Update of the like-sign dimuon charge asymmetry from the DØ experiment

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for the DØ Collaboration

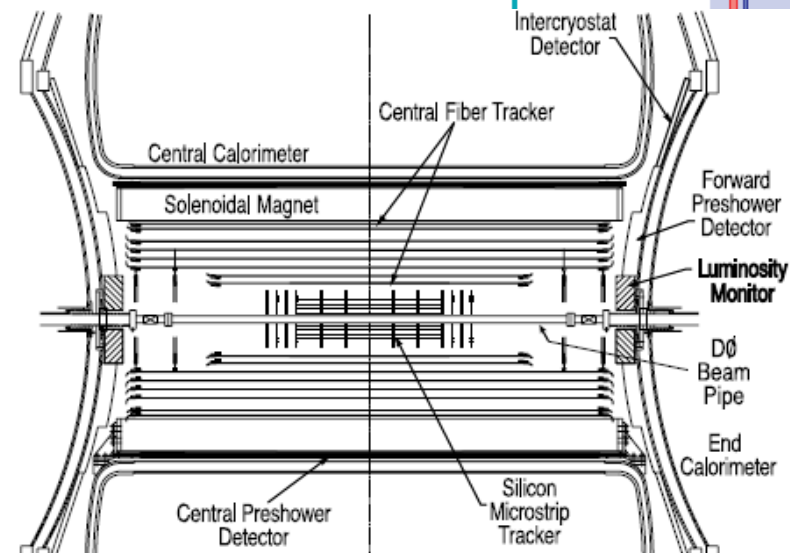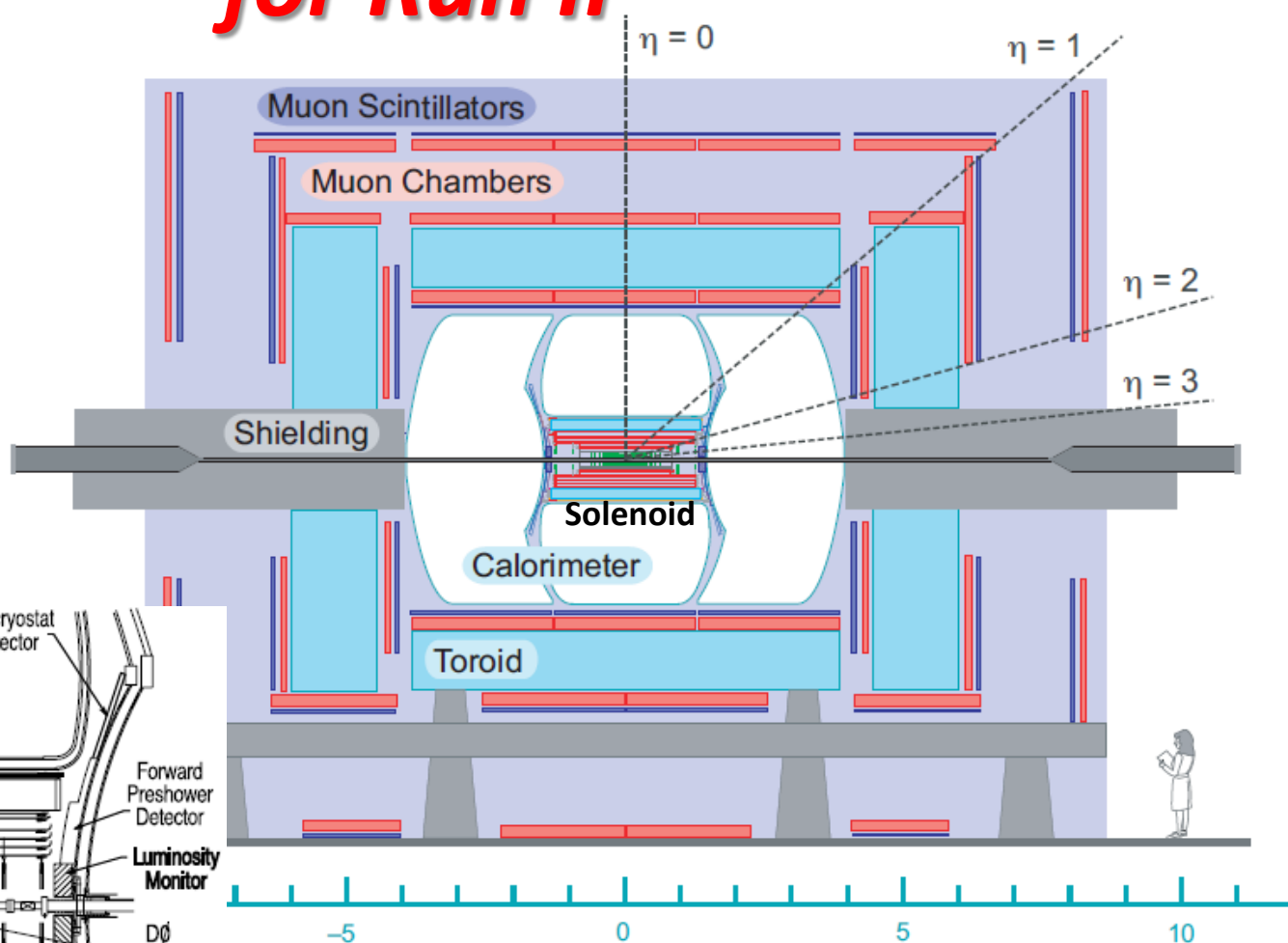**DPF, Santa Cruz, CA, August 16, 2013**

The DØ Detector for Run II

$\overline{p}p$ symmetry

excellent μ-id

flip magnets

$\sqrt{s}$ = 1.96 TeV

η = 0

η = 1

η = 2

η = 3

Muon Scintillators

Muon Chambers

Shielding

Solenoid

Calorimeter

Toroid

[m]

5

0

Intercryostat Detector

Central Fiber Tracker

Central Calorimeter

Solenoidal Magnet

Forward Preshower Detector

Luminosity Monitor

DØ Beam Pipe

End Calorimeter

Central Preshower Detector

Silicon Microstrip Tracker

DØ like-sign dimuon charge asymmetry - Garbincius - DPF - Santa Cruz - August 2013

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Mystery & Motivation

- DØ previously published 3 measurements of the like-sign dimuon charge asymmetry at 1 fb^{-1}, 6.1 fb^{-1}, & 9 fb^{-1}, each observing *A_{cp} ≠ SM* prediction at ~ *1.7 - 3.9 σ* significance

- This is one of only a few inconsistencies with SM

- *Repeating* with *full* 10.4 fb^{-1} Run II data sample, improved background subtraction, methodology

- *Is this observation real?*

- *Is our understanding of SM complete?*

- *Is there something else going on besides the SM?*

CP violation in mixing
$B^0 \leftrightarrow \bar{B}^0$ and $B_s^0 \leftrightarrow \bar{B}_s^0$

$\bar{p}p \rightarrow \bar{b}b \dots$ *etc.*

some examples

$b \rightarrow B^- \rightarrow \mu^- X$ "right-sign μ"

$\bar{b} \rightarrow \bar{B}^0 \rightarrow B^0 \rightarrow \mu^- X$ "wrong-sign μ"

or

$\bar{b} \rightarrow B^+ \rightarrow \mu^+ X$ "right-sign μ"

$b \rightarrow B^0 \rightarrow \bar{B}^0 \rightarrow \mu^+ X$ "wrong-sign μ"

also sequential decays, such as

$b \rightarrow c \rightarrow \mu^+$ are another source of

          "wrong-sign μ"

> *generic* % of $b \rightarrow \mu$
> *Pythia* simulation
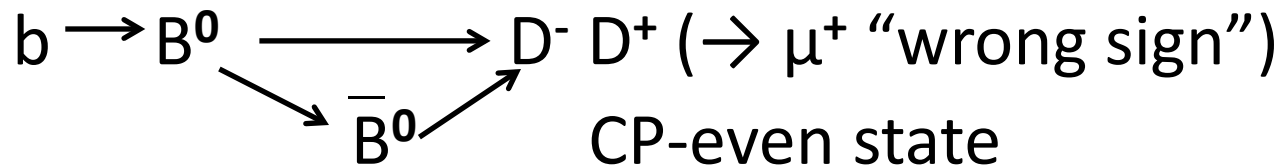> $b \longrightarrow \mu^-$ 73%
> $b \rightarrow \bar{b} \rightarrow \mu^+$ 11%
> $b \rightarrow c \rightarrow \mu^+$ 16%

SM Assumption

- (prior) *only* source of charge asymmetry for like-sign dimuons is *CP violation in mixing*

    for All IP1,IP2: $A_{CP}^{mix}(SM) = (-0.008 \pm 0.001)\%$

- *however,* (recently) G. Borissov & B. Hoeneisen Phys. Rev. D **87**, 074020 (2013) *added CP violation in interference between mixed and non-mixed final states*, such as

    b → B^0 ⟶ D$^-$ D$^+$ (→ μ$^+$ "wrong sign")

    ↘ $\overline{B^0}$ ↗ CP-even state

    This interference doesn't contribute to a_{CP} for single muons since D$^+$ → μ$^+$ and D$^-$ → μ$^-$ balance

- for scale, for All(IP1,IP2) bin:

$A_{CP}^{interference}(SM) = (-0.035 \pm 0.008)\% \sim 4 * A_{CP}^{mixing}(SM)$

$A_{CP}^{mixing}(SM) = (-0.008 \pm 0.001)\%$

$A_{CP}(SM) = A_{CP}^{mixing}(SM) + A_{CP}^{interference}(SM) = (-0.043 \pm 0.010)\%$

$A_{CP}(D\emptyset$ measured with 9 fb$^{-1}) = (-0.276 \pm 0.092)\%$

combined stat + syst uncertainty

- $A_{CP}^{interference}$ is linearly depended on $\Delta\Gamma_d/\Gamma_d$

so this gives possibility of ***measuring*** $\Delta\Gamma_d/\Gamma_d$

$\Delta\Gamma_d/\Gamma_d$: World Avg. = (1.5 ± 1.8)%   SM = (0.42 ± 0.08)%

anticipate D∅ can measure $\Delta\Gamma_d/\Gamma_d$ to ≈ ± 1%

- similar contribution of $\Delta\Gamma_s/\Gamma_s$ is much smaller
and is already determined well (see HFAG-2012)

Measurement Method

Use both:

single inclusive muons (denoted by lower case) and *like-sign dimuons* (upper case)

Do *not* expect to see charge asymmetries for single inclusive muons

=> serves as closure or consistency check that we are

not generating false asymmetries

Charge Asymmetries

RAW observed asymmetries (in each data bin):

$$a \equiv \frac{n^+ - n^-}{n^+ + n^-} \qquad A \equiv \frac{N^{++} - N^{--}}{N^{++} + N^{--}}$$

Residual (background subtracted) asymmetries

$$a_{CP} \equiv a - a_{bkg} \qquad A_{CP} \equiv A - A_{bkg}$$

a_{CP} and A_{CP} are normalized to all muons

sample: 2.2×10^9 $\mu^{\pm}$; 2.2×10^7 $\mu^+\mu^-$; 6.2×10^6 $\mu^{\pm}\mu^{\pm}$

$$a_{CP} = a - a_{bkg}$$

$$a_{bkg} = \textcolor{red}{a_\mu + f_K\, a_K} + f_\pi\, a_\pi + f_p\, a_p$$

$$\textcolor{red}{\textit{dominant}} \quad f_K\, a_K \approx +0.625\%,\ a_\mu \approx -0.288\%$$

f_K = fraction of charged K in μ sample, measured from
$\quad K^{*0} \to \pi^- K^+ (\to \mu^+)$ and $K^{*+} \to \pi^+ K_s^0 (\to \pi^+ \pi^-)$
$\quad$ and convert $f_{K^{*0}} + f_{K^{*+}} \to f_{K^\pm}$ by isospin invariance

a_K asymmetry due to $\sigma_{inelastic}(K^-) > \sigma_{inelastic}(K^+)$ is measured with
$\quad K^{*0} \to \pi^- K^+ (\to \mu^+ \nu)$ & c.c. and $\phi \to K^+ K^-$ (with $K^\pm \to \mu^\pm \nu$)

a_μ = muon detector charge asymmetry measured
$\quad$ with $J/\psi \to \mu^+ \mu^-$ central tracking only, no μ trigger

new check: f_K and f_π are cross-checked using tracks
$\quad$ measured in both central and local muon trackers,
$\quad$ differences are included in systematic uncertainties

evolution of this DØ measurement

This new full 10.4 fb^{-1} analysis is still in collaboration review and is ***not ready for public release*** yet

So I can only give a status report,
view of checks with single inclusive muons,
and indication of expected sensitivities!

$\int L dt$	asymmetry A_{CP}		(DØ), Phys.Rev. D
1.0 fb^{-1}	$(-0.28 \pm 0.13 \pm 0.09)\%$	1.7σ *	**74**, 092001 (2006)
6.1 fb^{-1}	$(-0.252 \pm 0.088 \pm 0.092)\%$	3.2σ *	**82**, 032001 (2010)
9.0 fb^{-1}	$(-0.276 \pm 0.067 \pm 0.063)\%$	3.9σ *	**84**, 052007 (2011)
10.4 fb^{-1}	$(? \pm 0.064 \pm 0.055)\%$	$?\sigma$ &	# (2013)

Analysis has changed significantly over this evolution

improved systematic uncertainties

* Discrepancy with $A_{CP}^{\text{mix}}(\text{SM})$ only.
& Discrepancy with $A_{CP}^{\text{mix}}(\text{SM})$ and $A_{CP}^{\text{int}}(\text{SM})$.

Muon Requirements

- Standard DØ single and multi-muon triggers
- Slightly tighter DØ tracking & quality requirements
- Require p_T > 4.2 GeV *or* $|p_z|$> 5.2 GeV
  - to ensure track penetrates through muon toroids
- p_T ≥ 1.5 GeV and p_T ≤ 25 GeV to suppress μ from $W^\pm$ & Z^0
- $M_{\mu\mu}$ > 2.8 GeV to avoid 2 μ from same b → μ^- ν c (→ μ^+)
- 9 Bins for each muon:
  - 0 ≤ |η| ≤ 0.7, p_T < 5.6, 5.7-7, 7-25 GeV
  - 0.7 ≤ |η| ≤ 1.2, p_T < 5.6, 5.6-25 GeV
  - 1.2 ≤ |η| ≤ 2.2, p_T < 3.5, 3.5-4.2, 4.2-5.6, 5.6-25 GeV
- 3 (transverse) I.P. bins: 0-50, 50-120, 120-3000 μm
  - μ from b decays are predominantly at large I.P.
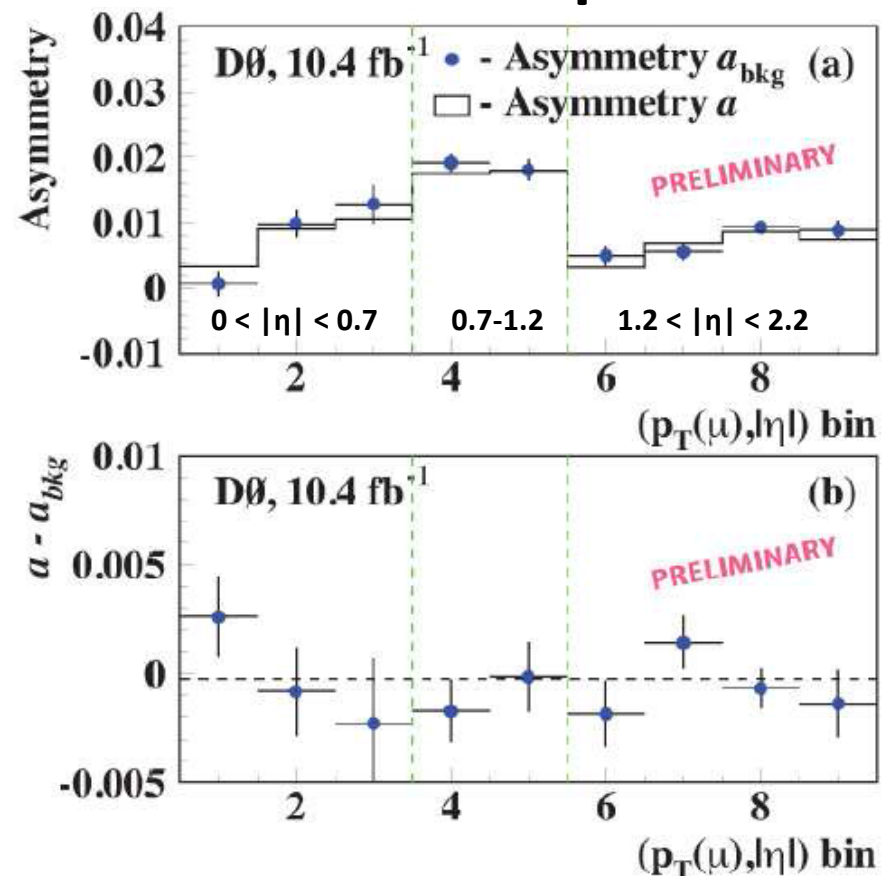 - μ from K and π decays are predominantly at small I.P.

closure test for single muons
expect a − a$_{bkg}$ = 0

bkg mostly K→μ $a_{bkg} \approx a_K f_K$
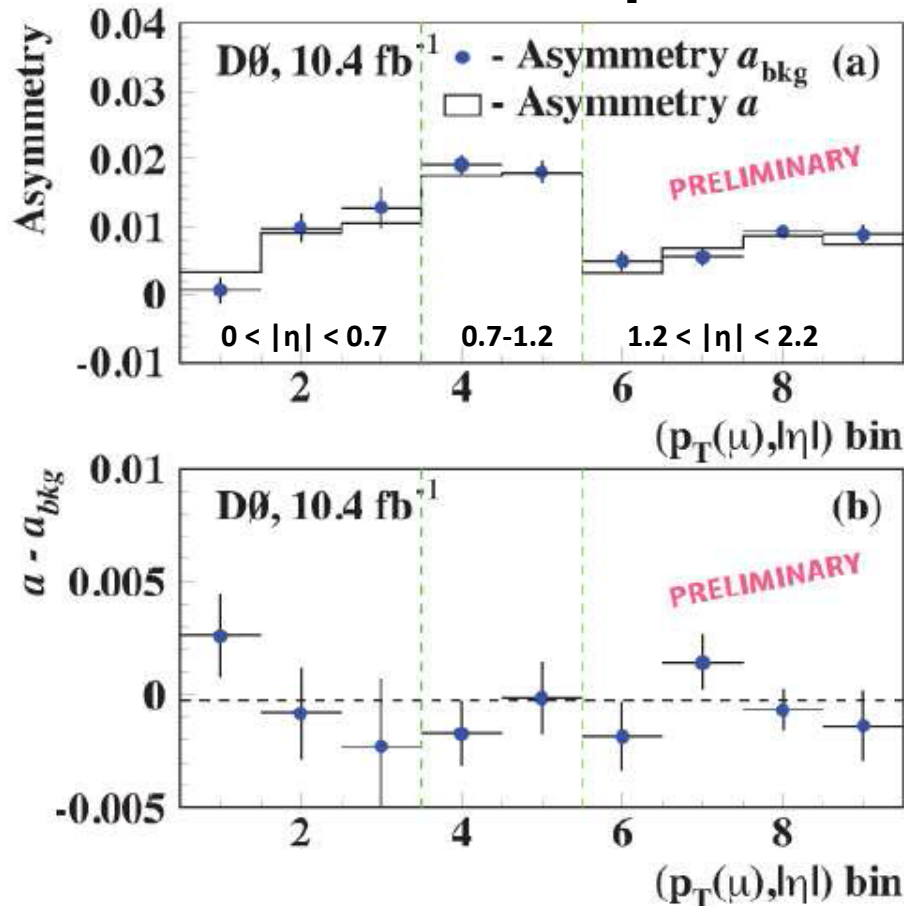
All IP
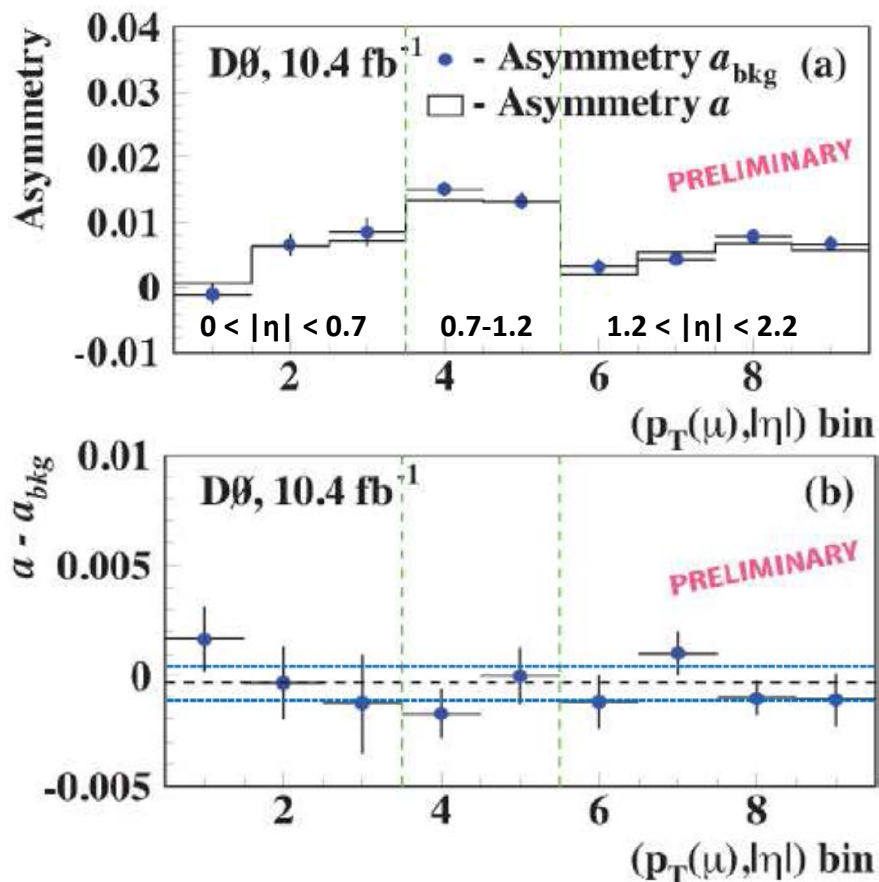
IP < 50 μm

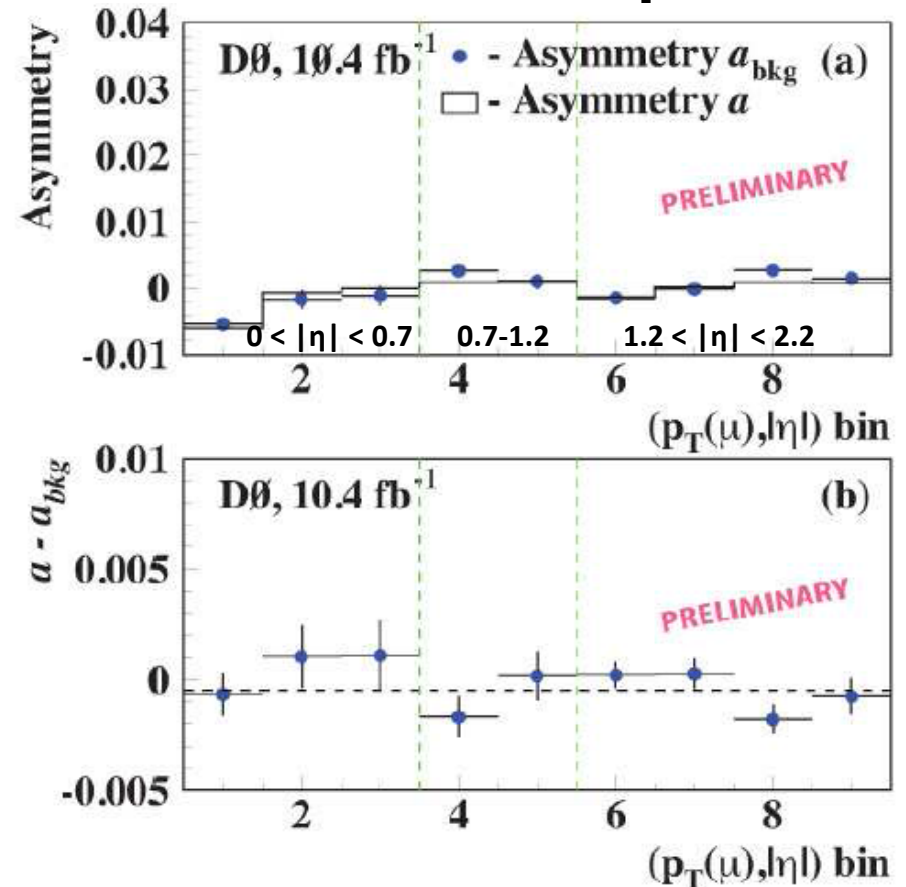# *closure test for single muons*
expect a – a$_{bkg}$ = 0

$$a_{bkg} = a_K f_K + a_\mu \approx 0$$

50 < IP < 120 µm

120 < IP < 3000 µm

These asymmetries are a linear combo of semi-leptonic decay asymmetries & $\Delta\Gamma_d/\Gamma_d$

a_{CP}^{b}(bins) = c_d(bins) a_{sl}^{d} + c_s(bins) a_{sl}^{s}

A_{CP}^{b}(bins) = C_d(bins) a_{sl}^{d} + C_s(bins) a_{sl}^{s} + C_{δ}(bins) $\Delta\Gamma_d/\Gamma_d$

DØ also measured these semi-leptonic asymmetries

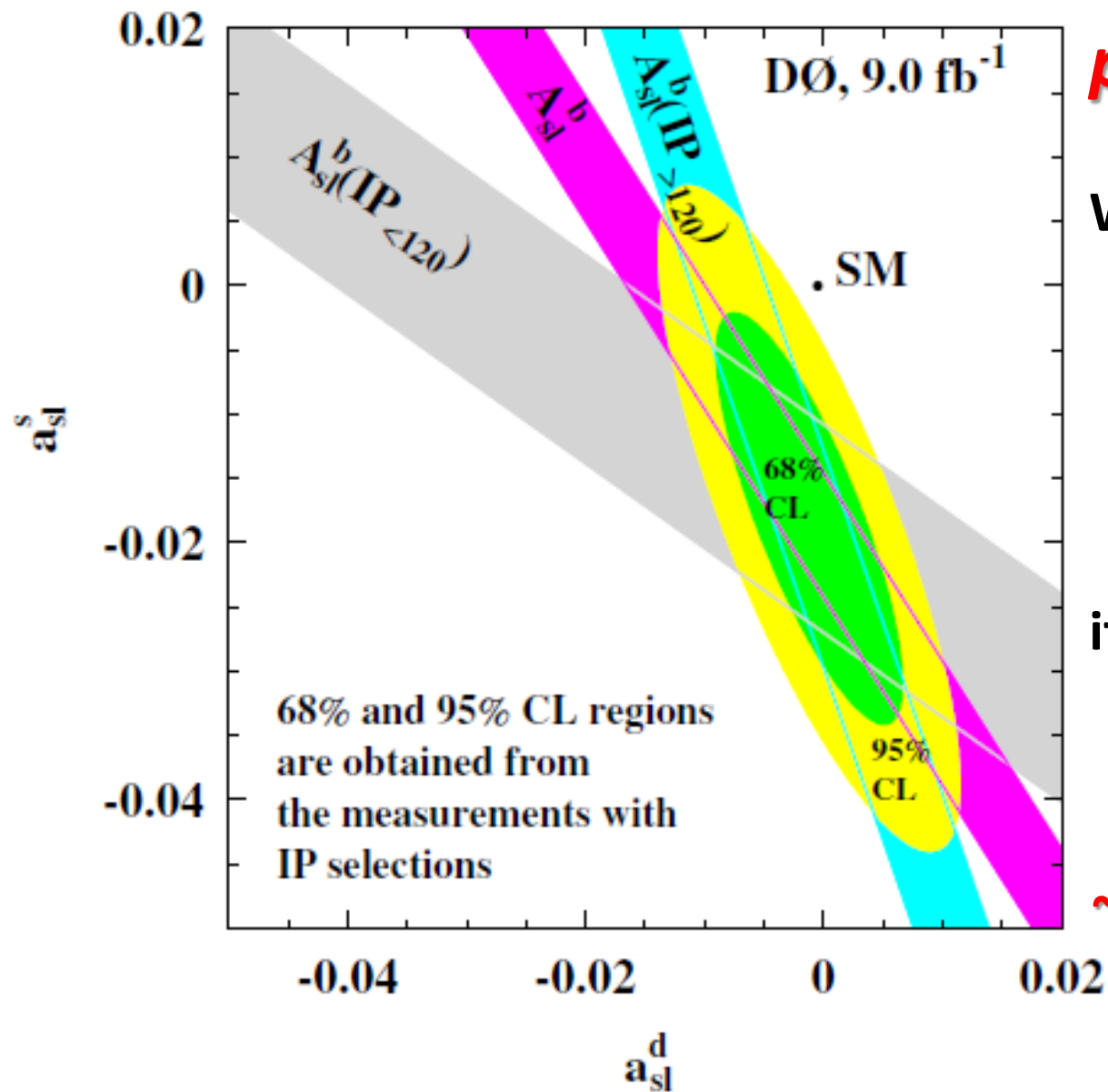a_{sl}^{d} in $B^0 \rightarrow D^- \mu^+ X$ and $B^0 \rightarrow D^{*-} \mu^+ X$ & *c.c.* decays

Phys. Rev. D **86**, 072009 (2012)

also measured by b-factories

a_{sl}^{s} in $B_s^0 \rightarrow D_s^- \mu^+ X$ & *c.c.* decays

Phys. Rev. Lett. **110**, 011801 (2013)

see Avdhesh Chandra's DPF presentation #235 - yesterday

prior 9 fb⁻¹ data

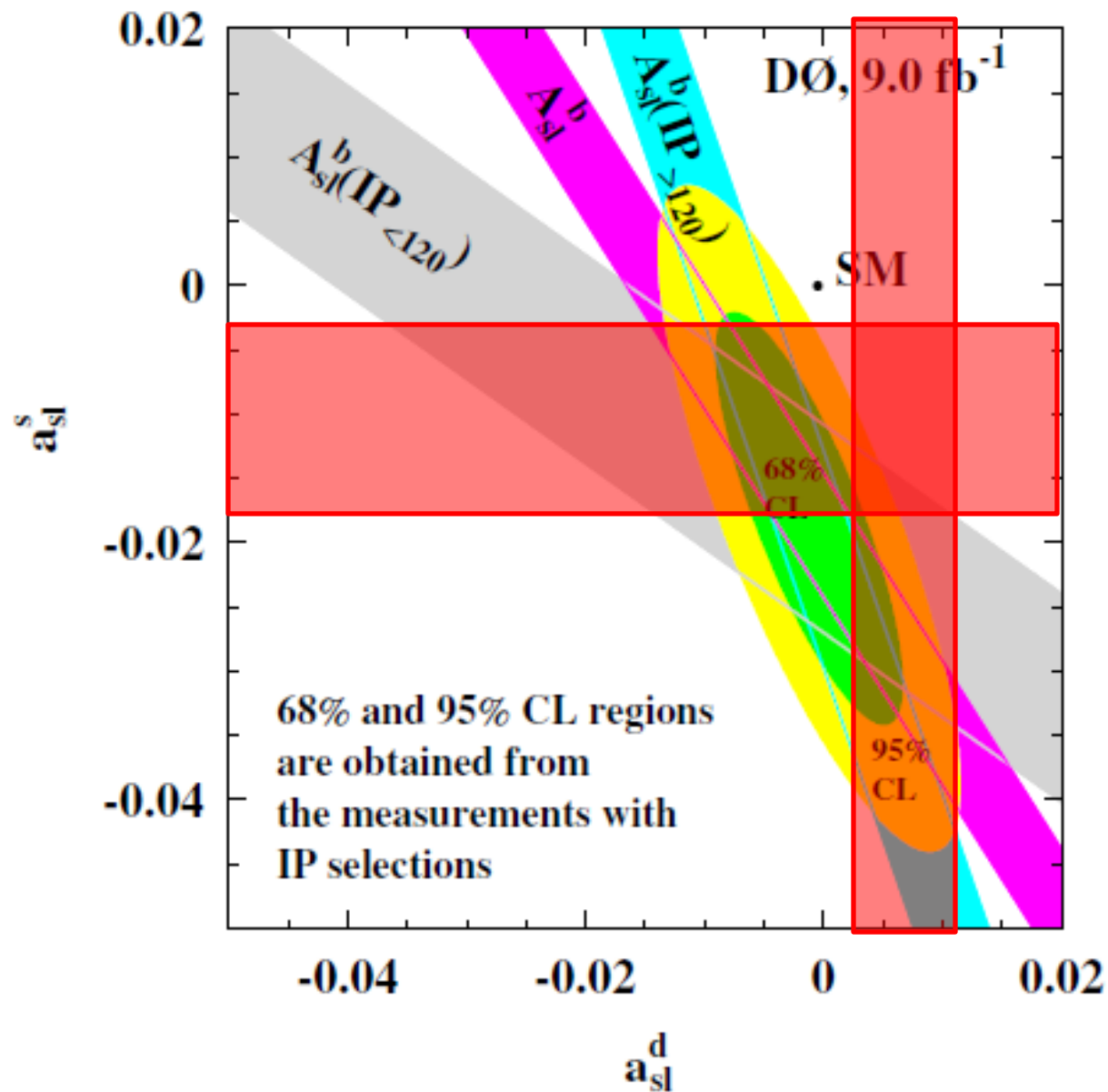**With full & improved 10.4 fb⁻¹ analysis with 3 IP bins 0-50 μm, 50-120 μm, 120-3000 μm it is expected that the *area* of these uncertainty ellipses will *decrease* to ~56 % of this prior area**
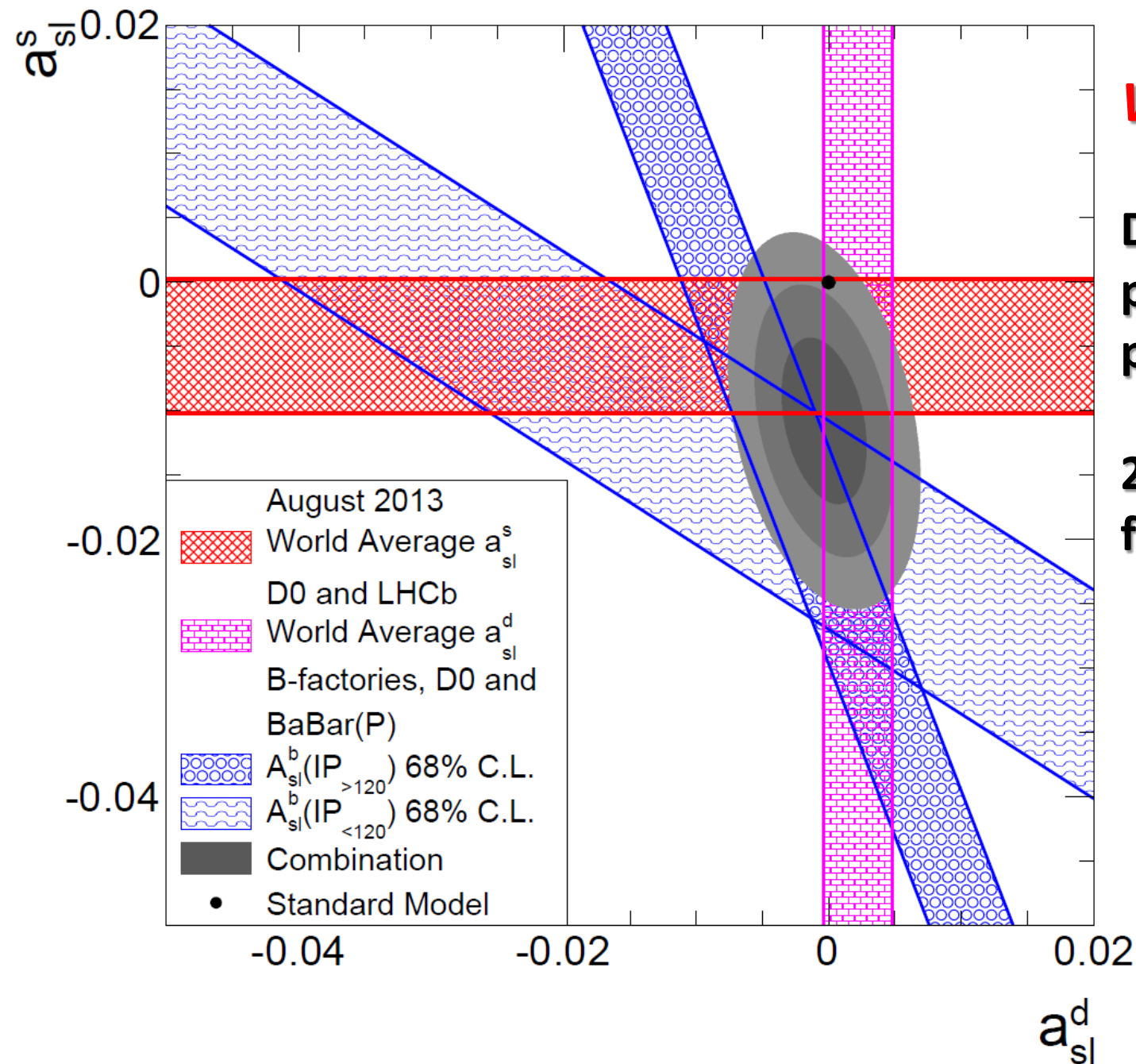
prior 9 fb⁻¹ data

indicating prior
DØ measurement of

$a_{sl}^d = (0.68 \pm 0.47)\%$
and
$a_{sl}^s = (-1.12 \pm 0.76)\%$

Figure labels: $A_{sl}^b(IP < 120)$, A_{sl}^b, $A_{sl}^b(IP > 120)$, DØ, 9.0 fb⁻¹, SM, 68% CL, 95% CL

68% and 95% CL regions
are obtained from
the measurements with
IP selections

World Combo

DØ (prior 9 fb^{-1}) plus LHCb plus B-Factories

2.26 σ deviation from SM

Legend (from figure):

August 2013
World Average a_{sl}^s
D0 and LHCb
World Average a_{sl}^d
B-factories, D0 and BaBar(P)
$A_{sl}^b(IP_{>120})$ 68% C.L.
$A_{sl}^b(IP_{<120})$ 68% C.L.
Combination
Standard Model

Axis labels: a_{sl}^s (vertical), a_{sl}^d (horizontal)

When? → *Soon!*

Remaining Questions:

- **Is it possible that the entire like-sign dimuon charge asymmetry is due to large $\Delta\Gamma_d/\Gamma_d$?**

- **Are there still missing SM contributions to A_{CP}?**

- **Is the DØ observation that $A_{CP} \neq$ SM prediction real? Need checking by other experiments.**

Thank you,

Peter

and *many thanks* to:

Guennadi Borissov, Lancaster University

Bruce Hoeneisen, Univ. San Francisco de Quito

Back-up Slides

Why study this asymmetry at DØ?

- *Charge Symmetric $\bar{p}p$ initial state*
  @ sqrt(s) = 1.96 TeV

- *Excellent µ id* – massive U-LAr calorimeter and
  magnetized iron muon toroid spectrometer
  – minimize hadronic punch through
  – remeasure & verify muon trajectory

- *Flip polarities* of solenoid and toroid magnets
  – cancels many acceptance systematic effects

Charge Asymmetries

RAW observed asymmetries (in each data bin):

$$a \equiv \frac{n^+ - n^-}{n^+ + n^-} \qquad\qquad A \equiv \frac{N^{++} - N^{--}}{N^{++} + N^{--}}$$

Residual (background subtracted) asymmetries

$$a_{CP} \equiv a - a_{bkg} \qquad\qquad A_{CP} \equiv A - A_{bkg}$$

a_{CP} and A_{CP} are normalized to all muons

prompt b→µ & c→µ, which are included in a_{CP} and A_{CP} are considered "short" decays (within the beam pipe). K→µ and π→µ decays within the central tracking volume are also treated as "short" decays since they have not had an appreciable chance to interact in matter before decaying and therefore are not a source of instrumental a_{bkg} charge asymmetry due to $\sigma_{inelastic}(h^-) > \sigma_{inelastic}(h^+)$. The K→µ and π→µ decays have small I.P. b→µ and c→µ have larger I.P.

regularly flip polarities of toroid magnet & solenoid magnet to reduce detector asymmetries
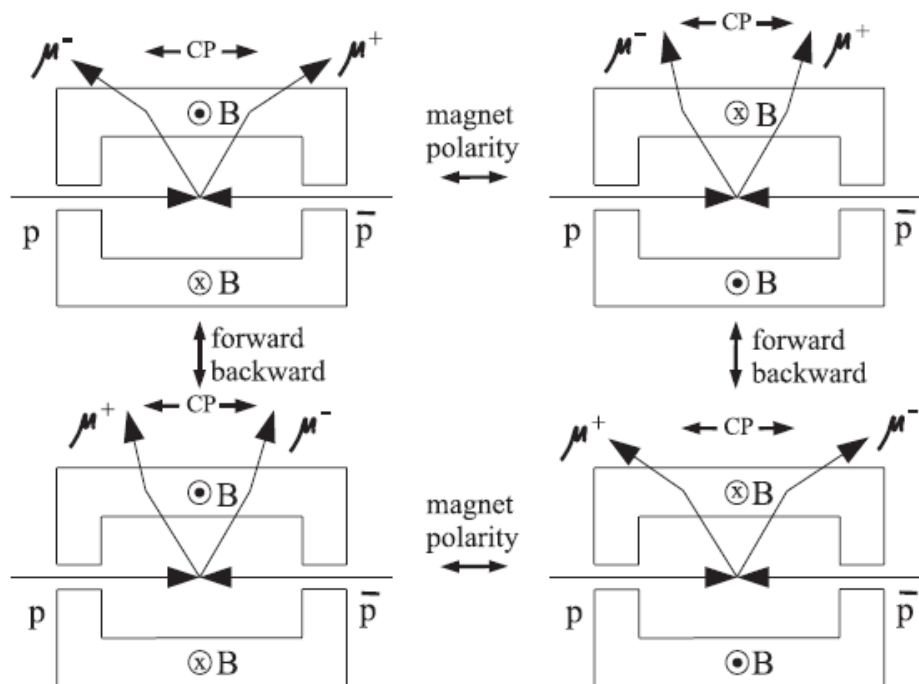
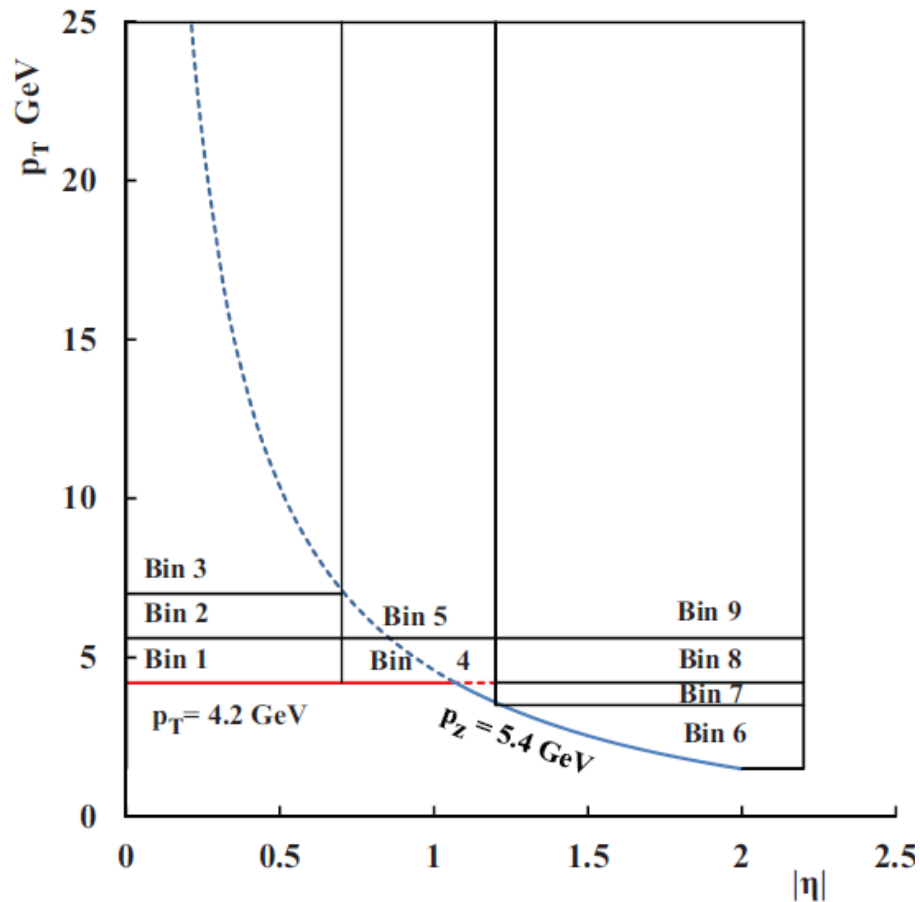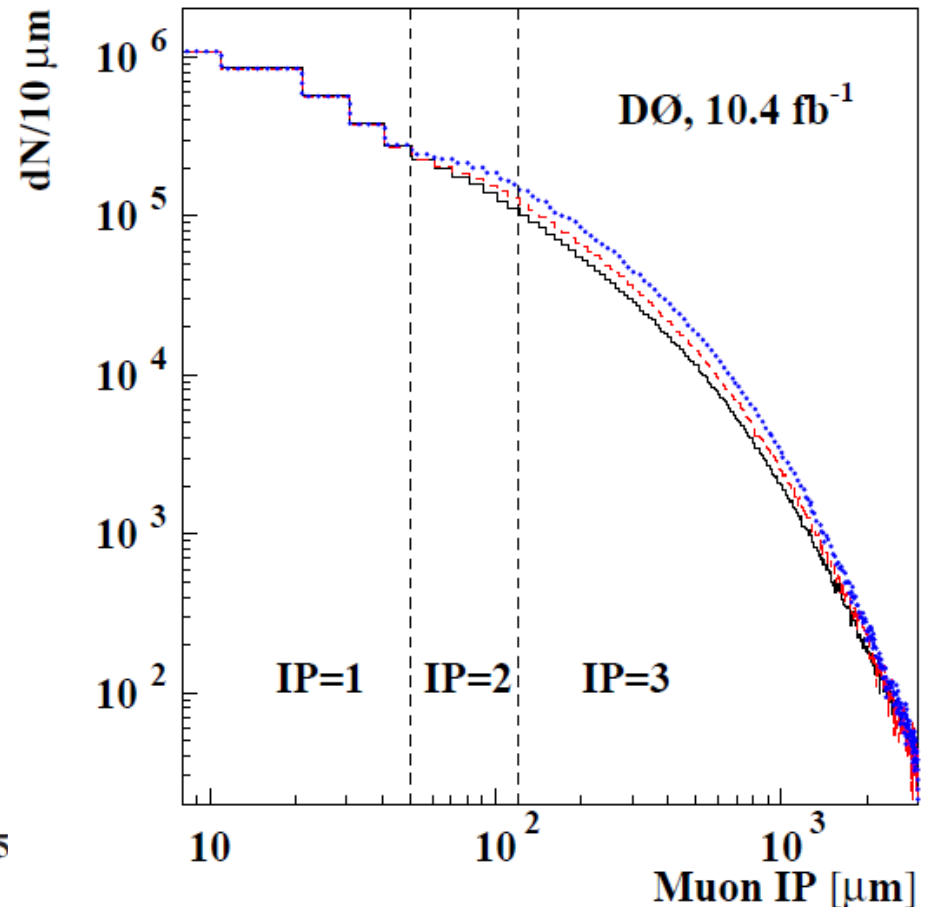| Solenoid polarity	Toroid polarity	$\mathcal{L}$ Weight inclusive muon	$\mathcal{L}$ Weight like-sign dimuon
−1	−1	0.954	0.967
−1	+1	0.953	0.983
+1	−1	1.000	1.000
+1	+1	0.951	0.984

FIG. 1: Definition of the $(p_T, |\eta|)$ bins. Global kinematic selections are $1.5 < p_T < 25$ GeV, ($p_T > 4.2$ GeV or $|p_z| > 5.4$ GeV), and $|\eta| < 2.2$.

IP of other muon when one muon is in **IP=1 bin**, **IP=2 bin**, and **IP=3** bin. Common normalization at lowest IP.

analysis improvements

- Use only "good" runs

- Increased track quality requirements #hits SMT ≥2 → ≥3

- New Monte Carlo simulation for $\bar{b}b \rightarrow \mu^+\mu^- X$ (without prior $E_{tot} > 20$ GeV cut) to calculate fraction of oscillated B^0 and $B_s^0 = C_b$ change by (+11±12)%

- Calculate K^{*0} reconstruction efficiency individually for each IP and ($p_T, |\eta|$) bins

- Alternative cross-check of background fraction using locally measured track parameters in μ detector for All IP agrees to within (-10±4)% → incl. in syst. uncert.

$$a_K = \frac{\varepsilon(K^+) - \varepsilon(K^-)}{\varepsilon(K^+) + \varepsilon(K^-)} = (1.05 \pm 0.04(\text{syst}))\%$$