# Up-down asymmetry in $B \to K\pi\pi\gamma$ decays

Vishal Bhardwaj[1] & Karim Trabelsi[2]

[1]IISER Mohali , [2]LAL Orsay

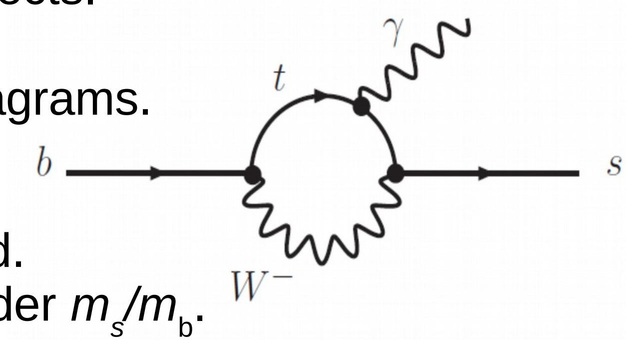
''let's embrace the future...''

Strasbourg, April 10, 2019

Photon polarisation in B→Kππγ decays Workshop

# Motivation

Rare $b \to s\gamma$ FCNC transitions are expected to be sensitive to NP effects.
In SM, $b \to s\gamma$ are forbidden at the tree level.
However they do proceed at loop level, with internal W bosons diagrams.




$\gamma$ emitted from $b \to s\gamma$ transition is predominately left-handed, since the recoiling $s$ quark (which couple to W boson) is left handed.
This implies maximal parity violation up to small corrections of the order $m_s/m_b$.

Measured inclusive $b \to s\gamma$ rate agrees with the SM calculations.
Few SM extensions are also compatible with the current measurments, but predict that the photon acquires a significant right-handed component, due to the exchange of heavy fermion in the electroweak penguin loop. *Atwood, Gronau and Soni* *PRL**79**,185(1997)*

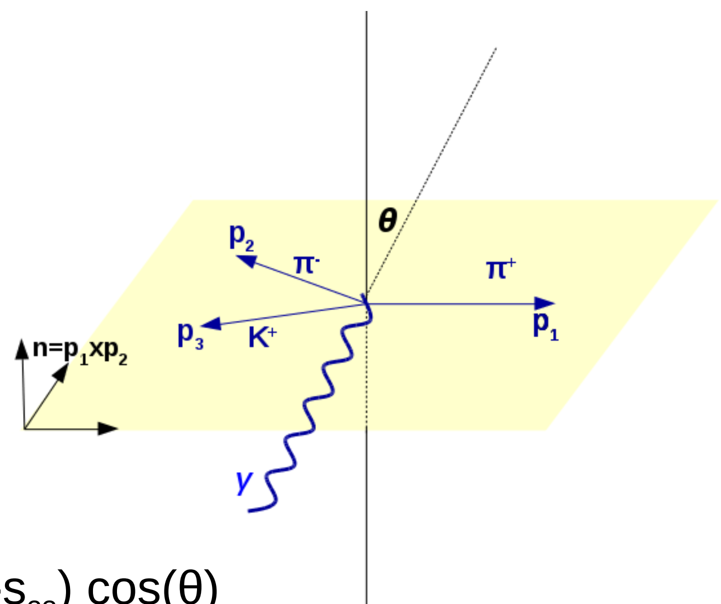
*Gronau, Grossman, Pirjol and Ryd* *PRL**88**,051802(2002),* suggested to measured the up-down asymmetry of the photon direction relative to the $K\pi\pi$ plane in the $K$ resonance rest frame.

- LHCb has observed so called up-down asymmetry in the $B^+ \to K^+\pi^+\pi^- \gamma$ *PRL **112**,161801(2014)*

they found a non-zero up-down asymmetry.

- Not enough to provide any quantitative measurement of the photon polarization.
- It has been suggested by Gronau *et al* that one expect larger asymmetry in mode having neutral pion in the final state.

*PRD**66**,054008(2002)* *PRD **96**, 013002 (2017)*




$\cos(\theta^c) = \mathrm{sgn}(s_{13}-s_{23}) \cos(\theta)$

# Motivation *(more information)*

Gronau & Prijol identify three types of interferences resulting in non-zero up-down asymmetry: *M. Gronau and D. Pirjol, PRD 96, 013002 (2017)*

$\mathcal{A}_a$ : Interferences of amplitudes for two $K^*\pi$ intermediate states. Such interferences, involving $K^{*0}\pi^+$ and $K^{*+}\pi^0$ in $K_1^+ \to K^0\pi^+\pi^0$ ($K^{*0}\pi^0$, $K^{*+}\pi^-$ in $K_1^0 \to K^+\pi^-\pi^0$). This occurs only in decays involving final neutral $\pi$.

$\mathcal{A}_b$ : Interferences of amplitudes for two $K^*\pi$ and $K\rho$ amplitudes. Such interferences occurs in all $K_1 \to K\pi\pi$ decays including both $K_1^+ \to K^+\pi^-\pi^+$, ($K_1^0 \to K^0\pi^-\pi^+$) and $K_1^+ \to K^0\pi^+\pi^0$ ($K_1^0 \to K^+\pi^-\pi^0$).

$\mathcal{A}_c$ : Inteferences of S and D wave amplitudes in $K_1 \to K^*\pi$. This kind of intereferences occurs in all four $K_1 \to K\pi\pi$ charged modes.

Large asymmetry is predicted in $\mathcal{A}_a$ which only occurs in the modes involving a final neutral pion.
Therefore, Belle has potential to contribute and search for up-down asymmetry.
Information from modes with $K_S^0$ and $\pi^0$ will provide crucial information on the photon polarization.

# Motivation

[M.Gronau and D.Pirjol, arXiv:1704.05280]

Reexamining the photon polarization in B→Kππγ

We reexamine, update and extend a suggestion we made fifteen years ago for measuring the photon polarization in $b \to s\gamma$ by observing in $B \to K\pi\pi\gamma$ an asymmetry of the photon with respect to the $K\pi\pi$ plane. Asymmetries are calculated for different charged final states due to intermediate $K_1(1400)$ and $K_1(1270)$ resonant states. Three distinct interference mechanisms are identified contributing to asymmetries at different levels for these two kaon resonances. For $K_1(1400)$ decays including a final state $\pi^0$ an asymmetry around $+30\%$ is calculated, dominated by interference of two intermediate $K^*\pi$ states, while an asymmetry around $+10\%$ in decays including final $\pi^+\pi^-$ is dominated by interference of $S$ and $D$ wave $K^*\pi$ amplitudes. In decays via $K_1(1270)$ to final states including a $\pi^0$ a negative asymmetry is favored up to $-10\%$ if one assumes $S$ wave dominance in decays to $K^*\pi$ and $K\rho$, while in decays involving $\pi^+\pi^-$ the asymmetry can vary anywhere in the range $-13\%$ to $+24\%$ depending on unknown phases. For more precise asymmetry predictions in the latter decays we propose studying phases in $K_1 \to K^*\pi, K\rho$ by performing dedicated amplitude analyses of $B \to J/\psi(\psi')K\pi\pi$. In order to increase statistics in studies of $B \to K\pi\pi\gamma$ we suggest using isospin symmetry to combine in the same analysis samples of charged and neutral $B$ decays.

Table 3: Up-down photon asymmetry $\bar{\mathcal{A}}$ in $B^+ \to K^0\pi^+\pi^0\gamma$ from intermediate $K_1(1400)$. The asymmetry $\bar{\mathcal{A}}_a$ neglects a contribution of a $\rho K$ amplitude as described in the text. For the total asymmetry we use $\alpha_S = 40°$, a value favored by the analysis of [21].

| $\delta_{DS}^{(K^*\pi)}$(degrees) | 0 | 45 | 90 | 135 | 180 | 225 | 270 | 315 |
|---|---|---|---|---|---|---|---|---|
| $\bar{\mathcal{A}}_a$ | 0.30 | 0.21 | 0.14 | 0.14 | 0.19 | 0.28 | 0.34 | 0.35 |
| $\bar{\mathcal{A}}_{\rm total}$ | 0.30 | 0.21 | 0.15 | 0.14 | 0.20 | 0.29 | 0.35 | 0.36 |

We wish to thank Karim Trabelsi for asking very useful questions which motivated this work and Jonathan Rosner for helpful correspondence.

# $A_{UD}$ extraction

M. Grnonau, D. Pirjol PRD 66, 054008(2002), PRD 96, 013002 (2017)
LHCb, PRL 112, 161801 (2014)

Differential decay rate of $B \to K\pi\pi\gamma$ can be written as :

Resonances in $K\pi\pi$

$$\frac{d\Gamma}{ds\,ds_{13}\,ds_{23}\,d\cos\theta} \propto \sum_{i=0,2,4} a_i(s, s_{13}, s_{23}) \cos^i\theta + \lambda_\gamma \sum_{j=1,3} a_j(s, s_{13}, s_{23}) \cos^j\theta$$

Photon Polarization

$S_{ij} = (p_i+p_j)^2$ and $s=(p_1+p_2+p_3)^2$ $p_1$,$p_2$ and $p_3$ are four-momenta of $\pi^-$, $\pi^+$ and $K^+$

$$\mathcal{A}_{ud} \equiv \frac{\int_0^1 d\cos\theta \frac{d\Gamma}{d\cos\theta} - \int_{-1}^0 d\cos\theta \frac{d\Gamma}{d\cos\theta}}{\int_{-1}^1 d\cos\theta \frac{d\Gamma}{d\cos\theta}}$$

Fourth-order legendre polynomial is used to fit the distribution

$$f(\cos\hat{\theta}; c_0=0.5, c_1, c_2, c_3, c_4) = \sum_{i=0}^{4} c_i L_i(\cos\hat{\theta})$$

$L_i$ is Legendre polynomial of order $i$

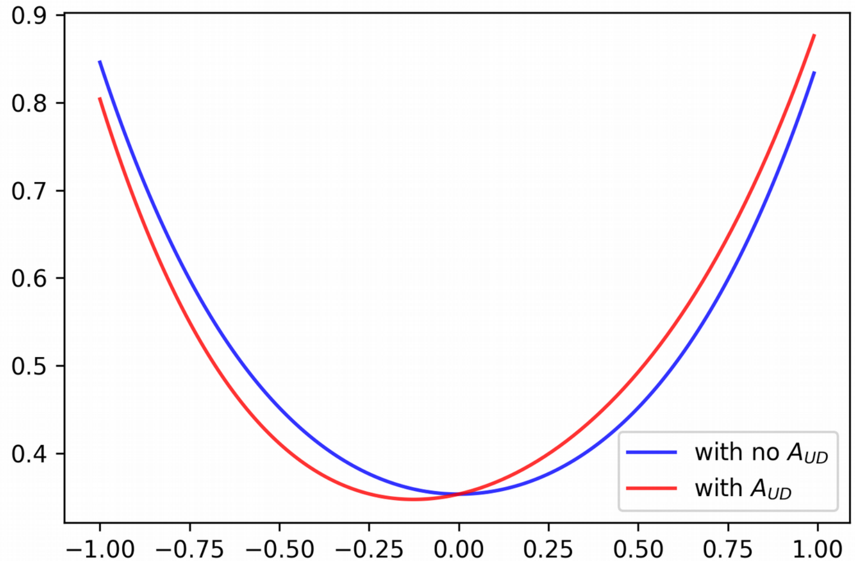
$c_i$ is corresponding coefficient

$A_{UD}$ can be expressed as

$$\mathcal{A}_{ud} = c_1 - \frac{c_3}{4}$$

$\cos(\theta^c) = \mathrm{sgn}(s_{13}-s_{23}) \cos(\theta)$

[1.1,1.3] GeV/$c^2$




Input values from LHCb measurement

# $A_{UD}$ extraction

M. Grnonau, D. Pirjol PRD 66, 054008(2002), PRD 96, 013002 (2017)
LHCb, PRL 112, 161801 (2014)

Differential decay rate of $B \to K\pi\pi\gamma$ can be written as :

Resonances in $K\pi\pi$

$$\frac{d\Gamma}{ds\, ds_{13}\, ds_{23}\, d\cos\theta} \propto \sum_{i=0,2,4} a_i(s, s_{13}, s_{23}) \cos^i \theta + \lambda_\gamma \sum_{j=1,3} a_j(s, s_{13}, s_{23}) \cos^j \theta$$

Photon Polarization

$S_{ij} = (p_i+p_j)^2$ and $s=(p_1+p_2+p_3)^2$ $p_1$,$p_2$ and $p_3$ are four-momenta of $\pi^-$, $\pi^+$ and $K^+$

$$\mathcal{A}_{ud} \equiv \frac{\int_0^1 d\cos\theta \frac{d\Gamma}{d\cos\theta} - \int_{-1}^0 d\cos\theta \frac{d\Gamma}{d\cos\theta}}{\int_{-1}^1 d\cos\theta \frac{d\Gamma}{d\cos\theta}}$$

Fourth-order legendre polynomial is used to fit the distribution

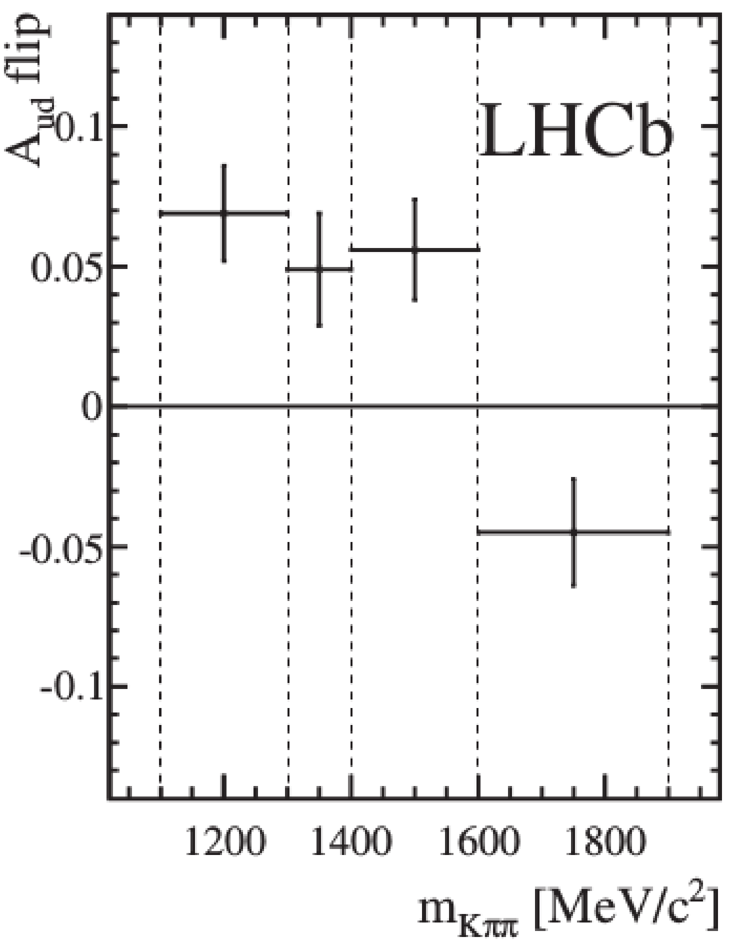
$$f(\cos\hat{\theta}; c_0 = 0.5, c_1, c_2, c_3, c_4) = \sum_{i=0}^{4} c_i L_i(\cos\hat{\theta})$$

$L_i$ is Legendre polynomial of order $i$

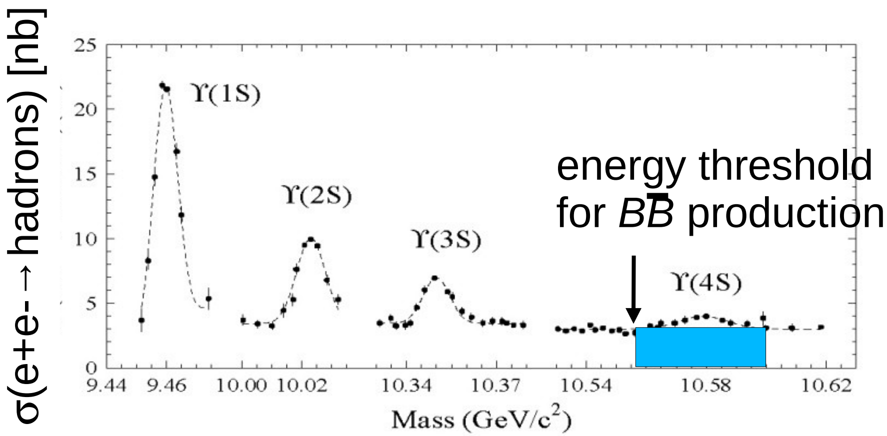
$c_i$ is corresponding coefficient

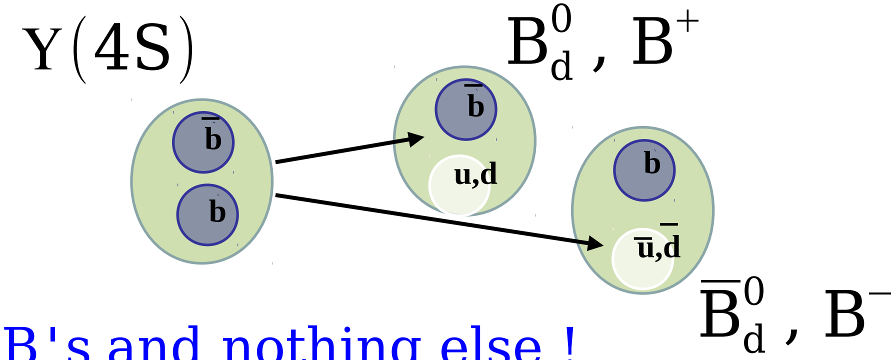
$A_{UD}$ can be expressed as

$$\mathcal{A}_{ud} = c_1 - \frac{c_3}{4}$$



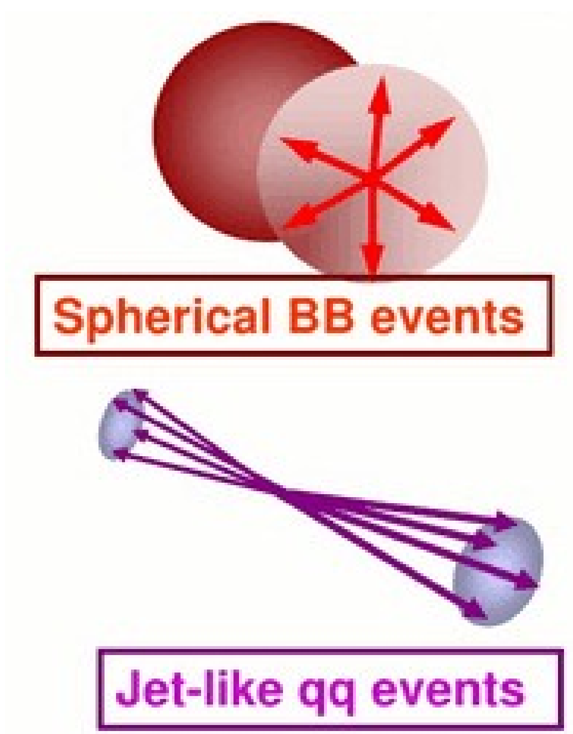
# Υ(4S) B-factory

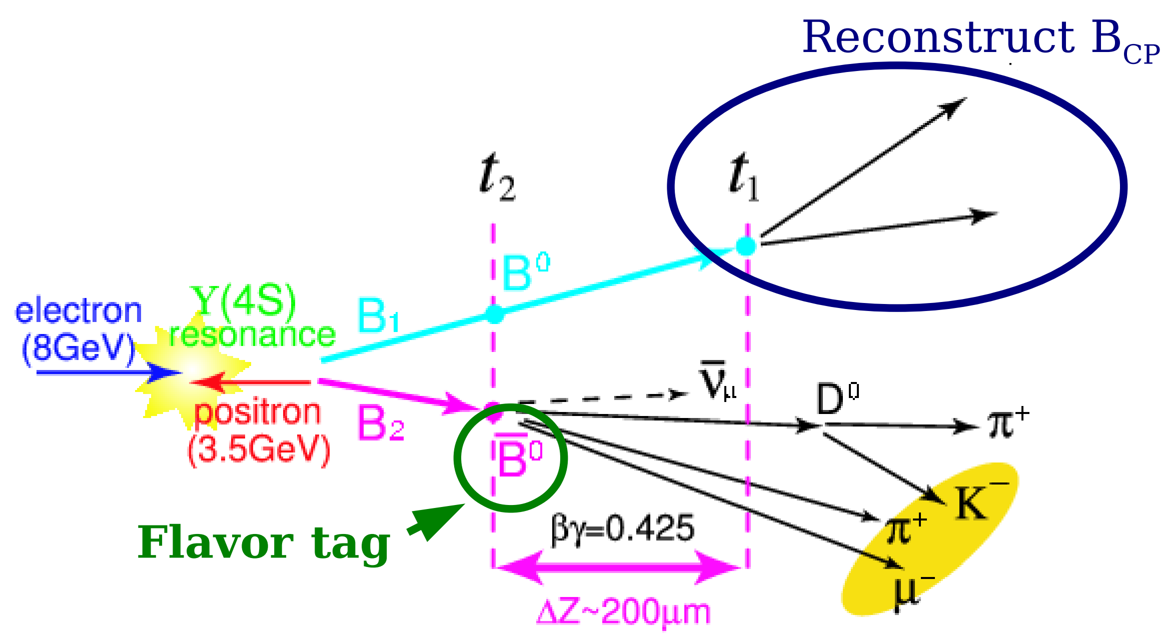



- 2 B's and nothing else !
- 2 B mesons are created simultaneously in a L=1 coherent state

⇒ before first decay, the final states contains a B and a $\overline{B}$




$\Delta z \sim c\beta\gamma\Delta t$

Effective tagging efficiency : $\epsilon_{tag}(1-2\omega_{tag})^2 \sim 30\%$

# Continuum Suppression

mthro : Magnitude of ROE thrust axis
mthrs : Magnitude of B thrust axis
costhr : cosine of angle between thrust axis of *B* and thrust axis of ROE
cosbt : Returns the cosine of angle between thrust axis of *B* and z-axis
cosb : Theta of B vector in CMS frame

cc1-cc9 : 9 Cleo cones

qr : Flavor information from Hamlet

ΔZ : $Z_{Brec} - Z_{btag}$

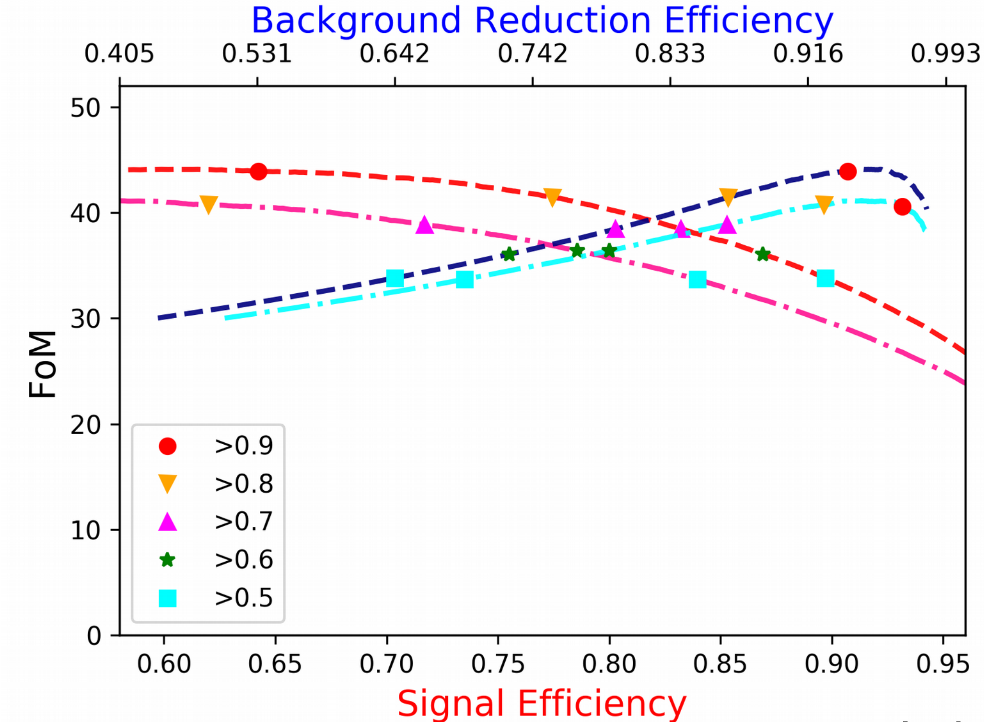
**Use 16+ 1 (LR using 18) variables as input to Neural Network (NeuroBayes)**

KSFW LR

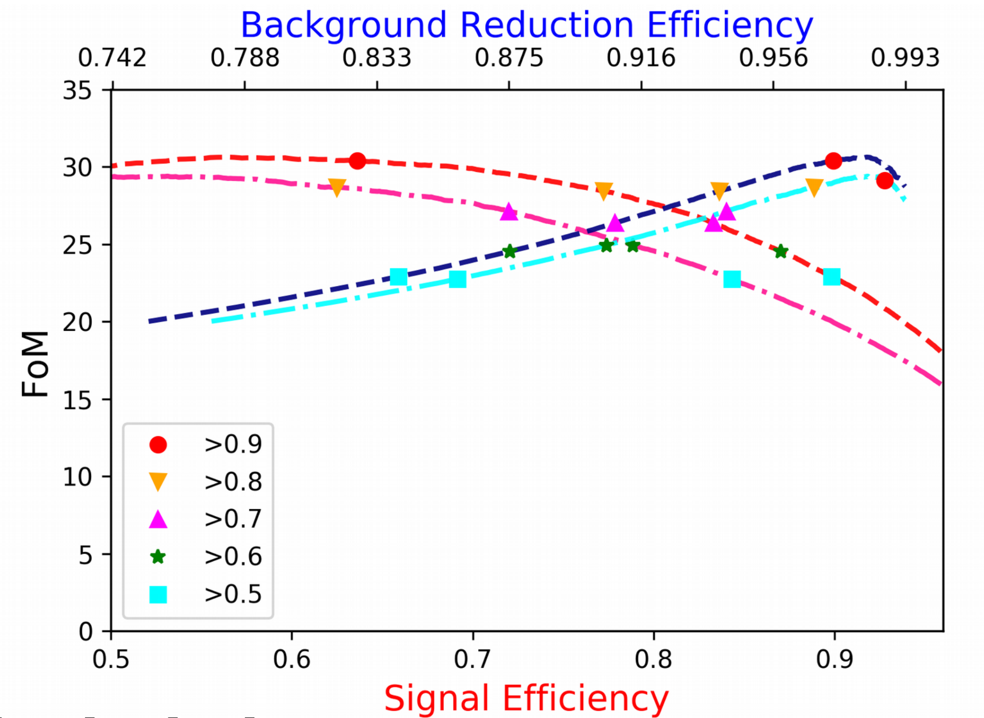
Et : Sum of transverse energy of all particles
MM2 : Missing mass square
Hoo0,1,2,3,4
Hso00,01,02,03,04 [using only charged tracks of other B]
Hso10,12,14 [using only photons of other B]
Hso20,22,24 [using only missing momentum]

# Optimizing the NB cut for continuum suppression

$B^+ \rightarrow K^+\pi^-\pi^+ \gamma$




$B^0 \rightarrow K^+\pi^-\pi^0 \gamma$




NB scaled from [-1,1] to [0,1]

Signal : NB KSFW
Background : NB KSFW

Optimized NB cut > 0.85
FoM : 44.1

Optimized NB cut > 0.85
FoM : 30.6

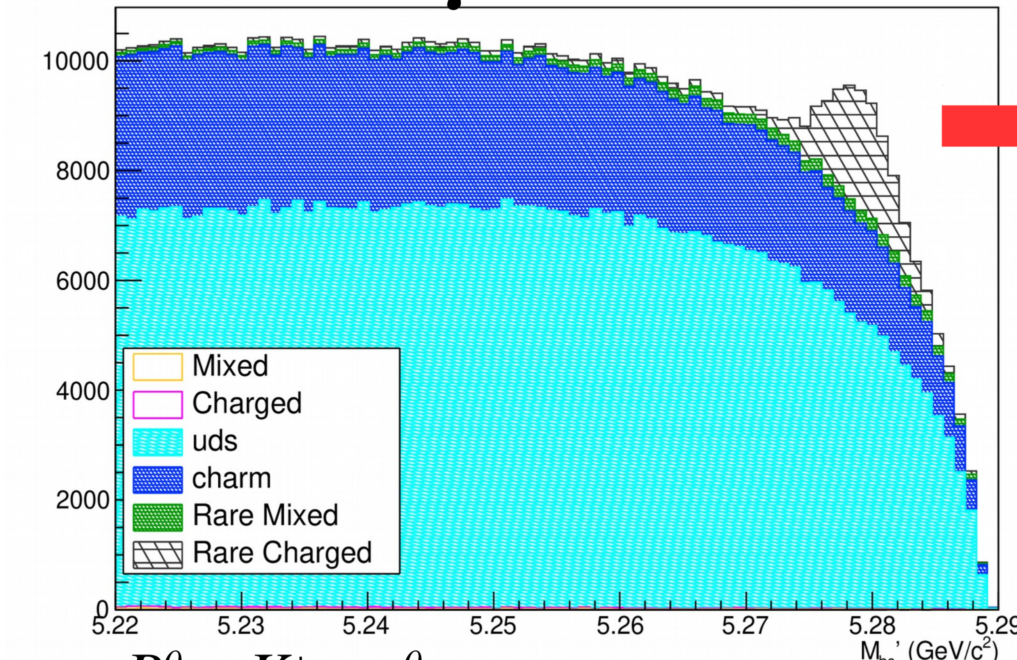


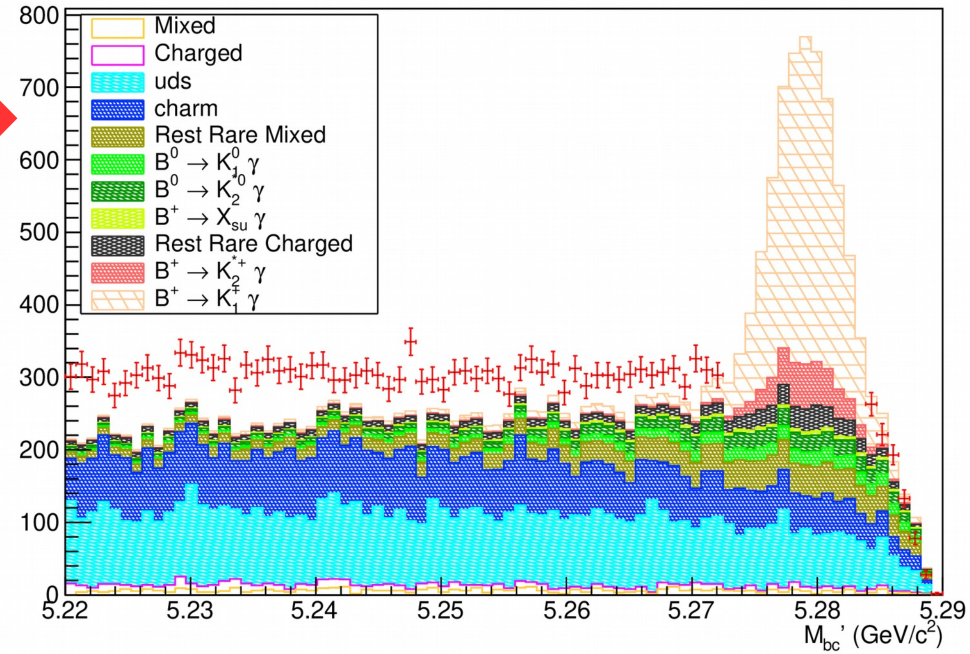
*The shown cut value is not scaled.*

$M'_{bc}$ distribution

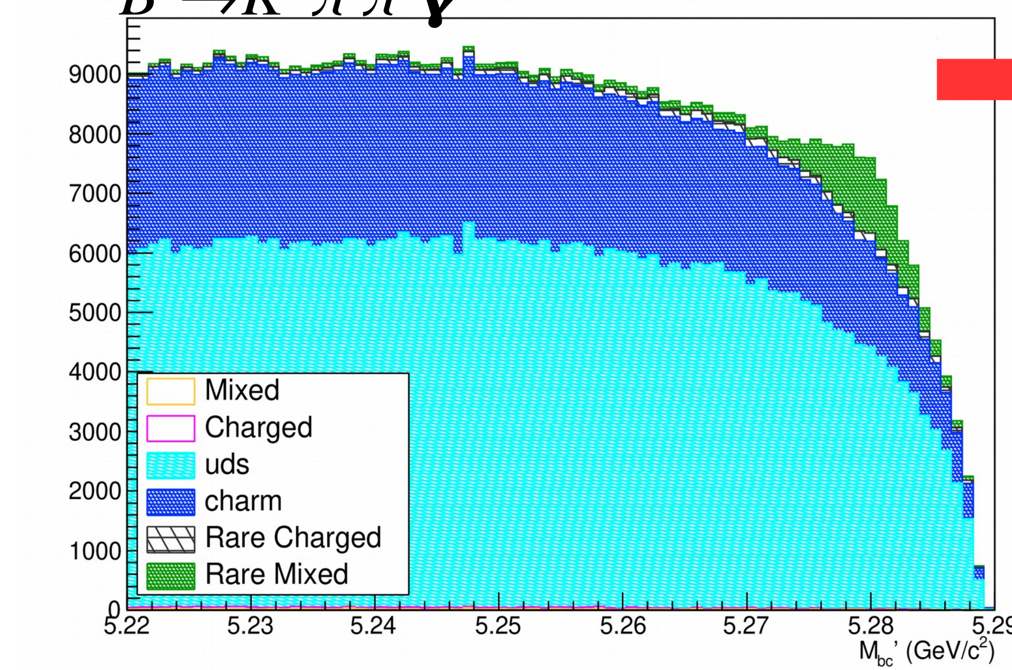
# Background study: continuum suppression

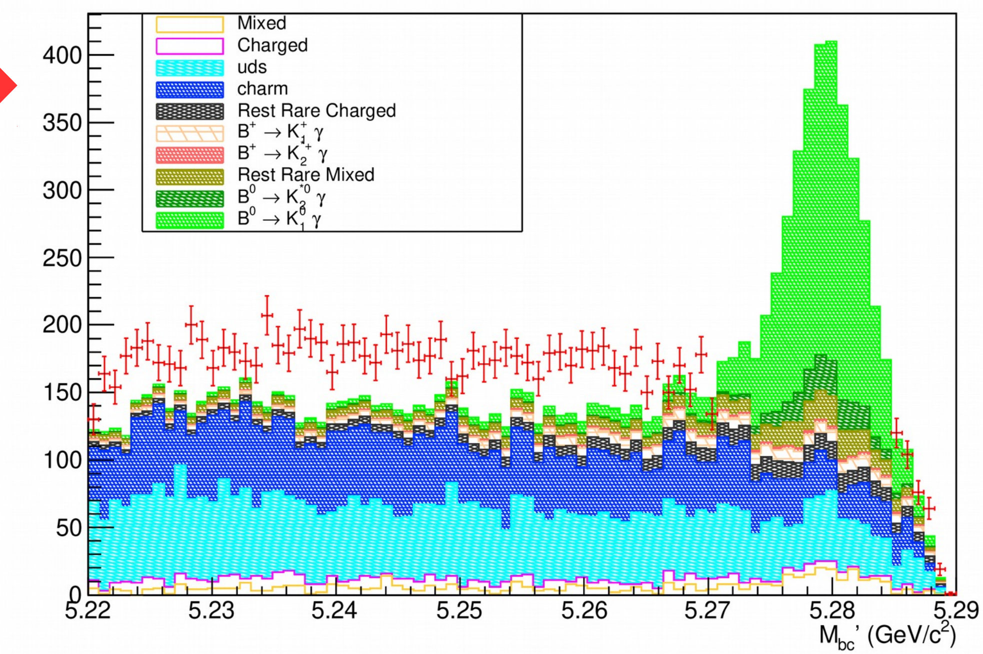
$B^+ \to K^+ \pi^- \pi^+ \gamma$




$B^0 \to K^+ \pi^- \pi^0 \gamma$



let's from now on assume that we have a modest sample of 2000 $K^- \pi^+ \pi^- \gamma$ and 1500 $K^- \pi^+ \pi^0 \gamma$ signal evts...

# GSIM study for $A_{UD}$ extraction

- Validate $A_{UD}$ extraction method, we performed GSIM study.
- Samples generated using modified version of MINT (from EPFL colleagues) with different models and different $A_{UD}$ input values.
- Four samples tested for $B^0 \rightarrow K^- \pi^+ \pi^0 \gamma$
- One sample used to test $B^+ \rightarrow K^+ \pi^- \pi^+ \gamma$
- Boosted the particles into Belle frame, add the other side B decay from separate evtgen generated sample  and pass the events through GSIM environment.
- Recover the generated level information.
- Reconstruct the signal .
- Compare the generated and recontructed value for any significant bias.

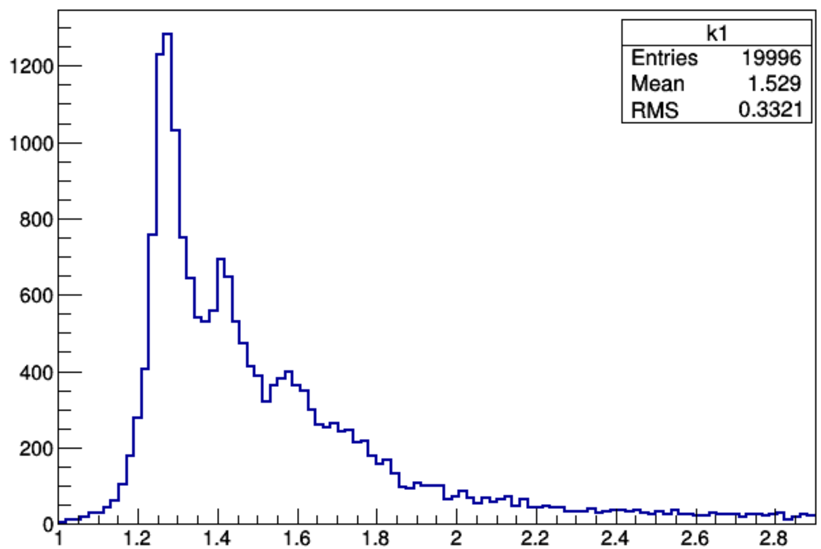
# $B^+ \to K^+\pi^-\pi^+\gamma$ study

A : 20 K events with LHCb model

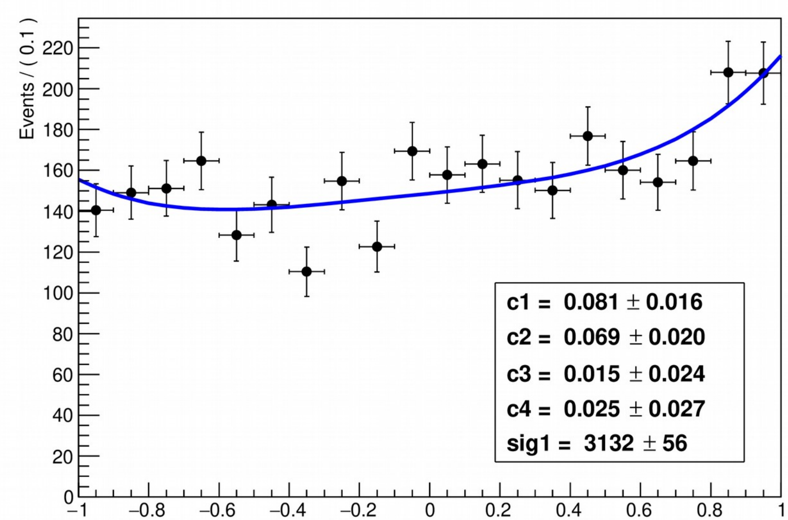
Input $A_{UD}$ = (5.93 ± 0.72)%

We expect around 2500 signal events.

| $J^P$ | Amplitude $k$ | $a_k$ | $\phi_k$ | Fraction (%) |
|---|---|---|---|---|
| $1^+$ | $K_1(1270)^+ \to K^*(892)^0\pi^+$ [S-wave] | 1 (fixed) | 0 (fixed) | 15.3 |
| | $K_1(1270)^+ \to K^*(892)^0\pi^+$ [D-wave] | 1.00 | −1.74 | 0.6 |
| | $K_1(1270)^+ \to K^+\rho(770)^0$ | 2.02 | −0.91 | 37.9 |
| | $K_1(1400)^+ \to K^*(892)^0\pi^+$ | 0.59 | −0.76 | 7.4 |
| $1^-$ | $K^*(1410)^+ \to K^*(892)^0\pi^+$ | 0.11 | 0.00 | 7.9 |
| | $K^*(1680)^+ \to K^*(892)^0\pi^+$ | 0.05 | 0.44 | 3.4 |
| | $K^*(1680)^+ \to K^+\rho(770)^0$ | 0.04 | 1.40 | 2.3 |
| $2^+$ | $K_2^*(1430)^+ \to K^*(892)^0\pi^+$ | 0.28 | 0.00 | 4.5 |
| | $K_2^*(1430)^+ \to K^+\rho(770)^0$ | 0.47 | 1.80 | 8.9 |
| $2^-$ | $K_2(1580)^+ \to K^*(892)^0\pi^+$ | 0.49 | 2.88 | 4.2 |
| | $K_2(1580)^+ \to K^+\rho(770)^0$ | 0.38 | 2.44 | 3.2 |
| | $K_2(1770)^+ \to K^*(892)^0\pi^+$ | 0.35 | 0.00 | 2.8 |
| | $K_2(1770)^+ \to K^+\rho(770)^0$ | 0.08 | 2.53 | 0.2 |
| | $K_2(1770)^+ \to K_2^*(1430)^0\pi^+$ | 0.07 | −2.06 | 0.6 |




M(Kππ)




Extracted $A_{UD}$ = (7.7±1.7)%

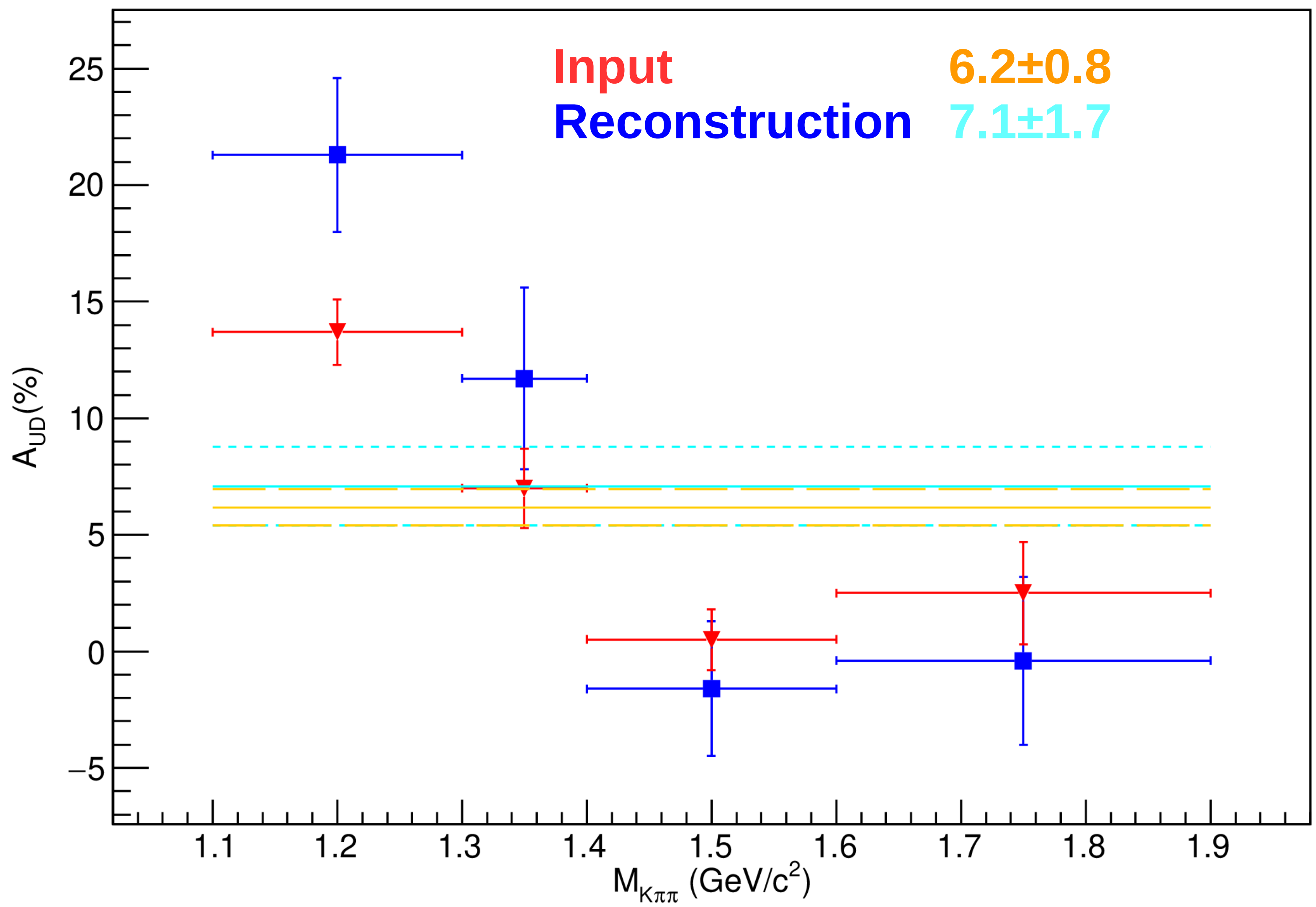
$$\mathcal{A}_{\rm ud} = c_1 - \frac{c_3}{4} \quad \cos(\theta^c)$$

Reconstructed $A_{UD}$ is consistent within one sigma.

$B^+ \rightarrow K^+\pi^-\pi^+ \gamma$

20K events

# In Bins of M(Kππ)



# $B^0 \to K^+\pi^-\pi^0 \gamma$ study

3 samples used :

A : 10K events with one Amplitude

$B^0 \to K_1(1270)\gamma$, $K_1(1270) \to K^*(892)^+\pi^-$, $K^*(892)^+ \to K^+\pi^0$

Input $A_{UD}$ = (0.56±1.01)%

B : 3K events with three Amplitudes

$B^0 \to K_1(1270)\gamma$, $K_1(1270) \to K^*(892)^+\pi^-$, $K^*(892)^+ \to K^+\pi^0$

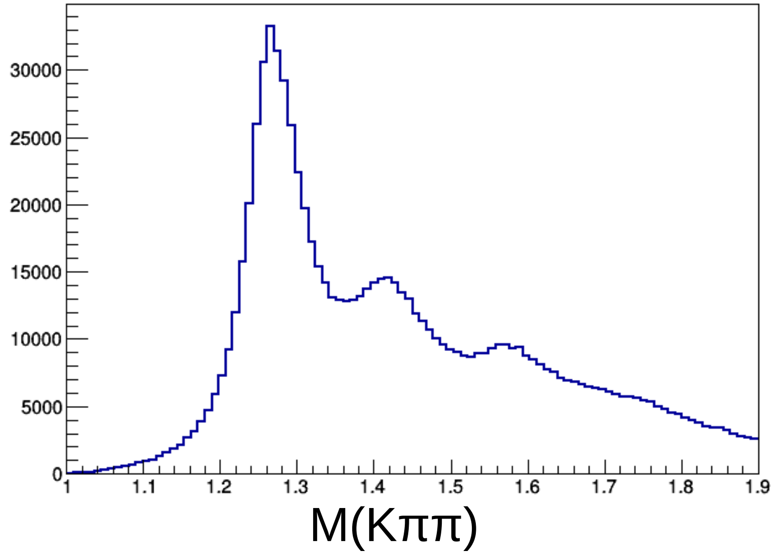
$B^0 \to K_1(1270)\gamma$, $K_1(1270) \to \rho^- K^+$, $\rho^- \to \pi^0\pi^-$

$B^0 \to K_1(1270)\gamma$, $K_1(1270) \to K^*(892)^0\pi^0$, $K^*(892)^0 \to K^-\pi^+$

Input $A_{UD}$ = (13.87 ± 1.7)%

C : 1 Million events with 21 Amplitudes

Input $A_{UD}$ = (11.4 ± 0.1)%



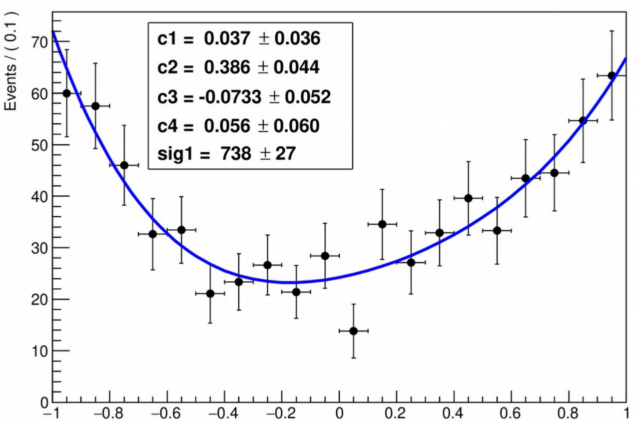

| $J^P$ | Amplitude $k$ | $a_k$ | $\phi_k$ | Fraction (%) |
|---|---|---|---|---|
| $1^+$ | $K_1(1270)^0 \to K^*(892)^0\pi^0$ [S-wave] | 1(fixed) | 0 (fixed) | 8.0 |
| | $K_1(1270)^0 \to K^*(892)^+\pi^-$ [S-wave] | 1.01 | 0.00 | 8.0 |
| | $K_1(1270)^0 \to K^*(892)^+\pi^-$ [D-wave] | 0.98 | −1.74 | 0.3 |
| | $K_1(1270)^0 \to K^*(892)^0\pi^0$ [D-wave] | 0.99 | −1.74 | 0.3 |
| | $K_1(1270)^0 \to K^+\rho(770)^-$ | 2.86 | −0.91 | 39.7 |
| | $K_1(1400)^0 \to K^*(892)^+\pi^-$ | 0.60 | −0.76 | 3.8 |
| | $K_1(1400)^0 \to K^*(892)^0\pi^0$ | 0.59 | −0.76 | 3.8 |
| $1^-$ | $K^*(1410)^0 \to K^*(892)^+\pi^-$ | 0.11 | 0.00 | 3.9 |
| | $K^*(1410)^0 \to K^*(892)^0\pi^0$ | 0.11 | 0.00 | 3.9 |
| | $K^*(1680)^0 \to K^*(892)^+\pi^-$ | 0.05 | 0.44 | 1.7 |
| | $K^*(1680)^0 \to K^*(892)^0\pi^0$ | 0.05 | 0.44 | 1.7 |
| | $K^*(1680)^0 \to K^+\rho(770)^-$ | 0.06 | 1.40 | 2.4 |
| $2^+$ | $K_2^*(1430)^0 \to K^*(892)^+\pi^-$ | 0.27 | 0.00 | 2.3 |
| | $K_2^*(1430)^0 \to K^*(892)^0\pi^0$ | 0.27 | 0.00 | 2.3 |
| | $K_2^*(1430)^0 \to K^+\rho(770)^-$ | 0.63 | 1.80 | 8.9 |
| $2^-$ | $K_2(1580)^0 \to K^*(892)^+\pi^-$ | 0.49 | 2.88 | 2.2 |
| | $K_2(1580)^0 \to K^*(892)^0\pi^0$ | 0.49 | 2.88 | 2.2 |
| | $K_2(1580)^0 \to K^+\rho(770)^-$ | 0.54 | 2.44 | 3.2 |
| | $K_2(1770)^0 \to K^*(892)^+\pi^-$ | 0.35 | 0.00 | 1.5 |
| | $K_2(1770)^0 \to K^*(892)^0\pi^0$ | 0.35 | 0.00 | 1.5 |
| | $K_2(1770)^0 \to K^+\rho(770)^-$ | 0.11 | 2.53 | 0.2 |
| | $K_2(1770)^0 \to K_2^*(1430)^+\pi^-$ | 0.07 | −2.06 | 0.3 |
| | $K_2(1770)^0 \to K_2^*(1430)^0\pi^0$ | 0.07 | −2.06 | 0.3 |

$B^0 \to K^+\pi^-\pi^0\gamma$

# Extracted $A_{UD}$ from reconstruction

Fit Mbc and get background subtract cos(θ)*sign($m_{13}$-$m_{23}$) distributon and fit the sPlot distribution to get $A_{UD}$

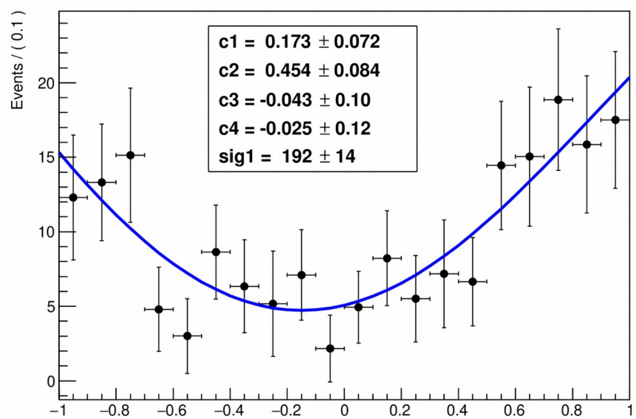
| Sample A | Sample B | Sample C |
|---|---|---|
| Input $A_{UD}$ = (0.6±1.0)% | $A_{UD}$ = (13.9 ± 1.7)% | $A_{UD}$ = (11.4 ± 0.1)% |




cos($\theta^c$)

Sample size is 1K

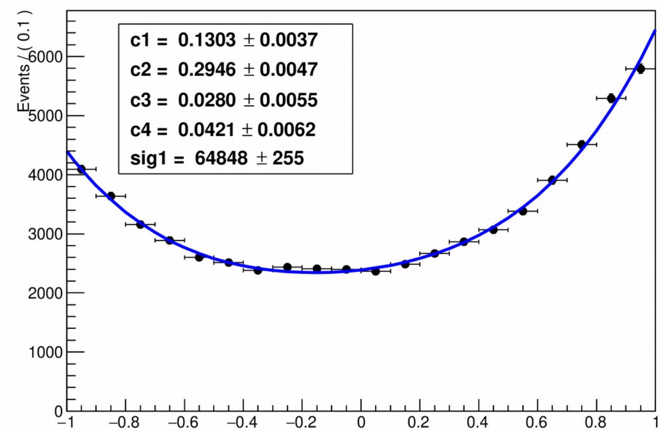
Extracted $A_{UD}$ = (5.5±3.8)%




cos($\theta^c$)

Sample size is 3K

$A_{UD}$ = (18.4 ± 7.6)%




cos($\theta^c$)

Sample size is 1 Million

$A_{UD}$ = (12.3 ± 0.4)%

Reconstructed $A_{UD}$ is consistent within one sigma.

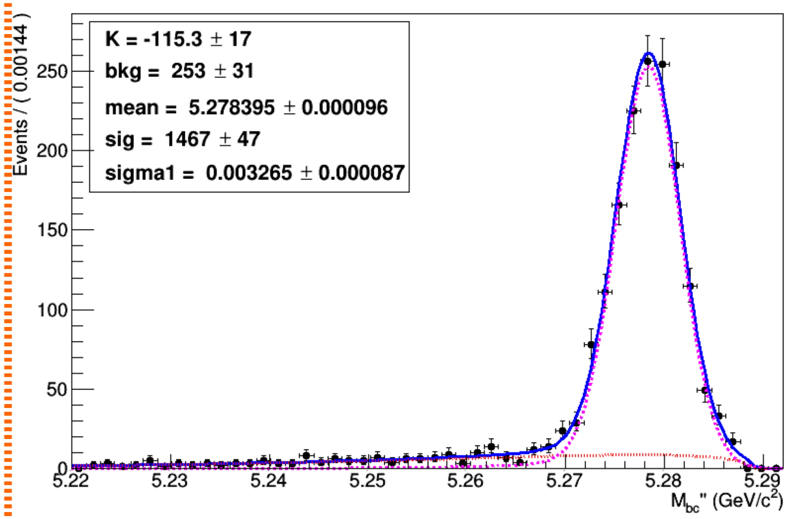
# $B^0 \to K^+\pi^-\pi^0\gamma$

Input : (11.5±0.1)%

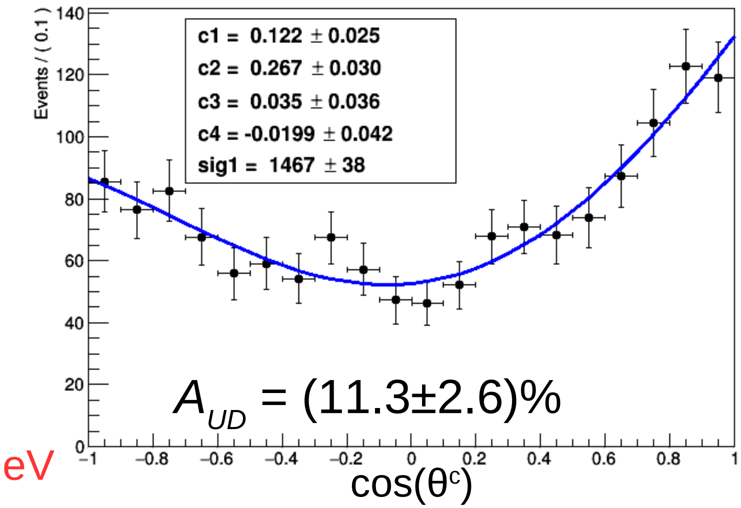
# Pull study

Expect around 1500 events

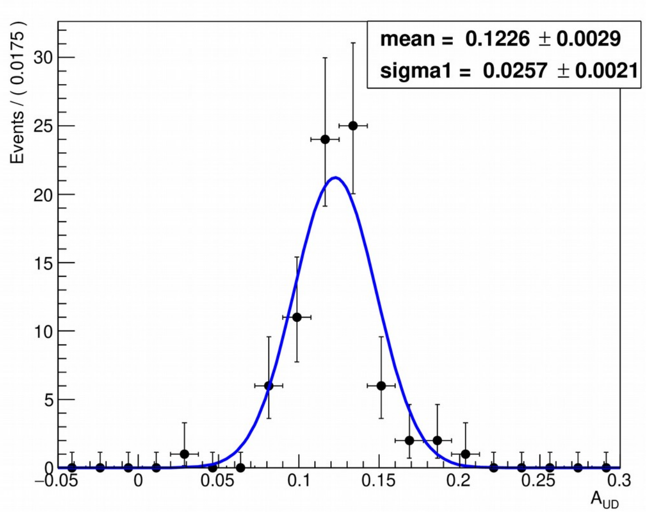
One pseudo-experiment



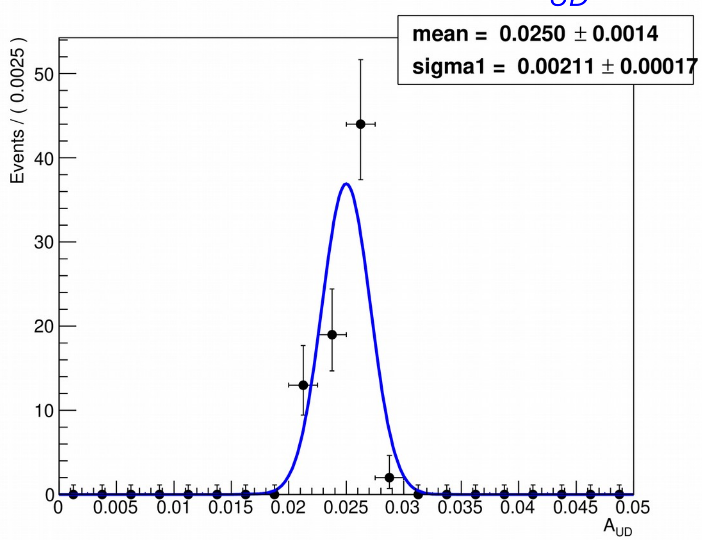

1.1< M(Kππ)< 1.9 GeV



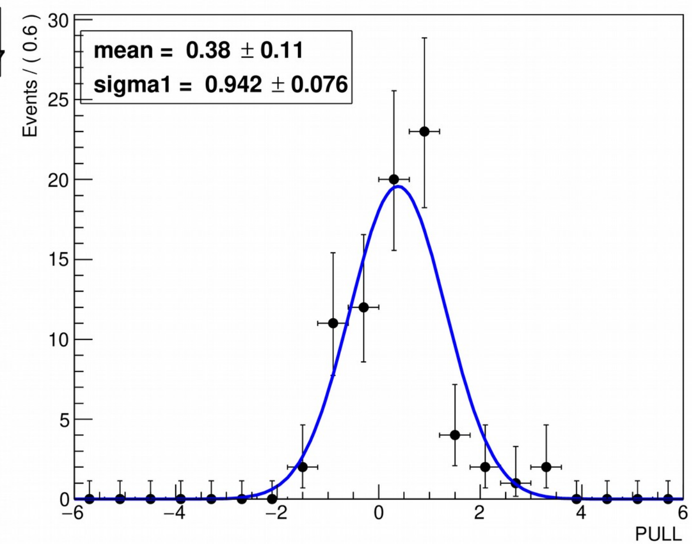

Extracted $A_{UD}$




Error on extracted $A_{UD}$




Pull distribution

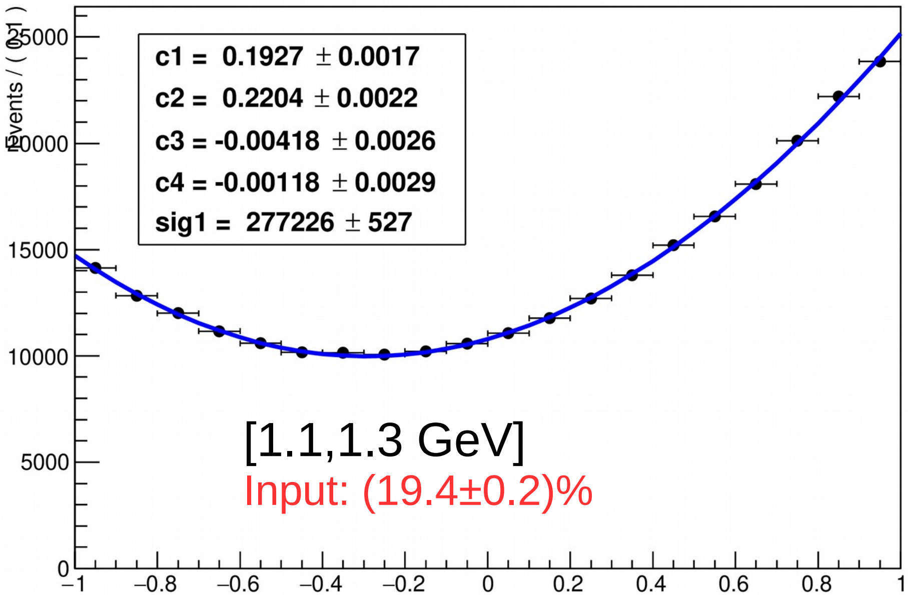


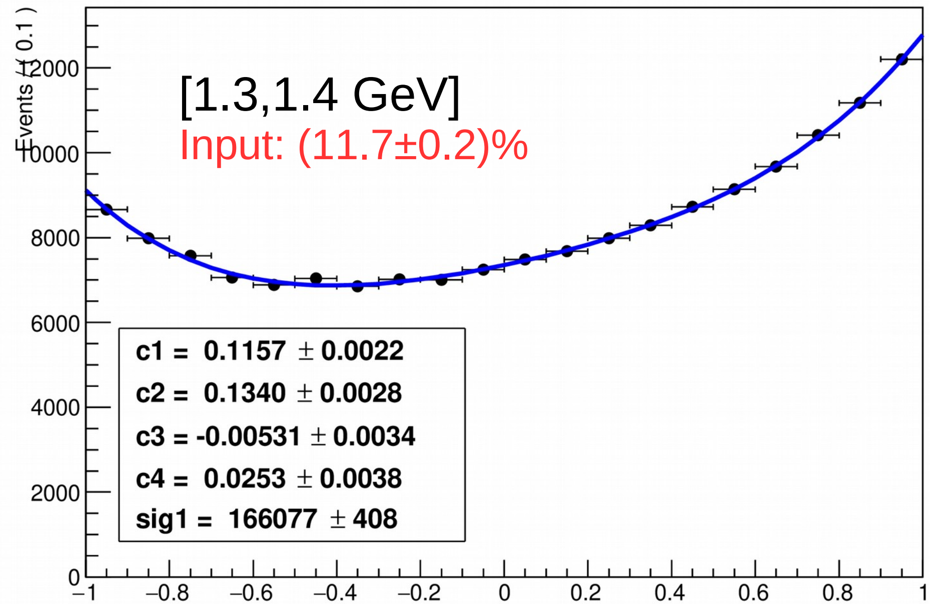

Extracted $A_{UD}$: (12.3± 2.5)%

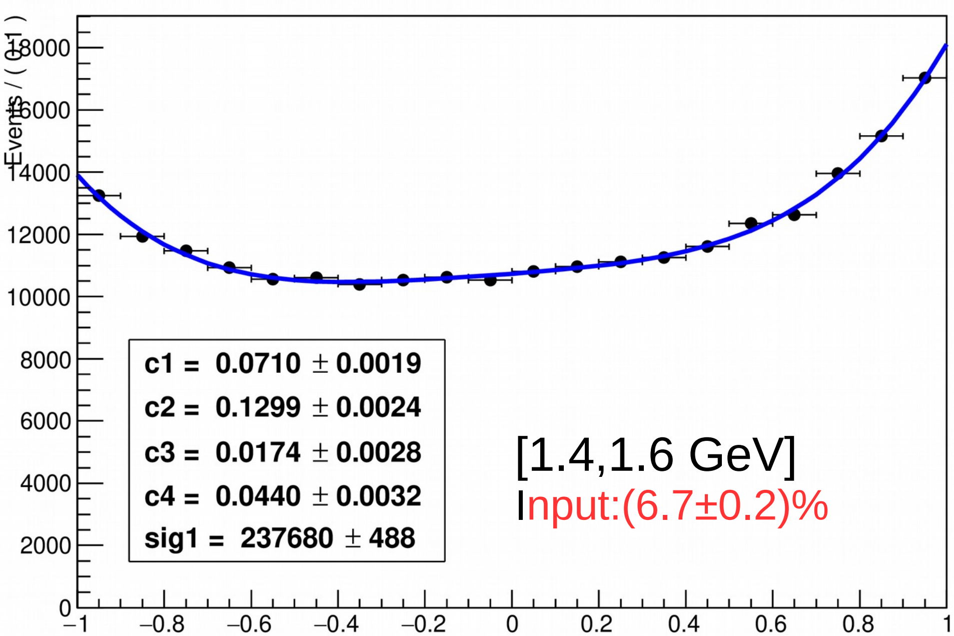


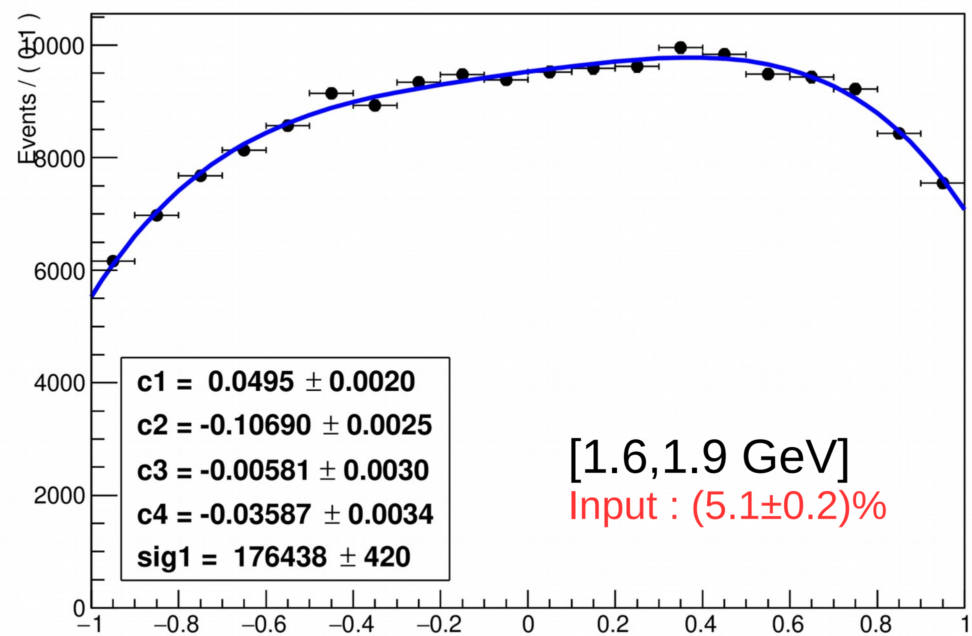
45 samples with 1500 signal yield used

# Generated $A_{UD}$ in $B \to K^+\pi^-\pi^0\gamma$



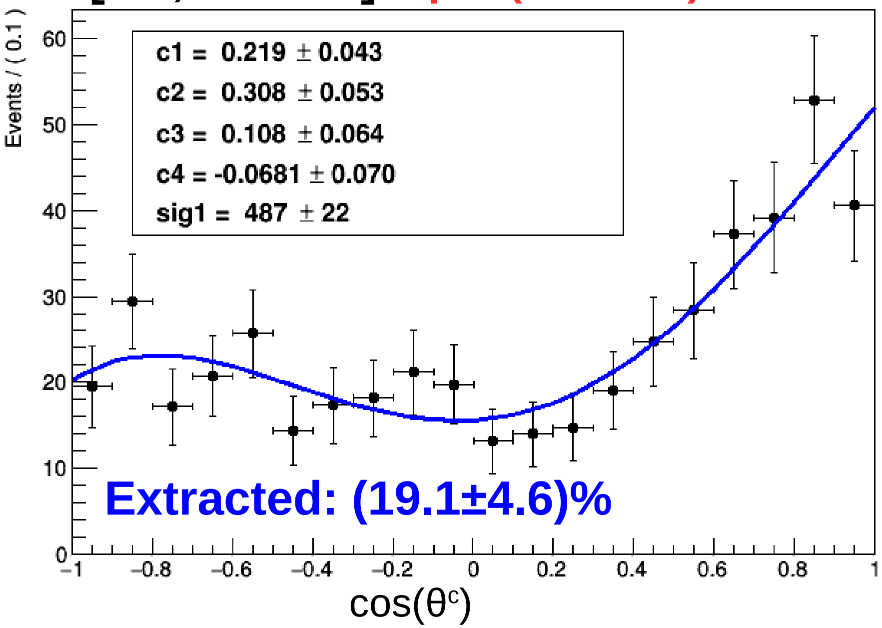



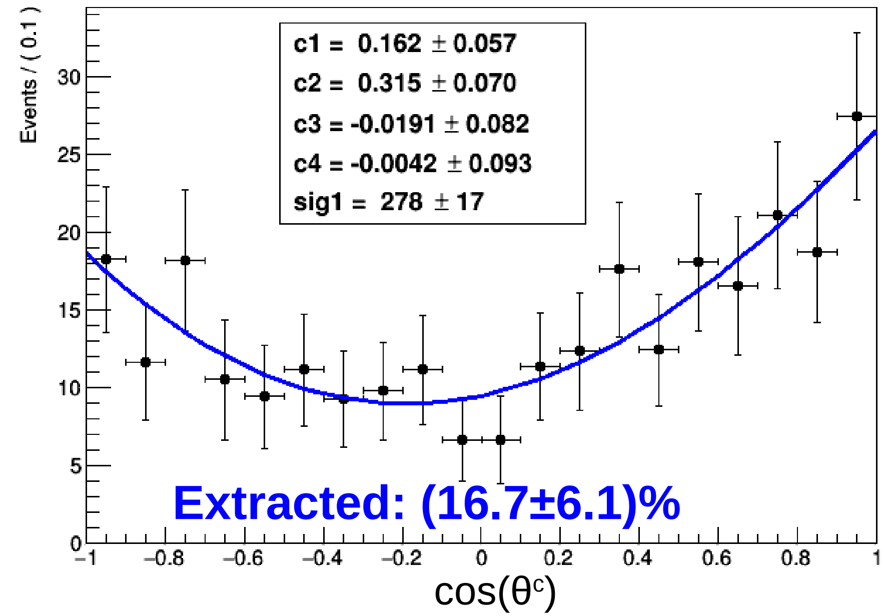
# $A_{UD}$ Bias study in bins of M(Kππ)

***A typical toy example***

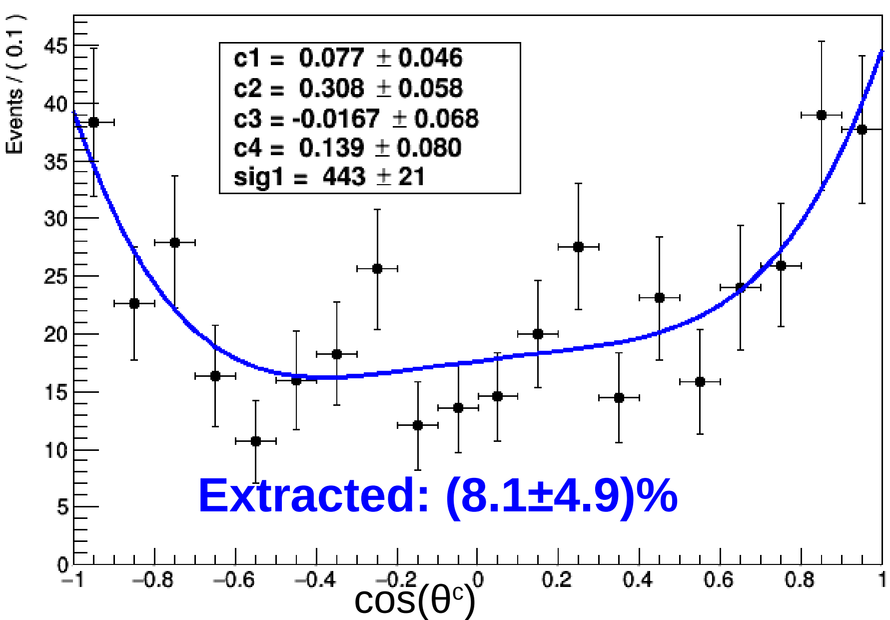
**[1.1,1.3 GeV]** Input:(19.4±0.2) %



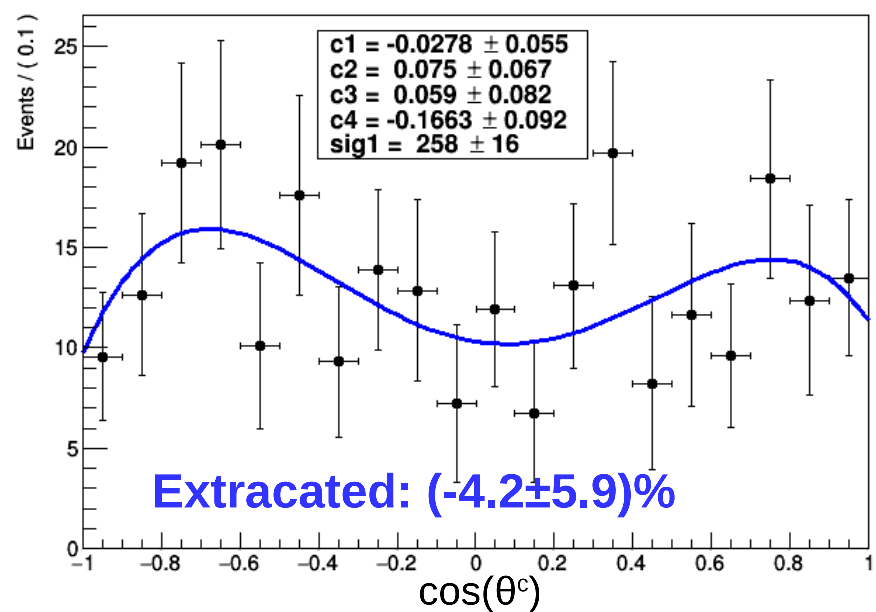

**[1.3,1.4 GeV]** Input: (11.7±0.2)%




**[1.4,1.6 GeV]** Input: (6.7±0.2) %



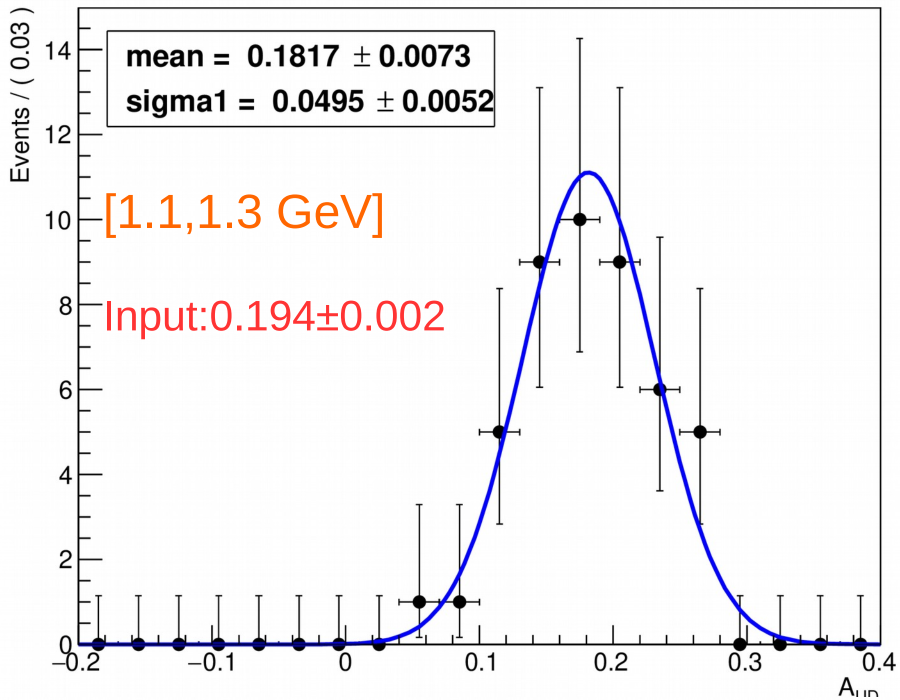

**[1.6,1.9 GeV]** Input : (5.1±0.2) %

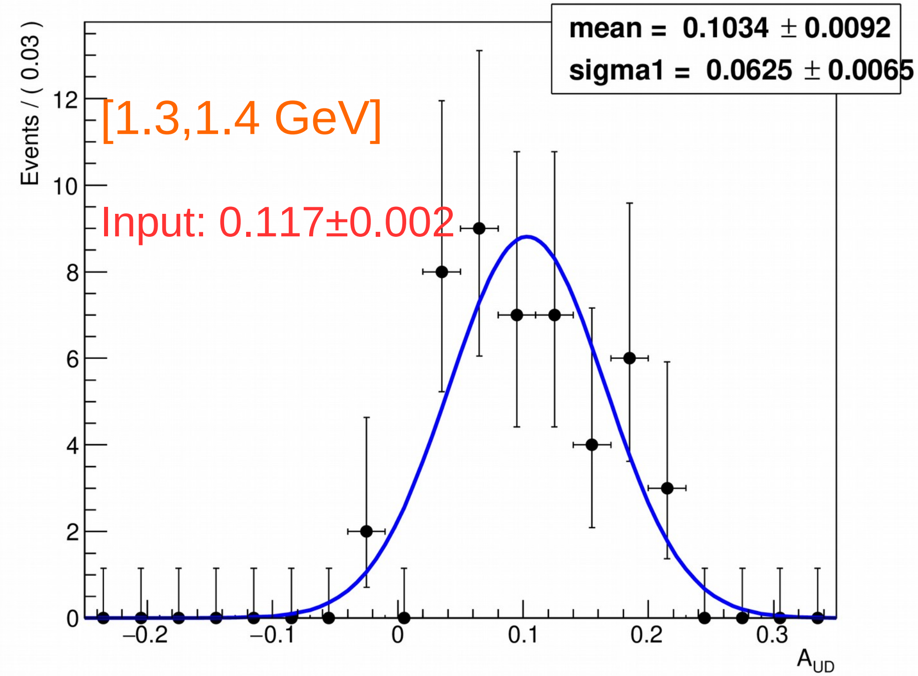


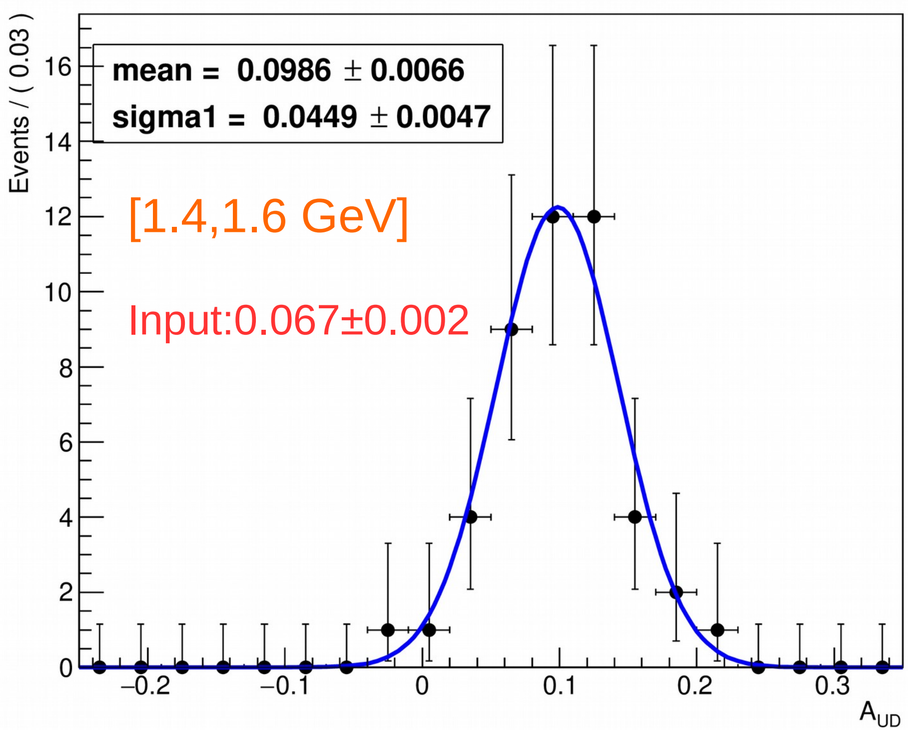
45 samples with 1500 signal yield used

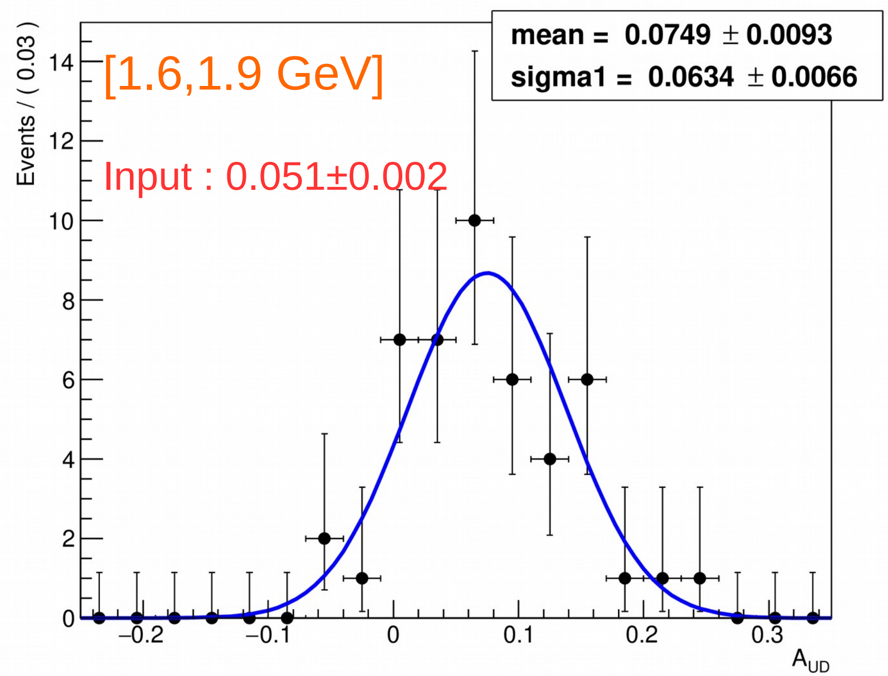
# $A_{UD}$ for $B \to K^+\pi^-\pi^0\gamma$

Input estimated from the generated level based on M(Kππ)



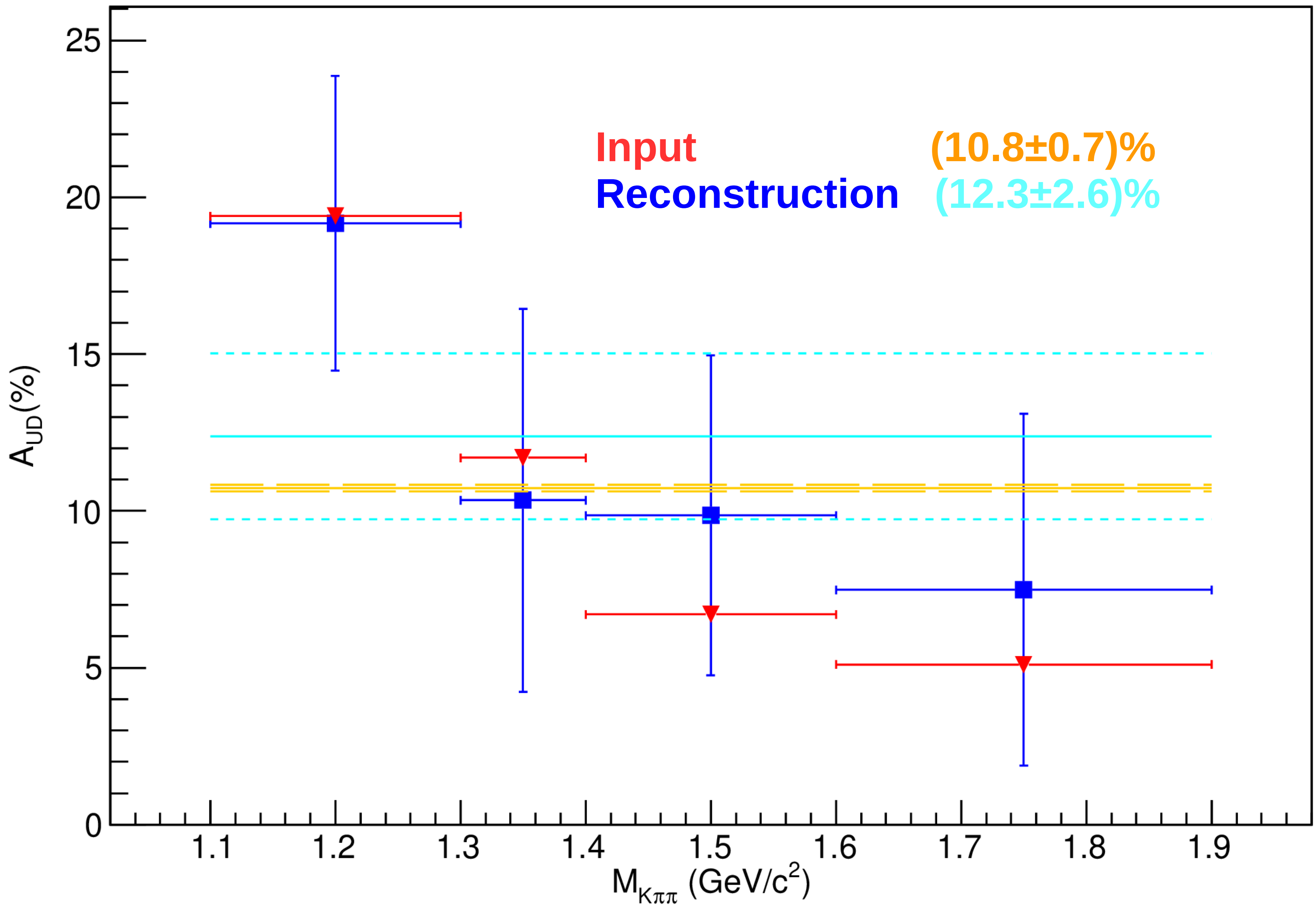



$B^0 \rightarrow K^+\pi^-\pi^0\gamma$

# $A_{UD}$ in Bins of M(Kππ)

*Toys based on One Million sample*

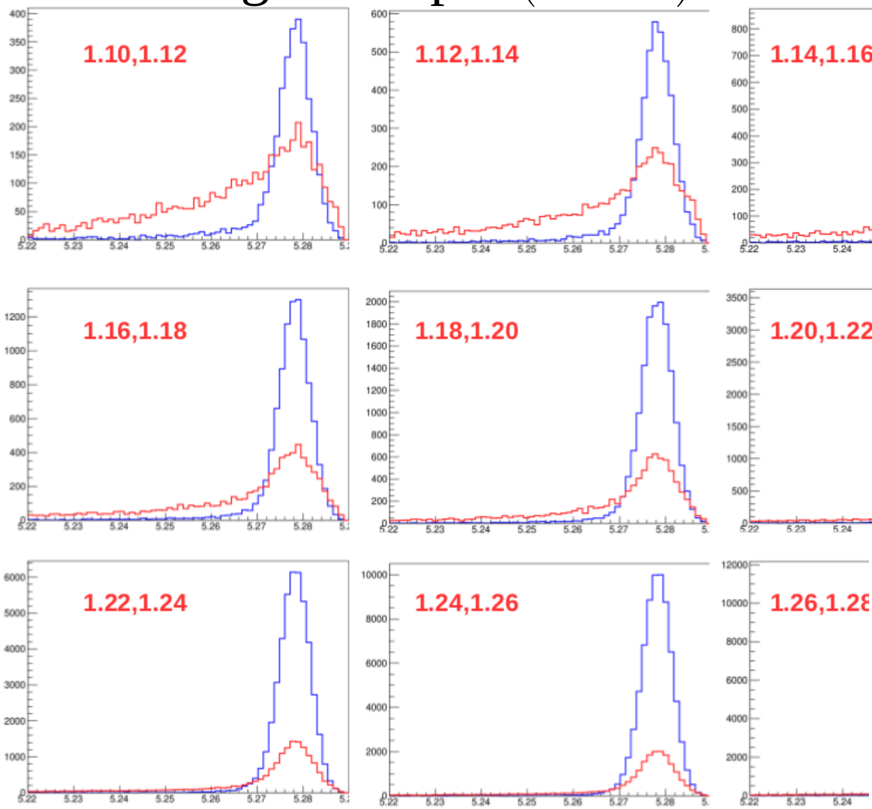



$A_{UD}$ estimated from 45 toys mean
Uncertainty estimated from 45 toys error

Mentioned $A_{UD}$ is Weighted Average

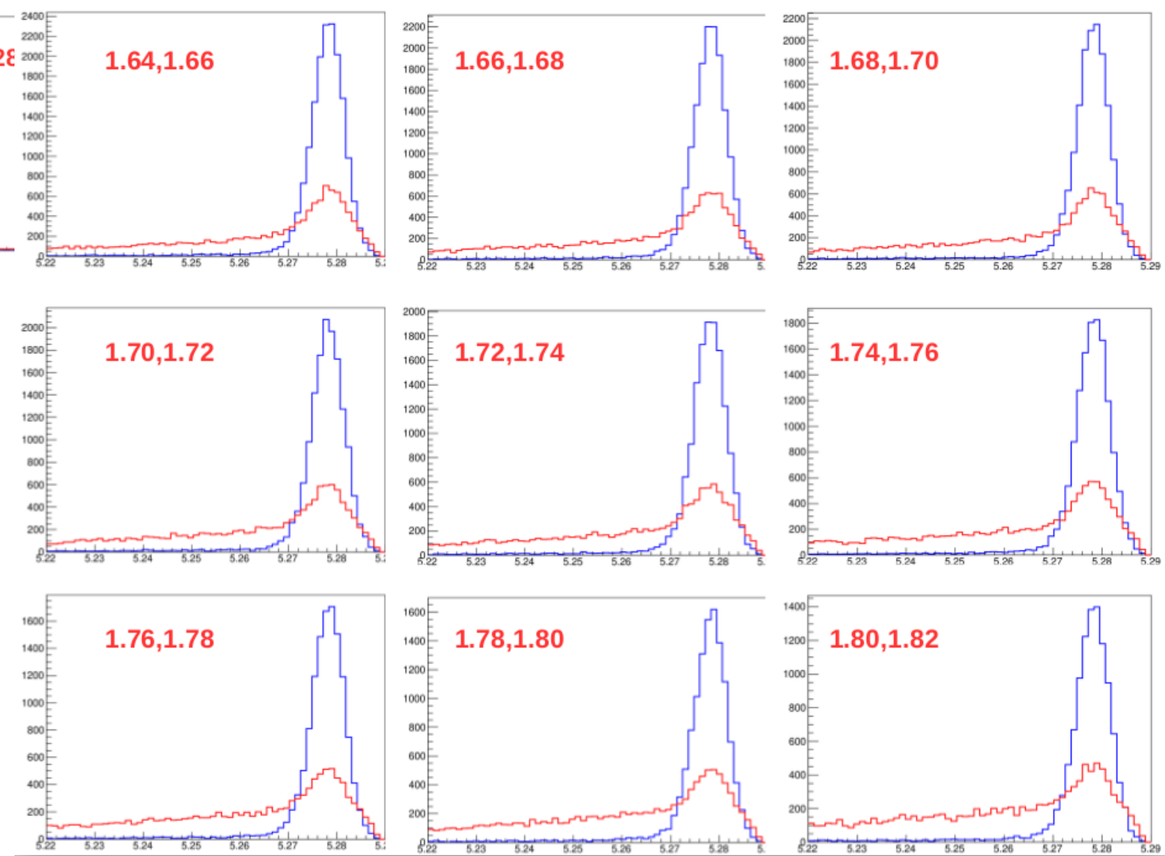
# Possible bias from SCF

much larger sample (20 M) allows detailed study




SCF is sizeable for some $M(K\pi\pi)$ bins:
reach 30% of signal (in $M_{bc}$ signal window)
$K\pi\pi^0$ system is not much constraint
easy to substitute one of the $\gamma$'s

(...)

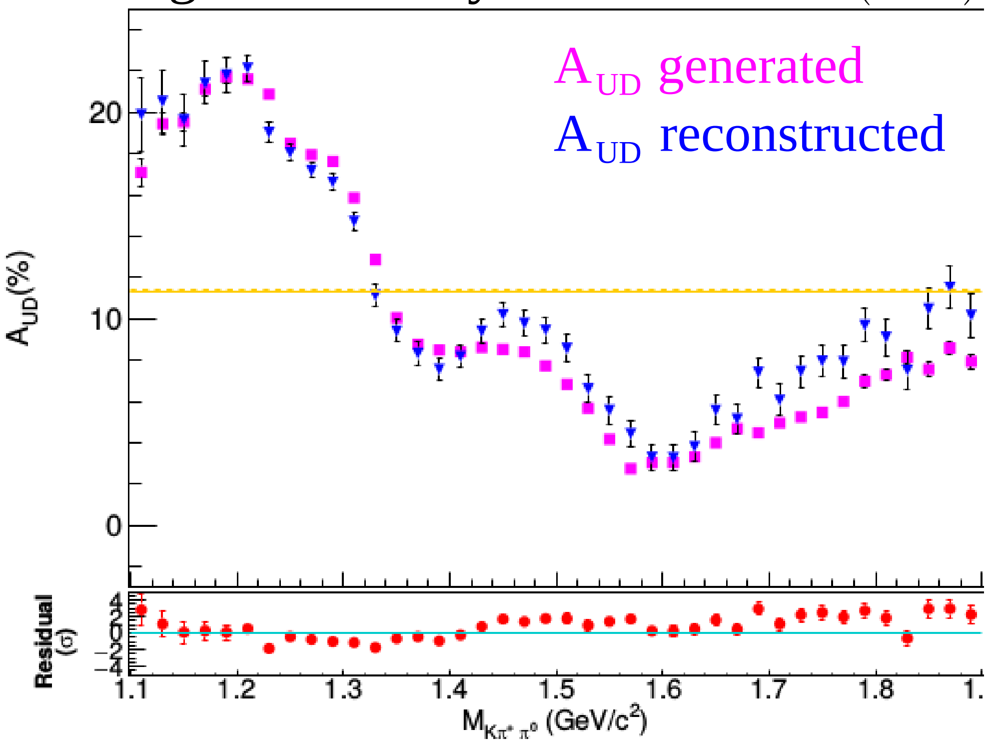


# Possible bias from SCF

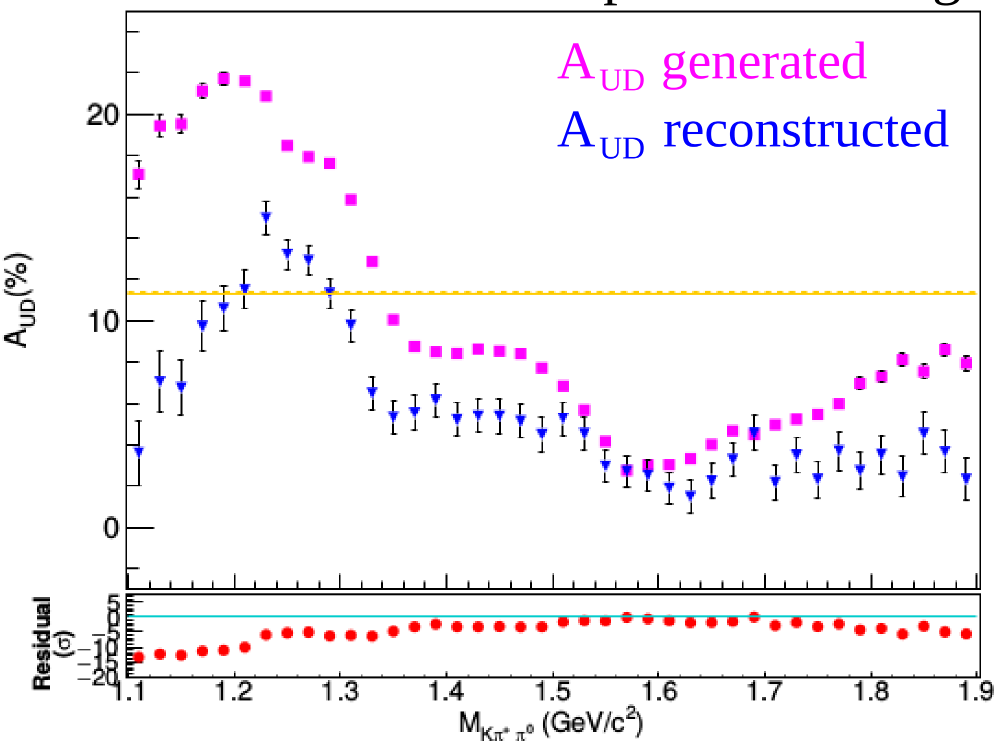
much larger sample (20 M) allows detailed study

Events in signal window:

signal correctly reconstructed (CR)

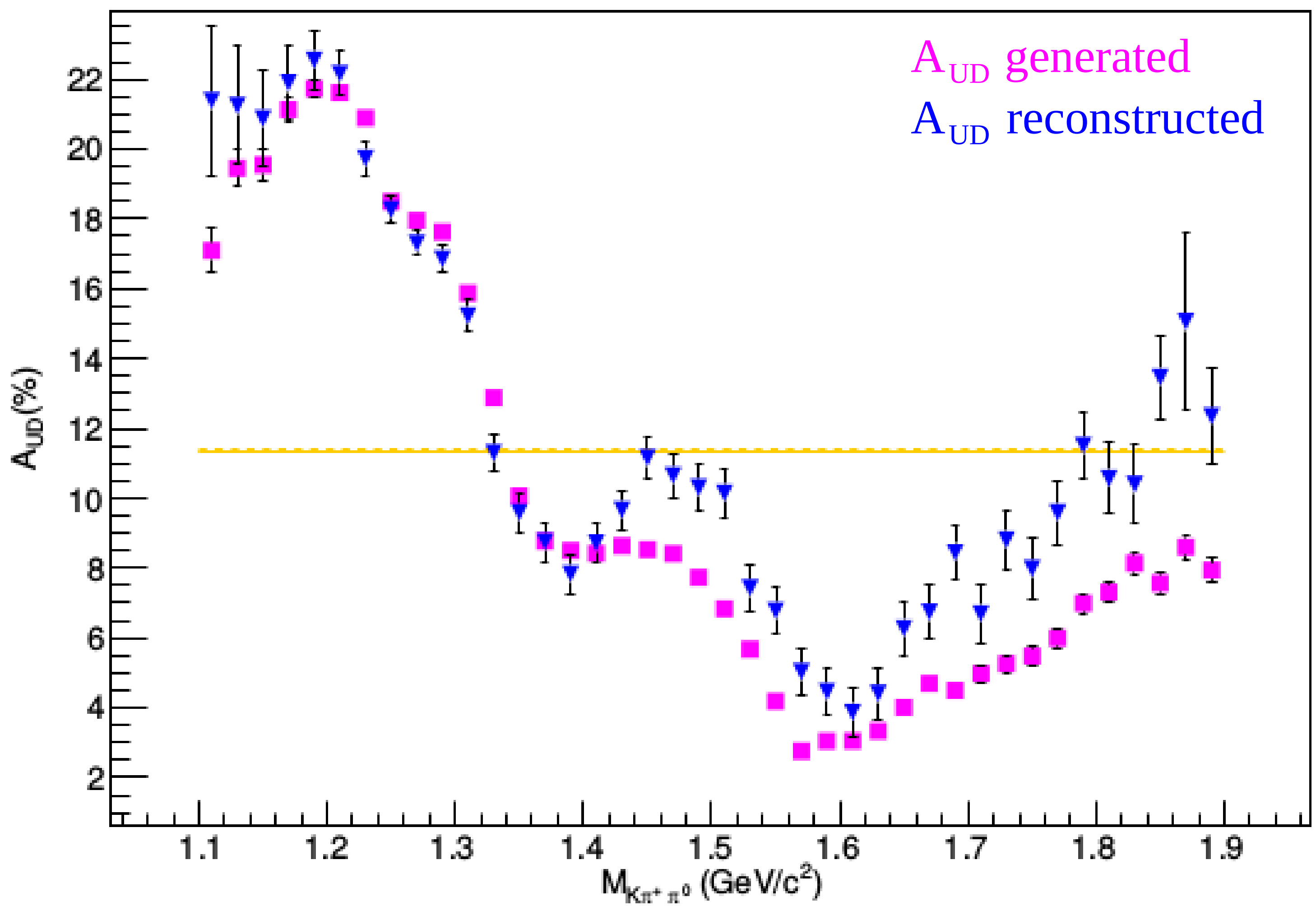



at least one final state particle not signal




$\Rightarrow A_{UD}$ strongly biased for SCF

angular distributions extracted from sPlot: moderate impact from SCF
still a bias exists at high $M(K\pi\pi)$ (visible also when using only CR events)



# Summary

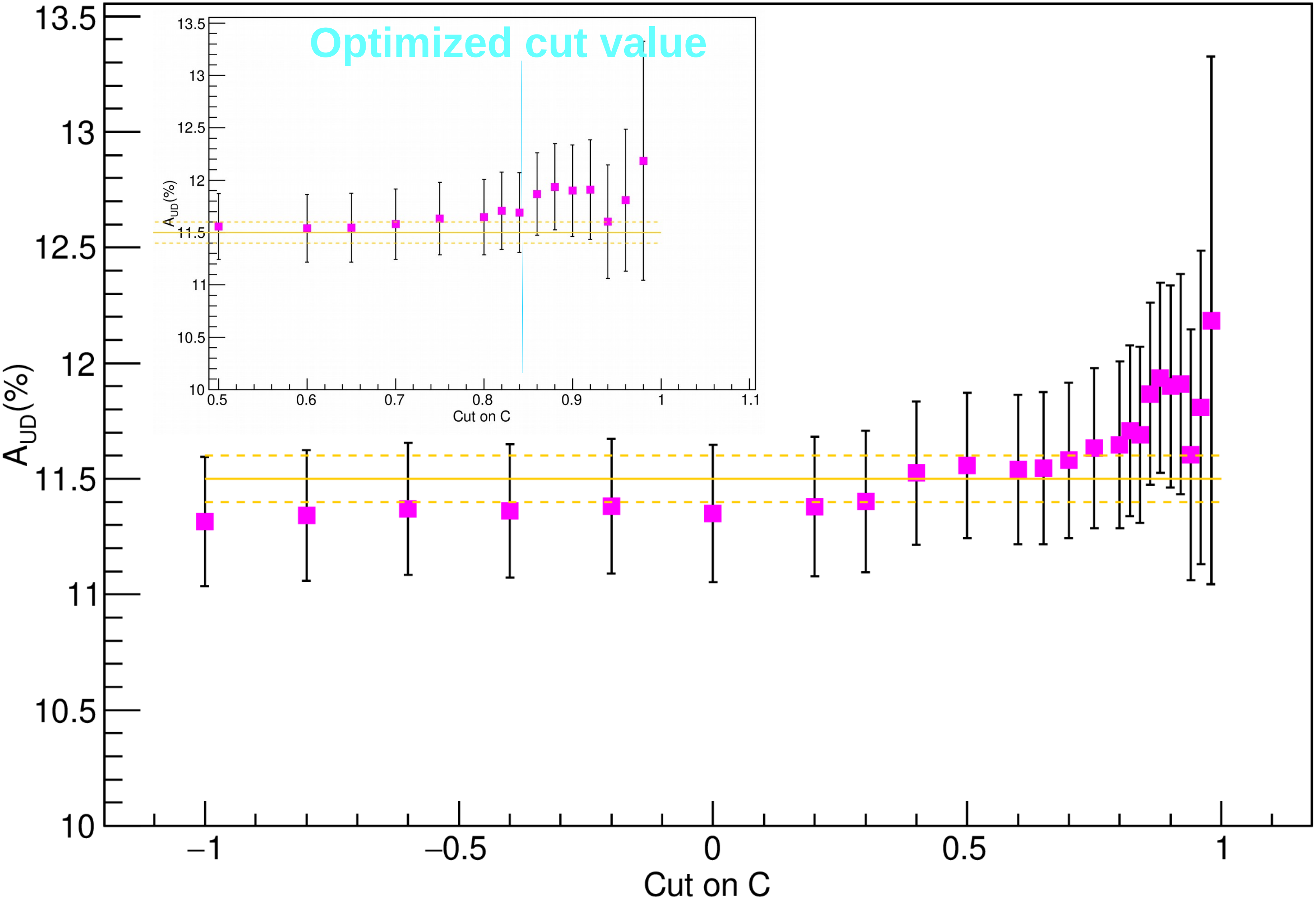
- We extract $A_{UD}$ by fitting cos(θ) for different M(Kππ) regions.
- Performed GSIM study in order to validate the up-down asymmetry extraction procedure.
- Samples generated using modified MINT (from EPFL colleagues) and GSIM samples obtained.
- Three different samples used for $B \rightarrow K^{+}\pi^{-}\pi^{0}\gamma$ having different $A_{UD}$ value and one sample of $B^{+} \rightarrow K^{+}\pi^{-}\pi^{+}\gamma$ decay mode.
- Able to extract $A_{UD}$ value within one sigma.
- $A_{UD}$ in M(Kππ) bins was extracted.
- Optimization of the NB cut is done.
- Used pseudo-experiment to check $A_{UD}$ extraction.

- Performed proper GSIM toy study to validate fitter, A_UD uncertainty is ~5-6% for each M(Kππ) bin and look for potential bias.
- Bias of 1-2% at larger M(Kππ) values (>1.4 GeV) to be investigated further before finalizing the analysis

# Thank you

# Dependence of $A_{UD}$ on NB cut

$B^0 \to K^+\pi^-\pi^0\gamma$



# Reconstruction / Selection criteria

$|dr|<1.0$ cm, $|dz|<3.5$ cm
Kid > 0.6 , πid > 0.4
$K_S^0$ : 0.4876-0.5176 GeV/$c^2$ [ nisKsFinder is used]
$\pi^0$ : E > 60 MeV and M : [123-147] MeV/$c^2$
$P_{\pi 0}$ > 0.33 GeV/$c^2$ && $\cos(\theta_{hel})>-0.87$ *[Optimized cuts ]*
M(Kππ) < 1.9 GeV/$c^2$
E > 500 MeV, $E_9/E_{25}$ > 0.85

Signal identification : $\Delta E = E^*_B - E^*_{beam}$ and $M'_{bc} = \sqrt{(E^*_{beam})^2 - (p'^*_B)^2}$

$$p'^*_B = p^*_{K\pi\pi} + \frac{p^*_\gamma}{|p^*_\gamma|} \times (E^*_{beam} - E^*_{K\pi\pi})$$

Signal region
-100 MeV < E < 50 MeV and $M'_{bc}$ > 5.22 GeV/$c^2$
BCS is based on
$\chi^2$(vertex fit to charged tracks) + $\chi^2$ (based on ΔE) + $\chi^2(K_S)^*$+ $\chi^2(\pi^0)^*$

Fit $M_{bc}$' to get background subtracted $\cos(\theta^c)$ distribution and extract $A_{UD}$ from fit to $\cos(\theta^c)$.

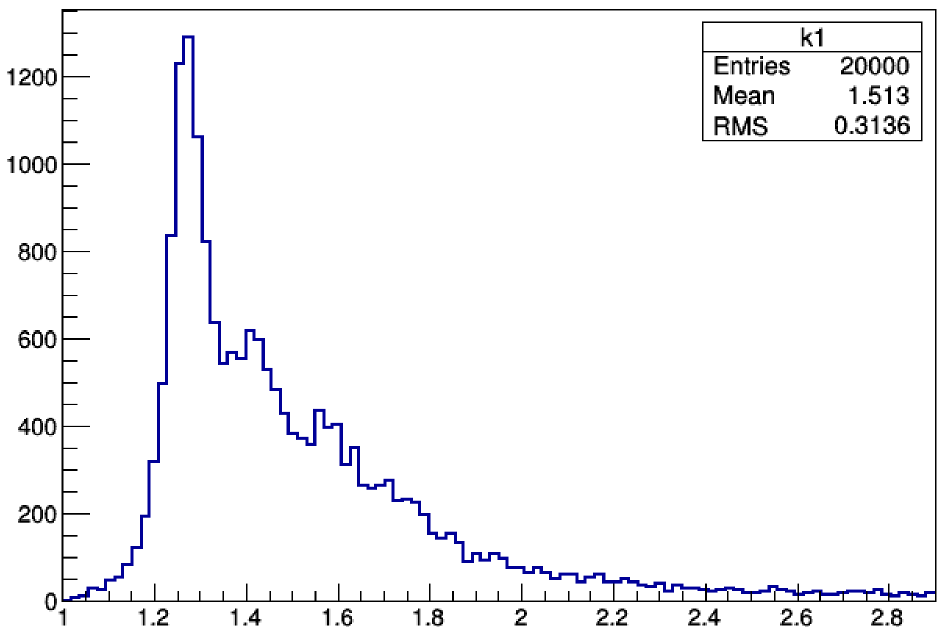


* for the decays including $\pi^0$ and $K_S$

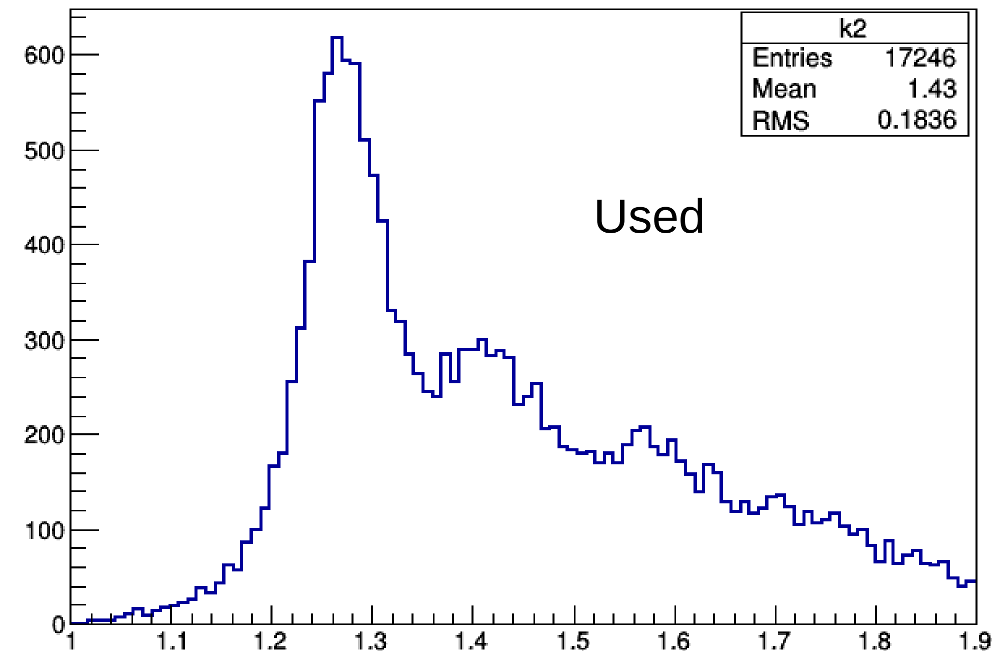
$\cos(\theta^c) = \cos(\theta)$ x Charge of B

# $B^0 \rightarrow K^+\pi^-\pi^0\,\gamma$

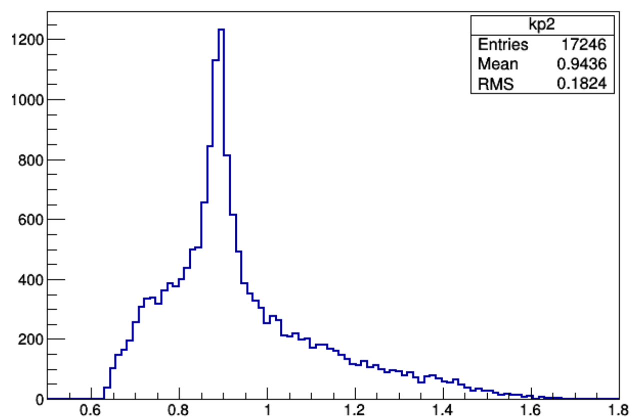
20,000 events



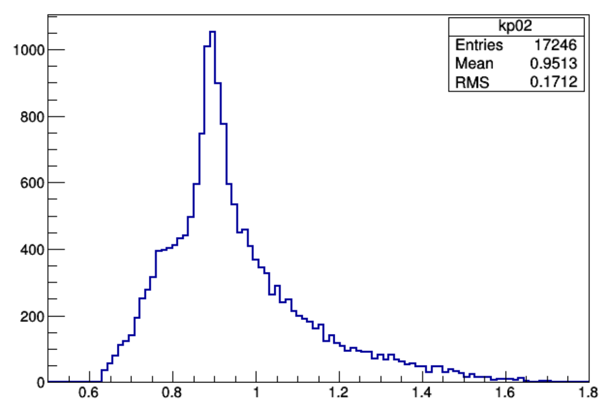

$M(K^-\pi^+\pi^0)$



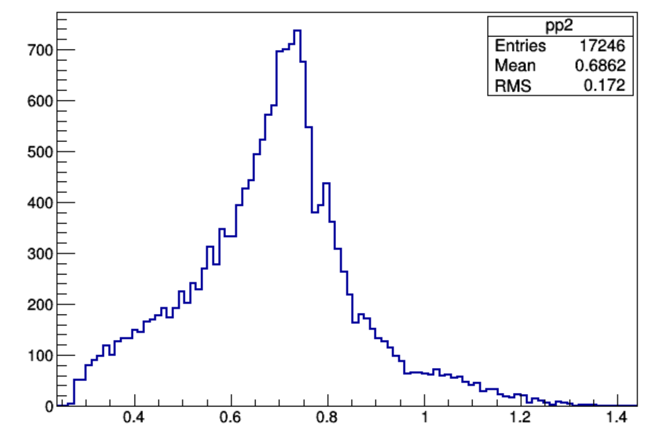

$M(K^-\pi^+\pi^0)$




$M(K^-\pi^+)$

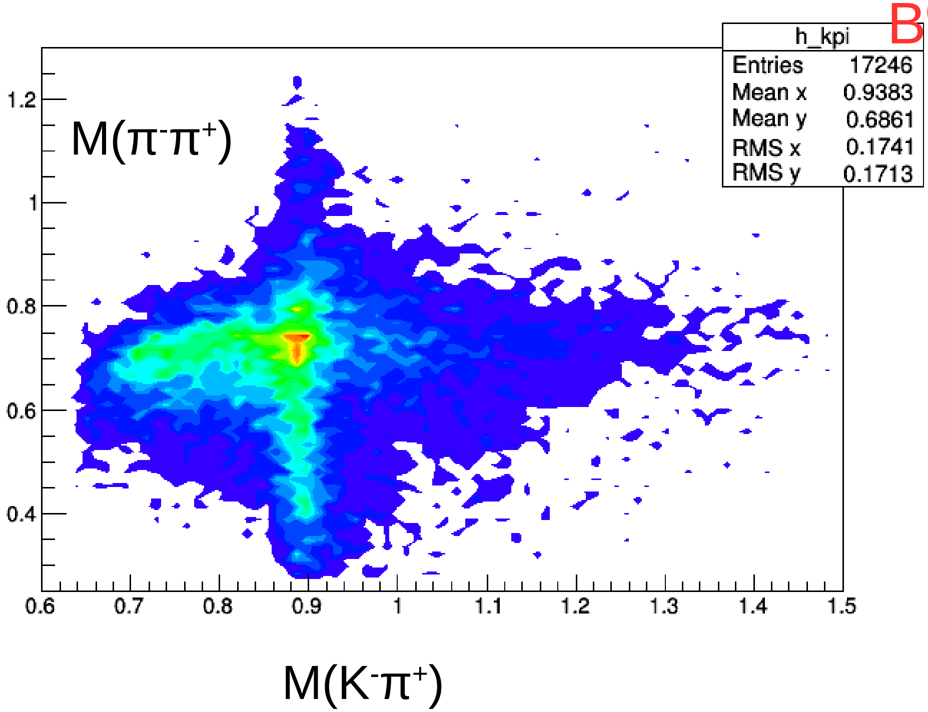


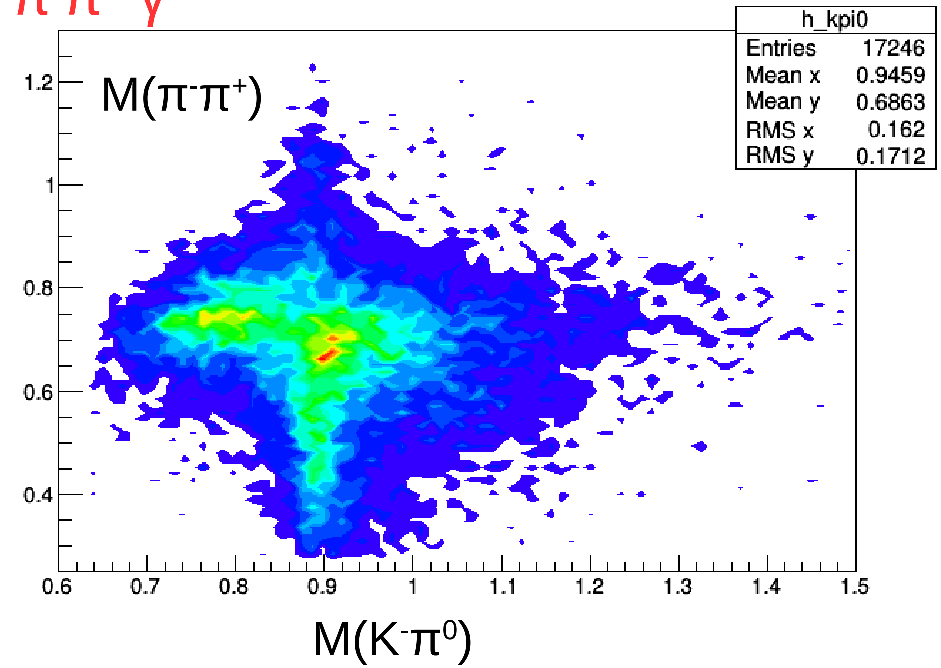

$M(K^-\pi^0)$

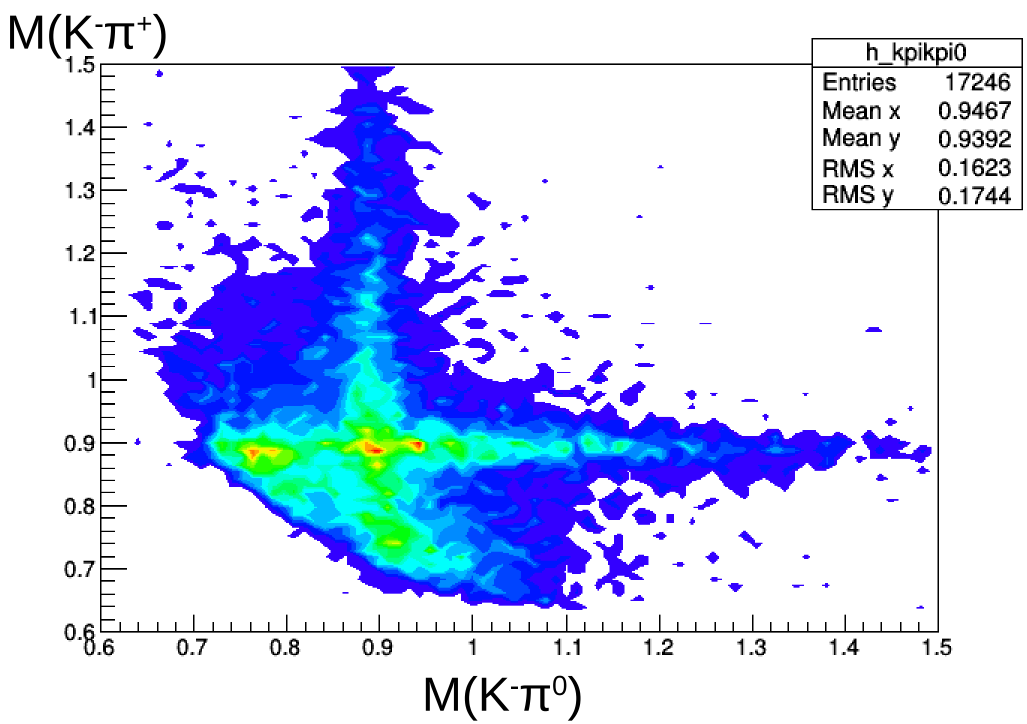



$M(\pi^+\pi^0)$

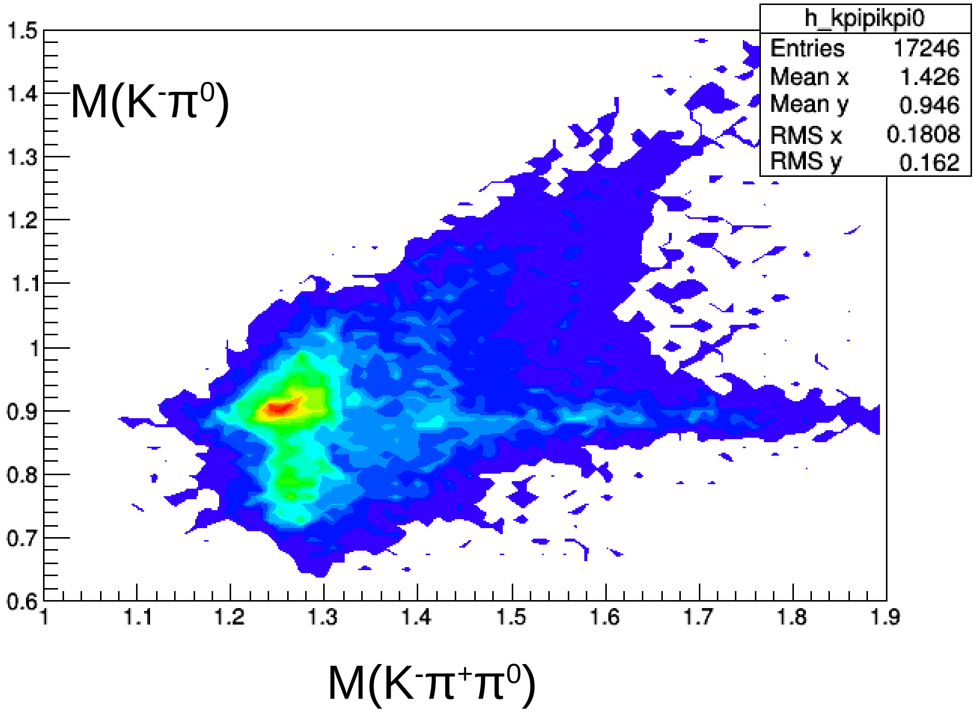
# $B^0 \to K^+\pi^-\pi^0\gamma$

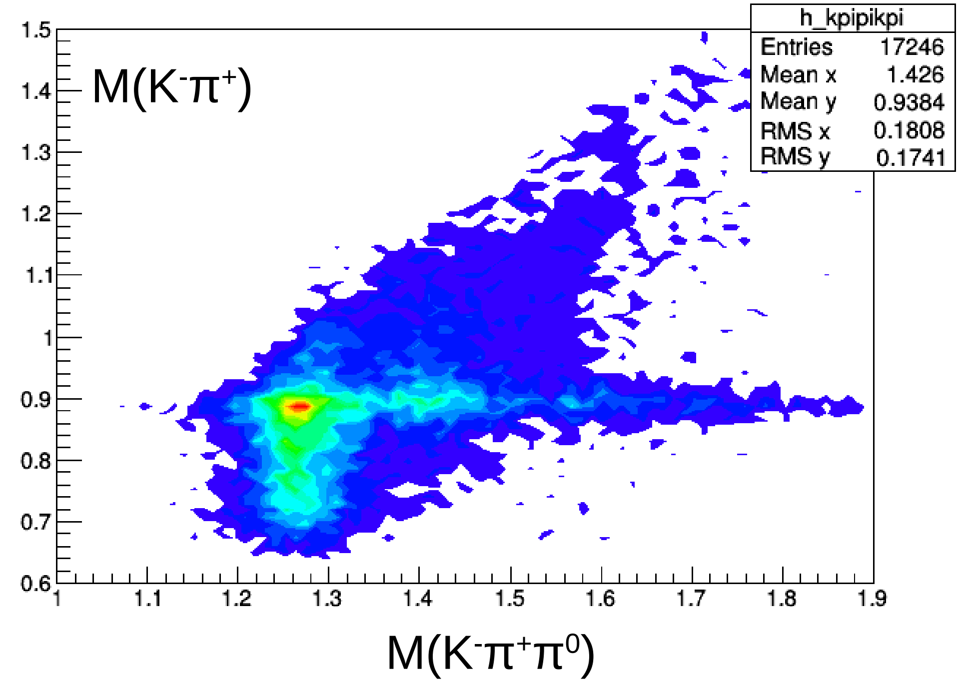


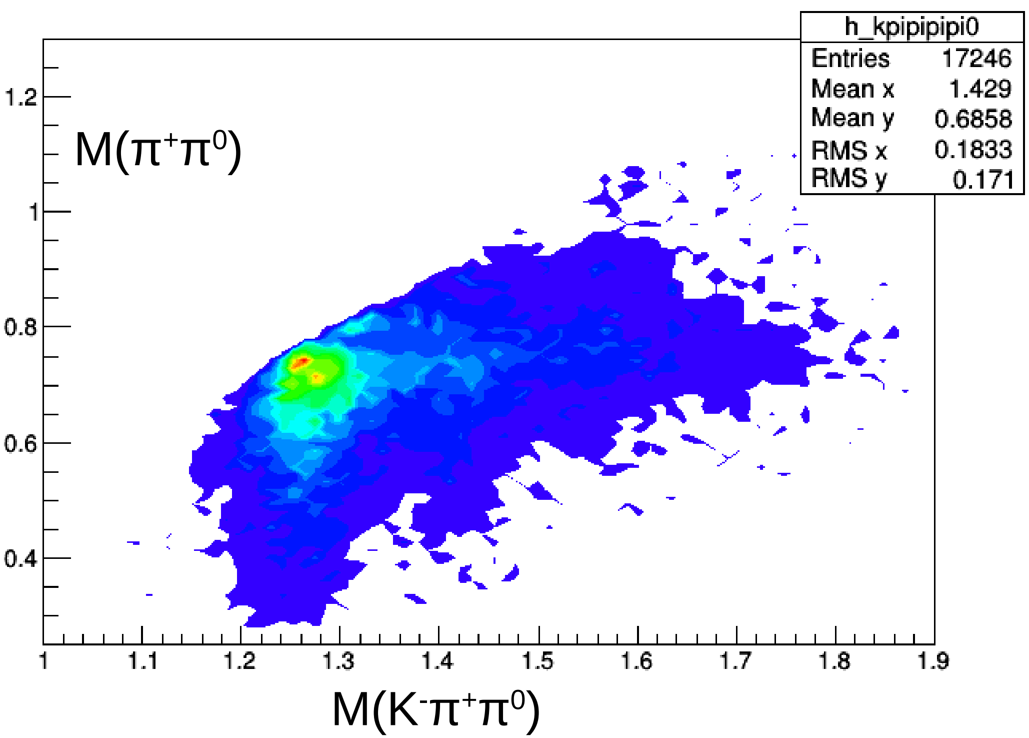



$B^0 \rightarrow K^+\pi^-\pi^0\gamma$

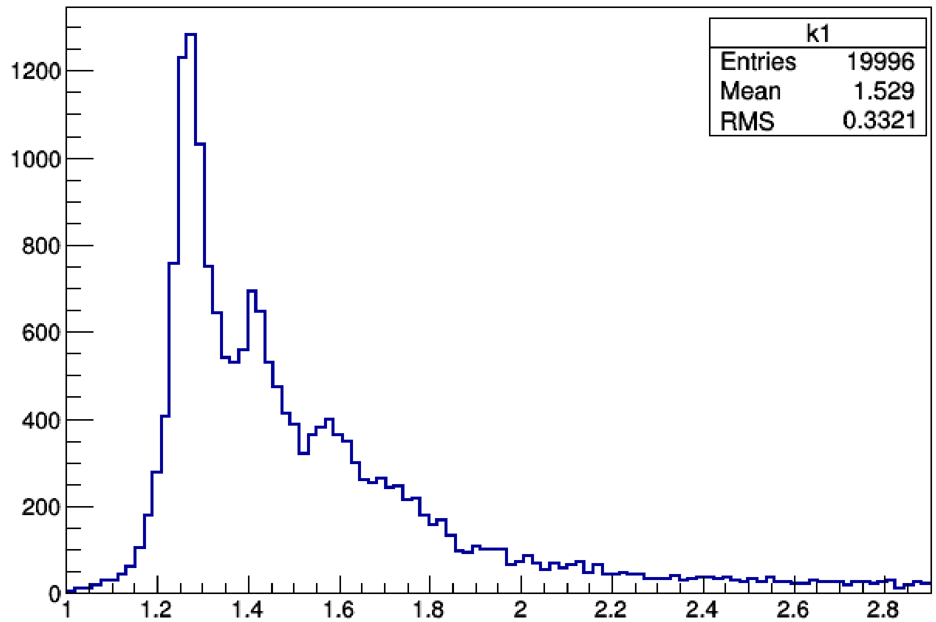


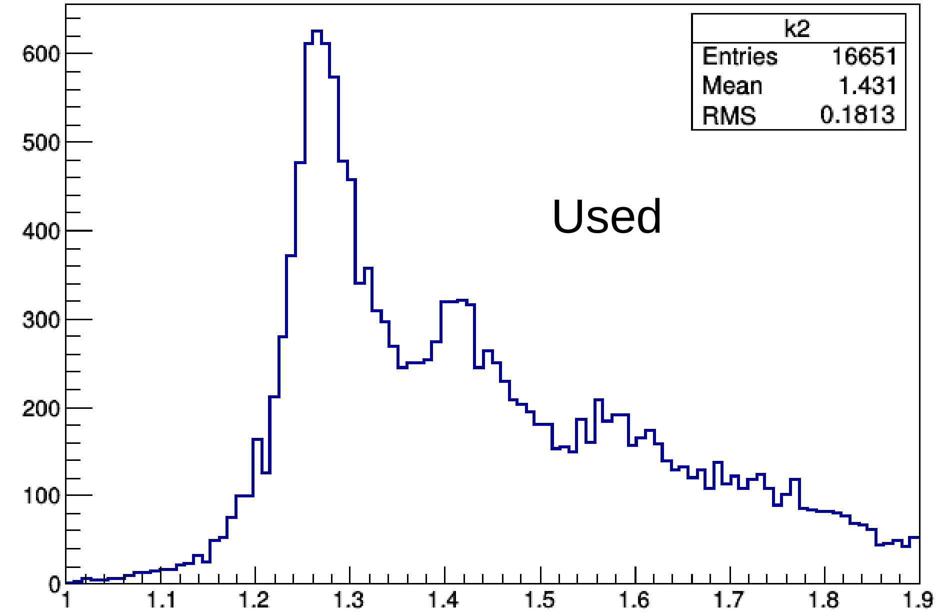



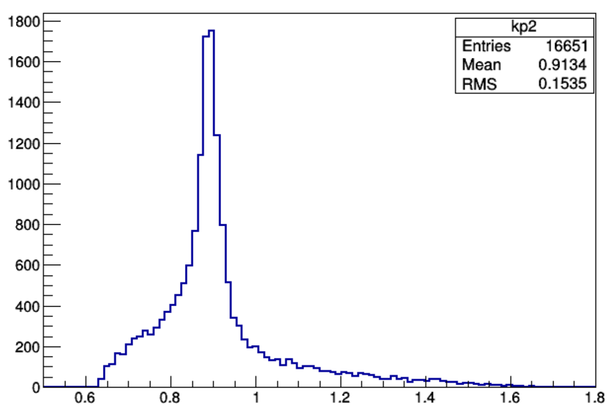
$B^+ \to K^+\pi^-\pi^+ \gamma$

20,000 events

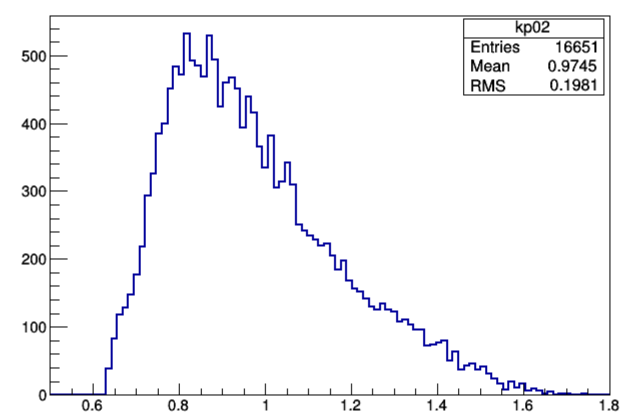


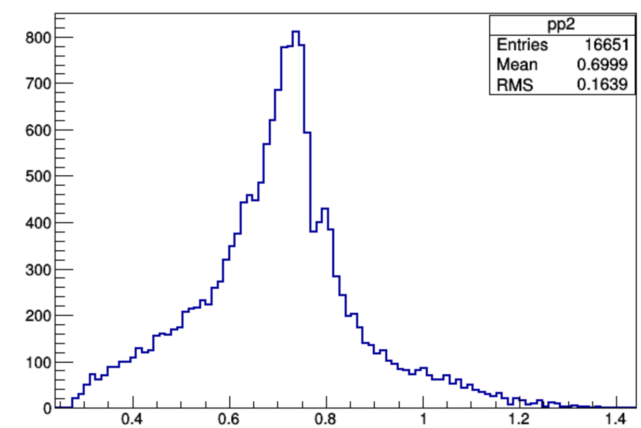

$M(K^+\pi^-\pi^+)$




$M(K^+\pi^-)$

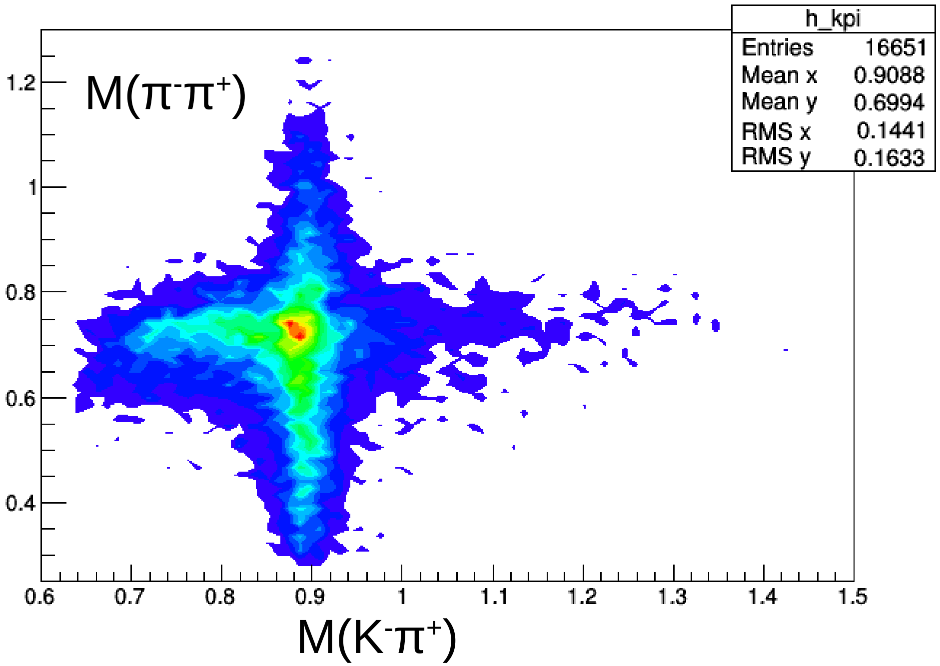


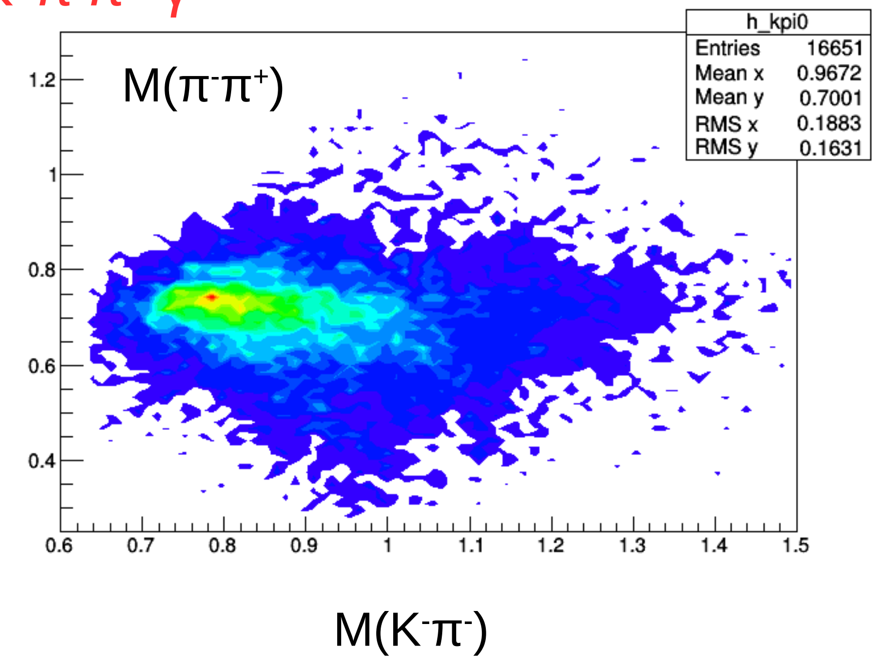

$M(K^+\pi^+)$

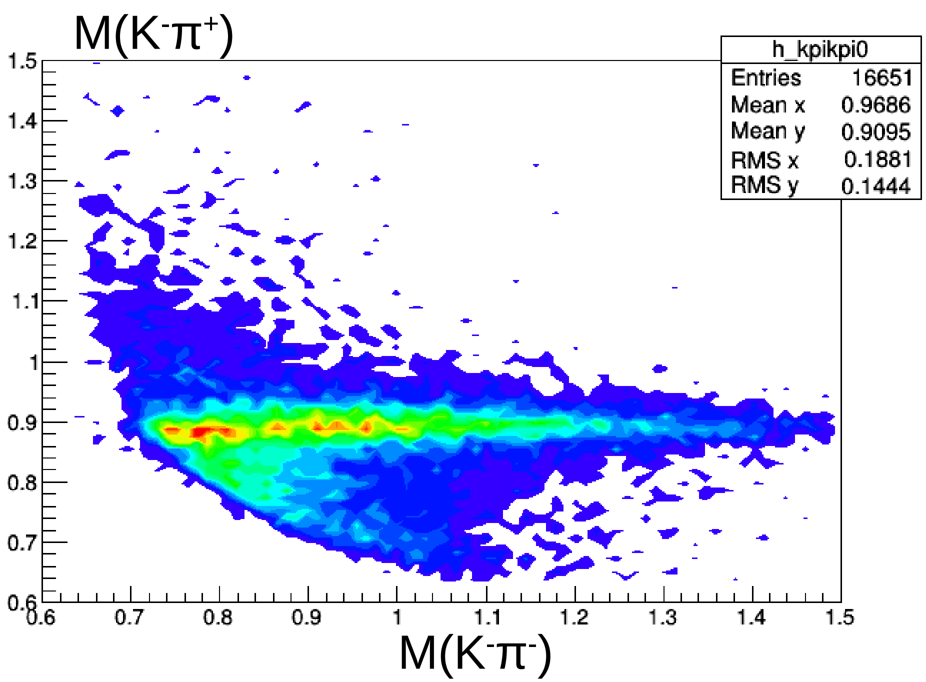



$M(\pi^+\pi^-)$

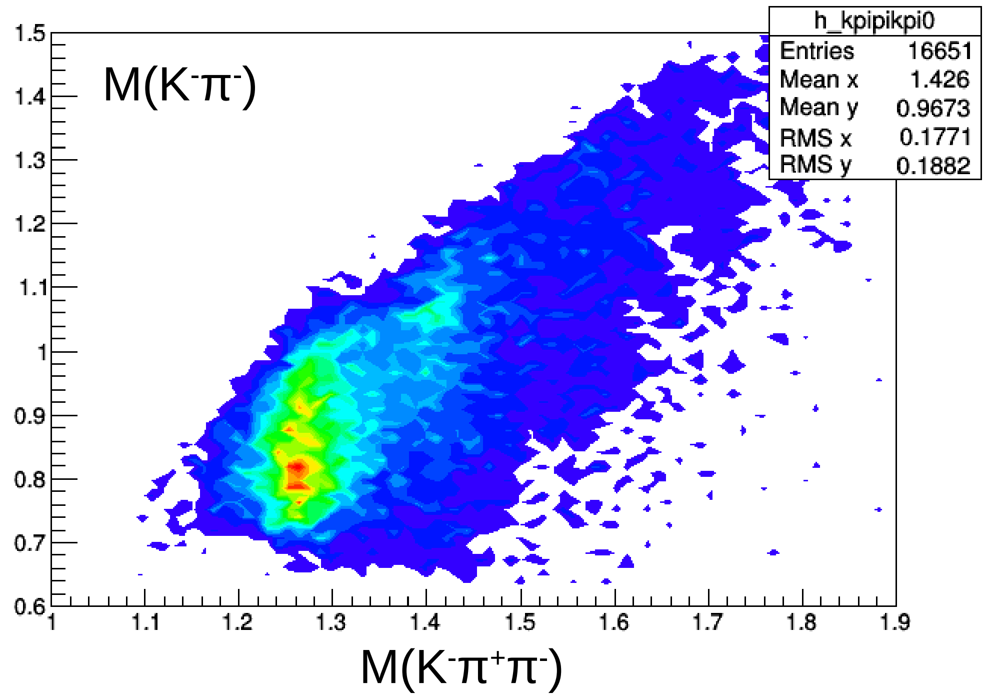
# $B^+ \to K^+\pi^-\pi^+\gamma$

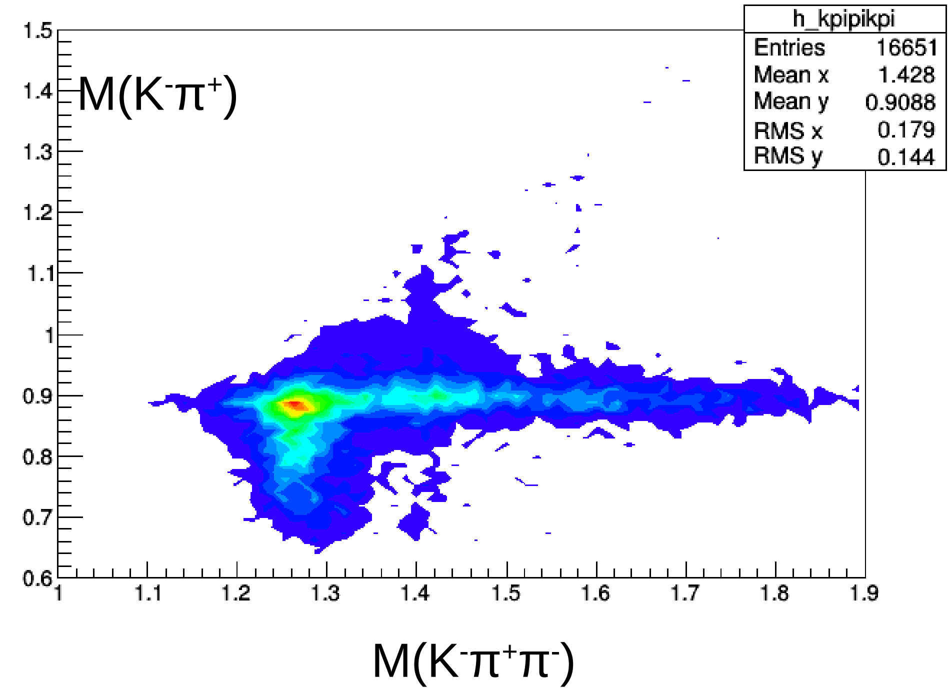


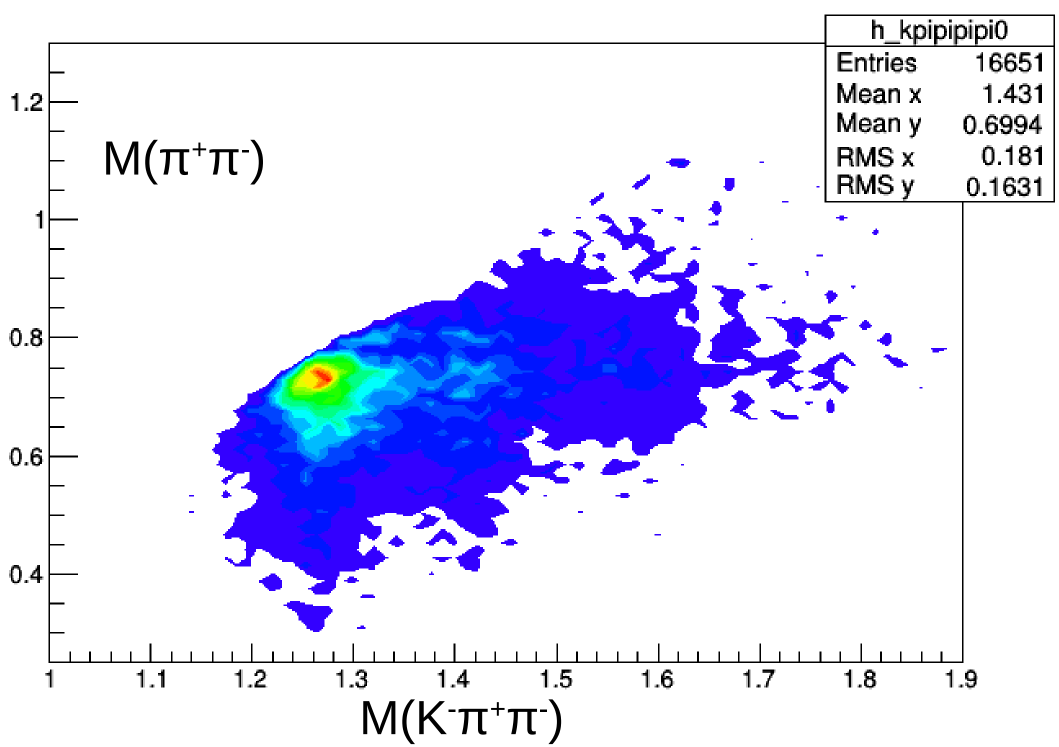



$B^+ \to K^+\pi^-\pi^+ \gamma$

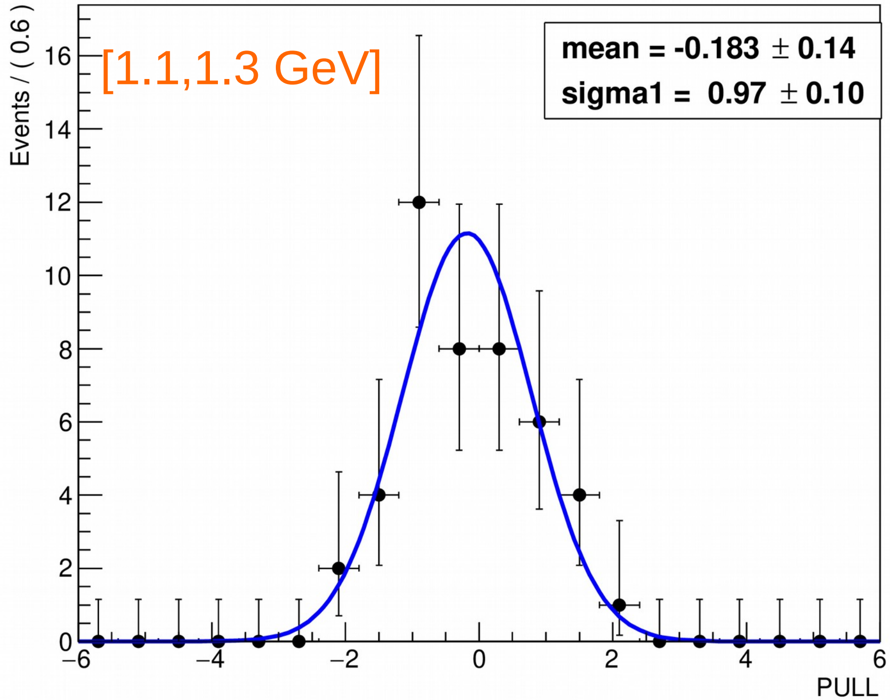


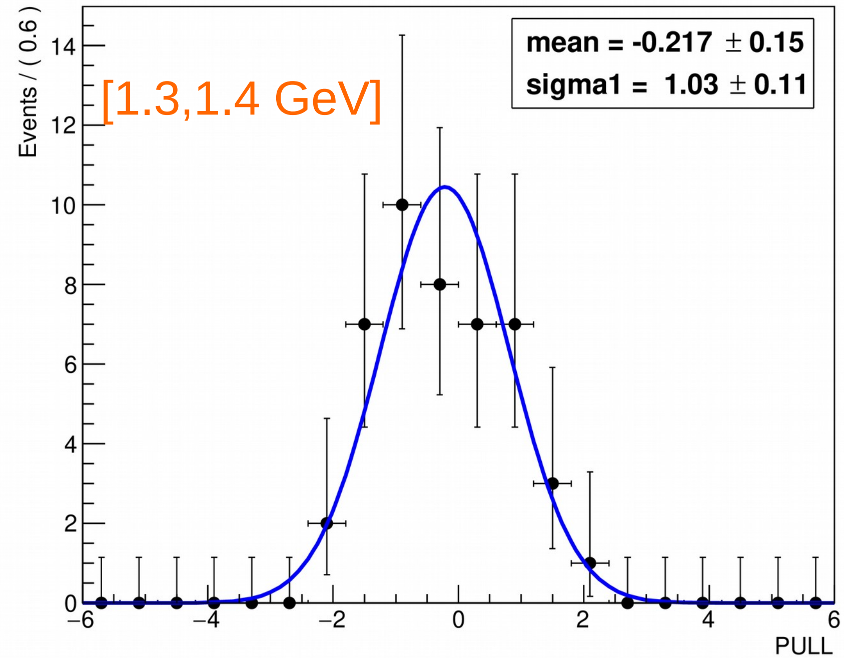



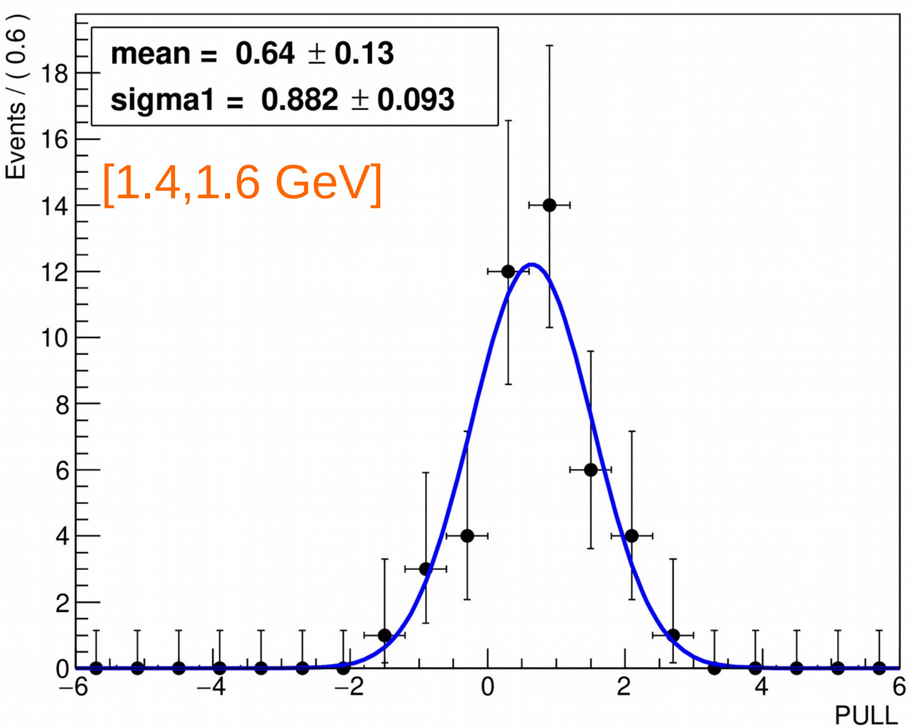



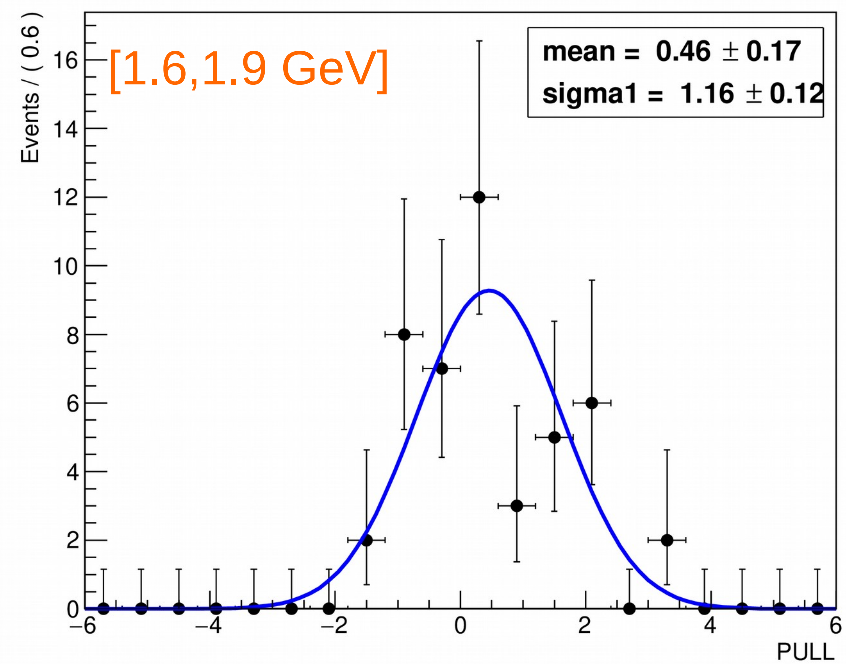
# Pull study for $B \rightarrow K^{+}\pi^{-}\pi^{0}\gamma$

45 samples with 1500 signal yield used



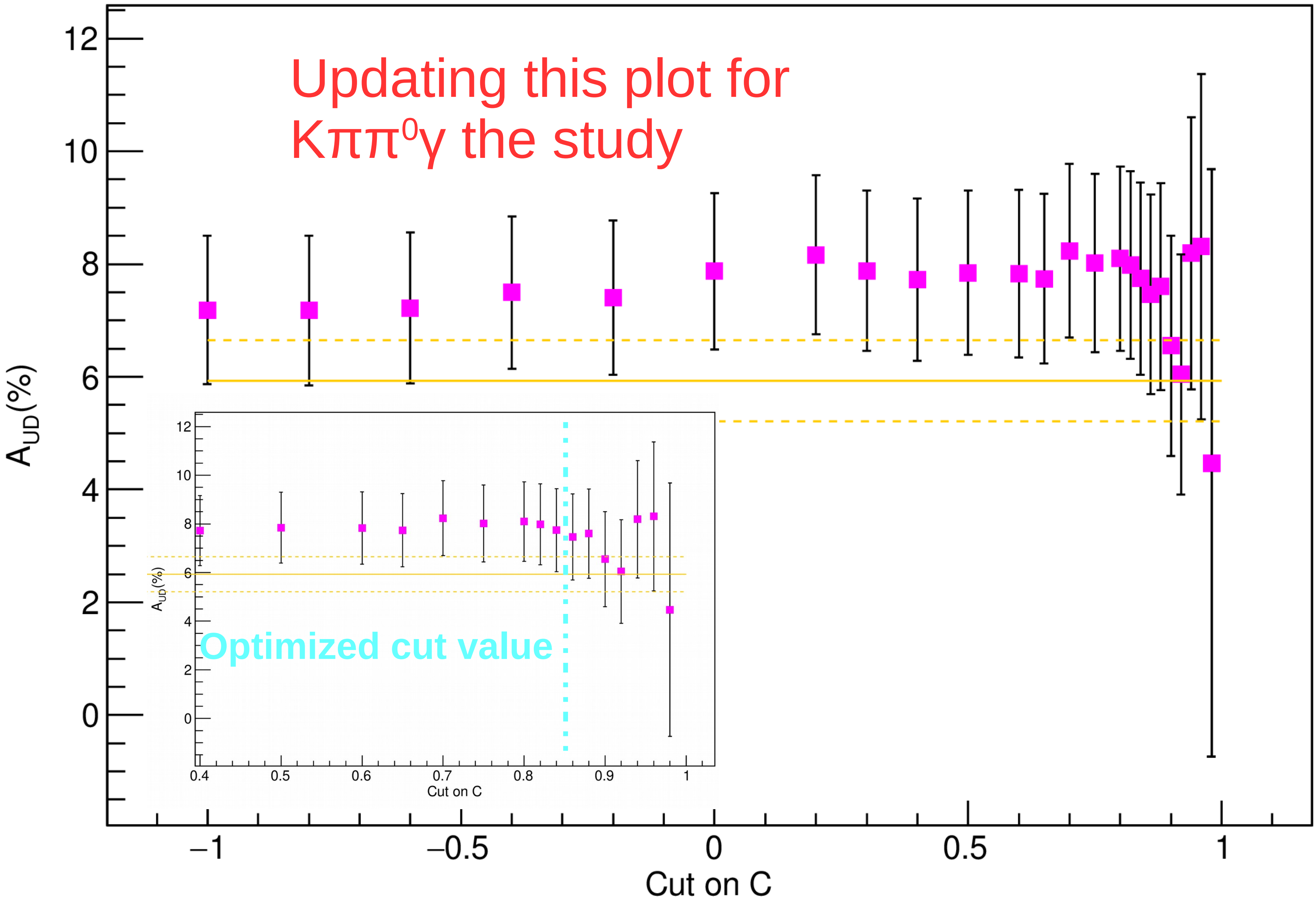



$B^+ \to K^+\pi^-\pi^+\gamma$

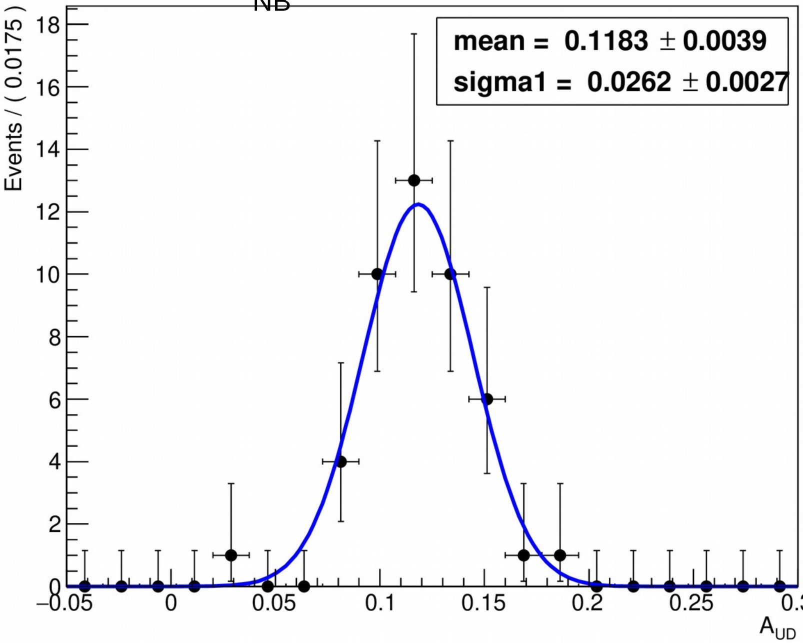
# Dependence of $A_{UD}$ on NB cut



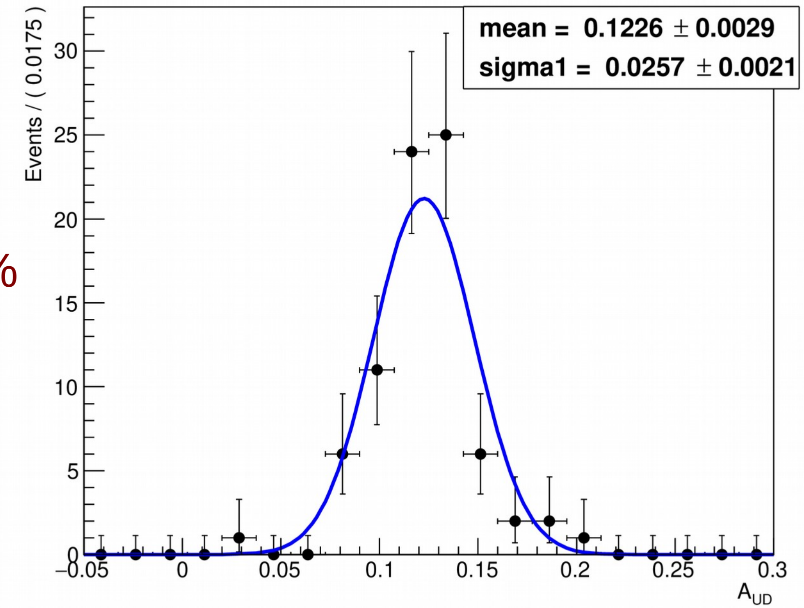
# $B^0 \to K^+\pi^-\pi^0\gamma$ 1 Million sample

1.1< M(Kππ)< 1.9 GeV

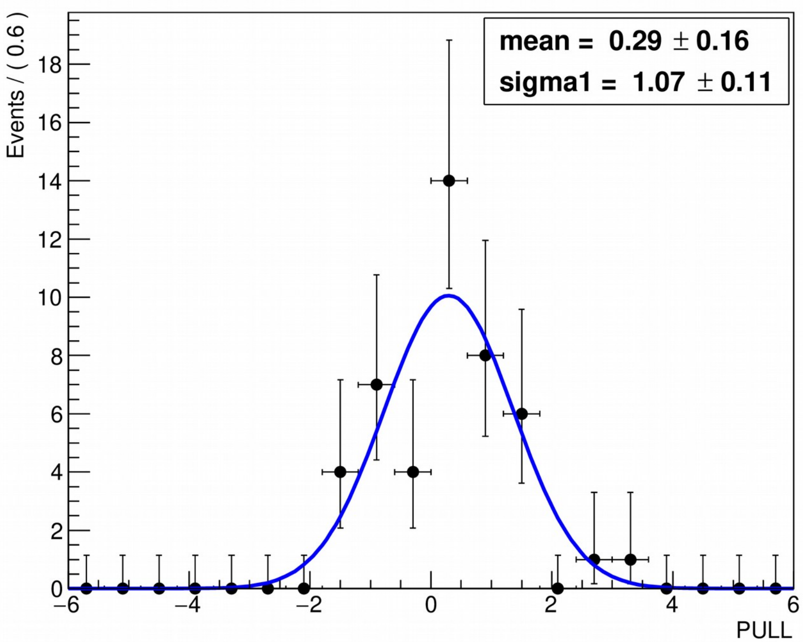
$C_{NB} > 0$

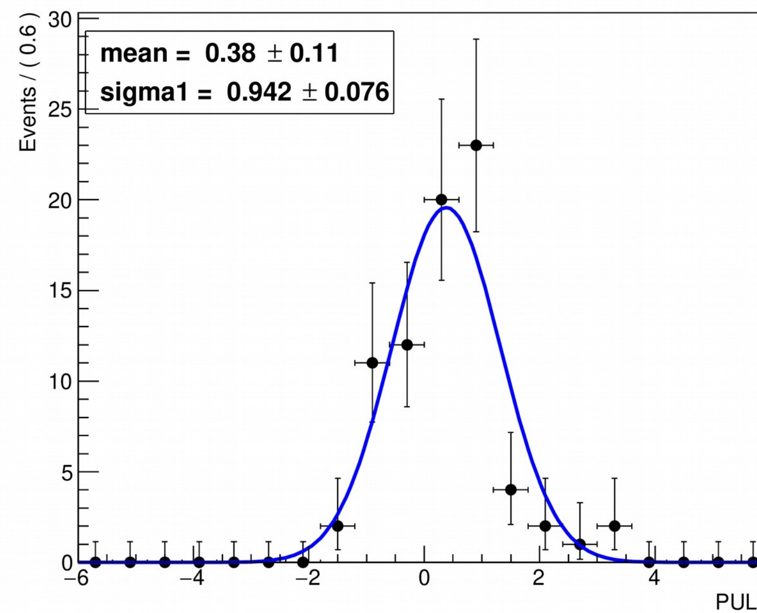



$C_{NB} > 0.85$




Input : (11.5±0.1)%



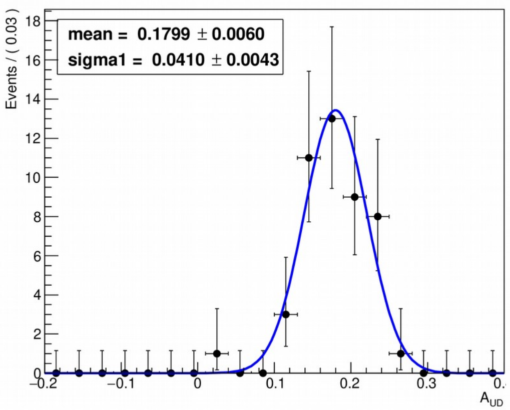



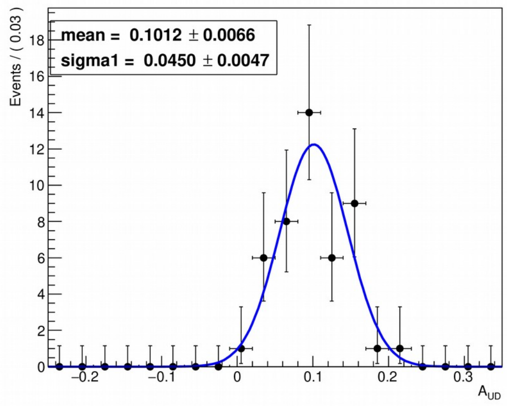
# $A_{UD}$ extracted in different bins

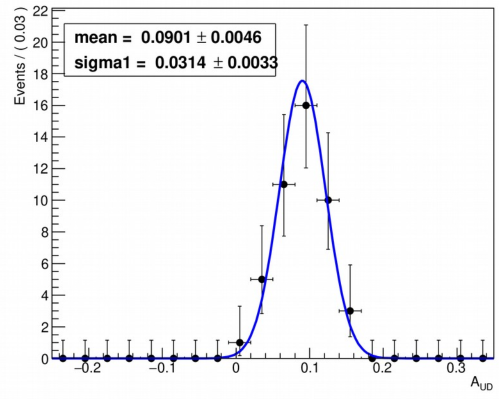
45 toys

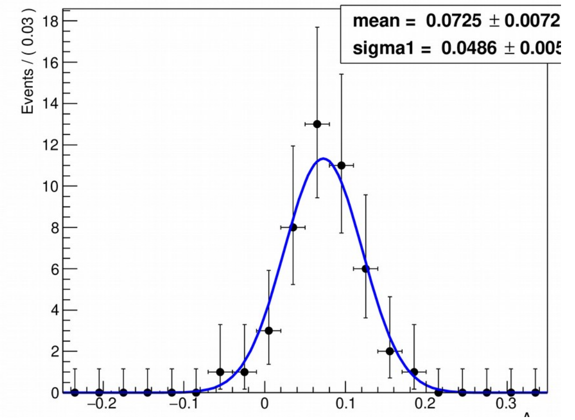
# $B^0 \rightarrow K^+\pi^-\pi^0\gamma$ 1 Million sample

$C_{NB} > 0$



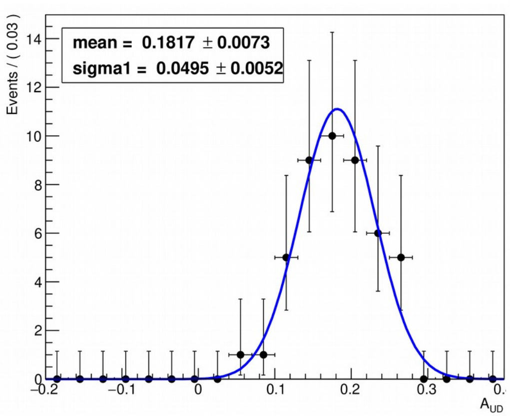



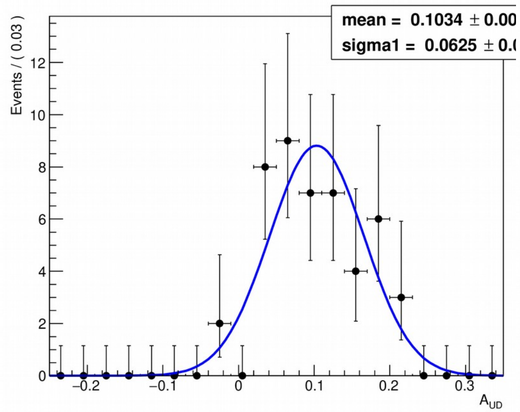

Input:0.194±0.002

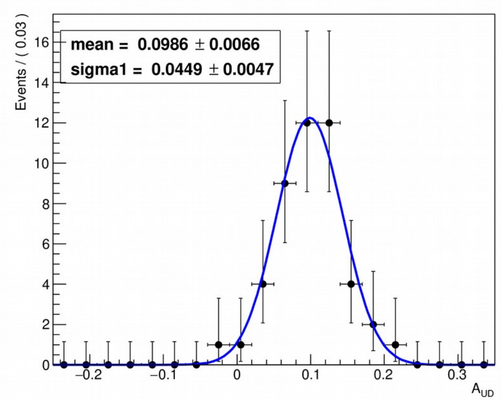
Input: 0.117±0.002

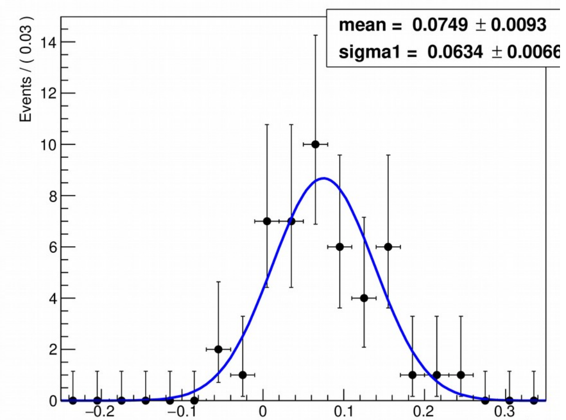
Input:0.067±0.002

Input : 0.051±0.002




$C_{NB} > 0.85$

[1.1,1.3]

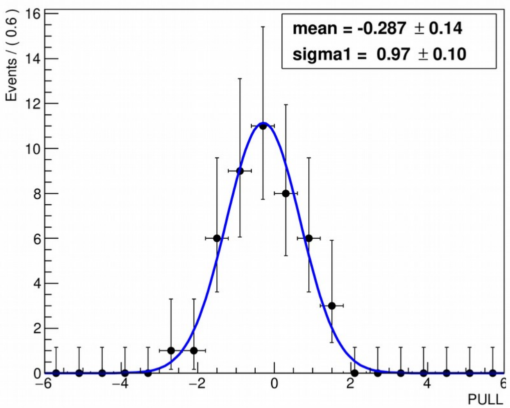
[1.3,1.4]

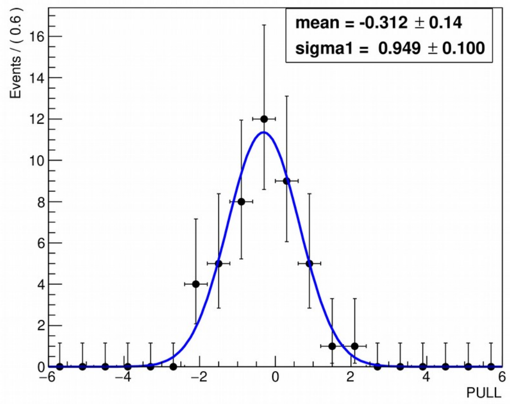
[1.4,1.6]

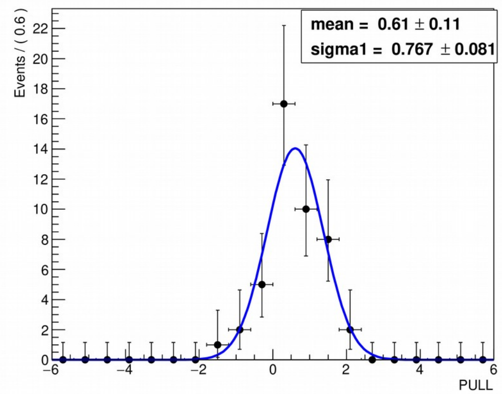
[1.6,1.9]

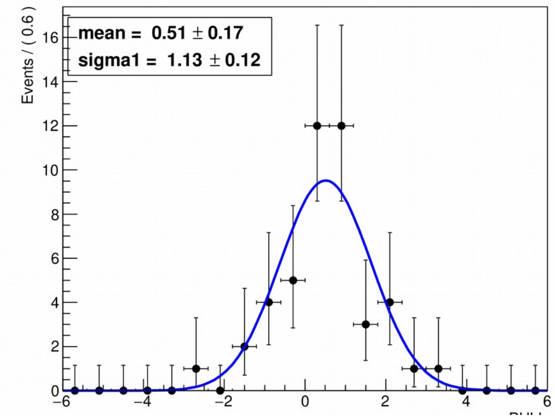
$A_{UD}$ extracted pull in different bins 45 toys

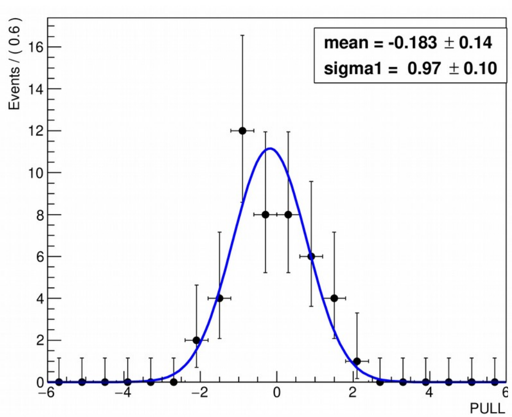
# $B^0 \rightarrow K^+\pi^-\pi^0\gamma$ 1 Million sample $C_{NB} > 0$

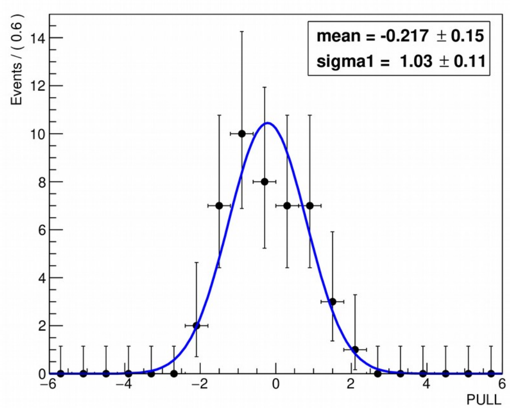


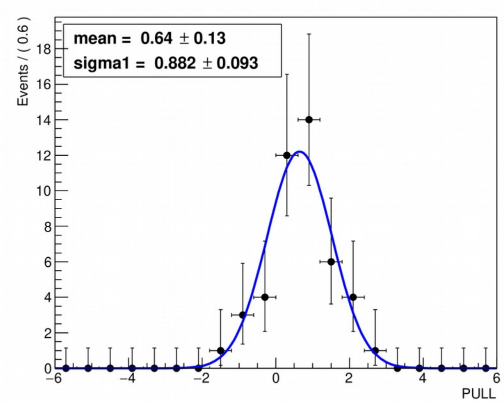



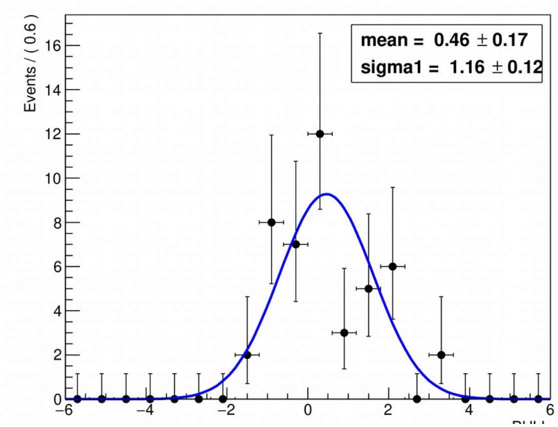




$C_{NB} > 0.85$

[1.1,1.3] [1.3,1.4] [1.4,1.6] [1.6,1.9]