TEVATRON HEAVY FLAVOR RESULTS

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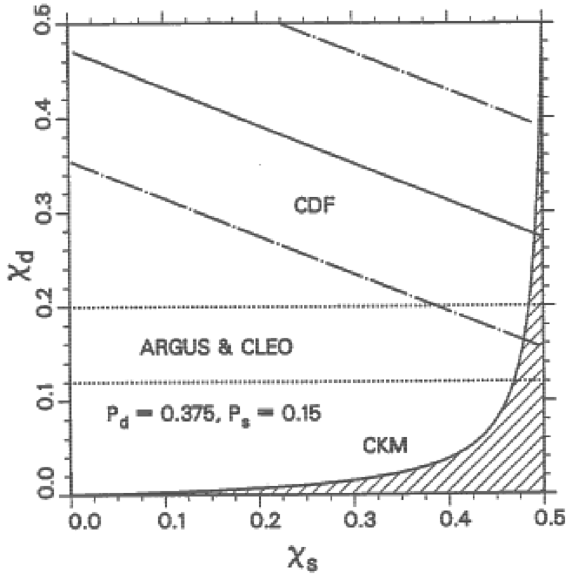
On behalf of the Tevatron coll.

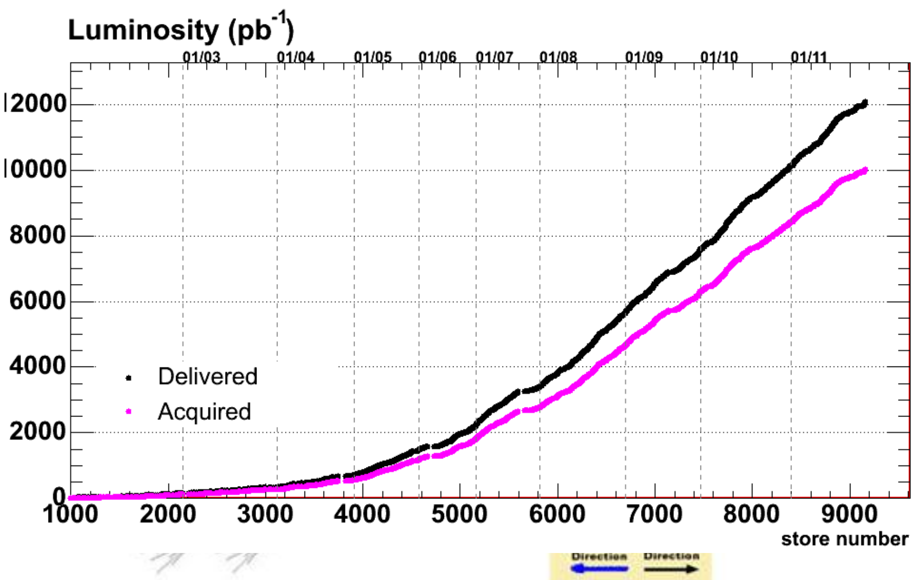
- ✓ Tevatron
- ✓ Bread & Butter (the plains)
- ✓ For conosseurs (the Rockies)
- ✓ Towards the Epilogue (the Alps)

HF @ Tevatron

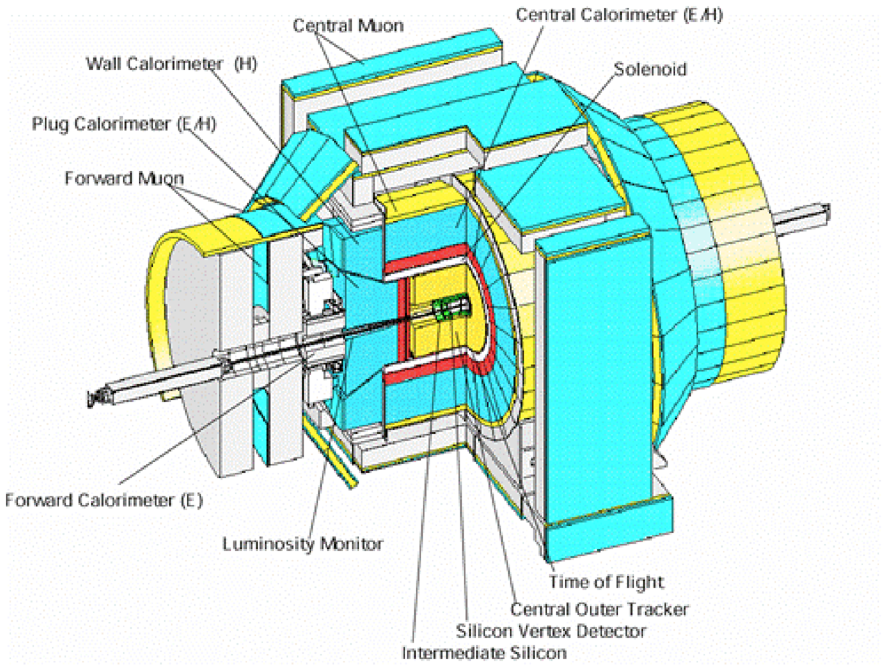
- Proudly exploring Heavy Flavor physics since 1991
- Pioneered the charm and beauty physics field using hadron collisions
- Tevatron shutdown → 10fb^{-1} of data
- New results on almost full stat.
- Wrapping up on most of the flagship analysis

1991 Time integrated mixing probability



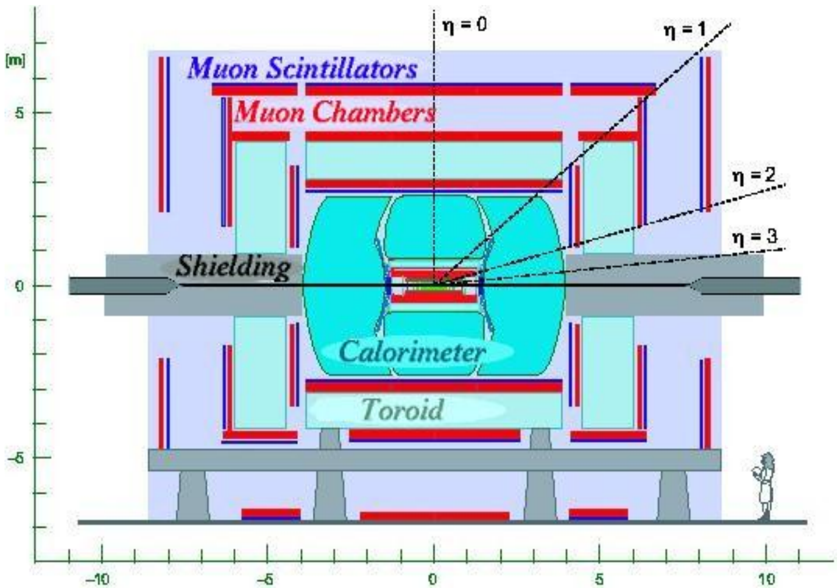


Tevatron Detectors



CDF II Detector

- Tracker: - Silicon Vertex Detector
  - Drift Chambers
- **Excellent Momentum Resolution**
- **Particle ID**: TOF and dE/dx
- Triggered Muon Coverage $|\eta|<1$
- Displaced track trigger (SVT)



DØ Detector

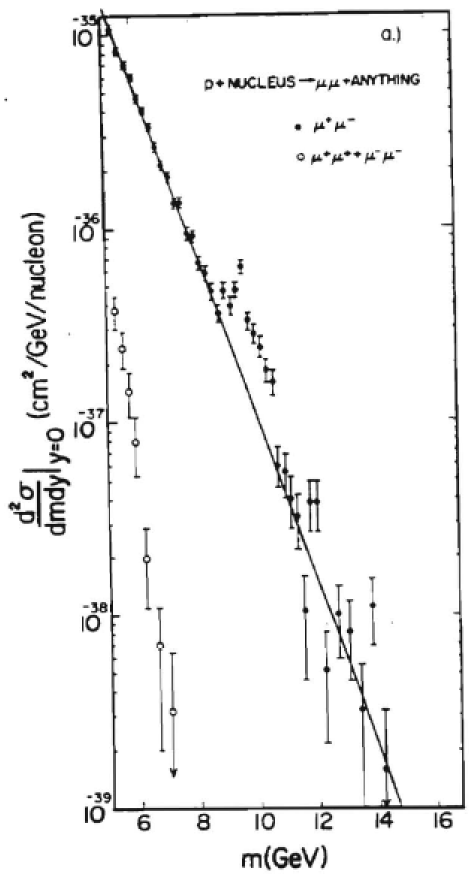
- **L00** installed in 2006
- Solenoid: 2T, weekly reversed polarity
- Excellent Calorimetry and electron ID
- **Triggered Muon Coverage** $|\eta| < 2.2$

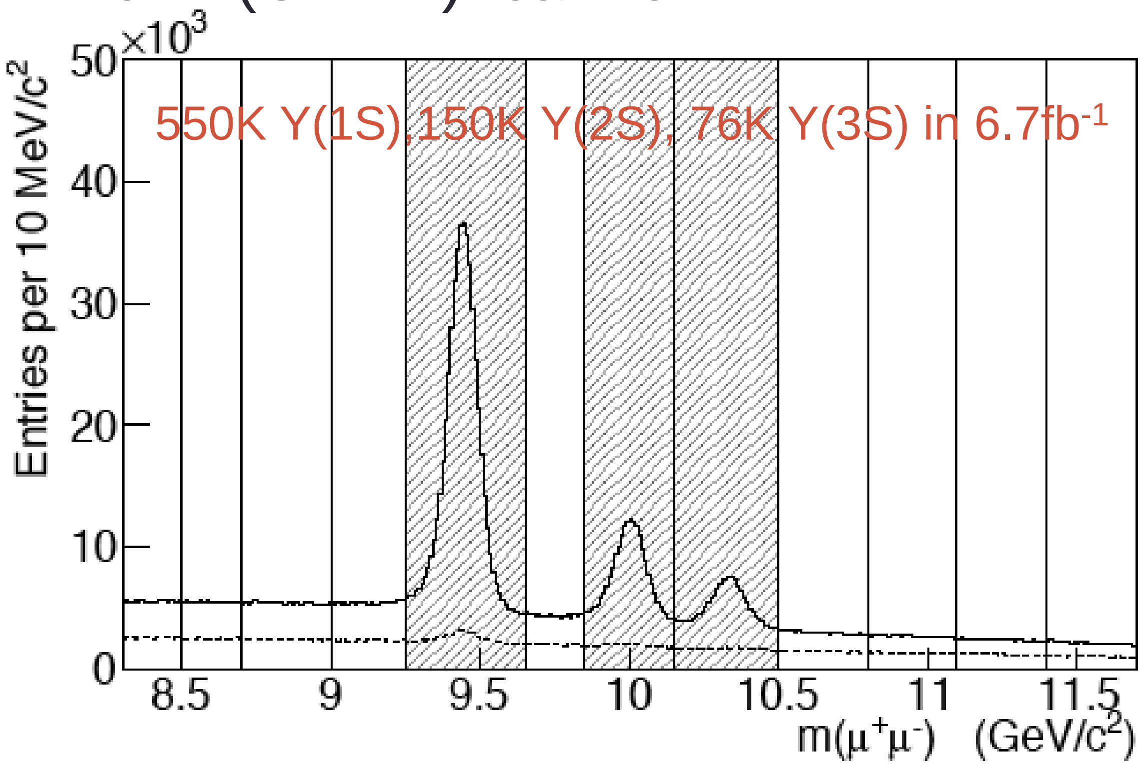
The Plains (or something we were supposed to be doing)

Y(nS) production

- Fermilab, birthplace of bbbar bound states

E288 ca. 1977 E924 (CDF II) ca. 2011





Basic production mechanism clear, details not at all → difficult theretically, different model exists

Advances requires looking carefully at more observables

First Y spin-alignment measurement

- Distinct theory prediction for Y spin alignment, experiments differ among each other and with theory
- But, measurements only looked at 1 angle distributions so far
- Need complete 3D treatment for a correct result

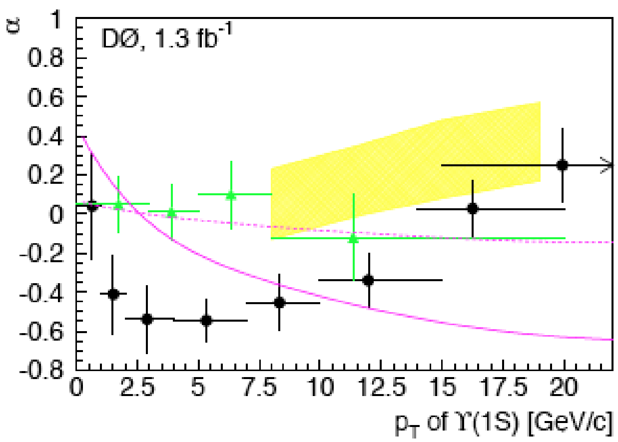


FIG. 3: [Color online] Dependence of α on p_T^Υ for inclusive $\Upsilon(1S)$ candidates. Black circles are data. The yellow band is the NRQCD prediction [8]. Curves are two limit cases (see text) of the k_t-factorization model [11]. Green triangles are the results of the CDF experiment [17].

- CDF Coll. arXiv:1112.1591
- Extract the 3 relevant parameters from

$$\frac{dN}{d\Omega} \sim 1 + \lambda_\theta \cos^2\theta + \lambda_\varphi \sin^2\theta \cos 2\varphi + \lambda_{\theta\varphi} \sin 2\theta \cos\varphi,$$

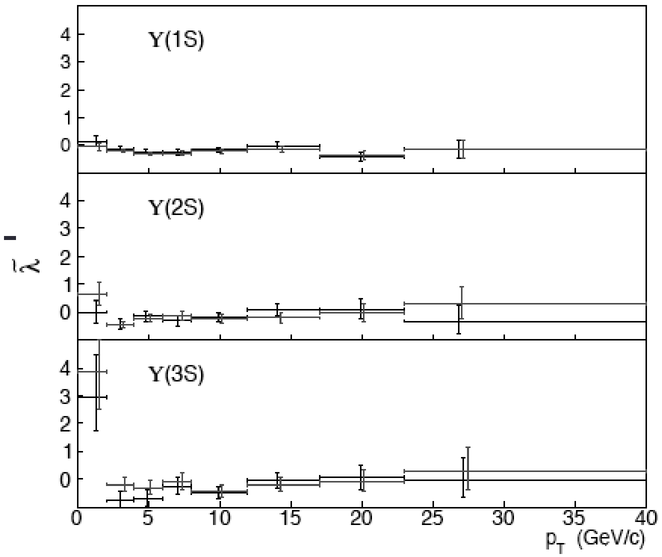
- Not invariant under a change in ref. system
- Significant polarization can be generated through λ_ϕ!=0 effect (and bias the measurement if acceptance non uniform in phi)
- Perform measurement in both Collin-Soper and S-Channel helicity frame

First Υ spin-alignment measurement

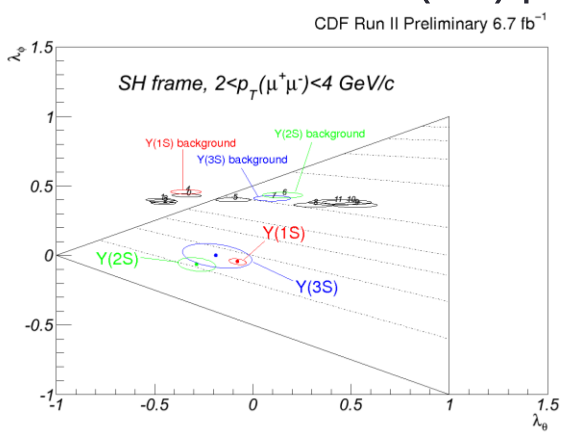
Consistency check: plot the invariant

$$\tilde{\lambda} = \frac{\lambda_\vartheta + 3\lambda_\varphi}{1 - \lambda_\varphi}$$

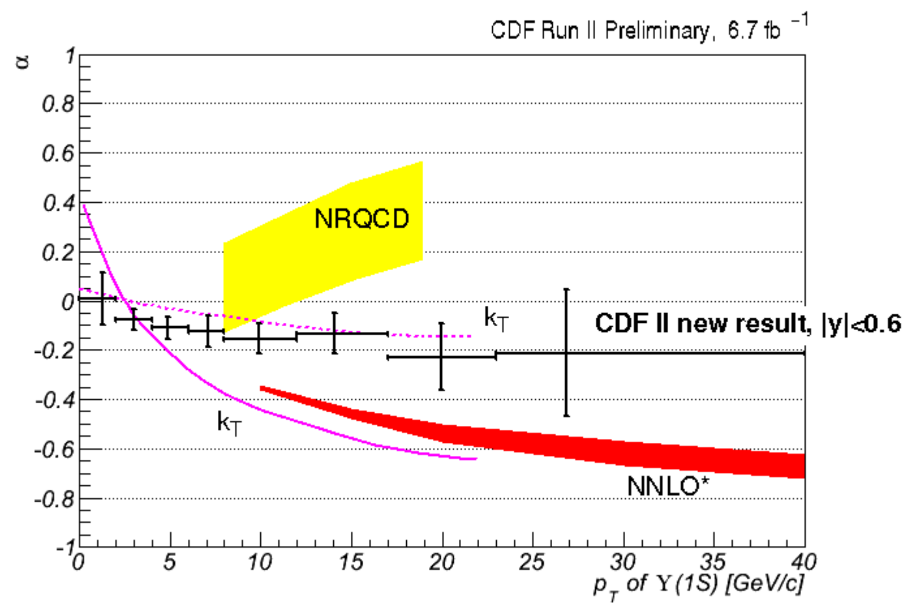
in two different frames (helicity and Collin-Soper) → OK (bound syst.)



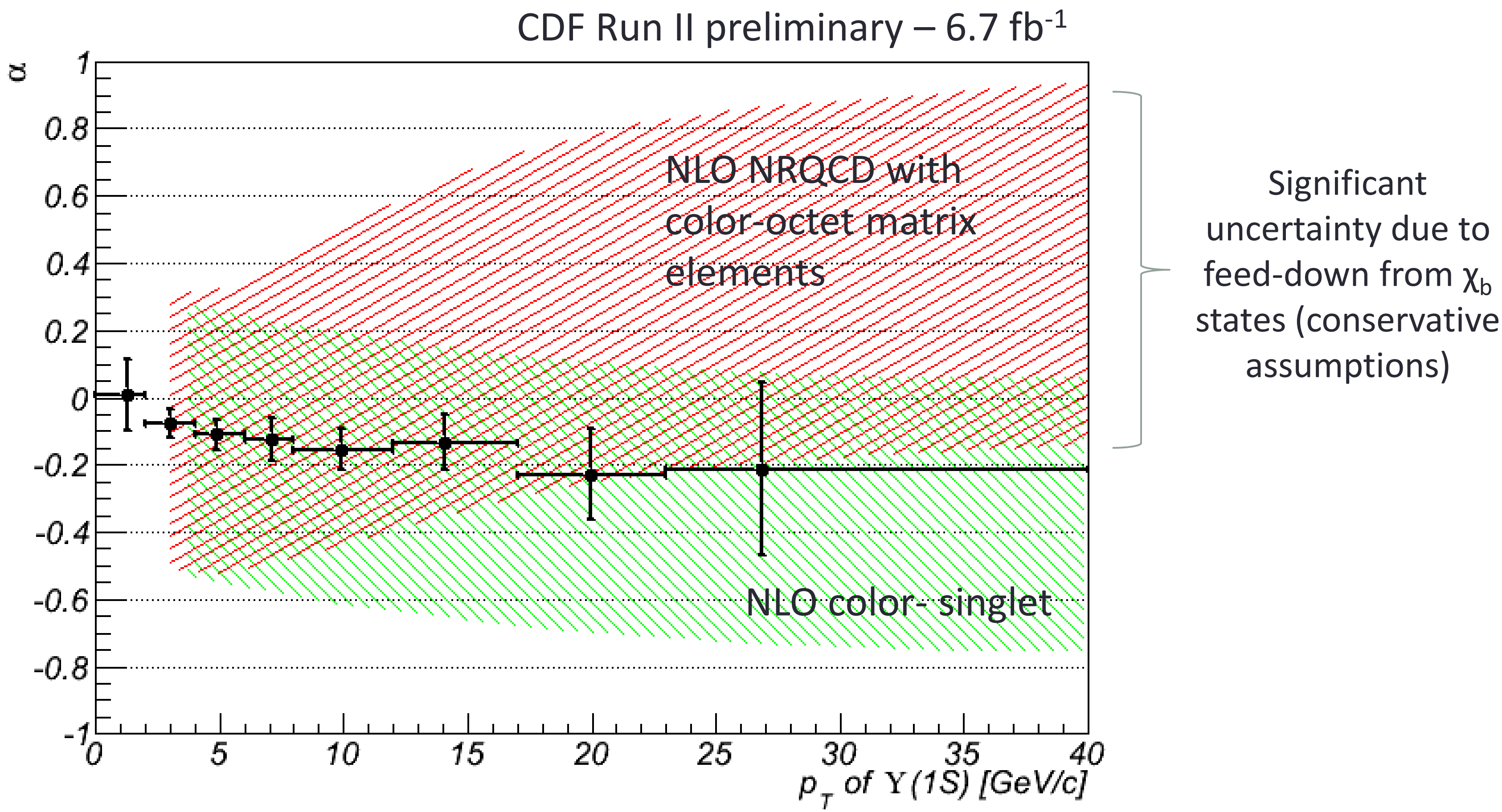
First measurement of Υ(3S) parameters!



- No sign of large polarization at high pT
- Not even for Υ(2S/3S)



Comparisons with newer calculations



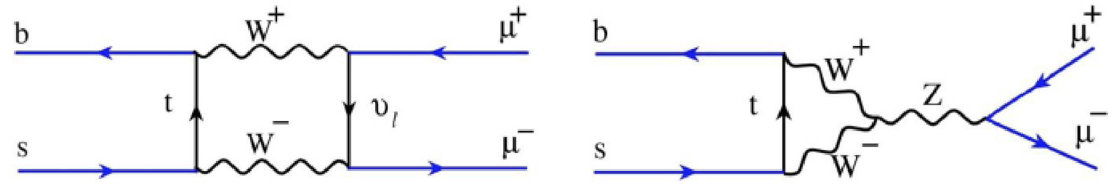
Nucl. Phys. B 214, 3 (2011) summary:

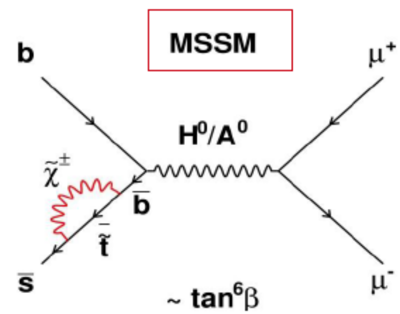
- NLO NRQCD – Gong, Wang & Zhang, Phys. Rev. D83, 114021 (2011)
- Color-singlet NLO and NNLO* - Artoisenent, *et al.* Phys. Rev. Lett. 101, 152001 (2008)

B→μμ search

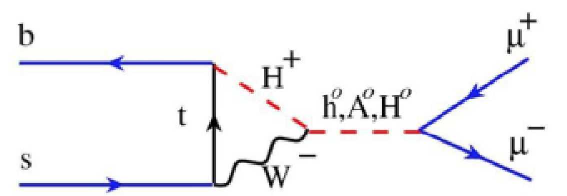
- FCNC forbidden at tree level; helicity suppression
- SM: BR(B_s→μμ)=3.2±0.2 x 10^{-9}
- Important constraint for NP model building,
- Often (but not always) NP predicts an higher BR
- Important also to get constraint on the related (in SM) mode B_d→μμ
- A long history of Tevatron searches brought down the uppper limit to the lower 10^{-8} range.
- Until last summer..

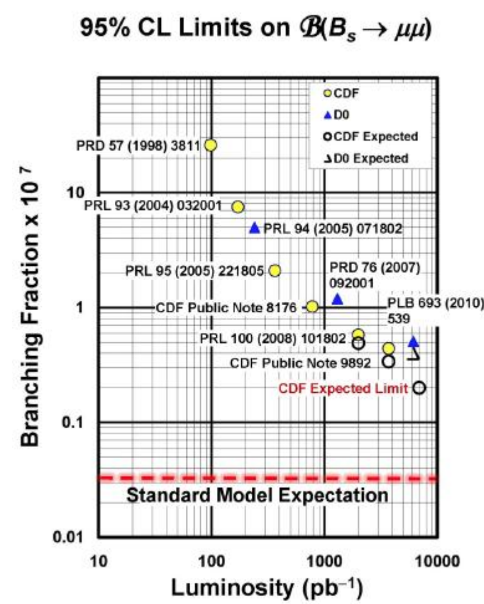
SM Diagrams





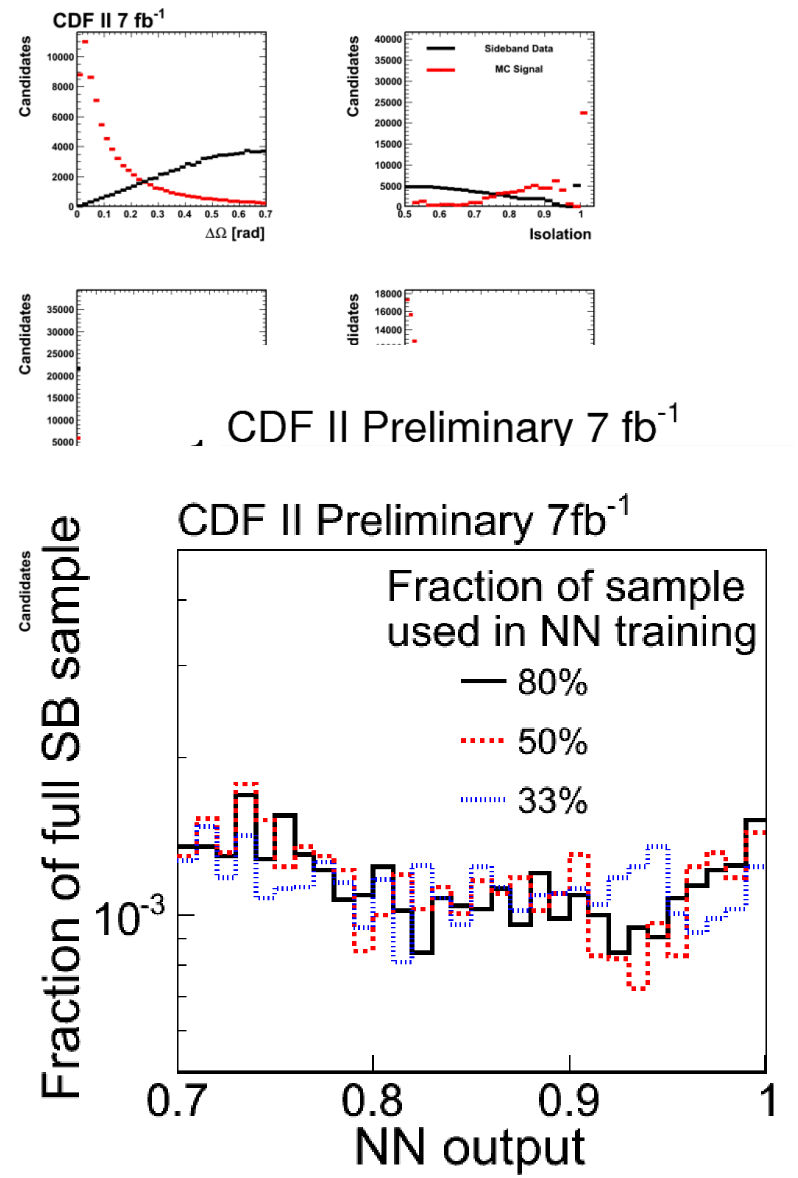
2HDM





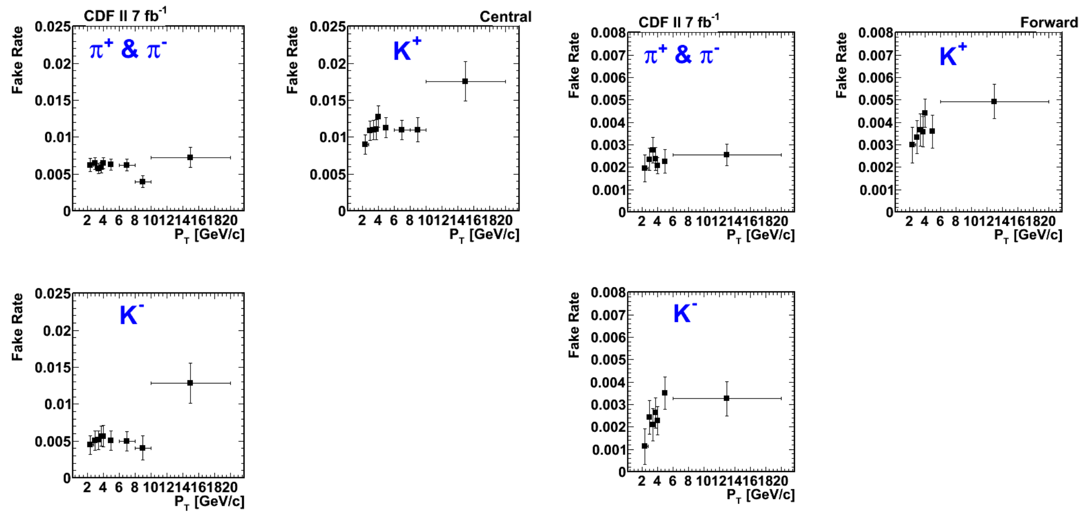
$B_s \rightarrow \mu\mu$ search strategy (1)

- Established over the years, but always improved beyond luminosity increases
- Require a dimuon trigger
- Split analysis in two main channel depending on the muon detectors: central (0.6<|h|<1) and forward (0.6<|h|<1) → CC / CF
- pT>2(2.2) for Central (Forward) muon
- Build a multivariate discriminant using kinematic and vertexing quantities
  - ☑ Train on signal MC and sideband data
  - ☑ Check for absence of bias in mass
  - ☑ Check for overtraining or dependence of amount of sideband data
  - ☑ Cross-check efficiency using normalization B→J/ψ K mode



$B_s \rightarrow \mu\mu$ search strategy (2)

- Control peaking bkg B→hh' via data-driven measurement of fake rate
- Not a significant background in Bs mass window
- More important for Bd
- Checked in orthogonal control sample characterized by lower quality muons (higher fake rate)



NN Bin	CC	CF
$0.700 < NN < 0.970$	0.03±0.01	0.01± <0.01
$0.970 < NN < 0.987$	0.01± <0.01	0.01± <0.01
$0.987 < NN < 0.995$	0.02± <0.01	0.01± <0.01
$0.995 < NN < 1.000$	0.08±0.02	0.03±0.01

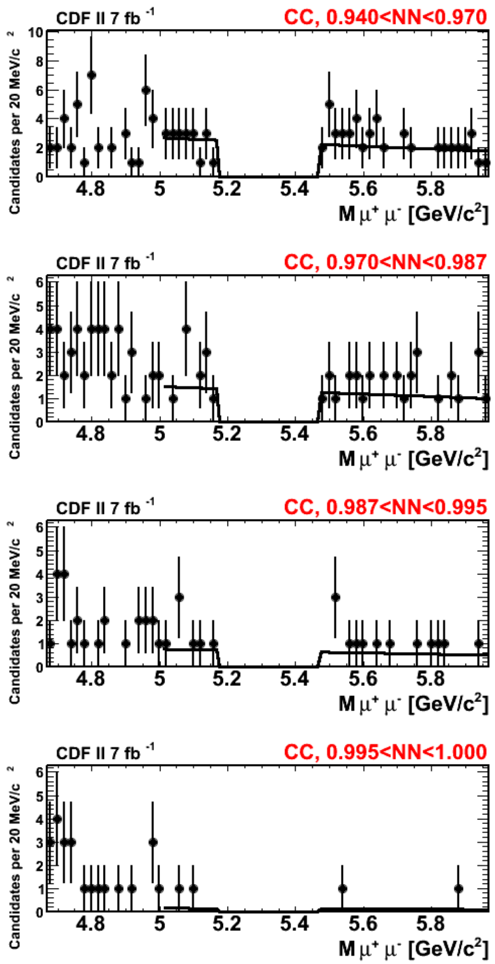
Table: B→hh B_s background for the 3 highest NN bins and the lower 5 bins combined.

NN Bin	CC	CF
$0.700 < NN < 0.970$	0.31±0.08	0.09±0.02
$0.970 < NN < 0.987$	0.13±0.03	0.05±0.01
$0.987 < NN < 0.995$	0.19±0.05	0.04±0.01
$0.995 < NN < 1.000$	0.72±0.20	0.20±0.05

Table: B→hh background in B_d mass window.

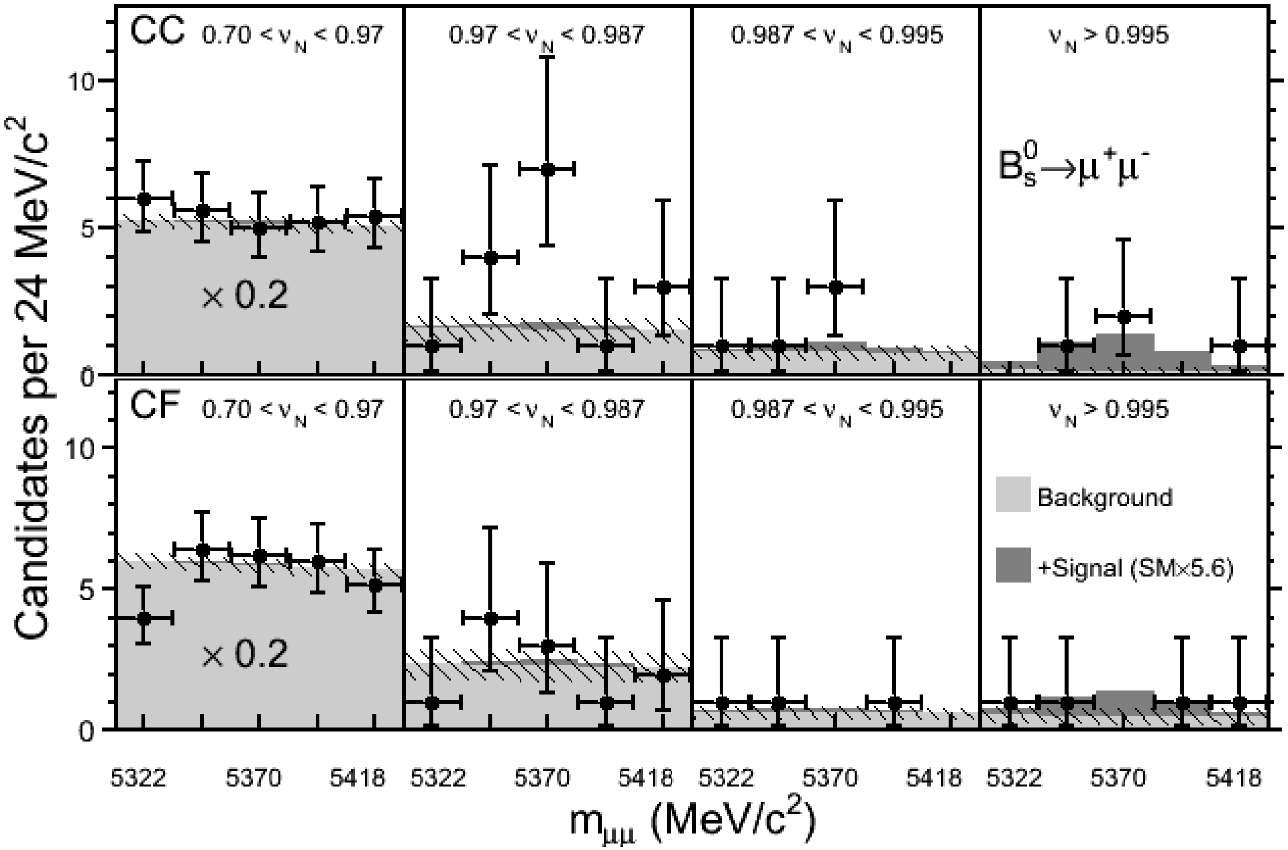
$B_s \rightarrow \mu\mu$ search strategy (3)

- Define signal regions around Bd&Bs masses
- Extrapolate combinatorial background from sidbands
- Vary conservatively bacgkround slope/parametrization
- A binned likelihood using 5 mass bins and 8 discriminant bins is used to fit for the presence of signal



$B_s \rightarrow \mu\mu$ search with $7fb^{-1}$ CDF Coll.

Phys. Rev. Lett. 107, 191801 (2011)



0.8±0.5 expected bkg

4 data

2.6±1.5 exp back

4 data

- Prob. of a background fluctuation is 0.27% (1.9% for bkg+SM signal)
- In the hypothesis of signal first two sided bound given:
- $0.46 \times 10^{-8} < Br < 3.9 \times 10^{-8}$ @ 90% C.L.
- Not incompatible with LHCb/CMS limits, similar sensitivity: (exp 95% U.L. 1.5/1.0/1.8 10^{-8} for CDF/LHCb/CMS)

$B_s \rightarrow \mu\mu$ search with full Run II data @ CDF

NEW

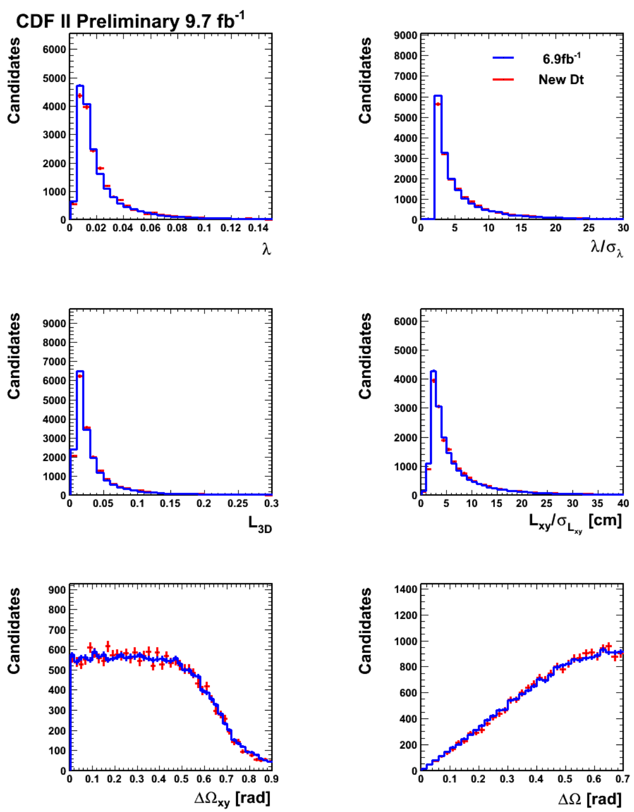
- Repeat the same analysis with the full Run II data, adding almost $3 fb^{-1}$
- New data behaves as old

NN Bin	CC Exp	CC Obs	CC p-val
0.700<NN<0.760	53.594	61	21%
0.760<NN<0.850	52.531	66	7%
0.850<NN<0.900	23.039	29	17%
0.900<NN<0.940	26.639	25	62%
0.940<NN<0.970	19.359	25	16%
0.970<NN<0.987	12.736	15	32%
0.987<NN<0.995	4.562	3	78%
0.995<NN<1.000	1.222	2	51%
Total	193.682	226	3.31%

Table: Comparison of expected and observed sideband yield in last 3 fb^{-1} of data for CC channel.

NN Bin	CF Exp	CF Obs	CF p-val
0.700<NN<0.760	42.018	41	57%
0.760<NN<0.850	50.316	43	83%
0.850<NN<0.900	25.970	29	32%
0.900<NN<0.940	18.208	19	45%
0.940<NN<0.970	19.469	16	77%
0.970<NN<0.987	12.881	9	86%
0.987<NN<0.995	3.699	4	49%
0.995<NN<1.000	3.817	4	51%
Total	176.377	165	56.77%

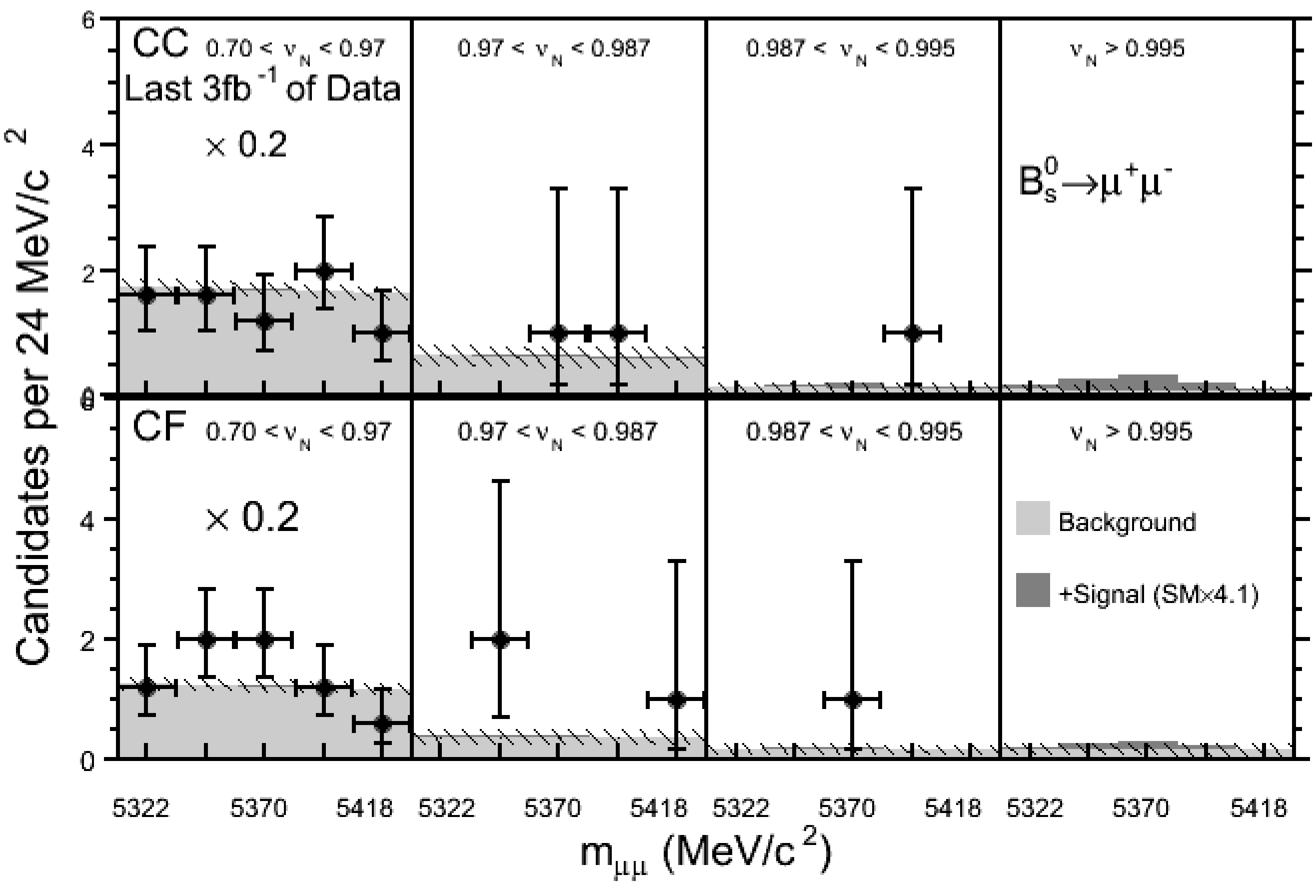
Table: Comparison of expected and observed sideband yield in last 3 fb^{-1} of data for CF channel.



- Expected/Observed events in the sideband (from which combinatorial backround derived)
- Expect 22-25% more signal events from $B+ \rightarrow J/\psi K+$ normalization sample
- Total SM signal in CC(CF) 1.4 (0.96) event with full RunII stat. (0.74+0.55 in the last NN bin)

$B_s \rightarrow \mu\mu$ signal region in extended data

NEW

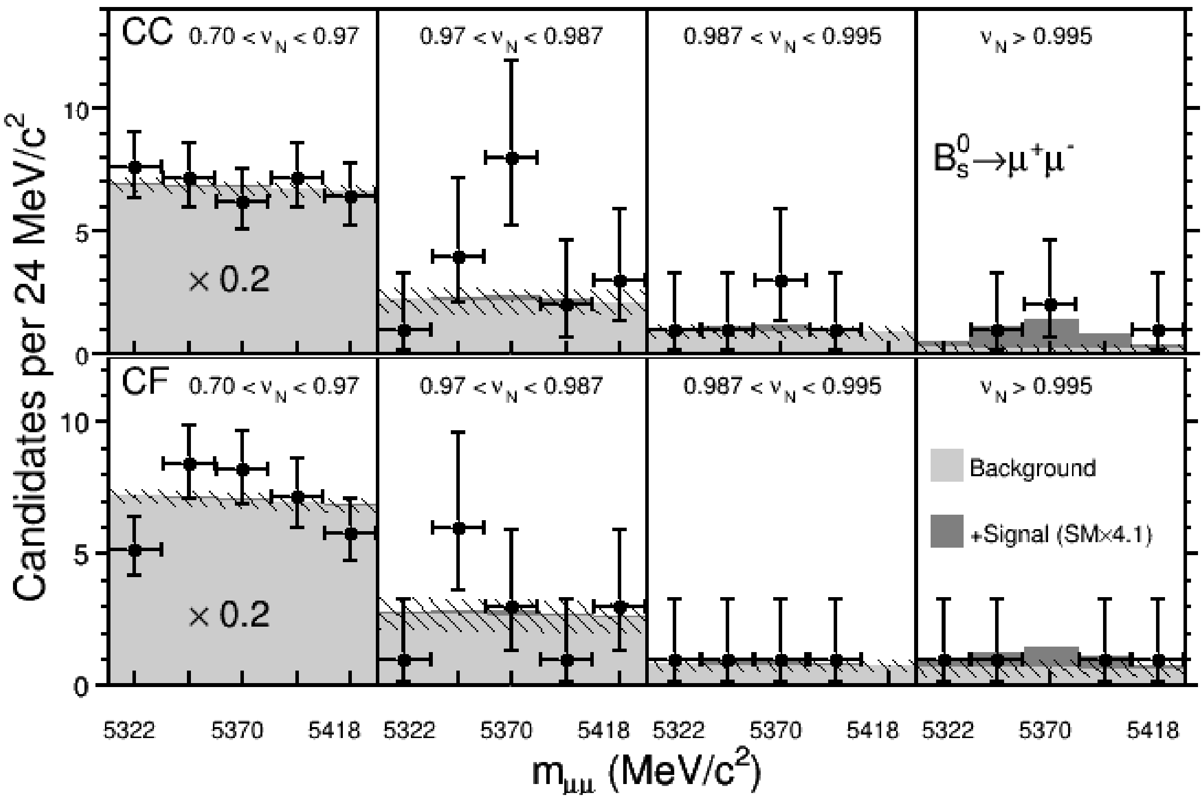


	Mass Bin (GeV)	Total
CC NN bin 0.7-0.76	Exp Bkg	12.45
	Obs	13
CC NN bin 0.76-0.85	Exp Bkg	13.47
	Obs	9
CC NN bin 0.85-0.9	Exp Bkg	5.92
	Obs	8
CC NN bin 0.9-0.94	Exp Bkg	5.11
	Obs	4
CC NN bin 0.94-0.97	Exp Bkg	5.11
	Obs	3
CC NN bin 0.97-0.987	Exp Bkg	3.07
	Obs	2
CC NN bin 0.987-0.995	Exp Bkg	0.62
	Obs	1
CC NN bin 0.995-1	Exp Bkg	0.44
	Obs	0
CF NN bin 0.7-0.76	Exp Bkg	8.46
	Obs	11
CF NN bin 0.76-0.85	Exp Bkg	8.88
	Obs	10
CF NN bin 0.85-0.9	Exp Bkg	5.99
	Obs	4
CF NN bin 0.9-0.94	Exp Bkg	3.92
	Obs	8
CF NN bin 0.94-0.97	Exp Bkg	3.3
	Obs	2
CF NN bin 0.97-0.987	Exp Bkg	1.86
	Obs	3
CF NN bin 0.987-0.995	Exp Bkg	0.83
	Obs	1
CF NN bin 0.995-1	Exp Bkg	0.83
	Obs	0

- No extra events in signal region (sigh!) , but ~1 event both in CF and CC expected even considering enhanced signal

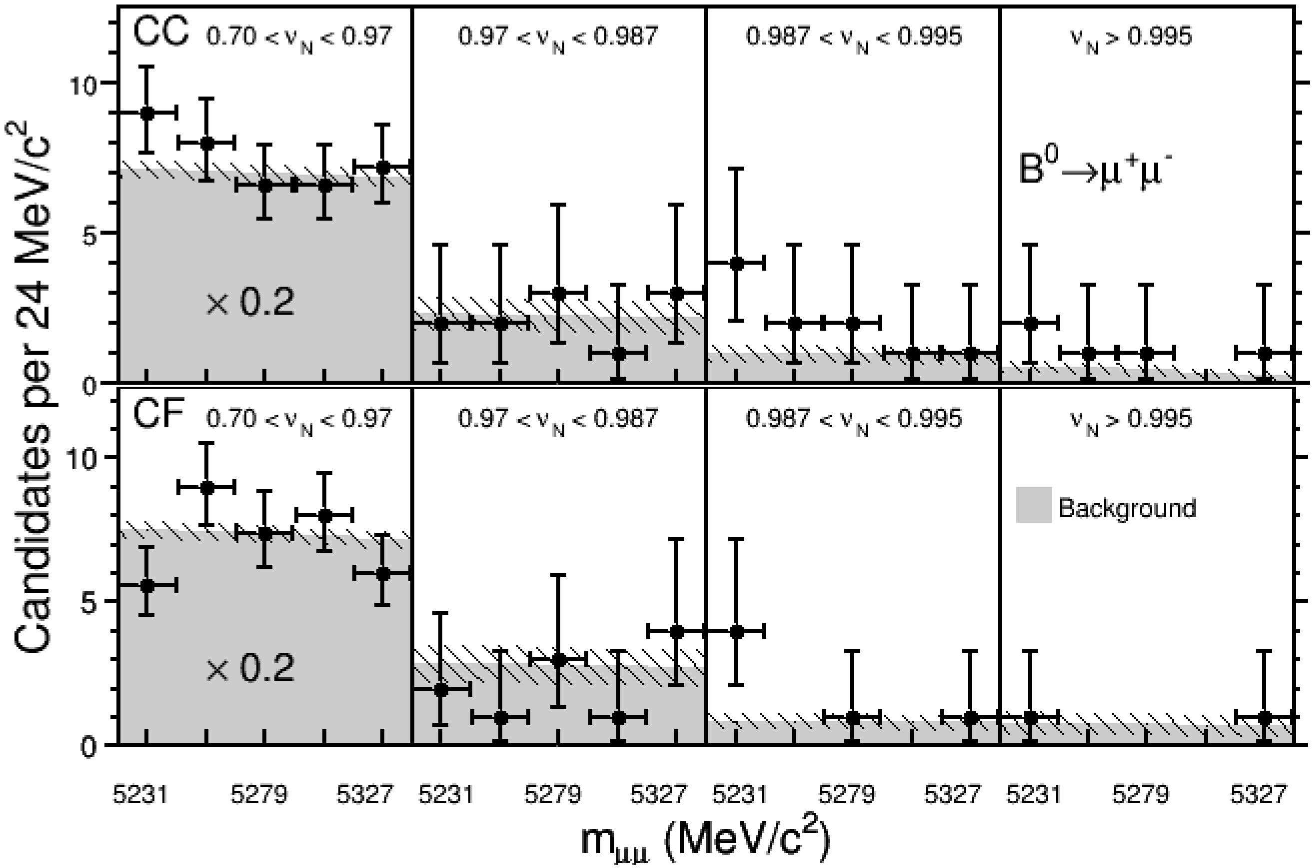
$B_s \rightarrow \mu\mu$ search with full Run II data @ CDF

NEW



- Prob. of a background fluctuation become 0.94% (7.1% for bkg+SM signal), was 0.27%/1.9%
- Considering two highest bin only p-value are 2.1% (22.4% for bkg+SM)
- Two sided bound: 0.22 × 10-8 < Br< 3.0 × 10-8 @ 90% C.L. [$Br(B_s \rightarrow \mu^+\mu^-) = 1.0^{+0.8}_{-0.6} \times 10^{-8}$ @1σ]
- UL 95% (90%) C.L.using CL_s is 3.1×10^{-8} (2.7×10^{-8})

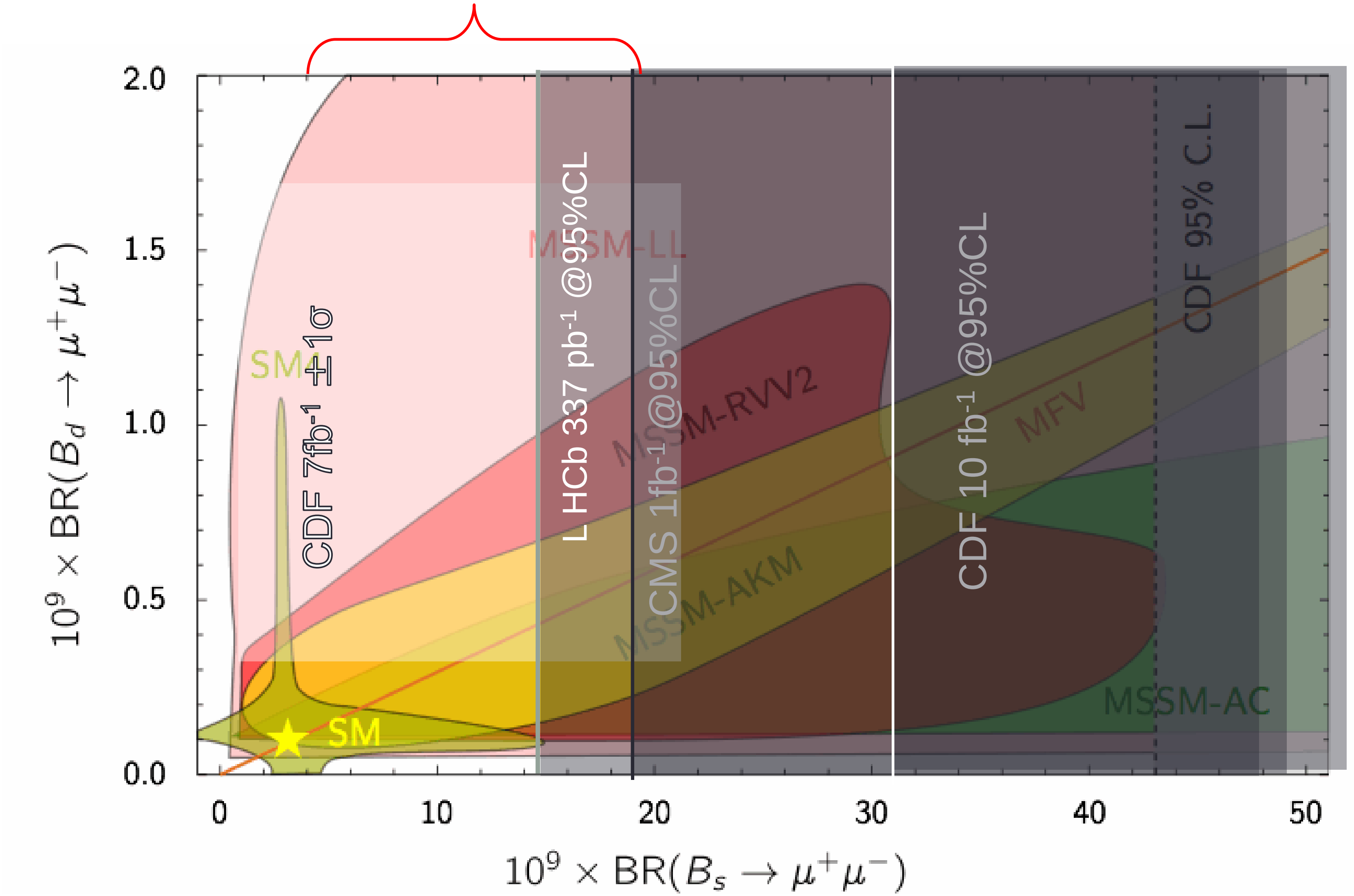
$B_d \rightarrow \mu\mu$ search with full Run II data @ CDF



- As in the publication no excess seen in B_d signal region p-value 44%
- Upper limit is set using CLs is $Br(B_d \rightarrow \mu\mu) < 4.6 \times$ 10-9 ($3.8 \times$ 10-9) @95% (90%)C.L.

B→μμ status

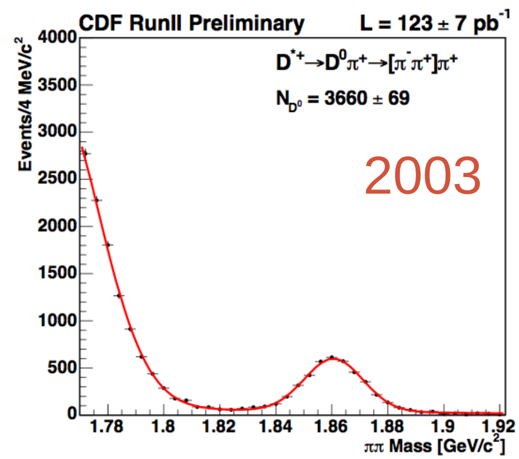
1 σ range from CDF 10 fb^{-1} Br(Bs→ μ+μ-) = $1.0^{+0.8}_{-0.6} \times 10^{-8}$ (still >2σ significance)

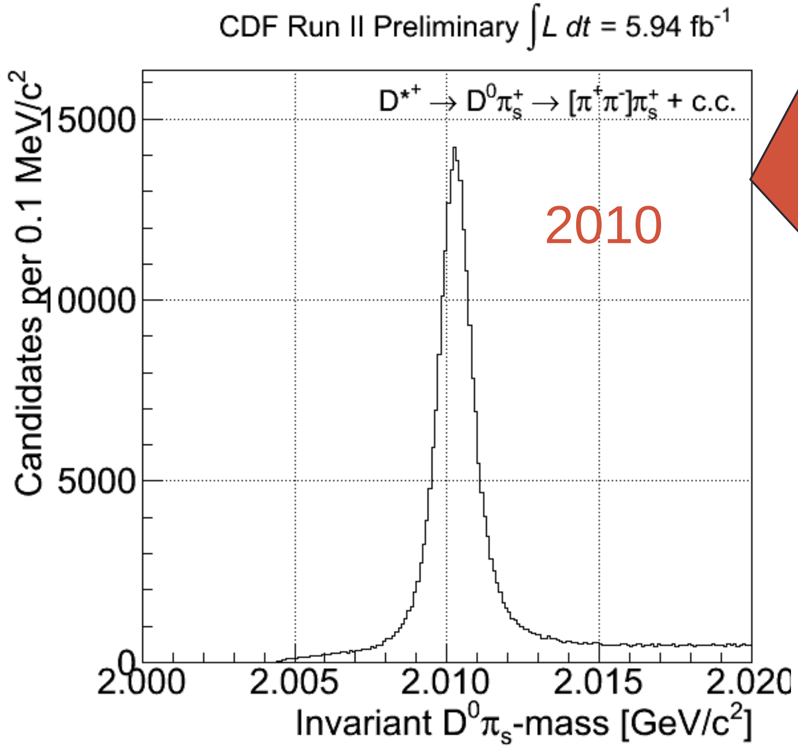


The Rockies (or something we did not expect to be doing)

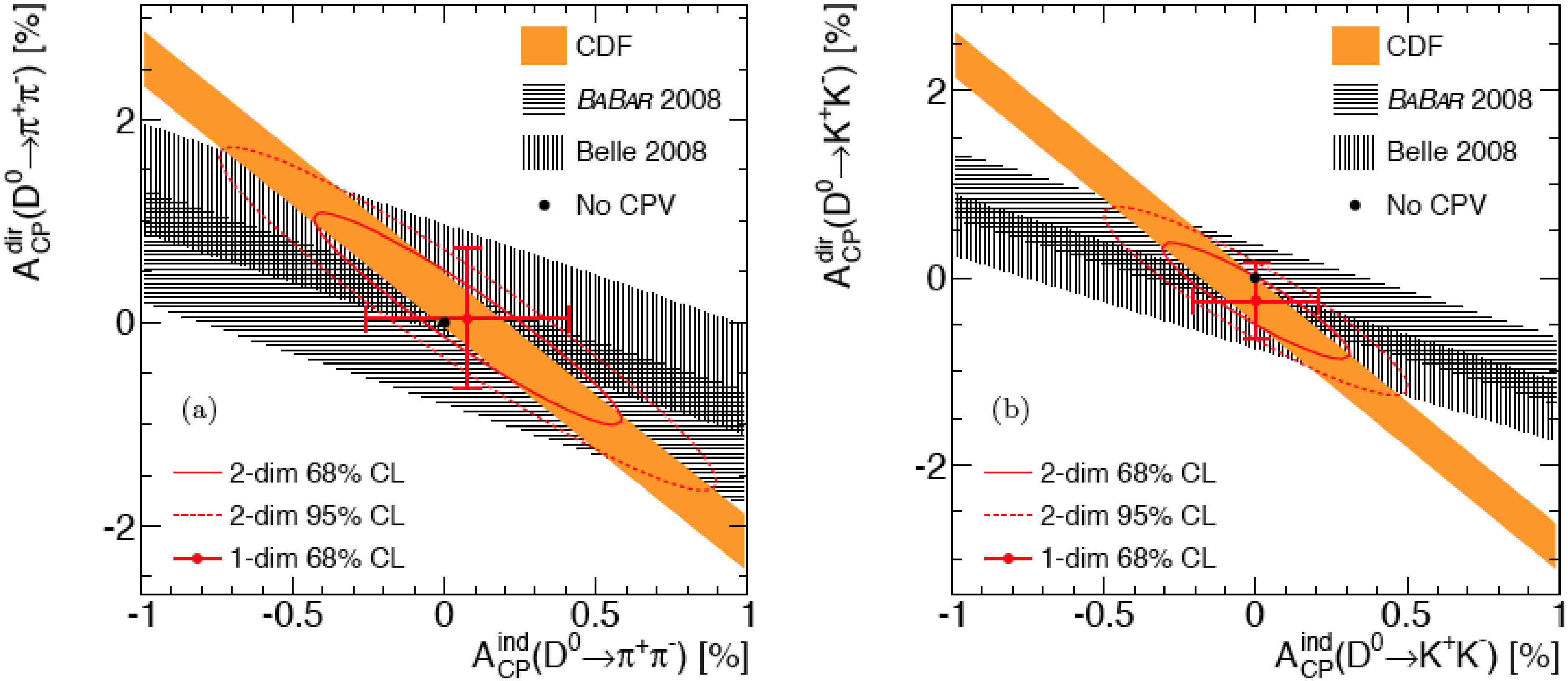
Charm Physics

- Thanks to the displaced track trigger CDF has been able to open up an entirely new field → charm physics at colliders
- Pioneering work on two body D0 decays:
  - DCS decays
  - D0 mixing
- World most precise measurement of direct CP violation in $D^0 \rightarrow \pi^+\pi^-$, and $D^0 \rightarrow K^+K^-$ CDF Coll. [Phys. Rev. D85.012009 (2012)]
- Use the then world largest sample of $D^* \rightarrow D^0\pi \rightarrow [KK,\pi\pi,K\pi]\pi$ collected in 5,9 fb^{-1} of CDF data





D0(K^+K^-) & D0($\pi^+\pi^-$) ACP results



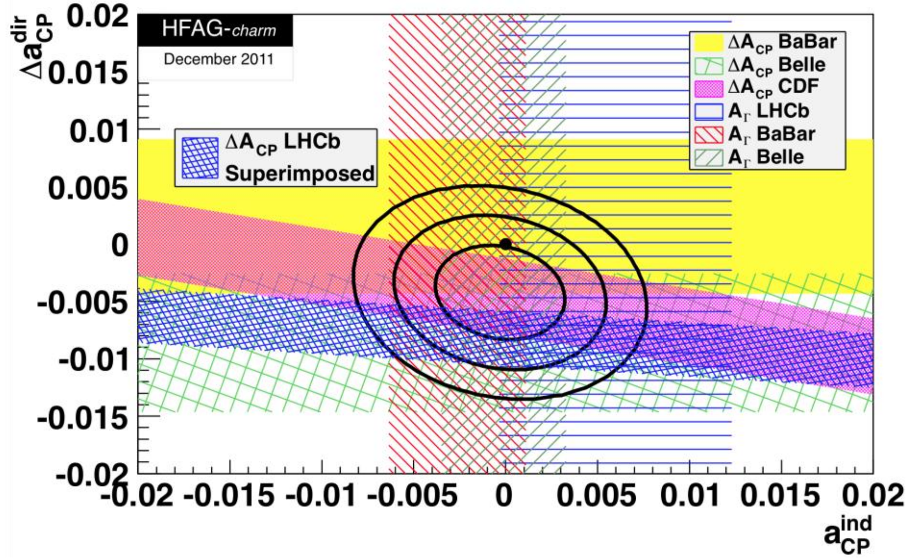
- The large <τ> of the CDF sample ($<\tau>_{KK}$= 2.65±0.03, $<\tau>_{\pi\pi}$= 2.40±0.03) allows increased sensitivity to indirect CP violation mixing :

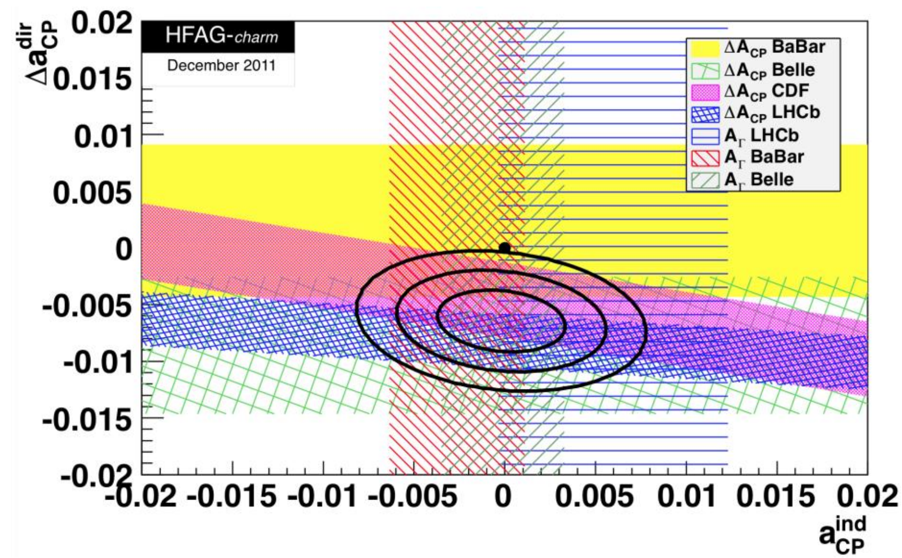
$$|A_{CP}^{\rm ind}(D^0)| < 0.13\ (0.16)\%\ \text{at the 90 (95)\% C.L.}$$

Δ(ACP) results

$A_\Gamma \equiv [\,|(D^0 \to K^+ K^-) - |(D^0 \to K^+ K^-)] / [\,|(D^0 \to K^+ K^-) + |(D^0 \to K^+ K^-)] = -a^{ind}$

- CDF provides also the CP asymmetry difference of the two modes
- CP in the individual mode have indeed opposite sign
- Δ(ACP) = [−0.46 ± 0.31 (stat) ± 0.12 (syst)]%
- Result consistent (at 1 σ) both with the no CP violation hypothesis and with the recent LHCb (3 sigma effect)



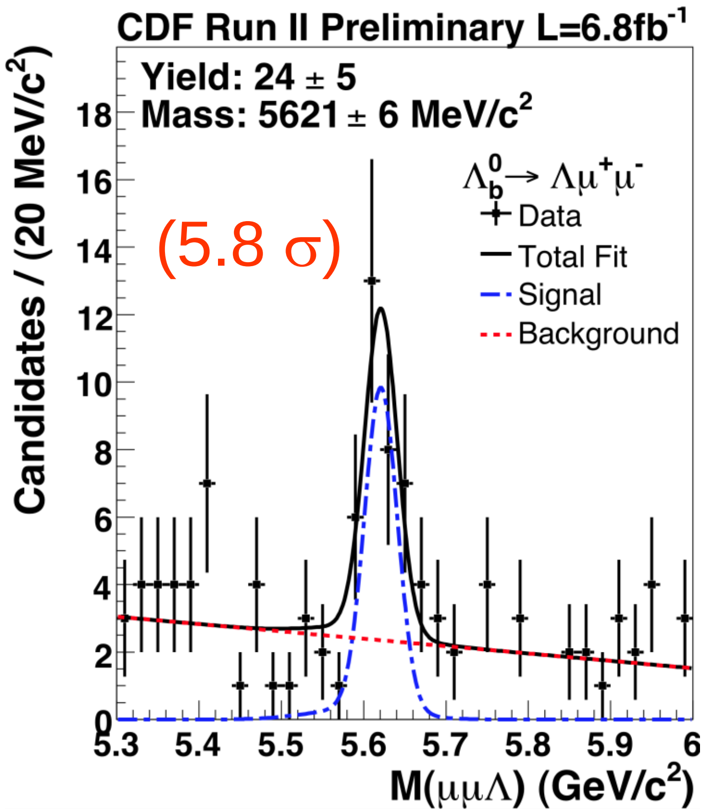


Exclusive $b \rightarrow s\mu^+\mu^-$

- New analysis based on 6.8 fb^{-1}: Phys. Rev. Lett. 107, 201802 (2011) [Λ_b, decay rates]
  arXiv:1108.0695 (PRL accepted) [angular analysis]
  - Trigger on dimuons (p_T^μ>2 GeV) forming a displaced vertex
  - Reconstruct:
    $B^+ \rightarrow K^+ \mu^+\mu^-$, $B_d \rightarrow K^0 \mu^+\mu^-$
    $B_d \rightarrow K^{*0} \mu^+\mu^- \rightarrow [K^+\pi^-] \mu^+\mu^-$,
    $B^+ \rightarrow K^{*+} \mu^+\mu^- \rightarrow [K^0\pi^+] \mu^+\mu^-$
    $B_s \rightarrow \phi \mu^+\mu^- \rightarrow [K^+K^-] \mu^+\mu^-$

    Search for:
    $\Lambda_b^0 \rightarrow \Lambda\mu^+\mu$
  - To reject $B \rightarrow J/\psi$ (ψ') remove:
    $8.68 < M^2_{\mu+\mu-} < 10.09 \cup 12.86 < M^2_{\mu+\mu-} < 14.18$ GeV^2
  - Vertex quality, PID (dE/dx and TOF) + kinematic variables combined in a Neural Network to optimize sensitivity of angular observables:
    - $S/(2.5+\sqrt{B})$ for Λ_b mode
  - Normalize rate to $B \rightarrow J/\psi\ h$ (h=K,K*,ϕ) to obtain differential decay rate

$\Lambda_b^0 \rightarrow \Lambda\mu^+\mu$ First Observation

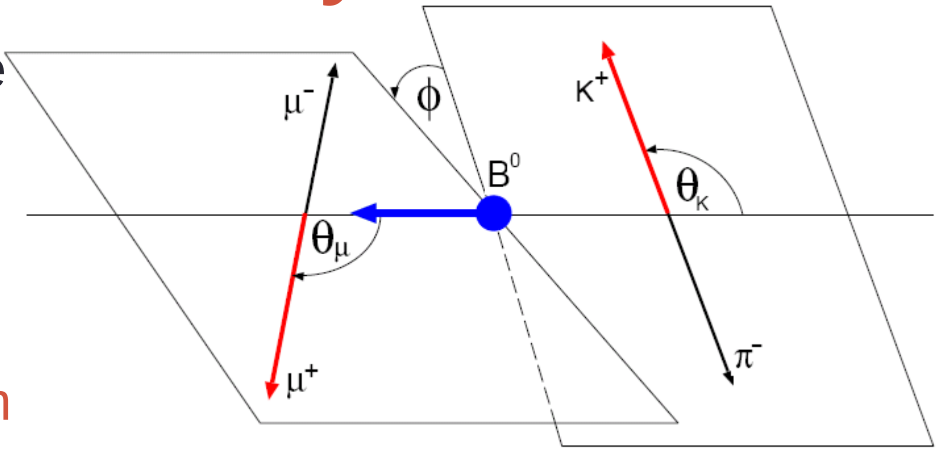


$$BR(\Lambda_b \rightarrow \Lambda\mu^+\mu^-) = \left(1.73 \pm 0.42(stat.) \pm 0.55(sys.)\right) \cdot 10^{-6}$$

Compare to $BR(\Lambda_b \rightarrow \Lambda\mu^+\mu^-) \sim (4.0 \pm 1.2) \cdot 10^{-6}$ T.M.Aliev et al PRD 78,114032(2010)

$B_d \to K^{*0}\mu^+\mu^-$ angular analysis

- Kaon and muon decay angle in the B rest frame 1d distribution give longitudinal decay fraction and forward backward asymmetry
- Angle between two decay planes give new observables $A_T^{(2)}$ and Aim



$$\frac{1}{\Gamma}\frac{d\Gamma(B^0 \to K^{*0}\mu^+\mu^-)}{d\cos\theta_K} = \frac{3}{2}\mathrm{F_L}\cos^2\theta_\mathrm{K} + \frac{3}{4}(1-\mathrm{F_L})(1-\cos^2\theta_\mathrm{K}),$$

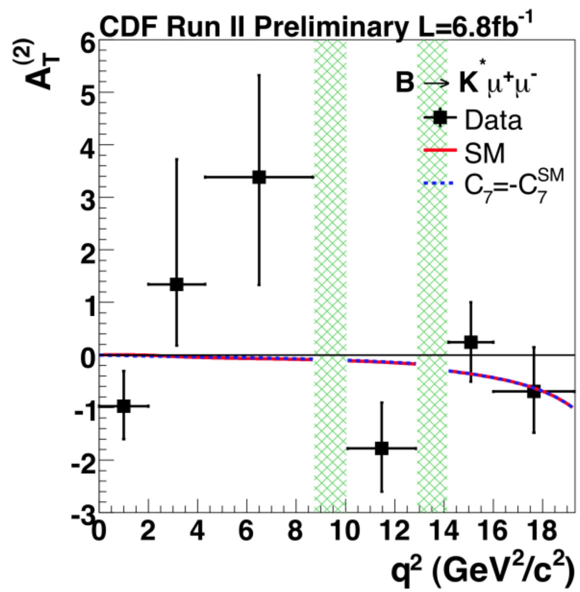
Fit Parameters

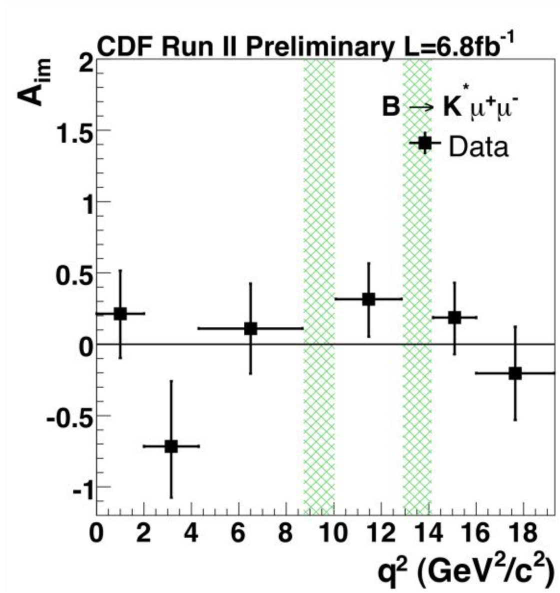
$$\frac{1}{\Gamma}\frac{d\Gamma(B^0 \to K^{*0}\mu^+\mu^-)}{d\cos\theta_\mu} = \frac{3}{4}\mathrm{F_L}(1-\cos^2\theta_\mu) + \frac{3}{8}(1-\mathrm{F_L})(1+\cos^2\theta_\mu) + \mathrm{A_{FB}}\cos\theta_\mu$$

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\phi} = \frac{1}{2\pi}\left[1 + \frac{1}{2}(1-F_L)A_T^{(2)}\cos 2\phi + A_{im}\sin 2\phi\right]$$

- Correct for acceptance via detailed simulation
- bin in $q^2 = m_{\mu\mu}^2$ excluding ccbar resonances
- Cross check with $B \to J/\psi$ X samples

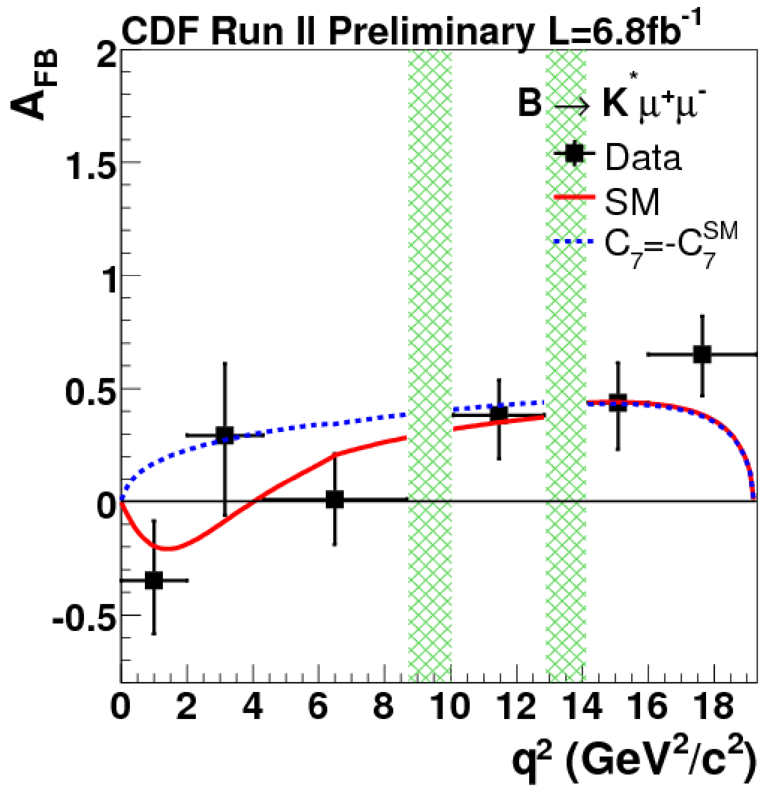
$A_T^{(2)}$ and A_{im}





- Sensitive to right-hand currents, A_{im} is T--violating
- Helpful for eliminating ambiguities when constraining NP parameters
- Consistent with expectation, dominated by statistical uncertainty

A_{FB} result $B_d \rightarrow K^*\mu^+\mu^-$



In the theoretically cleanest range $1<q^2<6$:

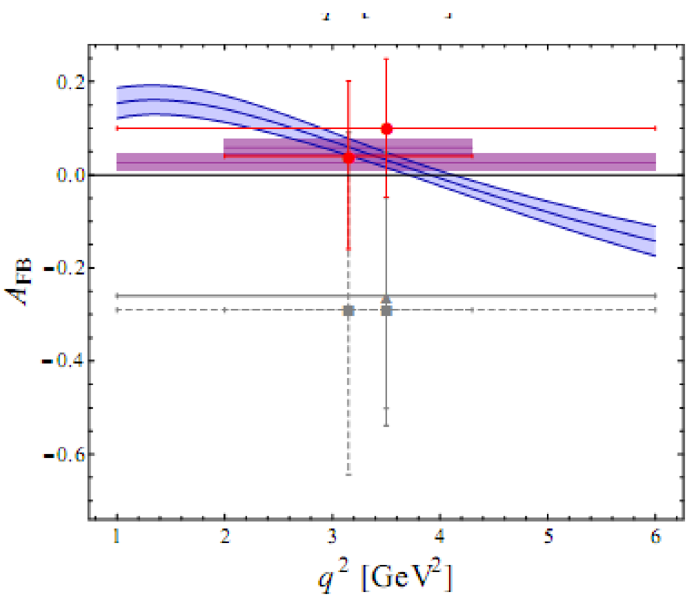
$$A_{FB}^{CDF}(1<q^2<6\,\mathrm{GeV}^2/c^4) = 0.29^{+0.20}_{-0.27} \pm 0.07$$

better than Belle 660x10[6] B

$$A_{FB}^{Belle}(1<q^2<6\,\mathrm{GeV}^2/c^4) = 0.26^{+0.27}_{-0.30} \pm 0.07$$

Comparable to LHCb 300 pb^{-1}

$$A_{FB}^{LHCb}(1<q^2<6\,\mathrm{GeV}^2/c^4) = -0.10 \pm 0.14 \pm 0.05$$

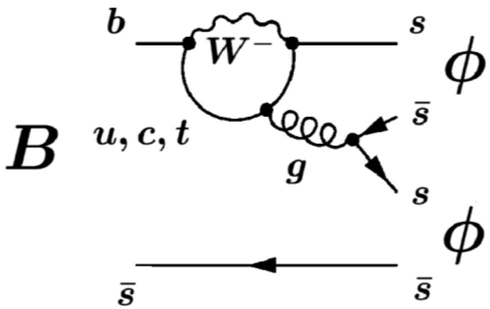


- Recent+LHCb does not indicate deviation → towards stringent bounds on NP!

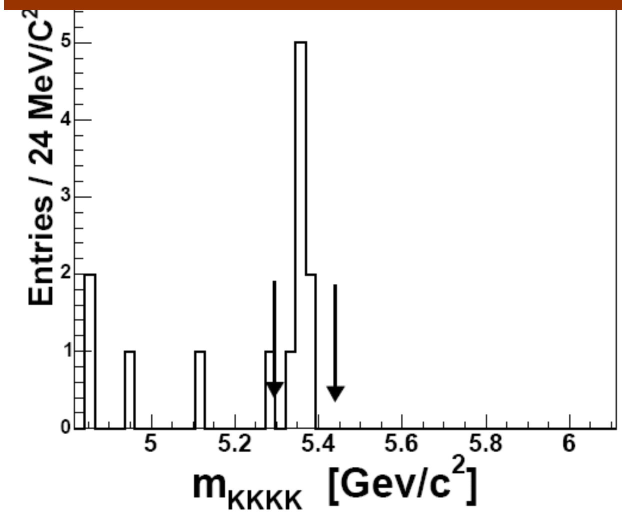
Altmannshoher,Paradisi,Straub arXiv:1111.1257

$B_s \to \phi\phi$ at CDF

- $b \to s$ penguin dominated decay



CDF Phys. Rev. Letters **95** 031801 (2005)



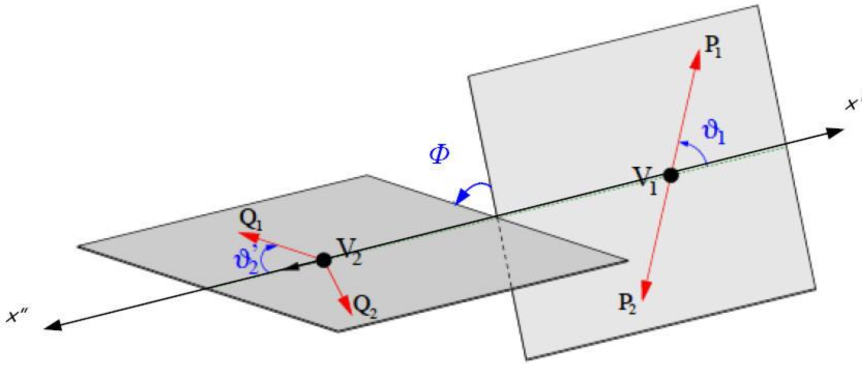
- Thanks to the CDF displaced track trigger :
  - First evidence in just 180 pb^{-1} of Run II data (2004) with 8 events

- With 2.9 fb^{-1} of data perform:
  - Improved BR measurement
  - Measurement of polarization amplitudes
    - First experimental data on charmless $B_s \to$Vector–Vector : insight into the so called “polarization puzzle”
- First search for T-violating effects in Triple Product asymmetries

Phys. Rev. Lett. 107, 261802 (2011)

$B_s \rightarrow \phi\phi$ Polarization

- Three independent polarization amplitudes A_0, $A_{//}$ (CP-even), $A_\perp$ (CP-odd)
- Measure polarization amplitudes from untagged time-integrated differential decays rate as a function of kaon decay angles (θ_1,θ_2) and the angle between the two decay planes (Φ)



$$g_s^{(\omega)} = \frac{d^3\Lambda(\vec{\omega})}{d\vec{\omega}} = \frac{9}{32\pi}\frac{1}{\tilde{W}}\left[\tilde{\mathcal{F}}_e(\vec{\omega}) + \tilde{\mathcal{F}}_o(\vec{\omega})\right]$$

Assume SM mixing phase: $\phi_{Bs\rightarrow\phi\phi}=0$

$$\tilde{\mathcal{F}}_e = \frac{2}{\Gamma_L}\left[|A_0|^2 f_1(\vec{\omega}) + |A_\parallel|^2 f_2(\vec{\omega}) + |A_0||A_\parallel|\cos\delta_\parallel f_5(\vec{\omega})\right]$$

$$\tilde{\mathcal{F}}_o = \frac{2}{\Gamma_H}|A_\perp|^2 f_3(\vec{\omega})$$

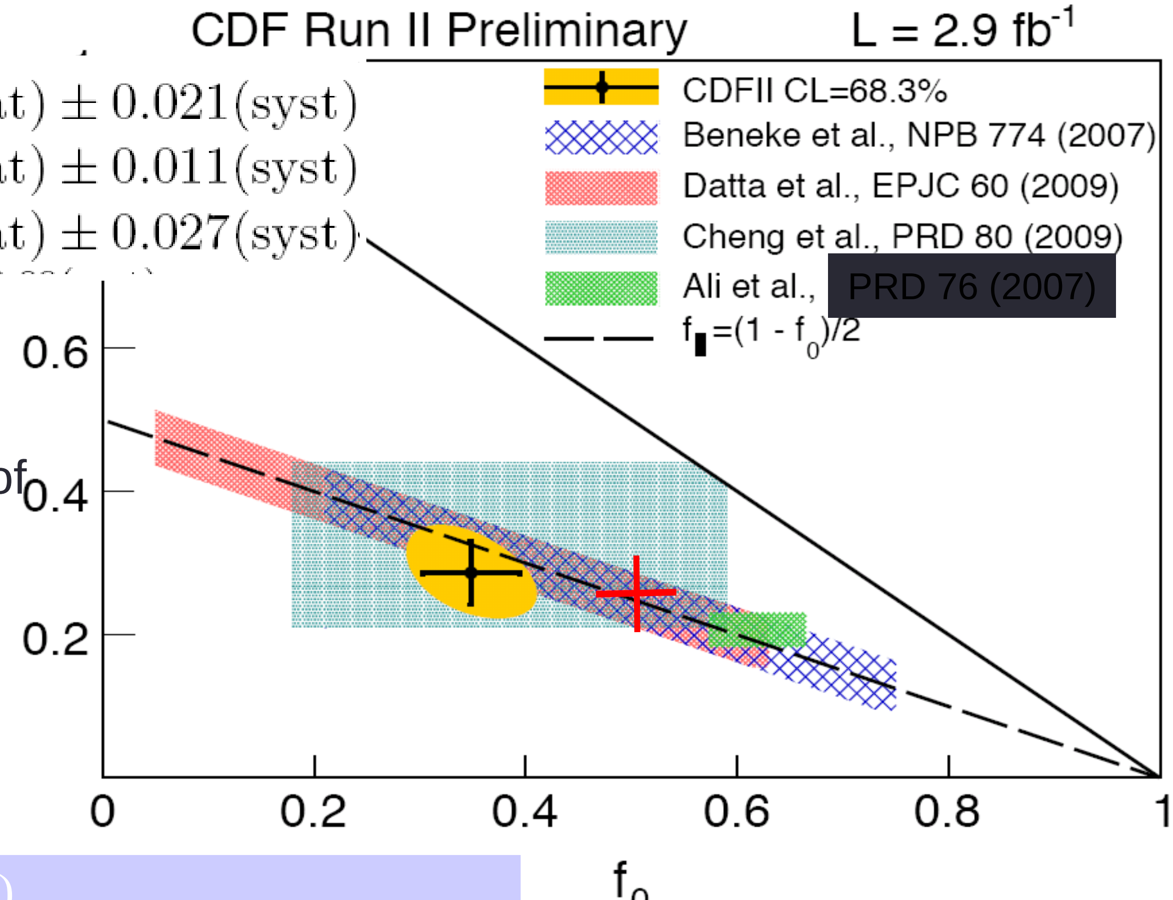
$$\tilde{W} = \frac{|A_0|^2 + |A_\parallel|^2}{\Gamma_L} + \frac{|A_\perp|^2}{\Gamma_H}$$

OBSERVABLES

Take Γ_L and Γ_H from PDG

$B_s \rightarrow \phi\phi$ Polarization Exp vs Theory

$$|A_0|^2 = 0.348 \pm 0.041(\text{stat}) \pm 0.021(\text{syst})$$
$$|A_{\parallel}|^2 = 0.287 \pm 0.043(\text{stat}) \pm 0.011(\text{syst})$$
$$|A_{\perp}|^2 = 0.365 \pm 0.044(\text{stat}) \pm 0.027(\text{syst})$$



Datta et. al. compare longitudinal fraction via ratio of BR with $B_d \rightarrow \phi K^*$

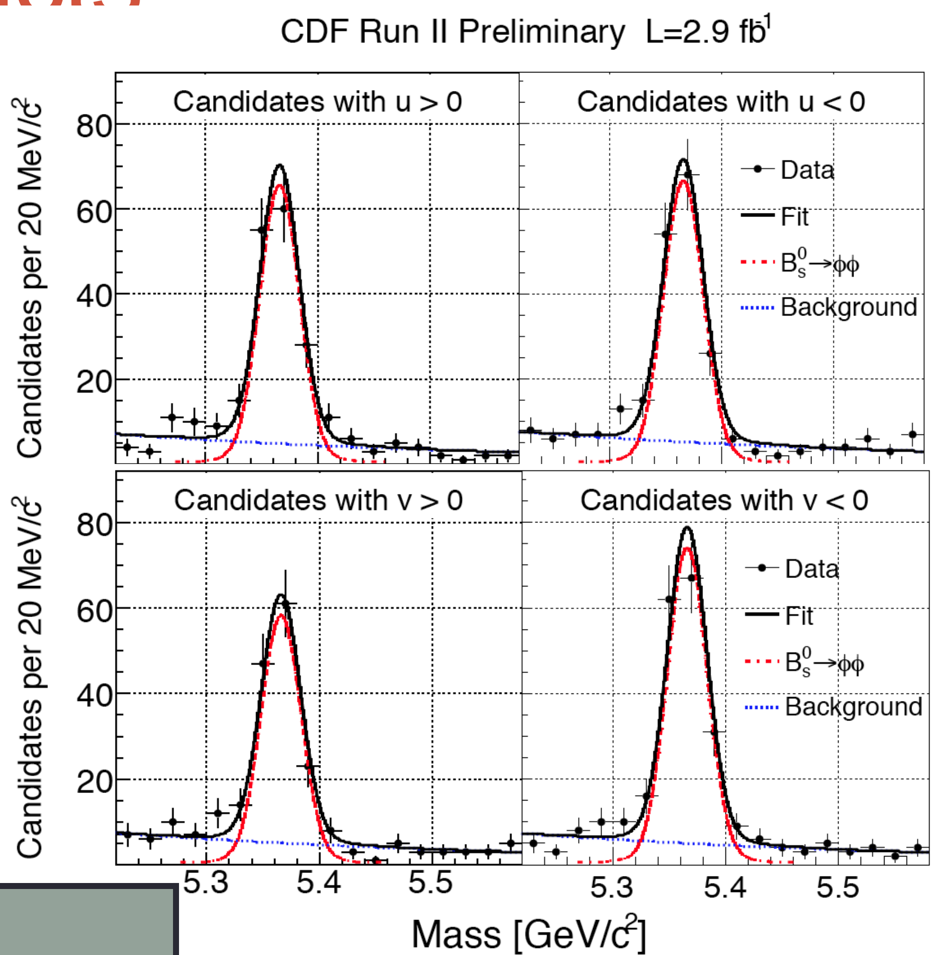
Beneke, Cheng (QCDf) and Ali (pQCD) all reproduce $B_d \rightarrow \phi K^*$ observables

	$\cos(\delta_{//})$	
CDF	$-0.91^{+0.15}_{-0.13}(stat) \pm 0.09(syst)$	
QCDF	$-0.80^{+0.31}_{-0.16}$	NP B774:64,2007
pQCD	$0.27^{+0.09}_{-0.27}$	PRD76:074018,2007

- Agreement with QCDF prediction favor polarization puzzle explanation via penguin-annihilation over FSI

$B_s \to \phi\phi$ Triple Products

- CP-odd/CP-even interference term are proportional to Triple products and are odd under time reversal
- For self-conjugate final state a T-violating asymmetry is observable in the untagged rate (no need for tagging). Look at asymmetries in:
- $u=\sin(2\phi) \to Im(A_{//}^{*}A_{\perp})$
- $v=\sin(\phi) \to Im(A_{0}^{*}A_{\perp})$
- Vanish in the SM ! Clean probe for new physics effect in penguin dominated Bs decays



	Au	Av
CDF	(-0.7 ± 6.4 ± 1.8)%	(-12.0 ± 6.4 ± 1.6)%
LHCb	(-6.4 ± 5.7 ± 1.4)%	(-7.0 ± 5.7 ± 1.4)%

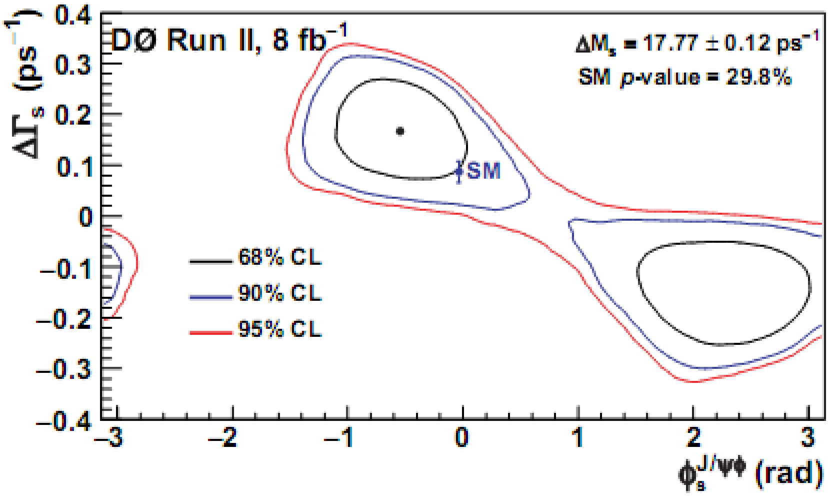
Promising, need more stat.!

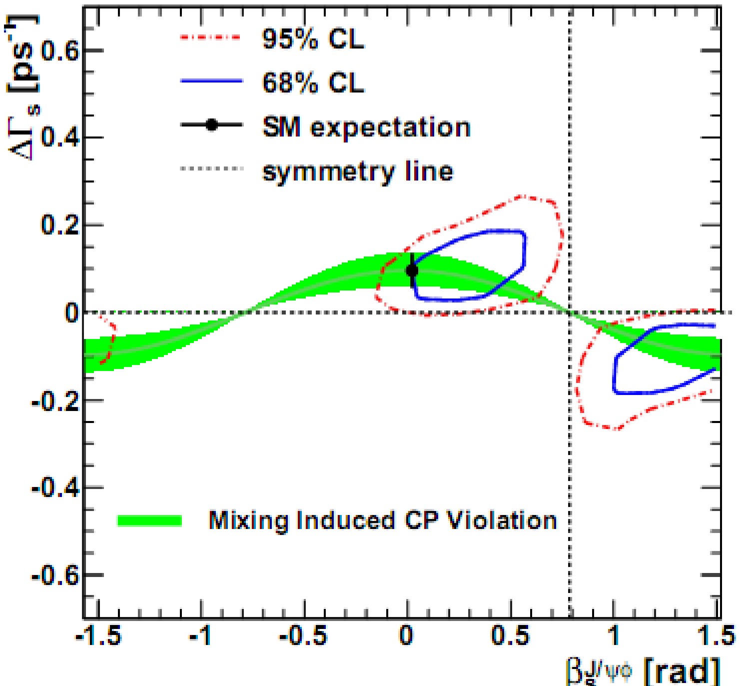
Towards the Alps (or something that we start doing with great excitement but need to be clarified elsewhere)

Status of ϕ_s

CDF arXiv:1112.1726 (5.2 fb^{-1})

D0 arXiv:1109.3166 (8 fb^{-1})





- 6500 signal ev.
- Bayesian MCMC integration

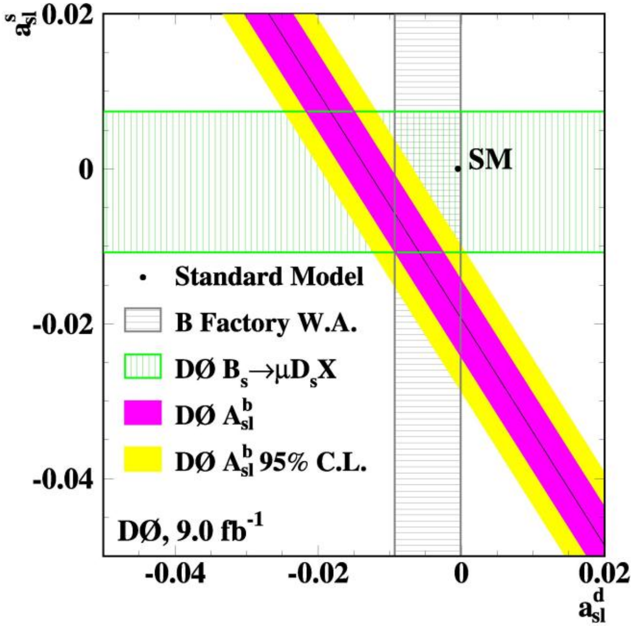
$$\Delta\Gamma_s = 0.163^{+0.065}_{-0.064}$$
$$\varphi_s = -0.55 \pm 0.38 \quad + \text{symmetric}$$
$$[\beta_s = 0.28 \pm 0.19]$$

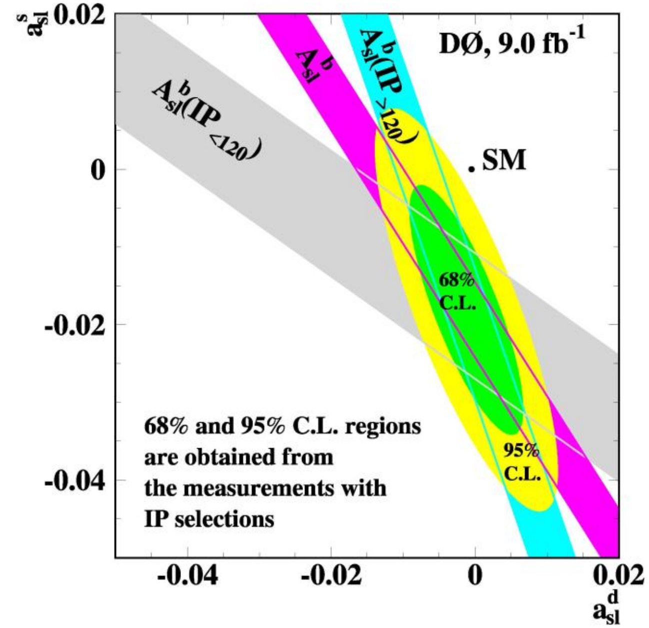
- 6500 signal ev. → will update soon
- Main result frequentistic confidence region with guaranteed coverage

$$\Delta\Gamma_s = 0.075 \pm 0.036 \; [\beta_s = \beta_s^{SM}]$$
$$0.02 < \beta_s < 0.52 @ 68\% CL \; [\text{freq.}]$$
$$0.11 < \beta_s < 0.41 @ 68\% CL \; [\text{Bayes}]$$

Asl

Phys. Rev. D 84, 052007 (2011)





- Accessing the same physics as in J/ψϕ
- Latest result from D0 confirmed the unexpect large effect already reported, deviating from the SM point by 3.9σ
- Hint at large deviation in the B_s system by looking at high vs low i.p. muons

Conclusions

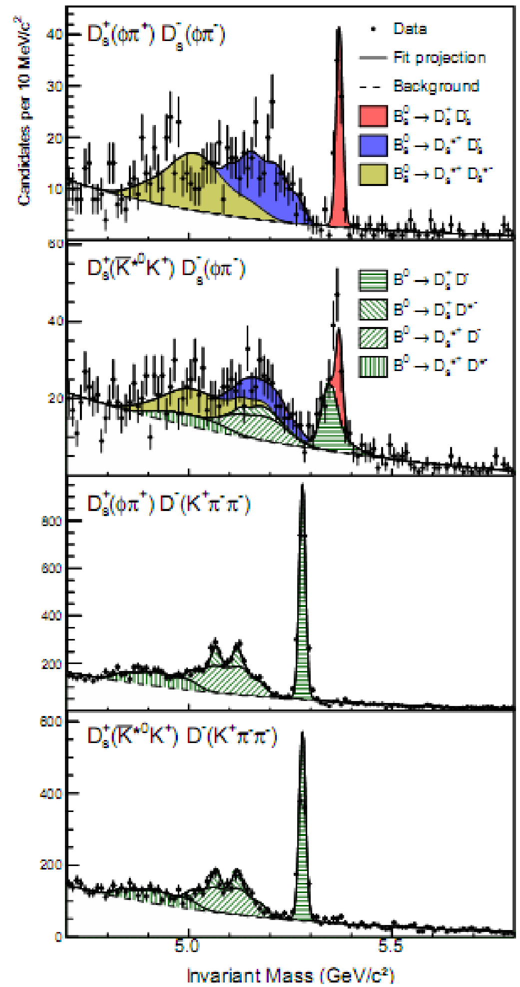
- Last year extremely fruitful for Tevatron experiments in the flavor field
- Succeded in the timely analysis of the largest samples of $B_{(s)}$ and D decays → results remained competitive with LHCb until at least last summer
- Innovation in the analysis techniques lead to many ground-breaking results
  - Tevatron handing the baton to LHCb for further exploration
- Some surprises… unfortunately not matched by LHC experiments so far
- Many recent result have been omitted due to lack of time/space. Some more still to come exploiting the full Run II stat. (e.g. CDF on ϕ_s)

BACKUP

Bs→Ds(*)Ds(*) Branching Ratio

NEW

- Reconstruct $D_s \rightarrow \phi\pi$ and $D_s \rightarrow K^*K$
- Take advantage of CDF displaced trigger and excellent mass resolution to resolve all the distinct peaks with 0/1/2 missing photon



$$Br(B_s \rightarrow D_s^+ D_s^-) = (0.49 \pm 0.06 \pm 0.05 \pm 0.08)\%$$

$$Br(B_s \rightarrow D_s^{*+} D_s^-) = (1.13 \pm 0.12 \pm 0.09 \pm 0.19)\%$$

$$Br(B_s \rightarrow D_s^{*+} D_s^{*-}) = (1.75 \pm 0.19 \pm 0.17 \pm 29)\%$$

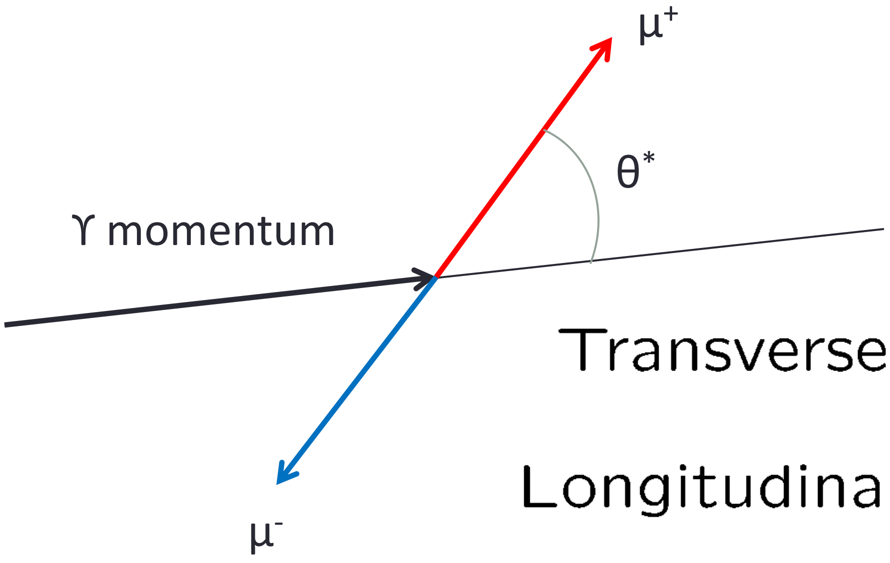
$$Br(B_s \rightarrow D_s^{(*)+} D_s^{(*)-}) = (3.38 \pm 0.25 \pm 0.30 \pm 0.56)\%$$

- Within certain appoximations (Shifman-Voloshin limit) these modes saturate Γ_{12}:

$$2\mathcal{B}(B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-}) \approx \frac{\Delta\Gamma_s}{\Gamma_s + \Delta\Gamma_s/2}, \quad \frac{\Delta\Gamma_s}{\Gamma_s} = (6.99 \pm 0.54 \pm 0.64 \pm 1.20)\%$$

Upsilon "Polarization"

- A better term is *spin alignment*...
  - *Transverse* polarization: $|J,\lambda\rangle = |1,\pm1\rangle$
  - *Longitudinal* polarization: $|J,\lambda\rangle = |1,0\rangle$



$$\frac{d\sigma}{d\cos\theta^*} \sim 1 + \alpha\cos^2\theta^*$$

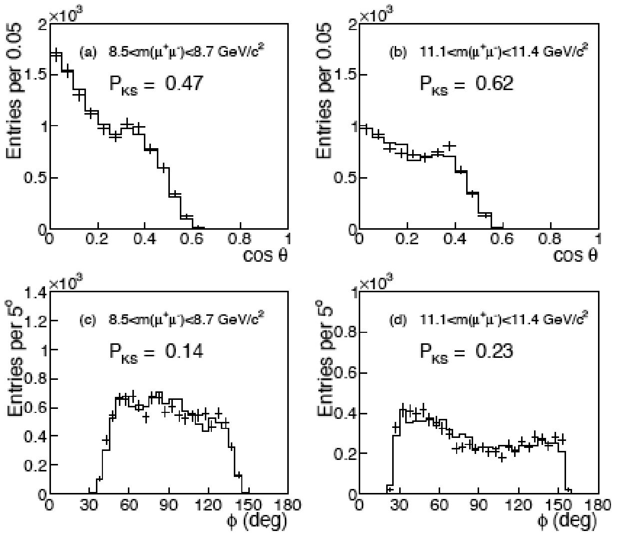
Transverse: $\frac{d\sigma}{d\cos\theta^*} \sim 1 + \cos^2\theta^*$

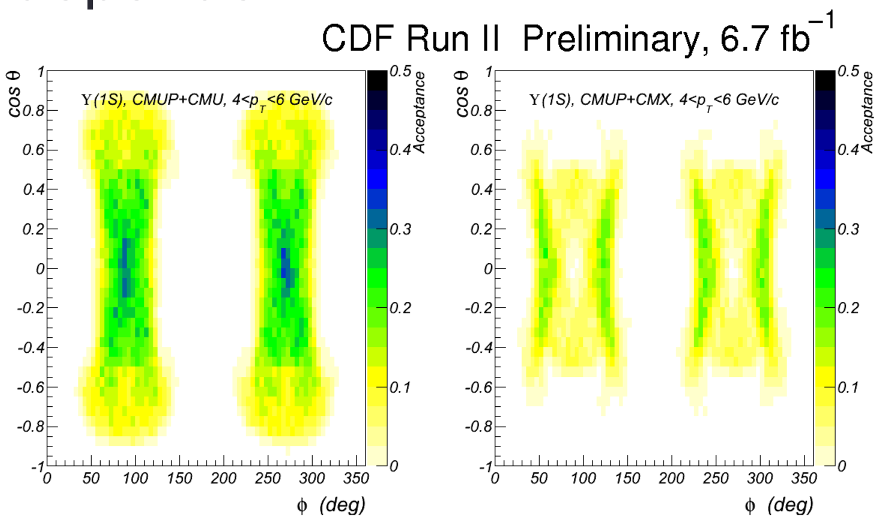
Longitudinal: $\frac{d\sigma}{d\cos\theta^*} \sim 1 - \cos^2\theta^*$

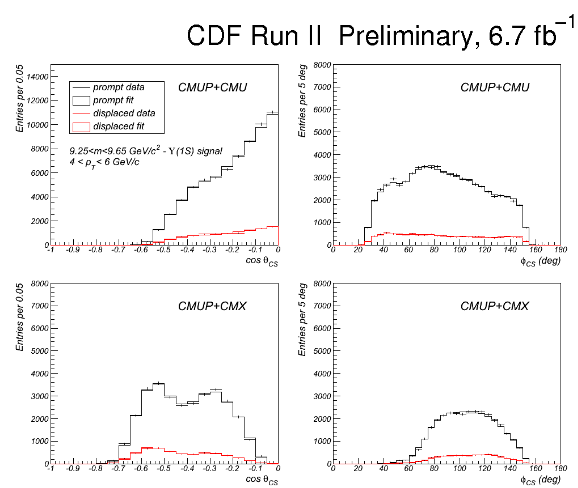
(this is called the s-channel helicity frame)

First Y spin-alignment measurement

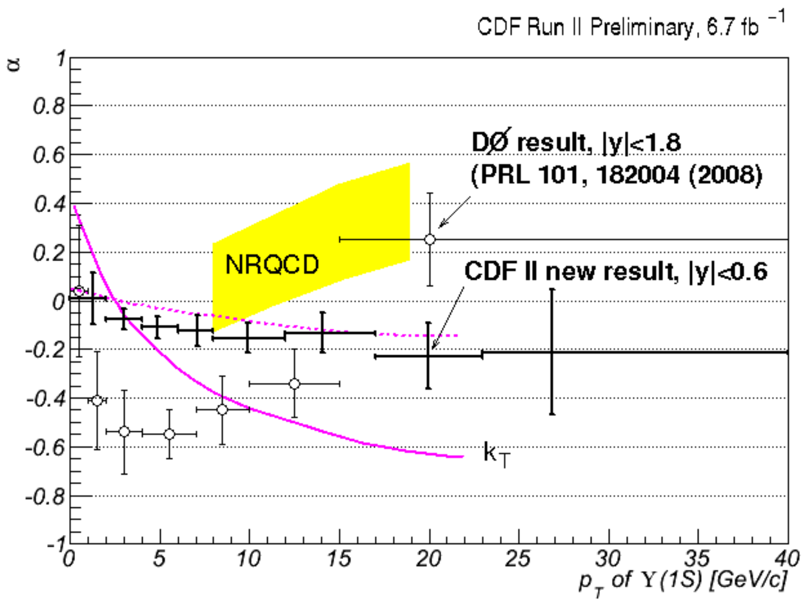
- Model background shape using non-prompt background control region
- Signal Acceptance from dedicated detailed MC simulation p_T and mass dependent

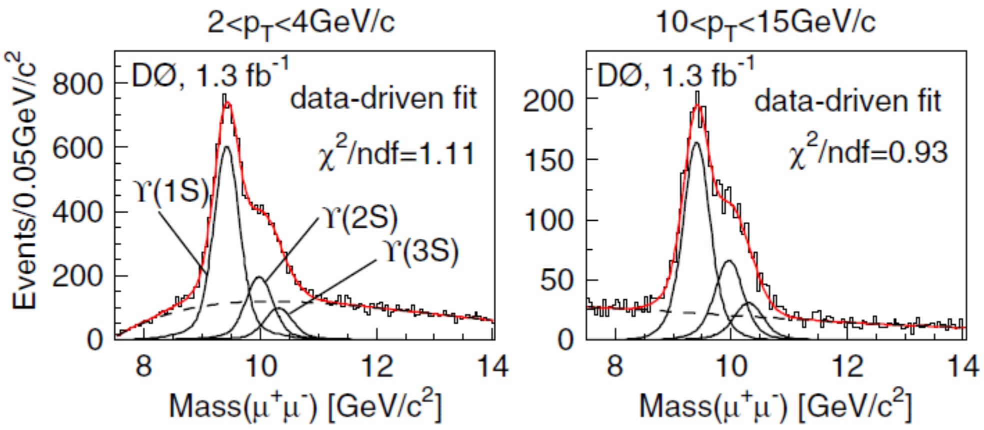






Comparison with previous results





- Does not agree with result from DØ at the 4.5σ level
  - Does the angular distribution evolve rapidly with rapidity?
  - Subtraction of highly polarized background?

Time integrated CP-violation in D0 decays

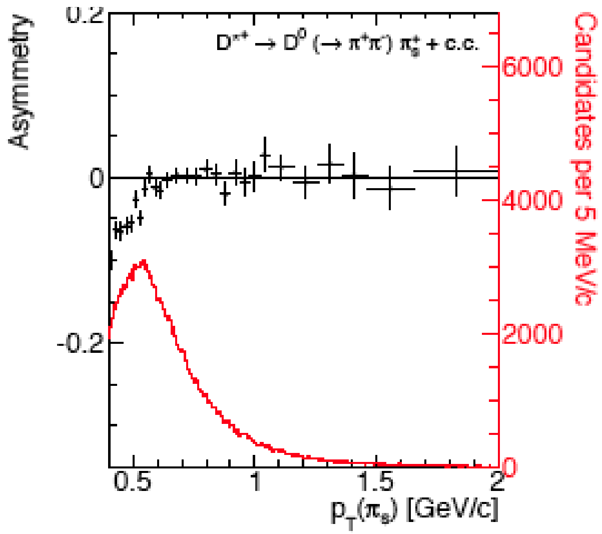
- Exploit the charge symmetric initial state of proton-antiproton collision to directly measure the time-integrated CP asymmetry
- In the presence of mixing sensitive to all type of CP violation → impact on global fits
- Sensitivity to indirect CP violation depend on the average decay time of the sample (larger in CDF due to impact parameter based trigger)

$$A_{CP}(h^+h^-;t) \approx A^{\rm dir}_{CP}(h^+h^-) + \frac{t}{\tau}\, A^{\rm ind}_{CP}(h^+h^-),$$

$$A^{\rm dir}_{CP}(h^+h^-) \equiv A_{CP}(t=0) = \frac{|\mathcal{A}(D^0\to h^+h^-)|^2 - |\mathcal{A}(\overline{D}^0\to h^+h^-)|^2}{|\mathcal{A}(D^0\to h^+h^-)|^2 + |\mathcal{A}(\overline{D}^0\to h^+h^-)|^2},$$

$$A^{\rm ind}_{CP}(h^+h^-) = \frac{\eta_{CP}}{2}\left[y\left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right)\cos\varphi - x\left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right)\sin\varphi\right],$$

$$A_{CP}(h^+h^-) = A^{\rm dir}_{CP}(h^+h^-) + \frac{\langle t\rangle}{\tau}\, A^{\rm ind}_{CP}(h^+h^-)$$



- Need to correct instrumental effect to per mil level

D0(K$^+$K$^-$) & D0($\pi^+\pi^-$) ACP

- A delicate subtraction in a nut-shell:
- Raw asymmetry in pp/kk due to soft pion

$$A(hh^*) = A_{CP}(hh) + \delta(\pi_s)^{hh^*}$$

- Obtain soft pion asymmetry with tagged Kpi decays

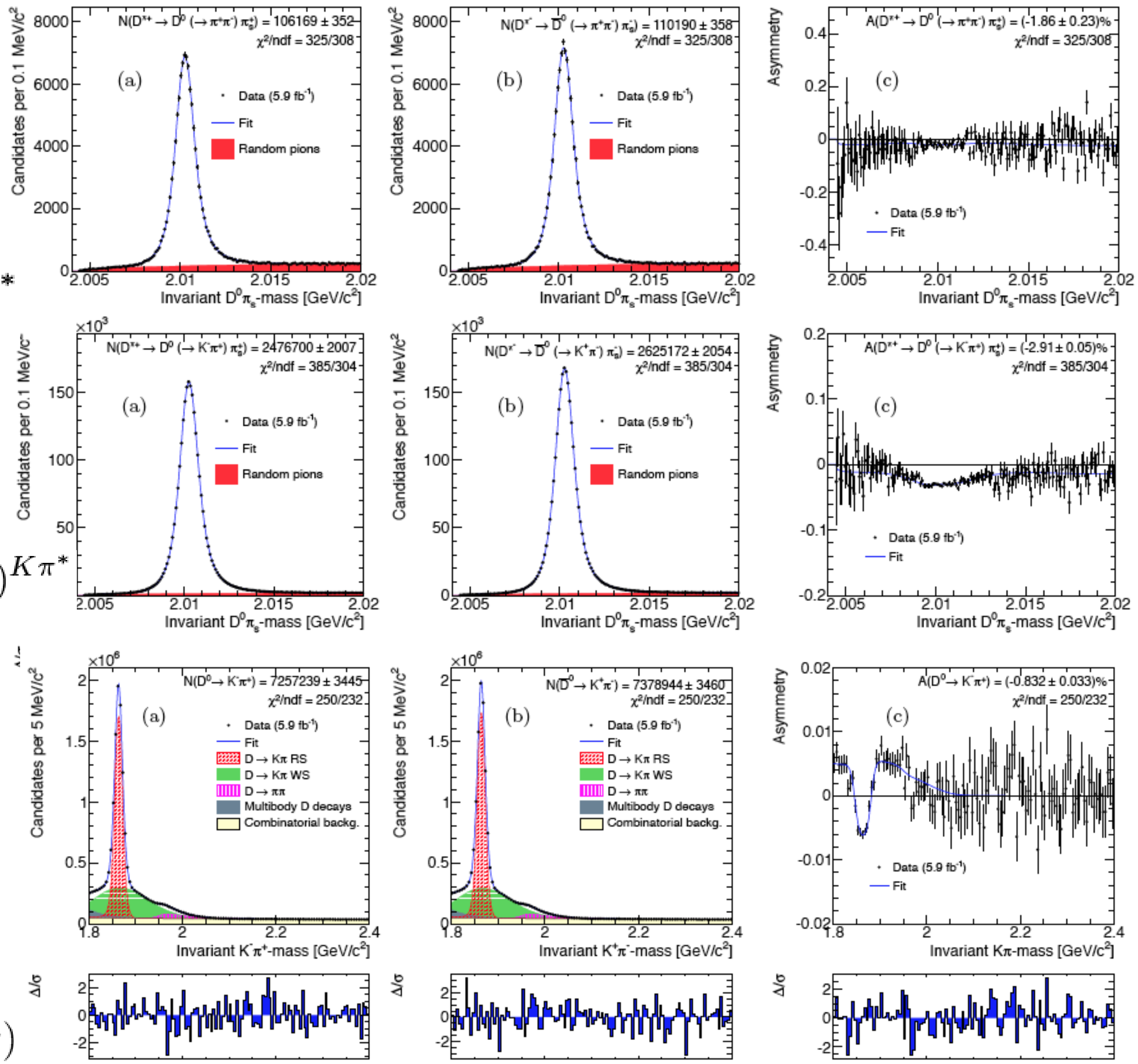
$$A(K\pi^*) = A_{CP}(K\pi) + \delta(\pi_s)^{K\pi^*} + \delta(K\pi)^{K\pi^*}$$

- Measure Kp/Kp asymmetry with untagged D0→Kpi

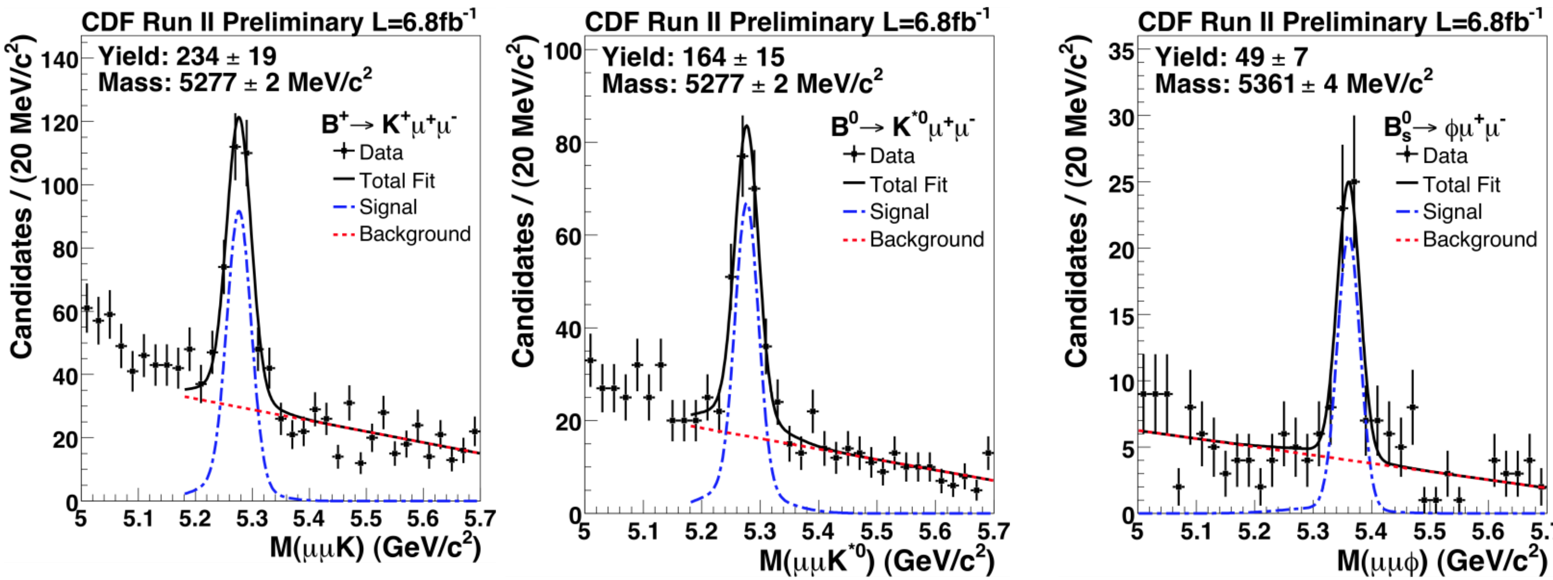
$$A(K\pi) = A_{CP}(K\pi) + \delta(K\pi)^{K\pi}$$

- Obtain corrected CP asymmetry as:

$$A_{CP}(hh) = A(hh^*) - A(K\pi^*) + A(K\pi)$$



B→K(*) $\mu^+\mu^-$ signals

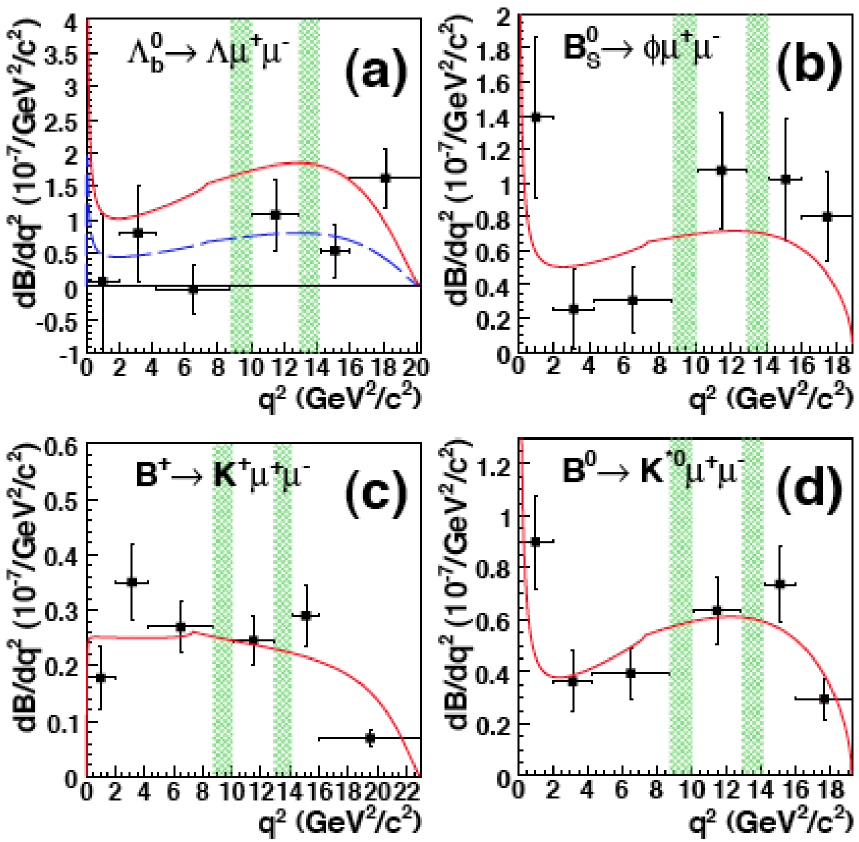


	$B^+ \to K^+\mu^+\mu^-$	$B^0 \to K^{*0}\mu^+\mu^-$	$B_s^0 \to \phi\mu^+\mu^-$
CDF	$[0.46\pm0.04\pm0.02]\times10^{-6}$	$[1.02\pm0.10\pm0.06]\times10^{-6}$	$[1.47\pm0.24\pm0.46]\times10^{-6}$
Babar	$[0.41\pm0.16\pm0.02]\times10^{-6}$	$[1.35\pm0.40-0.37\pm0.10]\times10^{-6}$	
Belle	$[0.53\pm0.08(+0.07-0.03]\times10^{-6}$	$[1.06+0.19-0.14\pm0.07]\times10^{-6}$	

PRL 102, 091803 (2009)

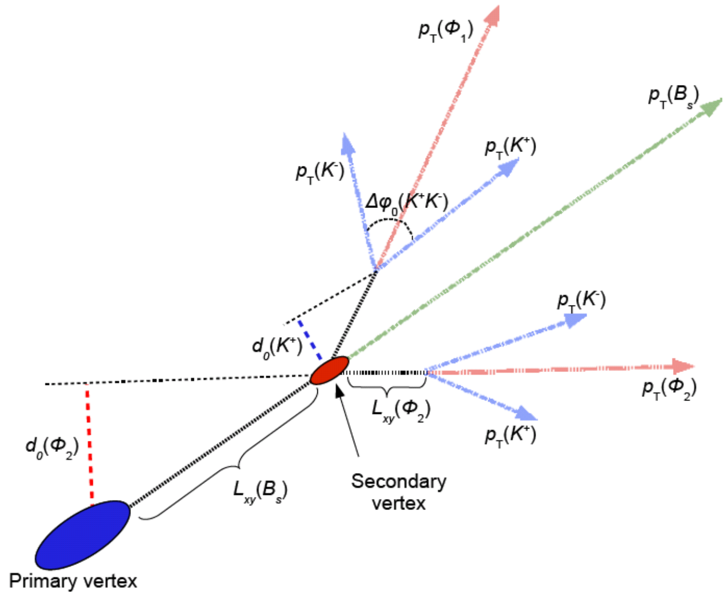
PRL. 103, 171801 (2009)

Exclusive b→sμ⁺μ⁻ Decay Rate



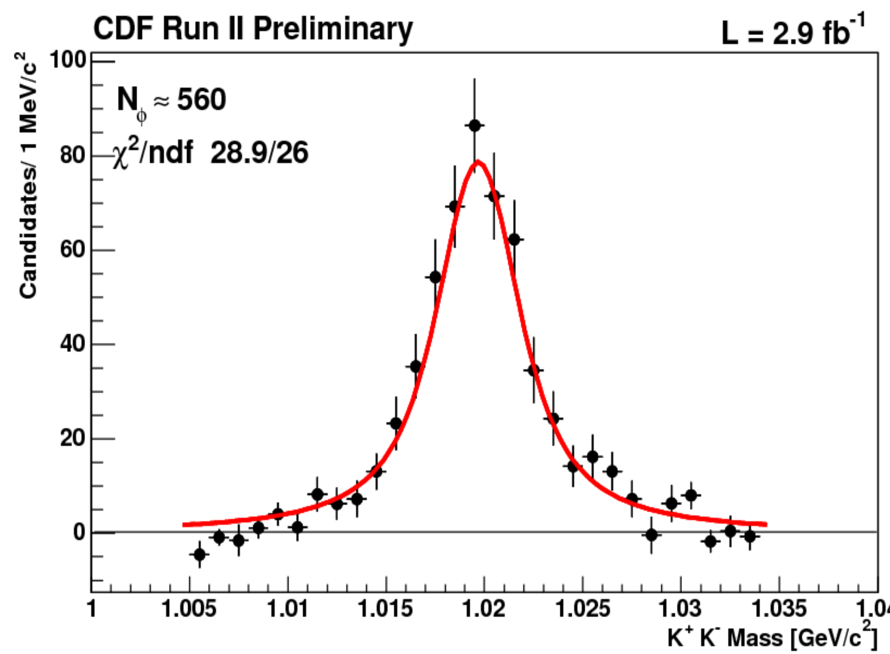
- First attempt at barion and Bs mode diff decay rate

$B_s \rightarrow \phi\phi \rightarrow [K^+K^-][K^+K^-]$ Signal

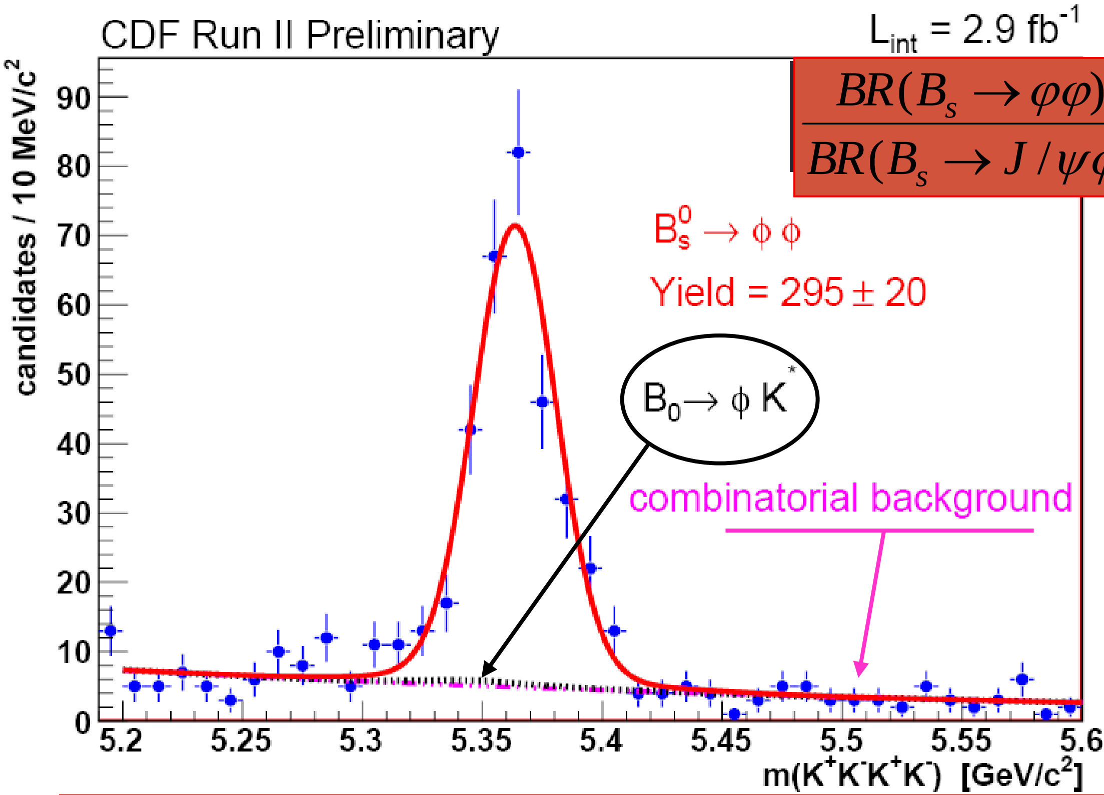


Variables		Requirements $B_s^0 \to \phi\phi$	$B_s^0 \to J/\psi\phi$
L_{xy}^B	$[\mu m]$	> 330	> 290
$p_{T\,min}^K$	$[GeV/c]$	> 0.7	
p_T^ϕ	$[GeV/c]$		> 1.4
χ^2_{xy}		< 17	< 15
d_0^B	$[\mu m]$	< 65	< 80
$d_0^{\phi\,max}$	$[\mu m]$	> 85	
$p_T^{J/\psi}$	$[GeV/c]$		> 2.0

- Take $|m(KK)-m_{\phi(1020)}|<15$ MeV/c^2
- $B_d \rightarrow \phi K^*$ reflection ~ 3%, no other peaking bkg from simulation of B_s or Λ_b decays
- Use $B_s \rightarrow J/\psi\phi$ with the same trigger selection for normalization in the BR measurement and as a powerful control sample for polarization measurement



Branching Ratio $B_s \to \phi\phi$



$$\frac{BR(B_s \to \varphi\varphi)}{BR(B_s \to J/\psi\varphi)} = \left(1.78 \pm 0.14(stat.) \pm 0.20(sys.)\right) \cdot 10^{-2}$$

- Syst. dominated by polarization uncertainties (will be reduced)
- Use $BR(B_s \to J/\psi\phi) = [13.5 \pm 4.6] \cdot 10^{-2}$
  - updated from PDG using more recent f_s/f_d

for absolute branching ratio:

$$BR(B_s \to \varphi\varphi) = \left(24.0 \pm 2.1(stat.) \pm 2.7(sys.) \pm 8.2(BR)\right) \cdot 10^{-6}$$

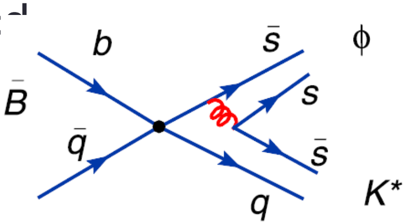
Consistent with both QCDF and pQCD (large uncertainties):

$$BR(B_s \to \varphi\varphi) = \begin{matrix} \left(19.5 \pm 1.0(par.)^{+13.1}_{-8.0}(th.)\right) \cdot 10^{-6} & \text{M.Beneke et al., hep-ph/0612290 (QCDF)} \\ (35.3^{+8.3}_{-6.9}(par.)^{+16.7}_{-10.2}(th.)) \cdot 10^{-6} & \text{A.Ali et al., hep-ph/0703162 (pQCD)} \end{matrix}$$

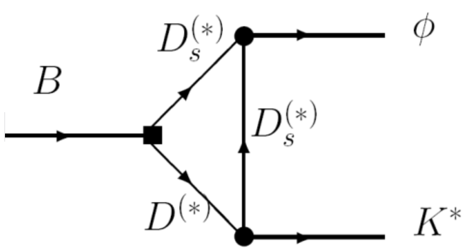
$B_s \rightarrow \phi\phi$ Polarization

- In $B \rightarrow VV$ decays 3 decay product relative angular momentum states possible:
  - 3 independent decay amplitudes
  - Best decomposed in a longitudinal and two transverse polarization amplitudes A_0,$A_{//}$(CP even), $A_{\perp}$(CP odd)

- Naïve expectation: $|A_0| >> |A_{//}| \sim |A_{\perp}|$
  - V-A nature of weak interaction and conservation helicity in qc



- Experimentally violated in penguin decays:
  - subleading contribution (penguin annihilation) **[e.g. A. L. Kagan, Phys. Lett. B 601, 151 (2004); Beneke Nucl.Phys. B774:64-101,2007]**
  - Final State Interaction (FSI) **[P. Colangelo, et al., Phys. Lett. 597, 291 (2004) + many others]**
  - New Physics ?



- $B_s \rightarrow \phi\phi$ Can help resolve the puzzle:
  - ➢ if PA is the reason can predict polarization in other modes e.g. $B_s \rightarrow \phi\phi$ **[A.Datta, et al. Eur.Phys.J.C60:279-284,2009]**

$B_s \to \phi\phi$ Polarization (formulae)

$$\frac{d^4\Gamma(\vec{\omega},t)}{dt\,d\vec{\omega}} = \frac{9}{32\pi}\sum_{i=1}^{6} K_i(t) f_i(\vec{\omega})$$

$$K_1(t) = \frac{1}{2}|A_0|^2\left[(1+\cos\phi_V)e^{-\Gamma_L t} + (1-\cos\phi_V)e^{-\Gamma_H t} + 2e^{-\Gamma t}\sin(\Delta m t)\sin\phi_V\right]$$

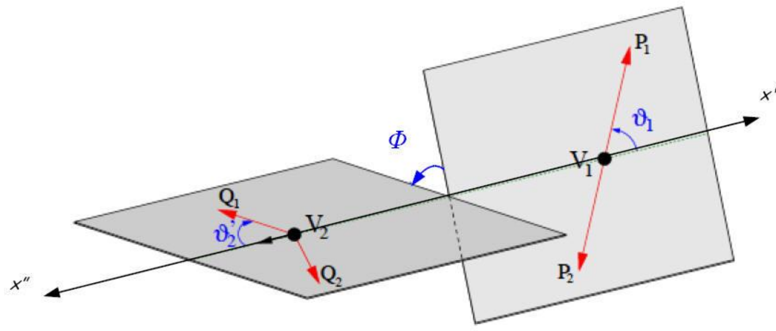
$$K_2(t) = \frac{1}{2}|A_{||}|^2\left[(1+\cos\phi_V)e^{-\Gamma_L t} + (1-\cos\phi_V)e^{-\Gamma_H t} + 2e^{-\Gamma t}\sin(\Delta m t)\sin\phi_V\right]$$

$$K_3(t) = \frac{1}{2}|A_{\perp}|^2\left[(1-\cos\phi_V)e^{-\Gamma_L t} + (1+\cos\phi_V)e^{-\Gamma_H t} - 2e^{-\Gamma t}\sin(\Delta m t)\sin\phi_V\right]$$

$$K_4(t) = |A_{||}||A_{\perp}|\left[e^{-\Gamma t}\left(\sin\delta_1\cos(\Delta m t) - \cos\delta_1\sin(\Delta m t)\cos\phi_V\right) - \frac{1}{2}\left(e^{-\Gamma_H t} - e^{-\Gamma_L t}\right)\cos\delta_1\sin\phi_V\right]$$

$$K_5(t) = \frac{1}{2}|A_0||A_{||}|\cos(\delta_2-\delta_1)\left[(1+\cos\phi_V)e^{-\Gamma_L t} + (1-\cos\phi_V)e^{-\Gamma_H t} + 2e^{-\Gamma t}\sin(\Delta m t)\sin\phi_V\right]$$

$$K_6(t) = |A_0||A_{||}|\left[e^{-\Gamma t}\left(\sin\delta_2\cos(\Delta m t) - \cos\delta_2\sin(\Delta m t)\cos\phi_V\right) - \frac{1}{2}\left(e^{-\Gamma_H t} - e^{-\Gamma_L t}\right)\cos\delta_2\sin\phi_V\right]$$



$$f_1(\vec{\omega}) = 4\cos^2\vartheta_1\cos^2\vartheta_2$$
$$f_2(\vec{\omega}) = \sin^2\vartheta_1\sin^2\vartheta_2(1+\cos 2\Phi)$$
$$f_3(\vec{\omega}) = \sin^2\vartheta_1\sin^2\vartheta_2(1-\cos 2\Phi)$$
$$f_4(\vec{\omega}) = -2\sin^2\vartheta_1\sin^2\vartheta_2\sin 2\Phi$$
$$f_5(\vec{\omega}) = \sqrt{2}\sin 2\vartheta_1\sin 2\vartheta_2\cos\Phi$$
$$f_6(\vec{\omega}) = -\sqrt{2}\sin 2\vartheta_1\sin 2\vartheta_2\sin\Phi$$

Untagged + ϕ_V=0

$$\frac{d^4\Gamma(\vec{\omega},t)}{dt\,d\vec{\omega}} = \frac{9}{32\pi}\left[\mathcal{F}_o(\vec{\omega})\mathcal{K}_L(t) + \mathcal{F}_e(\vec{\omega})\mathcal{K}_H(t)\right]$$

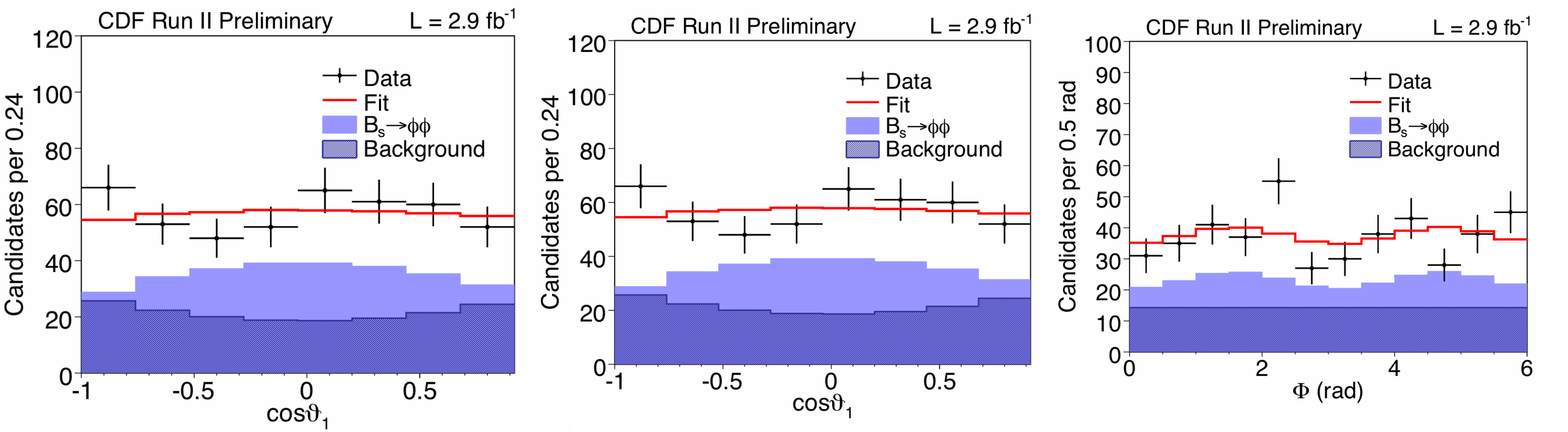
Systematic Tables

	$B_s^0 \to \phi\phi$	$B_s^0 \to J/\psi\phi$
	$\Delta N_{\phi\phi}/N_{\phi\phi}$	$\Delta N_{J/\psi\phi}/N_{J/\psi\phi}$
fit range	3%	-
signal parametrization	3%	2%
background subtraction: error on BRs	1%	1%
	$\Delta\varepsilon_{\phi\phi}/\varepsilon_{\phi\phi}$	$\Delta\varepsilon_{J/\psi\phi}/\varepsilon_{J/\psi\phi}$
polarization in MC	7%	6%
	$\Delta\varepsilon_{\phi\phi}/\varepsilon_{J/\psi\phi}$	
XFT particle dep.	4%	
p_T reweight	0.9%	
	$\Delta\varepsilon_{\mu}/\varepsilon_{\mu}$	
η parametrization & correlation	0.9%	

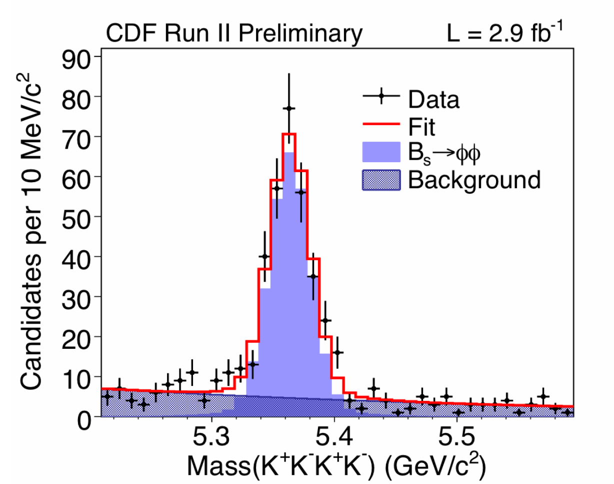
Table 16: *Contributions to the total relative uncertainty from the systematic uncertainty sources considered.*

	$\lvert A_0\rvert^2$ syst	$\lvert A_\parallel\rvert^2$ syst	$\lvert A_\perp\rvert^2$ syst	$\cos\delta_\parallel$ syst
MC reweight	±0.003	±0.001	±0.002	±0.007
Acceptance binning	±0.001	±0.001	±0.000	±0.004
Acceptance Model	±0.005	±0.002	±0.003	±0.005
Background Model	±0.001	±0.001	±0.002	±0.009
Acceptance ct-dependence	±0.000	±0.001	±0.001	±0.004
Reflection component	±0.008	±0.002	±0.006	±0.019
Non-resonant contribution	±0.013	±0.003	±0.010	±0.084
Satellite peak	±0.004	±0.000	±0.004	±0.020
Acceptance $\Delta\Gamma$-dependence	±0.009	±0.009	±0.016	±0.011
$\tau_{L(H)}$ uncertainties	±0.008	±0.006	±0.017	
total	±0.021	±0.011	±0.027	±0.089

$B_s \to \phi\phi$ Polarization Fit

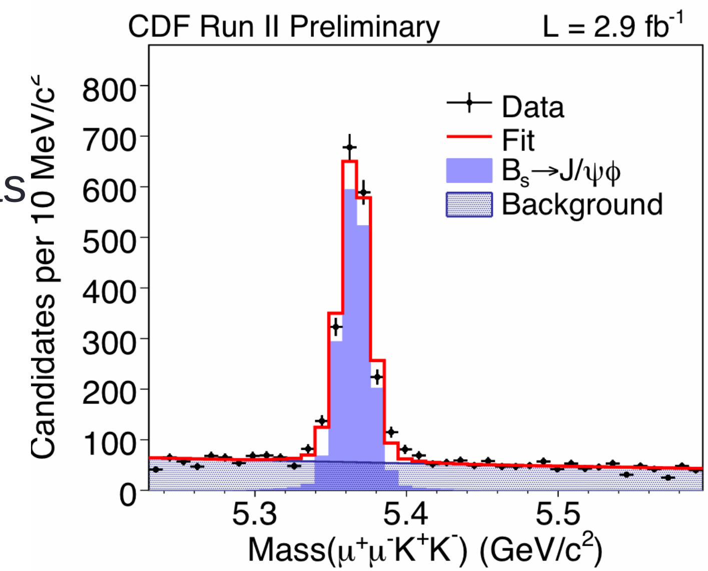


- Unbinned maximum likelihood fit to mass and decay angles
- Acceptance correction from simulation, background modeled on sideband (polinomials) and fitted in the whole mass range
- Cross check with $B_s \to J/\psi\phi$ collected in the same trigger (1700 ev.) consistent with WA within stat. uncertainties



$B_s \rightarrow J/\psi\phi$ Polarization

- Analysis performed in transversity basis
- Assume no CP violation: *bs = 0*
- Angular acceptance determined from simulation as in the *Bs* → *ΦΦ* case
- Compared to CDF measurement from di-muon trigger with 1.7 fb-1 [PRL 100, 121803 (2008)]
- and DØ measurement with 2.8 fb^{-1} [Phys.Rev.Lett.102:032001,2009]



		Dimuon sample result	
$\lvert A_0\rvert^2$	0.534 ± 0.019	$0.531 \pm 0.020(\text{stat}) \pm 0.007(\text{syst})$	0.555 ± 0.027
$\lvert A_{\parallel}\rvert^2$	0.220 ± 0.025	$0.239 \pm 0.029(\text{stat}) \pm 0.011(\text{syst})$	0.244 ± 0.032

Physical Review Letters, 100:121803, 2008