

Status of $B^0 \rightarrow \eta' K_S^0$ analysis

TDCPV Meeting
16/12/2019

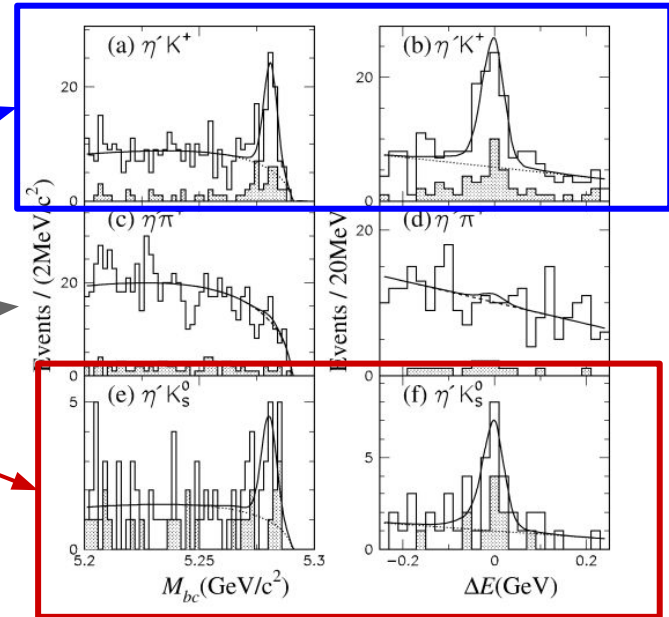
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Introduction

- From PDG:
- $BR(B^0 \rightarrow \eta' K_S^0) = (6.6 \pm 0.4) \times 10^{-5}$
 - $C_{CP}(B^0 \rightarrow \eta' K^0) = -0.06 \pm 0.04$
 - $-A_{CP} = S_{CP}(B^0 \rightarrow \eta' K_S^0) = 0.63 \pm 0.06$
- $BR(B^+ \rightarrow \eta' K^+) = (7.06 \pm 0.25) \times 10^{-5}$
- Can it be seen with 10/fb?
- It was done at Belle, both for:
 - B^+ : $BR = (79^{+12}_{-11} \pm 8) \times 10^{-6}$
 - B^0 : $BR = (55^{+19}_{-16} \pm 9) \times 10^{-6}$
 - Limit for $B^0 \rightarrow \eta' \pi^+$

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

Belle Collaboration



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

Final states considered (Belle)



- $\eta' \rightarrow \eta \pi^+ \pi^-$: BR=42.6%
 - $\eta \rightarrow \gamma \gamma$: BR=38.41%
 - $\eta \rightarrow \pi^+ \pi^- \pi^0$: BR=22.94%
- $\eta' \rightarrow \rho(\rightarrow \pi^+ \pi^-) \gamma$: BR=28.9%
 - Including non resonant $\pi^+ \pi^- \gamma$
- $K_S^0 \rightarrow \pi^+ \pi^-$: BR=69.2 %

Mode	N_S	Σ	ϵ (%)	ϵ_{B_S} (%)	$BF(10^{-6})$
$\eta'_{\eta\pi\pi} K^+$	$28.9^{+6.5}_{-5.7}$	9.4	21.7	3.78	69^{+15}_{-14}
$\eta'_{\rho\gamma} K^+$	$42.5^{+9.1}_{-8.3}$	7.5	14.2	4.18	92^{+20}_{-18}
$\eta'_{\eta\pi\pi} \pi^+$	$0.0^{+1.2}_{-0.0}$	0.0	23.7	4.11	–
$\eta'_{\rho\gamma} \pi^+$	$0.0^{+5.6}_{-0.0}$	0.0	15.4	4.55	–
$\eta'_{\eta\pi\pi} K^0$	$6.4^{+3.4}_{-2.7}$	3.5	20.8	1.25	46^{+25}_{-20}
$\eta'_{\rho\gamma} K^0$	$10.1^{+4.4}_{-3.6}$	4.0	11.5	1.16	79^{+34}_{-28}

In Belle, most of signal comes from

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

$\eta \rightarrow \pi^+ \pi^- \pi^0$ was not used here, only

$\eta \rightarrow \gamma \gamma$

Plan



- Rediscover η and η' in all final states, and compare with MC expectation
- Study selection and efficiency for $B^0 \rightarrow \eta' K^0$ in MC
 - $\eta' \rightarrow \eta (\rightarrow \gamma\gamma) \pi^+ \pi^-$,
 - $\eta' \rightarrow \eta (\rightarrow \pi^+ \pi^- \pi^0) \pi^+ \pi^-$,
 - $\eta' \rightarrow \rho (\rightarrow \pi^+ \pi^-) \gamma$
- Apply selection to generic Run dependent MC to check signal yield
 - Setup and 2D fit on $M_{bc} - \Delta E$ for signal extraction
- Study Data continuum and side bands for background assessment
- Repeat for B^+
- Document everything
- Finalize selection for Data
 - Review process toward unblinding
- Systematics and unblinding

Plan (today)



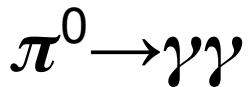
- Rediscover η and η' in all final states, and compare with MC expectation
- Study selection and efficiency for $B^0 \rightarrow \eta' K^0$ in MC
 - $\eta' \rightarrow \eta (\rightarrow \gamma\gamma) \pi^+ \pi^-$,
 - $\eta' \rightarrow \eta (\rightarrow \pi^+ \pi^- \pi^0) \pi^+ \pi^-$,
 - $\eta' \rightarrow \rho (\rightarrow \pi^+ \pi^-) \gamma$
- Apply selection to generic Run dependent MC to check signal yield
 - Setup and 2D fit on $M_{bc} - \Delta E$ for signal extraction (not today but ready)
- Study Data continuum and side bands for background assessment
- Repeat for B^+
- Document everything
- Finalize selection for Data
 - Review process toward unblinding
- Systematics and unblinding

A lot of work still needed,
hard for Moriond

Rediscover η and η' in all final states

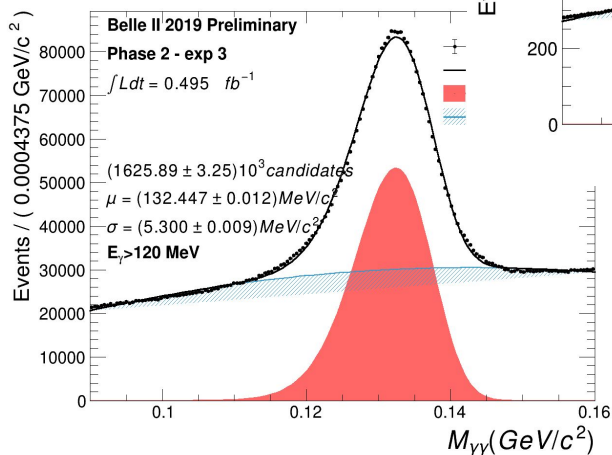
In phase III (and II) data

Documenting in BELLE2-NOTE-PH-2018-038.
Will be updated before x-mas break

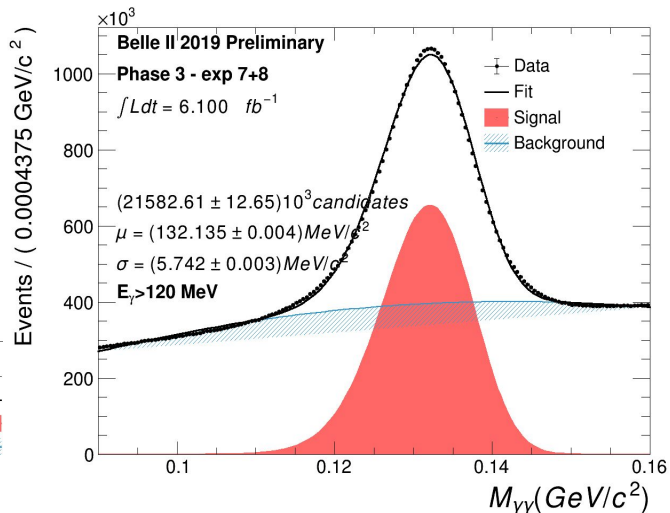


- γ in CDC volume
- $N_{\text{hits}} > 1.5$
- $E_g/E_{21} > 0.9$
- $E_\gamma > 120 \text{ MeV}$

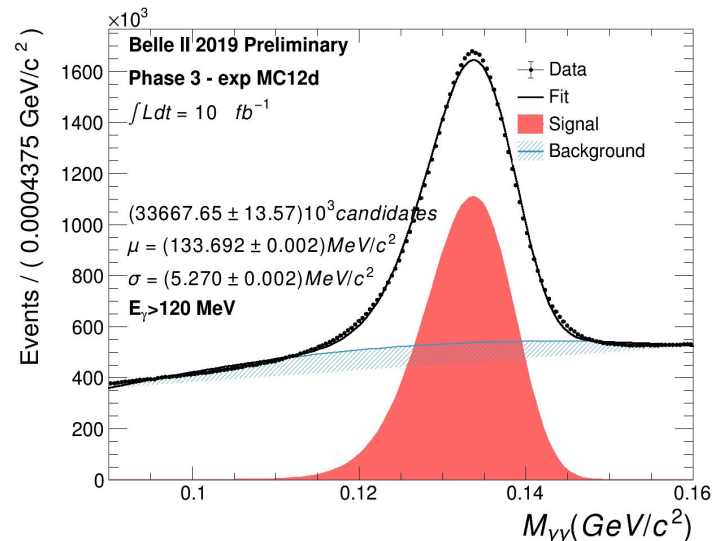
Phase 2



Phase 3

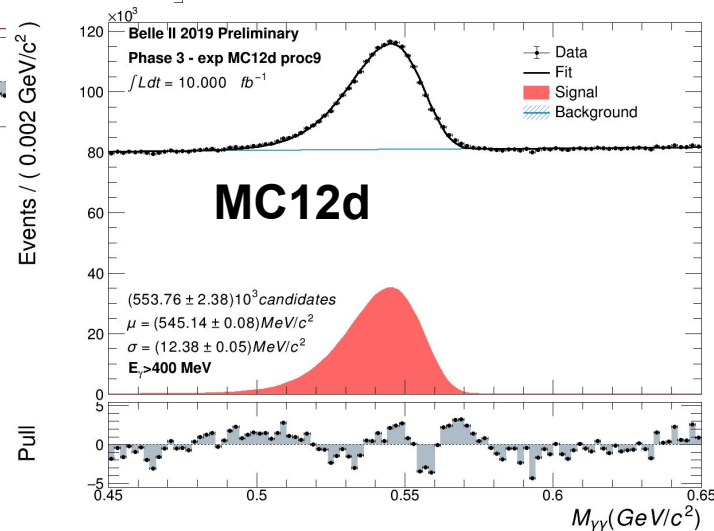
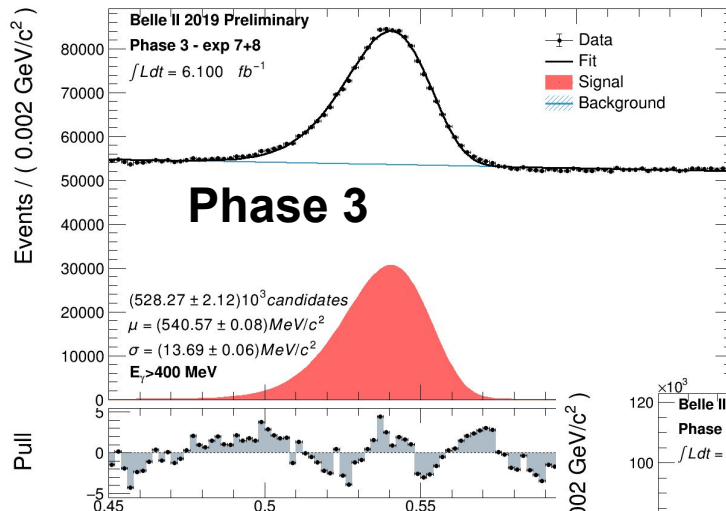
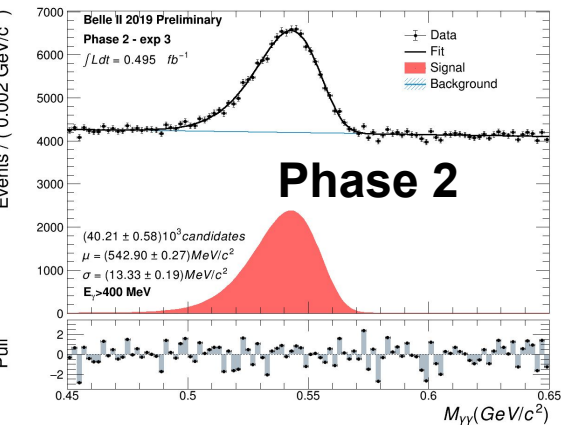


Run Dep MC12d



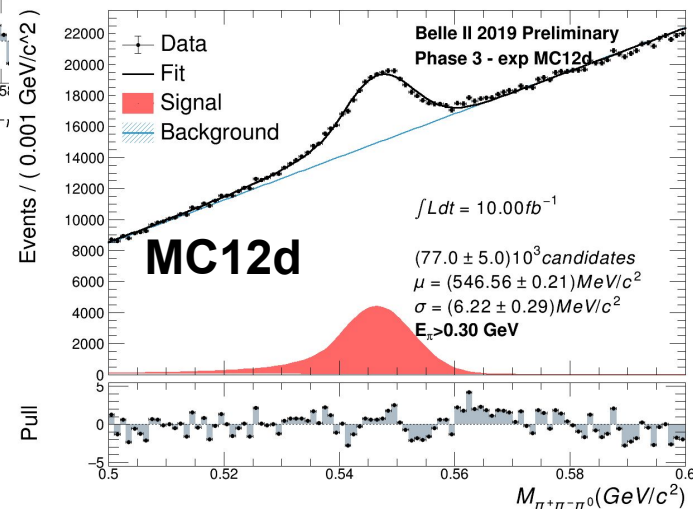
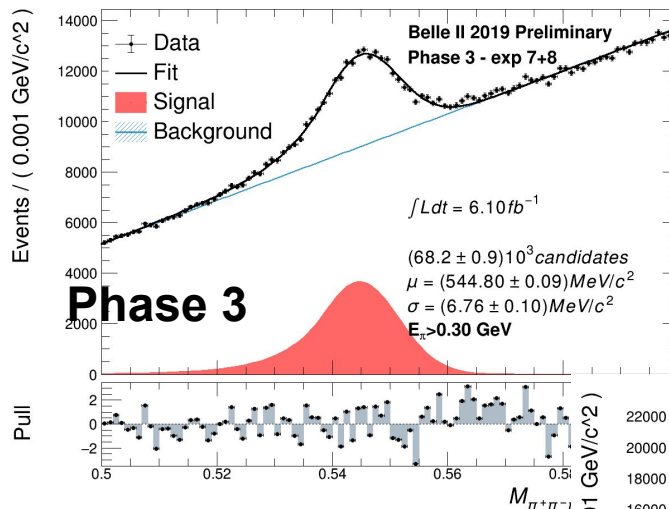
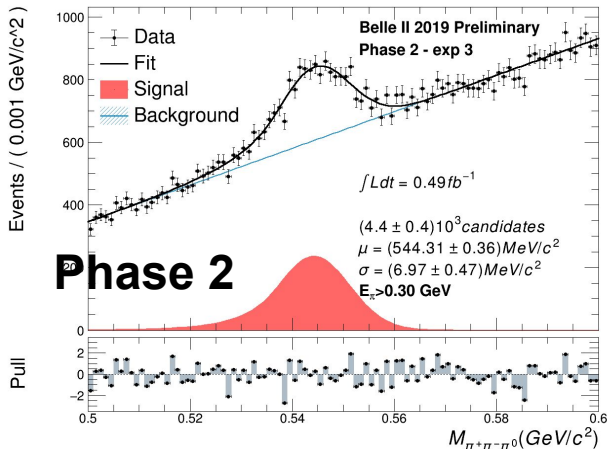
- Fit Novosibirsk + chebichev(2)
 - Not perfect pdf, good enough for peak and sigma.
- Peak Shift 1 MeV between Data and MC12d
- Width 5.3 vs 5.7 vs 5.3 (phase 2, 3, MC)

$$\eta \rightarrow \gamma\gamma$$



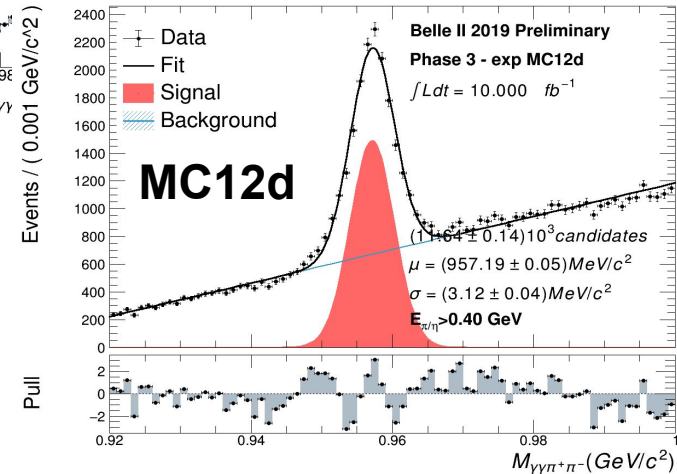
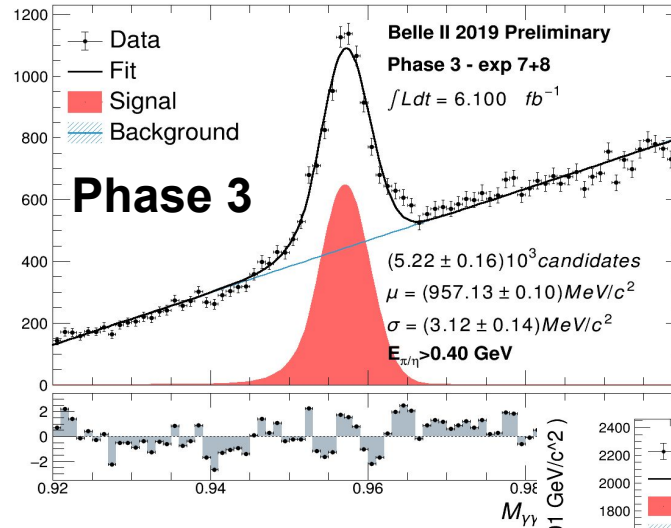
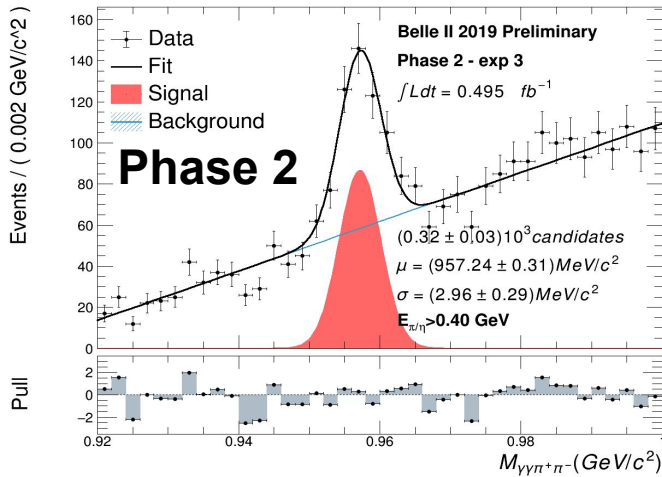
- Same cut as for $\pi^0 \rightarrow \gamma\gamma$
 - $E_{\gamma} > 400 \text{ MeV}$
- Peak: +5 MeV in MC phase3
- Width : 13 vs 14 vs 12.5 MeV (phase2, 3, MC12d)
 - At Belle (10.5 /fb)
 - $\eta \rightarrow \gamma\gamma$ width was 12 MeV/c²

$$\eta \rightarrow \pi^+ \pi^- \pi^0$$



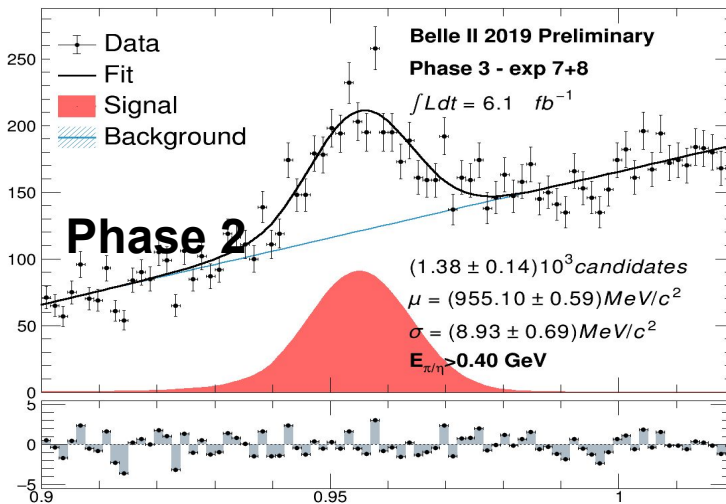
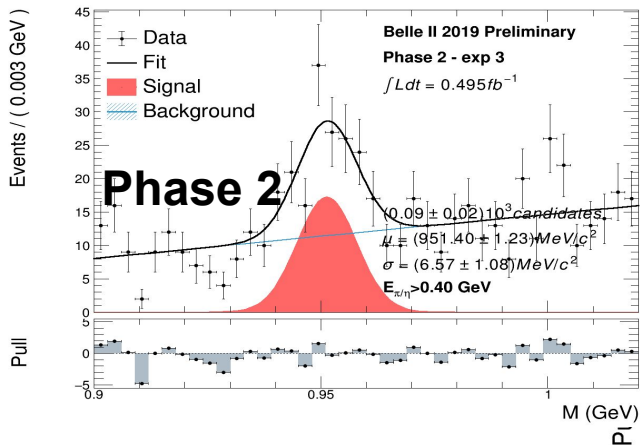
- $\pi^0 \rightarrow \gamma\gamma$
 - $E_{\gamma} > 200 MeV, 110 < m_{\pi^0} < 150 MeV,$
- π^{\pm} : $P(\square^2) > 10^{-4}, dr < 0.5 cm, |dz| < 2 cm$
- $p(\pi^{0\pm}) > 300 MeV$
- TreeFitter, π^0 mass constraint
- Peak: +2 MeV in MC phase3
- Width : 7 vs 7 vs 6.4 MeV (phase2, 3, MC12d)
 - Not used at Belle (10.5 /fb)

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

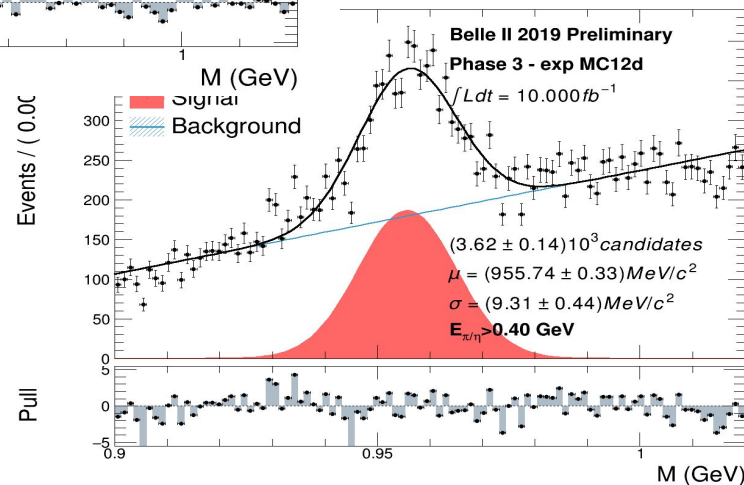


- γ and π^{\pm} as before
 - $480 < M_{\gamma\gamma} < 580 \text{ MeV}$, $E_{\gamma} > 400 \text{ MeV}$
- $p(\pi/\eta) > 400 \text{ MeV}$
- TreeFitter with η mass constraint
- Peak: same in data and MC
- Width : **3.0 vs 3.1 vs 3.1** (phase2, 3, MC12d)
 - at Belle (10.5 /fb), width was **2.7 MeV**

$$\eta' \rightarrow \eta (\rightarrow \pi^+ \pi^- \pi^0) \pi^+ \pi^-$$

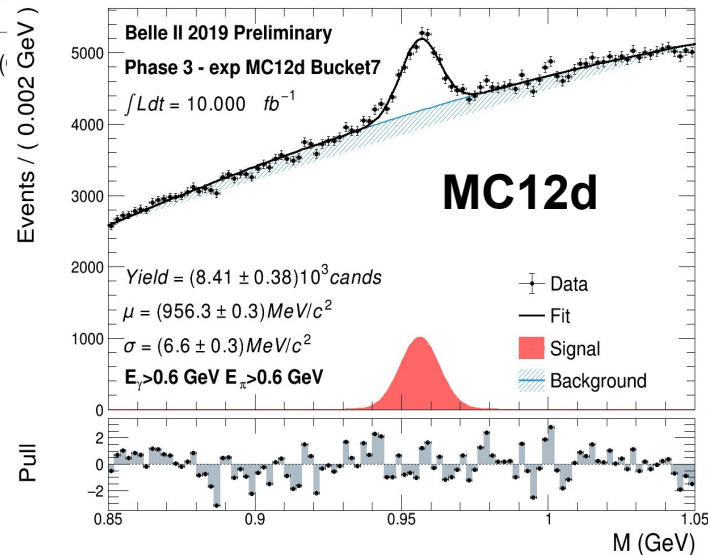
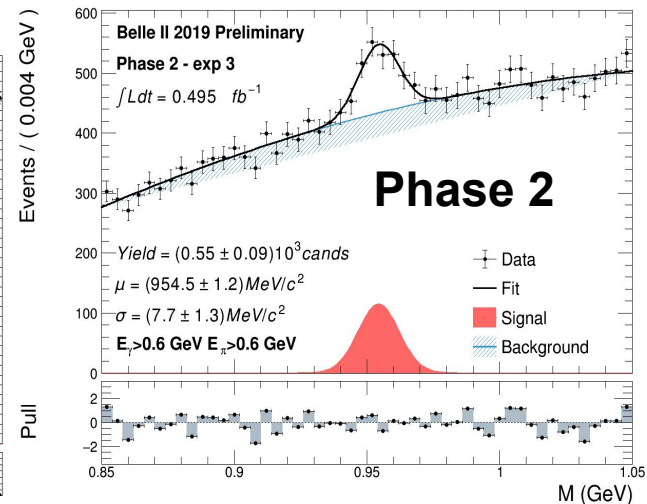
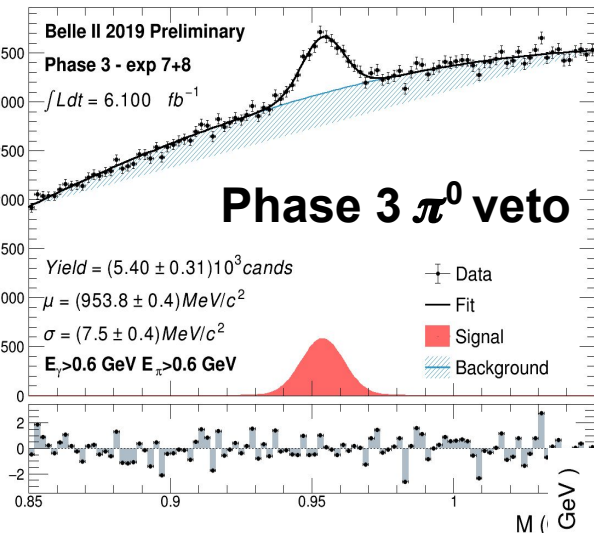
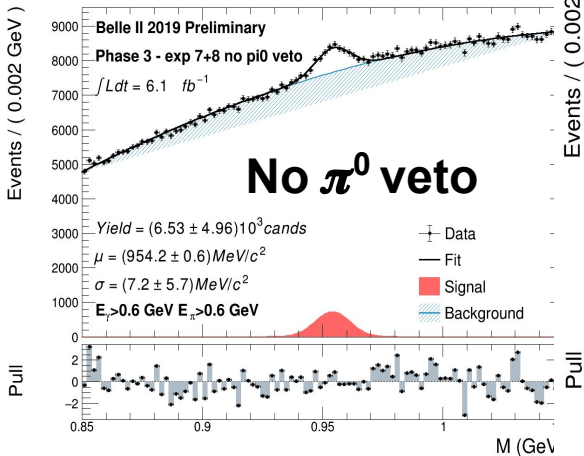


MC12d



- γ and $\pi^{+/-}$ as before
 - $510 < M_{\eta} < 580$ MeV, $E_{\pi} > 400$ MeV
- $p(\pi/\eta) > 400$ MeV
- TreeFitter with η and π^0 mass constraint
- Peak: same in data and MC (lower in phase 2)
- Width : **6.6 vs 8.9 vs 9.3** (phase2, 3, MC12d)
 - Not used at Belle (10.5 /fb)
- Yield (/fb) $(3\pi/2\gamma) \sim 0.23/0.85 \sim 0.27$ - $BR(3\pi/2\gamma) = 0.6$
 - $\epsilon(3\pi/2\gamma) \sim 0.5$

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



- γ and $\pi^{+/-}$ as before
 - $p(\pi/\gamma) > 600 \text{ MeV}$
 - **π^0 veto**: no γ in ROE with $120 < M_{\pi\gamma} < 145 \text{ MeV}$
- TreeFitter: without ρ mass constraint (large res)
- Peak: +3 MeV in MC
- Width : **7.7 vs 7.5 vs 6.6** (phase2, 3, MC12d)
 - At Belle (10.5 /fb) **8.8 MeV**
- Yield (/fb) ($\rho\gamma/2\gamma2\pi$) $\sim 0.85/0.85 \sim 1$ - $\text{BR}(\rho\gamma/2\gamma2\pi) = 2.3$
 - $\epsilon(3\pi/2\gamma) \sim 0.4$

Status of $B^0 \rightarrow \eta' K_s^0$ in MC12

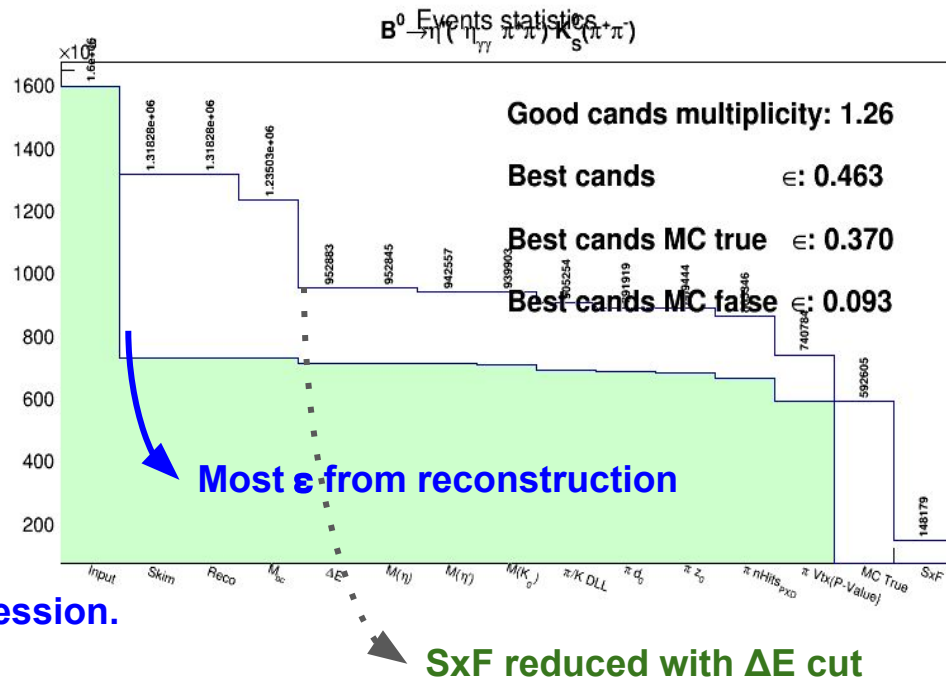
$$\eta' \rightarrow \eta (\rightarrow \gamma\gamma) \pi^+ \pi^-$$

Efficiency $B^0 \rightarrow \eta' (\rightarrow \eta (\rightarrow \gamma\gamma) \pi^+ \pi^-) K_S^0 (\rightarrow \pi^+ \pi^-)$



- Signal efficiency and SxF varied a lot depending:
 - MC campaign (simulated beam background)
 - Basf2 release (issue and improvement on reconstruction, mostly tracking and vertexing)

MC Campaign/Release	Efficiency	SxF
MC7/Rel-09 (B2TIP)	23 %	3.8 %
MC9/Rel-02	22 %	6.7 %
MC10/Rel-02	11 %	3.5 %
MC12b/Rel-03	19 %	4.5 %
MC12b/Rel-04	37 %	9.3 %

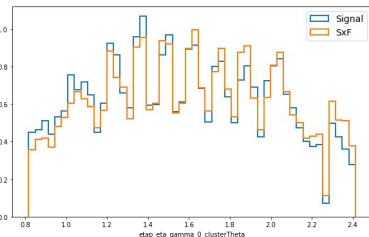
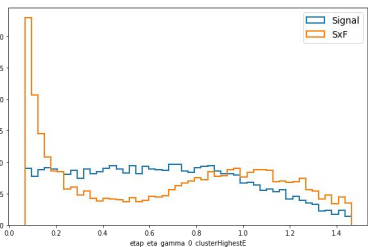


Optimized for Efficiency, not (yet) for SxF suppression.
Just using old (B2TIP) cuts.

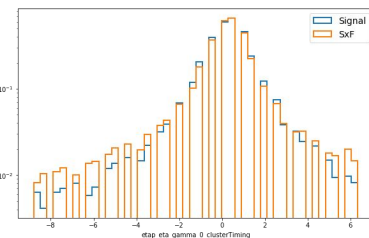
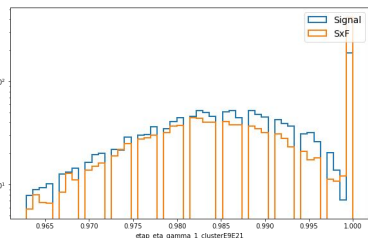
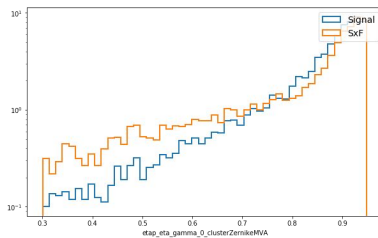
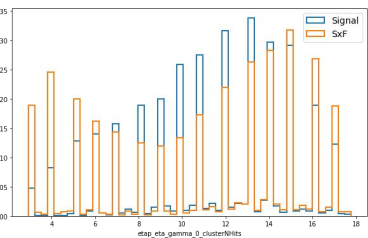
SxF reduced with ΔE cut

SxF Mitigation: fastBDT

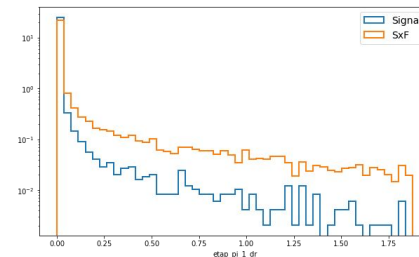
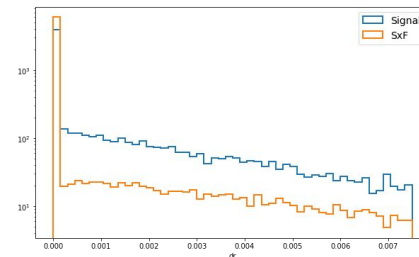
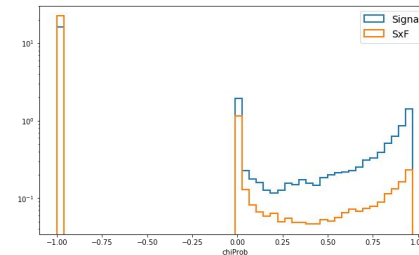
Almost 100% of SxF from $\eta(\rightarrow\gamma\gamma)$.



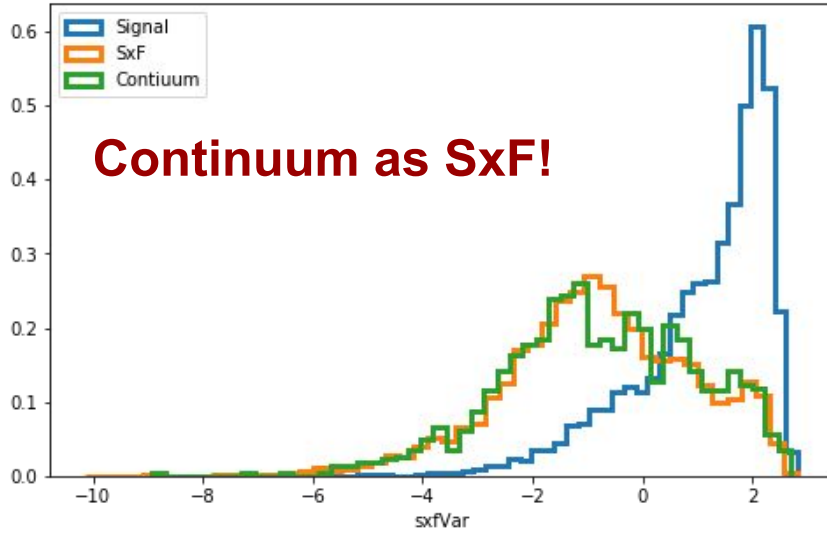
η variables



η' vertex variables



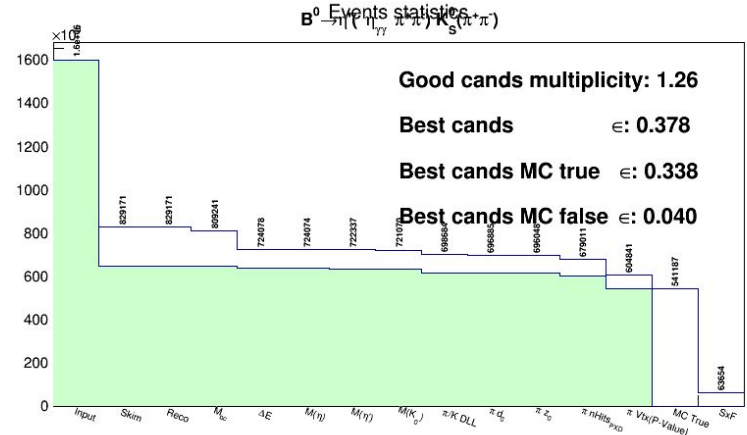
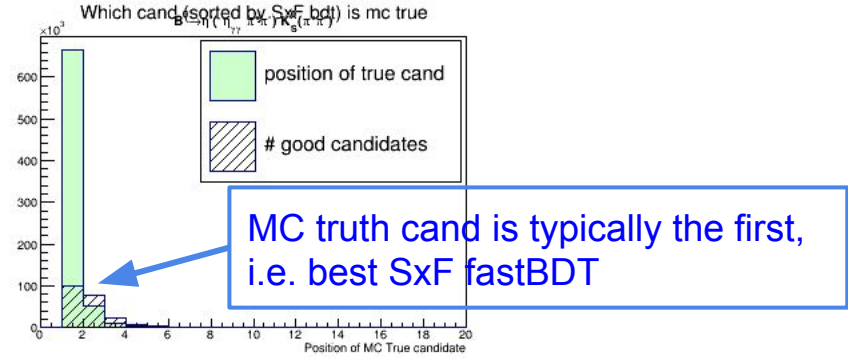
SxF FastBDT output



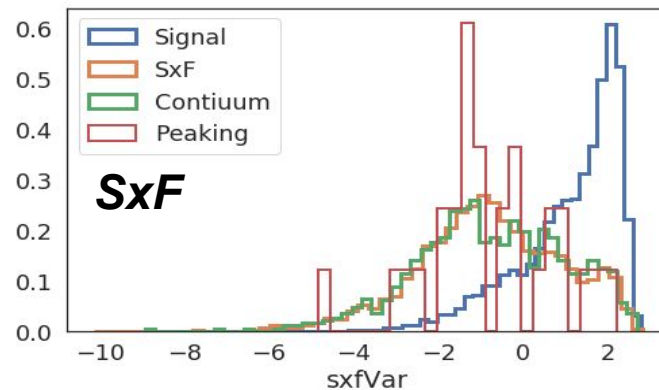
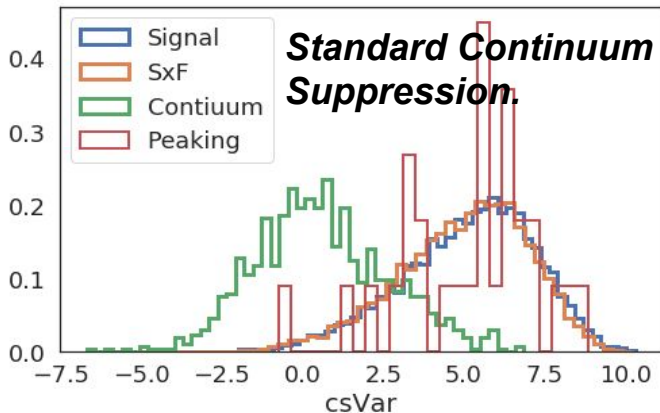
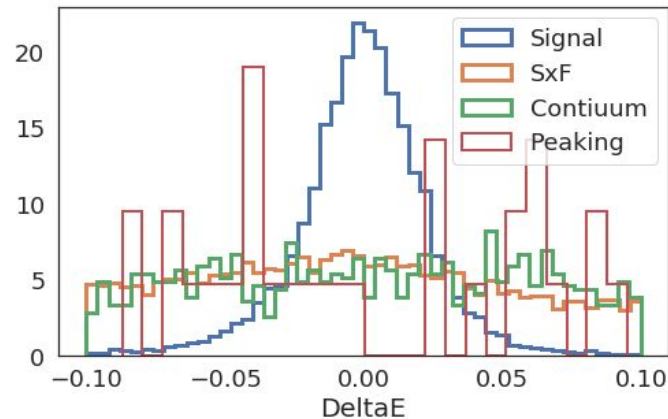
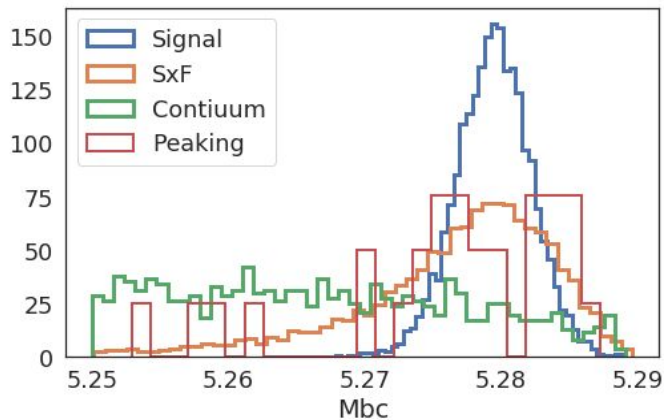
Selection	Efficiency	SxF
All candidates	37.0 %	9.3%
Best cand (SxF FBDT)	33.8 %	4.0 %

Need toys to understand which is better

Sorting Candidates by SxF FastBDT



Pdf: Signal - SxF - Bkg - BB



Correlation (for signal)

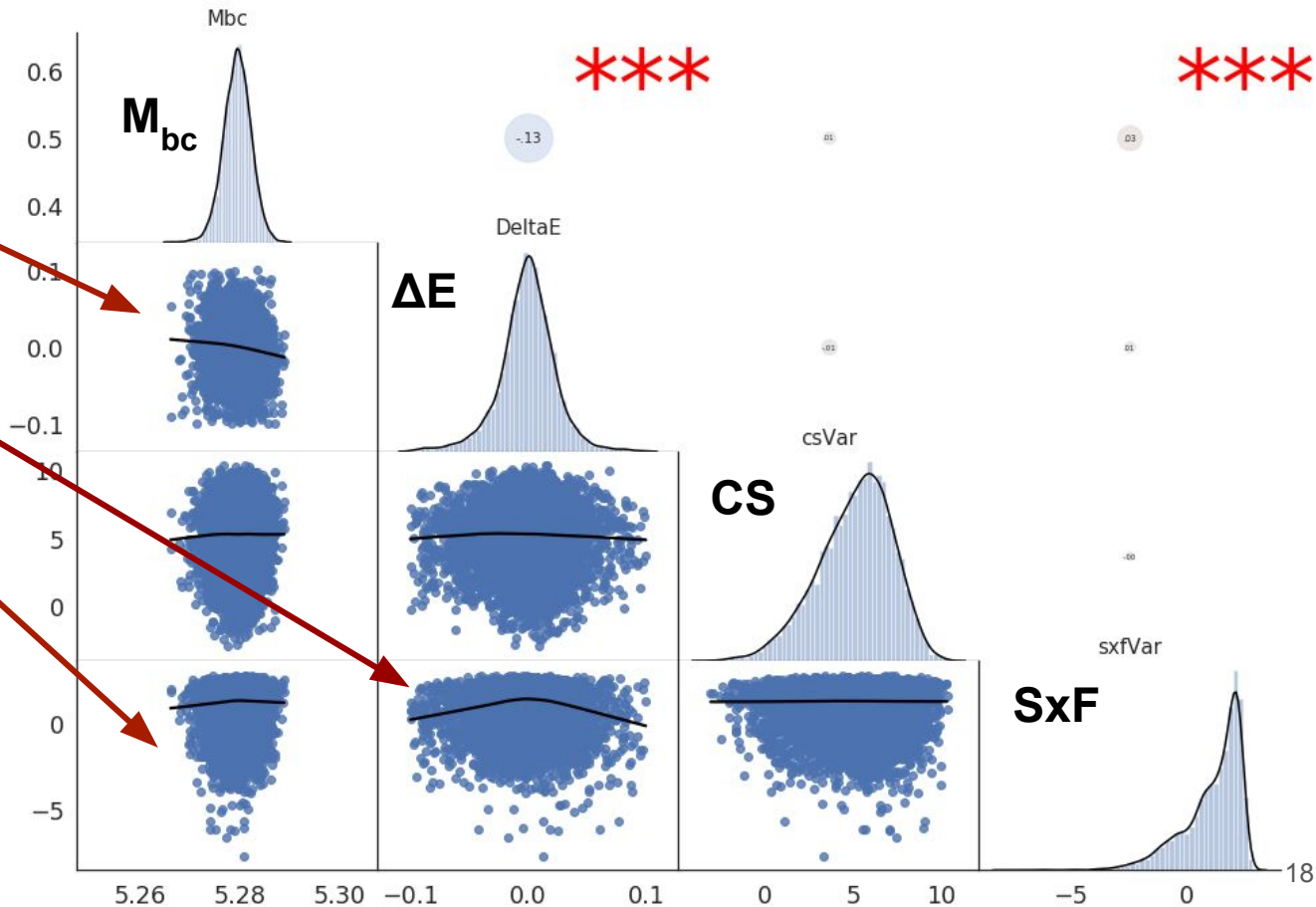
Correlation M_{bc} vs ΔE

0.13: know issue

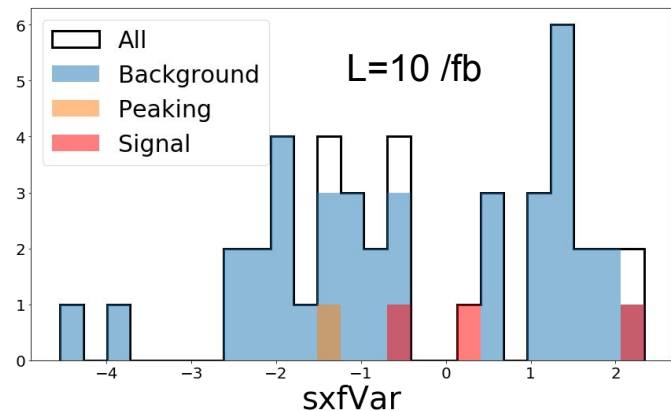
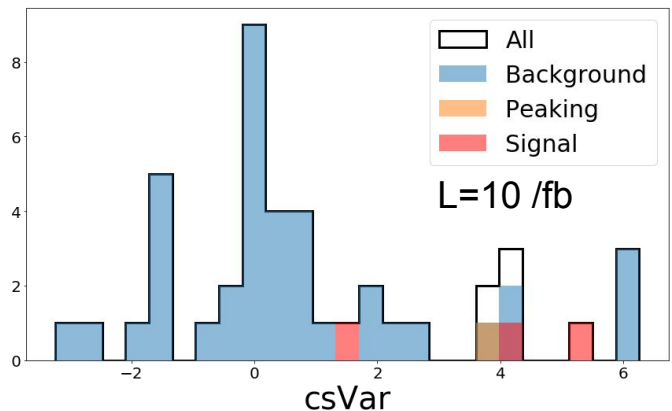
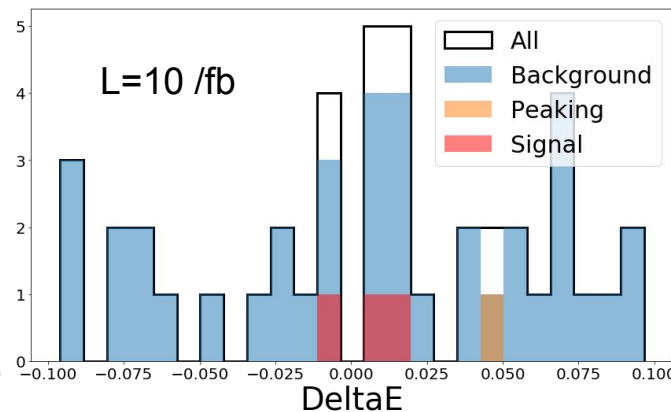
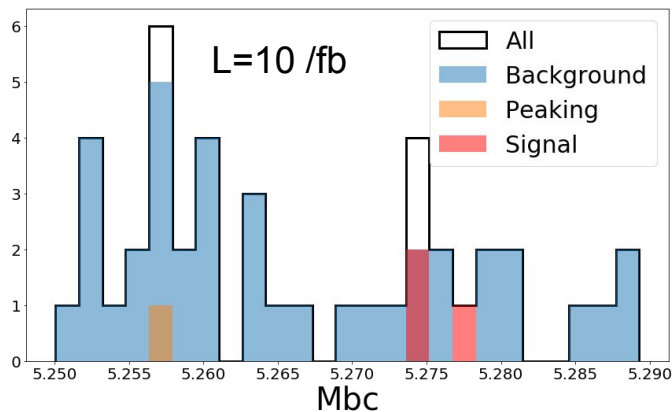
Cont suppression ok

ΔE vs SxF symmetric correlation

M_{bc} vs SxF small **0.09**



Test on Run Dependent MC12d



Continuum ($+ \tau$) + BB
L = 10 /fb

DS	Exp'd	Seen
Signal	~10	3
Bkg	~100	40
BB	~3	1

A quick test, much to be understood yet.

Data still blind

Summary



- η' seen in phase 3 (and phase 2) dataset in all final states
 - Good agreement with Run Dependent MC MC12d
- Status of $B^0 \rightarrow \eta' K_S^0$
 - First efficiency study for final state
 - With release-4 very good efficiency
 - SxF mitigation in place
 - First test on Run dependent MC
- Plan presented for next step
 - Lot of work, little time