SEARCH FOR A NEW TOPOPHYLLIC LEPTOPHOBIC Z'_{TC2} BOSON IN THE FULLY HADRONIC TTBAR FINAL STATE USING THE CMS DETECTOR

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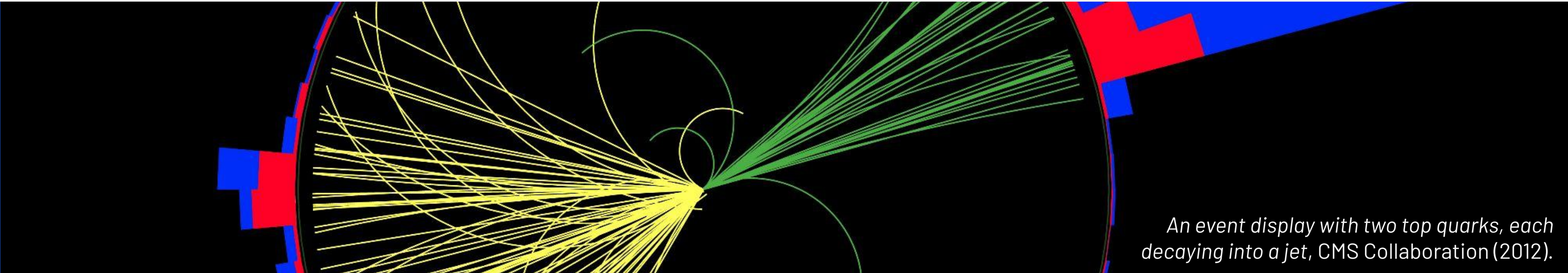
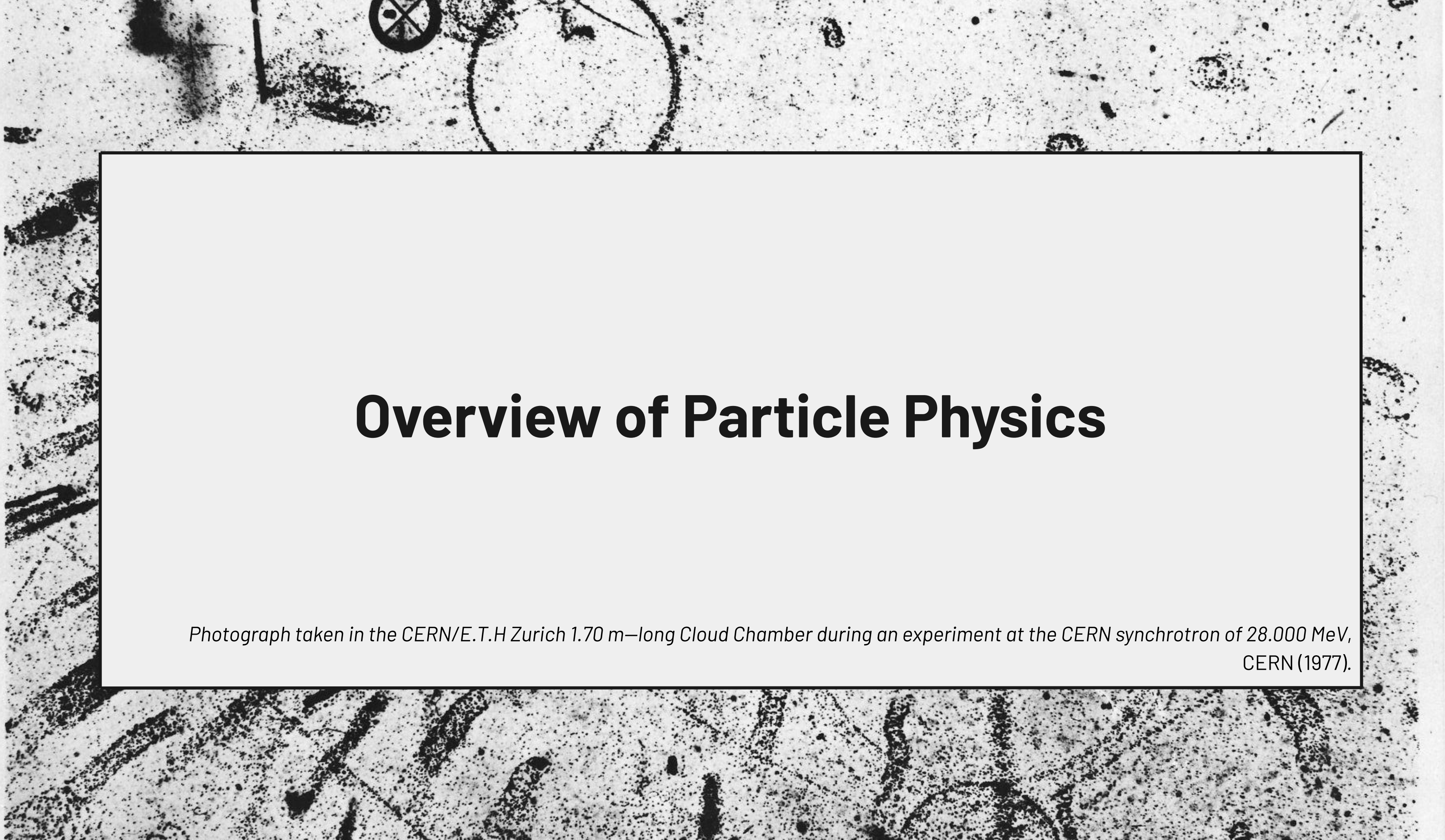
Undergraduate Thesis Presentation in Experimental Particle Physics	July 20 2023	School of Applied Mathematics and Physical Sciences (SAMPS), NTUA



An event display with two top quarks, each decaying into a jet, CMS Collaboration (2012).

Presentation Outline

Overview of Particle Physics
The CMS experiment at CERN
Motivation for the existence of a new Z'_{TC2} boson
Topcolour Assisted Technicolour: theory and phenomenology of a Z′
Experimental Methods Used by CMS
Analysis Strategy
Conclusions and future prospects

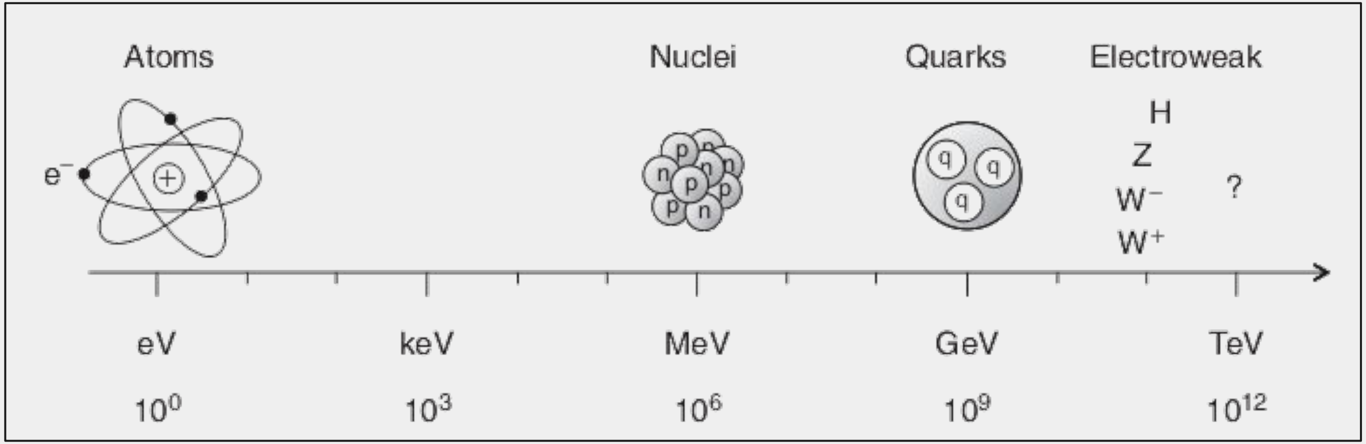


Overview of Particle Physics

Photograph taken in the CERN/E.T.H Zurich 1.70 m—long Cloud Chamber during an experiment at the CERN synchrotron of 28.000 MeV,
CERN (1977).

What is Particle Physics (PP)?

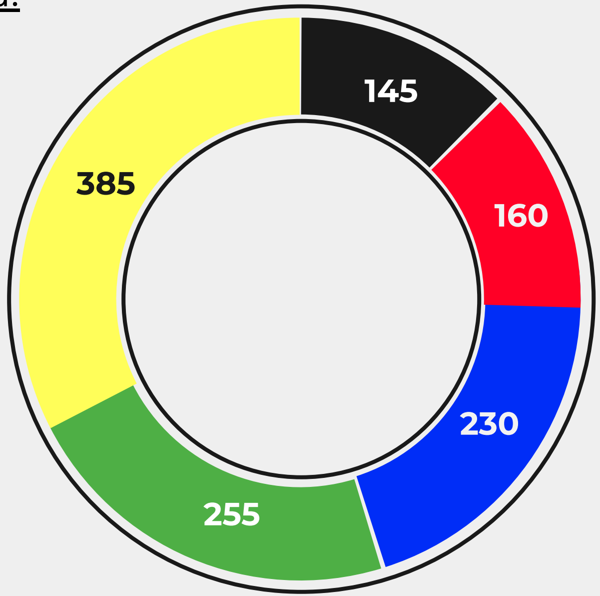
- Elementary constituents of matter
- Very early start: search for "substance of light " in Ancient Greece by Aristotle and Euclid
- Modern beginning:
  - Newton's corpuscular theory of light
  - Einstein's Nobel Prize for the photoelectric phenomenon



The Universe at different energy scales, from atomic physics to modern particle physics at the TeV scale., Thomson (2013).

PP in the Scientific Community

Top 5 Physics PhDs granted.
by subfield in 2022
(American Institute of Physics)



Biological Physics

Nuclear Physics

Particles and Fields

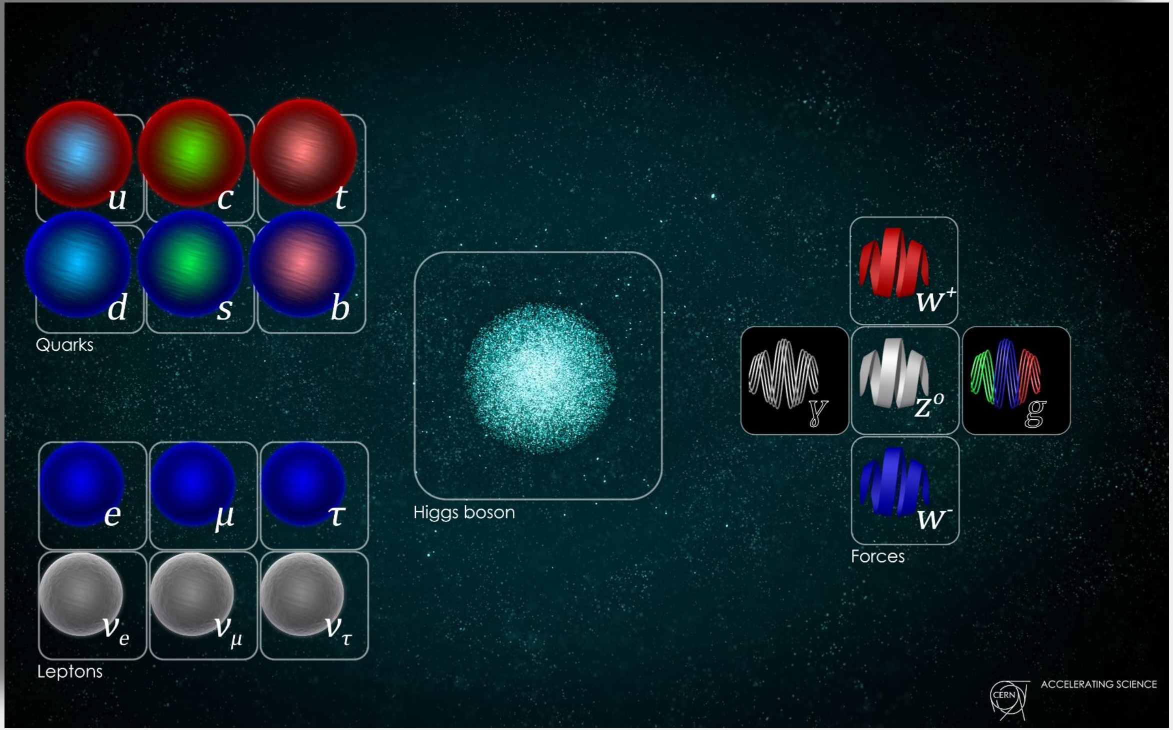
Condensed Matter

Astronomy; Astrophysics; Cosmology

Within this category:

Particle Physics (PP)
or
High Energy Physics (HEP)

The Standard Model (SM) particles



$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\psi} \not{D} \psi + h.c + \bar{\psi}_i y_{ij} \psi_j \phi + h.c. + |D_\mu \phi|^2 - V(\phi)$$

<u>SM in group theory:</u>

$SU(3)_C \times SU(2)_L \times U_Y(1)$

The Standard Model (SM) forces

4 fundamental forces/interactions:

Strong

Electromagnetism

Weak

Gravity

Relative strength:

1

0.01

0.00001

0.000000000000000000000
000000000000000001

gluon

W⁻ W⁺

Z⁰

QUANTUM CHROMODYNAMICS (QCD)

ELECTROWEAK INTERACTION

?

COSMOLOGY

GRAVITATIONAL WAVE THEORY

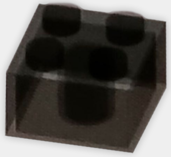
...

Graviton*

?

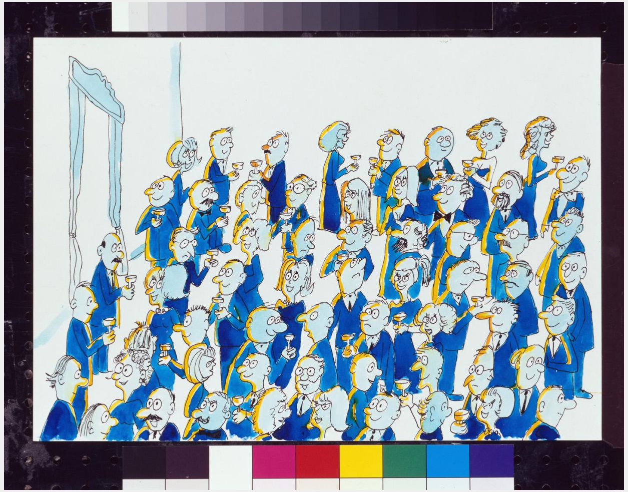
The Higgs mechanism

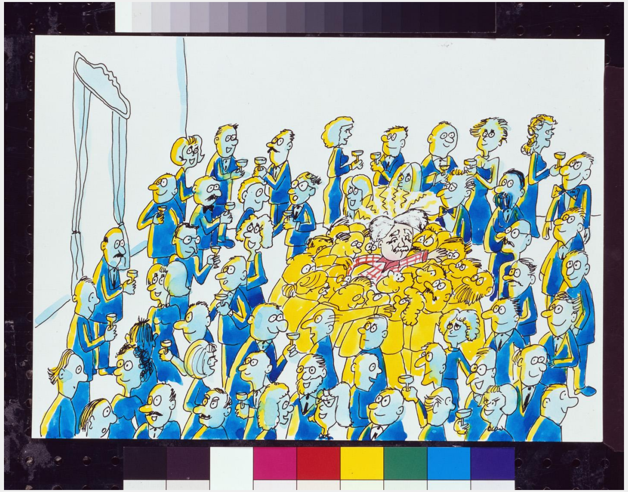
$SU(3)_C \times SU(2)_L \times U_Y(1) \longrightarrow SU(3)_C \times U_{em}(1)$ **: ElectroWeak Symmetry Breaking (EWSB)**



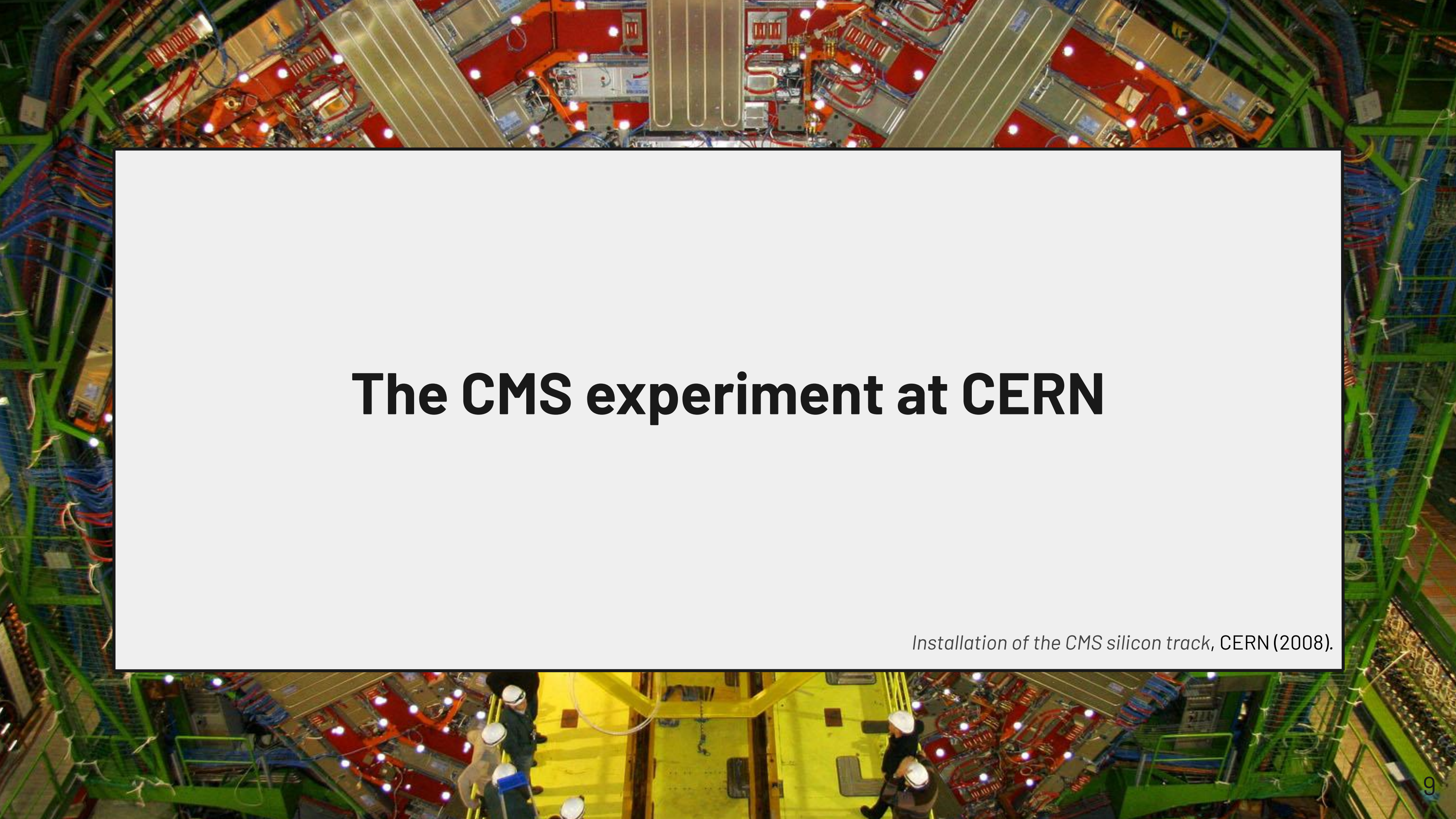
Higgs boson

- ➔ Higgs mechanism: gives mass to quarks, leptons, W & Z bosons
- ➔ No mass to to photon and gluons
- ➔ Higgs field





Illustrating the Higgs mechanism, drawings are by George Boixader, CERN (1996).

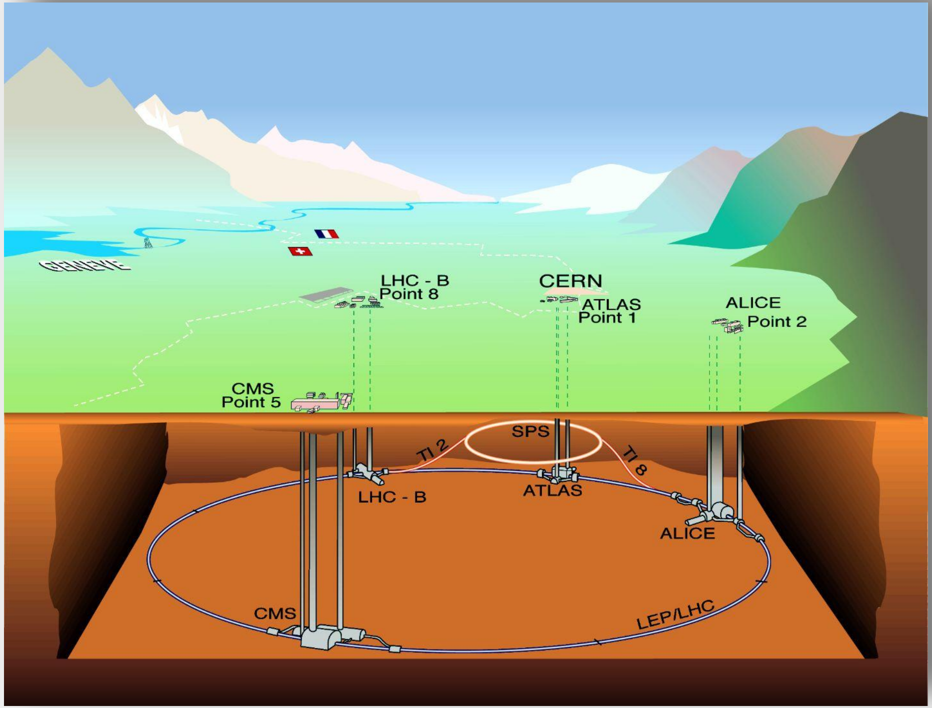


The CMS experiment at CERN

Installation of the CMS silicon track, CERN (2008).

Conseil Européen pour la Recherche Nucléaire (CERN)

The LHC tunnel at point 1, HPCwire, CERN (2022).



LHC map in 3D, Vittorio Frigo, CERN (1997).

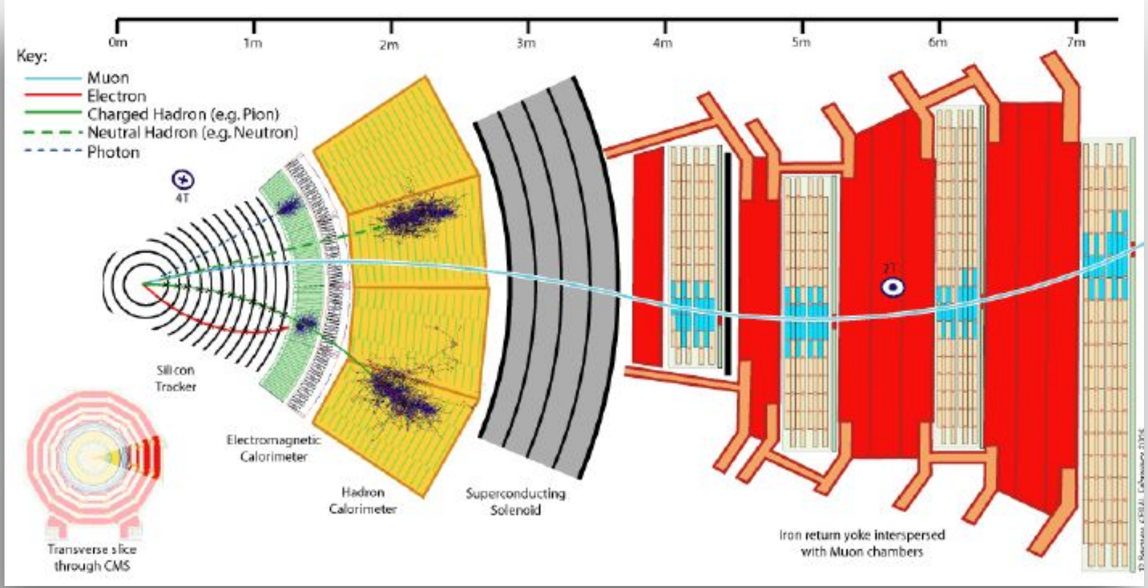
LHC: **L**arge **H**adron **C**ollider

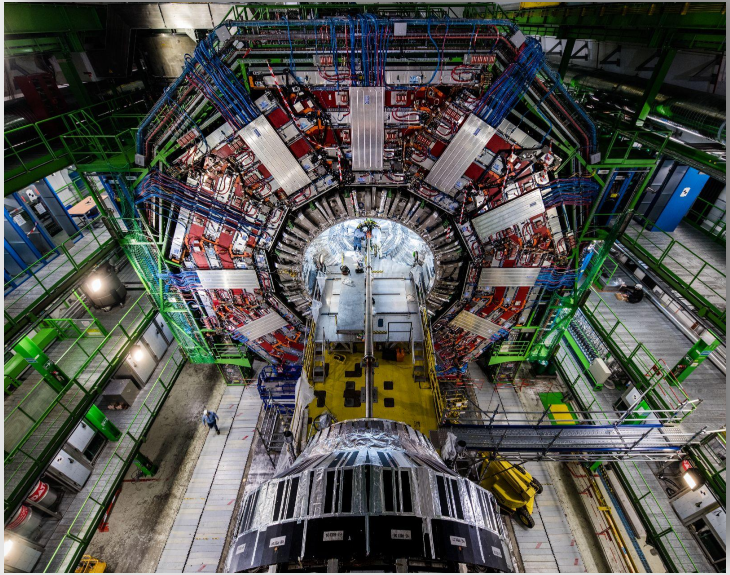
p ➡ ⬅ p

13TeV

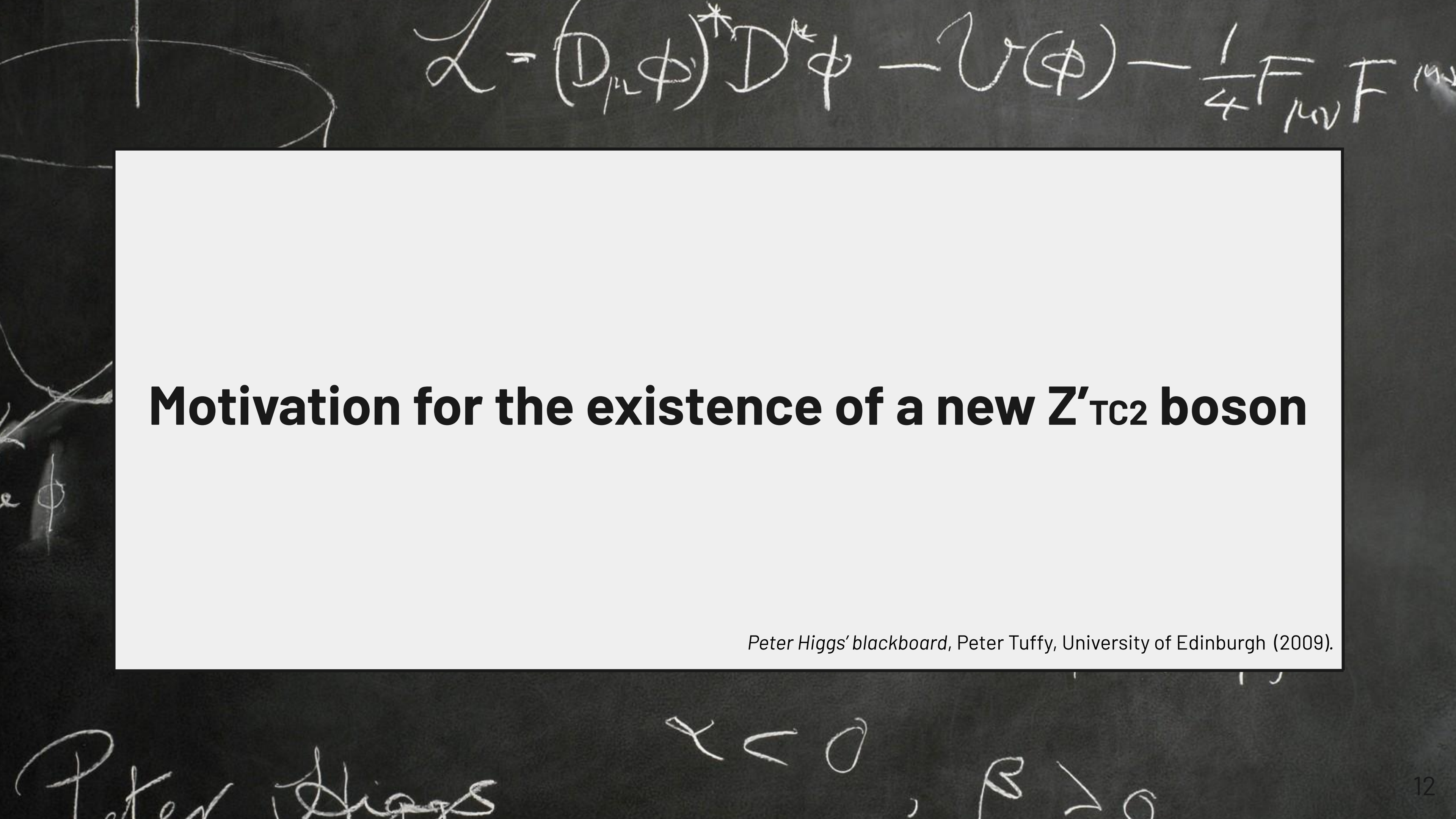
Compact Muon Solenoid (CMS)

Illustration of the detection of particles at the CMS experiment, Barney (2004)





The CMS detector, Maximilien Brice, CERN (2017).



Motivation for the existence of a new Z'_{TC2} boson

Peter Higgs' blackboard, Peter Tuffy, University of Edinburgh (2009).

The mystery of EWSB

2012

Discovery of the Higgs boson at CERN

- ❖ Provides the mechanism by which all other particles acquire mass
- ❖ Higgs boson = excitation of the Higgs field (QFT)

But...

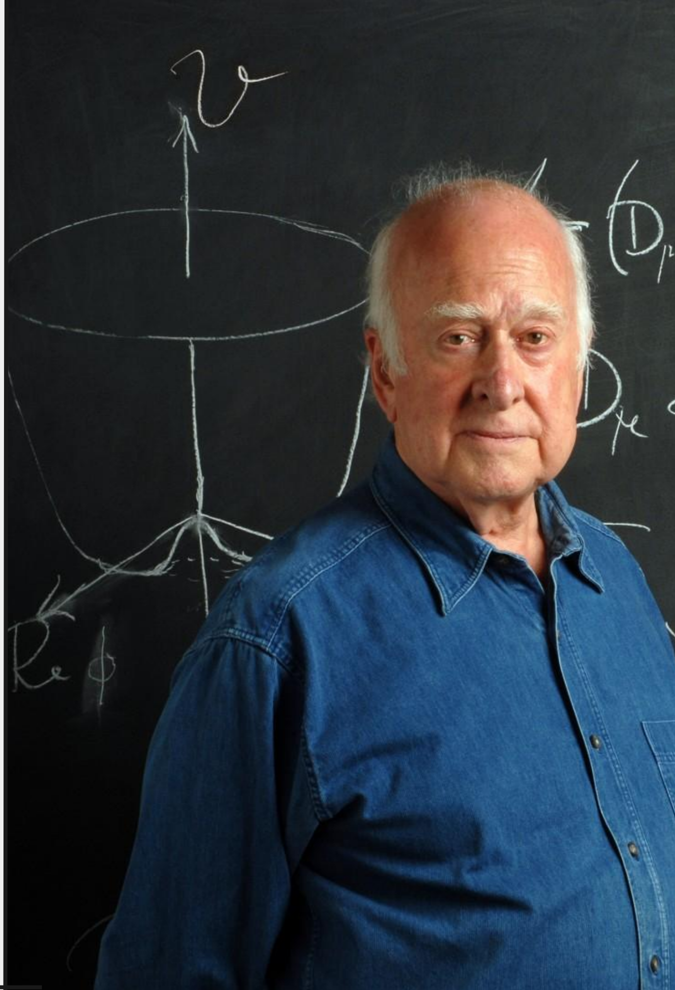
What is EWSB?

- ❖ What are the actual interactions ?
- ❖ Why at **v**$_{\text{weak}}$ (weak scale) ?
- ❖ Fundamental interactions ?

But...

What is the Higgs?

- ❖ Elementary particle ?
- ❖ Are there more “Higgses” ?
- ❖ ***Bound state* of other particles ?**



Peter Higgs in front of blackboard, Peter Tuffy, University of Edinburgh (2009).

13

Origin of the "weak scale": v_{weak}

Vacuum **E**xpectation **V**alue (**VEV**) of scalar Higgs field:

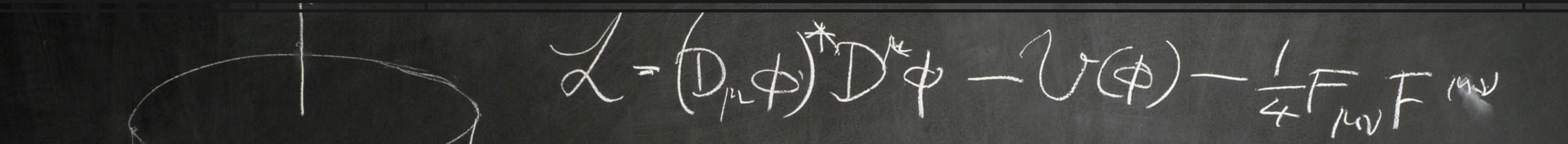
$$v_{weak} = \frac{1}{\sqrt{(2\sqrt{(2)}G_F)}} = 246\text{GeV} \sim O(100)\text{GeV}$$

$W^{\pm}$ mass: 80.4 GeV/c^2
Z^0 mass: 91.187 GeV/c^2

➔ Strong QCD scale: Λ_{QCD} ~ **O(100) MeV** ➡ well-defined quantity, arises directly from Quantum Mechanics (QM)

➔ Scale of gravity: M_{Panck} ~ **(10^{19}) GeV** ➡ gravitational effects comparable to gauge interactions, "limit of the universe"

➔ Weak mass scale: what causes it in nature? **+ fine-tuning** needed

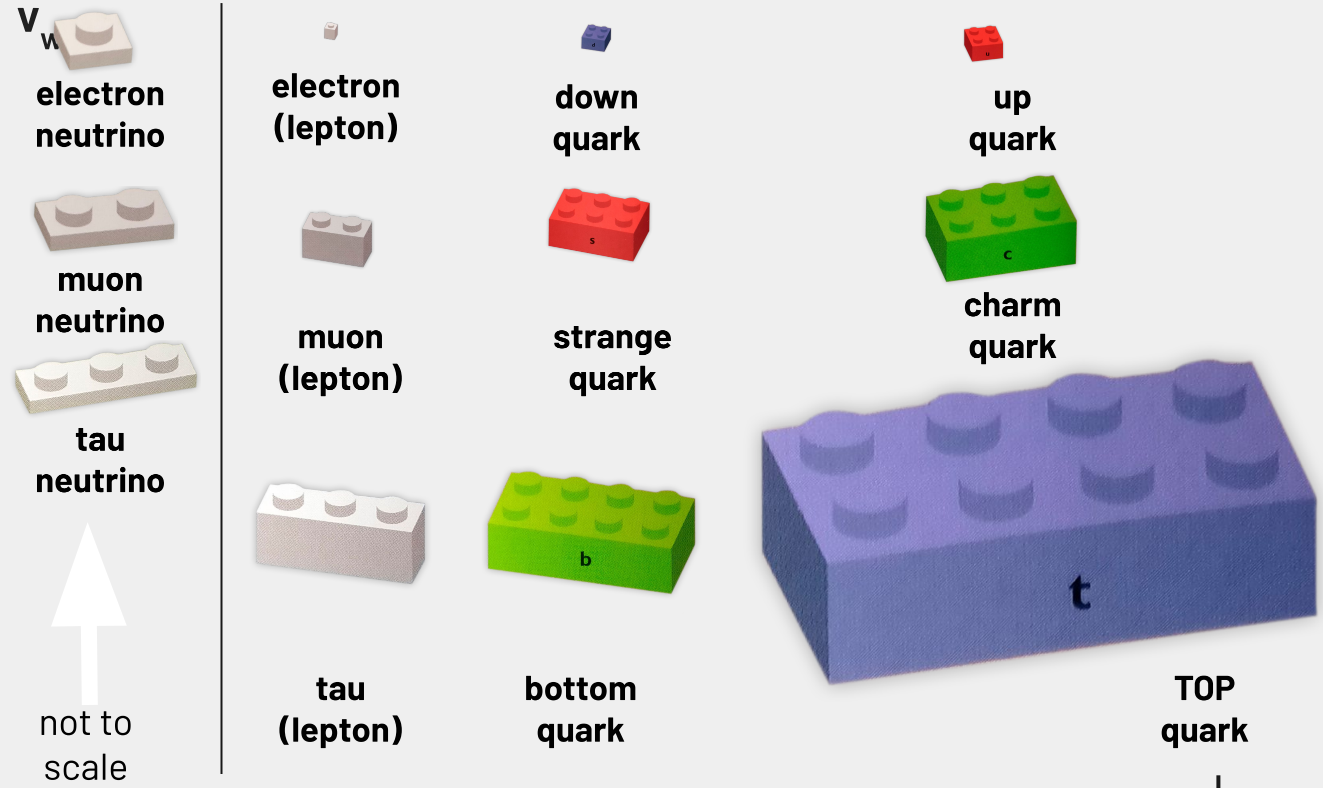


HUGE Top quark mass

$\boxed{m_t = 172.69 \pm 0.30\ \mathrm{GeV}/c^2\ \sim}$

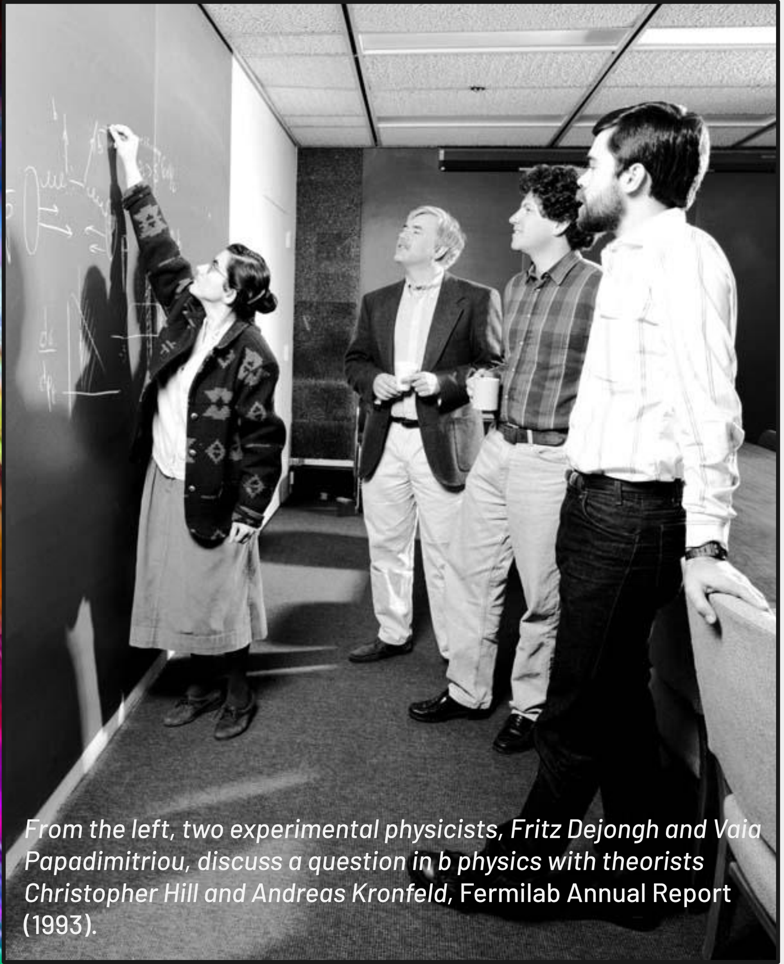
➡ >>> coupling to Higgs field

➡ Key to EWSB theories ?



Topcolour Assisted Technicolour: theory and phenomenology of a Z′

An Industry in Change: Unparalleled Demand for Content is an Opportunity to Push the Boundaries of Creativity and Diversity,
A Q & A with Sherri Potter, President, Worldwide Post Production at Technicolor (2019).



From the left, two experimental physicists, Fritz Dejongh and Vaia Papadimitriou, discuss a question in b physics with theorists Christopher Hill and Andreas Kronfeld, Fermilab Annual Report (1993).

Topcolour Assisted Technicolour (TC2)

Technicolour (TC) (1970s):

➔ *Technifermions, Techniquarks, Technigluons*:

➔ Novel Strong Dynamics (NSD)

Extended Technicolour (ETC):

➔ mechanism for EWSB to quarks and leptons

Topcolour Assisted Technicolour (TC2):

➔ Christopher T. Hill (1994, Fermilab)

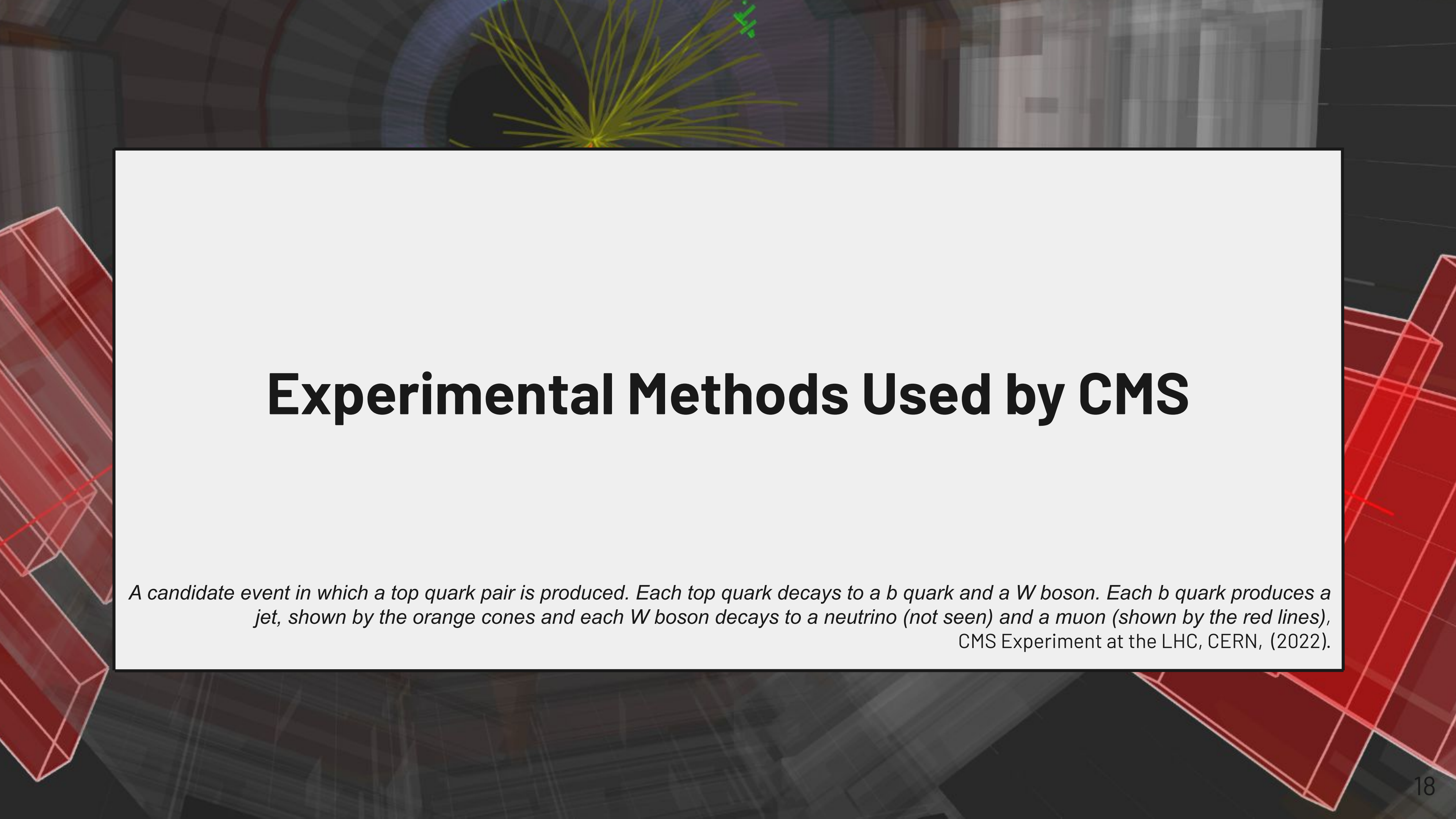
➔ **Idea:** Higgs = $t\bar{t}$ condensate $\langle \mathbf{t\bar{t}} \rangle$

➔ **Testable consequence! Z'_{TC2}**

Model IV

➔ quark generations **(1,3) ⊃ $U(1)_2$**

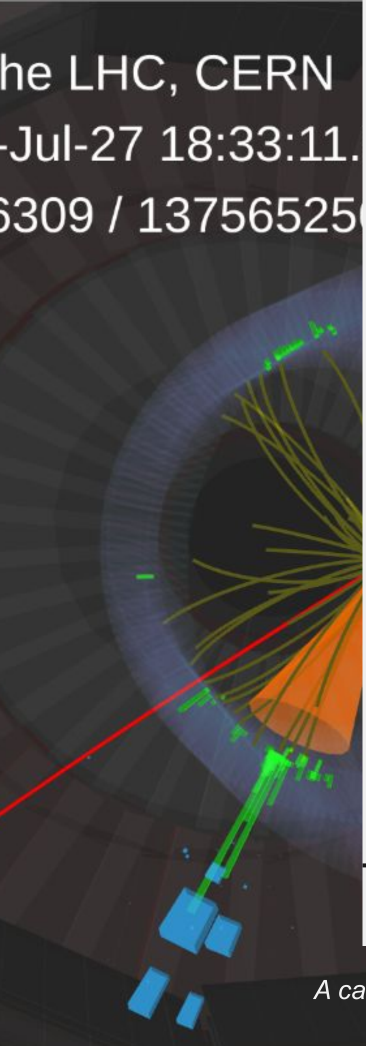
➔ $L'_{IV} = \left(\frac{1}{2} g_1 \cot\theta_H\right) Z'_\mu \left(\bar{t}_L \gamma_\mu t_L + \bar{b}_L \gamma_\mu b_L + f_1 \bar{t}_R \gamma_\mu t_R + f_2 \bar{b}_R \gamma_\mu b_R \right) - \bar{u}_L \gamma_\mu u_L - \bar{d}_L \gamma_\mu d_L - f_1 \bar{u}_R \gamma_\mu u_R - f_2 \bar{d}_R \gamma_\mu d_R$

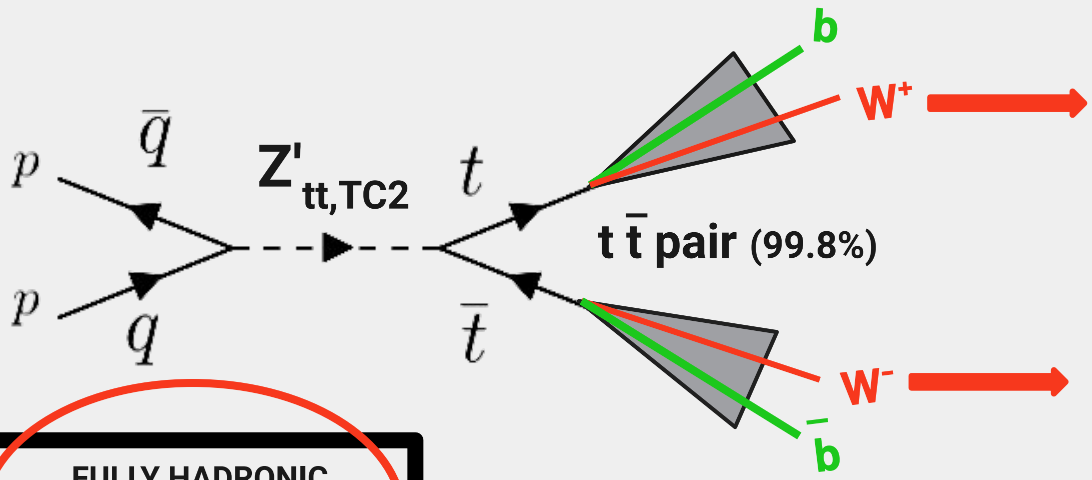


Experimental Methods Used by CMS

A candidate event in which a top quark pair is produced. Each top quark decays to a b quark and a W boson. Each b quark produces a jet, shown by the orange cones and each W boson decays to a neutrino (not seen) and a muon (shown by the red lines), CMS Experiment at the LHC, CERN, (2022).

Possible Z'TC2 Final States





67.6%: qq (cs ή ud)
32.4%: ℓ ν_ℓ

67.6%: qq (cs ή ud)
32.4%: ℓ ν_ℓ

FULLY HADRONIC
tt → W^+bW^-b, with W → qq'

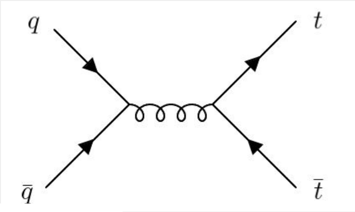
LEPTON+JETS (SEMILEPTONIC)
tt → W^+bW^-b, WITH W → qq', W' → $\ell\nu_\ell'$

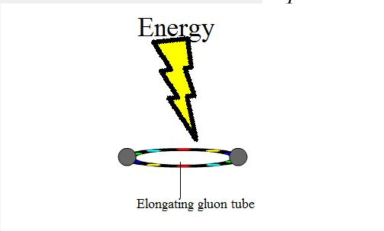
DILEPTONIC
tt → W^+bW^-b, with W → $\ell\nu_\ell'$

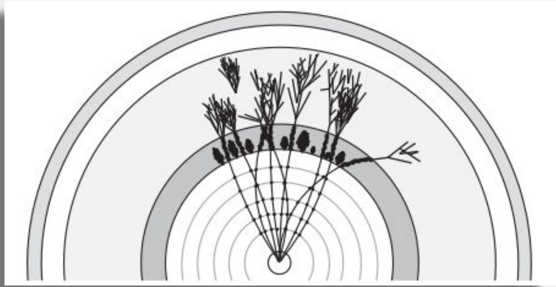
A candidate event in which a top quark pair is produced. Each top quark decays to a b quark and a W boson. Each b quark produces a jet, shown by the orange cones and each W boson decays to a neutrino (not seen) and a muon (shown by the red lines).
CMS Experiment at the LHC, CERN, (2022).

TTbar Events in the Detector

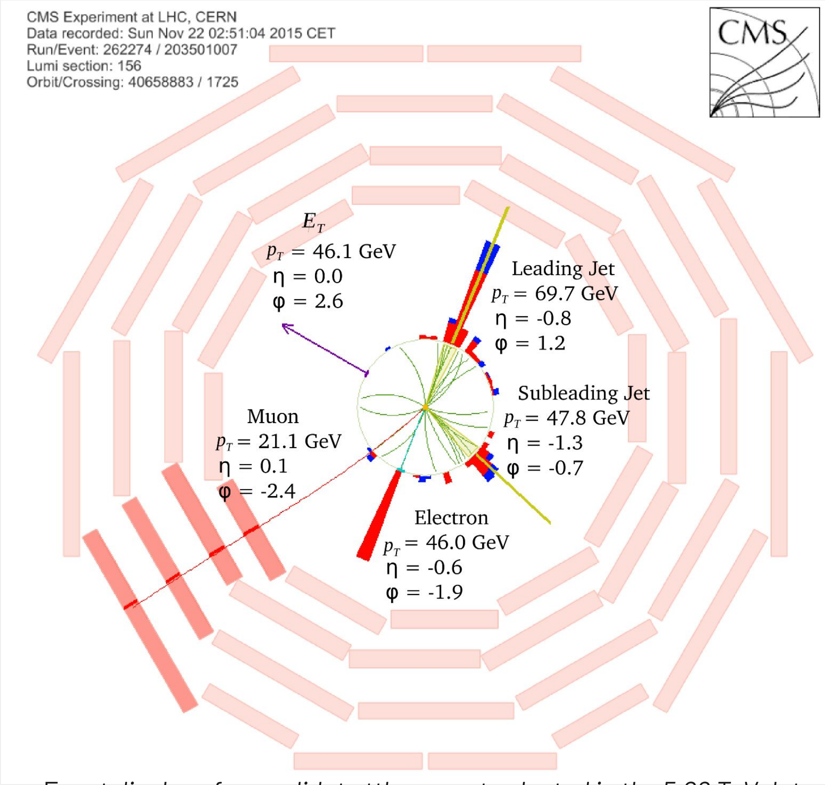
- Top decays before hadronisation -> can be seen “naked ” in the detector
- Top pair production: <u>qq annihilation</u> (15%) or gluon fusion



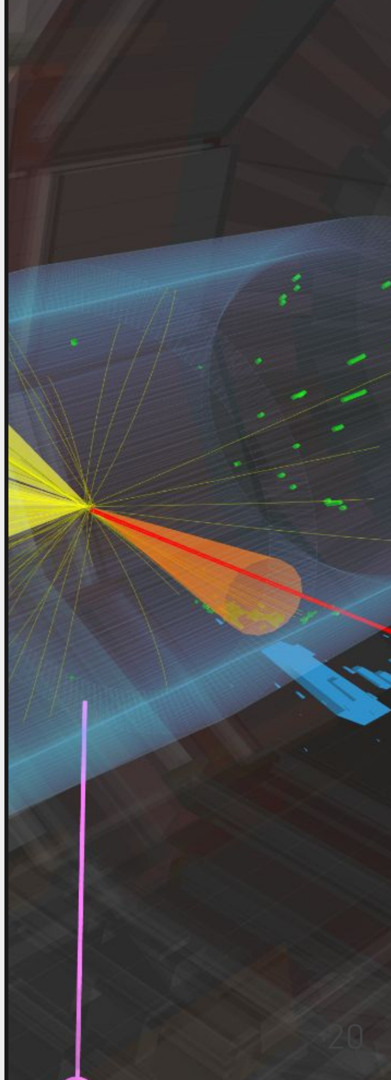




An illustration of the appearance of a jet in a detector. In practice, the individual particles are not resolved, Thomson (2013).



Event display of a candidate ttbar event selected in the 5.02 TeV dataset recorded by CMS, CMS, CERN (2020).



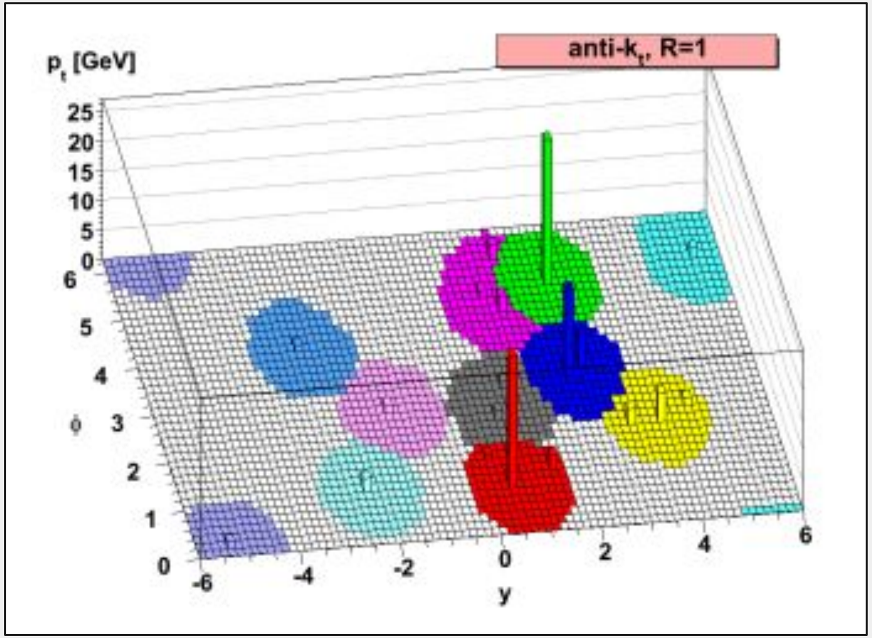
Anti-kt Clustering Algorithm

- Inclusive jet finding algorithms for hadron-hadron collisions
- Behave like an idealised *cone algorithm*
- Regularity of the boundaries of the resulting jets

$$\boxed{d_{ij} = \min(k_{ti}^{2p}, k_{tj}^{2p}) \frac{\Delta_{ij}^2}{R^2}}$$

$$\boxed{d_{iB} = k_{ti}^{2p}}$$

$$\boxed{\Delta_{ij}^2 = (y_i - y_j)^2 + (\varphi_i - \varphi_j)^2}$$

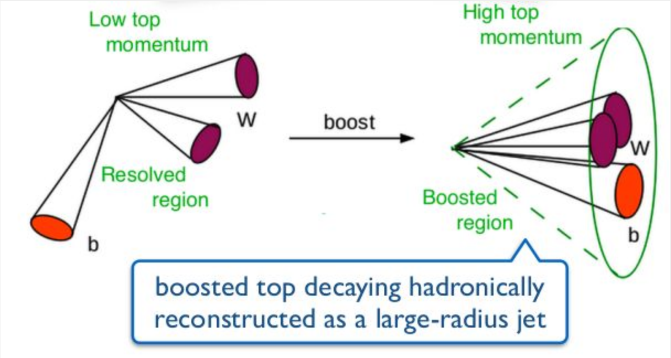


Parameter **p**: relative power of energy vs. geometric scales

The anti-k t jet clustering algorithm, Bakas, Cacciari and Salam, (2008).

N-Subjettiness

- Designed to identify boosted hadronicaly-decaying objects, *like top quarks*
- Tags boosted objects, *rejects QCD*
- N-subjettiness effectively *counts* the number of subjects in a given jet



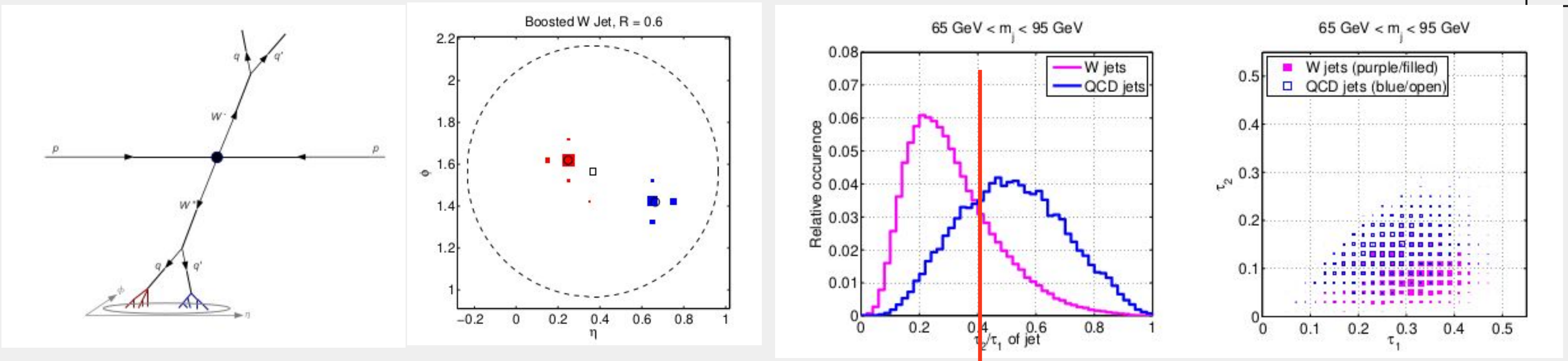
PhD presentation, Bakas, CMS and NTUA, (2023).

N-Subjettiness:

$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \min(\Delta R_{1,k}, \Delta R_{2,k}, \ldots, \Delta R_{N,k})$$

$$\Delta R_{J,k} = \sqrt{(\Delta\eta)^2 + (\Delta\varphi)^2}$$

$$d_0 = \sum_k p_{T,k} R_0$$



Identifying Boosted Objects with N-subjettiness, Thaller % Tilburg, (2011).

Discriminating:

$$\tau_N/\tau_M$$

- τ_N quantifies how N-subjetty a jet is, to what degree it can be regarded as **composed of N subjets**

Analysis Strategy

Event display of a H -> 4e candidate event, ATLAS Collaboration, CERN (2012).

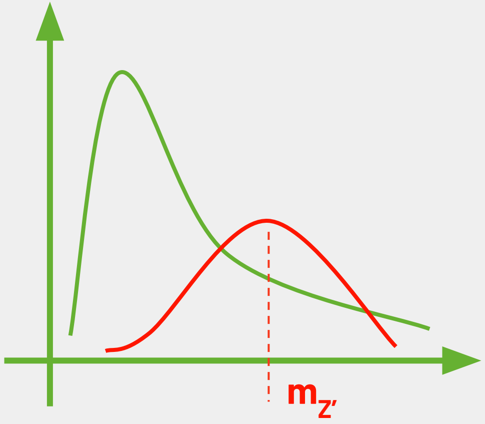
Outline of analysis - Main ideas

ROOT
by CERN

- Open-source data analysis framework used by high energy physics and others
- Mix of python and C++
- programme.C

Two Background processes (BGK):

- $t\bar{t}$ production from SM processes
- Other particles from QCD interactions



Strategy

1. Work with Monte Carlo (MC) simulations of BGK
2. Add Signal (S) MC simulations for Z′
3. Analyse Data sample from 2016

Files

<u>Background (QCD + tt) file:</u>

TT_TuneCUETP8M2T4_13TeV-powheg-pythia8.root

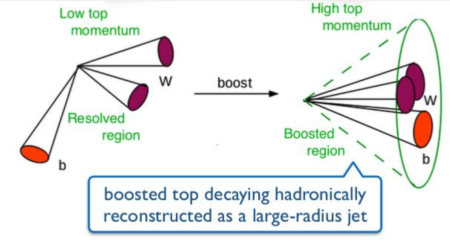
<u>Signal Z′ file:</u>

ZprimeToTT_**M3500_W35**_TuneCP2_PSweights_13TeV-madgraph-pythiaMLM-pythia8_20UL.root

Top Tagger Development

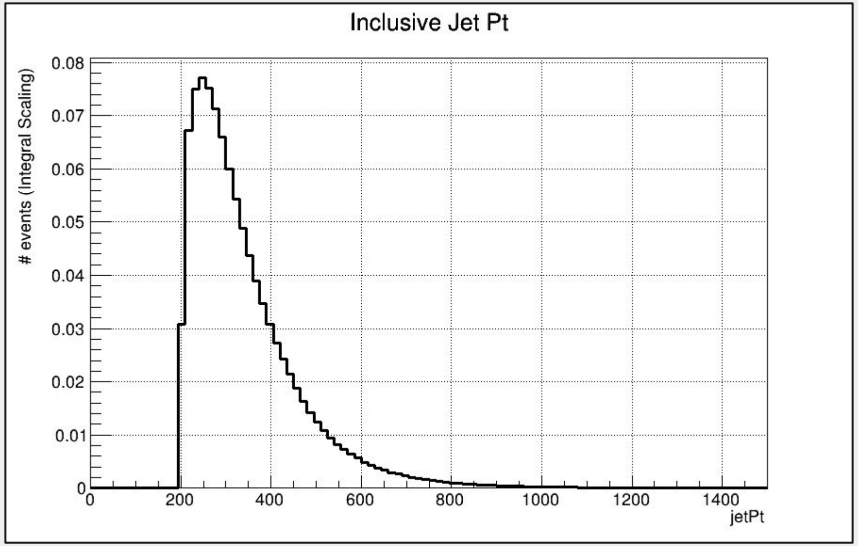
- TT’ and QCD background file:
  - “TT_TuneCUETP8M2T4_13TeV-powheg-pythia8.root”

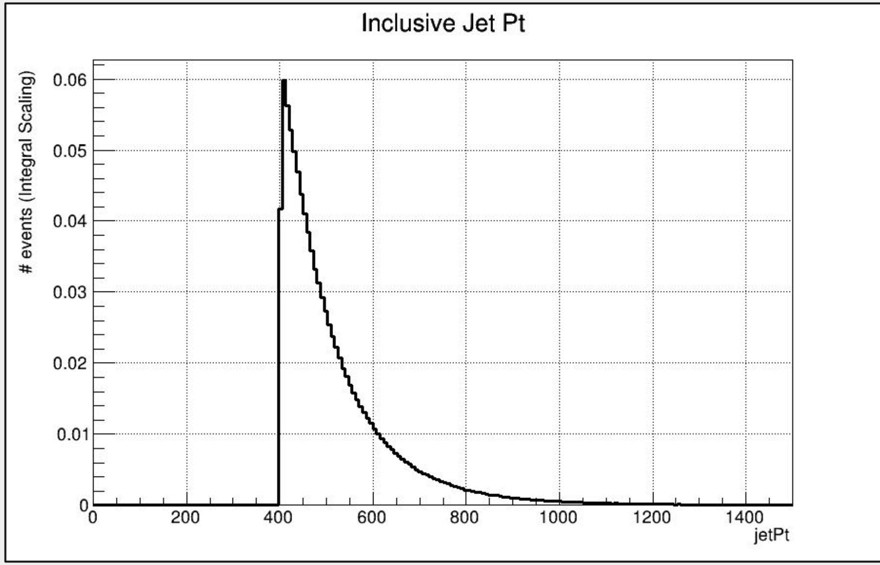
Top Tagger: p_t and mass cuts



Pt cuts for boosted jet phase space:

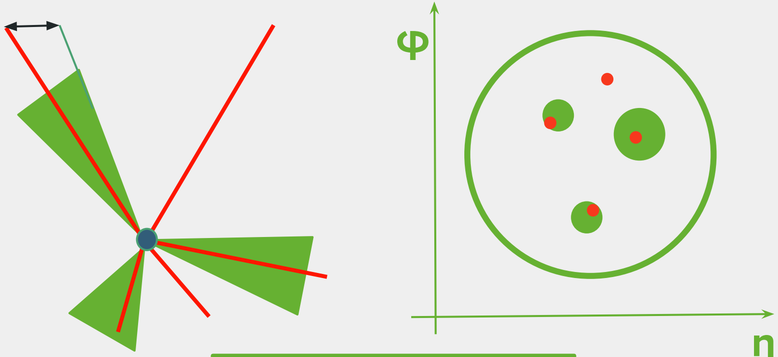
jetPt > 400 (GeV/c)





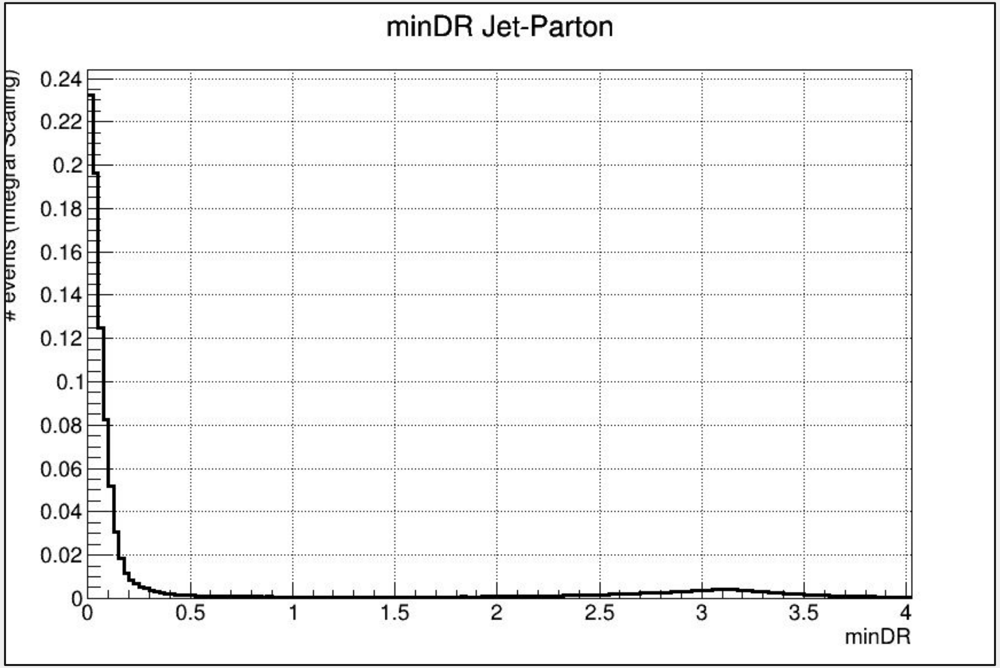
Top Tagger Development

Calculation of **DR** between Reconstructed Jet & Parton:



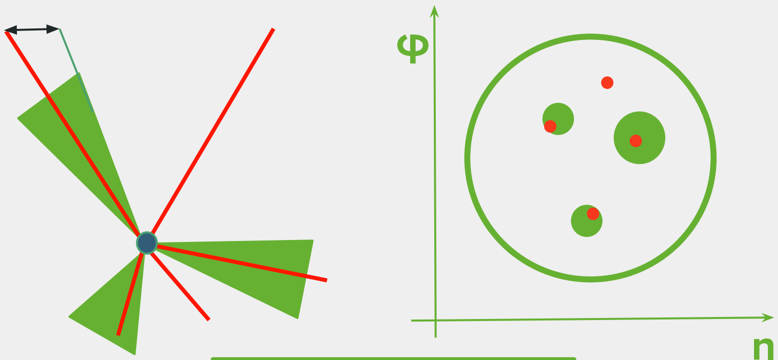
$$DR = \sqrt{(D\eta)^2 + (D\varphi)^2}$$

- Histogram of **min(DR)**
- Cuts:

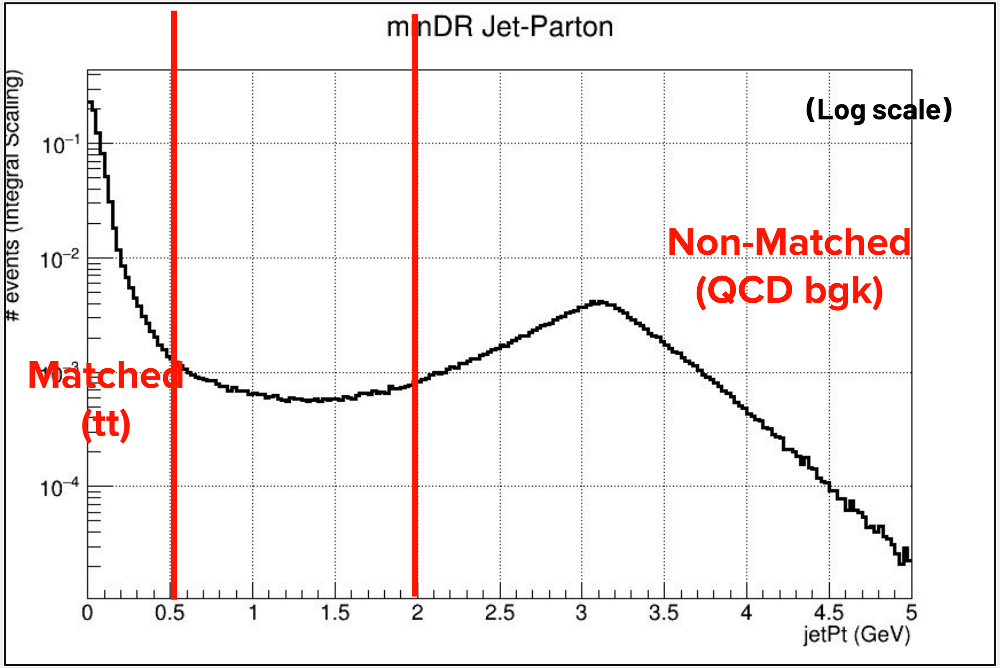


Top Tagger Development: DRmin

Calculation of **DR** between Reconstructed Jet & Parton:



$$DR = \sqrt{(D\eta)^2 + (D\varphi)^2}$$

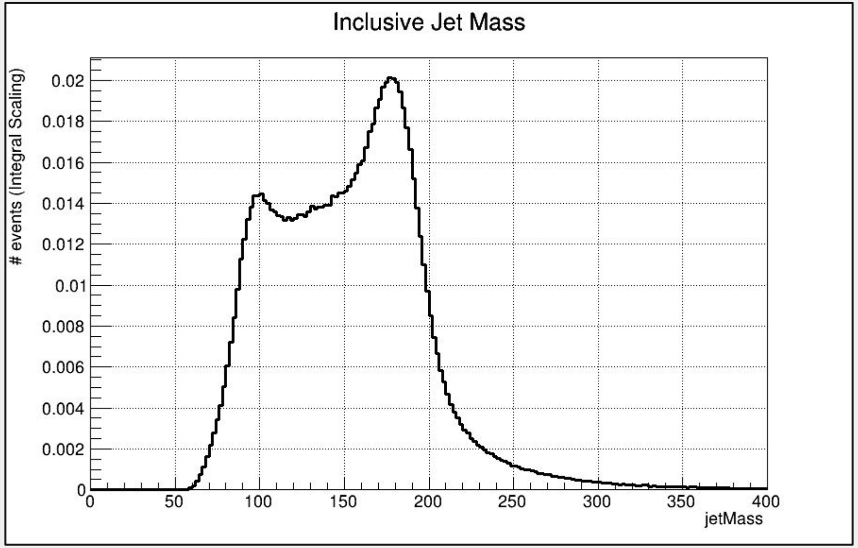


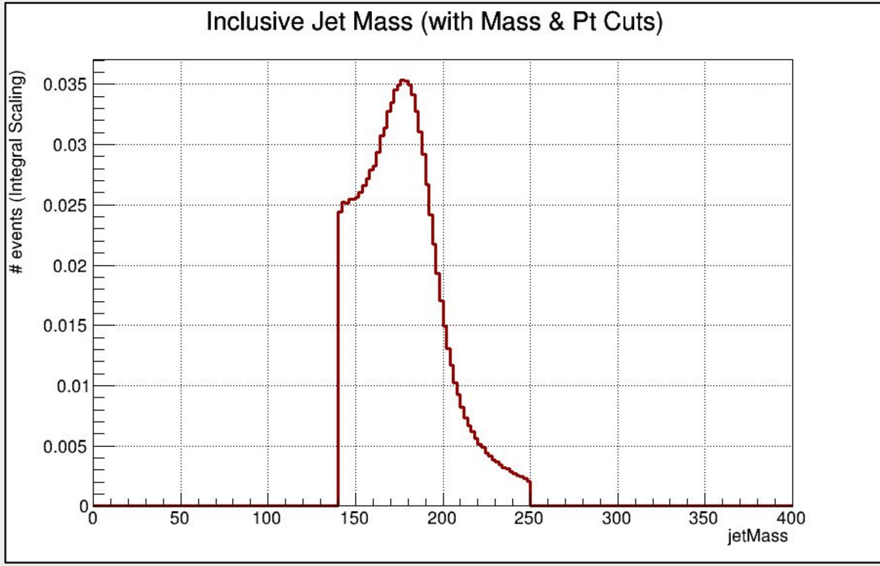
- Histogram of **min(DR)**
- Cuts: **DRmin < 0.5** (matched)
  DRmin > 2 (non-matched)

Top Tagger: p_t and mass cuts

Mass cuts for top jet:

140 < jetMass < 250 (GeV/c^2)





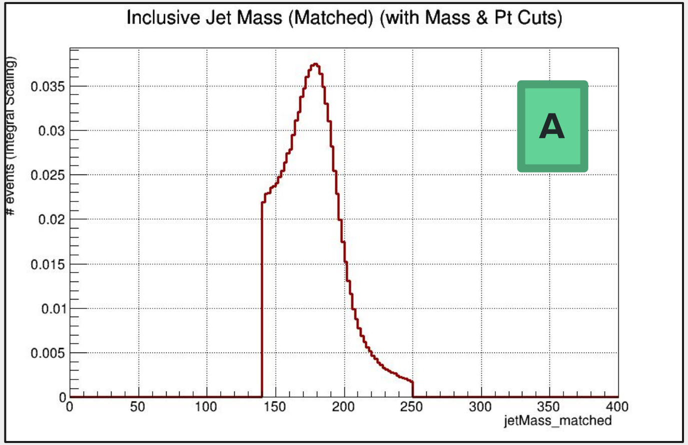
Top Tagger: 3 different mass cuts

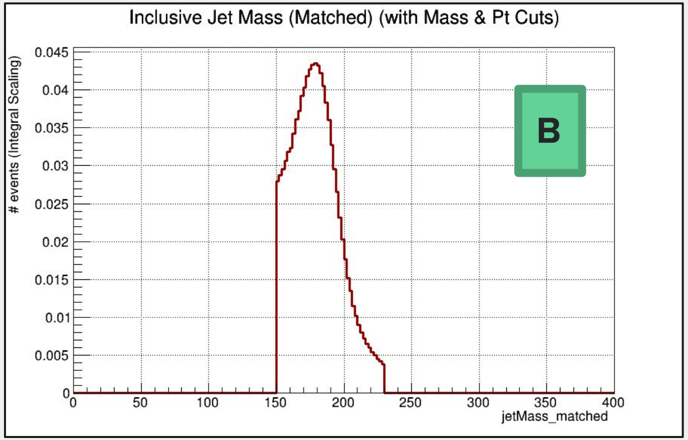
Mass Windows (GeV):

A: [140, 250]

B: [150, 230]

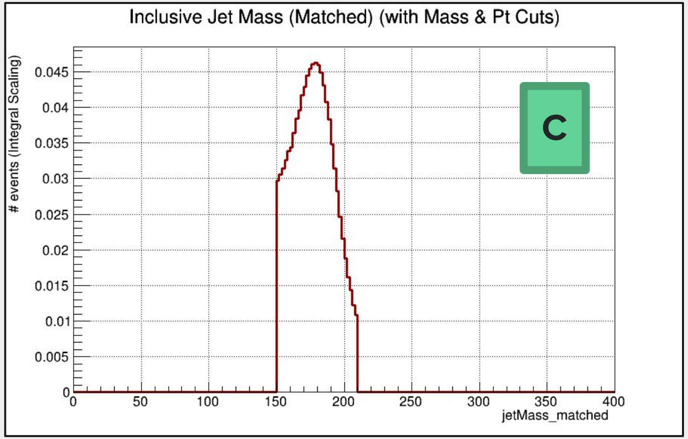
C: [150, 210]





Pt cuts:

jetPt > 400 (GeV)



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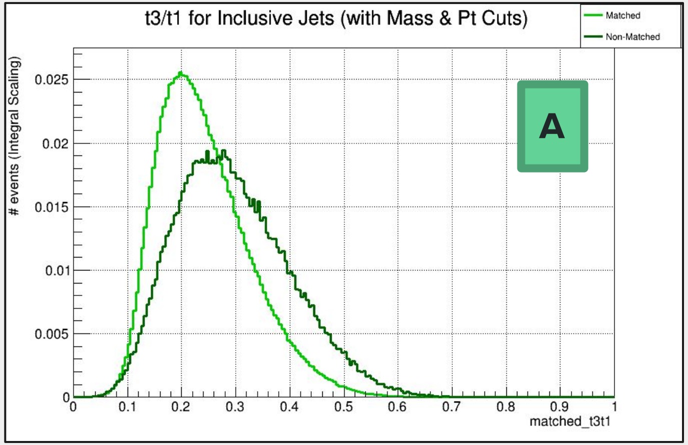
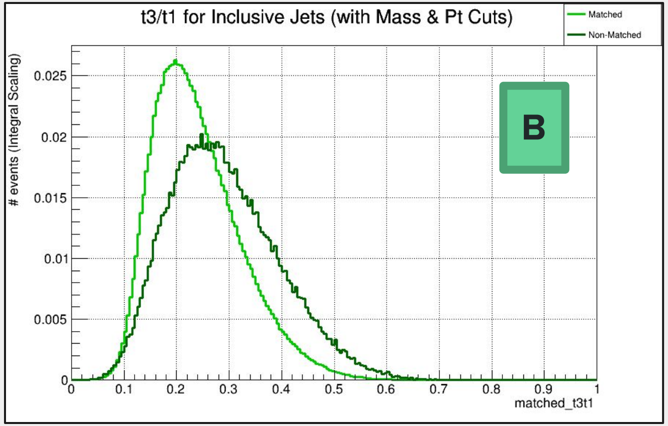
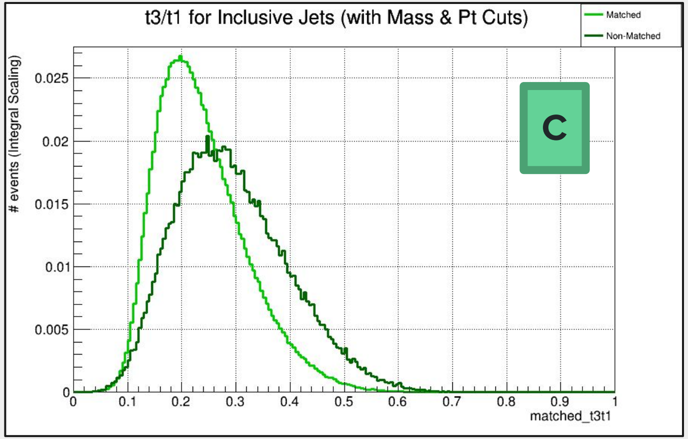




Matched

Non-Matched

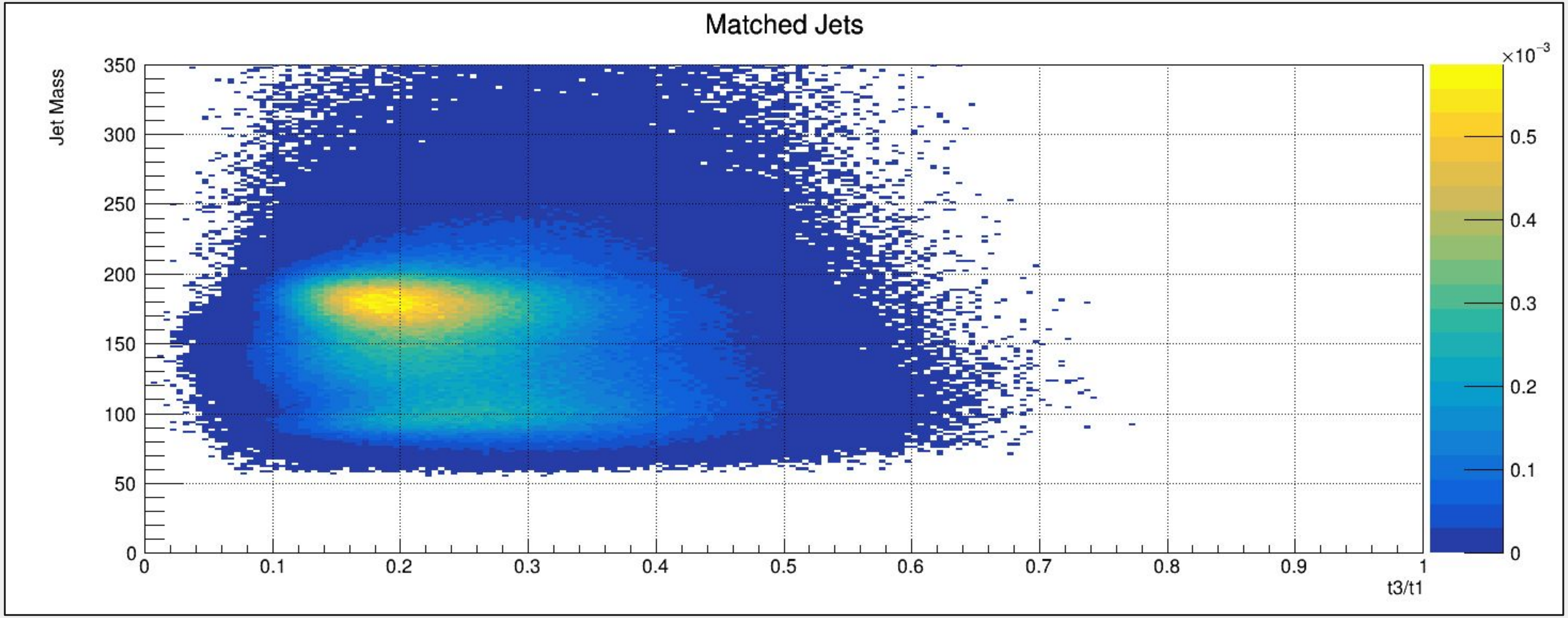
<u>Pt cuts:</u>
jetPt > 400 (GeV)



Top Tagger: jetMass vs. τ3/τ1

Mass cut **A** for top jet:

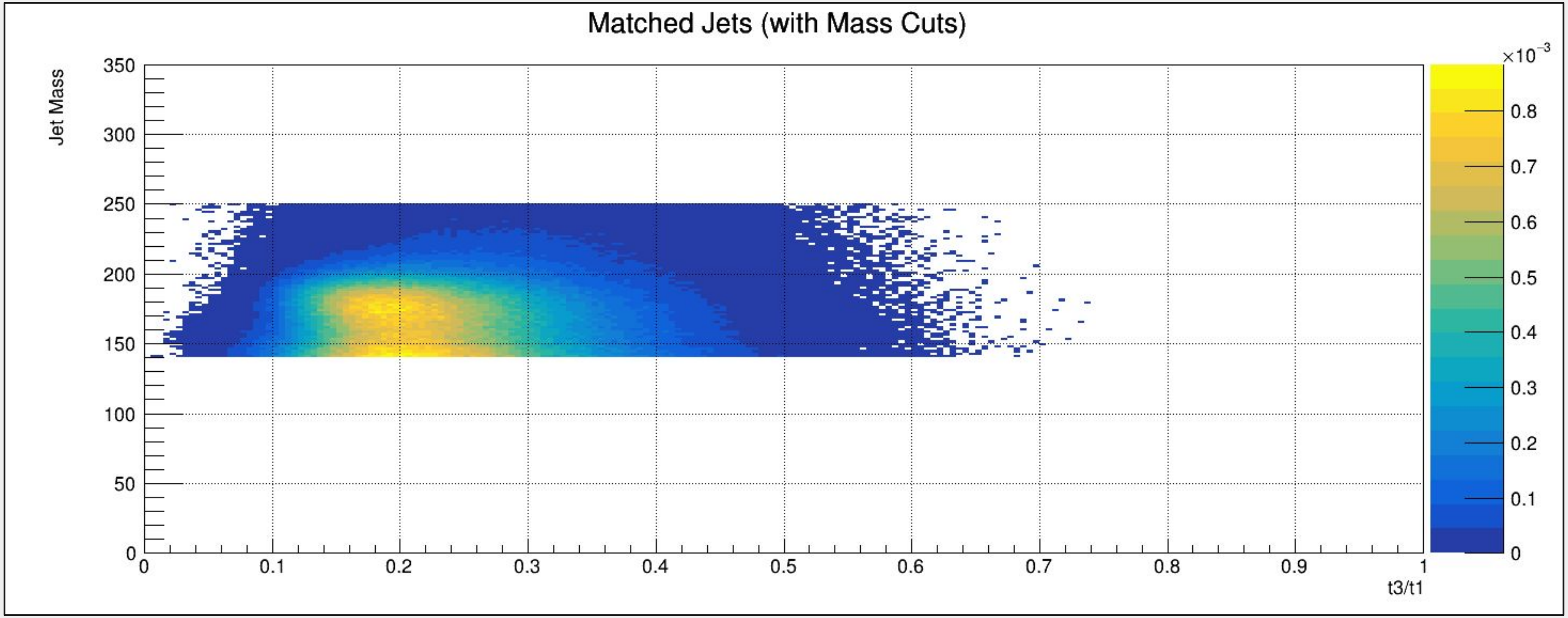
140 < jetMass < 250 (GeV/c^2)



Top Tagger: jetMass vs. τ3/τ1

Mass cut **A** for top jet:

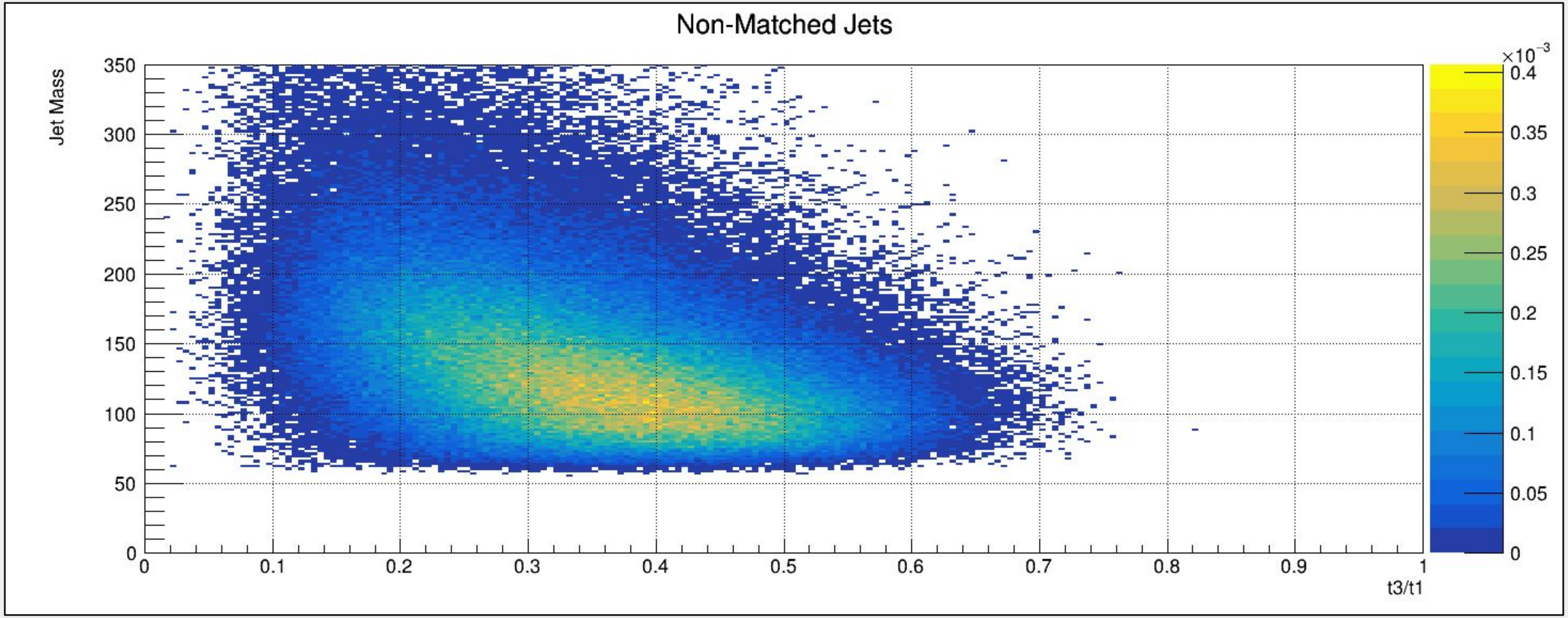
140 < jetMass < 250 (GeV/c^2)



Top Tagger: jetMass vs. τ3/τ1

Mass cut **A** for top jet:

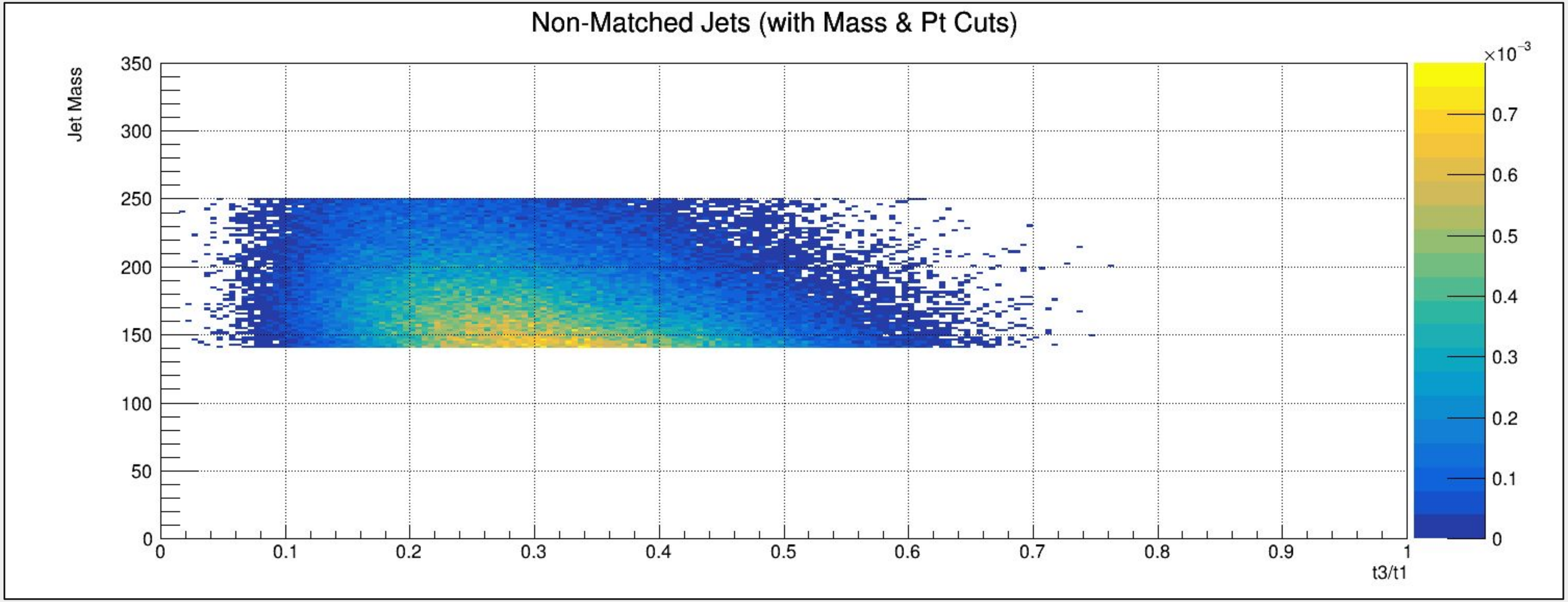
140 < jetMass < 250 (GeV/c^2)



Top Tagger: jetMass vs. τ3/τ1

Mass cut **A** for top jet:

140 < jetMass < 250 (GeV/c²)



Top Tagger: Efficiency diagram

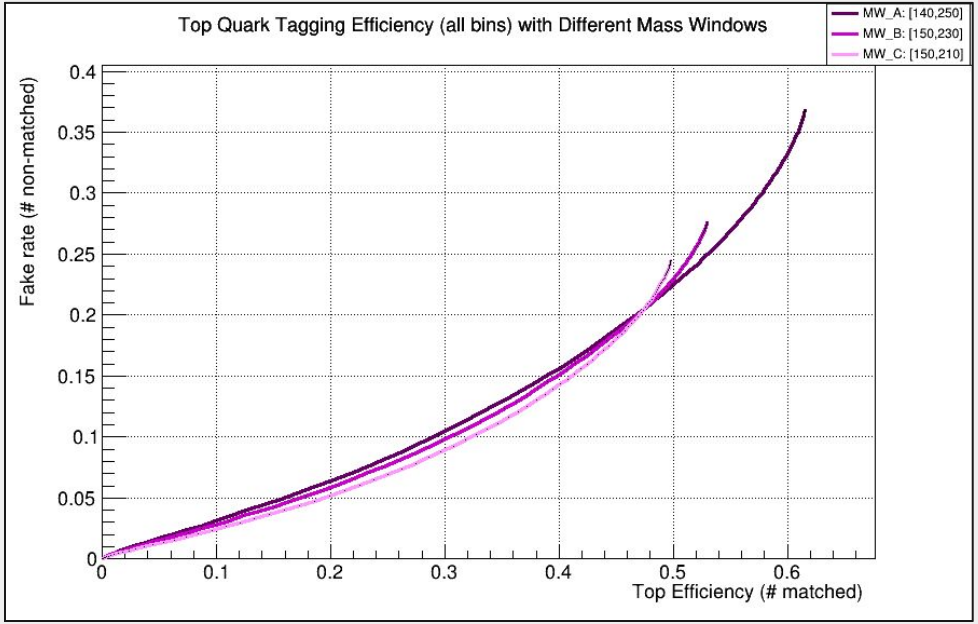
Mass Windows (GeV):

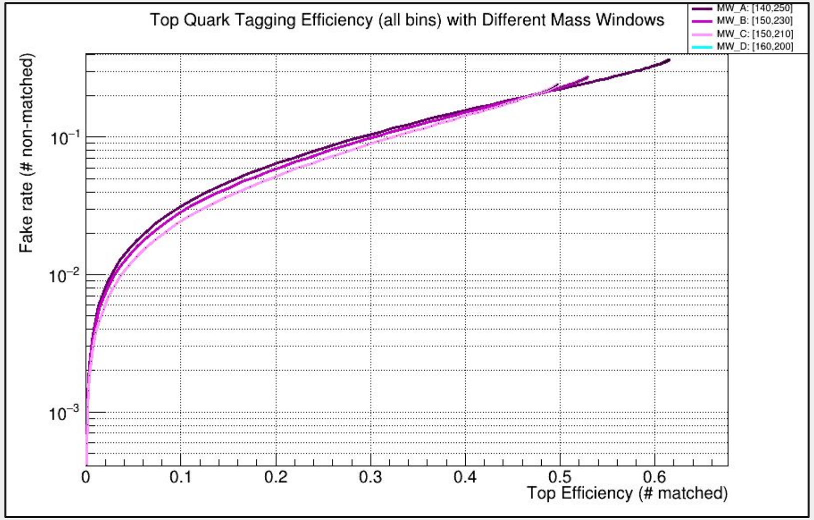
A: [140, 250]

B: [150, 230]

C: [150, 210]

$$\textbf{Efficiency} = \frac{\text{\#jets that pass } \textbf{mass cut} + \boldsymbol{\tau_3/\tau_1}\ \textbf{cut} \text{ with } \textbf{Pt} > \textbf{400}}{\text{\#jets with } \textbf{Pt} > \textbf{400}}$$





Top Tagger: Efficiency diagram

Mass Windows (GeV): **A:** [140, 250] **B:** [150, 230] **C:** [150, 210]

$$\textbf{Efficiency} = \frac{\#\text{jets that pass } \textbf{mass cut} + \tau_3/\tau_1 \textbf{ cut} \text{ with } \textbf{Pt > 400}}{\#\text{jets with } \textbf{Pt > 400}}$$

Tight working point:

30% Top Tagging efficiency (matched)

-> **Integral(τ_3/τ_1) = 0.3**

[150,210] Mass Window cut

Loose working point:

53% Top Tagging efficiency (matched)

-> **Integral(τ_3/τ_1) = 0.53**

[140,250] Mass Window cut

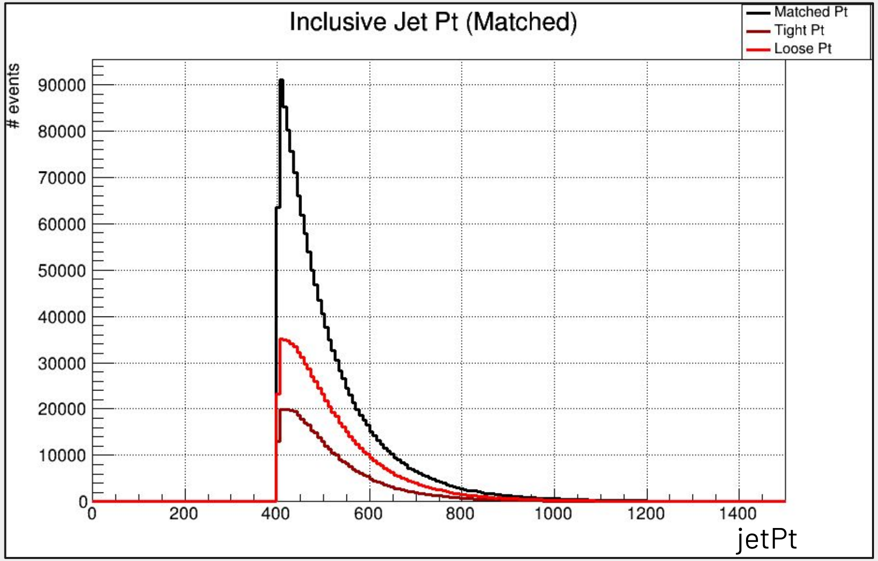
Top Tagger: P_t Efficiency Diagram

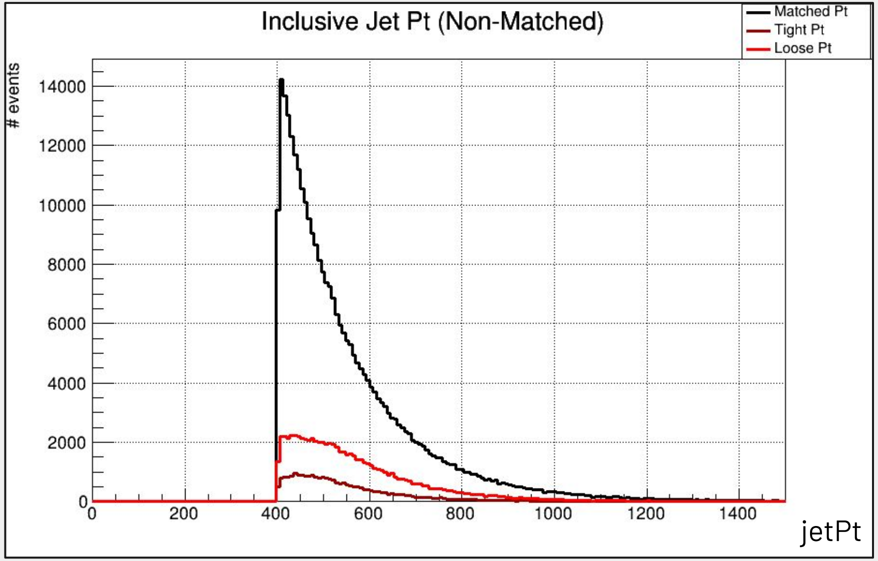
Loose

Tight

Pt cuts for boosted jet phase space:

jetPt > 400 (GeV)



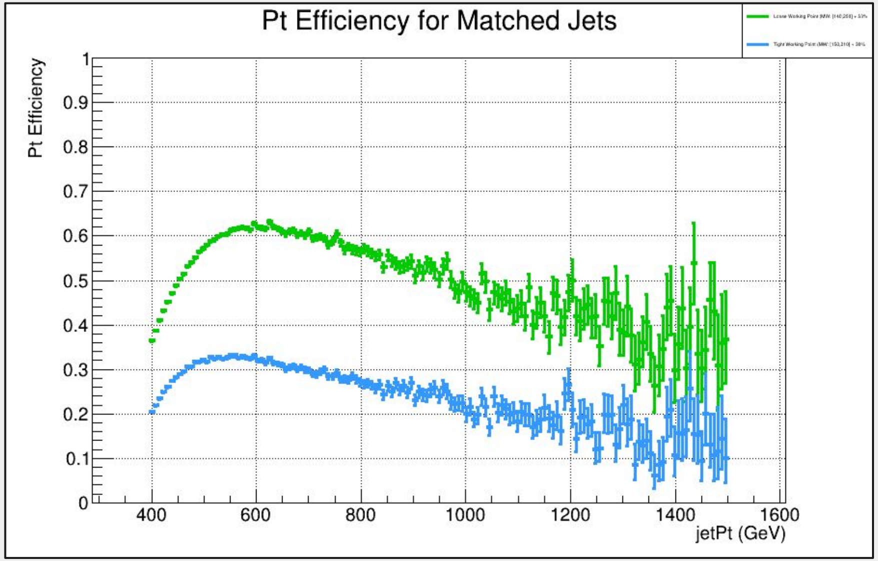


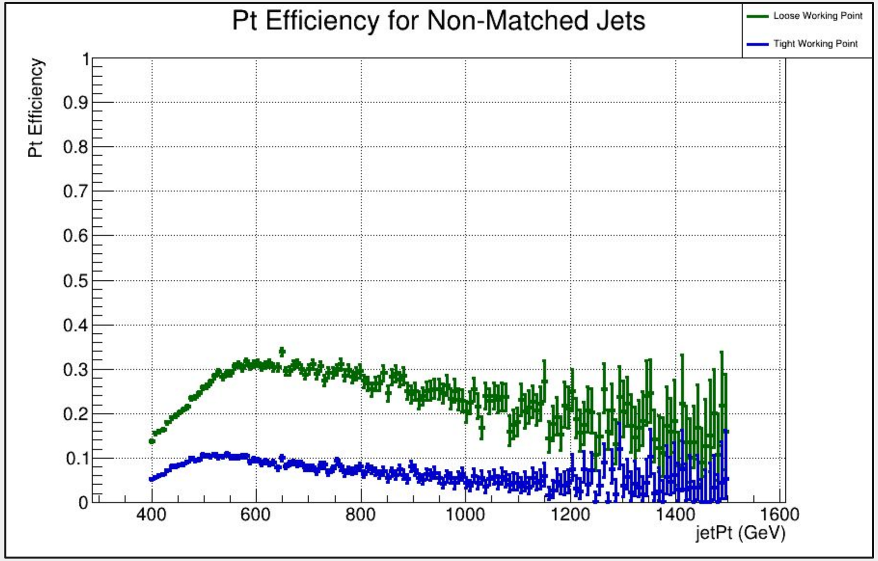
Top Tagger: P_t Efficiency Diagram

Loose

Tight

$$\text{Efficiency}^{M}_{\text{Loose}} = \frac{\text{jetPt histogram with } \textbf{LOOSE} \text{ w.p. (mass cut } \textbf{A} + \textbf{53\%} \text{ s.e.) with } \textbf{Pt > 400}}{\text{jetPt histo with } \textbf{Pt > 400}}$$

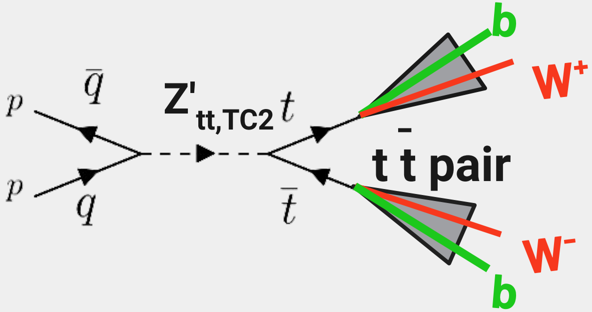


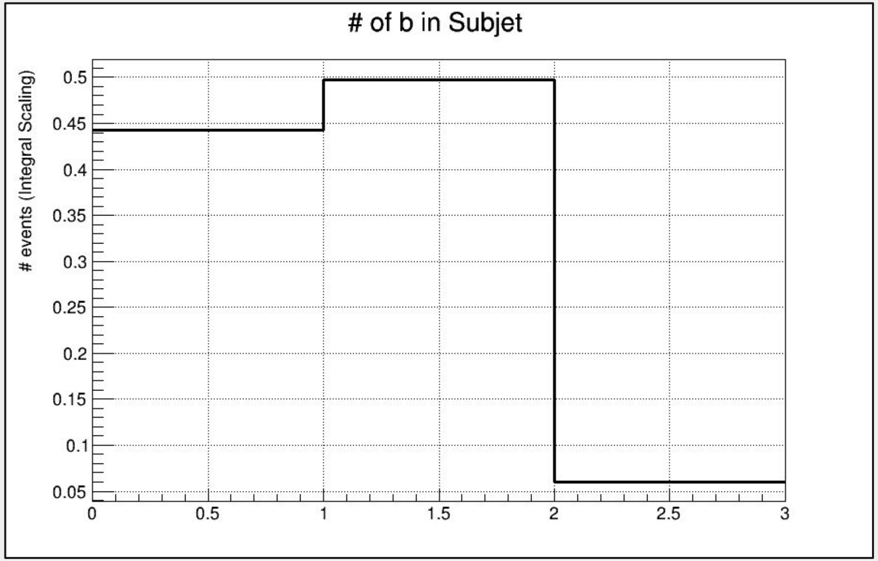


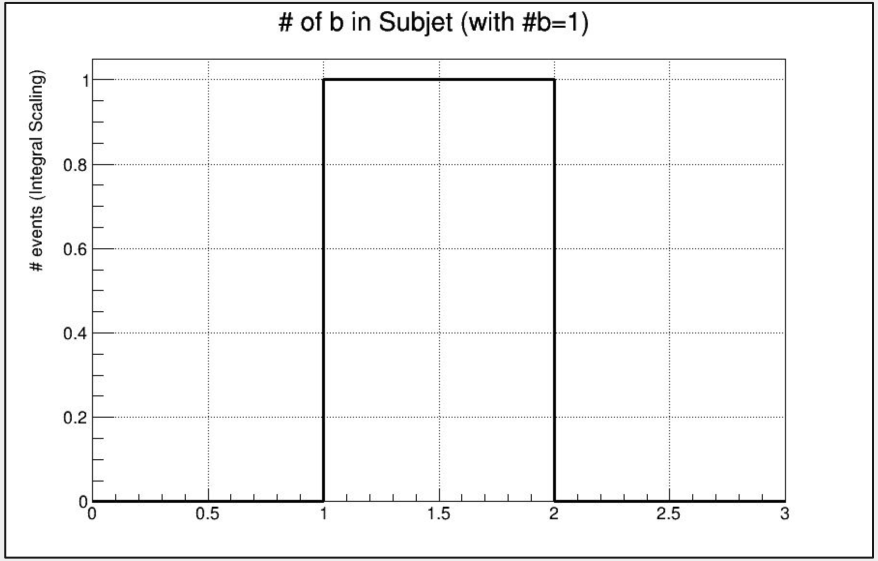
Top Tagger: Adding b quarks cuts

Bottom quark cuts for top jet:

 # b jets == 1







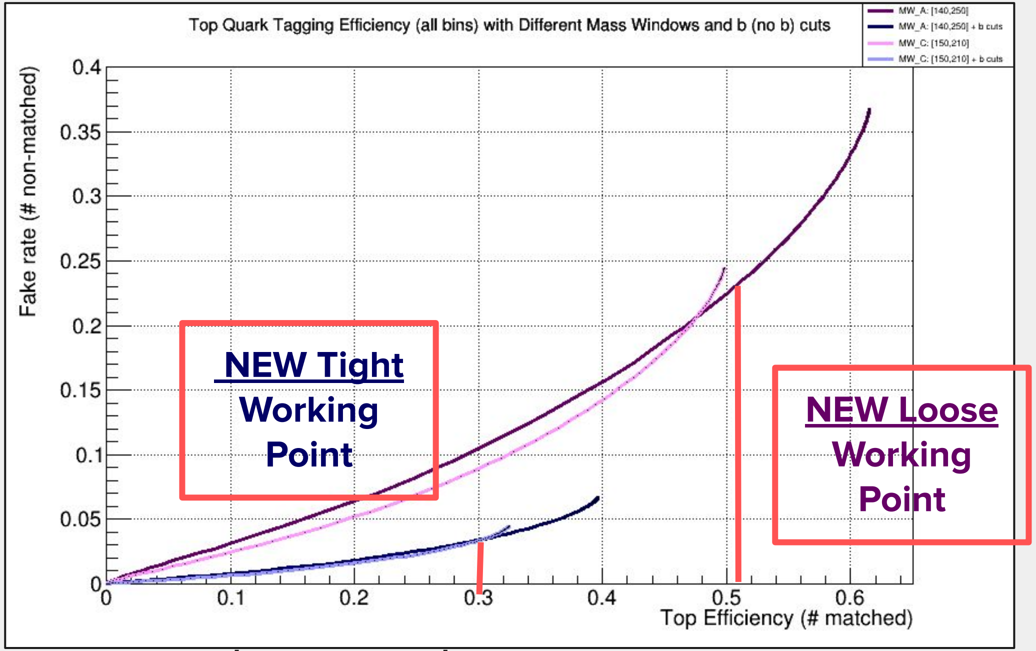
Top Tagger: Efficiency diagram with b cuts

jetMass: [140, 250]

jetMass: [150, 210]

jetMass: [140, 250]
#b = 1

jetMass: [150, 210]
#b = 1



NEW Tight working point:
30% Top Tagging efficiency (matched)
[150,210] Mass Window cut
b cuts

NEW Loose working point:
53% Top Tagging efficiency (matched)
[140,250] Mass Window cut
~~**b cuts**~~

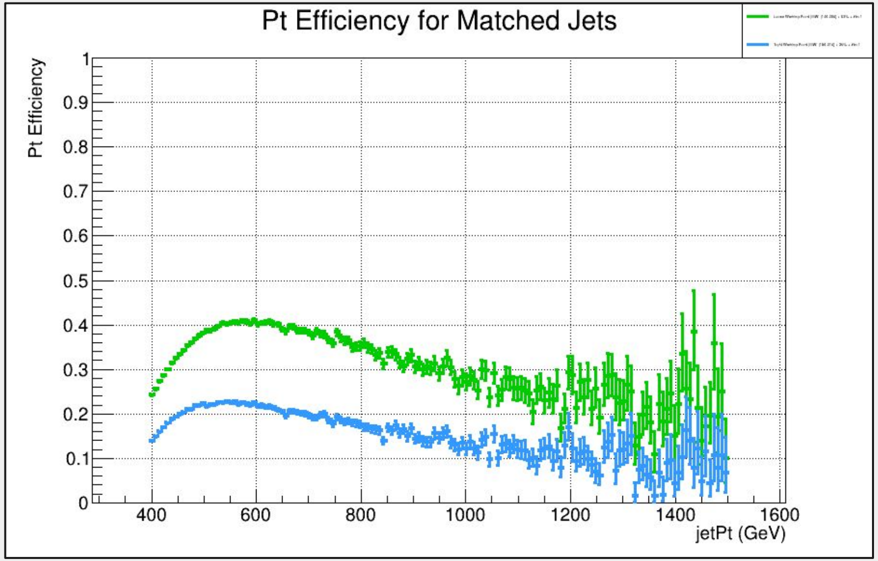
Top Tagger: P_t Efficiency Diagram with b cuts

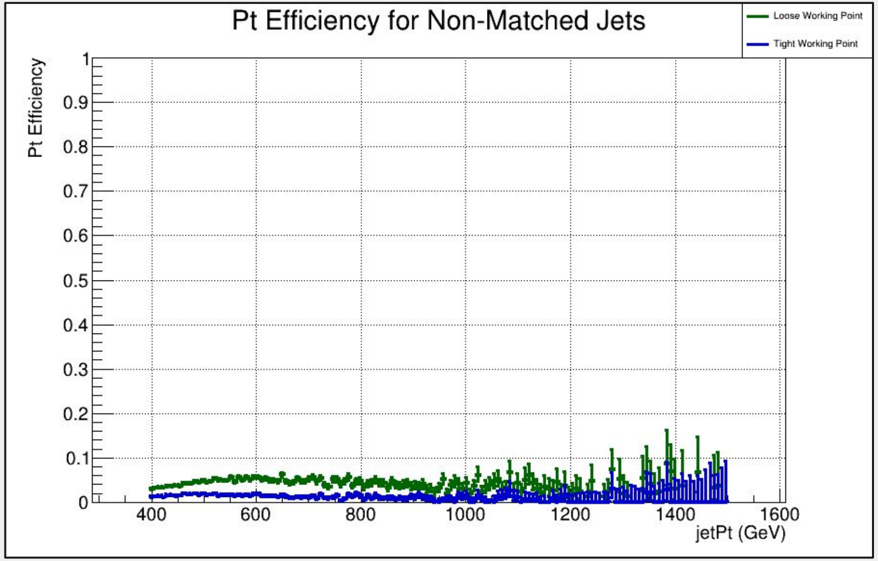
NEW Loose

NEW Tight

NEW Tight working point:
30% Top Tagging efficiency (matched)
[150,210] Mass Window cut
b cuts

NEW Loose working point:
53% Top Tagging efficiency (matched)
[140,250] Mass Window cut
~~**b cuts**~~

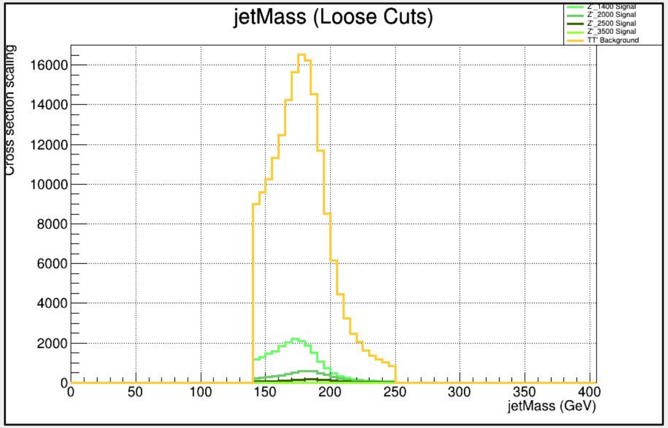




Sensitivity diagram

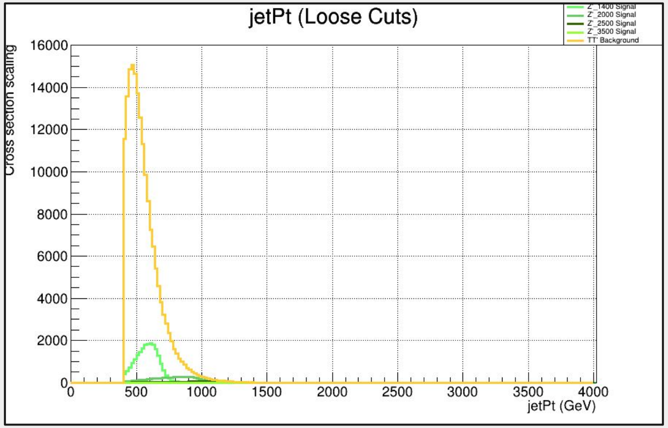
- **Add in Signal files;**
  - "**ZprimeToTT_M1400_W14_TuneCP2_Psweights_13TeV-madgraph-pythiaMLM-pythia8_20UL.root**", for simulating the Z' signal of mass **1400**GeV/c 2 and width 1%.
  - "**ZprimeToTT_M2000_W20_TuneCP2_Psweights_13TeV-madgraph-pythiaMLM-pythia8_20UL.root**", for simulating the Z' signal of mass **2000**GeV/c 2 and width 1%.
  - "**ZprimeToTT_M2500_W25_TuneCP2_Psweights_13TeV-madgraph-pythiaMLM-pythia8_20UL.root"**, for simulating the Z' signal of mass **2500**GeV/c 2 and width 1%.
  - "**ZprimeToTT_M3500_W35_TuneCP2_Psweights_13TeV-madgraph-pythiaMLM-pythia8_20UL.root**", for simulating the Z' signal of mass **3500**GeV/c 2 and width 1%.

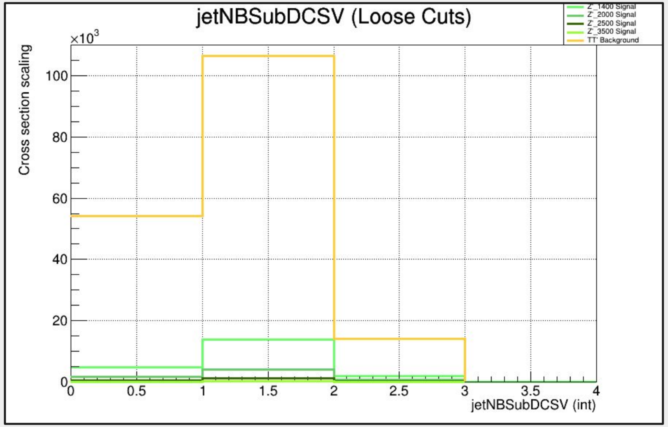
Sensitivity calculation: Absolute yield comparison



$$w_i = \frac{\sigma_i \times L}{\#\text{ of total events}}$$

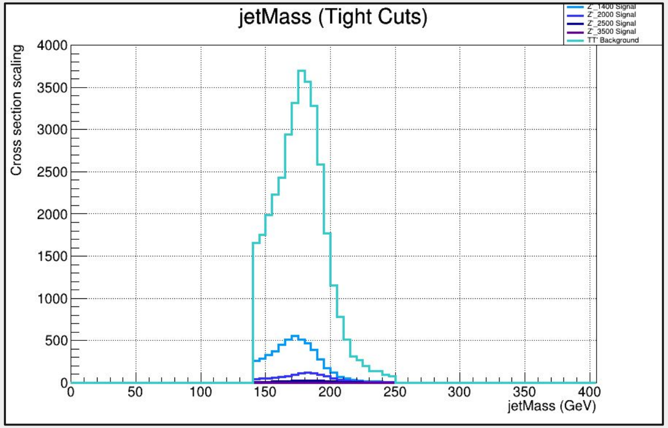
Luminocity L = 36 fb^{-1}





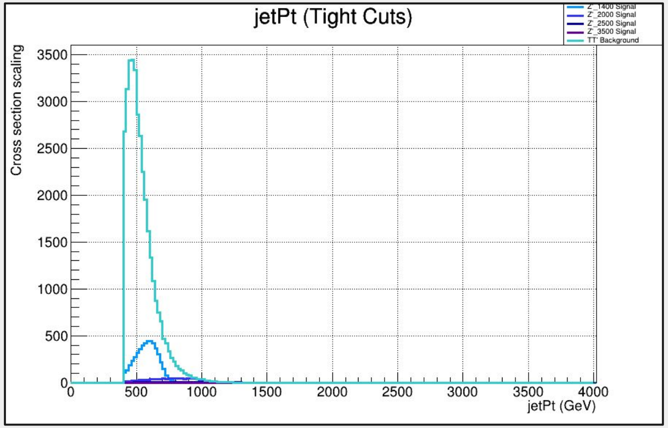
Z'mass	σ (pb)	Scaling factor w_i
tt BGK	832	0.760265179
1400	0.9095	0.251950026
2000	0.1662	0.047517521
2500	0.04749	0.013247152
3500	0.005105	0.001532231

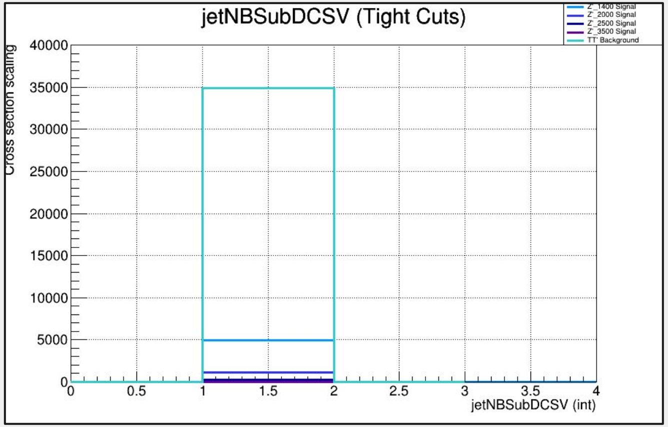
Sensitivity calculation: Absolute yield comparison



$$w_i = \frac{\sigma_i \times L}{\#\text{ of total events}}$$

Luminocity $L = 36\ fb^{-1}$





Z'mass	σ (pb)	Scaling factor w_i
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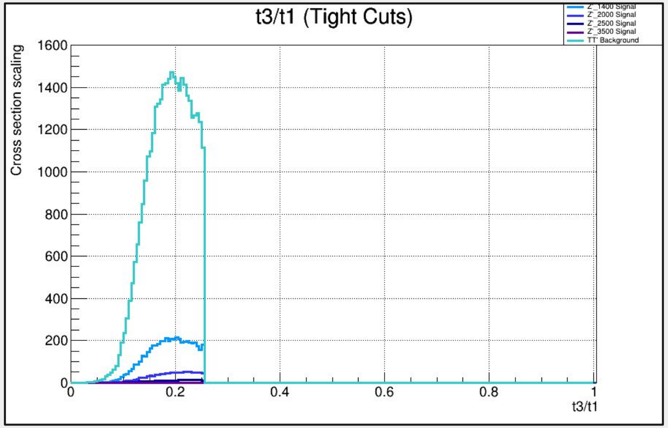
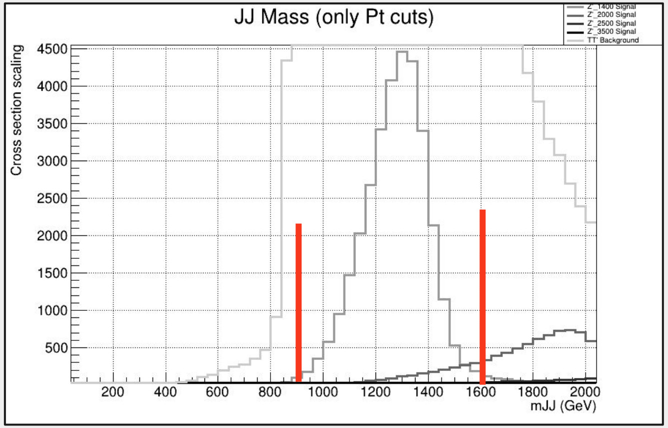
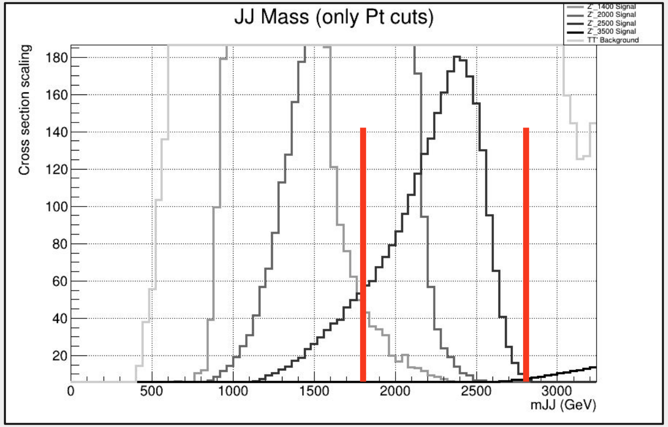
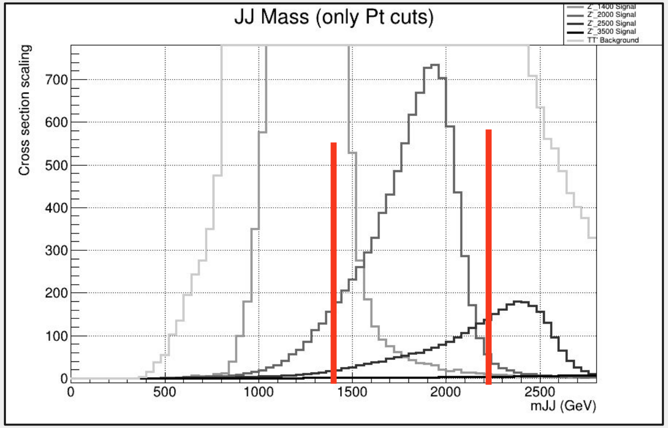


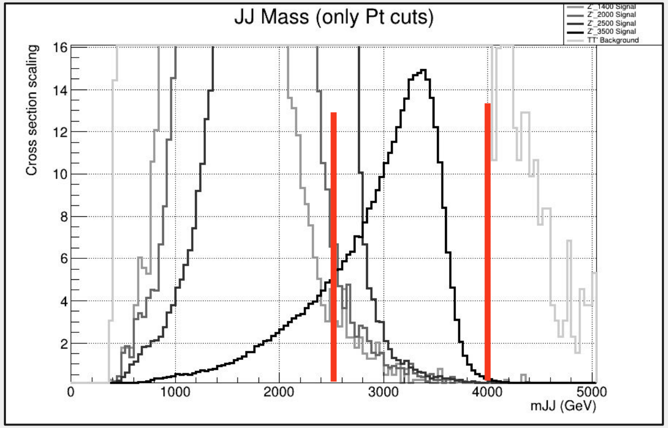
Sensitivity calculation: Different Z' masses



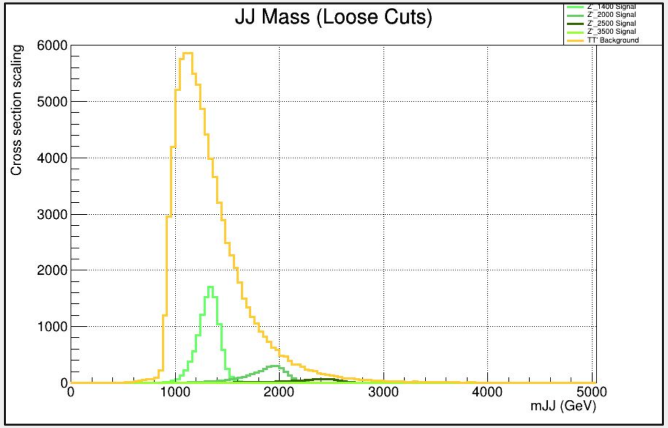


Z'mass	Mass window
1400	[900, 1600]
2000	[1400,2300]
2500	[1800,2800]
3500	[2500,4000]





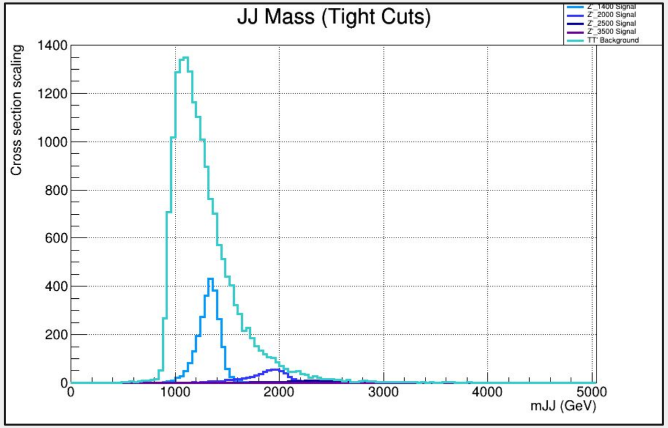
Sensitivity calculation: mJJ integration



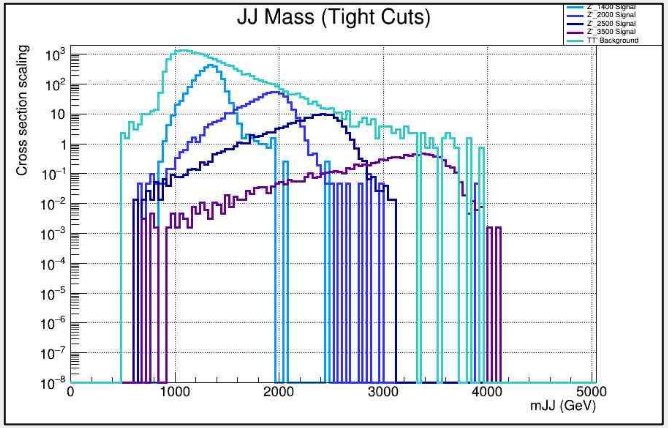
Sensitivity =

$$\frac{\textbf{Signal}}{\sqrt{(\textbf{QCD Bgk + TT' Bgk})}}$$

INTEGRATE



Z'mass	Mass window
1400	[900, 1600]
2000	[1400,2300]
2500	[1800,2800]
3500	[2500,4000]



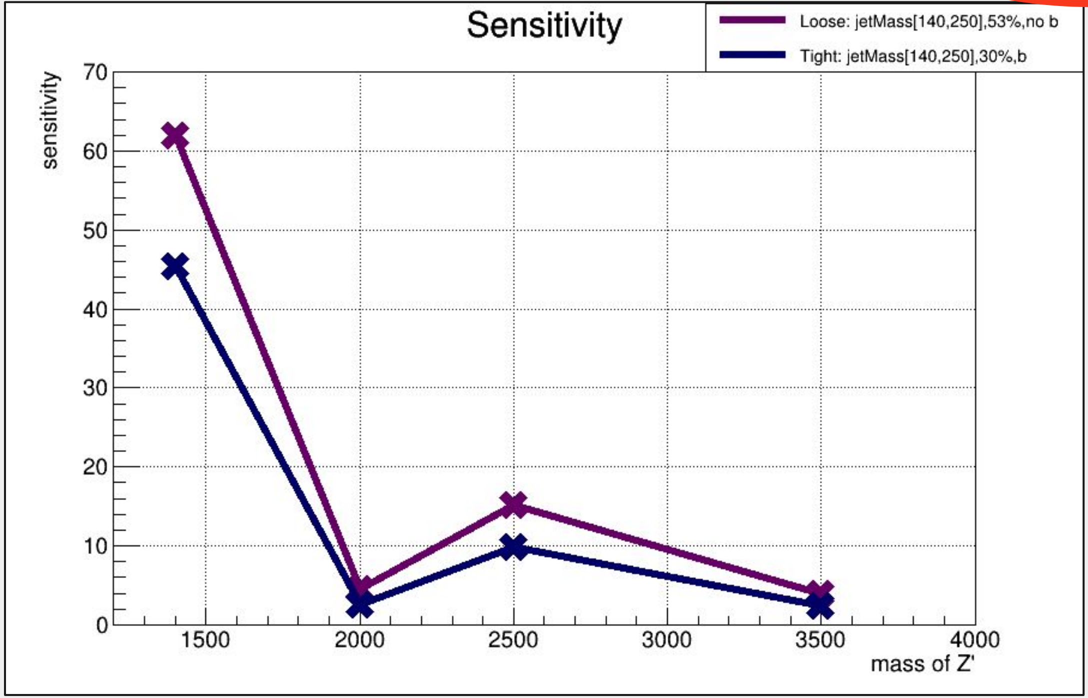
Sensitivity diagram

For different Z' masses:

$m_{Z'}$ = 1400, 2000, 2500, 3500 GeV/c^2

LOOSE:
jetMass: [140, 250]
53%
no b cuts

TIGHT:
jetMass: [140, 250]
30%
#b = 1



$$\textbf{Sensitivity} = \frac{\textbf{Signal}}{\sqrt{(\textbf{QCD Bgk} + \textbf{TT' Bgk})}}$$

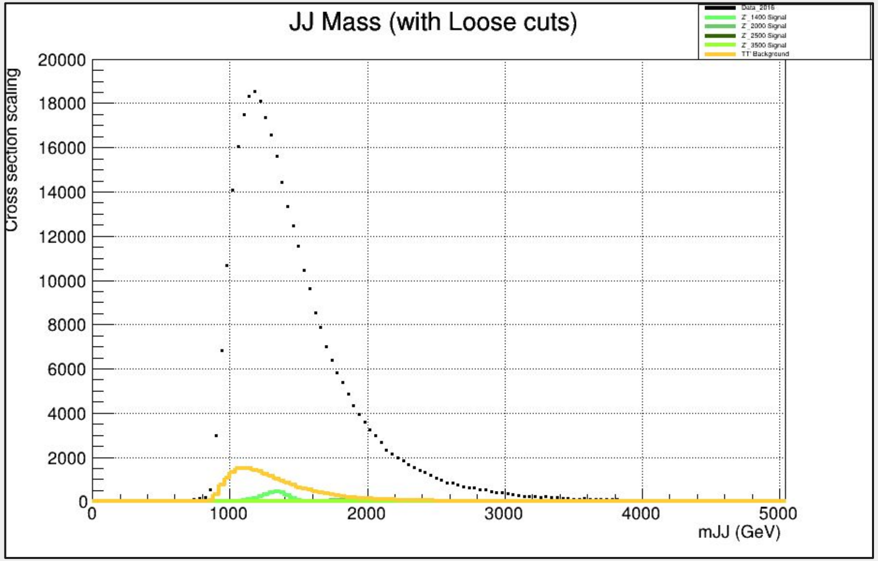
Data analysis and comparison with MC simulations

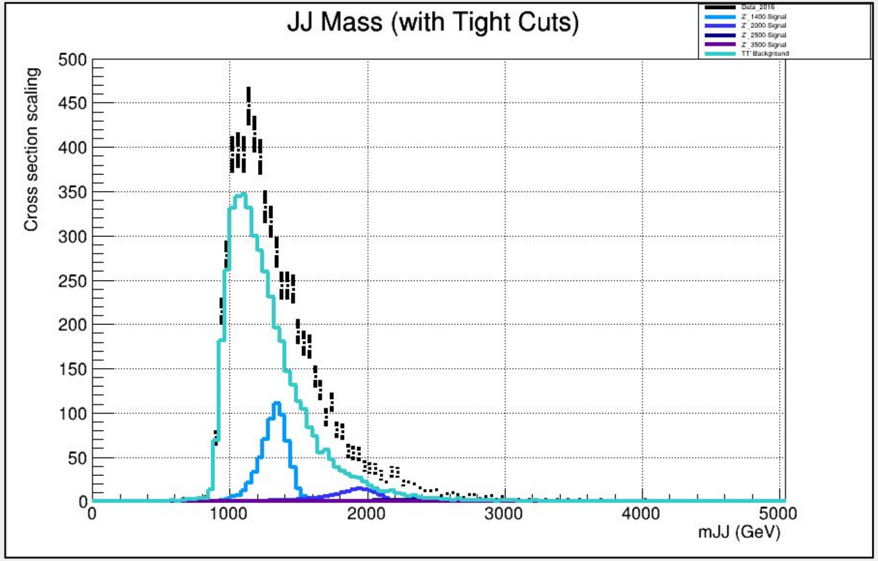
- **Add in Data file:**
  - "**JetHT_Run2016-17Jul2018.root**", **2016** data file, The CMS Collaboration, CERN
- **Calculate QCD using data-driven method**

Calculating the QCD bgk: mJJ

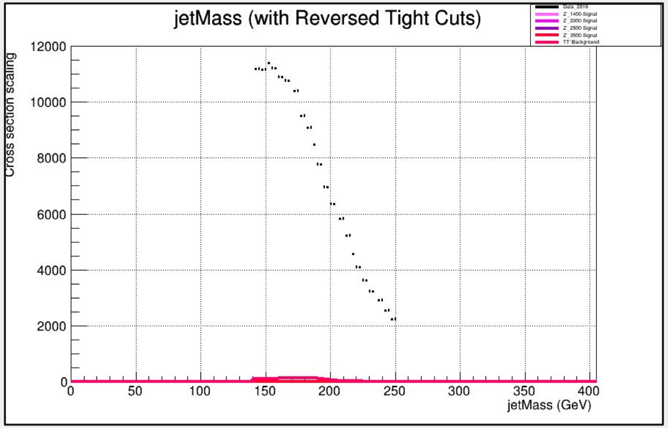
NEW Loose working point:
53% Top Tagging efficiency (matched)
[140,250] Mass Window cut
~~b cuts~~

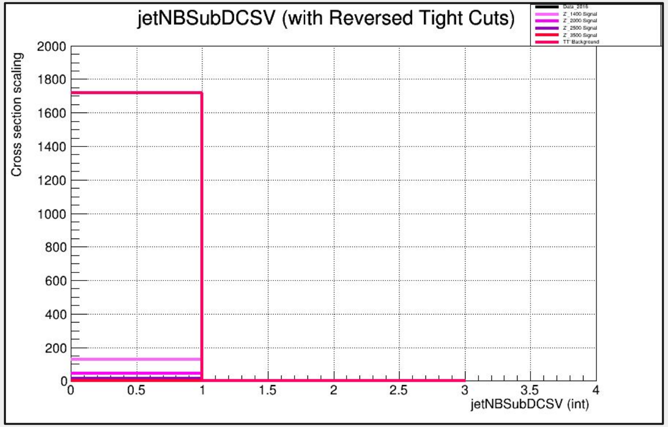
NEW Tight working point:
30% Top Tagging efficiency (matched)
[150,210] Mass Window cut
b cuts





Calculating the QCD bgk: Reversed Tight cuts (RC)

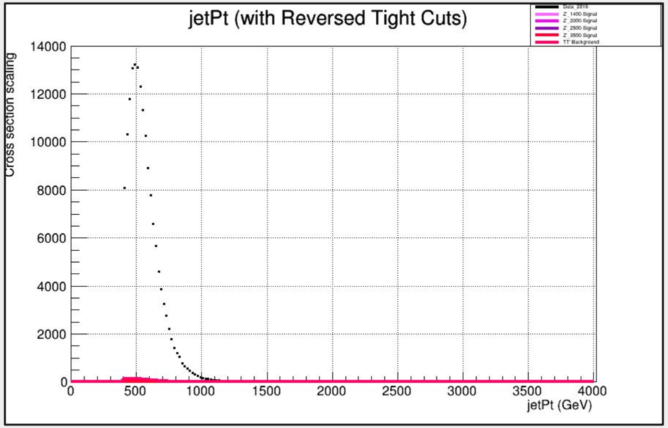


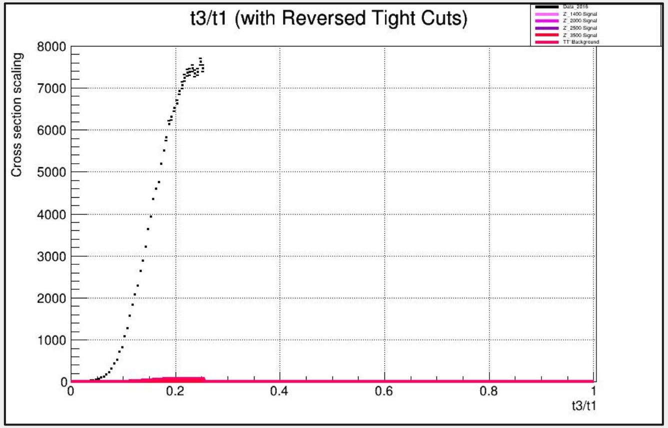


Tight working point:
30% Top Tagging efficiency (matched)
[150,210] Mass Window cut
b cuts

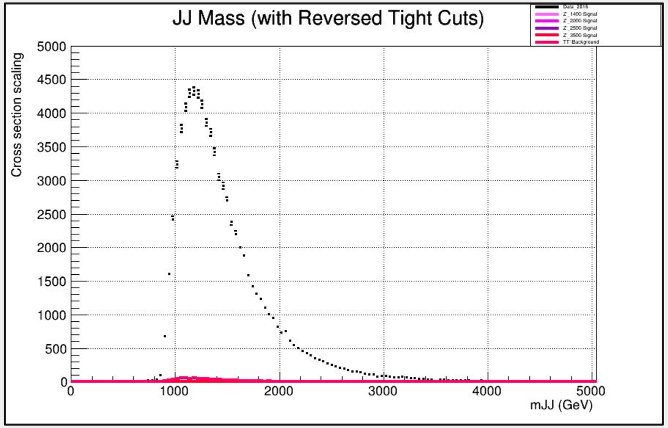
CONTROL REGION (CR)

REVERSED Tight working point:
30% Top Tagging efficiency (matched)
[150,210] Mass Window cut
NO b cuts (jetNBSubDCSV==0)





Calculating the QCD bgk: QCD Template



Data - TTbar

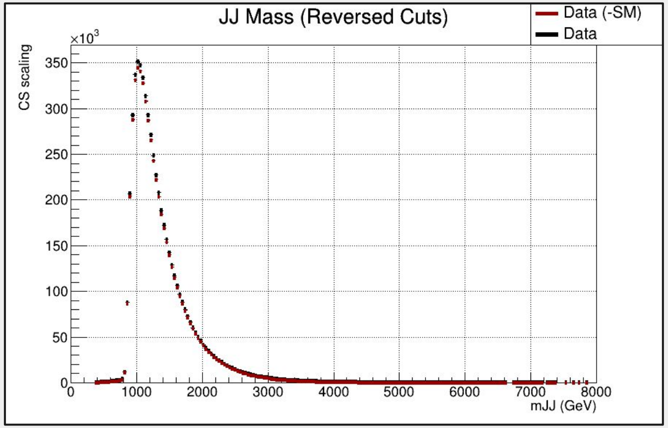
=

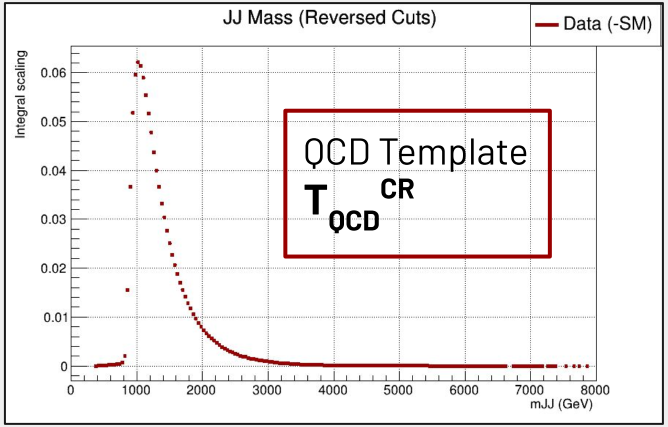
remove CONTAMINATION

QCD distribution

=

$$N_{QCD}^{SR} \times \text{Template}$$



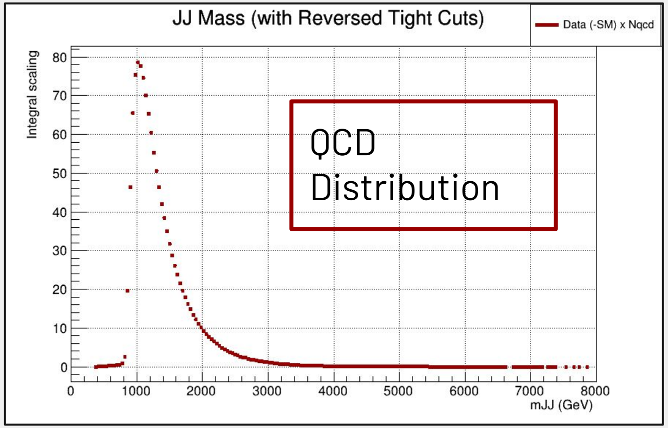


$$N_{QCD}^{SR} = N_{Data}^{SR} - N_{TT}^{SR}$$

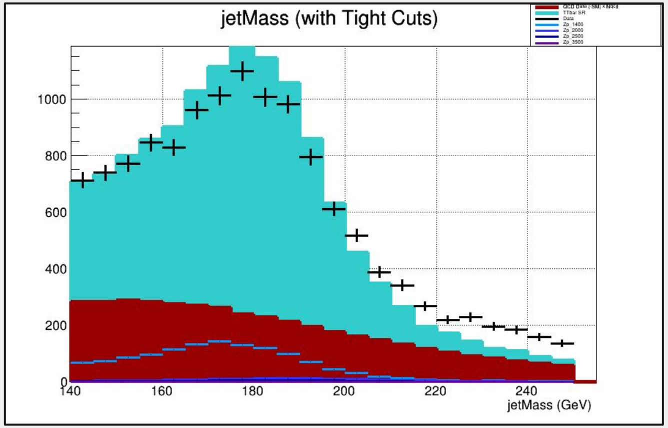
$$= 4040.13$$

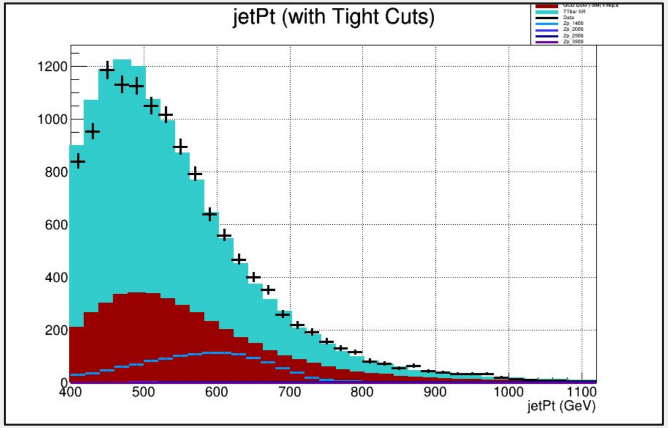
QCD distribution =

$$N_{QCD}^{SR}\, T_{QCD}^{CR}$$



Stacking background; Overlaying signal and data

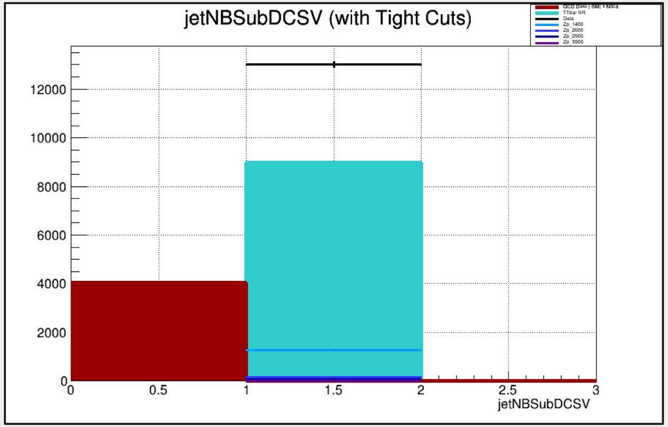


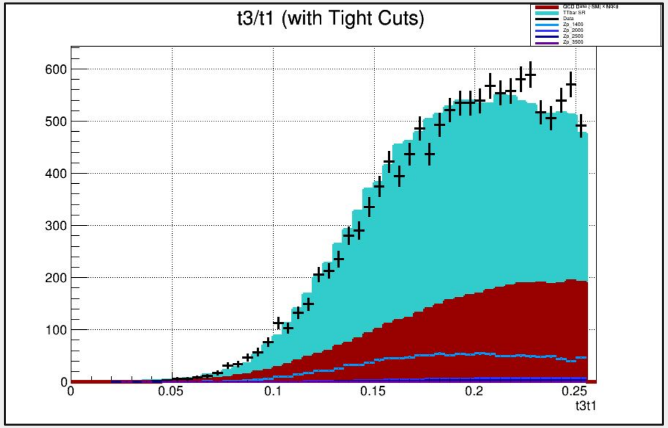


Data

TT’

QCD





1400

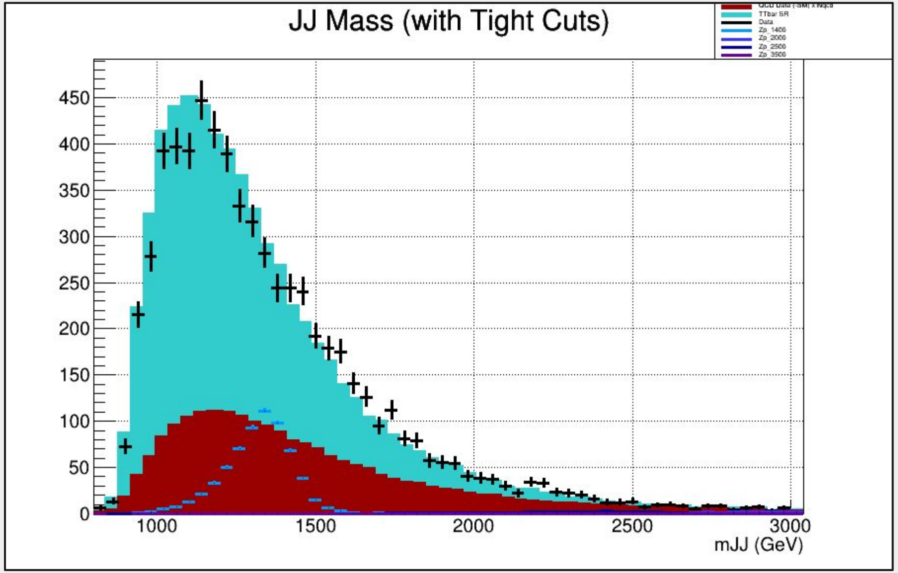
2000

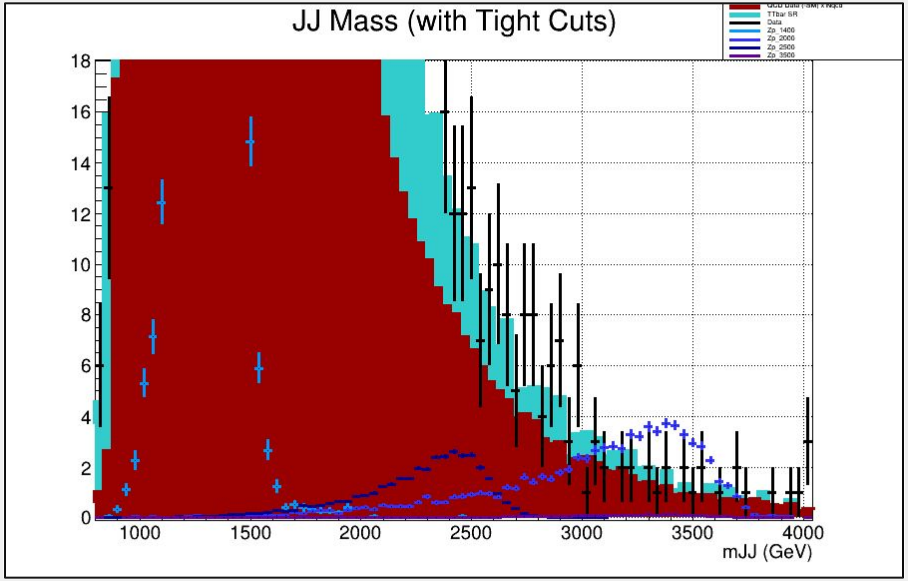
2500

3500

Stacking background; Overlaying signal and data

Data	1400
TT’	2500
QCD	2000
	3500





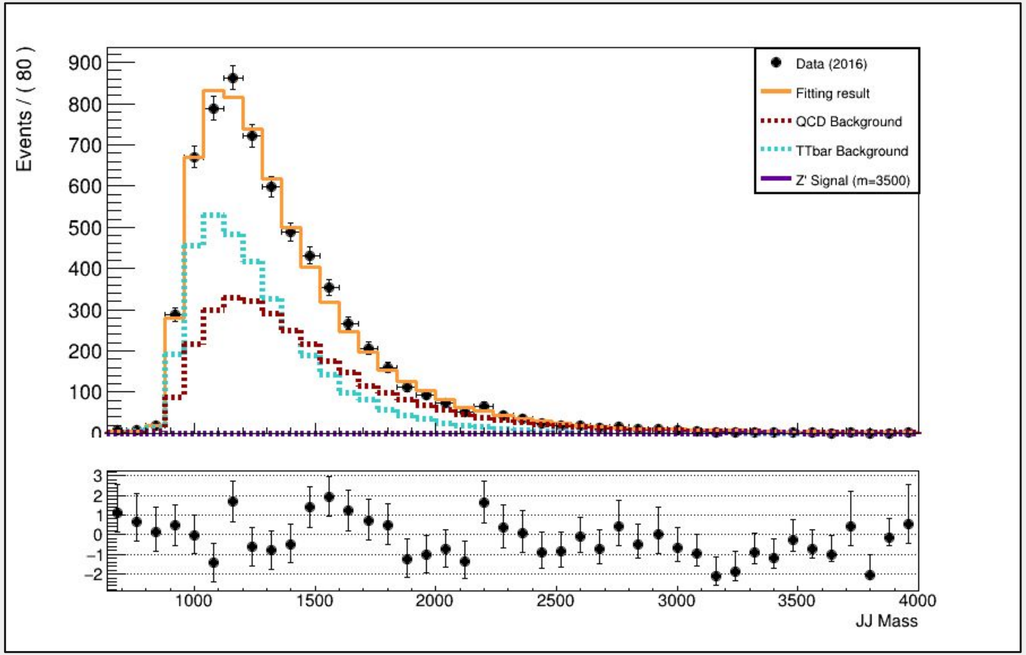
Fitting result: $m_{Z'TC2}$ = 3500 GeV/c^2

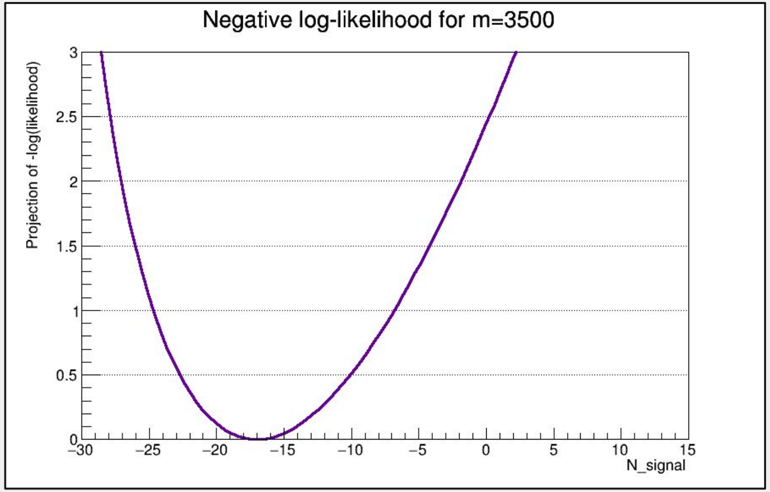
Fitting parameters:

- **N_tt**
- **N_QCD**
- **N_signal_i**

$$lnL(X|\vec{\theta}) = \sum_{i=1}^{N} \ln[p(\vec{x}_i|\vec{\theta})]$$

$$\partial \frac{lnL}{\partial \vec{\theta}} \bigg|_{\vec{\theta}=\hat{\vec{\theta}}} = 0$$



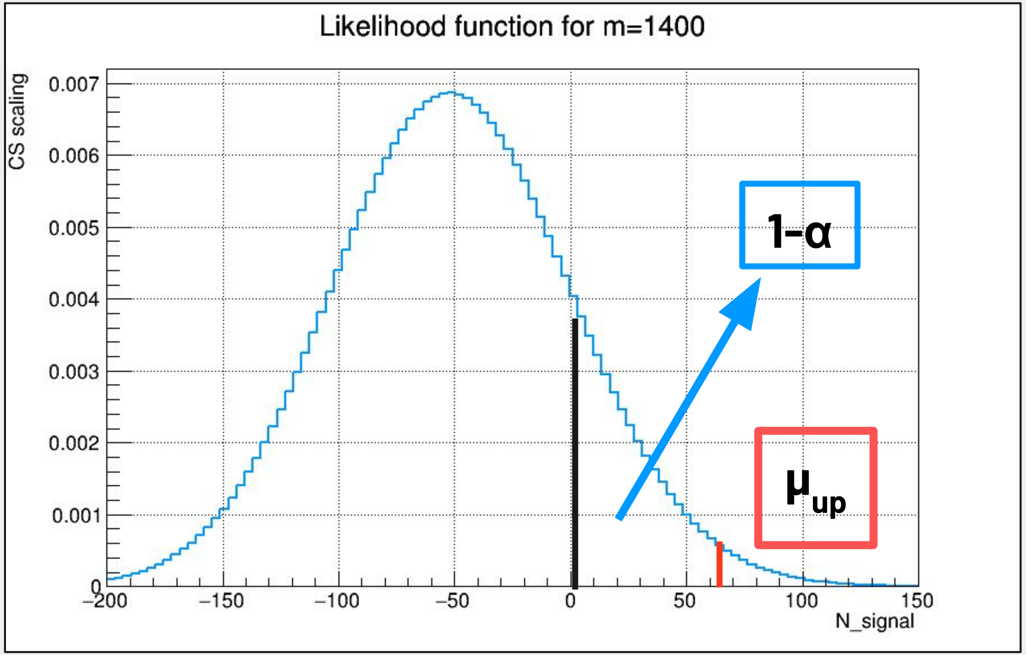


Likelihood function and Bayesian upper limits: 1400 case

Fitting parameters:

- **N_tt**
- **N_QCD**
- **N_signal_i**

$$lnL(X|\vec{\theta}) = \sum_{i=1}^{N} \ln[p(\vec{x}_i|\vec{\theta})] \qquad \partial \frac{lnL}{\partial \vec{\theta}}\Big|_{\vec{\theta}=\hat{\vec{\theta}}} = 0$$



α := credibility

2 cases:

α = 0.1 (90% Confidence Level)

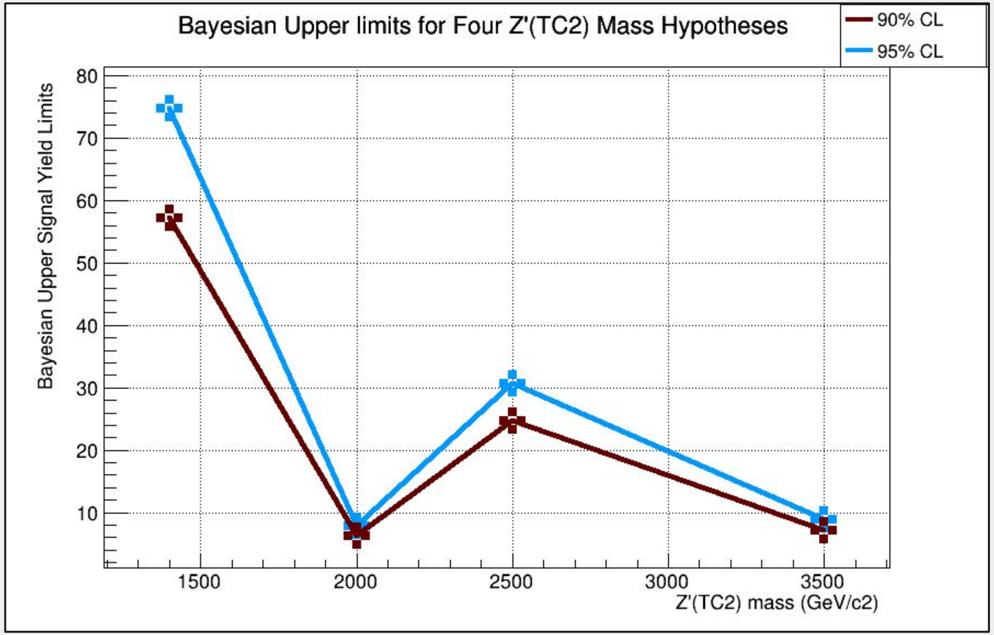
α = 0.05 (95% Confidence Level)

$$\int_0^{\mu_{up}} p(\mu) = (1-\alpha) \int_0^{\infty} p(\mu)\, d\mu$$

FINAL RESULT: Observed Bayesian Upper Limits vs. $M_{Z'TC2}$

- Signal Yield
  N_signal ~ σ_i

- **Decrease** in Signal Yield with **Increase** in mass



2 cases:

90% CL

95% CL

Conclusions and future prospects

2 cases:

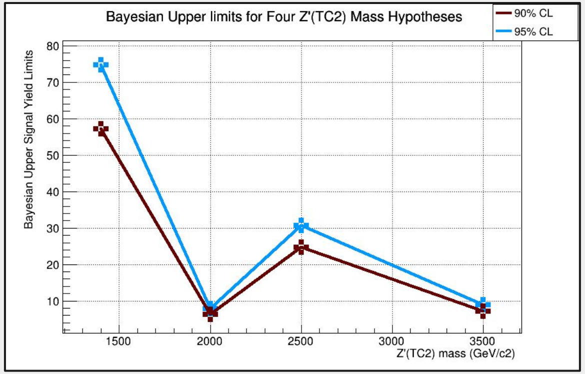
90% CL

95% CL

- Signal Yield **N_signal ~ σ_i**
- **Decrease** in Signal Yield with **Increase** in mass

- CMS and ATLS continue search for Z′
  "The ATLAS Collaboration , "Search for tt resonances in fully hadronic final states in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector" (2021), https://arxiv.org/abs/2005.05138."

- **Personal aspiration:** calculation of possible cross sections at the LHC for Models 1-III



Thank you!

Further reading:

- M. Thomson, Modern Particle Physics (Cambridge University Press, Cambridge, 2013).
- C.T. Hill and R,M. Harris and S.J. Parke, “Cross Section for Topcolor Z’ t decaying to tt” (1999), https://arxiv.org/pdf/hep-ph/9911288.pdf.
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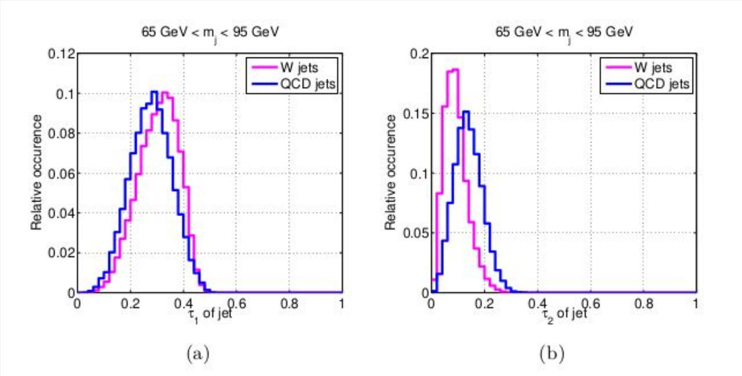
N-Subjettiness (part II)

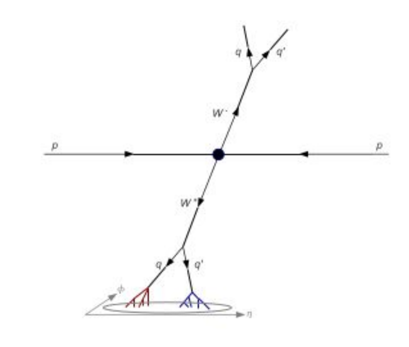
N-Subjettiness:

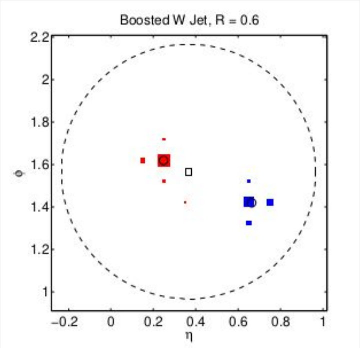
$$\Delta R_{J,k} = \sqrt{(\Delta\eta)^2 + (\Delta\varphi)^2}$$

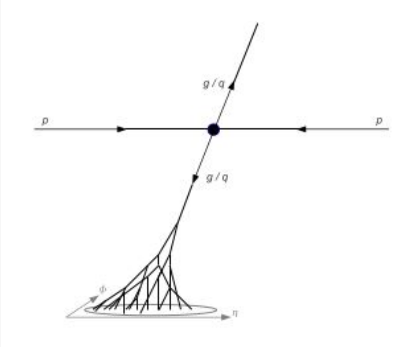
$$d_0 = \sum_k p_{T,k} R_0$$

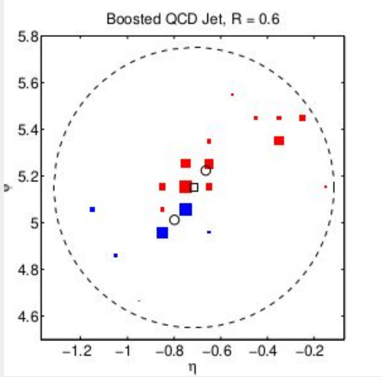
$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \, min(\Delta R_{1,k}, \Delta R_{2,k}, \ldots, \Delta R_{N,k})$$











W^+W^- and QCD dijet events

Backup Slides

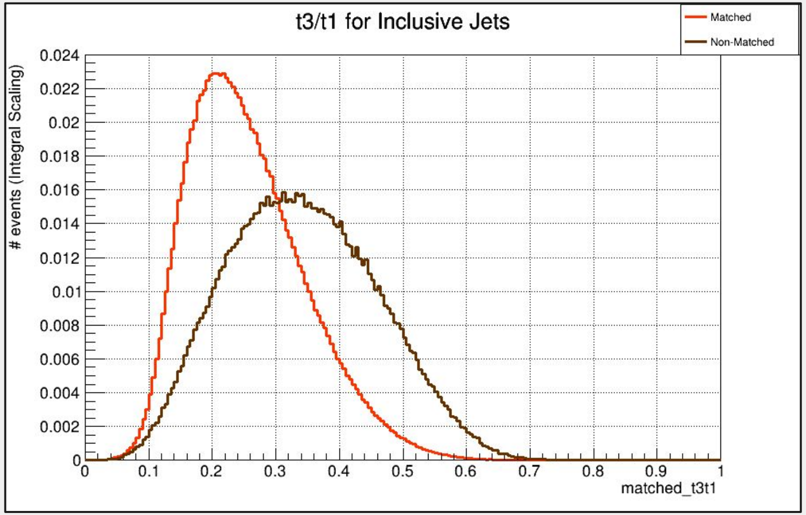
Top Tagger: p_t and mass cuts (t3/t2)

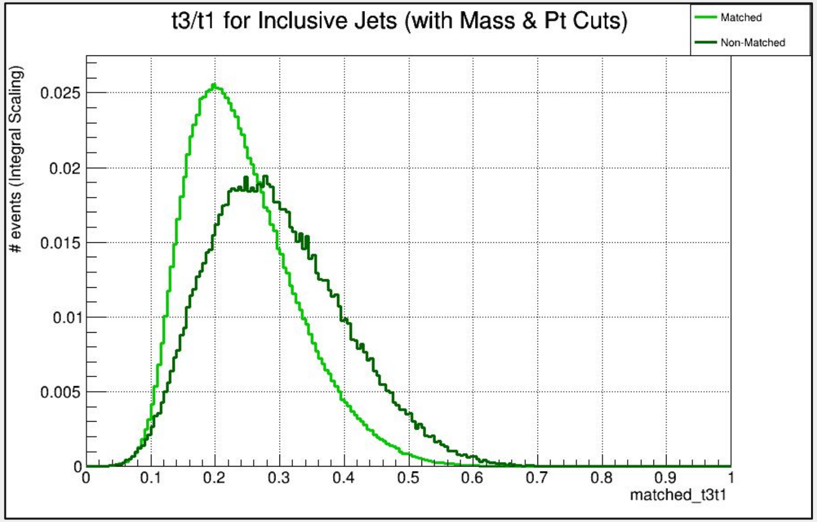
Matched

Non-Matched

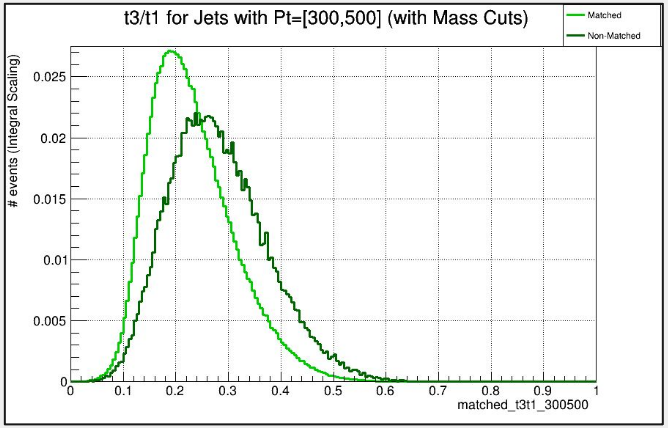
Pt cuts for boosted jet phase space:
jetPt > 400 (GeV)

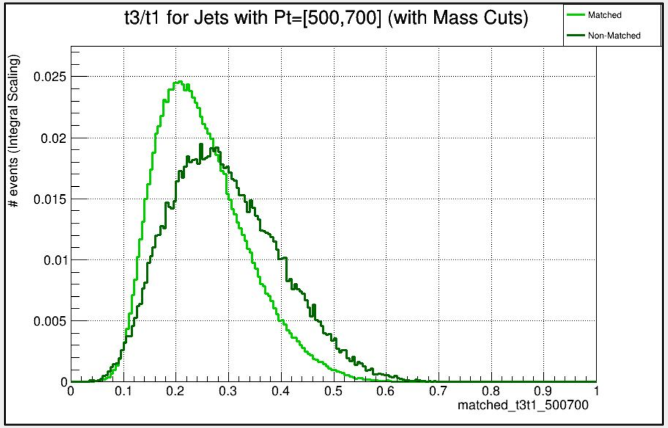
Mass cuts for top jet:
140 < jetMass < 250 (GeV/c^2)



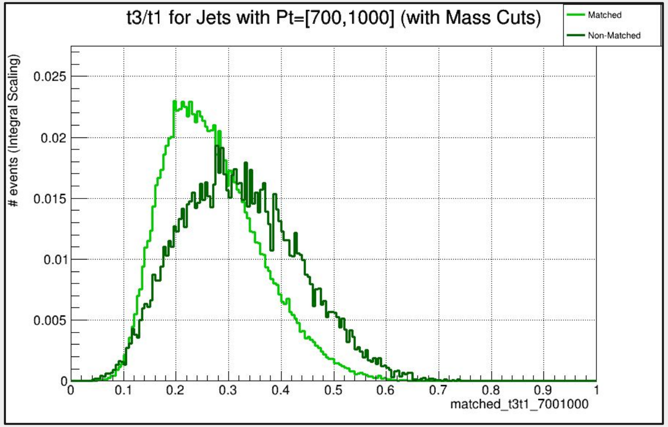


Top Tagger: Pt binned t3/t1



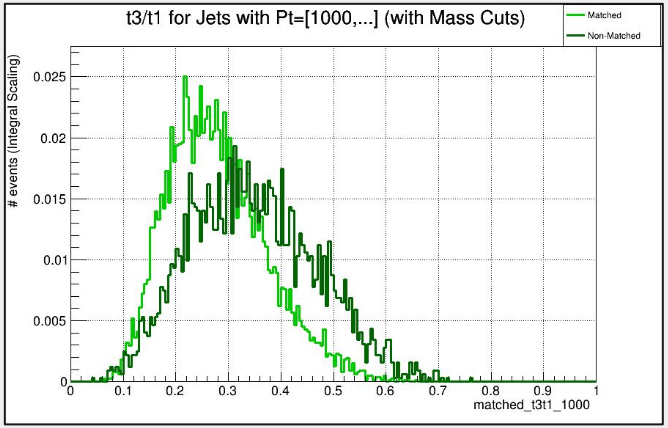


(light green)	Matched to Top Jets
(dark green)	Non-Matched to Top Jets



Pt (GeV) =

[300, 500]	[500, 700]
[700, 1000]	[1000, ...)



Top Tagger: p_t and mass cuts (t3/t2)

Matched

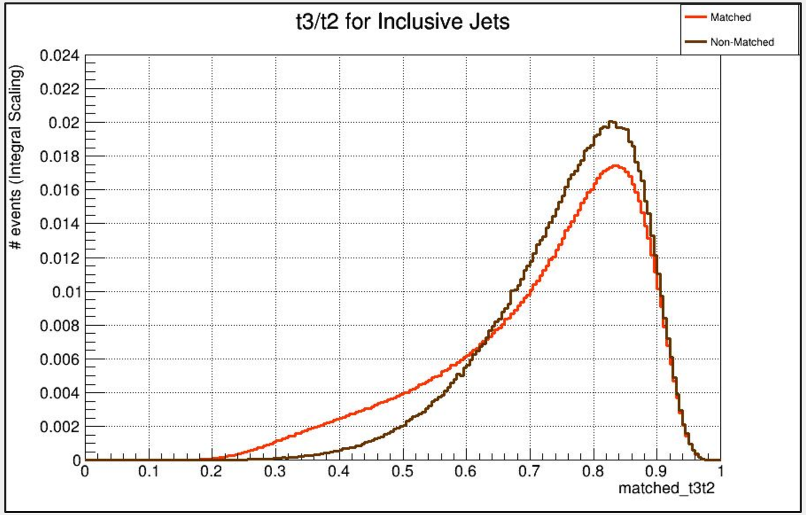
Non-Matched

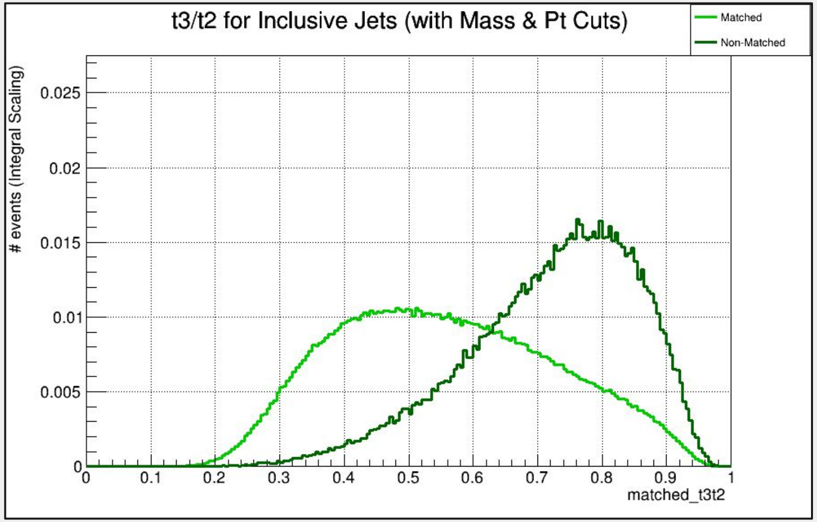
Pt cuts for boosted jet phase space:

jetPt > 400 (GeV)

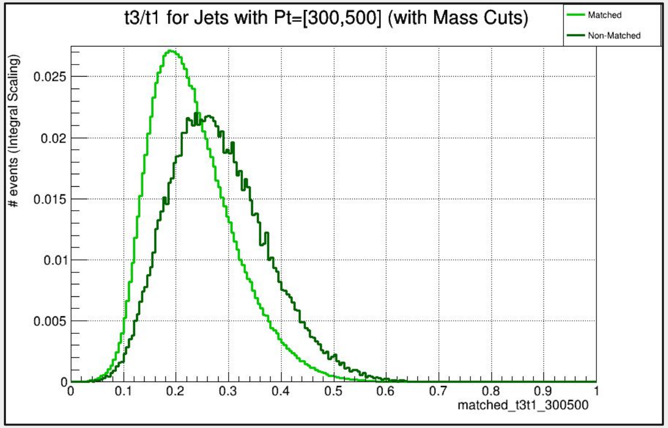
Mass cuts for top jet:

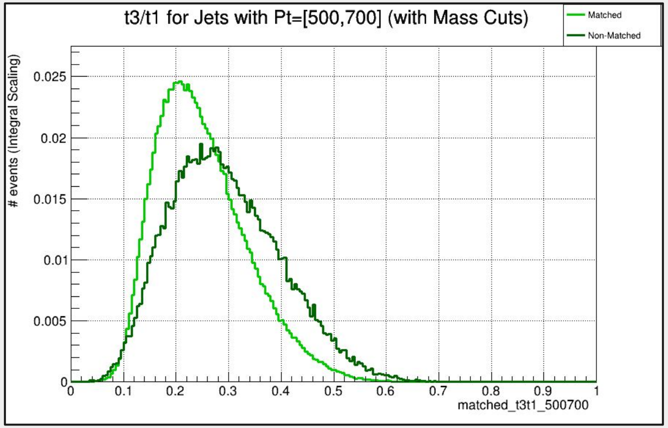
140 < jetMass < 250 (GeV/c^2)





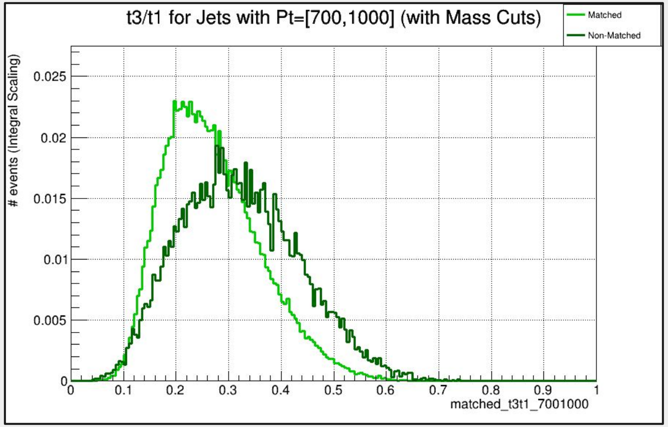
Top Tagger: Pt binnes t3/t2

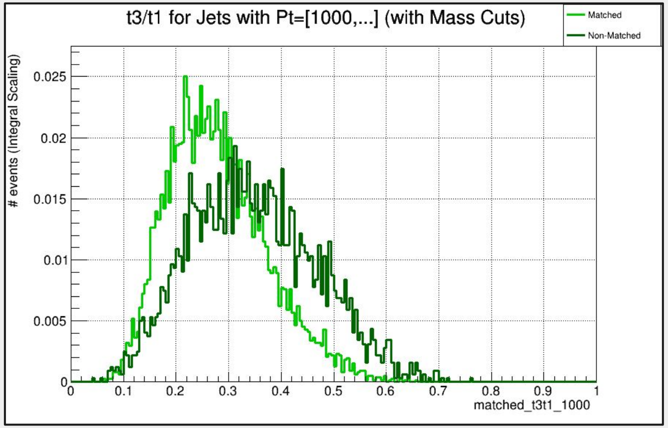




Matched to Top Jets

Non-Matched to Top Jets

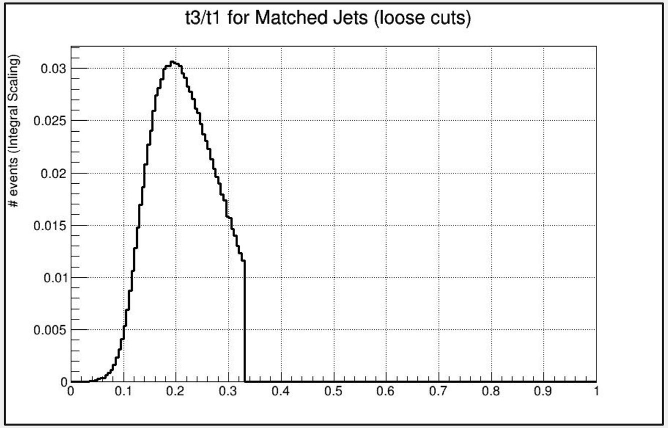


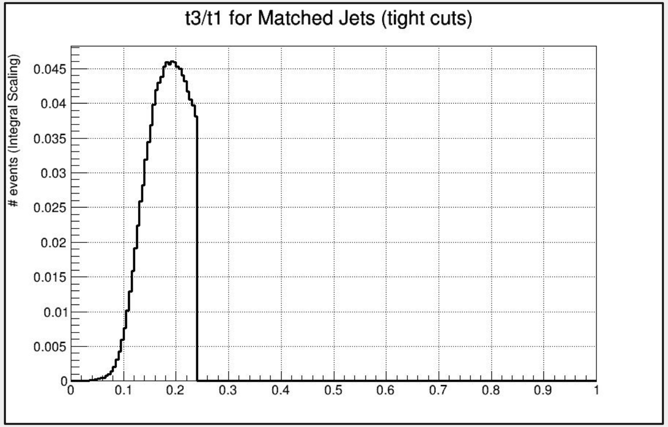


Pt (GeV) =

[300, 500]	[500, 700]
[700, 1000]	[1000, ...)

Top Tagger: loose and tight working points





Tight working point:

30% Top Tagging (matched)

-> **Integral(τ_3/τ_1) = 0.3**

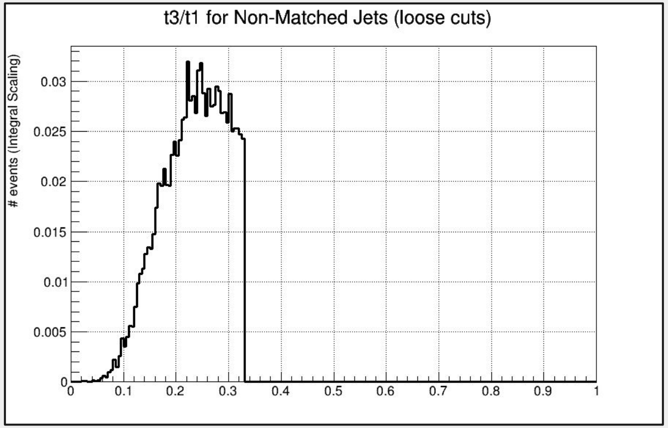
[150,210] Mass Window cut

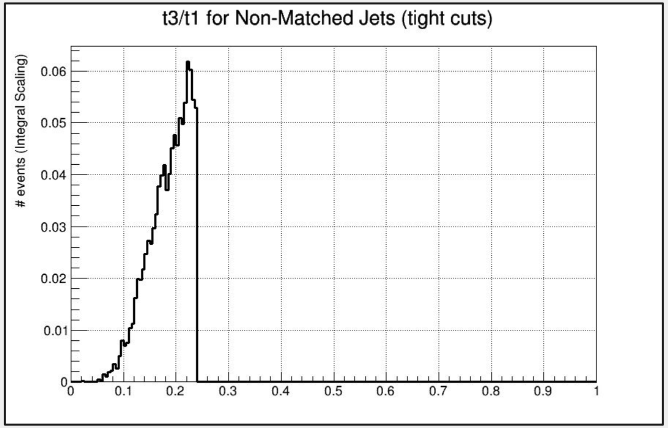
Loose working point:

53% Top Tagging (matched)

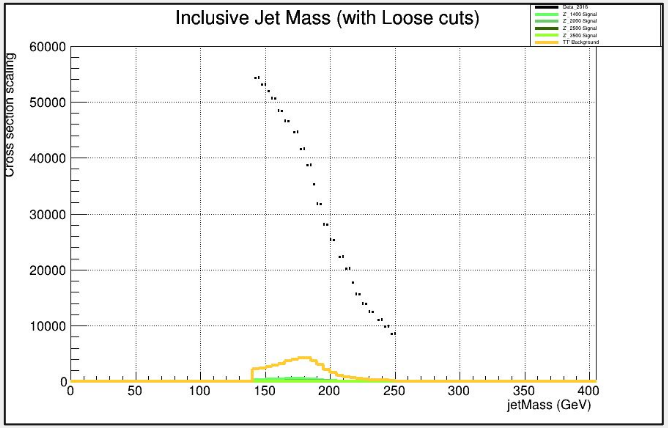
-> **Integral(τ_3/τ_1) = 0.53**

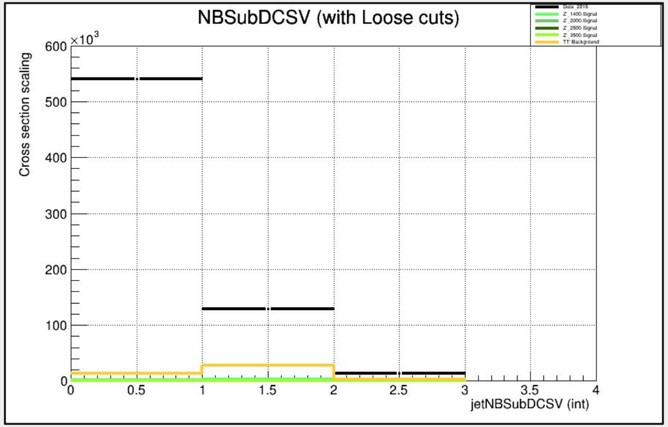
[140,250] Mass Window cut





Calculating the QCD bgk: loose cuts





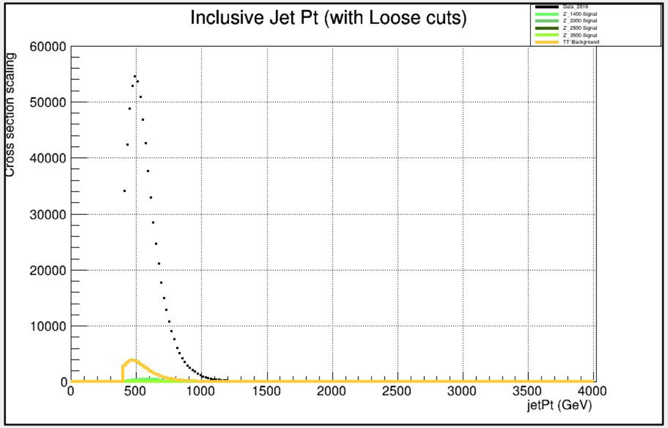
<u>NEW Loose working point:</u>

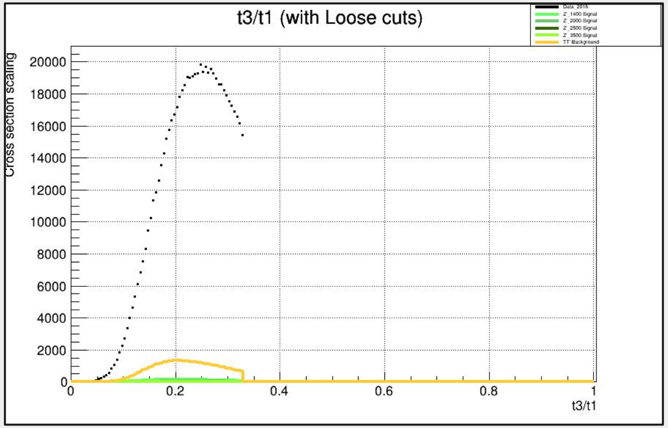
53% Top Tagging efficiency (matched)

[140,250] Mass Window cut

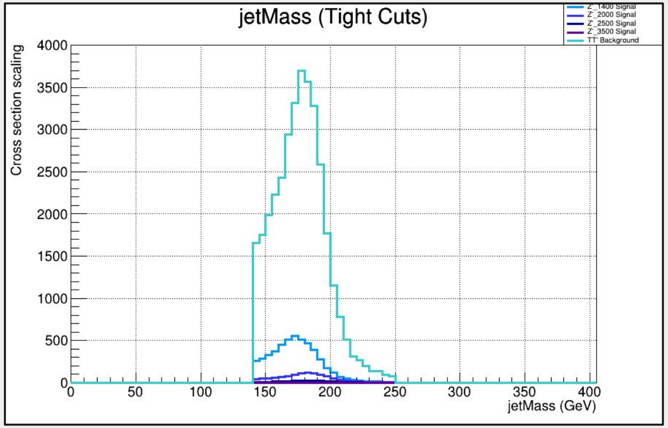
~~**b cuts**~~

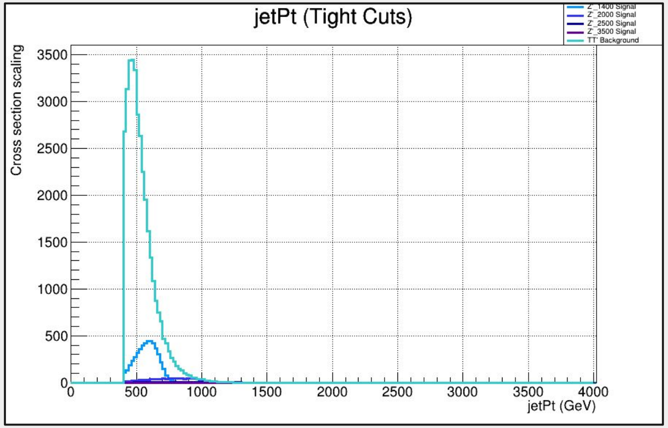
SIGNAL REGION (SR)



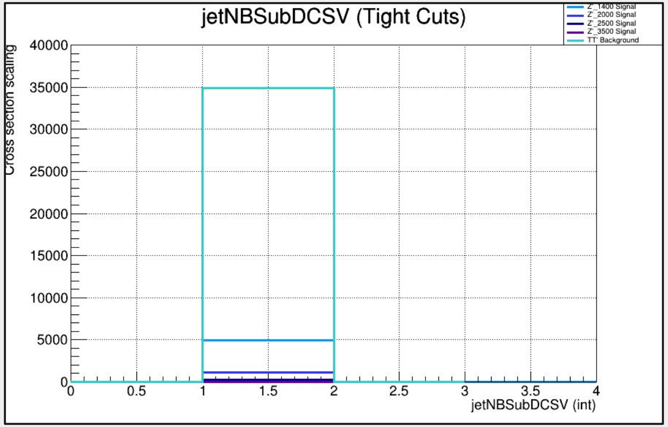


Calculating the QCD bgk: Tight cuts

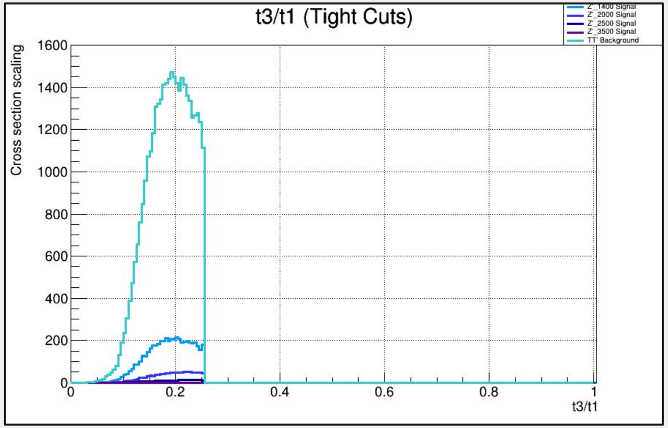




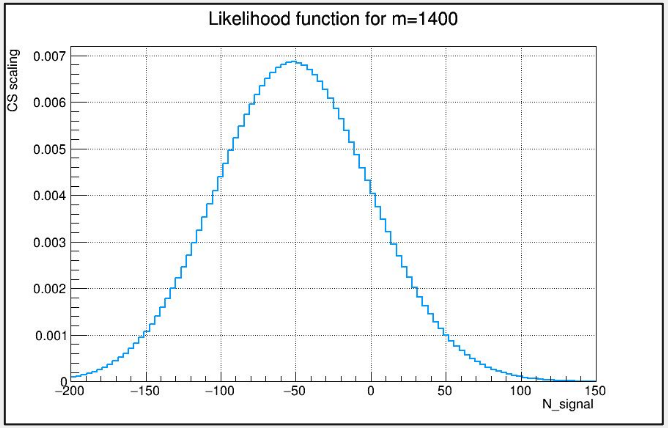
NEW Tight working point:
30% Top Tagging efficiency (matched)
[150,210] Mass Window cut
b cuts



SIGNAL REGION (SR)



Likelihood functions

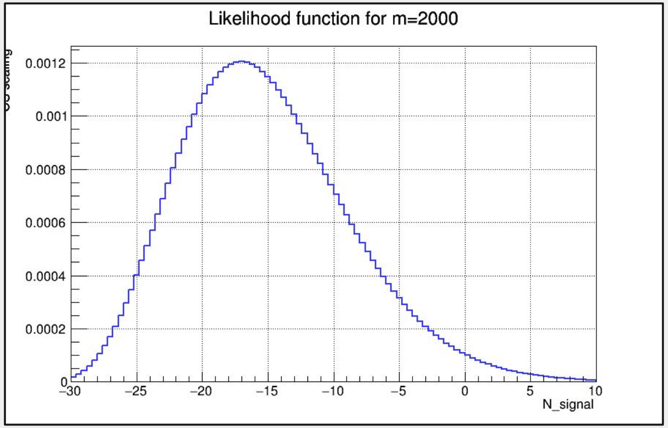


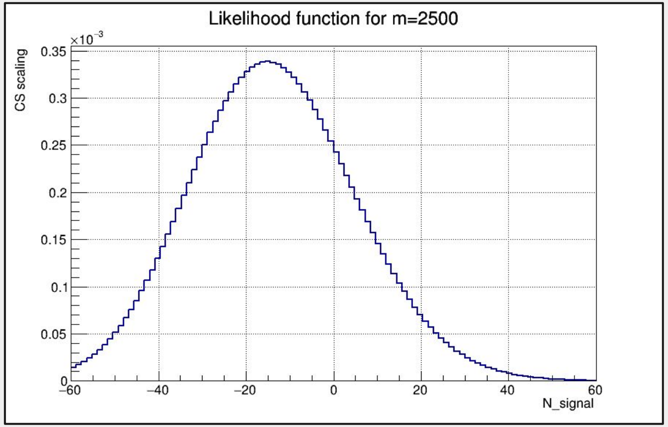
1400

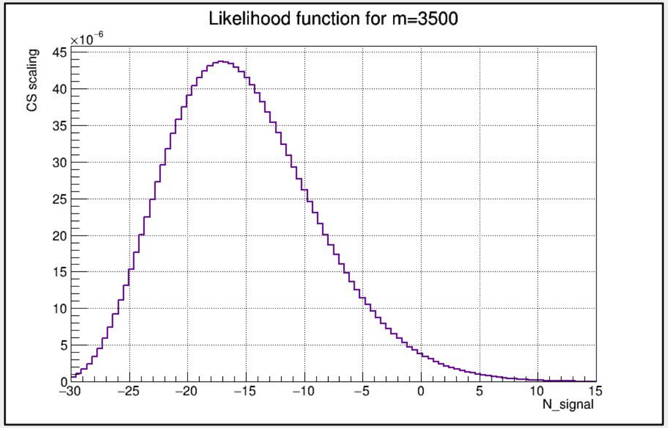
2000

2500

3500







Histogram of |cosθ*|

- Boost to CM reference frame
- Find Jet angle with z axis (θ*)