PHYSICS @ τ-c: A THEORIST'S VIEW

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- Introduction
- Charm Physics
- Tau Physics
- EW & QCD
- Conclusions and Outlook

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INTRODUCTION

- In the past 45 years, we (almost) always found what we expected, where we expected
- Distinguish between arguments and indirect evidence:
  - GIM: charm @ GeV
  - Unitarization of Fermi theory: NP at 10^2 GeV
  - GSW: $SU(2)_L \otimes U(1)_Y \rightarrow U(1)_Q$ w. Higgs boson
  - KM: 3^{rd} generation

INTRODUCTION II

- Flavour, EW fit: m_t~170 GeV
- EW fit: m_H=100±30 GeV

- Now we are left with arguments only:
  - Hierarchy problem: NP close to EW scale
  - WIMP miracle: NP close to EW scale
  - gauge coupling unification: NP (SUSY) close to EW scale
- *Although suprises are possible and would be very welcome, need more indirect evidence!*

INTRODUCTION III

- $\tau-c$ offers great opportunities for NP searches:
  - τ flavour and CP violation
  - CPV in D mixing & decays
  - EW physics
  - dark forces
- it can also help us to:
  - reduce uncertainties in other sectors
  - make progress in understanding QCD

CPV IN D MIXING

- D mixing is described by:
  - M_{12}
    - SM: long-distance dominated, not calculable (today, see lattice progress on ΔM_K) but real
    - NP: short distance, calculable w. lattice
  - Γ_{12}
    - SM: not calculable but real
  - $\Phi_{12}=\arg(\Gamma_{12}/M_{12})$
    - $\text{Im } M_{12} = -|M_{12}| \sin\Phi_{12}$ pure NP effect

See talk by A. Kagan

CPV IN D MIXING II

- Define $|D_{S,L}| = p|D^0| \pm q|D^0|$ and $\delta = (1-|q/p|^2)/(1+|q/p|^2)$. All observables can be written in terms of $x = \Delta m/\Gamma$, $y = \Delta\Gamma/2\Gamma$ and δ, with

$$
\begin{aligned}
\sqrt{2}\,\Delta m &= \mathrm{sign}(\cos\Phi_{12})\sqrt{4|M_{12}|^2 - |\Gamma_{12}|^2 + \sqrt{(4|M_{12}|^2 + |\Gamma_{12}|^2)^2 - 16|M_{12}|^2|\Gamma_{12}|^2\sin^2\Phi_{12}}}\,, \\
\sqrt{2}\,\Delta\Gamma &= 2\sqrt{|\Gamma_{12}|^2 - 4|M_{12}|^2 + \sqrt{(4|M_{12}|^2 + |\Gamma_{12}|^2)^2 - 16|M_{12}|^2|\Gamma_{12}|^2\sin^2\Phi_{12}}}\,, \\
\delta &= \frac{2|M_{12}||\Gamma_{12}|\sin\Phi_{12}}{(\Delta m)^2 + |\Gamma_{12}|^2}\,,
\end{aligned}
\tag{7}
$$

- Notice that $\phi = \arg(q/p) = \arg(y + i\delta x) - \arg\Gamma_{12}$
- $|q/p| \neq 1 \Leftrightarrow \phi \neq 0$ clear signals of NP

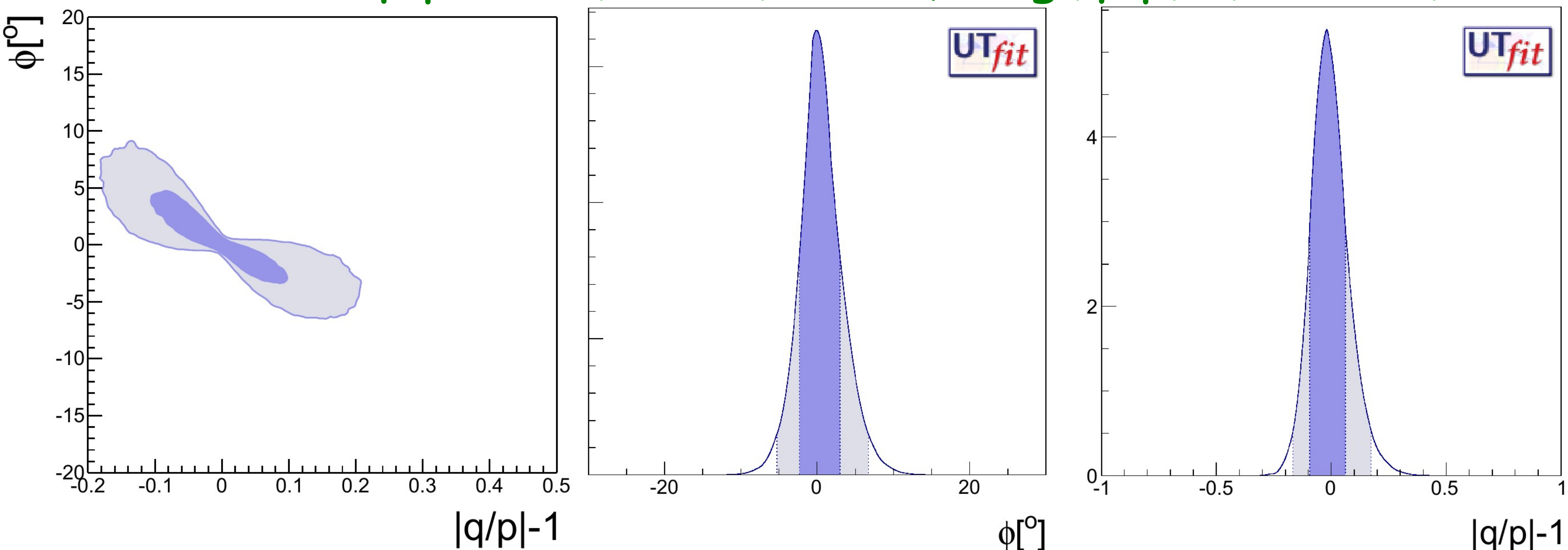
Ciuchini et al; Kagan & Sokoloff

CPV IN MIXING TODAY

- updating the UTfit average with latest LHCb data we obtain:

$x = (4.2 \pm 1.8)\ 10^{-3}$, $y = (6.4 \pm 0.8)\ 10^{-3}$,

$|q/p|-1 = (-2 \pm 8)\ 10^{-2}$, $\phi = \arg(q/p) = (0.3 \pm 2.6)^\circ$

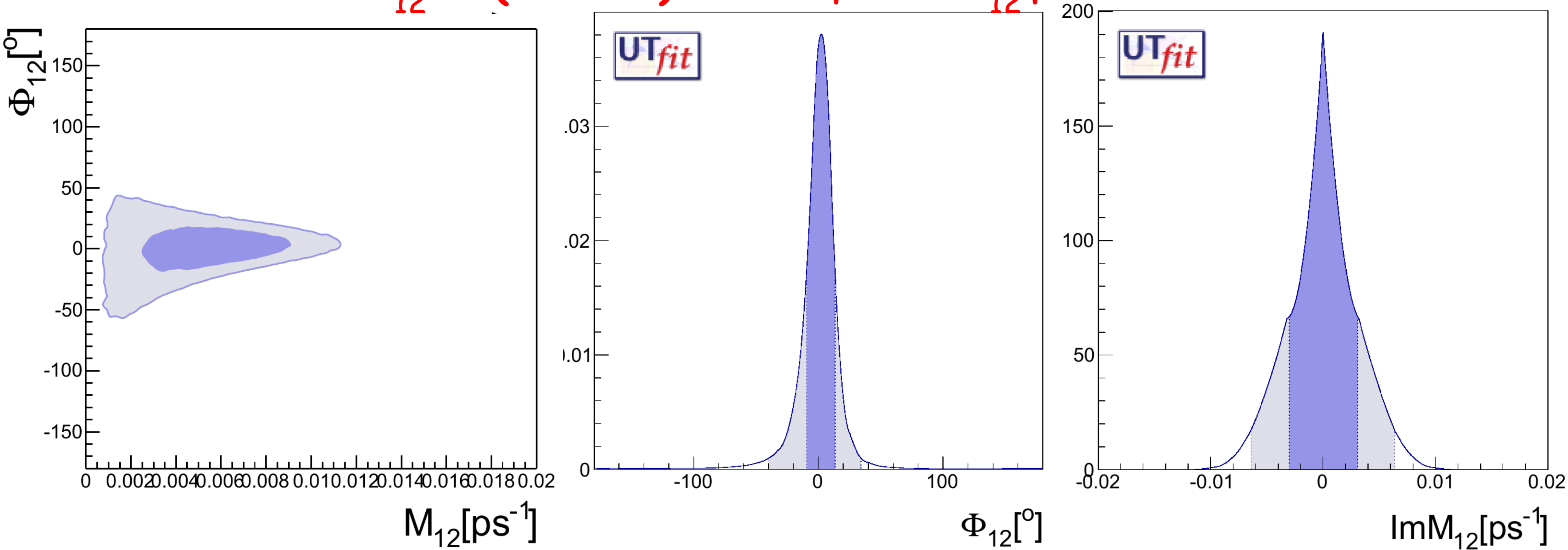


CPV IN MIXING TODAY II

- The corresponding results on fundamental parameters are

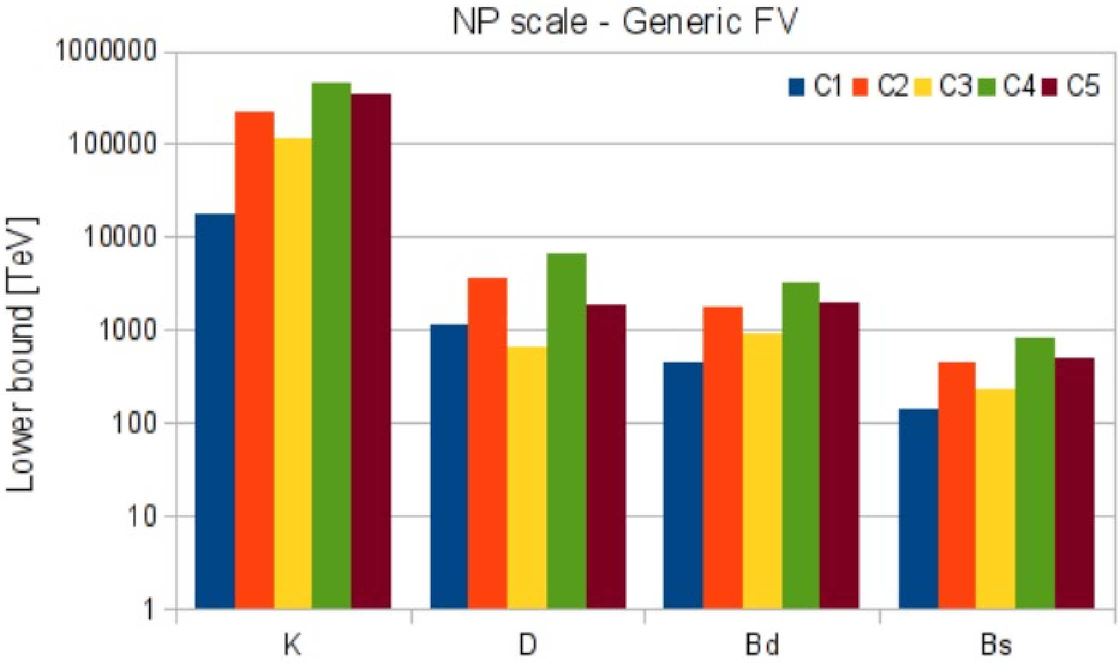
$|M_{12}|$ = (5 ± 2)/fs, $|\Gamma_{12}|$ = (16± 2)/fs,

Φ_{12} = (2 ± 11)° and $|Im\ M_{12}|$ < 6/fs @ 95%



IMPLICATIONS FOR NP SCALE

- The upper bound on $|\mathrm{Im}\, M_{12}|$ can be turned into a bound on the coefficients of the relevant effective Hamiltonian:
  - $H_{eff}=\Sigma_i (c_i/\Lambda^2)\, O_i^6$
- A lower bound of the NP scale Λ can be obtained for fixed couplings c_i, or an upper bound on the couplings c_i can be obtained for fixed NP scale Λ



Generic Flavor Violation

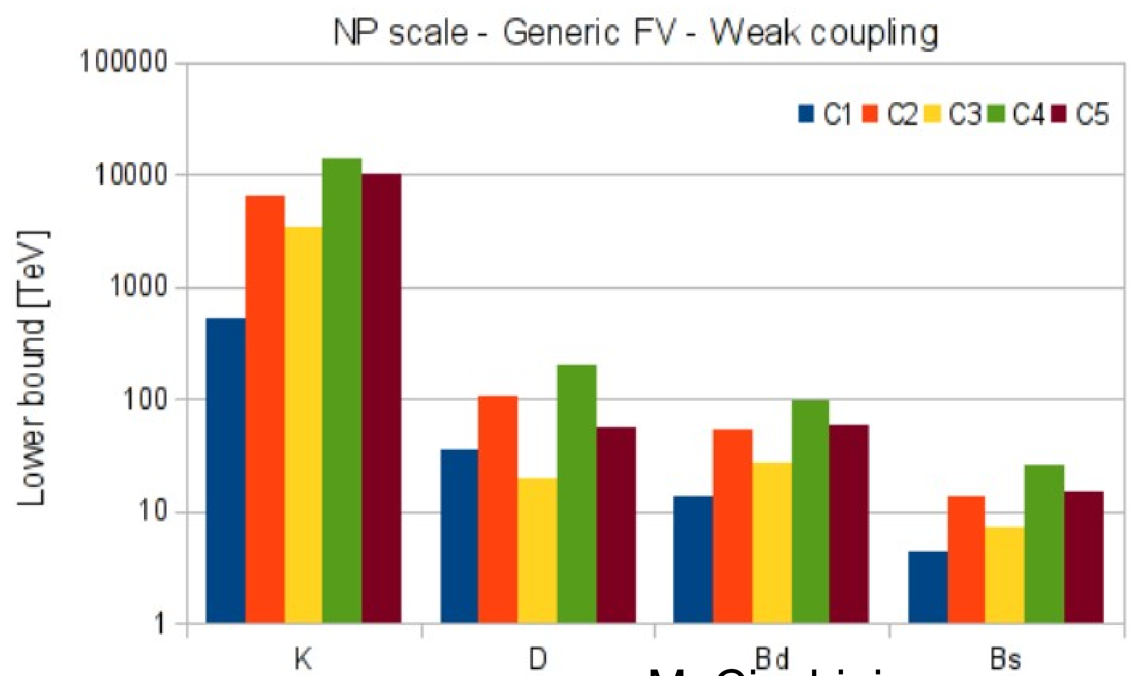
Non-perturbative NP

$\Lambda > 4.6\ 10^5$ TeV

NP in α_W loops

$\Lambda > 1.4\ 10^4$ TeV

preliminary results



M. Ciuchini

D MIXING @ SYMMETRIC e+e-

- Time-integrated decays of quantum-correlated D-anti D pairs, with Dbar decaying in a flavour-specific final state:

  $1 - r_f \cos(\delta_f+\phi)\,(1+\eta_c)\,y + r_f \sin(\delta_f+\phi)\,(1+\eta_c)\,x + O(x^2,y^2)$, with $r_f=\bar{A}_f/A_f$, δ_f strong phase

- At the $\psi(4040)$ produce DD^* pairs, obtain $\eta_c=-1$ for $D^*\to D\pi$ and $\eta_c=1$ for $D^*\to D\gamma$, exploit the linear terms for $\eta_c=1$ to measure x, y, ϕ

Bondar, Poluektov & Vorobiev

D MIXING CPV REACH

Preliminary estimates by Neri&Rama @ Dec meeting:

The sensitivities to mixing and CP violation observables reported in Table II are based on studies considering statistical error only but Belle-II that includes also systematic uncertainties:

- $\Psi(3770)$: time-dependent analyses with a CM boost in the range of $\beta\gamma = 0.3 - 0.6$ and a SuperB-like vertex detector (radius of Layer0 at about 1.5 cm);
- $\Psi(4040)$: based on sensitivity studies of Bondar et al. [2] using time-integrated measurements of $D^0 \to K^0_S\pi^+\pi^-$ and $D^0 \to K^+\pi^-\pi^0$;
- LHCb: based on sensitivity studies reported in [3]. Errors on x, y and $\arg(q/p)$ are based on $D^0 \to K^0_S\pi^+\pi^-$ and errors on $|q/p|$ are based on Wrong-sign/Right-sign $D^0 \to K\mu\nu$.
- Belle-II: based on sensitivity studies reported in [4]. Systematic uncertainties are included. Do not include $D^0 \to K^+\pi^-\pi^0$, $D^0 \to K^0_S K^+K^-$ and $\Psi(3770)$ results from BES-III.

TABLE II: Estimated precision of mixing and CP violation observables expected at a SuperτC running at $\Psi(3770)$ (3 ab^{-1}) and $\Psi(4040)$ (3 ab^{-1}) and compared with LHCb (50 fb^{-1}) and Belle-II (50 ab^{-1}) sensitivities.

Parameter	$\Psi(3770)$	$\Psi(4040)$	LHCb	Belle-II
$x(\%)$	0.02-0.05	0.03	0.015	0.08
$y(\%)$	0.02-0.03	0.03	0.010	0.04
$\|q/p\|(\%)$	2-5	0.9	1	5
$\arg(q/p)(^\circ)$	2-3	0.8	3	2.6

See talks by Inguglia, Hahn, Schwartz, Bonivento, Sokoloff

DIRECT CPV IN SCS DECAYS

- Early evidence for large DCPV in $D \rightarrow \pi\pi, KK$ now weaker, exp situation confused
- Separate measurements of $\pi\pi$ and KK asymmetries theoretically very helpful, since FSI differ → expect different CP asymm.

Franco, Mishima & LS

- More hadronic channels would help

Talk by Meadows

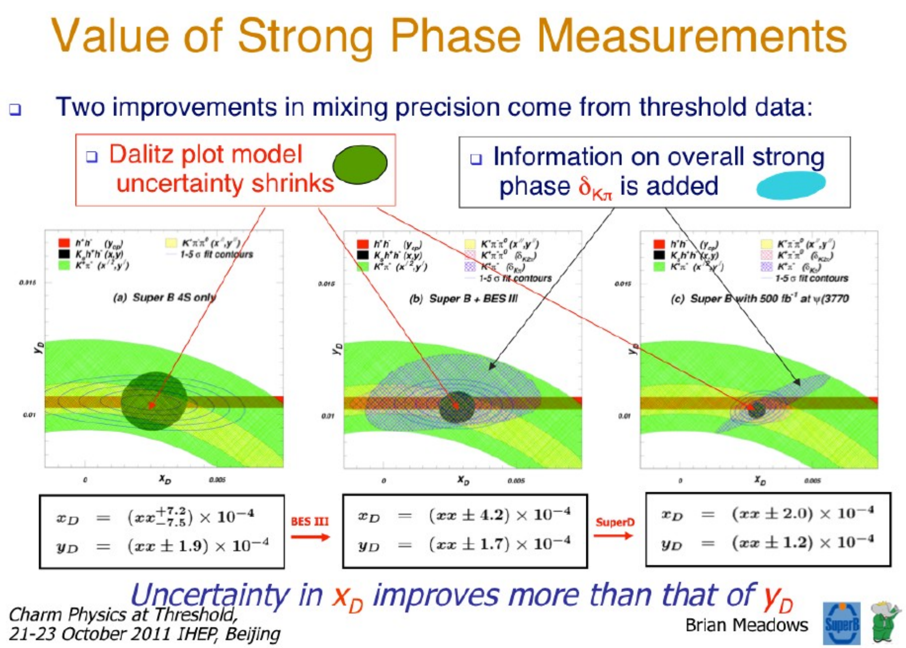
- If due to enhanced chromomagnetic, interesting to measure CPV in $D \rightarrow V\gamma$

Isidori & Kamenik

CP violation in D→ππ,KK

- Evidence for CP-violation puts us in the same situation as we've been in with ε' for decades: can we reliably predict the SM contribution?
  - Many challenges, both computational and theoretical
  - Hardest (still unsolved) is that, at energy M_D, 2π & 2K states mix in a finite box with 4π, 6π, etc. and need to disentangle
  - Some progress with 3π case [Hansen & SS]
- I expect progress on D→ππ, KK on a 5 year timescale
- D-Dbar mixing is more challenging

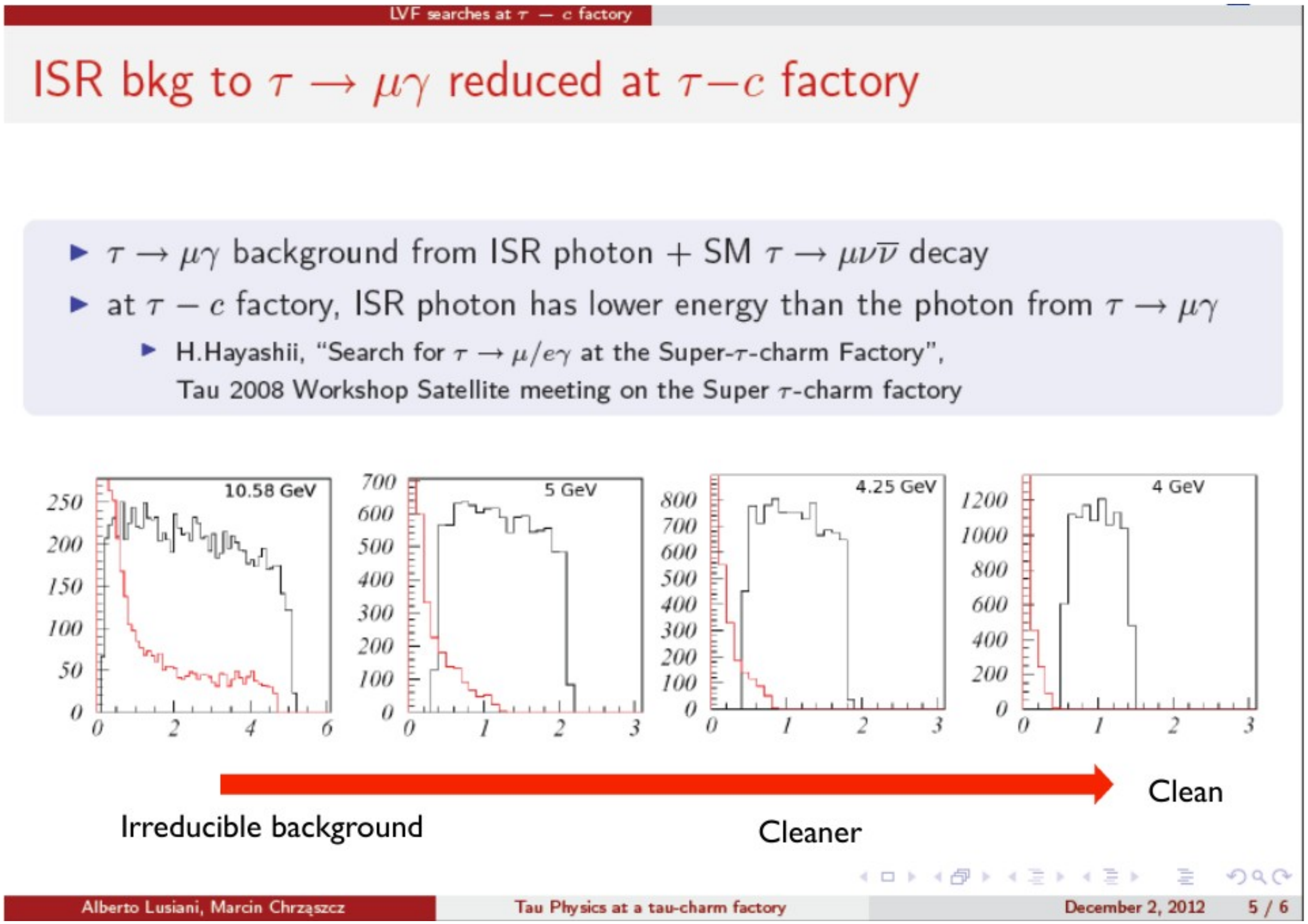
MUCH MORE ON CHARM…



See talks by Poluektov, Bona

- Also:
  - Rare decays
  - Triple products
  - Majorana neutrinos
  - …

τ LFV: $\tau \to \mu\gamma$



- Removing an irreducible background is a giant step forward wrt $\Psi(4s)$

LFV: $\tau \to \mu\gamma$ VS OTHER

- $\tau \to \mu\mu\mu$, $\tau \to \mu ee$ generically suppressed by α, but complementary since sensitive to different contributions (e.g. boxes)
- No model-independent correlation with $\mu \to e\gamma$, so full complementarity with $\mu \to e\gamma$ searches to understand the flavour structure in the leptonic sector
- Explore LFV in production (from γ^* as well as from contact interactions)

τ BEYOND $\tau \to \mu\gamma$

- Cover full range of LFV τ decays — See talk by Ghosh
- Extract useful information from hadronic τ decays: α_s, V_{us}, … — Talk by Passemar
- Test right-handed currents, lepton universality & other EW physics — Talk by M. Roney
- Probe CPV, EDM and g-2 — Talk by O. Vives
- …

SEVERAL ADDITIONAL TOPICS

- Charmonium spectroscopy — Talk by A. Polosa
- Dark forces — Talk by M. Roney
- Quantum correlations — Talk by A. Di Domenico
- Inclusive measurement of R_{had} at low energies:

TABLE I: Contributions to $\Delta\alpha^{(5)}_{\rm had}(m^2_{\rm Z})$

Range $\sqrt{s}$, GeV	$\Delta\alpha$	Relative error
ρ	0.00349	0.5 %
Narrow resonances	0.00184	3.1 %
1.05 – 2.0	0.00156	15 %
2.0 – 5.0	0.00371	5.0 %
5 – 7	0.00183	6 %
7 – 12	0.00304	1.4 %
$>$ 12	0.01203	0.2 %
	0.02750	1.2 %

Burkhardt & Pietrzyk

IMPACT OF $\Delta\alpha^5_{had}(M_Z^2)$

	Prediction	α_s	$\Delta\alpha^{(5)}_{\rm had}$	M_Z	m_t
M_W [GeV]	80.3625 ± 0.0085	± 0.0004	± 0.0060	± 0.0026	± 0.0054
Γ_W [GeV]	2.0889 ± 0.0007	± 0.0002	± 0.0005	± 0.0002	± 0.0004
Γ_Z [GeV]	2.4951 ± 0.0052	± 0.0003	± 0.0003	± 0.0002	± 0.0002
σ_h^0 [nb]	41.484 ± 0.004	± 0.003	± 0.000	± 0.002	± 0.001
$\sin^2\theta_{\rm eff}^{\rm lept}(Q_{\rm FB}^{\rm had})$	0.23149 ± 0.00012	± 0.00000	± 0.00012	± 0.00001	± 0.00003
$P_\tau^{\rm pol} = \mathcal{A}_\ell$	0.14725 ± 0.00094	± 0.00002	± 0.00091	± 0.00012	± 0.00022
$\mathcal{A}_c$	0.6680 ± 0.0004	± 0.0000	± 0.0004	± 0.0001	± 0.0001
$\mathcal{A}_b$	0.9346 ± 0.0001	± 0.0000	± 0.0001	± 0.0000	± 0.0000
$A_{\rm FB}^{0,\ell}$	0.01626 ± 0.00021	± 0.00000	± 0.00020	± 0.00003	± 0.00005
$A_{\rm FB}^{0,c}$	0.07377 ± 0.00052	± 0.00001	± 0.00050	± 0.00006	± 0.00012
$A_{\rm FB}^{0,b}$	0.10322 ± 0.00067	± 0.00001	± 0.00064	± 0.00008	± 0.00016
R_ℓ^0	20.734 ± 0.044	± 0.004	± 0.002	± 0.000	± 0.000
R_c^0	0.17222 ± 0.00002	± 0.00001	± 0.00001	± 0.00000	± 0.00001
R_b^0	0.215762 ± 0.000033	± 0.000002	± 0.000004	± 0.000007	± 0.000032

Ciuchini et al

Improving error on $\Delta\alpha^5_{had}(M_Z^2)$ crucial for TLEP

CONCLUSIONS

- Indirect searches for NP as important as ever after the 7-8 TeV LHC runs
- Several probes of NP available at tau-charm:
  - Charm mixing CPV with high sensitivity
  - Charm decay CPV in individual channels
  - τ LFV & CPV, complementary to μ
  - EW physics
  - Dark forces

CONCLUSIONS II

- Furthermore, tau-charm can provide valuable input to NP searches in other sectors
- It can contribute to improve substantially our knowledge of QCD
- Plenty of interesting topics to be discussed in the physics parallel sessions