6TH CHINA WINTER BELLE II SCHOOL | SPECTROSCOPY

Southeast University, Nanjing | 15th November 2026

Belle II Generators

Models, sampling and parameters: how simulated events are prepared, tuned, and made to trust

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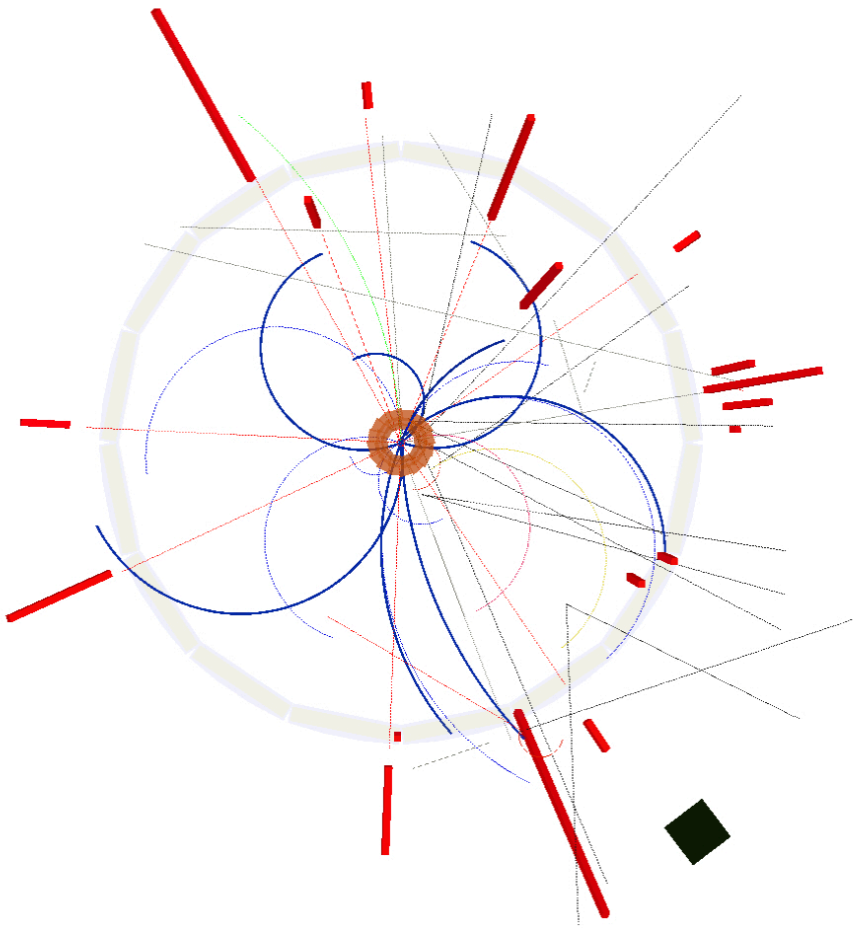


Belle II generators group activities

- Responsible for all event generator related activities in the collaboration

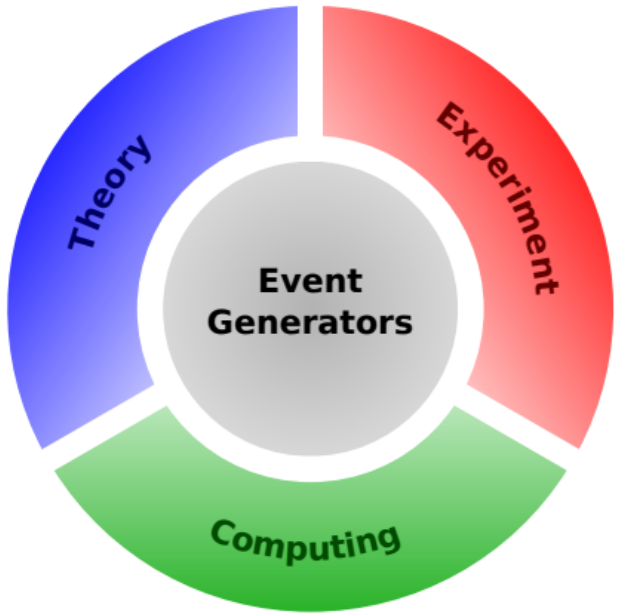
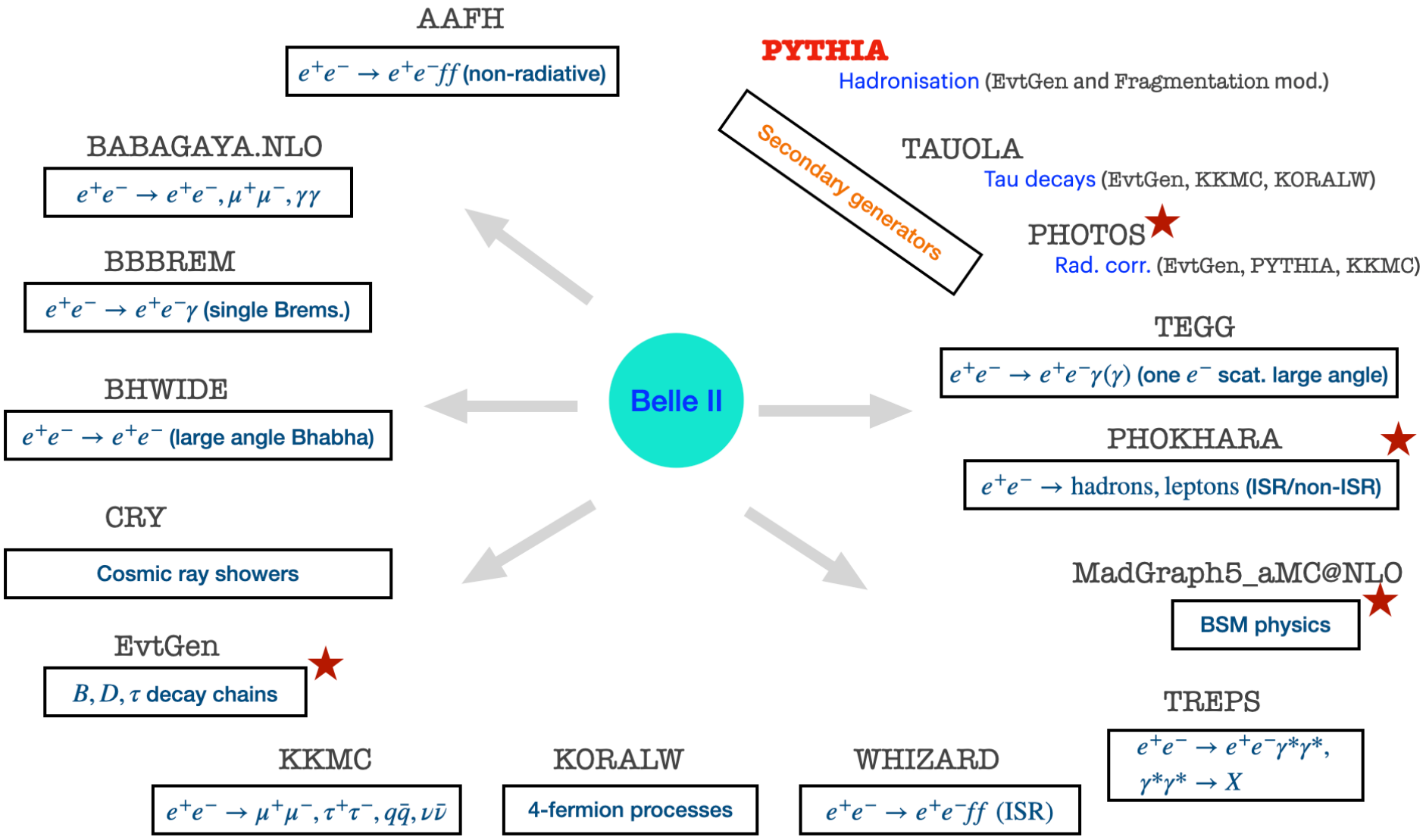


Image credit: arXiv:2203.11110v4

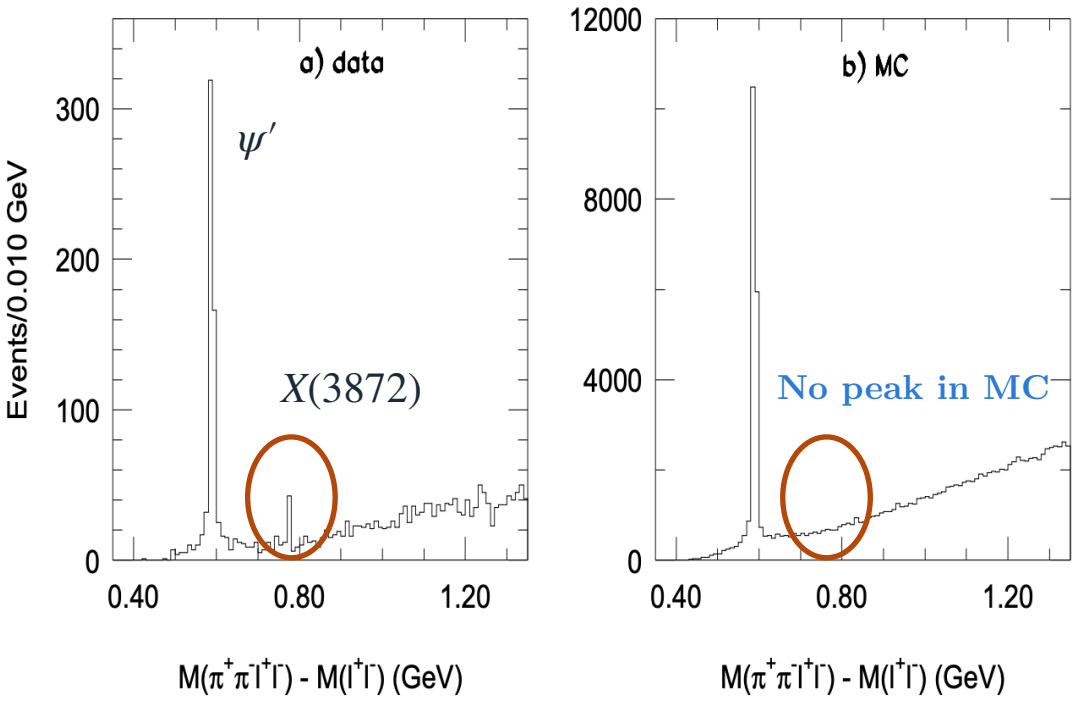
Activity	Goal	Proponents	Status
PYTHIA8.3 tuning	Continuum tuning with fragmentation measurements (Belle) using Professor and RIVET	Ralf Seidl (RIKEN)	Finished
PYTHIA8.3 tuning	Study influence of PYTHIA8.3 parameters on resonances (Professor) using Belle 2 data	Hazaravard Ghumaryan, Gevorg Karyan (AANL, Yeravan group)	Ongoing
PYTHIA 8.3 validation	Validation of tuned Pythia 8.3 continuum generator at detector level with Belle II data	Zheng Wang, Yubo Li, Wenbiao Yan (USTC, Xi'an Jiaotong Uni.)	Ongoing
PYTHIA8.3 update	Validate and replace PYTHIA8.2(basf2) with 8.3	Julius Materne, Gunar Schnell (Bilbao)	Ongoing
KKMC / TAUOLA	Implement newer tau production / decay modes	Swagato Banerjee (UofL)	Ongoing
EKHARA (implement for transition FF measurements)	Implement at Belle II (validation)	Hisaki Hayashii (NWU, Japan)	Ongoing
PHOKHARA	Resolve ISR calculation problems	Analyst no longer associated with Belle II	Stalled
New charm model implementations	Validate new charm models (from BESIII) and implement it at Belle II	Roman Sultanov (Uppsala), Jaeyoung Kim (Yonsei), Jiyuan Zhang, Yuping Guo, J. Borah, Lu Cao (Fudan)	Ongoing

Belle II generators



★ Pythia impacts several event generators

2003: a narrow peak at 3872 MeV



Spectroscopy lives on peaks!

Belle studied $B^+ \to K^+ J/\psi \pi^+ \pi^-$ and saw a narrow peak in $M(J/\psi\pi^+\pi^-)$: the $X(3872)$.

More than twenty years later, its nature and its lineshape are still being studied, at Belle II too.

- How do we know a peak is a state, and not an efficiency effect, or an unmodelled background ?
- And are the mass and width we quote properties of the state, or of the model we used?

Every answer goes through an event generator

Belle, S. K. Choi et al., Phys. Rev. Lett. 91, 262001 (2003)

THE PLAN

Build one event, then try to break it

Part 1

Make it by hand

$B^- \to X(3872)K^-$ from a handful of random numbers (21 in our event)

Part 2

Let basf2 make it

the same recipe, with real physics

Part 3

Parameters

quarks to hadrons, and tuning to data

Part 4

Models

EvtGen, resonances and spin

Part 5

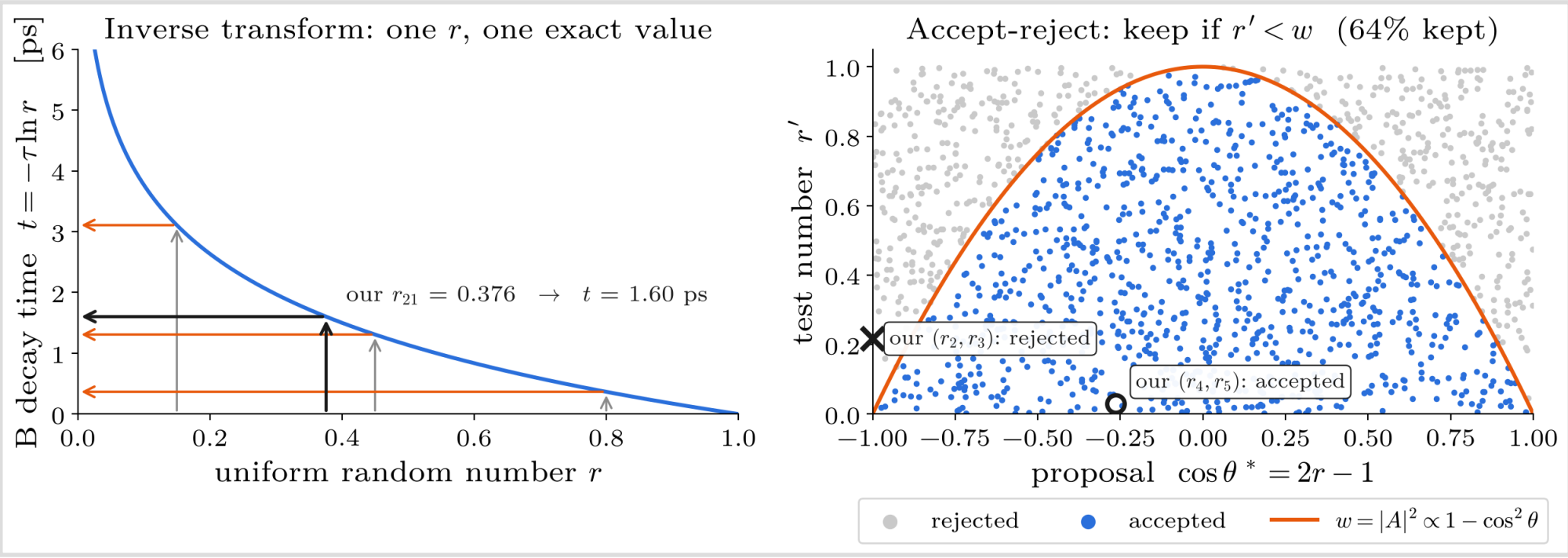
Break it

a wrong $X(3872)$ model that fits

What we will find: a generator is random sampling + physics models + tunable parameters, and every Belle II result inherits all three

Two basic tricks turn random numbers into physics

A computer gives uniform numbers r between 0 and 1. Nature gives decay times, angles and masses with known distributions. Every generator connects the two with only these tricks:



Inverse transform: solve $r = F(x)$ for x. Decay time: $t = -\tau \ln r$.

One r, one exact value. Used for r8 (X mass) and r21 (B decay time)

Accept–reject: one number proposes x, a second keeps it only if it is below $w(x)/w_{\max}$; otherwise draw a new pair. Works for any $|A|^2$, but each rejection costs two numbers

$\Upsilon(4S) \to B^+B^-$: seven random numbers

random number	what it decides	how
r1 = 0.161	B^+B^-(not $B^0\bar{B}^0$)	r below 0.514, the B^+B^- branching fraction
r2 = 0.0003, r3 = 0.217	proposal $\cos\theta^* = -0.999$; **rejected**	proposal for the B direction; test r3 = 0.217 is above $1-\cos^2\theta^* = 0.001$
r4 = 0.368, r5 = 0.002	proposal $\cos\theta^* = -0.264$; **accepted**	test r5 = 0.002 is below $1-\cos^2\theta^* = 0.930$
r6 = 0.193	$\phi^* = 69°$	$\phi^* = 2\pi r$, uniform (azimuthal angle of B direction)
r7 = 0.991	B^- is the signal B	our DEC file: 50 % each

7 numbers = 1 for the channel + 2 × 2 for the angle (one rejected try) + 1 for ϕ^* + 1 for the signal B

No random number for $|p^*|$: two-body kinematics fix it, $|p^*| = 0.328$ GeV at $\sqrt{s} = 10.579$ GeV.

Physics enters through the weights: $1-\cos^2\theta^*$ because the $\Upsilon(4S)$ is polarised along the beam.

- fixed $\sqrt{s}$, no ISR (simplifications stated in the code)
- Checked in basf2 release-09-00-20 (20 000 events): $1 + \alpha \cdot \cos^2\theta^*$with $\alpha = -1.001 \pm 0.008$

$B^- \to X(3872)K^- \to J/\psi\pi^+\pi^-K^-$: fourteen more

random numbers	what they decide	how
r8 = 0.787	$m(X) = 3872.39$ MeV	inverse transform of a Breit–Wigner, $\Gamma = 1.19$ MeV
r9, r10	X direction in the B frame	isotropic (spin-0 B); |p| = 1.140 GeV fixed
r11, r12	$m(\pi\pi) = 659$ MeV, rejected	phase-space weight 0.886 < r12 = 0.917
r13, r14	$m(\pi\pi) = 455$ MeV, accepted	weight 0.822 > r14 = 0.786 (PHSP model)
r15 – r20	$J/\psi, \pi^+, \mu^+$ directions	isotropic in each parent's rest frame
r21 = 0.376	B^- lives 1.60 ps	$t = -\tau$ ln r: it flies 133 μm in the lab

Total for this event: 7 + 14 = 21. The two rejected proposals cost 4 of them; an event with no rejections needs 17

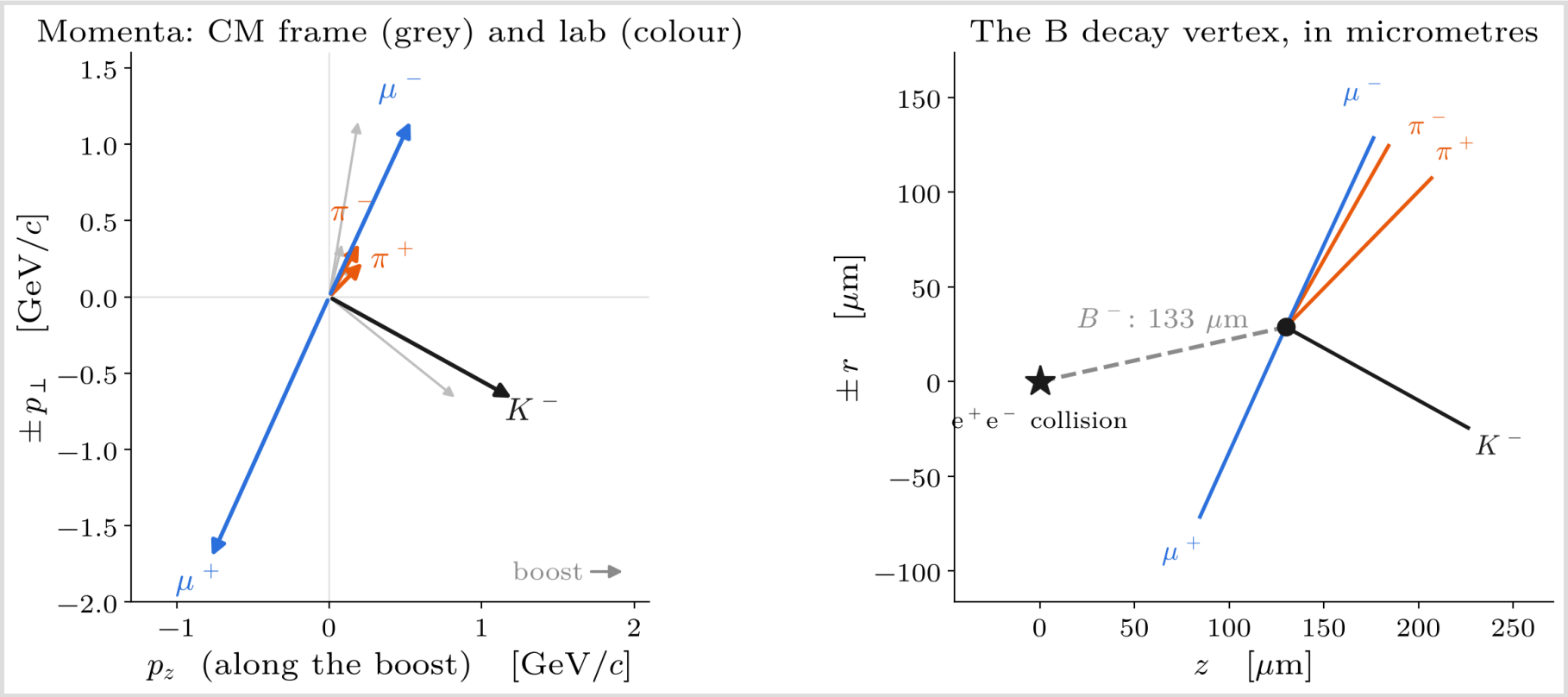
The minimum for this decay chain is 17 random numbers. Every rejected proposal costs 2 more, and our event had 2 rejections, so 21 random numbers are required

Then boost every particle up the chain: π frame → X frame → B frame → CM → lab.

Mark r8: the Breit–Wigner was our choice. In part 5 we change it.

X(3872): PDG Breit–Wigner average; $X \to J/\psi\pi\pi$ and $J/\psi \to \mu^+\mu^-$ as in our DEC file (PHSP, VLL)

21 random numbers, one physical event



Check: the five daughters add up to m = 5.27934 GeV (the B mass)

Boost: the lab arrows lean forward; the μ^+ still goes backward.

Detector: 133 μm is what the vertex detector must resolve.

Each particle is drawn in its own plane through the beam axis

What professional generators add to this recipe?

The real generators run the same recipe, with more physics

our event by hand	what basf2 adds	program
fixed $\sqrt{s}$	ISR photons and beam-energy spread, drawn per event	KKMC
one forced B decay	the other B from a table of measured channels, same r-ladder	EvtGen
isotropic angles, PHSP	decay amplitudes with spin, resonance lineshapes	EvtGen
no photons	final-state radiation from charged particles	PHOTOS
no quarks	$e^+e^- \to q\bar{q}$: quarks turned into hadrons	PYTHIA 8
$\mathrm{T} = -\tau \ln \mathrm{r}$	same for particles in the detector: distance to the next interaction $= -\lambda \ln \mathrm{r}$	Geant4

Each row is the same two tricks plus a physics model with parameters. Parts 3 and 4 open two of these rows.

Beam background is overlaid after Geant4 (recorded random-trigger data and simulation)

The same decay, generated by basf2

e^- 7 GeV · e^+ 4 GeV (flag: Initial) ➡ $\Upsilon(4S) \to B^+B^-$

Generic side (Belle II decay table)

$B^+ \to D_s^{*+} D^- \pi^+$

$D_s^{*+} \to D_s^+ \gamma$, $D_s^+ \to \pi^+\pi^+\pi^-$

$D^- \to K_S^0 \pi^- \pi^0$

$K_S^0 \to \pi^+\pi^-$, $\pi^0 \to \gamma\gamma$

Signal side (our DEC file)

$B^- \to X(3872) K^-$

$X(3872) \to J/\psi \pi^+\pi^-$

$J/\psi \to \mu^+\mu^-$ (PHOTOS on)

Same signal chain as by hand. B^- momentum in the CM: 0.312 GeV here, 0.328 GeV by hand: **the beam-energy spread changed $\sqrt{s}$ for this event.**

What we skipped: the other B, decayed from the table into 10 more stable particles, including K_S^0 and π^0 decays.

basf2 release-09-00-20, EvtGen + PHOTOS, event 1 of the running example (printMCParticles)

From 17 final-state particles to about 5000 simulated hits

Generator record, per event

charged particles	9.9
photons	6.2
neutral hadrons, neutrinos	1.3
all stored, incl. history	34.0

1000 events

After Geant4, per event

secondary particles	34
SimHits in CDC (drift chamber)	1714
SimHits in ECL (calorimeter)	2908
PXD, SVD, TOP, ARICH, KLM	661

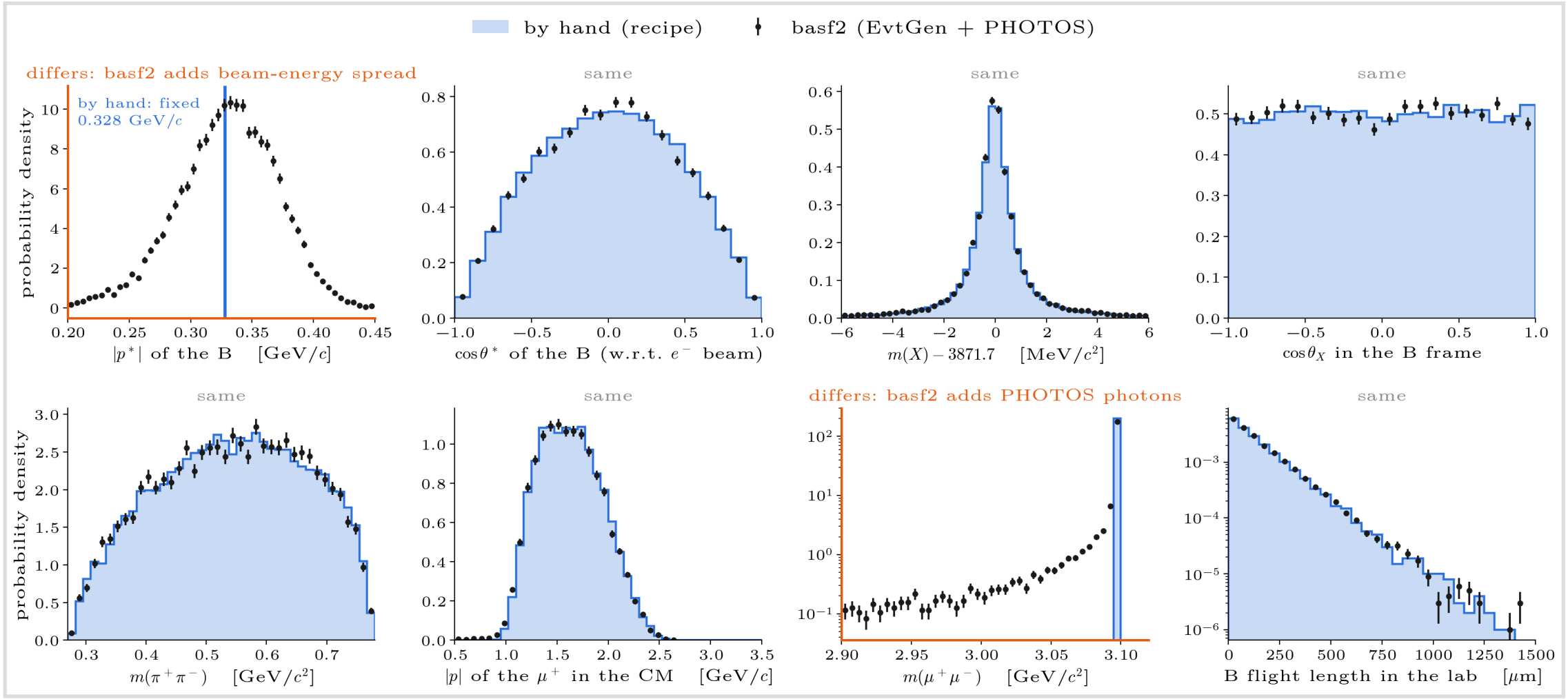
10 events, no beam background

(for illustration only)

One particle leaves many hits: a track crosses several CDC layers, photon showers over many ECL crystals, and a charged track makes tens of Cherenkov photons in TOP

The record is the full history of the 21-step recipe!

Same recipe, same distributions, except where basf2 adds physics



Most Belle II collisions contain no B meson

process at $\sqrt{s} = 10.58$ GeV	σ (nb)	generator in basf2
$\Upsilon(4S) \to B\bar{B}$	1.11	EvtGen
$u\bar{u}, d\bar{d}, s\bar{s}$	1.61, 0.40, 0.38	KKMC + PYTHIA 8 + EvtGen
$c\bar{c}$	1.30	KKMC + PYTHIA 8 + EvtGen
$\tau^+\tau^-$	0.919	KKMC + TAUOLA
$\mu^+\mu^-$	1.148	KKMC
e^+e^- (Bhabha), $\gamma\gamma$	$\approx$ 300, 4.99	BabaYaga@NLO
$e^+e^-e^+e^-$, $e^+e^-\mu^+\mu^-$	39.7, 18.9	AAFH
$e^+e^- \to \gamma$ + hadrons (ISR)	channel	PHOKHARA
$\gamma\gamma \to$ resonance	channel	TREPS

Light-quark and charm continuum is 3.7 nb against 1.1 nb for $B\bar{B}$. Continuum events start from "free" quarks, and quarks cannot be decayed from a decay table. **How does a generator turn quarks into hadrons?**

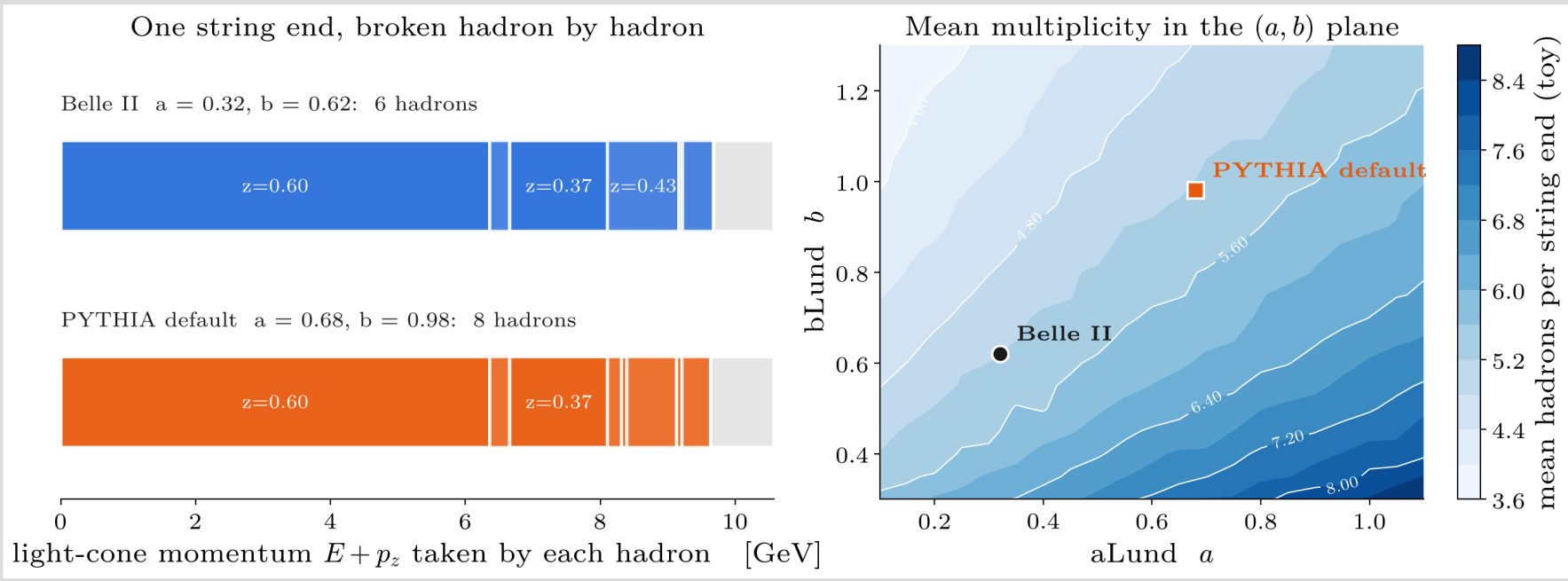
Cross sections: Belle II Physics Book, PTEP 2019, 123C01; QED values depend on the generator-level acceptance cuts

Quarks to hadrons: the same dice, over and over

- PYTHIA stretches a string between q and $\bar{q}$ and breaks it: each hadron takes a fraction z of what is left, z drawn by accept–reject from the Lund function

$$f(z) \propto \frac{1}{z}(1-z)^{a_{\text{Lund}}} \exp\left(-\frac{b_{\text{Lund}}\, m_T^2}{z}\right)$$

Lund function



Belle II (0.32, 0.62) and PYTHIA default (0.68, 0.98): 5.20 vs 5.28 hadrons. One measurement fixes a line, not a point. "a" and "b" are not calculated but obtained from fit to data

Toy: one string end, pions only, string stops below 1 GeV; not the Belle II multiplicity

Step 1: more observables to break the a–b "line"

Change of each observable when one parameter is raised by 30 %

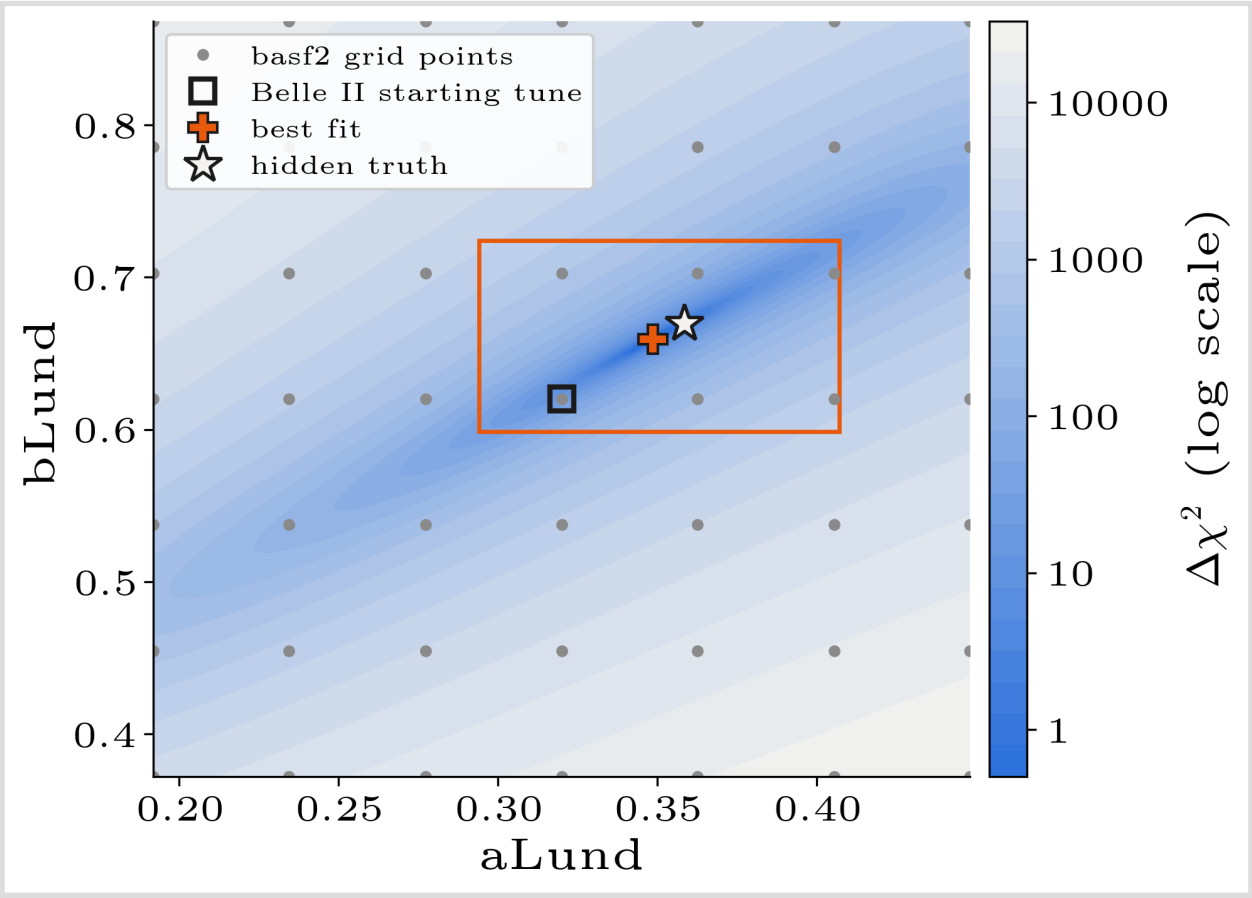
	$\langle n_{ch} \rangle$	$\langle x_p \rangle$	$\langle p_T \rangle$	$\langle S \rangle$	K/π
aLund ×1.3	+1.5%	−1.7%	−0.3%	+2.3%	−0.3%
bLund ×1.3	−2.0%	+2.4%	−0.1%	−4.2%	−0.6%
σ_{p_T} ×1.3	−5.7%	+6.8%	+9.7%	+5.9%	+0.7%
probStoUD ×1.3	−1.4%	+0.5%	−0.4%	−1.2%	+27.7%

- $e^+e^- \to q\bar{q}$ at 10.58 GeV in basf2 (KKMC + PYTHIA 8), each parameter moved alone.
- aLund and bLund move the same observables in opposite directions: they are correlated, **so they must be fitted together**.
- K/π fixes **probStoUD** almost alone.

n_{ch} : charge multiplicity; $x_p = p^*/p^*_{\max}$; S: sphericity; p_T: transverse momentum

how often a string break makes a strange pair instead of a light one

Step 2: scan, interpolate, minimise χ^2



1 Run basf2 on a grid of (aLund, bLund):
62 jobs, 15M events

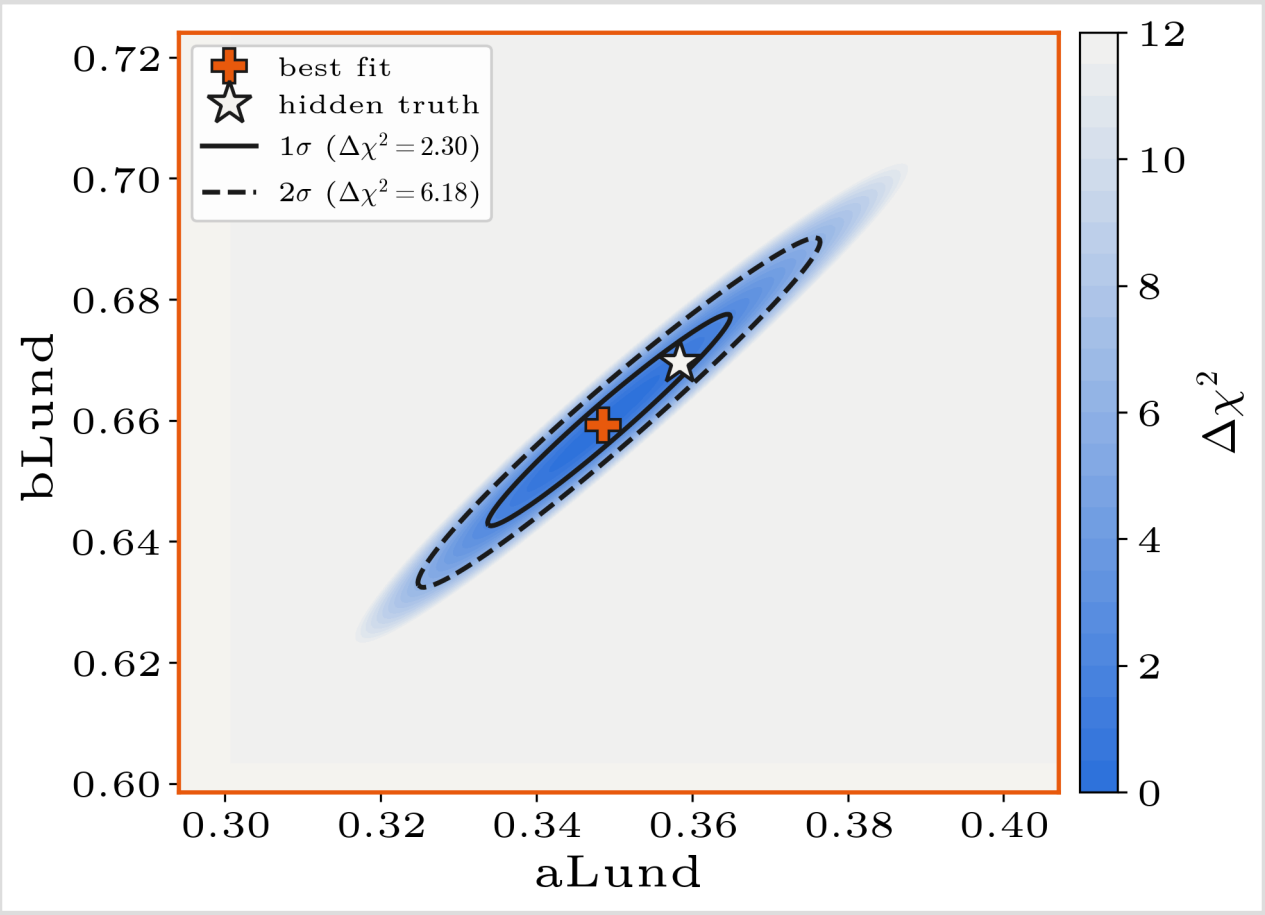
2 Fit each histogram bin with a polynomial in the parameters: a fast stand-in for PYTHIA

3 Compare the surrogate with "data" (n_{ch}, x_p) and find the minimum χ^2

A long, narrow valley: the same a–b correlation as in the string toy

"data" = basf2 pseudo-data at a hidden parameter point; method as in Professor (Buckley et al., EPJC 65 (2010) 331)

Step 3: a tune is a band, not a point



	hidden truth	tune
aLund	0.358	0.349
bLund	0.670	0.659

1σ ranges: aLund 0.339–0.359, bLund 0.649–0.671; correlation +0.98; χ^2 64.5/45 at the starting tune, 45.2/45 at the best fit

The tune recovers the hidden point. But many (a, b) pairs along the valley describe the data equally well.

> That spread of tunes is the generator uncertainty on every continuum background.

For spectroscopy, the production mechanism picks the quantum numbers

B decays

many J^{PC}; $X(3872)$, Z states, D^{**} in $B \to XK$, $B \to D^{**}\ell\nu$

EvtGen

Initial-state radiation

only $J^{PC} = 1^{--}$; a free scan below 10.58 GeV: ≈ 16 pb^{-1} per 10 MeV at 4.23 GeV

PHOKHARA

Two-photon fusion

C = +1 only, J ≠ 1 for real photons: η_c, χ_{c0}, χ_{c2}

TREPS

Continuum $c\bar{c}$

charmed mesons and baryons, excited D_s, excited Λ_c

KKMC + PYTHIA 8 + EvtGen

Υ(nS) decays

bottomonium transitions, light hadrons, exotic searches

EvtGen

τ decays

light mesons in a clean, low-mass environment

KKMC + TAUOLA

Our $X(3872)$ came from a B decay, so its physics model is an EvtGen model. What is inside one?

Our hand-made steps, written as an EvtGen DEC file

```
Decay Upsilon(4S)
0.5 myB+ B- VSS; # steps 2–3
0.5 B+ myB- VSS;
Enddecay

Decay myB-
1.0 myX3872 K- SVS; # step 4
Enddecay

Decay myX3872
1.0 myJpsi pi+ pi- PHSP; # step 5
Enddecay

Decay myJpsi
1.0 mu+ mu- PHOTOS VLL; # step 6
Enddecay

(Alias and CDecay lines not shown)
```

Each line = a branching fraction + a model. The first number is our r-ladder; the model name says which $|A|^2$ the accept–reject uses.

Not in the file: the $X(3872)$mass and Breit–Wigner width (step 4) come from the particle table.

Beyond our toy: EvtGen evaluates complex amplitudes for every spin state and passes the spin of each particle to its daughters.

For spectroscopy, two ingredients matter most: the lineshape and the spin

- EvtGen: D. J. Lange, NIM A 462 (2001) 152
- Checked in basf2 (20 000 events): X(3872) mass drawn from a Breit–Wigner, $\Gamma = 1.15$ MeV, kept within 3865.7–3888.9 MeV.

Ingredients to understand a lineshape

Lineshape: For a resonance, it describes how the resonance's contribution changes across mass, it's peak position, its width, and how it falls off on either side. Breit-Wigner (BW) or a Flatte formula is a model for that mass dependence

Breit-Wigner function

$$BW(m) = \frac{1}{(m_0^2 - m^2 - i m_0 \Gamma(m))}$$

Decay width

$$\Gamma(m) = \Gamma_0 \left(\frac{q}{q_0} \right)^{2L+1} \frac{m_0}{m} \frac{B_L^2(q)}{B_L^2(q_0)}$$

Flatte function

$$A(E) = \frac{1}{E - \varepsilon + \frac{i}{2}\left[\Gamma_0 + g\, k_0(E) + g\, k_+(E)\right]}$$

$$k(E) = \sqrt{2\mu\,(E - E_{\text{thr}})} \text{ above threshold, } i\sqrt{2\mu\,(E_{\text{thr}} - E)} \text{ below}$$

m_0: nominal mass; Γ : width; $q(q_0)$: daughter mom. ($m = m_0$)

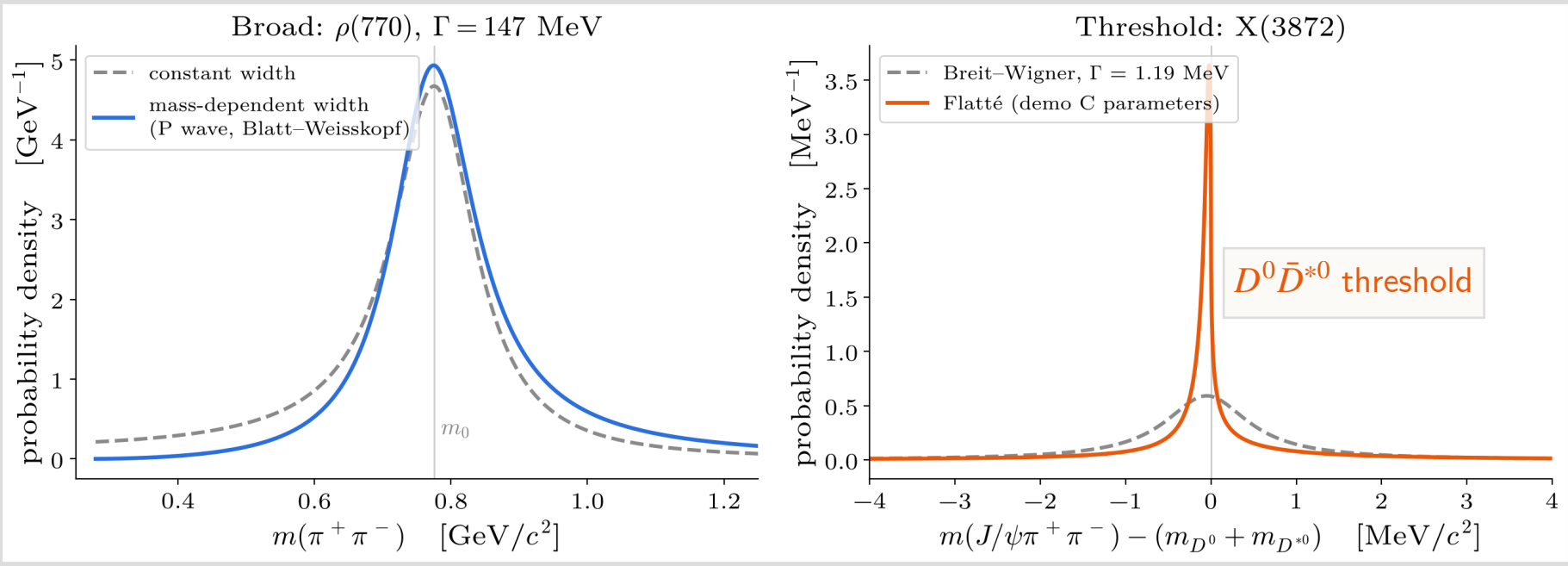
With constant Γ: a symmetric peak at m_0, with full width at half maximum Γ

BW: when the state is far from any "decay-channel threshold"

Blatt-Weisskopf factor (B_L): mom. dependent factor to model "centrifugal barrier" (near threshold, daughters have little relative mom., so high L are suppressed)

ϵ: bare-mass parameter; E: mass measured from "decay-channel" threshold (e.g., $D^0\bar{D}^{*0}$)

In a generator, a resonance is a lineshape "someone" chose



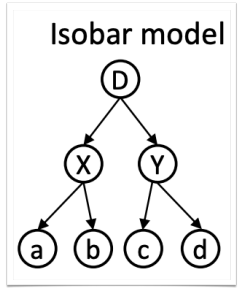
$$BW(m) = \frac{1}{(m_0^2 - m^2 - i m_0 \Gamma(m))}$$

$$\Gamma(m) = \Gamma_0 \left(\frac{q}{q_0} \right)^{2L+1} \frac{m_0}{m} \frac{B_L^2(q)}{B_L^2(q_0)}$$

Our step 4 used the grey curve on the right.

At a threshold the width changes within an MeV. Same peak position, a 12 times narrower core. Part 5 asks: would we notice?

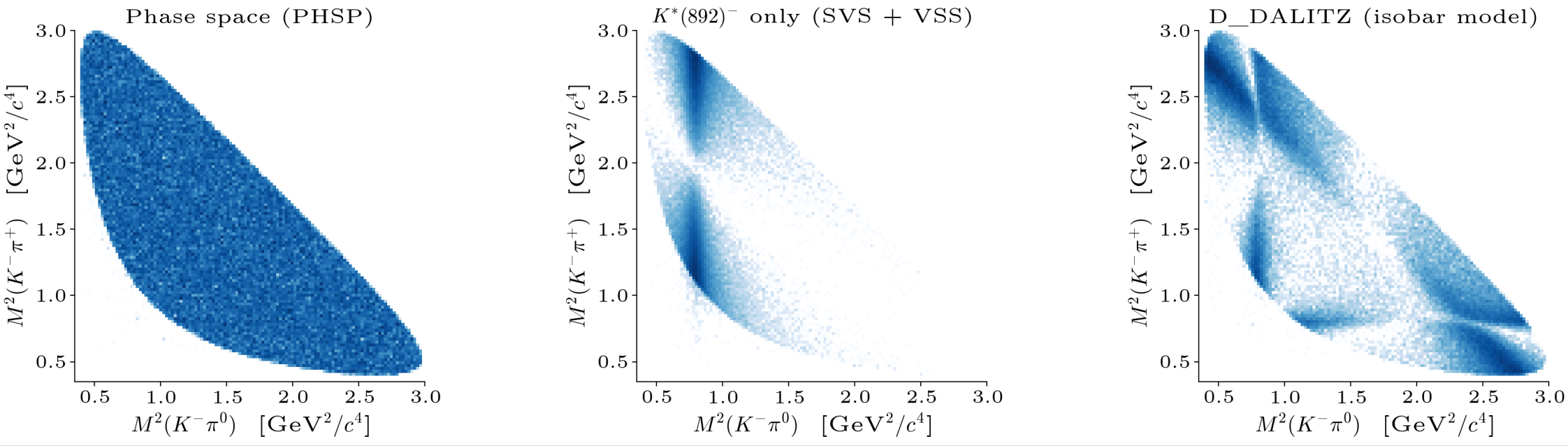
ρ: Blatt–Weisskopf radius 3 GeV^{-1} (illustrative); $X(3872)$ Flatté: parameters of demo C (illustrative, not a fit)



Same decay, three resonance models

Three-body decays add lineshapes with complex coefficients (isobar model): $A = \sum_k c_k \cdot BW_k \cdot (\text{spin factor})_k$

Belle II simulation: EvtGen, generator level, the same $D^0 \to K^-\pi^+\pi^0$ with three models (colour scale: log)



PHSP: uniform. No resonances, no spin.

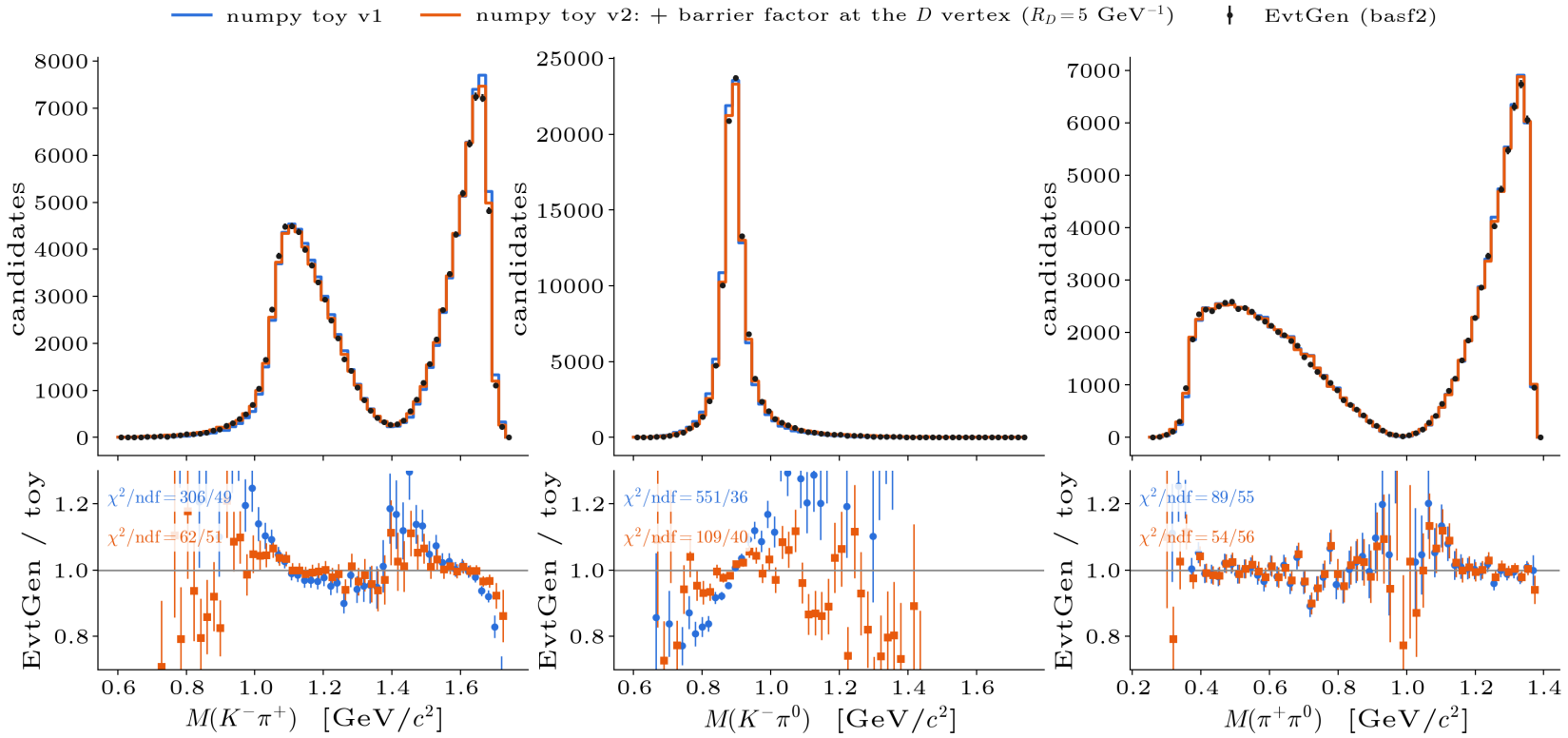
K^{*-} only: one band, with the empty middle of a spin-1 decay ($\cos^2\theta$).

D_DALITZ: $\rho^+, K^{*-}, \bar{K}^{*0}$ bands and their interference.

A selection that cuts on $M(K^-\pi^+)$ has a different efficiency in each panel.

$B^- \to D^0\pi^-$, $D^0 \to K^-\pi^+\pi^0$; **100k events per model, basf2 release-09-00-20 at KEKCC**

Is EvtGen a black box? We rebuilt the K^* model with our two tricks



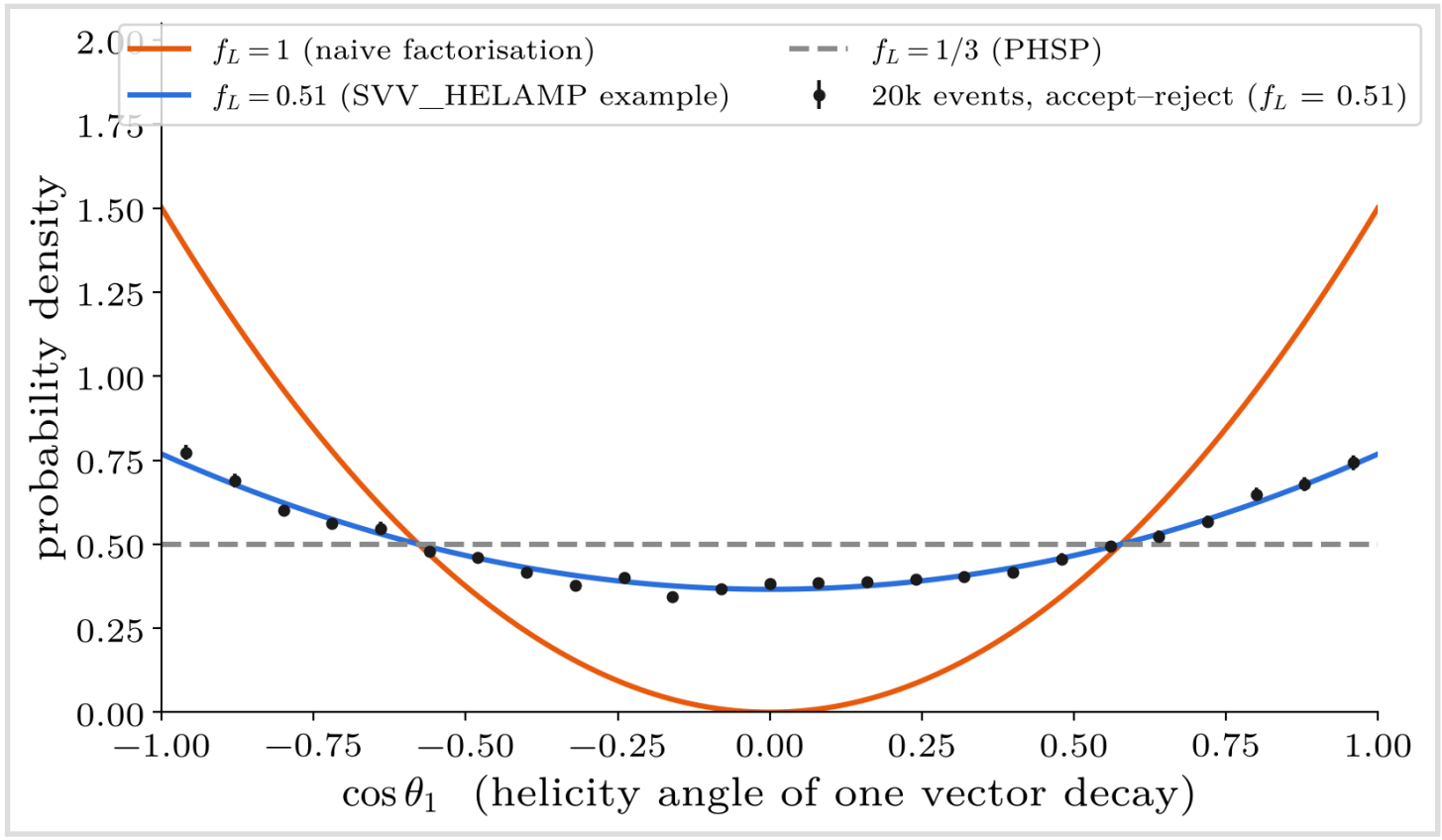
χ^2/ndf	toy v1	toy v2
$M(K^-\pi^+)$	306/49	62/51
$M(K^-\pi^0)$	551/36	109/40
$M(\pi^+\pi^0)$	89/55	54/56

v1: BW × spin factor: close, but not right

v2: adds the Blatt–Weisskopf factor at the D vertex, which EvtGen includes

Small conventions are visible with $\sim 100k$ events

What our toy left out: helicity decides the angles



In steps 5–6 we drew angles isotropically

For B → VV ($B^0 \to K^{*0}\rho^0, \phi K^*$) the angles follow the helicity amplitudes:

$$f_L = \frac{|H_0|^2}{(|H_0|^2 + |H_+|^2 + |H_-|^2)}$$

SVV_HELAMP 0.49 0.0 0.71 0.0 0.49 0.0

EvtGen passes the spin state of each vector to its decay, so both angles come out correlated.

PHSP is flat: it is the choice $f_L = 1/3$. Penguin decays measure ≈ 0.5; naive factorisation says ≈ 1.

SVV_HELAMP values illustrative ($|H_+|$, arg, $|H_0|$, arg, $|H_-|$, arg)

Back to step 4: what if the X(3872) is not a Breit–Wigner?

Generate with a Flatté amplitude $(E = M(J/\psi\pi\pi) - m(D^0) - m(\bar{D}^{*0}))$ **:**

$$A(E) = 1/[E - \epsilon + (i/2)\,(\Gamma_0 + gk_0(E) + gk_+(E))]$$

$k_0, k_+ : D^0\bar{D}^{*0}$ momenta, imaginary below each threshold. The width changes rapidly with E.

model inputs

$\varepsilon = -7.2$ MeV, g = 0.108, $\Gamma_0 = 1.0$ MeV

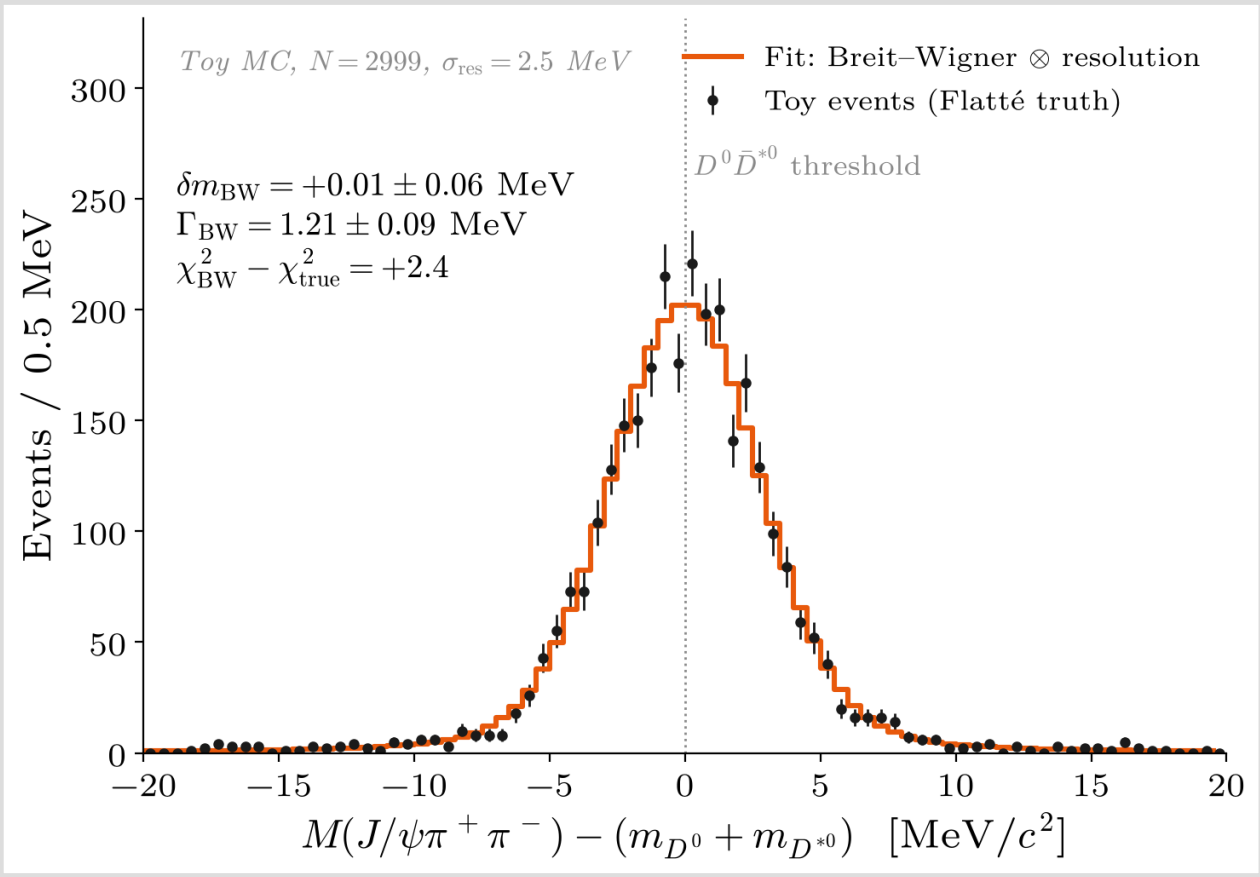
what the lineshape shows

peak at −22 keV, FWHM 99 keV

Then do what many analyses (and DEC files) do: fit a Breit–Wigner ⊗ resolution, with 3000 events and $\sigma = 2.5$ MeV.

Toy, illustrative parameters in the spirit of LHCb, PRD 102 (2020) 092005; not a fit result

Generate Flatté, fit Breit–Wigner: the fit looks fine



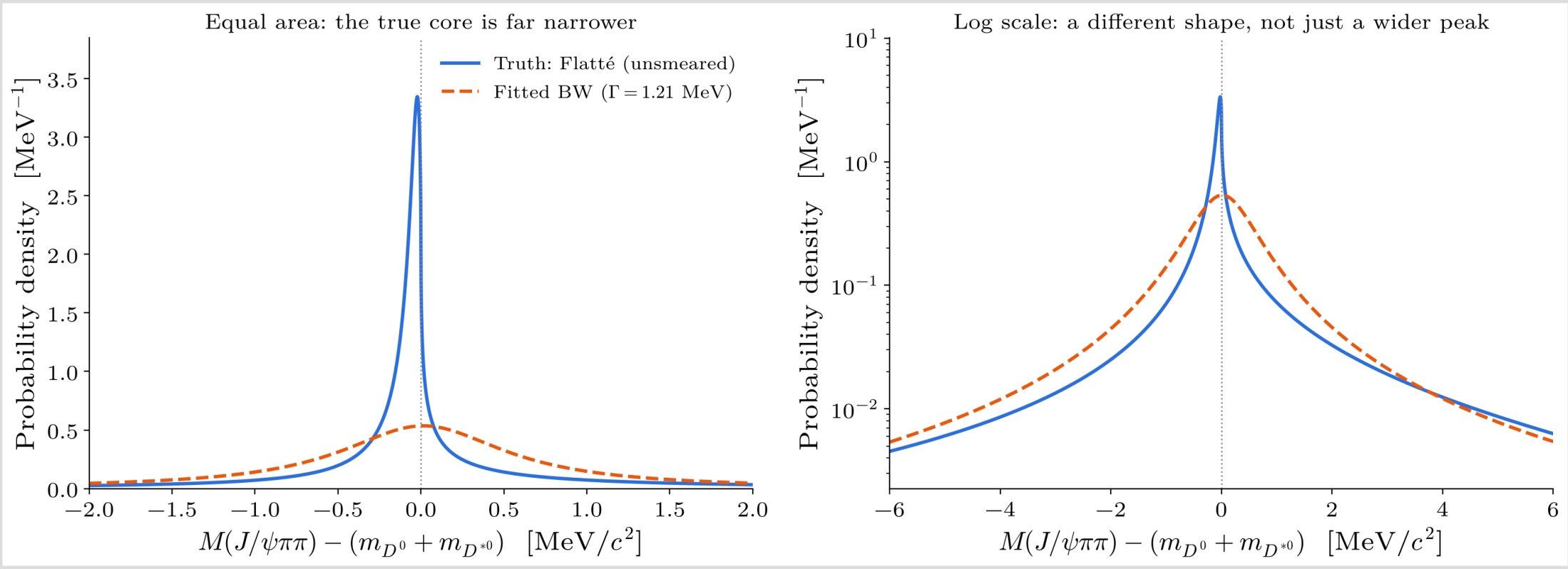
BW mass − threshold	+0.01 ± 0.06 MeV
BW width	1.21 ± 0.09 MeV
χ^2(BW) − χ^2(truth)	+2.4

Over 50 toys, $\Delta\chi^2$ averages +2.9 with a spread of 5.6: fit quality cannot tell the wrong model from the right one.

One could be tempted to write:
"$\Gamma = 1.21 \pm 0.09$ MeV"

Toy MC, N = 2999, Gaussian resolution σ = 2.5 MeV, binned Poisson likelihood fit

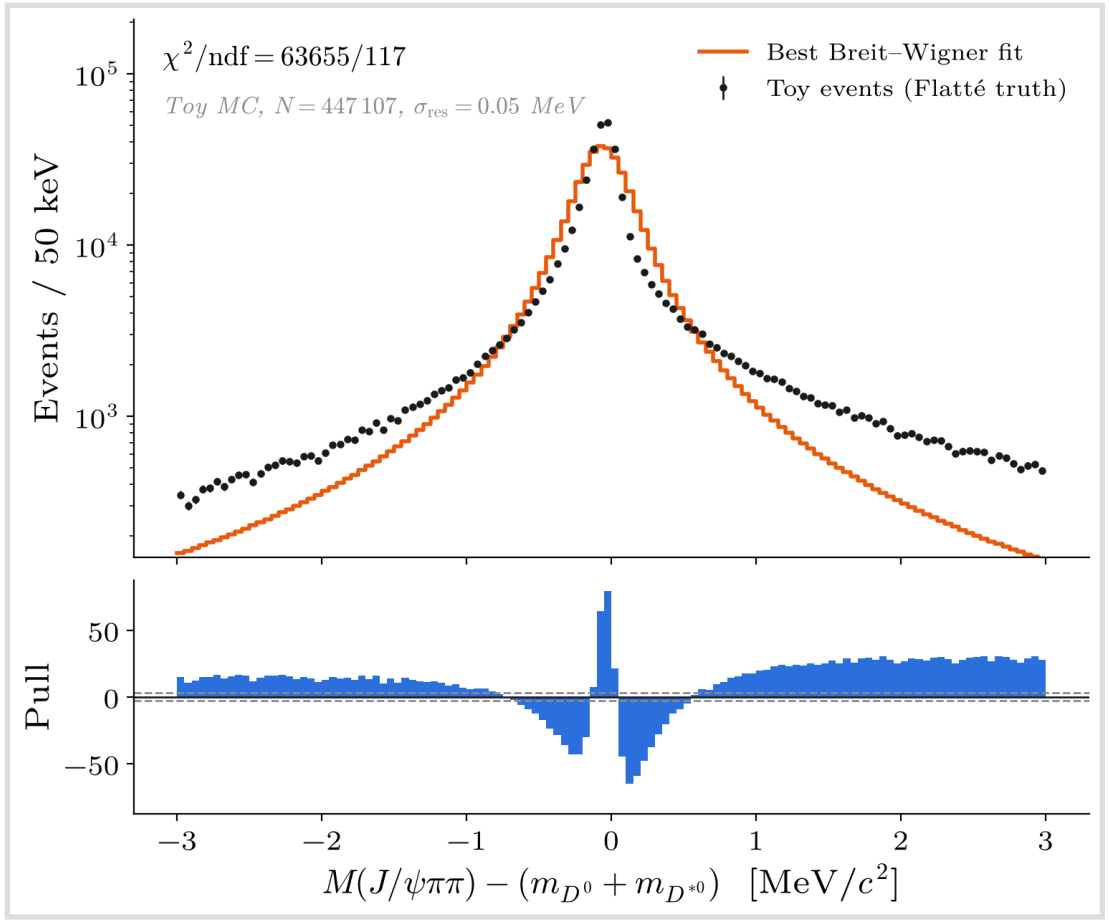
The fitted width is 12 times the true one



The true visible width is 99 keV, 12 times narrower than the fitted 1.21 MeV. The BW width is not just wider, it has a different shape as well (resolution hides the difference)

Both curves normalised to equal area; no resolution

Only perfect resolution reveals the wrong model



	realistic	ideal
events, σ	3k, 2.5 MeV	447k, 0.05 MeV
BW width	1.21 MeV	0.36 MeV
BW mass shift	+0.01 MeV	−0.06 MeV
fit verdict	"good"	$\chi^2/ndf = 63655/117$

The "width" changes from 1.21 to 0.36 MeV with resolution alone.

Our running example in basf2 generated exactly this Breit–Wigner. The wrong model would have passed every fit-quality test.

Ideal: experimentally limited; Toy MC; widths and shifts from BW ⊗ Gaussian fits, mass shift relative to the $D^0\bar{D}^{*0}$ threshold

The same effect in R(D*): excited charm (D**) states

The problem

D^{**} = the four orbitally excited (P-wave) charm mesons. $B \to D^{**}\ell\nu$ feeds down into the $B \to D^{*}\ell\nu$ signal region.

Their branching fractions, form factors and decays are poorly measured, and the sum of exclusive modes does not saturate the inclusive rate (the "semileptonic gap").

What the generator must decide

- form-factor model (e.g. LLSW) and its parameters
- branching fractions of each D** state
- how to fill the gap ($D^{(*)}\pi\pi\ell\nu, \eta$ modes, …)
- D^{**} lineshapes and decay modes

Each choice moves the background shape under the signal. In $R(D^{(*)})$ analyses this is among the leading systematic uncertainties. [arxiv:2609.21947]

LLSW: Leibovich, Ligeti, Stewart, Wise, PRD 57 (1998) 308

What our one event taught us

Random sampling

21 random numbers and two tricks made a complete B event. basf2 uses the same tricks in every program.

part 1 – 2

Tunable parameters

Different (a, b) gave the same multiplicity. Data fix a band of tunes, not a point.

part 3 · Demo B

Physics models

Three models, three Dalitz plots. A wrong $X(3872)$ lineshape fitted with $\Delta\chi^2 = 2.4$ and a width 12 times too large.

parts 4 – 5 · Demos A, C

> So how do we know the peak is a state? When its mass, width and yield do not move as we change the model and the parameters the generator was built on.

To read further

Belle II Physics Book: E. Kou et al., PTEP 2019, 123C01

EvtGen: D. J. Lange, NIM A 462 (2001) 152

KKMC: S. Jadach, B. F. L. Ward, Z. Wąs, CPC 130 (2000) 260

TAUOLA: S. Jadach et al., CPC 76 (1993) 361

BabaYaga@NLO: G. Balossini et al., NPB 758 (2006) 227

TREPS: S. Uehara, KEK Report 96-11 (1996)

$X(3872)$ discovery: Belle, S.-K. Choi et al., PRL 91 (2003) 262001

D^{**} form factors (LLSW): A. Leibovich et al., PRD 57 (1998) 308

basf2: T. Kuhr et al., Comput. Softw. Big Sci. 3 (2019) 1

PYTHIA 8.2: T. Sjöstrand et al., CPC 191 (2015) 159

PHOTOS: E. Barberio, Z. Wąs, CPC 79 (1994) 291

PHOKHARA: G. Rodrigo, H. Czyż, J. H. Kühn, M. Szopa, EPJC 24 (2002) 71

AAFH: F. A. Berends, P. H. Daverveldt, R. Kleiss, NPB 253 (1985) 441

Tuning (Professor): A. Buckley et al., EPJC 65 (2010) 331

$X(3872)$ lineshape: LHCb, PRD 102 (2020) 092005

MC methods: PDG Review, “Monte Carlo techniques”

Assistance from AI tools *(ChatGPT, Claude, and DeepSeek)* were sought for code executions

Thank you

A generator = random sampling + physics models + tunable parameters. Every Belle II result inherits all three.

To receive generator related updates, contribute, or attend to meetings, please subscribe to:

Generators group mailing list: software-generators@belle2.org

For any generator-related queries, please write to us:

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$R(D^{(*)})$ systematics, arXiv: 2609.21947

Table I. Summary of the relative uncertainties on $R(D^{(*)})$ and their correlation coefficients (ρ). The description of each systematic source is provided in the text.

Source	$R(D^*)$	$R(D)$	ρ
Simulation sample size	4.8%	8.4%	−0.44
Gap-mode branching fractions	2.7%	3.1%	0.00
$\bar{B} \to D^{**}\tau^-/(\ell^-)\bar{\nu}$ branching fractions	0.3%	1.3%	0.25
Hadronic B decay branching fractions	1.6%	1.5%	−0.26
Form factors	0.5%	0.9%	−0.70
Misreconstructed $D^{(*)}$ candidates	0.5%	1.2%	0.00
Continuum background	2.4%	2.1%	0.93
Fit biases	0.3%	1.2%	0.00
Low-momentum π^0 and γ efficiencies	2.2%	2.4%	0.99
B-tagging efficiency	0.9%	2.5%	−1.00
Other efficiency corrections	0.7%	1.4%	0.92
M^2_{miss} resolution	0.5%	0.8%	0.48
Total systematic uncertainty	6.7%	10.3%	−0.20
Statistical uncertainty	7.9%	12.5%	−0.40