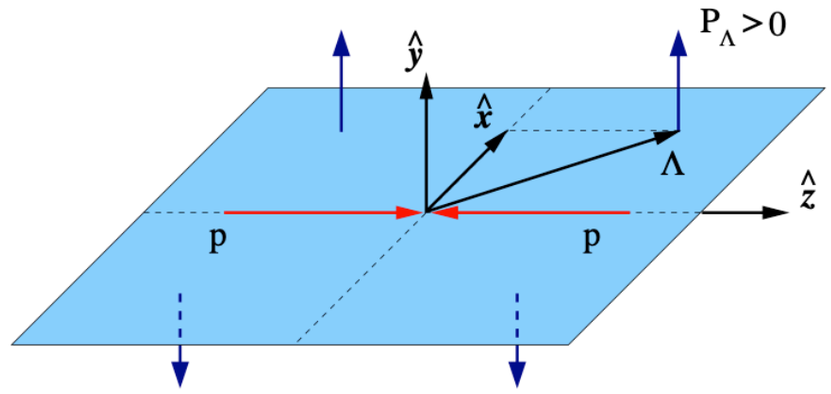
Lambda production at EIC

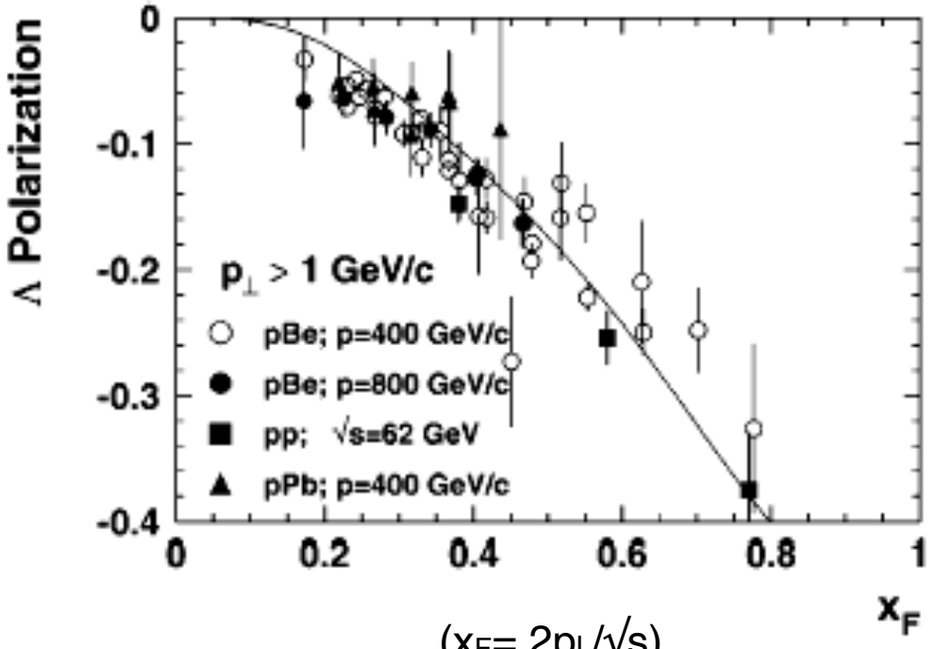
Jinlong Zhang
Sep 21, 2020

Why Lambda?

- Final state “polarimetry”
  - Self-analyzing weak decay: Lambda polarization can be measured from the angular distribution of its daughter particles, $\Lambda \to p\pi^-$(Br~64%) $\Lambda \to n\pi^0$ (Br~36%)



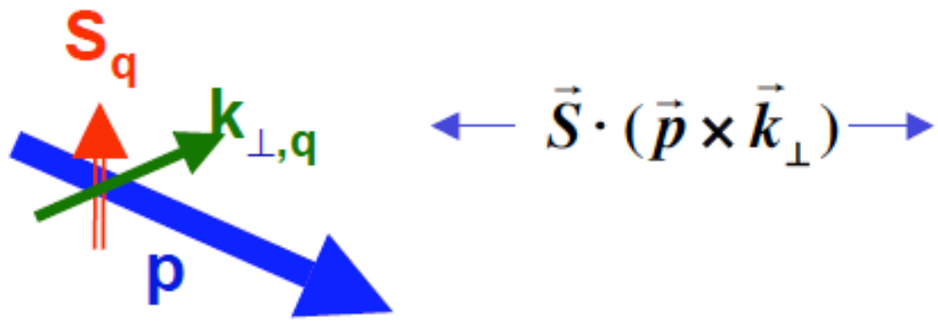
- Λ polarization plays an important role in spin physics
  - *Transverse polarization* in ***unpolarized*** pp, pA (G.Bunce et al 1976)
  - Study pol. fragmentation function and spin content of hyperon
  - Complementary to Kaon SIDIS, study spin structure of nucleon



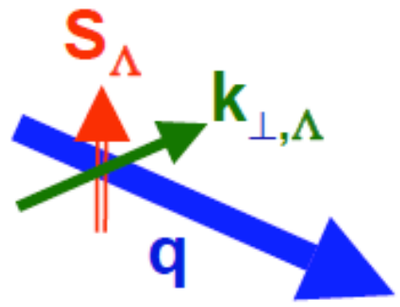
($x_F = 2p_L/\sqrt{s}$)

Theoretical Understanding

Polarizing distribution



Polarizing fragmentation



Quark pol.

Hadron pol.	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	$h_1, h_{1T}^\perp$

TMD PDFs

Quark pol.

Hadron pol.	U	L	T
U	D_1		$H_1^\perp$
L		G_{1L}	$H_{1L}^\perp$
T	$D_{1T}^\perp$	G_{1T}	$H_1, H_{1T}^\perp$

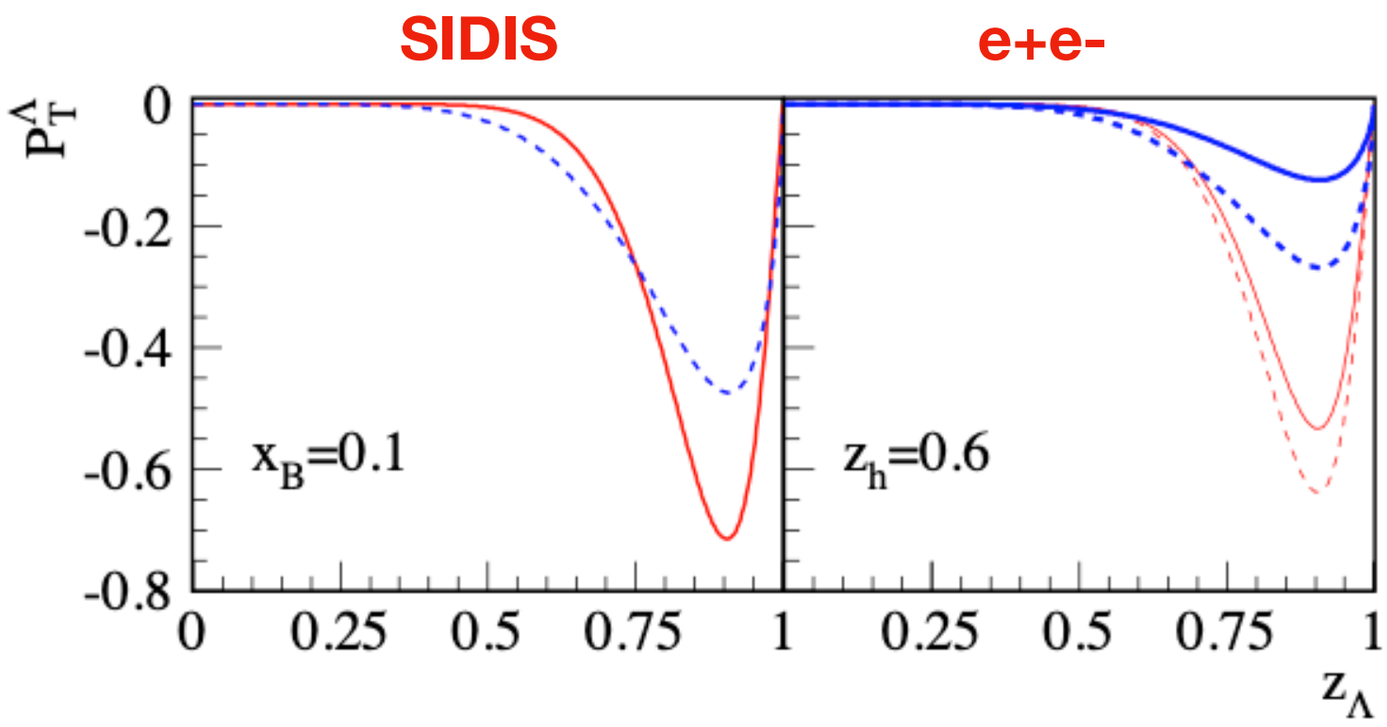
} Lambda

TMD FFs

Can not distinguish them in hadron-hadron reactions

But, lepton-hadron and e^+e^- can separate them.

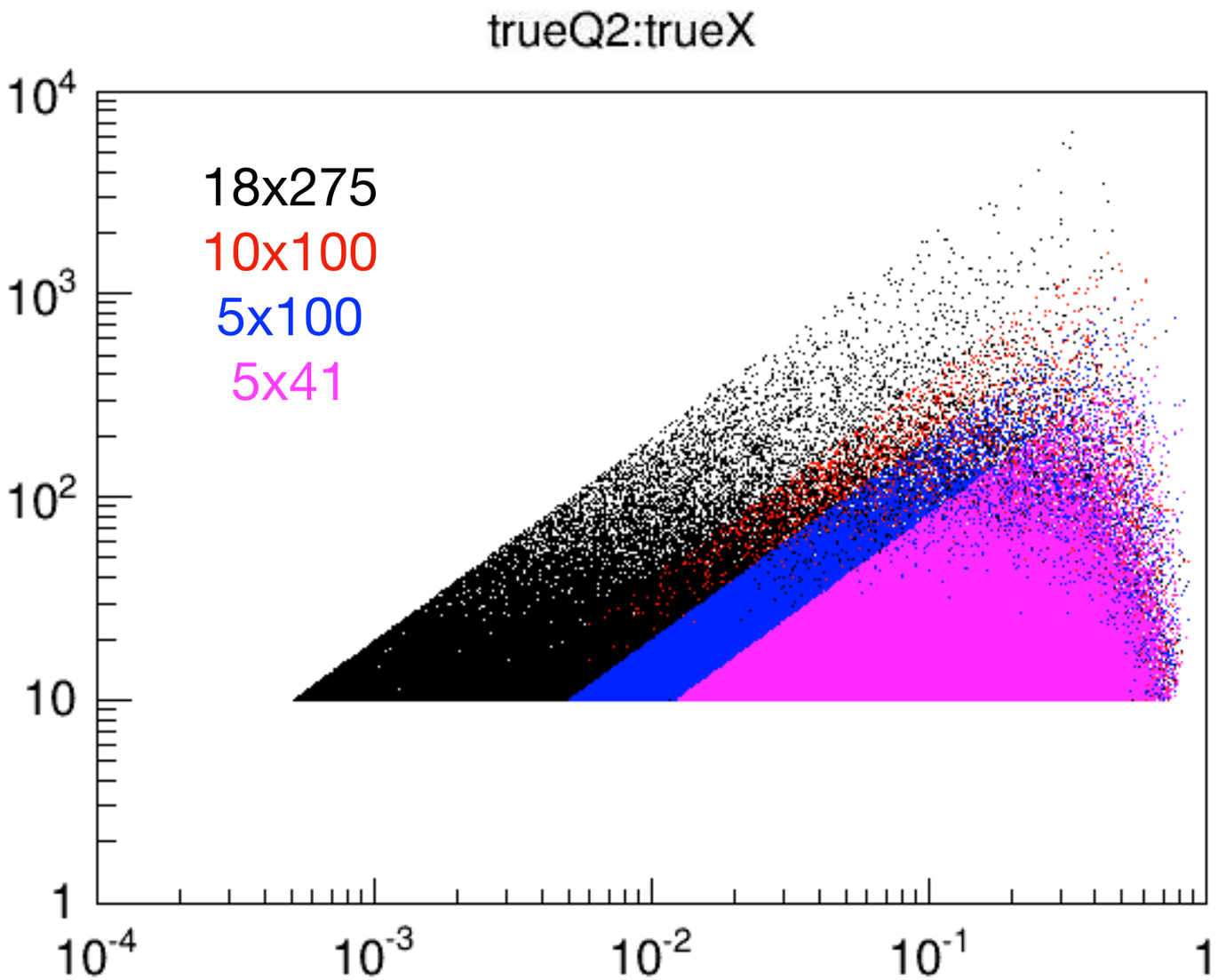
Universality tests for polarizing FFs



Boer, Kang, Vogelsang, Yuan, PRL'10

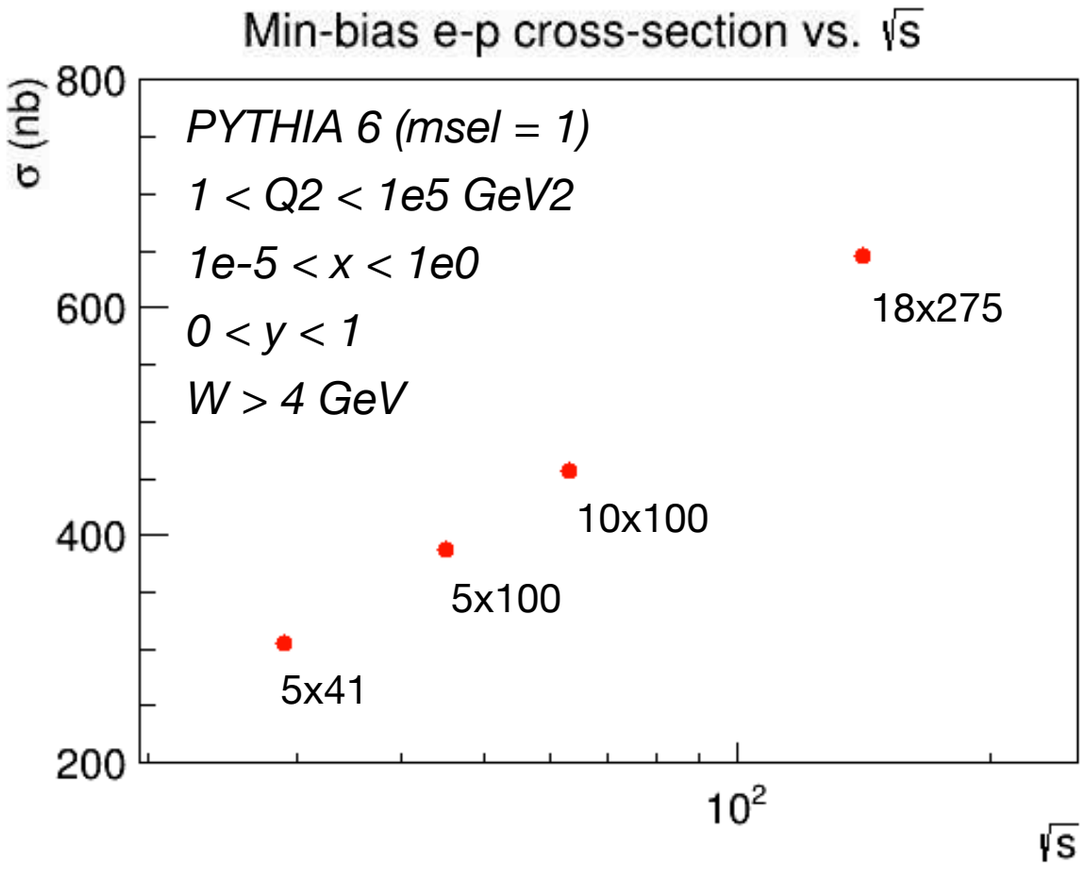
- Unlike the counterpart Sivers function changing sign between SIDIS and DY, polarizing FFs is predicted to be universal.
  - Metz, PLB 549 (2002) 139; Gamberg, Mukherjee, Mulders, PRD 77 (2008) 114026 Meissner, Metz, 0812.3783/hep-ph; Yuan, Zhou, 0903.4680/hep-ph
- e+e- data are existing, need test from SIDIS

Energy dependence



Lambda yields

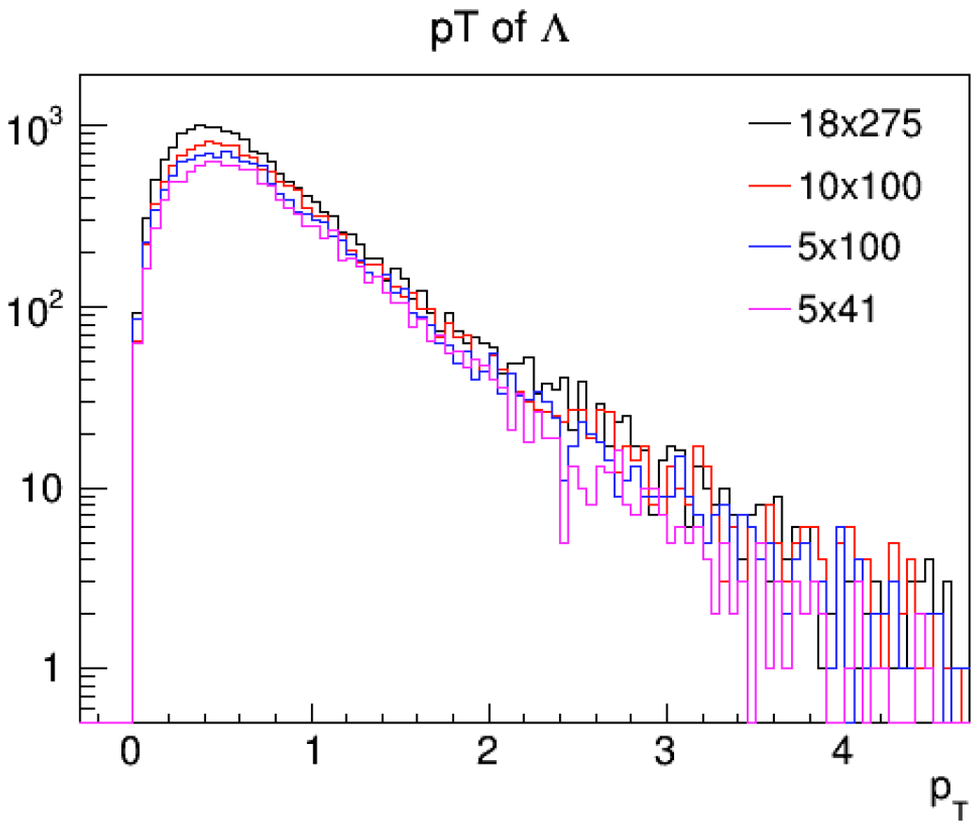
	# of generated	Luminosity of generated N_evt/x-section (fb-1)	Scale factor to 10 fb-1	# of lambda/Anti-Lambda generated	# of lambda/Anti-Lambda scaled
5x41	1M	1.55E-03	6.45E+03	594/733	3.83M/4.73M
5x100	1M	2.19E-03	4.57E+03	***912/763***	4.18M/3.49M
10x100	1M	2.58E-03	3.88E+03	968/1088	3.76M/4.22M
18x275	1M	3.28E-03	3.05E+03	1382/1424	4.22M/4.34M

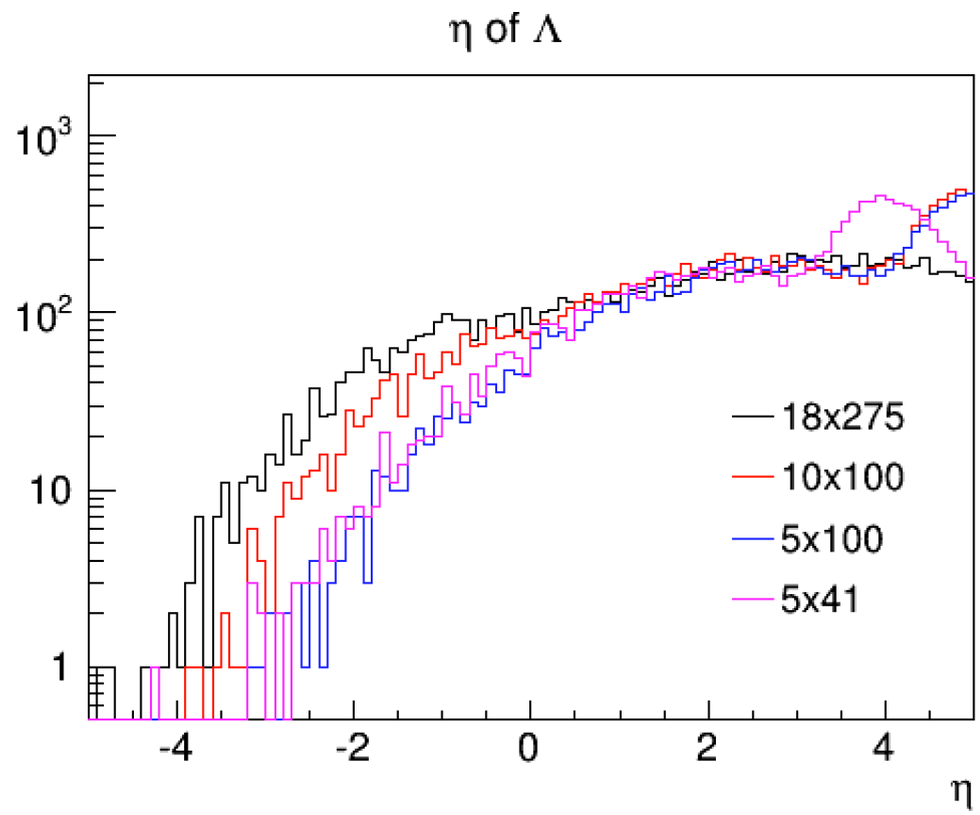


Cuts applied for # of lambda/Anti-Lambda generated

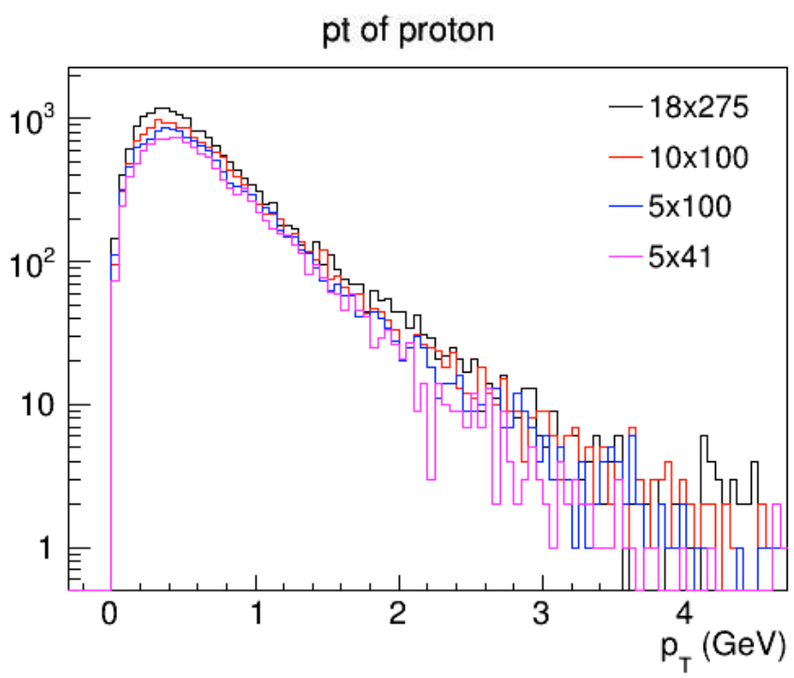
- decay to proton and pion only (~64%)
- Eta of proton/pion: (-3.5, 3.5)
- p_T of proton/pion: >0.3 GeV
- Feynman-x: > 0
- z_h : > 0.1

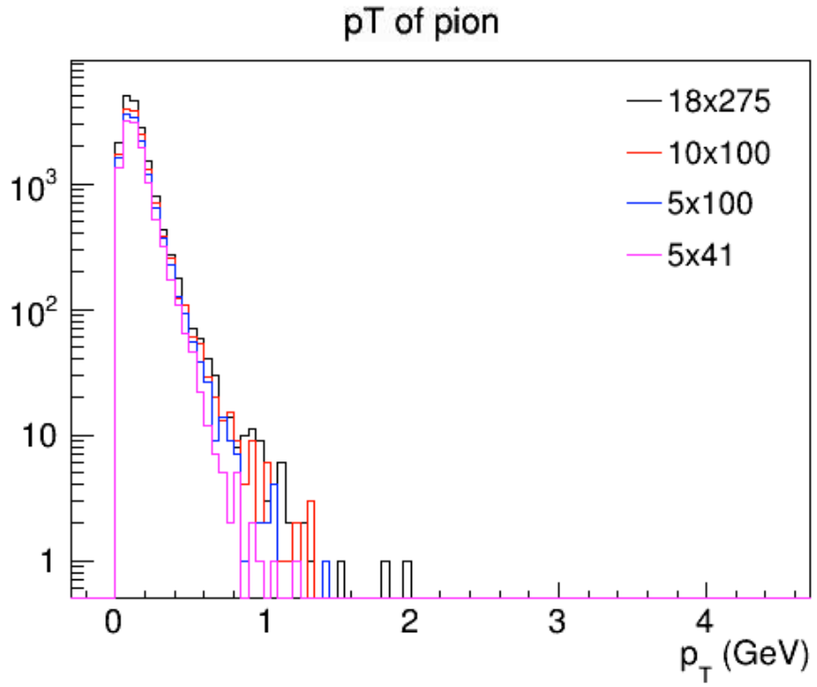
Lambda Kinematics

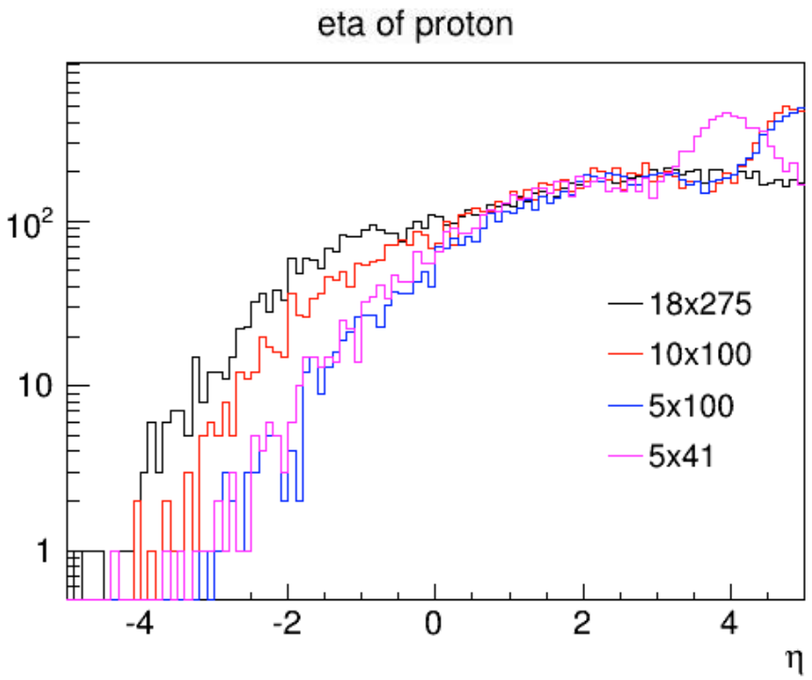


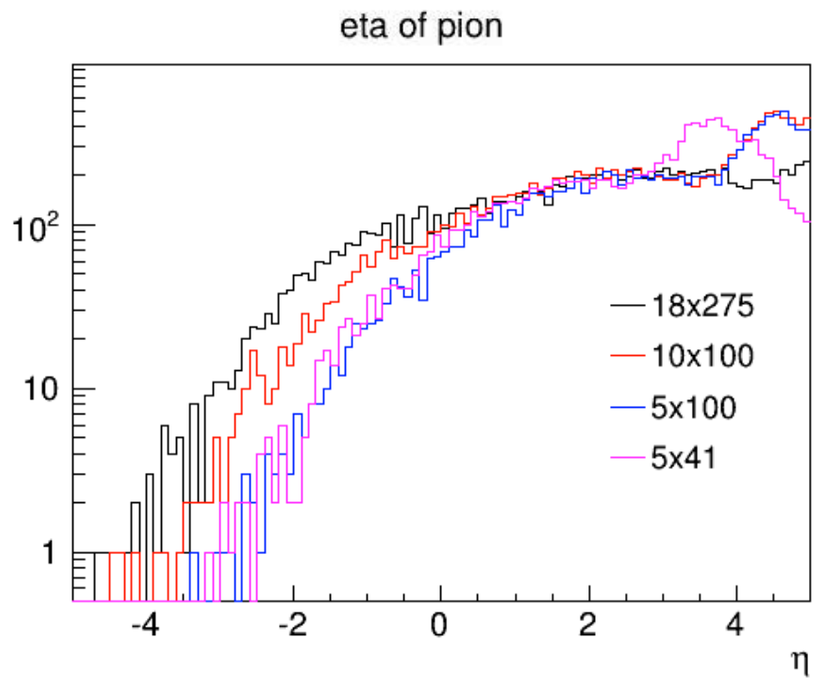


Lambda Daughters Kinematics

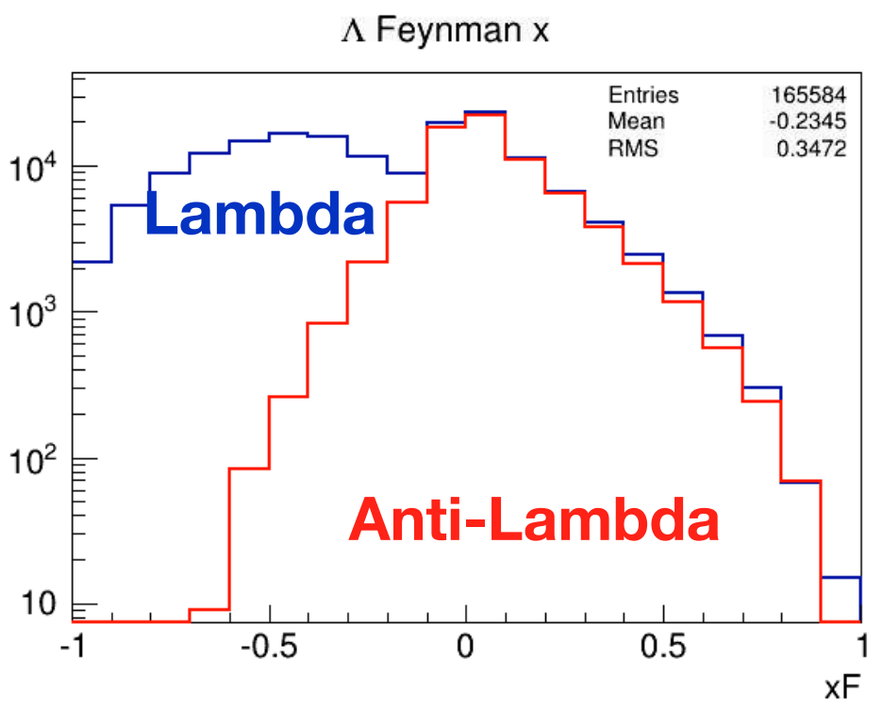


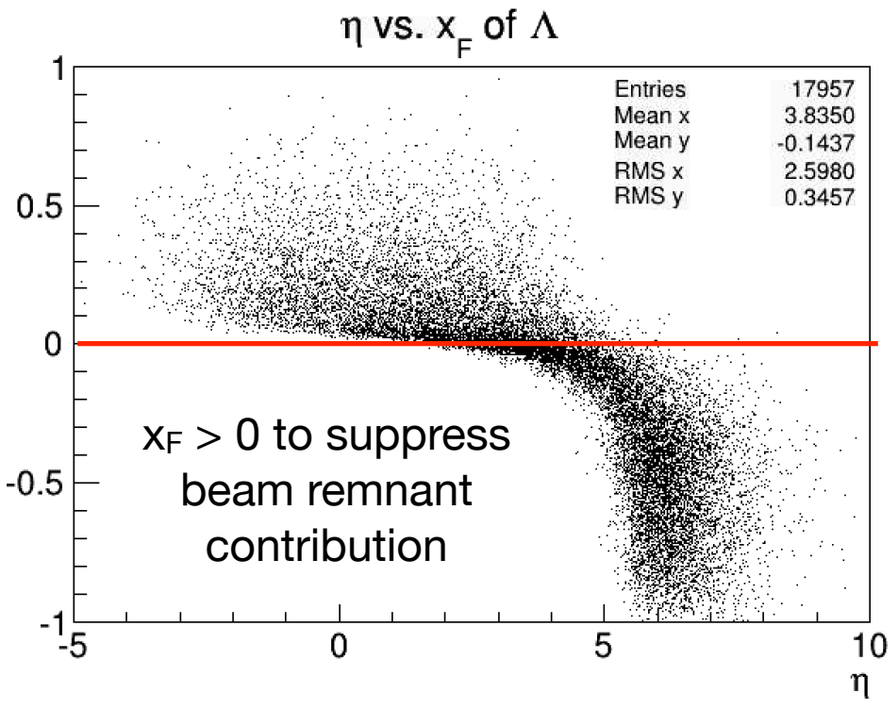


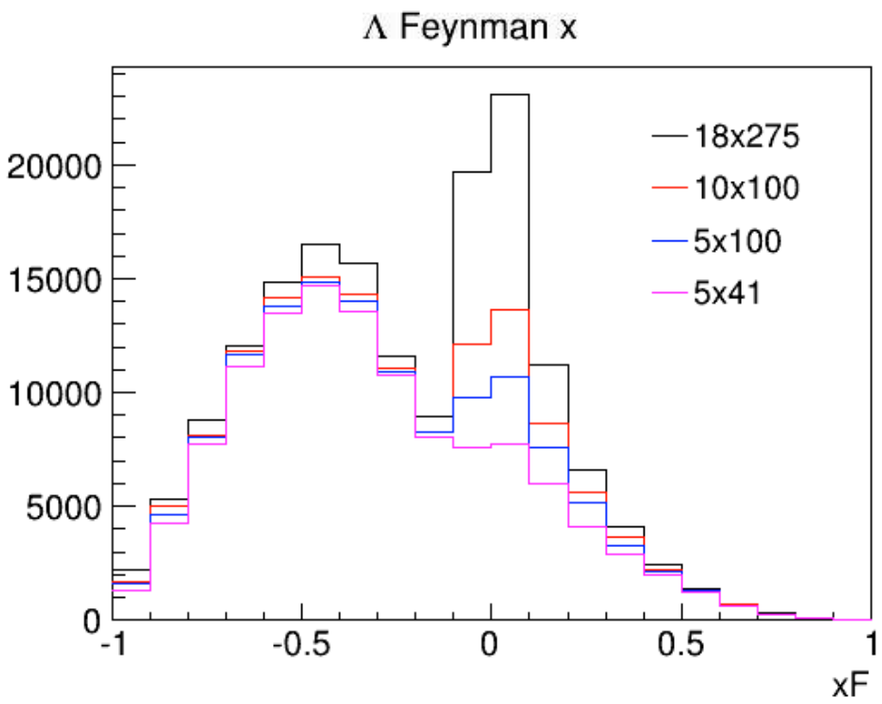


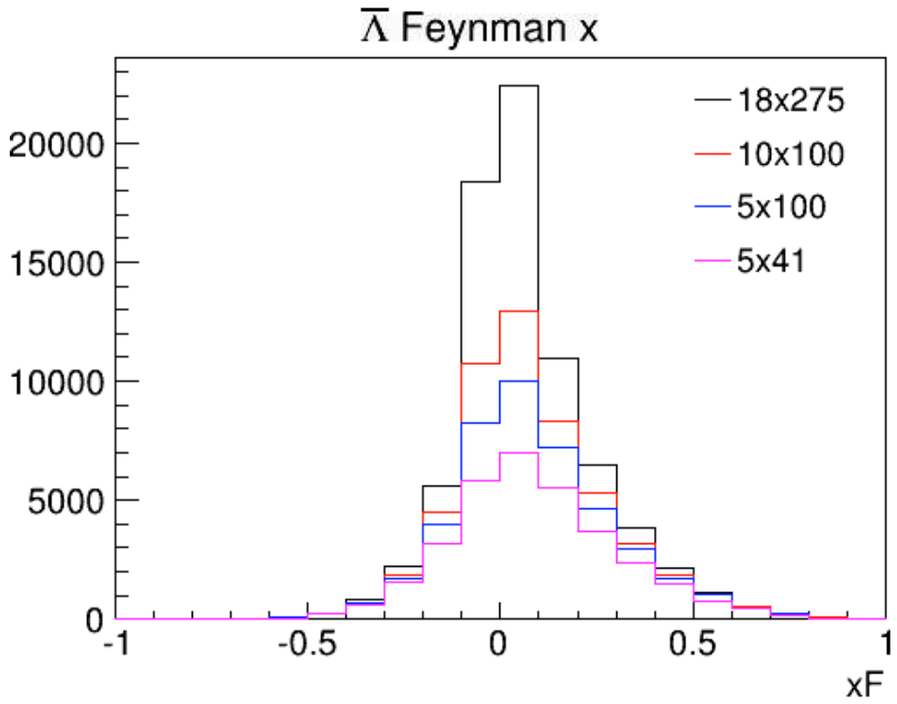


Feynman-x


Λ Feynman x
Entries 165584
Mean -0.2345
RMS 0.3472
Lambda
Anti-Lambda
xF

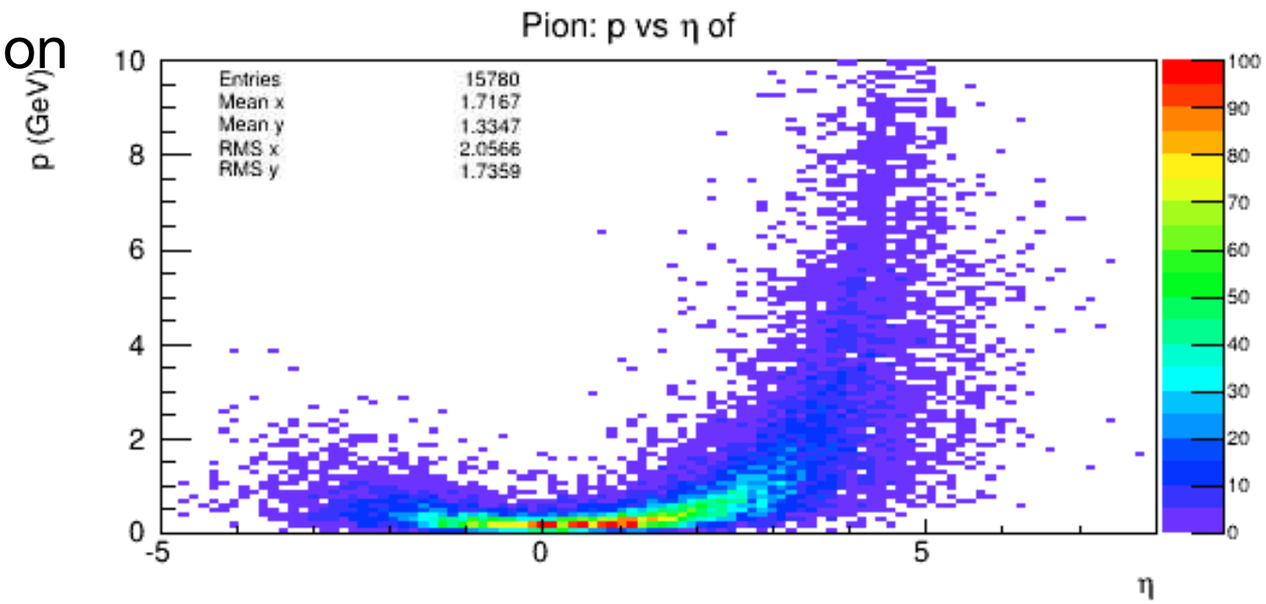

η vs. x_F of Λ
Entries 17957
Mean x 3.8350
Mean y -0.1437
RMS x 2.5980
RMS y 0.3457
x_F > 0 to suppress beam remnant contribution
η

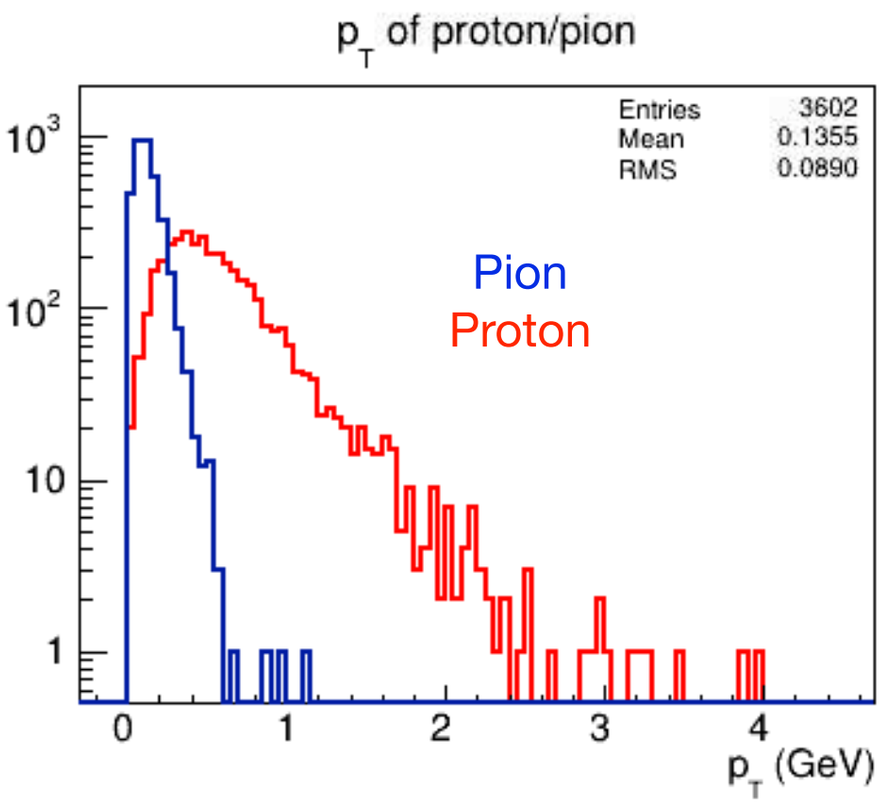

Λ Feynman x
18x275
10x100
5x100
5x41
xF

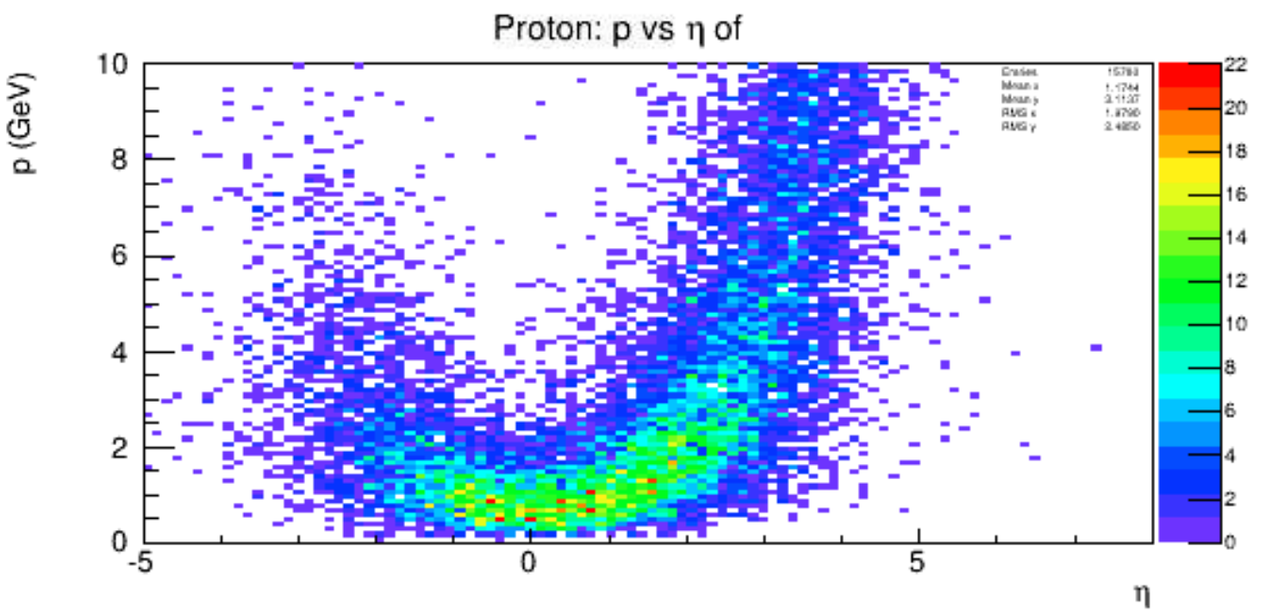

Λ̄ Feynman x
18x275
10x100
5x100
5x41
xF

Acceptance requirement

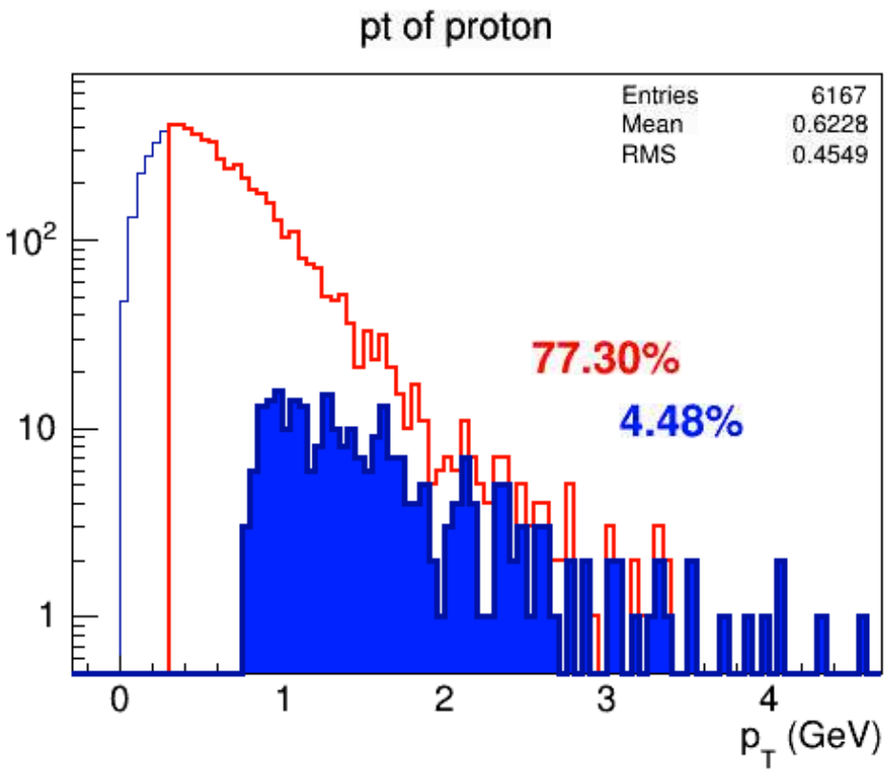
- Upper limit -> proton/pion identification
- Lower limit -> magnet filed
- General -> resolution

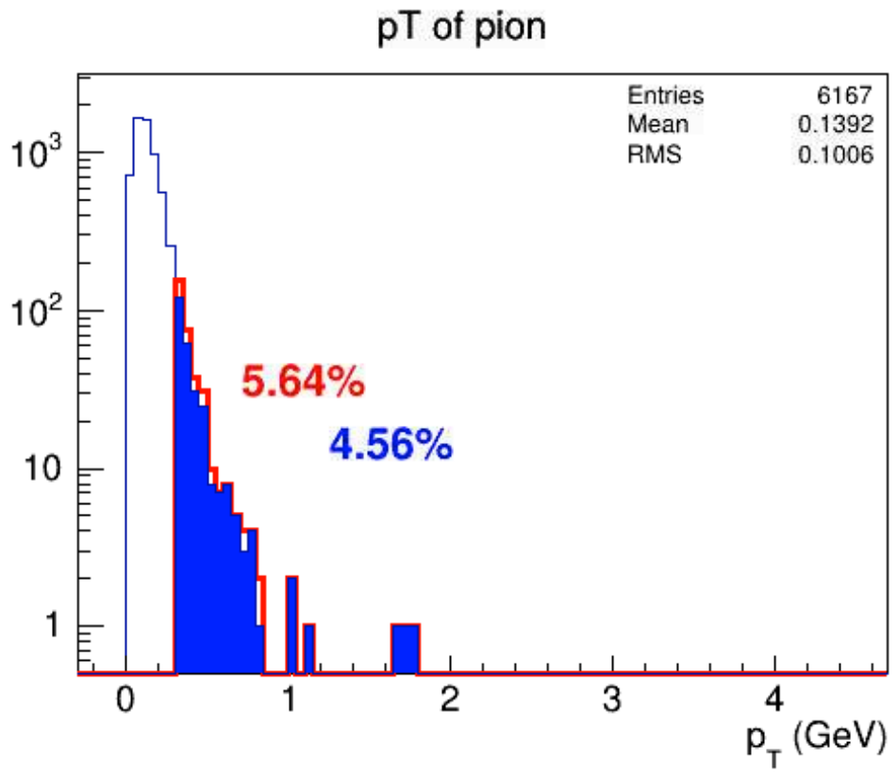






Limits from minimum p_T

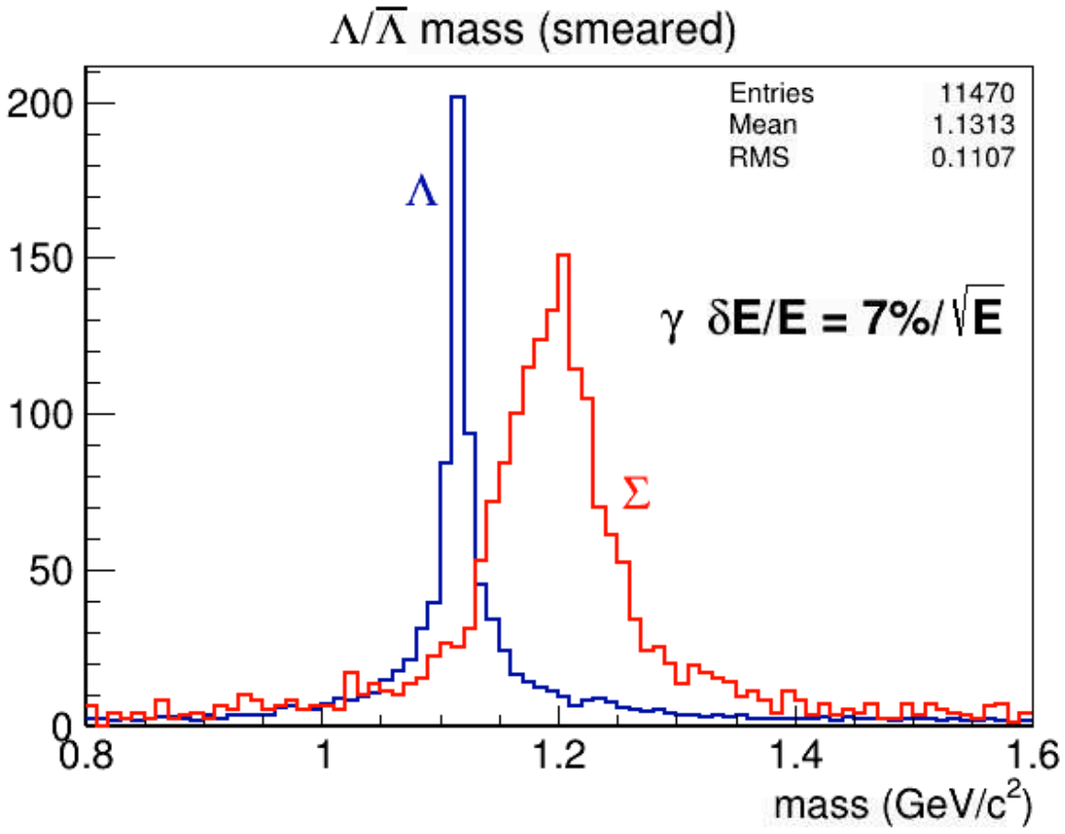


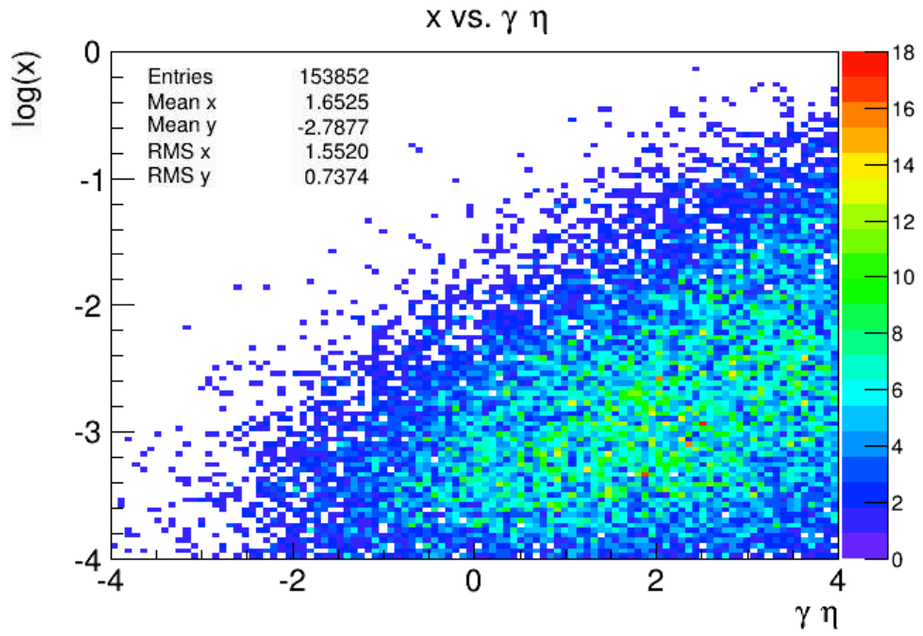


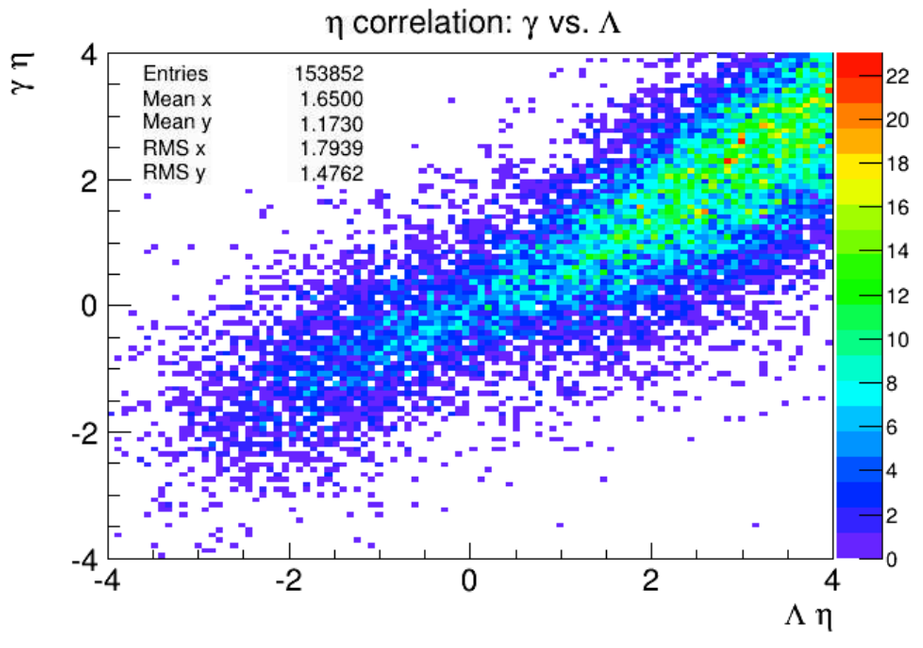
- p_T of pion and proton > 0.3 GeV
- Red is independent 0.3 GeV cut
- Blue filled is combined eta and pT cut

Pion pT acceptance plays dominant role

Acceptance requirement for Sigma0 separation

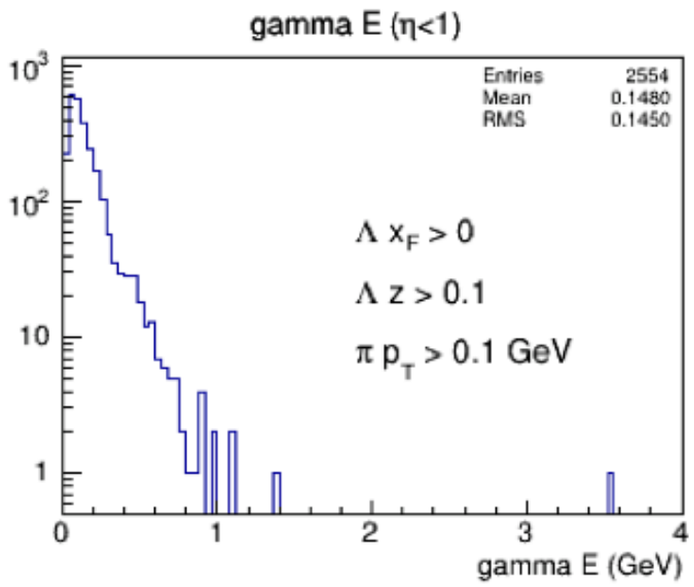


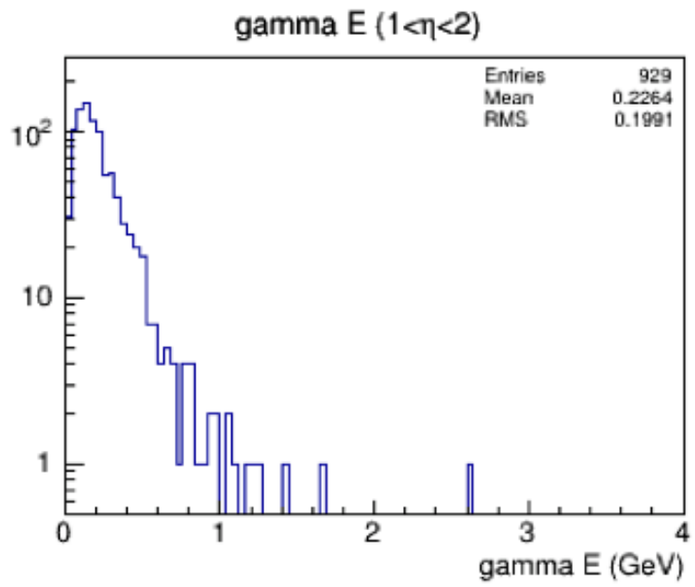


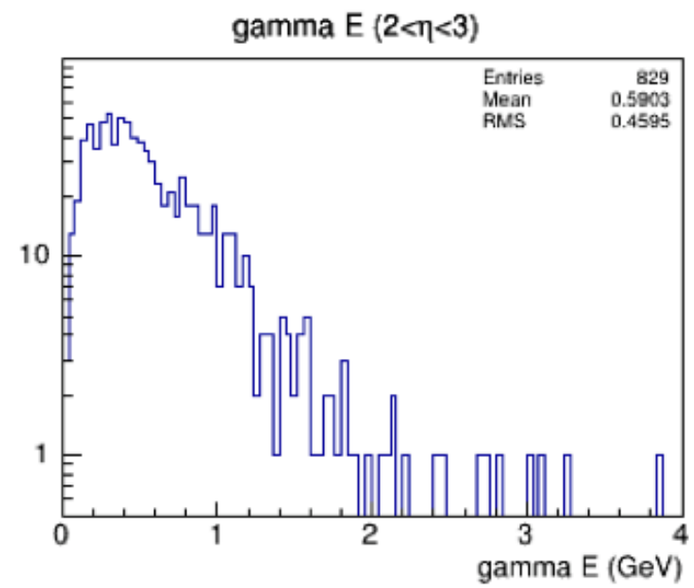


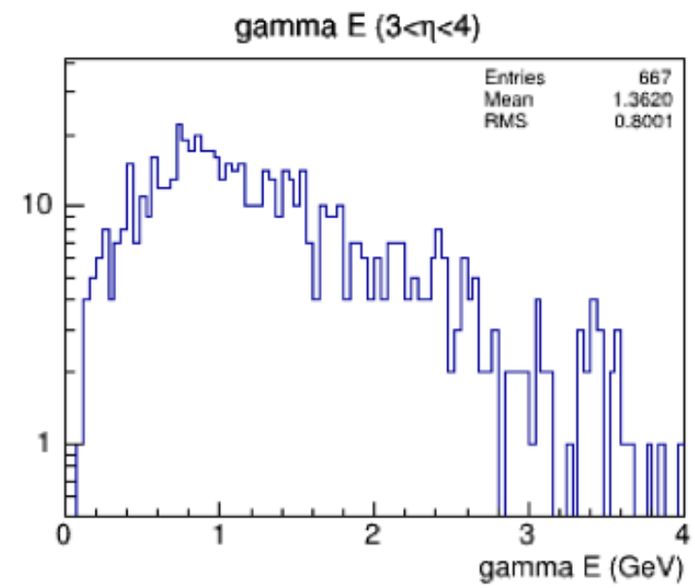
Medium x (10^-3 ~ 10^-2) measurement prefer to have Sigma 0 reconstruction at forward region

Gamma energy distributions



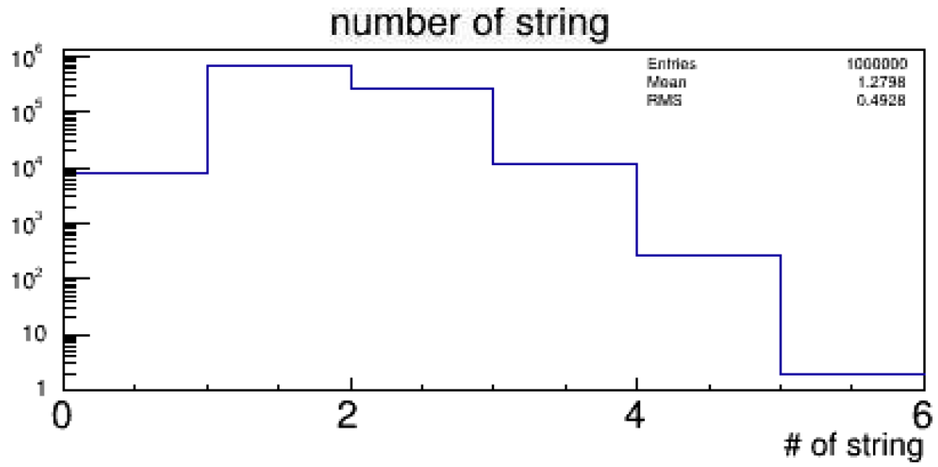


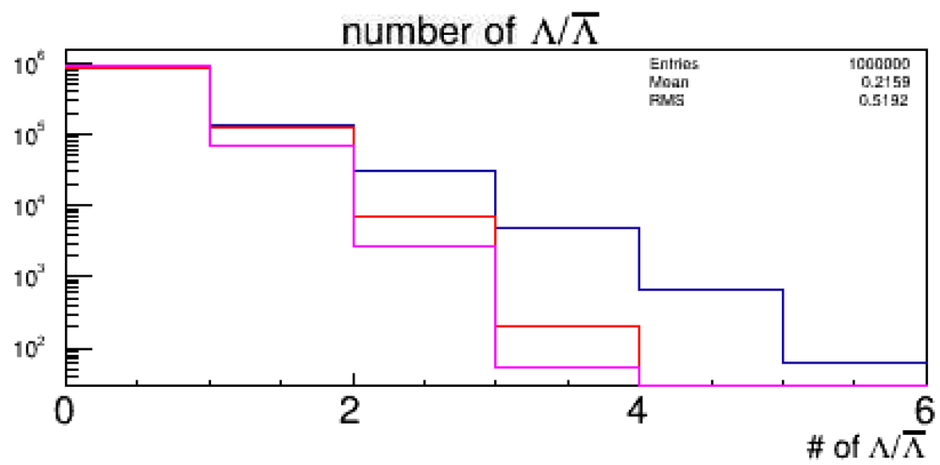


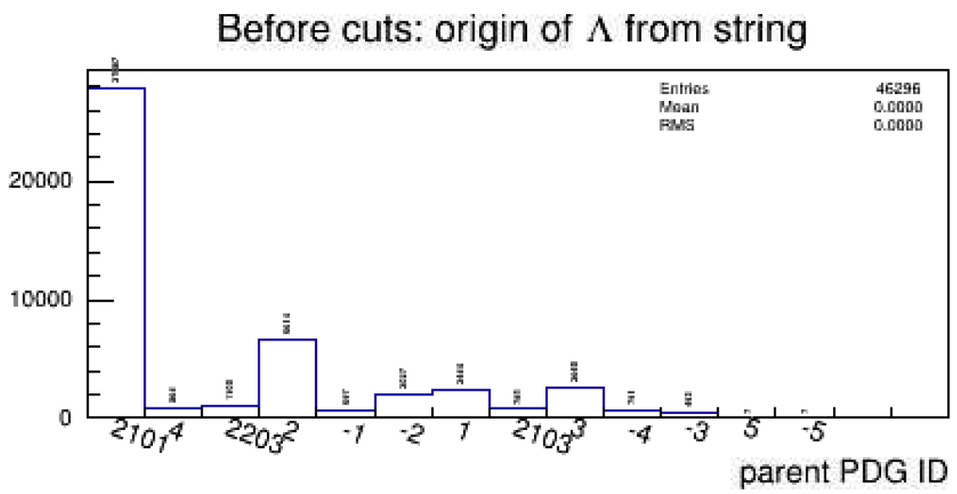


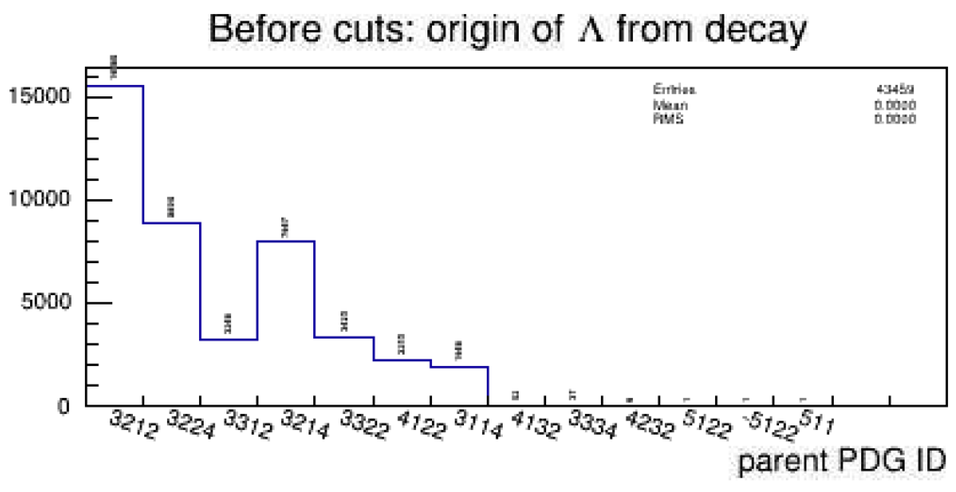
Needs gamma detection down to ~200 MeV or so.

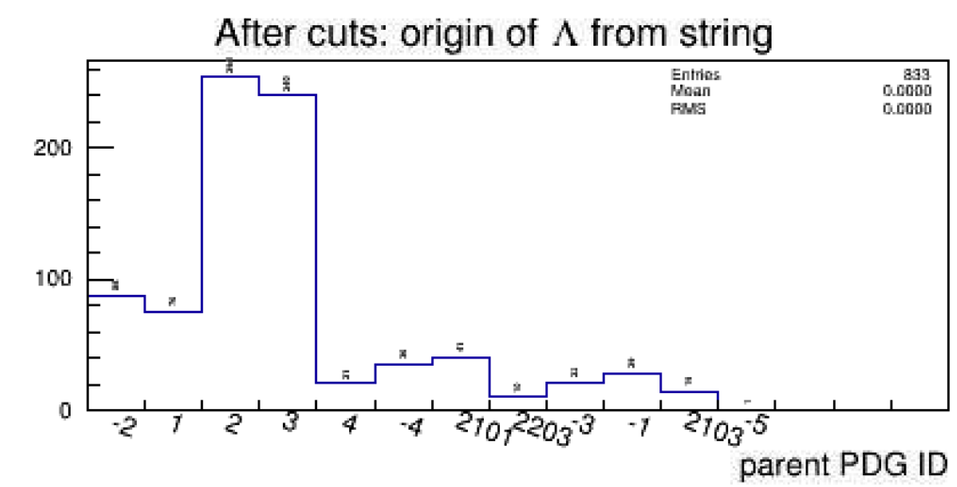
Origin of Lambda

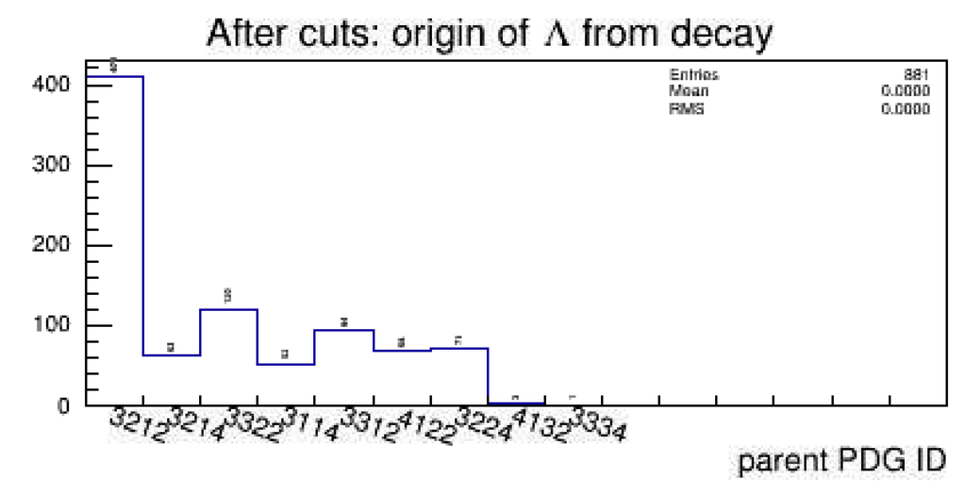












Direct lambda dominated by up and strange quark, feed-down dominated by sigma0

Lambda origin 18x275

This sample is from 1M min-bias DIS events, see earlier slides.

Lambda

particle name	pdg id	all lambda # of lambda	all lambda fraction	after cuts # of lambda	after cuts fration
diquark (ud)0	2101	43615	26.34%	27	1.95%
sigma0	3212	25887	15.63%	325	23.52%
sigma*+	3224	19118	11.55%	61	4.41%
sigma*0	3214	15017	9.07%	45	3.26%
proton	2212	12678	7.66%	0	0.00%
u	2	10325	6.24%	197	14.25%
lambda_c+	4122	6308	3.81%	77	5.57%
cascade0	3322	5431	3.28%	95	6.87%
cascade+	3312	5210	3.15%	78	5.64%
s	3	4556	2.75%	207	14.98%
d	1	3872	2.34%	57	4.12%
ubar	-2	3066	1.85%	72	5.21%
sigma*-	3114	3029	1.83%	42	3.04%
diquark (uu)1	2203	1714	1.04%	2	0.14%
c	4	1361	0.82%	13	0.94%
diquark (ud)1	2103	1235	0.75%	13	0.94%
cbar	-4	1160	0.70%	24	1.74%
dbar	-1	1078	0.65%	26	1.88%
sbar	-3	749	0.45%	17	1.23%
cascade_c0	4132	72	0.04%	3	0.22%
omega-	3334	54	0.03%	1	0.07%
cascade_c+	4232	17	0.01%	0	0.00%
b	5	11	0.01%	0	0.00%
bbar	-5	11	0.01%	0	0.00%
B0	511	4	0.00%	0	0.00%
lmabda_b0	5122	2	0.00%	0	0.00%
B+	521	1	0.00%	0	0.00%
lambda_b0	-5122	1	0.00%	0	0.00%
j/psi(1s)	443	1	0.00%	0	0.00%
B-	-521	1	0.00%	0	0.00%
		165584		1382	

Anti-Lambda

particle name	pdg id	all lambda-bar # of lambda	all lambda-bar fraction	after cuts # of lambda	after cuts fration
anti-simga0	-3212	16966	22.56%	284	19.94%
u	2	7893	10.50%	178	12.50%
diquark (ud)0	2101	6517	8.67%	35	2.46%
anti-cascade0	-3322	5587	7.43%	91	6.39%
cascade-	-3312	5431	7.22%	94	6.60%
sbar	-3	4321	5.75%	241	16.92%
ubar	-2	4062	5.40%	107	7.51%
anti-sigma*0	-3214	3621	4.82%	68	4.78%
sigma*-	-3224	3607	4.80%	58	4.07%
sigma*+	-3114	3191	4.24%	43	3.02%
d	1	2985	3.97%	44	3.09%
diquark (uu)1	2203	2920	3.88%	18	1.26%
diquark (ud)1	2103	2210	2.94%	8	0.56%
cbar	-4	1419	1.89%	14	0.98%
dbar	-1	1375	1.83%	38	2.67%
c	4	1167	1.55%	12	0.84%
lambda_c-	-4122	1101	1.46%	63	4.42%
s	3	682	0.91%	23	1.62%
omega+	-3334	61	0.08%	1	0.07%
anti-cascade_c0	-4132	50	0.07%	4	0.28%
bbar	-5	14	0.02%	0	0.00%
cascade_c-	-4232	12	0.02%	0	0.00%
b	5	4	0.01%	0	0.00%
j/psi(1s)	443	2	0.00%	0	0.00%
lambda_b0	-5122	1	0.00%	0	0.00%
B+	521	1	0.00%	0	0.00%
		75200		1424	

Cuts:
p+pi decay only
p/pi eta (-3.5, 3.5) && p/pi pt >0.3 GeV
&& xF > 0 && z > 0.1

Lambda origin 5x41

This sample is from 1M min-bias DIS events, see earlier slides.

		all lambda		**after cut**				all lambdabar		**after cuts**	
particle name	pdg id	# of lambda	fraction	# of lambda	fration	particle name	pdg id	# of anti-lambda	fractio n	# of anti-lambda	fration
diquark (ud)0	2101	46991	66.72%	65	8.63%	sigma*-	-3224	1379	4.20%	8	1.35%
simga0	3212	15305	21.73%	191	25.37%	anti-simga0	-3212	7501	22.83%	135	22.73%
sigma*+	3224	13933	19.78%	34	4.52%	diquark (ud)0	2101	4441	13.52%	66	11.11%
sigma*0	3214	12149	17.25%	40	5.31%	u	2	3551	10.81%	97	16.33%
proton	2212	8924	12.67%	0	0.00%	sbar	-3	2271	6.91%	103	17.34%
u	2	4911	6.97%	142	18.86%	anti-cascade0	-3322	2222	6.76%	25	4.21%
s	3	2934	4.17%	119	15.80%	cascade-	-3312	2114	6.43%	31	5.22%
lambda_c+	4122	2452	3.48%	17	2.26%	ubar	-2	1532	4.66%	38	6.40%
cascade0	3322	2002	2.84%	29	3.85%	diquark (uu)1	2203	1409	4.29%	13	2.19%
cascade+	3312	1794	2.55%	16	2.12%	diquark (ud)1	2103	1382	4.21%	15	2.53%
d	1	1626	2.31%	28	3.72%	sigma*-	-3214	1318	4.01%	9	1.52%
ubar	-2	1105	1.57%	30	3.98%	sigma*+	-3114	1209	3.68%	12	2.02%
sigma*-	3114	1008	1.43%	10	1.33%	d	1	1147	3.49%	18	3.03%
diquark (uu)1	2203	669	0.95%	9	1.20%	dbar	-1	564	1.72%	12	2.02%
diquark (ud)1	2103	654	0.93%	12	1.59%	lambda_c-	-4122	267	0.81%	4	0.67%
dbar	-1	433	0.61%	6	0.80%	s	3	178	0.54%	4	0.67%
sbar	-3	192	0.27%	3	0.40%	cbar	-4	170	0.52%	1	0.17%
c	4	163	0.23%	1	0.13%	c	4	159	0.48%	2	0.34%
cbar	-4	146	0.21%	0	0.00%	omega+	-3334	22	0.07%	0	0.00%
omega-	3334	18	0.03%	1	0.13%	anti-cascade_c0	-4132	18	0.05%	1	0.17%
cascade_c0	4132	9	0.01%	0	0.00%	cascade_c-	-4232	2	0.01%	0	0.00%
cascade_c+	4232	4	0.01%	0	0.00%						
lmabda_b0	5122	1	0.00%	0	0.00%						
Total #		70432		753		Total #		32856		594	

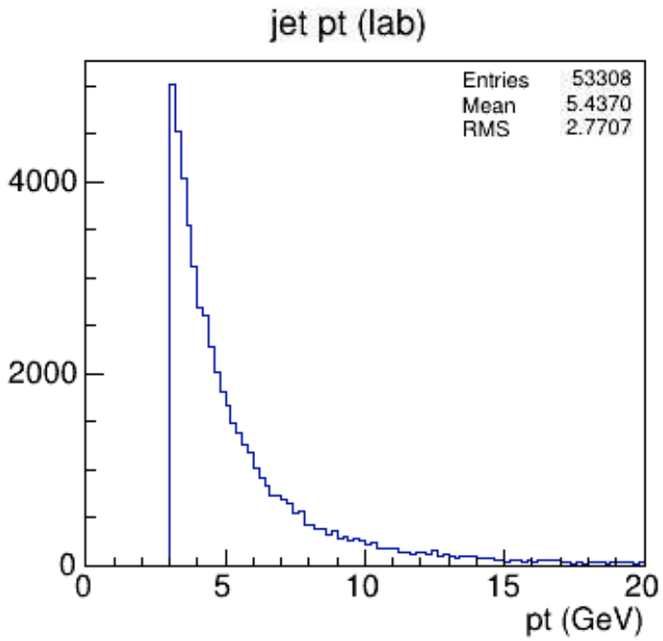
Cuts:

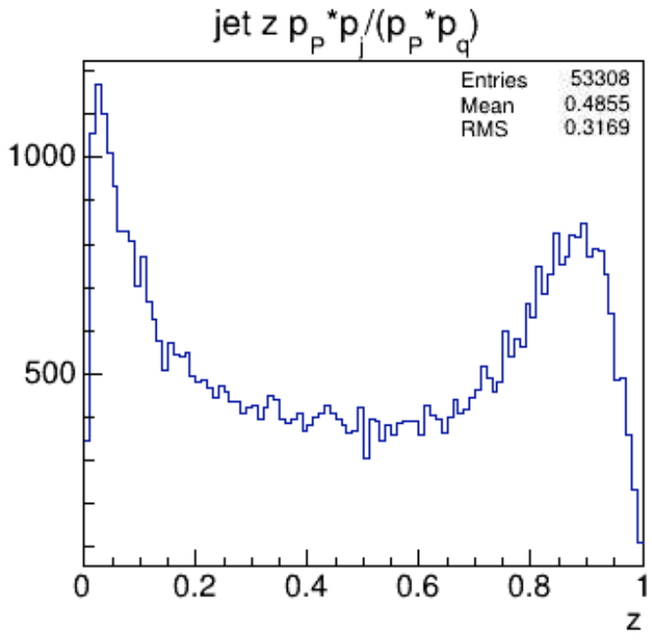
p+pi decay only

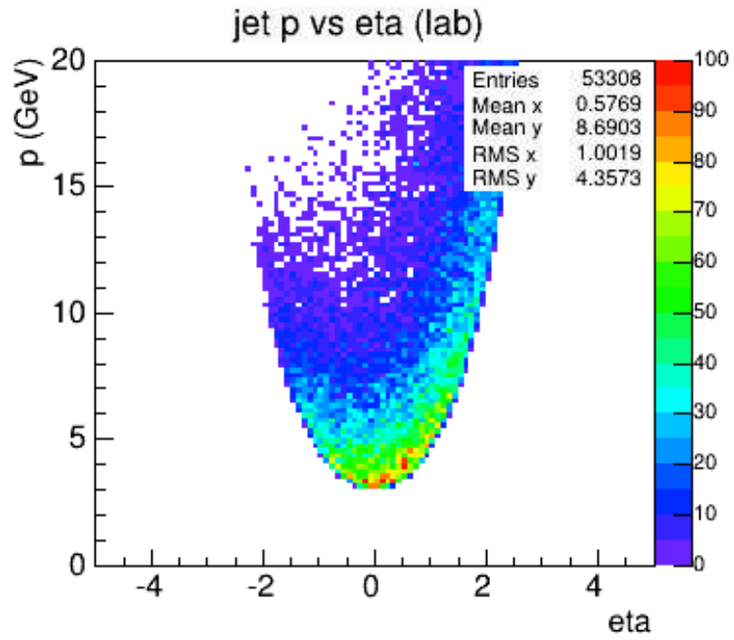
p/pi eta (-3.5, 3.5) && p/pi pt >0.3 GeV

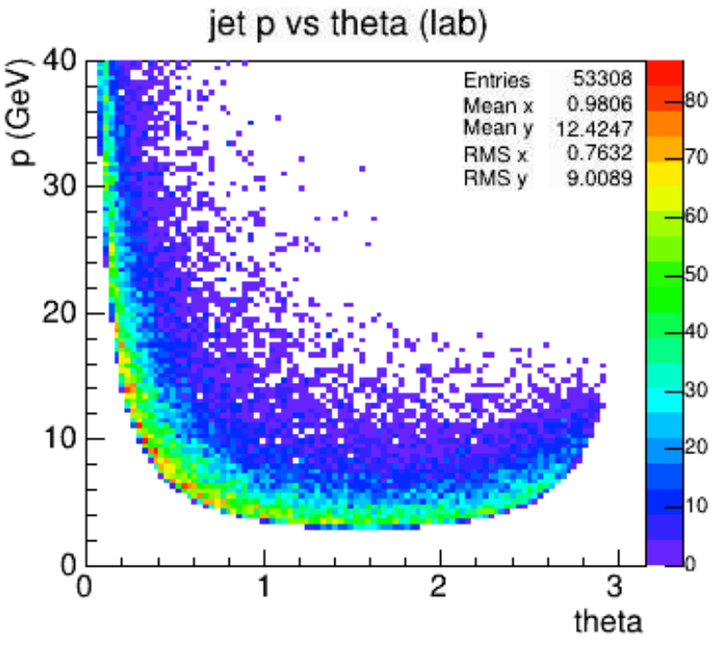
&& xF > 0 && z > 0.1

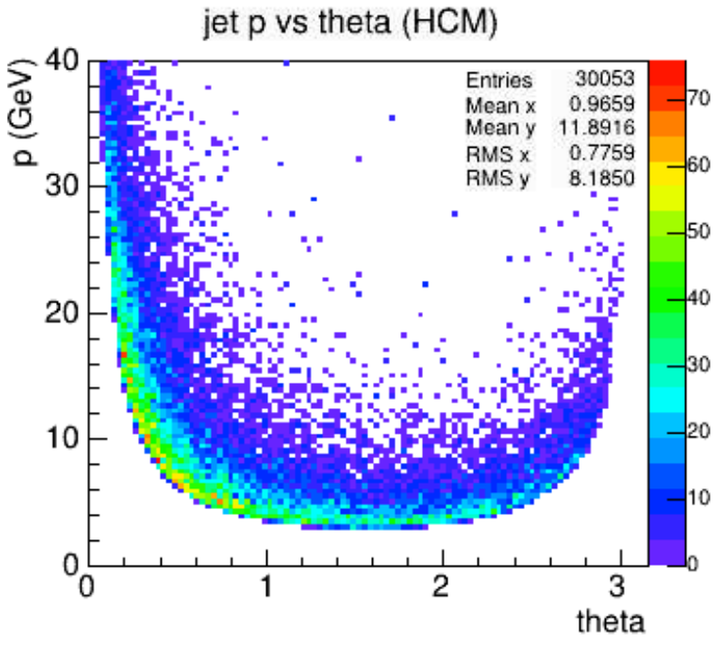
Jet reconstruction

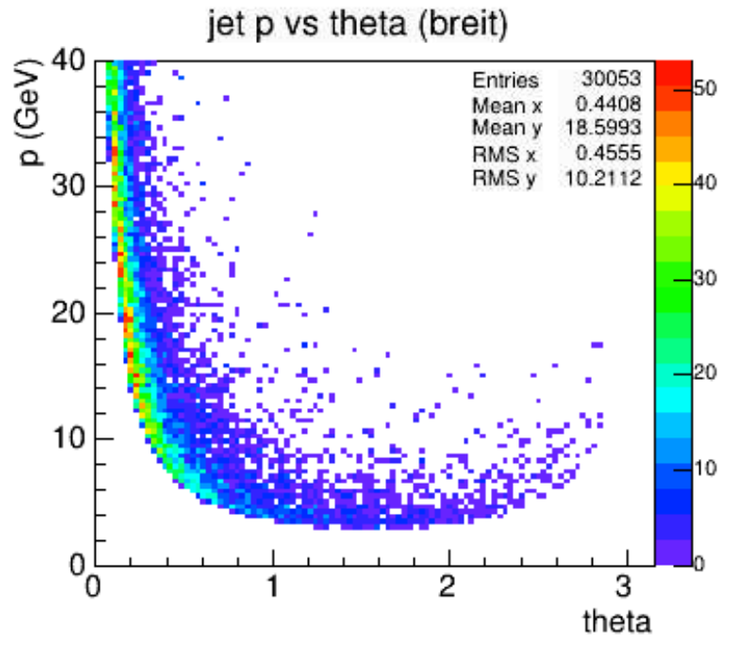




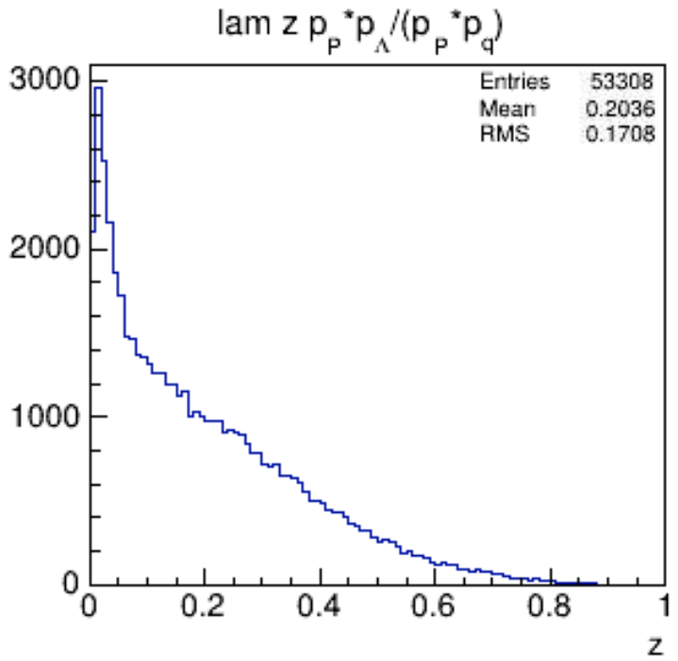


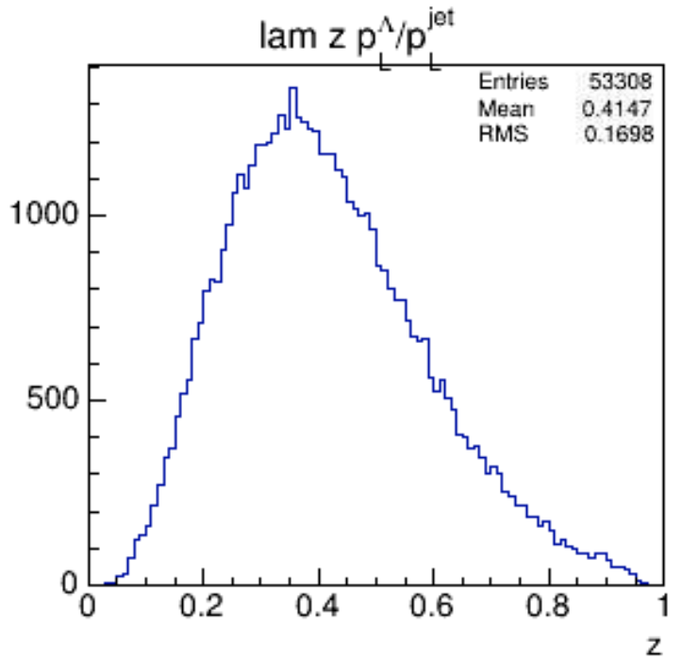


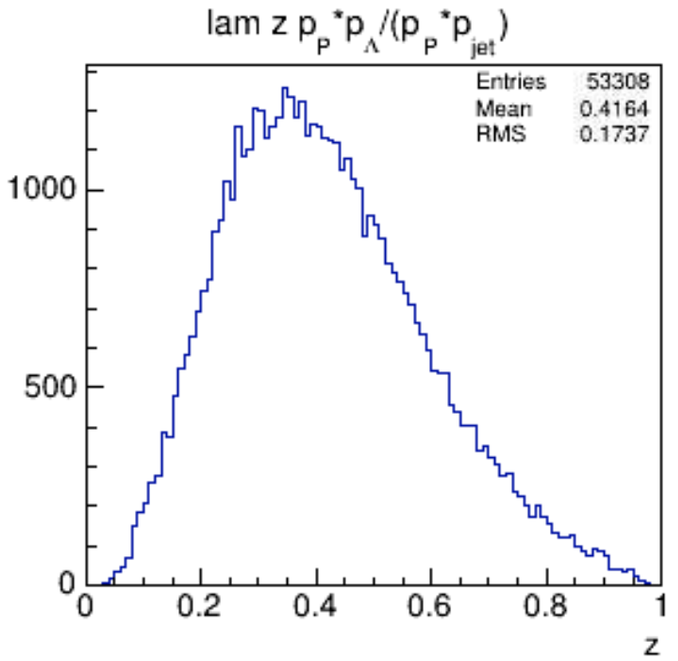


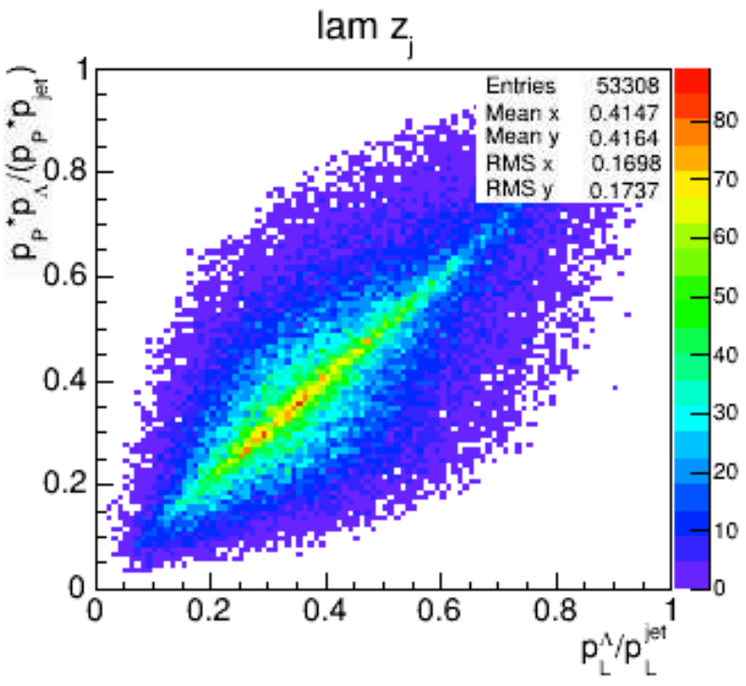


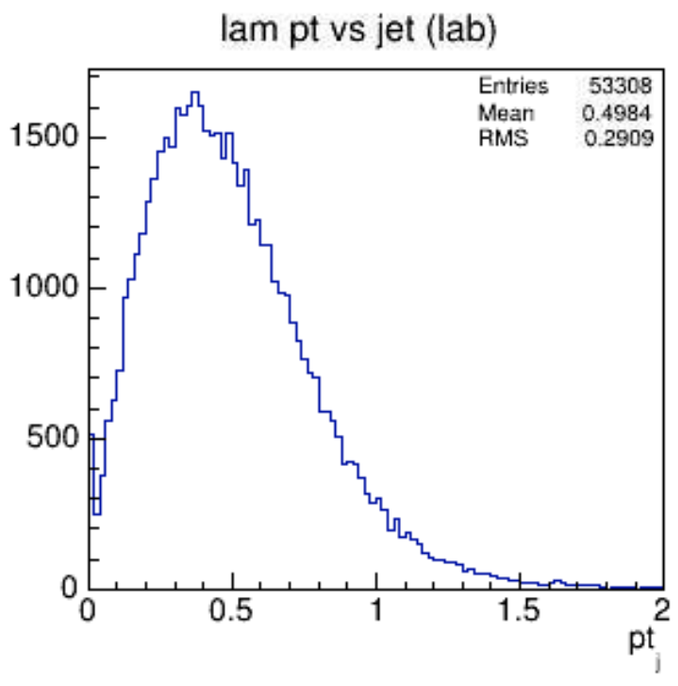
Lambda in jet







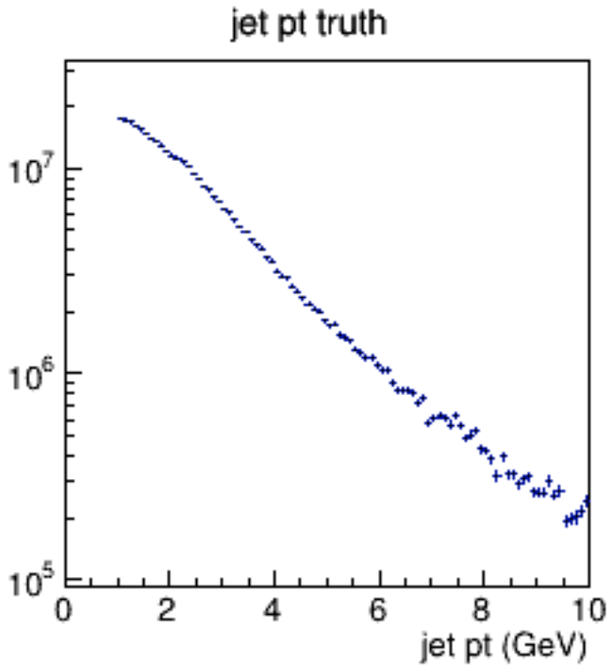


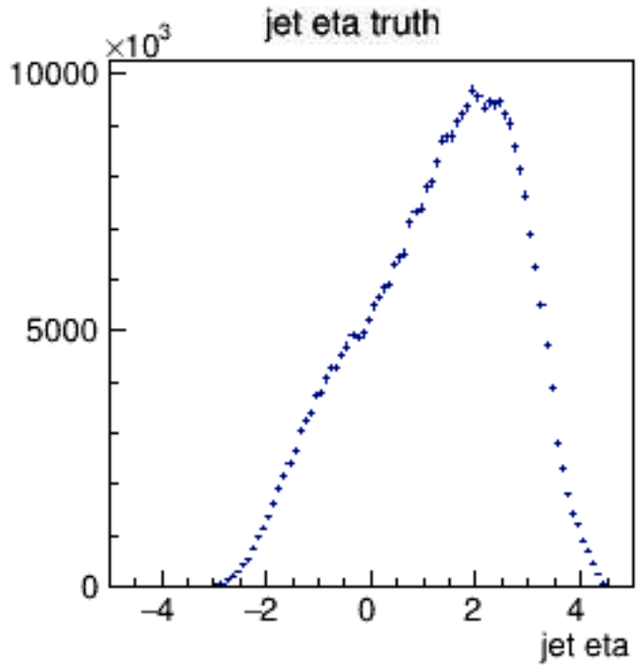


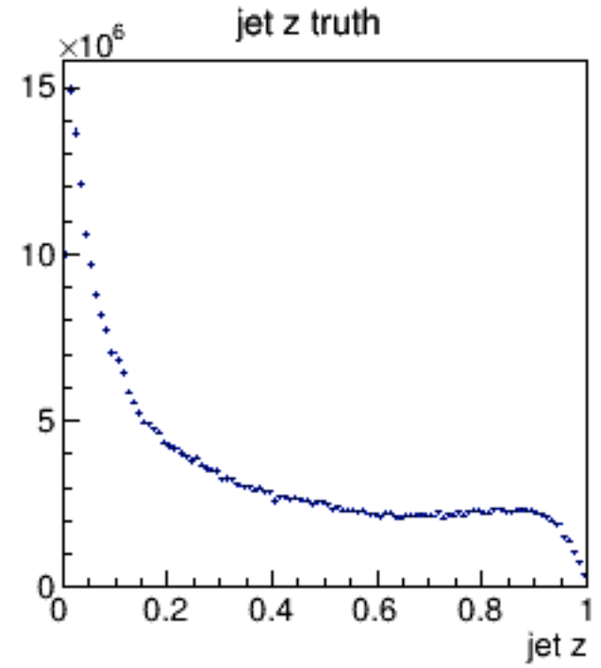
Jet smearing

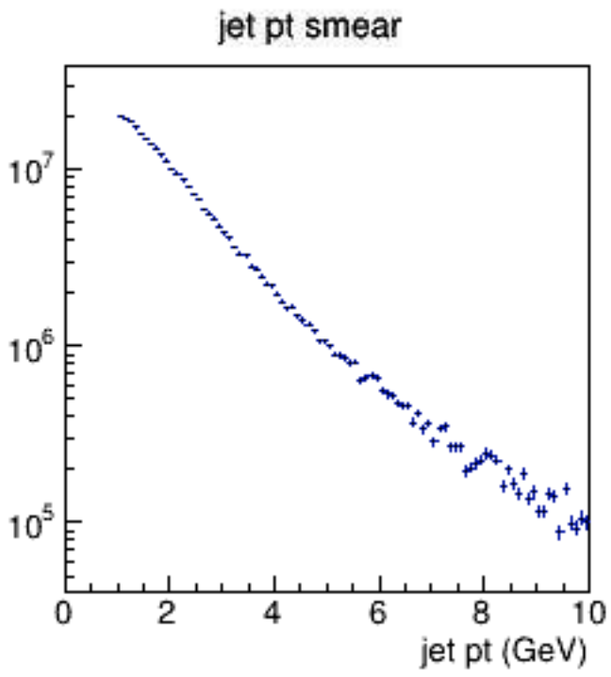
charged pion, charged kaon, proton	px, py, pz smeared, E calculated from mass
Neutron, K0 long	E, theta, phi smeared, pT calculated (mass)
gamma	E, theta, phi smeared, pT calculated
Electron	px, py, pz, E smeared

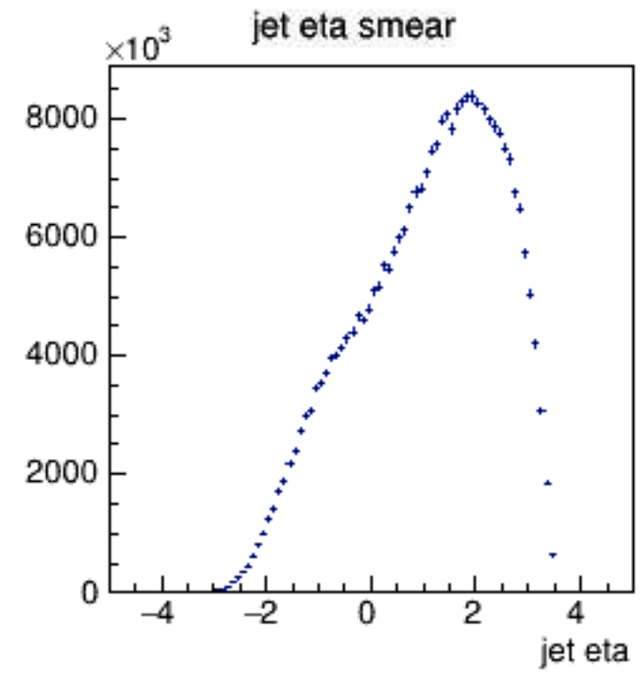
Jet projection 18x275

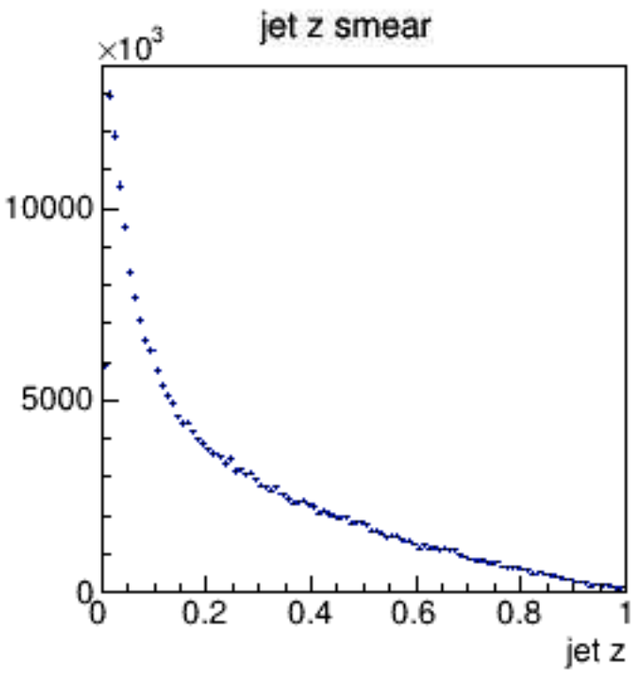






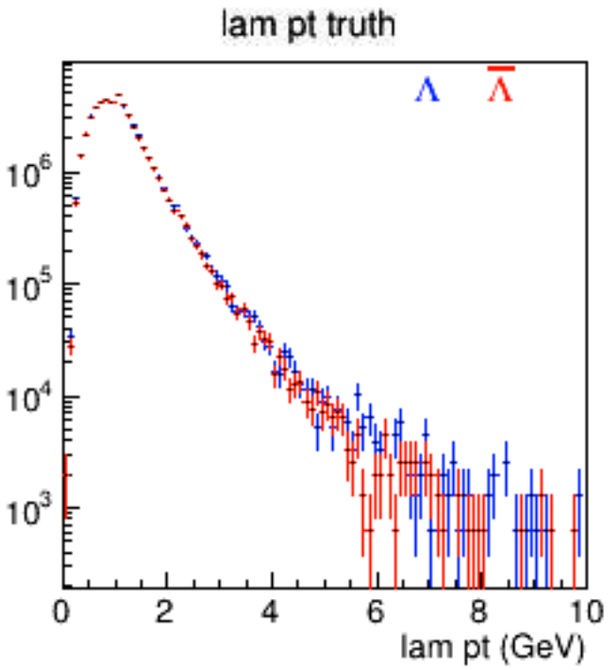


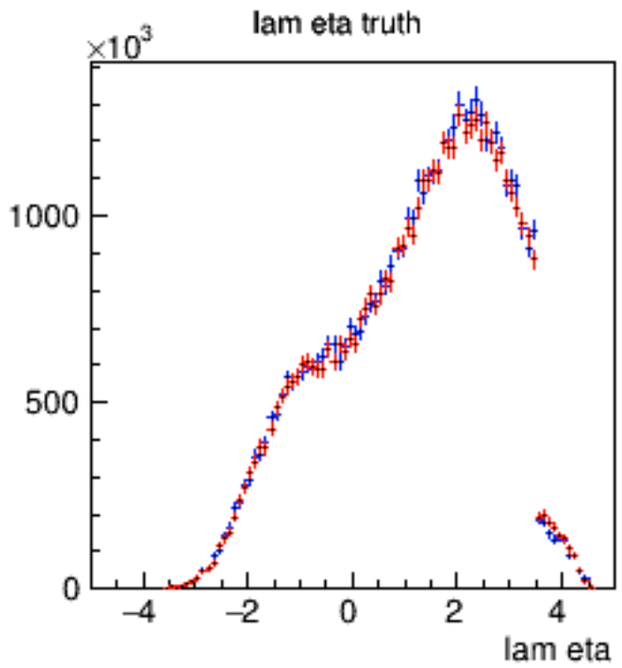


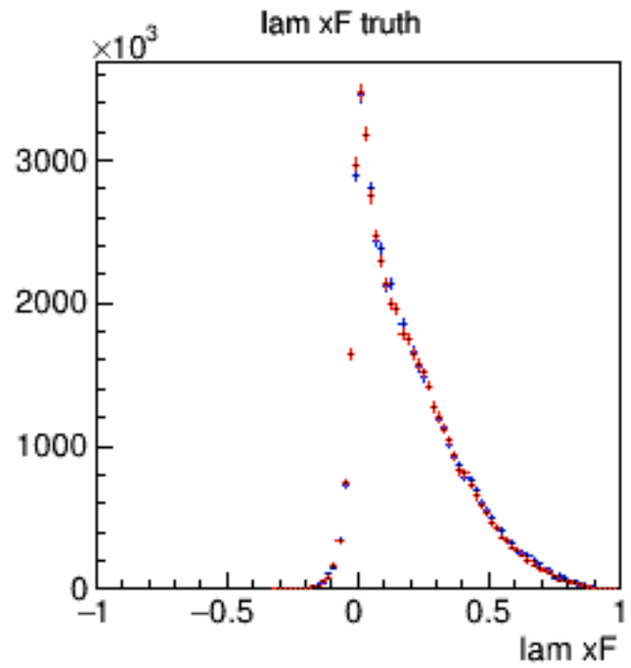


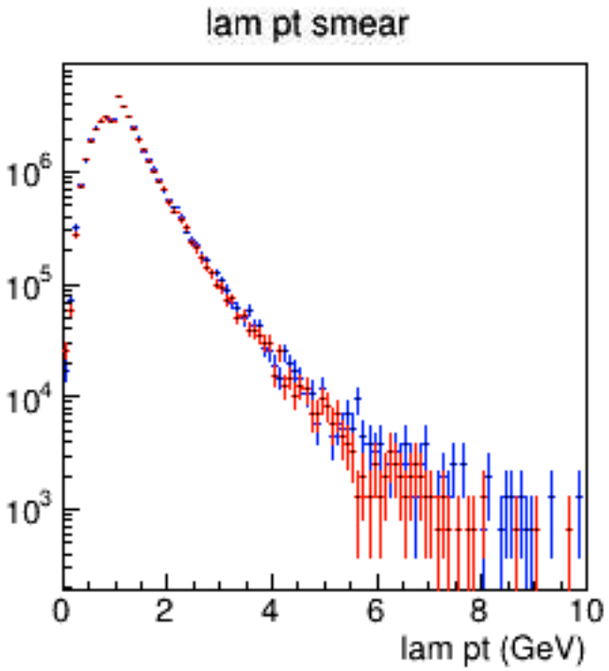
Lambda projections

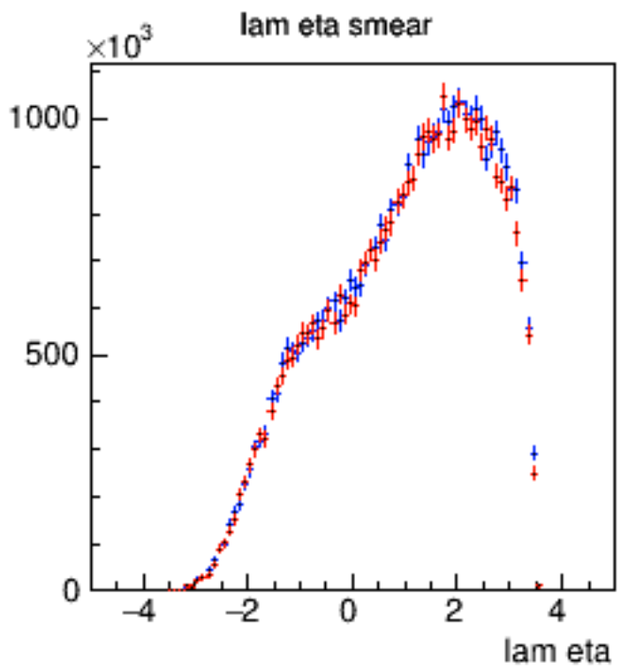
10 fb^-1 18x275

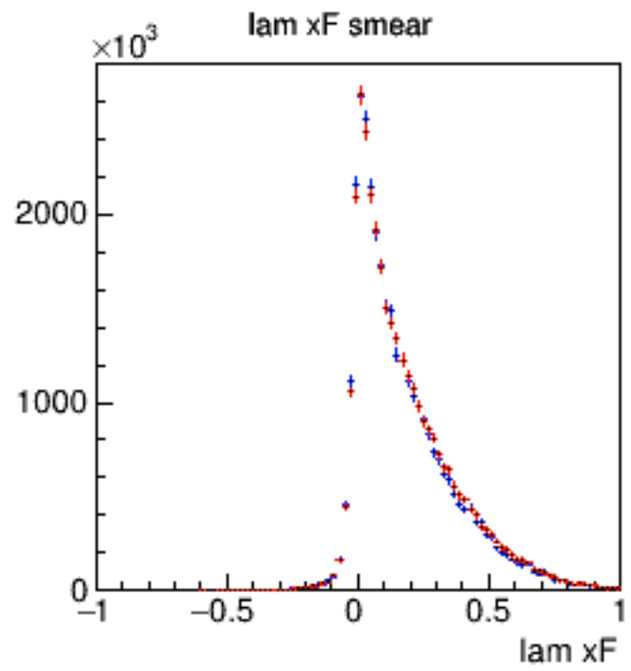






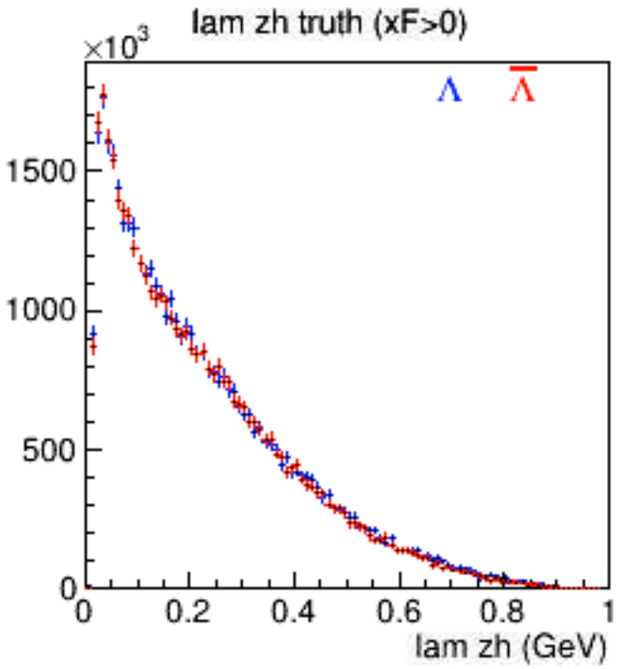


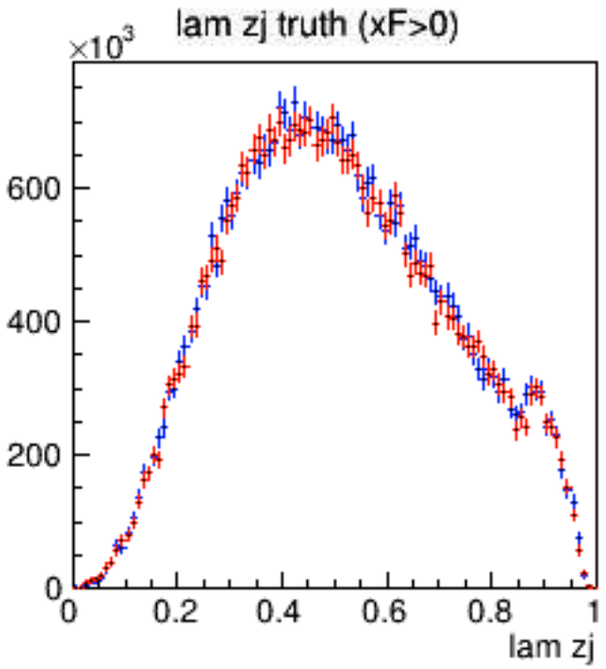


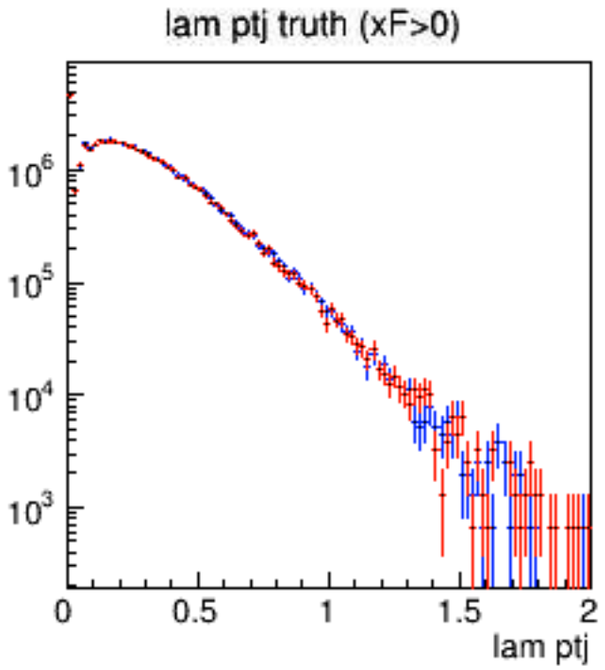


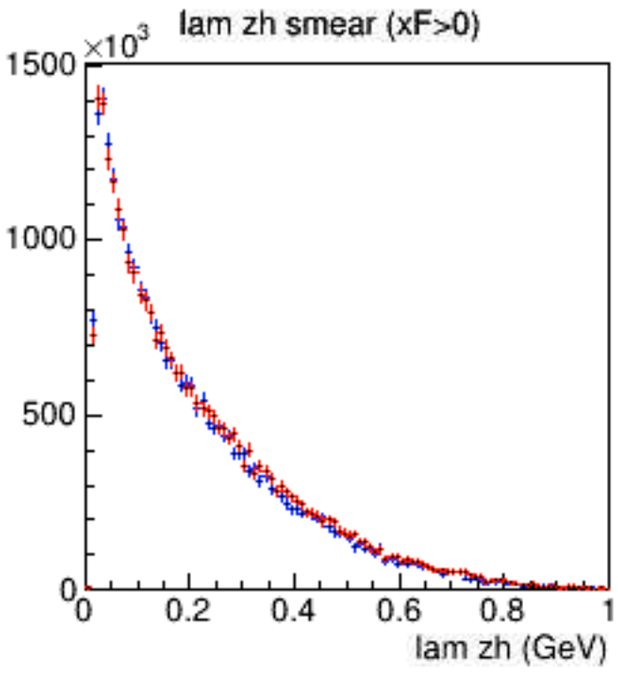
Lambda in jet

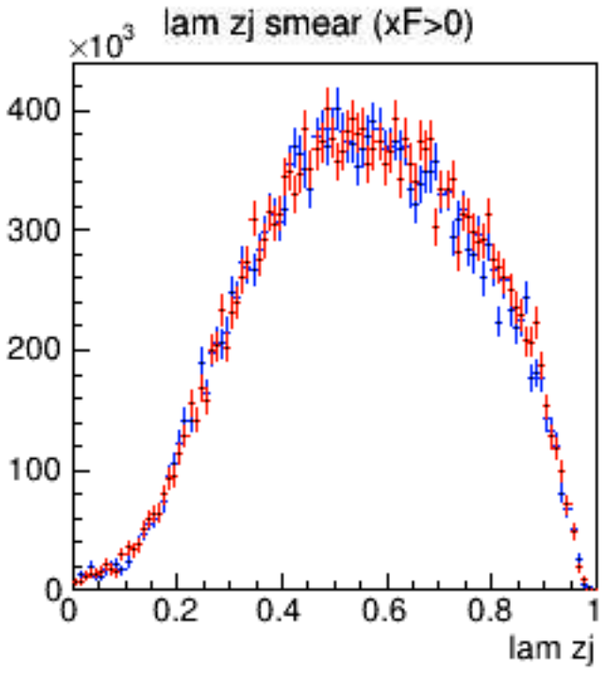
18x275

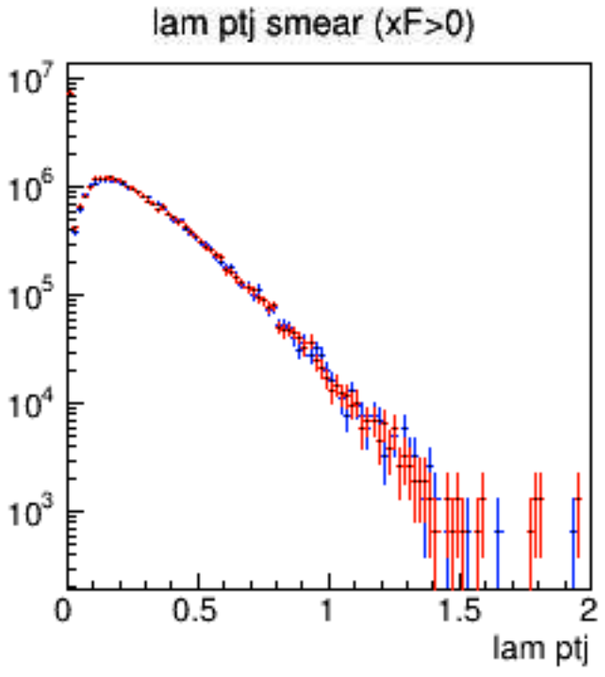












Summary and next step

- Millions of “good” Lambda/anti-lambda sample is expected from 10 fb-1 EIC data
- Simulation and analysis frame developed
- Next Steps:
  - Produce theoretical curves based on inputs from theorists (Kang et al)
  - Precision projections