Dark matter + tt in the dilepton channel: plans towards Moriond

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Introduction

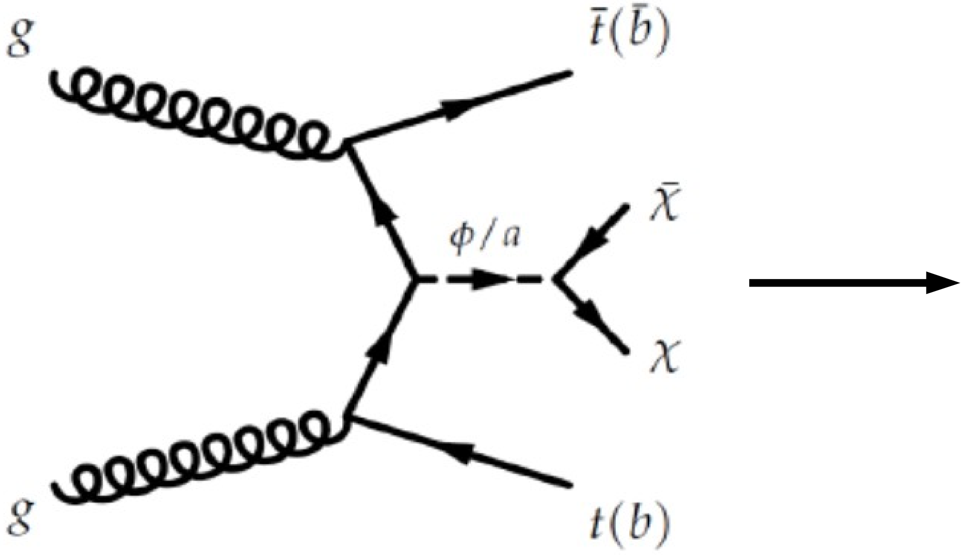
- The purpose of this talk is to collect all the information we have about the tt+DM analysis
- With the final aim of making a realistic working plan with high chances to be successful
- From the very beginning we assume that there will be 5 people involved in this effort

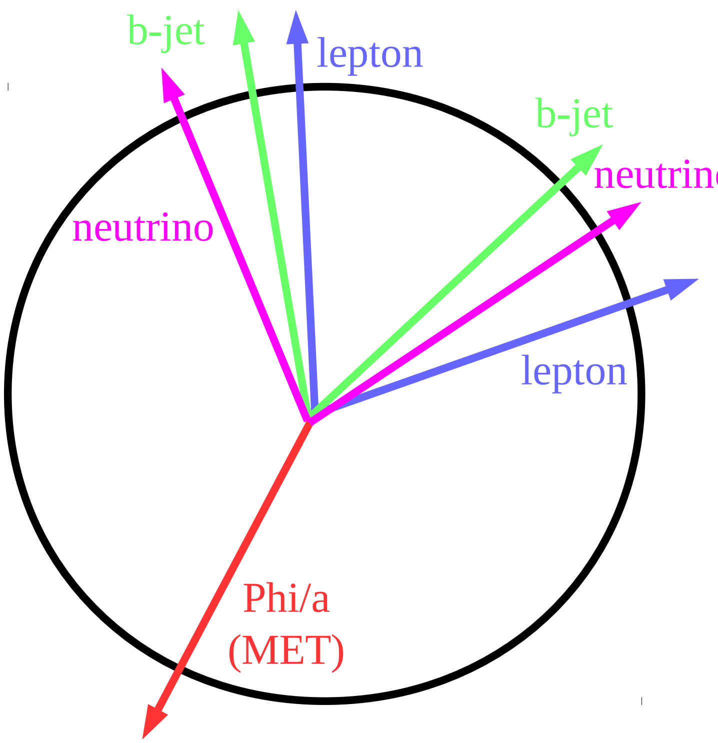
Juan (PhD student) Experienced	Cedric (Master student) (Joining effort)

Jonatan (postdoc) (??)	Rocio (senior) (??)	Pupi (senior) (Best Effort)	Pablo (postdoc) (Best Effort)

Our physics case

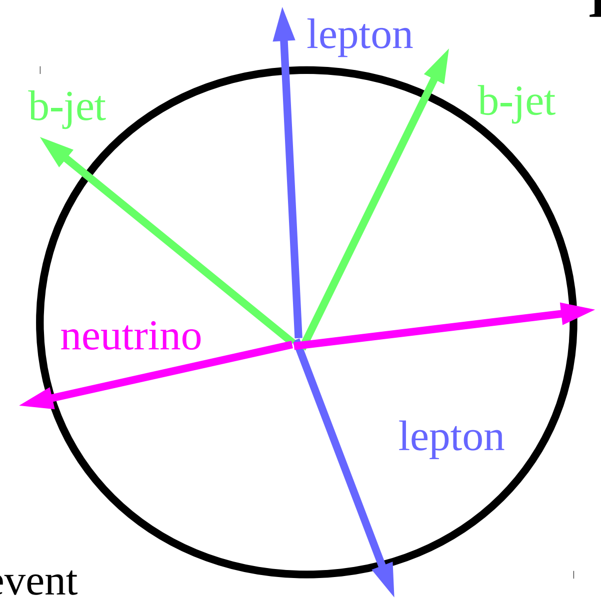
- Looking for dark matter produced in association with a pair of top-antitop going leptonically
- Ideally we would like to see how a ttbar system recoils against the dark matter particle
- How much boosted the two tops are will depend on the pt of the mediator
- The bigger the mediator mass, the higher the momentum and the less similar to a ttbar event
  - Why? See next



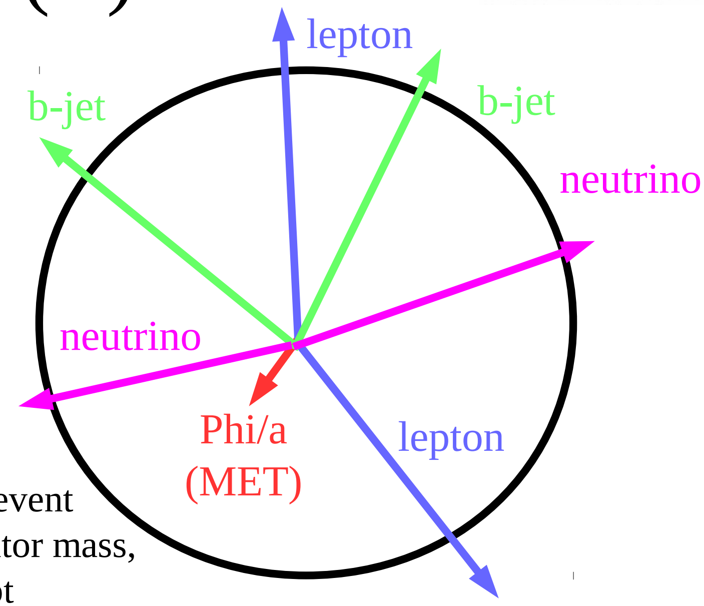


Our physics case (II)

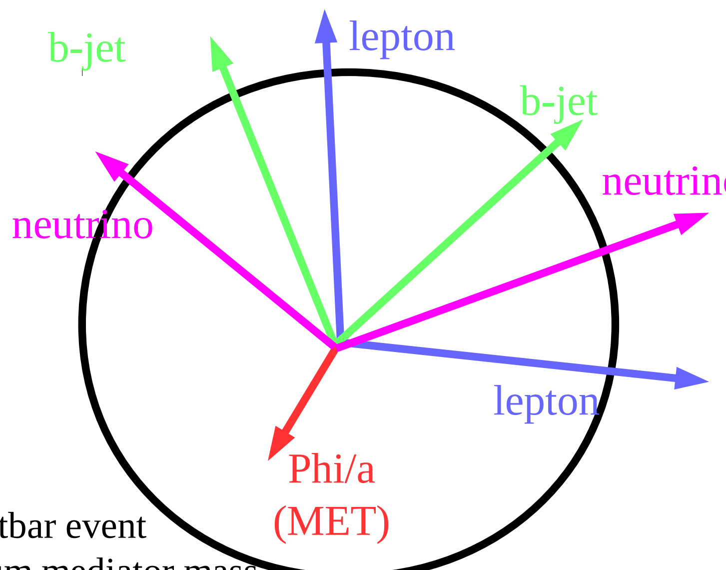
Similar



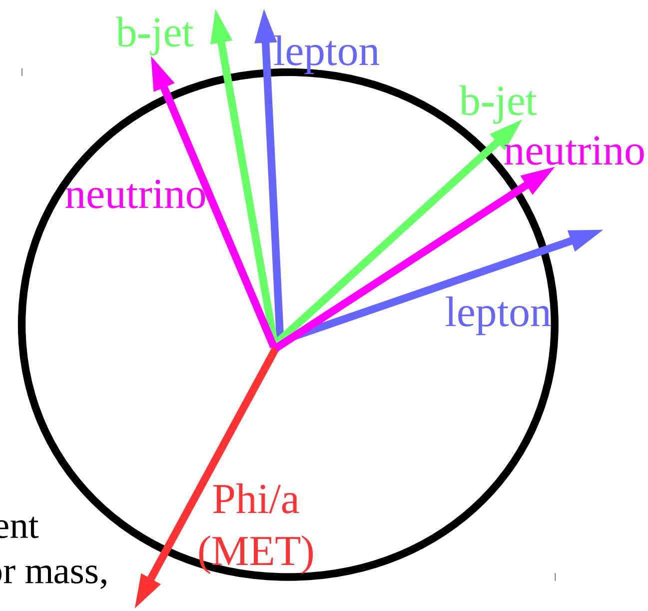
ttbar event



DM+ttbar event
Low mediator mass,
low Phi/a pt



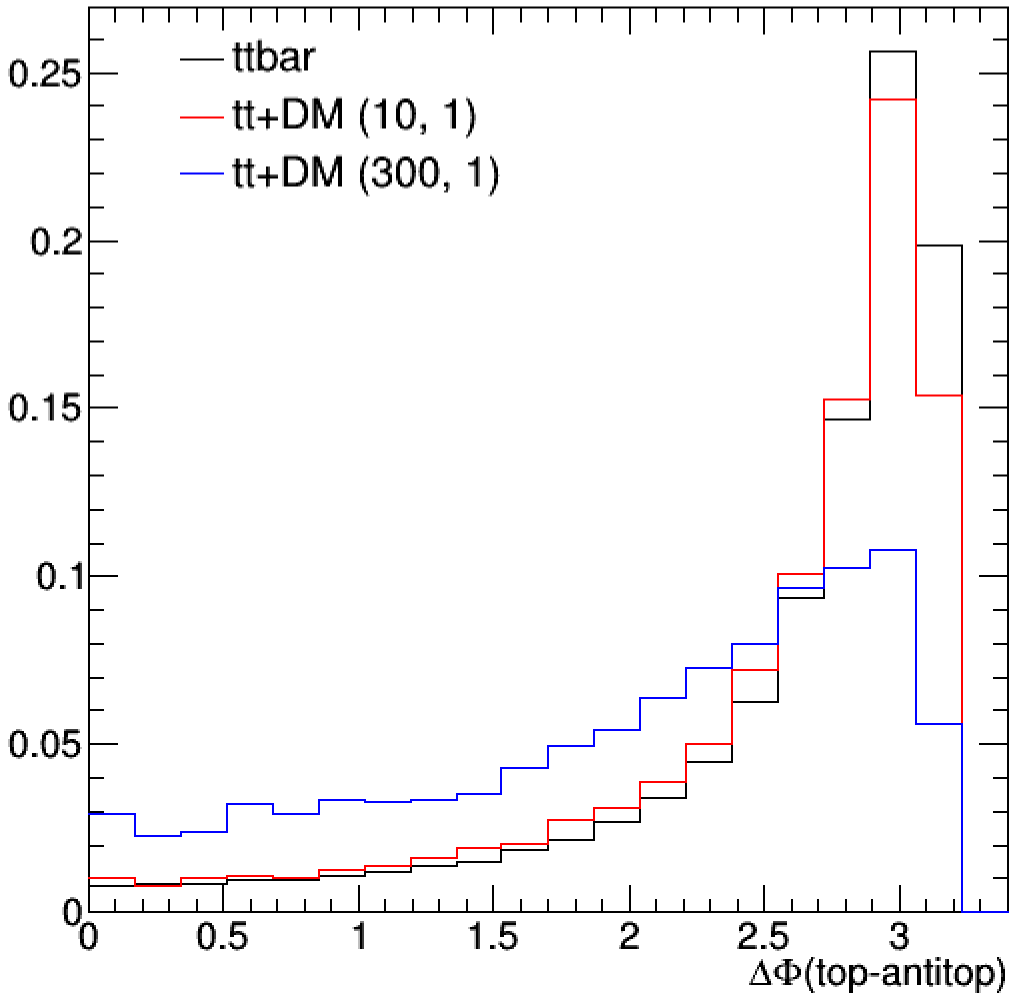
DM+ttbar event
Medium mediator mass
Medium Phi/a pt



DM+ttbar event
High mediator mass,
high Phi/a pt

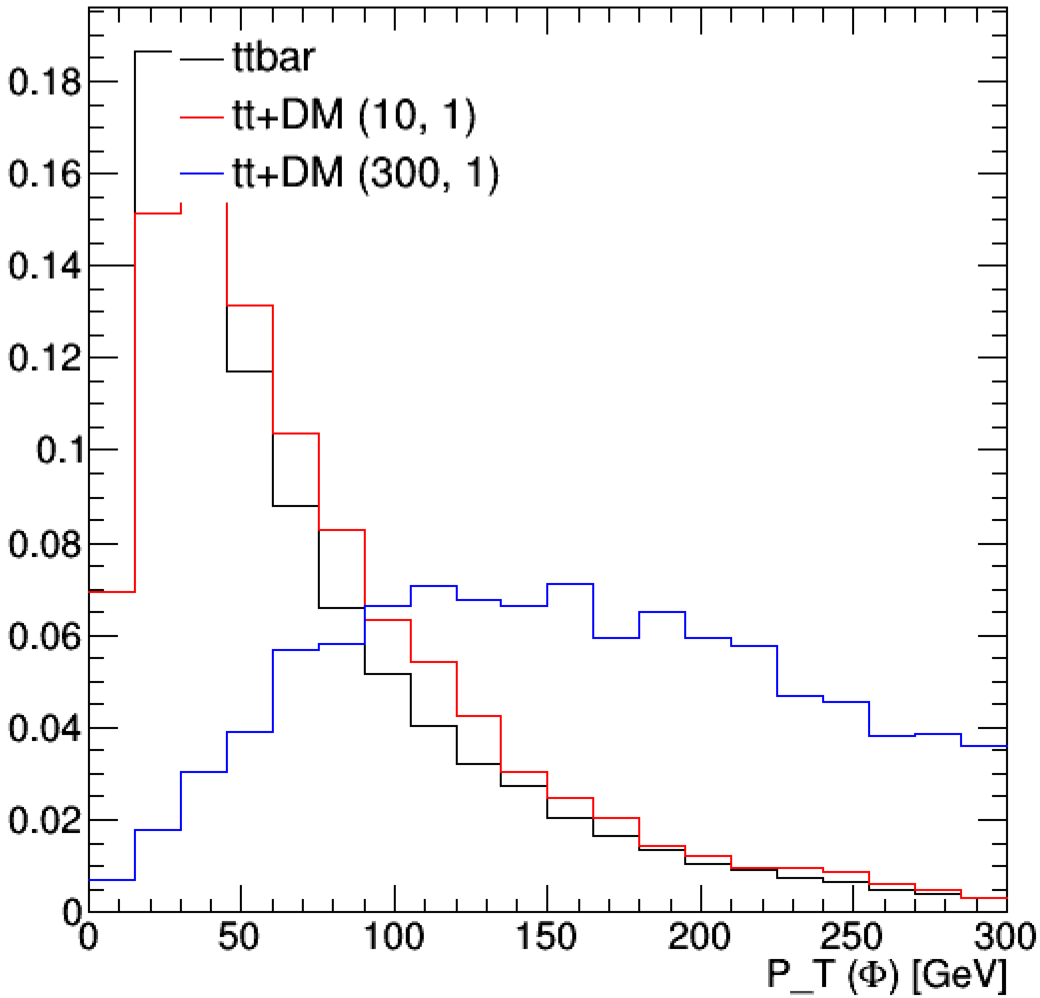
How can see this?

- The Delta Phi angle between the two tops increases with the mass of the mediator



How can see this?

- The Pt of the mediator also increases with the mass of the mediator



Why more m(Phi) takes more p(Phi)?

- This result is not intuitive at all and even if it's stated in many places it's never explained
- Funny to check that nor the people from Northwestern, nor the EXO MET+X subconveners, nor even the SM conveners knew why this is like this!
- Most of them are providing as a reason that for high masses of the mediator there's a lot of energy available for boosting the X particles and therefore a lot of MET.
- WRONG!!!!!: the momentum of the X system is equal to the momentum of the mediator, no matter the difference in mass between them. <u>The X are irrelevant for this discussion.</u>

Let's have a look at the kinematics

$$p_{gluon\,1}+p_{gluon\,2}=p_{\Phi}+p_{top}+p_{antitop} \longrightarrow (p_{gluon\,1}+p_{gluon\,2}-p_{\Phi})^2=(p_{top}+p_{antitop})^2$$

We calculate the first part in the system of reference in which the gluons are at rest.

$$\left\{\begin{pmatrix}\sqrt{s_{eff}}\\0\end{pmatrix}-\begin{pmatrix}E_{\Phi}\\\vec{p}_{\Phi}\end{pmatrix}\right\}^2=s_{eff}+m_{\Phi}^2-2\sqrt{s_{eff}}\,E_{\Phi}$$

We calculate the second part in the system of reference in which the top is at rest.

$$\left\{\begin{pmatrix}m_{top}\\0\end{pmatrix}-\begin{pmatrix}E_{antitop}\\\vec{p}_{antitop}\end{pmatrix}\right\}^2=2\,m_{top}^2+2\,m_{top}\,E_{antitop}$$

Equalizing the two sides and replacing the energy in terms of mass and momentum:

$$p_{\Phi}=\left\{\left(\frac{s_{eff}+m_{\Phi}^2-2\,m_{top}^2-2\,m_{top}\sqrt{m_{top}^2+p_{antitop}^2}}{2\sqrt{s_{eff}}}\right)^2-m_{\Phi}^2\right\}^{1/2}$$

Let's have a look at the kinematics

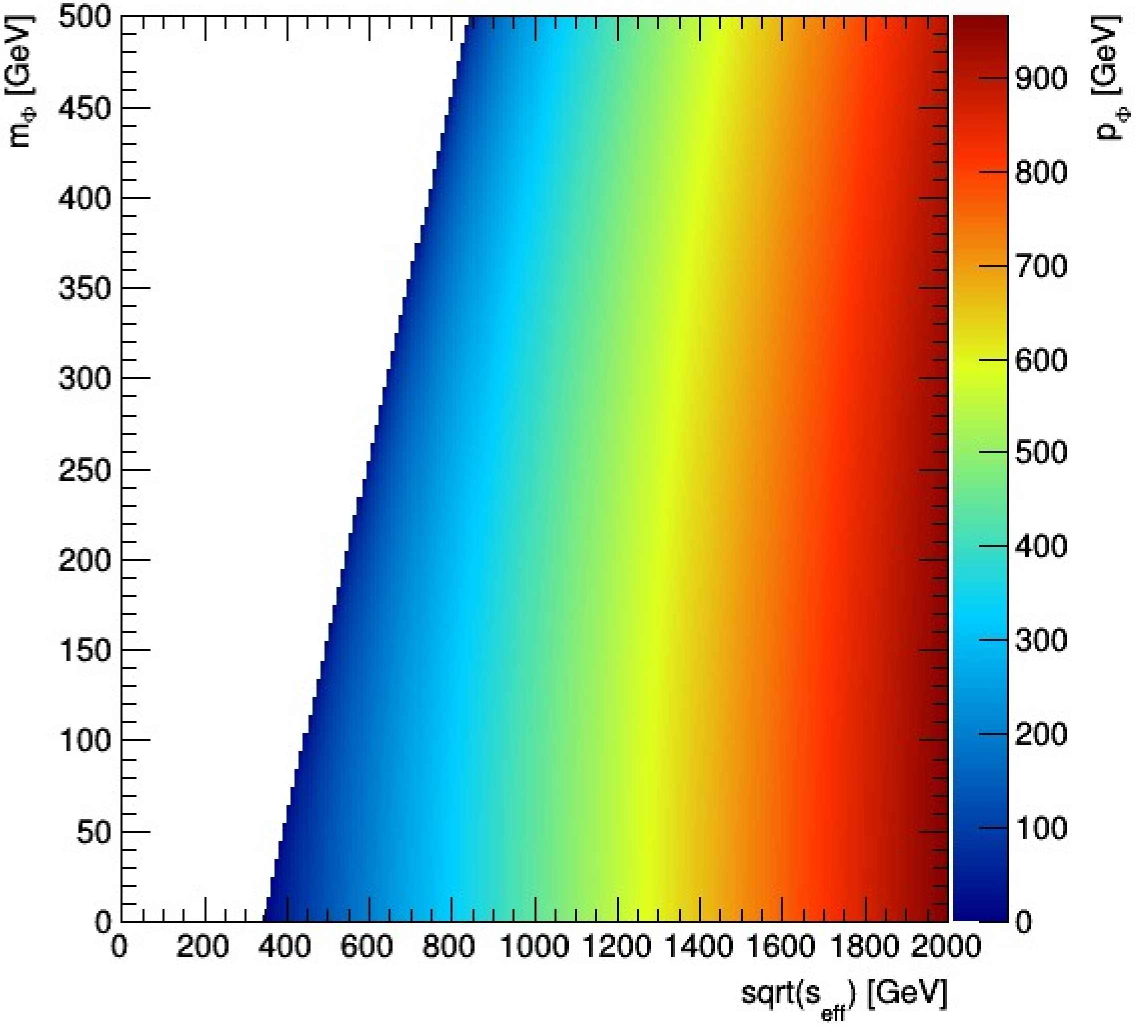
The equation before is monotonic on the momentum of the antitop. It's maximum is:

$$p_{\Phi}^{max} = \left\{ \left(\frac{s_{eff} + m_{\Phi}^2 - 4\, m_{top}^2}{2\sqrt{s_{eff}}} \right)^2 - m_{\Phi}^2 \right\}^{1/2}$$

Remember this is the momentum in the system of reference in which the two gluons are at rest, however this system of reference only differs in a boost along the Z direction, which means that the transversal distribution will never be accepted by this boost.

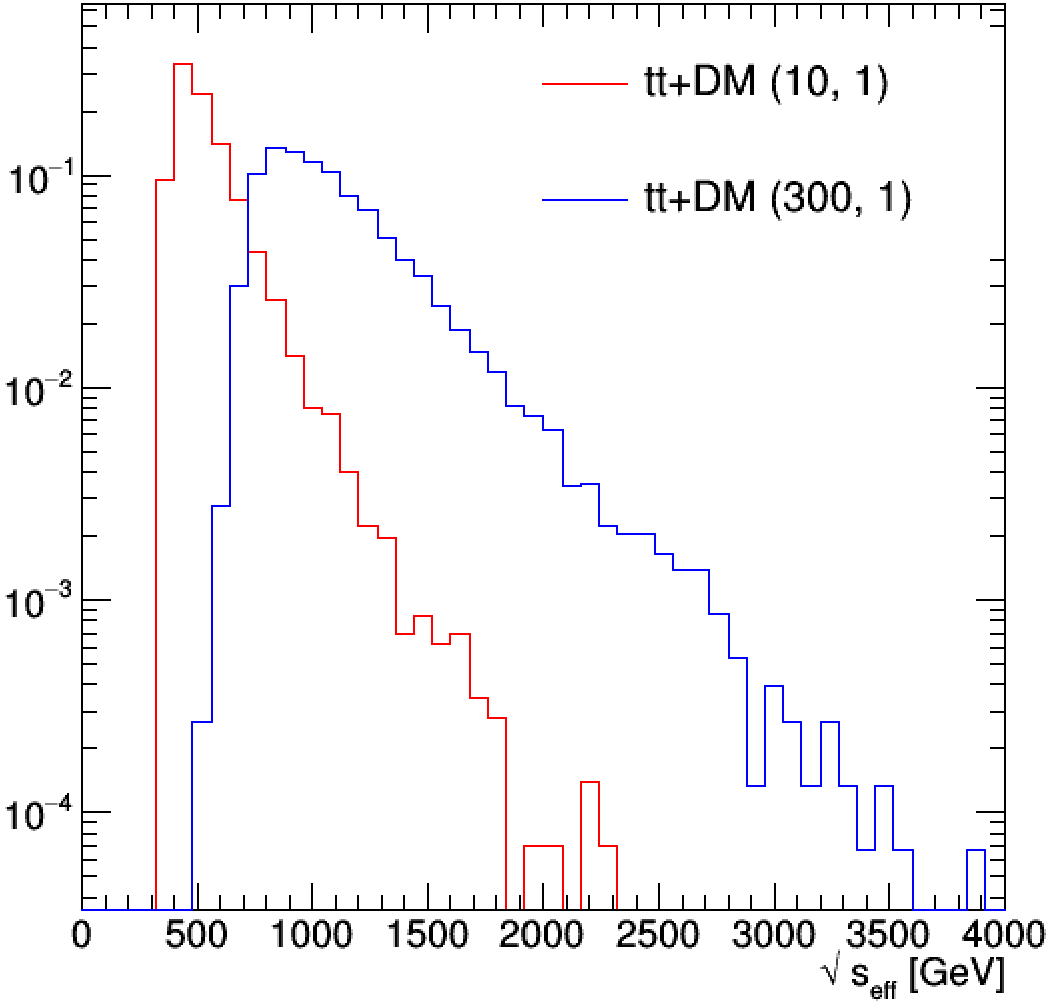
Let's have a look at the kinematics

- There's no kinematic reason for the momentum to be higher for higher masses



Let's have a look at the kinematics

- Unless the mass is selecting high values of s_eff → true because of the amount of available phase space



Typical signature

- We are looking for 2 opposite sign leptons, with at least 2 jets (1 b-jet) and some MET
- Very characteristic signature however this matches very well what you would ask for ttbar
- The challenge of this analysis is to discriminate the ttbar from the signal that contains ttbar
- And for this we need to exploit ideas that go to the core of the kinematical differences

What has been published so far? (I)

- Northwester (CMS, 2015) has performed an analysis based in the inspection of the MET
- The 2 main cuts they apply are MET > 50 and ΔΦ(dilepton, MET) > 1.2
- Very clearly they want to find situations where a lot of MET recoils against two leptons

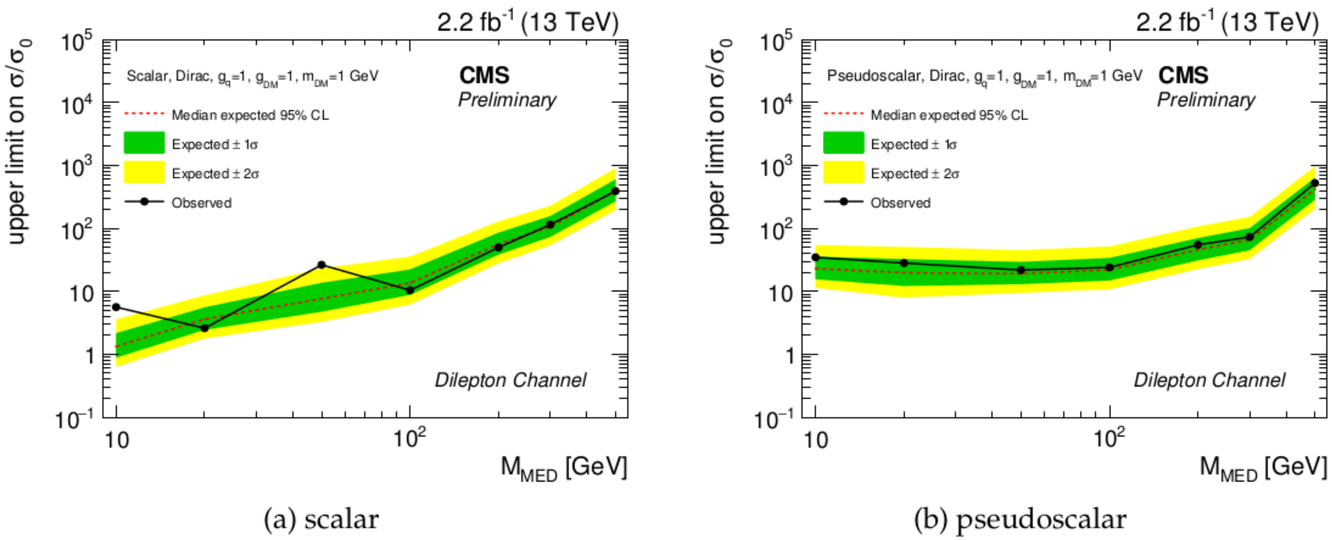


Figure 3: The observed and expected limits, expressed as the ratio of the 95% C.L. upper limit on DM production cross section to the cross section from simplified model expectations for 3a scalar and 3b pseudoscalar models with a dark matter mass of 1 GeV and $g_q = g_{DM} = 1$.

No exclusion achieved by this analysis in 2015!

What has been published so far? (II)

- ATLAS in 2015 also tried this analysis using 2 variables: MT2 and ΔΦ(dilepton, MET)
- Actually they have been able to exclude up to ~ 350 GeV for the mediator mass
  - WARNING: They are using a coupling g = 3.5 while CMS is using g=1
  - The results are not comparable, however looking at the region of 300 GeV seems like ATLAS is doing much better → MT2 seems to be a good thing

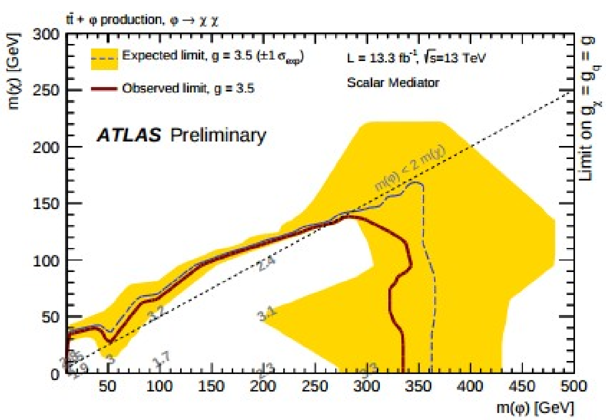


Figure 10: Exclusion limits at 95% CL from the analysis of 13.3 fb^{-1} of 13 TeV collision data on maximum coupling g as a function of the dark matter particle and mediator masses, assuming models with a scalar mediator. The dashed lines are the expected $g = 3.5$ limit and its $\pm1\sigma$ uncertainty, respectively. The thick solid line is the observed limit for the central value of the signal cross section. The expected and observed limits do not include the effect of the theoretical uncertainties on the signal cross section since they are only known at LO accuracy in QCD.

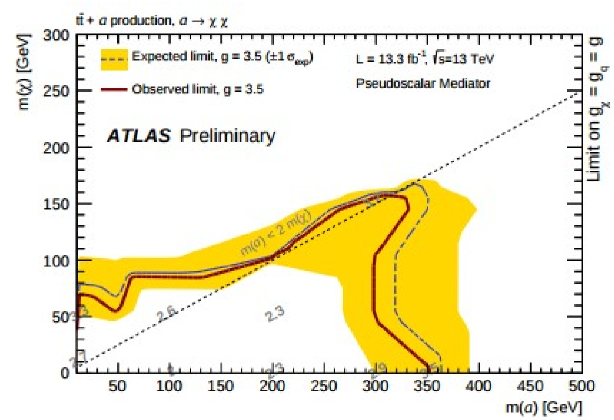
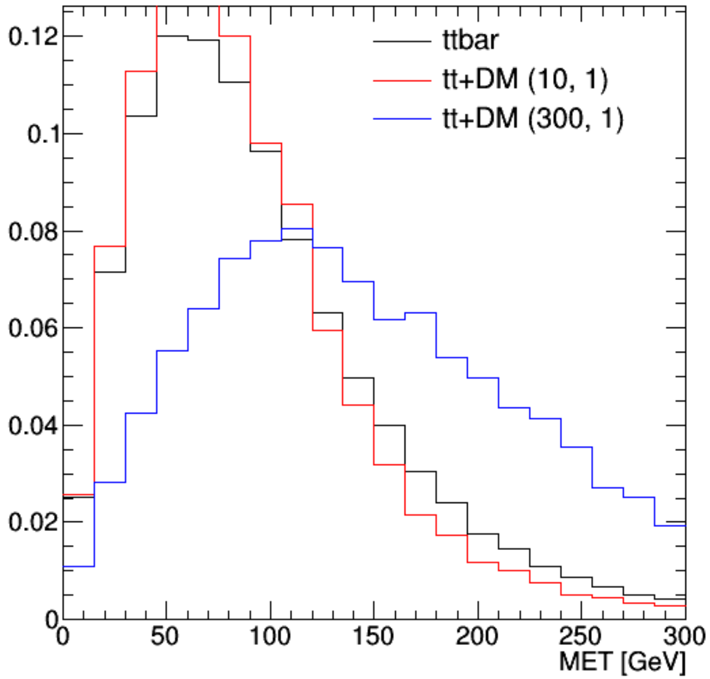
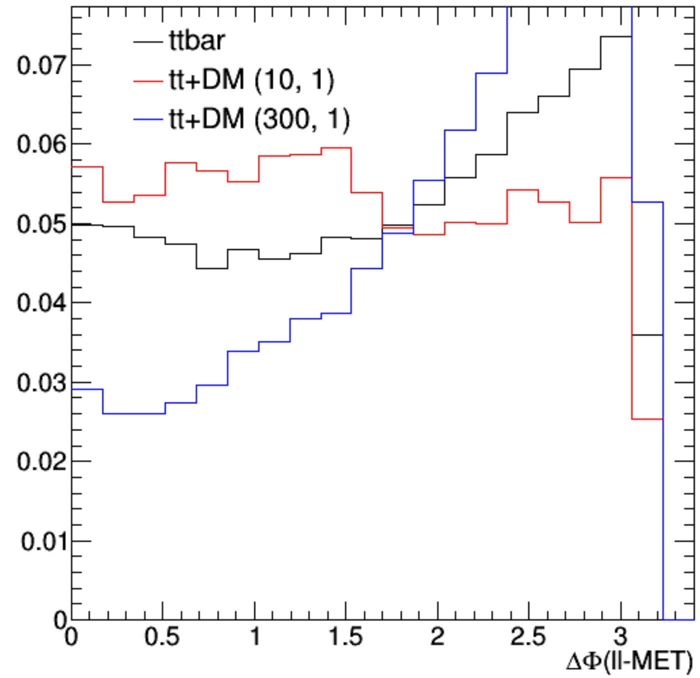


Figure 11: Exclusion limits at 95% CL from the analysis of 13.3 fb^{-1} of 13 TeV collision data on maximum coupling g as a function of the dark matter particle and mediator masses, assuming models with a pseudo-scalar mediator. The dashed lines are the expected $g = 3.5$ limit and its $\pm1\sigma$ uncertainty, respectively. The thick solid line is the observed limit for the central value of the signal cross section. The expected and observed limits do not include the effect of the theoretical uncertainties on the signal cross section since they are only known at LO accuracy in QCD.

Delta Phi and MET

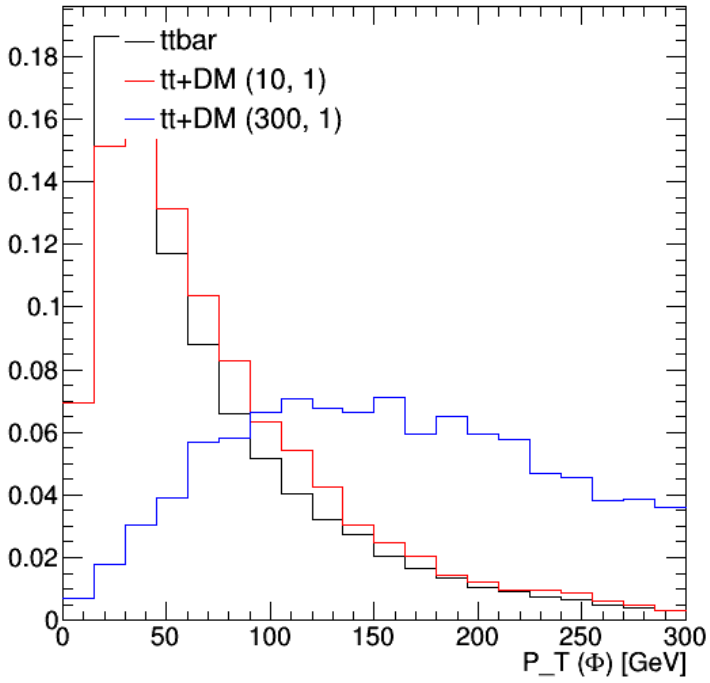
- These two variables are the basis of both the CMS and ATLAS analysis
- The problem is that the neutrinos also contribute to the MET and the variables don't discriminate anymore for small masses of the mediator (which have high cross sections)

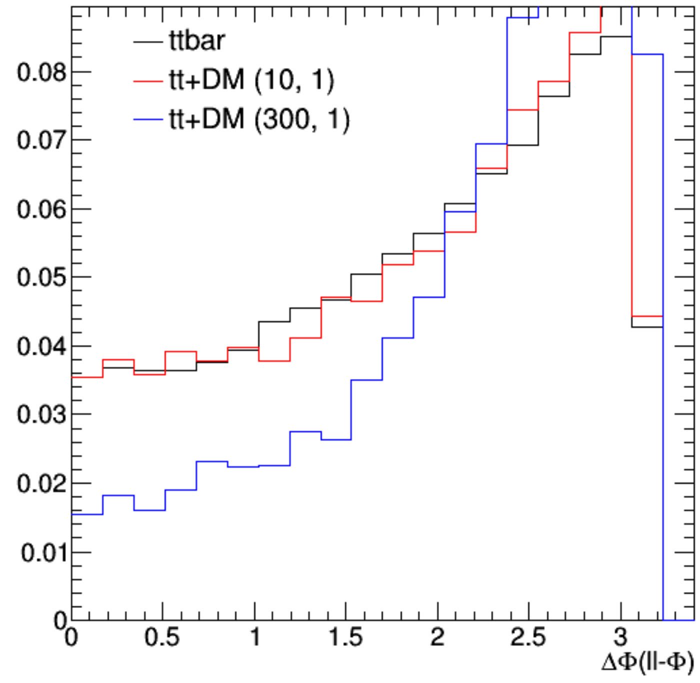




Delta Phi and MET: a solution?

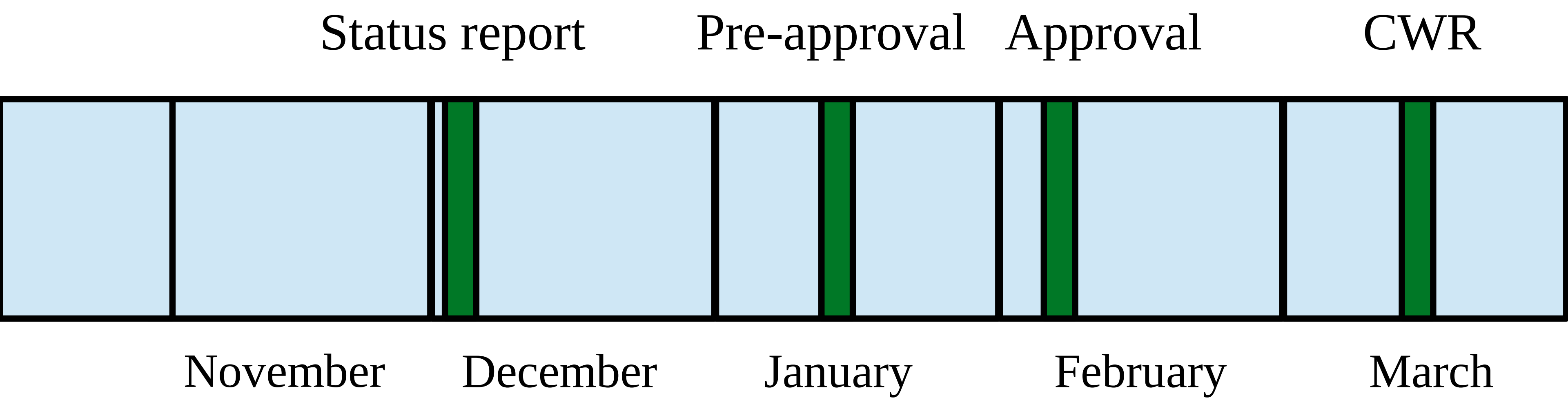
- The discrimination would come back if we could disentangle between neutrinos and Phi





Where are we now?

- CMS wants to publish the results of the whole 2016 dataset by Moriond 2017
- Upper limits starting to saturate already and no huge improvement is expected with more lumi
- Everything indicates that there won't be new intermediate publications or PASes after that
- The next chance to make a publication will be probably Moriond 2018 (or beyond)
- This gives us the following approximate schedule → really, really very tight



But there are more players in the game

- For the analysis of the 2016 dataset there are already 2 groups interested in this analysis
- We have University of Gant
  - They come with a carbon-copy of the analysis they have done for stop searches
  - They use MT2, however their cut MT2 > 100 GeV is probably too tight
  - Probably they won't be very competitive on the tough region (high mediator mass)
- We have also DESY
  - They have developed the top reconstruction mass
  - They have found something particularly useful (not completely unexpected though):
    - In signal events the top reconstruction and the ttbar recoil against MET are uncorrelated
    - Means that you can use the top reconstruction and apply there angular cuts!
- What is going to be our strategy? Collaboration? Confrontation? Specialization?

What do we have?

- Juan put together one analysis using 2015 data based on a neural network
- Analysis note ready and dedicated background prediction methods in place
- Performance of the ANN not really clear (correct me if I'm wrong)
- Background prediction methods put in place by Juan and Pupi
- We have also a working procedure to do the top mass reconstruction
- Current efforts based on the understanding of the performance of the ANN
- Cedric is also exploring other kinematic variables

My proposal (probably very ambitious)

- Perform the top mass reconstruction in order to get the 4-momentum of the 2 neutrinos
  - Splitting the MET in two components and sampling to get the best reconstruction
- Calculate in this way the approximate 4-momentum of the mediator
- Calculate the angular difference (phi) between the di-lepton system and the mediator
- Calculate the angular difference (eta) between the two tops (not clear it works)
- Use these variables in the neural network together with other variables:
  - The difference between Pt1 and Pt2 (to reject ISR jets)
  - Delta Phi between leptons (spin correlations for low mass scenarios)?
  - Other variables discovered by Cedric?

This proposal opens a way to collaborate with DESY since they could be the providers of the top mass reconstruction (even if we have our own).
The risk is that in the end a cut-based on those variables is already quite good...

Timeline I

- If we assume that we have to give a status report on the 7th of December we have 6 weeks

Week 1 (the technical week)

- Synchronize framework between Cedric and Juan
- Ensure we can produce plots in “minutes” (minitrees)
- Synchronize baseline selection
- Summary of new variables inspected by Cedrid
- Neural network and top reconstruction in place
- Meeting on Friday to see the checklist

Week 2 (reference + top reconstruction)

- Check the S/sqrt(B) with cuts in DeltaPhi and MET
- Check the S/sqrt(B) adding also Cedric's cuts
- Work in the top reconstruction algorithm
- Check the S/sqrt(B) adding top-based variables
- Meeting on Friday to see the checklist
- Decide which variables are the most useful

Timeline II

➢ If we assume that we have to give a status report on the 7th of December we have 6 weeks

Week 3 (data + the neural network)

- Start doing detailed comparisons data/MC
- Take the best ranked variables and apply the ANN
- Evaluate S/sqrt(B) of the final discriminator
- Meeting on Friday to see the checklist
- Decision: Several regions for several points?

Week 4 (background prediction)

- Revive the background prediction methods
- Perform CLOSURE TEST in MC
- Check systematics in detail
- Meeting on Friday to see the checklist
- Decide which variables are the most useful

Timeline II

- If we assume that we have to give a status report on the 7th of December we have 6 weeks

Week 5 (Interpretation + AN)

- Start writing an Analysis Note with partial results
- Setup all the code for setting upper limits
- Estimation of systematic uncertainties in signal
- Ask for status report to the EXO conveners

Week 6 (contingency)

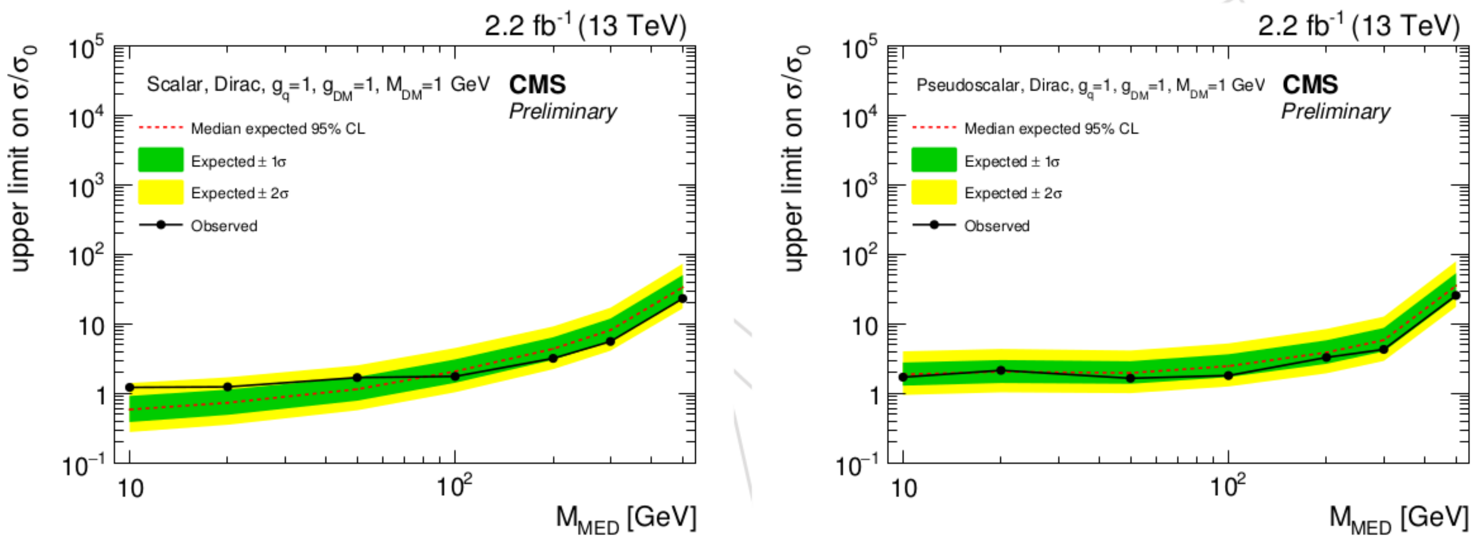
Conclusions

- Most likely our competitors will have the analysis ready in about ~ 6 weeks
- It's a very tight schedule and we need to decide if we want to make the effort or not
- If we do it we need to synchronize, focus and follow a plan (this or whatever)
- My proposal is to profit of the top reconstruction to perform more effective cuts
- And put that together with the ANN
- This opens maybe a possibility of collaboration with DESY

Backup

A side note for the future

- As I side note I just would like to comment on the relative potential of this analysis
- If we look at the combined 0-lepton, 1-lepton and 2-lepton upper limits we can see that the 2-lepton analysis is not really competitive anywhere in the mass spectrum



(a) scalar (b) pseudoscalar

Figure 4: The observed and expected limits, expressed as the ratio of the 95% C.L. upper limit on DM production cross section to the cross section from simplified model expectations for 4a scalar and 4b pseudoscalar models in the combination of dileptonic, semileptonic, and hadronic channels.