|g/p| Measurement with P.R. $B^0 \to D^* l$

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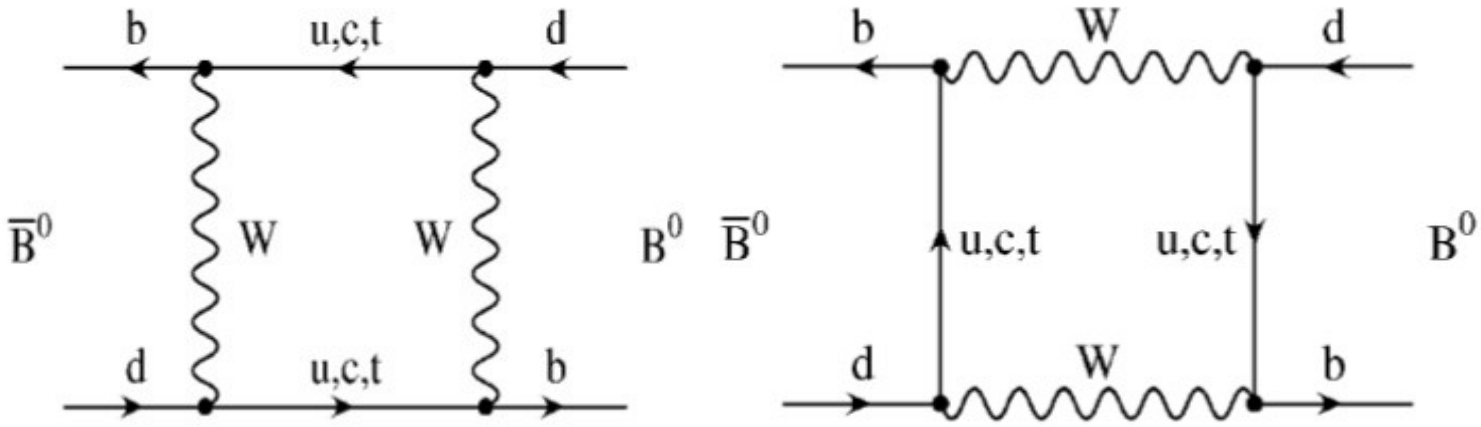
- Validation on MC
- Real Data Results
- Systematic Uncertainties
- Conclusions

Motivations

CPV in B^0 mixing



- New Particles in the boxes could modify SM expectations

- B^0_q - $\overline{B^0_q}$ oscillations & decay governed by an Effective Hamiltonian:

$$i\frac{d}{dt}\begin{pmatrix} B_q \\ \overline{B}_q \end{pmatrix} = \left[\begin{pmatrix} M^q_{11} & M^{q\,*}_{21} \\ M^q_{21} & M^q_{11} \end{pmatrix} - \frac{i}{2}\begin{pmatrix} \Gamma^q_{11} & \Gamma^{q\,*}_{21} \\ \Gamma^q_{21} & \Gamma^q_{11} \end{pmatrix}\right]\begin{pmatrix} B_q \\ \overline{B}_q \end{pmatrix}$$

$[M_{ij}]$ = mass matrix

$[\Gamma_{ij}]$ = decay matrix

- Physical Eigenstates with defined masses and widths:

$$|B_q^{L,H}\rangle = \frac{1}{\sqrt{1+|(q/p)_q|^2}}\left(|B_q\rangle \pm (q/p)_q\,|\overline{B}_q\rangle\right)$$

→ If $|(q/p)_q|=1$ they would be also CP Eigenstates

- Neglecting $o(m^2_b/M^2_W)$:

$$\Delta m_q = m_H - m_L = 2\left|M^q_{12}\right|;\ \Delta\Gamma_q = \Gamma_L - \Gamma_H = 2\left|\Gamma^q_{12}\right|\cos\phi$$

$$\phi = arg\left(-M^q_{12}/\Gamma^q_{12}\right)$$ CP violating phase

CPV in B^0 mixing

- $\Upsilon(4S)$ machines & Hadron Colliders: b quarks produced mainly in $b\bar{b}$ pairs
  - → CP Asymmetry (time-independent):

$$A_{CP} = \frac{Prob(\bar{B}^0 \to B^0, t) - Prob(B^0 \to \bar{B}^0, t)}{Prob(\bar{B}^0 \to B^0, t) + Prob(B^0 \to \bar{B}^0, t)} = \frac{N(B^0 B^0) - N(\bar{B}^0 \bar{B}^0)}{N(B^0 B^0) + N(\bar{B}^0 \bar{B}^0)}$$

- Experimentally: measure charge asymmetry in **mixed** semileptonic B^0 events:

$$A_{SL} = \frac{N(\ell^+\ell^+) - N(\ell^-\ell^-)}{N(\ell^+\ell^+) + N(\ell^-\ell^-)} = \frac{1 - |q/p|^4}{1 + |q/p|^4} = \frac{|\Gamma_{12}^q|}{|M_{12}^q|} \sin\phi$$

→CPV in mixing if:
$A_{SL} \neq 0 \leftrightarrow |q/p| \neq 1 \leftrightarrow \Phi \neq 0$

Standard Model predicts

(Lenz, Nierste, arXiv:1102.4274 (2011)):

- B_d: $A^d_{SL} = (-4.1 \pm 0.6)10^{-4}$
  $\Phi_d = -4.3° \pm 1.4°$
- B_s: $A^s_{SL} = (1.9 \pm 0.3)10^{-5}$
  $\Phi_s = 0.22° \pm 0.06°$

Beyond Standard Model

- New Physics could modify M_{12}^q and A_{SL} leaving Γ_{12}^q unchanged:

$$M_{12}^{NP,q} = M_{12}^{SM,q} \Delta_q ; \Delta_q = |\Delta_q| e^{i\phi_q^\Delta}$$

$$A_{SL}^{NP} = \frac{|\Gamma_{12}^q|}{|M_{12}^{SM,q}|} \frac{\sin(\phi_q^{SM} + \phi_q^\Delta)}{|\Delta_q|}$$

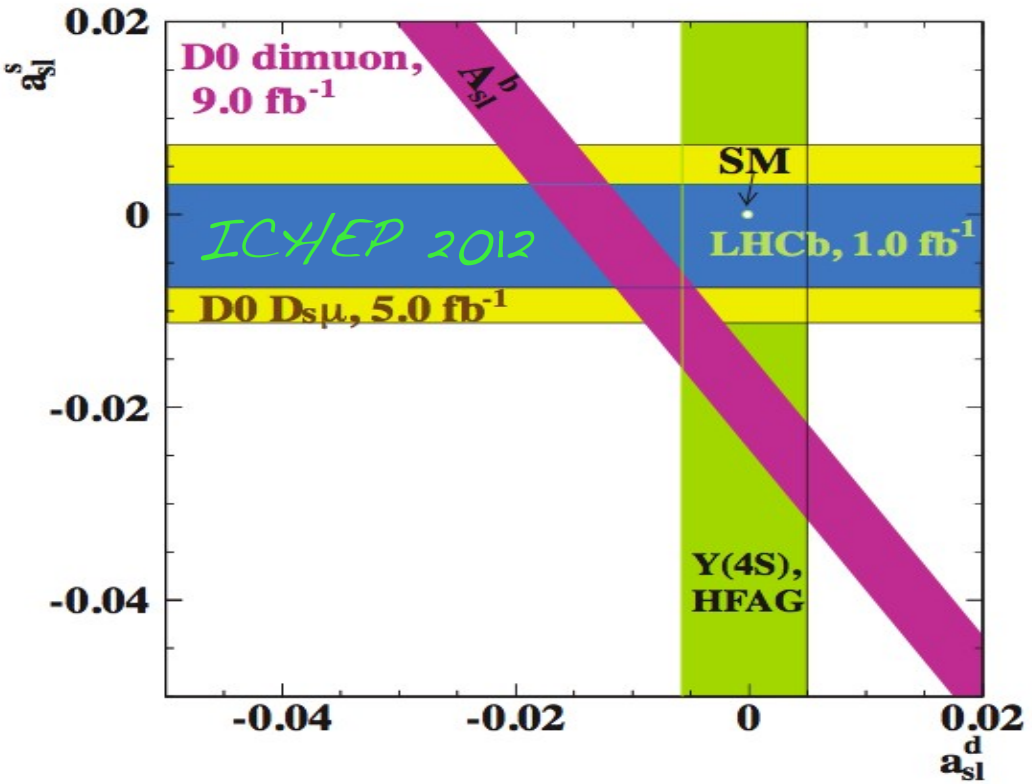
CPV in B^0 mixing

- HFAG average of Y(4S) measurements gives (arXiv:1207.1158v1):

$|q/p|_d = 1.0002 \pm 0.0028$

$A^d_{SL} = -0.0005 \pm 0.0056$

In agreement with SM



- Hadronic Colliders measure a combination of B^0_d & B^0_s CP parameters:

$A^b_{SL} = C_d A^d_{SL} + C_s A^s_{SL}$

→ $C_{d,s}$ depend on $B^0_{d,s}$ production rates & mixing probability

- SM predicts:

$A^b_{SL} = (-0.028\ ^{+0.005}_{-0.006})\%$

- New D0 result on charge Asymmetry of like-sign dimuons differs by 3.9 σ from SM expectation (Phys. Rev. D 84, 052007):

$A^b_{SL} = (-0.787 \pm 0.172 \pm 0.093)\%$

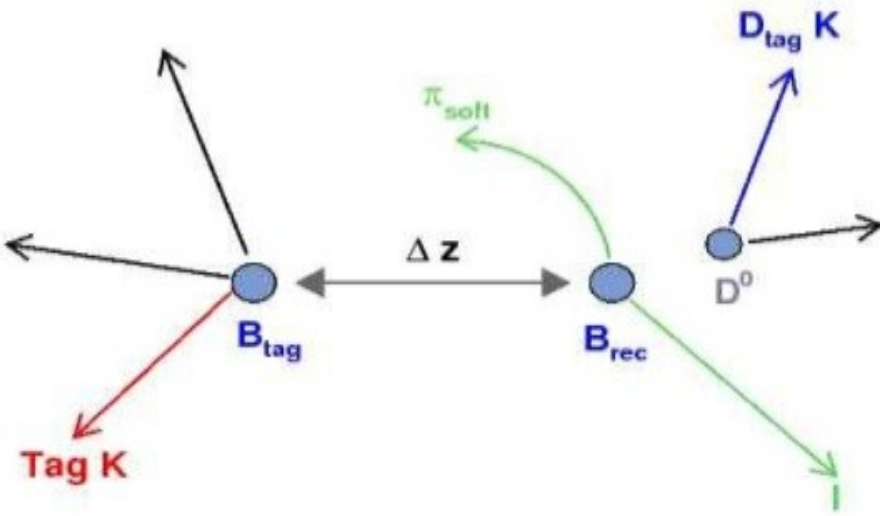
- New results from Beauty-Factories & LHCb will help to understand the discrepancy

Analysis Method

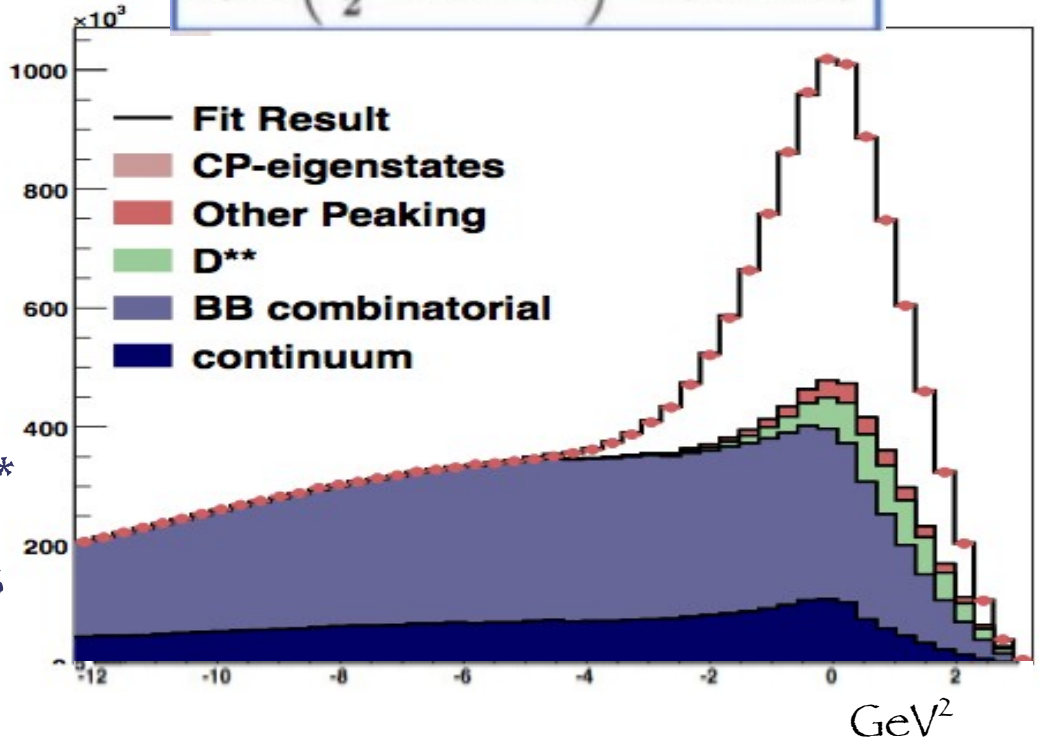
(See BADS 2514, 1738)

Partial Reconstruction

- Partial Reconstruction of $B^0 \to D^* l$ already exploited in several measurements (B^0, Δm, $|q/p|$ using Lepton Tag)
- Reconstruct only Lepton & π_{soft}
- Signal selection by means of missing neutrino mass with the approximation of B at rest
- D* energy from π_{soft} kinematics
- Sample composition from external fit to M^2 by floating D*, D** and Combinatorial using MC shapes
- Continuum from rescaled OffPeak

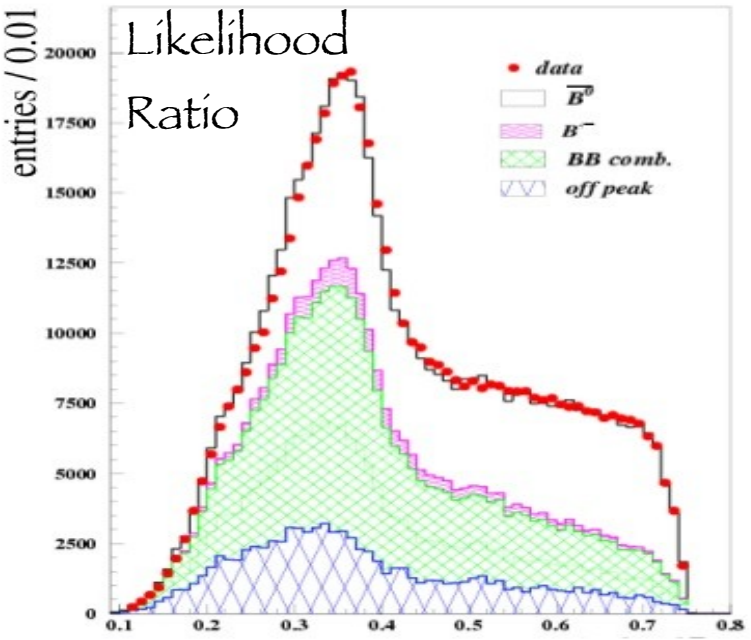


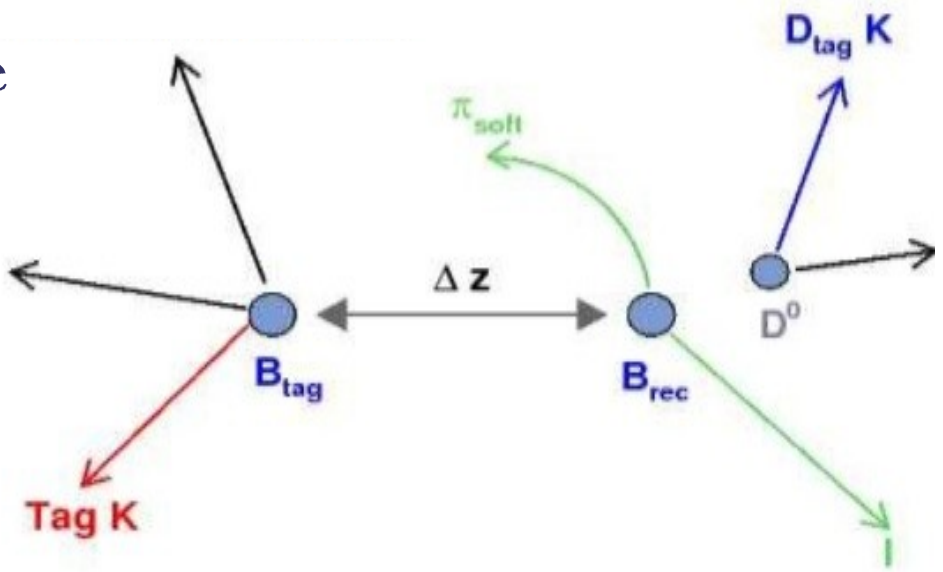
$$M_\nu^2 = \left(\frac{\sqrt{s}}{2} - \tilde{E}_{D^*} - E_\ell\right)^2 - (\tilde{\mathbf{p}}_{D^*} + \mathbf{p}_\ell)^2$$



Selection and Tagging

- $0.06 < P\pi_{soft} < 0.20$ GeV; $1.40 < P_{e/\mu} < 2.30$ GeV
- Selectors: e: PIDLHElectrons, μ: muNNLoose, K: LooseKaonMicro
- Best lepton π_{soft} pair per event choosen exploiting Likelihood Ratio (P_l, $P\pi_{soft}$, Vertex Probability)
- Continuum and Combinatorial BKG suppressed by means of Event Shape variables & Vertex Probability





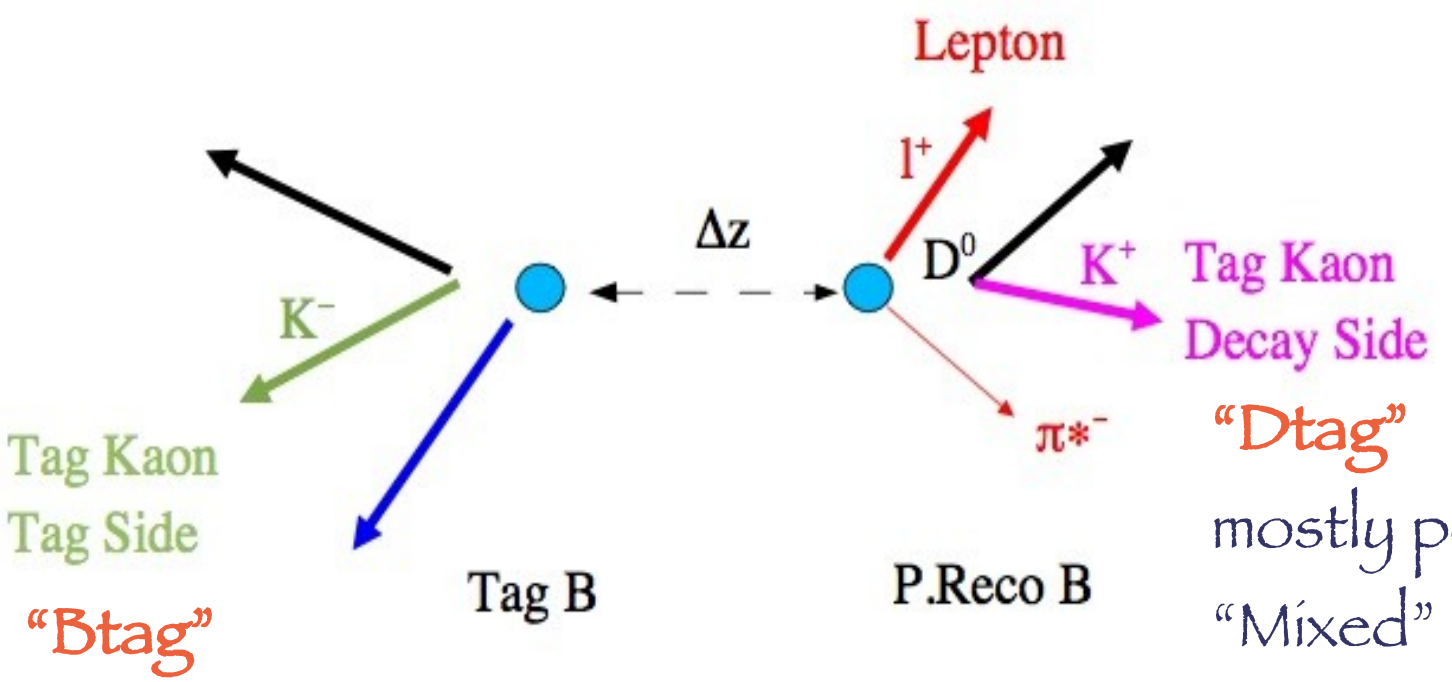
- Tag B Flavor from K charge
- Tag B Vertex from K & Beam Spot

K-Tagging Categories

Tagging Kaon Sample: { $b \to K + b \to c \to K$; $D^0 \to K$

From tag B "Btag"

From decay B "Dtag"



"Dtag" mostly populate the "Mixed" event sample (K-lepton charge correlation)

PDF(Δt) Description

- |q/p| obtained by a Binned Likelihood simultaneous Δt Fit to 4 subsamples: Unmixed (l^-K^+, l^+K^-); Mixed (l^+K^+, l^-K^-)
- Signal B^0 Btag PDF for Positive Mixed (l^+K^+) sample, (similar expressions apply for the other ones):

$$\mathcal{F}_{signal}(\Delta t, s_t, s_m) = \frac{\Gamma}{2(1+r'^2)} e^{-\Gamma|\Delta t|}\left|\frac{p}{q}\right|^2 \left[\left(1+\left|\frac{q}{p}\right|^2 r'^2\right)\cosh(\Delta\Gamma\Delta t/2) - \right.$$

$$\left. - \left(1-\left|\frac{q}{p}\right|^2 r'^2\right)\cos(\Delta m_d \Delta t) + \left|\frac{q}{p}\right|(b+c)\sin(\Delta m_d \Delta t)\right]$$

$$r' = \left|\overline{\mathcal{A}}_{DCS}/\mathcal{A}_{CF}\right|$$
$$b = 2r'\sin(2\beta+\gamma)\cos\delta'$$
$$c = -2r'\cos(2\beta+\gamma)\sin\delta'$$
$$\delta' = \delta_u - \delta_c$$

Assumptions:

- =0
- Double Cabibbo Suppressed parameters b, c are treated as effective parameters due to strong correlation with resolution function
- Only |q/p| is measured

PDF(Δt) Description

- In Real Life some Physics & Detector effects have to be taken into account:
- Physics
  - Mistag :

    $\omega^+ = \text{Prob}(B^0 \to K^-)$, $\omega^- = \text{Prob}(\overline{B^0} \to K^+)$, $\Delta\omega = \omega^+ - \omega^-$, $\omega = (\omega^+ + \omega^-)/2$
- Detector
  - Reconstruction Asymmetry:

    $\rho = \varepsilon(l^+, \pi^-)$, $\bar{\rho} = \varepsilon(l^-, \pi^+)$

    $$A_{rec} = (\rho - \bar{\rho})/(\rho + \bar{\rho})$$
  - Tagging Asymmetry:

    $\tau = \varepsilon(K^+)$, $\bar{\tau} = \varepsilon(K^-)$

    $$A_{tag} = (\tau - \bar{\tau})/(\tau + \bar{\tau})$$
  - **Δt** Resolution

PDF(Δt) Description

- Modified PDF for Positive Mixed (l^+K^+) sample, (similar expressions apply for the other ones):

$$\mathcal{F}_\chi^{meas}(\Delta t, s_t = 1, s_m = -1) = \rho\tau\left[(1-\omega_\chi^+)\mathcal{F}_\chi(\Delta t, 1, -1) + \omega_\chi^-\mathcal{F}_\chi(\Delta t, -1, 1)\right] =$$

$$= RT(1+A_{rec})(1+A_{tag})\left[(1-\omega_\chi^+)\mathcal{F}_\chi(\Delta t, 1, -1) + \omega_\chi^-\mathcal{F}_\chi(\Delta t, -1, 1)\right]$$

$$R = (\rho + \bar{\rho})/2$$

$$T = (\tau + \bar{\tau})/2$$

B_{rec} is a	B_{tag} is a	s_t	s_m
B^0	B^0	1	-1
$\bar{B}^0$	B^0	1	1
B^0	$\bar{B}^0$	-1	1
$\bar{B}^0$	$\bar{B}^0$	-1	-1

- Observed PDFs are obtained from the convolution of the modified PDFs with a resolution function (sum of Gaussians convoluted with exponentials)

CP-eigenstates & Continuum

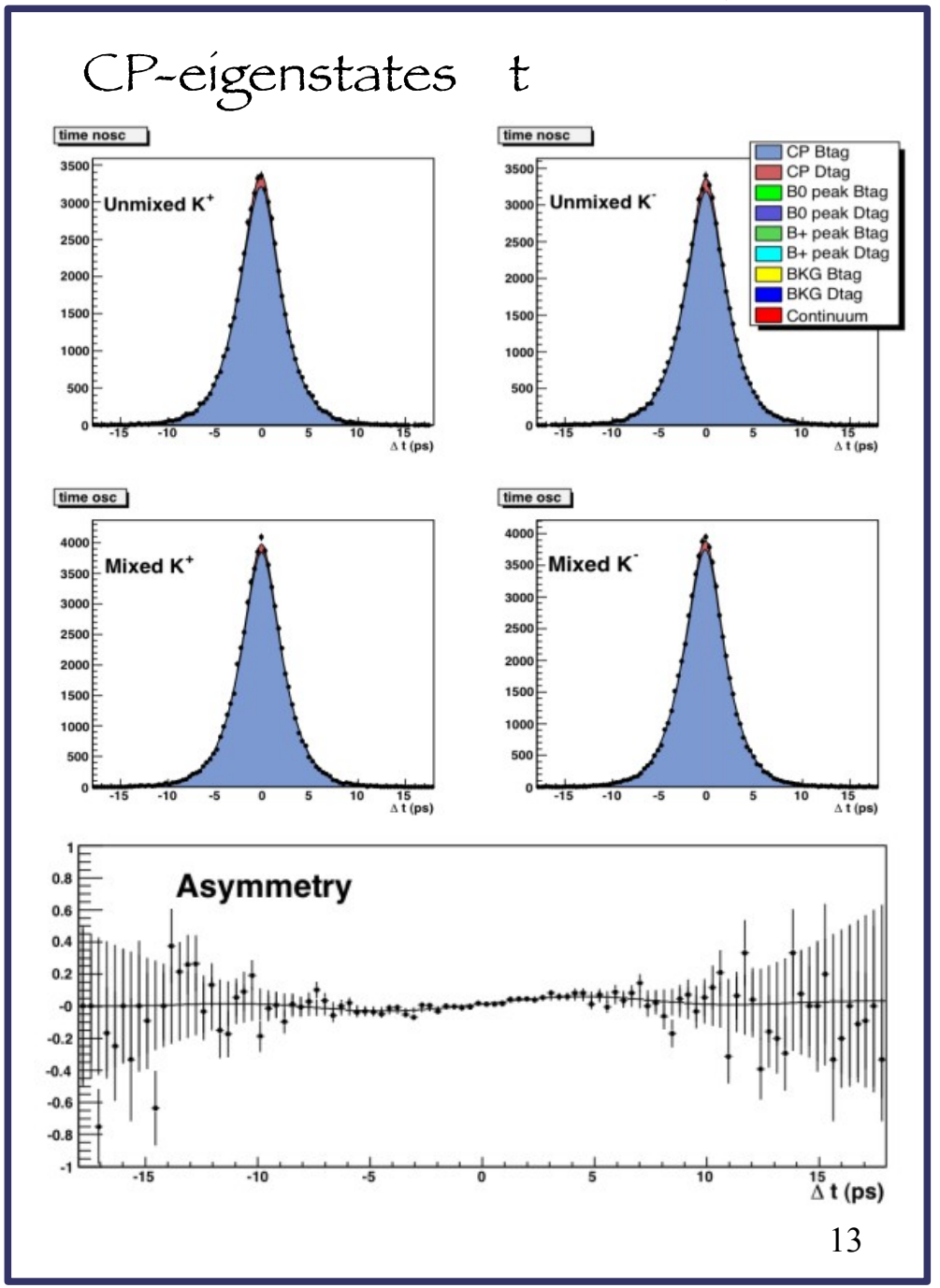
- About 1% of B^0 events decay into CP-eigenstates (mostly $D^* \overline{D}^{(*)}$)

  - Described by:

$$\mathcal{F}_{CPe}(\Delta t) = \frac{\Gamma_0}{4} e^{-\Gamma_0 |\Delta t|} (1 \pm S sin(\Delta m_d \Delta t) \pm C cos(\Delta m_d \Delta t)$$

  - S & C obtained from the simulation

- Continuum BKG modeled with a decaying exponential with effective lifetime



Analysis Strategy

- Crucial Issue: discriminate between Physical & Detector charge asymmetry **without relying on control samples**

- Different sub-samples (B^0, B^+)X(Peaking, BKG)X(Btag, Dtag) share Physical and/or Detector Asymmetries in different combinations.

- **Strategy: disentangle the Physical vs Detector Asymmetries by exploiting all the available informations from different sub-samples.**

  - ➔ **Also the BKG and the Dtag samples are useful!**

Analysis Strategy

- Observed Asymmetry in the different subsample used to disentangle Physical vs Detector contributions:

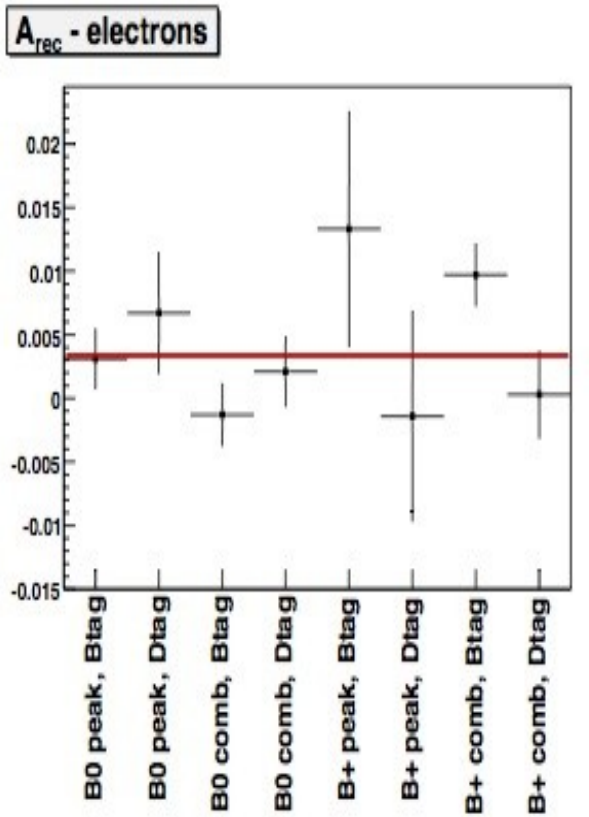
	B^0	B^+
Reco evts (Tag+Untag)	$A_{rec} + A_{sl}^{*}{}_{d}$	A_{rec}
Btag	$A_{rec} + A_{tag}(P_K) + A_{sl}$	$A_{rec} + A_{tag}(P_K)$
Dtag	$A_{rec} + A_{tag}(P_K) + A_{sl}^{*}{}_{d}$	$A_{rec} + A_{tag}(P_K)$

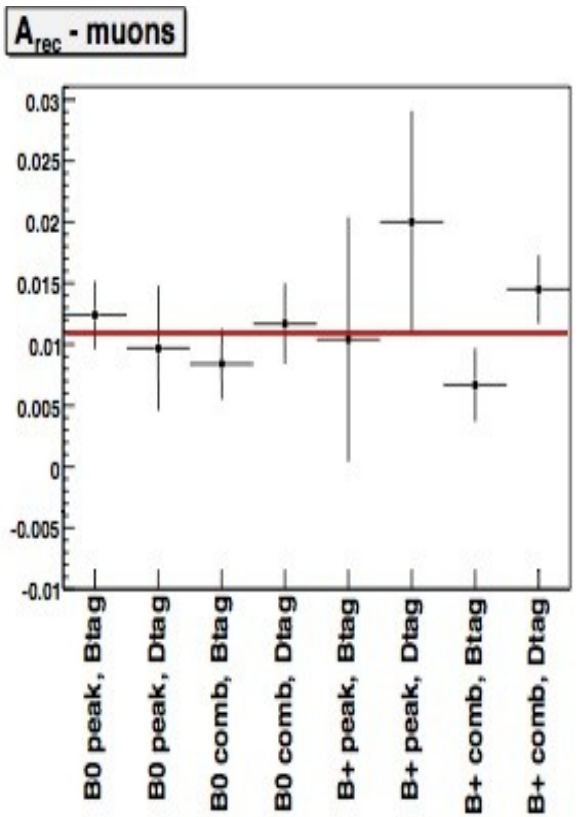
Analysis Strategy

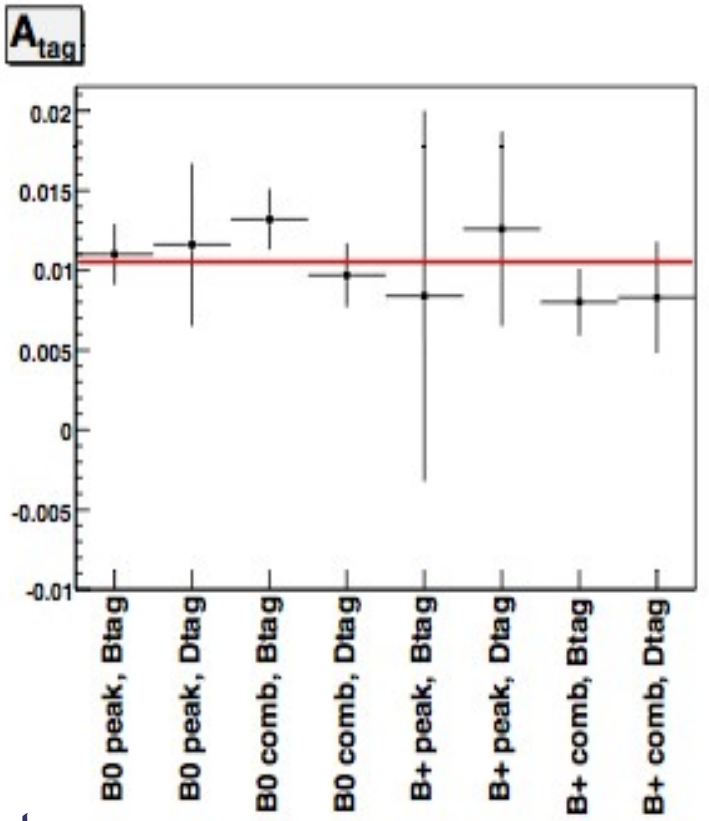
- Hypothesis: same Detector Asymmetries shared by different samples
- Verified on simulation:

$$A_{\ell K} = \frac{N(\ell^+ K^+) - N(\ell^- K^-)}{N(\ell^+ K^+) + N(\ell^- K^-)}$$

	Electrons	Muons
$A_{\ell K}(B_{tag})$	0.0149 ± 0.0013	0.0196 ± 0.0016
$A_{\ell K}(D_{tag})$	0.0152 ± 0.0009	0.0205 ± 0.0010
$A_{\ell K}(B_{tag})$ - $A_{\ell K}(D_{tag})$	-0.0003 ± 0.0016	-0.0009 ± 0.0019







- Last version of Fit uses different Arec for Peaking/BKG

Likelihood Constraints

- Best statistical accuracy on Physical/Detector Asymmetries and mistag obtained by applying to the Likelihood some multiplicative Binomial Constraints

- For every P_K bin of Signal B^0 Btag events, (similar expressions apply for the other samples):

$$C(\omega, Arec, Atag, |q/p|) = \binom{N}{N_M} p_M^{N_M} (1-p_M)^{N_U} \times$$

$$\binom{N_M}{N_{MK+}} p_{MK+,M}^{N_{MK+}} (1-p_{MK+,M})^{N_{MK-}} \binom{N_U}{N_{UK+}} p_{UK+,U}^{N_{UK+}} (1-p_{UK+,U})^{N_{UK-}}$$

- $N = N_{Mixed} + N_{Unmixed}$; $N_{Mixed} = N_{Mixed\ K+} + N_{Mixed\ K-}$; $N_{Unmixed} = N_{Unmixed\ K+} + N_{Unmixed\ K-}$
- Probabilities p_{XY} obtained from integrals of the relevant observed PDF(Δt) in terms of mistag, Physical and Detector Asymmetries
- 8 Detector-Asymmetry parameters floated in the fit

MC Validation

(Run1-Run6, Release 24, Analysis 5)

Mistag Determination

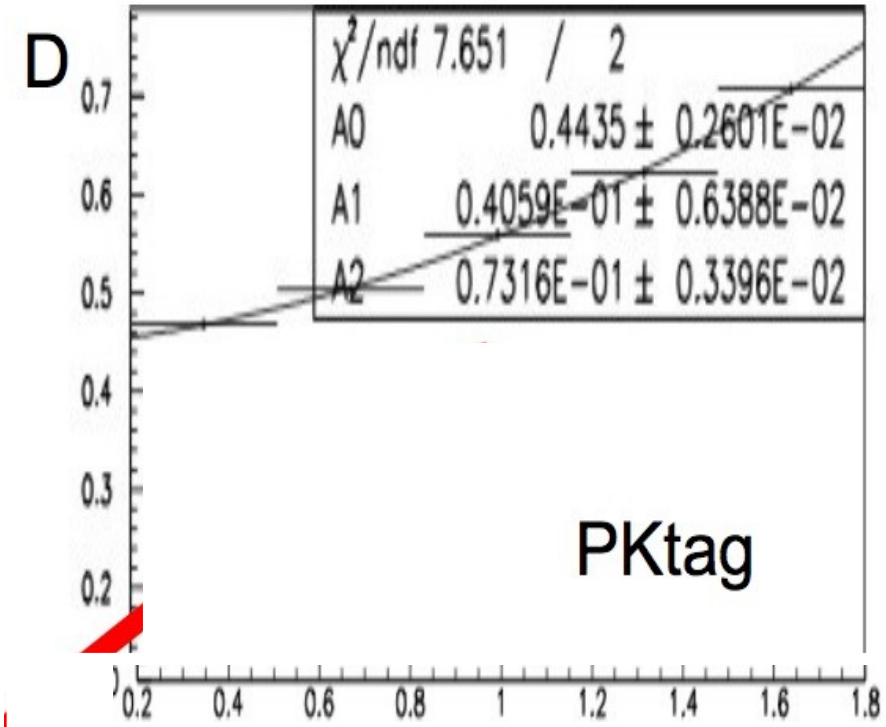
- Dilution $D(P_K)=1-2\omega$ floated
- ω lower at higher P_K
- $\Delta\omega(P_K)=\omega(K^+)-\omega(K^-)$ floated

Fit results in agreement with counting

B^0 PEAKING

$\omega(\text{Mixed})=\omega(\text{Unmixed})$

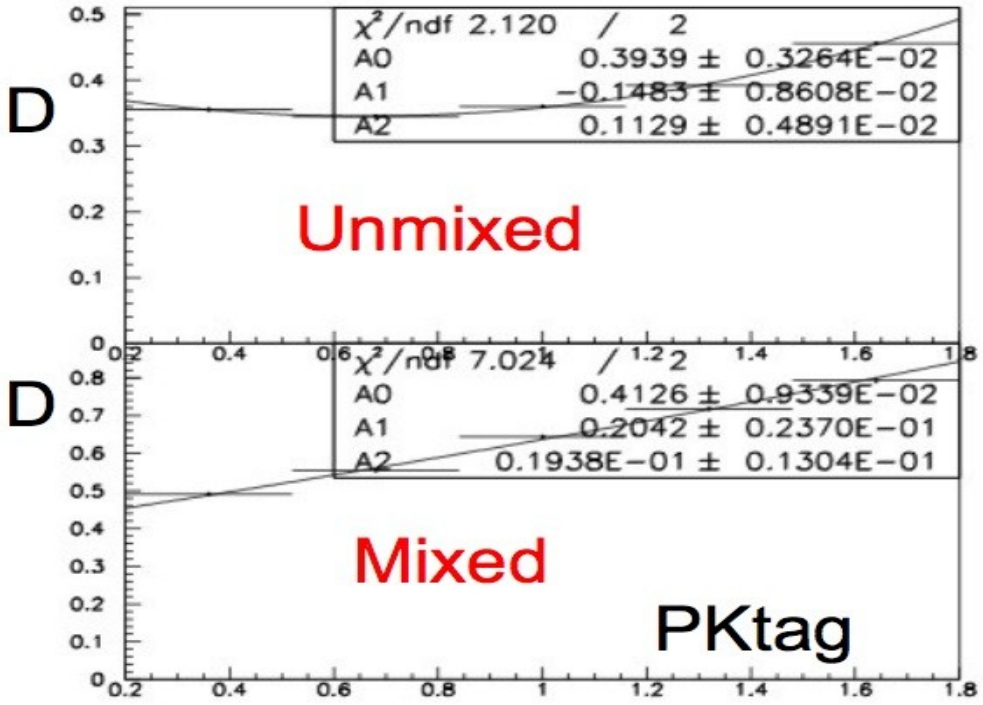
Mixed = True_Mixed*(1-ω)+True_Unmixed*ω
Unmixed=True_Unmixed*(1-ω)+True_Mixed*ω



B^0 Combinatorial BKG

$\omega(\text{Mixed})<\omega(\text{Unmixed})$!

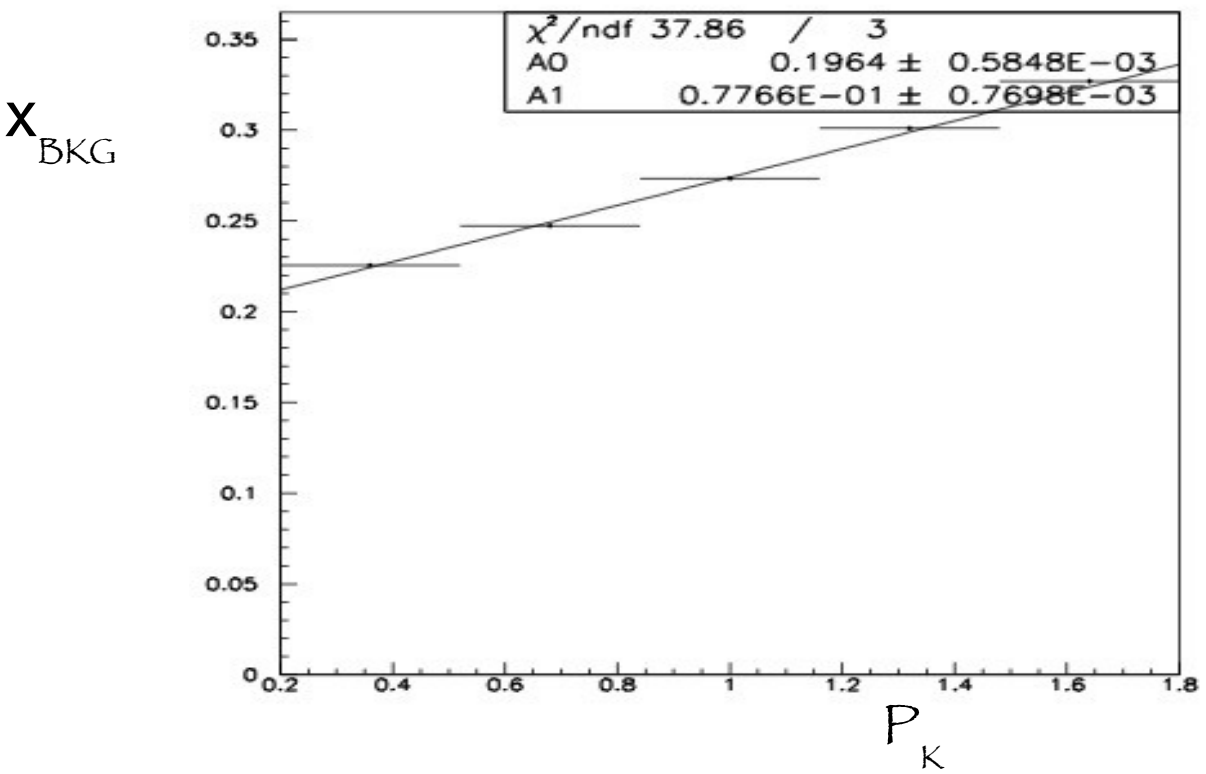
Mixed = True_Mixed*(1-ω_M)+True_Unmixed*ω_U
Unmixed=True_Unmixed*(1-ω_U)+True_Mixed*ω_M



B^0 Combinatorial: Effective $_d$

- Due to charge correlation between Lepton & π_{soft}, B^0 Combinatorial Sample shows a higher fraction of mixed events wrt Signal
- In BKG events it's possible to pick up Lepton & π_{soft} from the two different B^0 decays (more probable in "Mixed" events).

→ $\langle x_d(BKG)\rangle \sim 1.4\, x_d(SIG)$ depending on P_K



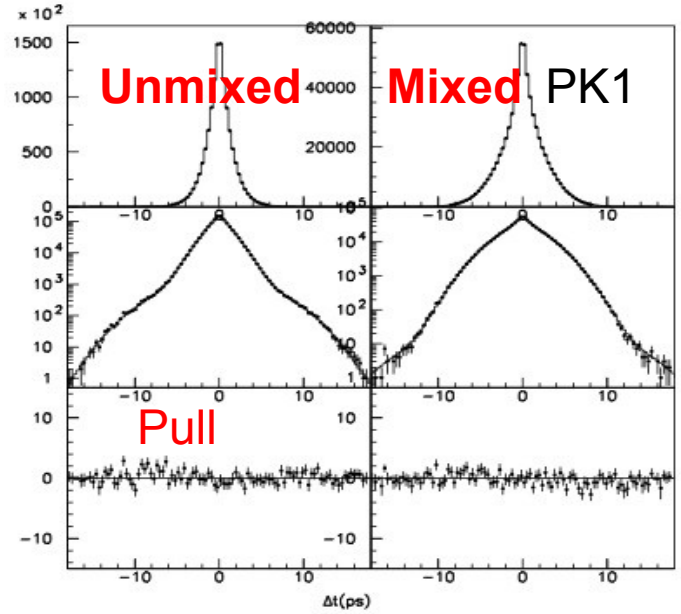
- B^0 BKG Observed PDF modified to include this effect

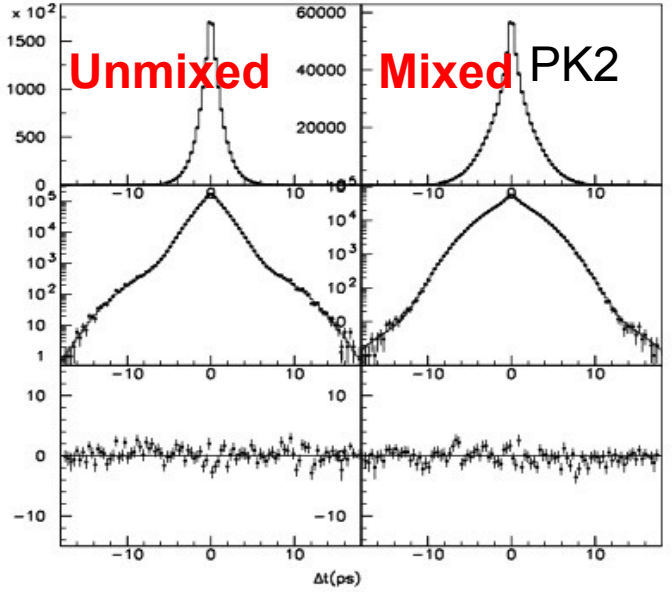
- 27 mistag & effective mixing parameters floated

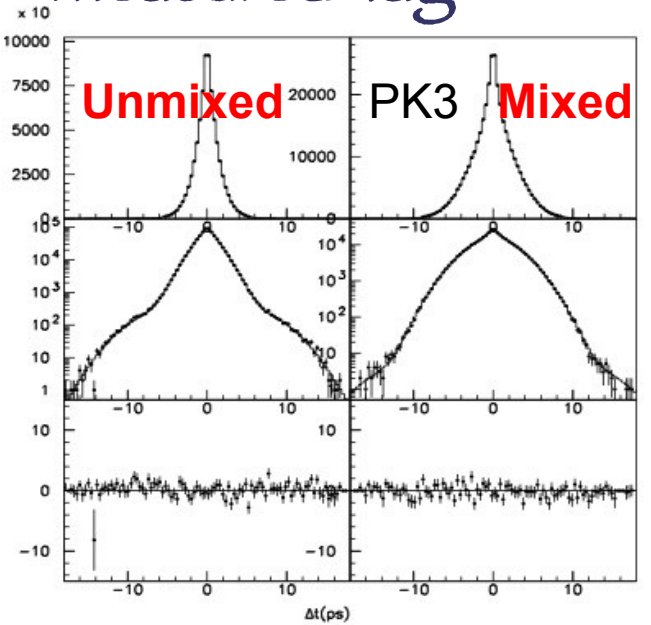
B^0 Peaking with Experimental Mistag

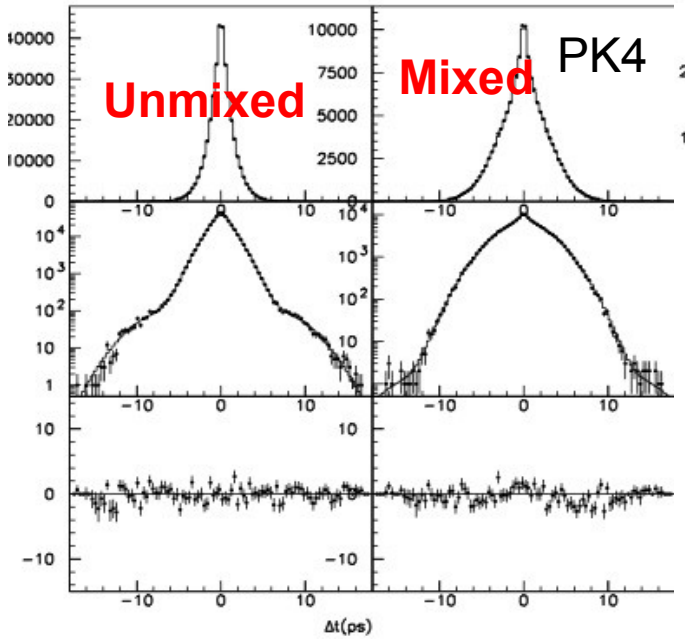
True Δt

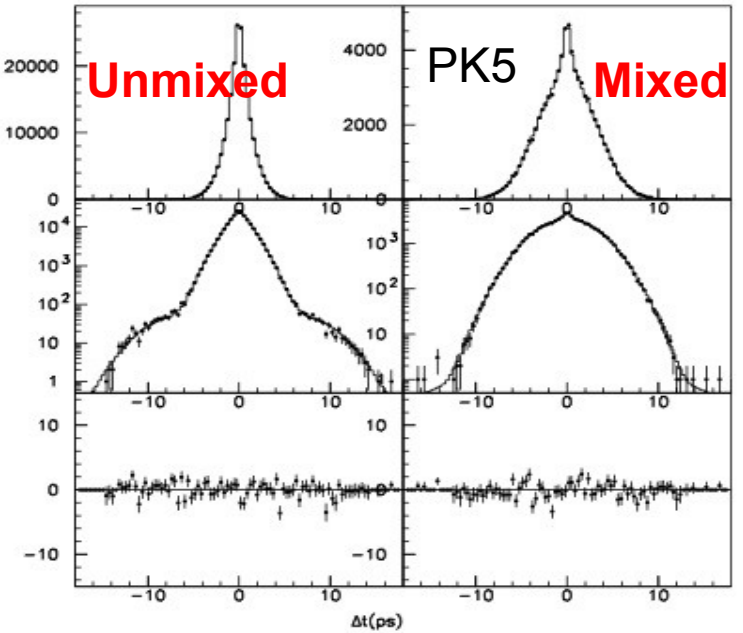
Measured Tag











Fit of mistag in different PKtag Bins:

PK1=(0.2-0.52) GeV

PK2=(0.52-0.84) GeV

PK3=(0.84-1.16) GeV

PK4=(1.16-1.48) GeV

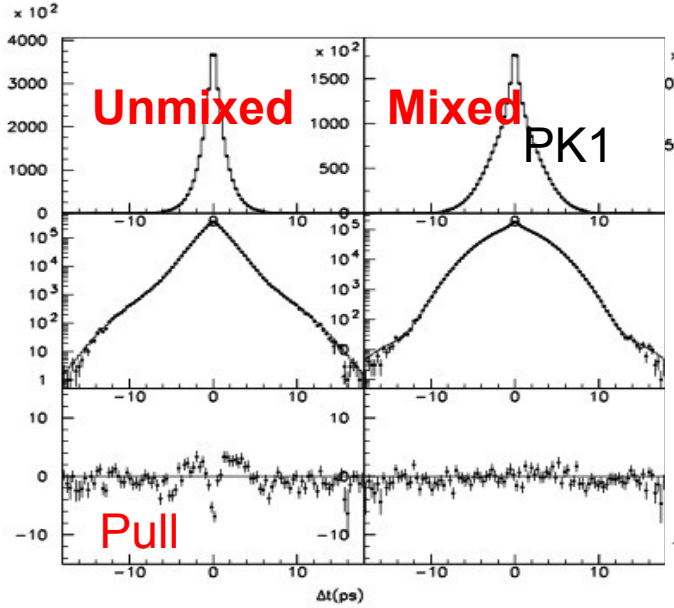
PK5>1.48 GeV

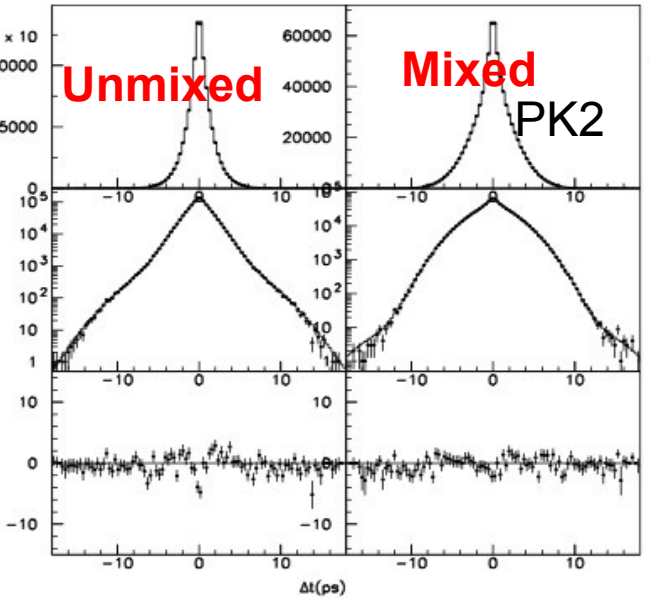
B^0 Comb. BKG with Experimental Mistag

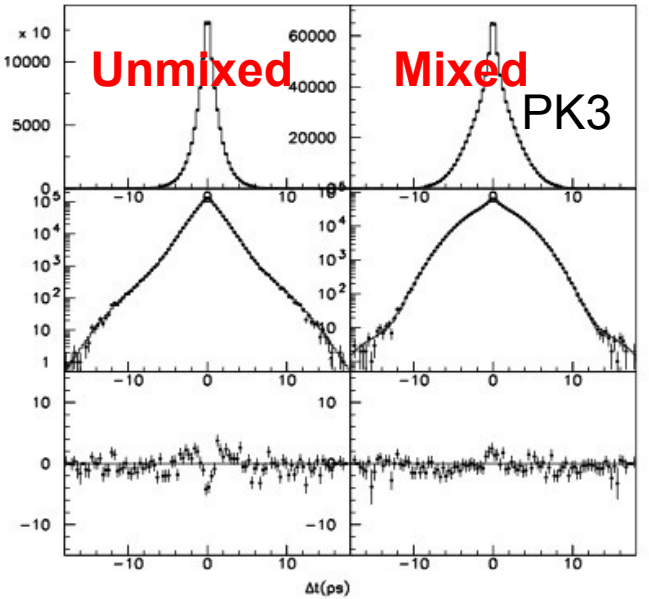
Effective $_{BKG}(P_K)$ taken into account in the PDF

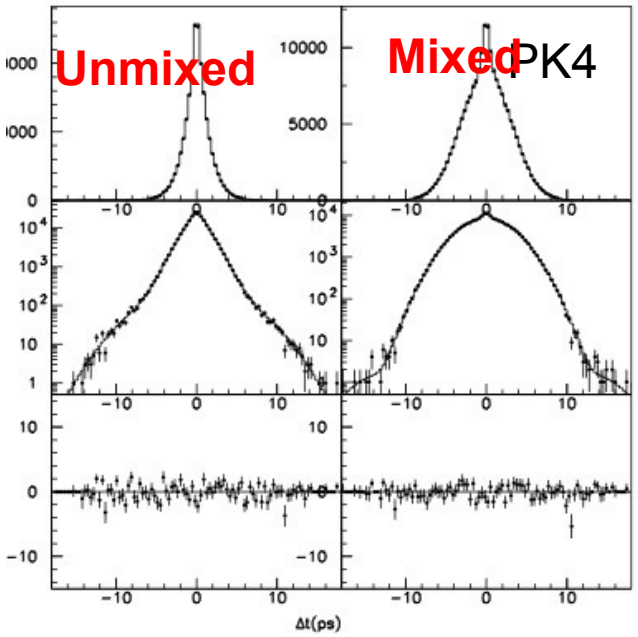
True Δt

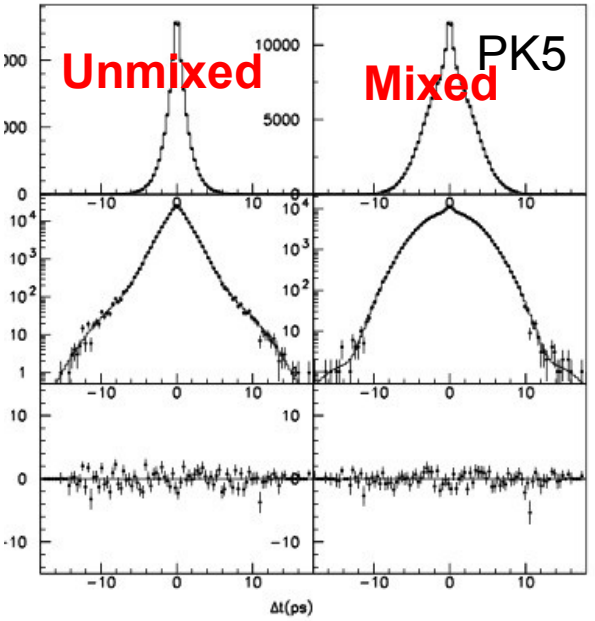
Measured Tag











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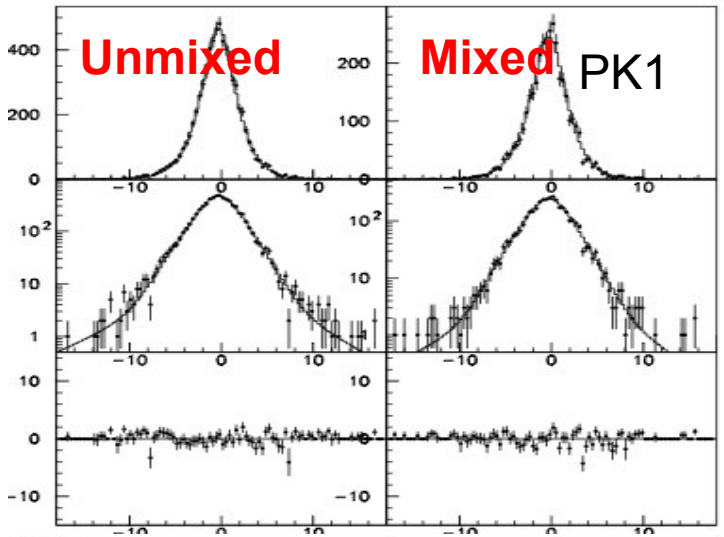
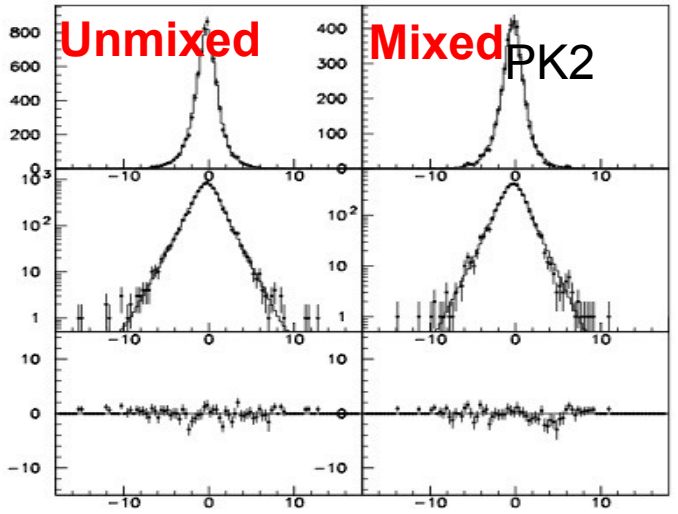
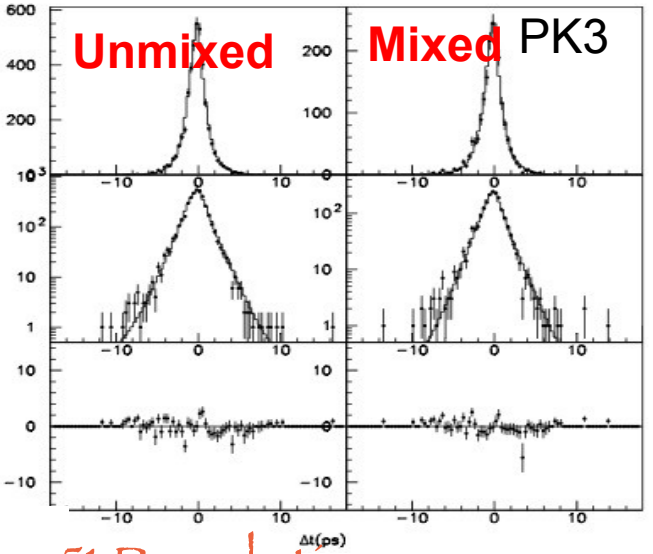
PK5>1.48 GeV

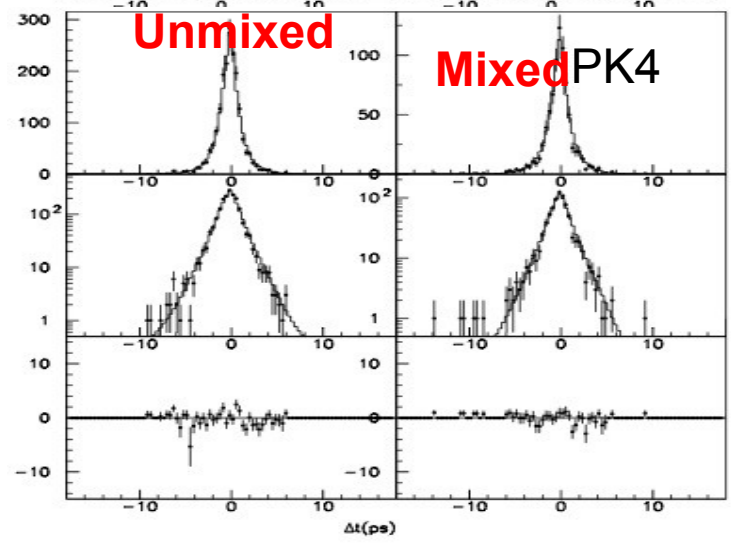
Δt Resolution

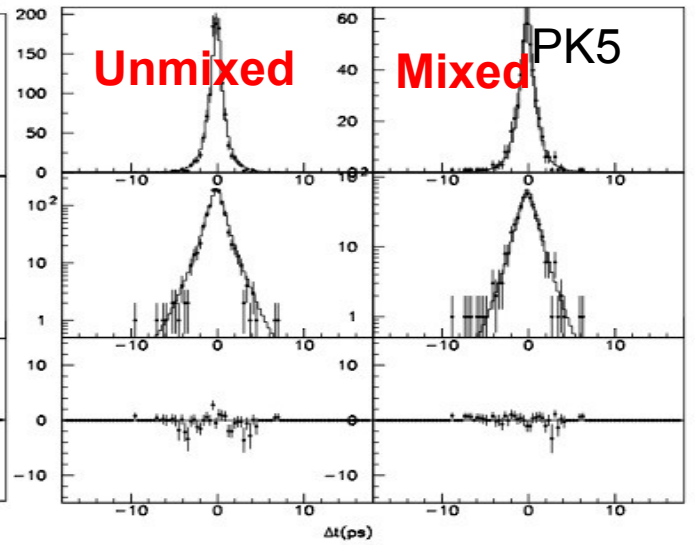
- Resolution Model optimized by fitting δt=Δt measured -Δt true (Physics & mistag effects removed)
- Resolution parameters shared between B^0 & B^+ (different for Peaking & BKG)











- 51 Resolution Parameters obtained using an iterative procedure and fixed in the last step of the analysis

Dtag Description

- Dominant "BKG" in Mixed events: shows single-tag semileptonic asymmetry

therefore Dtag Fraction depends on |q/p|:

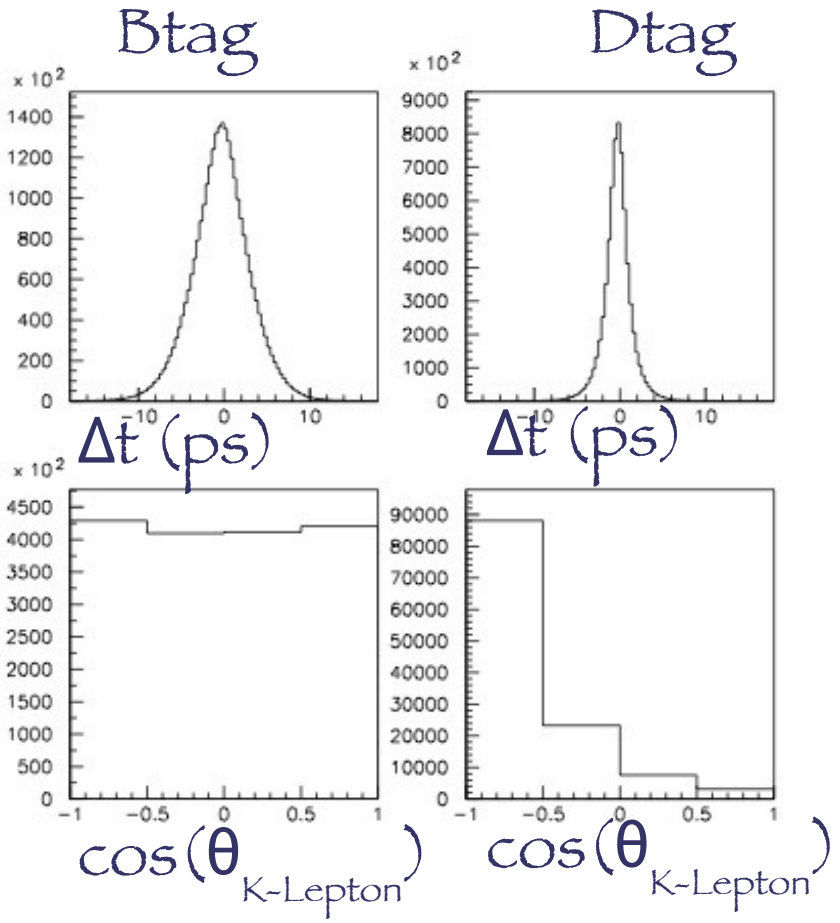
$F^{B0}_{Dtag}(|q/p|) = F^{B0}_{Dtag}(|q/p|=1) * g(|q/p|)$

  - → g(|q/p|) from integrals of the relevant Observed PDFs

- F_{Dtag} floated by exploiting the different Δt & θ(K-Lepton) distributions wrt Btag events in every P_K bin of the various subsamples

- Dtag fraction in B^+ events constrained to B^0 using simulation informations:

$F^{B+}_{Dtag} = R_{MC}(P_K) * F^{B0}_{Dtag}(|q/p|=1)$



- $\cos(\theta_{K\text{-Lepton}})$ PDF from MC
- Δt PDF from a High Purity selection on Real Data
- 40 parameters floated

Dtag Description

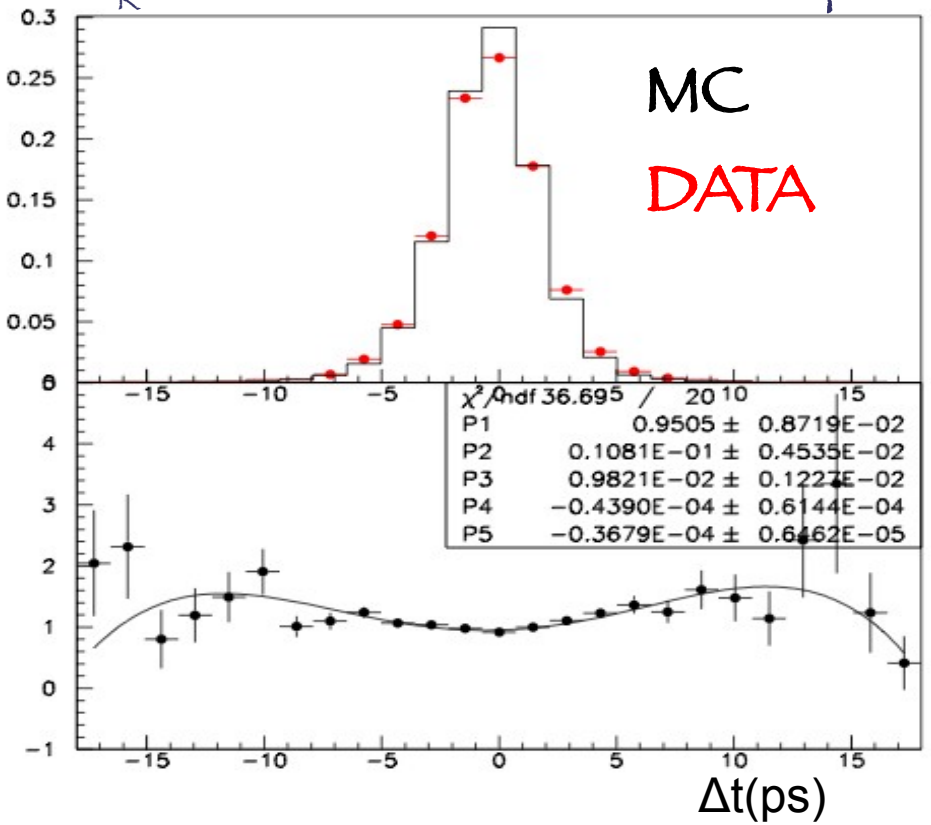
Dtag Δt shape from a High Purity selection, two strategies:

1) $PDF^{DATA} = PDF^{MC} * (PDF^{DATA}/PDF^{MC})_{\text{High Purity Selection}}$

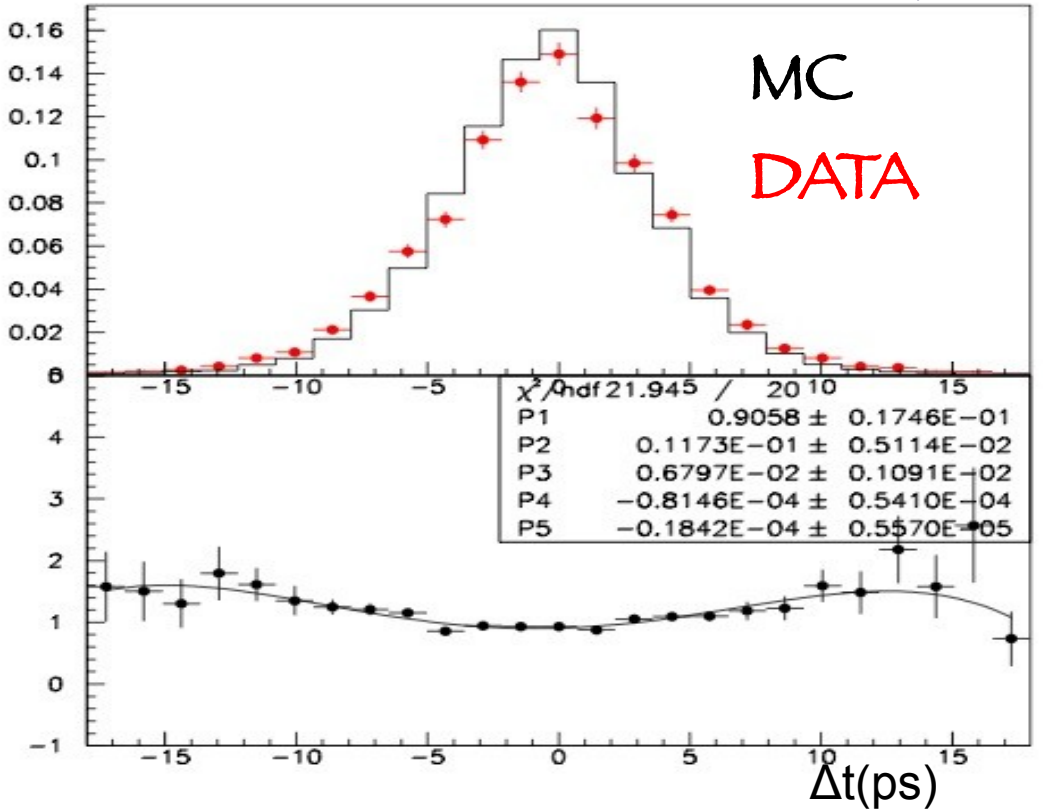
2) $PDF^{DATA} = PDF^{DATA}_{\text{High Purity Selection}}$

- Data/MC Corrections computed in bin of (P_K, σΔt)

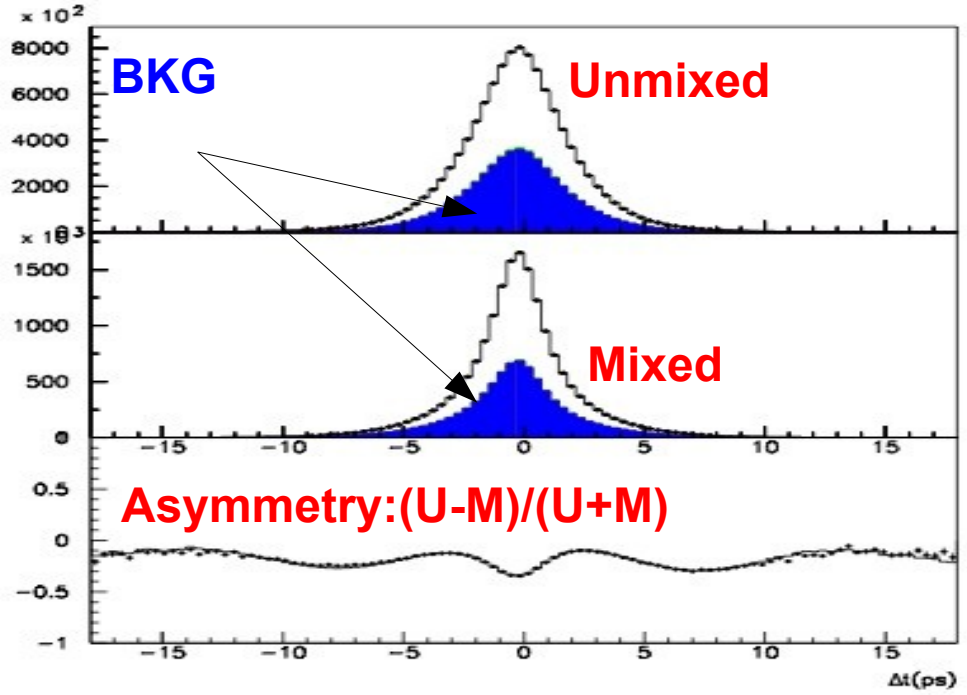
P_K=0.2/0.52 GeV, σΔt=1.2/1.8 ps

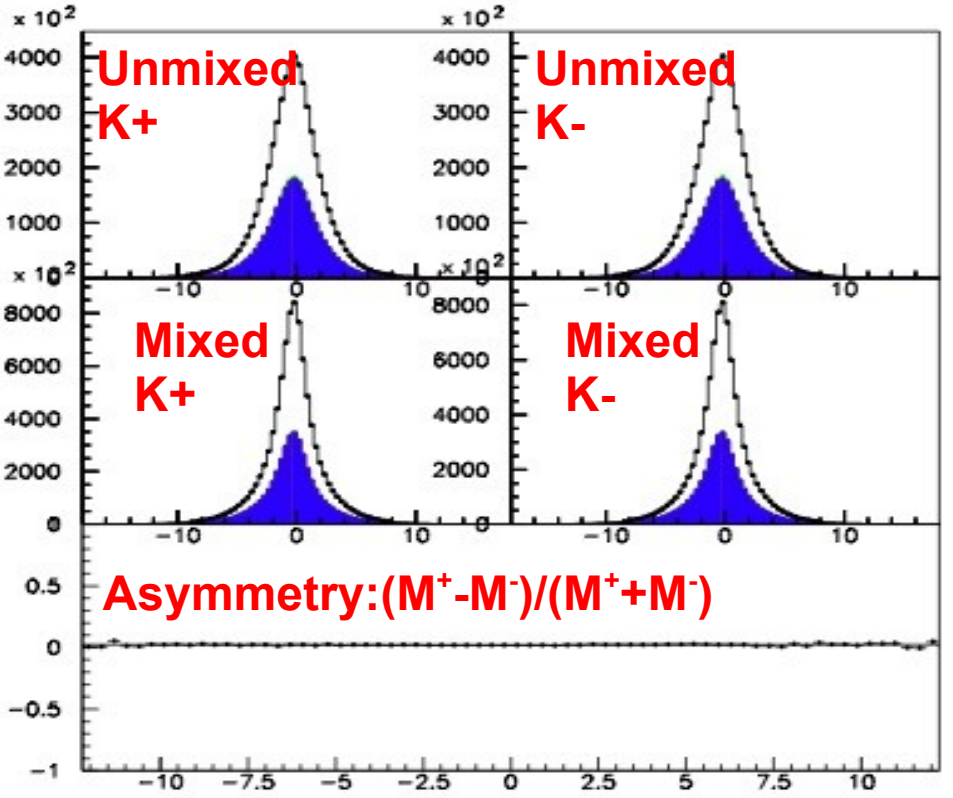


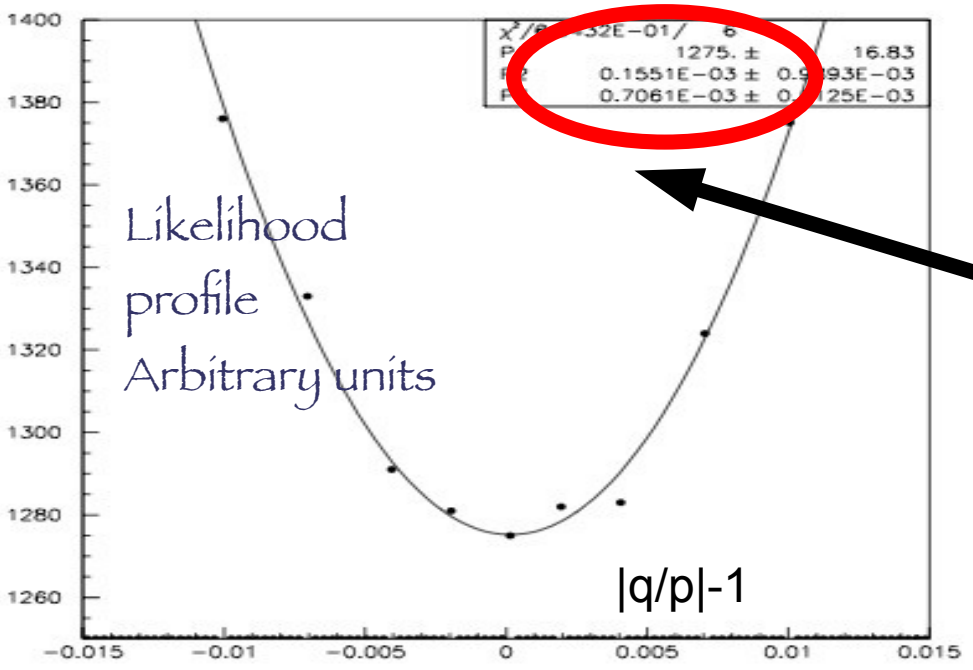
P_K=0.2/0.52 GeV, σΔt=2.4/3.0 ps



Results on B^0 Peaking+BKG





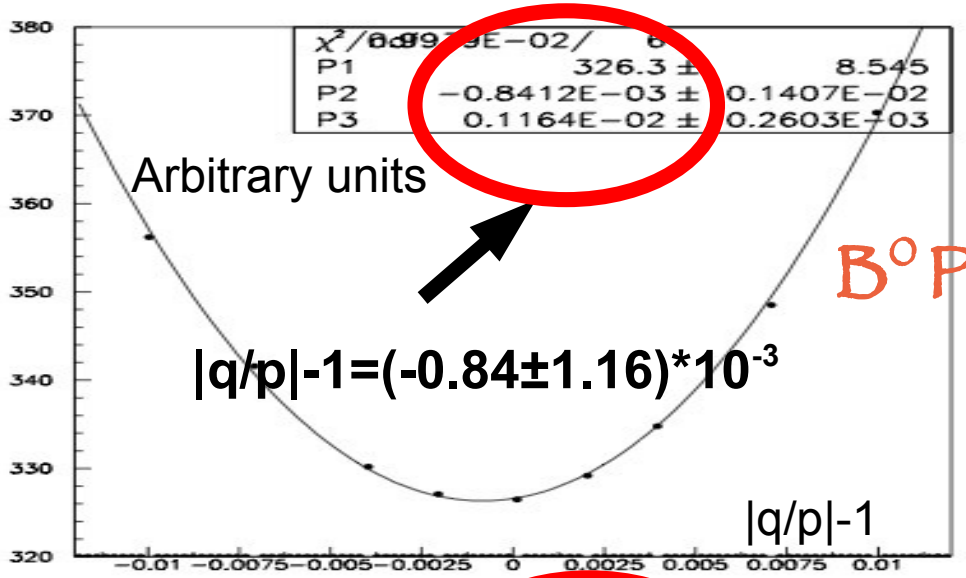


$|q/p|-1=(0.16\pm0.71)*10^{-3}$

No Bias found on MC with $|q/p|=1$

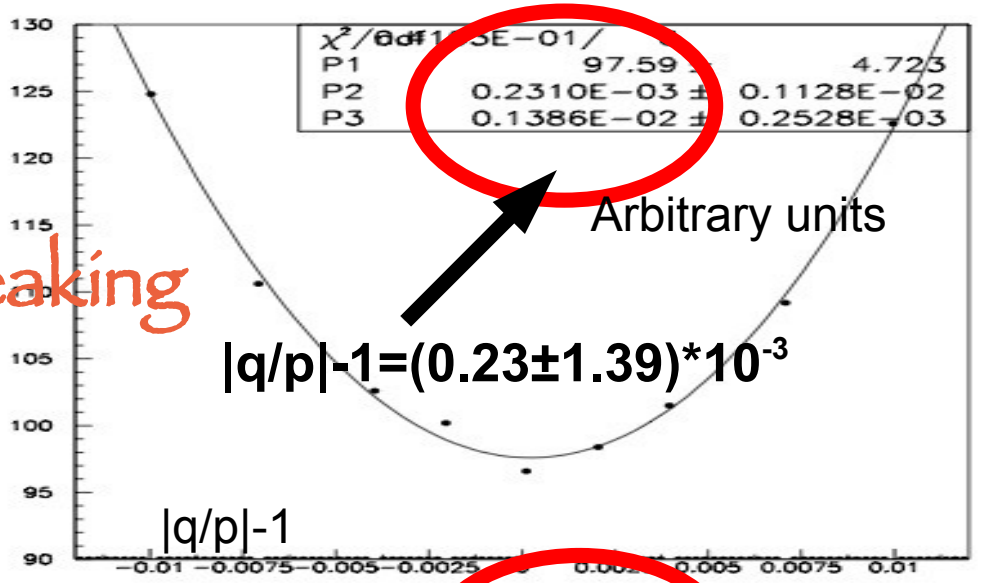
Results on B^0 Peaking vs BKG

Only Btag



$|q/p|-1=(-0.84\pm1.16)*10^{-3}$

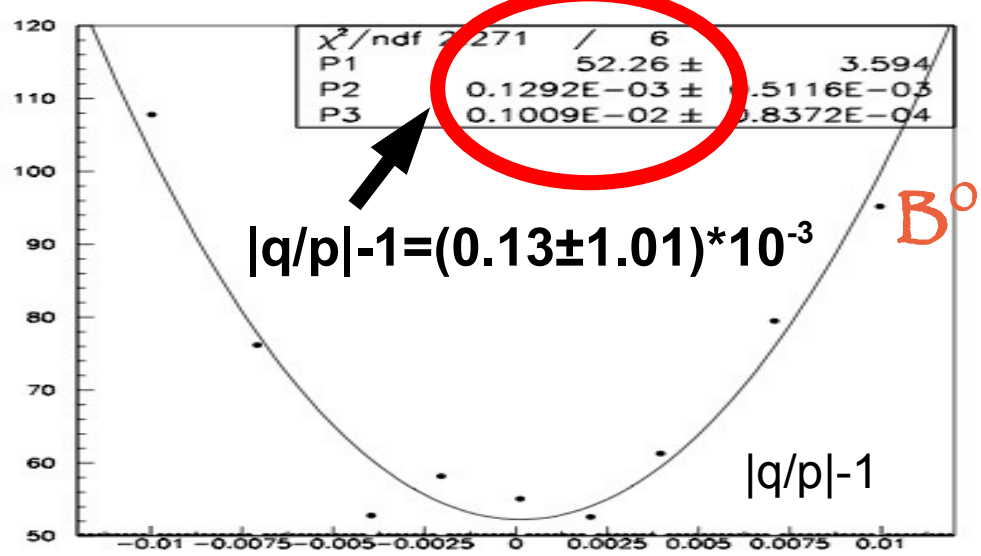
Btag + Dtag



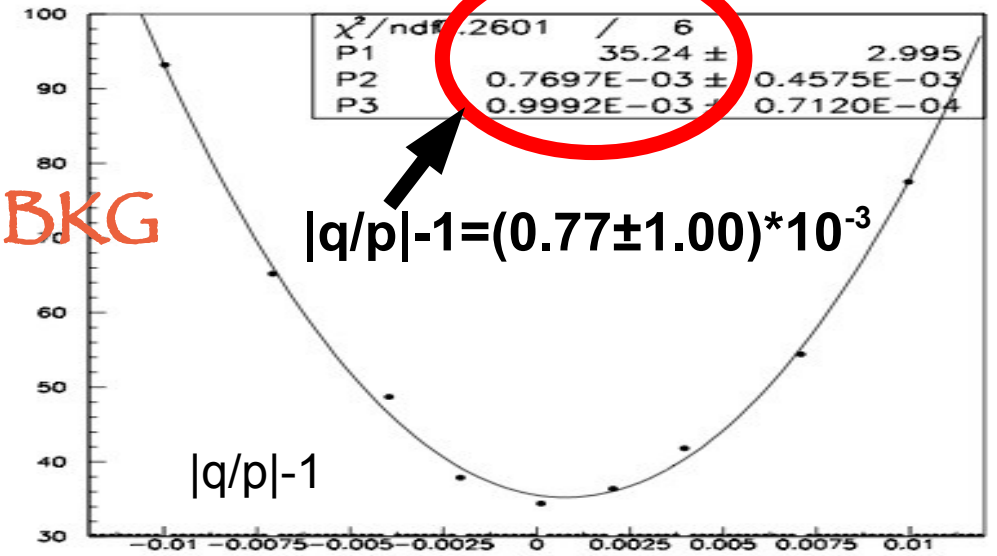
$|q/p|-1=(0.23\pm1.39)*10^{-3}$

B^0 Peaking

B^0 BKG



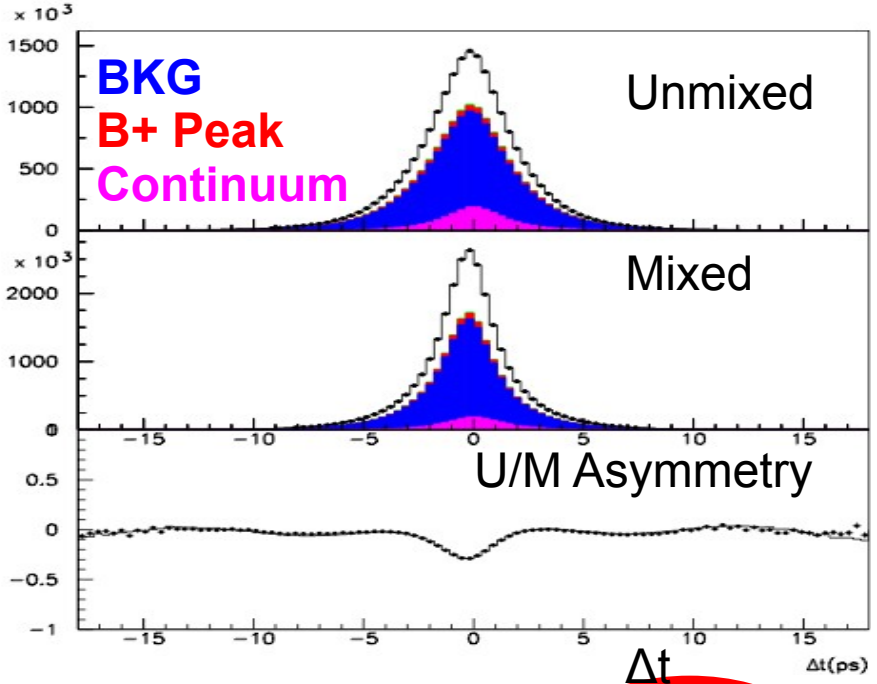
$|q/p|-1=(0.13\pm1.01)*10^{-3}$

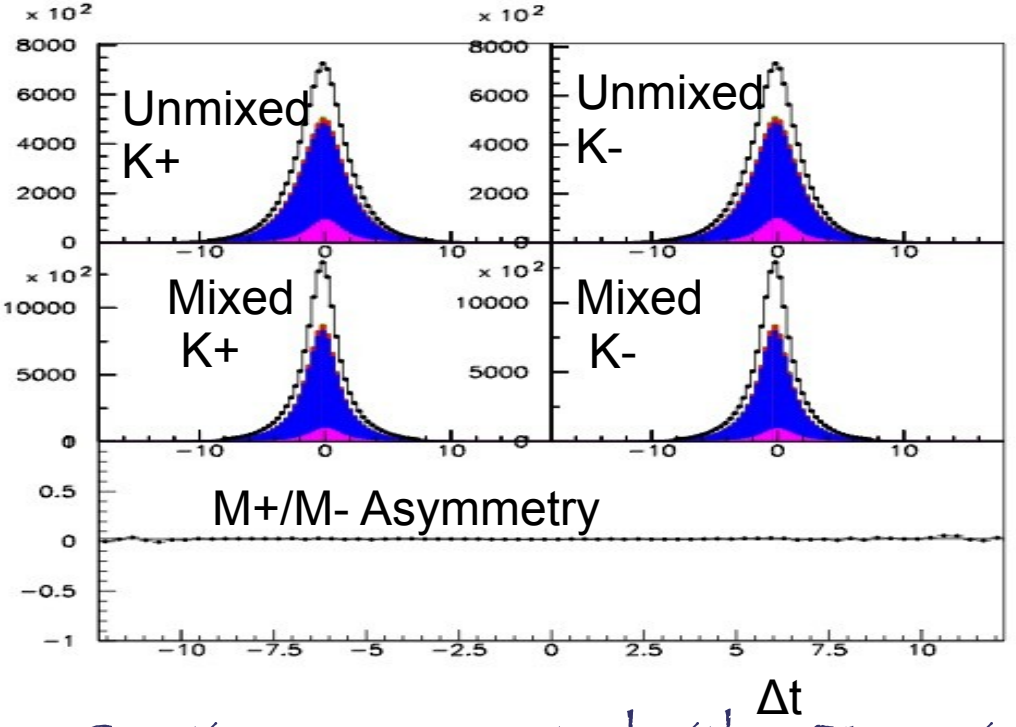


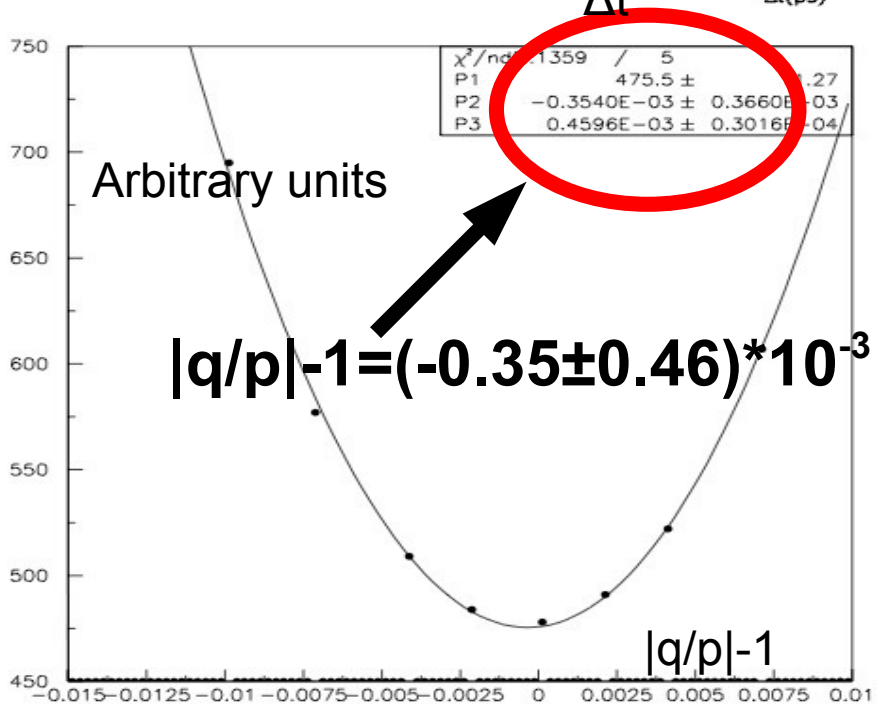
$|q/p|-1=(0.77\pm1.00)*10^{-3}$

No Bias found in both the samples on MC with $|q/p|=1$

Results on B^0+B^++Continuum Full Fit







- Continuum generated with a Toy using as input the OffPeak data sample relevant distributions and normalized to the MC statistics.

No Bias found on MC with |q/p|=1

Results on Modified MC with |q/p|≠1

- |q/p| related to Semileptonic Asymmetry:

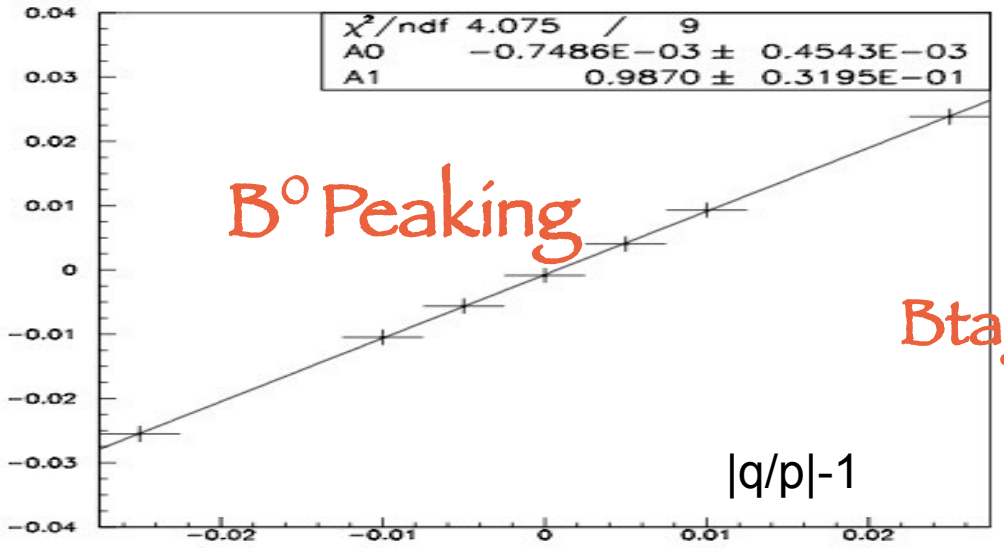
$$\mathcal{A}_{SL} = \frac{N(B^0B^0) - N(\overline{B}^0\overline{B}^0)}{N(B^0B^0) + N(\overline{B}^0\overline{B}^0)}$$

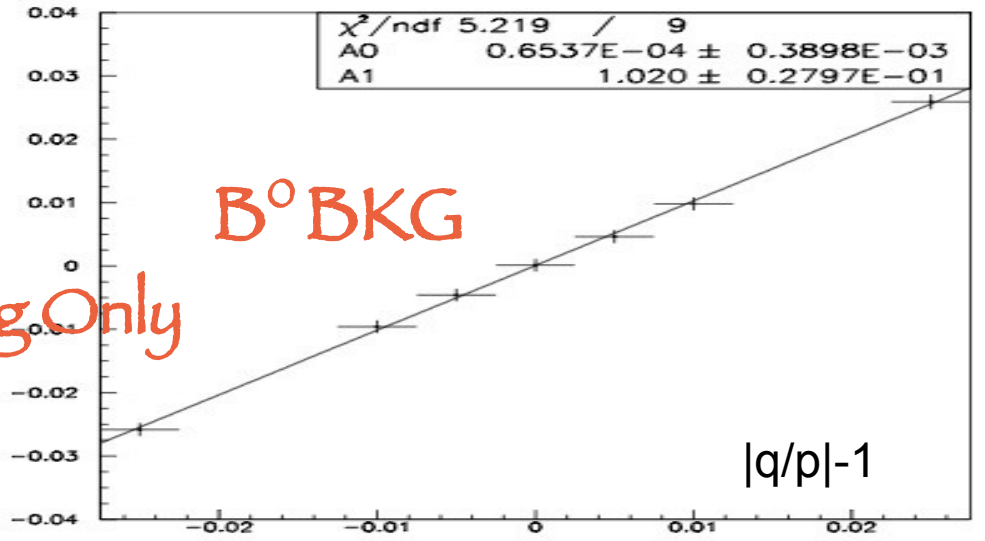
$$\mathcal{A}_{SL} = \frac{1 - |q/p|^4}{1 + |q/p|^4} \simeq 2\left(1 - \left|\frac{q}{p}\right|\right)$$

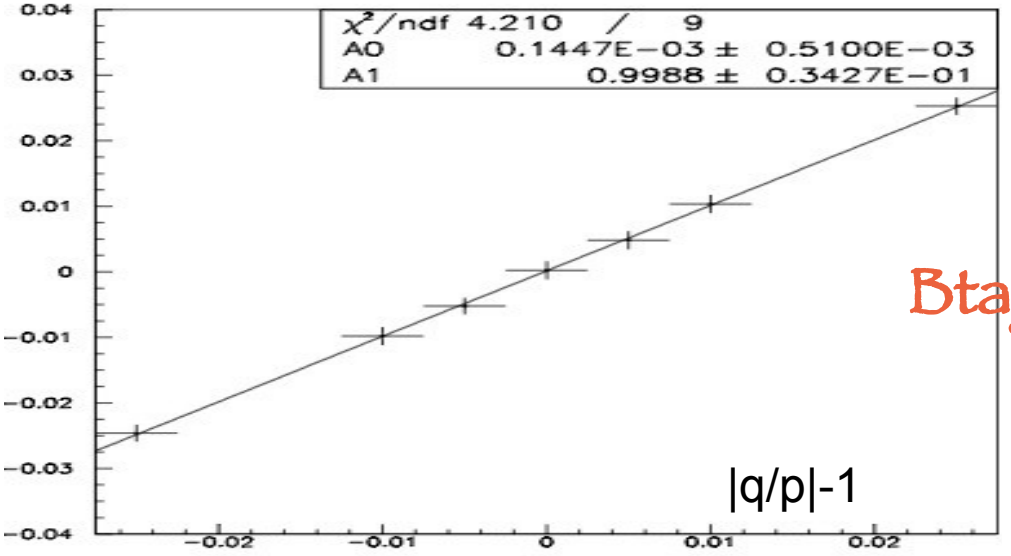
- MC with K=|q/p|-1≠0 obtained by random rejecting a fraction F=4K/(2K+1) of mixed B^0B^0 (K<0) or $\overline{B}^0\overline{B}^0$ (K>0) events
- Fraction F/2 of Unmixed events ($B^0\overline{B}^0$) rejected to preserve the correct $_d$=M/(U+M)
- Rejection performed by exploiting the MC truth on B^0 flavor

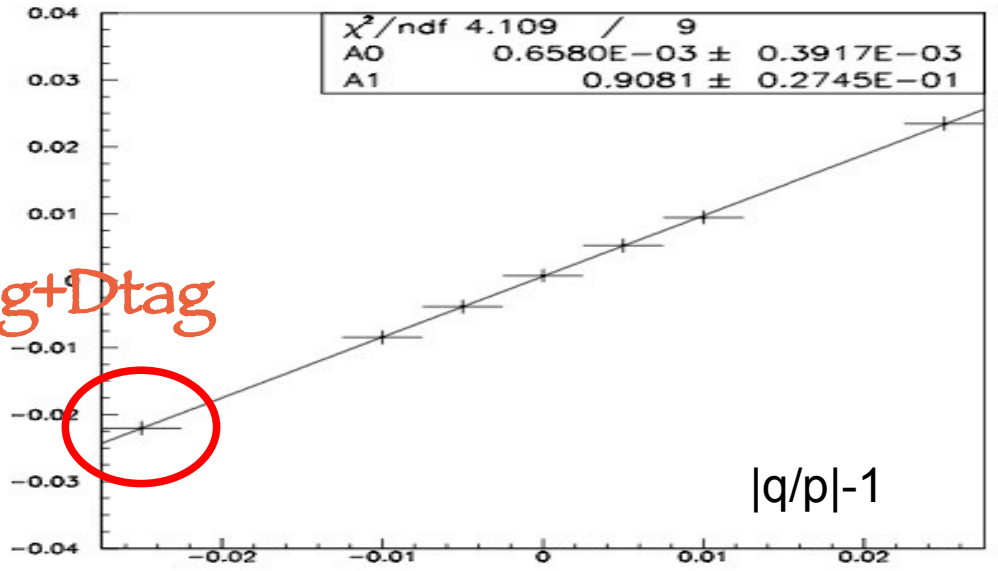
- This exercise checks correctness of algorithm, mistag, detector asymmetries and Dtag fraction determination

Fitted vs Generated |q/p|-1







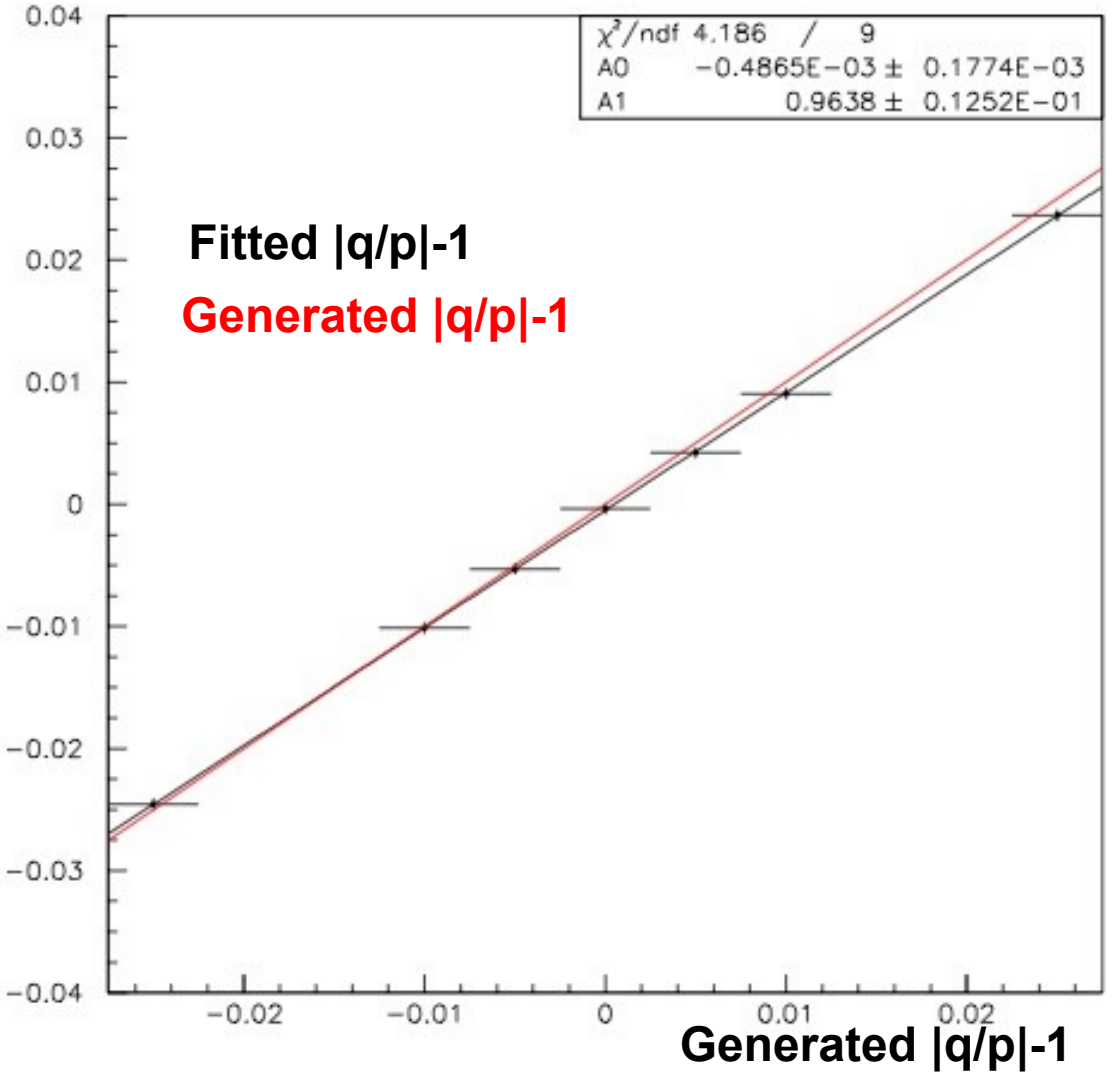


- B° Peaking: no bias found
- B° BKG only (Btag+Dtag):

10% bias (2.7 σ) on |q/p|-1 for |q/p|-1= -0.025

Fitted vs Generated |q/p|-1

Full MC Fit



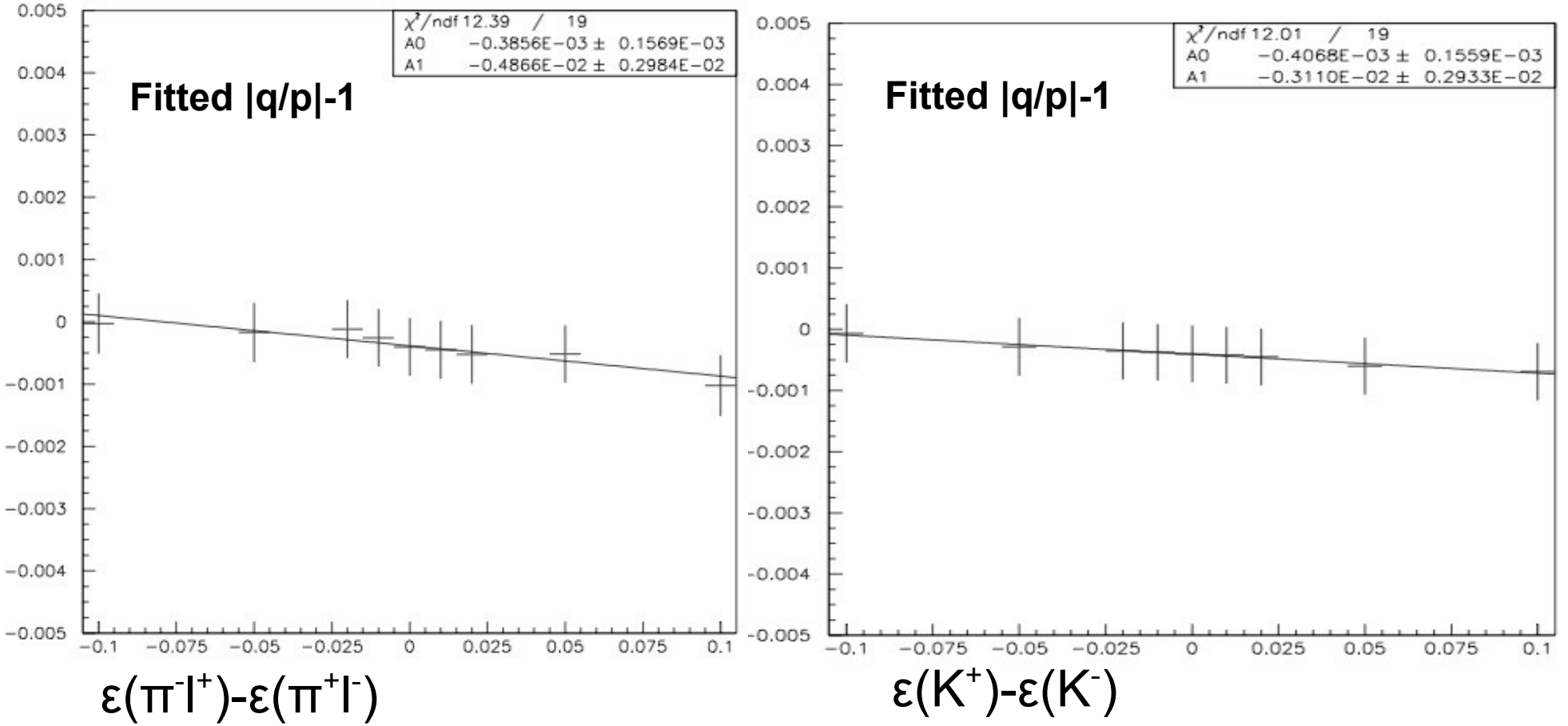
- Slope=0.96: ~4% relative bias on |q/p|-1 found
- Effect negligible compared with the expected statistical error

|q/p| vs detector Asymmetries

- Strategy of the measurement: disentangle the Physical vs Detector Asymmetries by exploiting all the available informations from different subsamples
- **|q/p| and detector Asymmetries are strongly related in the PDF**
- Test performed to look for possible bias on the |q/p| determination produced by a not correct description of the interconnection between Physical & Detector Asymmetries in the Fit constraints:
  - Modify the MC in order to produce an artificial efficiency asymmetry by random rejecting positive or negative leptons/kaons from the selected sample
  - Artificial $|\Delta\varepsilon|=|\varepsilon^{+}-\varepsilon^{-}| = 1\%, 2\%, 5\%, 10\%$ produced
- To be compared with:

Reco Asymm(l^+, l^-) <0.5%; Tag Asymm(K^+,K^-) ~1.5%

|q/p|-1 vs Δε: Full MC Fit



$\varepsilon(\pi^- l^+)-\varepsilon(\pi^+ l^-)$ $\varepsilon(K^+)-\varepsilon(K^-)$

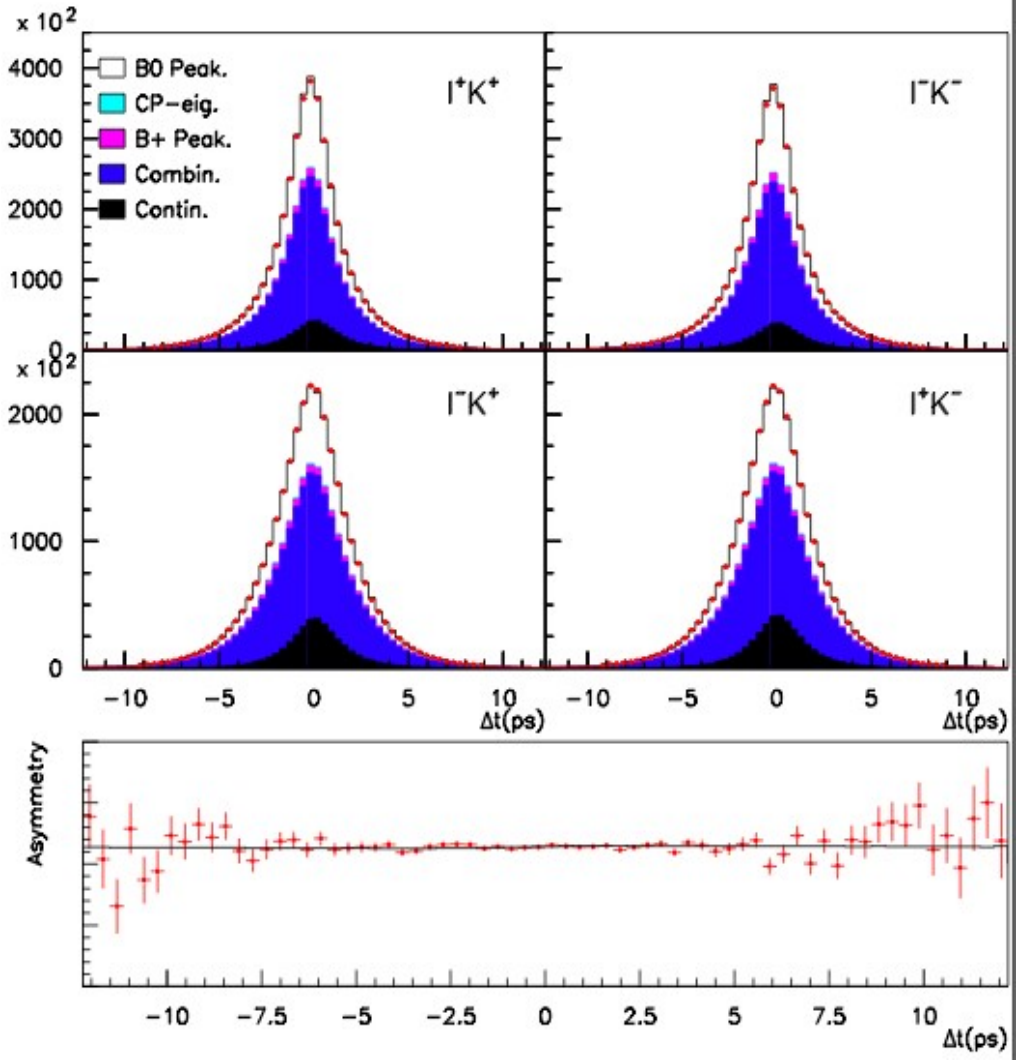
- Observed bias < 0.001 in all the Δε range of variation
- Δε varied in a huge range wrt reasonable values

→ The Fit correctly disentangles physical vs detector asymmetries

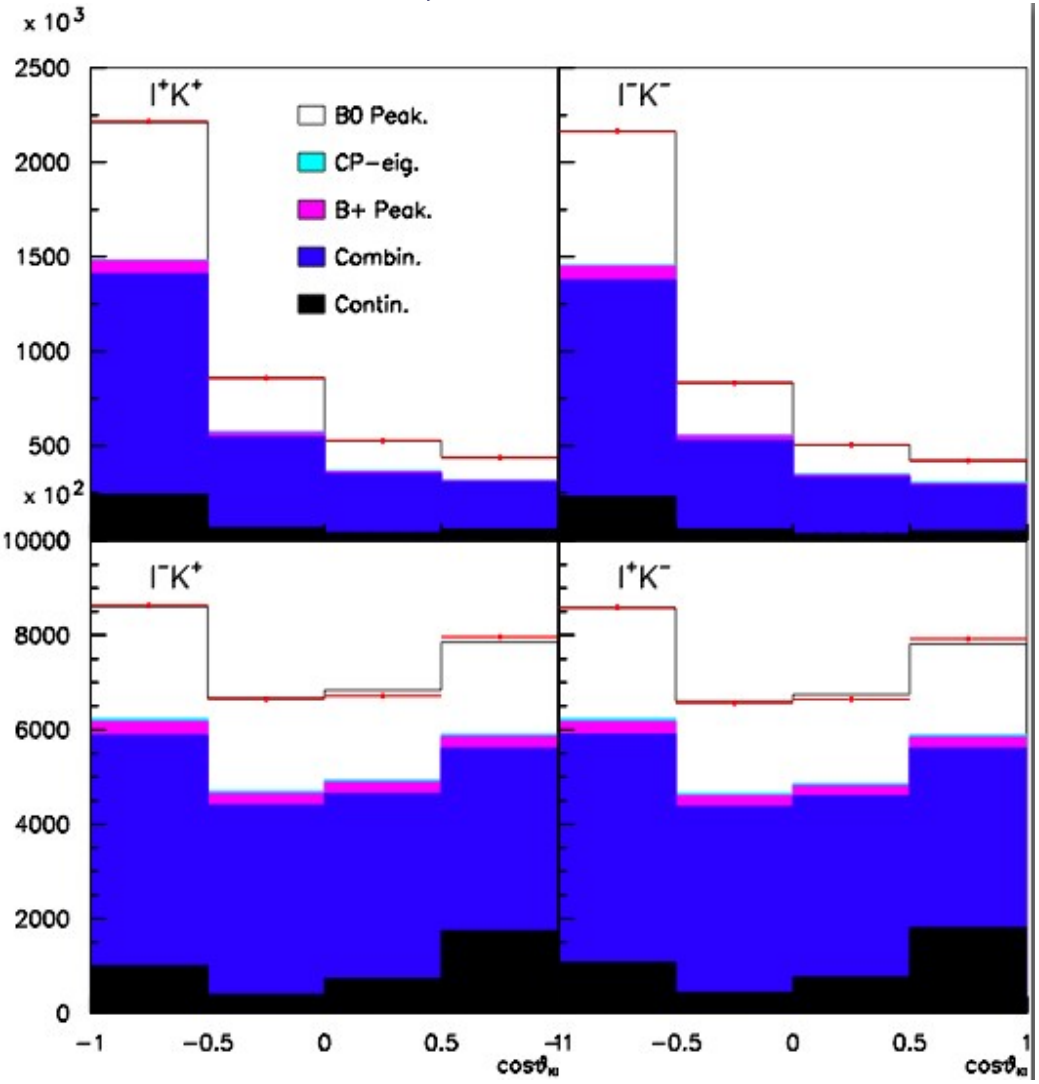
Real Data Results

Real Data Results

Fitted Δt Shapes

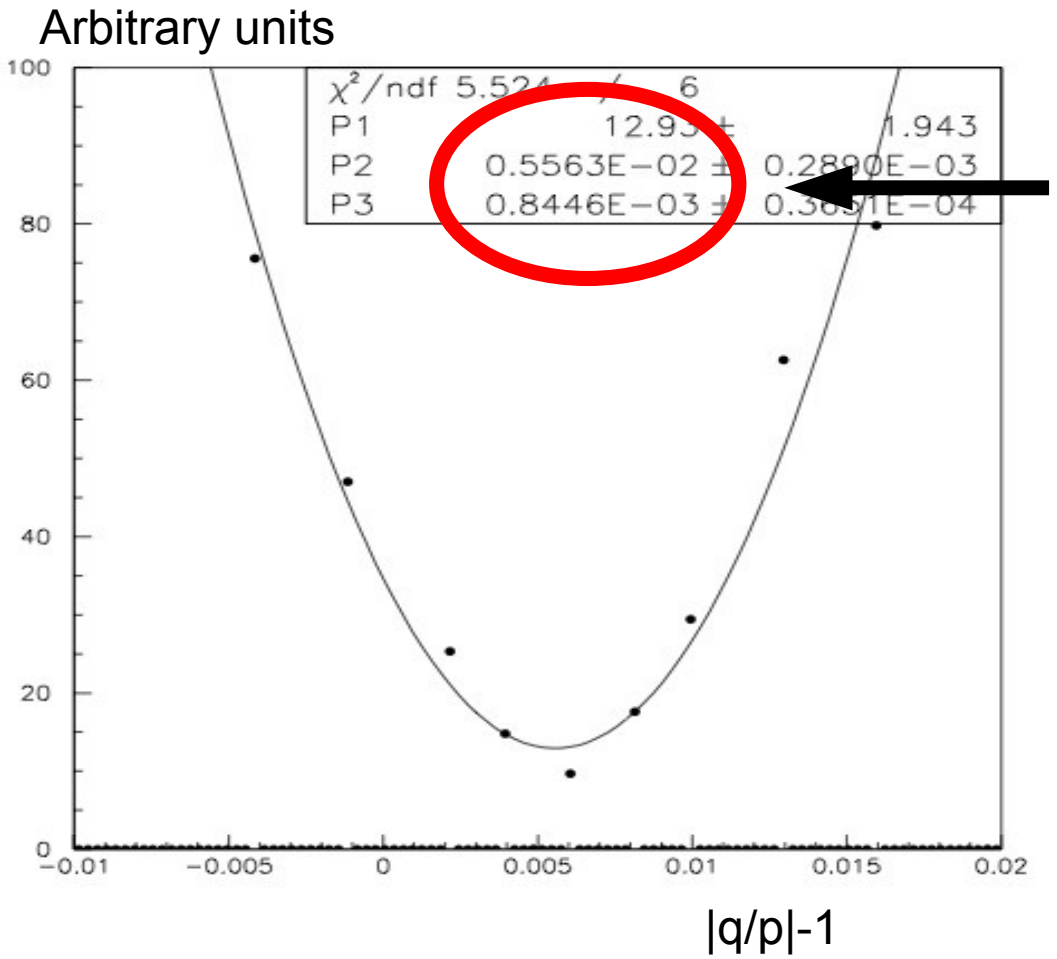


Fitted $\cos(\theta_{K\text{-}Lepton})$ Shapes



Raw $N(l^+K^+)/N(l^-K^-)$ Asymmetry

Real Data Results



Blind Result (Dtag strategy 1)

$|q/p|-1=(5.56\pm0.84)*10^{-3}$

- Statistical error scales correctly wrt Real Data/MC statistics
- By leaving free |q/p| we obtain

$|q/p|-1=(5.52\pm0.52)*10^{-3}$

- Central result in good agreement with likelihood profile
- Fit statistical error underestimated by 38%

➔ **Result to be validated by a Toy MC**

Toy MC Validation

Toy MC results

- MC and Real Data Fits separately validated

- Several pseudo-experiments generated

- Relevant distributions (PK, Δt, $\sigma\Delta t$, $\cos(\theta_{K\text{-}Lepton})$) randomized starting from the likelihood projections of the nominal fit.

- 96 event subsamples considered: (B^0,B^+)X(Peaking, BKG)X(Btag, Dtag), CP-eigenstates, Continuum, Off-Peak for all combination of (Lepton, Kaon) charges

Toy MC results (BLIND)

- Result from Likelihood Profile

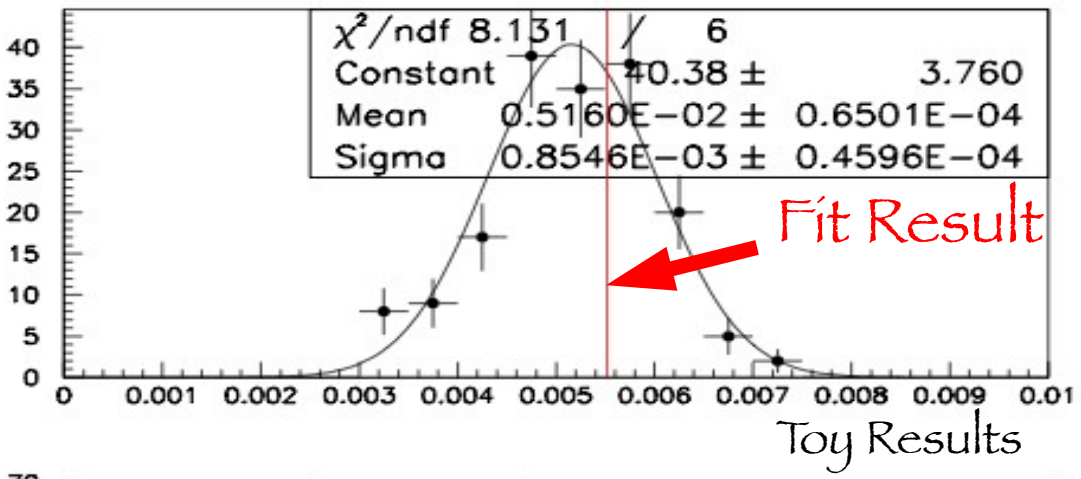
$|q/p|-1=(5.56\pm0.84)*10^{-3}$

- Result from Fit

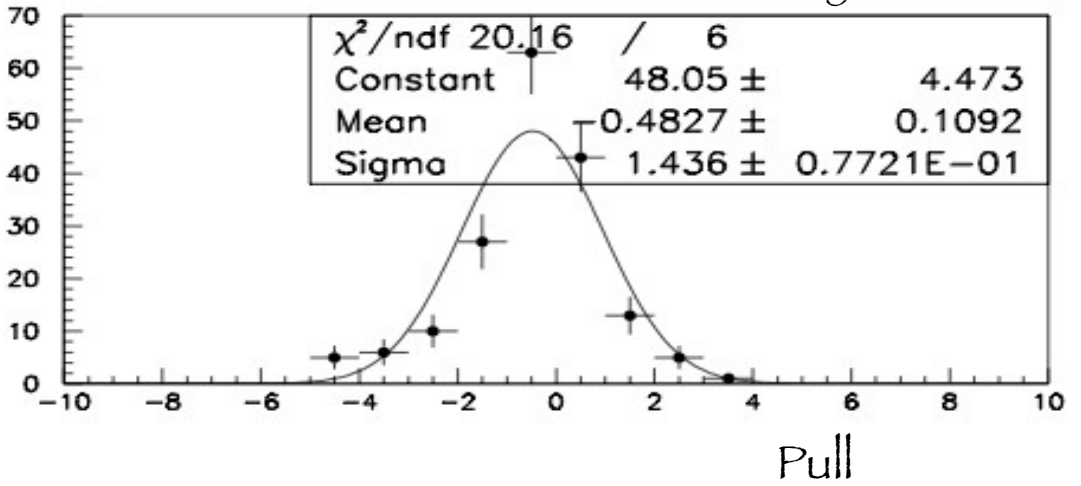
$|q/p|-1=(5.52\pm0.52)*10^{-3}$

- Result from Toy

$|q/p|-1=(5.16\pm0.85)*10^{-3}$



Toy Results



Pull

→ Toy Spread in very good agreement with statistical error from Likelihood Profile

→ Bias of $-3.6\ 10^{-4} < 0.5\ \sigma$ wrt Nominal Fit quoted as systematic error related to analysis bias

→ Pull = 1.44±0.08 in agreement with ratio of Likelihood Profile/Nominal Fit statistical errors

Systematic Uncertainties

Sample Composition

Sample Composition determined by an external Fit on M^2 by floating D*, D** and Combinatorial using shapes from MC

- Dominant systematic uncertainty

- Peaking Sample Uncertainty
  - Statistical error of external fit
  - Isospin symmetry violation: B^0/B^+ in the D^{**} = (50±25) %
  - CP-eigenstates yield varied by ±50%
  - Remnant Peaking yield (D* , D*DsX, D*h) obtained by difference and varied by ±20%

$$\Delta|q/p| = {}^{+1.17}_{-1.50} \times 10^{-3}$$

Sample Composition

- Combinatorial Sample Uncertainty

- Fraction of B^+ and B^0 in the Combinatorial fixed to MC expectations
  - Difference between B^0 and B^+ is expected when mixing takes place and the lepton is coupled with a slow pion from the tag side: $B^0 \rightarrow D^*X$, $D^* \rightarrow {}^*D^0$
  - B^0 BKG has 40% more mixed events than B^0 Peaking
  - Other BKG events have same probability between B^0 and B^+
  - Fraction of B^+ conservatively varied by ±4.5% which corresponds to the error on inclusive BR($B^0 \rightarrow D^{*+}X$) (from PDG)

$\Delta|q/p| = \pm 0.39 \times 10^{-3}$

Dtag Description

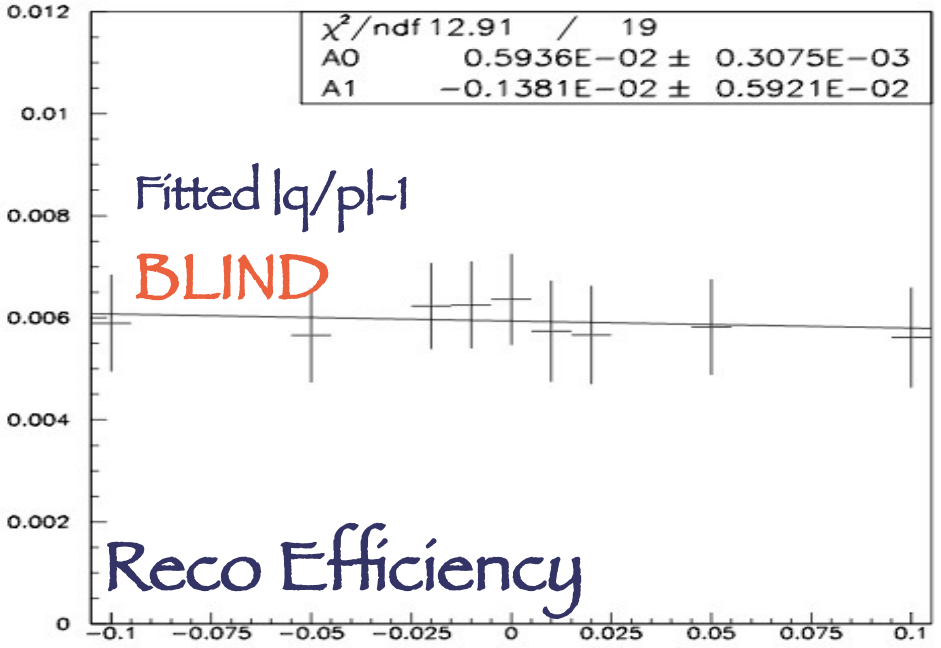
- Dtag Δt shape: use two strategies
  - $PDF^{DATA} = PDF^{MC} * (PDF^{DATA}/PDF^{MC})_{\text{High Purity Selection}}$
  - $PDF^{DATA} = PDF^{DATA}_{\text{High Purity Selection}}$
  - Central Value=average of the two results
  - Systematic uncertainty=semi-difference of the two

  $\Delta|q/p| = \pm 0.65 \times 10^{-3}$

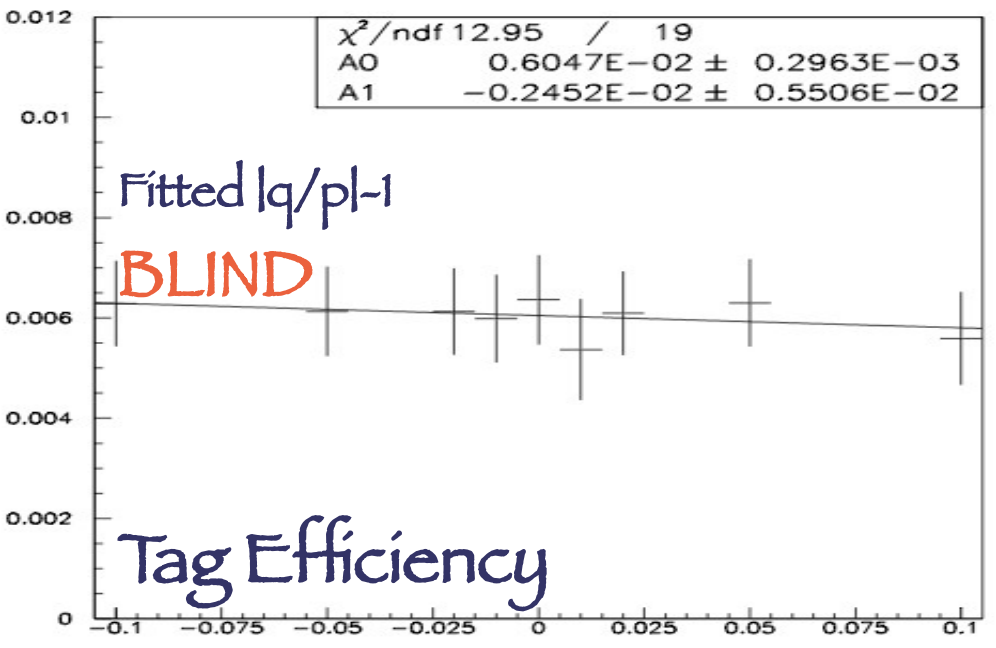
- Dtag Fraction in the B^+ sample constrained to the B^0 one using ratios $R_{MC}(P_K) = F^{B+}_{Dtag}/F^{B0}_{Dtag}$ from MC
  - $R_{MC} \sim BR(D^{*0} \to K^- X)/BR(D^{*+} \to K^- X)$; ΔR_{MC}=6.8% (from PDG)

  $\Delta|q/p| = \pm 0.11 \times 10^{-3}$

|q/p|-1 vs Δε



ε(l⁺π⁻)-ε(l⁻π⁺)



ε(K⁺)-ε(K⁻)

- Same approach as for MC
- Observed |q/p| variation < 0.001 in all the Δε range
- The Fit correctly disentangles physical vs detector asymmetries

- Negligible uncertainty on |q/p|

Other Systematic Uncertainties

- Δt Resolution Model:
  - Fit repeated by leaving free all the Resolution Parameters

  $\Delta|q/p| = +0.6 \times 10^{-3}$
- CP-eigenstates description
  - S & C Parameters varied according to their statistical error in simulation: negligible uncertainty
- Physical Parameters varied or fixed to world average
  - =0/0.02 ps^{-1}; m=0.508(Fit)/0.507(PDG)
  - B^0=1.553(Fit)/1.519(PDG); B^+=1.76(Fit)/1.4(PDG)

  $\Delta|q/p| = +0.28 \times 10^{-3}$
- Analysis Bias
  - MC Full Fit Statistical error & bias from Toy MC

  $\Delta|q/p| = {}^{+0.46}_{-0.58} \times 10^{-3}$

Table of Systematic Uncertainties

Source	$\Delta\lvert q/p\rvert$
Peaking Sample Composition	$^{+1.17}_{-1.50} \times 10^{-3}$
Combinatoric Sample Composition	$\pm 0.39 \times 10^{-3}$
ΔT Resolution Model	$+0.60 \times 10^{-3}$
Dtag fraction	$\pm 0.11 \times 10^{-3}$
Dtag ΔT distribution	$\pm 0.65 \times 10^{-3}$
Fit Bias	$^{+0.46}_{-0.58} \times 10^{-3}$
CP-eigenstate description	—
Physical Parameters	$+0.28 \times 10^{-3}$
Total	$^{+1.61}_{-1.78} \times 10^{-3}$

Blind Result:

(Average of the two different Dtag strategies)

$$|q/p|-1=(6.21\pm0.84\ ^{+1.61}_{-1.78}) \times 10^{-3}$$

Conclusions

Unblinded Result

After Unblinding:

$$|q/p|-1=(-0.76\pm0.84\,^{+1.61}_{-1.78})\times10^{-3}$$

After Bias Correction (see slide 31):

$$|q/p|-1=(-0.29\pm0.84\,^{+1.61}_{-1.78})\times10^{-3}$$

Conclusions

- We present a new precise measurement of the parameter governing CP violation in the B^0 mixing based on the full BaBar statistics and using an original technique

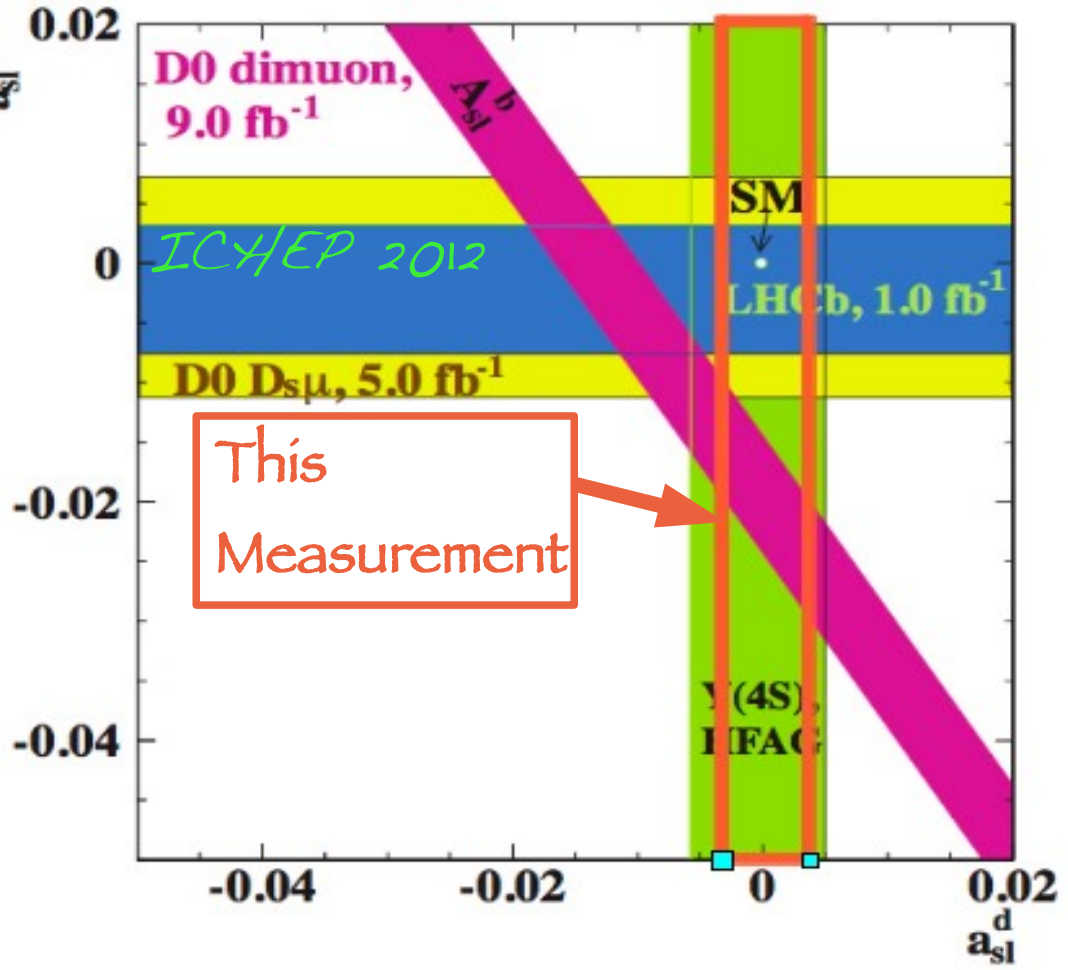
$$1-|q/p| = (0.29^{+1.82}_{-1.97}) \times 10^{-3}$$

$$A_{sl} = (0.06^{+0.36}_{-0.39})\%$$

To be compared with the B-Factories current average:

$$1-|q/p| = (-0.2 \pm 2.8) \times 10^{-3}$$

$$A_{sl} = (-0.05 \pm 0.56)\%$$



Backup

B^0 Combinatorial: Mistag vs Effective χ_d

- Combinatorial BKG B^0 Btag PDF for Positive Mixed (l^+K^+) sample, (similar expressions apply for the other ones):

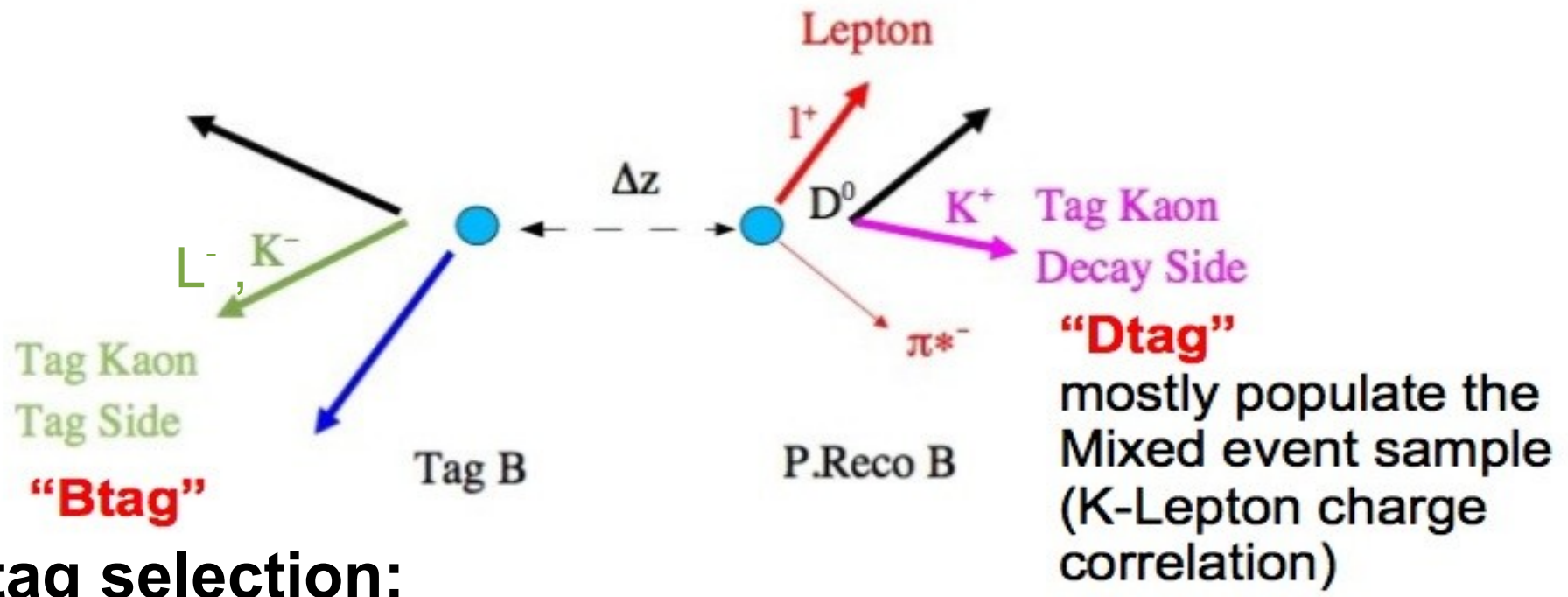
$$\mathcal{F}_\chi^{meas}(\Delta t, s_t = 1, s_m = -1) = \rho\tau \left[(1-\omega_\chi^+)\frac{\chi_d^{Bkg}}{\chi_0^{Bkg}}\mathcal{F}_\chi(\Delta t, 1, -1) + \omega_\chi^- \frac{1-\chi_d^{Bkg}}{1-\chi_0^{Bkg}}\mathcal{F}_\chi(\Delta t, -1, 1) \right] =$$

$$= RT(1+A_{rec})(1+A_{tag}) \left[(1-\omega_\chi^+)\frac{\chi_d^{Bkg}}{\chi_0^{Bkg}}\mathcal{F}_\chi(\Delta t, 1, -1) + \omega_\chi^- \frac{1-\chi_d^{Bkg}}{1-\chi_0^{Bkg}}\mathcal{F}_\chi(\Delta t, -1, 1) \right]$$

$$\chi_d^{Bkg}(P_K) = \chi_0^{Bkg} \times (a + bP_K)$$

$$\chi_0^{Bkg} = \frac{x_{Bkg}^2}{2(1+x_{Bkg}^2)}, \text{ where } x_{Bkg} = \tau_{B^0}^{Bkg}\Delta m_d^{Bkg}$$

High Purity Dtag Selection



Dtag selection:

- Look for same charge (L^+_{Reco}, K^+) pairs
- Opposite charge Tag Lepton L^- required to suppress Btag Mixed events B->K^+
- (L^+_{Reco}, L^-_{Tag}, K^+) sample has Dtag-Purity=87%
- 13% Residual Btag contamination from Tag Side B->D->K^+, Tag Side B->D->L^-, Reco Side B->D->L^-
- Purity can be increased from 87% to **94% (ε~5%)** by requiring K tracks to be assigned to Reco Side according to some angular variables included in a likelihood ratio

Δt Dtag PDF Determination on Real Data

Strategy:

- **High-Purity Dtag selection optimized with Purity =94%, ε~5%**

- Perform the same Dtag selection on MC & Real Data (OnPeak & OffPeak)

- Subtract residual Continuum BKG from OnPeak using Luminosity-rescaled selected OffPeak events

- Subtract residual Btag events (~6%) using MC predictions

- **Compute Real Data PDFs for the four different Dtag classes (B^0, B^+)X(Peaking, BKG):**

$$PDF^{DATA}_{Class\ i} = PDF^{MC}_{Class\ i} * (PDF^{DATA}/PDF^{MC})_{High\ Purity\ Selection}$$

- Systematic error on Real Data from the comparison of the |q/p| results obtained using the calculated PDFs or the High Purity Selection PDFs
- Method checked on MC using Standard vs High Purity Selection PDFs

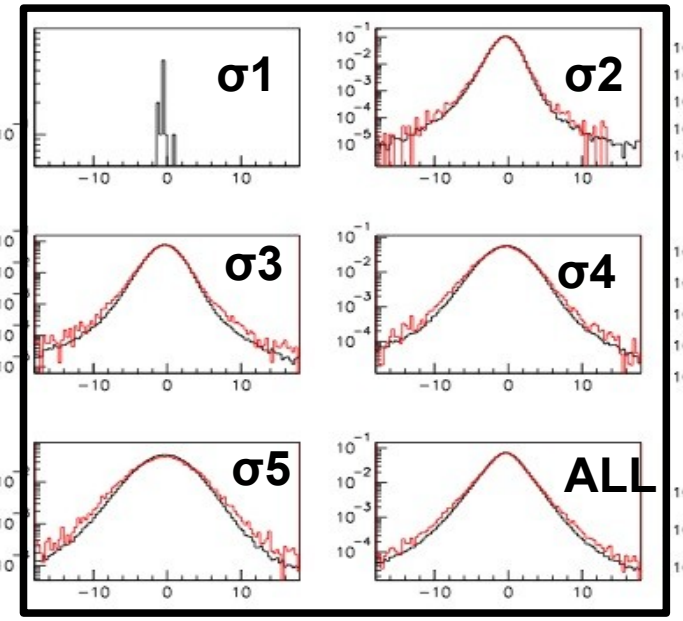
MC Dtag Δt PDF: Standard vs High Purity Selection

•Comparison in PK & σ(Δt) bins:

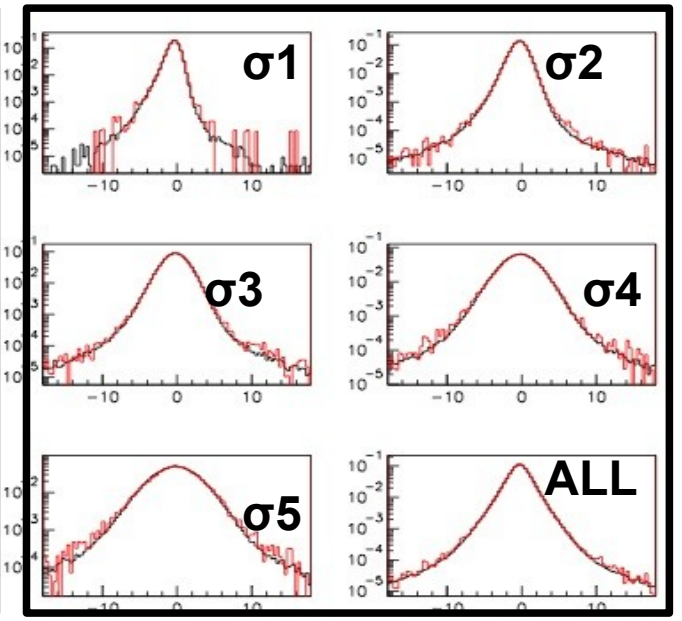
STANDARD

HIGH PURITY

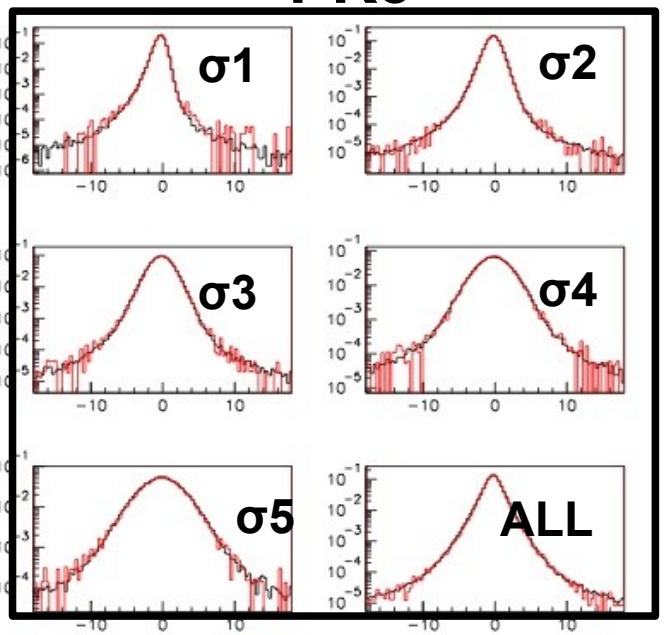
PK1



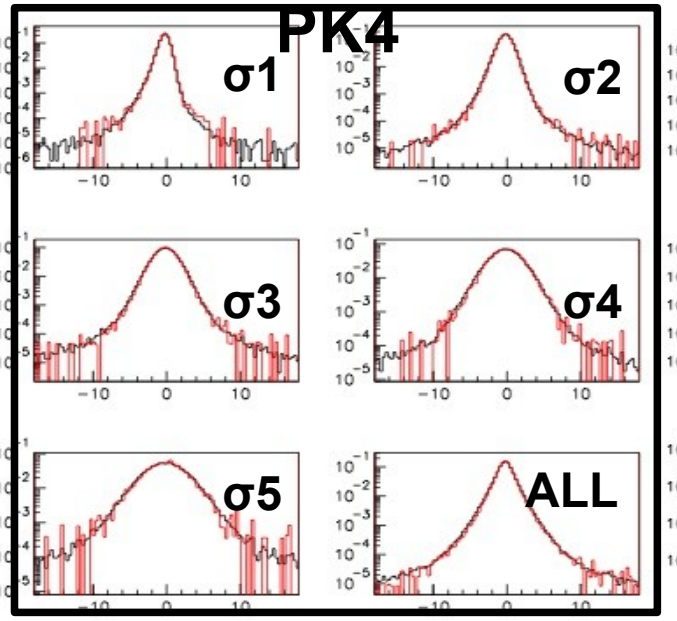
PK2



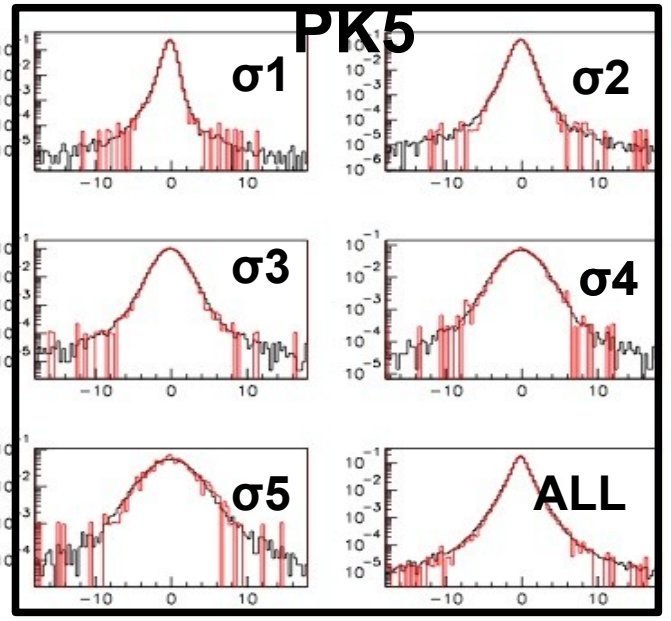
PK3



PK4



PK5



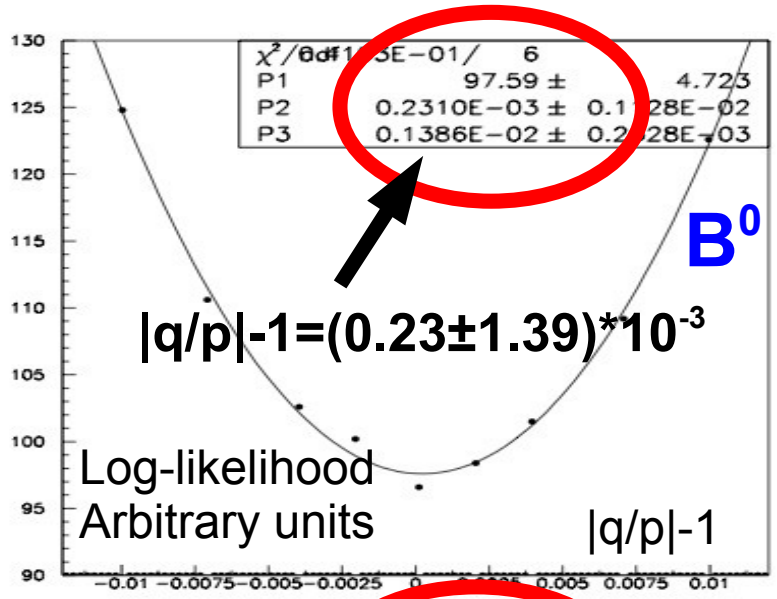
PK1=(0.2-0.52) GeV
PK2=(0.52-0.84) GeV
PK3=(0.84-1.16) GeV
PK4=(1.16-1.48) GeV
PK5>1.48 GeV

σ(Δt)1<0.6 ps
σ(Δt)2=(0.6-1.2) ps
σ(Δt)3=(1.2-1.8) ps
σ(Δt)4=(1.8-2.4) ps
σ(Δt)5=(2.4-3.0) ps

MC Dtag Δt PDF: Standard vs High Purity Selection

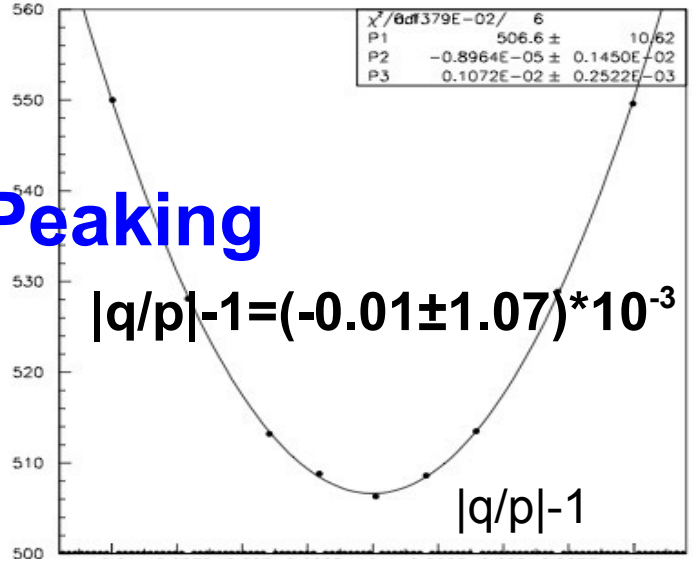
•Comparison of MC Fit results using the Standard or High Purity PDFs:

Standard PDF | **High Purity Selection** | **δ|q/p|**



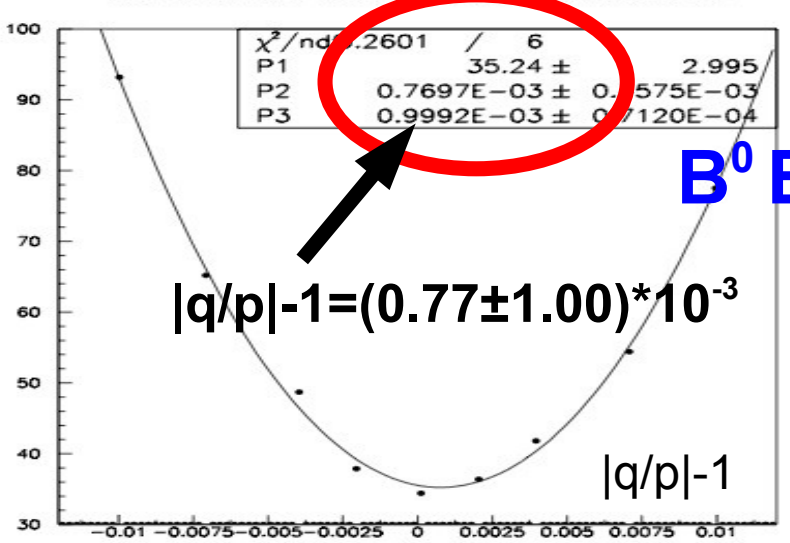
B^0 Peaking

|q/p|-1=(0.23±1.39)*10^{-3}



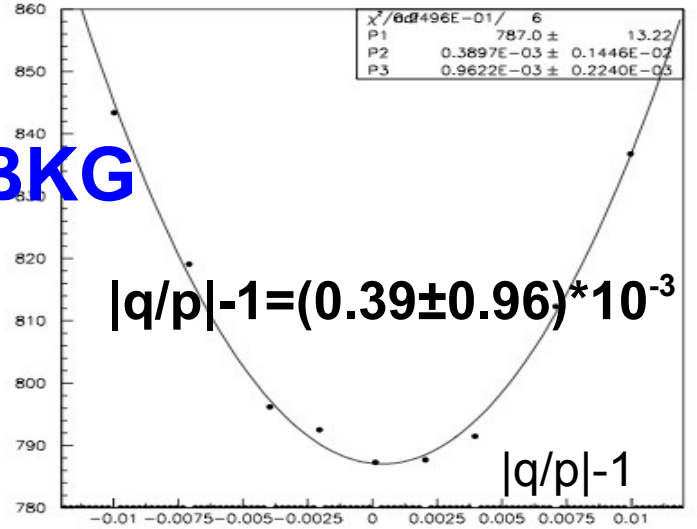
|q/p|-1=(-0.01±1.07)*10^{-3}

-0.24*10^{-3}



B^0 BKG

|q/p|-1=(0.77±1.00)*10^{-3}



|q/p|-1=(0.39±0.96)*10^{-3}

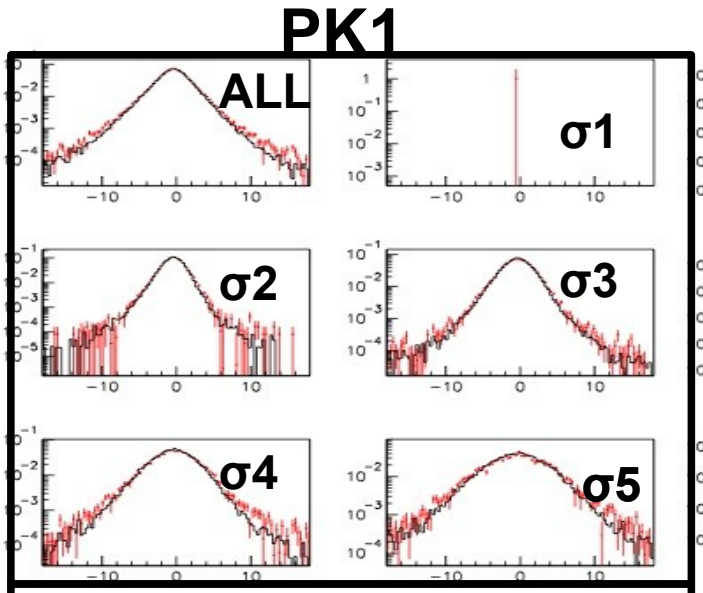
-0.38*10^{-3}

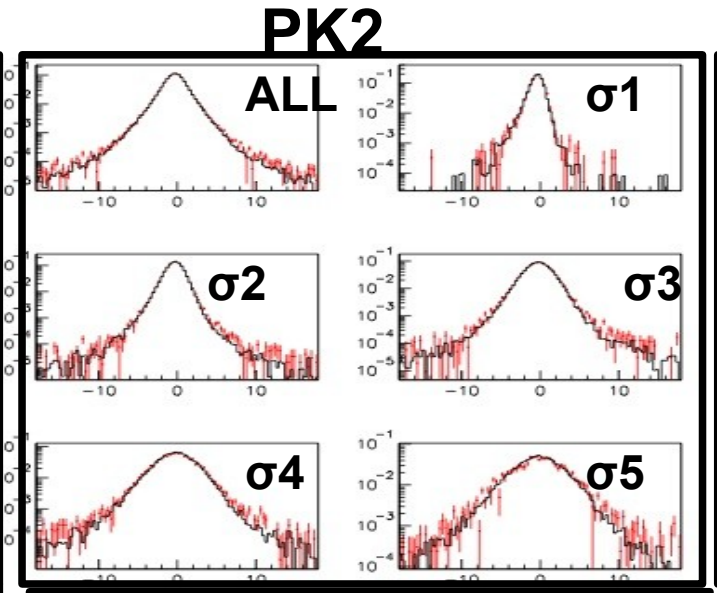
Effect~1/3 of MC Statistical σ

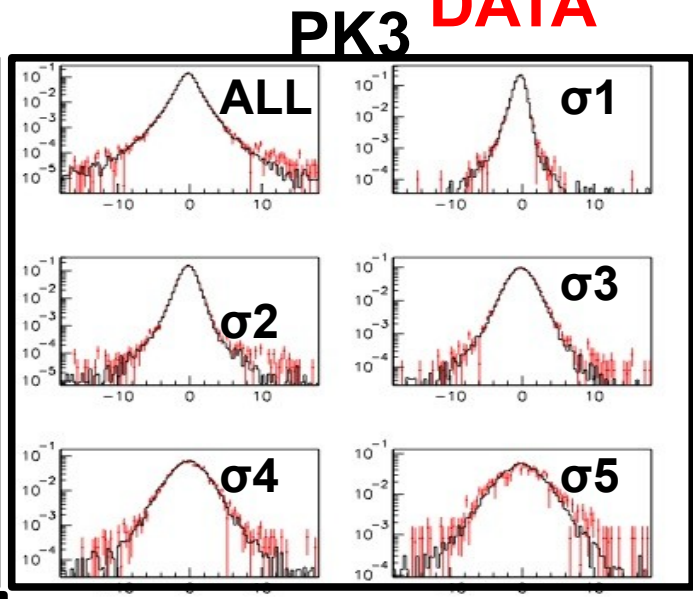
High Purity Dtag selection on Data & MC

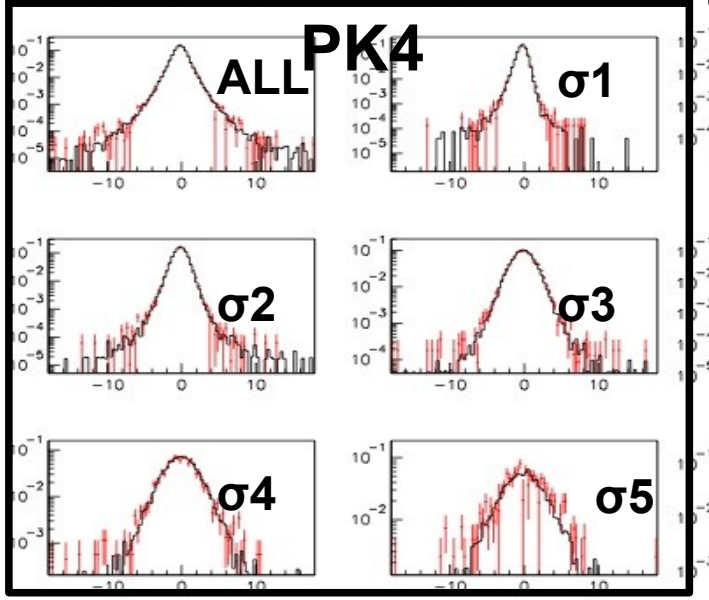
- Comparison in PK & σ(Δt) bins after Continuum & Btag Subtraction
- 264k events selected in Real Data

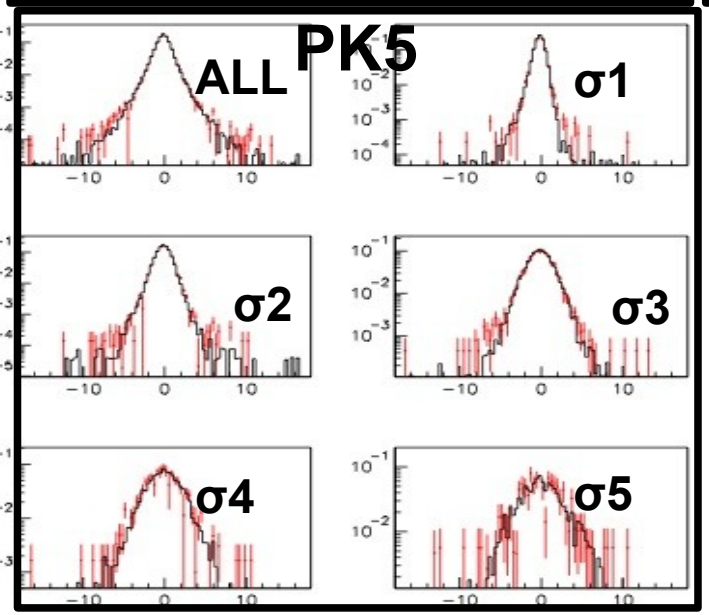
MC
DATA











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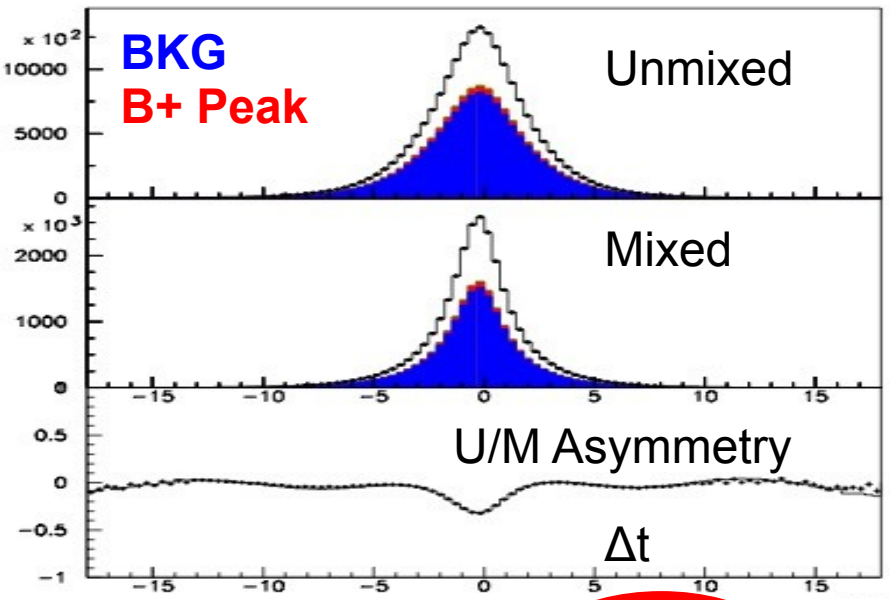
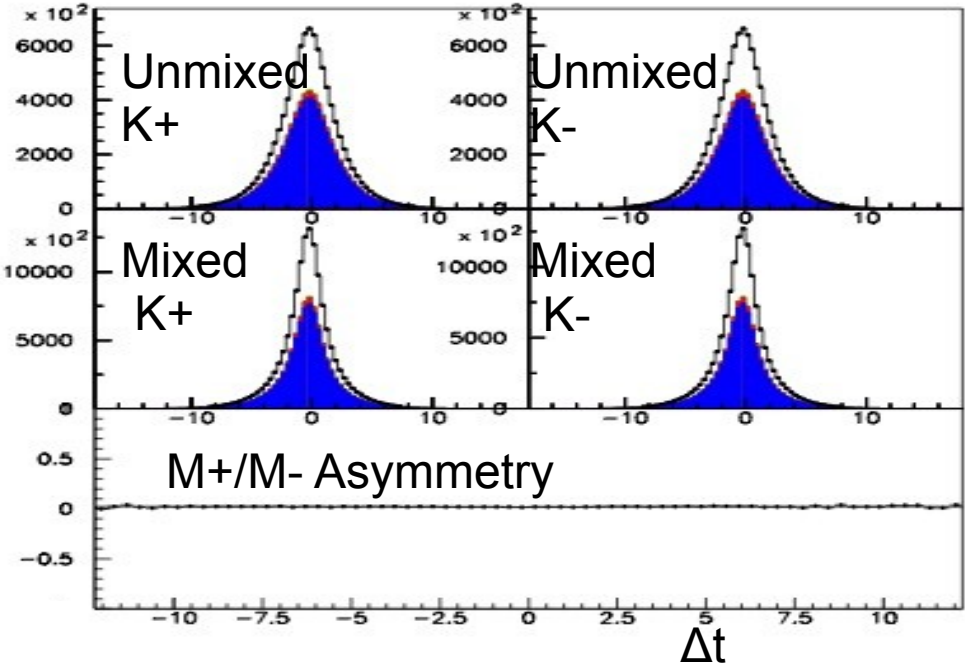
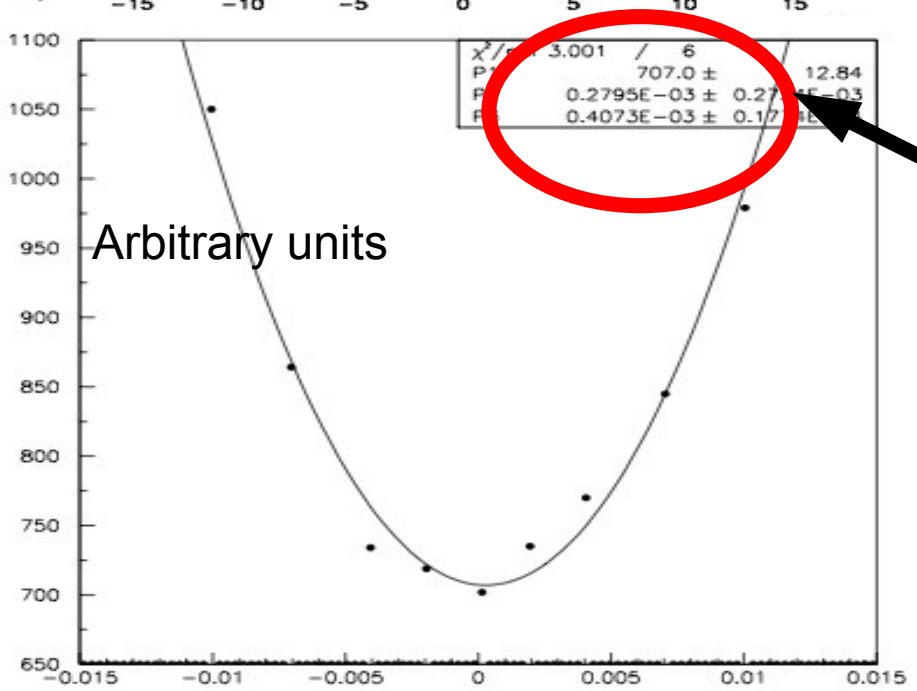
σ(Δt)4=(1.8-2.4) ps
σ(Δt)5=(2.4-3.0) ps

Results on B^0+B^+ Peaking+BKG





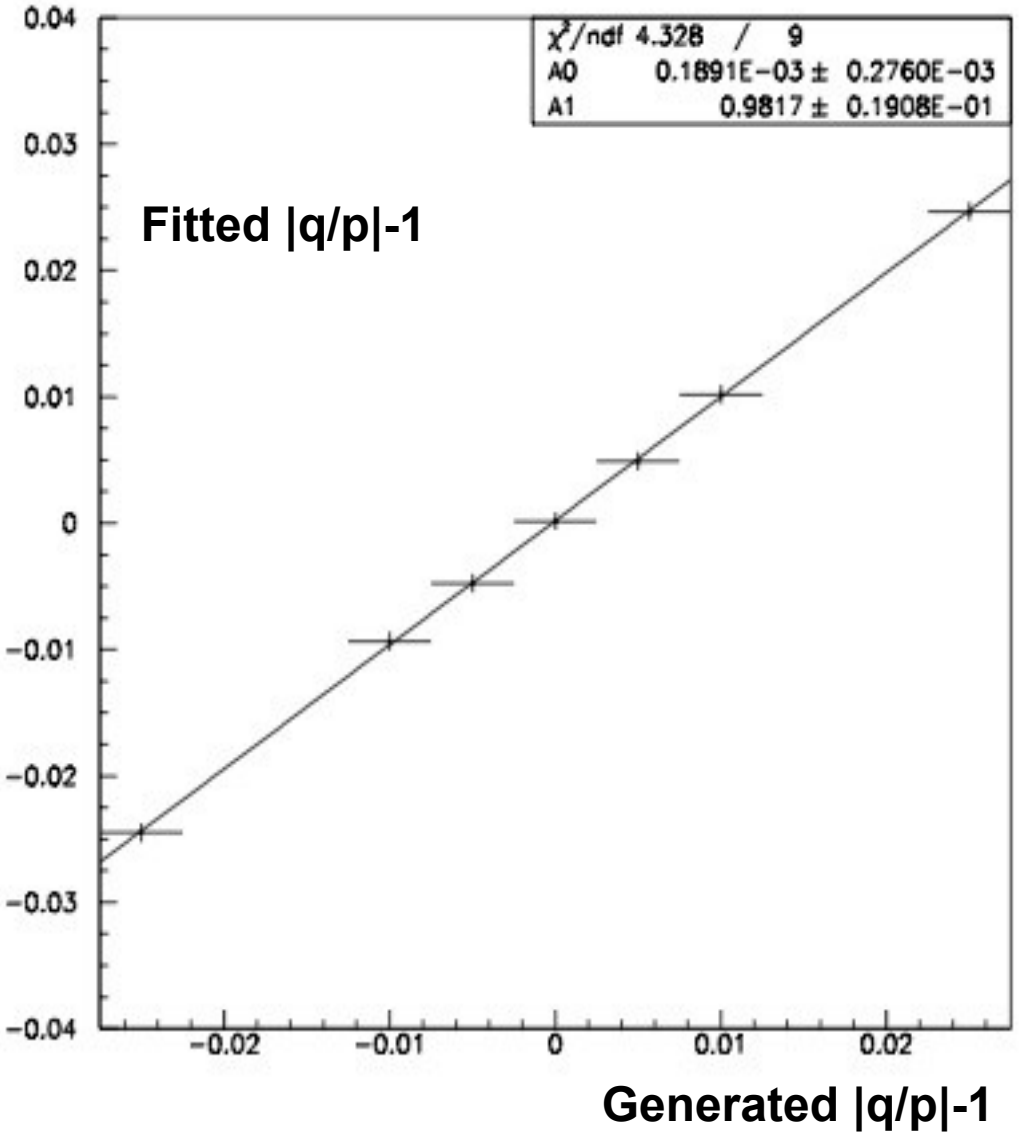


$|q/p|-1=(0.28\pm0.41)*10^{-3}$

No Bias found on MC with |q/p|=1

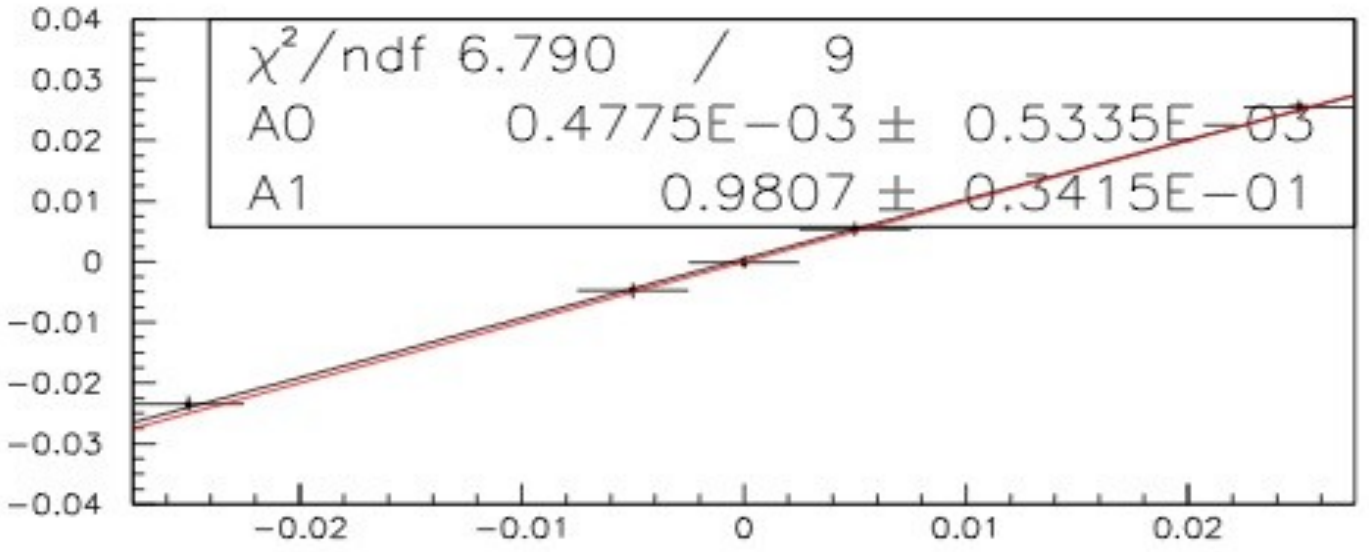
Fitted vs Generated K=|q/p|-1

B^0 Peaking+BKG Btag+Dtag

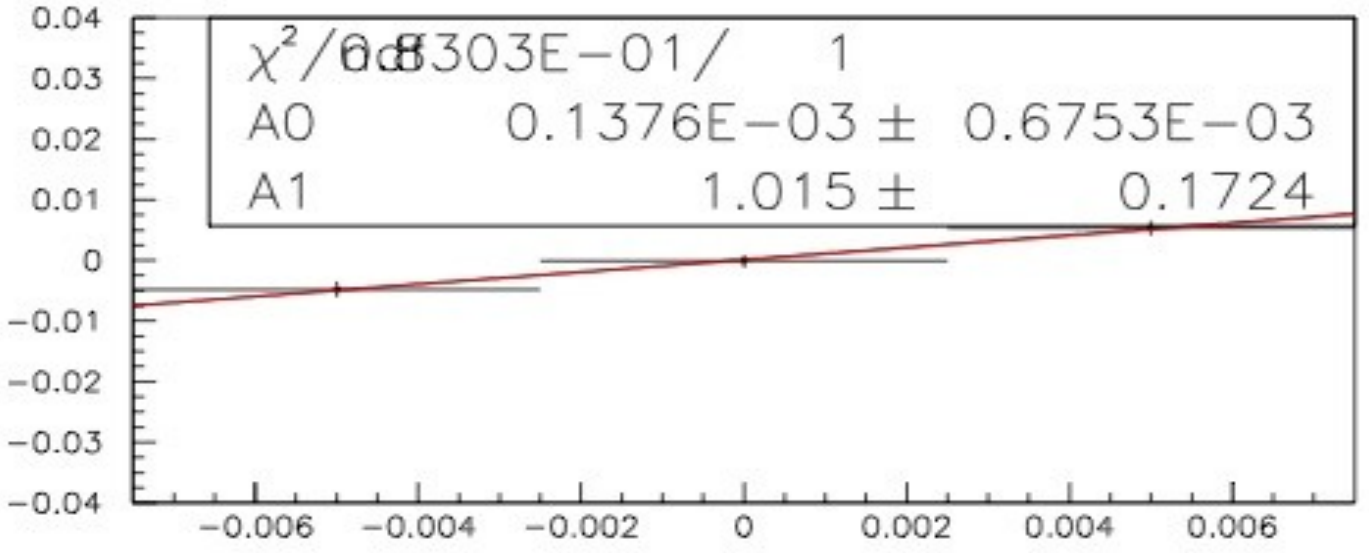


- Statistical errors correlated between different bins
- **Slope=0.98:**
  ~no bias on |q/p|-1 found
- Very wide |q/p| range as compared with the expectations

Fitted vs Generated 1g/p1-1

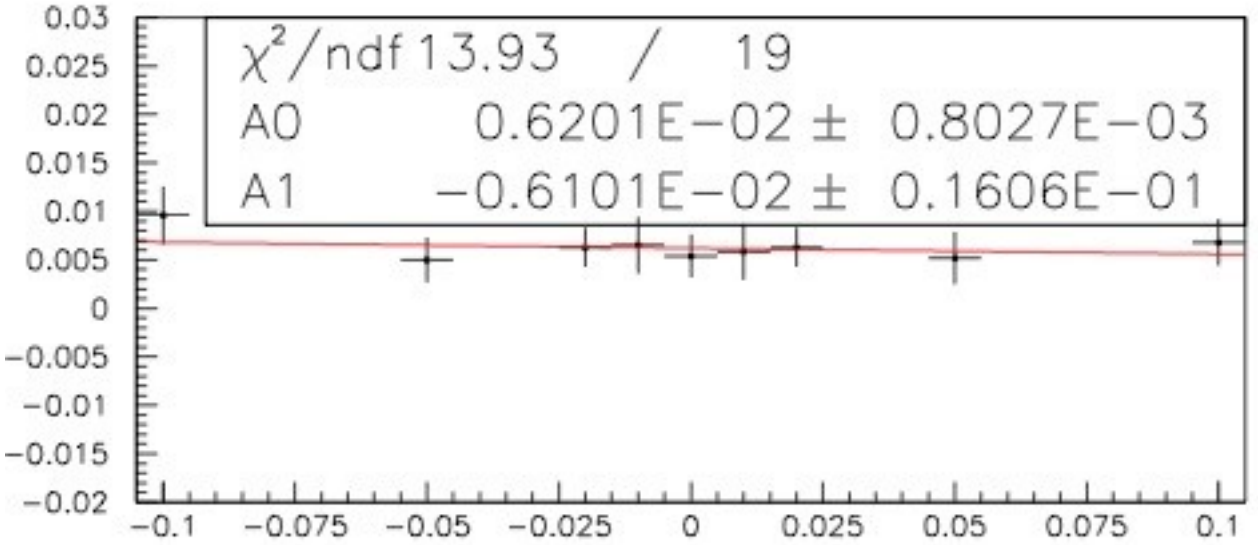


MC
Uncorrelated
Subsamples



Restricted
Range

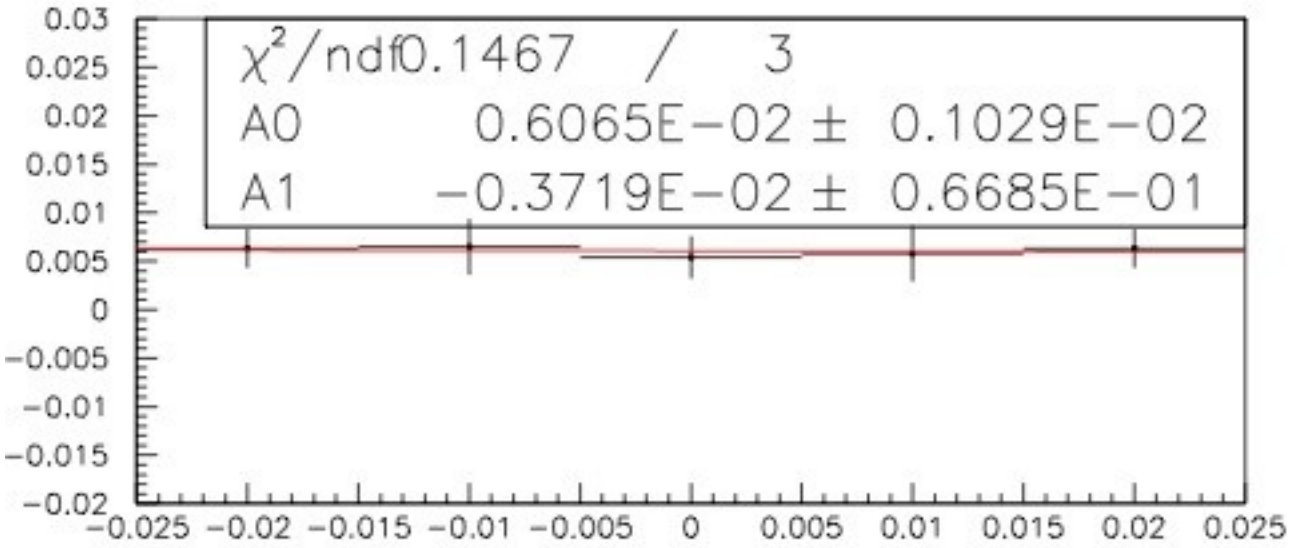
$|g/p|-1$ vs $\Delta\varepsilon_{Reco}$



Real Data

Uncorrelated

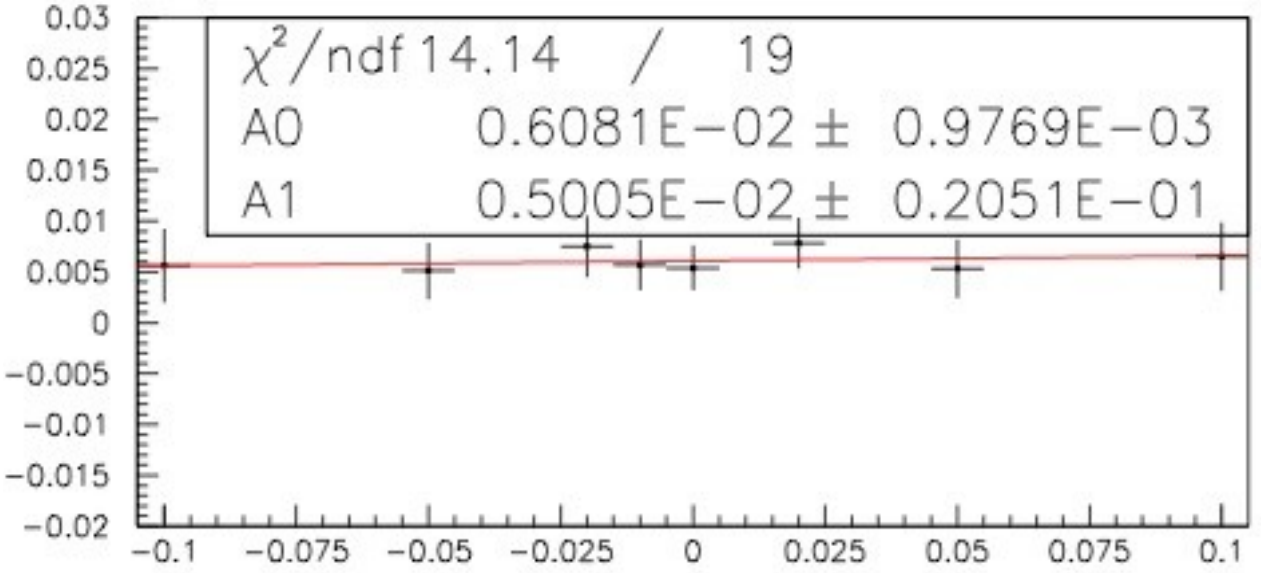
Subsamples



Restricted

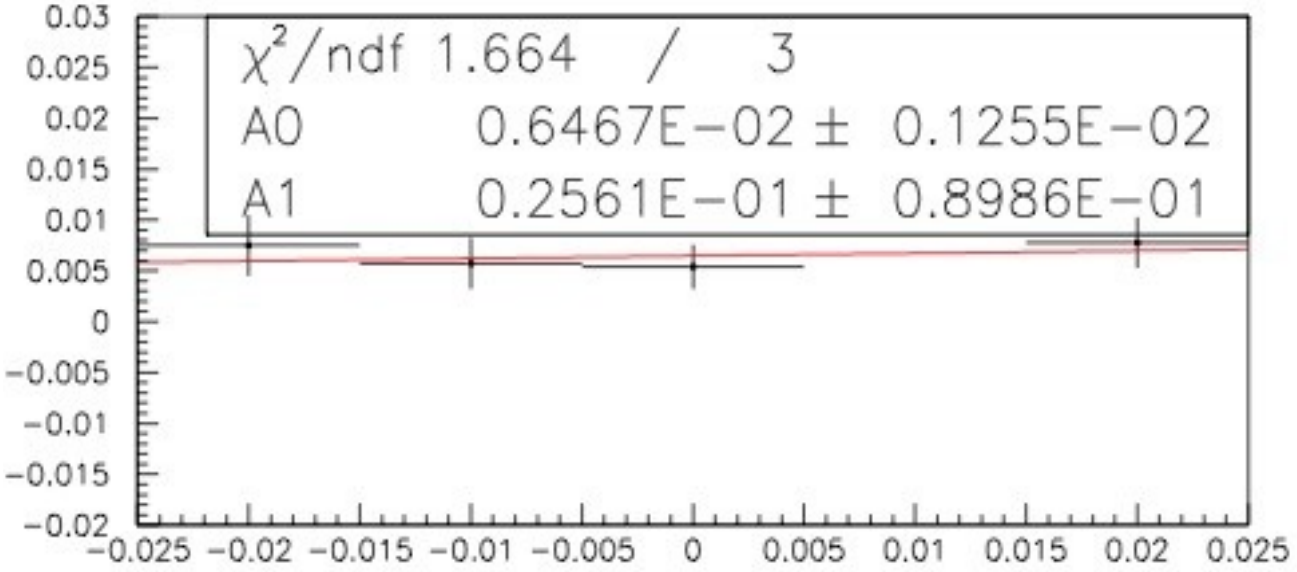
Range

$|g/p|-1$ vs $\Delta\varepsilon_{Tag}$



Real Data

Uncorrelated Subsamples



Restricted Range

Event Statistics

MC statistics: ~47 Mevents

B0 Btag Mixed Events

$\delta\lvert q/p\rvert_{stat}$		Limit	Meas.	Toy
Signal	1519576			
Combinatorial	2002682			
Total	3522258	$2.7\,10^{-4}$	$4.6\,10^{-4}$	$4.4\,10^{-4}$

Data statistics: ~14 Mevents

B0 Btag Mixed	~1174000	$4.6\,10^{-4}$	$8.4\,10^{-4}$	$8.7\,10^{-3}$