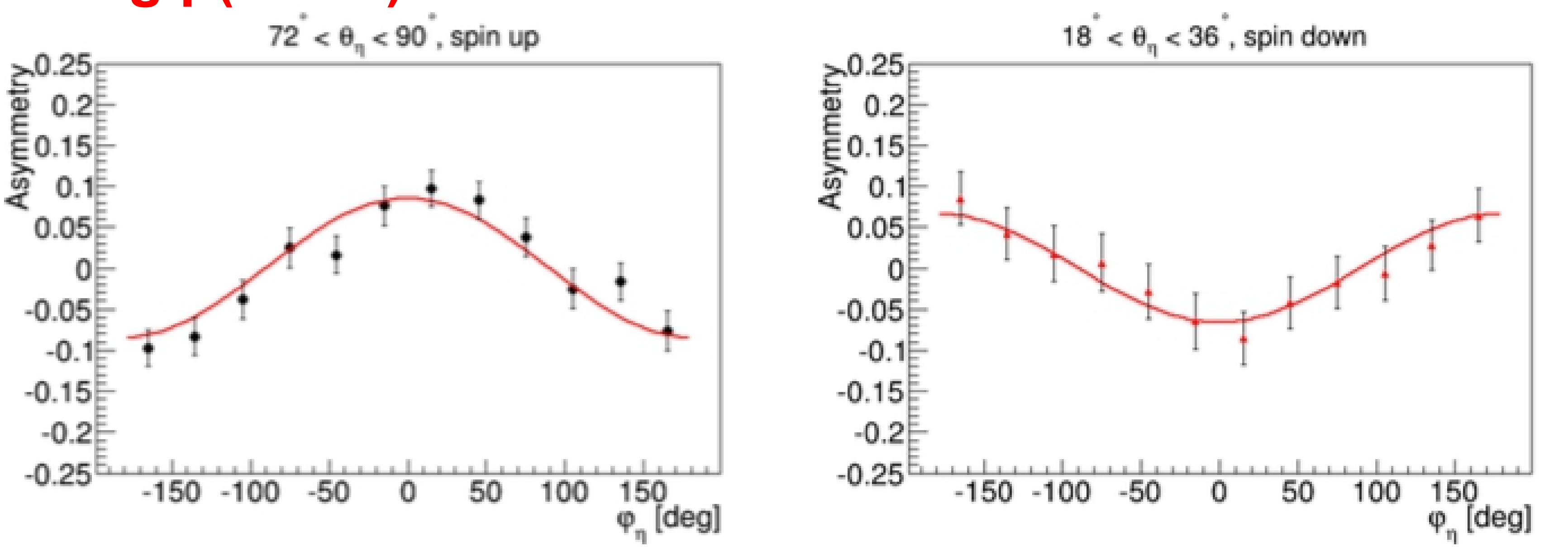




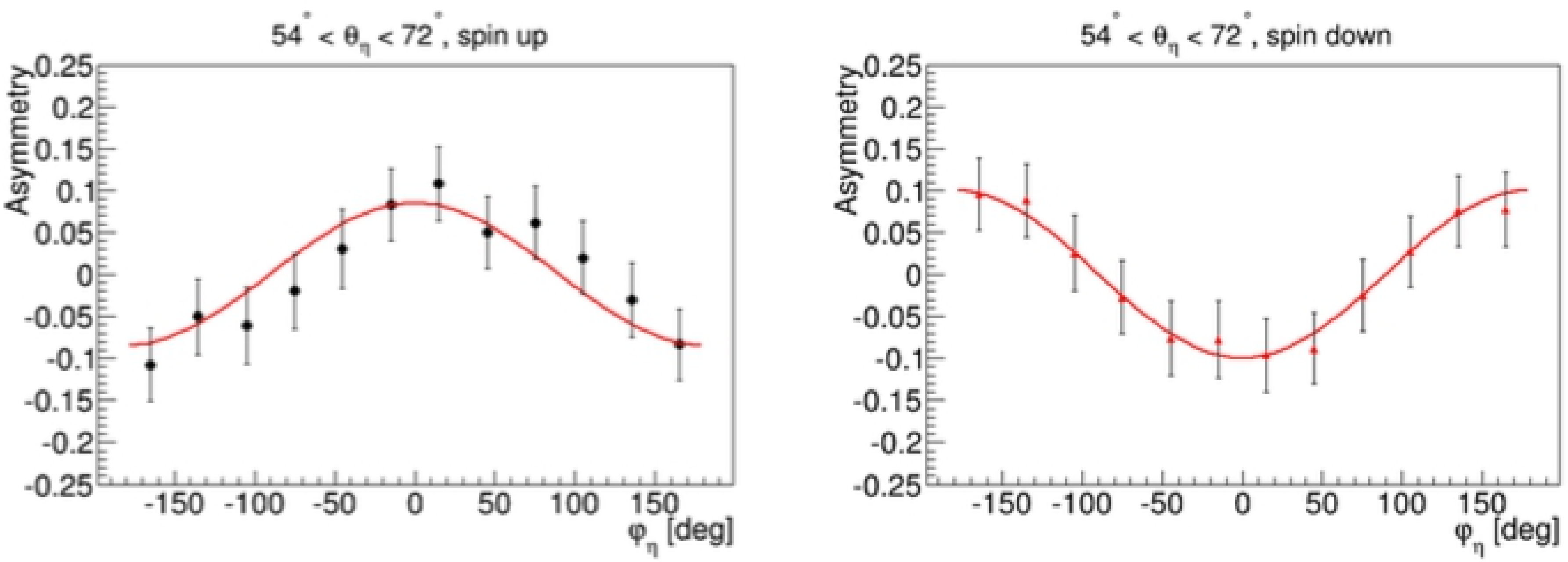
eta->6g   p(beam) = 2026 MeV/c



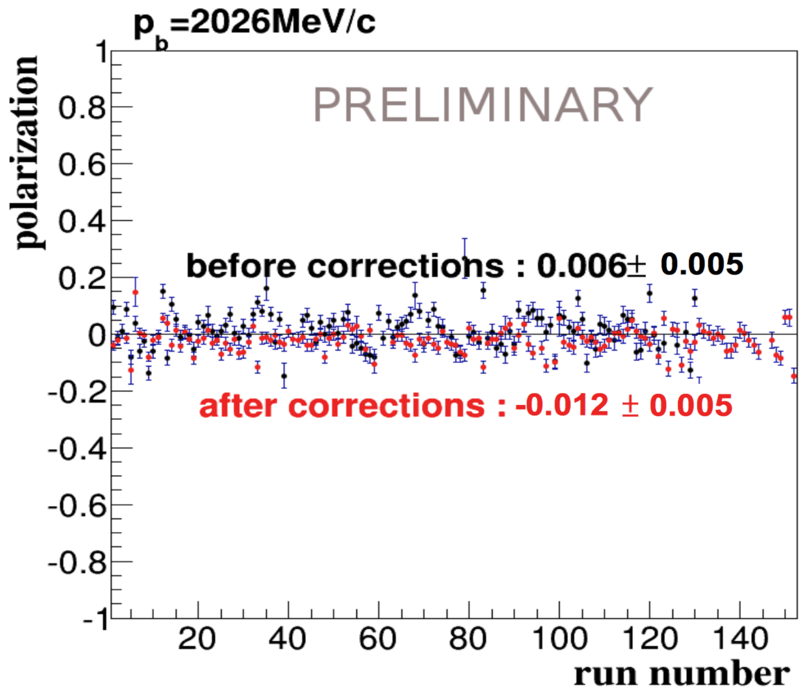
eta->2g p(beam) = 2188 MeV/c



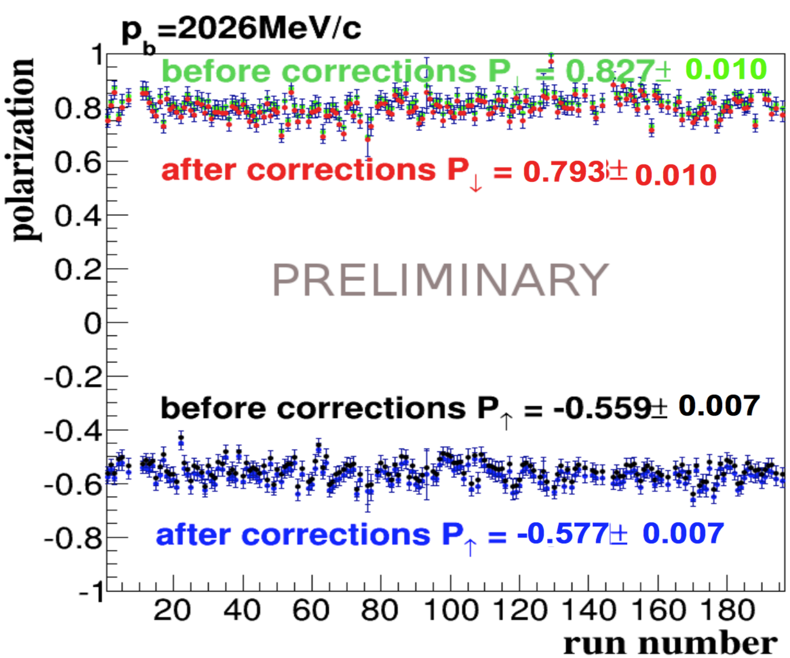
eta->6g   p(beam) = 2188 MeV/c

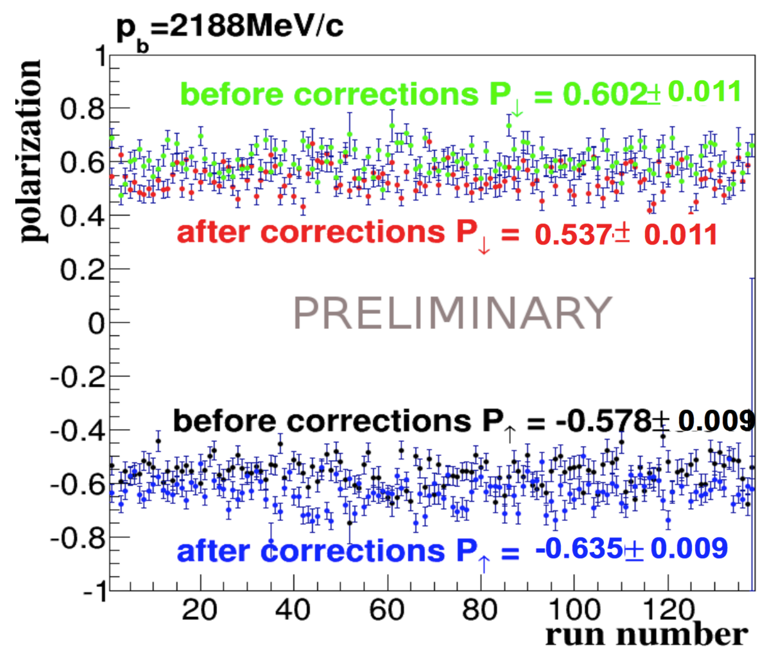


Result for the Polarization



Polarization stable during experiment





I. Schatti-Ozerianska, P. Moskal, M. Zielinski arXiv:1502.00434

Eta meson

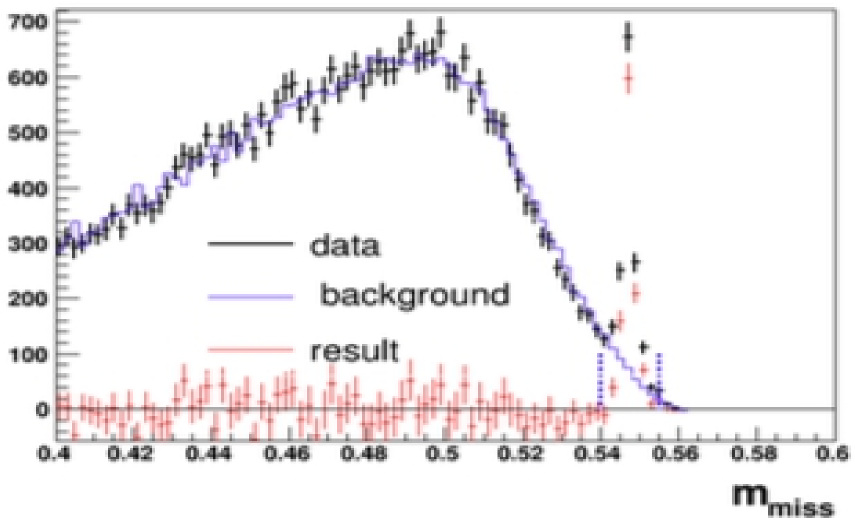
preselection

1. Only 2 charge in the FD;

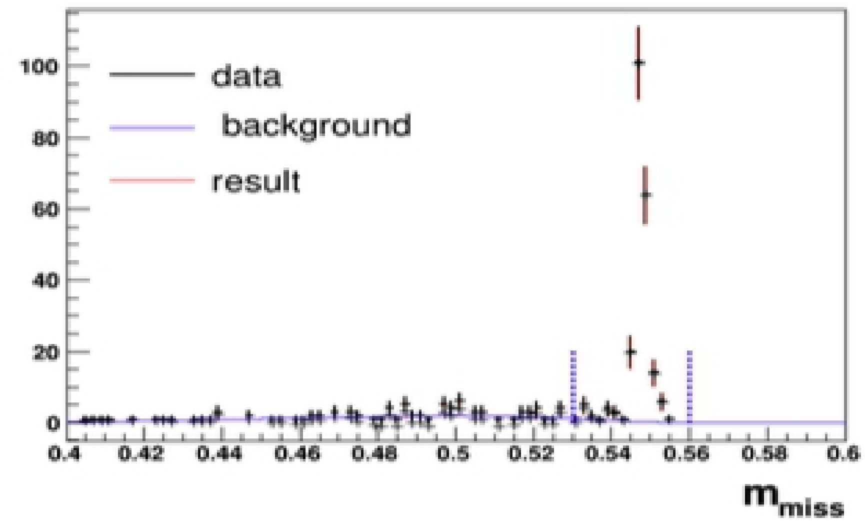
2. More then 2 neutral in the CD;

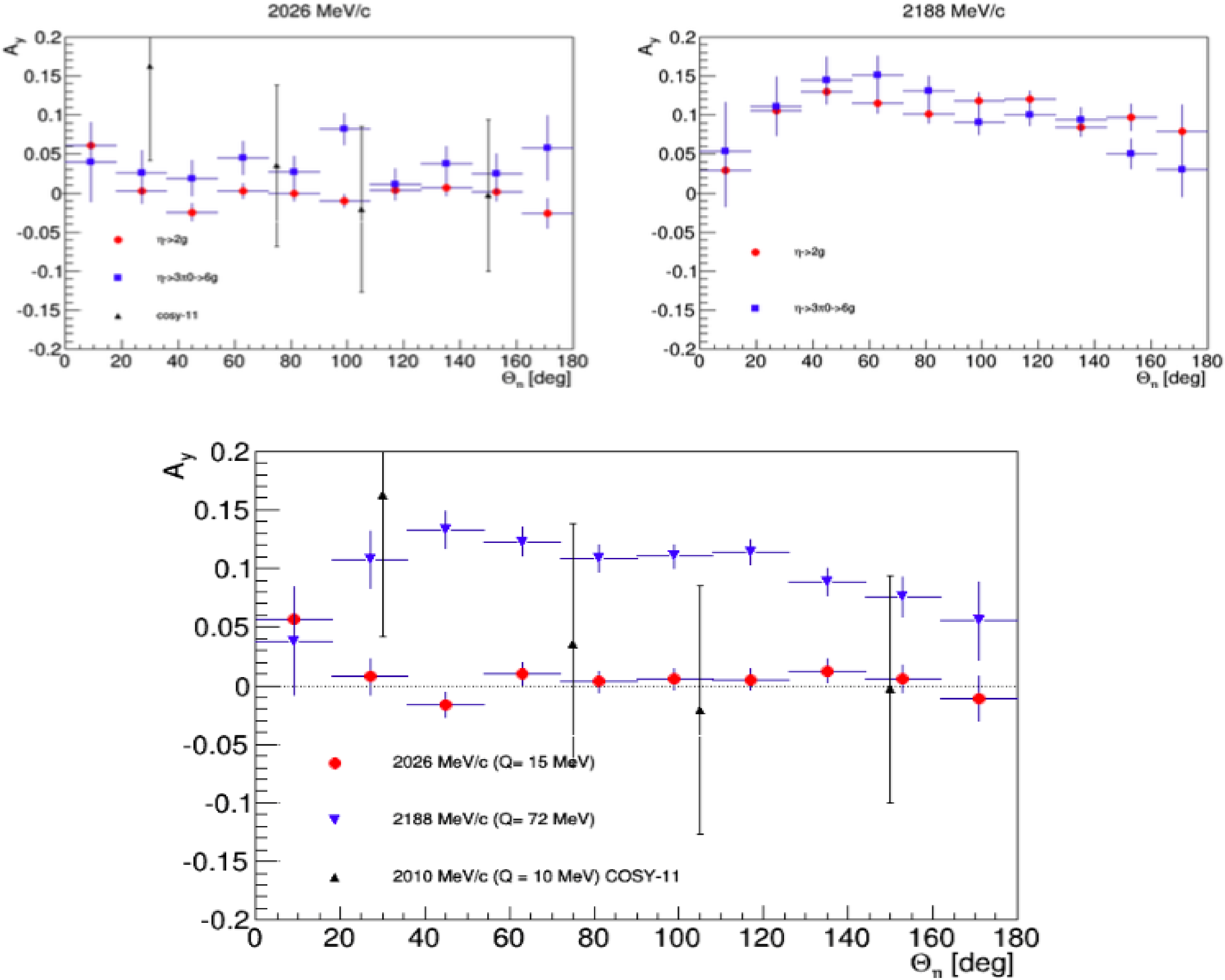
3. Cut for the deposit energy of the protons on FD

eta->2g



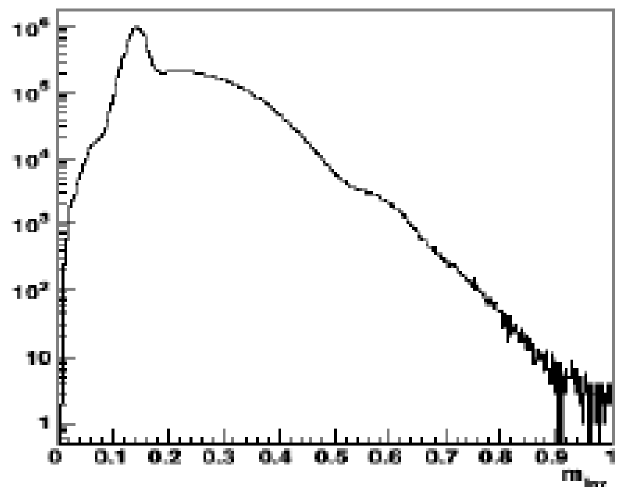
eta->3pi0

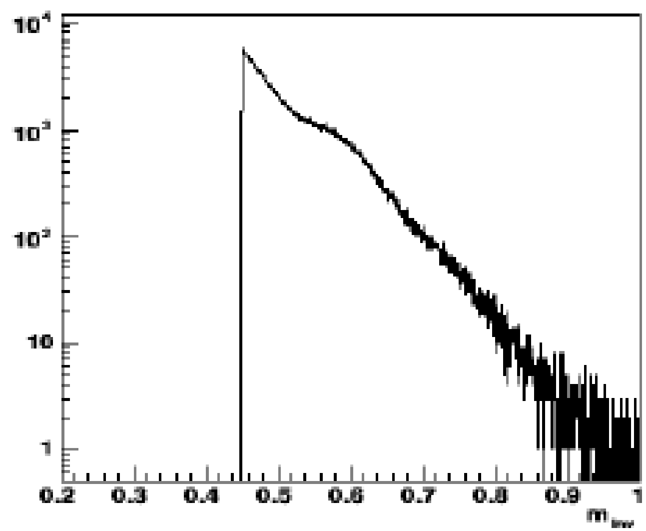



2026 MeV/c
A_y
η->2g
η->3π0->6g
cosy-11
Θ_n [deg]
2188 MeV/c
A_y
η->2g
η->3π0->6g
Θ_n [deg]
A_y
2026 MeV/c (Q= 15 MeV)
2188 MeV/c (Q= 72 MeV)
2010 MeV/c (Q = 10 MeV) COSY-11
Θ_n [deg]

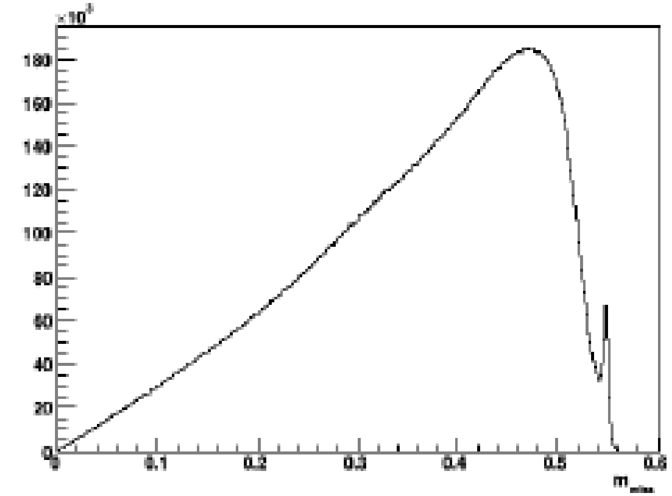
Cuts on the invariant Mass

Invariant Mass of η-data

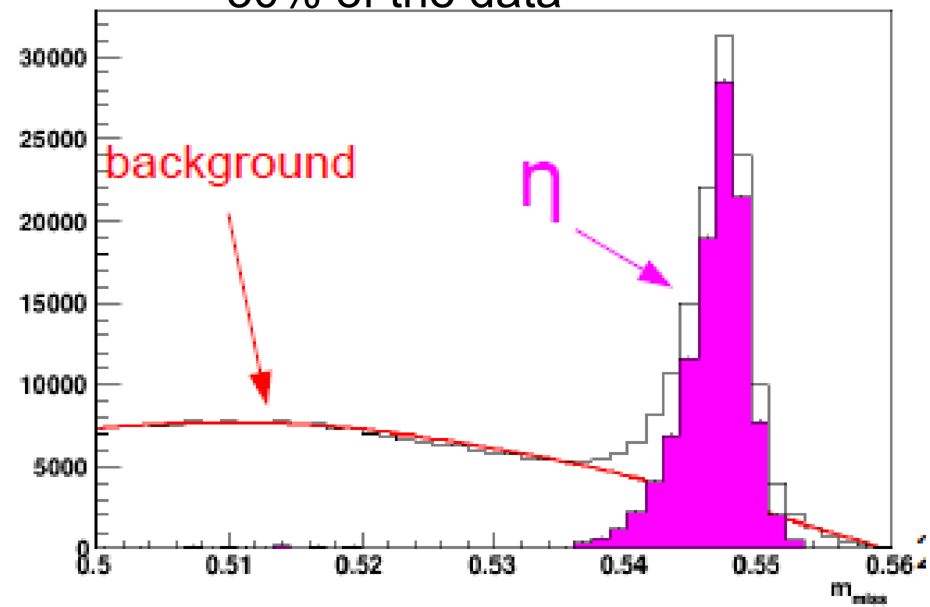




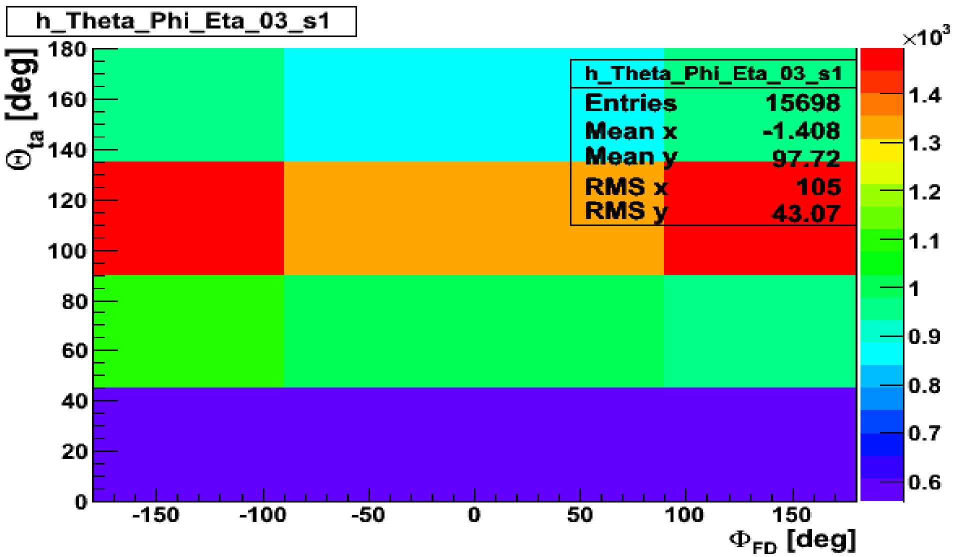
Missing Mass of pp data

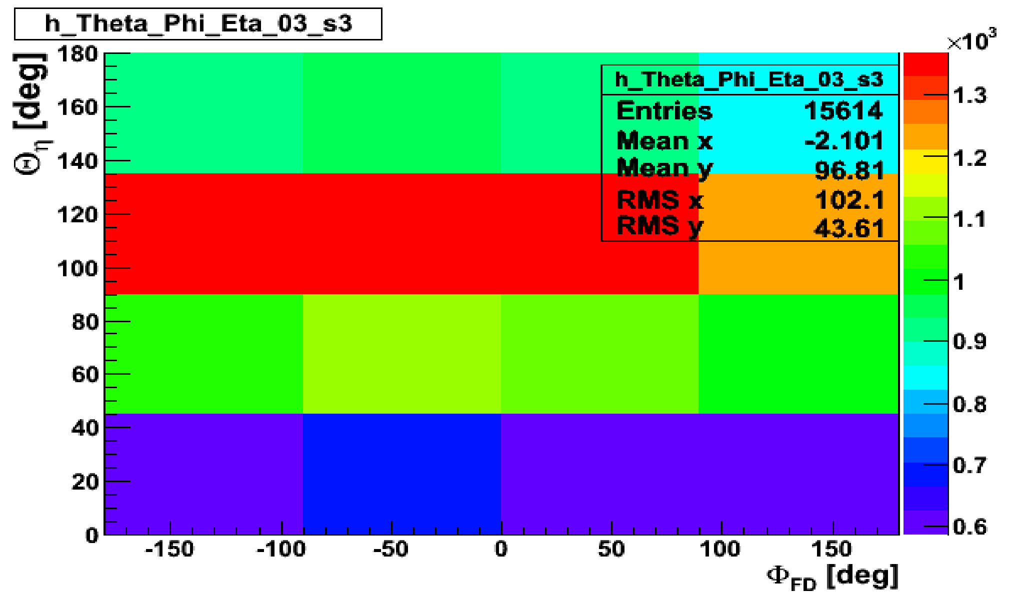


30% of the data

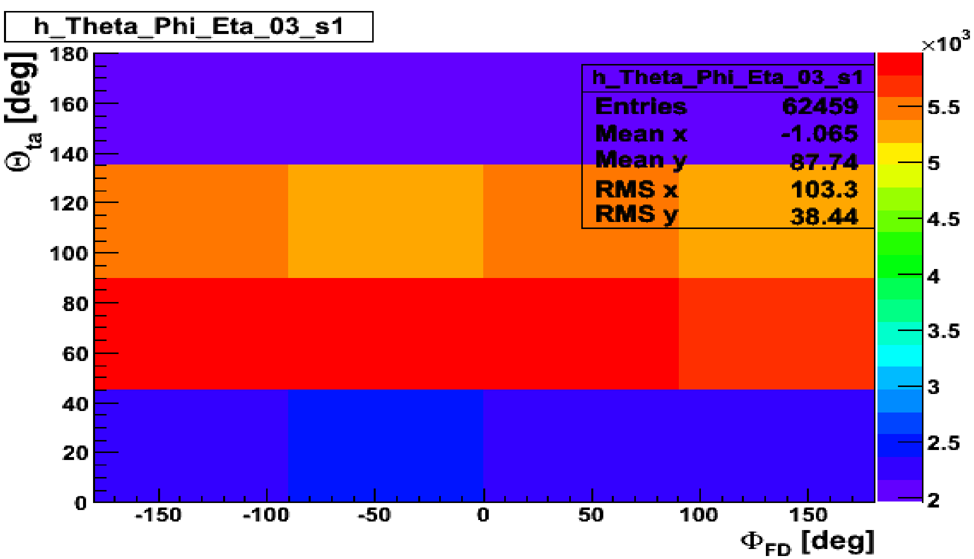


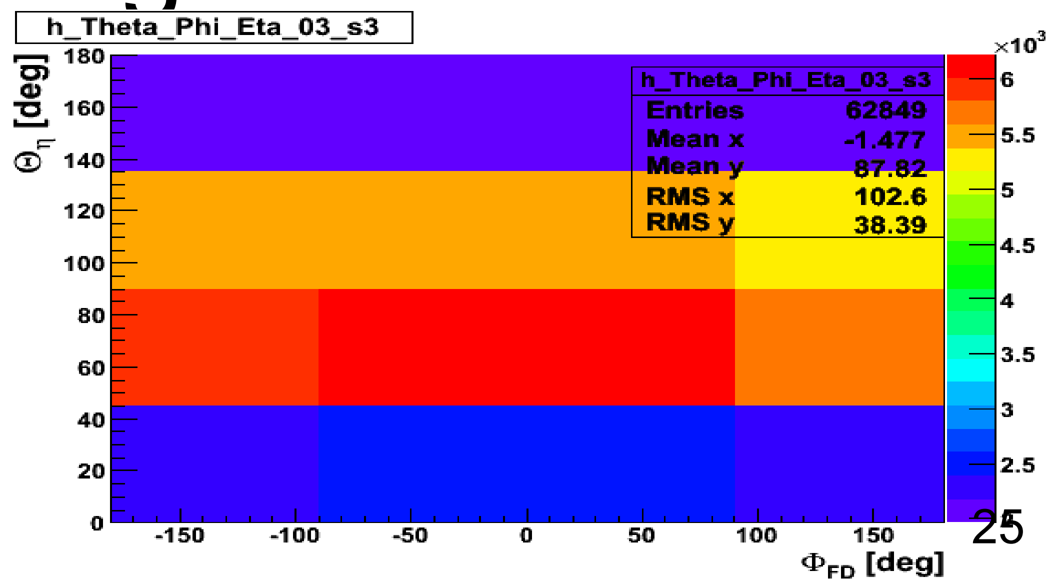
eta->3pi->6g





eta->2g





Luminosity

From trigger 17:

$$\frac{350kHz}{triger17} = \frac{10^{31}}{Luminosity}$$

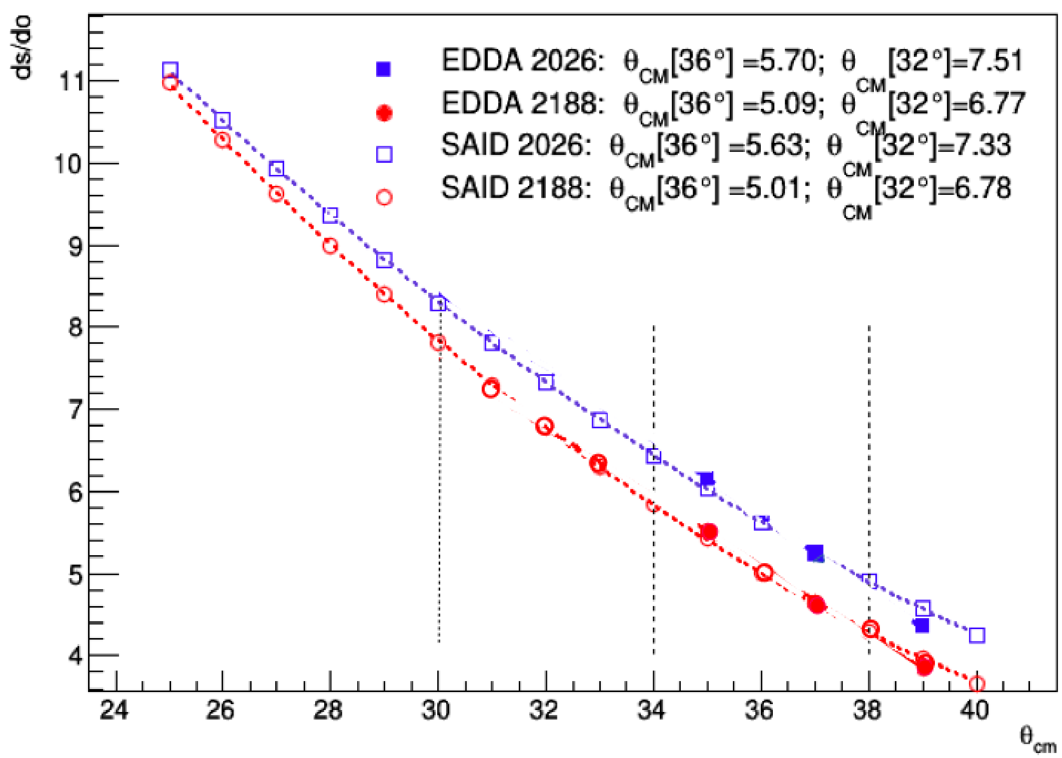
$$Luminosity = \frac{triger17 \cdot 10^{31}}{350kHz}$$

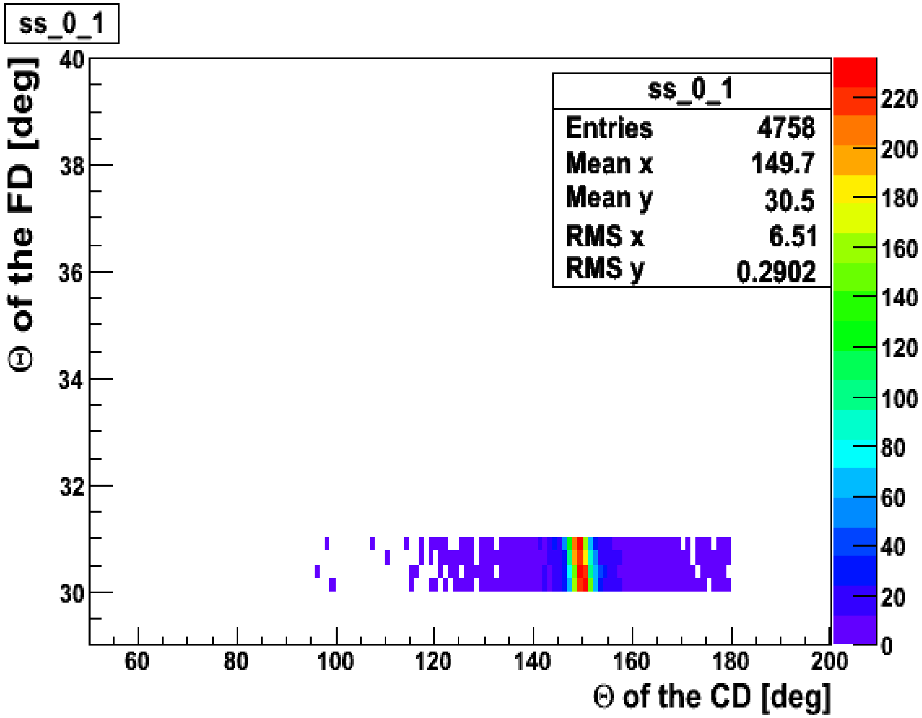
2026 MeV/c: $1.7 \cdot 10^{30} \frac{1}{cm^2} \cdot \frac{1}{s}$

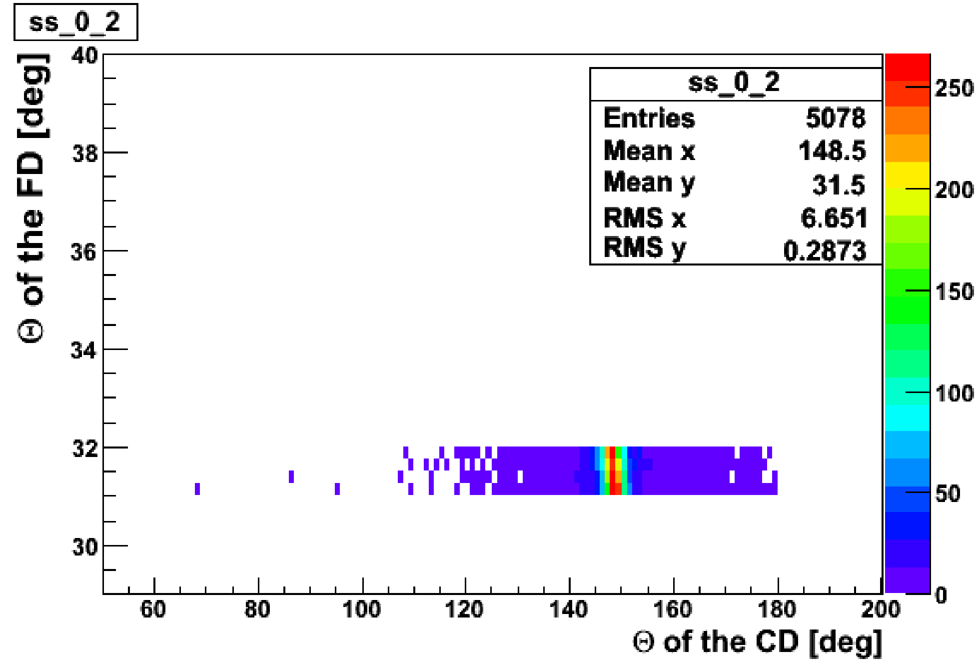
2188 MeV/c: $2.3 \cdot 10^{30} \frac{1}{cm^2} \cdot \frac{1}{s}$

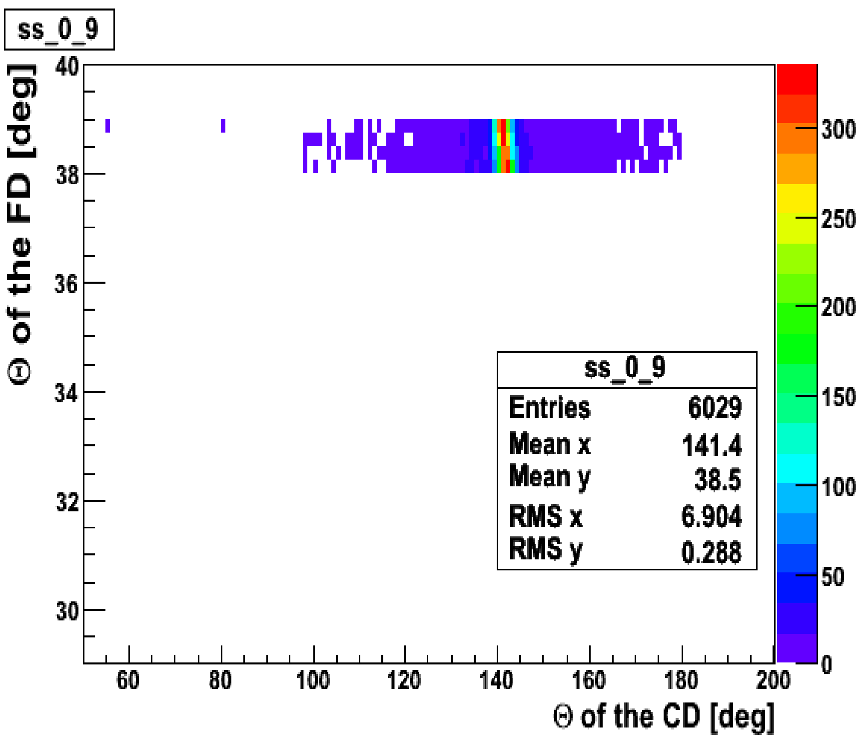
$$L = \frac{N_{exp}(\theta \pm \Delta\theta)}{\sigma_{SAID}(\theta \pm \Delta\theta) \cdot d\Omega(\theta \pm \Delta\theta)}$$

Extrapolation of the differential cross section

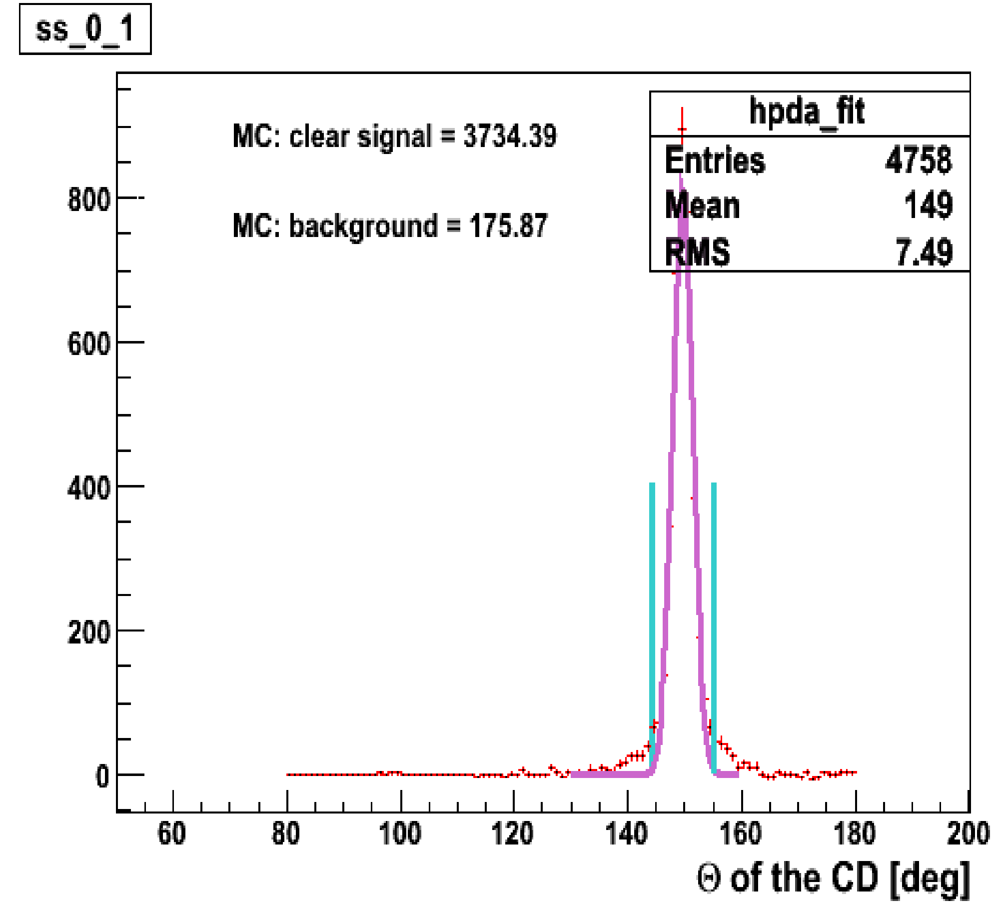


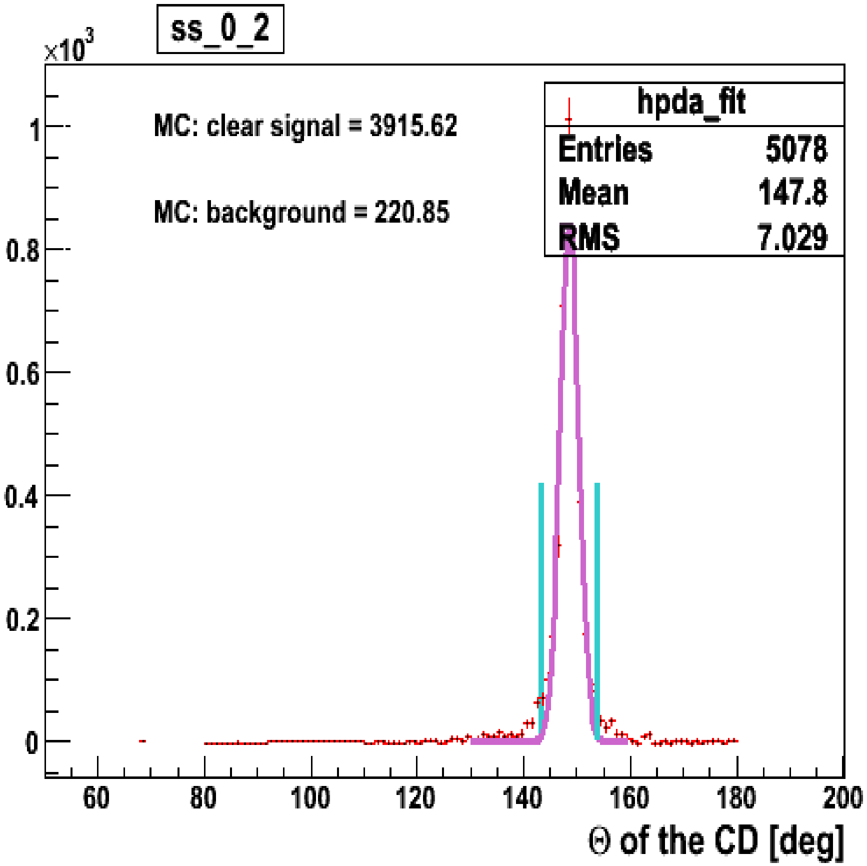


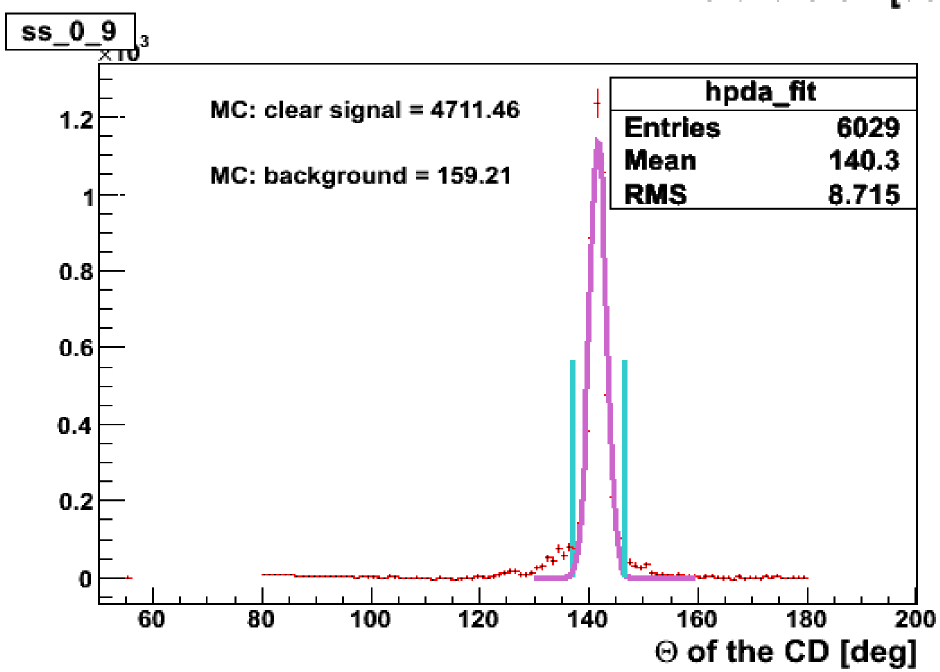




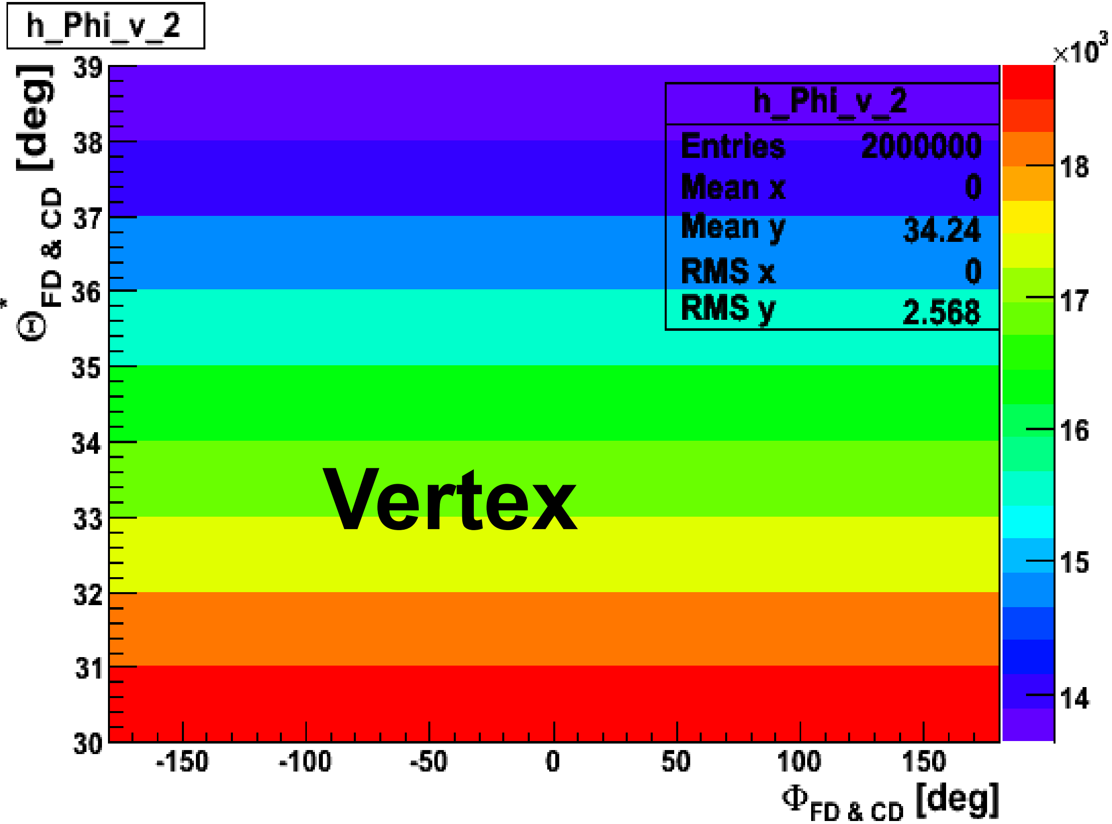
Fitting for the background ->

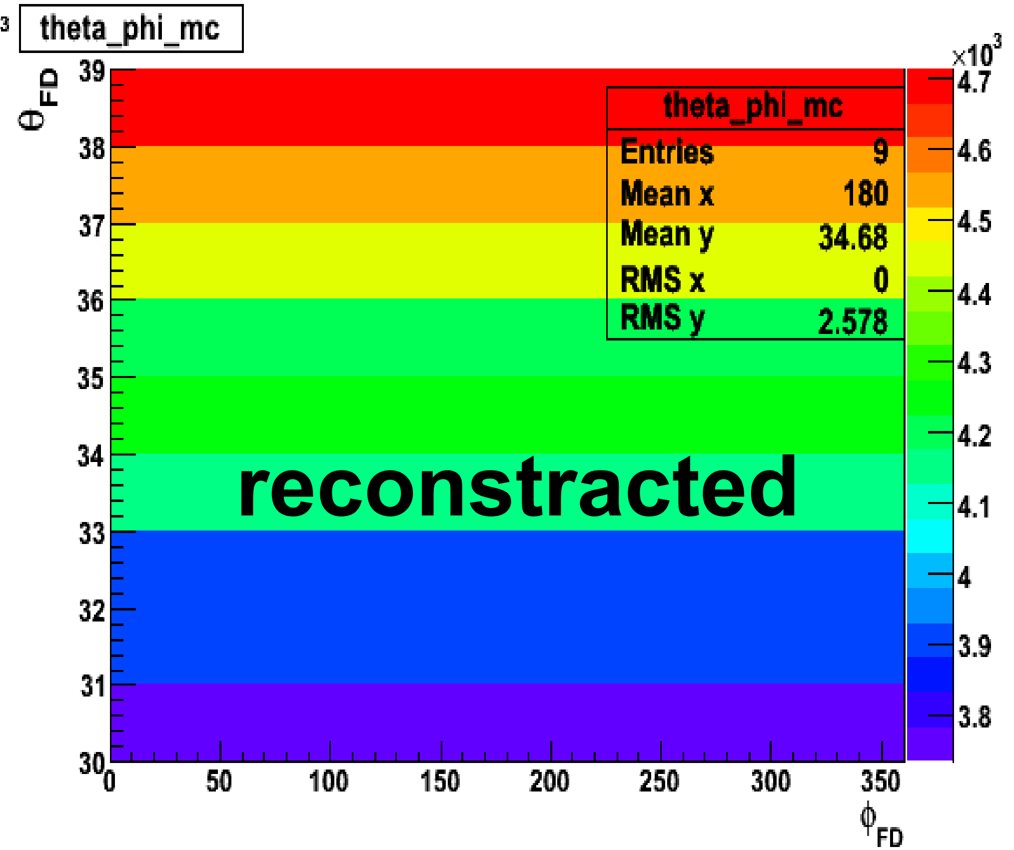


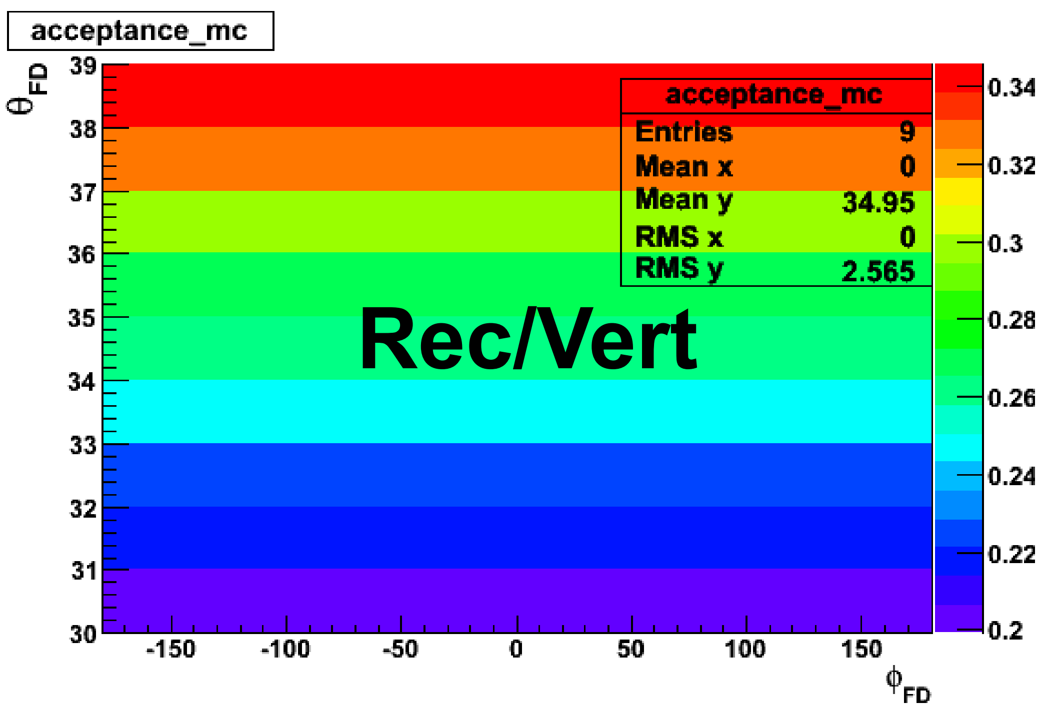


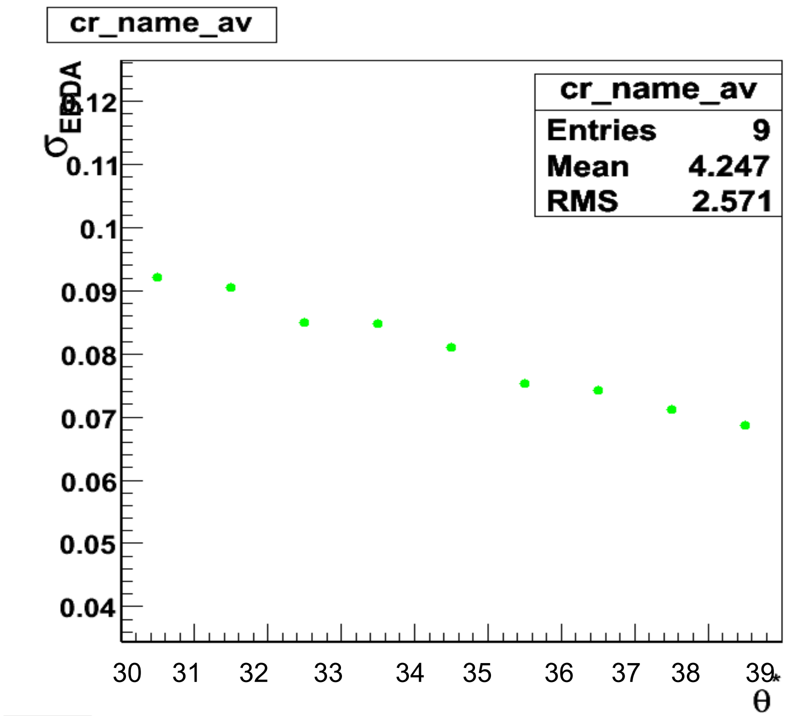


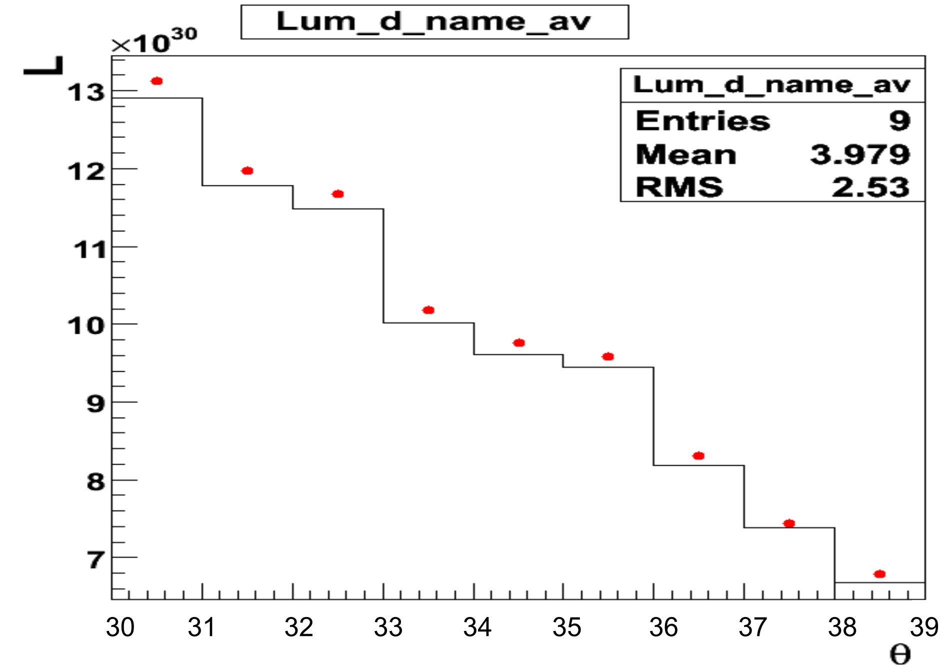
Put to the right order into 2D plot
For the acceptance

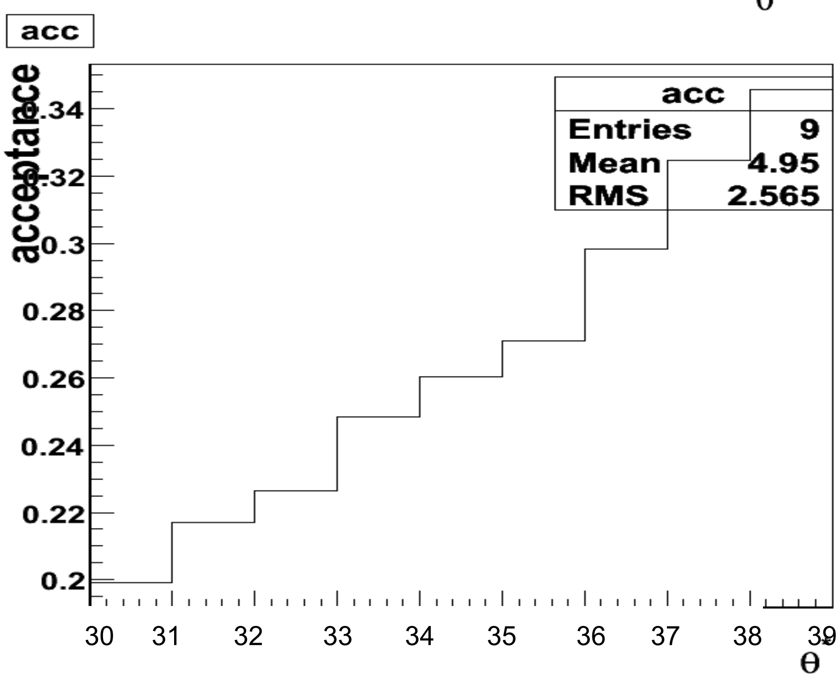

h_Phi_v_2
Entries 2000000
Mean x 0
Mean y 34.24
RMS x 0
RMS y 2.568
Vertex
$\Theta^*_{FD\ \&\ CD}$ [deg]
$\Phi_{FD\ \&\ CD}$ [deg]
$\times 10^3$

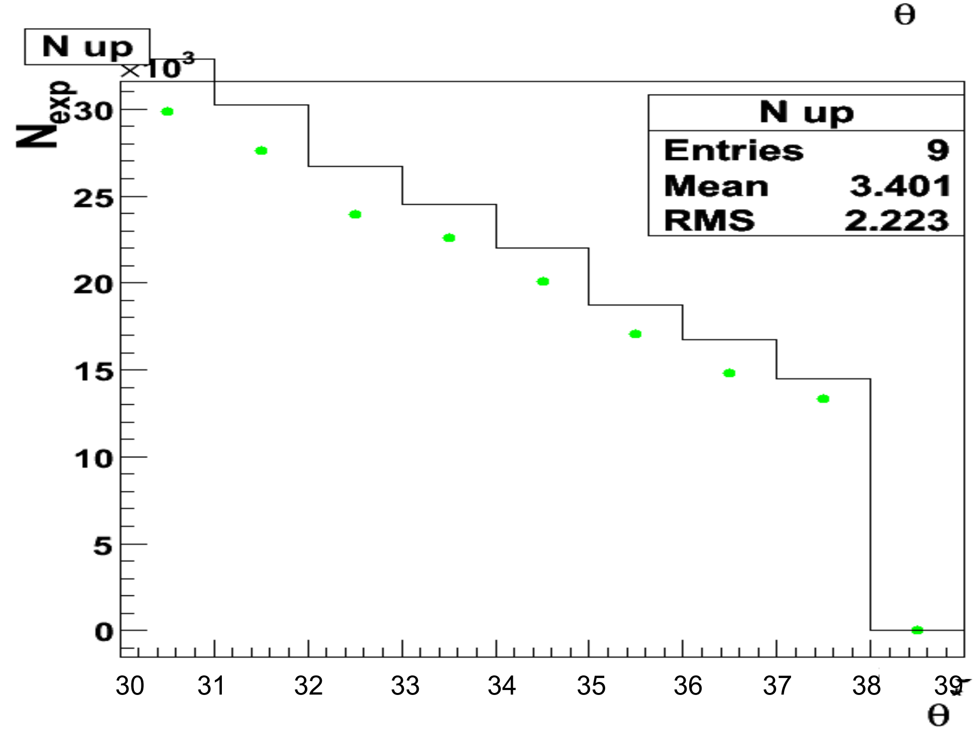

theta_phi_mc
Entries 9
Mean x 180
Mean y 34.68
RMS x 0
RMS y 2.578
reconstracted
θ_{FD}
ϕ_{FD}
$\times 10^3$


acceptance_mc
Entries 9
Mean x 0
Mean y 34.95
RMS x 0
RMS y 2.565
Rec/Vert
θ_{FD}
ϕ_{FD}

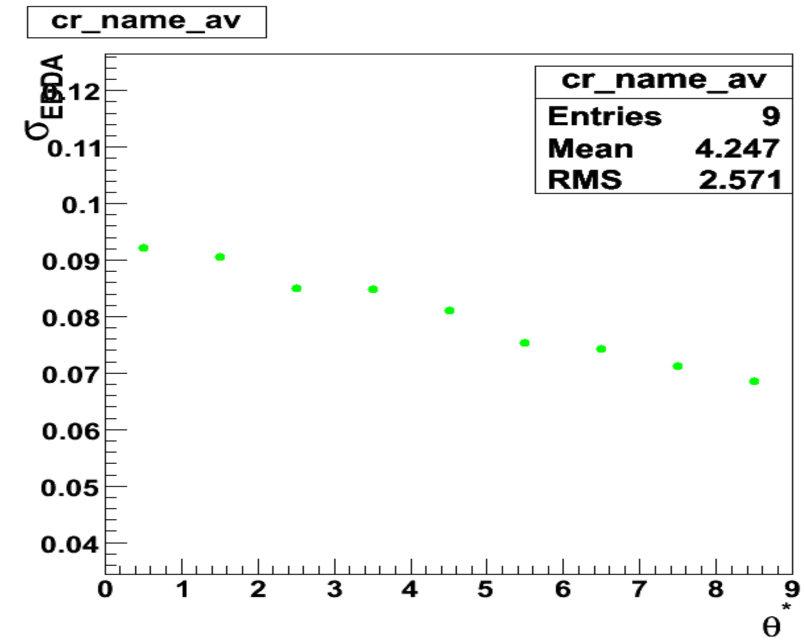

cr_name_av
cr_name_av
Entries 9
Mean 4.247
RMS 2.571
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
30 31 32 33 34 35 36 37 38 39
θ

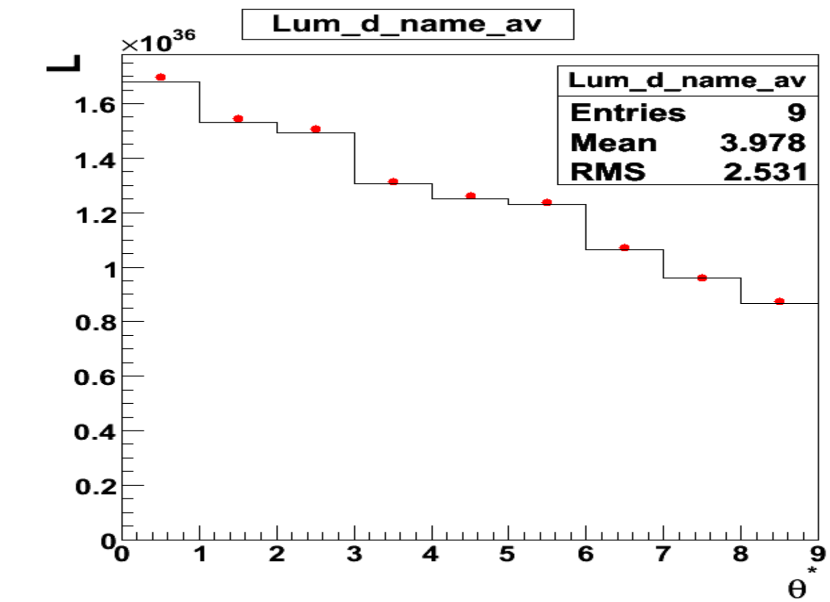

Lum_d_name_av
×10^30
L
Lum_d_name_av
Entries 9
Mean 3.979
RMS 2.53
13
12
11
10
9
8
7
30 31 32 33 34 35 36 37 38 39
θ

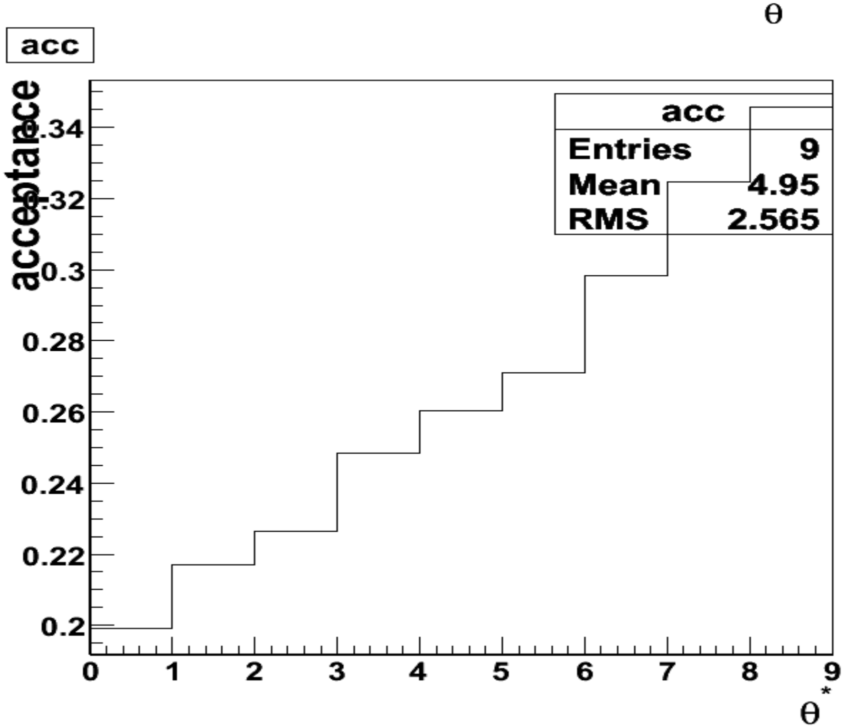

acc
acceptance
acc
Entries 9
Mean 4.95
RMS 2.565
0.34
0.32
0.3
0.28
0.26
0.24
0.22
0.2
30 31 32 33 34 35 36 37 38 39
θ

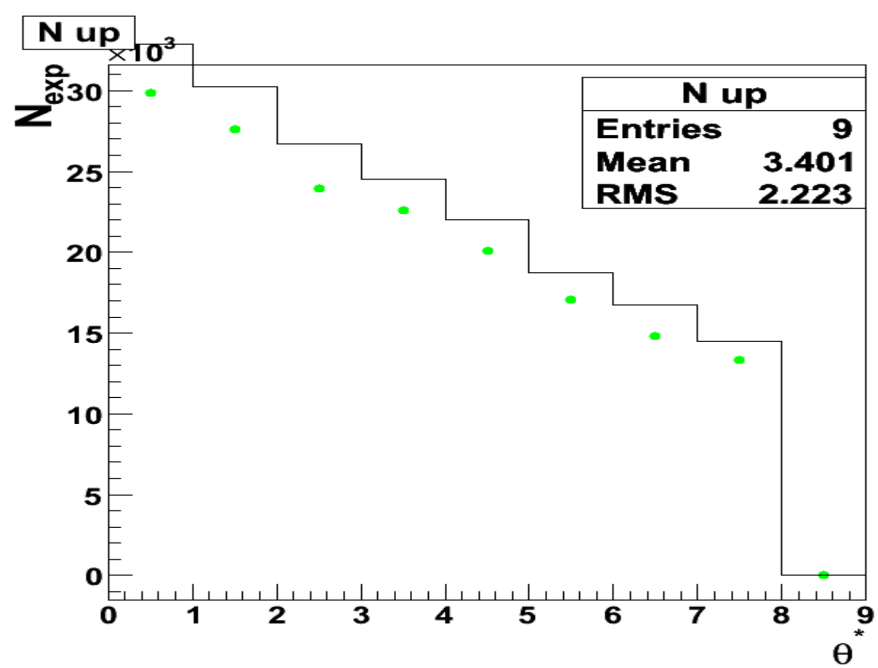

N up
×10^3
N_exp
N up
Entries 9
Mean 3.401
RMS 2.223
30
25
20
15
10
5
0
30 31 32 33 34 35 36 37 38 39
θ

$$L^{new} = L \cdot \frac{1}{10^{-27}}$$

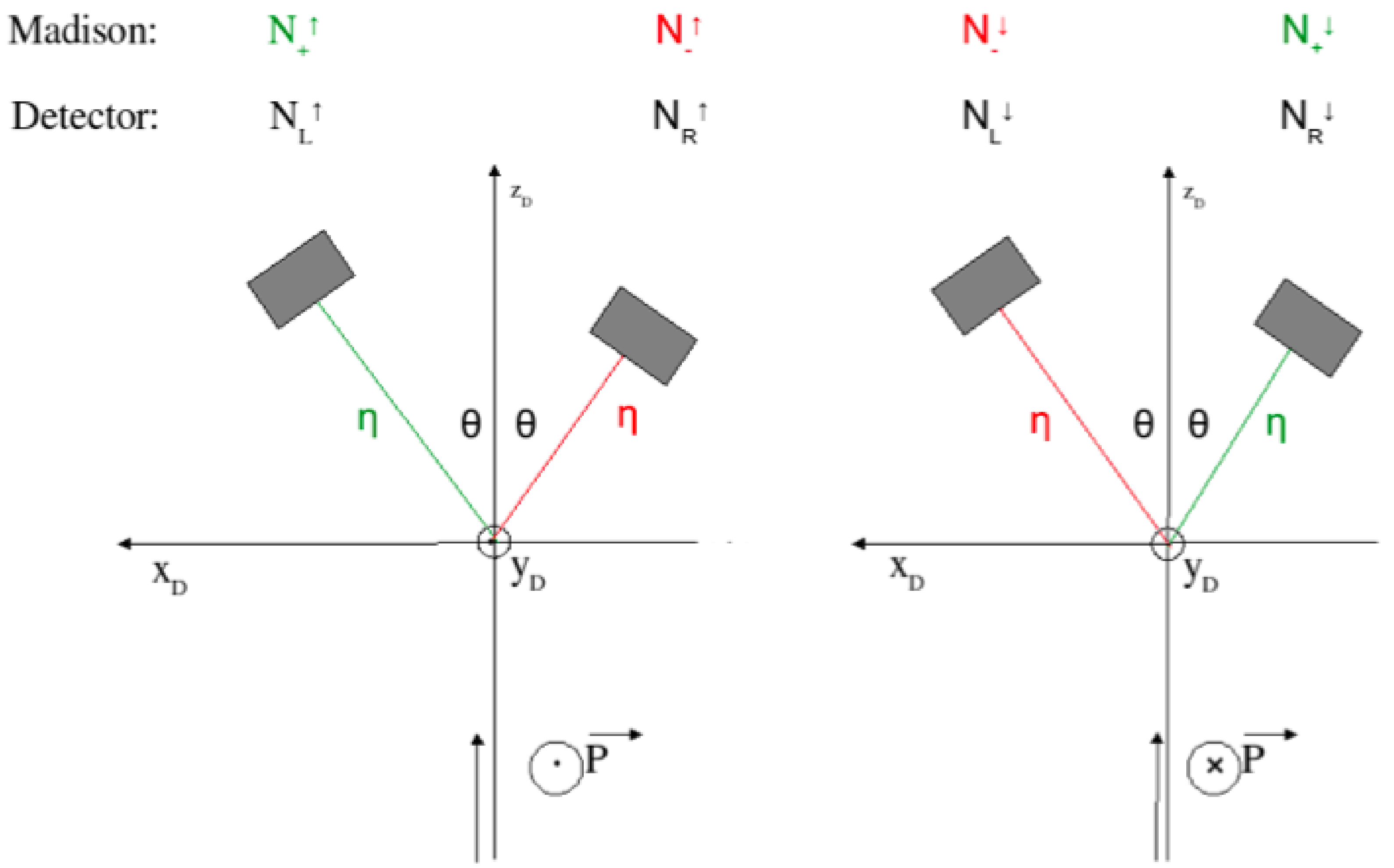




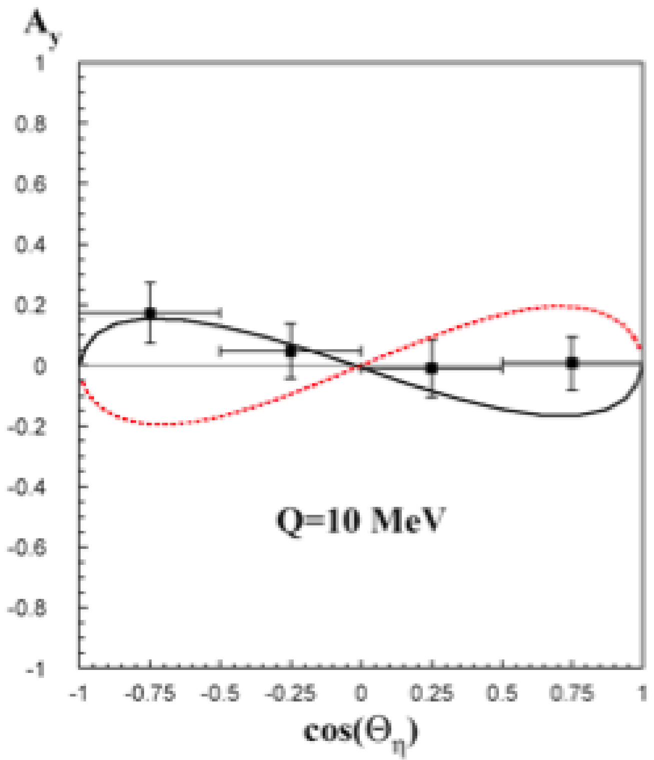


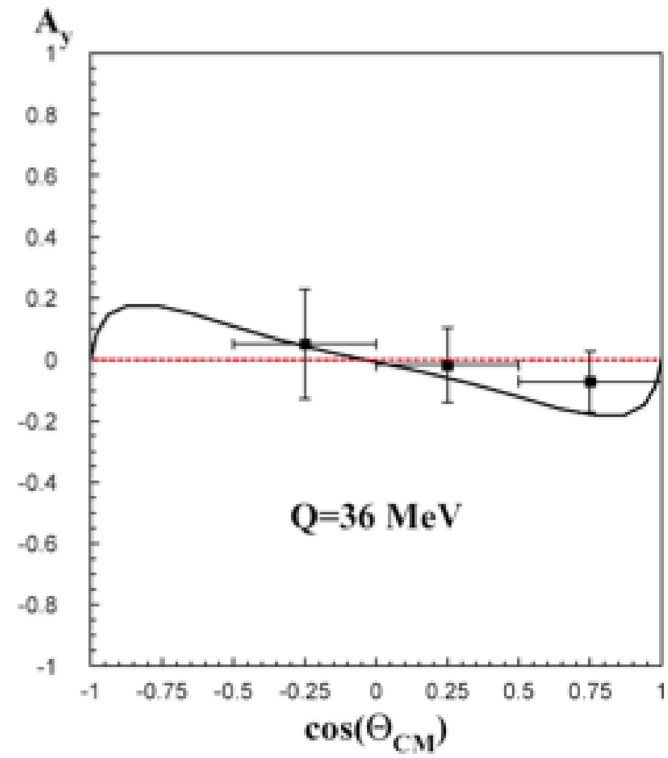


Madison convention



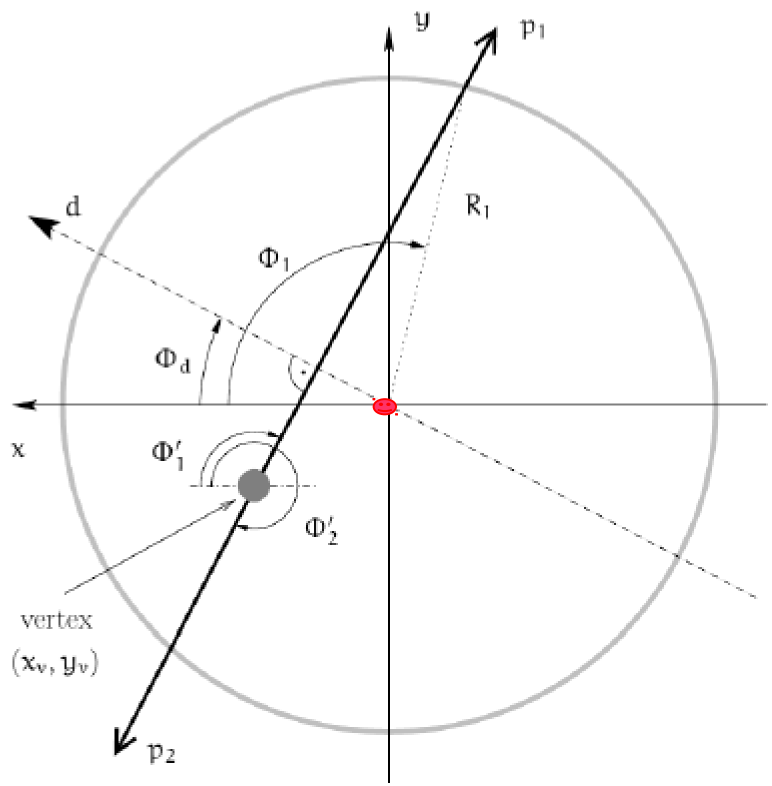
COSY-11



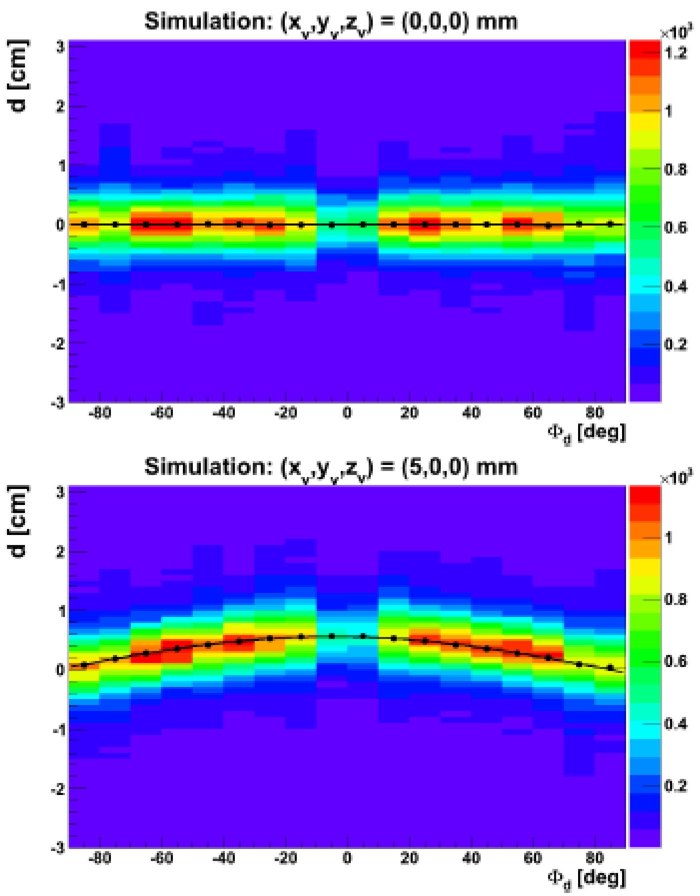


Vertex position determination:Levents

x and y vertex coordinates, the method



MC

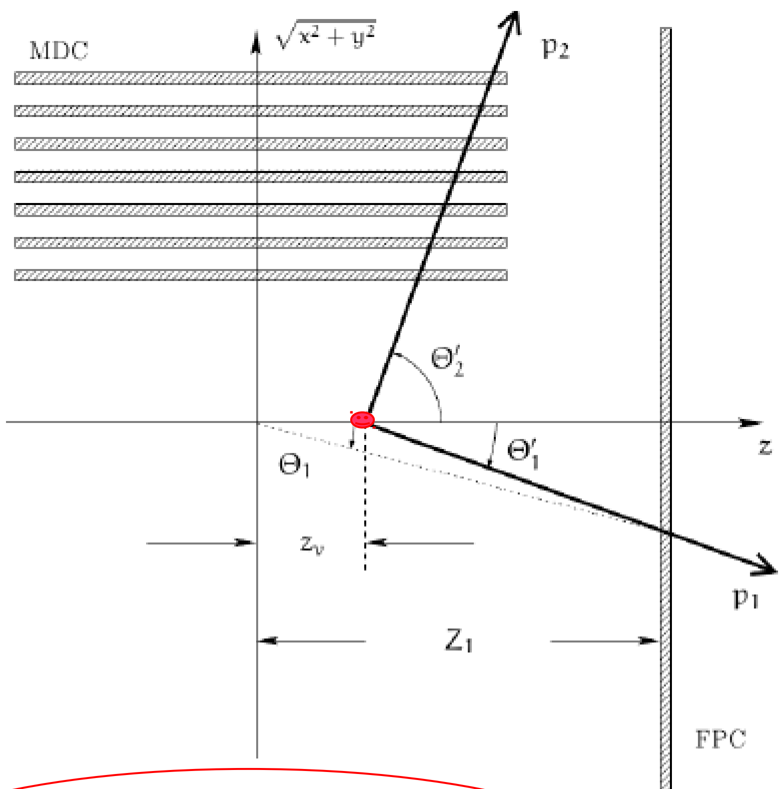


$$d = x^{vertex} \cos(\phi_d) + y^{vertex} \sin(\phi_d)$$

Fit

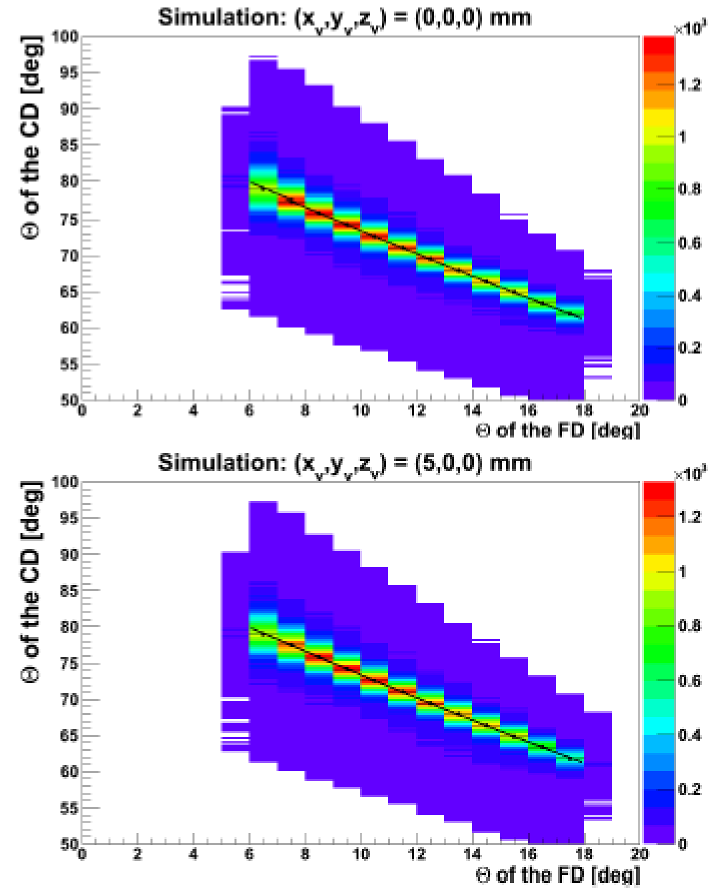
Vertex position determination: Levents

z-vertex coordinate, the method



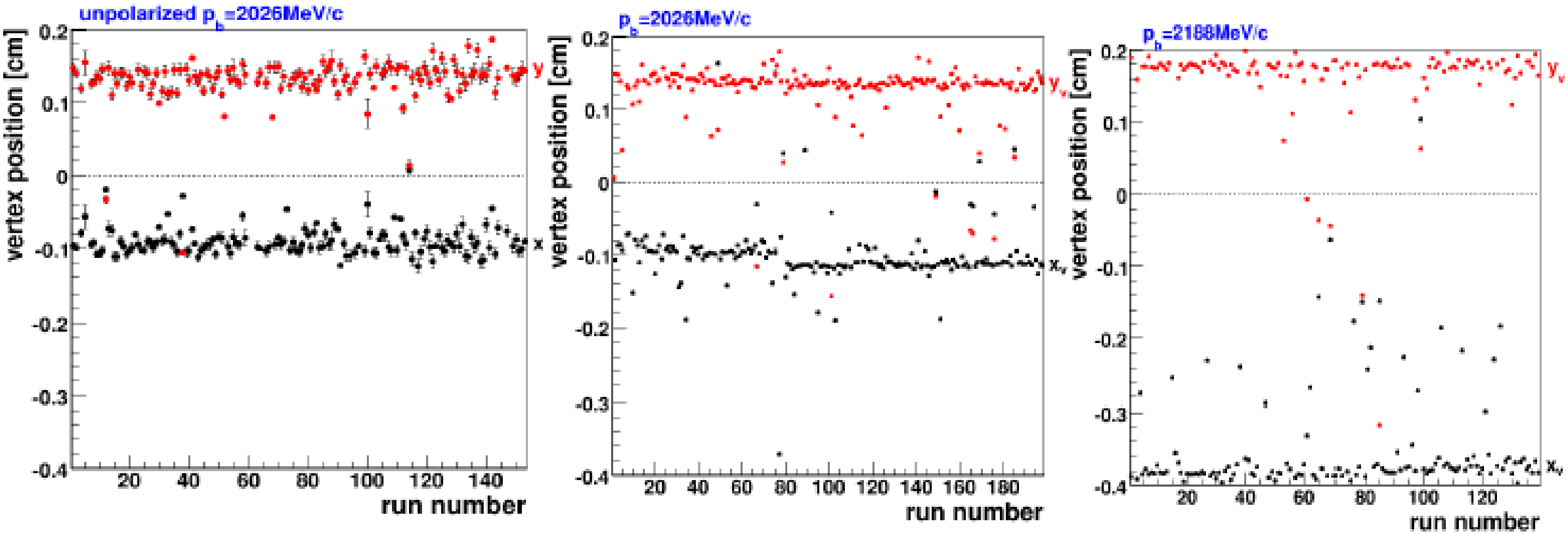
$$tg(\theta_2') = \frac{1-(z^{vertex}/z_{FTH})}{tg(\theta_1)} \bullet \gamma^2_{CMS}$$

MC



Fit

Result for the distance method



vertex	unpolarized P_{beam} = 2.026 Gev/c	P_{beam} = 2.026 Gev/c	P_{beam} = 2.188 Gev/c
	The χ^2 method		
x_v	-0.1164±0.0052	-0.1230±0.0011	-0.2834±0.0010
y_v	0.1119±0.0052	0.1099±0.0011	0.1551±0.0010
	The distance method		
x_v	-0.0908±0.0017	-0.0968±0.0012	-0.3755±0.0019
y_v	0.1386±0.0019	0.1369±0.0011	0.1793±0.0015

Fit parameters for Asymmetry

Spin up

Theta	A $\pm\sigma$A	B $\pm\sigma$B	P$\pm\sigma$P
$30 < \theta < 34$	0.2009$\pm$0.0058	-0.011$\pm$0.0042	0.5294$\pm$0.053
$34 < \theta < 38$	0.1997$\pm$0.0063	-0.0031$\pm$0.0045	0.5188$\pm$0.05
$38 < \theta < 42$	0.197$\pm$0.0070	-0.016$\pm$0.0050	0.5218$\pm$0.046
$42 < \theta < 46$	0.1925$\pm$0.0087	-0.008$\pm$0.0062	0.5218$\pm$0.051

Spin down

Theta	a $\pm\sigma$a	b $\pm\sigma$b	P$\pm\sigma$P
$30 < \theta < 34$	-0.255$\pm$0.0059	-0.0024$\pm$0.0043	-0.6719$\pm$0.066
$34 < \theta < 38$	-0.2427$\pm$0.0065	-0.0045$\pm$0.0046	-0.6306$\pm$0.06
$38 < \theta < 42$	-0.2417$\pm$0.0072	-0.0155$\pm$0.0052	-0.6403$\pm$0.055
$42 < \theta < 46$	-0.2341$\pm$0.0089	-0.0165$\pm$0.0064	-0.6346$\pm$0.06

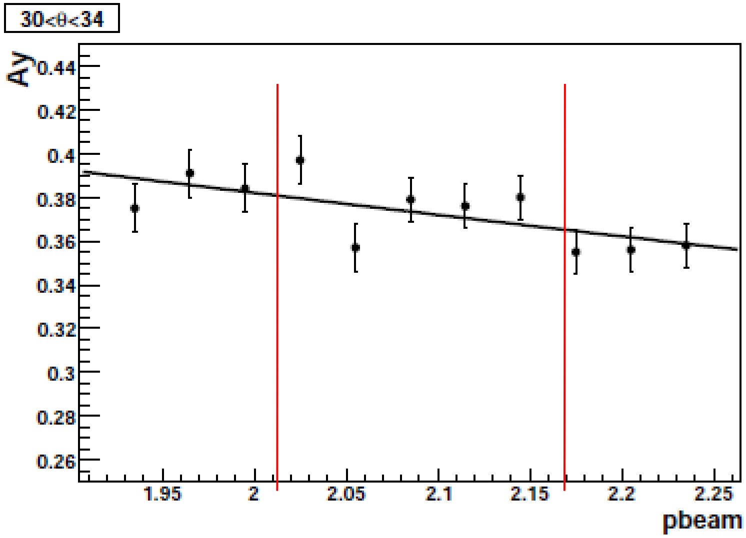
$$\overline{P} \equiv \frac{\sum_{n=1}^{4} \frac{p_n}{\sigma_n^2}}{\sum_{n=1}^{4} \frac{1}{\sigma_n^2}}$$

$$\sigma_{\overline{P}} \equiv \sqrt{\frac{1}{\sum_{n=1}^{4}\left(\frac{1}{\sigma_n^2}\right)}}$$

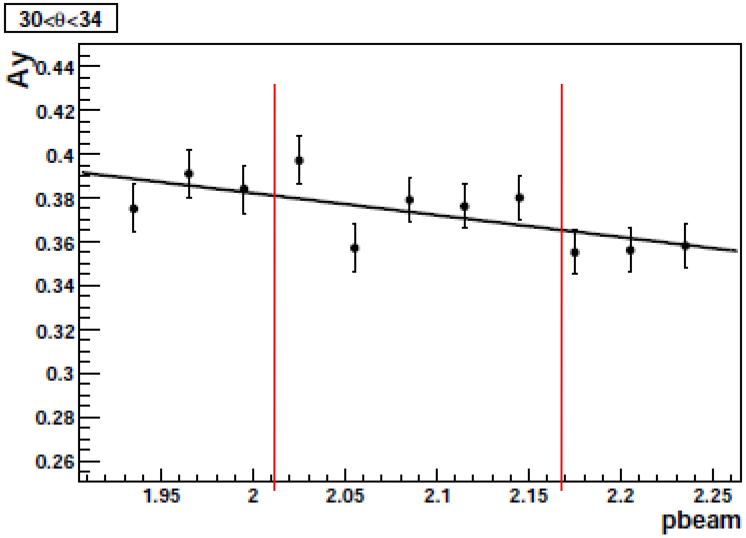
EDDA data base

$$A_y(p_{beam}) \equiv a \cdot p_{beam} + b$$

$$A_y(p_{beam}) \equiv \alpha \cdot e^{-\beta \cdot p_{beam}}$$



(a) exponential fit

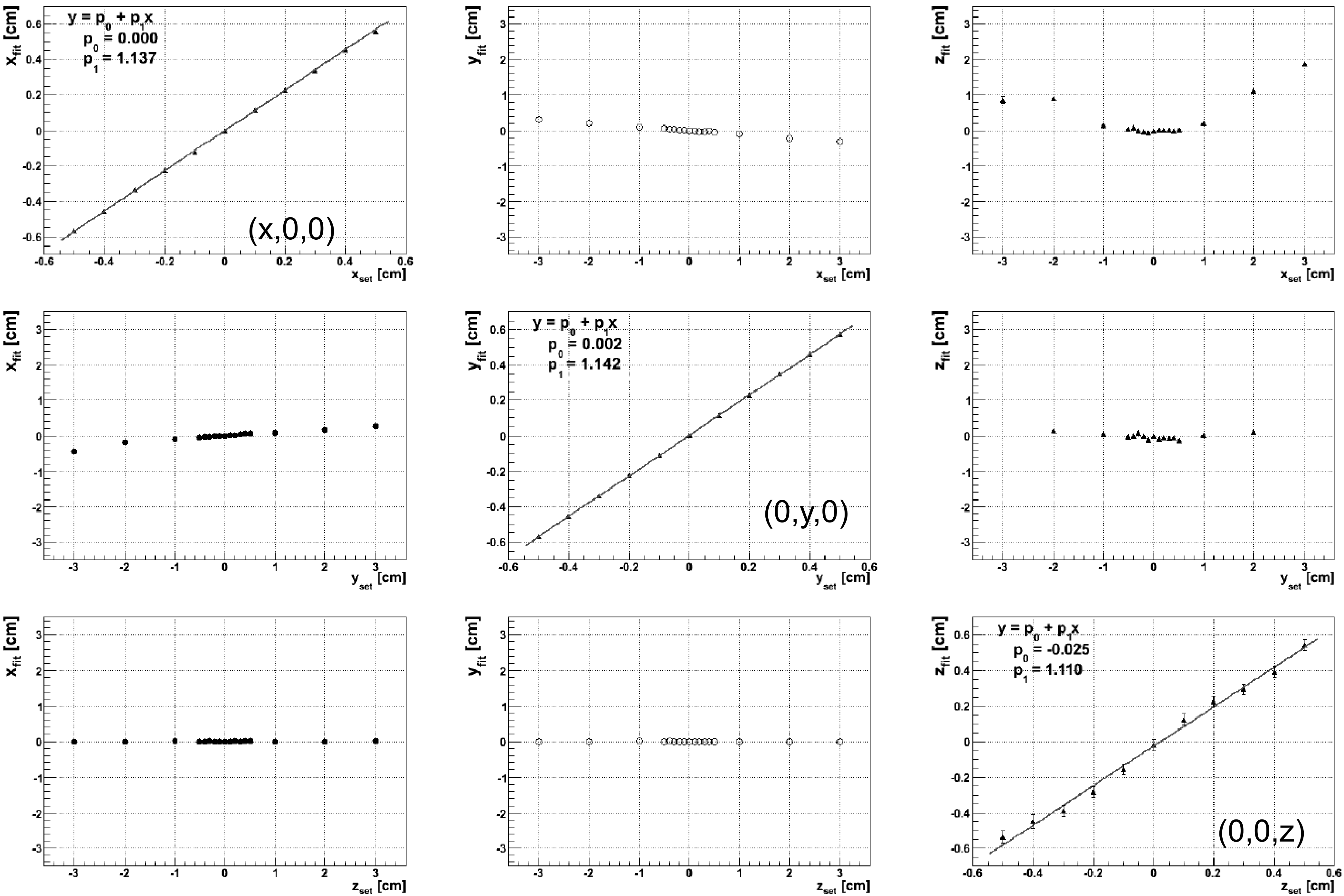


(b) line fit

Calculations of the error bars for Asymmetry(δε)

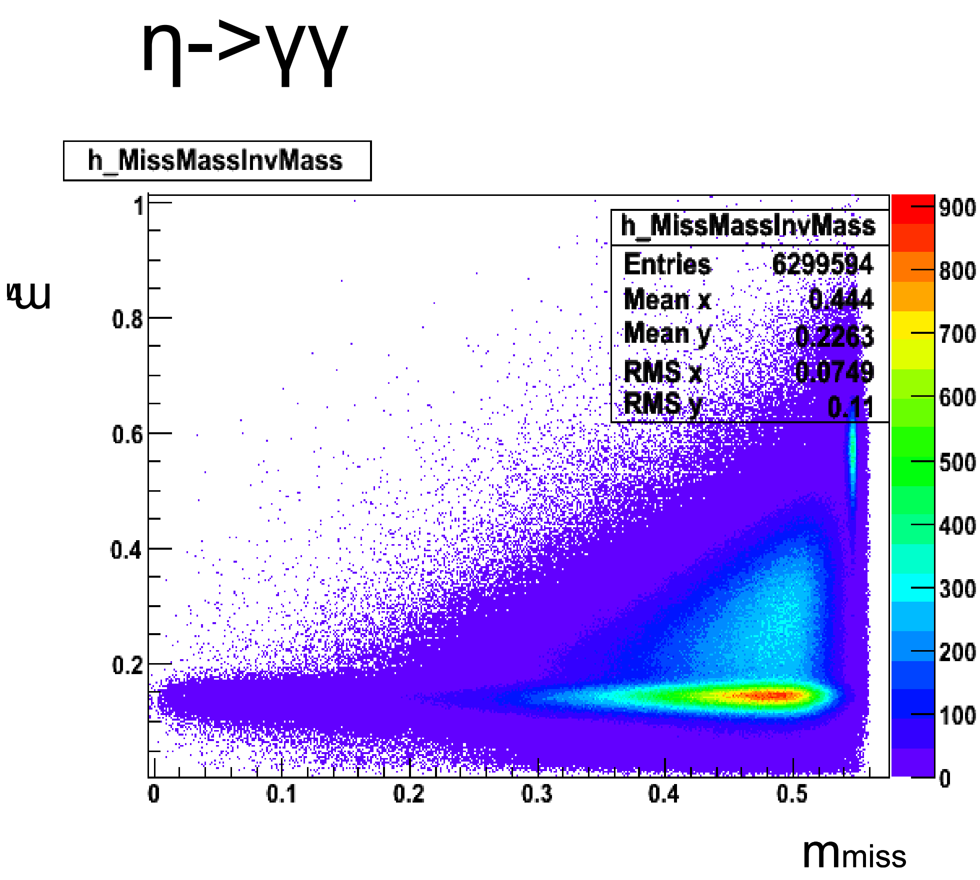
$$\delta\epsilon \equiv \sqrt{\left(\frac{\delta\epsilon}{\delta N_+}\cdot\delta N_+\right)^2+\left(\frac{\delta\epsilon}{\delta N_-}\cdot\delta N_-\right)^2}$$

MC for the shift of vertex position

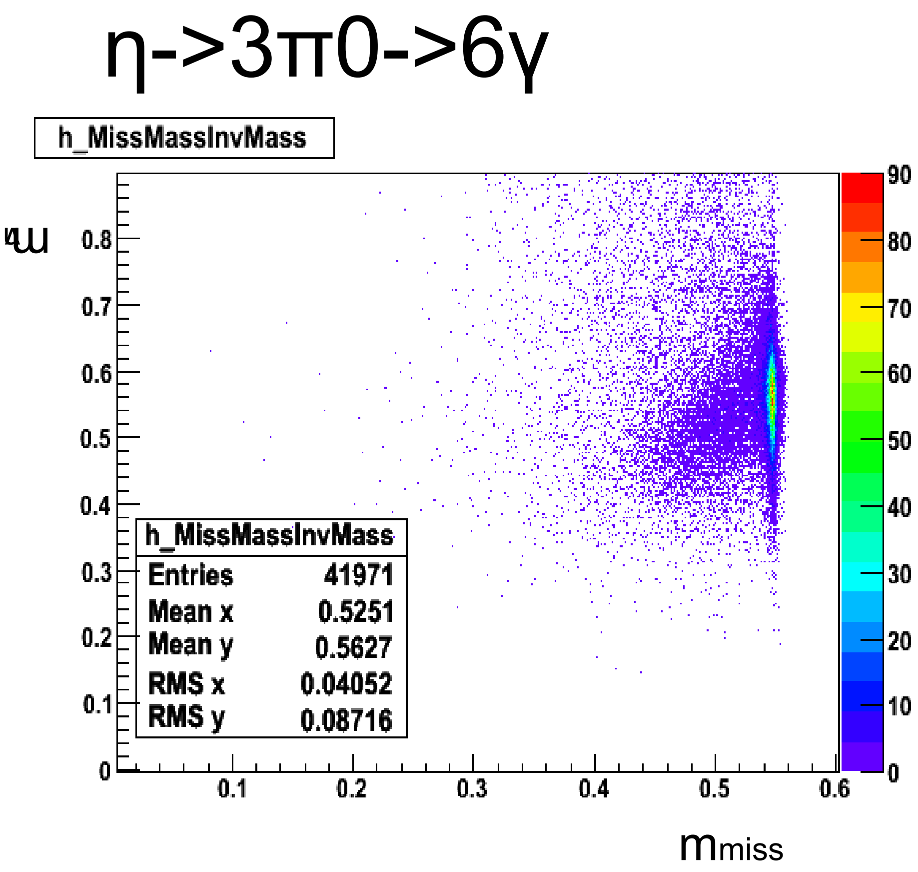


Hodana M. Moskal P. Ozerianska I. *http://arxiv.org/abs/1309.0430*

N	Theta	A_y	P Up	P Down
1	$28 < \theta < 32$	0.3817	0.56 ± 0.01	0.69 ± 0.01
2	$32 < \theta < 36$	0.3811	0.55 ± 0.02	0.68 ± 0.02
3	$36 < \theta < 40$	0.3788	0.56 ± 0.02	0.69 ± 0.02
4	$40 < \theta < 44$	0.3669	0.56 ± 0.03	0.69 ± 0.02
5	$44 < \theta < 48$	0.3339	0.55 ± 0.04	0.74 ± 0.04



η->γγ
h_MissMassInvMass
Entries 6299594
Mean x 0.444
Mean y 0.2263
RMS x 0.0749
RMS y 0.11
mmiss



η->3π0->6γ
h_MissMassInvMass
Entries 41971
Mean x 0.5251
Mean y 0.5627
RMS x 0.04052
RMS y 0.08716
mmiss

Experiment with WASA-at-COSY

Q [MeV/c]	P [MeV/c]
15	2026
72	2188

Compare with previous Experiment (reconstructed Eta=2000 events)

$N_{\eta\to\gamma\gamma}$	$N_{\eta\to 3\pi^o}$
99770	81861
447739	375580

R.Czyżykiewicz at al., Phys.Rev.Lett. **98**, 122003 (2007)

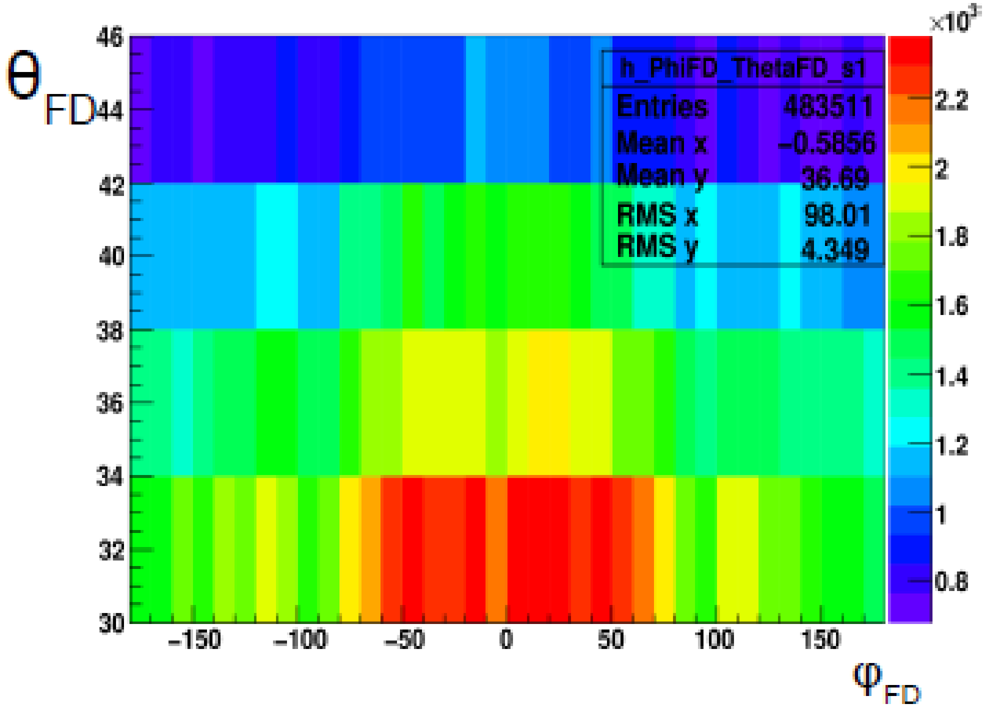
(control systematic error of the Polarization determination to about 1%)

Measurement time: 164 h

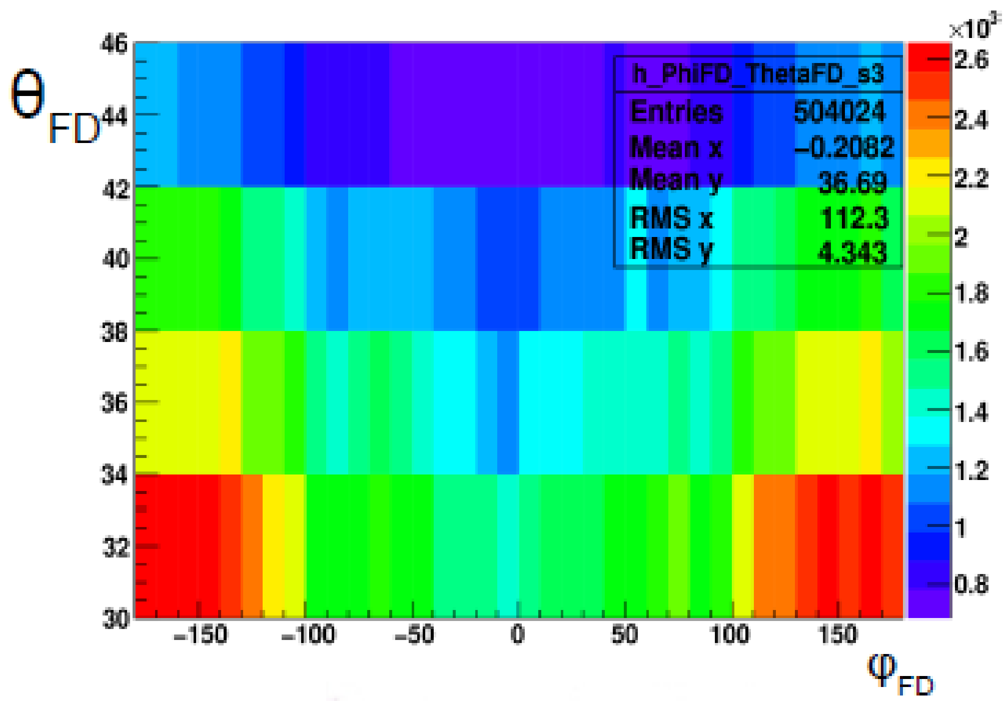
With P=70%: 74 h *With P=60%*: 47 h

Spin Up/Down measurements

Spin Up

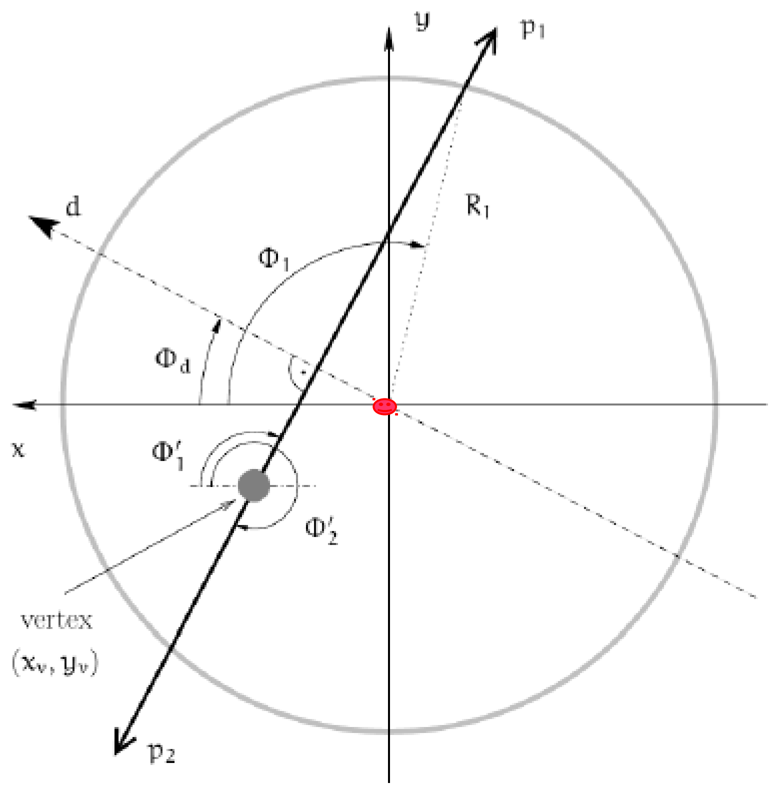


Spin Down

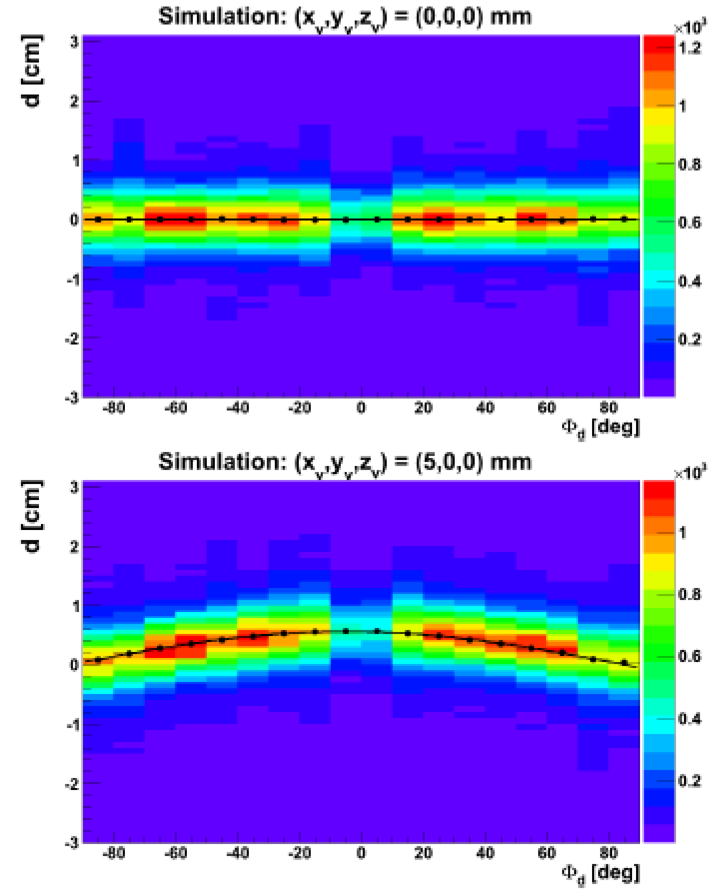


Vertex position determination: Levents

x and y vertex coordinates, the method



MC

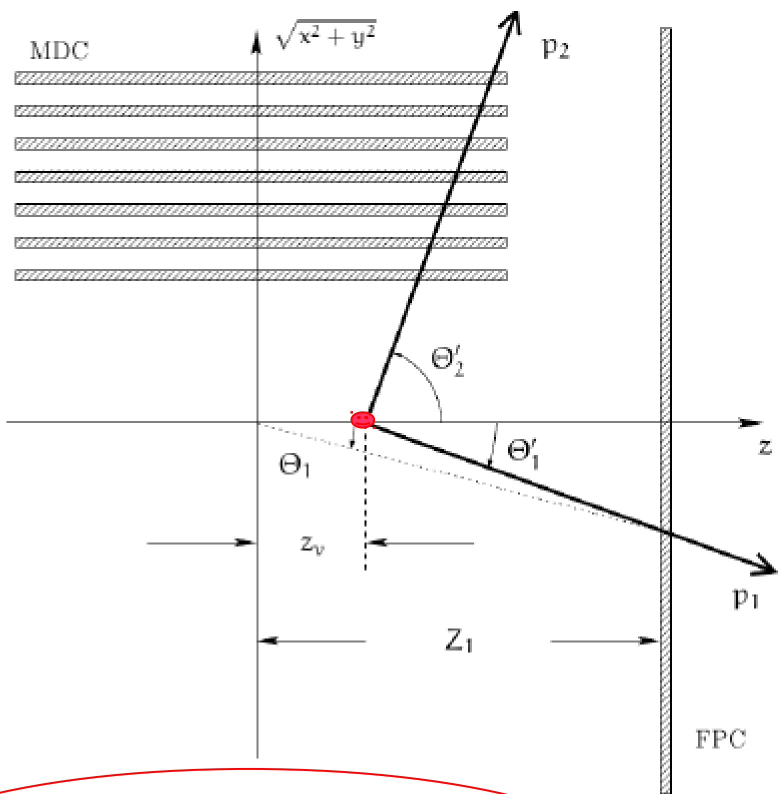


$$d = x^{vertex}\cos(\phi_d) + y^{vertex}\sin(\phi_d)$$

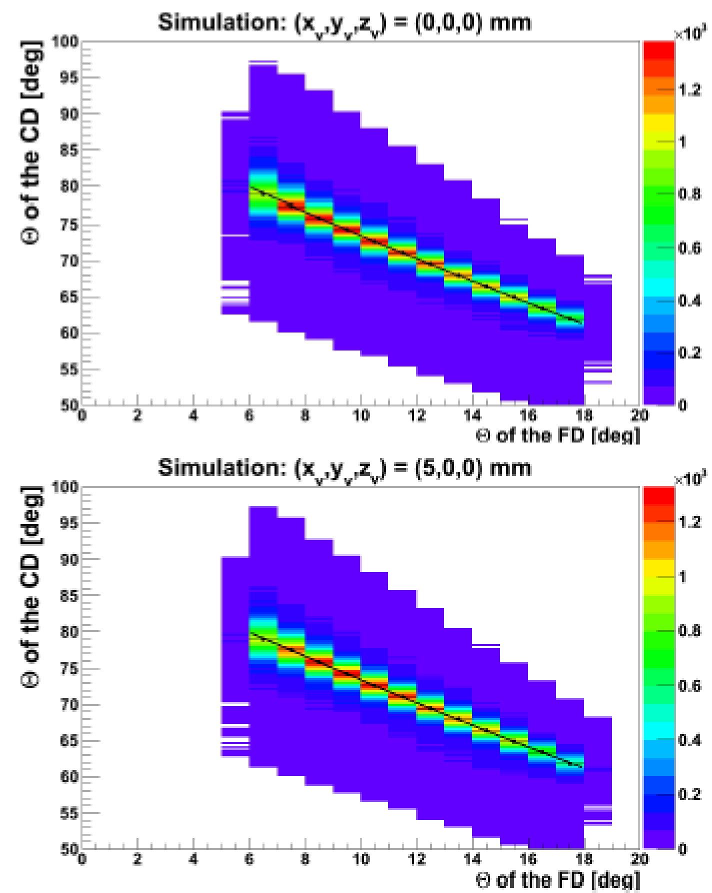
Fit

Vertex position determination: Levents

z-vertex coordinate, the method



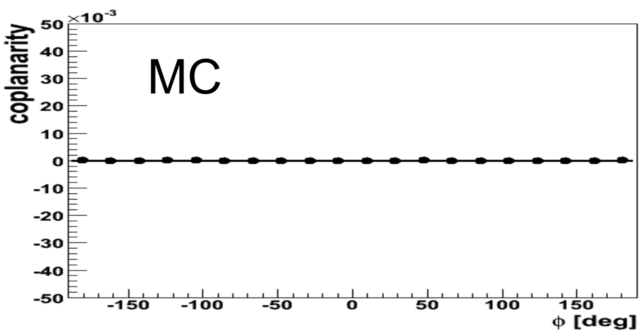
MC

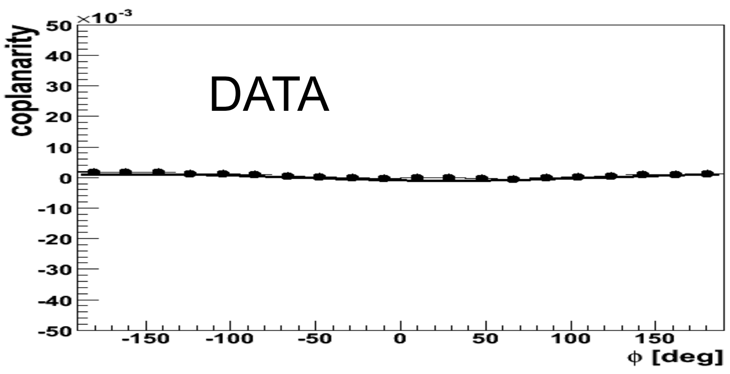


$$tg(\theta_2') = \frac{1-(z^{vertex}/z_{FTH})}{tg(\theta_1)} \bullet \gamma_{CMS}^2$$

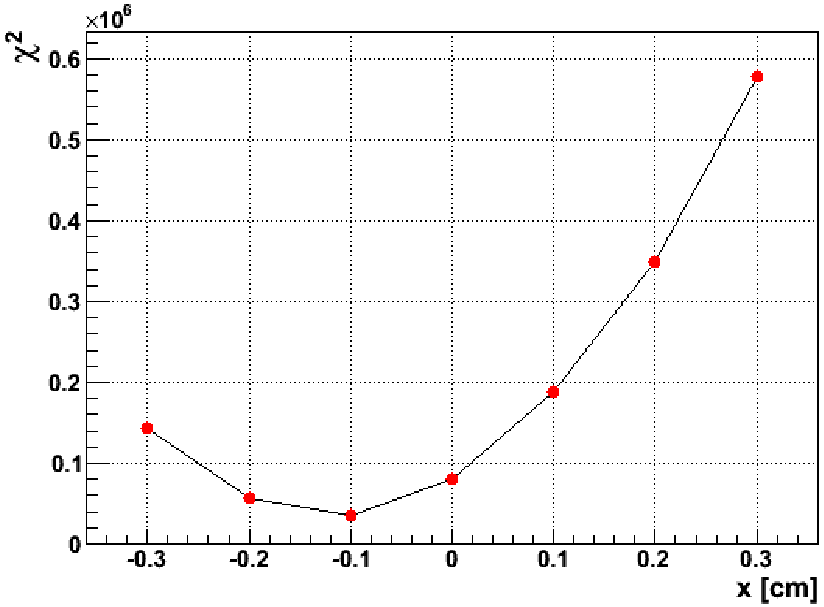
Fit

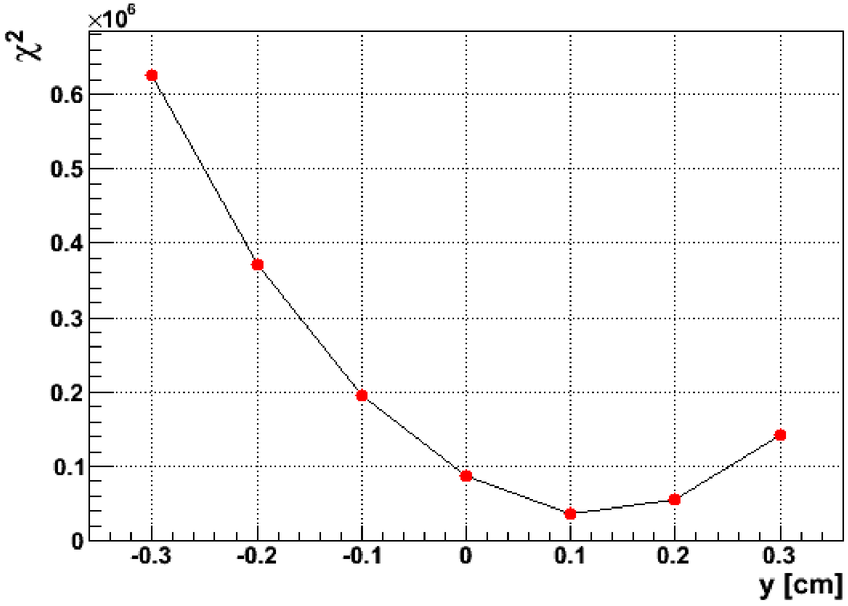
Vertex position determination:
coplanarity



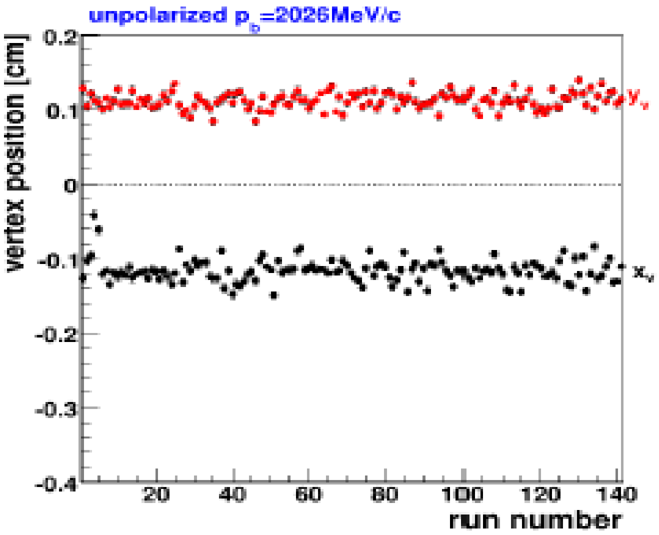


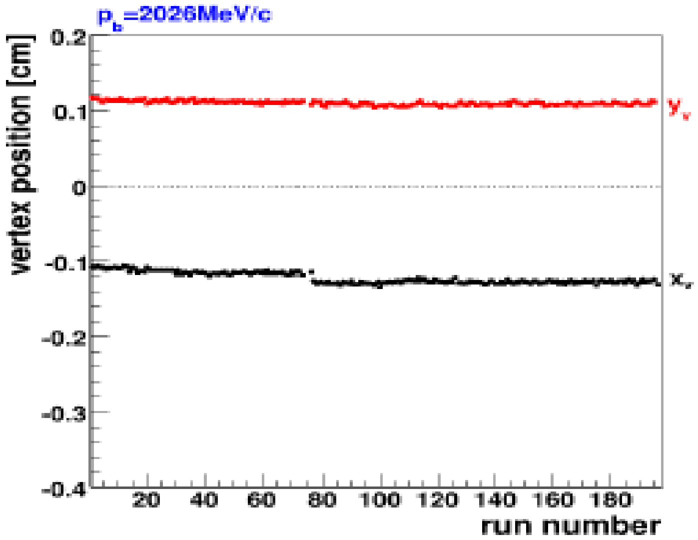
$$\chi^2 = \sum_i \frac{(M_i^{MC} - M_i^{exp})^2}{(\sigma_i^{exp})^2}$$

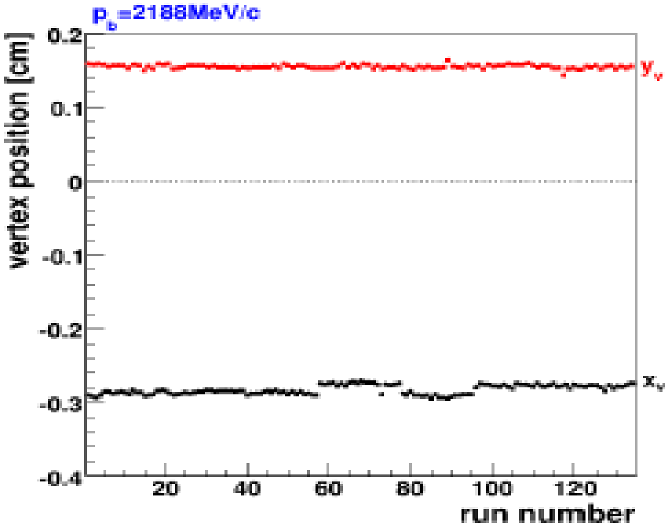




Result for the coplanarity method

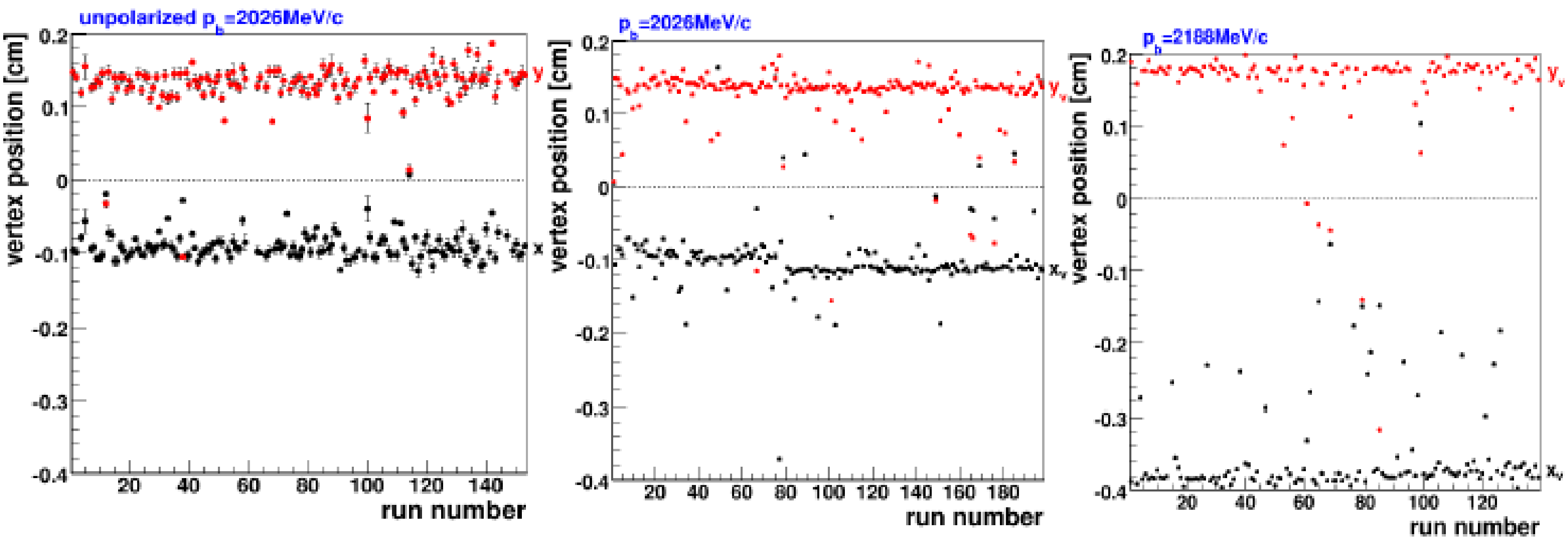






vertex	unpolarized P_{beam} = 2.026 Gev/c	P_{beam} = 2.026 Gev/c	P_{beam} = 2.188 Gev/c
The χ^2 method			
x_v	-0.1164±0.0052	-0.1230±0.0011	-0.2834±0.0010
y_v	0.1119±0.0052	0.1099±0.0011	0.1551±0.0010
The distance method			
x_v	-0.0908±0.0017	-0.0968±0.0012	-0.3755±0.0019
y_v	0.1386±0.0019	0.1369±0.0011	0.1793±0.0015

Result for the distance method



vertex	unpolarized P_{beam} = 2.026 Gev/c	P_{beam} = 2.026 Gev/c	P_{beam} = 2.188 Gev/c
The χ^2 method			
x_v	-0.1164±0.0052	-0.1230±0.0011	-0.2834±0.0010
y_v	0.1119±0.0052	0.1099±0.0011	0.1551±0.0010
The distance method			
x_v	-0.0908±0.0017	-0.0968±0.0012	-0.3755±0.0019
y_v	0.1386±0.0019	0.1369±0.0011	0.1793±0.0015