Charmed semileptonics with twisted-mass valence quarks

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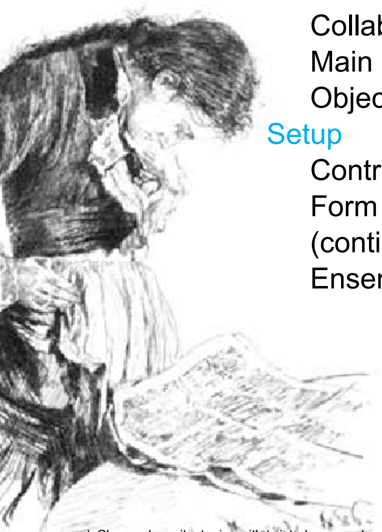
Overview



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Conclusion

Collaboration

JF, Andrea Bussone, Gregorio Herdoíza, Carlos Pena, Jose Ángel Romero, Javier Ugarrio
Project born at the IFT, Madrid. Within ALPHA/CLS

Alessandro Conigli: *Charm physics in tmQCD*, **earlier this morning**
Gregorio Herdoíza: *Light meson physics and scale setting from a mixed action with Wtm valence quarks*, **tomorrow 07:30**

Previous proceedings:

- [1711.06017]
- [1812.01474]
- [1812.05458]
- [1903.00286]
- [1911.02412]

Main idea

Charm physics is mostly about improving discretisation. Two sides:

CLS $N_f = 2 + 1$ configurations

- non-perturbative $O(a)$ improvement for sea effects
- OpenBC: Lowers the barrier between topological sectors
  Finer ensembles are accessible with good sampling

Twisted mass fermions

- Automatic $O(a)$ improvement (no am_h, residual sea effects)
- Applied to all valence quarks
- Not really a different action, same renormalisation
- Actually renormalisation is even simplified a bit

Objectives

Main form factors of interest:

- $D \to \pi l \nu$ at arbitrary q^2 ($|V_{cd}|$)
- $D \to K l \nu$ at arbitrary q^2 ($|V_{cs}|$)

$\Rightarrow$ Not only we have a charm quark, but we also need large momenta keeping both good systematics and signal

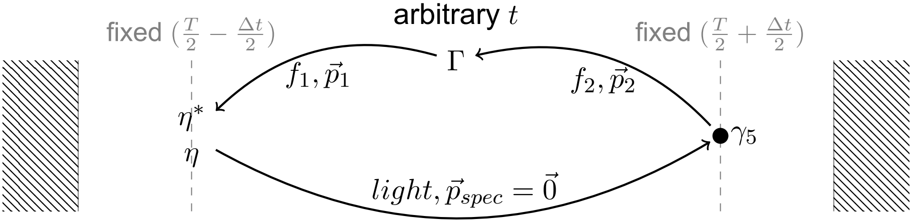
Future/ongoing:

- How far towards the B can we push?

Setup

Contractions

- One-hand trick and sequentials
- Spectator always light, other two take any flavour/twist
- Source and sink timeslices are kept fixed
- Time at the insertion of the matrix element operator is free



Form Factor decomposition (continuum)

$$< S > \;=\; \frac{M_D^2 - M_P^2}{\mu_c - \mu_l} f_0(q^2)$$

$$< \hat{V}_\mu > \;=\; \left[P_\mu - q_\mu \frac{M_D^2 - M_P^2}{q^2} \right] f_+(q^2) + q_\mu \frac{M_D^2 - M_P^2}{q^2} f_0(q^2)$$

Because of twisted mass

- When I write S, V in the physical basis, it is actually P, A in the code
- Only need the renormalised $\hat{V}$ (hence the hat), while $\mu < S >$ is already invariant
- We know $Z_{V,A}$ but simpler to impose from charge conservation, aka $\langle \pi(p) \mid O_\Gamma \mid \pi(p) \rangle$
- We have some Ward Identities relating those (redundancy/check)

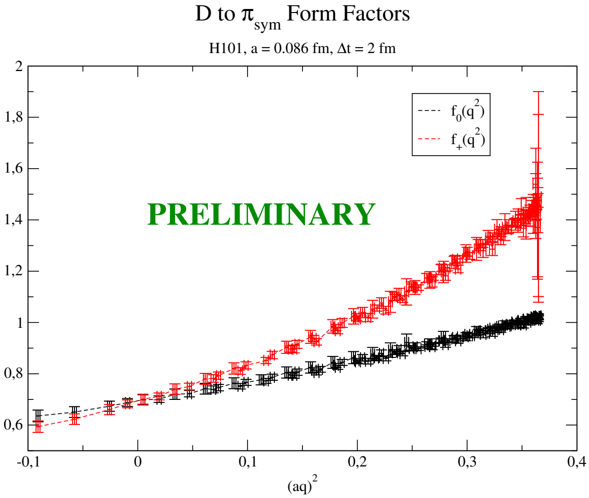
Ensembles and parameters

id	β	N_s	N_t	m_π[MeV]	m_K[MeV]	$m_\pi L$	Δt[fm]	N_η	$a\mu_c$
H101	3.40	32	96	420	420	5.8	1.3, 1.5, 2.0	1(+B)	0.22
H102	3.40	32	96	350	440	4.9	1.5	1	0.22
H105	3.40	32	96	280	460	3.9	1.5, 2.0	1	0.22
H400	3.46	32	96	420	420	5.2	1.9, 2.7	1, 6(+B)	0.21
H200	3.55	32	96	420	420	4.4	2.0, 2.6	1+6(+B), 1	0.18
N202	3.55	48	128	420	420	6.5	2.6	(B)	0.18
N203	3.55	48	128	340	440	5.4	2.0	1	0.18
N200	3.55	48	128	280	460	4.4	2.6	1	0.18
D200	3.55	64	128	200	480	4.2	2.0	1	0.18
N300	3.70	48	128	420	420	5.1	1.9, 2.5	1, 5(+B)	0.14
J303	3.70	64	192	260	470	4.1	1.9	1	0.14

- 4 βs along the $m_{ud} = m_s$ line (Fifth planned), $0.087 \ldots 0.050$ fm (0.039 fm)
- Many M_π, down to 200 MeV
- Handle on volume, in particular H200-vs-N202
- Noise sources currently not saturated

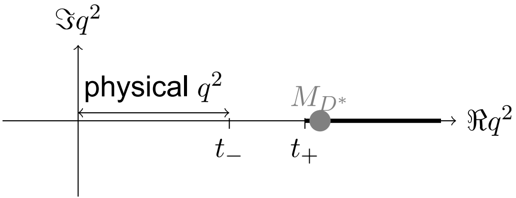
Selected preliminary results

Single ensemble preliminary results



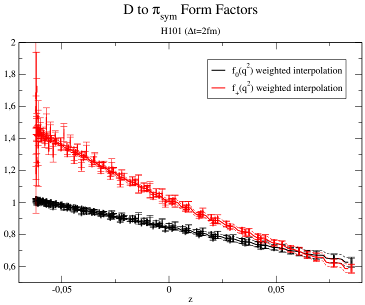
- Plenty of points $O(N_{\text{mom}}^2)$ fully model-independent
- Smooth curves
  No hypercubic terms
- Momentum does not degrade the signal (much)
- Can **int**erpolate $q^2 = 0$

Analytical structure and z-expansion



Conformal mapping of cut to disc allows an expansion around some t_0:

$$z(q^2, t_0) = \frac{\sqrt{t_+ - q^2} - \sqrt{t_+ - t_0}}{\sqrt{(t_+ - q^2)} + \sqrt{t_+ - t_0}}$$



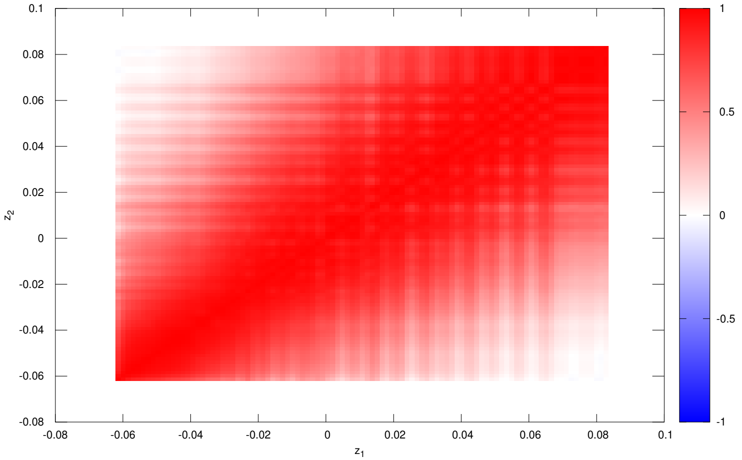
- Very linear in z, most of the curvature is absorbed
- Interpolating gets even easier
- However, significant curvature for $q^2 < 0$
  despite good correlated χ^2 for first-order BCL
  therefore our direct computation is useful

Momentum correlations

Correlations have to be taken into account to get correct fits *and* for a reasonable **balance of the CPU cost** between:

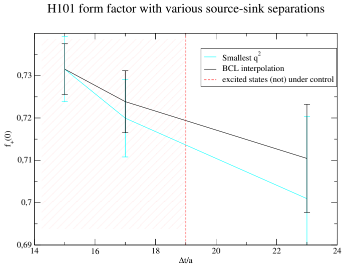
- more momenta
- more source-sink separations
- more source noises

$f_+(z)$ correlations for H101 (2 fm)



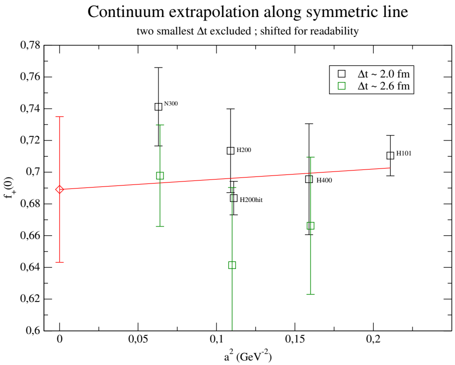
The choice of Δt

- Trade-off statistical precision vs excited-state contaminations
- Consistency checked on many q^2, not just this figure
- Hatched area shows obvious inconsistencies (sawteeth) on f_+ at large q^2, but f_0 and low-q^2 are quite robust
- Small Δt might still be useful: working on multi-exp (combined correlated Bayesian-averaged) fits
- Before chiral&continuum extrapolation, all points have errors smaller than FLAG avg for $D \to K$ and $D \to \pi$



Continuum limit

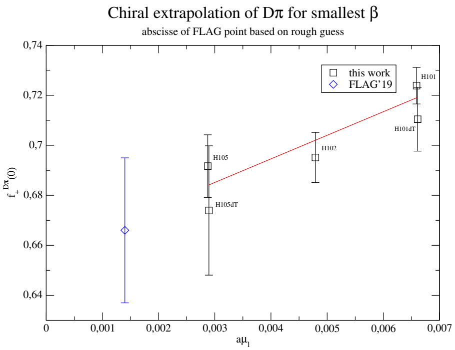
Here: Only a slice of the fit we want, will be included in a global fit.



Precision on finer ensemble is critical

- $f_+^{\mathrm{sym}}(0) = 0.689(46)$ is still far from the level of precision we need
- 4 extra noise hits on N300 (2 fm) should get us there. Planned
- Improving H101 and H400 is essentially free
- An extra J500 point would allow to make sure we only use points in the scaling regime.
  Not obvious now
- Anyway, statistically compatible with no discretisation effects at all

Chiral limit

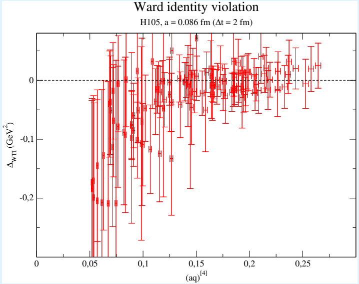


- At $q^2 = 0$ no chiral logs expected (large momenta) and far from the D^* (moving) pole
- Looks already well-controlled and having reached the minimal precision we need
- Error largely indep from mass, cost as well (except through volume)
- Data at this β is cheap to improve, until FV might become limiting factor ($M_\pi L \gtrsim 3.9$)

Ward identity and hypercubic effects

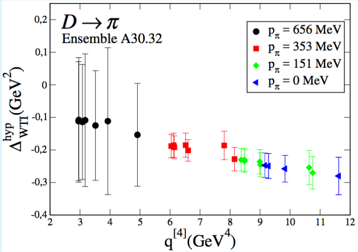
$$\Delta_{WTI} = (\mu_c - \mu_l)\langle S \rangle - q_\mu \langle \hat{V}_\mu \rangle$$

This work



Both **no signal** and **much smaller**
Extremely similar lattice

ETMc hep-lat/1706.03017



A model for hypercubic form factors was fitted from that.

Hypercubic effects: why does our action work so well?

Short answer: we do not know, any suggestion is welcome!

But it is worth noting a few things:

- We keep the NP c_{SW}. It is known that in some contexts it has a major impact on $O(a^2)$ effects [Becirevic:0605006]
- The critical mass is determined close to the chiral limit, so there is necessarily a small action-dependent mismatch of the charm twisting angle
- Maximal twisting on valence is simpler, can be done very precisely ensemble-by-ensemble
- Lüscher-Weisz vs Iwasaki gauge action
- We observed that an incorrect treatment of systematics such as excited states can produce Lorentz-breaking effects

Conclusion

- I presented a framework to reduce discretisation errors in charm physics while keeping a relativistic and manifestly local action
- Preliminary results show a very nice behaviour of charm semileptonics, both in terms of **signal** and manageability of the **discretisation effects**
- There are indications of a possible elimination of the worrying **hypercubic effects**
- The **whole range of kinematics** is directly accessible, which is encouraging for B physics where it will become more of a challenge
- Our precision and continuum limit are not yet satisfying, but with full statistics **improving over current FLAG values seems doable**
- **Finer ensembles** available, to be used anytime soon

Thank you!

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