Tool for reweighting semileptonic B decays - HAMMER

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Helicity Amplitude Module for Matrix Element Reweighting

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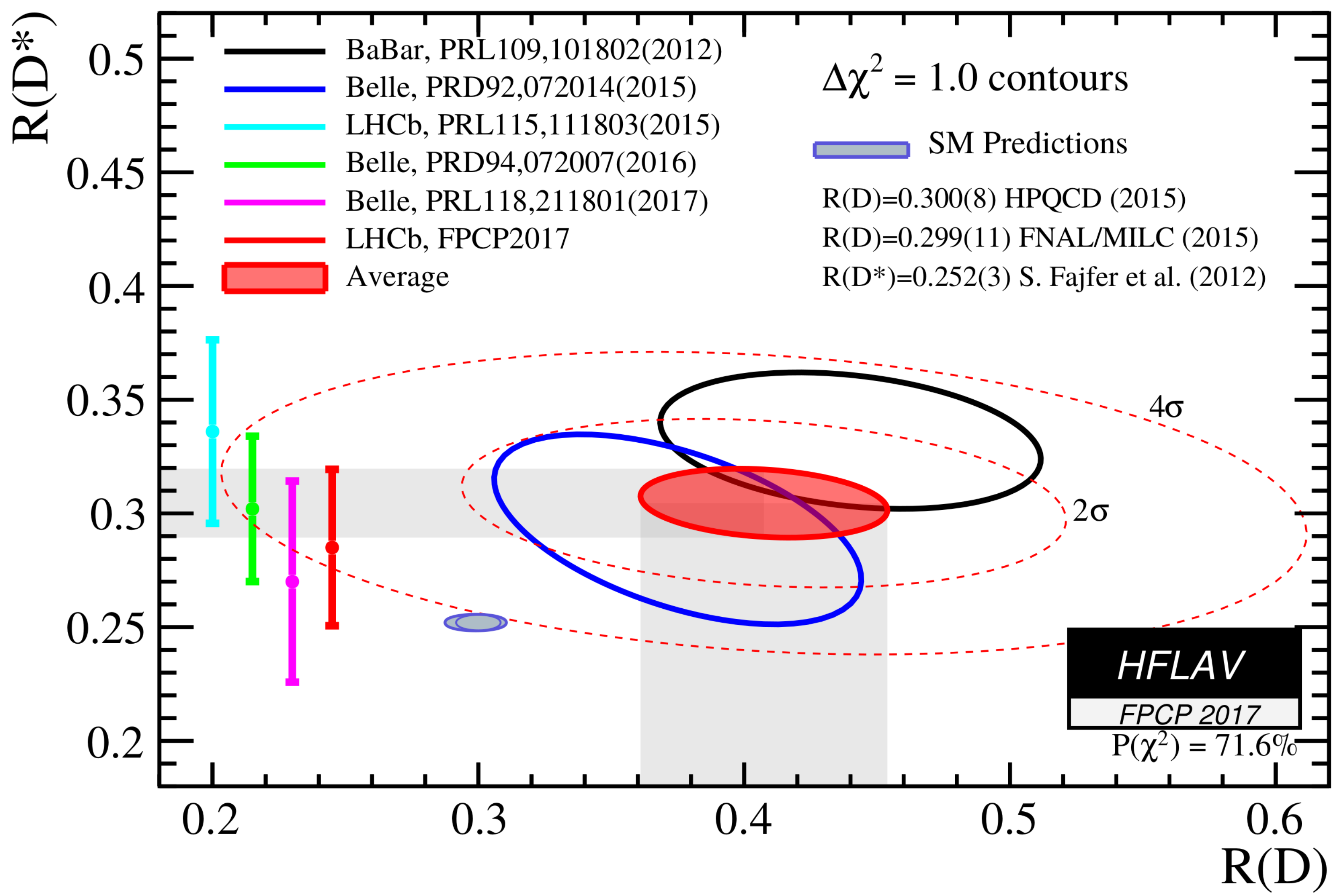
Michele Papucci, Dean Robinson

The Anomaly

- Persistent signals of lepton flavour universality violation in $R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\bar{\nu}_\tau)}{\mathcal{B}(B \to D^{(*)}l\bar{\nu}_l)}$ $l = e, \mu$

- Disagreement between data and Standard Model (SM) prediction at 4σ - Possibly New Physics (NP)?



Caveats

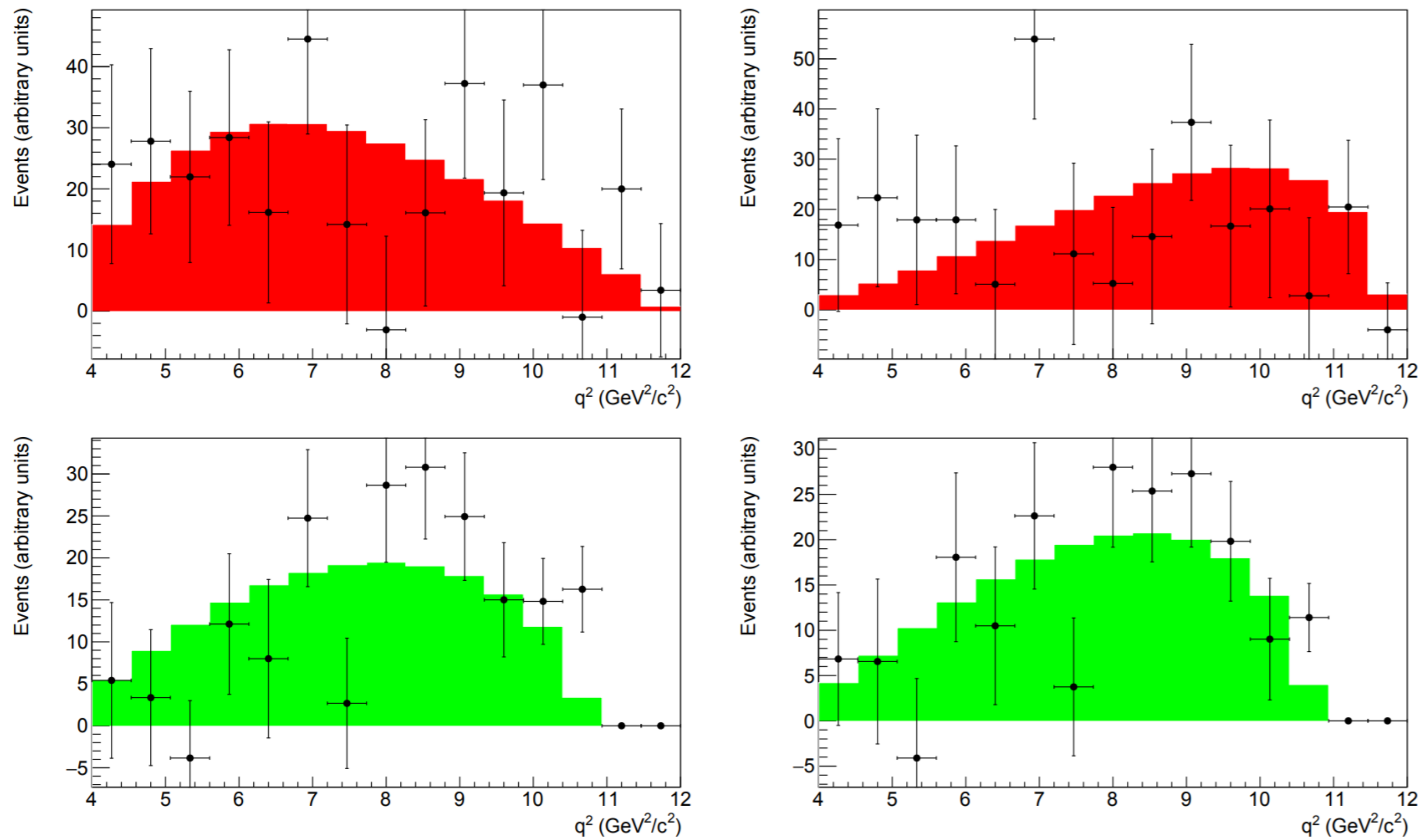
- Caveats when probing for NP:
- NP searches treat D* and tau as stable states
- We can only measure their decay products!
  - Non-trivial interference effects between the D(*) and tau final states
  - Non-trivial phase space cuts
  - Tau reference frame not reconstructible
- Simultaneous Signal + Background float: Model dependent fit templates!

Model dependency

- Extracted spectra may vary depending on signal model

SM	2HDM
$R(D) = 0.375 \pm 0.064 \pm 0.026$	$R(D) = 0.329 \pm 0.060 \pm 0.022$
$R(D^*) = 0.293 \pm 0.038 \pm 0.015$	$R(D^*) = 0.301 \pm 0.039 \pm 0.015$

[Belle 1507.03233]



[Belle 1507.03233]

FIG. 8. Background-subtracted q^2 distributions of the τ signal in the region of $M^2_{\rm miss} > 0.85\,{\rm GeV}^2/c^4$. The distributions are efficiency corrected and normalized to the fitted yield. The error bars show the statistical uncertainties. The histogram is the respective expected distribution from signal MC. Left: Standard Model result, right: Type-II 2HDM result with $\tan\beta/m_{H^+} = 0.5\,c^2/{\rm GeV}$, top: $\bar{B} \to D\tau^-\bar{\nu}_\tau$, bottom: $\bar{B} \to D^*\tau^-\bar{\nu}_\tau$

Problems

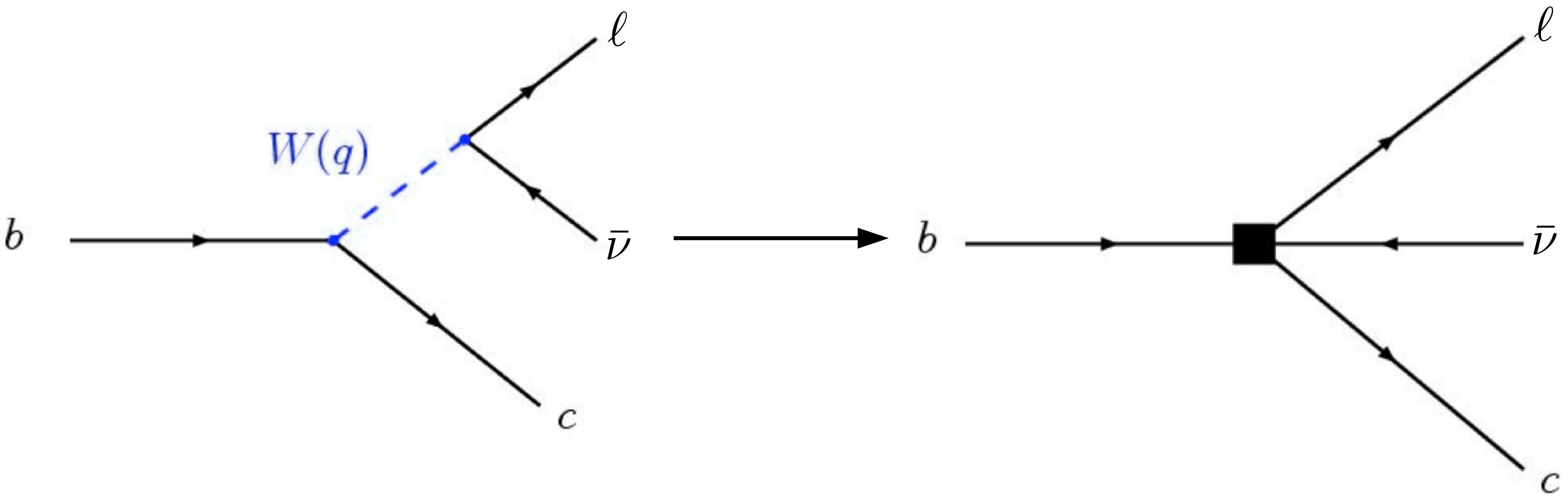
- Require a fully simulated dataset for any NP model to be analysed
- Belle/LHCb datasets are very large
- Detector simulation (computationally) very expensive
- Aim: Supply a tool to quickly perform forward-folded NP analyses without having to run the full simulation chain over and over again!

Idea

- Realization: Detector weights commute with model weights
- Compute compact amplitude expressions for all NP Matrix elements in $B \to D^{(*)} \tau \bar{\nu}_\tau$
  1711.03110 1703.05330 [Bernlochner, Ligeti, Papucci, Robinson]
- Interference effects between final states automatically included
- Calculations encoded into HAMMER

Amplitude Expressions

- Effective field theories often used (OPE)



$$\mathcal{H}_{\text{eff}} \propto \frac{G_F}{\sqrt{2}} V_{cb} \sum_i c_i(\mu) \mathcal{O}_i + h.c.$$

- New Physics (i.e. additional mediators) encoded in Wilson Coefficients

Theoretical approach

- Approach: Decompose amplitudes into vector of amplitudes and NP Wilson coefficients

$$\mathcal{M} = \vec{v}[\vec{\mathcal{M}}_v]$$

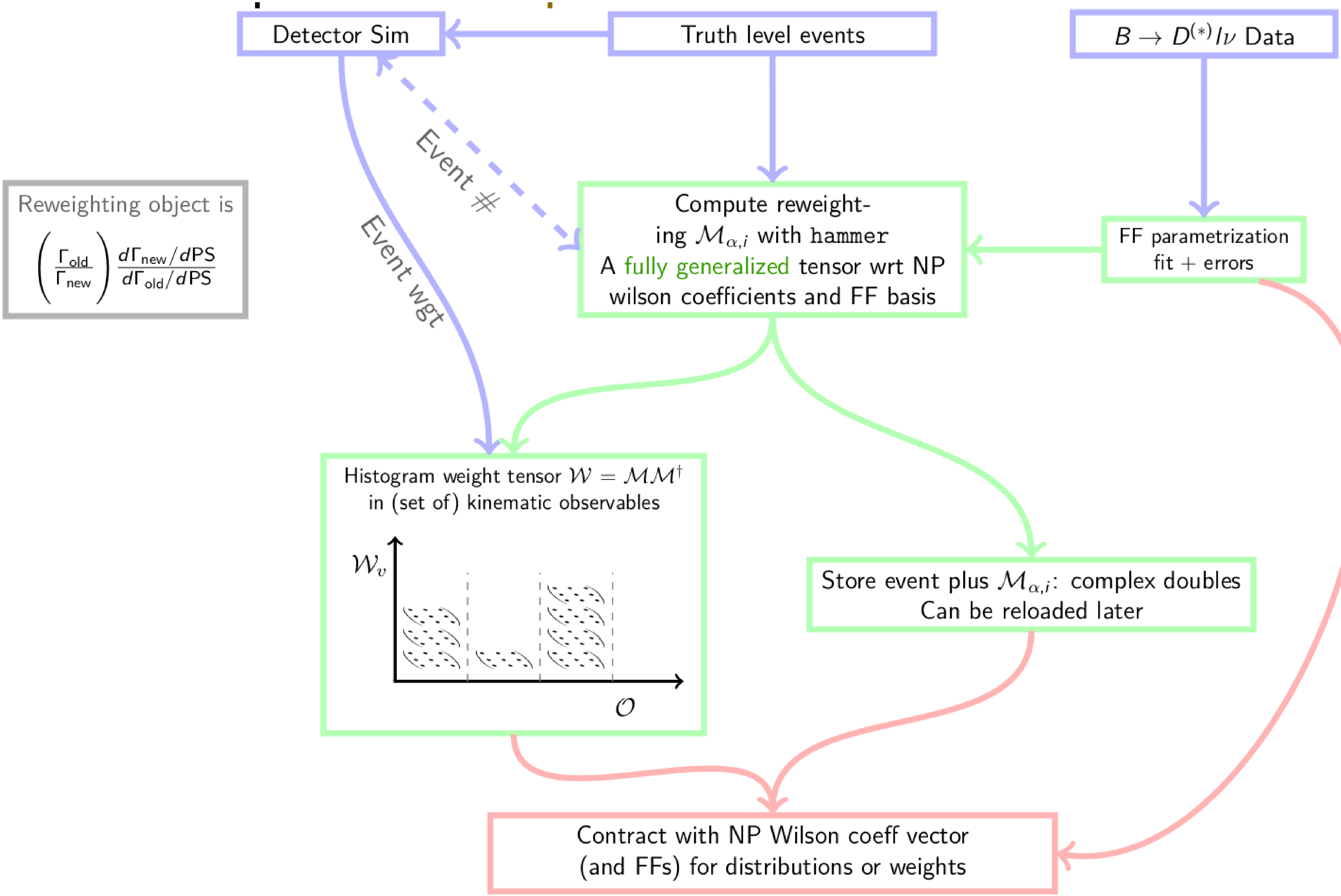
- $\vec{\mathcal{M}}_v$ is independent of particular NP model!
- Linearization in Form Factors also possible

$$\vec{v}_\alpha \, \mathrm{FF}_i \, [\vec{\mathcal{M}}_{\alpha,i}]$$

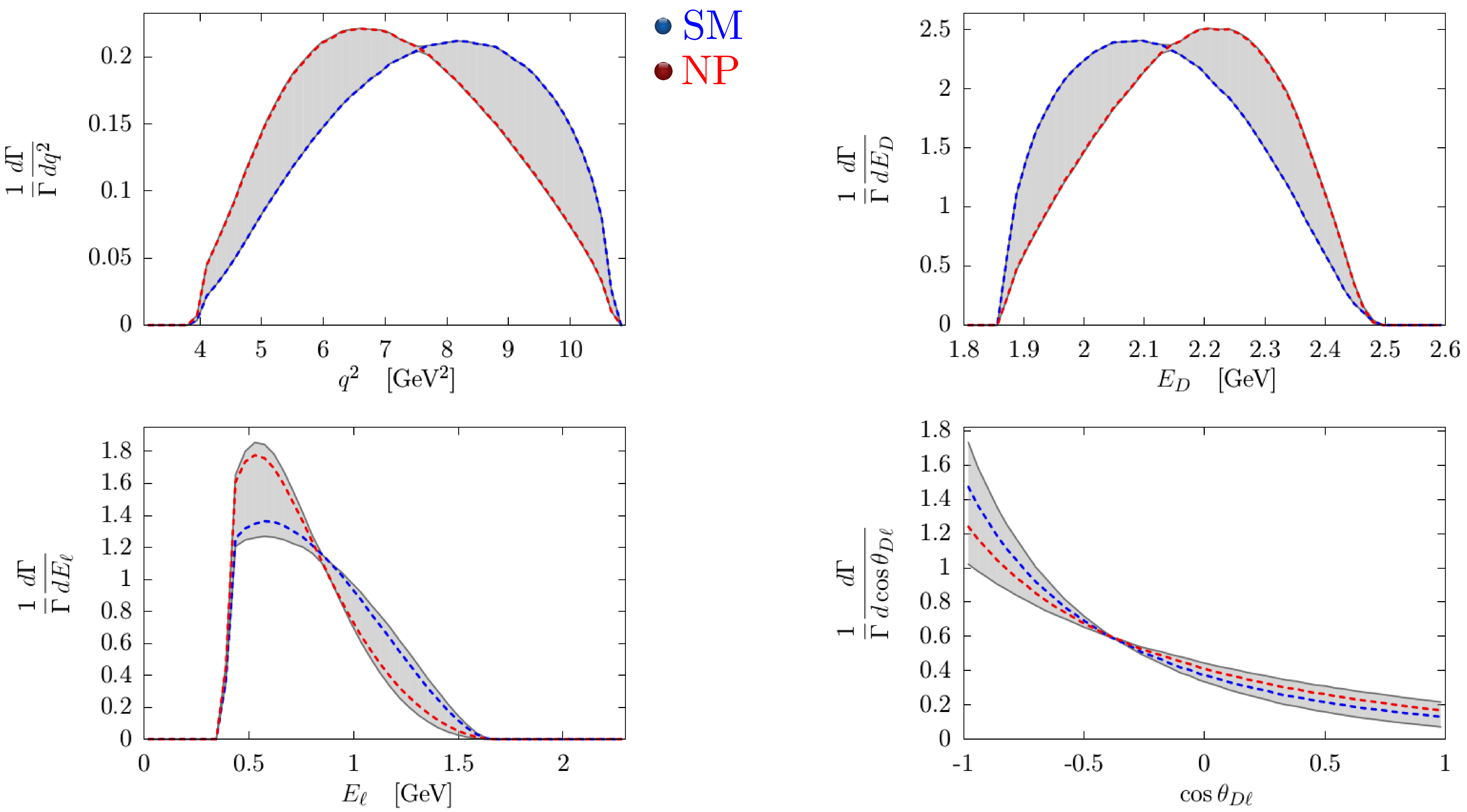
- Construct a weight tensor $\mathcal{W} \equiv [\mathcal{M}_{\beta,j}]^\dagger \mathcal{M}_{\alpha,i}$
- Event weight for arbitrary FF/NP theory is then

$$\vec{\mathrm{FF}}^\dagger \vec{v}^\dagger \, \mathcal{W} \, \vec{v} \vec{\mathrm{FF}}$$

HAMMER Workflow (rough sketch)



HAMMER Prototype output



Current Status

- HAMMER v0.9α is complete

- Included processes so far:

- $b \to c$
  - $B \to D\ell\nu_\ell$
  - $B \to D^*\ell\nu_\ell$

- τ modes
  - $\tau \to l\nu_l\nu_\tau$
  - $\tau \to \pi\nu_\tau$
  - $\tau \to 3\pi\nu_\tau$

- FFs
  - CLN
  - BLPR (HQET 1/m)
  - BGL
  - ISGW2

Current Status

- HAMMER v0.9α is complete

- Ongoing Plans:

- $b \to c$
  - $B \to D^{**}\ell\nu_\ell$
  - $B_c \to (J/\Psi \to ee)\ell\nu_\ell$
- τ modes
  - $\tau \to \rho\nu_\tau$
  - $\tau \to 4\pi\nu_\tau$
- FFs
  - ISGW2 for NP
  - NP Blaschke factors
  - LLSW

$b \to u$

$B \to K^{(*)}\ell\ell$

Summary

- NP analyses require a self-consistent and efficient tool to enable forward-folded analyses
- HAMMER will allow fast and efficient reweighting of large simulated data samples for arbitrary FF/NP theories
  - $B \to D^{(*)} \ell \nu_\ell$ Modes with $\ell = e, \mu, \tau$ already included
  - Plan to include many more modes
- Histogramming service working

Thank you for your attention!

Consistent HQET+Sum Rules

Can use QCD sum rules to control normalization and gradient of $\widehat{\chi}_{2,3}$, η at zero recoil. QCDSR central values lead to,

$$R_1(w)_{\mathrm{SR}} = 1.268 - 0.114(w-1) + \ldots$$
$$R_2(w)_{\mathrm{SR}} = 0.760 + 0.136(w-1) + \ldots$$

Each coeff is fixed! Compare with literature

Literature:
"$R_1(1)$, and $R_2(1)$, cannot be calculated; they must be extracted from data."
"$R_1(1)$ and $R_2(1)$ are left as fitting parameters"

$$R_1(w)_{\mathrm{SR}} = R_1(1) - 0.12\,(w-1) + \ldots$$
$$R_2(w)_{\mathrm{SR}} = R_2(1) + 0.11\,(w-1) + \ldots$$

Literature:
Uses HQET+SR predictions here and elsewhere

World Av: $R_1(1) \simeq 1.40 \pm 0.03$: inconsistent with $R_1(1)_{\mathrm{SR}}$!

- Floating only $R_{1,2}(1)$ first appears as an ad hoc fitting consistency check by CLEO, and propagated into later analyses
- We'll restore HQET consistency