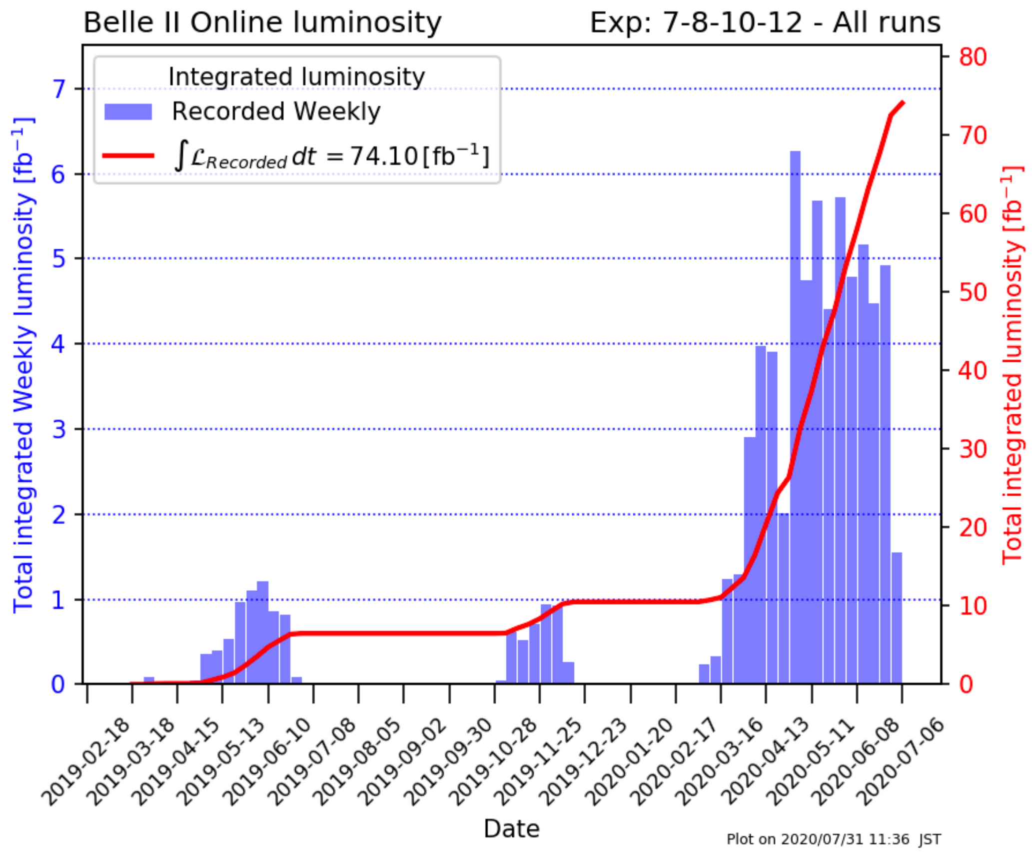


Non-Perturbative QCD at e^+e^- *B*-Factories

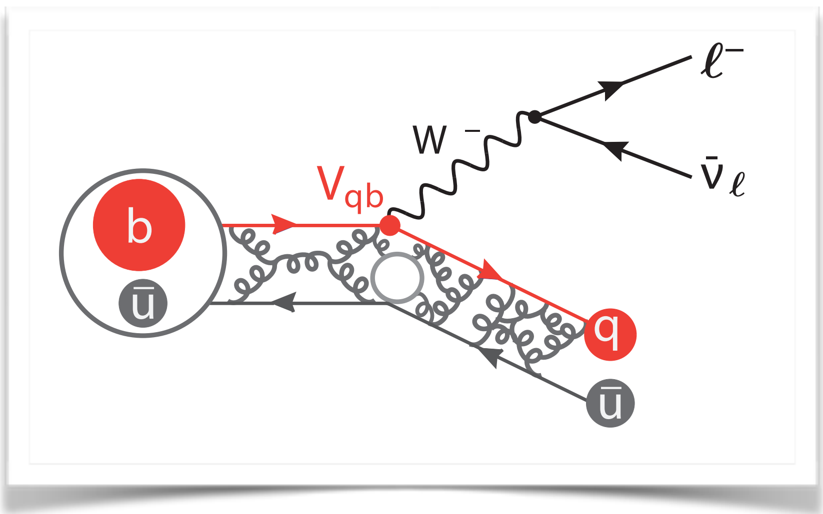
Snowmass 2021 — *EF05 Mini-Workshop on Non-Perturbative Uncertainties*

Florian Bernlochner
florian.bernlochner@uni-bonn.de

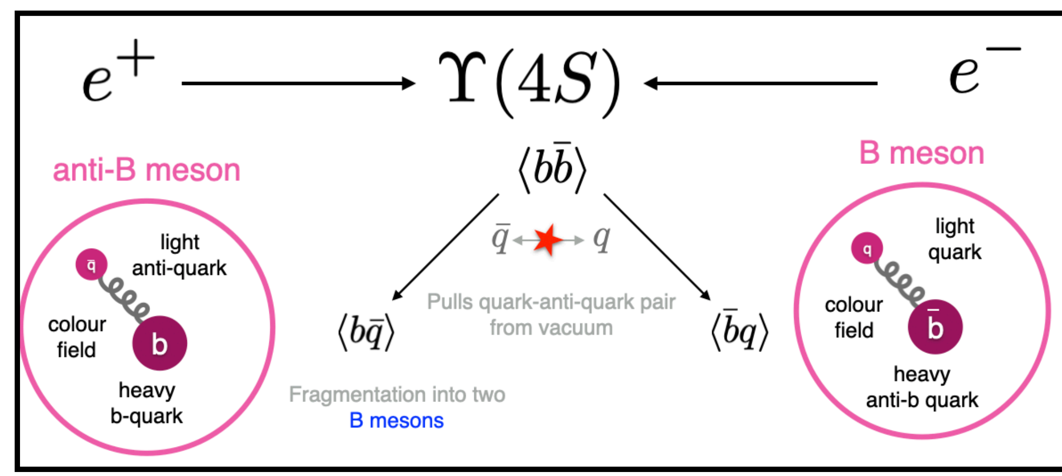
UNIVERSITÄT BONN

Non-Perturbative QCD at e+e- *B*-Factories

1. Simulation of Signal Processes



2. Simulation of Background Processes



3. Calculation of Matrix Elements / Decay rates to determine fundamental parameters

$$|V_{qb}| = \sqrt{\frac{\mathcal{B}(\bar{B} \to X_q \, \ell \, \bar{\nu}_\ell)}{\tau \, \Gamma(\bar{B} \to X_q \, \ell \, \bar{\nu}_\ell)}}$$

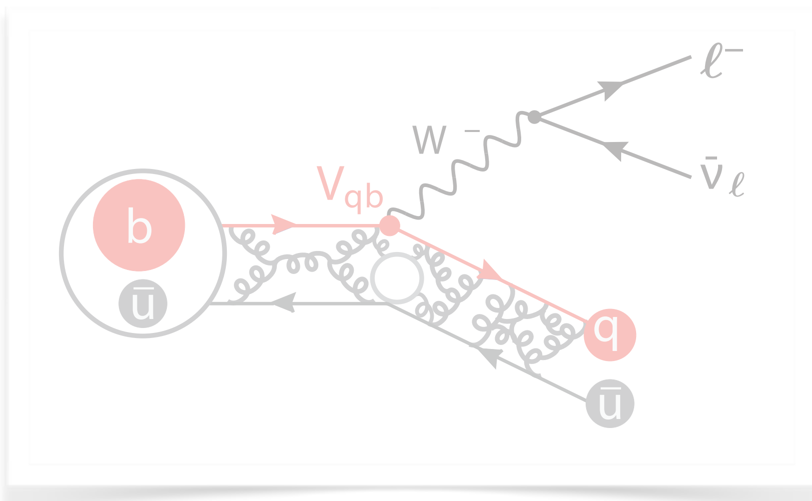
4. Data-driven improved simulations

5. How can Belle II help?

Belle II

Non-Perturbative QCD at e+e- *B*-Factories

1. Simulation of Signal Processes



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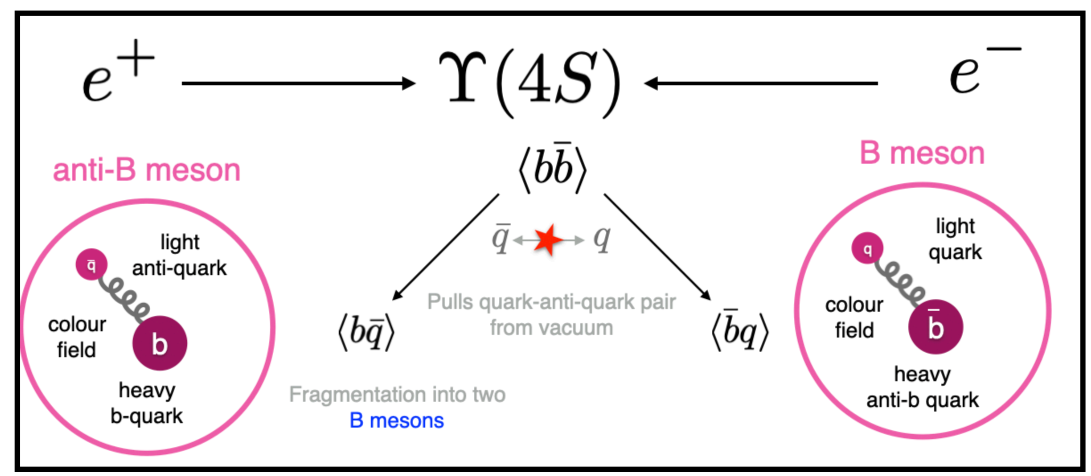

4. Data-driven improved simulations

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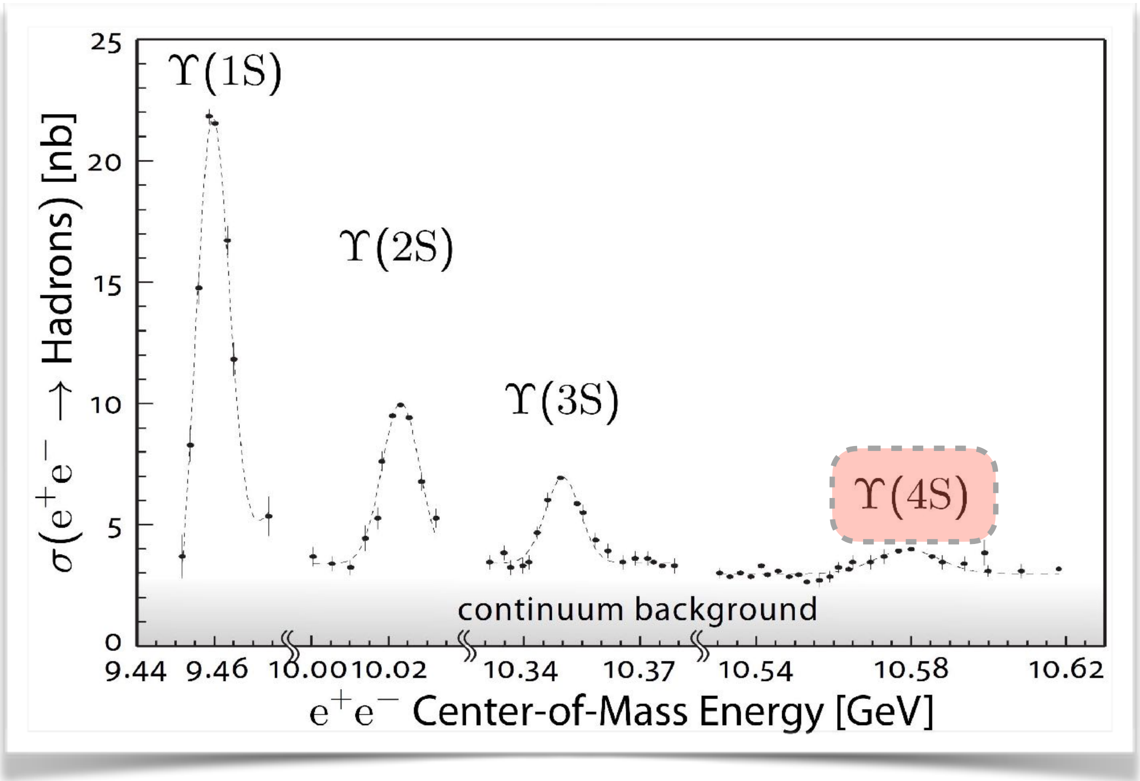
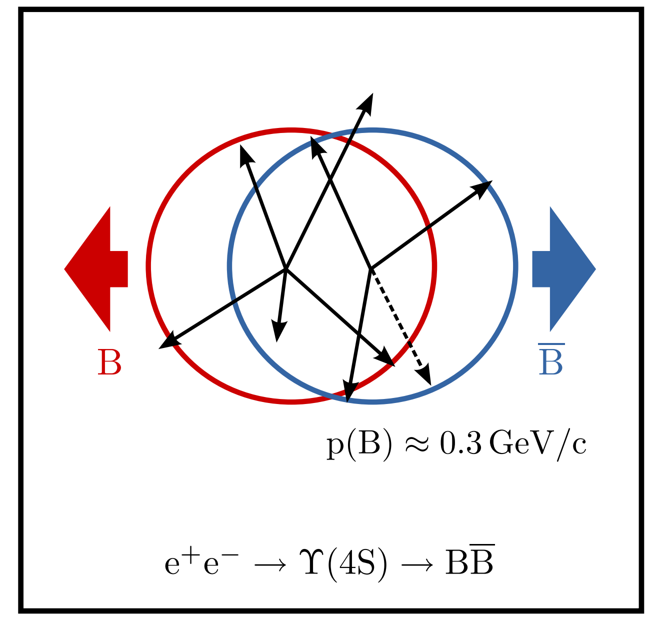
Belle II

Non-perturbative QCD in the Simulation of Backgrounds

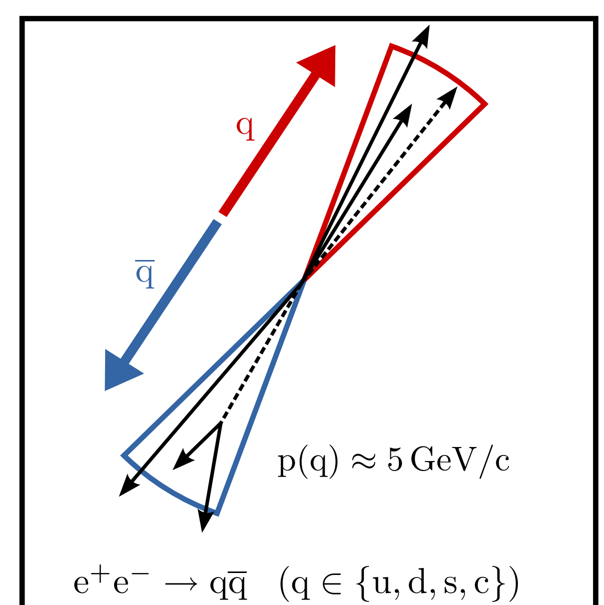
Non-perturbative QCD in background processes:



1. Simulation of **generic B-meson** decays



2. Simulation of **continuum** processes



Toolbox:
1. EvtGen + Pythia8
2. KKMC + Pythia8 + EvtGen

https://cds.cern.ch/record/591258/files/0211132.pdf

Precision calculation for $e^+e^- \to 2f$: the $\mathcal{KK}$ MC project*

B.F.L. Ward[a] and S. Jadach[b] and Z. Was[b]

[a]Department of Physics and Astronomy, University of Tennessee,
Knoxville, Tennessee 37996-1200, USA

[b]Henryk Niewodniczanski Institute of Nuclear Physics,
ul. Radzikowskiego 152, 31-342 Cracow, Poland

We present the current status of the coherent exclusive (CEEX) realization of the YFS theory for the processes in $e^+e^- \to 2f$ via the $\mathcal{KK}$ MC. We give a brief summary of the CEEX theory in comparison to the older (EEX) exclusive exponentiation theory and illustrate recent theoretical results relevant to the LEP2 and LC physics programs.

UTHEP-02-0901
Sept, 2002

Into the tool shed: EvtGen & Pythia8

Many analyses need generic B-Meson decay samples

* Simulated as mixture of **exclusive** modes

```
################################################
#                                              #
#                       B0                     #
#                                              #
################################################
Decay B0
# Updated to PDG 2017 using the isospin averaged BF
#                    b -> c semileptonic
#
0.05110    D*-     e+   nu_e              HQET3 0.912 1.205 1.15 1.404 0.854; #FF values taken from HFLAV 2016 (1612.07233)
0.02140    D-      e+   nu_e              BGL 0.0126 -0.094 0.34 -0.1 0.0115 -0.057 0.12 0.4; #[Belle measurement: 1510.03657]
0.00704    D_1-    e+   nu_e              LLSW 0.71 -1.6 -0.5 2.9;
0.00362    D_0*-   e+   nu_e              LLSW 0.68 -0.2 0.3;
0.00401    D'_1-   e+   nu_e              LLSW 0.68 -0.2 0.3;
0.00347    D_2*-   e+   nu_e              LLSW 0.71 -1.6 -0.5 2.9;
# the measured modes are already saturated by B->X_clnu; X_c->D(*)pi
# the values below give a rough estimate of max. allowed BF taking into uncertainties
0.00092   anti-D*0 pi-    e+    nu_e        GOITY_ROBERTS;
0.00046   D*-      pi0    e+    nu_e        GOITY_ROBERTS;
0.00092   anti-D0  pi-    e+    nu_e        GOITY_ROBERTS;
0.00046   D-       pi0    e+    nu_e        GOITY_ROBERTS;
# the B->Dpipilnu is the measured rate not covered by B->D_1lnu; D_1->Dpipi; modes with pi0 are infered asuming isospin symmetry
0.00021  D- pi+ pi-      e+    nu_e         PHSP;
0.00014  anti-D0 pi- pi0 e+    nu_e         PHSP;
0.00014  D- pi0 pi0      e+    nu_e         PHSP;
```

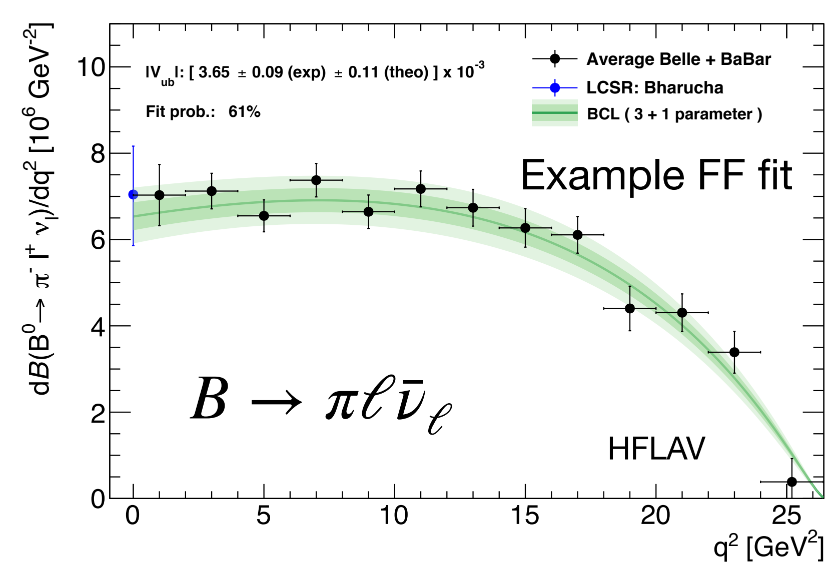
→ Phys. Rev. D 97, 075011 (2018)

→ Phase-Space

Explicit form factor models are included; parameters from measurements (combined with Lattice information if available)

As you can imagine it's a nightmare to keep these up-to-date

Recently started working on interface with PDG, but extremely challenging to keep things in sync.



Into the tool shed: EvtGen & Pythia8

Many analyses need generic B-Meson decay samples

* Pythia8 hadronized modes make up ca. **48%** (!) of all simulated decays

```
#  Lam_c X  / Sigma_c X      4.0 %
#
0.010520663 anti-cd_0 ud_0                               PYTHIA 23;
0.021041421 anti-cd_1 ud_1                               PYTHIA 23;

#  Xi_c X    2.5%
#
0.002869298 anti-cs_0 ud_0                               PYTHIA 23;
0.005738595 anti-cs_1 ud_1                               PYTHIA 23;

0.258091538 u       anti-d  anti-c  d                    PYTHIA 48;
0.043995612 u       anti-d  anti-c  d                    PYTHIA 13;
0.020084989 u       anti-s  anti-c  d                    PYTHIA 13;
0.017215691 u       anti-c  anti-d  d                    PYTHIA 48;
0.000860770 u       anti-c  anti-s  d                    PYTHIA 48;
#lange - try to crank up the psi production....
0.070775534 c       anti-s  anti-c  d                    PYTHIA 13;
0.005738595 c       anti-d  anti-c  d                    PYTHIA 13;
0.002869298 u       anti-d  anti-u  d                    PYTHIA 48;
0.003825730 c       anti-s  anti-u  d                    PYTHIA 48;
# JGS 11/5/02 This and similar a few lines above have been divided by two
# to solve a double-counting problem for this channel
0.001960649 u       anti-u  anti-d  d                    PYTHIA 48;
0.000066973 d       anti-d  anti-d  d                    PYTHIA 48;
0.000086068 s       anti-s  anti-d  d                    PYTHIA 48;
0.002104095 u       anti-u  anti-s  d                    PYTHIA 48;
0.001721541 d       anti-d  anti-s  d                    PYTHIA 48;
0.001434649 s       anti-s  anti-s  d                    PYTHIA 48;
0.004782163 anti-s  d                                    PYTHIA 32;
```

→

Modes for Matrix Element Processing

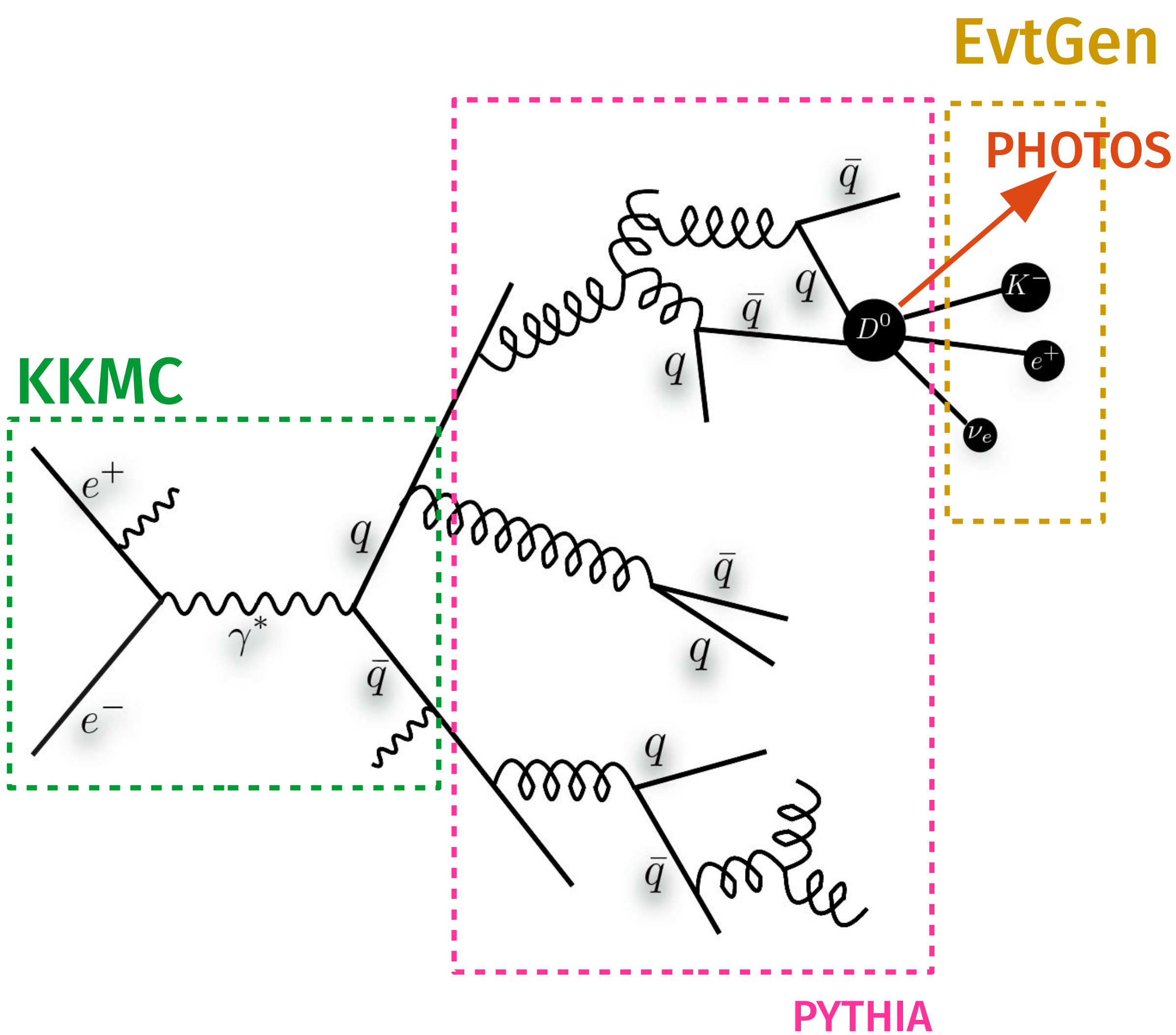
Some decays can be treated better than what pure phase space allows, by reweighting with appropriate matrix e
signaled by a nonvanishing `meMode()` value for a decay mode in the particle data table. The list of allowed poss
introduced, and most have been moved for better consistency. Here is the list of currently allowed `meMode()` co

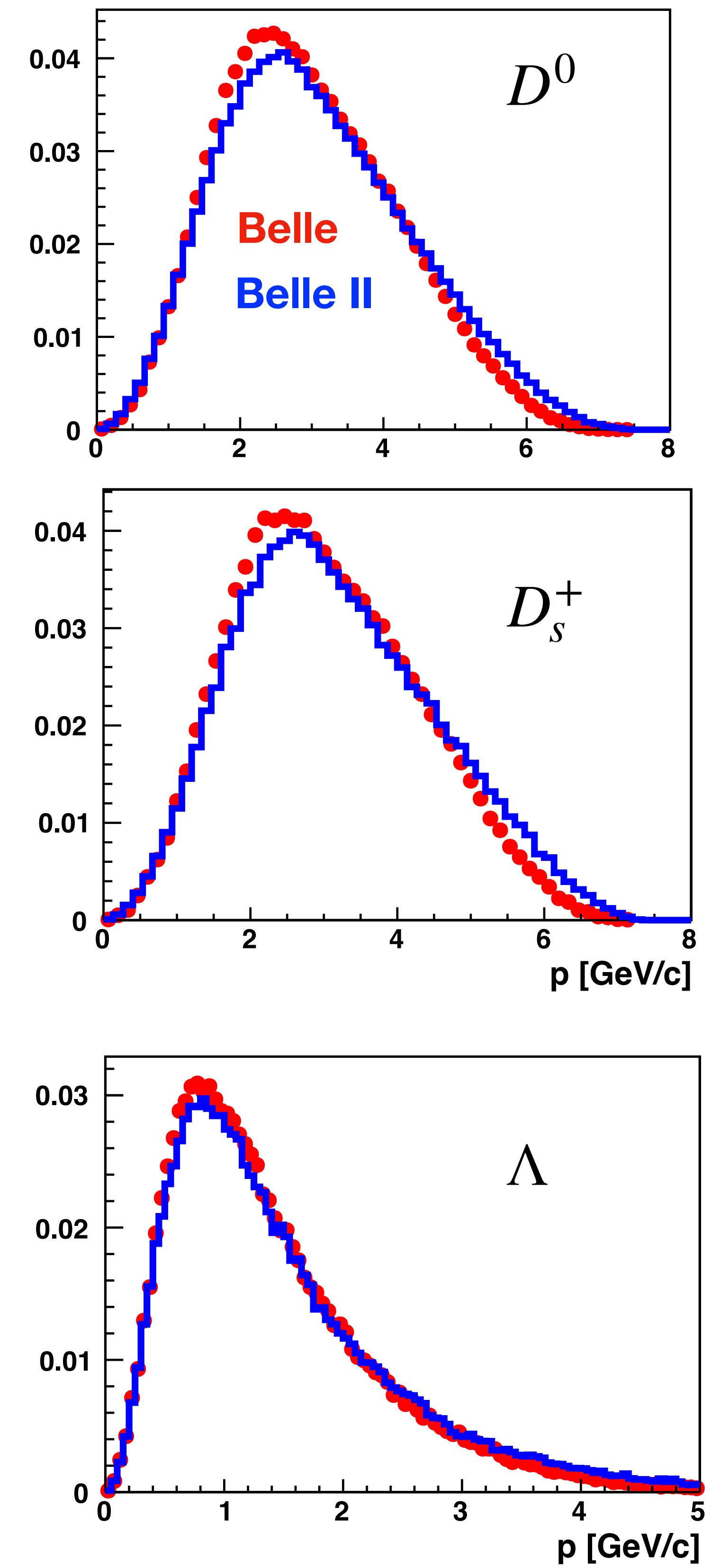
- 0 : pure phase space of produced particles ("default"); input of partons is allowed and then the partonic con
- 1 : *omega* and *phi → pi+ pi- pi0*
- 2 : polarization in *V → PS + PS* (*V* = vector, *PS* = pseudoscalar), when *V* is produced by *PS → PS + V* or *F*
- 11 : Dalitz decay into one particle, in addition to the lepton pair (also allowed to specify a quark-antiquark pa
- 12 : Dalitz decay into two or more particles in addition to the lepton pair
- 13 : double Dalitz decay into two lepton pairs
- 21 : decay to phase space, but weight up *neutrino_tau* spectrum in *tau* decay
- 22 : weak decay; if there is a quark spectator system it collapses to one hadron; for leptonic/semileptonic d
- 23 : as 22, but require at least three particles in decay
- 31 : decays of type B → gamma X, very primitive simulation where X is given in terms of its flavour content spectrum is weighted up relative to pure phase space
- 42 - 50 : turn partons into a random number of hadrons, picked according to a Poissonian with average val new try with another multiplicity if the sum of daughter masses exceed the mother one
- 52 - 60 : as 42 - 50, with multiplicity between `code` - 50 and 10, but avoid already explicitly listed non-parto
- 62 - 70 : as 42 - 50, but fixed multiplicity `code` - 60
- 72 - 80 : as 42 - 50, but fixed multiplicity `code` - 70, and avoid already explicitly listed non-partonic channel
- 91 : decay to *q qbar* or *g g*, which should shower and hadronize
- 92 : decay onium to *g g g* or *g g gamma* (with matrix element), which should shower and hadronize
- 93 : decay of colour singlet to *q qbar* plus another singlet, flat in phase space (and arbitrarily ordered), whe
- 94 : same as 93, but weighted with *V-A* weak matrix element if the decay chain is of the type *neutrino \rarr;*
- 100 - : reserved for the description of partial widths of resonances

Gevorg Karyan, Ami Rostomyan, Torben Ferber, Umberto Tamponi, Hulya Atmacan

KKMC & Pythia8 & EvtGen

Belle II Setup:





Belle Setup: Pythia + EvtGen

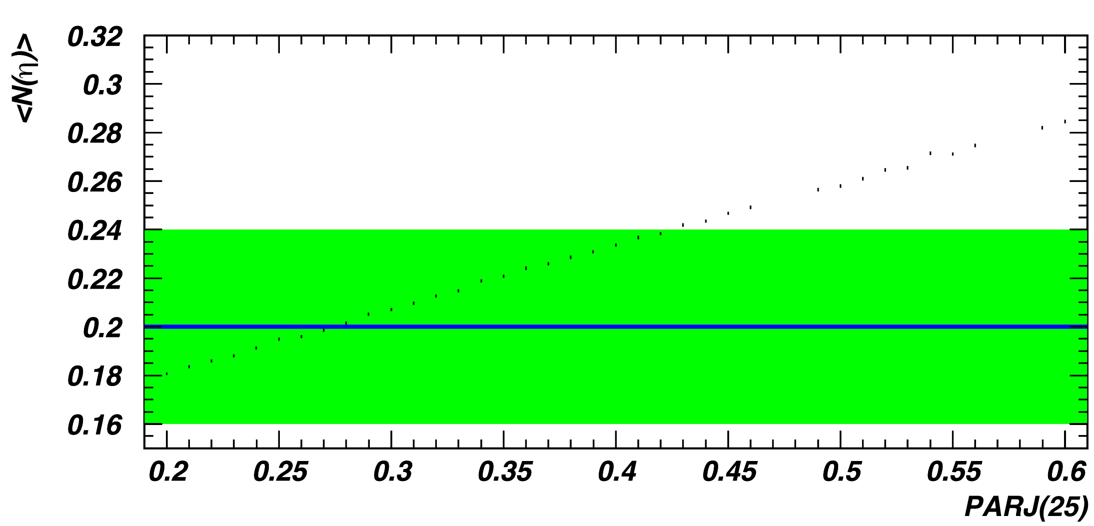
Belle Pythia6 Parameters

Belle used Pythia 6 with custom tunings

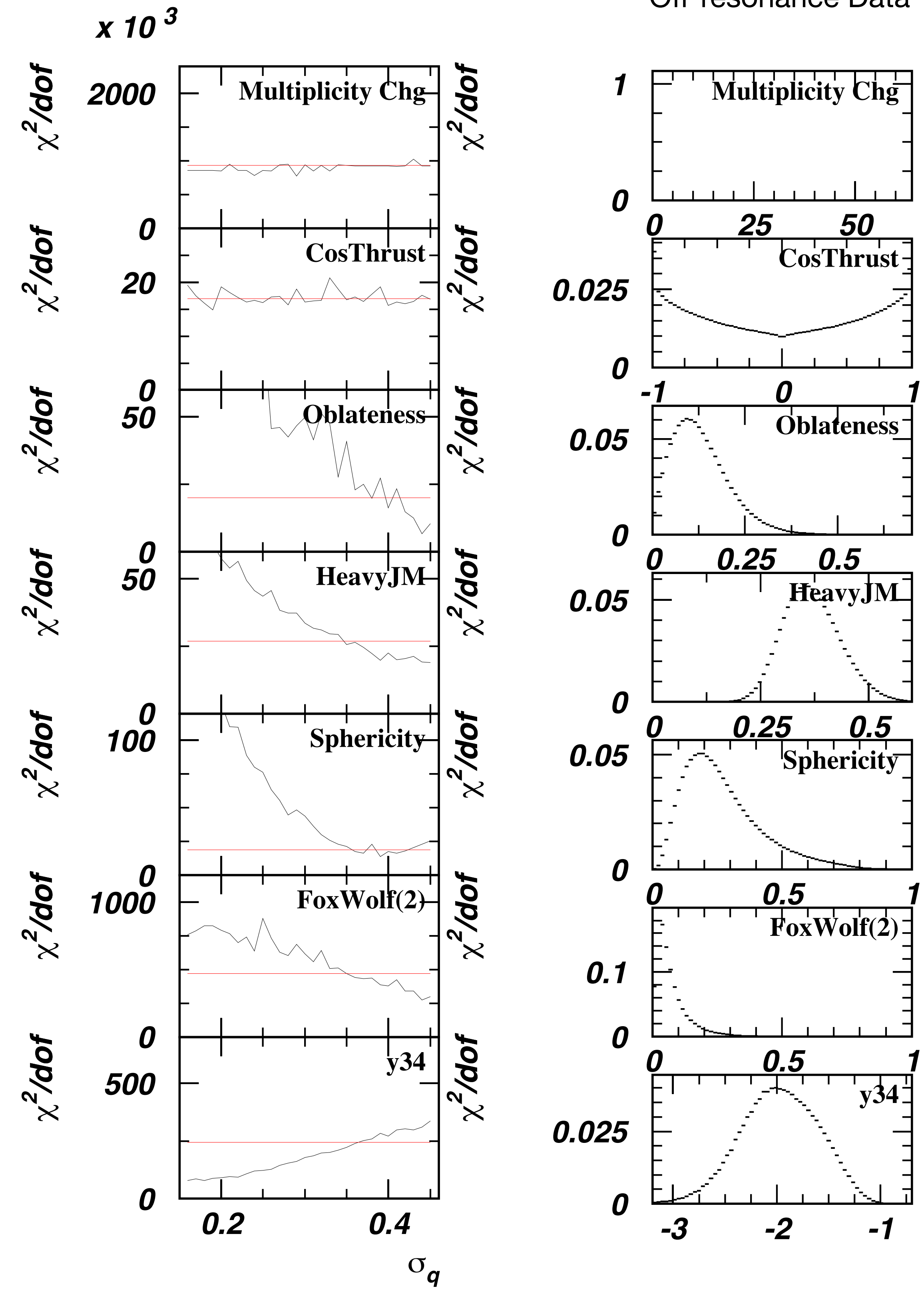
JetSetPar PARJ(21)=0.28	Default 0.36
JetSetPar PARJ(25)=0.27	Default 1
JetSetPar PARJ(26)=0.12	Default 0.4
JetSetPar PARJ(33)=0.3	Default 0.8
JetSetPar PARJ(35)=1.0	Default = PARJ(33)
JetSetPar PARJ(41)=0.32	Default 0.3
JetSetPar PARJ(42)=0.62	Default 0.58
JetSetPar PARJ(82)=0.38	Default 0.29
JetSetPar PARJ(82)=0.76	Default 1
JetSetPar PARP(2)=4.0	Default 10
JetSetPar MSTP(141)=1	Default 0
JetSetPar MSTP(171)=1	Default 0
JetSetPar MSTJ(104)=4	Default 5

Continuum $q\bar{q}$ was generated using the evtgen model PYCONT

```
Decay vpho

        # d u s c b t   e   mu  tau

1.0 PYCONT 0 0 0 1 0 0   0 0 0 0 0 0;

Enddecay
```



Off-resonance Data

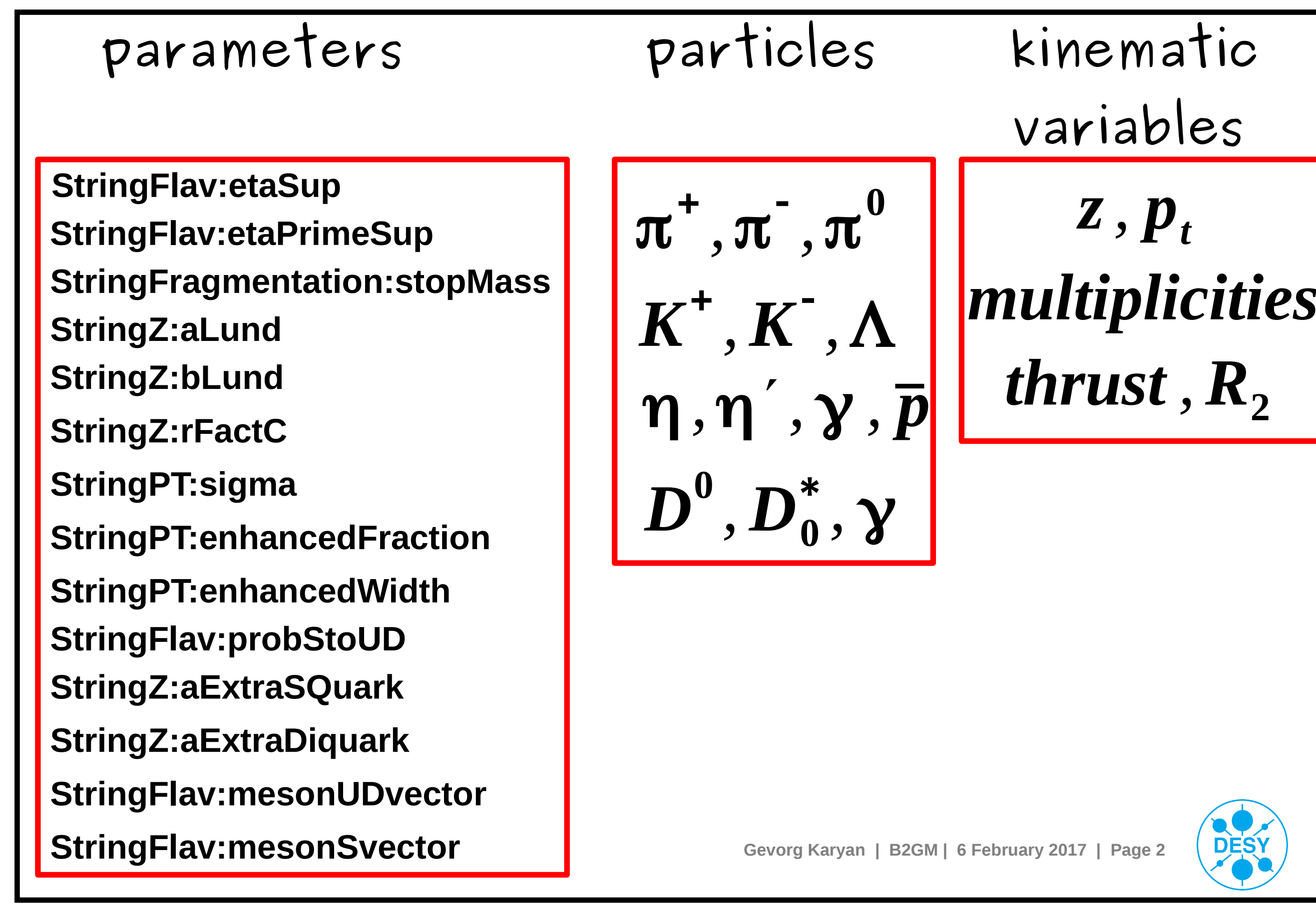


Belle II Translation

BelleII uses Pythia 8
→ **First challenge is to translate the Belle tunings from Pythia 6 to Pythia 8**

Current Proposal (by Hulya Atmacan)**:**
PythiaBothParam StringFlav:etaSup=0.27
PythiaBothParam StringFlav:etaPrimeSup=0.12
PythiaBothParam StringFragmentation:stopMass=1.1
PythiaBothParam StringZ:aLund=0.32
PythiaBothParam StringZ:bLund=0.62
PythiaBothParam StringZ:usePetersonC=off
PythiaBothParam StringZ:usePetersonB=off
PythiaBothParam StringZ:usePetersonH=off
PythiaBothParam StringZ:rFactC=1.0
PythiaBothParam StringPT:sigma = 0.4
PythiaBothParam TimeShower:pTmin = 0.38

→ Plan to use recorded **Belle II** (& maybe Belle) **data** to produce proper tune



As a comparison: Monash 2013

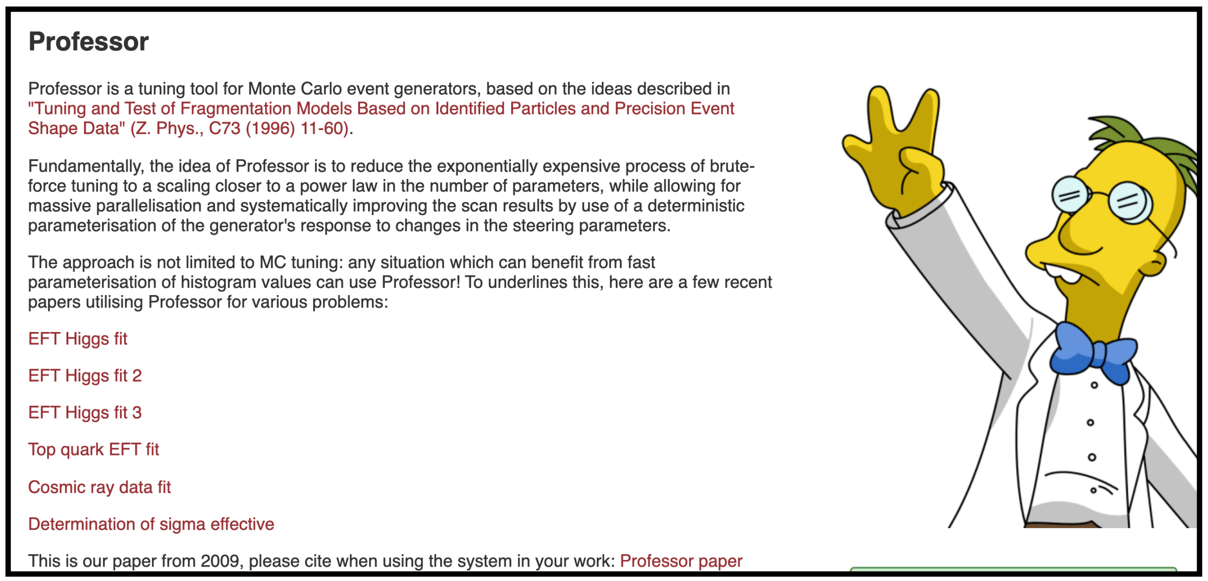
```
StringZ:aLund          =  0.68
StringZ:bLund          =  0.98
StringZ:aExtraDiquark  =  0.97
StringZ:aExtraSquark   =  0.00
```

Not much progress on this.

Full EvtGen + Pythia8 Tuning

Since for generic B decays only about 50% of all B mesons are hadronized via Pythia, possible that applying off-resonance tuning parameters might **be inadequate.**

* Long-standing idea: carry out a proper tuning using the Professor package (https://professor.hepforge.org/ by Holger Schulz and Andy Buckley)



Professor

Professor is a tuning tool for Monte Carlo event generators, based on the ideas described in "Tuning and Test of Fragmentation Models Based on Identified Particles and Precision Event Shape Data" (Z. Phys., C73 (1996) 11-60).

Fundamentally, the idea of Professor is to reduce the exponentially expensive process of brute-force tuning to a scaling closer to a power law in the number of parameters, while allowing for massive parallelisation and systematically improving the scan results by use of a deterministic parameterisation of the generator's response to changes in the steering parameters.

The approach is not limited to MC tuning: any situation which can benefit from fast parameterisation of histogram values can use Professor! To underlines this, here are a few recent papers utilising Professor for various problems:

EFT Higgs fit

EFT Higgs fit 2

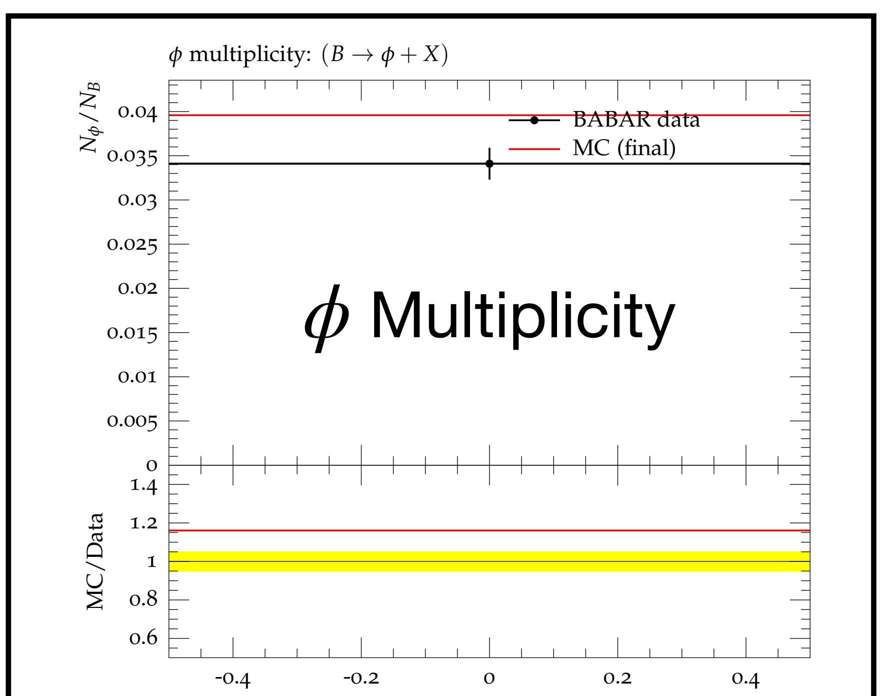
EFT Higgs fit 3

Top quark EFT fit

Cosmic ray data fit

Determination of sigma effective

This is our paper from 2009, please cite when using the system in your work: Professor paper



Example Inputs for such a tune:

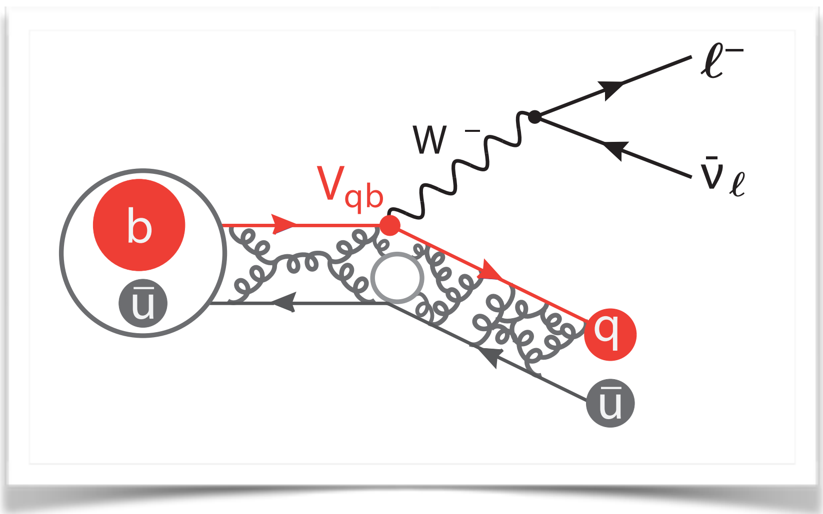
- Measurement of the average ϕ multiplicity in B meson decay PRD 69, 052005 (2004)[1]
- Study of inclusice B^- and $\bar{B}^0$ decays to flavor-tagged D, D_s and Λ_c^+ PRD 75, 072002 (2007)[1]
- Study of Inclusive Production of Charmonium Mesons in B Decay http://arxiv.org/abs/hep-ex/0207097 [2]
- Measurement of D_s^+ and D_s^{*+} production in B decays and from continuum e^+e^- annihilations at $\sqrt{s} = 10.6$ GeV, hep-ex/0107060
- Study of semi-inclusive production of η' mesons in B decays, hep-ex/0109034
- Study of high momentum η' production in $B \to \eta' X_s$, PRL 93, 061801 (2004)

[1] We have already implemented this analysis in rivet, to be submitted
[2] implemented in rivet

Not much progress on this.

Non-Perturbative QCD at e+e- *B*-Factories

1. Simulation of Signal Processes



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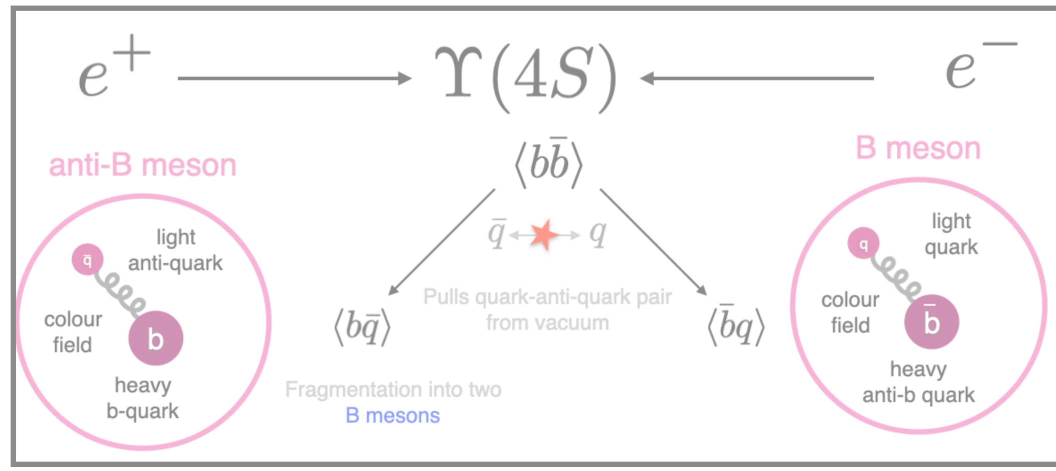

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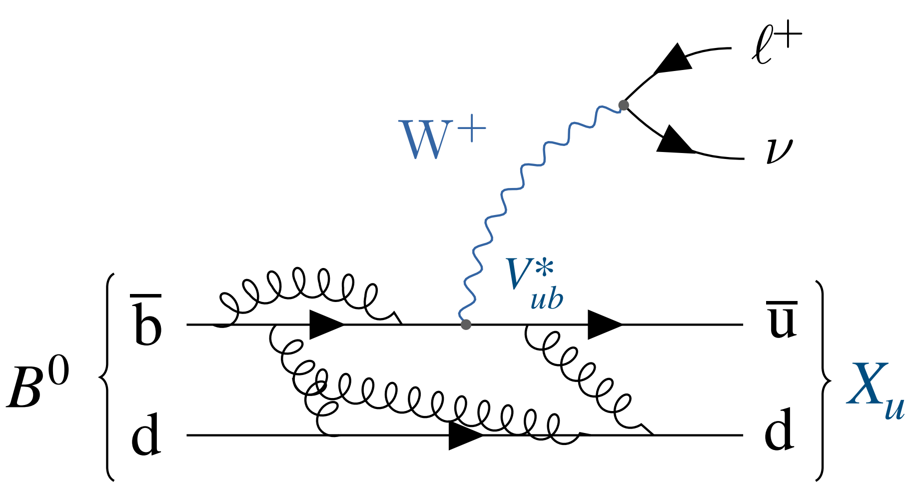
4. Data-driven improved simulations

5. How can Belle II help?

Going Hybrid: $B \to X_u \ell \bar{\nu}_\ell$

Many measurements target inclusive decays

- $B \to X_u \ell \bar{\nu}_\ell$ with $X_u \in [\pi, \rho, \omega, \eta, \eta',$ non-resonant decays, $\dots]$
- $B \to X_s \gamma$ or $B \to X_s \ell \ell$ with $X_s \in [K^*, K\pi,$ non-resonant, $\dots]$



Simulated as mix of **exclusive** & **inclusive** processes

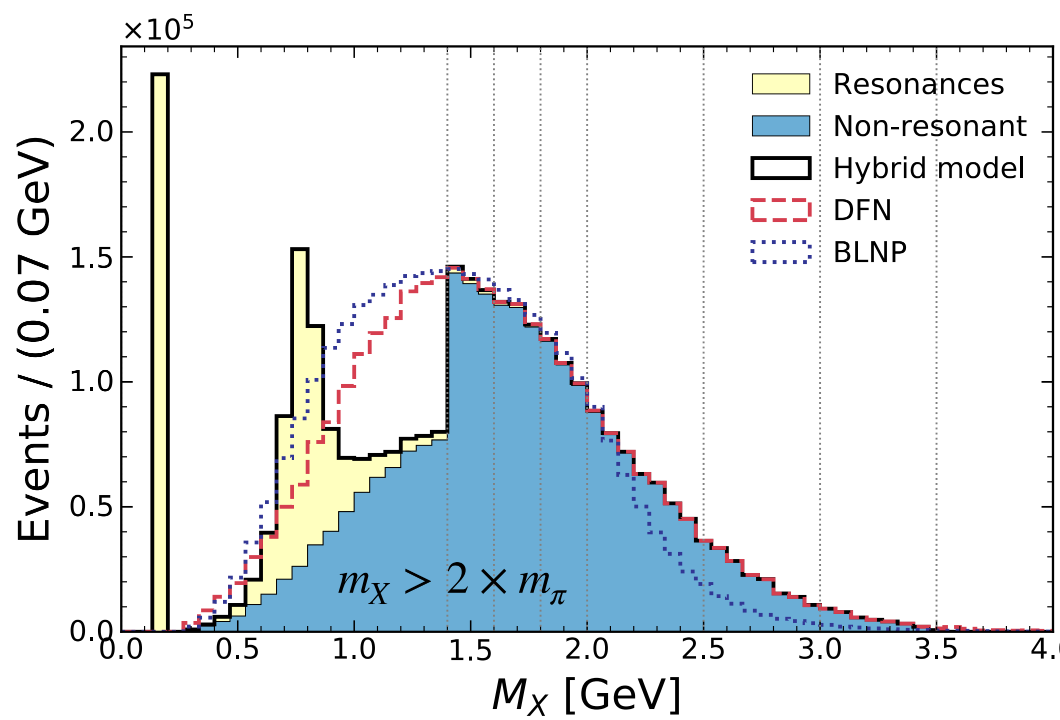
Inclusive: Simulate X system with kinematic properties following (N)NLO calculation w/ non-perturbative QCD input (e.g. from auxiliary measurements)

Hadronizied with Pythia / JETSET

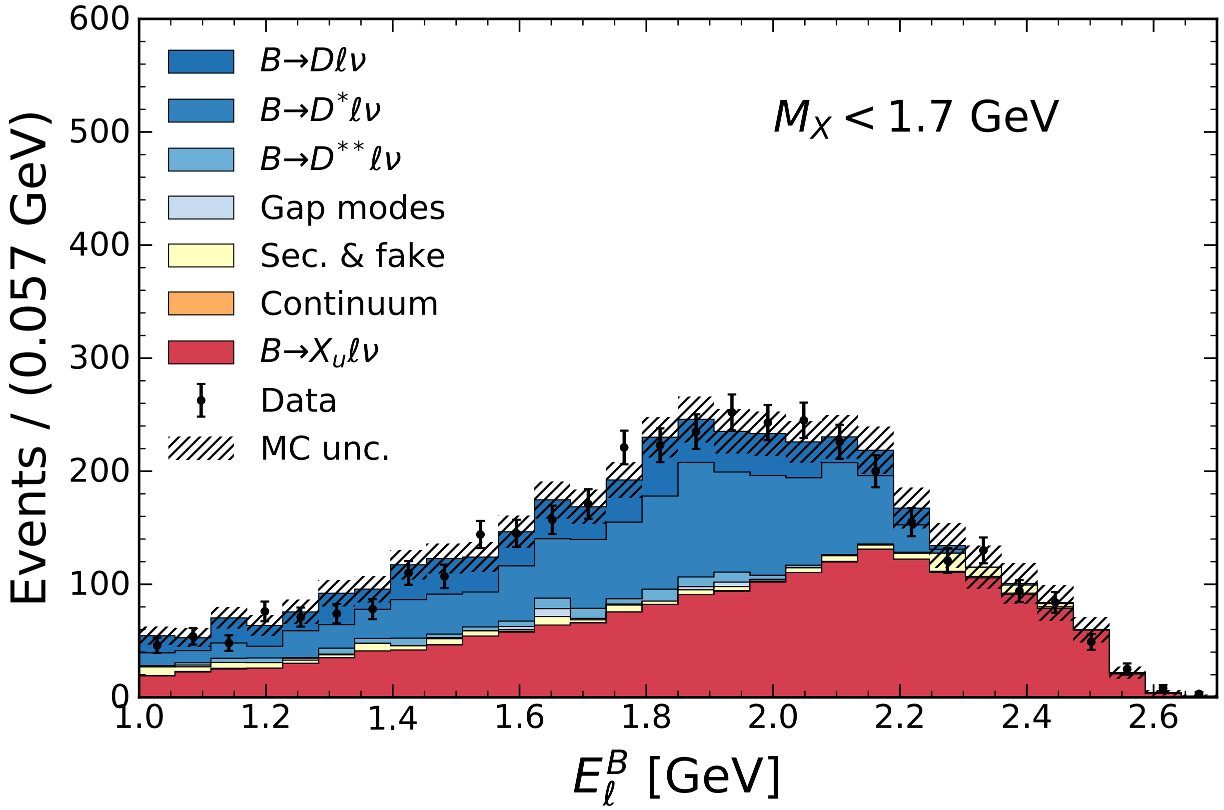
Hybrid Approach: Originally proposed by Phys. Rev. D **41**, 1496

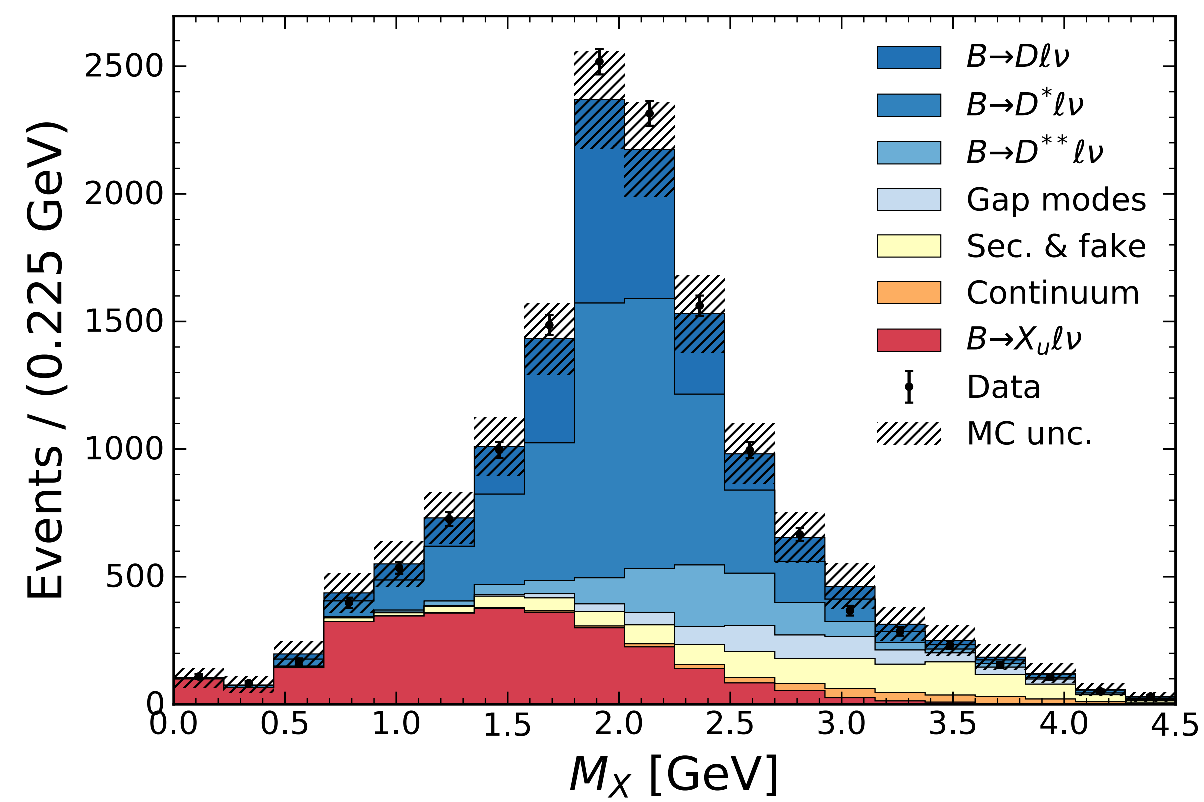
$$\Delta\mathcal{B}_{ijk}^{\mathrm{incl}} = \Delta\mathcal{B}_{ijk}^{\mathrm{excl}} + w_{ijk} \times \Delta\mathcal{B}_{ijk}^{\mathrm{incl}} \,,$$

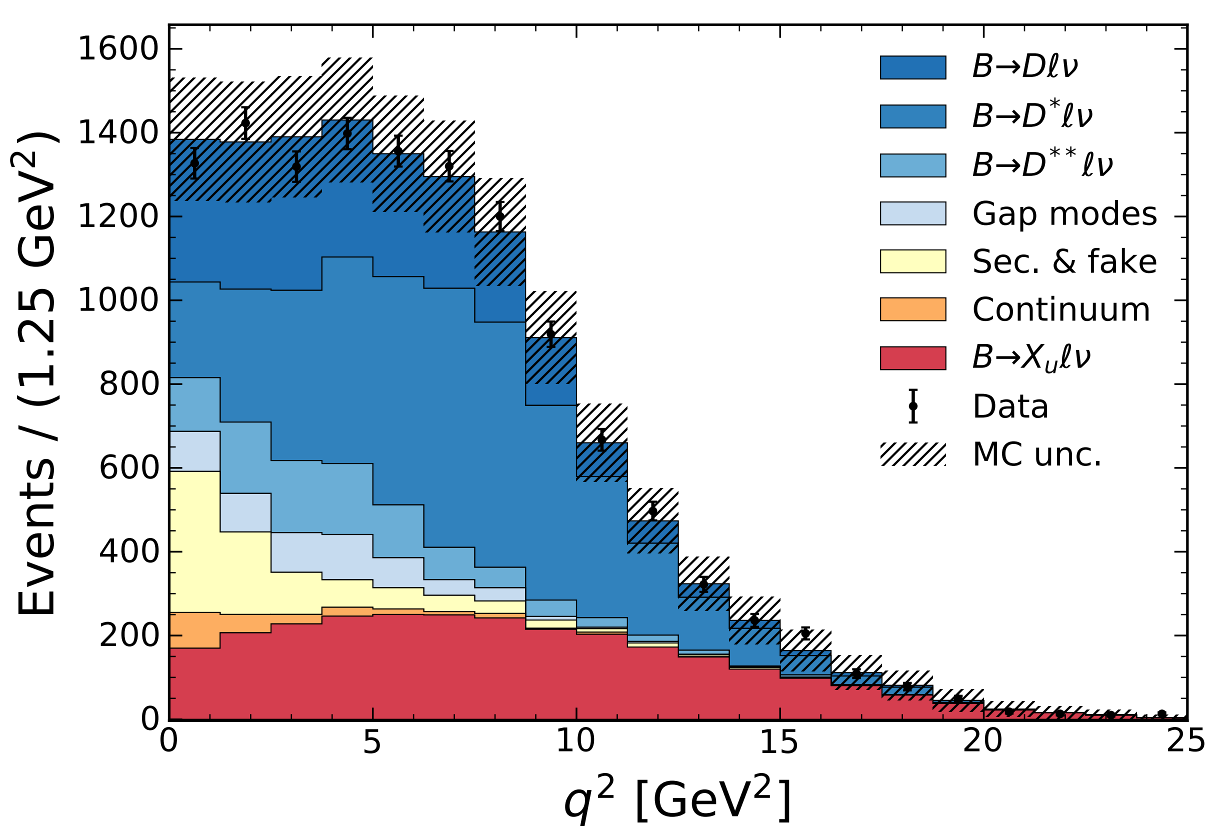
$$\begin{aligned} q^2 &= [0, 2.5, 5, 7.5, 10, 12.5, 15, 20, 25]\ \mathrm{GeV}^2 \,, \\ E_\ell^B &= [0, 0.5, 1, 1.25, 1.5, 1.75, 2, 2.25, 3]\ \mathrm{GeV} \,, \\ M_X &= [0, 1.4, 1.6, 1.8, 2, 2.5, 3, 3.5]\ \mathrm{GeV} \,. \end{aligned}$$



(Full Belle dataset)







Going Hybrid: $B \to X_u \ell \bar{\nu}_\ell$

Many measurements target inclusive decays

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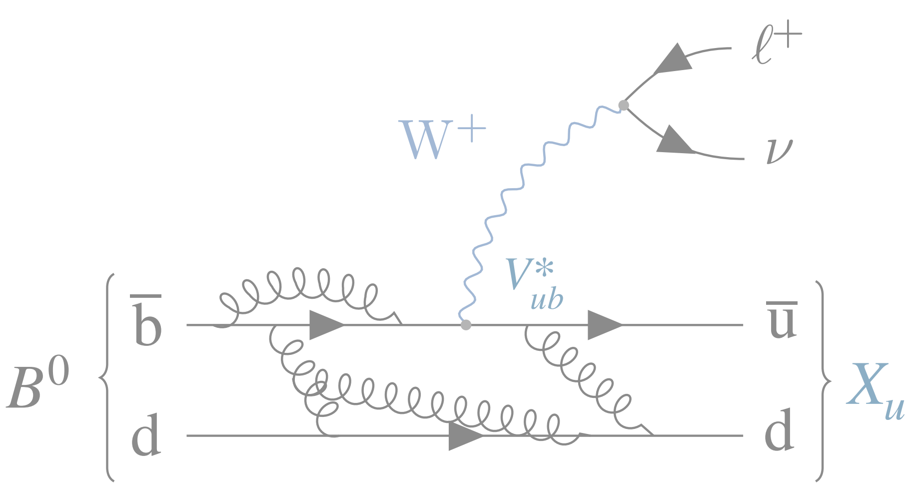
- $B \to X_s \gamma$ or $B \to X_s \ell \ell$ with $X_s \in [K^*, K\pi$, non-resonant, $\ldots]$



Simulated as mix of **exclusive** & **inclusive** processes

Inclusive: Simulate X system with kinematic properties following (N)NLO calculation w/ non-perturbative QCD input (e.g. from auxiliary measurements)

Hadronizied with Pythia / JETSET

Hybrid Approach: Originally proposed by Phys. Rev. D **41**, 1496

Assessment of uncertainties:

* Change excl. FFs and incl. admixture
* Changes to underlying model parameters
* Vary Pythia / JETSET parameters that affect e.g. scalar vs. vector final states, suppression of s quark production, η-meson suppression →

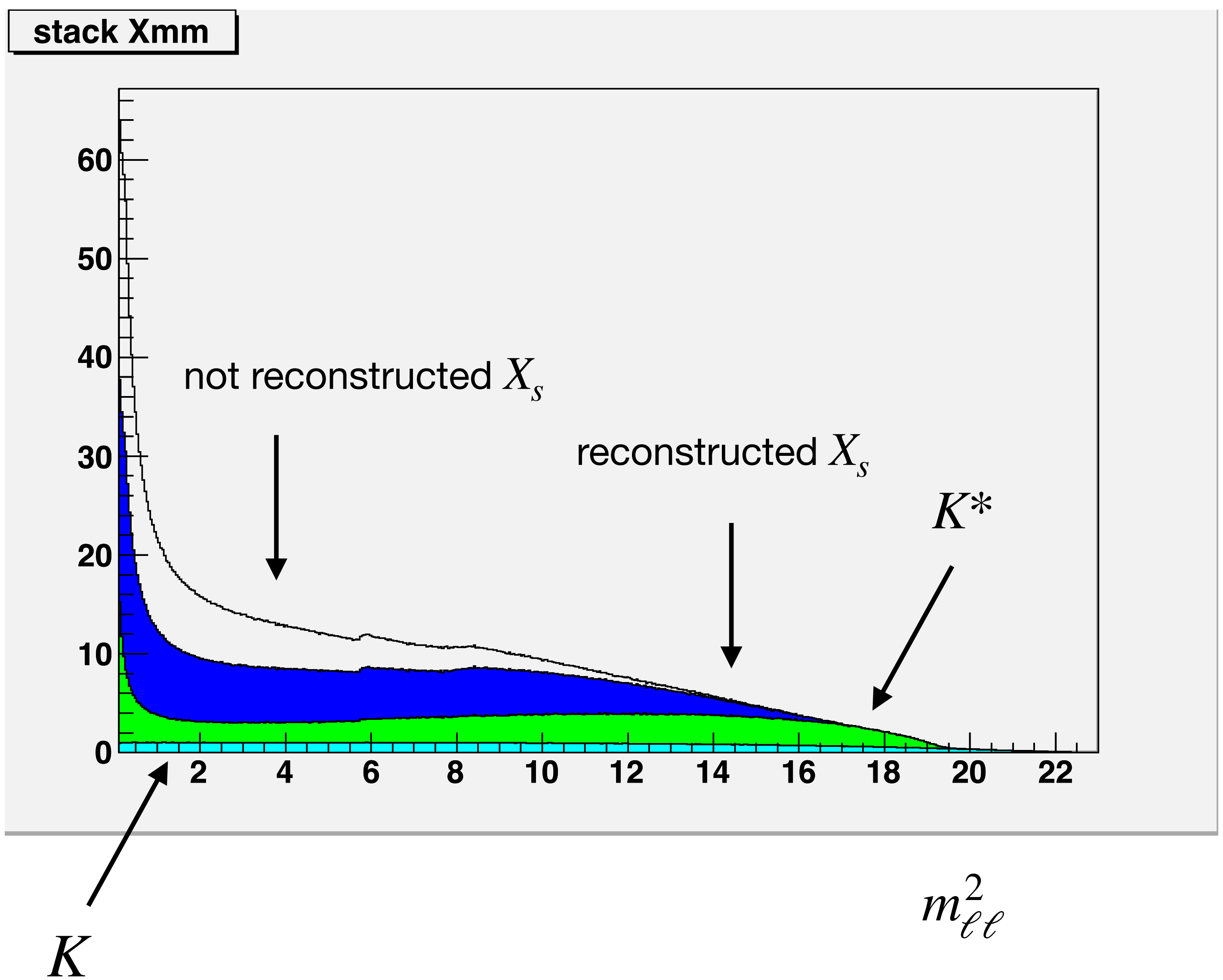
mesonUDvector, mesonSvector, mesonCvector	for the relative production ratio vector/pseudoscalar for light (u, d), s and c mesons
probStoUD	the suppression of s quark production relative to u or d production.
probQQtoQ	parameter for the suppression of diquark production relative to quark production, i.e. of baryon relative to meson production
etaSup	the η-meson suppression

Kevin Flood et al.

Going SEM: $B \to X_s\ell\ell$ or $B \to X_s\gamma$

Inclusive measurements sometimes uses so-called **SEM** approaches:
Sum over exclusive modes

Same approach: simulated as mix of **exclusive** & **inclusive** processes
inclusive X_s system hadronized using Pythia / JETSET



Targets about **70%** of all $B \to X_s\ell\ell$ decays

Reconstructed Mode	Reconstructed As
1	$B^0 \to K^0_S\ \mu^+\mu^-$
2	$B^+ \to K^+\ \mu^+\mu^-$
3	$B^0 \to K^0_S\ e^+e^-$
4	$B^+ \to K^+\ e^+e^-$
5	$B^0 \to K^{*0}\ (K^0_S\ \pi^0)\mu^+\mu^-$
6	$B^+ \to K^{*+}\ (K^+\ \pi^0)\mu^+\mu^-$
7	$B^+ \to K^{*+}\ (K^0_S\ \pi^+)\mu^+\mu^-$
8	$B^0 \to K^{*0}\ (K^+\ \pi^-)\mu^+\mu^-$
9	$B^0 \to K^{*0}\ (K^0_S\ \pi^0)e^+e^-$
10	$B^+ \to K^{*+}\ (K^+\ \pi^0)e^+e^-$
11	$B^+ \to K^{*+}\ (K^0_S\ \pi^+)e^+e^-$
12	$B^0 \to K^{*0}\ (K^+\ \pi^-)e^+e^-$
13	$B^+ \to K^0_S\ \pi^+\ \pi^0\ \mu^+\mu^-$
14	$B^0 \to K^+\ \pi^-\ \pi^0\ \mu^+\mu^-$
15	$B^0 \to K^0_S\ \pi^+\ \pi^-\ \mu^+\mu^-$
16	$B^+ \to K^+\ \pi^+\ \pi^-\ \mu^+\mu^-$
17	$B^+ \to K^0_S\ \pi^+\ \pi^0\ e^+e^-$
18	$B^0 \to K^+\ \pi^-\ \pi^0\ e^+e^-$
19	$B^0 \to K^0_S\ \pi^+\ \pi^-\ e^+e^-$
20	$B^+ \to K^+\ \pi^+\ \pi^-\ e^+e^-$
21	$B^0 \to K^0_S\ \pi^+\ \pi^-\ \pi^0\ \mu^+\mu^-$
22	$B^+ \to K^+\ \pi^+\ \pi^-\ \pi^0\ \mu^+\mu^-$
23	$B^+ \to K^0_S\ \pi^+\ \pi^-\ \pi^+\ \mu^+\mu^-$
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Same approach: simulated as mix of **exclusive** & **inclusive** processes
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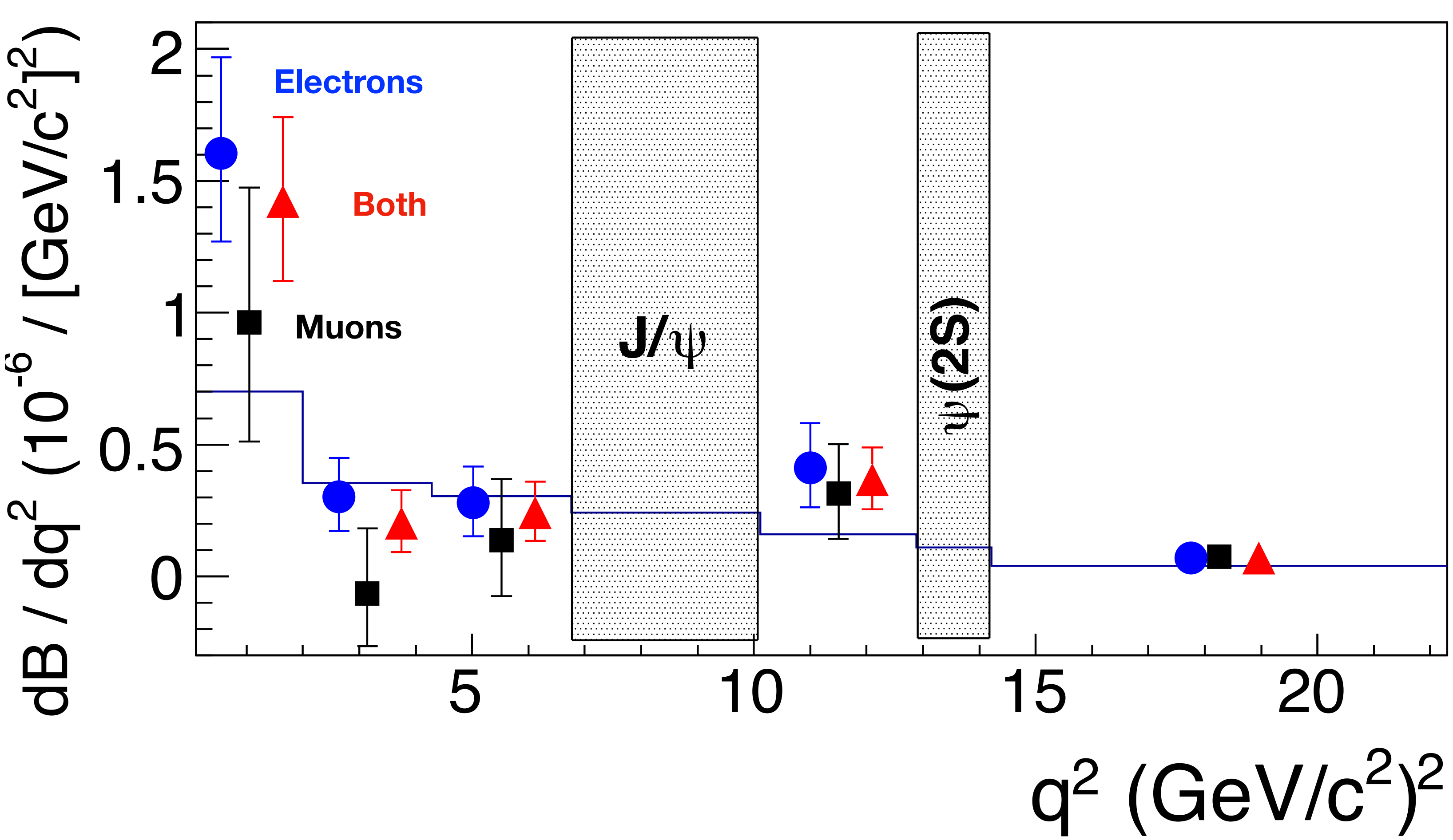

Targets about **70%** of all $B \to X_s \ell\ell$ decays

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Efficiency strongly dependent on **final state multiplicity / final state mode**

Reco Mode	qbin0 N_{gen}	qbin0 N_{rec}	qbin0 ε
1	48.4	1.5	0.031 ± 0.025
2	73.8	9.1	0.123 ± 0.038
3	49.6	3.5	0.070 ± 0.036
4	76.4	20.4	0.267 ± 0.051
5	80.9	0.7	0.009 ± 0.011
6	84.1	3.4	0.040 ± 0.021
7	152.4	3.4	0.023 ± 0.012
8	143.4	12.2	0.085 ± 0.023
9	81.5	1.9	0.023 ± 0.017
10	85.5	8.2	0.095 ± 0.032
11	156.1	7.3	0.047 ± 0.017
12	144.9	26.3	0.182 ± 0.032
13	95.7	0.7	0.007 ± 0.009
14	113.8	3.4	0.030 ± 0.016
15	95.3	1.4	0.014 ± 0.012
16	80.6	5.2	0.065 ± 0.027
17	92.5	1.5	0.016 ± 0.013
18	109.7	7.5	0.068 ± 0.024
19	92.1	2.9	0.031 ± 0.018
20	78.1	10.7	0.137 ± 0.039

N pions	modes	qbin0 N_{gen}	qbin0 N_{rec}	qbin0 ε	qbin1 N_{gen}	qbin1 N_{rec}	qbin1 ε
0	1–4	248.1	34.5	0.139 ± 0.022	105.9	10.3	0.097 ± 0.029
1	5–12	928.9	63.3	0.068 ± 0.008	648.7	35.2	0.054 ± 0.009
2	13–20	757.7	33.2	0.068 ± 0.008	569.2	20.1	0.035 ± 0.008

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TABLE VII: $B \to X_s\, e^+e^-$ branching fraction model-dependent extrapolation systematic uncertainties.

actual changes in tunings

"ad-hoc" variations

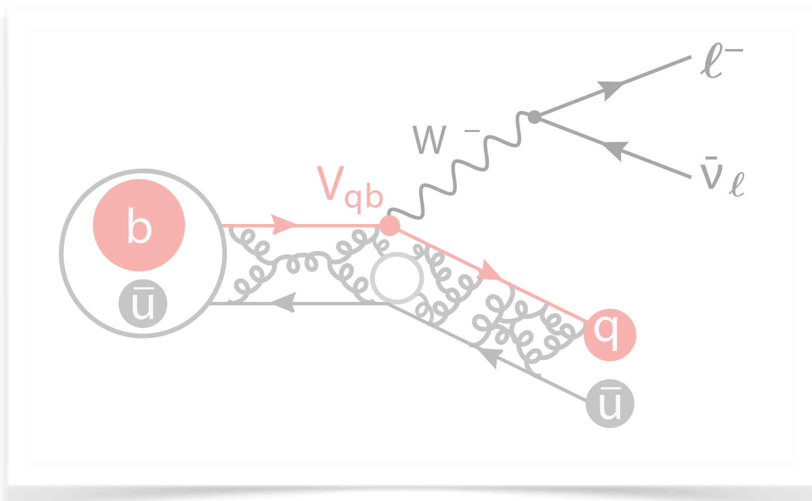
Variation	q_0^2	q_1^2	q_2^2	q_3^2	q_4^2	q_5^2	$m_{X_s,3}$	$m_{X_s,4}$
Jetset tunings	$^{+0.060}_{-0.059}$	$^{+0.011}_{-0.013}$	$^{+0.010}_{-0.012}$	$^{+0.011}_{-0.014}$	$^{+0.001}_{-0.002}$	$^{+0.031}_{-0.036}$	$^{+0.037}_{-0.036}$	$^{+0.075}_{-0.077}$
$\pm 50\%\ N_{\pi^0} > 1$	0.249	0.047	0.038	0.025	0.002	0.130	0.030	0.051
$\pm 50\%\ K$ multiplicity	0.046	0.008	0.006	0.002	0.000	0.022	0.000	0.006
$\pm 50\%\ \pi^+$ multiplicity	0.196	0.036	0.028	0.012	0.000	0.100	0.024	0.080
$\pm 1\sigma\ B \to K^{(*)}\ell^+\ell^-$ BFs	$^{+0.115}_{-0.129}$	$^{+0.024}_{-0.026}$	$^{+0.021}_{-0.023}$	$^{+0.018}_{-0.018}$	$^{+0.002}_{-0.002}$	$^{+0.067}_{-0.073}$	$^{+0.004}_{-0.005}$	$^{+0.000}_{-0.000}$
Total	$^{+0.346}_{-0.351}$	$^{+0.065}_{-0.066}$	$^{+0.053}_{-0.054}$	$^{+0.035}_{-0.036}$	$^{+0.003}_{-0.003}$	$^{+0.181}_{-0.184}$	$^{+0.053}_{-0.053}$	$^{+0.121}_{-0.123}$

TABLE VIII: $B \to X_s\, \mu^+\mu^-$ branching fraction model-dependent extrapolation systematic uncertainties.

Variation	q_0^2	q_1^2	q_2^2	q_3^2	q_4^2	q_5^2	$m_{X_s,3}$	$m_{X_s,4}$
Jetset tunings	$^{+0.035}_{-0.041}$	$^{+0.002}_{-0.003}$	$^{+0.005}_{-0.006}$	$^{+0.009}_{-0.012}$	$^{+0.001}_{-0.002}$	$^{+0.025}_{-0.020}$	$^{+0.015}_{-0.014}$	$^{+0.007}_{-0.008}$
$\pm 50\%\ N_{\pi^0} > 1$	0.154	0.011	0.020	0.021	0.002	0.047	0.012	0.005
$\pm 50\%\ K$ multiplicity	0.029	0.002	0.003	0.002	0.000	0.008	0.000	0.001
$\pm 50\%\ \pi^+$ multiplicity	0.122	0.008	0.015	0.010	0.000	0.036	0.010	0.008
$\pm 1\sigma\ B \to K^{(*)}\ell^+\ell^-$ BFs	$^{+0.027}_{-0.030}$	$^{+0.002}_{-0.002}$	$^{+0.004}_{-0.005}$	$^{+0.007}_{-0.007}$	$^{+0.001}_{-0.001}$	$^{+0.015}_{-0.019}$	$^{+0.001}_{-0.001}$	$^{+0.000}_{-0.000}$
Total	$^{+0.203}_{-0.205}$	$^{+0.014}_{-0.014}$	$^{+0.026}_{-0.026}$	$^{+0.026}_{-0.027}$	$^{+0.003}_{-0.003}$	$^{+0.066}_{-0.065}$	$^{+0.021}_{-0.021}$	$^{+0.012}_{-0.013}$

Non-Perturbative QCD at e+e- *B*-Factories

1. Simulation of Signal Processes



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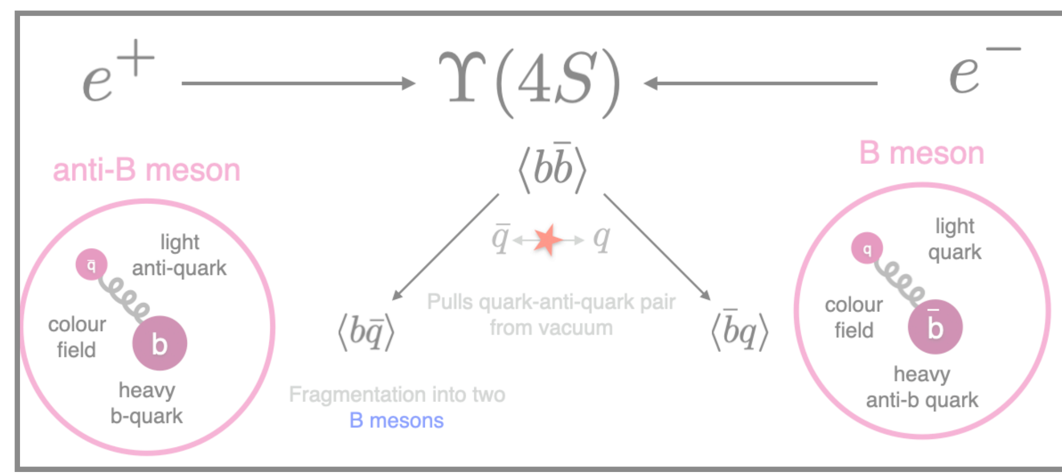

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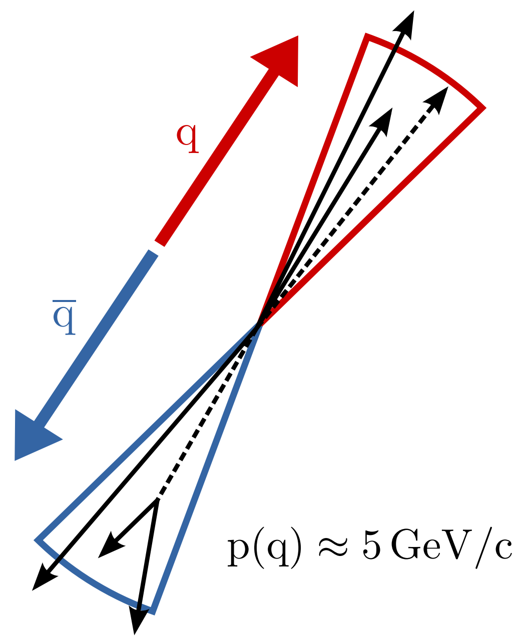
$$|V_{qb}| = \sqrt{\frac{\mathcal{B}(\bar{B} \to X_q \, \ell \, \bar{\nu}_\ell)}{\tau \, \Gamma(\bar{B} \to X_q \, \ell \, \bar{\nu}_\ell)}}$$

4. Data-driven improved simulations

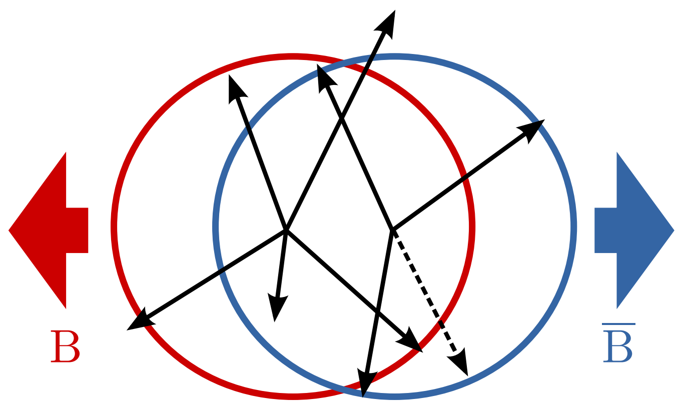
5. How can Belle II help?

Markus Prim, Lena Feld, FB

Leaving simulations behind

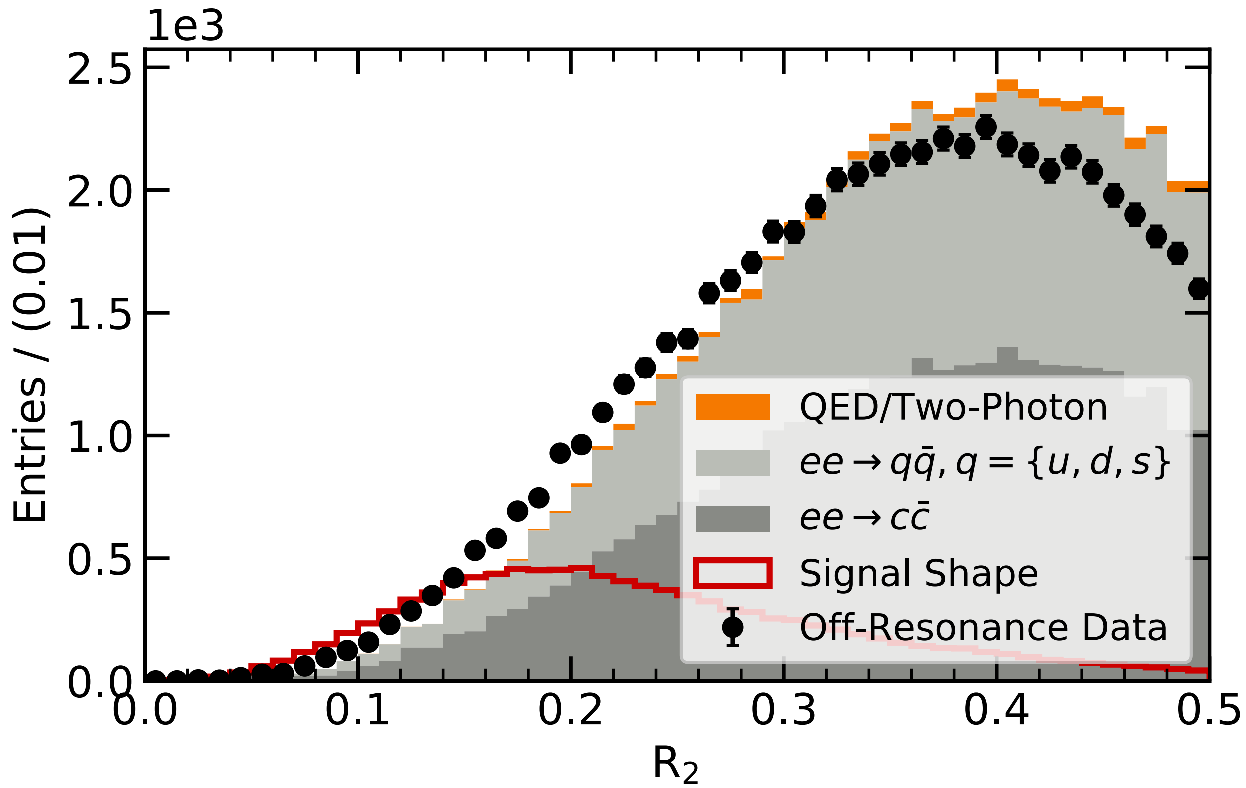


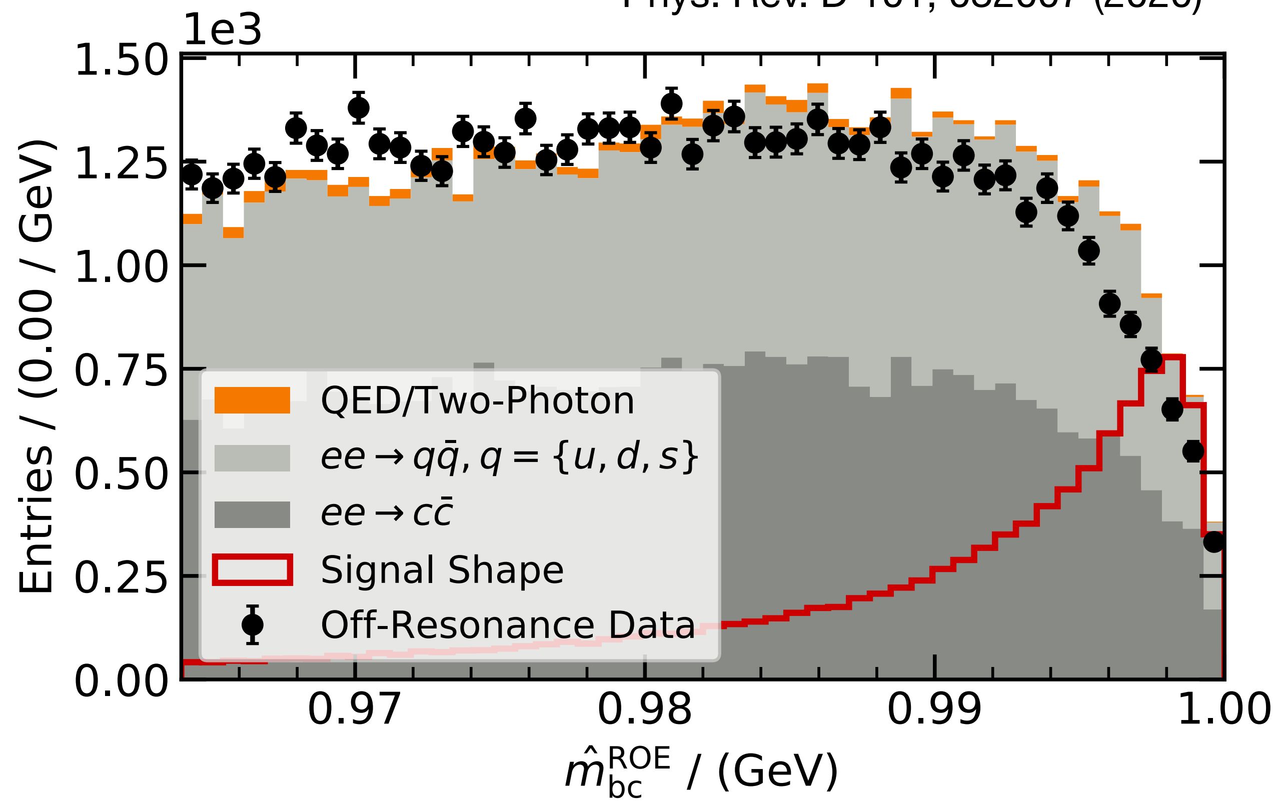
$e^+e^- \to q\overline{q} \quad (q \in \{u,d,s,c\})$



$e^+e^- \to \Upsilon(4S) \to B\overline{B}$

Phys. Rev. D 101, 032007 (2020)





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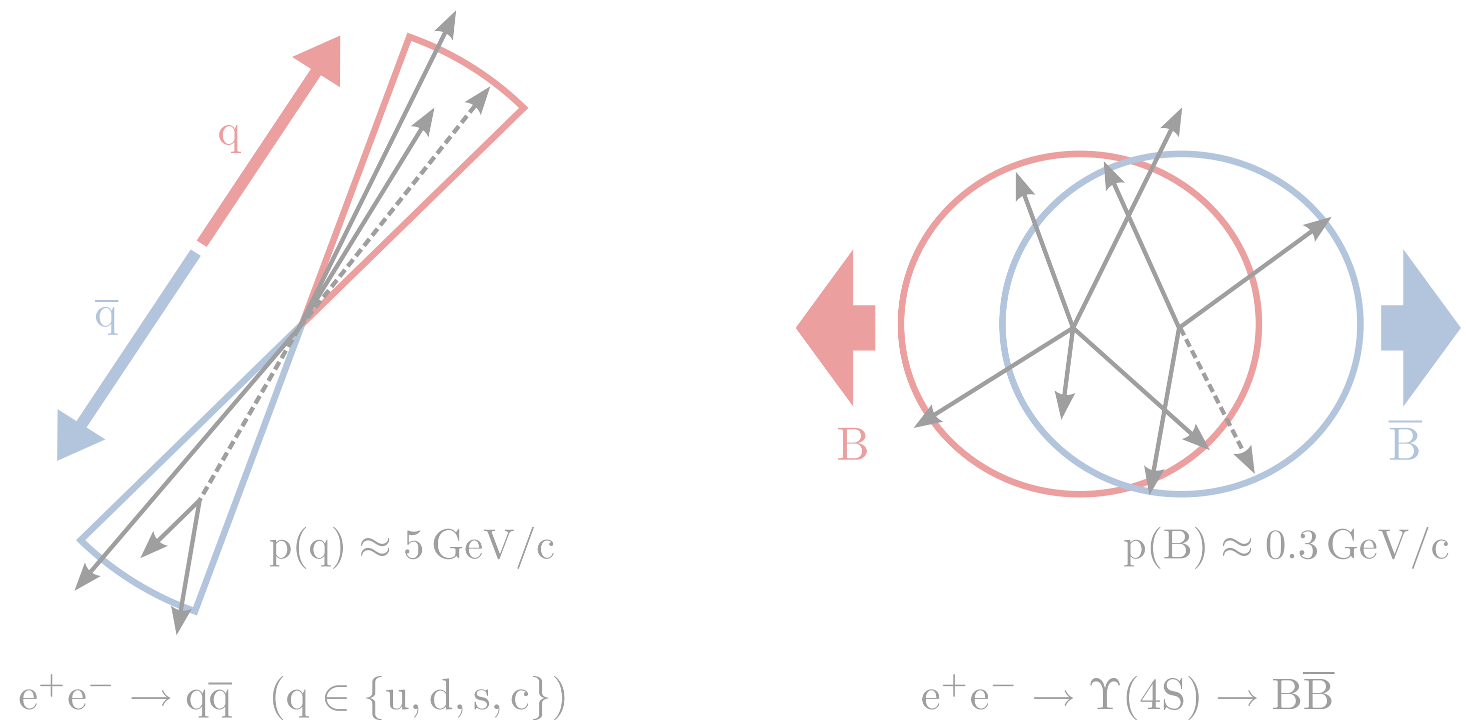
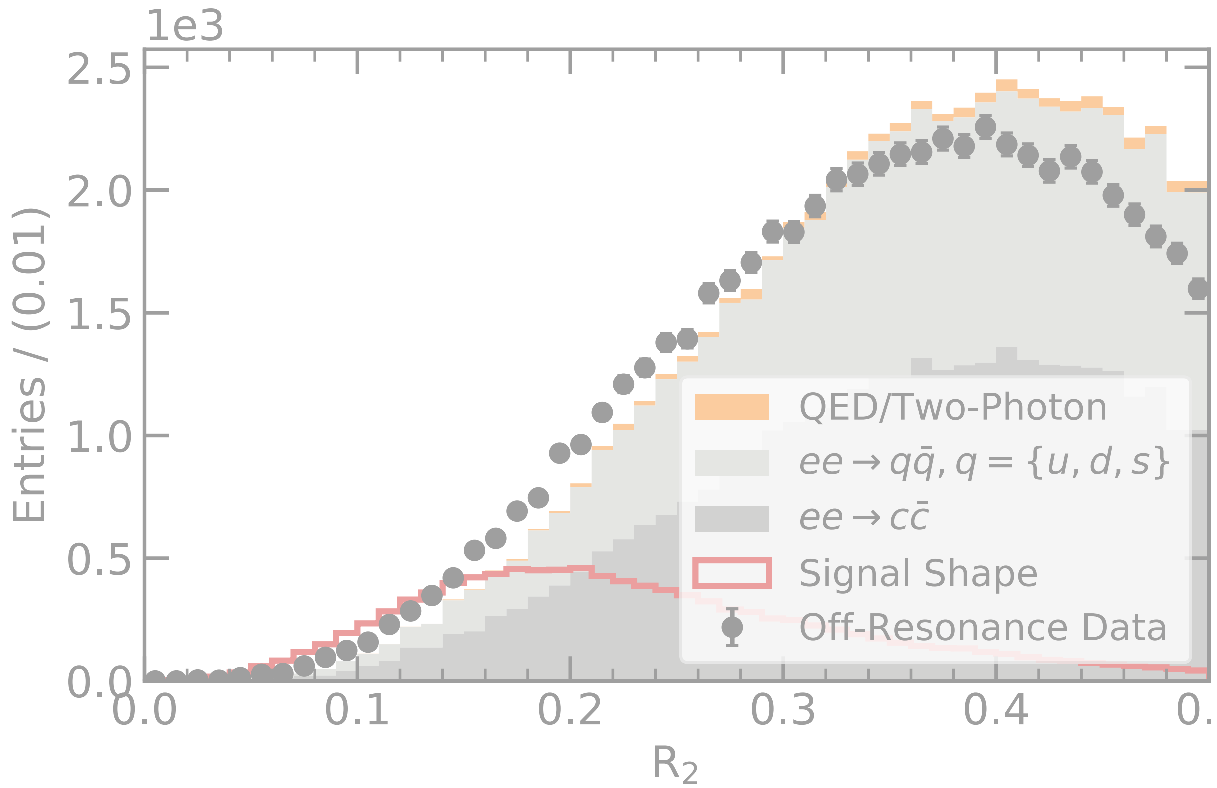
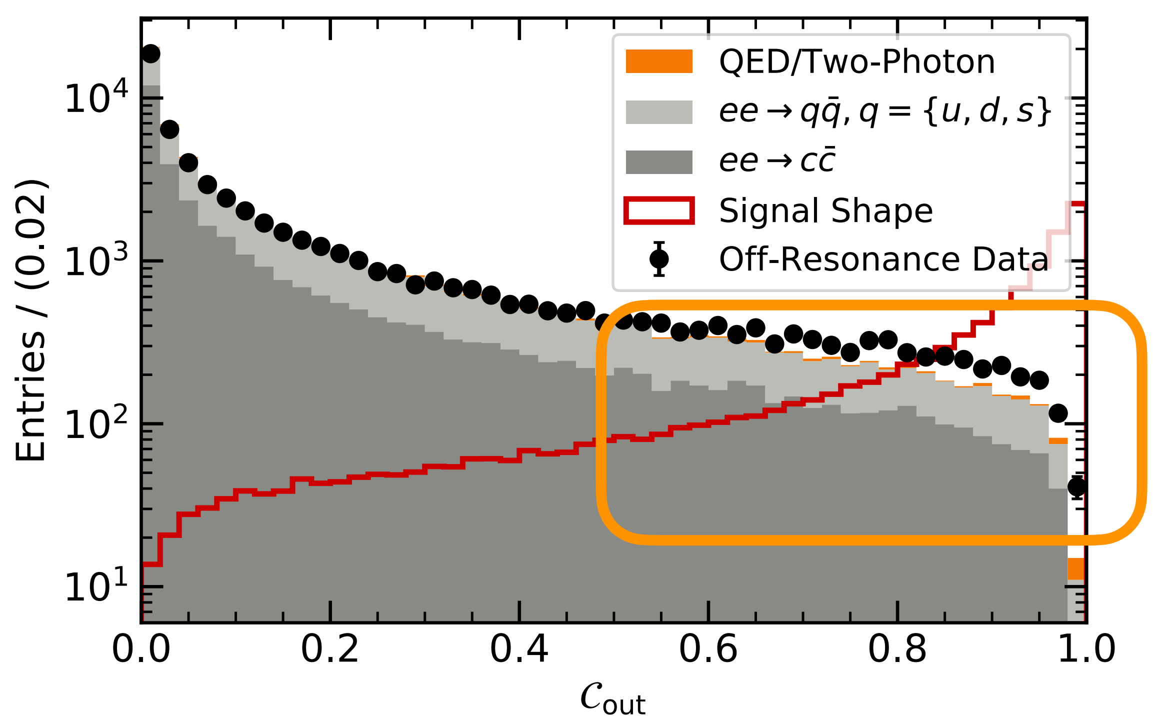
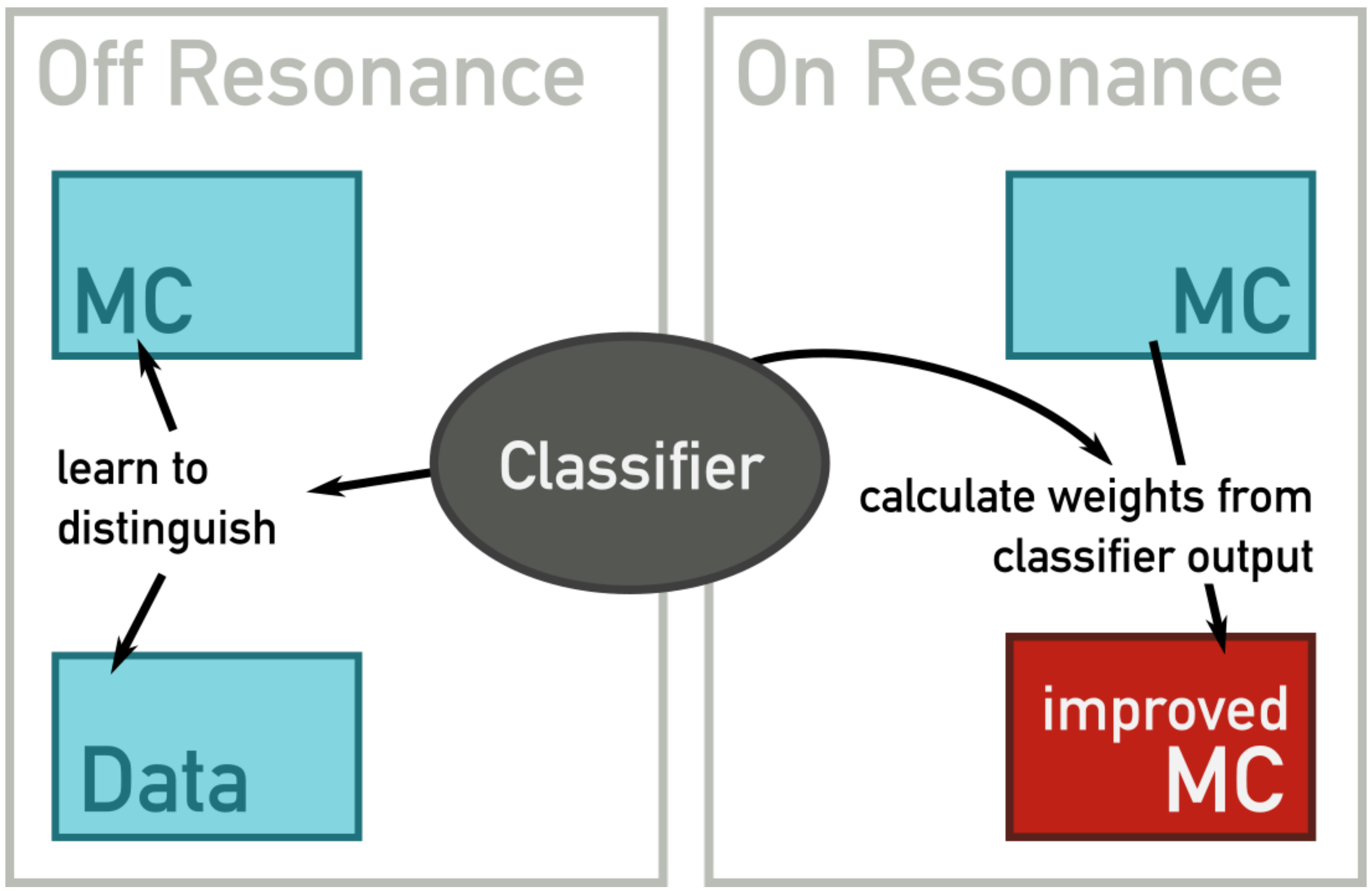






Leaving simulations behind

D Martschei et al 2012 J. Phys.: Conf. Ser. 368 012028

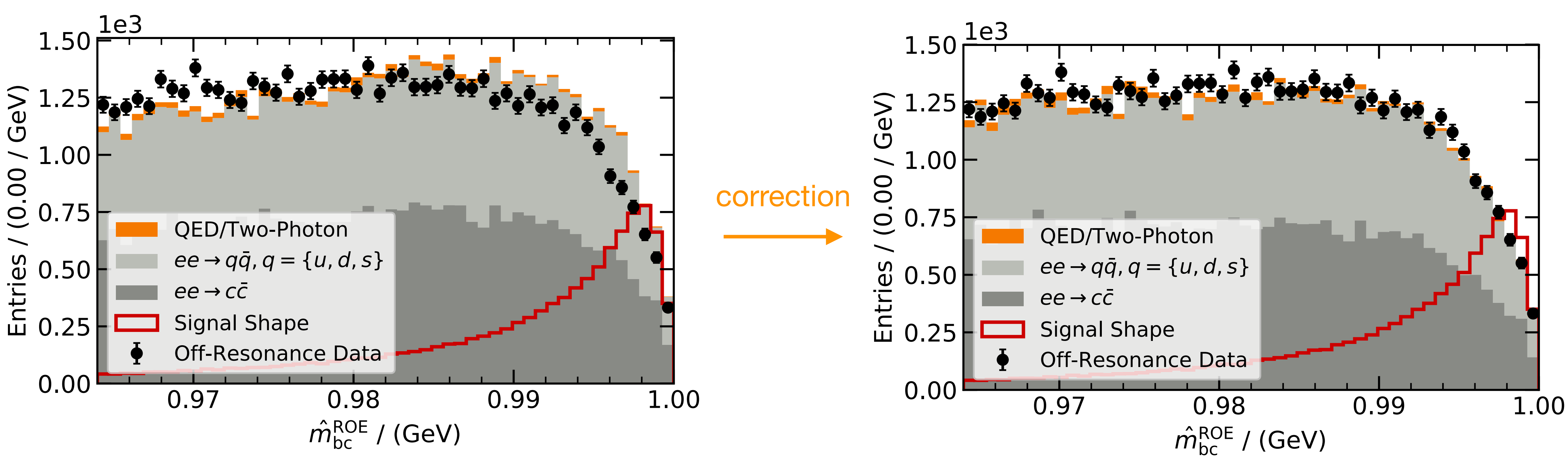


Train a classifier to distinguish simulated and recorded continuum processes ($e^+e^- \to q\bar{q}$, $e^+e^- \to c\bar{c}$, QED/Two-Photon)

Can use classifier output $p \in [0,1)$ to correct simulated distributions with a weight:

$$w = \frac{p}{1-p},$$

Benefit: Takes into account underlying correlations



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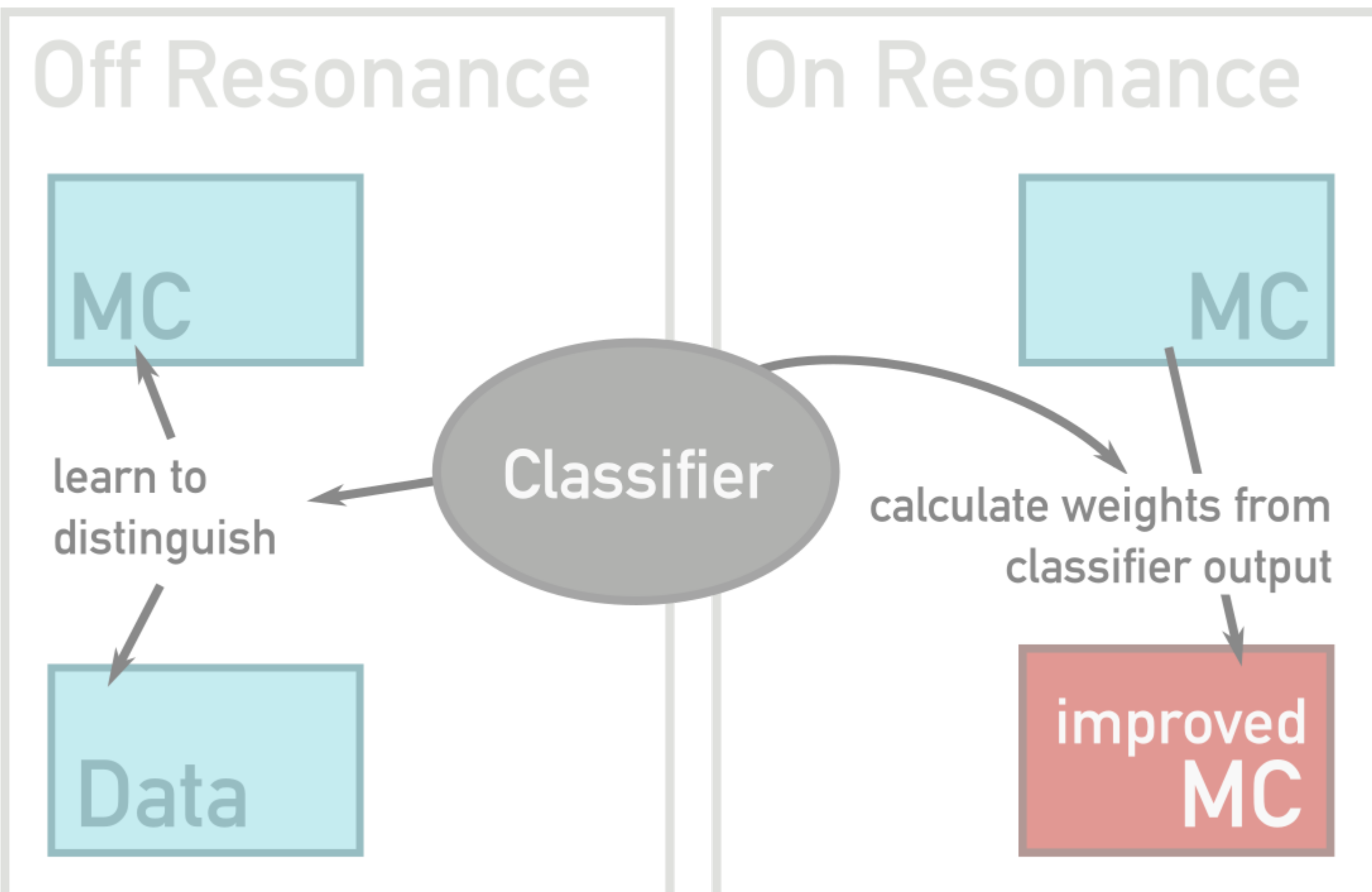

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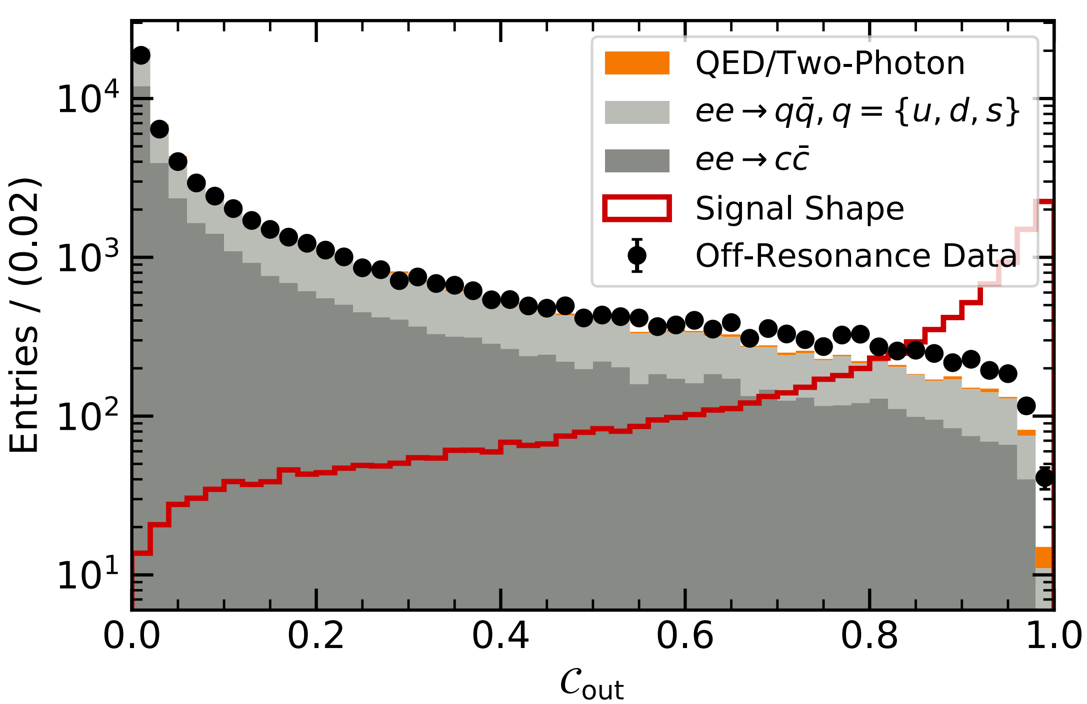
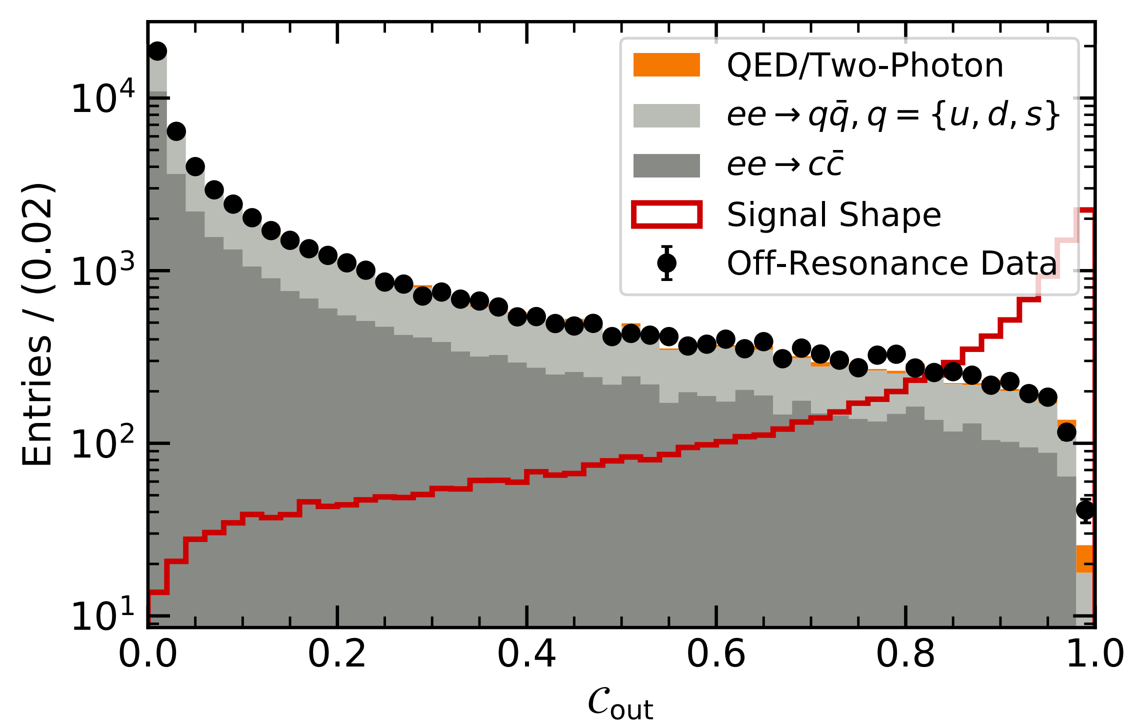


correction



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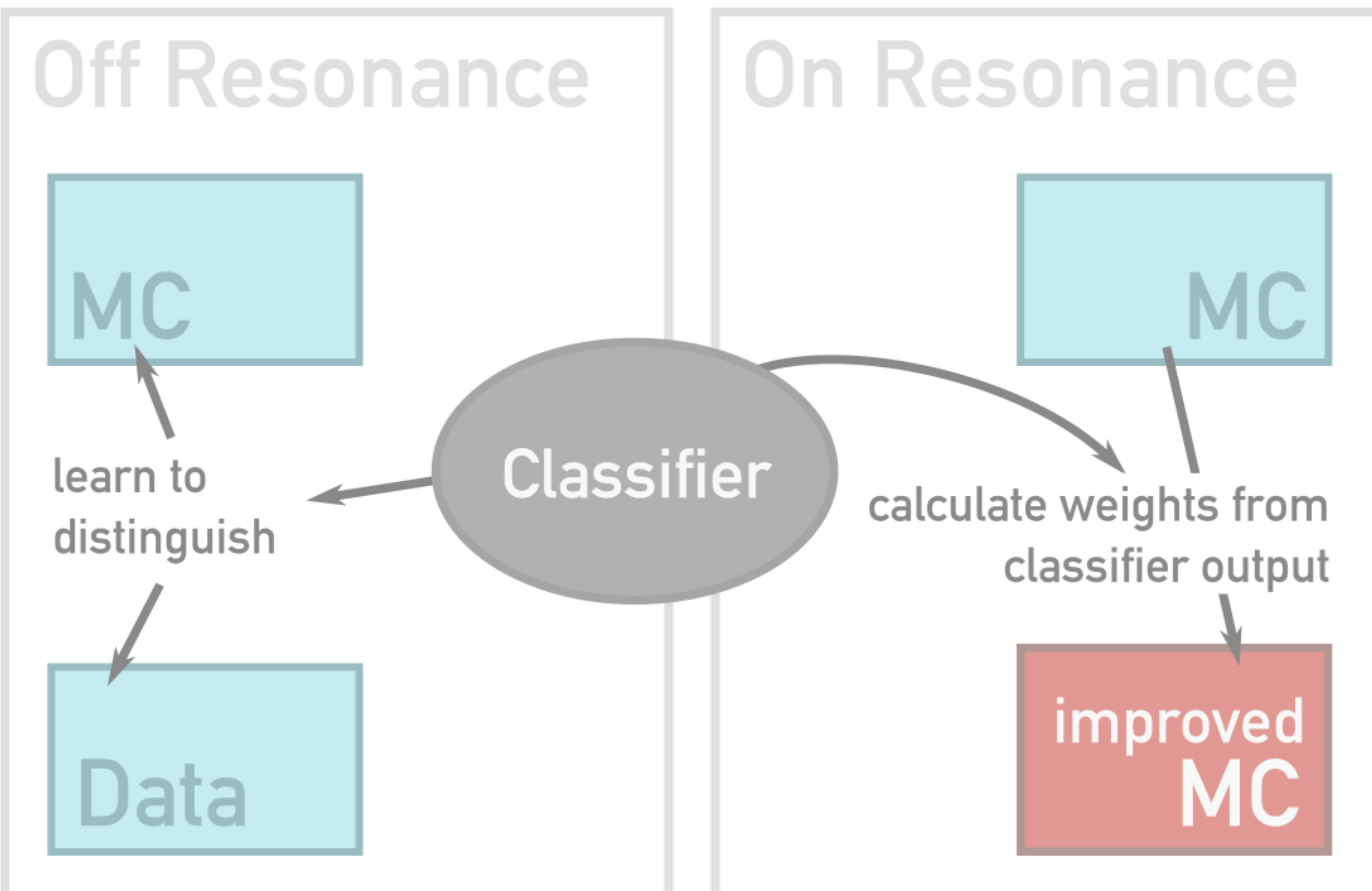

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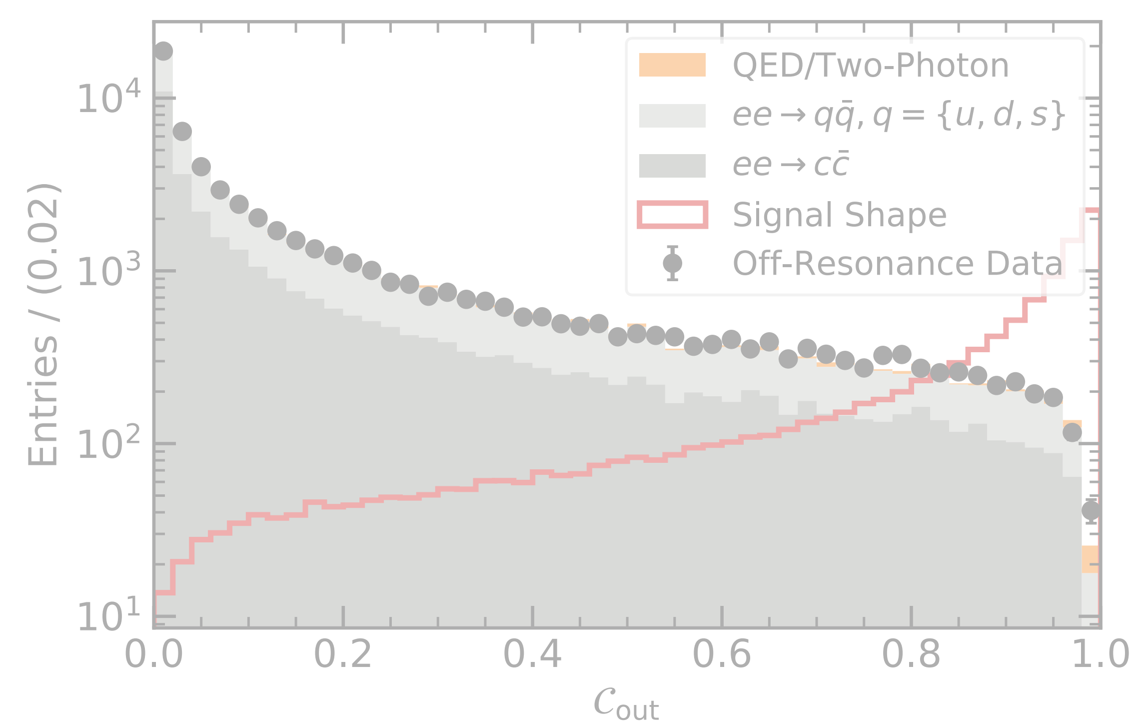
Assess uncertainty of correction via bootstrapping the data and derive ensembles of correction weights.



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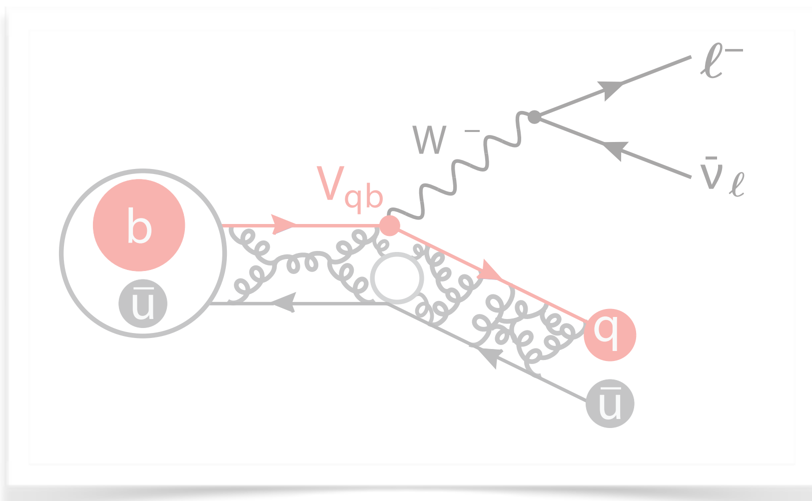

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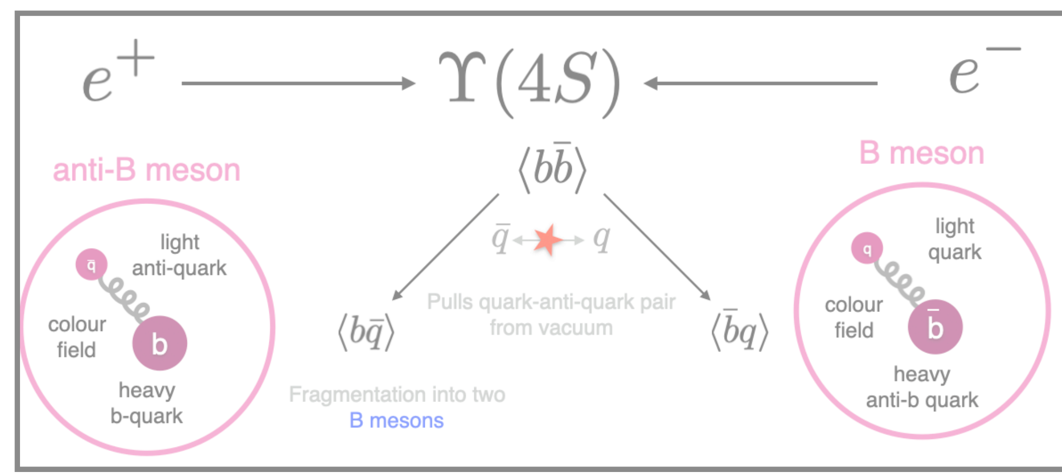

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Future and past data to improve simulations

Essentially most tuning we did in the past, built upon internal data with the obvious drawbacks:
* Not reproducible, not available for outsiders

(My personal opinion): I think we should make sure to change this to preserve our physics results

Large available Belle data set, that can be processed in the Belle II software framework:

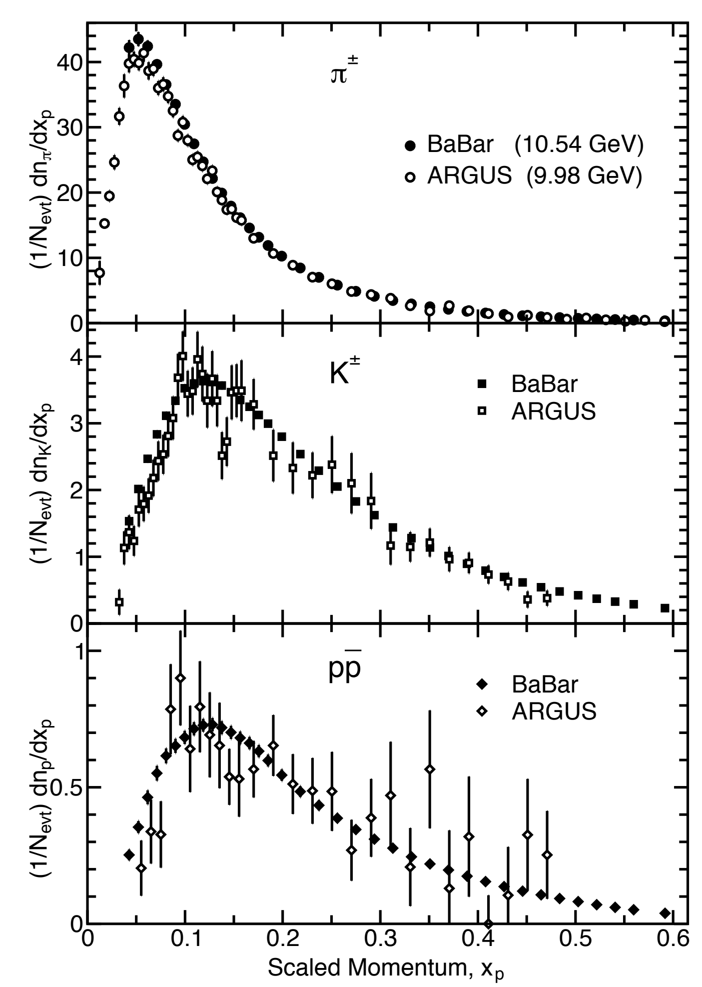
B2BII https://arxiv.org/pdf/1810.00019.pdf

Data conversion from Belle to Belle II

Moritz Gelb[1] · Thomas Keck[1] · Markus Prim[1] · Hulya Atmacan[2] · Jochen Gemmler[1] · Ryosuke Itoh[3] · Bastian Kronenbitter[1⋆] · Thomas Kuhr[4] · Matic Lubej[5] · Felix Metzner[1] · Chanseok Park[6] · Seokhee Park[6] · Christian Pulvermacher[1⋆] · Martin Ritter[4] · Anze Zupanc[5⋆]

Treasure trove for tuning; available for all Belle II members for technical work

https://arxiv.org/pdf/1306.2895.pdf



But also many interesting measurements available from **BaBar** and **Belle** in the public domain already. E.g. light hadron multiplicity as a function of x_p.

Typically these measurements need an excellent understanding of ones detector; not a low-hanging fruit :-)

$$x_p = \frac{2|p|}{E_{\mathrm{cm}}}$$

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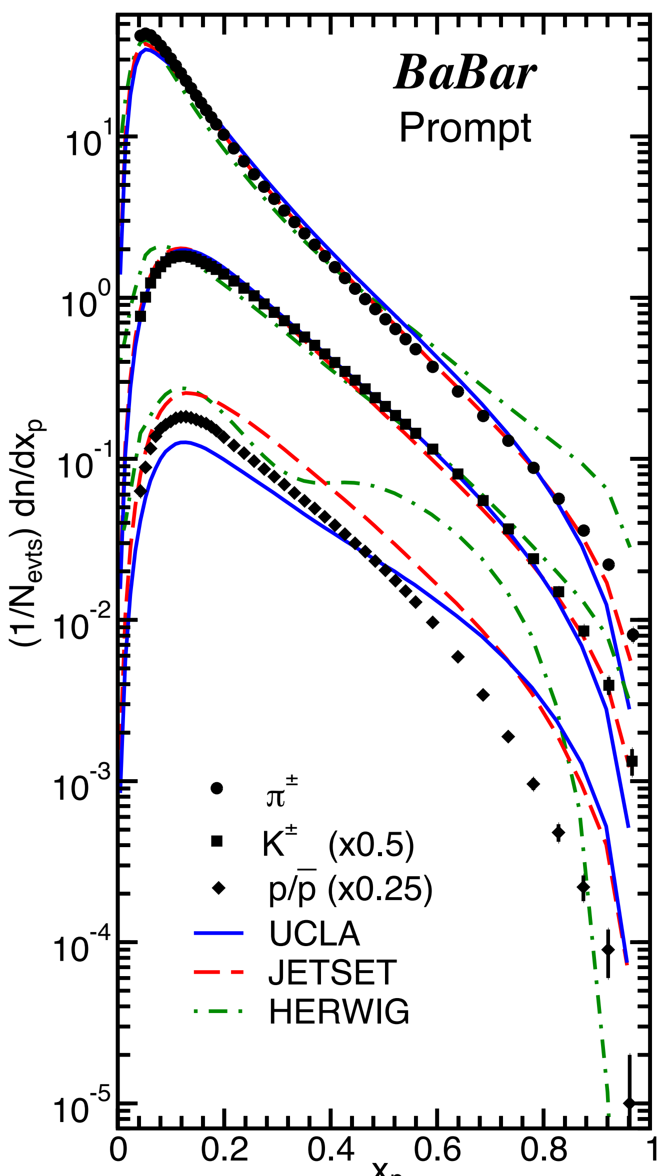

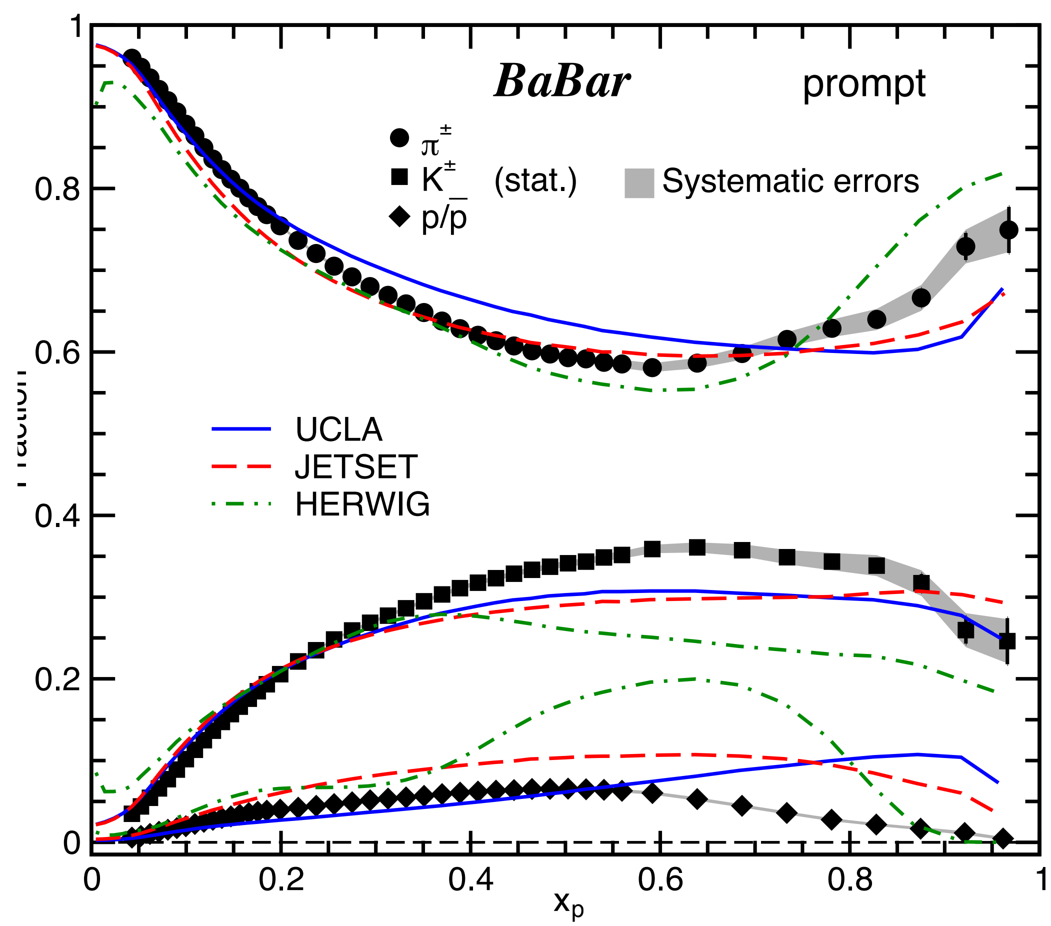

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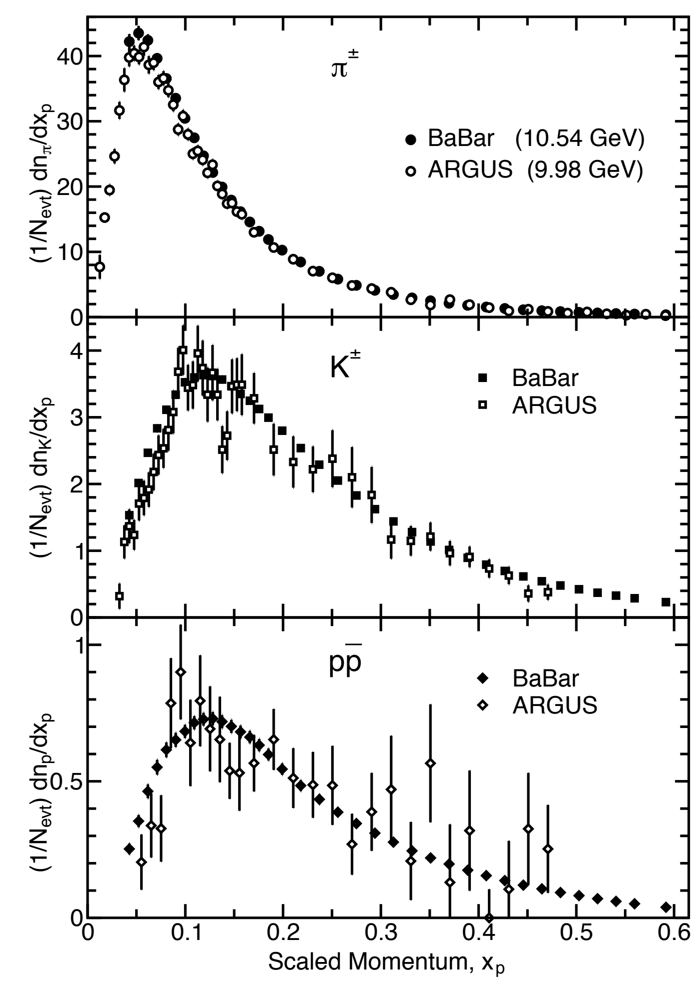
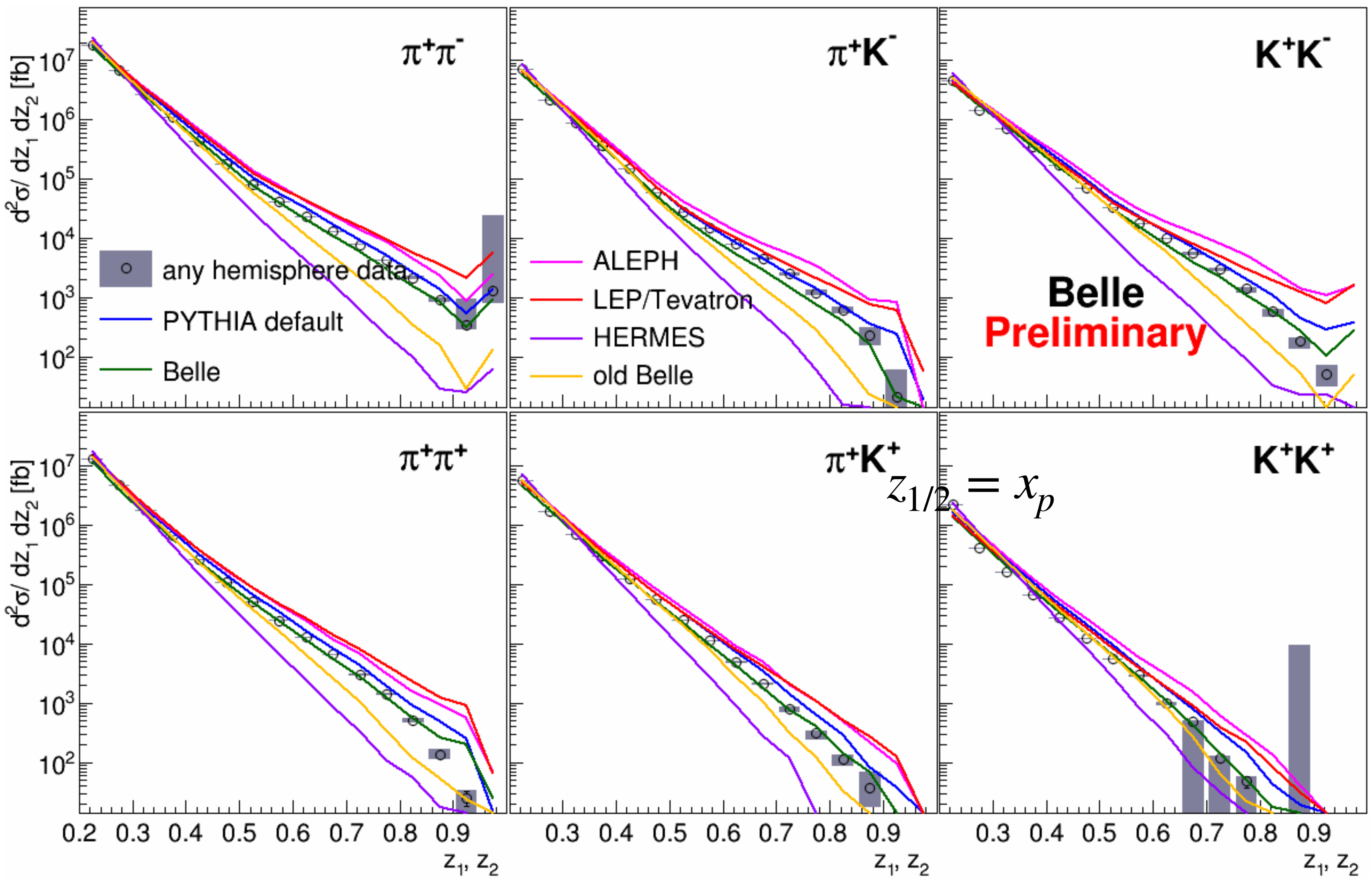


Another example: Belle data

https://pos.sissa.it/234/456/pdf



Some of these results are in HEPData, but more work likely needed.

Rivet Analysis Cross sections for the reactions $e^+e^- \to K_S^0K_L^0, K_S^0K_L^0\pi^+\pi^-, K_S^0K_S^0\pi^+\pi^-,$

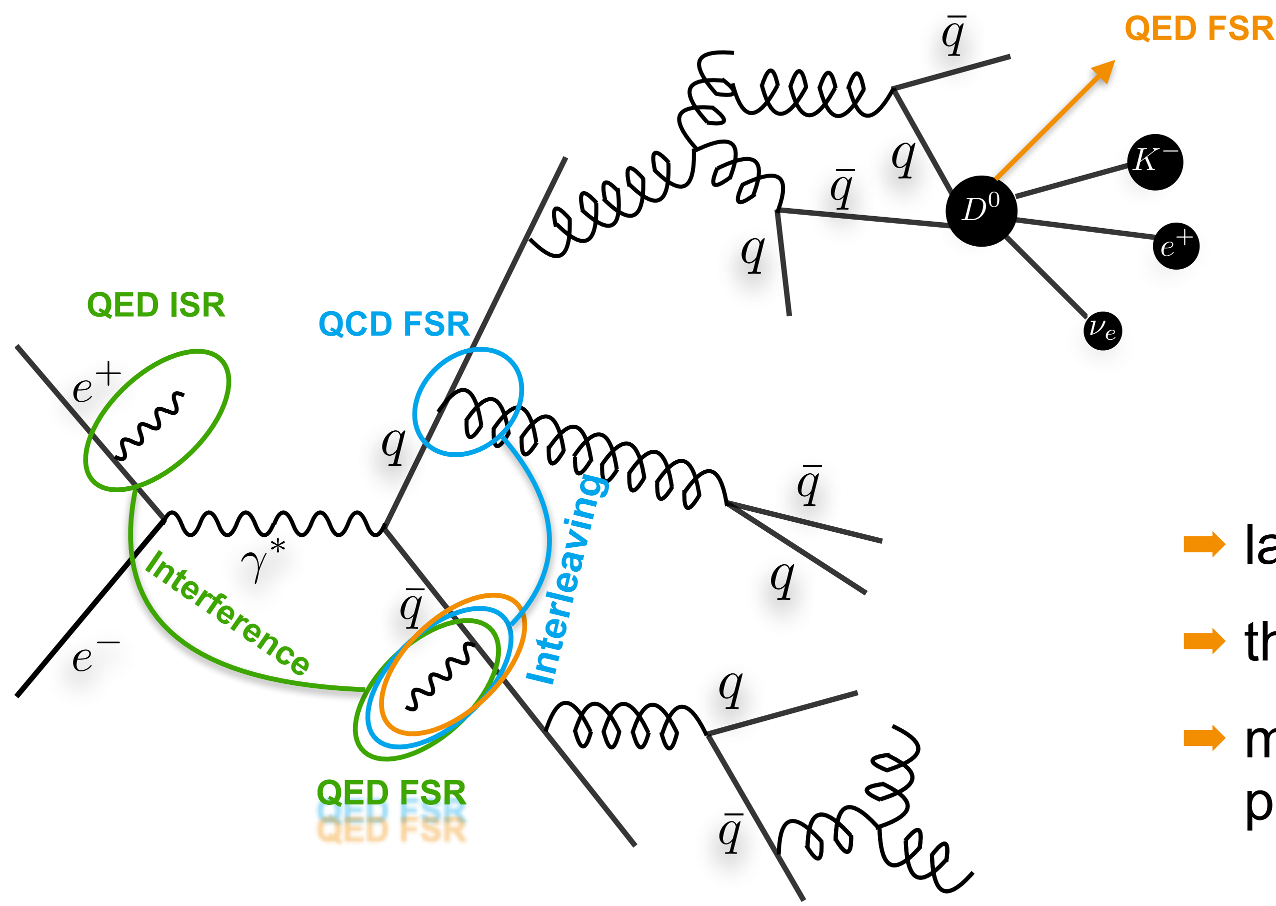
The BaBar collaboration Lees, J.P. ; Poireau, V. ; Tisserand, V. ; *et al.*

Phys.Rev. D89 (2014) 092002, 2014.

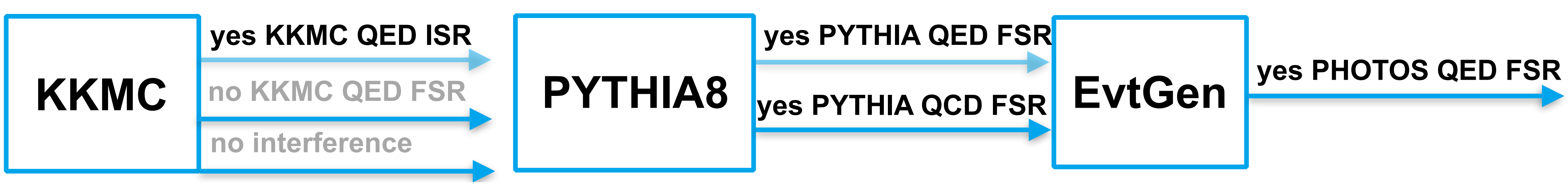
Currently main focus at Belle II lies in understanding the detector and beam backgrounds; but eventually we will need to also focus on tuning aspects to achieve the precision we aim for.

More Information

Continuum Simulation at Belle II

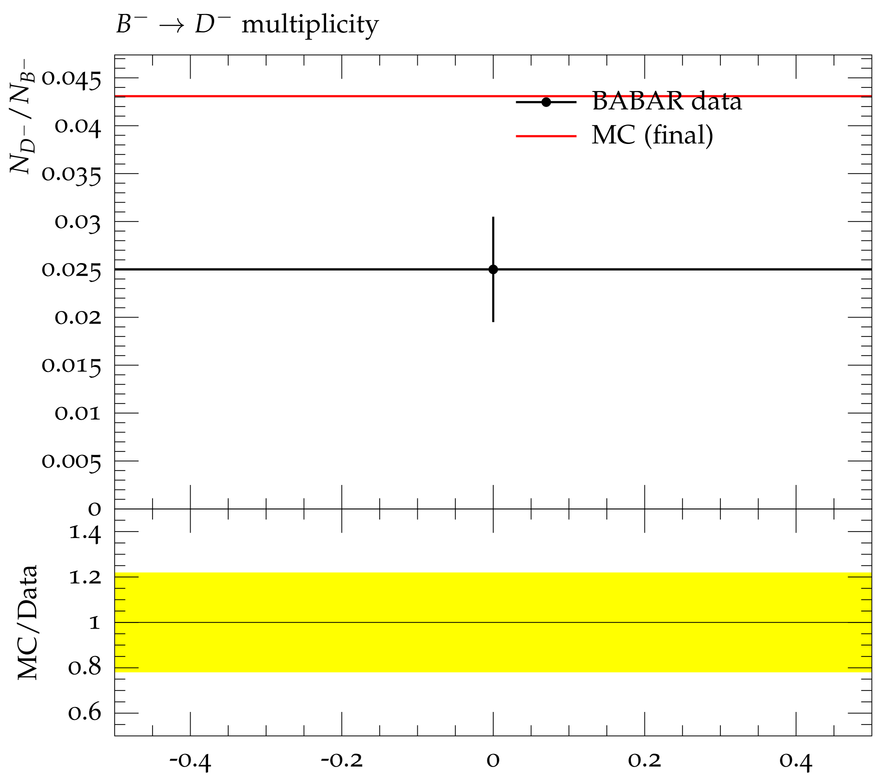


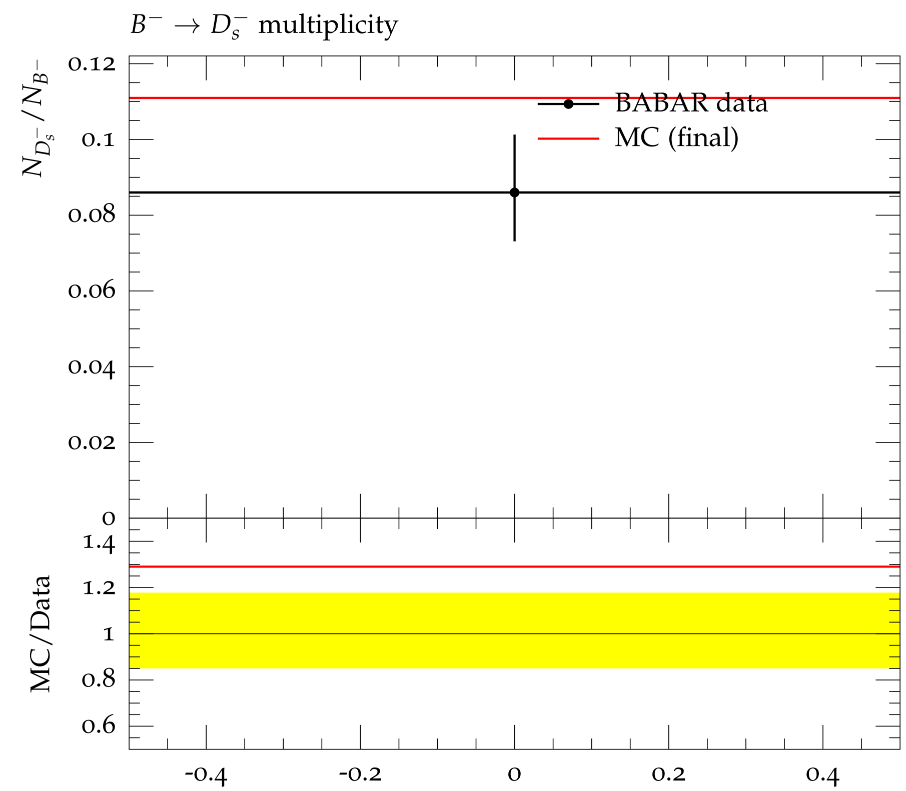
- ➡ large effect of ISR
- ➡ three options to generate the FSR
- ➡ maximum 10-20% effect of FSR on radiated photon spectrum at low momenta
  - ➡ source of systematic uncertainty
- ➡ tiny effect of ISR/FSR interference

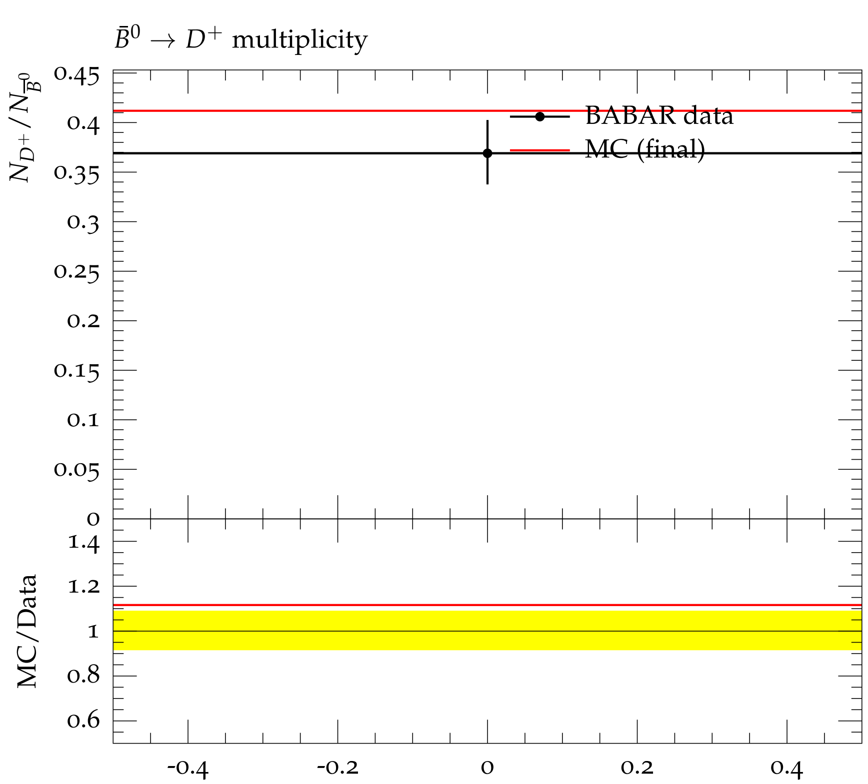


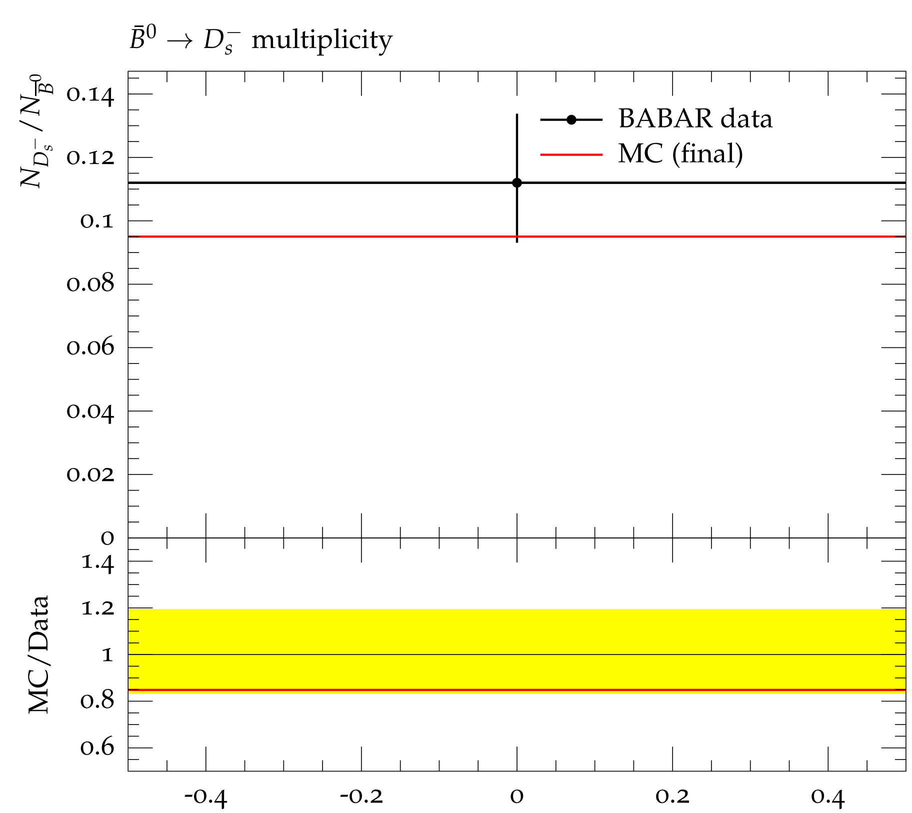
Michael Große, Heiko Lacker

Some more inclusive distributions



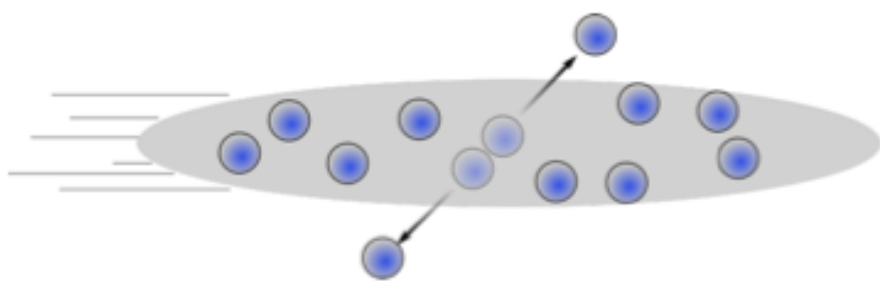




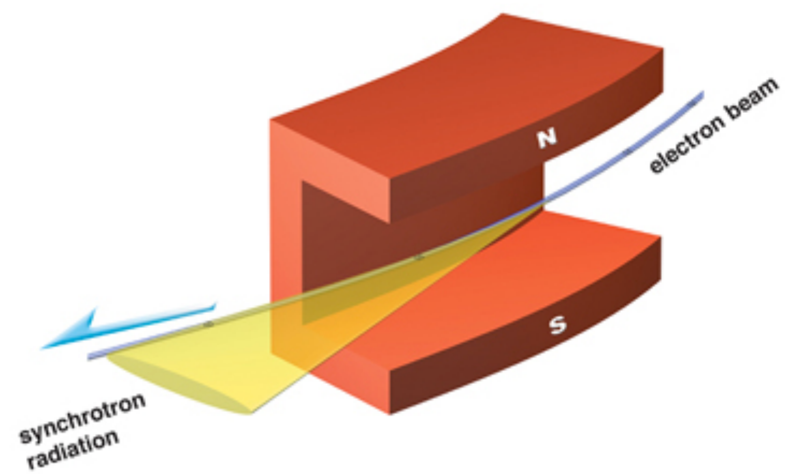


Beam backgrounds

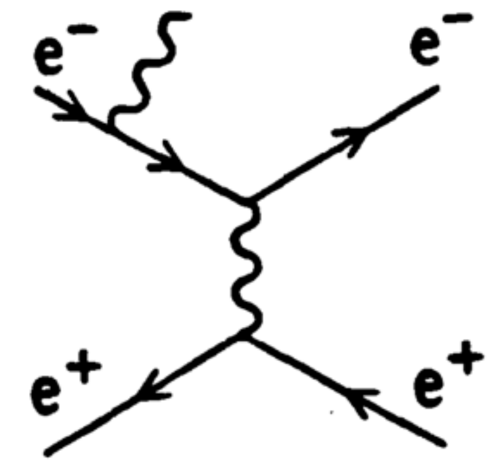
Touschek Scattering



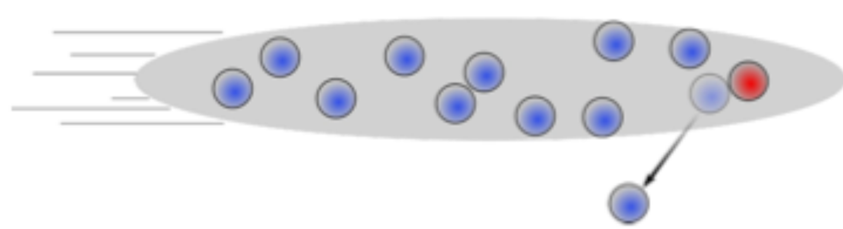
Synchrotron Radiation



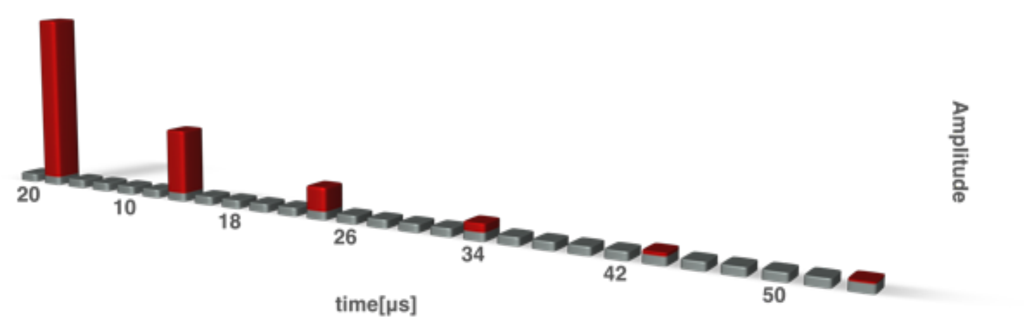
Radiative Bhabha



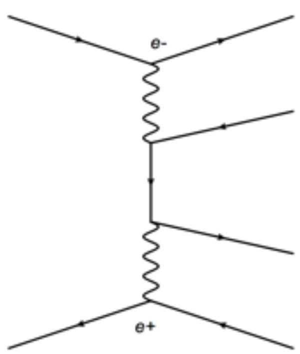
Beam-gas



Injection Background



Two photon process



Use simulated but also recorded beam backgrounds (from random triggered events) and overlay them with simulated events.