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Physics goals and detector requirements, summary and next steps

Christopher S. Hill, Leandro Nisati, Gavin Salam, Andi Weiler

On behalf of Physics Goals and Performance Reach (PG1) Working Group
ECFA HL-LHC Workshop
October 3, 2013

Thanks to PG1 speakers: Gavin S., Bill M., Isabell M.P., Marie-Helene S., A. Dainese and Bryan D.

From Manfred's Opening Talk

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Update of the European Strategy for Particle Physics adopted 30 May 2013 in a special session of CERN Council at Brussels.

Statement c:

> c) The discovery of the Higgs boson is the start of a major programme of work to measure this particle's properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme. *Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.*

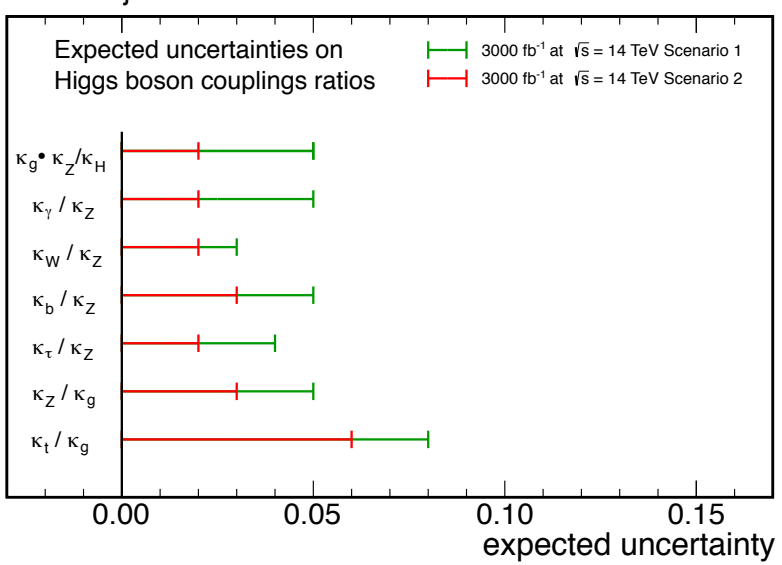
What we have done during this workshop is flesh out this (very nicely worded) paragraph

Exploitation of the Higgs

"The discovery of the Higgs boson is the start of a major programme of work to measure this particle's properties with the highest possible precision for testing the validity of the Standard Model"

- Area of significant progress
  - *Experiments have revisited/validated earlier projections*
  - *Experiments have coordinated assumptions*
    - **Consistent presentation of results**
  - *Range of projections largely agree*
    - **~2-8% on ratios of couplings with HL-LHC**

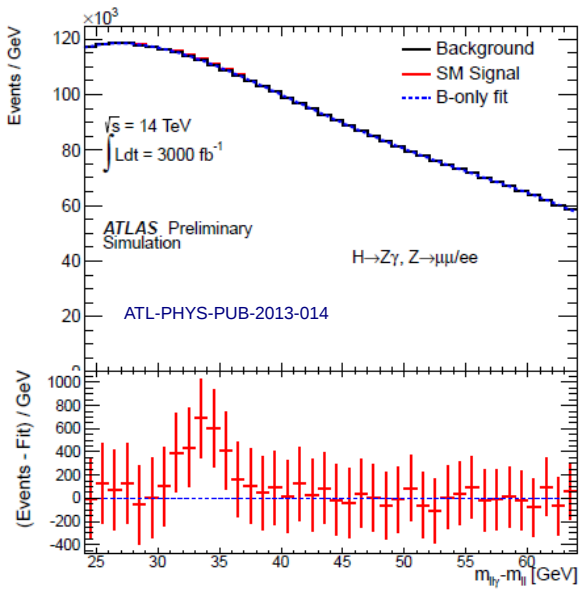
CMS Projection

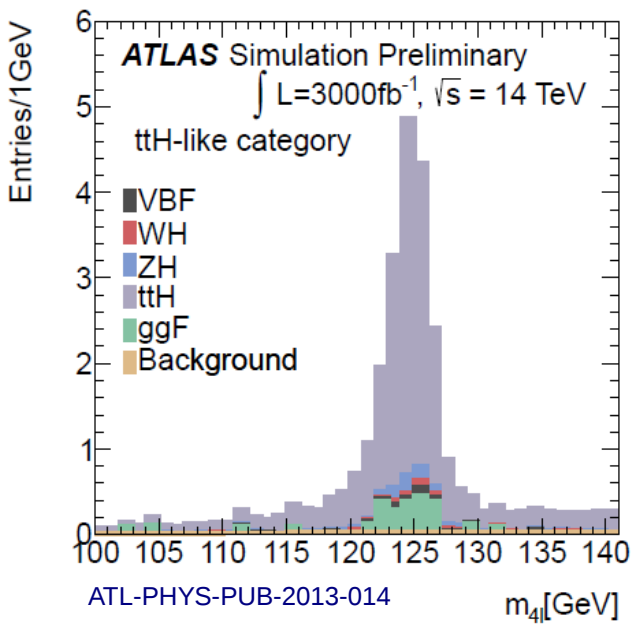


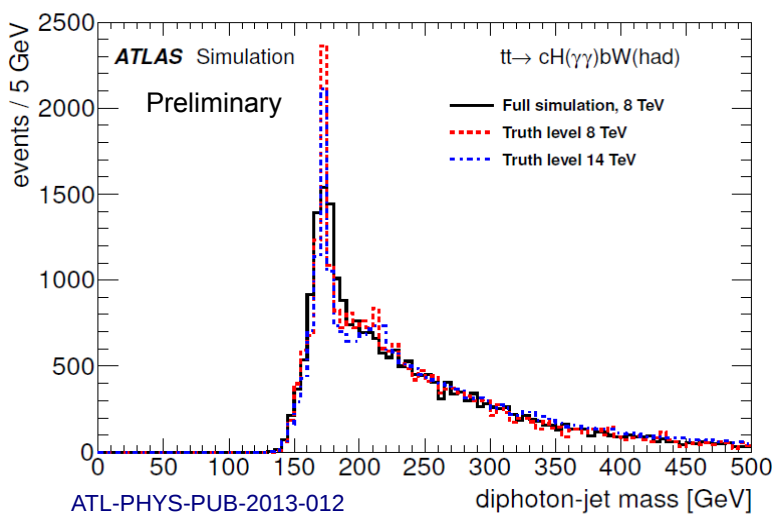
		$K_g\kappa_{Z/}\kappa_H$	K_W/κ_Z	K_γ/κ_Z	K_g/K_Z	K_b/K_Z	K_τ/K_Z	K_μ/K_Z	$\kappa_{Z\gamma}K_Z$	K_t/K_g
3000fb^{-1}	ATLAS	[2,5]	[2,3]	[2,7]	[5,6]	N/a	[7,10]	[6,9]	[29,30]	[6,7]
	CMS	[2,5]	[2,3]	[2,5]	[3,5]	[3,5]	[2,4]	[7,8]	[12,12]	[6,8]

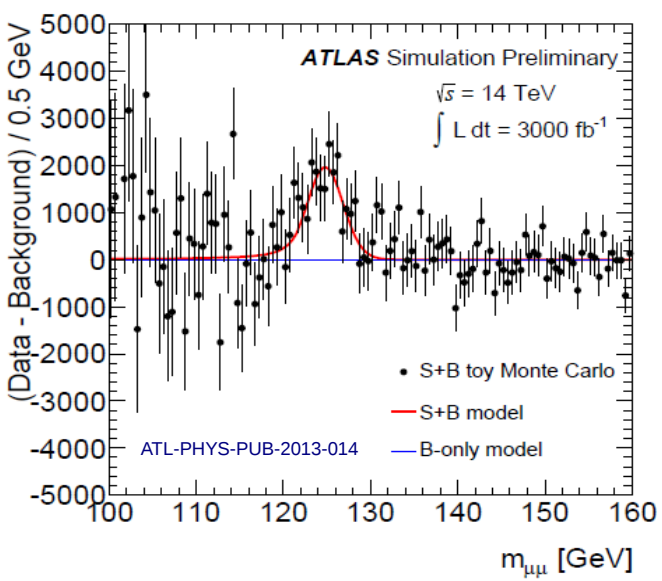
Rare & Suppressed Higgs Processes

- HL-LHC luminosity allows study of important rare Higgs modes
- Several new studies from experiments presented
  - *ttH (H to ZZ)*
  - *H to μμ*
    - **2nd generation couplings**
  - *H to Zγ*
    - **compositeness**
  - *t to cH*
    - **FCNC**









HL-LHC is also a Discovery Machine

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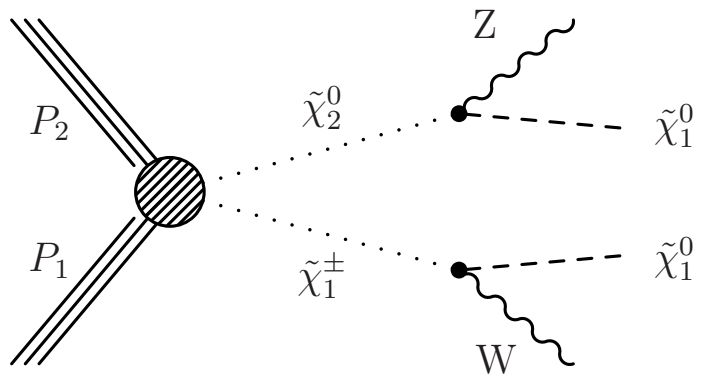
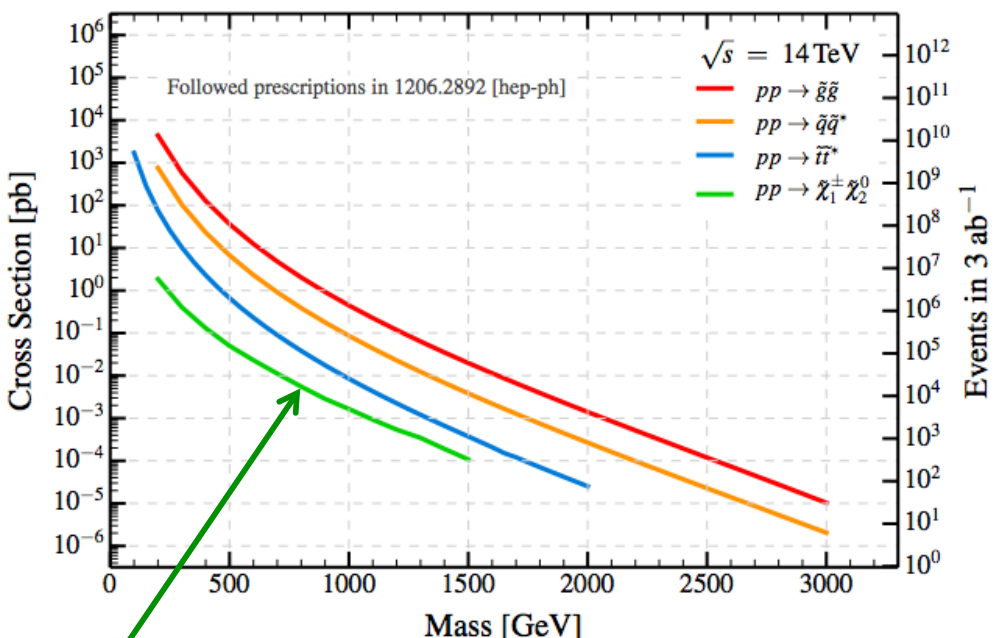
"... And to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme"

- HL-LHC offers a **unique multi-pronged opportunity** to discover the BSM physics anticipated to stabilize the observed Higgs mass against quadratic divergences (or to rule out such "natural" explanations)
  - *Era of precision Higgs physics & tests of EWSB mechanism*
    - **Uniquely capable of some critical measurements**
  - *Continue direct search for new particles (SUSY incl. extra Higgs, or other solutions to hierarchy problem)*
    - **Access small cross-section x BR production and/or inefficient decays**
  - *Luminosity sufficient to search for rare SM processes (enhanced in BSM)*
    - **Might yield the clue we need to move the field forward (has in the past ...)**

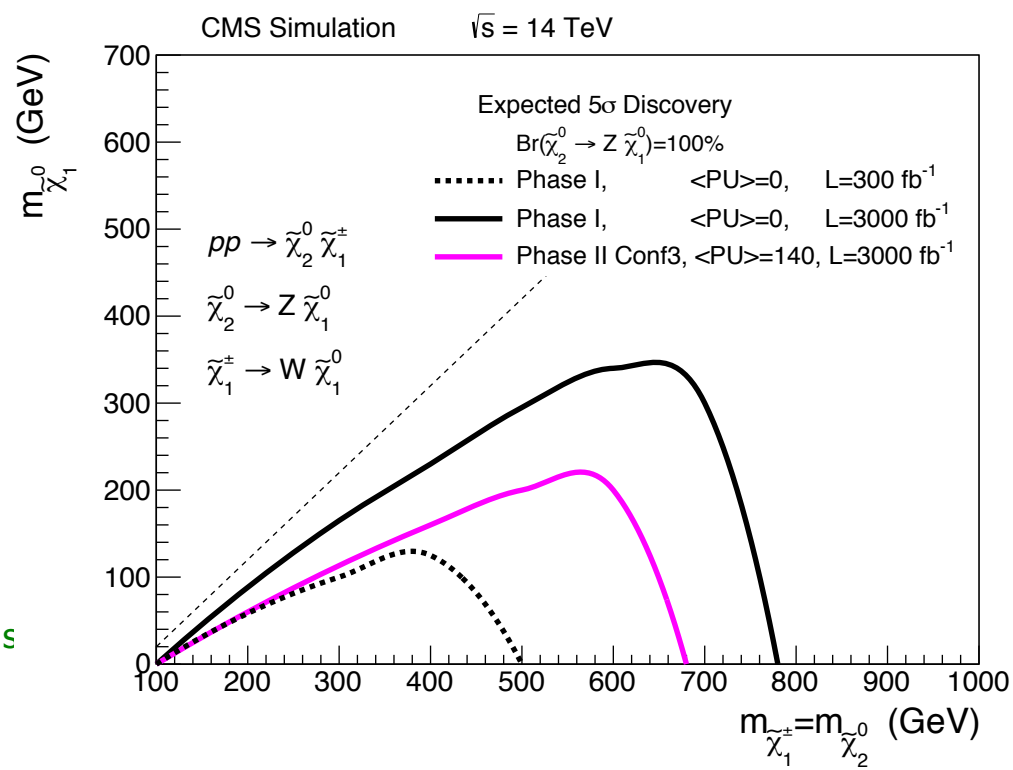
Direct Searches for BSM Particles

- HL-LHC luminosity needed to discover certain BSM scenarios
  - *E.g. SUSY through direct production of charginos/neutralinos*



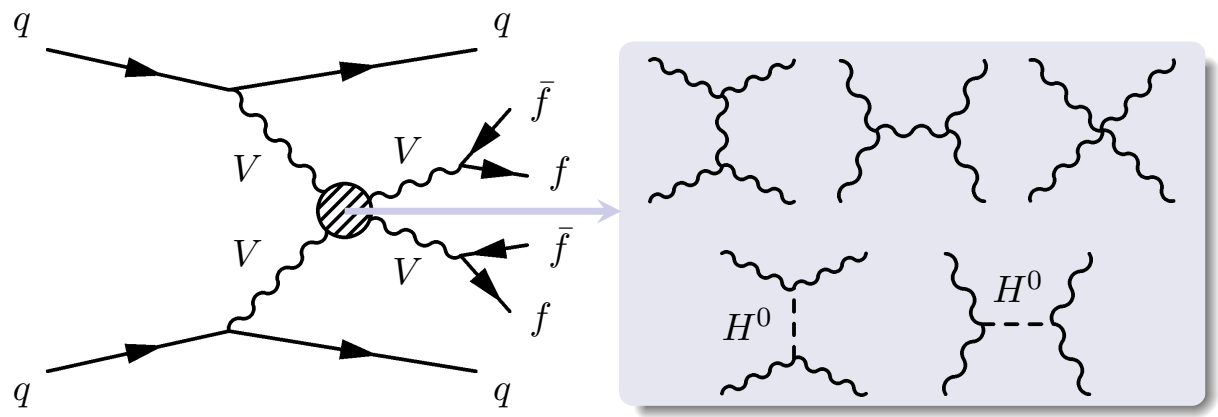


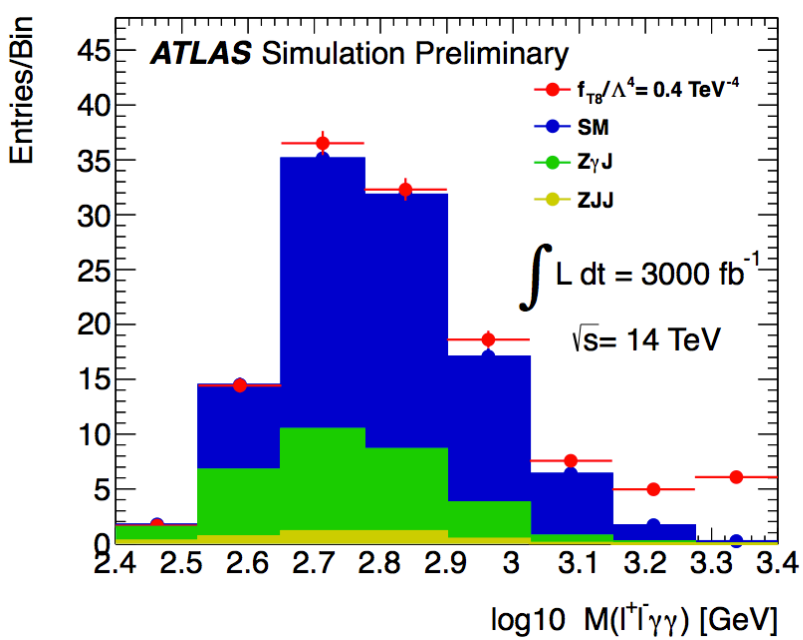
Neutralino/chargino cross sections (here assuming Wino states) are very s
→ need high luminosity!!!

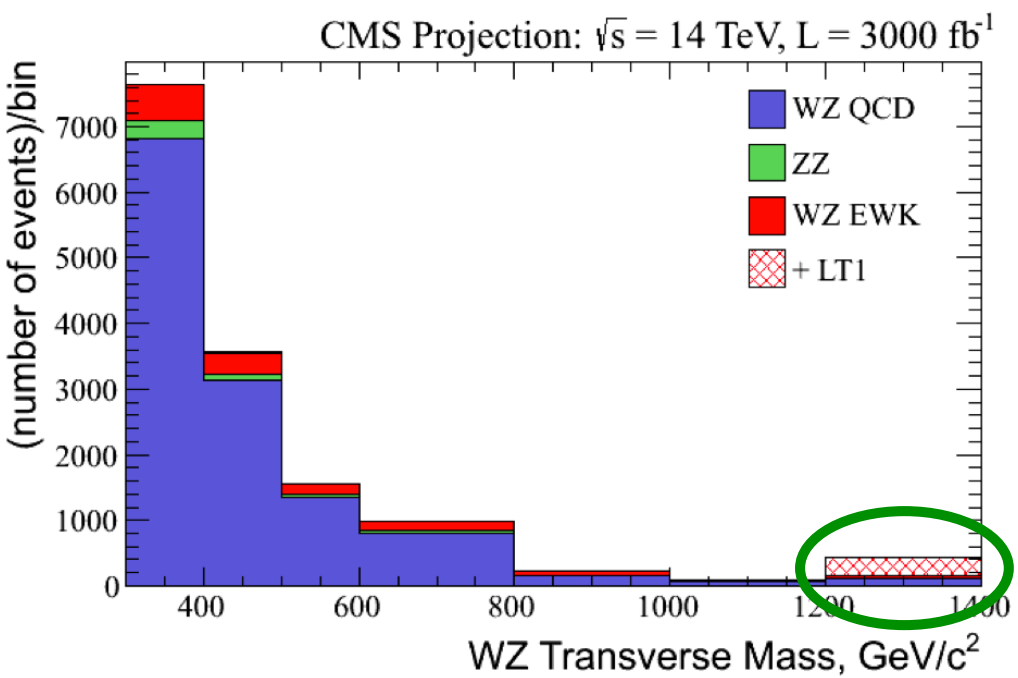


V V Scattering

- Verification of Higgs's presumed role in canceling divergences in VBS will come by end of Run 3
- However, HL-LHC with access to highest p_T events, becomes increasingly sensitive to anomalous gauge couplings







Flavor Physics

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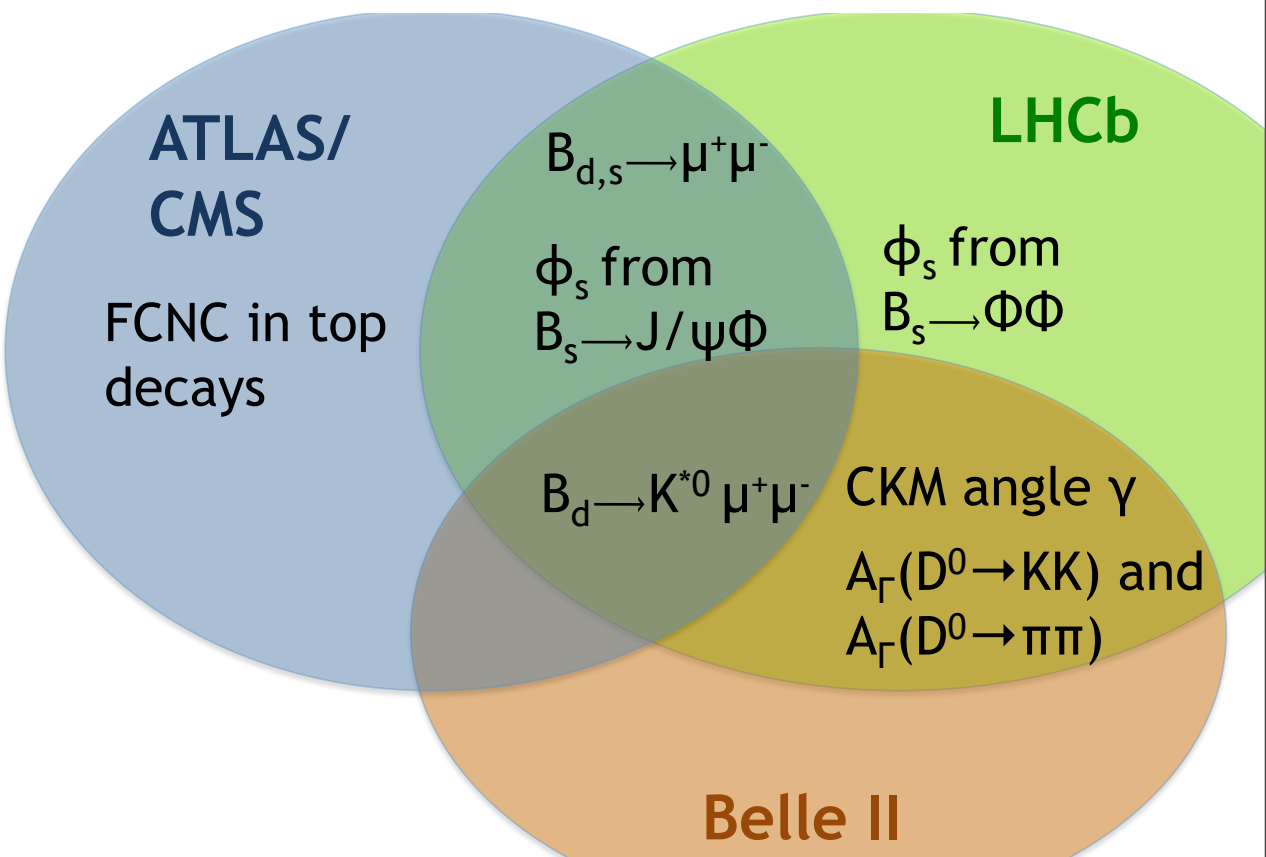
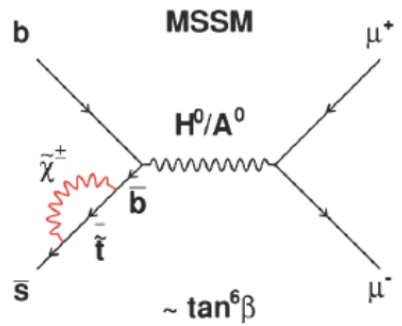
"This upgrade programme will also provide further exciting possibilities for the study of flavour physics"

- Discovery of new physics through indirect effects
  - *New particles in loops change observables from SM prediction*
- Variety of measurements have been studied (some ongoing)
  - *Diverse program*
  - *Complementarity of experiments*
  - *Rare phenomena, need HL-LHC luminosity*

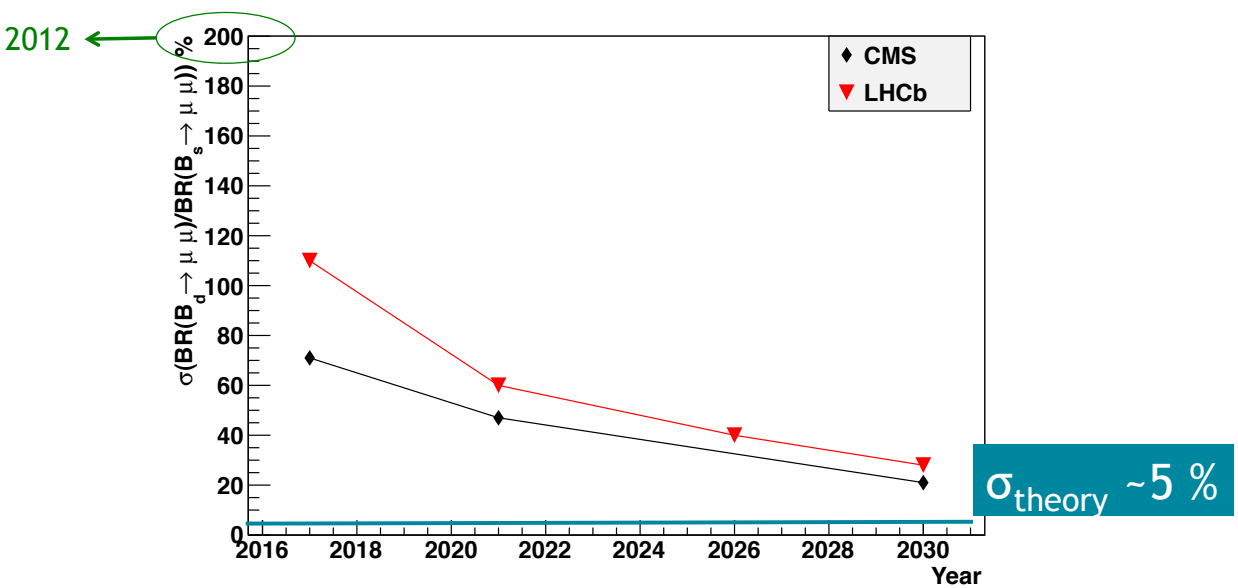


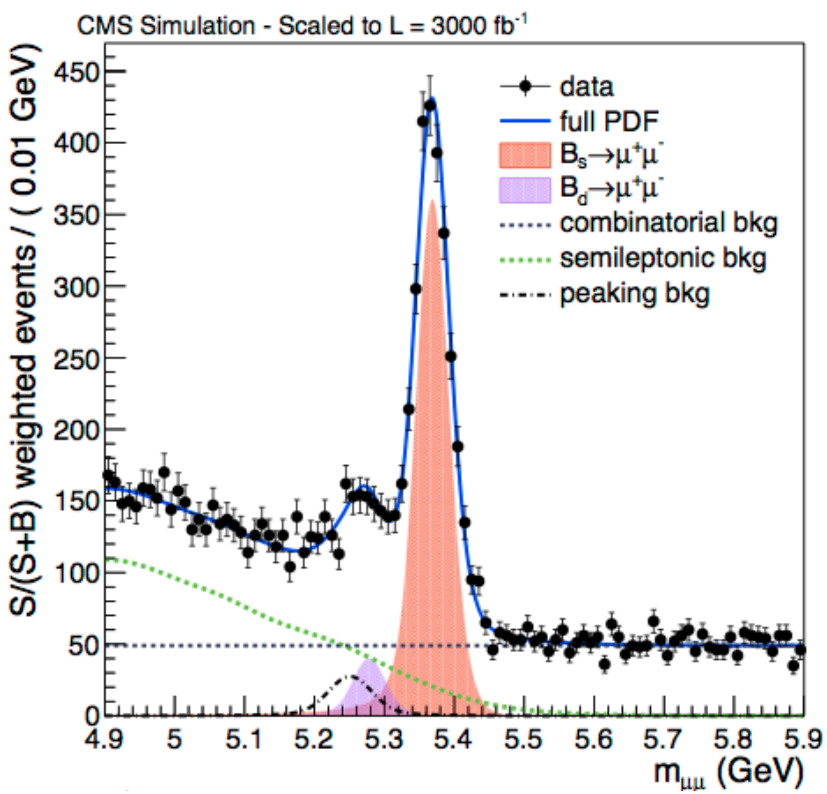
E.g. $B_{s,d}$ to $\mu^+\mu^-$

- Measure B_d and B_s
  - *NP effects can be different*
- CMS and LHCb can make precise measurements or BRs with HL-LHC



Expected precision on BR($B_d \to \mu^+\mu^-$)/BR($B_s \to \mu^+\mu^-$)



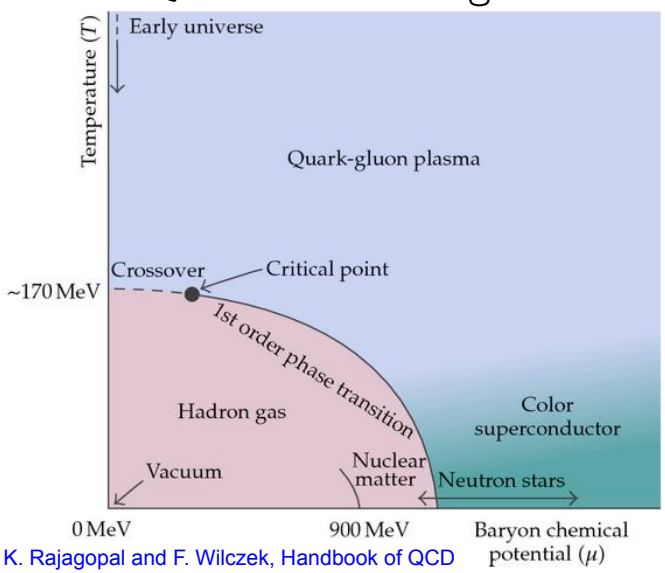


Heavy Ions

"... and the quark gluon plasma"

- Experiments plan major upgrades during LS2
- HL-HI-LHC defined as Runs 3+4
  - *>10 nb^{-1} Pb-Pb physics run, x10 stats of Run 2*
  - *p-Pb "high lumi" run*
  - *pp reference (5.5. TeV)*
  - *Possibly light ions*

QCD Phase Diagram

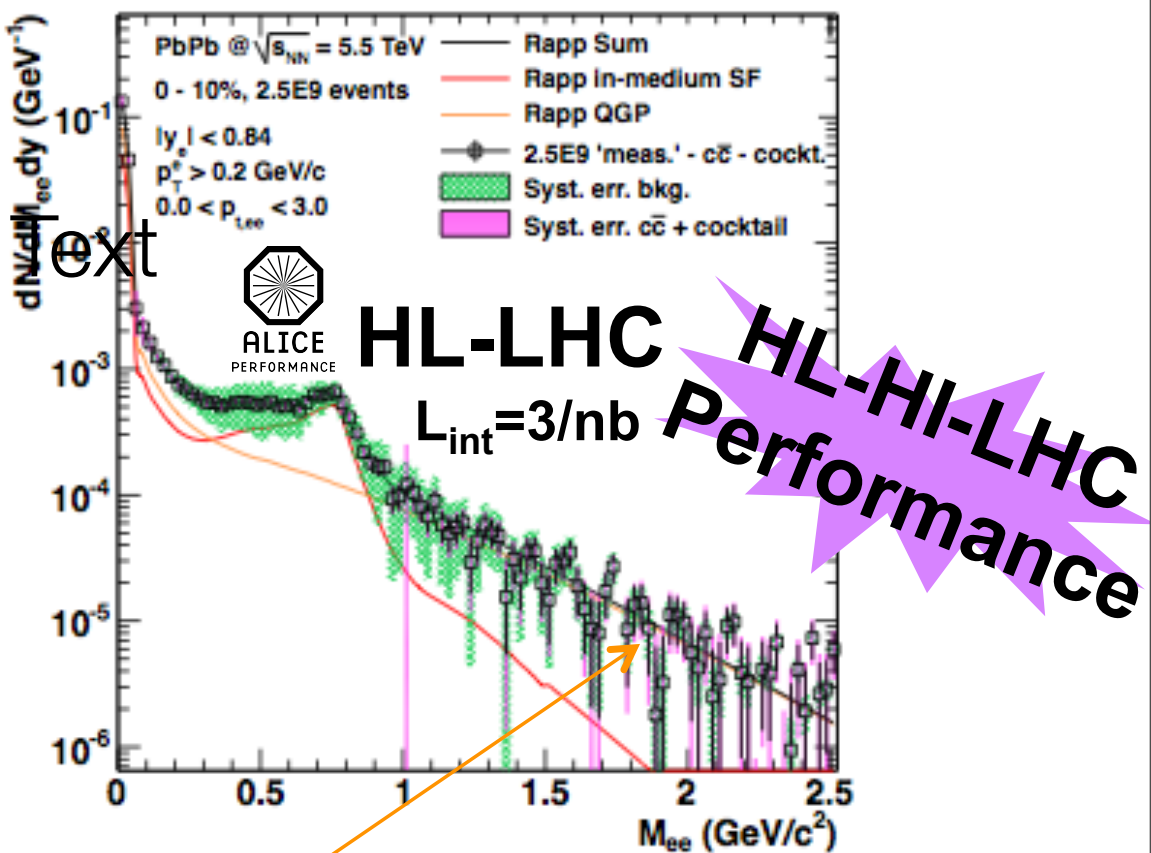


K. Rajagopal and F. Wilczek, Handbook of QCD

- HL-HI-LHC Physics Program
  - *Variety of measurements that study different aspects of the medium*
    - **Jets, Heavy Flavour Probes, Quarkonium, Low-mass Dileptons**
  - *All require high stats (and upgraded detectors) of HL-LHC*

E.g. Measuring the Temperature

- Use thermally radiated photons measure temperature of medium
  - *Do not interact in the medium*
  - *Reconstruct γ to e^+e^-*
    - **Slope of M_{ee} spectrum inversely related to T**
    - **Different M_{ee} correspond to different times during the collision (evolution)**
  - *Statistics obviously important*



Precision of ~10% on the inverse slope → *T*

Detector Requirements

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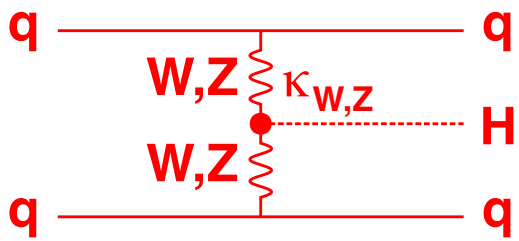
"Europe's top priority should be the full exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors "

- The first detector requirement is easy to state
  - *Have one that is not dead*

- Due to radiation damage, LHC detectors will **not survive beyond ~500 fb^{-1}**
  - *Must **replace** inoperable elements*
    - **Tracking detectors, endcap calorimeters (CMS)**
  - *Must **upgrade** electronics to cope with increased rates (esp. trigger)*

Others - Particular Physics Needs



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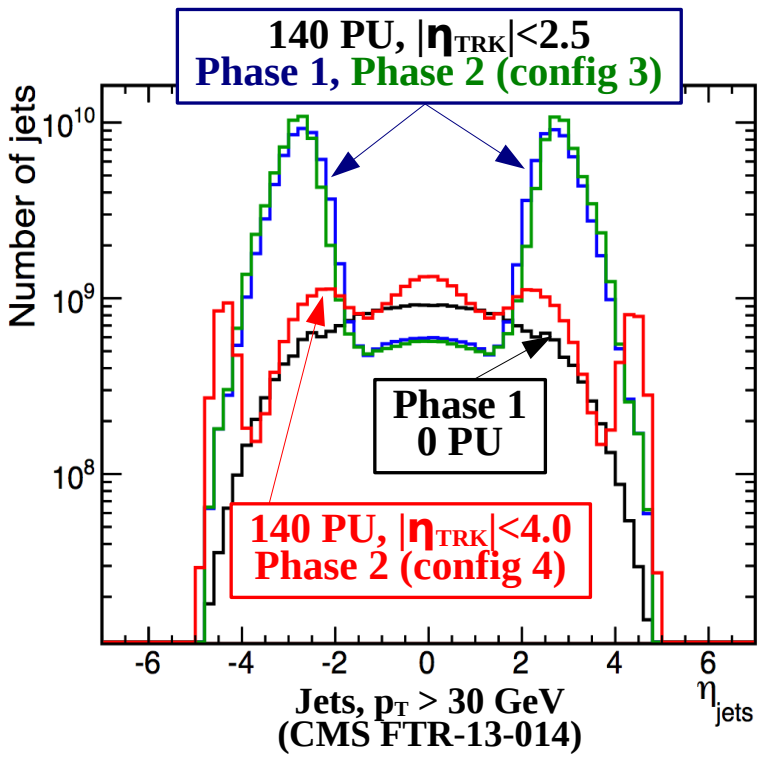
- Some physics processes make specific demands on the HL-LHC detectors
  - *E.g. important part of the HL-LHC physics program will be VBF produced physics (Higgs, VBS, EWKinos)*
  - *Current VBF measurements rely on shower shapes in calorimeters to distinguish VBF jets from pile-up (beyond tracking coverage)*
    - **Known to be insufficient with HL-LHC pile-up**
  - *Can possibly be mitigated by extending tracking coverage and/or calorimeter improvements (e.g. precision timing)*
    - **Needs more detailed study, R&D**



With optimistic tracking performance, large impact on VBF EWkino backgrounds ... can invert this and set a target for design

Design Targets Based on Physics Aspirations?

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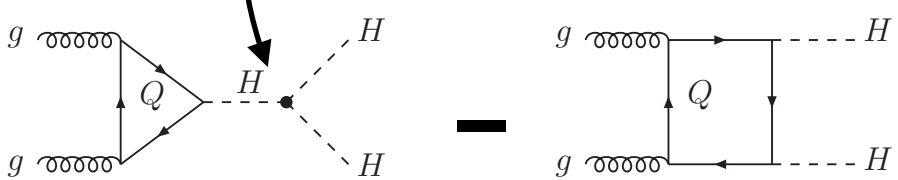
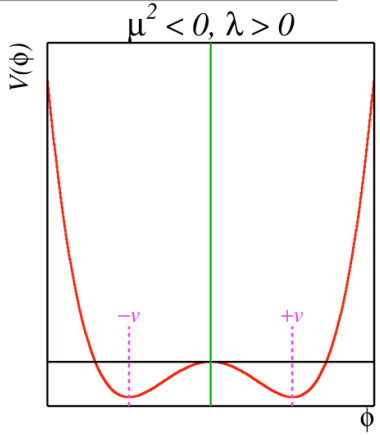
- Higgs self-coupling is an important parameter of SM
  - *Test through di-HIggs production*
- Experiments are still working on projections of precision
  - *Critically dependent on detector many aspects of detector performance*
    - **b-tagging, resolution, fake rates**
- Small cross-section, large backgrounds
  - *Clearly needs full HL-LHC luminosity*
  - *And detectors that maximize the experimental efficiency*

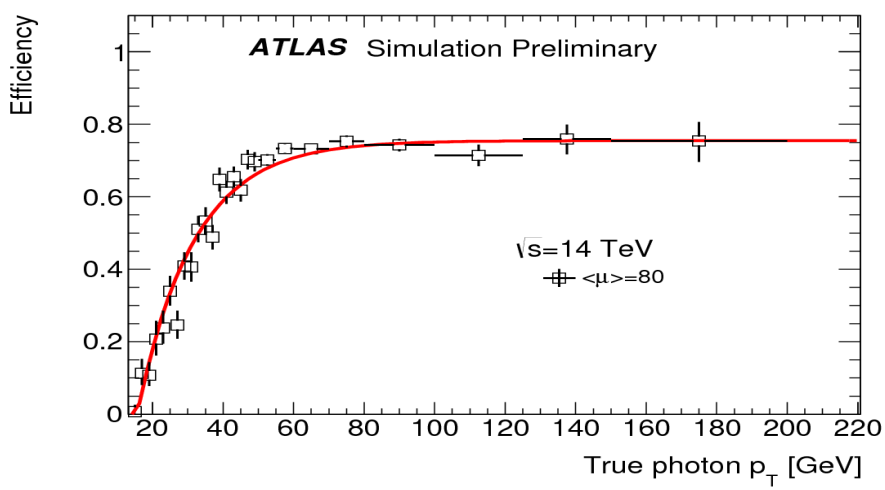
$$M_H^2 = \lambda v^2 \qquad g_{hhh} \equiv 3\lambda v = \frac{3M_H^2}{v}$$





Expected events

bbWW	30000
bbττ	9000
WWWW	6000
γγbb	320
γγγγ	1



Instead of asking with what precision can observe di-Higgs, easier (and maybe more useful) might be to set detector requirements to make N σ measurement

Next Steps

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- Perhaps the most important outcome of the ECFA workshop is the focus of activity it has provided
  - *Fostered interest in physics of HL-LHC, interplay with detector upgrades*
    - **Outcome of this is/will be new ideas**
    - **Continued investigation should be encouraged**
  - *Communication & collaboration between experiments established*
    - **Valuable exchange of information (again ideas ...)**
    - **Forums for such discourse should endure**

- Immediate future (next weeks), some work in progress that did not quite make this workshop will be completed
  - *But how to continue this activity beyond this?*

Future Workshops

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- Experiments must build on established momentum and continue to drive such studies in order to inform their upgrade designs and future physics programs
  - *Another ECFA HL-LHC workshop in ~1 years time might again help focus this activity*
- In the interim, topical mini-workshops could be arranged to sustain momentum and keep communication channels open
  - *These could be hosted by LPCC perhaps*
  - *They could focus on important physics topics*
    - **How to make sure LHC is able to observe di-Higgs production**
  - *They could focus on important detector performance issues*
    - **How to get achieve pileup mitigation for VBF produced physics**
  - *Or other topics of interest to the community*
  - *First such meeting early 2014?*

Summary

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- **Many new studies on physics reach and performance goals prepared for this workshop**
  - *Precision Higgs physics (ATLAS/CMS)*
  - *Direct searches for BSM particles (ATLAS/CMS)*
  - *Searches for deviations from rare processes in the SM (ATLAS/CMS/LHCb)*
  - *Heavy Ions (ATLAS/CMS/ALICE)*

- **This workshop has provided people, tools, and fora to establish HL-LHC physics goals and assess detector performance**
  - *At lot of progress, but key questions remain*
  - *This work must continue, building on the established momentum*
  - *Propose a follow-up workshop 1 year from now*
    - **Interim period interspersed with topical mini-workshops**