



$B \rightarrow \eta' K$ rediscovery

36th B2GM

~~KEK~~ My living room

25/06/2020

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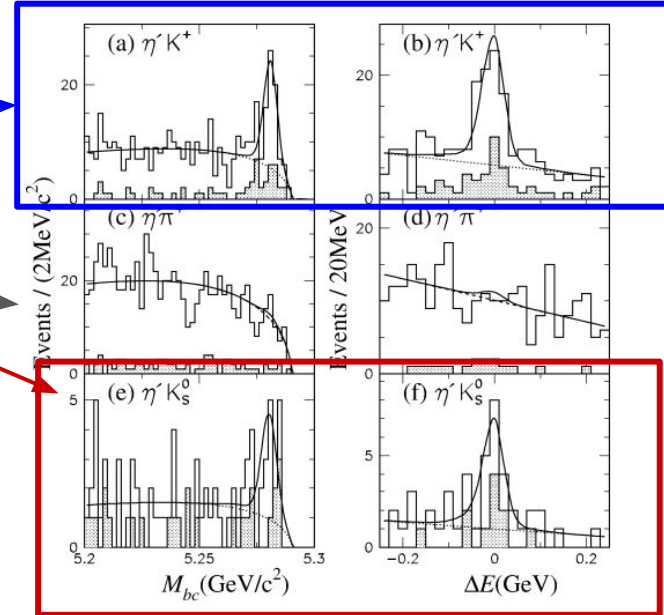
Motivation

- $BR(B^0 \rightarrow \eta' K_S^0) = (6.6 \pm 0.4) \times 10^{-5}$
 - $C_{CP}(B^0 \rightarrow \eta' K^0) = -0.06 \pm 0.04$
 - $-A_{CP} = S_{CP}(B^0 \rightarrow \eta' K_S^0) = 0.63 \pm 0.06$
- $BR(B^+ \rightarrow \eta' K^+) = (7.06 \pm 0.25) \times 10^{-5}$
- Seen by Belle with 10/fb?
 - B^+ : $BR = (79^{+12}_{-11} \pm 8) \times 10^{-6}$
 - B^0 : $BR = (55^{+19}_{-16} \pm 9) \times 10^{-6}$
 - Limit for $B^0 \rightarrow \eta' \pi^+$
- Final states used at Belle
 - $\eta' \rightarrow \rho(\rightarrow \pi^+ \pi^-) \gamma$ (42/10 ev B^+/B^0)
 - $\eta' \rightarrow \eta(\rightarrow \gamma \gamma) \pi^+ \pi^-$ (29/6 ev)
 - $\eta' \rightarrow \eta(\rightarrow \pi^+ \pi^- \pi^0) \pi^+ \pi^-$ not used

Measurement of the branching fraction for $B \rightarrow \eta' K$ and search for $B \rightarrow \eta' \pi^+$

Belle Collaboration

Belle 10.5 /fb



Shaded $\eta' \rightarrow \eta \pi \pi$, white all (including $\eta' \rightarrow \rho \gamma$)

Dataset and Technicalities



- Data: proc11 + prompt (**bucket9-10-11**) **new**
 - $L=8.86+ 25.8= 34.6$ /fb
- Montecarlo **MC13a** (Run independent, BGx1) **new**
 - qqbar+ taus $L=500$ /fb
 - bbbar (charged and mixed) $L=1000$ /fb
 - Using **unskimmed** dataset
 - Skimmed one produced and will be used for analysis skim validation
- Initially MC13b was used (see past WG presentation)
 - Not enough statistics ($L=10$ /fb)
- Signal: MC13a
 - 20K events for channel: $L\sim 9-72$ /ab (depending on channel)
- Release: **light-2002-janus**
- Analysis stash <https://stash.desy.de/users/lacaprar/repos/etaprime/browse>

Selection η'

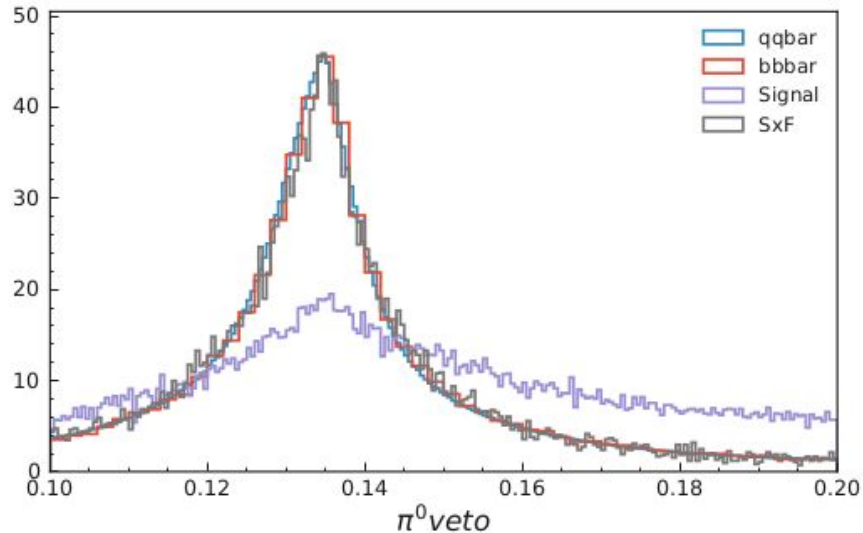


$$\eta' \rightarrow \eta(\rightarrow \gamma\gamma)\pi^+\pi^-$$

- Gamma:loose
- $60 \text{ MeV} < E_\gamma < 6 \text{ GeV}$
- $0.4 < M_{\gamma\gamma} < 0.7 \text{ GeV}/c^2$
- Pi:loose
 - opposite charge
- Global PID(π)>0.1
- $0.9 < M_{\eta'} < 1.1 \text{ GeV}/c^2$

$$\eta' \rightarrow \rho(\rightarrow \pi^+\pi^-)\gamma$$

- Pi:loose
- $0.47 < M_{\pi^+\pi^-} < 1.07 \text{ GeV}/c^2$
- No pi0 veto: losing too much signal

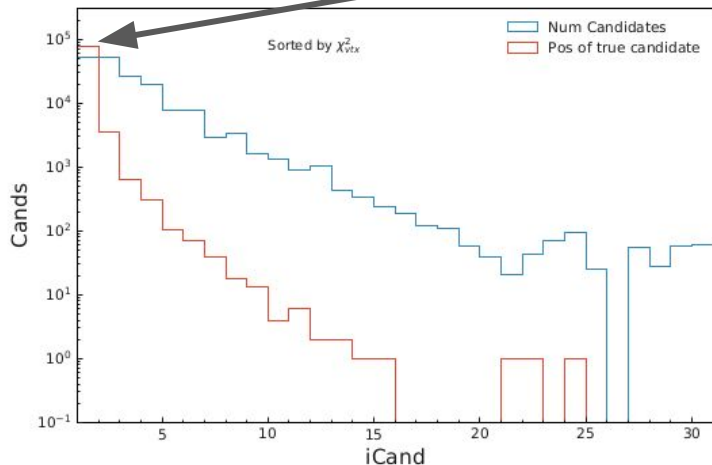


Selection B



- Adding **K** or **Ks** to η'
- K:loose
 - Global PID(K) > 0.1
- K_S0:merged (V0+hh)
 - $450 < M_{\pi^+ \pi^-} < 550 \text{ MeV}/c^2$
 - Vertex fit not failing

- B_0 and B^+ decay chain fitted with **treeFit** algo
 - Mass constraint on η, η' ,
 - pValue > 0
 - NO **IP** vertex constraint
- $M_{bc} > 5.2 \text{ GeV}$ $|D_e| < 0.2 \text{ GeV}$
- Keep only one candidate per event
sortex by vtx pValue

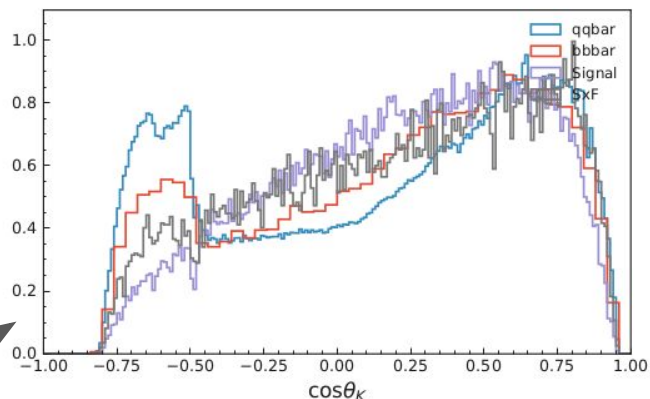


Average multiplicity on data

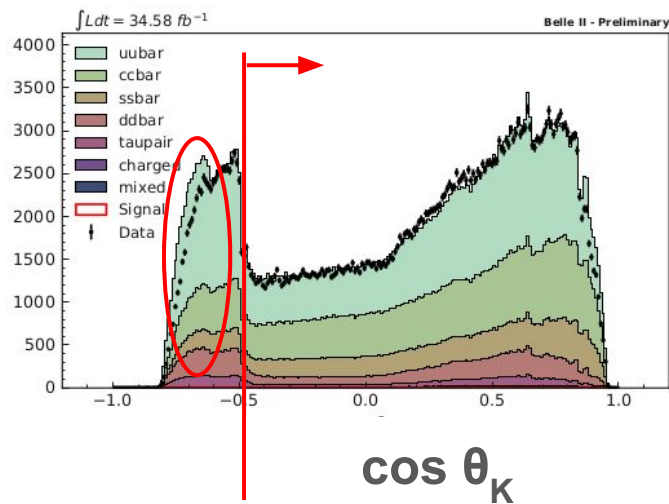
Channel		N_{cands}
$B^0 \rightarrow \eta' K_S^0$	$\eta' \rightarrow \eta \pi^+ \pi^-$	2.23
	$\eta' \rightarrow \rho \gamma$	6.19
$B^\pm \rightarrow \eta' K^\pm$	$\eta' \rightarrow \eta \pi^+ \pi^-$	1.77
	$\eta' \rightarrow \rho \gamma$	5.65

Additional selection

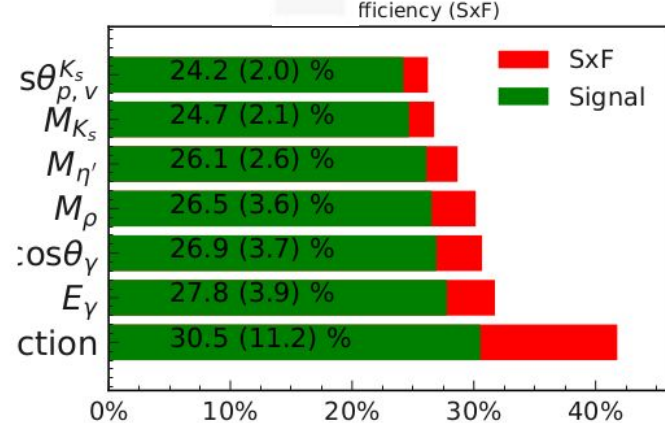
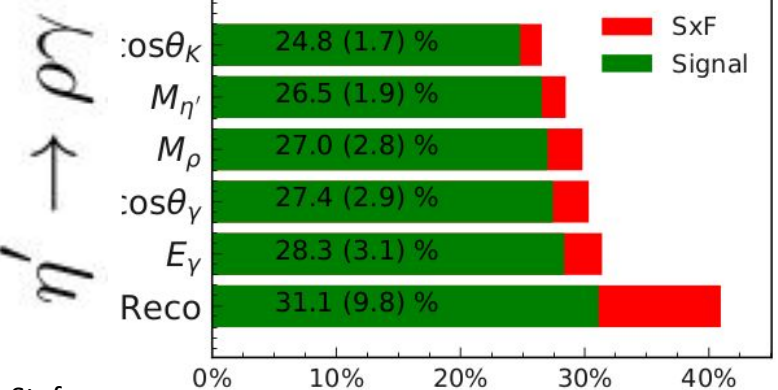
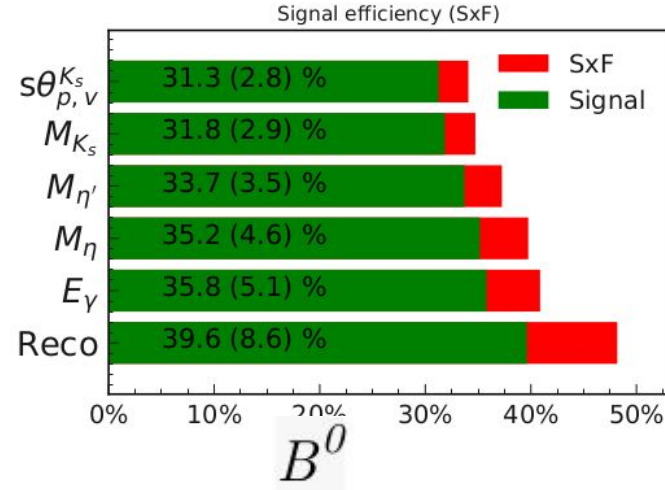
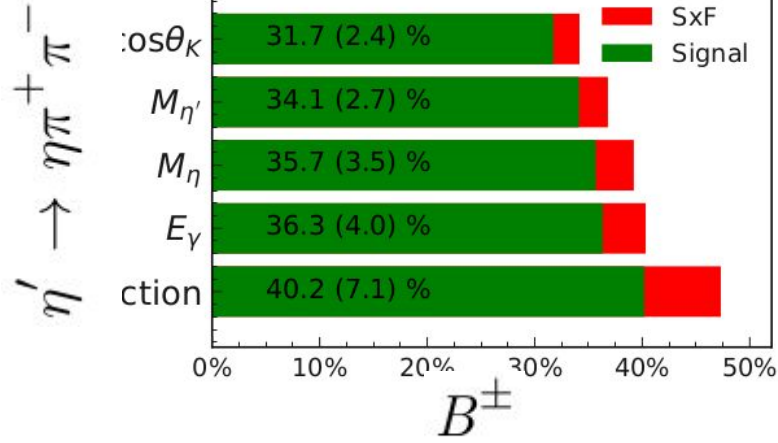
- $\eta' \rightarrow \eta \pi^+ \pi^-$
 - $E_\gamma > 150 \text{ MeV}$
 - $0.5 < M_\eta < 0.57 \text{ GeV}/c^2$
 - $0.92 < M_{\eta'} < 1.0 \text{ GeV}/c^2$
- $\eta' \rightarrow \rho \gamma$
 - $E_\gamma > 150 \text{ MeV}$
 - $\cos \theta_\gamma > -0.64$
 - $0.51 < M_\rho < 1.0 \text{ GeV}/c^2$
 - $0.92 < M_{\eta'} < 1.0 \text{ GeV}/c^2$
- K
 - $\cos \theta_K > -0.5$
- K_s
 - $\cos \theta_{p,v} > 0.99$
 - $0.49 < M_{K_s} < 0.51 \text{ GeV}/c^2$
- **So far optimized for signal(eff) and SxF rejection.**



normalized to L_{Data} · Other plots in backup



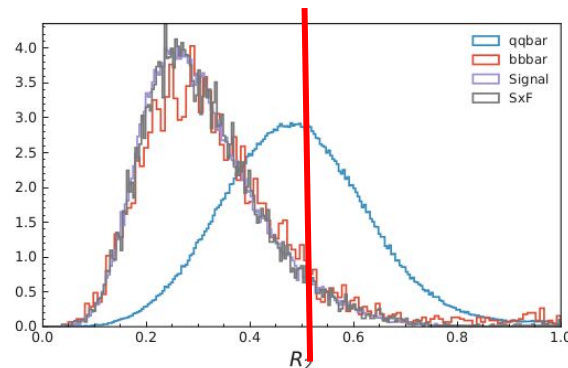
Selection efficiency



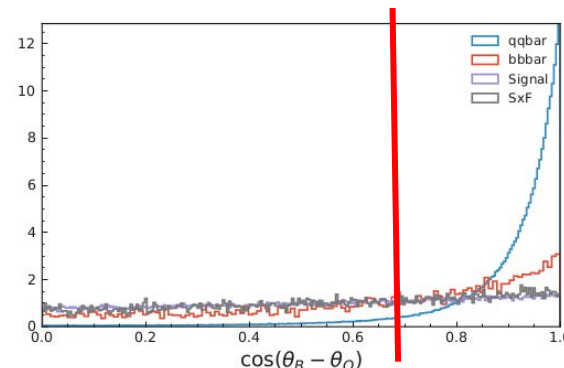
- High selection efficiency **24-30%**
- SxF **10-→2%**
- **no CS cut (next slides)**

Continuum suppression

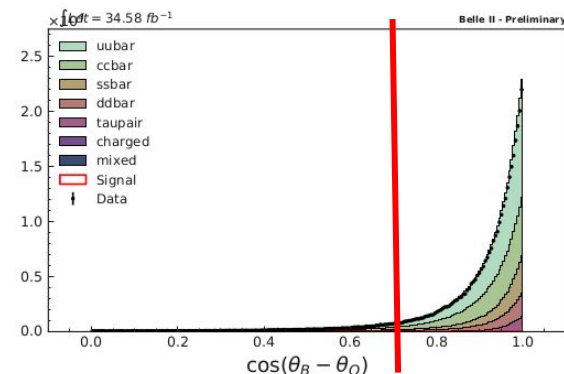
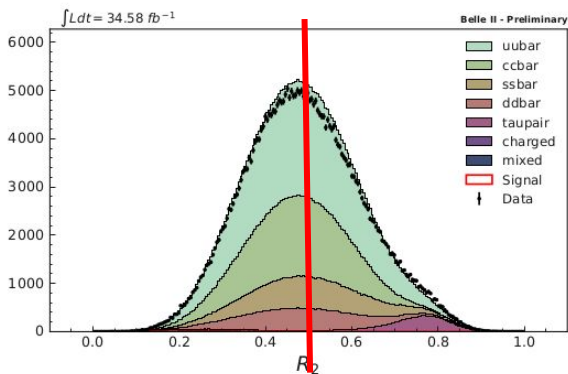
- Using only **R2** and **CosTBTO**
- Started MVA but still some correlation with data not understood
 - For next iteration
- Optimization of cut based on
- $FoM = S / \sqrt{S + B}$
 - S and B in signal region from MC
 - $M_{bc} > 5.27$
 - $-70 < D_e < 50$ MeV
- **R2 < 0.5**
- **CosTBTO < 0.7**
 - Probably too hard



R2



cosTBTO



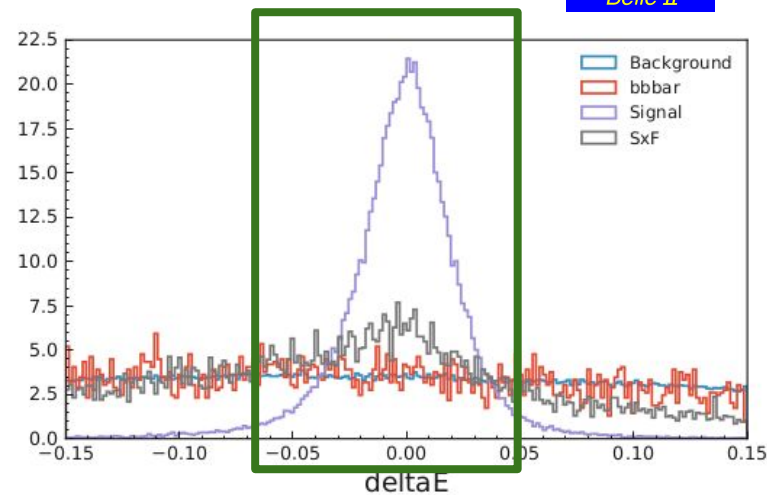
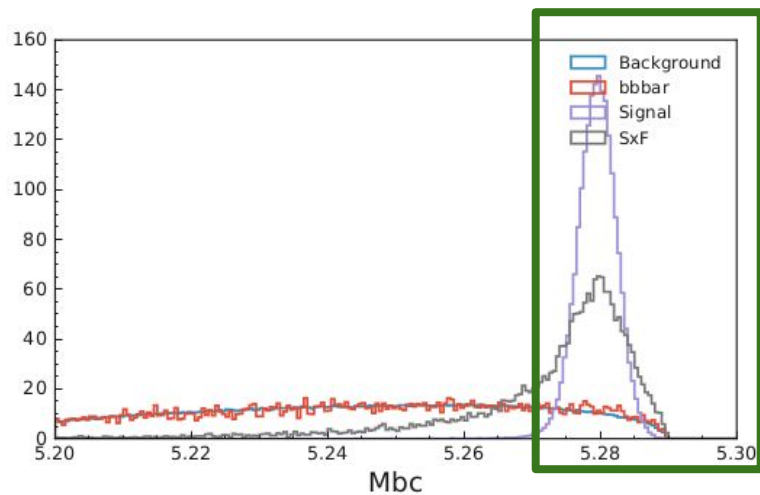
Full signal efficiency (including CS)



Channel	$B^\pm \rightarrow \eta' K^\pm \mid B^0 \rightarrow \eta' K_S^0$ $\eta' \rightarrow \eta \pi^+ \pi^-$		$B^\pm \rightarrow \eta' K^\pm \mid B^0 \rightarrow \eta' K_S^0$ $\eta' \rightarrow \rho \gamma$	
	ϵ %	ϵ %	ϵ %	ϵ %
Selection	31.7 ± 0.1	31.3 ± 0.1	24.8 ± 0.1	25.2 ± 0.1
Continuum suppression	63.4 ± 0.2	63.0 ± 0.2	62.6 ± 0.2	61.7 ± 0.2
Total	20.1 ± 0.2	19.7 ± 0.2	15.5 ± 0.2	15.6 ± 0.2
Belle (10.5 /fb)	21.7	20.8	14.2	11.5

- Margin for improvement with MVA selection (future)
 - Both for CS and for signal selection
- Also can avoid cut on CS and include in UML fit

Control and Signal regions



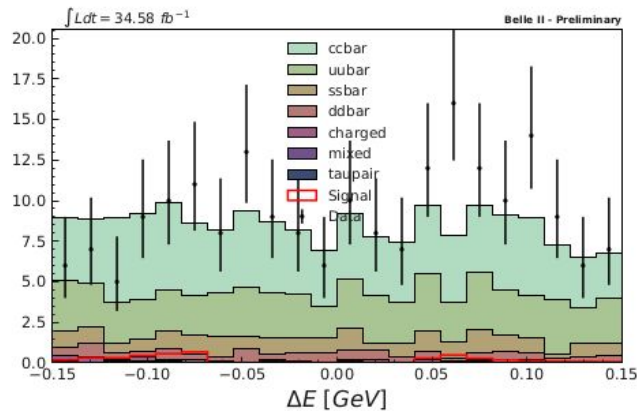
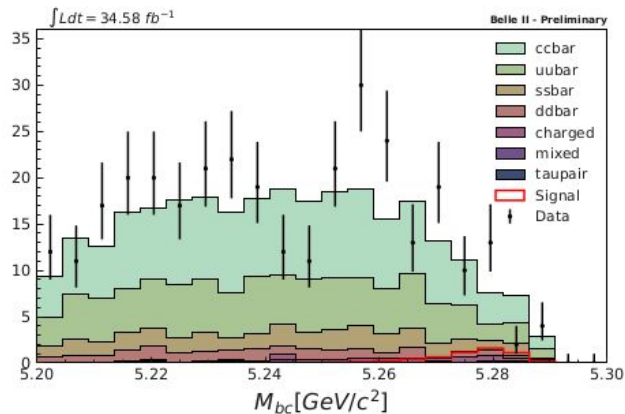
- **Signal region:** $M_{bc} > 5.27 \text{ GeV}$ & $-70 < \Delta E < 50 \text{ MeV}$
- **Control region:** $M_{bc} > 5.2 \text{ GeV}$ & $|\Delta E| < 150 \text{ MeV}$ & **NOT SR**
- **Signal region is kept blind for Data**

Expected and seen candidates



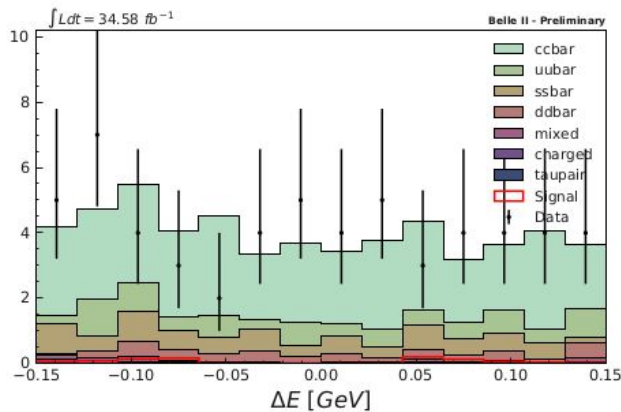
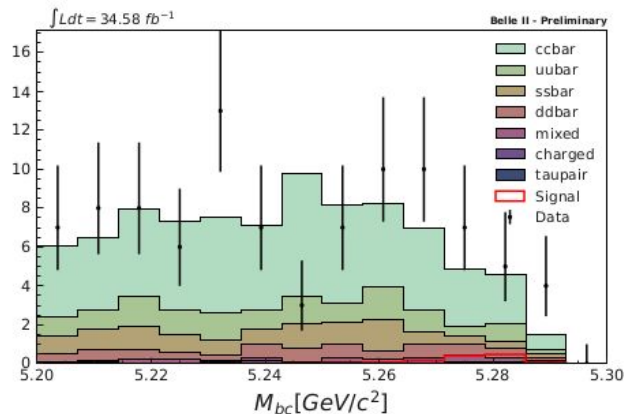
Channel	Region	$B^\pm \rightarrow \eta' K^\pm$	$B^0 \rightarrow \eta' K_S^0$	$B^\pm \rightarrow \eta' K^\pm$	$B^0 \rightarrow \eta' K_S^0$
		$\eta' \rightarrow \eta \pi^+ \pi^-$		$\eta' \rightarrow \rho \gamma$	
Continuum	SB	348.0 ± 5.0	99.5 ± 2.6	3530.0 ± 15.0	826.0 ± 8.0
	SR	12.2 ± 0.9	3.7 ± 0.5	141.7 ± 3.1	41.6 ± 1.7
Peaking	SB	7.9 ± 0.5	3.1 ± 0.3	188.9 ± 2.6	55.2 ± 1.4
	SR	0.83 ± 0.17	1.9 ± 0.26	16.6 ± 0.8	6.9 ± 0.5
Signal	SB	5.9 ± 0.11	1.28 ± 0.03	6.7 ± 0.16	2.29 ± 0.05
	SR	89.3 ± 0.4	19.07 ± 0.1	115.3 ± 0.7	36.01 ± 0.21
Data	SB	405 ± 20.0	114 ± 11.0	3530 ± 60.0	779 ± 28.0
	SR	blind			

Control region Mbc and DeltaE



$$B^\pm \rightarrow \eta' K^\pm$$

$$\eta' \rightarrow \eta \pi^+ \pi^-$$



$$B^0 \rightarrow \eta' K^0$$

MC normalized to L_{DATA}

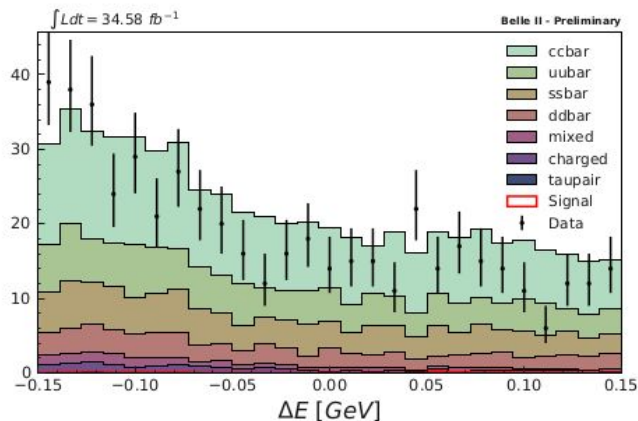
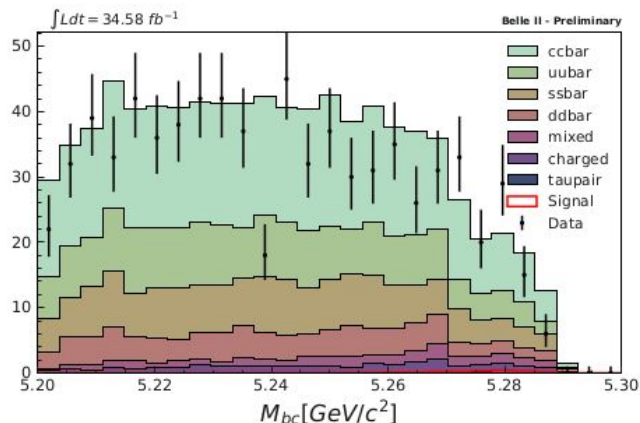
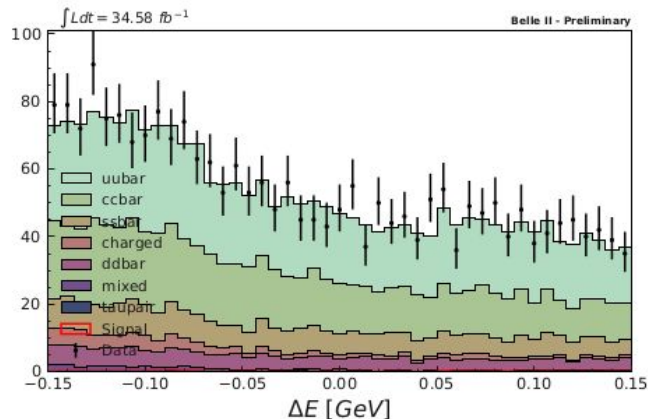
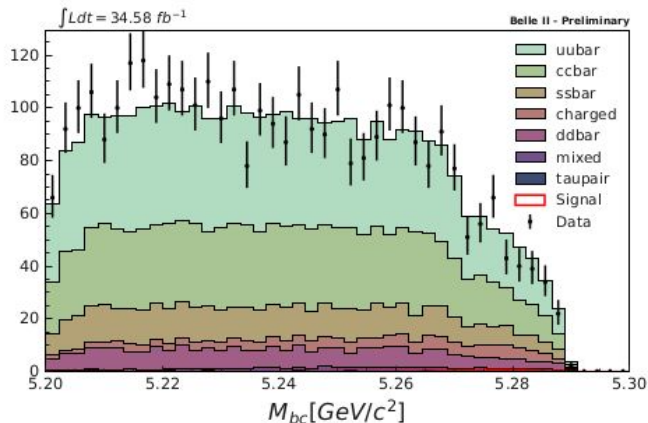
Control regions

$$B^{\pm} \rightarrow \eta' K^{\pm}$$

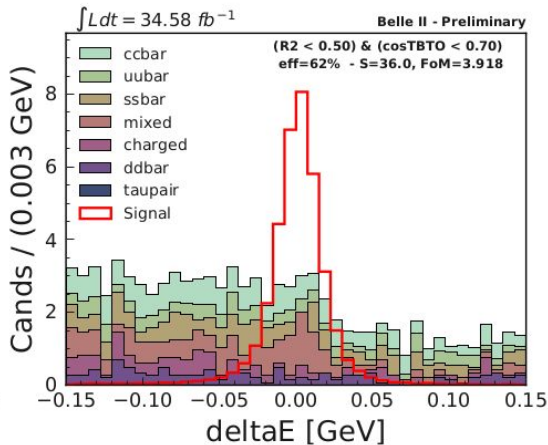
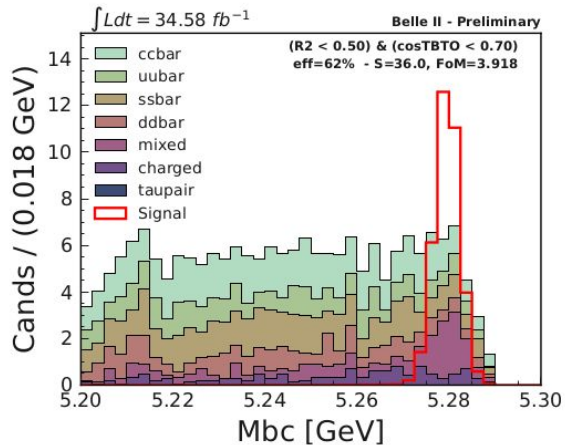
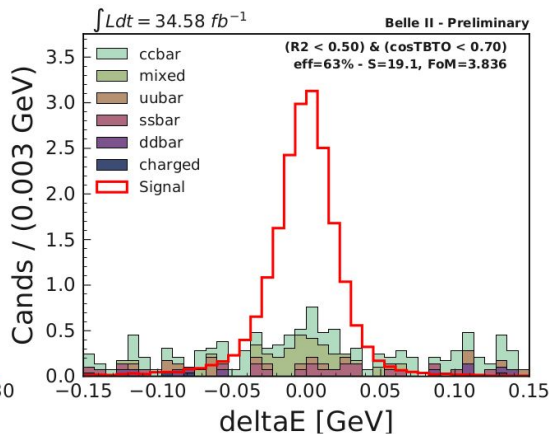
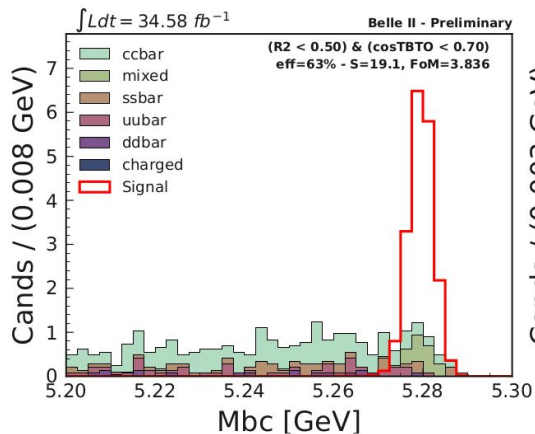
$$\eta' \rightarrow \rho \gamma$$

$$B^0 \rightarrow \eta' K^0$$

MC normalized to L_{DATA}



Signal region for B^0 (blind for data)



$$B^0 \rightarrow \eta' K^0$$

$$\eta' \rightarrow \eta \pi^+ \pi^-$$

- For each plot select CR on the other variable
- Background and signal normalized to L_{DATA}
- Signal removed from bbbar montecarlo

$$B^0 \rightarrow \eta' K^0$$

$$\eta' \rightarrow \rho \gamma$$

Likelihood fit



- Use M_{bc} , ΔE , and $M(\eta')$
 - Last gives some lever against SxF, not much
- Separate component for **Signal, SxF, Continuum, Peaking**
- Define pdf for each component and for each decay channel
 - Trying to have just one set for all channels
- Pdf parameters fitted on MC and fixed
- **Extended UML to get yield for each component**
 - Probably would be better to fix SxF and BB yield (possibly relative to signal and qqbar, respectively) given the small statistics

	Signal	SxF	$q \bar{q}$	$B \bar{B}$
	$B \rightarrow \eta' K, \eta' \rightarrow \eta \pi^+ \pi^-$			
M_{bc}	Gauss(2)	Gauss(3)	Argus	Argus+Gauss(1)
ΔE	Gauss(2)	Gauss(2)	Pol(1)	Pol(1)
$M_{\eta'}$	Gauss(2)	Gauss(2)	Pol(1)+Gauss(2)	Pol(1)+Gauss(1)

Example pdf

$$B^\pm \rightarrow \eta' K \text{ with } \eta' \rightarrow \eta \pi^+ \pi^-$$

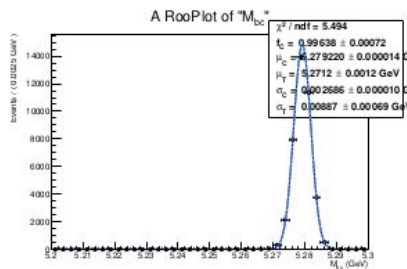


M_{bc}

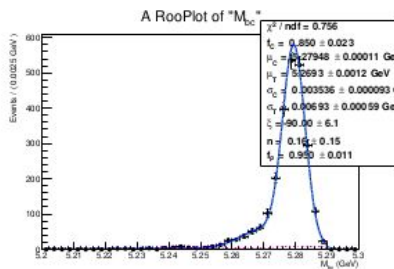
ΔE

$M(\eta')$

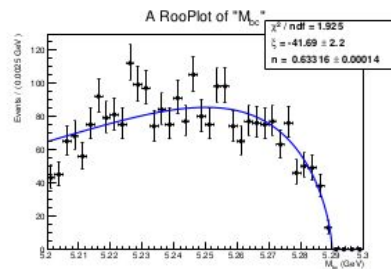
Signal



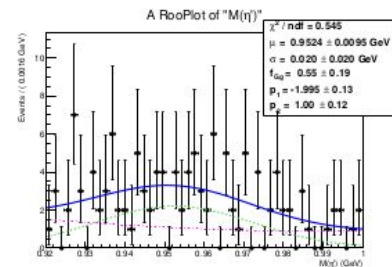
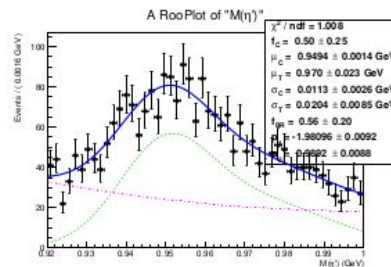
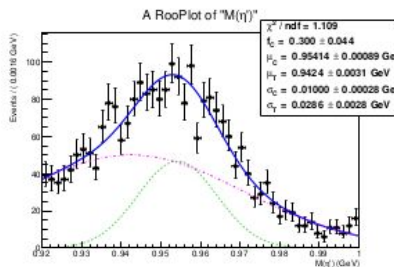
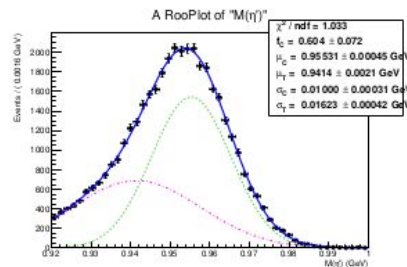
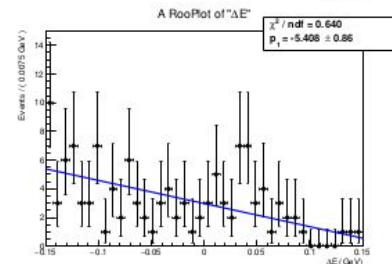
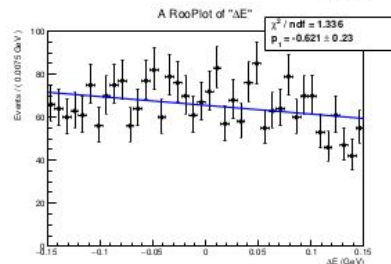
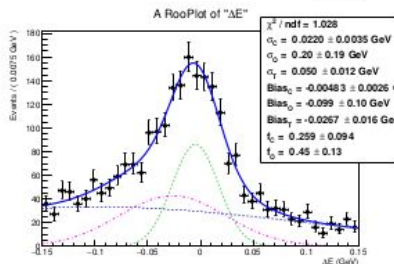
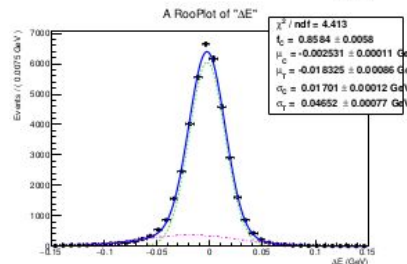
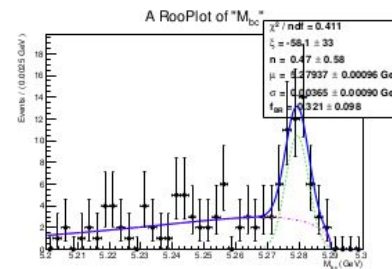
qqbar



peaking

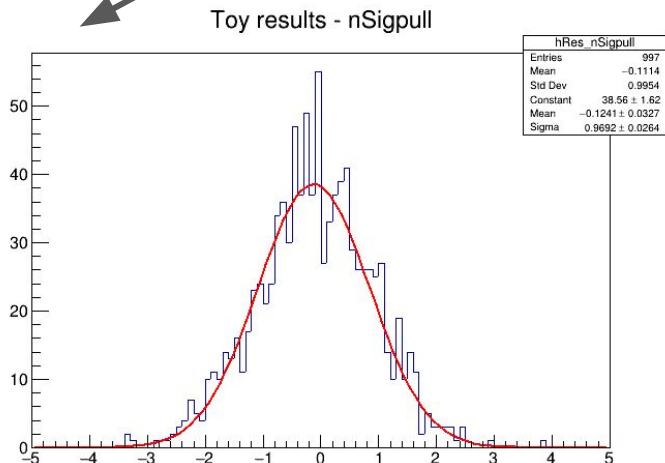
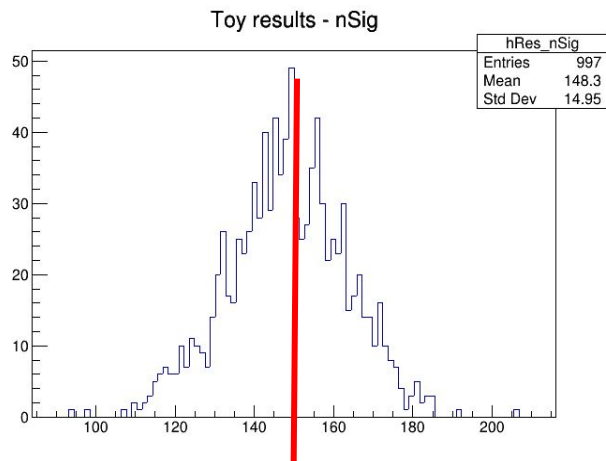


SxS



Toys test

- Fix background to MC expectation
- Vary signal around the expected yield
 - Embedded Toys for signal (and SxF)
 - Pure (pdf) for continuum and peaking
 - Not enough statistics for embedded
- No significant bias found on signal yield
 - nSig Pulls ok.

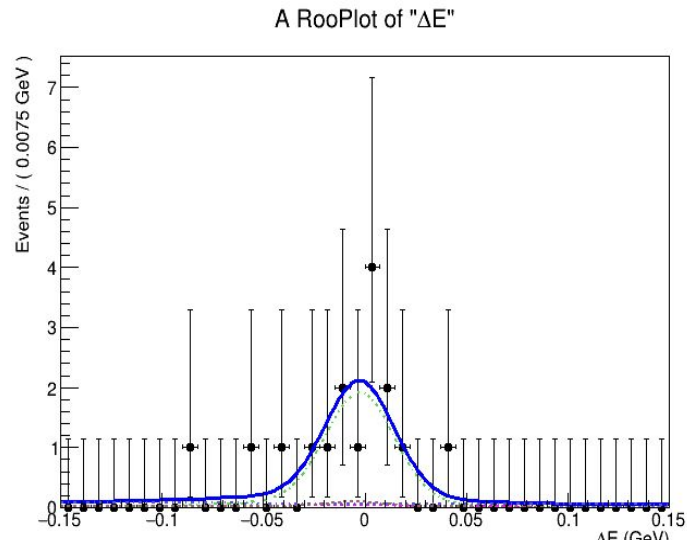
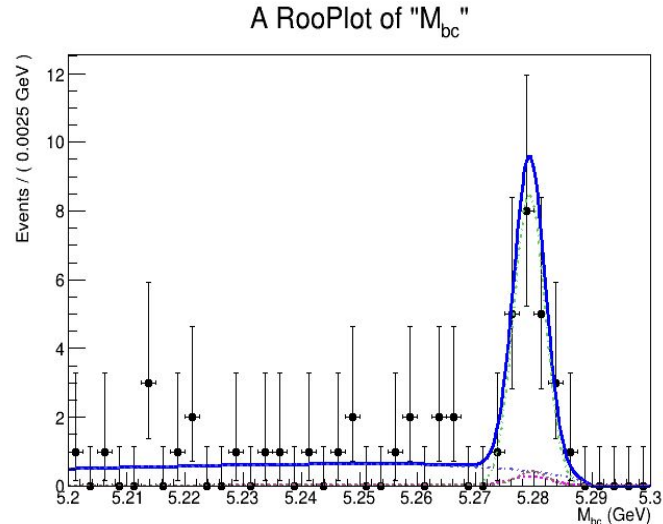
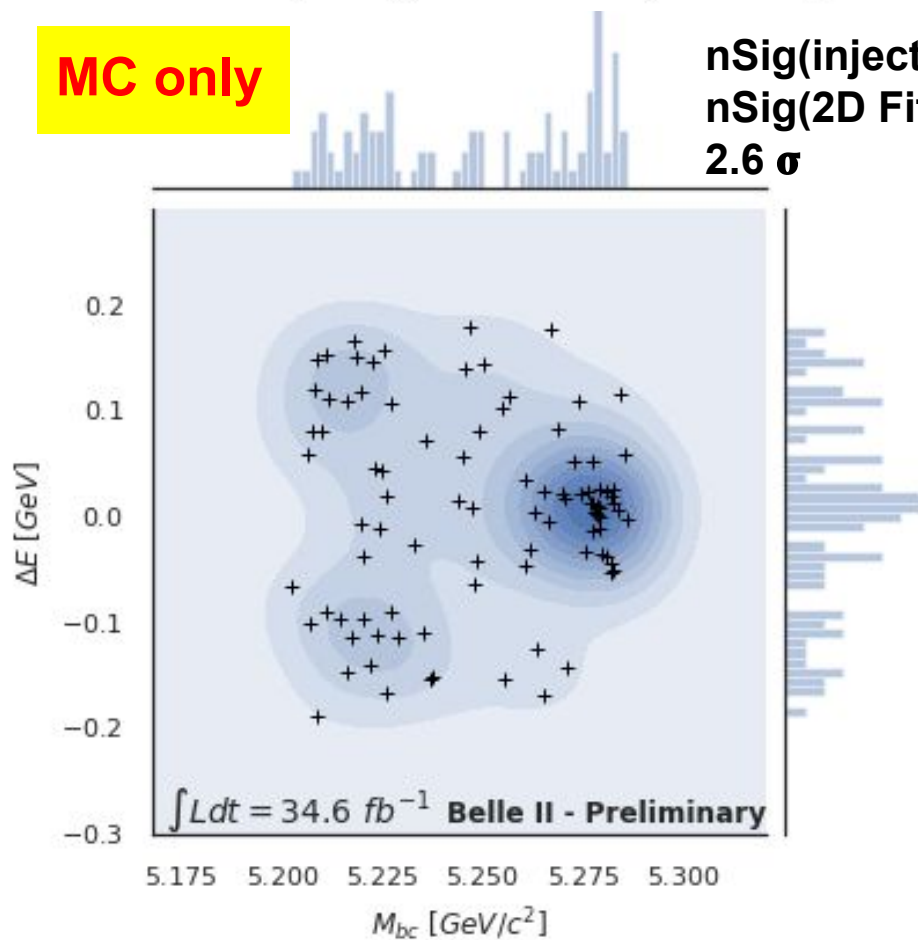


	injected	fit results	rms
<hr/>			
Bpch1			
	70	70.37 ± 1.07	10.61
	95	93.73 ± 1.09	10.75
	110	108.79 ± 1.37	13.68
	150	148.67 ± 1.37	13.61
<hr/>			
B0ch1			
	10	10.24 ± 0.39	3.86
	21	20.26 ± 0.53	5.33
	30	27.94 ± 0.68	6.80
	50	48.73 ± 0.86	8.56
<hr/>			
Bpch3			
	30	30.38 ± 0.69	6.91
	100	99.79 ± 1.17	11.58
	120	120.16 ± 1.25	12.39
	130	129.59 ± 1.34	13.24
	200	197.15 ± 1.72	17.09
<hr/>			
B0ch3			
	20	20.83 ± 0.67	6.64
	30	30.17 ± 0.74	7.30
	50	49.37 ± 0.86	8.53
	70	71.19 ± 0.92	9.08
	100	99.38 ± 1.12	10.96

$$B^0 \rightarrow \eta' K_S^0 \text{ with } \eta' \rightarrow \eta \pi^+ \pi^-$$

MC only

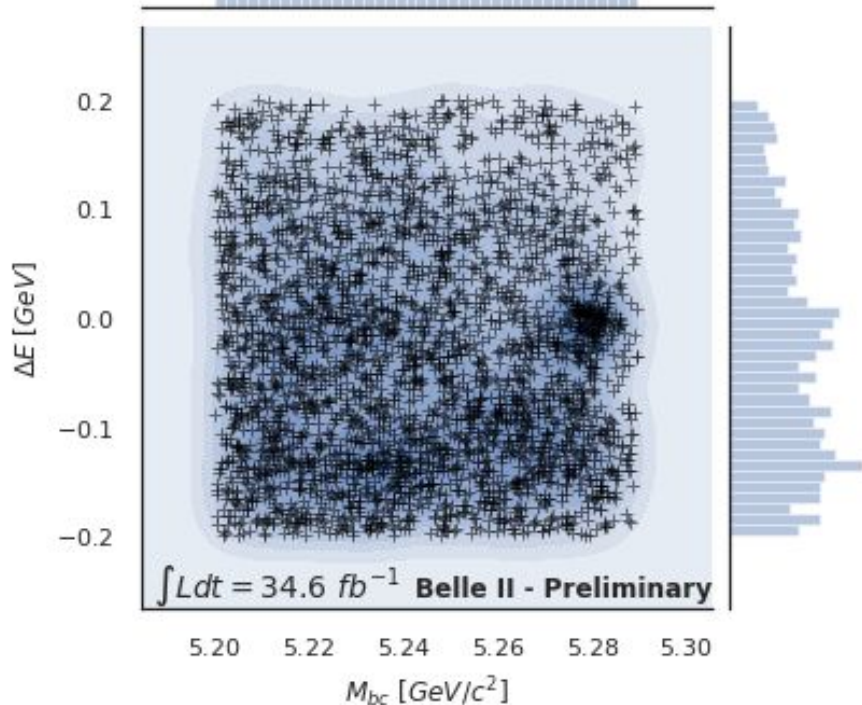
nSig(injected) = 20
nSig(2D Fit) = 22 +/- 8
2.6 σ



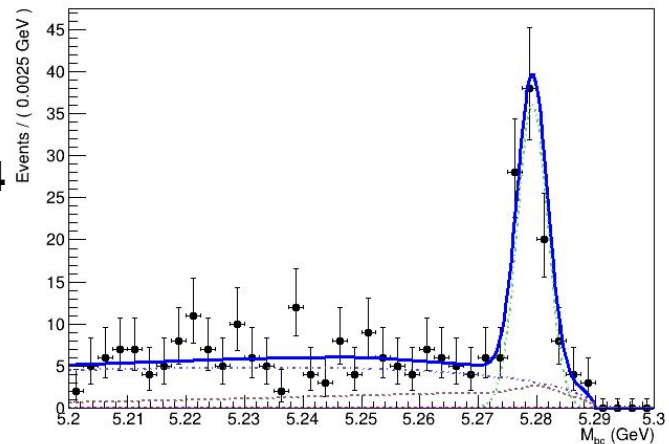
$$B^\pm \rightarrow \eta' K^\pm \text{ with } \eta' \rightarrow \rho\gamma$$

MC only

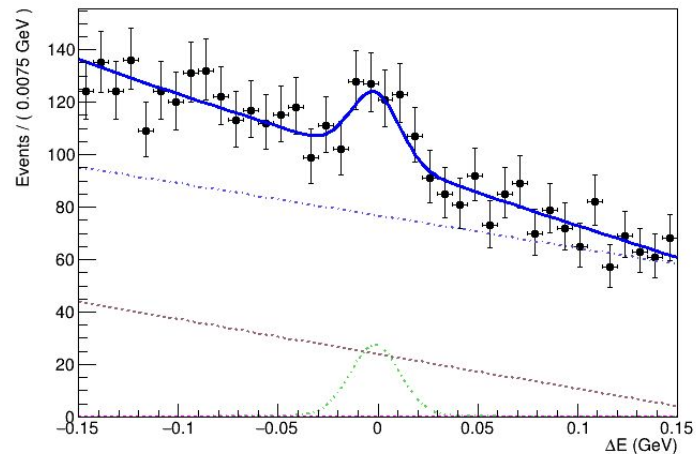
nSig(injected) = 122
nSig(2D Fit) = 123 +/- 14
12 σ



A RooPlot of " M_{bc} "



A RooPlot of " ΔE "



Documentation



- Note v1 almost ready
- Will upload first version by tomorrow



BELLE2-NOTE-XX-YYYY-ZZZ
DRAFT Version 1.0
June 24, 2020

Rediscovery of $B \rightarrow \eta' K$ in Belle II data

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INFN sezione of Padova

(The Belle II Collaboration)

Abstract

This note describe the rediscovery of $B \rightarrow \eta' K$ decay in Belle II data, both in the charged and neutral final state $B^0 \rightarrow \eta' K_S^0$ and $B^\pm \rightarrow \eta' K^\pm$. The η' is searched for in two decay modes: $\eta' \rightarrow \eta \pi^+ \pi^-$, with $\eta \rightarrow \gamma \gamma$ and $\eta' \rightarrow \rho \gamma$. The analysis uses data collected in 2019 (and 2020) and processed with procl1 and prompt.

The signal was seen in all decay channels and the yield is consistent with expectation within the statistical uncertainties.

Summary and plan



- Analysis is in a good shape, but I'd like to do some more work
 - Fit procedure can be improved, in particular SxF and peaking yield
 - Use off-res for continuum
 - Further optimization of selection and CS
- Documentation is in good shape, but can be improved as well
 - Need to be review by WG before calling for a RC
- I'm a bit late for ICHEP
 - Plus, I'll be on vacation from july 20th and very busy until then.
- **If there is no strong push for ICHEP, I would like to have a bit more time**
 - Can also include measurement of A_{CP} in charged mode
 - Maybe include also pi+ final state ?
- Will anyhow push first version of belle2note to invenio for first round of comment

Backup

Branching fractions

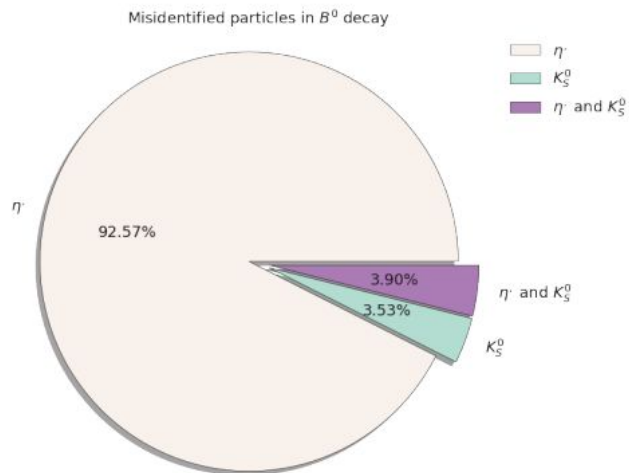


Mode	Decay channel	Branching fraction
$B^+ \rightarrow \eta' K^+$	inclusive	7.06×10^{-5}
	$\eta' \rightarrow \eta(\rightarrow \gamma\gamma)\pi^+\pi^-$	1.19×10^{-5}
	$\eta' \rightarrow \rho(\rightarrow \pi^+\pi^-)\gamma$	2.04×10^{-5}
	total	3.23×10^{-5}
$B^0 \rightarrow \eta' K$	inclusive	6.6×10^{-5}
	$\eta' \rightarrow \eta(\rightarrow \gamma\gamma)\pi^+\pi^-$	5.54×10^{-6}
	$\eta' \rightarrow \rho(\rightarrow \pi^+\pi^-)\gamma$	9.54×10^{-6}
	total	1.51×10^{-5}

- Effective BR twice for charged state due to K^+ vs K_s

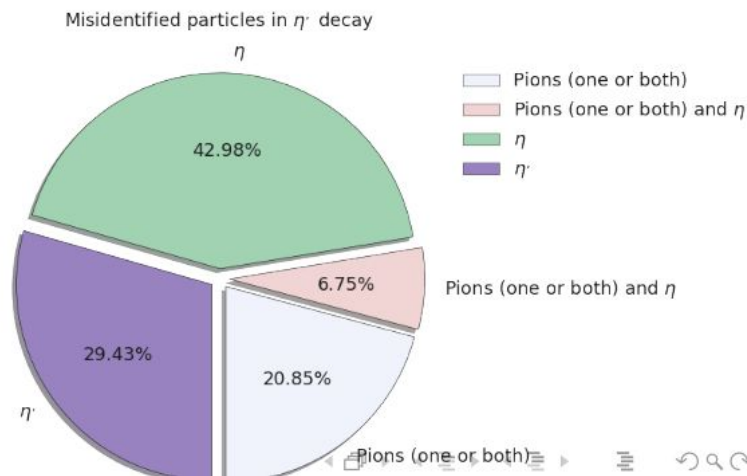
Recap

SxF candidates are misreconstructed Signal candidates

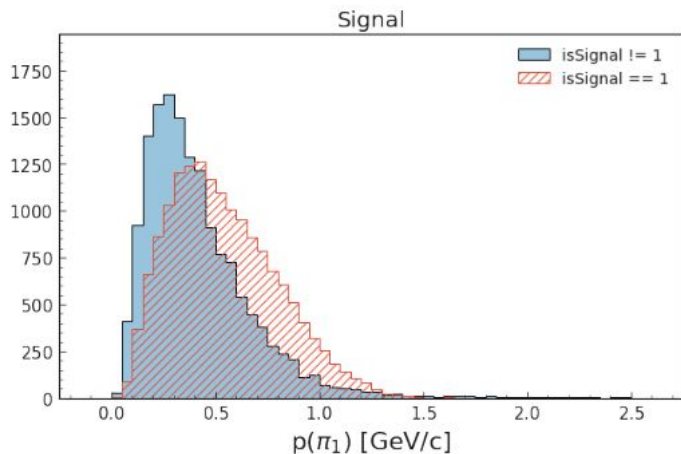


The incorrect reconstruction of B^0 ($isSignal = 0$) is mainly due to η' reconstruction.

The incorrect reconstruction of the η' particle is mainly due to the η reconstruction ($\sim 50\%$), but also pions are frequently mistaken.

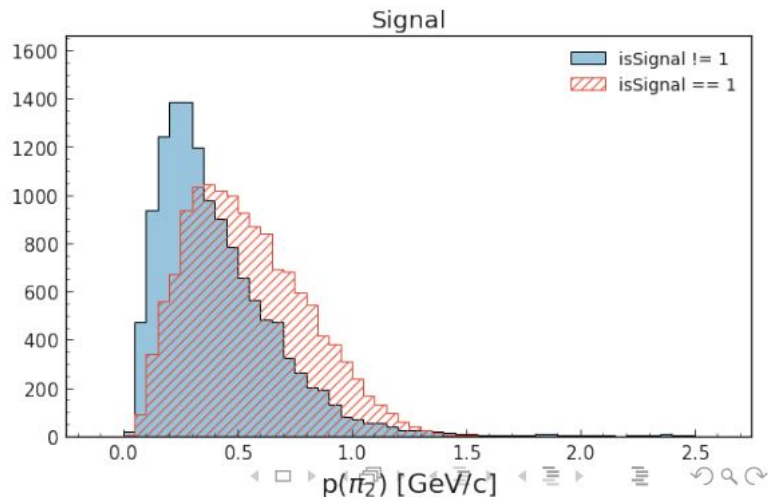


Momentum of misreconstructed pions in $\eta' \rightarrow \eta(\gamma\gamma)\pi^+\pi^-$ decay

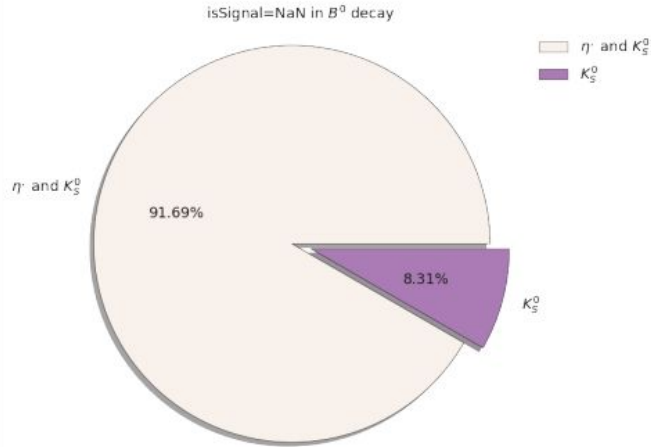


Incorrectly reconstructed pions tend to have low momentum.

Same area normalization for histograms.

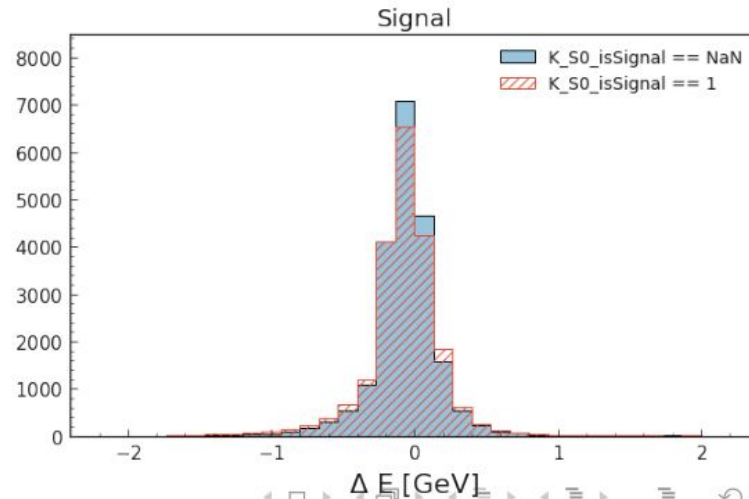


K_S^0 when isSignal=NaN

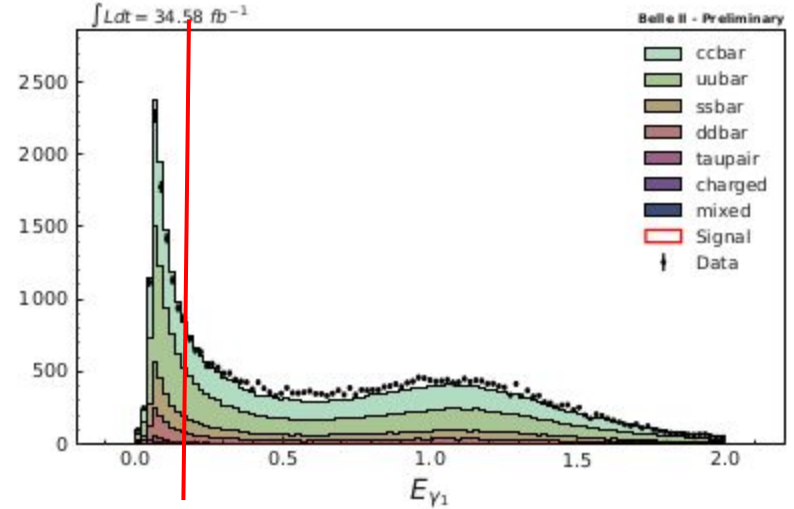
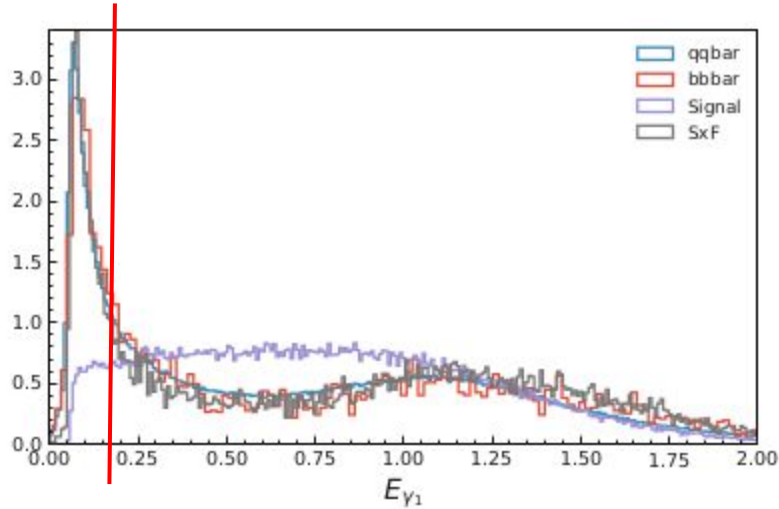


Whenever isSignal is NaN for the B_0 , it is NaN also for the K_S^0

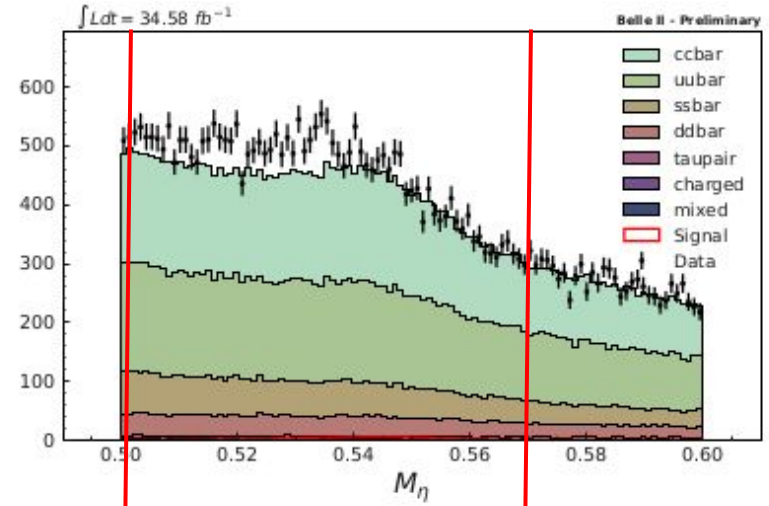
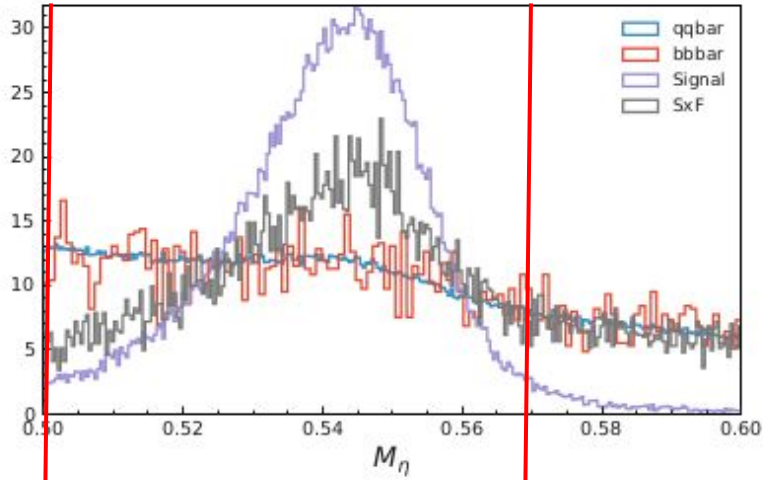
ΔE distribution for these candidates is similar to the Signal distribution (histograms scaled to have same area)



E gamma (eta->gamma gamma)

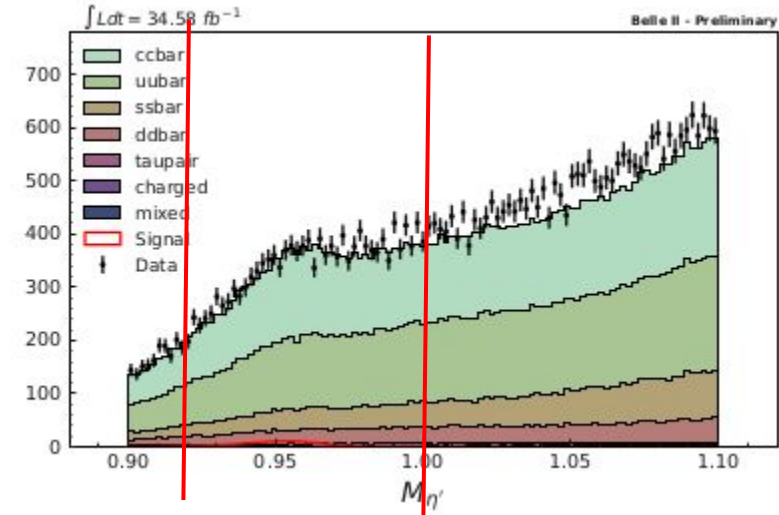
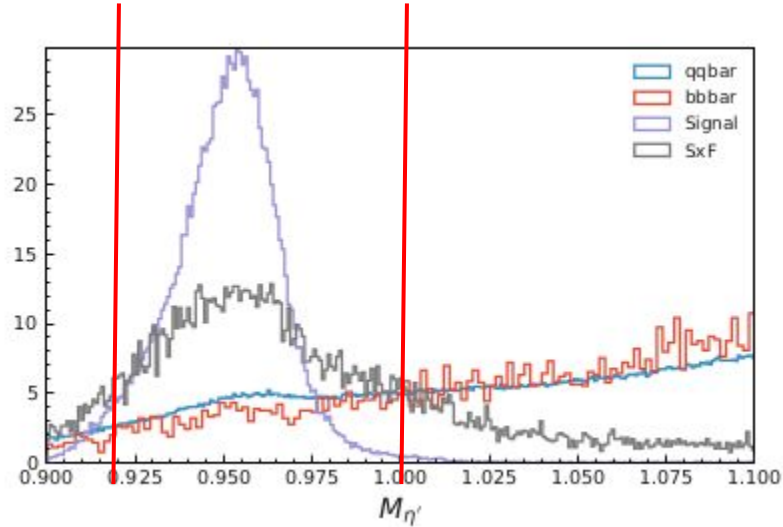


M(eta)



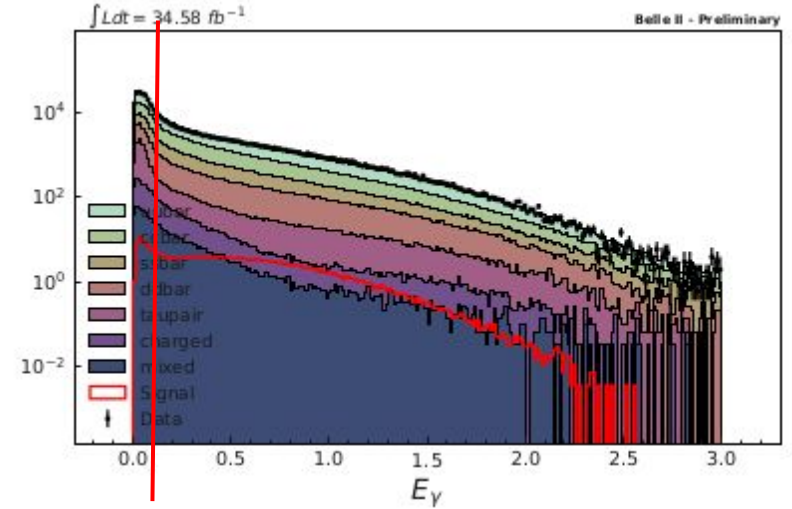
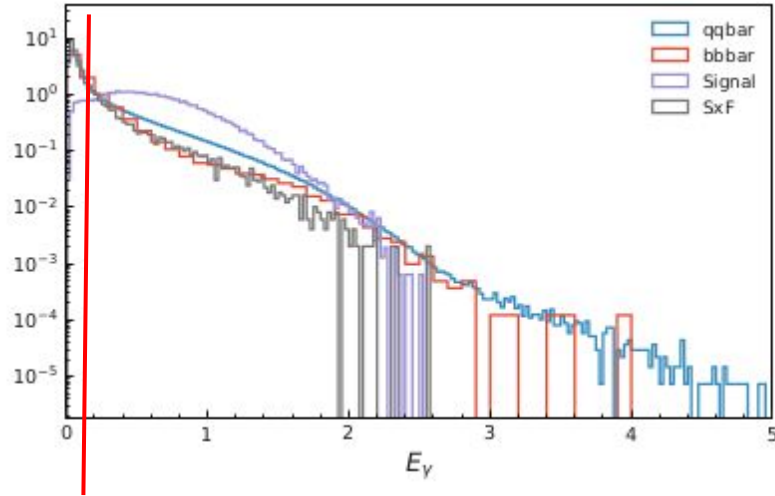
eta->gg peak not well visible due to low gamma threshold (60 MeV)

M(η')

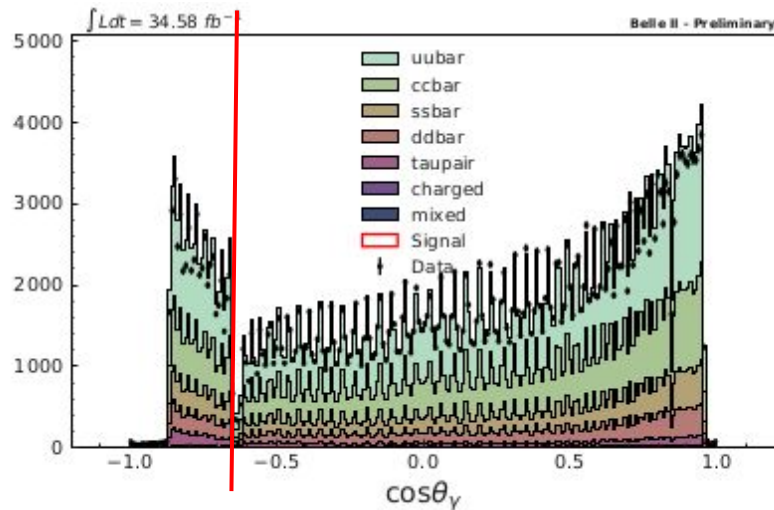
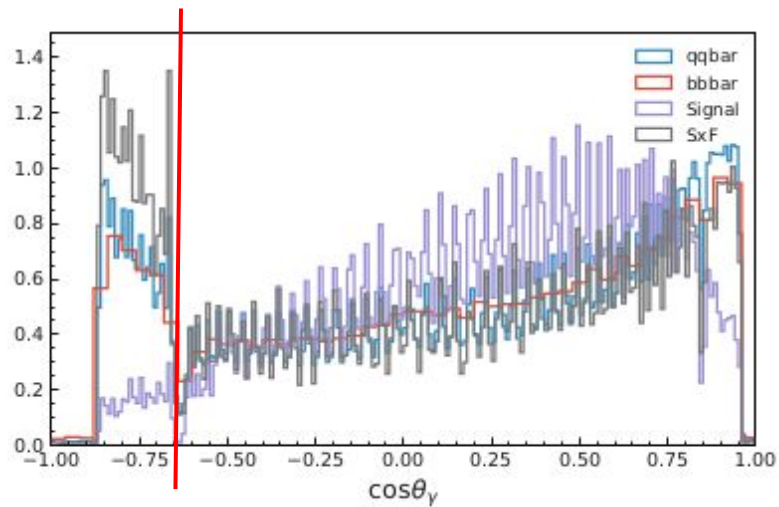


$\eta' \rightarrow \eta(\text{gg})\pi\pi$ peak not well visible due to low gamma threshold (60 MeV) and pion ones

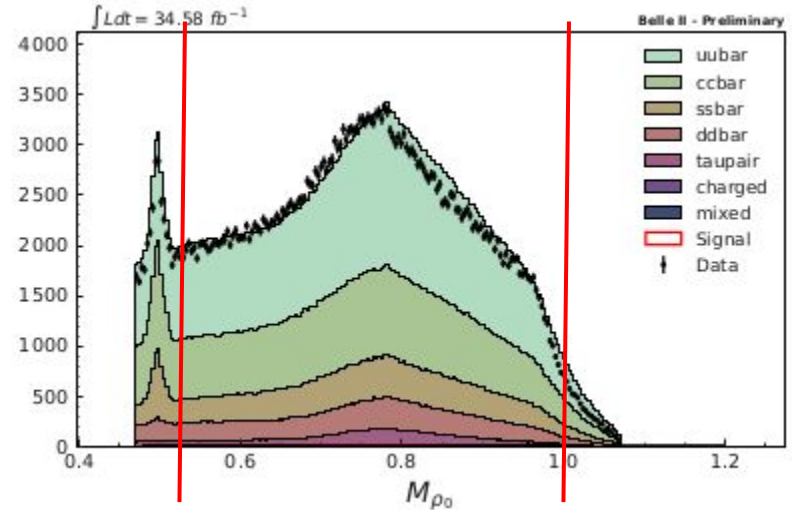
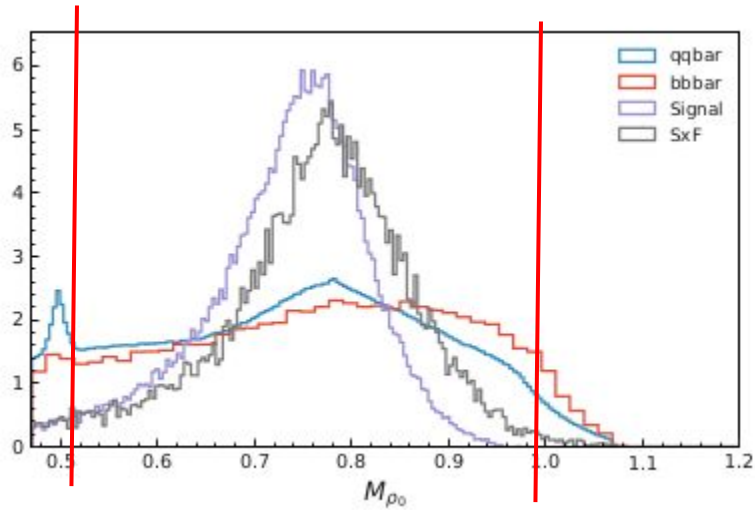
E(gamma) from eta' -> rho gamma



cos(theta gamma)

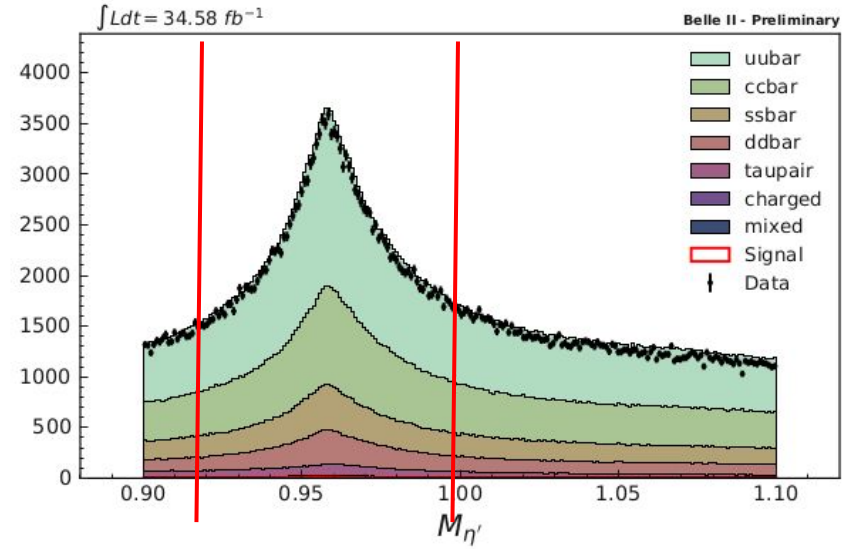
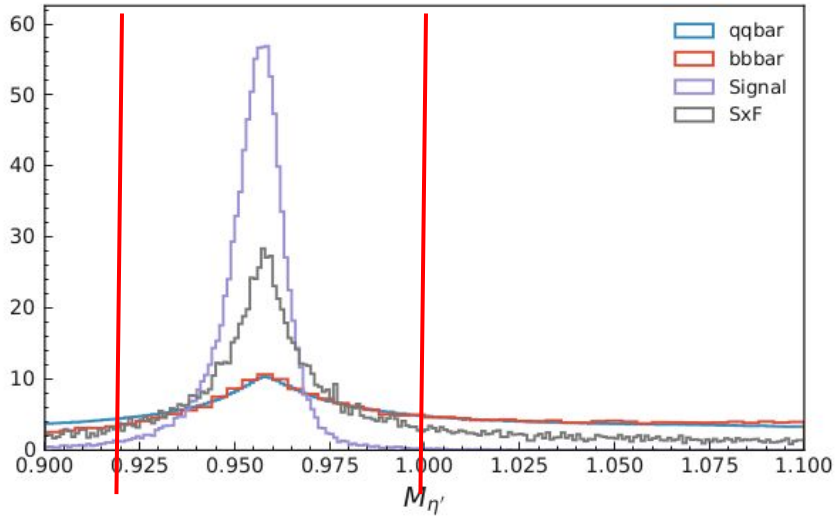


M(pi+ pi-)

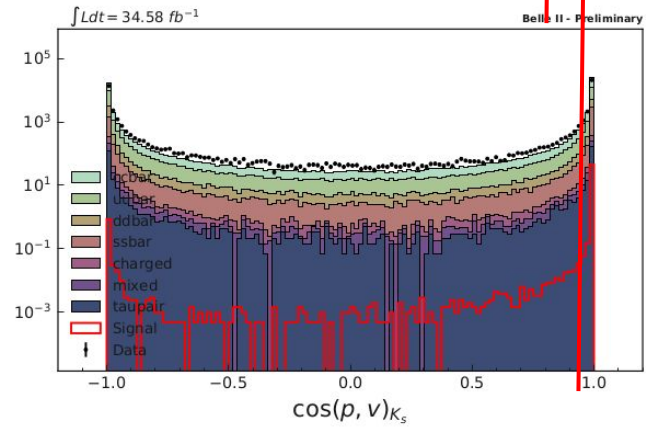
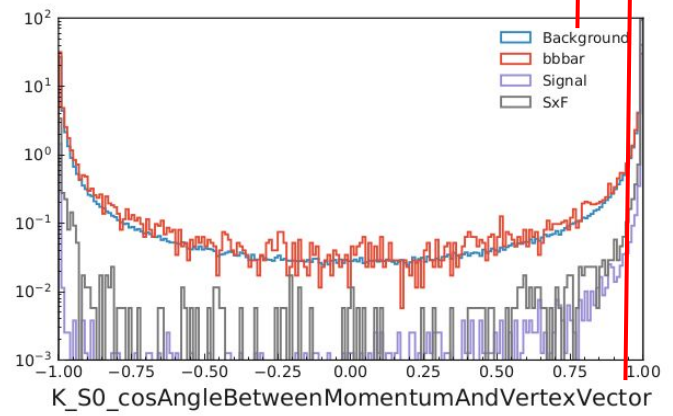
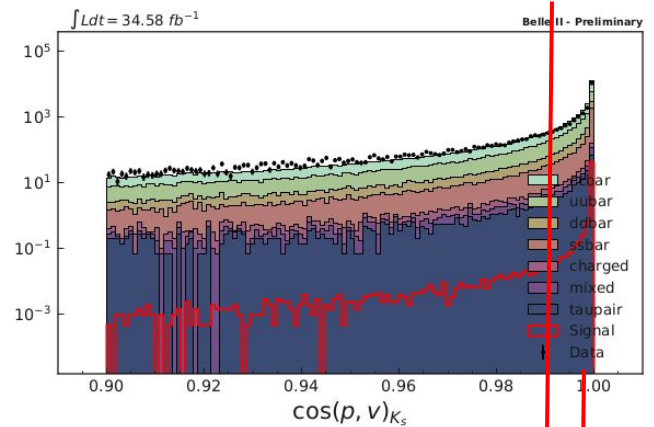
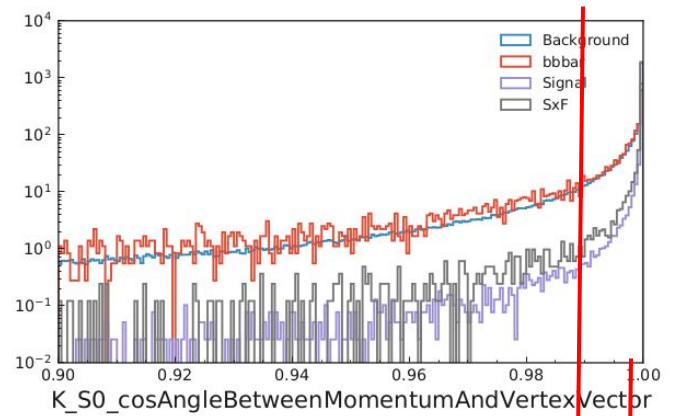


- Clear Ks peak
- Shift between rho peak for signal and SxF

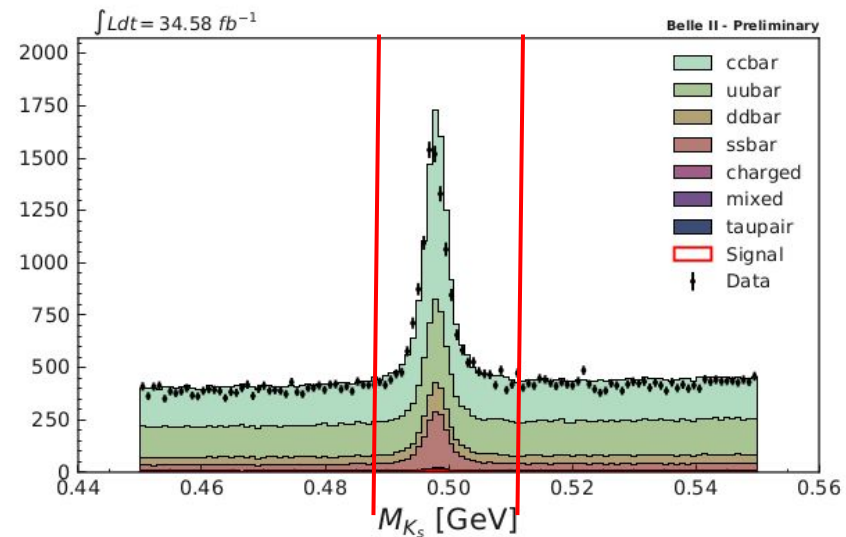
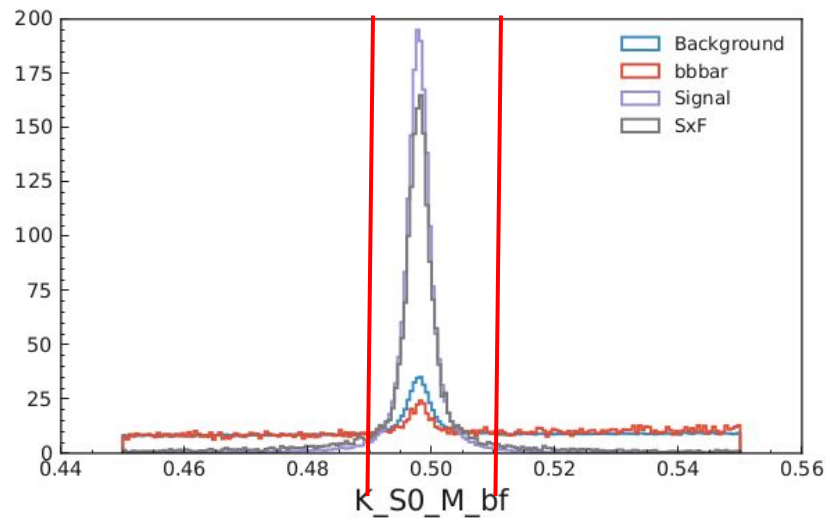
M(η')



cos(alpha) (momentum vs vertex)

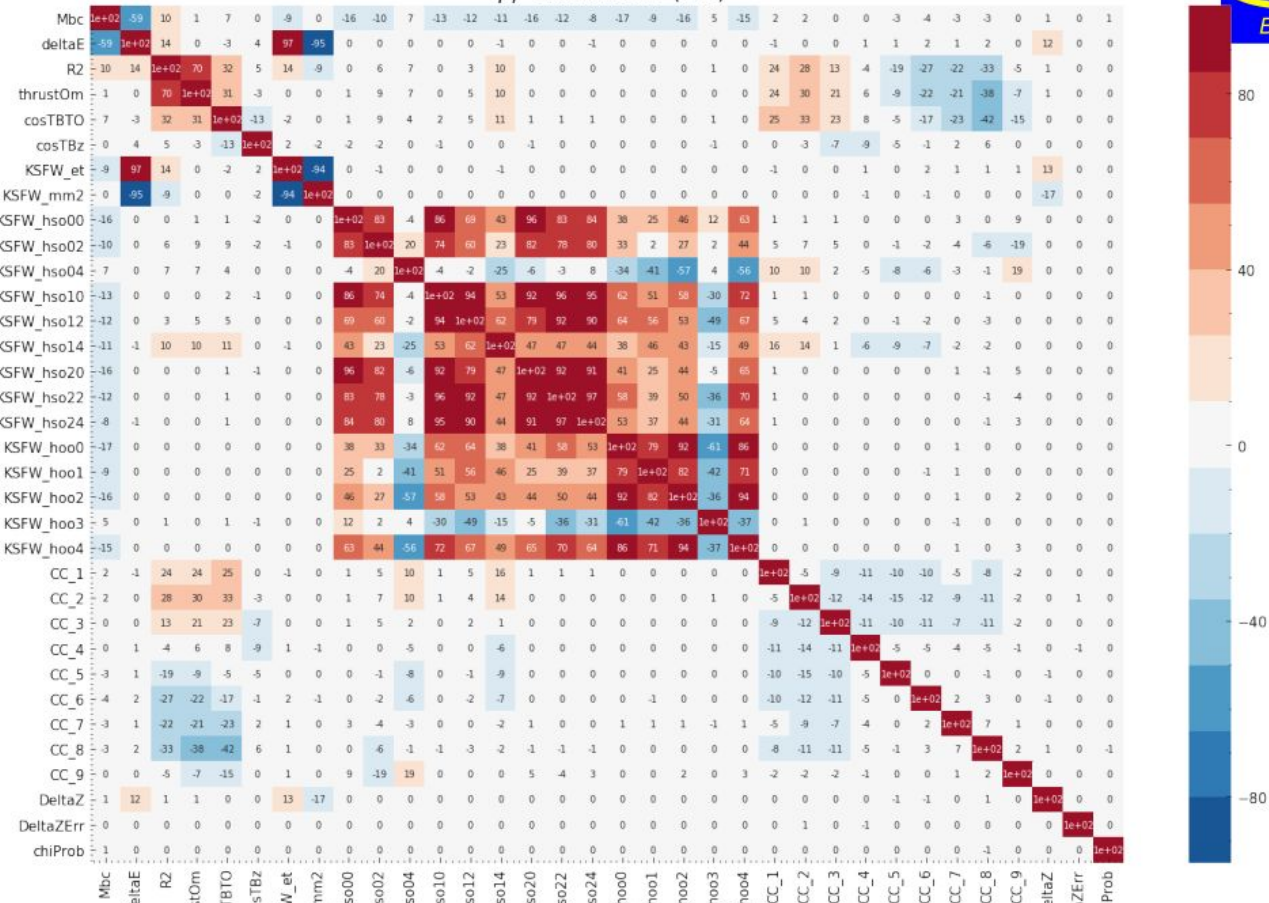


M(Ks)

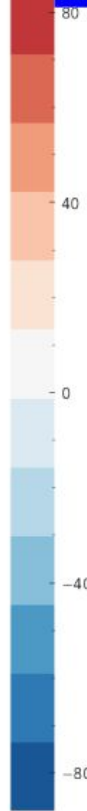
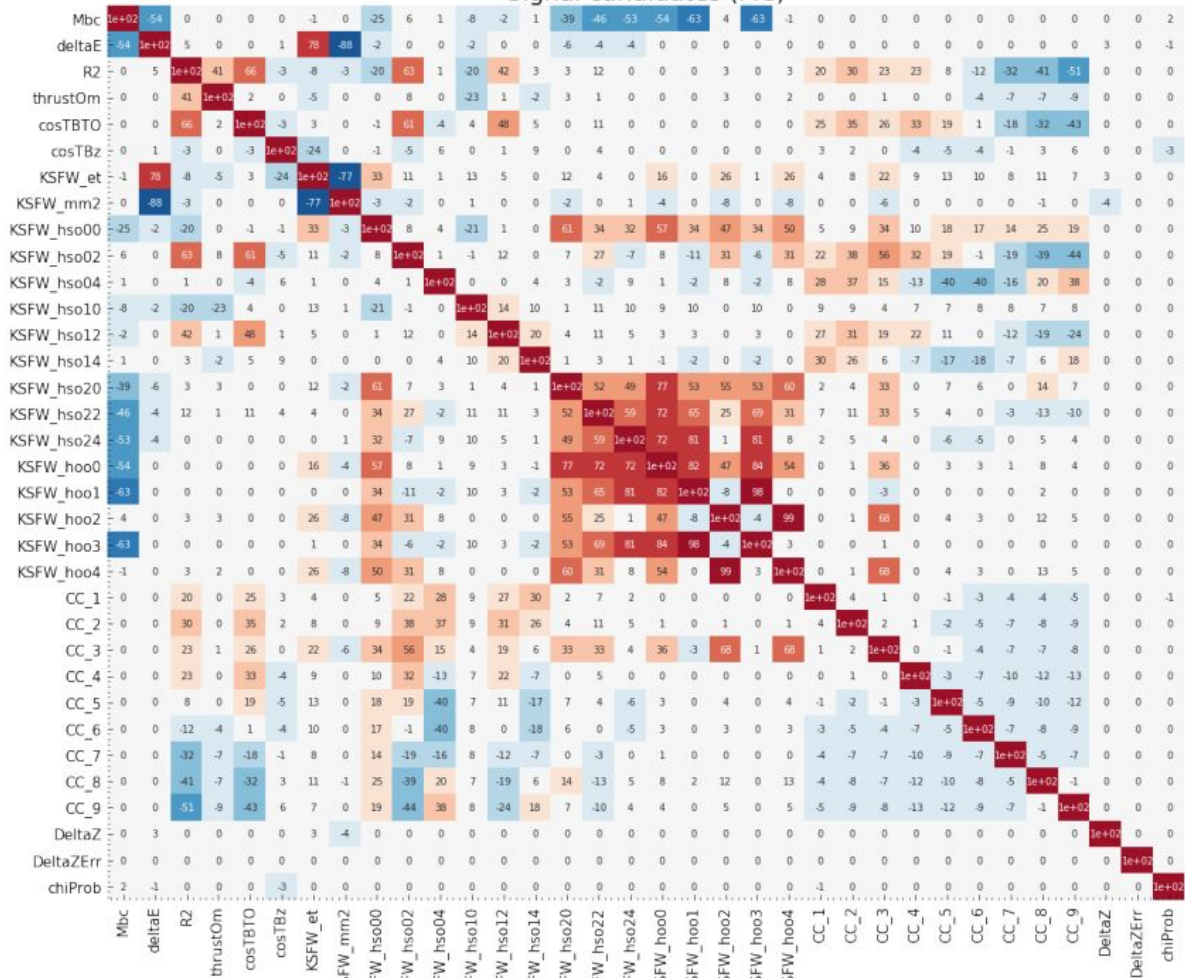


Correlation between training variables and fit variables (M_{bc} and ΔE)

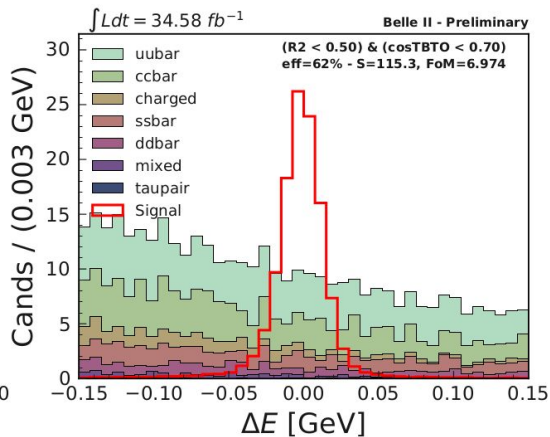
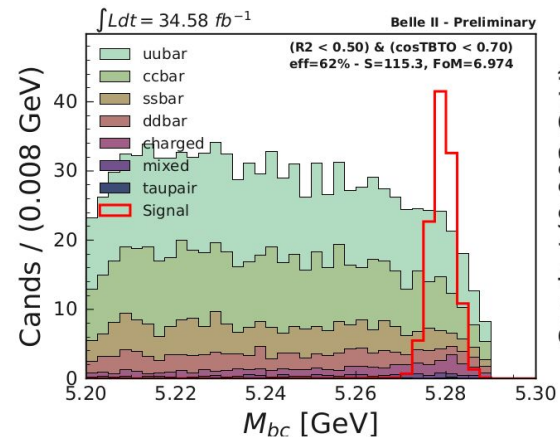
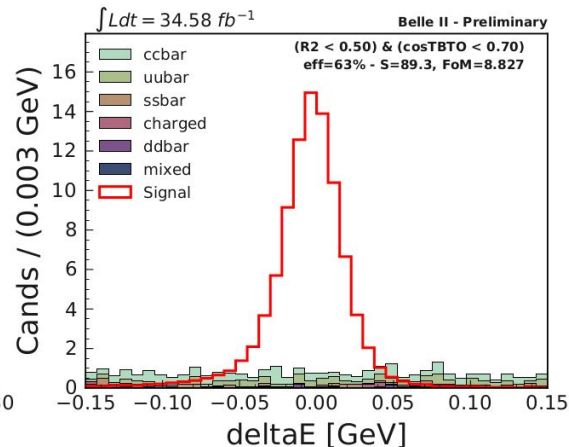
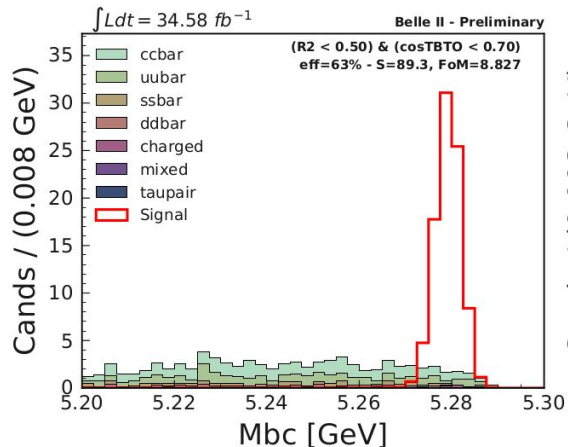
qq Candidates (MC)



Signal candidates (MC)



Signal Region B⁺



$$B^{\pm} \rightarrow \eta' K^{\pm}$$

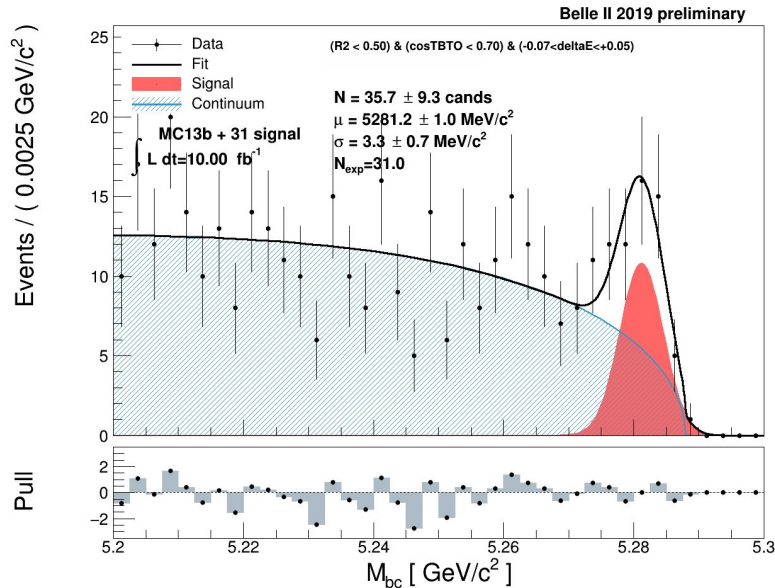
$$\eta' \rightarrow \eta \pi^{+} \pi^{-}$$

- For each plot select CR on the other variable
- Background and signal normalized to L_{DATA}
- Signal removed from bbbar montecarlo

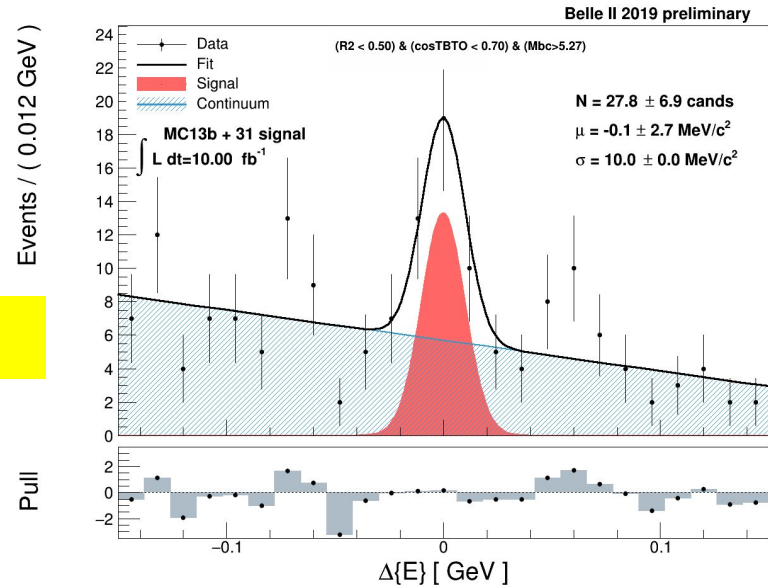
$$B^{\pm} \rightarrow \eta' K^{\pm}$$

$$\eta' \rightarrow \rho \gamma$$

Try to fit signal: only MC + signal injection



MC13b



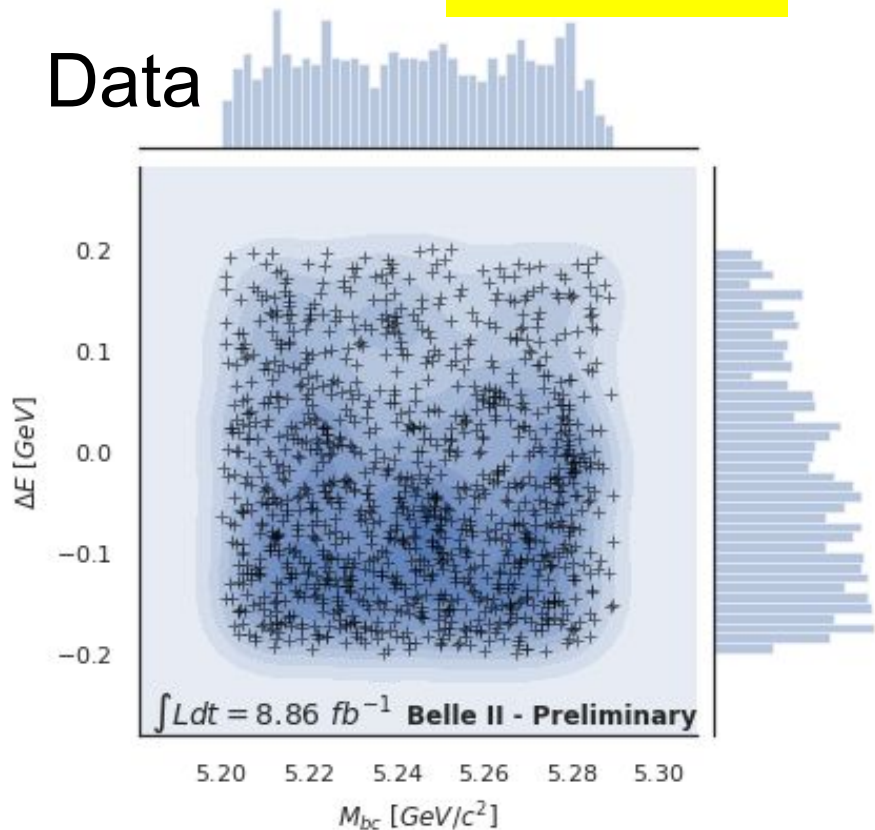
- Cut $M_{bc} > 5.27 \text{ GeV}/c^2$ and $-7 < \Delta E < +5 \text{ MeV}$ in the other plot.
 - 1D plot shown (2D implemented)
- Injected 31 events, seen 35.7 ± 9 (Mbc) and 28 ± 7 (De)

DeltaE vs Mbc

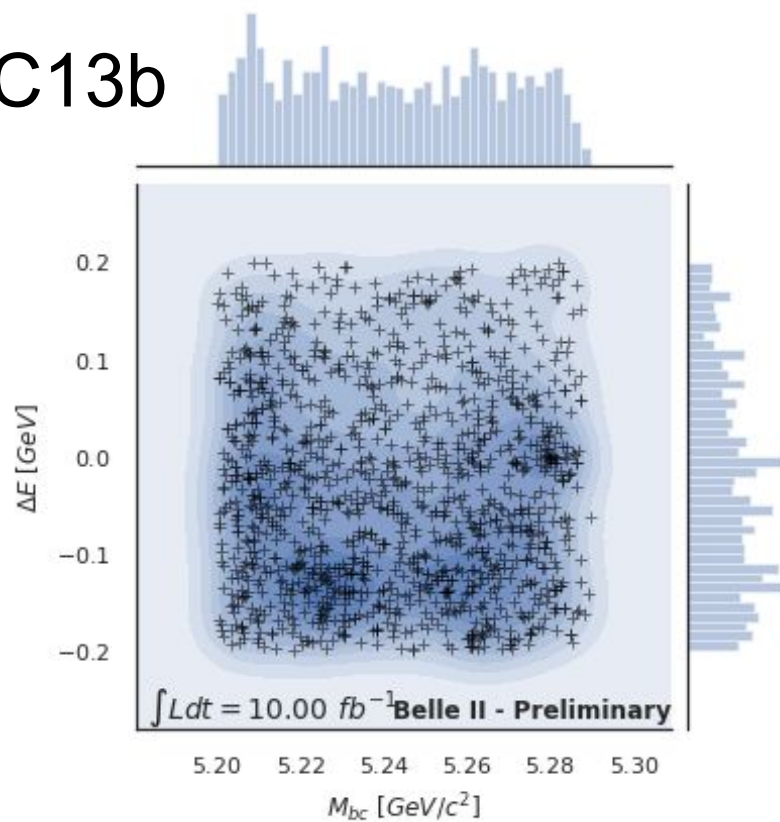


Proc10 + bucket8

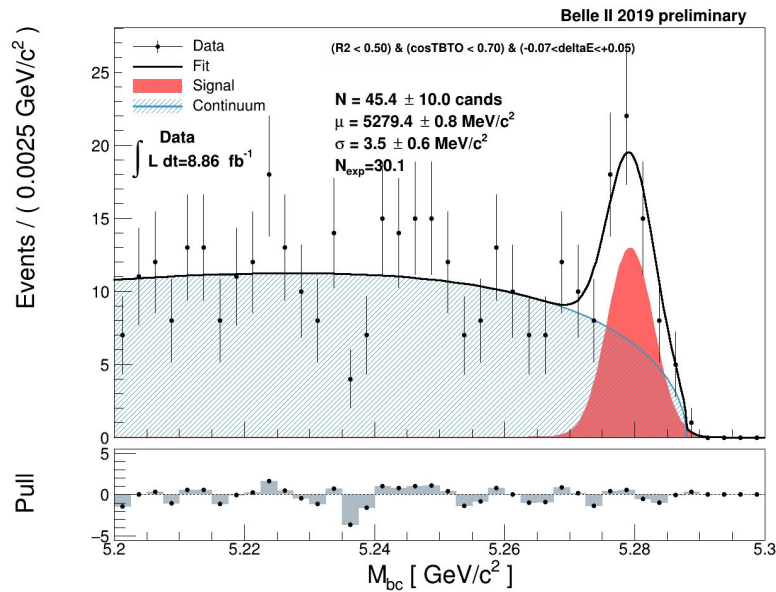
Data



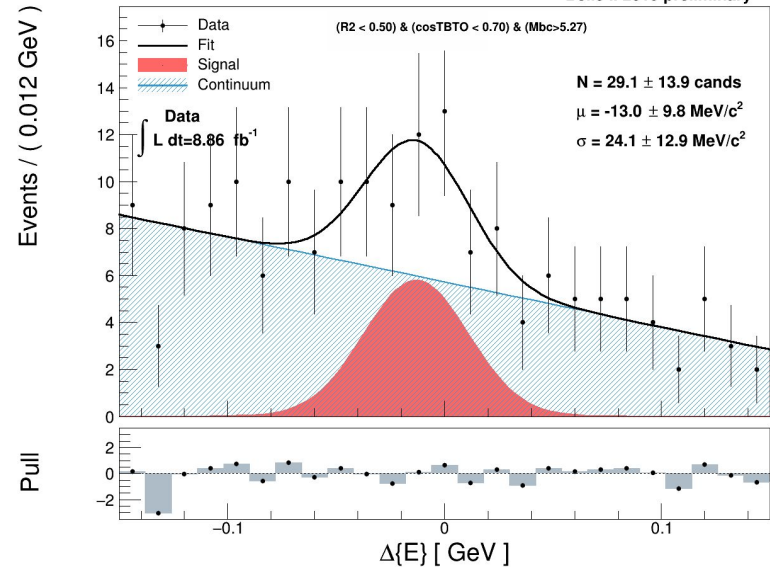
MC13b



Try to fit signal: Data



Proc10 + bucket8

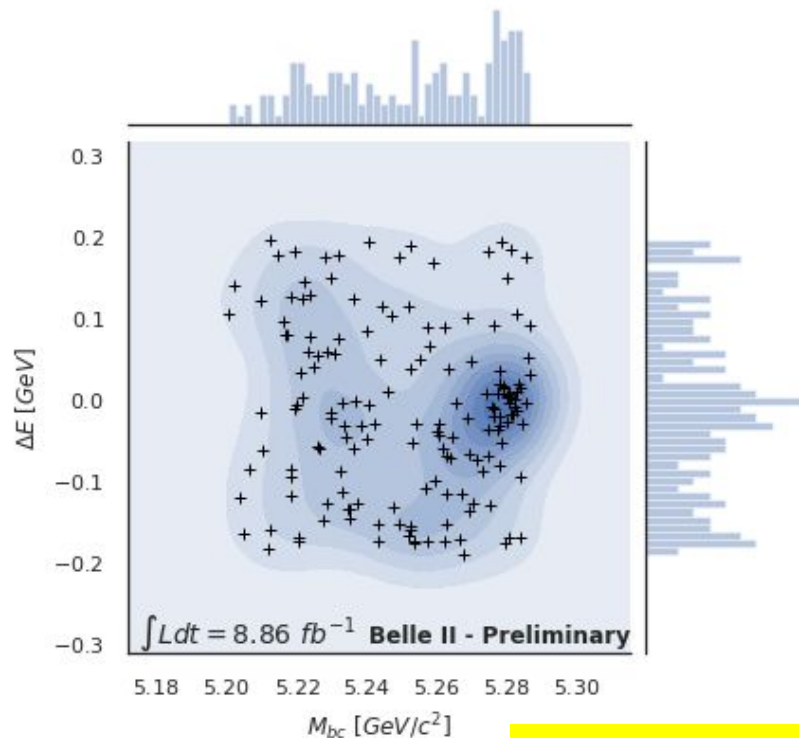
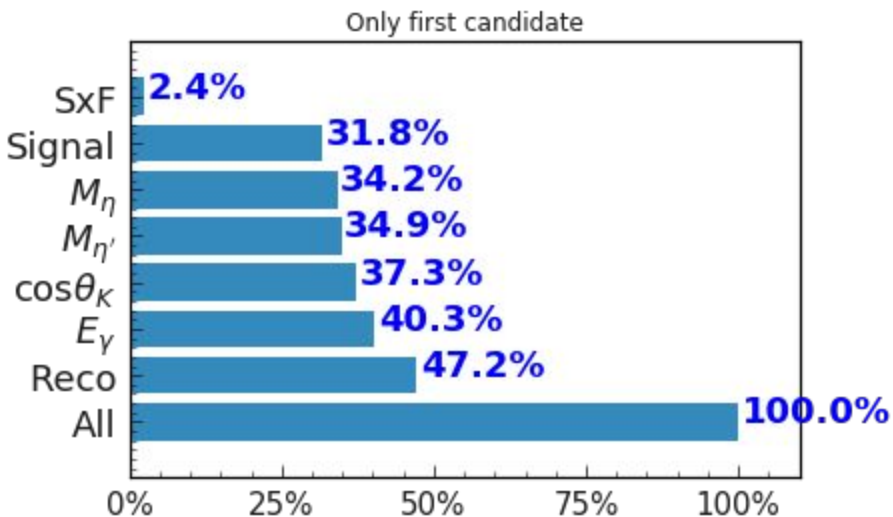


- Clear signal visible
 - Projection w/ selection on other variable
- seen 45.7+/-10 (Mbc) and 29.1.4+/-14 (De)
 - Expected: 31
- Still 1D fit: later for 2D

$B^+ \rightarrow \eta' (-\rightarrow \eta (\gamma\gamma)) \pi^+\pi^- K^+$

- Simple signal selection

- Signal eff 32% (40% reconstruction only)
- SxF 2.4 (vs 7.1 %)
- w/ CS eff: $32 * 0.75 = 24\%$
- Belle was 22%

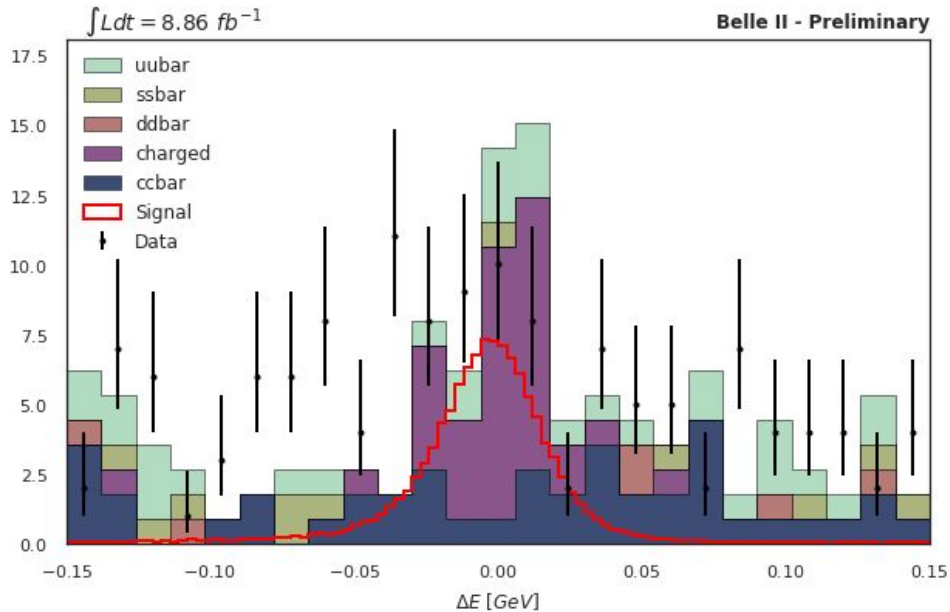
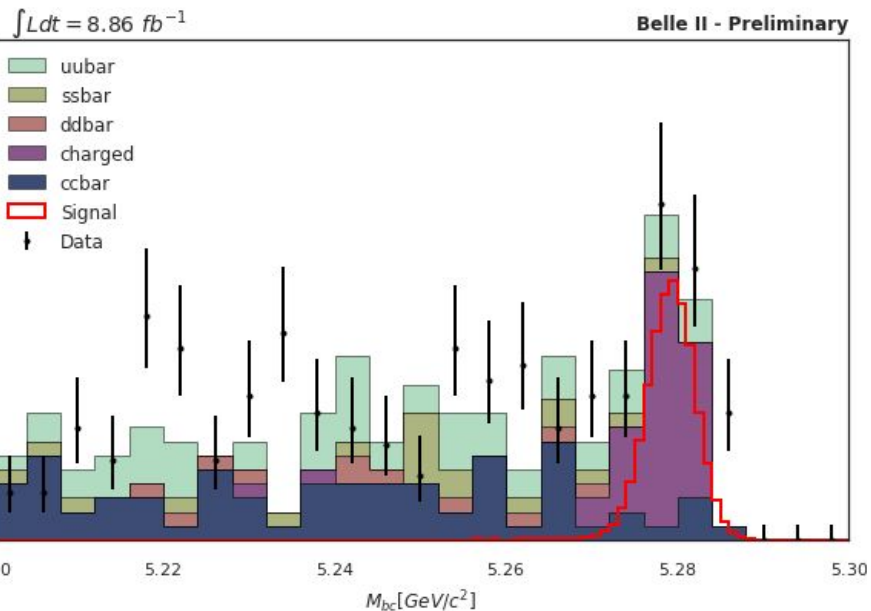


Proc10 + bucket8

- Low Background
- Tested with MC w/ signal injection
- And MC w/o signal removal

$$B^+ \rightarrow \eta' (-\rightarrow \eta (\gamma\gamma)) \pi^+ \pi^- K^+$$

Proc10 + bucket8

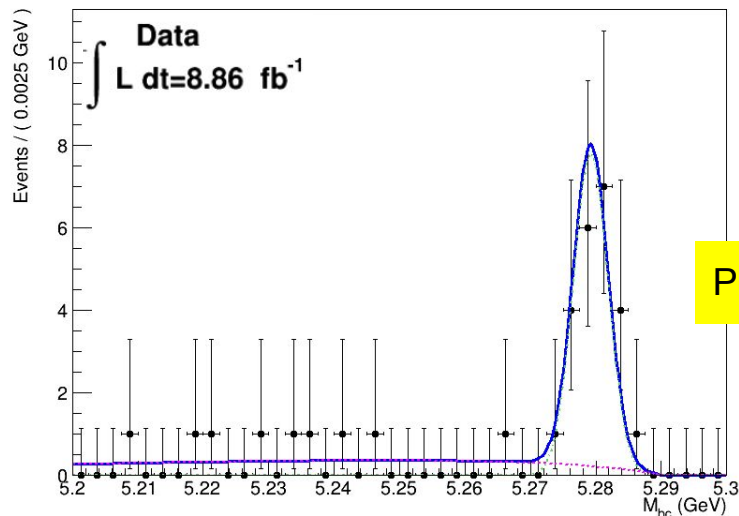


Data vs MC with expected signal

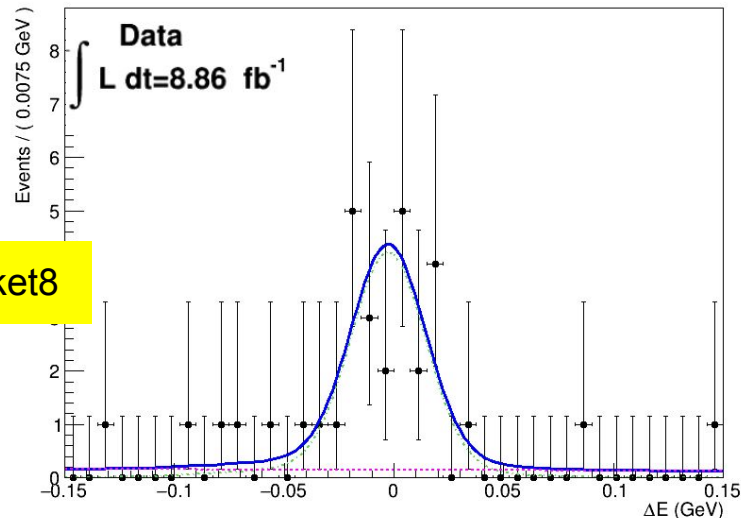
$B^+ \rightarrow \eta' (-\rightarrow \eta (\gamma\gamma)) \pi^+ \pi^- K^+$ 2D FIT



A RooPlot of " M_{bc} "



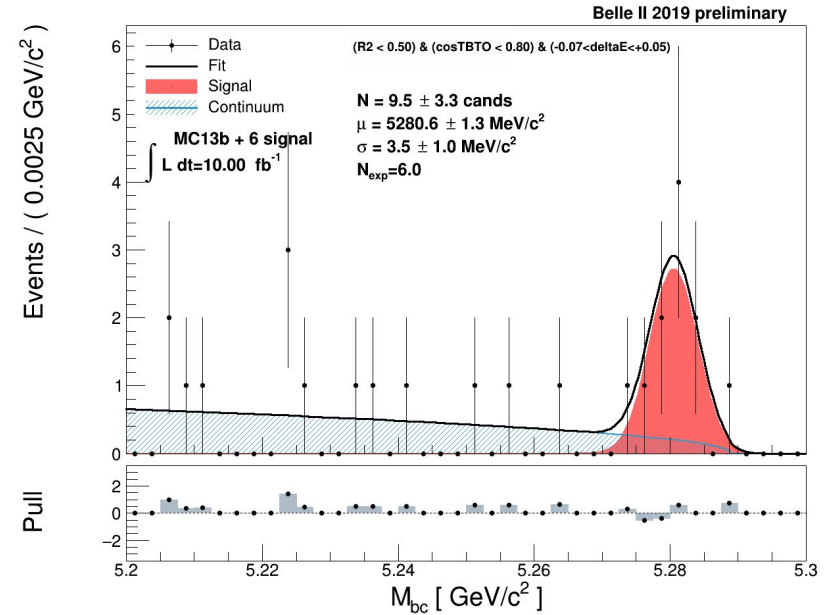
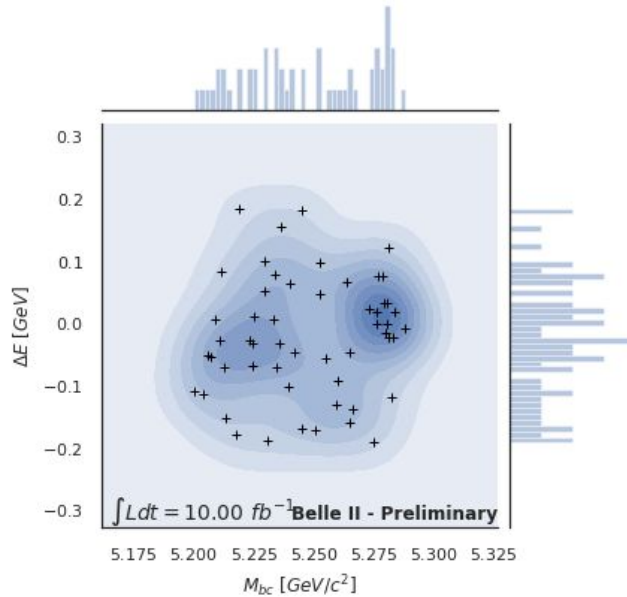
A RooPlot of " ΔE "



- 2D fit for M_{bc} and ΔE
 - **Fit result: 29.0 +/- 10 events**
 - **Expected 31 events**
- Fit on MC and Toy studies (injected 10-100) looks good

Expected signal (MC + injection)

MC13b



- Small signal yield with current lumi
 - but very low background
- Closure test ok: **injected 6, fit 9.5 +/- 3.3**