Study of HWRD process $\Xi^0 \to \Sigma^0\gamma$

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Motivation

Hara theorem
In hyperon weak radiative decay(HWRD):
B^{PV} should vanish under SU(3) limit $\rightarrow \alpha_\gamma = 0$
Take the weak breaking of SU(3) symmetry into consideration $\alpha_\gamma \sim \pm 0.2$

$$\alpha_\gamma = \frac{2\mathrm{Re}(A^{PC} * B^{PV})}{|A^{PC}|^2 + |B^{PV}|^2}$$

- α_γ: decay asymmetry
- A^{PC}: parity conserving amplitude
- B^{PV}: parity violating amplitude

Motivation

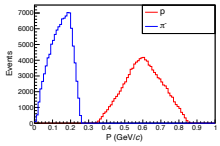
Measurements of decay asymmetry for $\Xi^0 \to \Sigma\gamma$

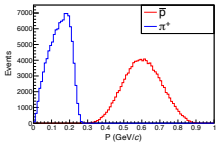
Experiments	BR/10^{-3}	α	Events
1989 SPEC	$3.56 \pm 0.42 \pm 0.10$	$+0.20 \pm 0.32 \pm 0.05$	85
2000 NA48	$3.16 \pm 0.76 \pm 0.32$	–	17
2001 KTEV	$3.34 \pm 0.05 \pm 0.09$	$-0.63 \pm 0.08 \pm 0.05$	4045
2010 NA48	–	$-0.729 \pm 0.030 \pm 0.076$	15k

Analysis Strategy

$$J/\psi \to \Xi^0\bar{\Xi}^0,\ \bar{\Xi}^0 \to \bar{\Sigma}^0\gamma,\ \Xi^0 \to \Lambda\pi^0, \bar{\Sigma}^0 \to \bar{\Lambda}\gamma$$

- Full Reconstruction
- Charged Tracks
  - $\cos\theta < 0.93$
  - $N \geq 4$
  - PID
    - p: $P_p > 0.3\text{GeV}$ && Prob(p)>Prob(K), Prob(p)>Prob(π)
    - π: $P_\pi < 0.3\text{GeV}$
  - $N_p, N_{\pi^-}, N_{\bar{p}}, N_{\pi^+} \geq 1$





- $\Lambda\&\bar{\Lambda}$: Primary vertex fit, loop $p\pi^-(\bar{p}\pi^+)$ pairs to find the best(no χ^2 requirement)
- Neutral Tracks
  - Angle between n.t. and c.t. ($\bar{p}$) larger than 10° (20°)
  - $25\text{MeV}@|\cos\theta| < 0.8$ && $50\text{MeV}@0.86 < |\cos\theta| < 0.92$&& $0 \leq \text{TDC} \leq 14$
  - $N_\gamma \geq 4$
  - 1C get a set of π^0 ($\chi^2_{\pi^0} < 20$)
- Kinematics Fit(7C)
  - Constrain $m_{\bar{\Xi}}$, m_Ξ
  - Loop π^0 and $\gamma\gamma$ pairs to optimize
- Main BKG KF(8C) && $\Lambda\bar{\Lambda}$ 2^{nd} VF

Feasibility analysis – Generator

Decay amplitude

$$\mathcal{W} = \sum_{\mu,\ \nu=0}^{3} C_{\mu\nu} \sum_{\mu',\ \nu',\ \rho=0}^{3} a^{\Xi}_{\mu\mu'} a^{\bar{\Xi}}_{\nu\nu'} a^{\Lambda}_{\mu' 0} a^{\bar{\Sigma}}_{\nu'\rho} a^{\bar{\Lambda}}_{\rho 0} \qquad (1)$$

For $1 \to \frac{1}{2} + \frac{1}{2}$ decay $(J/\psi \to \Xi^0 \bar{\Xi}^0)$

$$C_{\mu\nu} = \begin{pmatrix} 1+\alpha_\psi \cos^2\theta & 0 & \beta_\psi \sin\theta\cos\theta & 0 \\ 0 & \sin^2\theta & 0 & \gamma_\psi \sin\theta\cos\theta \\ -\beta_\psi \sin\theta\cos\theta & 0 & \alpha_\psi \sin^2\theta & 0 \\ 0 & -\gamma_\psi \sin\theta\cos\theta & 0 & -(\alpha_\psi + \cos^2\theta) \end{pmatrix} \qquad (2)$$

For $\frac{1}{2} \to \frac{1}{2} + 1$ decay $(\bar{\Xi}^0 \to \bar{\Sigma}\gamma,\ \bar{\Sigma} \to \bar{\Lambda}\gamma)$

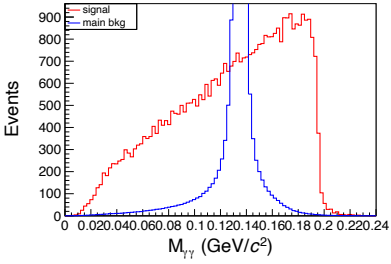
$$a_{\nu\nu'} = \begin{pmatrix} 1 & 0\ 0 & -\alpha \\ \alpha\cos\phi\sin\theta & 0\ 0 & -\cos\phi\sin\theta \\ \alpha\sin\theta\sin\phi & 0\ 0 & -\sin\theta\sin\phi \\ \alpha\cos\theta & 0\ 0 & -\cos\theta \end{pmatrix}$$

For $\frac{1}{2} \to \frac{1}{2} + 0$ decay $(\Xi^0 \to \Lambda\pi^0,\ \Lambda \to p\pi)$

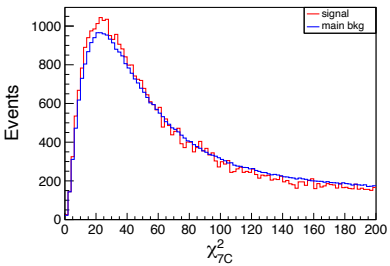
$$a_{\mu\mu'} = \begin{pmatrix} 1 & 0 & 0 & \alpha \\ \alpha\cos\phi\sin\theta & \gamma\cos\phi\cos\theta - \beta\sin\phi & -\beta\cos\phi\cos\theta - \gamma\sin\phi & \cos\phi\sin\theta \\ \alpha\sin\phi\sin\theta & \beta\cos\phi + \gamma\cos\theta\sin\phi & \gamma\cos\phi - \beta\cos\theta\sin\phi & \sin\phi\sin\theta \\ \alpha\cos\theta & -\gamma\sin\theta & \beta\sin\theta & \cos\theta \end{pmatrix} \qquad (3)$$

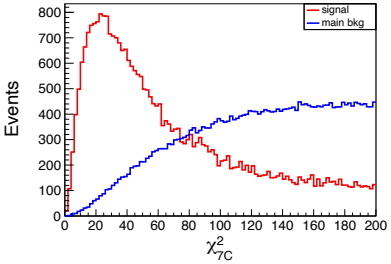
Feasibility analysis – Further Selection

- 600,000 Signal MC
- 21,000,000 Main Background MC



$0.115 < M_{\gamma\gamma} < 0.15$





$\chi^2_{7C} < 40$

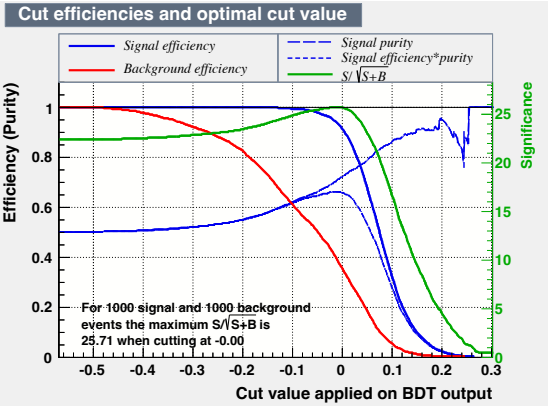
Feasibility analysis – Event Level BDT

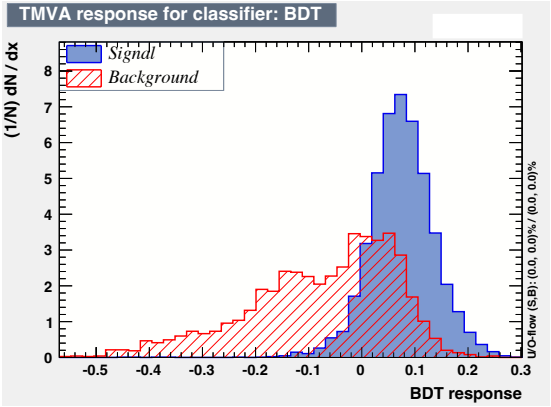
$$J/\psi \to \Xi^0\bar{\Xi}0,\ \bar{\Xi}0 \to \bar{\Sigma}^0\gamma(\gamma 2),\ \Xi^0 \to \Lambda\pi^0, \bar{\Sigma}^0 \to \bar{\Lambda}\gamma(\gamma 1)$$

- Input Sample: Signal(11918) & Main BKG(6909) MC after further selection
- Input Variables:

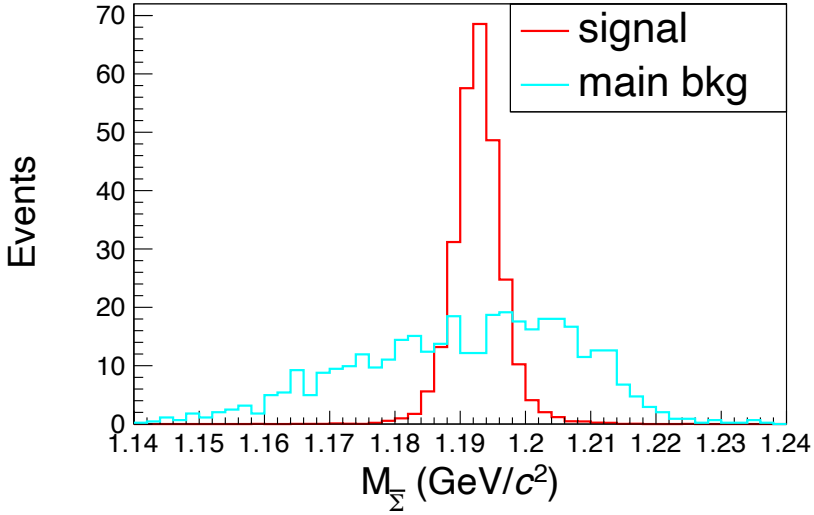
$$\gamma 1,\ \gamma 2's\ E,\ showershape,\ \cos\theta\ \&\ \bar{\Lambda}'s\ p,\ \cos\theta(cms)$$

Feasibility analysis – Event Level BDT





Feasibility analysis – Event Level BDT



Normalize to 10 billion J/ψ (not include charge conjugate channel)

$N_{sig} \doteq 273$

$N_{mbkg} \doteq 383$

Feasibility analysis – Cutflow

Criteria	Signal MC			Main Bkg MC		
	Events	Relative Effi	Effi	Events	Relative Effi	Effi
NTotal	600000	-	-	21000000	-	-
Good Charged Track	318822	53.14%	53.14%	11050400	52.62%	52.62%
PID for $p\pi^-$	243234	76.29%	40.54%	8403188	76.04%	40.02%
Vertex Fit forΛ	220109	90.49%	36.68%	7618629	90.67%	36.28%
γ	170321	77.38%	28.39%	5802051	76.16%	27.63%
KF	40996	24.07%	6.83%	1414786	24.38%	6.74%
$M_{\gamma\gamma}$	30895	75.36%	5.15%	172618	12.20%	0.82%
χ^2_{7C}	12003	38.85%	2.00%	7696	4.46%	0.037%
Event-Level BDT	10318	85.96%	1.72%	1697	22.05%	0.008%
Relative Effiency	215 times					

Bkg analysis – Topology

12, 18 inclusive

Table 1: Decay trees and their respective initial-final states.

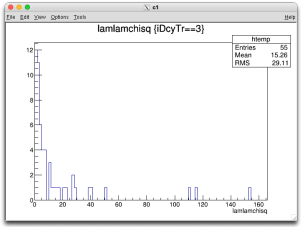
rowNo	decay tree (decay initial-final states)	iDcyTr	iDcyIFSts	nEtr	nCEtr
1	$J/\psi \to \Xi^0\bar{\Xi}^0, \bar{\Xi}^0 \to \pi^0\bar{\Lambda}, \bar{\Lambda} \to \pi^- p, \Lambda \to \pi^+ \bar{p}$ $(J/\psi \dashrightarrow \pi^0\pi^0\pi^+\pi^- p\bar{p})$	0	0	879	879
2	$J/\psi \to \Sigma^{*0}\bar{\Sigma}^{*0}, \Sigma^{*0} \to \pi^0\Lambda, \bar{\Sigma}^{*0} \to \pi^0\bar{\Lambda}, \bar{\Lambda} \to \pi^- p, \Lambda \to \pi^+ \bar{p}$ $(J/\psi \dashrightarrow \pi^0\pi^0\pi^+\pi^- p\bar{p})$	3	0	55	934
3	$J/\psi \to \pi^0\Sigma^0\bar{\Sigma}^0, \Sigma^0 \to \Lambda\gamma, \bar{\Sigma}^0 \to \bar{\Lambda}\gamma, \bar{\Lambda} \to \pi^- p, \Lambda \to \pi^+ \bar{p}$ $(J/\psi \dashrightarrow \pi^0\pi^+\pi^- p\bar{p}\gamma\gamma)$	1	1	49	983
4	$J/\psi \to \Sigma^0\bar{\Sigma}^{*0}, \bar{\Sigma}^0 \to \bar{\Lambda}\gamma, \bar{\Sigma}^{*0} \to \pi^0\bar{\Lambda}, \bar{\Lambda} \to \pi^+\bar{p}, \Lambda \to \pi^- p$ $(J/\psi \dashrightarrow \pi^0\pi^+\pi^- p\bar{p}\gamma)$	2	2	5	988
5	$J/\psi \to \Sigma^0\bar{\Sigma}^{*0}, \Sigma^0 \to \Lambda\gamma, \bar{\Sigma}^{*0} \to \pi^0\bar{\Lambda}, \bar{\Lambda} \to \pi^- p, \Lambda \to \pi^+\bar{p}$ $(J/\psi \dashrightarrow \pi^0\pi^+\pi^- p\bar{p}\gamma)$	5	2	5	993
6	$J/\psi \to \pi^0\bar{\Lambda}\Sigma^{*0}, \bar{\Lambda} \to \pi^+\bar{p}, \Sigma^{*0} \to \pi^0\Lambda, \Lambda \to \pi^- p$ $(J/\psi \dashrightarrow \pi^0\pi^0\pi^+\pi^- p\bar{p})$	6	0	4	997
7	$J/\psi \to \Xi^0\bar{\Xi}^0, \Xi^0 \to \pi^0\Lambda, \bar{\Xi}^0 \to \pi^0\bar{\Lambda}, \Lambda \to \pi^- p, \bar{\Lambda} \to \pi^+\bar{p}\gamma'$ $(J/\psi \dashrightarrow \pi^0\pi^0\pi^+\pi^- p\bar{p}\gamma')$	13	4	3	1000
8	$J/\psi \to \eta_c\gamma, \eta_c \to \Xi^0\bar{\Xi}^0, \Xi^0 \to \pi^0\Lambda, \bar{\Xi}^0 \to \pi^0\bar{\Lambda}, \Lambda \to \pi^- p, \bar{\Lambda} \to \pi^+\bar{p}$ $(J/\psi \dashrightarrow \pi^0\pi^0\pi^+\pi^- p\bar{p}\gamma)$	22	8	3	1003
9	$J/\psi \to \Sigma^{*+}\bar{\Sigma}^{*-}, \Sigma^{*+} \to \pi^0\Sigma^+, \bar{\Sigma}^{*-} \to \pi^-\bar{\Lambda}, \Sigma^+ \to \pi^0 p, \bar{\Lambda} \to \pi^+\bar{p}$ $(J/\psi \dashrightarrow \pi^0\pi^0\pi^+\pi^- p\bar{p})$	16	0	2	1005

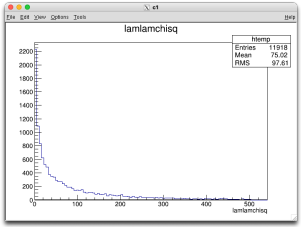
$J/\psi \to \Xi^0\bar{\Xi}^0, \Xi^0 \to \pi^0\Lambda, \bar{\Xi}^0 \to \pi^0\bar{\Lambda}, \Lambda \to \pi^- p, \bar{\Lambda} \to \pi^+\bar{p}(879)$

$J/\psi \to \Sigma^{*0}\bar{\Sigma}^{*0}, \Sigma^{*0} \to \pi^0\Lambda, \bar{\Sigma}^{*0} \to \pi^0\bar{\Lambda}, \Lambda \to \pi^- p, \bar{\Lambda} \to \pi^+\bar{p}(55)$

$J/\psi \to \pi^0\Sigma^0\bar{\Sigma}^0, \Sigma^0 \to \Lambda\gamma, \bar{\Sigma}^0 \to \bar{\Lambda}\gamma, \Lambda \to \pi^- p, \bar{\Lambda} \to \pi^+\bar{p}(49)$

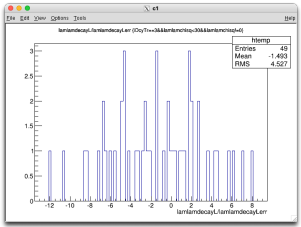
Bkg analysis – Supress 2^{nd} bkg

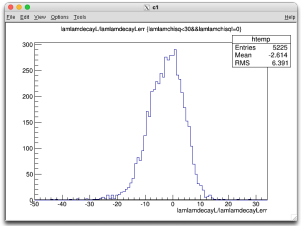




Keep $\chi^2 > 30 \&\& \chi^2 = 0$

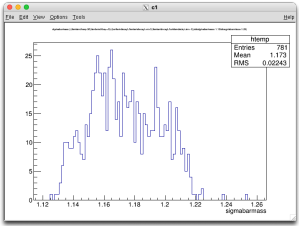
For remaining part

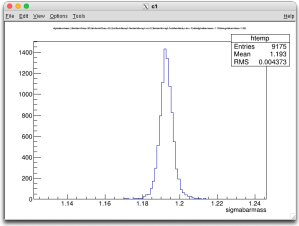




Keep $L/\sigma_L > 3,\ L/\sigma_L < -6$

Result





Efficiency: $75.94\% : 76.98\%$

Backup

Cutflow of previous version of ana program

Criteria	Signal MC			Main Bkg MC		
	Events	Relative Effi	Effi	Events	Relative Effi	Effi
NTotal	600000	-	-	3000000	-	-
Good Charged Track	318822	53.14%	53.14%	1713931	57.13%	57.13%
PID for $p\pi^-$	243234	76.29%	40.54%	1326980	77.42%	44.23%
Vertex Fit forΛ	146471	60.22%	24.41%	794247	59.85%	26.47%
γ	42483	29.00%	7.08%	201602	25.38%	6.72%
KF	10067	23.70%	1.68%	47477	23.55%	1.58%
$M_{\gamma\gamma}$	7647	75.96%	1.27%	4202	8.85%	0.14%
χ^2_{7C}	3354	43.86%	0.56%	150	3.57%	0.005%
Event-Level BDT	3167	94.42%	0.53%	47	33.10%	0.0015%
Relative Effiency	337 times					

Cutflow of latest version of ana program

Criteria	Signal MC			Main Bkg MC		
	Events	Relative Effi	Effi	Events	Relative Effi	Effi
NTotal	600000	-	-	21000000	-	-
Good Charged Track	318822	53.14%	53.14%	11050400	52.62%	52.62%
PID for $p\pi^-$	243234	76.29%	40.54%	8403188	76.04%	40.02%
Vertex Fit forΛ	220109	90.49%	36.68%	7618629	90.67%	36.28%
γ	170321	77.38%	28.39%	5802051	76.16%	27.63%
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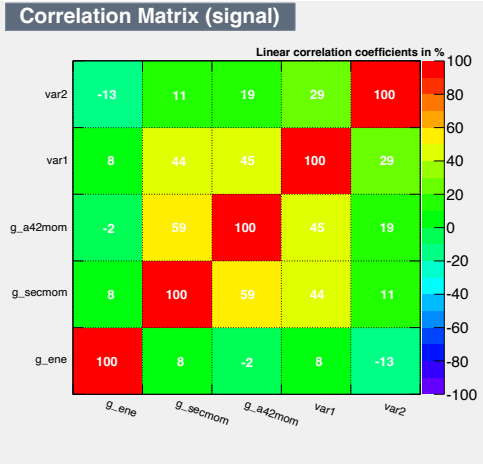
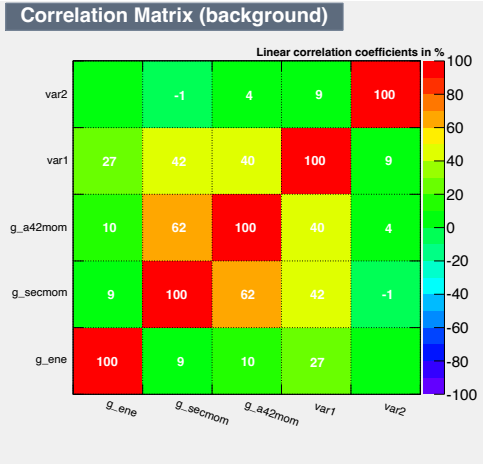
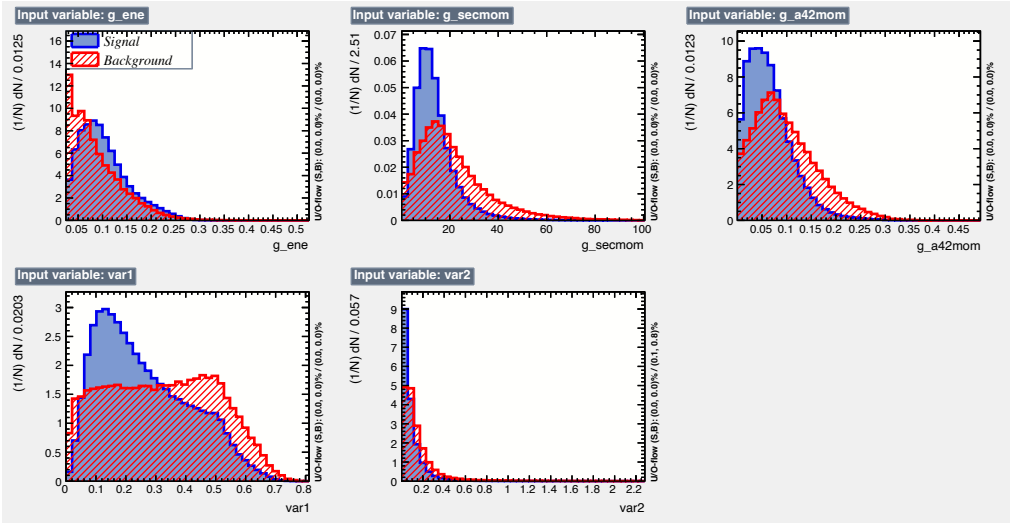
χ^2_{7C}	12003	38.85%	2.00%	7696	4.46%	0.037%
Event-Level BDT	10318	85.96%	1.72%	1697	22.05%	0.008%
Relative Effiency	215 times					

Backup – Track Level BDT

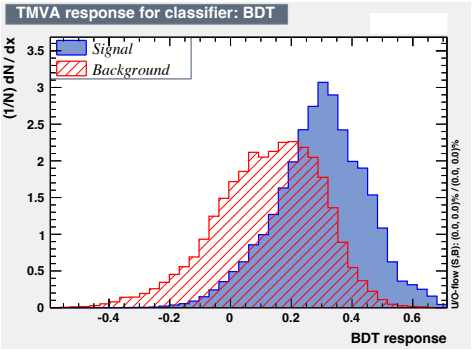


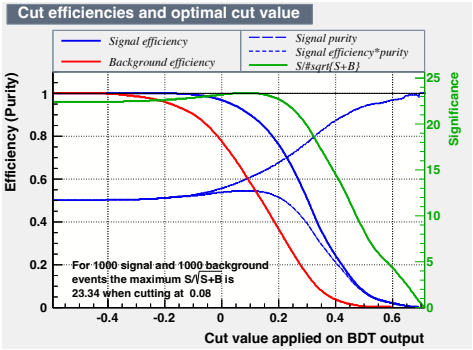


Backup – Track Level BDT



Backup – Track Level BDT





Backup – Event Level BDT

```
--- BDT                    : ------------------------------------------------------
--- BDT                    : Rank : Variable           : Variable Importance
--- BDT                    : ------------------------------------------------------
--- BDT                    :    1 : g1s_e5x5           : 1.247e-01
--- BDT                    :    2 : g2s_e5x5           : 1.212e-01
--- BDT                    :    3 : lambdabars_rho     : 8.379e-02
--- BDT                    :    4 : lambdabars_cos     : 8.149e-02
--- BDT                    :    5 : g1s_cos_cms        : 7.167e-02
--- BDT                    :    6 : g2s_eSeed          : 6.962e-02
--- BDT                    :    7 : g1s_eSeed          : 6.324e-02
--- BDT                    :    8 : g1s_cos            : 6.201e-02
--- BDT                    :    9 : g2s_cos            : 5.977e-02
--- BDT                    :   10 : lambdabars_cos_cms : 5.963e-02
--- BDT                    :   11 : g1s_secmom         : 5.826e-02
--- BDT                    :   12 : g1s_a42mom         : 4.991e-02
--- BDT                    :   13 : g2s_a42mom         : 4.890e-02
--- BDT                    :   14 : g2s_secmom         : 4.585e-02
--- BDT                    : ------------------------------------------------------
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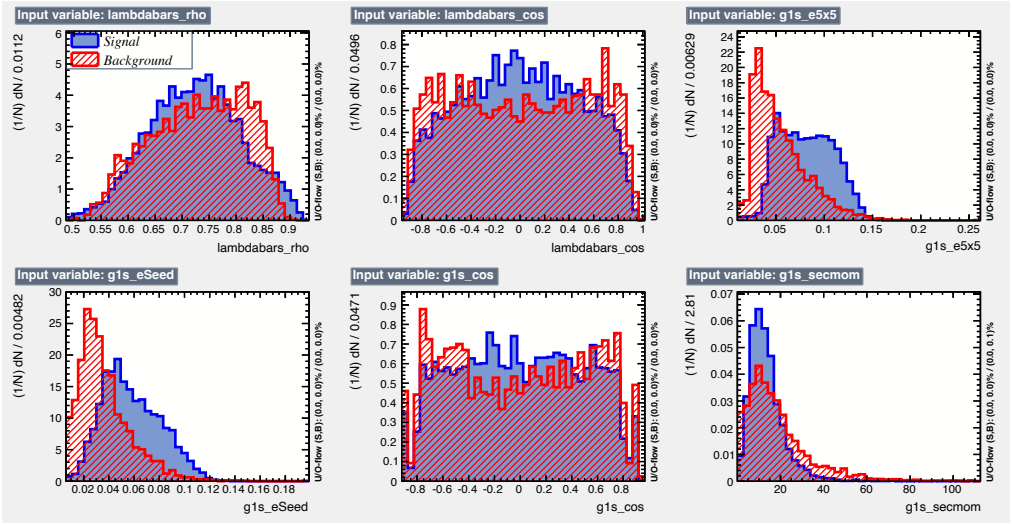
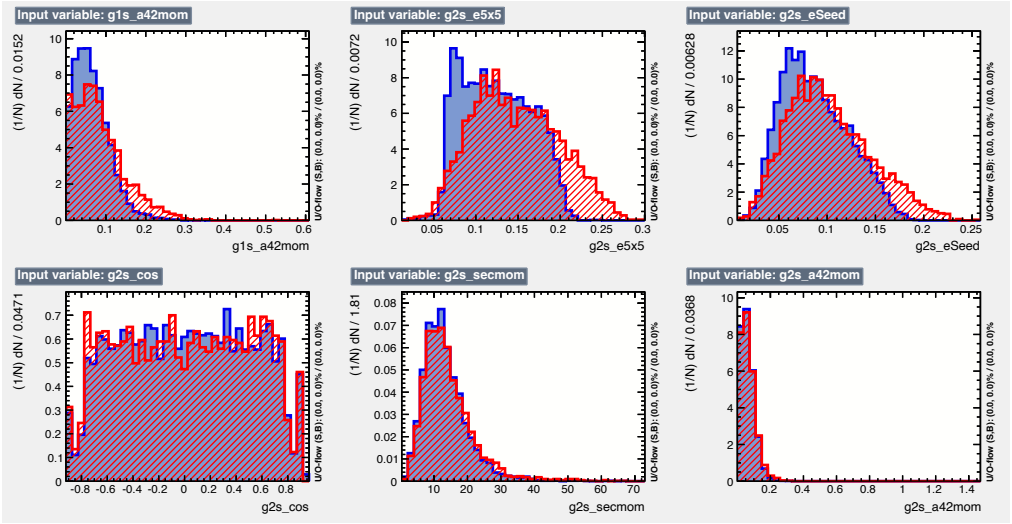
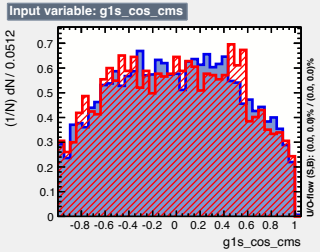
Backup – Event Level BDT

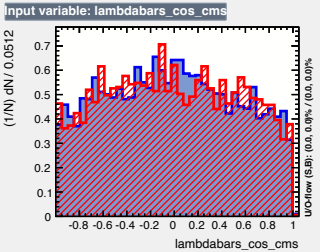


Backup – Event Level BDT



Backup – Event Level BDT





Backup – Event Level BDT