Event Generators at Belle II

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Frascati, 20.04.2015

HELMHOLTZ ASSOCIATION

Belle II

DESY

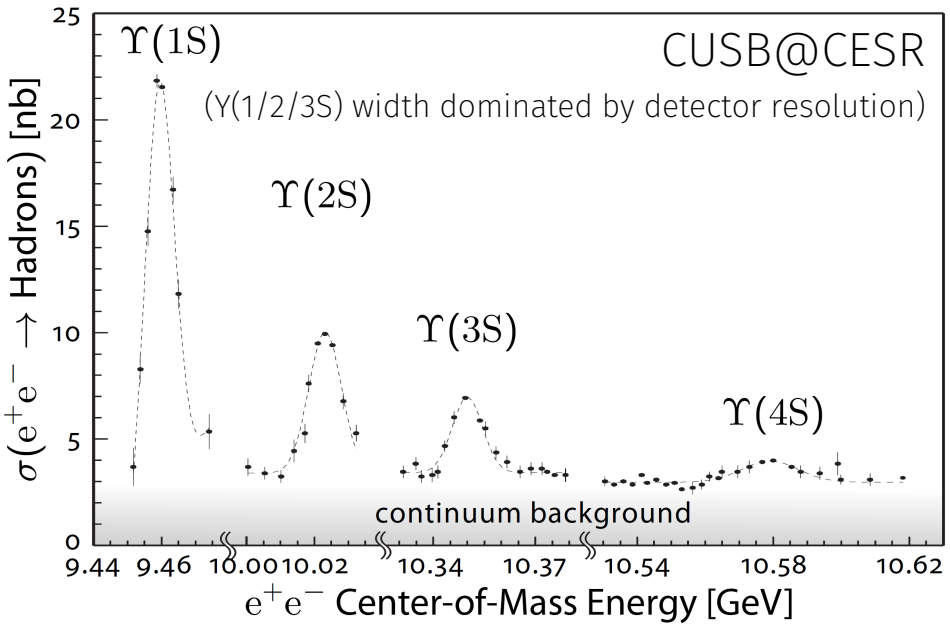
Outline.

- Belle II at SuperKEKB
- Belle II Software Framework
- Event Generators
- Belle II Theory Interface Platform (B2TIP)

Belle II at SuperKEKB

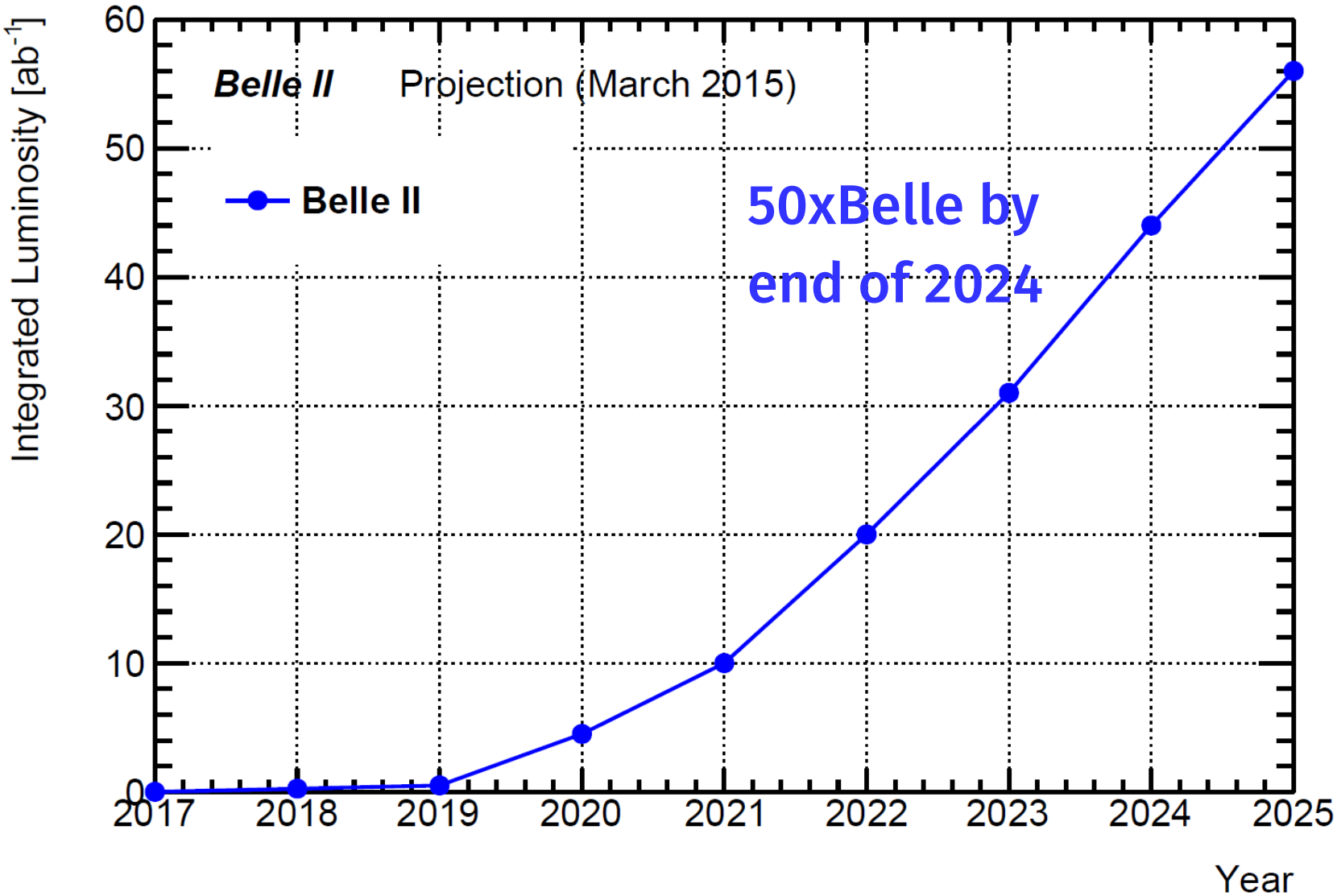
Belle II Overview.

- Accelerator currently being upgraded to SuperKEKB:
  - $8 \times 10^{35}/cm^2/s$ (~40xBelle)
  - $50ab^{-1}$ by end of 2024 (~50xBelle)
- Beam energy:
  - Mainly at Y(4S)=10.58 GeV
  - BF(Y(4S)→$B\bar{B}$) > 96%
  - ~Y(1S) to ~Y(6S) technically possible



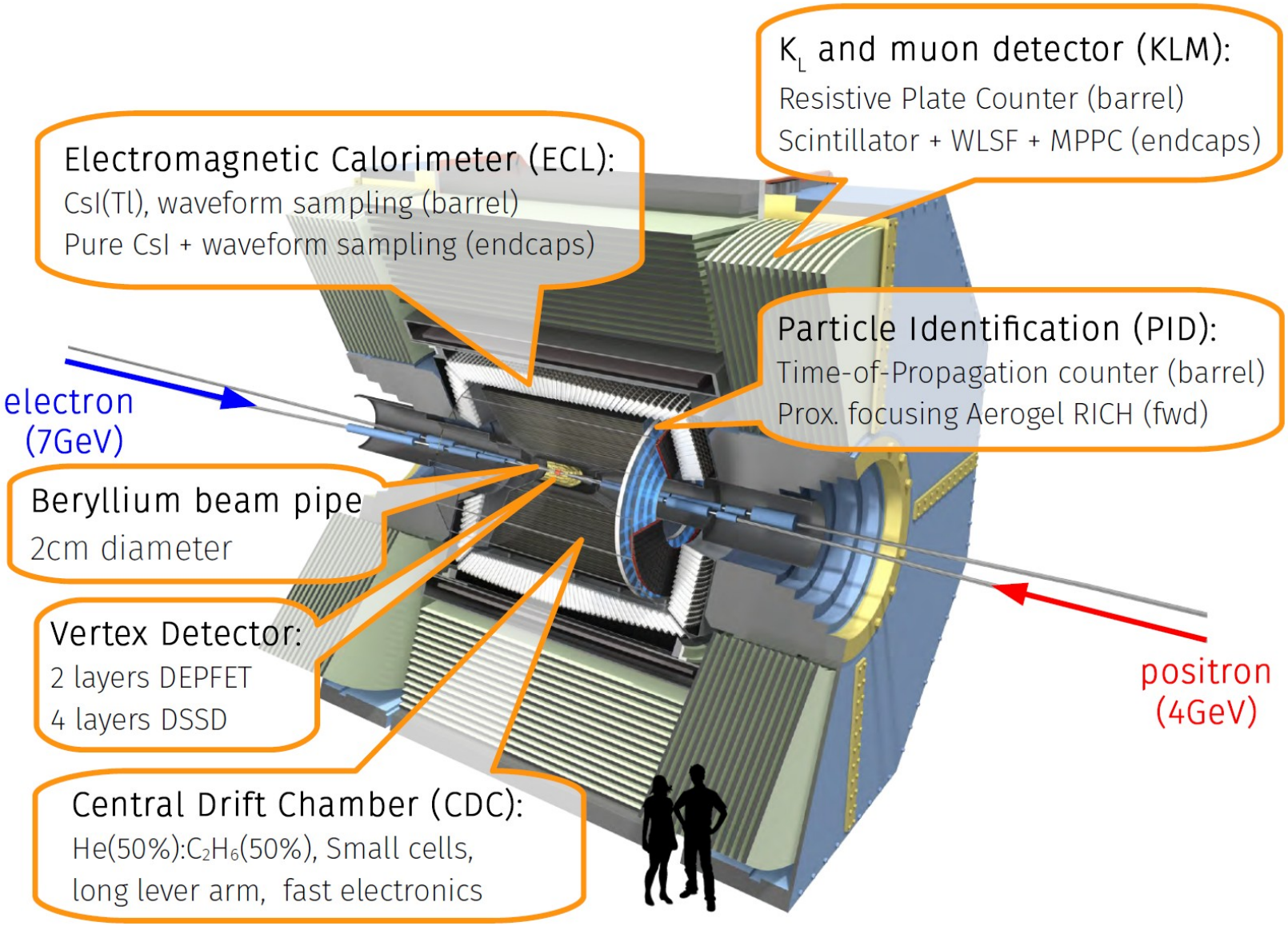
- Asymmetric beams:
  - 7.0GeV e^-/4.0 GeV e^+ (8.0GeV e^-/3.5GeV e^+ at Belle)
  - Crossing angle: 83mrad (22mrad at Belle)

Belle II Luminosity Profile.

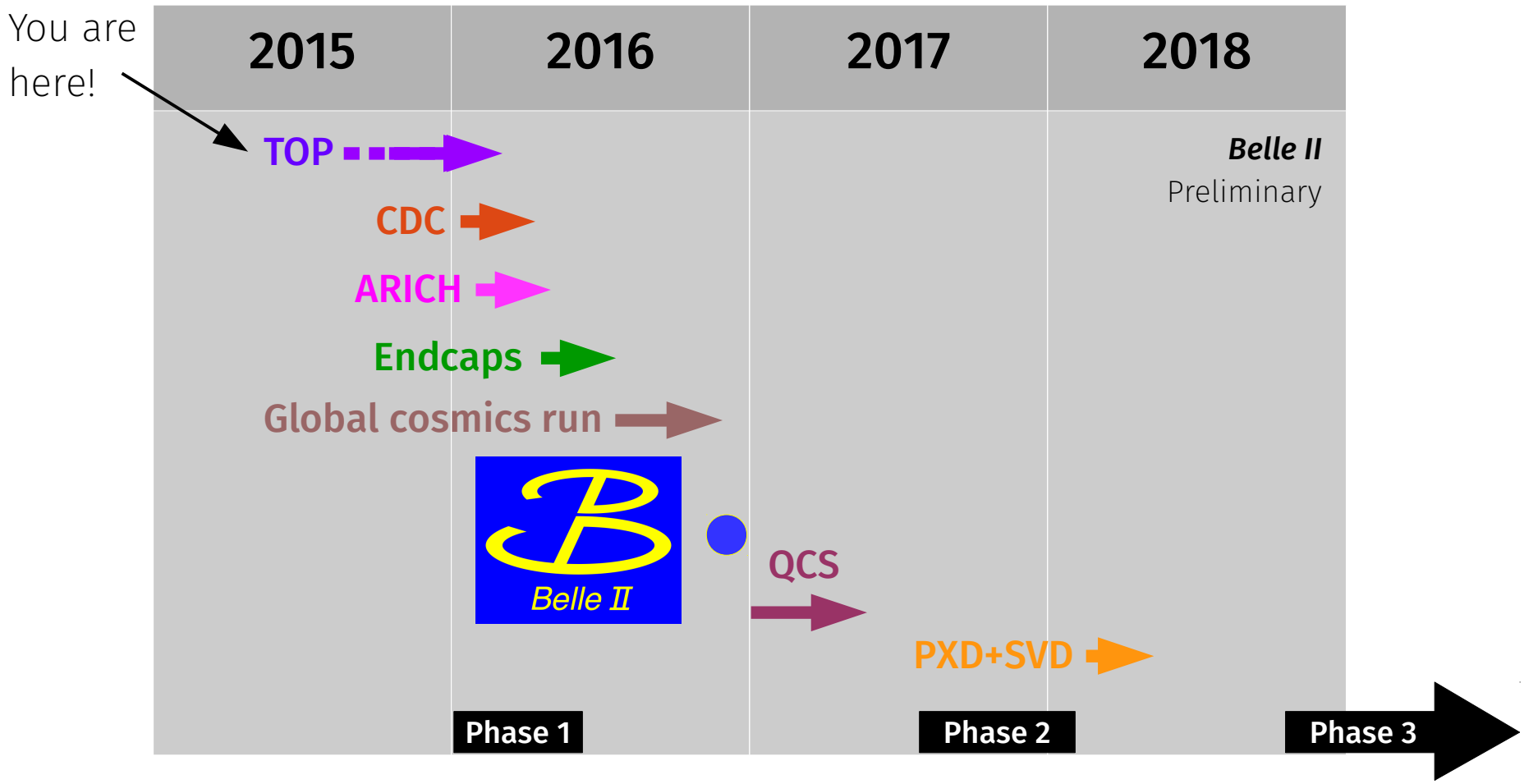


Belle II at SuperKEKB.

Detector Upgrade: Belle II at SuperKEKB.



Belle II Schedule.



Phase 1: 2016 — BEAST/SuperKEKB, cosmics

Phase 2: Mid 2017- Early 2018 — BEAST with partial Belle II

Phase 3: Oct 2018- — Physics with full Belle II

First Physics.

- "Maximize original physics research in the first year"
- Possible caveats: Calibration, alignment, background
- Possible benefits: Looser trigger, different energy

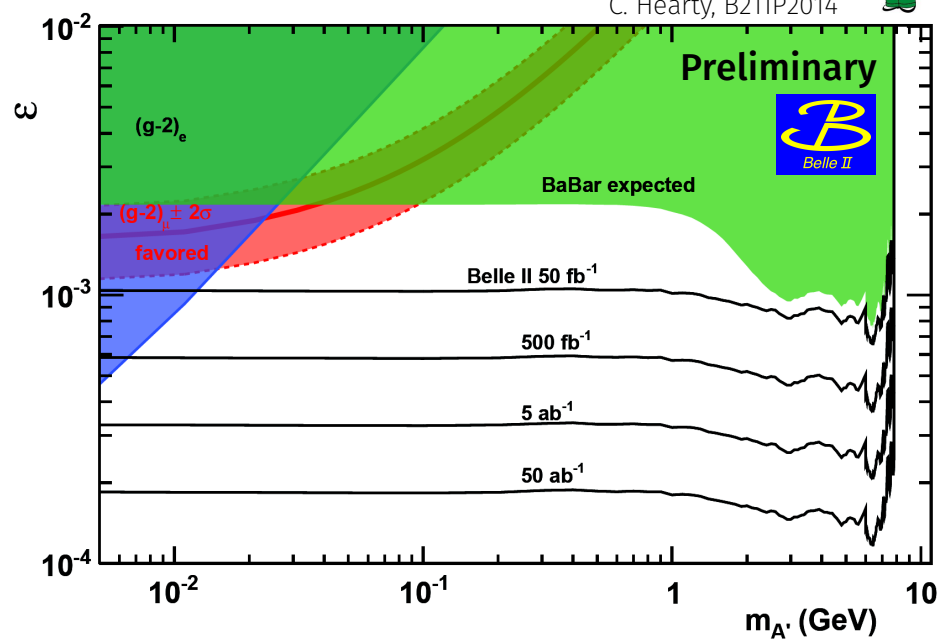
  → ~300fb^{-1} non-Y(4S) data in first year (2018+)
- Likely scenario: **Runs at and below Y(3S)**

Experiment	Scans/Off. Res.	$\Upsilon(5S)$		$\Upsilon(4S)$		$\Upsilon(3S)$		$\Upsilon(2S)$		$\Upsilon(1S)$	
		10876 MeV		10580 MeV		10355 MeV		10023 MeV		9460 MeV	
	fb^{-1}	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6	fb^{-1}	10^6
CLEO	17.1	0.4	0.1	16	17.1	1.2	5	1.2	10	1.2	21
BaBar	54	R_b scan		433	471	30	122	14	99	–	
Belle	100	121	36	711	772	3	12	25	158	6	102

First Physics example: Dark Photon into invisible.

- If A' is not the lightest "Dark Sector" particle:
  - Annihilation into dark matter (A' → χχ) dominates
- Signal: Single, mono-energetic photon γ_{ISR}
- Belle II First Physics: Dedicated "single photon trigger" at E_γ~1 GeV
  - Also needed for search of a weakly interacting particle in non resonant ee →γχχ (via overall γ-rate increase)

Υ(3S) →γA⁰[A⁰-> Invisible], arXiv: 080.0017
limit: e.g. Essig et al., arXiv:1309.5084
C. Hearty, B2TIP2014



Belle II Software Framework (basf2)

Belle II Software Framework: basf2.

- Modern C++ framework for acquisition, simulation, reconstruction and analysis of Belle II data
- 50+ developers from 15+ countries, weekly meetings
- Six subgroups: database, simulation, background, tracking, alignment and generators
- Buildbot for several automated tasks:
  - Incremental build on commit for fast feedback
  - Full builds with different compilers and system on commit
  - Nightly build, memcheck, and validation
  - Monthly build of tagged packages

basf2: Example Generator Steering (BABAYAGA.NLO).

```python
from basf2 import *

# set the global log level
set_log_level(LogLevel.INFO)

eventinfosetter = register_module('EventInfoSetter')
eventinfosetter.param('evtNumList', [100])  # we want to process 100 events
eventinfosetter.param('runList', [1])  # from run number 1
eventinfosetter.param('expList', [1])  # and experiment number 1

## register the BABAYAGA.NLO module
babayaganlo = register_module('BabayagaNLOInput')

# set the mode for the boost of the generated particles: 0 = no boost, 1 = BELLE II, 2 = BELLE
babayaganlo.param('BoostMode', 1)

# set the logging level for the BABAYAGA.NLO module to INFO in order to see the cross sections etc.
babayaganlo.set_log_level(LogLevel.INFO)

# events (weighted) to be used for maximum weight search before generation (recommended for ee, theta>15deg: use more than >500,000 events)
babayaganlo.param('SearchMax', 500000)

# final state: ee or gg, mm is unstable!
babayaganlo.param('FinalState', 'ee')

# minimum energy for leptons (ee mode) or photons (gg mode) in the final state, in GeV (default 0.15GeV)
babayaganlo.param('MinEnergy', 0.15)

# maximum acollinearity angle between finale state leptons (ee mode) or photons (gg mode), in degrees CMS
babayaganlo.param('MaxAcollinearity', 180.0)

# min/max angle in CMS, applied to primary produced leptons (ee mode) or the two highest energetic photons (gg mode), in degrees CMS
babayaganlo.param('ScatteringAngleRange', [15., 165.])

# extra outfile (contains the used weights, user should check against FMax value)
babayaganlo.param('ExtraFile', 'extrababayaganlo.root')

# geometry parameter database
gearbox = register_module('Gearbox')

## Register the Progress module and the Python histogram module
progress = register_module('Progress')

# output
output = register_module('RootOutput')
output.param('outputFileName', './babayaganlo_out.root')

# Create the main path and add the modules
main = create_path()
main.add_module(eventinfosetter)
main.add_module(progress)
main.add_module(gearbox)
main.add_module(babayaganlo)
main.add_module(output)
process(main)
```

basf2: Example Analysis.

```python
#!/usr/bin/env python
# -*- coding: utf-8 -*-

from basf2 import *
from modularAnalysis import *
from stdLooseFSParticles import *

inputMdst('DstarSignal.mdst.root') #input file

# fill particle lists with predefined cuts
stdVeryLoosePi() # creates "pi+:all" ParticleList (and c.c.)
stdLoosePi() # creates "pi+:loose" ParticleList (and c.c.)
stdLooseK() # creates "K+:loose" ParticleList (and c.c.)

# reconstruct D0 and D*+ decays incl. vertex fit
reconstructDecay('D0:kpi -> K-:loose pi+:loose', '1.8 < M < 1.9')
vertexKFit('D0:kpi', 0.001)

reconstructDecay('D*+ -> D0:kpi pi+:all', '0.0 <= Q < 0.02 and 2.5 < p_CMS < 5.5')
vertexKFit('D*+', 0.001)

# match MC truth information
matchMCTruth('D*+')

# create and fill flat Ntuples
toolsDST = ['EventMetaData', '^D*+']
toolsDST += ['InvMass[BeforeFit]', '^D*+ -> ^D0 pi+']
toolsDST += ['CMSKinematics', '^D*+']
toolsDST += ['MCTruth', '^D*+ -> ^D0 ^pi+']

# write output file
ntupleFile('output.root')
ntupleTree('dsttree', 'D*+', toolsDST)

#process events
process(analysis_main)
```

Need generator information:

- ISR or FSR photons
- PHOTOS photons
- Intermediate resonances
- Mother/daughter relations

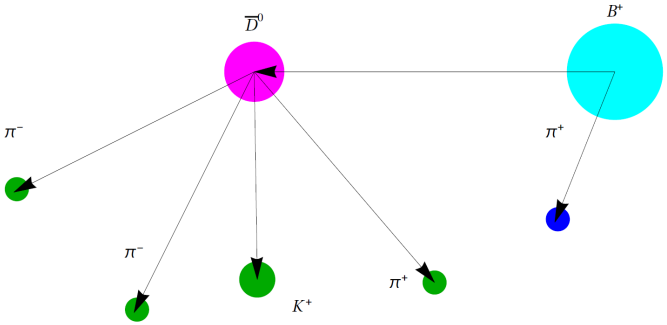
Event Generators

Event Generators: Y(nS).

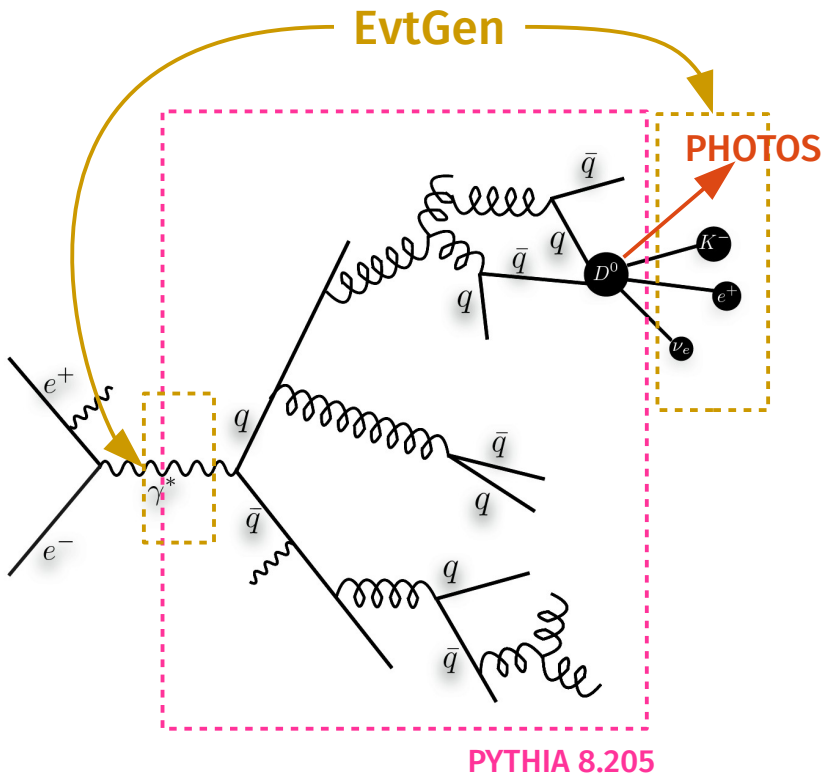
- EvtGen R01-03-00 (mainly for B/D decay chains)

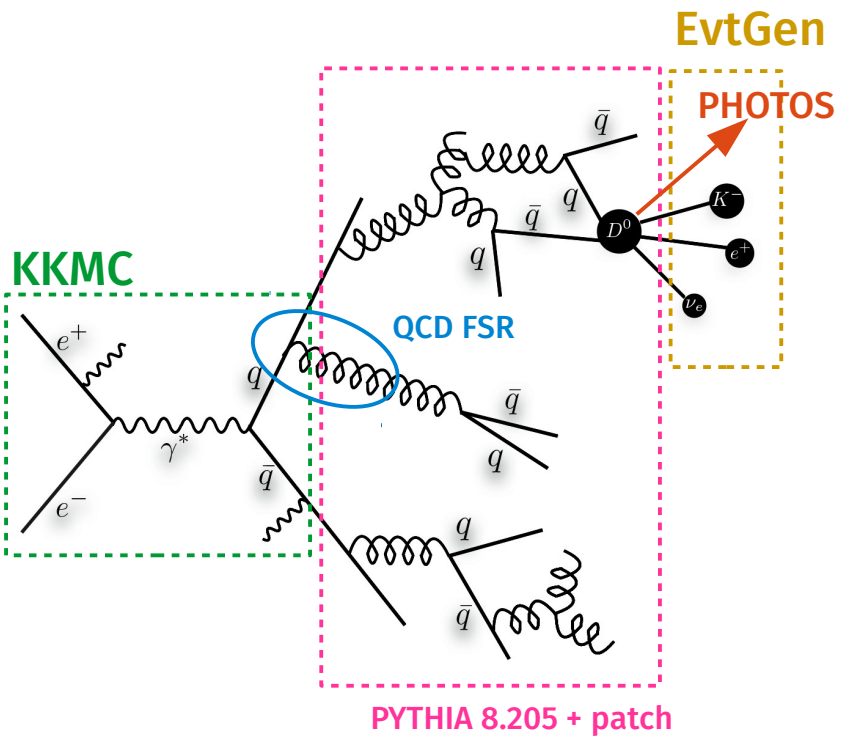
  → Upgrade to R01-04-00 in preparation

  - TAUOLA 1.1.4
  - PHOTOS 3.54 (3.56 with gcc 4.9.2)
  - PYTHIA 8.205
- Decay files in SVN, automatized test on check-in
- Common validation framework in preparation:
  - Compare PDG-$B_{\text{inclusive}}$ to .DEC-$B_{\text{inclusive}}$
  - Reconstruction on generator level



Event Generators: ee → qq (Continuum).





- Very recently: EvtGen called from PYTHIA8.205 for all decays to ensure background and signal compatibility
- PYTHIA8 tuning in preparation (using Belle data)

Event Generators: ee → ee(γ) (Bhabha).

- BABAYAGA.NLO (default, also for γγ)
  - Latest official version implemented, tested on GRID (O(10^8 events))
  - Modifications by BABAYAGA.NLO authors: (soon in basf2)
    - Novosibirsk running α_{QED} and Im(α_{QED})
      → Crucial when running at narrow resonance like Y(3S)
    - Beam energy spread modification (~0.1% effect at Babar)
- BHWIDE 1.05 (ready)
- BBREM (default beam bkgd.)
  - C++ version of the K&B generator
- TEEGG (impl. in work)
  - For anti-tagged photon backgrounds, running α_{QED} included

e.g. needed for:
- Luminosity measurements
- Precision Bhabha analyses
- L1 trigger studies
- Background for e.g. dark photon A → ee
- anti-tagged: Main bkgd. for A → χχ

Event Generators: ee → μμ(γ) (Muon pairs).

- KKMC 4.19b (default):
  - ~1:1 copy from Belle generator, tested on GRID (O(10^8 events))
  - Mod. REPI: Burkhardt α_{QED} ("IHVP=4")
  - "Physics" shortcomings:
    - QED interference: NLO and mass effects
    - Spacelike running α_{QED} approximation, issue even for small statistics at Υ(3S)

e.g. needed for:
- ECL calibration
- Trigger studies
- Beam energy/boost measurements
- ISR normalization
- AFB (γ inclusive, dσ/dcos(θ))
- Background for e.g. A → μμ, τ→μγ, ...

- Other available generators:
  - PHOKHARA9.1b (ready)
    - Full two loop corrections
  - BABAYAGA.NLO (ready, not tested yet)
    - Interference of resonance and continuum

Event Generators: ee → ττ(γ) (Tau pairs).

e.g. needed for:
- Tau physics (long list...!)
- Background for AFB

KKMC 4.19b(default):

- ~1:1 copy from Belle generator, tested on GRID (O(10^8 events))
- TAUOLA-exp-11-10-2005
  - Hadronic current for τ→4πν based on CMD-2@VEPP
  - Hadronic currents based on CLEO otherwise

Future plans (tau and muon pairs):

- Interface to TAUOLA++ 1.1.4
- Interface to PHOTOS++ 3.56

Same as for EvtGen , discuss at next B2TIP (maintenance, consistency, ...)

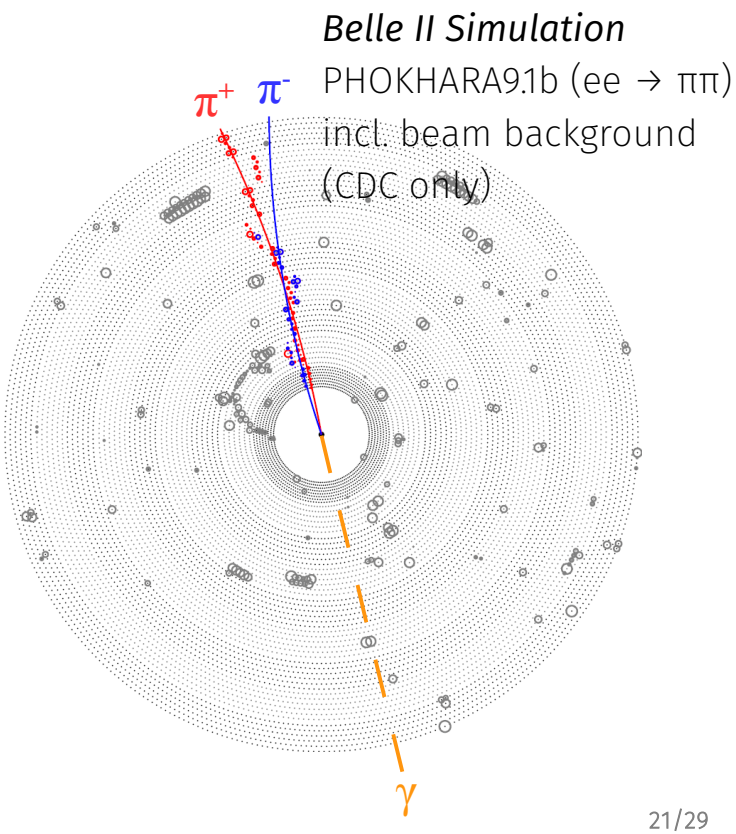
- Information about ISR, FSR and PHOTOS photons for MCTruth matching
- For Υ(3S) runs (first physics): α_{QED} needs to be modified
- PYTHIA tau decay engine for cross checks?

Event Generators: ISR.

PHOKHARA 9.1b (default)

- Latest official version implemented
- "Physics" shortcomings for Belle II:
  - Runtime for NLO!?
  - Missing Upsilon resonances
  - Missing Z
  - Missing NLO soft photons

e.g. needed for:
- ISR physics
- Trigger studies
- AFB (inclusive, ds/dcos(θ))
- Background for e.g. A → ππ, ...



Other generators: (under study)

- Generator from Novosibirsk group?

Event Generators: Two Photon.

- AAFH (physics default):
  - Validated against Belle-AAFH generator
- KORALW (beam bkgd. default)

e.g. needed for:
- Two photon physics
- Trigger studies
- Backgrounds
- PID calibration

- Other generators: (under study)
  - “Generic” hadronic final states: TWOGAM and PYTHIA6
  - TREPS (arXiv:1310.0157)
  - EKHARA

Event Generators: New Physics.

> MadGraph 5:

- Standalone in basf2 externals package
- Interface for LHE output (next slide)
- Any new physics "madgraph" models can be used, e.g. Dark Photon model from Yi-Ming Zhong and Rouven Essig:

e.g. needed for:
- Dark Photon
- Light Higgs
- Magnetic Monopoles
- Effective SM Born for checks

```
import model darkphoton
generate e+ e- > a ap, ap > chi ~chi
output /nfs/dust/belle2/user/ferber/output
launch

set WAp 1.0e-3
set MAp 5.01291
set MChi 0.01e0

set ebeam1 5.28695
set ebeam2 5.28695
set nevents 10000
set iseed 843753998
```

Event Generators: Generic Input/Output.

- Input modules for HepEvt and LHE (Les Houches Event) textfiles:

```
from basf2 import *
from simulation import *
from reconstruction import *

lhereader = register_module('LHEInput') # register module
lhereader.param('useWeights', False) # all events have the same weight
lhereader.param('nVirtualParticles', 0) # set particles virtal (bypass GEANT4)
lhereader.param('boost2Lab', True) # boost to Belle II frame
lhereader.param('wrongSignPz', True) #revert e+/e- direction
lhereader.param('inputFileList', ['madgraph_darkphoton_5.122.lhe'])

main = create_path()

main.add_module(lhereader)
add_simulation(main) # full detector simulation
add_reconstruction(main) # reconstruction

process(main)
```

- HepEvt output (can be read in Belle and Belle II frameworks)

basf2: FORTRAN Generators in basf2.

C++

```
extern "C" {

  //main subroutine
  void babayaga_(int* mode, double* xpar, int* npar);

  // final state particles
  extern struct {
    double bp1[4];          /**< 4-momenta of incoming positron. */
    double bq1[4];          /**< 4-momenta of incoming electron. */
    double bp2[4];          /**< 4-momenta of outgoing positron. */
    double bq2[4];          /**< 4-momenta of outgoing electron. */
    double bphot[4][100]; /**< 4-momenta of real photons. */
    int bnphot;             /**< Number of photons. */
  } momset_;

  // ...

  // replace internal random generator with the framework random gene
  double babayaganlo_rndm_ (int*) {
    double r = gRandom->Rndm();
    return r;
  }
}
```

input parameters

4-vectors in common block

framework random generator

FORTRAN

input parameters

```
subroutine babayaga(MODE,XPAR,NPAR)

DIMENSION XPAR(0:99), NPAR(0:99)
COMMON / BRESULTS / RESCROSS, RESCROSSERR,
COMMON / BHITNMISS / HNMCROSS, HNMCROSSERR
COMMON / BBIAS / BIASBIASHIT, BIASBIASHITP
integer BNPHOT
COMMON / MOMSET / BP1(0:3),BQ1(0:3),BP2(0:
```

4-vectors in common block

in: subroutine babayaga(MODE, ...)

```
IF (MODE.EQ.-1) THEN
! intialization

ELSE IF (MODE.EQ.1) THEN
! per event

ELSE IF (MODE.EQ.2) THEN
!finalize

ENDIF
```

init/ event/ finalize

```
void BabayagaNLO::generateEvent(MCParticleGraph& mcGraph)
{
  //Generate event
  int mode = 1;
  belle_(&mode, m_xpar, m_npar);

  //Store the initial particles as virtual particles into the M
  storeParticle(mcGraph, momset_.bq1, 11, true);
  storeParticle(mcGraph, momset_.bp1, -11, true);

  // ...
}
```

e.g. event with mode=1

Ideally, we modify only technical details of your FORTRAN code.

In reality it is often complicated and very hard to follow updates...

General wishlist.

Technical:

- Make compilation as simple as possible
- Provide standalone examples with makefile
- Provide reference numbers (cross sections, differential distributions, ...)
- HepEvt output format
- Separated INIT, EVENT, FINALIZE routines
- Revision control (e.g. SVN)
- Bugtracker, Forum, Mailinglists, ...

Physics general:

- Provide all possible information (intermediate resonances, ISR/FSR photons, ...) not only the final state

Belle II Theory Interface Platform (B2TIP).

- Joint theory-experiment effort to study the potential impacts of the Belle II program

What's new in Belle II compared to Belle and Babar?
- Efficiencies, precision of hardware
- New software
- New analysis methods
-...

What's new in theory after Belle, Babar and LHCb?
- Progress in QCD
- New Physics models and constraints
- New observables
- ...

NEW IDEAS!

- Next **open** B2TIP workshop: **27.-29.04.2015, Krakau**

http://kds.kek.jp/conferenceDisplay.py?confId=17654

Belle II Theory Interface Platform (B2TIP).

> WG8 “Tau, Low Multiplicity and Electroweak”

WG8: g-2 (TBC) *VANDERHAGEN, M.* — *Crown Piast hotel, Krakow* 09:00 - 09:30	**WG8: g-2: estimate of light by light contribution using a dispersive approach** *SOFFER, A.*
WG8: Hadronic Vacuum Polarisation in g-2 and αQED *TEUBNER, T.*	**WG8: g-2** *MASJUAN, P.* — *Crown Piast hotel, Krakow* 11:15 - 11:45
WG8: Status of MC Generators for Energy Scans and Radiative Return (PHOKHARA) *CZYZ, H.*	**WG8: g-2** *MOUSSALLAM, B.* — *Crown Piast hotel, Krakow* 11:45 - 12:15

WG8: Study of mesonic τ decay modes with TAUOLA *SHEKHOVTSOVA, O.*	**WG8: π → γ γ* and η(`) → γ γ*** *OFFEN, N* — *Crown Piast hotel, Krakow* 13:15 - 13:35
WG8: tau lepton theory and experiment: MC fits, software, systematic errors *WAS, Z.*	**WG8: tau → π η(`) ν hadronic form factor models** *GONZALEZ-SOLI, S*
WG8: |Vus| measurement using τ decays *LUSIANI, A.*	**"Shopping list" for tau analysis at Belle II** *HAYASAKA, Kiyoshi*

Summary.

- Unique non-Υ(4S) data planned for the first year
- Broad low multiplicity program at Belle II, including Dark Sector and Electroweak Precision Physics
- Significantly improved two track trigger, better Bhabha veto and single photon trigger planned
- Flexible and modern software framework with many event generators ready, development ongoing
- Belle II physics data taking will start 2018

Backup

Precision EW physics far below the Z pole.

- Precision measurement at Z pole:
  - $A_{FB} \sim g_V^2 g_A^2/(g_V^2+g_A^2)^2$ → Sensitive to the weak mixing angle and **ρ**
- Precision measurement at Belle II (~25 billion μ-pairs):
  - $A_{FB} \sim \rho g_A^2$ (dominated by interference $\sigma_{\gamma Z}$) → Only sensitive to **ρ**
  - Expected statistical uncertainty: $\boldsymbol{\sigma_{abs}(A_{FB}) \approx 10^{-5}}$ with $\boldsymbol{A_{FB\,(EW)} \approx -10^{-2}}$ at Belle II

    → Measurement of weak loop corrections to **ρ**
  - Largest corrections and systematics: QED asymmetry (theory: KKMC, ZFITTER, ...) and detector charge asymmetry
- Belle II First Physics:
  - Fine tuning of two track trigger, trigger systematics

Backup: Belle II and LHCb.

TABLE XLI: Expected errors on several selected flavour observables with an integrated luminosity of 5 ab^{-1} and 50 ab^{-1} of Belle II data. The current results from Belle, or from BaBar where relevant (denoted with a †) are also given. Items marked with a ‡ are estimates based on similar measurements. Errors given in % represent relative errors.

	Observables	Belle or LHCb* (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	LHCb 8 fb^{-1}(2018)	LHCb 50 fb^{-1}
UT angles	$\sin 2\beta$	$0.667 \pm 0.023 \pm 0.012(1.4^\circ)$	0.7°	0.4°	1.6°	0.6°
	α [°]	85 ± 4 (Belle+BaBar)	2	1		
	γ [°] $(B \to D^{(*)}K^{(*)})$	68 ± 14	6	1.5	4	1
	$2\beta_s(B_s \to J/\psi\phi)$ [rad]	$0.07 \pm 0.09 \pm 0.01^*$			0.025	0.009
Gluonic penguins	$S(B \to \phi K^0)$	$0.90^{+0.09}_{-0.19}$	0.053	0.018	0.2	0.04
	$S(B \to \eta' K^0)$	$0.68 \pm 0.07 \pm 0.03$	0.028	0.011		
	$S(B \to K^0_S K^0_S K^0_S)$	$0.30 \pm 0.32 \pm 0.08$	0.100	0.033		
	$\beta_s^{\rm eff}(B_s \to \phi\phi)$ [rad]	$-0.17 \pm 0.15 \pm 0.03^*$			0.12	0.03
	$\beta_s^{\rm eff}(B_s \to K^{*0}\bar{K}^{*0})$ [rad]	–			0.13	0.03
Direct CP in hadronic Decays	$\mathcal{A}(B \to K^0\pi^0)$	$-0.05 \pm 0.14 \pm 0.05$	0.07	0.04		
UT sides	$\lvert V_{cb}\rvert$ incl.	$41.6 \cdot 10^{-3}(1 \pm 2.4\%)$	1.2%			
	$\lvert V_{cb}\rvert$ excl.	$37.5 \cdot 10^{-3}(1 \pm 3.0\%_{\rm ex.} \pm 2.7\%_{\rm th.})$	1.8%	1.4%		
	$\lvert V_{ub}\rvert$ incl.	$4.47 \cdot 10^{-3}(1 \pm 6.0\%_{\rm ex.} \pm 2.5\%_{\rm th.})$	3.4%	3.0%		
	$\lvert V_{ub}\rvert$ excl. (had. tag.)	$3.52 \cdot 10^{-3}(1 \pm 10.8\%)$	4.7%	2.4%		
Leptonic and Semi-tauonic	$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	$96(1 \pm 26\%)$	10%	5%		
	$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	< 1.7	20%	7%		
	$R(B \to D\tau\nu)$ [Had. tag]	$0.440(1 \pm 16.5\%)^\dagger$	5.6%	3.4%		
	$R(B \to D^*\tau\nu)^\dagger$ [Had. tag]	$0.332(1 \pm 9.0\%)^\dagger$	3.2%	2.1%	...	
Radiative	$\mathcal{B}(B \to X_s\gamma)$	$3.45 \cdot 10^{-4}(1 \pm 4.3\% \pm 11.6\%)$	7%	6%		
	$A_{CP}(B \to X_{s,d}\gamma)$ $[10^{-2}]$	$2.2 \pm 4.0 \pm 0.8$	1	0.5		
	$S(B \to K^0_S\pi^0\gamma)$	$-0.10 \pm 0.31 \pm 0.07$	0.11	0.035		
	$2\beta_s^{\rm eff}(B_s \to \phi\gamma)$	–			0.13	0.03
	$S(B \to \rho\gamma)$	$-0.83 \pm 0.65 \pm 0.18$	0.23	0.07		
	$\mathcal{B}(B_s \to \gamma\gamma)$ $[10^{-6}]$	< 8.7	0.3	–		
Electroweak penguins	$\mathcal{B}(B \to K^{*+}\nu\overline{\nu})$ $[10^{-6}]$	< 40	< 15	30%		
	$\mathcal{B}(B \to K^+\nu\overline{\nu})$ $[10^{-6}]$	< 55	< 21	30%		
	C_7/C_9 $(B \to X_s\ell\ell)$	~20%	10%	5%		
	$\mathcal{B}(B_s \to \tau\tau)$ $[10^{-3}]$	–	< 2	–		
	$\mathcal{B}(B_s \to \mu\mu)$ $[10^{-9}]$	$2.9^{+1.1*}_{-1.0}$			0.5	0.2

Backup: Belle II and LHCb.

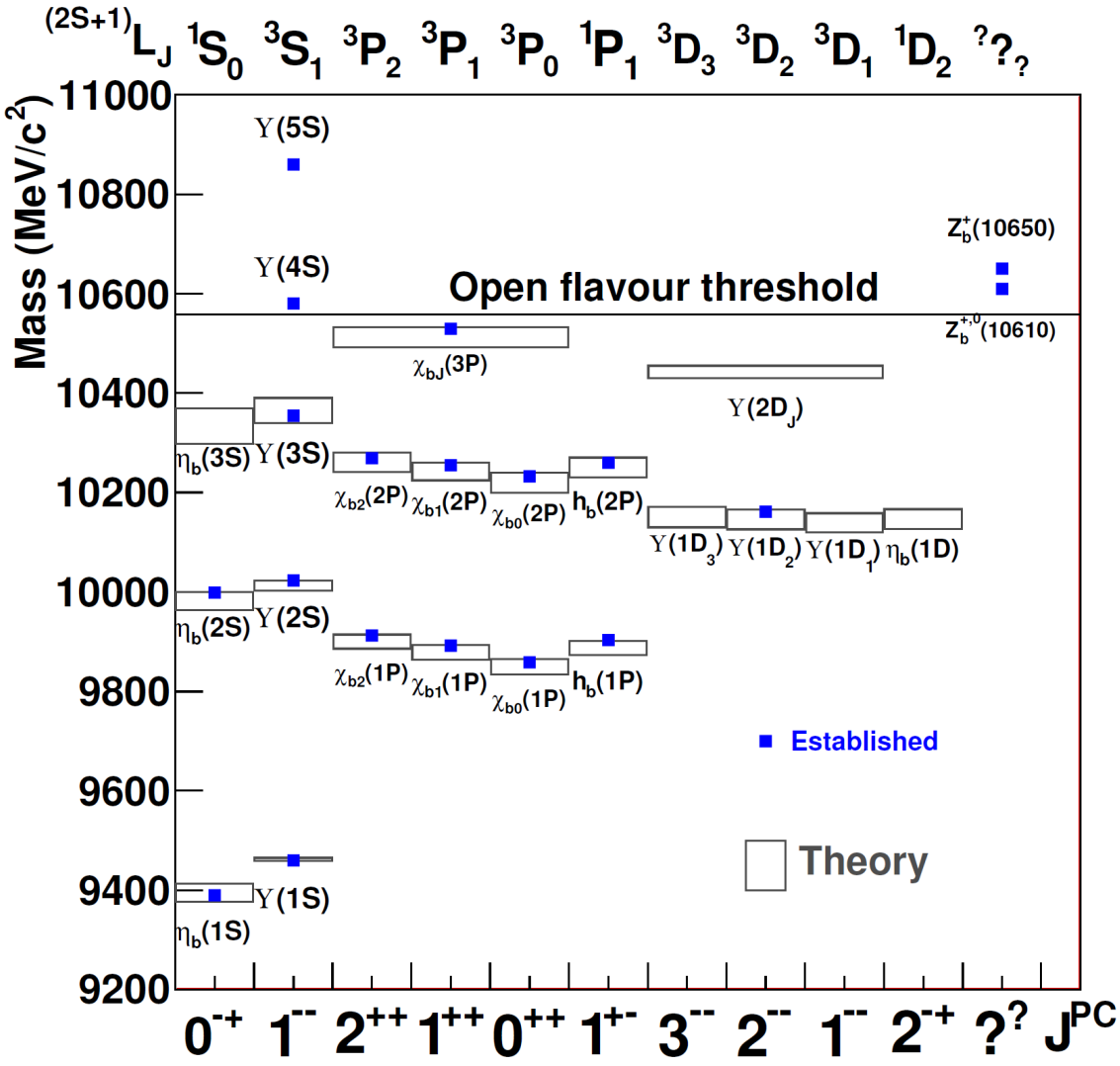
TABLE XLII: Continued from previous page.

	Observables	Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}	LHCb 2018	LHCb 50 fb^{-1}
Charm Rare	$\mathcal{B}(D_s \to \mu\nu)$	$5.31 \cdot 10^{-3}(1 \pm 5.3\% \pm 3.8\%)$	2.9%	0.9%		
	$\mathcal{B}(D_s \to \tau\nu)$	$5.70 \cdot 10^{-3}(1 \pm 3.7\% \pm 5.4\%)$	3.5%	2.3%		
	$\mathcal{B}(D^0 \to \gamma\gamma)$ $[10^{-6}]$	< 1.5	30%	25%		
Charm CP	$A_{CP}(D^0 \to K^+K^-)$ $[10^{-4}]$	$-32 \pm 21 \pm 9$	11	6		
	$\Delta A_{CP}(D^0 \to K^+K^-)$ $[10^{-4}]$	3.4^*			0.5	0.1
	A_Γ $[10^{-2}]$	0.22	0.1	0.03	0.02	0.005
	$A_{CP}(D^0 \to \pi^0\pi^0)$ $[10^{-2}]$	$-0.03 \pm 0.64 \pm 0.10$	0.29	0.09		
	$A_{CP}(D^0 \to K_S^0\pi^0)$ $[10^{-2}]$	$-0.21 \pm 0.16 \pm 0.09$	0.08	0.03		
Charm Mixing	$x(D^0 \to K_S^0\pi^+\pi^-)$ $[10^{-2}]$	$0.56 \pm 0.19 \pm {}^{0.07}_{0.13}$	0.14	0.11		
	$y(D^0 \to K_S^0\pi^+\pi^-)$ $[10^{-2}]$	$0.30 \pm 0.15 \pm {}^{0.05}_{0.08}$	0.08	0.05		
	$\lvert q/p\rvert(D^0 \to K_S^0\pi^+\pi^-)$	$0.90 \pm {}^{0.16}_{0.15} \pm {}^{0.08}_{0.06}$	0.10	0.07		
	$\phi(D^0 \to K_S^0\pi^+\pi^-)$ $[^\circ]$	$-6 \pm 11 \pm {}^{4}_{5}$	6	4		
Tau	$\tau \to \mu\gamma$ $[10^{-9}]$	< 45	< 14.7	< 4.7		
	$\tau \to e\gamma$ $[10^{-9}]$	< 120	< 39	< 12		
	$\tau \to \mu\mu\mu$ $[10^{-9}]$	< 21.0	< 3.0	< 0.3		

Backup: First physics "Bottomonium below Y(4S)".

$\eta_b(1S)$	Resolve discrepancies on the mass and width, based on measurements of radiative transitions.
$\eta_b(2S)$	Independent confirmation of $\Upsilon(2S)$ properties, and tests of hyperfine splitting against theoretical predictions.
$\Upsilon(1^3D_1)$, $\Upsilon(1^3D_3)$	Precise measurement of multi-photon cascade decays to separate $J = 1,\ 3$ (not seen) states from the $J = 2$ (seen) state.
$\Upsilon(1^3D_1)$	Inclusive photon spectra of $\Upsilon(3S)$ decays.
R_b near $\Upsilon(3S)$, $\Upsilon(2^3D_2)$-triplet	Search for unseen $\Upsilon(1D)$ states and the unseen $\Upsilon(2^3D_2)$ triplet via R_b scan methods.
h_b	First observation and resonance characterisation.
Inclusive decays (χ_b, Υ)	Surveys of inclusive hadronic transitions of χ_b and $\Upsilon(2S,\ 3S)$.
Dipion transitions	Surveys of dipion transitions between χ_b states (analogous to Υ).

Backup: First physics “Bottomonium below Υ(4S)”.



Backup: First physics "Bottomonium above Y(4S)".

R_b	Inclusive b cross section as a function of E_{CM} up to $\Upsilon(6S)$
Z_b from scans	Analysis of $\pi + Z_b$ substructure through $\sigma(\Upsilon + 2\pi)$ and $\sigma(h_b(nP) + 2\pi)$ through an E_{CMscan}
Z_b near resonance	Analysis of Z_b charged and neutral from $\Upsilon(6S)$
Tetra quark states	Analysis of radiative or 2π transitions from $\Upsilon(6S)$
Other exotica	Searches for exotic states with single π transitions from $\Upsilon(5S)$ and $\Upsilon(6S)$
$\sigma(B^{(*)}B^{(*)})$ and $\sigma(B_s^{(*)}B_s^{(*)})$	
W_b, X_b	Studies of radiative transitions from $\Upsilon(6S)$ to new bottomonium-like states and χ_{bJ}.
m_b	Accurate determination of m_b via bottomonium sum-rules. Precision tests of discrepancies between pQCD and e^+e^- data near the accelerator threshold region.

Backup: First physics “Bottomonium above Y(4S)”.

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$$|Z_b'\rangle = \frac{1}{\sqrt{2}} 0^-_{bb} \otimes 1^-_{Qq} - \frac{1}{\sqrt{2}} 1^-_{bb} \otimes 0^-_{Qq}$$

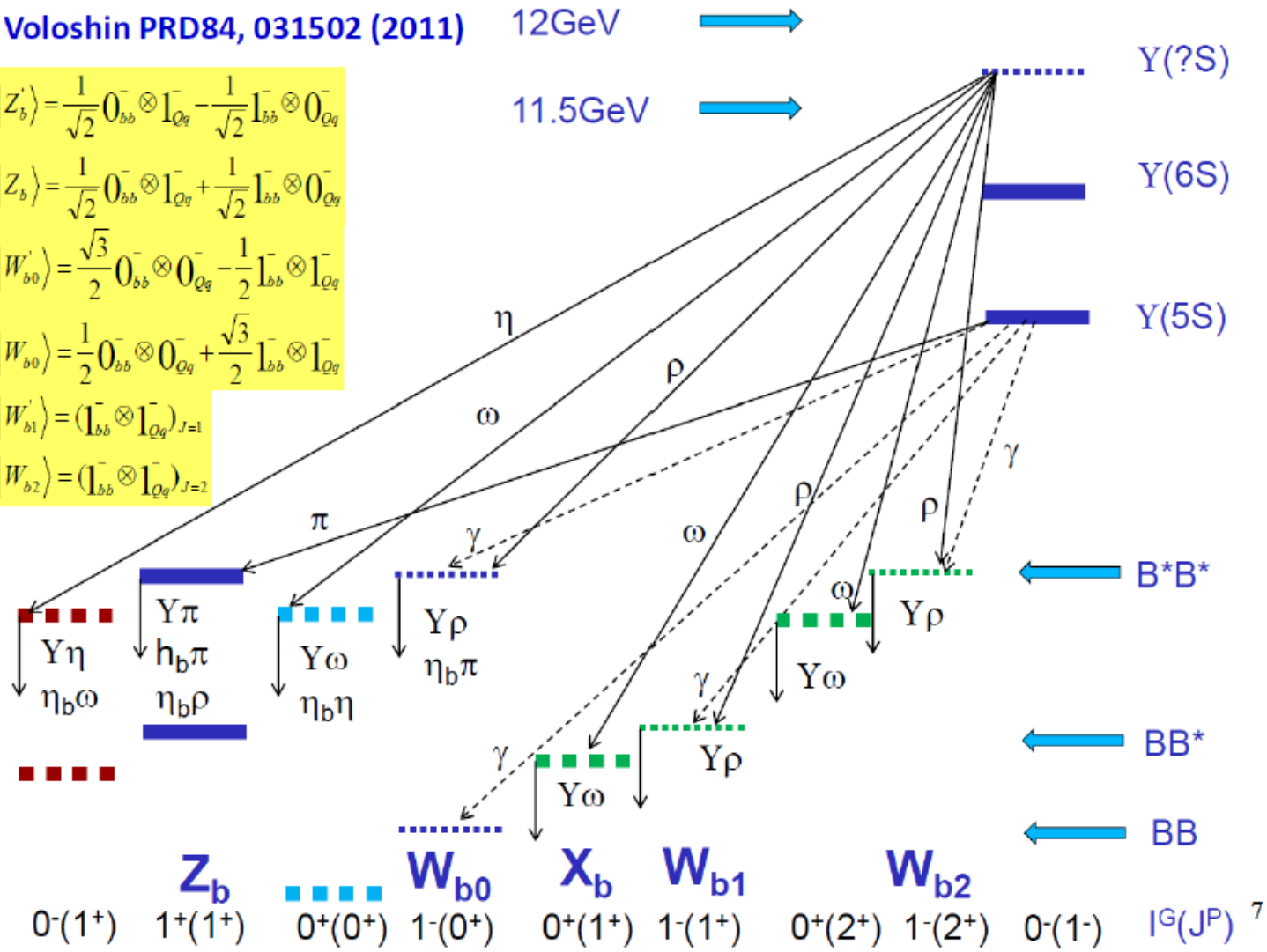
$$|Z_b\rangle = \frac{1}{\sqrt{2}} 0^-_{bb} \otimes 1^-_{Qq} + \frac{1}{\sqrt{2}} 1^-_{bb} \otimes 0^-_{Qq}$$

$$|W_{b0}'\rangle = \frac{\sqrt{3}}{2} 0^-_{bb} \otimes 0^-_{Qq} - \frac{1}{2} 1^-_{bb} \otimes 1^-_{Qq}$$

$$|W_{b0}\rangle = \frac{1}{2} 0^-_{bb} \otimes 0^-_{Qq} + \frac{\sqrt{3}}{2} 1^-_{bb} \otimes 1^-_{Qq}$$

$$|W_{b1}'\rangle = (1^-_{bb} \otimes 1^-_{Qq})_{J=1}$$

$$|W_{b2}\rangle = (1^-_{bb} \otimes 1^-_{Qq})_{J=2}$$



Physics process	Cross section [nb]
Y(4S) → BB	1.2
Light quark pairs	2.8
Muon pairs	1.1
Tau pairs	0.9
Bhabha (θ_{lab}>17°)	44
Photon pairs (θ_{lab}>17°)	2.4
Two photon (θ_{lab}>17°)	~80
Total	**~130**

	L1 rate	Physics rate	Event size
Belle	500 Hz	90 Hz	40kB
Belle II	30 kHz	3-10 kHz	200kB

Physics process	Cross section [nb]	Rate [Hz] @ final L.
Y(4S) → BB	1.2	960
quark pairs	2.8	2200
Muon pairs	1.1	880
Tau pairs	0.9	720
Bhabha (θ_{lab}>17°)	44	350*
γ pairs (θ_{lab}>17°)	2.4	19*
Two photon (θ_{lab}>17°)	~80	~15000
Total	~130	~20000