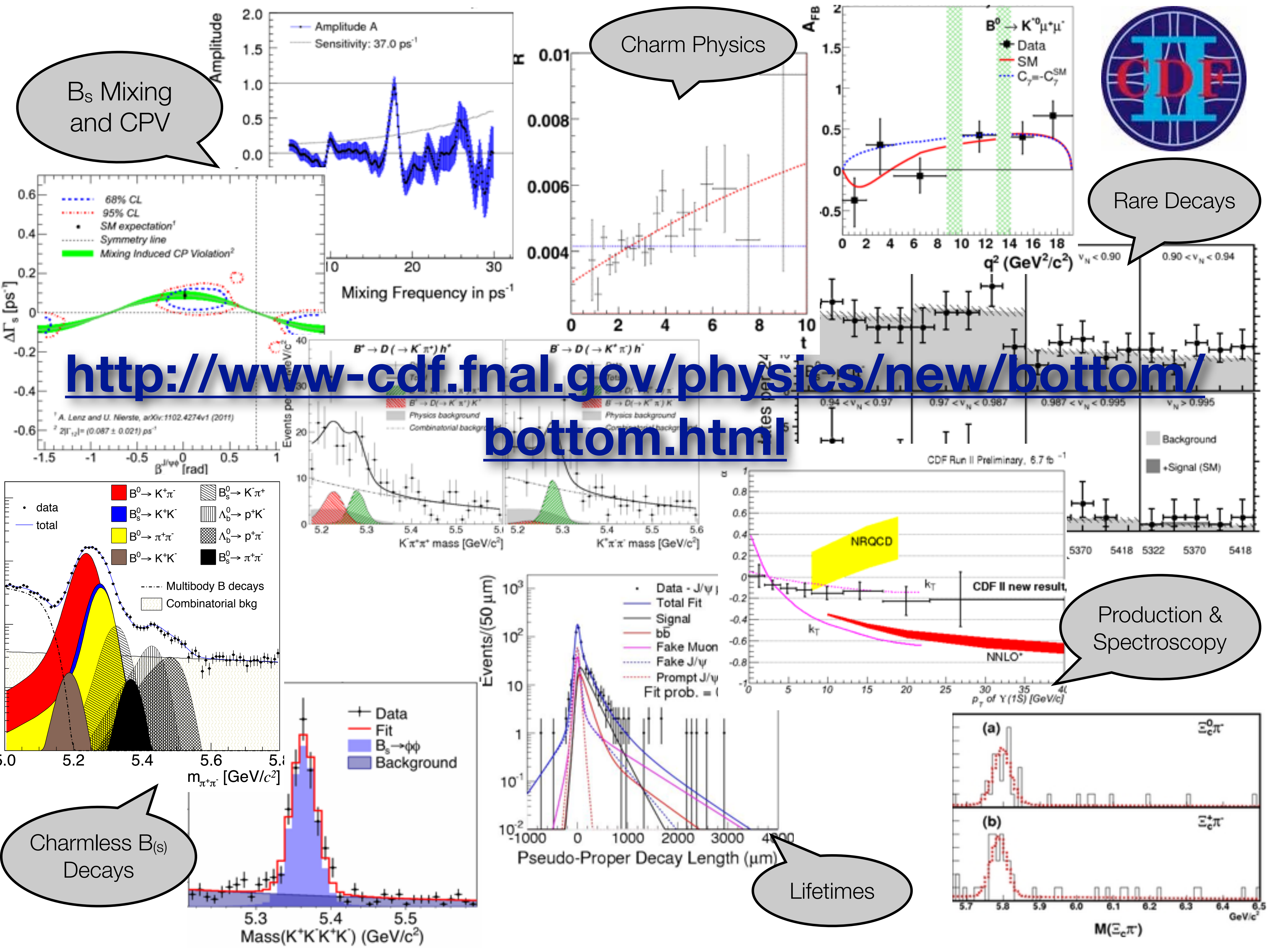
XXVI Rencontres de Physique de la Vallée d'Aoste
Feb 26th-Mar 3rd 2012, La Thuile, Italy

Charm Physics at CDF

Angelo Di Canto
(INFN Pisa, University of Heidelberg)
on behalf of the CDF Collaboration

Heavy Flavor at the Tevatron

- In ~10 years of data-taking Tevatron's experiments pioneered and established the study of HF physics in hadron collisions
  - Unique access to B_s physics
  - World-leading rare decays searches
  - World leading masses/lifetimes
  - b-baryons discoveries
  - Precision CPV/mixing in charm
  - ...



Bs Mixing and CPV

Charm Physics

Rare Decays

Production & Spectroscopy

Charmless B(s) Decays

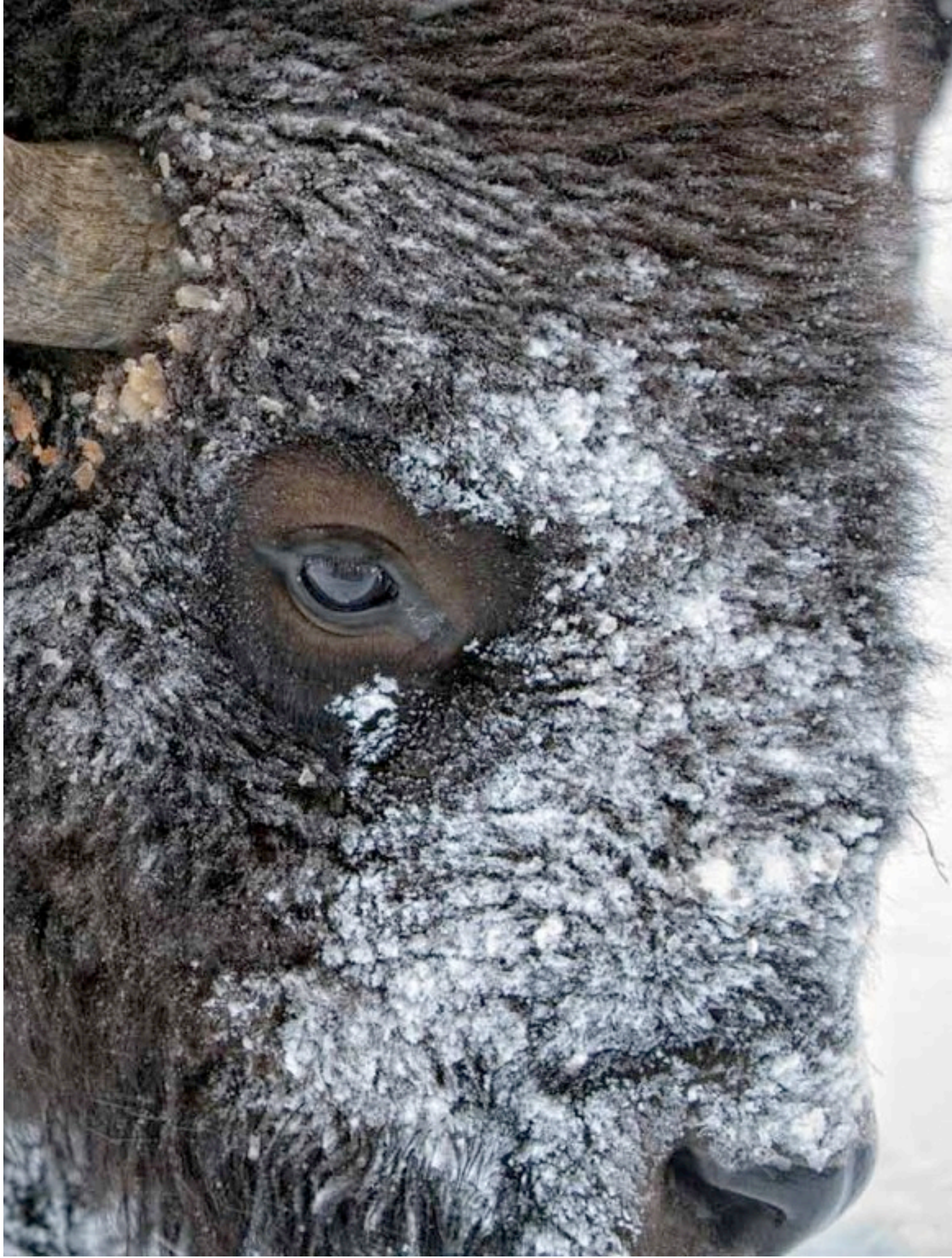
Lifetimes

http://www-cdf.fnal.gov/physics/new/bottom/bottom.html

This talk

- Brand new CDF measurements in the Charm Physics area

- Other HF results from Tevatron (especially B_s physics) will be in Hideki's talk later today

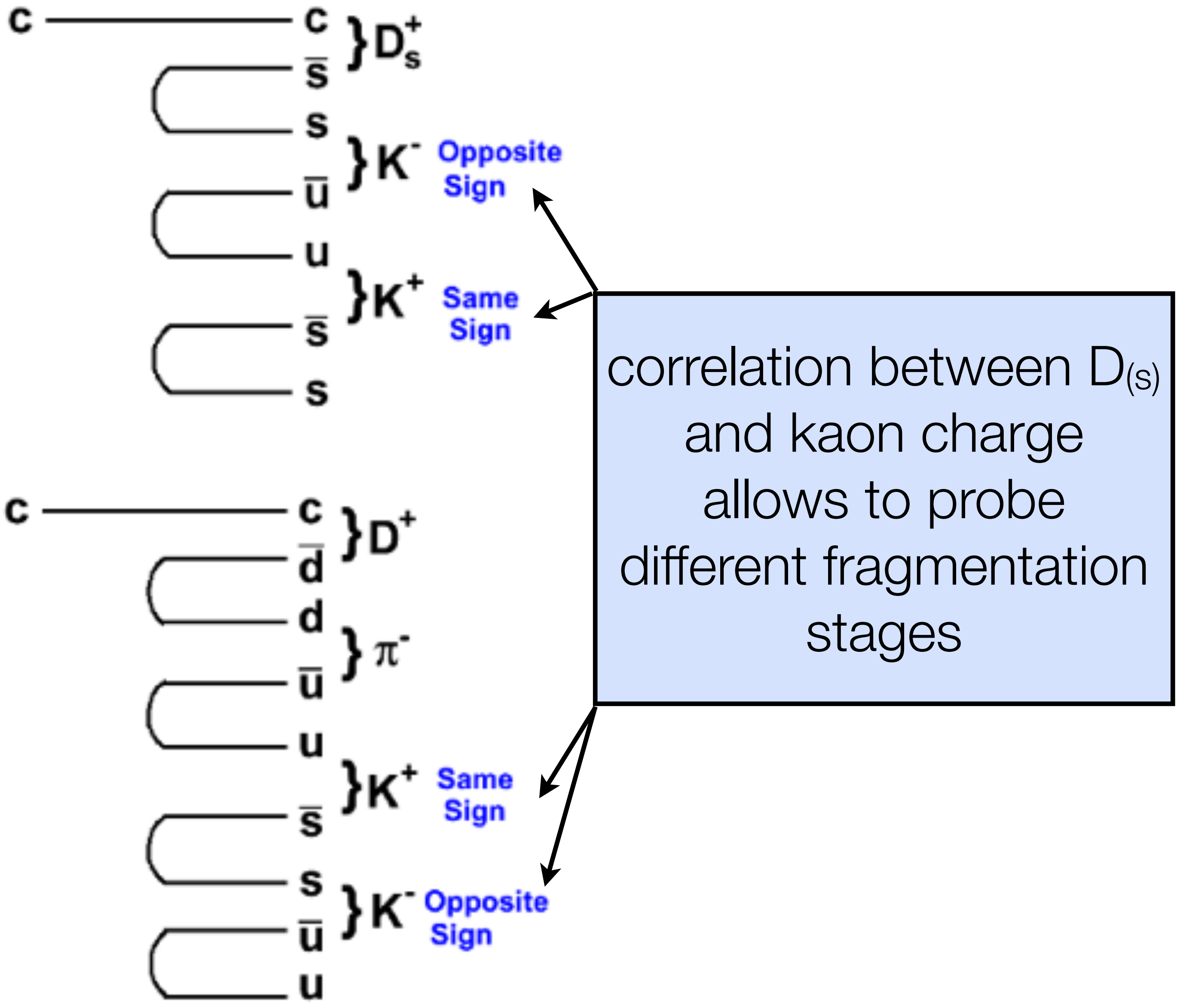


Fragmentation of charm quarks

- A study of quark fragmentation using kaons produced in association with prompt $D_{(s)}^{\pm}$ mesons

Measuring kaon production in association with prompt $D_{(s)}^{\pm}$ mesons

- Quark fragmentation process is described only by phenomenological models which need to be validated on data
- Study of charged particle production around heavy quarks provides unique ways to probe quark fragmentation
- We measure kaons produced around prompt $D_{(s)}^{\pm} \rightarrow \varphi\pi^{\pm}$ using a sample of ~260k $D_s^{\pm}$ and ~140k $D^{\pm}$ reconstructed in 360/pb of data
- Good performances of B_s flavor tagging at CDF also based on fragmentation kaons
- $D_s^{\pm}$ allows to study it in more detail since the it doesn't oscillate and there are no know P-wave strong decays

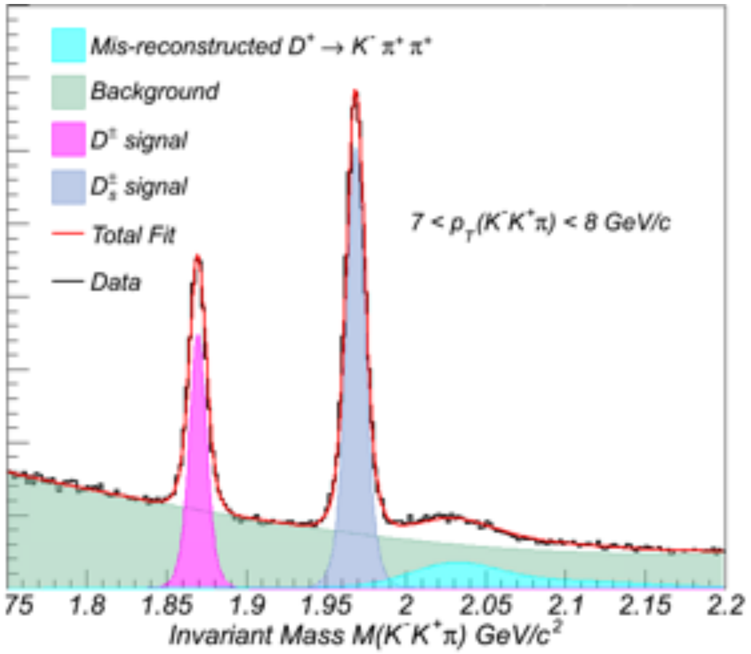


correlation between $D_{(s)}$ and kaon charge allows to probe different fragmentation stages

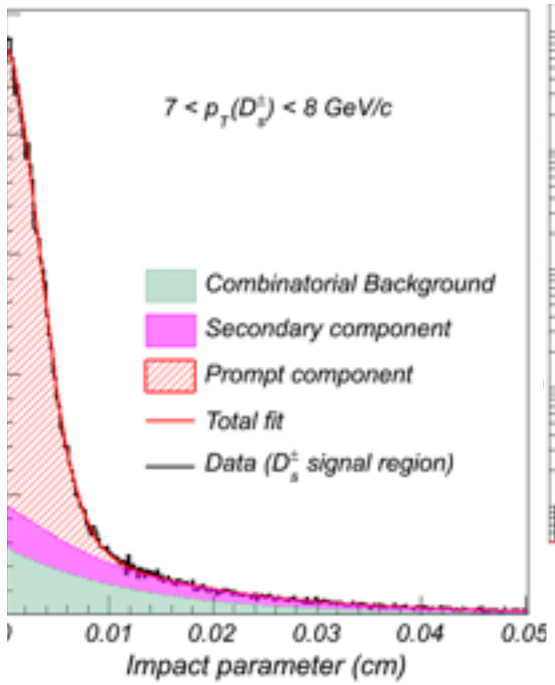
Analysis overview

- Using the sample of maximum-p_T tracks in a $\Delta R = 0.7$ cone around a KKπ candidate, we measure the kaon fraction around the prompt $D_{(s)}^{\pm}$ component by performing a multidimensional likelihood fit:

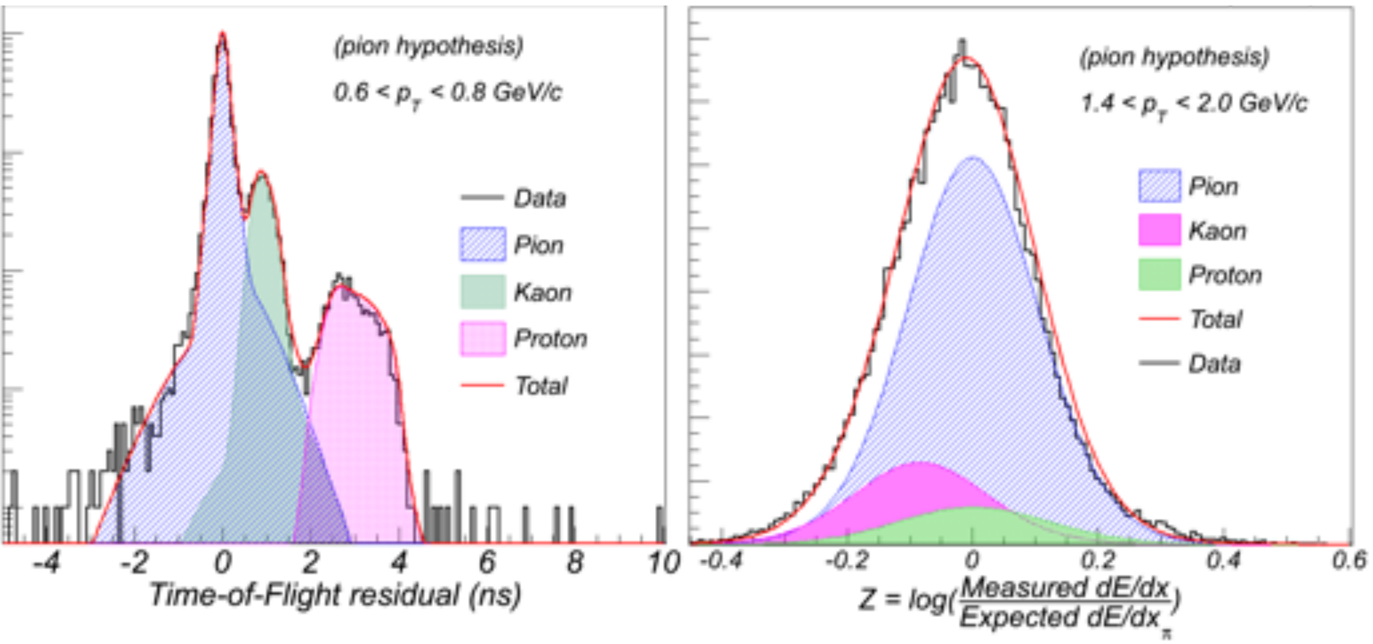
$$\mathcal{L}(m, d_0, t_r, Z) = (1 - f_{D_s^\pm} - f_{D^\pm}) F_B(m, d_0, t_r, Z) \; + \sum_{D_i \in \{D_s^\pm, D^\pm\}} f_{D_i} F_{D_i}(m, d_0, t_r, Z)$$



signal from background



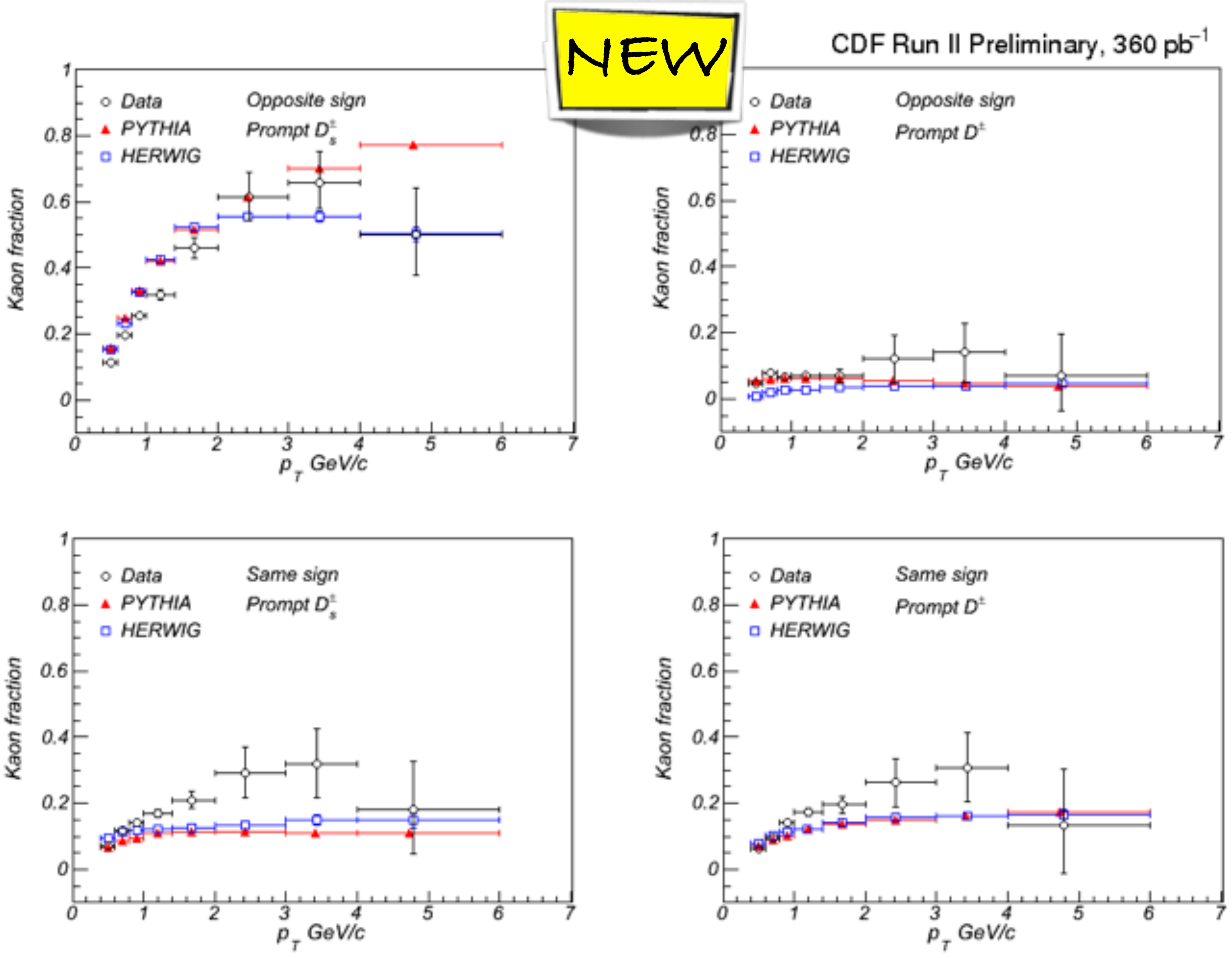
prompt from secondary



kaons from pions/protons

Results

- Compare results with predictions from PYTHIA and HERWIG
- p_T distribution for early fragmentation kaons in better qualitative agreement with predictions, compared to kaons produced in later fragmentation branches
- In addition to p_T, we also compare Δy and M_{DK} distributions



More information in CDF Public Note 10704

CP Violation in neutral charmed mesons

- Time-integrated search for CPV in $D^0 \to K_S \pi^+ \pi^-$
- Updated measurement of $\Delta A_{CP}(D^0 \to h^+ h^-)$

CP Violation in neutral charmed decays

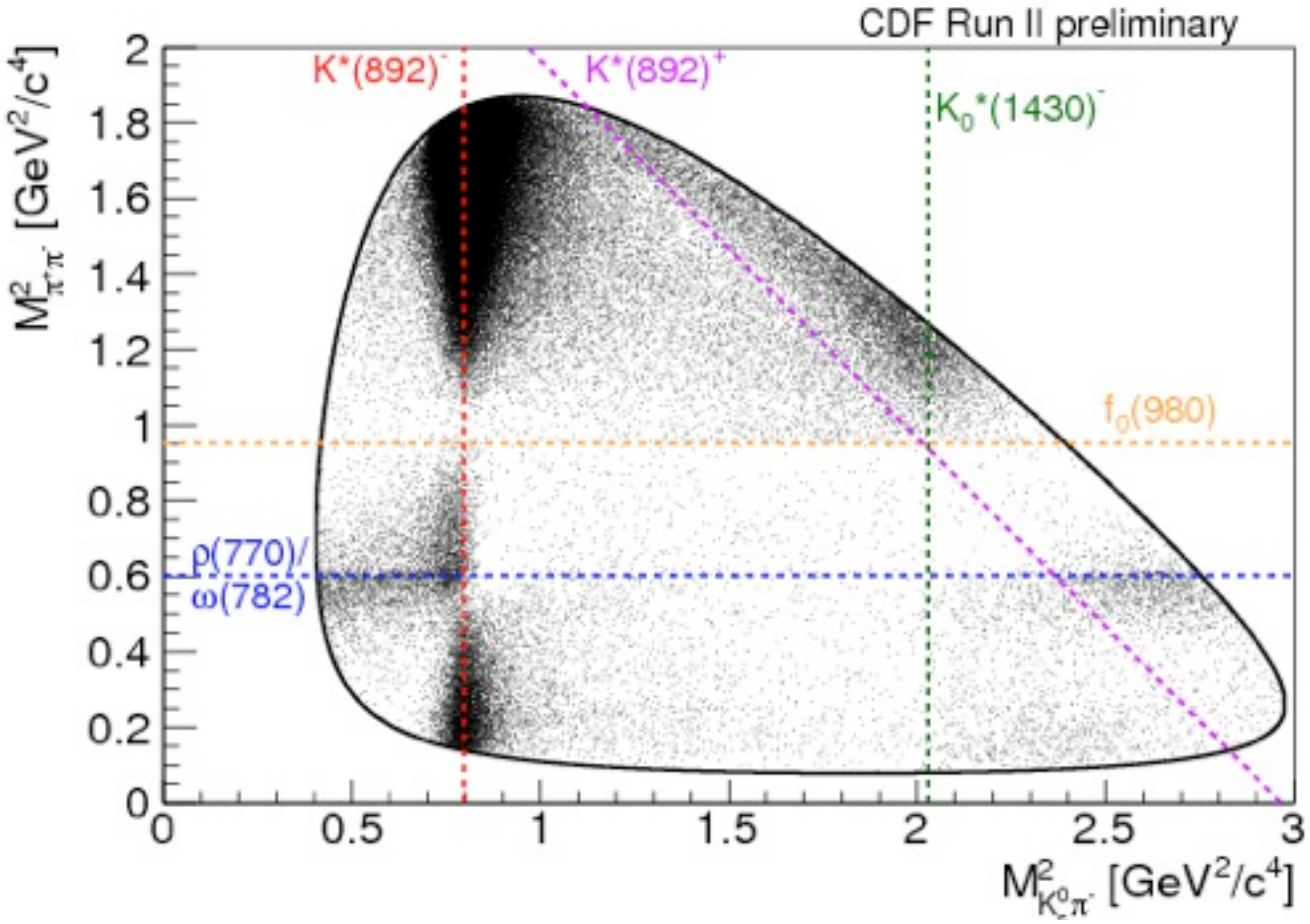
- Charm transitions involve first two generations of quarks, thus CPV in SM is expected to be very small... but how much?

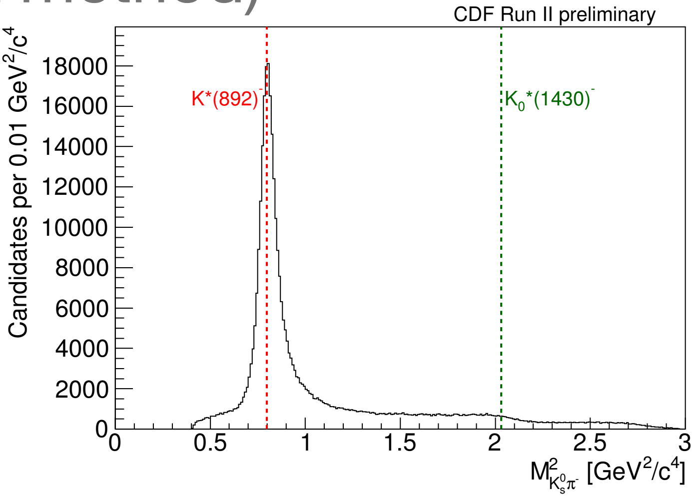
$$V_{\text{CKM}} = \begin{array}{cc} \begin{array}{ccc} d & s & b \end{array} & \\ \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3\left(\rho - i\eta\right) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3\left(1-\rho-i\eta\right) & -A\lambda^2 & 1 \end{pmatrix} & \begin{array}{c} u \\ c \\ t \end{array} \end{array}$$

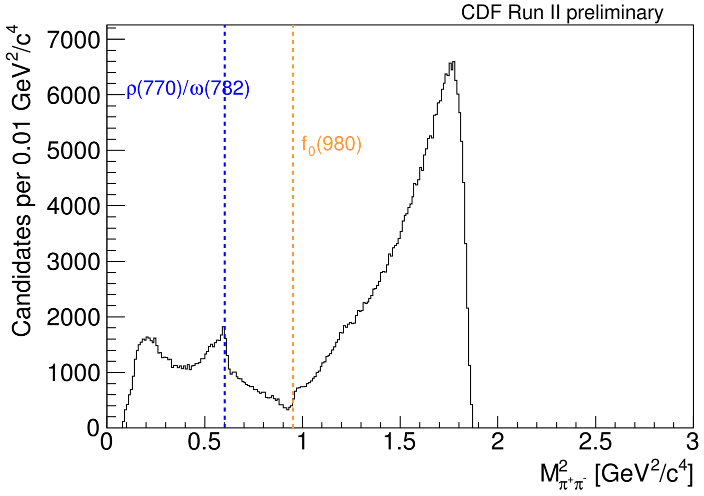
  - For long time there has been consensus that direct CPV in charm at 1% level would be a striking signal of New Physics...
  - ...now, after LHCb measurement of $\Delta A_{CP}(D^0 \rightarrow h^+h^-)$, there is no consensus anymore
- Thus, it is important to provide as much experimental information as possible

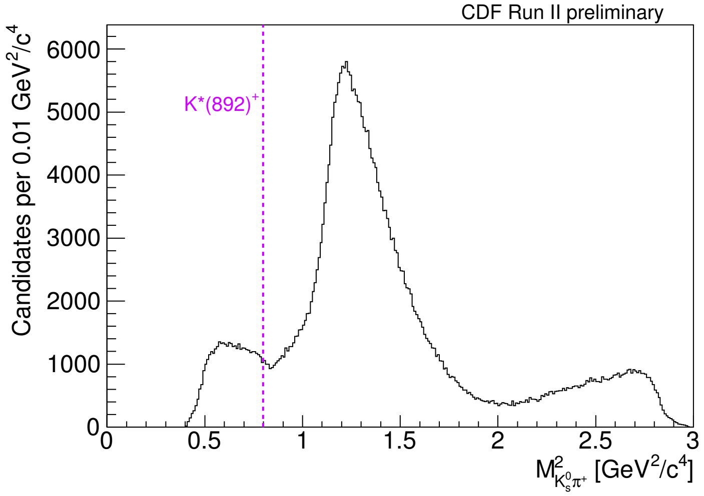
CP Violation in the $D^0 \rightarrow K_S\pi^+\pi^-$ Decay

- In 6/fb of two-track trigger data we search for time-integrated CPV in the resonant substructures of the 3-body $D^0 \rightarrow K_S\pi^+\pi^-$ decay
- First full Dalitz analysis at hadron collider
- Model-independent bin-by-bin comparison of the D^0 and $\bar{D}^0$ Dalitz plots (Miranda method)









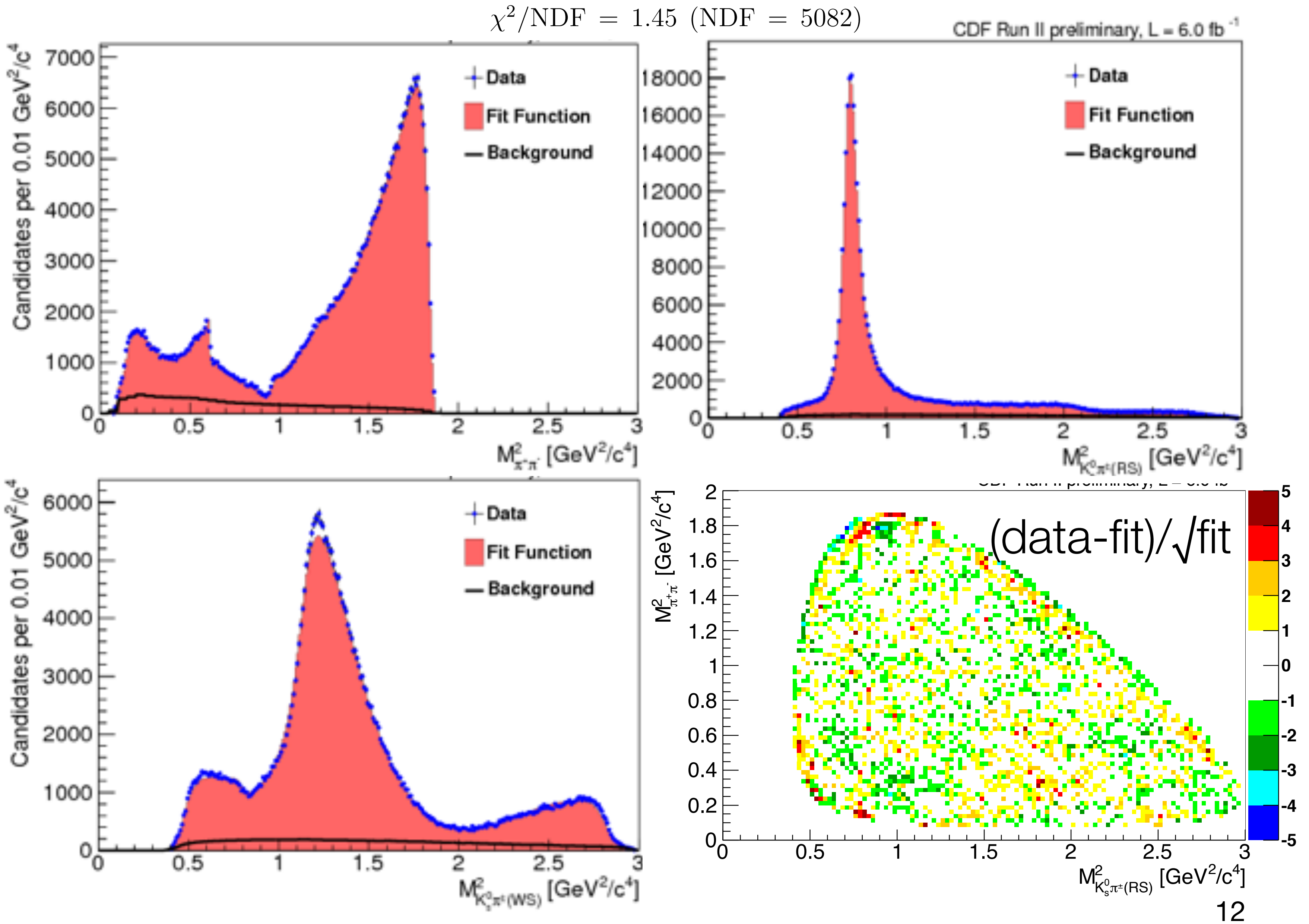
Dalitz fit description

- NN selection isolates ~350k D*→D^0(→$K_S\pi^+\pi^-$)π^+ + c.c. decays

$$\mathcal{L} = \text{Efficiency} \cdot |\mathcal{M}|^2 + \text{Background}$$

$$\mathcal{M} = a_0 \cdot e^{i\delta_0} + \sum_j a_j \cdot e^{i\delta_j} \cdot \mathcal{A}_j$$

- Separate/combined binned fit to D^0 and $\overline{D}^0$ Dalitz plots to search for CPV
  - Each asymmetry self normalized: no need to worry about overall spurious effects
  - Isobar model to describe the resonance structures
  - Efficiency taken from MC, background from mass sidebands



$\chi^2/\text{NDF} = 1.45$ (NDF = 5082)

CDF Run II preliminary, L = 6.0 fb^{-1}

Results

- Table lists asymmetries between sub-resonances fit fractions
  - Big improvement wrt previous results from CLEO (PRD 70, 091101 (2004))...
  - ...but still no hints for any CP violating effect
- The measured value for the overall integrated CP asymmetry is

CDF Run II preliminary

Resonance	$\mathcal{A}_{\rm FF}$ (CDF) [%]	$\mathcal{A}_{\rm FF}$ (CLEO) [%]
$K^*(892)^-$	$0.36 \pm 0.33 \pm 0.40$	$2.5 \pm 1.9\,^{+1.5}_{-0.7}\,^{+2.9}_{-0.3}$
$K_0^*(1430)^-$	$4.0 \pm 2.4 \pm 3.8$	$-0.2 \pm 11.3\,^{+8.6}_{-4.9}\,^{+1.9}_{-1.0}$
$K_2^*(1430)^-$	$2.9 \pm 4.0 \pm 4.1$	$-7 \pm 25\,^{+8}_{-26}\,^{+10}_{-1}$
$K^*(1410)^-$	$-2.3 \pm 5.7 \pm 6.4$	$\cdots$
$\rho(770)$	$-0.05 \pm 0.50 \pm 0.08$	$3.1 \pm 3.8\,^{+2.7}_{-1.8}\,^{+0.4}_{-1.2}$
$\omega(782)$	$-12.6 \pm 6.0 \pm 2.6$	$-26 \pm 24\,^{+22}_{-2}\,^{+2}_{-4}$
$f_0(980)$	$-0.4 \pm 2.2 \pm 1.6$	$-4.7 \pm 11.0\,^{+24.9}_{-7.4}\,^{+0.3}_{-4.8}$
$f_2(1270)$	$-4.0 \pm 3.4 \pm 3.0$	$34 \pm 51\,^{+25}_{-71}\,^{+21}_{-34}$
$f_0(1370)$	$-0.5 \pm 4.6 \pm 7.7$	$18 \pm 10\,^{+2}_{-21}\,^{+13}_{-6}$
$\rho(1450)$	$-4.1 \pm 5.2 \pm 8.1$	$\cdots$
$f_0(600)$	$-2.7 \pm 2.7 \pm 3.6$	$\cdots$
σ_2	$-6.8 \pm 7.6 \pm 3.8$	$\cdots$
$K^*(892)^+$	$1.0 \pm 5.7 \pm 2.1$	$-21 \pm 42\,^{+17}_{-28}\,^{+22}_{-4}$
$K_0^*(1430)^+$	$12 \pm 11 \pm 10$	$\cdots$
$K_2^*(1430)^+$	$-10 \pm 14 \pm 29$	$\cdots$
$K^*(1680)^-$	$\cdots$	$-36 \pm 19\,^{+9}_{-35}\,^{+5}_{-1}$

$$A_{CP}\,(D^0 \rightarrow K_S\pi^+\pi^-) = (-0.05 \pm 0.57\ (\text{stat.}) \pm 0.54\ (\text{syst.}))\%$$

More information in CDF Public Note 10654

CP Violation in $D^0 \rightarrow h^+h^-$ Decays

- Last year, using 5.9/fb of two-track trigger data, CDF produced the world's most precise measurement of CP asymmetries in 2-body D^0 decays:

$$A_{CP}(D^0 \rightarrow K^+K^-) = (-0.24 \pm 0.22 \pm 0.09)\%$$

$$A_{CP}(D^0 \rightarrow \pi^+\pi^-) = (+0.22 \pm 0.24 \pm 0.11)\%$$

$$\Delta A_{CP} = A_{CP}(K^+K^-)-A_{CP}(\pi^+\pi^-) = (-0.46 \pm 0.31 \pm 0.12)\%$$

(PRD 85, 012009 (2012))

- In late November LHCb reported a more precise measurement of ΔA_{CP}, showing first evidence for CP violation in charm decays measuring:

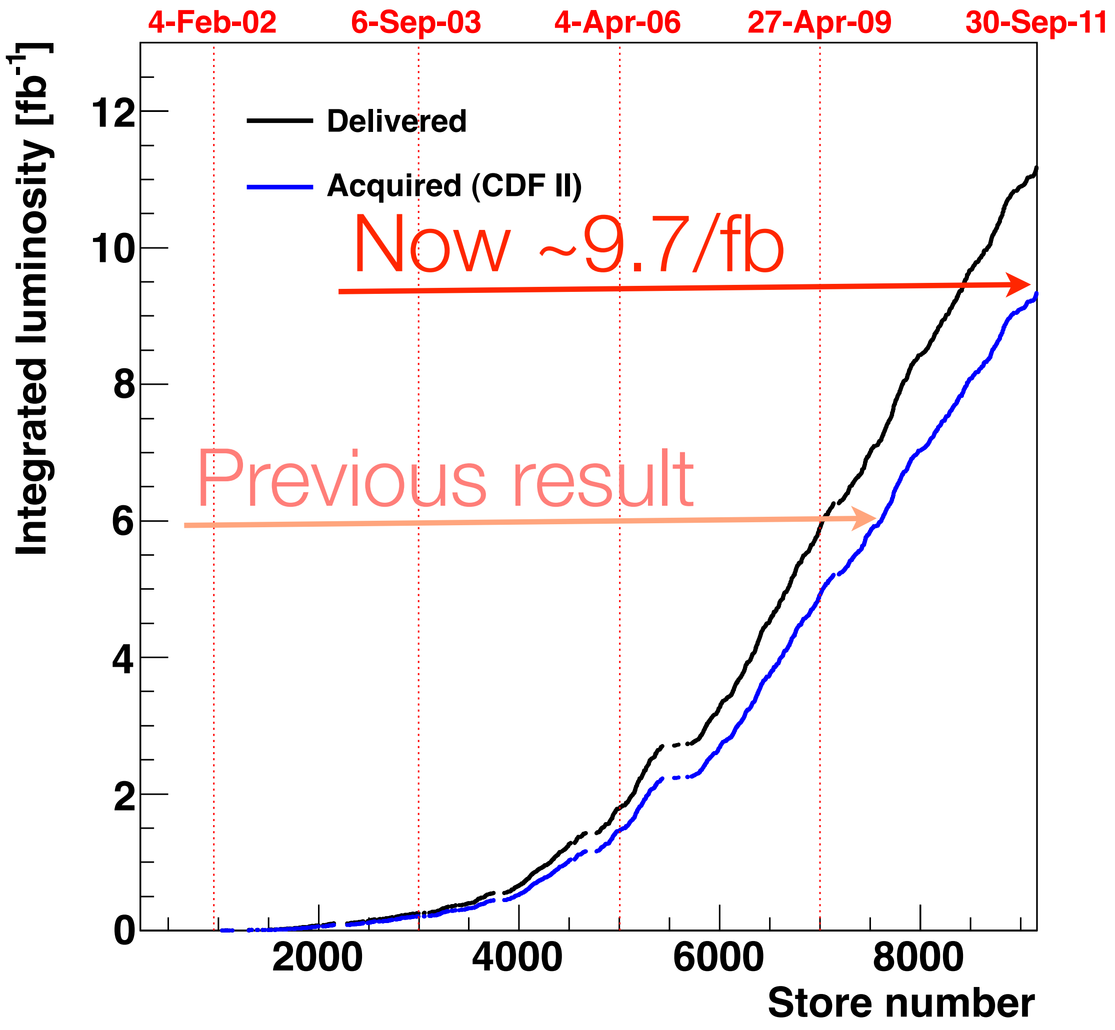
$$\Delta A_{CP}(\text{LHCb}) = (-0.82 \pm 0.21 \pm 0.11)\%$$

(arXiv:1112.0938)

- CDF difference compatible with LHCb but also with zero, insufficient resolution for a conclusive statement

$\Delta A_{CP}(D^0 \to h^+h^-)$ with full Run II dataset

- Measurement updated with full Run II data sample
- Analysis strategy unchanged but new selection has been designed to specifically improve the resolution on ΔA_{CP}
  - About twice more signal events used in the new measurement
  - Expected resolution is competitive with LHCb

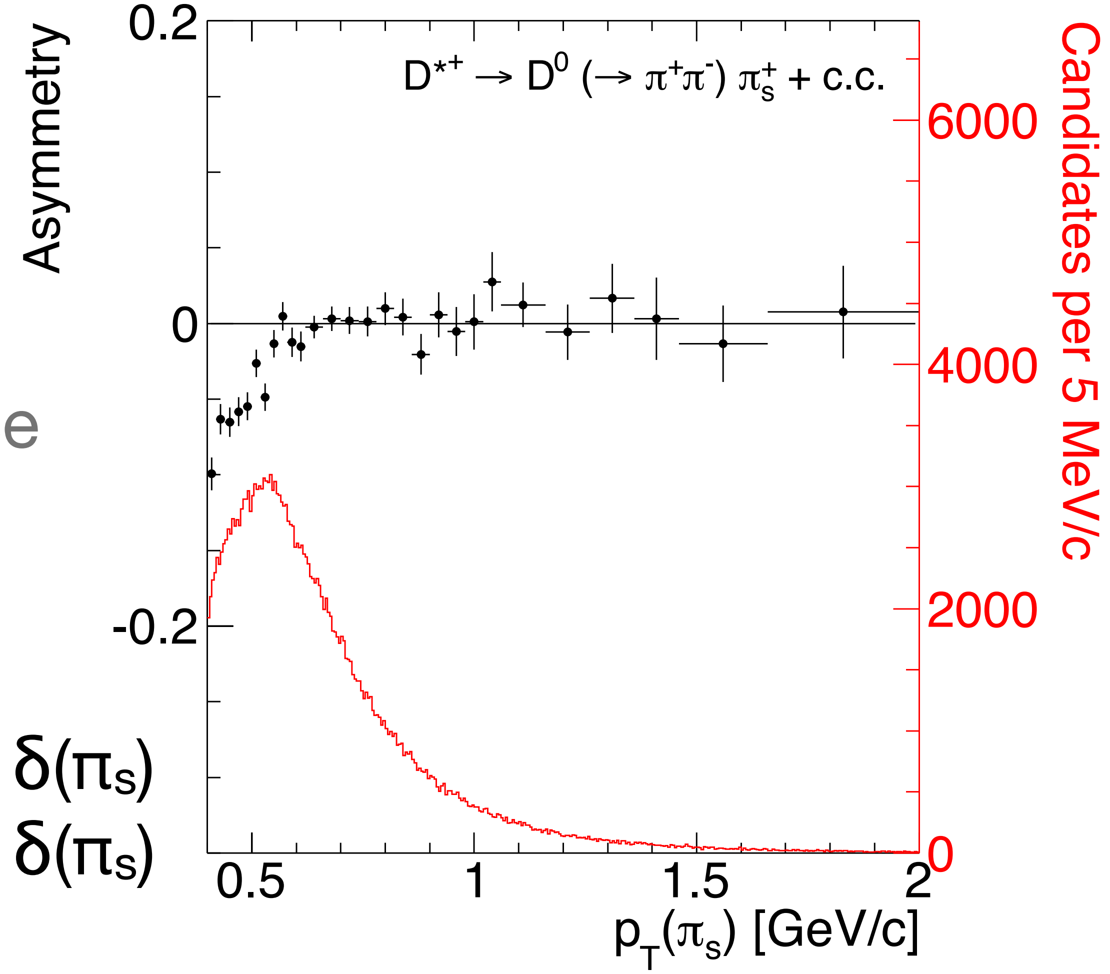


Now ~9.7/fb

Previous result

Analysis overview

- D^0 flavor determined through the $D^* \to D^0\pi_s$ decay, but soft pion induces O(1%) artificial asymmetries



- Cancel detector effects through the difference between raw asymmetries, A, of the two samples:

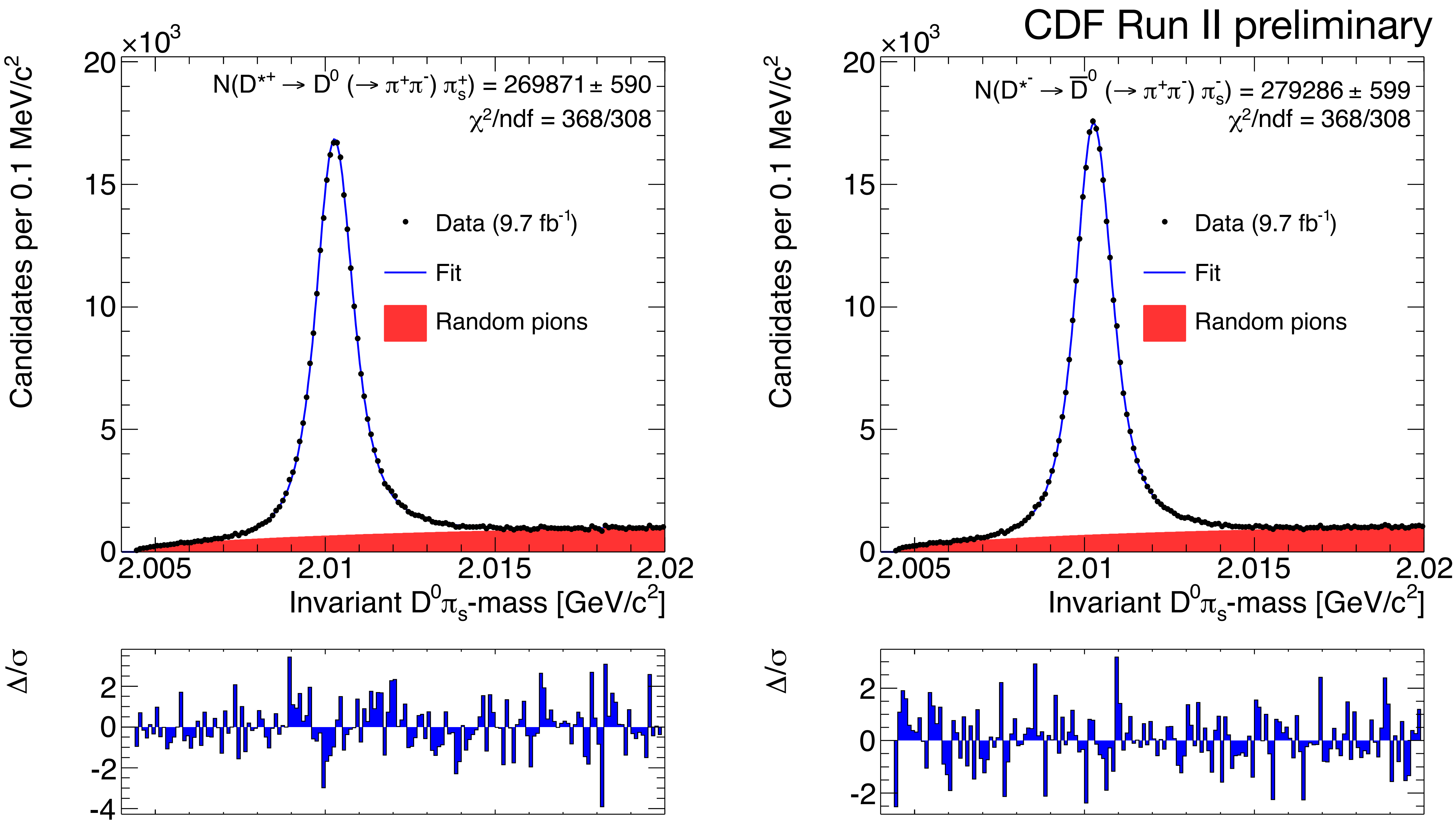
D^*-tagged $D^0 \to K^+K^-$ $\quad A(KK^*) = A_{CP}(K^+K^-) + \delta(\pi_s)$

D^*-tagged $D^0 \to \pi^+\pi^-$ $\quad A(\pi\pi^*) = A_{CP}(\pi^+\pi^-) + \delta(\pi_s)$

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

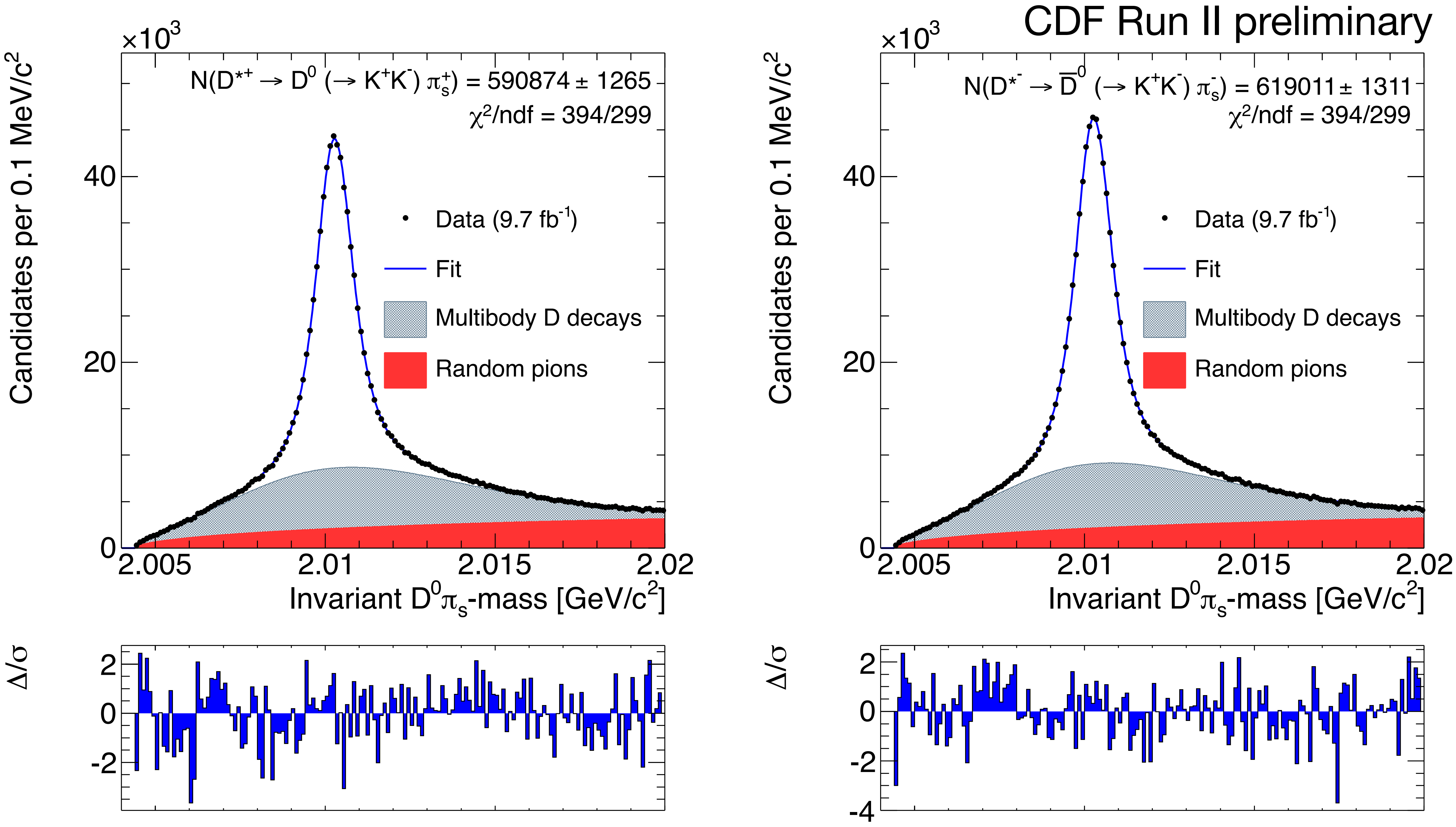
- Detector asymmetries are kinematic dependent, cancellation works if π_s distributions are the same between KK and ππ, make them equal by reweighting

$D^0 \rightarrow \pi^+\pi^-$ fit results



Raw $A(\pi^+\pi^-) = (-1.71 \pm 0.15)\%$

$D^0 \rightarrow K^+K^-$ fit results



Raw $A(K^+K^-) = (-2.33 \pm 0.14)\%$

Final result

NEW

CDF Run II preliminary

$$\Delta A_{CP} = [-0.62 \pm 0.21\ (\text{stat}) \pm 0.10\ (\text{syst})]\%$$

- New CDF result confirms LHCb result: same resolution, <1σ difference in central value

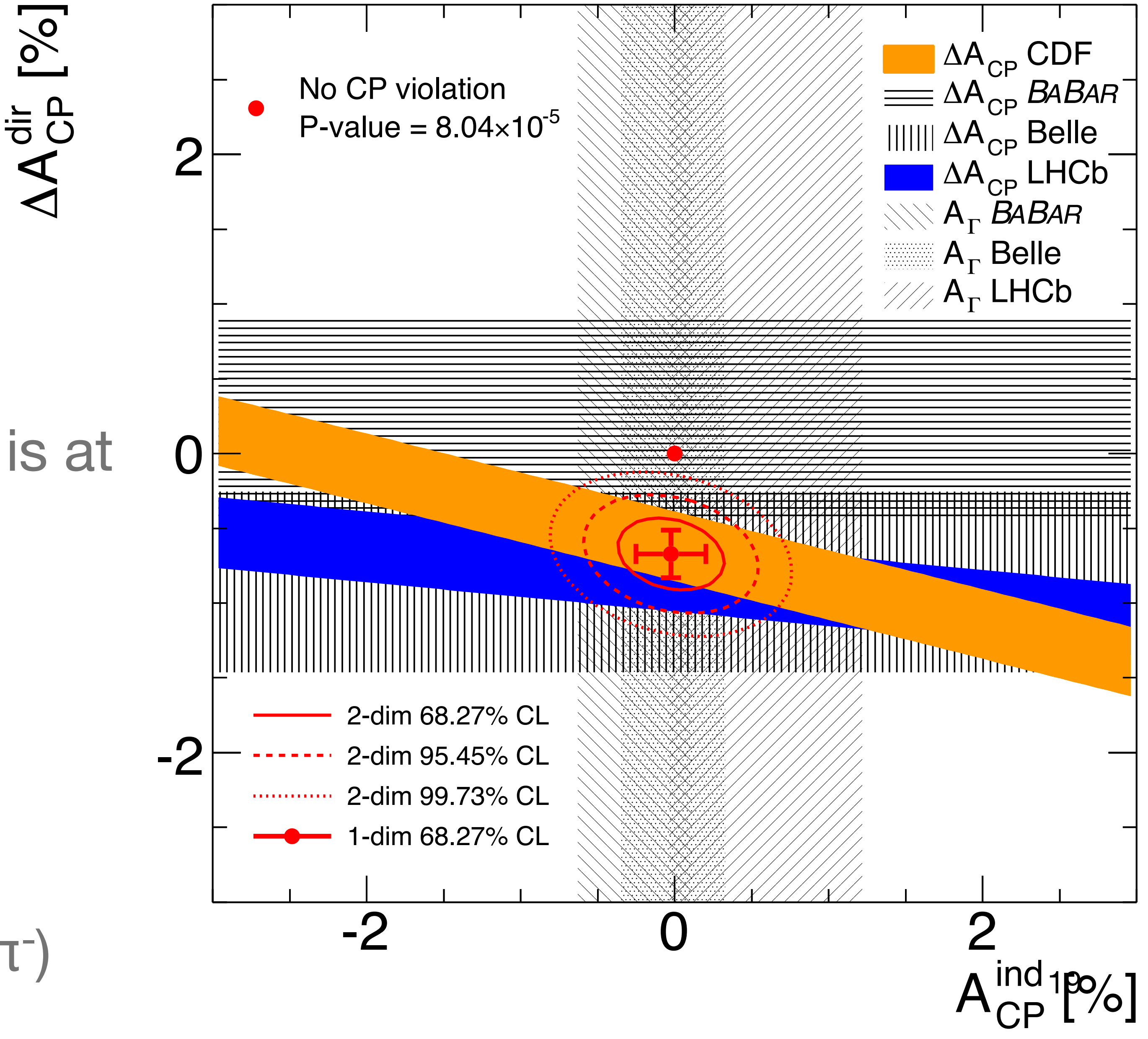
$\Delta A_{CP}(\text{LHCb}) = [-0.82 \pm 0.21 \pm 0.11]\%$

- When combining à la HFAG with other available measurements, no CPV point is at ~3.8σ and

$$\Delta A_{CP}^{dir} = (-0.67 \pm 0.16)\%$$
$$A_{CP}^{ind} = (-0.02 \pm 0.22)\%$$

- CDF will also produce separate measurements of $A_{CP}(K^+K^-)$ and $A_{CP}(\pi^+\pi^-)$

More information in CDF Public Note 10784



Conclusions

- Tevatron continuing to produce a rich program in HF physics
    - Complementary to e^+e^- machines and LHC experiments
- Three brand new, world-leading results shown today... more with full Run II dataset underway...
    - Confirm sizable CPV effects in charm sector