

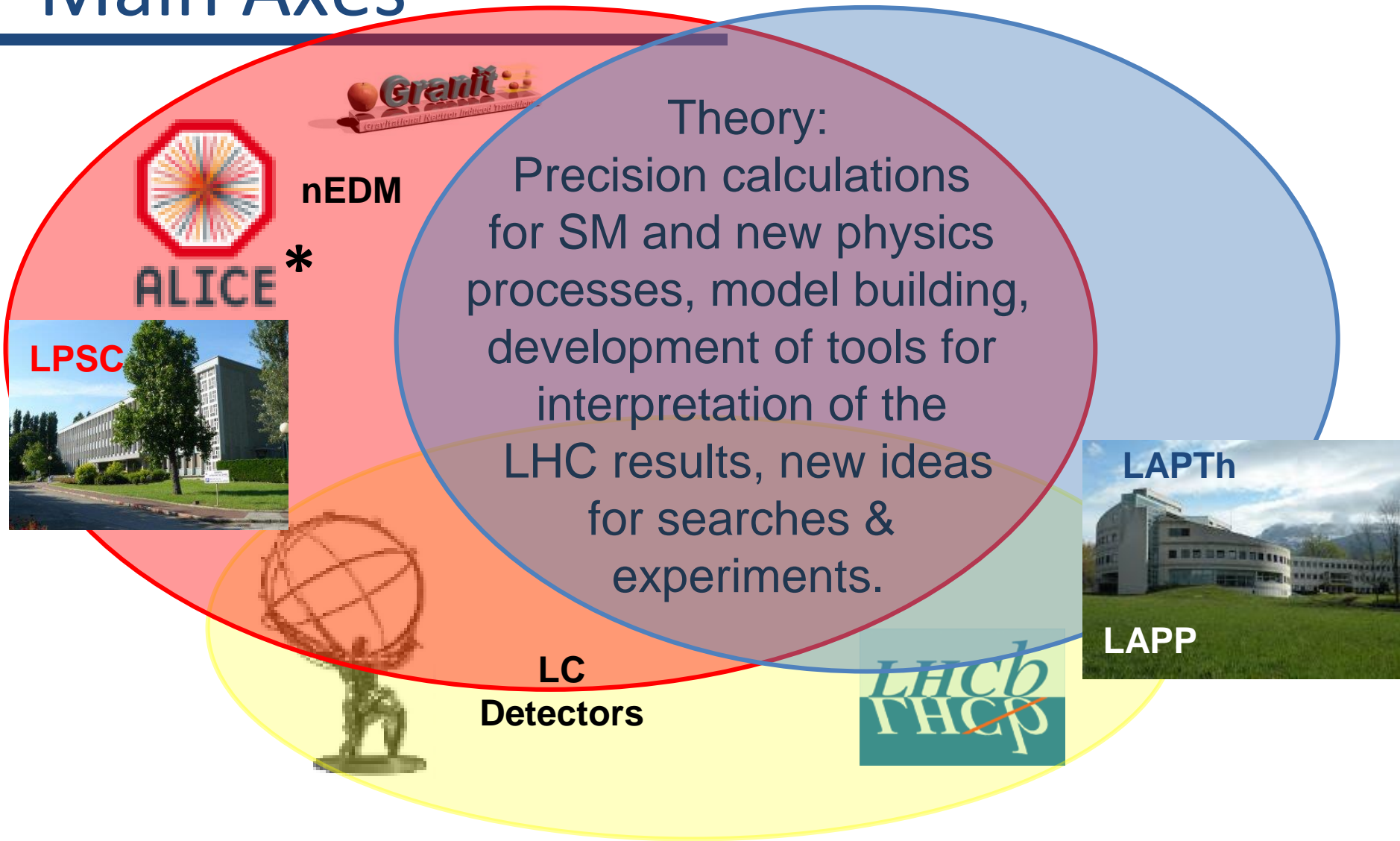
Report from Collider & Particle Physics Work-Package

Tetiana Berger-Hryn'ova

ENIGMASS Meeting

20/07/2017

Main Axes

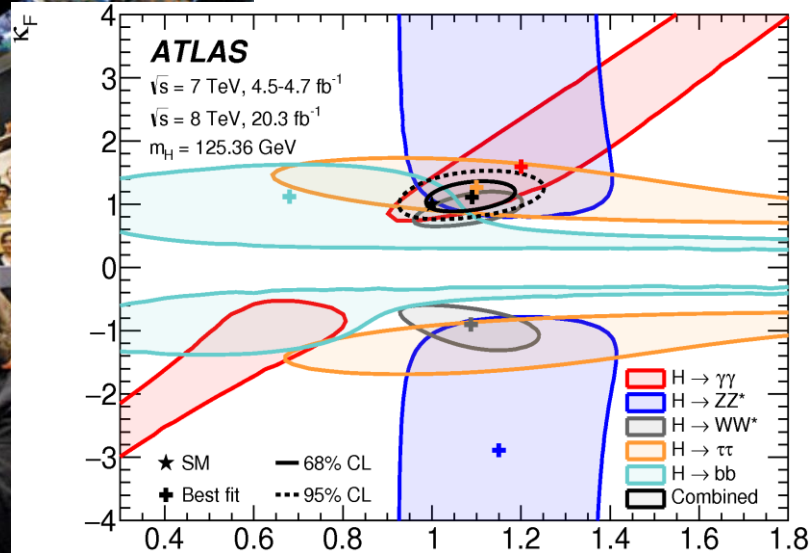
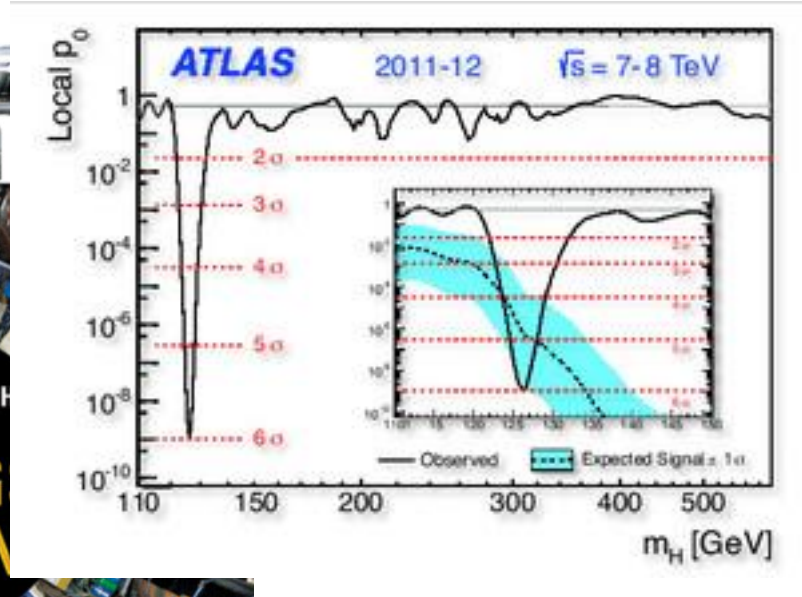


* New for the ENIGMASS renewal

Achievements 2012-2017



Higgs Discovery:
Nobel Prize
(Physics) 2012



ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits
Status: July 2017

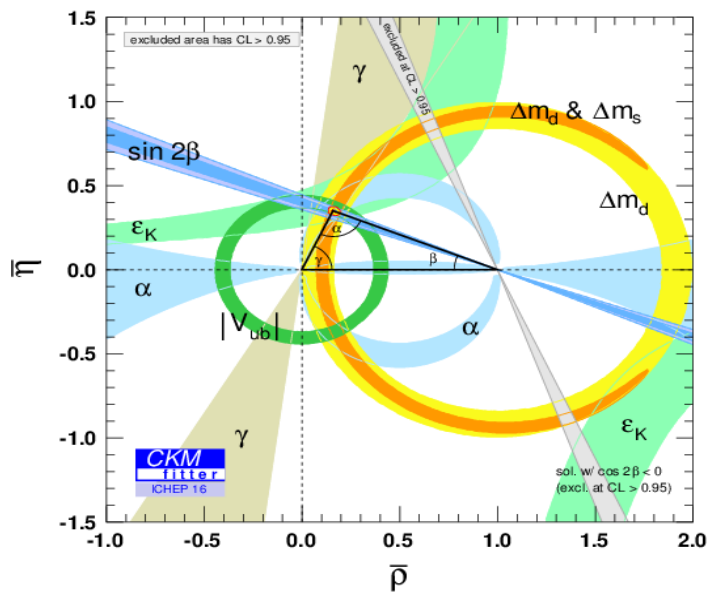
Status: July 2017

ATLAS Preliminary

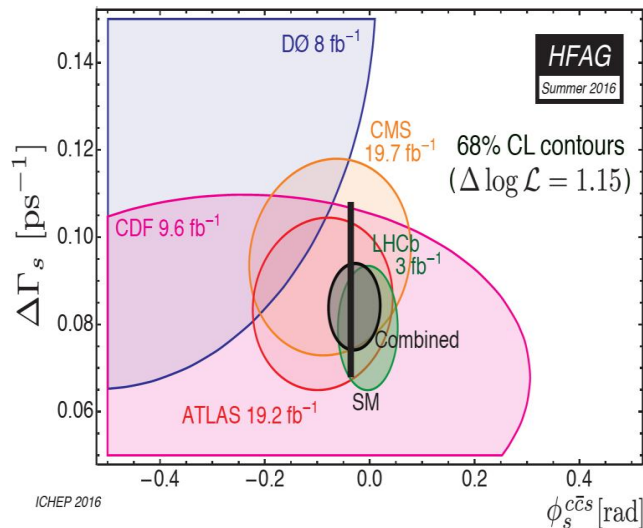
$$\int \mathcal{L} dt = (3.2 - 37.0) \text{ fb}^{-1}$$
 $\sqrt{s} = 8, 13 \text{ TeV}$

	Model	L, γ	Jets: ϵ	$E_{\text{miss}}^{\text{true}}$	$ \mathcal{L}_{\text{eff}}[\text{fb}^{-1}]$	Limit	Reference
Extra dimensions	ADD $G_{\mu\mu} + g/g$	$0 \leq p$	$1-4j$	Yes	81	$M_{\text{Pl}} = 1.22 \times 10^{19} \text{ GeV}$ $M_{\text{Pl}} = 1.22 \times 10^{19} \text{ GeV}$	ATLAS-COM-2017-066
	ADD non resonant $\gamma\gamma$	2γ	—	—	367	8.8 TeV	CEPP-CP-2017-12
	ADD GBH	$2j$	$2j$	—	370	8.8 TeV	1703.0751
	ADD BH multiplet	$2, 1 \leq p, r \leq 2$	$2, 1 \leq p, r \leq 2$	—	370	8.8 TeV	$n = M_2 - 1 \text{ TeV}$ or BH 1606.2265
	ADD H $\gamma\gamma$	2γ	$2j$	—	36	$M_{\text{Pl}} = 1.22 \times 10^{19} \text{ GeV}$	1912.0308
	RS1 $G_{\mu\mu} + \gamma\gamma$	2γ	$2j$	—	387	8.8 TeV	CEPP-AN-2017-017
	Bulk RS $G_{\mu\mu} \rightarrow WW \rightarrow e\bar{e}\nu$	$1, 2\gamma$	$1, 2j$	Yes	361	$M_{\text{Pl}} = 1.22 \times 10^{19} \text{ GeV}$	ATLAS-COM-2017-066
	ZUED $\rightarrow \text{BB}^{\dagger}$	$1, 2\gamma$	$2, 2b, 2, 3j$	Yes	132	1.8 TeV	ATLAS-COM-2017-066
	SSM $Z \rightarrow f\bar{f}$	$2, 2\gamma$	—	—	381	Z mass	ATLAS-COM-2017-027
	SSM $Z \rightarrow \nu\bar{\nu}$	2γ	—	—	381	Z mass	ATLAS-COM-2017-027
Gauge bosons	Leptoquark $Z' \rightarrow b\bar{b}$	2γ	$2b$	—	382	Z mass	1603.3971
	Leptoquark $Z' \rightarrow t\bar{t}$	$1, 2\gamma$	$2, 1b, 2, 1Q, 2j$	Yes	382	Z mass	ATLAS-COM-2016-014
	SSM $W \rightarrow f\bar{f}$	$1, 2\gamma$	$2j$	—	381	W mass	1706.3474
	HVT $W' \rightarrow WW + \text{easy model B}$	$2, 2\gamma$	$2, 2\gamma$	—	387	W mass	CEPP-CP-2017-147
	HVT $W' \rightarrow WH, Z$ model B	multi-channel	—	—	387	W mass	ATLAS-COM-2017-066
	LRSM $W_2 \rightarrow b\bar{b}$	$1, 2\gamma$	$2, 1b, 2, 1j$	Yes	203	W mass	1410.4123
	LRSM $W_2 \rightarrow \nu\bar{\nu}$	2γ	$2, 1b, 2, 1j$	Yes	203	W mass	1403.2632
	Ci open	$2, 2\gamma$	$2j$	—	370	25.8 TeV	1703.3971
	Ci closed	$2, 2\gamma$	$2, 2\gamma$	—	381	40.1 TeV	ATLAS-COM-2017-027
	Ci unit	$2, 2\gamma$	$2, 2\gamma$	—	381	40.1 TeV	1504.2043
DM	Anal-vector mediator (Drap DM)	$2, 2\gamma$	$1-4j$	Yes	81	1.0 TeV	ATLAS-COM-2017-066
	Vector mediator (Drap DM)	$2, 2\gamma$	$1-4j$	Yes	81	1.0 TeV	1710.2848
LQ	Scalar LQ 1^{st} gen	2γ	$2j$	—	32	1.0 TeV	1605.3033
	Scalar LQ 2^{nd} gen	2γ	$2j$	—	32	1.0 TeV	1605.3033
	Scalar LQ 3^{rd} gen	2γ	$2j$	—	32	1.0 TeV	1605.3033
	Scalar LQ 1^{st} gen	2γ	$2j$	—	32	1.0 TeV	1605.3033
Heavy quarks	VLT $Q \rightarrow H\bar{c}$	$0, 1 \leq p, r \leq 2, 2b, 2j$	$2, 2j$	Yes	132	1.8 TeV	ATLAS-COM-2017-066
	VLT $TT \rightarrow T\bar{c}$	$1, 2\gamma$	$2, 1b, 2, 1j$	Yes	361	1.8 TeV	1703.0751
	VLT $TT \rightarrow W\bar{c}$	$1, 2\gamma$	$2, 1b, 2, 1j$	Yes	361	1.8 TeV	CEPP-CP-2017-064
	VLT $Q\bar{Q} \rightarrow H\bar{c}$	$1, 2\gamma$	$2, 2b, 2, 2j$	Yes	203	1.8 TeV	1703.3043
	VLT $Q\bar{Q} \rightarrow W\bar{c}$	$2, 2\gamma$	$2, 2b, 2, 2j$	Yes	203	1.8 TeV	1409.8550
	VLT $Q\bar{Q} \rightarrow W\bar{c}$	$1, 2\gamma$	$2, 2b, 2, 2j$	Yes	203	1.8 TeV	CEPP-AN-2017-054
	VLT $Q\bar{Q} \rightarrow W\bar{c}$	$1, 2\gamma$	$2, 2j$	—	36	1.8 TeV	1503.3421
	VLT $Q\bar{Q} \rightarrow W\bar{c}$	$1, 2\gamma$	$2, 2j$	—	36	1.8 TeV	1503.3421
	VLT $Q\bar{Q} \rightarrow W\bar{c}$	$1, 2\gamma$	$2, 2j$	—	36	1.8 TeV	1503.3421
	VLT $Q\bar{Q} \rightarrow W\bar{c}$	$1, 2\gamma$	$2, 2j$	—	36	1.8 TeV	1503.3421
Exotic fermions	Exotic quark $q' \rightarrow qg$	1γ	$2j$	—	370	W mass	1703.3971
	Exotic quark $q' \rightarrow q\gamma$	1γ	$1j$	—	367	8.8 TeV	CEPP-CP-2017-144
	Exotic quark $q' \rightarrow b\gamma$	1γ	$1b, 1j$	—	370	8.8 TeV	ATLAS-COM-2016-065
	Exotic quark $q' \rightarrow W\bar{t}$	$1, 2\gamma$	$1, 2b, 1Q, 2, 2b, 2j$	Yes	203	1.8 TeV	1510.2026
	Exotic lepton ℓ'	$2, 2\gamma$	$2j$	—	370	8.8 TeV	1411.7501
Other	1RSM Higgsino χ	$2, 2\gamma$	$2j$	—	203	$m(\tilde{W}_2) = 2.4 \text{ TeV}$ or nothing	1506.2029
	Higgs triplet $H^{\pm\pm} \rightarrow f\bar{f}$	$2, 2, 1\gamma$ (SS)	—	—	381	870 GeV	ATLAS-COM-2017-055
	Higgs triplet $H^{\pm\pm} \rightarrow f\bar{f}$	$2, 2, 1\gamma$	—	—	203	870 GeV	1411.292
	Motivated from pre-prob	$1, 2\gamma$	$1b$	203	870 GeV	$\Delta a_\mu = 26.0 \times 10^{-11}$	1410.3434
	Mix of charged particles	$1, 2\gamma$	$2j$	—	370	870 GeV	1501.1819
Magnetic monopoles	$1, 2\gamma$	$2j$	—	70	1.34 TeV	1509.3059	

*Only a selection of the available mass limits on new states or phenomena is shown.

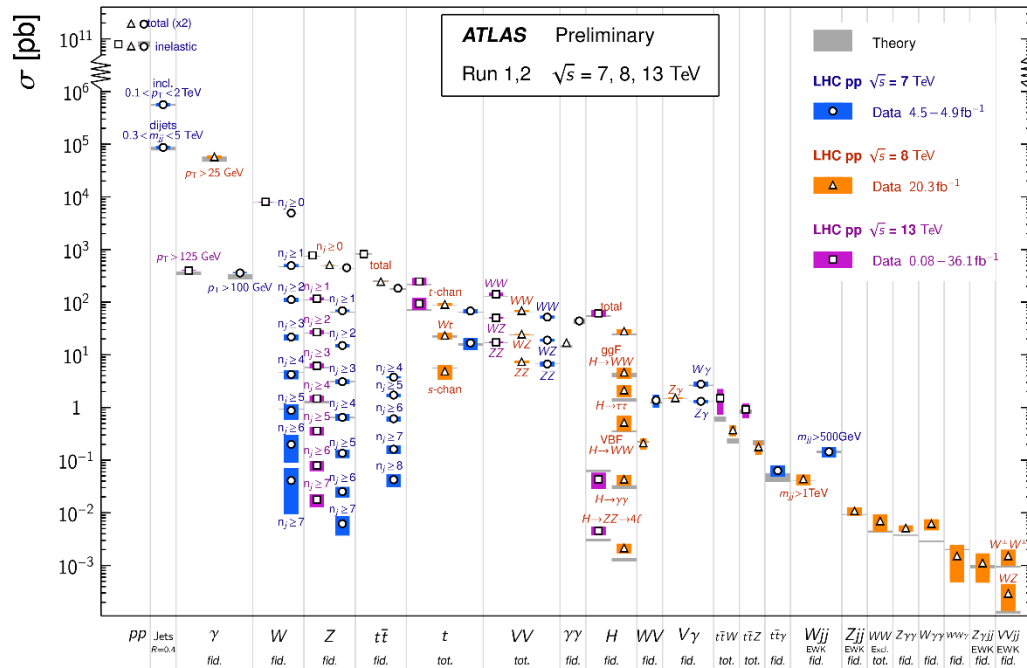
* Small-radius (large-radius) jets are denoted by the letter i (J).

Measurements:
WZ & $\gamma\gamma$,
top polarization,
Higgs
properties
CKM angles
(β , γ , ϕ_s); $B \rightarrow K^* \gamma$
etc..

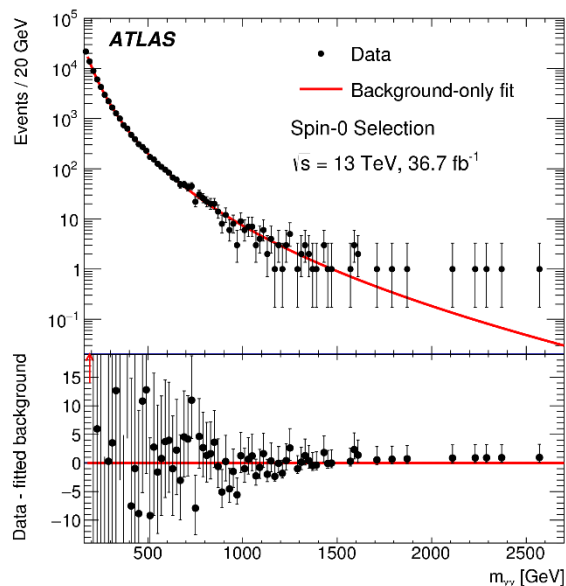


Standard Model Production Cross Section Measurements

Status: May 2017



ENIGMASS Highlights Experiment

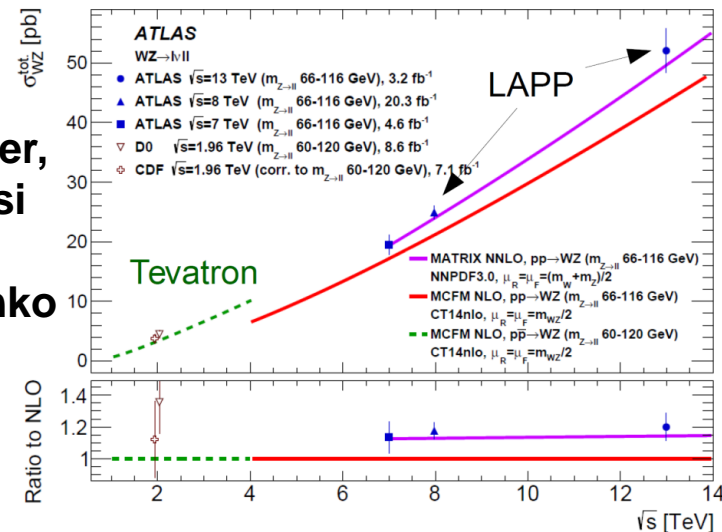


$\gamma\gamma$: SM,
Higgs &
BSM

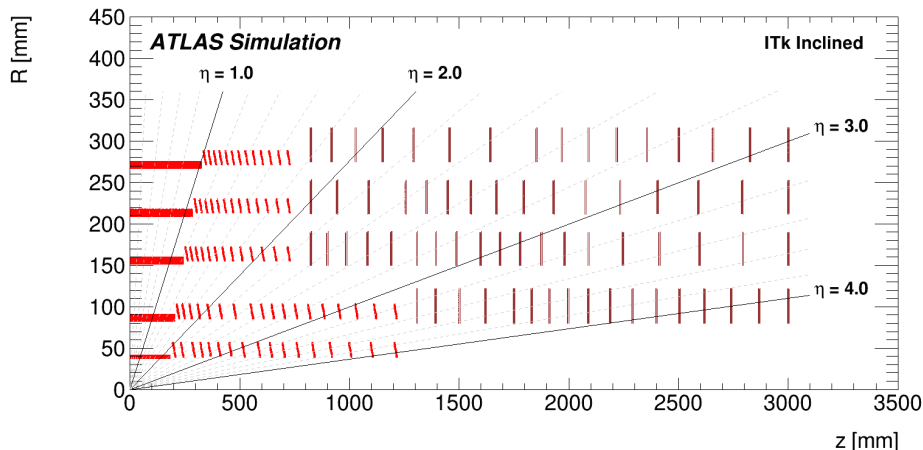
PhD:
Z. Barnovska
K. Grevtsov,
PD: O. Kivernyk

SM WZ

PhD:
A. Burger,
O. Dartsi
PD:
E. Yatsenko

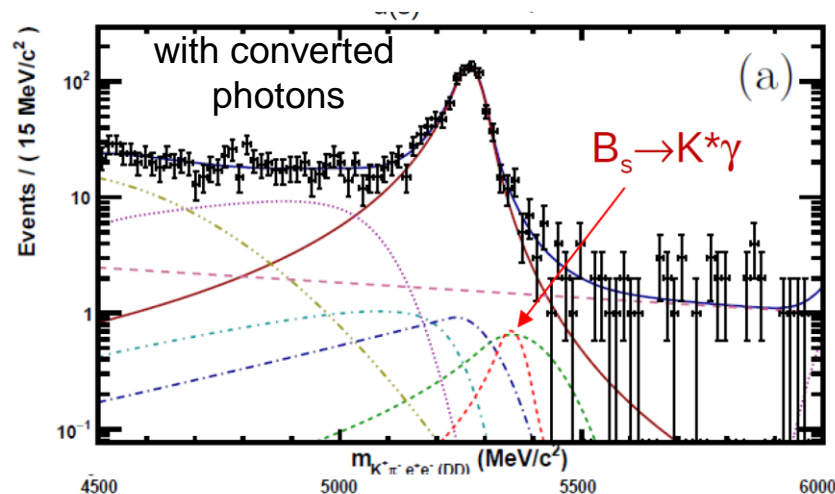


ATLAS Tracking Upgrade: Inclined



PD: A. Bethani, B. Smart, N. Readoff,
A. Rummler + hardware

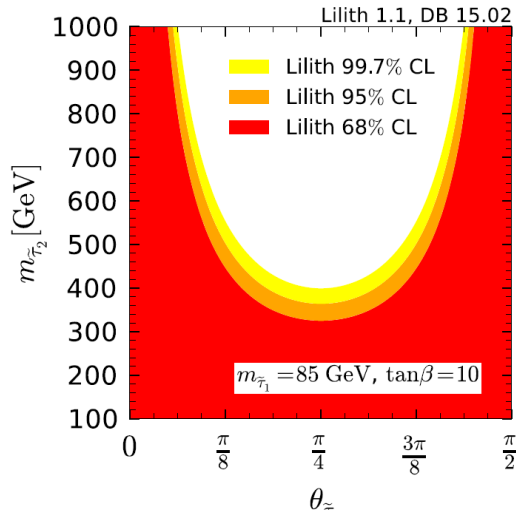
Radiative $B_{d,s}$ decays



PhD: L. Beaucourt

ENIGMASS Highlights Theory

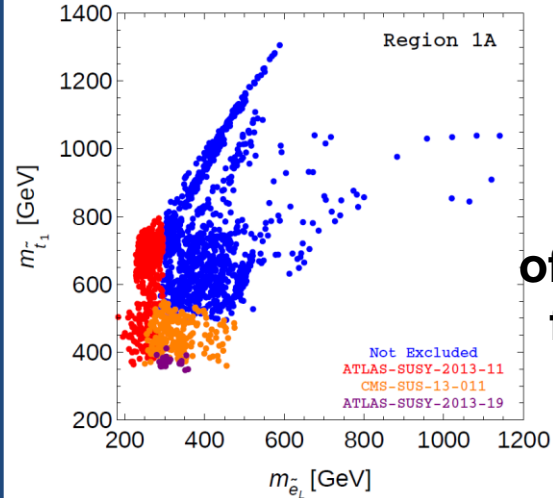
Constrain NP from measurements



New Tool:
Lilith

PhD: J. Bernon

Recasting Tools



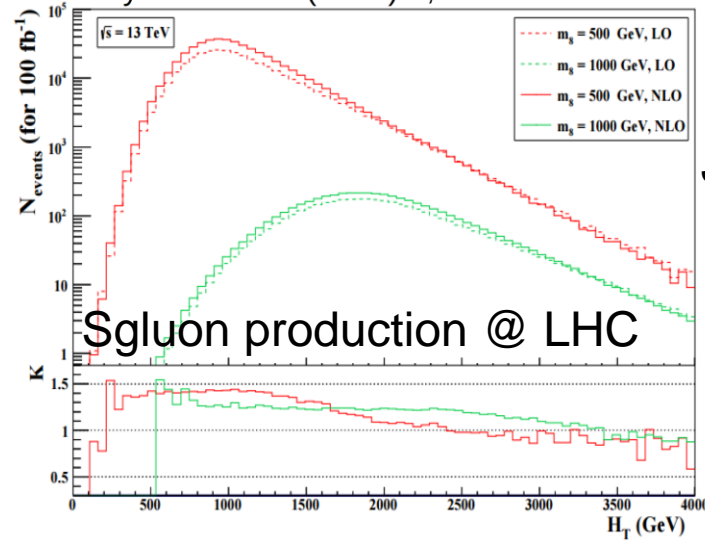
Tools:
Smodels
MadAnalysis5

Forums:
Interpretation
of the LHC results
for BSM studies

PhD: U. Laa

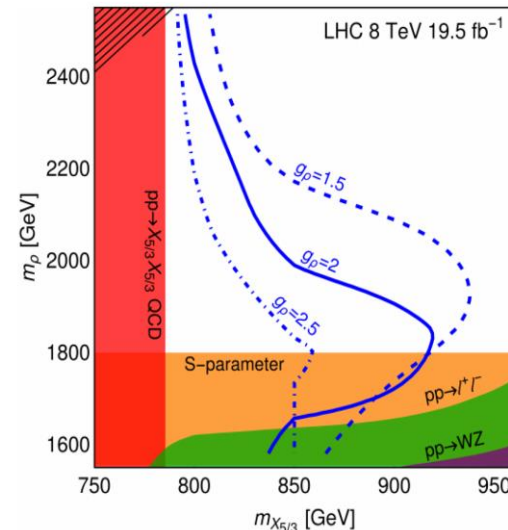
Higher Order Computations

Phys.Rev. D91 (2015) 9, 094005



PhD:
J. Proudom

New models, search proposals...



PD: C. Delaunay

Theory-Experiment Example

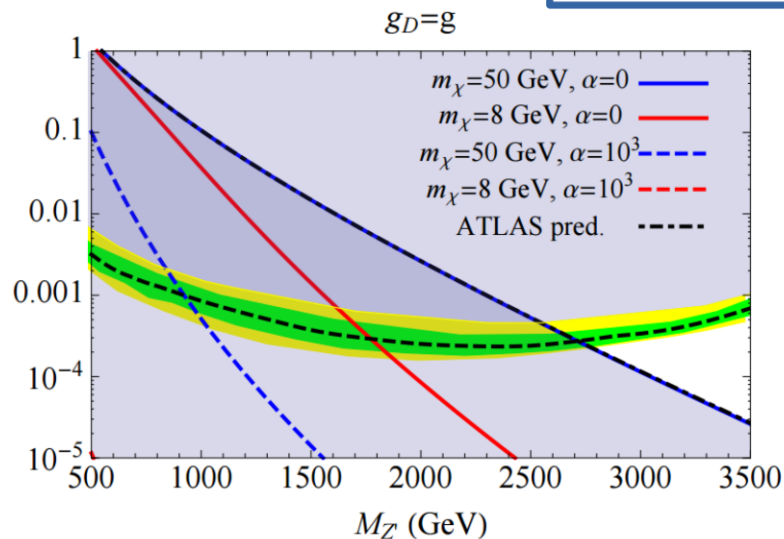
Proposal in Dark Matter Working group (Sept 2016) by **B. Zaldivar** (**PD ENIGMASS**):

Model: Sequential Z' with extra coupling to DM

$$\Delta\mathcal{L} \supset g_D \bar{\chi} \gamma^\mu (V_D^\chi - A_D^\chi \gamma^5) \chi Z'_\mu + g_D \sum_f \bar{f} \gamma^\mu (V_D^f - A_D^f \gamma^5) f Z'_\mu.$$

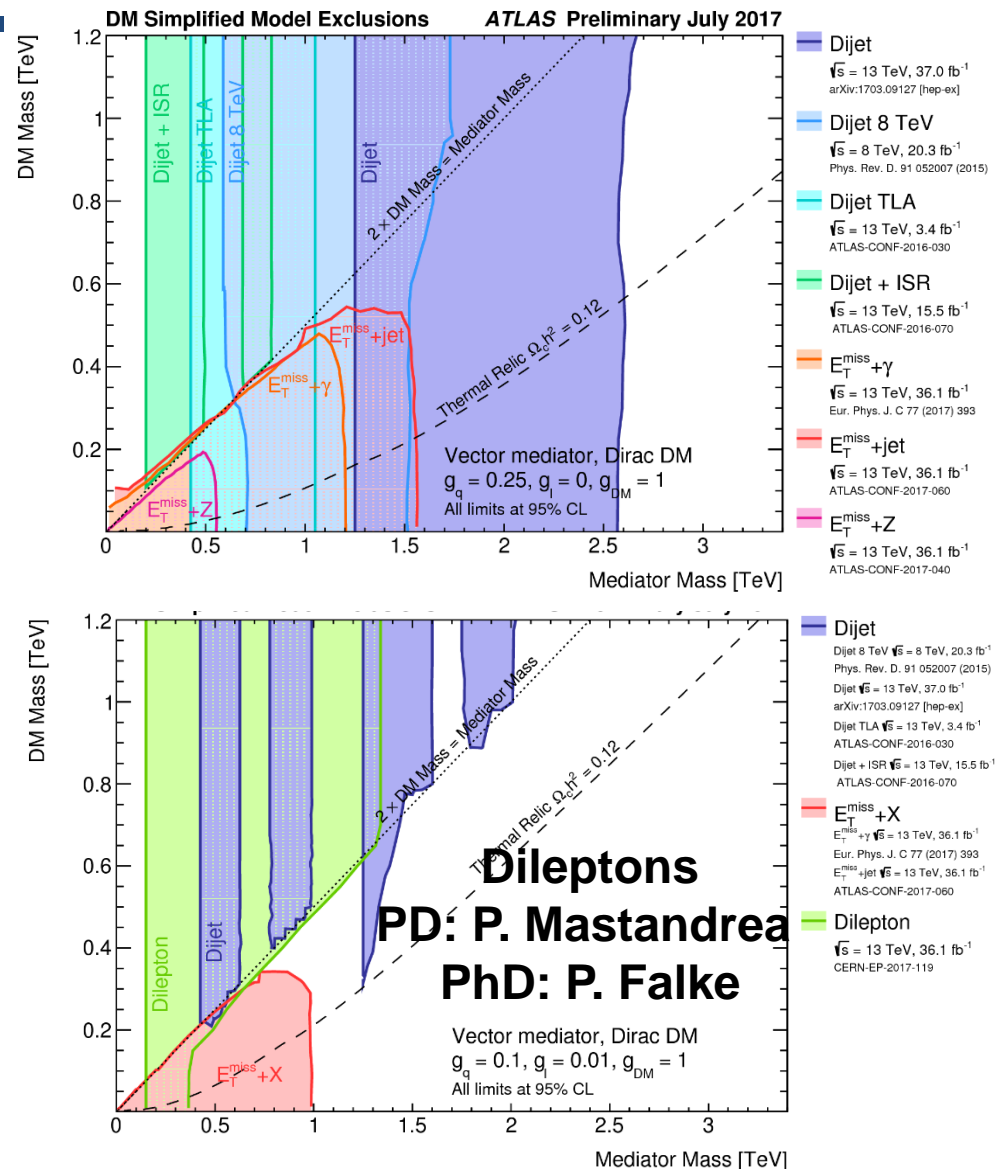
$$\alpha \equiv A_D^\chi / V_D^\chi$$

arXiv:1401.0221



based on:

- ATLAS, 1209.2535, 7TeV, ~5/fb
- LUX, 1310.8214



Also common PhDs: M. Reboud (LHCb-LAPTh) LFV in B decays;
S. Berlendis (LPSC ATLAS-Theory), Searches in same-sign tt final state

Next 10 years

Search for any deviations from Standard Model predictions



Direct
observation:



In-direct
observation:

Our searches: $\gamma\gamma$, γ +MET,
ll, tb, tt, etc.

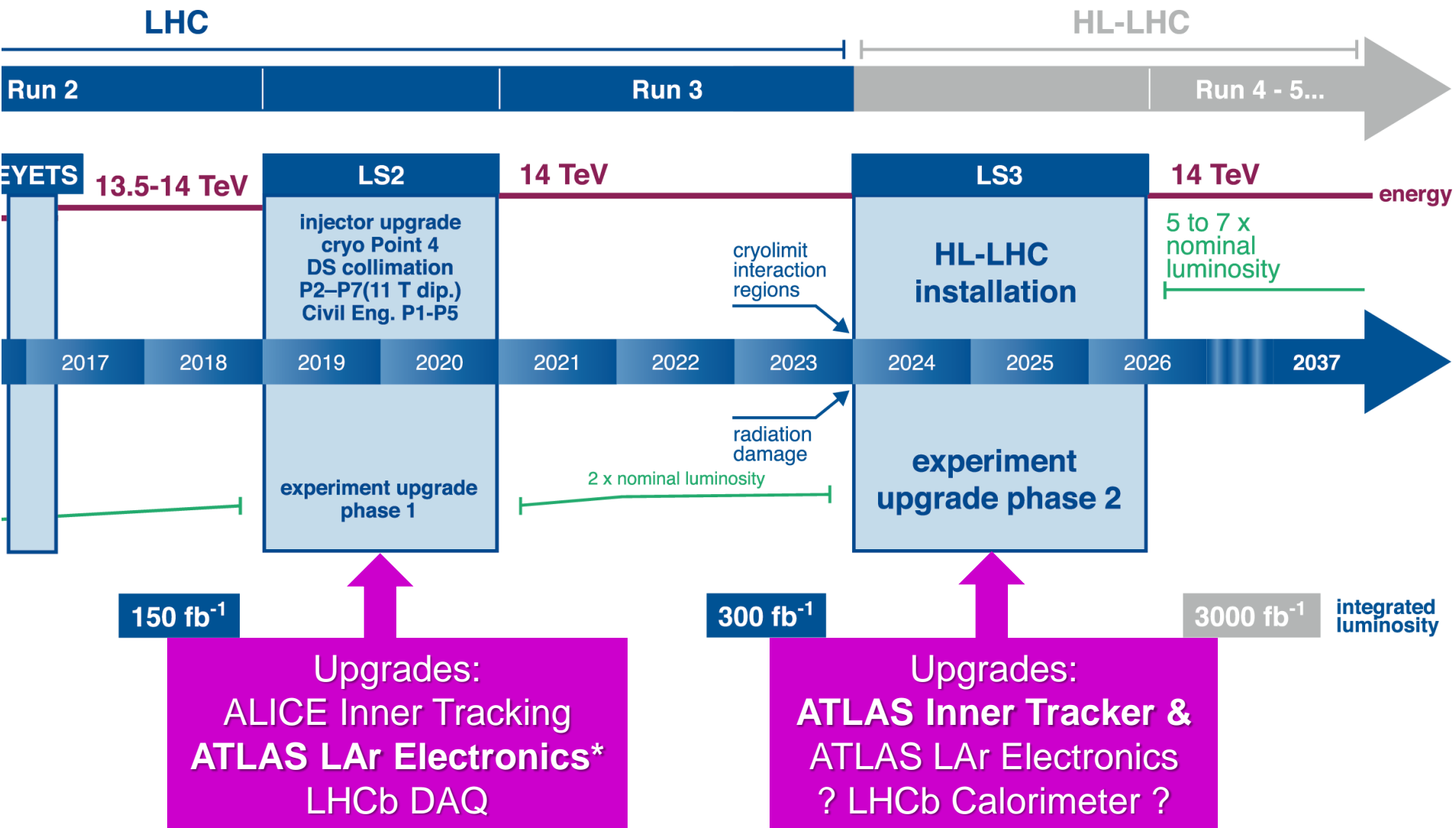
Vector Boson Scattering,
Double Higgs production,
Measurements of CKM angles,
Flavour anomalies,
Precision QCD...

Recasting of existing searches,
New models, search proposals

Higher Precision Calculations,
EFT extension of SM

Measurement of neutron electric dipole moment,
Measurement of magnetic resonant transitions between neutron quantum
states in the gravity field... Future collider experiments.

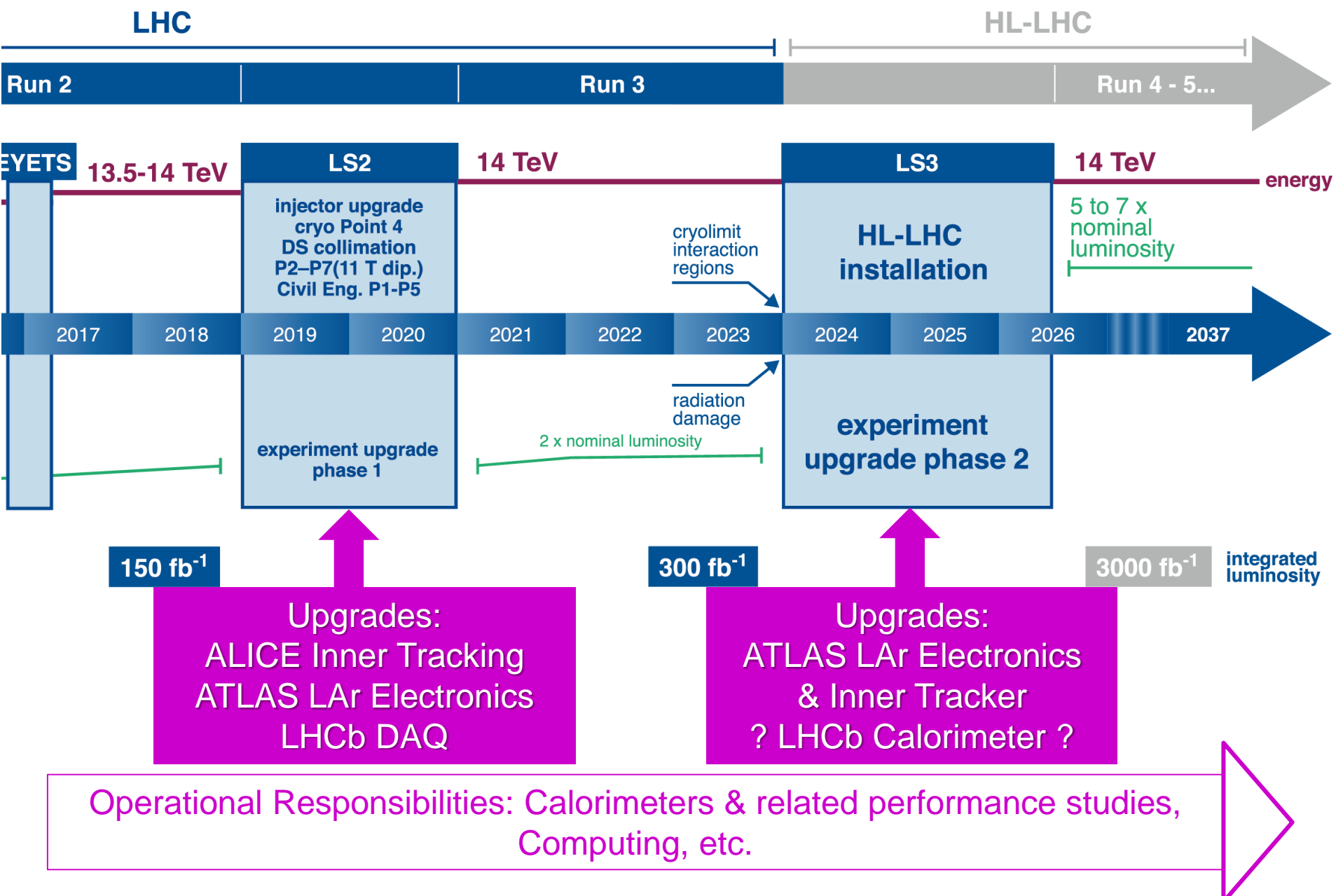
LHC Timeline



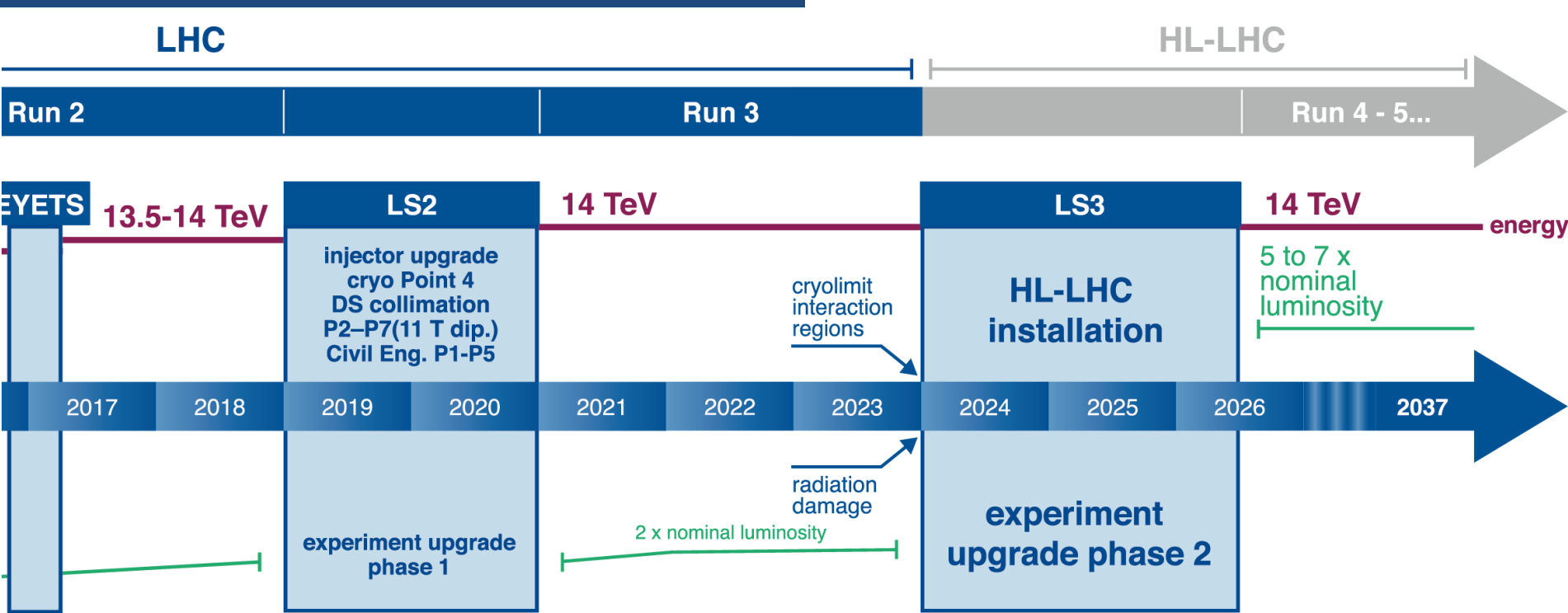
ENIGMASS funded-activity in bold

* PhD P. Falke, PD Gabaldon-Ruiz

LHC Timeline



LHC Timeline



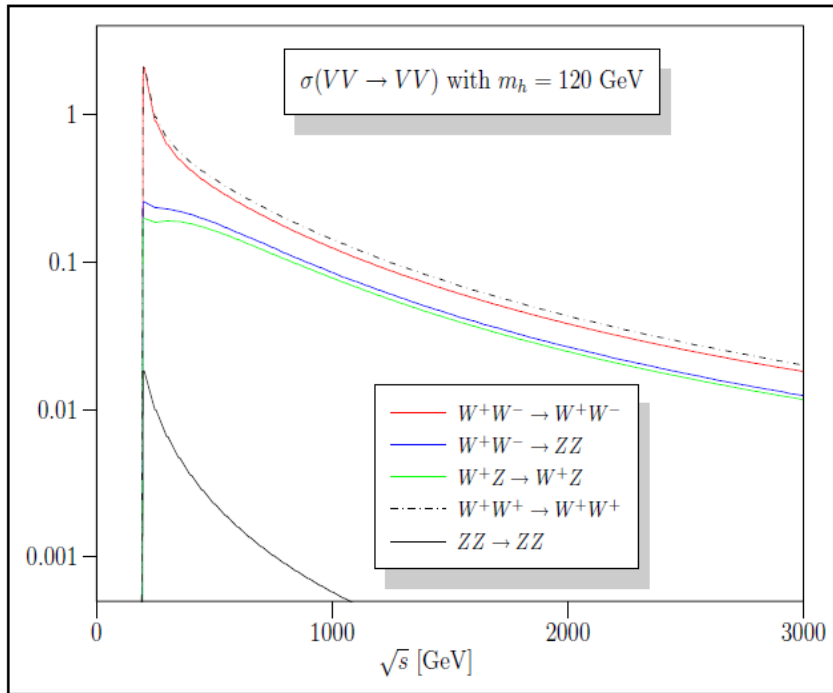
	ATLAS	LHCb	ALICE (HI)
2017	40fb ⁻¹	5fb ⁻¹	1nb ⁻¹
2019	150fb ⁻¹	8fb ⁻¹	
2024	300fb ⁻¹	28fb ⁻¹	
2028	1000fb ⁻¹	42fb ⁻¹	10nb ⁻¹

Probing Nature of EWSB: New@HL-LHC

VBS cross-section in longitudinal mode is sensitive to new physics.

Crucial to check consistency with SM predictions.

SM with a 120 GeV Higgs boson



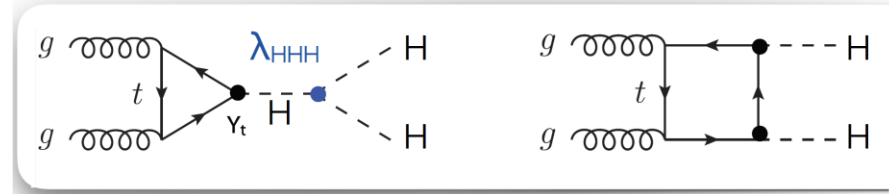
CERN-LHCC-2017-005

$$\frac{\Delta\sigma}{\sigma}$$

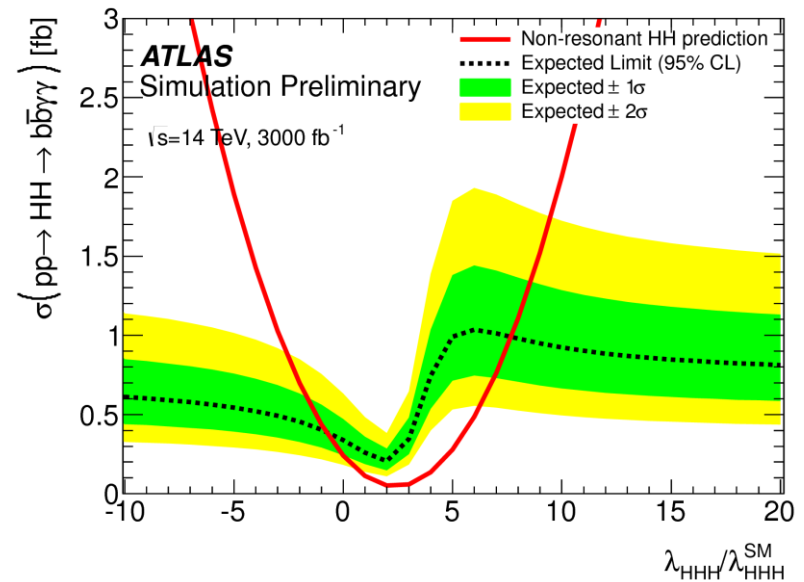
Without forward tracking 4.5%

With forward tracking 3.9%

Double Higgs production: probes the shape of the scalar Higgs potential



Negative interference between HH production with and w/o HHH vertex.



In $b\bar{b}\gamma\gamma$ expect 9.5 signal over 90.9 bkg events in 3 ab⁻¹ ($\sim 1\sigma$) Need to combine with other channels & CMS.

ATL-PHYS-PUB-2017-001

SM Effective Field Theory (EFT)

- SM scale $\sim v = 246 \text{ GeV}$, no BSM physics seen below $\Lambda \sim 1 \text{ TeV}$
 \Rightarrow parameterize the BSM using an **EFT extension of the SM**

$$L = L_{SM}^{(d \leq 4)} + \frac{1}{\Lambda^2} \sum_i c_i^{(d=6)} O_i^{(d=6)} + \frac{1}{\Lambda^4} \sum_i c_i^{(d=8)} O_i^{(d=8)} + \dots$$

- Usually(*) leading effect from **interference of d=6 and SM** $\sim (v/\Lambda)^2$ and can **neglect** $d \geq 8$ and $|c^{(d=6)}|^2$.

\Rightarrow **Report experimental constraints on the c_i** , compare to model predictions

- Straightforward to extend to higher orders in SM couplings
- Many operators: 2499** for $n_{\text{gen}}=3$

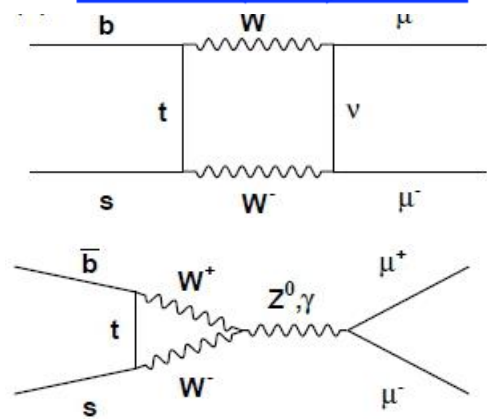
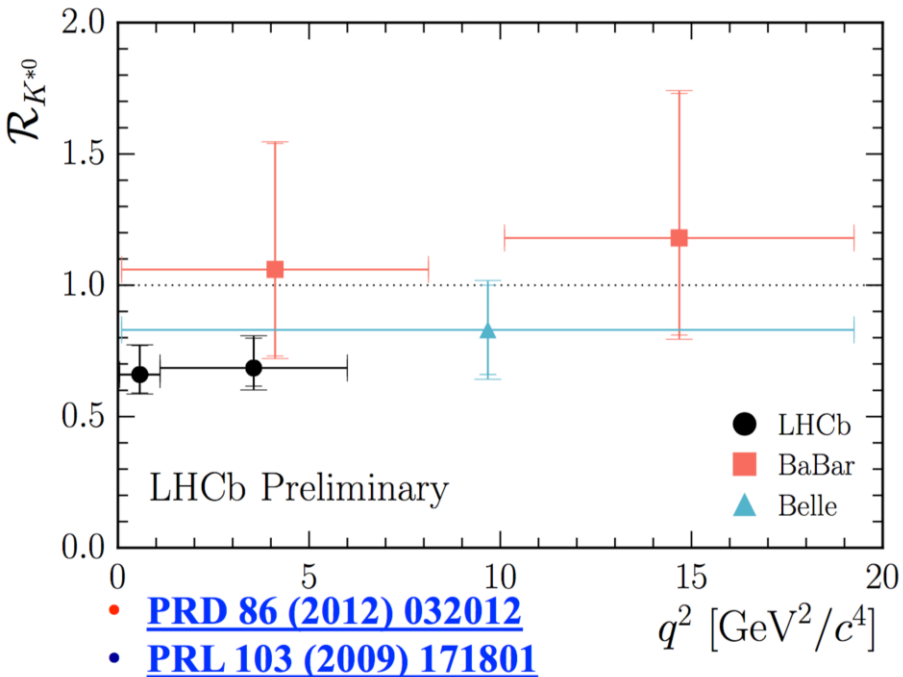
- Higgs operators
- Other EW operators (TGCs)
- 4-fermion operators (flavour measurements)

Meas-
urements
planned



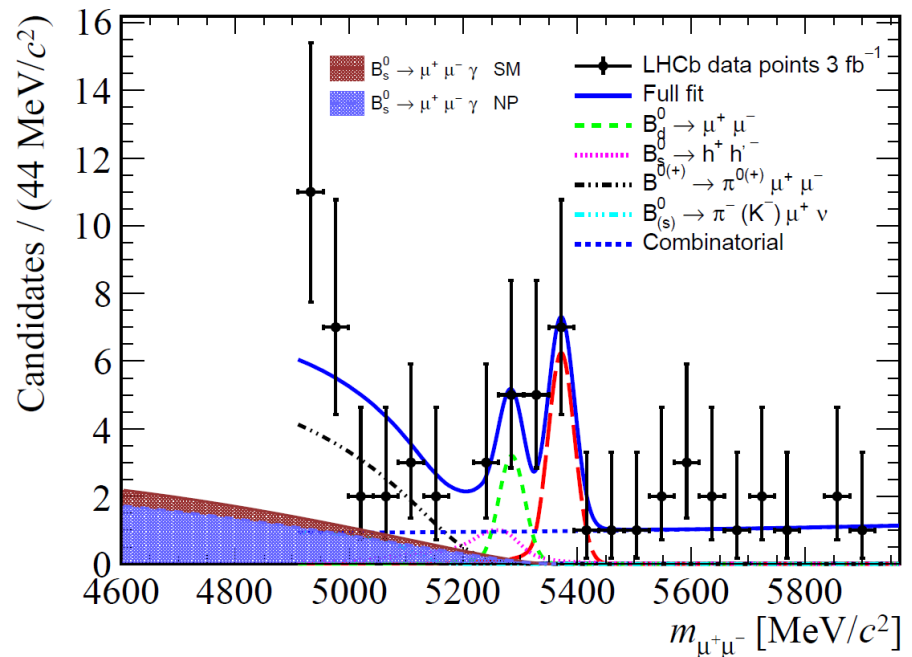
Theory
predictions
are crucial.

Flavour Anomalies ($b \rightarrow sl$ & $b \rightarrow c\tau\nu$)



$\text{BR}_{\text{obs}}(B_s \rightarrow \mu\mu) / \text{BR}_{\text{SM}}(B_s \rightarrow \mu\mu) = 0.76^{+0.20}_{-0.17}$
 \Rightarrow More precise measurement needed.

$\text{BR}(B_s \rightarrow \mu\mu\gamma) \sim 5 \text{ BR}(B_s \rightarrow \mu\mu)$, not seen yet.
 Also interesting to see $B_s \rightarrow e\mu\gamma$.



arXiv:1610.00629

Sign of New Physics? Stat Fluctuations?
 QCD effects not fully accounted for?

Probing QCD with Quark Gluon Plasma (QGP)

- Study of QGP in **Pb-Pb**: new constraints on strong interaction
- Study of **pp** collisions: baseline for the QGP study and for comparisons with QCD calculations;
- **p-Pb** collisions: cold nuclear effect

ALICE @ LHC:

Inclusive jets, jet-jet and photon-hadron/jet correlations measurements

→ parton fragmentation related observables

→ in-medium modification of parton energy loss and energy redistribution at \sim low p_T

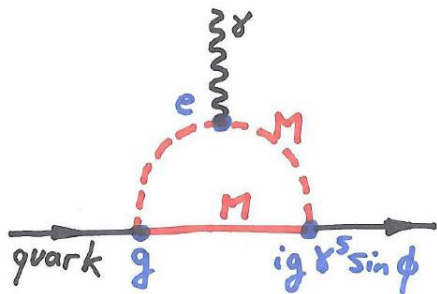
New b-tagging methods for heavy flavour identification in jets:

→ use to study quark flavor dependence of energy loss in QGP: test dead cone effect prediction

Beside LHC

nEDM: Search for BSM CP violation mechanism

- Possible contribution from new physics: multi-TeV BSM sensitivity



$$d_n \approx \frac{eg^2 \sin \phi}{16\pi^2} \frac{\hbar c m_q}{M^2}$$

$$\approx \left(\frac{1 \text{ TeV}}{M} \right)^2 \times \sin \phi \times 10^{-25} \text{ e cm}$$

- Test of electroweak baryogenesis (requires also BSM scalar sector)
- Timeline :
 - 2018 : publication slightly improved result / RAL-Sussex result : $d_n < 3 \cdot 10^{-26} \text{ e cm}$
 - 2017 – 2020: design/construction n2EDM spectrometer
 - 2020-2025: Data taking with n2EDM at the PSI UCN source $\rightarrow d_n \sim 10^{-27} \text{ e cm}$
- LPSC contribution (ANR and ERC grants): Hg magnetometry, B mapping, UCN switch

GRANIT: Testing Gravity using neutron quantum bouncer

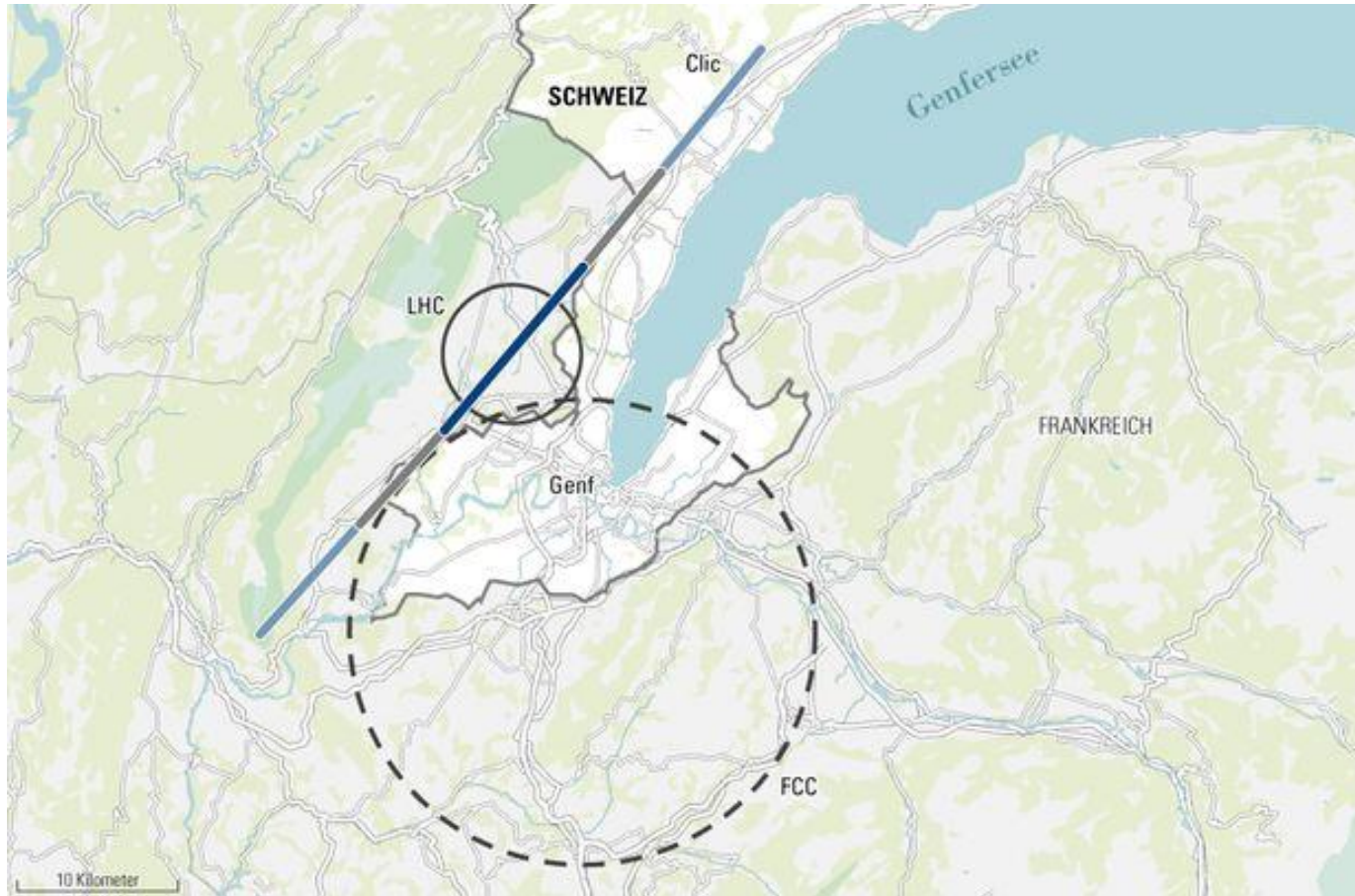
- Unique test of weak equivalence principle
 \rightarrow independent measurements of inertial and gravitational masses

$$-\frac{\hbar^2}{2m_i} \frac{d^2 \psi}{dz^2} + m_g g z \psi = E \psi$$

- Test of modified gravity and new short range interactions: cosmological chameleon, symmetron...
- Collaboration LPSC-ILL



Beyond LHC: new colliders



Small ILC
groups @
LAPP & LPSC

Following
developments
on FCC,
CLIC and
ILC.

Current Research Team Composition

	ALICE LPSC	ATLAS LAPP	ATLAS LPSC	ILC LAPP	ILC LPSC	nEDM/ GRANIT	LAPTh PP	LHCb LAPP	LPSC Theory
PERM PHYS	5	13	11	2^{&}	1^{&}	3	9	8^{&}	4
PD	0	6(4)	1(1)	0	0	1	2(1)	1	2
PhD	4	7(4)	5^y	0	0	2	3^{x*}(1^x)	1[*]	5^{yx}(1^x)

& Not full time

x One shared LAPTh-LPSC

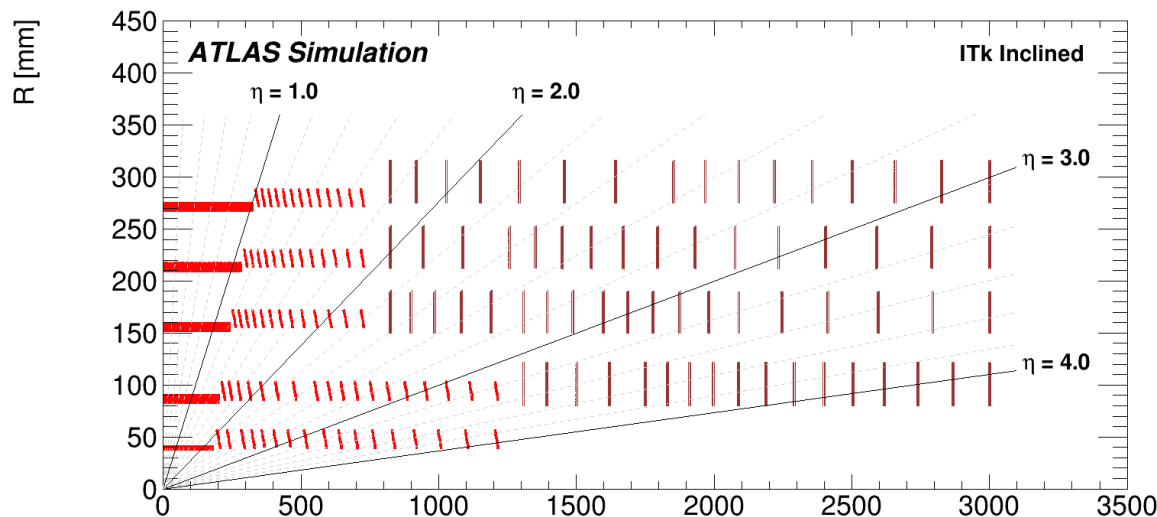
* One shared LAPTh-LHCb

y One shared LPSC ATLAS- LPSC Theory

() Currently funded by ENIGMASS

Backup

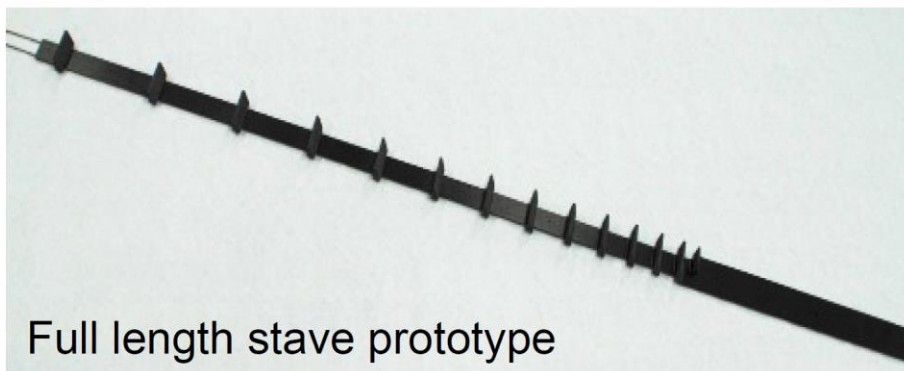
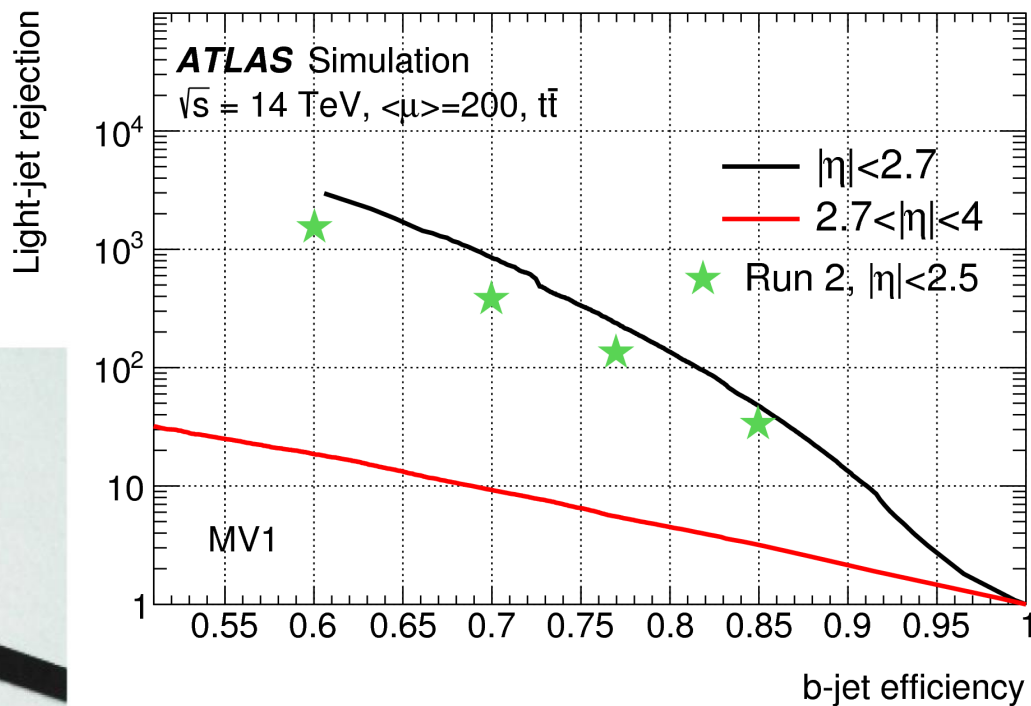
ATLAS Tracking Upgrade (2024-25)



Goals: improved tracking performance in higher pile-up & radiation environment

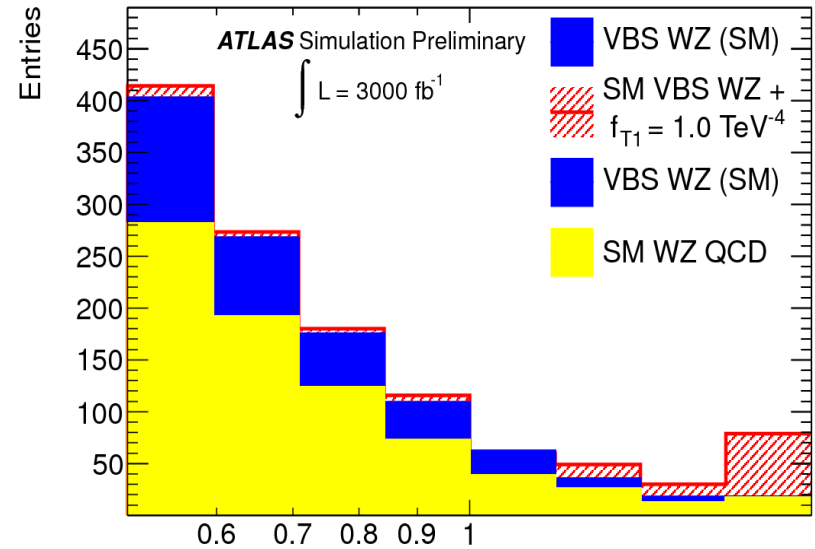
Inclined Layout
Idea initiated at LAPP:
less material, less silicone

LAPP & LPSC: Layout Simulation, Thermal & Mechanical tests, Electronics (Services),.. Future construction

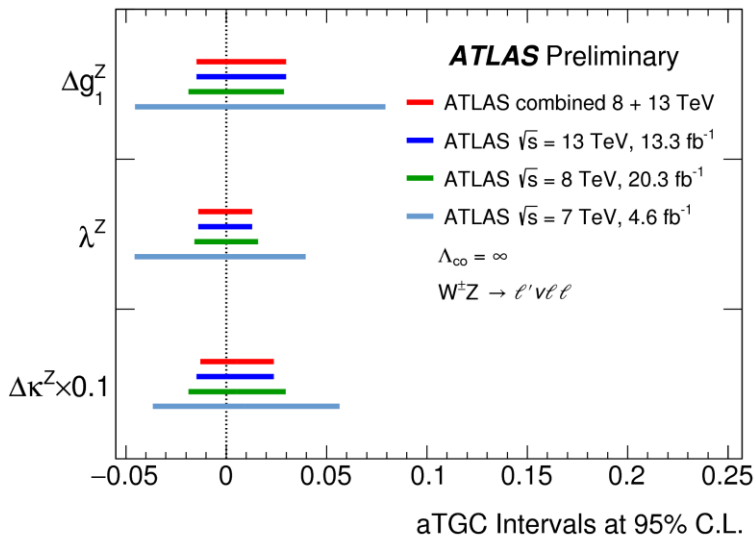
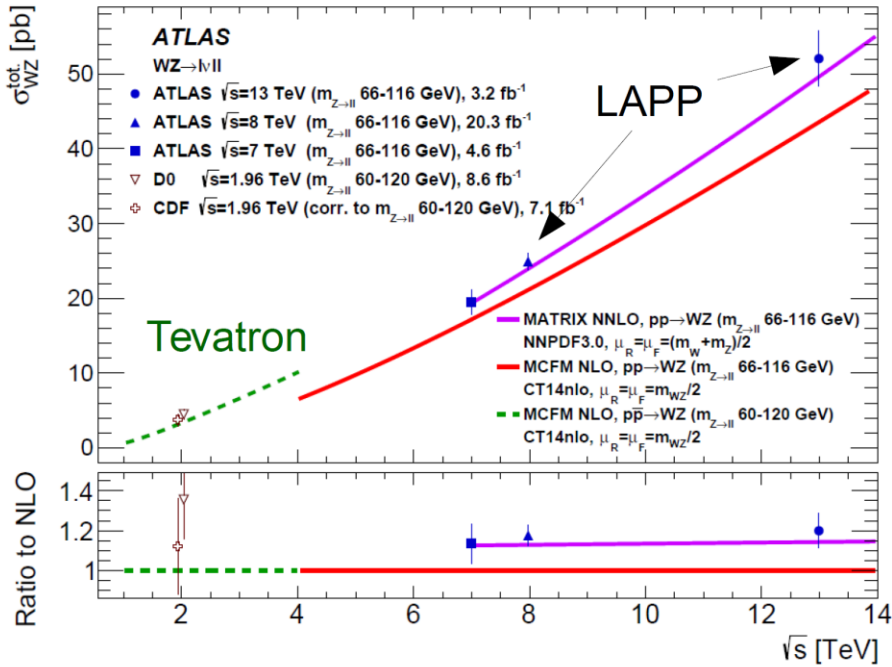
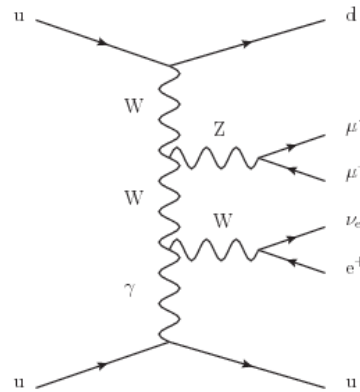
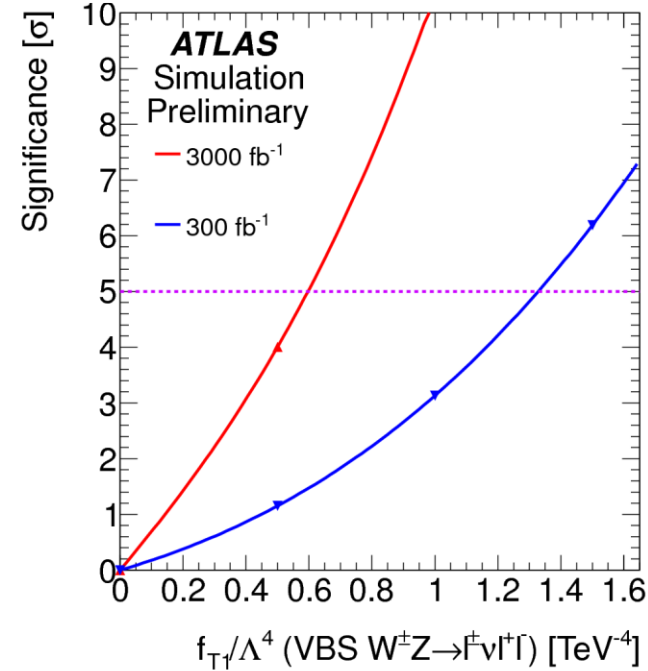
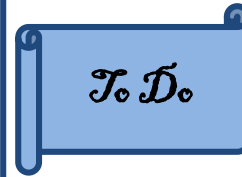


Dibosons to VBS

ATL-PHYS-PUB-2013-006



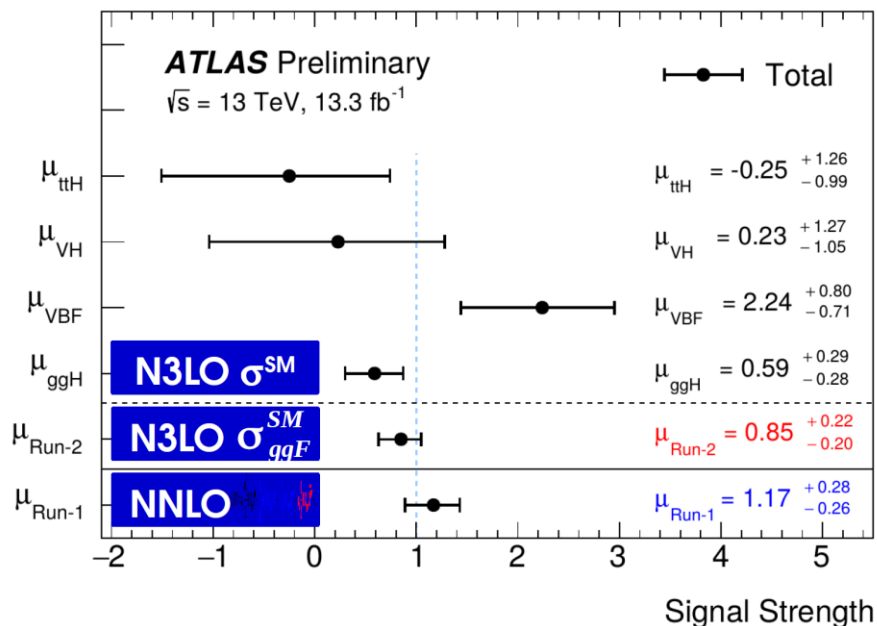
$$\mathcal{L}_{T,1} = \frac{f_{T1}}{\Lambda^4} \text{Tr}[\hat{W}_{\alpha\nu} \hat{W}^{\mu\beta}] \times \text{Tr}[\hat{W}_{\mu\beta} \hat{W}^{\alpha\nu}]$$



ATLAS-CONF-2016-043

H→γγ couplings

ATLAS-CONF-2016-067



New ggF N3LO calculation

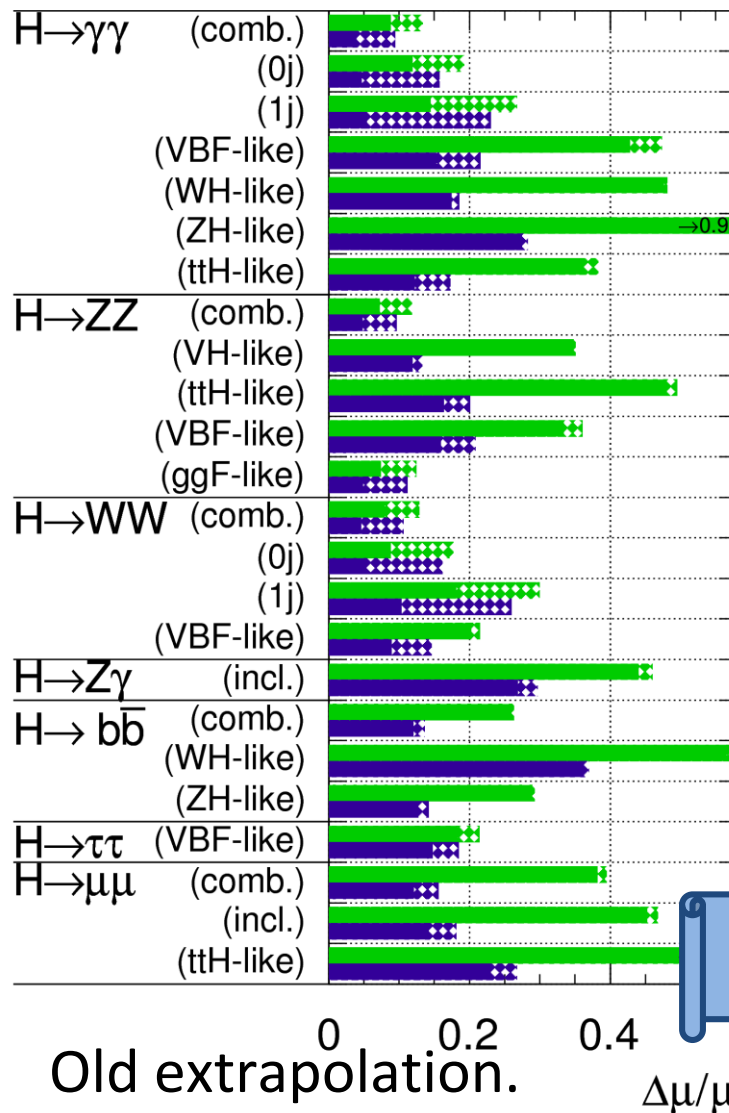
- +3% change in $\sigma_{\text{ggF}}^{\text{SM}}$
- QCD pert. uncert. 7.8% → 3.8%
- PDF+ α_s uncert.: ~7% → 3.2%

Experimental precision needs
to catch up with theory!

JHEP(2016)058

ATLAS Simulation Preliminary

$\sqrt{s} = 14 \text{ TeV}$: $\int \mathcal{L} dt = 300 \text{ fb}^{-1}$; $\int \mathcal{L} dt = 3000 \text{ fb}^{-1}$



Old extrapolation.

Analyses improved.

Sizable theory uncertainties!

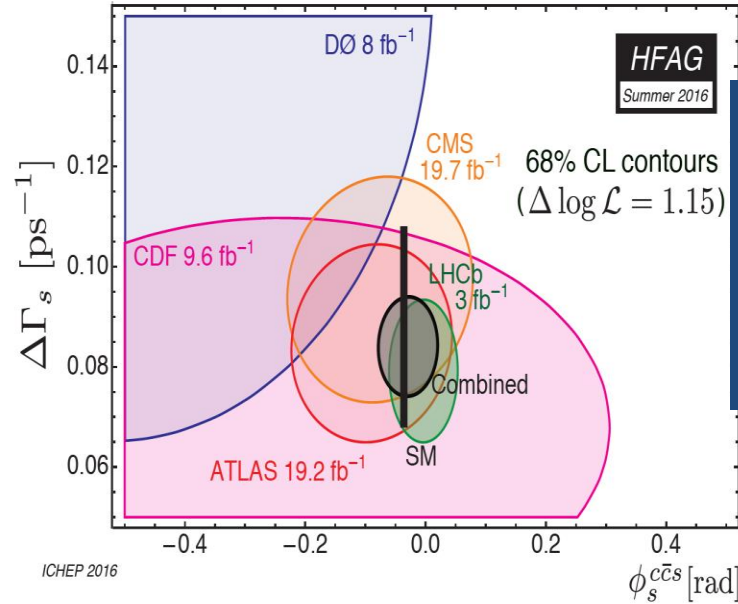
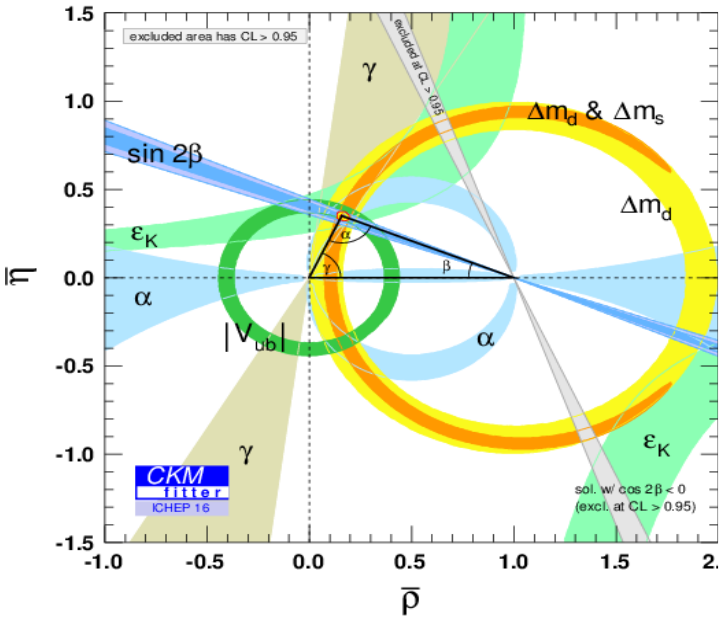
ATL-PHYS-PUB-2014-016

$\mathcal{T}_0 \mathcal{D}_0$

CKM angles

arXiv:1612.07233

\mathcal{T}_D



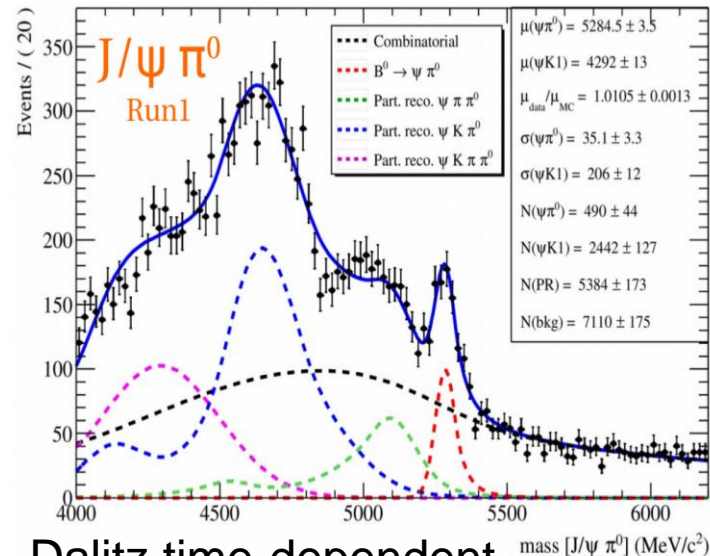
Now (CKMFitter):
 $\sin 2\beta = 0.691 \pm 0.017$
 $\gamma = (72.2^{+5.3}_{-5.8})^\circ$
 $\phi_s = -0.015 \pm 0.035 \text{ rad}$



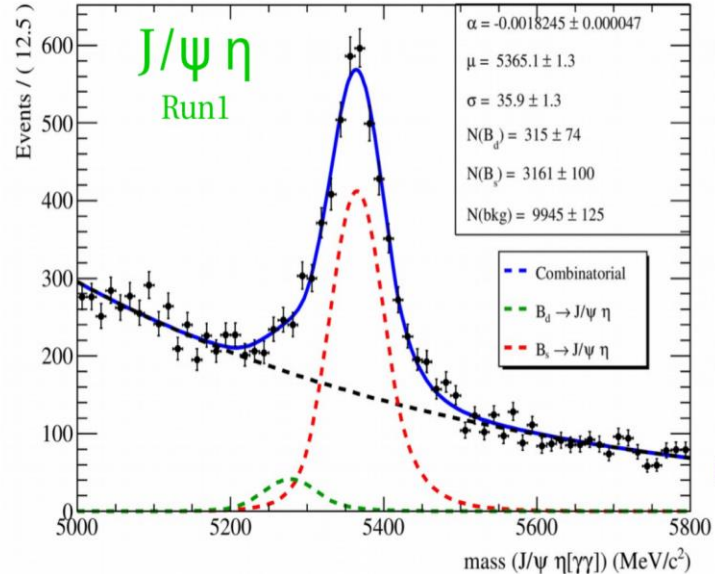
LHCb
Uncertainty
End of
Run 4

β	0.031°
γ	0.9°
ϕ_s	0.009 rad

Testing SM
predictions



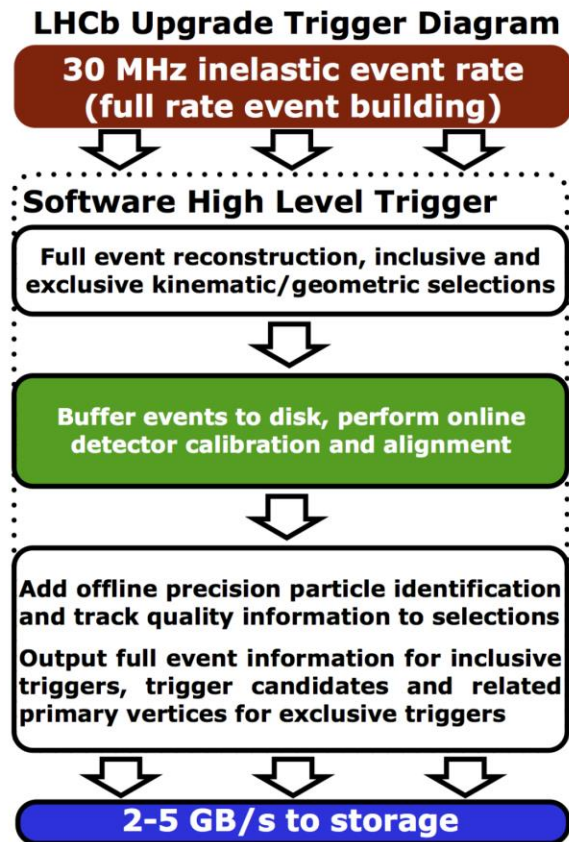
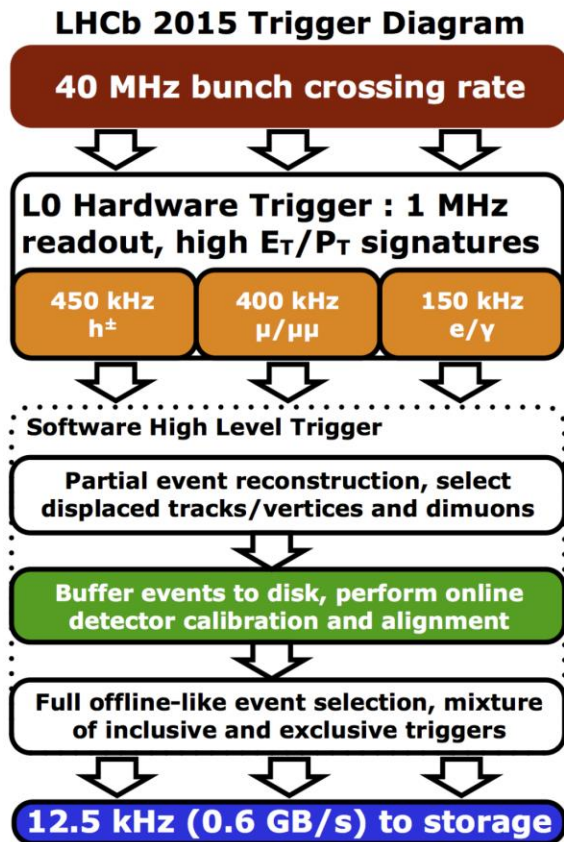
Dalitz time-dependent
analysis for Run 2



Also $B_s \rightarrow J/\psi \eta' (\rho^0 \gamma, \eta \pi^+ \pi^-)$

LHCb DAQ Upgrade (2019-20)

Goal: Remove Hardware Trigger

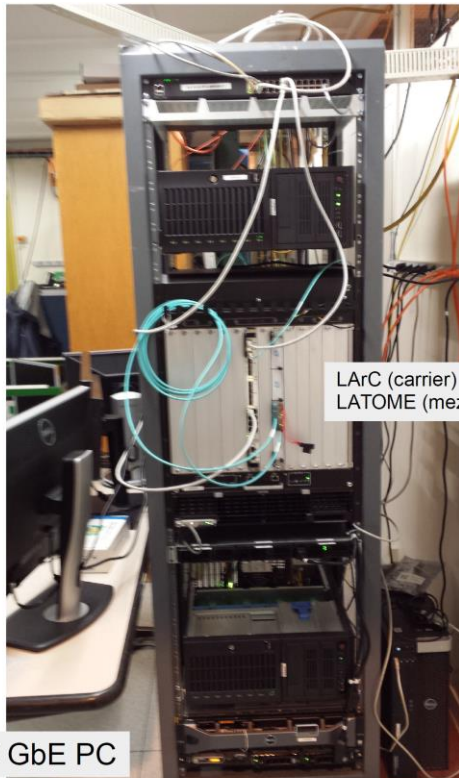


LAPP coordinates
firmware
development for
Prototype Readout
Board Used for
Event Building

ATLAS LAr Calorimeter Upgrade (2019-20)

Goal: increase calorimeter hardware trigger granularity and to do digitisation at 40 MHz

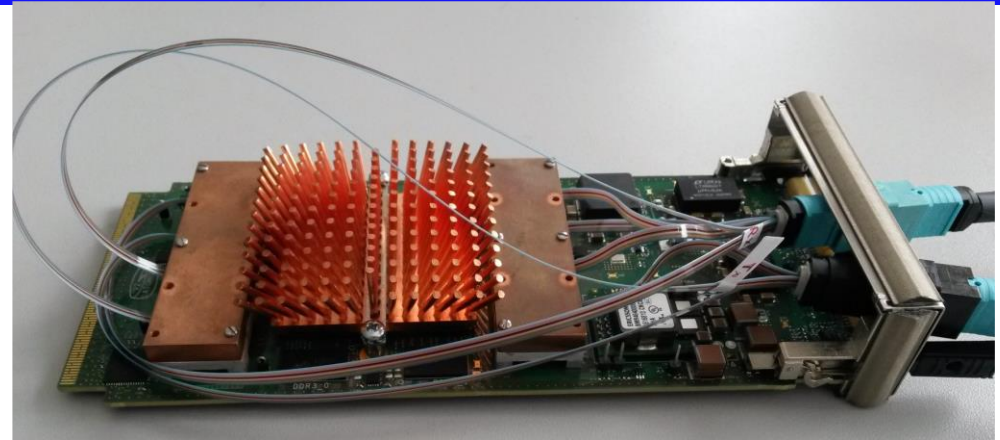
LAPP developed a fast and dense processing unit (E_T calculation, LHC bunch crossing identification etc.)



LArC (carrier)
LATOME (mezzanine)

10 GbE PC

Coordination of tests at CERN



LAPP coordinates firmware development

IPMC : ATCA controller card developed at LAPP

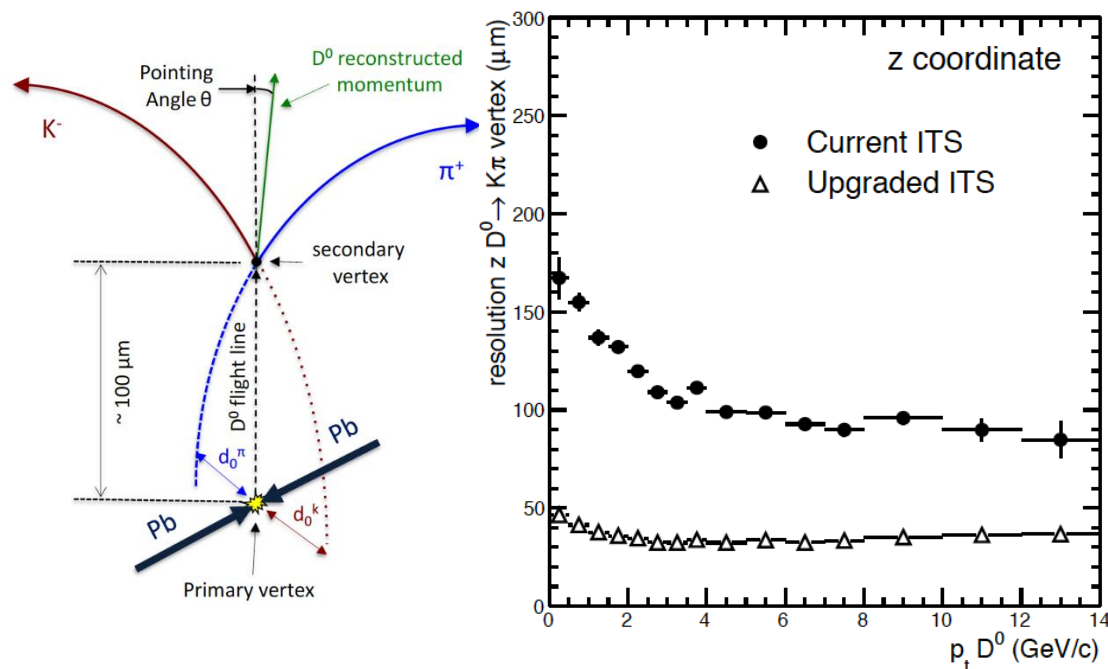


ATLAS LAr Electronics upgrade 2024-2025: back-end & calibration card

ALICE Tracking Upgrade (2019-20)



Goals: improve tracking performance



LPSC: Construction of manufacturing molds for staves.
Design and production of the Middle Barrel staves assembly tool.

Potential Synergy with ATLAS Tracking Upgrade in LPSC

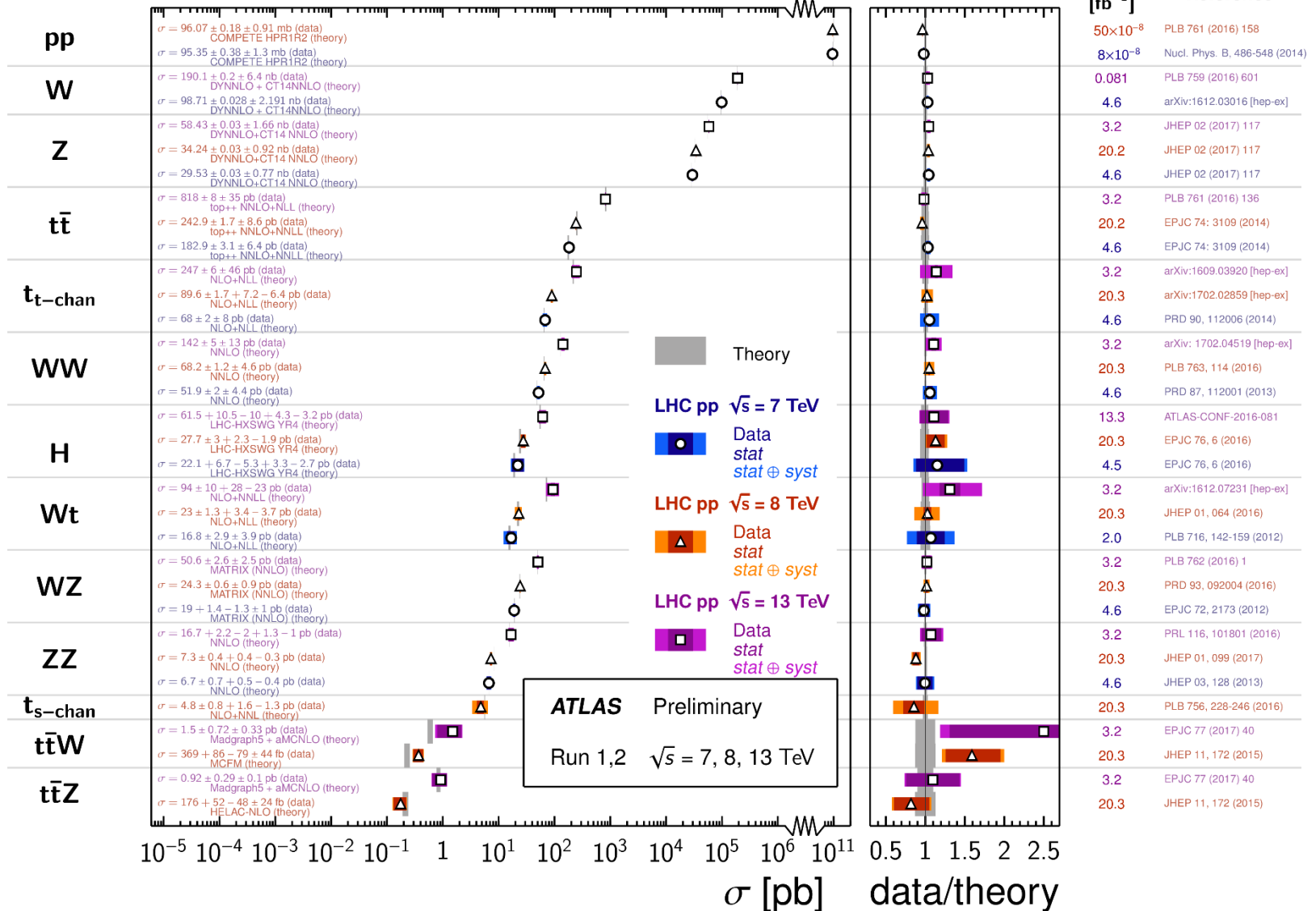
Indirect Searches = Measurements

Standard Model Total Production Cross Section Measurements

Status:
March 2017

$\int \mathcal{L} dt$
[fb⁻¹]

Reference



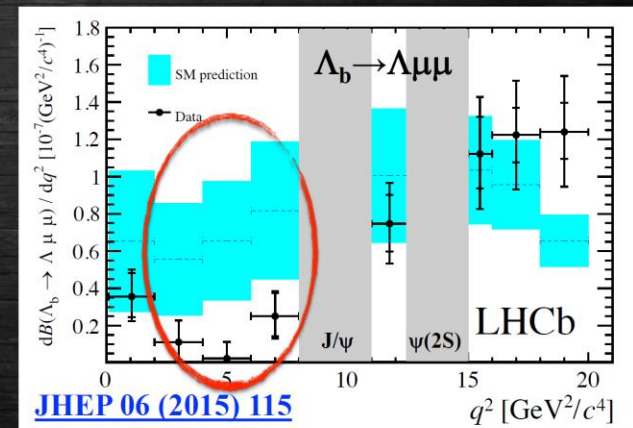
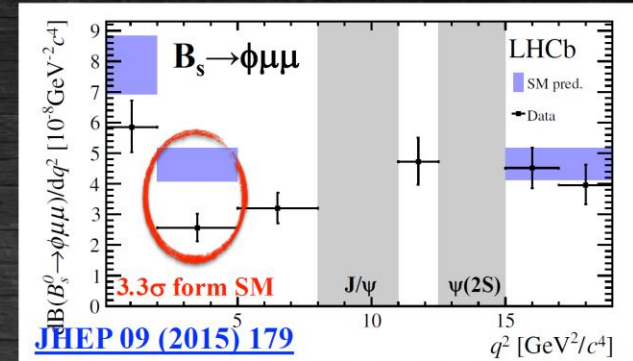
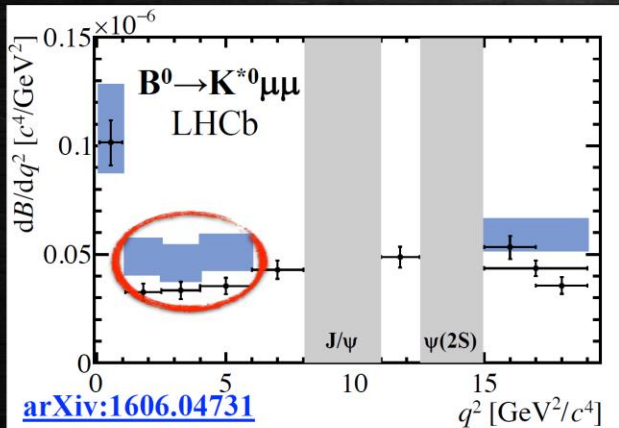
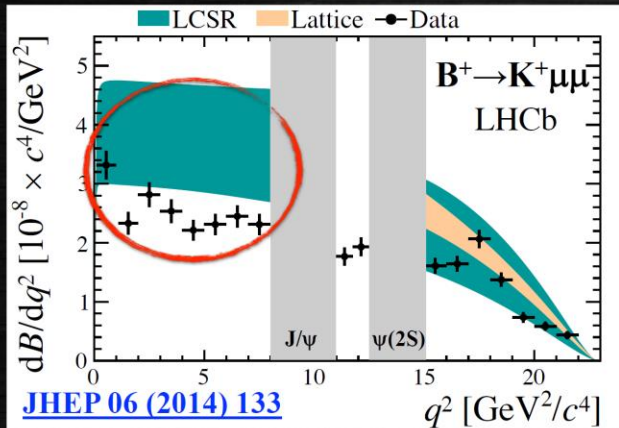
LHCb anomalies (1)



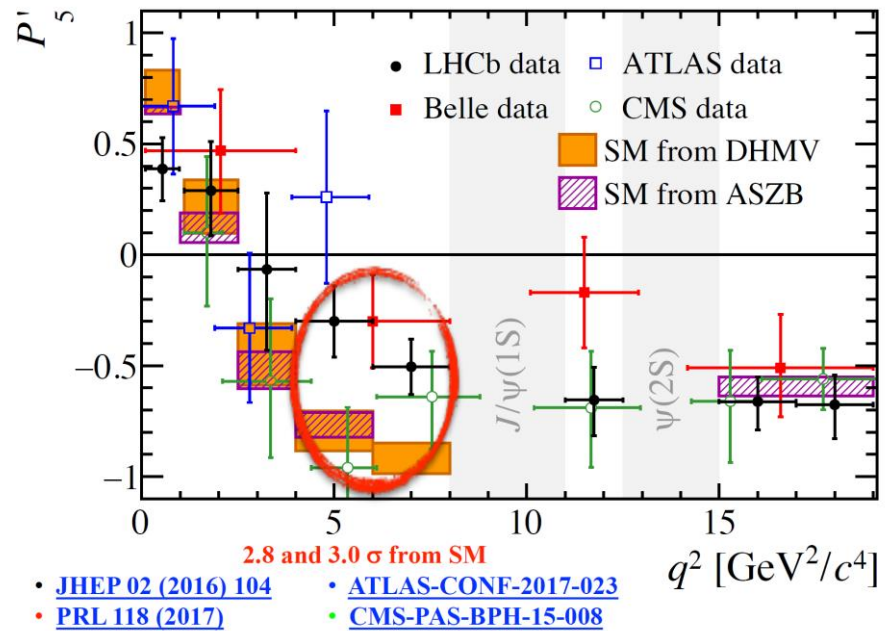
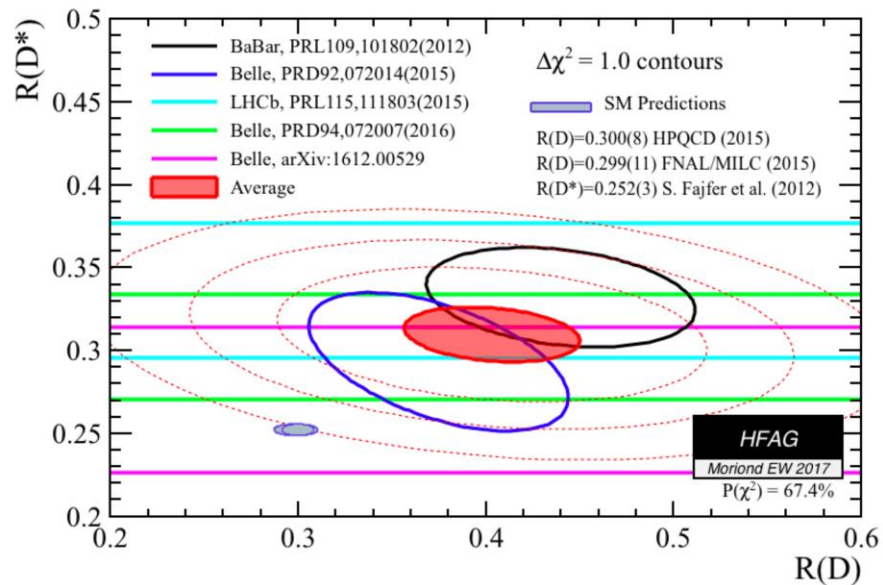
Differential Branching Fractions



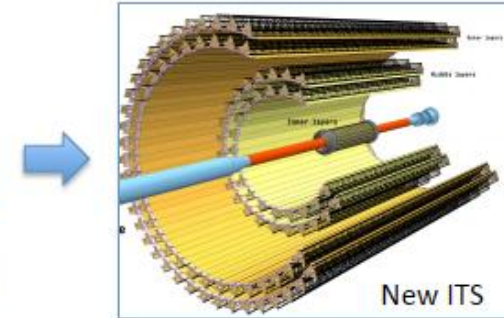
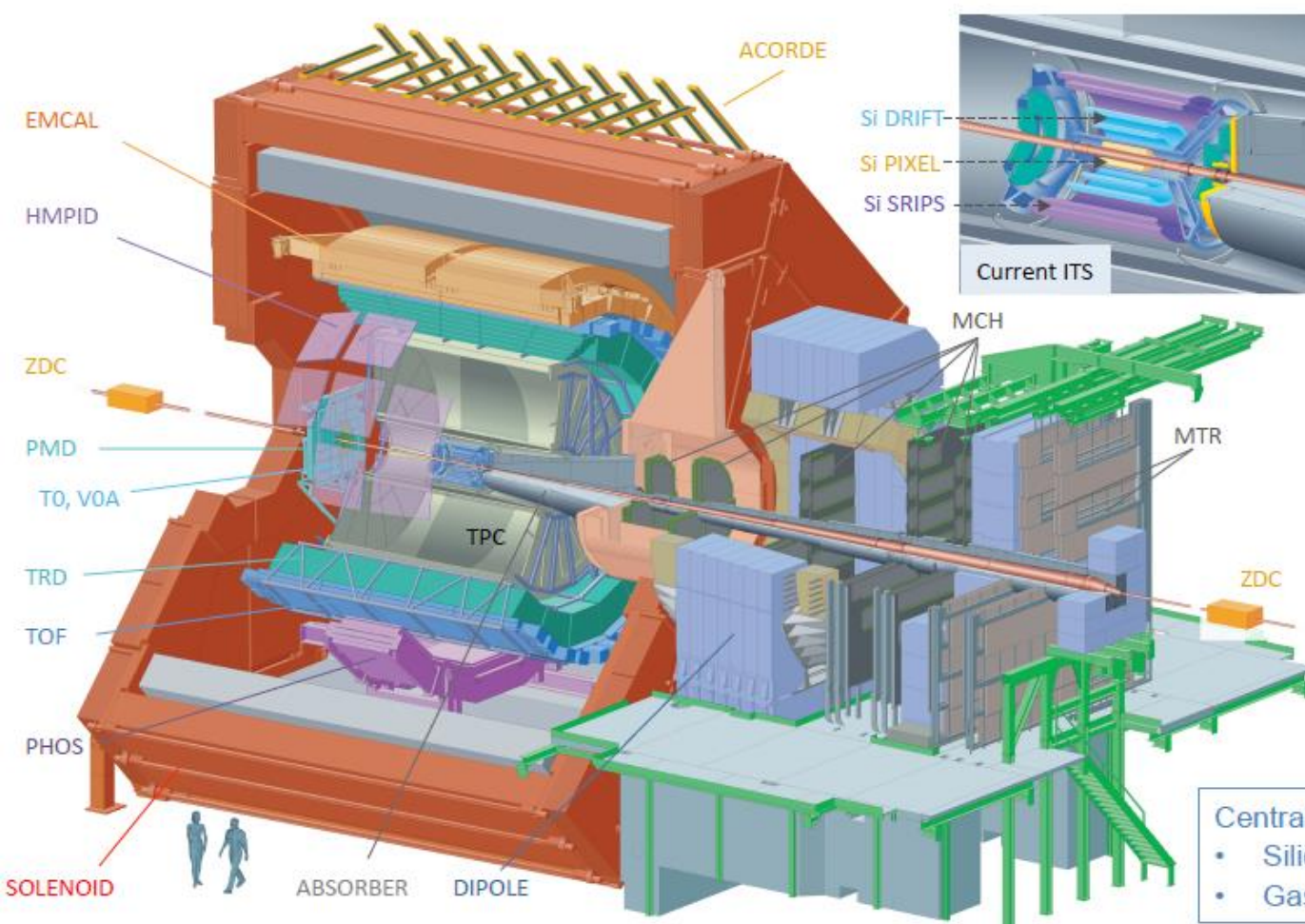
› Results consistently lower than SM predictions



LHCb anomalies (2)



Upgrade d'ALICE run 3&4



Readout rate is currently limited by TPC and ITS (SDD)

~ 1kHz for Pb-Pb

Central Barrel Tracking

- Silicon: 39 – 430 mm
- Gas (TPC, TRD): 88 – 368 cm

- New electronics (TPC, TOF, TRD, Muon spectro...) + New DAQ & HLT (50 kHz Pb-Pb, O2 project)
 - New detectors: Internal Tracking System and MFT (Muon Forward tracking)

Quark Gluon Plasma & ALICE experiment

LPSC team:

- **5 permanents** : G. Conesa-Balbastre (CR), J. Faivre (MdC), C. Furget (PR), R. Guernane (CR), C. Silvestre (CR)
- **4 PhD**: A. Vauthier (UGA), H. Yokoyama (Tsukuba/UGA), R. Hosokawa (Tsukuba/UGA), H. Hassan (Liban/UGA)

Physics goals:

- Study of high density deconfined matter like QGP produced in Pb-Pb collision at LHC provides new constraints on strong interaction at the partonic level (95% of the nucleon mass).
- Study p-p collisions as a baseline for the QGP study and for comparisons with QCD calculations; study cold nuclear effect study in p-Pb collisions
- Favoured topics: **study of parton energy loss in QGP** through jets production and photon-hadron correlations

Technical involvement:

- Electromagnetic calorimeter: assembly, energy calibration, Level 1 trigger, reconstruction+analysis

Projects for run 3&4:

- ALICE upgrade during LS2: improve the tracking performance and increase the statistics by 10
- New jet observables, study of in-medium energy loss for heavy flavours and precise measurements of the parton energy loss through jet-jet and photon-hadron/jet correlations