Future Physics prospects with the CMS detector at the High Luminosity LHC

Chiara Aimè
University of Pavia, Italy
on behalf of the CMS collaboration

High Luminosity LHC

UNIVERSITÀ DI PAVIA

High Luminosity LHC

- Collision energy: 14 TeV
- Instantaneous luminosity: 7.5 10^{34} Hz/cm^2 (factor ~5 w.r.t. Run II)
- Integrated luminosity: 3000 fb^{-1}
- Pile up: 200

CMS upgrade

UNIVERSITÀ DI PAVIA

L1-Trigger/HLT/DAQ

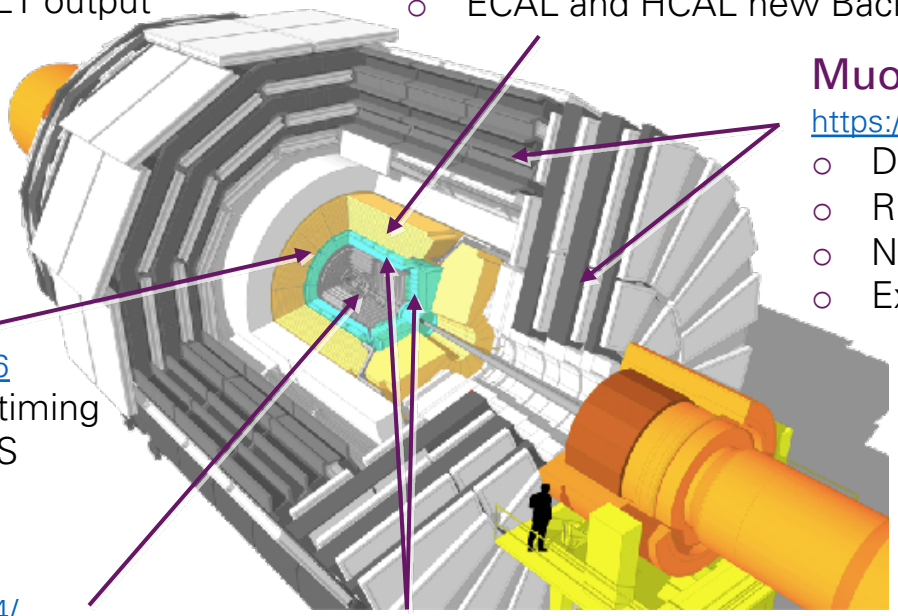
https://cds.cern.ch/record/2714892
https://cds.cern.ch/record/2283193

- Tracks in L1-Trigger at 40 MHz
- PFlow selection 750 kHz L1 output
- HLT output 7.5 kHz
- 40 MHz data scouting

Barrel Calorimeters

https://cds.cern.ch/record/2283187

- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards



Muon systems

https://cds.cern.ch/record/2283189

- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \sim 3$

Calorimeter Endcap

https://cds.cern.ch/record/2293646

- 3D shower and precision timing
- Si, Scint+SiPM in Pb/W-SS

Tracker

https://cds.cern.ch/record/2272264/

- Si strips and pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to $\eta \sim 3.8$

Talk by Davide Zuolo

MIP Timing Detector

https://cds.cern.ch/record/2667167

Precision timing with:

- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

CMS HL-LHC Future Physics

UNIVERSITÀ DI PAVIA

http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/FTR/index.html

Projected Physics Results		
CMS-PAS-FTR-21-001	Prospects for the measurement of vector boson scattering production in leptonic $W^{\pm}W^{\pm}$ and WZ diboson events at $\sqrt{s} = 14$ TeV at the High-Luminosity LHC	July 2021
CMS-PAS-FTR-18-040	Search for a new scalar resonance decaying to a pair of Z bosons at the High-Luminosity LHC	February 2019
CMS-PAS-FTR-18-037	HL-LHC searches for new physics in hadronic final states with boosted W bosons or top quarks using razor variables	February 2019
CMS-PAS-FTR-18-035	Projection of searches for exotic Higgs boson decays to light pseudoscalars for the High-Luminosity LHC	February 2019
CMS-PAS-FTR-18-030	Sensitivity study for a heavy gauge boson W' in the decay channel with a tau lepton and a neutrino at the High-Luminosity LHC	February 2019
CMS-PAS-FTR-18-019	Prospects for HH measurements at the HL-LHC	December 2018
CMS-PAS-FTR-18-028	Prospects for exclusion or discovery of a third generation leptoquark decaying into a τ lepton and a b quark with the upgraded CMS detector at the HL-LHC	December 2018
CMS-PAS-FTR-18-027	Constraining nuclear parton distributions with heavy ion collisions at the HL-LHC with the CMS experiment	December 2018
CMS-PAS-FTR-18-036	Anomalous couplings in the ttZ final state at the HL-LHC	December 2018
CMS-PAS-FTR-18-029	Search for excited leptons in $\ell\ell\gamma$ final states in proton-proton collisions at the HL-LHC	December 2018
CMS-PAS-FTR-18-025	Performance of jet quenching measurements in pp and PbPb collisions with CMS at the HL-LHC	December 2018
CMS-PAS-FTR-18-033	Study of the expected sensitivity to the P'_5 parameter in the $B^0 \to K^{*0}\mu^+\mu^-$ decay at the HL-LHC	December 2018

Physics results in Yellow Report (arXiv:1902.10229)

- Standard Model
- Higgs
- Beyond SM
- Flavour
- High density QCD

Future Physics assumptions

Physics analyses use:

- projections of previous analyses
- full simulation of Phase 2 detector
- DELPHES simulation

Uncertainties scenarios

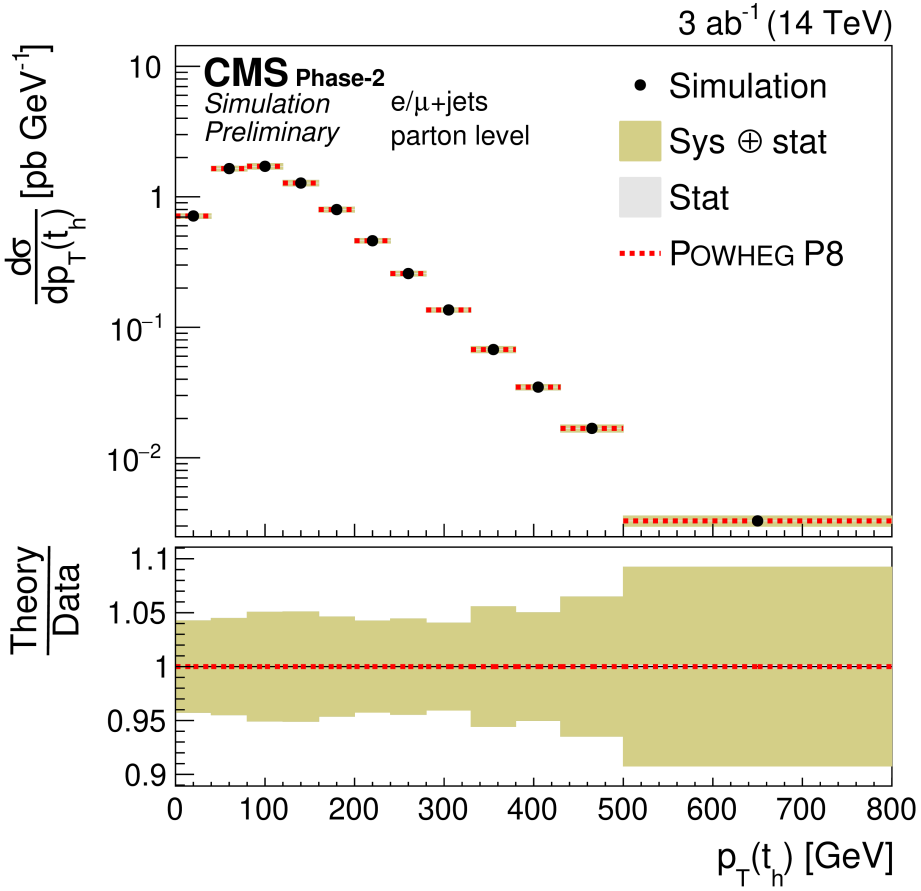
- Statistical only
- Run 2:
  - systematic unchanged
  - statistical scaled as $1/\sqrt{L/L_{ref}}$
- YR18:
  - theoretical scaled down by a factor 2
  - experimental systematic scaled as $1/\sqrt{L/L_{ref}}$ up to 50%

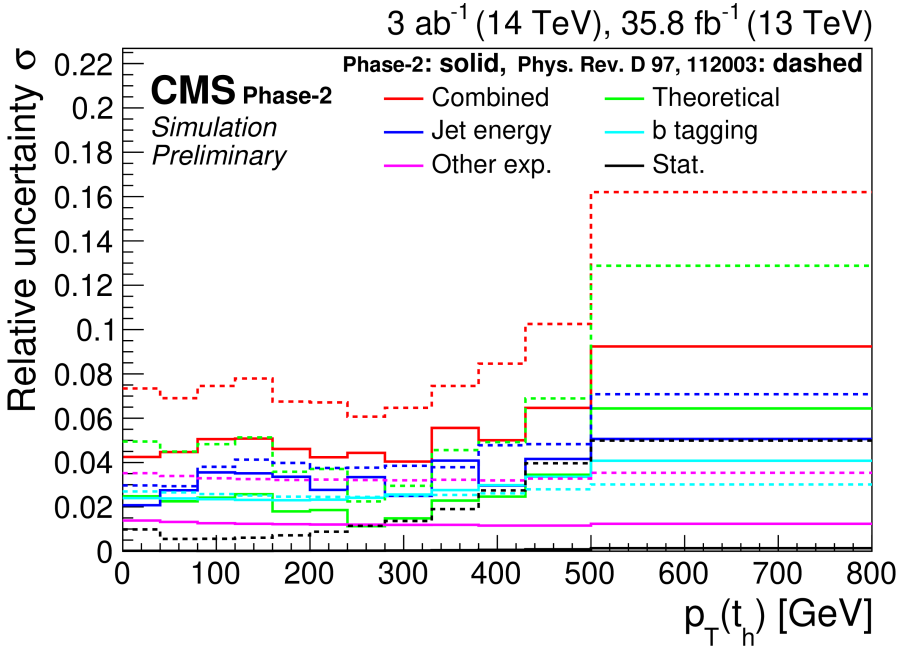
Uncertainty in integrated luminosity: 1%

SM: $t\bar{t}$ differential cross section

UNIVERSITÀ DI PAVIA

CMS-PAS-FTR-18-015



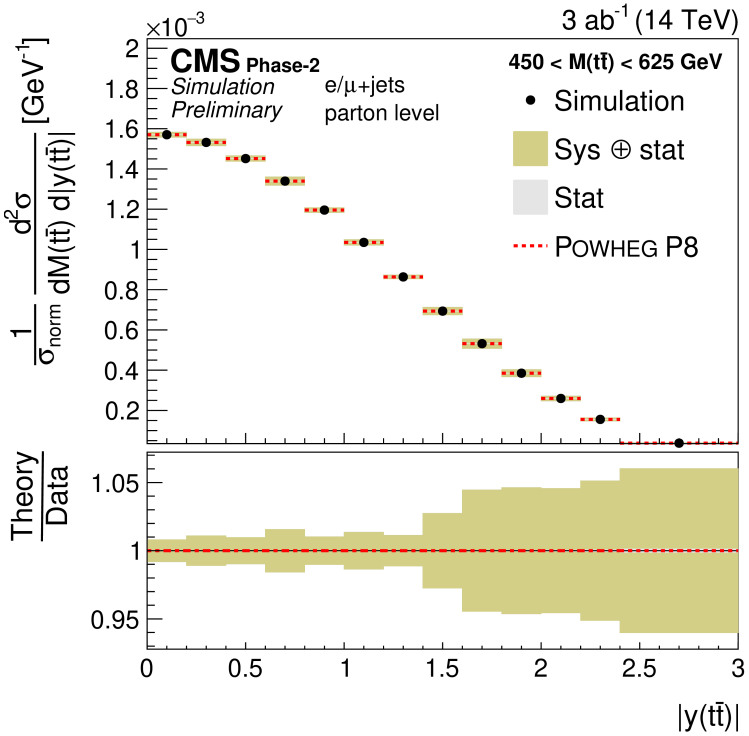


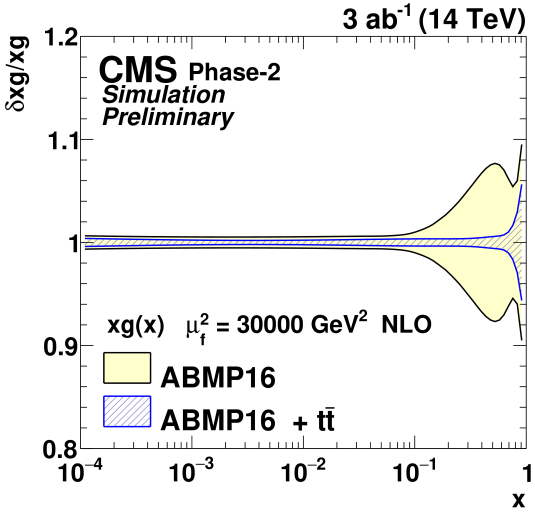
- Precision on differential cross section will profit from enormous amount of data and extended η –range

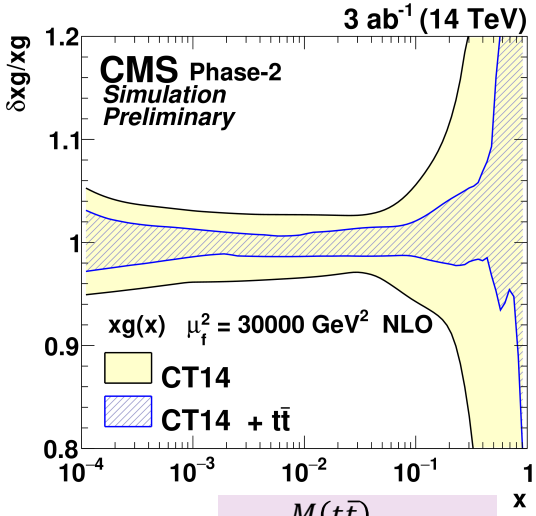
SM: $t\bar{t}$ differential cross section

UNIVERSITÀ DI PAVIA

PDF constraints from double differential cross section







$$x = \frac{M(t\bar{t})}{\sqrt{s}}\, e^{\pm|y(tt)|}$$

- A consistent impact of the $t\bar{t}$ data on all PDF dataset is observed.

The improvement is mainly due to improved jet energy calibration and reduction in b-jet identification

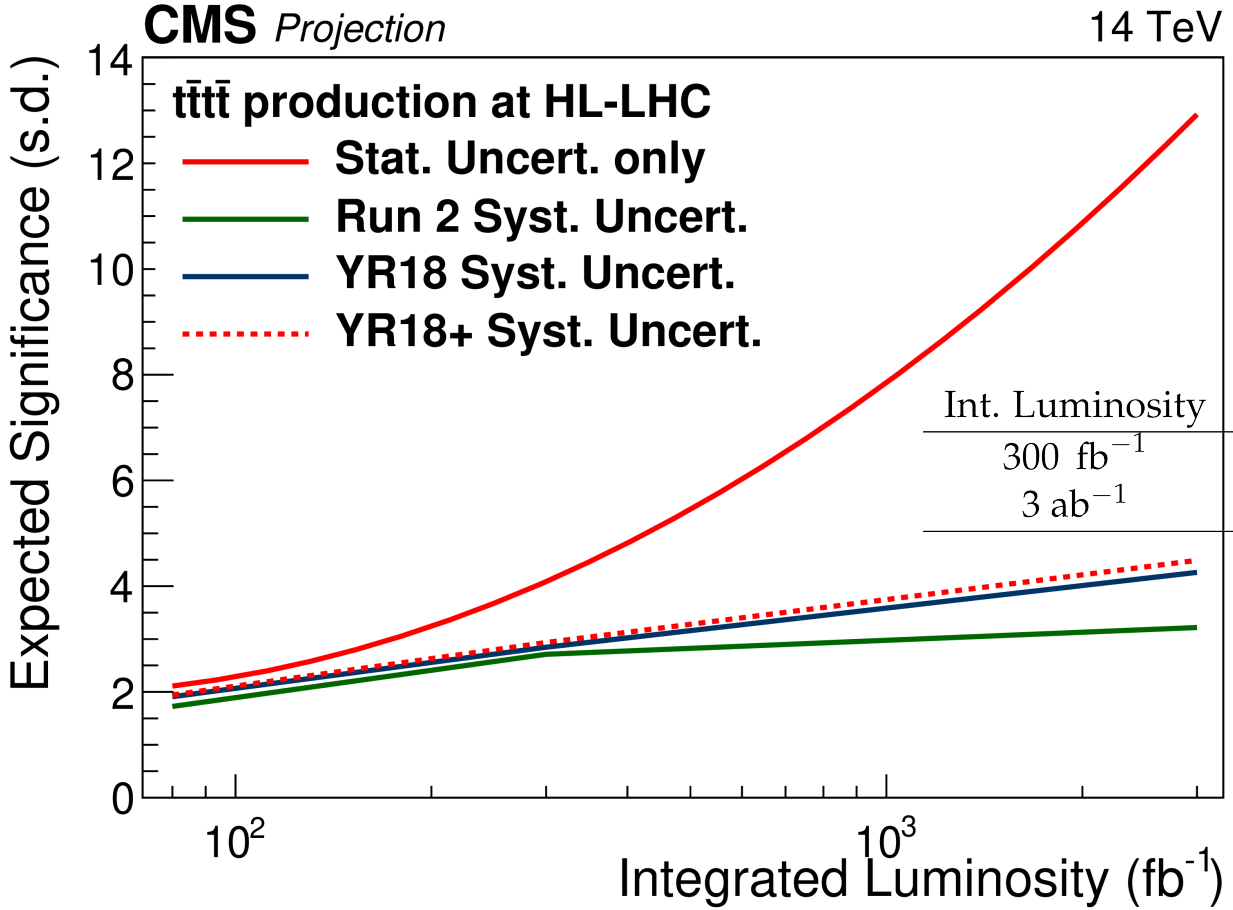
CMS-PAS-FTR-18-015

SM: $t\bar{t}t\bar{t}$ production

UNIVERSITÀ DI PAVIA

CMS-PAS-FTR-18-031

Talk by Nicolas Stylianou



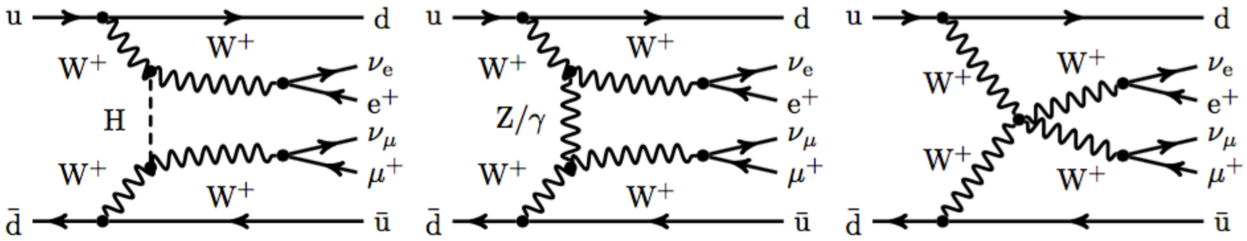
Int. Luminosity	*Stat. only*	*Run 2*	*YR18*	*YR18+*
300 fb^{-1}	4.09	2.71	2.85	2.93
3 ab^{-1}	12.9	3.22	4.26	4.49

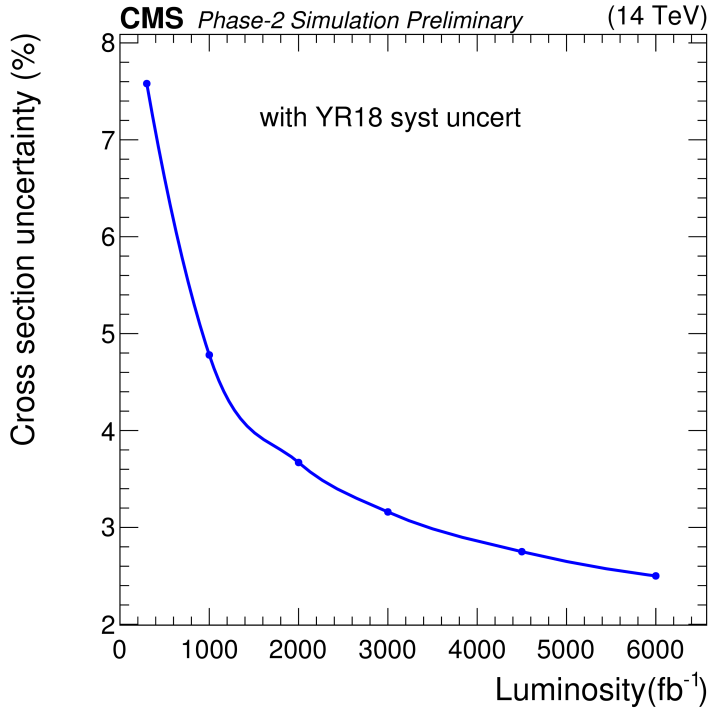
- With 3 ab^{-1} cross section constrained to 9% statistical uncertainty and the total uncertainty ranges between 18% and 28%

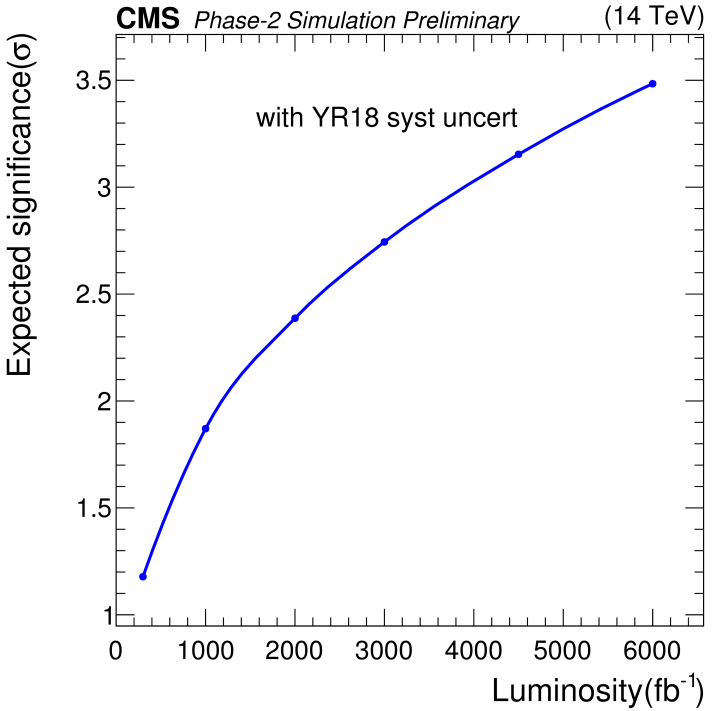
SM: $W^{\pm}W^{\pm}$ VBS and polarized cross section

UNIVERSITÀ DI PAVIA

CMS-PAS-FTR-18-005





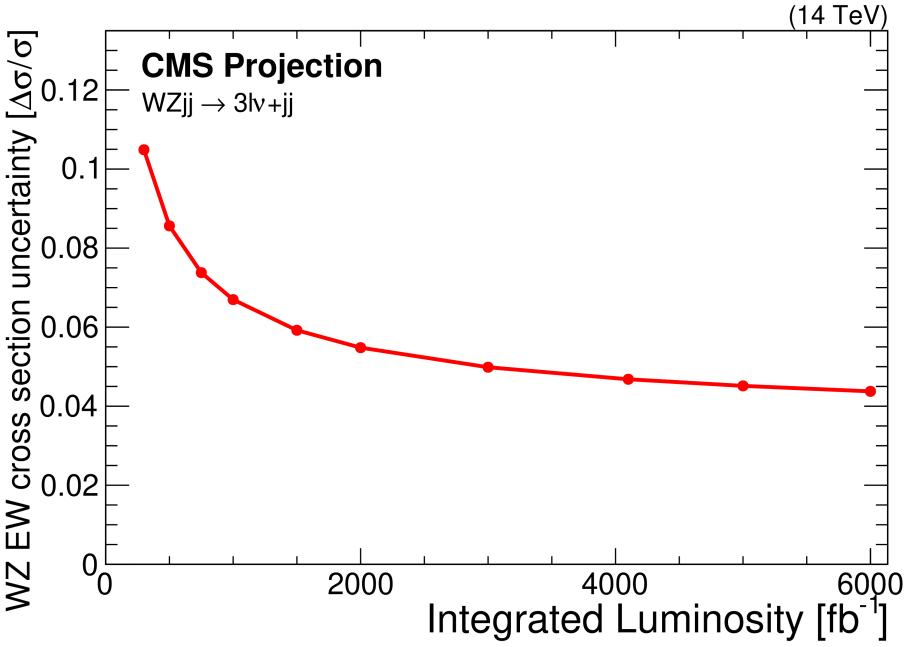


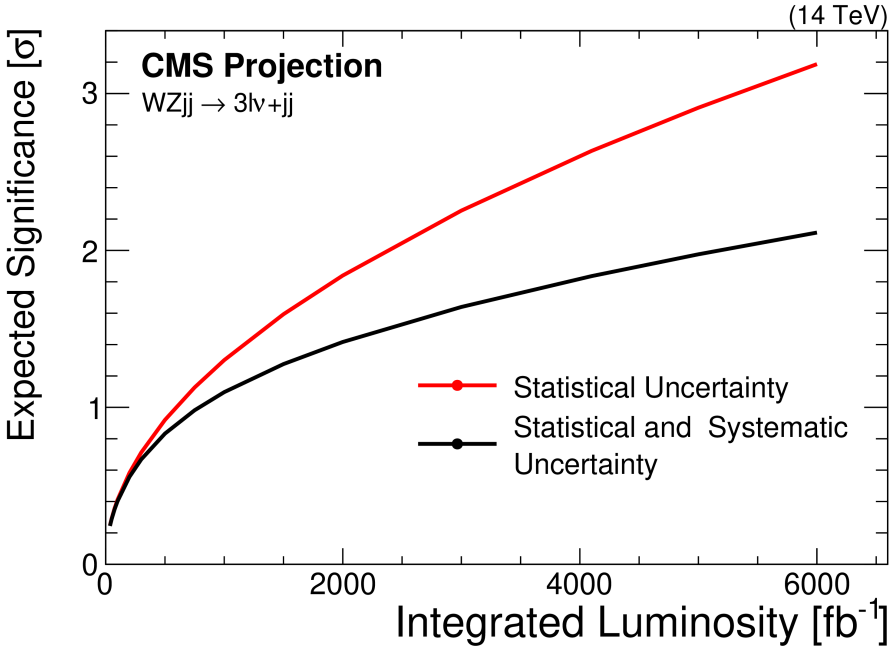
❖ Experimental uncertainty: <3% ❖ Significance for LL: 2.7σ at 3 ab^{-1}

SM: WZ VBS and polarized cross section

UNIVERSITÀ DI PAVIA

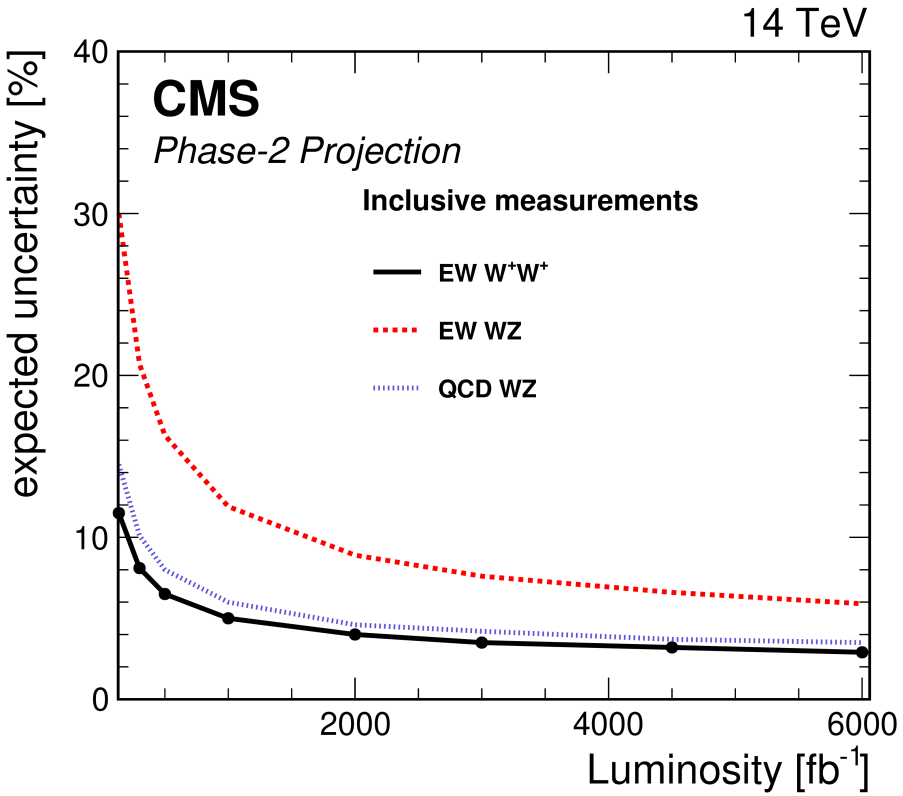
CMS-PAS-FTR-18-038

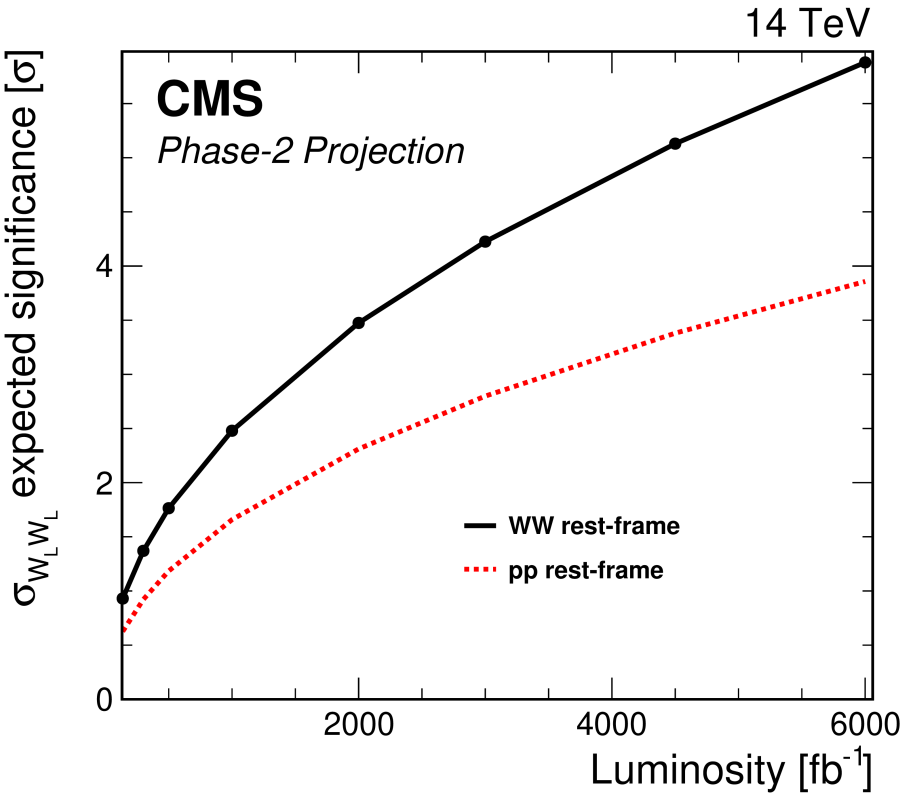




- The accuracy of the EW WZ cross section measurement is expected to significantly improve down to 5% at 3000 fb^{-1}

SM: VBS in leptonic WW and WZ diboson





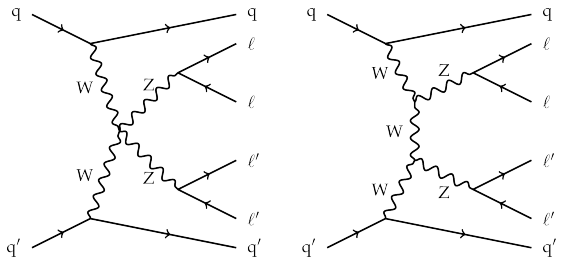
- The expected uncertainties are consistent with previous studies
- Projections for longitudinally polarized W-boson pairs scattering are better (W_LW_L uncertainties: 30-40%)

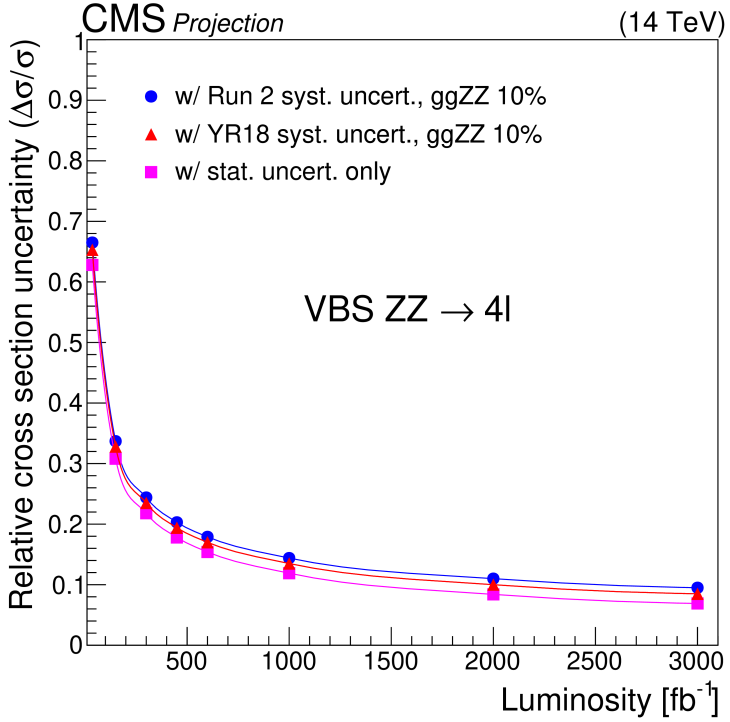
CMS-PAS-FTR-21-001

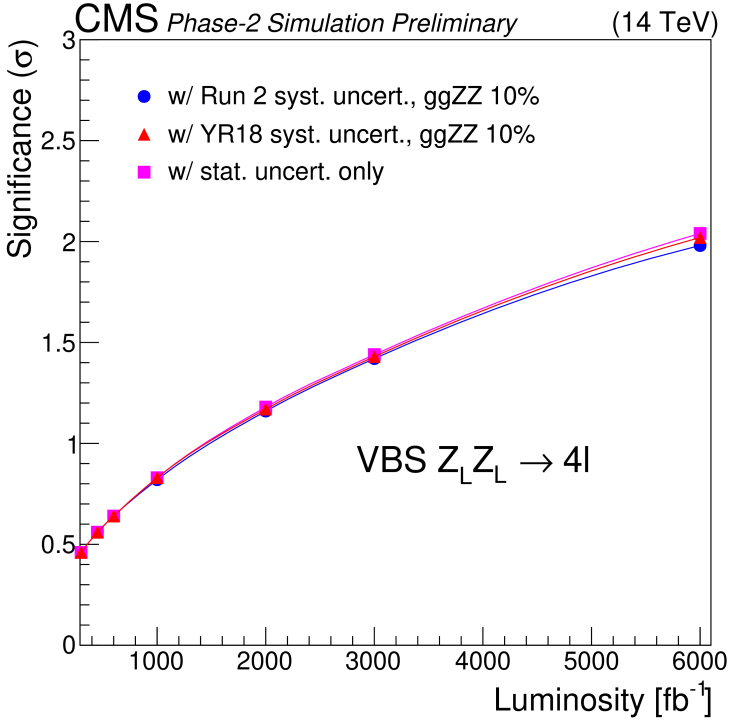
SM: ZZ VBS and polarized cross section

UNIVERSITÀ DI PAVIA

CMS-PAS-FTR-18-014







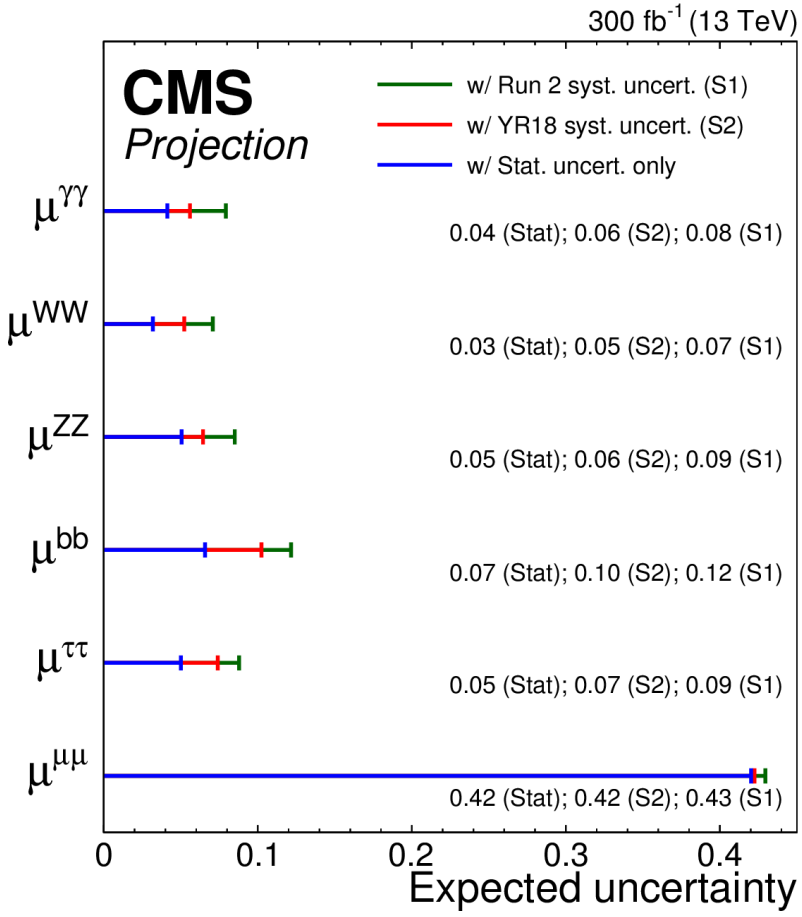
- Experimental uncertainty: 8.5-10.3%
- Significance for LL: 1.4σ at 3 ab^{-1}

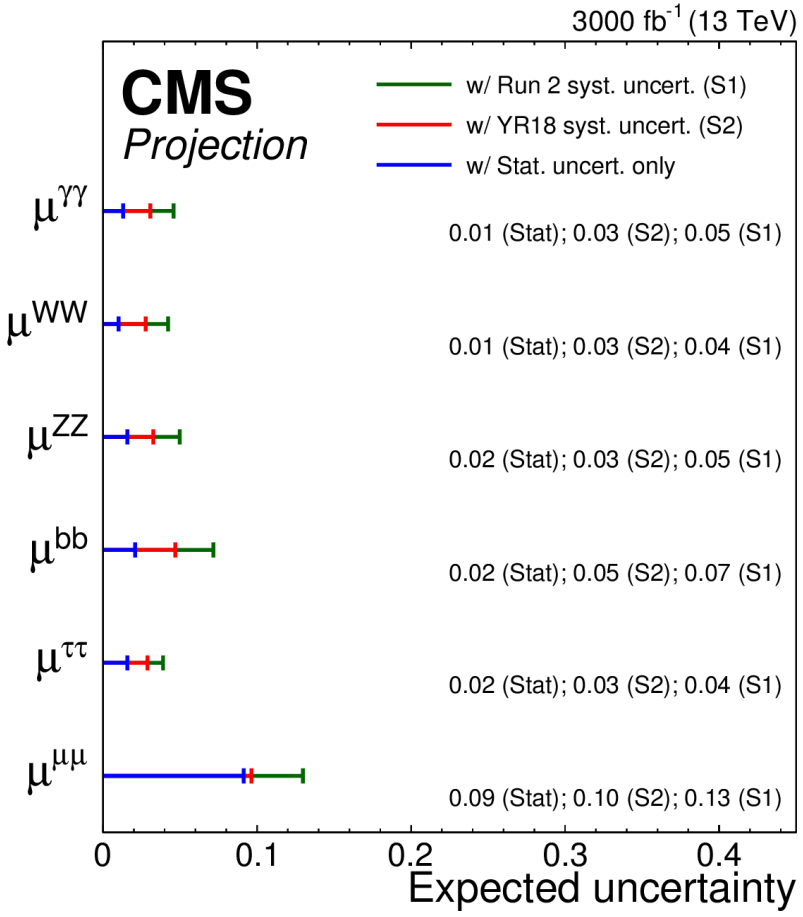
Higgs boson properties: cross section

UNIVERSITÀ DI PAVIA

CMS-PAS-FTR-18-011

Per-decay-mode signal strength



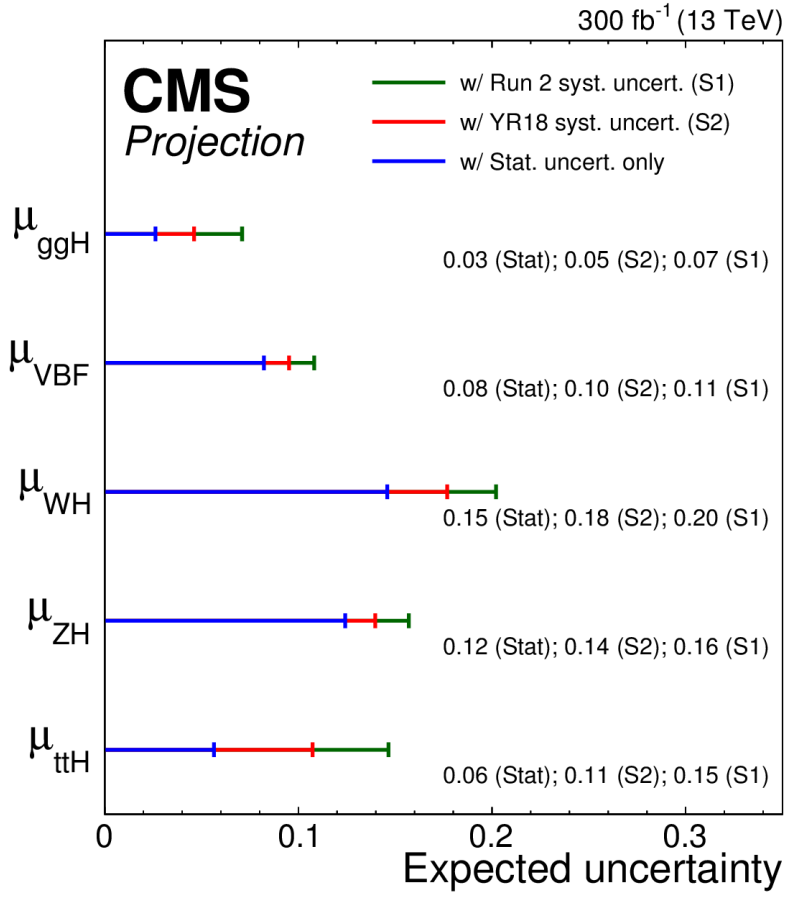


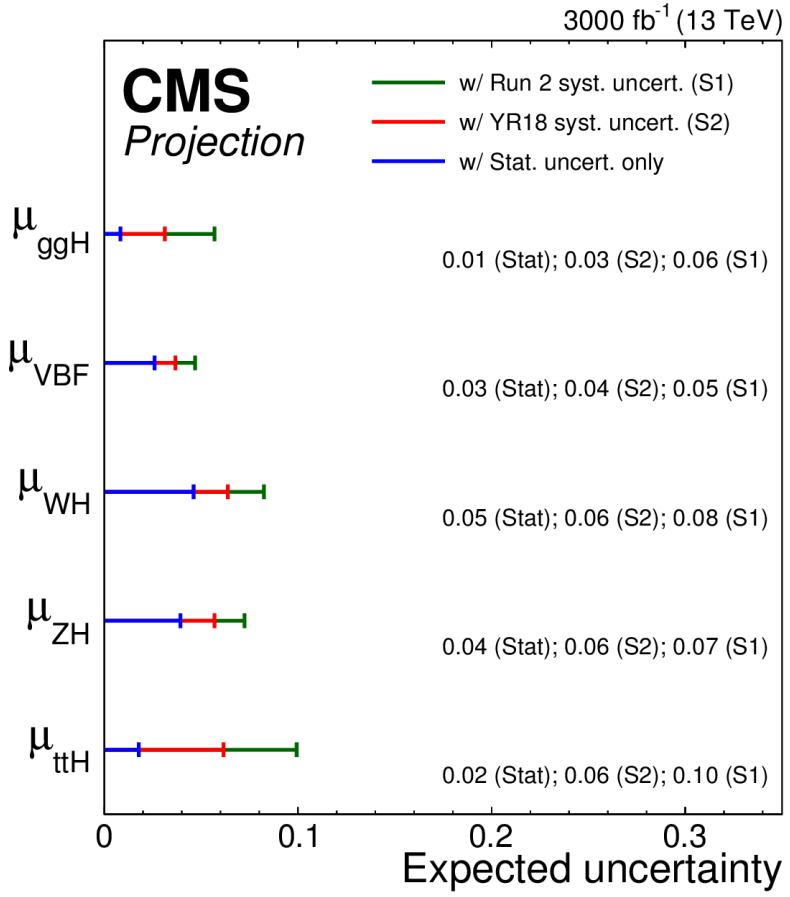
Higgs boson properties: cross section

UNIVERSITÀ DI PAVIA

CMS-PAS-FTR-18-011

Per-production-mode signal strength





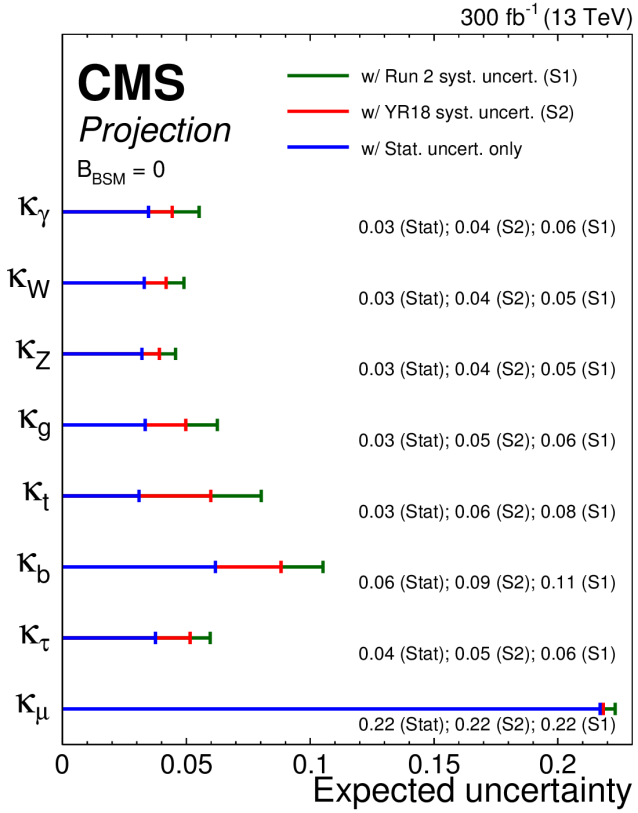
Higgs boson properties: coupling modifiers

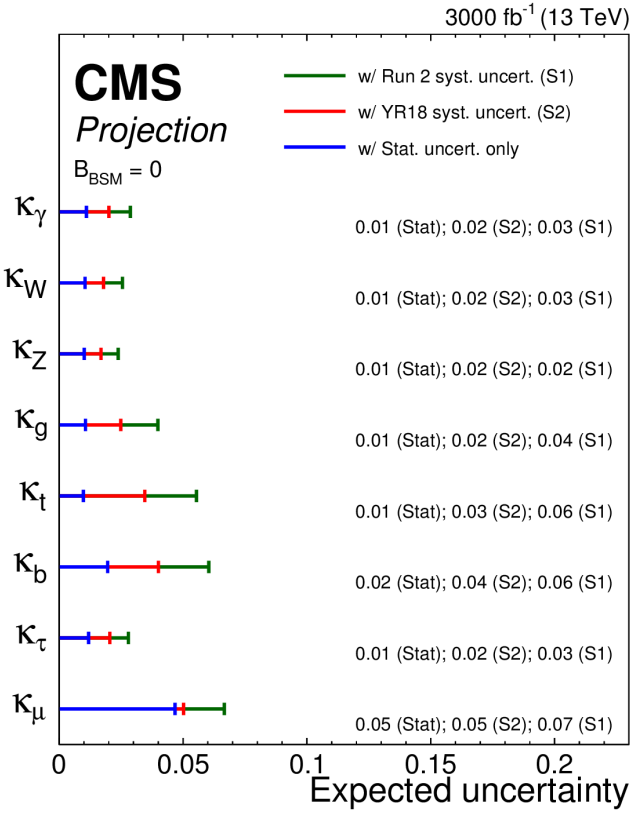
UNIVERSITÀ DI PAVIA

$$\frac{\Gamma_H}{\Gamma_H^{SM}} = \sum_j B_{SM}^j \kappa_j^2 \Big/ (1 - B_{BSM})$$

$$\kappa_j^2 = \frac{\Gamma_j}{\Gamma_j^{SM}}$$

CMS-PAS-FTR-18-011



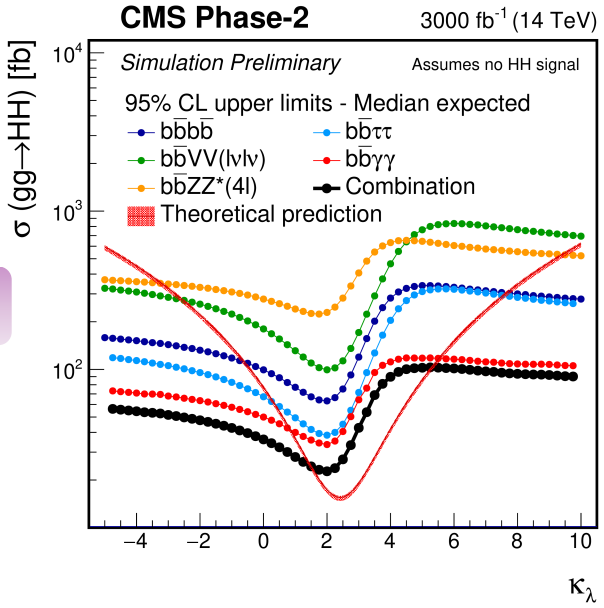


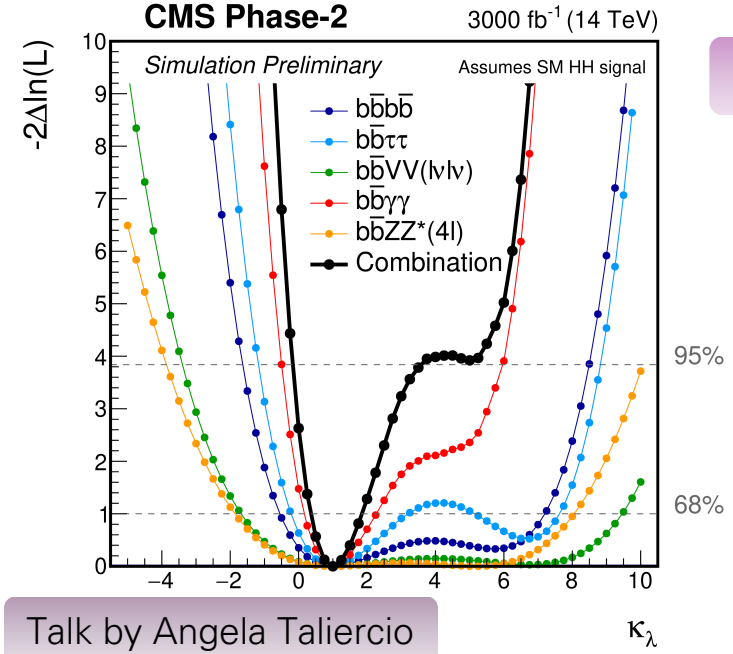
- $\frac{\Gamma_H}{\Gamma_H^{SM}}$ 0.05 (0.16 MeV) in Run 2
  0.04 (0.21 MeV) in YR18

HH production and self coupling

Channel	Significance		95% CL limit on $\sigma_{HH}/\sigma_{HH}^{SM}$	
	Stat. + syst.	Stat. only	Stat. + syst.	Stat. only
bbbb	0.95	1.2	2.1	1.6
bb$\tau\tau$	1.4	1.6	1.4	1.3
bbWW($\ell\nu\ell\nu$)	0.56	0.59	3.5	3.3
bb$\gamma\gamma$	1.8	1.8	1.1	1.1
bbZZ($\ell\ell\ell\ell$)	0.37	0.37	6.6	6.5
Combination	2.6	2.8	0.77	0.71

- Expected significance for the SM HH signal: 2.6σ





CMS-PAS-FTR-18-019

Talk by Angela Taliercio

Expected confidence levels for $\lambda_{HHH}/\lambda_{SM}$:

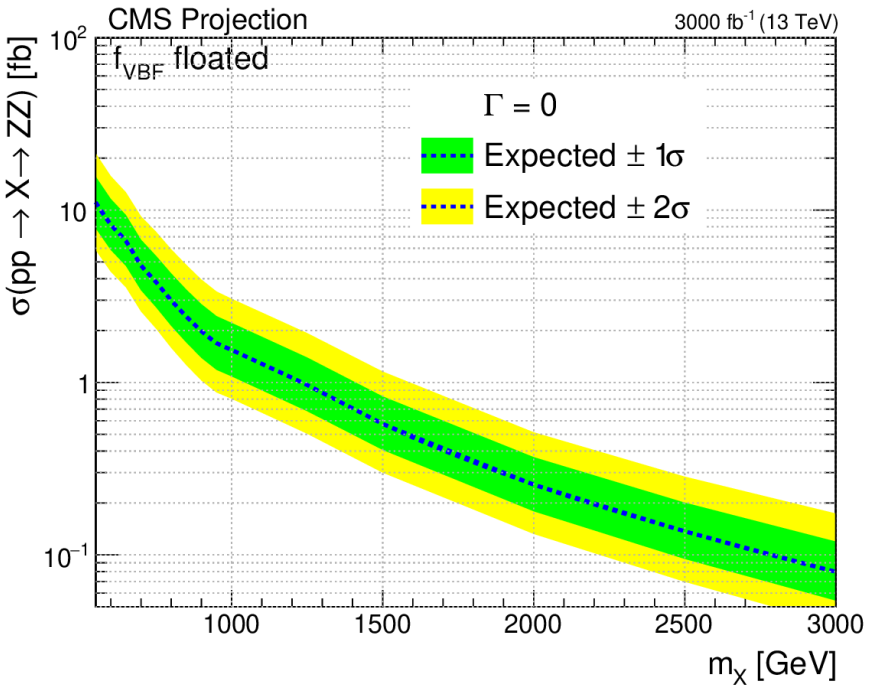
- 68% CL = [0.35, 1.9]
- 95% CL = [-0.18, 3.6]

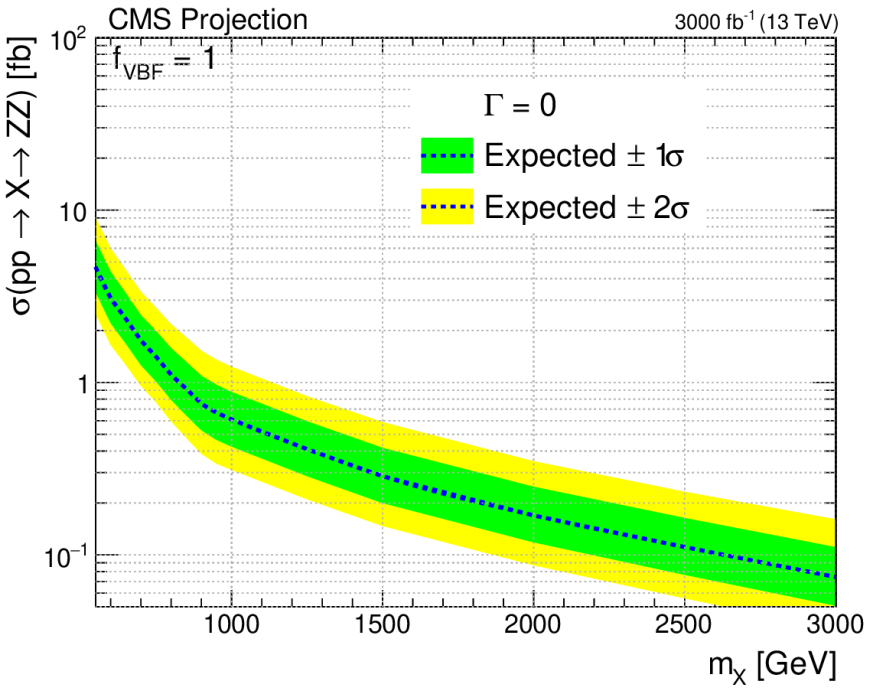
BSM: new scalar resonance

UNIVERSITÀ DI PAVIA

CMS-PAS-FTR-18-040

$$f_{VBF} = \frac{EW\ cross\ section}{total\ cross\ section}$$



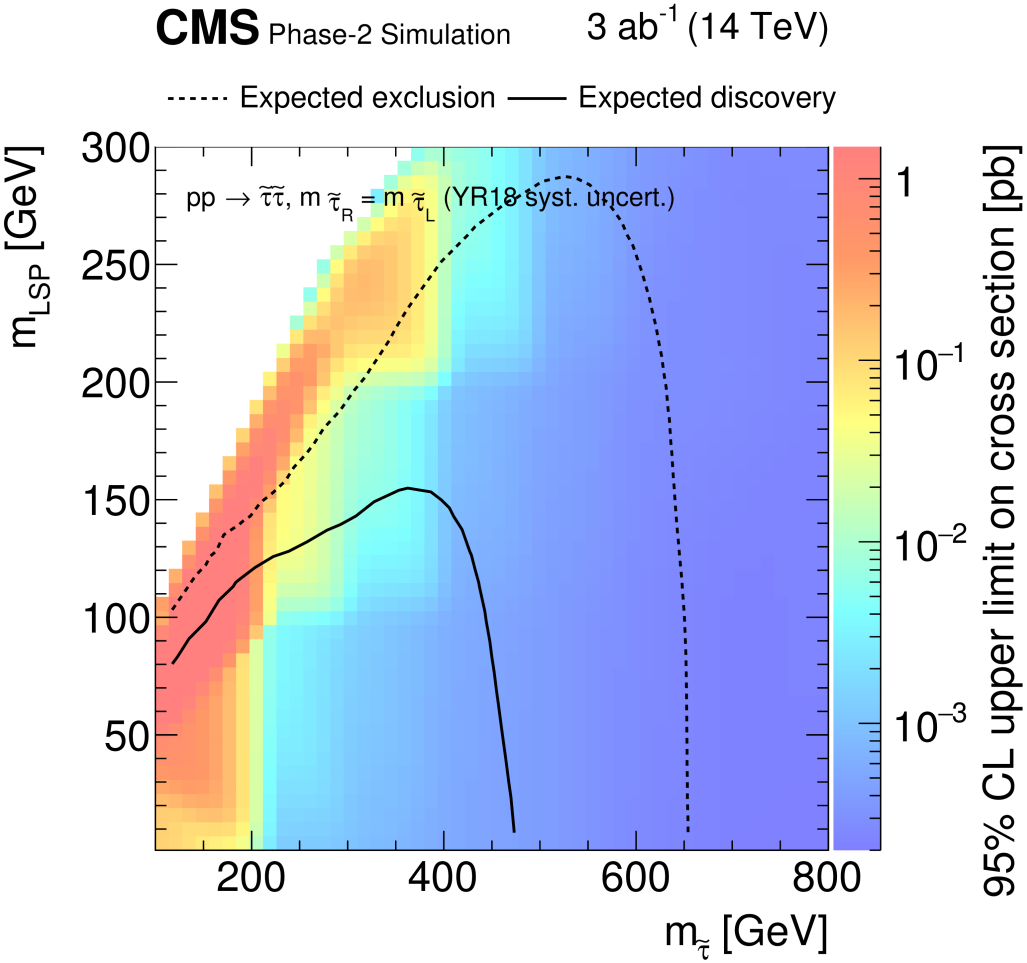


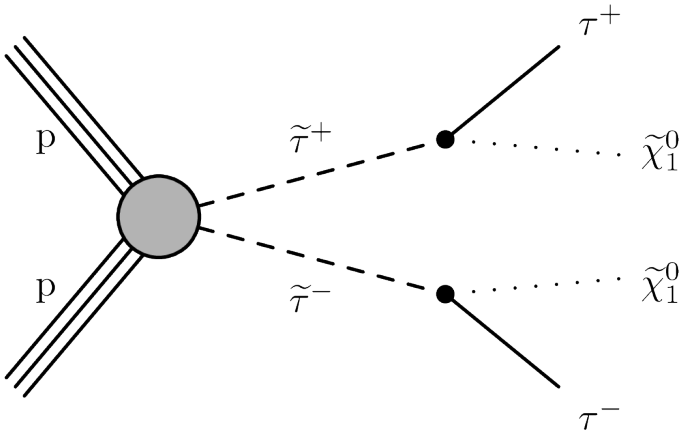
- Factor 10 improvement w.r.t. Run2

BSM: supersymmetry

Direct stau production

CMS-PAS-FTR-18-010



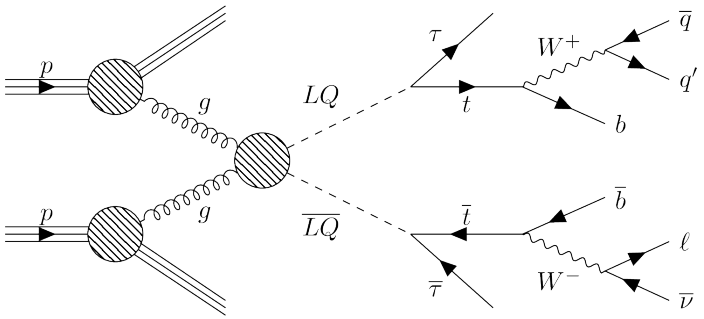


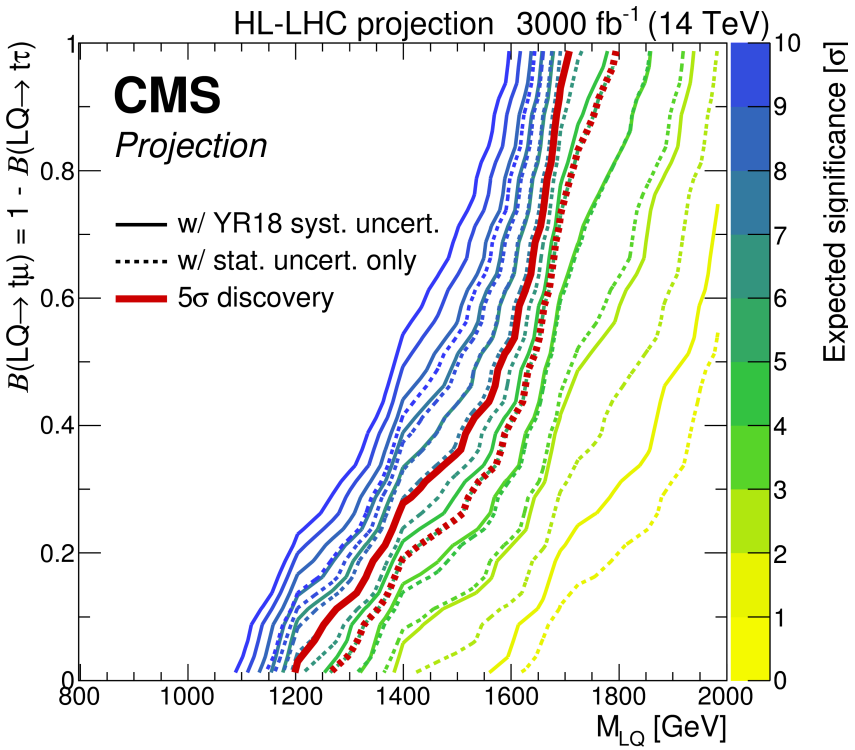
- $\tau_h\tau_h$ drives sensitivity, but $l\tau_h$ enlarges exclusion bounds by 60-80 GeV

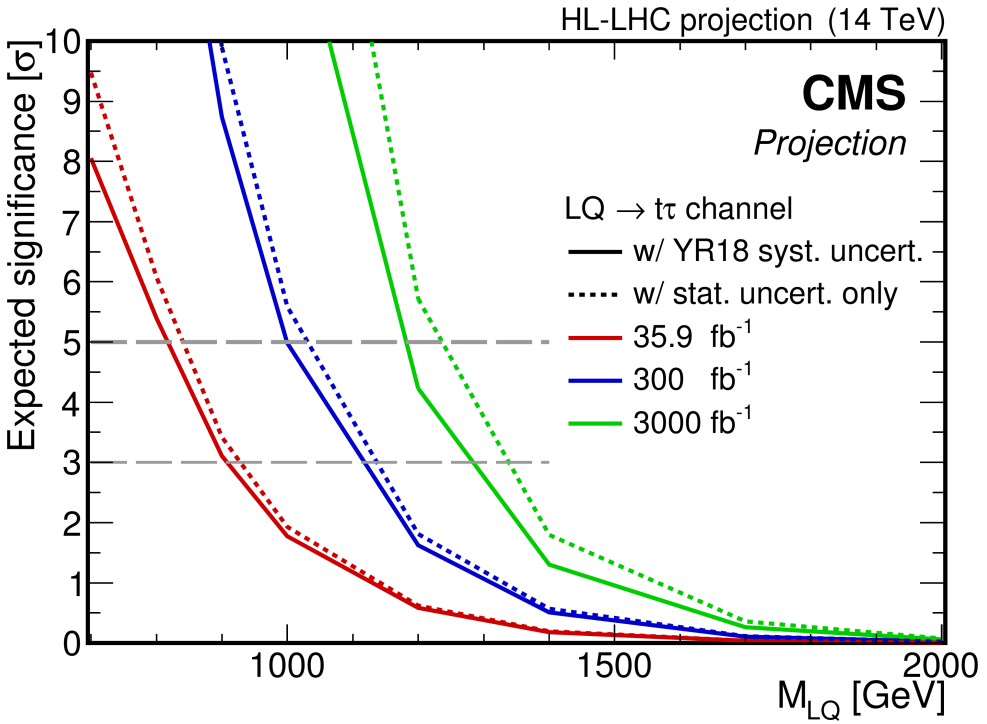
BSM: leptoquarks

UNIVERSITÀ DI PAVIA

CMS-PAS-FTR-18-008





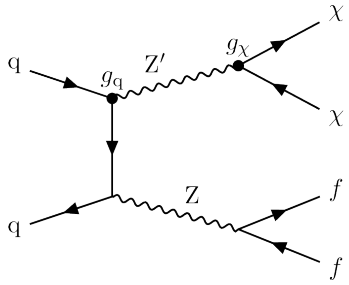


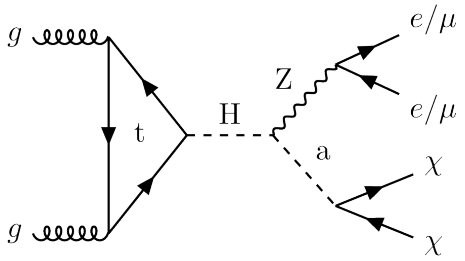
- LQ mass ~ 1200 GeV

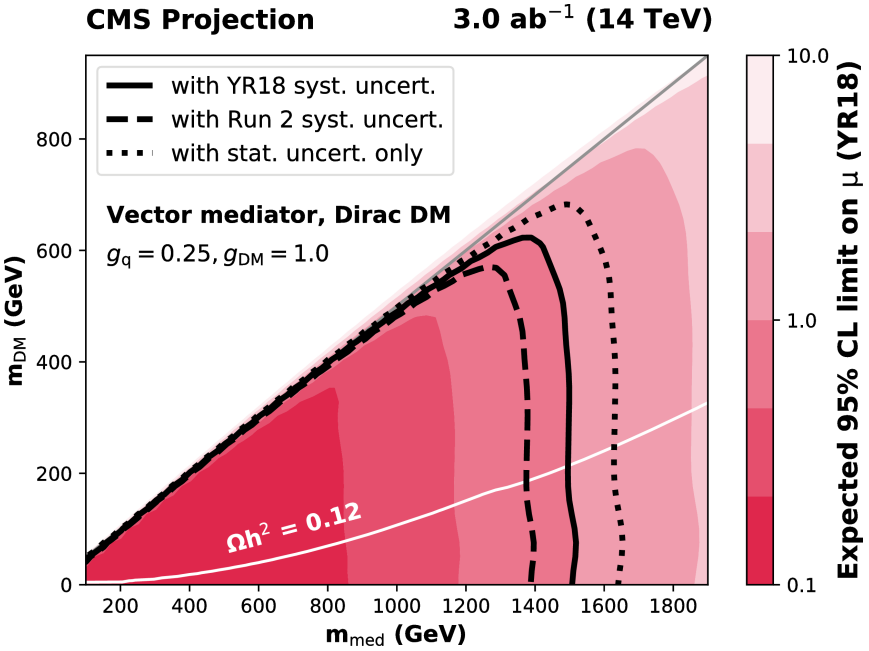
BSM: dark matter mono-Z

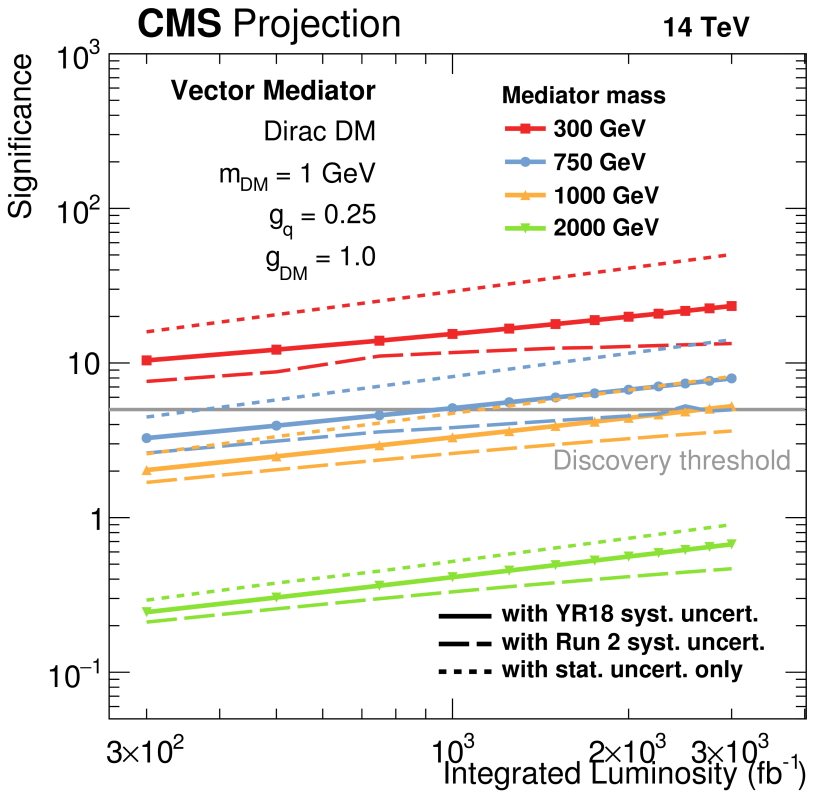
UNIVERSITÀ DI PAVIA

CMS-PAS-FTR-18-007









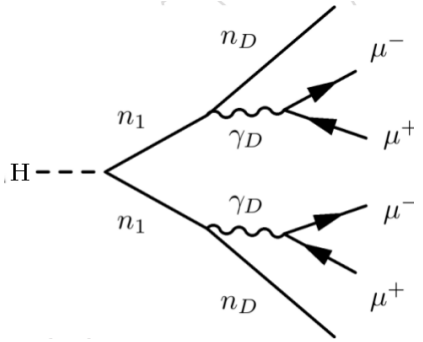
- At 3 ab^{-1} vector mediated DM production can be probed up to mediator mass 1.5 TeV

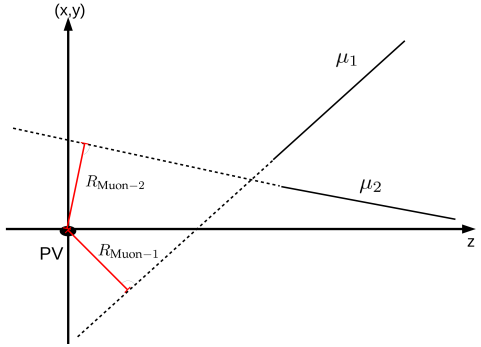
Talk by Siqi Yuan

BSM: dark photon at displaced vertices

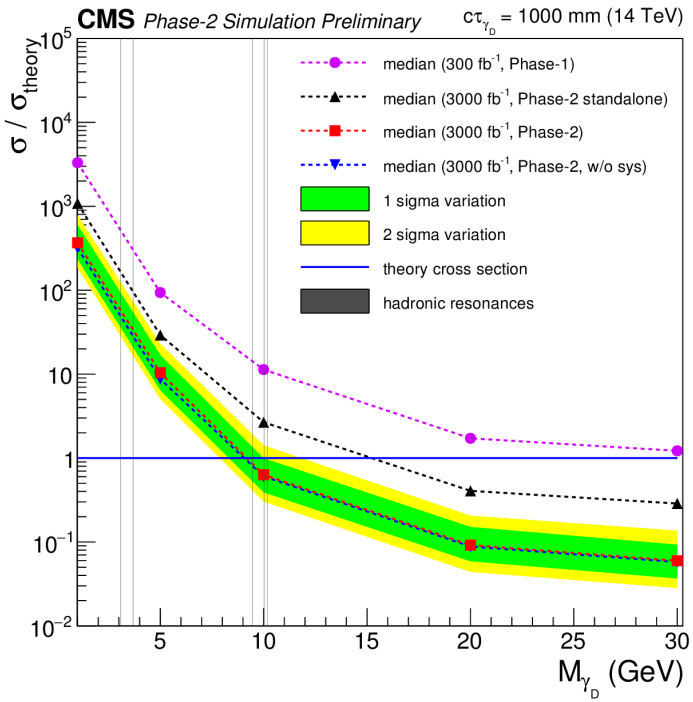
UNIVERSITÀ DI PAVIA

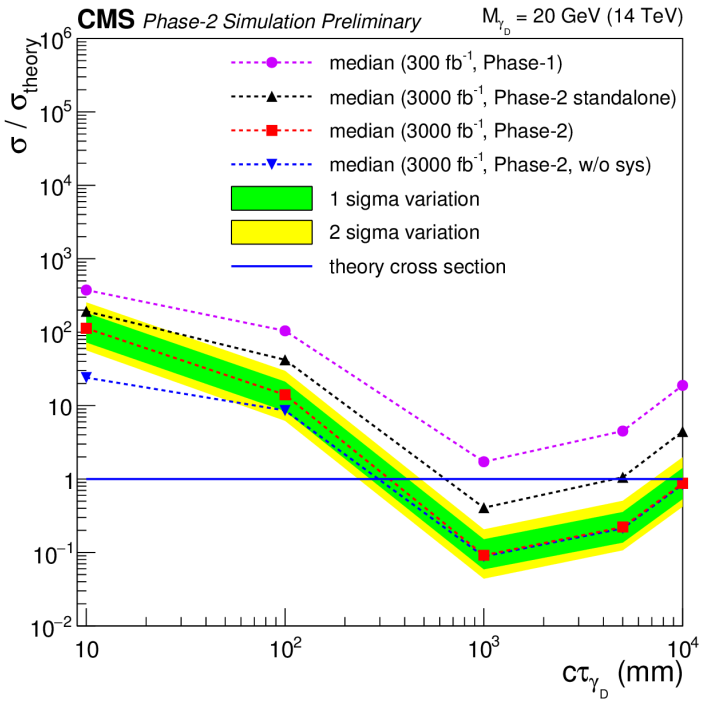
CMS-PAS-FTR-18-002





- Phase 2 sensitive to dark photon higher masses and longer lifetimes





Conclusions

HL-LHC will significantly increase the physics reach of LHC experiments

- allowing to repeat many important measurements with significantly improved precision
- exploring new processes with extremely low cross sections and branching fractions, hopefully to find new physics