

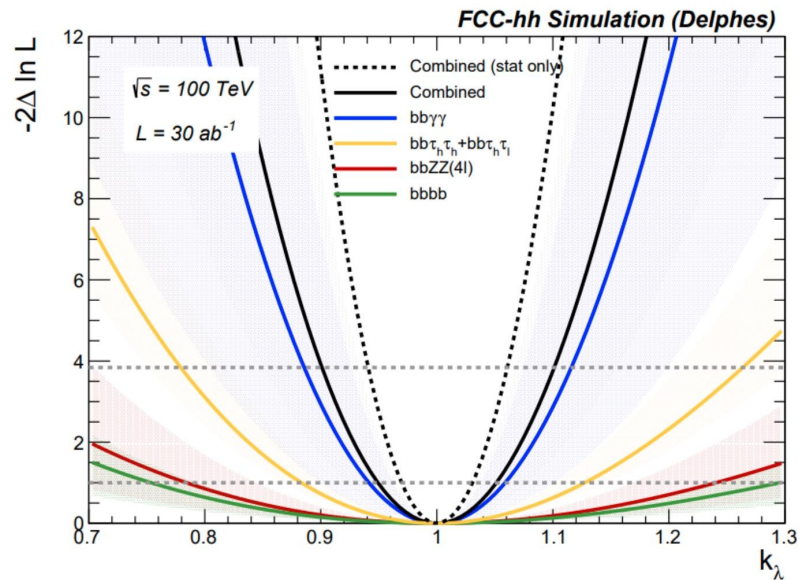
FCC-hh di-Higgs bbtatau

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The Physics

- Studies on HH at FCC include:
 - HH \rightarrow bbbb channel
 - HH \rightarrow bb $\tau\tau$ channel
 - HH \rightarrow bby γ channel
- Focus on full hadronic bb $\tau\tau$ channel
 - Lephad channel ready but need to verify numbers

	bb	WW	$\tau\tau$	ZZ	$\gamma\gamma$
bb	34%				
WW	25%	4.6%			
$\tau\tau$	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
$\gamma\gamma$	0.26%	0.10%	0.028%	0.012%	0.0005%

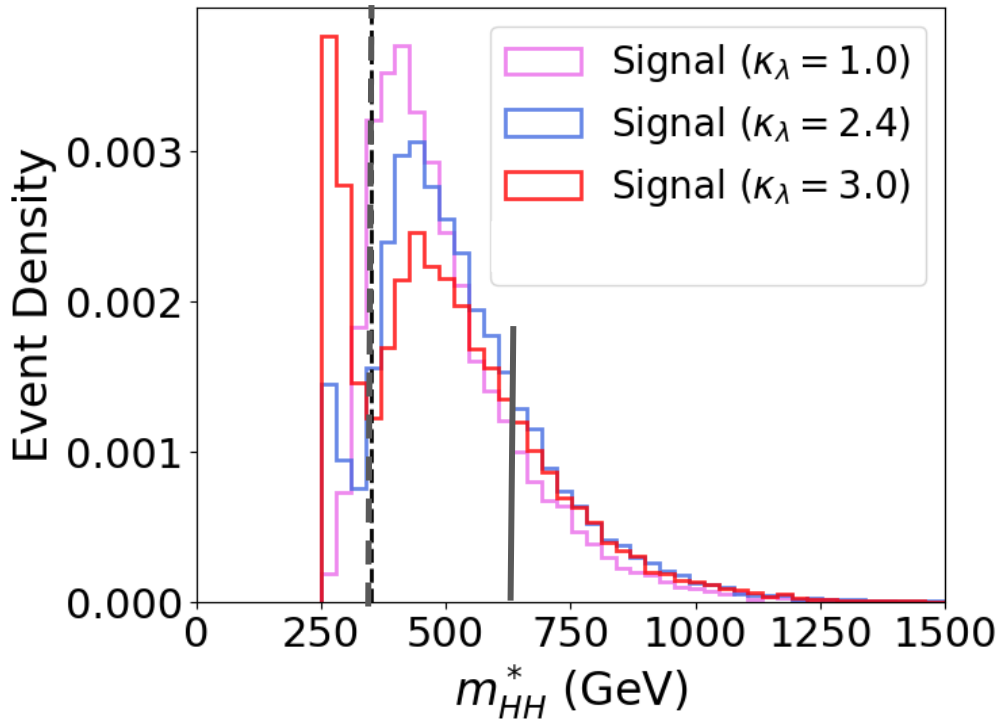


Analysis overview

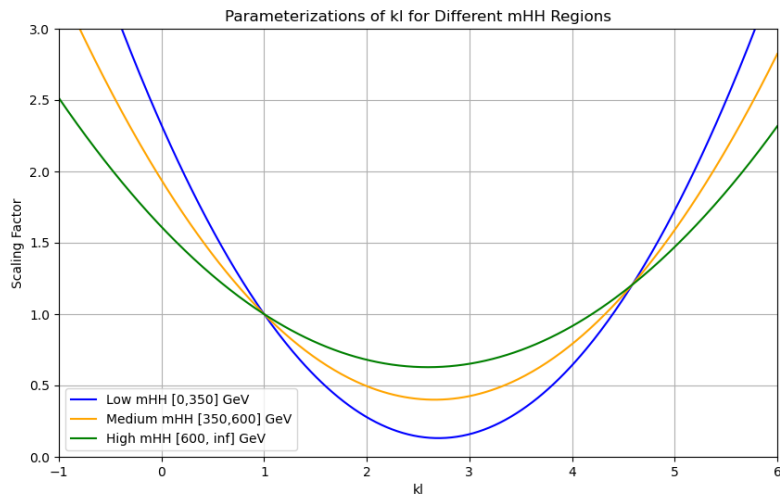
- Train a GNN to discriminate background from signal
 - tt di-leptonic as background, used for background estimation
 - Scale up background to account for missing contributions
- Create 3 regions based on $m_{HH^*} = M_{HH} - m_{tt} - m_{bb} + 250$
 - [<350 , $350 < 600$, >600]
- In each region create histogram of the GNN score for signal and background.
- Fit κ_{λ}
- More information can be found in previous update: <https://indico.cern.ch/event/1523755/#4-bbtautau-status-update>
- Note available here: <https://repository.cern/records/d1a0b-6x721>

Categorization in m_{HH}^*

- $m_{HH}^* = m_{HH} - m_{bb} - m_{tt} + 250$
- m_{HH}^* spectrum changes under the strength of the self-coupling
- Use 3 regions to increase sensitivity
- Estimate κ_λ dependency in each m_{HH}^* region



Mhh category splitting



We have 3 different categories:

- mHH_low [0,350]
- mHH_med [350,600]
- mHH_high [600, inf]

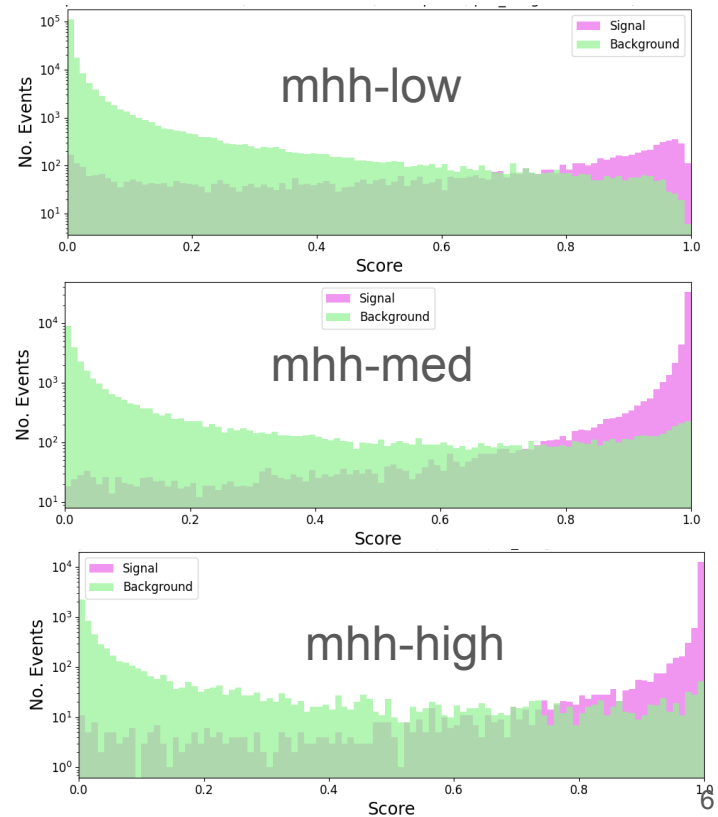
Three regions will remove redundancy in lambda

KI extraction: GNN score distributions (SM)

Good separation between background and signal in all regions :

- mhh*-low binning:
[0.8,0.9,0.95,0.98]
- mhh*-med binning:
[0.9,0.95,0.99,0.995,0.997,0.999]
- mhh*-high binning:
[0.9,0.97,0.99,0.997]

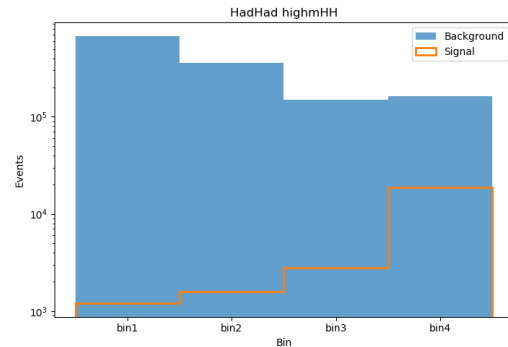
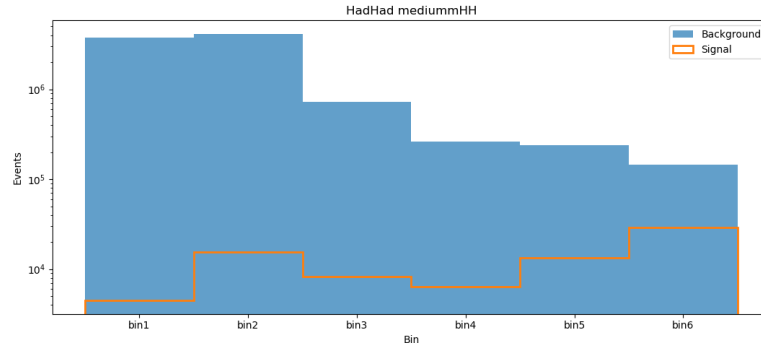
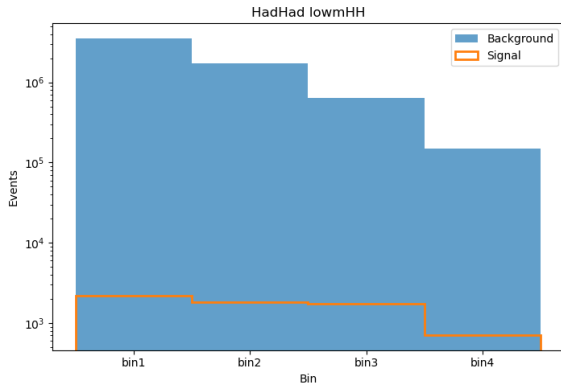
Not including too low scores to reduce extrapolation uncertainties from low GNN scores to high GNN scores



Binned histograms in fit

Binning:

- mhh*-low binning: [0.8,0.9,0.95,0.98]
- mhh*-med binning: [0.9,0.95,0.99,0.995,0.997,0.999]
- mhh*-high binning: [0.9,0.97,0.99,0.997]



KI extraction: Systematic uncertainties

Uncertainties	Scen I	Scen II	Scen III
Lumi	0.5%	1%	2%
Btagging (total)	1%	2%	4%
tau ID (total)	1%	2%	4%
Bkg uncertainty (lnN) cross-section	1% in all bins (1NP)	1% in all bins (1NP)	1% in all bins (1NP)
bkg uncertainty (lnN) region unc	1% all bins (1NP per region)	3% all bins (1NP per region)	5% all bins (1NP per region)
Bkg uncertainty (lnN) shape	Linear shape up to 2% in last bin (1NPs)	Linear shape up to 3% in last bin (1NPs)	Linear shape up to 5% in last bin (1NPs)
BKG uncertainty (lnN) last bin	1% in last bin (3NPs)	2% in last bin (3NPs)	4% in last bin (3NPs)

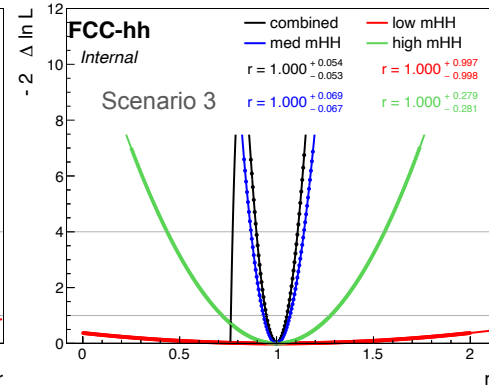
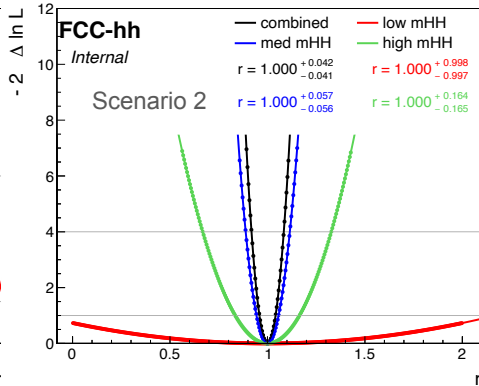
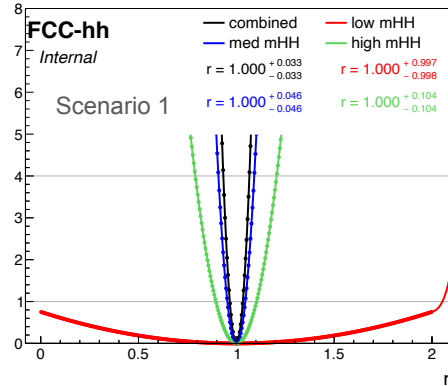
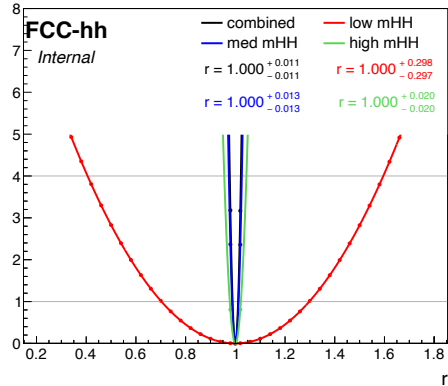
More information on background uncertainties on next slide. We can debate about their size.

Background uncertainties

- Cross-section uncertainty (1NP):
 - Will come from a data driven CR which will be statistically limited → 1% correlated in each bin for all scenarios
- Region uncertainty (3NP):
 - Will change the overall yield in 1 region. Incorporates differences between control region and signal region (usually a few percent)
- Linear shape uncertainty (3NP):
 - Incorporates both experimental effects, tau/jet energy-scale for example, or Modelling uncertainty of showering
 - Generally shifts events from lower GNN scores to higher GNN scores
 - Correlated between regions → but could be uncorrelated between regions?
- Finally 1 uncertainty that only affects last bin of GNN in each region to incorporate MC-stat and other effects that mimic a bbtatau signal (1NP per region)
 - usually a few percent as well

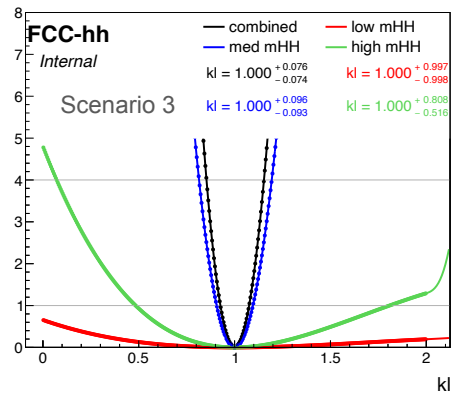
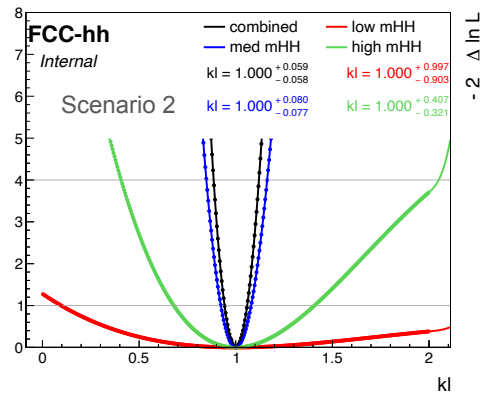
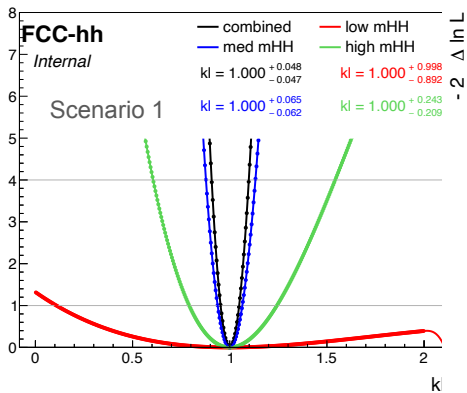
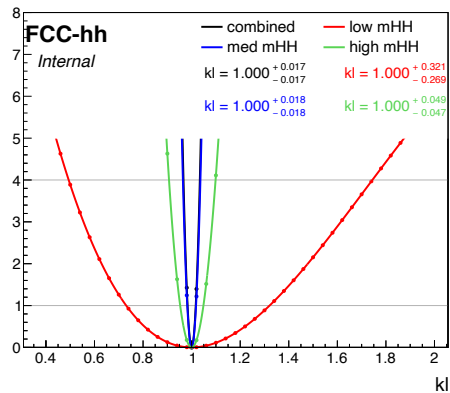
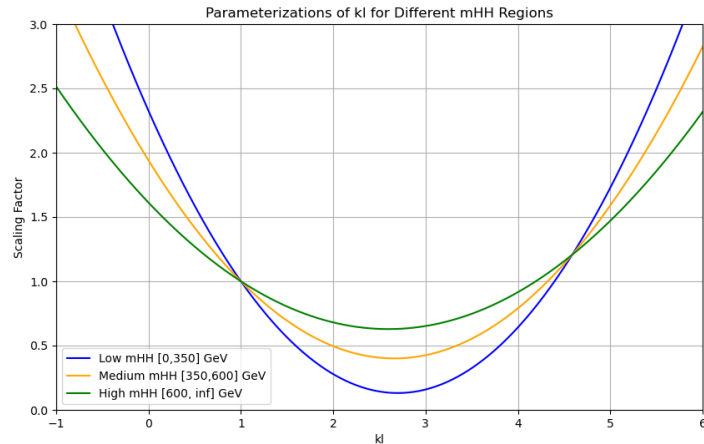
Fit on signal strength (r)

- Can measure r both combined and in each individual channel
 - Might be interesting for EFT fits
- Good sensitivity in med/high mHH region. Limited sensitivity in low mHH
- Add uncertainty to medium second to last bin as well? [$r=6(7)\%$ for scenario 1(2)]
- Systematics start to dominate uncertainty



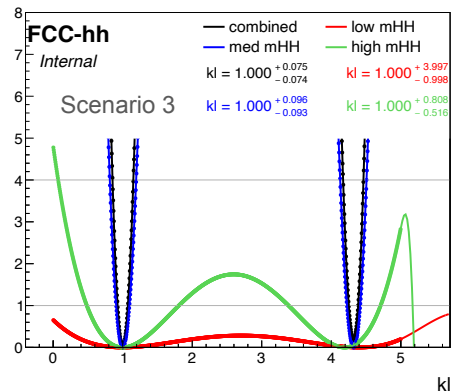
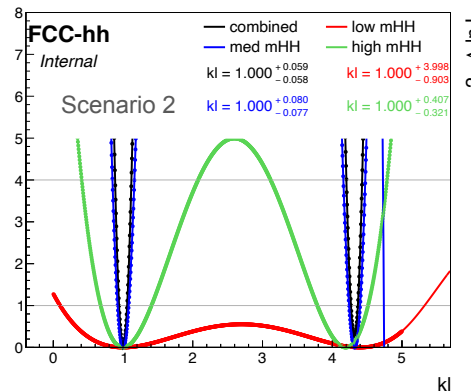
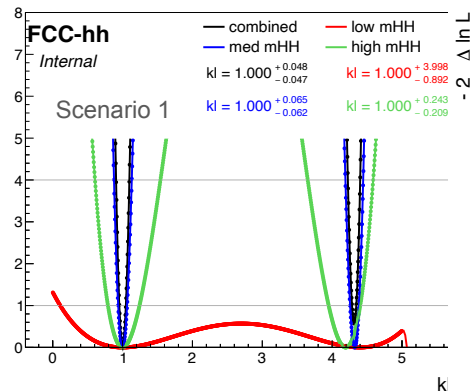
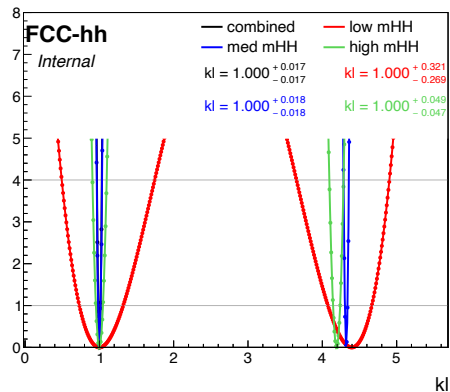
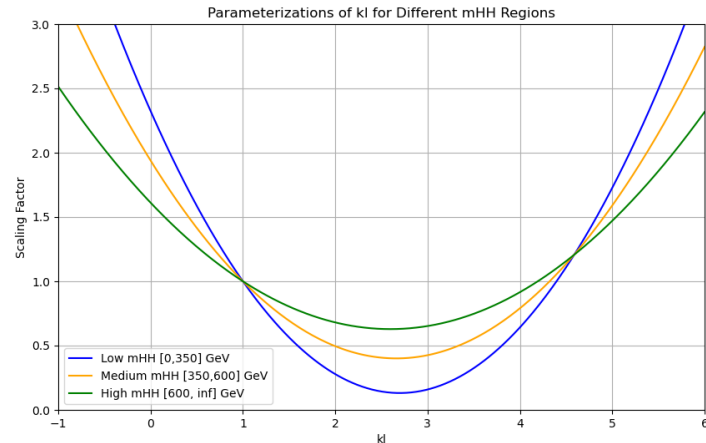
Fits for kLambda

- KL sensitivity mostly from medium mHH category
 - There is a second minimum for kl around 4.5
→ lets zoom out

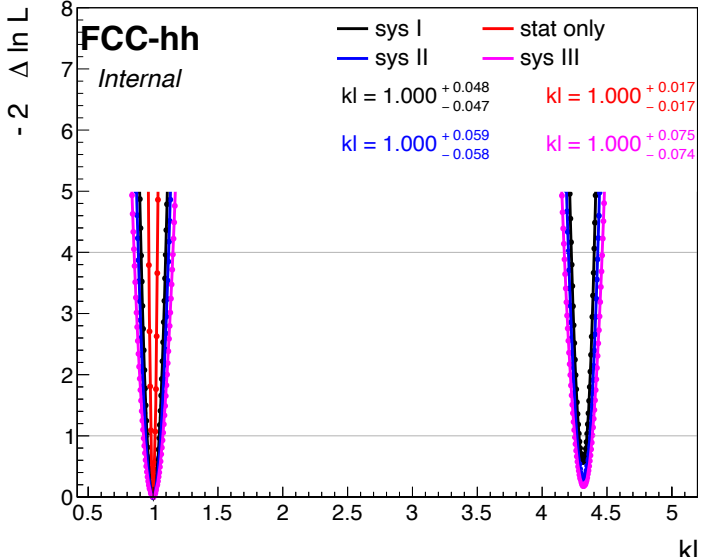
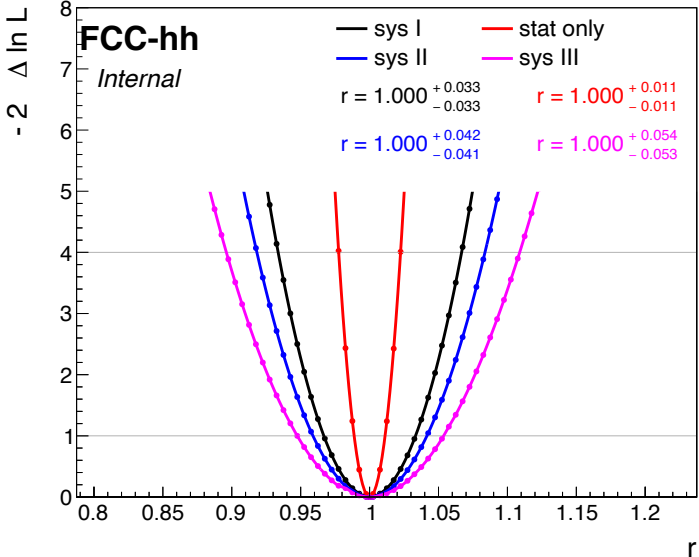


Fits for kLambda

- KL sensitivity mostly from medium mHH category
 - There is a second minimum for kl around 4.5
 - Statonly fit able to resolve double minima from different kl dependency in different regions
 - For higher uncertainties these double minima get

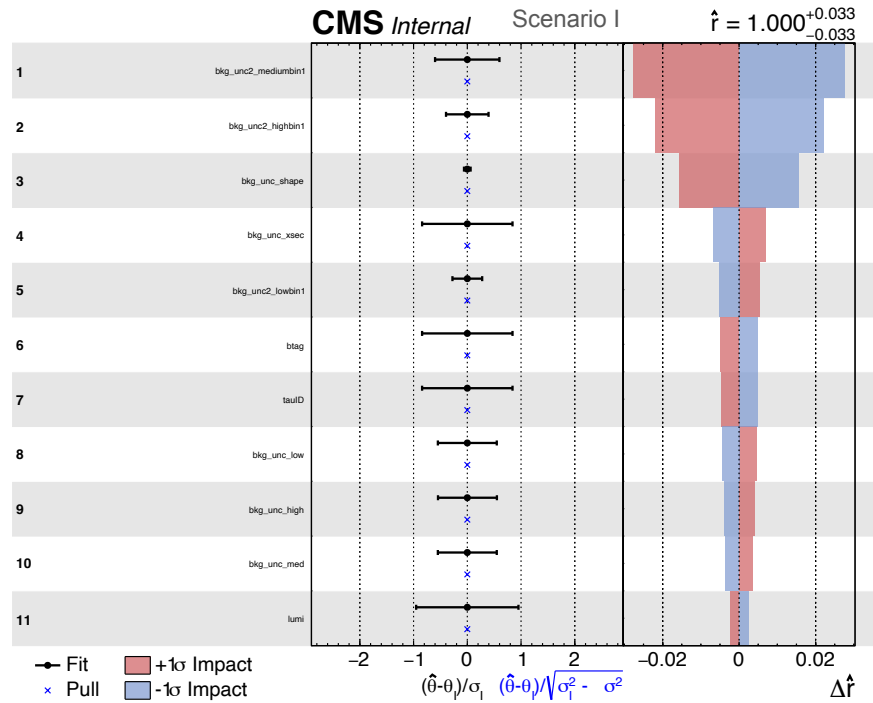


Summary plots



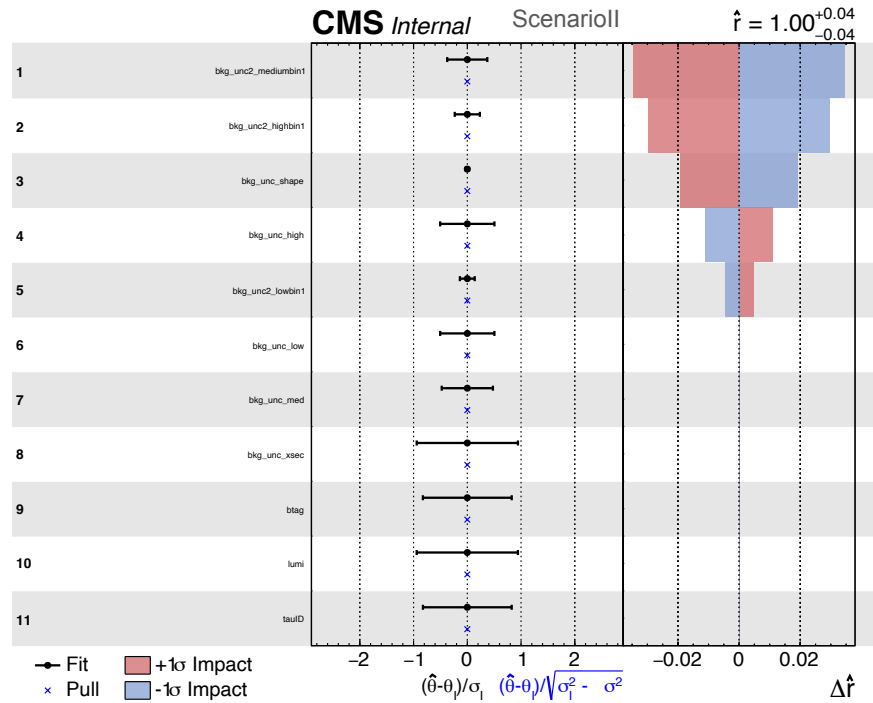
Rankings scenario I (r)

- Reasonable constraints apart from linear (correlated) bkg unc shape



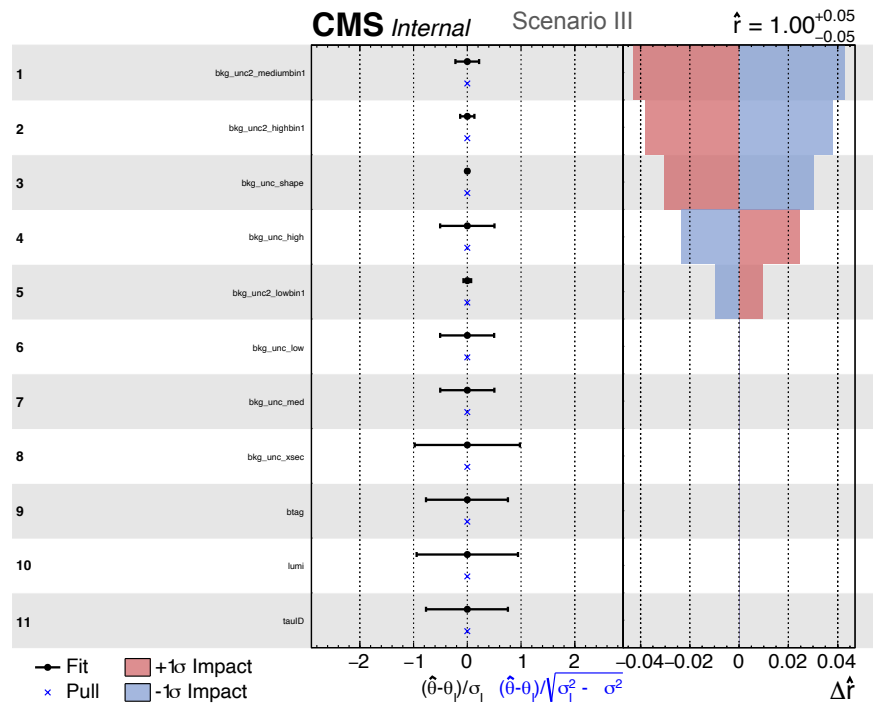
Rankings scenario II (r)

- Reasonable constraints apart from linear (correlated) bkg unc shape



Rankings scenario III (r)

- Reasonable constraints apart from linear (correlated) bkg unc shape



Summary and ongoing work

- Fits with systematics result in uncertainty within $r\pm 8\%$, $k\pm 10\%$
- Any new systematic scenario's can be easily implemented
 - Added systematic on bkg modelling in last bin
- LepHad channel is ready but still need to do fit (~ 1 day)
- Work on a bbgg+bbtt combination

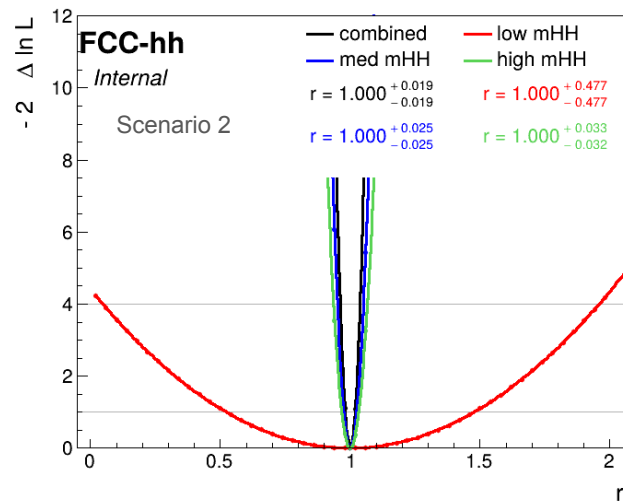
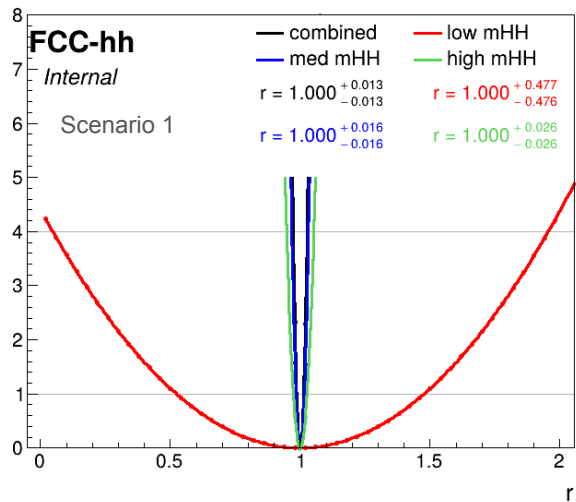
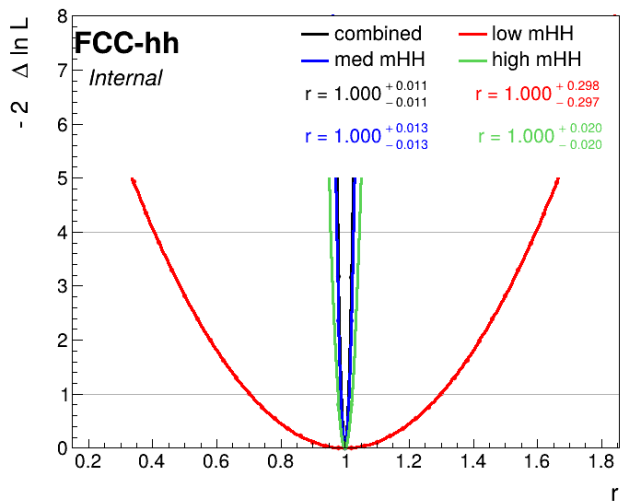
Publication plans and documentation:

- Samples/Selections/GNN already documented in Note: <https://repository.cern/records/p8y5f-23w42>
- Need to consolidate results with systematics
- Combined publication with bbgg?
 - Would also be happy with bbtt stand-alone publication

Backup

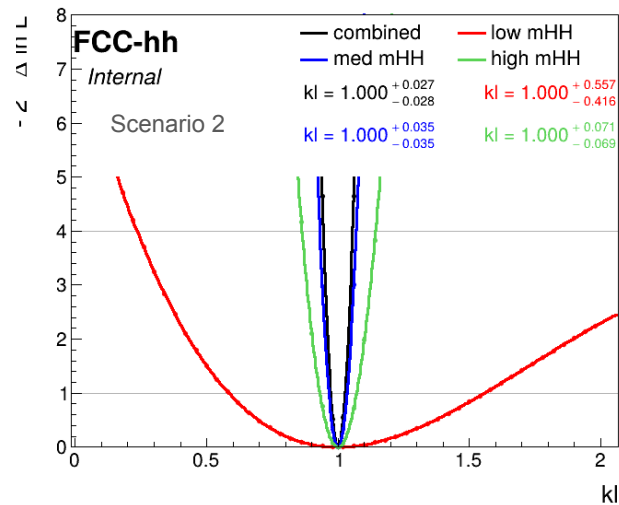
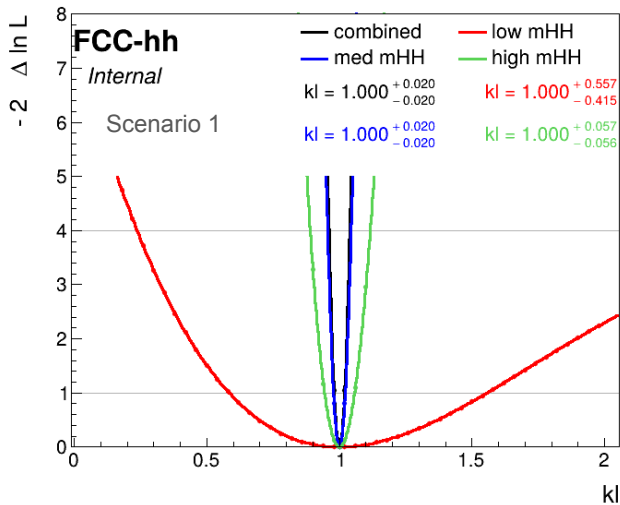
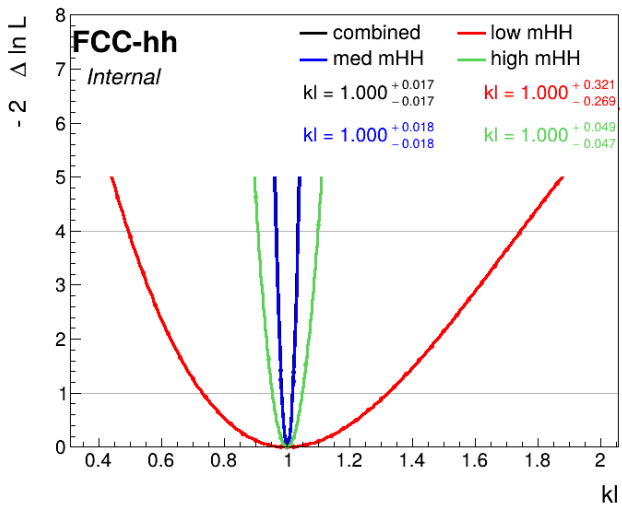
Fits for xsec parameter (r)

- Can measure r both combined and in each individual channel
 - Might be interesting for EFT fits
- Good sensitivity in med/high mHH region. Limited sensitivity in low mHH
- Systematics start to dominate uncertainty



Fits for kLambda

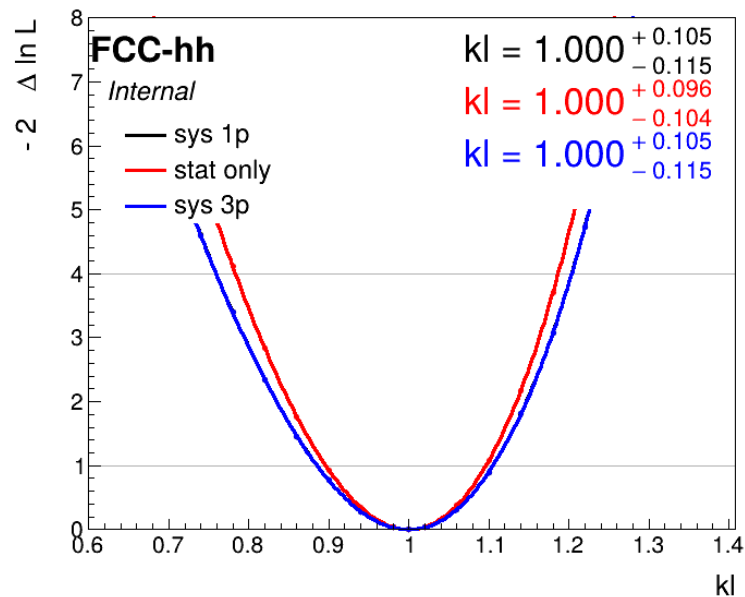
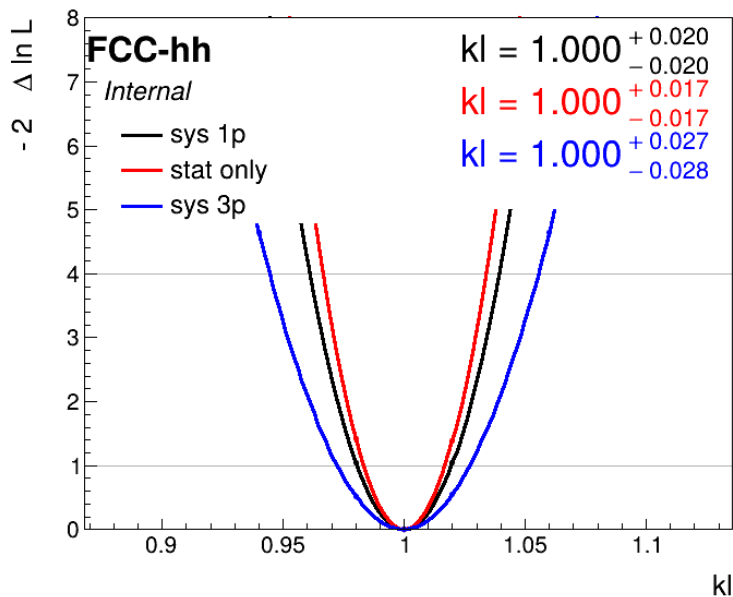
- KL sensitivity mostly from medium mHH category
 - Need multiple regions to get rid of redundancy @kl=4.5



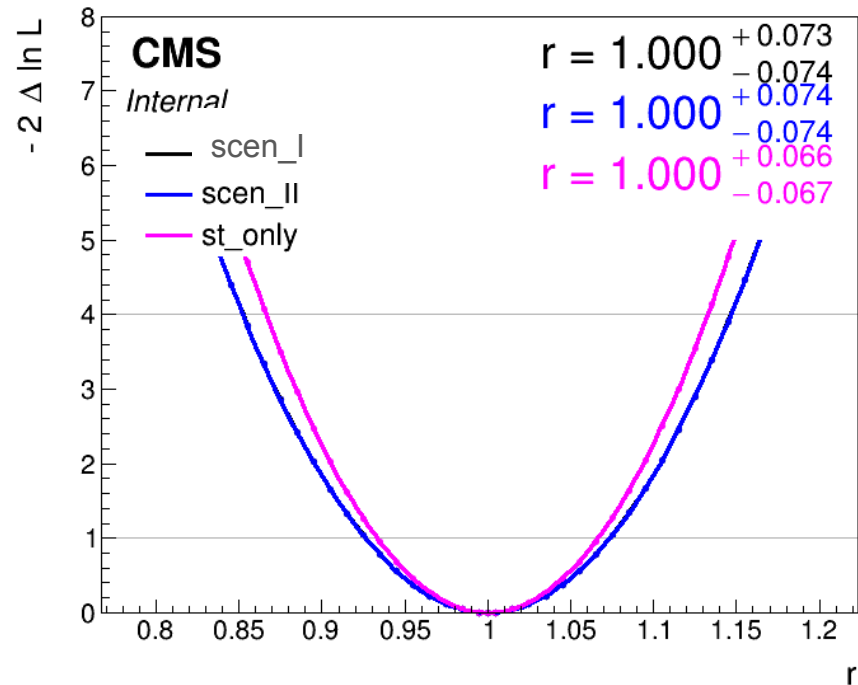
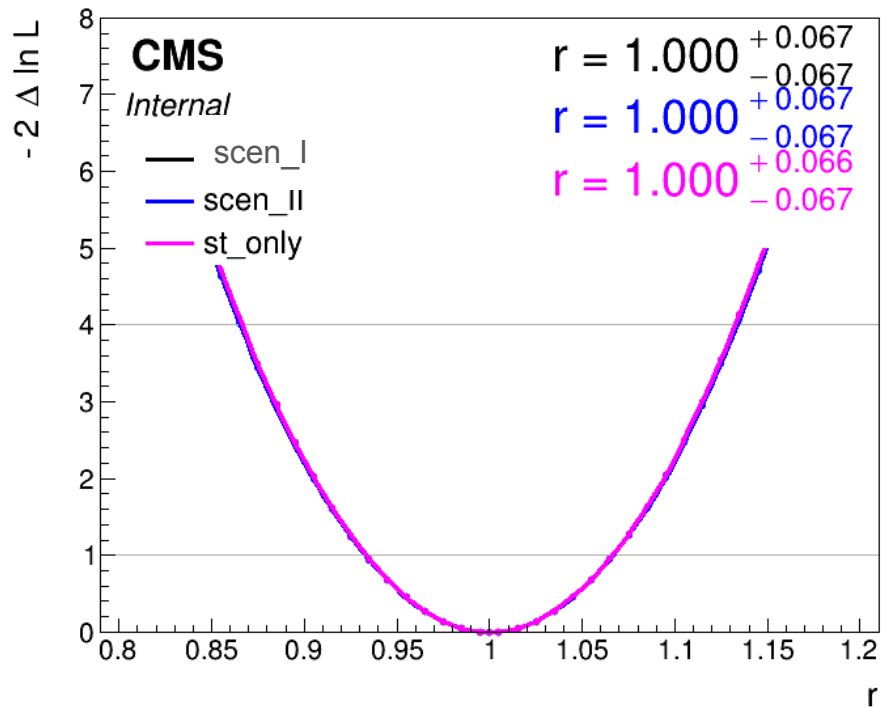
Fit for k-lambda floating r

Floating r in the fit to estimate sensitivity from shape of mHH*

→ Shape of mHH* usually less sensitive to systematics

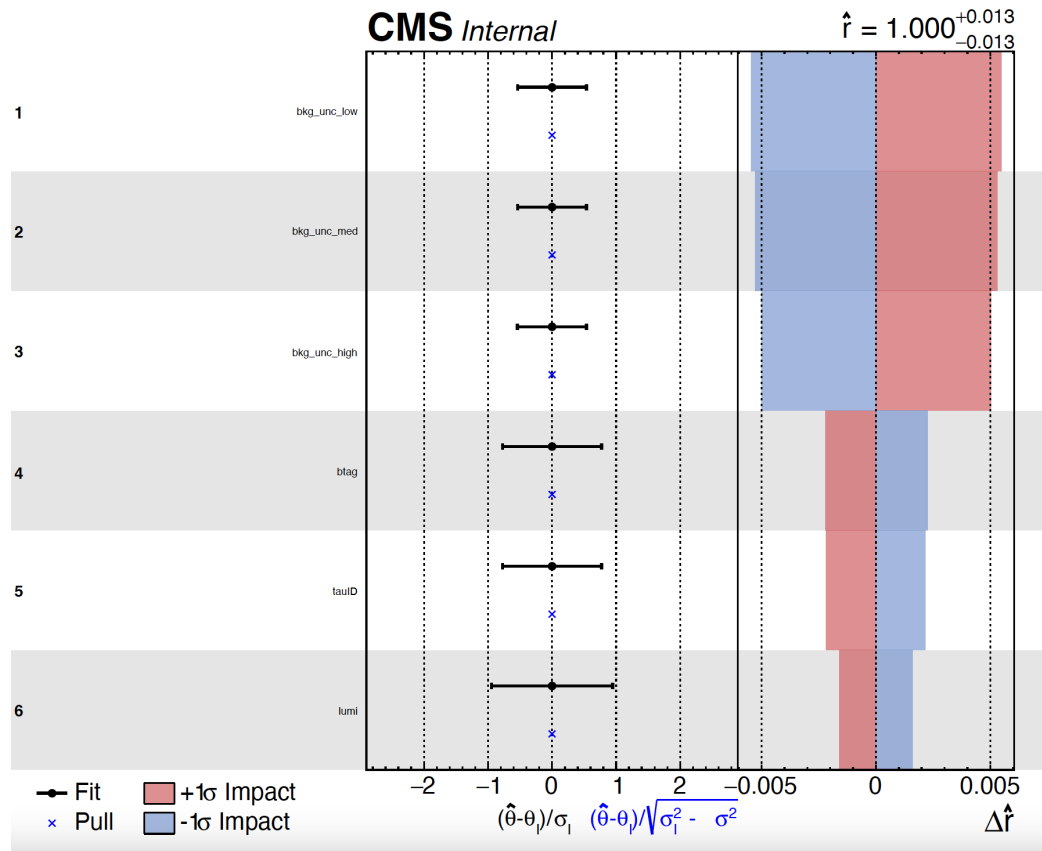


r extraction: Sensitivity results



*bkg unc applied not only to the last bin₂₂

Old setup constrained btag/lumi and tau



Comparing distributions for different gnn bins

GNN picks out regions where signal and background are more similar

Distributions between lowest bins and slightly higher GNN scores similar

Justifies the lower GNN score events to use for constraining background in fit

