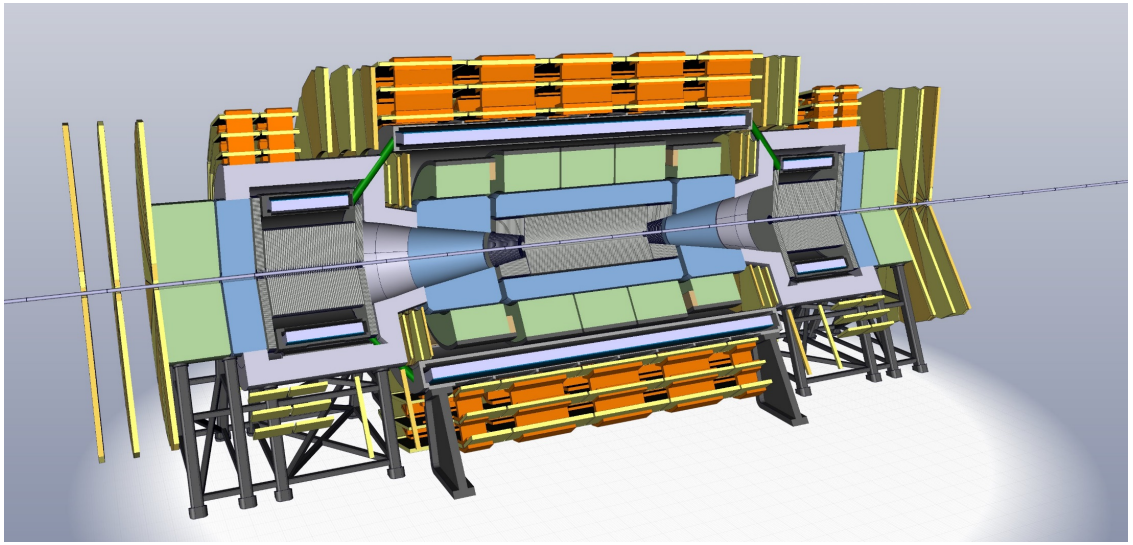
FCC-hh

Update on FCC-hh physics analyses

Heather Gray, Filip Moortgat, Michele Selvaggi (CERN)



Physics Analysis Meetings

We started a new series of informal “physics analysis” meetings dedicated to discussing progress of 100 TeV physics studies in view of the 2018 CDR

First Meeting was on February 21st

https://indico.cern.ch/event/613195/

30-40 people attended, summary will follow.

Next meeting: March 27th at 2pm

https://indico.cern.ch/event/618771/

Reminder

How to get started on 100 TeV Physics studies?

- Pick a topic from the list of 100 TeV Physics Benchmarks:

See Heather's talk at the last meeting

- Follow the FCC Pythia + Delphes + Heppy tutorial (Michele Selvaggi):

http://fccsw.web.cern.ch/fccsw/tutorials/fcc-tutorials/FccFullAnalysis.html

- Check the MC event database (Clement Helsens):

http://fcc-physics-events.web.cern.ch/fcc-physics-events/index.php

First meeting agenda

16:00 → 16:15 **Introduction** 15m

Speakers: Filip Moortgat (CERN) , Heather Gray (LBNL)

FCC_Analysis_Meeti...

16:15 → 16:30 **Status Report on HH->bbgg** 15m

Speaker: Michele Selvaggi (CERN)

hhbbaa_status_210...

16:30 → 16:50 **Invisible Higgs at 100 TeV** 20m

Speaker: Philip Coleman Harris (CERN)

PCH_DMExp100TeV...

16:50 → 17:05 **Stop search at 100 TeV** 15m

Speaker: Owen Robert Colegrove (Univ. of California Santa Barbara (US))

FCC_2_21_UCSB.pdf

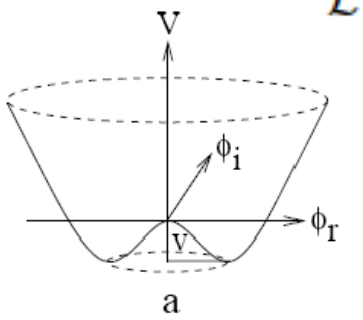
17:05 → 17:20 **Studies on Top FCNC and Charged Higgs Searches at FCC-hh** 15m

Speaker: Orhan Cakir (Ankara University (TR))

Study_V07.pdf

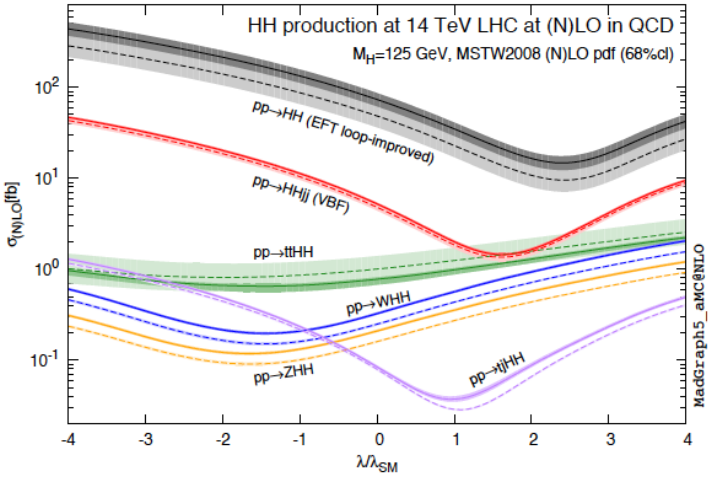
30-40 people attending

HH to bbgg



$$\mathcal{L} = -\frac{1}{2}m_h^2 h^2 - \lambda_3 \frac{m_h^2}{2v} h^3 - \lambda_4 \frac{m_h^2}{8v^2} h^4$$

In SM: $\lambda_3 = \lambda_4 = 1;$



Golden Channel: pp → HH → bbγγ

- Detailed study performed already in 2016
  - results obtained with *Contino, Panico, Papaefstathiou, Son* are summarised in the 100 TeV report
- Perform the analysis:
  - with latest detector description (4T vs 6T)
    - better in terms of jet energy resolution
  - **shape analysis** instead of cut-based
  - include discussion on **systematics**

Michele Selvaggi (CERN)

HH to bbgg

Cut and count analysis

Michele Selvaggi (CERN)

Further apply: $m_{bb} \in [100, 150]$ GeV

$|m_{\gamma\gamma} - m_h| < 2.0, 2.5, 4.5$ GeV

Process	Acceptance cuts [fb]	Final selection [fb]	Events ($L = 30$ ab^{-1})
$h(b\bar{b})h(\gamma\gamma)$ (SM)	0.73	0.40	12061
$bbj\gamma$	132	0.467	13996
$jj\gamma\gamma$	30.1	0.164	4909
$t\bar{t}h(\gamma\gamma)$	1.85	0.163	4883
$b\bar{b}\gamma\gamma$	47.6	0.098	2947
$b\bar{b}h(\gamma\gamma)$	0.098	7.6×10^{-3}	227
$bj\gamma\gamma$	3.14	5.2×10^{-3}	155
Total background	212	1.30	27118

Old

```
HH : 0.848 +/- 0.012
ttH : 6.424 +/- 0.146
-------------------------
jjaa : 86.149 +/- 0.542
jjja : 184.513 +/- 2.431
-------------------------
jjaa : 77.374 +/- 1.829
bbja : 187.706 +/- 0.794
bbaa : 39.57 +/- 0.153
bjaa : 11.826 +/- 0.141
```

New

← 5f →

← 4f →

```
HH : 12300.903 +/- 254.507
ttH : 14213.855 +/- 1188.622
-------------------------
jjaa : 45334.416 +/- 2153.903
jjja : 22810.698 +/- 4376.07
-------------------------
jjaa : 14272.417 +/- 4303.296
bbja : 16697.744 +/- 1214.665
bbaa : 7078.155 +/- 354.351
bjaa : 1873.356 +/- 307.978
```

HH to bbgg

Cut and Count

Michele Selvaggi (CERN)

- Disclaimer: very preliminary!!
  - Signal yield looks compatible
  - Background ~ x2 larger overall
- (Statistical) Precision:
  - Report: $\Delta\mu/\mu = 1.6\%$ ($\Delta\lambda/\lambda = 3.4\%$)
  - Here: $\Delta\mu/\mu = 2.1\%$ ($\Delta\lambda/\lambda = 4.2\%$)

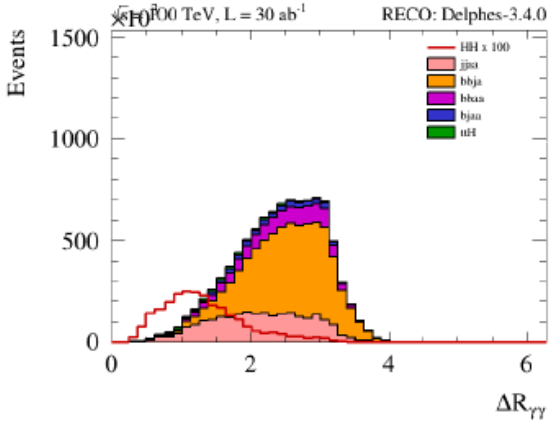
NO SYSTEMATICS !!

HH to bbgg

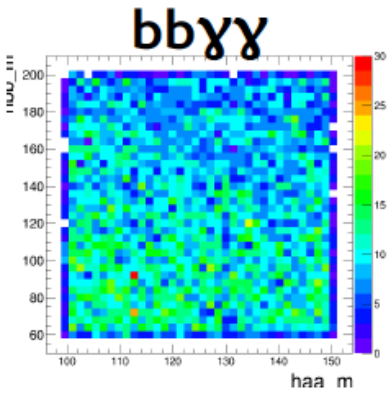
Possible improvements

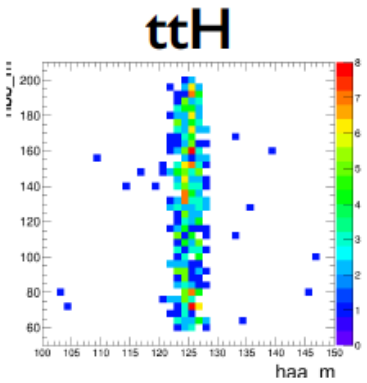
Michele Selvaggi (CERN)

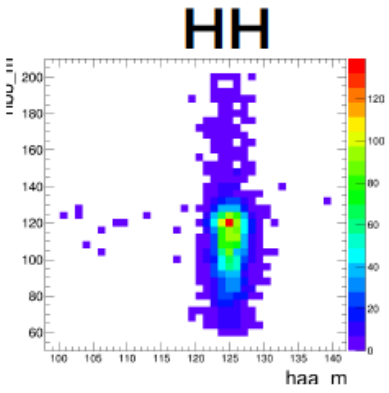
- Optimize event selection
  - $\Delta R < 2$ (although probably very correlated with p_T^{pair})
  - build categories based on jet multiplicities (non b-jet veto)



- Perform a shape analysis:
  - do not throw away precious events
  - exploit correlations, ex: $m_{\gamma\gamma}$ vs m_{bb}







HH to bbgg

2D binned shape analysis

Michele Selvaggi (CERN)

- Just a preliminary test, no systematics:
  - 2D binned max likelihood fit
  - $\Delta\mu/\mu$ = 1.6% ($\Delta\lambda/\lambda$ = 3.4%)

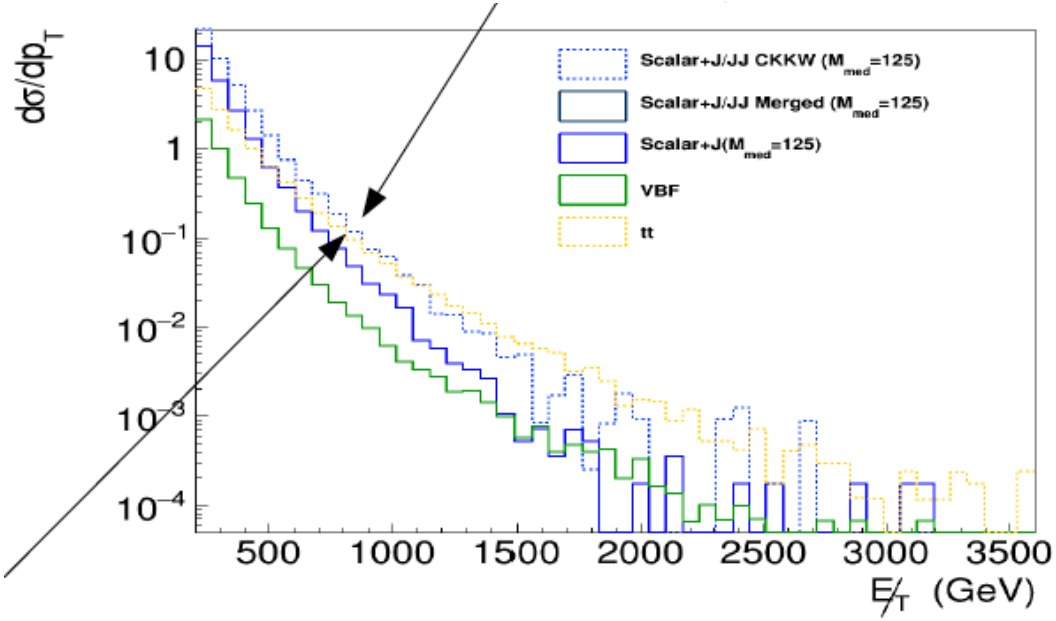
- Can be improved by:
  - background smoothening (now stat. limited despite several M events generated)
  - eventually parametric shape analysis

NO SYSTEMATICS !!

Invisible Higgs

Phil Harris (CERN)

- Currently investigating H→Invisible
  - Monojet and tt+H are the dominant productions
  - ttH is hugely enhanced wrt 14 TeV
  - When compared with H+1j form gluon fusion it wins
  - However H+2j is also large



Invisible Higgs

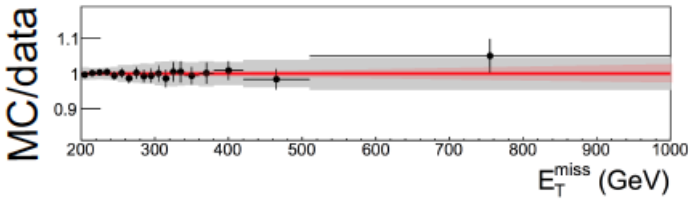
Essence of the search

- Rely on control regions to model signal region
  - Control regions have small signal fraction
  - Use the control region to derive :
    - Corrections to the *MET* scale and resolution
    - Missing higher order corrections in the MC
  - This eliminates the dominant uncertainties
  - Analysis scales with statistical power of control regions
    - As long as they continue to grow : not systematics limited

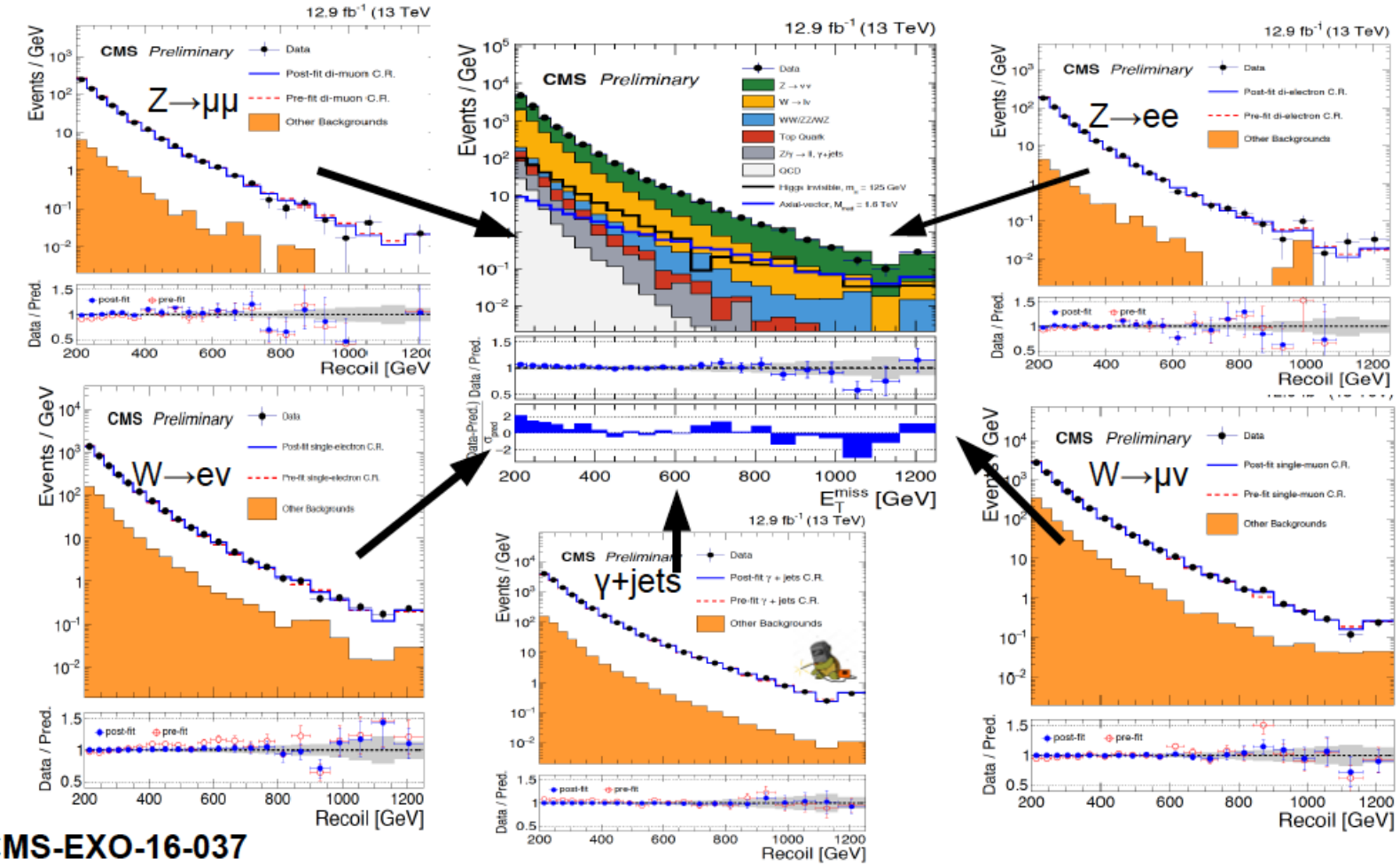
- All the control regions are fit simultaneously
  - By fitting simultaneously rely on the ratio of production

Invisible Higgs

Phil Harris (CERN)



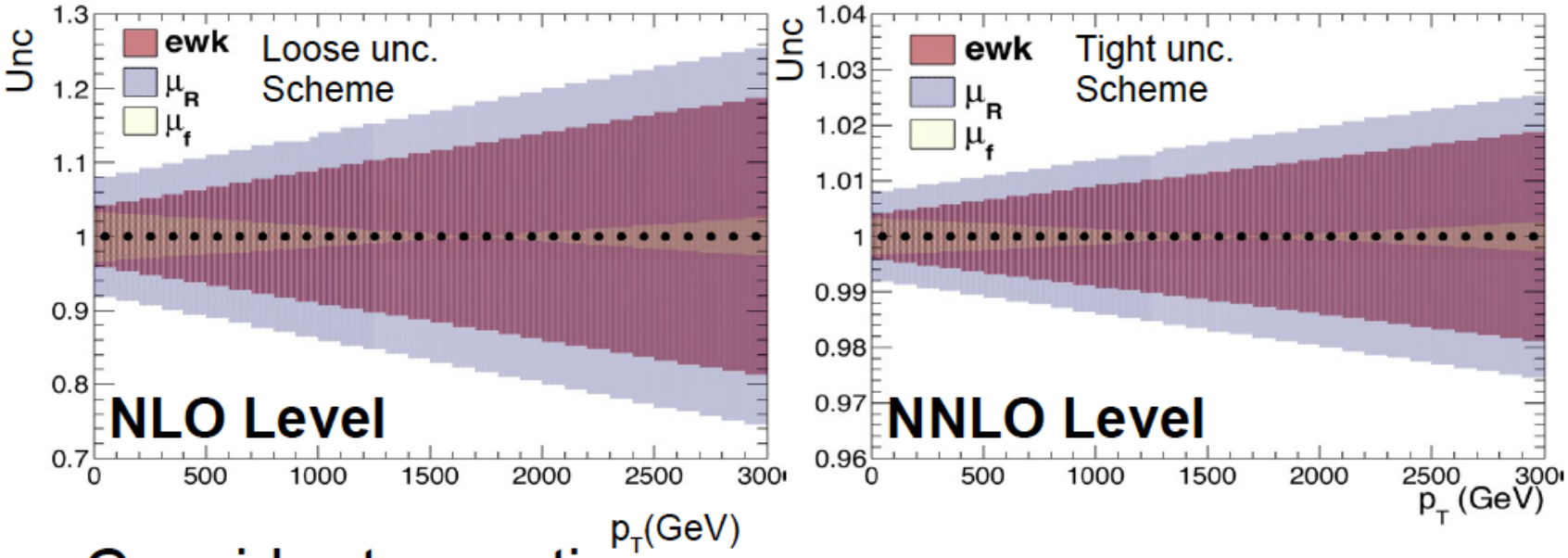
5 Control regions
15% uncertainty @ 1 TeV



CMS-EXO-16-037

Invisible Higgs

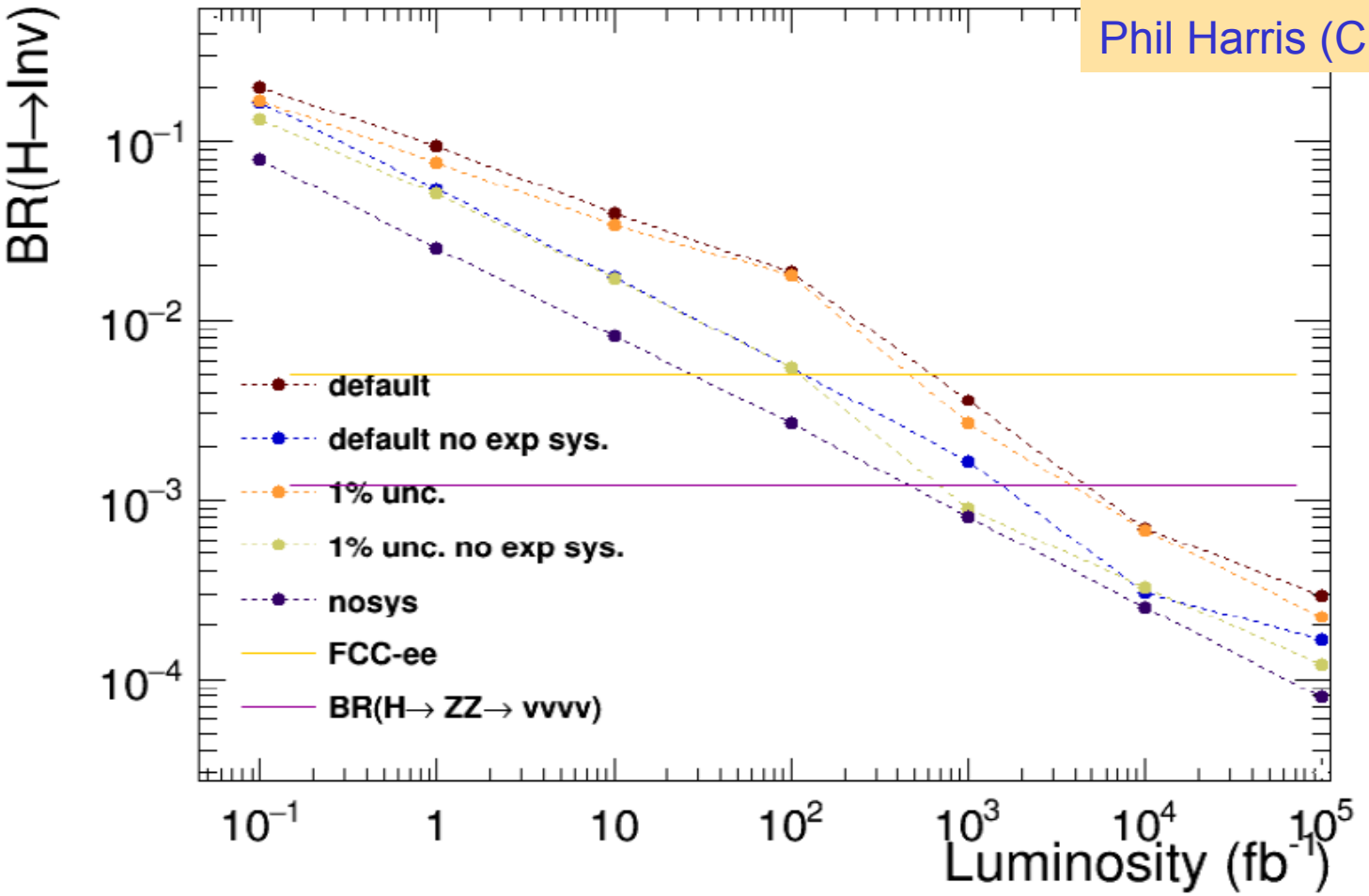
- What are reasonable uncertainty choices



- Consider two options :
  - A Loose uncertainty →Comparable to NLO
  - A Tight uncertainty →Comparable to NNLO
- Using : 0.5%/0.25%/5% e/μ/τ efficiency & 1% lumi

Invisible Higgs

Phil Harris (CERN)



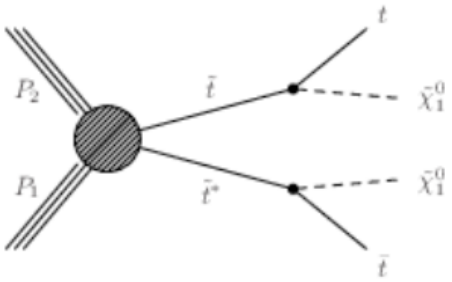
Cross the SM neutrino wall at FCC with < 1 ab^{-1}

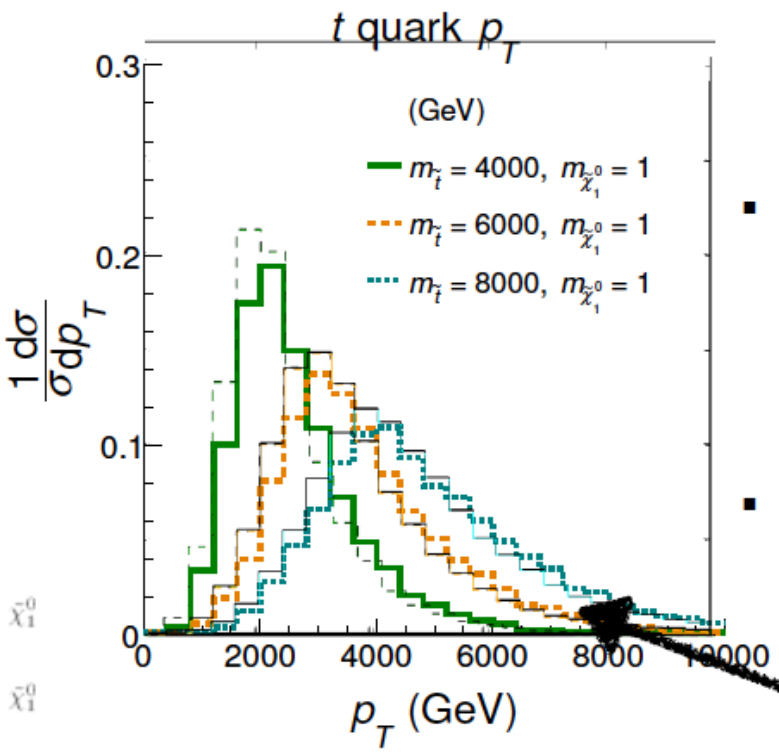
Stop search

Owen Colegrove (UCSB)

Search for supersymmetric partner of the top quark

$\tilde{t} \rightarrow t \tilde{\chi}^0$





- Decayed LHE files generated from Madgraph for 100 TeV pp collisions.
  - 50,000K Events for M_stop in [4,6,8 [GeV]], M_lsp = 1 GeV.
- Gen-lvl distributions for tops from stop decay are shown to the left.

$\Delta R \sim 2\, m_T/p_T$

Expect small jet radii

- Our LHE samples are overlayed w/ inverted line-style to compare results from "Boosting Stop Searches", ref to come.

https://arxiv.org/abs/1406.4512

Stop search

Top Tagger Efficiency vs. Granularity

Owen Colegrove (UCSB)

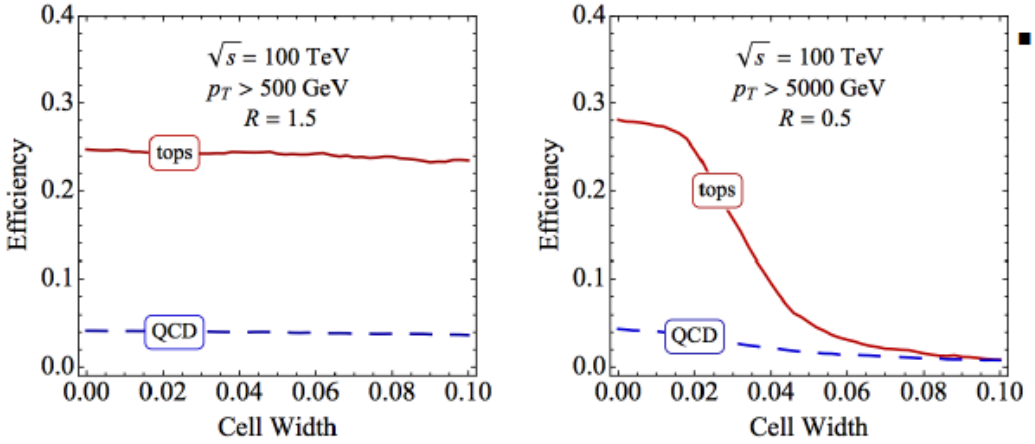


FIG. 2: HEP top tagger performance for jets with $p_T > 500$ GeV [left] and > 5 TeV [right]. The red solid curve shows the tagging efficiency for top quarks, and the blue dashed curve shows the mis-tag rate for light-flavor QCD jets.

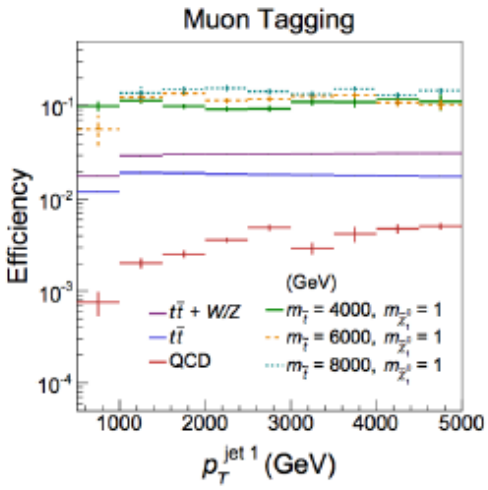
- Granularity
  - **Cell width $\Delta\varphi \times \Delta\eta \approx 0.02 \times 0.02$** or less is necessary for hadronic sub-structure (~4 x current CMS granularity)
  - Similar results obtained by S. Chekanov https://indico.cern.ch/event/382815/contributions/910644/attachments/1139429/1666195/PhysicsRequirementsHCAL_boost2015.pdf

Source : Boosting Stop Searches with a 100 TeV Proton Collider
https://arxiv.org/abs/1406.4512

Stop search

Muonic Top Tagger?

Owen Colegrove (UCSB)



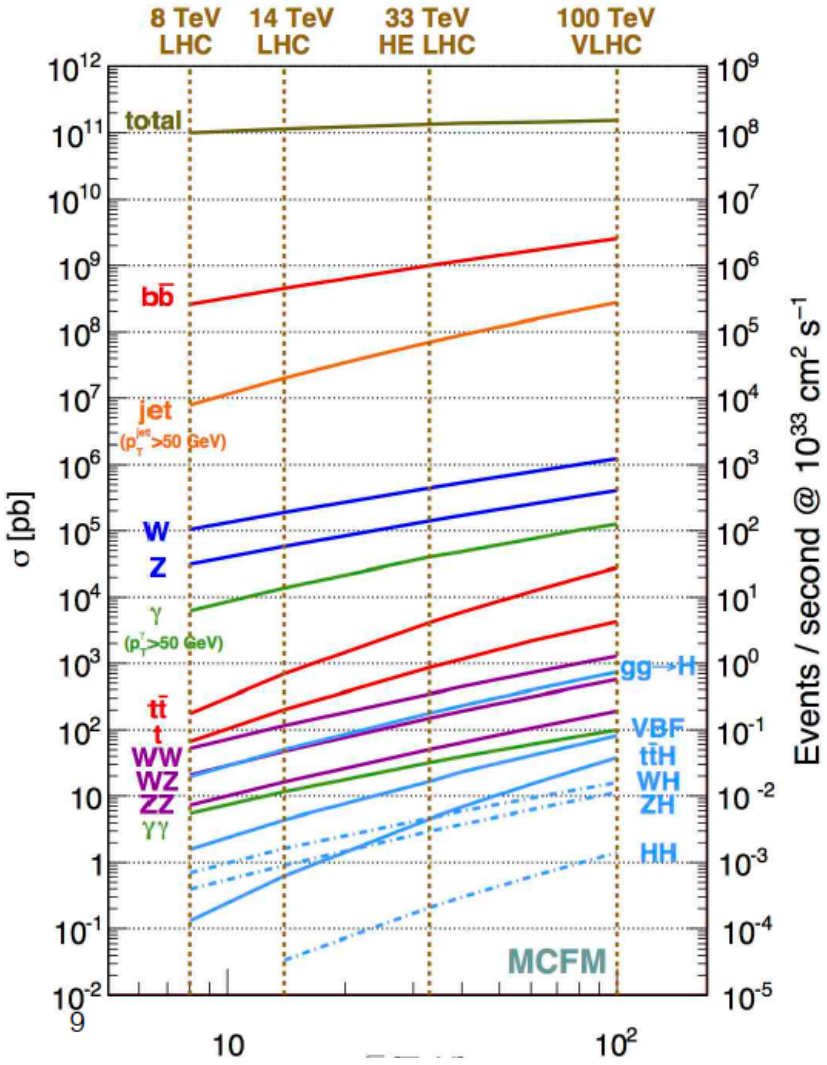
- Muonic Top Tagger
  - Look for muonic W decay + collaminated hadronic b decay or vice versa
  - An efficient top tagger for a low granularity detector
  - Can be combined with "QCD" cuts for better bkg rejection.

FIG. 3: Efficiency for finding a $\mu^{\pm}$ with $p_T > 200$ GeV within $\Delta R < 0.5$ of the leading jet for three choices of stop mass, along with the $t\bar{t} + W/Z$, $t\bar{t}$ and QCD backgrounds. ("Boosting Stop Searches")

Stop search

Thoughts

- Reproduce "boosted tops" analysis results?
  - It would be a nice starting point to build confidence
- Generate relevant samples?
  - High p_T ttbar, ttbar+X, single t, X+jets, diboson, QCD?
- Compare w/ a granularity driven search?



Charged Higgs

High mass charged Higgs boson

Orhan Cakir (Ankara)

Workpackage:

- Take mass 500 GeV, 1 TeV, 2 TeV
- H^+->tb~ channel (t->W^+b, 2b-tagging, top boosted?, W->hadronic/leptonic)
- H^+->tau nu channel (tau-tagging, MET)
  - Includes: b-tagging, MET, tau-tagging

Study Plan:

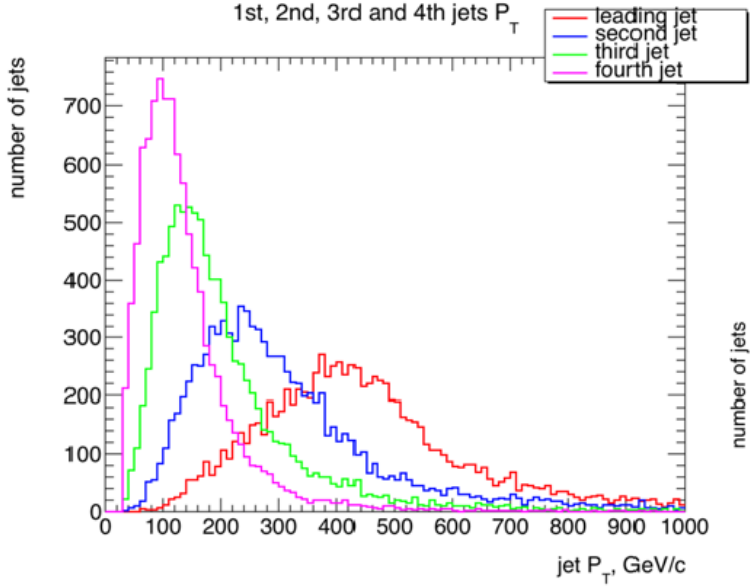
O.Cakir, I.Turk Cakir, H.Denizli, A.Senol, A.Yilmaz

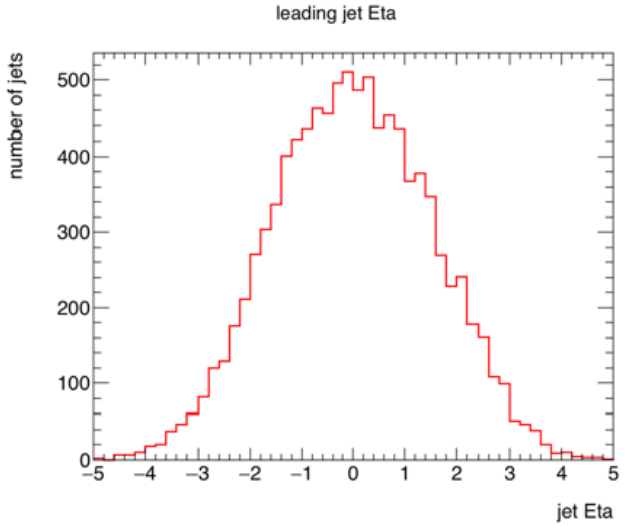
- Use FCCSW
- Model framework (2HDM or Model independent)
- Generate events (Pythia8 or MG5)
- Detector simulation with FCC card (Delphes 3.4 and FCChh.tcl)
- Analysis (C++ or Python)
- Plots (Root6)
- Abstract (ID138) submission for poster presentation at **FCC Week 2017**, "Production of High Mass Charged Higgs Boson at FCC-hh"

Charged Higgs

Charged Higgs boson (mass 1000 GeV)

Orhan Cakir (Ankara)





Top FCNC

Top quark FCNC couplings

Orhan Cakir (Ankara)

Workpackage:

- Study process p p -> (t a + t~ a) -> (W+b a + W-b~ a) with on-shell top and off-shell top (with b-tagging, top boosted?, W->hadronic/leptonic)
  - includes: b-tagging, jets, photon, MET, lepton
- Study sensitivity to FCNC couplings λ_q and ζ_q at different FCC-hh luminosity projections

Study Plan:

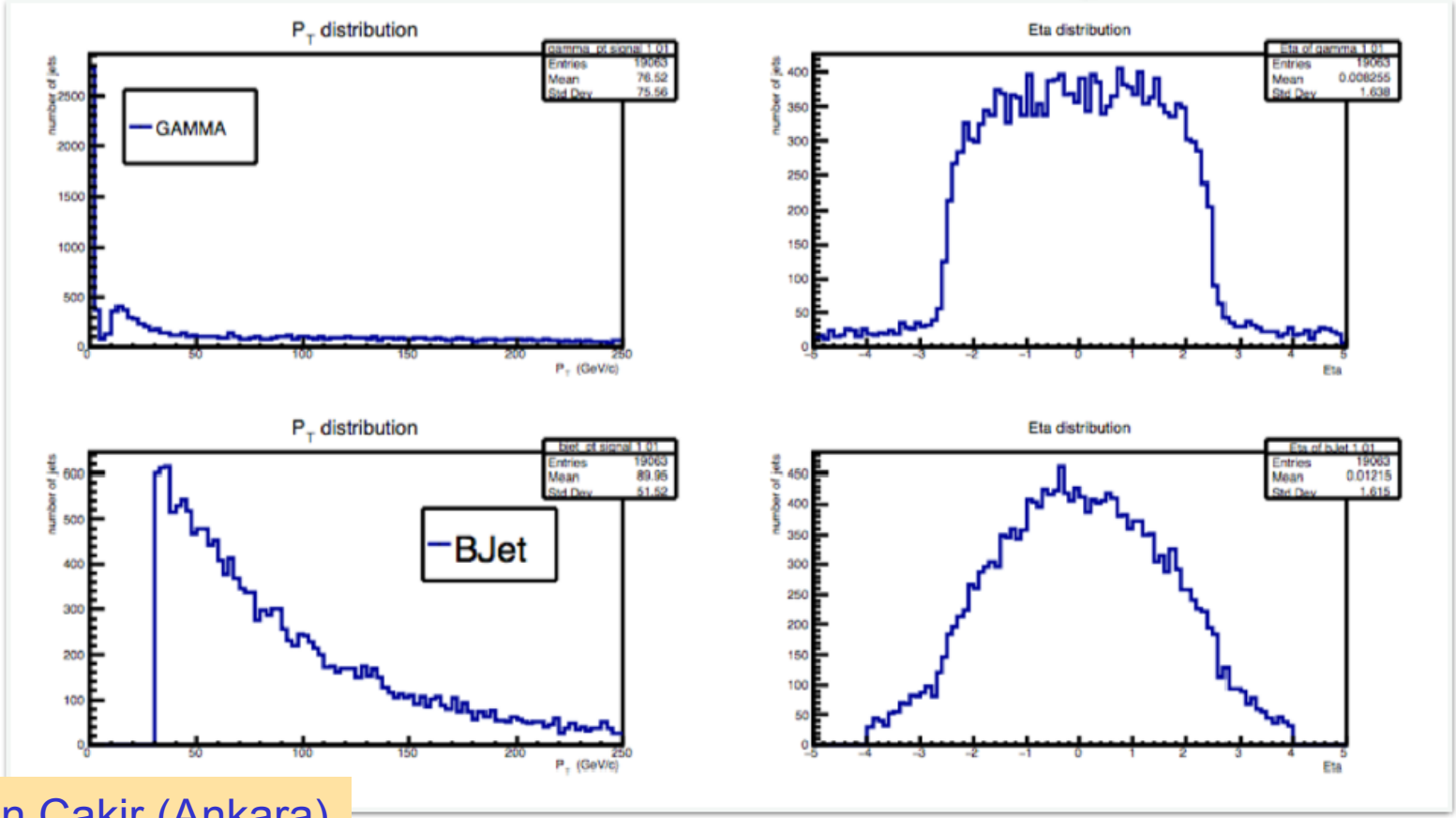
- Model framework (2HDM or Model independent)
- Generate events with MG5 and PS with Pythia8
- Detector simulation with FCC card (Delphes 3.4 and FCChh.tcl)
- Analysis (C++ or Python) and plots (Root6)
- Abstract (ID137) submission for oral presentation at **FCC Week 2017**, "Probing FCNC couplings through photon associated single top quark production at FCC-hh"

O.Cakir, I.Turk Cakir, H.Denizli, A.Senol, A.Yilmaz

Top FCNC

Signal (tqγ)

Madgraph5+Pythia8 +Delphes3.4+Root6



Summer students

Some good news concerning FCC summer students:

- Yesterday received message that most of our FCC Summer Student projects were accepted in the regular programme.

- We can look at other options for the projects that were not accepted (non-member state students, “stage” students)

Summary

- Started monthly meetings to discuss progress on physics studies towards 2018 FCC-hh CDR
- Several groups reported on progress and/or plans
- Please contact us if you're interested in starting or participating in a study
- Next meeting: Monday March 27th at 14:00