EOS - A New Tool for Flavor Observables

Danny van Dyk
based on work with
Frederik Beaujean, Christoph Bobeth, Christian Wacker

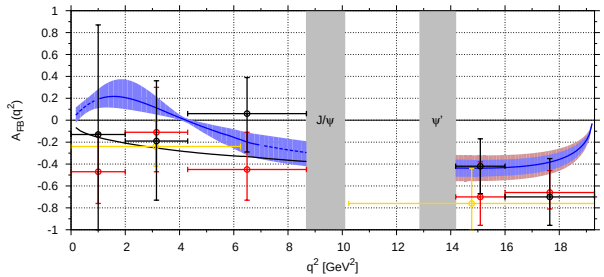
TU Dortmund

Rare B Decays @ Low Recoil 2011
DESY Hamburg

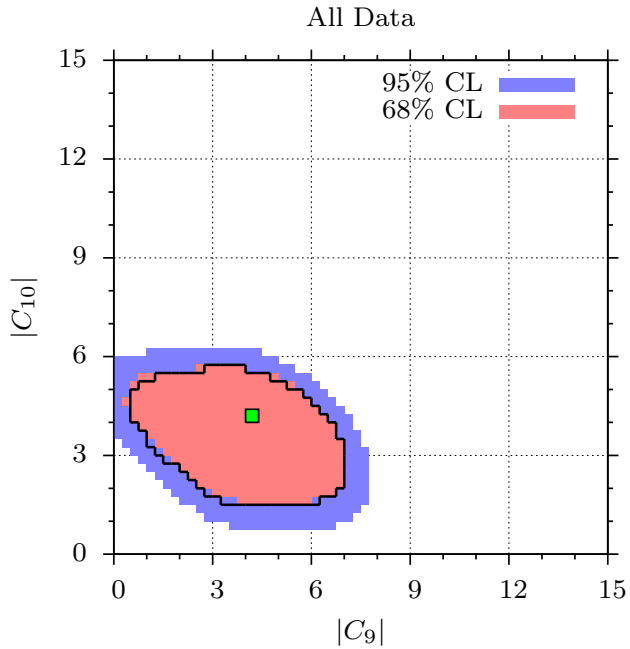
Use Cases

- calculation of flavor observables incl. theory uncertainty
  - within the SM
  - model independently via $\mathcal{C}_i(m_b)$
  - easy integration of new models is possible via new classes
  - preparations for MSSM studies

    →Stefan Schacht



- parameter scans with experimental constraints
  - simple lattice scans
  - full Bayesian scans using Markov chain sampling→Frederik Beaujean



Aimed at experimentalists and theorists alike!

EOS Implementation

Dependencies

- written in C++0x, needs >=g++-4.4
- written for Linux, but any UNIXoid OS should do
- minimal library dependencies: **NO ROOT!**
- GNU Scientific Library for special functions, random number generation, simplex method
- HDF5 for input/output

Extent

- multi-threaded calculations (POSIX threads!)
- extensive collection of test cases
- $\sim$150 File of Code, $\sim$30k Lines of Code

EOS Design

- every EOS client works on `Observables`
- every `Observable` has a unique name: `PROCESS::NAME@SUFFIX`
  e.g. `B->K^*ll::A_FB(s)@LowRecoil`
- to evaluate an `Observable` we need its `Parameters`, `Kinematics` and `Options`
- `Parameters` include any parameters that may be freely modified at run time: CKM parameters, masses, life times, form factor parameters, ...
- `Kinematics` include kinematic values that will only be supplied at runtime
- `Options` include choices that stay unchanged for an observable such as: model for short-distance couplings, final state lepton flavor, spectator quark flavor, choice of form factors parametrisation, ...

Extensions

- a `Model` provides running couplings $(\alpha_s, \mathcal{C}_i)$ and running quark masses
- for some exclusive decays, form factor values are provided by `FormFactor<Transition>`
- adding a new `Model` or a new `FormFactor` is a trivial exercise (code-wise)
- any `Observable` requests its model and (optionally) its form factors at construction

So for a full specification of an observable we could choose, e.g.

```
B->K^*ll::A_FB(s)@LowRecoil,q=d,l=mu,model=SM,form-factors=KMPW2010
B_q->ll::BR,q=s,l=mu,model=WilsonScan
B->X_sll::BR@HLMW2005,l=mu,model=SM
```

Exclusive Observables (I)

$\bar{B} \to \bar{K}^* \ell^+ \ell^-$

hi-q^2 $\mathcal{B}$, $A_{\rm FB}$, $F_{\rm L}$, $A_{\rm T}^{(i)}$, $H_{\rm T}^{(i)}$, $a_{\rm CP}^{(i)}$ checked

all observables: q^2-integrated and single-differential in q^2
calculation according to C. Bobeth,G. Hiller,DvD '10

$\bar{B} \to \bar{K} \ell^+ \ell^-$

hi-q^2 $\mathcal{B}$, $F_{\rm H}$, $R_K^{\mu/e}$, $a_{\rm CP}^{(1)}$ (work in progress)

all observables: q^2-integrated $\mathcal{B}, F_{\rm H}$: also single-differential in q^2
calculation according to C. Bobeth,G. Hiller,DvD,C. Wacker (in prep.)

Exclusive Observables (II)

$\bar{B} \to \bar{K}^* \ell^+ \ell^-$

lo-q^2 $\mathcal{B}$, A_{FB}, F_{L}, $A_{\mathrm{T}}^{(i)}$ checked

all observables: q^2-integrated and single-differential in q^2
calculation according to M. Beneke,Th. Feldmann,D. Seidel '01 and '04

$\bar{B} \to \bar{K} \ell^+ \ell^-$

lo-q^2 $\mathcal{B}$, F_{H}, $R_K^{\mu/e}$ checked

all observables: q^2-integrated $\mathcal{B}, F_{\mathrm{H}}$: also single-differential in q^2
calculation according to M. Beneke,Th. Feldmann,D. Seidel '01 and '04

Exclusive Observables (III)

$\bar{B} \to \bar{K}^* \gamma$

$\mathcal{B}$, $S_{K^*\gamma}$ checked

calculation according to M. Beneke,Th. Feldmann,D. Seidel '01 and '04 for $q^2 \to 0$

$\bar{B}_{s,d} \to \ell^+ \ell^-$

$\mathcal{B}$ checked

calculation according to C. Bobeth,T. Ewerth,F. Krüger,J. Urban '02

[Also: $\bar{B} \to X_s \ell\ell$ is implemented for the SM Basis only.]

We are interested in adding more observables! Do not hesitate to approach us and/or contribute!

Frequently Needed Utilities

Physics

- NNLO matching (SM) and running of $\Delta B = 1$ Wilson coefficients→Christoph Bobeth
- NNLO running of α_s (no decoupling yet)
- NNLO running of $\overline{\text{MS}}$ quark masses (no decoupling yet)

Statistics

- Bayesian analysis class→Frederik Beaujean
- configurable Markov chain sampling→Frederik Beaujean

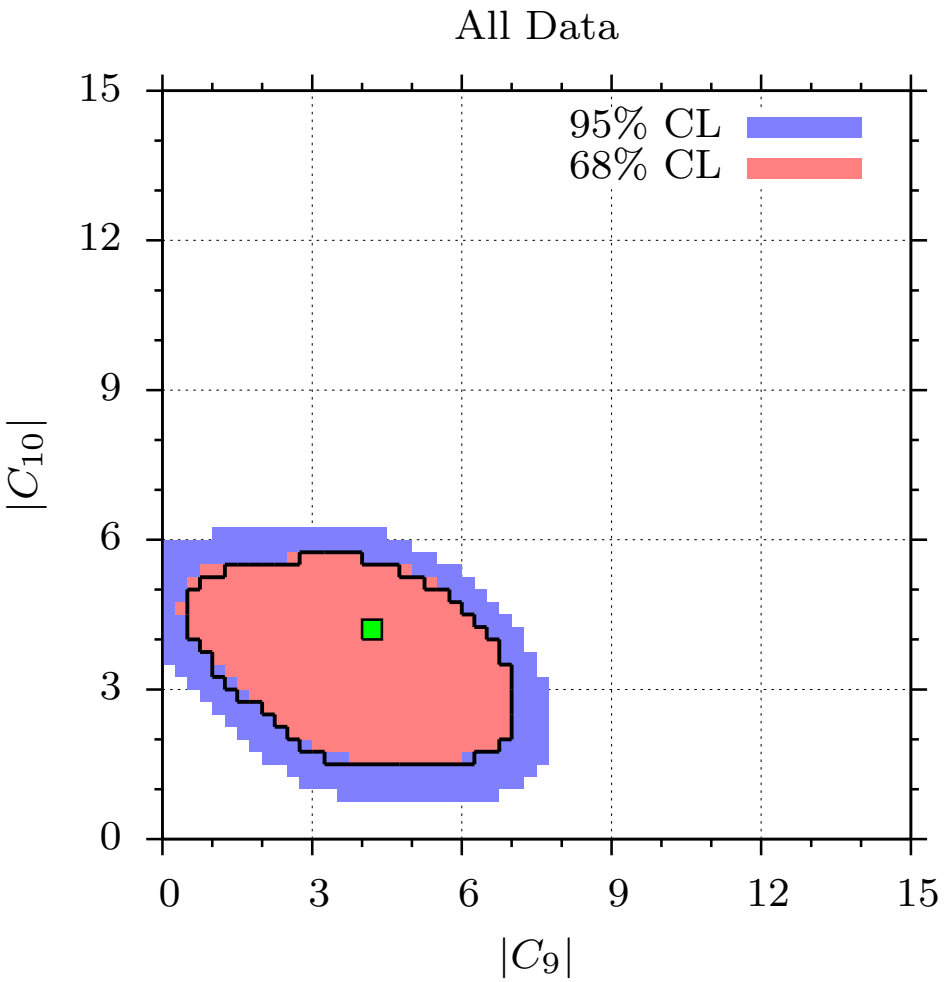
Speedup

- multi-threading via Task/Ticket abstraction
- memoisation of expensive function calls

Procedure for Parameter Scans

sample the N-dim parameter space	`eos-scan`, `eos-scan-polynomial`, `eos-scan-mc`
↓	↓
[find confidence regions (CRs)]	`eos-find-crs`
↓	↓
marginalise [or project] onto 1-dim/2-dim	`eos-marginalise`
↓	↓
plot the result distributions [or CRs]	`eos-filter`, `eos-contour`, `gnuplot`

Results (I)



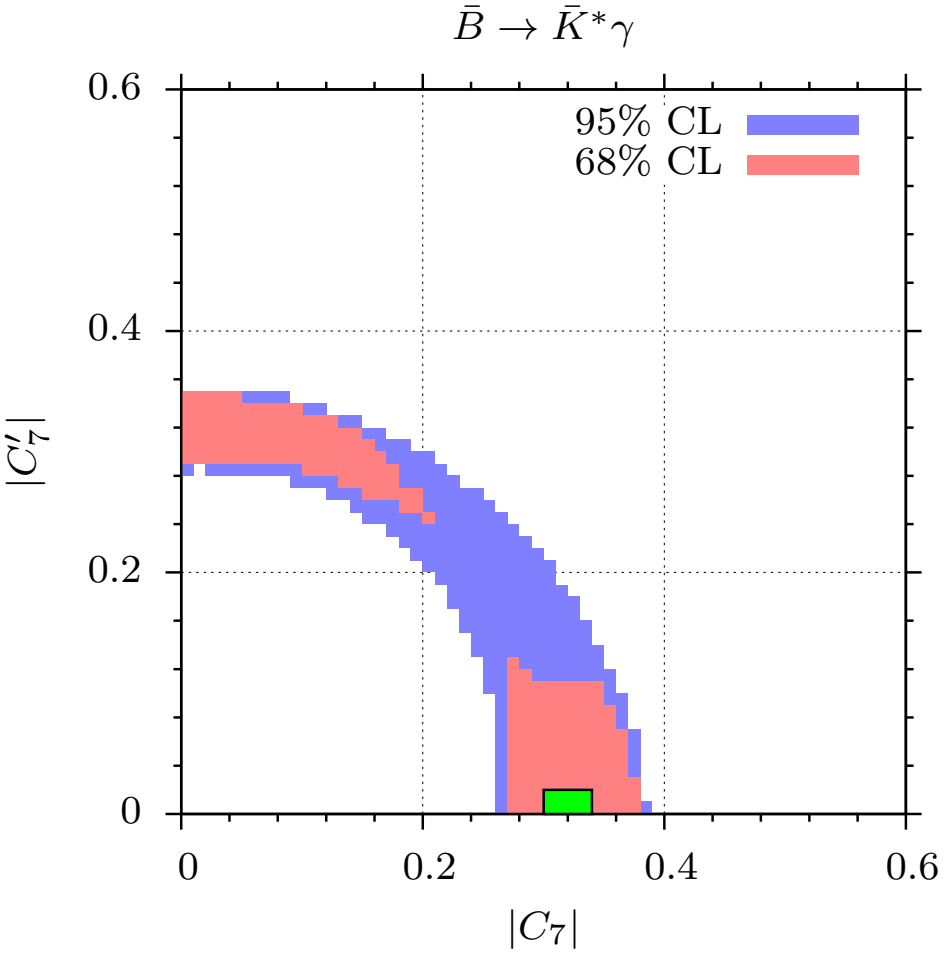
Polynomial

Lattice scan: $|\mathcal{C}_{7,9,10}|$, $\arg \mathcal{C}_{7,9,10}$ + theory uncertainty

2 scans with $5.9 \cdot 10^8$ points, evaluates via polynomial in $\mathcal{C}_i$

each scan: 138 hours runtime $\rightarrow$ 42 GB output

Results (II)



Markov Chains (Preliminary)

Toy scan: $|\mathcal{C}_7^{(\prime)}|$, $\arg \mathcal{C}_7^{(\prime)}$, $\overline{m}_b$

4 chains $\times$ 256 chunks
$\times$ 1024 points $\times$ 5 parameters

each scan: 90 min runtime
$\to$ 250 MB output

Wishlist

Physics

- NNLO $\mathcal{B}[\bar{B} \to X_s \ell^+ \ell^-]$: add right-handed currents
- NNLO $\mathcal{B}[\bar{B} \to X_s \gamma]$: implement
- hadronic $\Delta B = 1$ decays ($B \to PP$, $B \to VV$)
- further form factor implementations (relativistic quark model, lattice)

Features

- **continuation** of Markov Chain Monte Carlo scans
- automated production of 1D/2D plots
- "Factorization of Efforts": use Kernel Density Estimations to parametrise (N-dim) posteriors, use posterior as prior for further scans
  →expertise needed
- loading/storing of numerical input parameters (Flavor LHA?)

Availability

Homepage

`http://project.het.physik.tu-dortmund.de/eos/`

Source code and its history available at

`http://project.het.physik.tu-dortmund.de/eos/source`

Preliminary documentation in the source code

```
make doxygen
```

License is GNU Public License v2