

Report from Collider & Particle Physics Workpackage

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ENIGMASS General Meeting

28/04/2017

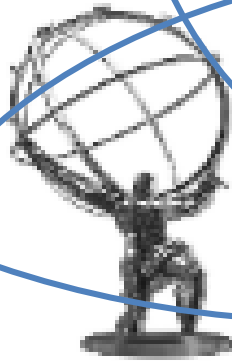
Main Axes



nEDM



Theory:
Precision calculations
for SM and new physics
processes, model building,
development of tools for
interpretation of the
LHC results, new ideas
for searches &
experiments.



Highlights 2012-2017

Higgs Discovery 2012



Nobel Prize
(Physics) 2012



Add Higgs
Discovery plot
+ Higgs
Measurements

No New Physics yet 2017

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

ATLAS Exotics Searches* - 95% CL Exclusion

Status: August 2016

ATLAS Preliminary

$\int \mathcal{L} dt = (3.2 - 20.3) \text{ fb}^{-1}$

$\sqrt{s} = 8, 13 \text{ TeV}$

Model	ℓ, γ	Jets [†]	E_T^{miss}	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Limit	Reference		
Extra dimensions	ADD $G_{KK} + g/q$	-	$\geq 1j$	Yes	3.2	M_0 6.58 TeV	$n = 2$	1604.07773
	ADD non-resonant $\ell\ell$	$2 e, \mu$	-	-	20.3	M_2 4.7 TeV	$n = 3 \text{ HLZ}$	1407.2410
	ADD QBH $\rightarrow \ell q$	$1 e, \mu$	$1j$	-	20.3	M_{th} 5.2 TeV	$n = 6$	1311.2006
	ADD QBH	-	$2j$	-	15.7	M_{th} 8.7 TeV	$n = 6$	ATLAS-CONF-2016-069
	ADD BH high $\sum p_T$	$\geq 1 e, \mu$	$\geq 2j$	-	3.2	M_{th} 8.2 TeV	$n = 6, M_0 = 3 \text{ TeV, rot BH}$	1606.02265
	ADD BH multijet	-	$\geq 3j$	-	3.6	M_{th} 9.55 TeV	$n = 6, M_0 = 3 \text{ TeV, rot BH}$	1512.02586
	RS1 $G_{KK} \rightarrow \ell\ell$	$2 e, \mu$	-	-	20.3	$G_{KK} \text{ mass}$ 2.68 TeV	$k/\bar{M}_{Pl} = 0.1$	1405.4123
	RS1 $G_{KK} \rightarrow \gamma\gamma$	2γ	-	-	3.2	$G_{KK} \text{ mass}$ 3.2 TeV	$k/\bar{M}_{Pl} = 0.1$	1606.03833
	Bulk RS $G_{KK} \rightarrow WW \rightarrow qq\ell\nu$	$1 e, \mu$	$1J$	Yes	13.2	$G_{KK} \text{ mass}$ 1.24 TeV	$k/\bar{M}_{Pl} = 1.0$	ATLAS-CONF-2016-062
	Bulk RS $G_{KK} \rightarrow HH \rightarrow bbbb$	-	$4b$	-	13.3	$G_{KK} \text{ mass}$ 360-860 GeV	$k/\bar{M}_{Pl} = 1.0$	ATLAS-CONF-2016-049
Bulk RS $G_{KK} \rightarrow tt$	$1 e, \mu$	$\geq 1b, \geq 1J/2j$	Yes	20.3	$G_{KK} \text{ mass}$ 2.2 TeV	$BR = 0.925$	1505.07018	
2UED / RPP	$1 e, \mu$	$\geq 2b, \geq 4j$	Yes	3.2	$KK \text{ mass}$ 1.46 TeV	Tier (1,1), $BR(A^{(1,-)} \rightarrow t\bar{t}) = 1$	ATLAS-CONF-2016-013	
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	$2 e, \mu$	-	-	13.3	$Z' \text{ mass}$ 4.05 TeV		ATLAS-CONF-2016-045
	SSM $Z' \rightarrow \tau\tau$	2τ	-	-	19.5	$Z' \text{ mass}$ 2.02 TeV		1502.07177
	Leptophobic $Z' \rightarrow bb$	-	$2b$	-	3.2	$Z' \text{ mass}$ 1.5 TeV		1603.08791
	SSM $W' \rightarrow \ell\nu$	$1 e, \mu$	-	Yes	13.3	$W' \text{ mass}$ 4.74 TeV		ATLAS-CONF-2016-061
	HVT $W' \rightarrow WZ \rightarrow qq\nu\nu$ model A	$0 e, \mu$	$1J$	Yes	13.2	$W' \text{ mass}$ 2.4 TeV	$g_V = 1$	ATLAS-CONF-2016-082
	HVT $W' \rightarrow WZ \rightarrow qq\nu\nu$ model B	-	$2J$	-	15.5	$W' \text{ mass}$ 3.0 TeV	$g_V = 3$	ATLAS-CONF-2016-055
CI	CI $qqqq$	-	$2j$	-	15.7	Λ 19.9 TeV	$\eta_{LL} = -1$	ATLAS-CONF-2016-069
	CI $\ell\ell qq$	$2 e, \mu$	-	-	3.2	Λ 25.2 TeV	$\eta_{LL} = -1$	1607.03669
	CI $uutt$	$2(SS)/\geq 3 e, \mu \geq 1b, \geq 1j$	Yes	20.3	Λ 4.9 TeV	$ C_{RR} = 1$	1504.04605	
DM	Axial-vector mediator (Dirac DM)	$0 e, \mu$	$\geq 1j$	Yes	3.2	m_A 1.0 TeV	$g_a = 0.25, g_s = 1.0, m(\chi) < 250 \text{ GeV}$	1604.07773
	Axial-vector mediator (Dirac DM)	$0 e, \mu, 1 \gamma$	$1j$	Yes	3.2	m_A 710 GeV	$g_a = 0.25, g_s = 1.0, m(\chi) < 150 \text{ GeV}$	1604.01306
	$ZZ\chi\chi$ EFT (Dirac DM)	$0 e, \mu$	$1J, \leq 1j$	Yes	3.2	M_* 550 GeV	$m(\chi) < 150 \text{ GeV}$	ATLAS-CONF-2015-080
LQ	Scalar LQ 1 st gen	$2 e$	$\geq 2j$	-	3.2	LQ mass 1.1 TeV	$\beta = 1$	1605.06035
	Scalar LQ 2 nd gen	2μ	$\geq 2j$	-	3.2	LQ mass 1.05 TeV	$\beta = 1$	1605.06035
	Scalar LQ 3 rd gen	$1 e, \mu$	$\geq 1b, \geq 3j$	Yes	20.3	LQ mass 640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \rightarrow Ht + X$	$1 e, \mu$	$\geq 2b, \geq 3j$	Yes	20.3	T mass 855 GeV	T in (T,B) doublet	1505.04306
	VLQ $YY \rightarrow Wb + X$	$1 e, \mu$	$\geq 1b, \geq 3j$	Yes	20.3	Y mass 770 GeV	Y in (B,Y) doublet	1505.04306
	VLQ $BB \rightarrow Hb + X$	$1 e, \mu$	$\geq 2b, \geq 3j$	Yes	20.3	B mass 735 GeV	isospin singlet	1505.04306
	VLQ $BB \rightarrow Zb + X$	$2/\geq 3 e, \mu$	$\geq 2/\geq 1b$	-	20.3	B mass 755 GeV	B in (B,Y) doublet	1409.5500
	VLQ $QQ \rightarrow WqWq$	$1 e, \mu$	$\geq 4j$	Yes	20.3	Q mass 690 GeV		1509.04261
	VLQ $T_{5/3} T_{5/3} \rightarrow WtWt$	$2(SS)/\geq 3 e, \mu \geq 1b, \geq 1j$	Yes	3.2	$T_{5/3} \text{ mass}$ 990 GeV		ATLAS-CONF-2016-032	
Excited fermions	Excited quark $q^* \rightarrow q\gamma$	1γ	$1j$	-	3.2	$q^* \text{ mass}$ 4.4 TeV	only u' and d' , $\Lambda = m(q')$	1512.05910
	Excited quark $q^* \rightarrow qg$	-	$2j$	-	15.7	$q^* \text{ mass}$ 5.6 TeV	only u' and d' , $\Lambda = m(q')$	ATLAS-CONF-2016-069
	Excited quark $b^* \rightarrow b\gamma$	-	$1b, 1j$	-	8.8	$b^* \text{ mass}$ 2.3 TeV		ATLAS-CONF-2016-060
	Excited quark $b^* \rightarrow Wt$	$1 \text{ or } 2 e, \mu$	$1b, 2-0j$	Yes	20.3	$b^* \text{ mass}$ 1.5 TeV	$f_g = f_t = f_R = 1$	1510.02664
	Excited lepton l^*	$3 e, \mu$	-	-	20.3	$l^* \text{ mass}$ 3.0 TeV	$\Lambda = 3.0 \text{ TeV}$	1411.2921
	Excited lepton ν^*	$3 e, \mu, \tau$	-	-	20.3	$\nu^* \text{ mass}$ 1.6 TeV	$\Lambda = 1.6 \text{ TeV}$	1411.2921
Other	LSTC $a_T \rightarrow W\gamma$	$1 e, \mu, 1 \gamma$	-	Yes	20.3	$a_T \text{ mass}$ 960 GeV		1407.8150
	LRSM Majorana ν	$2 e, \mu$	$2j$	-	20.3	$N^0 \text{ mass}$ 2.0 TeV	$m(W_R) = 2.4 \text{ TeV, no mixing}$	1506.06020
	Higgs triplet $H^{\pm\pm} \rightarrow ee$	$2 e (SS)$	-	-	13.9	$H^{\pm\pm} \text{ mass}$ 570 GeV	DY production, $BR(H^{\pm\pm} \rightarrow ee) = 1$	ATLAS-CONF-2016-051
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$	$3 e, \mu, \tau$	-	-	20.3	$H^{\pm\pm} \text{ mass}$ 400 GeV	DY production, $BR(H^{\pm\pm} \rightarrow \ell\tau) = 1$	1411.2921
	Monopole (non-res prod)	$1 e, \mu$	$1b$	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{\text{non-res}} = 0.2$	1410.5404
	Multi-charged particles	-	-	-	20.3	multi-charged particle mass 785 GeV	DY production, $ q = 5e$	1504.04188
	Magnetic monopoles	-	-	-	7.0	monopole mass 1.34 TeV	DY production, $ g = 1g_D, \text{spin } 1/2$	1509.08059

*Only a selection of the available mass limits on new states or phenomena is shown. Lower bounds are specified only when explicitly not excluded.

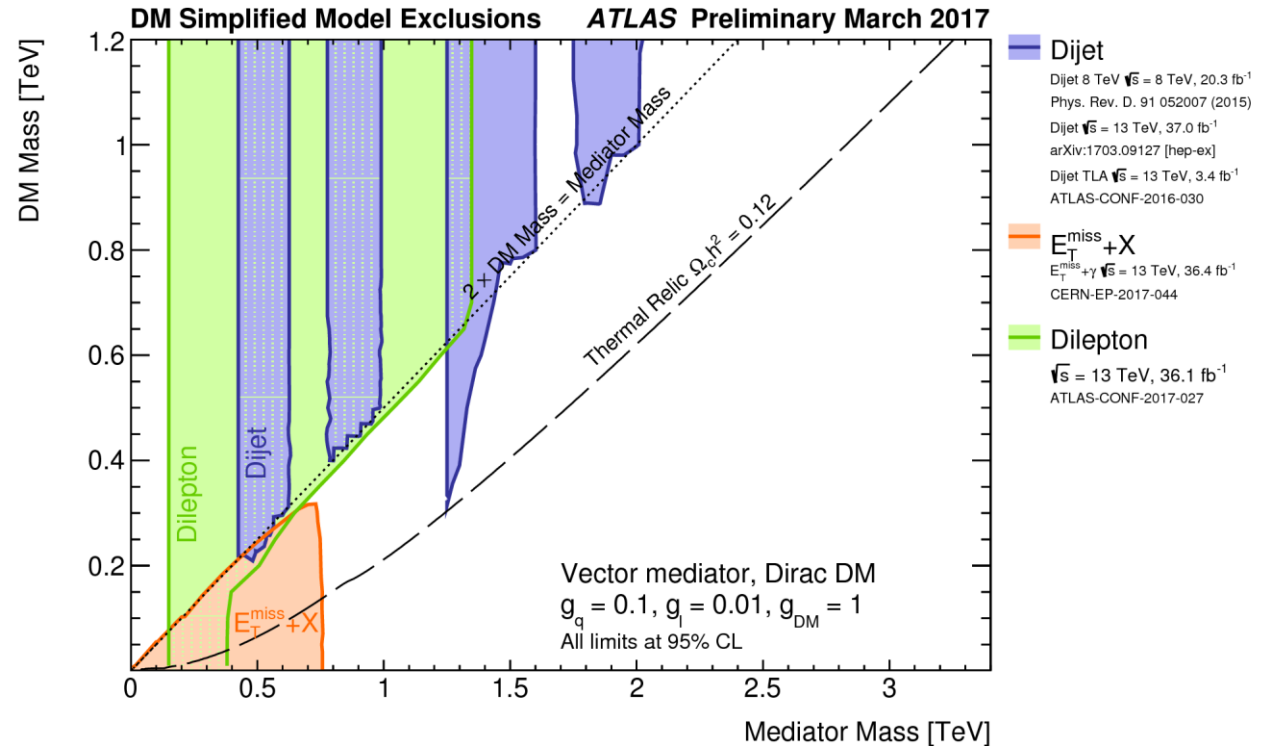
†Small-radius (large-radius) jets are denoted by the letter j (J).

Searches will continue!

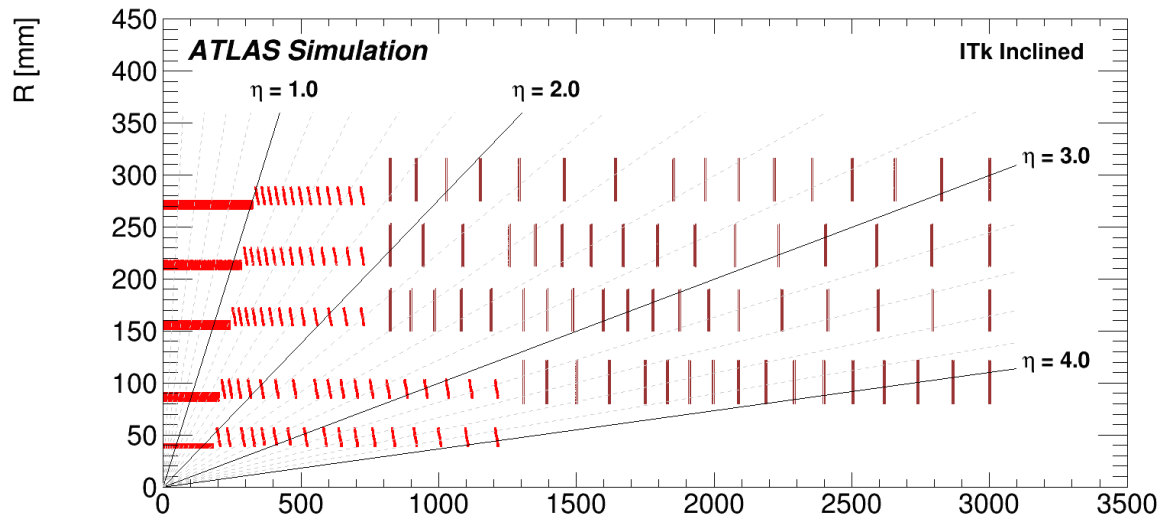


Searches Theory (& Experiment)

- BSM phenomenology: SUSY@NLO, Composite Higgs, Dark Matter...
- Tools: SModels, MadAnalysis5, Lilith...
- Forums: Interpretation of the LHC results for BSM studies, Dark Matter WG



ATLAS Tracking Upgrade (2024-25)

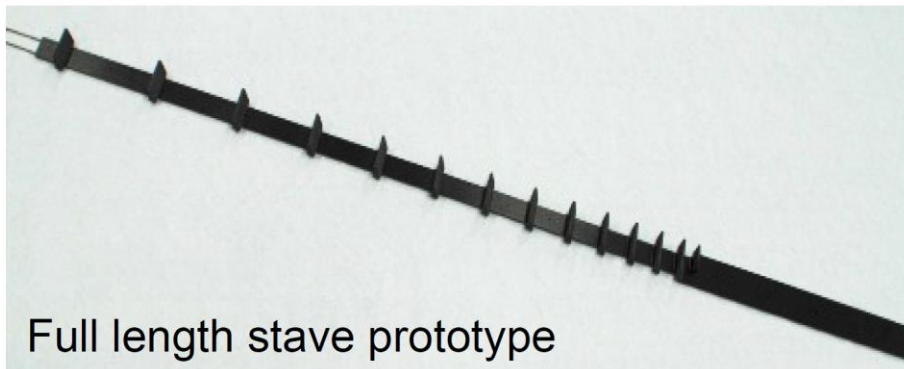
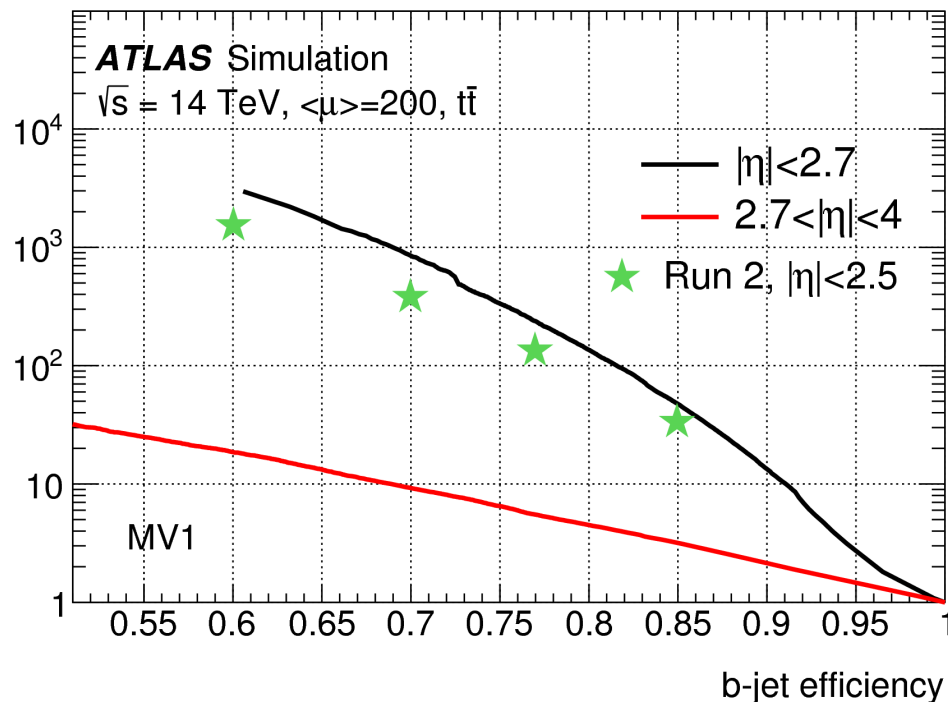


Goals: improved tracking performance in higher pile-up & radiation environment

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

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

Light-jet rejection



Next 10 years

Beyond Standard Model

Search for any deviations from Standard Model predictions

Direct observation:



In-direct observation:

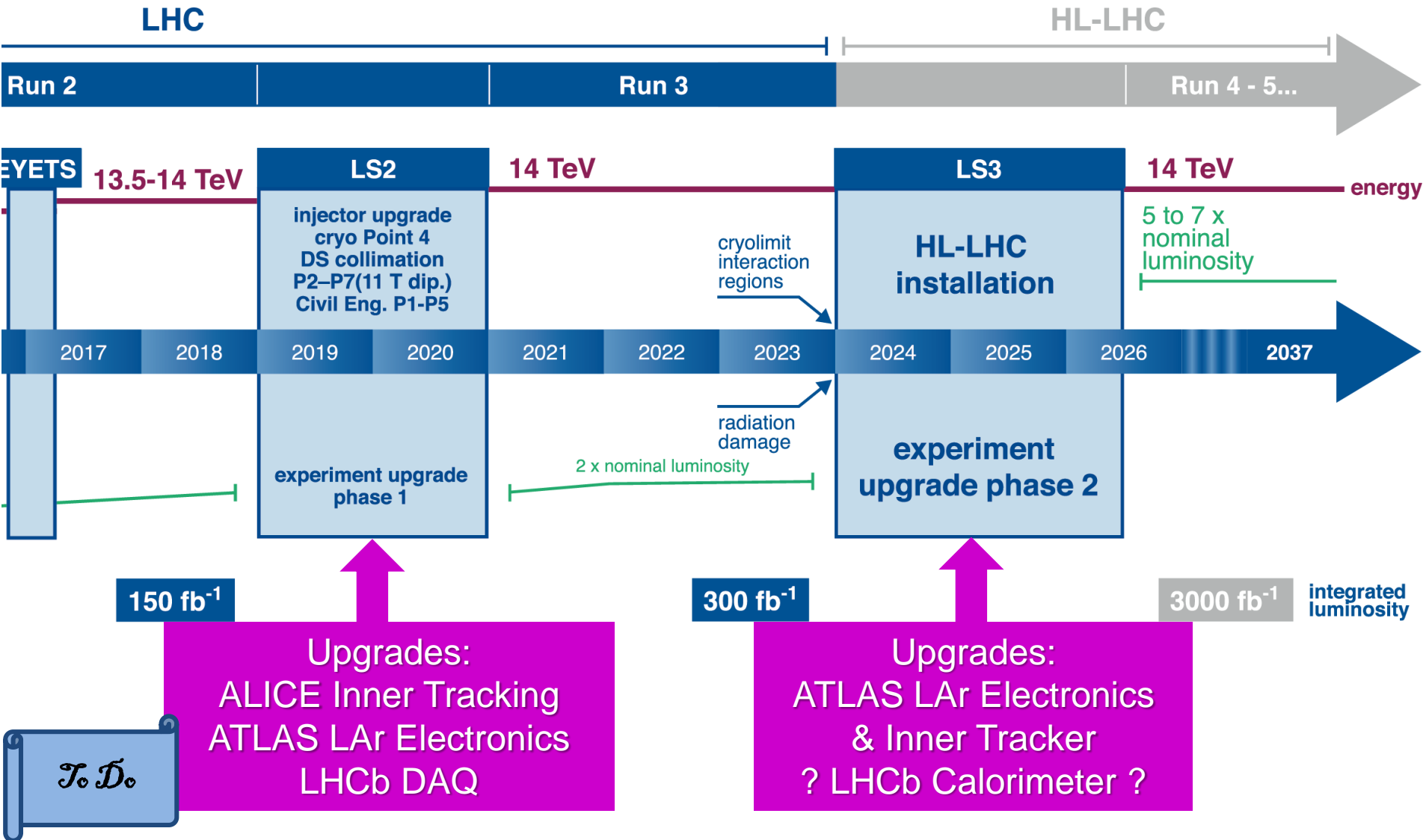


Our searches: $\gamma\gamma$, γ +MET,
ll, tb, tt, etc.

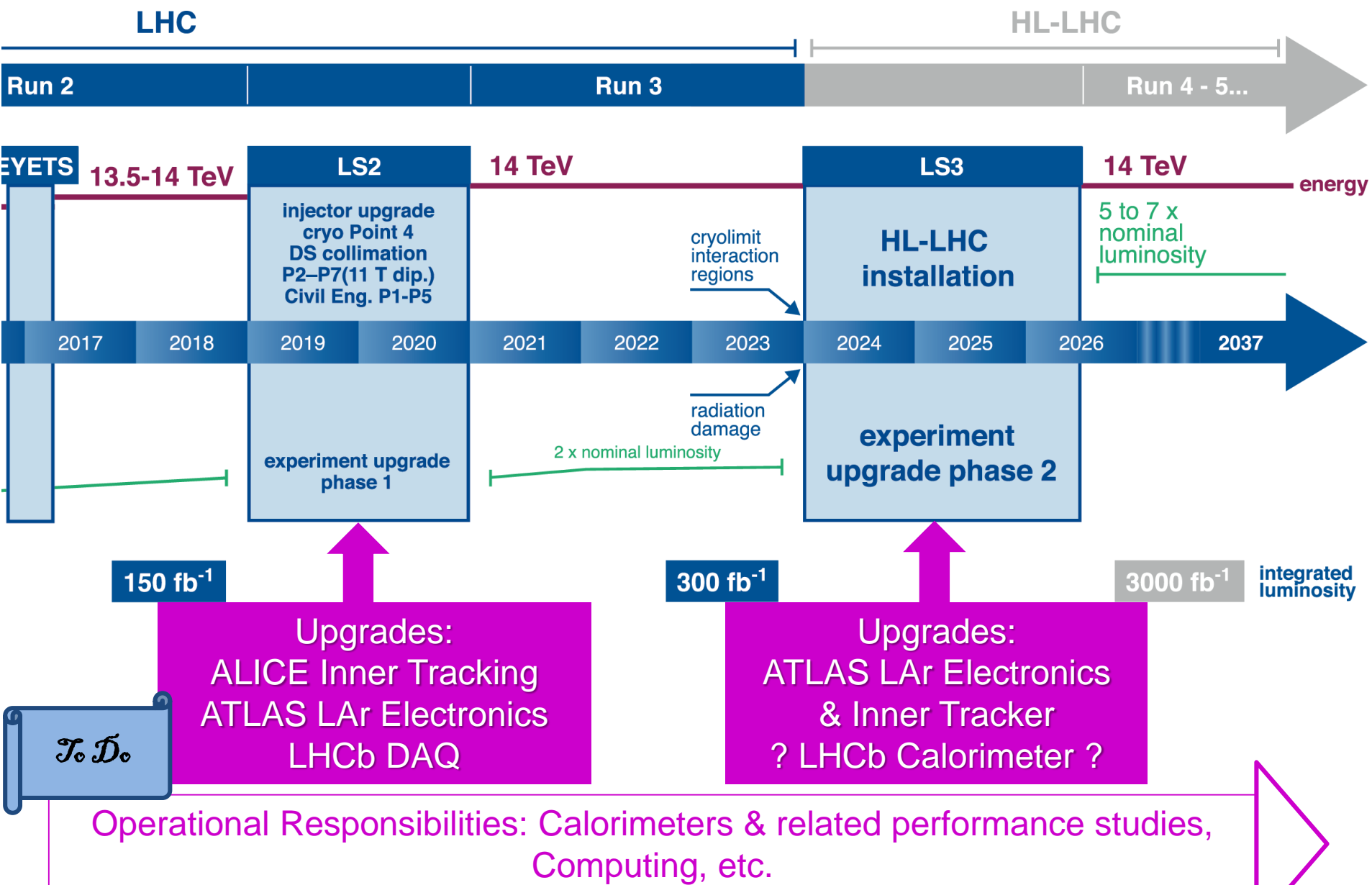
Diboson measurements (VBS),
Double Higgs production,
Measurements of CKM angles,
Flavour anomalies,
Precision QCD...

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

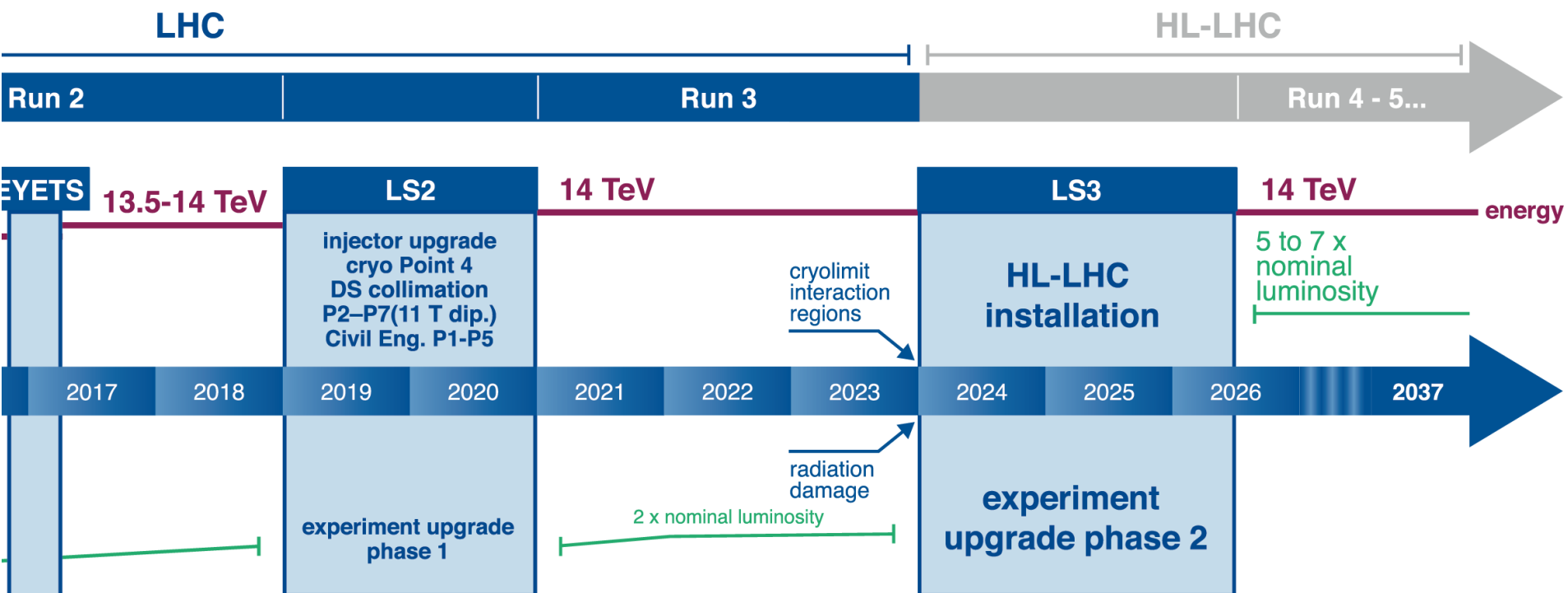
LHC Timeline



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

SM EFT

To Do

- 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)

Measurements planned



Theory predictions are crucial.

Double Higgs Production



Direct information on the shape of the scalar Higgs potential

$\sigma_{gg \rightarrow HH} = 33.49^{+4.3}_{-6.0} \text{ (scale)} \pm 2.1 \text{ (PDF)} \pm 2.3 \text{ (}\alpha_s\text{) fb}$

[13 TeV, NNLO + NNLL with top mass effects, HXSWG, arXiv:1610.07922]

Chan.	Obs. (exp.) 95% C.L. limit on σ/σ_{SM}	
bbbb	29 (38)	342 (308)
bbWW	-	410 (227) □
bb $\tau\tau$	-	28 (25) □
bb $\gamma\gamma$	117 (161)	91 (90)
WW $\gamma\gamma$	747 (386)	-

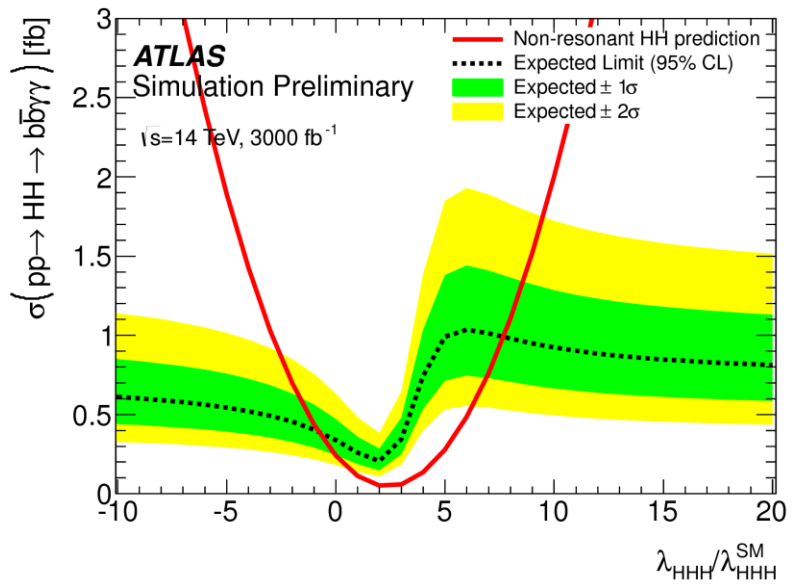
2.3-3.2 fb⁻¹

13.3 fb⁻¹

35.9 fb⁻¹

□: Test of anomalous HH couplings

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

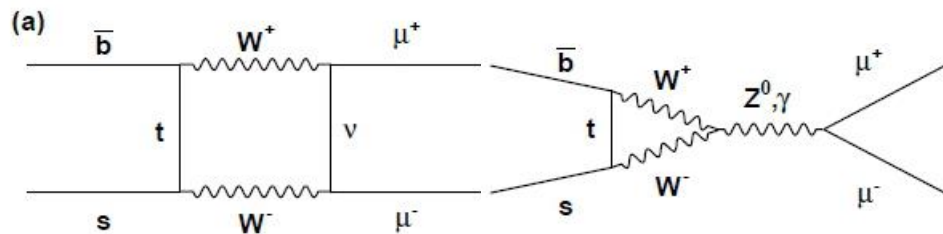


In bb $\gamma\gamma$ expect 9.5 signal over 90.9 bkg events in 3 ab⁻¹ ($\sim 1\sigma$) Need to combine with other channels & CMS.

ATL-PHYS-PUB-2017-001

L. Cadamuro @Moriond EW 2017

Flavour Anomalies



$$\text{BR}_{\text{obs}}(B_s \rightarrow \mu\mu) / \text{BR}_{\text{SM}}(B_s \rightarrow \mu\mu) = 0.76^{+0.20}_{-0.17}$$

\Rightarrow More precise measurement needed.

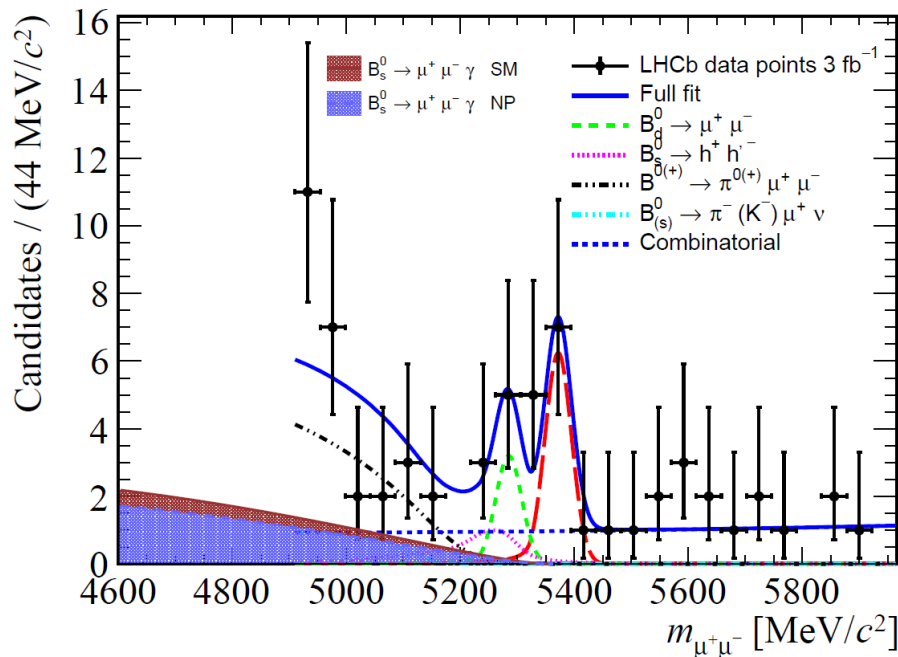
$\text{BR}(B_s \rightarrow \mu\mu\gamma) \sim 5 \text{ BR}(B_s \rightarrow \mu\mu)$, not seen yet.
Also interesting to see $B_s \rightarrow e\mu\gamma$.

LHCb reported 2-3 sigma anomalies in various

$b \rightarrow sll$ measurements (BRs, angular observables, ...) and in $b \rightarrow c\tau\nu$. FCNC sensitive to BSM contributions through the loops.

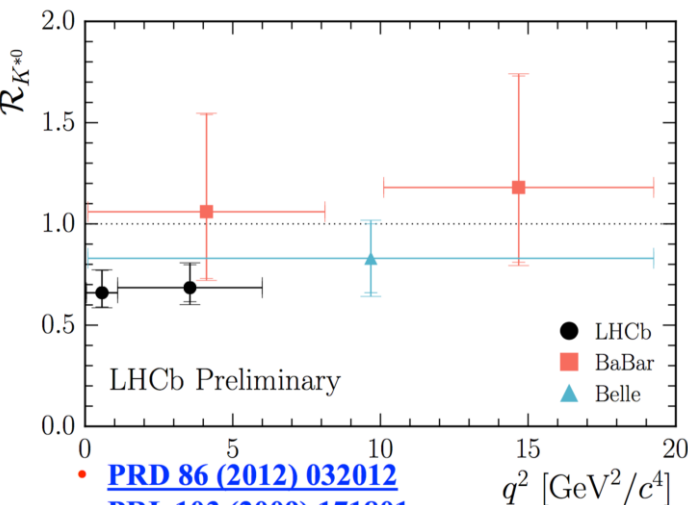


T. D.



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

arXiv:1610.00629



- [PRD 86 \(2012\) 032012](#)
- [PRL 103 \(2009\) 171801](#)

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:

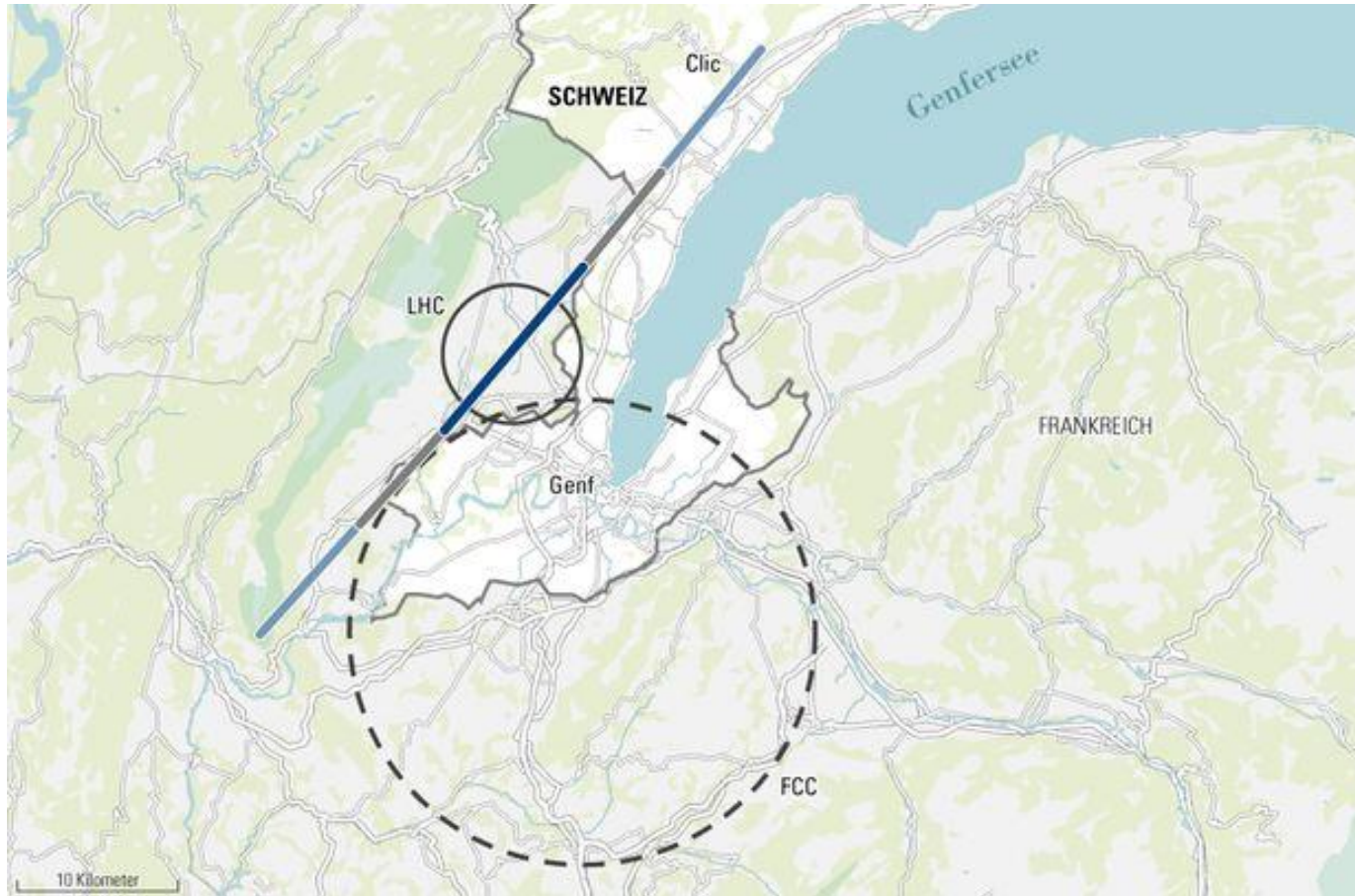
→ use to study quark flavor dependence of energy loss in QGP: test dead cone effect prediction



Beyond LHC: nEDM

Beyond LHC: GRANIT

Beyond LHC: new colliders

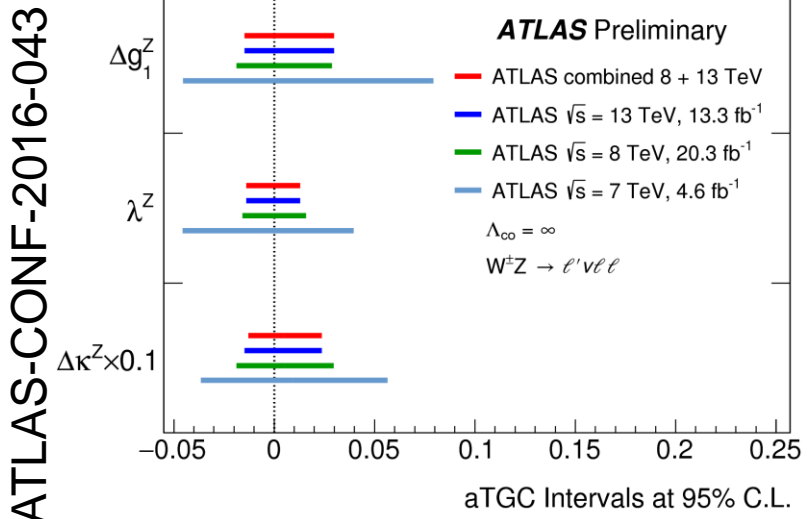
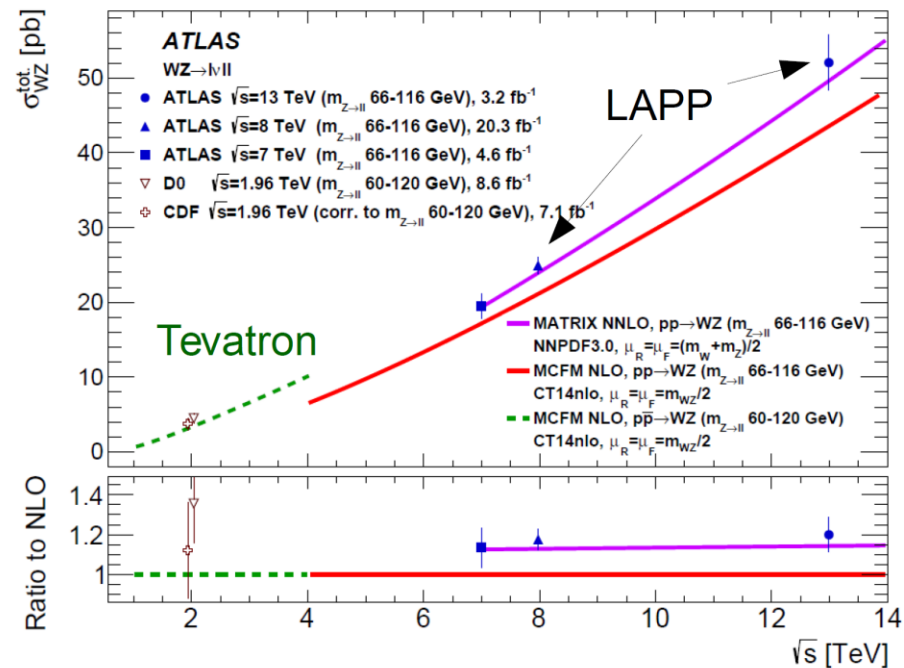


Small ILC
groups @
LAPP & LPSC

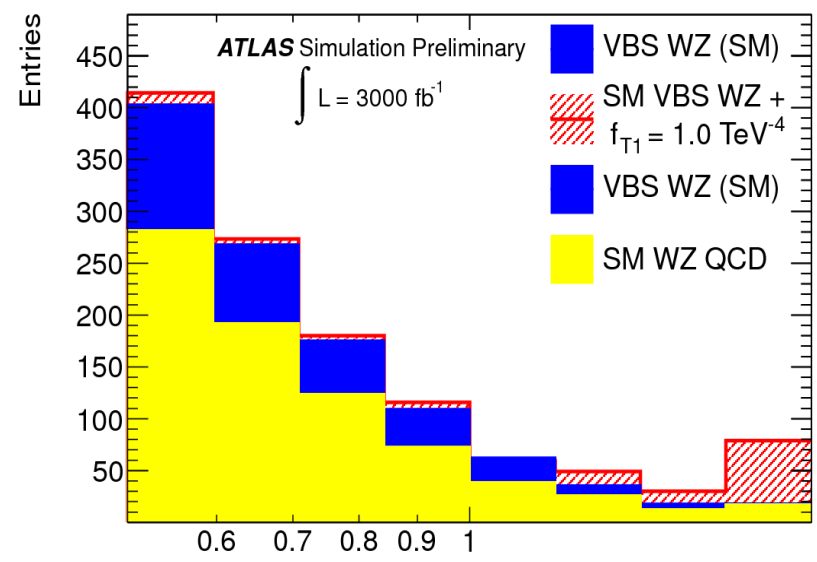
Following
developments
on FCC,
CLIC and
ILC.

Backup

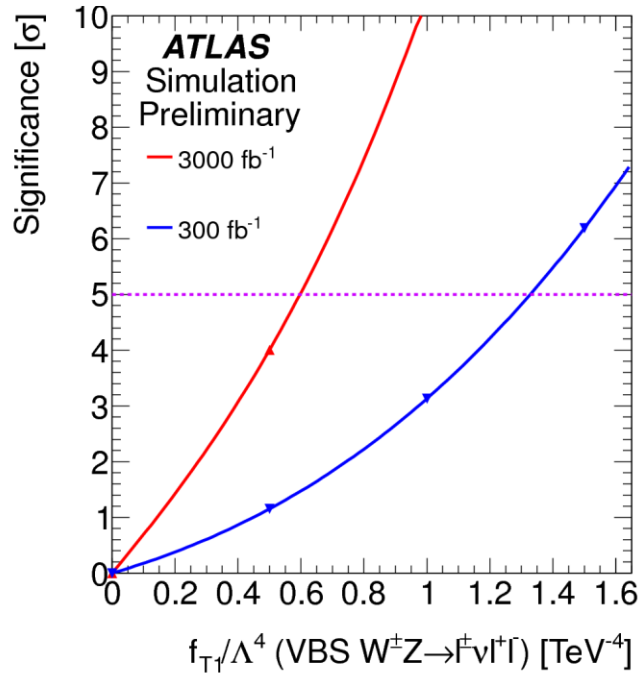
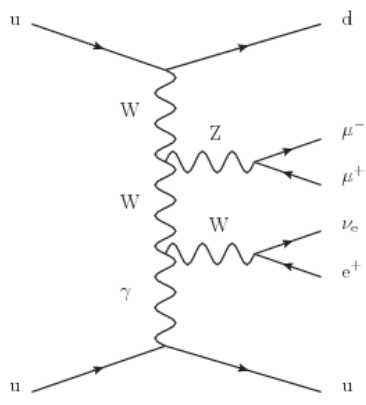
Dibosons to VBS



ATL-PHYS-PUB-2013-006



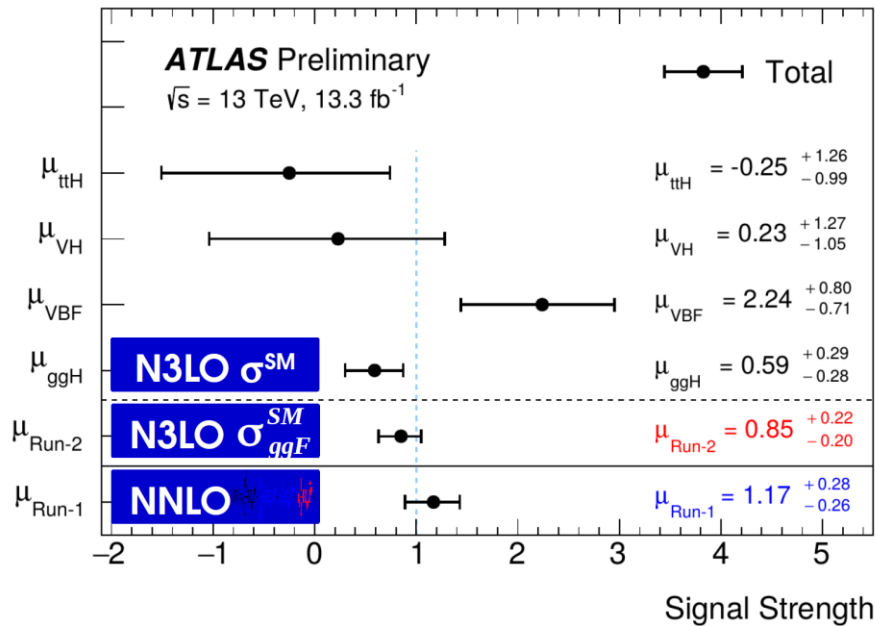
$$\mathcal{L}_{T,1} = \frac{f_{T1}}{\Lambda^4} \text{Tr}[\hat{W}_{\alpha\nu} \hat{W}^{\mu\beta}] \times \text{Tr}[\hat{W}_{\mu\beta} \hat{W}^{\alpha\nu}]$$



ATLAS-CONF-2016-043

H → γγ couplings

ATLAS-CONF-2016-067



New ggF N3LO calculation

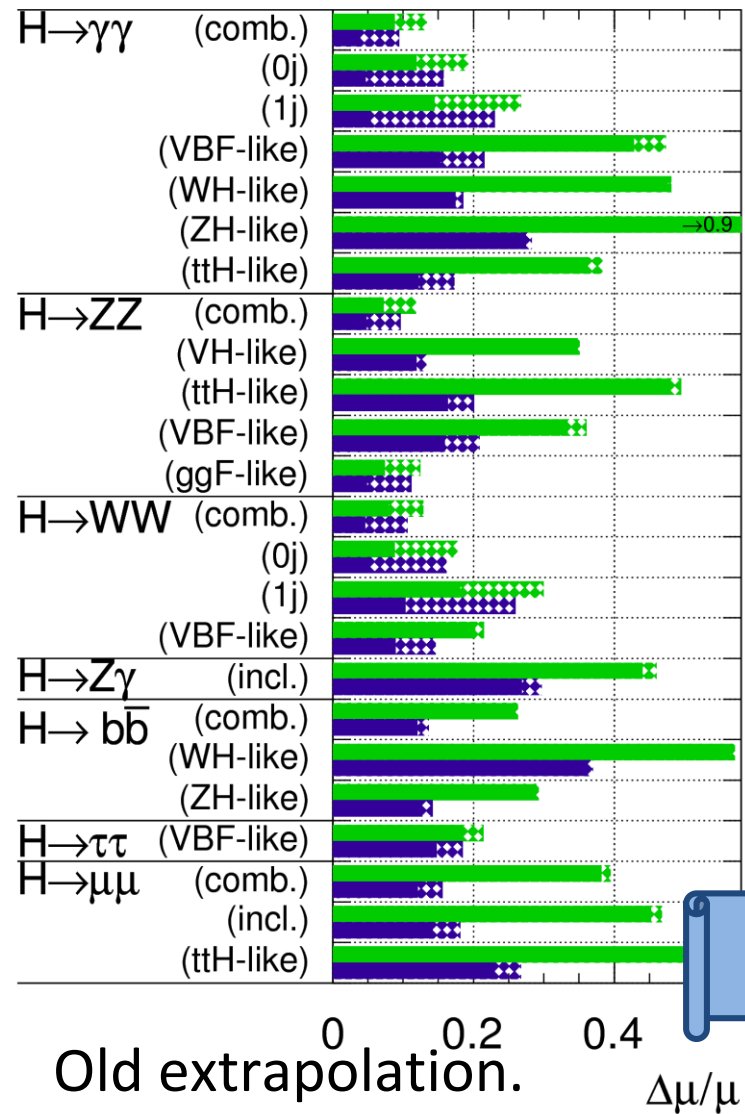
- +3% change in $\sigma_{\text{ggF}}^{\text{SM}}$
- QCD pert. uncert. 7.8% → 3.8%
- PDF+ α_s uncert.: ~7% → 3.2%

Experimental precision needs to catch up with theory!

JHEP(2016)058

ATLAS Simulation Preliminary

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



Old extrapolation. $\Delta\mu/\mu$

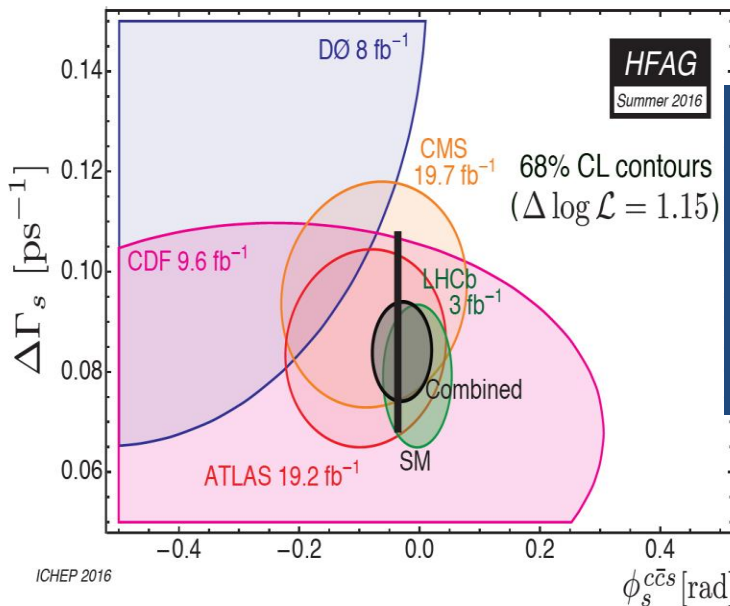
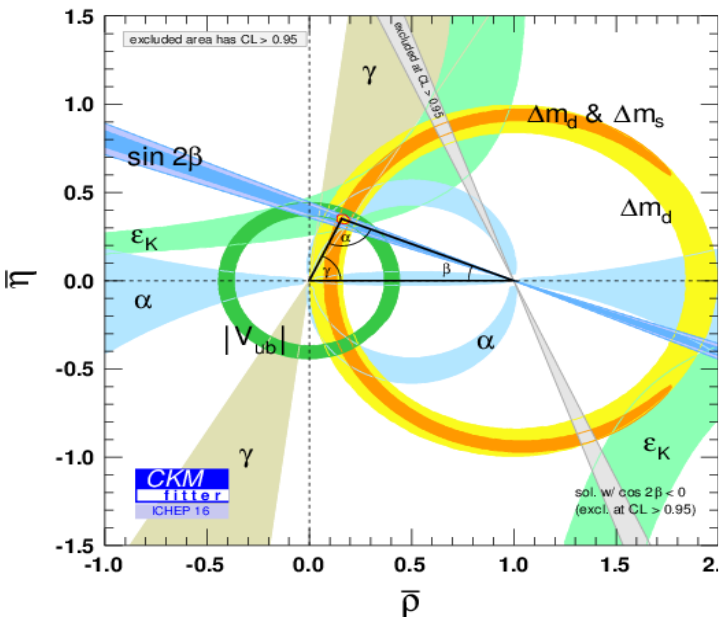
Analyses improved.

Sizable theory uncertainties!

ATL-PHYS-PUB-2014-016

CKM angles

arXiv:1612.07233

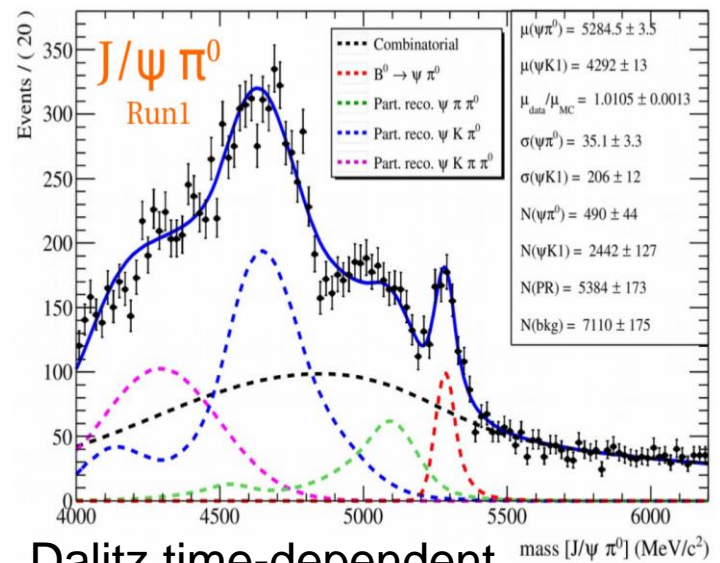


Now (CKMFitter):
 $\sin 2\beta = 0.691 \pm 0.017$
 $\gamma = (72.2^{+5.3}_{-5.8})^\circ$
 $\phi_s = -0.015 \pm 0.035 \text{ rad}$

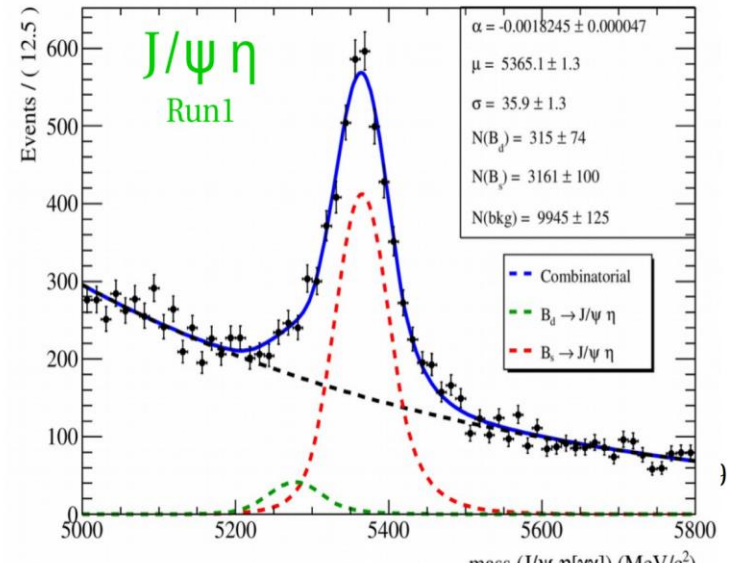


**LHCb
Uncertainty
End of
Run 4**

β	0.031°
γ	0.9°
ϕ_s	0.009 rad



Dalitz time-dependent analysis for Run 2

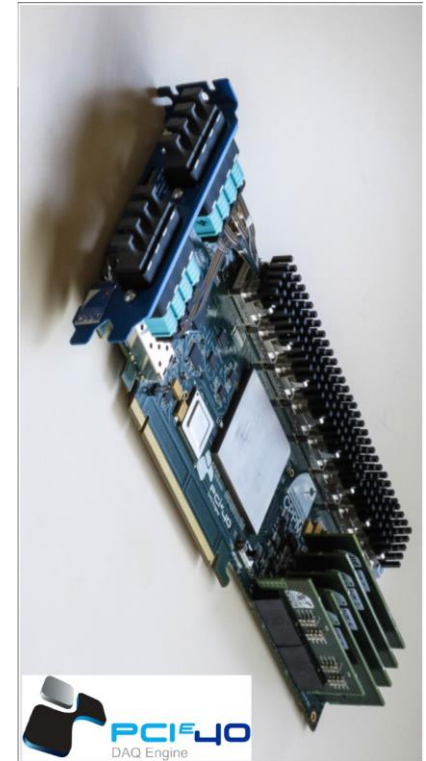
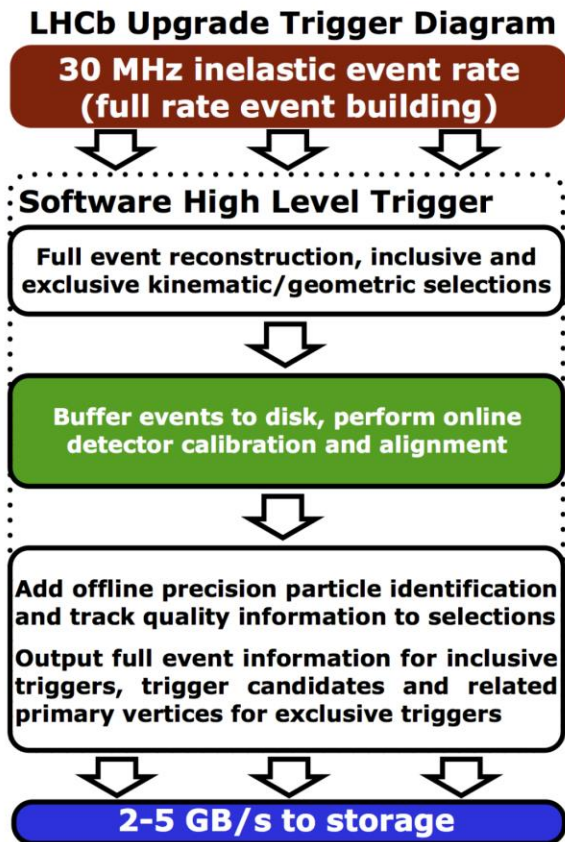
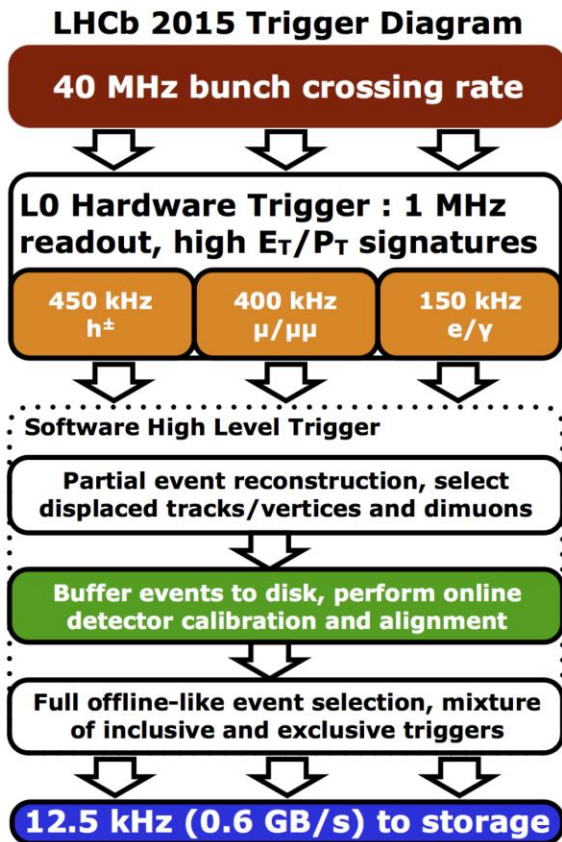


Also $B_s \rightarrow J/\psi \eta' (\rho^0 \gamma, \eta \pi^+ \pi^-)$

Testing SM predictions

LHCb DAQ Upgrade (2019-20)

Goal: Remove Hardware Trigger

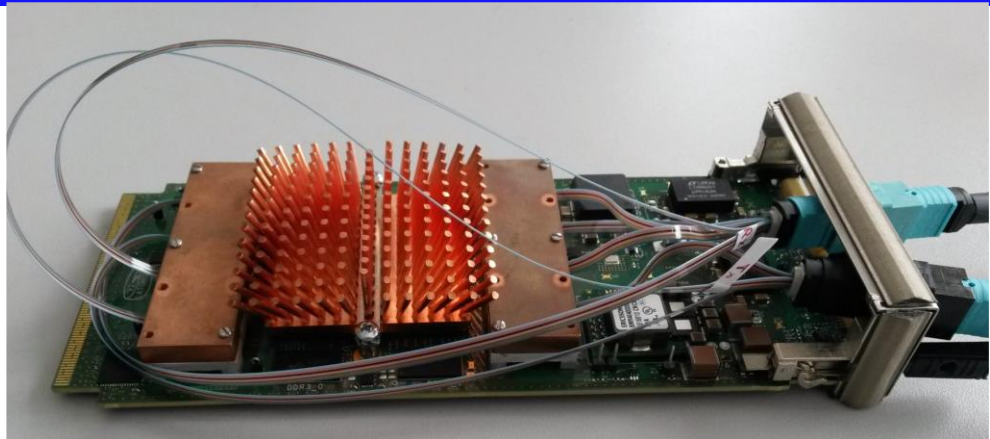
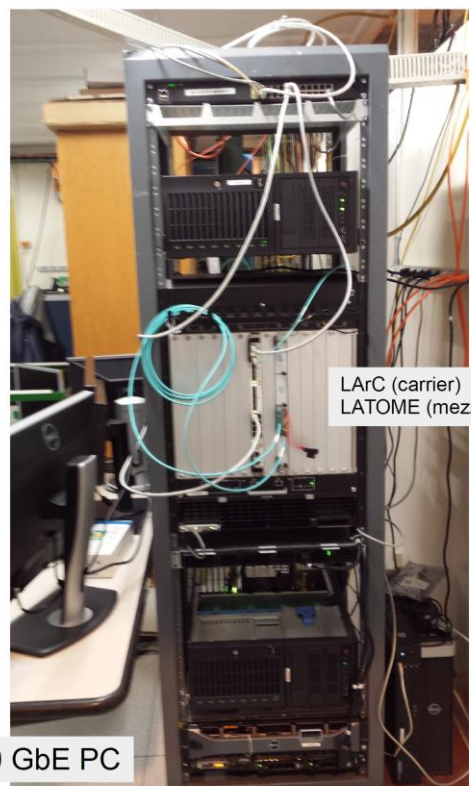


LAPP coordinates firmware development for Prototype Readout Board Used for Event Building

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.)



LAPP coordinates firmware development

IPMC : ATCA controller card developed at LAPP



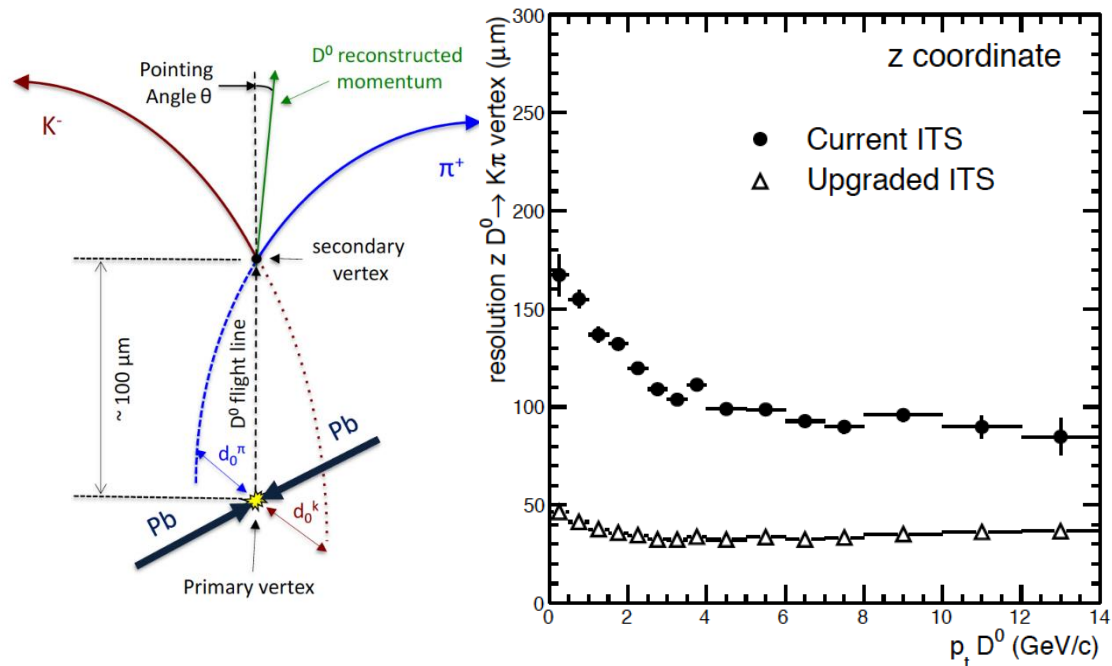
Coordination of tests at CERN

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

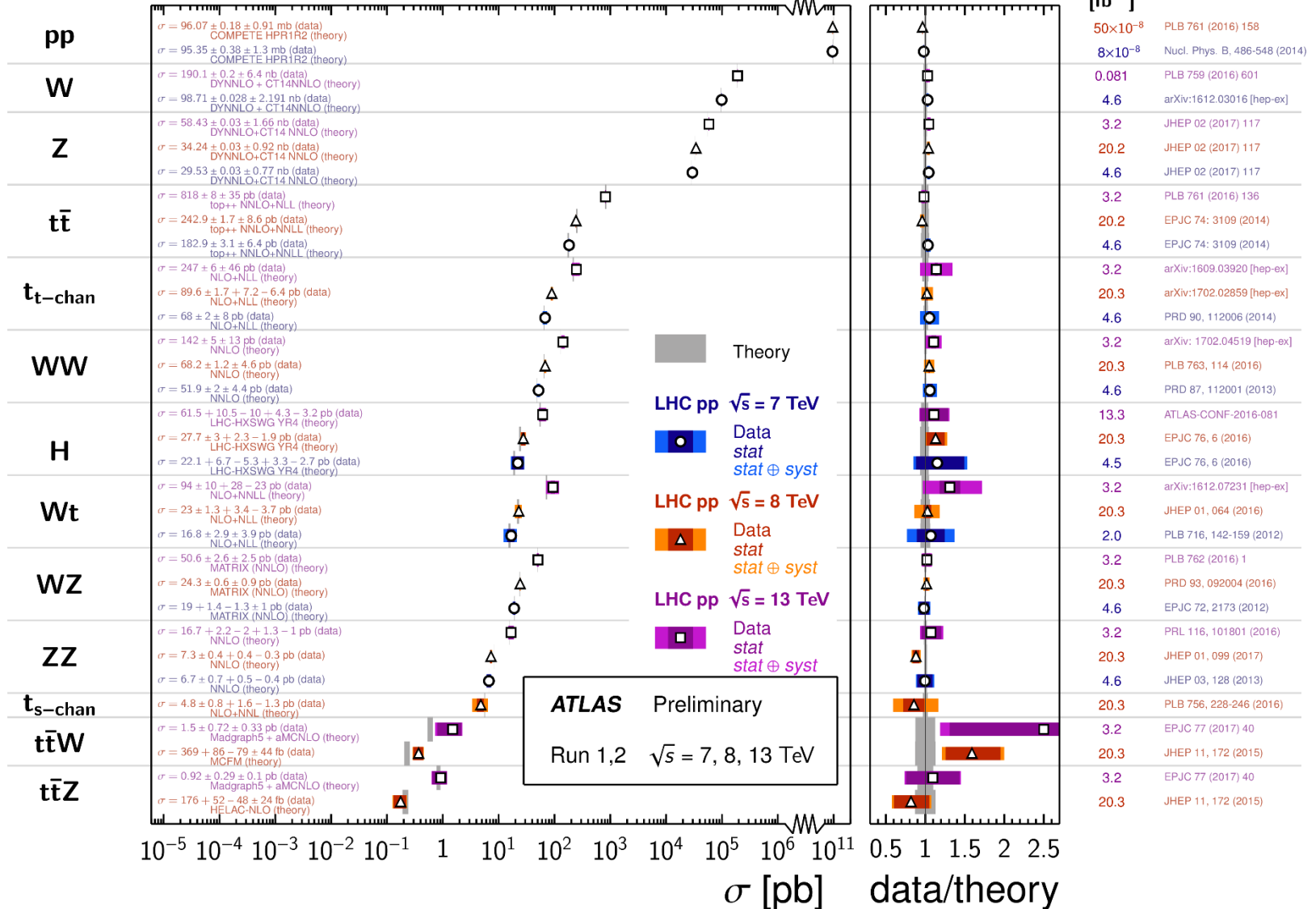
Indirect Searches = Measurements

Standard Model Total Production Cross Section Measurements

Status:
March 2017

$\int \mathcal{L} dt$
[fb⁻¹]

Reference



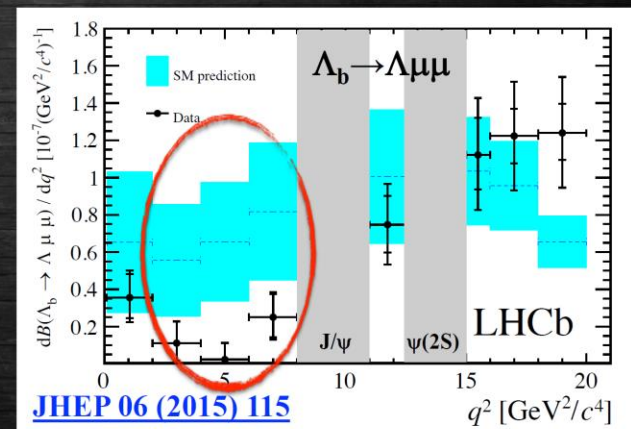
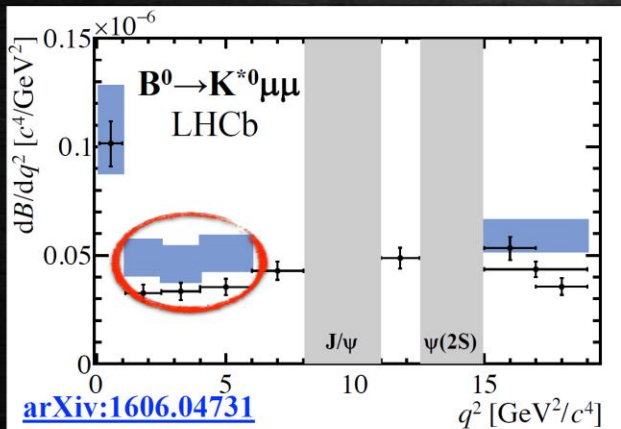
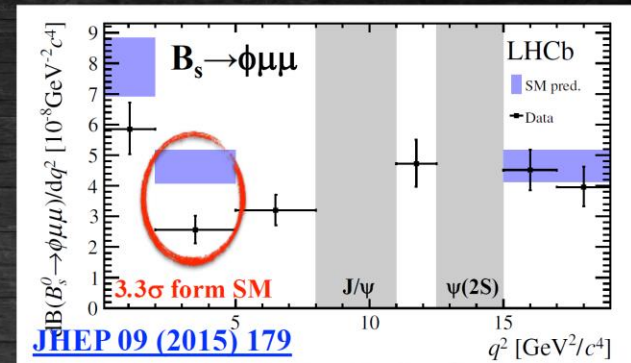
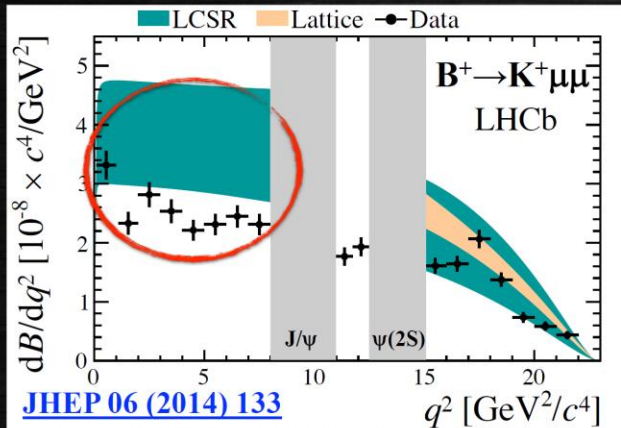
LHCb anomalies (1)



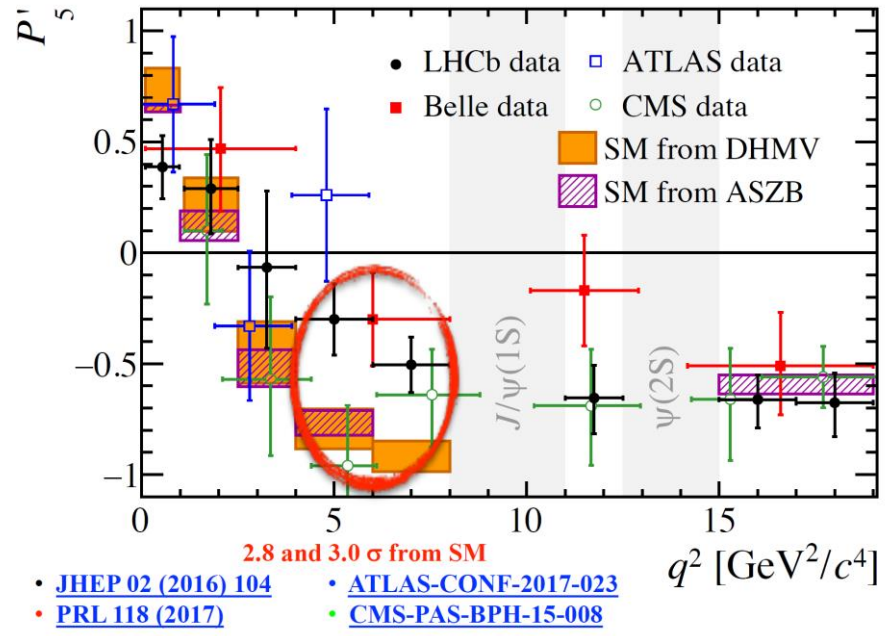
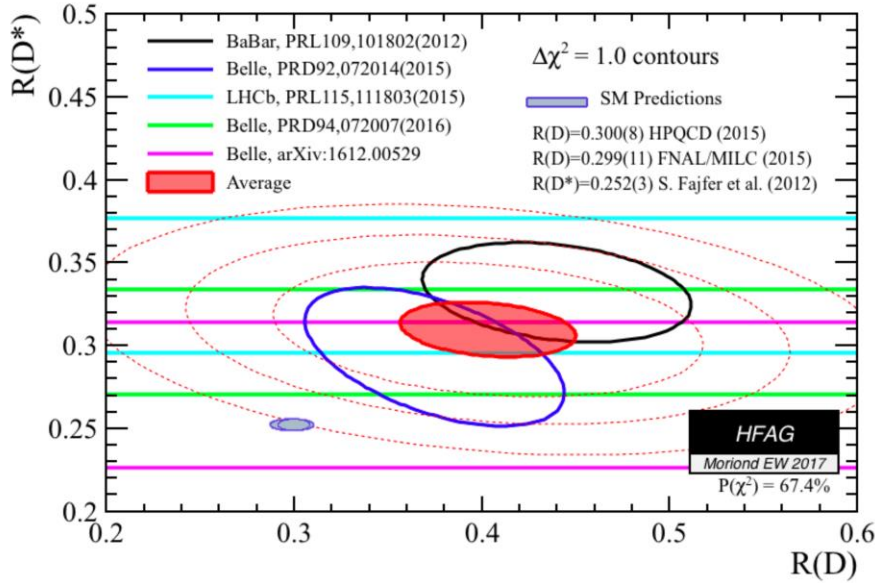
Differential Branching Fractions



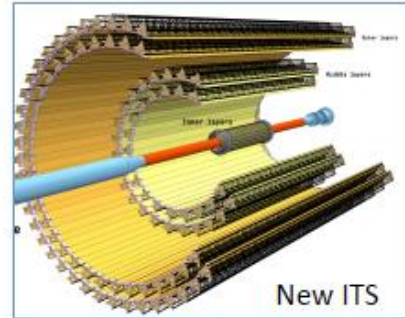
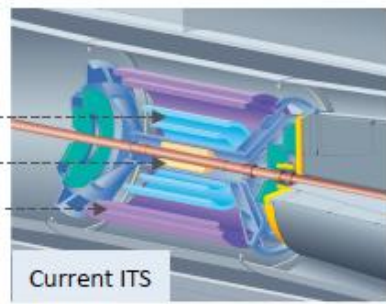
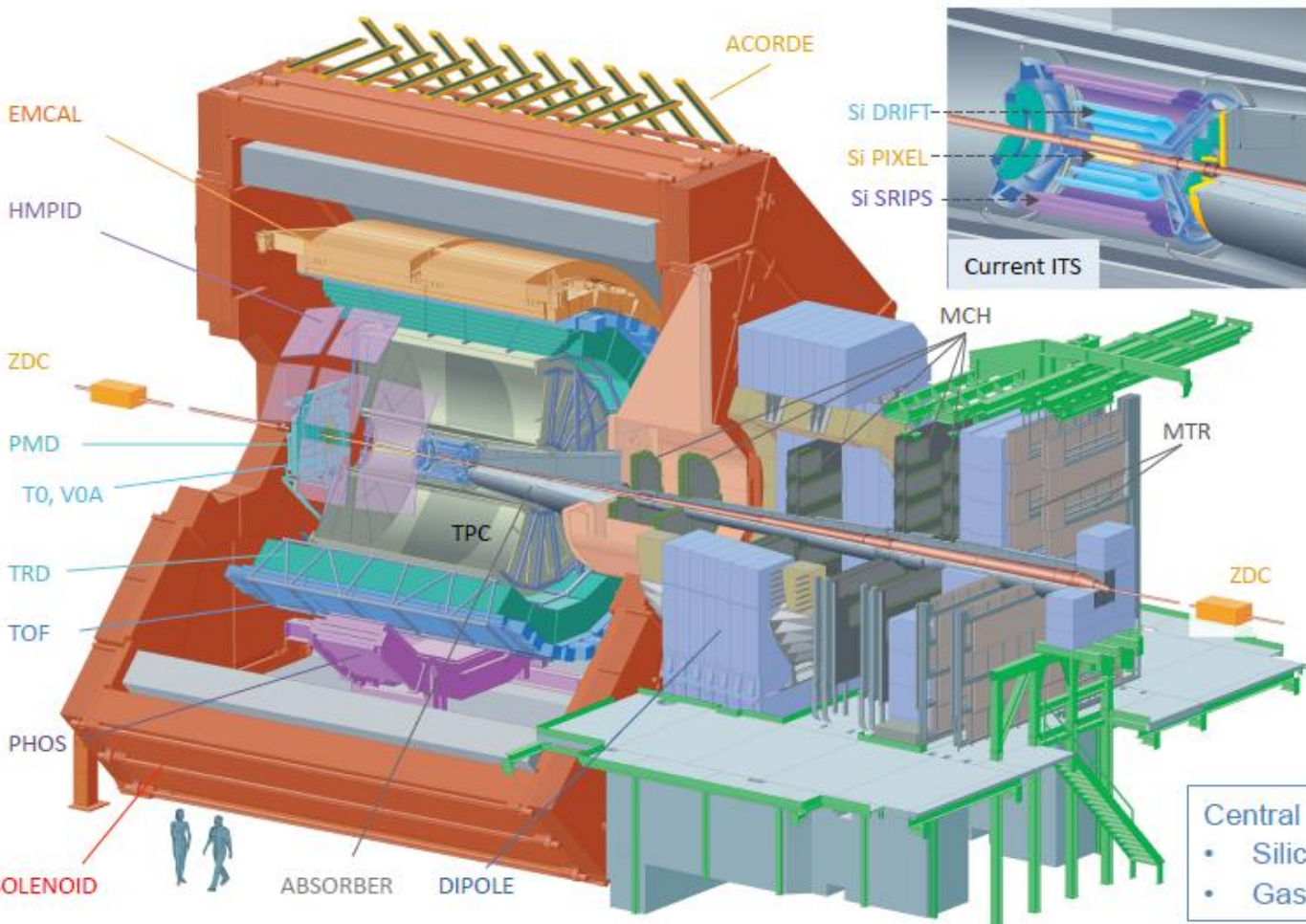
› Results consistently lower than SM predictions



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