HH non-resonant searches at future pp colliders
with SNOWMASS Campaign

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UCLouvain

Higgs Self Couplings: Measurements at Future proton-proton Collider

LoI: SNOWMASS21-EF1_EF2-196

- Experimentalists
  - P. C. Bhat, L. Cadamuro, A. Canepa, C. Caputo, N. De Filippis, D. F. Guerrero Ibarra, E. Koenig, J. Konigsberg, I. Margjeka, P. Merkel, F. Ravera, S. R. Rosenzweig, A. Taliercio, P. Vischia **P. Mastrapasqua**

- Theorists
  - S. Baum, M. Carena, C. Gao, S. Gori, H. Haber, P. Huang, Z. Liu, I. Low, N. Shah, C. E. M. Wagner

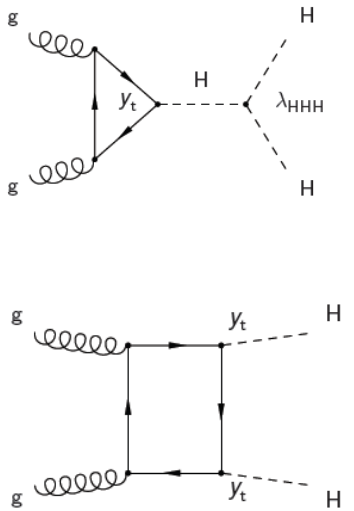
Physics Motivation

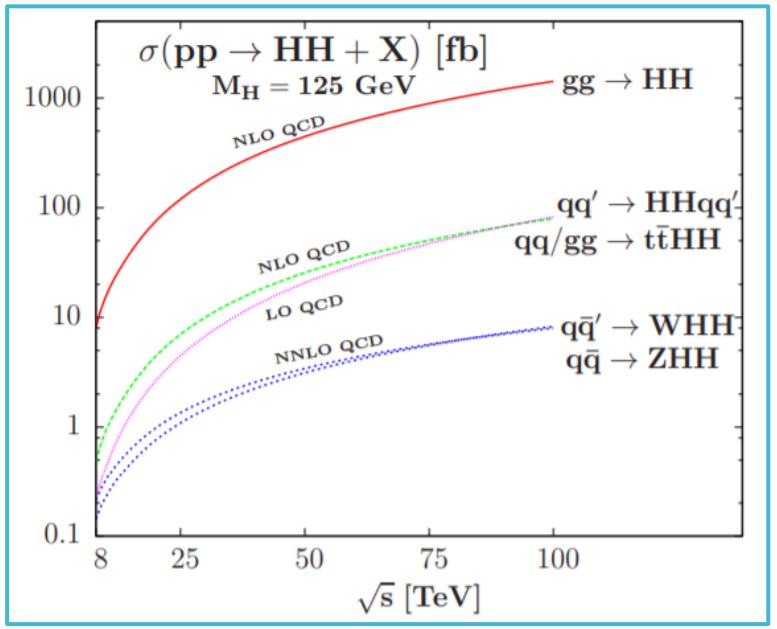
- **Study Higgs potential**: $V_{SM} = -\frac{m_h^2}{2}h^2 - \lambda v h^3 - \frac{\kappa}{4}h^4$
- **Test SM** + **Probe BSM theories** as predict sizeable effects on λ
- λ estimate → measurement of non-resonant Higgs pair production
- At 14 TeV expected ~ 37 fb → **3 orders of magnitude** smaller than single Higgs production
- More ambitious than the discovery of Higgs itself!

Trilinear coupling

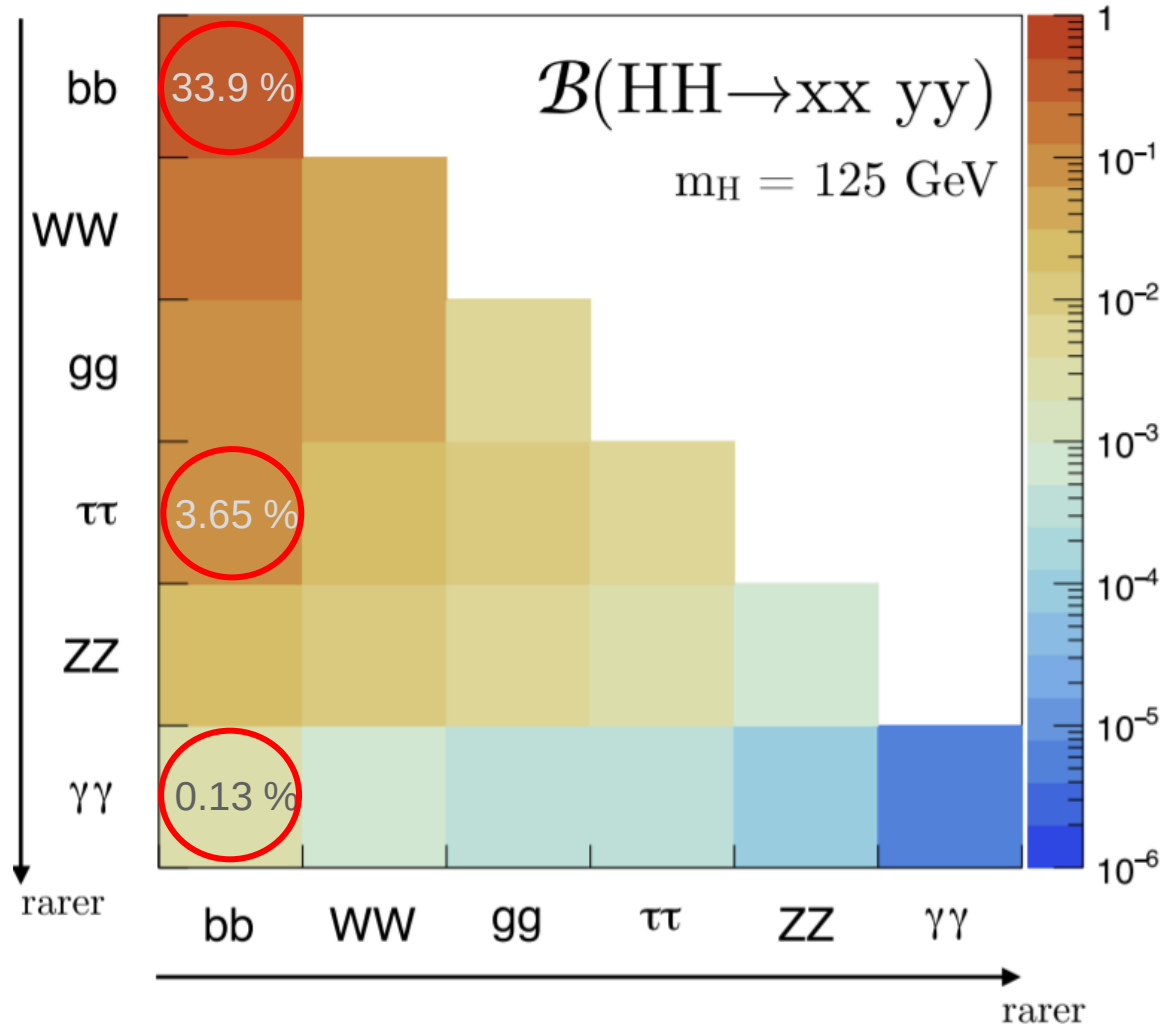
$$\lambda = \frac{m_h^2}{2v^2}$$

LO SM Feynman diagrams





Di-Higgs decays



$b\bar{b}b\bar{b}$ → highest BR, all objects can be reconstructed, lack of object convenient to trigger on, high QCD and tt bkg

$b\bar{b}\tau\tau$ → medium BR, easy to trigger, relatively low background

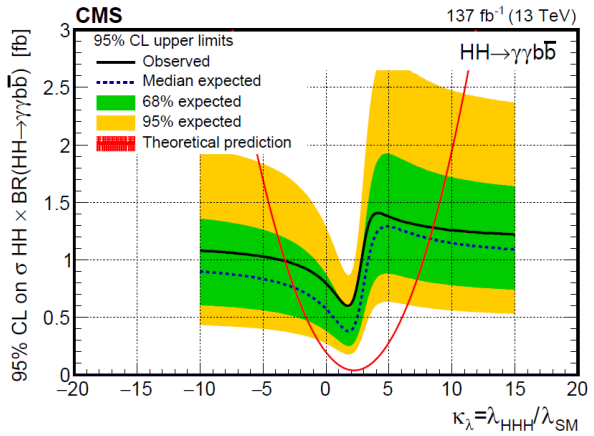
$b\bar{b}\gamma\gamma$ → highest purity, all objects can be reconstructed, very low BR

Di-Higgs in LHC Run-2 by CMS

- HH → $b\bar{b}\gamma\gamma$

  Observed (expected) 95% CL upper limit:

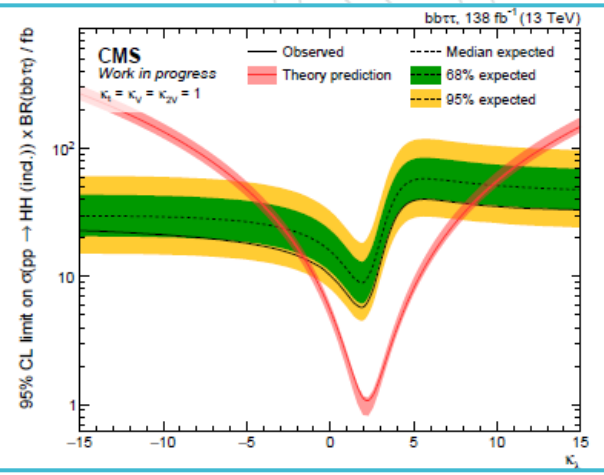
  σ/σ_{SM} = 7.7 (5.2), -3.3 (-2.5) < κ_λ < 8.5 (8.2)



- HH → $b\bar{b}\tau\tau$

  Observed (expected) 95% CL upper limit:

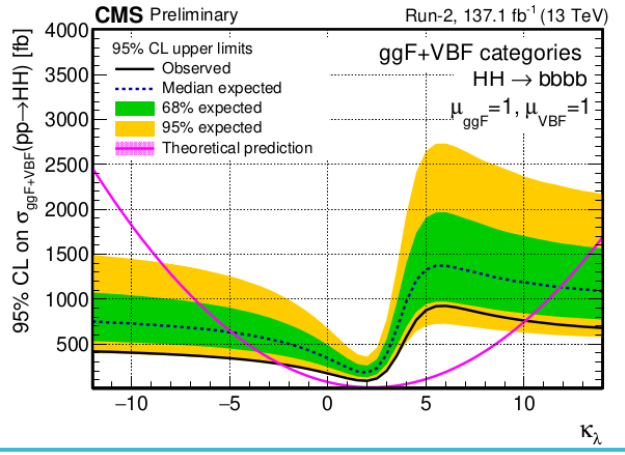
  σ/σ_{SM} = 3.3 (5.1), -1.5 (-2.8) < κ_λ < 8.5 (9.7)



- HH → $b\bar{b}b\bar{b}$

  Observed (expected) 95% CL upper limit:

  σ/σ_{SM} = 3.5 (7.2), -2.5 (-5) < κ_λ < 10 (12)



Work plan

Research goal: study of the three channels at HL-LHC (14 TeV) and at future pp colliders for 28 and 100 TeV center of mass energy

What we have done so far: perform analysis of the three channels in parallel at HL-LHC 14 TeV, 3000 fb-1 (see next slides)

Framework: Bamboo analysis framework (see next slide)

Basic idea: Baseline analysis of Run-2 + new machine learning technique to optimize the study + combination of all channels

Timeline: we plan to finalize the study of the three channels and combine the results for HL-LHC, then proceed with the other future collider scenarios (end date by March)

A quick view on Bamboo (docs here)

- Analysis framework based on RDataFrame in python
- Used in several CMS analyses that adopt NanoAOD
- Goals:
  1. avoid the black box effect
  2. analysis code as simple and compact as possible
  3. be as fast as possible → turnaround of a few hours for O(100) plots (thousands of histograms) of the CMS Run2 data on a batch system
- Main ingredients:
  1. High-level python analysis code to define plots and selections
  2. Decorated version of the input TTree: an event looks like a set of containers of physics objects (jets, leptons, tracks etc.) and (groups of) per-event quantities
  3. Expressions (selection, weight, variable) are composed of simple python objects, built from decorators, and decorated to behave as a value
  4. When the analysis is complete: convert expressions to strings for RDataFrame, run over all samples, and make plots

What we have done so far: $HH \rightarrow b\bar{b}\gamma\gamma$

Upcoming step

Kinematic preselection
Diphoton ($\gamma\gamma$) and dijet (jj)candidates

ttH tagger
(similar topology to sig)

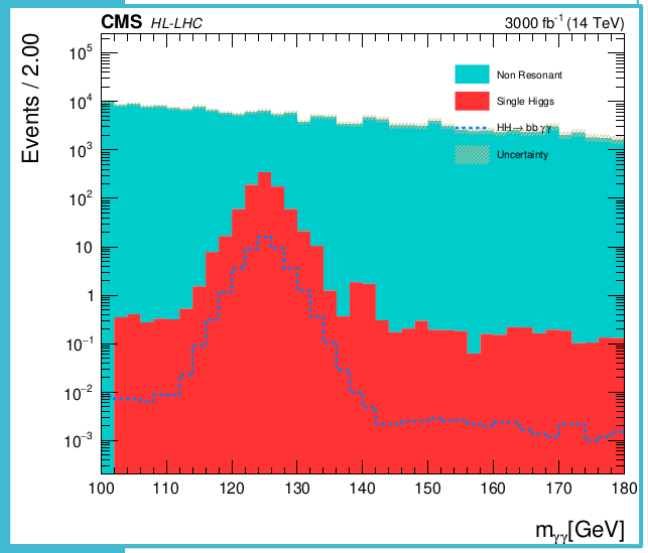
Global DNN
(sig VS all other bkg)

Event classification
according to $jj\gamma\gamma$ invariant mass and global dnn score

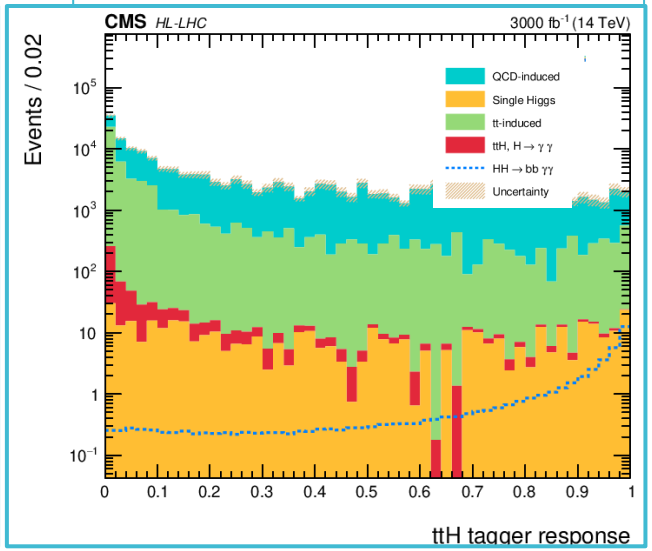
Simultaneous fit
of dijet and diphoton invariant mass in each category

Extraction of significance
through Combine framework

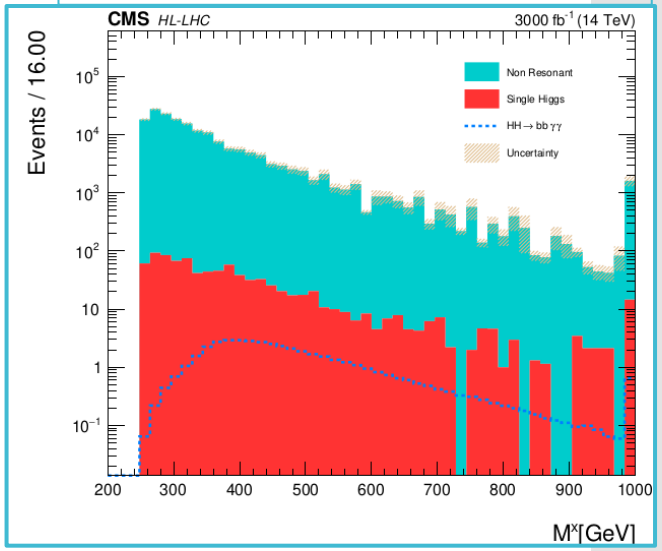
~45 sig events after preselections



95% sig eff. – 15% ttH/tt-bkg cont.



$M_x = M_{jj\gamma\gamma} - M_{\gamma\gamma} - M_{jj} + 250$ GeV



What we have done so far: HH → $b\bar{b}\tau\tau$

Upcoming step

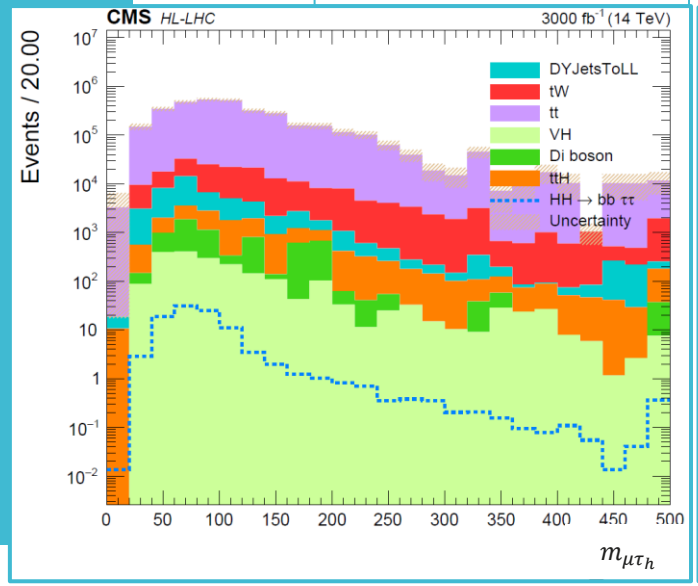
Event selection
Ditau ($\tau\tau = \mu\tau_h, e\tau_h, \tau_h\,\tau_h$) and dijet ($jj$) candidates

Training of MVA classifier
One for each considered final states

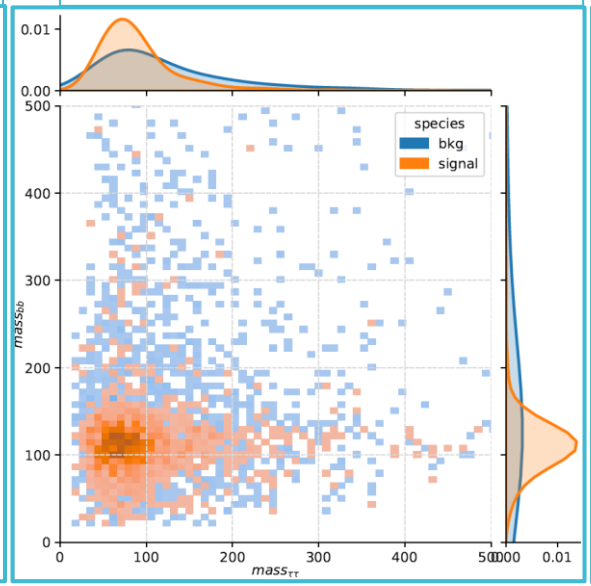
Simultaneous fit
of MVA discriminator distributions for the three considered final states

Extraction of significance
through Combine framework

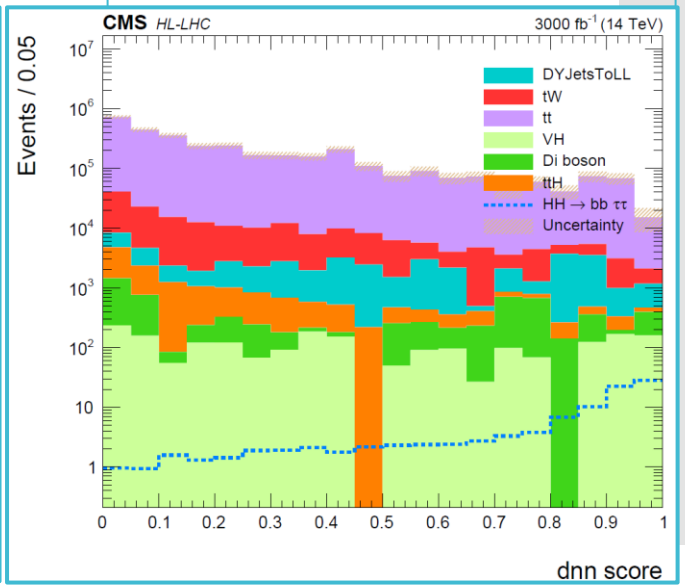
~100 sig events $\mu\tau_h$
~ 68 sig events $e\tau_h$
~ 60 sig events in $\tau_h\tau_h$



$m_{bb}, m_{\tau\tau}$ normalized to 1 in $\mu\tau_h$ cat.



AUC ~ 90%
good discrimination against main bkg



What we have done so far: HH → $b\bar{b}b\bar{b}$

Upcoming step

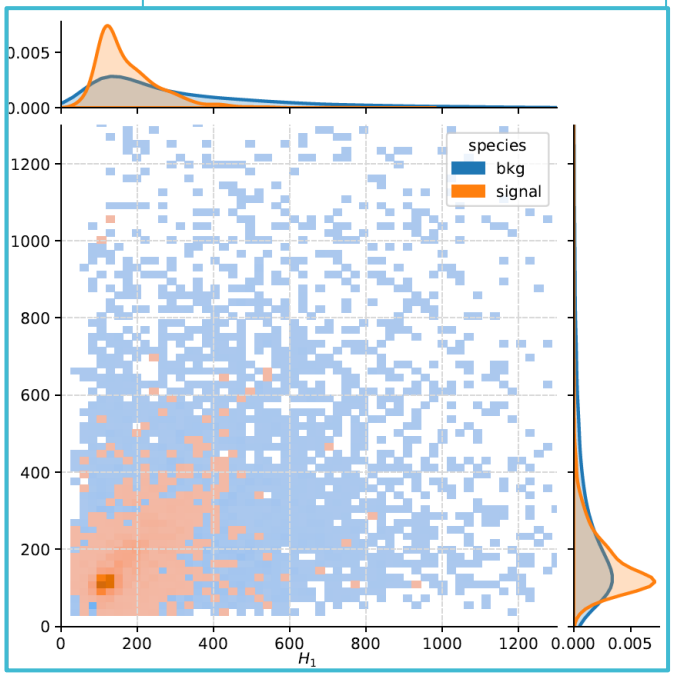
Event selection
four jets are paired in the two Higgs candidates minimizing $|m_{H_1} - m_{H_2}|$

Training of MVA classifier

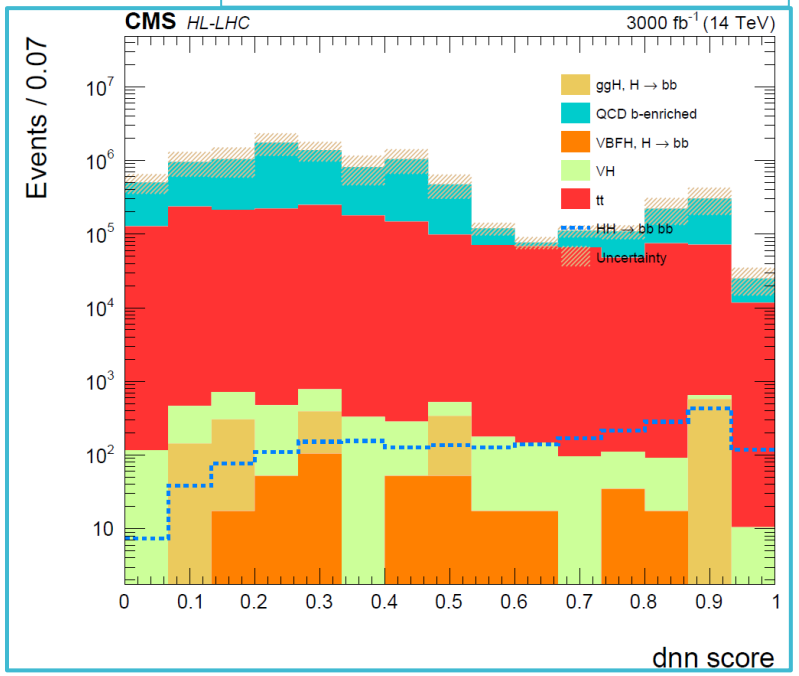
Fit
of the MVA discriminator distribution

Extraction of significance
through Combine framework

$m_{H_1} m_{H_2}$ normalized to 1



AUC ~ 80%
good discrimination against main bkg



Summary & Future plans

☑ All analyses are started and in a good shape → detailed presentations in the next meetings

\+ Investigate other center of mass energy and finalise the analyses

? Up to now we are using private samples → access to snowmass one?

🕐 Group deadline to meet?

THANKS!

Any questions?