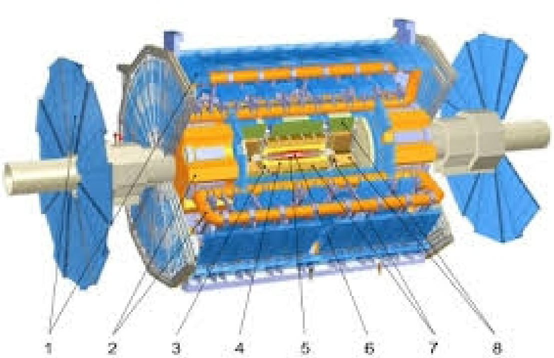
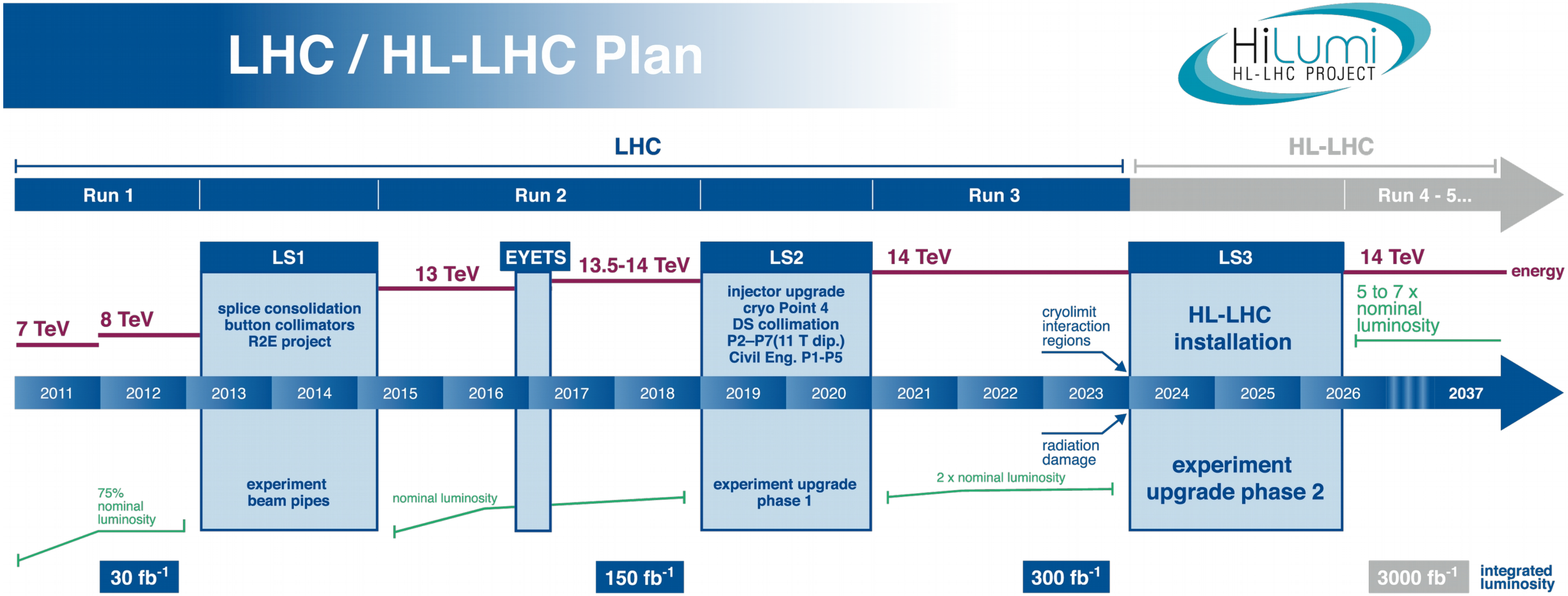
ATLAS & CMS HLLHC Upgrades & Flavor Physics Prospects



Franco Simonetto Universita' & INFN Padova

LHC Upgrade plan



Run	Year	√s (TeV)	$\mathcal{L}$ $(10^{34}/cm^2s)$	$\int\mathcal{L}\,dt$ (fb^{-1})	Atlas	CMS
1	2009-2012	7-8	0.5	30		
2	2015-2018	13-14	1	150		
3	2021-2023	14	2	300		
4-5	2026-2035	14	5-7	3000	Major	Upgrades

HL-LHC : the challenge

High Luminosity (5 to 7 x $\mathcal{L}$ wrt now):

- larger collision rate
- larger pile up: 40 (now) -> 140/200 interactions per crossing
- higher detector occupancy
- large radiation background

Long running Time (~ 10 Years)

- radiation damage
- ageing & obsolescence

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Long running Time (~ 10 Years)

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Maintain / improve present performances
Exploit at best the HLLC Physics potential

Omni Purpose Challenge

Exploit collider potential to:

- extend reach for New Physics
- improve SM measuremnts
  - Higgs properties ,
  - top properties ,
  - diboson scattering , ...
- improve precision measurements in the Flavor sector
  - ~~CP~~, rare B decays
  - top FCNC

This talk

Upgrade detectors without compromising any of the above

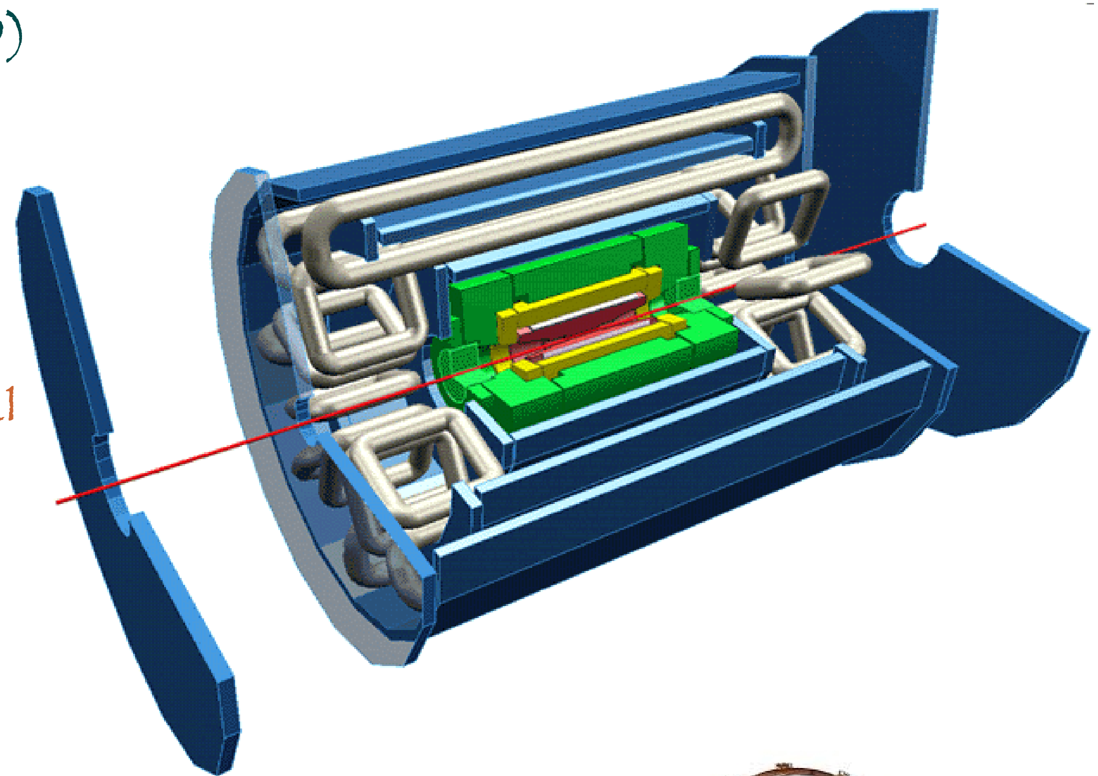
ATLAS Upgrade

Significant upgrade for RUN2 (2019)

- μ small wheel forward
- Fast Tracking Trigger at L1.5
- Higher granularity calorimeter @ L1

Phase 2

- Upgrade part of the μ system
- HW L1 trigger
- Replace tracking :
  - Si+Gas –> Si only



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ATLAS Tracking at HLLHC

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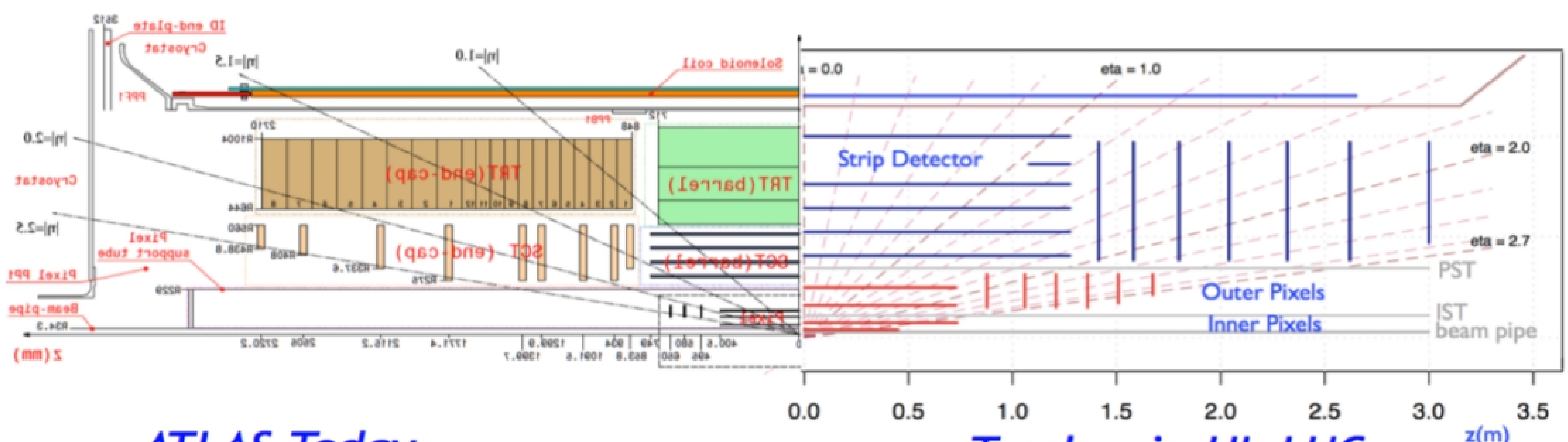
Completely NEW Si -based detector

Granularity increased x 4

Track trigger information + rough topological selection @ HW level



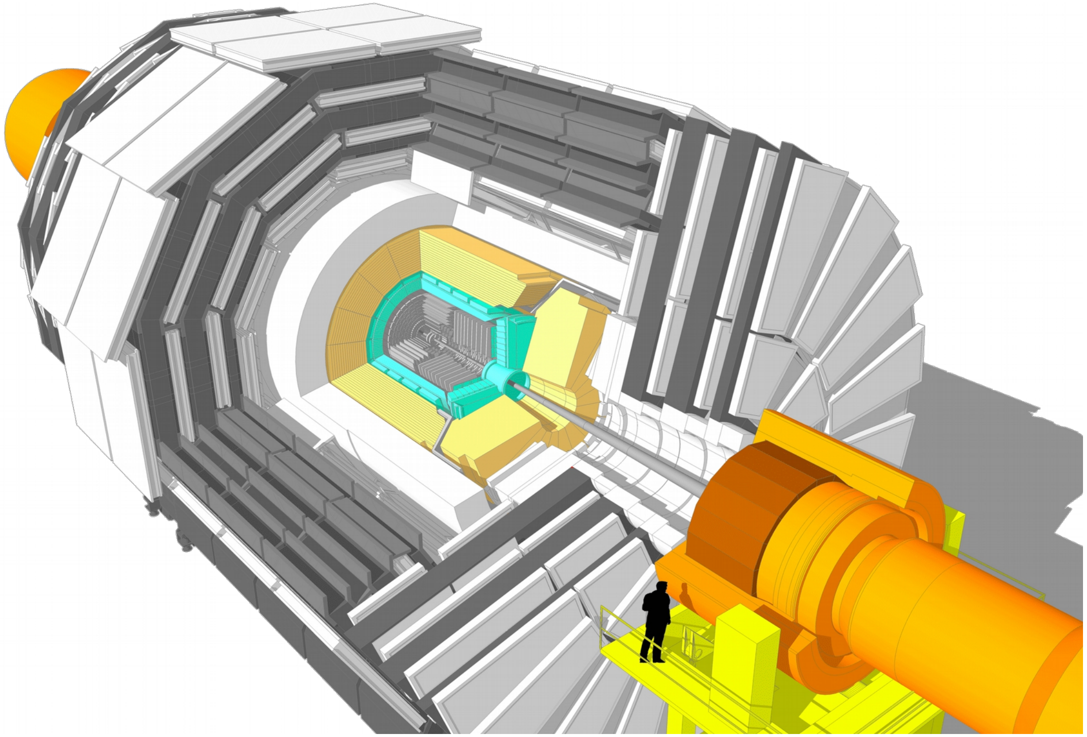
ATLAS Today

Tracker in HL-LHC

CMS Upgrade

Trigger+DAQ

- L1 @ 750 KHz, 12.5 μs (now 3.6) latency , HLT output 7.5 KHz (now ~ 1):
  - Bandwidth x 10/15, CPU x 15/30
  - New electronics for Barrel EMC
  - New electronics for μ-system (CSC,DT)
  - high p_T tracks @ L1



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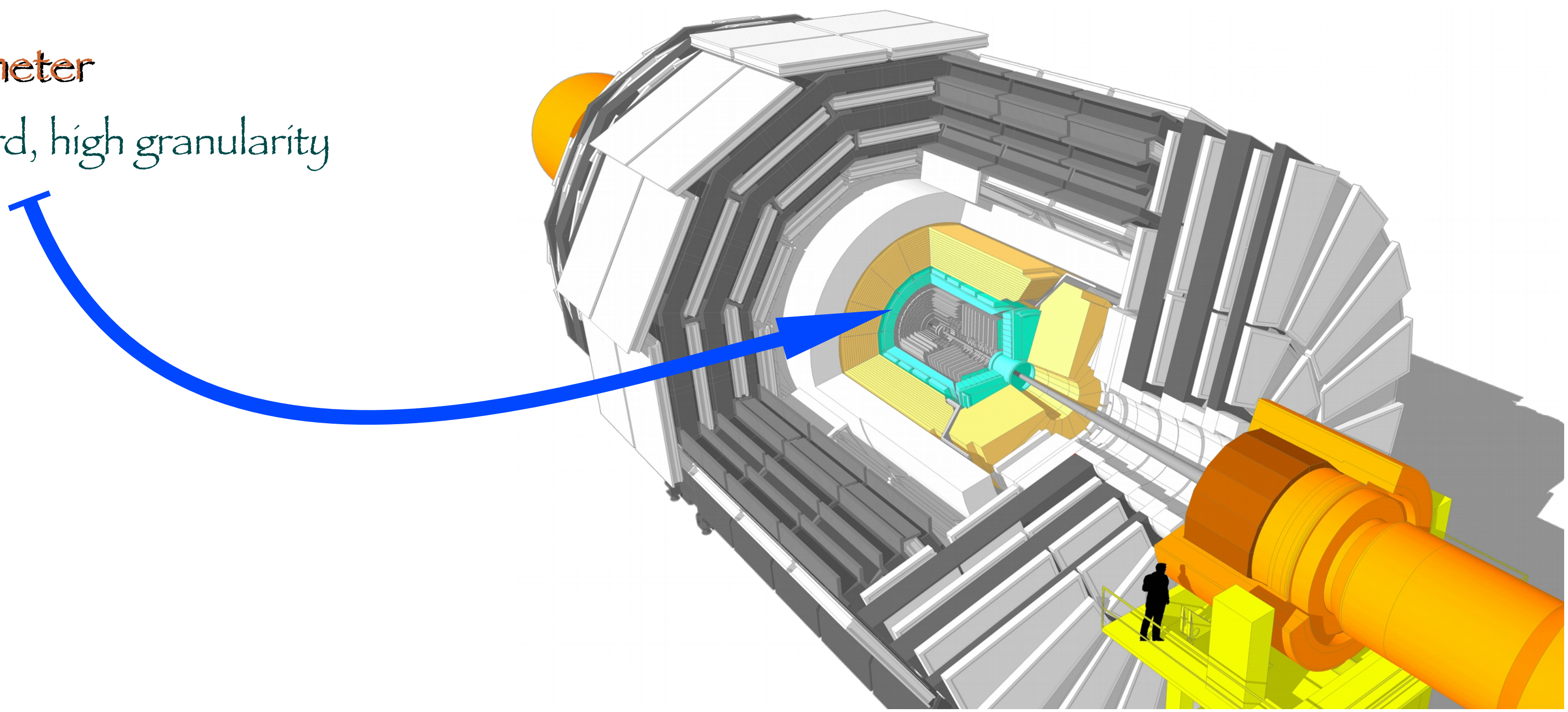
NEW Fw Calorimeter

- radiation hard, high granularity



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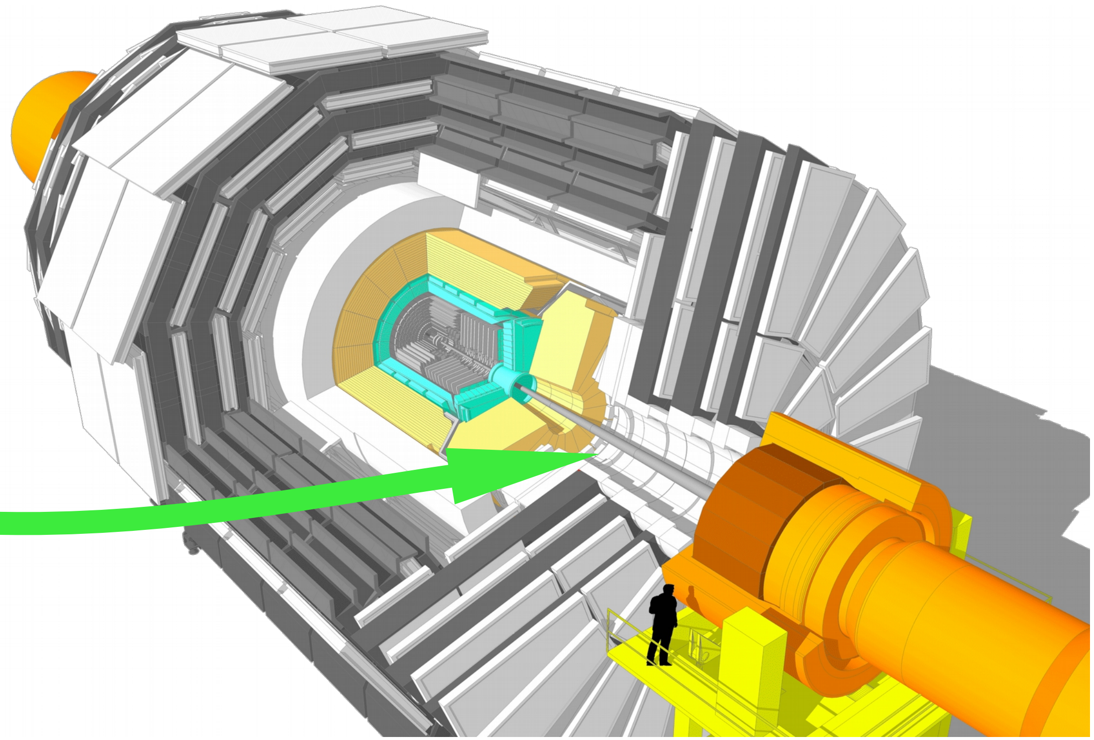
Extend μ coverage η<3

- GEM + RPC



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NEW Fw Calorimeter

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Extend μ coverage η<3

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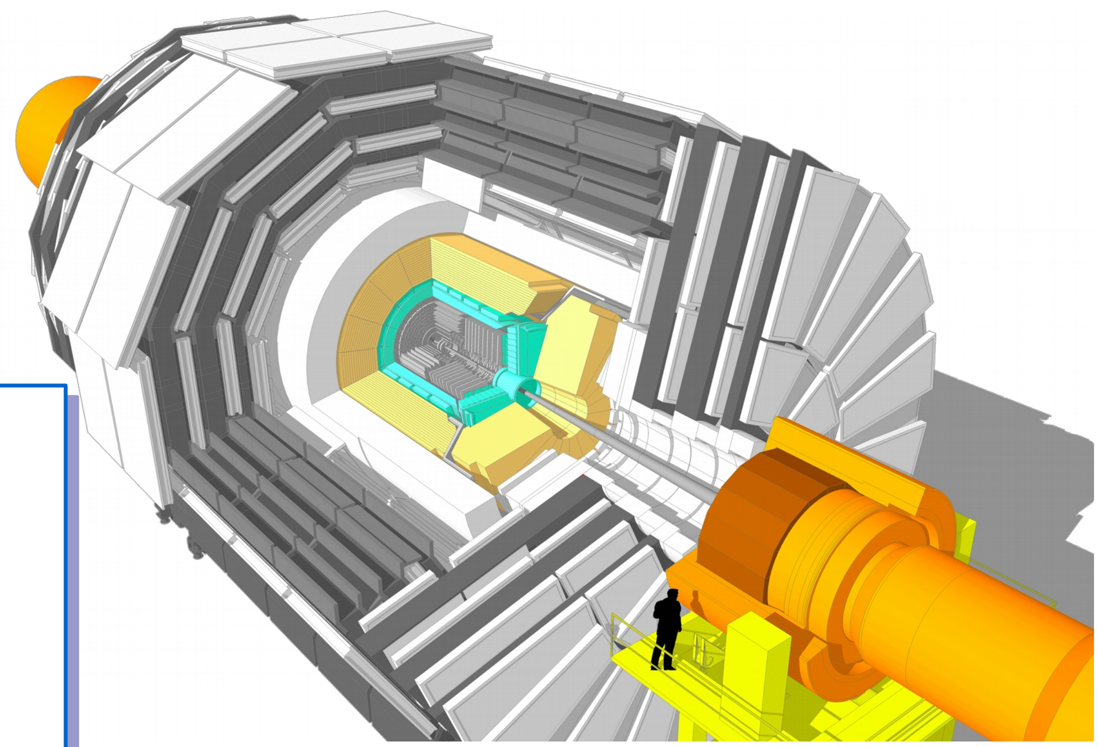
New Tracker

- radiation hard
- high granularity
- larger acceptance (η<4)
- readout high p_T tracks @ 40 MHz for L1

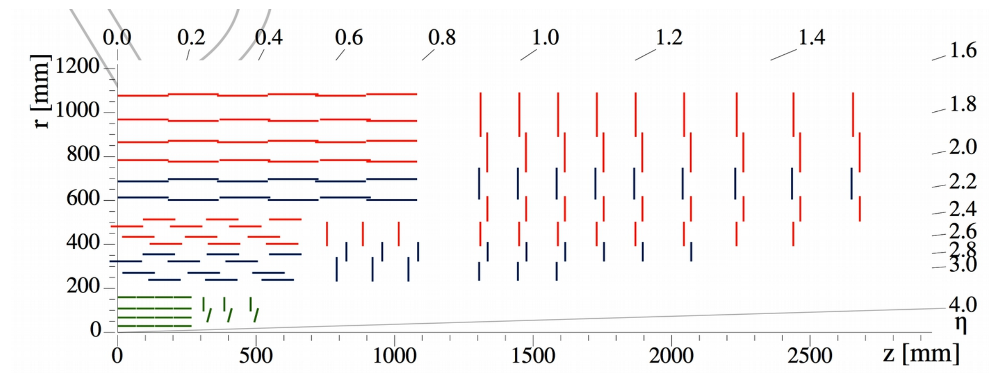


The New CMS Tracker

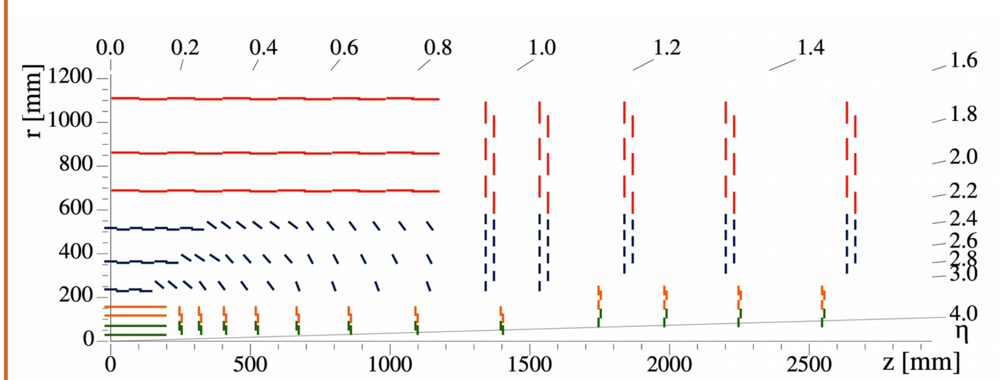
NEW Layout

- less detector layers
- pixel extended down to $\eta<4$

NOW



HL-LHC



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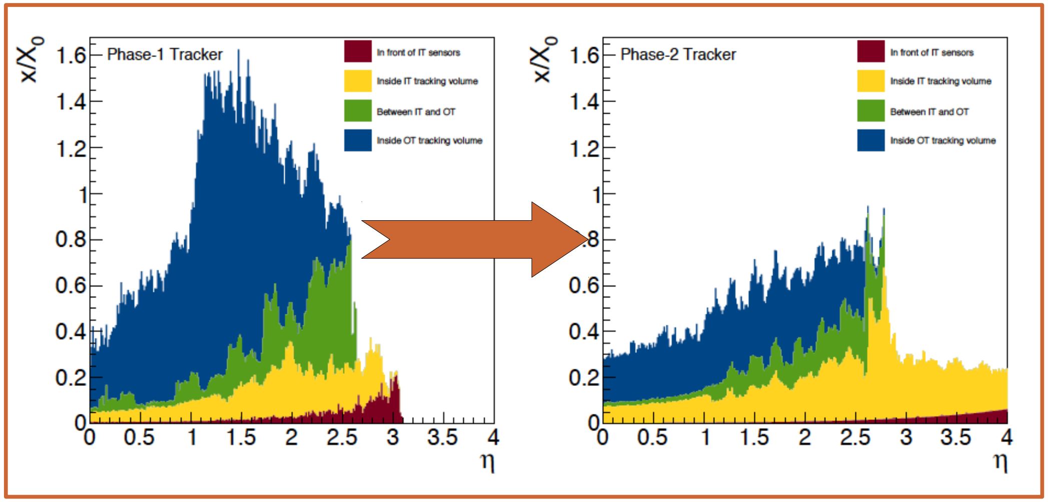
Radiation Hard

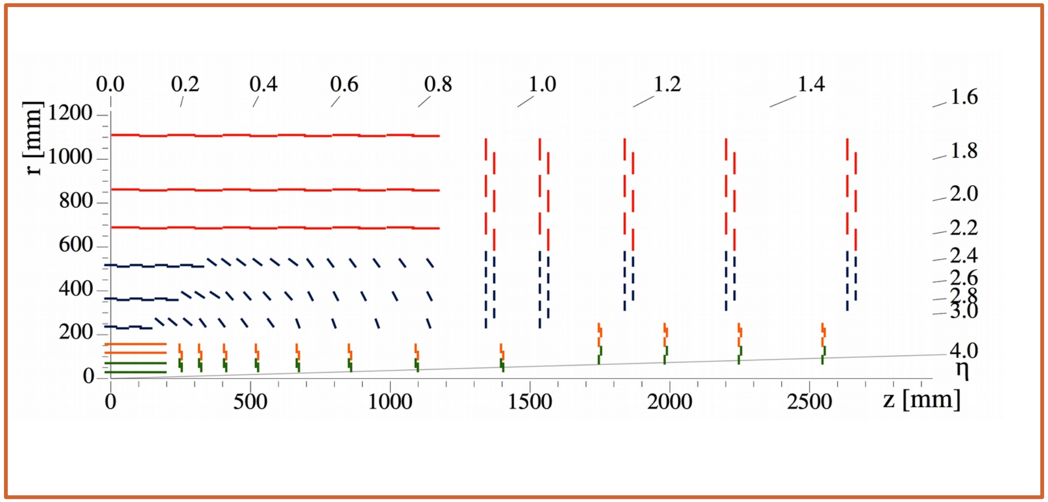
- n on p detectors (now p on n)

Increase granularity

- ~ same pitch
- reduce strip lenght

Reduced material budget





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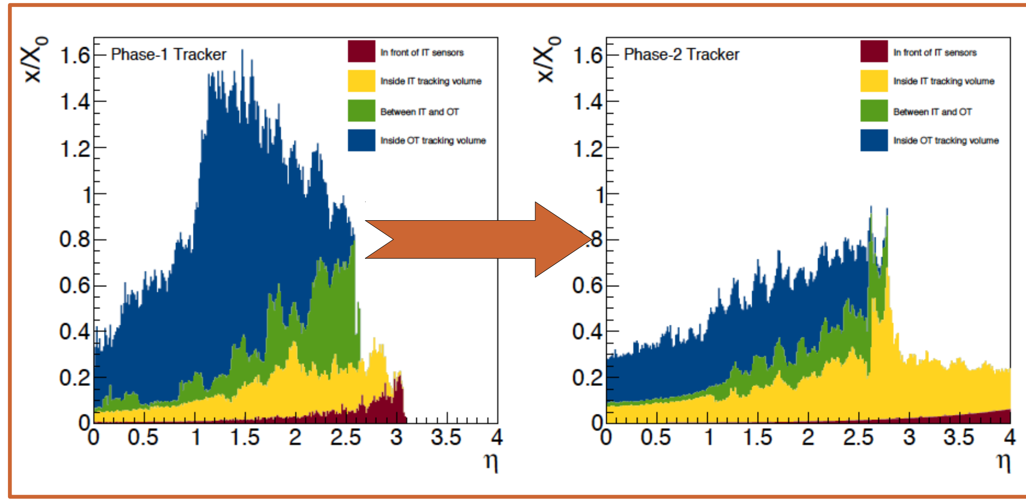

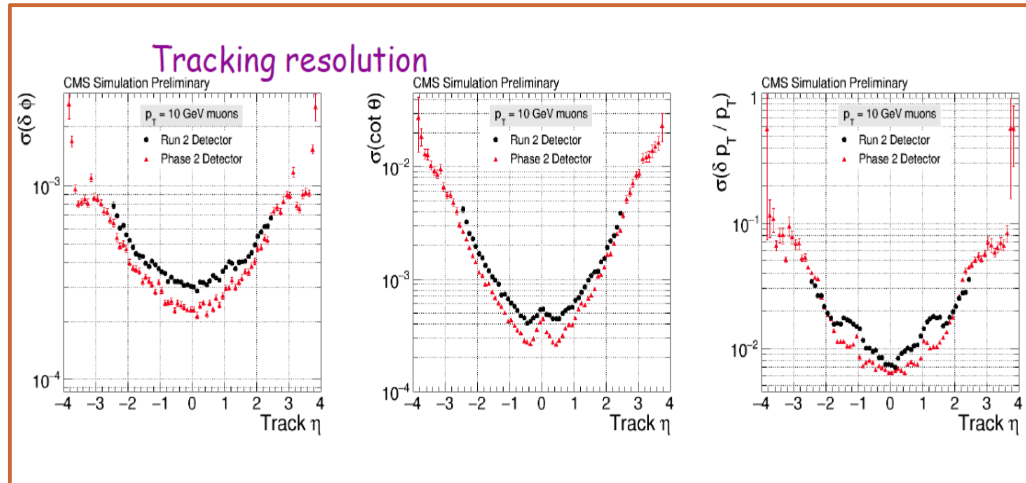

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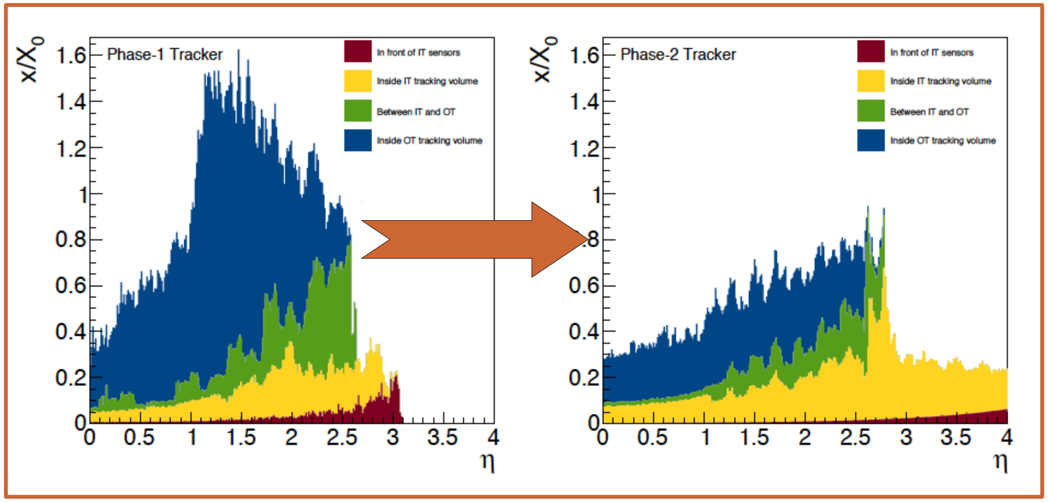
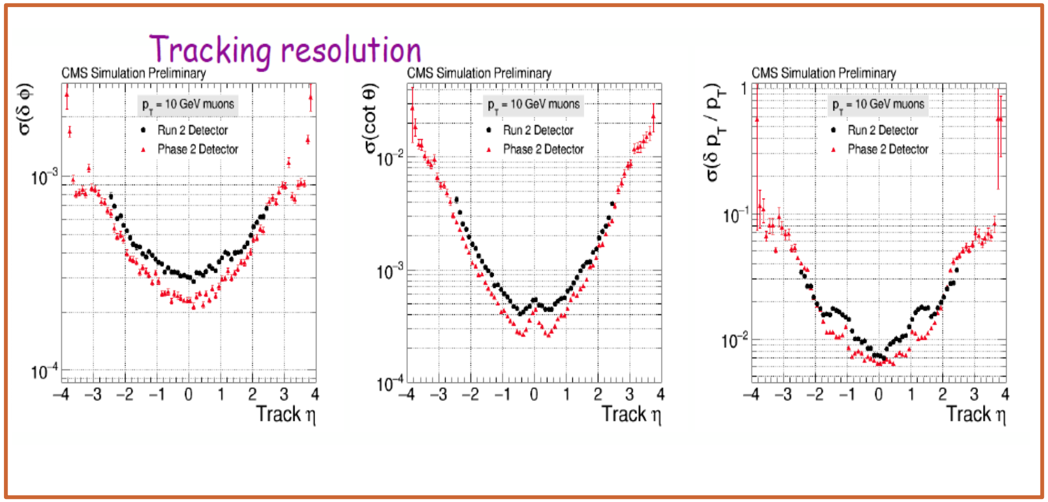


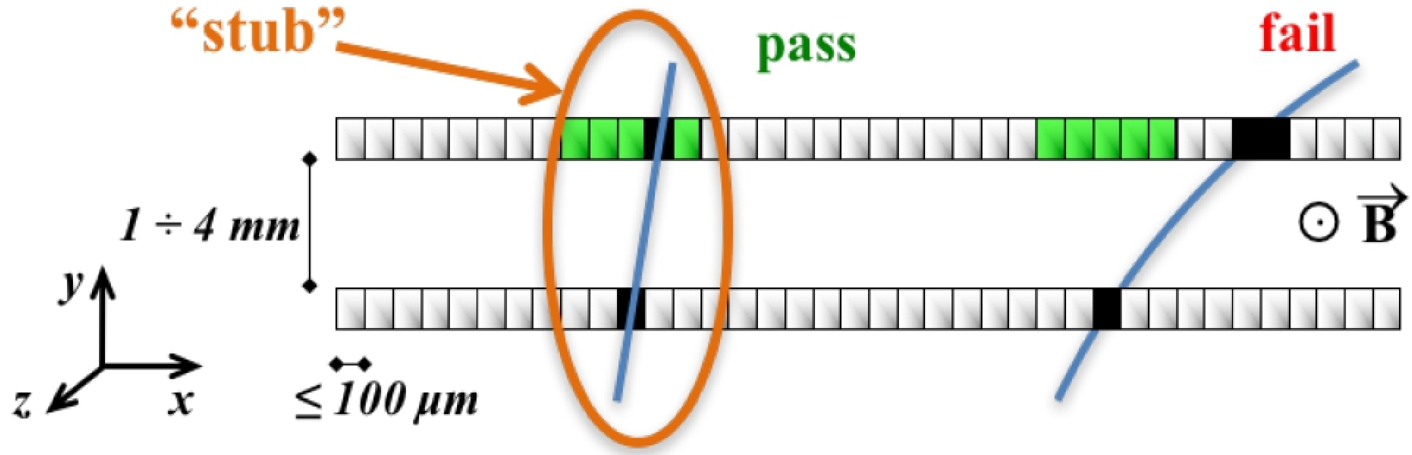


L1 track trigger : P on S, S on S modules

L1 tracking with new CMS tracker

Two Si sensors stacked in one detector module, readout by the same chip

- Inner : Pixel + Strip (PS)
- Outer : Strip + Strip



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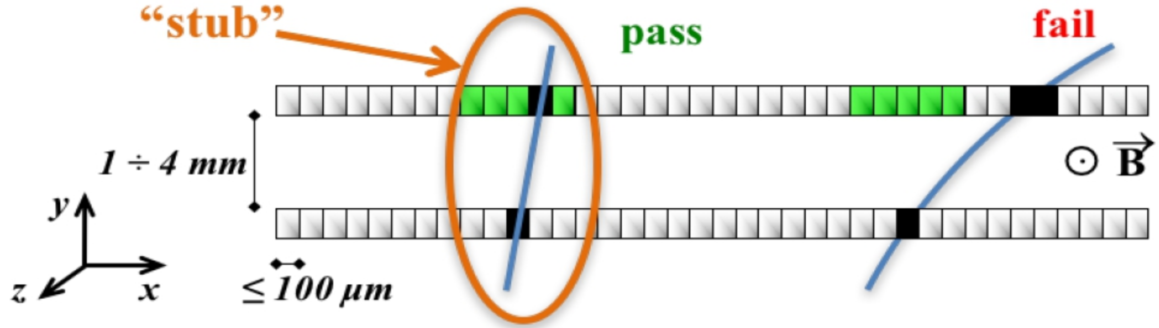
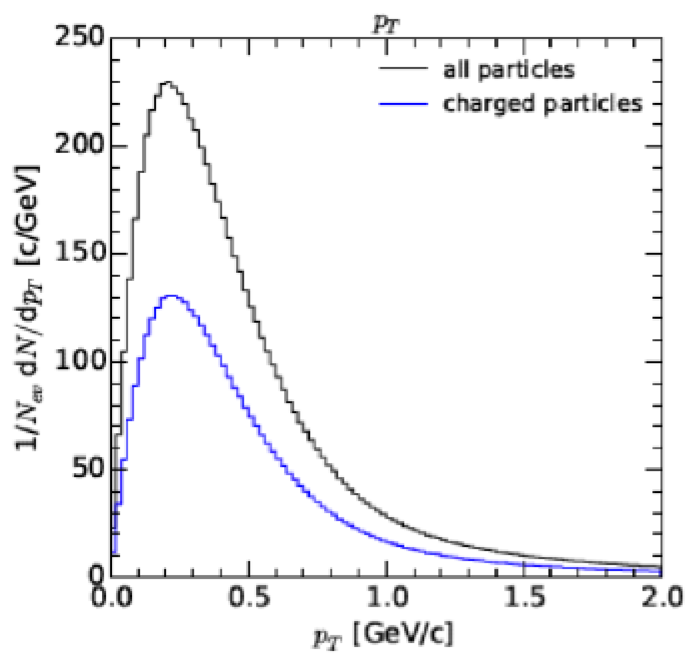


Allows fast selection of p_T > 2 GeV tracks

- data size reduced by x10
- transmitted at 40 MHz BX frequency to the L1



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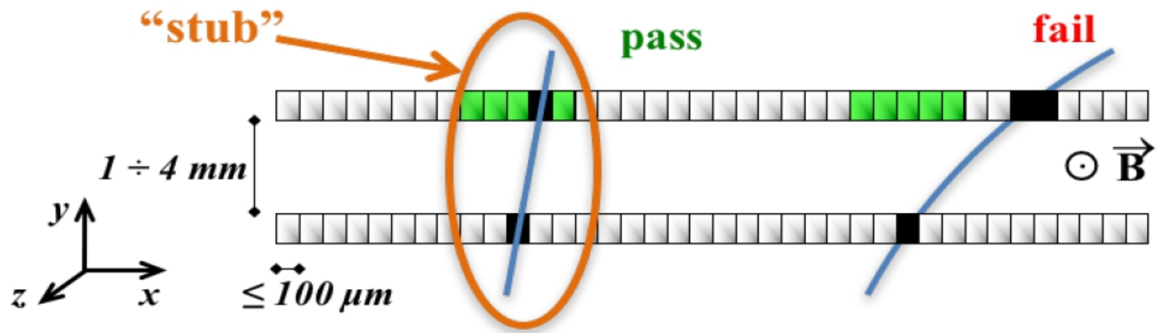

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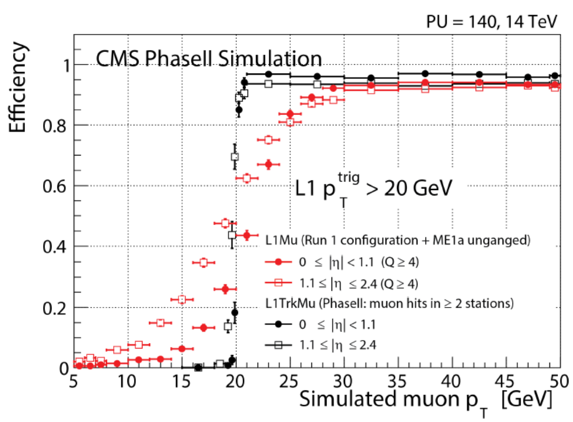
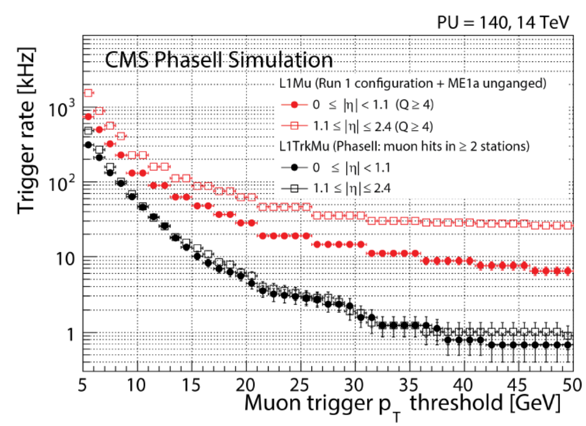
Sizeable improvement of trigger performances



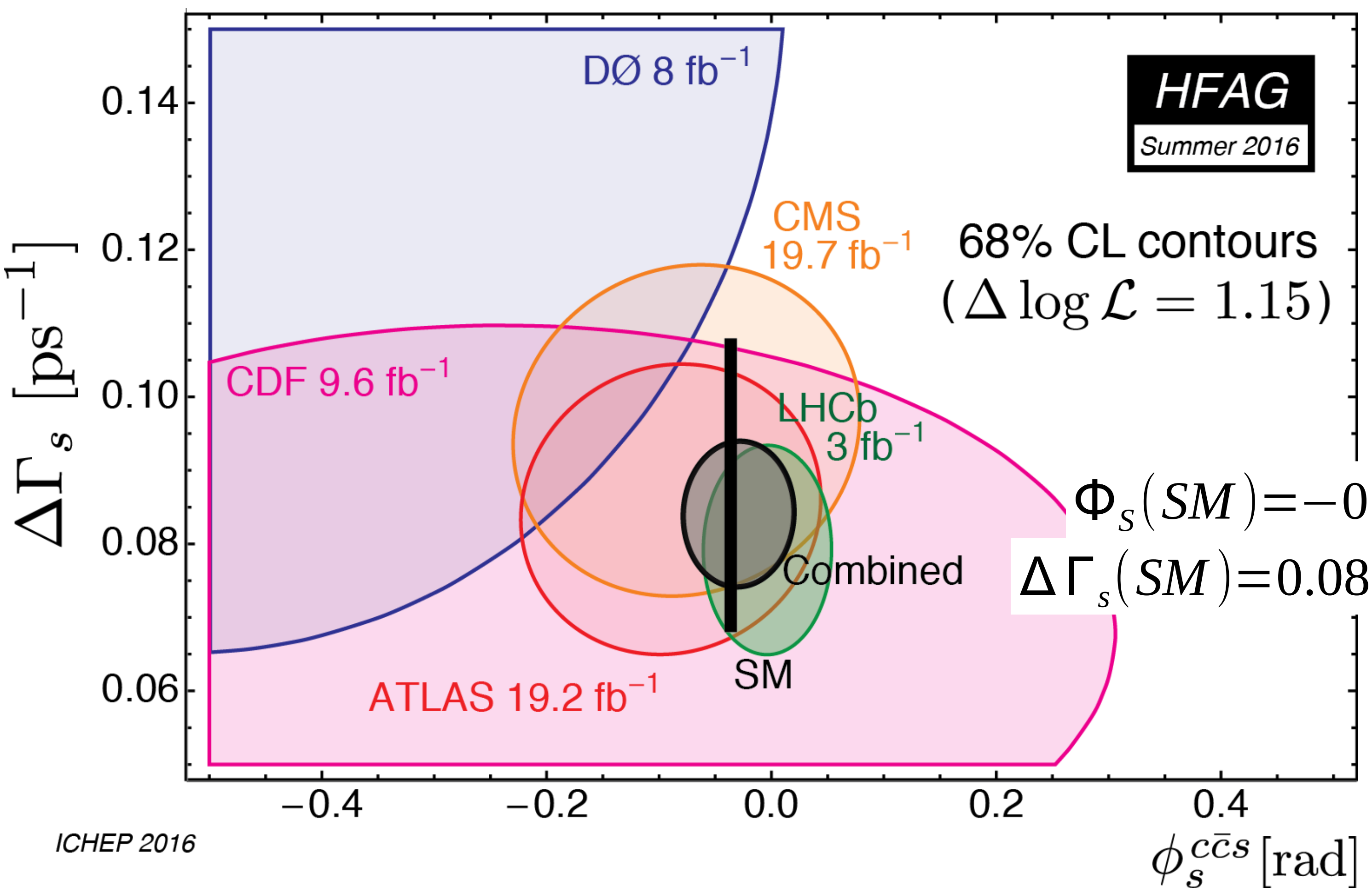


Flavor Benchmark studies:

- B_s -> J/ψΦ (ATLAS)
- B_s -> μμ (CMS)
- B_s -> ΦΦ (CMS)
- t -> q Z /W/H/γ FCNC (ATLAS,CMS)

B_s -> J/ψΦ with ATLAS at the HLLHC

Current experimental precision on ϕ_s much worse than SM expectation



$$\Phi_s(SM) = -0.037 \pm 0.002$$

$$\Delta\Gamma_s(SM) = 0.088 \pm 0.020\ ps^{-1}$$

B_s -> J/ψΦ with ATLAS at the HLLHC

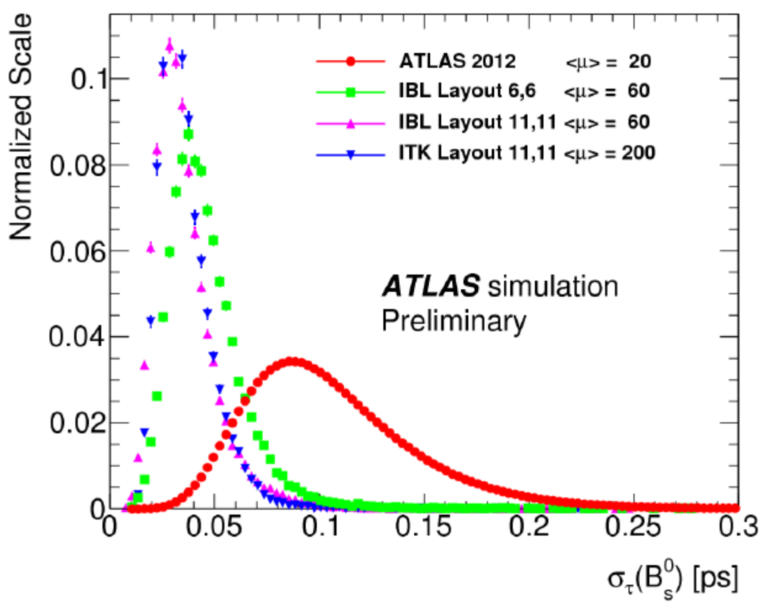
Current experimental precision on ϕ_s much worse than SM expectation

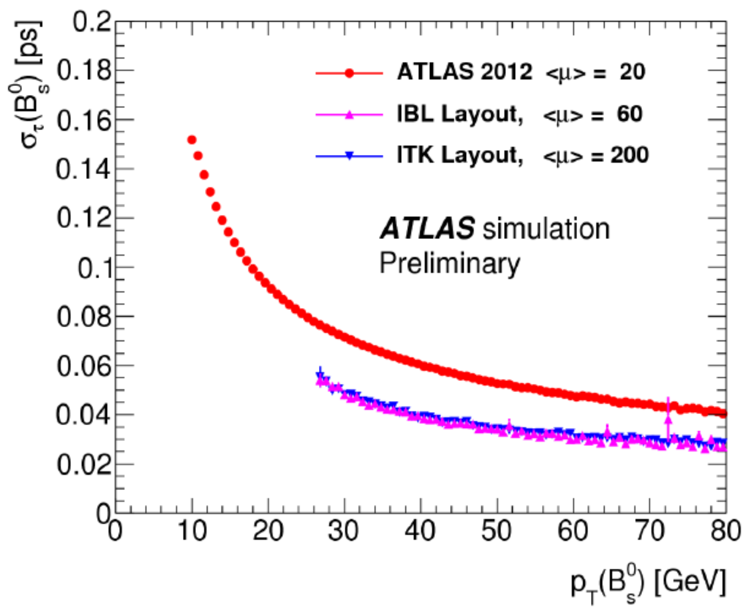
New detector sizably improves on $\sigma(t(B_s))$ (100 -> 35 fs)

Need to increase trigger thresholds:

- $p_T(\mu) > 3.5+3.5$ (now)
- $p_T(\mu) > 6+6$ or 11+11 (Run2)
- $p_T(\mu) > 11+11$ (HLLHC)

Harder cuts improve $\sigma(t(B_s))$ by ~ 30%





B_s –> J/ψΦ with ATLAS : expectations

	2011 *)	2012	2015-17		2019-21	2023-30+
Detector	current	current	IBL		IBL	ITK
Average interactions per BX $<\mu>$	6-12	21	60		60	200
Luminosity, fb^{-1}	4.9	20	100		250	3 000
Di-μ trigger p_T thresholds, GeV	4 - 4(6)	4 - 6	6 - 6	11 - 11	11 - 11	11 - 11
Signal events per fb^{-1}	4 400	4 320	3 280	460	460	330
Signal events	22 000	86 400	327 900	45 500	114 000	810 000
Total events in analysis	130 000	550 000	1 874 000	284 000	758 000	6 461 000
MC $\sigma(\phi_s)$ (stat.), rad	0.25	0.12	0.054	0.10	0.064	0.022

Results from toy MC study, based on 2011 and 2012 data

Harder p_T implies sizable reduction (x 10) on event yield

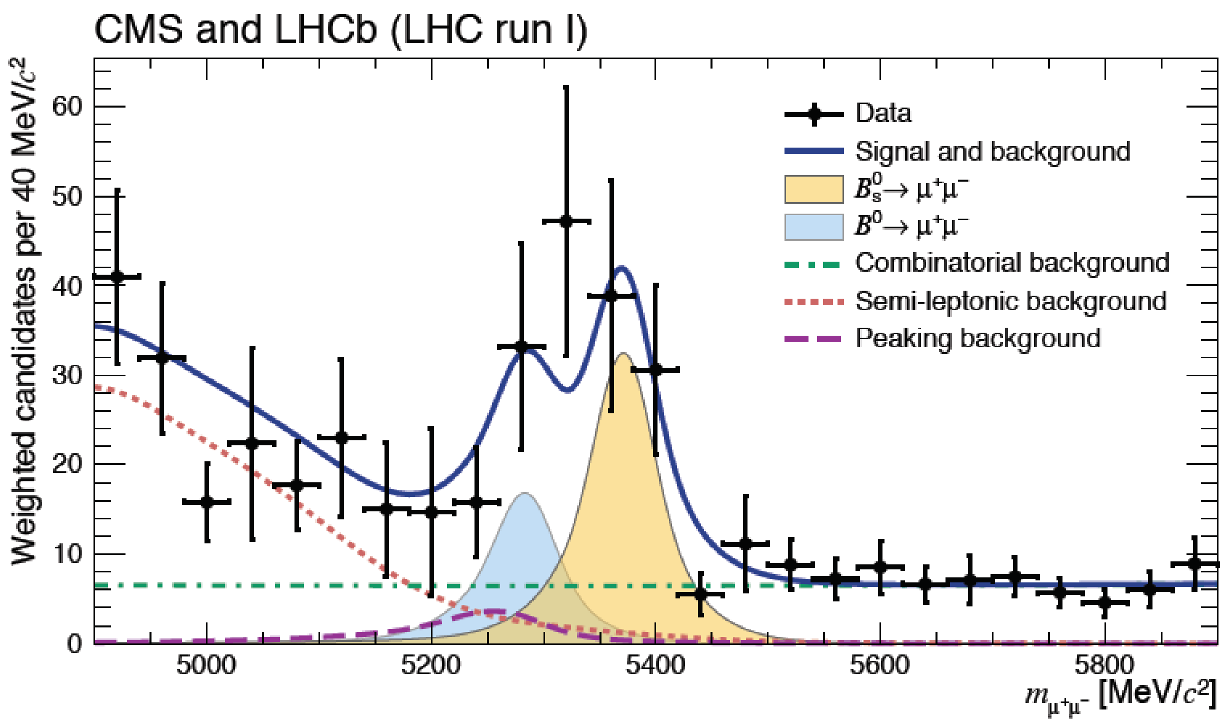
Two scenarios (6+6 vs 11+11) studied for RUN2, the second one is probably more realistic

Only statistical uncertainties

B –> μμ : perspectives

B_s –> μμ established by CMS+LHCb at 6.2 σ in RUN1

Confirmed by new LHCb data



To do :

— Bs lifetime & CPV

— Observe B_d –> μμ :

need full HLLHC data set

B->μμ at CMS : hypotesys

Reach computed including sensible assumptions fo systematic uncertainties

Trigger :

- L1 track-Trigger allows same L1 thresholds as now ($p_T(\mu) > 3$ GeV)

Efficiency :

- pileup : $\varepsilon(\mu\mu)$ ↓ 30% (isolation)
- μ reco & trigger : $\varepsilon(\mu\mu)$ ↓ 2 x 5%

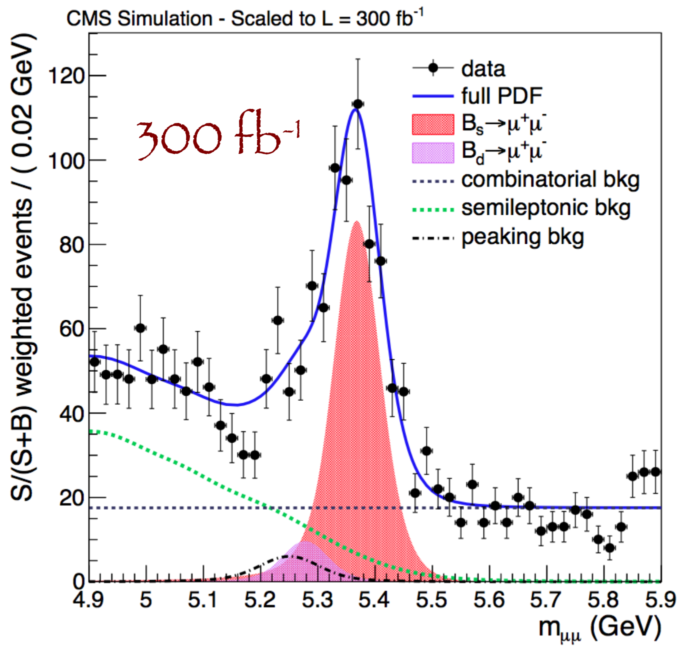
σ(syst) :

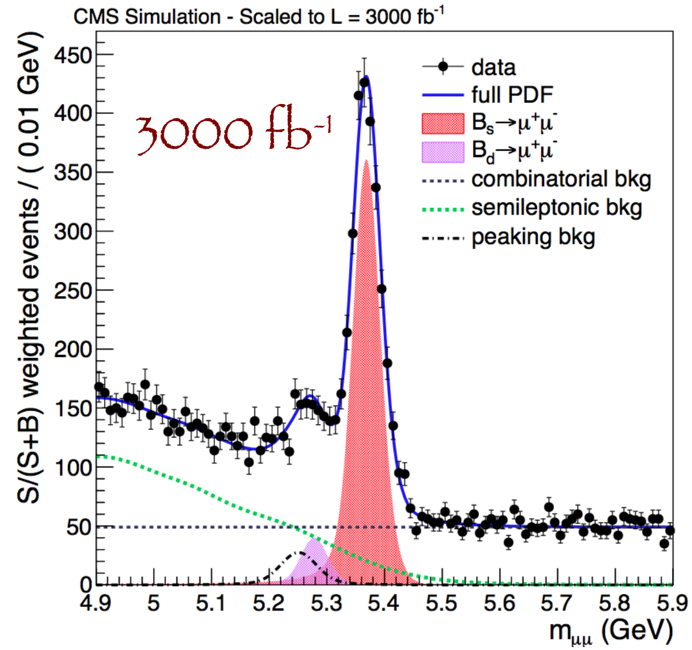
- f_s/f_u : 5% (now) → 3%
- Normalization ($B^+ \rightarrow \psi K^+$): $3\%^{(BR)} \oplus 5\% / \sqrt{\mathcal{L}_{INT}/20\ fb^{-1}}$ (Rate)
- Peaking Backround : $10\%^{(BR)} \oplus 50\% / \sqrt{\mathcal{L}_{INT}/20\ fb^{-1}}$ (Control Sample)
- Semileptonic Background : $20\%^{(BR)} \oplus 50\% / \sqrt{\mathcal{L}_{INT}/20\ fb^{-1}}$ (Control Sample)

Resolution:

- ↓ 1.6 (Barrell) ↓ 1.2 (Forward)
- ignore improvement due to 1st pixel layer

B–>μμ : expectations from CMS





L (fb^{-1})	No. of B^0_s	No. of B^0	$\delta\mathcal{B}/\mathcal{B}(B_s{}^0 \to \mu^+\mu^-)$	$\delta\mathcal{B}/\mathcal{B}(B^0 \to \mu^+\mu^-)$	B^0 sign.	$\delta\frac{\mathcal{B}(B^0\to\mu^+\mu^-)}{\mathcal{B}(B^0_s\to\mu^+\mu)}$
20	16.5	2.0	35%	>100%	0.0–1.5 σ	>100%
100	144	18	15%	66%	0.5–2.4 σ	71%
300	433	54	12%	45%	1.3–3.3 σ	47%
3000	2096	256	12%	18%	5.4–7.6 σ	21%

- 3000 fb^{-1} : statistic is not an issue
- Use just barrel events, resolution good enough to separate B_d/B_s/B->hh'

Br (B_d) > 5 σ (if SM, CMS only)

B_S –> ΦΦ : a test case for L1 track trigger (CMS)

Rare penguin decay, not covered by existing triggers (ATLAS and CMS)

Bench mark for L1 Track trigger:

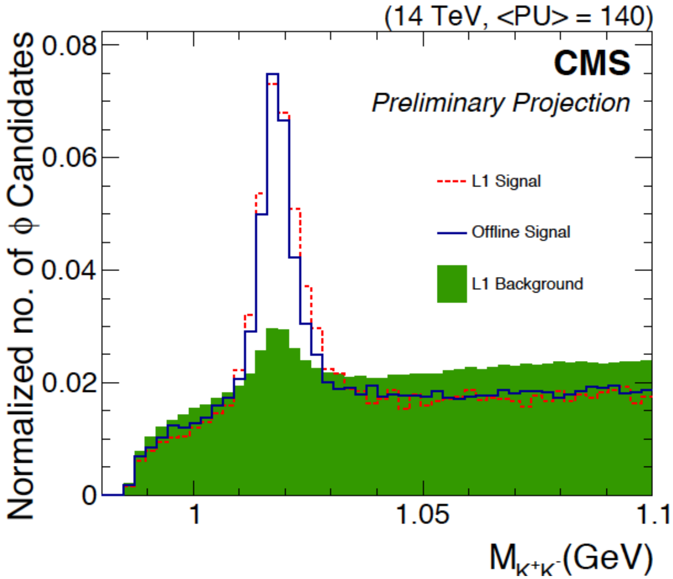
- p_T (K) > 2 GeV (close to threshold)
- topological cuts : ΔR, M(KK), M(ΦΦ)

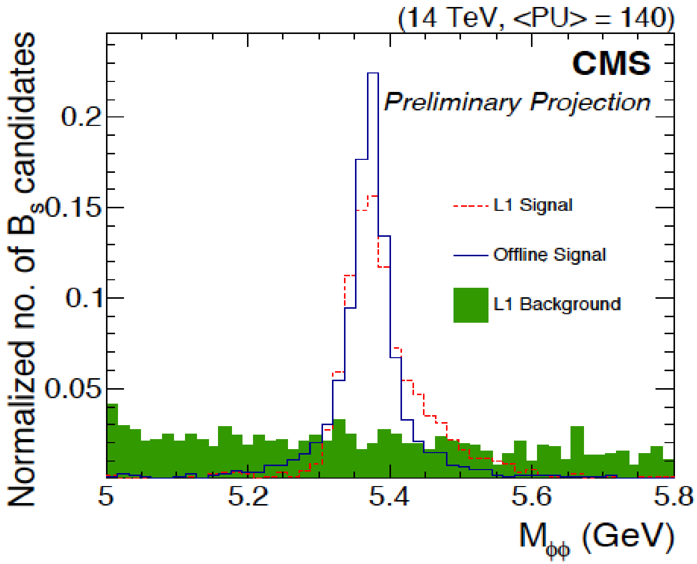
Completed by offline analysis

Compare different pileup, different set of cuts

Very preliminary study to compute

- signal efficiency
- trigger rates



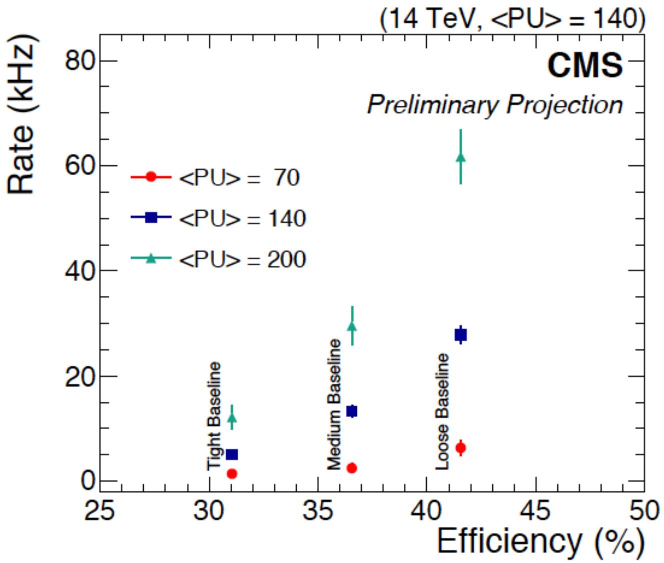


B –> ΦΦ : CMS expectations

Baseline	Efficiency (%)		Rate (kHz)		
	L1	Offline	<PU> = 70	<PU> = 140	<PU> = 200
Loose	41.6 ± 1.2	61.5 ± 1.3	6.3 ± 1.5	27.9 ± 1.7	61.8 ± 5.2
Medium	36.6 ± 1.1	55.3 ± 1.2	2.5 ± 0.9	13.3 ± 1.2	29.6 ± 3.6
Tight	31.1 ± 1.0	55.1 ± 1.2	1.4 ± 0.7	5.1 ± 0.7	12.2 ± 2.3

Conclusions:

- Signal efficiency satisfactory
- HLT rate still to large, further cuts needed



Top FCNC : t->H/Z/γ q

Marcus' talk :

- SM expects Br 10^{-14} 10^{-17}
- New Physics : up to 10^{-4}
- Present limits: $\simeq o\left(10^{-4}\right) \quad (Zq)$

$$\simeq o\left(10^{-3}\right) \quad (Hq)$$

Process	SM	2HDM(FV)	2HDM(FC)	MSSM	RPV	RS
$t \to Zu$	7×10^{-17}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to Zc$	1×10^{-14}	$\leq 10^{-6}$	$\leq 10^{-10}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-5}$
$t \to gu$	4×10^{-14}	–	–	$\leq 10^{-7}$	$\leq 10^{-6}$	–
$t \to gc$	5×10^{-12}	$\leq 10^{-4}$	$\leq 10^{-8}$	$\leq 10^{-7}$	$\leq 10^{-6}$	$\leq 10^{-10}$
$t \to \gamma u$	4×10^{-16}	–	–	$\leq 10^{-8}$	$\leq 10^{-9}$	–
$t \to \gamma c$	5×10^{-14}	$\leq 10^{-7}$	$\leq 10^{-9}$	$\leq 10^{-8}$	$\leq 10^{-9}$	$\leq 10^{-9}$
$t \to hu$	2×10^{-17}	6×10^{-6}	–	$\leq 10^{-5}$	$\leq 10^{-9}$	–
$t \to hc$	3×10^{-15}	2×10^{-3}	$\leq 10^{-5}$	$\leq 10^{-5}$	$\leq 10^{-9}$	$\leq 10^{-4}$

arXiv:1311.2028 [hep-ph] (2013)

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t->Zq,Hq in different scenarios for detector upgrade (reference/middle/low) and systematic uncertainties (negligible / improved / as now)

Top FCNC : t->H/Z/γ q

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ATLAS

t->Zq,Hq in different scenarios for detector upgrade (reference/middle/low) and systematic uncertainties

CMS Compact Muon Solenoid

t->γq extrapolated from 8 TeV analysis ,

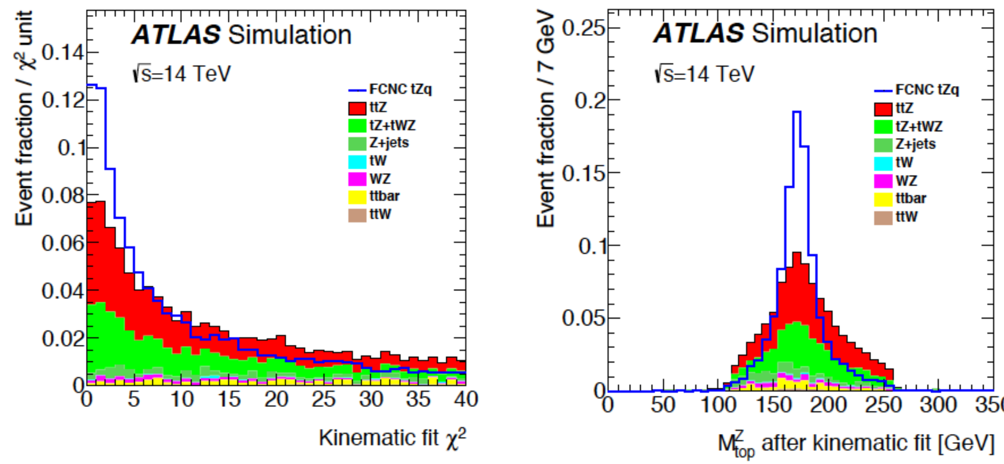
(not optimized for 14 TeV)

Università degli Studi di Padova

ATLAS: top FCNC

INFN

$t \rightarrow Zq \rightarrow 3\ell X$



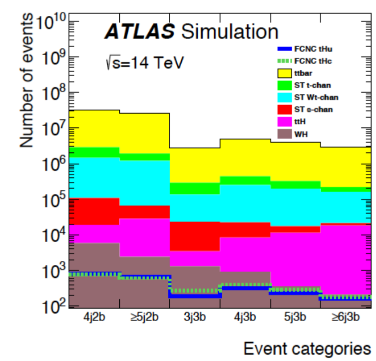
$$\chi^2 = \frac{\left(m_Z - m^{\rm reco}_{\ell_1\ell_2}\right)^2}{\sigma_Z^2} + \frac{\left(m_W - m^{\rm reco}_{\ell_3\nu}\right)^2}{\sigma_W^2} + \frac{\left(m_t - m^{\rm reco}_{\ell_3\nu j_b}\right)^2}{\sigma_{t\to Wb}^2} + \frac{\left(m_t - m^{\rm reco}_{\ell_1\ell_2 j_u}\right)^2}{\sigma_{t\to Zq}^2}$$

	"γ" t→Zu	"σ" t→Zu	"γ" t→Zc	"σ" t→Zc	"γ" t→Zu+Zc	"σ" t→Zu+Zc
Reference	$4.3\cdot10^{-5}$	$4.3\cdot10^{-5}$	$5.6\cdot10^{-5}$	$5.8\cdot10^{-5}$	$2.4\cdot10^{-5}$	$2.5\cdot10^{-5}$
Middle	$4.5\cdot10^{-5}$	$4.6\cdot10^{-5}$	$6.0\cdot10^{-5}$	$6.3\cdot10^{-5}$	$2.6\cdot10^{-5}$	$2.7\cdot10^{-5}$
Low	$5.1\cdot10^{-5}$	$5.2\cdot10^{-5}$	$6.7\cdot10^{-5}$	$7.0\cdot10^{-5}$	$2.9\cdot10^{-5}$	$3.0\cdot10^{-5}$

Sensitivity increase by 2 to 6 depending on scenario

$t \rightarrow H(b\bar{b})q$

MVA optimized for different topologies (2/3 b, N(jets))



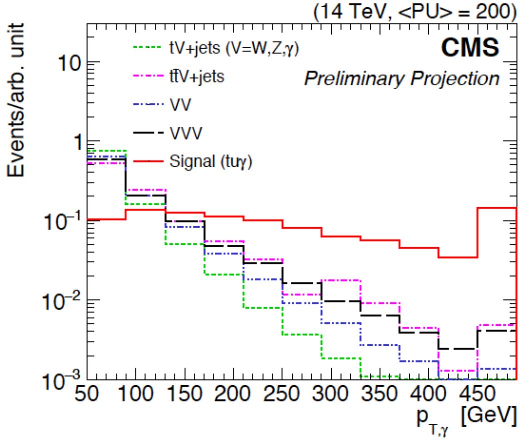
Layout	Set	t→Hu	t→Hc	t→Hu+Hc
Reference	A	$2.4\cdot10^{-4}$	$2.0\cdot10^{-4}$	$1.1\cdot10^{-4}$
	B	$2.4\cdot10^{-4}$	$2.0\cdot10^{-4}$	$1.1\cdot10^{-4}$
Middle	A	$2.9\cdot10^{-4}$	$2.4\cdot10^{-4}$	$1.3\cdot10^{-4}$
	B	$2.9\cdot10^{-4}$	$2.4\cdot10^{-4}$	$1.3\cdot10^{-4}$
Low	A	$3.5\cdot10^{-4}$	$3.0\cdot10^{-4}$	$1.7\cdot10^{-4}$
	B	$3.5\cdot10^{-4}$	$3.0\cdot10^{-4}$	$1.7\cdot10^{-4}$

Sensitivity increase by up to 20

t –> c/u γ FCNC @ CMS

Similar selection as per 8 TeV search with

- same σ(syst)
- improved σ(syst)



Results (200 pilep with new detector configuration)

	$19.7\ fb^{-1}$ at 8 TeV	$3\ ab^{-1}$ at 14 TeV (Scenario 1)	$3\ ab^{-1}$ at 14 TeV (Scenario 2)
$B(t \to u+\gamma)$	1.7×10^{-4}	4.6×10^{-5}	2.7×10^{-5}
$B(t \to c+\gamma)$	2.2×10^{-3}	3.4×10^{-4}	2.0×10^{-4}

Sensitivity increase by 3 to 10

Conclusions

HL-LHC rises a hard challenge to ATLAS and CMS

Collaborations turn the challenge into an opportunity by:

- developing innovative detectors (here focus on tracker devices)
- upgrading aged electronics to state of art
- overall improving the detector performance

New detector performances extensively tested at simulation level for

- searches / high p_T SM measurements / flavor

Despite the diffcult experimental conditions, sizable progress is expected

Actual results depend on many unknowns

- evolution of systematic uncertainties
- actual configuration of to-come detectors

Backup

Top FCNC : scenarios

CMS

- Consider two scenarios for systematics
  - 1) No change w.r.t public 8 TeV
  - 2) Based on estimates/studies for an improvement with Phase II detector / statistics

ATLAS

SetA

- 2% lumi
- 6% WZ and signal
- 62% Z+jets, $t\bar{t}$
- 50% tZ, tWZ
- 30% $t\bar{t}V$

SetB

- 2% lumi
- 6% WZ and signal
- 30% Z+jets, $t\bar{t}$
- 10% tZ, tWZ
- 6% $t\bar{t}V$