Search for anomalous direct and indirect CP violation in b to c transitions at DØ

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on behalf of the DØ collaboration

SUSY '07 Karlsruhe

Outline

Analyses overview

1. $p\bar{p} \rightarrow \mu\mu X$ hep-ex/0609014, PRD 74, 092001 (2006)
2. $B_s^0 \rightarrow \mu^+ D_s^- \nu X$ hep-ex/0701007, PRL 98, 151801 (2007)
3. $B^+ \rightarrow J/\psi K^+$ D0 preliminary http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B49/B49.pdf

Other sources of charge asymmetry

- Detector asymmetries
- Kaons

Results + combinations (hep-ex/0702030)

CP violation

Semileptonic charge asymmetry in B_s^0 mixing

1 — $p\bar{p} \rightarrow \mu\mu X$ (1 fb^{-1})

2 — $B_s^0 \rightarrow \mu^+ D_s^- \nu X$ (1.3 fb^{-1})

$B_s^0 \rightarrow \mathrm{J}/\psi\phi$

(cf. James Walder's talk)

$$A_{SL}^s = \frac{\Delta\Gamma_s}{\Delta M_s} tan\phi_s$$

SM: $\phi_s \approx (4.2 \pm 1.4) \times 10^{-3}$

Charge asymmetry in

3 — $B^+ \rightarrow J/\psi K^+$ (1.6 fb^{-1})

Direct CPV in $b \rightarrow c\bar{c}s$

SM: $A_{CP}(B^+ \rightarrow J/\psi K^+) < 1\%$

"lack firm SM prediction"

CP violation in B_s^0 mixing

1 $p\bar{p} \to \mu\mu X$

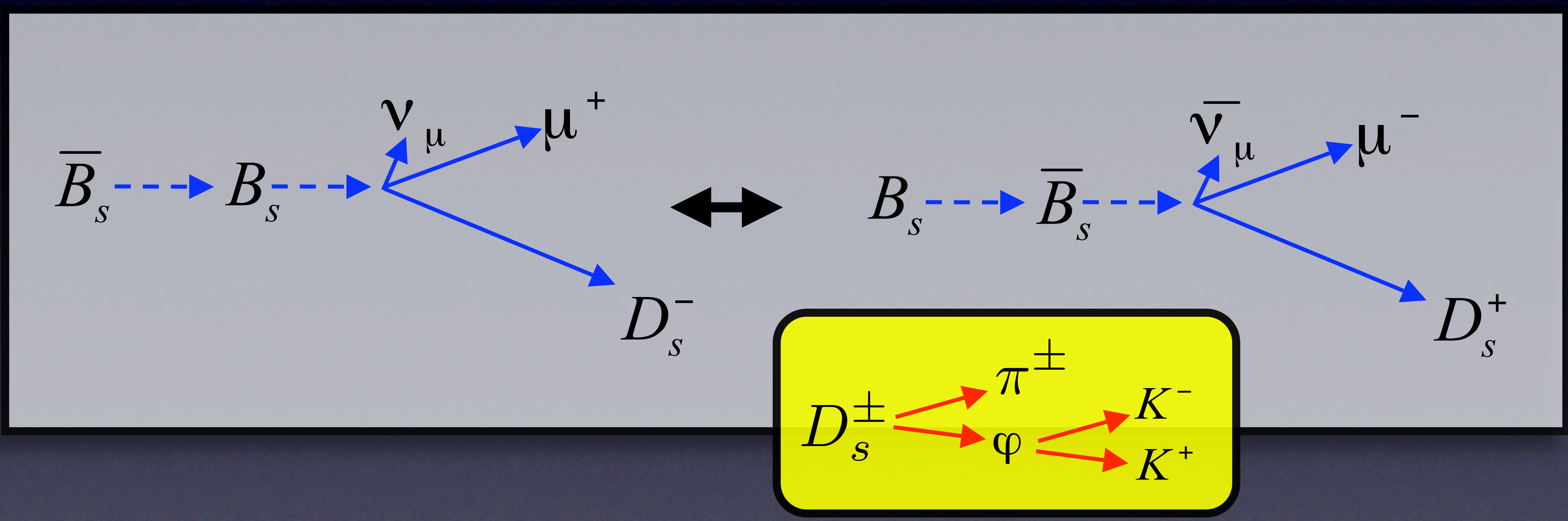
Extract A^s_{SL} from dimuon charge asymmetry

$$A^{\mu\mu}_{SL} = \frac{N(\mu^+\mu^+) - N(\mu^-\mu^-)}{N(\mu^+\mu^+) + N(\mu^-\mu^-)} = \frac{1}{4f}[A^d_{SL} + \frac{f_s\chi_{s0}}{f_d\chi_{d0}}A^s_{SL}]$$

$A^{\mu\mu}_{SL}$	observed dimuon charge asymmetry
f	accounts for other processes
A^d_{SL}	from B-factories
$\frac{f_s\chi_{s0}}{f_d\chi_{d0}}$	production rates, mixing probabilities

CP violation in B_s^0 mixing

2 $B_s^0 \rightarrow \mu^+ D_s^- \nu X$



$$A_{SL}^{\mu,untagged} = \frac{N(\mu^+ D_s^-) - N(\mu^- D_s^+)}{N(\mu^+ D_s^-) + N(\mu^- D_s^+)} = \frac{1}{2f} A_{SL}^s$$

CP violation in B_s^0 mixing

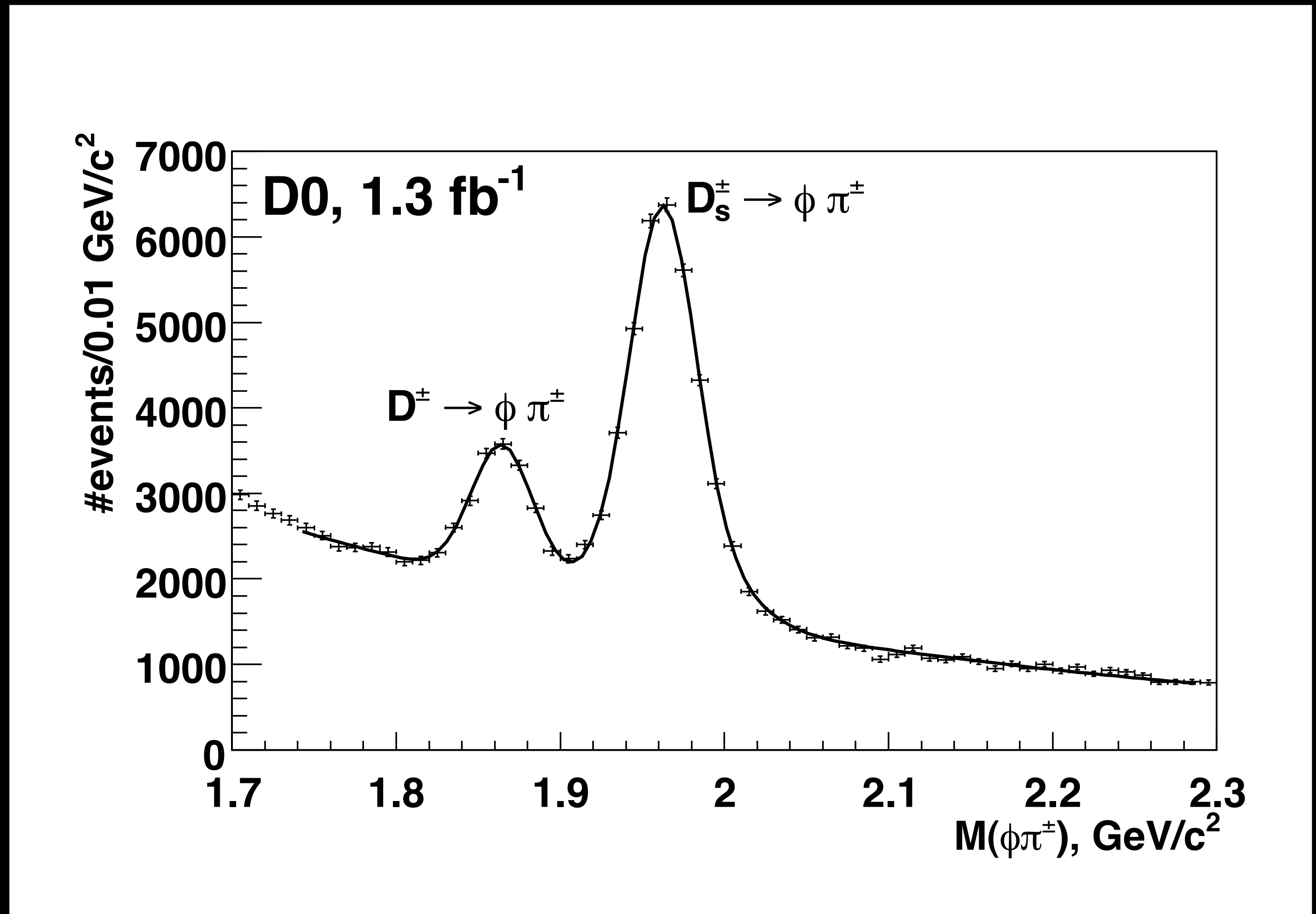
2 $B_s^0 \rightarrow \mu^+ D_s^- \nu X$

$(5.9 \pm 1.7)\%\ c\bar{c}(b\bar{b})$

from data

Other processes from PYTHIA

$(83.2 \pm 3.3)\%\ B_s^0$



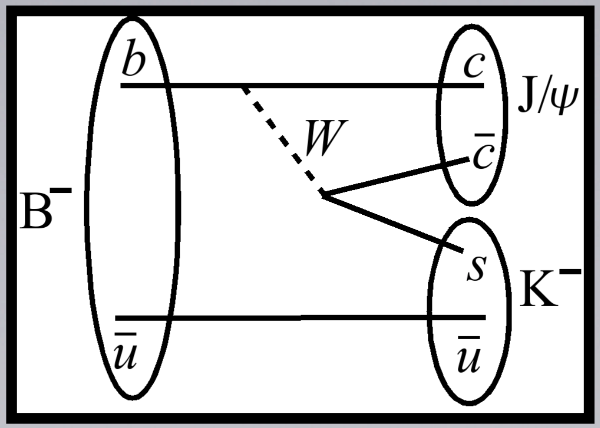
$27,300 \pm 300\ D_s^\pm$ events

Direct CPV in $b \to c\bar{c}s$

3

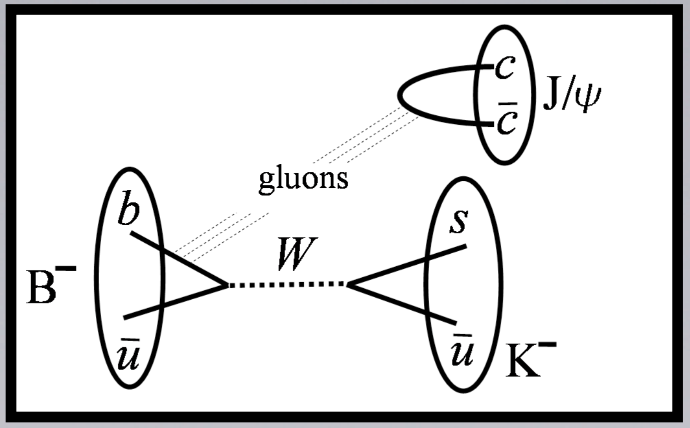
$$B^+ \to J/\psi K^+$$

direct



+

annihilation



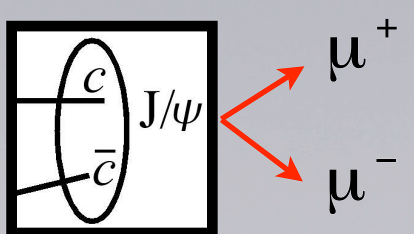
$$A_{\mathrm{DCPV}} = \frac{N(\mathrm{J}/\psi\mathrm{K}^-) - N(\mathrm{J}/\psi\mathrm{K}^+)}{N(\mathrm{J}/\psi\mathrm{K}^-) + N(\mathrm{J}/\psi\mathrm{K}^+)}$$

Kaon as charge tag

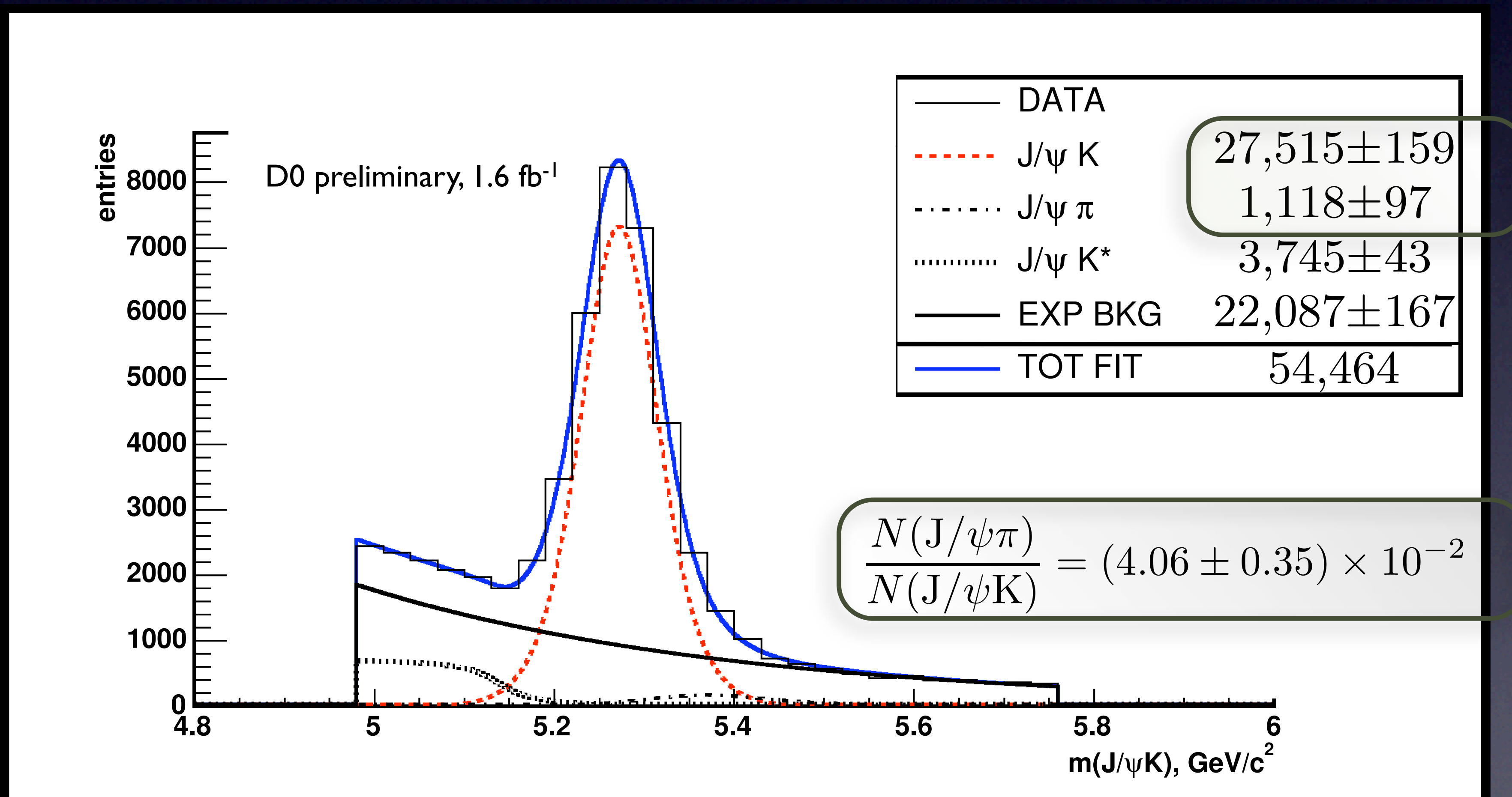
Direct CPV in $b \to c\bar{c}s$

3

$$B^+ \to J/\psi K^+$$



reconstruct in excl. dimuon decay



Unbinned likelihood fit

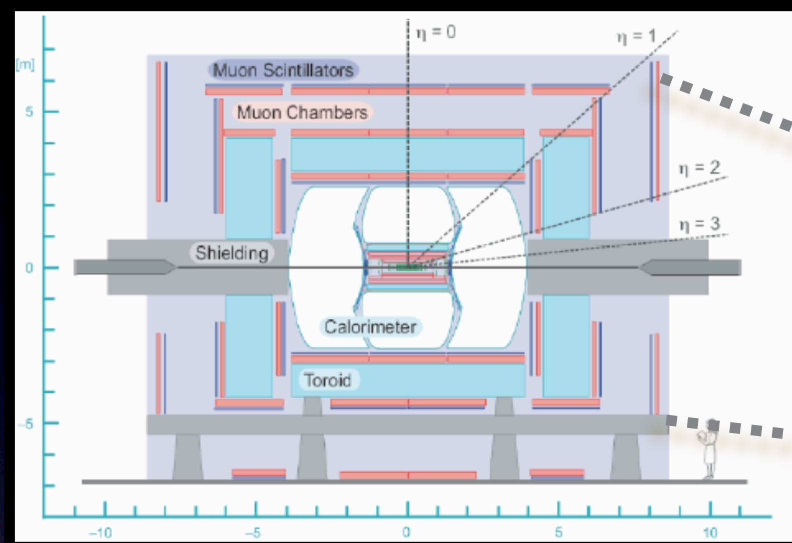
Other sources of charge asymmetry

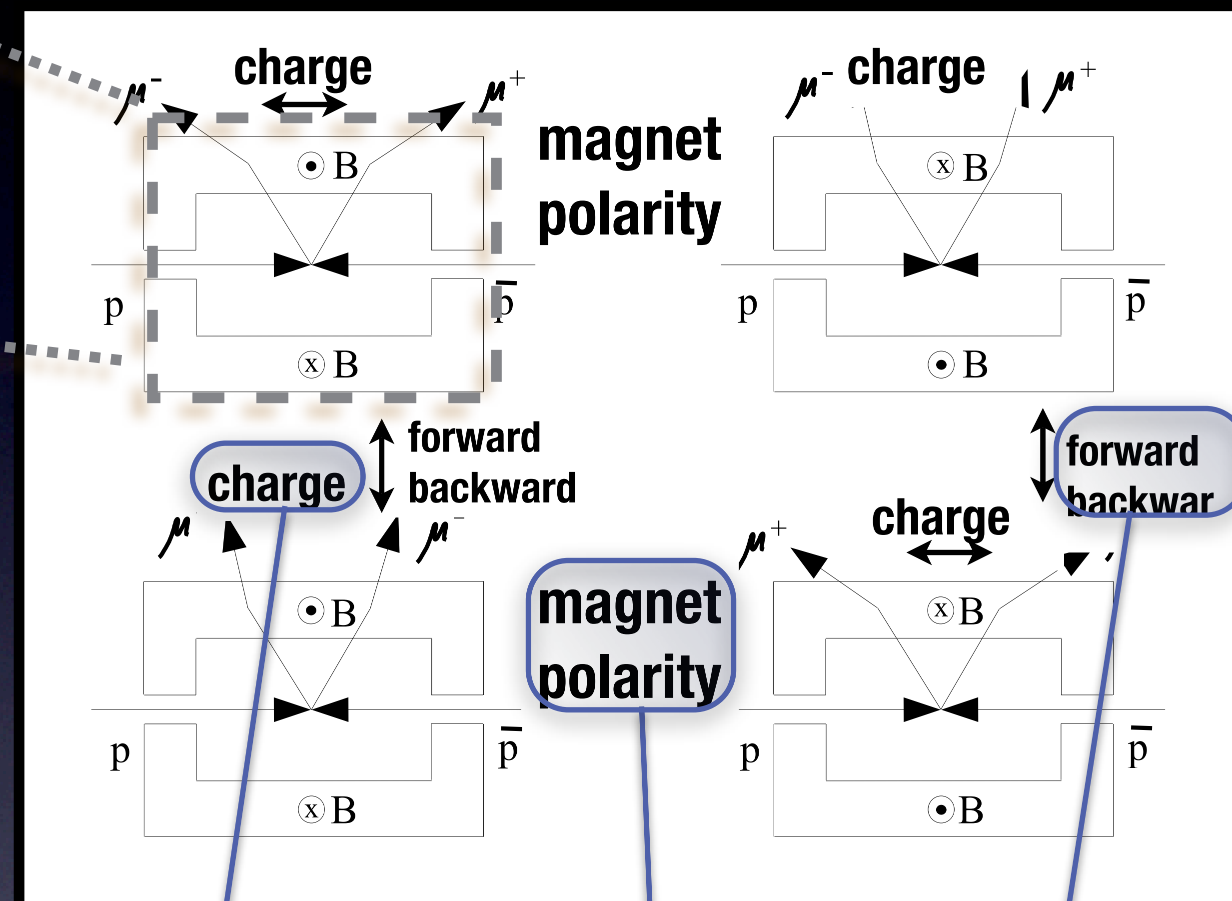
Detector Introduces apparent charge asymmetries (1) (2) (3)

Kaons K^+ has longer inelastic interaction length than K^- (1) (3)

Other sources of charge asymmetry

Detector





toroid (1, 2) solenoid(3) polarity reversal

$$q(+,-) \otimes \beta(+,-1) \otimes \gamma(+,-) \ : \ 8$$

$$n_q^{\beta\gamma} = \frac{1}{4} N \epsilon^{\beta} (1+qA)(1+q\gamma A_{\mathrm{fb}})(1+\gamma A_{\mathrm{det}})(1+q\beta\gamma A_{\mathrm{ro}})(1+q\beta A_{q\beta})(1+\beta\gamma A_{\beta\gamma})$$

nr of muons/kaons

measured asymmetry

detector asymmetries

Largest effect: range out

measured to be consistent with zero

Other sources of charge asymmetry

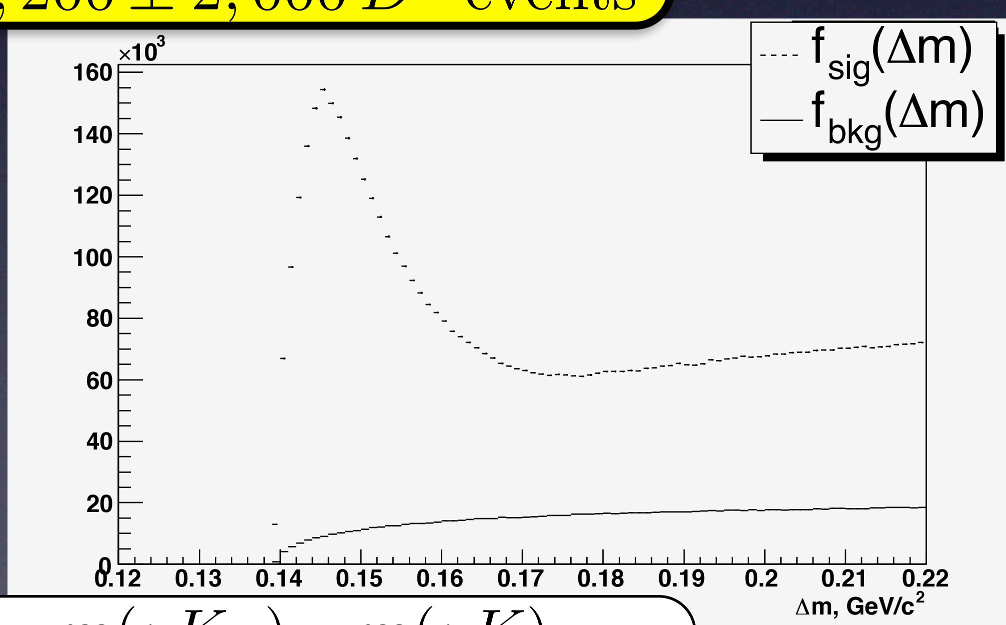
Kaons

K^+ has longer inelastic interaction length than K^-

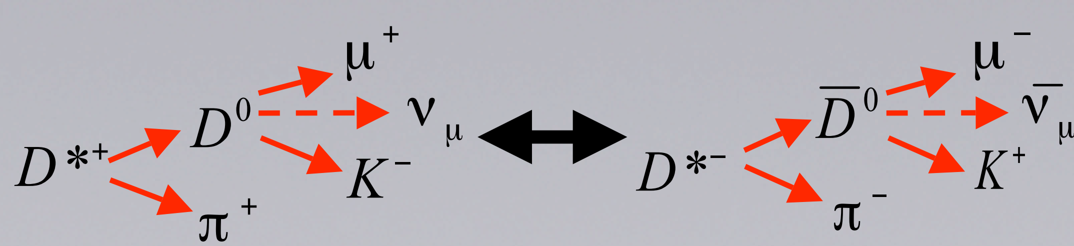
$$A_K = \frac{N(K^+) - N(K-)}{N(K^+) + N(K-)} > 0$$

Measured on large sample

$1,670,200 \pm 2,000\ D^*$ events



$\Delta m = m(\mu K \pi) - m(\mu K)$



The combinatorial background is sideband-subtracted from D* signal

$$A_K = 0.01262 \pm 0.00171(\mathrm{stat}) \pm 0.00023(\mathrm{syst})$$

CP violation in B_s^0 mixing

1

$$p\bar{p} \rightarrow \mu\mu X$$

$$A_{SL}^d + \frac{f_s \chi_{s0}}{f_d \chi_{d0}} A_{SL}^s = -0.0092 \pm 0.0044(\text{stat}) \pm 0.00032(\text{syst})$$

Using world average

Dominated by uncertainty on A_K

From B-factories: $A_{SL}^d = +0.0011 \pm 0.0055$

$$A_{SL}^s = -0.0147 \pm 0.00113(\text{stat} + \text{syst})$$

CP violation in B_s^0 mixing

2

$$B_s^0 \rightarrow \mu^+ D_s^- \nu X$$

$$A(\mu D_s) = +0.0102 \pm 0.0081(\text{stat})$$

Correcting for sample composition

Dominated by uncertainties from sample composition and mass fit

$$A_{SL}^s = 2f \times A_{SL}^{\mu,untagged} = +0.0245 \pm 0.0193(\text{stat}) \pm 0.0035(\text{syst})$$

The two measurements are nearly independent

CP violation in B_s^0 mixing

1 2 Combined constraints on ϕ_s at D0

$$A_{SL}^s = 0.0001 \pm 0.0090(\text{stat} + \text{sys})$$

from fit to time-dependent angular distribution in $B_s^0 \to J/\psi\phi$

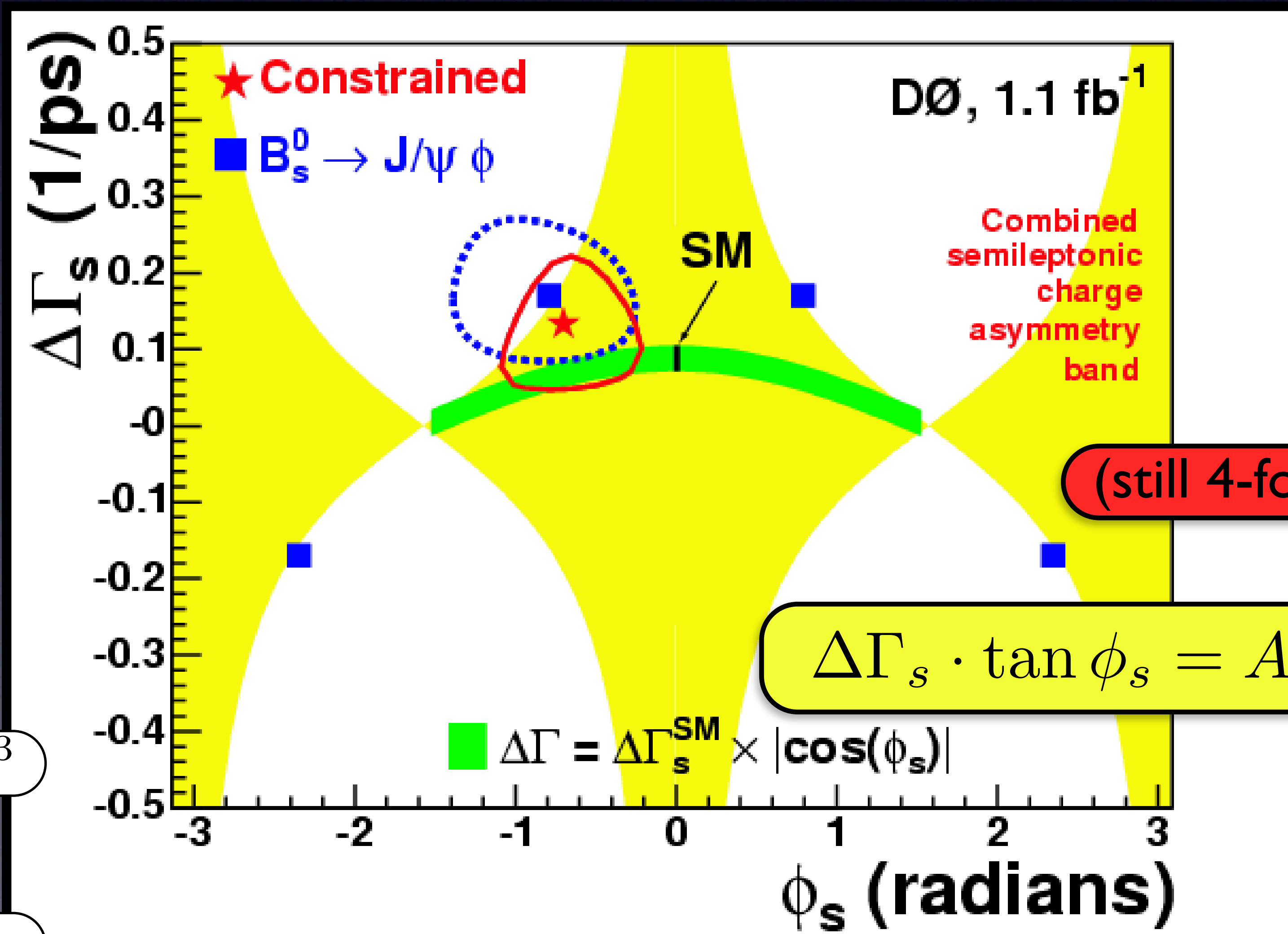
constrained with l.t. and semileptonic charge asymmetries

$$\phi_s = -0.70^{+0.47}_{-0.39}$$

$\text{SM}: \ \phi_s = (4.2 \pm 1.4) \times 10^{-3}$

$$\Delta\Gamma_s = 0.13 \pm 0.09 \, \text{ps}^{-1}$$

$\text{SM}: \ \Delta\Gamma_s = 0.088 \pm 0.017$



(still 4-fold ambig.)

$$\Delta\Gamma_s \cdot \tan\phi_s = A_{SL}^s \cdot \Delta M_s$$

CDF

Direct CPV in $b \to c\bar{c}s$

3

$$B^+ \to J/\psi K^+$$

$$A(J/\psi K) = -0.0072 \pm 0.0073(\text{stat})$$

Contains $A_K(J/\psi K) = 0.0139 \pm 0.0013(\text{stat})$

$$A_{CP} = +0.0067 \pm 0.0060(\text{stat}) \pm 0.0026(\text{syst})$$

Most precise measurement

Previous measurements

$(+)0.030 \pm 0.014 \pm 0.010(\text{BaBar})$

$-0.026 \pm 0.022 \pm 0.017(\text{Belle})$

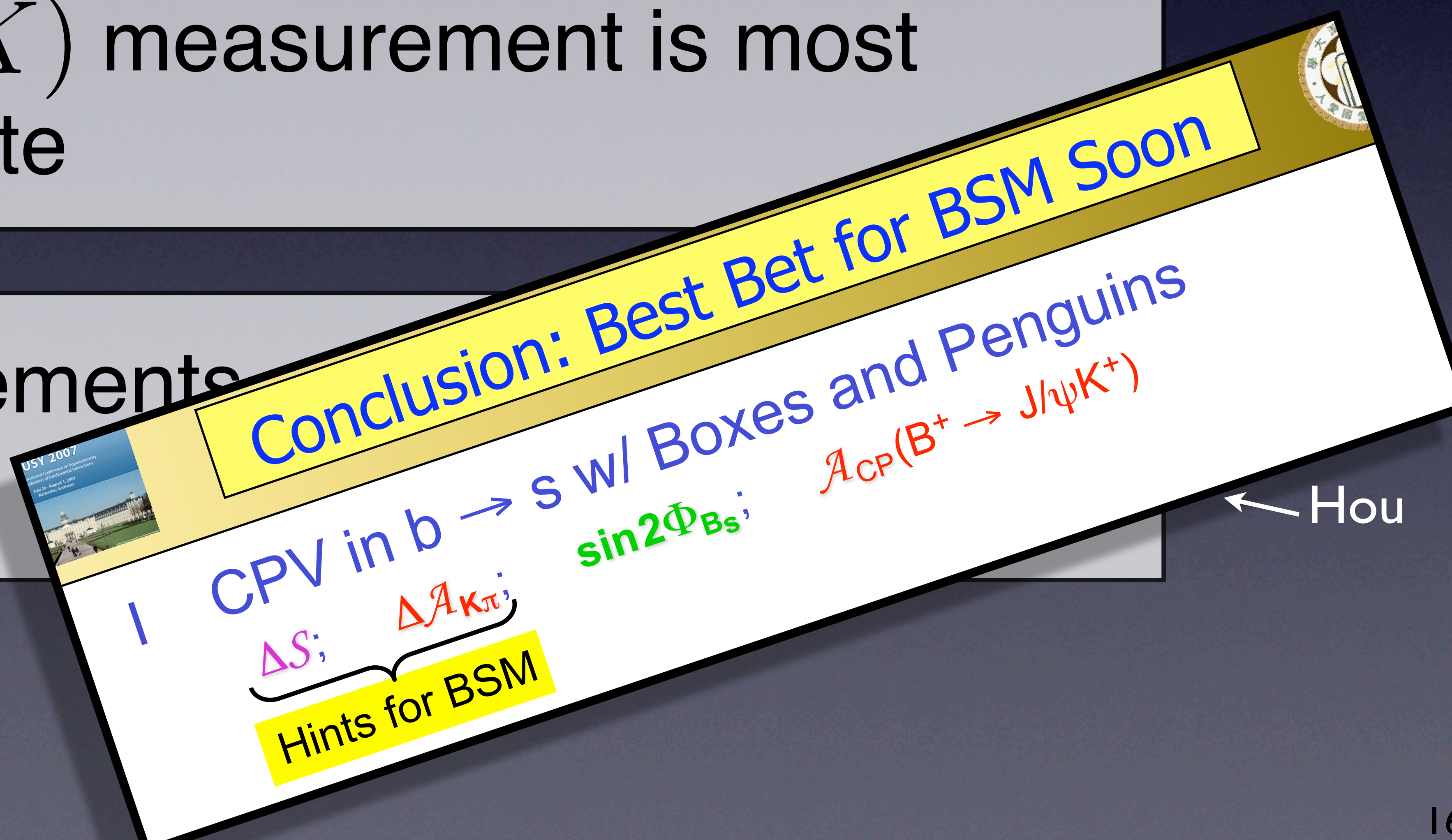
$0.018 \pm 0.043 \pm 0.004(\text{CLEO})$

Conclusions

For the first time ϕ_s is constrained through measuring A^s_{SL}

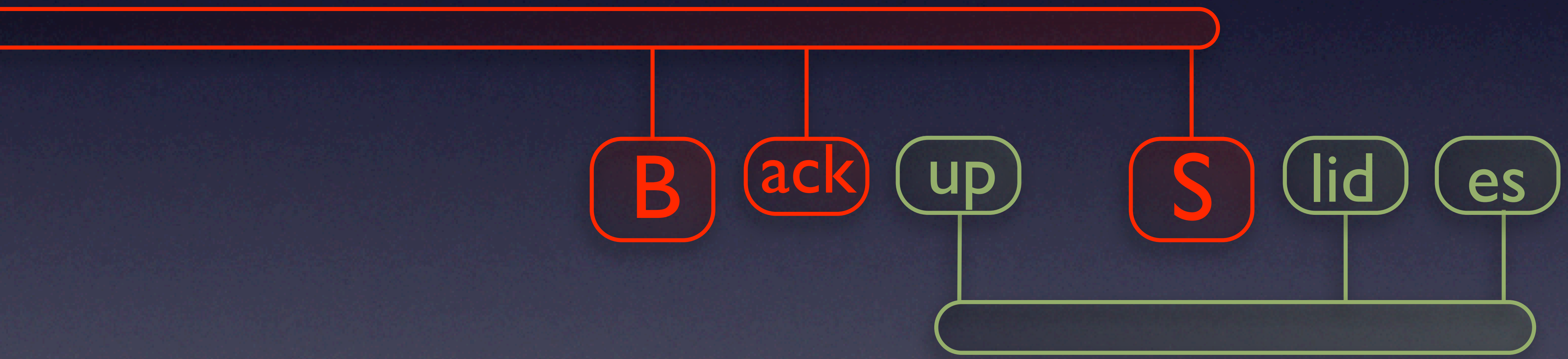
$A_{CP}(J/\psi K)$ measurement is most precise to date

The measurements ... predictions



← Hou

THE END


B
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es

$p\bar{p} \to \mu\mu X$

TABLE V: Weights of dimuon processes for standard cuts (obtained as described in the text). Note that 64% of dimuons are from direct-direct $b\bar{b}$ decay.

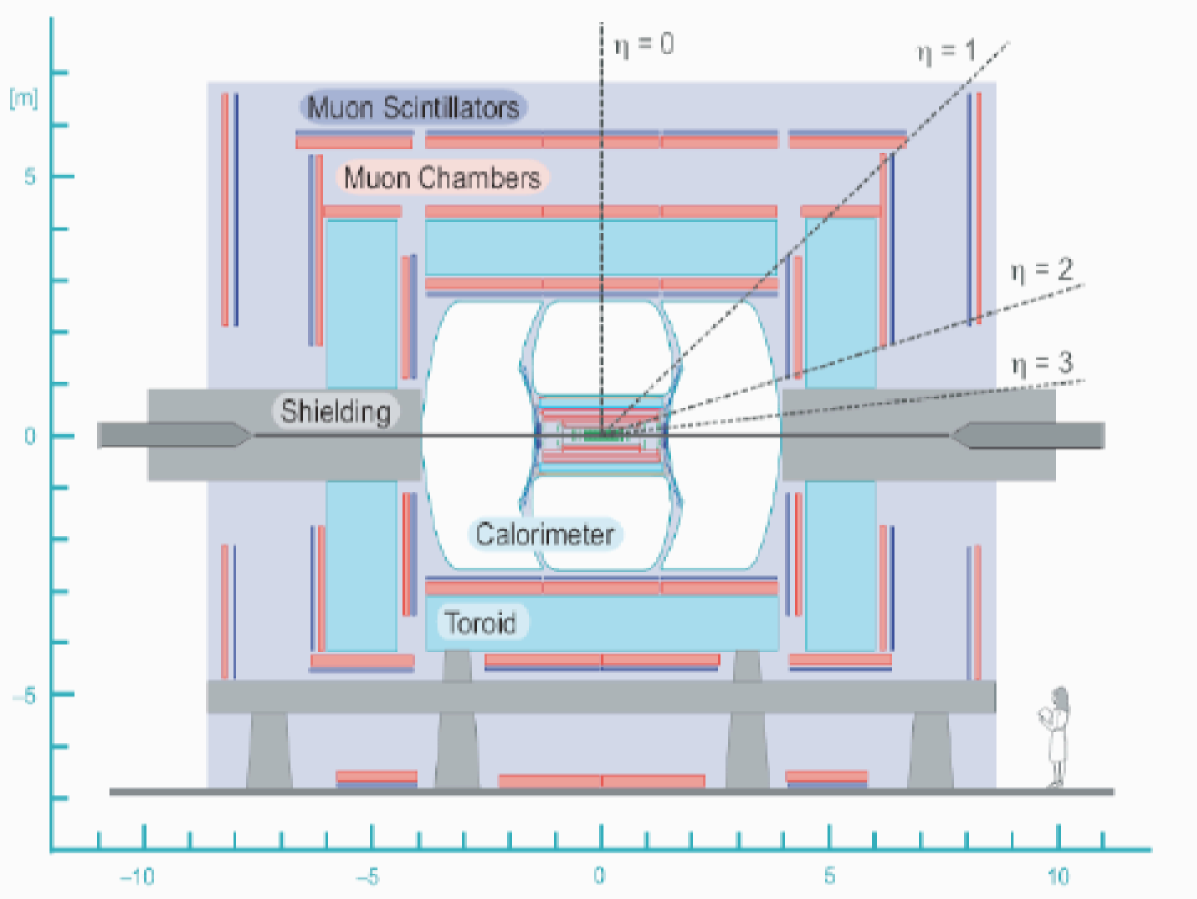
P_1	$\equiv 1$
P_2	0.116 ± 0.055
P_3	0.003 ± 0.003
P_4	0.093 ± 0.049
P_5	0.070 ± 0.042
P_6	0.023 ± 0.023
P_7	0.003 ± 0.003
P_8	0.078 ± 0.023
P_9	0.0001 ± 0.0001
P_{10}	0.001 ± 0.001
P_{11}	0.0002 ± 0.0002
P_{12}	0.163 ± 0.066
P_{13}	0.0005 ± 0.0005

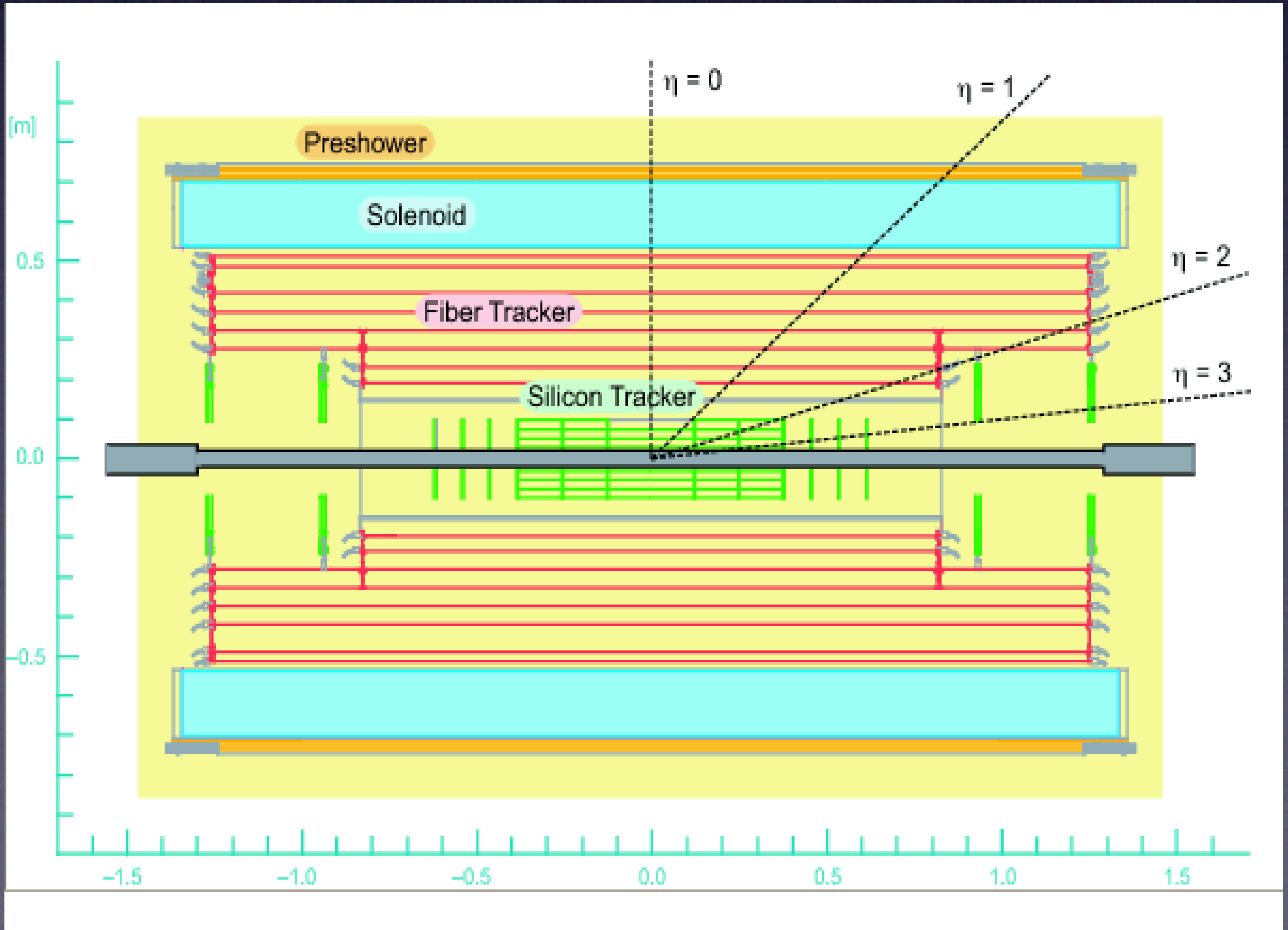
TABLE IV: Processes contributing to dimuon ev
mixing. The weights are normalized to direct-di
that b quarks decay as $\bar{b}$. $\bar{\chi} = f_d\bar{\chi}_d + f_s\chi_s$ is the p
b decay is $\rho' \equiv 0.6 \pm 0.15$ [8]. $\rho \equiv \frac{1}{2}\rho'(\chi - \bar{\chi})$. a
symmetry is assumed. For example, the number o

process	weight
$b \to \mu^-$, $\bar{b} \to \mu^+$	$P_1 \equiv 1$
$b \to \mu^-$, $\bar{b} \to \bar{c} \to \mu^-$	P_2
$b \to c \to \mu^+$, $\bar{b} \to \bar{c} \to \mu^-$	P_3
$b \to \mu^- c \to \mu^+$	P_4
$c \to \mu^+$, $\bar{c} \to \mu^-$	P_5
Drell-Yan, J/ψ, Υ	P_6
dimuon cosmic rays	P_7
μ + $K^\pm$ decay	P_8
μ + cosmic	P_9
μ + punch-through	P_{10}
μ + combinatoric	P_{11}
other	P_{12}
dimuon w. wrong sign	P_{13}

Muon system:

- 1.8 T toroid for local muon tracking, |η|<2
- cosmic ray rejection
- low punch-through





Central tracking:

- Silicon (innermost) + fiber tracker in 2T solenoid, |η|<3
- High efficiency (~95% in the central region) and resolution: $\sigma(p_T)/p_T^2 \approx 0.002$

Muon selection

- Hits in all 3 layers of muon chambers;
- Associated central track;
- Good quality of track;
- P_T > 4.2 GeV or $|P_Z|$>6.4 GeV;
- 3.0 < P_T < 15 GeV;
- Impact parameter to primary interaction: < 0.3 cm;
- at least one scintillator hit with $|\Delta t|$<5 ns;

Cuts on di-muons

- ΔP > 0.2 GeV
- 10° < Opening angle < 170°
- Δz < 2 cm
- Distance between hits in muon chamber Δr > 5 cm;

Systematics in $A_{CP}(B^{+}$ ® $J/\psi K^{+})$

- from J/ψKX: repeat the analysis with fraction of J/ψKX fixed to 0
- from A(J/ψπ), A(J/ψKX):
  repeat the analysis with A(J/ψπ), A(J/ψKX) artificially suppressed by fixing the ratios
  R = (J/ψπ fraction)/(BKG fraction), (J/ψKX fraction)/(BKG fraction)
  in every subsample to the value determined from "all" fit.

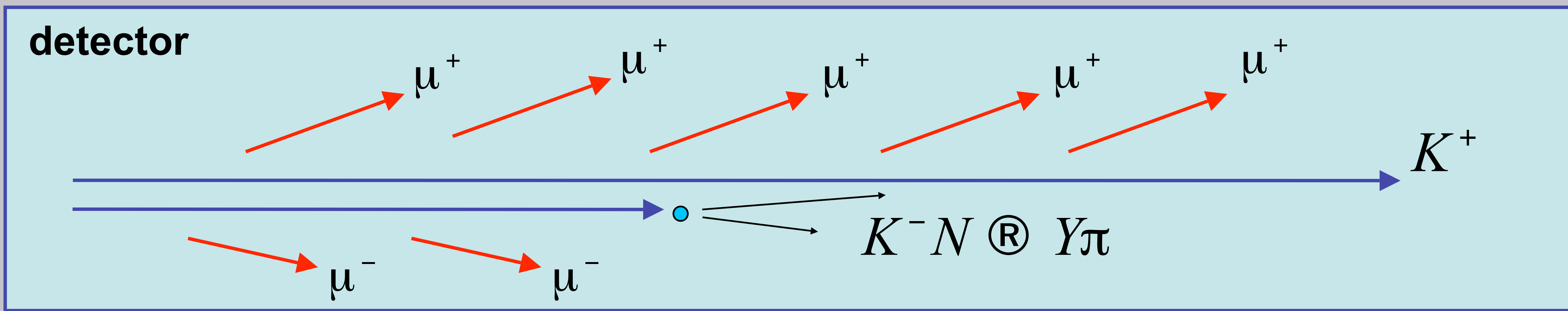
Fixing	A($J/\psi K$)	A($J/\psi\pi$)	A($J/\psi K^*$)	A(BKG)
$J/\psi K^*$ fraction $\rightarrow 0$	−0.0079	−0.2098	−	0.0043
$R_{J/\psi\pi} \rightarrow$ "all" value	−0.0078	0.0488	−0.0581	0.0198
$R_{J/\psi K^*} \rightarrow$ "all" value	−0.0077	−0.1847	0.0035	0.0041
$R_{J/\psi\pi}, R_{J/\psi K^*} \rightarrow$ "all" value	−0.0098	−0.0086	0.0077	0.0076

this deviates maximally from the nominal
$A = -0.0072$

suppressed

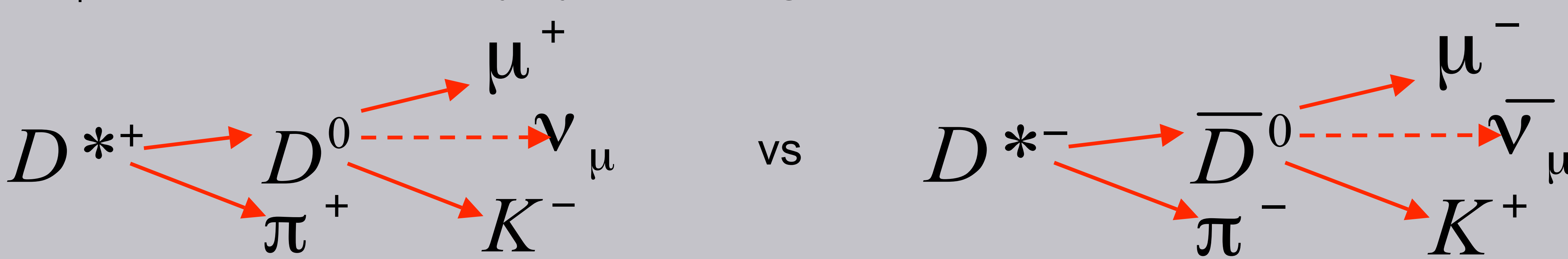
Kaon asymmetry

Technical complication: $\mu\mu$ and $J/\psi K$ samples are affected by:



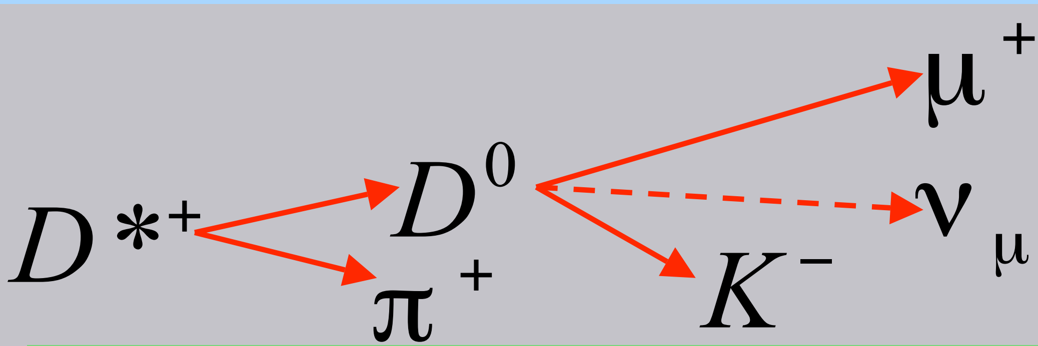
For p_K=10 GeV: $\sigma(K-d)$=38mb, $\sigma(K+d)$=28 mb

- for $\mu\mu$: Estimated from distance to calorimeter and K^-d, K^+d cross-sections
- for $J/\psi K$: Measured directly by comparing:



no physics asymmetry, $A_K = -A_\mu$

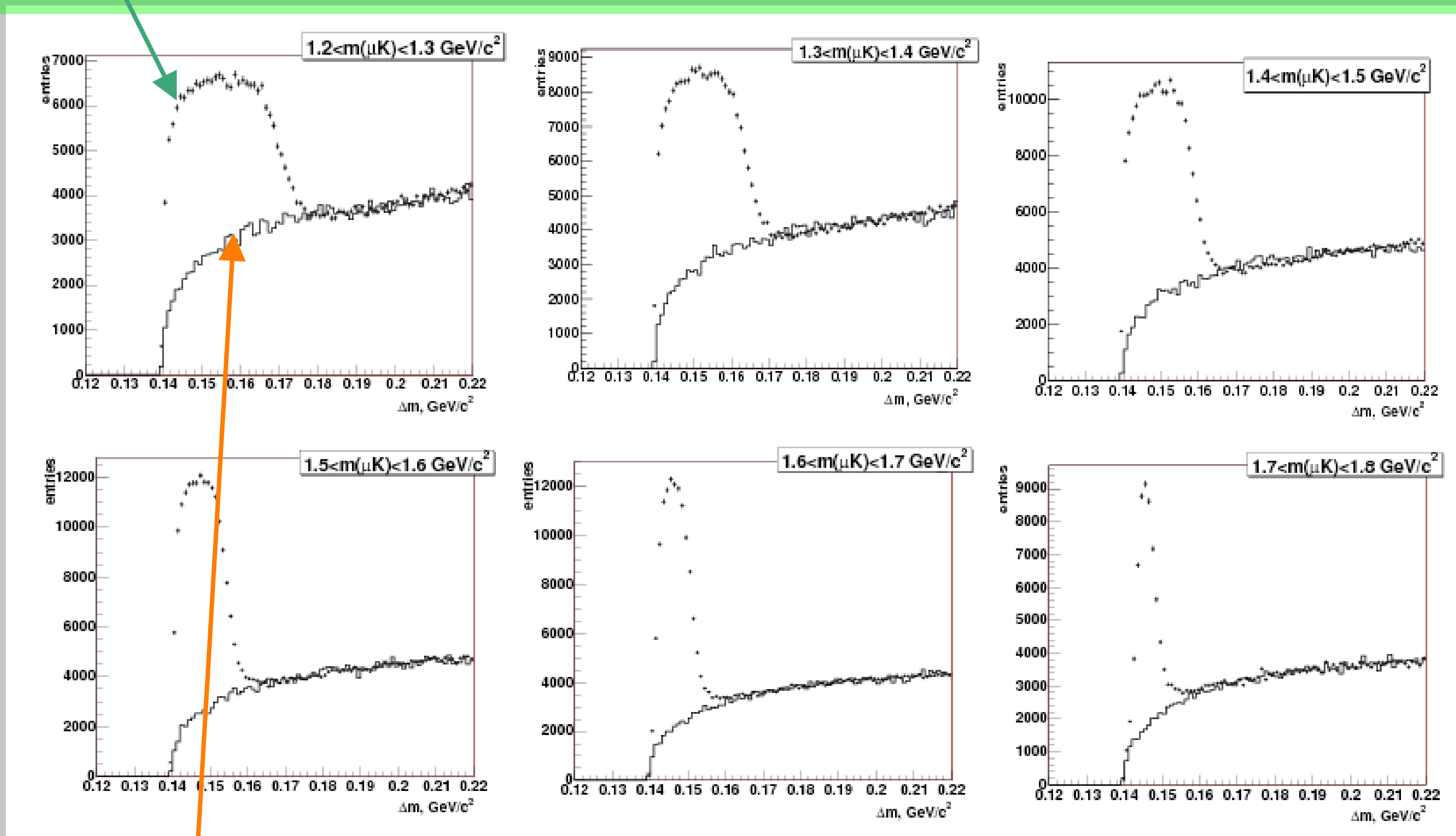
Details: Kaon asymmetry



$$\Delta m = m(\mu K\pi) - m(\mu K)$$

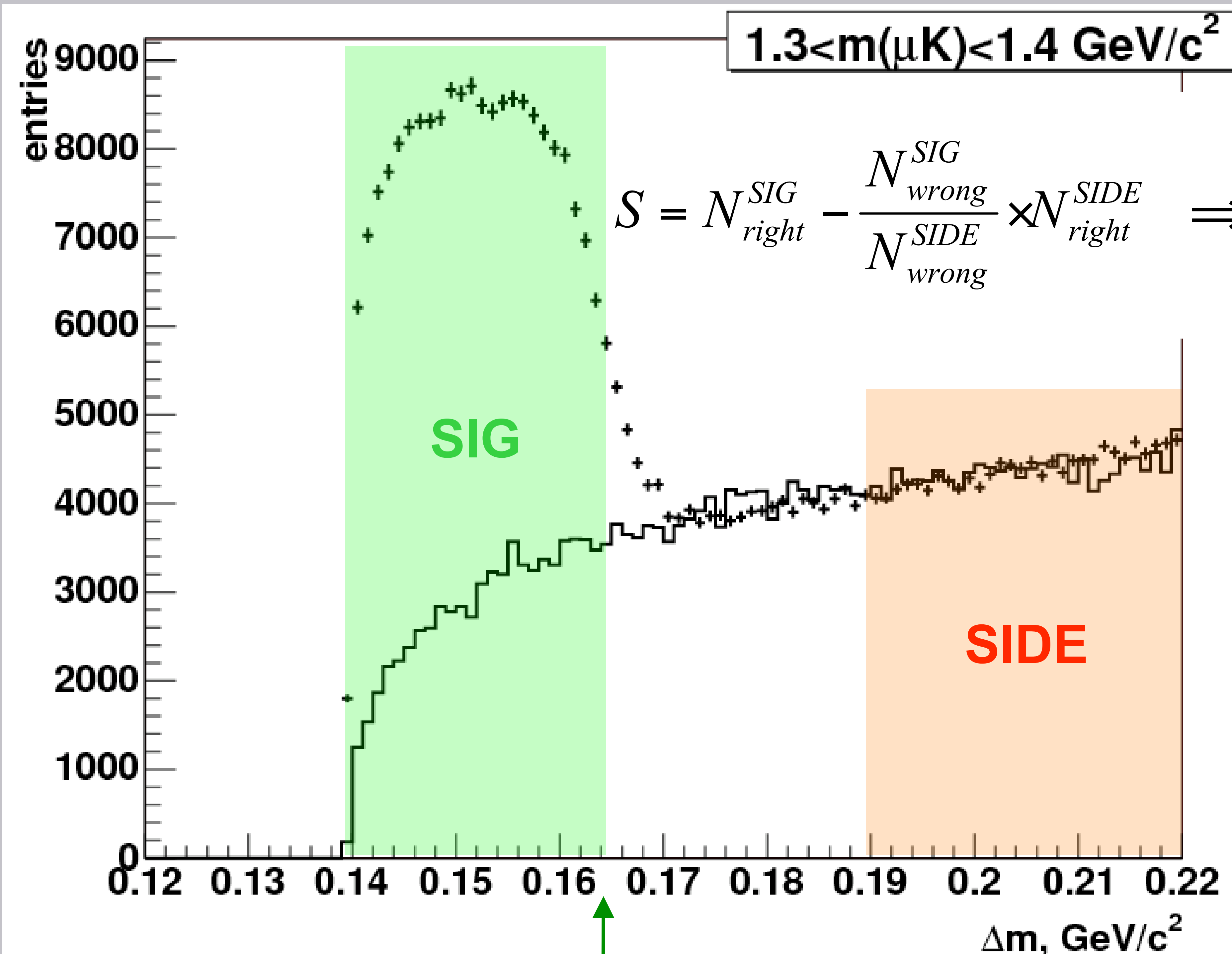
in different $m(\mu K)$ bins:

$\mu(+)K(-)\pi(+)$ or $\mu(-)K(+)\pi(-)$ - right charge corr., D* peak



$\mu(+)K(+)\pi(+)$ or $\mu(-)K(-)\pi(-)$ - wrong charge corr., background

Details: Kaon asymmetry



$$S = N^{SIG}_{right} - \frac{N^{SIG}_{wrong}}{N^{SIDE}_{wrong}} \times N^{SIDE}_{right} \Rightarrow n^{\beta\gamma}_{q} = \sum_{m(\mu K)} S$$

$$\frac{S}{\Delta S}$$

nabbed from K. Holubyev (Lancaster University)

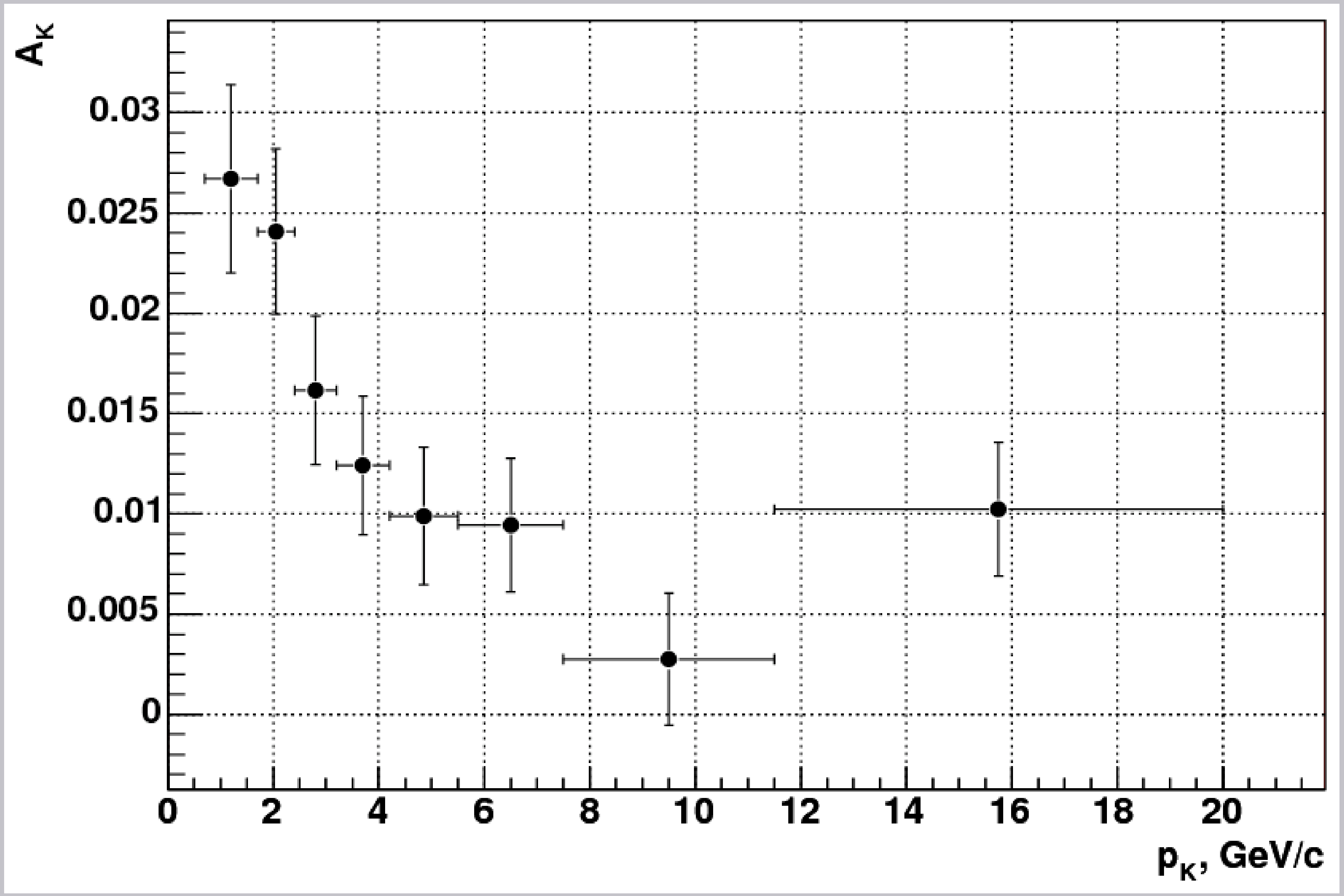
Details: Kaon asymmetry

To get Kaon asymmetry in J/ψK sample:

- $A_K(p_K)$ was measured (detector characteristics)
- … and convoluted with pdf of p_K in J/ψK sample to give

$$A_K = 0.0139 \pm 0.0013(stat) \pm 0.0004(syst)$$

← unknown reco efficiency of some D* decay modes



Polarity reversal: reducing detector systematics

In any case ($A_{SL}^{\mu\mu}, A_{SL}^{\mu,unt}, A_{DCPV}, A_K$) we want: $A = \frac{n_+ - n_-}{n_+ + n_-} \Rightarrow n_q = \frac{1}{2}N(1+qA)$

$$eff^+ \neq eff^-$$

μ^-

But:

Detector introduces apparent charge asymmetries. Example (for muons): range out in the toroid:

$$n_q = \frac{1}{2}N[1 + q(A + A_{ro})]$$

$$n_q^\beta = \frac{1}{2}N(1 + qA + q\beta A_{ro})$$ - linear

$$n_q^\beta = \frac{1}{2}N(1 + qA)(1 + q\beta A_{ro})$$ - includes higher order effects

apparent A

$$n_q = \frac{1}{2}N[1 + q(A - A_{ro})]$$

Polarity reversal significantly reduces systematics from detector asymmetries

Detector effects

To account for detector-induced asymmetries **to all orders** – generalize $n_{\pm}$ to detector model

$$n_q^{\beta\gamma} = \frac{1}{4} N \varepsilon^{\beta} (1 + qA)(1 + q\gamma A_{fb})(1 + \gamma A_{NS})(1 + q\beta\gamma A_{ro})(1 + \beta\gamma A_{\beta\gamma})(1 + q\beta A_{q\beta})$$

If N - total number of events in the sample, and
ε^{β} - fraction of events with toroid/solenoid polarity β

then #events with specific:

- toroid/solenoid polarity β
- sign of particle pseudorapidity γ
- particle charge q

depends on asymmetries:

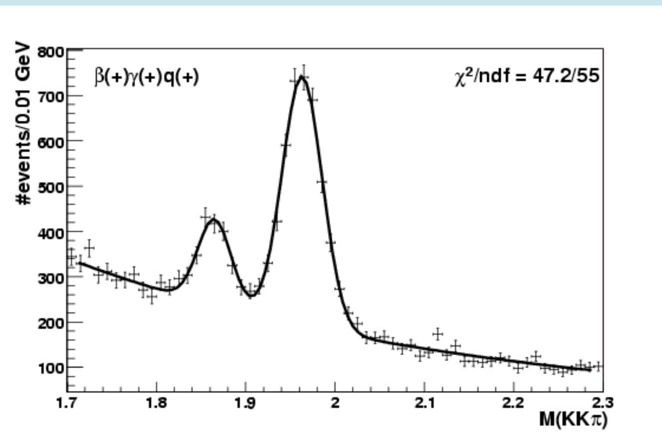
- charge - the one we are after
- forward-backward
- North-South
- range out
- the remaining two complete the system

To consistently account for correlations and errors:

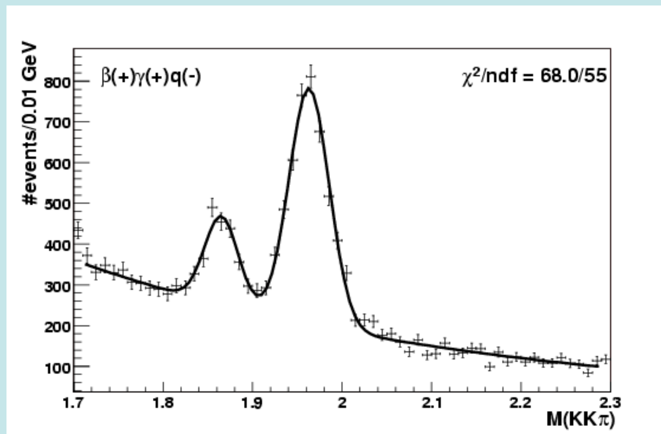
- Divide sample into 8 subsamples according to the signs of β, γ, q
- In each subsample extract $n_q^{\beta\gamma}$ by whatever method
- Solve 8 simultaneous equations for N, ε^{β}, and asymmetries

$A_{SL}^{s,unt}$: 8 subsamples

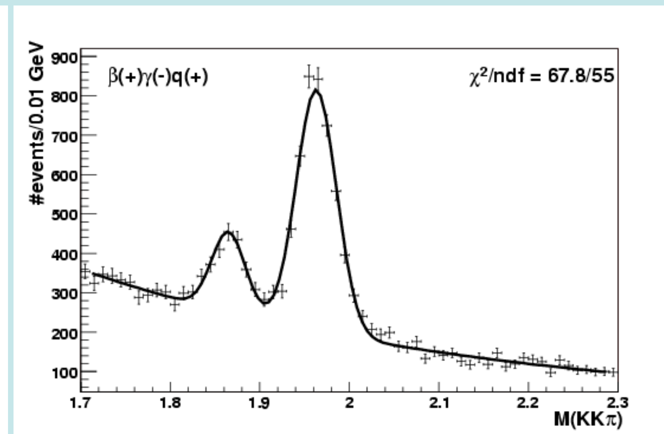
$n_q^{\beta\gamma}$



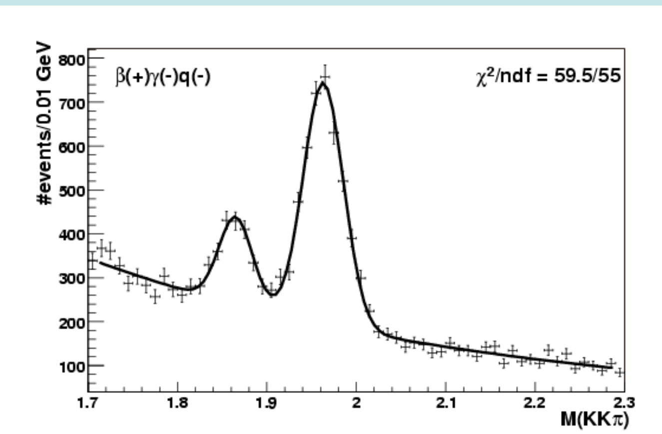
3,216±76



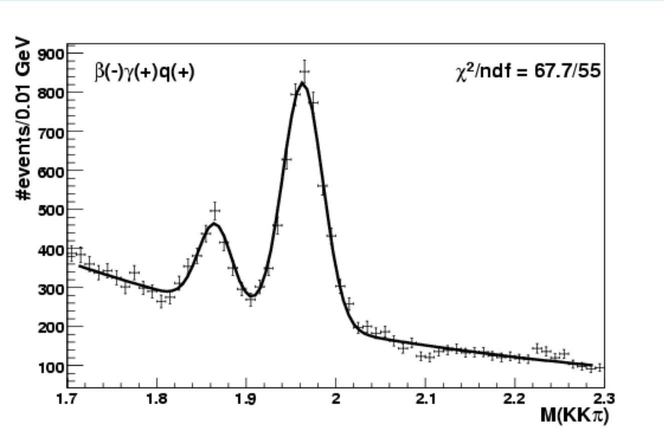
3,391±78



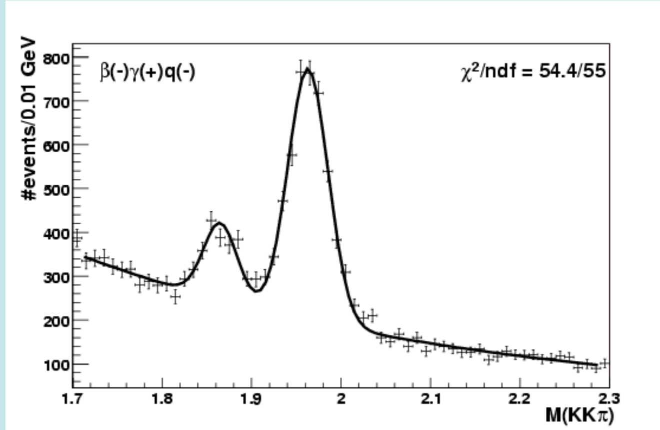
3,586±79



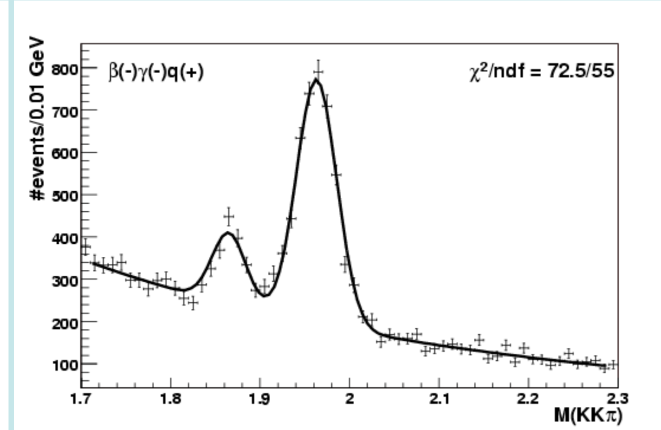
3,225±76



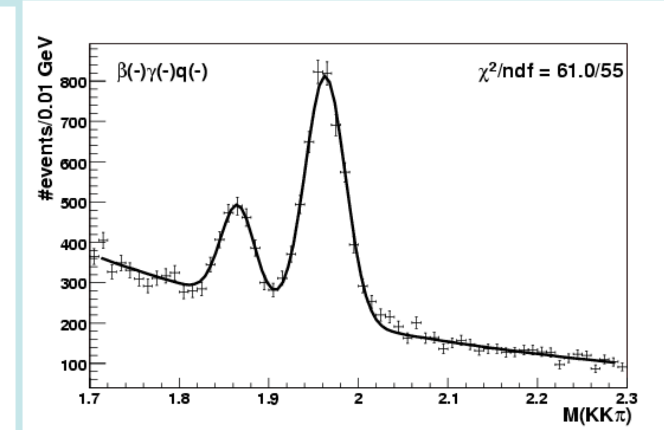
3,616±80



3,353±77



3,370±77

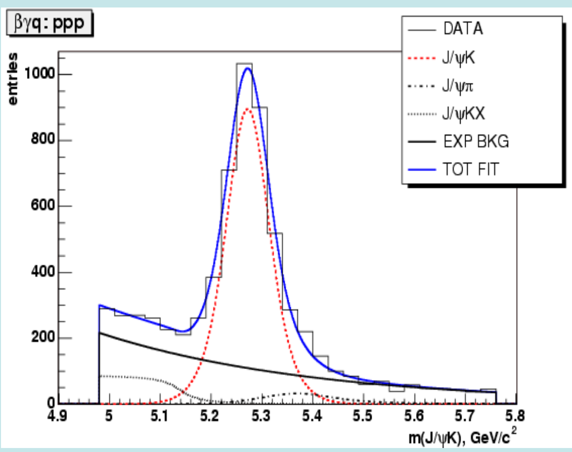


3,532±79

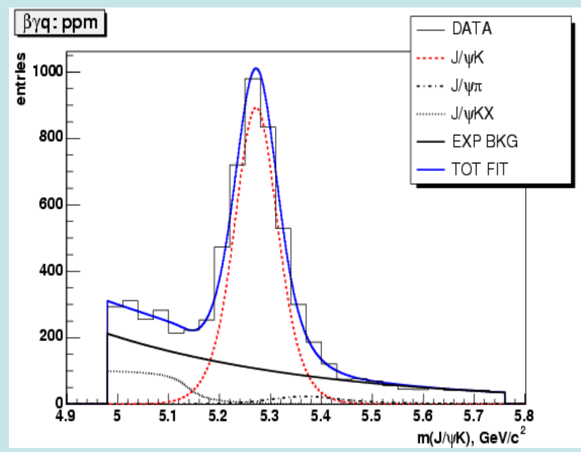
$A_{CP}(B^+ \text{®} J/\psi K^+)$: 8 subsamples

$n_q^{\beta\gamma}$

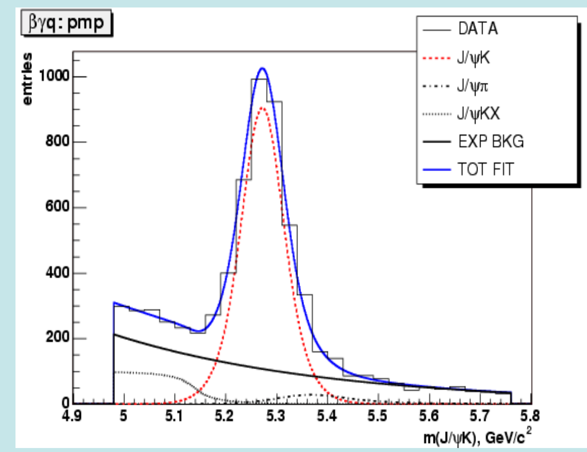
D0 Preliminary, 1.6 fb^{-1}



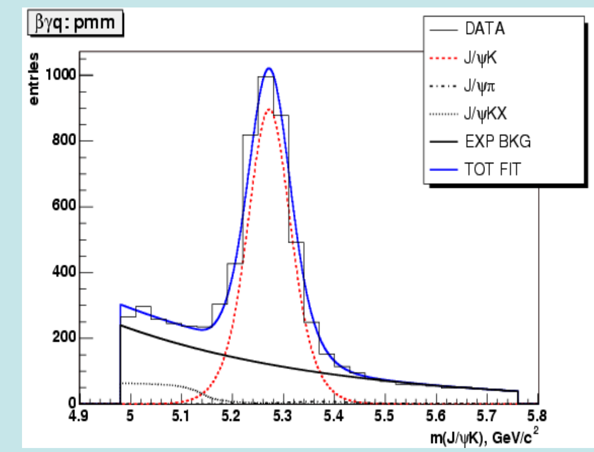
3,376±57



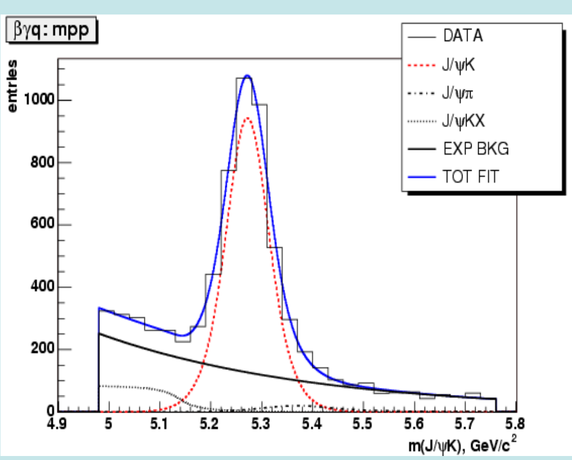
3,343±57



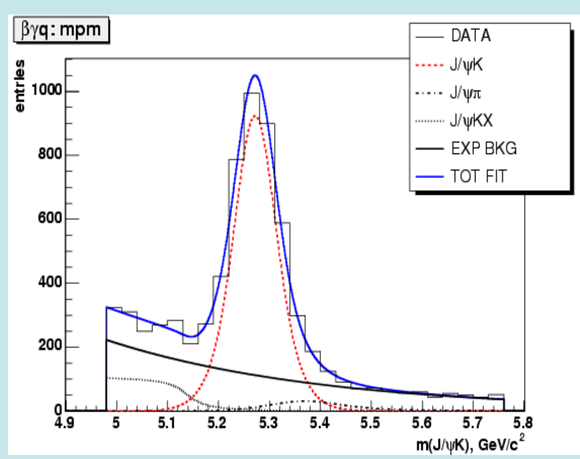
3,399±57



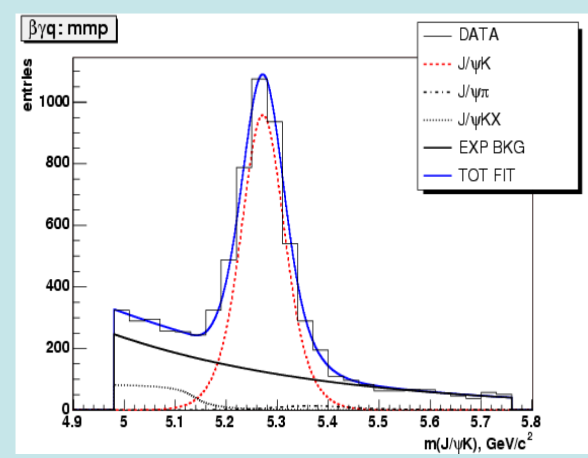
3,369±57



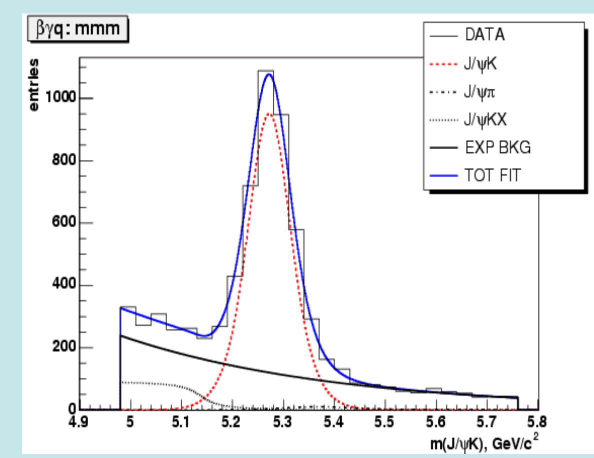
3,546±59



3,467±58



3,626±59



3,565±59

Some math

If n_1 and n_2 independent:

$$A = \frac{n_1 - n_2}{n_1 + n_2} = \frac{\Delta n}{N}, \Delta n_1^2 + \Delta n_2^2 = \Delta N^2$$

$$\left(\frac{\Delta A}{A}\right)^2 = \frac{\Delta N^2}{(\Delta n)^2} + \frac{\Delta N^2}{N^2} = \frac{\Delta N^2 (N^2 + \Delta n^2)}{\Delta n^2 N^2} \approx \frac{\Delta N^2}{\Delta n^2}$$

we neglect $\Delta n^2 << N^2$

Therefore for any asymmetry: $\Delta A = \frac{\Delta N}{N}$

If A_K: $n_q \propto (1 + qA_{CP})(1 + qA_K)$

$$\propto (1 + qA_{CP} + qA_K) \propto (1 + q(A_{CP} + A_K))$$

therefore $A = A_{CP} + A_K$