Discussion hooks
Hadron colliders session

25/7/2018

Thanks to Alessandro, Daniel, Pascal for sharing a preview of their slides!

Context and Caveats

I'm assuming a rather miopic view here:

- there will be only hadron colliders in the future (lepton colliders are discussed somewhere else)
- the physics we are interested in is only Higgs related, or BSM searches based on Higgs analyses
- given that I'm only given three slides and I'm using one for CAVEATS I have to oversimplify and try to be provocative (and add a couple of slides more, sorry!)

As a consequence, the discussion might be totally different in a bigger context.

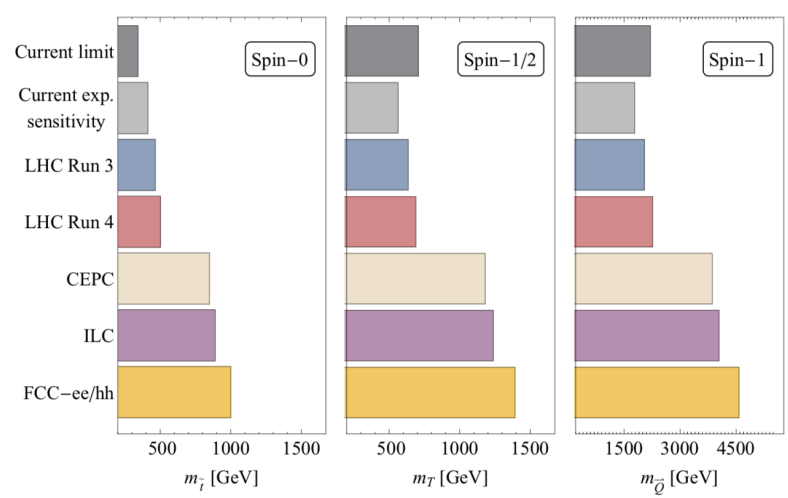
General comment: many of the "projections" are in the process of being revisited for the HL/HE-LHC yellow report due in a few months. Many baseline assumptions already surpassed by Run2 results!

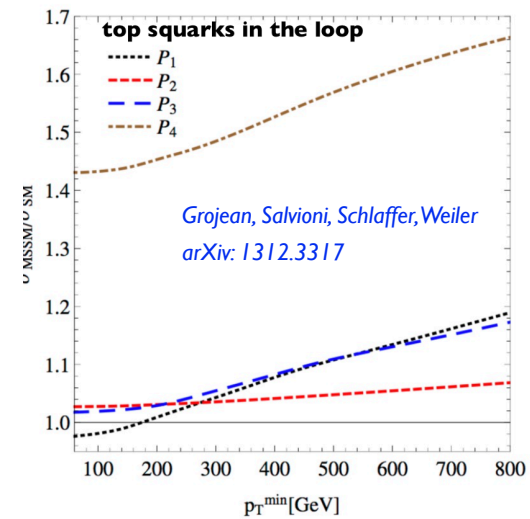
The goals

What are the main goals in Higgs physics for the future generations/ colliders that will not be fully exploited by the LHC (up to Run3):

- Higgs potential:
  - self-coupling
  - vector boson scattering (in particular $W_L W_L$)
- Couplings below 5% accuracy (BSM territory)
- High pT(H) regime (BSM territory)

Essig, Meade, Ramani, Zhong Salvioni, arXiv: 1707.03399





- HL-LHC ($3ab^{-1}$) will give us a glimpse on λ_{HHH} and VBS (expect 1 to 2 sigma "evidence" in most optimistic scenarios)
- couplings (mu) will reach, and in a few cases will go below, the 5% level.
- will start to explore second generation couplings: VH(cc) < 6 SM @95%CL (would be interesting to see experiments y_c projections from differential distributions!)
- The highest pT(H) regime that we will be able to probe is O(100 GeV), probably not enough to be sensitive to new physics above 1 TeV scale (but it will not be syst. dominated!)

Machines performance

	LHC / HL-LHC	HE-LHC (tentative)	FCC-hh Initial	FCC-hh Ultimate
Cms energy [TeV]	14	27	100	100
Luminosity [$10^{34}cm^{-2}s^{-1}$]	1 / 5	16	5	20-30
Machine circumference	26.7	26.7	97.75	97.75
Arc dipole field [T]	8	16	16	16
Bunch charge	1.15 / 2.2	2.2	1	1
Bunch distance [ns]	25	25	25	25
Background events/bx	27 / 135	440	170	<1020
Bunch length [cm]	7.5	7.5	8	8

The questions

Let's start with a fact: the HL-LHC (phase 2) is granted.

What is the gain, for Higgs physics, in going to HE-LHC (27 TeV)?

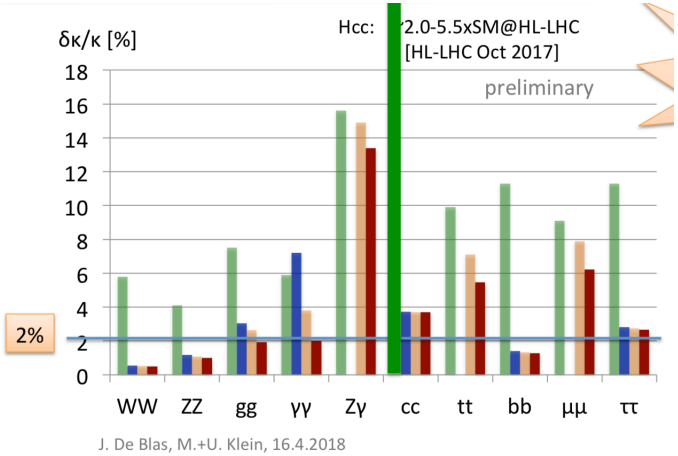
- Xsec = 3x(14 TeV), lumi(and PU!)=2-4 times,
- production rate is ~5-10x (i.e. 1 year HE-LHC ~ 5-10 years HL-LHC)
- **Higgs yield ~10-15x (uncertainties down by ~3x)**
- we might touch the 30% accuracy on Higgs self-coupling (not reachable by HL-LHC)
- **BUT: uncertainties might hit the same "flooring" due to systematics (even though the enlarged phase space might help) !! (see next slide for discussion)**

FCC-hh seems to be a clearer case:

- **200x more stats, >5x kinematical reach**
- rare decays will be fully explorable
- Higgs self coupling (and VBS) will be studied at percent level
- percent precision also on pT(H) ~ 500 GeV
- no idea about systematics

ep versions (LHeC, FCC-eh)

- seems rather interesting options:
- VBF (CC and NC) dedicated signatures
- **not far from pp reach for couplings, <u>beat down the systematics</u> and goes into the ILC regime (too good to be true?)**

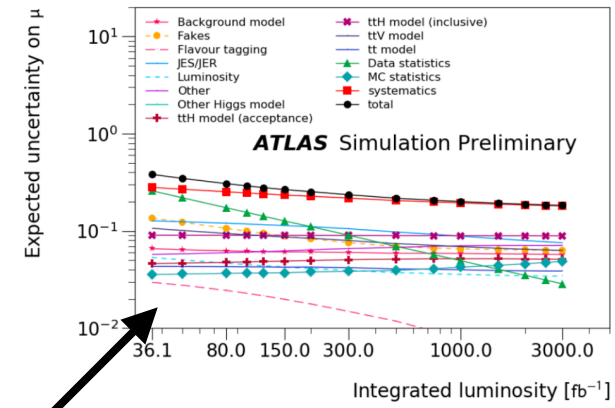


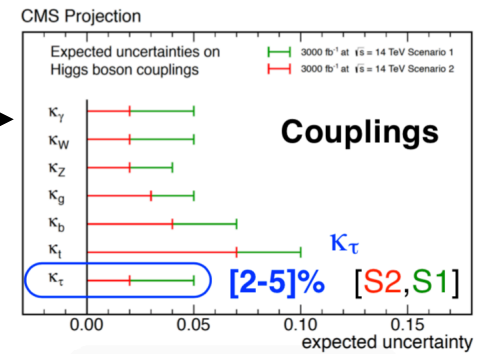
The questions

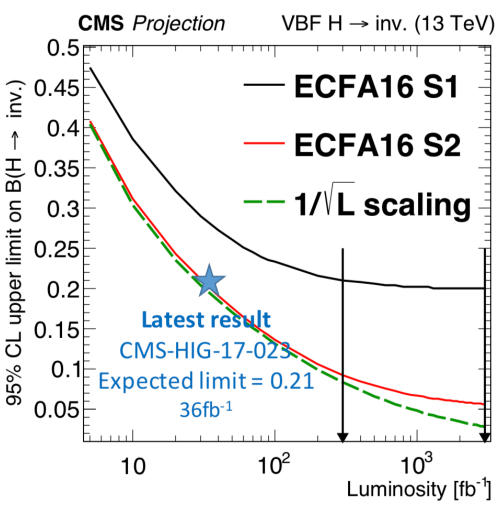
Systematics is one of the key points, if not THE point (current projected syst. effects ~10x statistics):

- we experimentalists don't have much control on theoretical ones
  - **can we bracket theory systematics directly from data? What about combined fits?**

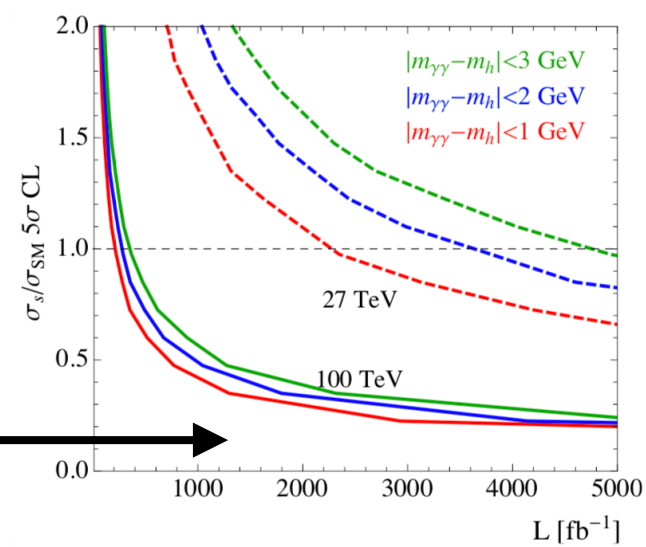
- how optimistic we can be with experimental systematics?
  - we know that despite detectors will not get much better analyser/ analyses gets smarter and smarter
  - we might hit the floor before the 3ab^{-1} but what is the floor?
  - **on the positive side we see first evidence of 1/sqrt(L) reduction of systematics (see P.Meridiani's session and plot below) and even BETTER than 1/sqrt(L) (see L. Borgonovi)**







New phase space (energy) might be beneficial in terms of S/B (HH→bbγγ)



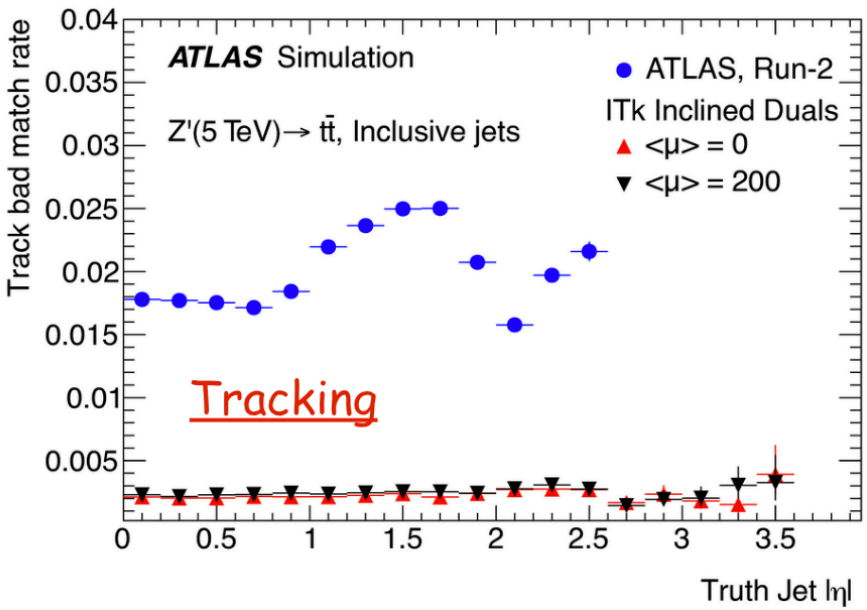
BACKUP

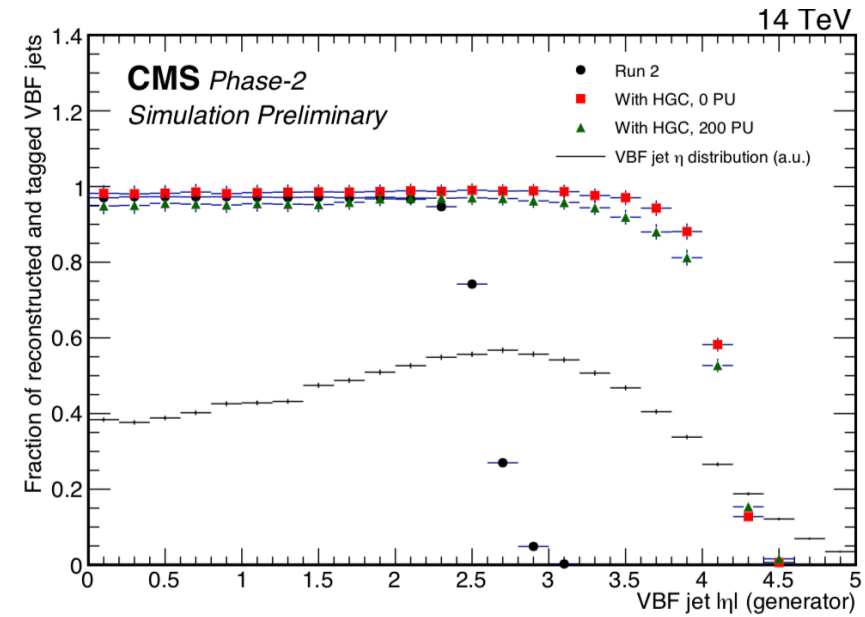
HL-LHC di-Higgs comparison (from R. Salerno)

	CMS	ATLAS
bbbb	0.39σ	$\mu < 5.2(1.5)^{(3)}$ $-4.1<\lambda/\lambda_{SM}<8.7$ $(0.2<\lambda/\lambda_{SM}<7.0)$
bb$\tau\tau$	$0.39\sigma^{(1)}$ / $\mu <1.6^{(2)}$	$\mu <4.3^{(4)}$ $-4.0<\lambda/\lambda_{SM}<12$
bb$\gamma\gamma$	1.43σ	$1.5\sigma^{(3)}$ $0.2<\lambda/\lambda_{SM}<6.9$ (stat only)
bbVV	0.45σ	
ttHH(bbbb)		0.35σ

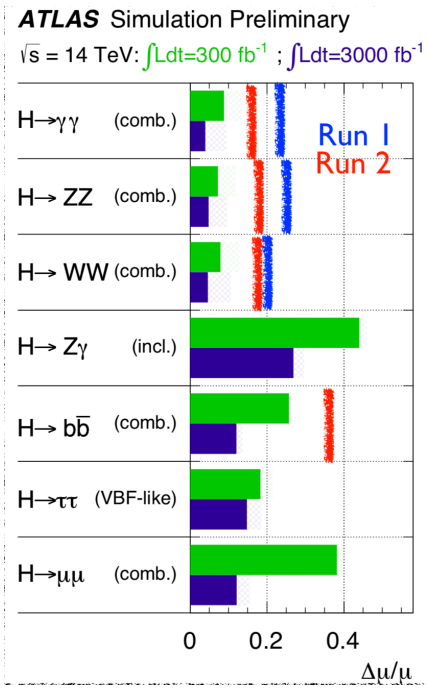
Detectors for HL-LHC

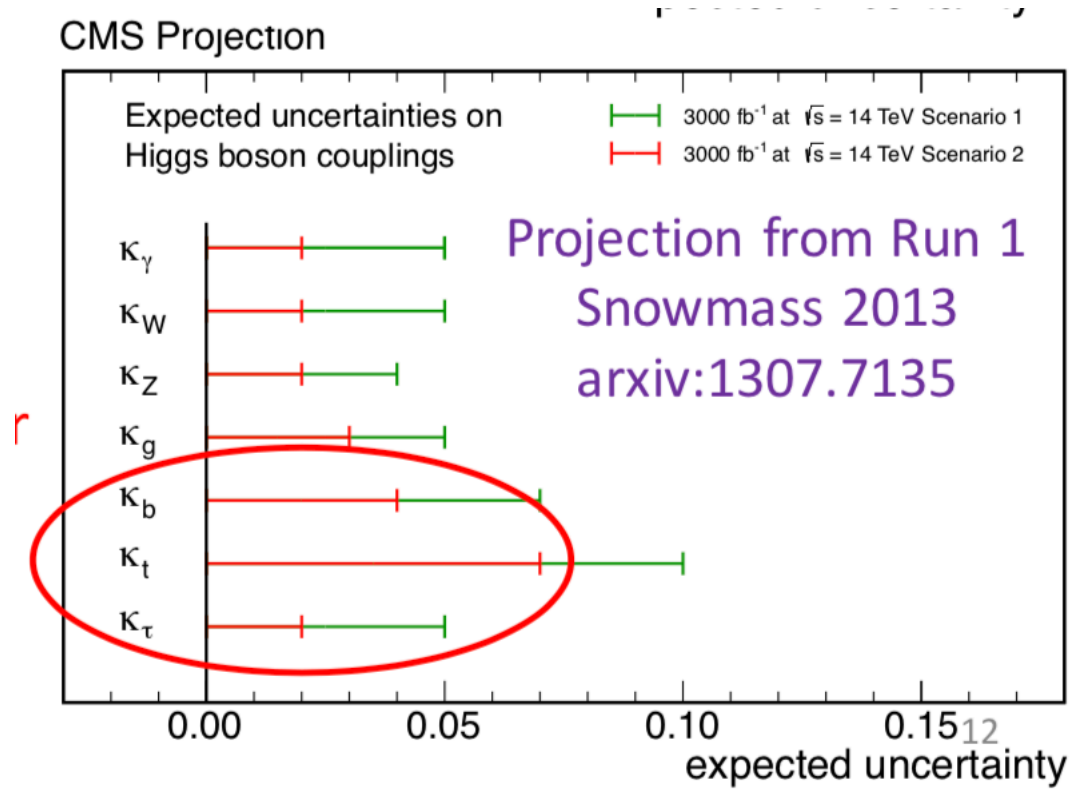
- Extended coverage (VBF coverage and missing E_T)
- Track trigger at early stage of trigger
- Timing capabilities @30ps





Additional systematics comparison





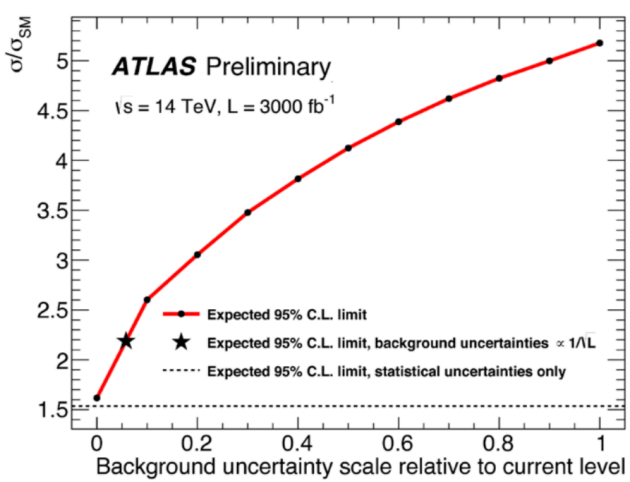


Table 1.2: Target precision for the parameters relative to the measurement of various Higgs couplings, the Higgs self-coupling λ, Higgs branching ratios B and ratios thereof. Notice that lagrangian couplings have a precision that is typically half that of what is shown here, since all rates and branching ratios depend quadratically on the couplings.

Observable	Parameter	Precision (stat)	Precision (stat+syst)
$\mu = \sigma(H) \times B(H \to \mu\mu)$	$\delta\mu/\mu$	0.5%	0.9%
$\mu = \sigma(H) \times B(H \to \gamma\gamma)$	$\delta\mu/\mu$	0.1%	1%
$\mu = \sigma(H) \times B(H \to 4\mu)$	$\delta\mu/\mu$	0.2%	1.6%
$\mu = \sigma(t\bar{t}H) \times B(H \to b\bar{b})$	$\delta\mu/\mu$	1%	tbd
$\mu = \sigma(HH) \times B(H \to \gamma\gamma)B(H \to b\bar{b})$	$\delta\lambda/\lambda$	3.5%	5.0%
$R = B(H \to \mu\mu)/B(H \to 4\mu)$	$\delta R/R$	0.6%	1.3%
$R = B(H \to \gamma\gamma)/B(H \to 2e2\mu)$	$\delta R/R$	0.17%	0.8%
$R = B(H \to \gamma\gamma)/B(H \to 2\mu)$	$\delta R/R$	0.6%	1.4%
$B(H \to \text{invisible})$	B@95%CL	1×10^{-4}	2.5×10^{-4}