Status update on $B^0 \to \eta'(\to \eta\pi^+\pi^-)K^0_S$ Time Dependent $\not{CP}$ analysis

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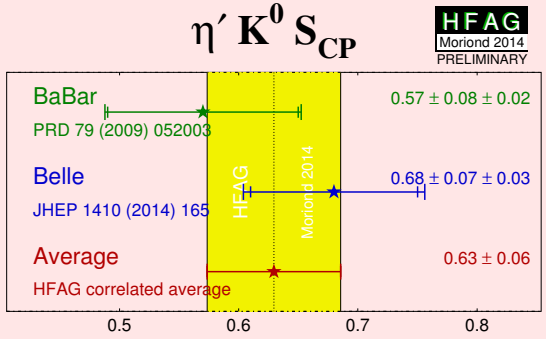
WG3 kickoff meeting,
KEK, march, 10^{th}, 2016

A sensitivity study for Time-Dependent CP violation analysis in the $B^0 \to \eta' K^0$ channel, a charmless $b \to s q \bar{q}$ decay

- CP asymmetry from time-dependent decay rate into CP eigenstates;
- not as sensitive as $b \to c q \bar{q}$ ($\sin 2\phi_1$)
  - $S_{\eta' K^0} = \sin 2\phi_1^{eff}$ tightly related to $\sin 2\phi_1$
  - $\Delta S_{\eta' K^0}$ can be shifted more than SM prediction in case new physics is present in the loop



- Similar to $B^0 \to \phi K^0_S$
  - more complex final state;
  - large BR: $\sim 6.6 \cdot 10^{-5}$ ($\sim 10 x \mathrm{BR}(B^0 \to \phi K^0_S)$)[CLEO(1998)]
  - actual uncertainties **statistically dominated** $\sigma_{stat} = 0.07, \sigma_{syst} = 0.03$[Belle(2014)]
  - projected for 50 ab^{-1} $\sigma_{stat} = 0.008, \sigma_{syst} = 0.008$[Urquijo(2015)]
  - no competition from LHCb (neutrals);

What's new

- first presented at last B2GM [link];
- today concentrate only in final state with $K^0_S \to \pi^+\pi^-$;
  - neglecting $K^0_S \to \pi^0\pi^0$ and K^0_L
- final states considered:
  - $\eta'(\to \eta_{\gamma\gamma})\pi^+\pi^-)$
  - $\eta'(\to \eta_{3\pi})\pi^+\pi^-)$
- moved to new version `rel-00-06-00`;
- analyzed full background BGx1 available statistics (200 fb^{-1});
- added peaking background (mixed and charged);
  - detailed selection breakdown
- update/corrige on Δt resolution,
  - signal and tag side resolution on Δz;
- continuum suppression status;
- started with multi dimensional fit.

Selection

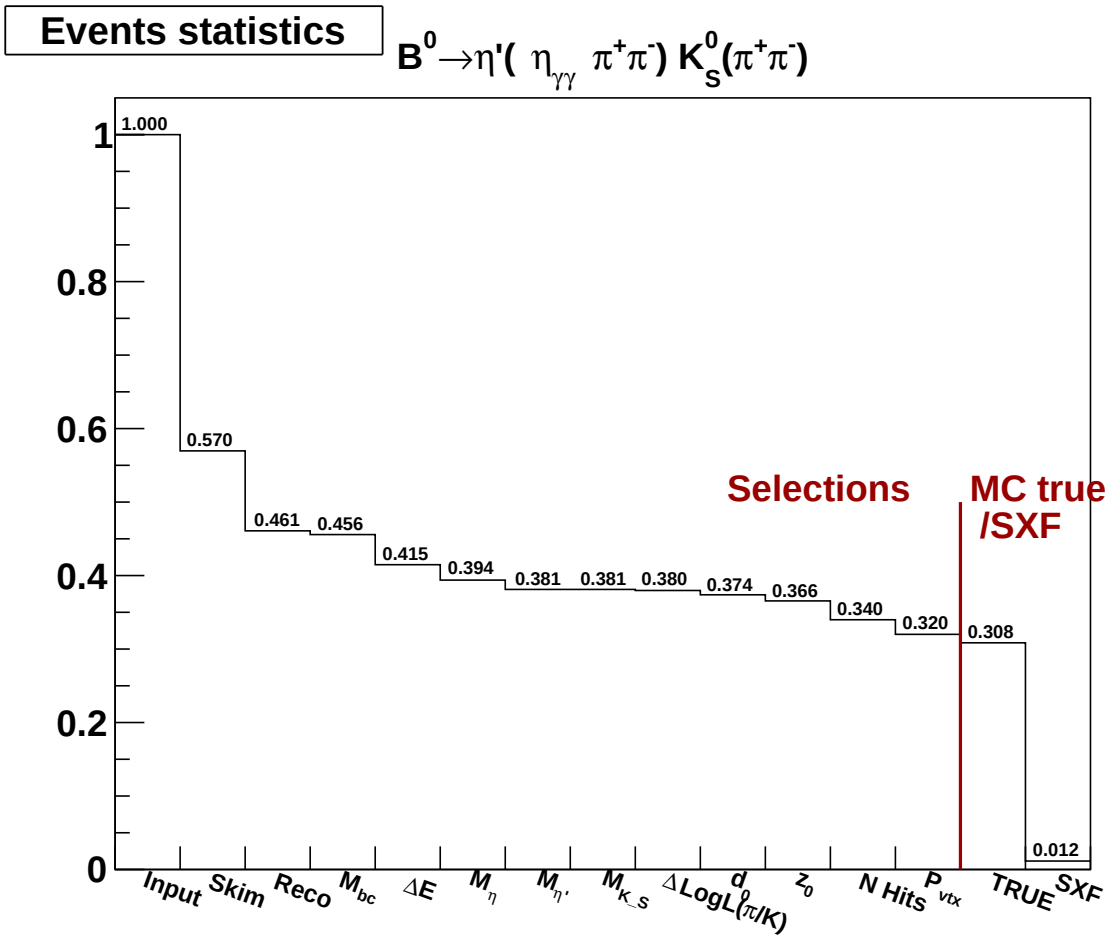
good candidate selection $B^0 \to \eta'(\to \eta_{\gamma\gamma}\pi^+\,\pi^-)K_S^{0+-}$:

- Reconstruct decay chain with mass constrains for η, η', K_S^0,
  - vertex only (w/o mass) for B^0

- $\eta \to \gamma\gamma$:
  - `gamma:all`: $0.06 < E_\gamma < 6\,\text{GeV}$, $-150 < clus_{time} < 0$, $E_9/E_{25} > 0.75$
  - $M(\eta_{\gamma\gamma}) \in [0.52, 0.57]\,\text{GeV}$;
- $\eta' \to \eta_{\gamma\gamma}\pi^+\pi^-$:
  - `pi:all`
  - $\Delta\log\mathcal{L}(\pi, K) > -10$; new
  - $d_0(\pi^\pm) < 0.08\text{mm}$;
  - $z_0(\pi^\pm) < 0.1\text{mm}$;
  - N hits$_{PXD}(\pi^\pm) > 1$
  - $M(\eta') \in [0.93, 0.98]\,\text{GeV}$;
- $K^0 \to \pi^+\pi^-$:
  - `K_S0:mdst`
  - $M(K_S^0 \to \pi^+\pi^-) \in [0.48, 0.52]\,\text{GeV}$;
- $B^0 \to \eta'(\to \eta_{\gamma\gamma}\pi^+\,\pi^-)K_S^{0+-}$
  - $M_{bc} > 5.25\,\text{GeV}$;
  - $|\Delta E| < 0.1\,\text{GeV}$;
  - P-value$_{vtx}(B_0, \eta', K_S^0) > 1 \cdot 10^{-5}$

if $N_{cands} > 1$, select candidate with highest P-value$_{vtx}(B_0, \eta', \eta, K_S^0)$

Selection breakdonw



Using full MC5 available statistics: 2 MEv

Combinatorics

Cands mult.: 1.88

Good cands mult.: 1.06

Efficiency %	
skim	57.0
preselection	46.1
good cands	32.0
MC true	30.8
SXF	1.1

Selection

good candidate selection $B^0 \to \eta'(\to \eta_{3\pi}\pi^+\pi^-)(K^0_S \to \pi^+\pi^-)$:

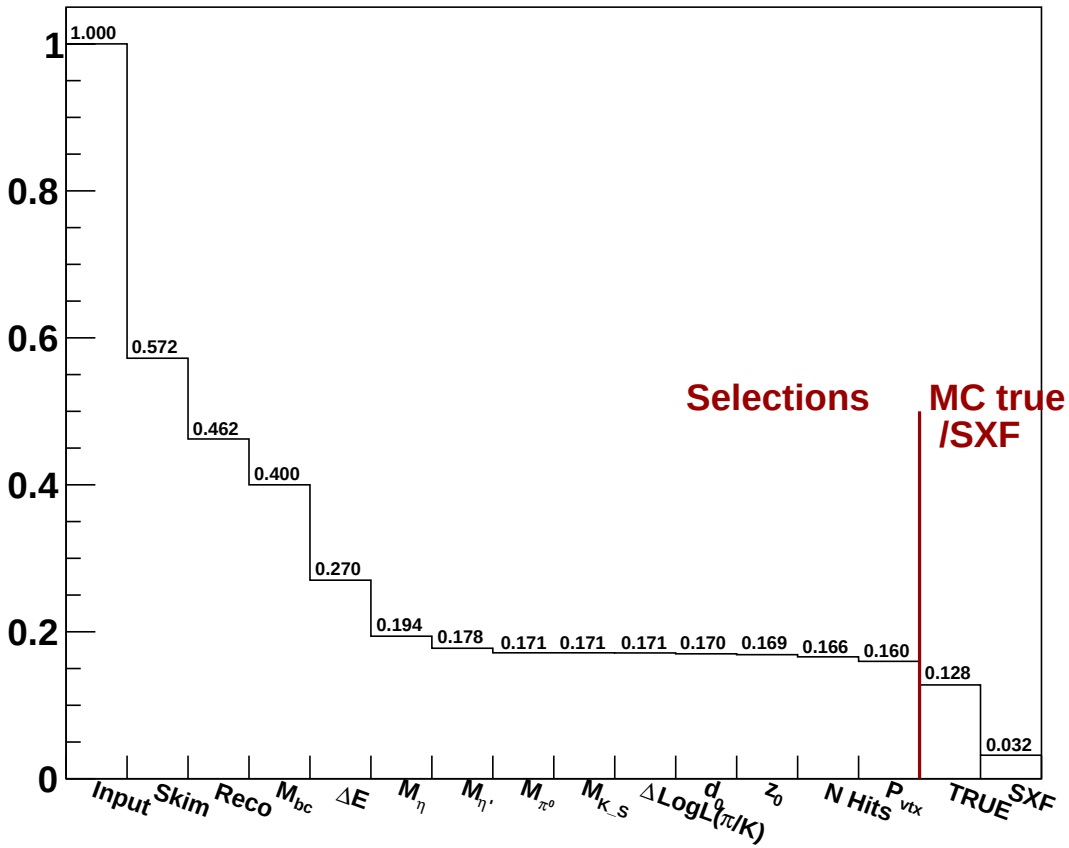
- Reconstruct decay chain with mass constrains for η, η', K^0_S,
  - vertex only (w/o mass) for B^0

- π^0:
  - `gamma:all`: $0.06 < E_\gamma < 6\,\text{GeV}$, $-150 < clus_{time} < 0$, $E_9/E_{25} > 0.75$
  - $M(\pi^0) \in [100, 150]\,\text{MeV}$
- $\eta \to \pi^+\pi^-\pi^0$:
  - `pi:all`
  - $\Delta\log\mathcal{L}(\pi, K) > -10$; new
  - $M(\eta_{3\pi}) \in [0.52, 0.57]\,\text{GeV}$;
  - $d_0(\pi^\pm) < 0.08\text{mm}$;
  - $z_0(\pi^\pm) < 0.1\text{mm}$;
  - N hits$_{PXD}(\pi^\pm) > 1$
- $\eta' \to \eta_{3\pi}\pi^+\pi^-$:
  - $M(\eta') \in [0.93, 0.98]\,\text{GeV}$;
- $K^0 \to \pi^+\pi^-$:
  - `K_S0:mdst`
  - $M(K^0_S \to \pi^+\pi^-) \in [0.48, 0.52]\,\text{GeV}$;
- $B^0 \to \eta'(\to \eta_{\gamma\gamma}\pi^+\,\pi^-)K^{0+-}_S$
  - $M_{bc} > 5.25\,\text{GeV}$;
  - $|\Delta E| < 0.15\,\text{GeV}$;
  - P-value$_{vtx}(B_0, \eta', K^0_S) > 1 \cdot 10^{-5}$

if $N_{cands} > 1$, select candidate with highest P-value$_{vtx}(B_0, \eta', \eta, K^0_S)$

Selection breakdonw

Events statistics $B^0 \to \eta'(\eta_{3\pi}\ \pi^+\pi^-)\ K^0_S(\pi^+\pi^-)$



Combinatorics

Cands mult.: 21.5

Good cands mult.: 1.45

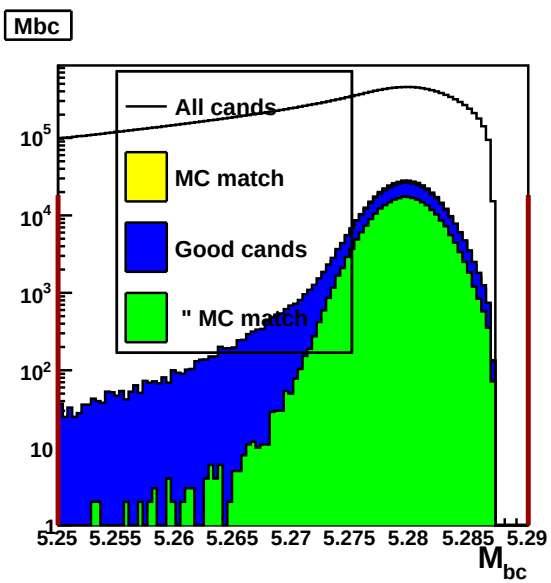
Efficiency %	
skim	57.2
preselection	46.2
good cands	**15.7**
MC true	12.6
SXF	3.2

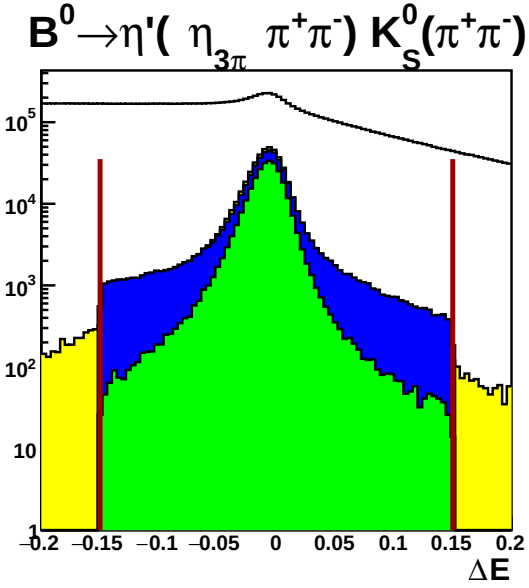
Using full MC5 available statistics: 2 MEv

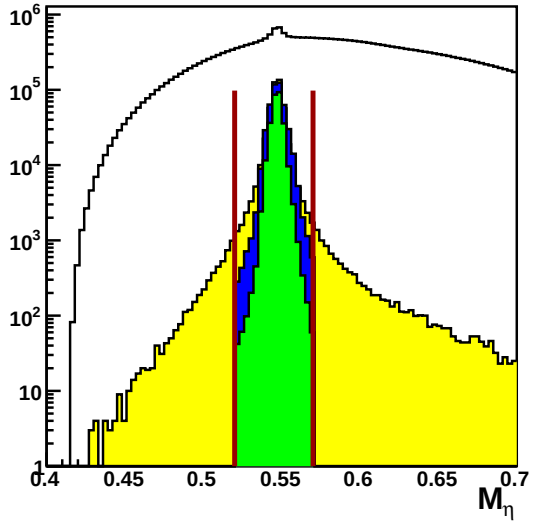
Reco eff is as good as $\eta_{\gamma\gamma}$ channel.

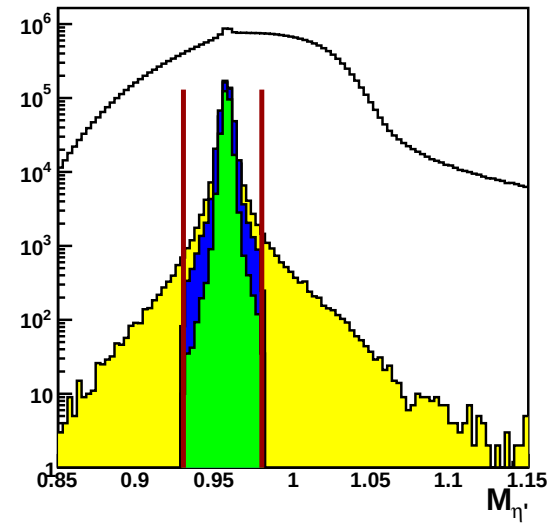
50% eff drop due to poor resolution on ΔE, M_η, $M_{\eta'}$ all coming from π^0 reconstruction in $\eta \to \pi^+\pi^-\pi^0$ decay

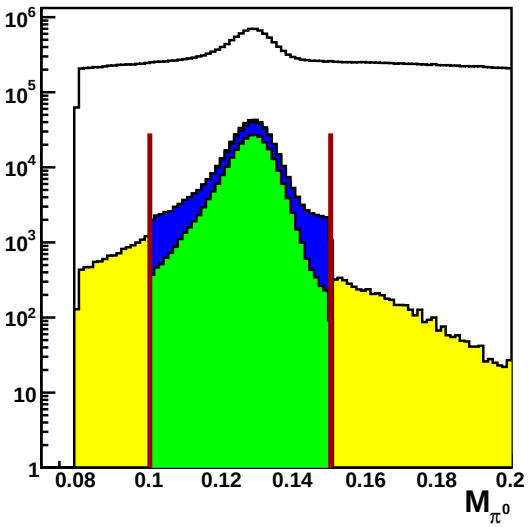
Good candidates distributions

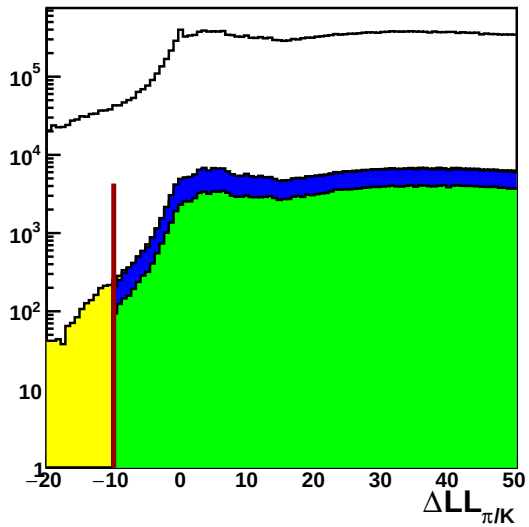






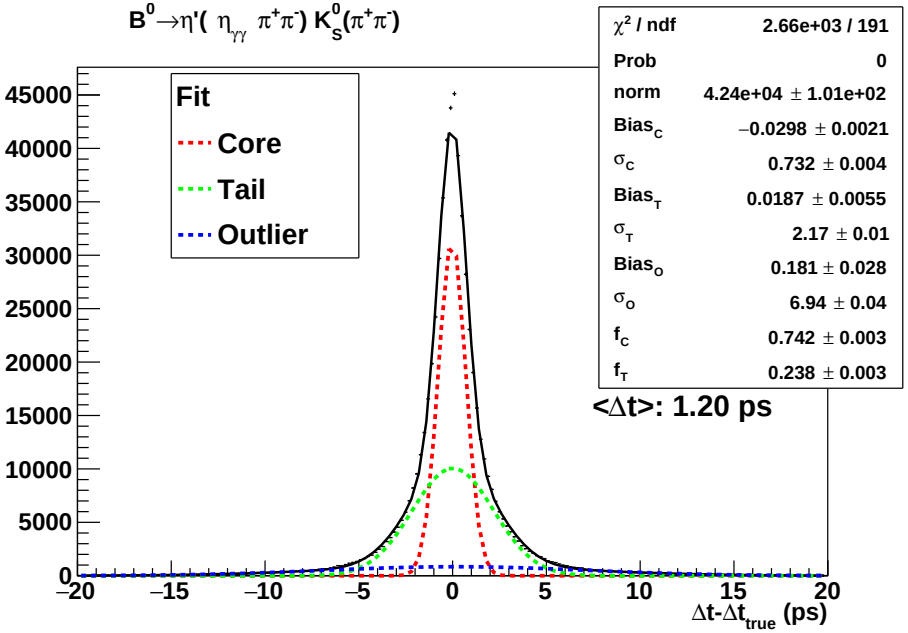


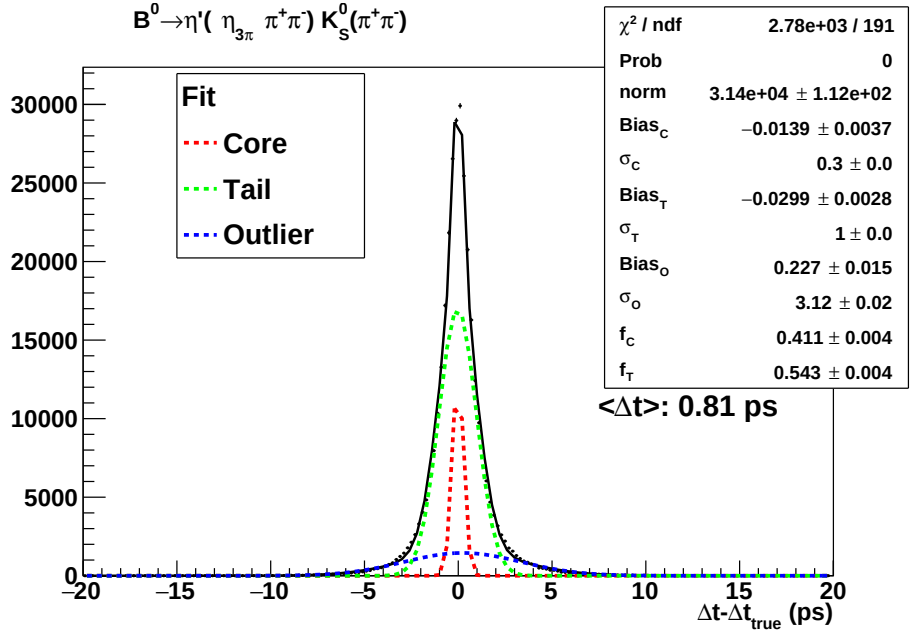




Time resolution

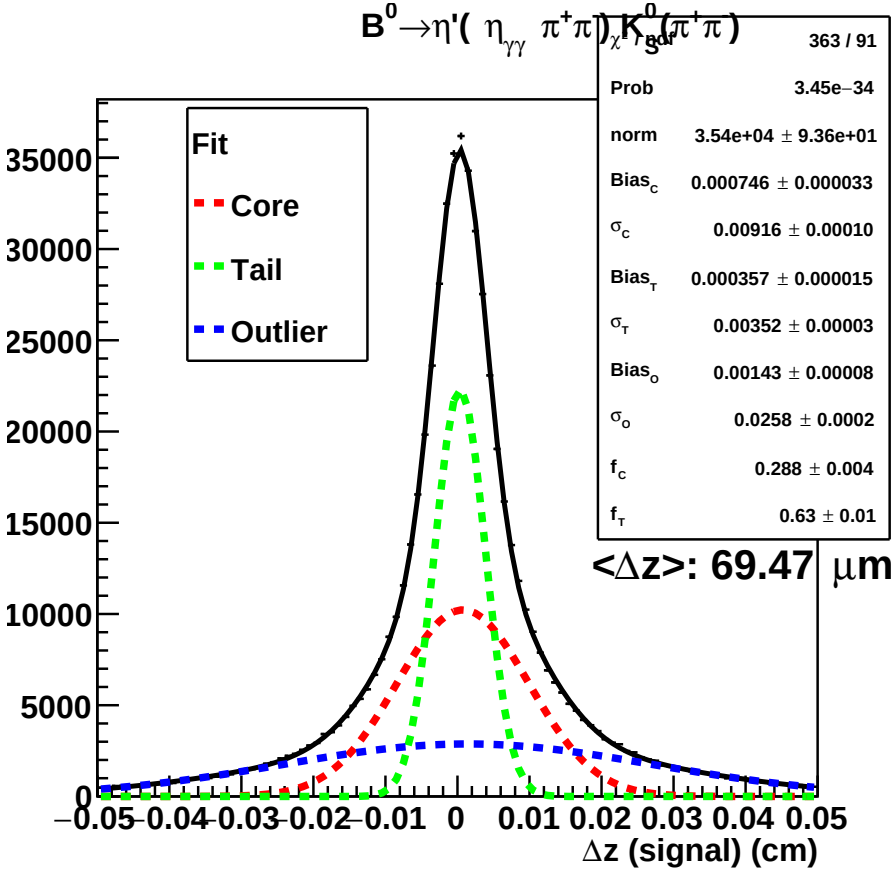
NB: bug found after presentation at last B2GM. Wrong reso reported. Now corrected

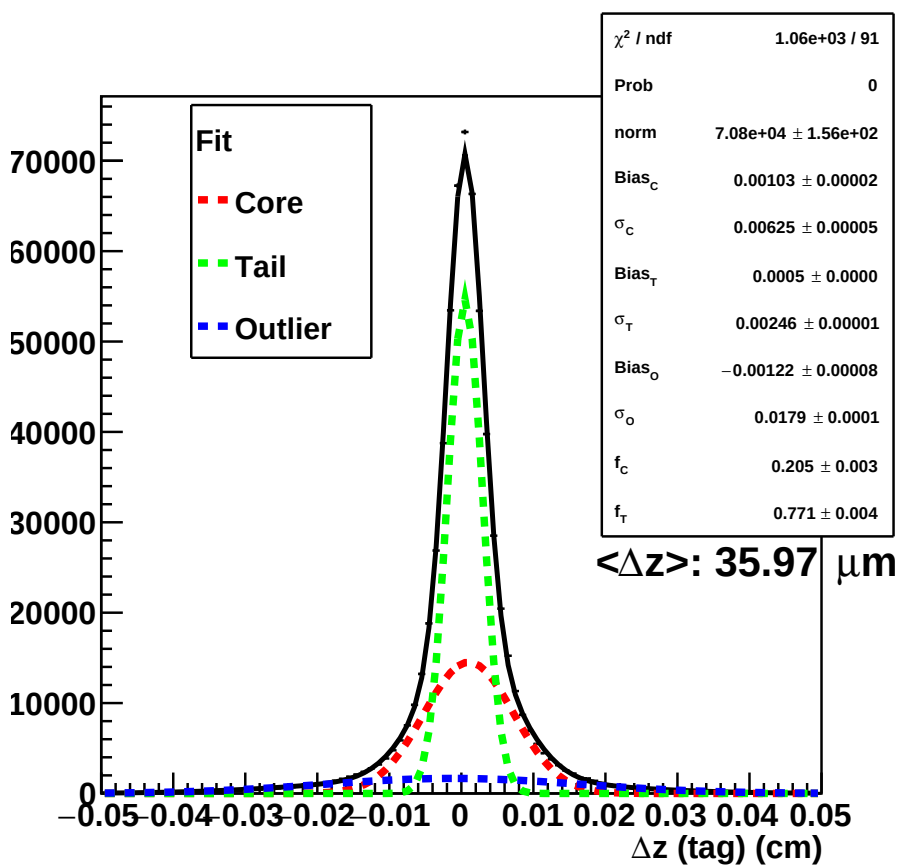




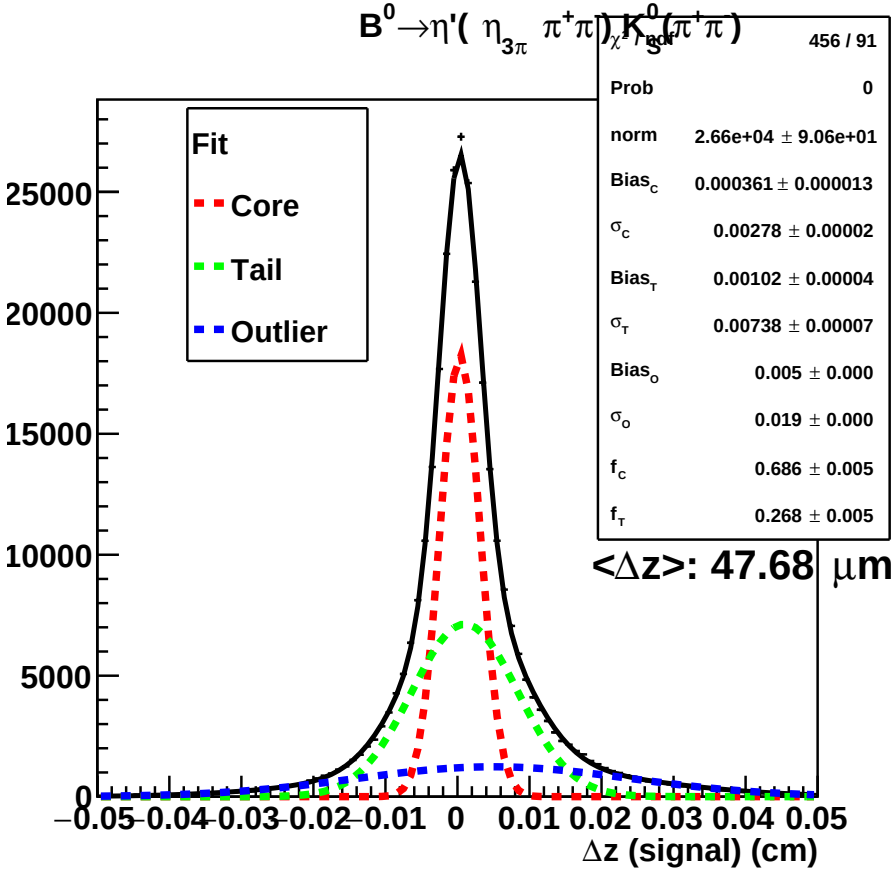
Fit with three gaussian (core, tail, and outlier)

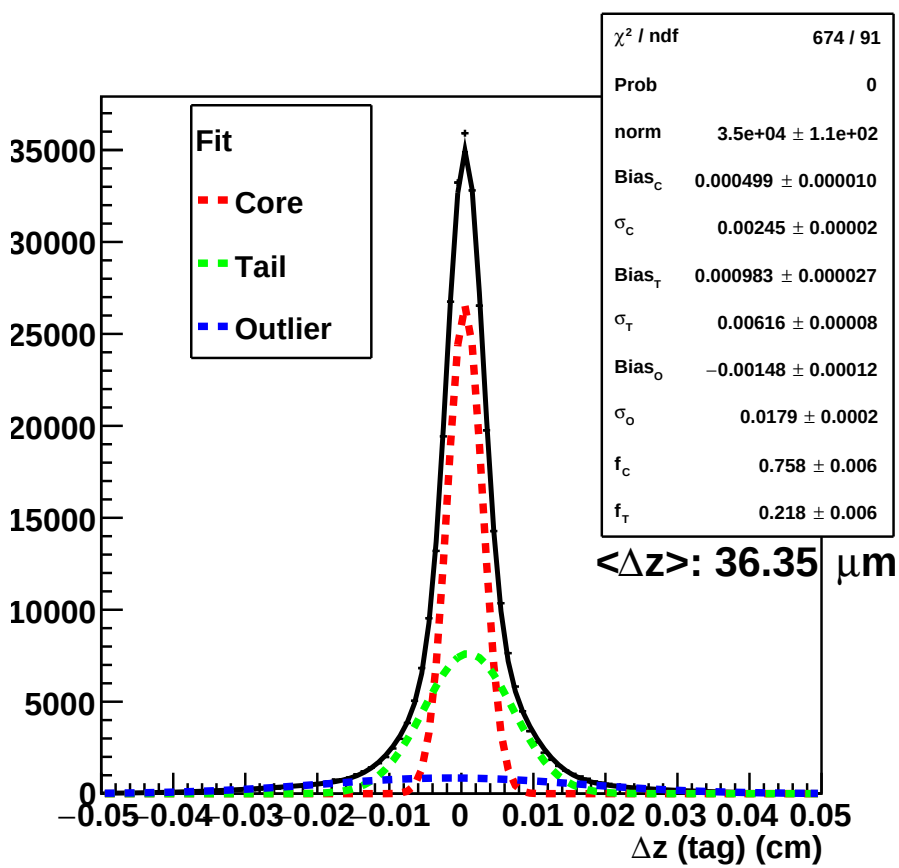
Δz resolution for signal and tag vertexes





Δz resolution for signal and tag vertexes





$\Delta z(\text{signal}) = 69.5\ \mu m$ for $\eta_{\gamma\gamma}$ and $47.5\ \mu m$ for $\eta_{3\pi}$

$\Delta z(\text{tag}) = 36\ \mu m$ for both

Background reduction

- Background MC sample **BGx1**
- single skim for both $K^0_S \to \pi^+\pi^-$ channels ($\eta_{\gamma\gamma}$, $\eta_{3\pi}$);
  - Not skimming for $K^0_S \to \pi^0\pi^0$final state: problem with memory, jobs crashed.
  - my guess combinatorics some time too large?
  - Should I try an harder skimming?
- Using all available statistics: $\int \mathcal{L}dt = 200\,\mathrm{fb}^{-1}$;
  - Skim produced at KEKCC (LSF)
  - Skim output moved to local sorage in Padova
  - First from KEKCC to Naples Tier2, then to Padova
  - much better bandwidth than direct trasnfer!
- Numbers before cut on continuum discriminating variable

Background reduction

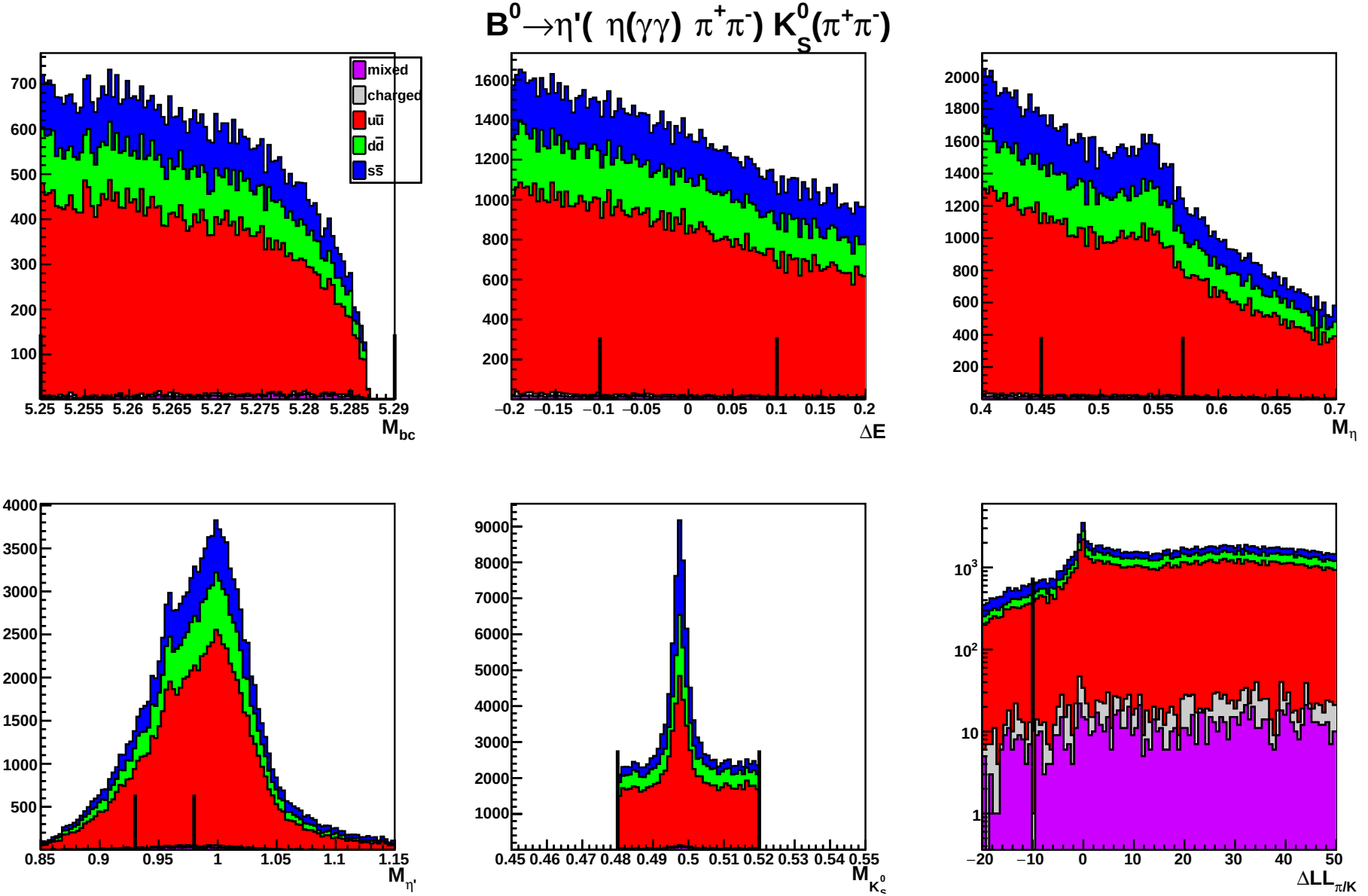
$B^0 \to \eta'(\to \eta_{\gamma\gamma}\pi^+\pi^-)K_S^{0+-}$

Sample	# Ev (M)	Skim (M)	ϵ_{skim}	pre-sel	sel	ϵ_{sel}
$u\bar{u}$	321	2.33	$0.72 \cdot 10^{-2}$	52353	673	$2.10 \cdot 10^{-6}$
$d\bar{d}$	80.2	.617	$0.77 \cdot 10^{-2}$	14568	181	$2.26 \cdot 10^{-6}$
$s\bar{s}$	76.6	.807	$1.05 \cdot 10^{-2}$	14801	126	$1.64 \cdot 10^{-6}$
$c\bar{c}$	266	3.85	$1.45 \cdot 10^{-2}$	71112	924	$3.48 \cdot 10^{-6}$
$B^0\overline{B}^0$	111	.123	$0.11 \cdot 10^{-2}$	601	14	$0.13 \cdot 10^{-6}$
B^+B^-	106	.130	$0.12 \cdot 10^{-2}$	504	7	$0.07 \cdot 10^{-6}$
total	960	2.662	$0.82 \cdot 10^{-2}$	153939	1925	$2.00 \cdot 10^{-6}$

$B^0 \to \eta'(\to \eta_{3\pi}\pi^+\pi^-)(K_S^0 \to \pi^+\pi^-)$

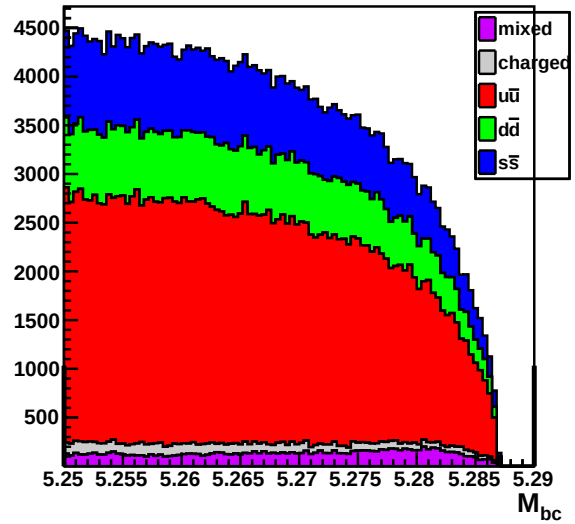
Sample	# Ev (M)	Skim (M)	ϵ_{skim}	pre-sel	sel	ϵ_{sel}
$u\bar{u}$	321	2.33	$0.72 \cdot 10^{-2}$	153401	83	$0.26 \cdot 10^{-6}$
$d\bar{d}$	80.2	.617	$0.77 \cdot 10^{-2}$	41965	31	$0.39 \cdot 10^{-6}$
$s\bar{s}$	76.6	.807	$1.05 \cdot 10^{-2}$	60287	27	$0.35 \cdot 10^{-6}$
$c\bar{c}$	266	3.85	$1.45 \cdot 10^{-2}$	378406	240	$0.90 \cdot 10^{-6}$
$B^0\overline{B}^0$	111	.123	$0.11 \cdot 10^{-2}$	8795	17	$0.15 \cdot 10^{-6}$
B^+B^-	106	.130	$0.12 \cdot 10^{-2}$	9368	2	$0.02 \cdot 10^{-6}$
total	960	2.662	$0.82 \cdot 10^{-2}$	652222	400	$0.42 \cdot 10^{-6}$

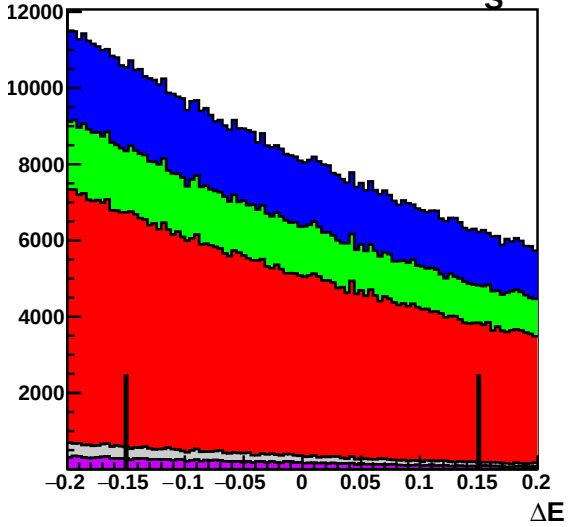
Background distributions

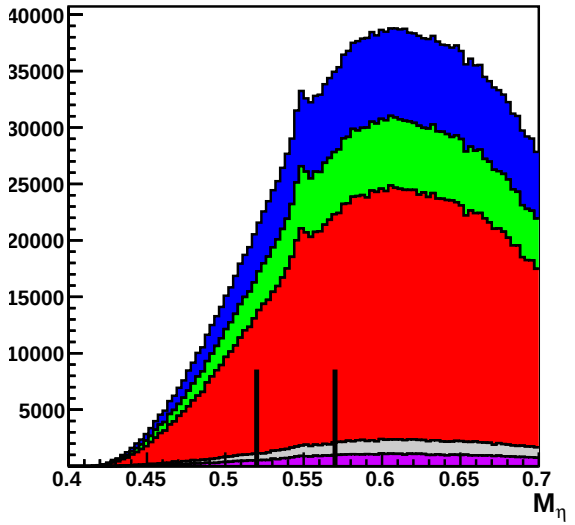


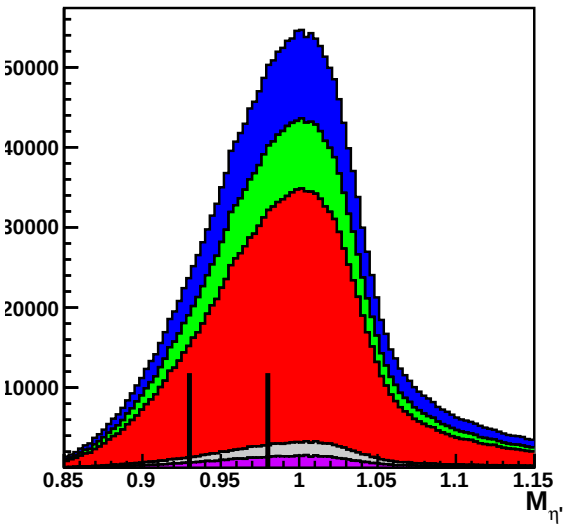
Background distributions

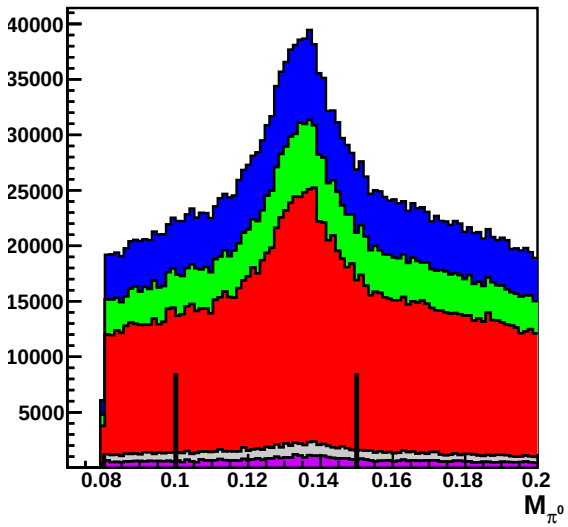
$B^0 \to \eta'(\ \eta(\pi^+\pi^-\pi^0)\ \pi^+\pi^-)\ K^0_S(\pi^+\pi^-)$

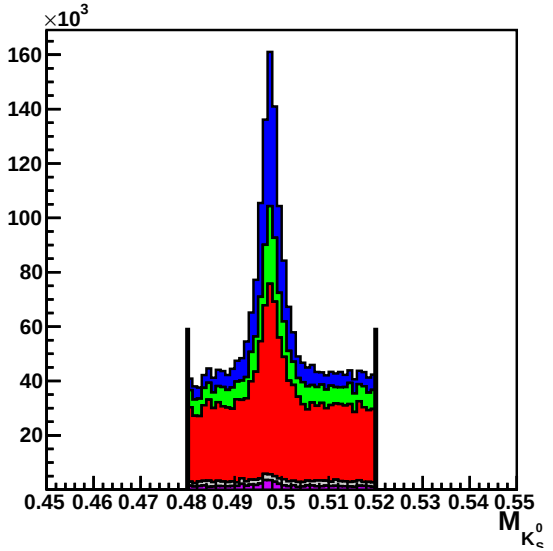








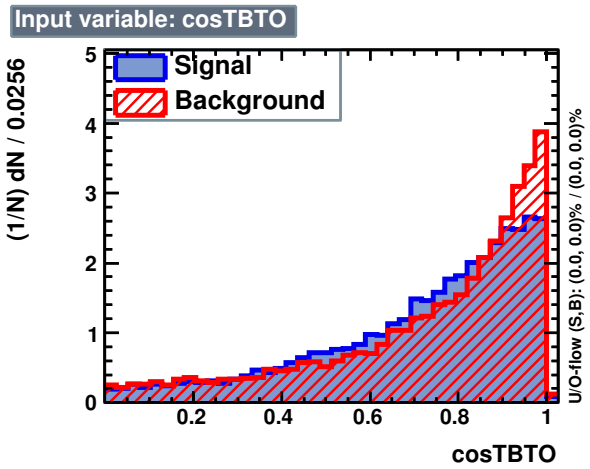


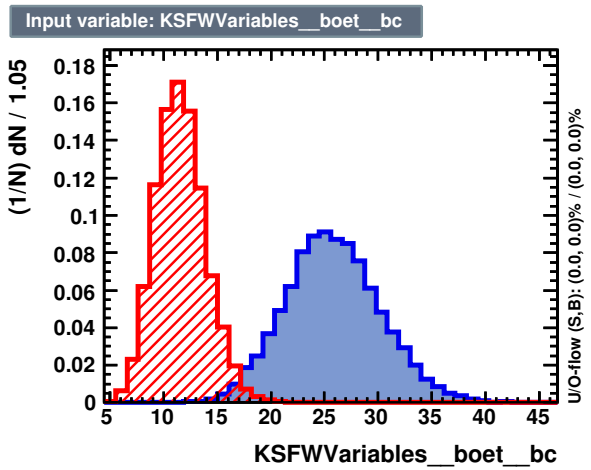


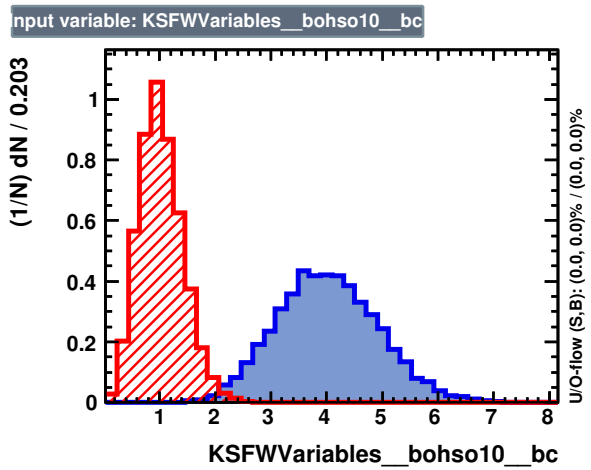
Continuum suppression

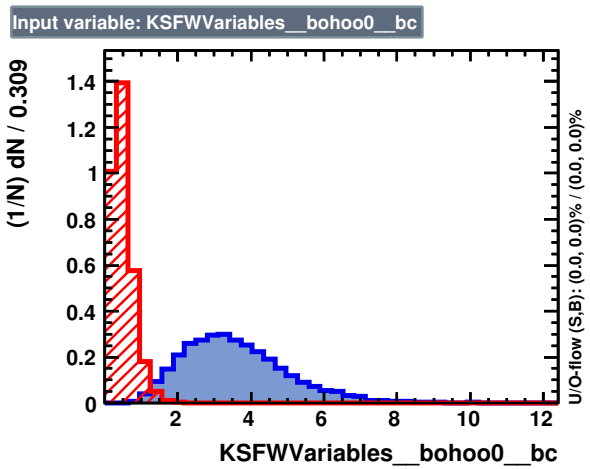
- Start playing with continuum suppression variable;
- Looked at distribution for signal and continuum for all standard 30 variables;
- Known problem with $\cos_{TBTO}$: signal is more jet-like than continuum background;
- other variables are exceptionally discriminating
  - *eg*: `KSFW(et)`, `KSFW(hso10)`, `KSFW(hoo0)`
  - Very strong correlation among these three, both for signal and background;
- Overall discriminating power of MVA based on 30 variables is extreme!
- Tried to play with variables
  - remove the three above
  - reduce total number of variables used ($30 \rightarrow 20 \rightarrow 10$), by removing the ones with lower rank (BDT)

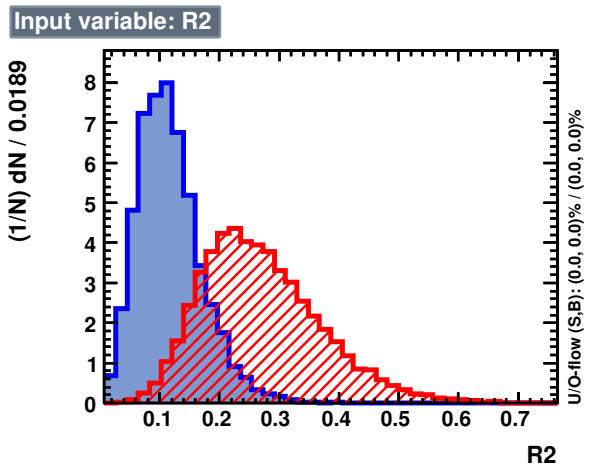
Continuum suppression

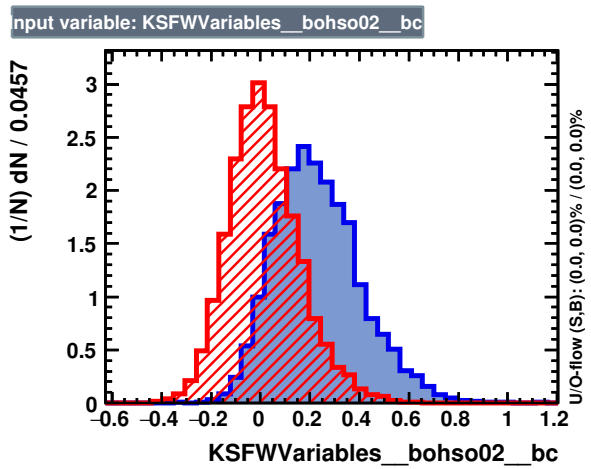








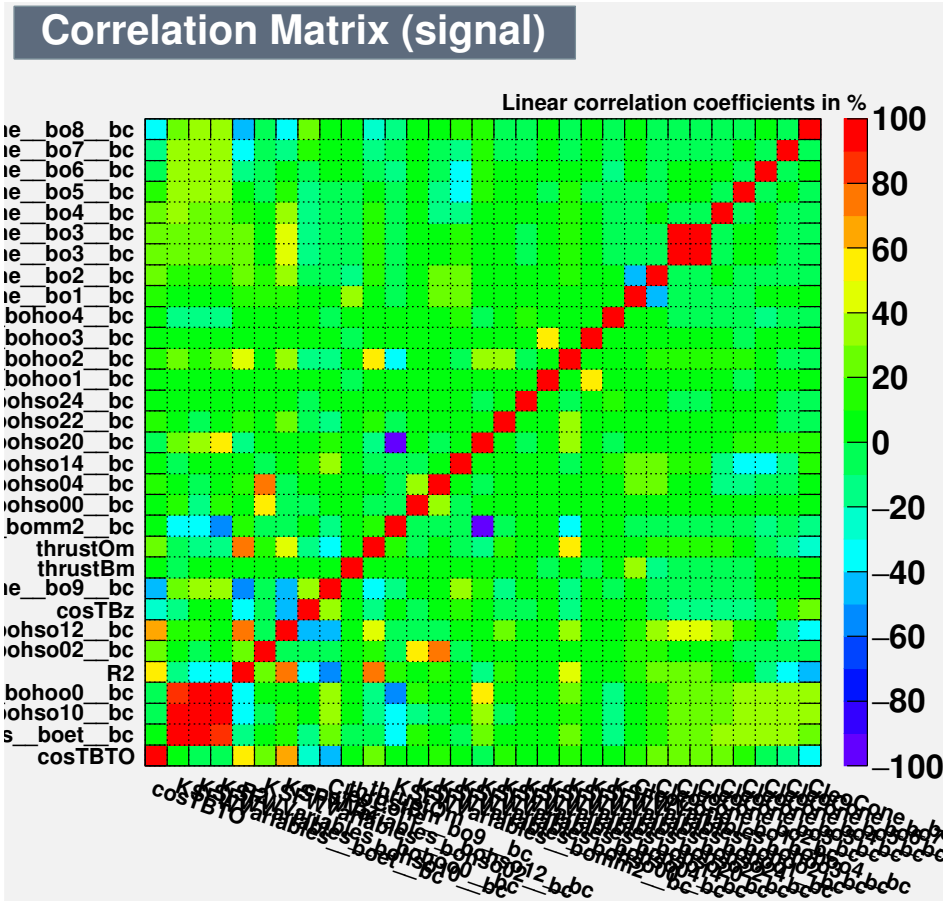




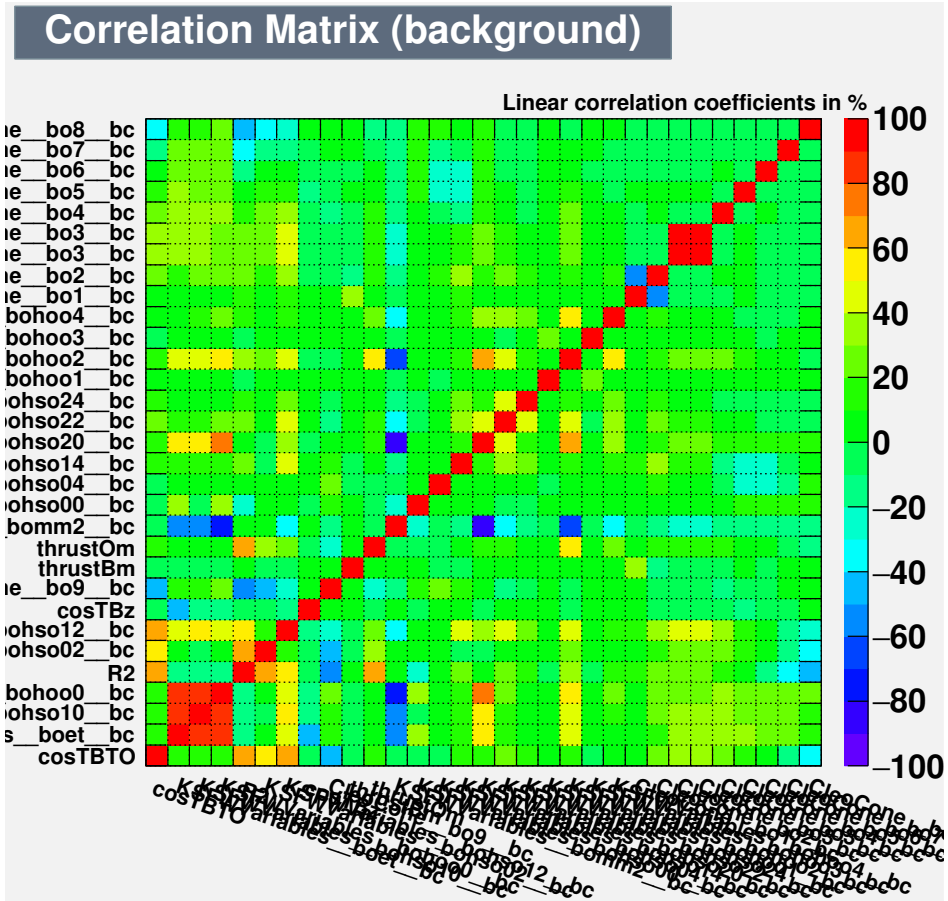
distributions for all 30 variables in backup

Correlation

Signal

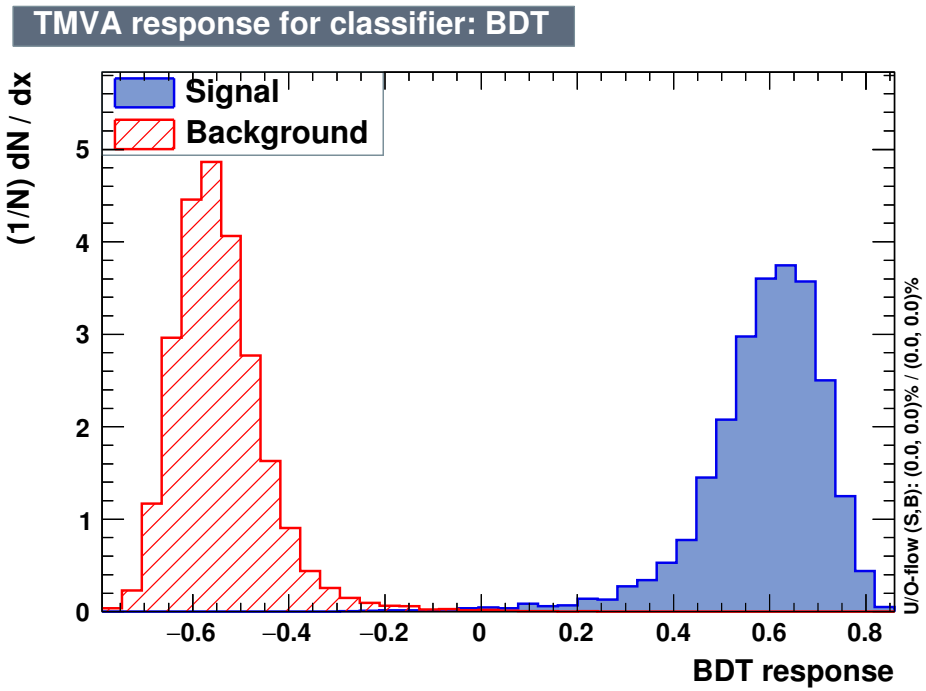


Background

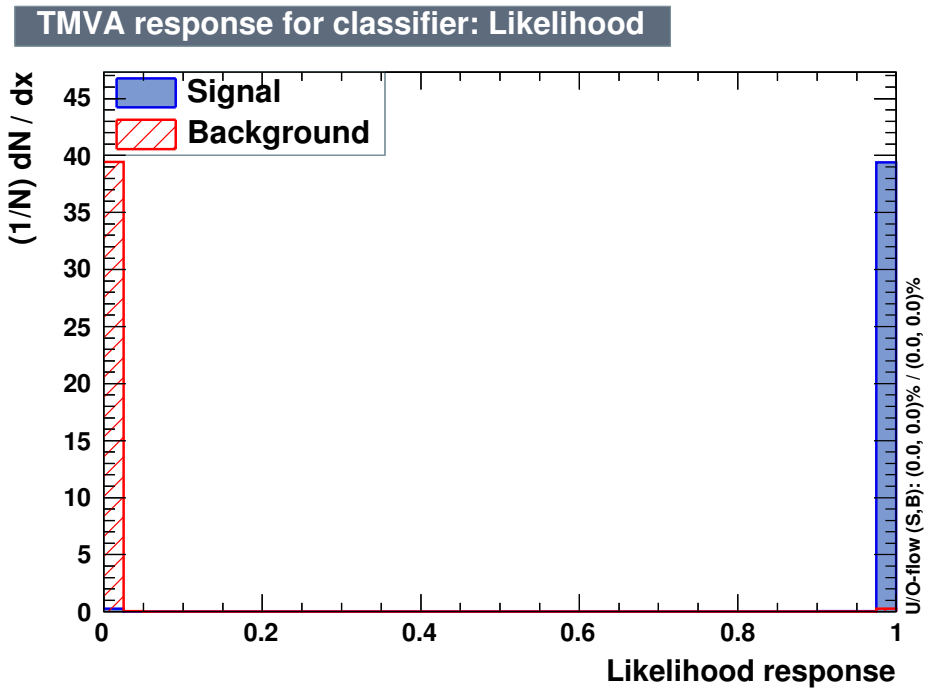


TMVA for continuum suppression

BDT



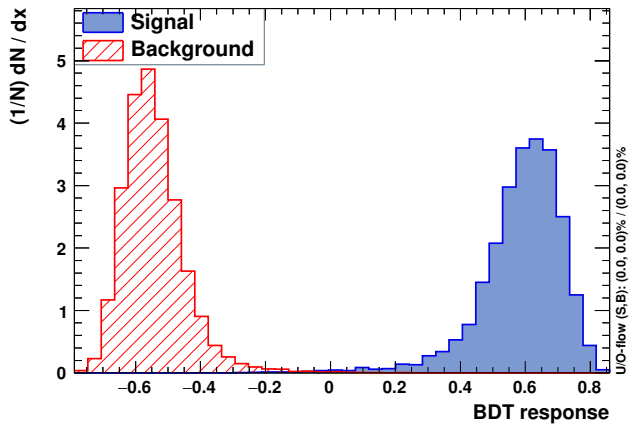
Likelihood



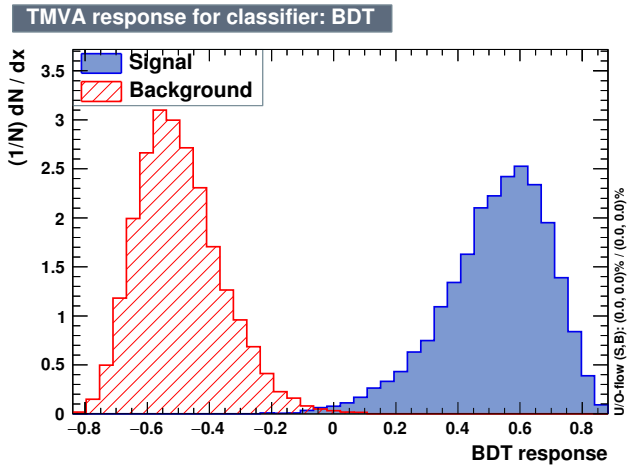
Too good to be true?

TMVA for continuum suppression (II)

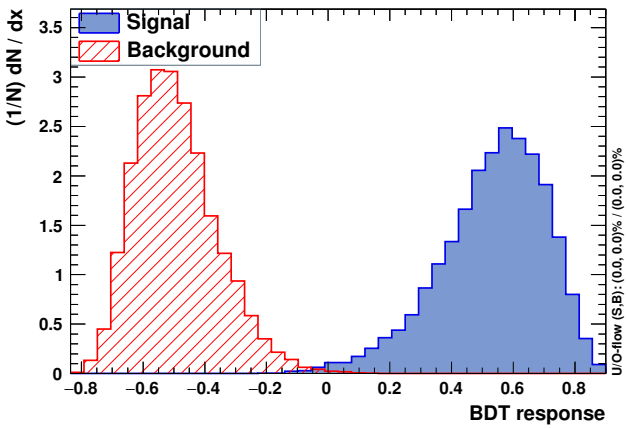
BDT (30 variables)



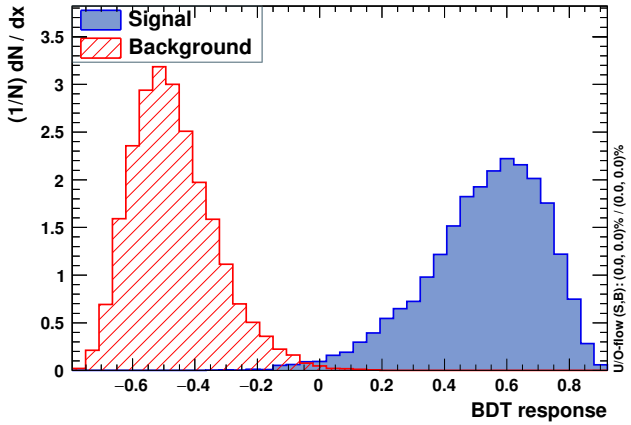
Removing KSFW(et), KSFW(hso10), KSFW(hoo0)



BDT (20 variables, by ranking)



BDT (10 variables, by ranking)

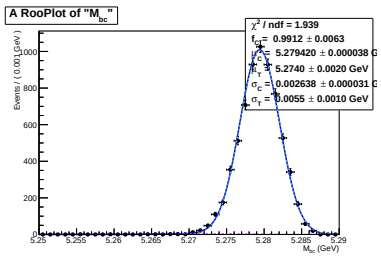


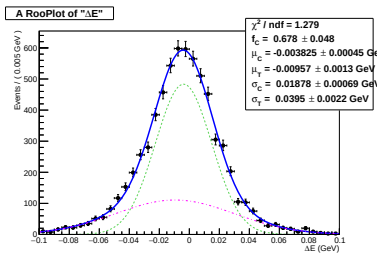
Still too good...

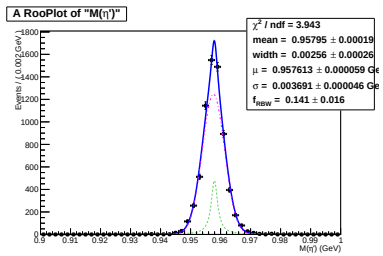
Maximum likelihood fit

- Try to work toward a multidimensional fit to extract parameter of interest (**S** and **C**)
- using package `RooRarFit` with `root6`
- reusing Alessandro work as much as possible
- Variables used in the fit:
  - (Δt)
  - ΔE
  - M_{bc}
  - $M_{\eta'}$
  - (contiuum suppression variable - not yet)
- So far, fit works w/o time-dependent part
- Trying to generate toys, but not yet there

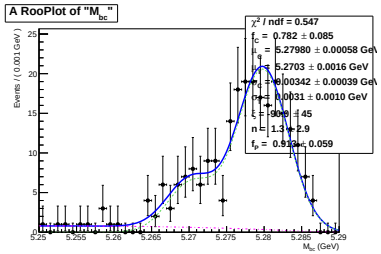
PDF fit results examples

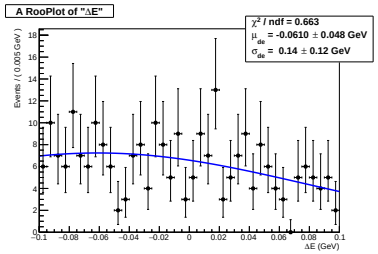


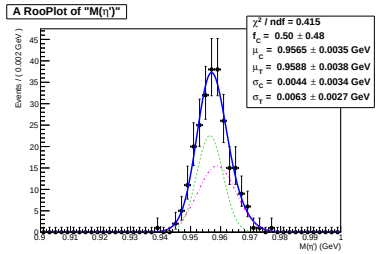




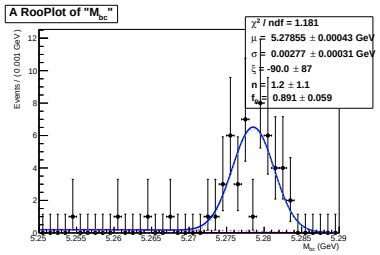
Signal

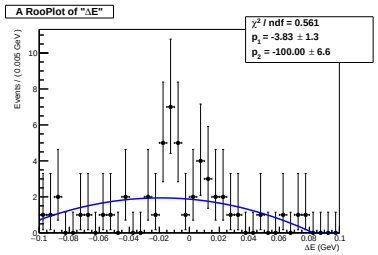


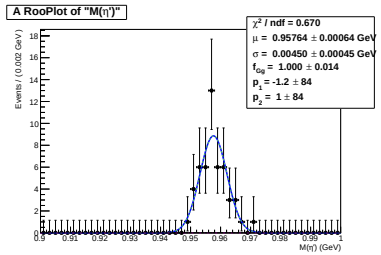




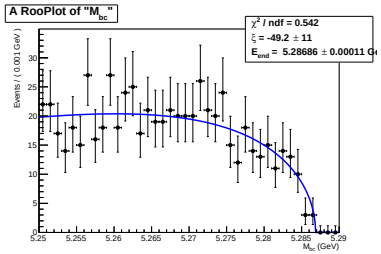
SxF

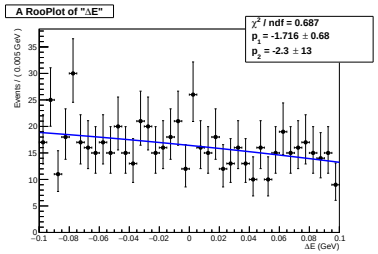


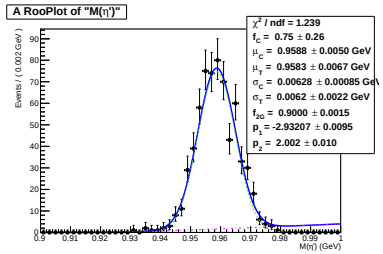




Peaking bkgnd







Continuum bkgnd

ΔE M_{bc} $M_{\eta'}$

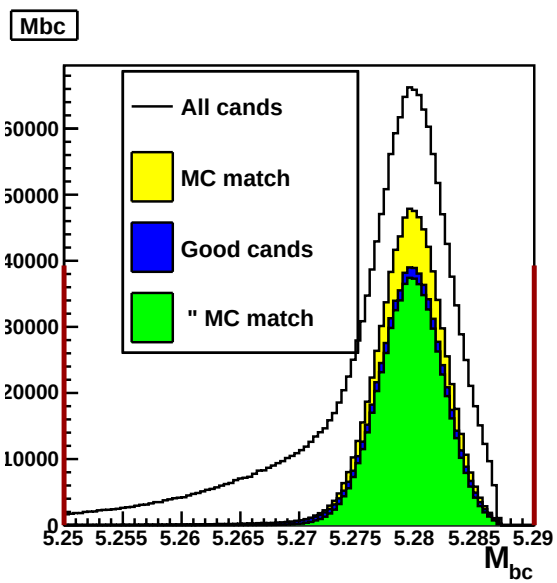
Summary

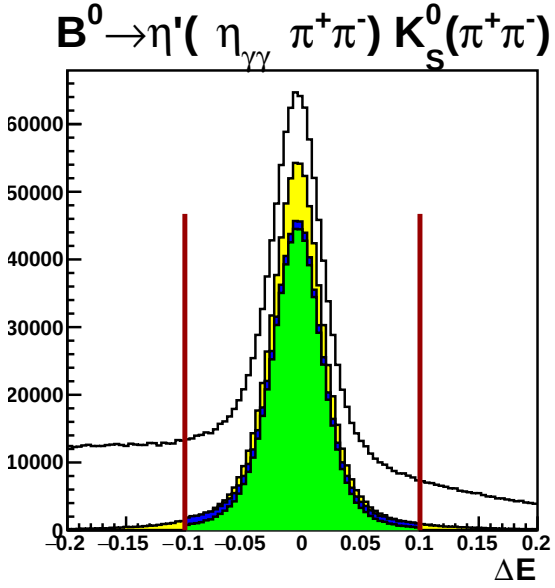
- Some progress since previous presentation;
  - not as much as I'd have liked;
- Some of the missing pieces are in place;
  - full background, including peaking;
  - continuum suppression technically there;
  - first working multidimensional fit;
- **TODO:**
  - undesrtand/fix for continuum suppression;
  - Work on fit
    - ★ time dependent part, toys, stability, ...
  - redo for $K^0_S \to \pi^0\pi^0$
- Still on track for B2TIP
- help is welcome!

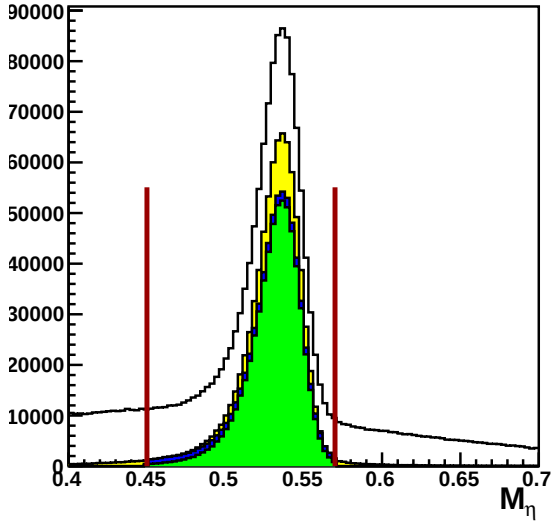
Additional stuff

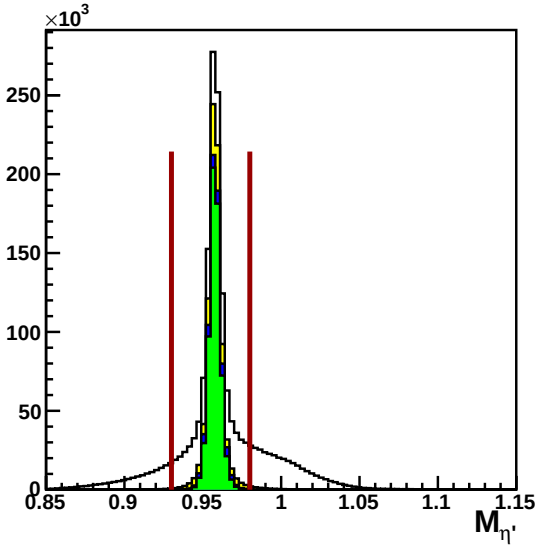
Additional or backup slides

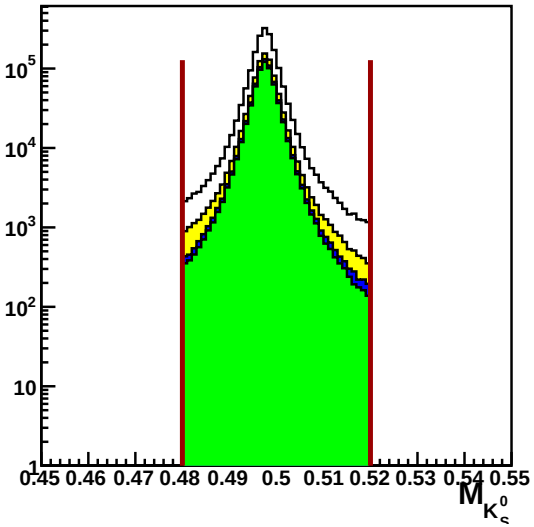
Good candidates distributions

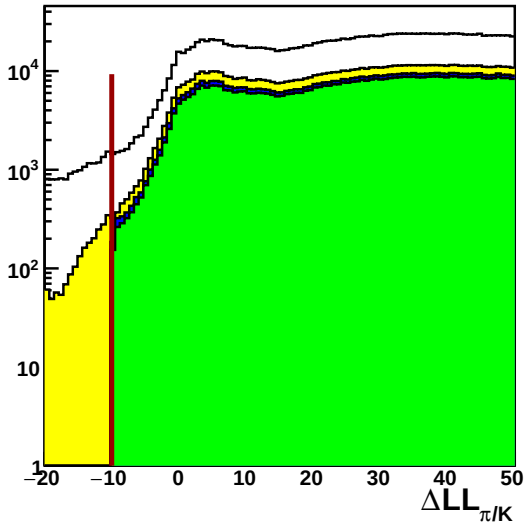




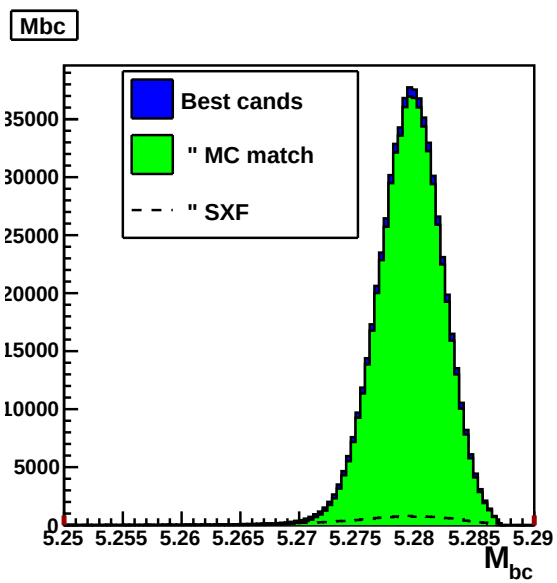


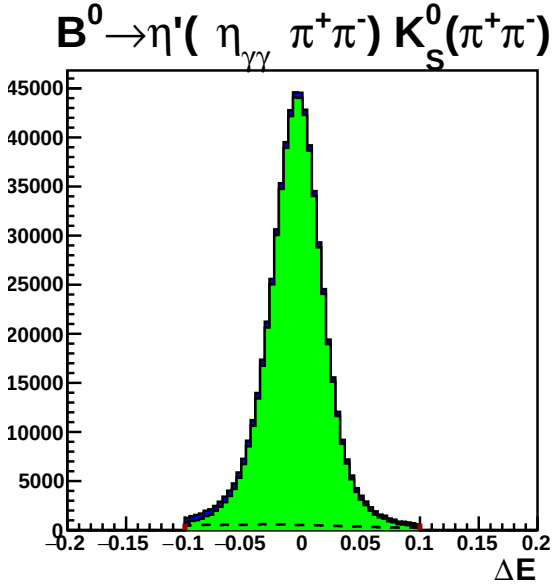


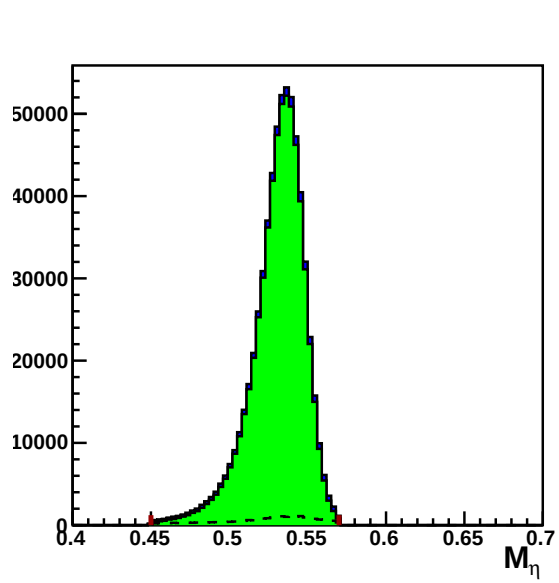


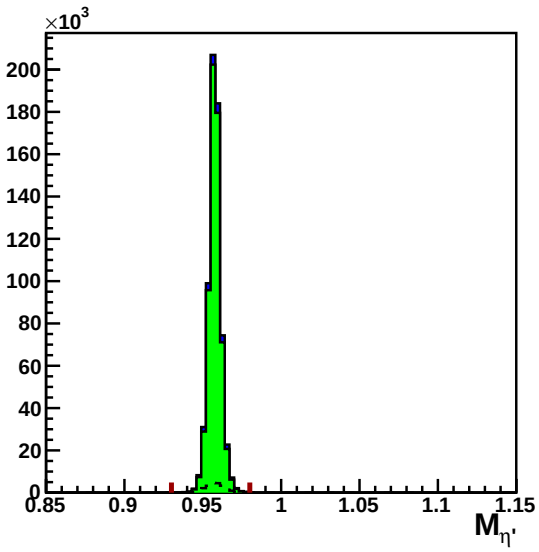


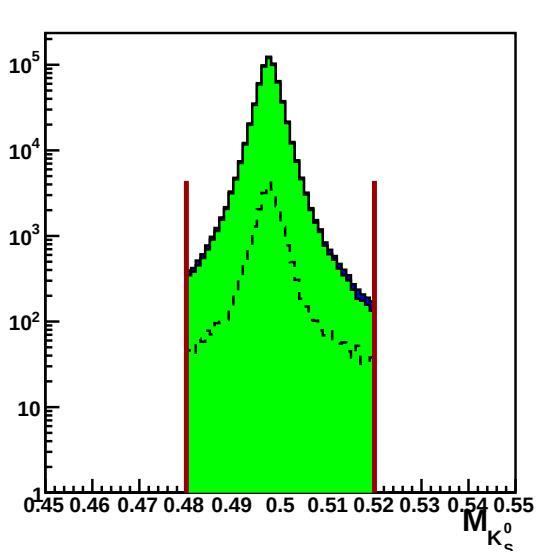
Best candidate distributions

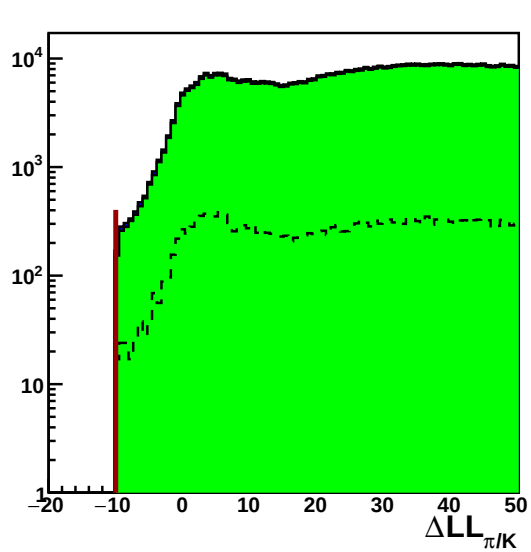




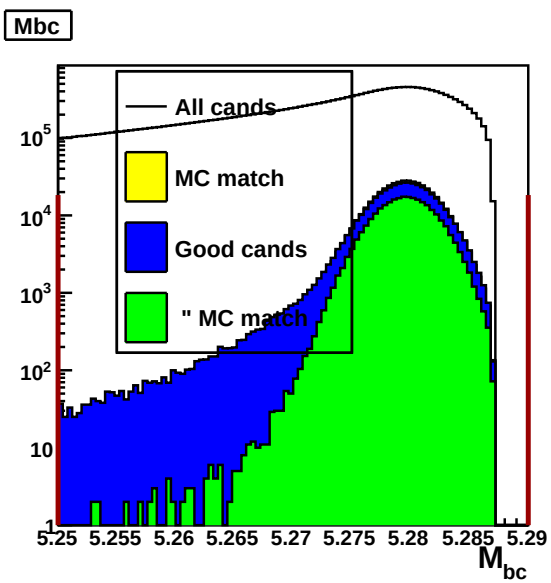


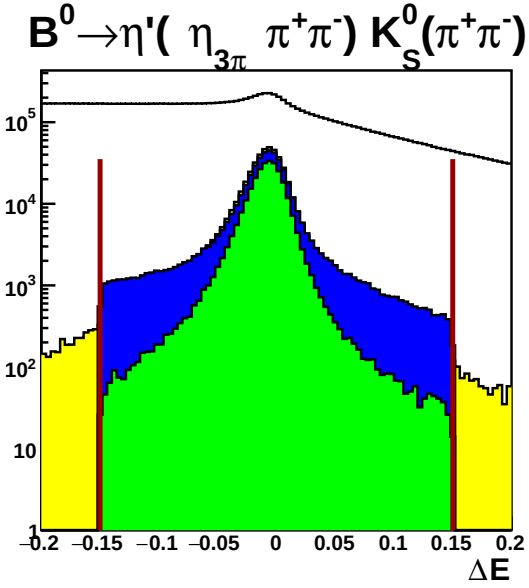


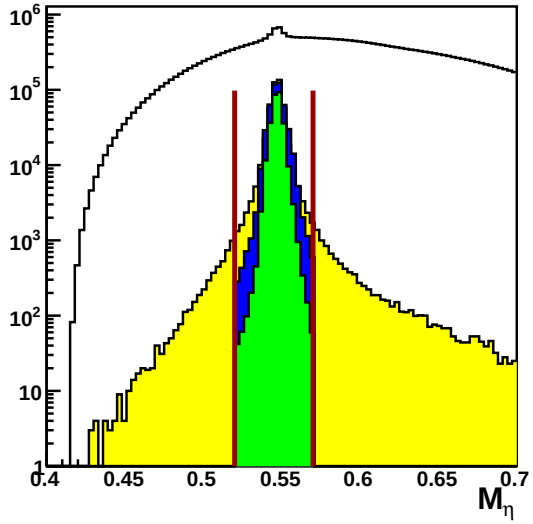


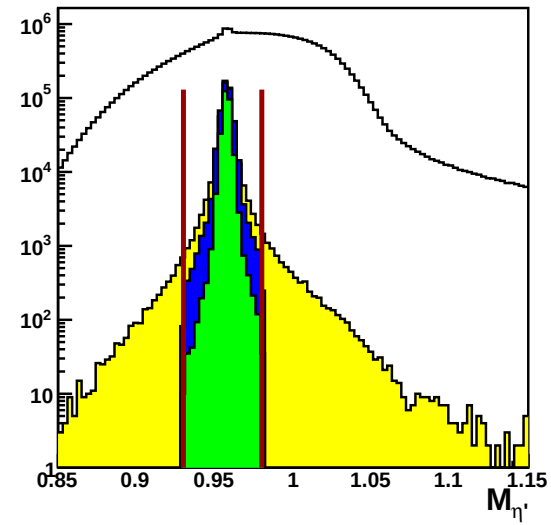


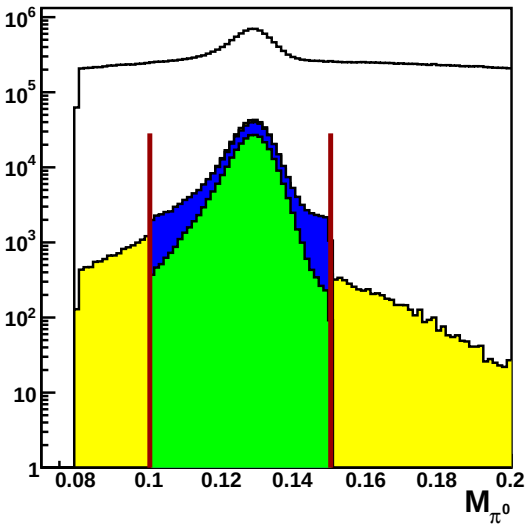
Good candidates distributions

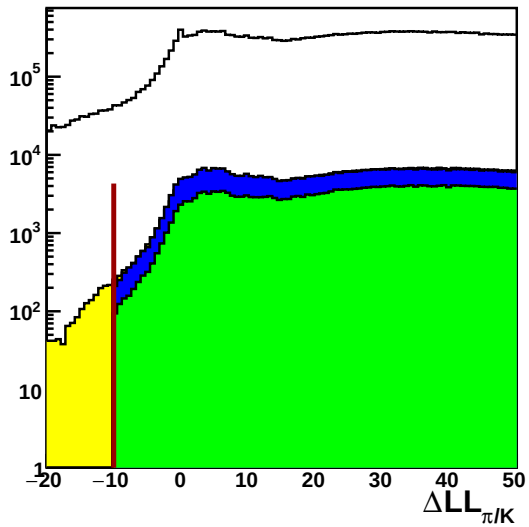




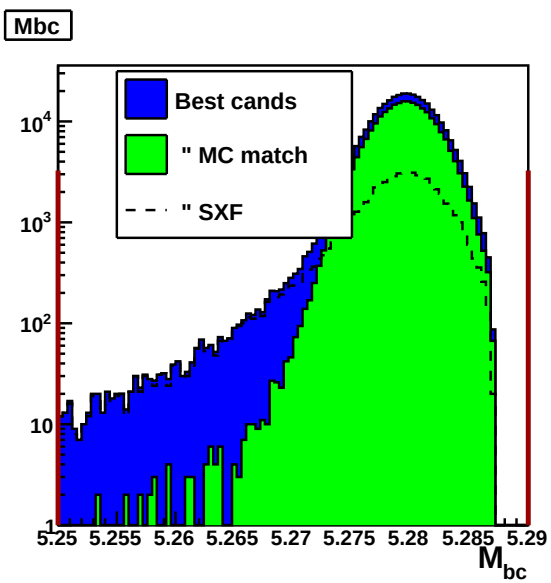


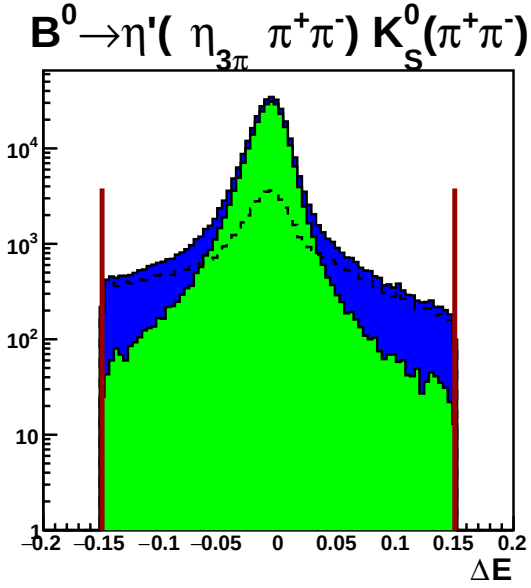


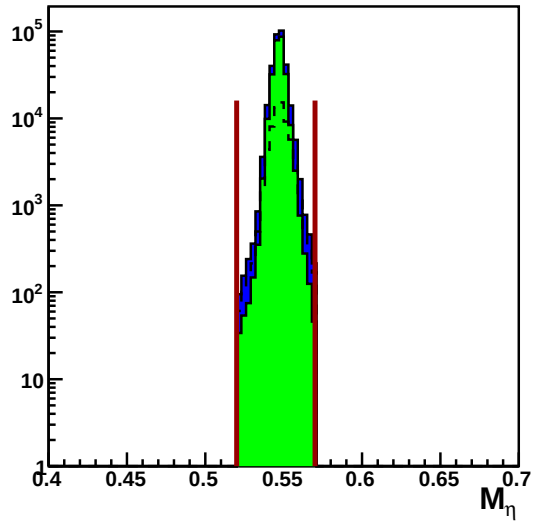


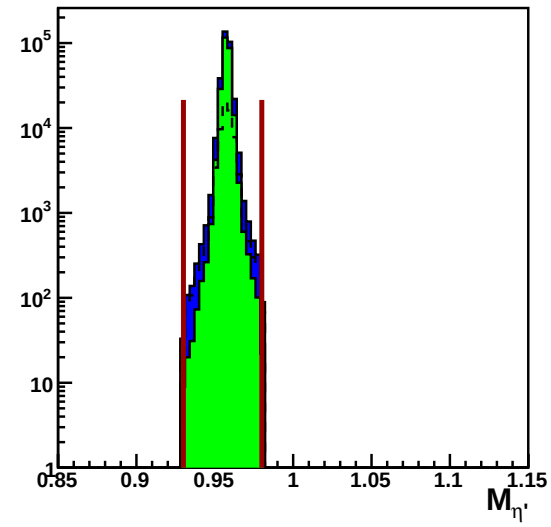


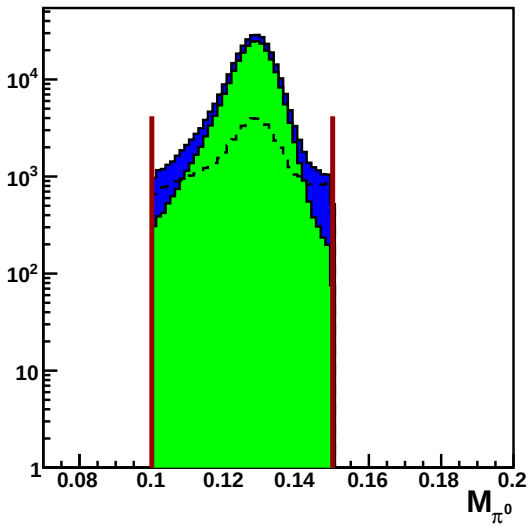
Best candidate distributions

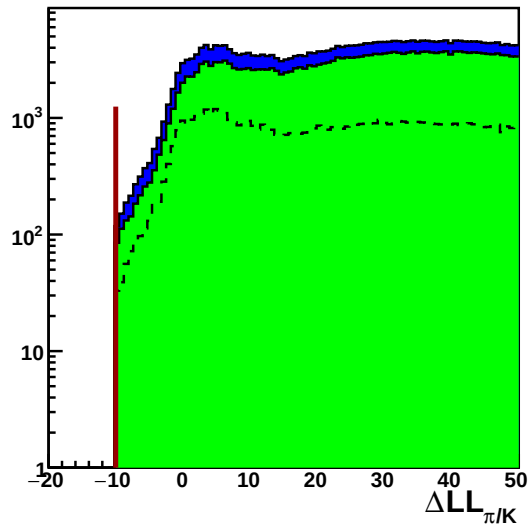




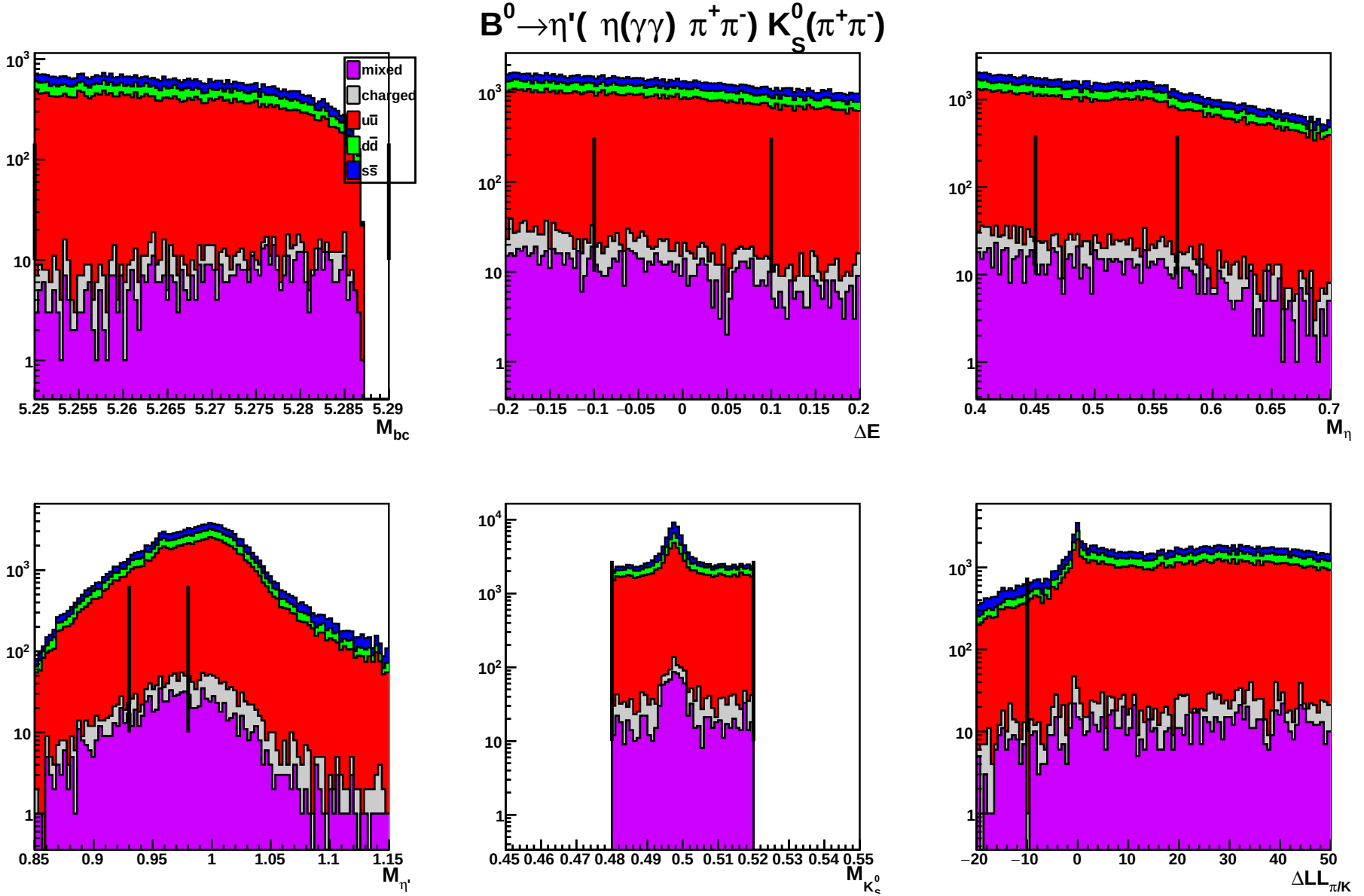




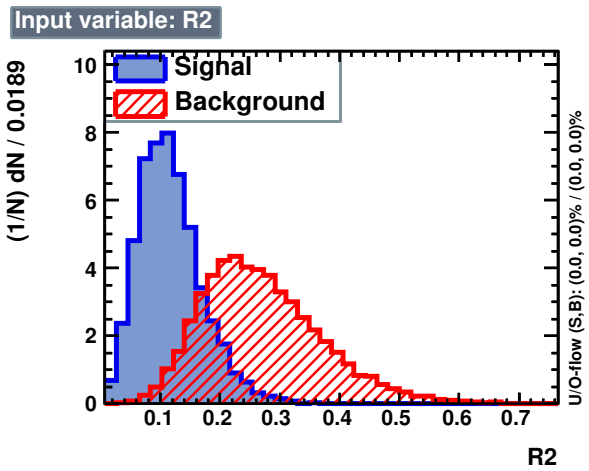


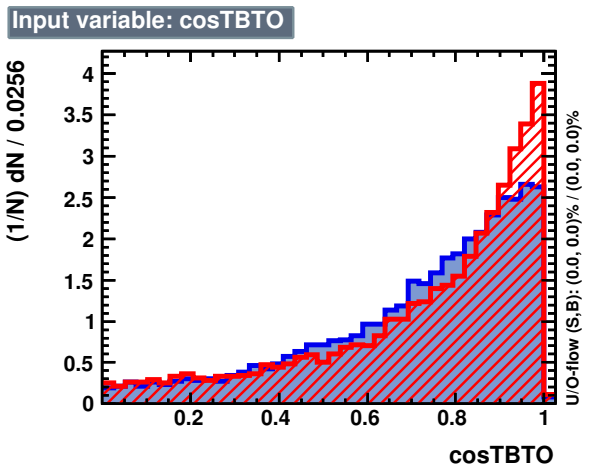


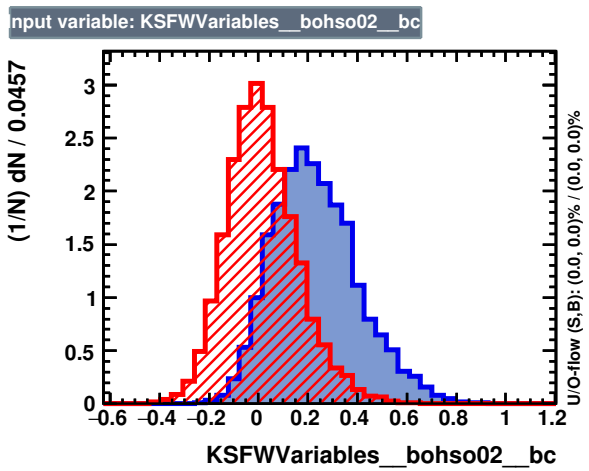
Background distributions

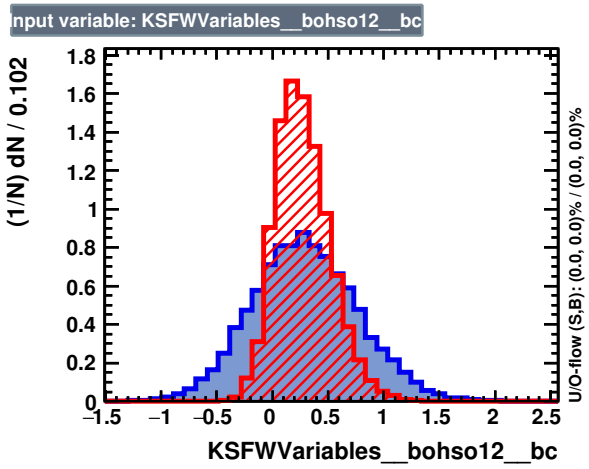


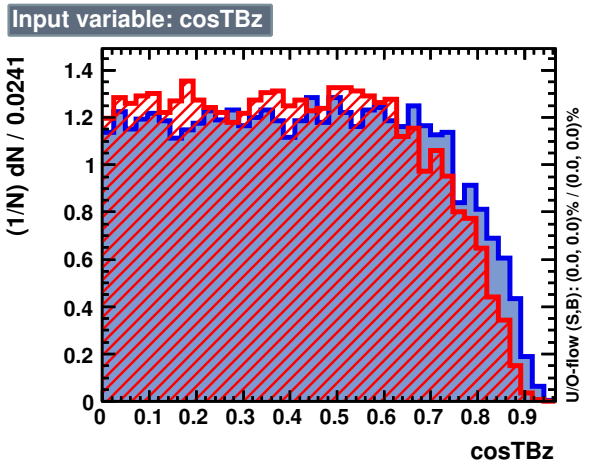
Continuum suppression

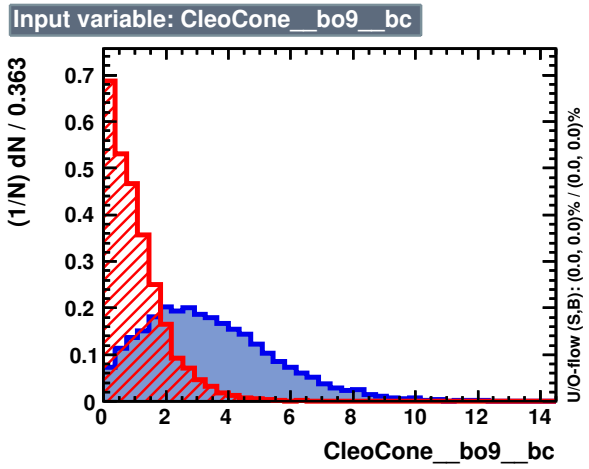












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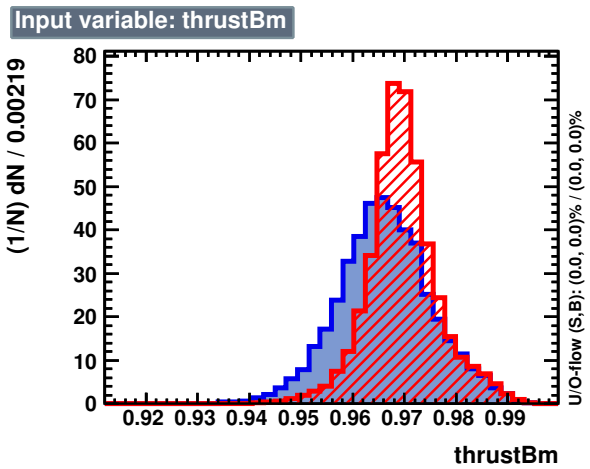
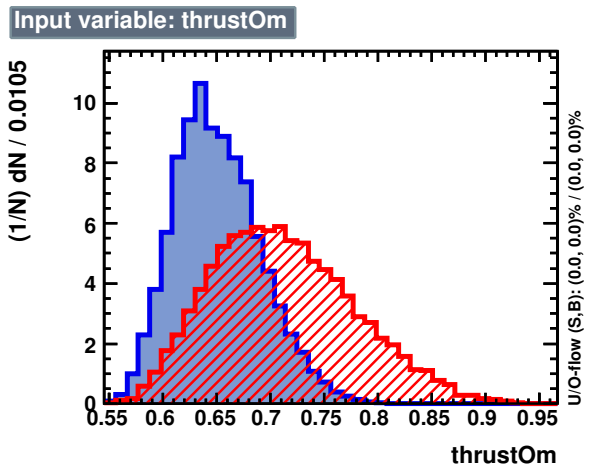
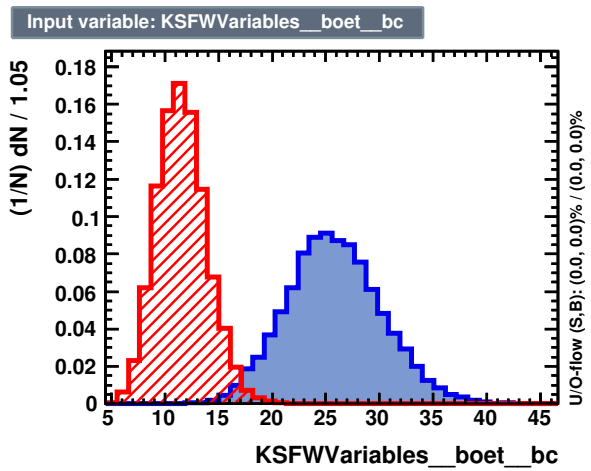
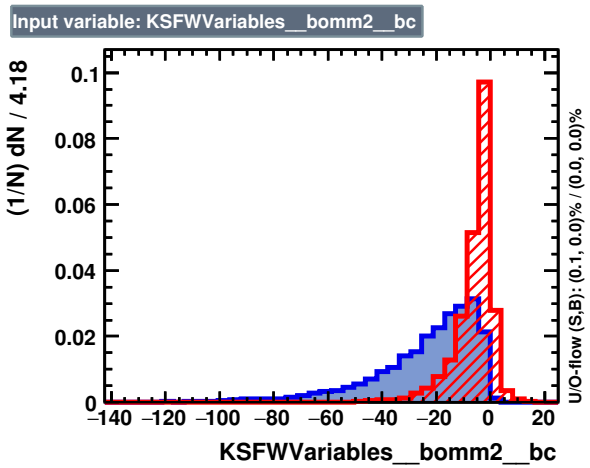
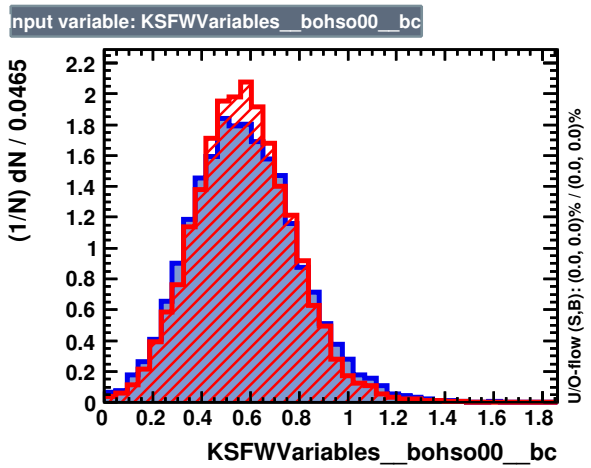
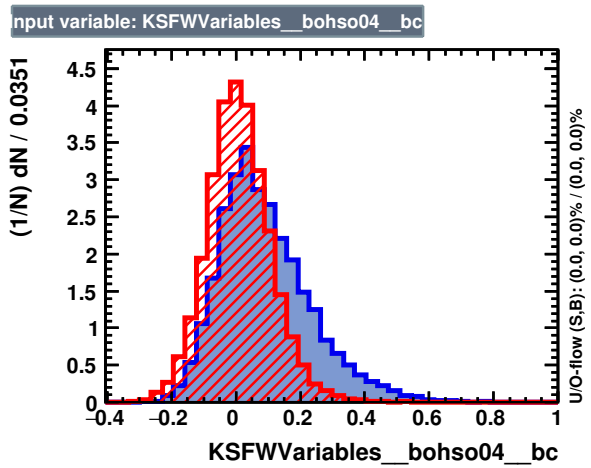




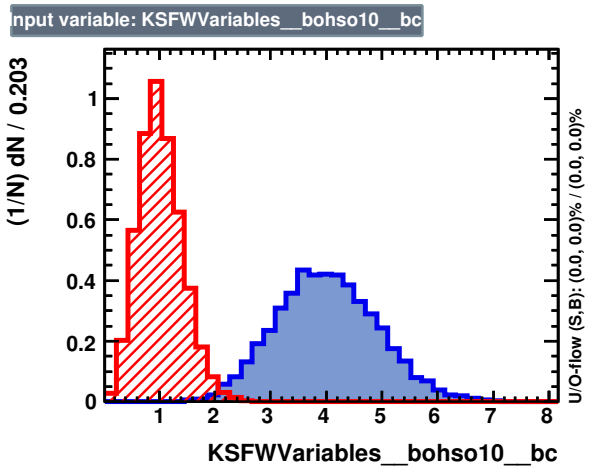


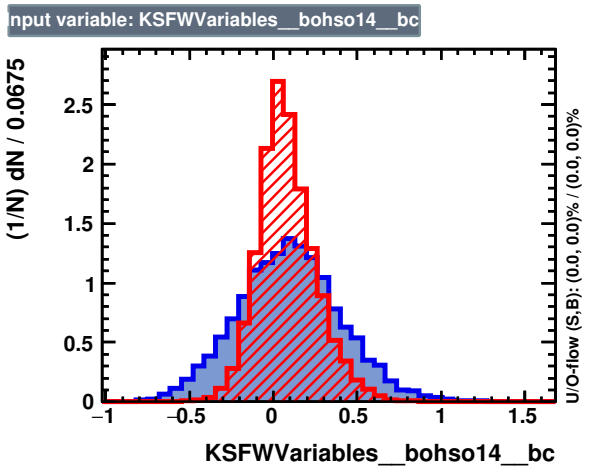


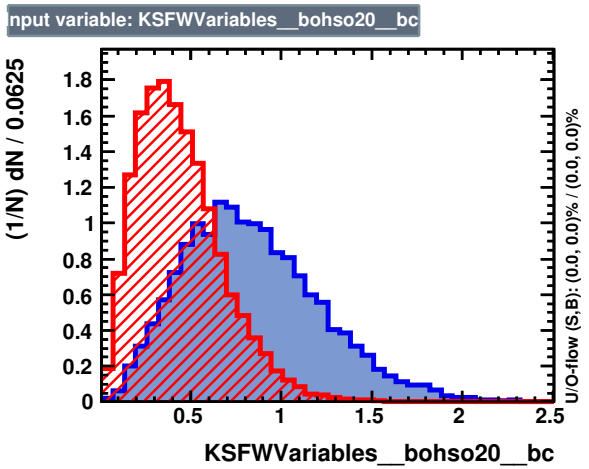


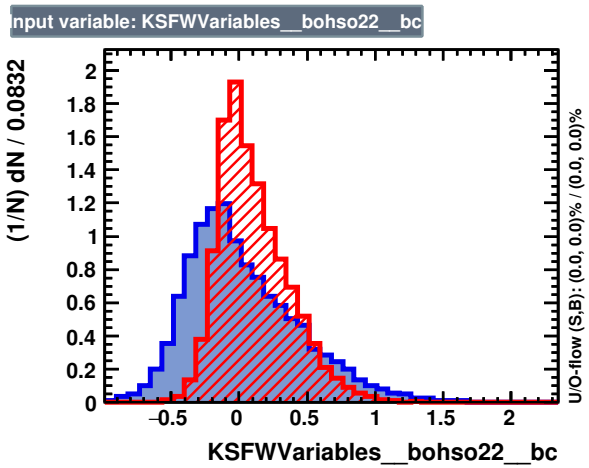


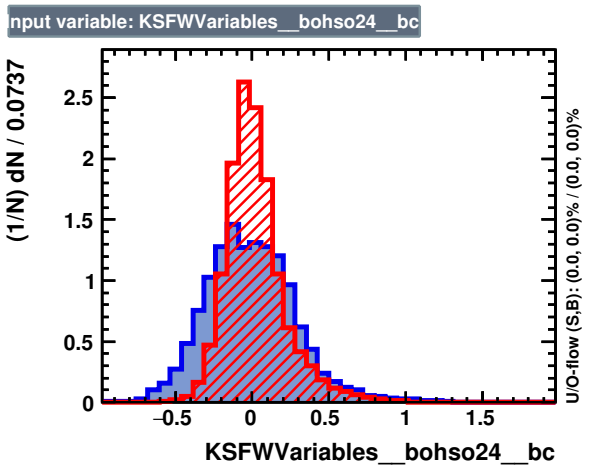
Continuum suppression

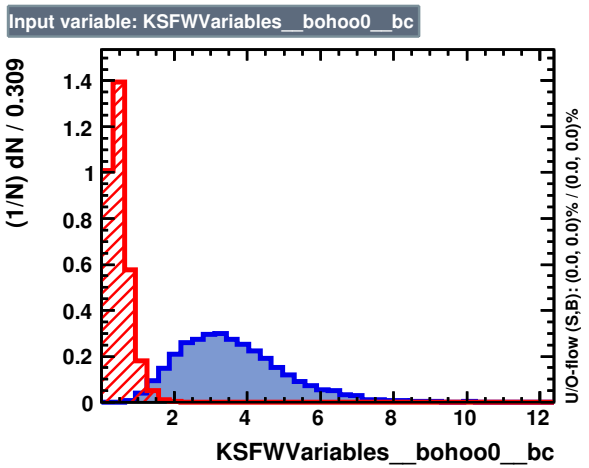




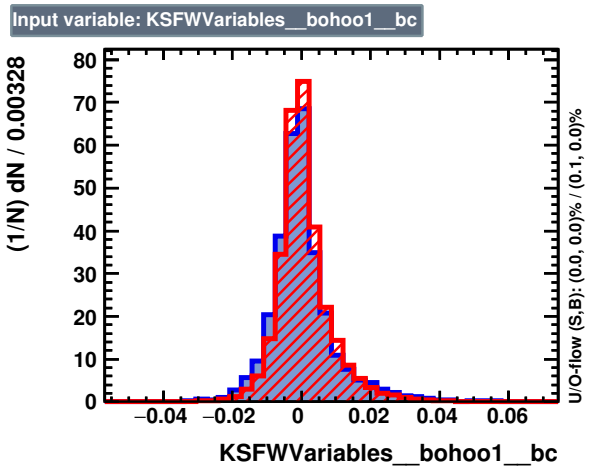


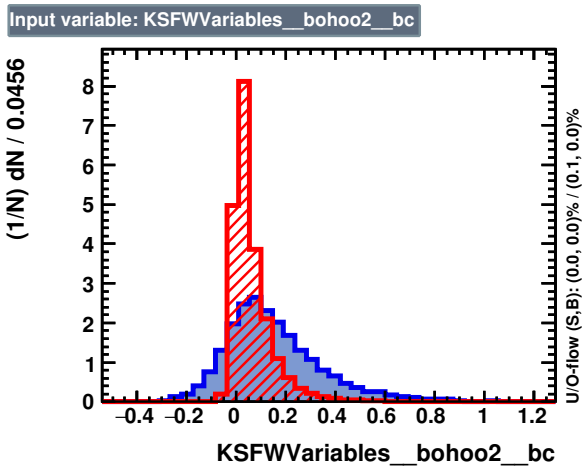


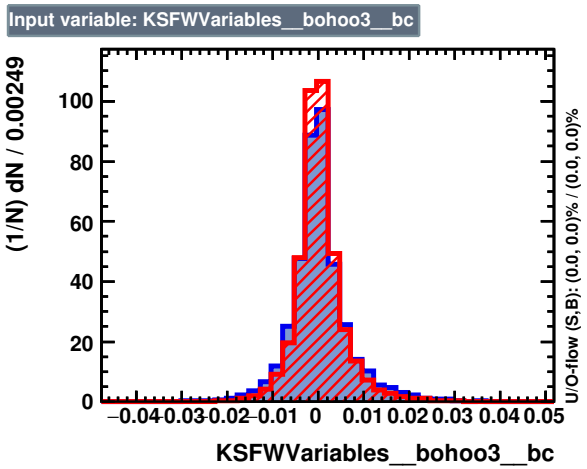


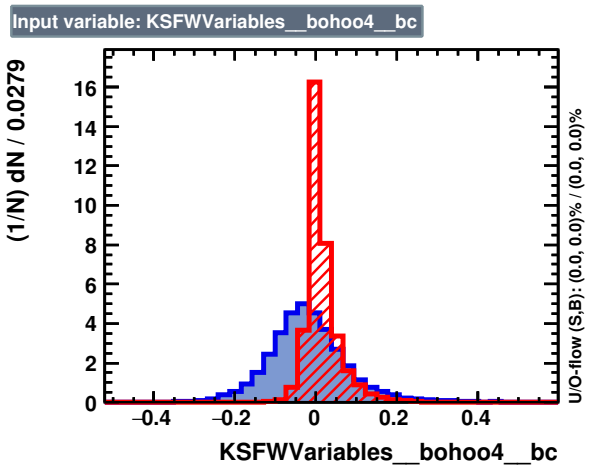


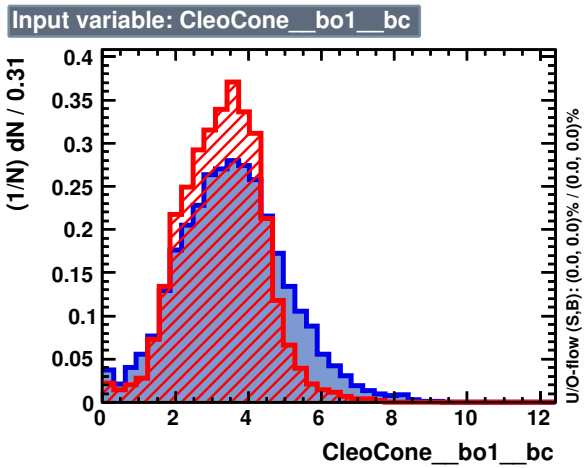
Continuum suppression

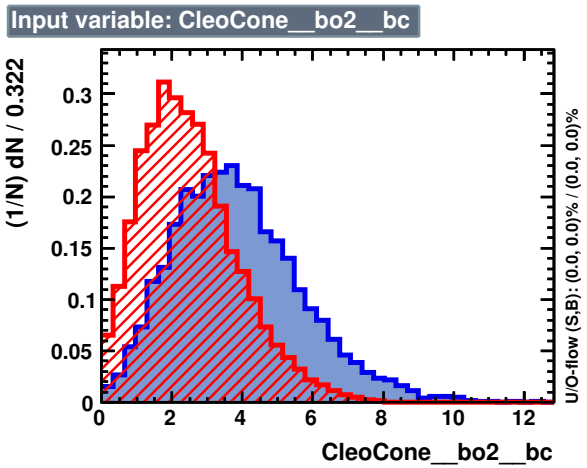




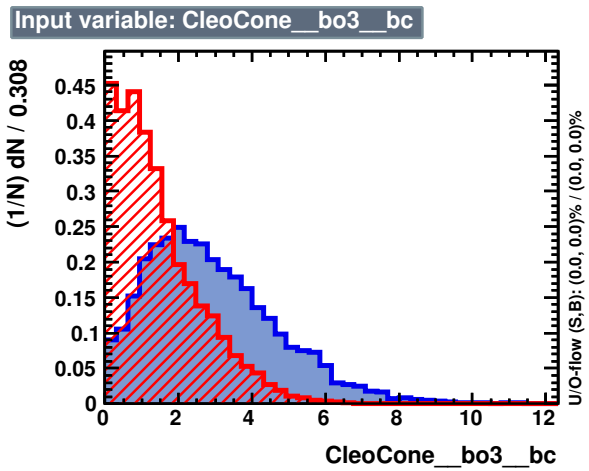


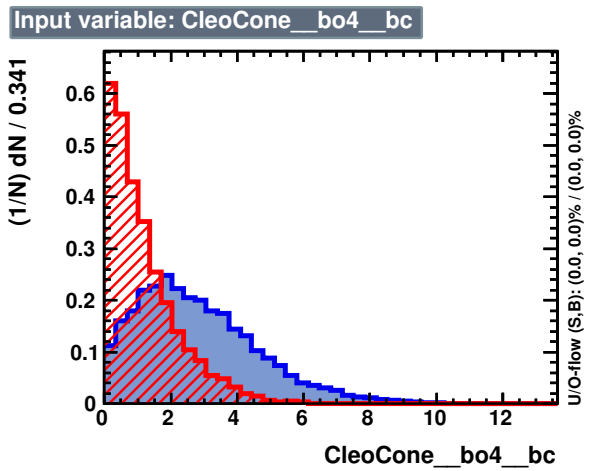


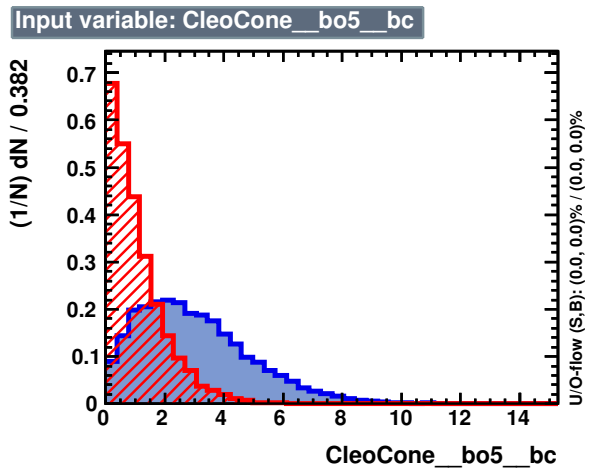


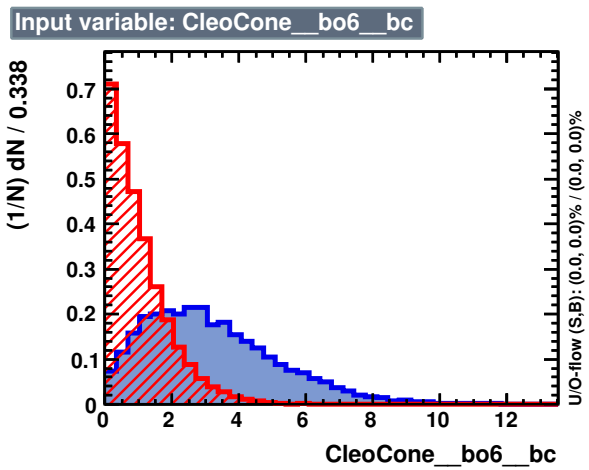


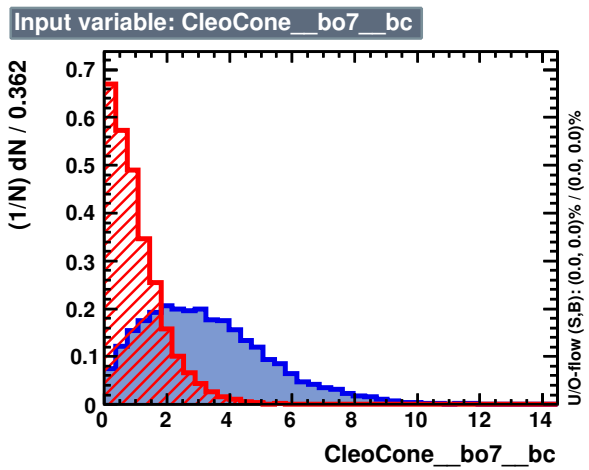
Continuum suppression

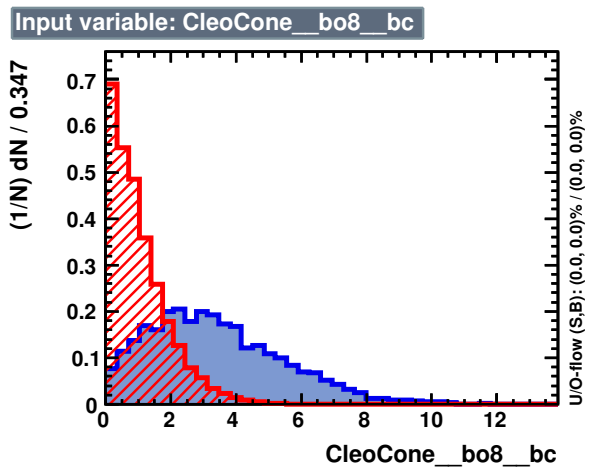








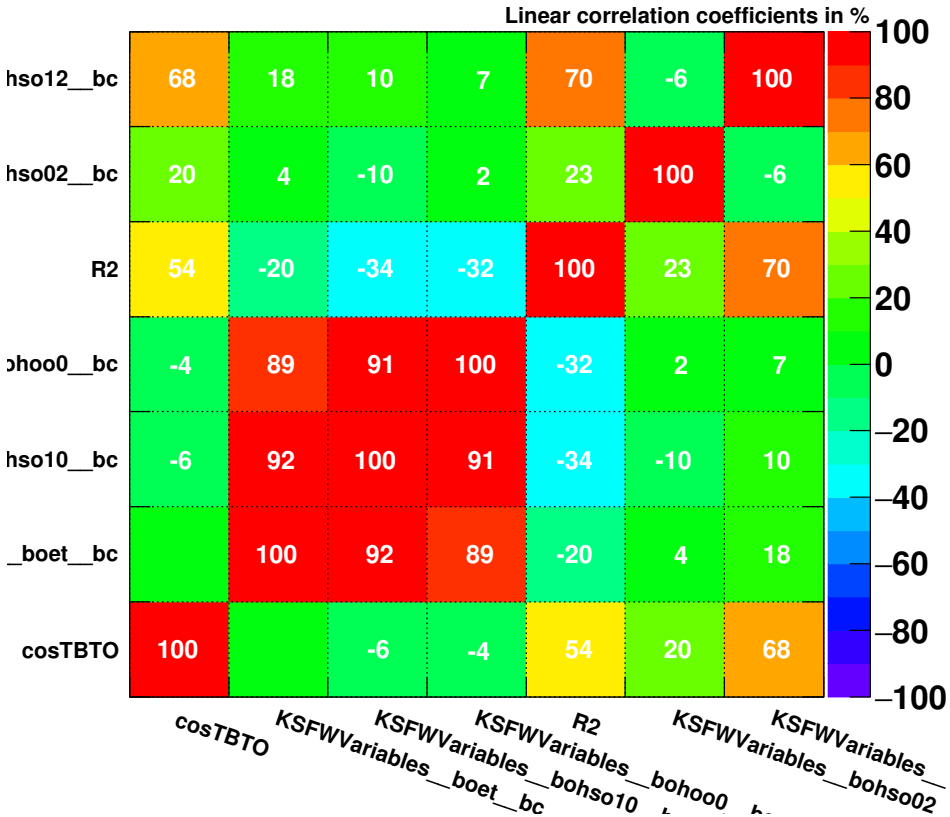




Correlation

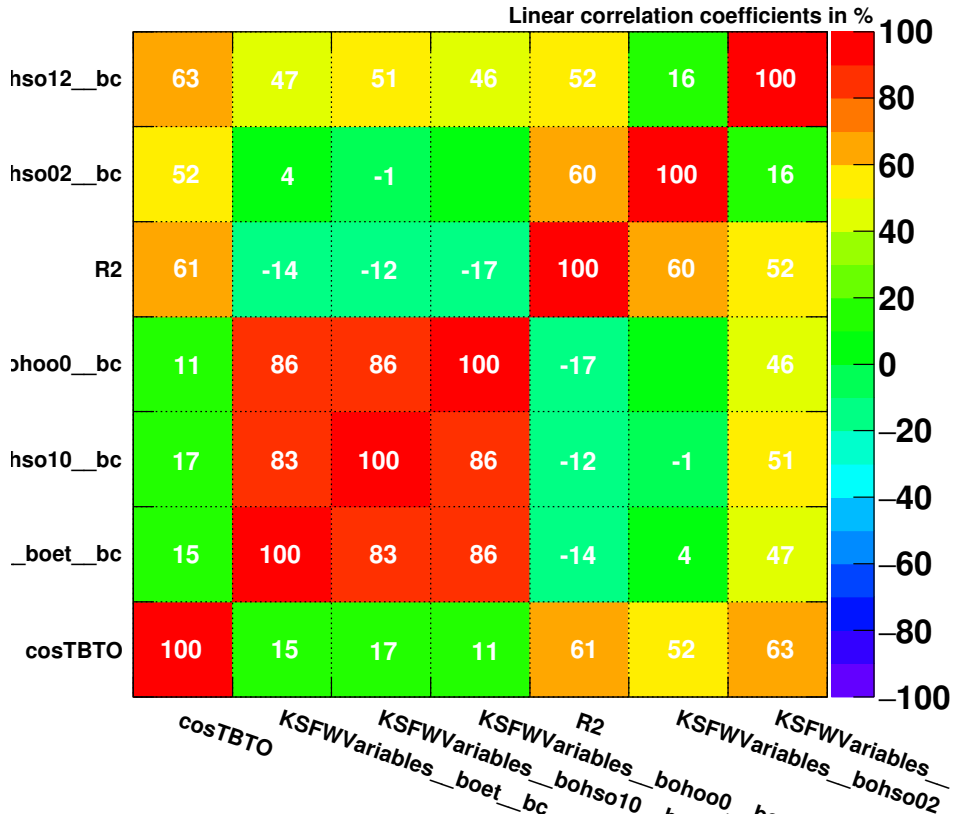
Signal

Correlation Matrix (signal)

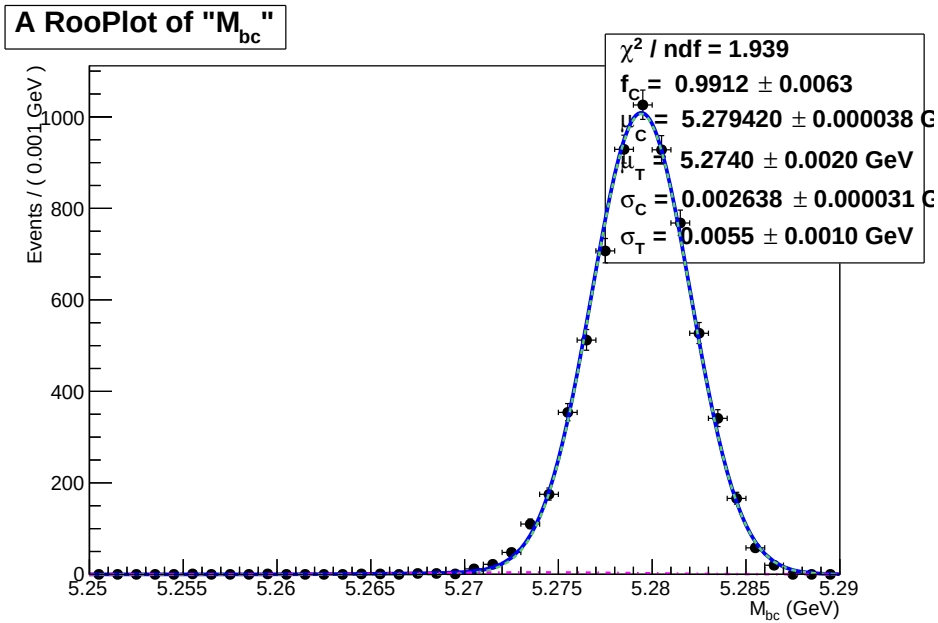


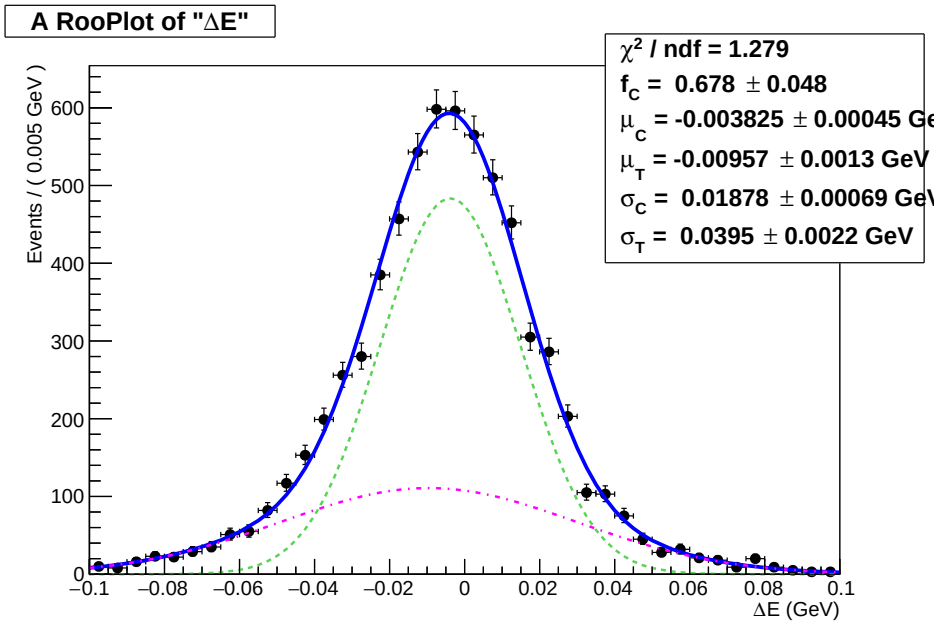
Background

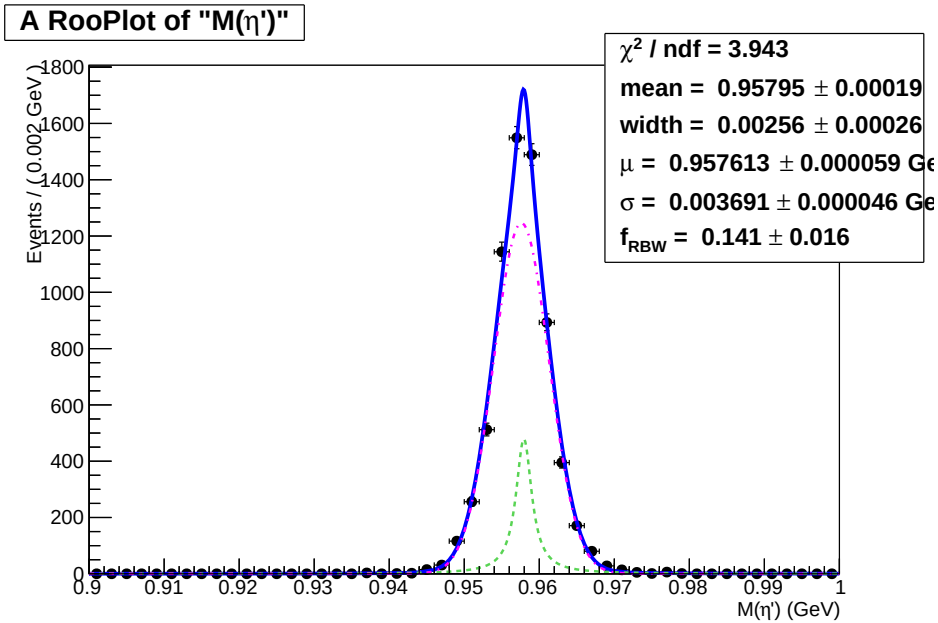
Correlation Matrix (background)



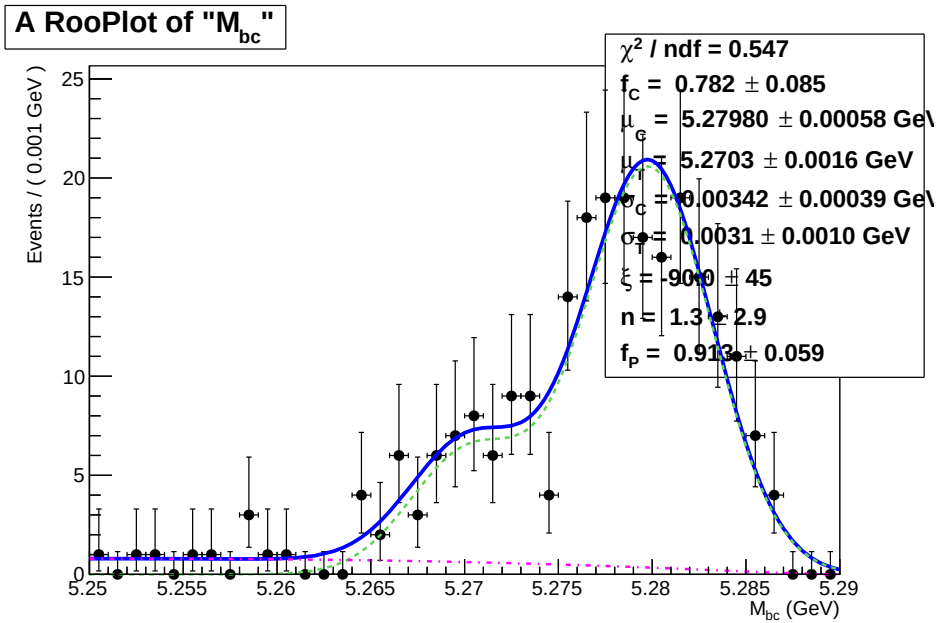
Signal PDF

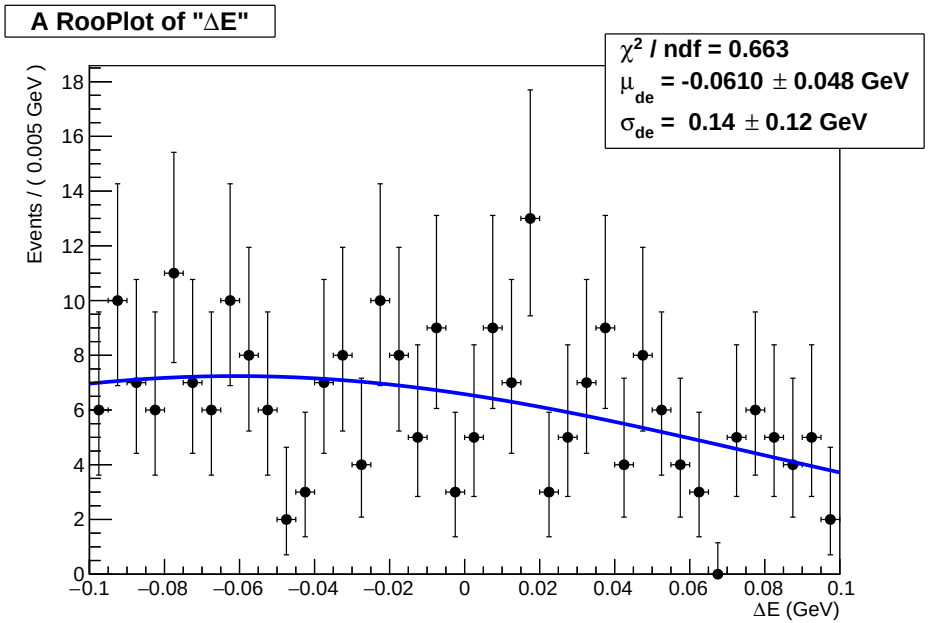

A RooPlot of "M$_{bc}$"
χ^2 / ndf = 1.939
f_C = 0.9912 ± 0.0063
μ_C = 5.279420 ± 0.000038 G
μ_T = 5.2740 ± 0.0020 GeV
σ_C = 0.002638 ± 0.000031 G
σ_T = 0.0055 ± 0.0010 GeV
Events / (0.001 GeV)
M$_{bc}$ (GeV)

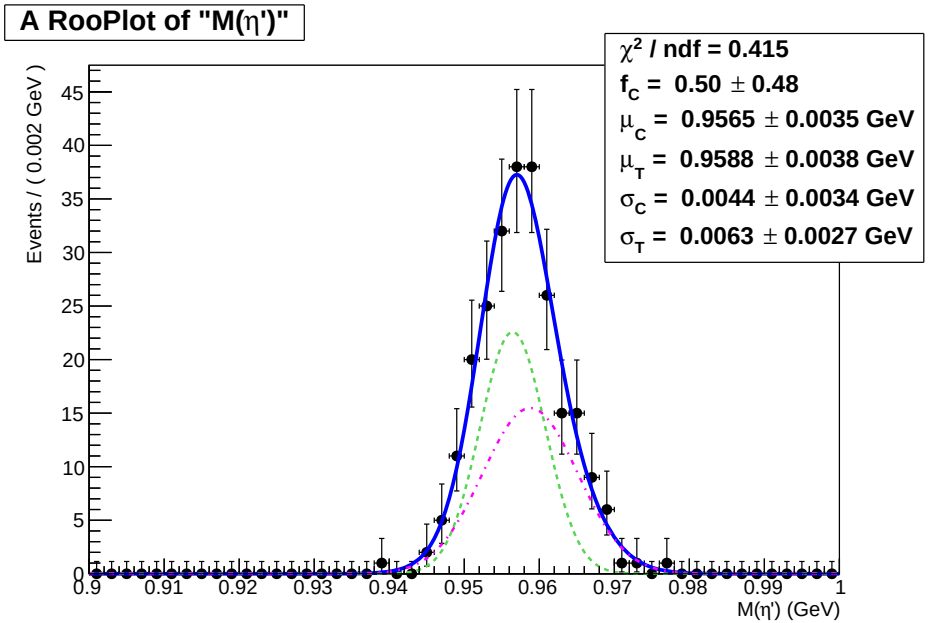

A RooPlot of "ΔE"
χ^2 / ndf = 1.279
f_C = 0.678 ± 0.048
μ_C = -0.003825 ± 0.00045 Ge
μ_T = -0.00957 ± 0.0013 GeV
σ_C = 0.01878 ± 0.00069 GeV
σ_T = 0.0395 ± 0.0022 GeV
Events / (0.005 GeV)
ΔE (GeV)


A RooPlot of "M(η')"
χ^2 / ndf = 3.943
mean = 0.95795 ± 0.00019
width = 0.00256 ± 0.00026
μ = 0.957613 ± 0.000059 Ge
σ = 0.003691 ± 0.000046 Ge
f_{RBW} = 0.141 ± 0.016
Events / (0.002 GeV)
M(η') (GeV)

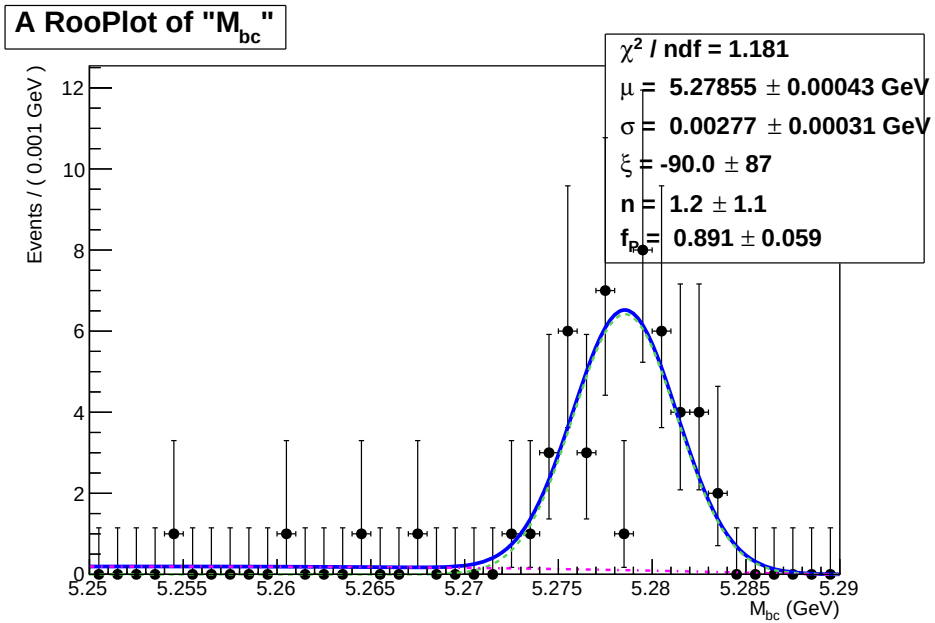
Signal cross Feed PDF

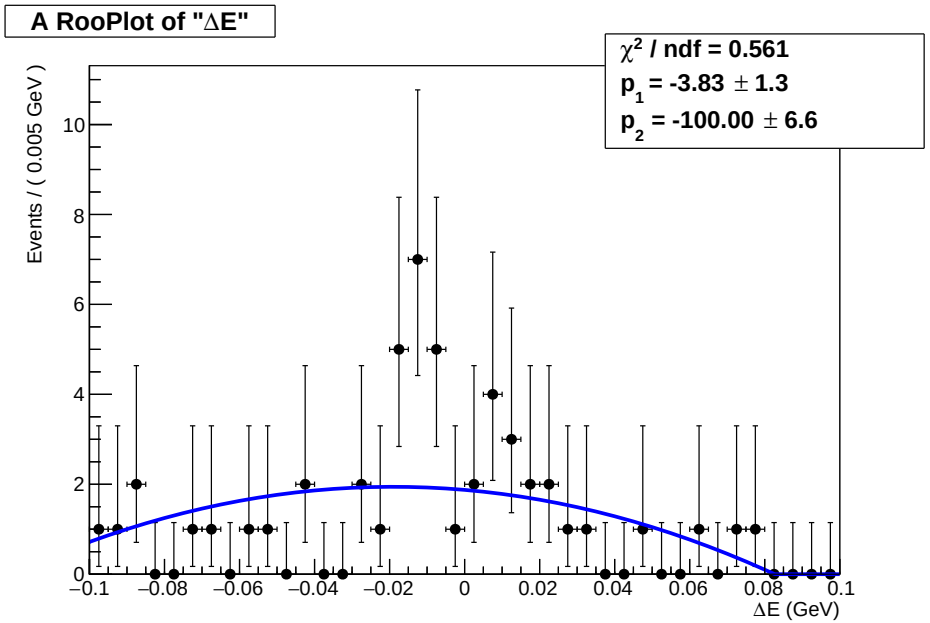


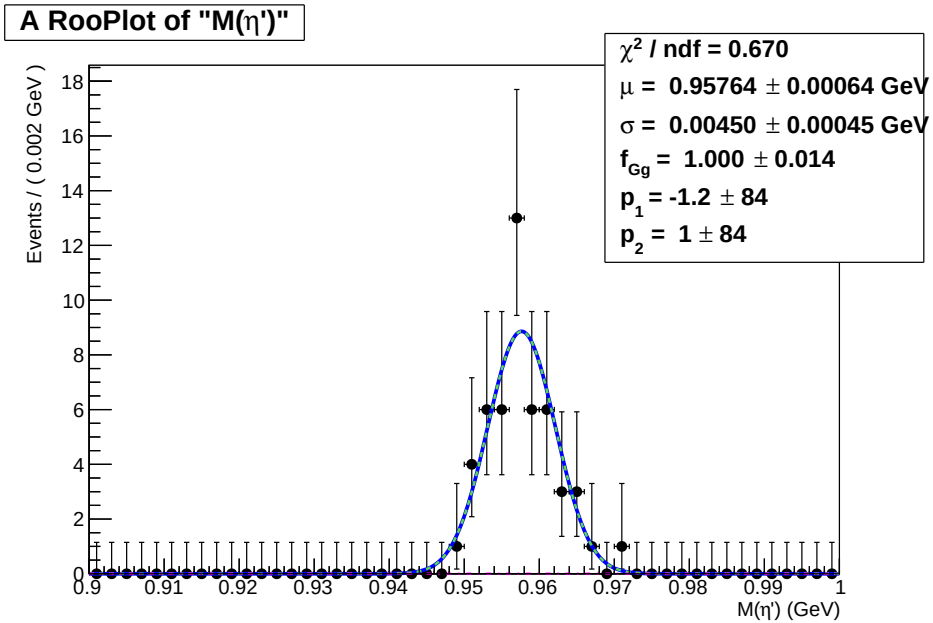




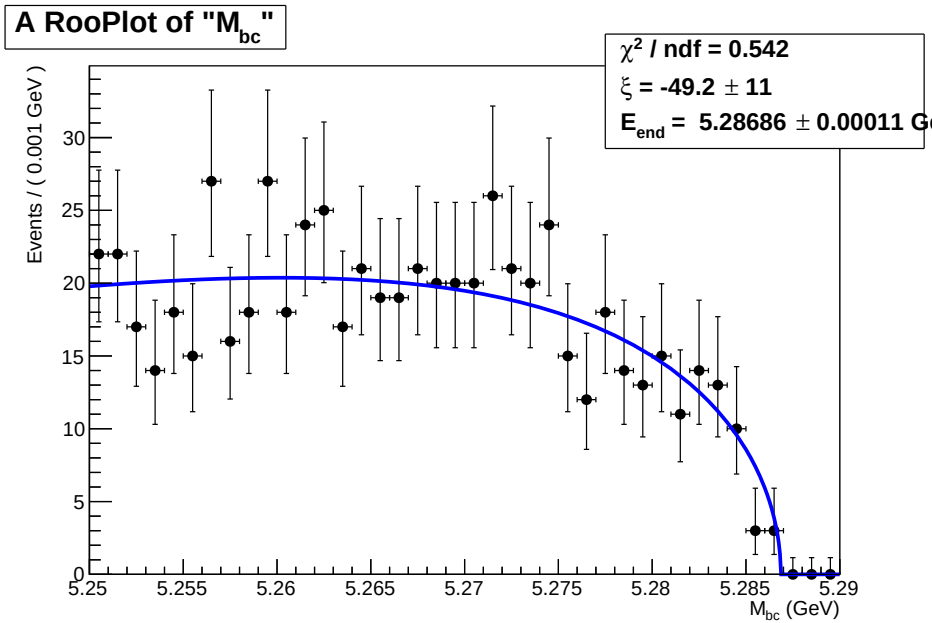
Peaking background PDF

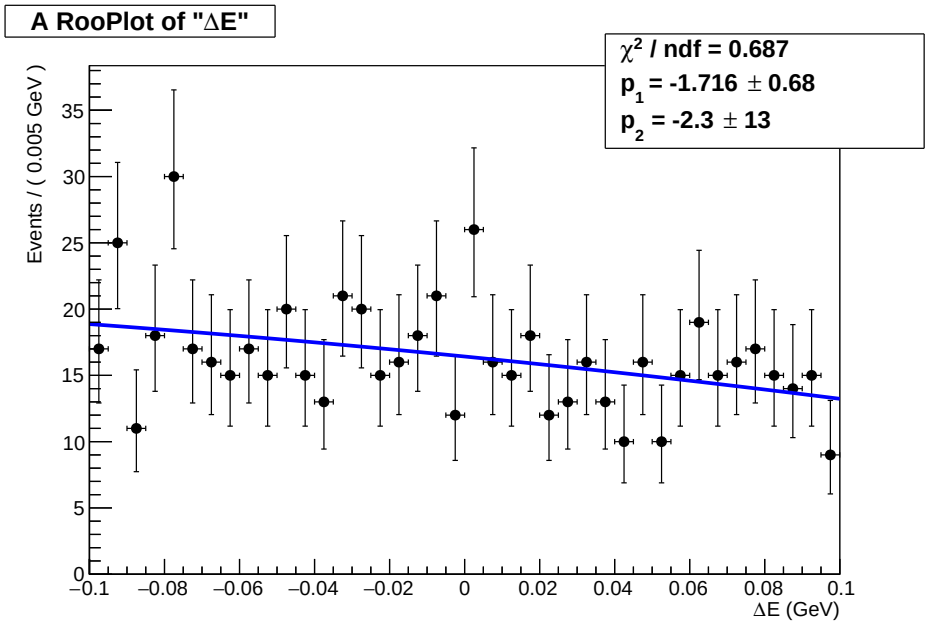


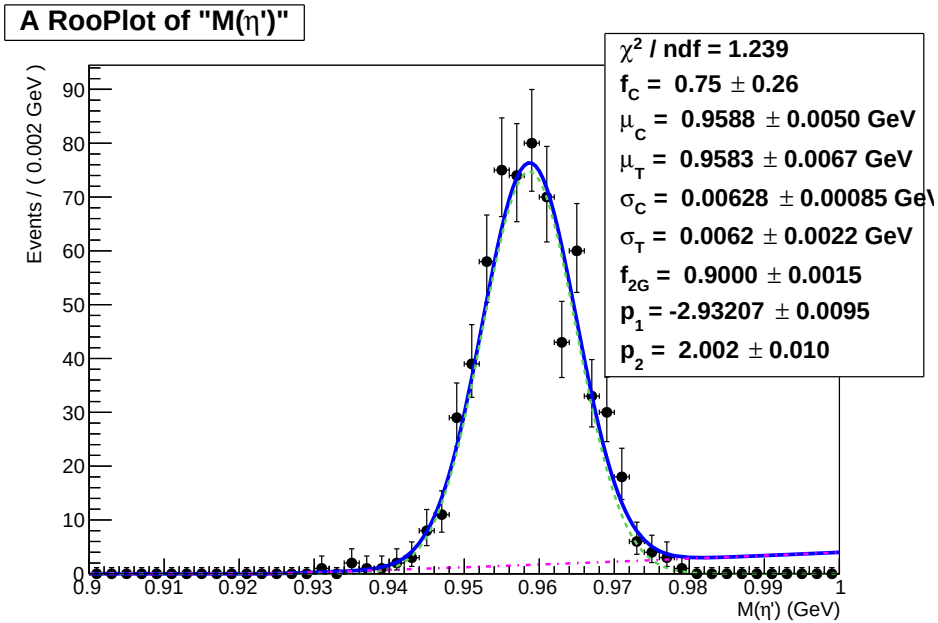




Continuum background PDF







Bibliography I

[CLEO(1998)] CLEO. Observation of high momentum η' production in B decays. *PRL*, 81:1786, 1998. doi: 10.1103/PhysRevLett.81.1786. URL http://link.aps.org/doi/10.1103/PhysRevLett.81.1786.

[Belle(2014)] Belle. Measurement of time-dependent cp violation in $b_0 \to \eta' k_0$ decays. *Journal of High Energy Physics*, 2014 (10):165, 2014. doi: 10.1007/JHEP10(2014)165. URL http://dx.doi.org/10.1007/JHEP10%282014%29165.

[Urquijo(2015)] Phillip Urquijo. Comparison between belle ii and lhcb physics projections. Technical Report BELLE2-NOTE-PH-2015-004, Apr 2015.