Triple Top Model (ML)

David Lai

One Higgs Doublet Model (SM)

- 4 parameters: 4 degrees of freedom in the Higgs field
- Higgs field gives [massless W1, W2, Z] mass, performing W+, W-, Z bosons. Each mass giving loses one degree of freedom to Higgs field. Higgs field is left with 1 degree of freedom.

Higgs field before Spontaneous Symmetry Breaking:

$$\phi_H = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \begin{pmatrix} \phi_1^+ + i\phi_2^+ \\ \phi_1^0 + i\phi_2^0 \end{pmatrix},$$

with $\phi^+, \phi^0 \in \mathbb{C}$ and $\phi_1^+, \phi_2^+, \phi_1^0, \phi_2^0 \in \mathbb{R}$.

Two-Higgs Doublet Model (2HDM)

- motivation: in search for extra Higgs bosons (A, H)
- Without the Z2 symmetries (each type of charged fermions couples to a single Higgs doublet) offers extra Yukawa couplings that induce flavor-changing neutral Higgs (FCNH) interactions.
- there are five physical scalar states, the CP even neutral Higgs bosons h and H (where H is heavier than h by convention), the CP odd pseudoscalar A and two charged Higgs bosons $H\pm$.
- neutral charge (h, H, A) and +- charged ($H \pm$)

Two-Higgs Doublet Model (2HDM)

- similar to below notation, two Higgs Doublet Model has another Psi', which gives additional 4 degree of freedom.
- Combining with one Higgs model, it has 5 degrees of freedom.

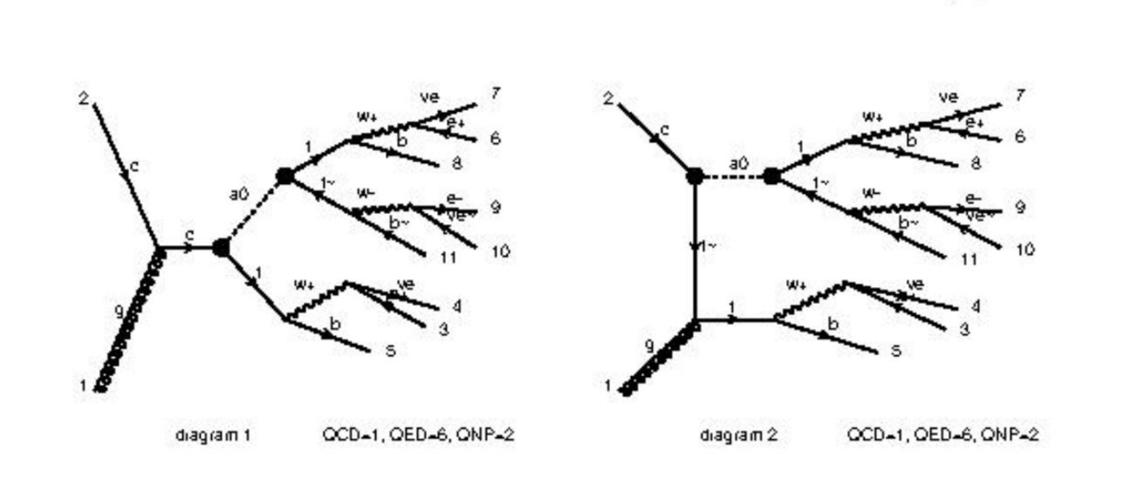
Before Spontaneous Symmetry Breaking:

$$\phi_H = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \begin{pmatrix} \phi_1^+ + i\phi_2^+ \\ \phi_1^0 + i\phi_2^0 \end{pmatrix},$$

with $\phi^+, \phi^0 \in \mathbb{C}$ and $\phi_1^+, \phi_2^+, \phi_1^0, \phi_2^0 \in \mathbb{R}$.

Triple Top

- Triple-top signature: denoted as 3b3l, defined as at least three leptons and at least three jets, of which at least three are b-jets, and E_T_miss.
- Dominant SM backgrounds are ttZ + jets and 4t
- ug, cg -> tS (S = H, A) -> tt t-bar
- SM: cg -> c -> s + W+

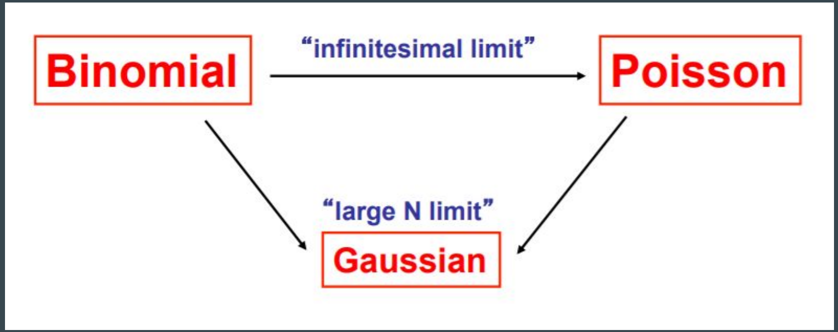


Overview (11.19.2021)

- Binomial, Poisson, Gaussian Distribution
- Cross Section vs Mass Update
- Kinematic Plots
- Branching Ratio & Decay width
- Monte Carlo

Binomial, Poisson, Gaussian Distribution

- Binomial Distribution
  - random process with 2 outcomes with probability p and (1-p)
  - repeat process a **fixed number of times** -> distribution of outcomes
- Poisson distribution
  - **discrete** random process with **fixed mean**
- Gaussian distribution
  - **continuous** high statistics limit



Binomial Distribution

- applies for **a fixed number of trials** when there are **two possible outcomes**
  - i.e. tossing a coin ten times
- sample mean = (number of trials) * (probability)
- variance = np*(1-p)
- Efficiency uncertainty
  - best estimate of efficiency = ε = k/n
  - σ^2 = ε*(1- ε)/n
    - i.e. 90/100 events pass trigger requirements
    - ε = 0.90 ± 0.03

$$\Pr(k;n,p) = \Pr(X=k) = \binom{n}{k} p^k (1-p)^{n-k}$$

$$\binom{n}{k} = \frac{n!}{k!(n-k)!}$$

Poisson Distribution

$$\Pr(X{=}k) = \frac{\lambda^k e^{-\lambda}}{k!},$$

$$\lambda = \mathrm{E}(X) = \mathrm{Var}(X).$$

- **discrete** random process with **fixed mean (λ)**
- From binomial distribution,

$$p(n;\mu) = \lim_{N\to\infty} \delta p^n (1-\delta p)^{N-n} \frac{N!}{n!(N-n)!}$$

$$\delta p = \mu \frac{\delta t}{t} = \frac{\mu}{N}$$

- For N events, the estimated uncertainty on the mean of the underlying Poisson distribution is √N

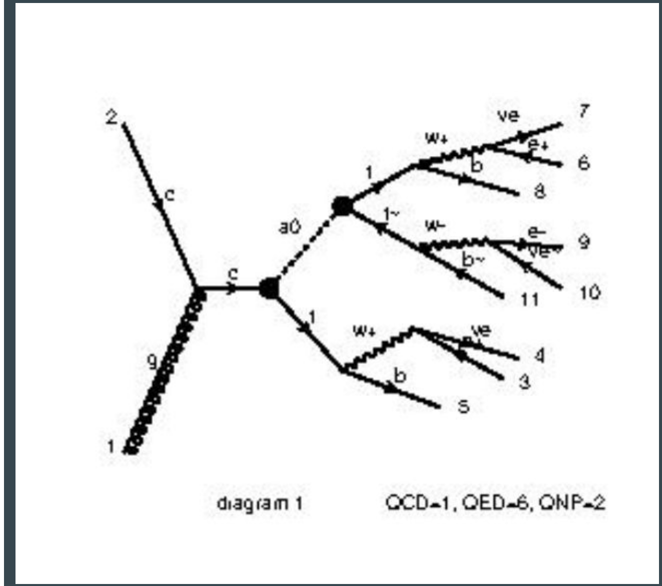
Gaussian Distribution

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

- parameters: mean (μ) & standard deviation (σ)
- property:
  - The mean, mode and median are all equal.
  - The curve is symmetric at the center (mean)
  - The total area under the curve is 1.
- Empirical Rule
  - 1σ: 68%, 2σ: 95%, 3σ: 99%

Particle Information Print Out

	mass	PID	Particle	mother1	mother2	e	px	py	pz	status
0	0.000000	21.0	g	0.0	0.0	1018.060894	0.000000	0.000000	1018.060894	-1.0
1	0.000000	4.0	c	0.0	0.0	183.401074	-0.000000	-0.000000	-183.401074	-1.0
2	171.421532	6.0	t	1.0	2.0	345.742140	-172.122123	-73.367527	234.826460	2.0
3	81.170992	24.0	W+	3.0	3.0	325.724657	-171.837734	-72.954573	254.277892	2.0
4	400.718307	5000001.0	A0	1.0	2.0	537.569126	203.257324	82.517533	283.342055	2.0
5	170.645900	6.0	t	5.0	5.0	216.841820	122.618484	-23.747535	47.969922	2.0
6	78.950911	24.0	W+	6.0	6.0	140.894814	101.527050	-54.664804	-17.947690	2.0
7	172.252943	-6.0	t~	5.0	5.0	320.727306	80.638840	106.265069	235.372133	2.0
8	79.106743	-24.0	W-	8.0	8.0	125.778071	-18.329159	61.904986	73.444271	2.0
9	0.000000	-11.0	e+	4.0	4.0	265.151122	-135.413661	-34.116438	225.398151	1.0
10	0.000000	12.0	ve	4.0	4.0	60.573536	-36.424072	-38.838135	28.879741	1.0
11	4.700000	5.0	b	3.0	3.0	20.017482	-0.284389	-0.412954	-19.451432	1.0
12	0.000000	-13.0	mu+	7.0	7.0	75.896123	71.829300	2.797157	-24.350546	1.0
13	0.000000	14.0	vu	7.0	7.0	64.998691	29.697750	-57.461961	6.402856	1.0
14	4.700000	5.0	b	6.0	6.0	75.947006	21.091434	30.917268	65.917612	1.0
15	0.000000	11.0	e-	9.0	9.0	81.863410	22.012870	52.348036	58.963842	1.0
16	0.000000	-12.0	ve	9.0	9.0	43.914660	-40.342029	9.556950	14.480429	1.0
17	4.700000	-5.0	b~	8.0	8.0	194.949235	98.967999	44.360083	161.927863	1.0
18	0.000000	21.0	g	1.0	2.0	318.150702	-31.135201	-9.150006	316.491304	1.0



Cross Section Uncertainty

- Cross section uncertainty is an estimation of the statistic error.
- For small number of events (~100 events) generation, one would expect ~8% for the statistical uncertainty
- The statistical error decreases when one increases the number of events.

Collider	Banner	Cross section (pb)	Events
p p 7000.0 x 7000.0 GeV	tag_1	0.03485 ± 7.7e-05 ± systematics	10000
p p 7000.0 x 7000.0 GeV	tag_1	0.02053 ± 4.3e-05 ± systematics	10000
p p 7000.0 x 7000.0 GeV	tag_1	0.01266 ± 2.5e-05 ± systematics	10000
p p 7000.0 x 7000.0 GeV	tag_1	0.007965 ± 1.6e-05 ± systematics	10000

```
MS0 400 σ: 0.22095%
MS0 500 σ: 0.20945%
MS0 600 σ: 0.19747%
MS0 700 σ: 0.20088%
```

Figure: p p -> t t~ S0, with rho_tt = 1 & MS0 = [400, 500, 600, 700]

Cross Section vs Mass

Previous : QCD=99; Use pdf set 274000

Current: Turn off QCD=99; Use default pdf set 230000

Paper:

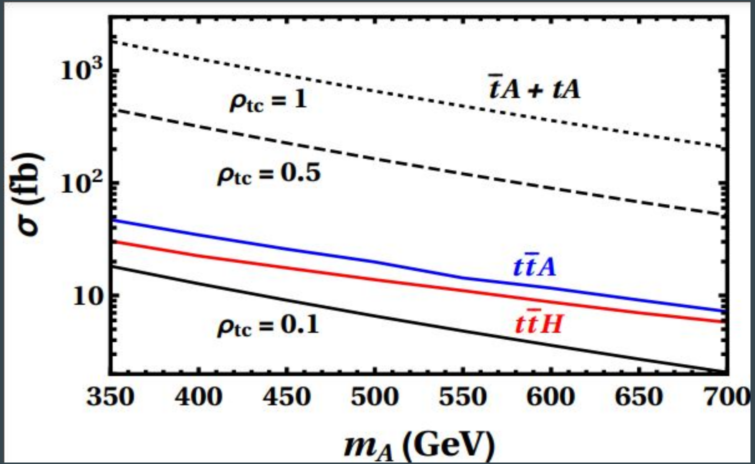
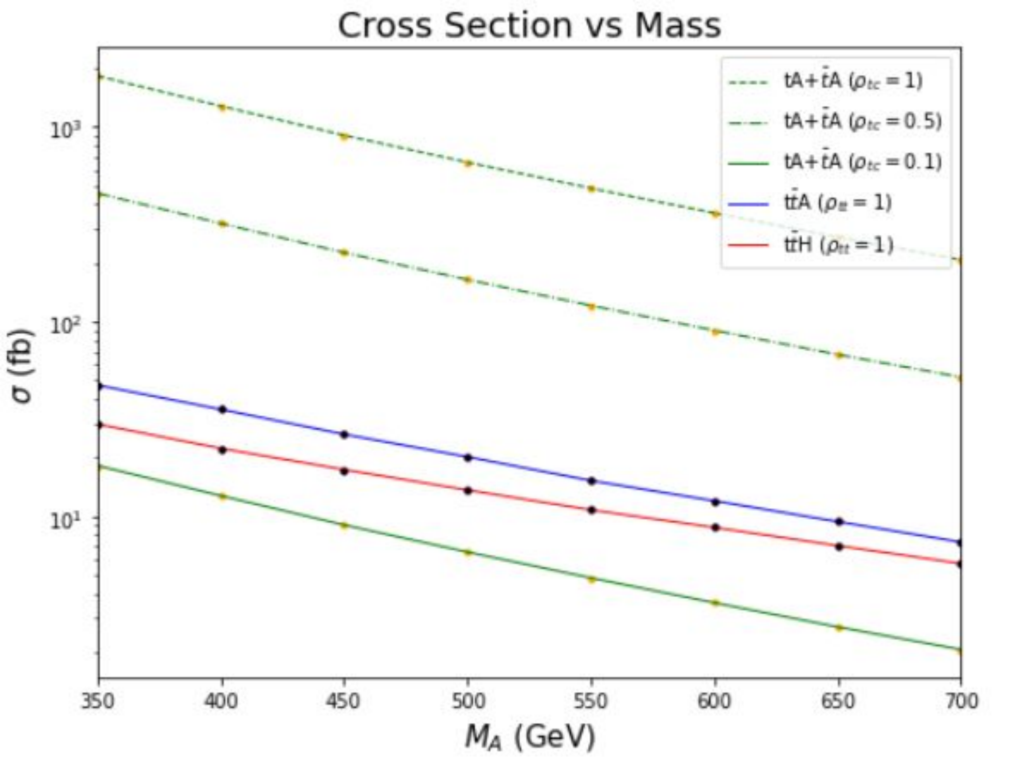
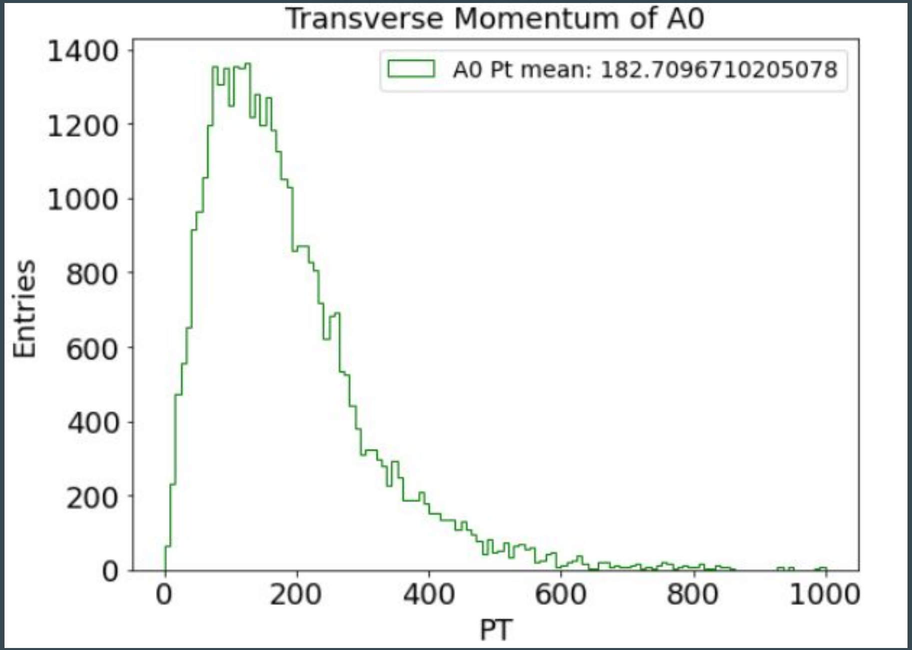


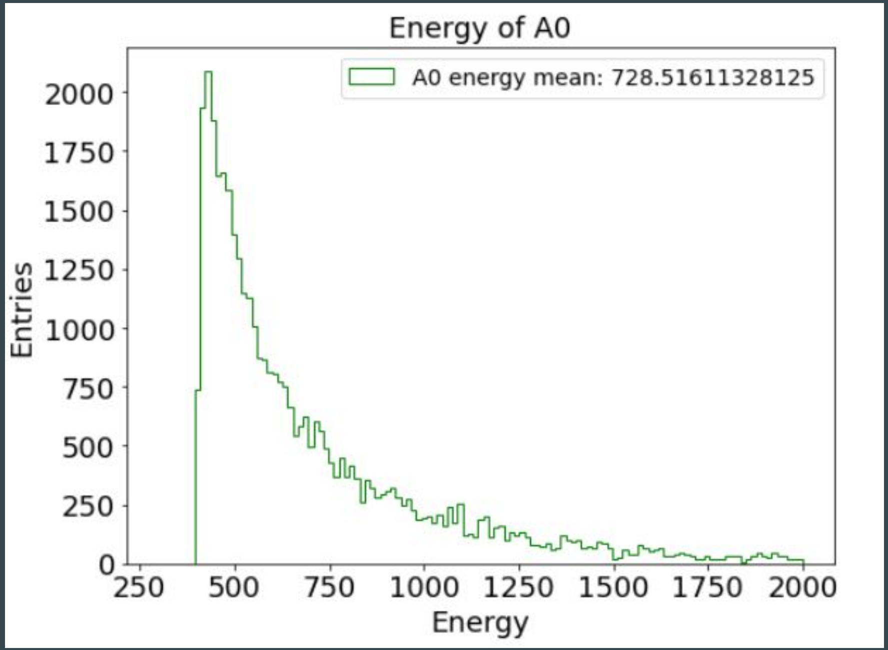
FIG. 1. Cross sections at $\sqrt{s} = 14$ TeV for $pp \to tS^0$, $\bar{t}S^0$ where $S^0 = H^0$, A^0, for $\rho_{tc} = 0.1$ (solid), 0.5 (dashed) and 1 (dots), and $pp \to t\bar{t}H^0$, $t\bar{t}A^0$ (for $\rho_{tt} = 1$) as marked.

My Result:

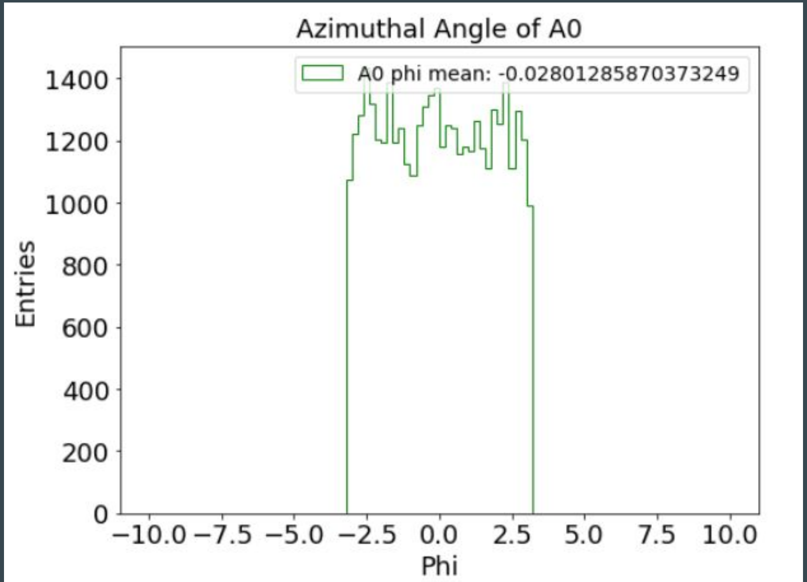


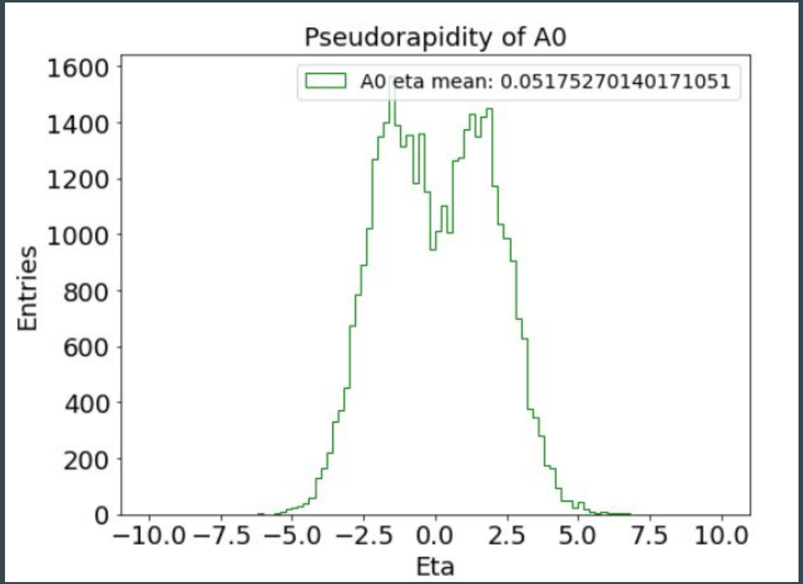
Kinematic Plots (A0 400GeV)



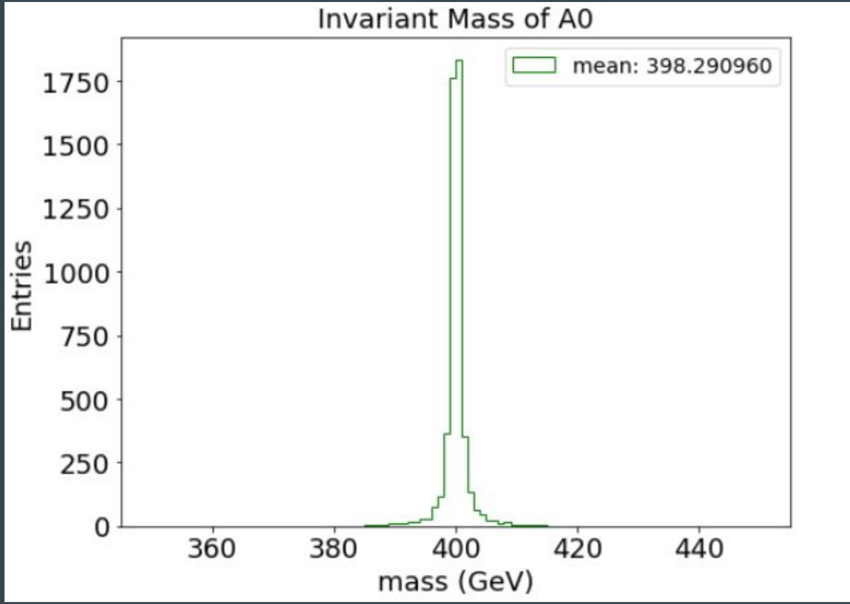


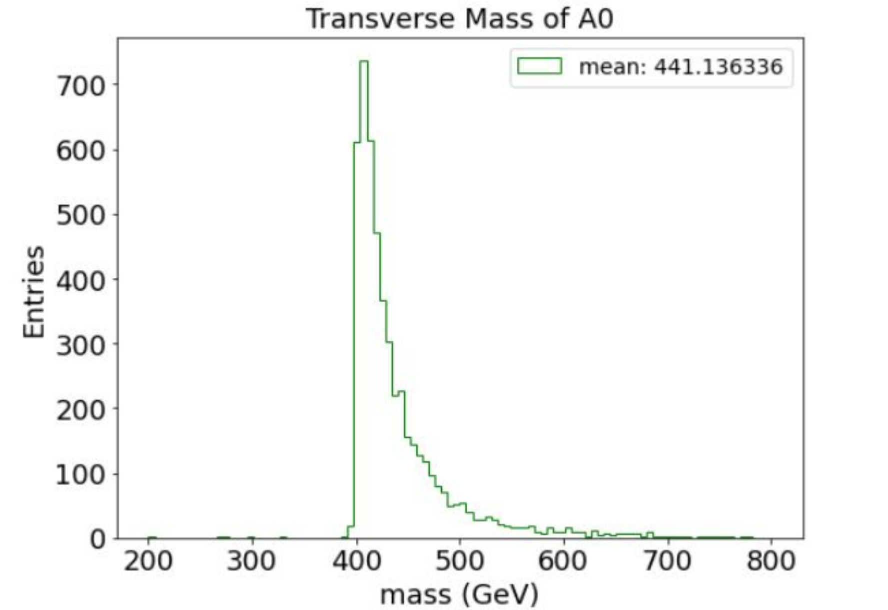
Kinematic Plots (A0 400GeV)





Kinematic Plots (A0 400GeV)





Decay Width

- Γ_tt + Γ_tc~t~c

A decay width

A → f fbar (Will be used for A → t tbar decay)

In[92]:= $\Gamma\text{Affbar}[rff\_, MA\_, mf\_, Nc\_] := \dfrac{Nc\,\sqrt{\lambda[MA^2, mf^2, mf^2]}}{8\,\pi\,MA^3}\left(\left(\text{Abs}\left[-\dfrac{\text{i}\,rff}{\sqrt{2}}\right]\right)^2 MA^2\right);$

In[124]:= ΓAffbar[1, 400, mt, 3]

Out[124]= $\dfrac{3\sqrt{651}}{2\,\pi}$

A → t cbar + tbar c

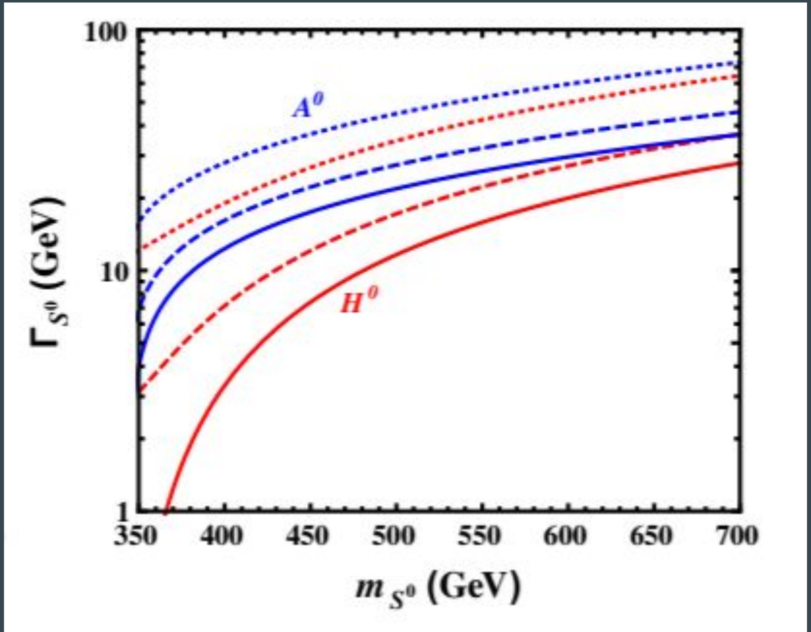
In[94]:= $\Gamma\text{Atc}[rtc\_, MA\_, Nc\_] := Nc\,\dfrac{\sqrt{\lambda[MA^2, mt^2, mc^2]}}{8\,\pi\,MA^3}\,\dfrac{1}{8}\left((rtc)^2\left(MA^2-(mt+mc)^2\right)+(rtc)^2\left(MA^2-(mt-mc)^2\right)\right)$

In[123]:= ΓAtc[0.1, 400, 3]

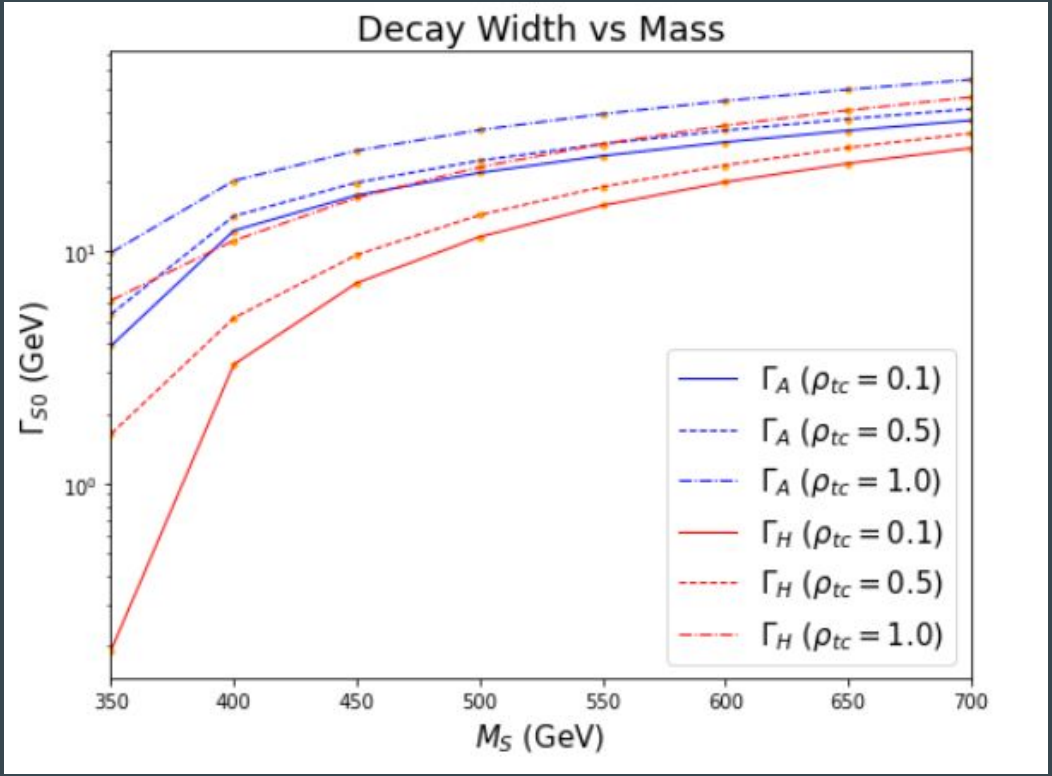
Out[123]= 0.079303

Decay Width vs Mass

Paper:



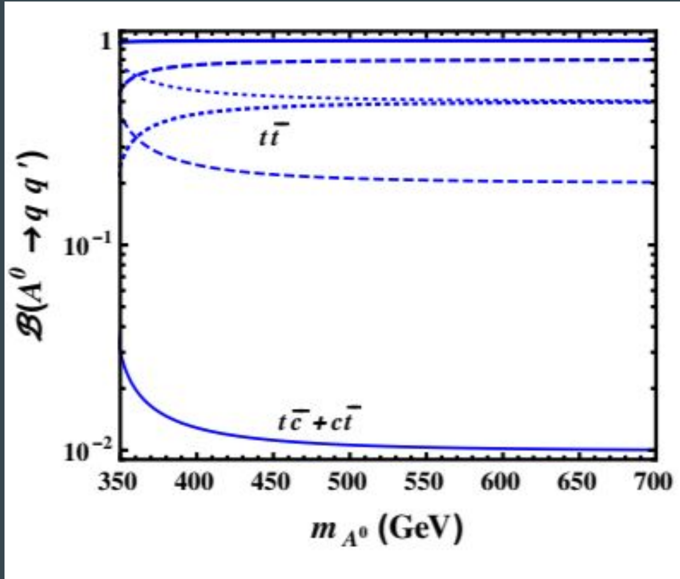
My Result:

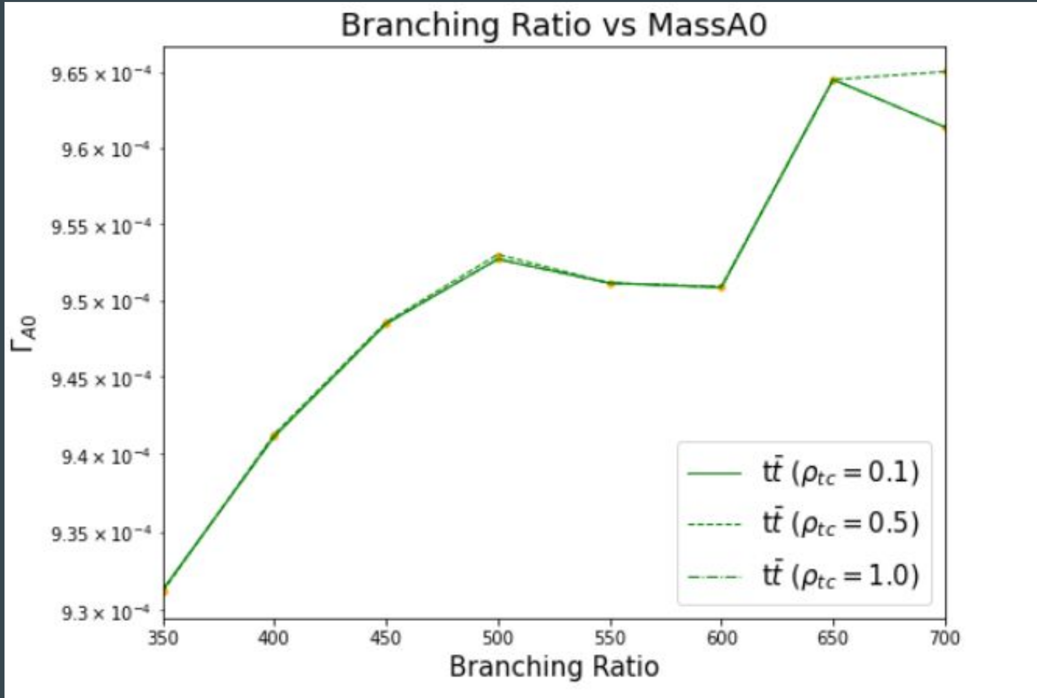


Branching Ratio

- (cross section with t t~ decay) / (cross section with no decay).
- Problem: inconsistent plot & Unable to generate cross section of ct~+c~t
- The branching ratio (branching fraction) is the fraction of events for a chosen particle measured to decay in a certain way. The sum of branching ratios for a particle is one. The branching ratio is defined as the partial decay width divided b y the total width.

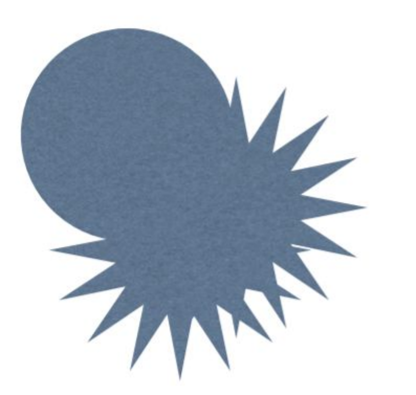
$$BR(i) = \frac{\Gamma_i}{\Gamma}$$

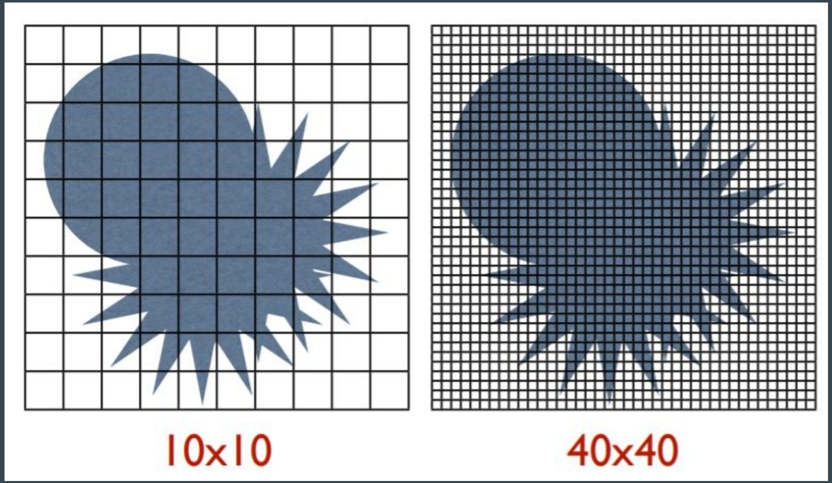




Monte Carlo

- analysis: random sampling -> simulate real world
- variable is random (AKA stochastic)
- PDF of a single stochastic variable
    - defined on an interval [a, b]
    - nonnegative on that interval
    - normalized (integral of f(x) from a to b = 1)

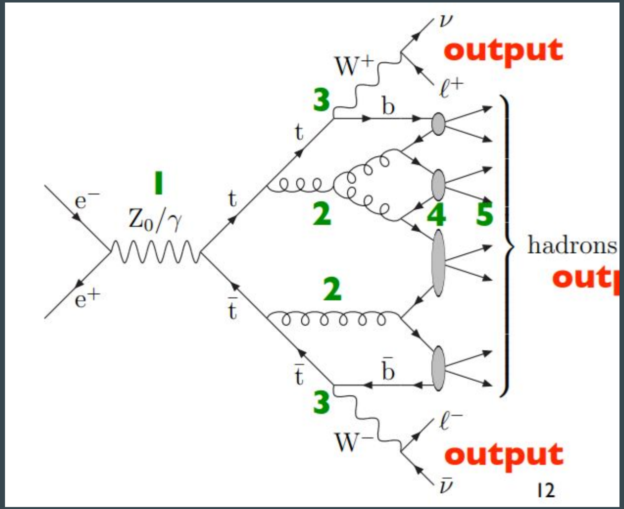




Area = (Number of hits)/(Total squares) * (Total Area)
https://upload.wikimedia.org/wikipedia/commons/8/84/Pi_30K.gif

Monte Carlo

- Central Limit Theorem (CLT) obtains an estimate of an expected value & an estimate of the uncertainty in the estimate.
- MC event generator process: Hard process -> Parton-shower phase -> Hard particles decay before hadronizing -> Hadronization -> Unstable hadrons decay



To-do:

- Analysis flow for particle physics
- derive the mean and variance of binomial distribution
- Branching Ratio (ask Ali)
- Decay Width (ask Tanmoy)
- Decay channel for the signals
    - one, two, three lepton channels (calculate each BR)
- design an analysis for one lepton channels * (read the paper)
- feynman diagrams SM backgrounds/ different processes (focus on one lepton)

Overview

- derive the mean and variance of binomial distribution
- decay width & branching ratio
- analysis flow for particle physics

Binomial Distribution

- applies for **a fixed number of trials** when there are **two possible outcomes**
  - i.e. tossing a coin ten times
- sample mean = (number of trials) * (probability)
- variance = np*(1-p)
- Efficiency uncertainty
  - best estimate of efficiency = ε = k/n
  - σ^2 = ε*(1- ε)/n
    - i.e. 90/100 events pass trigger requirements
    - ε = 0.90 ± 0.03

$$\Pr(k;n,p) = \Pr(X=k) = \binom{n}{k} p^k (1-p)^{n-k}$$

$$\binom{n}{k} = \frac{n!}{k!(n-k)!}$$

Derive mean & variance for Binomial Distribution

$$P(x) = \binom{n}{x} p^x q^{n-x} \quad , \quad \text{expected value} : \; E(x) = \sum_{x=0}^{n} x \binom{n}{x} p^x q^{n-x}$$

$$E(x) = \sum_{x=0}^{n} x \frac{n!}{(n-x)!\, x!} p^x q^{n-x}$$

$$= \sum_{x=1}^{n} \frac{n!}{(x-1)!\,(n-x)!} p^x q^{n-x}$$

$$= \sum_{x=1}^{n} \frac{n(n-1)!}{(x-1)!\,(n-x)!} (p)\, p^{x-1} q^{n-x}$$

$$= np \sum_{x=1}^{n} \frac{(n-1)!}{(x-1)!\,[(n-1)-(x-1)]!} p^{x-1} q^{n-x}$$

$$= np \sum_{x=1}^{n} \binom{n-1}{x-1} p^{x-1} q^{n-x}$$

$$= np \left[{}^{n-1}C_0\, q^{n-1} + {}^{n-1}C_1\, p q^{n-2} + {}^{n-1}C_2\, p^2 q^{n-3} + \cdots + {}^{n-1}C_{n-1}\, p^{n-1} \right]$$

$$= np[p+q]^{n-1} \qquad (\text{Binomial Expansion of } (p+q)^{n-1})$$

$$= np. \qquad (\text{mean})$$

$$Var(x) = E(x^2) - [E(x)]^2$$

$$E(x^2) = \sum_{x=0}^{n} x^2 \binom{n}{x} p^x q^{n-x}$$

$$\Downarrow$$

$$[x(x-1)+x]$$

$$= \sum_{x=0}^{n} [x(x-1)] \binom{n}{x} p^x q^{n-x} + \underbrace{\sum_{x=0}^{n} x \binom{n}{x} p^x q^{n-x}}$$

$$= \sum_{x=2}^{n} \frac{x(x-1)n(n-1)(n-2)!}{(n-x)!\, x(x-1)(x-2)!} p^x q^{n-x} + np.$$

$$= n(n-1)p^2 \sum_{x=2}^{n} \frac{(n-2)!}{(x-2)!\,(n-x)!} p^{x-2} q^{n-x} + np.$$

$$= n(n-1)p^2 \sum_{x=2}^{n} \binom{n-2}{x-2} p^{x-2} q^{n-x} + np.$$

$$= n(n-1)p^2 [p+q]^{n-2} + np.$$

$$E(x^2) = n(n-1)p^2 + np$$

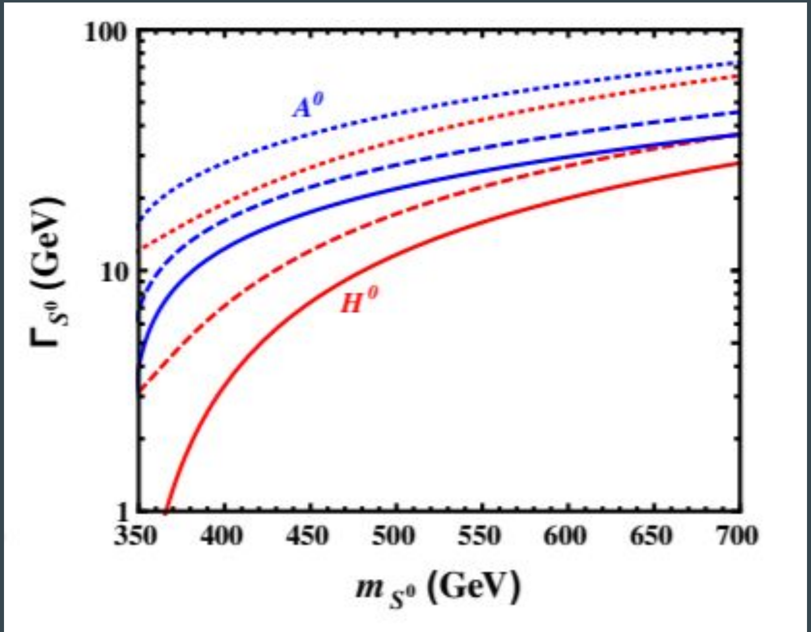
$$Var(x) = n^2p^2 - np^2 + np - n^2p^2$$

$$= np(1-p)$$

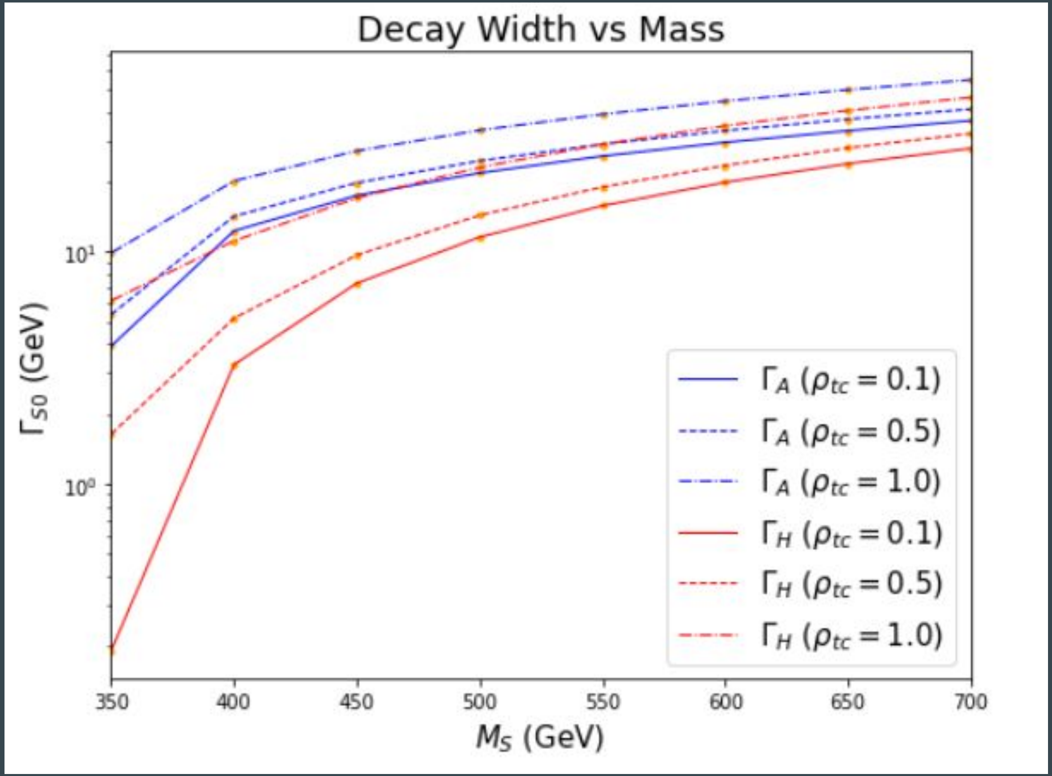
$$= npq$$

Decay Width vs Mass (old)

Paper:



My Result:



Decay Width Calculation

- Γ_tt + Γ_tc~t~c

A decay width

$A \rightarrow$ f fbar (Will be used for $A \rightarrow$ t tbar decay)

In[92]:= $\Gamma\text{Affbar}[rff\_, MA\_, mf\_, Nc\_] := \dfrac{Nc\,\sqrt{\lambda[MA^2, mf^2, mf^2]}}{8\,\pi\,MA^3}\left(\left(\text{Abs}\left[-\dfrac{i\,rff}{\sqrt{2}}\right]\right)^2 MA^2\right);$

In[124]:= ΓAffbar[1, 400, mt, 3]

Out[124]= $\dfrac{3\sqrt{651}}{2\,\pi}$

$A \rightarrow$ t cbar + tbar c

In[94]:= $\Gamma\text{Atc}[rtc\_, MA\_, Nc\_] := Nc\,\dfrac{\sqrt{\lambda[MA^2, mt^2, mc^2]}}{8\,\pi\,MA^3}\,\dfrac{1}{8}\left((rtc)^2\left(MA^2-(mt+mc)^2\right)+(rtc)^2\left(MA^2-(mt-mc)^2\right)\right)$

In[123]:= ΓAtc[0.1, 400, 3]

Out[123]= 0.079303

Decay Width Calculation (new)

Total width for *A* (under the aforementioned assumptions) is sum of A→ t cbar +tbar c + t tbar partial decay widths. If $m_A > m_H + m_Z$ the partial decay width of A→ Z H also needs to added. The following function automatically takes care of these decays once H and A masses are chosen.

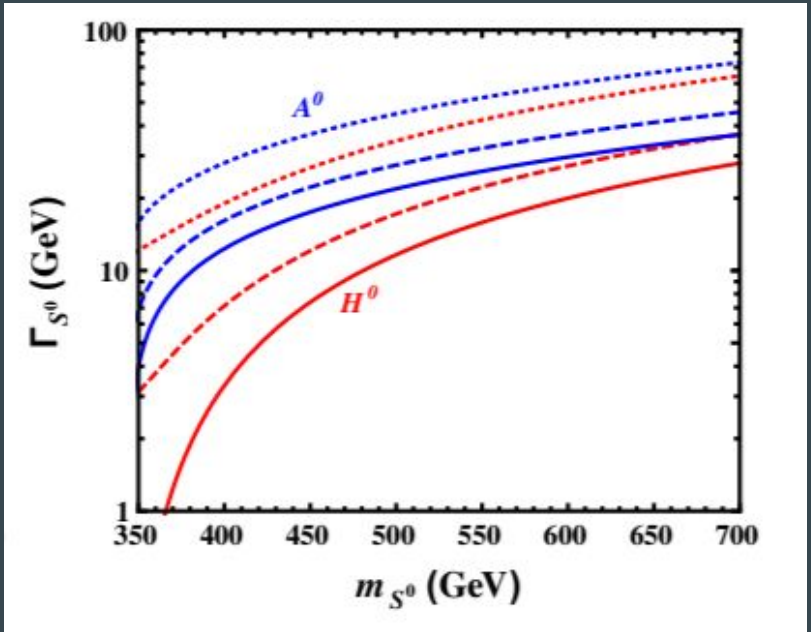
```
In[413]:= ΓtotA[rtt_, rtu_, rtc_, KAZH_, KAZh_, MA_, MH_] := If[MA > mt + mc, 2 ΓAtc[rtc, MA, 3], 0] + If[MA > mt + mu, 2 ΓAtu[rtu, MA, 3], 0] +
    If[MA > 2 mt, ΓAffbar[rtt, MA, mt, 3], 0] + If[MH > 0, If[MA > MH + mZ, ΓAZH[KAZH, MA, MH], 0], 0] + If[MH > 0, If[MA > mh + mZ, ΓAZh[KAZh, MA, MH], 0], 0];

In[452]:= ΓtotA[1, 0, 0.1, 0.37037, 0.37037, 700, 0]

Out[452]= 36.7542
```

Total decay width for *H*

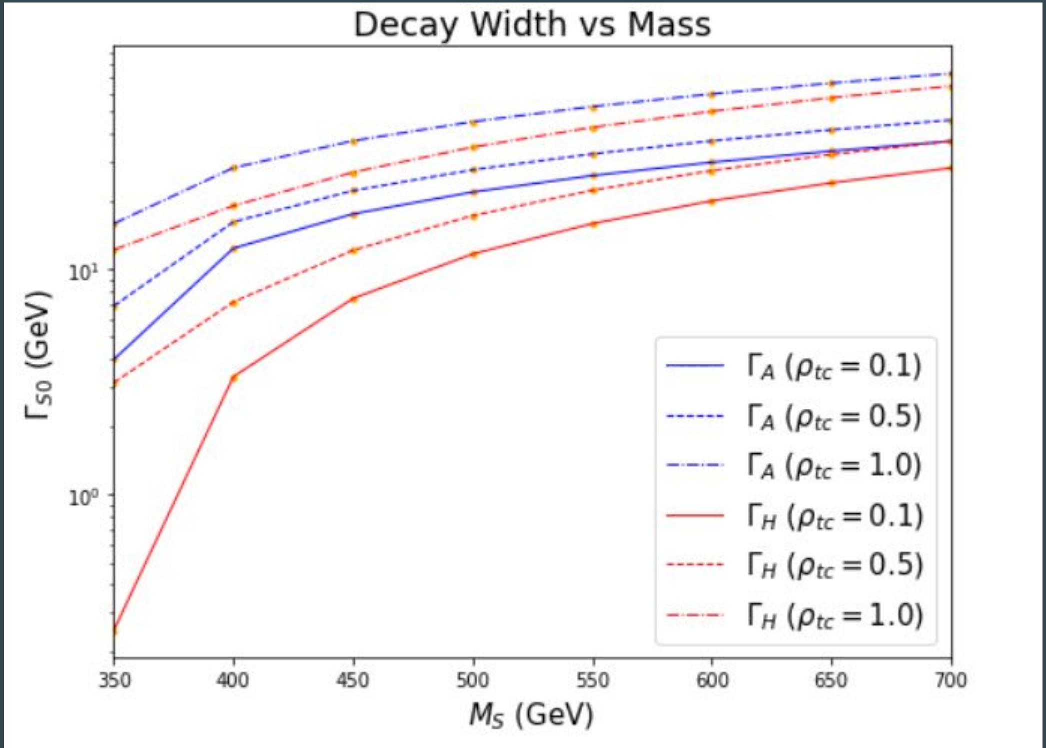
```
In[467]:= ΓtotH[rtt_, rtu_, rtc_, KHAZ_, λHhh_, MA_, MH_] := If[MH > mt + mc, 2 ΓHtc[rtc, MH, 3], 0] + If[MH > mt + mu, 2 ΓHtu[rtu, MH, 3], 0] +
    If[MH > 2 mt, ΓHffbar[rtt, MH, mt, 3], 0] + If[MH > 0, If[MH > MA + mZ, ΓHZA[KHAZ, MH, MA], 0], 0] + If[MH > 2 mh, ΓHhh[λHhh, MH], 0];

In[500]:= ΓtotH[1, 0, 0.1, 0.370372, 1, 700, 700]

Out[500]= 27.9671
```

Decay Width (unscaled)

Paper:



My Result:

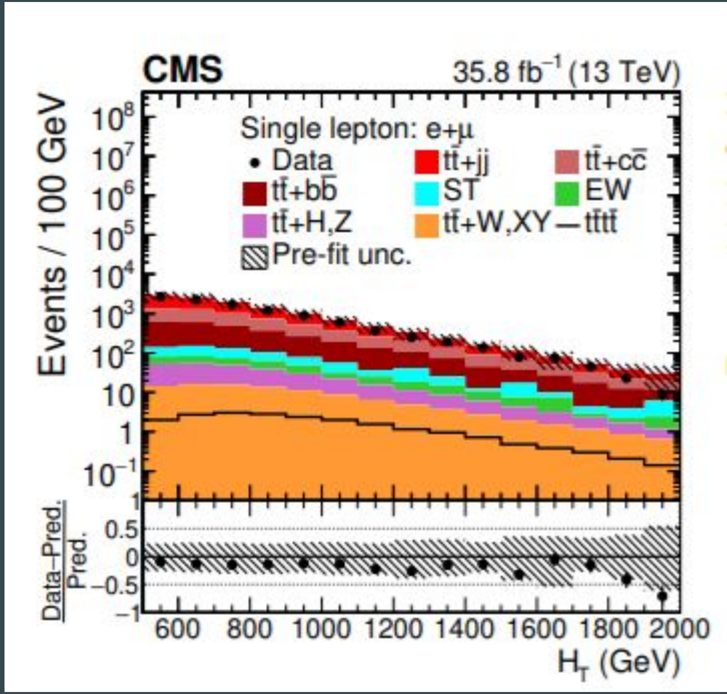


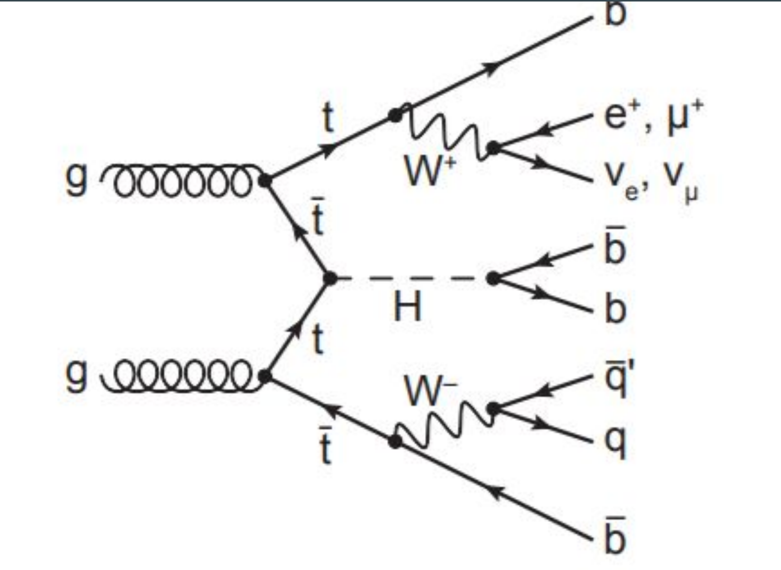
Branching Ratio

4.3. **Branching Ratio.** An unstable particle decays in general in several different decay chains, involving different final states. For each decay chain a **branching ratio** is defined as the probability that the particle decays in that chain. If Γ is the **total width** of the particle and Γ_i is the **partial width** in the decay chain i, we have:

$$BR(i) = \frac{\Gamma_i}{\Gamma} \tag{82}$$

To-do: find/generate Feynman diagram for each decay channel

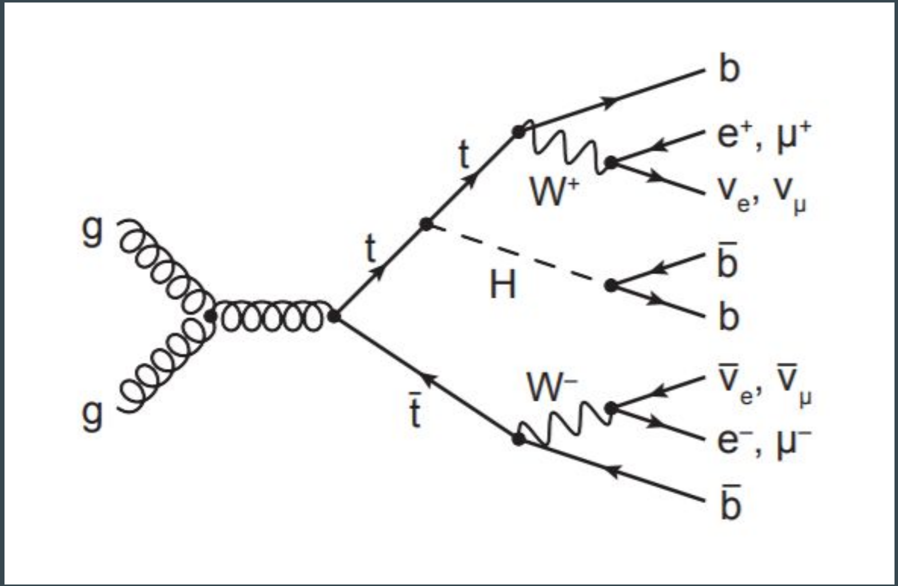




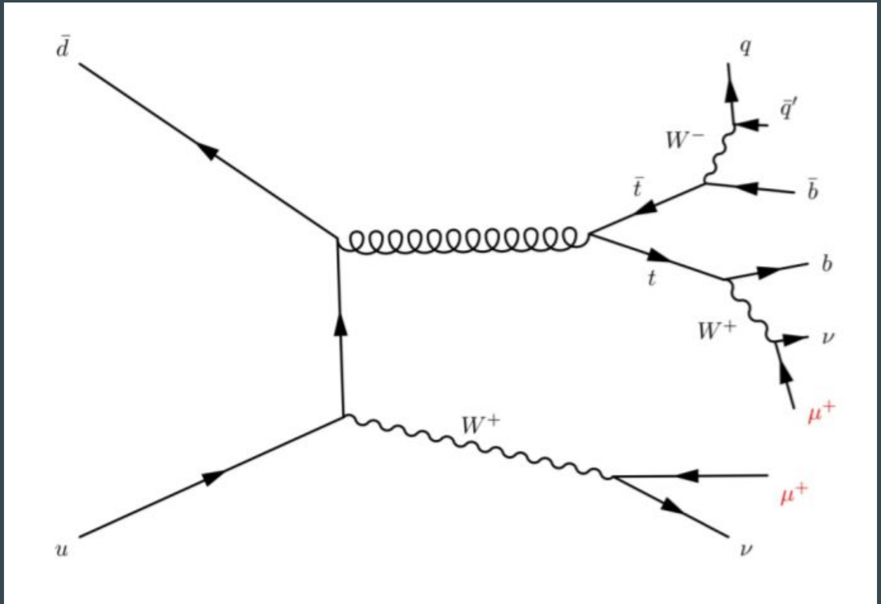
Same Sign Dilepton

Backgrounds	Cross section (fb)
$t\bar{t}Z$	0.04
$t\bar{t}W$	0.72
tZ+jets	0.001
$3t+j$	0.0002
$3t+W$	0.0004
$t\bar{t}h$	0.024
$4t$	0.04
Q-flip	0.04

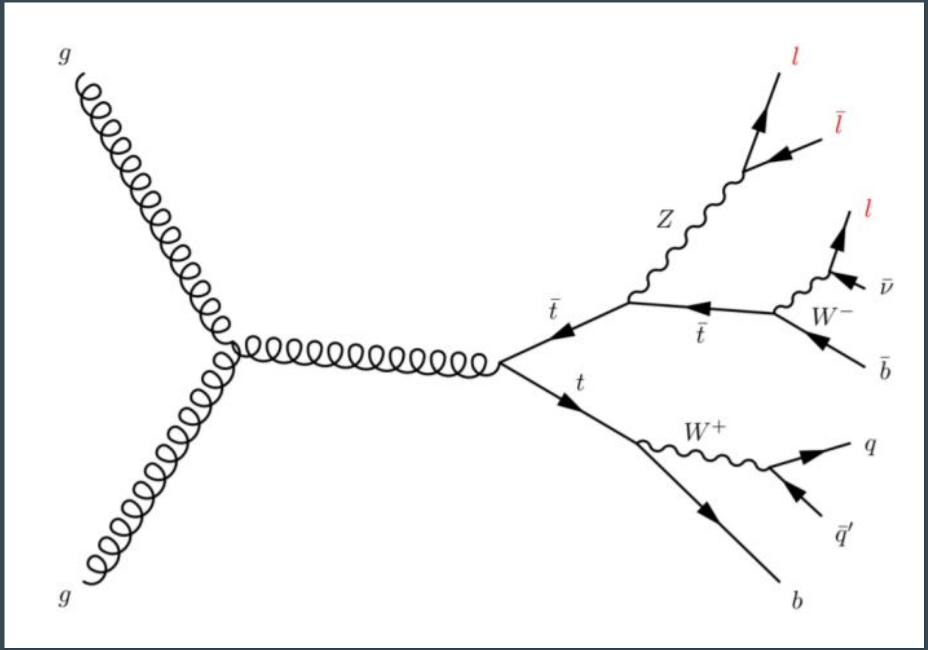
Paper (2 leptons):



Background:



Trilepton

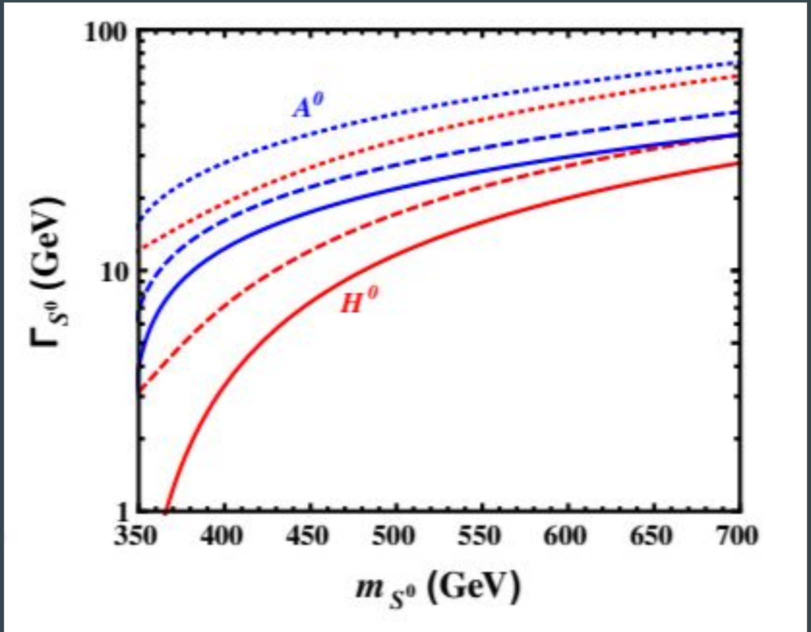


Overview

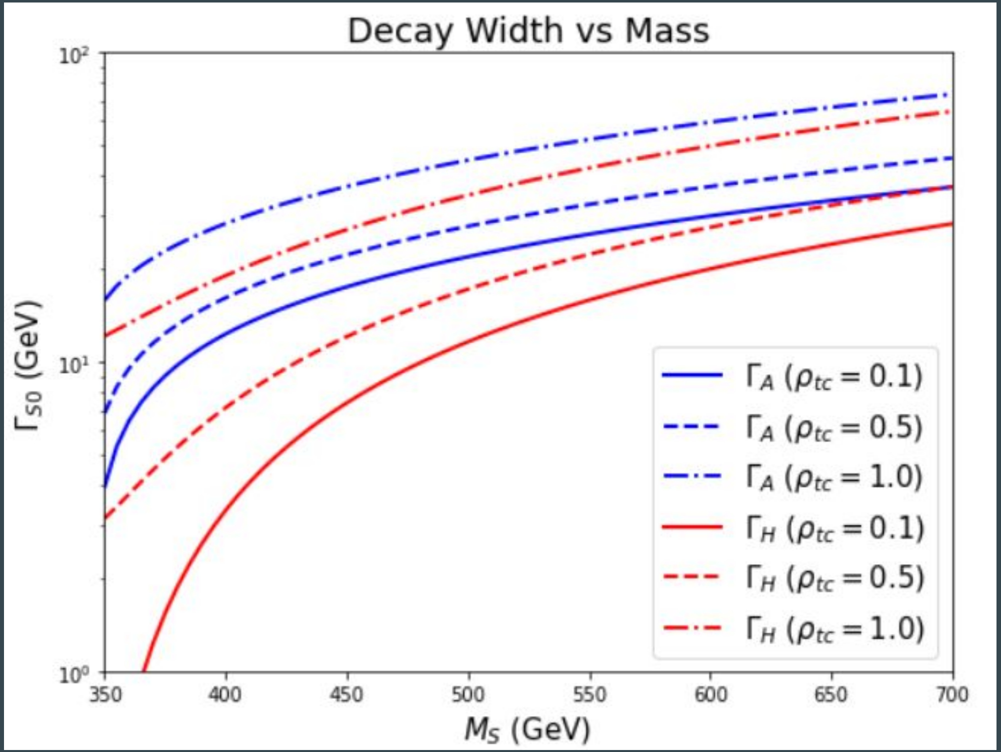
- Brief update on decay width vs mass & branching ratio
- Pie chart: branching ratio for W and Z boson
- Analysis flow
- Signal and background feynman diagrams

Decay Width

Paper:

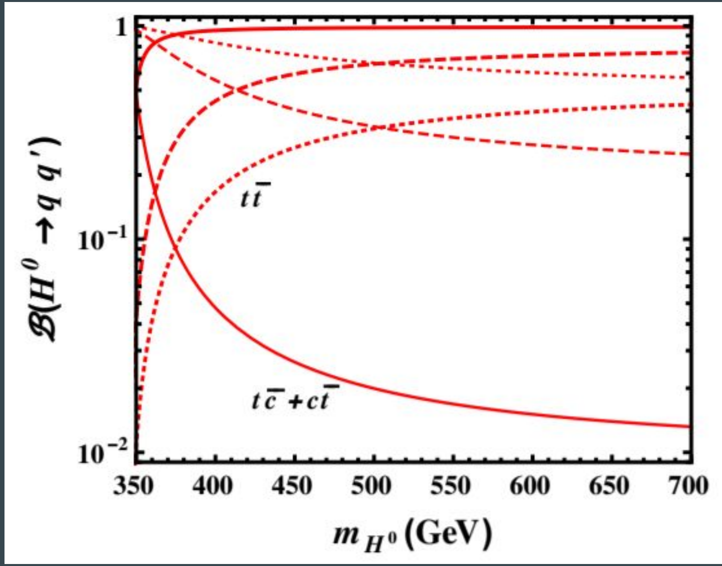


My Result:

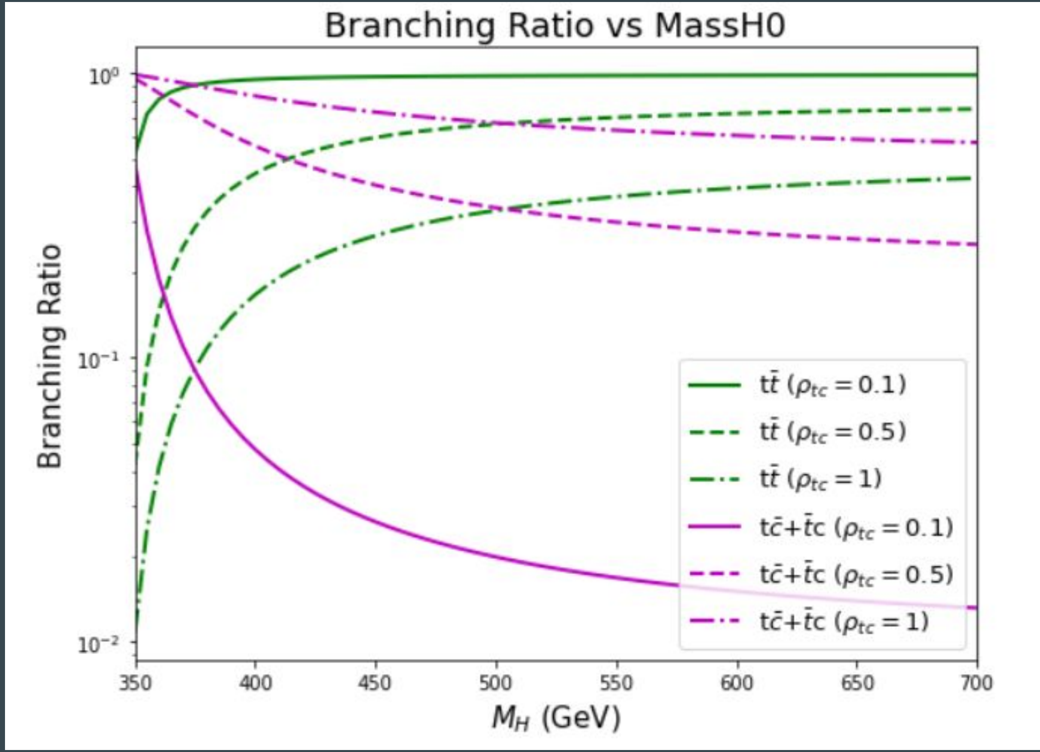


Branching Ratio (H0)

Paper:

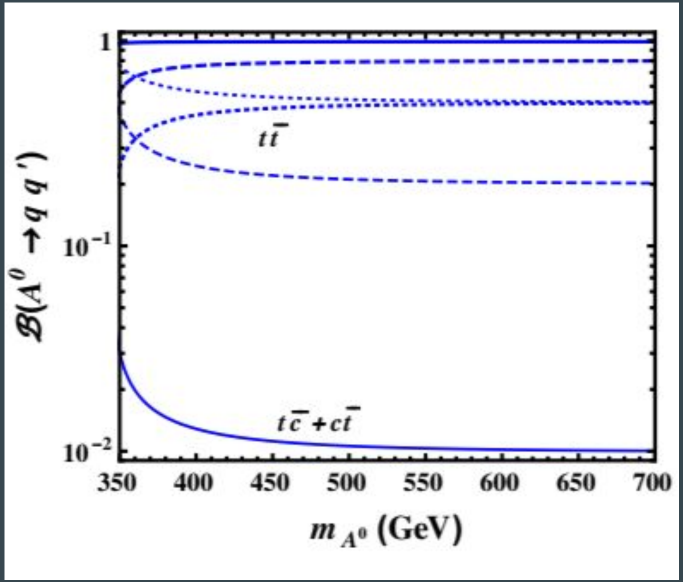


My Result:

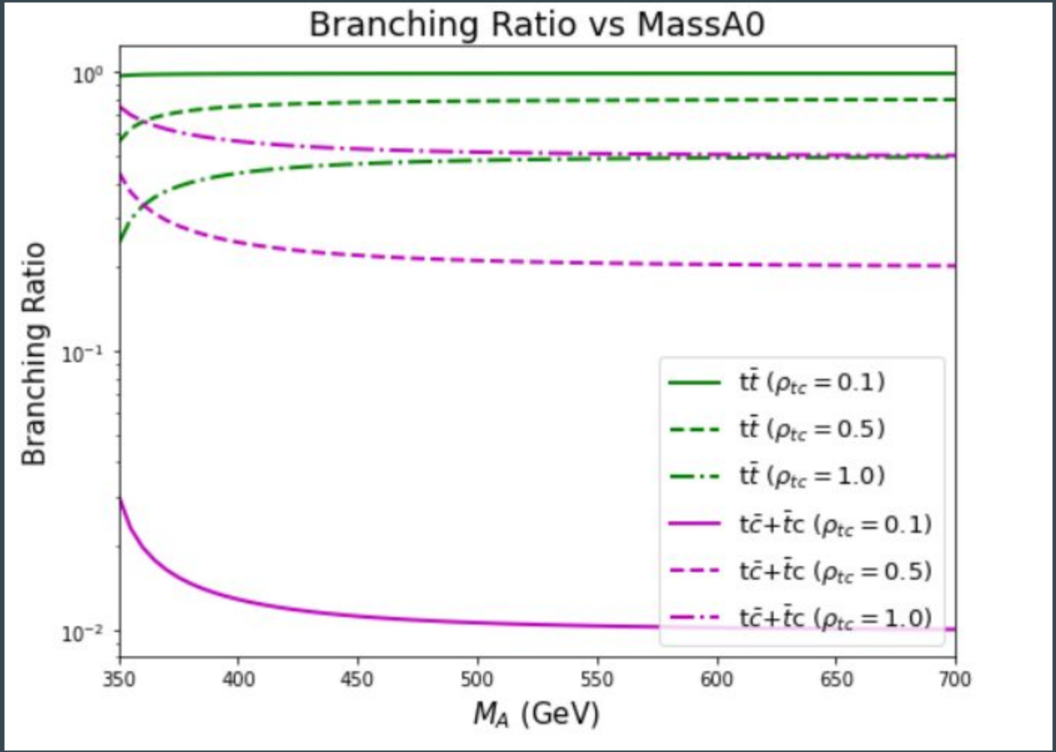


Branching Ratio (A0)

Paper:

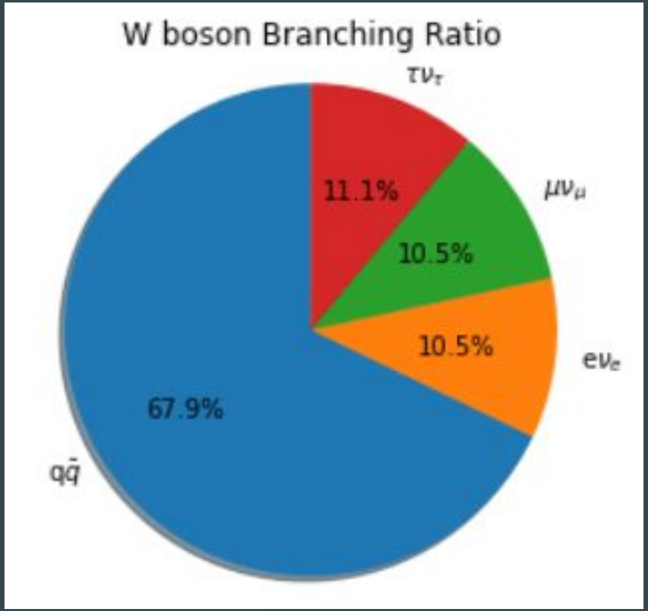


My Result:



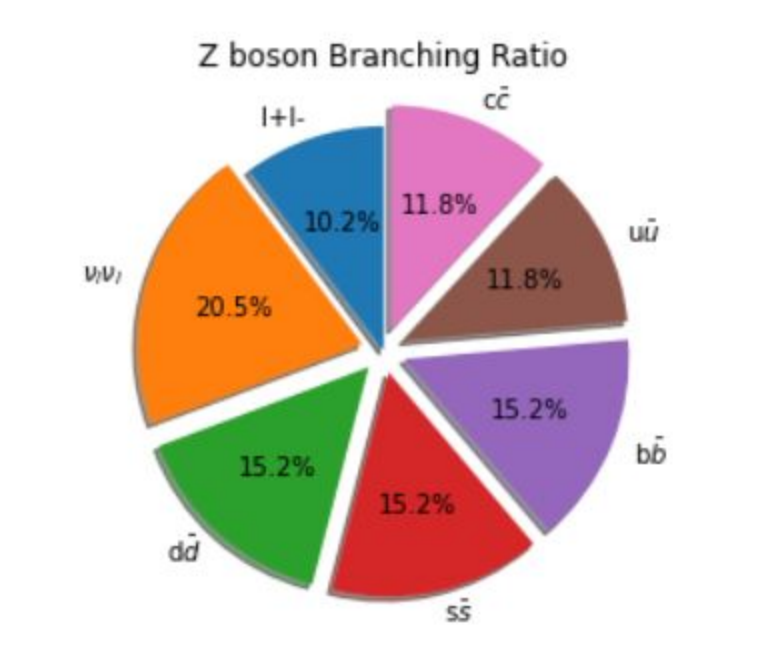
Pie charts: Branching Ratio for W boson

Leptons		Quarks					
$e^+ \nu_e$	1	$u\bar{d}$	$3\,\lvert V_{ud}\rvert^2$	$u\bar{s}$	$3\,\lvert V_{us}\rvert^2$	$u\bar{b}$	$3\,\lvert V_{ub}\rvert^2$
$\mu^+ \nu_\mu$	1	$c\bar{d}$	$3\,\lvert V_{cd}\rvert^2$	$c\bar{s}$	$3\,\lvert V_{cs}\rvert^2$	$c\bar{b}$	$3\,\lvert V_{cb}\rvert^2$
$\tau^+ \nu_\tau$	1	Decay to t is not allowed by energy conservation					

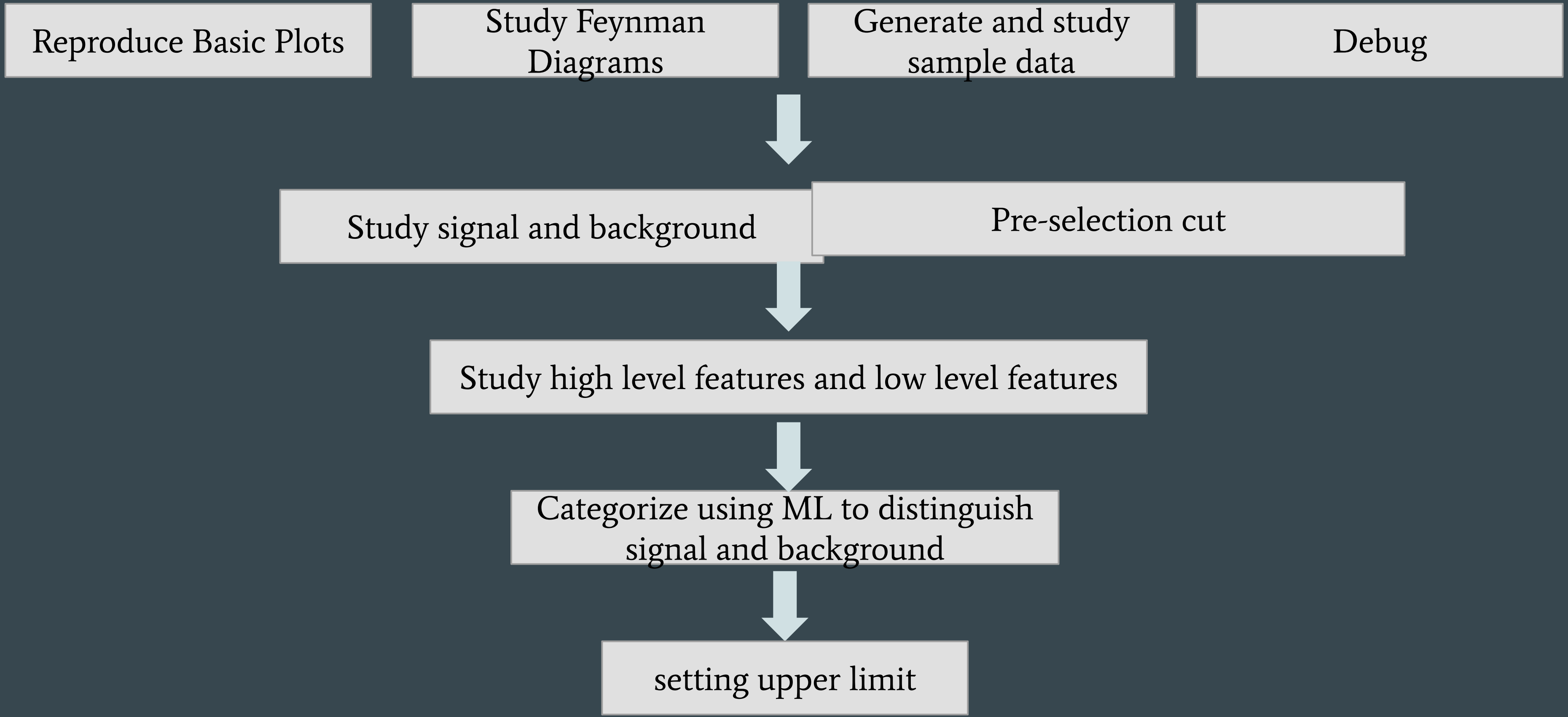


Pie charts: Branching Ratio for Z boson

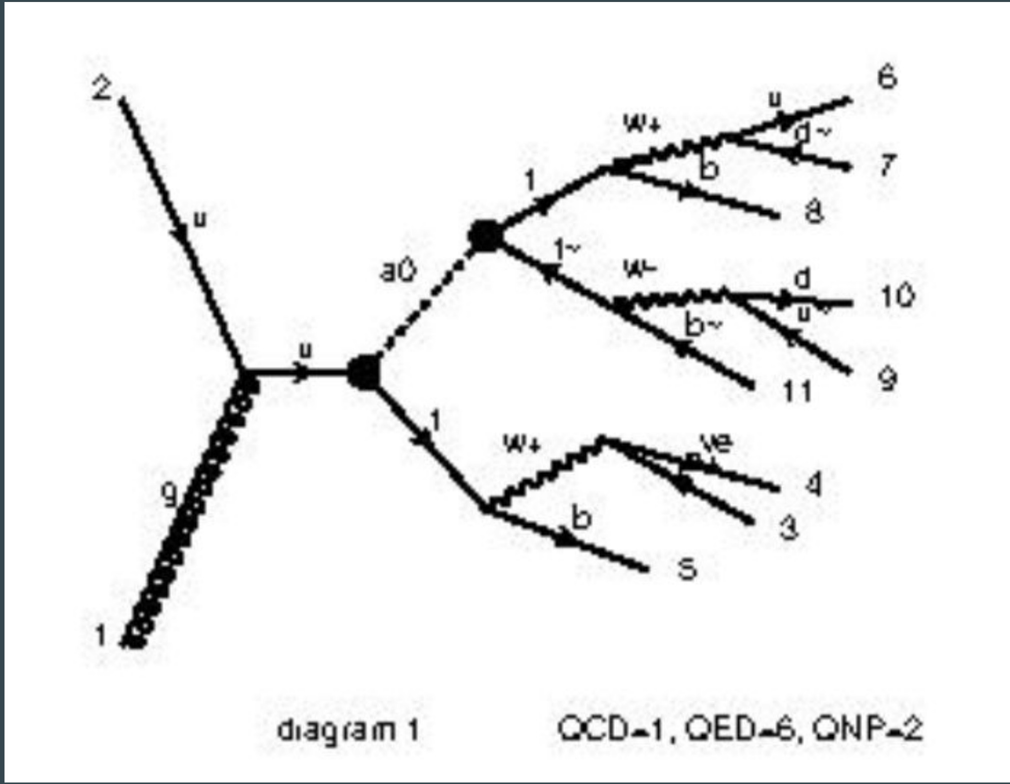
$$\Gamma(Z \to e^+e^-) = \Gamma(Z \to \mu^+\mu^-) = \Gamma(Z \to \tau^+\tau^-) = 84 \text{ MeV}$$
$$\Gamma(Z \to \nu_e\bar{\nu}_e) = \Gamma(Z \to \nu_\mu\bar{\nu}_\mu) = \Gamma(Z \to \nu_\tau\bar{\nu}_\tau) = 166 \text{ MeV}$$
$$\Gamma(Z \to \mathrm{d\bar{d}}) = \Gamma(Z \to \mathrm{s\bar{s}}) = \Gamma(Z \to \mathrm{b\bar{b}}) = 354 \text{ MeV}$$
$$\Gamma(Z \to \mathrm{u\bar{u}}) = \Gamma(Z \to \mathrm{c\bar{c}}) = 276 \text{ MeV}$$



Analysis Flow Chart

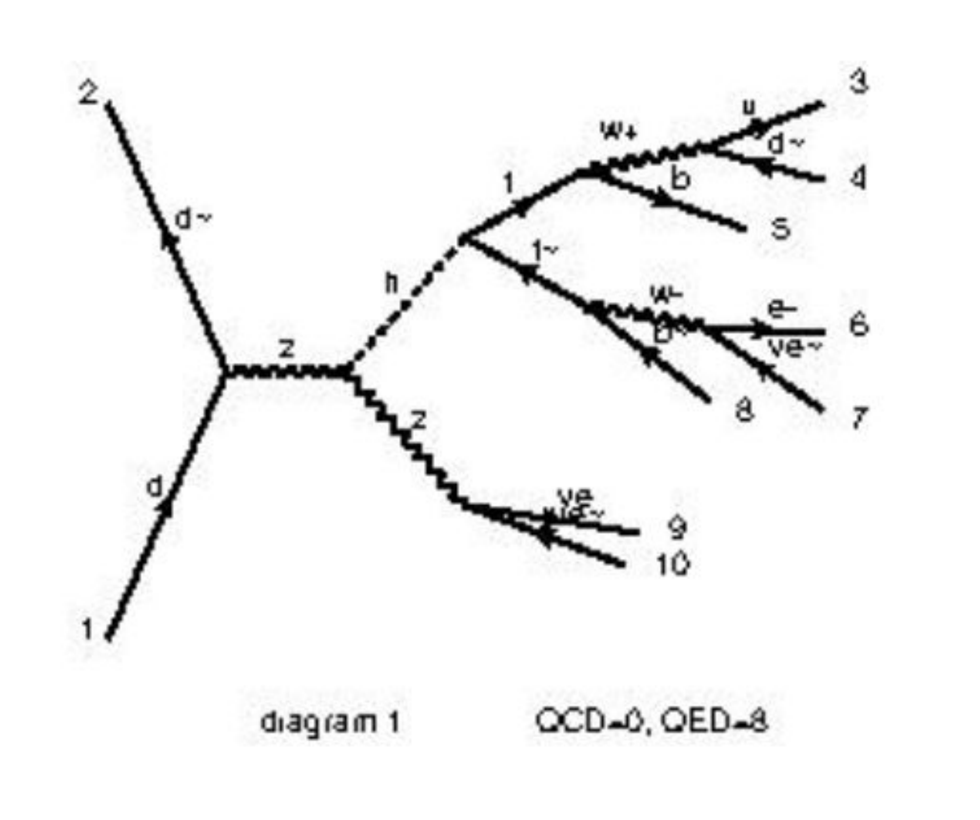


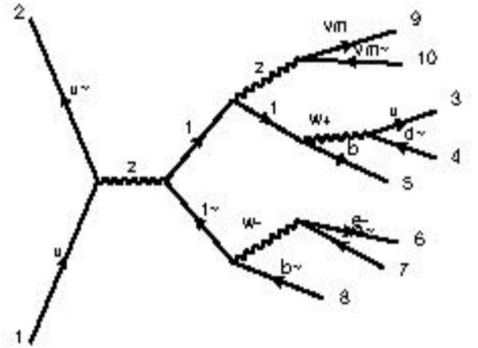
Signal: tA

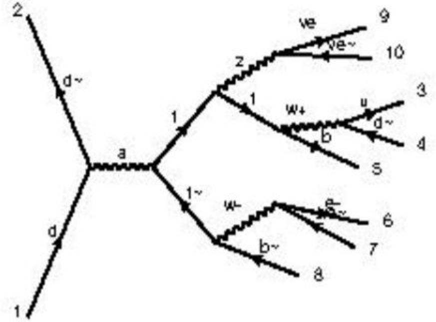


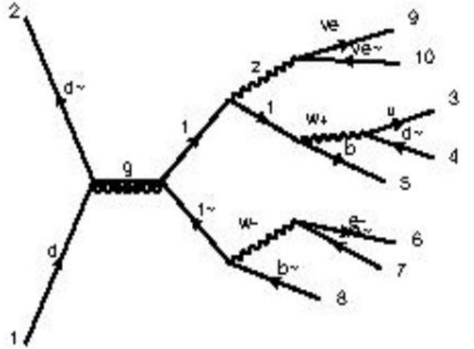
2
u
u
g
1
a0
1
1~
w+
u
d~
b
6
7
8
w-
d
u~
b~
10
9
11
1
w+
ve
b
4
3
5
diagram 1
QCD=1, QED=6, QNP=2

SM Background: tt~Z

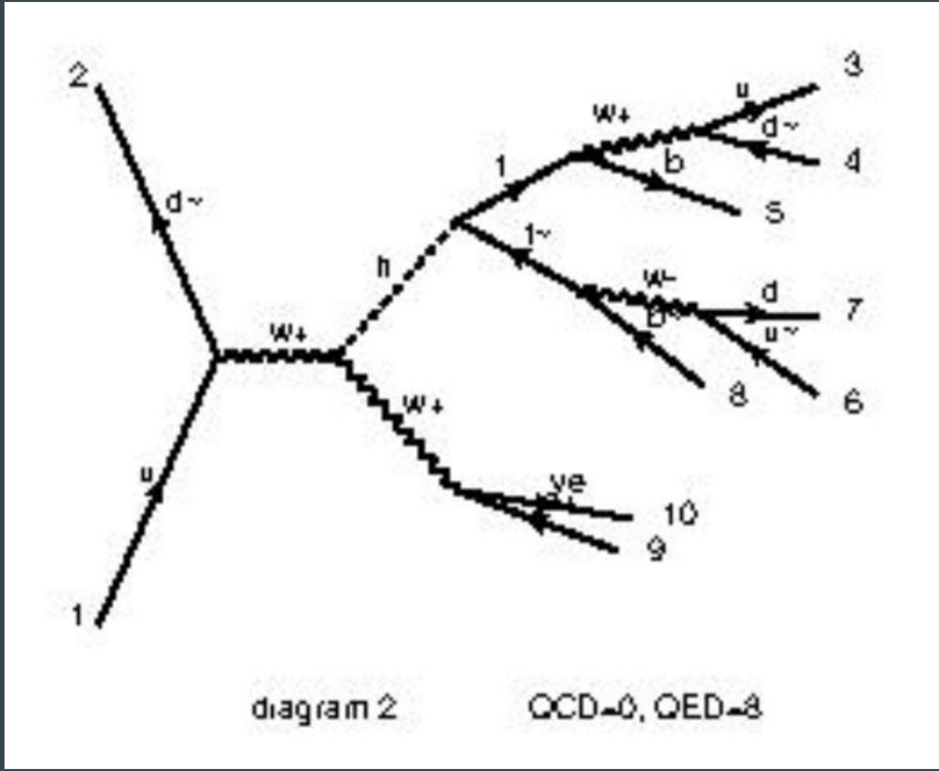


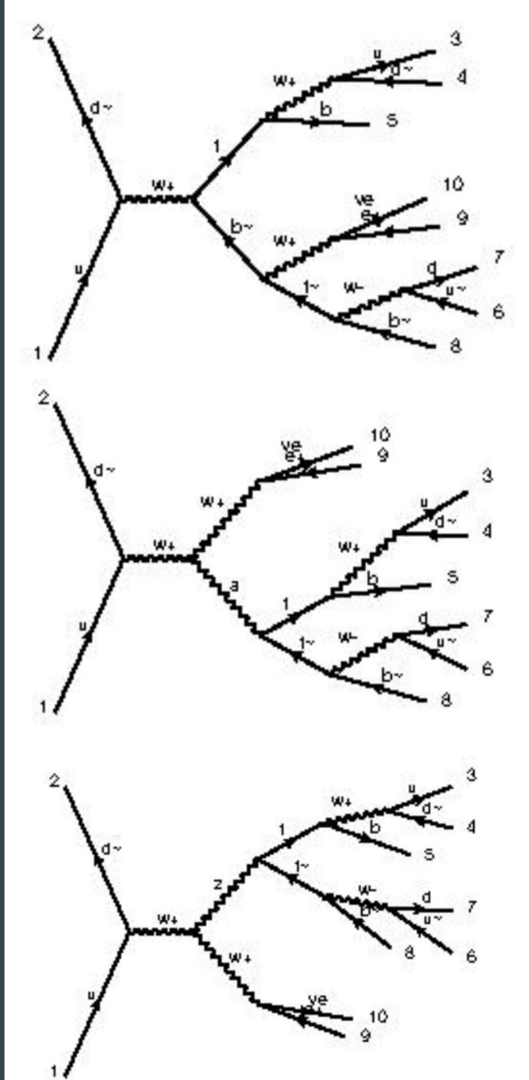




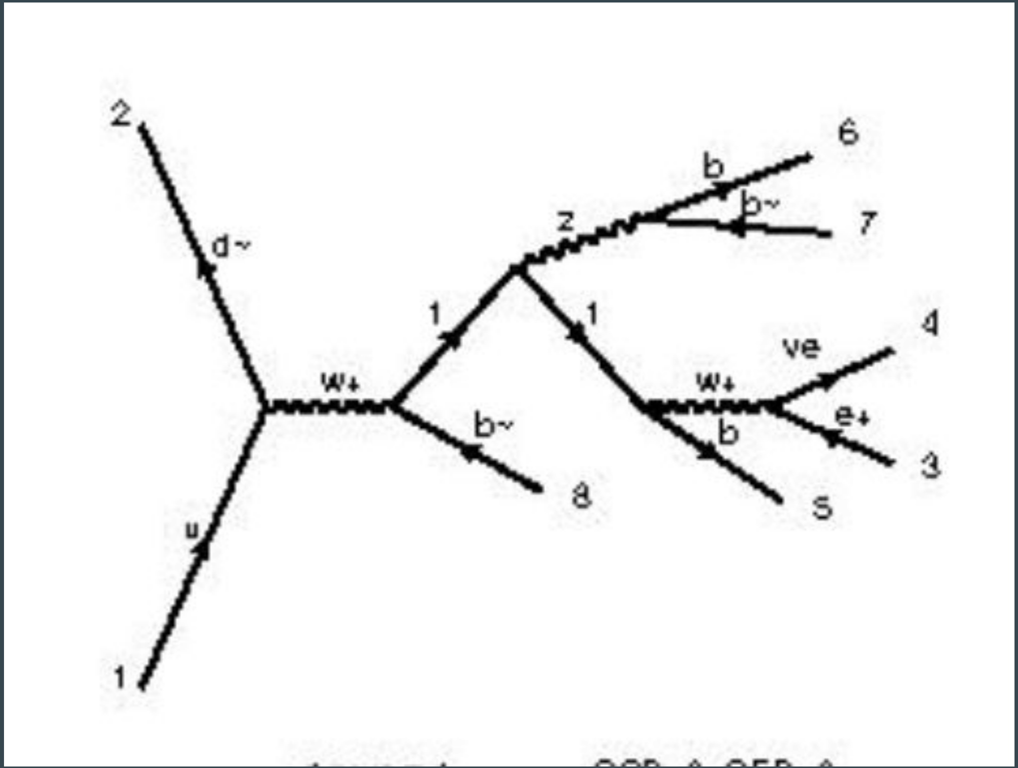


SM Background: tt~W

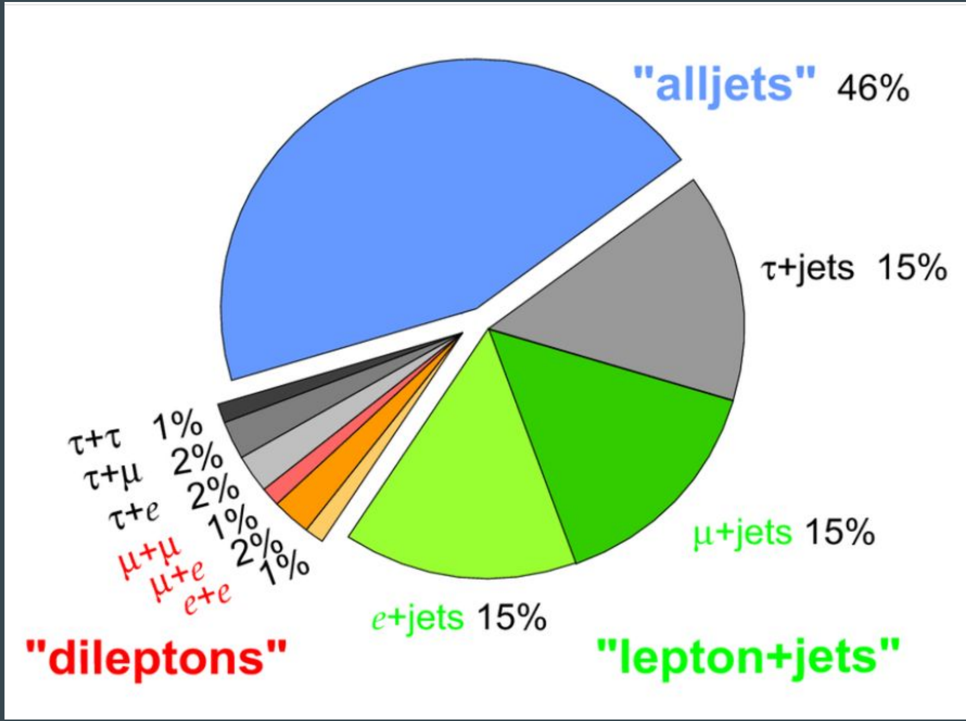




SM Background: tZ + j



Top pair branching ratio pie chart



Parameter of the model

- import gen2HDM model (insert the information for H0, A0)
- set the process (H, A -> t, t-bar) with defined decay process
- The mass of A and H set to 400 GeV
- rho_tc = 0.5, rho_tu = 0.2, and rho_tt = 0.5 (upper limit at ATLAS)
- Enter [rho_tc, mA, mt, Nc_] into mathematica to calculate the delay width.
- enable lhapdf 247000

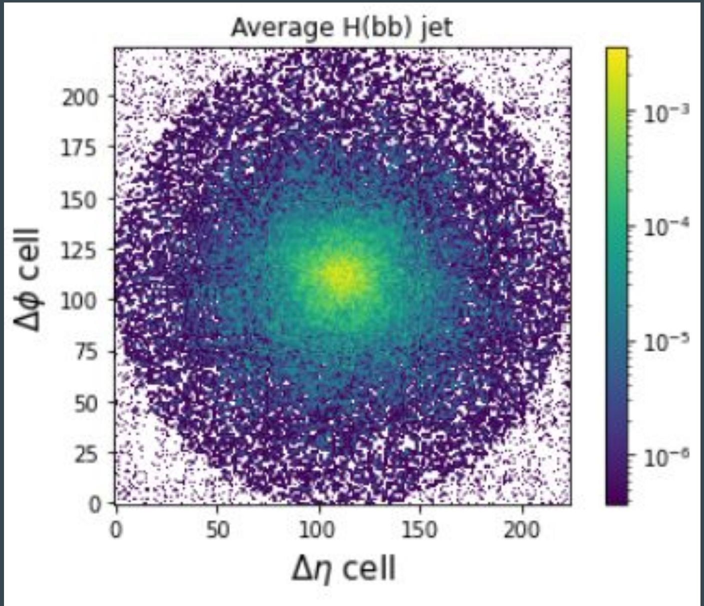
```
import model gen2HDM_UFO
define p = p b b~
define j = p
generate p p > t A0 QCD=99, (t > w+ b , w+ > l+ vl) ,( A0 > t t~ , (t > w+ b , w+ > l+ vl),(t~ > w- b~ , w- > l- vl~) )
add process p p > t A0 j QCD=99, (t > w+ b , w+ > l+ vl) ,( A0 > t t~ , (t > w+ b , w+ > l+ vl),(t~ > w- b~ , w- > l- vl~) )
add process p p > t~ A0 QCD=99, (t~ > w-  b~ , w- > l- vl~) ,( A0 > t t~ , (t > w+ b , w+ > l+ vl),(t~ > w- b~ , w- > l- vl~) )
add process p p > t~ A0 j QCD=99, (t~ > w-  b~ , w- > l- vl~) ,( A0 > t t~ , (t > w+ b , w+ > l+ vl),(t~ > w- b~ , w- > l- vl~) )

output Att_400

launch Att_400

shower=PYTHIA8
detector=delphes

set rtc 0.5
set rtt 0.5
set rtu 0
set nevents 5000
set ebeam1 7000.0
set ebeam2 7000.0
set pdlabel lhapdf
set lhaid 247000
set MA0 400
set MS0 400
set ebeam1 7000.0
set ebeam2 7000.0
```

Prove: setting MH0 won't affect the cross section of pp -> tA + t~ A

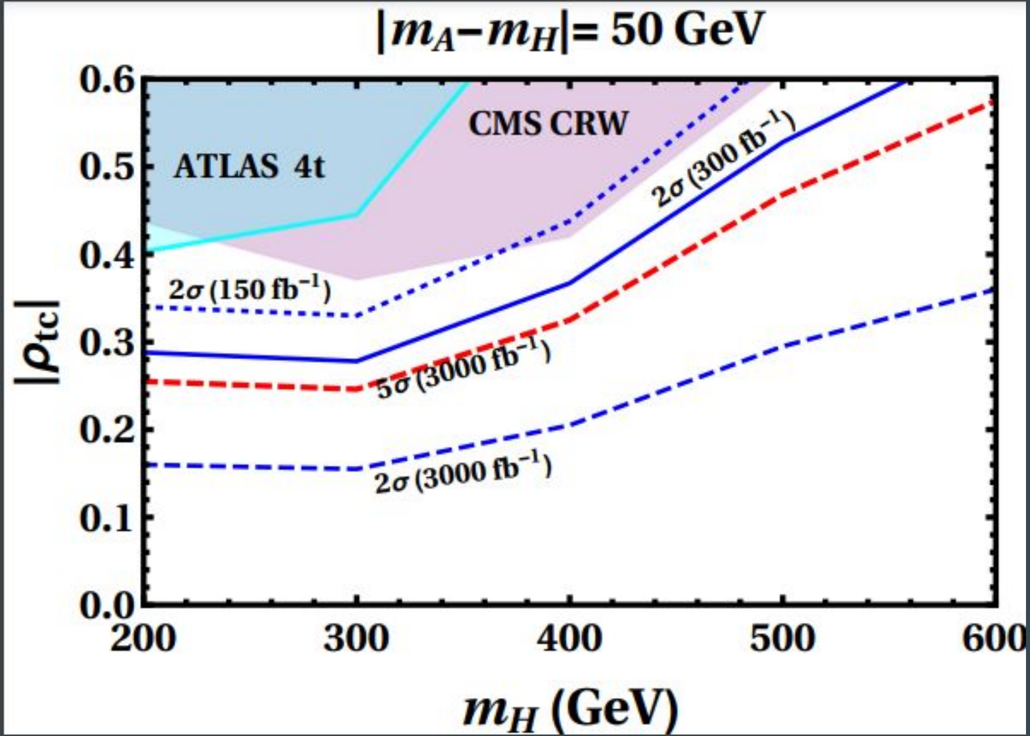
Run	Collider	Banner	Cross section (pb)	Events	Data	Output	Action
run_01	p p 7000.0 x 7000.0 GeV	tag_1	1.201 ± 0.0056 ± systematics	500	parton madevent	LHE MA5_report_analysis1	remove run launch detector simulation
run_02	p p 7000.0 x 7000.0 GeV	tag_1	0.609 ± 0.0027 ± systematics	500	parton madevent	LHE MA5_report_analysis1	remove run launch detector simulation
run_03	p p 7000.0 x 7000.0 GeV	tag_1	0.3177 ± 0.0015 ± systematics	500	parton madevent	LHE MA5_report_analysis1	remove run launch detector simulation
run_04	p p 7000.0 x 7000.0 GeV	tag_1	0.1785 ± 0.00096 ± systematics	500	parton madevent	LHE MA5_report_analysis1	remove run launch detector simulation
run_05	p p 7000.0 x 7000.0 GeV	tag_1	1.201 ± 0.007 ± systematics	500	parton madevent	LHE MA5_report_analysis1	remove run launch detector simulation
run_06	p p 7000.0 x 7000.0 GeV	tag_1	0.6015 ± 0.0032 ± systematics	500	parton madevent	LHE MA5_report_analysis1	remove run launch detector simulation
run_07	p p 7000.0 x 7000.0 GeV	tag_1	0.3219 ± 0.0019 ± systematics	500	parton madevent	LHE MA5_report_analysis1	remove run launch detector simulation
run_08	p p 7000.0 x 7000.0 GeV	tag_1	0.1795 ± 0.0011 ± systematics	500	parton madevent	LHE MA5_report_analysis1	remove run launch detector simulation
run_09	p p 7000.0 x 7000.0 GeV	tag_1	1.213 ± 0.0054 ± systematics	500	parton madevent	LHE MA5_report_analysis1	remove run launch detector simulation
run_10	p p 7000.0 x 7000.0 GeV	tag_1	0.6071 ± 0.0032 ± systematics	500	parton madevent	LHE MA5_report_analysis1	remove run launch detector simulation
run_11	p p 7000.0 x 7000.0 GeV	tag_1	0.3198 ± 0.0016 ± systematics	500	parton madevent	LHE MA5_report_analysis1	remove run launch detector simulation
run_12	p p 7000.0 x 7000.0 GeV	tag_1	0.178 ± 0.00081 ± systematics	500	parton madevent	LHE MA5_report_analysis1	remove run launch detector simulation
run_13	p p 7000.0 x 7000.0 GeV	tag_1	1.206 ± 0.0055 ± systematics	500	parton madevent	LHE MA5_report_analysis1	remove run launch detector simulation
run_14	p p 7000.0 x 7000.0 GeV	tag_1	0.6063 ± 0.0028 ± systematics	500	parton madevent	LHE MA5_report_analysis1	remove run launch detector simulation
run_15	p p 7000.0 x 7000.0 GeV	tag_1	0.3196 ± 0.0014 ± systematics	500	parton madevent	LHE MA5_report_analysis1	remove run launch detector simulation
run_16	p p 7000.0 x 7000.0 GeV	tag_1	0.1781 ± 0.0008 ± systematics	500	parton madevent	LHE MA5_report_analysis1	remove run launch detector simulation

Machine Learning

- https://jmduarte.github.io/capstone-particle-physics-domain/weeks/05-jet-images.html
- use particles' eta and psi relate to its pt as input
- tt~Z, tt~W, tZ+j, 3t+j, 3t+W, 4t, and tt~h



Back up slide



10/20/2021 update

- Finished reading document "Top-Assisted Di-Higgs boson Production Motivated by Baryogenesis" and some of its references BUT not understand all the material.
- Successfully ran the gen2HDM_UFO model and generate events

Code:

```
import model gen2HDM_UFO
define p = p b b~
define j = p
generate p p > t A0 QCD=99, (t > w+ b , w+ > l+ vl) ,( A0 > t t~ , (t > w+ b , w+ > l+ vl),(t~ > w- b~ , w- > l- vl~) )
add process p p > t A0 j QCD=99, (t > w+ b , w+ > l+ vl) ,( A0 > t t~ , (t > w+ b , w+ > l+ vl),(t~ > w- b~ , w- > l- vl~) )
add process p p > t~ A0 QCD=99, (t~ > w-  b~ , w- > l- vl~) ,( A0 > t t~ , (t > w+ b , w+ > l+ vl),(t~ > w- b~ , w- > l- vl~) )
add process p p > t~ A0 j QCD=99, (t~ > w-  b~ , w- > l- vl~) ,( A0 > t t~ , (t > w+ b , w+ > l+ vl),(t~ > w- b~ , w- > l- vl~) )
output sig_schannel

open index.html
launch sig_schannel

```

S-channel vs T-channel

- s-channel corresponds to the particles 1,2 joining into an intermediate particle that eventually splits into 3,4: the s-channel is the only way that resonances and new unstable particles may be discovered provided their lifetimes are long enough that they are directly detectable.
- The t-channel represents the process in which the particle 1 emits the intermediate particle and becomes the final particle 3, while the particle 2 absorbs the intermediate particle and becomes 4.

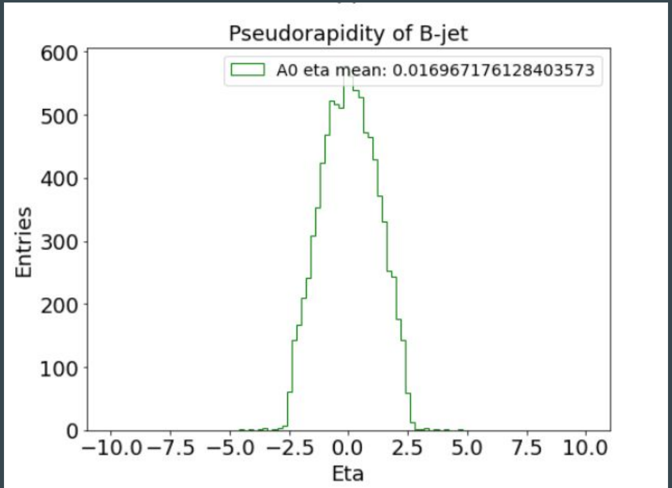
the indices in the event record where the first and last mothers are stored, if any. There are six allowed combinations of `mother1` and `mother2`:

1. `mother1 = mother2 = 0`: for lines 0 - 2, where line 0 represents the event as a whole, and 1 and 2 the two incoming beam particles;
2. `mother1 = mother2 > 0`: the particle is a "carbon copy" of its mother, but with changed momentum as a "recoil" effect, e.g. in a shower;
3. `mother1 > 0, mother2 = 0`: the "normal" mother case, where it is meaningful to speak of one single mother to several products, in a shower or decay;
4. `mother1 < mother2`, both > 0, for `abs(status) = 81 - 86`: primary hadrons produced from the fragmentation of a string spanning the range from `mother1` to `mother2`, so that all partons in this range should be considered mothers; and analogously for `abs(status) = 101 - 106`, the formation of R-hadrons;
5. `mother1 < mother2`, both > 0, except case 4: particles with two truly different mothers, in particular the particles emerging from a hard $2 \rightarrow n$ interaction.
6. `mother2 < mother1`, both > 0: particles with two truly different mothers, notably for the special case that two nearby partons are joined together into a status 73 or 74 new parton, in the $g + q \rightarrow q$ case the q is made first mother to simplify flavour tracing.

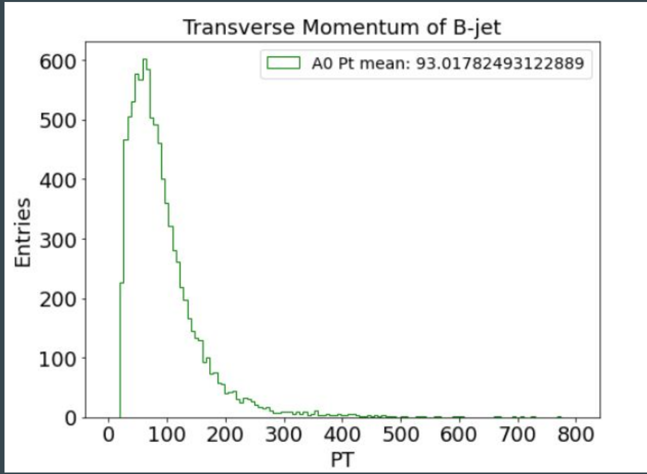
Reference

https://www.sciencedirect.com/science/article/pii/S0550321320302273 (Feynman Diagrams)

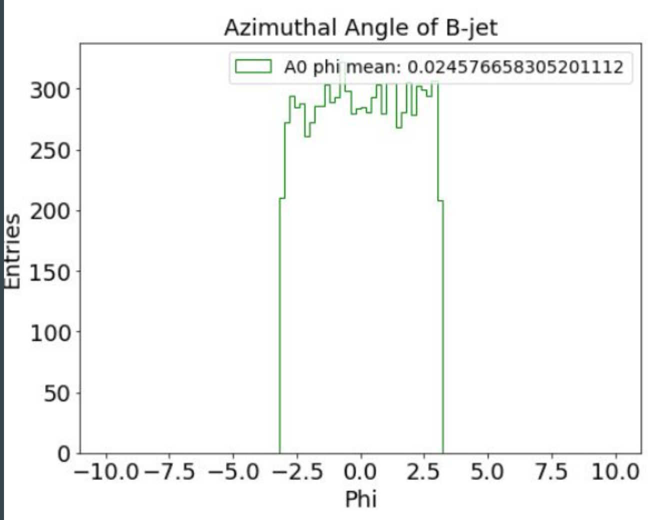
B-jet



Pseudorapidity of B-jet
A0 eta mean: 0.016967176128403573
Entries
Eta
600
500
400
300
200
100
0
−10.0 −7.5 −5.0 −2.5 0.0 2.5 5.0 7.5 10.0



Transverse Momentum of B-jet
A0 Pt mean: 93.01782493122889
Entries
PT
600
500
400
300
200
100
0
0 100 200 300 400 500 600 700 800



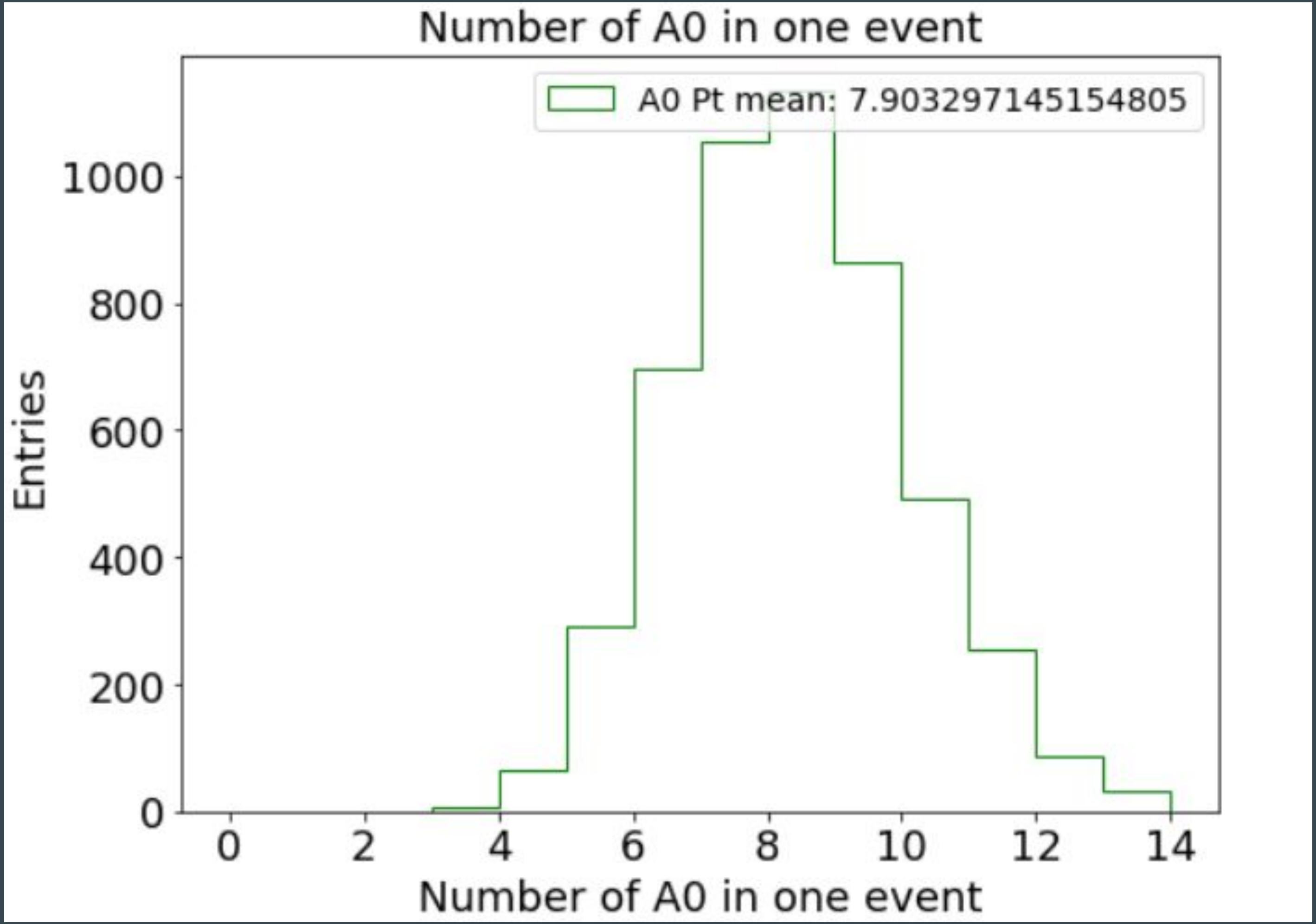
Azimuthal Angle of B-jet
A0 phi mean: 0.024576658305201112
Entries
Phi
300
250
200
150
100
50
0
−10.0 −7.5 −5.0 −2.5 0.0 2.5 5.0 7.5 10.0

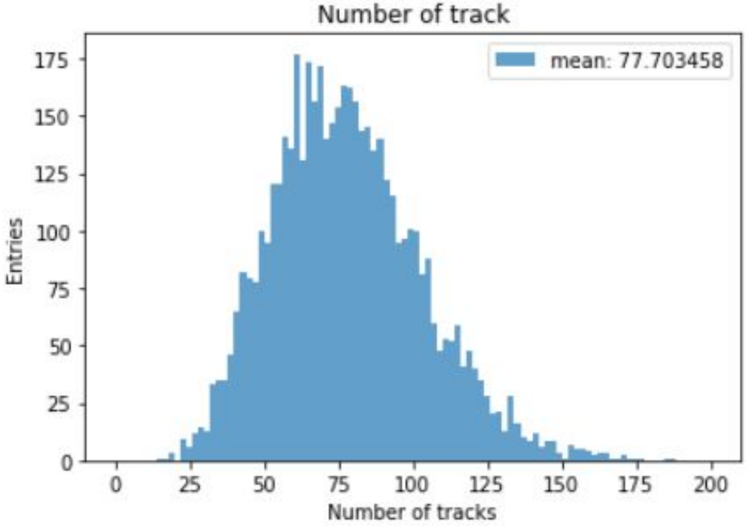
Lagrangian

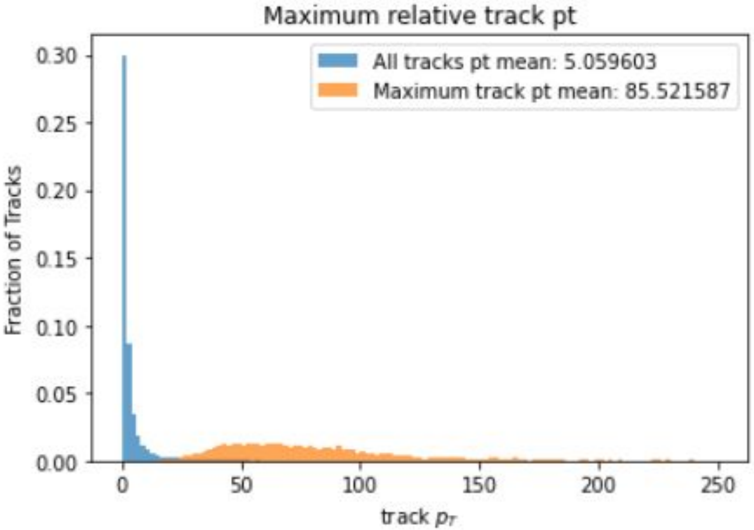
- rho_tc
- s = sin(), c = cos()

$$\mathscr{L} = -\frac{1}{\sqrt{2}} \sum_{f=u,d,\ell} \bar{f}_i[(-\lambda^f_{ij} s_\gamma + \rho^f_{ij} c_\gamma)h$$

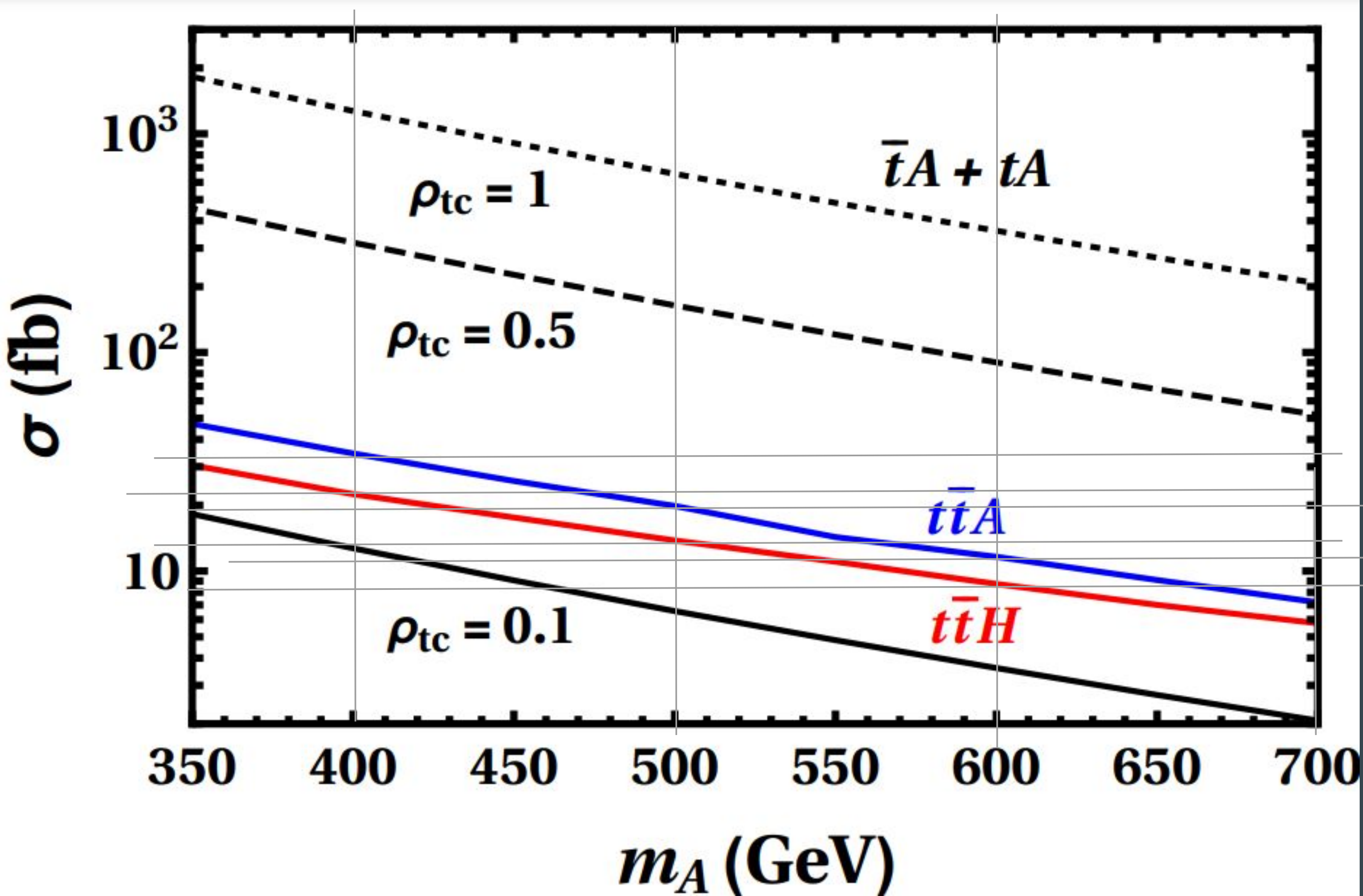
$$+ (\lambda^f_{ij} c_\gamma + \rho^f_{ij} s_\gamma)H - i\,\mathrm{sgn}(Q_f)\rho^f_{ij} A] R f_j + \mathrm{H.c.}\,,$$


Number of A0 in one event
A0 Pt mean: 7.903297145154805
Entries
0
200
400
600
800
1000
0
2
4
6
8
10
12
14
Number of A0 in one event


Number of track
mean: 77.703458
Entries
Number of tracks
0
25
50
75
100
125
150
175
200


Maximum relative track pt
All tracks pt mean: 5.059603
Maximum track pt mean: 85.521587
Fraction of Tracks
track p_T
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0
50
100
150
200
250

To



σ (fb)
10^3
10^2
10
$\rho_{tc} = 1$
$\rho_{tc} = 0.5$
$\rho_{tc} = 0.1$
$\bar{t}A + tA$
$t\bar{t}A$
$t\bar{t}H$
350
400
450
500
550
600
650
700
m_A (GeV)

Distribution/pdf	Example use in HEP
Binomial	Branching ratio
Multinomial	Histogram with fixed N
Poisson	Number of events found
Uniform	Monte Carlo method
Exponential	Decay time
Gaussian	Measurement error
Chi-square	Goodness-of-fit
Cauchy	Mass of resonance
Landau	Ionization energy loss
Beta	Prior pdf for efficiency
Gamma	Sum of exponential variables
Student's t	Resolution function with adjustable tails

Statistical Uncertainties:

- Random fluctuations
  - e.g. shot noise, measuring small currents, how many electrons arrive in a fixed time
  - Tossing a coin N times, how many heads

Systematic Uncertianies:

- Biases
  - e.g. energy calibration wrong
  - Thermal expansion of measuring device
  - Imperfect theoretical predications

Blunders, i.e. errors:

- Mistakes
  - Forgot to include a particular background in analysis
  - Bugs in analysis code