EOS – A Software for Flavour Physics Phenomenology

Computational Tools for High Energy Physics and Cosmology – Lyon – 23/11/2021

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The EOS Software

EOS:

- **3 main use cases**:

  1) produce **publication-quality theory predictions** for flavour observables

  2) infer theory parameters from an extendable database of likelihoods;

  3) produce **high-quality Monte Carlo samples** of flavour processes for sensitivity studies.

- **C++** back-end, **C++ and python** front-end (Jupyter Notebook)

- Short presentation – Tutorial this afternoon

https://eos.github.io/

The EOS Software

How does EOS compare to other software?

SuperIso

https://flav-io.github.io/

http://superiso.in2p3.fr/

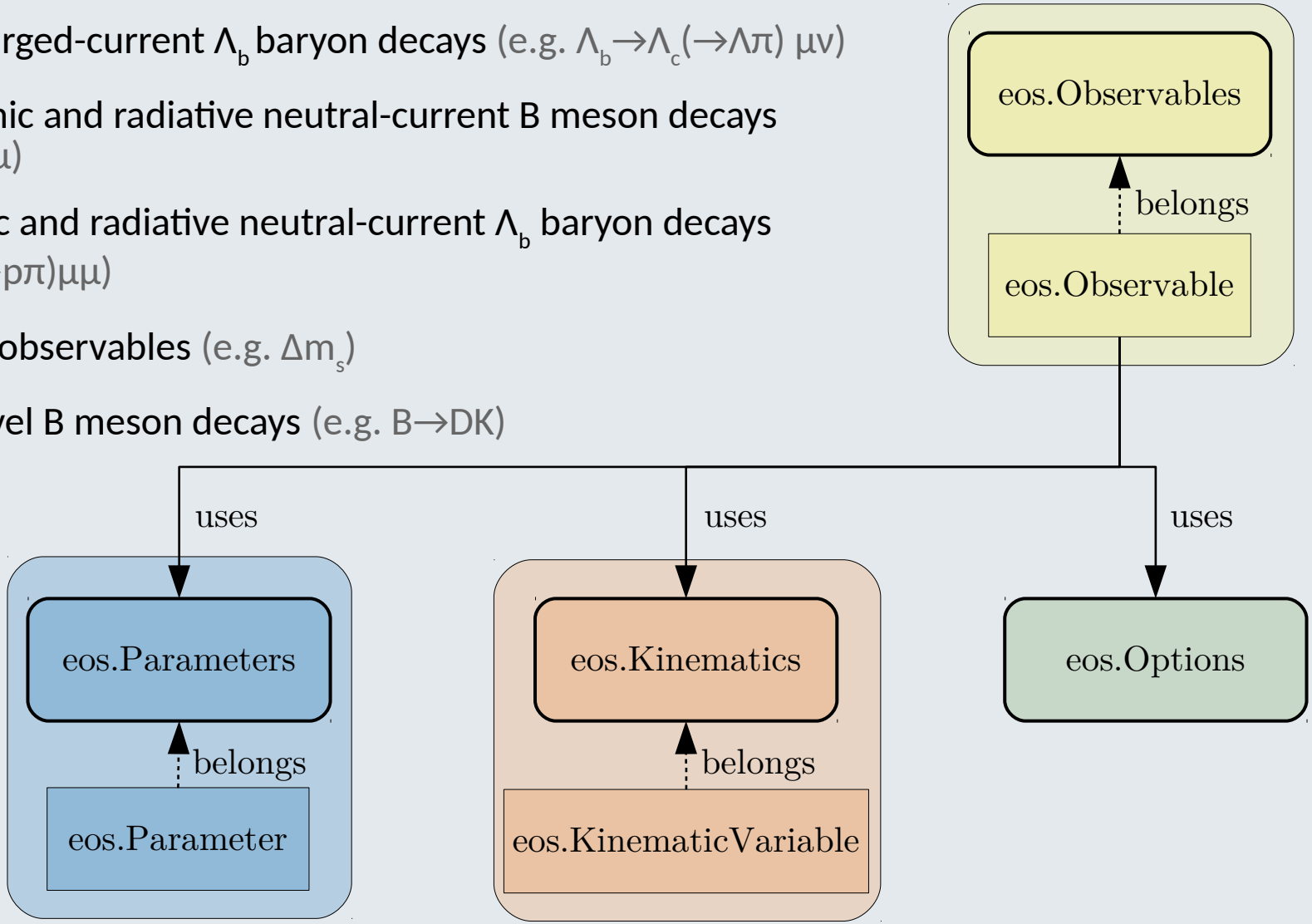
FlavBit: 1705.07933
(among others...)

- Simultaneous **inference of hadronic and BSM parameters**
- **Modularity of hadronic matrix elements** (models, parametrizations...)
- **Production of pseudo-events** for use in sensitivity studies and in preparation for experimental measurements
- Prediction of **hadronic matrix elements** from QCD sum rules

Predictions and Uncertainties

838 (pseudo-)observables:

- (semi)leptonic charged-current B meson decays (e.g. $B \to D^* \tau\nu$)
- semileptonic charged-current Λ_b baryon decays (e.g. $\Lambda_b \to \Lambda_c(\to \Lambda\pi)\, \mu\nu$)
- rare (semi)leptonic and radiative neutral-current B meson decays (e.g. $B \to K^* \mu\mu$)
- rare semileptonic and radiative neutral-current Λ_b baryon decays (e.g. $\Lambda_b \to \Lambda(\to p\pi)\mu\mu$)
- B-meson mixing observables (e.g. Δm_s)
- hadronic tree-level B meson decays (e.g. $B \to DK$)



Predictions and Uncertainties

```
In [3]: eos.Observable.make('B->Dlnu::BR',
                           eos.Parameters.Defaults(),
                           eos.Kinematics(q2_min=0.02, q2_max=11.60),
                           eos.Options(l = 'mu')
                          )
```

executed in 69ms, finished 18:23:54 2021-11-20

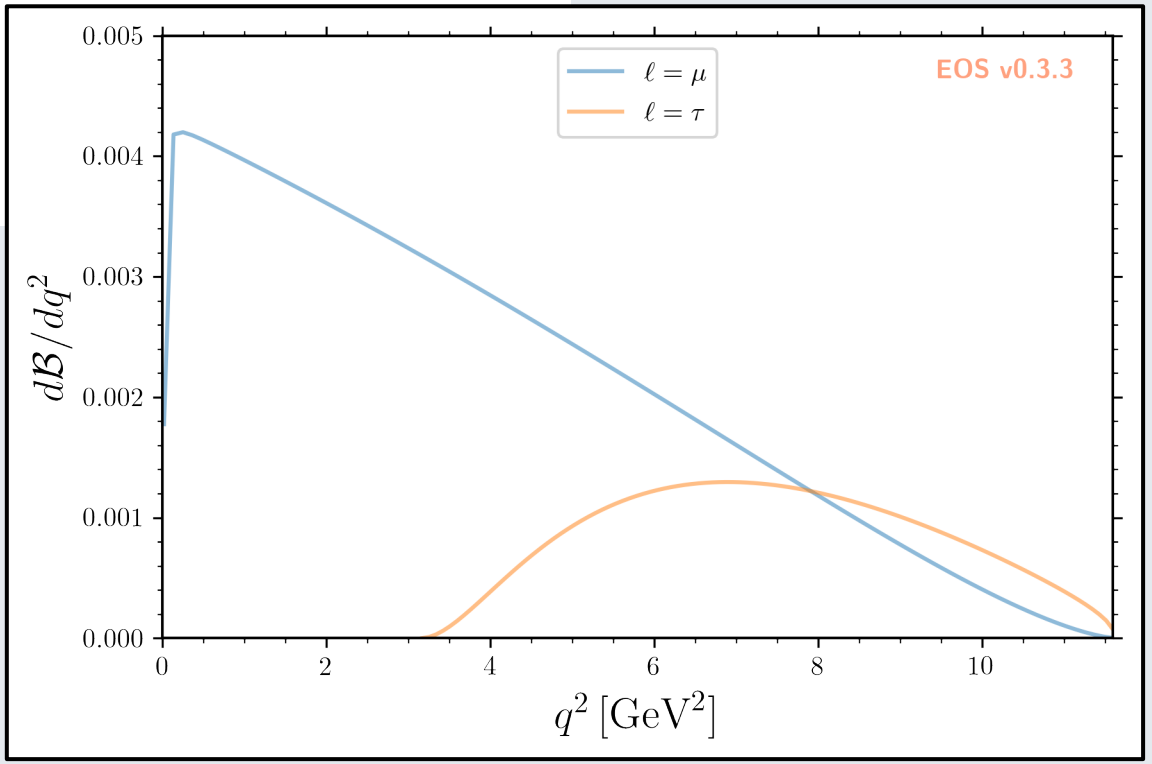
Out[3]:

B->Dlnu::BR	(eos.Observable)	
kinematics	q2_min	0.02
	q2_max	11.6
options	l	1/2
	U	c
	l	mu
current value	0.02417	

Fast evaluation of observables:

- Multi-threading
- Observable cache

Versatile plotting framework based on matplotlib

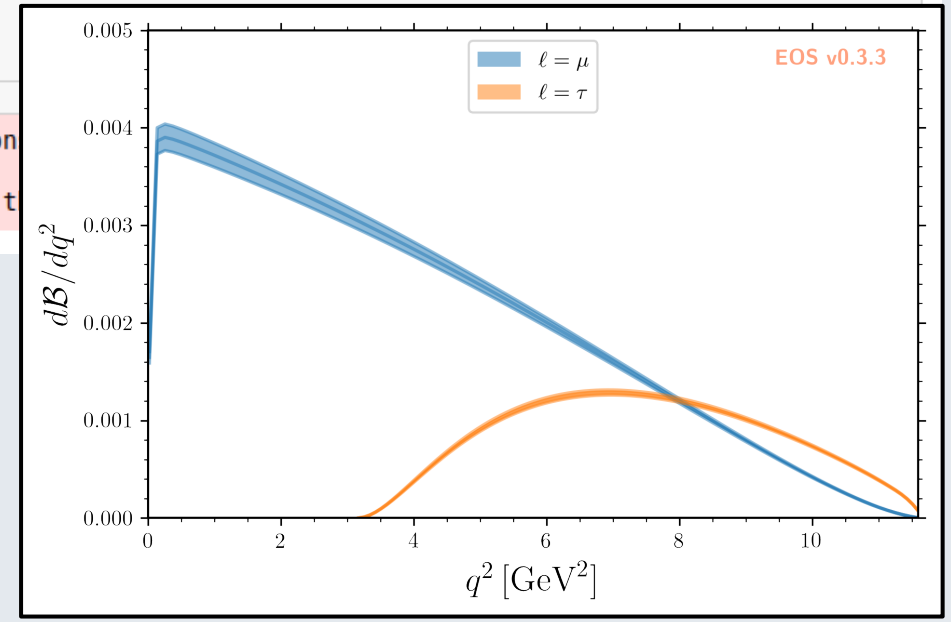


Predictions and Uncertainties

Theory uncertainties are estimated using **Monte Carlo techniques**, specifically importance sampling technique using **pypmc** (https://pypmc.github.io/)

```
In [7]: analysis_args = {
            'priors': [
                { 'parameter': 'B->D::alpha^f+_0@BSZ2015', 'min':  0.0, 'max':  1.0, 'type': 'uniform' },
                { 'parameter': 'B->D::alpha^f+_1@BSZ2015', 'min': -5.0, 'max': +5.0, 'type': 'uniform' },
                { 'parameter': 'B->D::alpha^f+_2@BSZ2015', 'min': -5.0, 'max': +5.0, 'type': 'uniform' },
                { 'parameter': 'B->D::alpha^f0_1@BSZ2015', 'min': -5.0, 'max': +5.0, 'type': 'uniform' },
                { 'parameter': 'B->D::alpha^f0_2@BSZ2015', 'min': -5.0, 'max': +5.0, 'type': 'uniform' }
            ],
            'likelihood': [
                'B->D::f_++f_0@HPQCD:2015A',
                'B->D::f_++f_0@FNAL+MILC:2015B'
            ]
        }
        analysis = eos.Analysis(**analysis_args)

executed in 725ms, finished 19:18:37 2021-11-20

INFO:EOS:Creating analysis with 5 priors, 2 EOS-wide con
nd 0 fixed parameters.
INFO:EOS:likelihood probably depends on 3 parameter(s) t
```

Markov Chains Monte Carlo

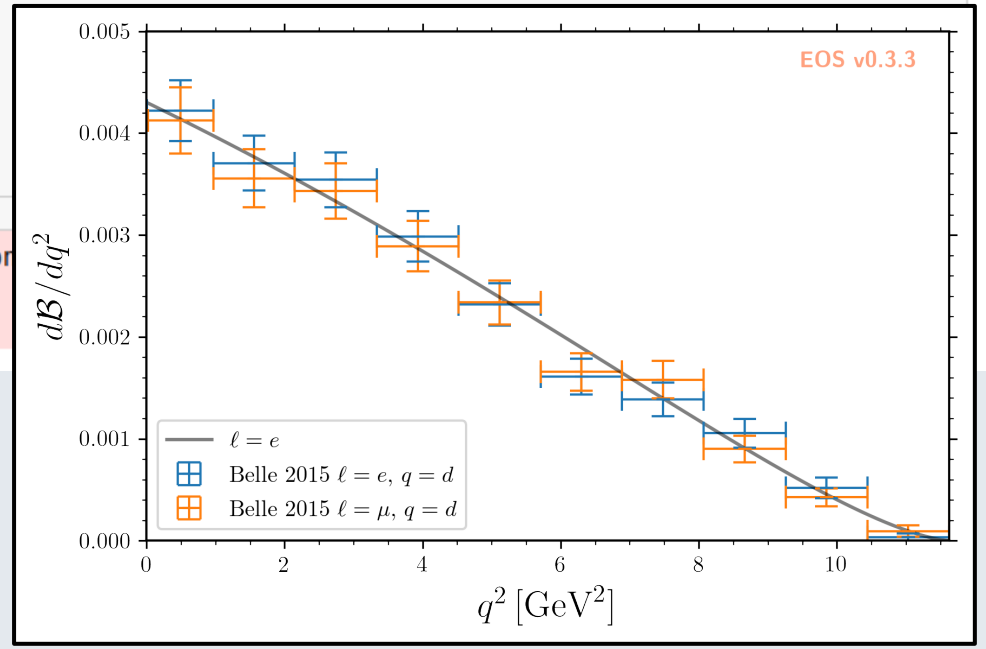


Parameter Inference

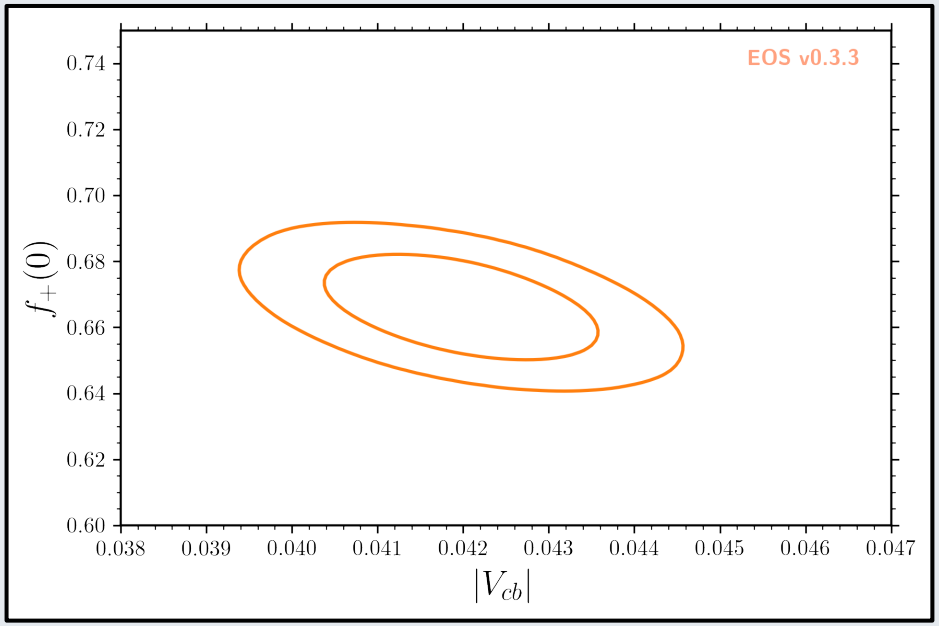
Parameters can be inferred from a **database of experimental or theoretical constraints**

```
In [5]: analysis_args = {
            'global_options': { 'form-factors': 'BSZ2015', 'model': 'CKM' },
            'priors': [
                { 'parameter': 'CKM::abs(V_cb)',           'min':  38e-3, 'max':  45e-3 , 'type': 'uniform'},
                { 'parameter': 'B->D::alpha^f+_0@BSZ2015', 'min':  0.0,   'max':  1.0   , 'type': 'uniform'},
                { 'parameter': 'B->D::alpha^f+_1@BSZ2015', 'min': -4.0,   'max': -1.0   , 'type': 'uniform'},
                { 'parameter': 'B->D::alpha^f+_2@BSZ2015', 'min': +4.0,   'max': +6.0   , 'type': 'uniform'},
                { 'parameter': 'B->D::alpha^f0_1@BSZ2015', 'min': -1.0,   'max': +2.0   , 'type': 'uniform'},
                { 'parameter': 'B->D::alpha^f0_2@BSZ2015', 'min': -2.0,   'max':  0.0   , 'type': 'uniform'}
            ],
            'likelihood': [
                'B->D::f_++f_0@HPQCD:2015A',
                'B->D::f_++f_0@FNAL+MILC:2015B',
                'B^0->D^+e^-nu::BRs@Belle:2015A',
                'B^0->D^+mu^-nu::BRs@Belle:2015A'
            ]
        }
        analysis = eos.Analysis(**analysis_args)
        analysis.parameters['CKM::abs(V_cb)'].set(42.0e-3)

executed in 310ms, finished 11:23:40 2021-11-21

INFO:EOS:Creating analysis with 6 priors, 4 EOS-wide cor
nd 0 fixed parameters.
INFO:EOS:likelihood probably depends on 48 parameter(s)
```

SciPy optimization



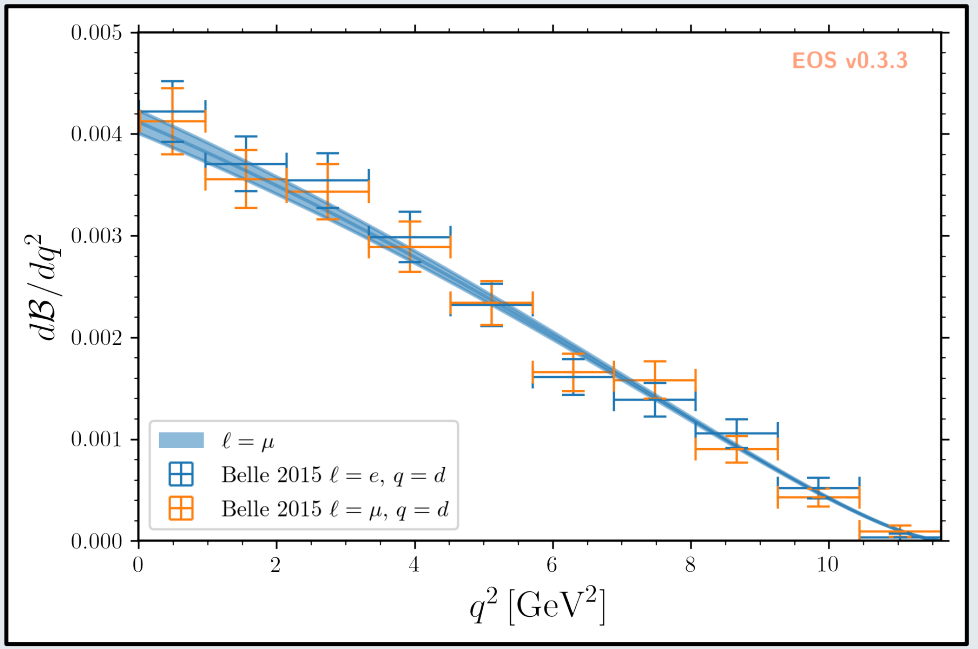
Parameter Inference



Output of the sampling are **genuine python objects**

$|V_{cb}| = 0.0420 \pm 0.0009$

Publication-quality plots

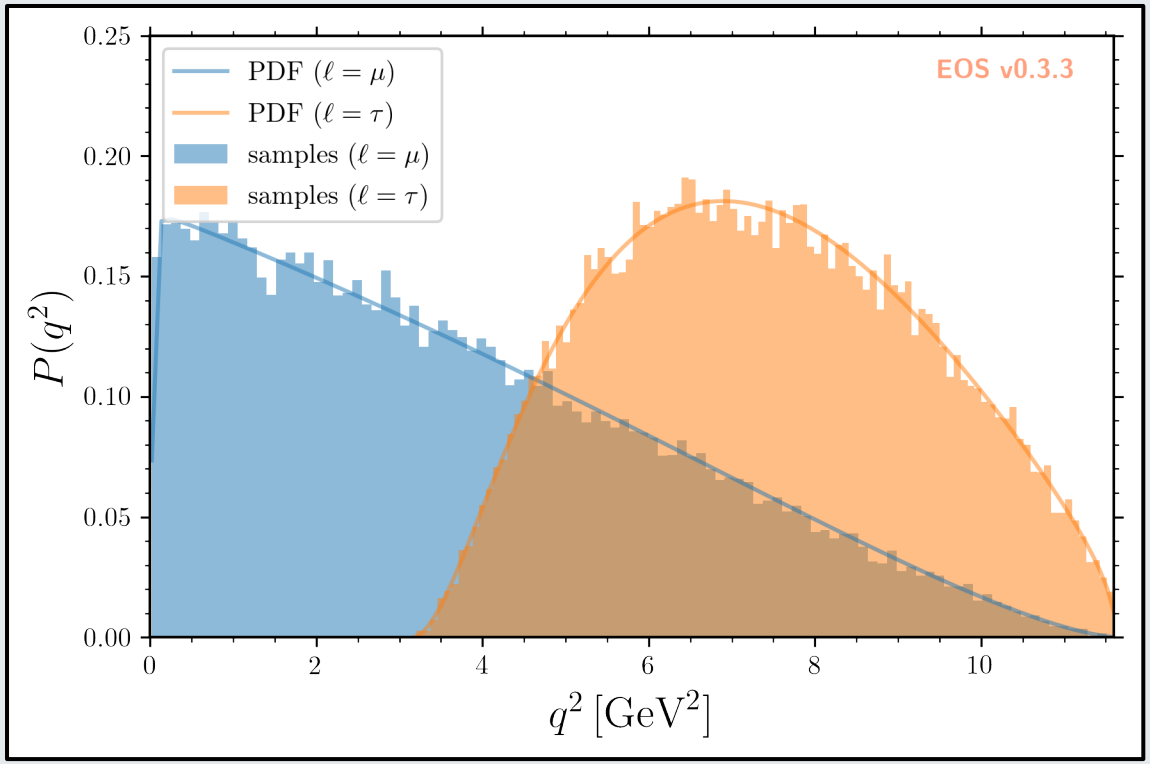


Simulation of Pseudo Events

Event simulation from a set of **built-in PDFs** using Markov chain Monte Carlo techniques.

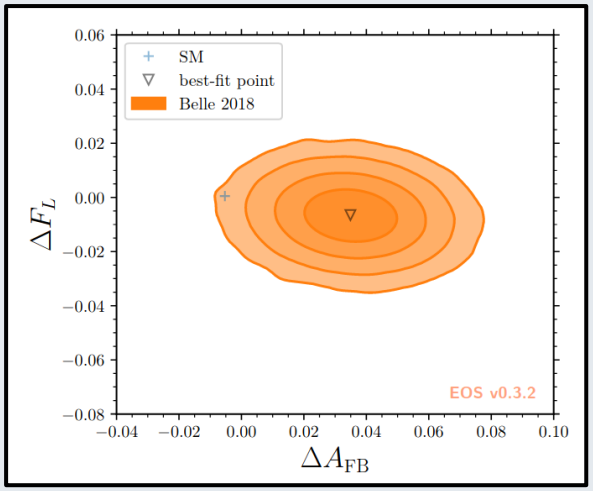
→ **Sensitivity studies**

Excellent matching between produced samples and built-in PDFs



Outlook

- EOS v1.0 is **imminent**
- **~1000** observables, **~1000** parameters, **~500** constraints
  - Your observables are welcome!
- Online documentation and tutorials:
  https://eos.github.io/doc/
- 18 contributors, github issue tracker:
  https://github.com/eos/eos/issues
- Used in **~30 theory papers** and **many experimental papers**, e.g.**:**
  - LFNU in $B \to D^* \ell \nu$ [2104.02094]
  - $B \to \pi$ form factors, impact on $|V_{ub}|$ [2102.07233]



Thank you!
(and come to the tutorial)

The tutorial – 23/11/2021 – 4pm

- 1h tutorial:
  - EOS installation:
    https://eos.github.io/doc/installation.html
  - Basic Tutorials:
    https://eos.github.io/doc/use-cases.html
  - Suggested exercise:

    Fit **C_9 vs. C_{10}** on R_K, R_{K^*} and $B_s \to \mu\mu$
  - **Come with your wishes, projects, analysis, …**