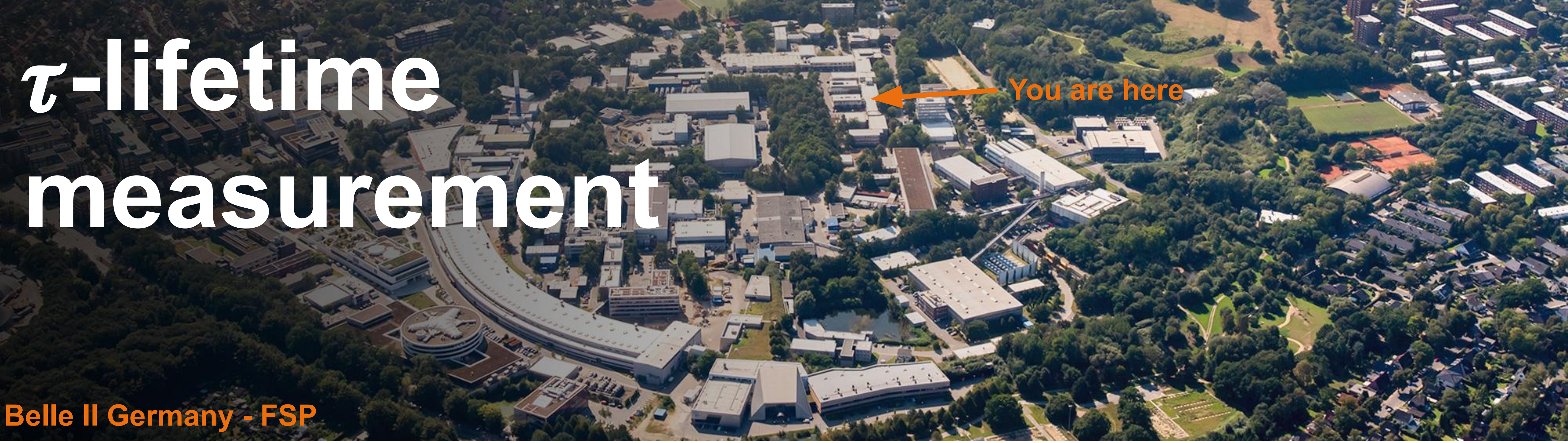
τ-lifetime measurement



Belle II Germany - FSP

Anselm Baur, Fabian Becherer, Daniel Pitzl, Armine Rostomyan
DESY, 01.10.2024

HELMHOLTZ

Motivation and current status

Lepton masses and lifetimes are fundamental parameters of SM

- E.g. Precise values are crucial for lepton universality tests of SM

Current mass values in MeV	**Current lifetime values in s**
e: 0.51 ± **3×10^{-8} %**	e: >2.1×10^{37} CL: 90 %
μ: 105.65 ± **2×10^{-6} %**	μ: 2.1×10^{-6} ± **1×10^{-4} %**
τ: 1776.86 ± **6×10^{-3} %**	τ: 290.3×10^{-15} ± **1×10^{-1} %**

⇒ More precise measurements for lighter leptons

Lepton Flavor Universality (LFU) in the SM:

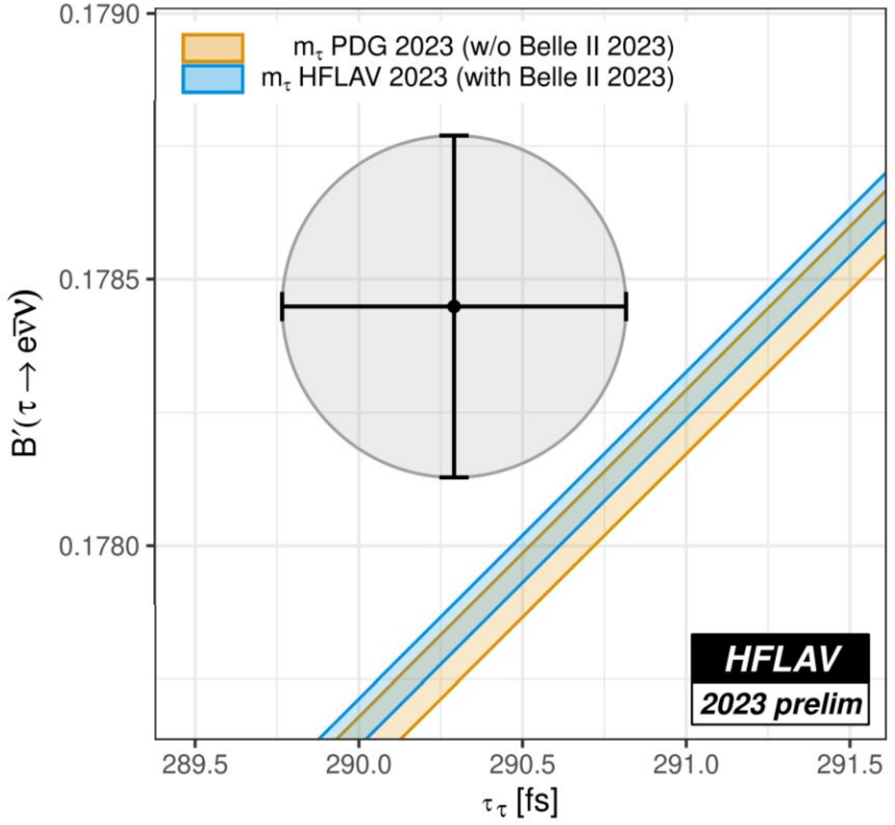
- Branching fraction depends on lifetime and mass

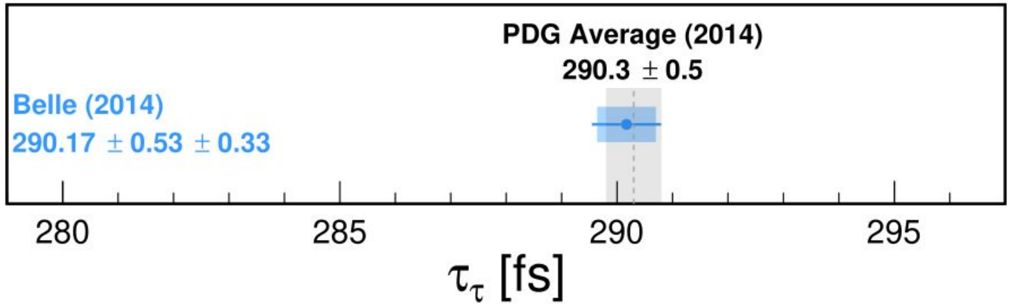
$$B_{\tau e} \propto B_{\mu e} \frac{\tau_\tau}{\tau_\mu} \frac{m_\tau^5}{m_\mu^5}$$

Most precise measurement by Belle

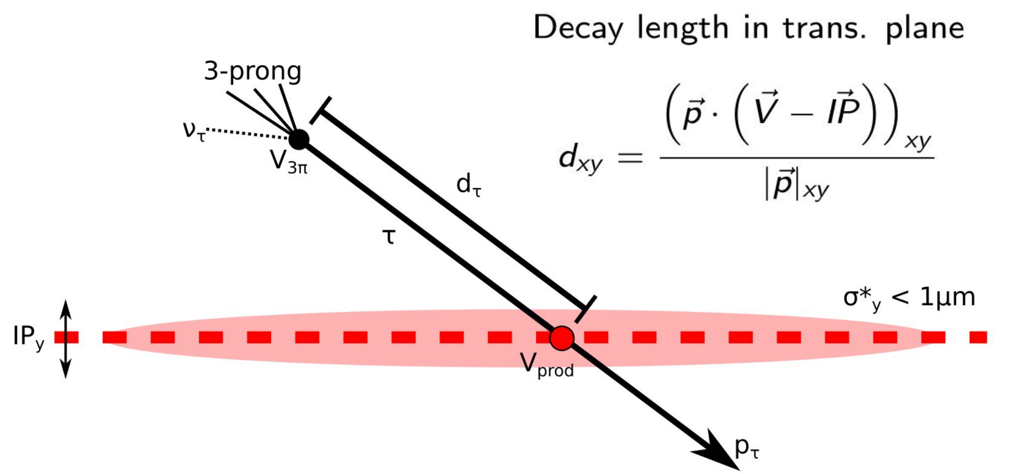
- Data set size: Belle 711 fb^{-1}
- 3x3 topology used
- 1.1 million data events
- ~98% signal purity

- Main systematic source
  - SVD alignment
  - Fit method related uncertainties
  - Energy and FSR/ISR uncertainties





The Belle II measurement overview



Data selection:

- Data set size: 362 fb^{-1} (Run 1, except Exp. 8, 9)
- 3x1 topology (>11 times BR of 3x3)
- New event selection
    - Make use of superior detector
    - Achieve comparable/better event quantities with looser selection criteria
- ~ 15 million data events after selection
- Signal purity of 97.5%

⇒ Higher data statistic

Production vertex:

- Use beam spot constraint
- Project events on p_T to distinguish between detector resolution and lifetime shift

Decay vertex:

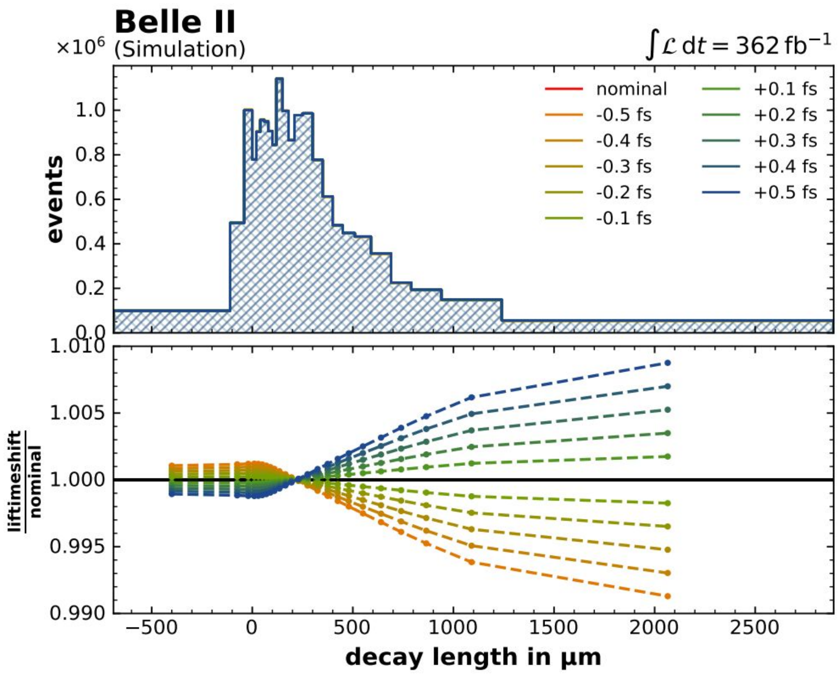
- Improved vertex resolution due to PXD

⇒ Reduced vertex uncertainties

Signal extraction:

- Use template fit(s)
    - Generate simulated data for different lifetime values (template)
      ⇒ Smearing of detector resolution described by simulated events
    - Use Likelihood fit to estimate best template

⇒ Reduced uncertainties from signal extraction/fit method



It's all about the shape!
Need precise MC modelling!

Template fit(s) to extraction τ-lifetime

$$\mathcal{L}(n^{data}|n^{exp}(\vec{\mu},\vec{\theta})) = \prod_i P_{Pois}(n_i^{data}|n_i^{exp}(\vec{\mu},\vec{\theta})) \cdot constr(\vec{\theta})$$

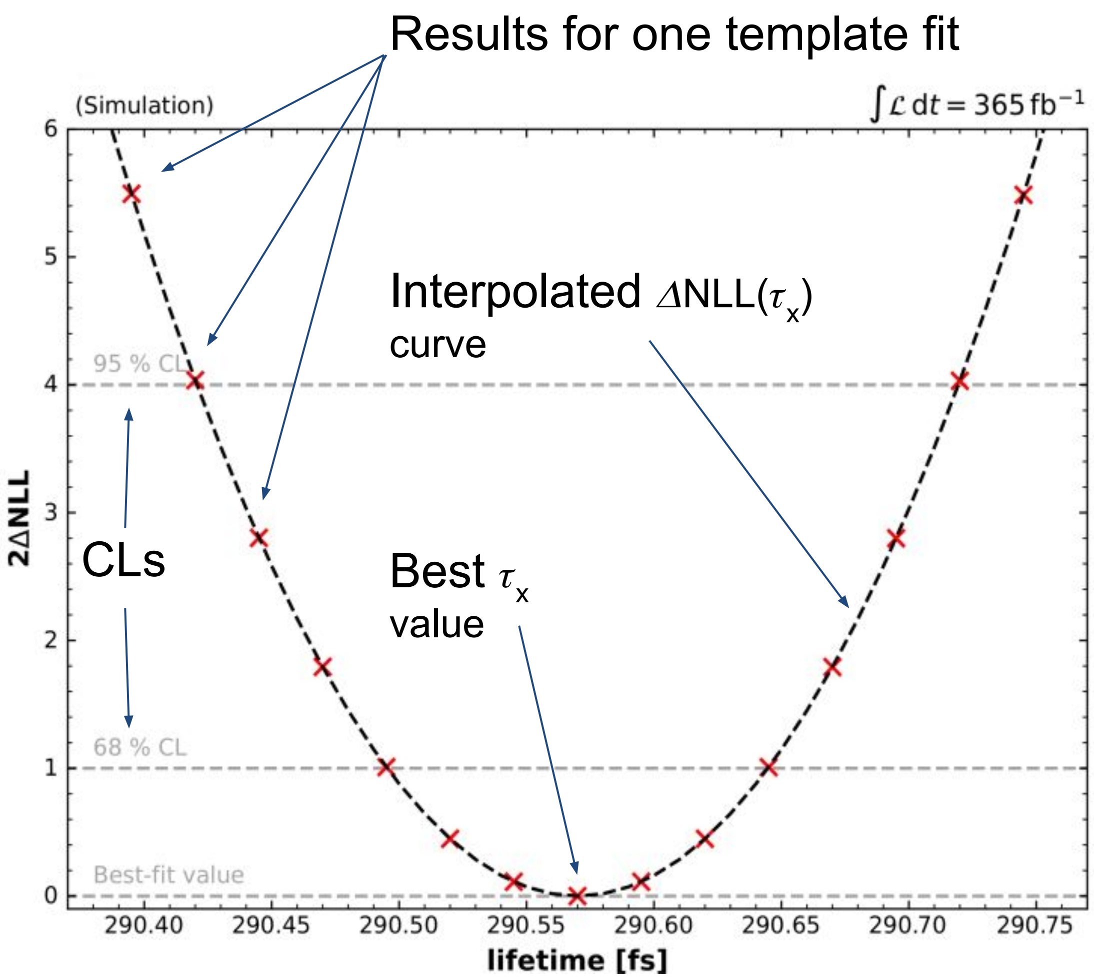
$$n_i^{exp}(\vec{\mu},\vec{\theta}) = \mu_{global} \cdot \left(n_i^{sig,\tau_x}(\vec{\theta}) + \sum_u^{bkgs} n_i^u(\vec{\theta}) \right)$$

Likelihood model:

- Decay length distribution used as observable
- Signal template depends on lifetime value
- Include free global normalization factor (global eff. correction)
- Systematic unc. included as NP with constraint terms

2-step fit:

- Estimate minimum NLL(τ_x) for each template
- Best model parameters (μ,θ) can differ for each template
- Calculate/Approximate 2ΔNLL(τ_x) curve
  - Estimate minimum and confidence level intervals (CL)
  - CL includes systematic uncertainties



Event selection

Observable	Symbol	Value/Range
thrust	V_{thrust}	[0.9, 0.99]
visible event energy (CMS)	$E_{\text{evt}}^{\text{vis},*}$	[3.5, 9] GeV
missing event momentum (CMS)	$p_{\text{evt}}^{\text{miss},*}$	≥ 0.3 GeV
polar angle of missing event mom. (CMS)	$\theta_{p,\text{evt}}^{\text{miss},*}$	[0.45, 2.8] rad
transverse momentum of $\pi_{3p,1}^{\pm}$	$p_{T\pi_{3p,1}}$	[0.3, 5] GeV
transverse momentum of $\pi_{3p,2}^{\pm}$	$p_{T\pi_{3p,2}}$	≥ 0.3 GeV
transverse momentum of $\pi_{3p,2}^{\pm}$	$p_{T\pi_{3p,3}}$	≥ 0.1 GeV
polar angle of $\pi_{3p}^{\pm}$ directions	$\theta_{\pi_{3p,1}} = \theta_{\pi_{3p,2}} = \theta_{\pi_{3p,3}}$	[0.45, 2.6] rad
transverse momentum of reconstructed $\tau_{3p}^{\pm}$	$p_{T\tau_{3p}}$	≥ 1 GeV
polar angle of reconstructed $\tau_{3p}^{\pm}$	$\theta_{\tau_{3p}}$	[0.4, 2.6] rad
number of photons 3-prong side	$n_{\gamma_{3p}}$	≤ 1
number of π^0s 3-prong side	$n_{\pi_{0,3p}}$	$== 0$
number of photons 1-prong side	$n_{\gamma_{1p}}$	≤ 1
number of π^0 1-pring side	$n_{\pi_{0,1p}}$	≤ 1
vertex resolution	$d_{\text{xy},2x1}$	[100, 100] μm
reconstructed decay length	d_{xy}	[-400, 1500] μm
reconstructed $\tau_{3p}^{\pm}$ mass (signal region)	$M_{\tau_{3p}}$	[0.75, 1.5] GeV
reconstructed $\tau_{3p}^{\pm}$ mass (side region)	$M_{\tau_{3p}}$	[1.8, 2.5] GeV

Event yields

Process	Events	Fraction [%]
signal	**15363868**	**97.50**
background	**394121**	**2.50**
uubar	212095	1.35
ssbar	62657	0.40
ccbar	55953	0.36
ddbar	41558	0.26
llXX	20204	0.13
bbbar	1007	0.01
ee	539	<0.01
eell	99	<0.01
mumu	6	<0.01
hhISR	3	<0.01

MC Modeling

Challenge:

- Template fits depend on good MC to data agreement
- Only shape difference in decay length important

What to study?

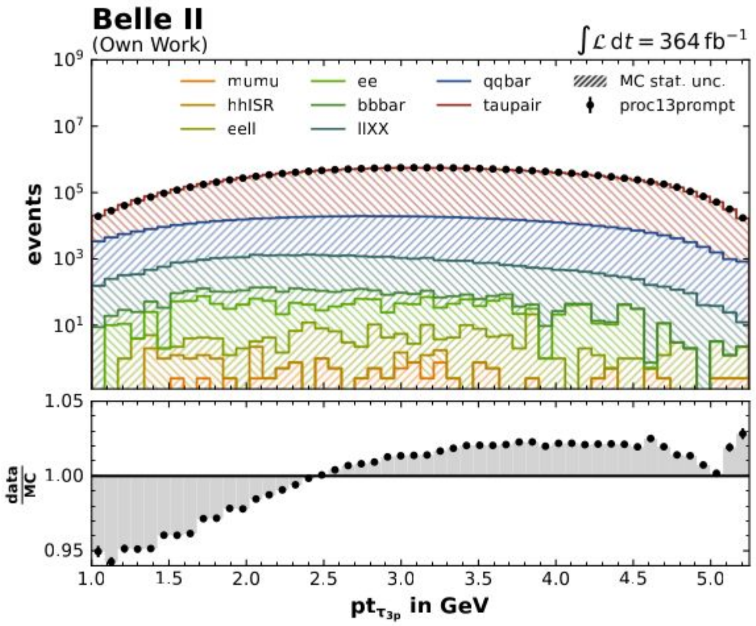
1. Variables with direct impact on reconstructed decay length
   -> τ-3prong transverse momentum and polar angle (p_T and θ)
2. Modelling of variables used for event selection (second order)

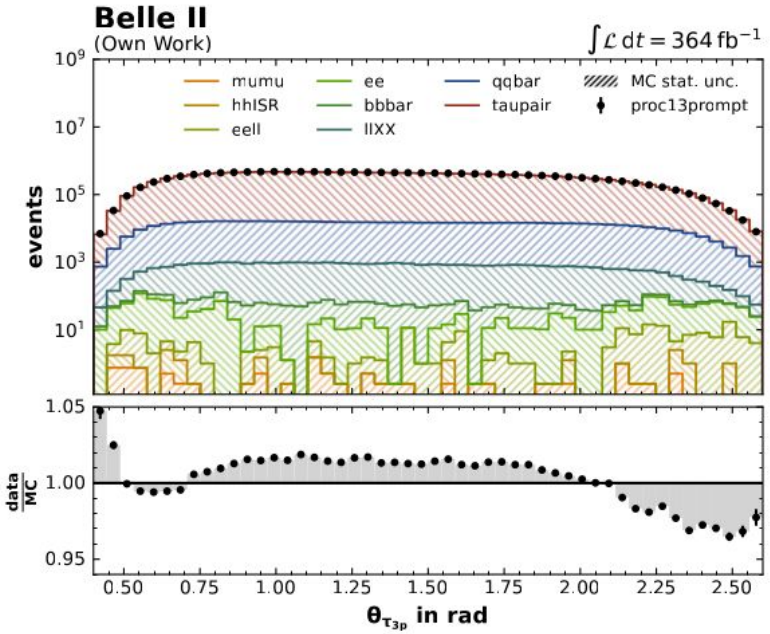
Source of mismodelling?

1. Different processes can have different shapes
   If process compositions not well predict -> Combined shape not well modeled
2. Not well modelled detector / physics effects
   a. FSR/ISR
   b. Alignment
   c. Material budget
   d. …

How to handle?

1. First remove/reduce effect from 1.
2. Study remaining mis-modelling from 2.





Correct process contributions

Idea and challenge
- Estimate yield for each process with different shape separately from data
- Some process difficult to distinguish
- Limit statistic

-> We are not able to treat each process separately

Solution:
- Derive normalization for groups of processes
  - Find best compromise between sensitivity and finest splitting
- Estimate additional systematic uncertainties for composition of group

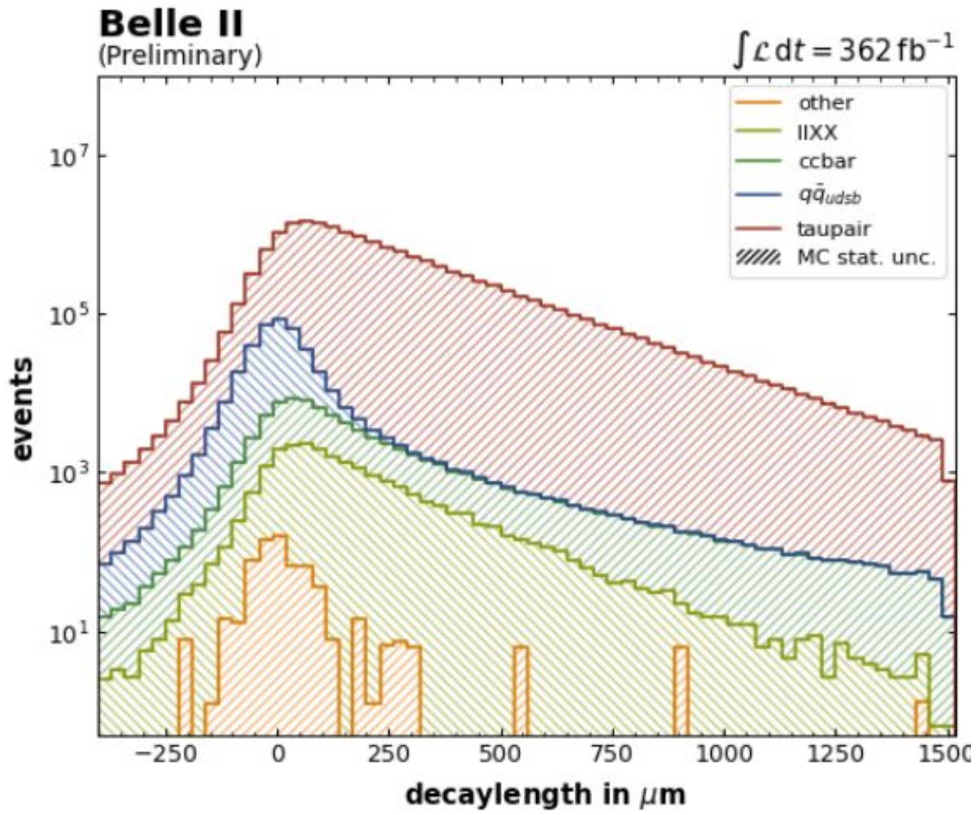
What do we do:

$\tau\tau$: Composition of τ -> 3 π and other decay mode
- Estimate combined yield from data
- Study composition and impact of other decay modes on decay length

llXX: 99% ee$\tau\tau$, 1% $\mu\mu\tau\tau$
- Get yield from MC (no clean control region)
- Derive systematic by varying process by cross section uncertainty of ee$\tau\tau$

ccbar: Processes with different lifetimes
- Derive combined correction from data
- Study impact of composition on shape

qqbar$_{usb}$ and others: No lifetime -> Resolution distribution around 0
- Derive yield correction from data (composition insignificant)



Normalization of taupair and qqbar

Goal:

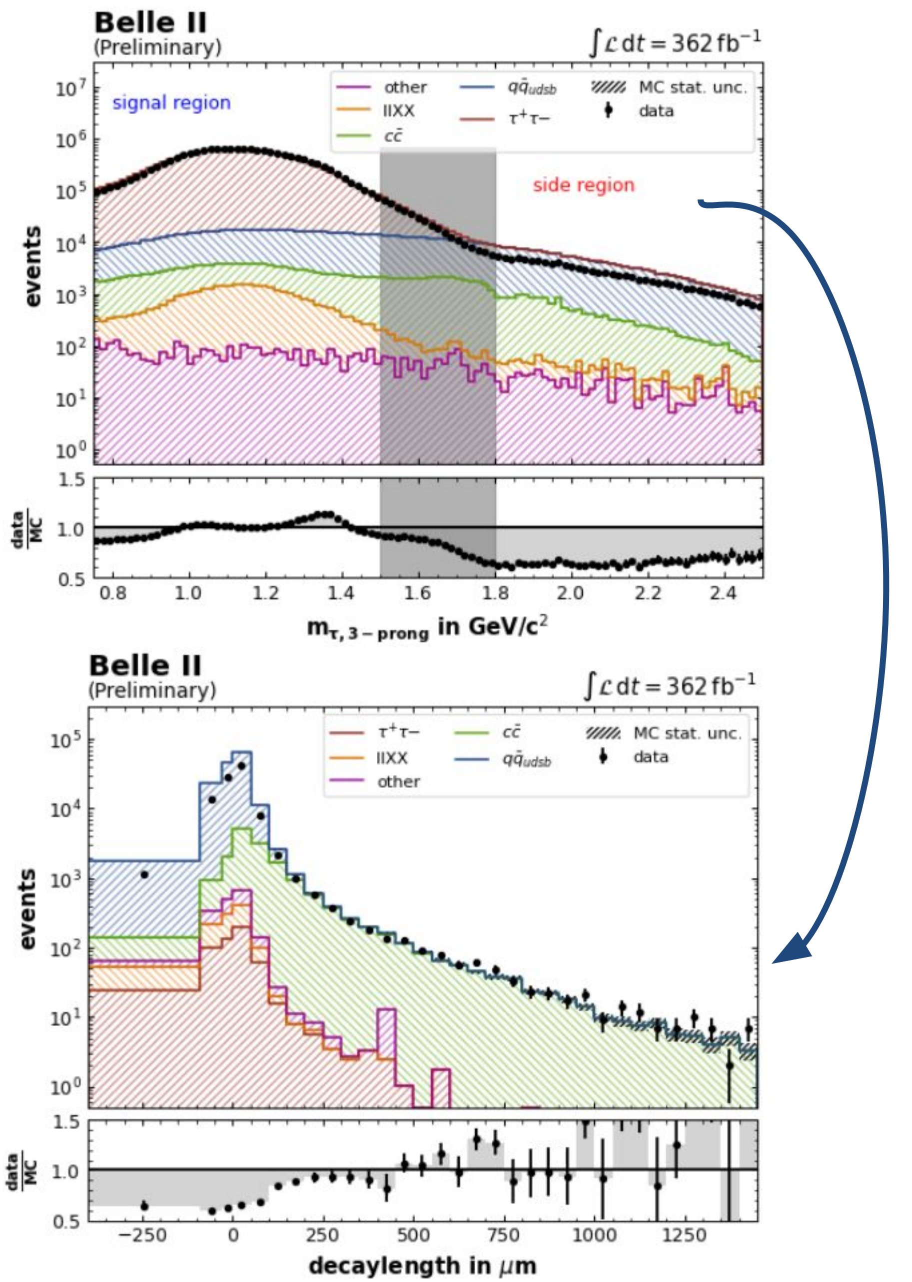
- Estimate normalization of taupair, $qqbar_{usb}$ and ccbar simultaneously
- Use a likelihood fit to estimate yields
  - Use single bin distribution in signal region to constraint taupair
    - No shape information -> No unblinding
  - Use side region to constraint qqbar
    - Use decay length distribution in sideregion to distinguish ccbar
    - Signal contribution negligible -> No sensitivity to τ-lifetime

Process	Events	Fraction [%]
signal	**566**	**0.4**
background	**152267**	**99.6**
ccbar	14324	9.4
other qqbar	136145	89.4
llXX	572	0.4
others	660	0.4

$$\mathcal{L}(n^{data}|n^{exp}(\vec{\mu},\vec{\theta})) = P_{Pois}(n^{data}_{sig}|n^{exp}_{sig}(\vec{\mu},\vec{\theta})) \cdot \prod_i P_{Pois}(n^{data}_{i,\,side}|n^{exp}_{i,\,side}(\vec{\mu},\vec{\theta})) \cdot constr(\vec{\theta})$$

$$n^{exp}_{sig}(\vec{\mu},\vec{\theta}) = \mu_{sig} \cdot n^{sig}_{sig}(\vec{\theta}) + \mu_{ccbar} \cdot n^{ccbar}_{sig}(\vec{\theta}) + \mu_{qqbar_{uds}} \cdot n^{qqbar_{uds}}_{sig}(\vec{\theta}) + \sum_u^{other\ bkgs} n^u_{sig}(\vec{\theta})$$

$$n^{exp}_{i,\,side}(\vec{\mu},\vec{\theta}) = \mu_{sig} \cdot n^{sig}_{i,\,side}(\vec{\theta}) + \mu_{ccbar} \cdot n^{ccbar}_{i,\,side}(\vec{\theta}) + \mu_{qqbar_{uds}} \cdot n^{qqbar_{uds}}_{i,\,side}(\vec{\theta}) + \sum_u^{other\ bkgs} n^u_{i,\,side}(\vec{\theta})$$



Results of normalization fit

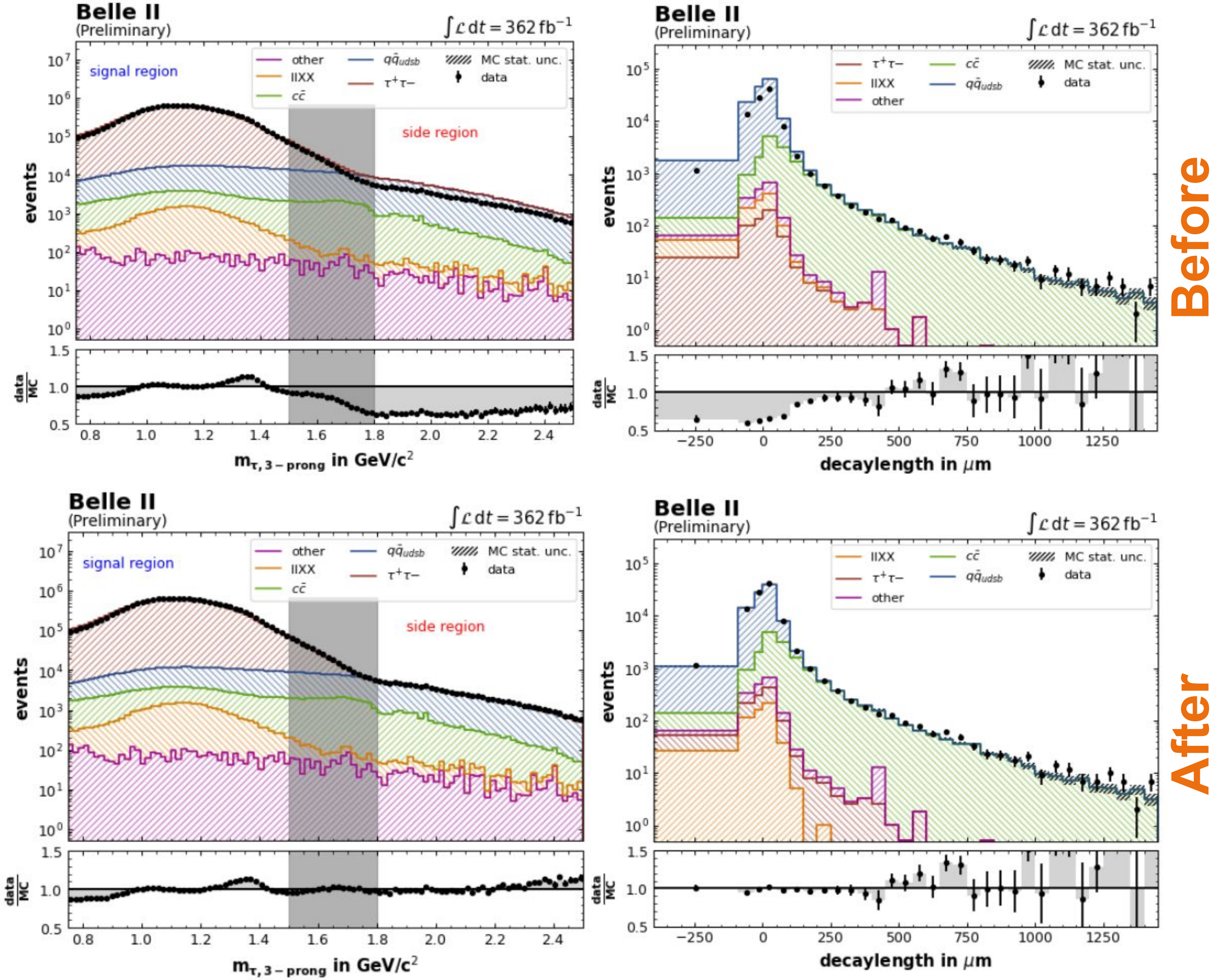
PoI	result
signal	1.023±0.011
other qqbar	0.605±0.007
ccbar	0.972±0.019
llXX	fixed
others	fixed

Challenge:

- ccbar composed of processes with different lifetimes
  - If composition in signal and side-region is different normalization could be wrong
  - If relative composition in signal region is not correct ccbar shape could be wrong

Solution:

- Compare ccbar composition in signal and side-region
  - Trend for large decay length
  - Split ccbar further ?
- Derive systematic uncertainty on ccbar by varying individual ccbar components



Background composition variation

Current status and plans:

- Example estimation of systematic for ccbar contribution in qqbar
  - Currently included as place holder systematic
  - In final setup we will derive systematic unc. in this way for
    - Rel. contributions in ccbar, llXX and taupair

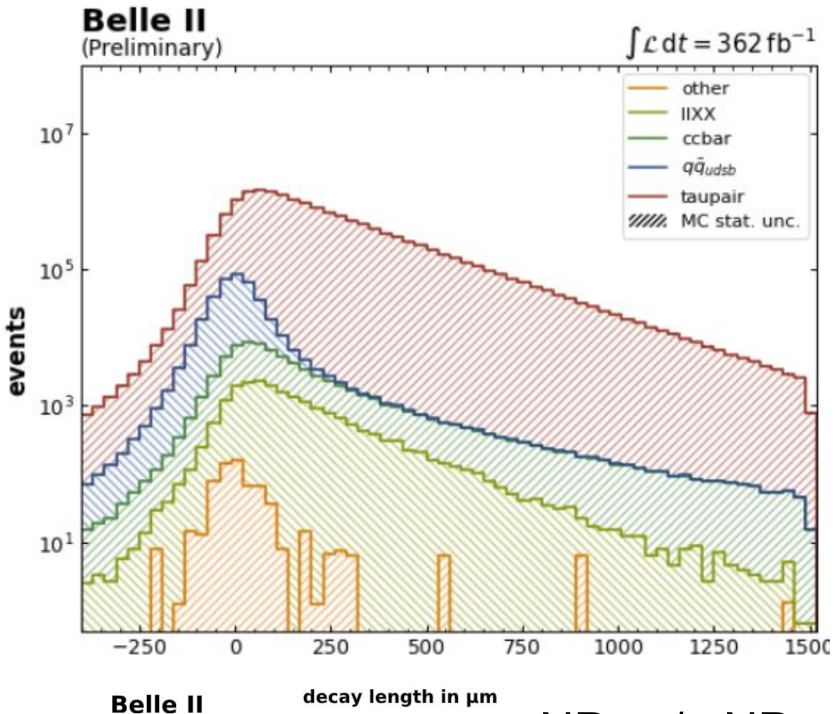
Strategy:

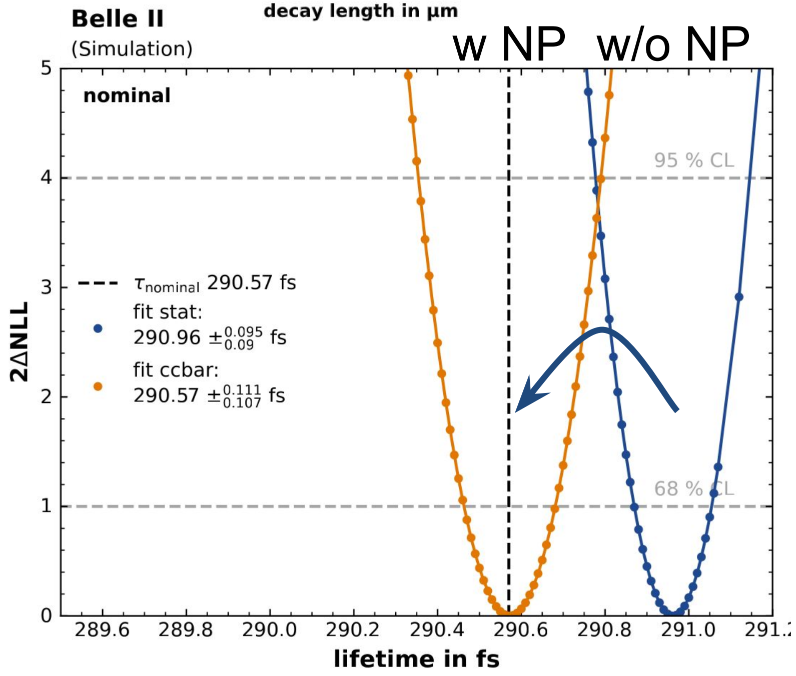
- Derive systematic uncertainty on composition
- Take ccbar sample and scale it to 0 (down) and 200 % (up) (smaller for final syst. uncs.)
- Re-scale other qqbar background samples to keep overall background normalization (keep other samples unchanged)
- Include shape difference in decay length between varied and nominal distribution as NP

Validation:

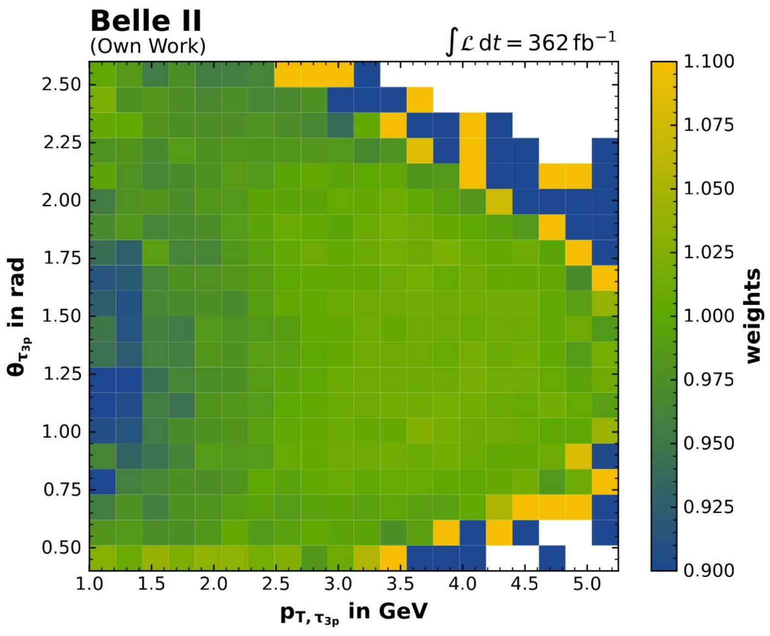
1. Create pseudo data set in which rel. ccbar contri. in bkg is increased by 50%
2. Perform fit with data + mc stat
3. Perform fit with additional included background NP

- Without NP large lifetime shift (bias) visible
- Including NP absorbs shift
  -> Fit can correct wrong ccbar contribution in MC by pulling NP





Remaining MC Mismodeling



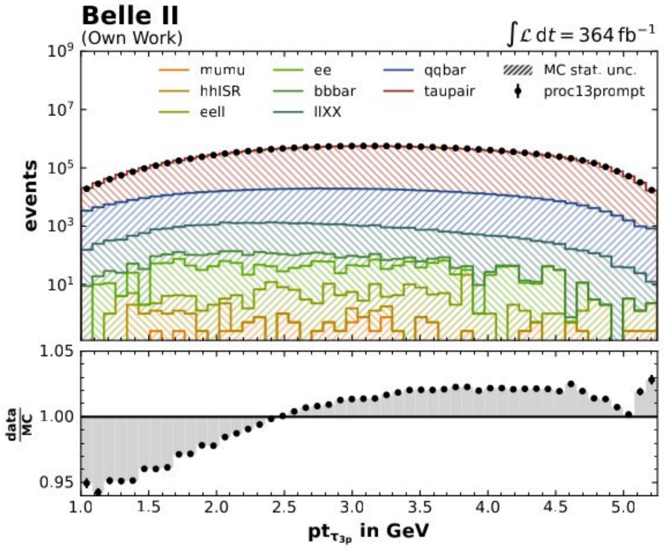
How to account for mismodeling?

- We derive for individual detector effects individual systematic uncertainties
- Central values not well estimated in MC -> Mismodelling
    - Estimate better pre-fit values to reduce potential pulls and impact on lifetime

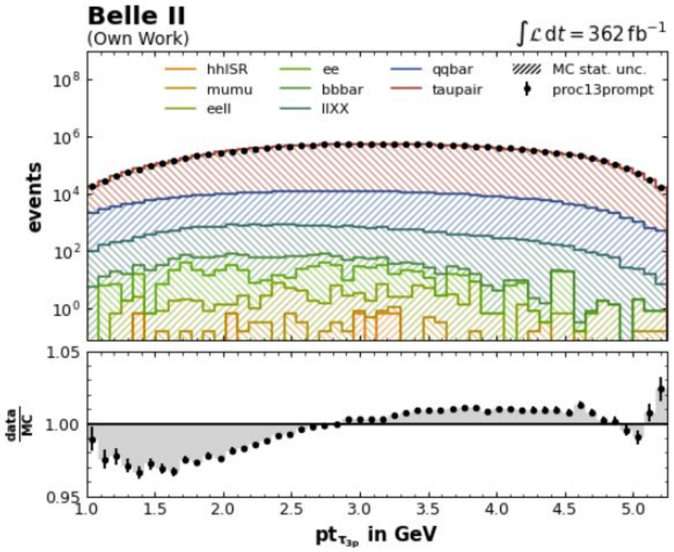
How to estimate pre-fit values?

- Compare kinematic distributions between data and MC
    - Mismodelling arises from detector effects that do not change our true lifetime value
- Cannot distinguish individual sources of the mismodelling
  -> Combined central correction for all sources
- Reweight nominal template based of important observables for decay length distribution
    - Assumption: Similar effects on reconstructed decay length and selected kinematic distribution
    - 2D - reweighting in τ_{3p} p_T and θ
    - Derive systematic on choice of reweighting variables

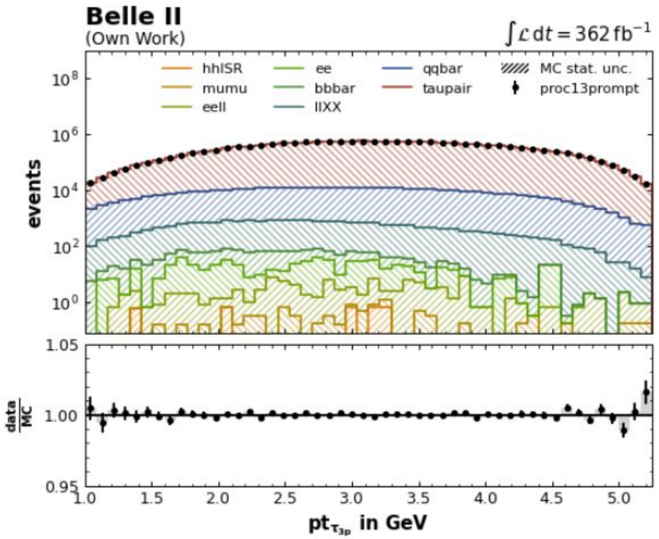
Raw



Yield corrections



2D - reweighting



Summary of systematic uncertainties

MC composition
- Vary composition in MC production
- Currently ccbar variation as placeholder for Bkg
- Kaon composition for signal included (1p contamination missing)

⇒ 2 (-> X) NPs

Reweighting
- Compare shape difference of different reweighting choices
- Include shape differences as systematic uncertainties

⇒ 2 NPs

Vertex resolution
- Estimate pseudo vertex resolution with 2-track vertex vs third track
- Apply shape difference in MC and data as systematic uncertainty

⇒ 1 NPs

Misalignment
- Four different scenarios that partial double counting
- Currently all four scenarios implemented as systematic unc.
- In final setup only include scenario with largest impact

⇒ 4 (->1) NPs

Material budget
- Change density of beam-pipe by ±5 %
- Include as up/dn variation

⇒ 1 NPs

Trigger efficiency
- Estimate rel. trigger eff in MC and data
- Include shape difference as function of decay length as systematic

⇒ 1 NPs

Luminosity and tracking efficiency
- Normalization only systematics with 0.45% (0.96%)
- Lifetime only depends on shape -> No impact expected

⇒ 2 NPs

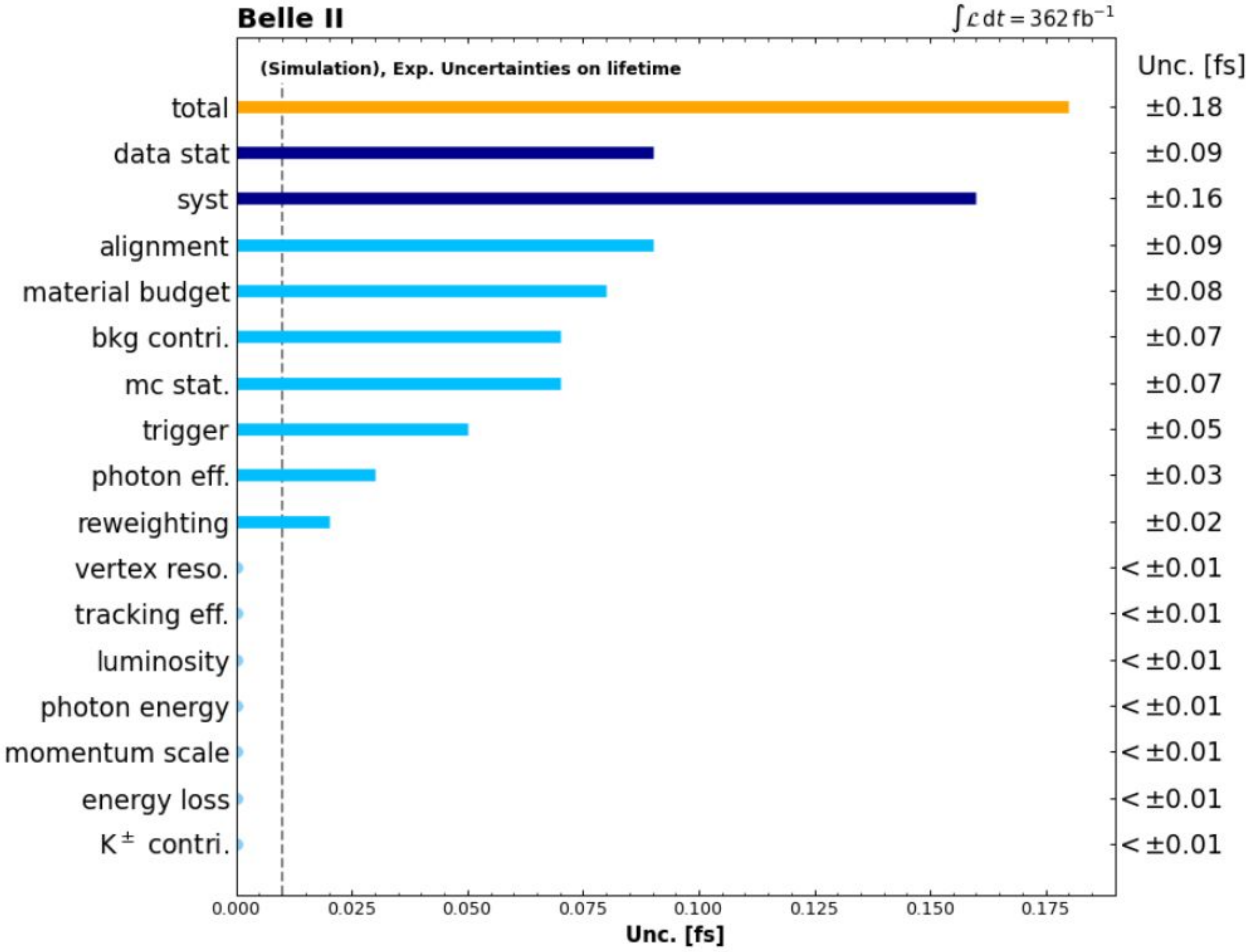
Momentum scale
- Vary correction to alternative values
- Estimate each systematic source independent
- Variation can affect MC and/or Data
  - Estimate systematic unc. independent
  - Transfer residuals from data variation on MC templates

⇒ 8 NPs

Photon efficiency and energy
- Vary correction to alternative values
- Estimate each systematic source independent

⇒ 2 NPs

Fit results with nominal template as pseudo data set

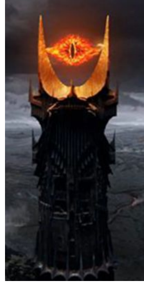


Results

- Analysis dominated by systematic uncertainties
- Alignment, material and background systematic uncertainty are dominating
- Momentum scale uncertainties have negligible impact
- Only photon efficiency with sizeable impact

Reminder: PDG(2014) uncert is +/- 0.5 fs

Summary and outlook



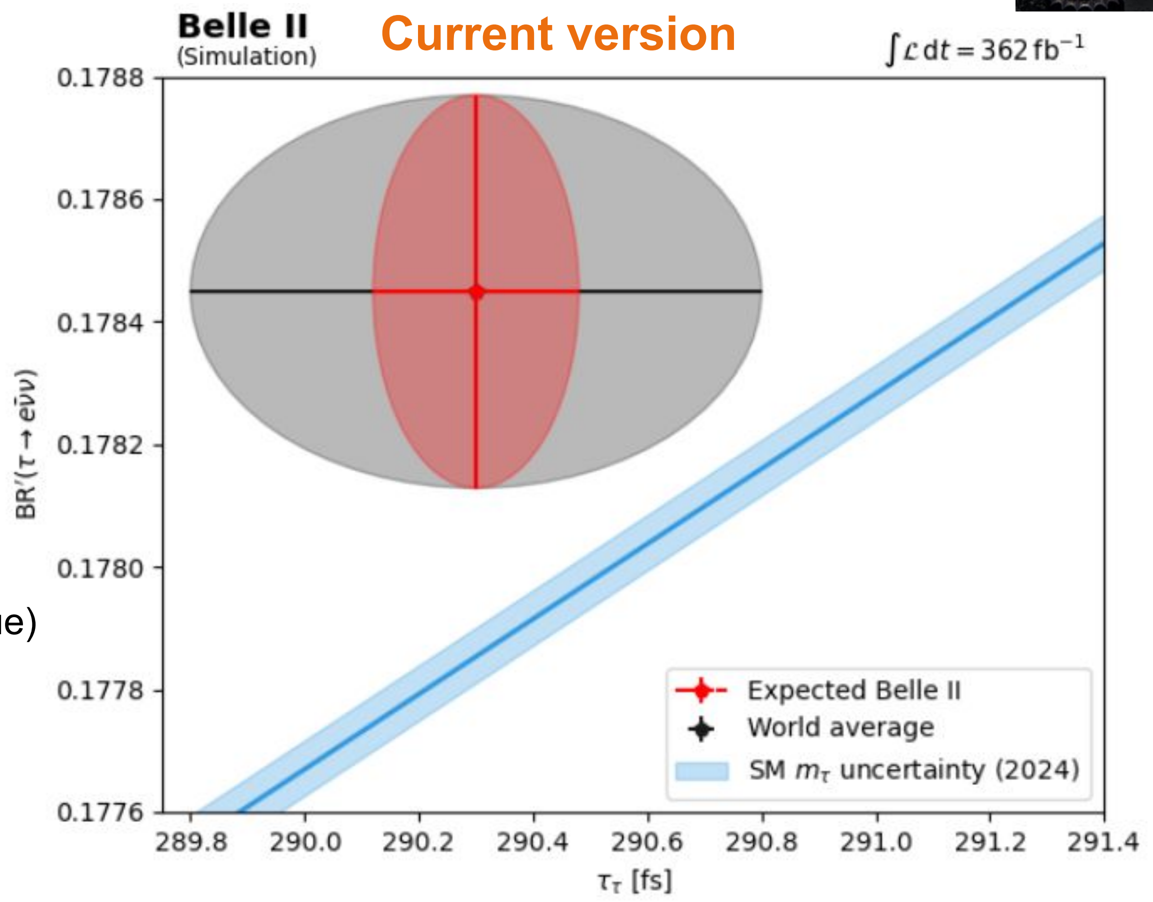
Open points

- Misalignment systematic
  - Reduce from 4 to 1 NP in final setup
- Background contribution systematics (ccbar, llXX, taupair)
  - Switch to final systematic for individual components
- Check impact of IP resolution on result
  -> Blinded data fit studies
- Some fine tuning of shape fit
  - Binning and window cut in decay length
- Note content almost ready, currently text and layout polishing
- Started with paper skeleton

Next steps:

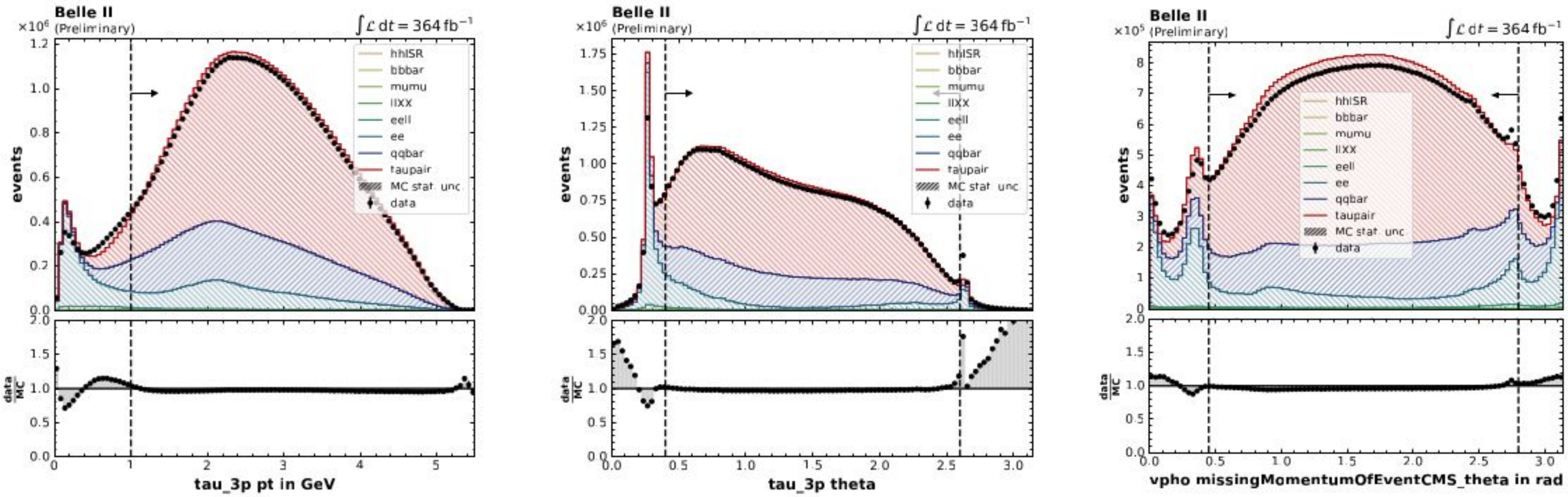
- Want to start with “blinded” data fit studies (no distribution and lifetime value)
  - We see that our main systematic unc. have quite some correlation
  - Check behaviour of NPs (pulls and constraints) with data
- Run data fits in different region of phase space without unblinding
  - Check difference between the lifetime values of the individual fits
    -> E.g. as function of τ kinematics and event kinematics

⇒ Ensure fit and lifetime stability



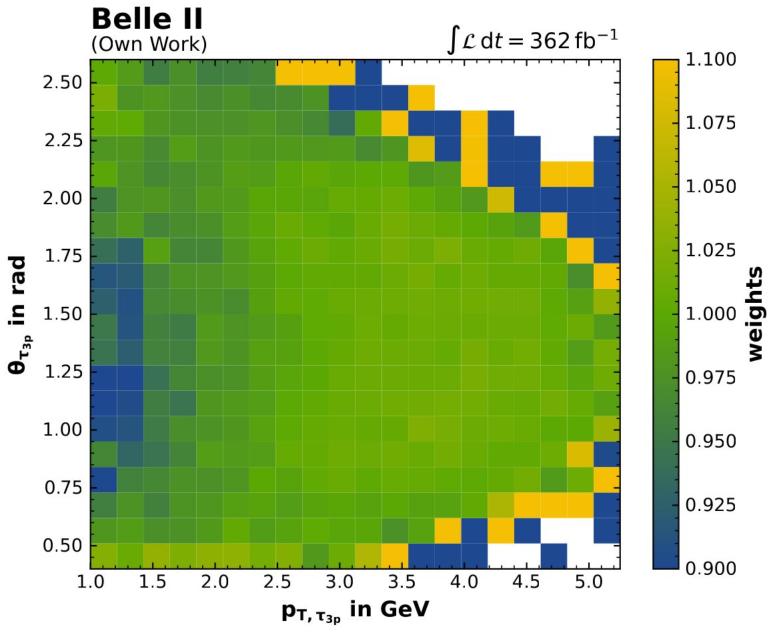
Backup

Event selection examples



- Reduce background contribution
- Remove not well modelled region of phase space

MC reweighting



How do reweight?

- 2D reweighting of τ_{3p} p_T and θ

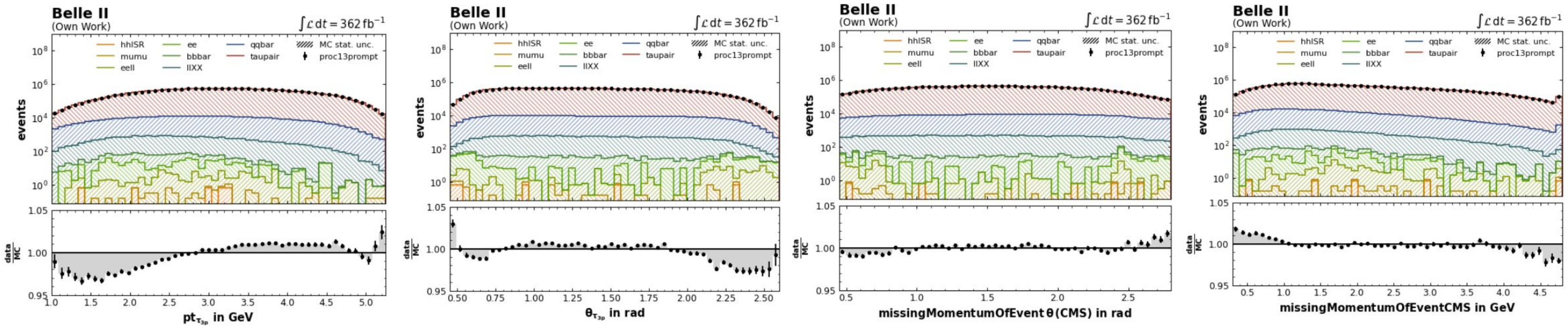
How to verify reweighting?

- Check modelling of 1-d projection in τ_{3p} p_T and θ after reweighting
- Check modelling of other variables after reweighting

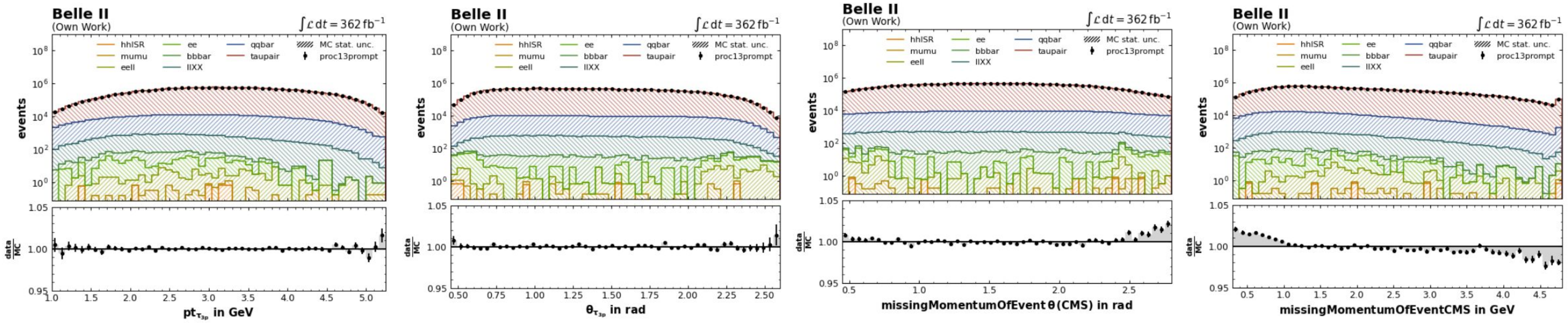
Benefits of re-weighting

- Kinematic correction of events
  - Includes effects from ISR/FSR, but also e.g. momentum scale correction
- Reduces impact of mis-modelling on final result

Before



After



τ-lifetime templates

Challenge:

- Need high MC statistic to be able to improve Belle result
- Cannot produce new MC for each lifetime template

Solution:

- Produce only one nominal template (290.57 fs)
- Produce alternative template via re-weighting
- Weights calculated on generator level
- Weights applied on reconstructed events

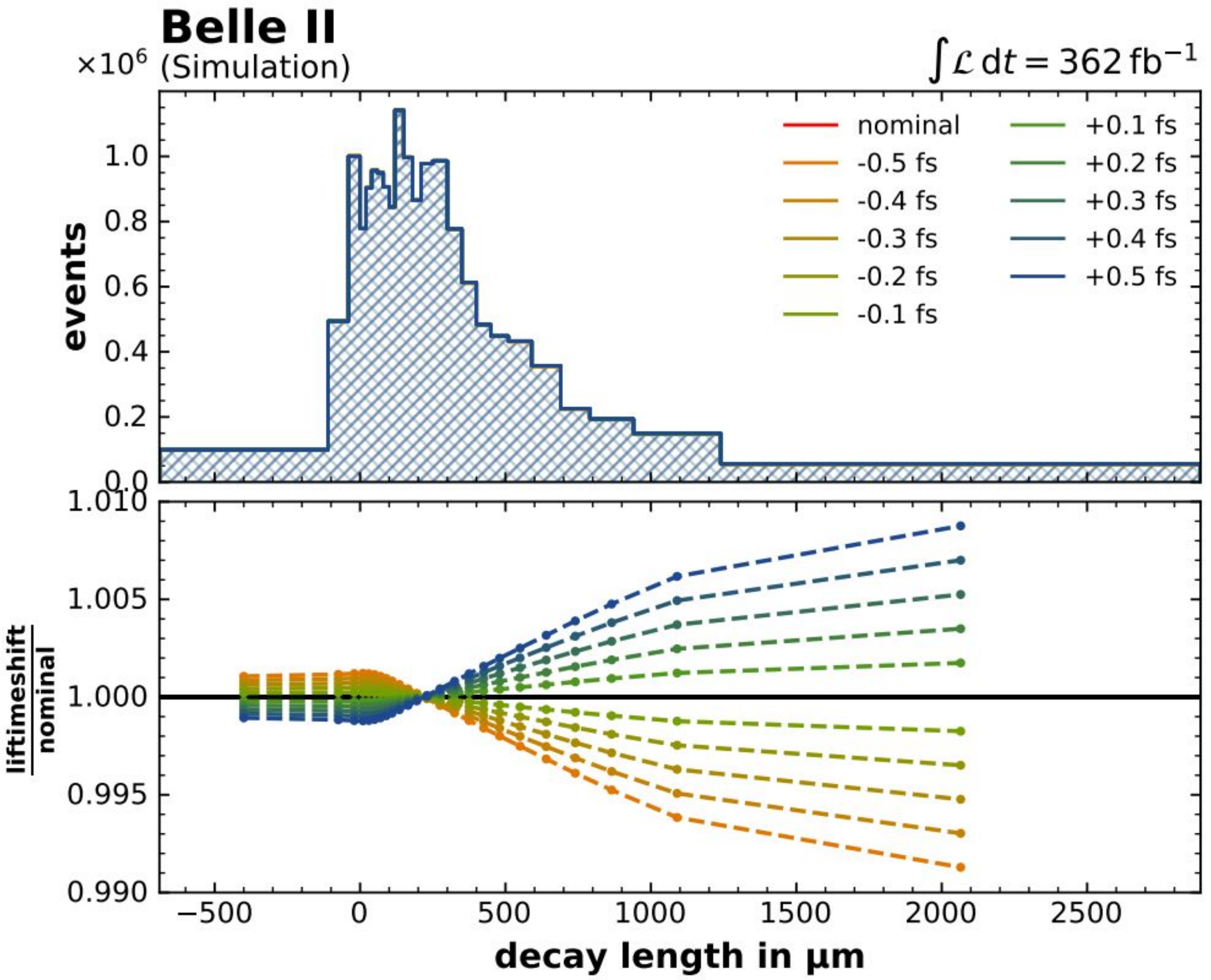
Weights:

$$w_{\bar{\tau}} = \frac{\bar{\tau}}{\tau} \cdot \frac{e^{\frac{-t}{\tau}}}{e^{\frac{-t}{\bar{\tau}}}} = \frac{\bar{\tau}}{\tau} \cdot e^{\frac{t}{\bar{\tau}} - \frac{t}{\tau}}$$

$$w_{\bar{\tau}} = \frac{\bar{\tau}}{\tau} \cdot e^{\frac{d}{c} \cdot \left(\frac{1}{\bar{\tau}} - \frac{1}{\tau}\right)}$$

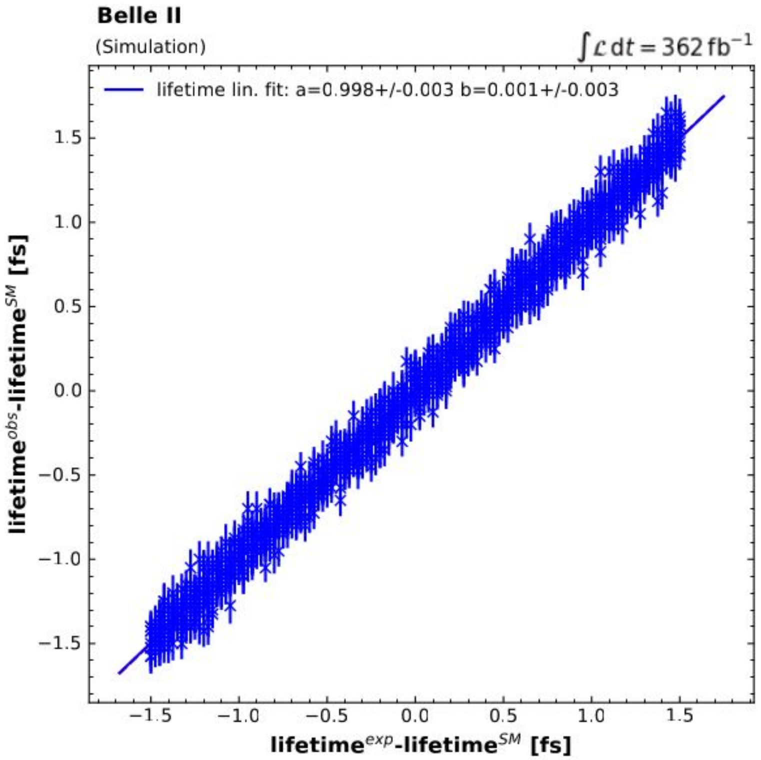
Assumption:

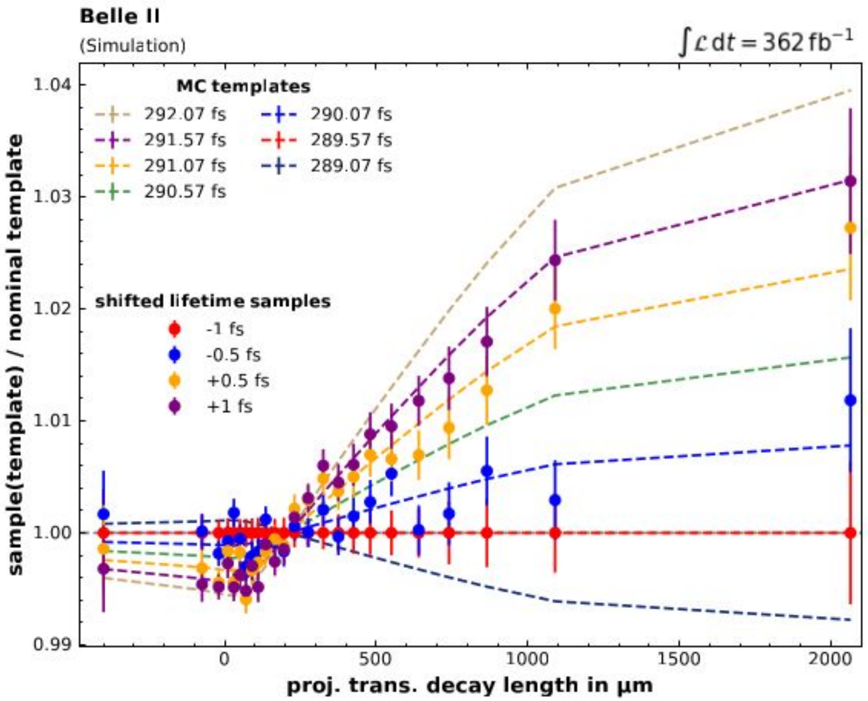
- Resolution function does not depend on decay length

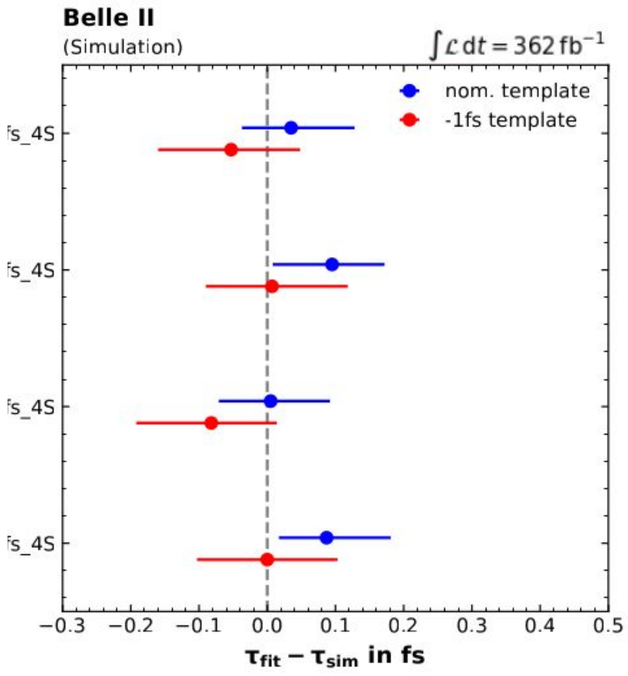


It's all about the shape!
Need precise MC modelling!

Method validation







Fit validation -> Toy study:

- Use radom MC lifetime template to create pseudo data
- Add stat. fluctuation per bin -> multiply random var with gaus(n,√n)

Result:

- No bias observed

Lifetime re-weighting validation:

- Produce additional MC samples with shifted lifetime
- Compare to re-weighted distribution
- Fit re-weighted templates to alternative samples as pseudo-data

Result:

- No bias observed

MC samples and object definitions

MC samples

- Run-depended Monte carlo `MC15rd` (4x data set size)
- TauThrust skim used

Signal definition:

- Use all $\tau \rightarrow 3$ prong events

	Process	σ [nb]	$\int \mathcal{L}dt$ [fb^{-1}]	N [10^6]
$\tau^+\tau^-$	$e^+e^- \rightarrow \tau^+\tau^-$	0.919	1455.052	1.34×10^3
$q\bar{q}$	$e^+e^- \rightarrow c\bar{c}$	1.329	1455.052	1933.76
	$e^+e^- \rightarrow d\bar{d}$	0.401	1455.052	583.48
	$e^+e^- \rightarrow s\bar{s}$	0.383	1455.052	557.28
	$e^+e^- \rightarrow u\bar{u}$	1.605	1455.052	2335.36
$b\bar{b}$	$e^+e^- \rightarrow B^+B^-$	0.54	1455.052	785.73
	$e^+e^- \rightarrow B^0\bar{B}^0$	0.51	1455.052	742.08
$\ell\ell(\gamma)$	$e^+e^- \rightarrow e^+e^-(\gamma)$	295.8	36.3731	10 759.16
	$e^+e^- \rightarrow \mu^+\mu^-(\gamma)$	1.148	1455.052	1670.40
$e^+e^-\ell\ell$	$e^+e^- \rightarrow e^+e^-e^+e^-$	39.55	363.767	14 386.98
	$e^+e^- \rightarrow e^+e^-\mu^+\mu^-$	18.83	363.767	6849.73
$\ell\ell XX$	$e^+e^- \rightarrow e^+e^-\pi^+\pi^-$	1.895	363.767	689.34
	$e^+e^- \rightarrow e^+e^-K^+K^-$	0.0798	363.767	29.03
	$e^+e^- \rightarrow e^+e^-p\bar{p}$	0.0117	363.767	4.26
	$e^+e^- \rightarrow e^+e^-\tau^+\tau^-$	0.01836	363.767	6.68
	$e^+e^- \rightarrow \mu^+\mu^-\tau^+\tau^-$	1.441×10^{-4}	363.767	5.24×10^{-2}
	$e^+e^- \rightarrow \tau^+\tau^-\tau^+\tau^-$	2.114×10^{-7}	363.767	7.69×10^{-5}
hhISR	$e^+e^- \rightarrow K^+K^-\gamma$	0.0163	363.767	5.93
	$e^+e^- \rightarrow K^0\bar{K}^0\gamma$	0.008864	363.767	3.22
	$e^+e^- \rightarrow \pi^+\pi^-\gamma$	0.1667	363.767	60.64
	$e^+e^- \rightarrow \pi^+\pi^-\pi^0\gamma$	0.02378	363.767	8.65

Object definitions:

Tracks

Parameter	Value Range	Description
`abs(dz)`	< 3 cm	distance of the track to IP in z
`dr`	< 1 cm	point of closest approach in r-ϕ plane
`nTracks`	4	number of tracks
`sum(charge)`	0	net charge of the event

For all tracks pion hypothesis used
-> Impact study (slide)

Photons

Parameter	Value Range
`abs(clusterTiming)`	< 200
`cosTheta`	$-0.8660 <$ `cosTheta` < 0.9563
`clusterNHits`	> 1.5
`isDescendantOfList(pi0)`	0
`E`	0.2 GeV
`minC2TDist or E`	> 40 or > 0.4

minC2TDist or E cut only applied in TauThrust skim

Pi0

Parameter	Value Range
`abs(clusterTiming)`	< 200
`cosTheta`	$-0.8660 <$ `cosTheta` < 0.9563
`clusterNHits`	> 1.5
`minC2TDist or E`	> 40 or > 0.4
`leadingclusterEn`	Depending on detector region
`subleadingclusterEn`	
`cosAngle2Photons`	
`p`	
$M_{\gamma 1} + M_{\gamma 2}$	$0.115 < M_{\gamma\gamma} < 0.152$ GeV

Pseudo vertex resolution

Definition

- Shortest distance between vertex of the two sub-leading tracks and the leading track

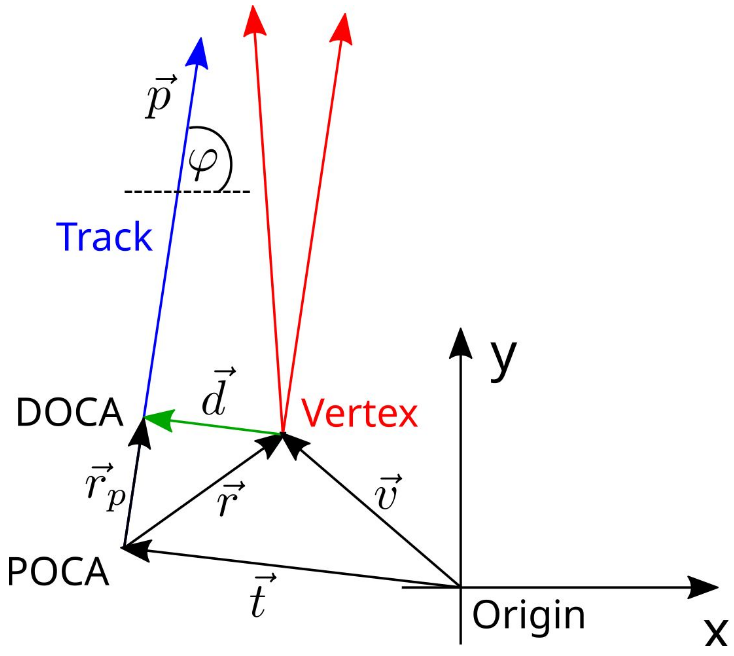
Event selection

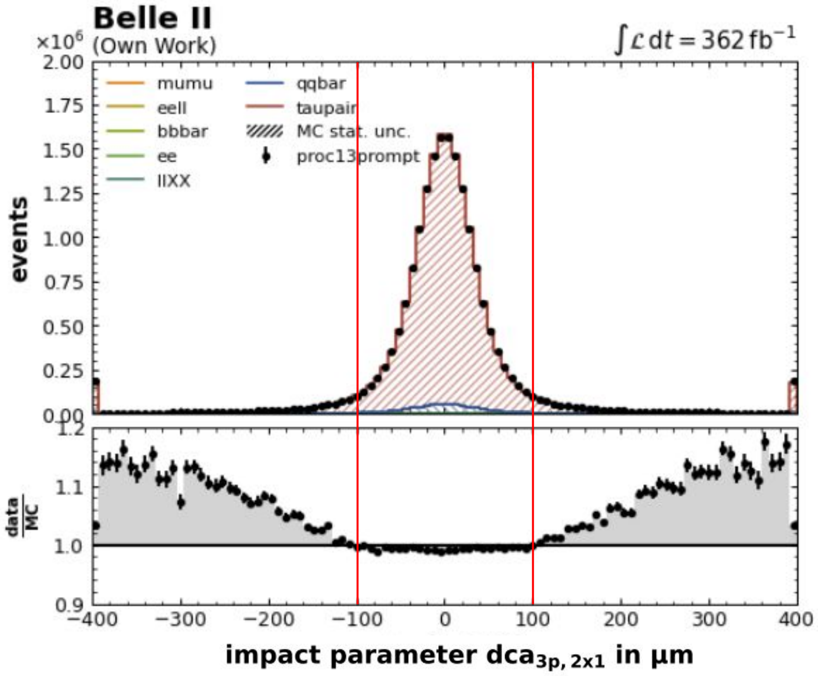
- Bad modelling in tails only in tails (events with “bad” vertexing)
- Events in tails are mainly in not well modelled PXD region e.g. clue gaps
- Cutting removes events with bad vertexing -> Mainly event without PXD hits

⇒ Use windows cut [-100,100] μm

Systematic uncertainty

- Estimate systematic that covers potential vertex mismodelling between data and MC
- Use shape difference between MC and data after selection

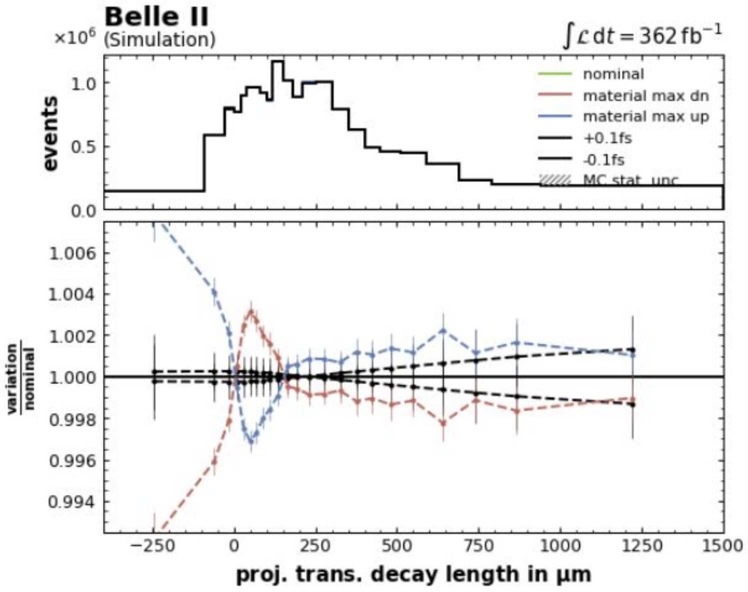




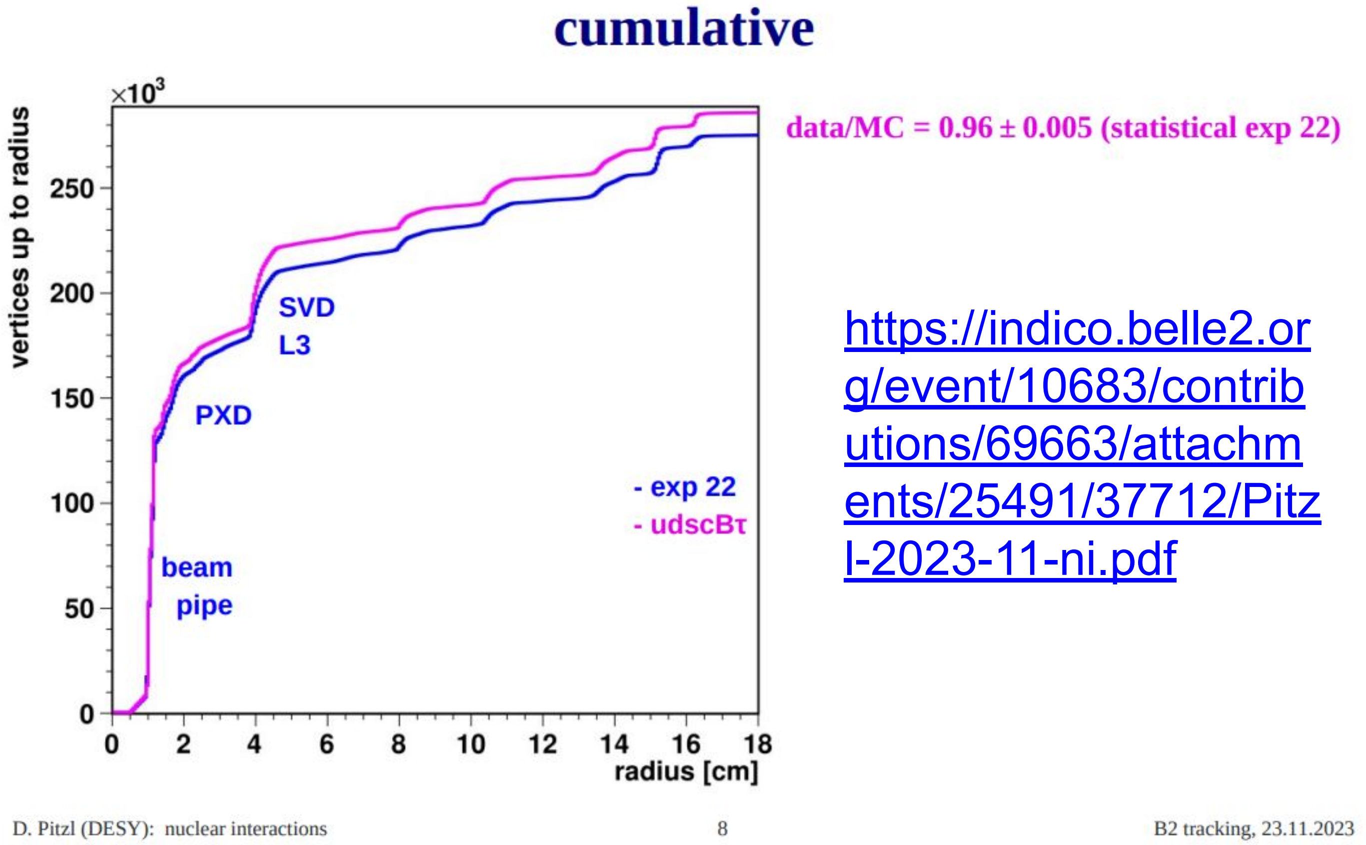
Material budget

- Produced new samples (MC15ri, 1ab^{-1})
- Use same strategy as previous papers (e.g. tau mass)
  - Vary material density of beampipe by 5% (up/dn)
- This strategy is just an approximation
  - Beampipe shows only ~2% variation
  - PXD and SVD L3 also important (total cumulative 5% variation)

  -> We put all the variation into the beampipe
- We started with a toy study to check if this under/overestimates the true material budget impact
- Correct implementation would need to vary density of silicon as well (large effort to produce)



Nuclear interaction

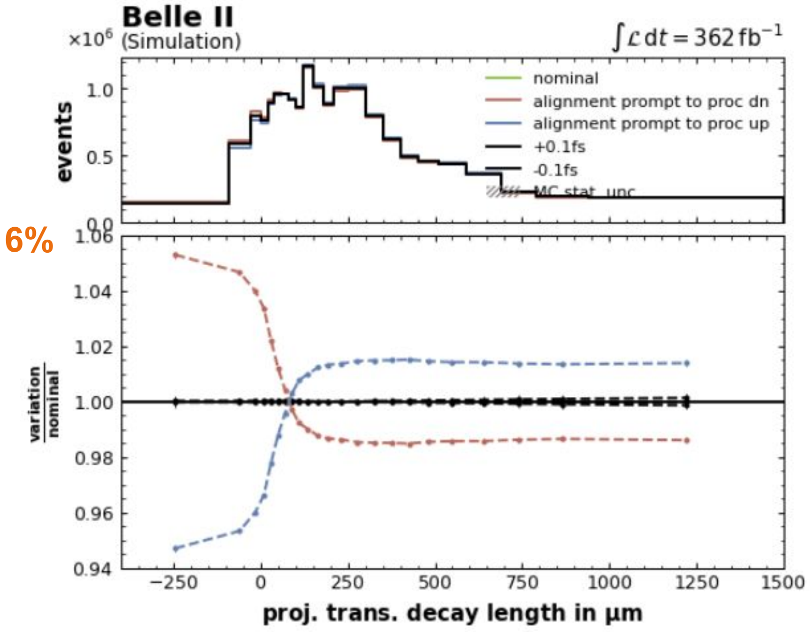


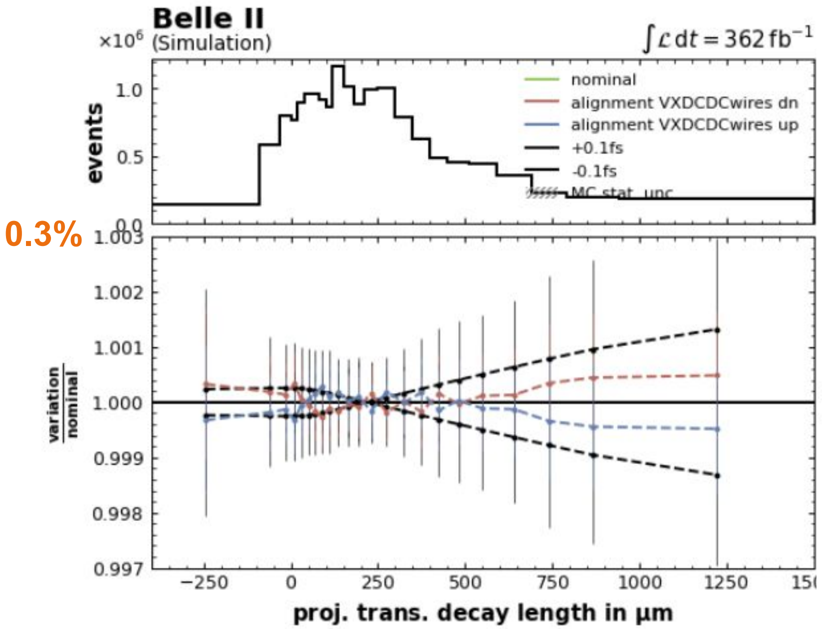
https://indico.belle2.org/event/10683/contributions/69663/attachments/25491/37712/Pitzl-2023-11-ni.pdf

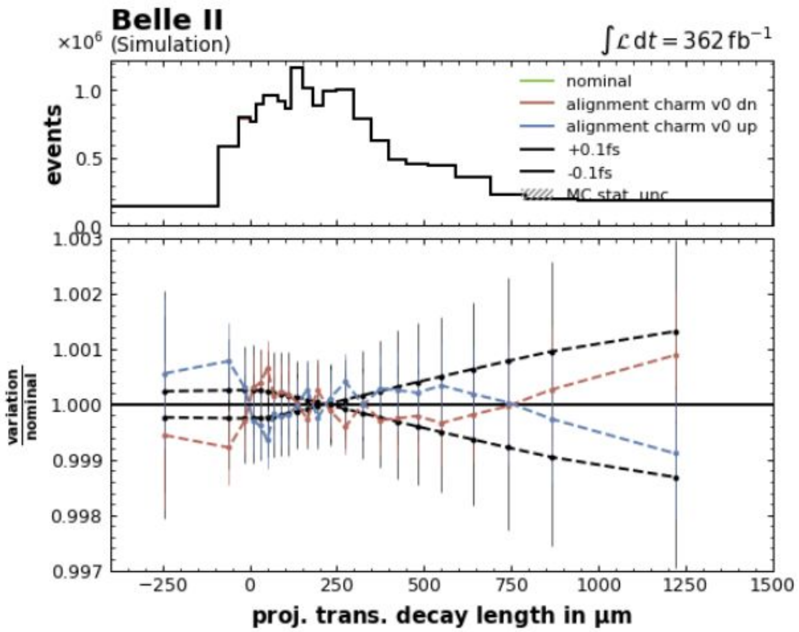
- Similar study for photon conversion showed similar size but reversed sign (up/dn variation)

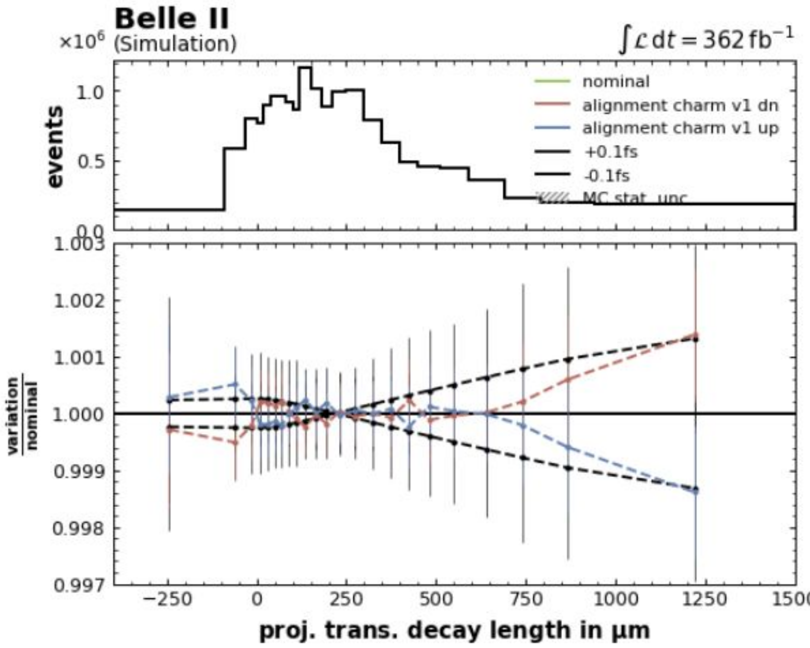
Misalignment

- Produced new samples (MC15ri, 50fb^{-1})
  - Hopefully soon 500 fb^{-1}
- Four different alignment scenarios
  - Include all four as independent NPs
- Prompt to proc show by far largest variation (less affect by statistic)
- Other scenarios one magnitude smaller -> more affected by low statistic
  - Multiple zero crossing (reduces impact on lifetime)
  - Impact could be sizable after increasing statistic
- Each scenario gives only a one sided systematic
  -> Fully symmetrize each variation around nominal -> very conservative









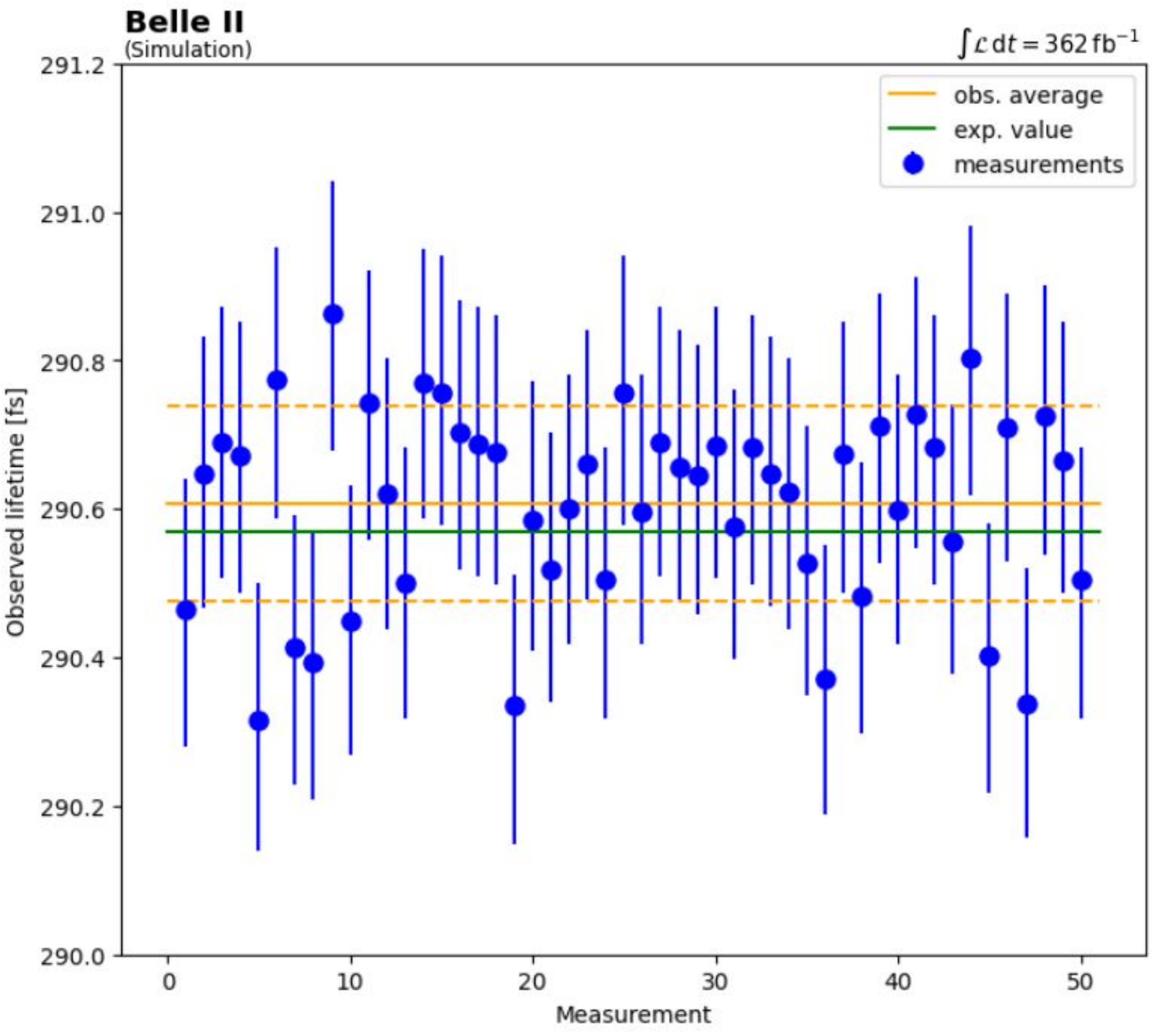
Final stability test

Setup

- Use nominal template as base for pseudo data set
- Add Gauss fluctuation on each bin to mimic data stat fluctuations
- Created 50 pseudo data sets

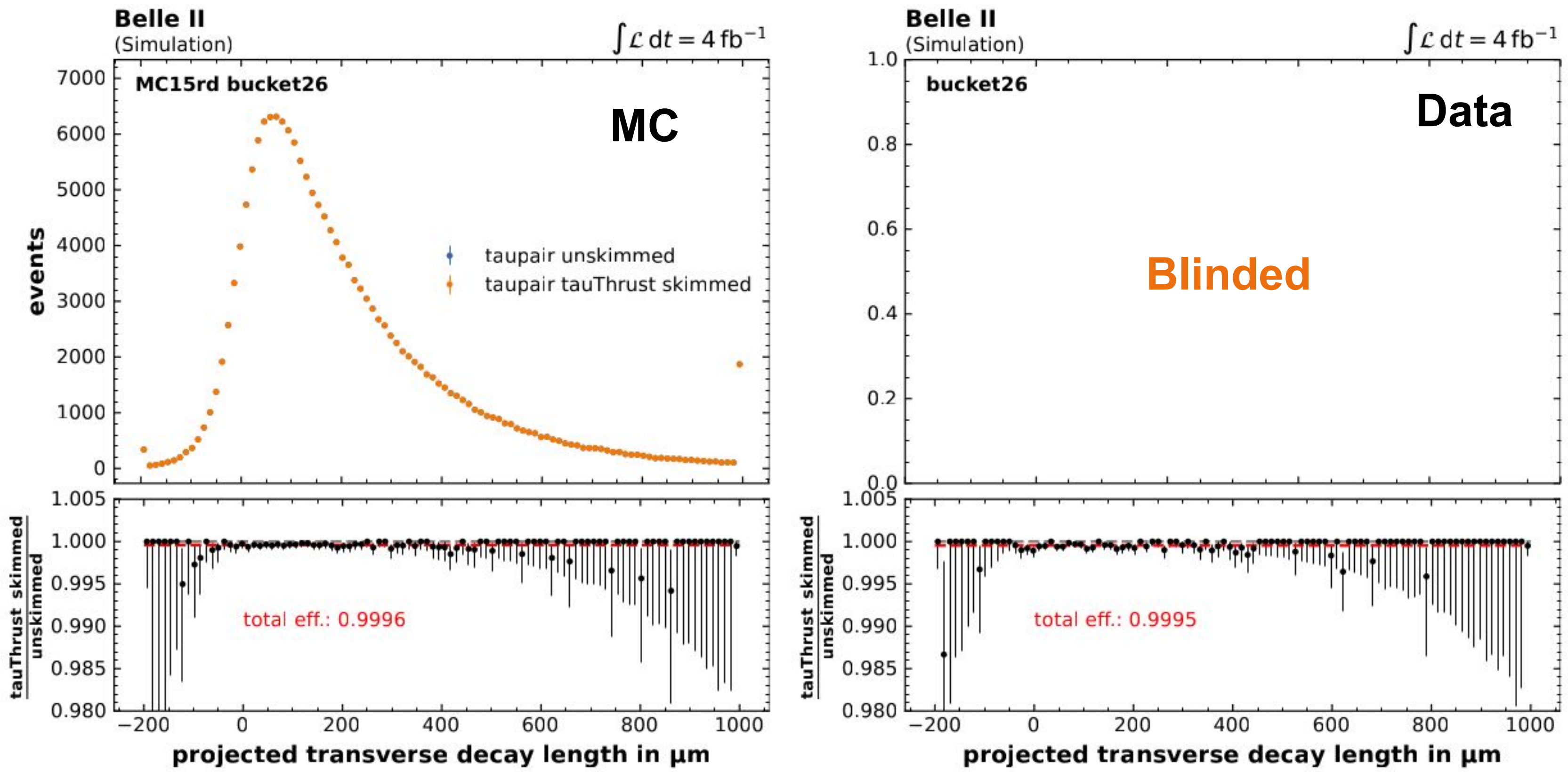
Results

- No bias observed
- Fit seem stable against data stat. fluctuation



Impact of TauThrust skim

- Check impact of TauThrust skim on event selection



- Efficiency over 99.95 % for data and MC
- Efficiency flat over decay length distribution

⇒ Impact of TauThrust skim negligible

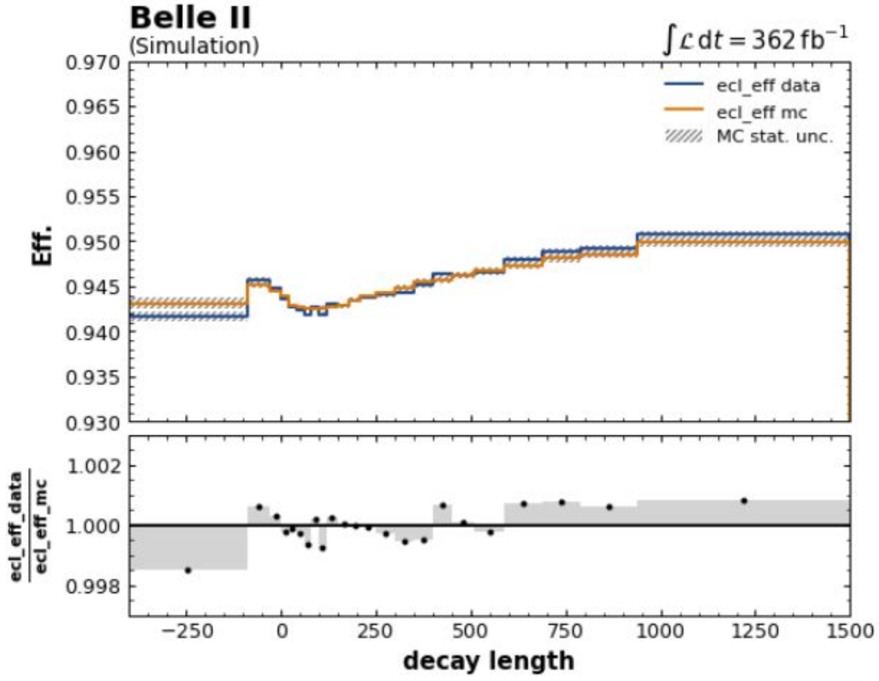
Trigger efficiency

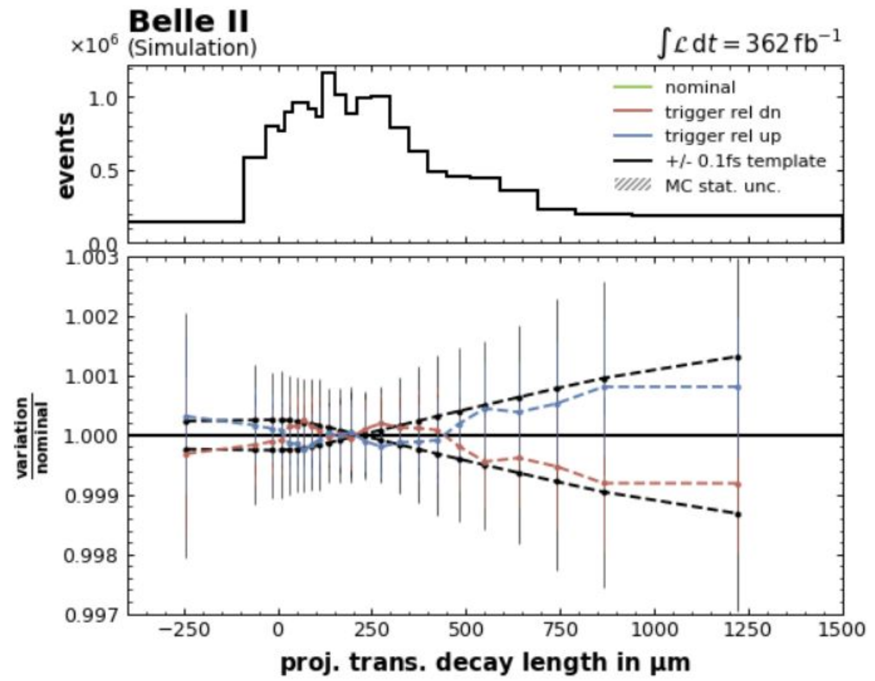
- Estimate rel. trigger eff. in data and MC
  - Use orthogonal CDC trigger as reference

    rel. eff. trg (ecl) = N(ecl $\wedge$ cdc) / N(cdc)

Trigger Bit	$\varepsilon_{\text{trg}}^{\text{signalregion}}$ Exp. Data	Sim. Data
hie	0.856	0.853
lml0	0.513	0.512
lml1	0.123	0.125
lml2	0.011	0.011
lml4	0.000	0.000
lml6	0.088	0.082
lml7	0.005	0.004
lml8	0.151	0.149
lml9	0.215	0.216
lml10	0.439	0.435
lml12	0.792	0.792
lml13	0.058	0.055
Total	**0.949**	**0.944**

- Derive systematic from difference between data and MC
- Include systematic in Likelihood as NP
  -> Only one-sided variation -> Fully symmetrized around nominal (very conservative)

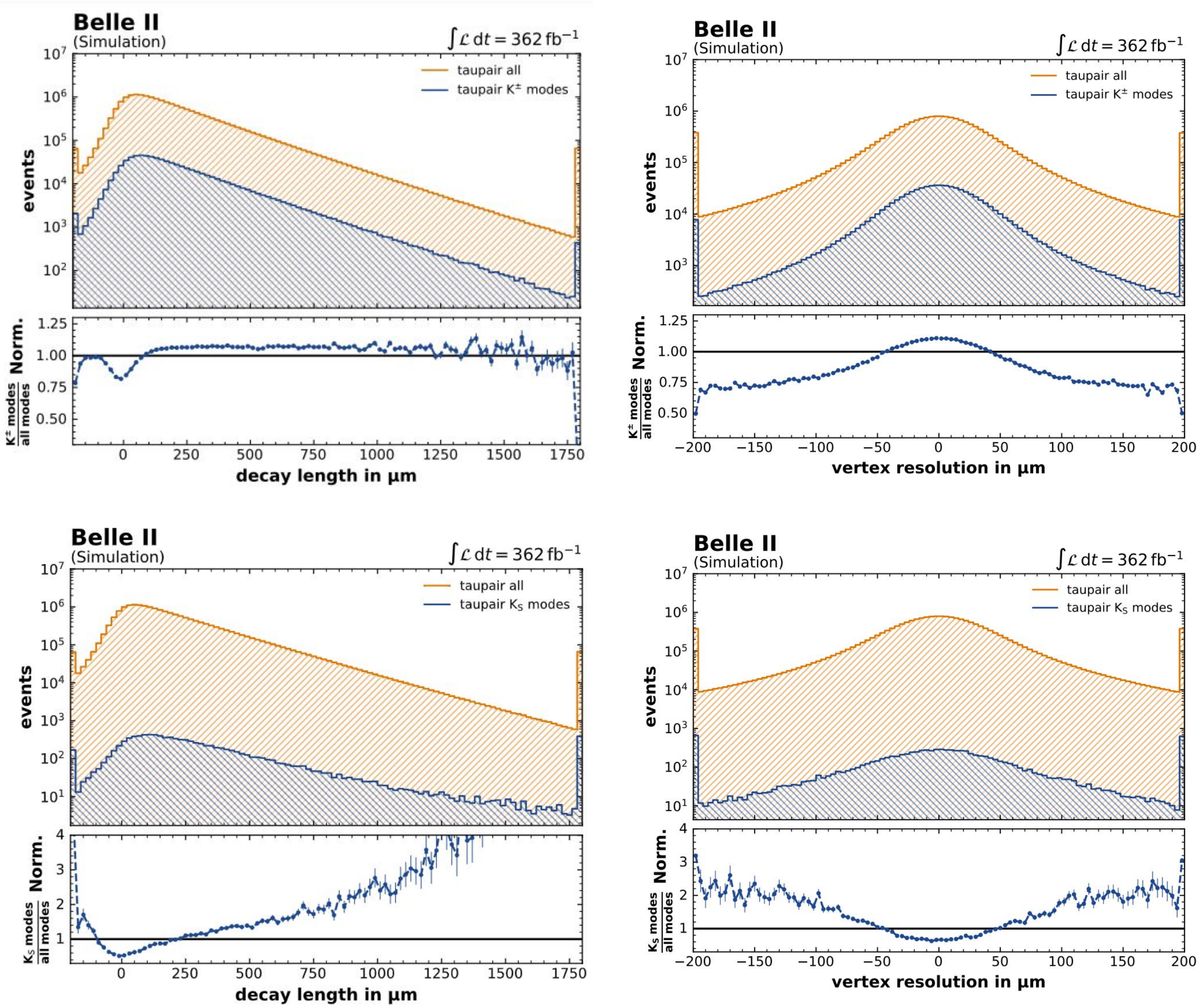




Contributions of tau decays

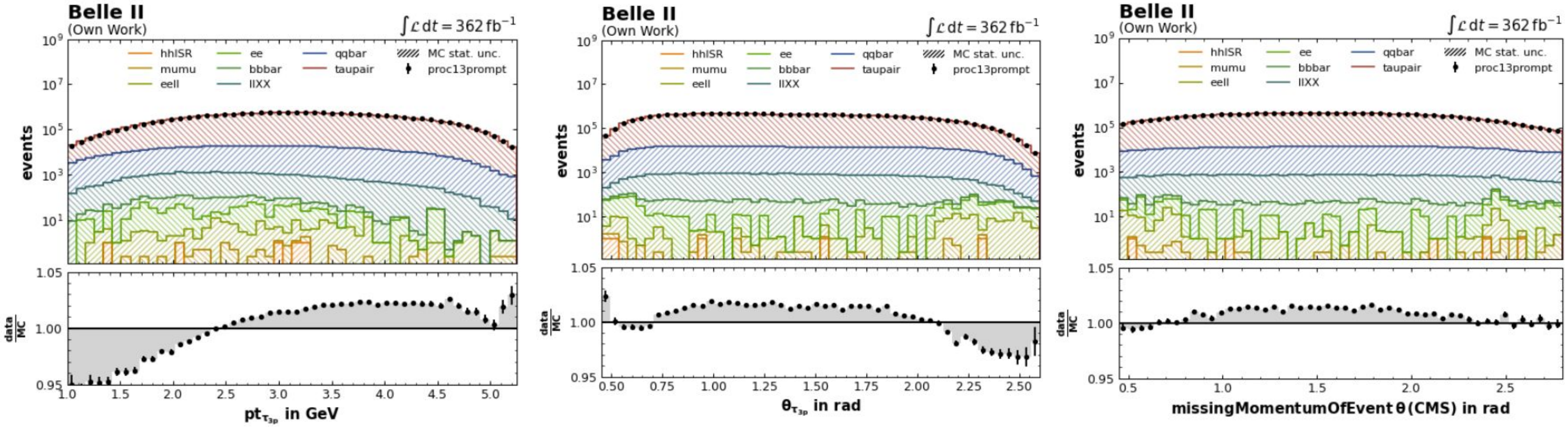
- Check $\tau \rightarrow$ 3 prong events with Kaons in decay
- $K^{\pm}$ sizeable but small contribution (4.39%)
  - Only trend around 0 in decay length
    -> Different vertex resolution
  - Checked impact on tau lifetime fit by vary $K^{\pm}$ by branching fraction uncertainty
    -> No impact on result
- K^0_s negligible contribution (0.06%)

⇒ Decay length distribution not affected by Kaon decay mods

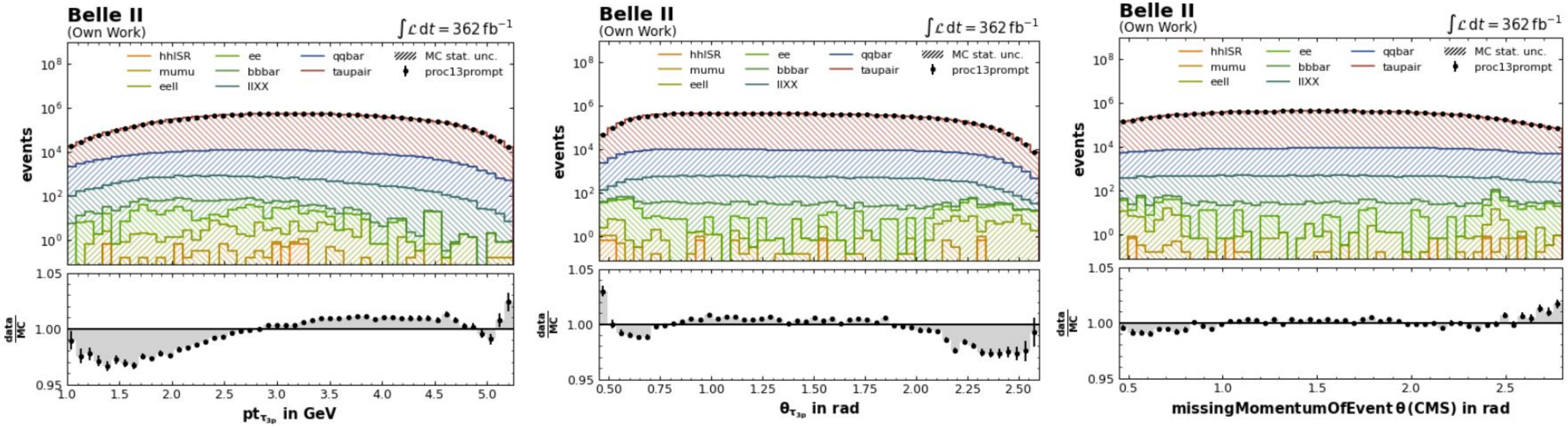


Modelling before after yield correction

Before



After



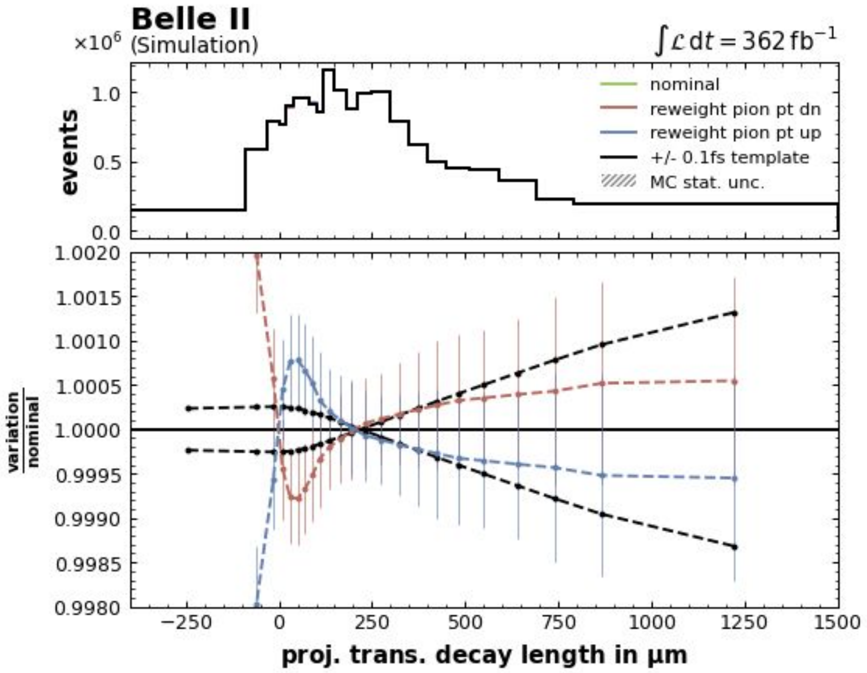
- Modelling of important variables improved after yield correction

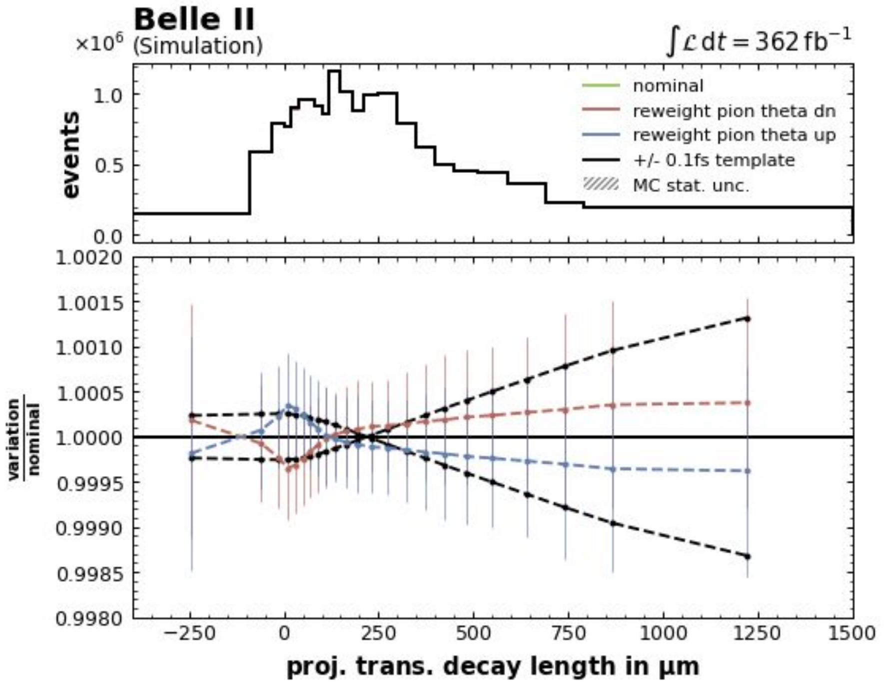
-> Mis-modelling partially introduced by wrong signal to background ratio

MC reweighting

How to assign a systematic uncertainty

- Use two “projected” 3D-reweightings
  - One in all three pions p_T
  - One in all three pions θ
- Estimate difference between both 3D-reweightings and 2D-τ_{3p} in the decay length distribution
- Symmetrize both differences to create up and down variation for each
- Include both as two independent NPs in Likelihood model





ccbar size impact

Group \bkg var.	200 %	150 %	130 %	120 %	110 %
total	0.181	0.178	0.174	0.172	0.170
syst	0.161	0.158	0.153	0.151	0.149
alignment	0.088	0.084	0.081	0.080	0.082
material	0.083	0.076	0.066	0.063	0.057
bkg contri.	0.065	0.056	0.041	0.032	0.018
mc_stat	0.072	0.069	0.066	0.066	0.063
trigger	0.053	0.056	0.055	0.058	0.060
photon_eff	0.027	0.033	0.026	0.032	0.032
reweighting	0.019	0.019	0.019	0.019	0.026
vertex	0.000	0.000	0.000	0.000	0.000
photon_en	0.000	0.000	0.000	0.000	0.000

Lumi and tracking eff. uncertainty

- Both uncertainties have no shape component
- Implement both as normalization uncertainty

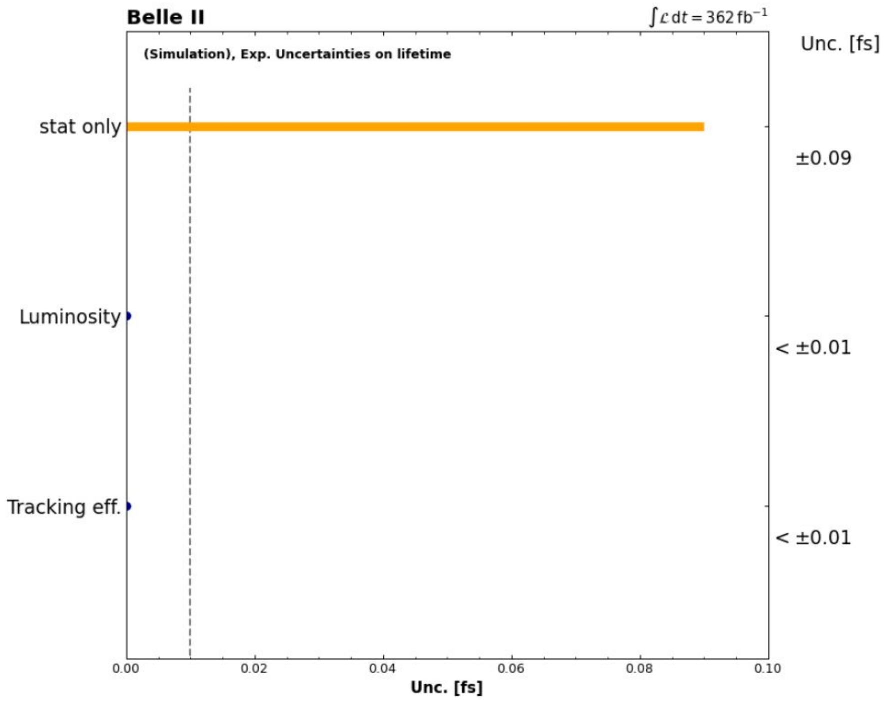
Lumi:
https://arxiv.org/abs/2407.00965

- Lumi Paper: 364.49 +/- 1.64 (0.45 %)

Tracking eff. uncertainty:
https://indico.belle2.org/event/8043/contributions/51113/attachments/20577/30471/tau_eff_f2f_31jan23.pdf

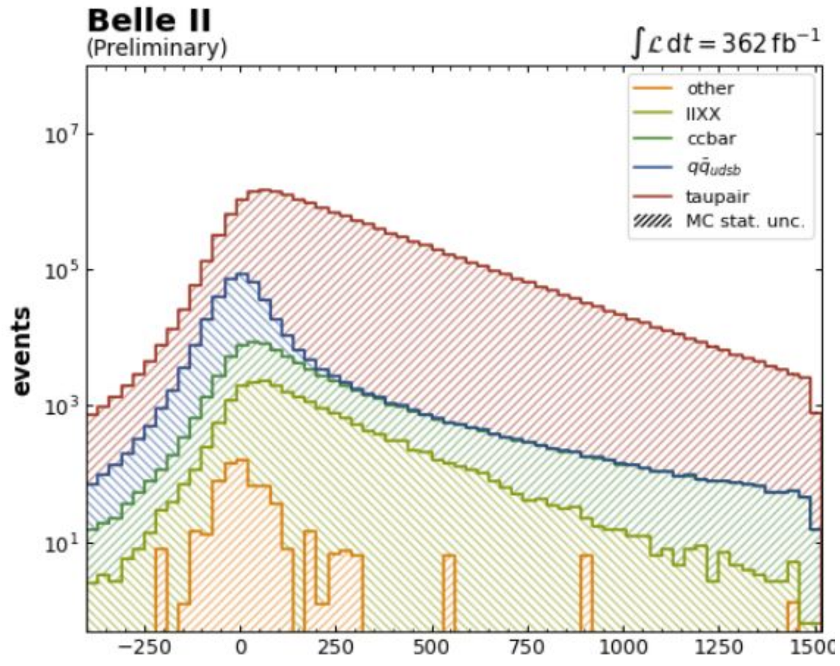
- 0.24 % per track (4-tracks: $0.9976^4 = 0.9904$)
- Unc: 0.96%

- Impact unc. of mu_sig and mu_bkg in normalization fit
  -> Input uncertainty propagates to fit unc.
- No impact on lifetime measurement estimated via shape only



	mu_sig_unc	mu_bkg_unc
data + mc stat.	0.03 %	0.25 %
+ lumi.	0.45 %	0.52 %
+ track. eff.	0.97 %	1.00 %
+ lumi. and track. eff	1.07 %	1.10 %

Background composition llXX



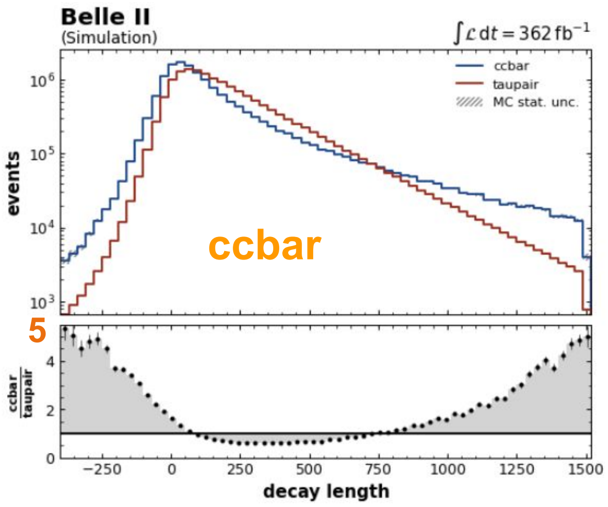
Overview:

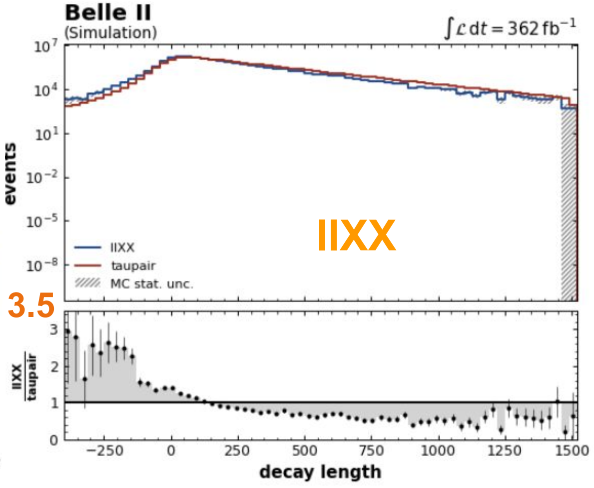
- llXX contains τ-decays -> has lifetime (similar as ccbar)
- llXX one magnitude smaller than ccbar but has different decay shift

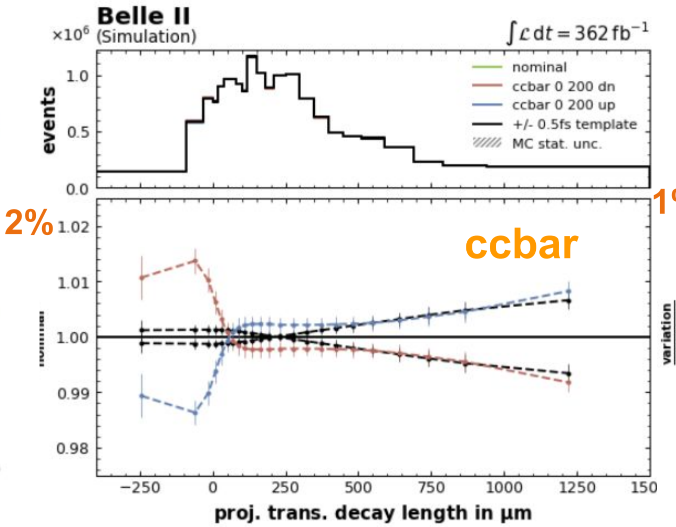
Suggestion:

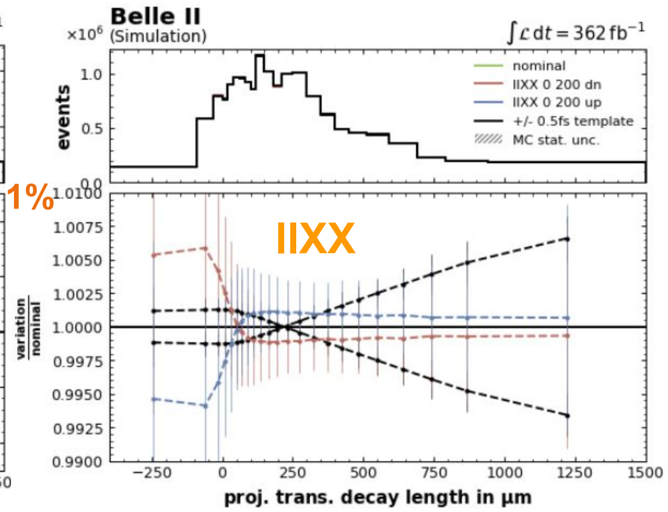
- Vary as for ccbar llXX variation 0 (down) and 200 % (up) (what size is reasonable?)
- Re-scale other background samples (except of ccbar) to keep overall background normalization
- Include as additional NP in fit

-> Until now not included in default fit setup

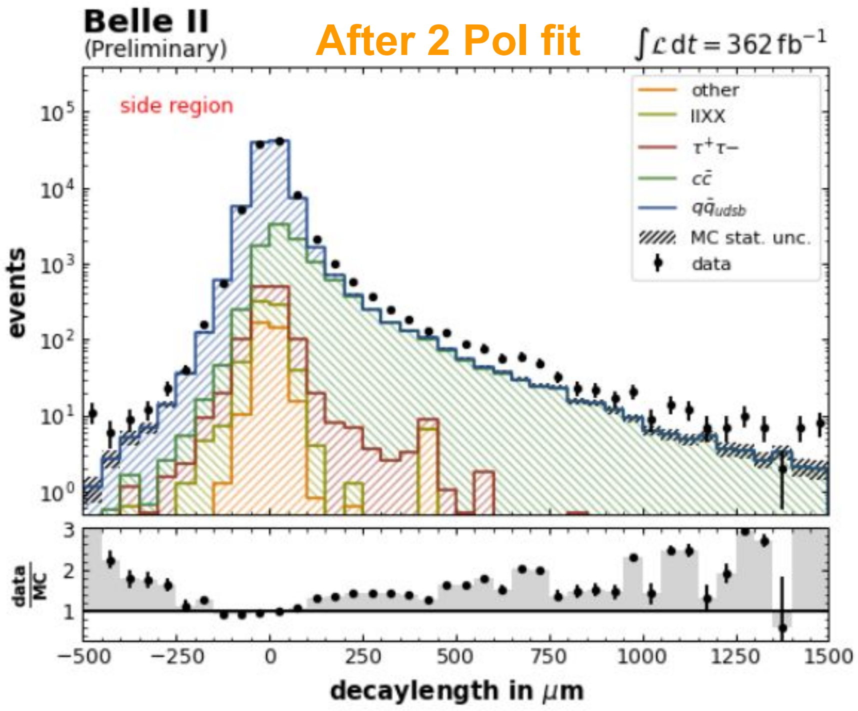


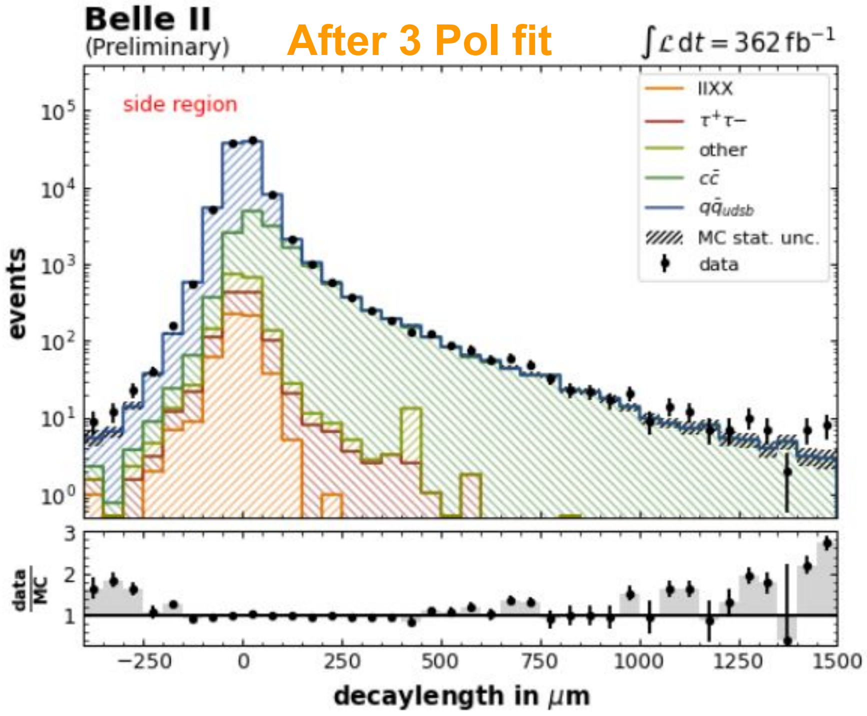






Use the sideband region after 2 and 3 PoI scaling





PoI	result
signal	1.022±0.011
tot. bkg	0.645±0.007

PoI	result
signal	1.023±0.011
ccbar	0.605±0.007
other qqbar	0.972±0.019
llXX	fixed
others	fixed

PoI	result
signal	1.023±0.011
ccbar	0.606±0.007
other qqbar + others	0.973±0.019
llXX	fixed

- Default 2 PoI fit
  - One PoI for signal
  - One PoI for tot. bkg (all bkg scaled)
- Two different 2 PoI fit setting
  - Both fits have
    i. One PoI for signal
    ii. One PoI for ccbar
    iii. Fix llXX
  - First fit has in add.
    i. One PoI for other qqbar
    ii. fixed other bkg
  - Second fit has in add.
    i. One PoI that includes other qqbar and other bkg
- Both 3 PoI results very similar and no differences visible in post-fit distribution
- 2 PoI not sufficient to correct decay length distribution, while 3 PoI is

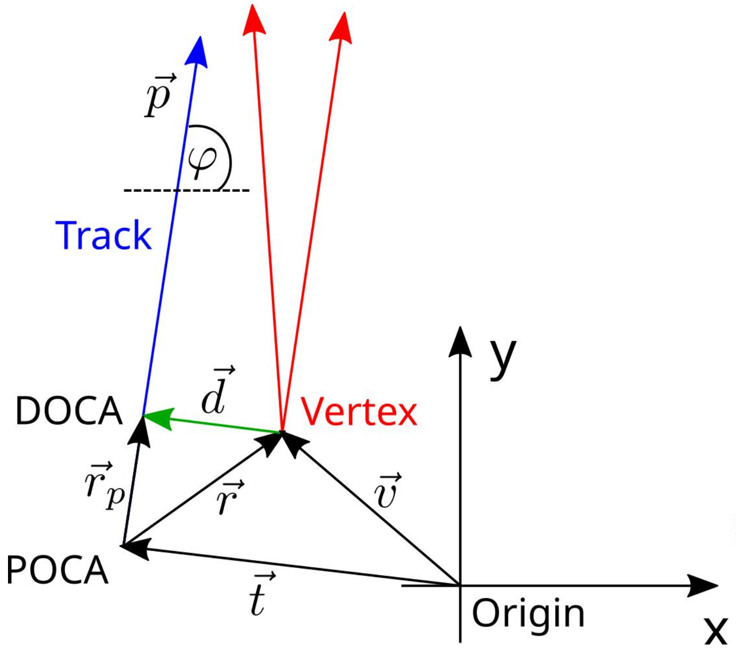
Suggestion:

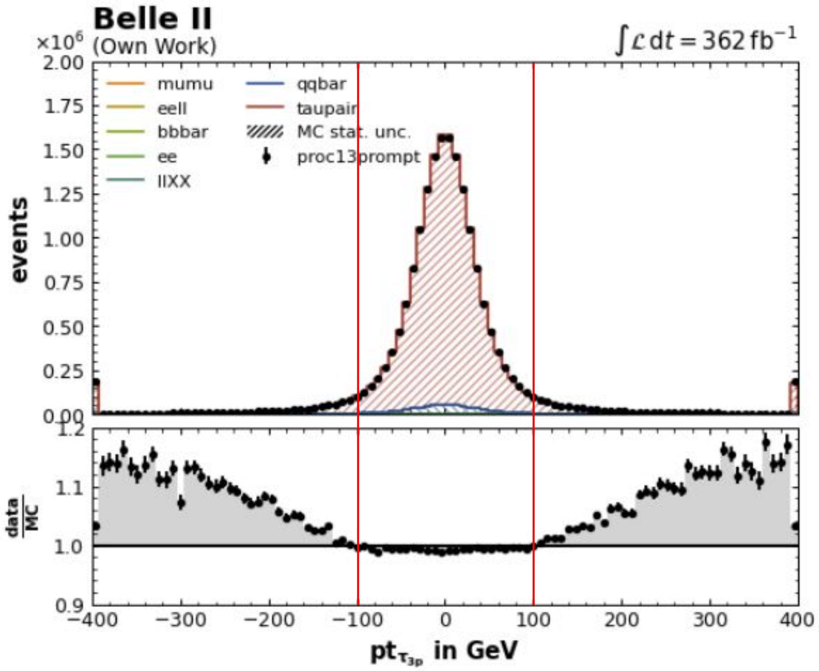
- Use 3 PoI fit to correct ccbar and others separately
- Use uncertainty on ccbar PoI as borders for ccbar variation systematic
- Try to find additional sideregion for llXX to correct it as well
- Some technical things was needed to be implemented

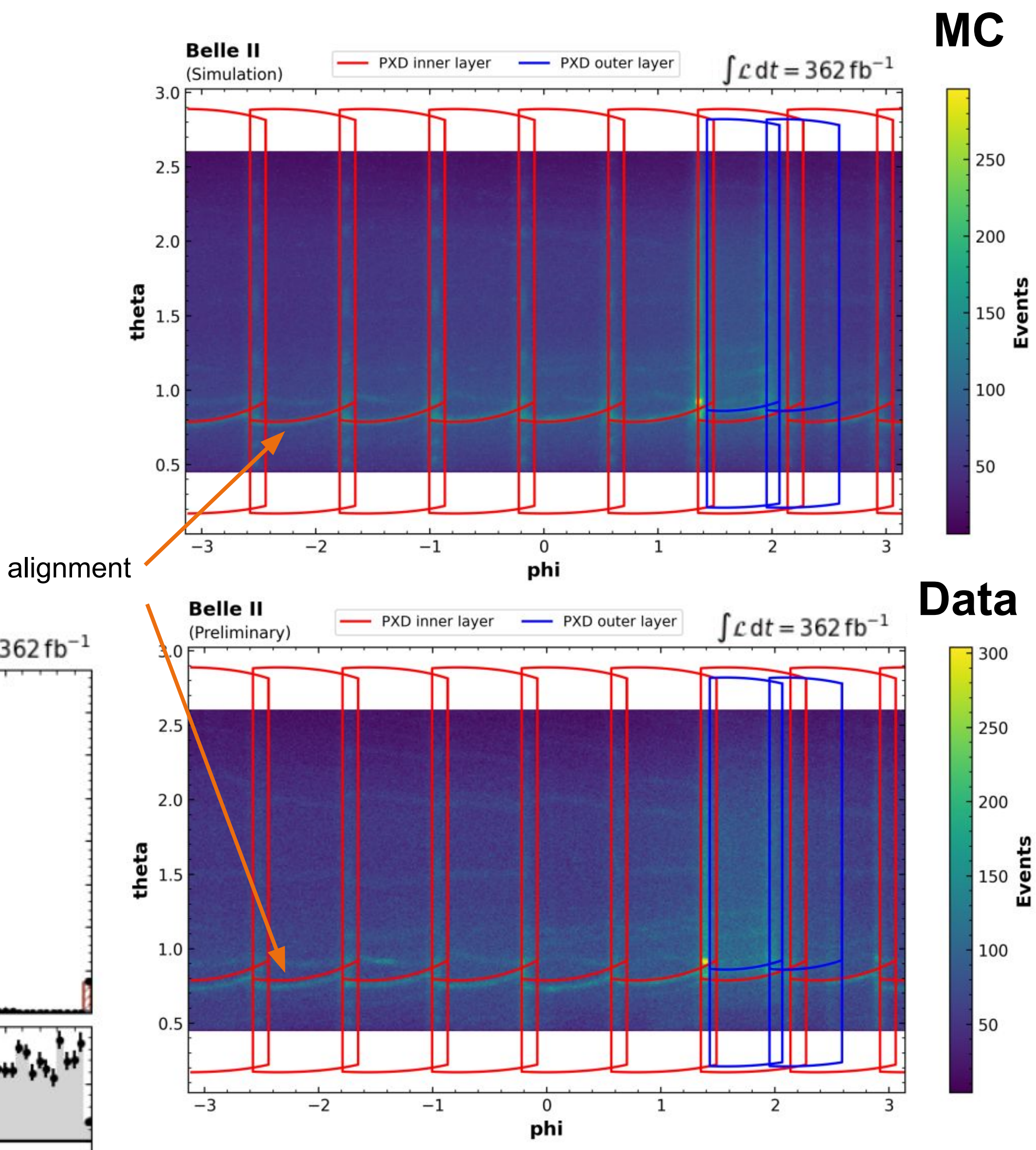
PXD and vertex resolution

- PXD not well modelled in MC (E.g. alignment missing in MC)
  - E.g. Cutting directly on PXD hits increases mismodelling in ϕ
  - But also other modelling of other variables get worse
- Use instead pseudo vertex resolution
  - Bad modelling in tails only in tails (events with “bad” vertexing)
  - Events in tails are mainly in not well modelled PXD region e.g. clue gaps
  - Cutting removes events with bad vertexing/PXD modelling
- Use shape difference between MC and data as systematic uncertainty

⇒ Use windows cut [-100,100] μm







Smoothing

Smoothing:

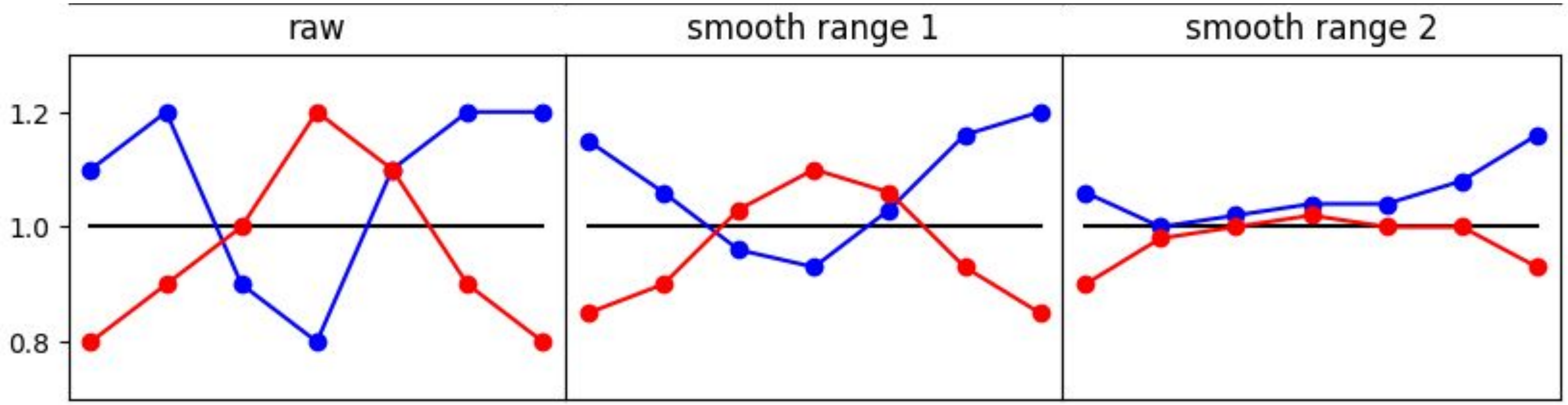
1. Estimate decay length distribution for alternative nominal and variation
   a. Use same binning as default template
2. Calculate ratio between them
3. Remove normalization part (just take shape difference)
4. Smooth histograms with neighbouring bins,
   For each bin calculate variation combined with neighbouring bins
5. Multiply ratio to default template bin-by-bin
   -> Final variation template

Con:

- Events/Bins used in calculation of multiple variations

Pro:

- No sharp edge between two neighbours



Symmetrisation

flip a

Directions of variation:
Bins with variation in different directions
- Keep both

Bins with variation in same directions
- Keep sign of larger variation
- Mirror smaller around nominal

Absolute size of variation:
- Keep size of both

sym. average

Directions of variation:
Bins with variation in different directions
- Keep both

Bins with variation in same directions
- Keep sign of larger variation
- Mirror smaller around nominal

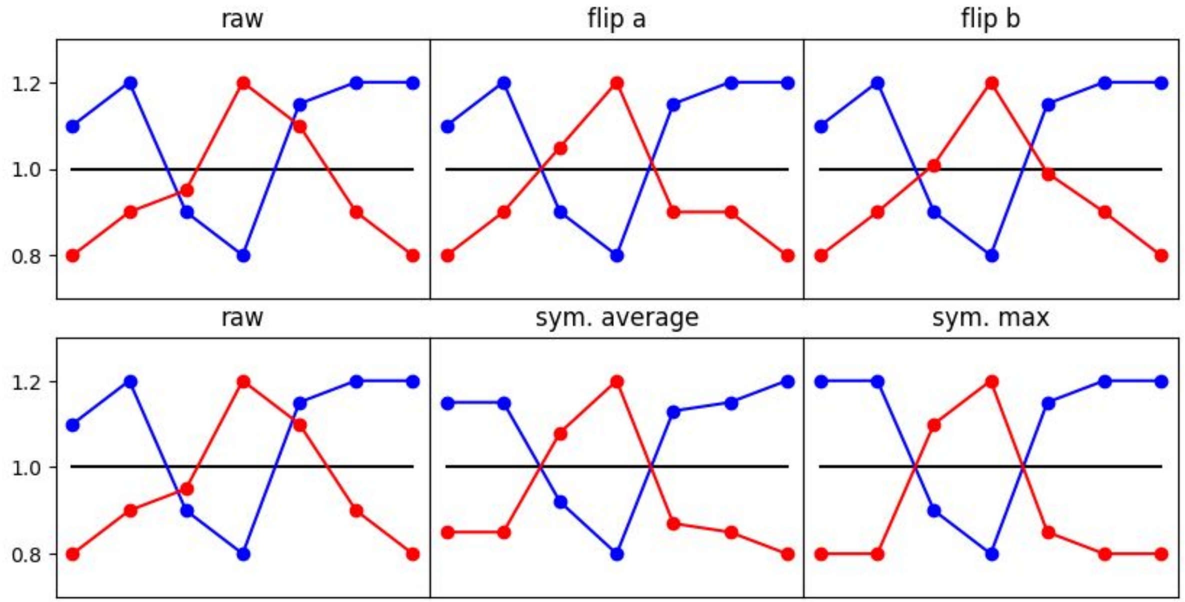
Absolute size of variation:
- Set absolute size of both to abs. average of both

sym. max

Directions of variation:
Bins with variation in different directions
- Keep both

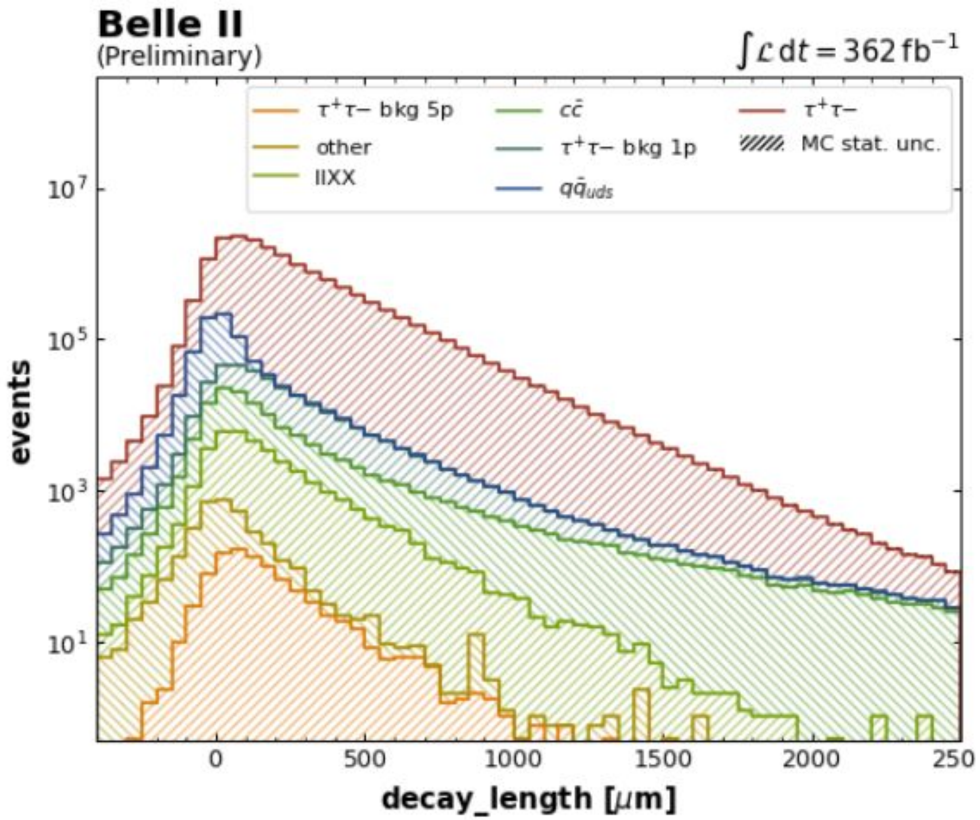
Bins with variation in same directions
- Keep sign of larger variation
- Mirror smaller around nominal

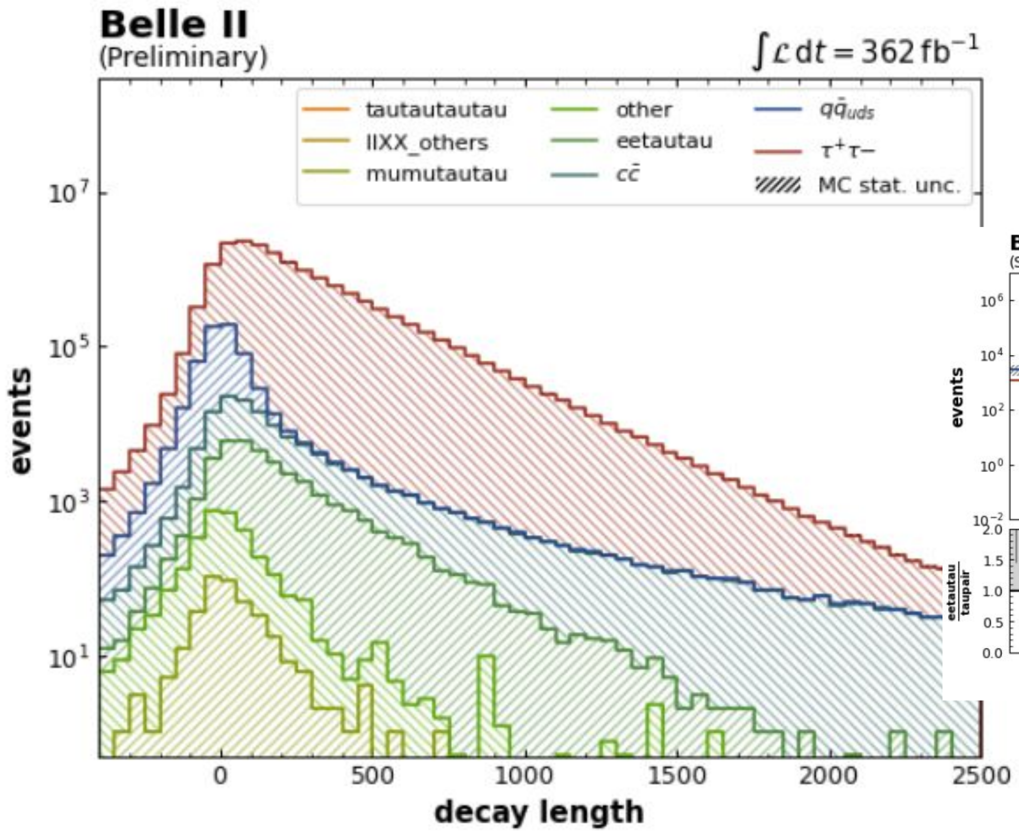
Absolute size of variation:
- Set absolute size of both to maximum of both

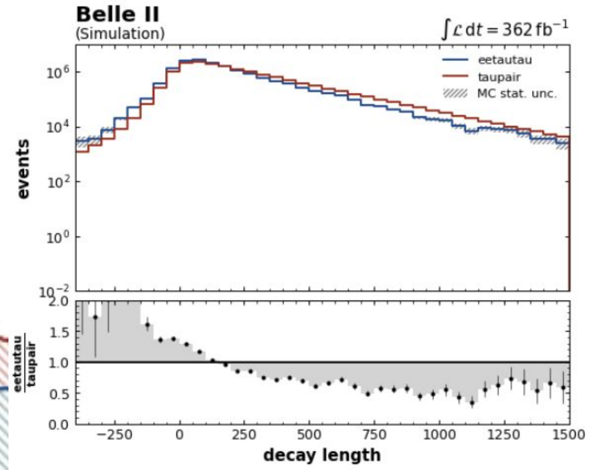


taupair split

llXX split







taupair split	llXX split
14838765.0 94.9	15019123.0 96.1
188591.0 1.2	
916.0 0.0	
492171.0 3.1	492415.0 3.1
88381.0 0.6	88362.0 0.6
31536.0 0.2	31166.0 0.2
	384.0 0.0
	0.0 0.0
	0.0 0.0
2596.0 0.0	2596.0 0.0

- Split not available for exp 20 ~1%
- Removed exp 20 for llXX, increased other exp by 1%