THE PHYSICS OF HIGH-LUMINOSITY LHC

PIACENZA, NOV 30 2017

Patrizia Azzi, INFN-PD

WHAT AFTER LHC?

- Standard Model works beautifully at the LHC: no direct evidence of new physics
- Key questions remain unanswered
  - What gives rise to the matter-antimatter asymmetry in the universe?
  - What is dark matter made of? What is dark energy?
  - Why is gravity so weak? ➔ hierarchy problem
    - Small Higgs mass requires spectacular cancellations if SM is valid to Planck scale
    - Strong motivation for new physics at the TeV scale (➔ new particles, interactions, dimensions)
- The answers may still lie at the TeV scale…
- HL-LHC will deliver 3/ab (x50 today's data sample) @ 14 TeV
  - Study the Higgs boson in detail —> BSM physics could manifest itself in deviations from SM predictions
  - Measure rare SM processes —> BSM could have a large effect
  - Search for new particles/phenomena at the TeV scale
- HE-LHC might double the collision energy to 27 TeV
  - Higher mass reach for new physics – deeper exploration of TeV scale

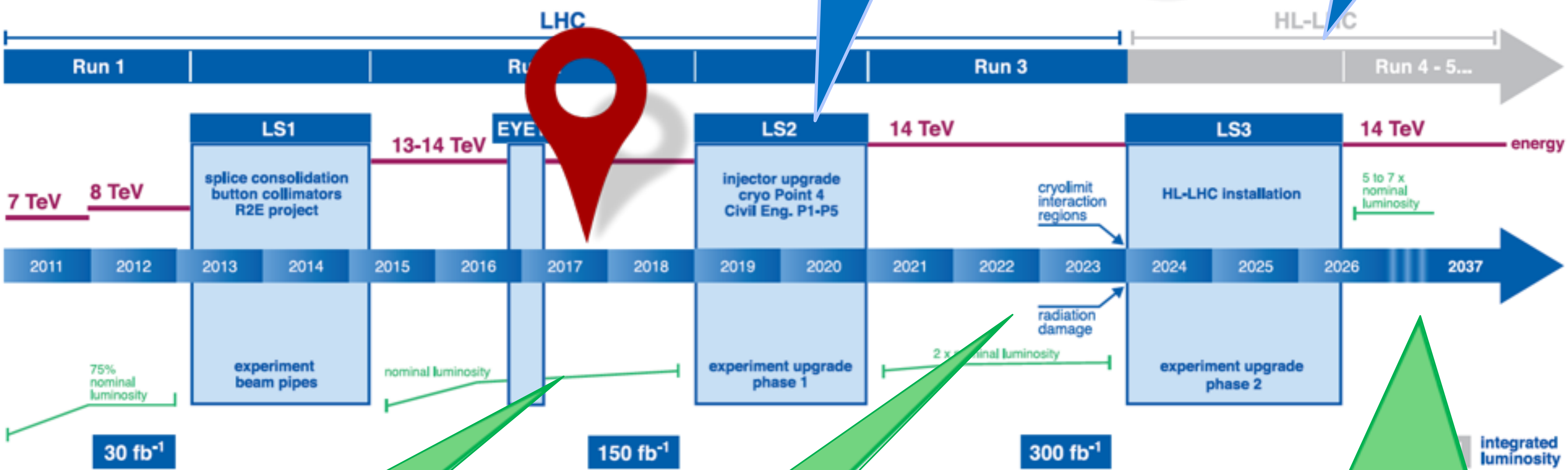
My view: take the opportunity to ask ourselves not hat we CAN do at HL-LHC but what do we NEED to study.

upgrade of injector chain to deliver brighter bunches

new interaction region layout and crab cavity

LHC

HL-LHC



Run 2:
Design $\mathcal{L} = 10^{34}/cm^2/s$

Run 3:
$\mathcal{L} = 2{\times}10^{34}/cm^2/s$
for 300/fb

HL-LHC: Peak $\mathcal{L} = 2 \times 10^{35}/cm^2/s$
level luminosity to
Nominal scenario: $\mathcal{L} = 5 \times 10^{34}/cm^2/s$
for 3000/fb; Pile-up <μ> = 140
Ultimate Scenario: $\mathcal{L} = 7.5 \times 10^{34}/cm^2/s$
for 4000/fb; Pile-up <μ> = 200
⇒25% increase in integrated lum.

HL-LHC PLAN

HE-LHC

- Center of mass energy: 27 TeV pp collision
  - [~ 14 TeV x 16 T/8.33T]
  - "This "Energy Doubler" option with high-field magnets constitutes an adiabatic approach to pp-collisions at higher energy."*[1]
  - Target luminosity ≥ 4 x HL-LHC
  - Integrated Luminosity: >10 ab^{-1} over 20 years
- Pile up of up to ~800 at 25 ns bunch spacing
  - (~400 at 12.5 ns or with luminosity leveling)
  - excellent prospects for lepton-hadron & heavy-ion collisions

- HE-LHC main challenges
  - Technical schedule defined by the magnet program
- Earliest technically possible start of physics: 2040
  - This would require HL-LHC stop at LS5 (in 2034)

- [1] For details see presentations at the HL/HE-LHC kick-off workshop at CERN: https://indico.cern.ch/event/647676/.

Workshop Goals

http://lpcc.web.cern.ch/hlhe-lhc-physics-workshop

- **Review, extend and further refine our understanding of the physics potential of HL-LHC**
  - stimulate new ideas for measurements and observables,
  - extend the LHC discovery reach
  - improve the modelling of LHC phenomena towards measurements at ultimate precision
  - prepare to exploit the HL-LHC data to the fullest possible extent.
  - begin a more systematic study of physics at the HE-LHC (a possible pp collider in the LHC ring with energy of about 27 TeV).

- **5 Working Groups (organised by WG convenors, 1 from each LHC experiment and 2 from theory):**
  - Standard Model: Patrizia Azzi - CMS UPSG L3: Jan Kieseler, Sasha Savin
  - Higgs: Maria Cepeda - CMS UPSG L3: Maria Cepeda, Predrag Milenovic
  - BSM: Keith Ulmer - CMS UPSG L3: Kerstin Höpfner, Juliette Alimena
  - Flavour: Sandra Malvezzi - CMS UPSG L3: Jan Kieseler, Sasha Savin
  - Heavy Ions: Yen-Jie Lee - directly with HIN PAG: Marta Verweij, Camelia Mironov

- **The results of the Workshop will be documented in a Yellow Report, to be completed by the end of 2018 for submission to the next review of the European strategy for particle physics.**

Yellow Report Structure and Authorship

- **5 chapters (one per WG):**
  - Max. 150 pages each (full detailed descriptions can be published separately by respective authors)
  - Chapters will submitted to arXiv individually and also to the European Strategy repository of submissions
  - Physical Yellow Report will be assembled as a book, once all is in place. An additional Executive Summary is being considered.

- **Authorship: each chapter is authored by a group of individuals (not by the collaborations).**
  - Names of steering group contacts will be on the Yellow Report title page.
  - Chapters will be signed by the WG convenors + contributors.
  - List of CMS contributors (CMS members signing the chapter as individuals) will be defined by CMS WG convenor. Persons qualify as CMS contributors through
    - active contribution to the working group and CMS UPSG, e.g. through talks,
    - production and documentation of analysis results
    - development and maintenance of necessary technical tools and infrastructure, including Monte Carlo production and validation.

  We hope/think that this regulation will provide an incentive for CMS members to centrally contribute to the CMS effort

- **Public results from CMS (same for ATLAS):**
  - Will be documented in public documents (TDR and PAS, authored by the CMS Collaboration)
  - (According to a compromise with ATLAS) the relevant CMS PAS (and ATLAS notes) will be collated in a Volume 2 of the Yellow Report where they can be referenced from Volume 1

WORKSHOP TIMELINE

- **WG meetings timeline**
  - Kick-off Meeting 30 Oct-1 Nov 2017
  - In the coming year: periodic WG meetings, organized by the individual WGs
    - least one meeting before Xmas
    - a few more before June
    - possibly a meeting in the US in Spring (joined between two or more WG?)
  - Next plenary meeting tentatively scheduled for week of June 18, 2018

- **Report timeline:**
  - December 2017: skeleton Table of Contents with list of top-priority items
  - March/April 2018: Draft Table of Contents
  - June 2018 (Plenary Meeting): Close-to-final Table of Contents, start filling with material
  - September 2018: Full draft
  - December 2018: Submission

➤CMS UPSG will still be dealing with LHCC for HGCAL TDR in Jan/Feb 2018

➤Real work for HL workshop should start in January though, possibly adding resources from PAGs.

➤Analysis groups not involved in TDR work

  ➤ Higgs is special case. As extrapolation strictly connected to Run2 results.

CMS Resources

- **Overlap with TDR efforts will continue until early 2018.**
  At the same timescale each WG is expected to:
    - Produce draft table of contents
    - Start / continue analyses for delivery of final results by June 2018
    - Organise at least one (better two) WG meetings

- **So far, no influx of new people into UPSG**
  - Zero new people have volunteered for physics or for basic tool development
  - Enhanced risk of loosing people to YR, as individual contributions are encouraged.

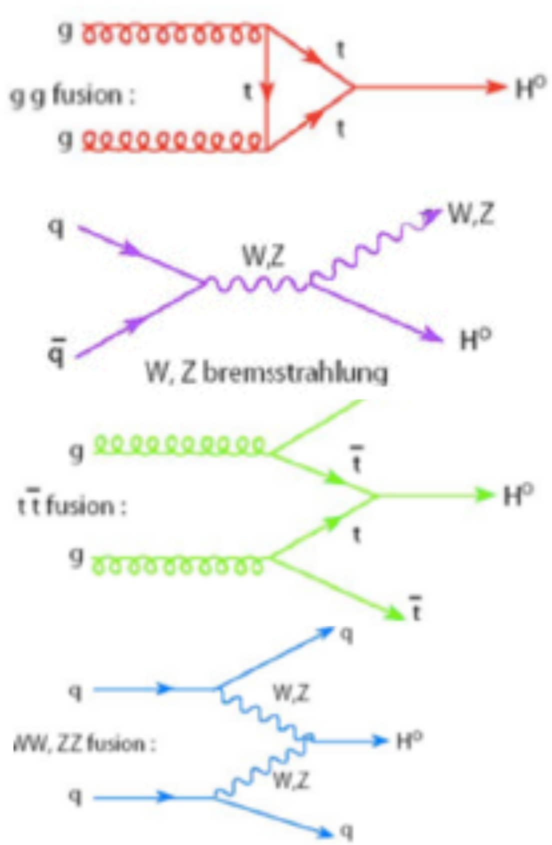
- **Advertise work within CMS:**
  - must-have physics topics
  - development and maintenance of tools, infrastructure and production data samples

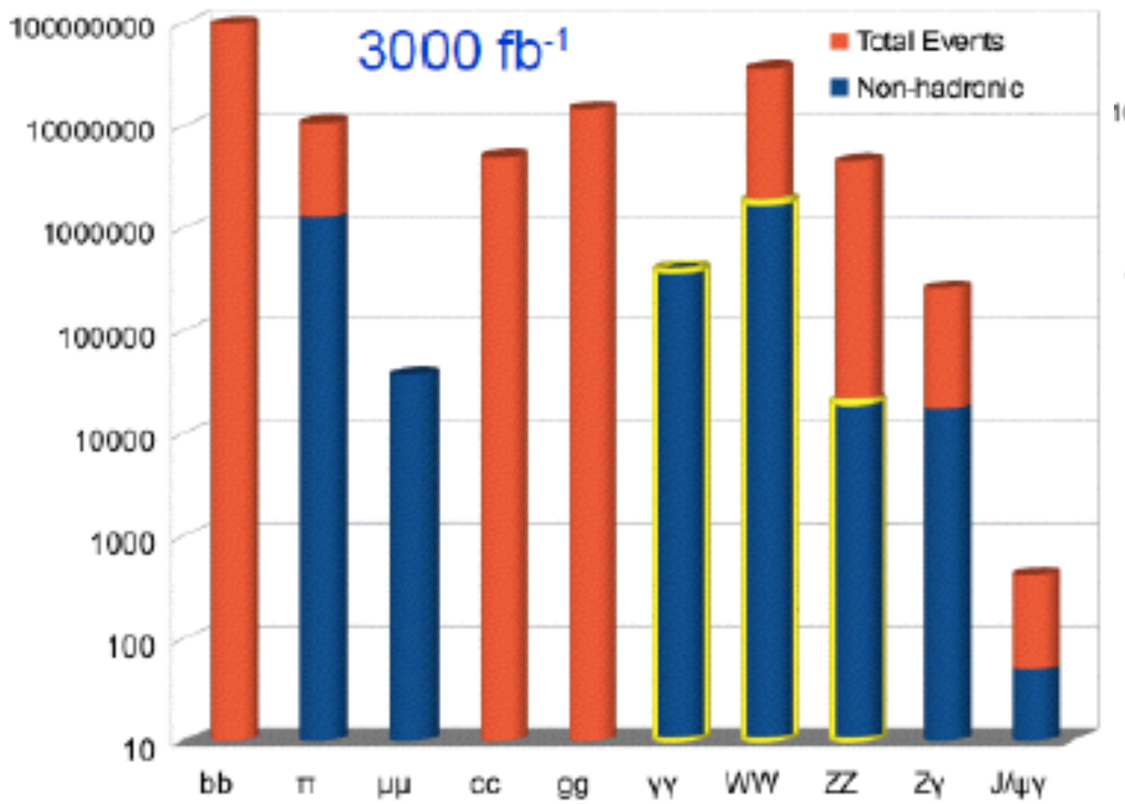
- **Limit/control additional work on CMS-non-specific aspects**
  - e.g. “generic” DELPHES or even common samples. Need to make a detailed task list in order to control and limit exhaustion of our limited resources

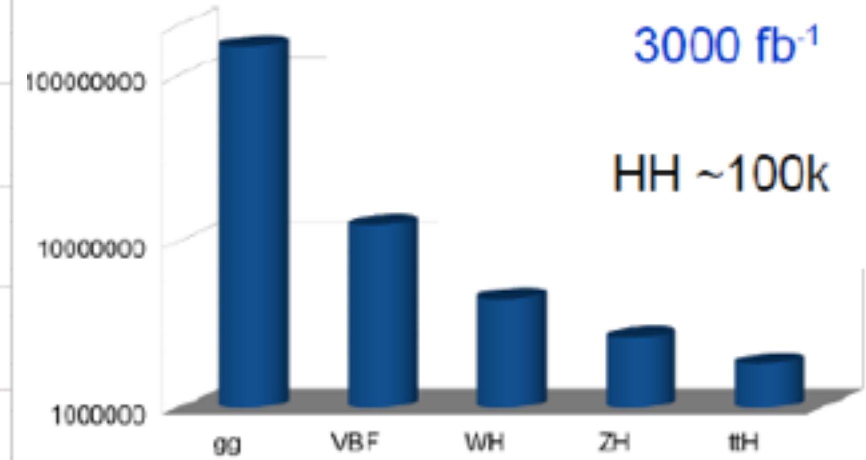
THE HIGGS SECTOR

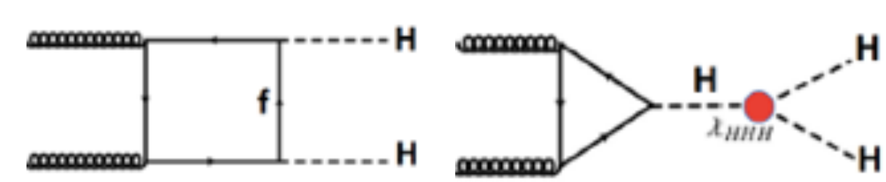
HL-LHC AS A HIGGS FACTORY

- ➤At HL-LHC, we expect to produce ~170M Higgs Bosons, including ~120k of pair produced events
- ➤Over 1Million for each of the main production mechanisms, spread over many decay





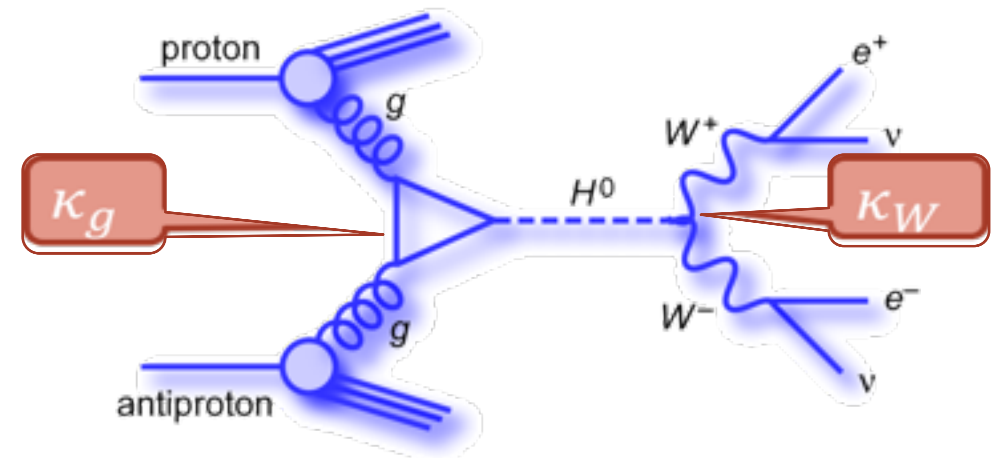


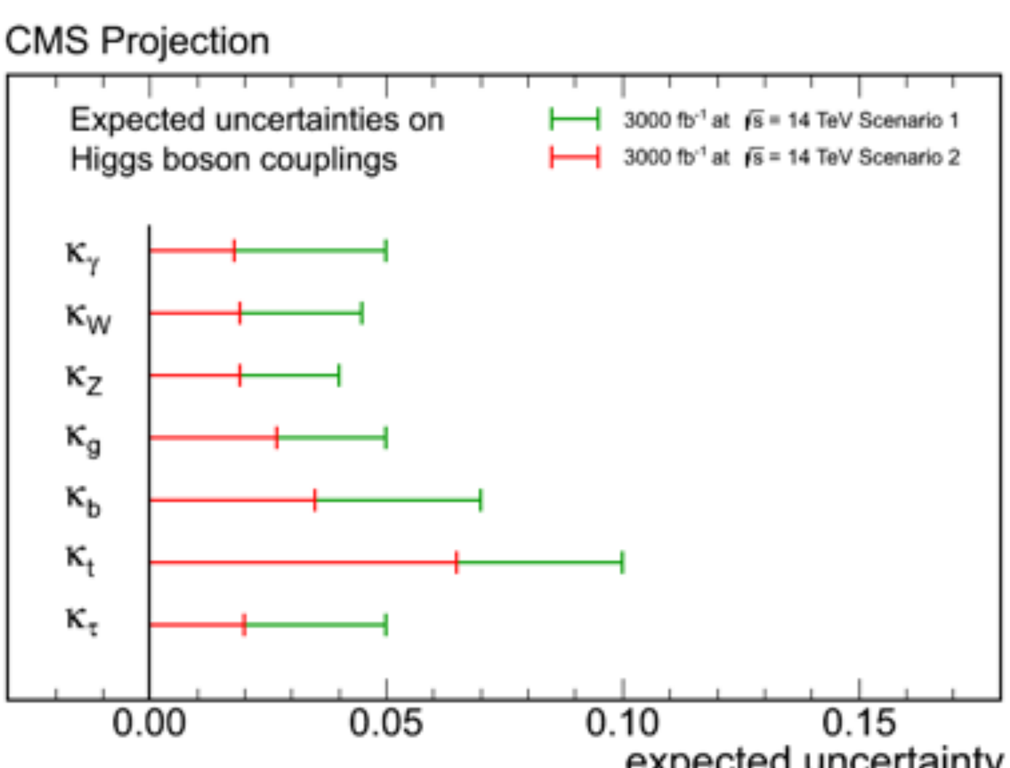


- ➤Enables a broad program:
  - ➤ Precision O(few-10%) measurements of coupling across broad kinematics
  - ➤ Exploration of Higgs potential (hh production)
  - ➤ Sensitivity to rare decays involving new physics
  - ➤ extend BSM Higgs searches (extra scalars, BSM Higgs resonances, exotic decays…)

HIGGS COUPLINGS

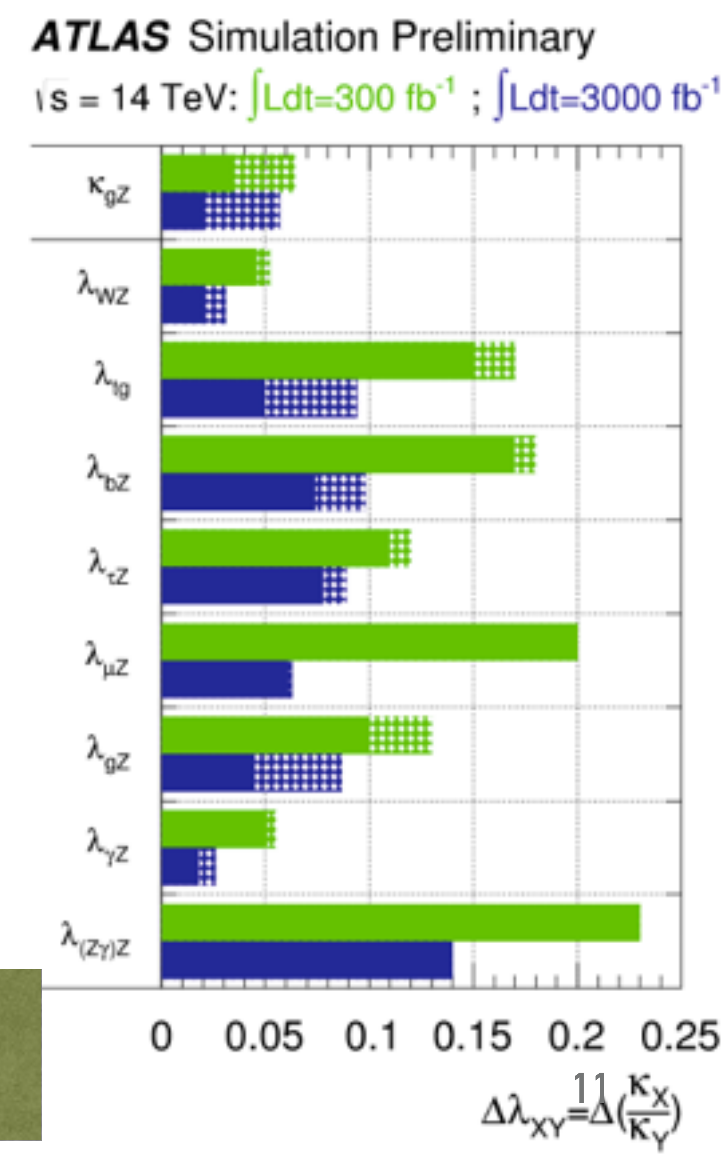
- Coupling measurements:
- Rate of a given process depends on several couplings
- Example gg→h→WW: $\sigma B \propto \frac{\kappa_g^2 \kappa_W^2}{\kappa_H^2}$
  - The κ's multiply the SM couplings. κ_g is a function of κ_t and κ_b.
  - κ_H multiplies the Higgs width and depends on all couplings
- Currently κ's are typically measured to ≈20%.
- Expected deviations from SM predictions by various models (Singlet mixing, 2HDM, Decoupling MSSM, Composite, Top Partner..) predicted to be between 1-10%.
- Comprehensive study of Higgs couplings at the HL-LHC





Projections at 3-10%-level with 3000 fb^{-1}.
HL-LHC will improve measurement precision by a factor 2-3!

Reduced theoretical uncertainties needed (improvement since 2014)



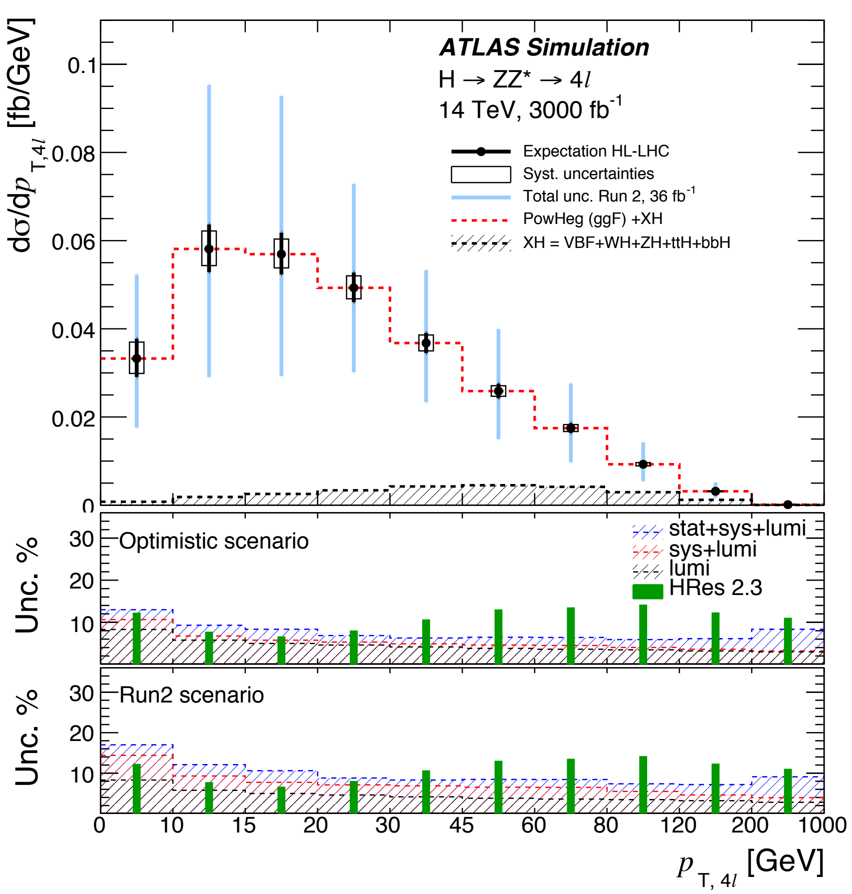
New extrapolations will be done in 2018 based on Run2 data

HIGGS PRODUCTION & COUPLINGS (H →ZZ)

Differential Cross Section $p_T(h)$

- probes perturbative QCD calculations
- information on (new) particles contribution to the gluon fusion loop
- Sensitive to κ_b/κ_c (low p_T) κ_t/BSM (high p_T)

- @high p_T dominated by stat. unc ≈4-9%
- For 300 fb^{-1} stat. uncertainty: 10-29%!



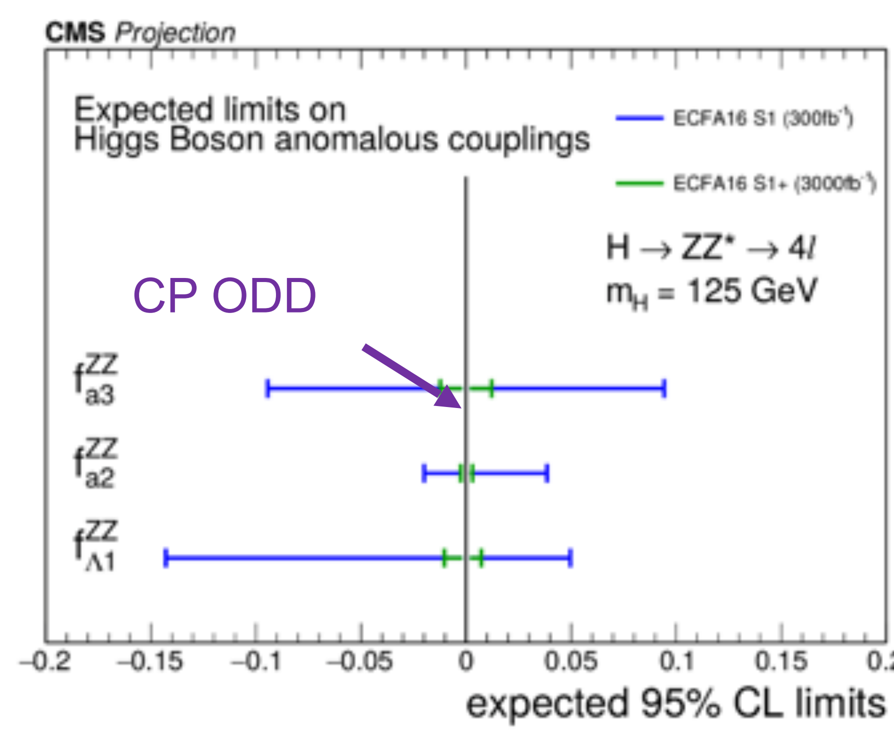
Anomalous couplings

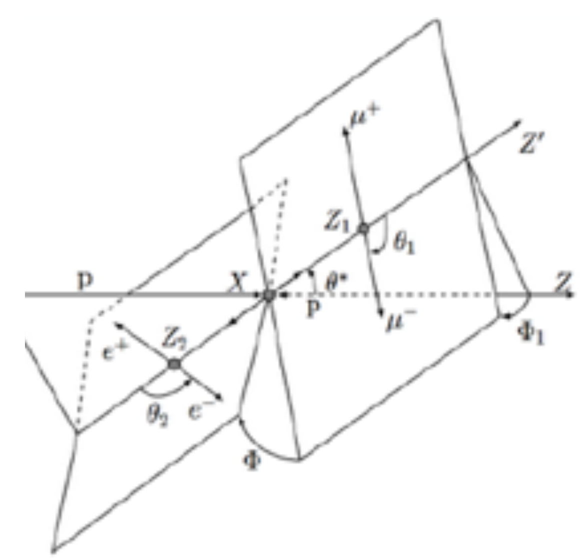
$$A(H \to ZZ) = v^{-1}\left(a_1 m_Z^2 \epsilon_1^\star \epsilon_2^\star + a_2 f_{\mu\nu}^{\star(1)} f^{\star(2),\mu\nu} + a_3 f_{\mu\nu}^{\star(1)} \tilde{f}^{\star(2),\mu\nu}\right)$$

SM tree processes — loop CP-even contributions — CP-odd contributions (BSM)

- H ZZ 4l : reconstruct the full angular decay structure
- Expect to constrain f < ~1%

$$f_{ai} = \frac{|a_i|^2\sigma_i}{\sum_j |a_j|^2\sigma_j},\ \phi_{ai} = \tan^{-1}(a_i/a_1)$$





- Statistically dominated: huge increase in sensitivity going from 300 to 3000 fb^{-1}.

HIGGS BSM SEARCHES

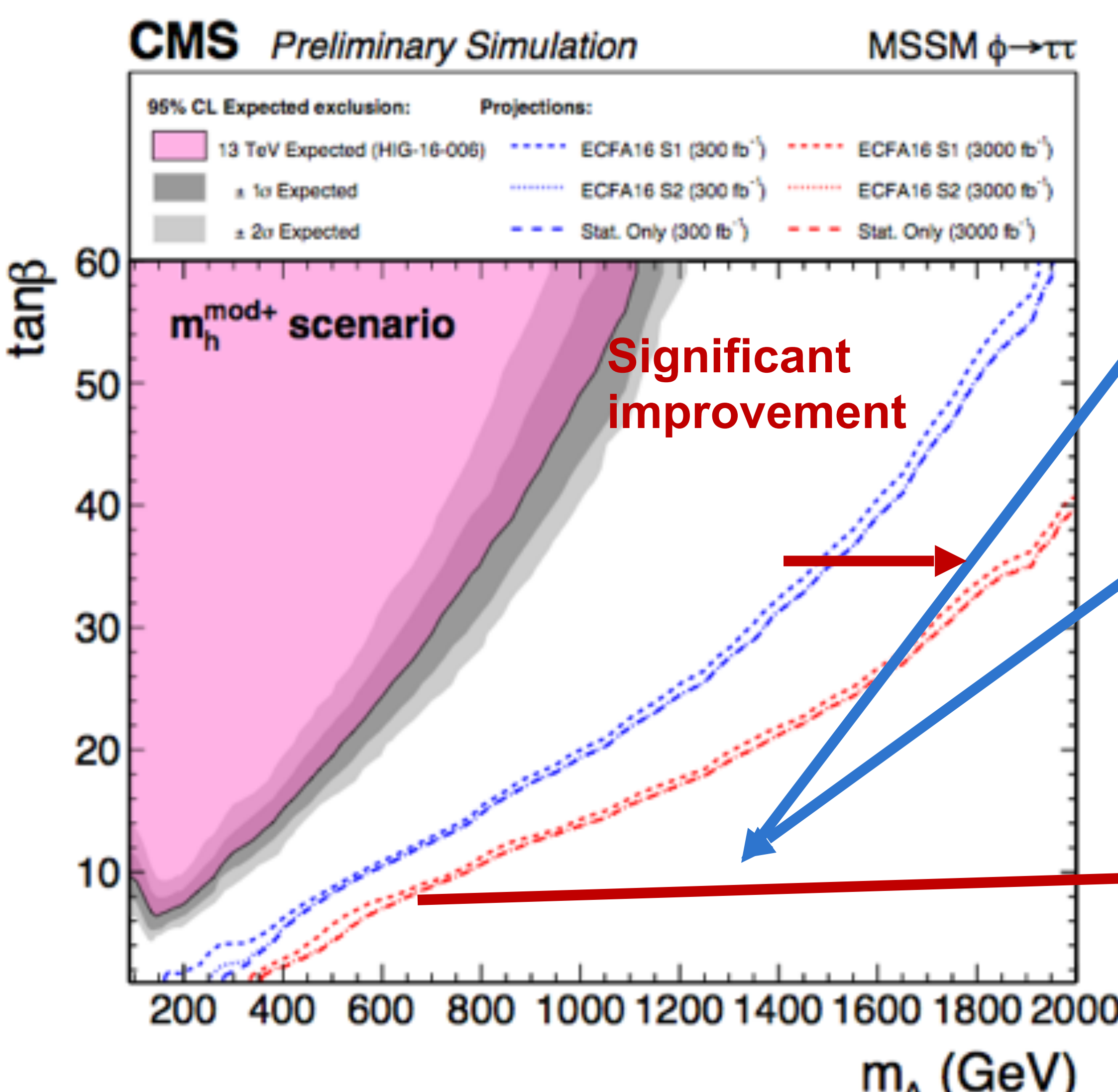
➤MSSM Φ -> τ τ

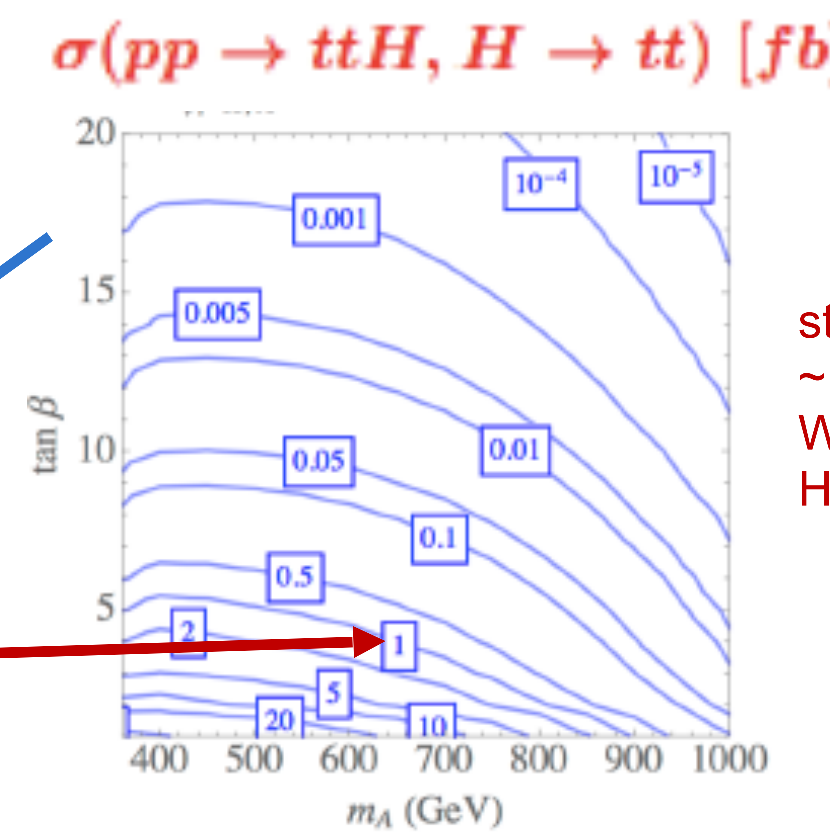
- ➤ One of the most sensitive channels to constrain extended Higgs sectors
- ➤ MSSM parameter space can be constrained to a heavy Higgs boson with masses up to 2 TeV.

What about the low tanβ vs M_A region?

Consider tau-phobic signatures
A possible scenario is ttH production
Signatures: 4top or 2b+2top

CMS-PAS-HIG-16-006

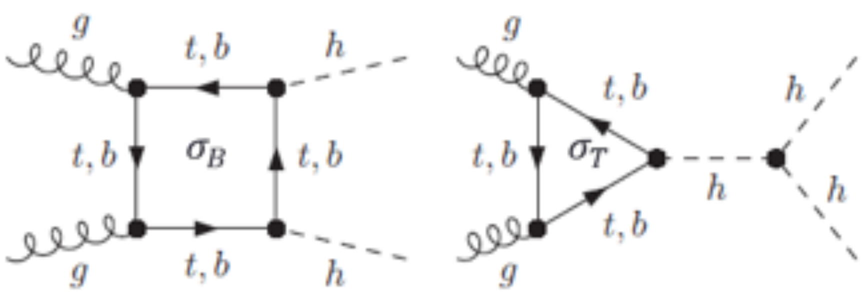




statistics limited!
~ 60 events now
Will benefit from
HL-LHC, HE-LHC

Gori et al, 1602.02782

HIGGS PAIR PRODUCTION AND SELF COUPLING

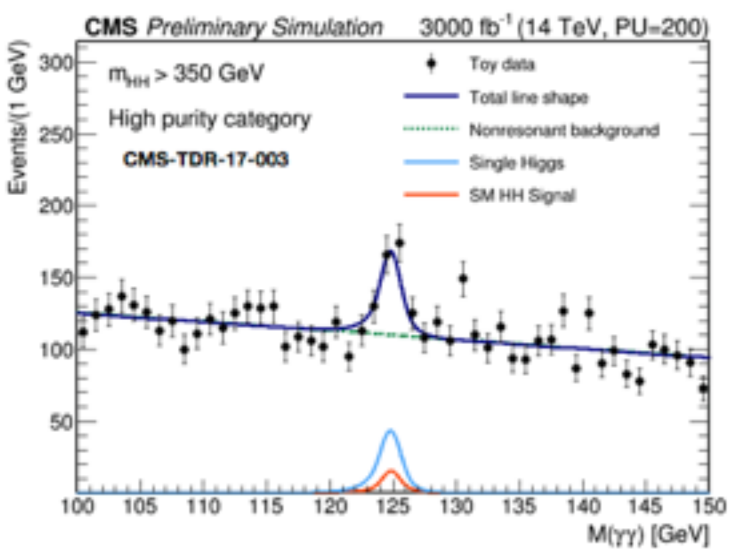


HH physics is a benchmark channel for HL-LHC program

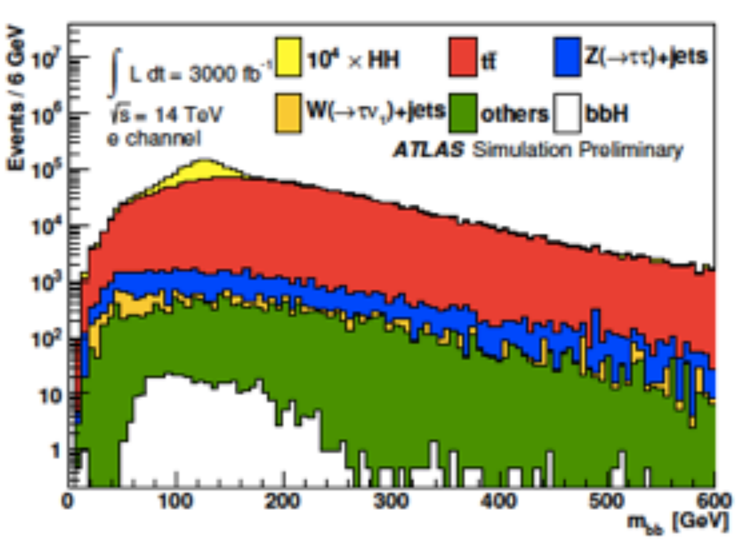
- Run II results are reaching 15 times SM, with loose constraint on κ_λ between -9 and 15.
- Exp. significance per experiment ≈1-2 σ (HL-LHC)
- The possibility of "evidence" of HH can be reached combining all channels in CMS and ATLAS.

- Improvement foreseen driven by :
  - Detector optimization, analysis algorithms
  - Theory : Impact of NLO correction on differential distributions ?

HH → bbγγ



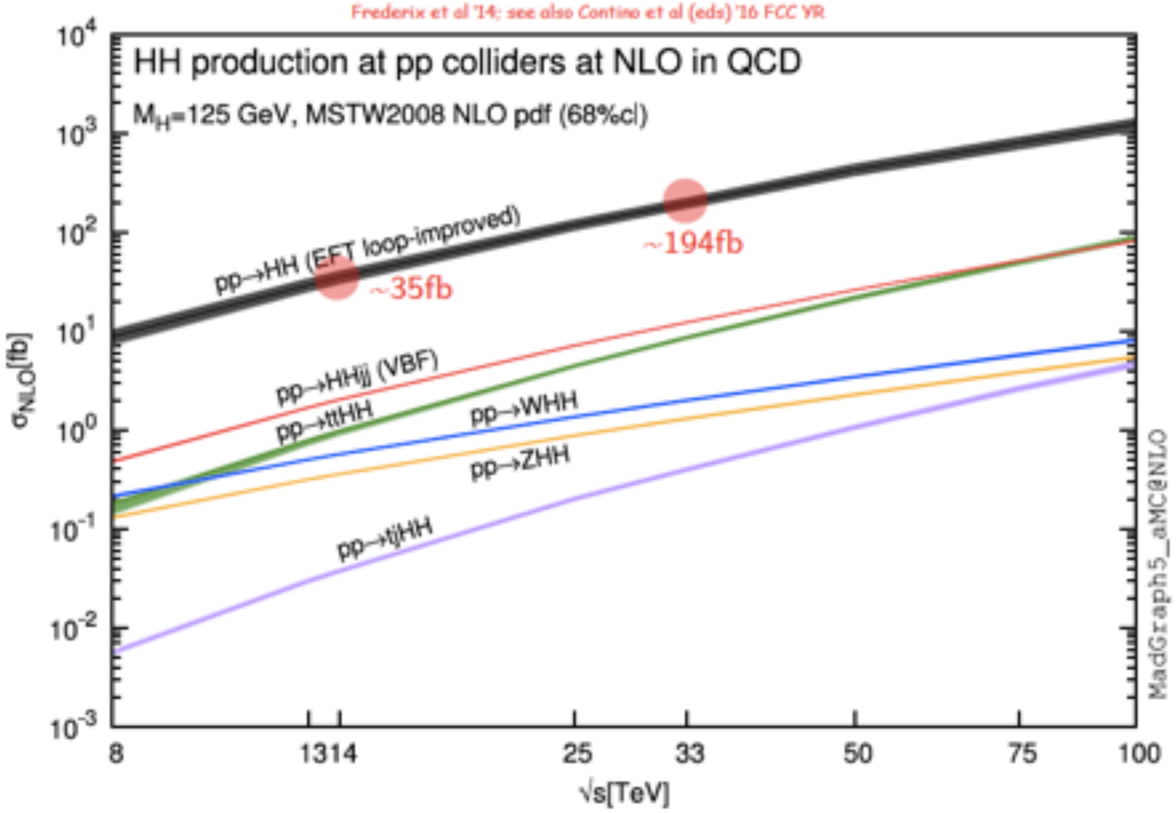
HH → bbττ



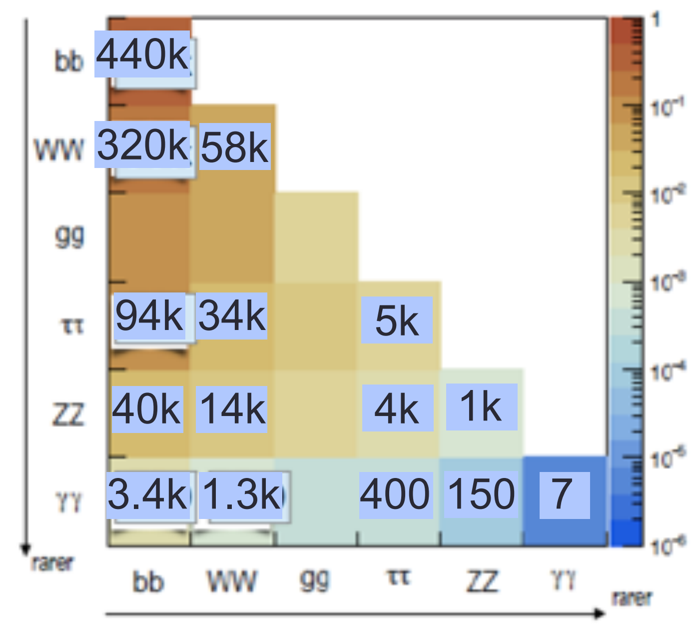
Final state	ATLAS	CMS
HH→bbγγ	1.05 σ $-0.8<k_\lambda<7.7$	1.43 σ
HH→bbττ	0.6 σ $-4.0<k_\lambda<12$	0.39 σ
HH→bbbb	$-3.5<k_\lambda<11$	0.39 σ
HH→bbVV		0.45 σ
ttHH, HH→bbbb	0.35 σ	

HIGGS PAIR PRODUCTION AT HE-LHC

➤HH cross section @ 27 TeV = 128 fb (±11%)



Expected number of events @ 27 TeV and 10/ab



➔ event yields increase by factor 10

➤Projections for λ from hh production: $\delta\kappa_\lambda$ ($\kappa_\lambda=\lambda/\lambda_{SM}$)

$\delta\kappa_\lambda$ bound / scenario	68%	95%
HL: h incl, hh incl	[0, 2.5] U [4.9, 7.4]	[−0.8, 8.5]
HL: h incl, hh diff	[-1.1, 1.3]	[−1.7, 6.5]
HE: h incl, hh incl	[-0.3, 0.3] U [5.0, 6.0]	[-0.5, 0.7] U [4.5, 6.7]
HL + HE	[-0.3, 0.3]	[-0.5, 0.6] U [4.8, 6.0]
FCC 100 TeV 30/ab h incl, hh diff	[−0.03, 0.03]	[−0.06, 0.06]

Factor of 3-10 improvement wrt HL-LHC

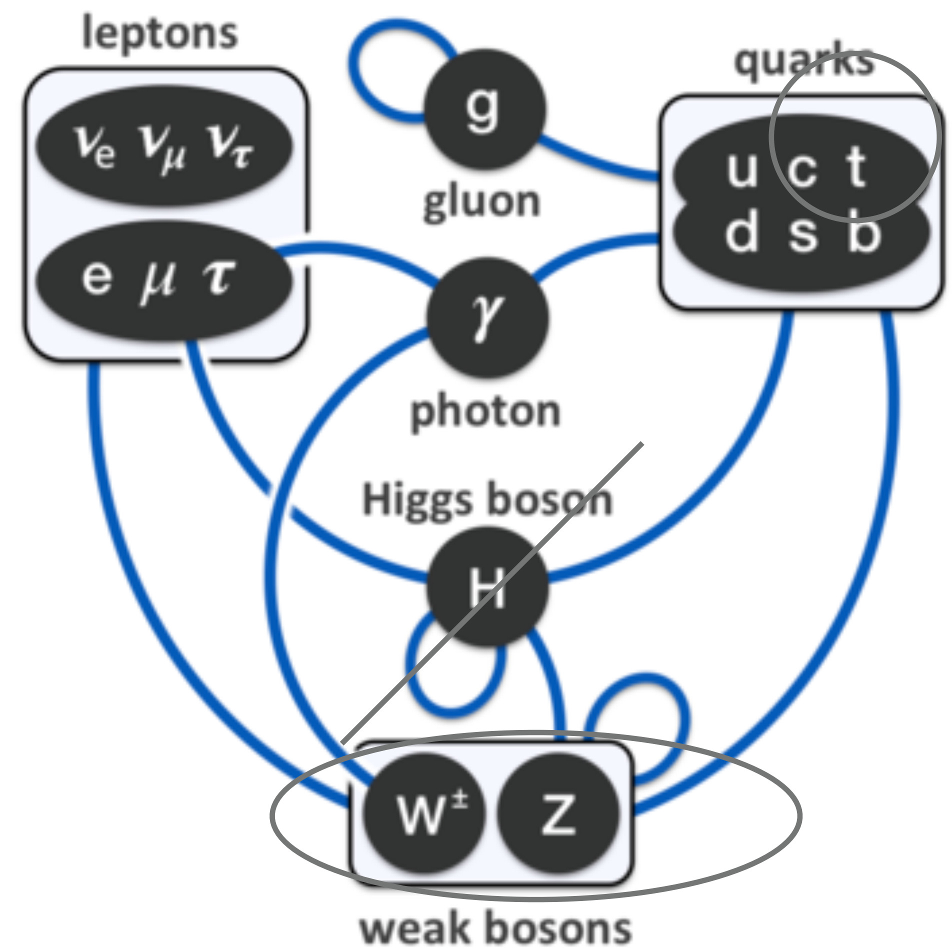
Work is just starting

S. Di Vita HE/HL-LHC workshop, Nov 2017

STANDARD MODEL PHYSICS (BACK IN THE SPOTLIGHT)

SM PHYSICS FOR THE HL-LHC

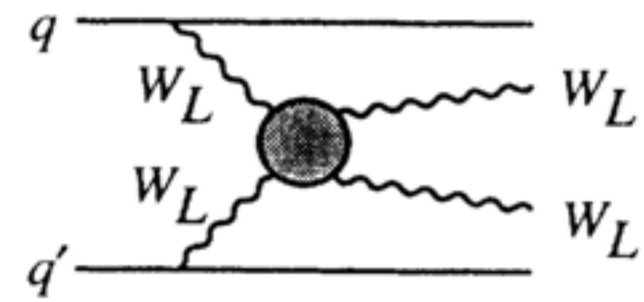
- Only moderate increase in energy
- But: incredibly high statistics
- Era of precision measurements
  - Need to improve our understanding of systematic uncertainties and their interplay
  - Improve techniques for uncertainty mitigation
  - High precision differential measurements
  - Era of ‘dark’ corners of phase space (BSM sensitivity at high Q2/Λ2 → tails!)



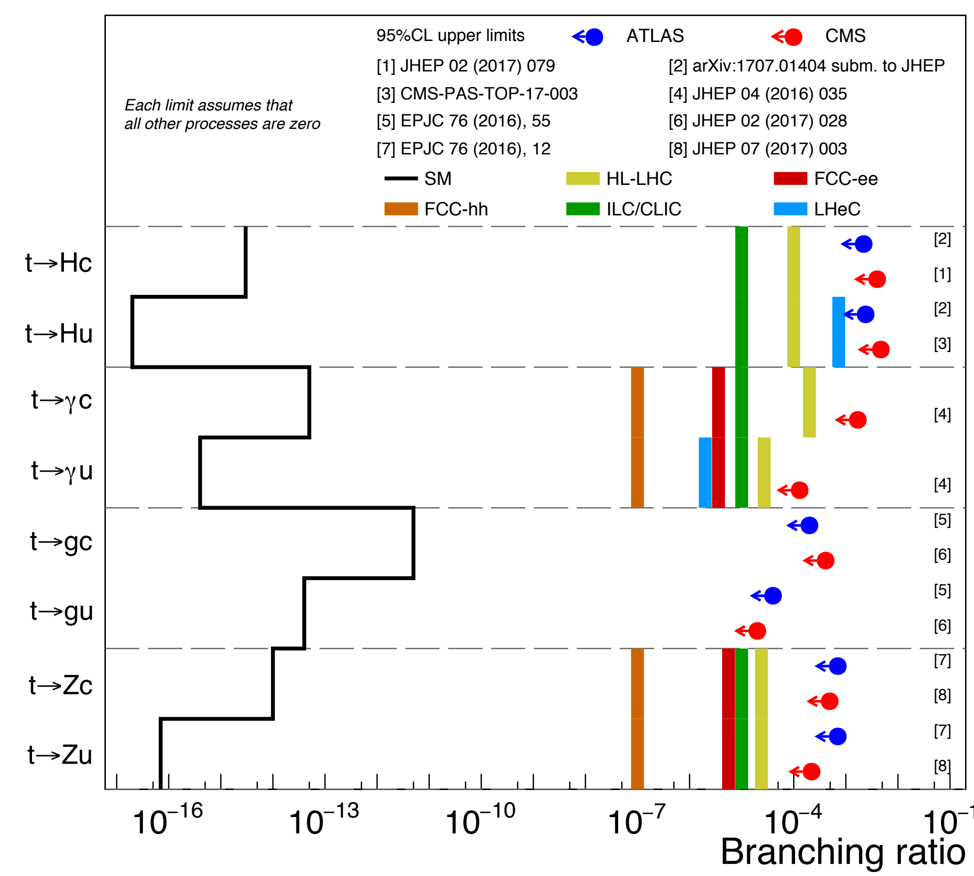
- Renewed recognition of importance of Standard model measurements

SELECTED CHANNELS

- **Vector Boson Scattering**
  - Strong cancellation in SM of terms from TGC, QGC and Higgs boson exchange
    - Sensitive to no-Higgs scenario
    - Additional 8-dim EFT operators
    - Partial unitarisation
  - Distinct signature in the detector
  - Precision at high scales will provide strong sensitivity to new physics
- **Tri-boson production**
  - Complementary to QGC
  - Study production of Z bosons in association with 2 photons
  - Contributions from BSM (EFT) in tails
- **Top FCNC**
  - In SM: Forbidden at tree level; Only via loops, but highly suppressed
  - Search: Single top (production), Top-pair (decay)
  - New analyses: tZq, tHQ, tγq (in progress tgq for HGCAL TDR)
  - Very strong potential for HL-LHC



WWjj, WZjj: Δσ/σ < 10% (CMS)
$V_LV_L \to V_LV_L$ discovery significance up to 2.75σ (combining WWjj+WZjj)



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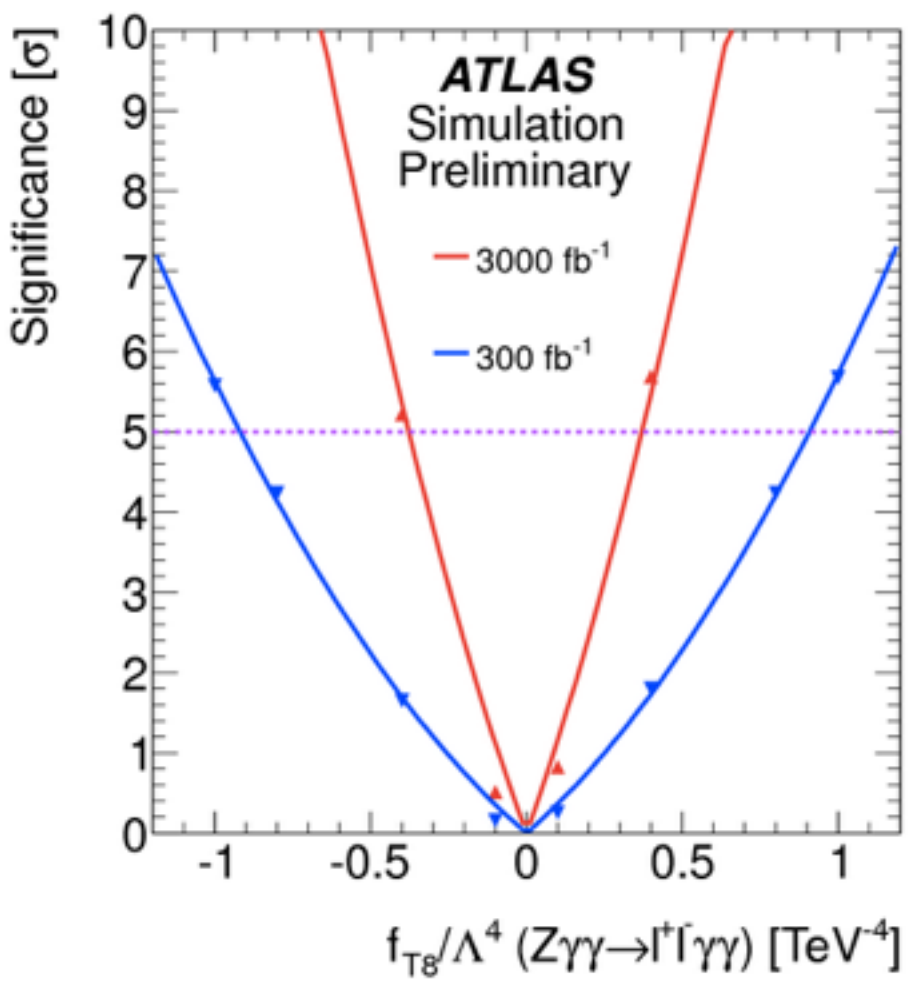
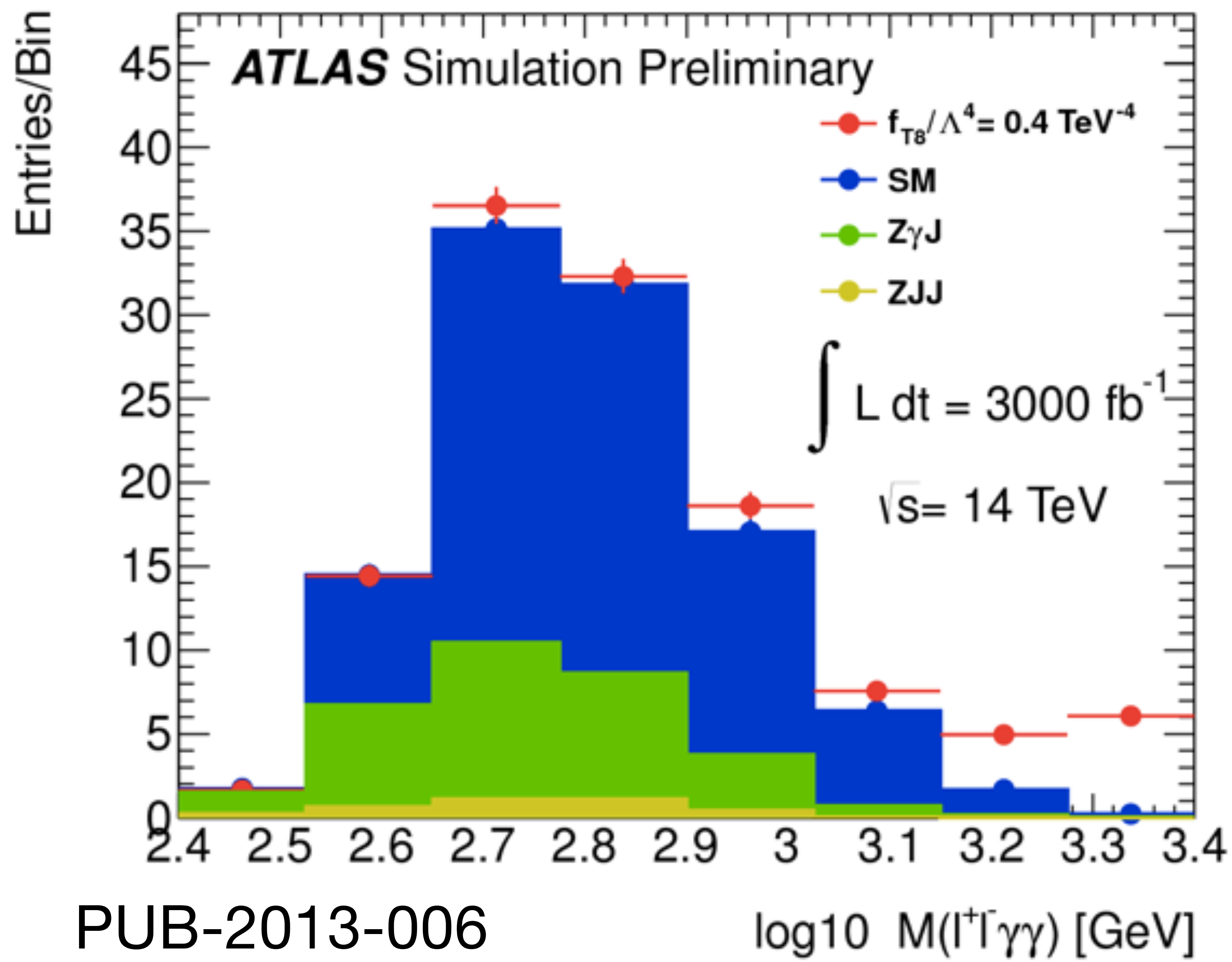




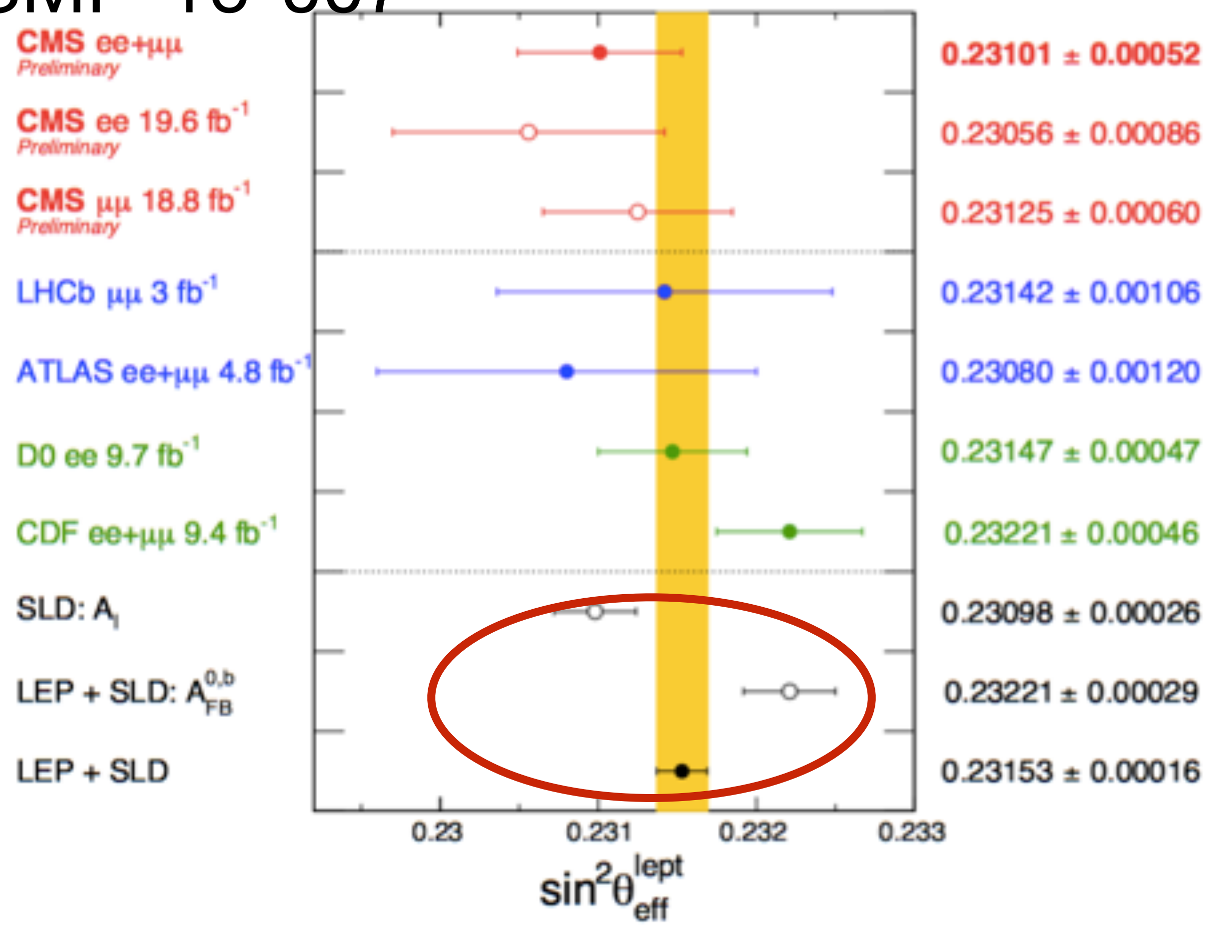
PUB-2013-006

High sensitivity gain from statistics

Requires excellent PU rejection (timing, high-granularity)

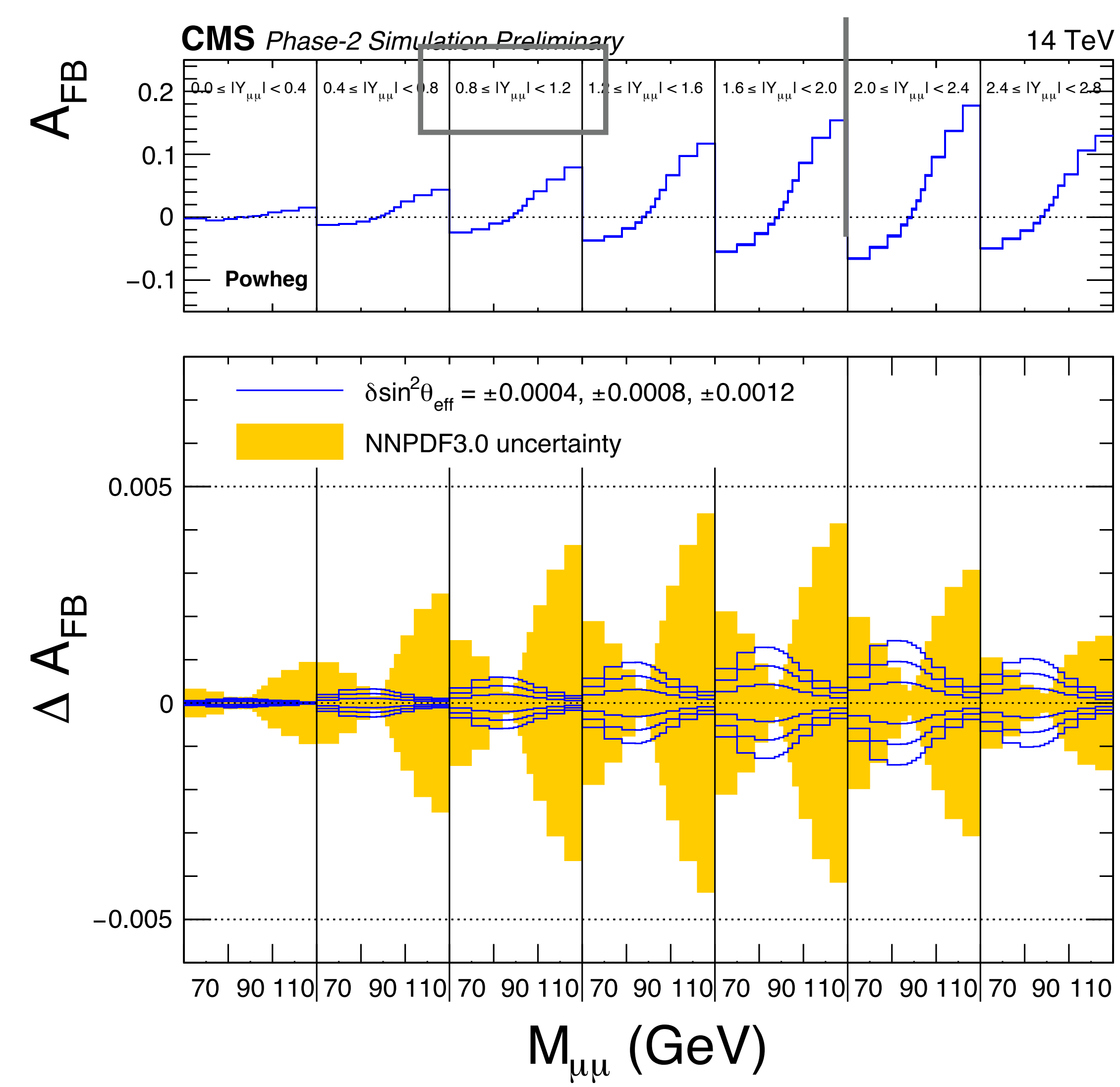
ELECTROWEAK MIXING SIN2 ΘW

SMP-16-007



- ➤ Strong consistency test of the SM in global EWK fits
  - ➤ Δsin2θW = 16e-5 ⟺ ΔmW = 8 MeV
- ➤ LEP/SLD discrepancy mandates further investigation
- ➤ Current results from LHC still statistics + PDF limited
- ➤ Reduce PDF uncertainty
  - ➤ go to high Y - even more possibilities with extended tracking

CMS-FTR-17-001



L_{int}	$\delta^{constrained}_{nnpdf3.0}$ $[10^{-5}]$	
(fb^{-1})	$\lvert\eta\rvert < 2.4$	$\lvert\eta\rvert < 2.8$
10	39	29
100	27	20
500	20	16
1000	18	14
3000	15	12
19	27	
19 (from [1])	32	

- ➤ Total uncertainty likely reduced by a factor of 3 @ HL-LHC
- ➤ Individual measurements reach current world-combination uncertainty ($16 \cdot 10^{-5}$)
- ➤ Strong benefit from tracker/muon system coverage

THE TOP-QUARK MASS

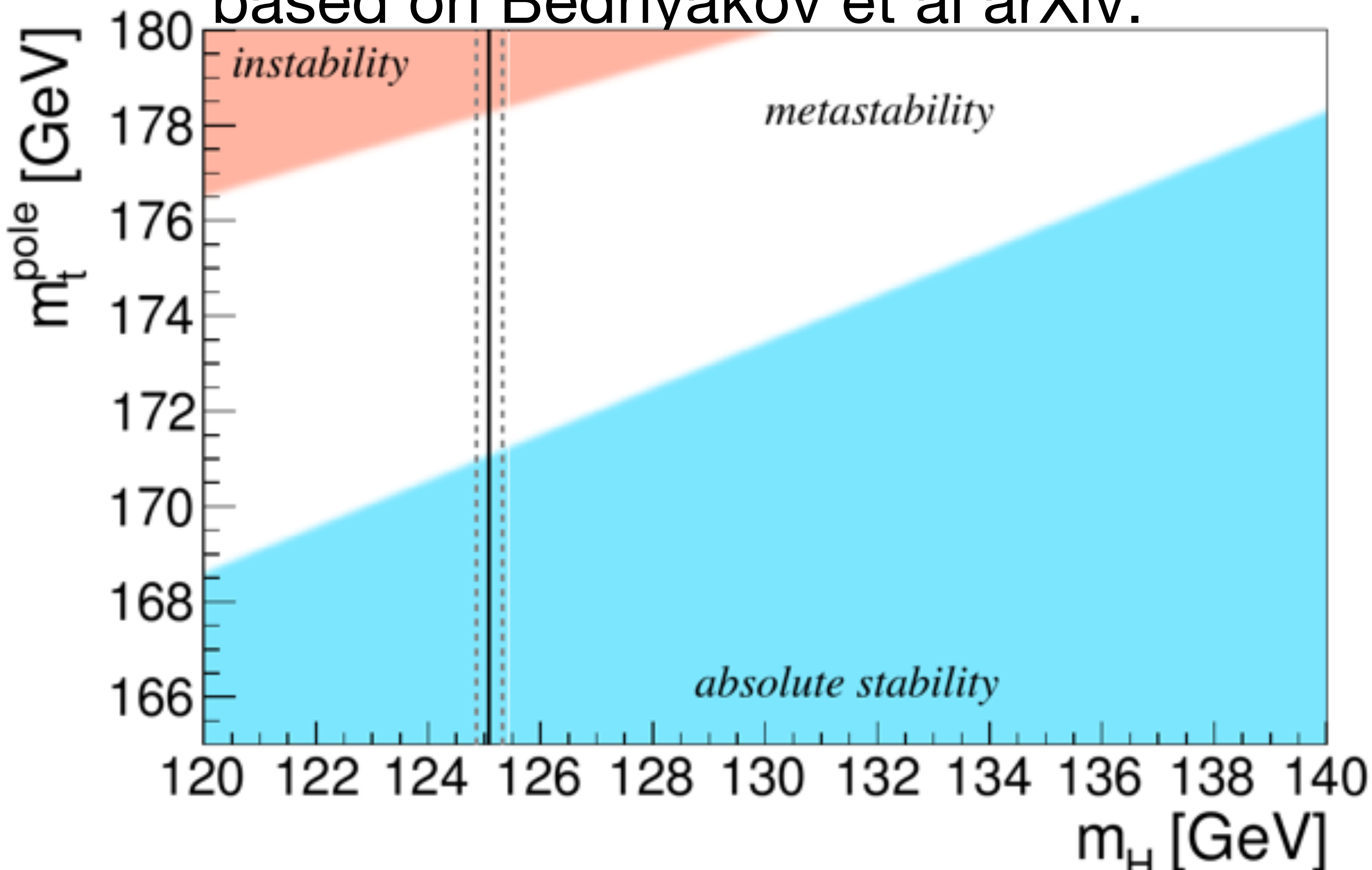
➤The top-quark mass - theory perspective

- ➤ Parameter in the Lagrangian
- ➤ Beyond LO: renormalisation
- ➤ Definition becomes scheme dependent (pole, MSR MSbar…)
- ➤ Essential for EWK precision fits, EWK vacuum stability

➤The top-quark mass - experimental perspective

- ➤ Highly precise MC mass measurements
- ➤ Pole mass measurements with increasing precision, work ongoing to relate both
- ➤ Systematics limited measurements, require full detector

based on Bednyakov et al arXiv:

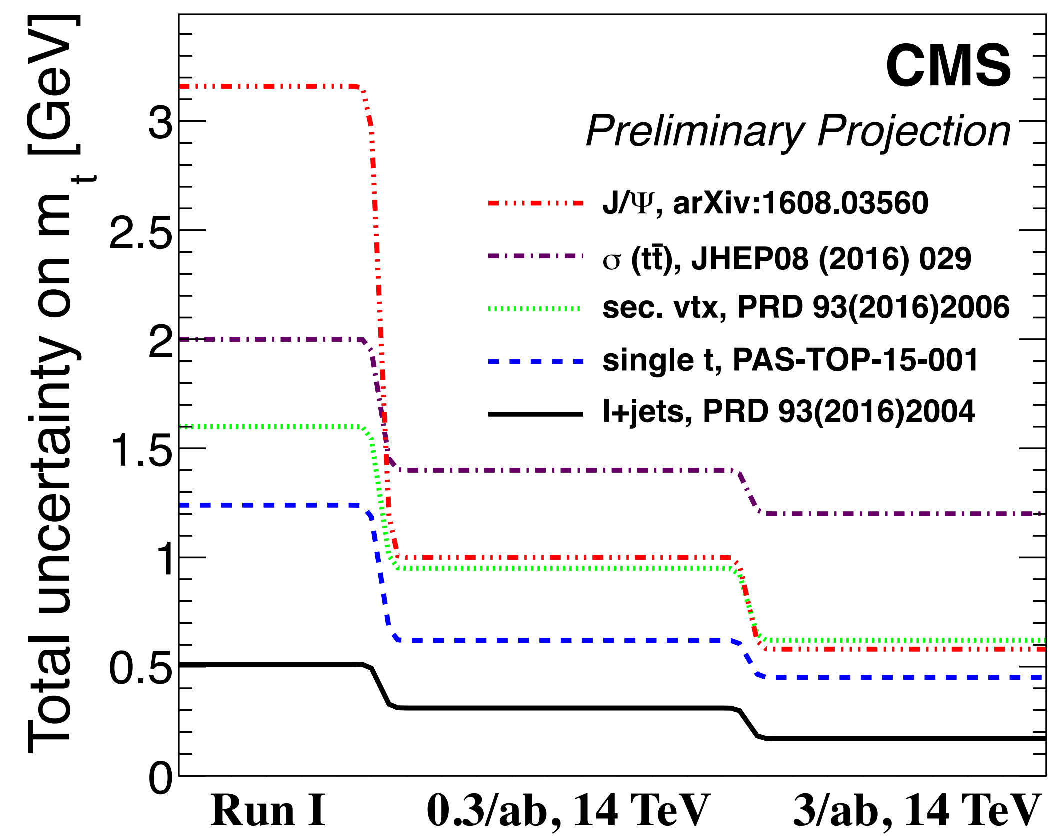


➤Worth to continue measuring the top-quark (MC) mass with HL-LHC?

- ➤ High-precision 'direct' pole/running mass measurements
- ➤ Possible to go (multi) differential measurements
  - ➤ Gain insight into tunes, different corners of phase space
- ➤ Almost unlimited possibilities for data-driven constraints

TOP QUARK MASS EXTRAPOLATIONS

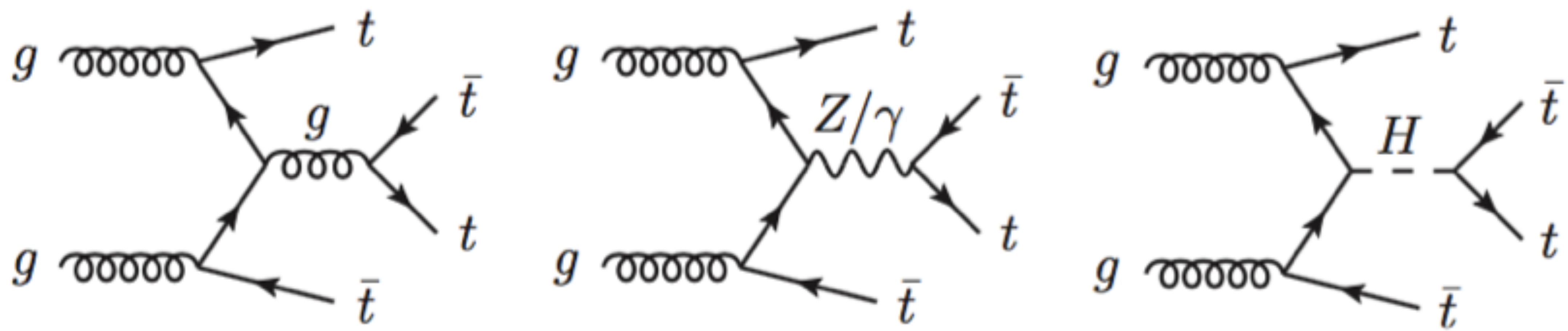
- Clear benefit from statistics for J/Psi
  - Independent of JES, uses mJ/Ψ,l
- Moderate improvement for pole mass from cross sections
  - Ultimately limited by luminosity uncertainty and theory uncertainty (no N3LO assumed)
- Single top:
  - EWK process, complementary to other techniq
  - Benefit from statistics and modelling improvements
- ‘standard’ l+jets
  - Benefit from differential studies constraining modelling



FTR-16-006

- **All MC mass analysis will go well below 1 GeV uncertainty.**
  - Differences in production/decay mechanism may become visible
    - Still not to forget that theory uncertainties of few ~100MeV
- **Likely even more analyses techniques become available not covered here**
  - More in-situ constraints, differential (pole/MSbar) mass measurements…

HL/HE-LHC: 4-TOP PRODUCTION



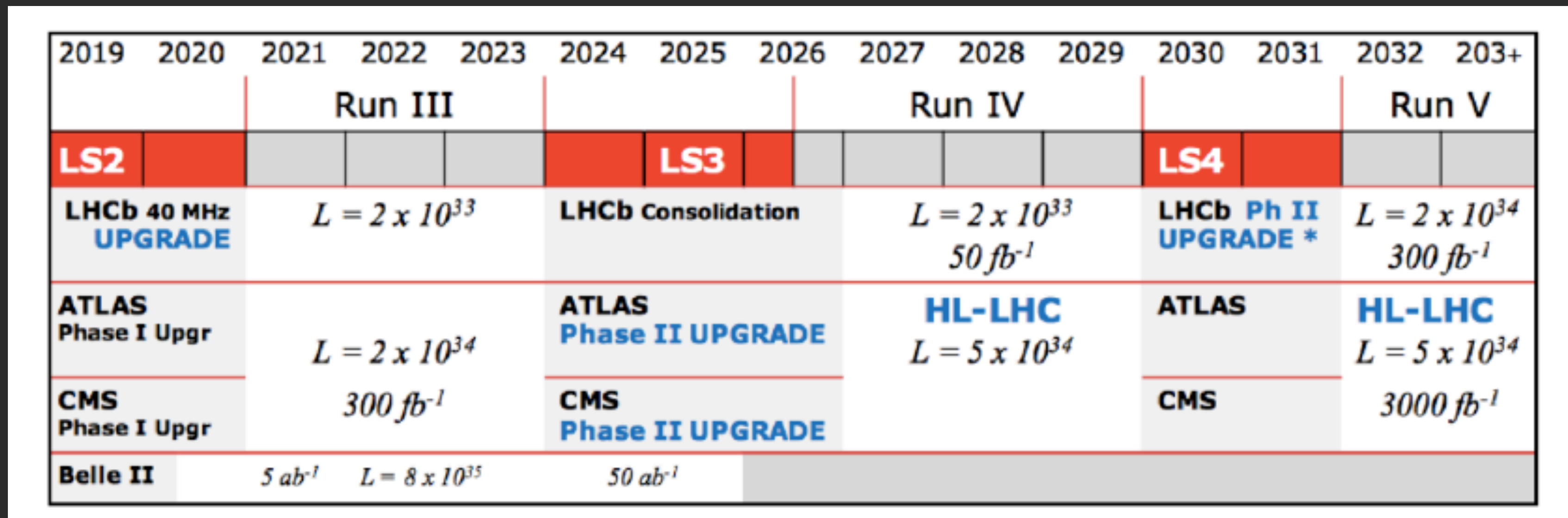
Q. Cao et al, PRD 95, 053004 (2017)

- Observation of 4-top production feasible with > 300 fb-1
- Gives access to top-yukawa coupling and Higgs width
- Challenges for detector performance (complex final state)
  - High jet multiplicity
  - Multiple b-tagging
  - Combinatorics
- 4*mt: strong increase in cross-section for 28 TeV (HE-LHC) to be expected

ADD SOME FLAVOR…

WHICH FLAVOUR PHYSICS FOR THE YR?

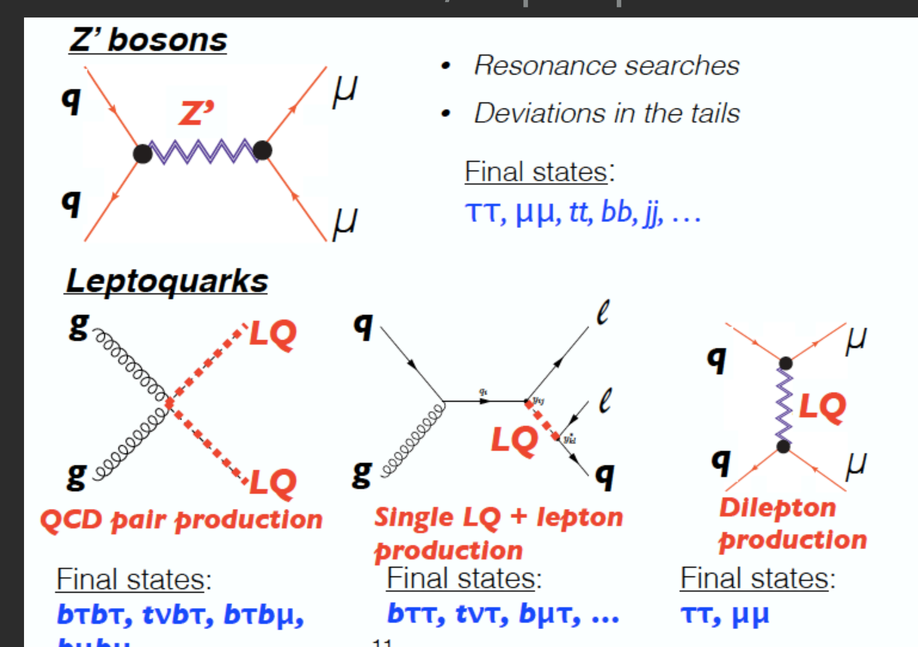
info from Sandra and Martino!Grazie!



- Strengths and complementarities
  - Belle2 : measurements involving neutral states
  - LHCb: very rare decays (exclusive modes)

- Anomalies:
  - Both Belle2 and LHCB can rule out current anomalies by 2026
  - leptonic flavor changing NC, ratio of Brranching fraction with different lepton generations
- New physics in B->sll and Time dependence of B->Vll
- Connection with High-pt physics

- Connection with Z′, Leptoquark searches

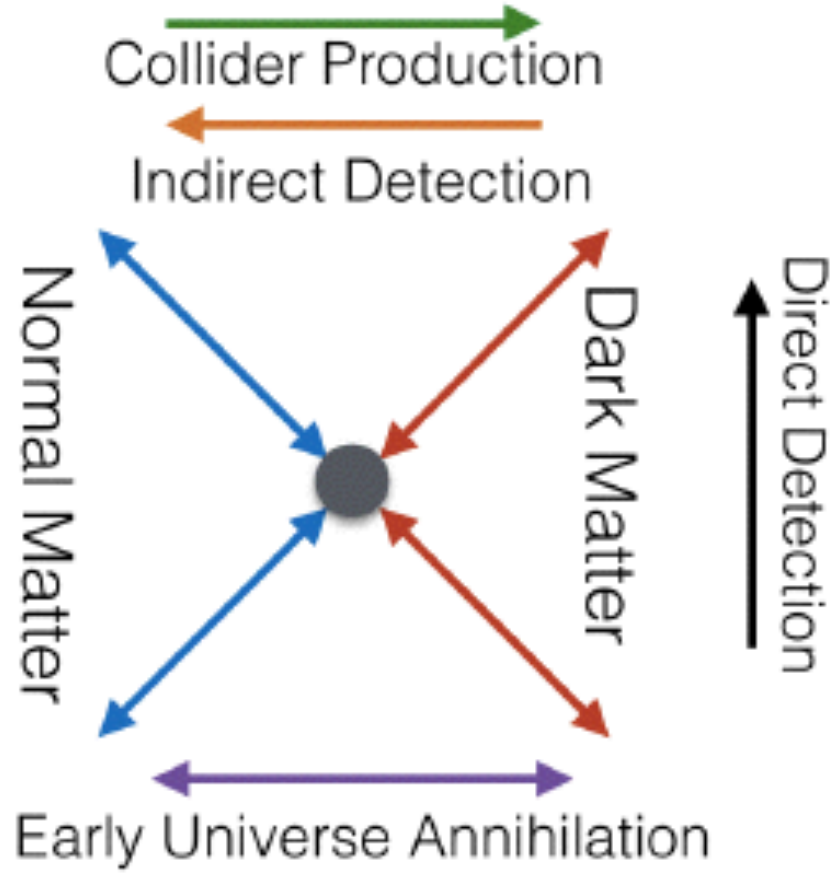


THE FLAVOUR PHYSICS PICTURE

- Some inclusive reference numbers (for us to gauge the CMS flavours potential), independently of specifically designed low pT triggers
  - $\sim 10^{15}$ bb produced in 3000 fb^{-1}
  - MinBias :~ 0,7% bb (PRL118, 052002 (2017))
    - Multiple P.U interactions yield unbiased data (ZBT: 0.5- 1 fb^{-1} arXiv: 1608.06299)
    - Acceptance and efficiency reconstruction to be studied
- B from Top $sigma_{tt}$@14TeV ~1nb —> ~ 3B tt are produced In 3000 fb^{-1}
  - B physics **in** and **from** Top needs to be exploited
    - not only fragmentation studies, but profit of the statistics
    - this is probably the biggest new approach that could be taken

BEYOND THE STANDARD (MODEL) SEARCHES

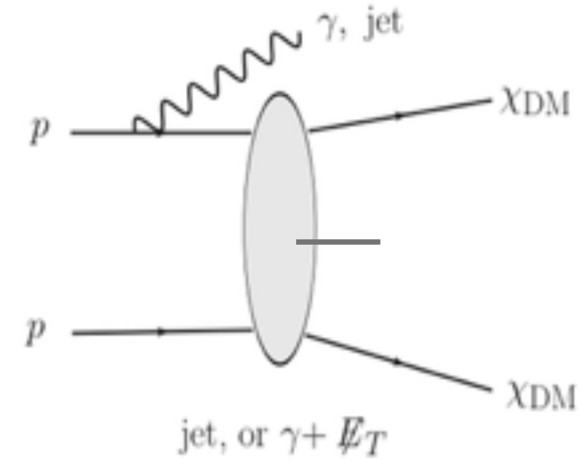
DARK MATTER



- ➤Next discovery?
  - Guess: DM is a thermal relic of the early universe
  - Weak-scale interactions with the SM
  - LHC searches complement direct detection experiments.
  - Complication: translation between annihilaton and experimental cross section very model dependent.
- ➤In recent years significant theoretical and experimental developments, e.g. EFT->simplified models.

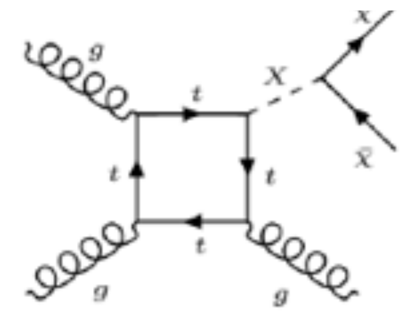
DARK MATTER SEARCHES

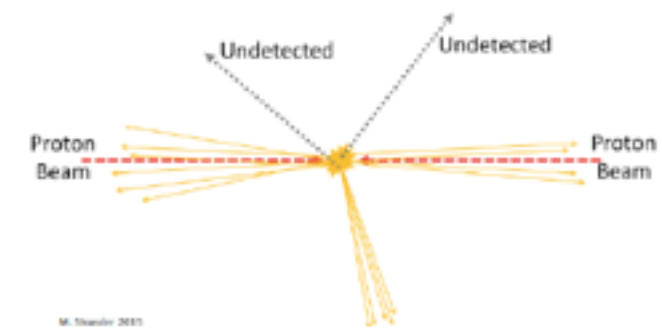
γ, jet, lepton, h



EFT or

simplified model

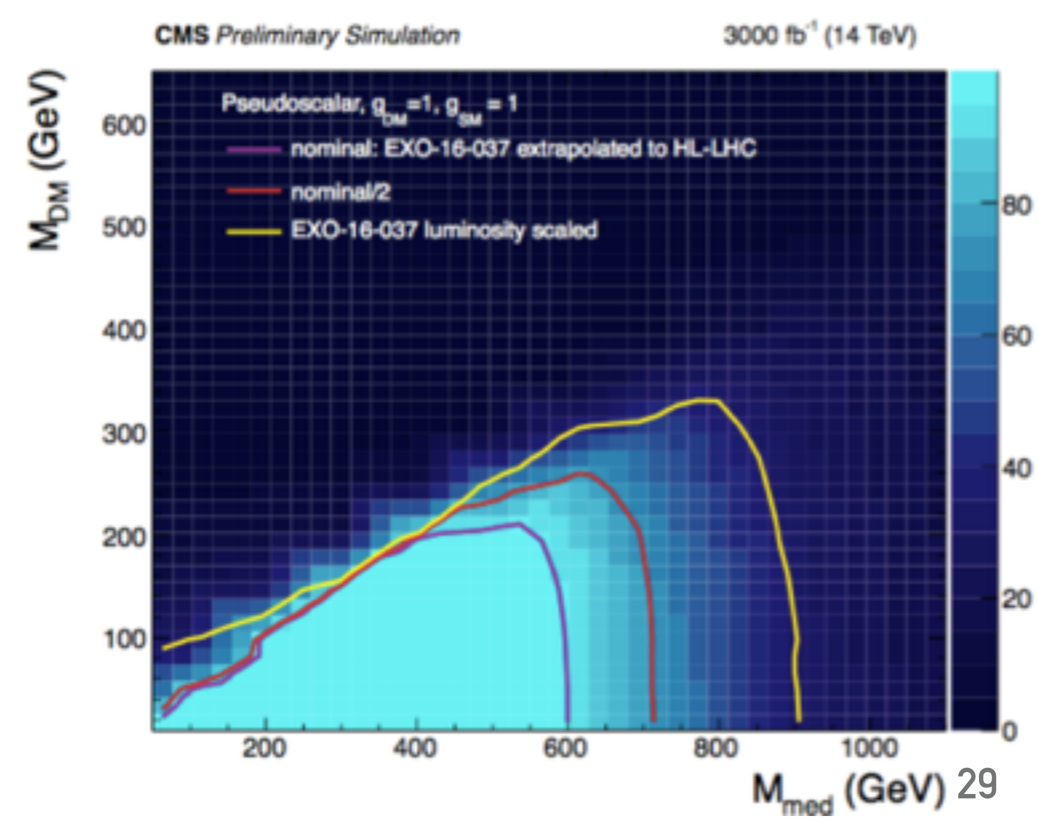




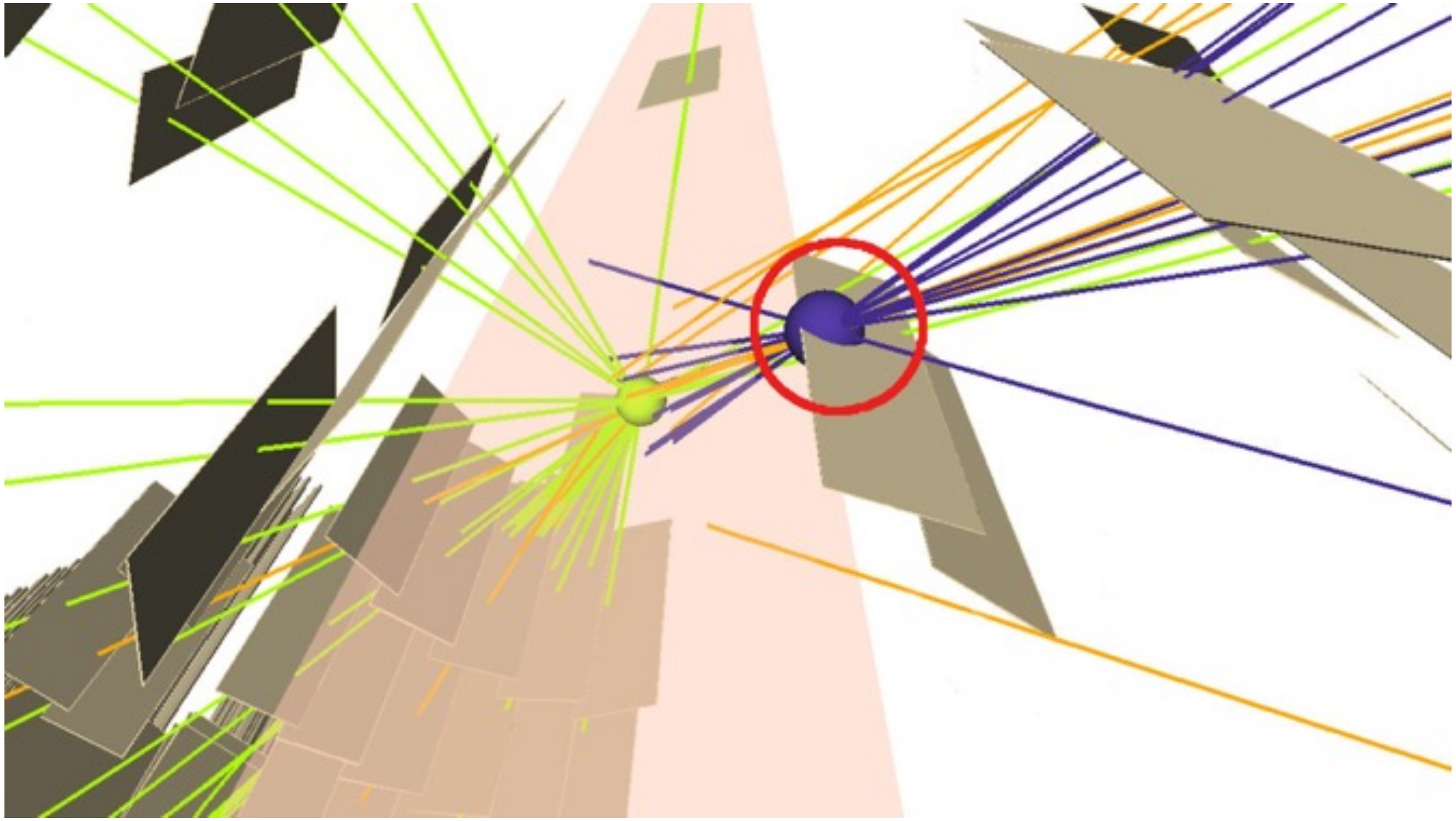
- ➤Searches based on Simplified Models
  - Dirac WIMP mediators
    - scalar, pseudoscalar, vector/axial-vector
  - With distinct kinematic distributions
  - Aids in design of generic searches
    - Missing ET+ X (jets, g, Z, leptons, dileptons, ..)

- ➤Search for Dark Matter in Missing ET+jets
  - Suppressed in direct detection.
  - LHC provides complementary sensitivity.
  - Benchmark among many DM collider searches.
- ➤Interpretation in simplified models with 4 parameters (Mmed, mDM, gSM, gDM)

- ➤Axial vector mediator :
  - Exclusion possible up to 3 TeV. (current reach ~2TeV)
- ➤Pseudoscalar Mediator:
  - Spin-0 mediator, pseudoscalar gSM = 1, gDM = 1
  - Exclusion possible up to 900 GeV (current ~0.4 TeV)
  - Reach in mediator mass influenced by systematics.



LONG-LIVED PARTICLES (LLP) AND SPECIAL SIGNATURES

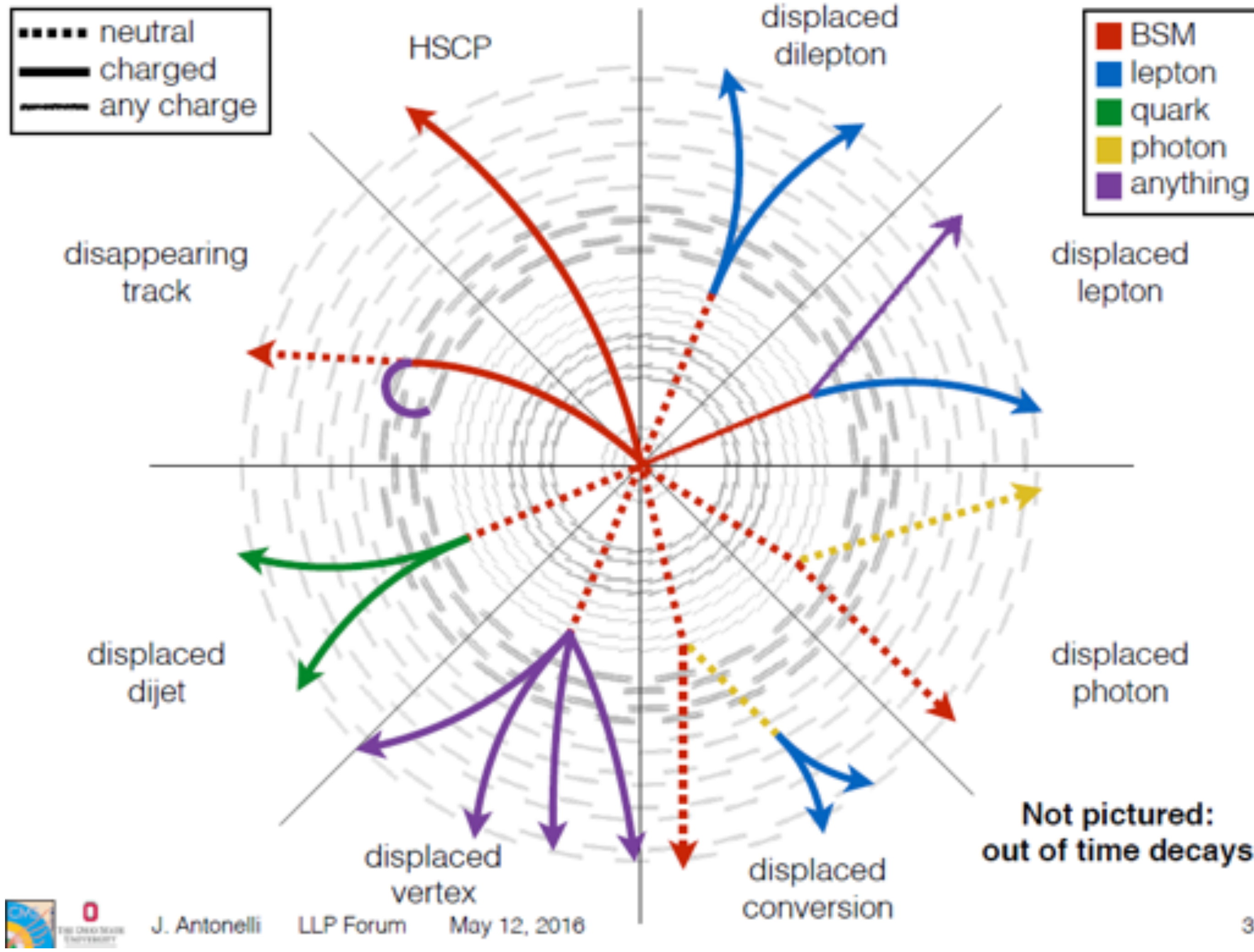


The secret lives of long-lived particles

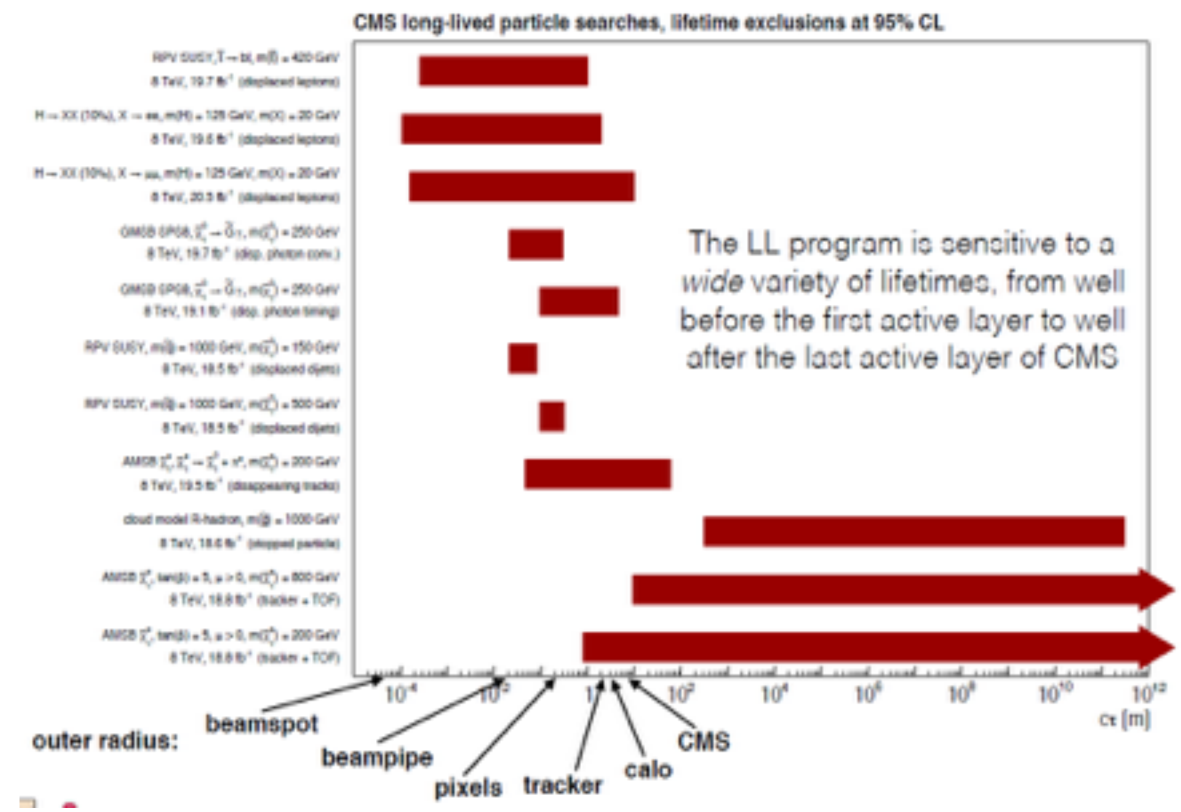
09/16/16 | By Sarah Charley

A theoretical species of particle might answer nearly every question about our cosmos—if scientists can find it.

LONG LIVED PARTICLES (LLP)



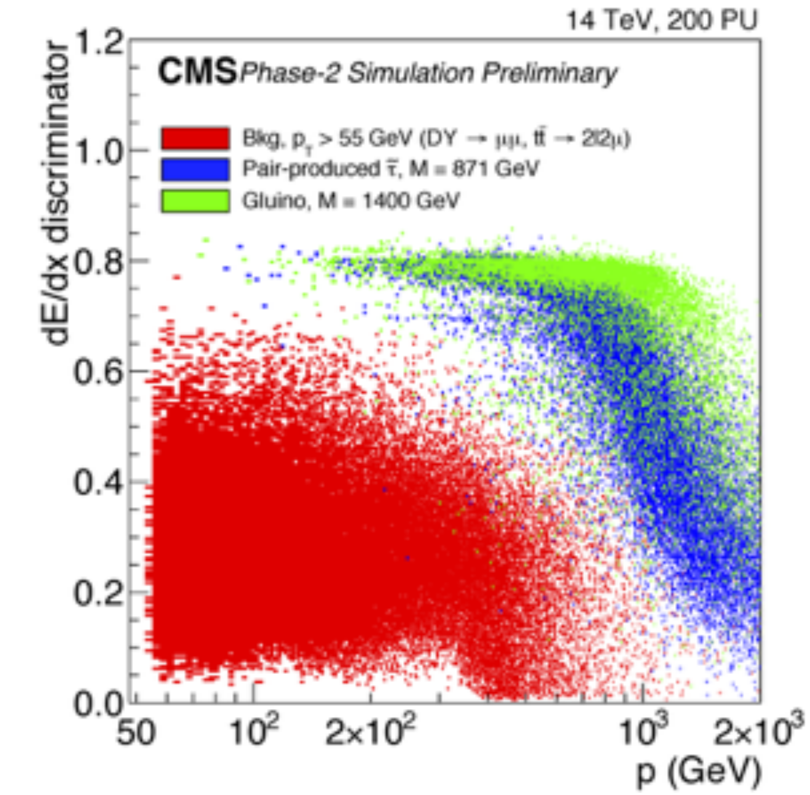
Target complementary lifetimes and ranges. Variety of dedicated techniques to cover whole range of lifetimes (cτ)



- ➤Particles decaying non-promptly are a new focus at the LHC, for present and future
- ➤Long-lived neutral particle (X) decays after some cτ to displaced leptons or jets.
- ➤Signature driven searches, with great discovery potential, Issues and opportunities with LLP signatures:
  - ➤ Need dedicated tools for non-standard objects, custom trigger/reconstruction/simulation
  - ➤ Potential gains from high luminosity, track-trigger, fast timing, better directionality.

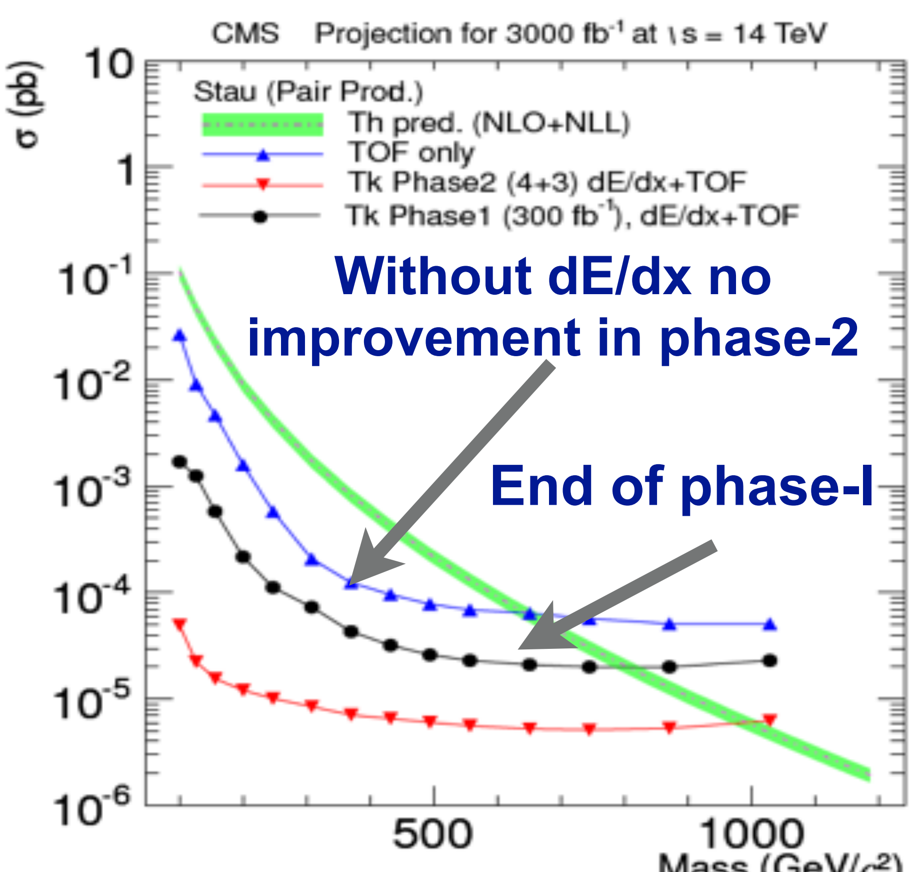
HEAVY STABLE CHARGED PARTICLES

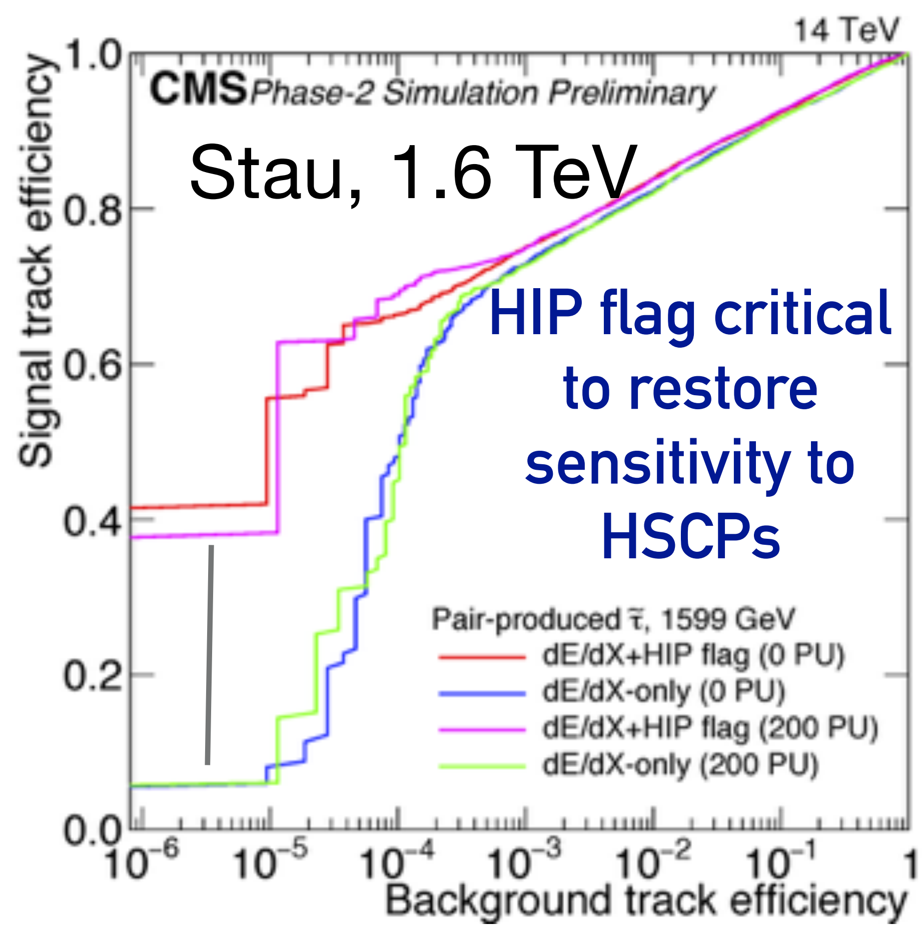
- ➤HSCPs: New, heavy particles could propagate through the detector before decaying
- ➤Needs HL-LHC for sensitivity because of small xsec.
- ➤Detection technique
  - ➤ Could look like heavy, highly-ionizing, slow-moving muons
  - ➤ dE/dx discriminator shows large separation between signal and background
  - ➤ Physics studied demonstrated the need to keep dE/dx capability in the tracker

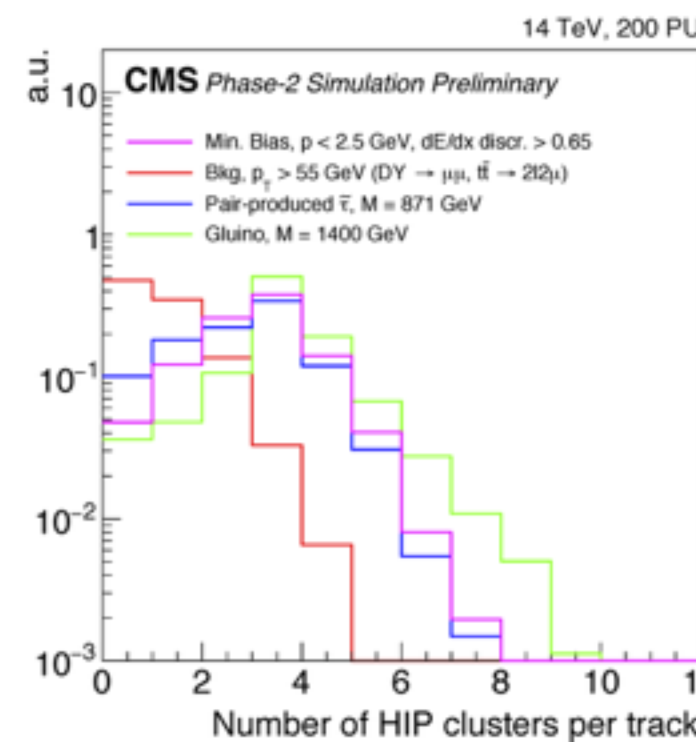


CMS TP and

CMS-PAS-EXO-14-007







SUMMARY

- The HL-LHC program is a high-value flagship program of the HEP scientific community.

- HL-LHC will reach unprecedented running conditions, very challenging for the detectors but offering exciting physics perspectives
- Main challenge is mitigation of large number of pileup interactions
  - Trigger – more bandwidth, new capabilities
  - Increased detector granularity and acceptance in η
  - Timing measurements will add an additional dimension to pileup rejection
- Baselines for the upgraded detectors have been defined

- Compelling program of precision measurements in Higgs sector, testing further the SM and constraining BSM
- Continued exploration of the TeV scale via heavy new particle searches
- Various Physics prospects are under study with simulations that are continuously optimized.

- HE-LHC – needed for discoveries; increased sensitivity to larger masses
  - Work on compiling the physics prospects is beginning (in the context of European Strategy document)
- We look forward to an exciting physics program at LHC for the next 20+ years

SUMMARY(2)

- YR should define the « physics case » for the HL-LHC in view of the European strategy. It will not be about everything we can do, but about what we should be doing.
  - also community quite small as taken by Run2. Trying to engage theorists again.
    - Theorists more involved in HE proposals.
  - Work will happen into UPSG for analyses coordination hoping to have an influx of new groups from the PAGs. Different goals from TDR.
    - Known samples and backgrounds will be available by January (both for FullSim and Delphes). Tools to analyze both together already available.
- Will take the opportunity to push for important signatures that are not usually top of the list (apart from the Higgs). My favorite list:
  - Standard Model: VBS, EWK precision, Top
  - Exotica: unusual signatures HSCP, Long Lived (need new developments to fully profit of new detector)
  - BPH: get closer to Top and focus on unique measurements
- CMS Italy has large experience in all these topics. Could make a big impact.

MATRICE PROCESSI STUDIATI PER I TDR

Channel vs TDR/ Studies	$H\to ZZ \to 2\mu 2e, 4\mu, 4e$	$H\to 2\mu$	$H\to 2\gamma$	$H\to 2\tau$ (VBF)	H→Inv.	$HH\to 4b, 2b2\tau, bb\gamma\gamma$	Long Lived/ displaced HSCP	$B\to \mu\mu$, $B\to \phi\phi \to 4K$	Top mass with J/ψ	DM (γ,jett)	VBS	Di-boson res.	VLQ ($T\to th$)	FCNC $t\gamma$, 4t
Tracker														
Extension	✓	✓		✓		✓	✓		✓					
Resolution	✓	✓						✓						
PU			✓	✓										
B/tau-tag				✓		✓	✓							
Track-trig								✓						
Muon														
Extension	✓	✓					✓	✓	✓					
Trigger							✓	✓						
Barrel Calo														
Reso e/γ/jet	✓		✓			✓				✓	✓			
PU mitig.			✓											
SubStruct.												✓	✓	
Endcap														
Extension	✓		✓	✓	✓	✓								✓
Forward jet				✓						✓	✓		✓	
Resolutions	✓		✓	✓	✓	✓				✓	✓	substr.		
PU mitig.			✓							✓				

REFERENCES

- CMS Collaboration, "Technical Proposal for the Phase-II Upgrade of the Compact Muon Solenoid", Technical Report CERN-LHCC-2015-010, LHCC-P-008, 2015.
- CMS scope document LHCC-G-165, 2015.
- Documents on ATLAS and CMS Public Results pages
- For details see presentations at the HL/HE-LHC kick-off workshop at CERN: https://indico.cern.ch/event/647676/.
- Higgs Working Group Report of the Snowmass 2013 Community Planning Study, arXiv:1310.8361 [hep-ex]
- Slides of previous talks by colleagues
  - Some of which I have shamelessly borrowed from (many thanks).

BACKUP

Workshop Misc. Issues

- **DELPHES**
  - CMS internal DELPHES will further be optimised. We assume that it stays internal
  - There is interest in a public DELPHES card for a "generic" HL-LHC detector with ATLAS/CMS performance. This ensures that results of analyses from outside CMS or ATLAS can be directly compared and possibly combined.
  - <u>To be discussed:</u>
    - would need 2 people (1 from CMS and 1 from ATLAS) to prepare generic DELPHES card
    - production of public samples? Could create a lot of work

- **Combinations (CMS/ATLAS)**
  - Simplest case: extend to 6 ab^{-1} (i.e. assuming identical detector performance)
  - However: Combinations help revisit systematics
  - Also important: to have points that are called “LHC” not “ATLAS” and/or “CMS”

- **Additional Chapters and Publications**
  - chapter 0 (?) and volume 2
  - overall performance paper (ATLAS is planning this), <u>CMS also to do this</u>?
  - supplementary publications (e.g. machine learning, DELPHES, etc.)
  - executive summary