Corrections in $B^+ \to K^+ \nu\nu$ (ITA)

- charm scaling
- K_L efficiency

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Introduction

- Search for $B^+ \to K^+ \nu\nu$ with inclusive tagging method
- Corrections introduced in the analysis:
  1) K^0_L efficiency correction
  2) Energy scaling of neutrals not matched to photons
  3) PID weight
  4) Scaling of $B \to X_c (\to K^0_L + X) +$ anything

This talk will be about: 1) K^0_L efficiency correction, 2) Energy scaling of neutrals not matched to photons and 4) Scaling of $B \to X_c (\to K^0_L + X) +$ anything

(also showed on previous talk at EWP meeting: Filippo@EWP)

Overview of selections and background suppression

Basic event selections:

- Good tracks: |dr| < 0.5 cm, |dz| < 3 cm, pT > 0.1 GeV/c, E < 5.5 GeV
- *Signal K^+: good track, nPXDHits > 0, $\theta \in$ CDC, nCDCHits > 20, kaonID > 0.9*

Neutrals in the rest of the event:

- K^0_S: 'merged', 0.495 < m(π+π-) < 0.500 GeV/c2, cosθ (p, v) > 0.98, flightTime > 0.007 ns, kFit > 0.001
- **γ: 0.1 < E < 5.5 GeV, $\theta \in$ CDC**, 0.3 < θ(pmiss) < 2.8, Evisible > 4 GeV

Reconstructed di-neutrino squared mass: $q_{rec}^2 = s/4 + M_K^2 - \sqrt{s} E_K^*$

Single candidate selection: B candidate with lowest q_{rec}^2

Background suppression:

- BDT1: (fastBDT) **12** event-topology variables
- BDT2: (xgboost) trained with **35** input variables with BDT1 > 0.9 to further suppress the background

-> μ(BDT2): signal efficiency quantile

- the analysis is sensitive to mismodeling of K^+ +missing energy

PID sideband samples

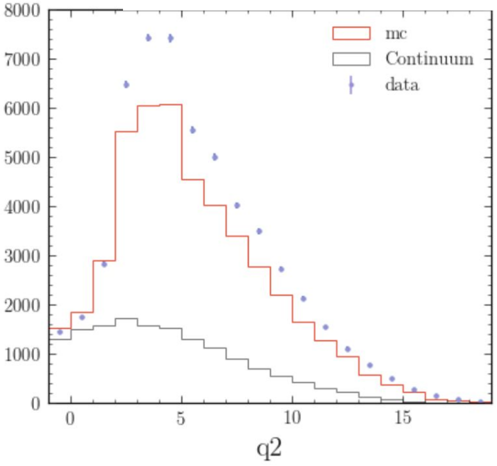
- ➢ PID sidebands allow to evaluate the analysis with orthogonal data samples.
- ➢ Sidebands: pionID sideband, muonID sideband, electronID sideband
  - ○ Nominal signal selections except the PID cut for signal Kaon

sample	PID selection	PID weights
pionID sideband	PionID >0.9	pion eff + Fake mu->pi
electronID sideband	electronID_noSVD_noTOP>0.9	electron eff + Fake pi->e
muonID sideband	muonID_noSVD > 0.9	muon eff + Fake pi-> mu

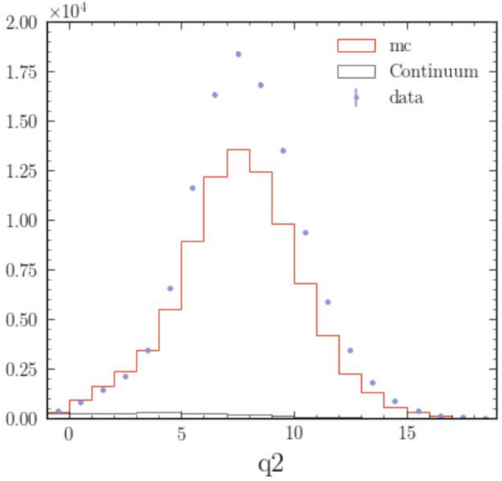
Where we start

- ➔ q^2 distribution for different PID sideband in signal search region (μ(BDT2) > 0.92)
  - ◆ **large discrepancy** between data and MC without any corrections for $q^2 > 4\ GeV^2/c^4$
- ➔ Tried to apply the corrections to address:
  1) Detection mismodeling
  2) Physics mismodeling at charm threshold

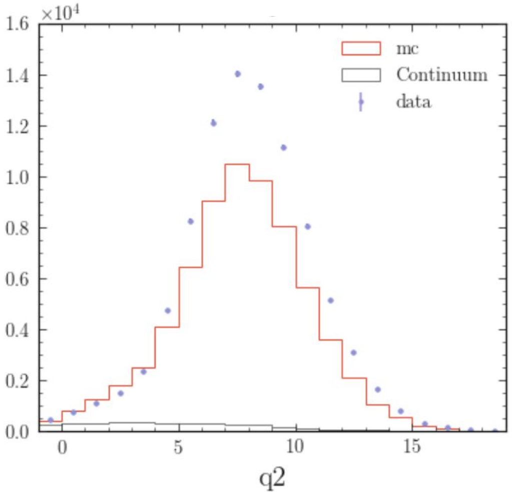
pionID sideband



muonID sideband



electronID sideband



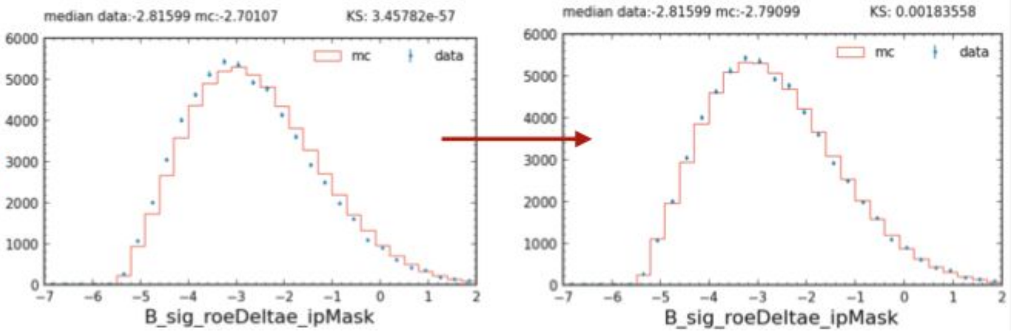
Correct for detection mismodeling

1) Energy scaling of neutral clusters unmatched to photons (Eldar@unmatchedNeutral)
   - Shift of energy distribution in simulation wrt data
   - Mostly coming from unmatched-to-photons clusters
   - The shift is reduced by scaling unmatched photon energy **down by 10%** in simulation
2) K^0_L efficiency correction (Eldar@KLefficiency)
   - K^0_L contributes to background significantly
   - introduce a data-driven correction of the K^0_L efficiency (**global 17% degradation)**

```
ma.getNeutralHadronGeomMatches(['gamma:sel'],addKL=True, addNeutrons=True, path=path)
# Efficiency correction:
ma.applyCuts('gamma:sel',cut='distanceToMcKl>0',path=path)
```

← Comes with light-2305-korat

Energy scaling of unmatched neutral clusters in off-resonance data:



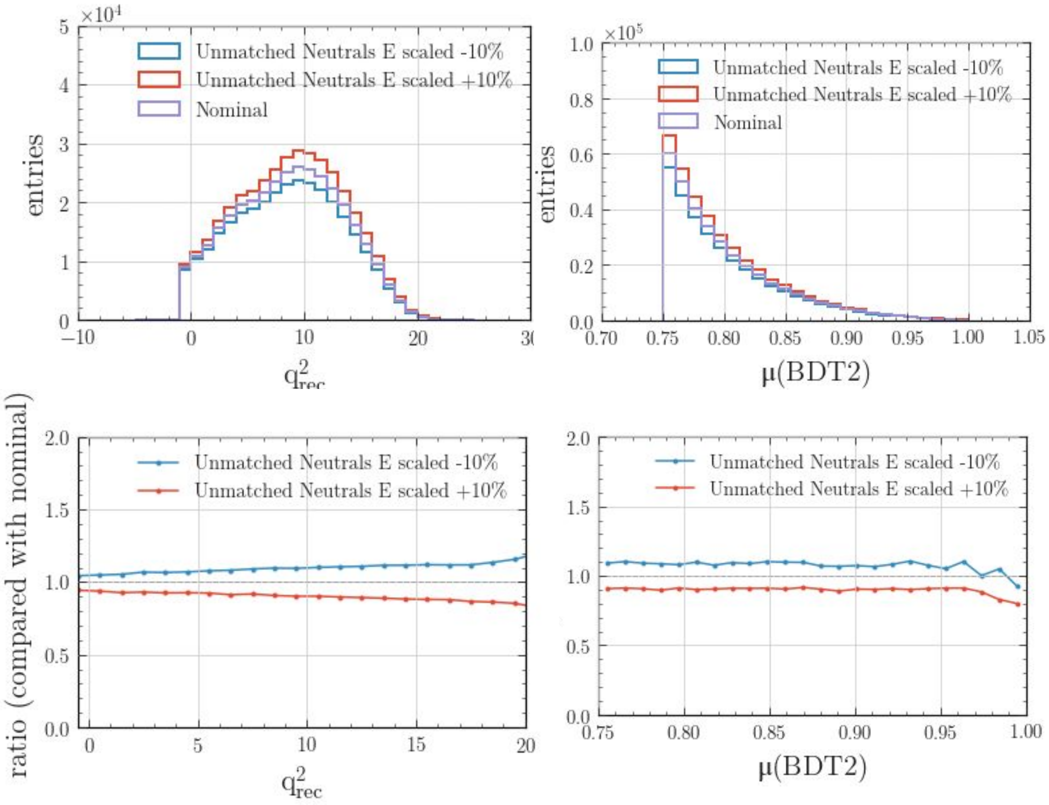
The mismatch in e-scale increased from MC14ri to MC15ri.

Energy scaling of unmatched photon clusters (nominal sample)

In nominal sample:

- Scale down the energy of unmatched photons by 10% **(by default)**
- keep 10% systematic uncertainty

➔ check the effect of this correction in the region with μ(BDT2)>0.75 using 200 fb^{-1} MC sample



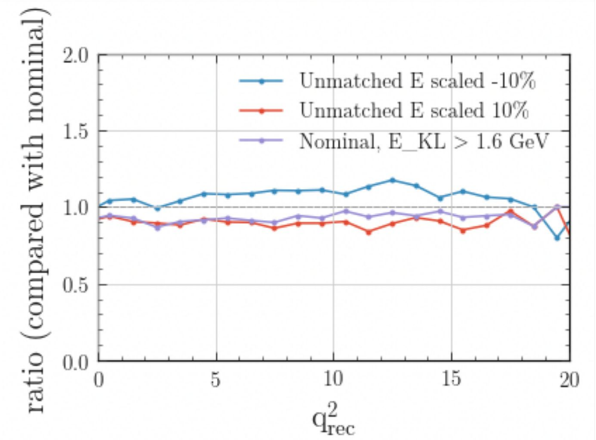
K^0_L detection efficiency (nominal sample)

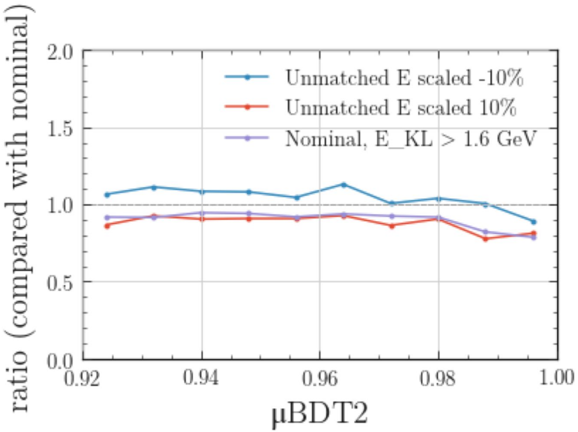
- ➔ Correction for mismodelling of K^0_L detection efficiency in MC
  - ◆ Study with $e^+e^- \rightarrow \gamma_{ISR}\varphi_0(\rightarrow K_L K_S)$ samples Eldar@KL
  - ◆ **Module introduced** to match KL geometricly to ECL clusters
  - ◆ corrections: decrease K^0_L efficiency in simulation by 17% (8.5% uncertainty)

$$\varepsilon(K^0_L) = \frac{N(K^0_L \text{ distance to ECL cluster} < 15\text{cm})}{N(\text{total})}$$

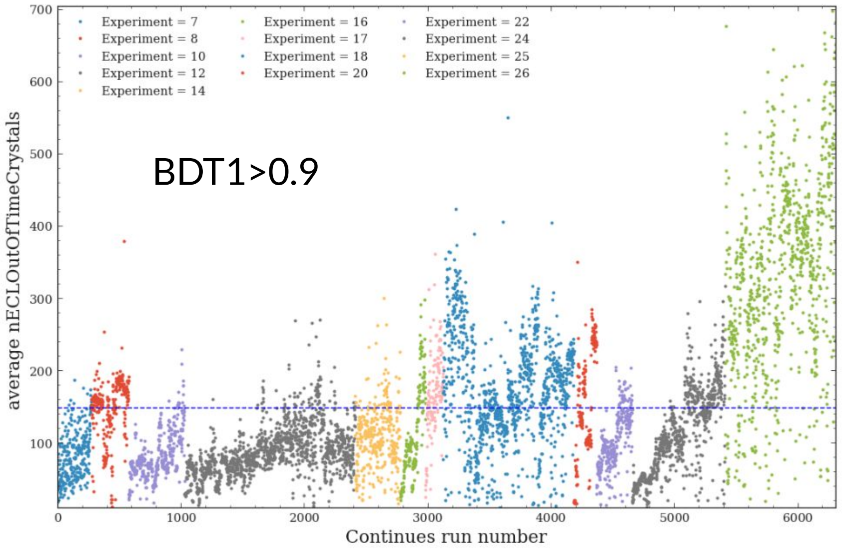
- ➔ ***Test to validate the corrections***:
  - ◆ apply correction only to K^0_L with E > 1.6 GeV and drop clusters within 15cm of the inferred K^0_L direction for K^0_L with E < 1.6GeV

- ➔ Ratio compared with the nominal MC samples (200 fb^{-1} in μ(BDT2)>0.92 region):
  - ● Flat correction observed
  - ● Coverd by the unmatched neutral energy scaling effect





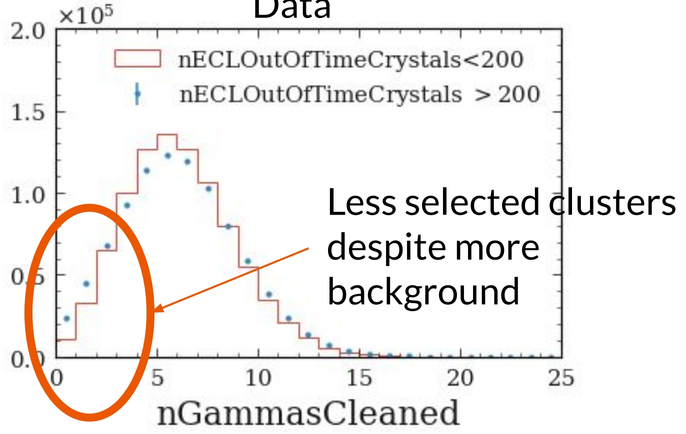
N gamma distribution and ECL out-of-time clusters



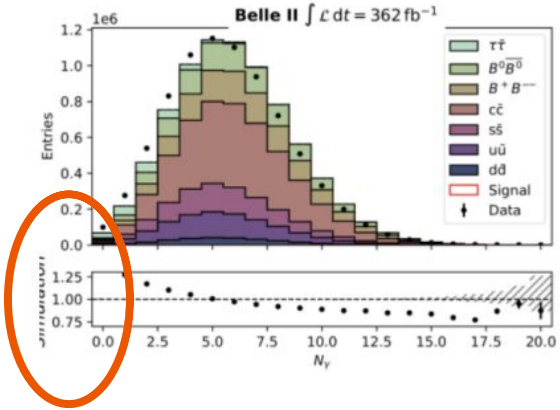
← Large increase in out-of-time clusters in ECL for late experiments due to higher background

Combined with the clustering bug, this leads to a run-dependent inefficiency for photons in ECL, see [talk from Chris]

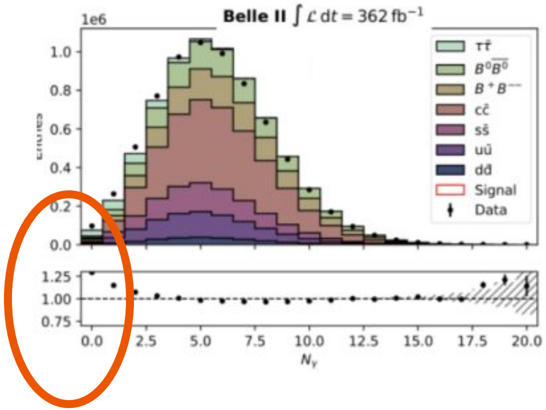
Visible impact on nGamma distribution. Increase at low values is likely due to → inefficiency



Effect of corrections on N gamma distribution (nominal sample)

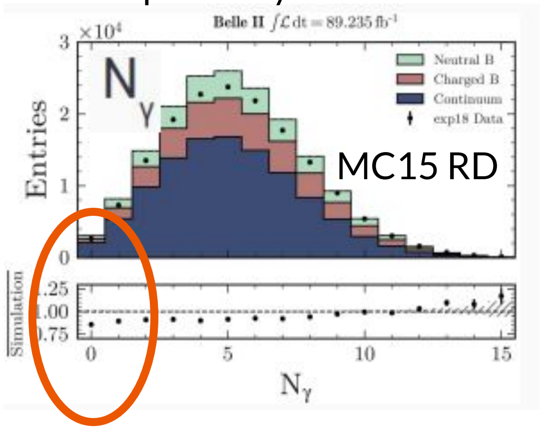


No corrections



+unmatched photon energy scaling
+KL efficiency

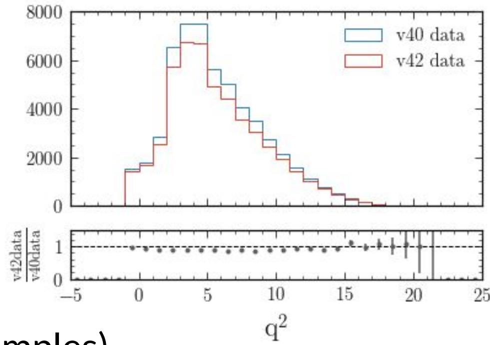
exp 18 only



+Use run-dependent MC

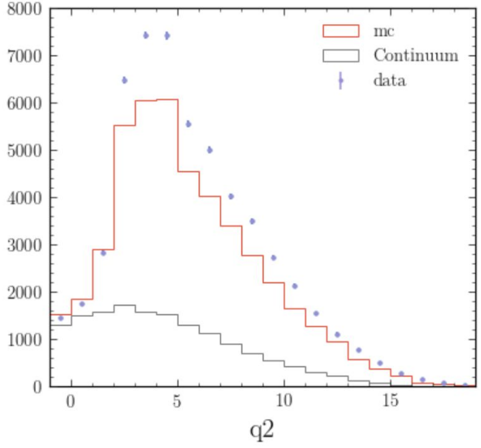
→ Discrepancy in N gamma distribution can be caused by detector modeling issues
More details in @Eldar's talk and @Filippo's talk

With all the detection corrections

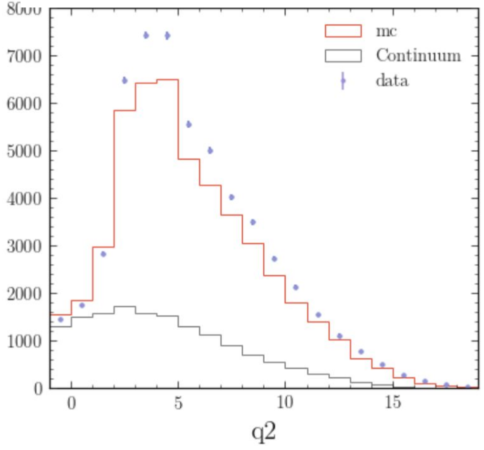


➔ **Improved agreement** between data and simulation in PionID sideband:
- unmatched-neutral energy scaling
- continuum normalization factor (extracted from PID sideband offres samples)
- K^0_L efficiency correction

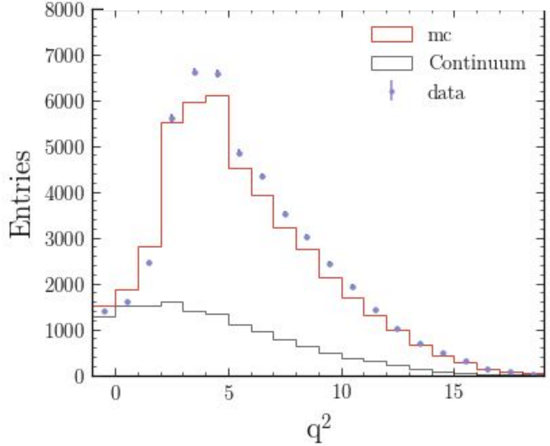
continuum normalization



unmatched-neutral energy scaled
continuum normalization

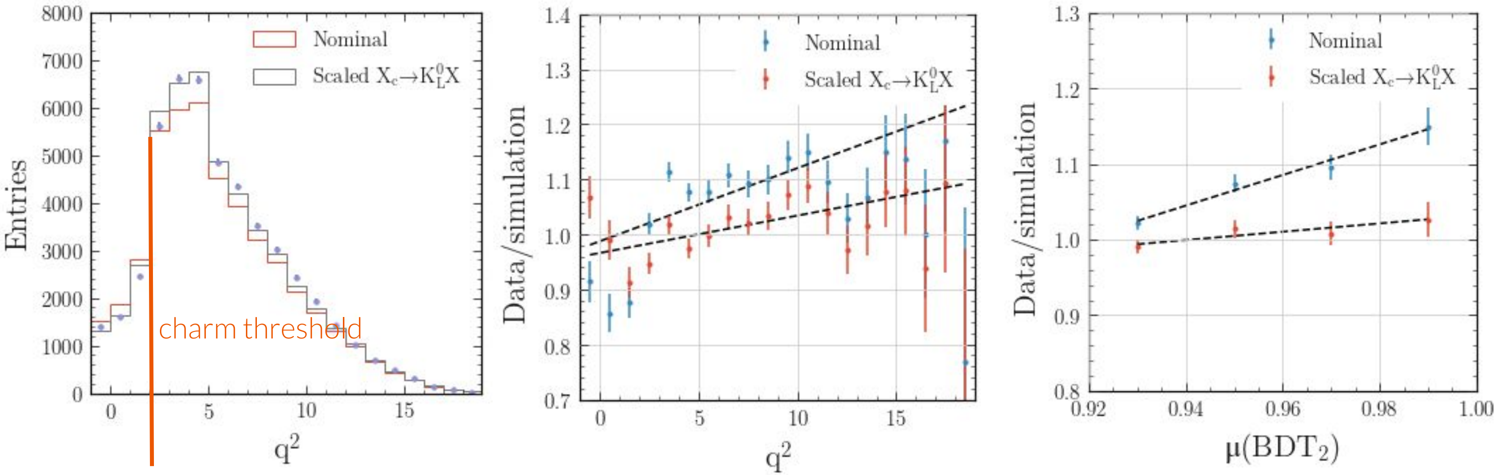


unmatched-neutral energy scaled
continuum normalization
K0L efficiency



Scaling of B -> X_c (-> K^0_L + X) + anything in pionID sideband

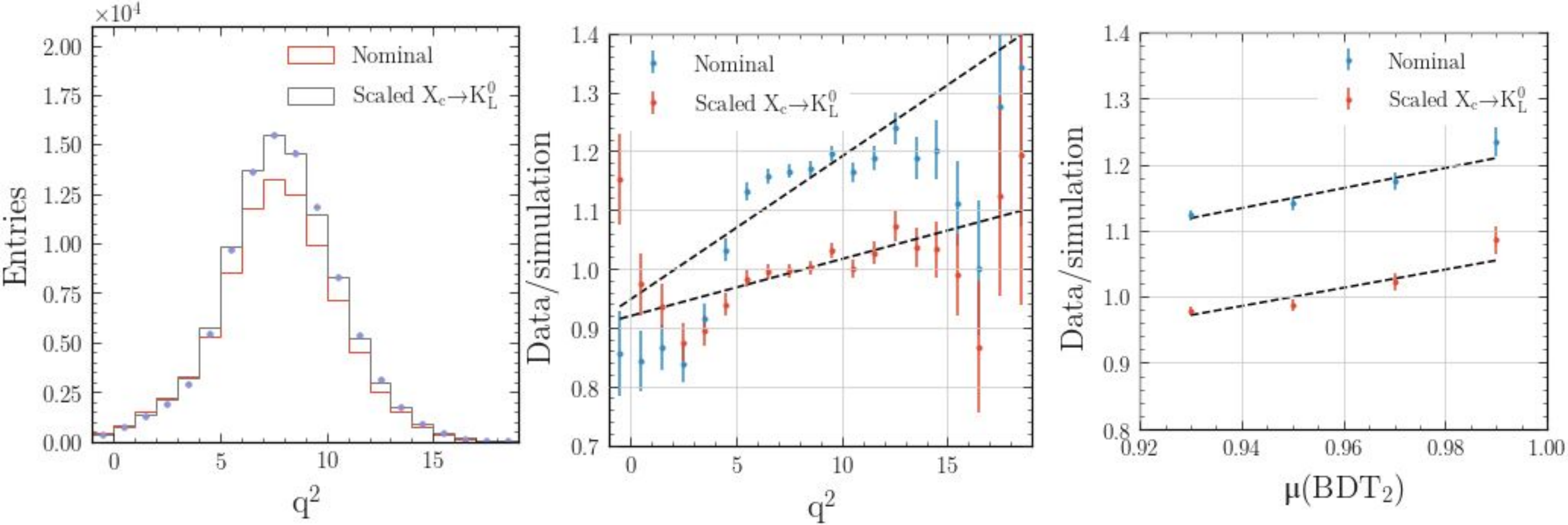
- ➔ Goal: correction for mismodelling of charm decays with K^0_L in the final states
- ➔ Binned fit of q_{rec}^2 with sghf in signal seach region (μ(BDT2)> 0.92) to determine the scaling of charm decay involving a K^0_L in BB events:
  - select events with **truth-matched** X_c (-> K^0_L + X) in the signal side
  - fit with 3 components: B→ X_c (-> K^0_L + X) , BB background (exclude 1st component), continuum background
  - normalisation uncertainties set to: 10000%, 1%, 10%
- ➔ Result of the fit: **scale up X_c (-> K^0_L + X) by a factor of 1.30 (+-0.02)**



improved data-simulation agreement

Scaling of B -> X_c (-> K^0_L + X) + anything in muonID sideband

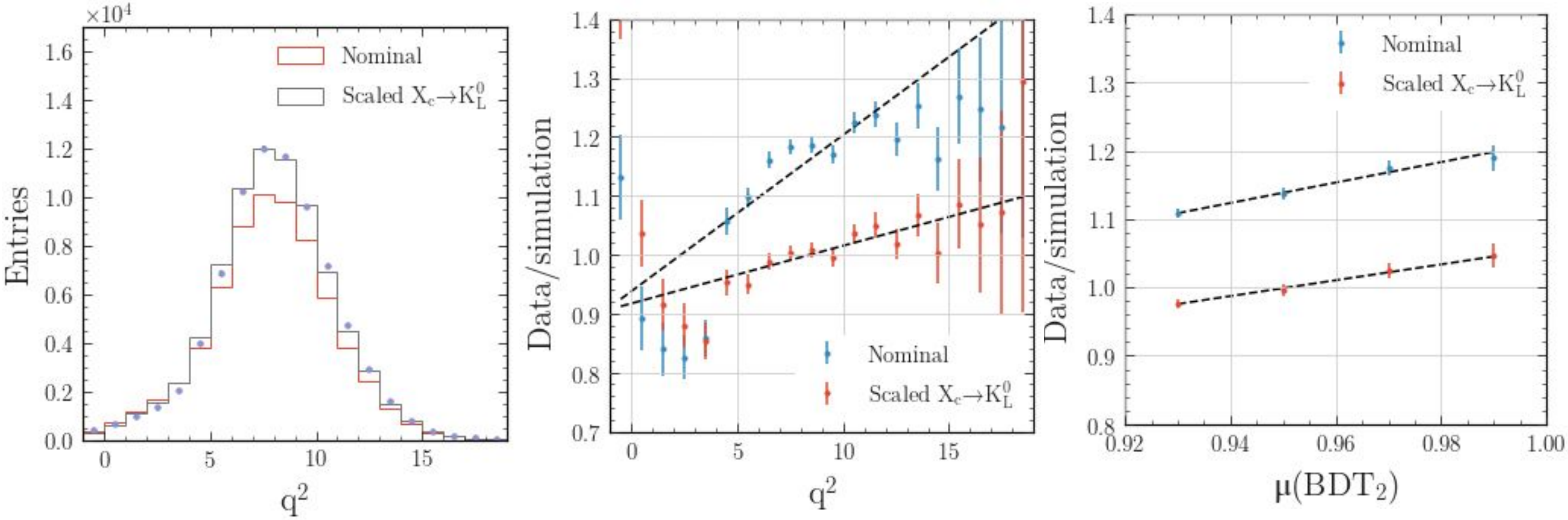
➔ Same fit in the MuonID sideband
- result of the fit suggesting to scale up the X_c (-> K^0_L + X) by a factor of **1.35 +- 0.01**



- improved data-simulation agreement in q^2 and μ(BDT2)

Scaling of B -> X_c (-> K^0_L + X) + anything in electronID sideband

- ➔ Same fit in the electronID sideband
  - ◆ result of the fit suggesting to scale up the X_c (-> K^0_L + X) by a factor of **1.38 +- 0.01**

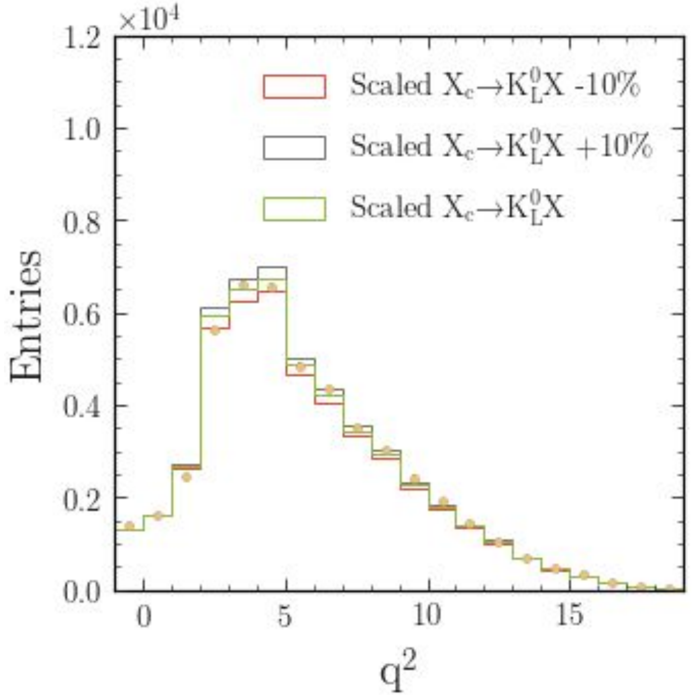


- improved data-simulation agreement in q^2 and μ(BDT2)

Scaling of X_c -> K^0_L X

➔ The scaling factor:

sample	scaling factors
pionID sideband	1.30 +- 0.02
electronID sideband	1.38 +- 0.01
muonID sideband	1.35 +- 0.01



➔ PionID sideband is the most-relevant sideband due to the larger misIdentificication rate

➔ Correction for the nominal sample **1.30 +- 0.10**

(New systematic uncertainty corresponding to 33% of the corrections to cover the variation)

Summary

- New corrections introduced:
  - Energy scaling of neutrals not matched to photons
  - K^0_L efficiency correction
  - Scaling of B-> X_c (-> K^0_L + X) + anything

- Better data-simulation agreement was achieved

- The new corrections were included in the systematic uncertainties

Systematic uncertainty

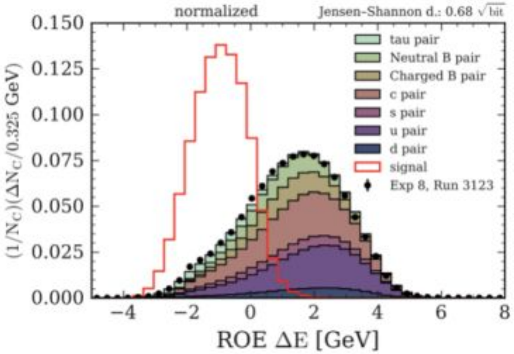
Source	Correction	Uncertainty type	Uncertainty size	Impact on μ
Normalization of continuum and $B\bar{B}$ background	—	Global, 7 NP	50%	0.74
Leading B-decays branching fractions	—	Shape, 5 NP	$O(1\%)$	0.25
Branching fraction for $B \to D^{(**)}$	—	Shape, 1 NP	50%	0.30
Branching fraction for $B^+ \to n\bar{n}K^+$	q^2 dependent $O(100\%)$	Global, 1 NP	100%	0.25
Branching fraction for $D \to K_L X$	+30%	Shape, 1 NP	10%	0.06
Continuum background modeling, BDT$_c$	—	Shape, 1 NP	O(5%)	0.04
Integrated luminosity	—	Global, 1 NP	1%	0.00
Number of $B\bar{B}$	—	Global, 1 NP	1.5%	0.02
Off-resonance sample normalization	—	Global, 1 NP	5%	0.00
Track finding efficiency	—	Shape, 1 NP	0.9%	0.09
Signal kaon PID	p, θ dependent $O(10-100\%)$	Shape, 7 NP	$O(1\%)$	0.06
Photon energy scale	—	Shape, 1 NP	0.5%	0.02
Hadronic energy scale	−10%	Shape, 1 NP	10%	0.49
K_L^0 efficiency in ECL	−17%	Shape, 1 NP	8%	0.21
Signal SM form factors	q^2 dependent $O(1\%)$	Shape, 3 NP	$O(1\%)$	0.02
Global signal efficiency	—	Global, 1 NP	3%	0.03
Signal efficiency shape	—	Shape, 1 NP	$O(1\%)$	0.07

*signal region bin-dependent uncertainties were introduced for the corrections

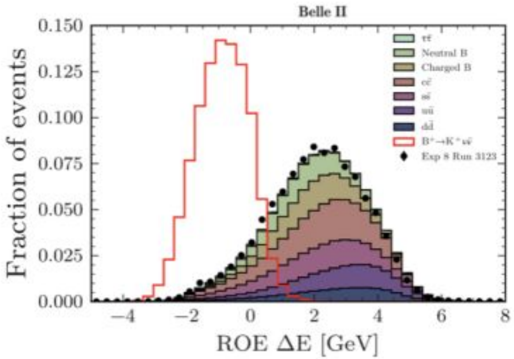
THE SHIFT

- One of the variables that we use to discriminate signal from the background is ΔE_{ROE}
- We have observed shift in data distribution wrt simulation in three iterations of analysis

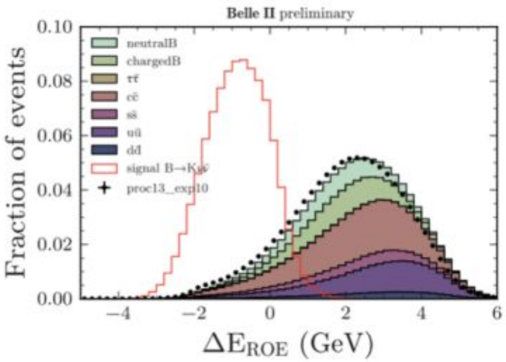
MC13 + rel4 data



MC14 + rel5 data

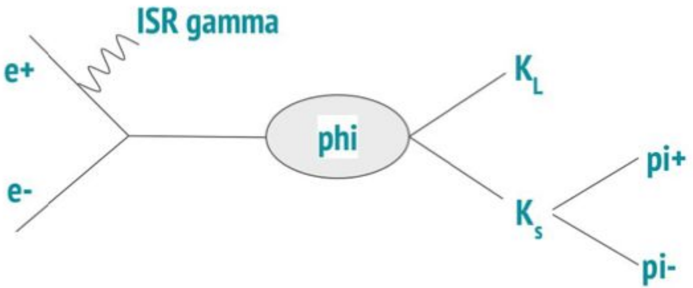


MC15 + rel6 data



https://indico.belle2.org/event/9214/contributions/60443/attachments/22019/32557/b2knunu%40PhysPerf_250423_v2.pdf

KL efficiency

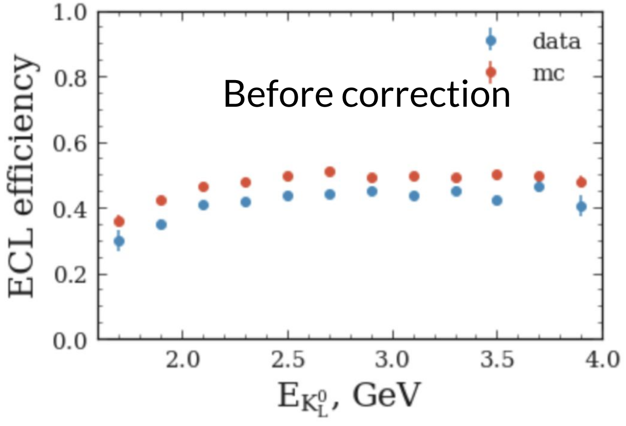


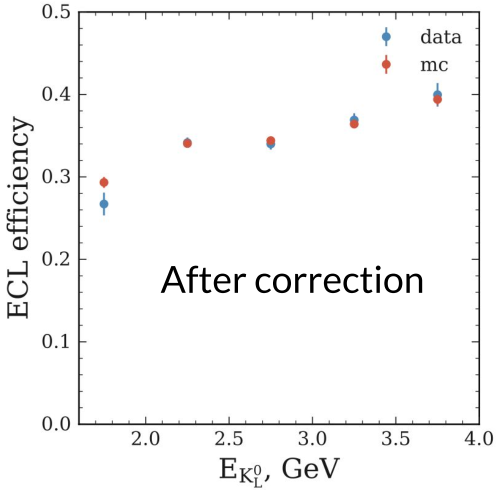
Studies with $e^+e^- \to \gamma_{ISR}\varphi_0(\to K_L K_S)$:

Efficiencies calculated by matching K^0_L candidates geometrically to ECL clusters (matching done by a new module, which will come with new light release)

$$\varepsilon(K^0_L) = \frac{N(K^0_L \text{ distance to ECL cluster} < 15\text{cm})}{N(\text{total})}$$

➔ Decrease KL efficiency in MC by **17%**

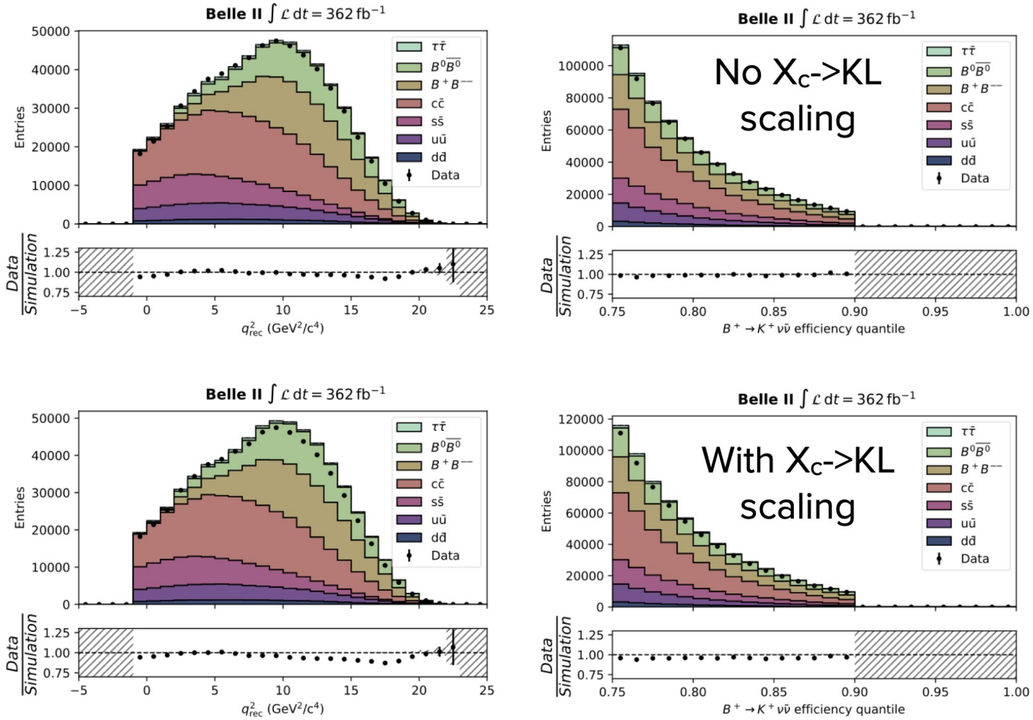




Propagate to nominal sideband

- ➔ check the data-mc agreement in nominal sideband region (0.75 < μ(BDT2)< 0.9):
  - ◆ With and without scaling of $X_c \to K_L X$
- ➢ The remained data-simulation normalization difference without and with the re-scaling of charm to K_L is 3% (0.7%)

*Continuum background is scaled up by 26% which is determined by the off-res data and bb in 0.75 < μ(BDT2)< 0.9 region



contribution of fakes

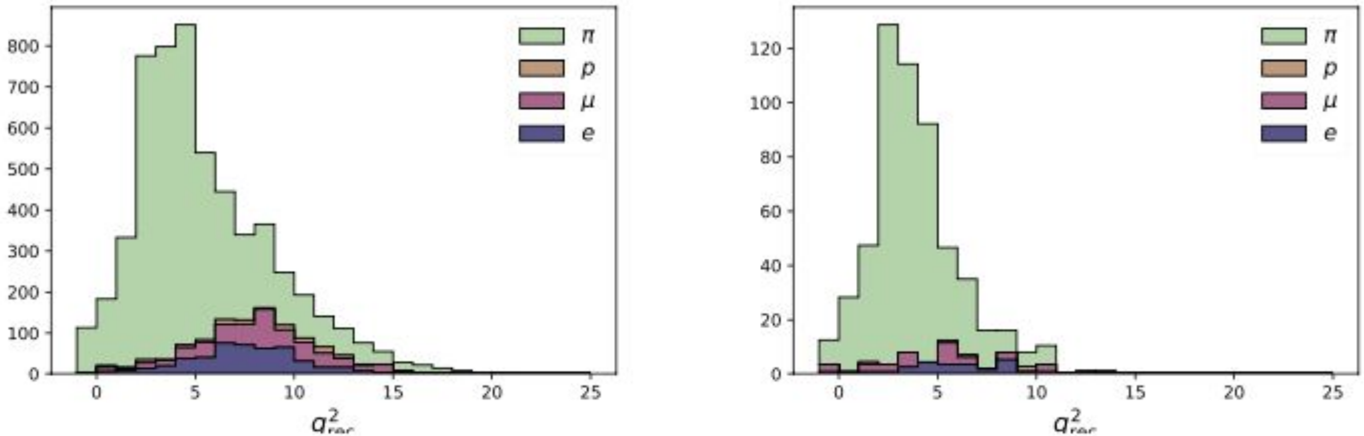


Fig. 95: Contribution of fakes in $\mu(BDT2)$ >0.92 (left) and $\mu(BDT2)$ >0.98 region (right)