B→ η' K rediscovery

Status update

TDCPV meeting

08/09/2020

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Quick recap and what's new

- Include bucket13 and 14 for exp12
  - Dataset: proc11 + prompt
  - L=49.6 /fb
- Development of CS fBDT
- Include CS variable in UML fit
- Fix SxF fraction wrt signal in UML
- Toys with new UML fit

Selections

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

- $E_\gamma > 150$ MeV
- $0.5 < M_\eta < 0.57 \ \frac{GeV}{c^2}$
- $0.92 < M_{\eta'} < 1.0 \ \frac{GeV}{c^2}$

$\eta' \to \rho\gamma$

- $E_\gamma > 150$ MeV
- $\cos\theta_\gamma > -0.64$
- $0.51 < M_\rho < 1.0 \ \frac{GeV}{c^2}$
- $0.92 < M_{\eta'} < 1.0 \ \frac{GeV}{c^2}$

K

- $\cos\theta_K > -0.5$

K_s^0

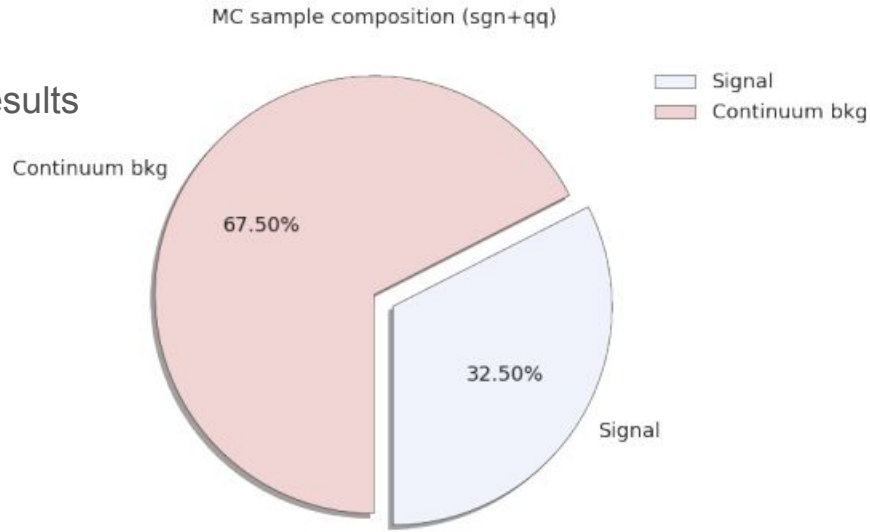
- $\cos\theta_{p,v} > -0.64$
- $0.49 < M_{K_s^0} < 0.51 \ \frac{GeV}{c^2}$

CS fBDT

- So far, used only R2 and cos(TB-TO) as Continuum Suppression variables
  - Hard cut on both
- Move to fBDT
  - Variables considered
  - 31 variables have been selected looking at those used in BELLE2-NOTE-PH-2020-007 v2.0:
    - R2
    - cosTBT0
    - cosTBz
    - thrustOm
    - KSFWVariables (mm2): missing mass squared
    - KSFWVariables (et): transverse energy
    - Kakuno-Super-Fox-Wolfram moments
    - CLEO cones (CC_i, for i = 1, ..., 9)
    - DeltaZ and DeltaZErr
  - No TagV variables

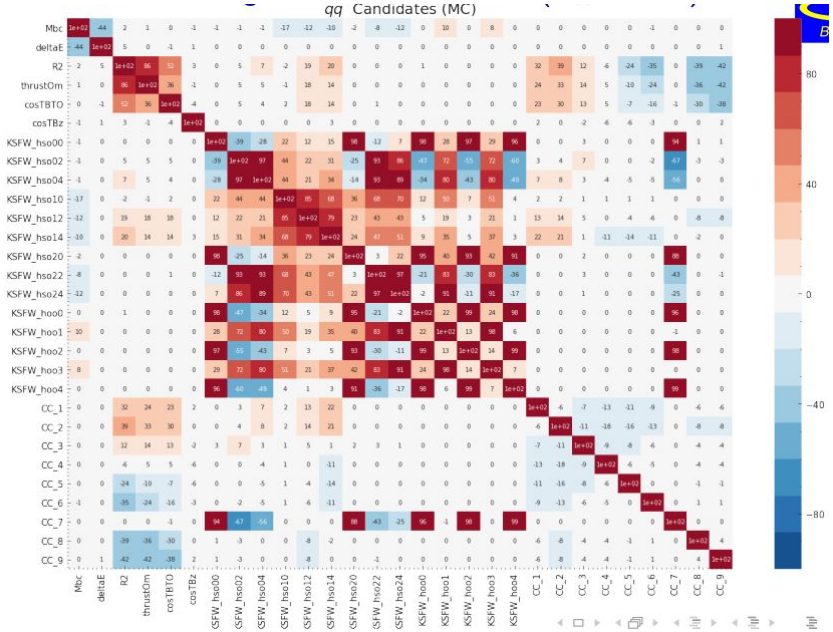
Training

- Use signal and Continuum after signal selection
- Train together all four channels (charged/neutral, eta'->rho gamma, eta'->eta pipi)
  - Investigating possible overlap of background for different channels
  - Same background event for B0->eta' Ks and B+->eta' K+
  - Unlikely for different eta' decay modes
    - Possible for neutral/charged state
  - Test earlier with separate training, similar results

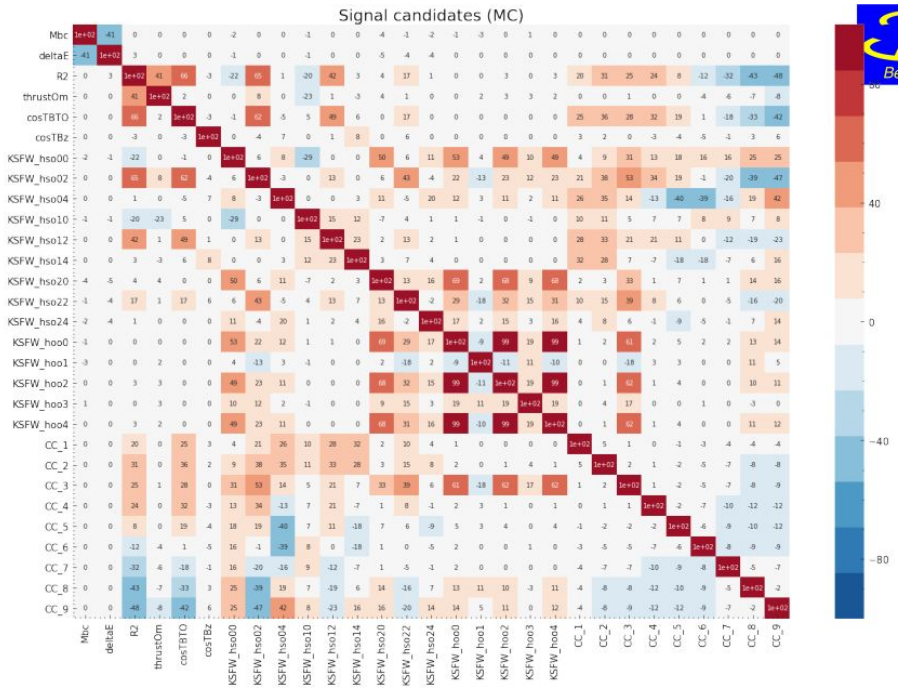


Correlations

- Large correlation w/ Mbc and DeltaE for mme and et (excluded)
- For continuum also for some KSFW moments, not for signal (kept)



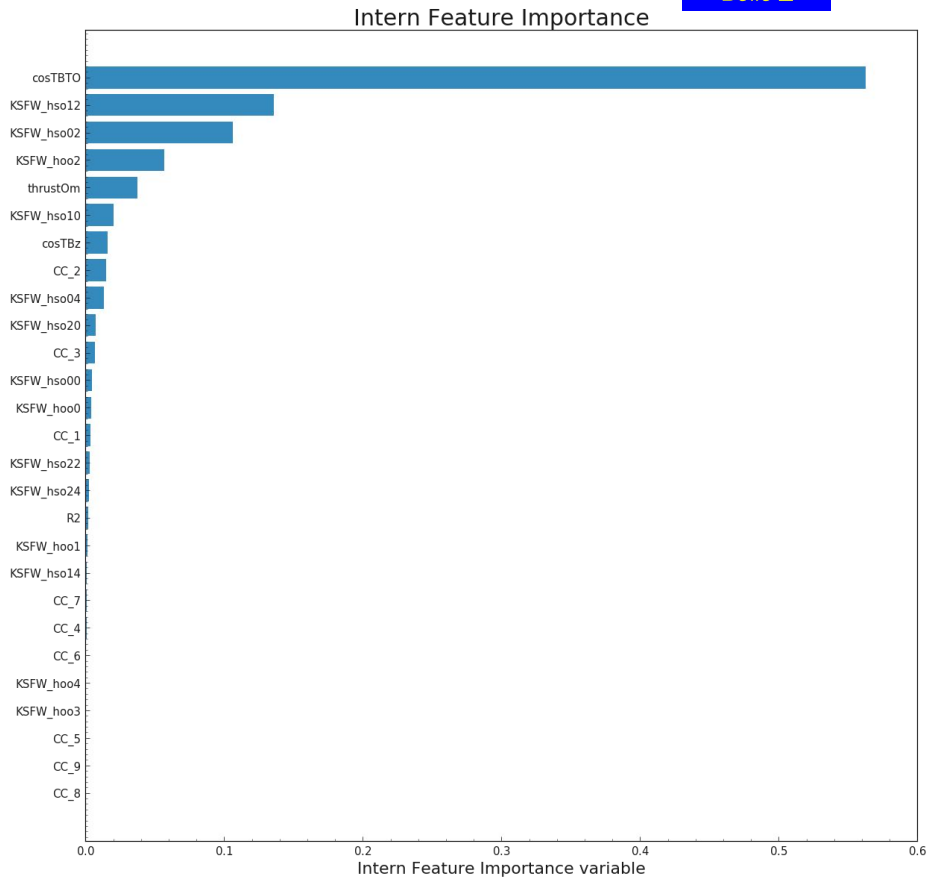
Continuum



Signal

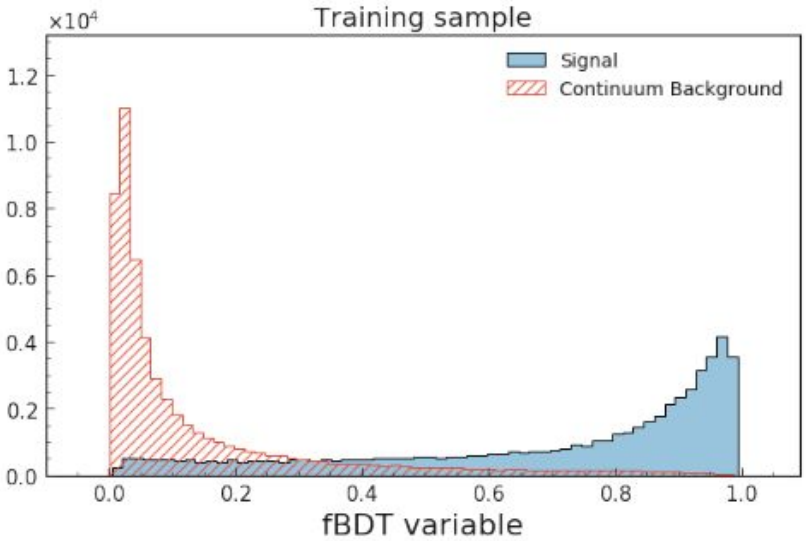
Intern feature importance

- cos(TB-TB) by far the most discriminating variables
- Most of correlated variables not very important
- Tried with less variables, basically same performances
- Could remove many w/o any significant change



Training (and Validation)

- Dataset divided in training (50%) - Validation (30%) - Test (20%)



Confusion matrix:

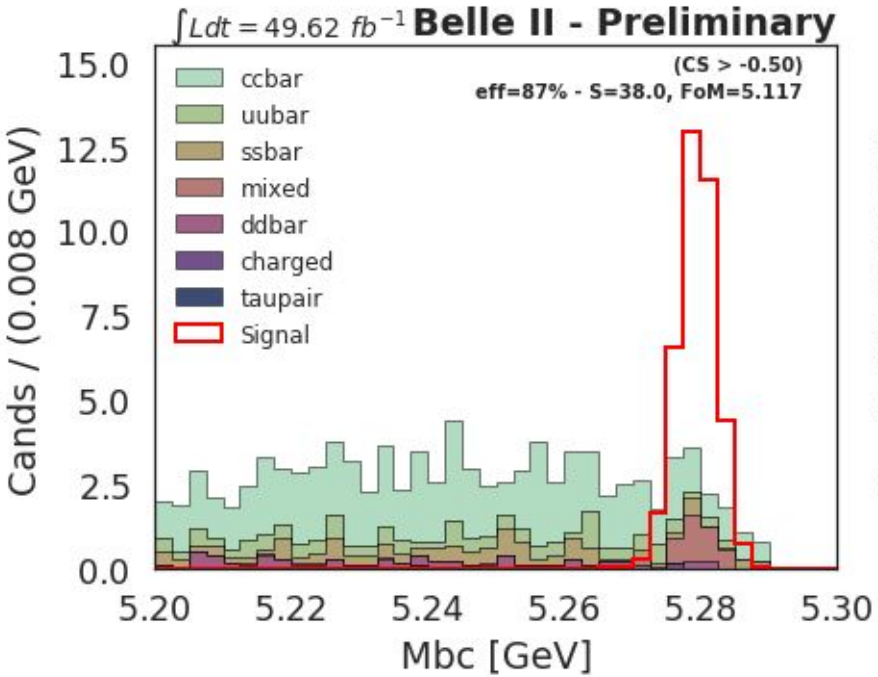
	pred bkg	pred sgn
true bkg	0.92	0.08
true sgn	0.25	0.75

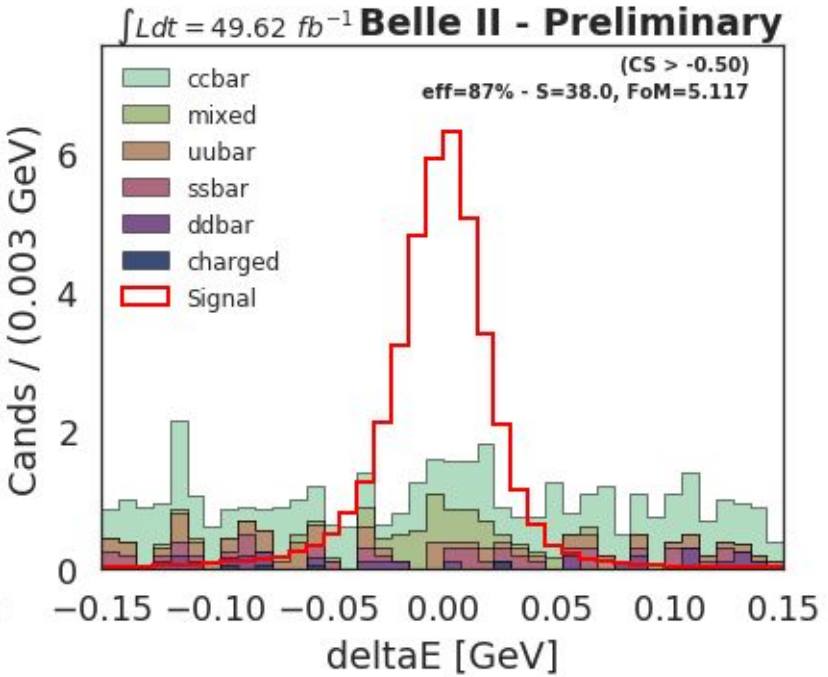
Score (fBDT<>0.5) 0.8666

Same performances for validation sample

CS selection impact

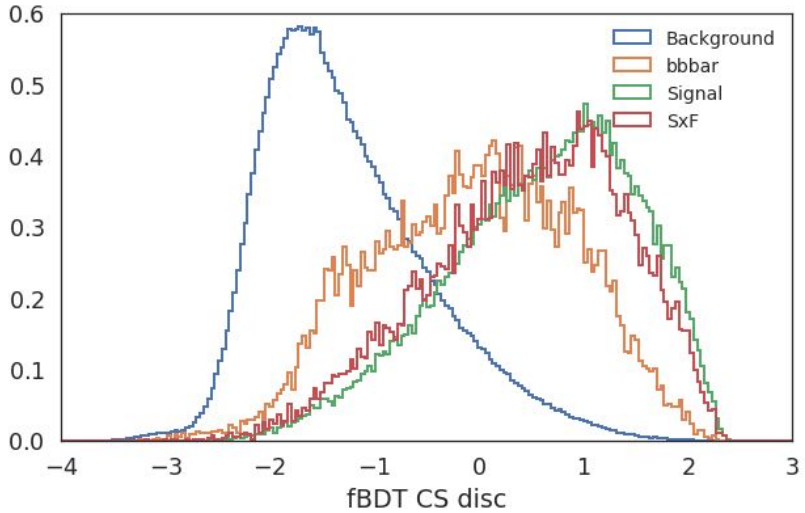
- Mbc and De with cut on CS fBDT maximizing FoM=S/√(S+B) in signal region
- Eff=90% (was 62% with R2/cosTBTO cut)

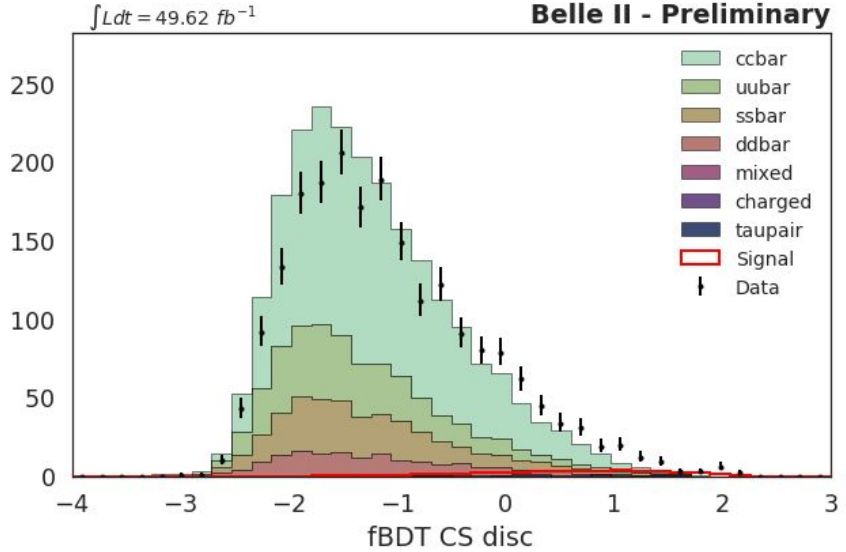




CS usage in UML

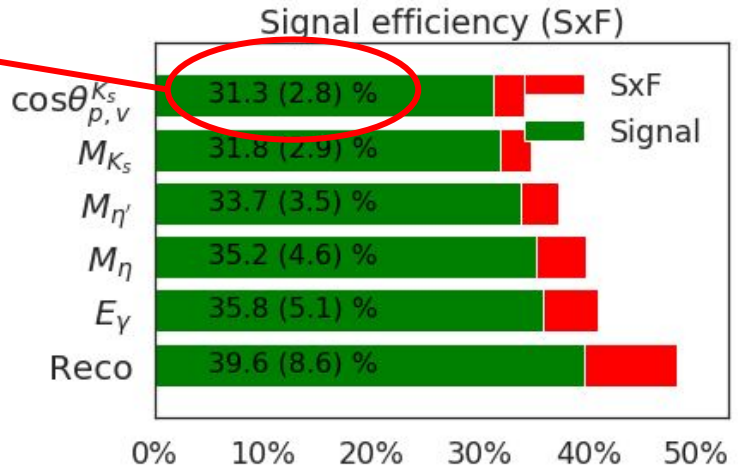
- Use it in the UML to extract signal
  - Use non transformed fBDT for easier parametrization (bifurcate gauss)
- Previous rectangular cut on R2 - CosTB-TO has 62% signal efficiency
  - Recover 40% of signal
- Good Data - MC agreement after signal selections



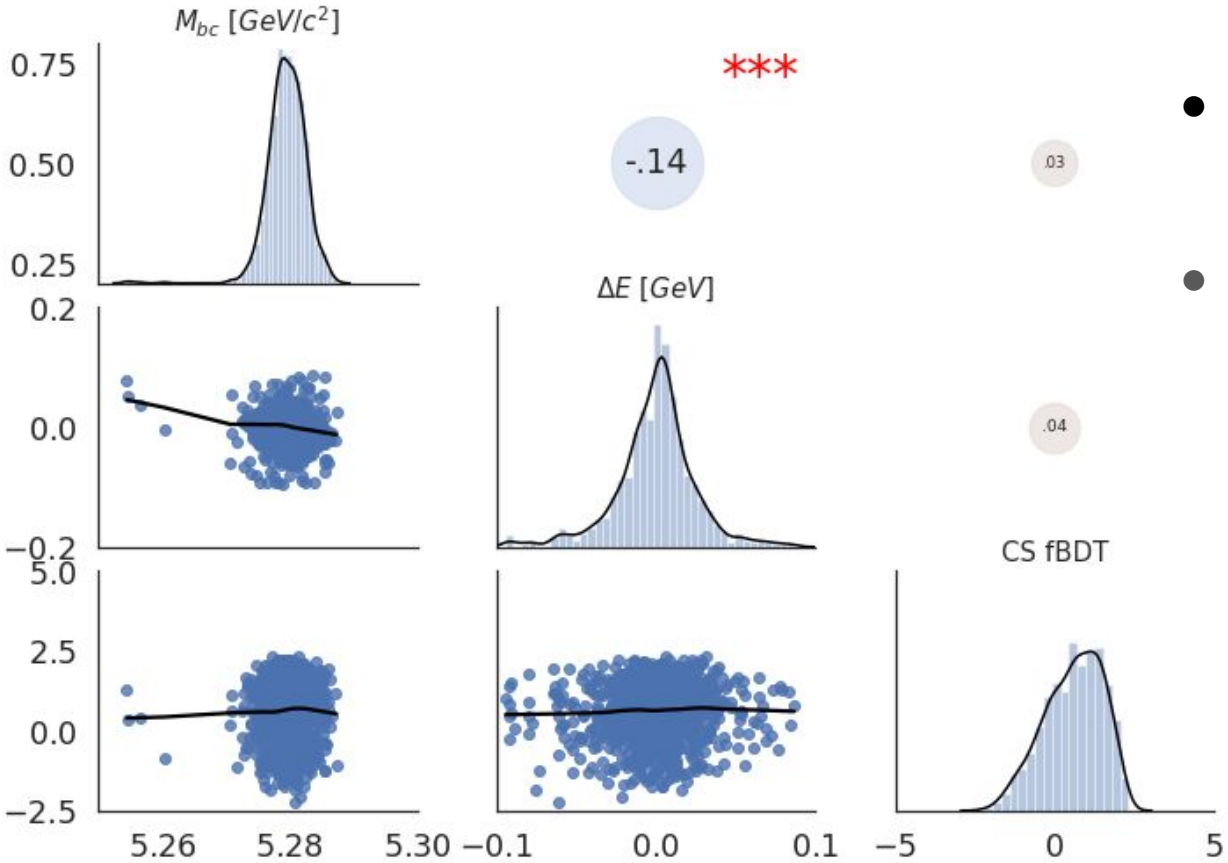


UML improvement

- Fit variables:
  - **M_{bc}, ΔE, CS**
  - Remove M(η') not very discriminating
- Signal MC shows that SxF is about 10% of sign after selections
  - Given the integrated luminosity, SxF is expected to be c the order few events
  - Not enough to separate that component from signal
- Fix ratio of SxF to Signal from MC, and fit with 3 components:
  - **Continuum**
  - **Peaking**
  - **Signal+SxF**
- Medium term plan: develop BDT Signal/SxF to be added to UML as 4th variables (as in B2TIP)



Correlation among fit variables



- Very limited correlation between CS and M_{bc}, ΔE
- Some between M_{bc}, ΔE

PDF

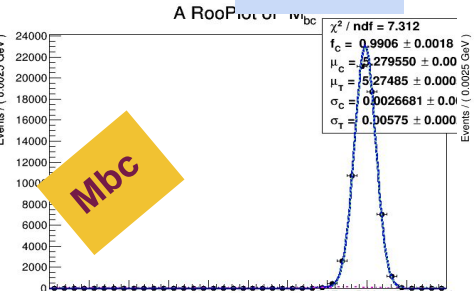
Signal

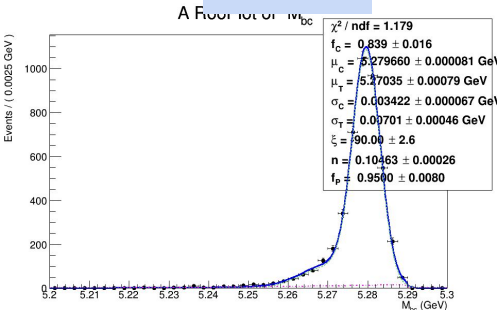
SxF

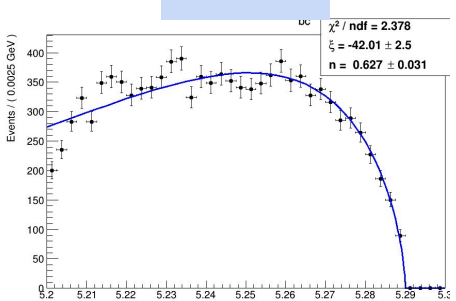
Cont

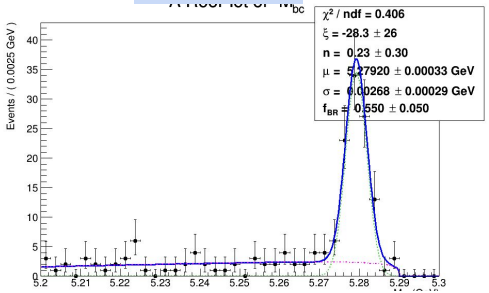
Peak

Mbc

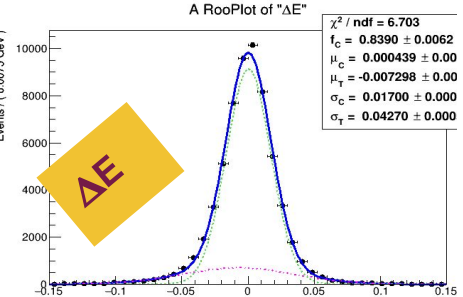


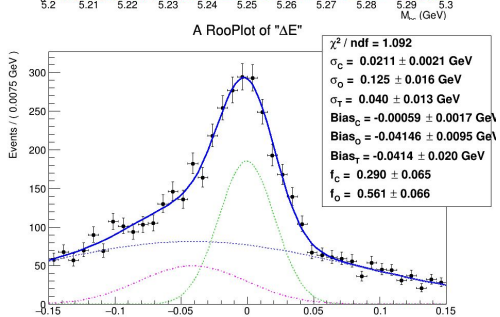


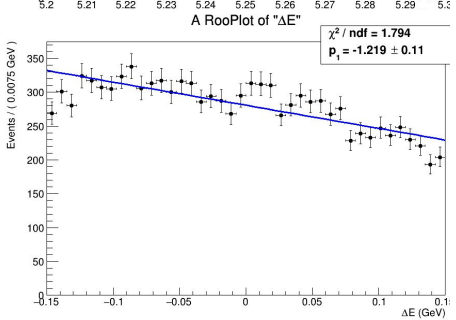


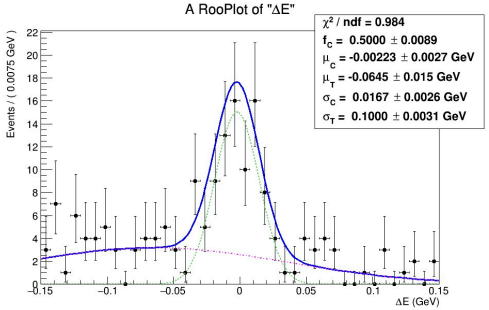


ΔE

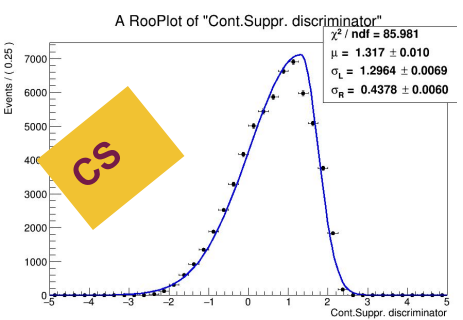


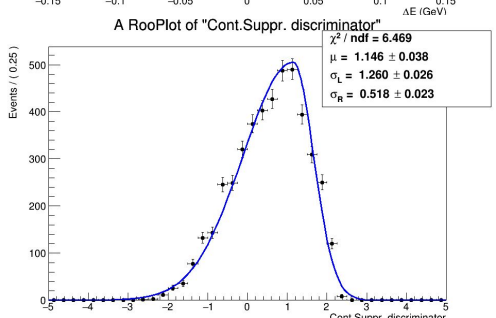


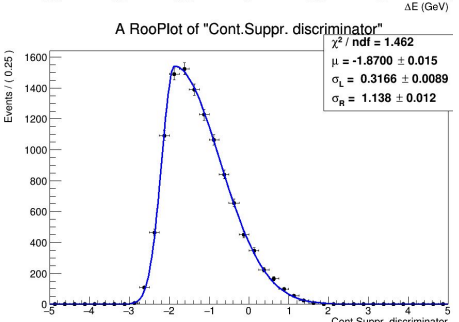


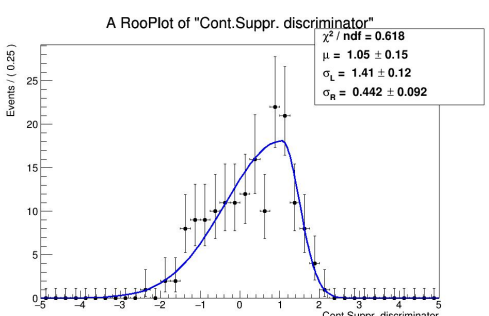


CS



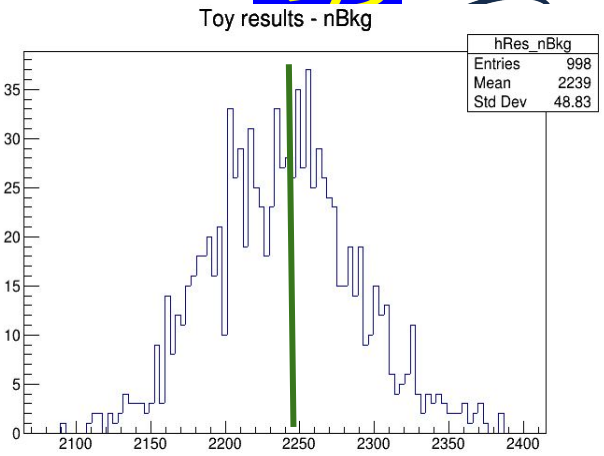


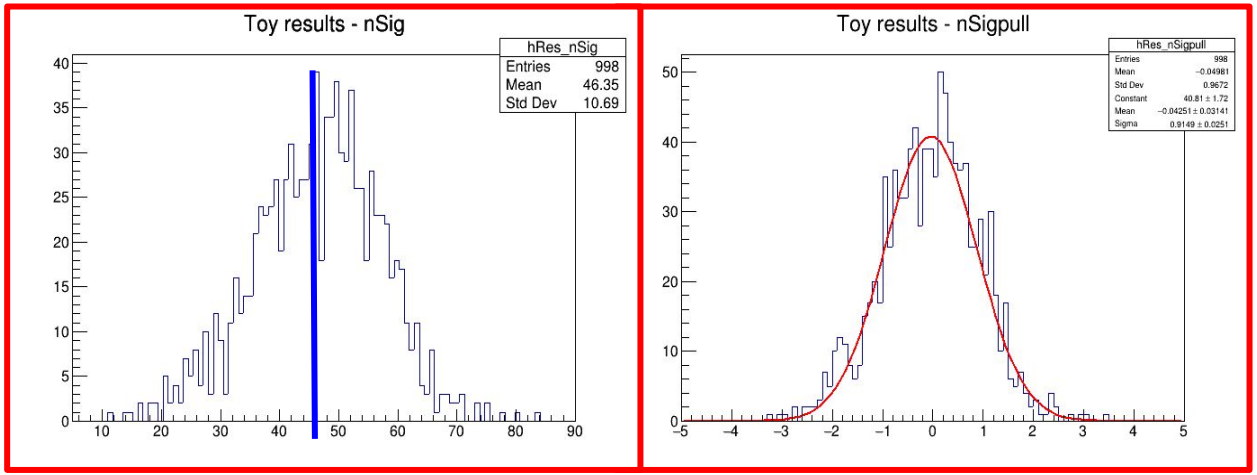


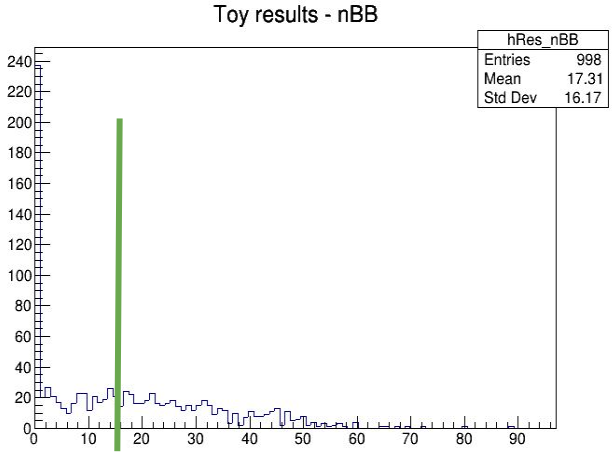


Toys

- UML tested with toys
  - Embedded for Signal and SxF
  - Pdf for Continuum and Peaking
- Good results for signal (including pools)
  - Ok for continuum, many 0s for peaking (avg ok)

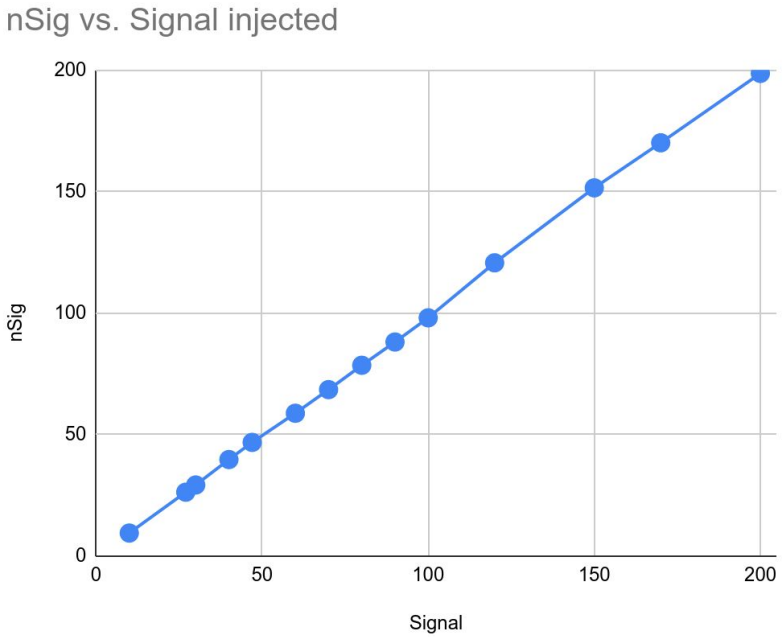


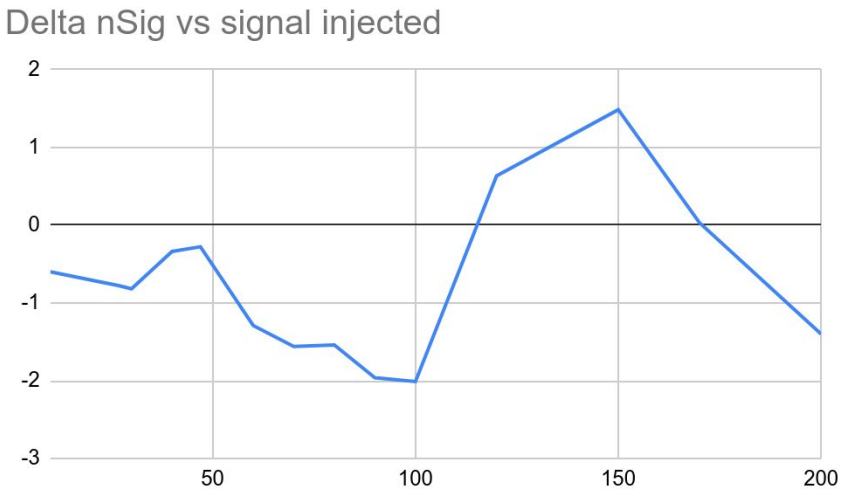




Toy linearity

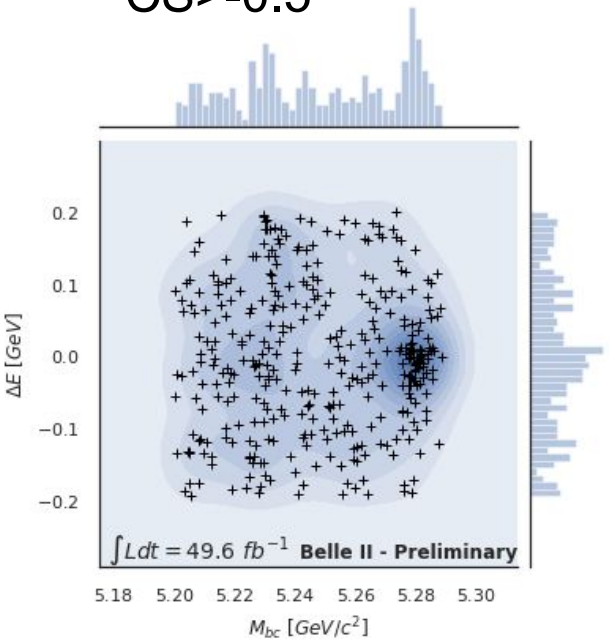
- Tested varying signal but keeping cont+peaking fixed
- A bit of underestimation of nSignal (well within uncert)

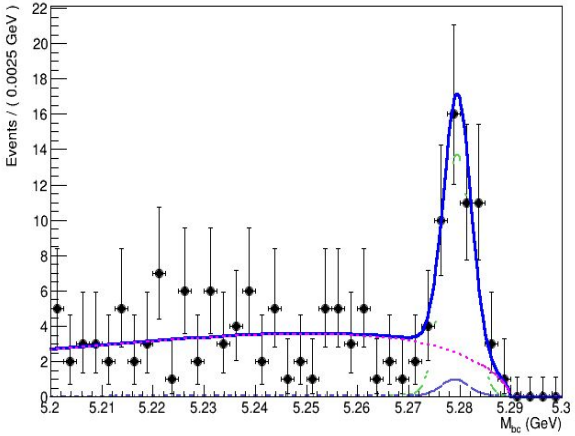


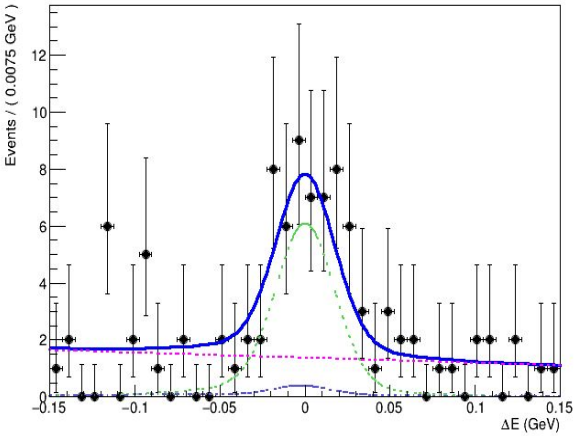


UML fit results (on MC)

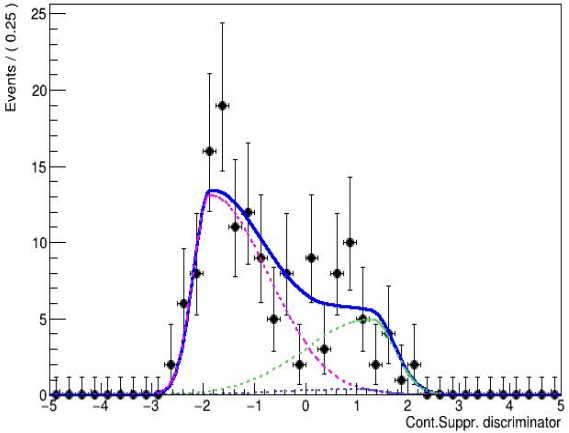
CS>-0.5





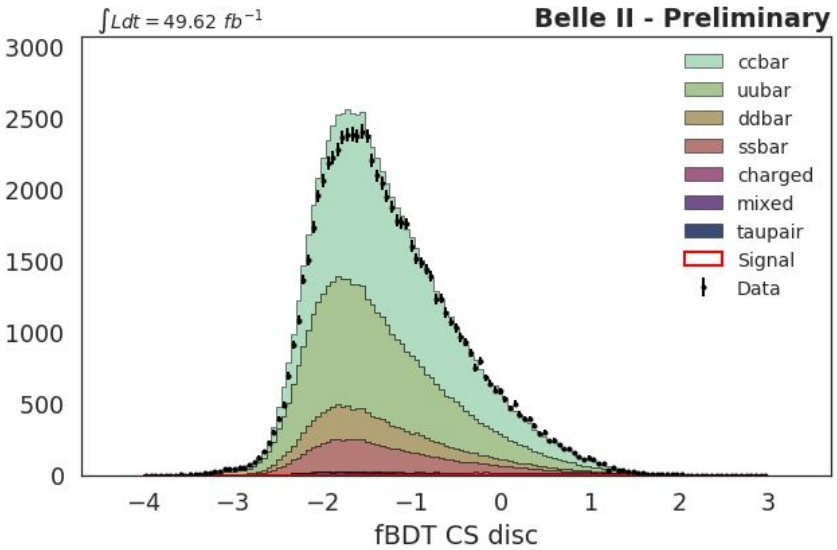


Likelihood S/B > 0.7



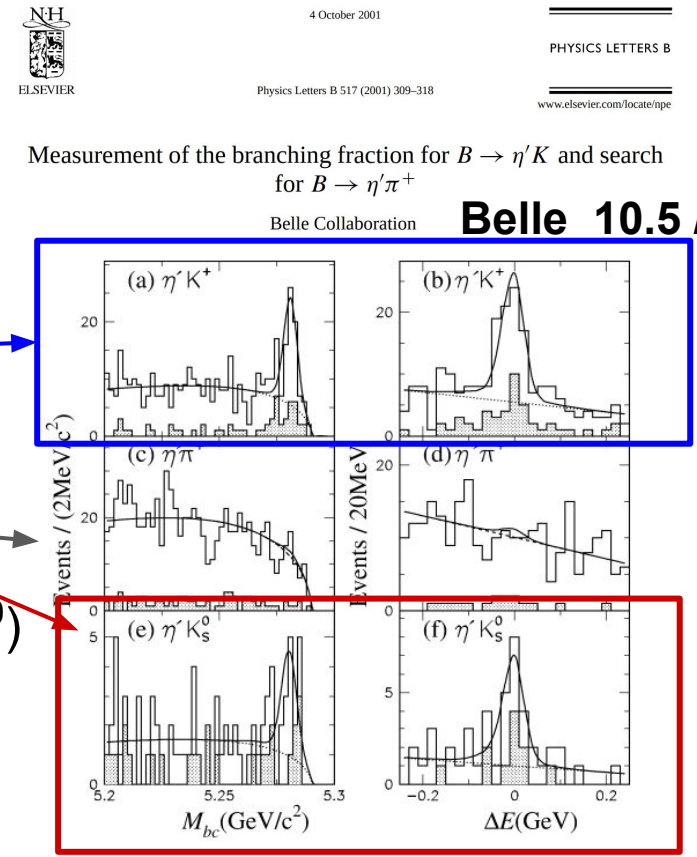
Summary and plan

- Some progress in CS handling and UML fit
- Still need to better optimize signal selection
  - Done some work (not shown today)
- Develop fBDT signal vs SxF to be included in UML fit
  - Probably not needed for current luminosity
- Work on TDCPV udst skim
  - Trace the origin of 40% efficiency drop
- Extend CS UML and toys to other channels as well
- Update documentation


$\int Ldt = 49.62\ fb^{-1}$
Belle II - Preliminary
ccbar
uubar
ddbar
ssbar
charged
mixed
taupair
Signal
Data
3000
2500
2000
1500
1000
500
0
−4
−3
−2
−1
0
1
2
3
fBDT CS disc

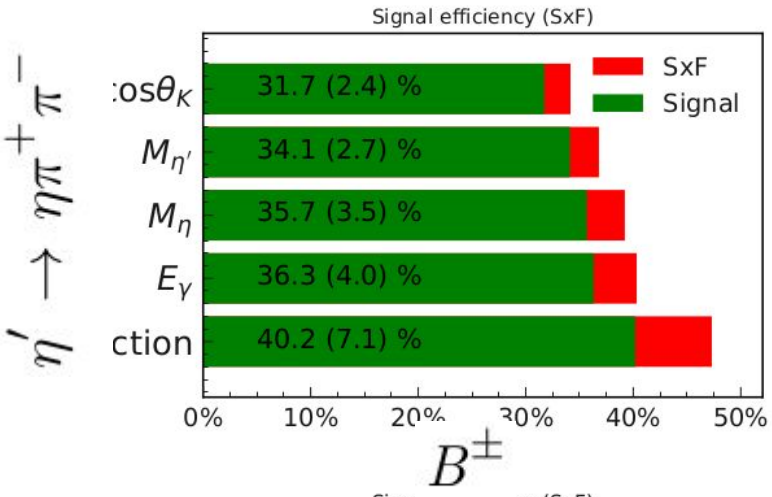
Motivation

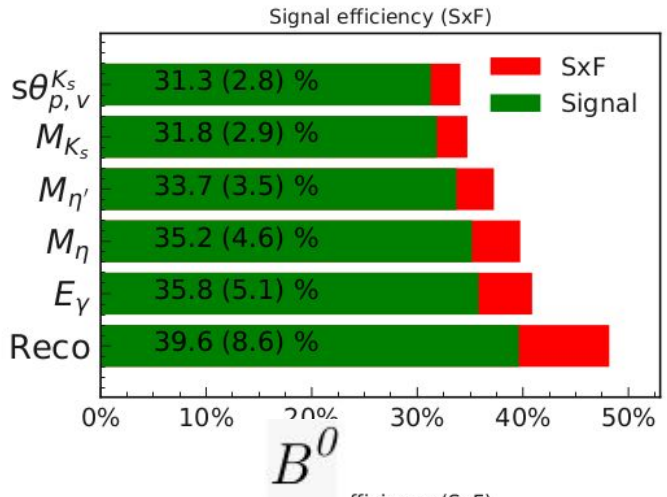
- BR($B^0 \to \eta' K^0_S$) = (6.6 ± 0.4) × 10^{-5}
  - C_{CP} ($B^0 \to \eta' K^0$) = −0.06 ± 0.04
  - $-A_{CP}=S_{CP}$ ($B^0 \to \eta' K^0_S$) = 0.63 ± 0.06
- BR($B^+ \to \eta' K^+$) = (7.06 ± 0.25) × 10^{-5}
- Seen by Belle with 10/fb?
  - B^+: BR=$(79^{+12}_{-11} \pm 8) \times 10^{-6}$
  - B^0 :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

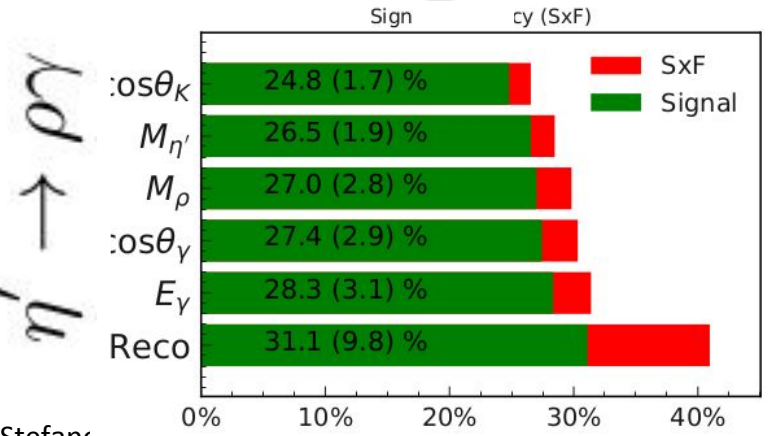


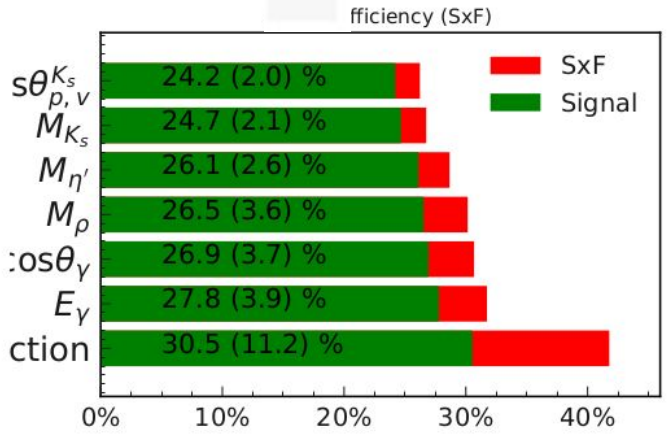
Shaded $\eta' \to \eta\pi\pi$, white all (including $\eta' \to \rho\gamma$)

Selection efficiency





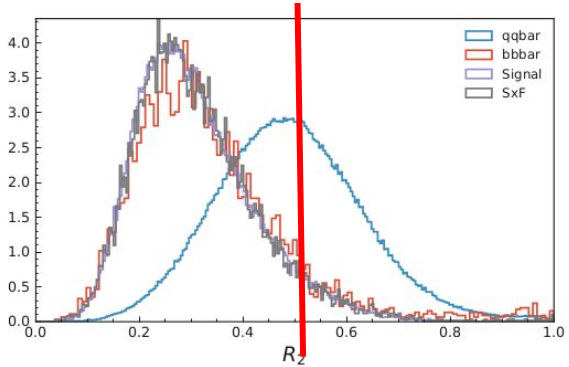




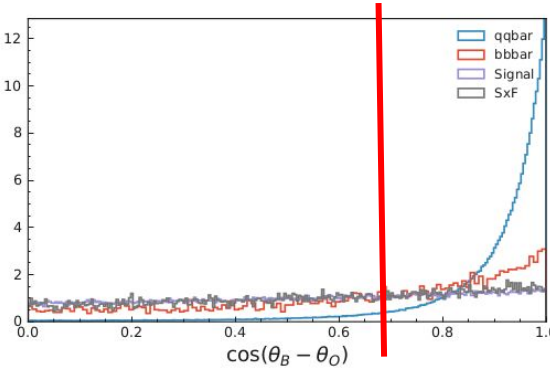
- High selection efficiency **24-30%**
- SxF **10->2%**
- **no CS cut (next slides)**

Continuum suppression

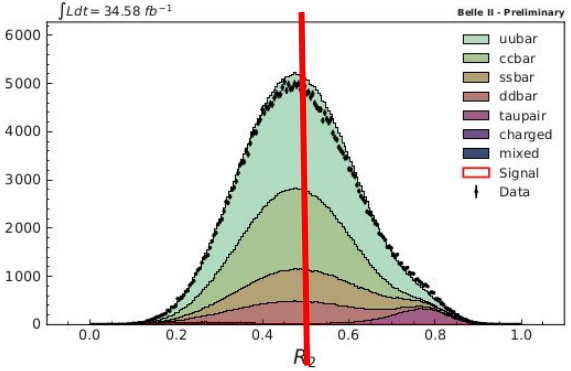
- Using only **R2** and **CosTBTO**
- Started MVA but still some correlation with data not understood
  - For next iteration
- Optimization of cut based on
- FoM=S/sqrt(S + B)
  - S and B in signal region from MC
  - Mbc>5.27
  - -70<De<50 MeV
- **R2<0.5**
- **CosTBTO<0.7**
  - Probably too hard

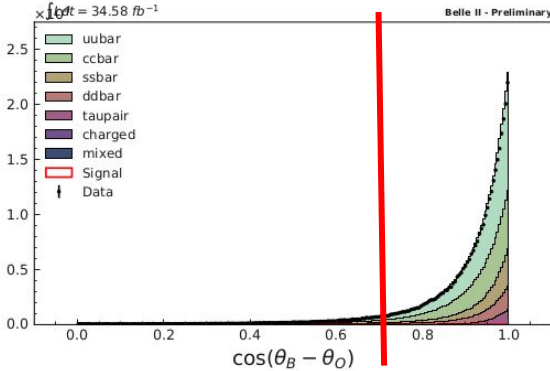


R2



cosTBTO



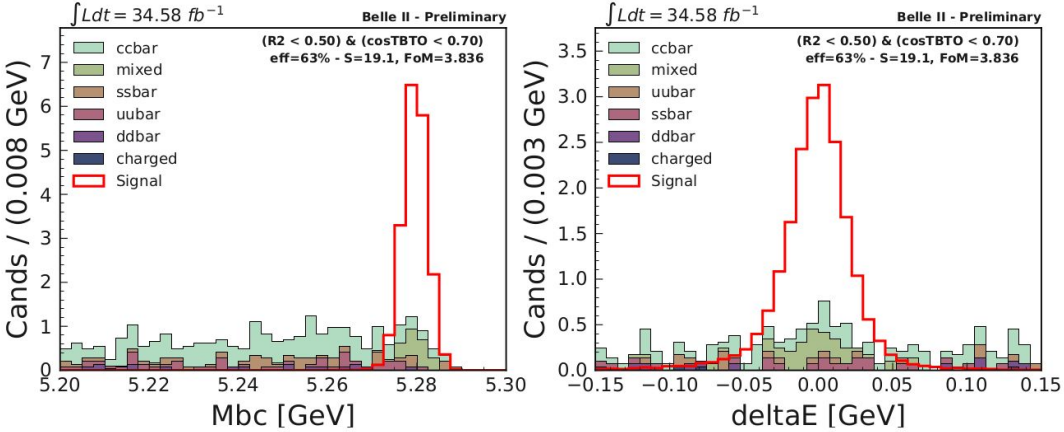


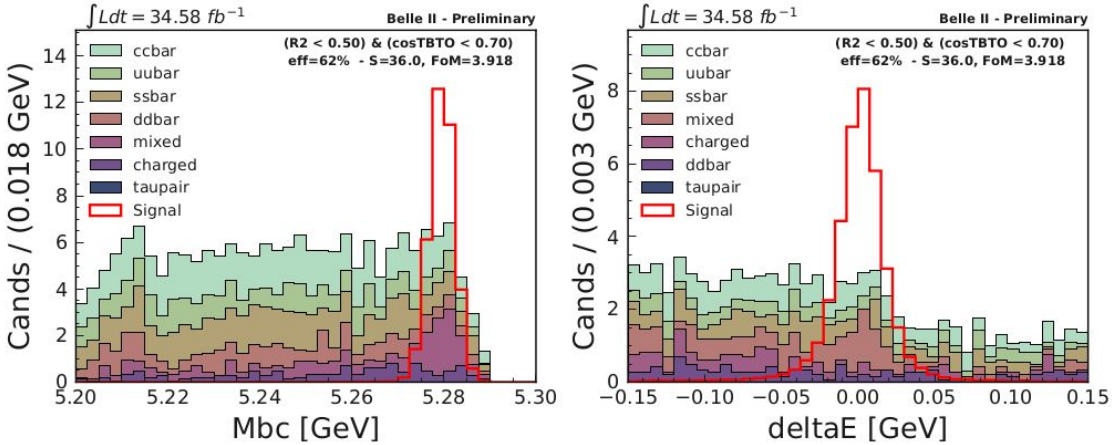
Full signal efficiency (including CS)

Channel	$B^\pm \to \eta' K^\pm$, $\eta' \to \eta\pi^+\pi^-$	$B^0 \to \eta' K^0_S$, $\eta' \to \eta\pi^+\pi^-$	$B^\pm \to \eta' K^\pm$, $\eta' \to \rho\gamma$	$B^0 \to \eta' K^0_S$, $\eta' \to \rho\gamma$
	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

Signal region for B^0 (blind for data)





$$B^0 \to \eta' K^0$$
$$\eta' \to \eta\pi^+\pi^-$$

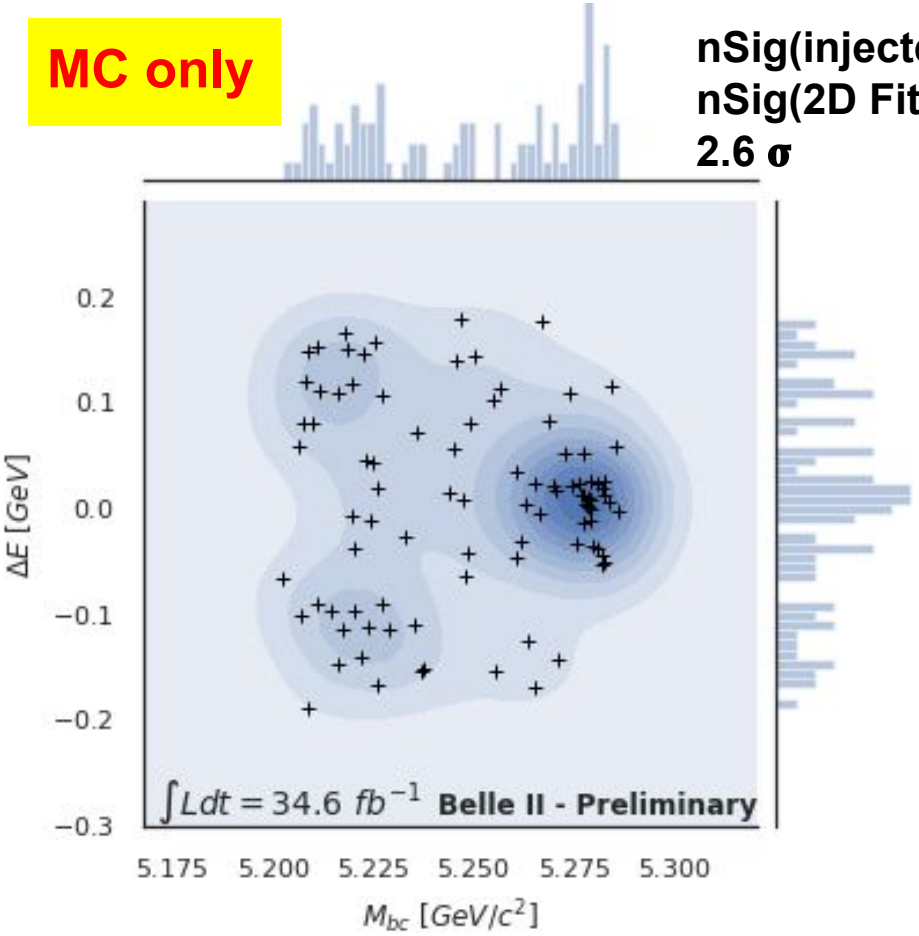
- For each plot select CR on the other variable
- Background and signal normalized to L_{DATA}
- Signal removed from bbbar montecarlo

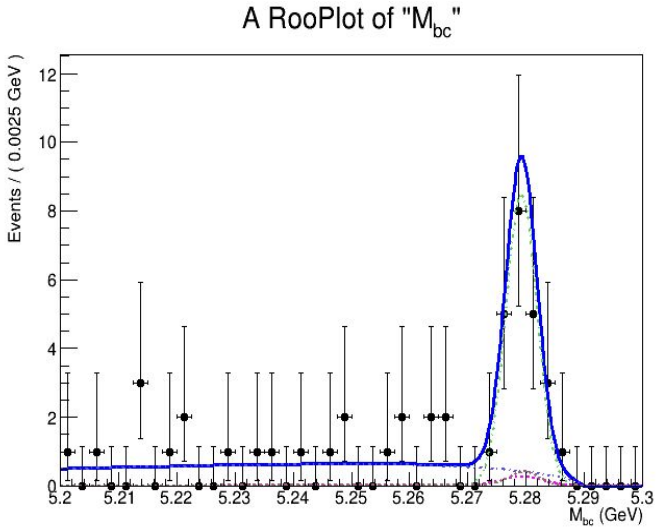
$$B^0 \to \eta' K^0$$
$$\eta' \to \rho\gamma$$

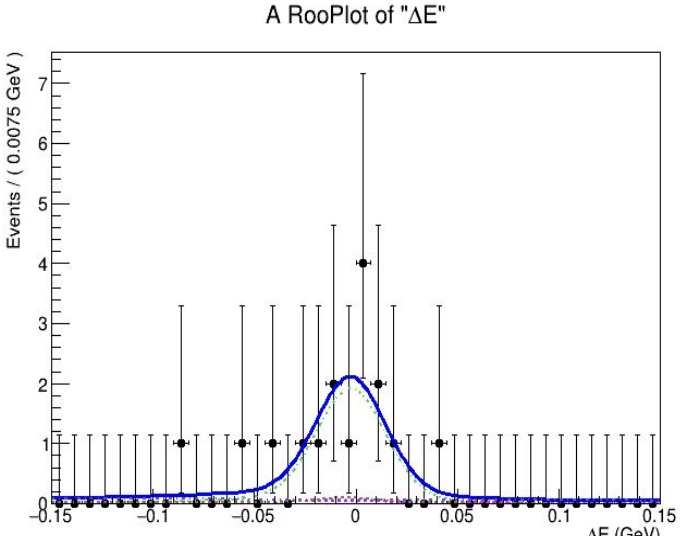
$B^0 \to \eta' K_S^0$ with $\eta' \to \eta\pi^+\pi^-$

MC only

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



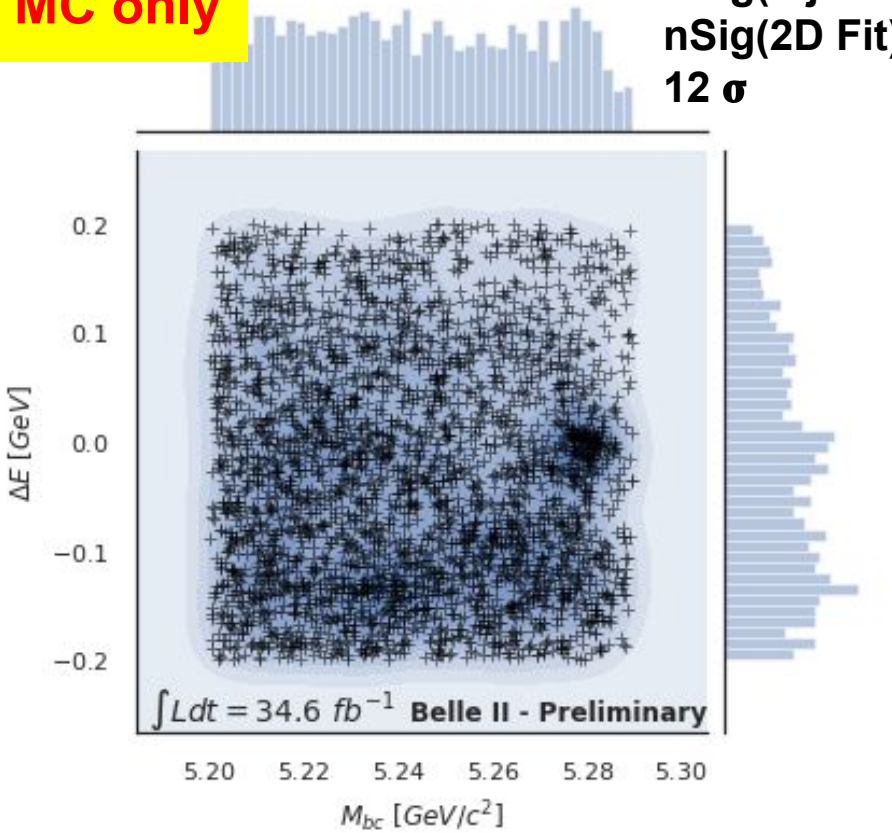


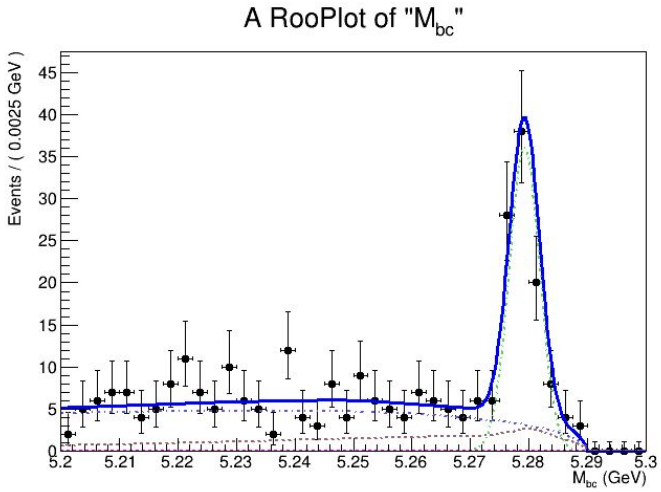


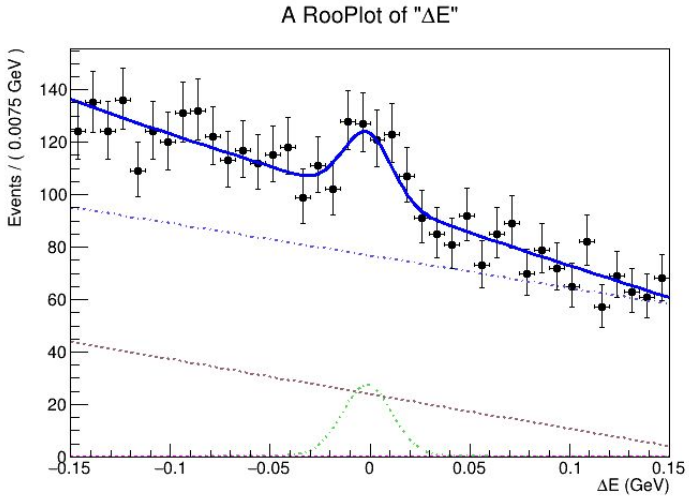
$B^{\pm} \to \eta' K^{\pm}$ with $\eta' \to \rho\gamma$

MC only

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







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 $B \to \eta' K$ in Belle II data

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INFN sezione of Padova

(The Belle II Collaboration)

Abstract

This note describe the rediscovery of $B \to \eta' K$ decay in Belle II data, both in the charged and neutral final state $B^0 \to \eta' K^0_S$ and $B^\pm \to \eta' K^\pm$. The η' is searched for in two decay modes: $\eta' \to \eta\pi^+\pi^-$, with $\eta \to \gamma\gamma$ and $\eta' \to \rho\gamma$. Tha analysis uses data collected in 2019 (and 2020) and processed with proc11 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 $\mathbf{A_{CP}}$ in charged mode
  - Maybe include also pi+ final state ?
- Will anyhow push first version of belle2note to invenio for first round of comment

Backup

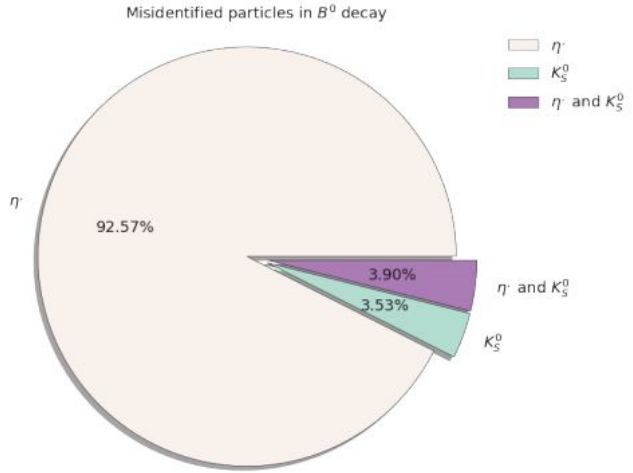
Branching fractions

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

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

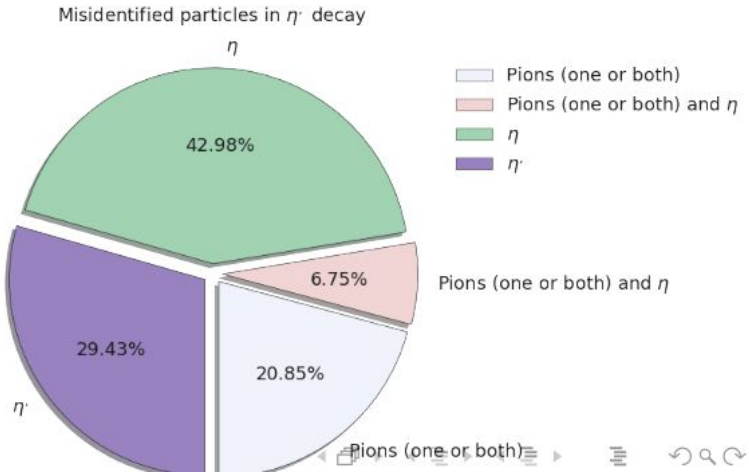
Recap

SxF candidates are misreconstructed Signal candidates

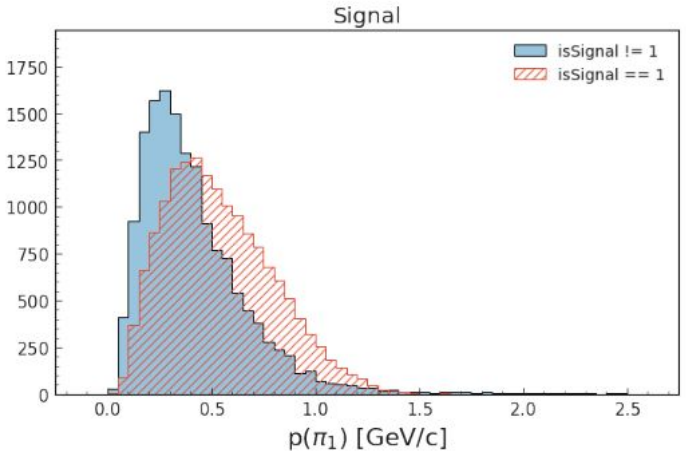


The incorrect reconstruction of B^0 $(isSignal = 0)$ is mainly due to η' reconstruction.

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

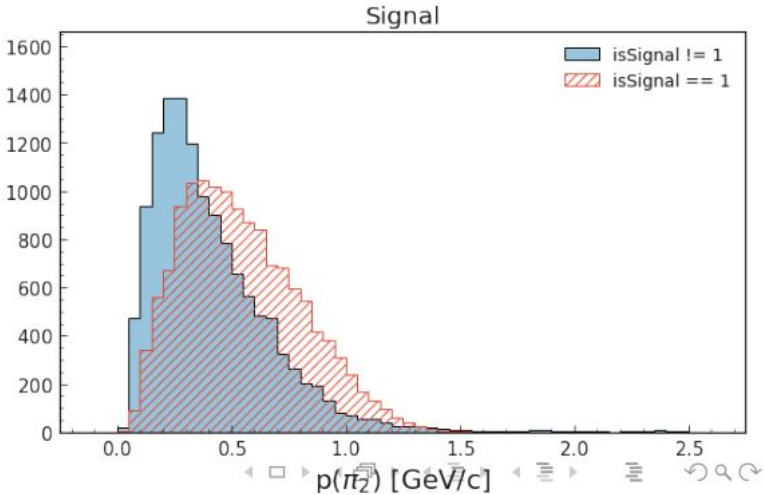


Momentum of misreconstructed pions in $\eta' \to \eta(\gamma\gamma)\pi^+\pi^-$ decay

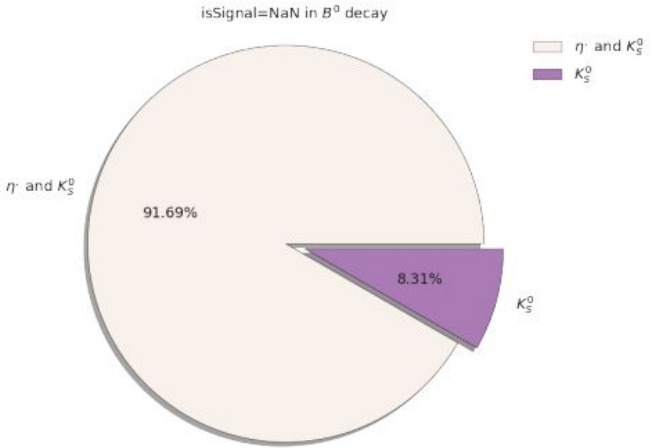


Same area normalization for histograms.

Incorrectly reconstructed pions tend to have low momentum.

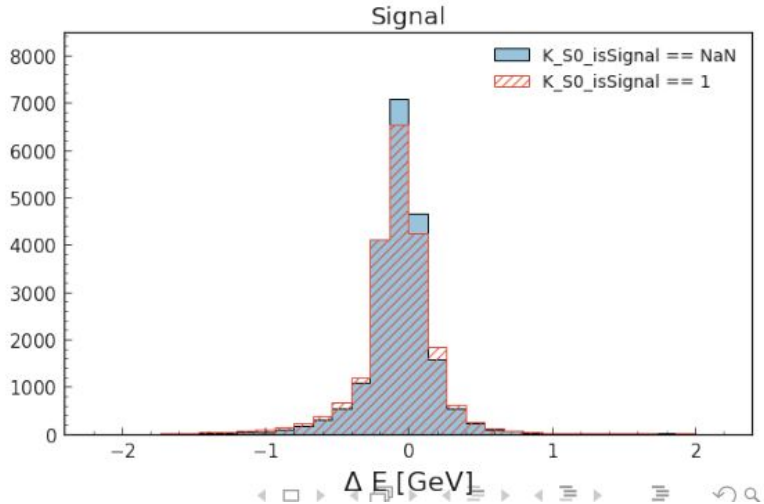


K^0_S when isSignal=NaN

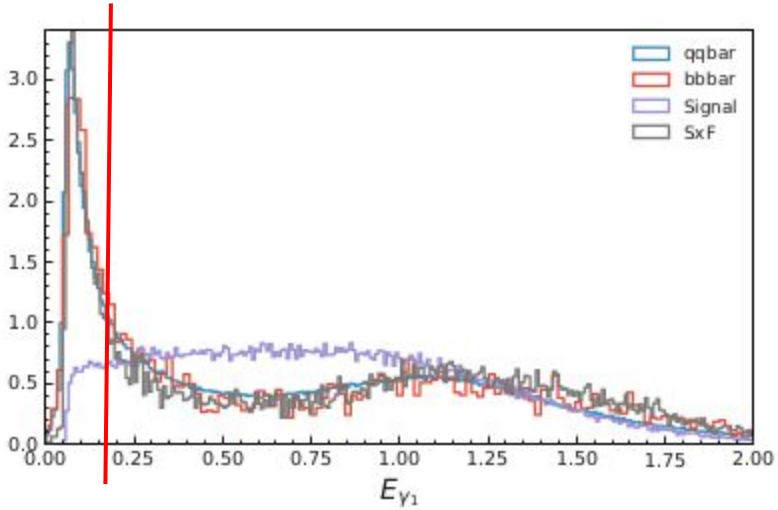


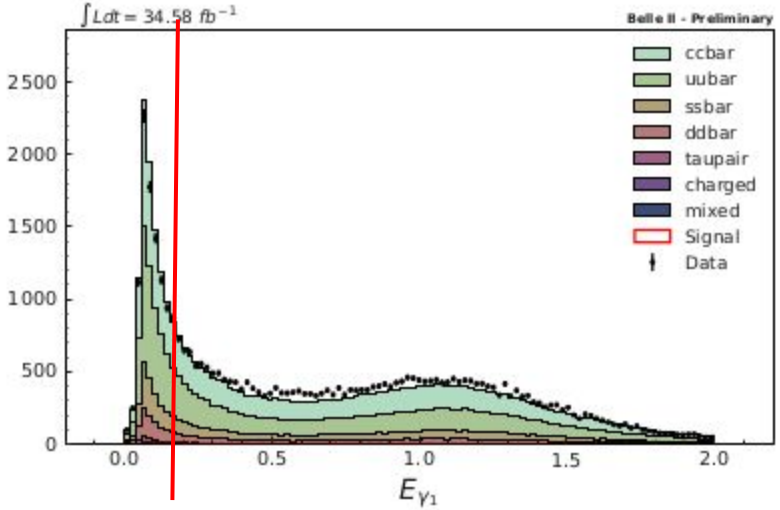
Whenever isSignal is NaN for the B_0, it is NaN also for the K^0_S

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

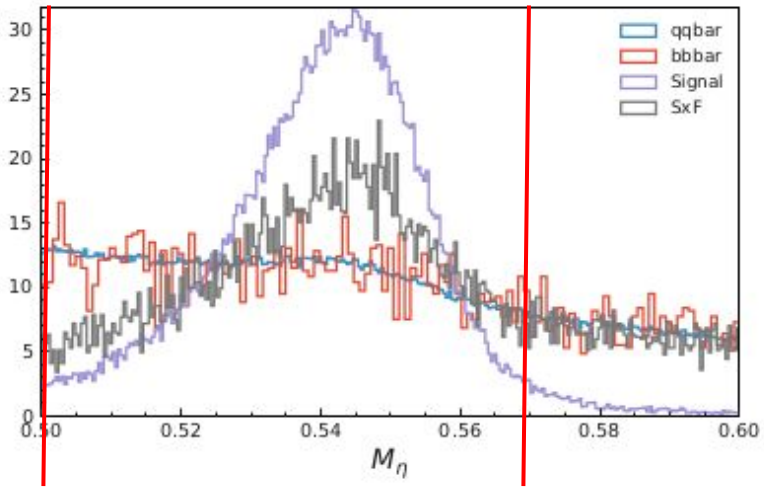


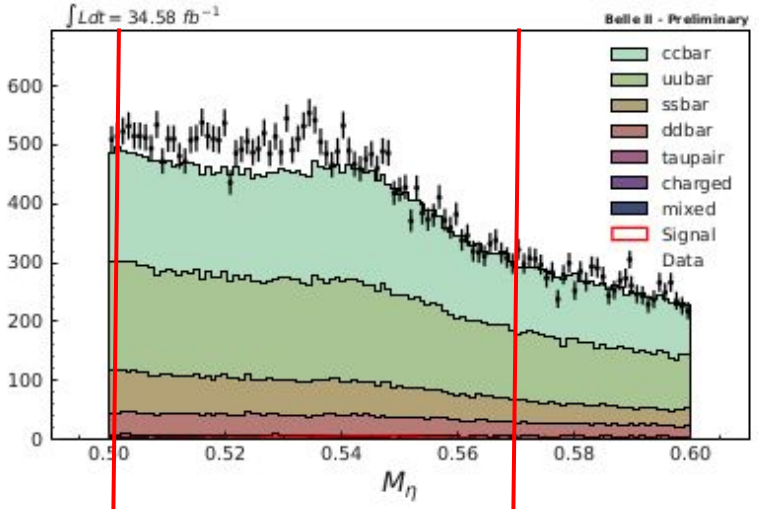
E gamma (eta->gamma gamma)





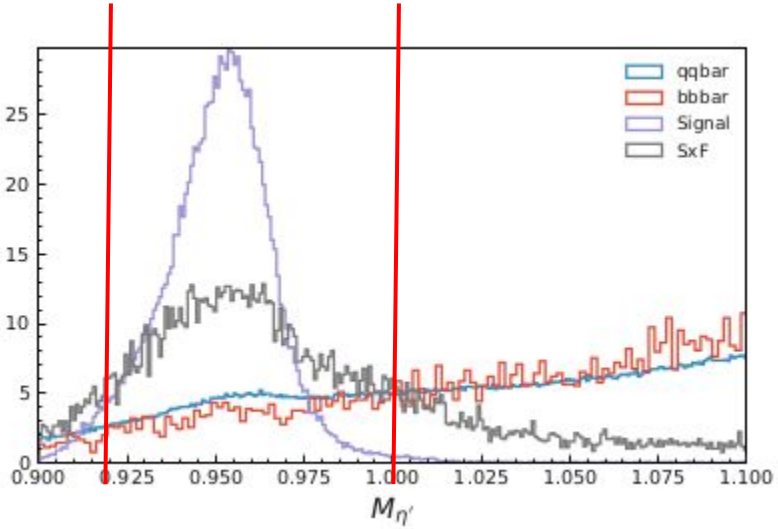
M(eta)

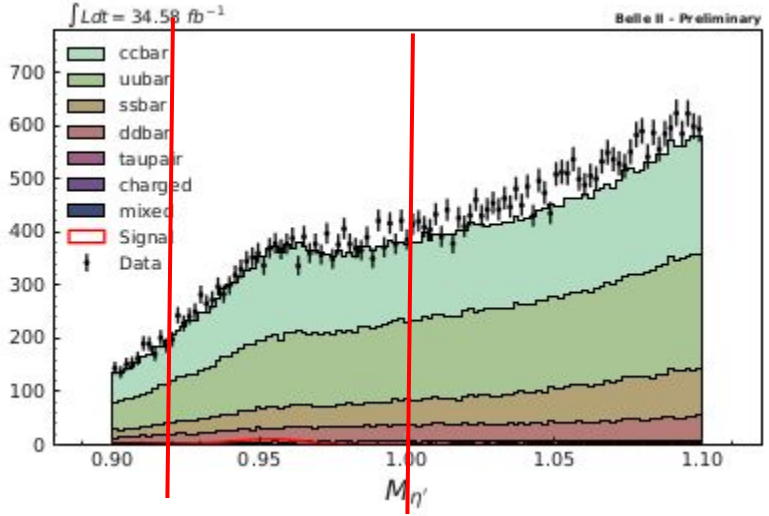




eta->gg peak not well visible due to low gamma threshold (60 MeV)

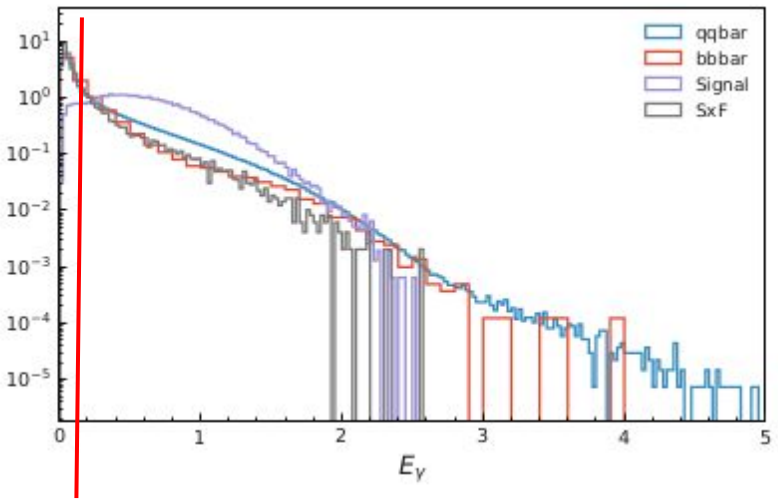
M(etaprime)

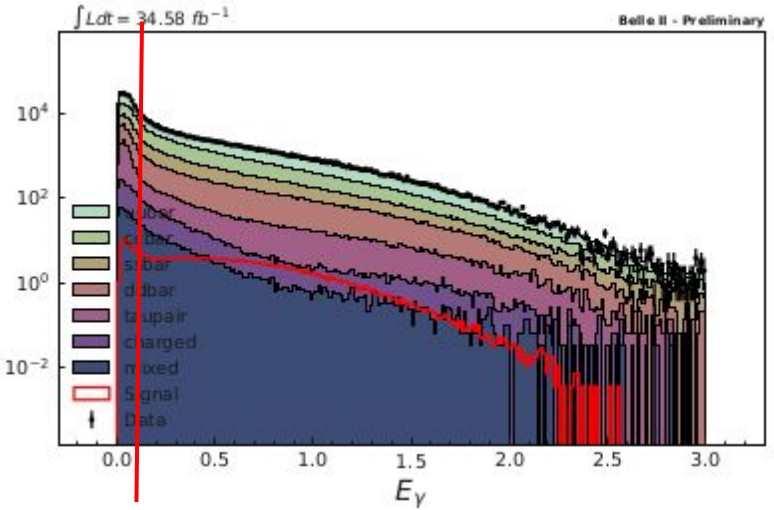




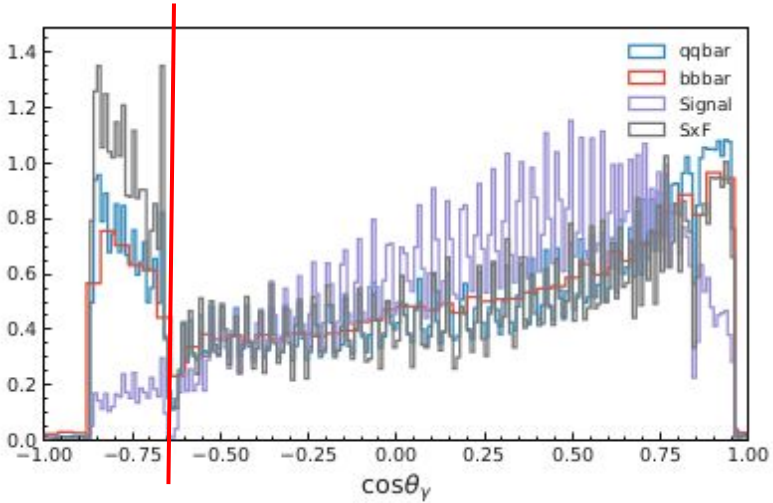
eta'->eta(gg)pipi peak not well visible due to low gamma threshold (60 MeV) and pion ones

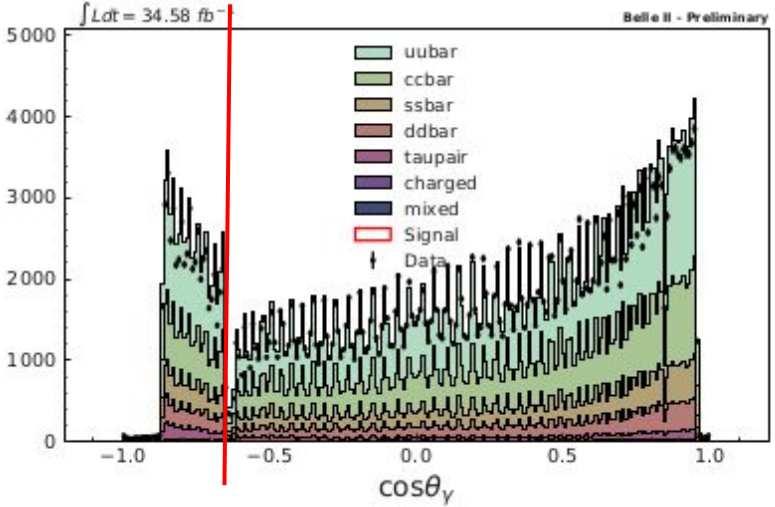
E(gamma) from eta'->rho gamma



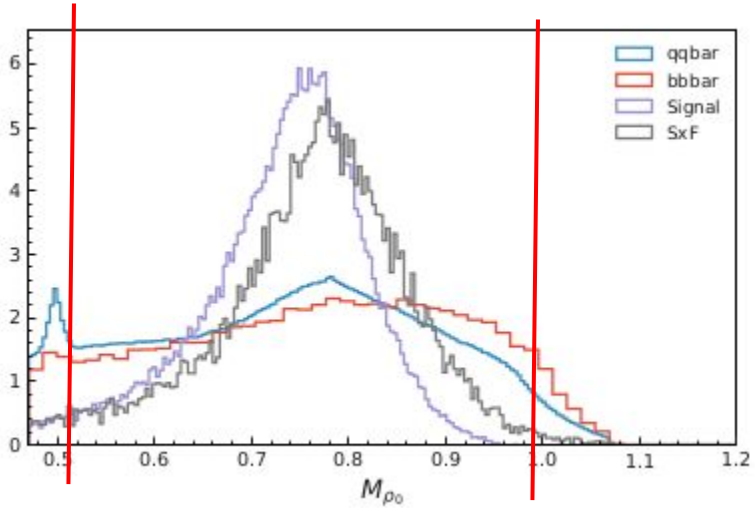


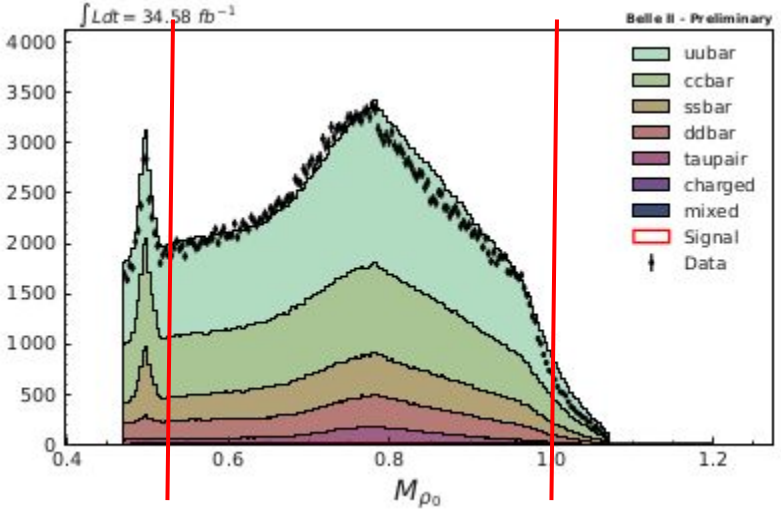
cos(theta gamma)





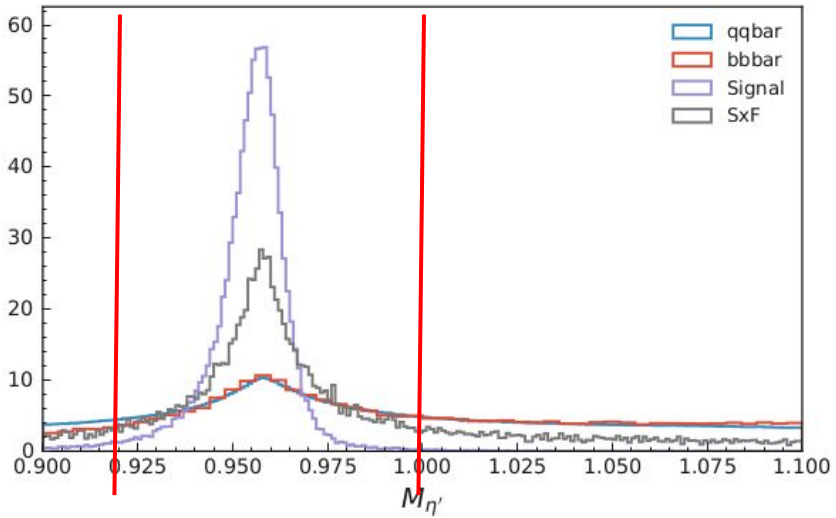
M(pi+ pi-)

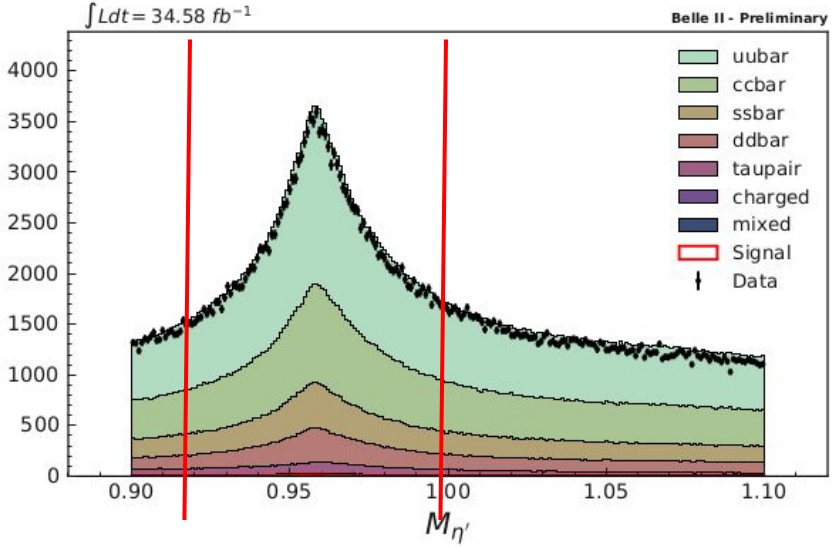




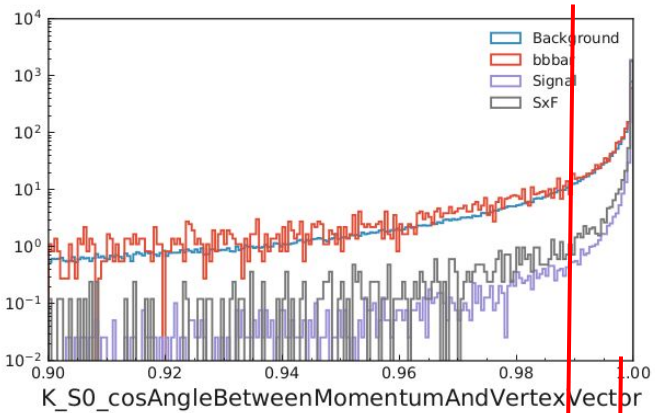
- Clear Ks peak
- Shift between rho peak for signal and SxF

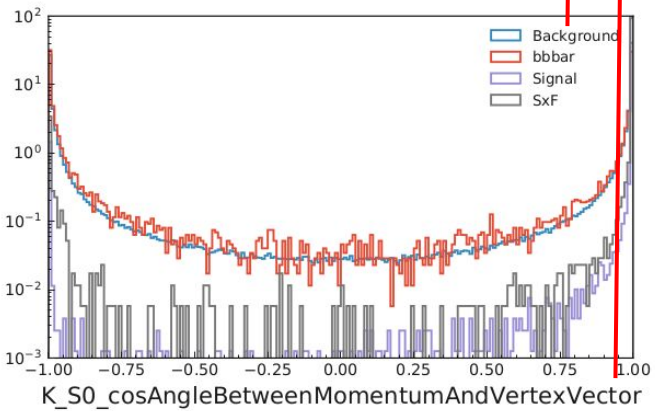
M(etaprime)

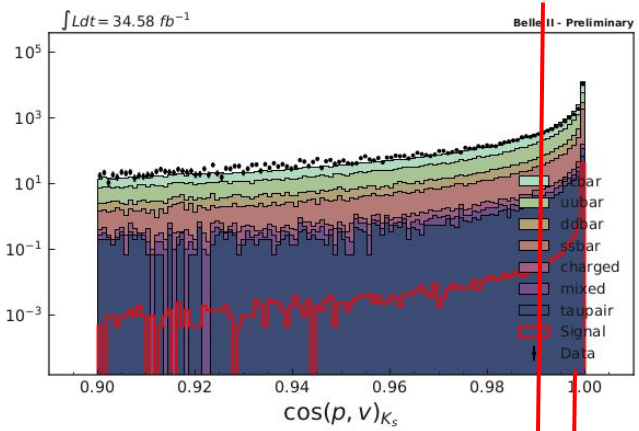

qqbar
bbbar
Signal
SxF
$M_{\eta'}$

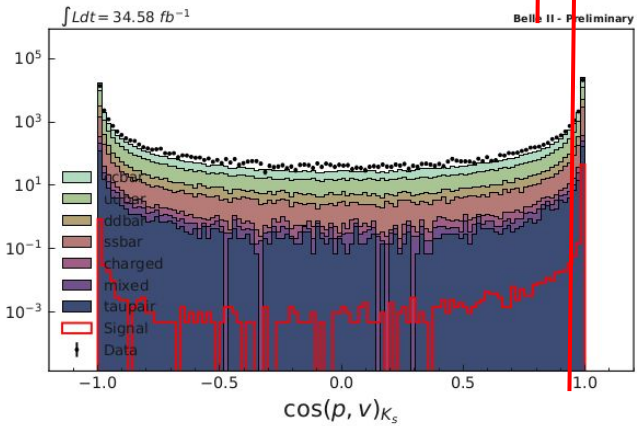

$\int Ldt = 34.58\ fb^{-1}$
Belle II - Preliminary
uubar
ccbar
ssbar
ddbar
taupair
charged
mixed
Signal
Data
$M_{\eta'}$

cos(alpha) (momentum vs vertex)

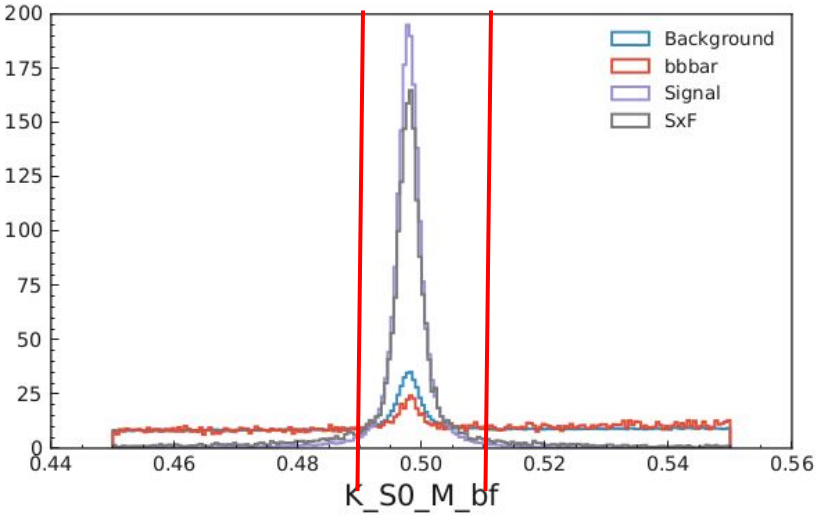


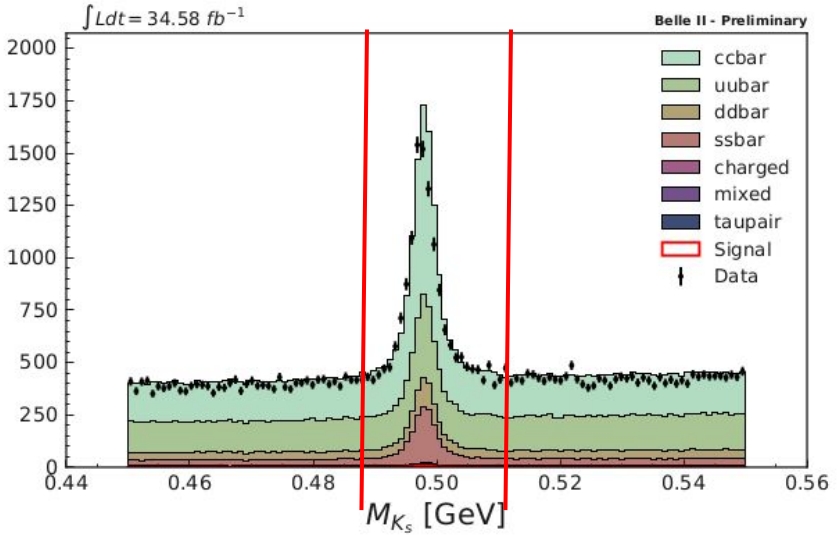




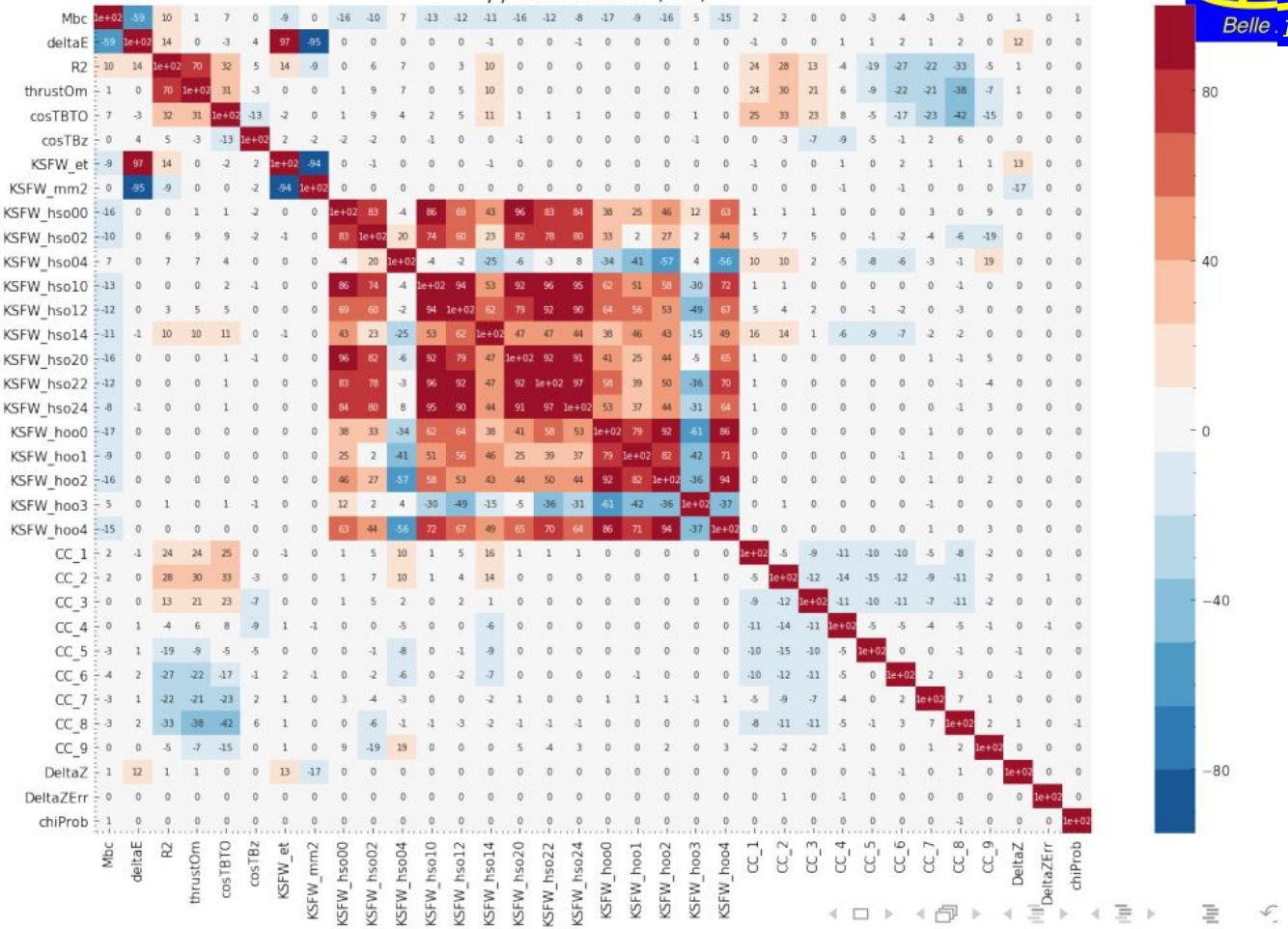


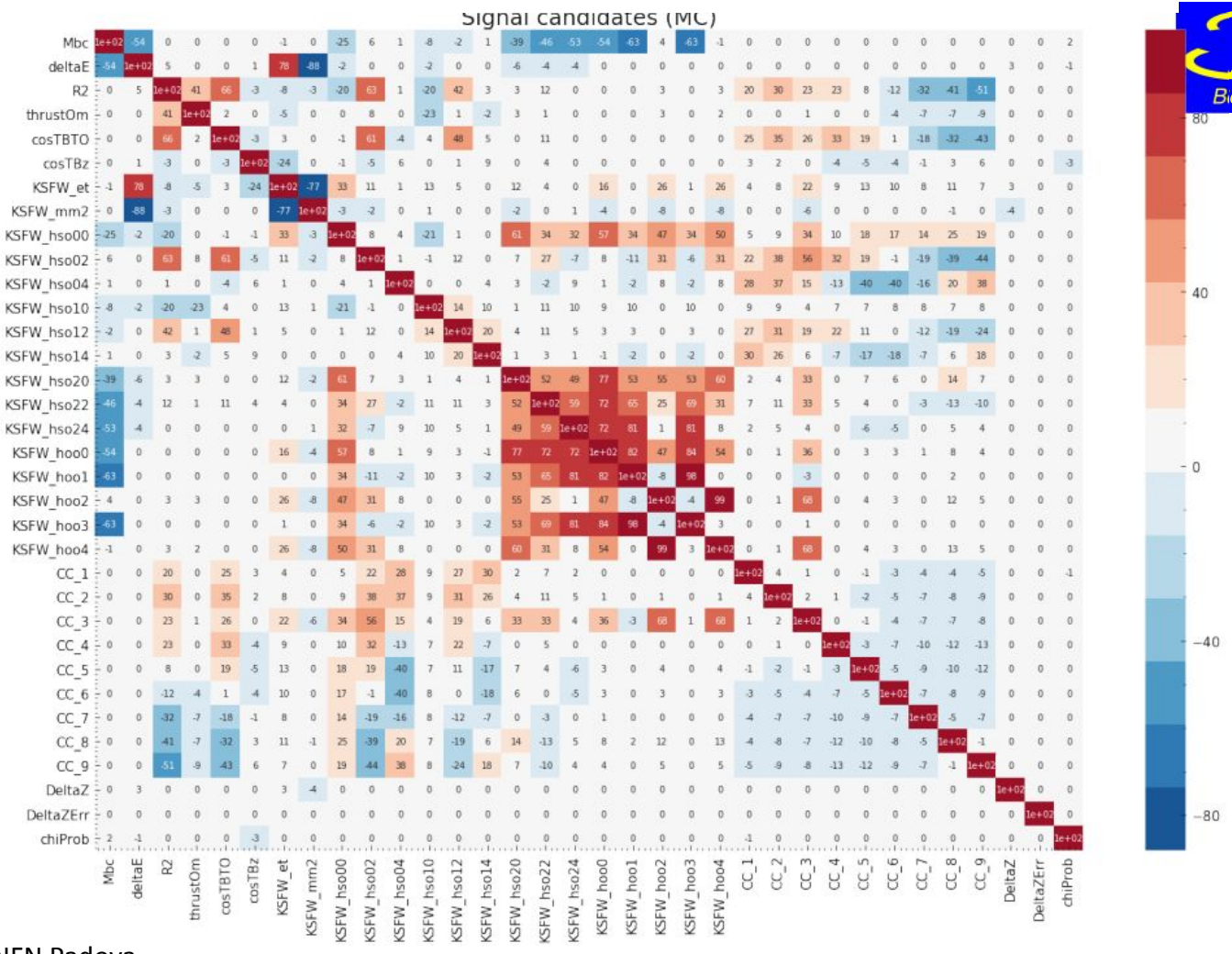
M(Ks)


Background
bbbar
Signal
SxF
K_S0_M_bf

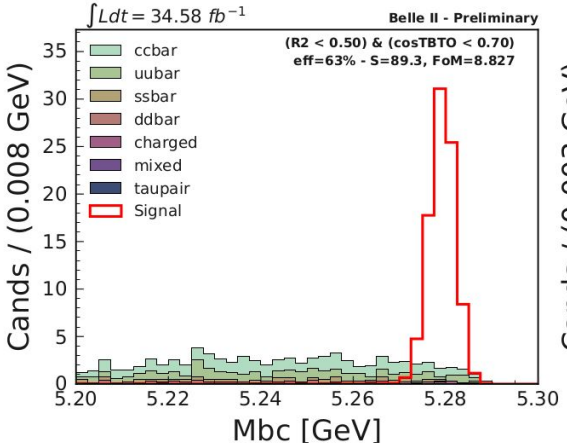

$\int Ldt = 34.58\ fb^{-1}$
Belle II - Preliminary
ccbar
uubar
ddbar
ssbar
charged
mixed
taupair
Signal
Data
M_{K_S} [GeV]

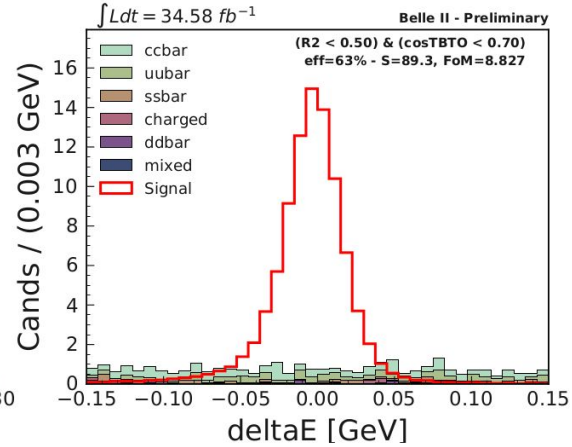
Correlation between training variables and fit variables (M_{bc} and ΔE)

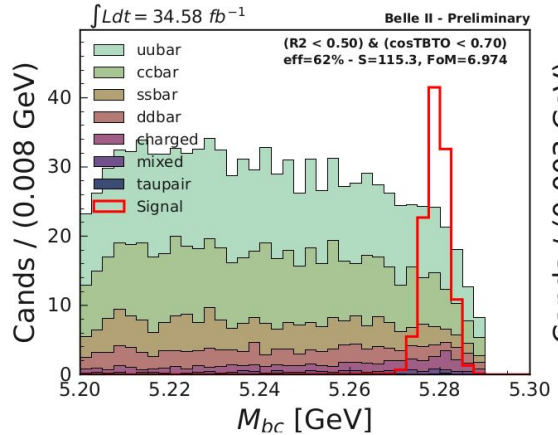


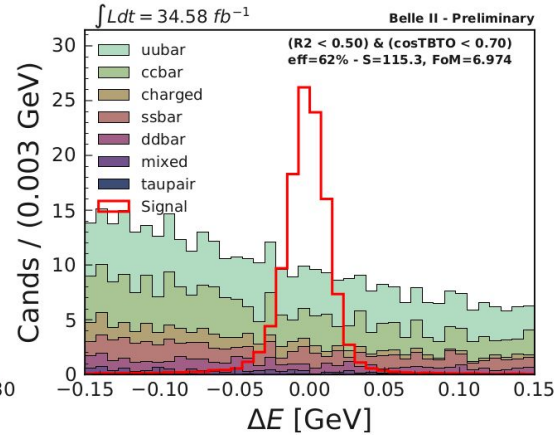

Signal candidates (MC)
Mbc
deltaE
R2
thrustOm
cosTBTO
cosTBz
KSFW_et
KSFW_mm2
KSFW_hso00
KSFW_hso02
KSFW_hso04
KSFW_hso10
KSFW_hso12
KSFW_hso14
KSFW_hso20
KSFW_hso22
KSFW_hso24
KSFW_hoo0
KSFW_hoo1
KSFW_hoo2
KSFW_hoo3
KSFW_hoo4
CC_1
CC_2
CC_3
CC_4
CC_5
CC_6
CC_7
CC_8
CC_9
DeltaZ
DeltaZErr
chiProb
80
40
0
−40
−80

Signal Region B^+







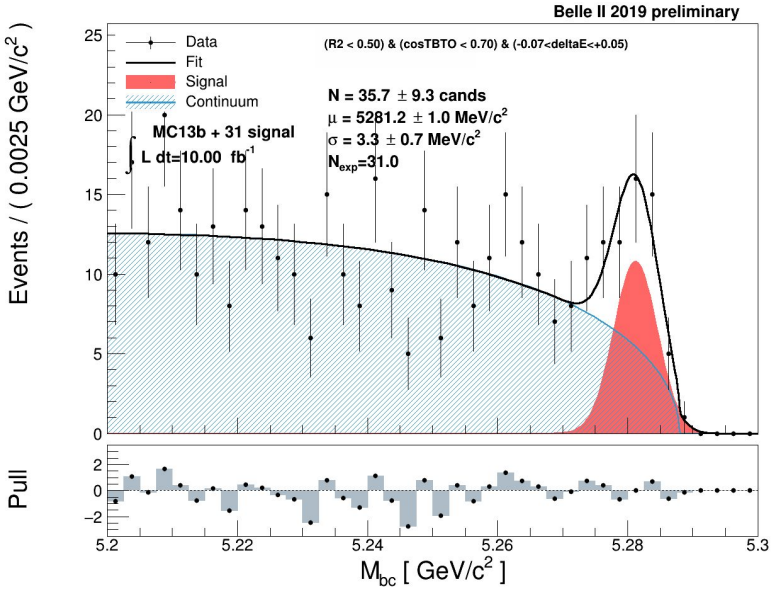


$$B^{\pm} \to \eta' K^{\pm}$$
$$\eta' \to \eta\pi^+\pi^-$$

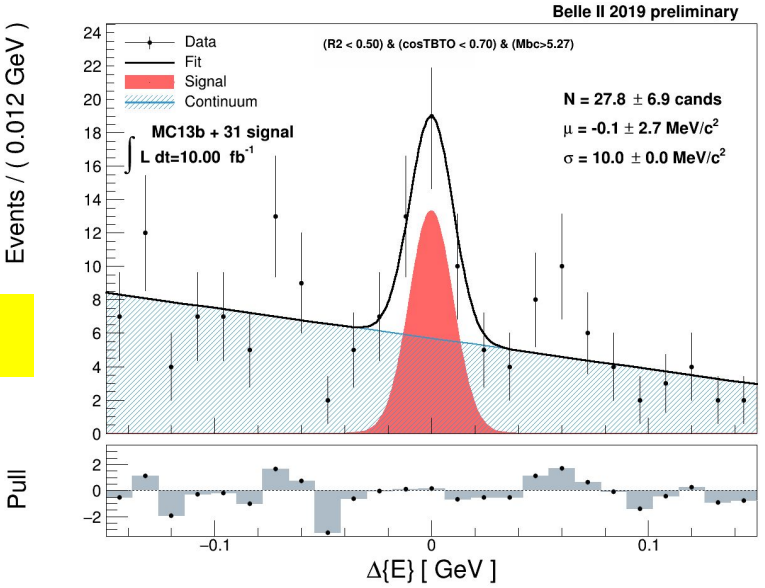
- For each plot select CR on the other variable
- Background and signal normalized to L_{DATA}
- Signal removed from bbbar montecarlo

$$B^{\pm} \to \eta' K^{\pm}$$
$$\eta' \to \rho\gamma$$

Try to fit signal: only MC + signal injection



MC13b

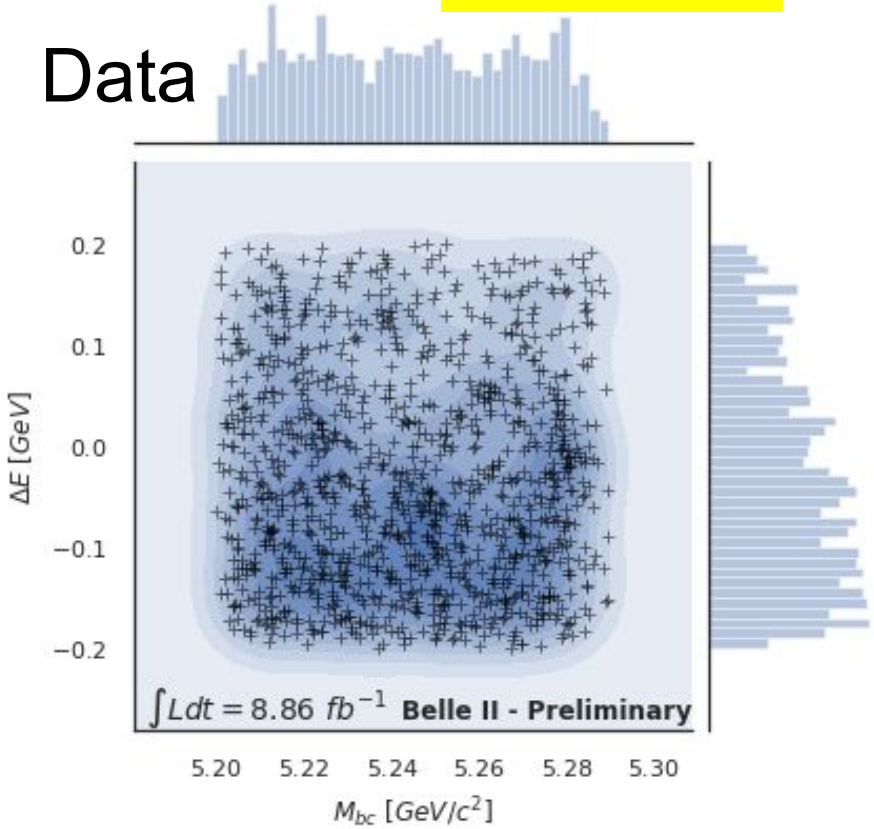


- Cut **Mbc>5.27 GeV/c²** and **-7<De<+5 MeV** in the other plot.
  - **1D plot shown (2D implemented)**
- Injected 31 events, seen 35.7+/-9 (Mbc) and 28+/-7 (De)

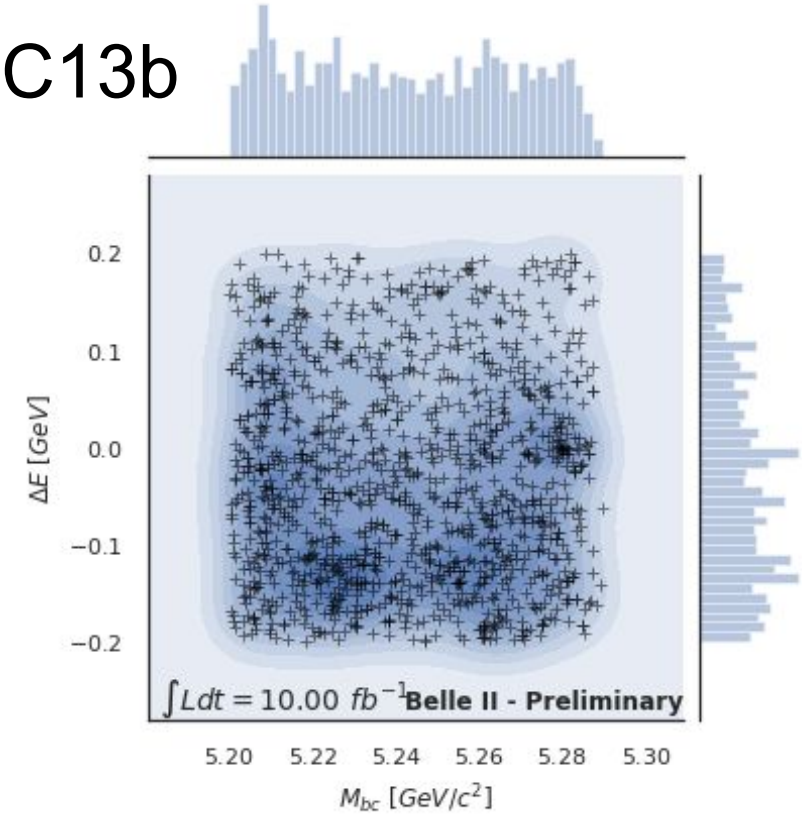
DeltaE vs Mbc

Proc10 + bucket8

Data

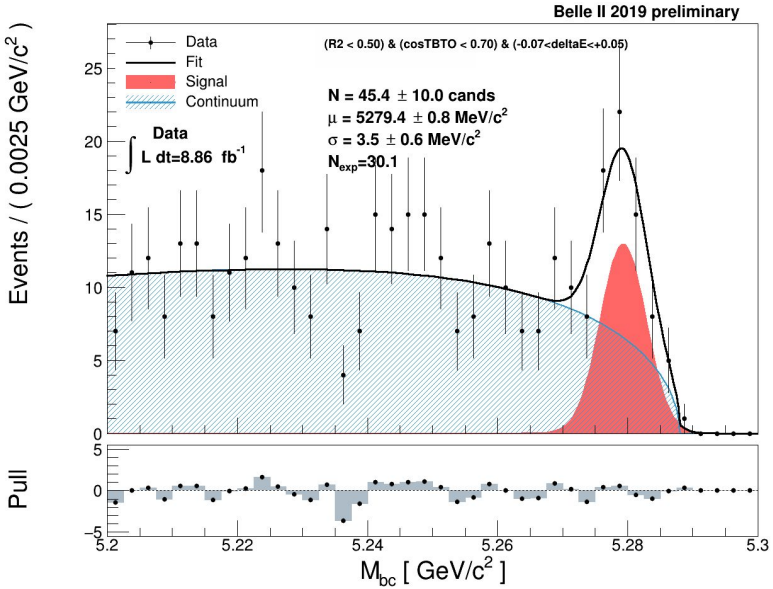


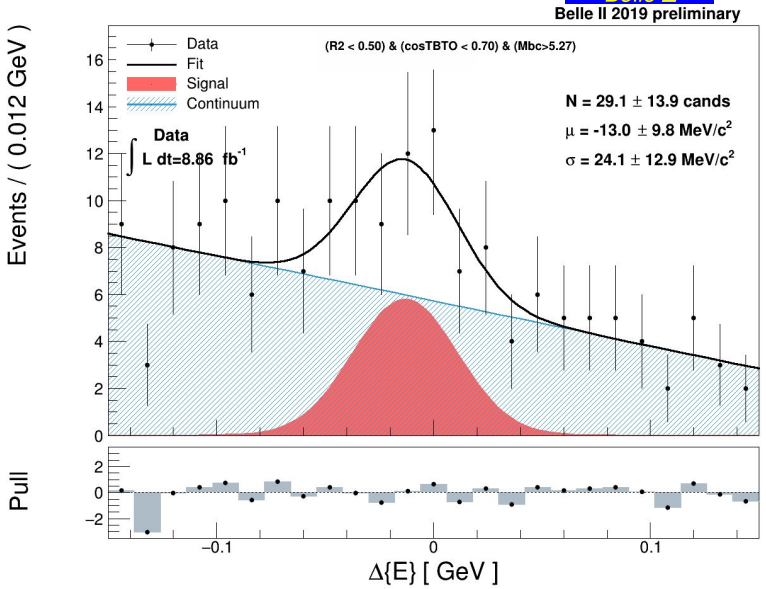
MC13b



Try to fit signal: Data

Proc10 + bucket8

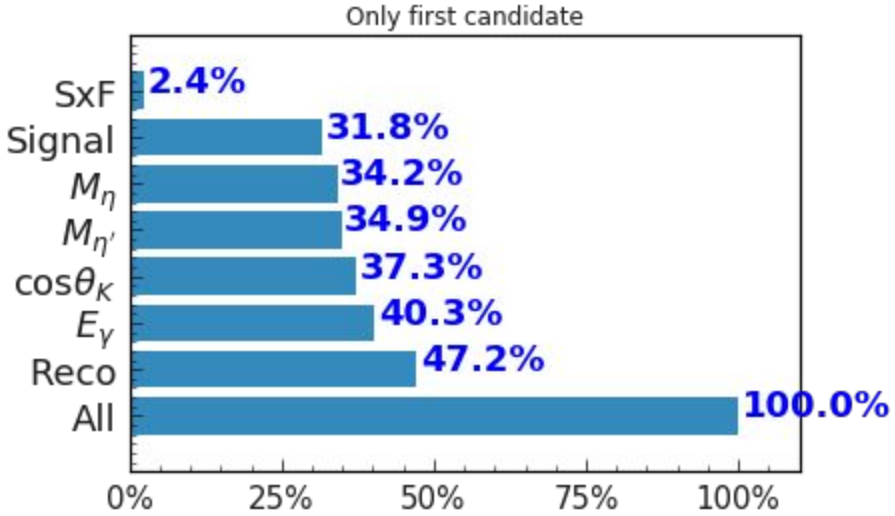


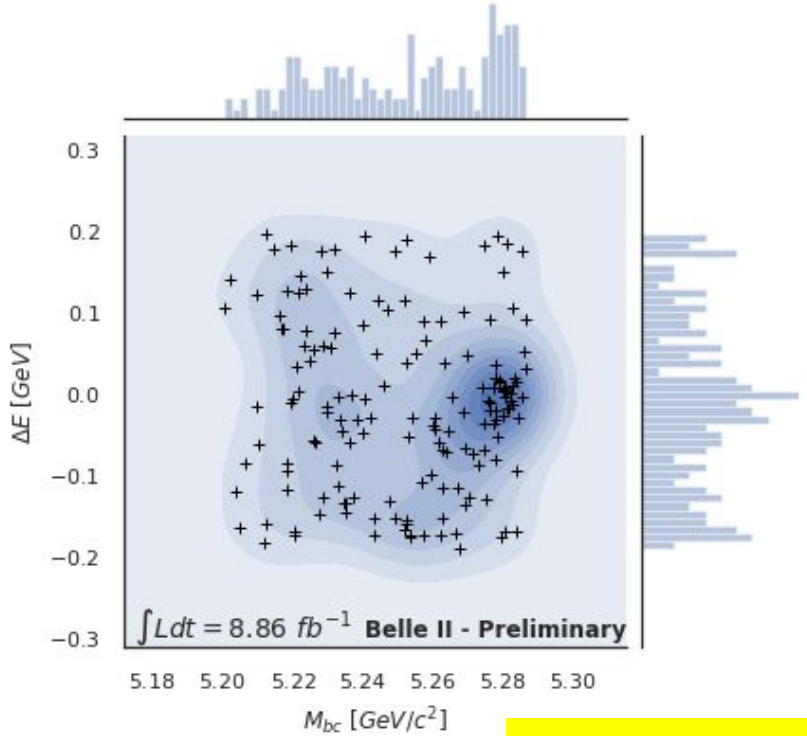


- Clear signal visible
  - Projection w/ selection on other variable
- seen 45.7+/-10 (Mbc) and 29.1.4+/-14 (De)
  - Expected: 31
- Still 1D fit: later for 2D

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

- 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%**



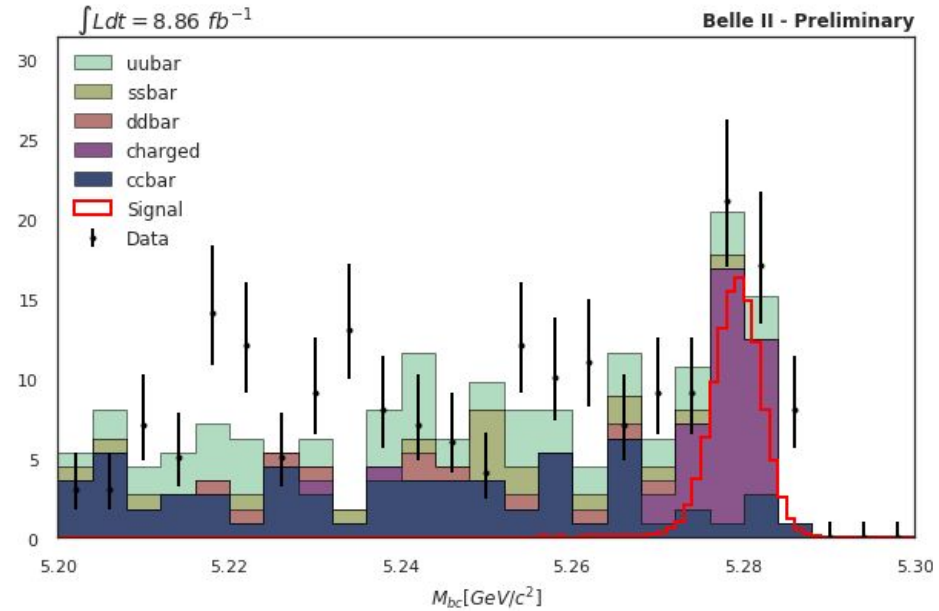


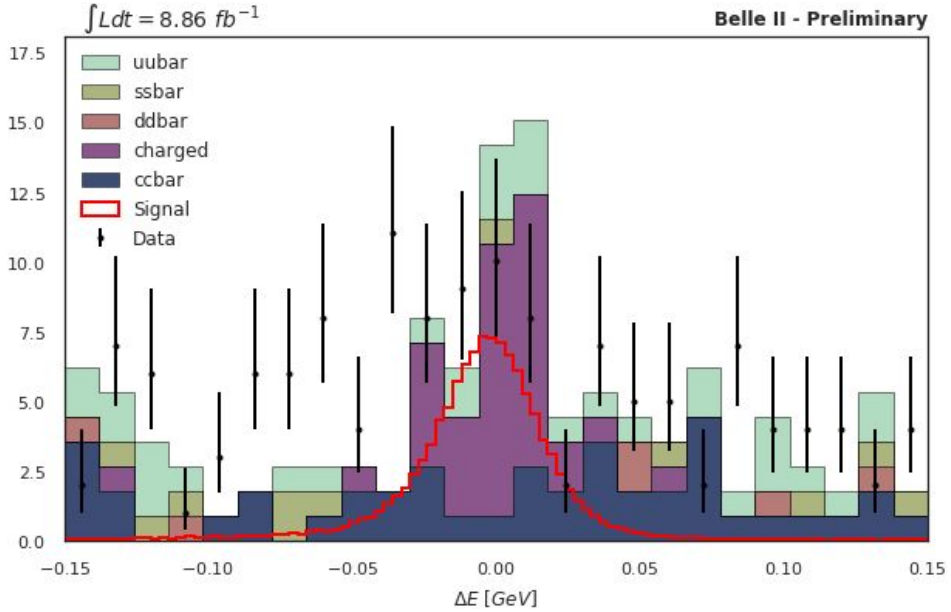
Proc10 + bucket8

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

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

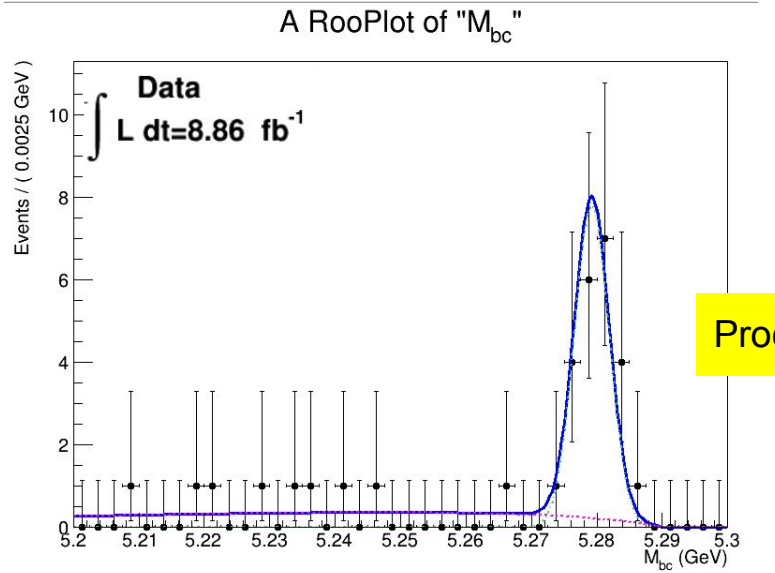
Proc10 + bucket8



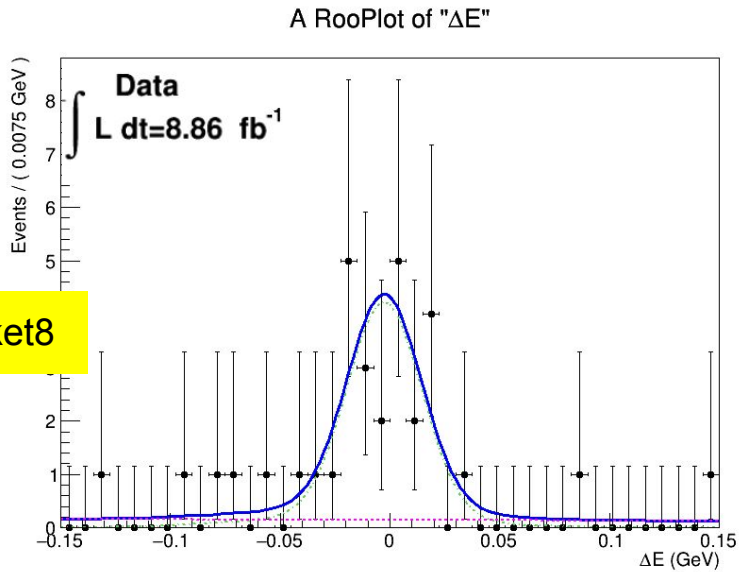


Data vs MC with expected signal

B^+ -> η' (->η (γγ) $\pi^+\pi^-$) K^+ 2D FIT

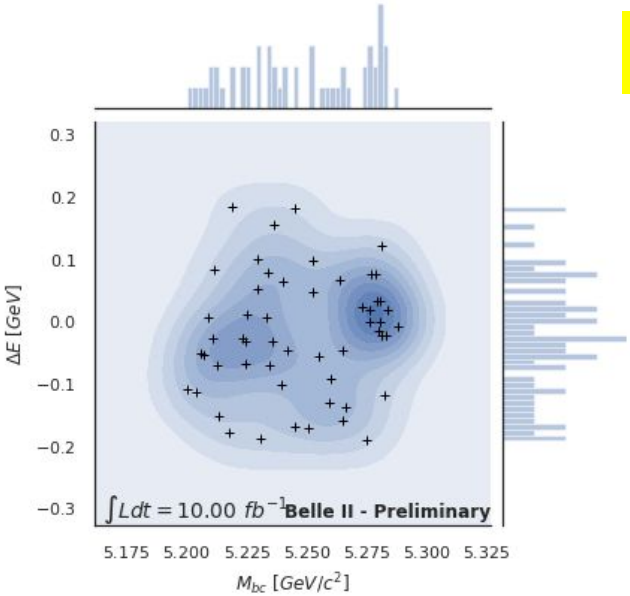


Proc10 + bucket8

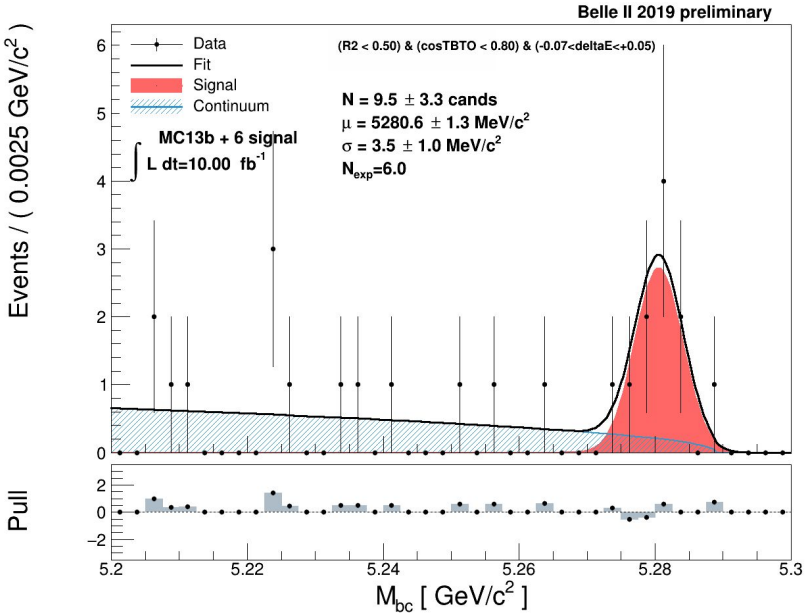


- 2D fit for Mbc and DeltaE
  - **Fit result: 29.0 +/- 10 evevents**
  - **Expected 31 events**
- Fit on MC and Toy studies (injected 10-100) looks good

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**