



$B \rightarrow \eta' K$ rediscovery

Status update

TDCPV meeting

19/10/2020

Stefano Lacaprara,

Valeria Fioroni, Daniele Dal Santo

INFN Padova & University

Quick recap and what's new



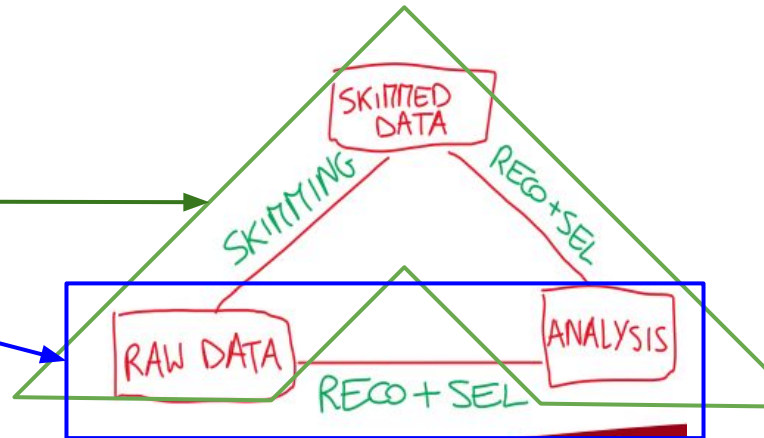
- Study on Analysis skims (Daniele)
- Study of background overlap among different channels (Valeria)
- Included bucket15
 - No GRL yet, so including all runs
 - Dataset: proc11 + prompt
 - $L=62.5$ /fb
- Update on all four channels with
 - fBDT CS
 - 3 variables UML fit (Mbc, DeltaE, CS)
 - Comparison with Belle

Analysis Skim impact on analysis (Daniele)



We will focus on $e^+e^- \rightarrow \Upsilon(4s) \rightarrow B^0\bar{B}^0$ with $B^0 \rightarrow \eta'K_S$,
 $\eta' \rightarrow \eta(\rightarrow \gamma\gamma)\pi^+\pi^-$ and $K_S \rightarrow \pi^+\pi^-$.

- General idea:
 - Check signal efficiency on signal MC
 - Doing skim + selection
 - Starting from all events
- Starting from 200k events
 - ~80k reconstructed directly
 - ~50k skim+reconstruction
 - Skimming lose ~40% of signal events



$$r_1 = \frac{49402}{79267} = 62.3_{-0.2}^{+0.2} \%$$

- Ratio unchanged w/ or w/o signal selection

AnaSkim cuts



- Main difference between Skim and Reco is list of pions
 - Skim uses pi:loose
 - Reco uses pi:all

The additional cuts implemented in pi:loose are:

- $dr < 0.5 \text{ cm}$
 - $|dz| < 2 \text{ cm}$
 - $nCDCHits > 20$
 - $pionID > 0.1$,
- } Distance between the B decay vertex and the interaction one.

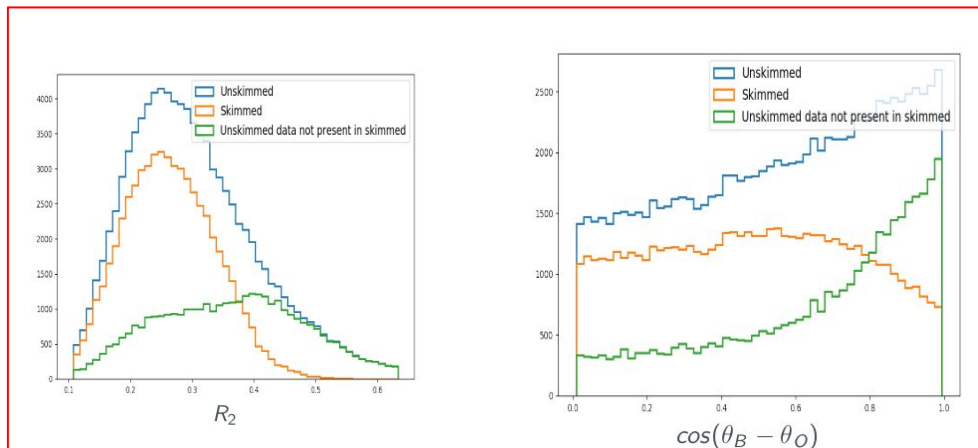
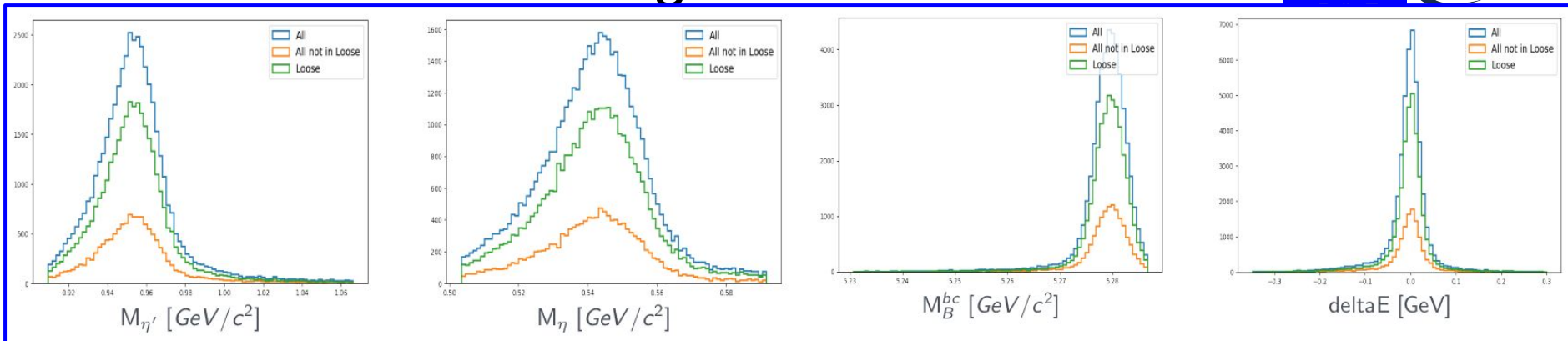
but the relevant ones are the last two.

pi:all	pi:all+nCDCHits	pi:all+pionID	pi:all+pionID+nCDCHits	pi:loose
43.8%	36.8%	33.8%	28.3%	28.4%

Reconstruction efficiency changing the pion list used.

- nCDC hits and PID responsible for 40% loss

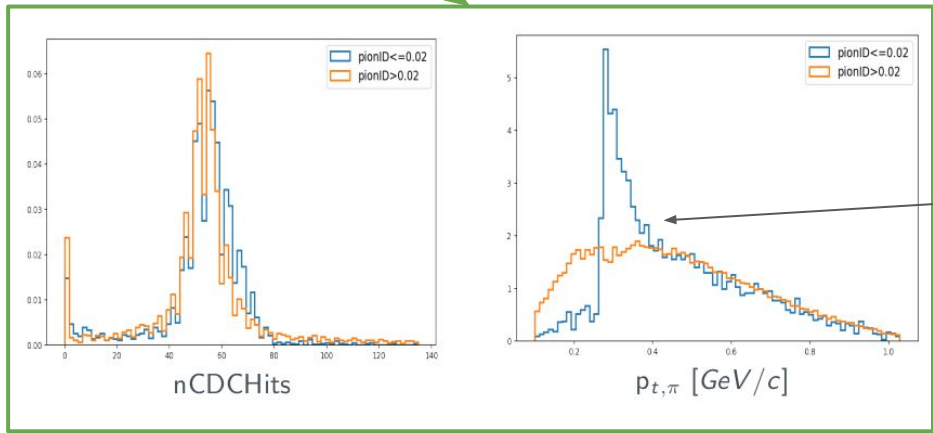
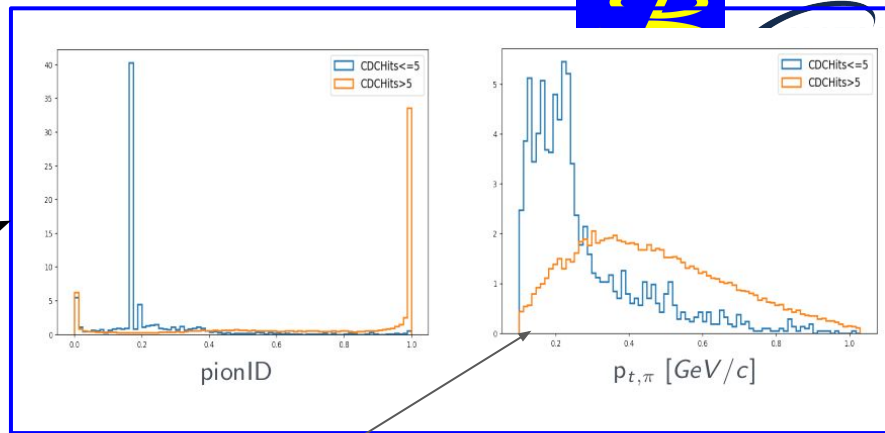
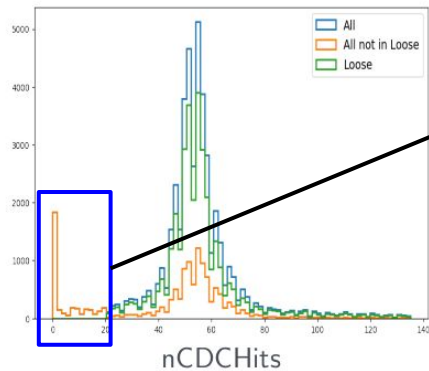
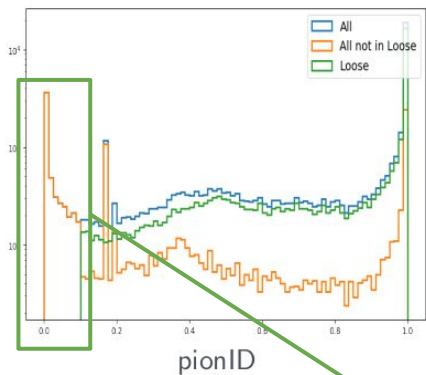
Pi:all vs Pi:loose for signal



- Candidates with pi:all but not pi:loose are signal like for M and DeltaE

- But more continuum like looking at R2 and CosTBTO

AnaSkim con'd



- Low pt
 - Do not reach top/arich
 - PID is $\frac{1}{6}$
 - Or reach and PID is 0
- High pt
 - Reach top/arich
 - PID answer is wrong

AnaSkim with pi:all

- Relative eff increase
 - 62->74% →
 - But not ~100% yet
 - Probably need to work on R2/cosTBT0 cut
- Impact on retention rate negligible
 - NB pi:all only in eta' skim!

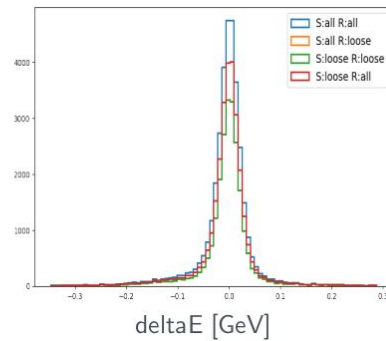
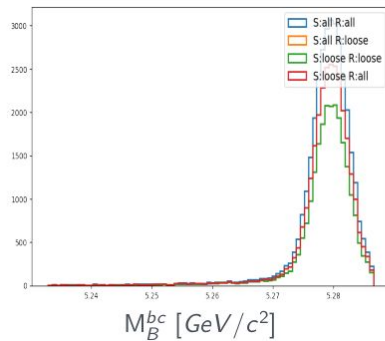
- $\epsilon_{Skim_pi:all, Reco_pi:all} = 29.4 \pm 0.1 \%$
 $\rightarrow r_{Skim_pi:all, Reco_pi:all} = 74.4^{+0.2}_{-0.2} \%$
- $\epsilon_{Skim_pi:loose, Reco_pi:all} = 24.7 \pm 0.1 \%$
 $\rightarrow r_{Skim_pi:loose, Reco_pi:all} = 62.5^{+0.2}_{-0.2} \%$

using pi:loose for the skim

$$\epsilon_{c\bar{c}}^{bkg} = 5.7^{+0.2}_{-0.2} \% \quad \epsilon_{u\bar{u}}^{bkg} = 5.2^{+0.2}_{-0.2} \%$$

using pi:all for the skim

$$\epsilon_{c\bar{c}}^{bkg} = 5.8^{+0.2}_{-0.2} \% \quad \epsilon_{u\bar{u}}^{bkg} = 5.3^{+0.2}_{-0.2} \%$$



Preliminary conclusion: it is safe and good to use pi:all for skimming, but not enough.

fBDT for CS background overlap (Valeria)



- CS using fBDT - presented on 9/9/2020
- Use signal and Continuum after signal selection
 - Train together all four channels (charged/neutral, $\eta' \rightarrow \rho \gamma$, $\eta' \rightarrow \eta \pi \pi$)
 - Investigating possible overlap of background for different channels
 - Same background event for $B^0 \rightarrow \eta' K_s$ and $B^+ \rightarrow \eta' K^+$
 - Unlikely for different η' decay modes
 - Possible for neutral/charged state

AND	B0ch1	B0ch3	Bpch1	Bpch3
B0ch1	22428 (100%)	254 (~ 1%)	225 (~ 1%)	128 (~ 0.5%)
B0ch3	254 (~ 0.1%)	(207997) 100%	150 (~ 0.07%)	3090 (~ 1.5%)
Bpch1	225 (~ 0.3%)	149 (~ 0.2%)	80594(100%)	1548 (~ 2%)
Bpch3	128 (~ 0.015%)	3100 (~ 0.3%)	1552 (~ 0.2%)	830758 (100%)

Conclusion: overlap small/negligible.

Will exclude duplicates candidates anyhow, no difference for fBDT training

Analysis update

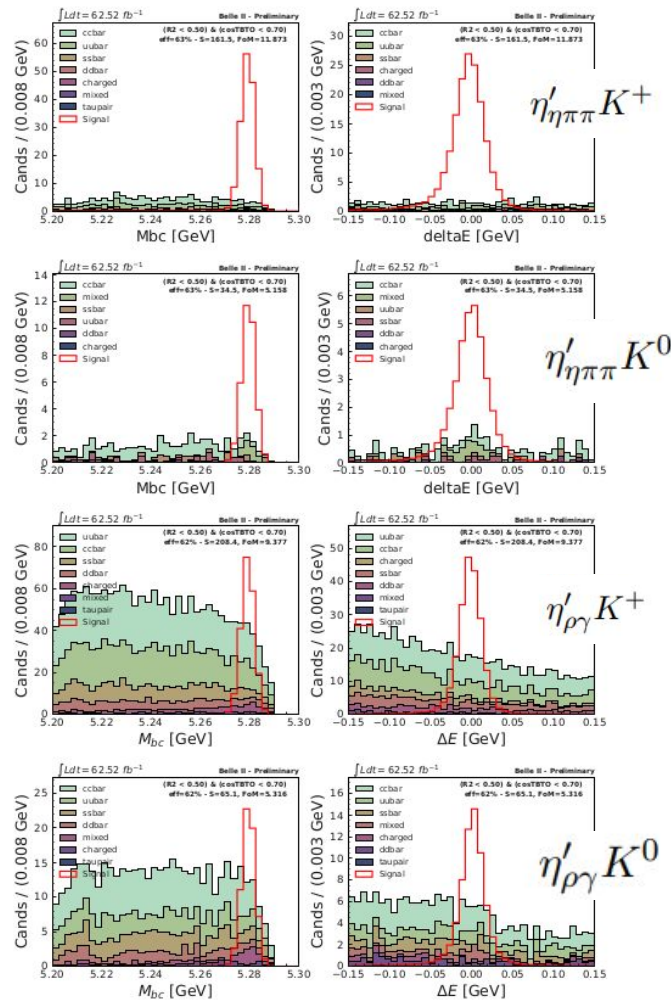


- Moriond2021 dataset proc11+prompt
 - Included also bucket15
 - All runs (no GRL yet)
 - Online lumi (12.9 /fb)
- Total Lumi 62.5 /fb
- CS
 - R2-cosTBTO selection
 - fBDT selection
 - No cut

dataset	experiment	$\int Ldt$ [pb^{-1}]
proc11	7	425.5 ± 0.3
proc11	8	4597.4 ± 0.9
proc11	10	3741.3 ± 1.1
bucket9	12	2768.7 ± 1.1
bucket10	12	10361.1 ± 2.1
bucket11	12	12687.1 ± 2.3
bucket13	12	5055.1 ± 1.5
bucket14	12	9986.9 ± 2.1
bucket15	12	$12.9 \pm \text{a}$
proc11	7+8+10	8764.2 ± 2.5
prompt	12	53758.9 ± 4.2
total	7-12	62523.8 ± 4.4

CS w/ R2+ cosTBT0 selection

- Cut optimising FoM $S/\sqrt{S+B}$ on signal region
 - $R2 < 0.5$
 - $\cos TBT0 < 0.7$
- Expected (MC) signal and background for four channels



luminosity of 62 fb^{-1}

Channel	Region	$B^\pm \rightarrow \eta' K^\pm \mid B^0 \rightarrow \eta' K_S^0$		$B^\pm \rightarrow \eta' K^\pm \mid B^0 \rightarrow \eta' K_S^0$	
		$\eta' \rightarrow \eta \pi^+ \pi^-$		$\eta' \rightarrow \rho \gamma$	
Continuum	SB	628.0 ± 9.0	180.0 ± 5.0	5921.0 ± 27.0	24880.0 ± 60.0
	SR	22.0 ± 1.7	6.8 ± 0.9	256.0 ± 6.0	1129.0 ± 12.0
Peaking	SB	14.3 ± 0.9	5.6 ± 0.6	342.0 ± 5.0	194.0 ± 3.0
	SR	1.5 ± 0.31	3.4 ± 0.5	29.9 ± 1.4	22.2 ± 1.2
Signal	SB	10.67 ± 0.21	2.31 ± 0.04	12.12 ± 0.29	7.69 ± 0.13
	SR	161.5 ± 0.8	34.47 ± 0.17	208.4 ± 1.2	105.5 ± 0.5
Data	SB	758 ± 28.0	202 ± 14.0	6440 ± 80.0	21040 ± 150.0
	SR			blind	

CS w/ fBDT

- Cut optimising FoM $S/\sqrt{S+B}$ on signal region
 - Similar to what Belle did (likelihood vs fBDT)
 - Different for each channel
 - Quite hard for $B^+ \rightarrow \eta'(\rho\gamma) K^+$ of 62 fb^{-1}

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	1182.0 ± 12.0	471.0 ± 8.0	3179.0 ± 20.0	1232.0 ± 12.0
	SR	47.0 ± 2.4	16.5 ± 1.4	124.0 ± 4.0	60.3 ± 2.7
Peaking	SB	21.8 ± 1.2	8.9 ± 0.7	298.0 ± 4.0	103.9 ± 2.5
	SR	2.1 ± 0.4	5.1 ± 0.6	25.9 ± 1.3	13.8 ± 0.9
Signal	SB	13.89 ± 0.24	3.3 ± 0.05	10.67 ± 0.27	4.29 ± 0.1
	SR	209.5 ± 0.9	47.89 ± 0.2	196.0 ± 1.1	69.9 ± 0.4
Data	SB	1450 ± 40.0	535 ± 23.0	3760 ± 60.0	1220 ± 30.0
	SR	blind			

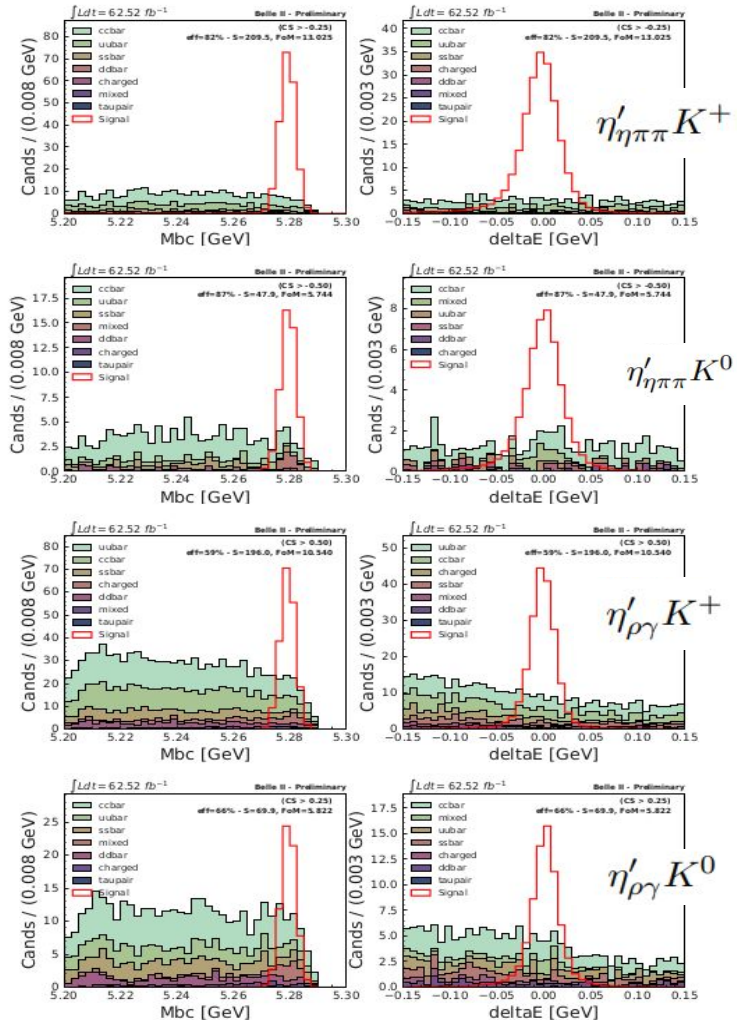
Channel	CS type	$B^\pm \rightarrow \eta' K^\pm$	$B^0 \rightarrow \eta' K_S^0$	$B^\pm \rightarrow \eta' K^\pm$	$B^0 \rightarrow \eta' K_S^0$
		$\eta' \rightarrow \eta\pi^+\pi^-$		$\eta' \rightarrow \rho\gamma$	
		$\epsilon\%$	$\epsilon\%$	$\epsilon\%$	$\epsilon\%$
Selection		31.7 ± 0.1	31.3 ± 0.1	24.8 ± 0.1	25.2 ± 0.1
CS		63.4 ± 0.2	63.0 ± 0.2	62.6 ± 0.2	61.7 ± 0.2
Total	R2+cosTBTO	20.1 ± 0.2	19.7 ± 0.2	15.5 ± 0.2	15.6 ± 0.2
	fBDT >	-0.25	-0.5	0.5	0.25
CS	fBDT	82.2 ± 0.2	87.5 ± 0.1	58.7 ± 0.2	81.0 ± 0.2
Total		26.1 ± 0.2	27.7 ± 0.2	14.8 ± 0.2	20.4 ± 0.2

R2/cosTBTO

fBDT

BELLE

21.7 20.8 14.2 11.5



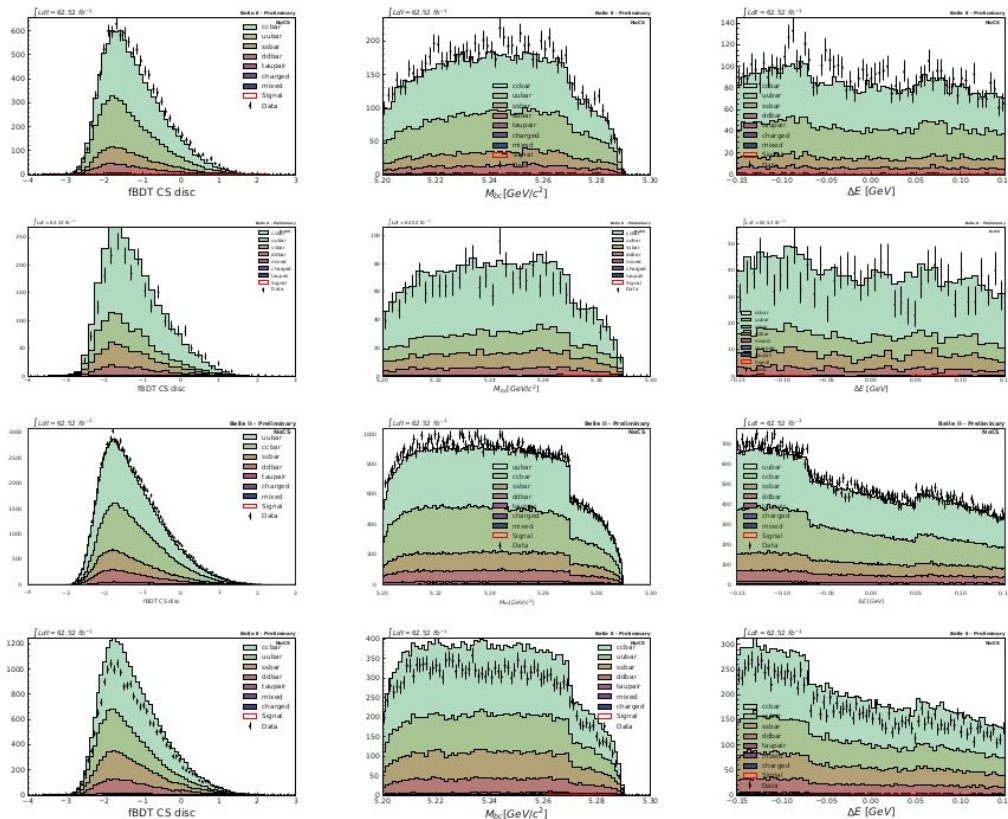
CS w/ fBDT no cut

- Expected yield

Montecarlo and data without CS selection, corresponding to an integrated luminosity of 62 fb^{-1}

Channel	Region	$B^\pm \rightarrow \eta' K^\pm \mid B^0 \rightarrow \eta' K_S^0$		$B^\pm \rightarrow \eta' K^\pm \mid B^0 \rightarrow \eta' K_S^0$	
		$\eta' \rightarrow \eta \pi^+ \pi^-$	$\eta' \rightarrow \eta \pi^+ \pi^-$	$\eta' \rightarrow \rho \gamma$	$\eta' \rightarrow \rho \gamma$
Continuum	SB	9690.0 ± 30.0	2699.0 ± 18.0	99270.0 ± 110.0	24880.0 ± 60.0
	SR	386.0 ± 7.0	105.0 ± 4.0	4614.0 ± 24.0	1129.0 ± 12.0
Peaking	SB	36.4 ± 1.5	12.6 ± 0.9	666.0 ± 6.0	194.0 ± 3.0
	SR	3.1 ± 0.4	6.1 ± 0.6	52.3 ± 1.8	22.2 ± 1.2
Signal	SB	17.79 ± 0.27	3.98 ± 0.06	22.8 ± 0.4	7.69 ± 0.13
	SR	254.8 ± 1.0	54.75 ± 0.22	334.1 ± 1.5	105.5 ± 0.5
Data	SB	10520 ± 100.0	2450 ± 50.0	103500 ± 300.0	21040 ± 150.0
	SR			blind	

- Signal extraction via 3 variables
UML fit



CS
Control region only
 $M_{bc} < 5.27 \text{ GeV}/c^2$
 $\Delta E < -0.07 \text{ OR } > 0.05 \text{ GeV}$

DeltaE

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



Signal

SxF

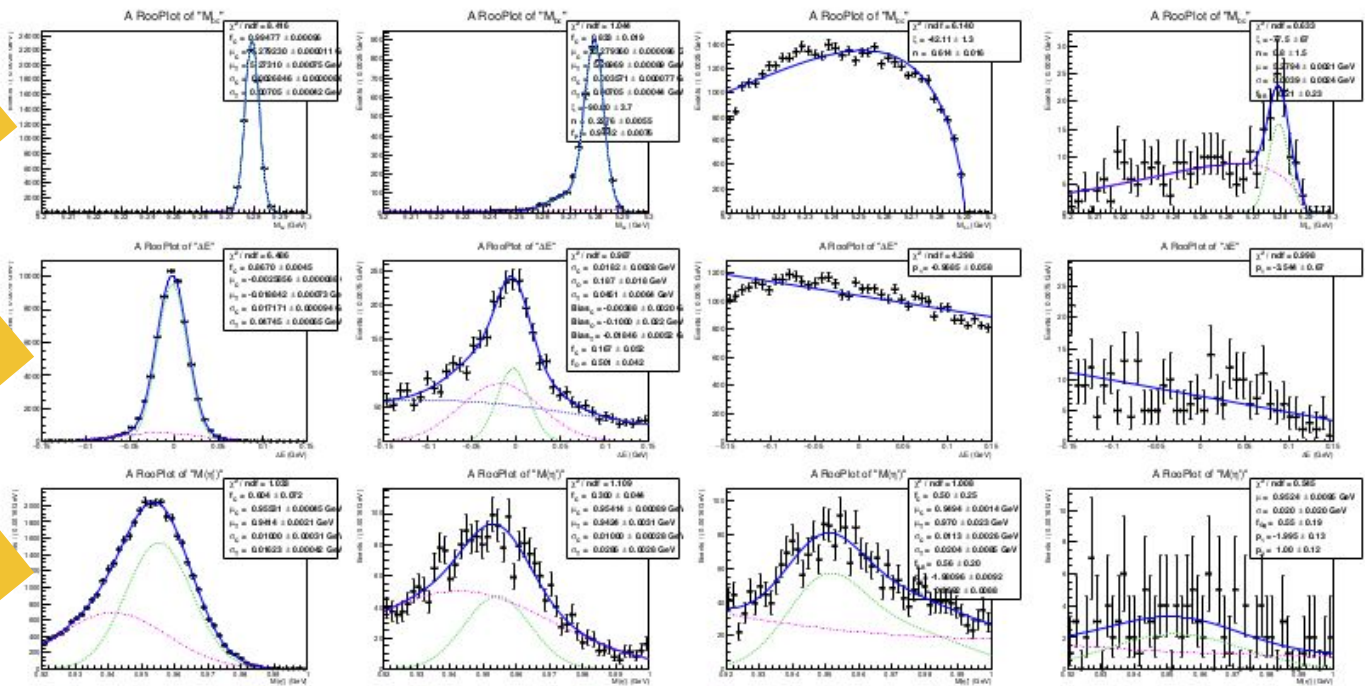
Cont

Peak

Mbc

ΔE

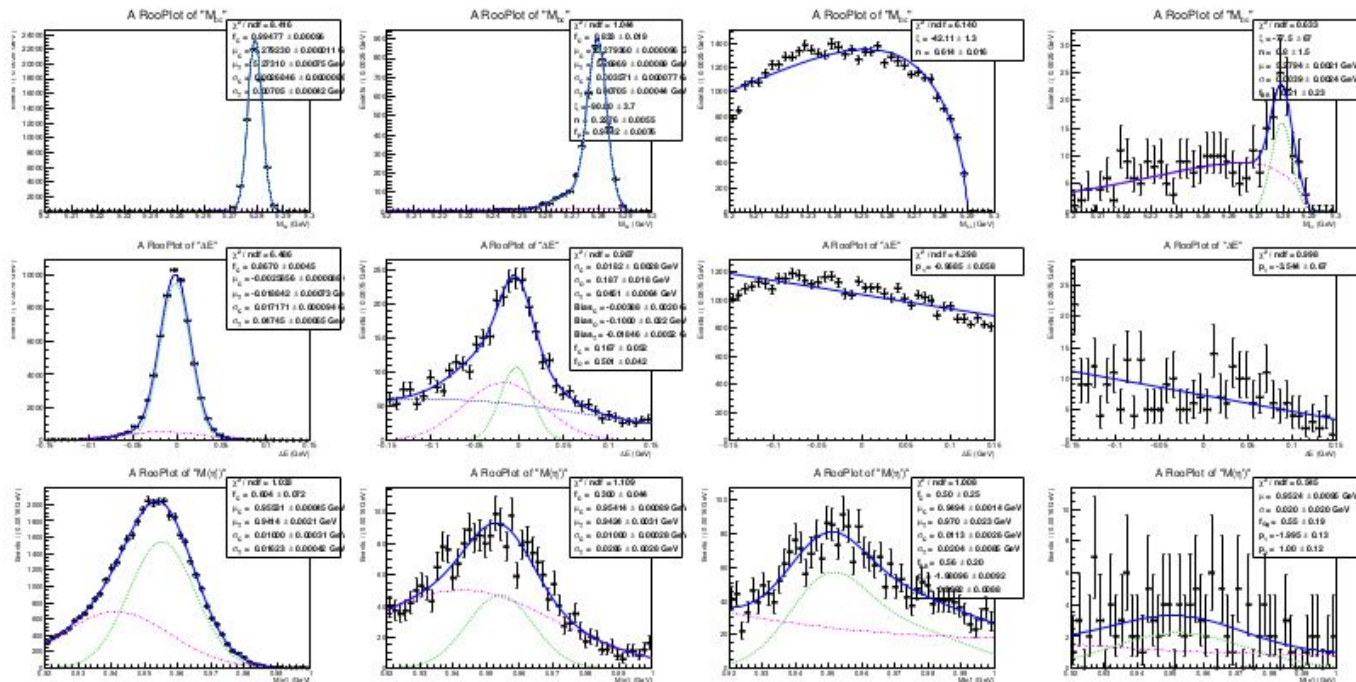
CS



PDF defined for all four channels
CS pdf ~identical, as expected

Fit with Sgn+SxF together, ratio
fixed from MS

3 variable UML fit w/ CS selection

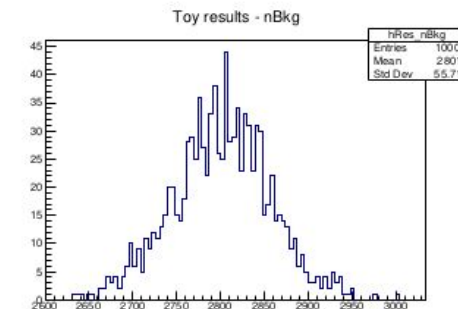
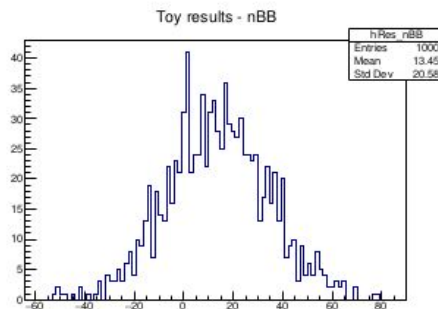
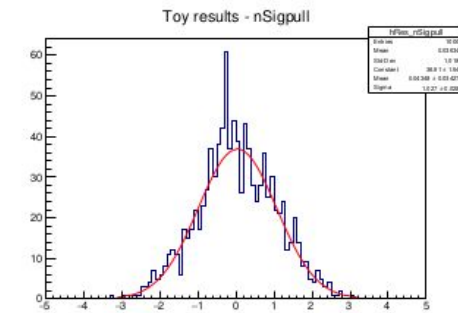
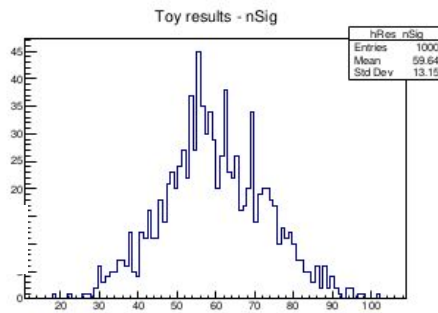
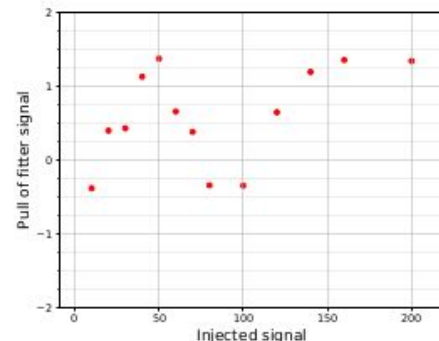
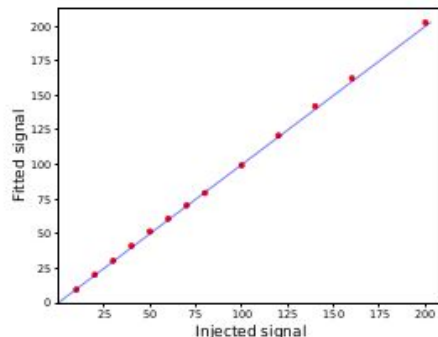


- Pdf defined for all four channels
- CS pdf ~identical, as expected

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

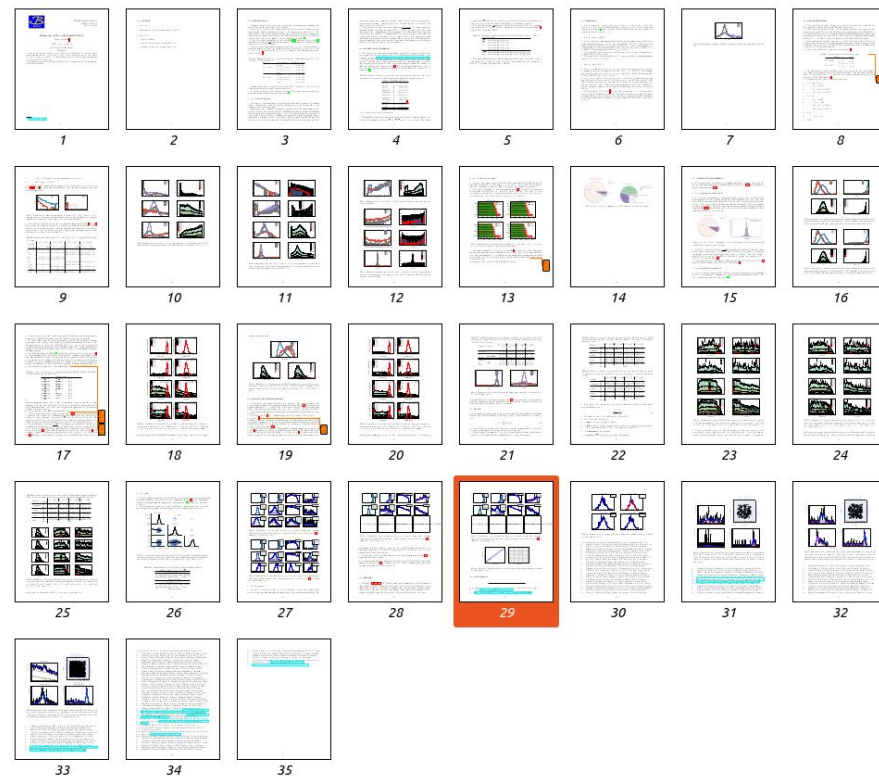
Toy MC for linearity

- Tested for $B \rightarrow \eta' K$ with $\eta' \rightarrow \eta \pi^+ \pi^-$.
 - Linearity
 - Fitted vs injected signal yield within 1 sigma
 - Good pulls
 - Also for NBB
 - was a problem last time due to >0 request, now removed
- To be done for $B^0 \rightarrow \eta' K_S^0$ with $\eta' \rightarrow \rho \gamma$
 - Can be tricky due to larger background
- Preliminary test ar fine



Conclusion and plan

- Overall analysis is in good shape
 - Still some small item to be completed
 - ETA ~days
- Documentation is being updated
 - ETA ~1 week
- In good shape for Moriond 2021
 - Will like to present at B2GM
- Can we start RC ?
 - Do I need to have also a few pages conference papers ready before starting with RC?
 - Should I present the work also at Charmless WG?



Backup

Selections



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

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

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

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

K

- $\cos\theta_K > -0.5$

K_s^0

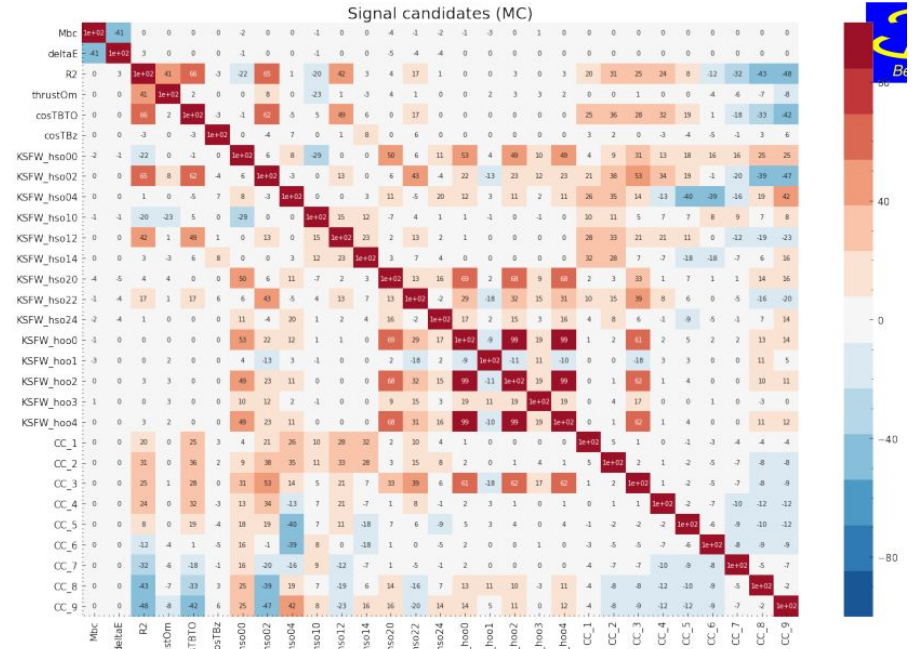
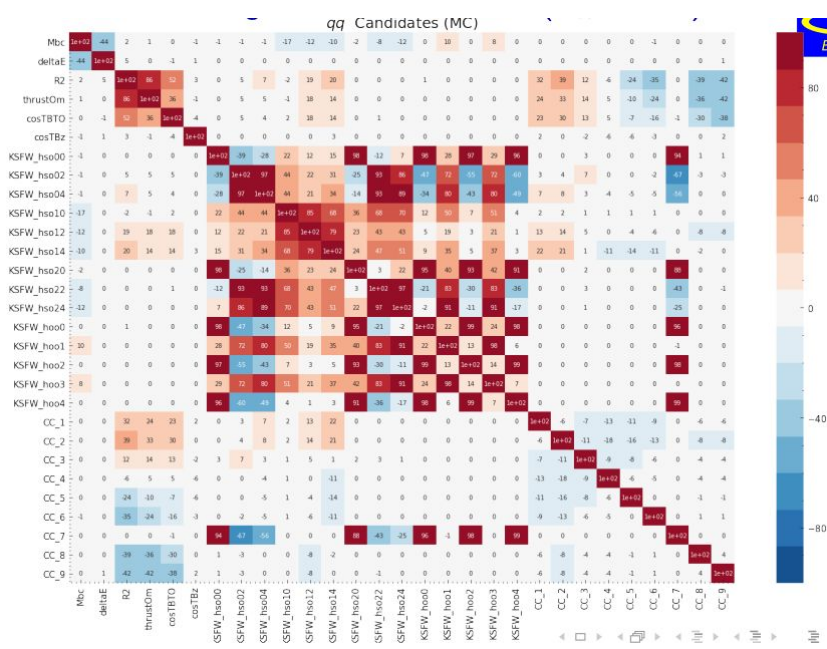
- $\cos\theta_{p,v} > -0.64$
- $0.49 < M_{K_s^0} < 0.51 \frac{\text{GeV}}{c^2}$

- So far, used only R2 and $\cos(\text{TB}-\text{TO})$ as Continuum Suppression variables
 - Hard cut on both
- Move to fBDT
 - Variables considered
 - No TagV variables

Variable name		
KSFW_hso00	KSFW_hoo0	CC_1
KSFW_hso02	KSFW_hoo1	CC_2
KSFW_hso04	KSFW_hoo2	CC_3
KSFW_hso10	KSFW_hoo3	CC_4
KSFW_hso12	KSFW_hoo4	CC_5
KSFW_hso14	R2	CC_6
KSFW_hso20	thrust0m	CC_7
KSFW_hso22	cosTBTO	CC_8
KSFW_hso24	cosTBz	CC_9

Correlations

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



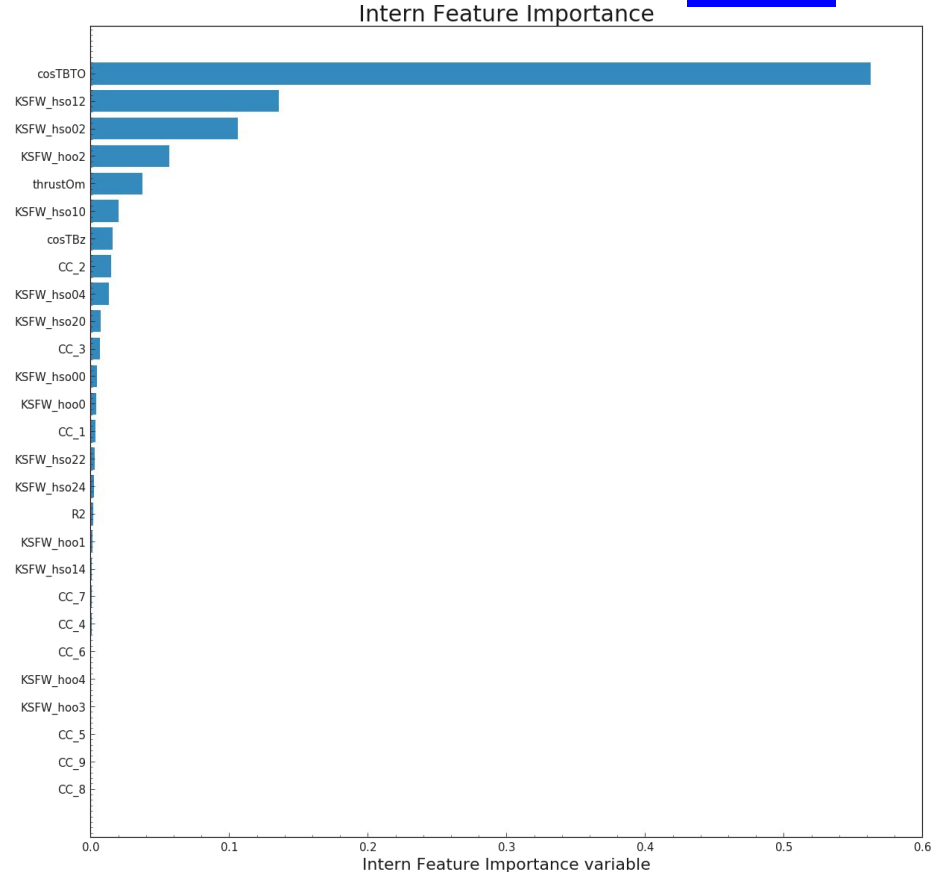
Continuum

Signal

Intern feature importance

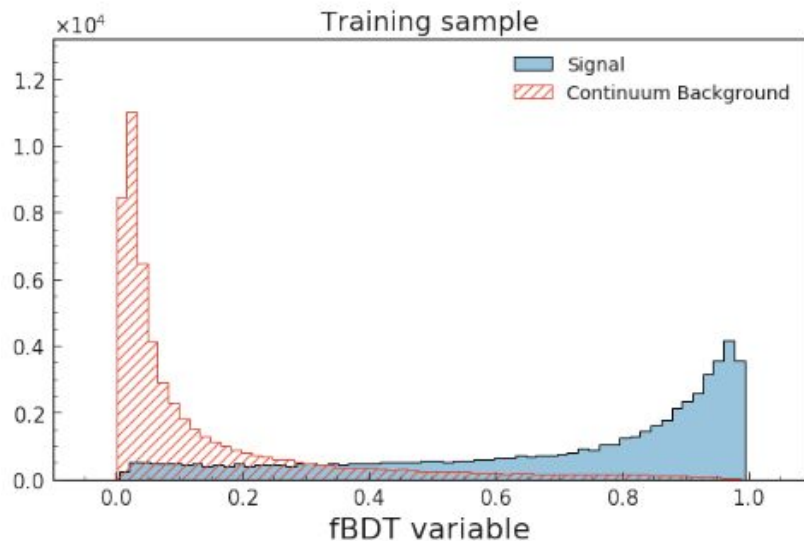


- $\cos(\text{TB-TB})$ by far the most discriminating variables
- Most of correlated variables not very important
- Tried with less variables, basically same performances
- Could remove many w/o any significant change



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

Motivation

- $\text{BR}(B^0 \rightarrow \eta' K_S^0) = (6.6 \pm 0.4) \times 10^{-5}$
 - $C_{\text{CP}}(B^0 \rightarrow \eta' K^0) = -0.06 \pm 0.04$
 - $-A_{\text{CP}} = S_{\text{CP}}(B^0 \rightarrow \eta' K_S^0) = 0.63 \pm 0.06$
- $\text{BR}(B^+ \rightarrow \eta' K^+) = (7.06 \pm 0.25) \times 10^{-5}$
- Seen by Belle with 10/fb?
 - B^+ : $\text{BR} = (79^{+12}_{-11} \pm 8) \times 10^{-6}$
 - B^0 : $\text{BR} = (55^{+19}_{-16} \pm 9) \times 10^{-6}$
 - 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



4 October 2001

Physics Letters B 517 (2001) 309–318



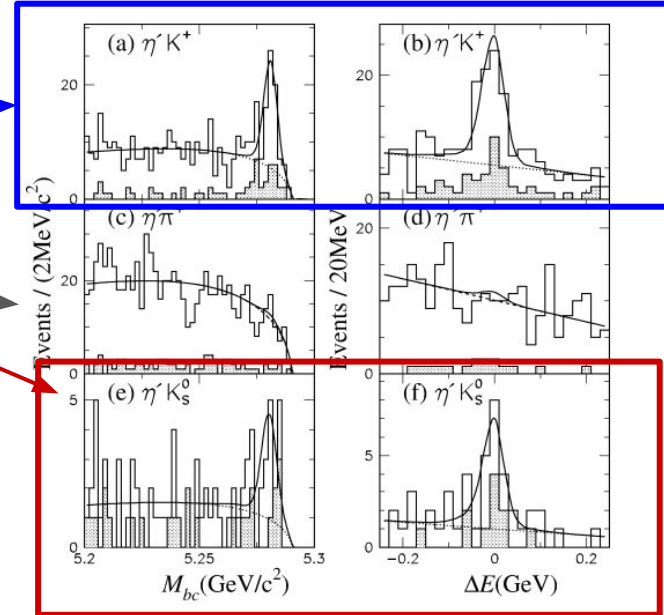
PHYSICS LETTERS B

www.elsevier.com/locate/npe

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

Belle Collaboration

Belle 10.5 /fb



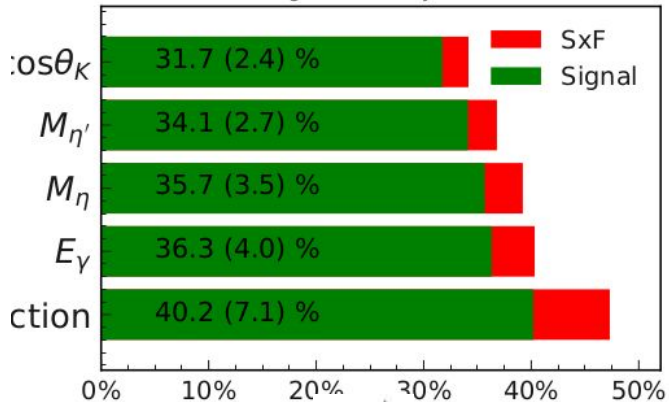
Shaded $\eta' \rightarrow \eta \pi \pi$, white all (including $\eta' \rightarrow \rho \gamma$)

Selection efficiency



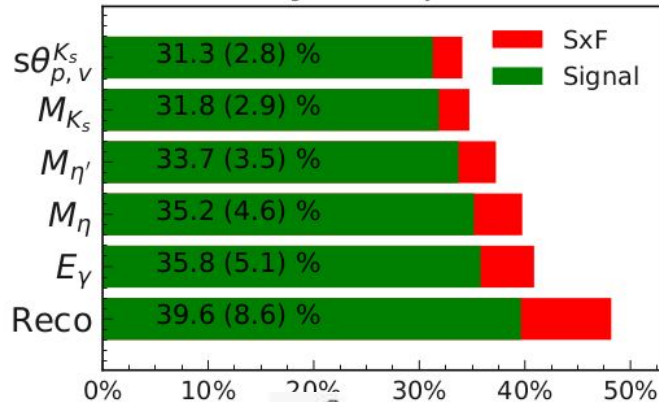
$\eta' \rightarrow \eta \pi^+ \pi^-$

Signal efficiency (SxF)



B^\pm

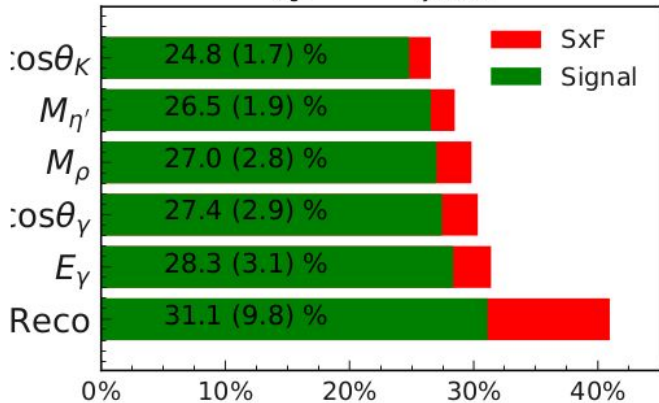
Signal efficiency (SxF)



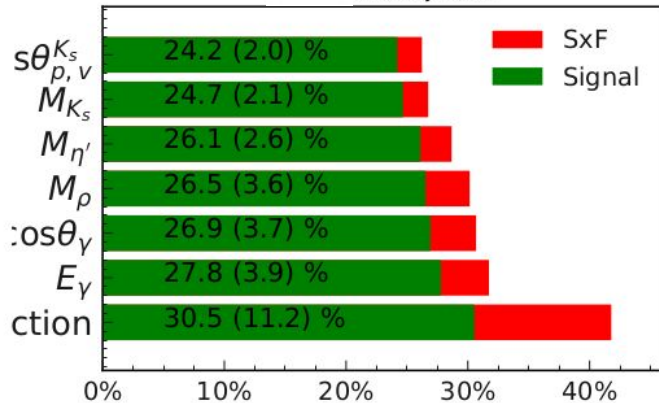
B^0

$\eta' \rightarrow \rho \gamma$

Signal efficiency (SxF)



Signal efficiency (SxF)



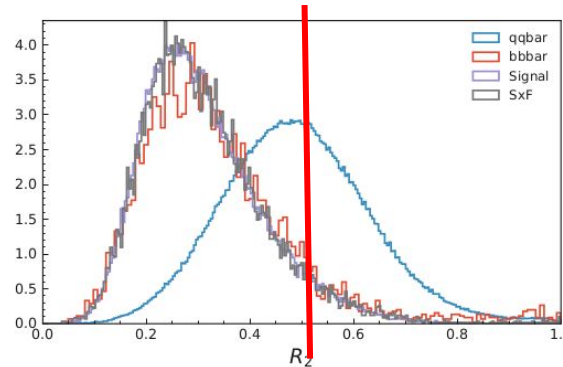
- High selection efficiency **24-30%**

- SxF **10-→2%**

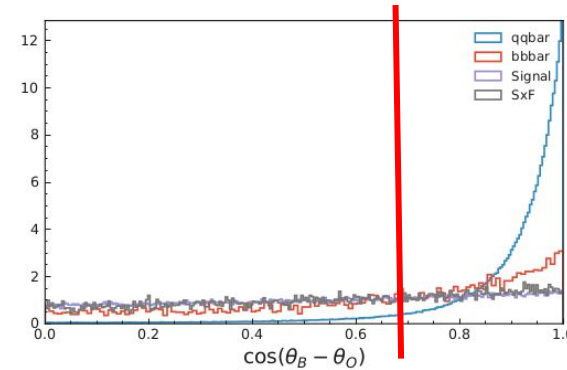
- **no CS cut (next slides)**

Continuum suppression

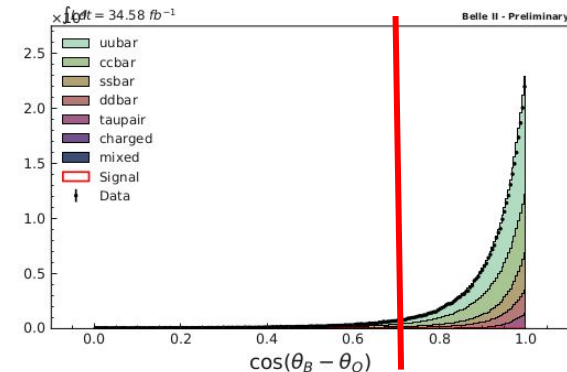
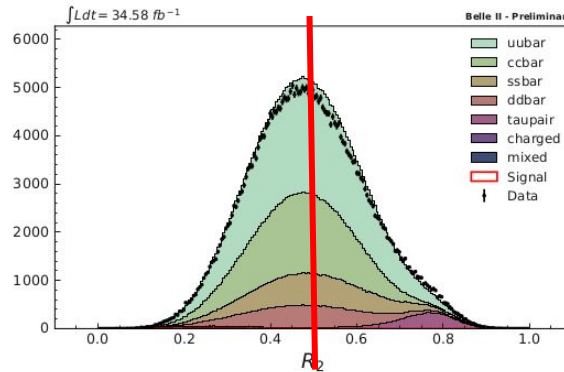
- Using only **R2** and **CosTBTO**
- Started MVA but still some correlation with data not understood
 - For next iteration
- Optimization of cut based on
- $FoM = S / \sqrt{S + B}$
 - S and B in signal region from MC
 - $M_{bc} > 5.27$
 - $-70 < D_e < 50$ MeV
- **$R_2 < 0.5$**
- **$\text{CosTBTO} < 0.7$**
 - Probably too hard



R2



cosTBTO



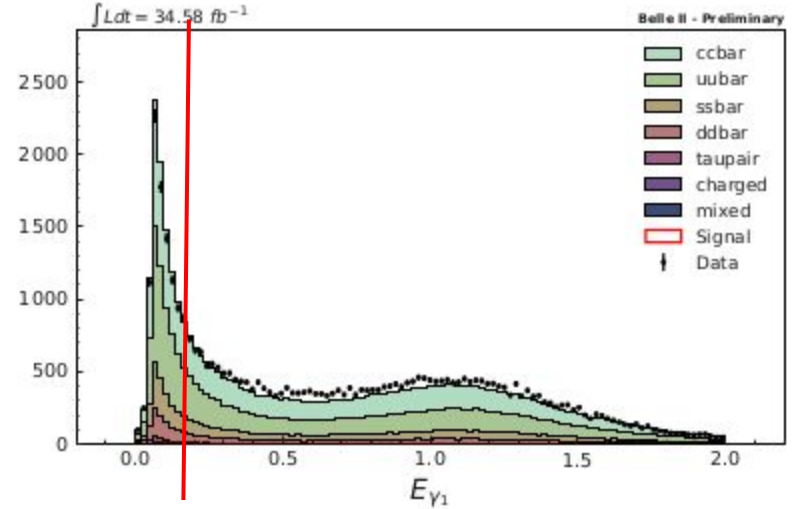
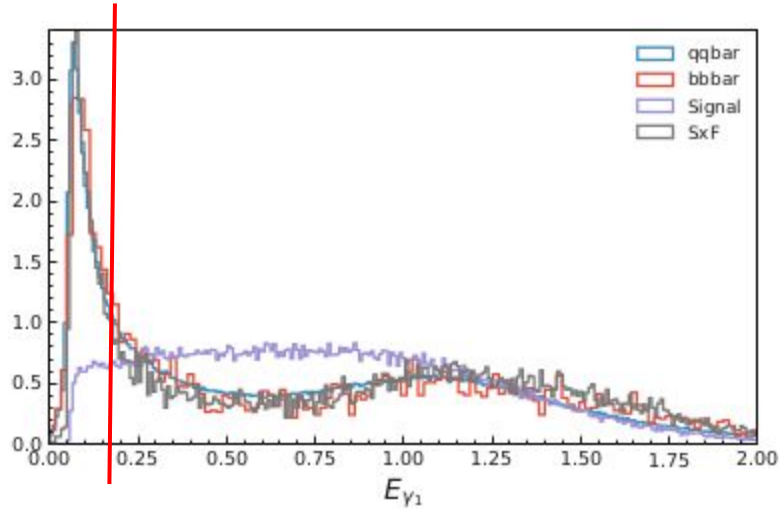
Branching fractions



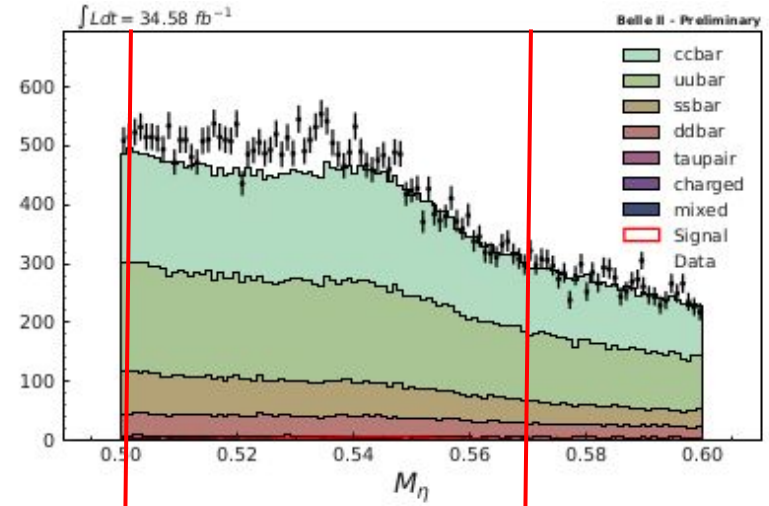
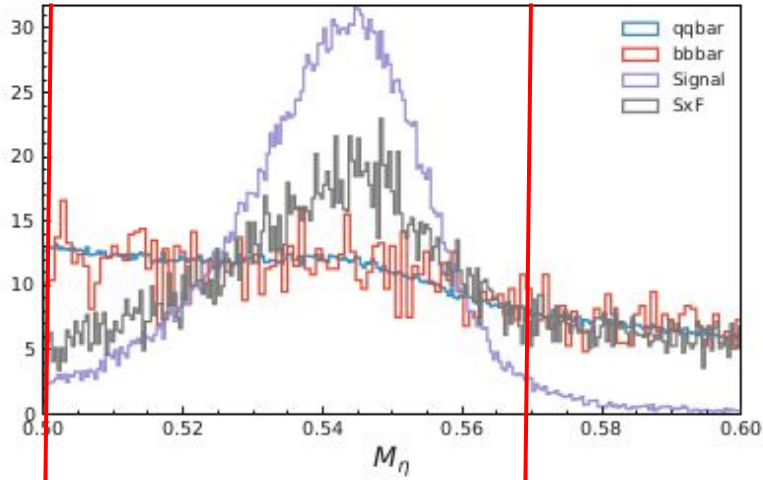
Mode	Decay channel	Branching fraction
$B^+ \rightarrow \eta' K^+$	inclusive	7.06×10^{-5}
	$\eta' \rightarrow \eta(\rightarrow \gamma\gamma)\pi^+\pi^-$	1.19×10^{-5}
	$\eta' \rightarrow \rho(\rightarrow \pi^+\pi^-)\gamma$	2.04×10^{-5}
	total	3.23×10^{-5}
$B^0 \rightarrow \eta' K$	inclusive	6.6×10^{-5}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

E gamma ($\eta \rightarrow \gamma \gamma$)

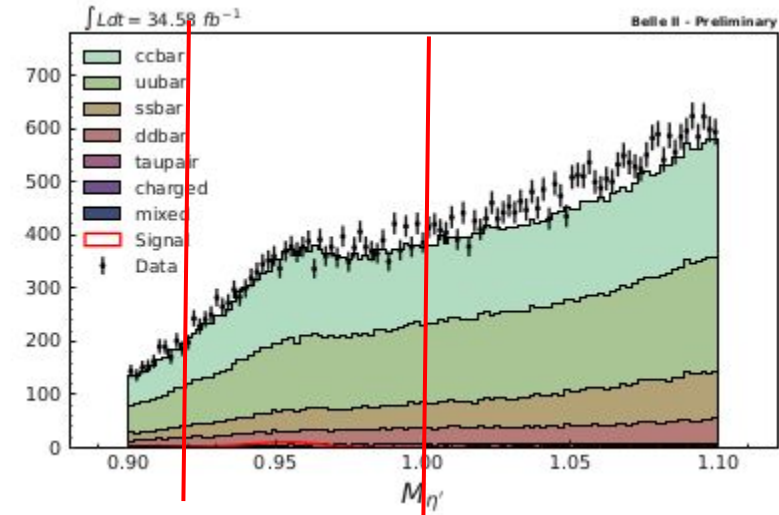
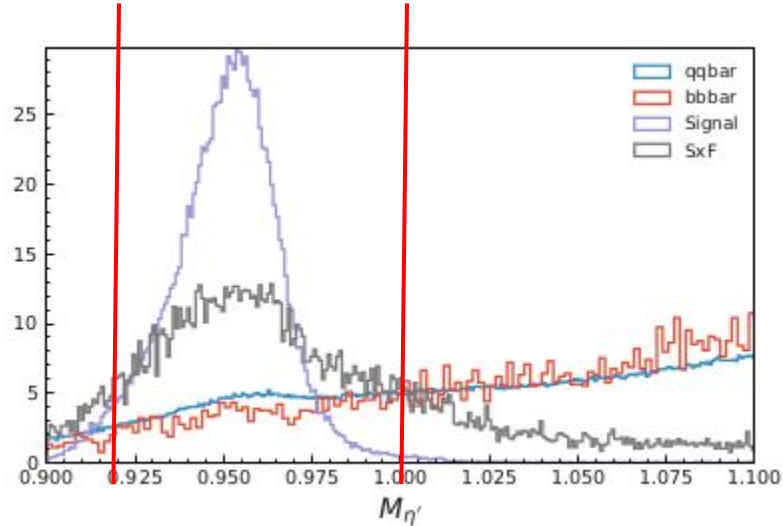


M(eta)



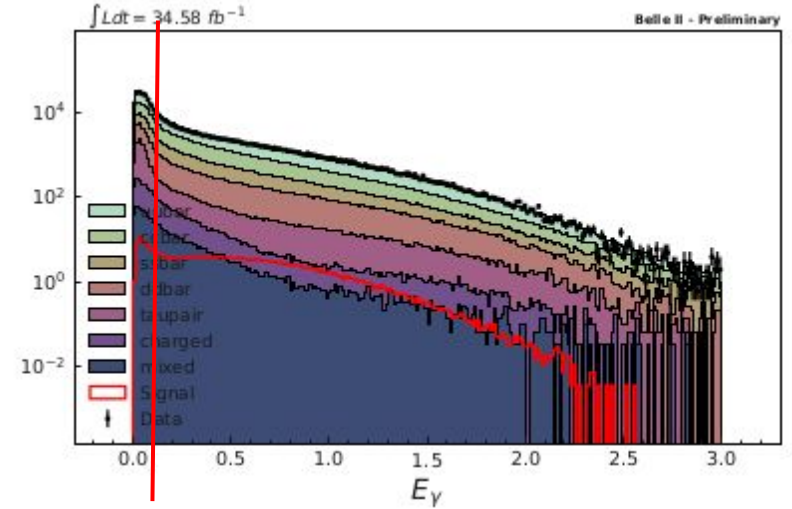
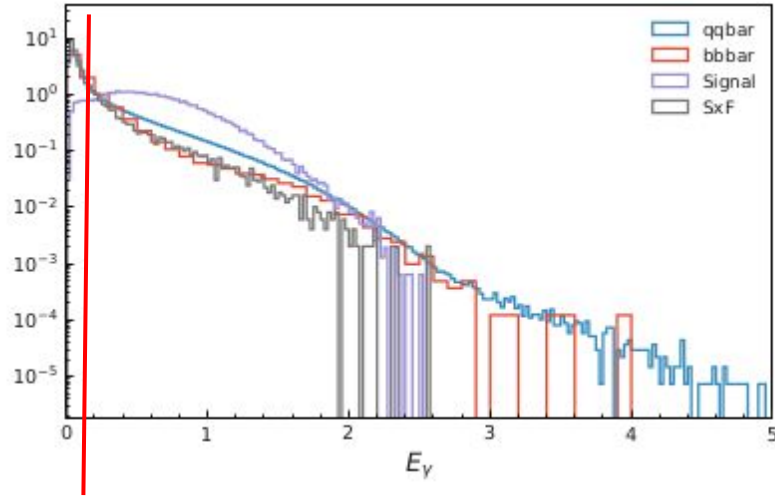
eta->gg peak not well visible due to low gamma threshold (60 MeV)

M(η')

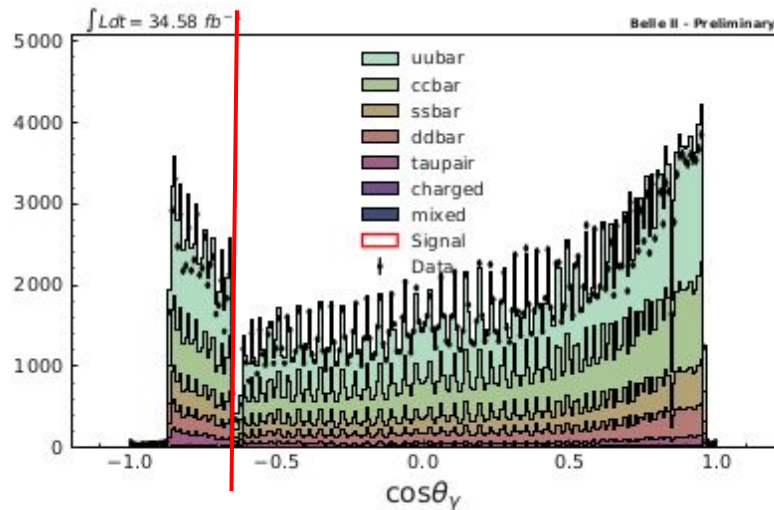
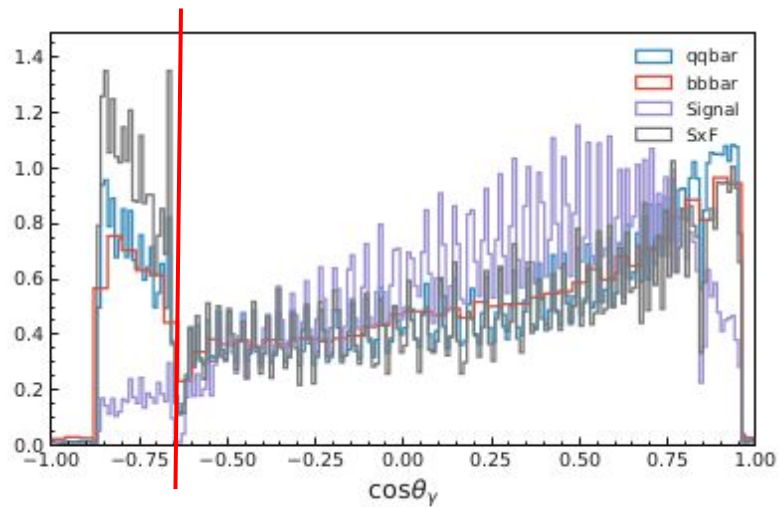


$\eta' \rightarrow \eta(\text{gg})\pi\pi$ peak not well visible due to low gamma threshold (60 MeV) and pion ones

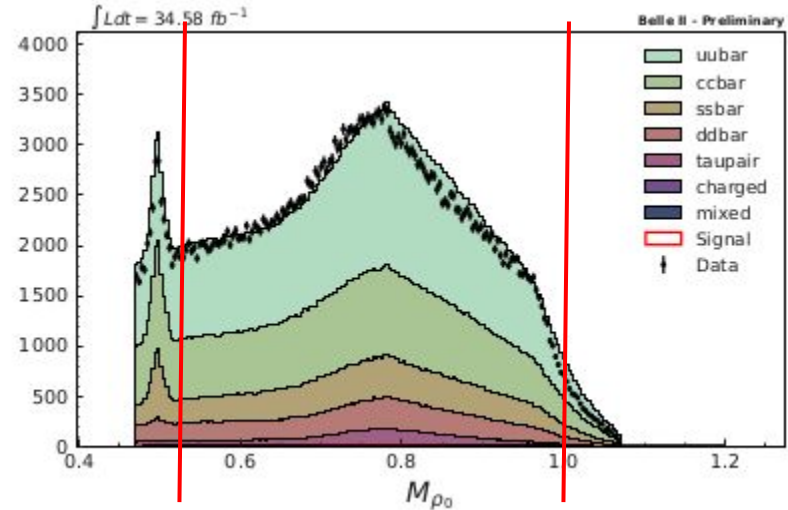
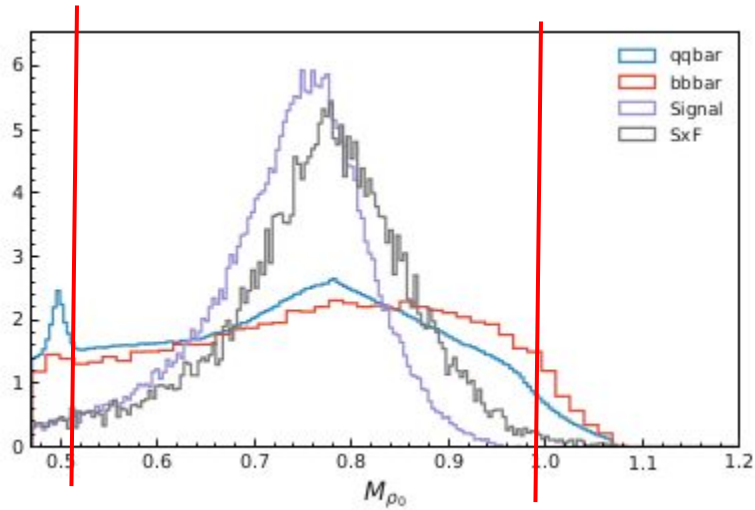
E(gamma) from eta' -> rho gamma



cos(theta gamma)

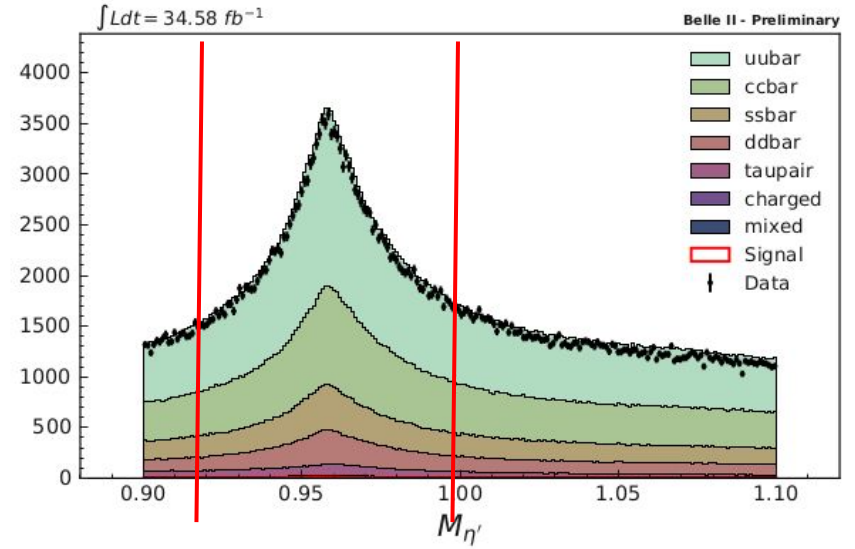
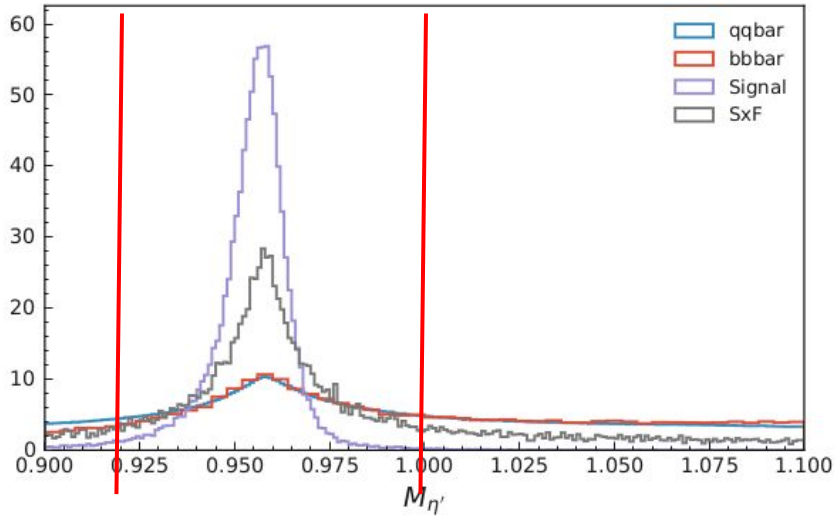


M(pi+ pi-)

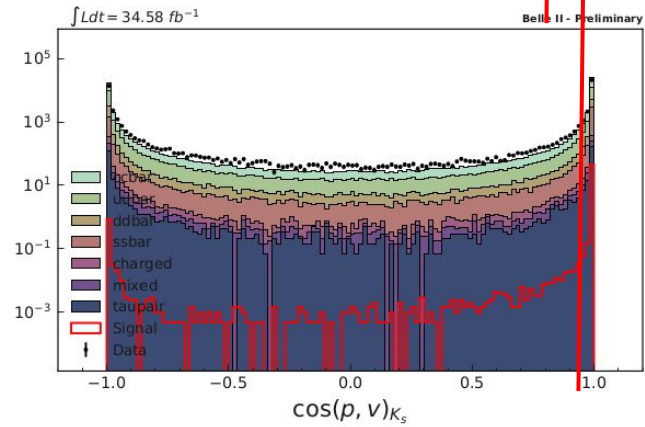
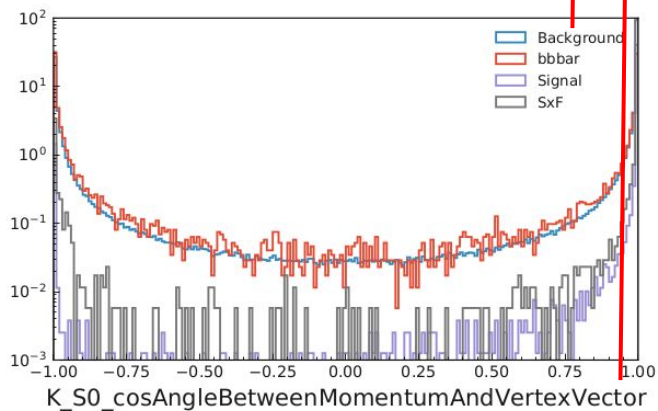
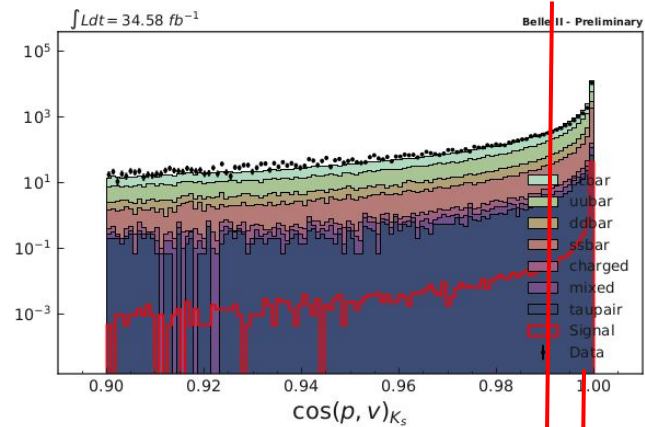
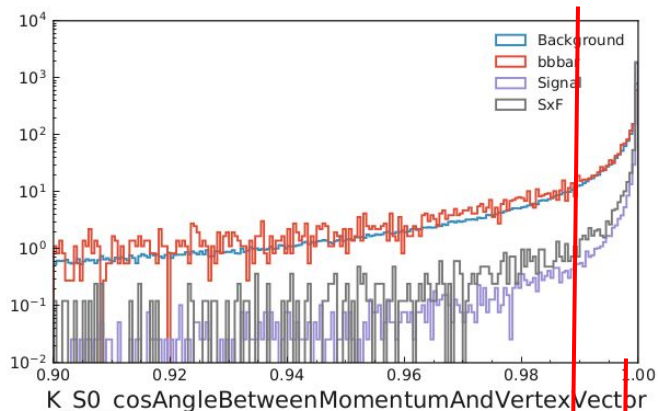


- Clear Ks peak
- Shift between rho peak for signal and SxF

M(η')



cos(alpha) (momentum vs vertex)



M(Ks)

