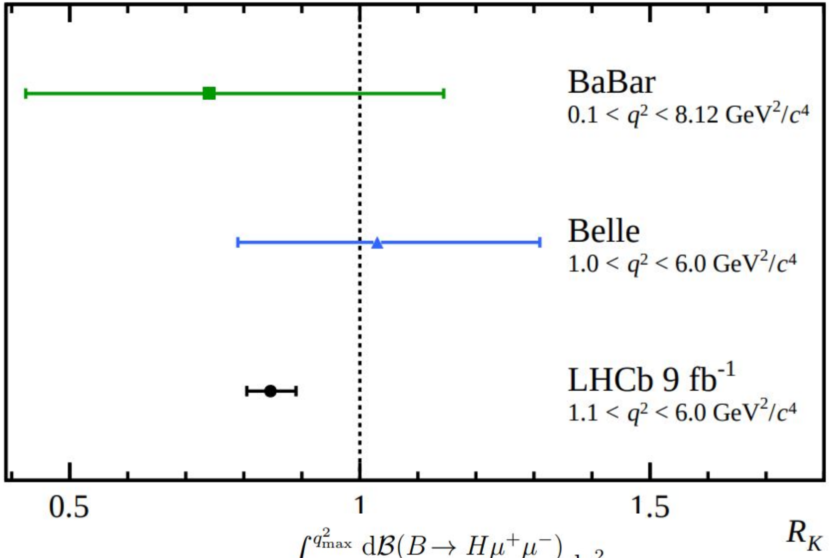
Search for B->K nunu at Belle II

S. Glazov, Liverpool 12/05/21

arxiv:2104.12624

FCNC and b->sll anomalies

arXiv:2103.11769



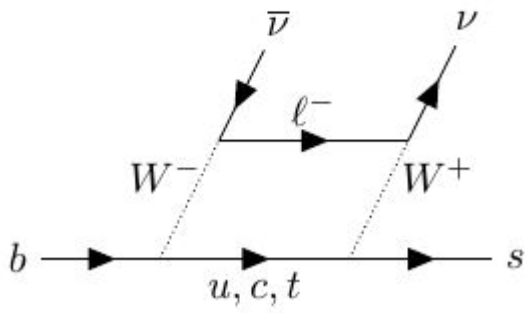
$$R_H \equiv \frac{\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{\mathrm{d}\mathcal{B}(B\to H\mu^+\mu^-)}{\mathrm{d}q^2}\mathrm{d}q^2}{\int_{q^2_{\rm min}}^{q^2_{\rm max}} \frac{\mathrm{d}\mathcal{B}(B\to He^+e^-)}{\mathrm{d}q^2}\mathrm{d}q^2} .$$

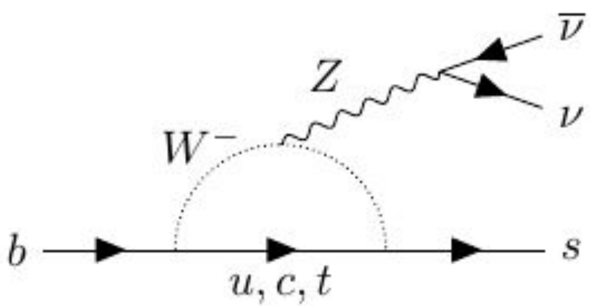
FCNC transitions are forbidden in SM at tree level by GIM mechanism. Appearing at loop level, the transitions are sensitive to NP effects.

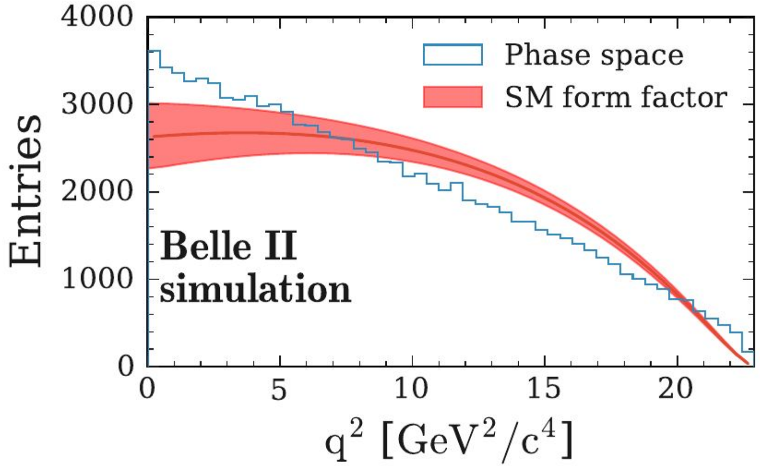
A number of anomalies observed for B->K^(*) ll transitions, including recent R_K measurement. Important to study similar B->K^(*) nunu processes.

B+-> K+ nunu: SM theory

arXiv:1608.02556





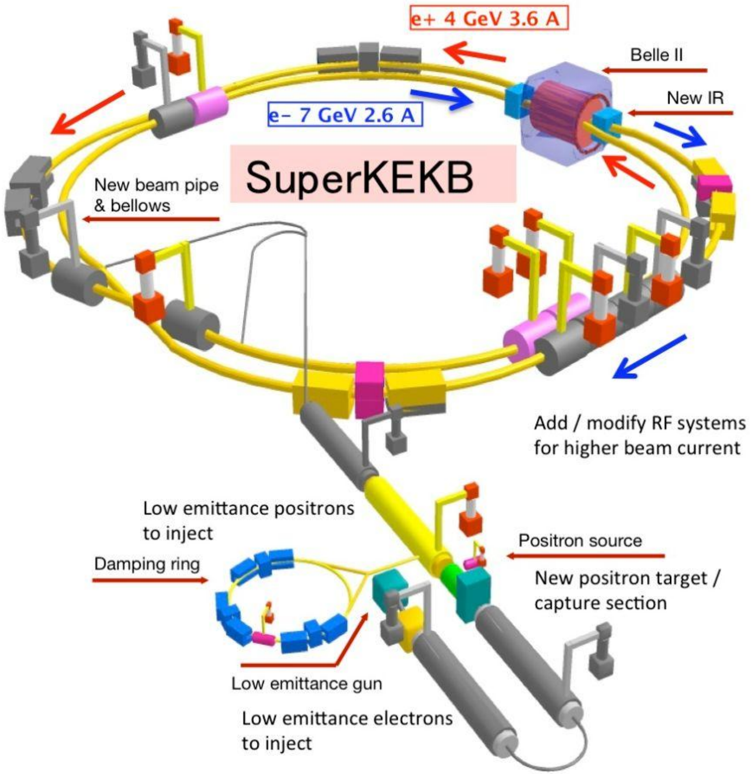


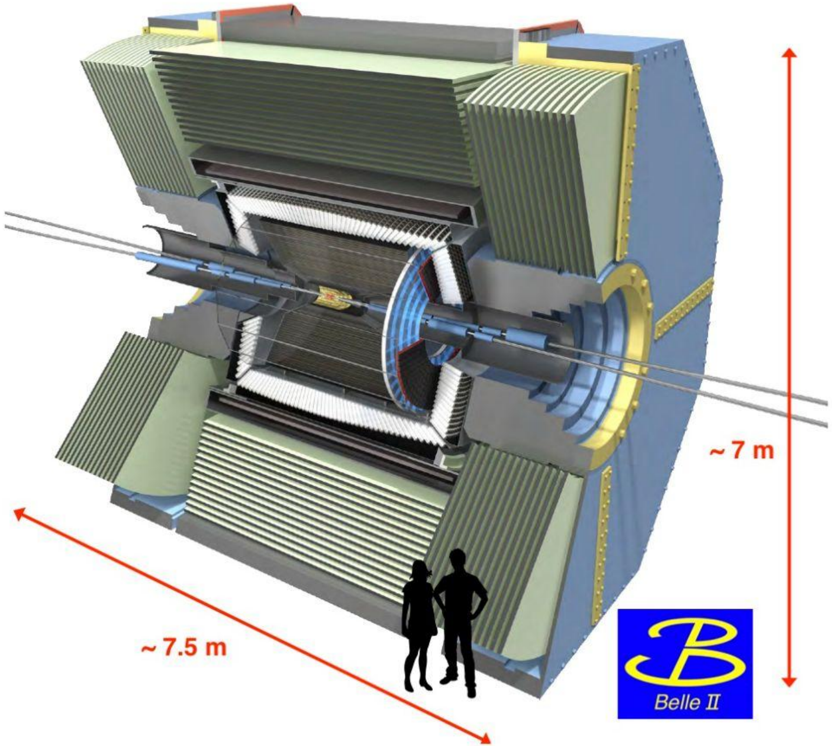
$$\frac{d\mathrm{BR}(B^+ \to K^+ \nu \bar{\nu})}{dq^2} = \tau_{B^+} 3 |N|^2 \frac{X_t^2}{s_w^4} \rho_K(q^2)$$

$$N = V_{tb} V_{ts}^* \frac{G_F \alpha}{16\pi^2} \sqrt{\frac{m_B}{3\pi}}$$

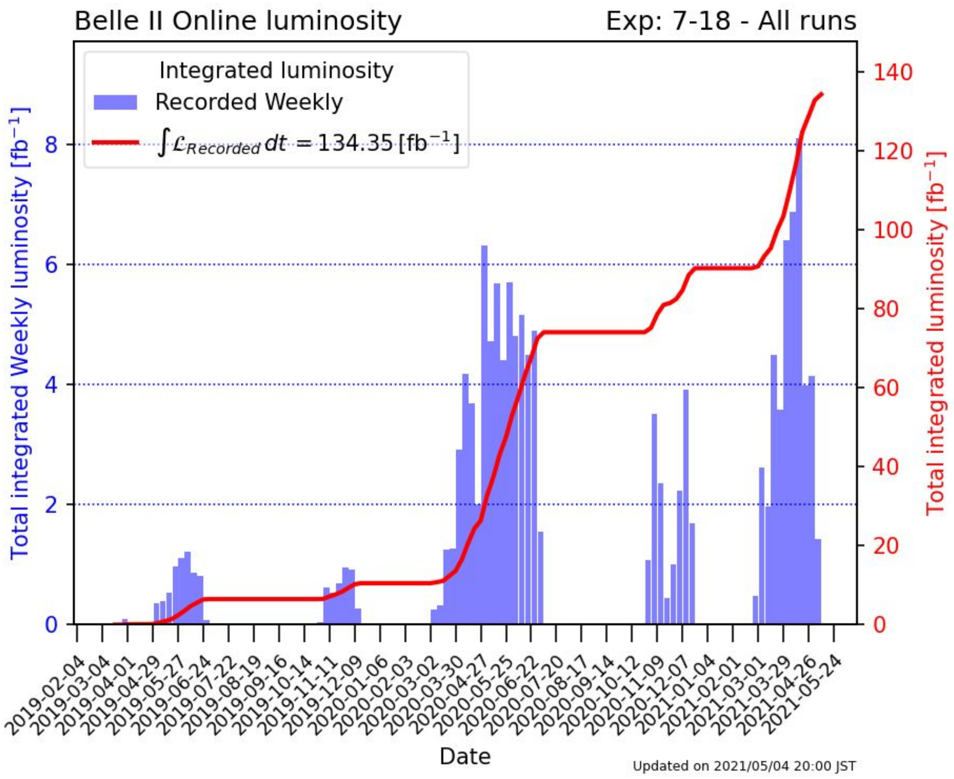
$$\mathrm{BR}_{\mathrm{SM}} = (4.6 \pm 0.5) \times 10^{-6}$$

SuperKEKB and Belle II





Luminosity and data sample

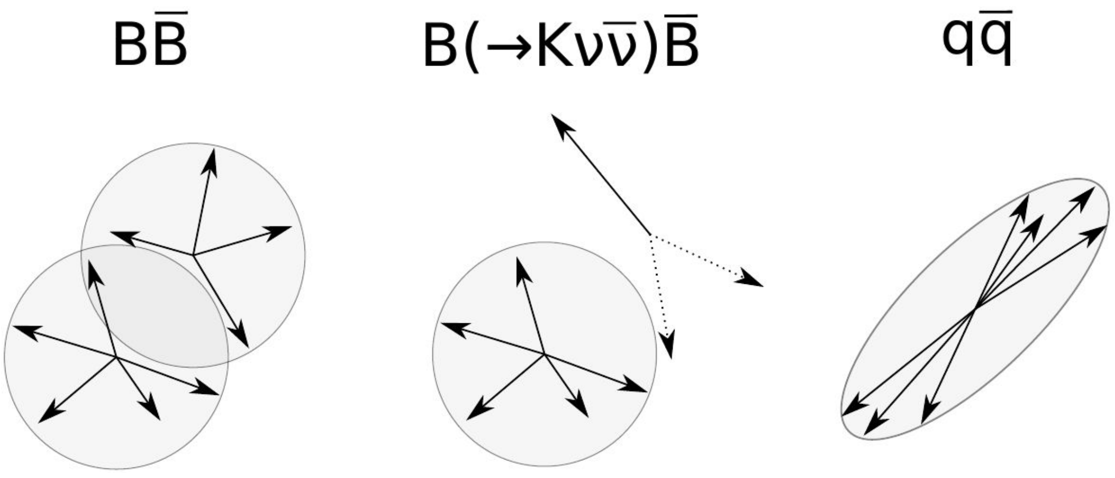


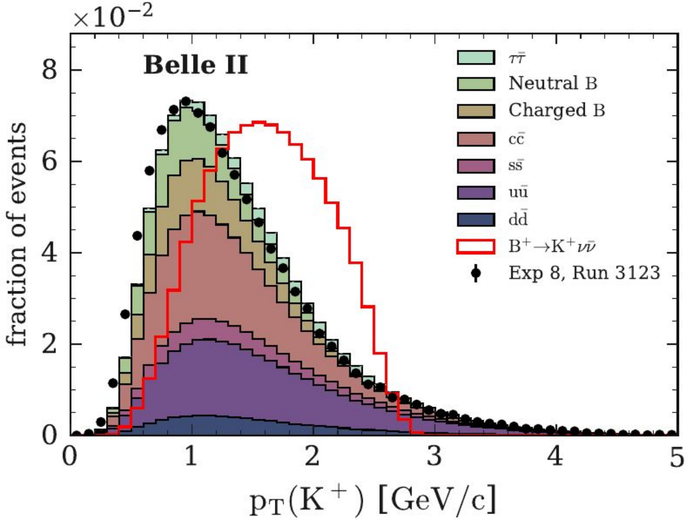
Phase III data

- As we speak, Belle II continues data taking
- World record luminosity achieved last year
- Difficulties with dynamic aperture and high background levels

Data used for the analysis were collected in 2019-2020 (summer), corresponds to 63fb-1 at Y(4S) (68 mln BB events) and 9 fb-1 at 50 MeV below Y(4S).

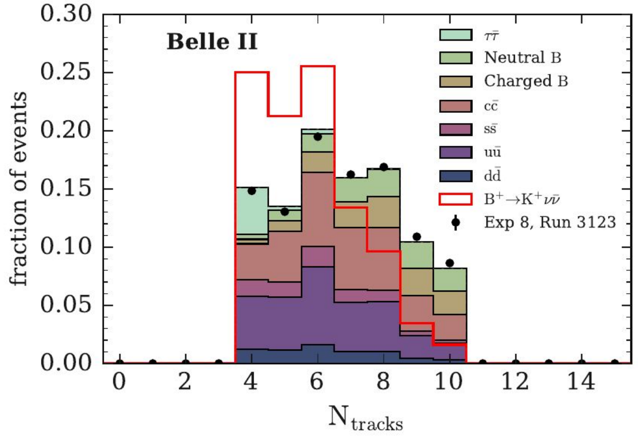
Inclusive tagging method

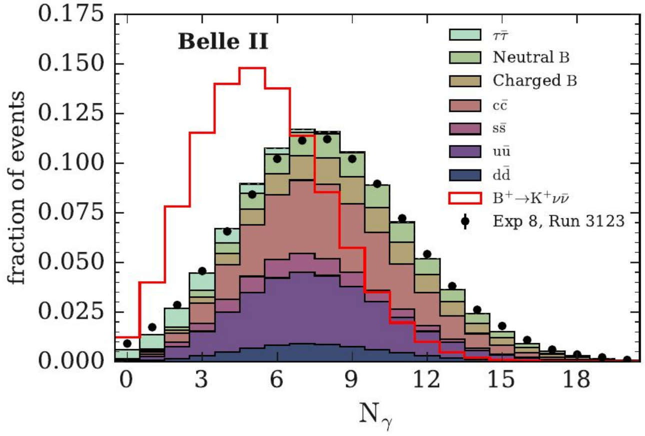




- Standard approaches: first find companion B (“tag”), next reconstruct the signal. Suffers from low efficiency (max 0.2% for semileptonic tag)
- Inclusive tag: start with the signal decay. Highest pT track gives correct candidate in 78% cases. Use event properties to suppress backgrounds.

Object definition and basic selection





$p_{t,\mathrm{track}} > 100\mathrm{MeV},\ \ d_r < 0.5\mathrm{cm},\ \ |d_z| < 3\mathrm{cm}$

$E_\gamma > 100\mathrm{MeV}$

$E < 5.5\mathrm{GeV}$

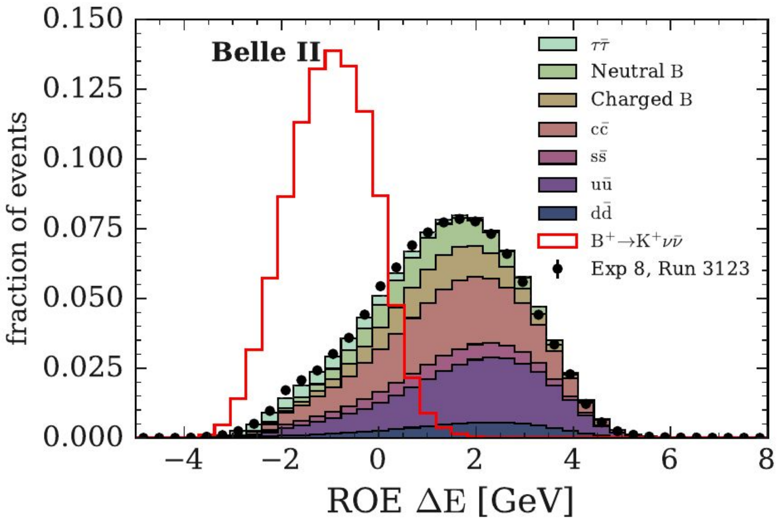
$4 \leq N_{\mathrm{track}} \leq 10$

$E_{\mathrm{visible}} > 4\mathrm{GeV}$

$17^\circ < \theta_{\mathrm{miss}} < 160^\circ$

Object reconstruction is designed to be simple and beam background resistant. Selection on visible energy and missing momentum direction removes gamma-gamma background, ensure detector efficiency.

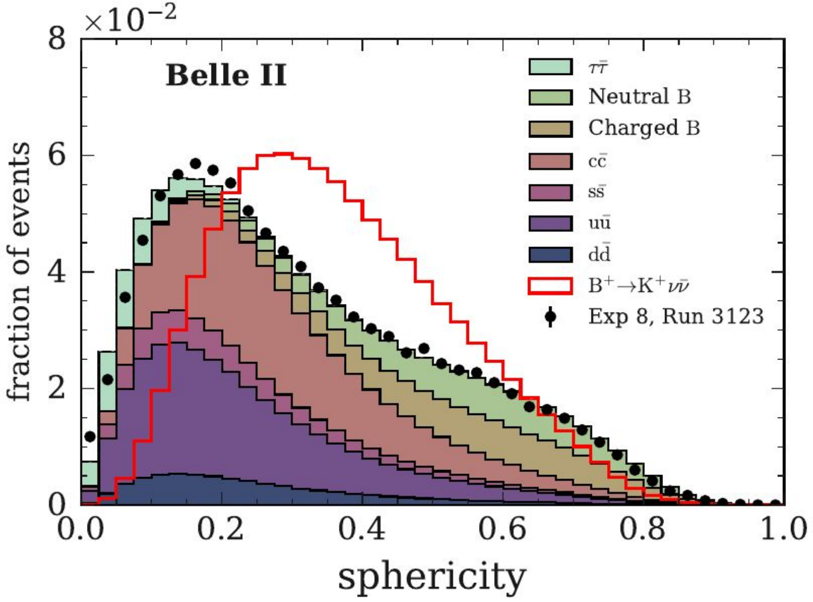
Input variables: Rest Of Event properties

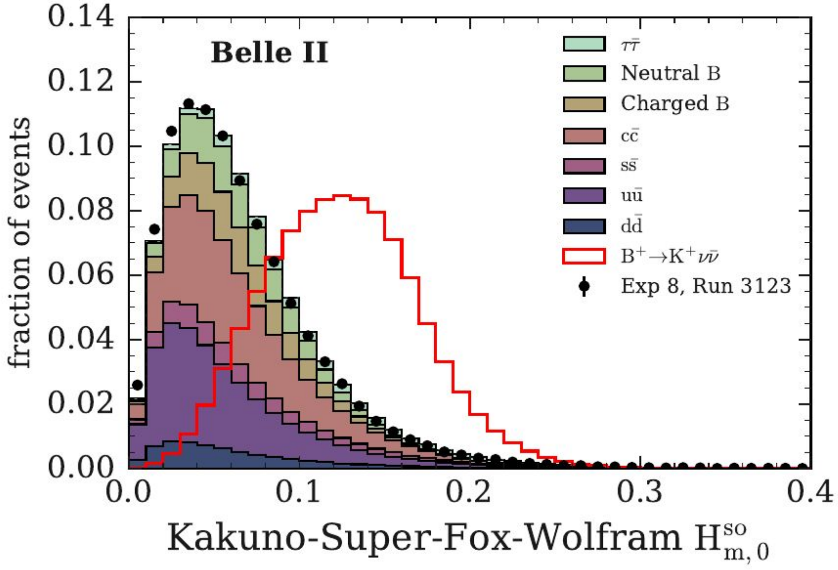


$$\Delta E = E_B^* - \sqrt{s}/2$$

The key idea of the inclusive tagging approach is that for most of background events ROE consists of wrong "too large" combination of charged tracks/photons while for the signal some objects can be missing.

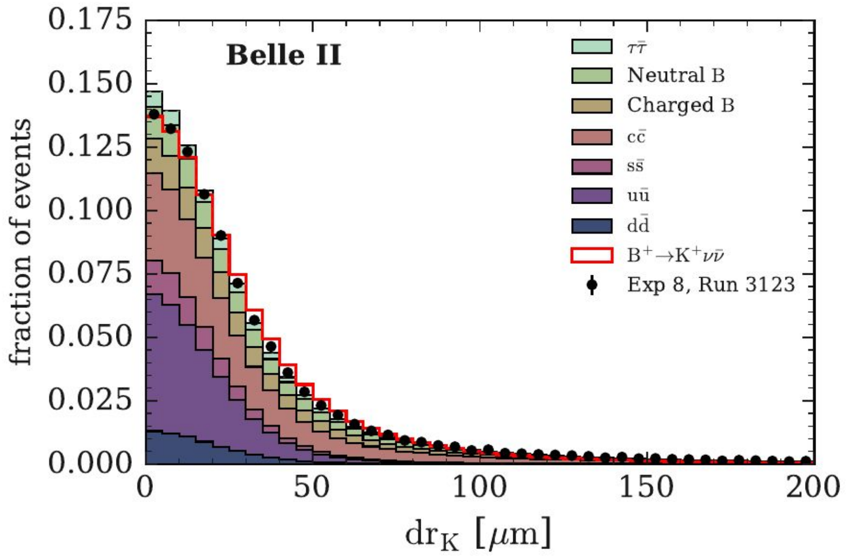
Input variables: event properties

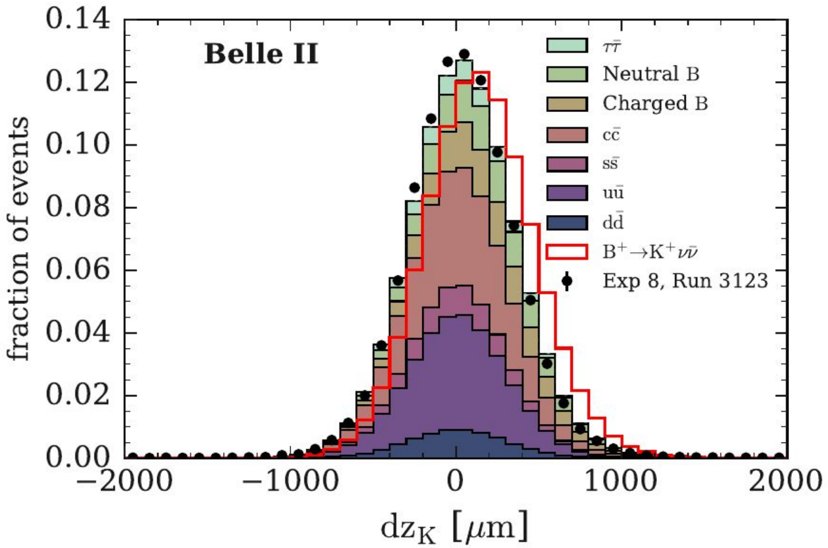




As expected, sphericity of the signal events is in between continuum and BBbar background. Events also have large missing momentum.

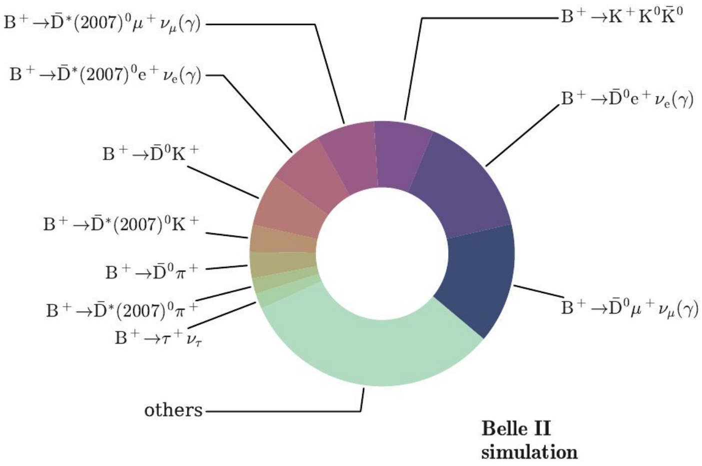
Input variables: vertex information

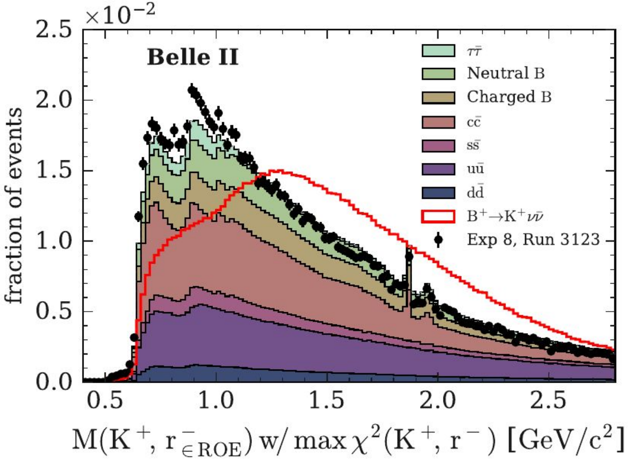




Kaon track vs beam spot variables provide additional discriminating power, orthogonal to energy/momentum variables.

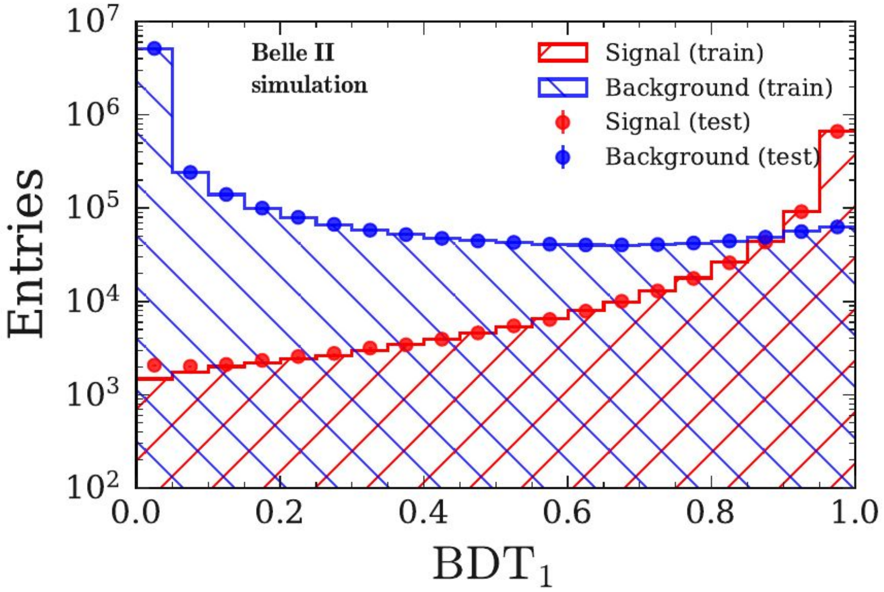
Input variables: D0/D+ decay suppression

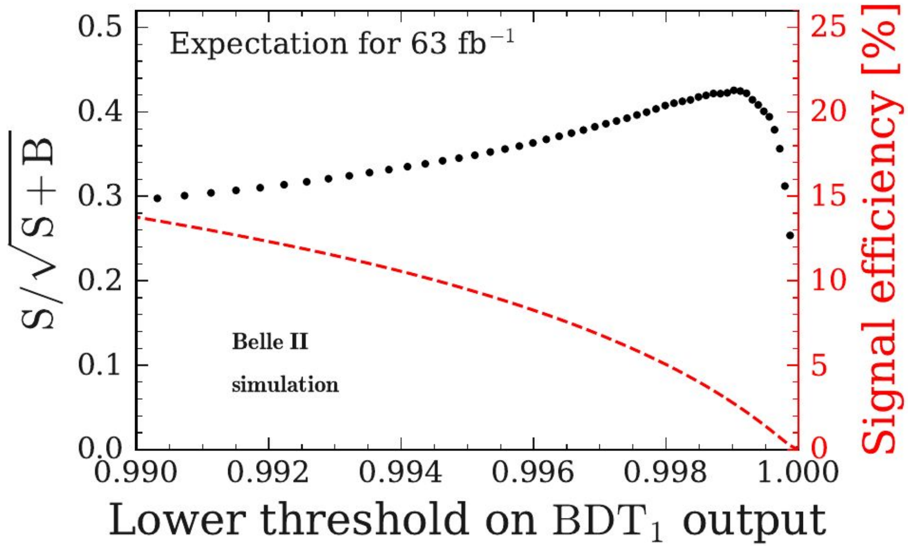




Significant fraction of background events for the high purity region comes from D0/D+ decays. Dedicated variables to identify them.

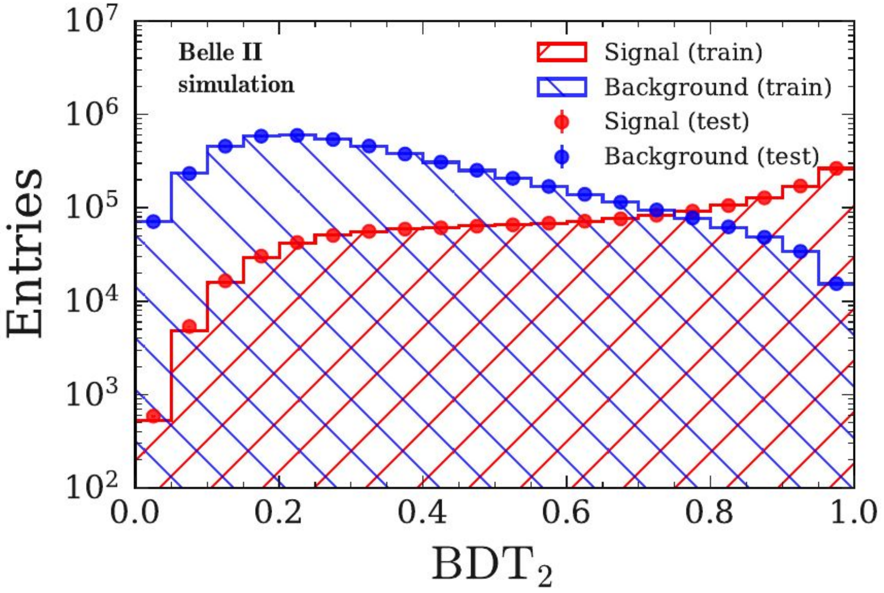
Boosted Decision Tree classifier

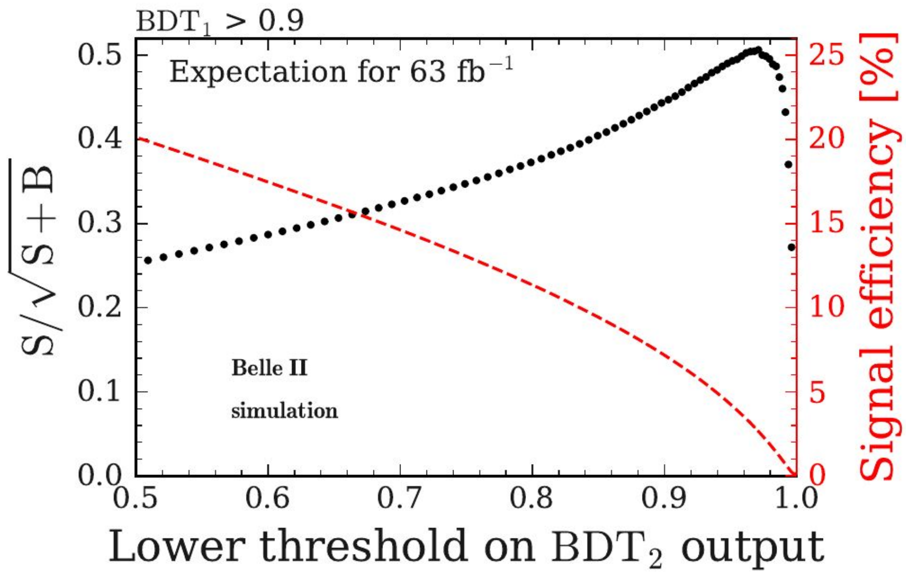




Test close to 100, use 51 variables, which are well described and improve discrimination. Optimize BDT structure, avoid overfitting.

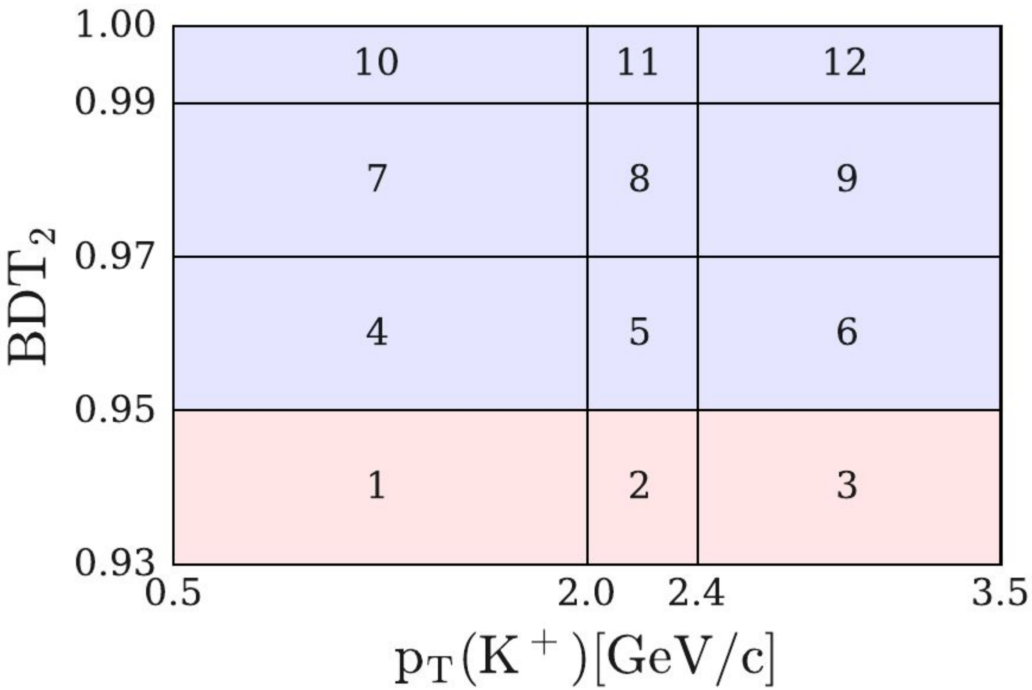
Boosting BDT in high purity region





Increase statistics of training for BDT1>0.9 region. Use 100 fb-1 of background MC. Significant improvement in discrimination.

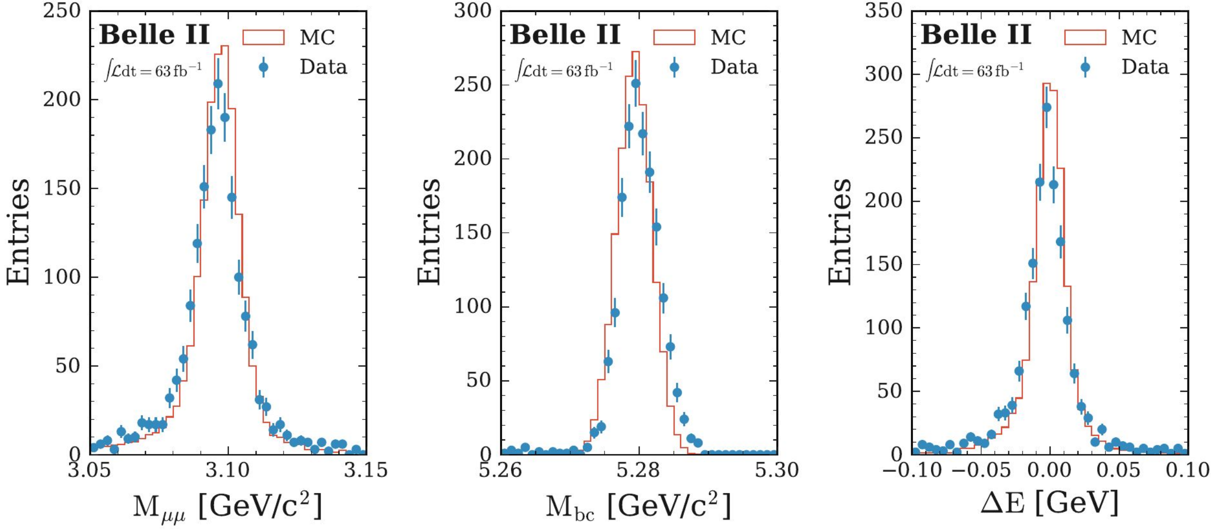
Definition of the signal region



Binned likelihood signal extraction: background shapes simulated by MC.

2D fit in twelve bins of PtK and BDT2 output, plus same twelve bins using 9fb-1 off-resonance data.

Validation channel: selection

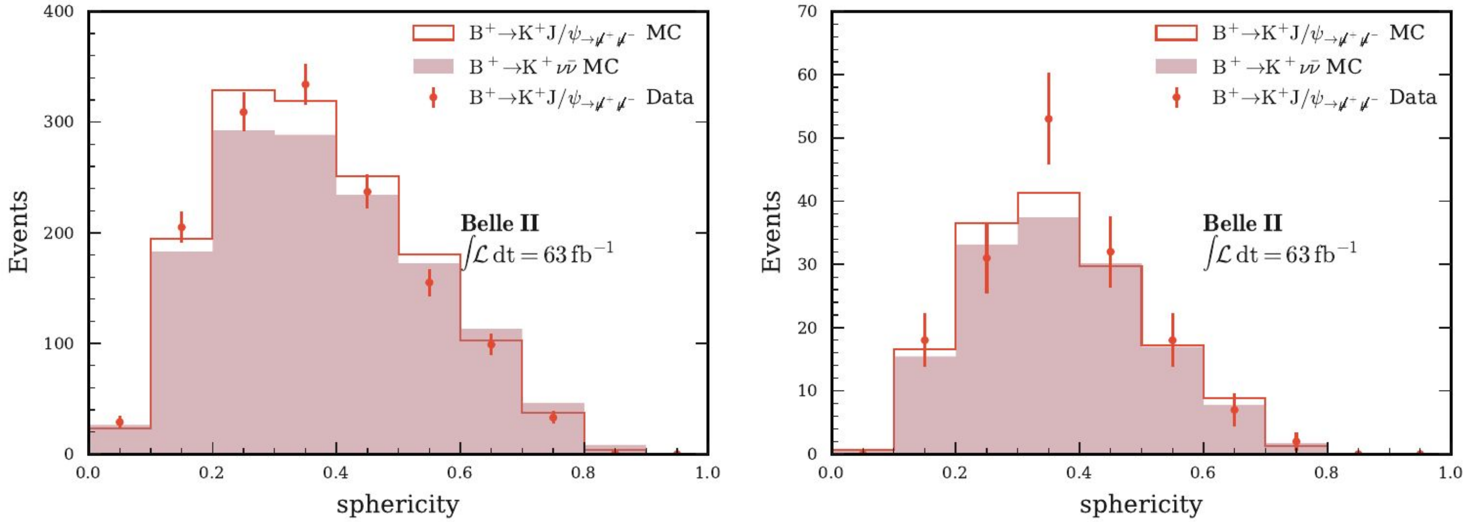


$$M_{bc} = \sqrt{s/4 - {p_B^*}^2}$$

$$\Delta E = E_B^* - \sqrt{s}/2$$

Select pure sample of B -> J/psi (mu+mu-) K+ decays for classifier validation for signal-like events. Remove muon tracks, modify kaon kinematics.

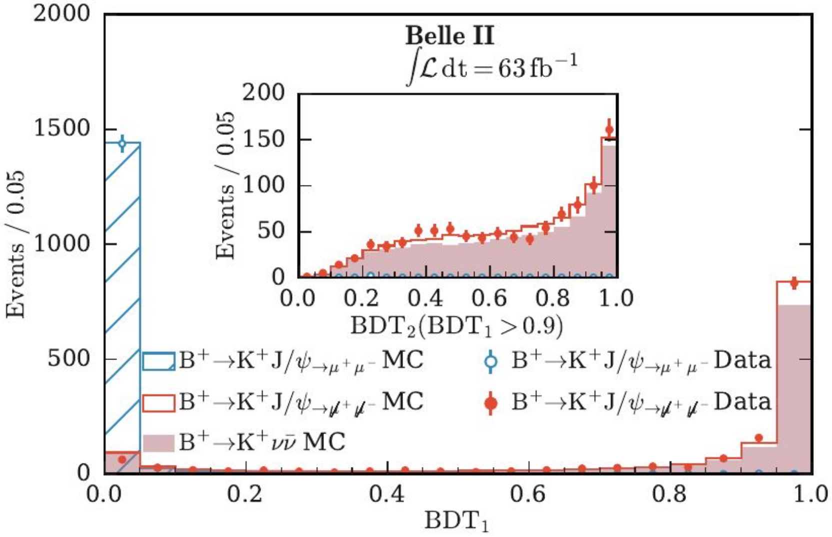
Validation channel: input variables



The modified J/psi K+ MC events look very similar to signal MC.

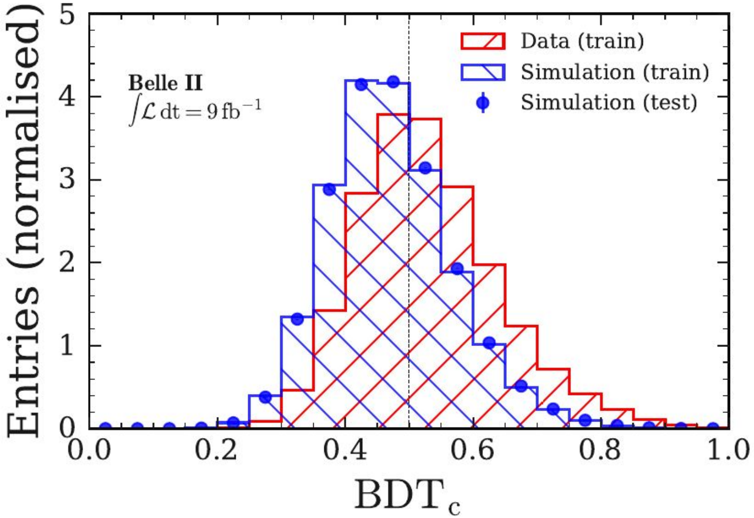
Good data to MC agreement for BDT input variables before/after cuts.

Validation channel: classifier validation



Very good agreement between data and MC for B+⟶ J/psi K+ before and after muon removal. The selection efficiency ratio between data and MC for the signal region is 1.06+-0.10

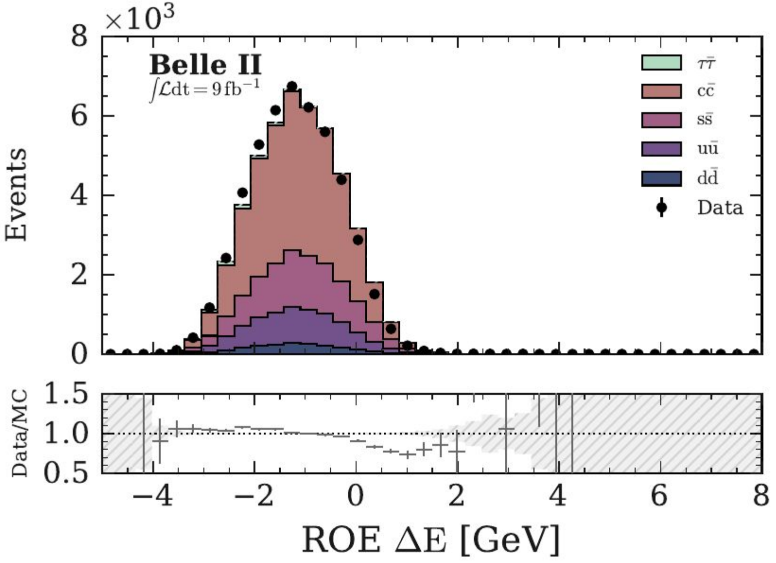
Off-resonance data tuning

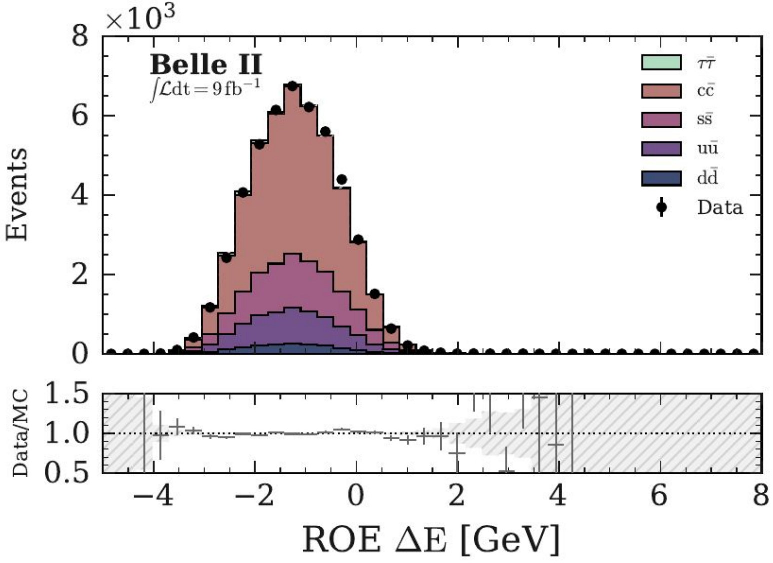


Control channel for continuum background: 9 fb-1 of off-resonance data.

Train the same BDT to distinguish between Data and MC. For perfect MC, distributions should look the same and peak at 0.5

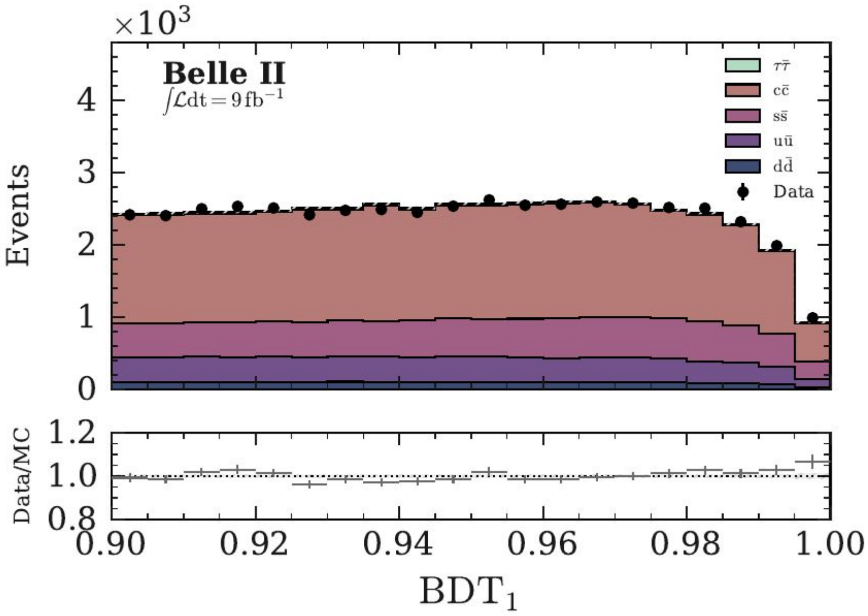
Off-resonance data checks

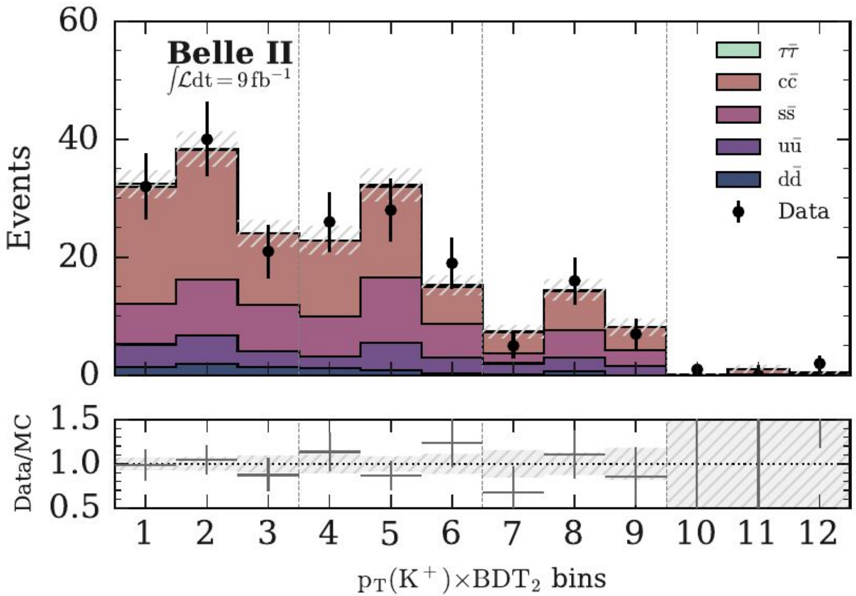




Apply weights based on BDTc output. Significant improvement for shapes of distributions of all input variables.

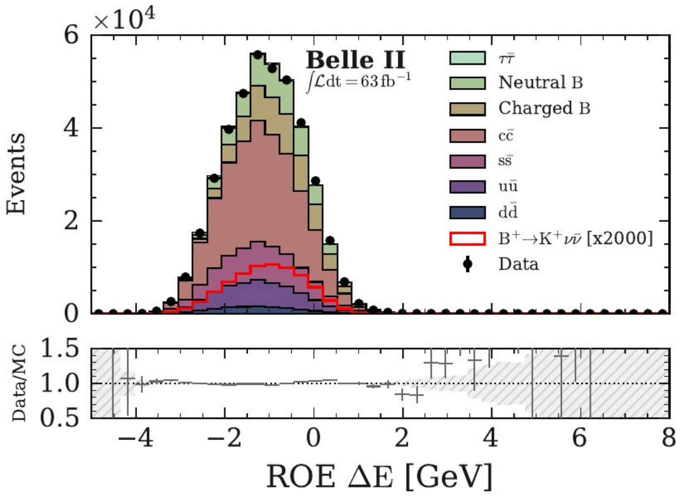
Off-resonance data checks

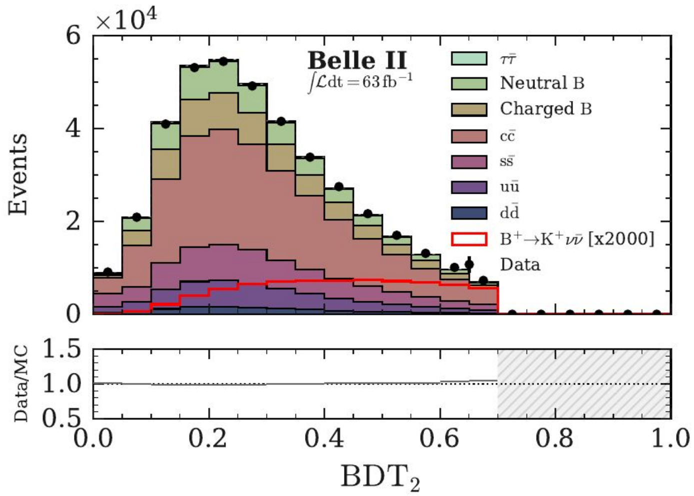




While shapes are improved, there is a remaining normalisation problem. For the signal region, data/MC normalisation is 40+-12%. Use 50% systematics for each background source.

Y(4S) sideband region



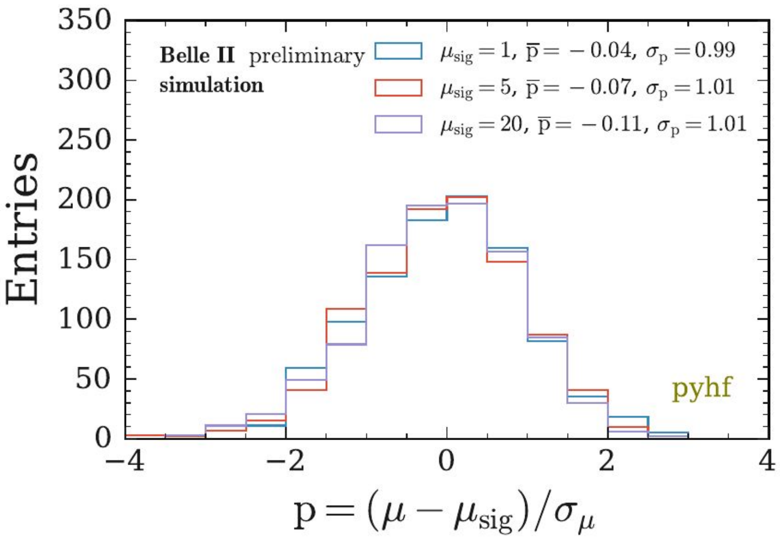


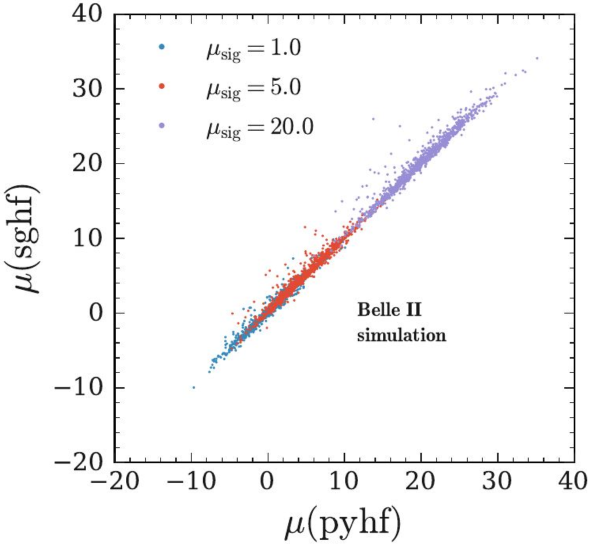
Check background description for 0.9<BDT1<0.99 and BDT2<0.7 sideband region. Scale continuum background using findings from off-resonance data. Good agreement for shape and normalisation.

Fitting setup

- Binned profiled likelihood fit using pyhf ("python histfactory") with scipy backend.
- Extensive validation using various tools, including sghf ("simplified Gaussian histfactory")
- Fit model includes 175 nuisance parameters for systematic uncertainties (most of them for MC stats)
- Main systematic sources are normalisations for all background components (50% each)
- Other sources include tracking efficiency, neutral energy scale (EM and HAD), PID, leading background branching fractions, signal form factor.

Fitting validation

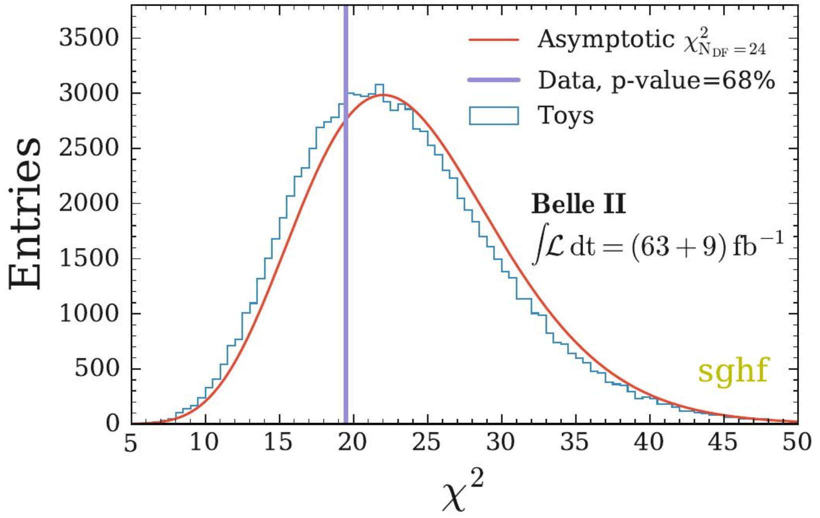


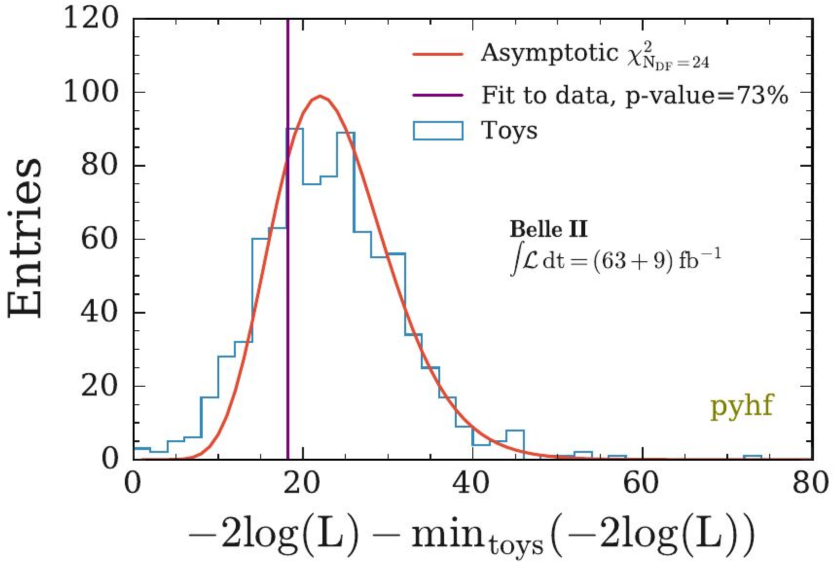


Signal injection studies with signal strength mu = 1 (SM expectation), 5 and 20.

Good agreement between pyhf and sghf fit results.

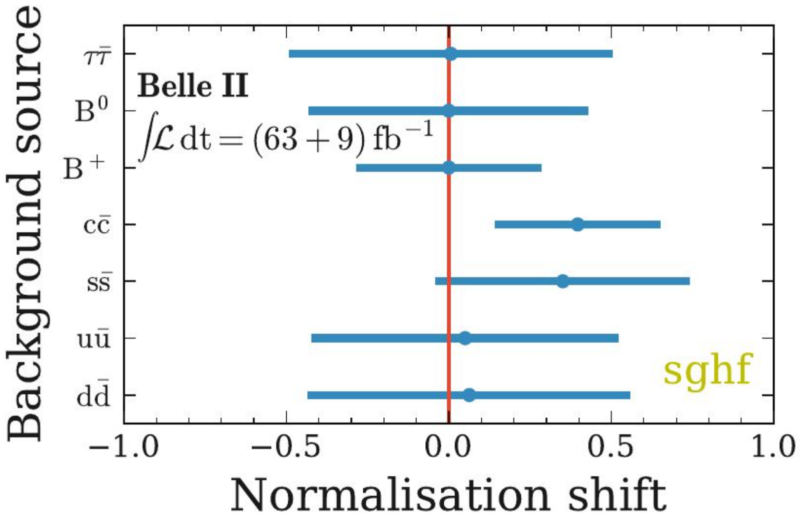
Data / fit compatibility

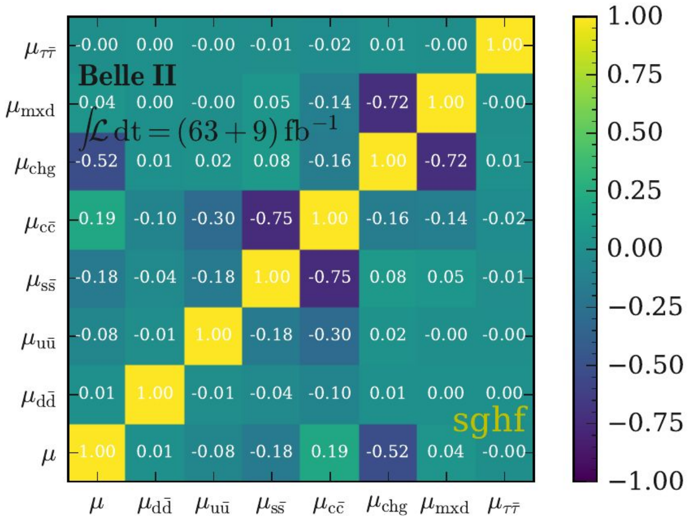




Use toy experiments to get expected fit quality. For both sghf and pyhf, toys show close to asymptotic chi2 distribution. Excellent data to model compatibility (first step before box opening).

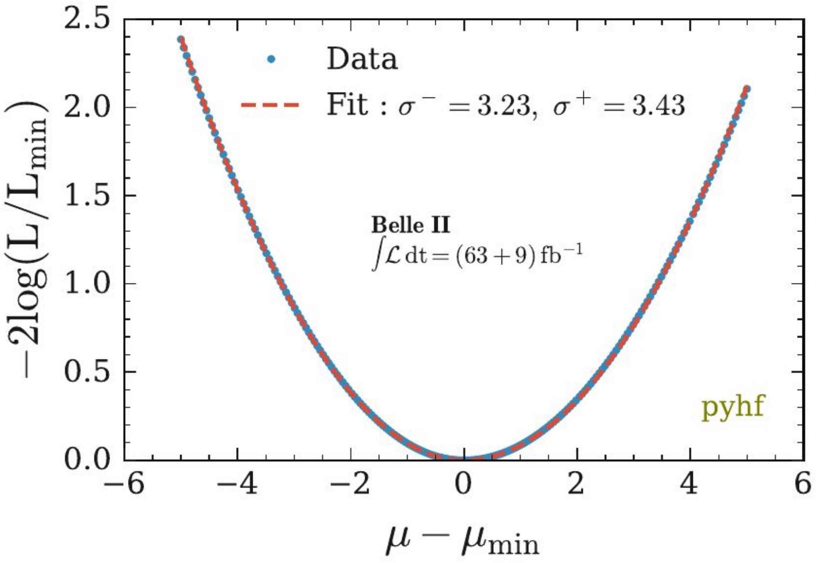
Shifts of background sources





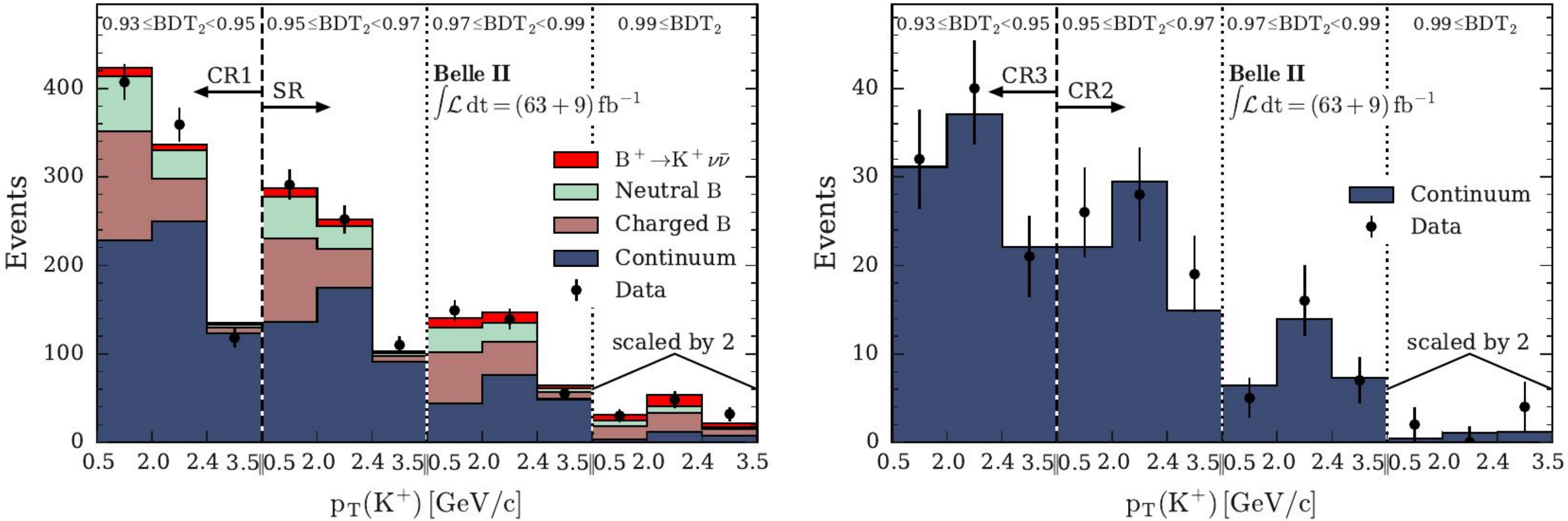
Shifts of the systematic nuisance parameters are investigated next. As expected, large 1 sigma shifts for continuum sources. No shifts for B+ and B0 backgrounds.

Final tests before box opening (scan)



Total uncertainty from profiled likelihood scan around the minimum, fitted by one sided parabola (small asymmetry observed). Statistical component is determined using toy experiments (full fit, stat. only fluctuations).

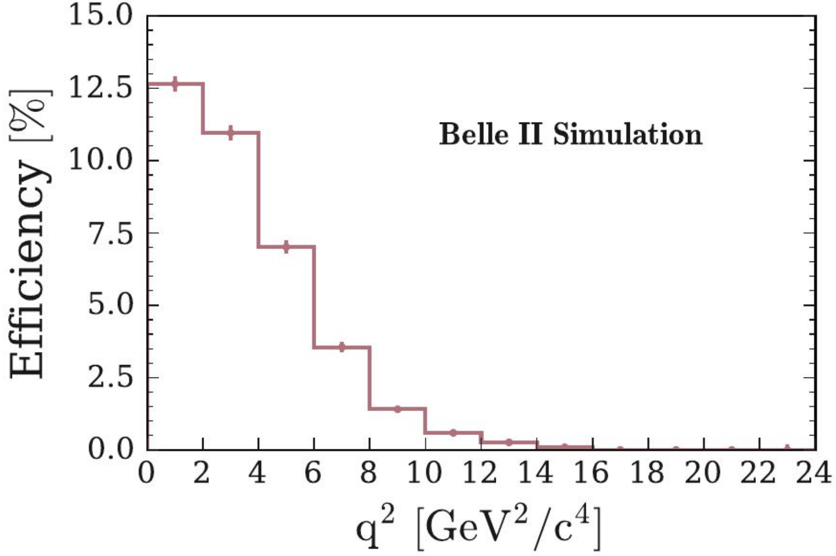
Signal strength mu

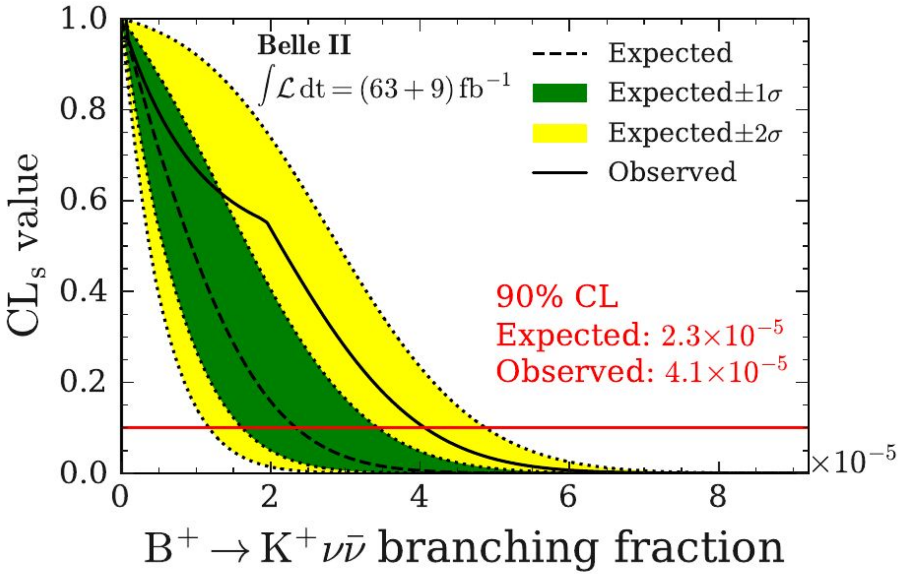


The measured signal strength is $\mu = 4.2^{+2.9}_{-2.8}(\mathrm{stat})^{+1.8}_{-1.6}(\mathrm{syst}) = 4.2^{+3.4}_{-3.2}$

The signal purity is 6% for SR and 22% for BDT2 > 0.99 region

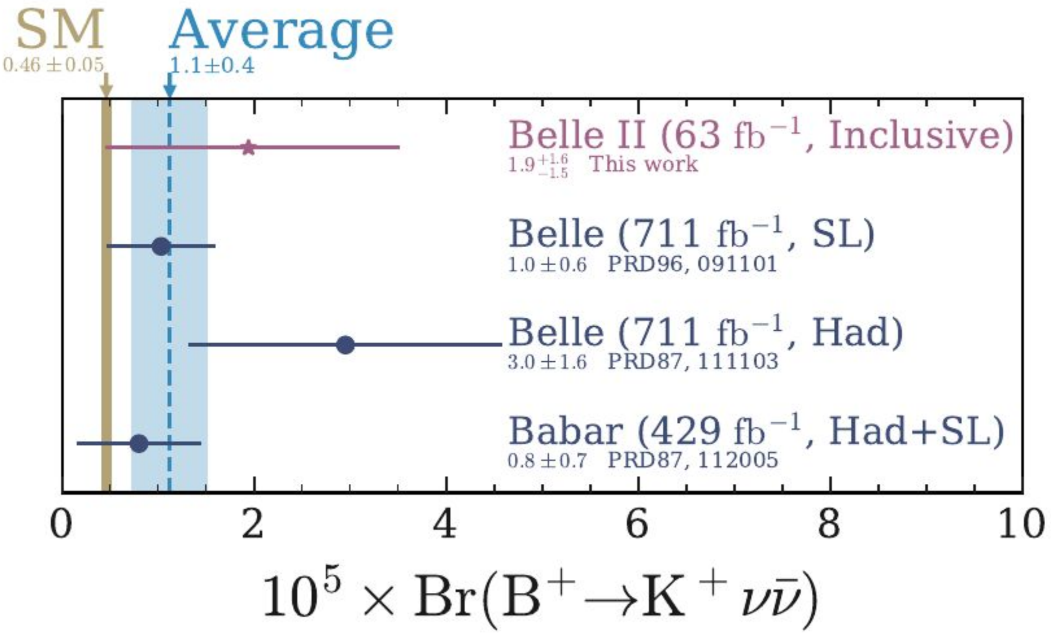
Upper limit





Since BR is consistent with zero, an upper limit on the process is determined using CLs method. When integrated with SM q^2 spectrum, signal efficiency is 4.3%

Comparison to previous measurements



The measurement of the signal strength can be converted to the branching fraction and compared with previous results.

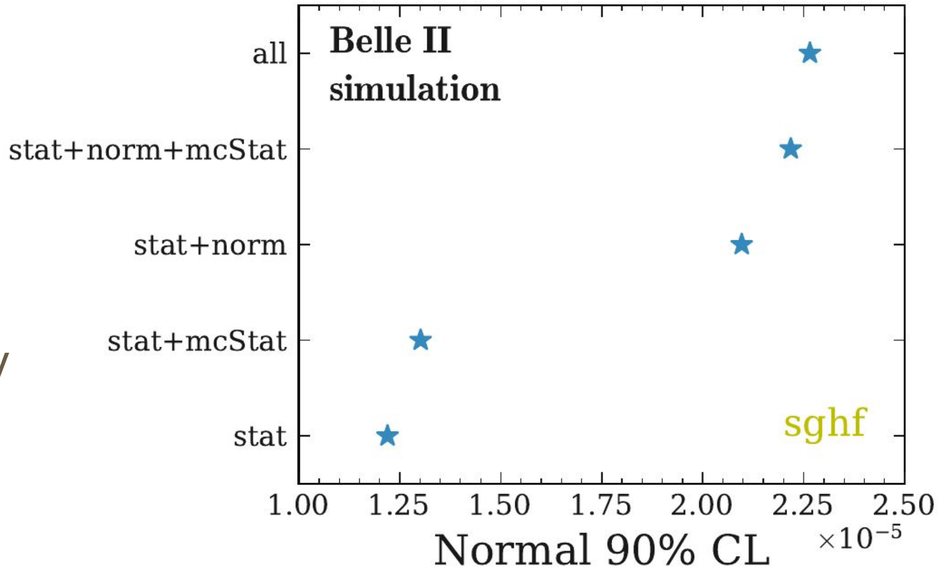
When converted to the same luminosity, the inclusive tag measurement outperforms semileptonic tagging by 10-20%

→ still some way to get to SM sensitivity. Beyond that, is 10% accuracy of SM prediction

Perspectives

- More data
- More variables (e.g. K_L)
- More channels (K^*)
- Reduce systematics: continuum modelling improvements
- Other classifiers: mix of NN and BDT looks promising.

A quantum leap in the tagging efficiency could bring further additional improvements.



Summary

- First measurement using “nominal” Belle-II configuration based on data collected in 2019-2020.
- First B-physics Belle II paper focusing on the “golden” for B-factores channel.
- New inclusive tagging, improving selection efficiency and sensitivity
- No significant signal observed, limits comparable with previous results

→ Some work ahead, a few ideas how to improve further.