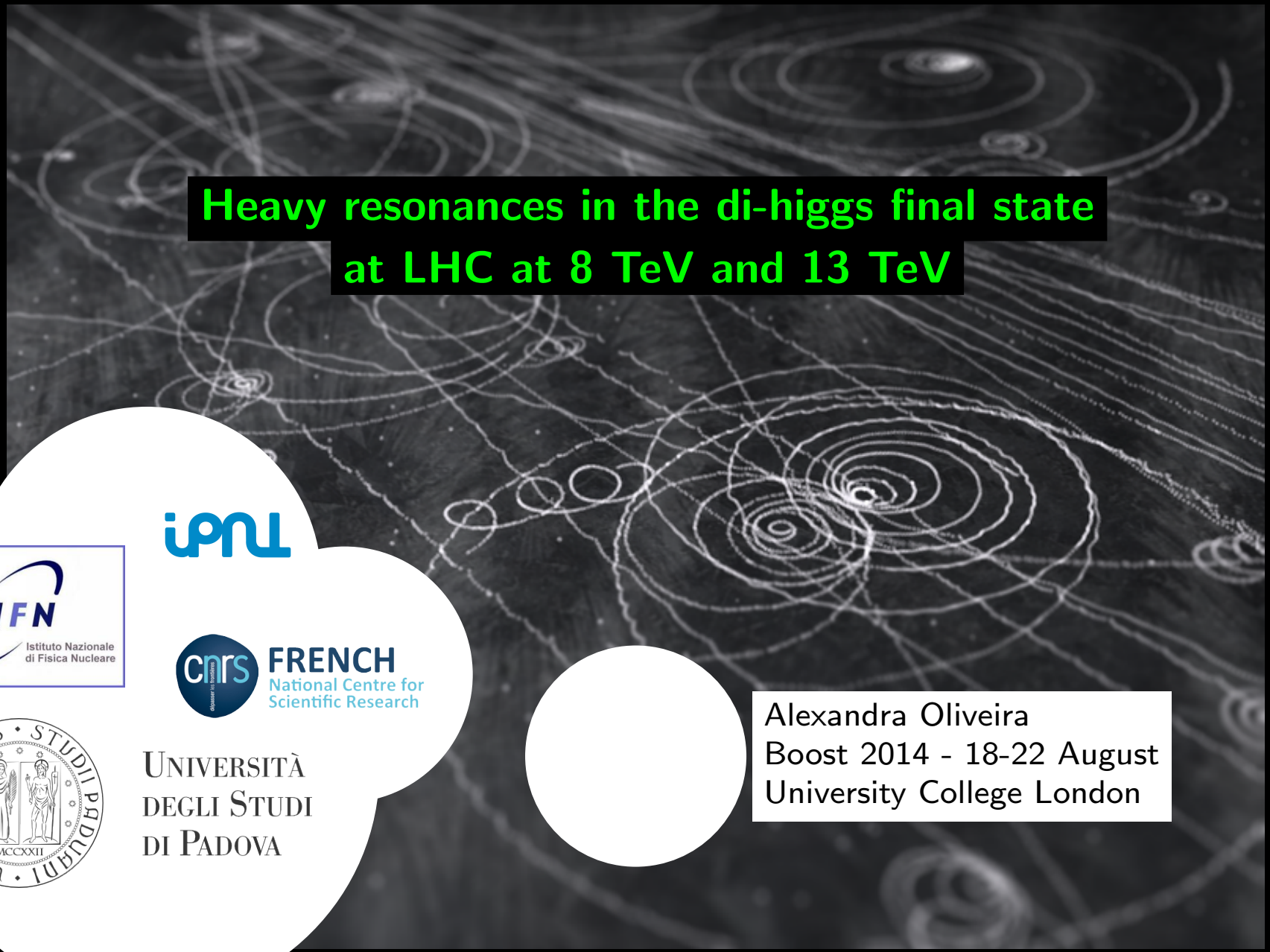


Heavy resonances in the di-higgs final state at LHC at 8 TeV and 13 TeV

Alexandra Oliveira

Boost 2014 - 18-22 August

University College London

Looking for new physics and the di-higgs channel

After the big discovery of a 125 GeV **very** SM higgs-like we expect more!

New Physics is expected to be linked to EWSB sector, whatever new state pops up it should also appear also in channels with higgs bosons in the final state.
How competitive this final state can be as a discovery channel?

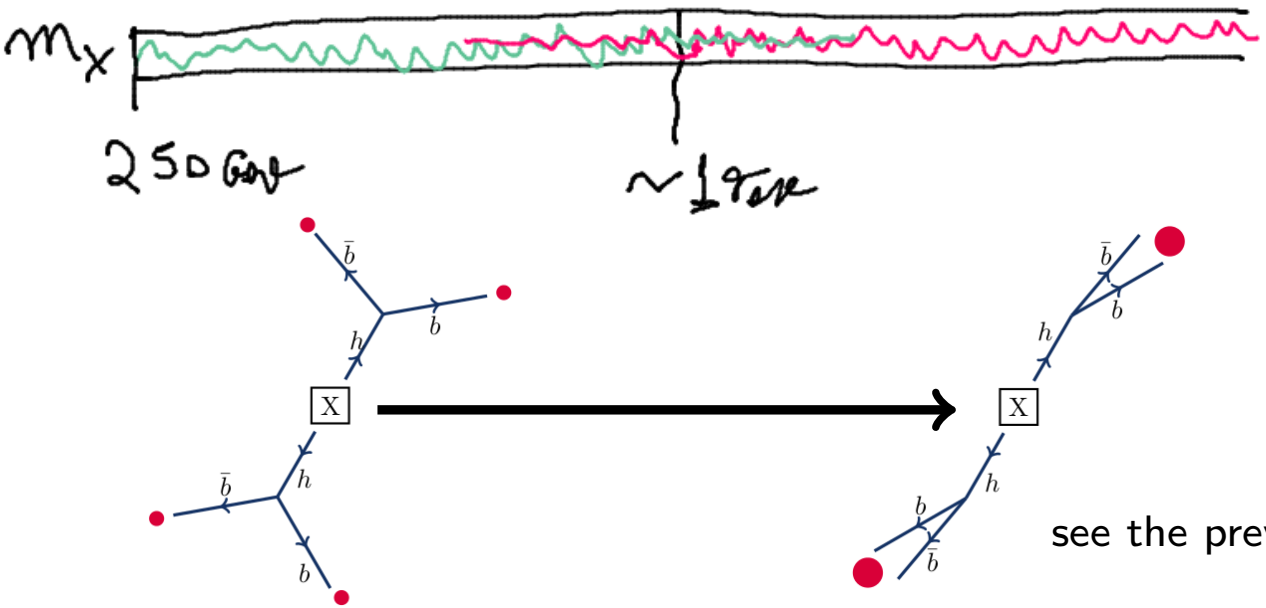
- Compare the recent released 8 TeV di-higgs searches with other channels
  $\Rightarrow$ spin-2 and spin-0 benchmarks where di-higgs is an important channel.

- Prospect the di-higgs channel for LHC Run II (sqrt(s) = 13 TeV)
  $\Rightarrow$ re-entering the scope of the session!

How to look for a di-higgs resonance?

When the resonance X is produced at rest and the higgses decay only to light states.

- $hh \to \gamma\gamma\, b\bar{b}$, 0.26% branching ratio for a SM-like higgs.
- $hh \to b\bar{b}\, b\bar{b}$, 33% " " ".

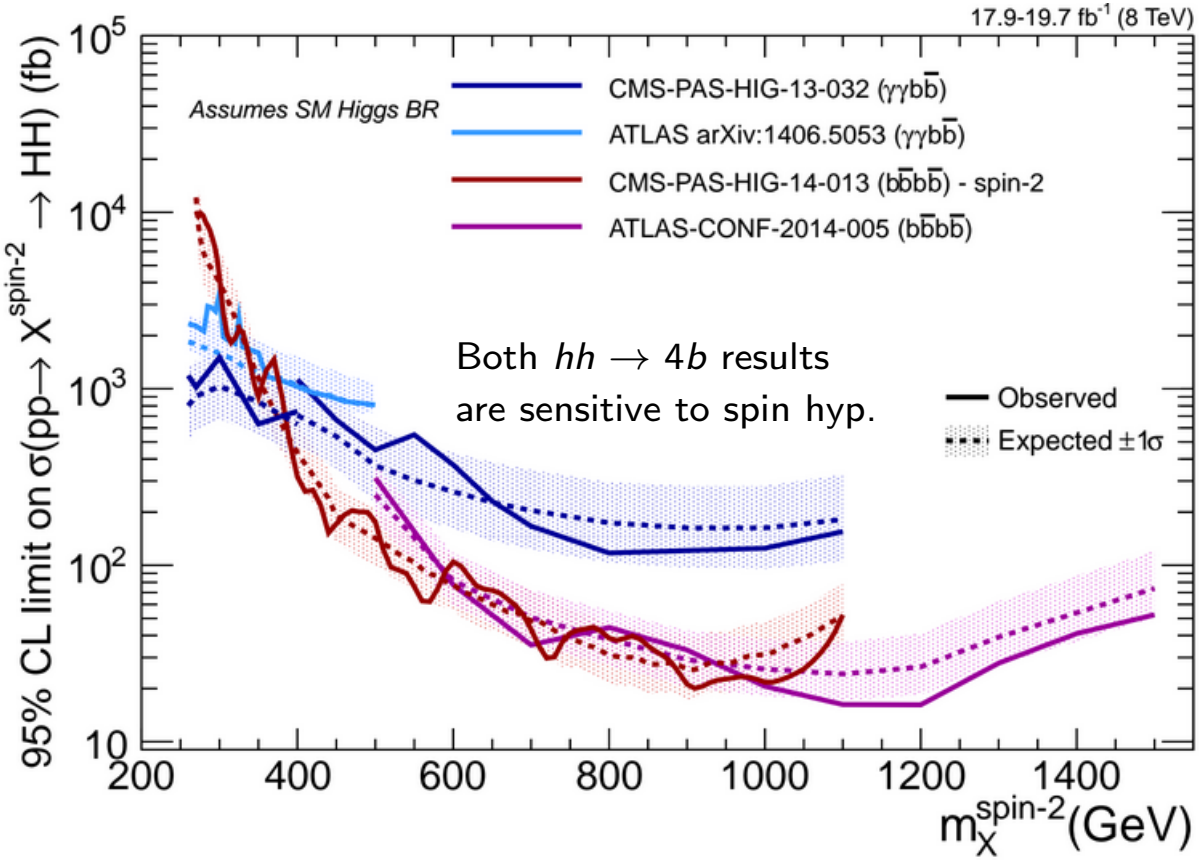


see the previous talk!

J.Rojo, G. Salam, M.Gouzevitch, V.Sanz, R.Rosenfeld, A.O'13
B.Cooper, N.Konstantinidis, L.Lambourne, D.Wardrope'13

The firsts di-higgs results from ATLAS and CMS

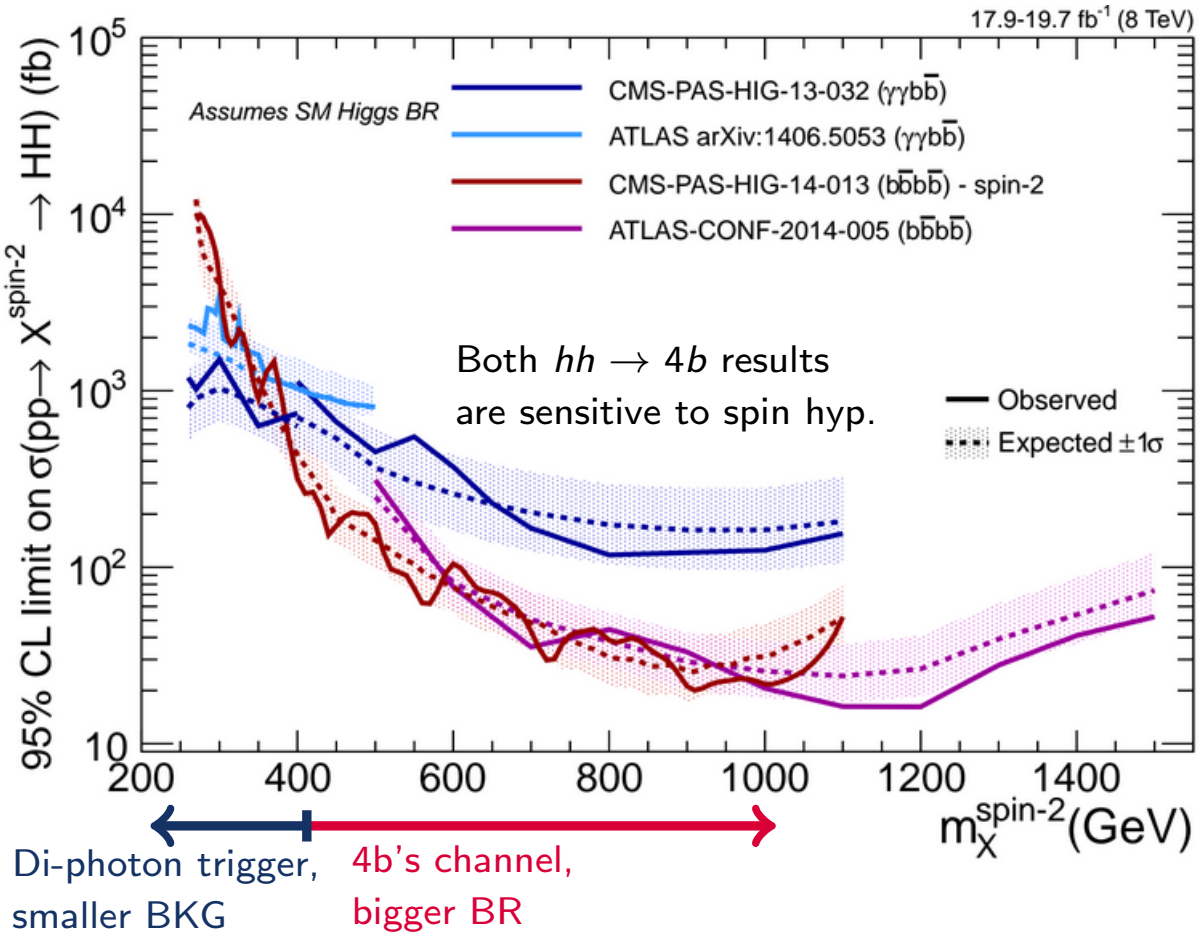
All resolved analysis! Full statistics of 8 TeV LHC run.



Thanks to all ATLAS and CMS teams for provide the info numerically!

See ATLAS and CMS talks tomorrow for a review of the analyses!

The firsts di-higgs results from ATLAS and CMS



If we assume the 125 GeV boson to be THE neutral component of the Higgs doublet

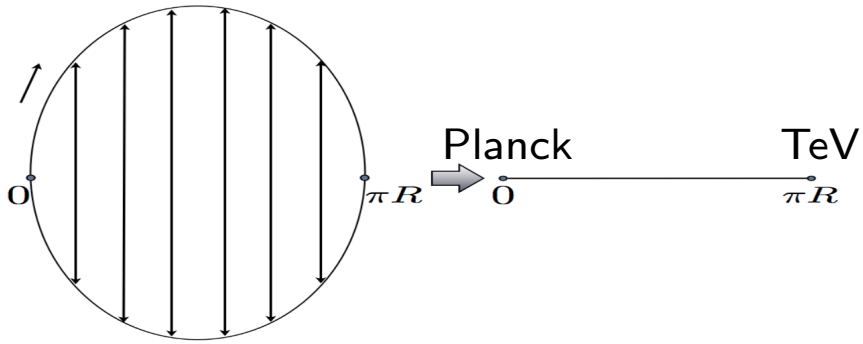
What couples to a SM-like higgs also couples at least to Weak bosons

We use as benchmark Warped Extra Dimension (Randall-Sundrum) scenario as examples where the NP resonance is linked to EWSB sector.

Super fast reminder:

The ED is introduced as a circumference compactified as a S_1/Z_2 symmetry.

A curvature factor (k) along the ED dilutes the mass hierarchy problem.



Perturbations of metric appears in 4D world as towers of spin-0 and spin-2 particles

First spin-2 mode: KK-graviton, massive

To define WED geometry and KK-graviton pheno:

$$\frac{k}{\overline{M}_P l} \sim O(1) \lesssim 2, \qquad m_{Gr} \sim O(0.1) - O(1) \text{ TeV}$$

L.Randall, R.Sundrum'99

Zero spin-0 mode: radion, additional mechanism is needed to make it massive.

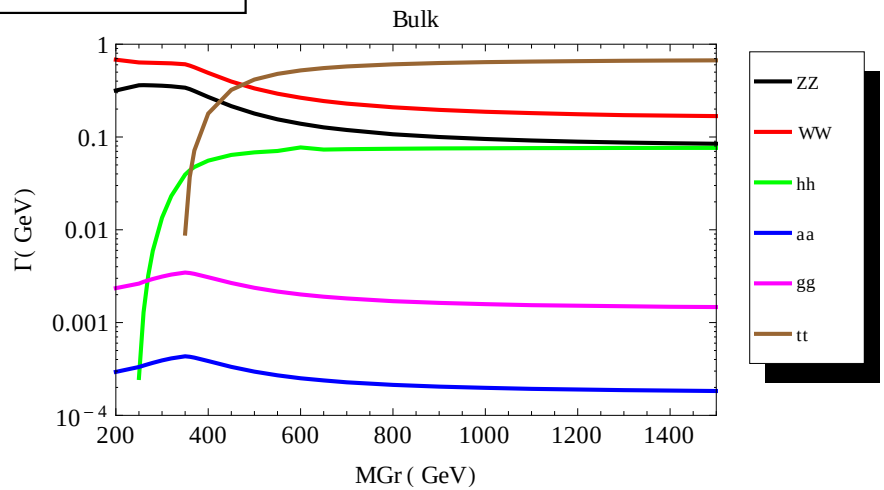
Goldberger Wise'99

KK-graviton

The di-higgs channel is interesting in the bulk matter scenario.

- couplings to light quarks can be neglected
- couplings to massless bosons are suppressed (wrt massive states)

⇒ Inclusive production is gluon fusion
⇒ Coupling to W/Z is mainly longitudinal modes
⇒ BRs to massive particles are dominant*



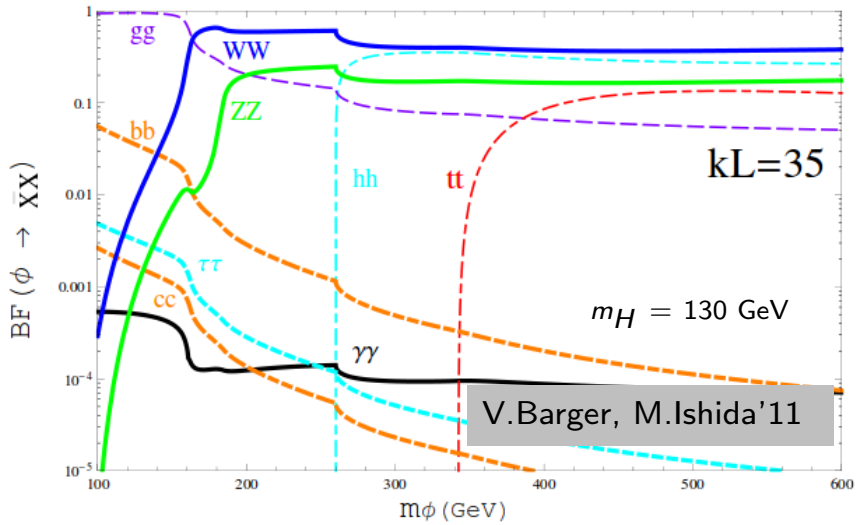
*For definitiveness we consider the fermion embedding introduced by H.Davoudiasl *et* all'00. (TeV localized RH top)

Radion

Very higgs boson like object

- Couplings with massive particles through mass term supressed by an overall UV mass scale.
- Couplings to non-massive particles through fermion loop, + **trace anomaly and bulk terms.**

⇒ Inclusive production is gluon fusion.
⇒ BRs to massive particles are dominant



The impact of bulk matter in radion BFs is minimal, see C.Csaki, J.Hubisz, S.J. Lee'07

Now we can check the power of the di-higgs channel

Comparing di-higgs searches with other channels

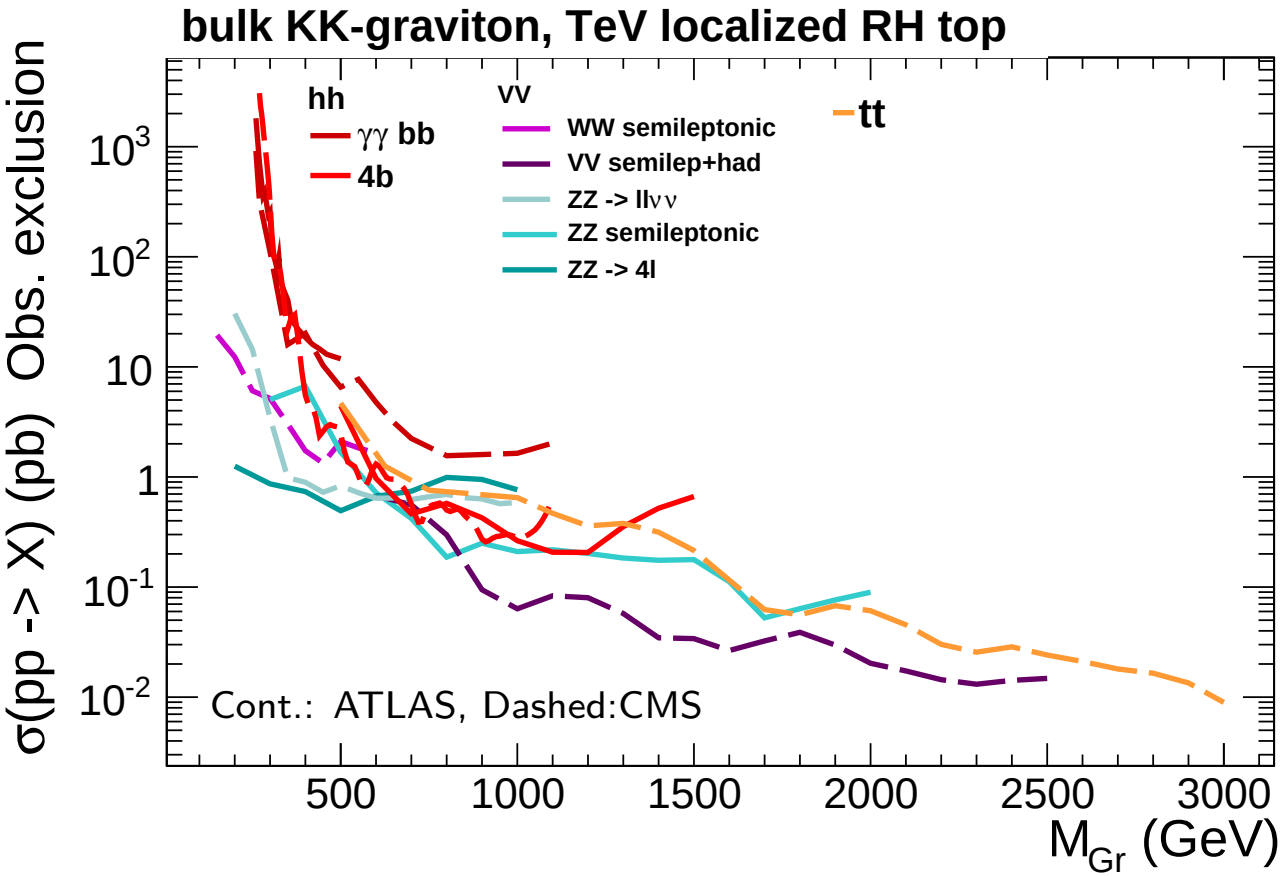
We consider only results with full 8 TeV statistics

Channel	Experiment	Reference	Range
VV had	CMS	1405.1994	500 GeV to 3 TeV
WW semileptonic	CMS	CMS-PAS-HIG-12-021	150 GeV - 600 GeV
	CMS	1405.3447	500 GeV to 3 TeV
ZZ semileptonic	ATLAS	ATLAS-CONF-2014-039	300 GeV - 2 TeV
	CMS	1405.3447	500 GeV to 3 TeV
$ZZ \to 4l$	ATLAS	ATLAS-CONF-2013-013	200 GeV - 1 TeV
$ZZ \to ll\nu\nu$	CMS	CMS-PAS-HIG-13-014	200 GeV - 1 TeV
$hh \to 4b$	ATLAS	ATLAS-CONF-2014-005	500 GeV - 1.5 TeV
	CMS	CMS-PAS-HIG-14-013	260 GeV - 1.1 TeV
$hh \to \gamma\gamma b\bar{b}$	ATLAS	1406.5053	260 GeV - 500 GeV
	CMS	CMS-PAS-HIG-13-032	260 GeV - 1.1 TeV
$t\bar{t}$	CMS	1309.2030	500 GeV - 3 TeV

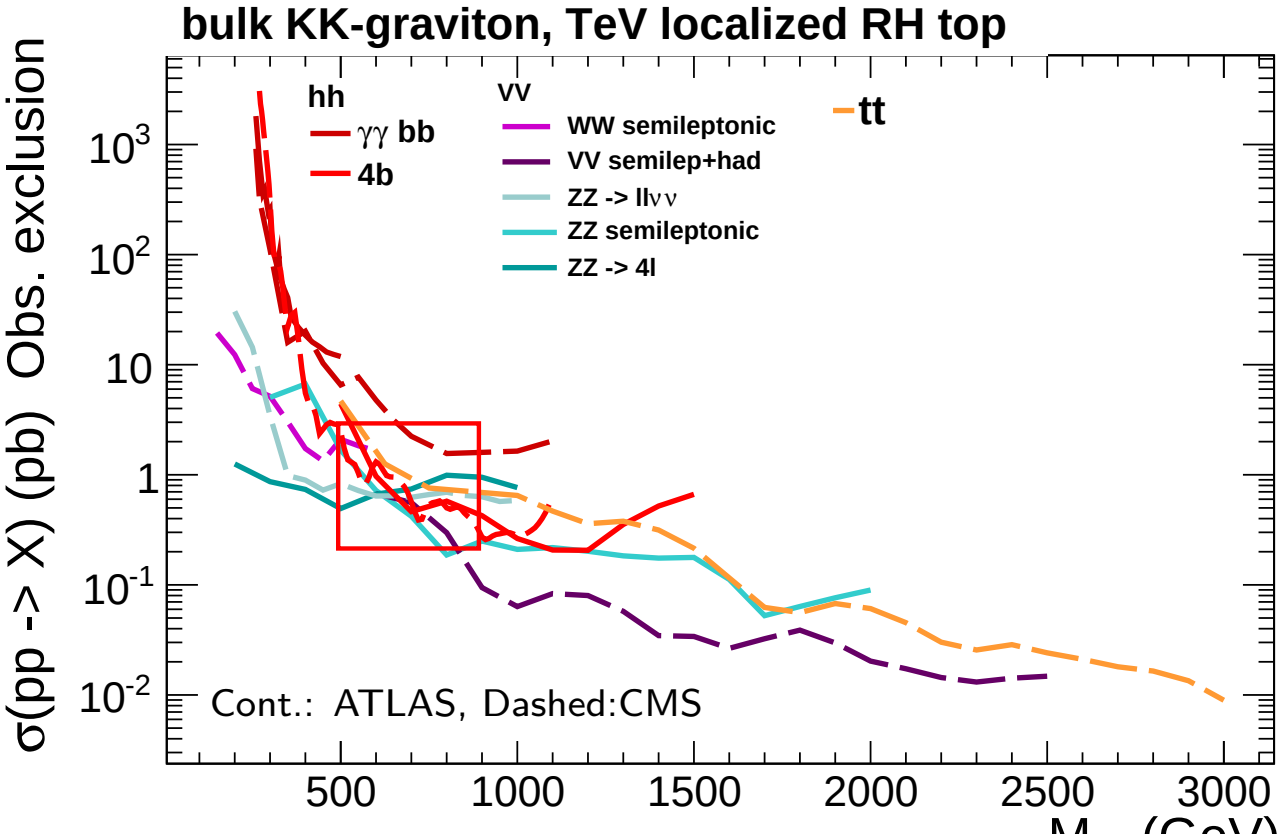
Thanks to M.Gouzevich, O.Bondu and P.Hebda for discussions in the analyses.

Comparing with other channels for bulk KK-graviton

Results that are not sensitive to spin hypothesis or where derived to the benchmark.

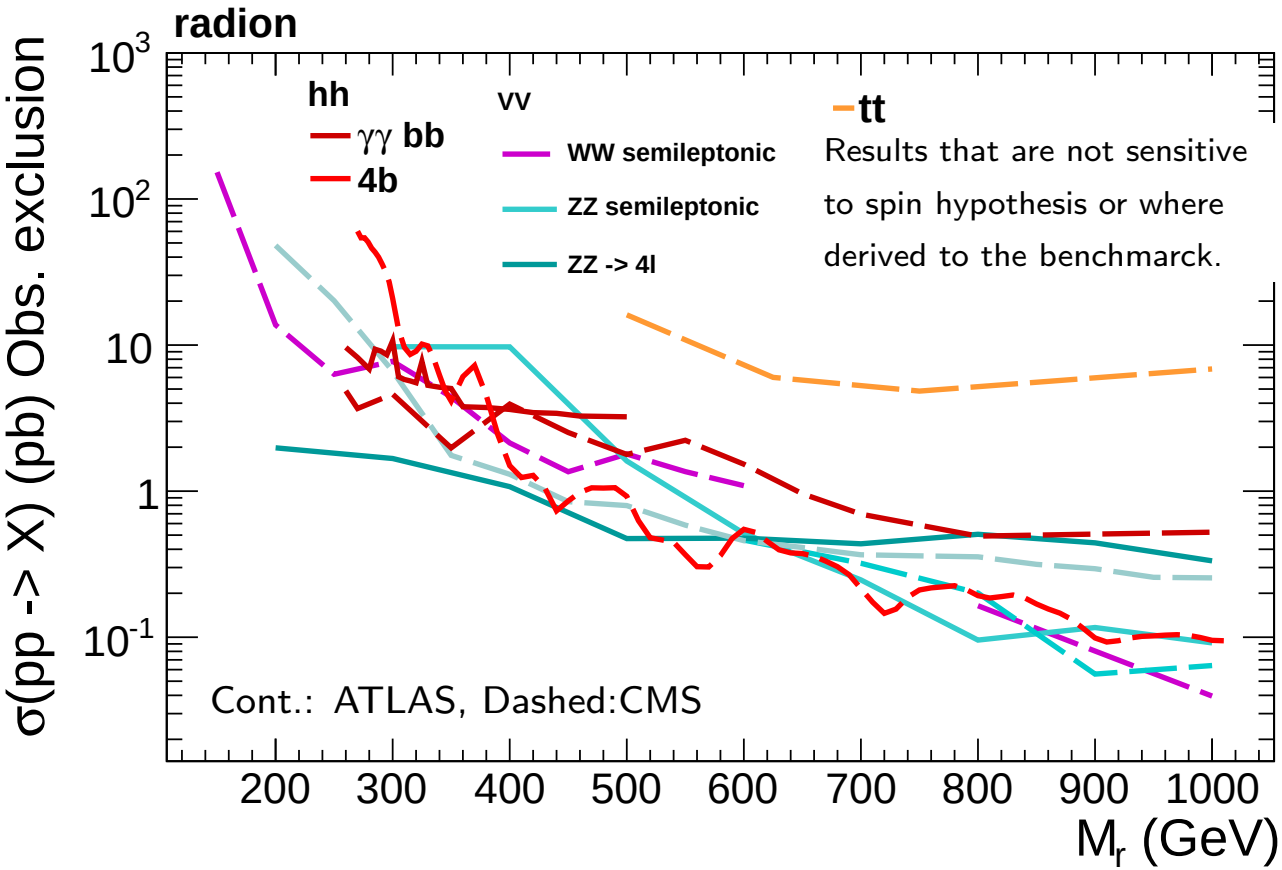


Comparing with other channels for bulk KK-graviton benchmark



Di-higgs channel is competitive with VV if $M_{Gr} \subset\sim$[500,900] GeV.

Comparing with other channels for radion benchmark



Di-higgs channel start to be competitive with VV in all search range

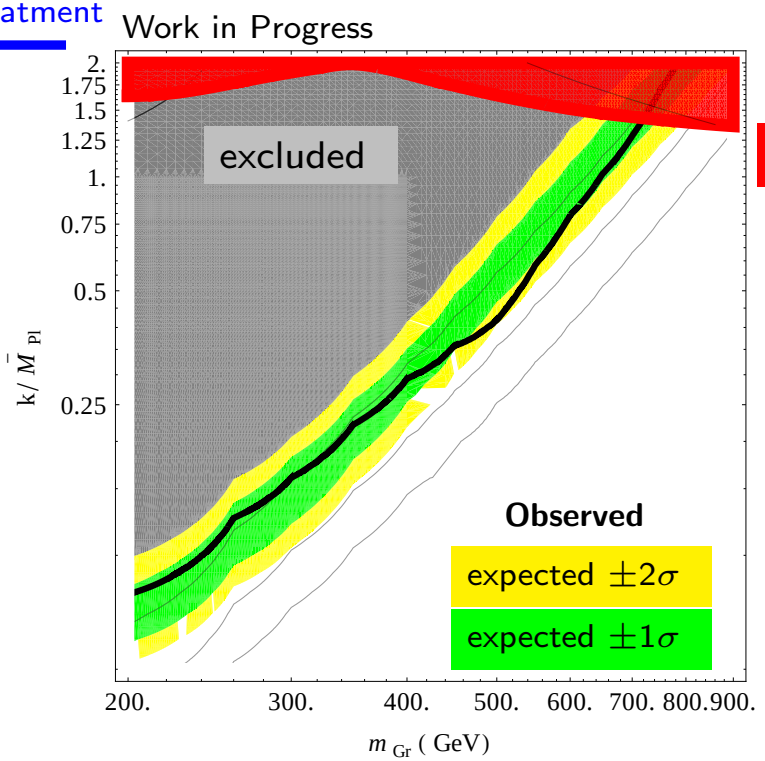
Thanks to V.Barger an M.Ishida for calculate the NLO radion BFs to 125 GeV higgs case.

What do LHC exclude from the bulk WED models?

Extreme case where spin-2 particle couples to Higgs sector + maximal $t\bar{t}$ coupling
Gluon fusion signal cross sections (CTEQ6L).

From the best expected limits for bulk KK-graviton inclusive production of each range:

Validity of perturbative treatment

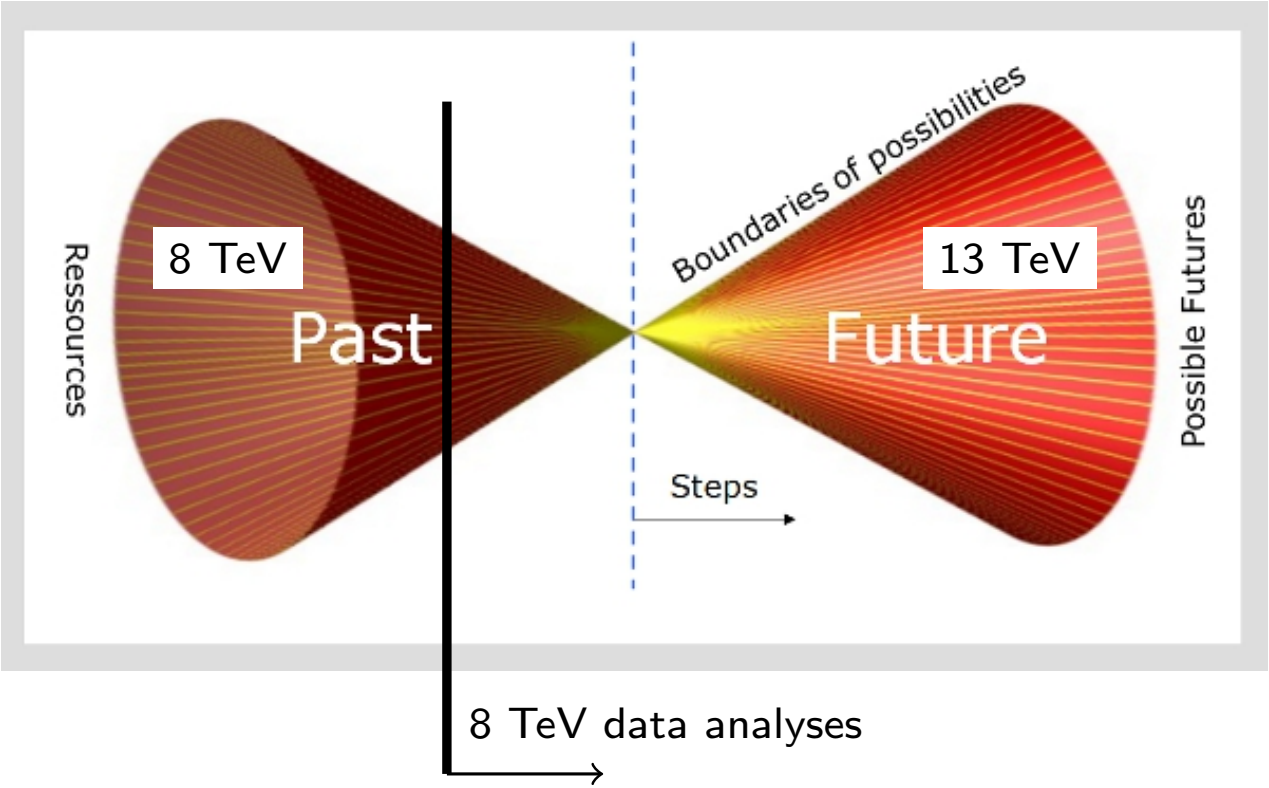


$\Gamma_{Gr} > M_{Gr} \times 10\%$

The validity of exclusion limits will depend of each analysis.

The scale of radion couplings is disconnected from the basic parameters of the theory.

What can we expect from LHC Run II



The inclusive channel in the $h(b\bar{b})h(b\bar{b})$ final state

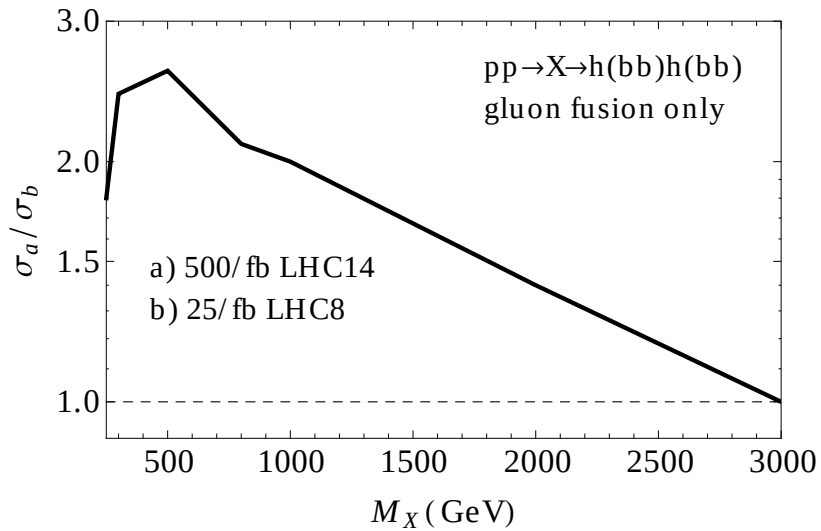
Estimation of the relative sensitivity gain when considering 25/fb data from LHC8 to 500/fb of data from LHC14.
Hadron level study, detector conditions mimic generic cylindrical detector@LHC8.

Scale invariant analysis strategy to interpolate topology regimes
mass-drop (CA1.1)+filtered mass (AkT0.3) to tag boosted and angular+mass cuts to tag resolved h's

BKG: QCD enriched with 2b and 4b (Pythia8)
Signal: inclusive gluon fusion
(CTEQ6L in M_X scale)

The signal σ increases with $\sqrt{s}$,
the QCD multi-jet BKG also increases.

⇒ The sensitivity gain decreases when the candidades resonance mass increases.



Interpretation of results of: J.Rojo, G. Salam, M.Gouzevitch, V.Sanz, R.Rosenfeld, A.O '13

Complementary production mode for a heavy di-higgs resonance?

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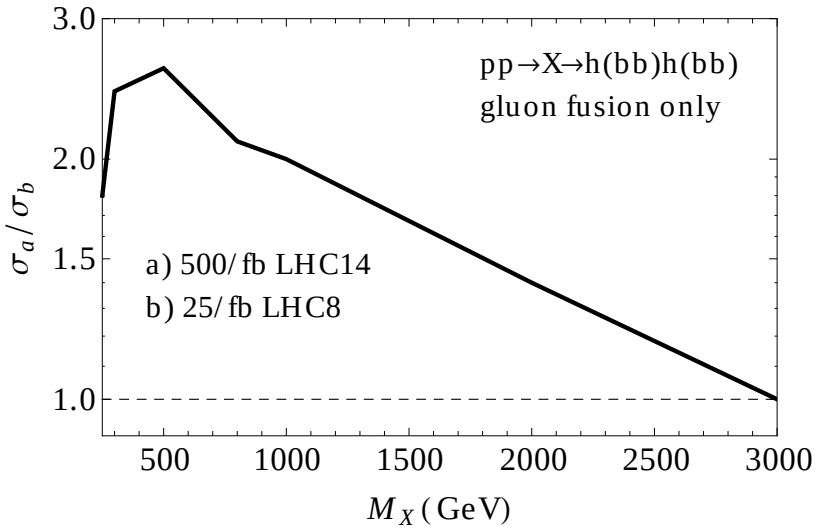
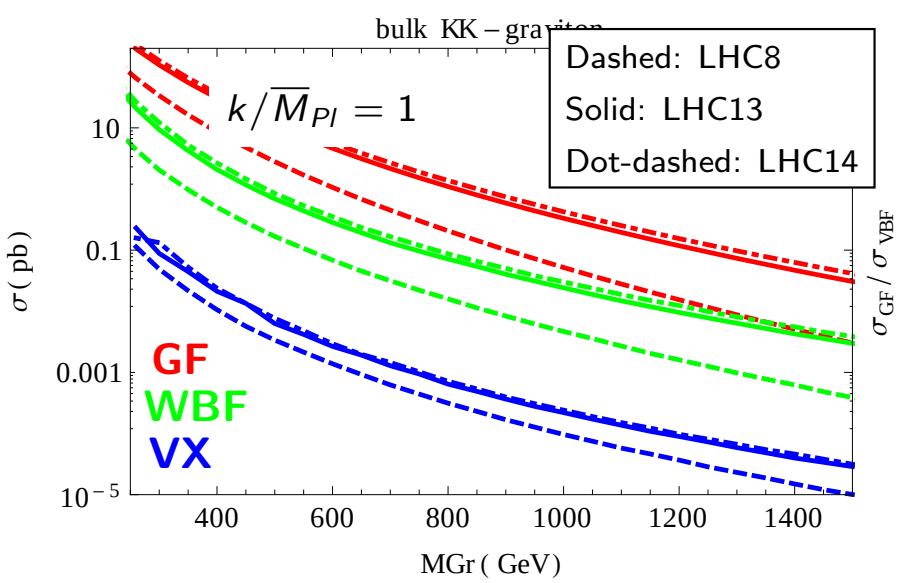


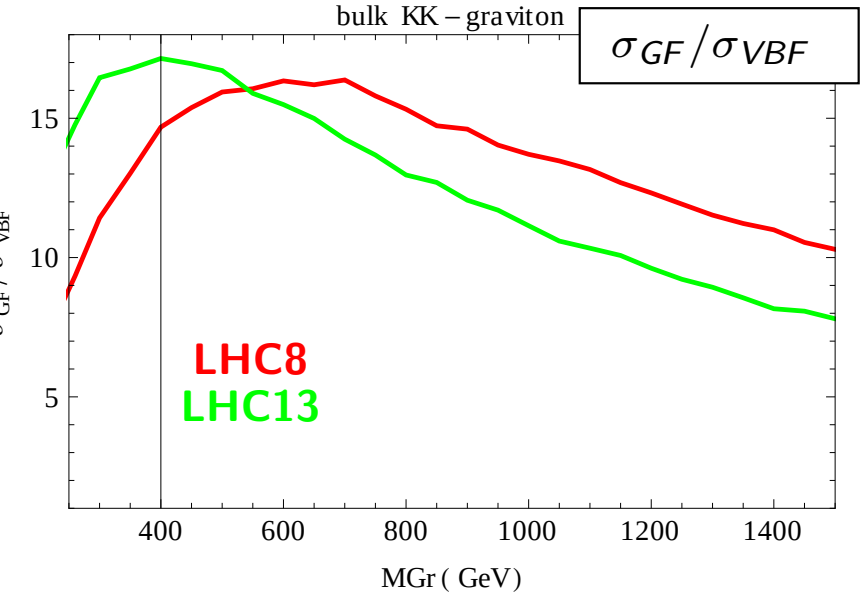
Interpretation of results of: J.Rojo, G. Salam, M.Gouzevitch, V.Sanz, R.Rosenfeld, A.O '13

Complementary production mode for a heavy di-higgs resonance?

VBF as complementary channel to look for bulk KK-gravitons

The VBF production mode at most 1 order of magnitude lower than GF!!!!

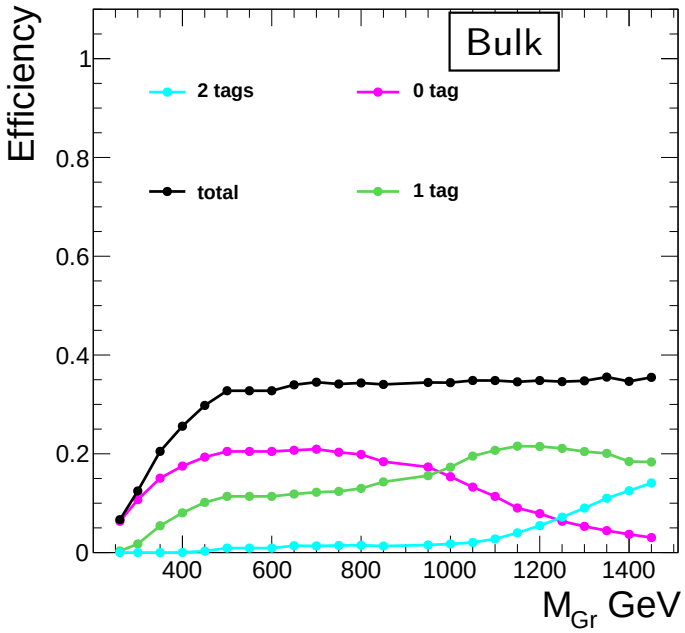




How the additional jets help in sensitivity?
In this case which is the signal topology of a $h(b\bar{b})h(b\bar{b})$?

The VBF mode for bulk KK-graviton $\rightarrow h(b\bar{b})h(b\bar{b})$

Scale invariant analysis strategy to study of number of fat-tags (mass-drop + filtered mass tag) + VBF cuts to signal reconstruction at parton level:



Back-reaction of the WBF jets in the resonance

$\Rightarrow$ A non negligible rate of signal have least one fat-jet in all the mass range.

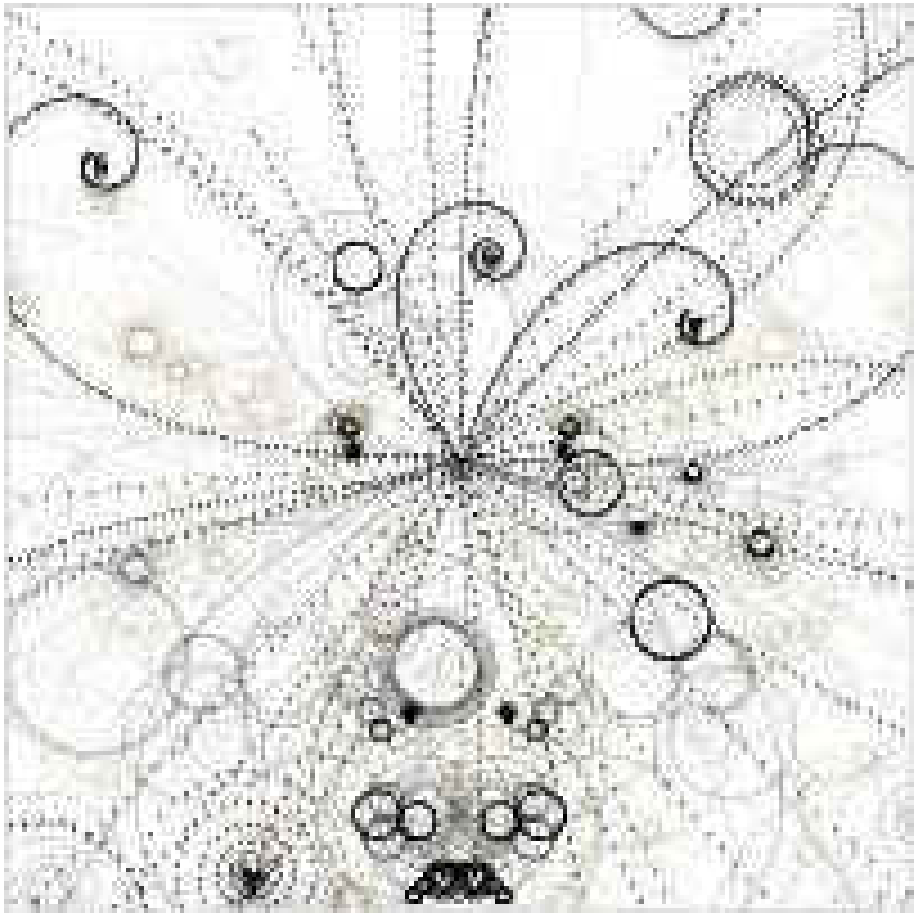
The complete results are working in progress.

Preliminary in V.Sanz, R.Rosenfeld, A.O, S.Belyaev, O. Bondu, A. Massironi - LH report 2014

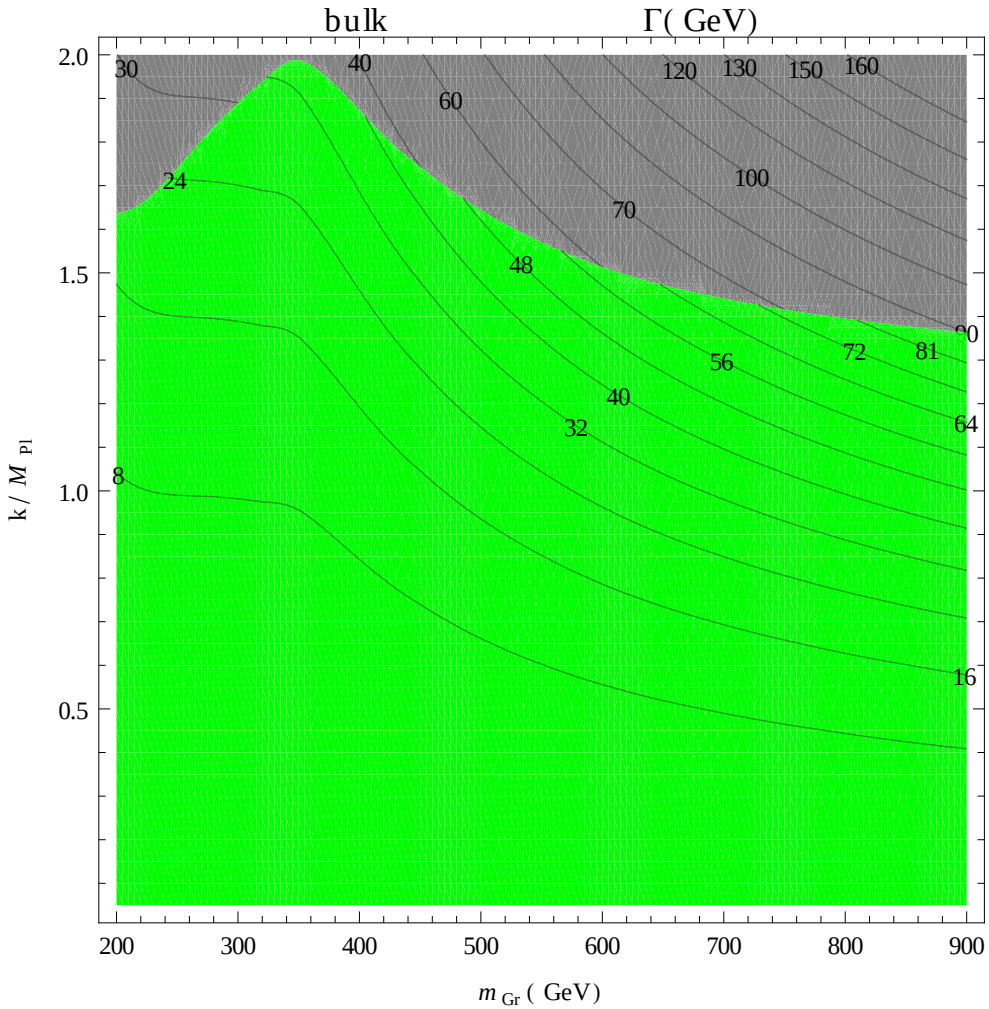
Conclusions

- Comparing the sensitivity of inclusive di-higgs searches with other channels:
  - In the spin-2 case, where the bulk KK-graviton search in di-higgs is motivated, this channel starts to be competitive with VV channel to resonance masses $\gtrsim$ 500 GeV. Spot for the $h(b\bar{b})h(b\bar{b})$ channel.
  - In the spin-0 case (radion) the di-higgs start to be competitive to $\gtrsim$ 260 GeV. Spot for both $h(b\bar{b})h(b\bar{b})$ and $h(\gamma\gamma)h(b\bar{b})$ channels.
- The LHC resonance searches are not yet sensitive to a TeV range KK-graviton from bulk WED scenario in the region where gravity can be treated perturbativelly.
- The VBF channel is a promising channel for di-higgs resonances.
  It requires use of sub-jet information for full profit of the channel.

Thank you for attention!

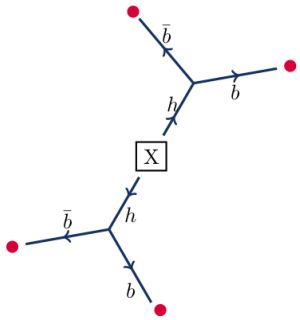


bulk KK-graviton total width



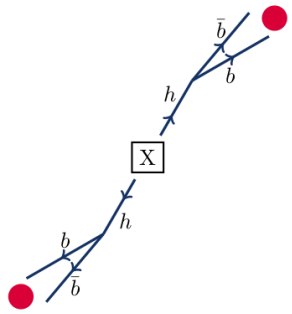
The scale invariant tagger

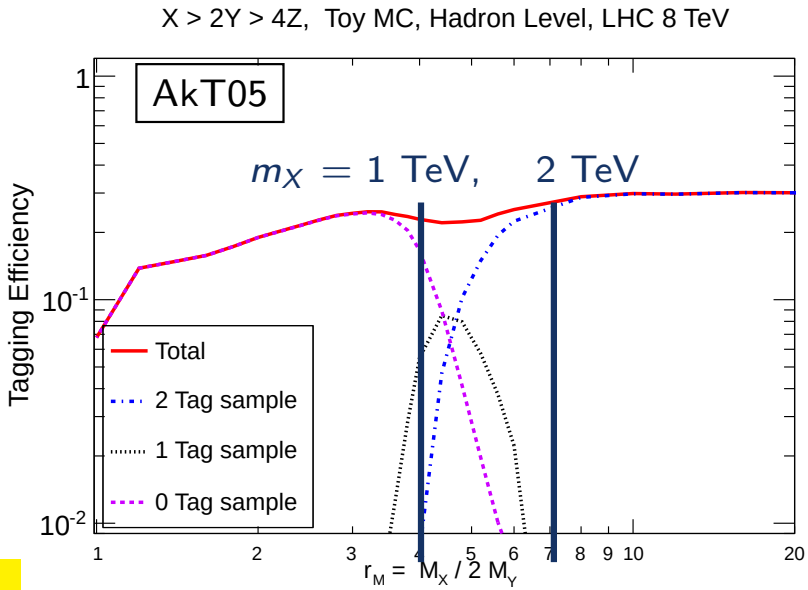
In principle one unique analysis can combine resolved and boosted analysis techniques.
`Pythia8` shower but no hadronization.



boost $= m_X/2m_h$

Transition point
3 jets case (1 fat jet higgs tagged)

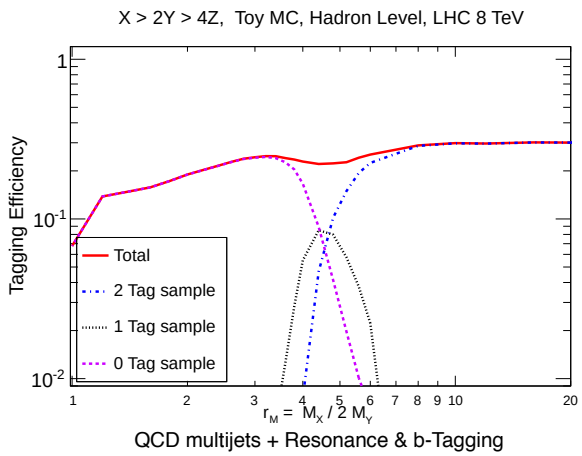


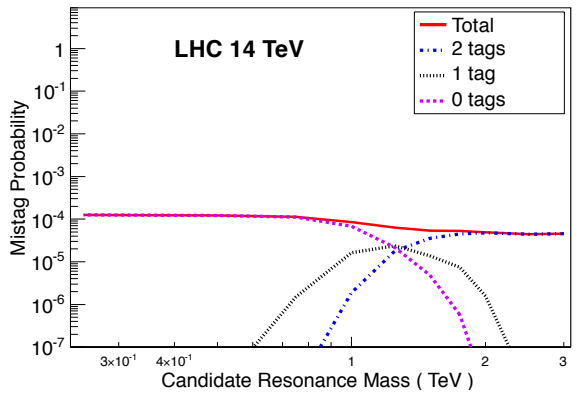


arxiv : 1303.6636*

Inclusive production - Scale invariant tagger

We classify events in number of fat tags to reach scale invariant efficiency.





higgses reconstruction:

15% of mass window tolerance.

$\Delta y^{jj}_{max} = 1.3$ avoids t–channel QCD radiation.

***X* reconstruction:**

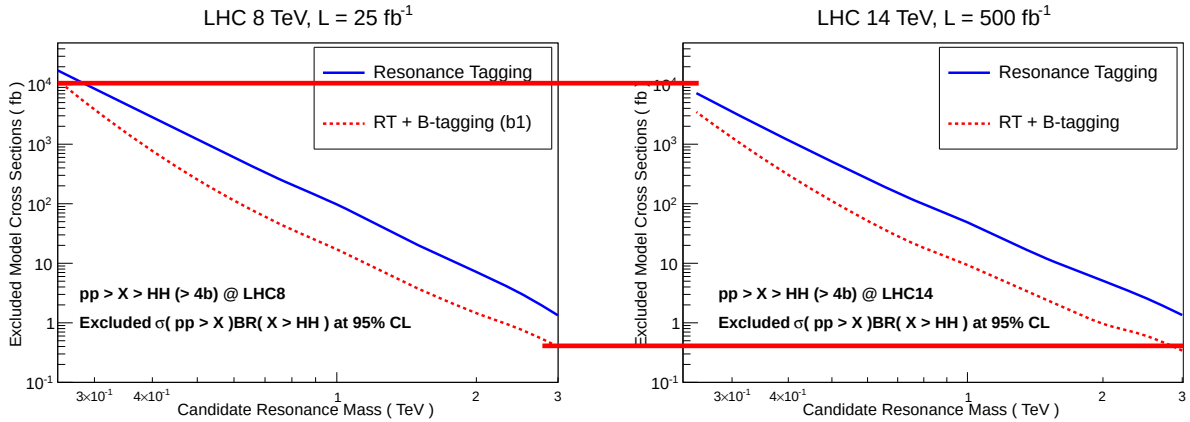
15% of mass window tolerance.

$\Delta y^{res\ HH}_{max} = 1.5$ assures flat parton level eff.

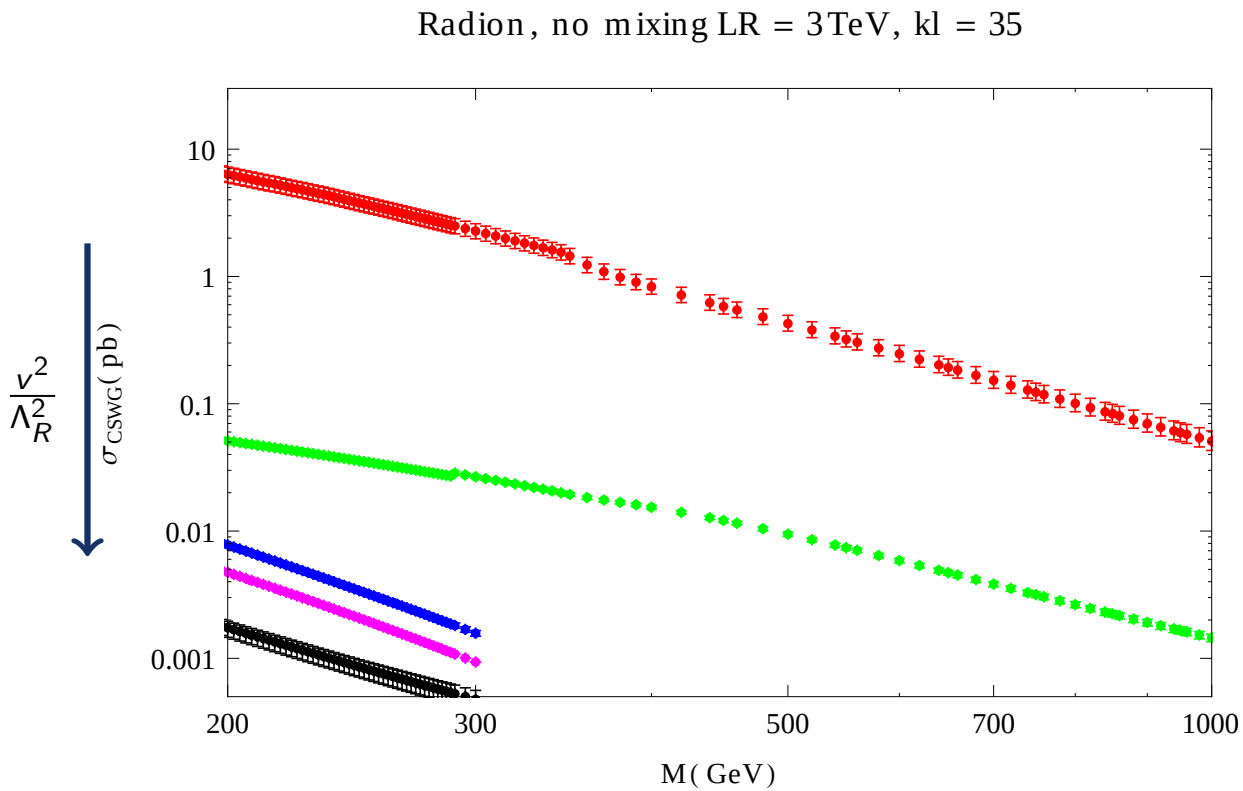
higgses reco quality:

Resolved: Minimal $|m_{ij} - m_{kl}|$.

Similar angular and mass symmetry requirements are used in all regimes.



VBF for radion



**At first approximation SM higgs production and decay state-of art radiative corrections (NLL QCD + NLO EW) can be extrapolated to radion case.