Measurement of the top quark mass using a leptonic observable in the semileptonic ttbar events

(with full Run 2 CMS pp collision data)

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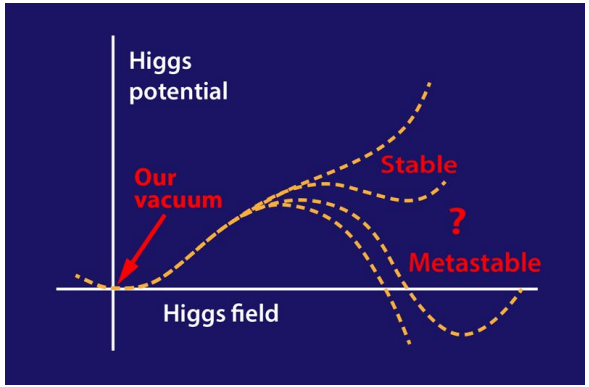
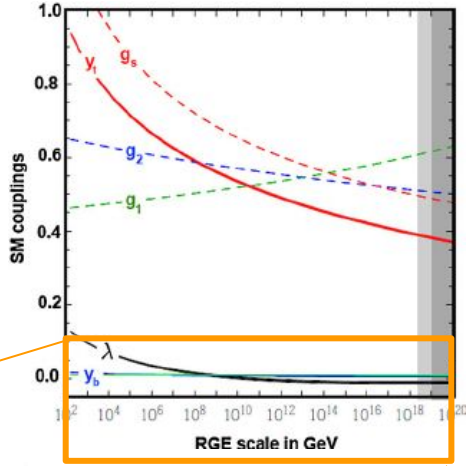
Isfahan (May 30, 2024)

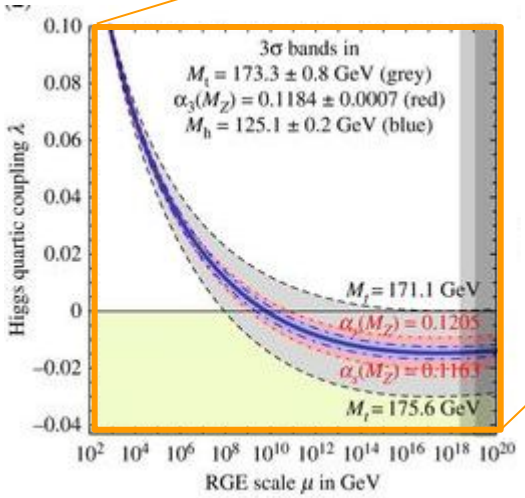
Theoretical motivation

- Vacuum stability or metastability?



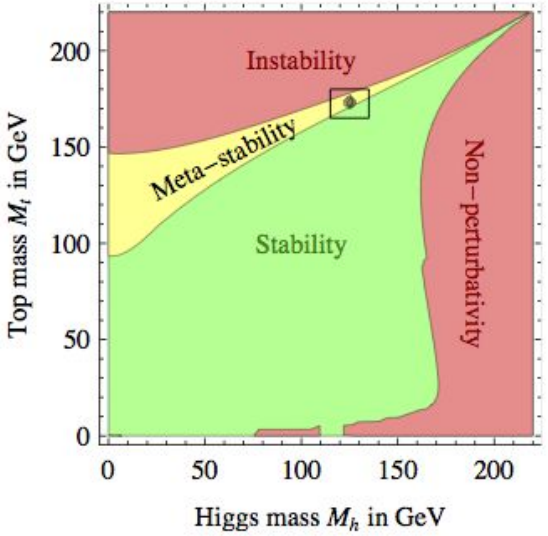
- The origin of various vevs: quantum corrections to Higgs coupling constant
  - Mostly affected by top quark mass

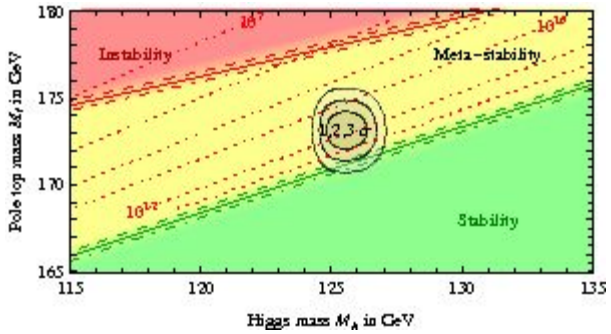




Importance of precision top quark mass measurement

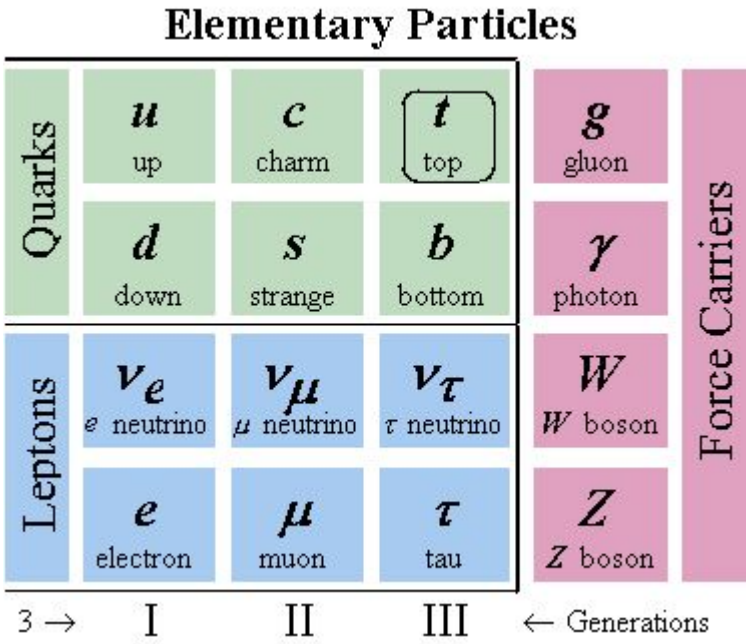
- Higgs boson mass is likely to be on the metastable side
- A definitive answer requires much more precise measurements of the top quark's poll mass

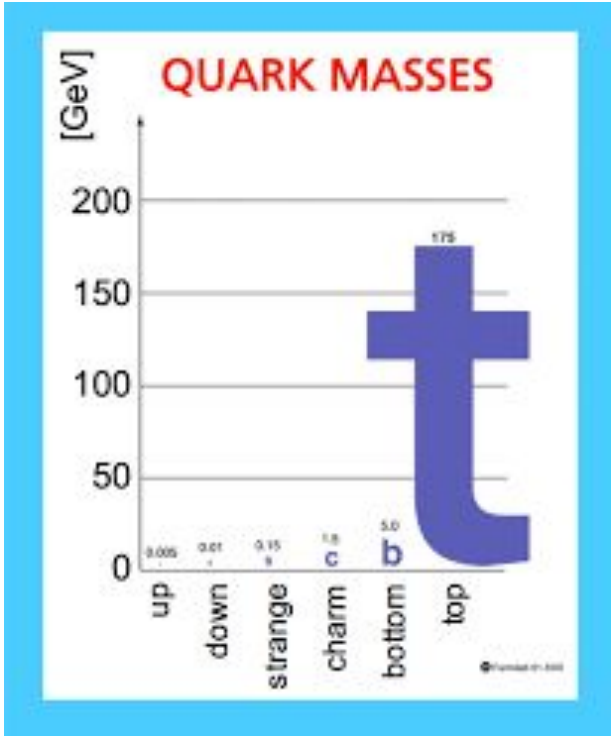




Top quark as the heaviest SM particle

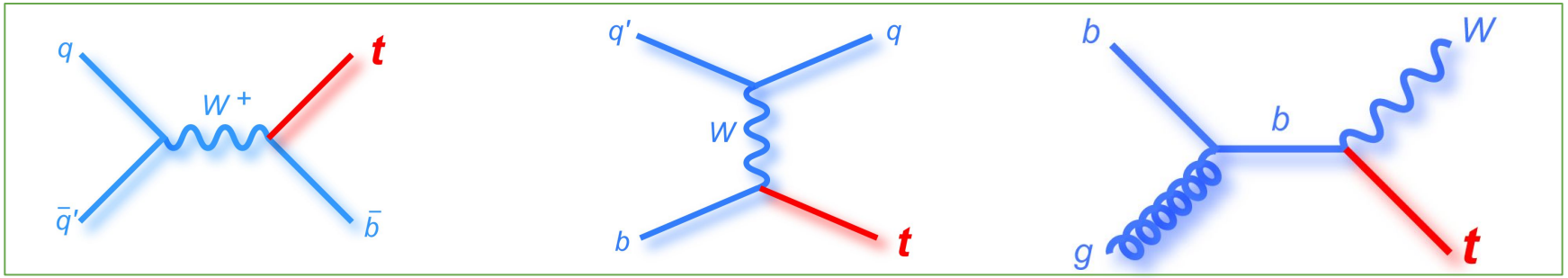
- Top quark has the largest weight : 172.5 GeV



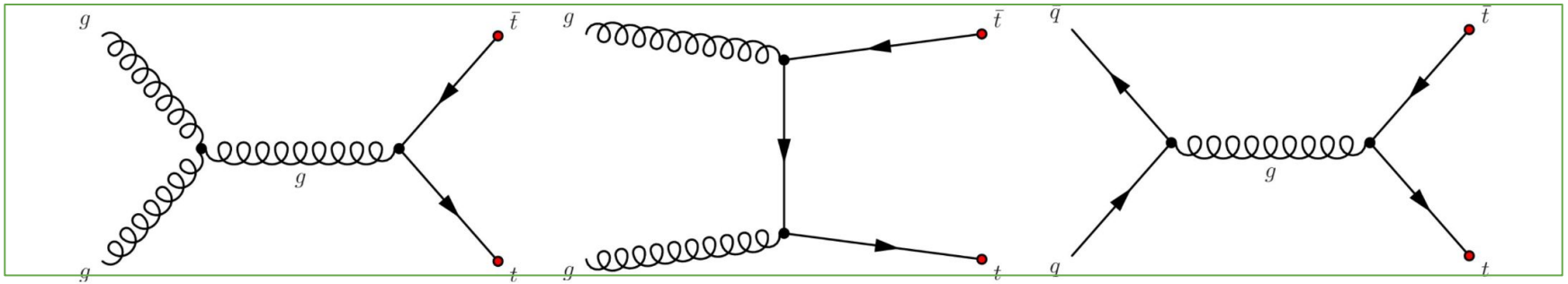


Top quark production at LHC

- Single top production

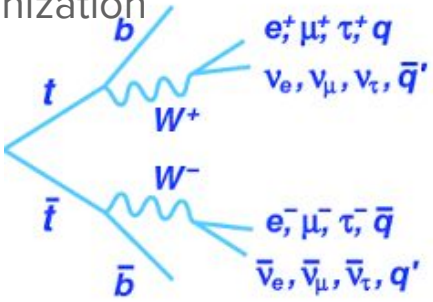


- Top pair production

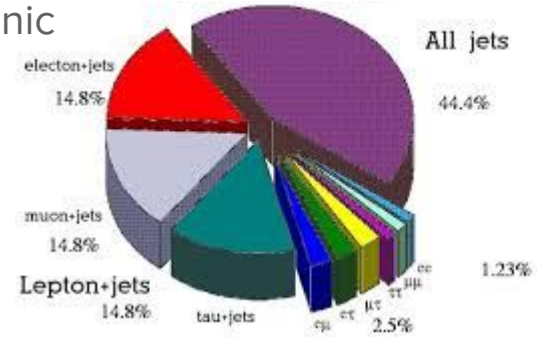


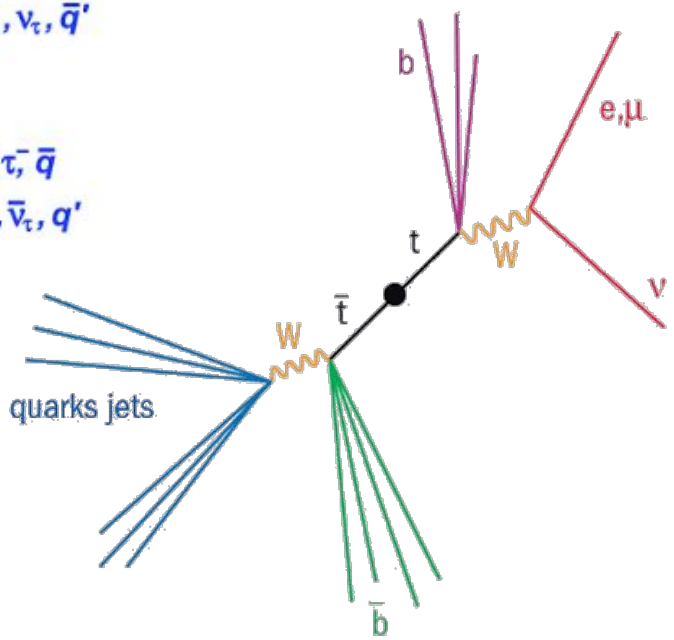
Top pair decay channels

- τ_{top} ~10^{-25} , decays before hadronization
- The decay products of W boson:
  - leptonic & hadronic

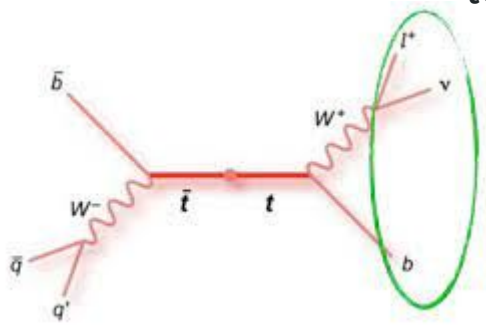


- Top pair decay channels:
  - Dileptonic
  - Semileptonic
  - Full hadronic

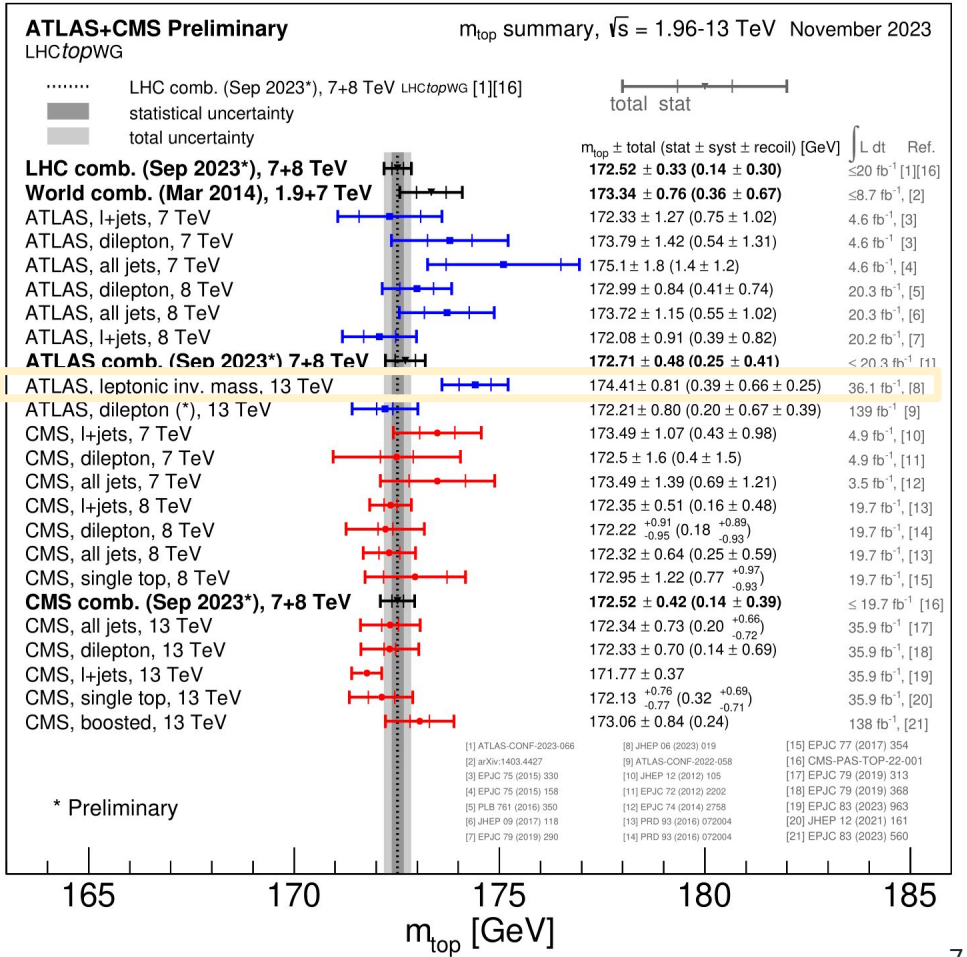




Latest measured M_{top}



- LHC combined (Run1) : 172.5 ± 0.3
- M_{top} measurement in different phase spaces, by CMS & ATLAS:
  - Several decay channels of ttbar
  - Single top event
- ATLAS measured the top quark mass using leptonic invariant mass
  - A similar analysis was done by CMS, using (TOP-15-014) at 8 TeV



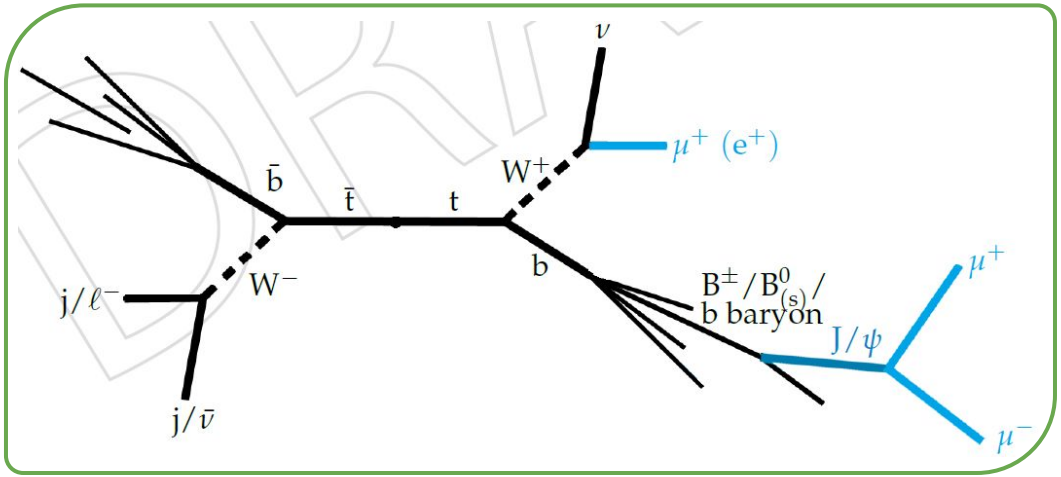
Previous activities in CMS

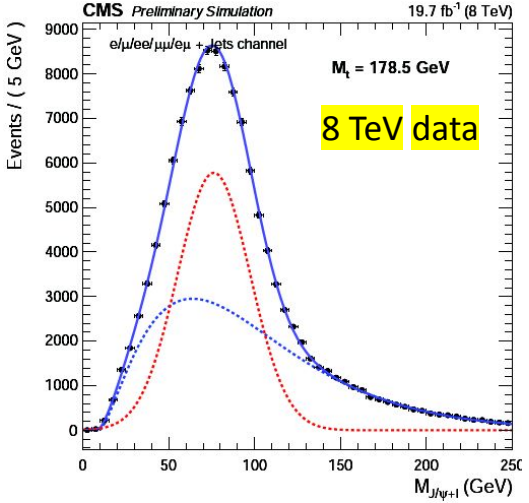
AN2015_218_v10.pdf

TOP-15-014

- Run 1 data were processed
- In **CMS**: $\mathbf{m_{J/\psi+l}}$ is constructed
  - Samples with different M_{top} produced
- A simultaneous fit method is used

$$P_{\text{sig+bg}}(M_{J/\psi+\ell}) = \alpha \frac{1}{\sigma_g\sqrt{2\pi}} \exp\left(-\frac{(M_{J/\psi+\ell}-\mu_g)^2}{2\sigma_g{}^2}\right) + (1-\alpha)\frac{\beta_\gamma{}^{-\gamma_\gamma}}{\Gamma(\gamma_\gamma)}(M_{J/\psi+\ell}-\mu_\gamma)^{\gamma_\gamma-1}\exp\left(-\frac{M_{J/\psi+\ell}-\mu_\gamma}{\beta_\gamma}\right),$$

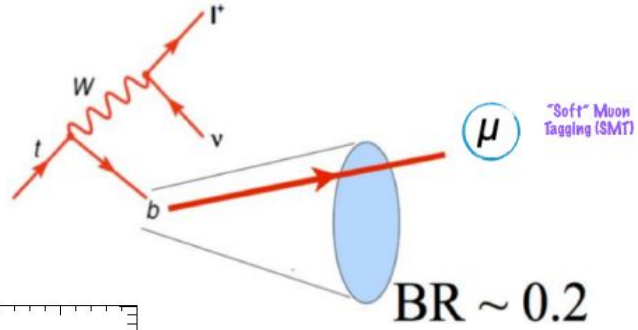




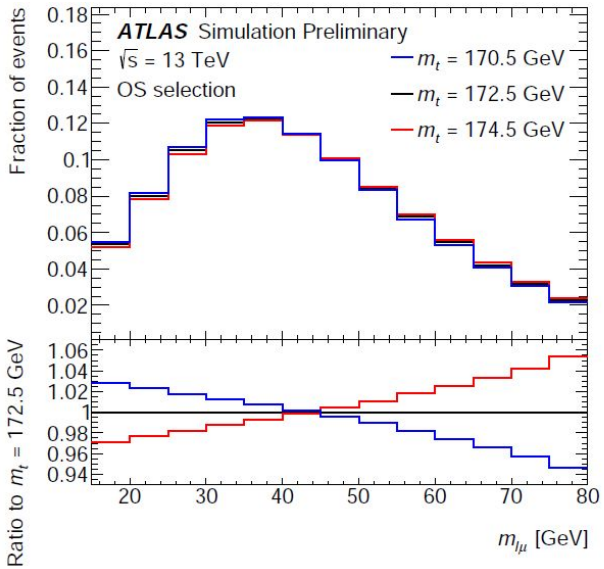
Previous activities in ATLAS

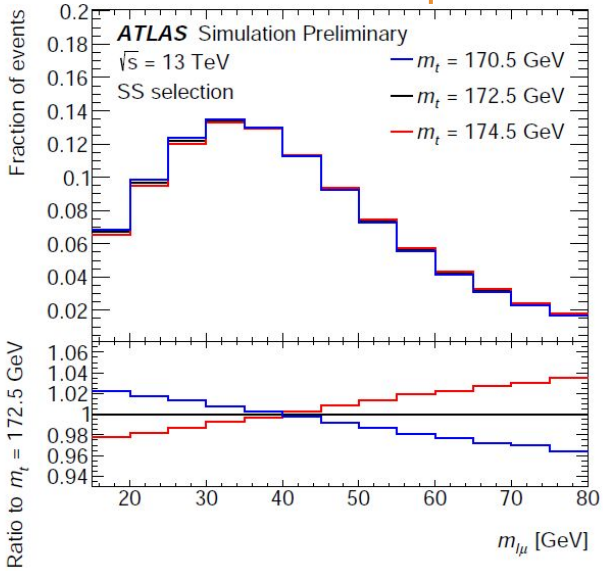
ATLAS-CONF-2019-046

- Part of run 2 data were processed (36.1/fb, ref)
- In **ATLAS**: $\mathbf{m_{l\mu}}$ is constructed
- Binned template profile likelihood fit is used
  - SS and OS categories, according to the charge signs of primary lepton and the soft muon



2016 data



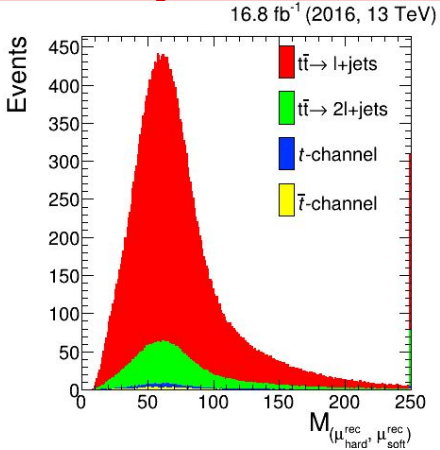


Proposal

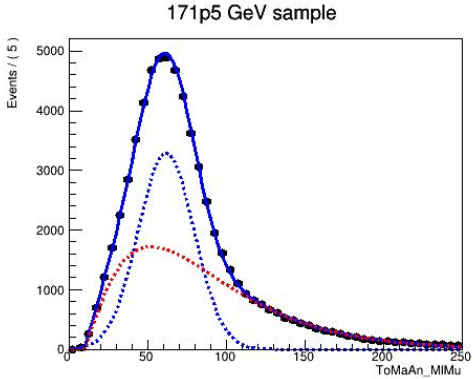
- A direct top quark mass measurement exploiting a partial, leptonic-only, invariant mass reconstruction of the top-quark decay products with the full Run 2 CMS data , is proposed
- The idea is to measure the M_t with the leptonic observables; $\mathbf{m_{l\mu}}$
- And use a simultaneous fit method as introduced in the **CMS J/ψ** analysis
- Run over full 13 TeV UL data

Overview of the analysis with a first look at the MC simulation

- No data included
- Only a part of 2016 simulated data used
- Not all relevant bkgs are considered



- An example of postfit distribution
- Same pdf as proposed in J/ψ analysis is used
- Seems the method also works here, for $m_{l\mu}$ distribution



Analysis overview

- Analysis has been initiated by checking the data-MC consistency plots
  - Started to run on 2018 data to establish the method
  - In the next step, other remaining Run 2 data are taken into account
- NanoAODv9 (UL) samples are processed
- The *Bamboo FW* is used to analyze the datasets

- Personpower:
  - 1 PostDoc (myself)
  - 1 potential PhD student
  - 1 potential MSc student
- Project timeline:
  - Expected to have some public results for 2025 spring conferences

Data and MC simulated samples

- Data:
  - SingleMuon_Run2018A/B/C/D
- Ttbar:
  - TTToSemiLeptonic, TTToHadronic, TTTo2L2Nu
- Single Top:
  - ST_t-channel_(anti)top, ST_tW_(anti)top
- DYJetsToLL
  - M-10to50* and M-50
- WjetsToLNu
  - Both inclusive and HT-bins (from 70To100 to 2500ToInf) are processed
  - Today only inclusive WJets are presented
- QCD
  - HT-bins (from 50to100 to 2000toInf)*
- Diboson:
  - WZTo3LNu, ZZTo4L

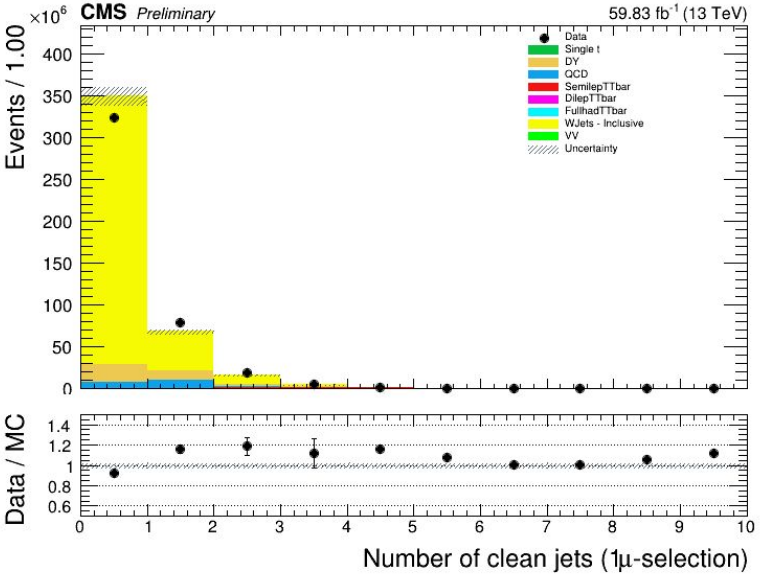
Object selection

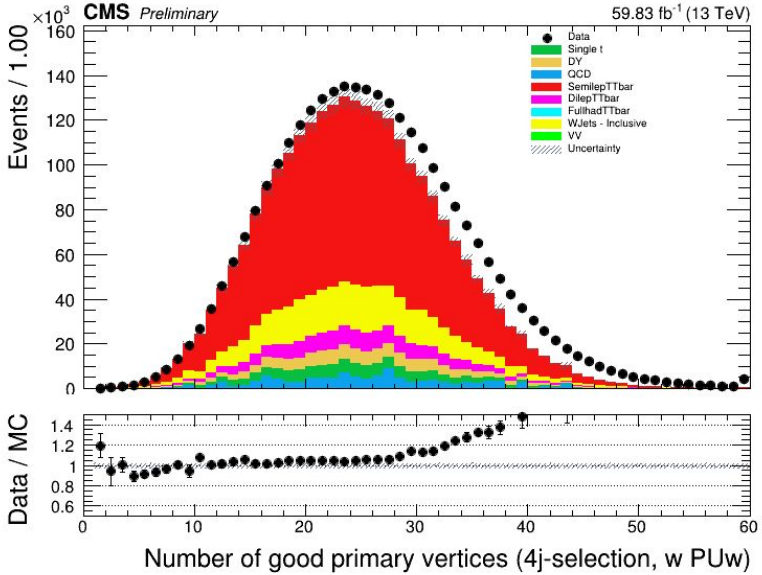
- Muons:
  - pt>30 GeV, |eta|<2.4, tightID, tightIso, dxy<=0.05, dz<=0.1, sip3d<=8
- Electrons:
  - (pt > 34 && |eta|<2.5) || (pt>30 && |eta|<2.1),
  - (absEtaSC < 1.4442 || absEtaSC > 1.566),
  - (absEtaSC <= 1.479 && |dxy| < 0.05 && |dz| < 0.1) || (absEtaSC > 1.479 && |dxy| < 0.1 && |dz| < 0.2),
  - tight cut-based ID
- VetoElectrons:
  - pt>15 GeV, |eta|<2.5, veto cut-based ID
- Jets:
  - pt>30 GeV, |eta|<2.4, tight lepton veto jet ID, loose puID for jets with pt<50 GeV, should be far from electrons and muons (DR>0.4)
- B-tagged jets:
  - BtagDeepFlavB tagger with medium WP is used

Event weights and selection

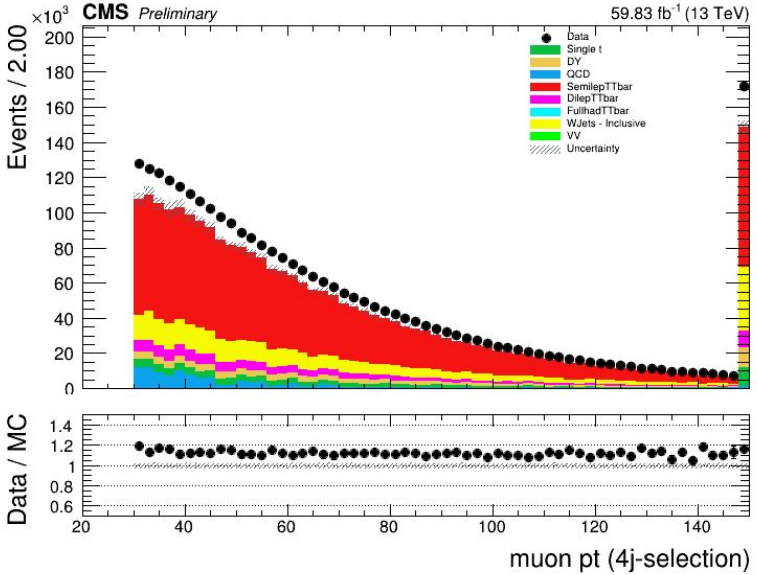
- MC genWeight is applied
- MET filters are required
  - Like HBHENoiseFilter, goodVertices, EcalDeadCellTriggerPrimitive Filter, etc.
- At least one good PV, requiring ndof>5
- HLT.IsoMu24
- 1 muon and 0 electron are applied
  - Muon Rec/Iso/Id/L1Prefiring/Trigger SFs are applied
- At least 4 jets are required
- Pileup weight is applied
- At least 2 medium b-tagged jets applied
  - Events are reweighted with b–tagging weights
- Might need to apply additional event weights like top pt re-weighting, etc

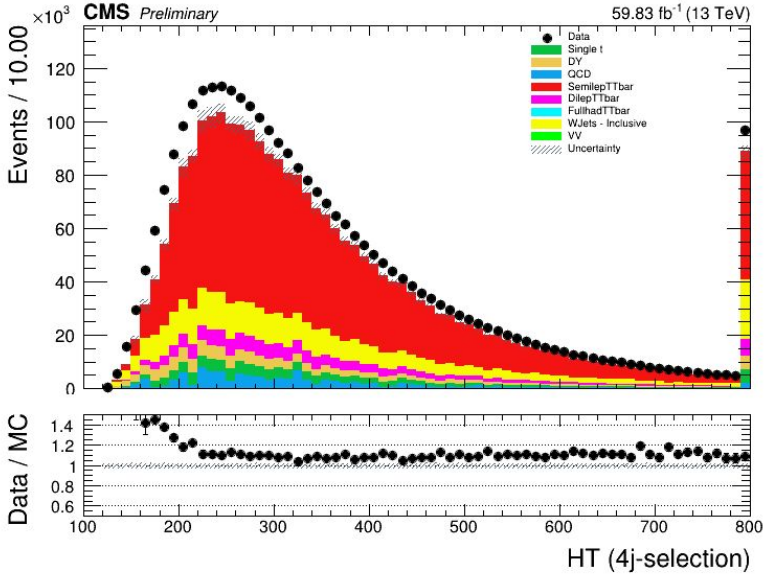
Jet multiplicity and Nr of good PVs



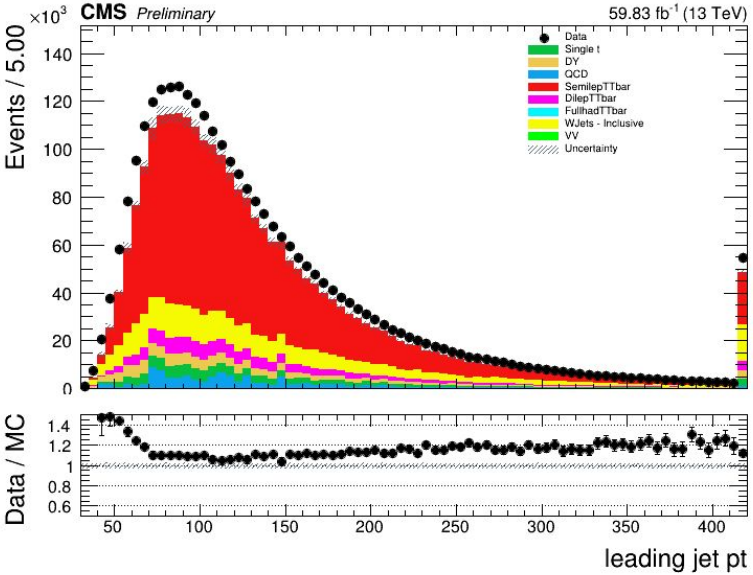


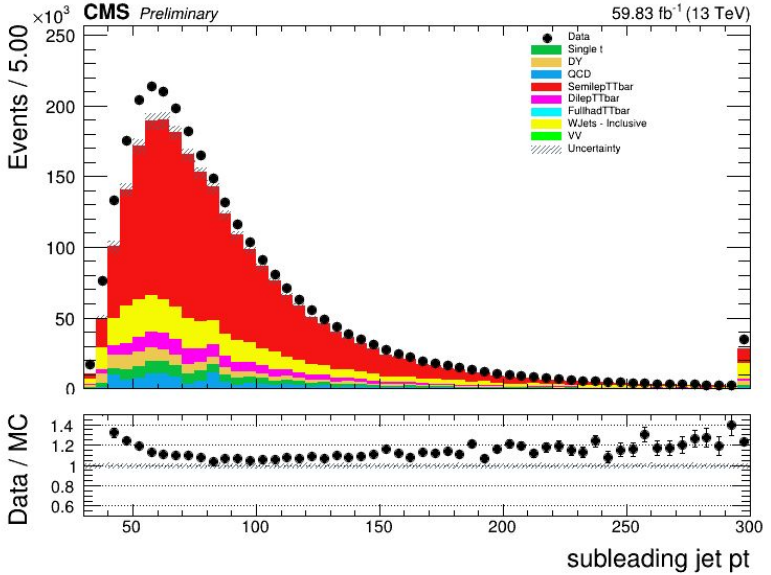
Muon p_T and HT (=p_T sum of all clean-jets)



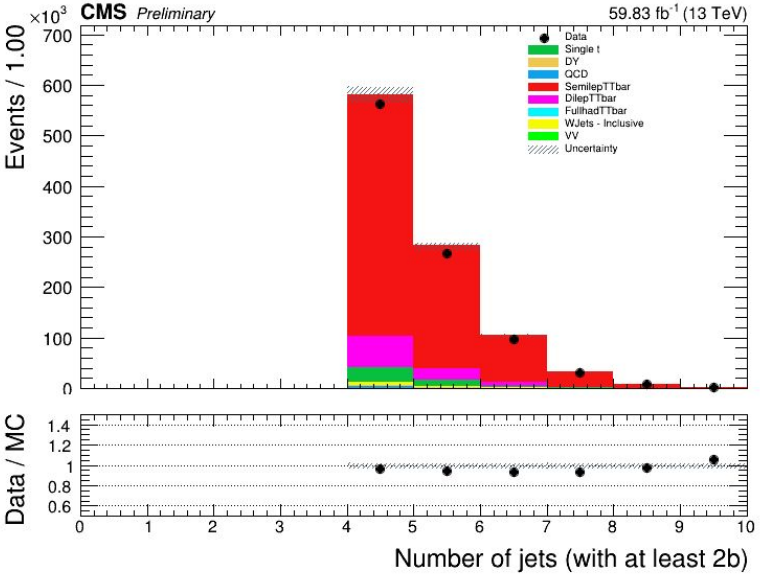


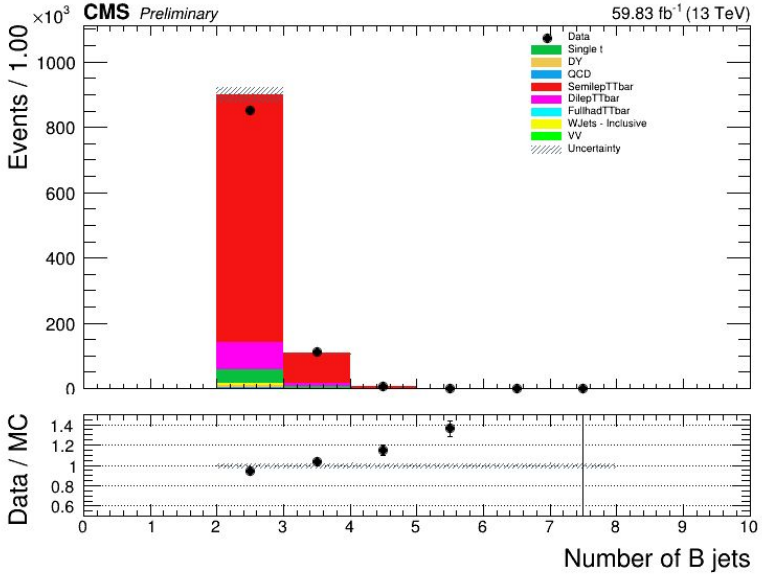
Leading and subleading jet p_T



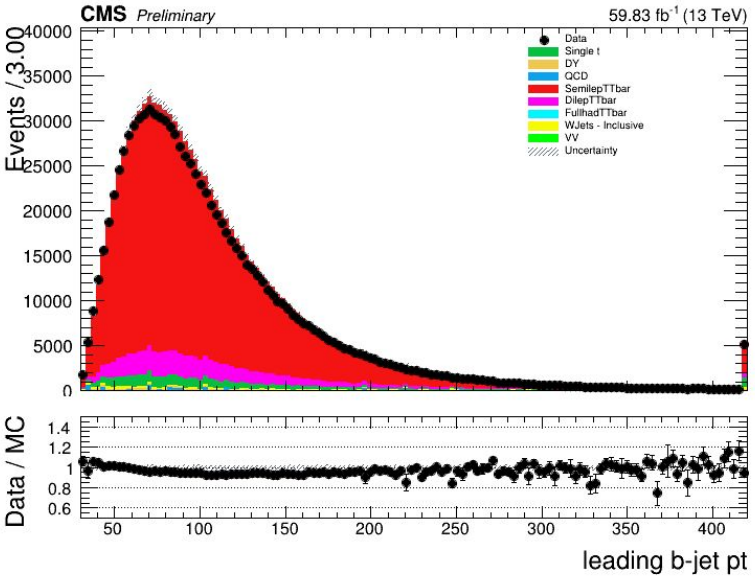


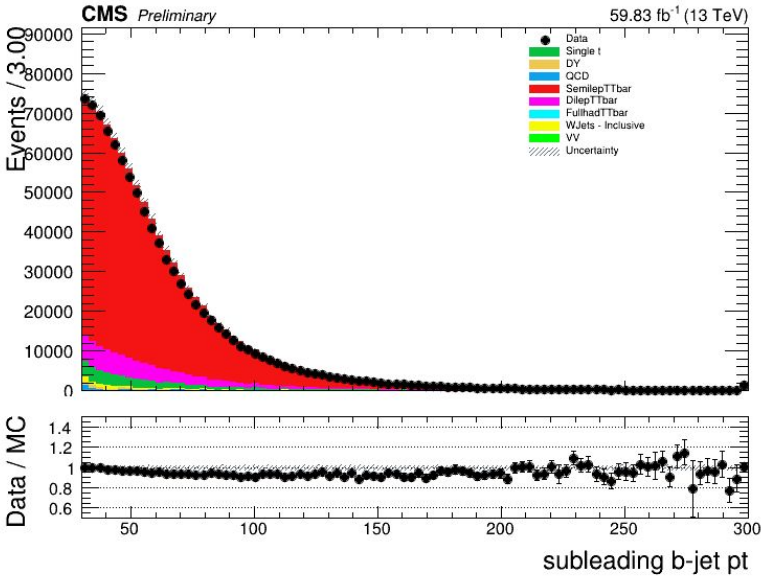
Jet and b-tagged jet multiplicity





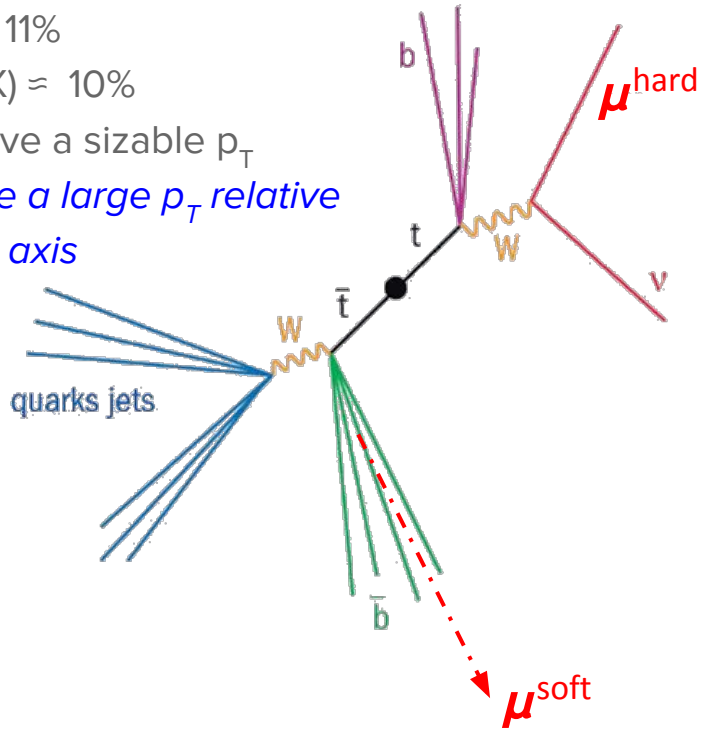
Leading and subleading b-jet p_T (w/ b-tag weight)





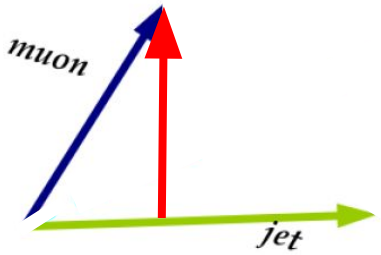
soft-muon selection at reconstruction level

- Now, we need to tag a soft-muon (μ) originating from b-hadrons
  - BR(b → $\mu\nu$X) ≃ 11%
  - BR(b → c → $\mu\nu$X) ≃ 10%
  - Soft-muons have a sizable p_T
    - *Also have a large p_T relative to the jet axis*



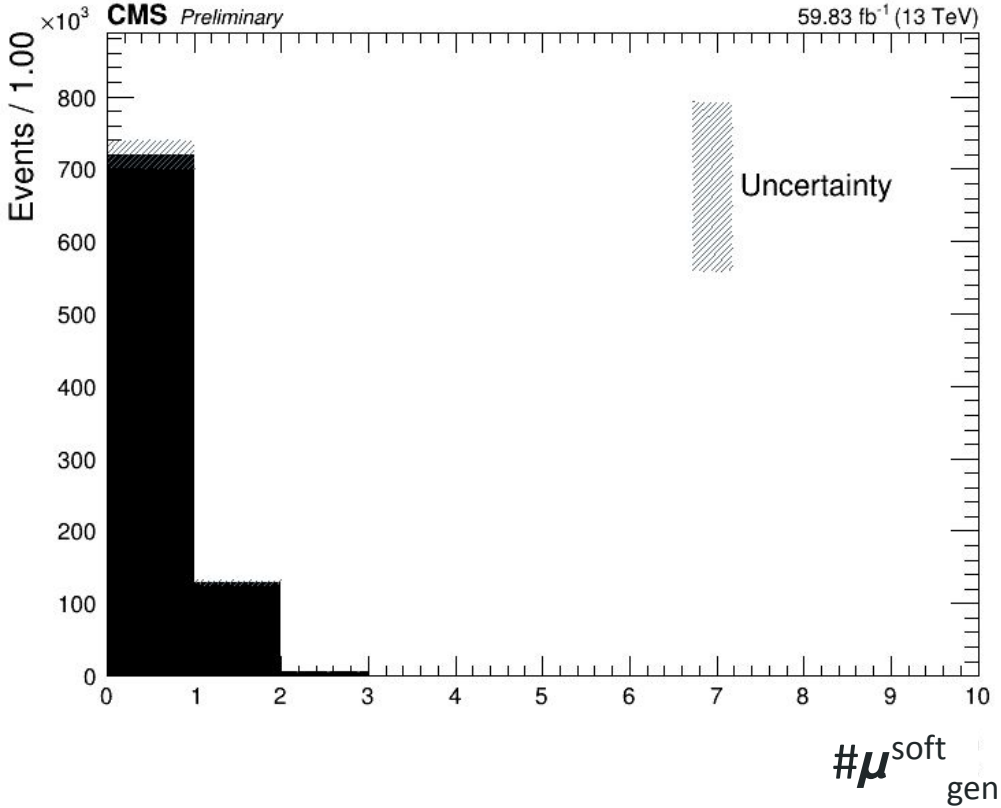
How is P_T^{rel} defined?

- In ATL-PHYS-SLIDE-2017-503 , p_T^{rel} is defined as the orthogonal projection of the p_T^{μ} onto the jet axis



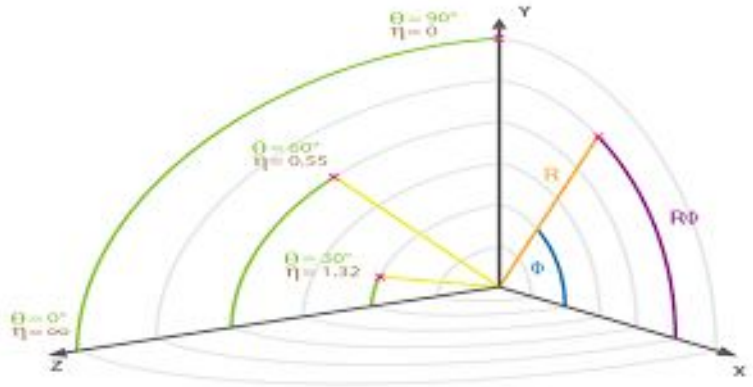
P_T^{rel} ? $= |p^{\mu} \times p^{jet}| / |p^{jet}|$

soft-muon selection at generator level



- Gen soft muons:
  - |pdgId|=13
  - Check if mother is BHadron
  - |gMother.pdgId| = (5 or isBHadron)
  - A top quark should exist among ancestors (not originating from ISR/FSR)
  - isDirectHadronDecayProduct, not a tauDecayProduct
  - Stable particle (status=1)
- ~20% of events contain 1 soft mu

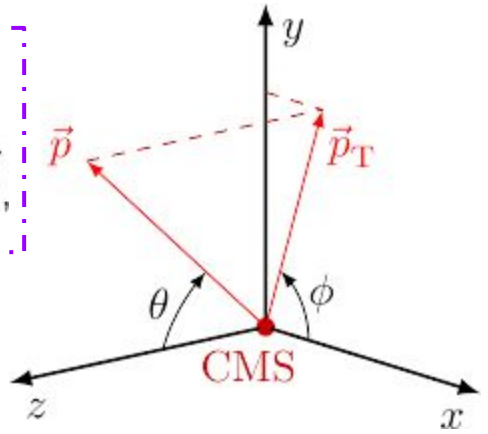
ΔR ($\mu_{soft}^{pre\text{-}sel}$, associated-jet)



- Selection criteria:
  - **Preselection cuts**
    - pt >= 10
    - |eta| <= 2.4,
    - looseId
    - dxy < 0.3, dz < 20
    - nTrackerLayers > 5
    - Check it's not the hard muon
    - muon.jetIdx = B_{1OR2}JetIdx
  - *Cut on* $\mathbf{P_T^{rel}}$

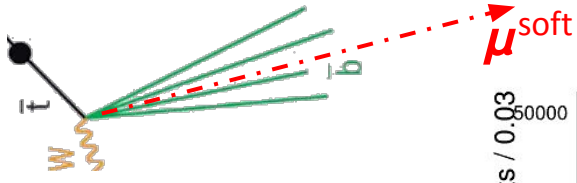
$$\eta = -\ln[(\tan(\theta/2)]$$

$$\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2},$$

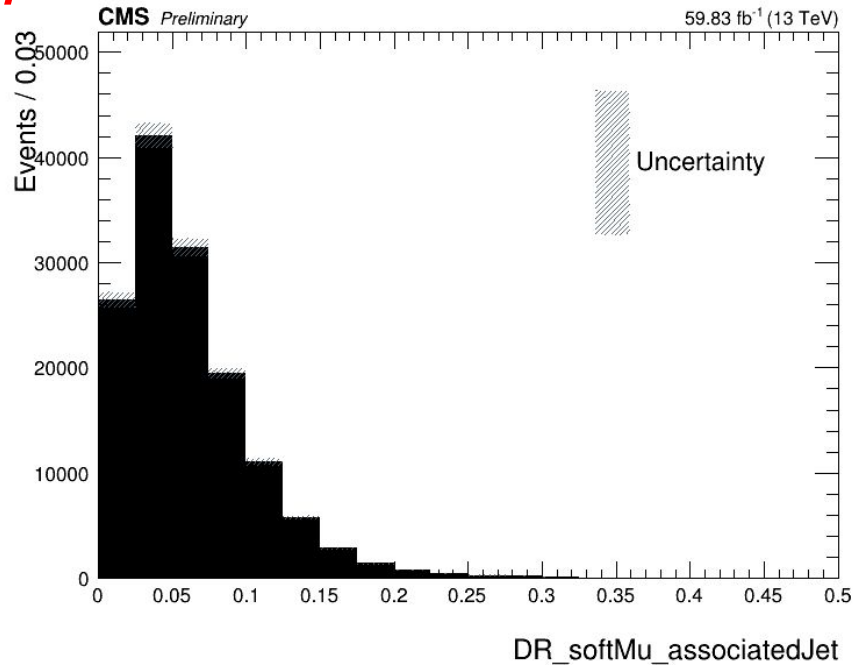


ΔR ($\mu_{soft}^{pre\text{-}sel}$, associated-jet)

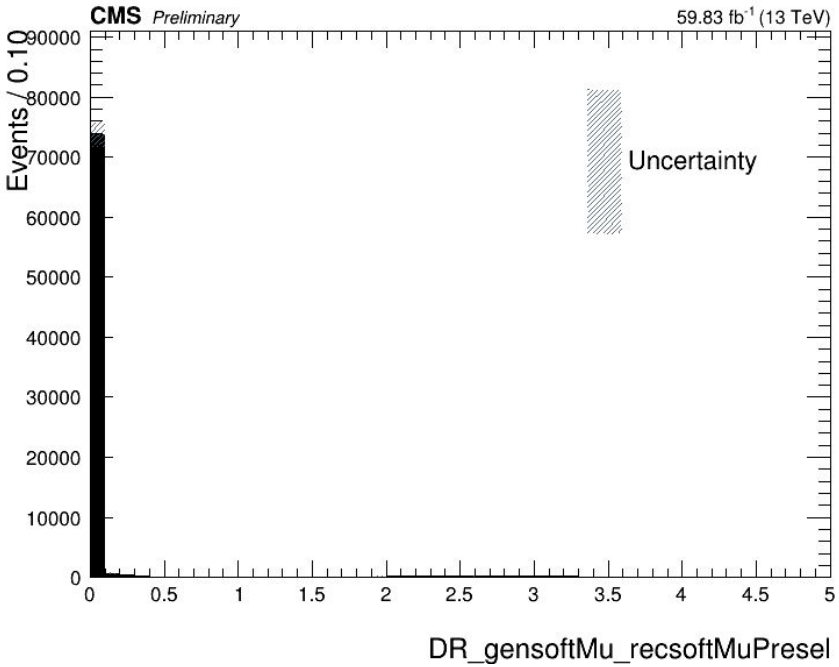
B-hadron jet



- Selection criteria:
  - **Preselection cuts**
    - pt >= 10
    - |eta| <= 2.4,
    - looseId
    - dxy < 0.3, dz < 20
    - nTrackerLayers > 5
    - Check it's not the hard muon
    - muon.jetIdx = B_{1OR2}JetIdx
  - *Cut on* P_T^{rel}

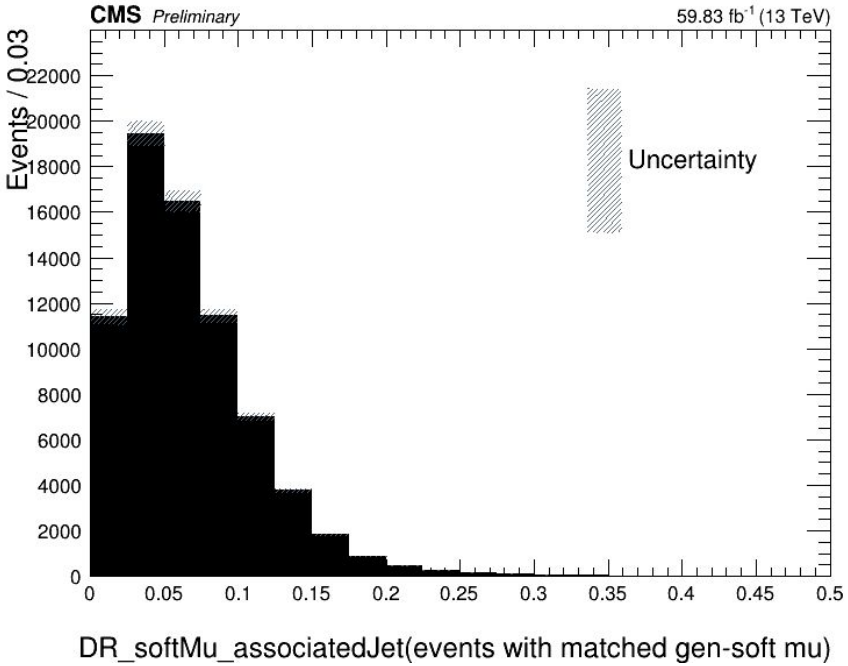


$\Delta R\,(\mu_{soft}^{pre\text{-}sel}, \mu_{soft}^{gen})$

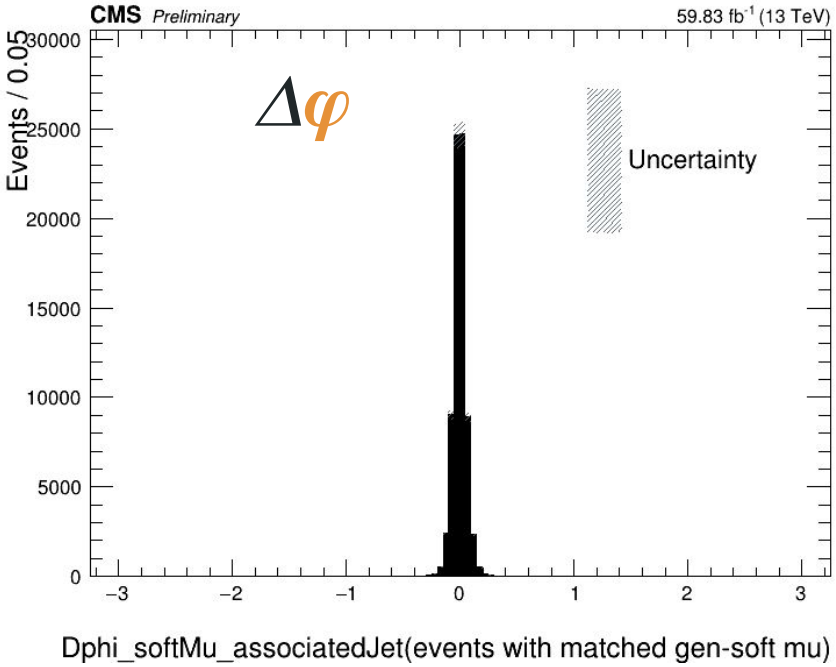


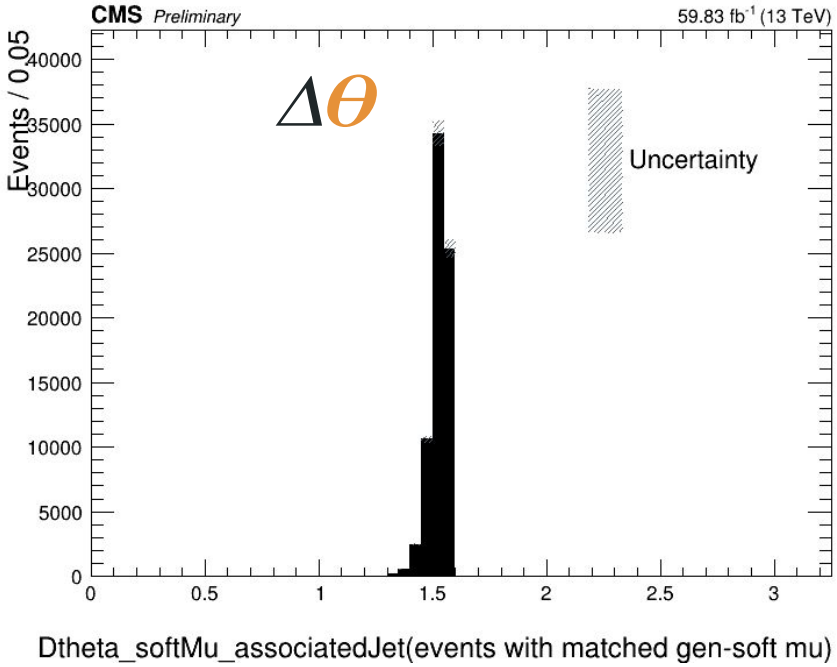
- *In the events where exactly one gen soft mu is found*
- Matched_soft_mu:
  - If $\Delta R\,(\mu_{soft}^{pre\text{-}sel}, \mu_{soft}^{gen}) < 0.05$
- Next slides look at some properties of those matched μ_{soft}^{gen}

ΔR ($\mu_{soft}^{pre\text{-}sel}$, associated-jet) [$\mu_{soft}^{pre\text{-}sel}$ is matched to μ_{soft}^{gen}]



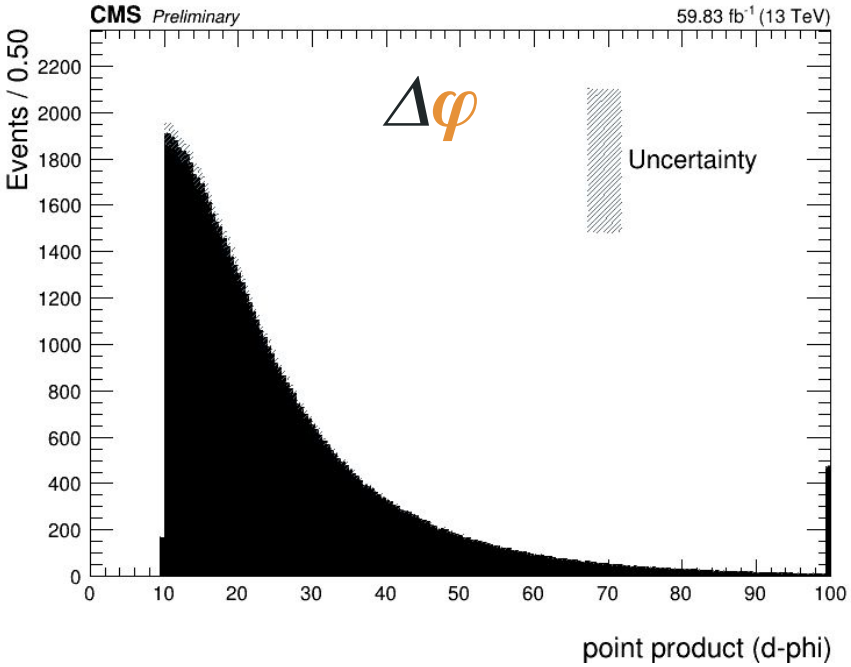
$\Delta\varphi/\theta$ ($\mu_{soft}^{pre\text{-}sel}$, associated-jet) [$\mu_{soft}^{pre\text{-}sel}$ is matched to μ_{soft}^{gen}]

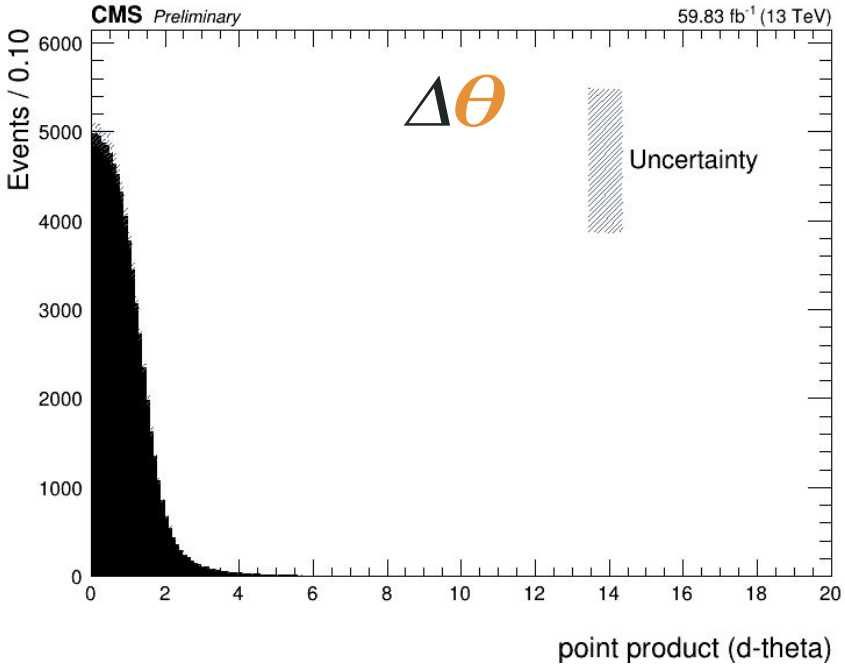




dEta = op.sqrt(op.pow(op.deltaR,2)-op.pow(op.deltaPhi,2))
dTheta = 2.*op.atan(op.exp(-1.*dEta))

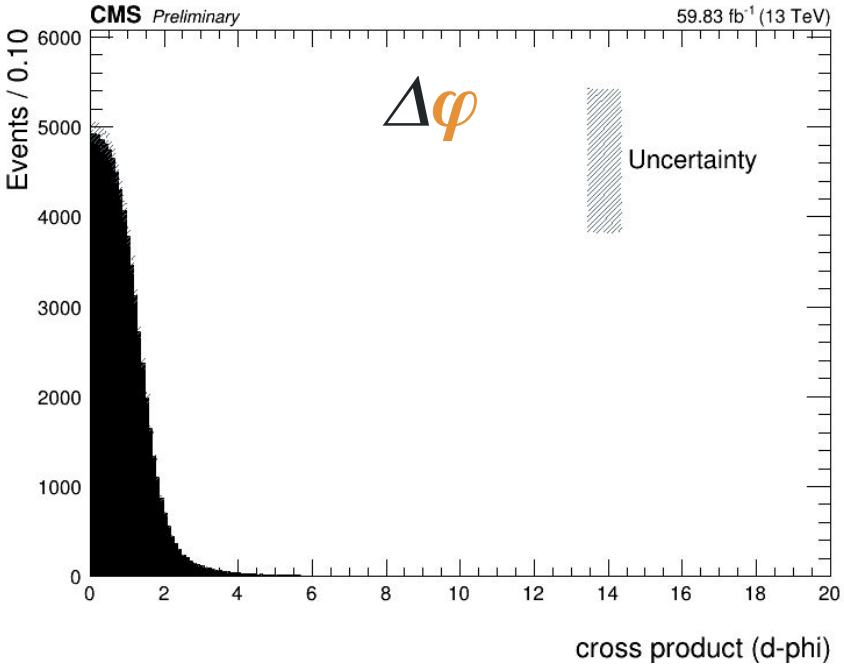
$p_T^{\text{soft-}\mu} \times \cos(\Delta\varphi/\Theta(\mu_{\text{soft}}^{\text{pre-sel}}, \text{associated-jet}))$ [$\mu_{\text{soft}}^{\text{pre-sel}}$ is matched to $\mu_{\text{soft}}^{\text{gen}}$]

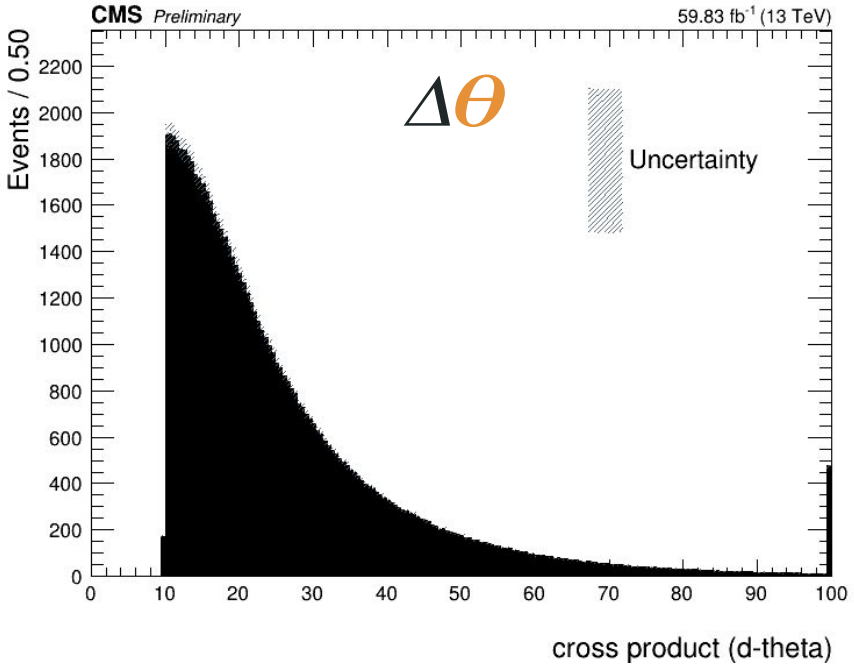




Point product: $|p^{\mu} \times p^{jet}|/|p^{jet}|$ → p^{μ} cos

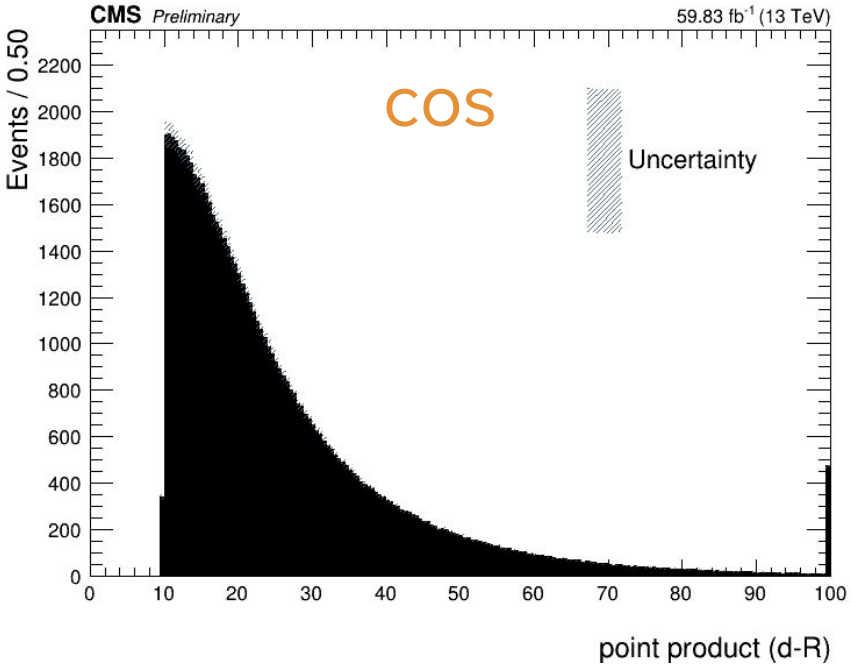
$p_T^{\text{soft-}\mu} \times |\sin(\Delta\varphi/\Theta(\mu_{\text{soft}}^{\text{pre-sel}}, \text{associated-jet}))|$ [$\mu_{\text{soft}}^{\text{pre-sel}}$ is matched to $\mu_{\text{soft}}^{\text{gen}}$]

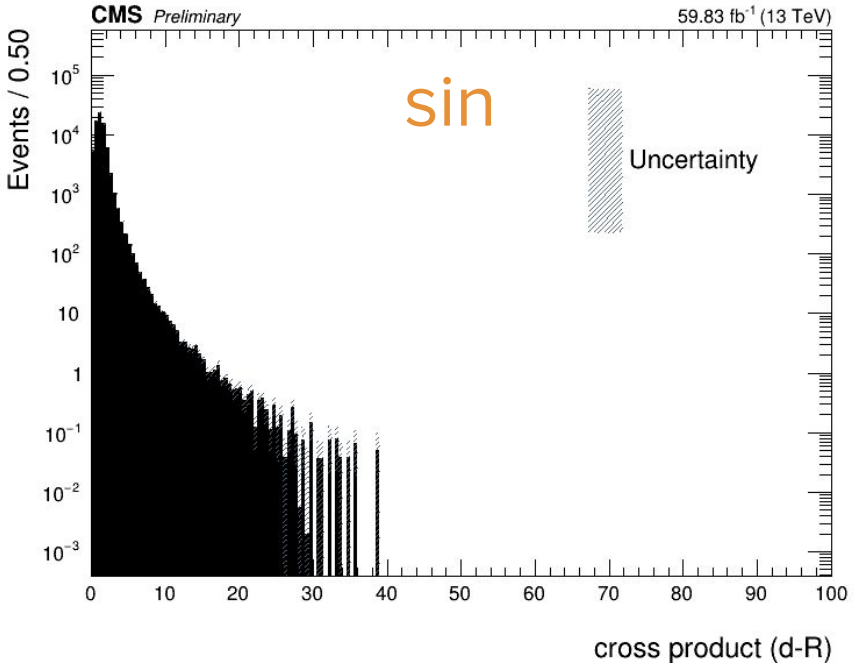




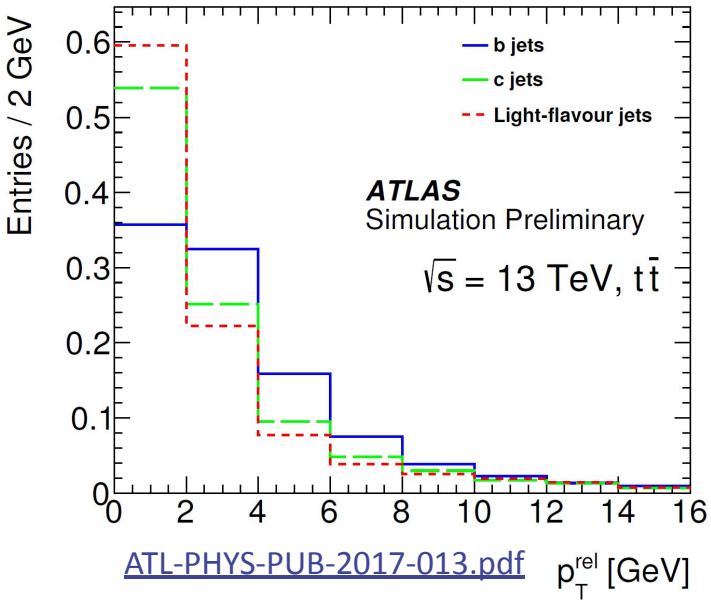
Cross product: $|p^{\mu} \times p^{jet}|/|p^{jet}|$ → p^{μ} sin

$p_T^{\text{soft-}\mu} \times \cos/\sin(\Delta R(\mu_{\text{soft}}^{\text{pre-sel}}, \text{associated-jet}))$ [$\mu_{\text{soft}}^{\text{pre-sel}}$ is matched to $\mu_{\text{soft}}^{\text{gen}}$]





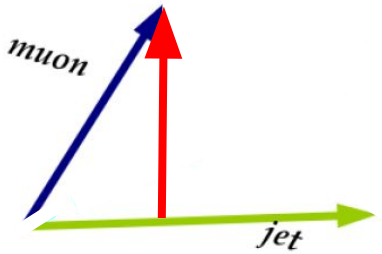
Coming back to the definition of P_T^{rel}



ATL-PHYS-PUB-2017-013.pdf

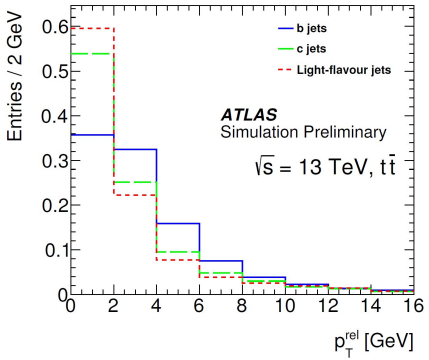
How is P_T^{rel} defined?

- In ATL-PHYS-SLIDE-2017-503 , p_T^{rel} is defined as the orthogonal projection of the p_T^{μ} onto the jet axis

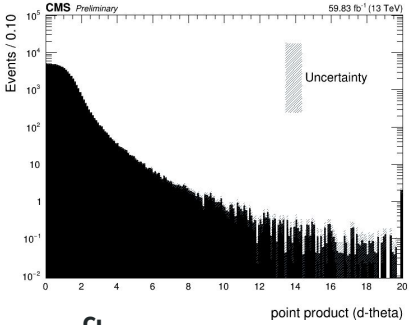


P_T^{rel} ? $= |p^{\mu} \times p^{jet}| / |p^{jet}|$

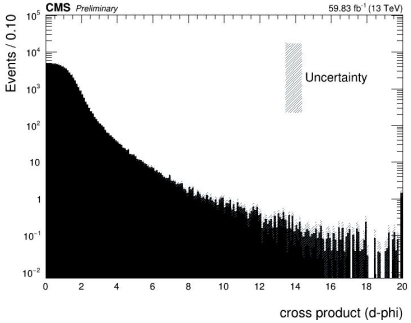
P_T^{rel} vs P_T ratio



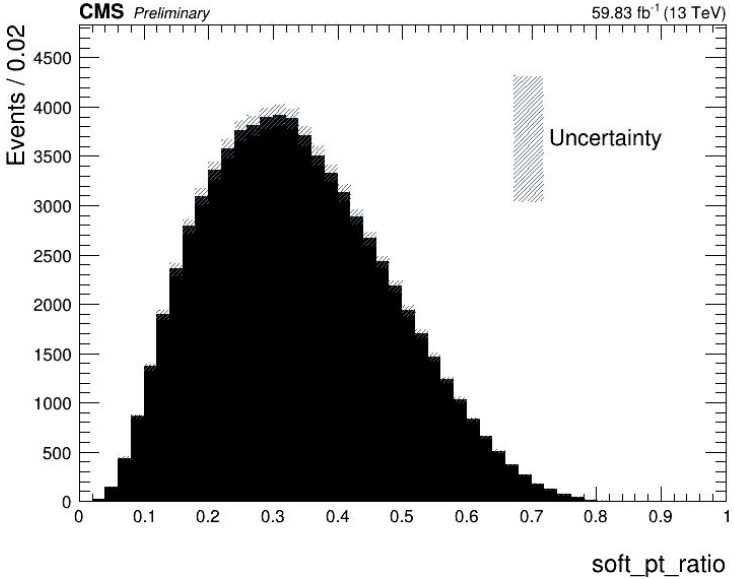
- $p_T^{soft\text{-}\mu} \times \text{Cos}\ \Delta\theta$



- $p_T^{soft\text{-}\mu} \times \text{Sin}\ \Delta\varphi$



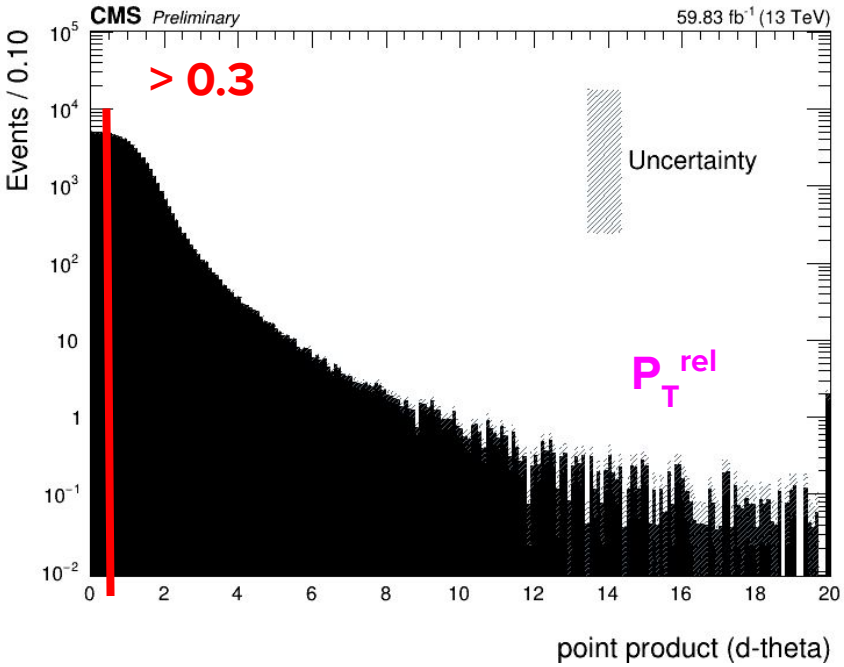
- P_T ratio:
  - $p_T^{soft\text{-}\mu} / p_T^{associated\text{-}jet}$



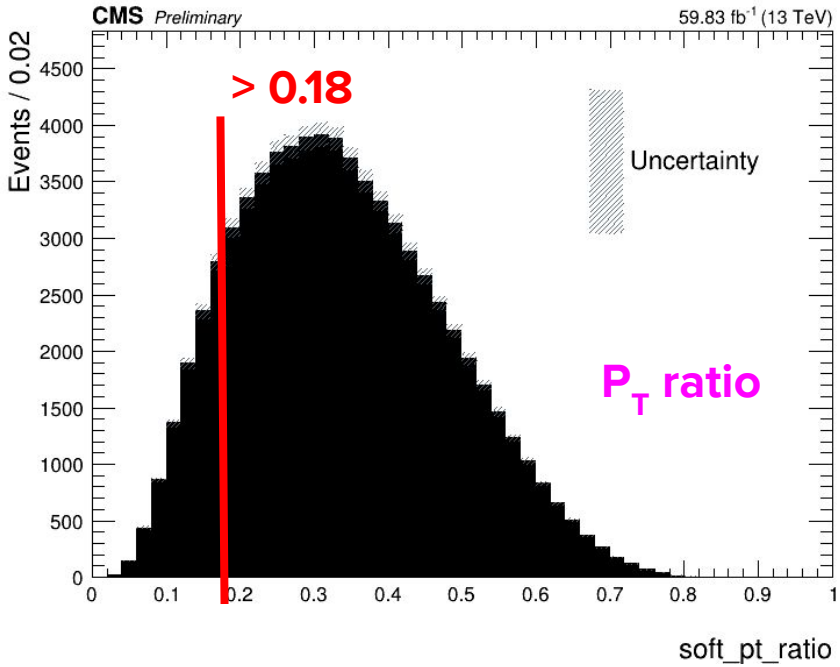
$[\mu_{soft}^{pre\text{-}sel}$ is matched to $\mu_{soft}^{gen}]$

$[\mu_{soft}^{pre\text{-}sel}$ is matched to $\mu_{soft}^{gen}]$

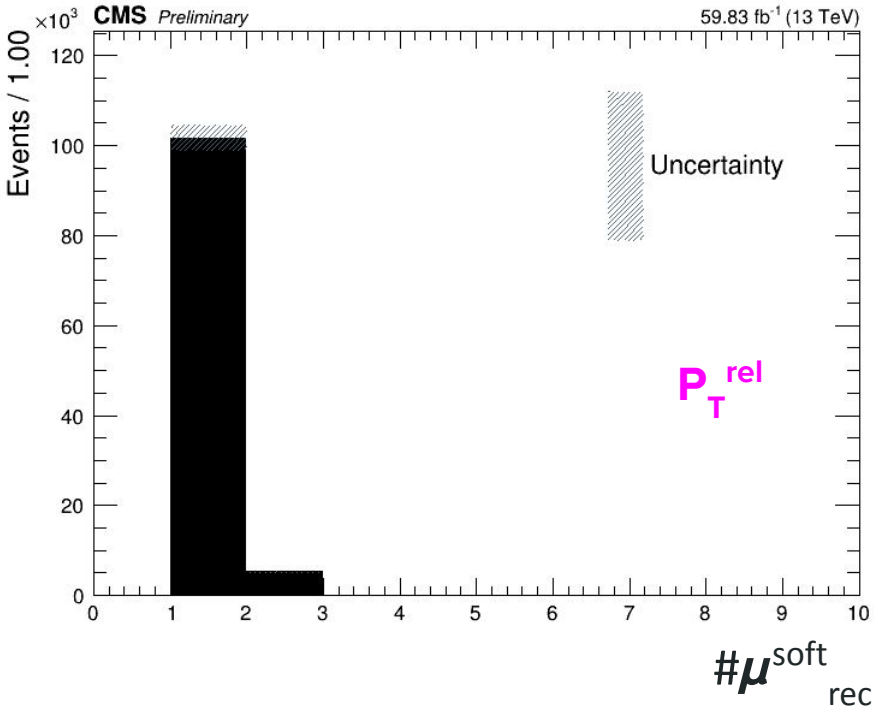
- $p_T^{soft\text{-}\mu} \times \text{Cos}\ \Delta\theta$

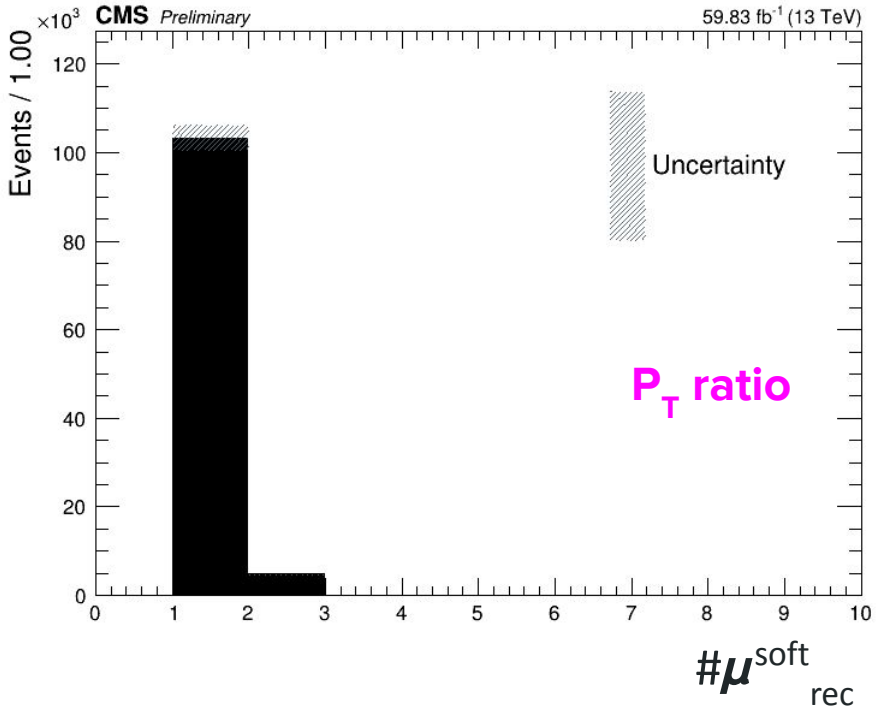


- $p_T^{soft\text{-}\mu} / p_T^{associated\text{-}jet}$

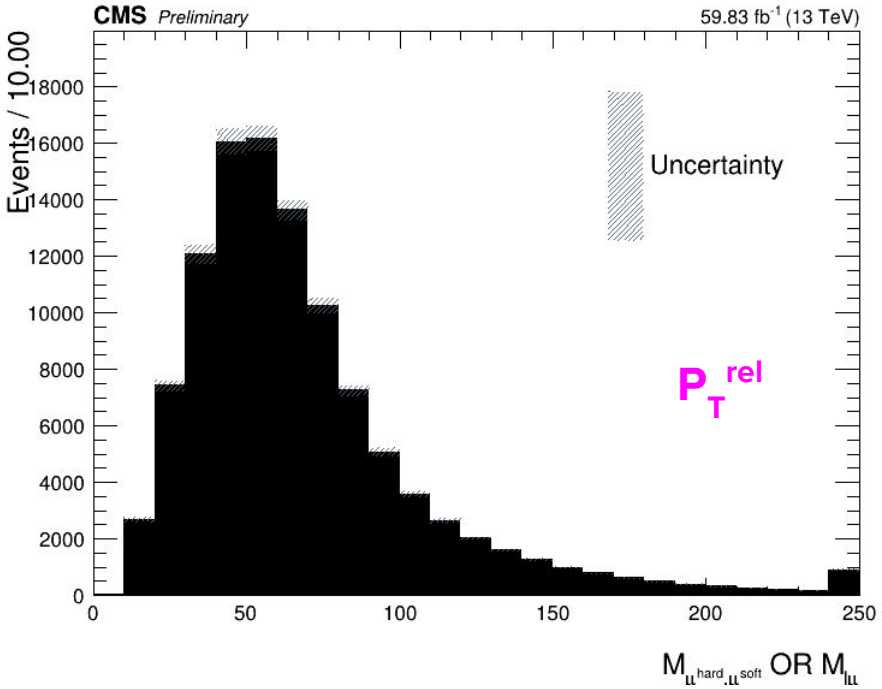


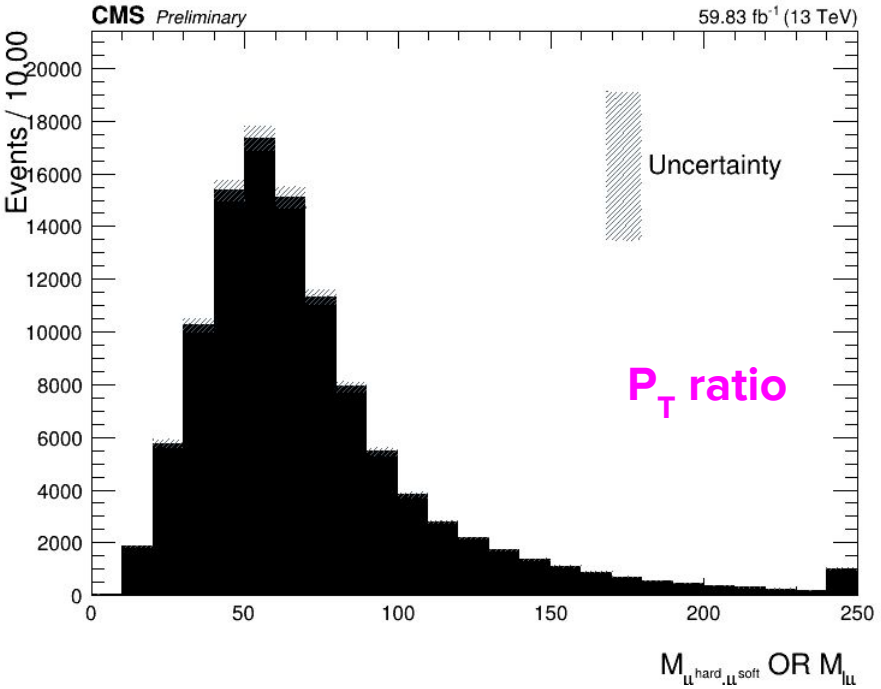
soft-muon selection at reconstruction level





$M_{\mu\ell}$ distribution





Analyses involved

Code	Name	Status	PAS	PAPER	ARC
LUM-20-002 » | ▲show	**Luminosity measurement for the Run 2 PbPb data-taking periods**	PRE-APP			Nicola Bacchetta

LUM-20-002 (*Sat, 25 May 2024 09:54:50*)

Name	Luminosity measurement for the Run 2 PbPb data-taking periods	**Description**	Luminosity measurement for the 2015 PbPb data-taking period, and combination with the 2018 PbPb luminosity measurement
Status	**PRE-APP**	**Contact Person**	Maryam Zeinali (ISFAHAN-IUT)
Twiki	LUM-20-002	**Forum**	PubTalk LUM-20-002
Data,Samples	DataSet: Run2 Samples: not set	**Conference**	
Target Date PreApp	29/11/2022	**Target Date PhysApp**	
Talks	Pre-Approval Talk » | No Approval Talk	**Actions**	Not in Edit Mode
Related Analyses	LUM-18-001	**Related CMS Notes**	AN-2020/137 | AN-2019/159

Code	Name	Status	PAS	PAPER	ARC
HIG-22-007 » | ▲show | ▼CDS | ▼EPJC	Search for H->aa->2mu2b/2tau2b	PUB	P		Philippe Gras

HIG-22-007 (*Sat, 25 May 2024 09:56:00*)

Name	Search for H->aa->2mu2b/2tau2b	**Description**	H->aa->2mu2b or 2tau2b (+combination)
Status	**PUB**	**Contact Person**	Pallabi Das (PRINCETON)
Twiki	HIG-22-007	**Forum**	PubTalk HIG-22-007
Data,Samples	DataSet: Run2 Samples: not set	**Conference**	
Target Date PreApp	02/08/2022	**Target Date PhysApp**	03/03/2023
Talks	Pre-Approval Talk » | Approval Talk »	**Actions**	Not in Edit Mode
Related Analyses	HIG-21-021	**Related CMS Notes**	AN-2020/213 | AN-2021/058

Recently initiated analyses

- Top quark mass measurement
  - Independently promoted
    - More challenges, to set up the FW
    - Method has been validated using simulated samples (Farbod Naderpour, MSc thesis, 2023)
- Ttbar cross section calculation
  - BSc student is being trained (Nazanin Zahra Norouzi)
  - Also a MSc student is taking part (Shahrzad Barzegar Mirzaei)