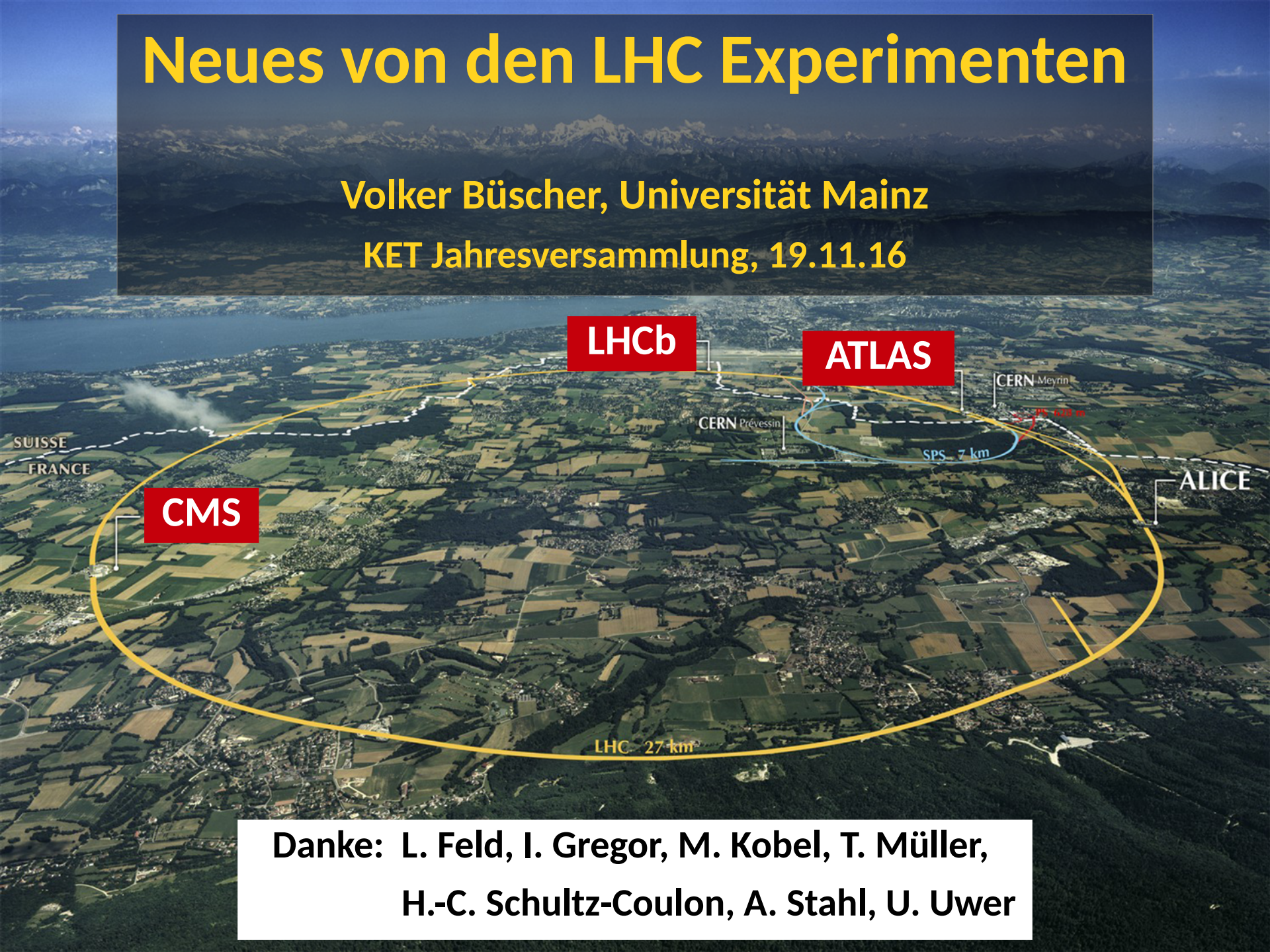
Neues von den LHC Experimenten

Volker Büscher, Universität Mainz

KET Jahresversammlung, 19.11.16



Danke: L. Feld, I. Gregor, M. Kobel, T. Müller,
H.-C. Schultz-Coulon, A. Stahl, U. Uwer

Verstärkung der “cross-FSP” Strukturen

FSP 103 ATLAS

CMS Germany BMBF FSP-CMS

FSP 105 LHCb

Experimentbegleitende Theorie

Neu: Controlling Office für FIS-Projekt

Neu: Erkenntnisvermittlung, Nachwuchsgewinnung

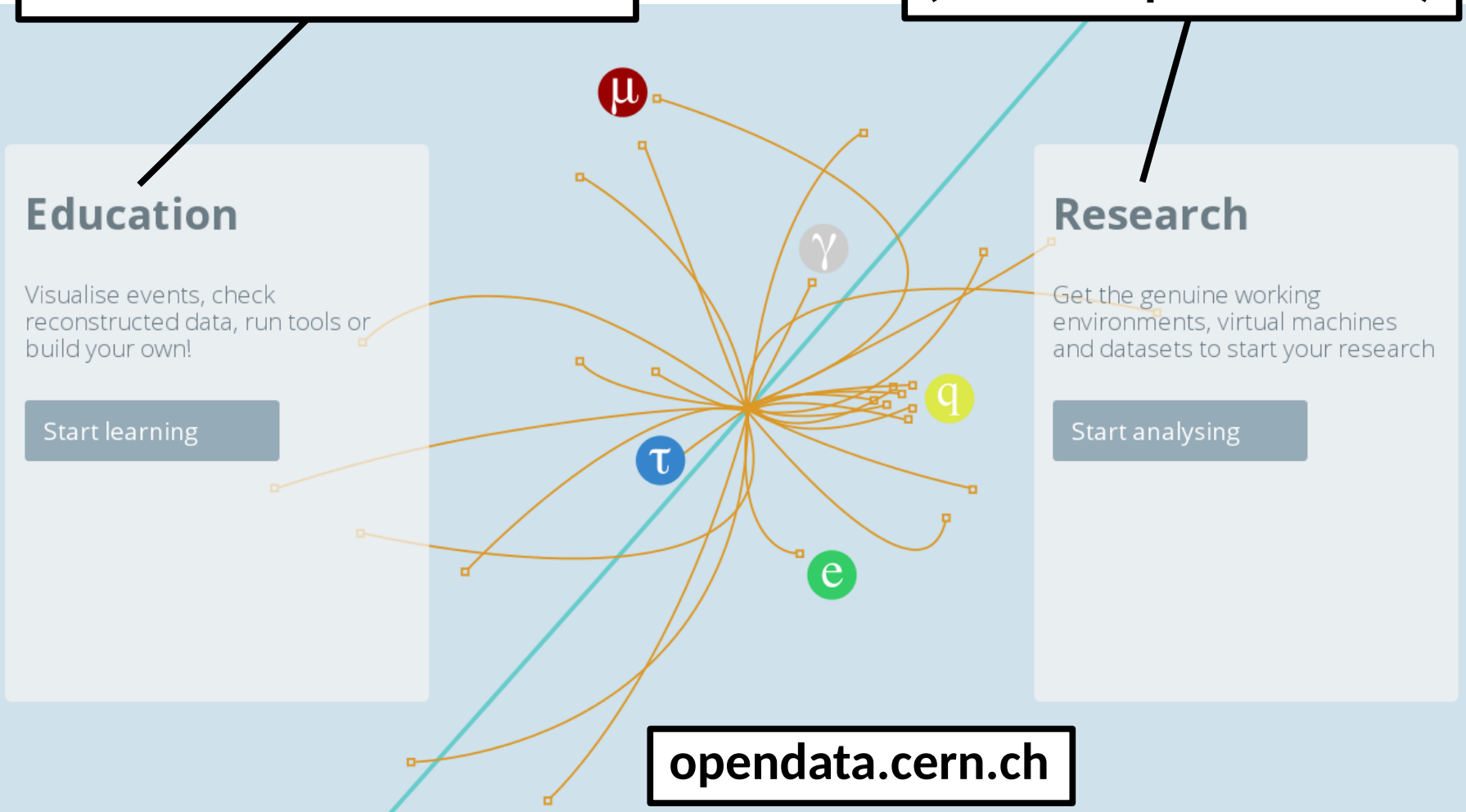
Gefördert durch BMBF!

Highlight: LHC Open Data Portal

Neu: LHC Experimente machen Daten (und Simulationen) öffentlich

für Schüler/Studenten, interessierte Öffentlichkeit

für Wissenschaftler (und data preservation)



opendata.cern.ch

Highlight: LHC Open Data Portal

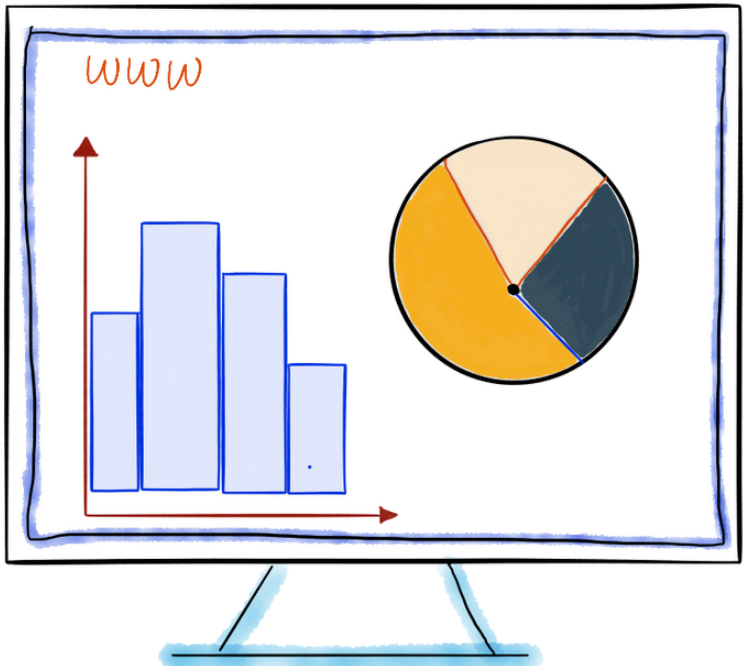
Neu: LHC Experimente machen Daten (und Simulationen) öffentlich

Level 1: **Get Started**

Physicists at the ATLAS Experiment visualise collision data with histograms. They are used in every publication, from simple analyses to headline-making discoveries. *In this section*, you will learn how the data is visualised.

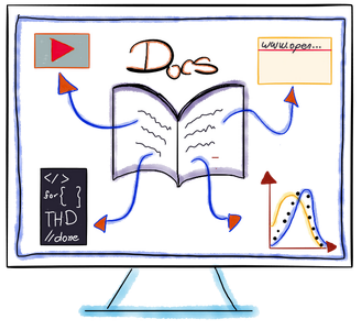
Explore:

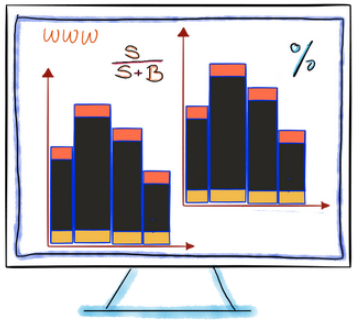
- **Documentation:** a step-by-step guide to using Histogram Analyser and ROOTbrowser
- **Histogram Analyser:** a web based tool for fast, cut-based analysis of data. Visualise data using online histograms
- **ROOTbrowser:** a web based tool for displaying histograms individually. More freedom to plot different variables
- **Live events:** see live events from the ATLAS experiment

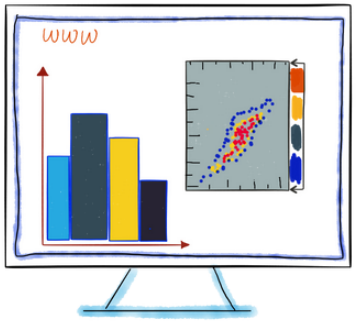


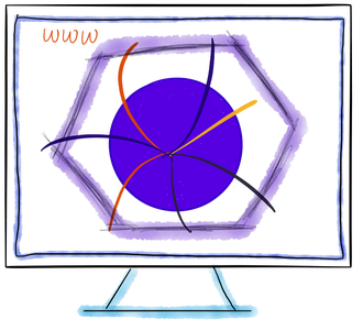
Explore

Documentation | Histograms Analyser | ROOT browser | Live Events









Deutsche Beteiligung an Leitungspositionen (nur Level 1)

Top-Level Management

ATLAS Sprecher (ab 03/17): Karl Jakobs

ATLAS Stellv. Sprecherin: Beate Heinemann

Physikgruppen

ATLAS Standardmodell: Ulla Blumenschein

ATLAS Standardmodell: Matthias Schott

ATLAS Exotics: Klaus Mönig

Rekonstruktion/Computing

LHCb Flavour Tagging: J. Wishahi

LHCb Tracking: M. De Cian

CMS Statistics Comm. Chair: O. Behnke

CMS Computing RB Chair: M. Kasemann

Detektor/Upgrade

CMS Muon IB Chair: H. Reithel

CMS Tracker IB Chair: L. Feld

CMS BRIL IB Chair: W. Lohmann

LHCb Project Leader HLT: M. Vesterinen

LHCb Project Leader SciFi Tracker: U. Uwer

LHCb Upgrade Perf. Coordinator: J. Albrecht

Committees

CMS Engagement Office: K. Borras

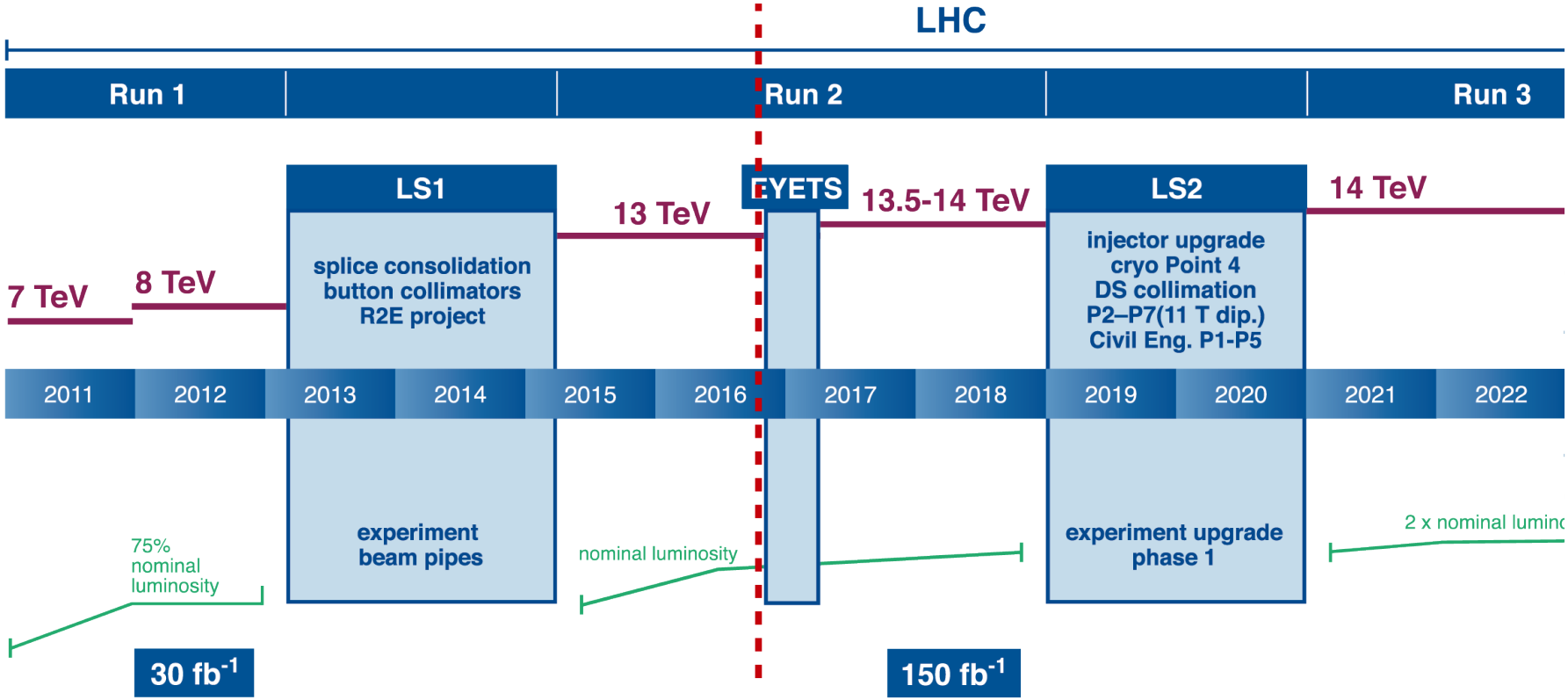
CMS Conference Committee Chair: A. Meyer

CMS Authorship Board Chair: M. Kasemann

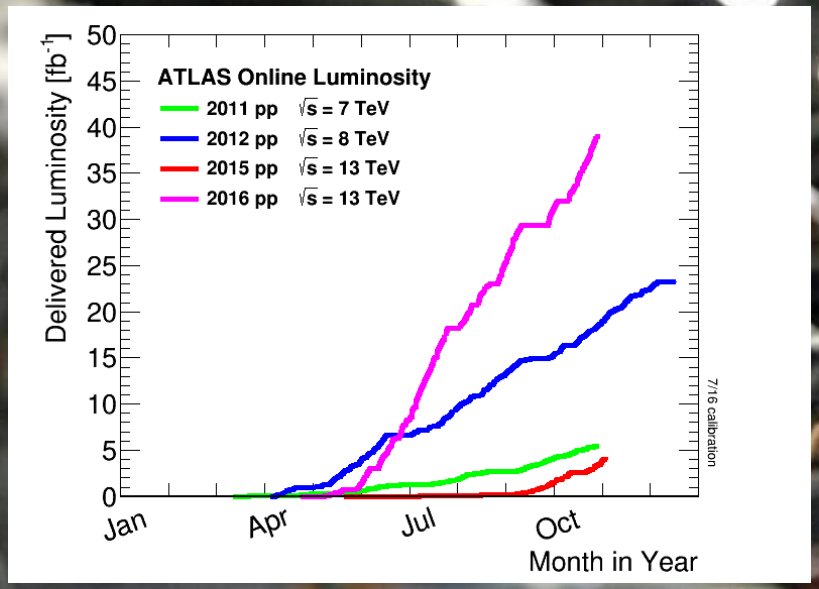
LHCb Editorial Board Chair: M. Schmelling

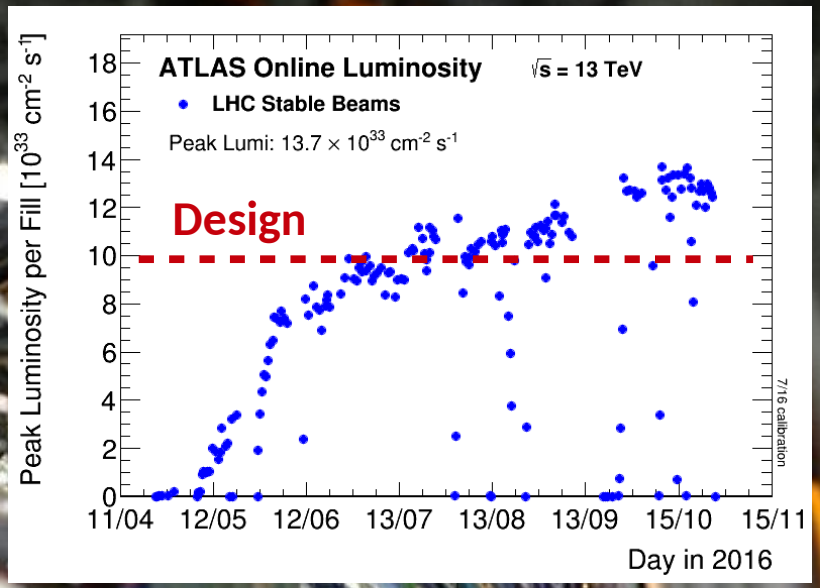
LHCb CB Chair: B. Spaan

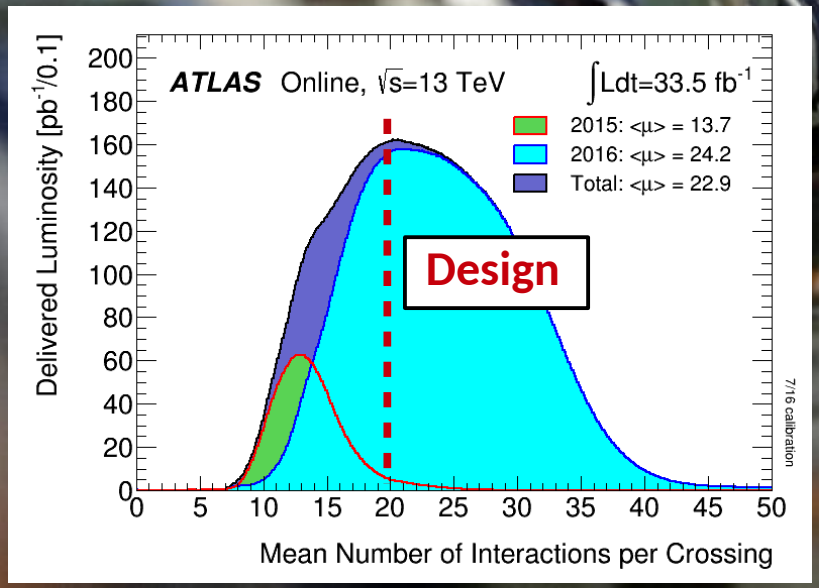
LHC Run II


LHC
Run 1
Run 2
Run 3
LS1
splice consolidation
button collimators
R2E project
experiment
beam pipes
EYETS
LS2
injector upgrade
cryo Point 4
DS collimation
P2–P7(11 T dip.)
Civil Eng. P1-P5
experiment upgrade
phase 1
7 TeV
8 TeV
13 TeV
13.5-14 TeV
14 TeV
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
75%
nominal
luminosity
nominal luminosity
2 x nominal lumino
30 fb-1
150 fb-1

2016: LHC bricht alle Rekorde







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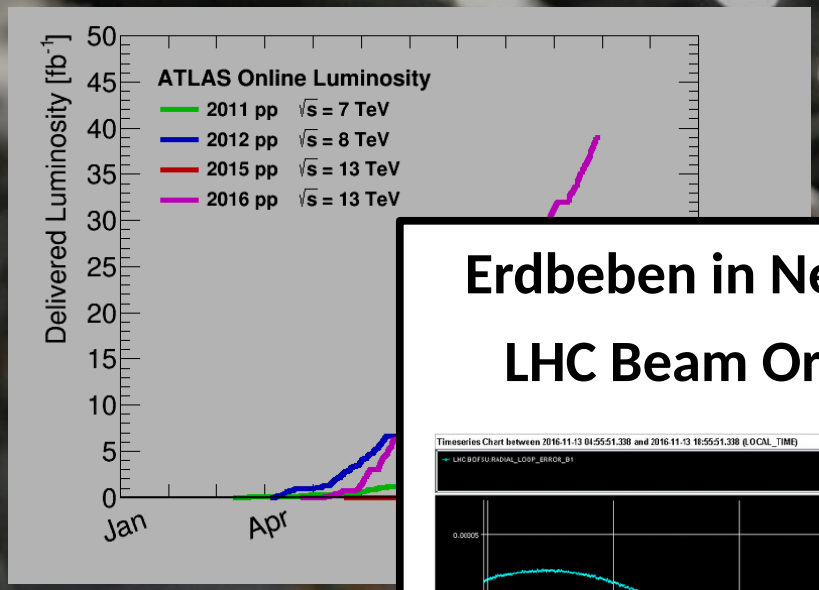
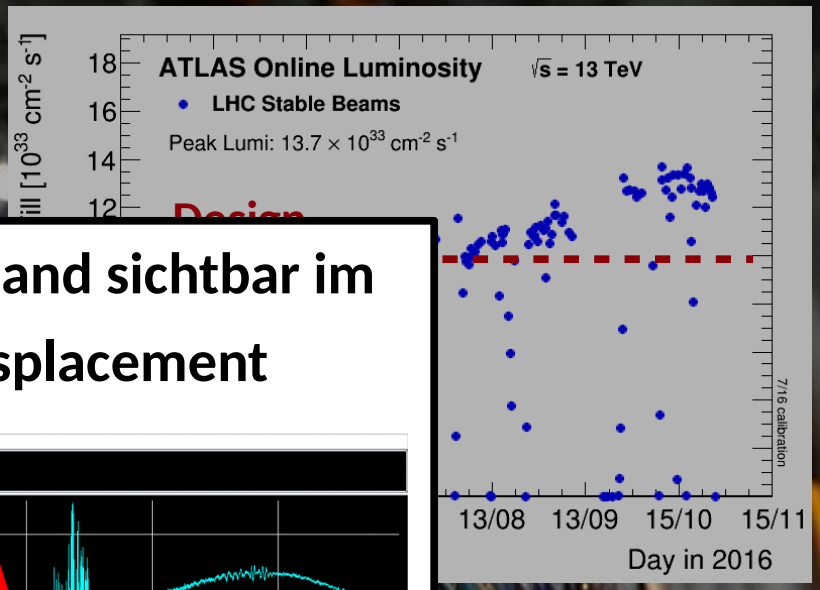
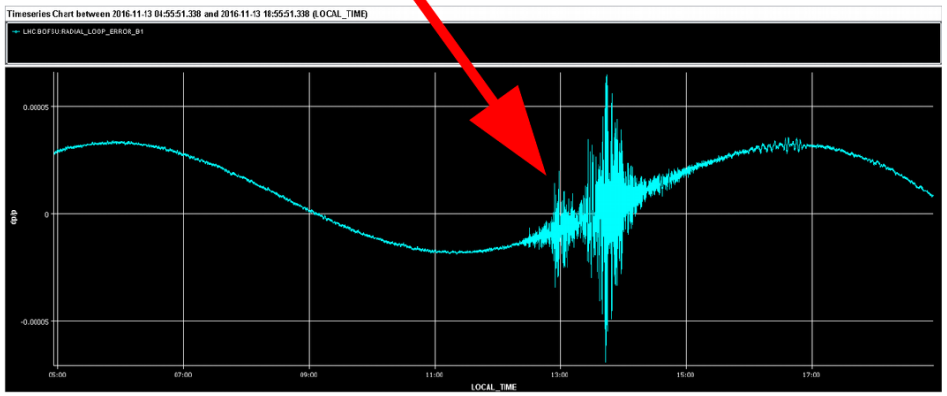
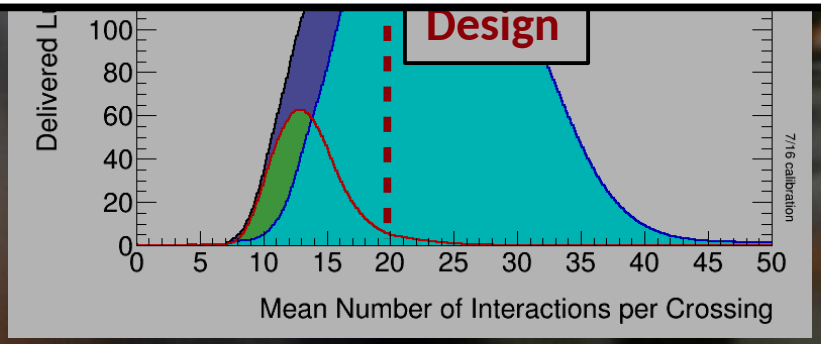




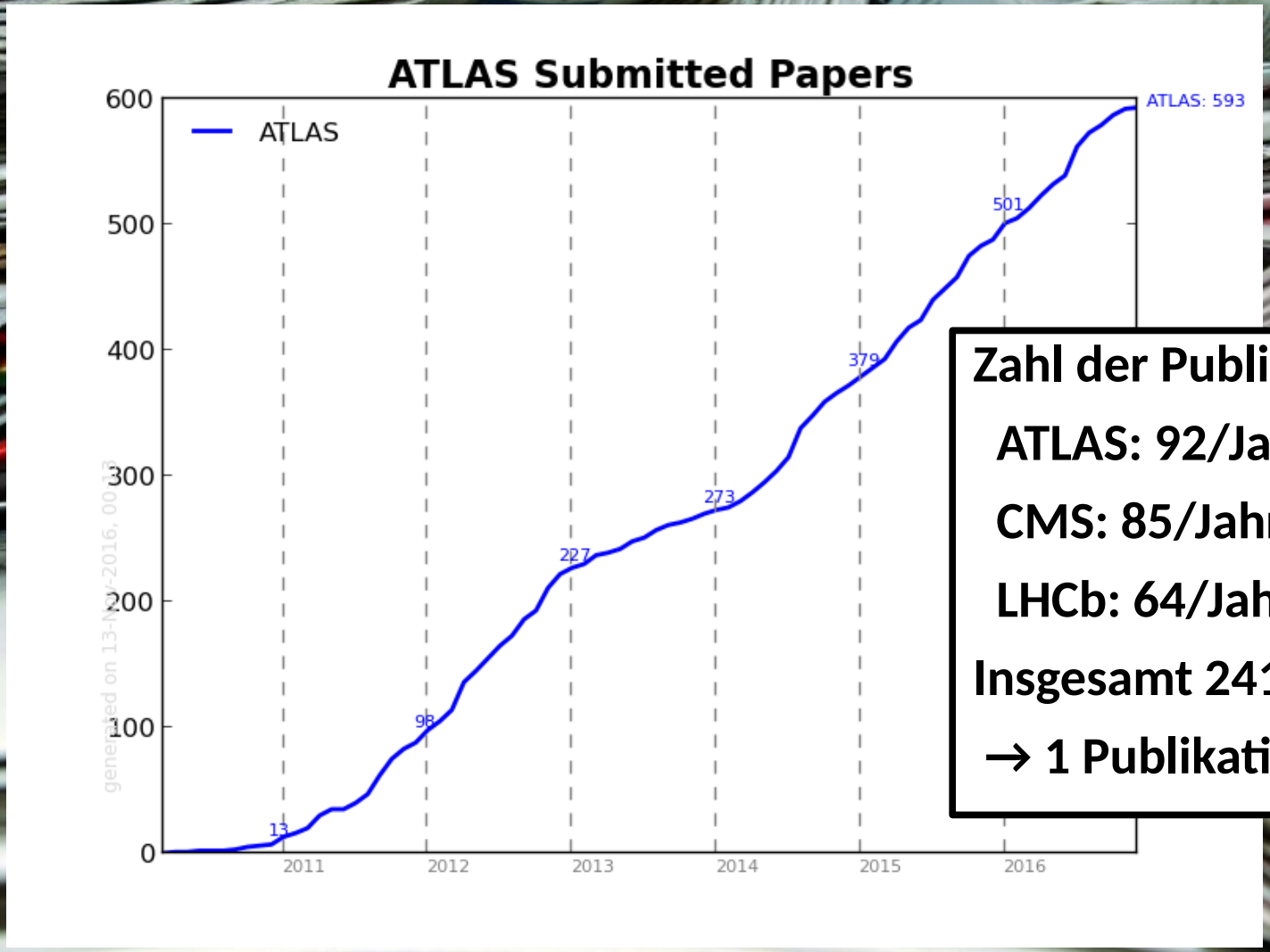
Erdbeben in Neuseeland sichtbar im LHC Beam Orbit Displacement





LHC Veröffentlichungen

Der LHC ist eine Erkenntnisfabrik



Zahl der Publikationen:

ATLAS: 92/Jahr

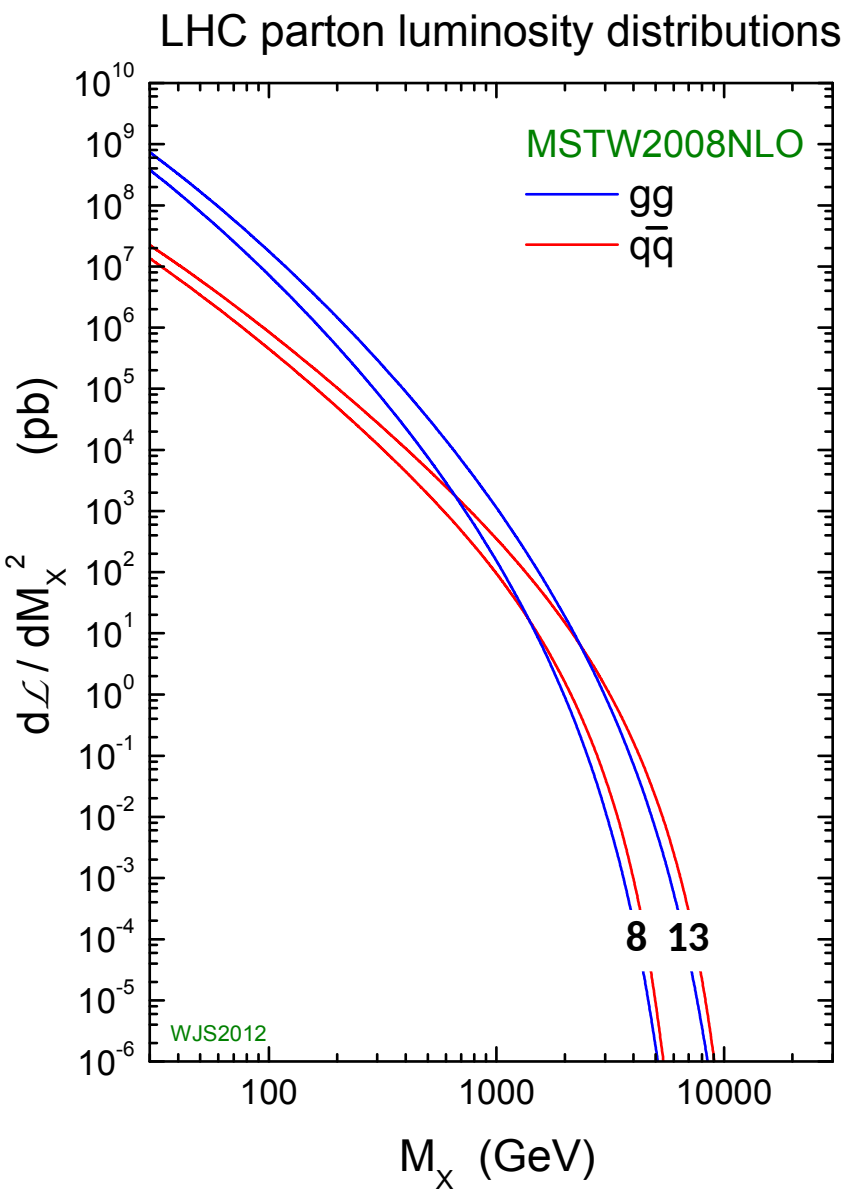
CMS: 85/Jahr

LHCb: 64/Jahr

Insgesamt 241/Jahr

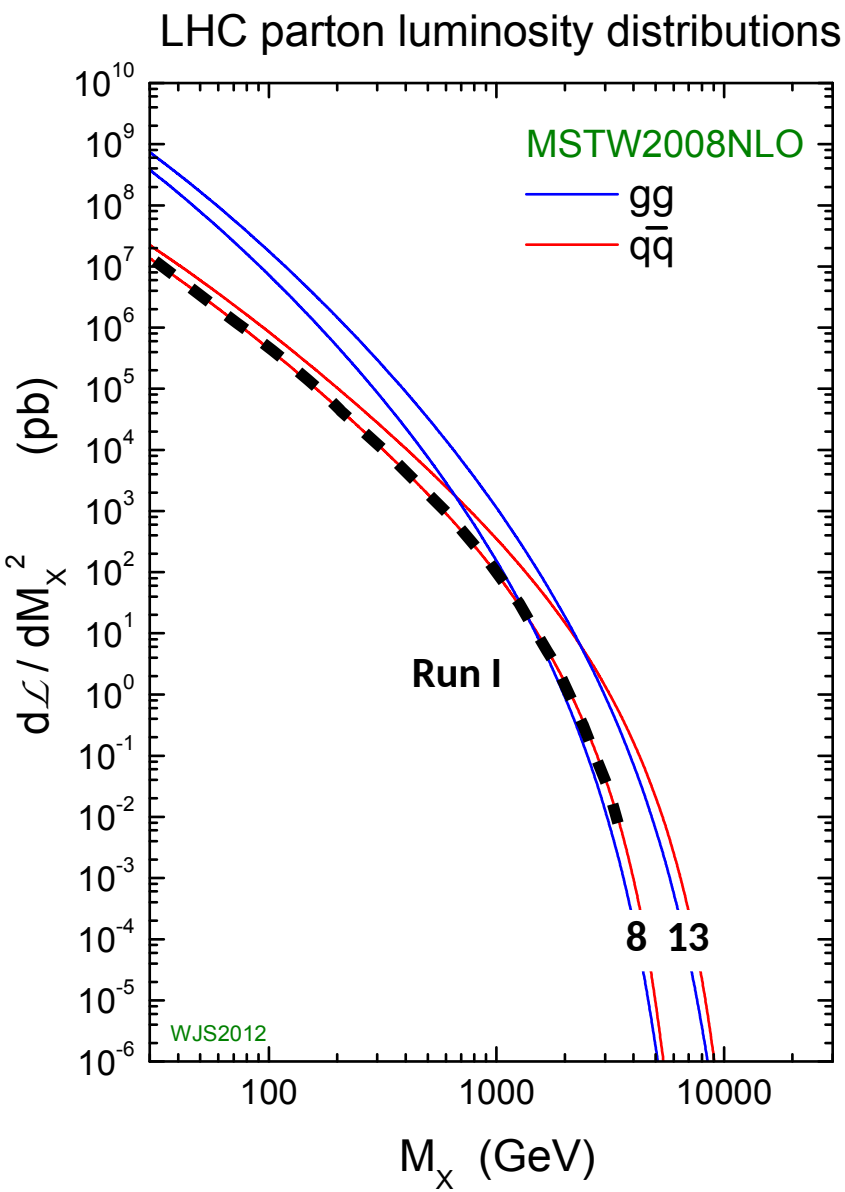
→ 1 Publikation pro Werktag!

13 TeV: Zugang zu unerforschtem Terrain



- **Produktionsraten bestimmt durch Partonluminositäten**
- **dramatischer Einbruch bei hohen Massen**

13 TeV: Zugang zu unerforschtem Terrain



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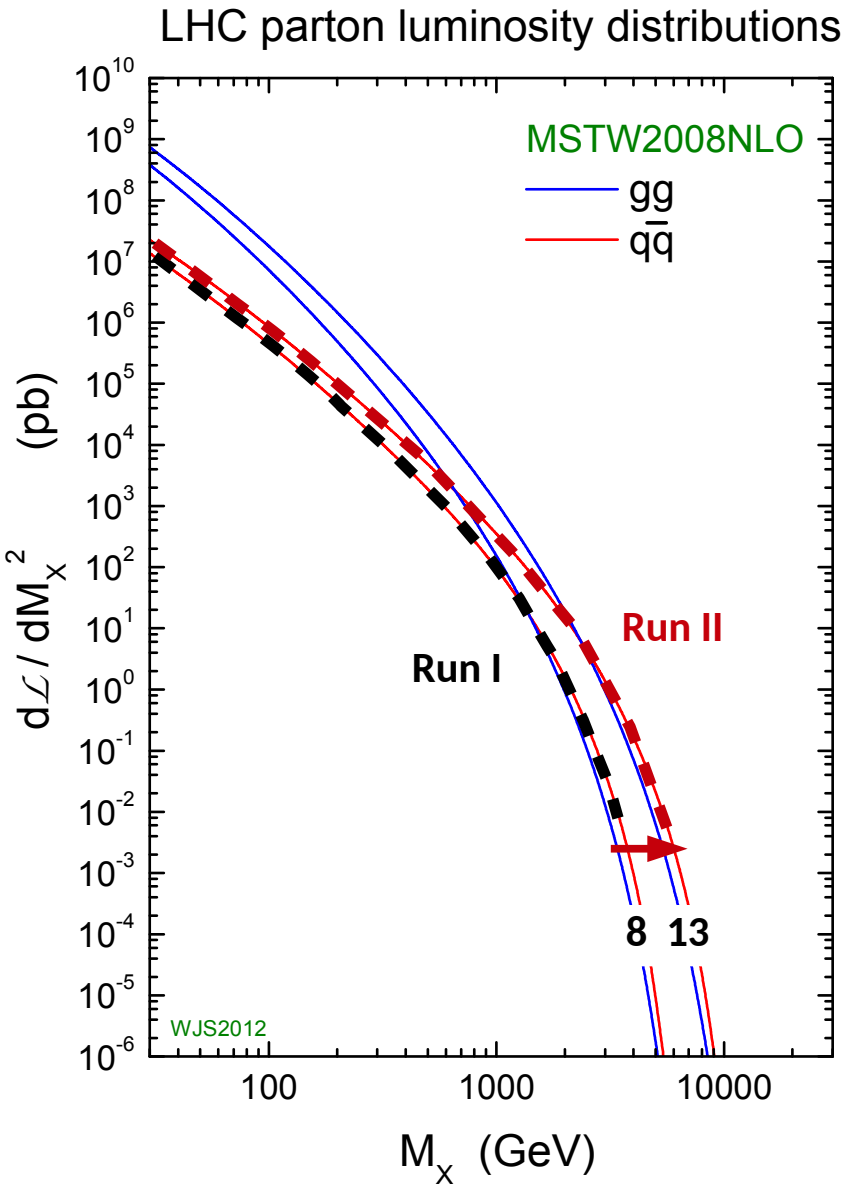


- Produktionsraten bestimmt durch Partonluminositäten
- dramatischer Einbruch bei hohen Massen

→ 2016: Sensitivitätsgewinn durch Energieerhöhung voll sichtbar

13 TeV: Zugang zu unerforschtem Terrain

ATLAS Exotics Searches* - 95% CL Exclusion

Status: August 2016

ATLAS Preliminary

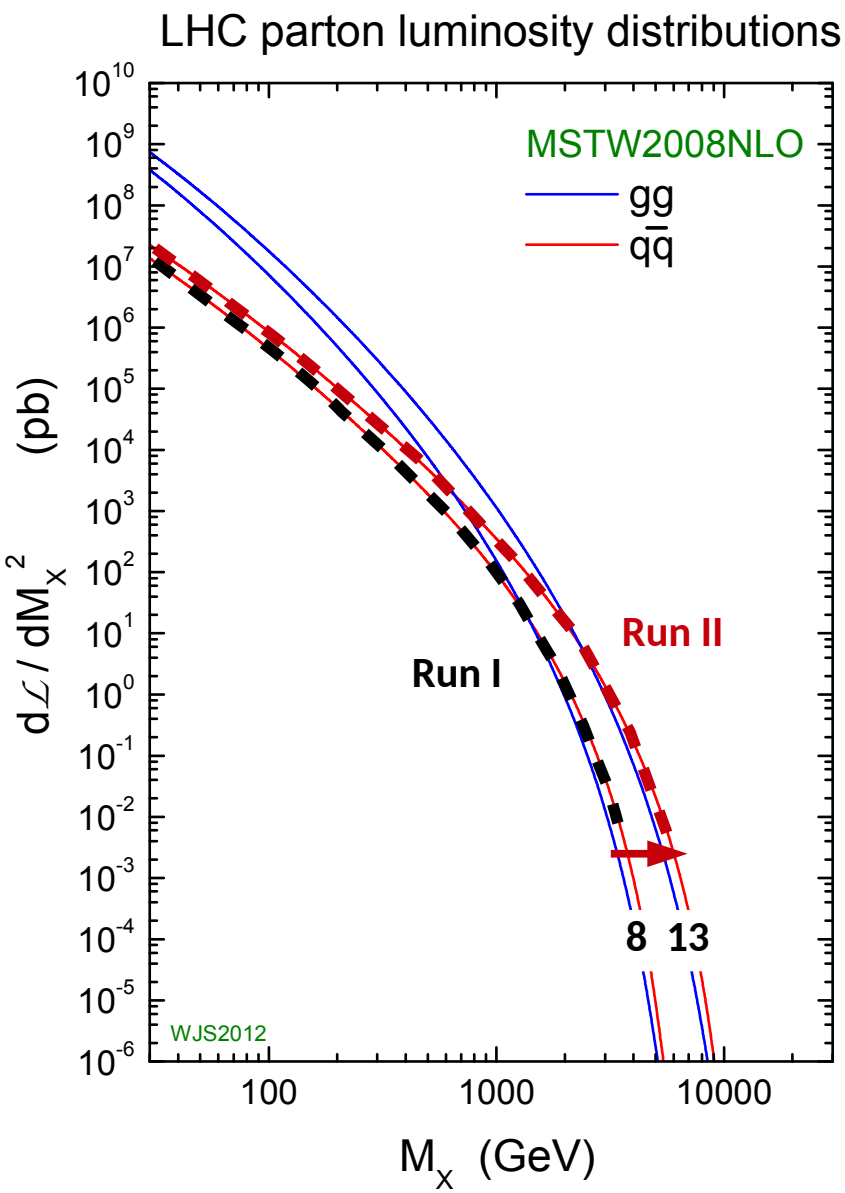
$\int \mathcal{L}\, dt = (3.2 - 20.3)\ \mathrm{fb}^{-1}$ $\sqrt{s} = 8, 13$ TeV

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	–	≥ 1 j	Yes	3.2	M_D 6.58 TeV	$n = 2$	1604.07773
	ADD non-resonant $\ell\ell$	2 e, μ	–	–	20.3	M_S 4.7 TeV	$n = 3$ HLZ	1407.2410
	ADD QBH $\to \ell q$	1 e, μ	1 j	–	20.3	M_{th} 5.2 TeV	$n = 6$	1311.2006
	ADD QBH	–	2 j	–	15.7	M_{th} 8.7 TeV	$n = 6$	ATLAS-CONF-2016-069
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	3.2	M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \ell\ell$	2 e, μ	–	–	20.3	G_{KK} mass 2.68 TeV	$k/\overline{M}_{Pl} = 0.1$	1405.4123
	RS1 $G_{KK} \to \gamma\gamma$	2 γ	–	–	3.2	G_{KK} mass 3.2 TeV	$k/\overline{M}_{Pl} = 0.1$	1606.03833
	Bulk RS $G_{KK} \to WW \to qq\ell\nu$	1 e, μ	1 J	Yes	13.2	G_{KK} mass 1.24 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2016-062
	Bulk RS $G_{KK} \to HH \to bbbb$	–	4 b	–	13.3	G_{KK} mass 360-860 GeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2016-049
	Bulk RS $g_{KK} \to tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	20.3	g_{KK} mass 2.2 TeV	BR = 0.925	1505.07018
	2UED / RPP	1 e, μ	≥ 2 b, ≥ 4 j	Yes	3.2	KK mass 1.46 TeV	Tier (1,1), BR($A^{(1,1)} \to tt$) = 1	ATLAS-CONF-2016-013
Gauge bosons	SSM $Z' \to \ell\ell$	2 e, μ	–	–	13.3	Z' mass 4.05 TeV		ATLAS-CONF-2016-045
	SSM $Z' \to \tau\tau$	2 τ	–	–	19.5	Z' mass 2.02 TeV		1502.07177
	Leptophobic $Z' \to bb$	–	2 b	–	3.2	Z' mass 1.5 TeV		1603.08791
	SSM $W' \to \ell\nu$	1 e, μ	–	Yes	13.3	W' mass 4.74 TeV		ATLAS-CONF-2016-061
	HVT $W' \to WZ \to qq\nu\nu$ model A	0 e, μ	1 J	Yes	13.2	W' mass 2.4 TeV	$g_V = 1$	ATLAS-CONF-2016-082
	HVT $W' \to WZ \to qqqq$ model B	–	2 J	–	15.5	W' mass 3.0 TeV	$g_V = 3$	ATLAS-CONF-2016-055
	HVT $V' \to WH/ZH$ model B	multi-channel			3.2	V' mass 2.31 TeV	$g_V = 3$	1607.05621
	LRSM $W'_R \to tb$	1 e, μ	2 b, 0-1 j	Yes	20.3	W' mass 1.92 TeV		1410.4103
	LRSM $W'_R \to tb$	0 e, μ	≥ 1 b, 1 J	–	20.3	W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	15.7	Λ 19.9 TeV	$\eta_{LL} = -1$	ATLAS-CONF-2016-069
	CI $\ell\ell qq$	2 e, μ	–	–	3.2	Λ 25.2 TeV	$\eta_{LL} = -1$	1607.03669
	CI $uutt$	2(SS)/≥3 e,μ	≥1 b, ≥1 j	Yes	20.3	Λ 4.9 TeV	$\lvert C_{RR}\rvert = 1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	0 e, μ	≥ 1 j	Yes	3.2	m_A 1.0 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 250$ GeV	1604.07773
	Axial-vector mediator (Dirac DM)	0 $e, \mu, 1\ \gamma$	1 j	Yes	3.2	m_A 710 GeV	g_q=0.25, g_χ=1.0, $m(\chi) < 150$ GeV	1604.01306
	$ZZ\chi\chi$ EFT (Dirac DM)	0 e, μ	1 J, ≤ 1 j	Yes	3.2	M_* 550 GeV	$m(\chi) < 150$ GeV	ATLAS-CONF-2015-080
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	3.2	LQ mass 1.1 TeV	$\beta = 1$	1605.06035
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	3.2	LQ mass 1.05 TeV	$\beta = 1$	1605.06035
	Scalar LQ 3rd gen	1 e, μ	≥1 b, ≥3 j	Yes	20.3	LQ mass 640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \to Ht + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	T mass 855 GeV	T in (T,B) doublet	1505.04306
	VLQ $YY \to Wb + X$	1 e, μ	≥ 1 b, ≥ 3 j	Yes	20.3	Y mass 770 GeV	Y in (B,Y) doublet	1505.04306
	VLQ $BB \to Hb + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	B mass 735 GeV	isospin singlet	1505.04306
	VLQ $BB \to Zb + X$	2/≥3 e, μ	≥2/≥1 b	–	20.3	B mass 755 GeV	B in (B,Y) doublet	1409.5500
	VLQ $QQ \to WqWq$	1 e, μ	≥ 4 j	Yes	20.3	Q mass 690 GeV		1509.04261
	VLQ $T_{5/3}T_{5/3} \to WtWt$	2(SS)/≥3 e,μ	≥1 b, ≥1 j	Yes	3.2	$T_{5/3}$ mass 990 GeV		ATLAS-CONF-2016-032
Excited fermions	Excited quark $q^* \to q\gamma$	1 γ	1 j	–	3.2	q^* mass 4.4 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1512.05910
	Excited quark $q^* \to qg$	–	2 j	–	15.7	q^* mass 5.6 TeV	only u^* and d^*, $\Lambda = m(q^*)$	ATLAS-CONF-2016-069
	Excited quark $b^* \to bg$	–	1 b, 1 j	–	8.8	b^* mass 2.3 TeV		ATLAS-CONF-2016-060
	Excited quark $b^* \to Wt$	1 or 2 e, μ	1 b, 2-0 j	Yes	20.3	b^* mass 1.5 TeV	$f_g = f_L = f_R = 1$	1510.02664
	Excited lepton ℓ^*	3 e, μ	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	LSTC $a_T \to W\gamma$	1 $e, \mu, 1\ \gamma$	–	Yes	20.3	a_T mass 960 GeV		1407.8150
	LRSM Majorana ν	2 e, μ	2 j	–	20.3	N^0 mass 2.0 TeV	$m(W_R) = 2.4$ TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm} \to ee$	2 e (SS)	–	–	13.9	$H^{\pm\pm}$ mass 570 GeV	DY production, BR($H_L^{\pm\pm} \to ee$)=1	ATLAS-CONF-2016-051
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	3 e, μ, τ	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, BR($H_L^{\pm\pm} \to \ell\tau$)=1	1411.2921
	Monotop (non-res prod)	1 e, μ	1 b	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, $\lvert q\rvert = 5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	monopole mass 1.34 TeV	DY production, $\lvert g\rvert = 1g_D$, spin 1/2	1509.08059

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

10^{-1} 1 10 **Mass scale [TeV]**

13 TeV: Zugang zu unerforschtem Terrain



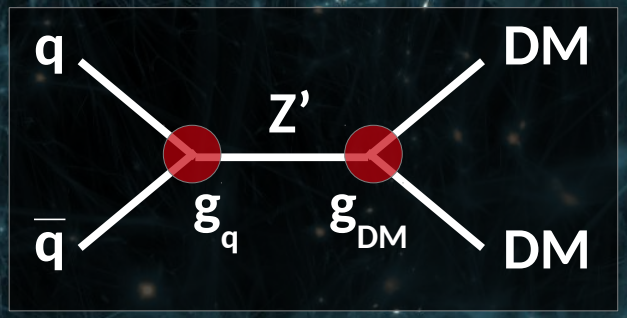
- Produktionsraten bestimmt durch Partonluminositäten
- dramatischer Einbruch bei hohen Massen

→ 2016:
Sensitivitätsgewinn durch Energieerhöhung voll sichtbar

→ ab 2017:
viele Suchen am kinematischen Limit, neuer Fokus auf seltene Prozesse (im gesamten Massenbereich)

Suche nach dunkler Materie

Im Fokus: das dunkle Universum



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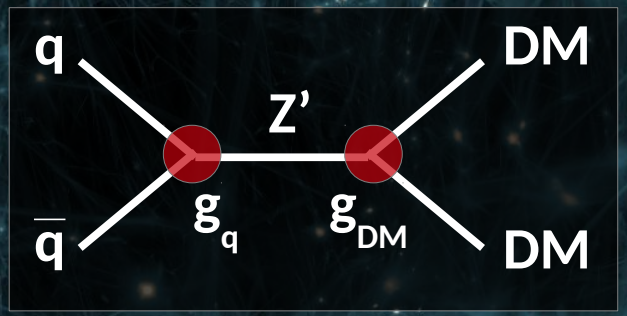
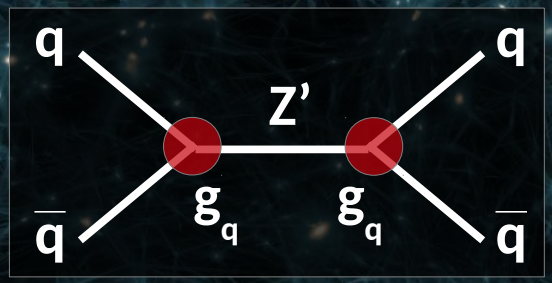
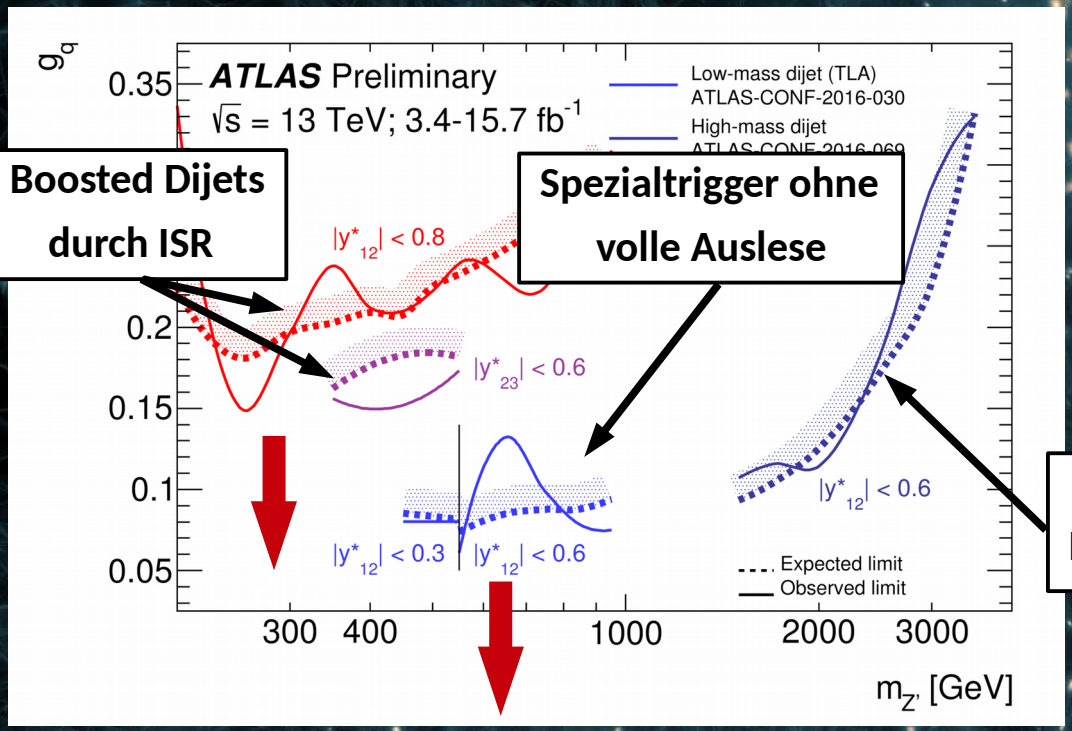






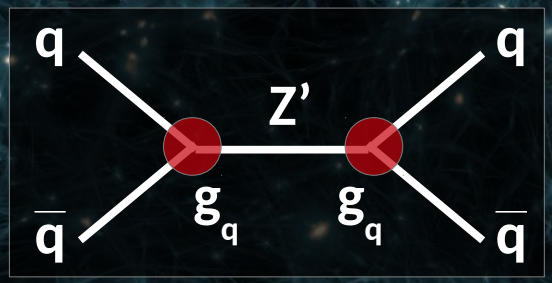
Boosted Dijets durch ISR

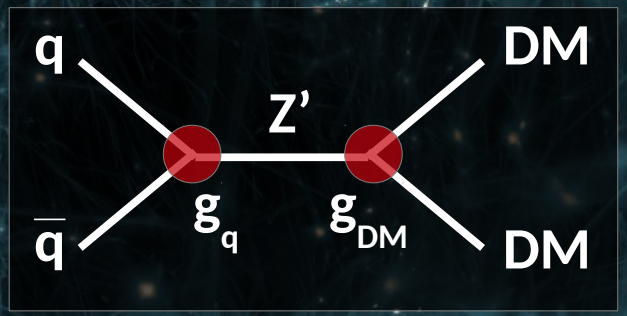
Spezialtrigger ohne volle Auslese

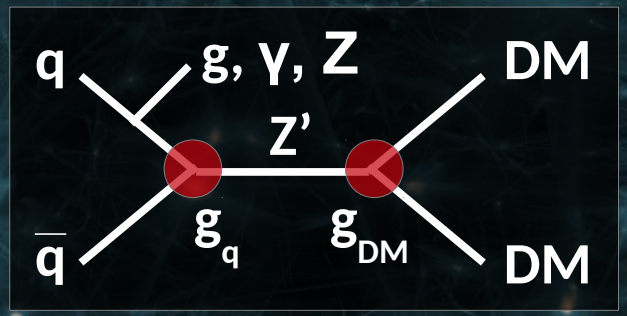
Klassische Dijet-Resonanz-Analyse

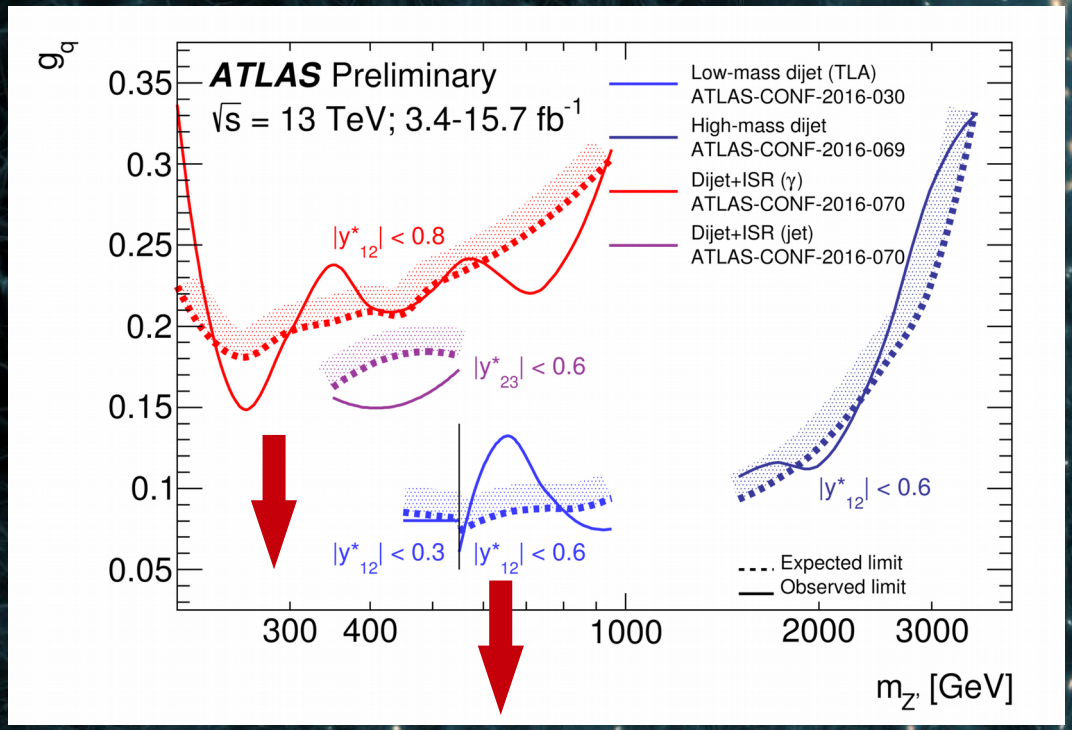
Suche nach dunkler Materie

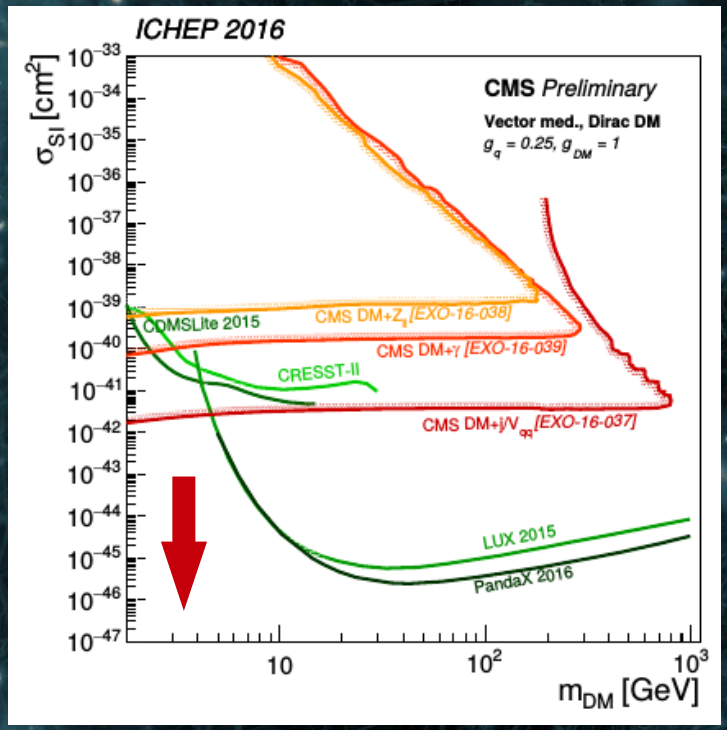
Im Fokus: das dunkle Universum





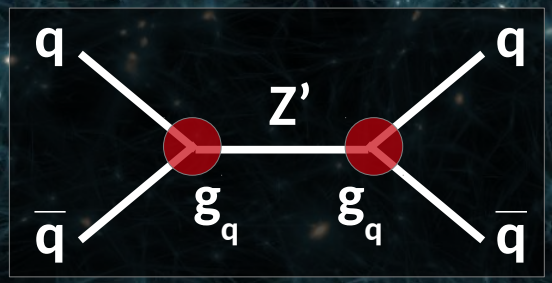


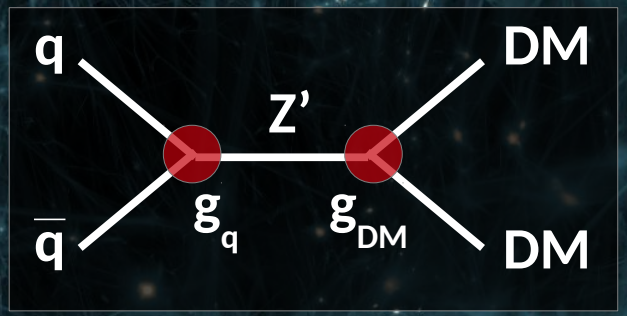


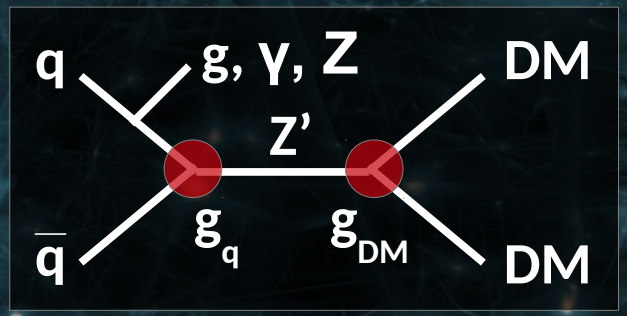


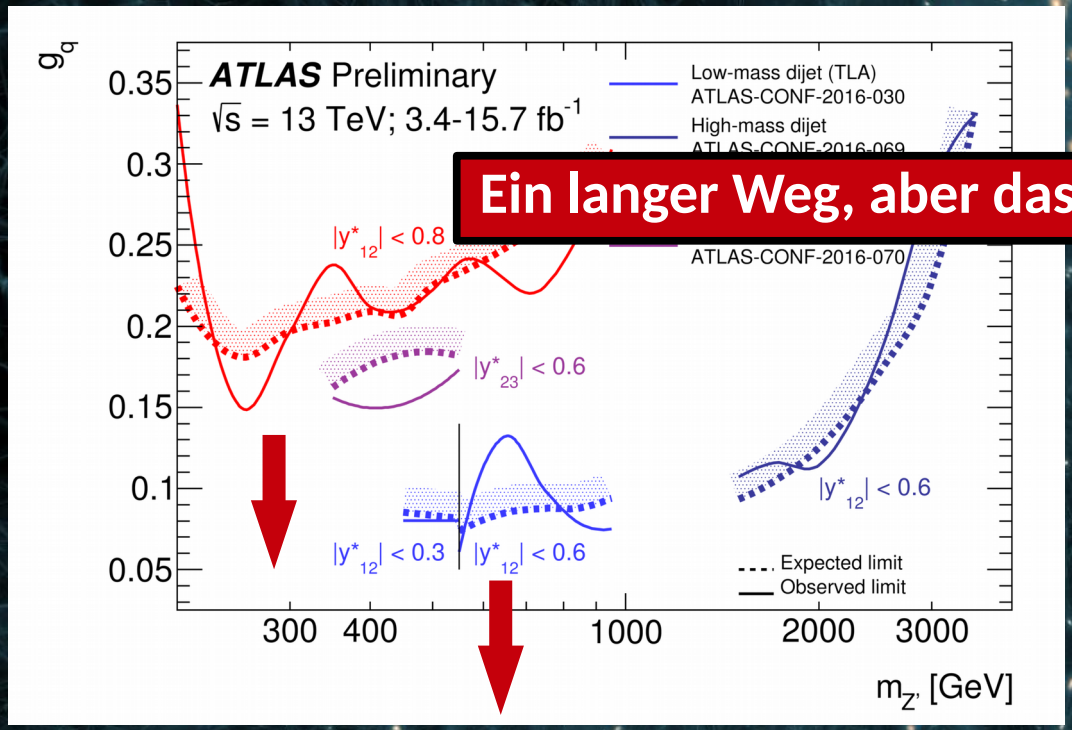
Suche nach dunkler Materie

Im Fokus: das dunkle Universum

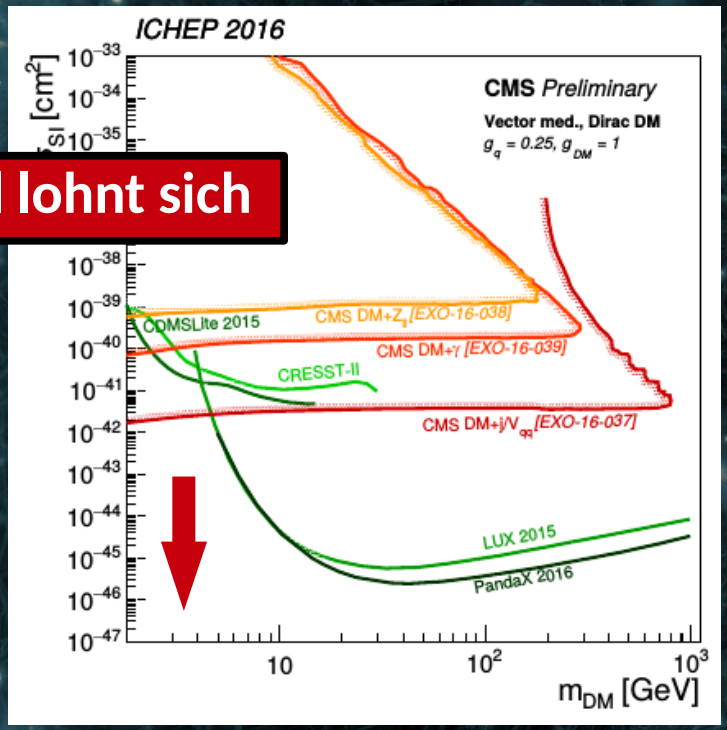






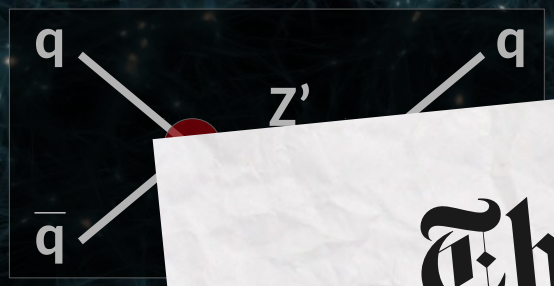


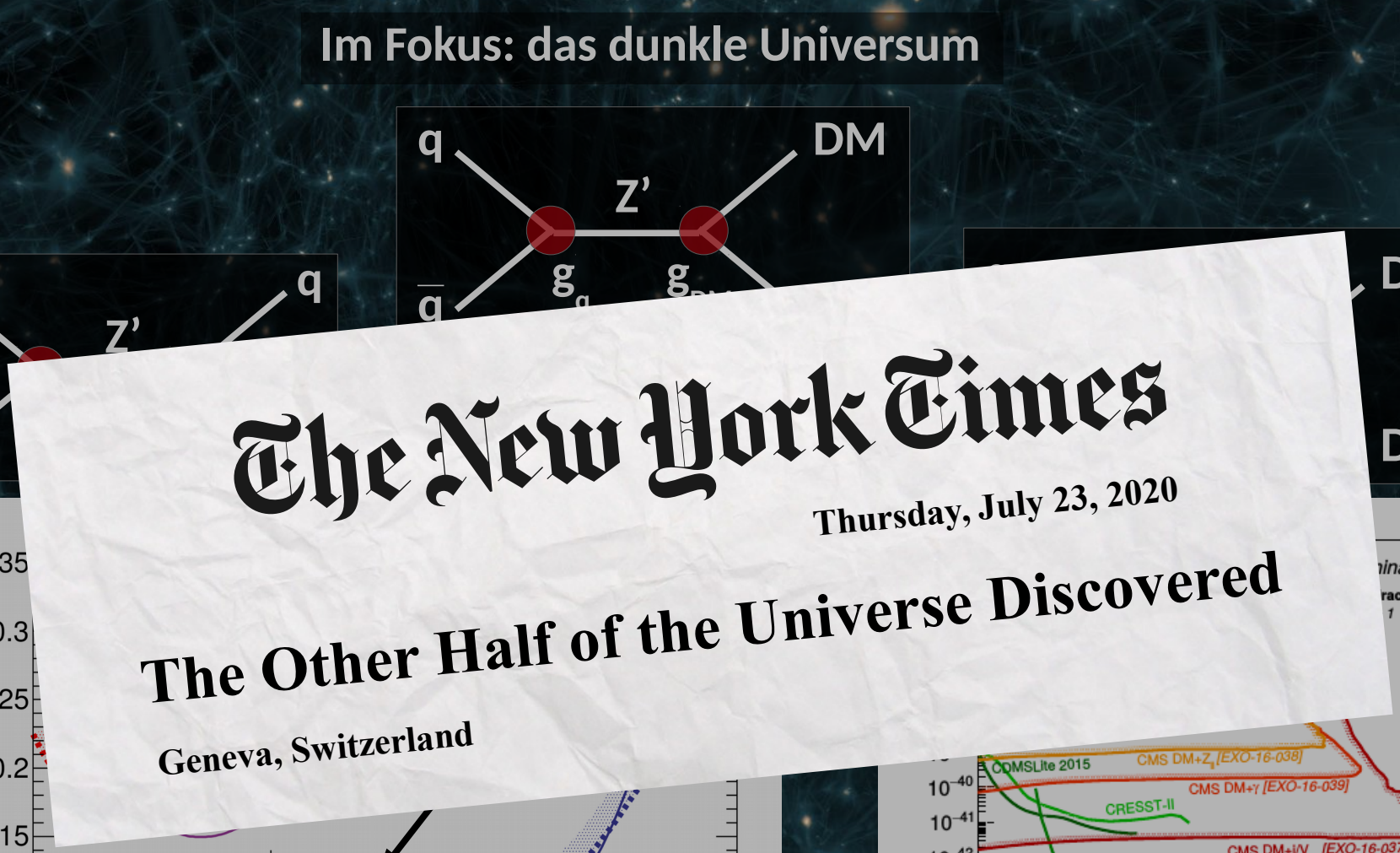
Ein langer Weg, aber das Ziel lohnt sich



Suche nach dunkler Materie

Im Fokus: das dunkle Universum



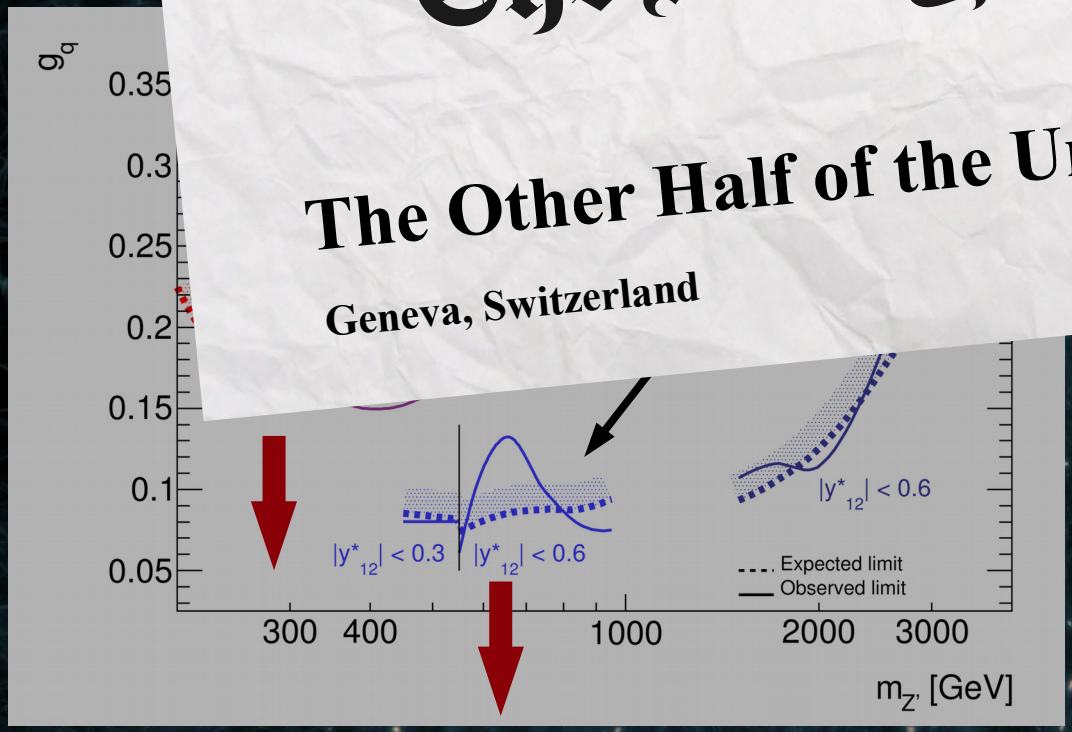


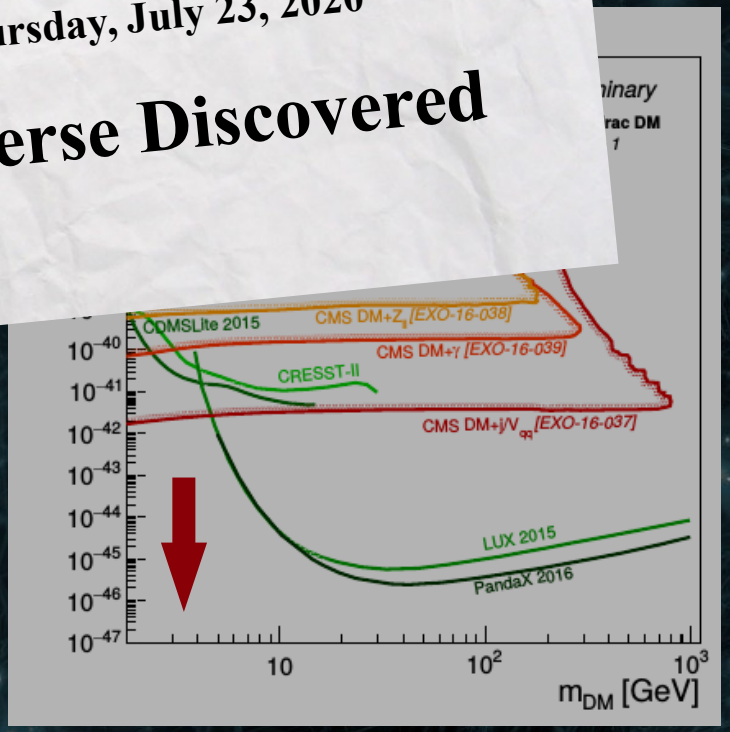
The New York Times

Thursday, July 23, 2020

The Other Half of the Universe Discovered

Geneva, Switzerland

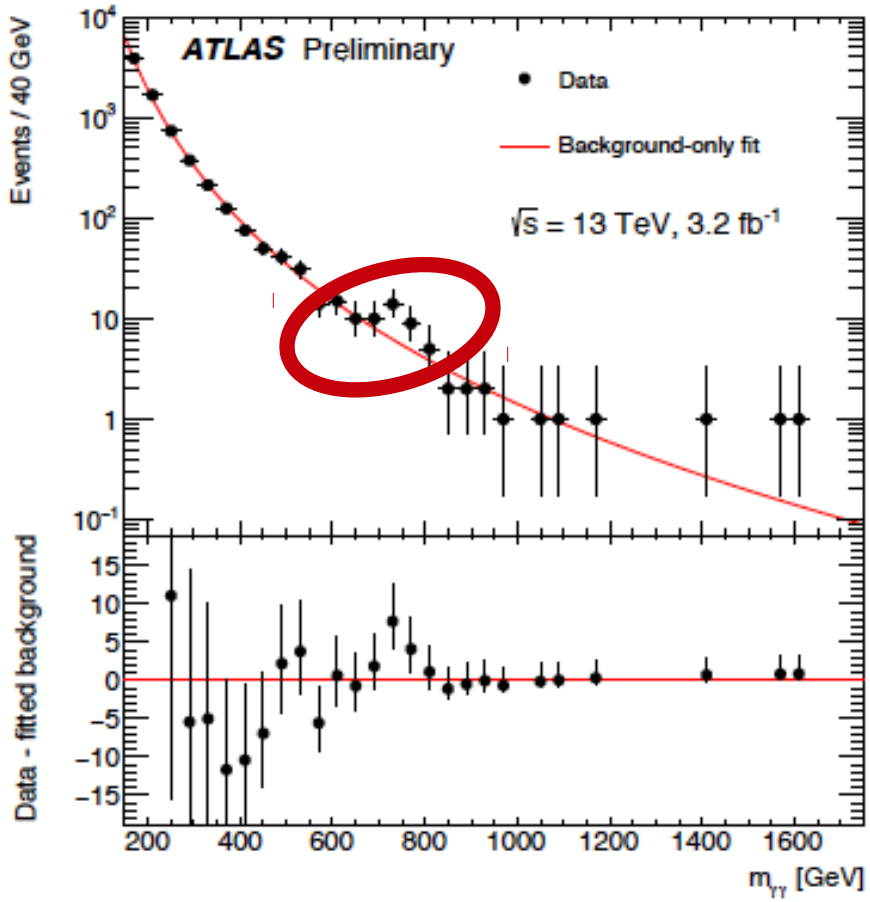


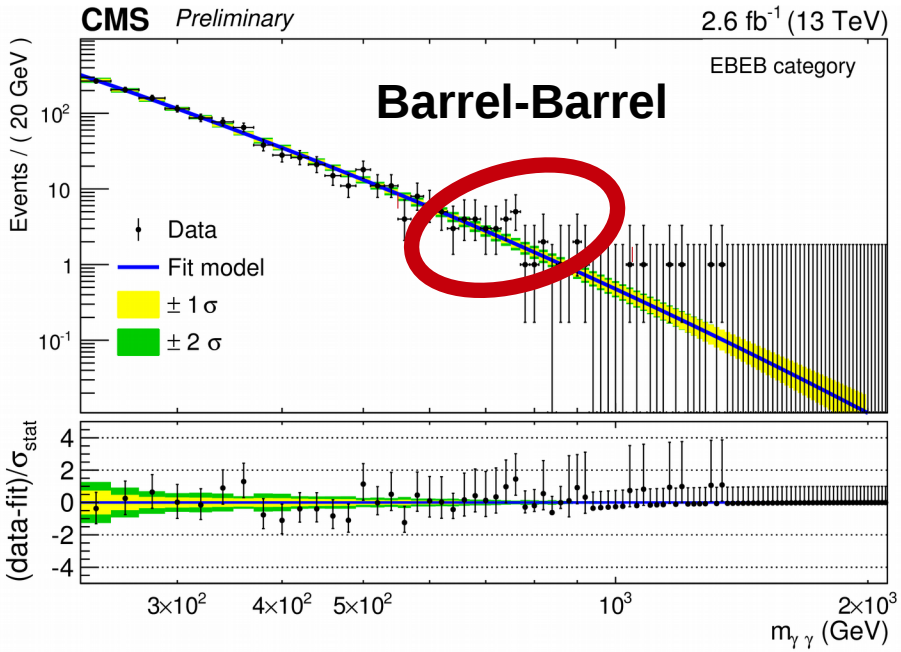


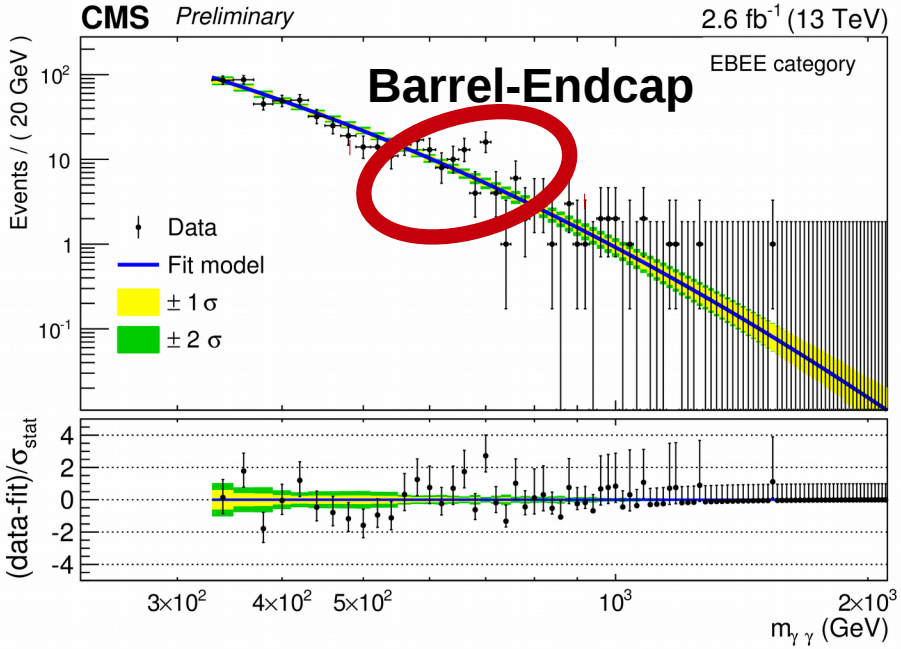
Ein Überschuss taucht auf...

Dezember 2015:

- **Überschuss in γγ-Massenspektrum bei 750 GeV in ATLAS+CMS**
- **kombinierte Signifikanz >3σ**

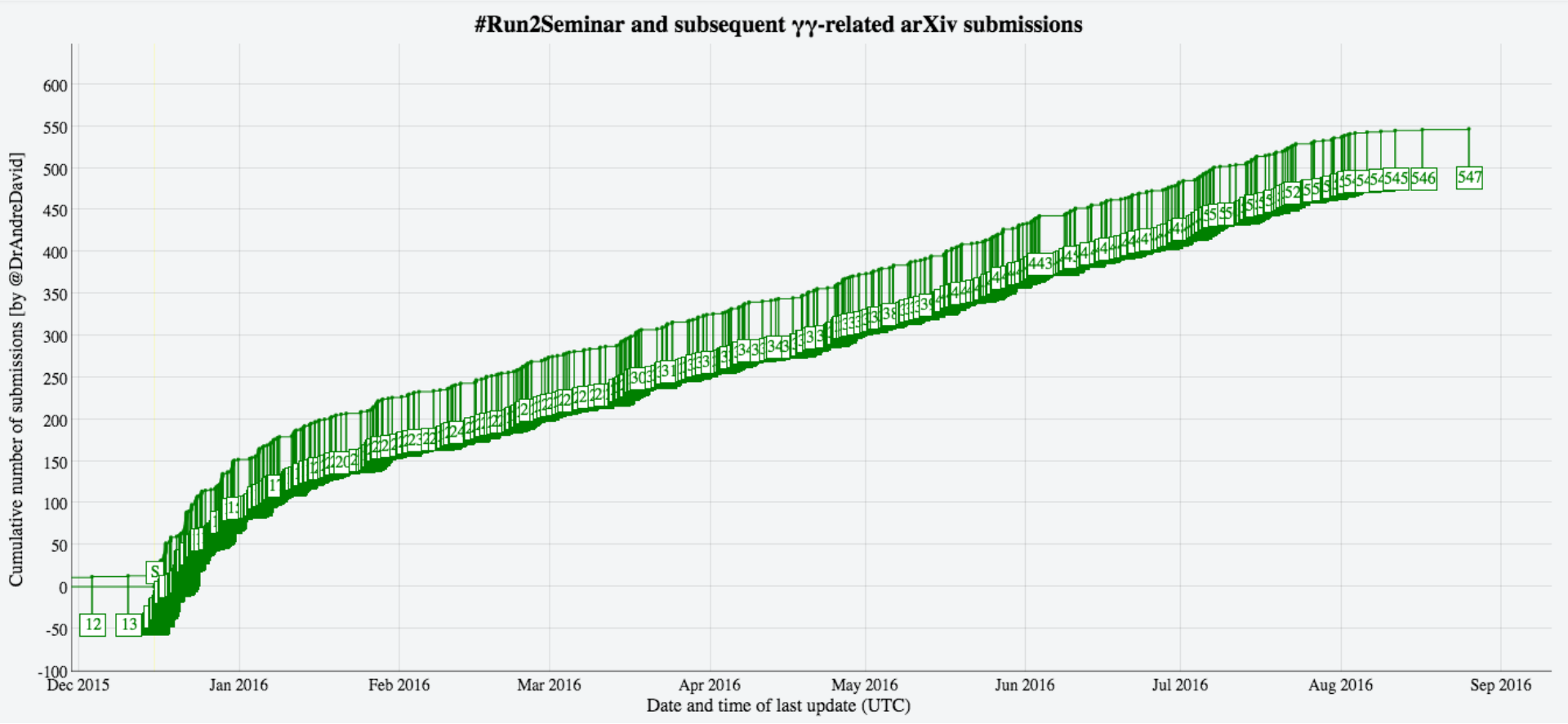






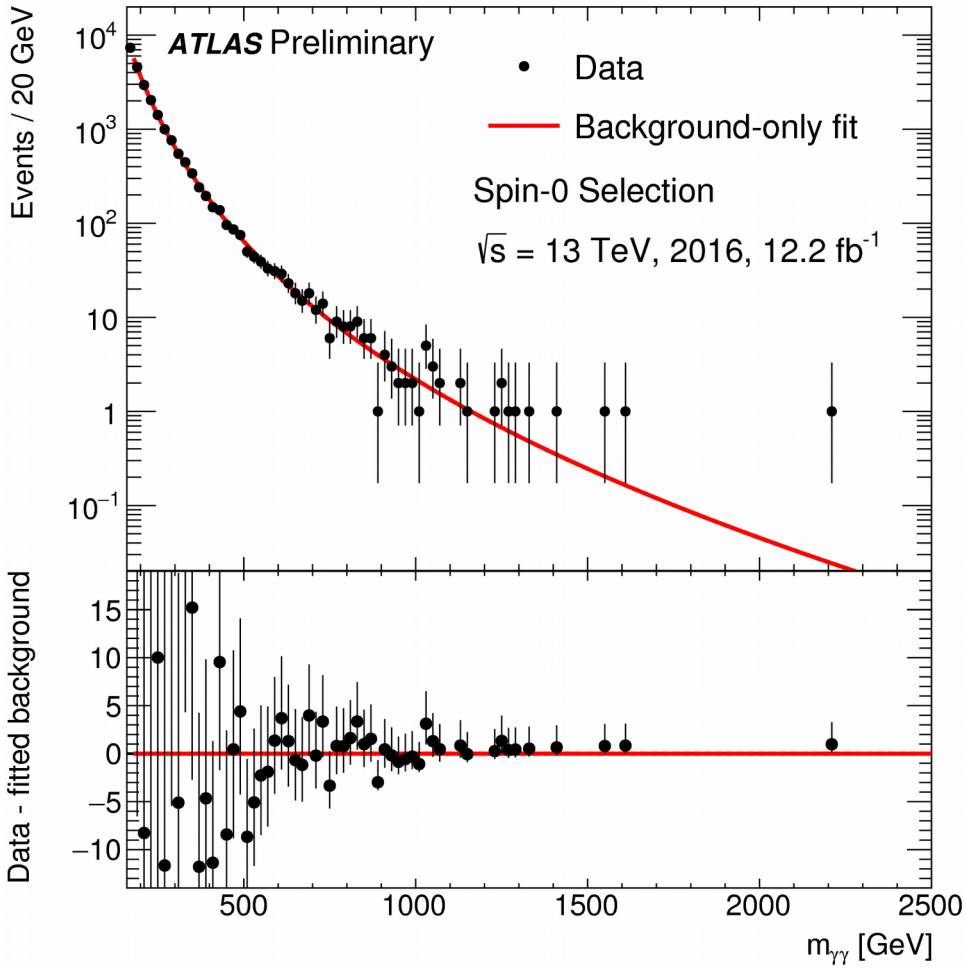
Ein Überschuss taucht auf, wird erklärt...

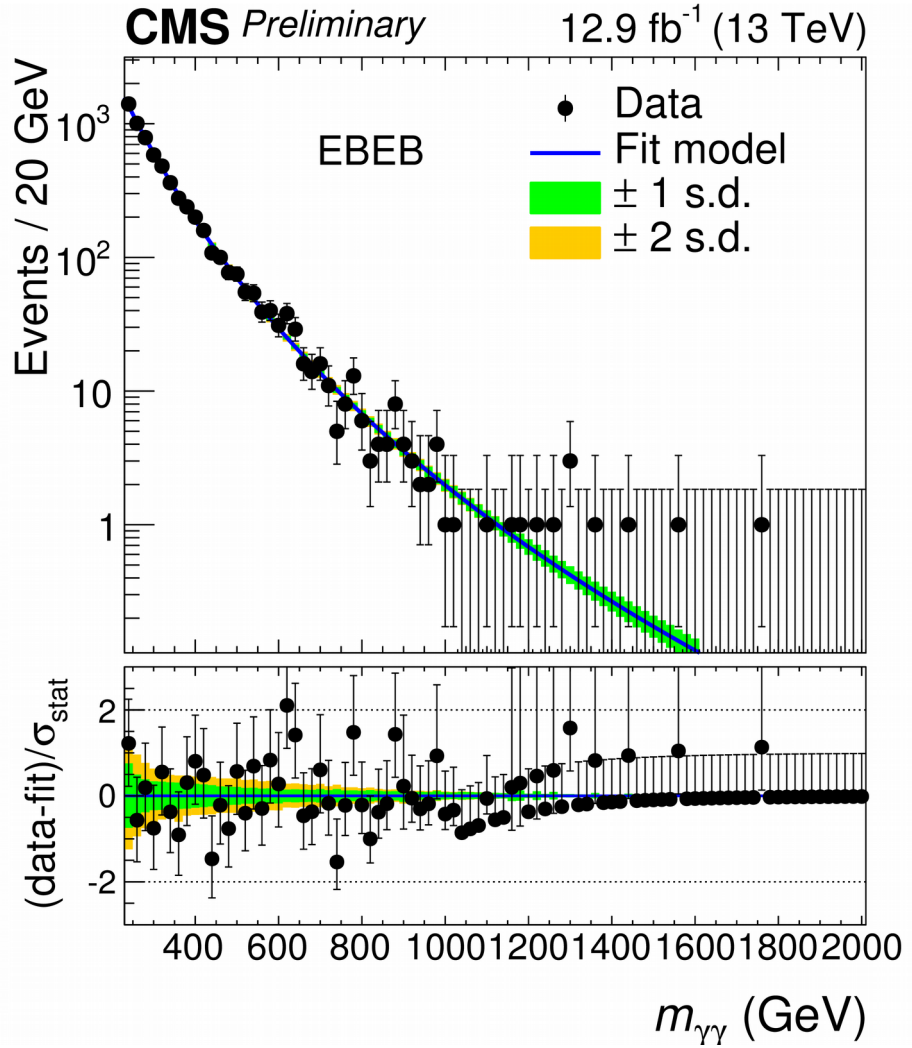
Deutlich über 500 Theorie-Publikationen in 8 Monaten!



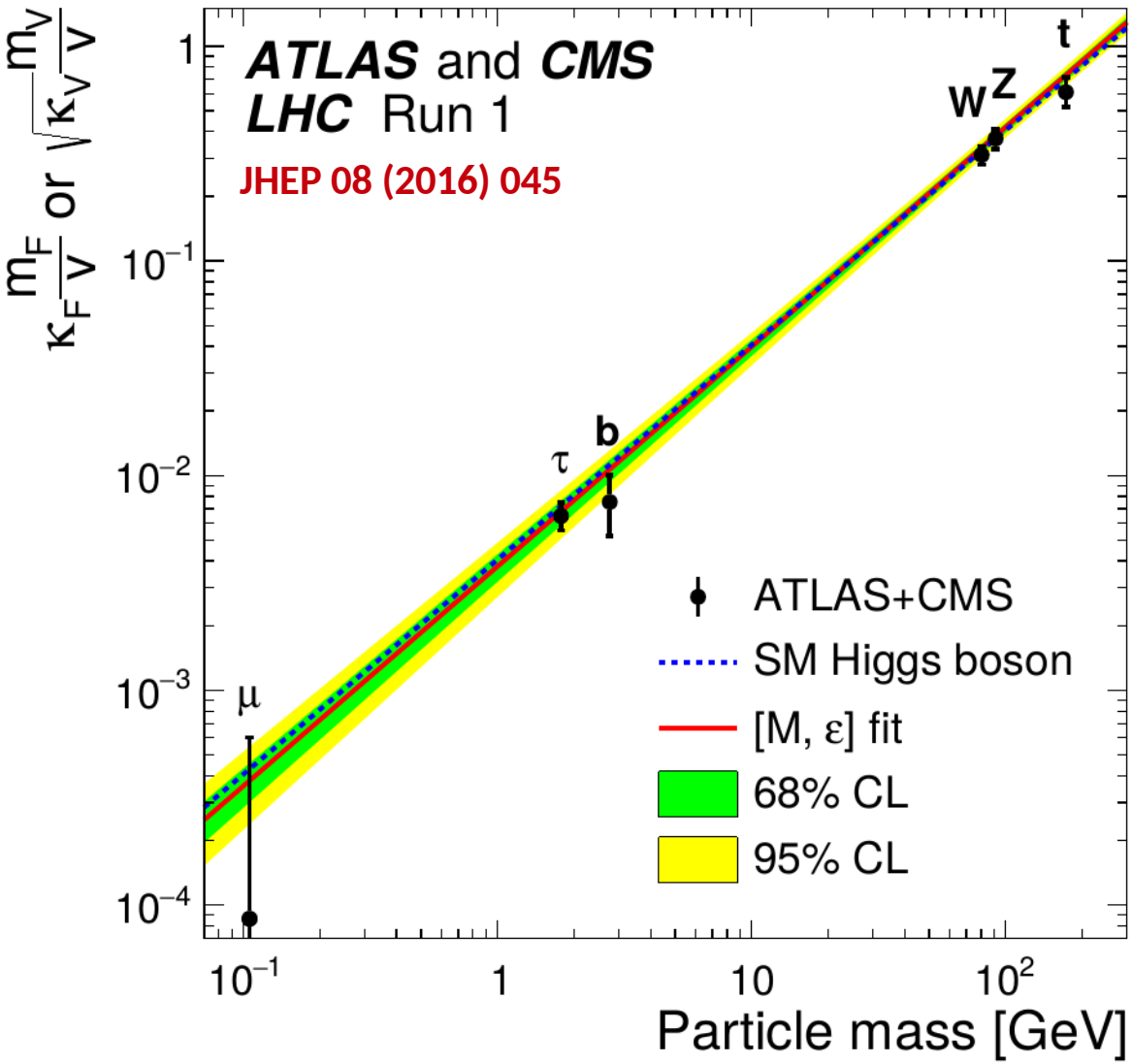
Ein Überschuss taucht auf, wird erklärt… und verschwindet

Sommer 2016: neue Daten zeigen keinen Überschuss → Fluktuation

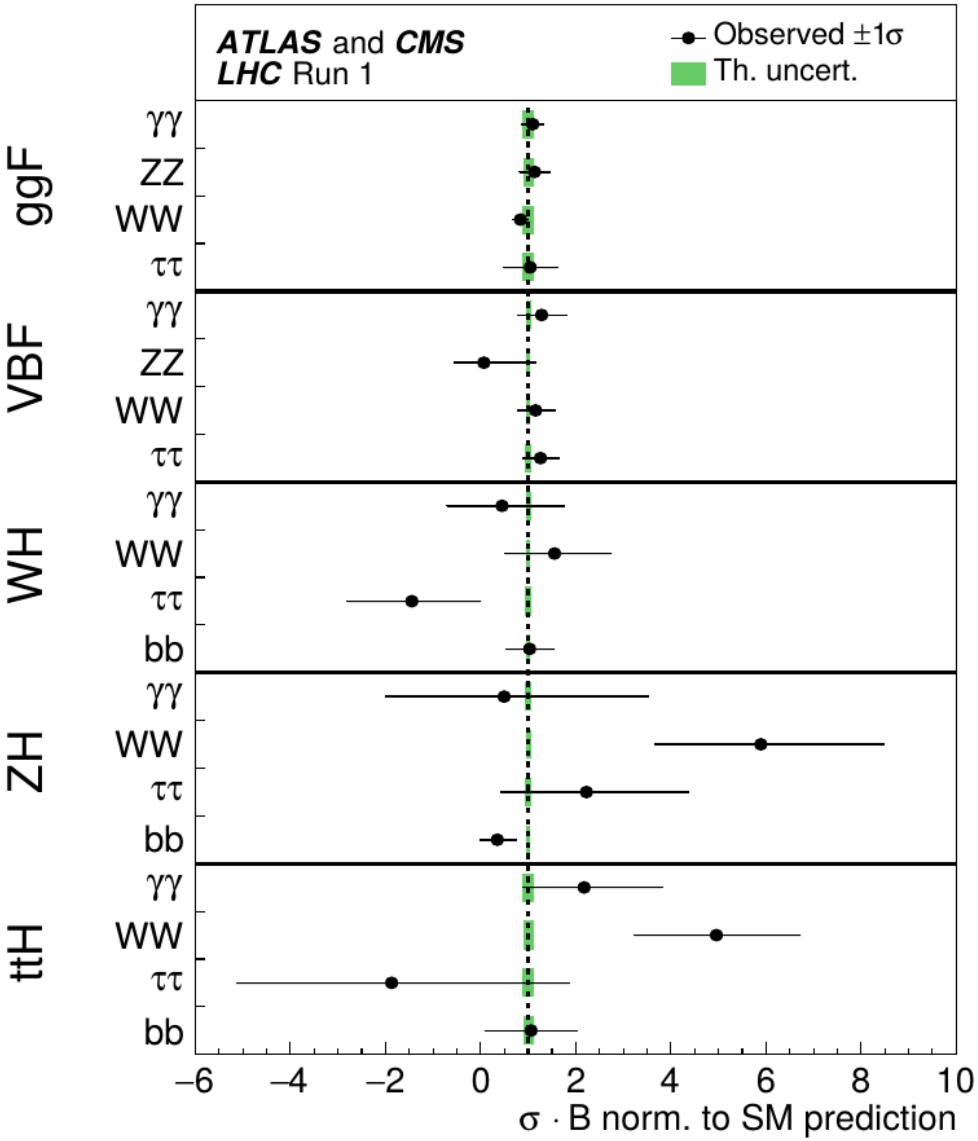




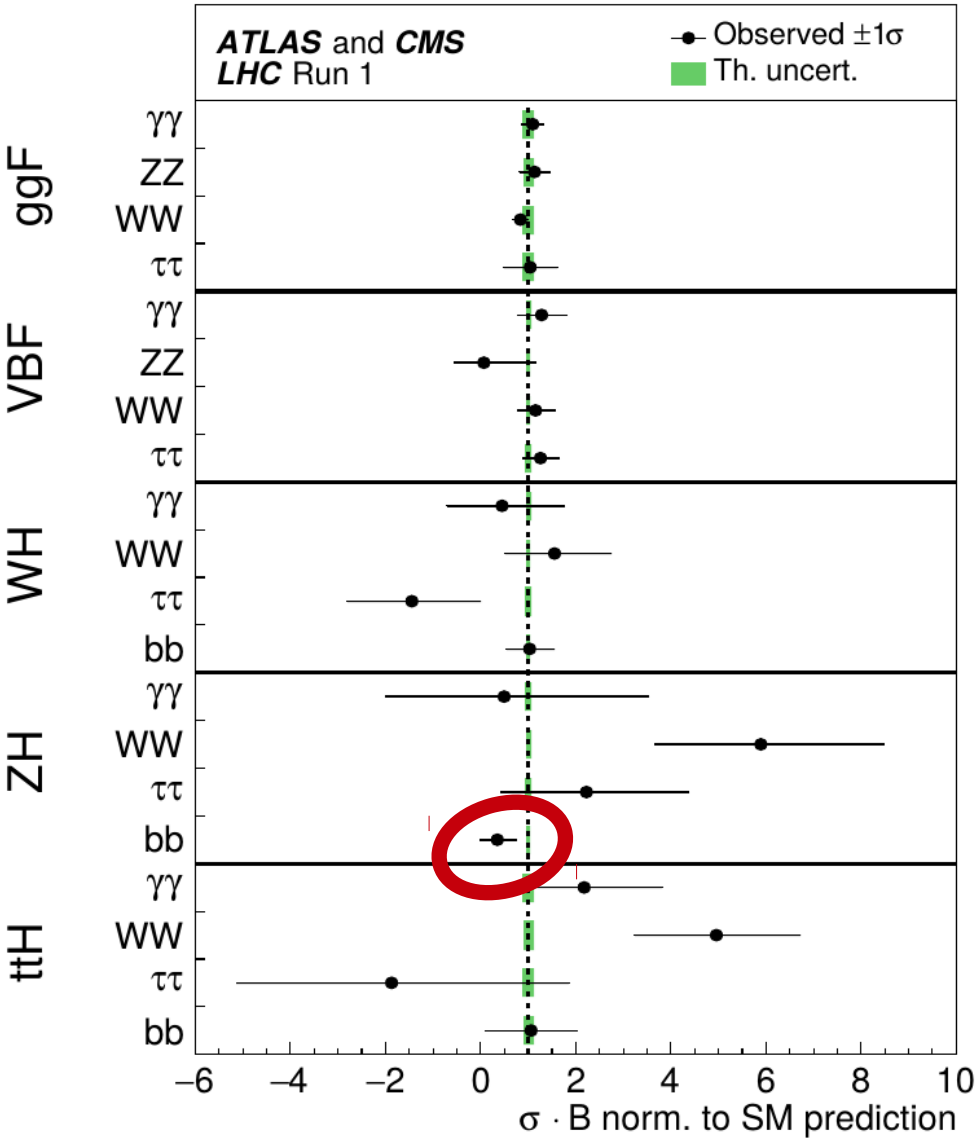
Ein Bild für die Lehrbücher: der Higgs-Mechanismus ist Realität!



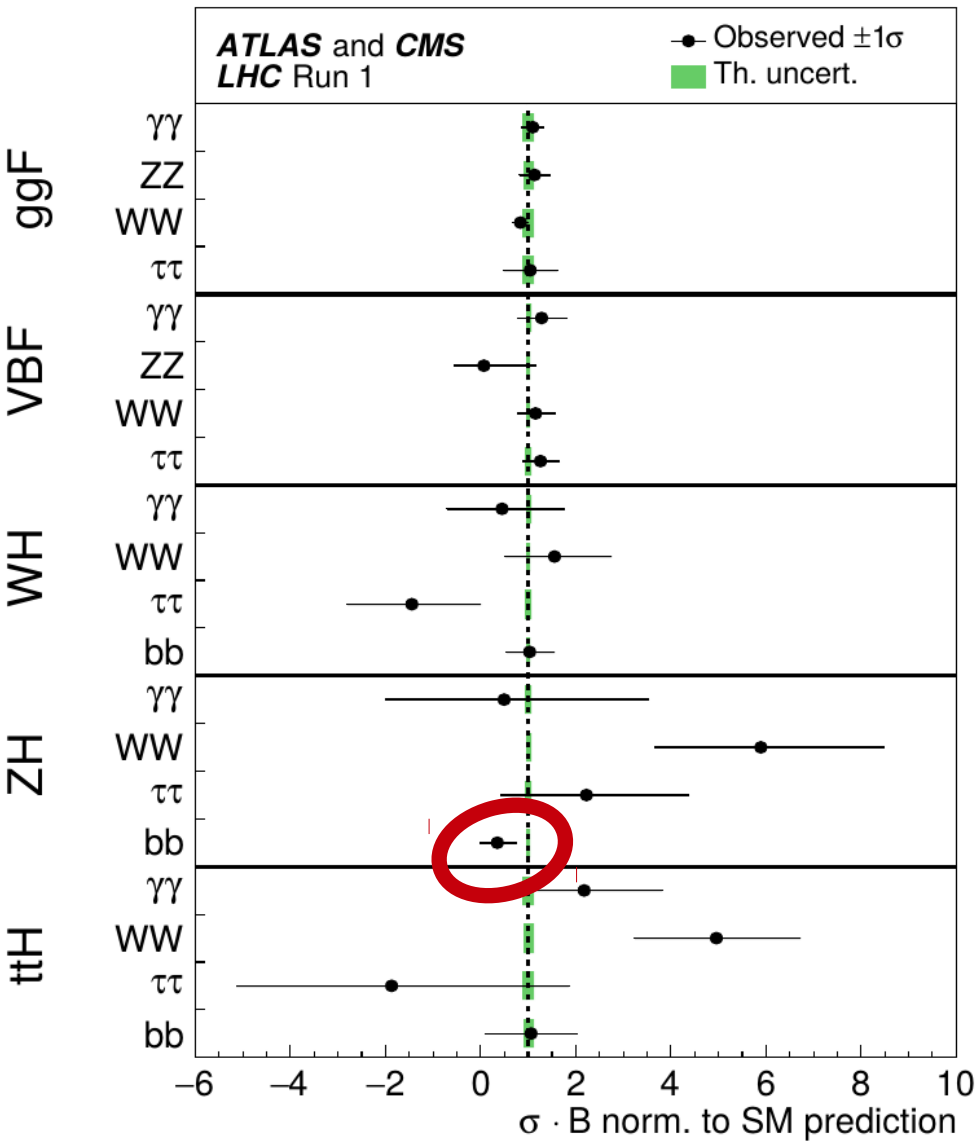
Die zugrundeliegenden Messungen:



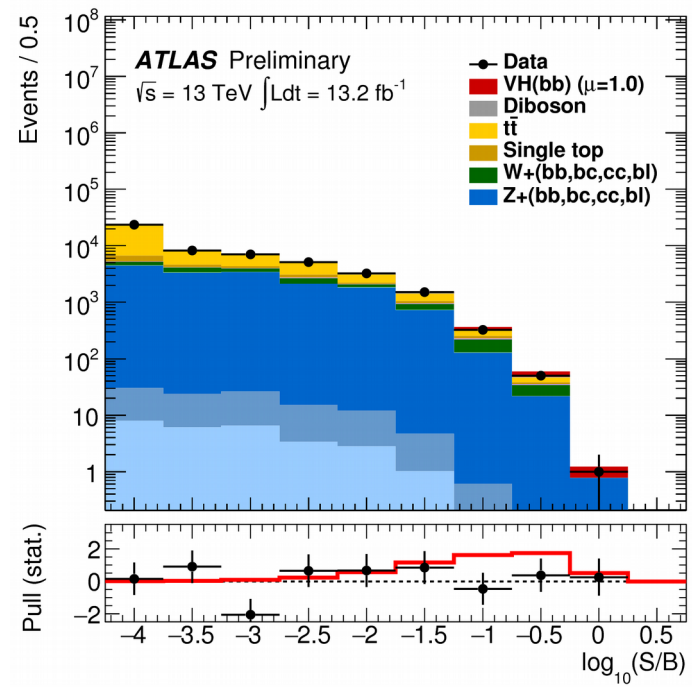
Die zugrundeliegenden Messungen:

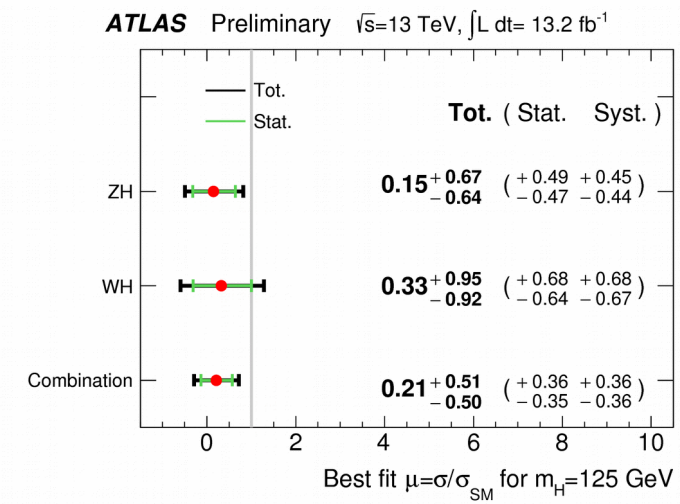


Die zugrundeliegenden Messungen:



VH mit H → bb: erste Run II Ergebnisse





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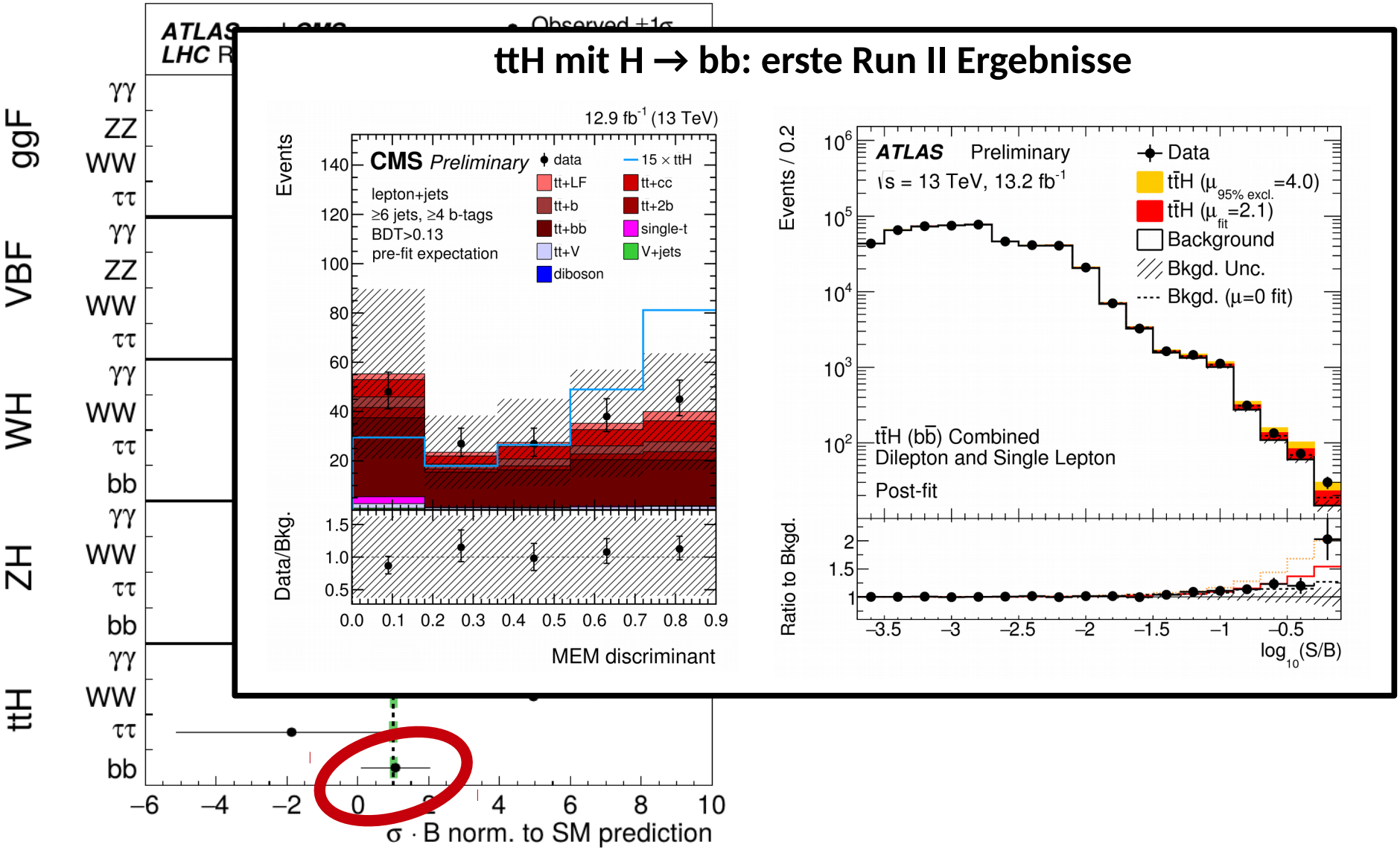
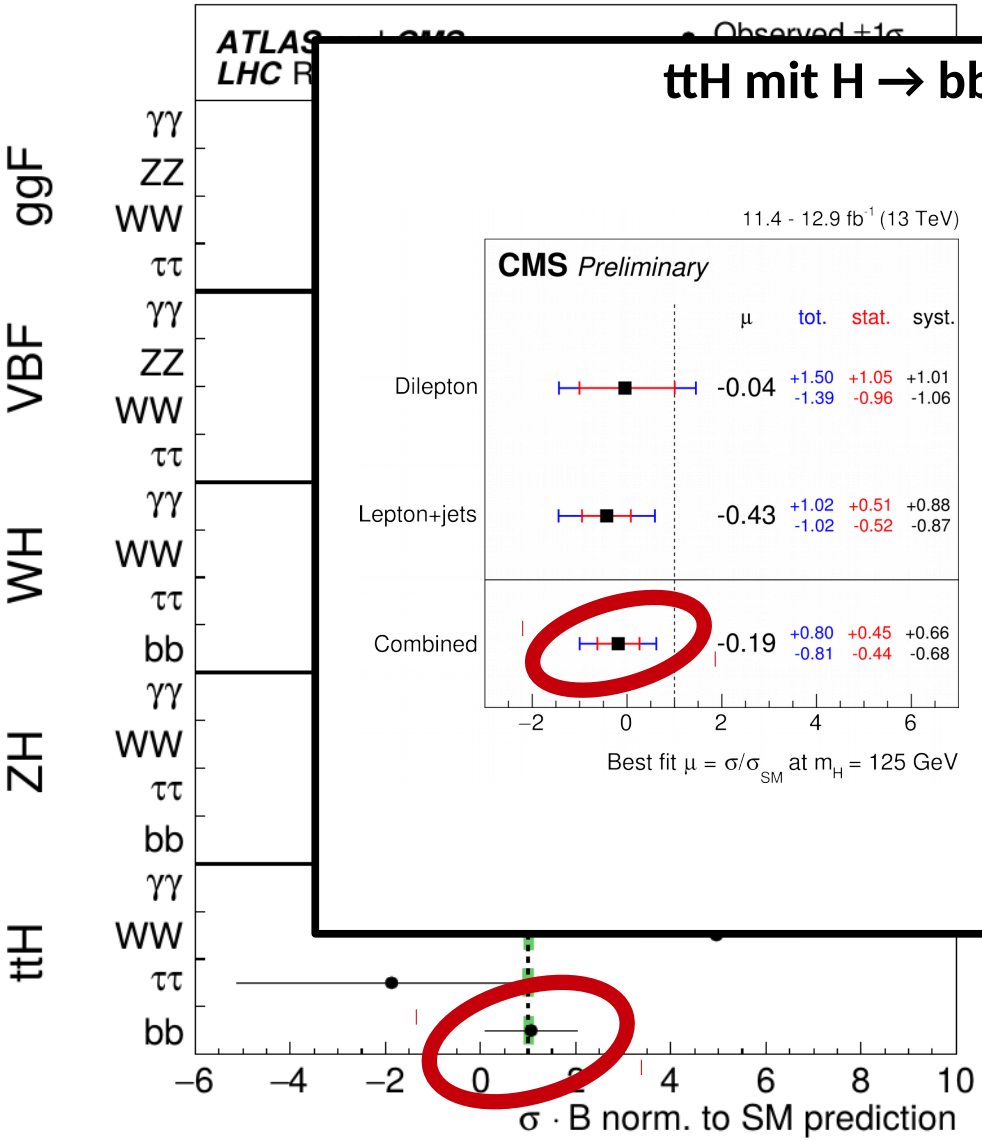
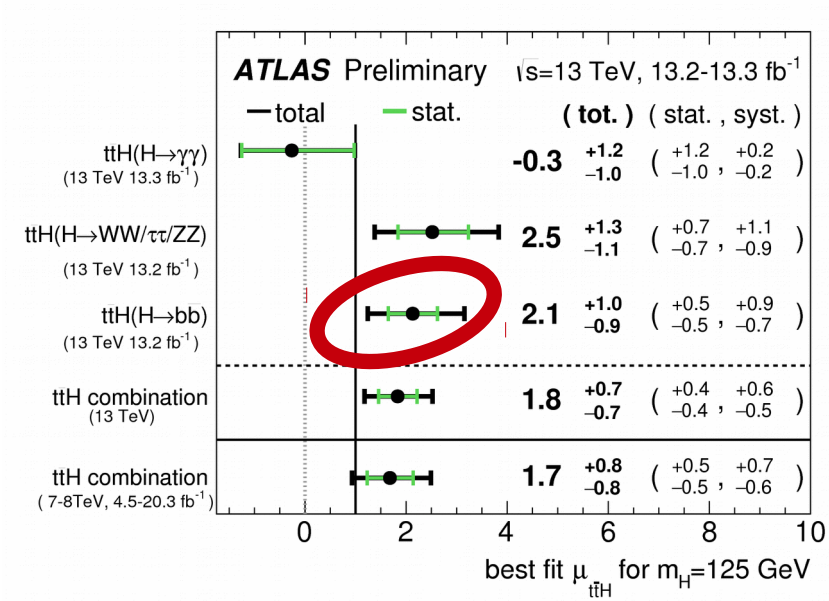


Die zugrundeliegenden Messungen:



ttH mit H → bb: erste Run II Ergebnisse



Im Fokus: Materie-Antimaterie Asymmetrie

LHCb: CP-Verletzung erstmals in Baryonzerfällen beobachtet

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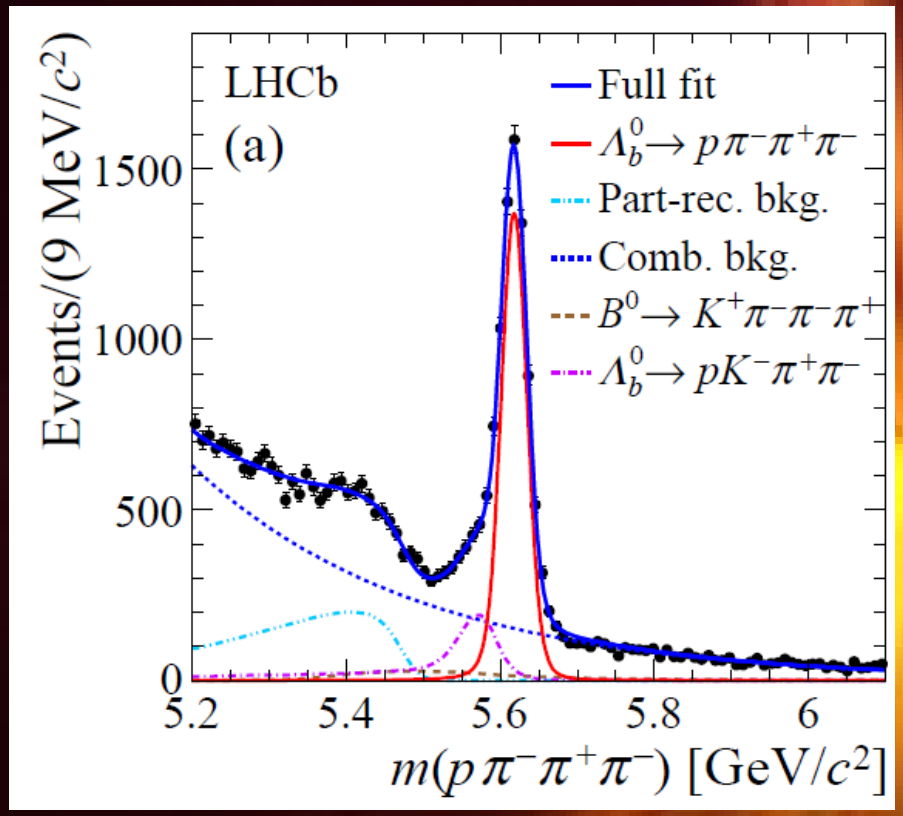
LHCb: CP-Verletzung erstmals in Baryonzerfällen beobachtet



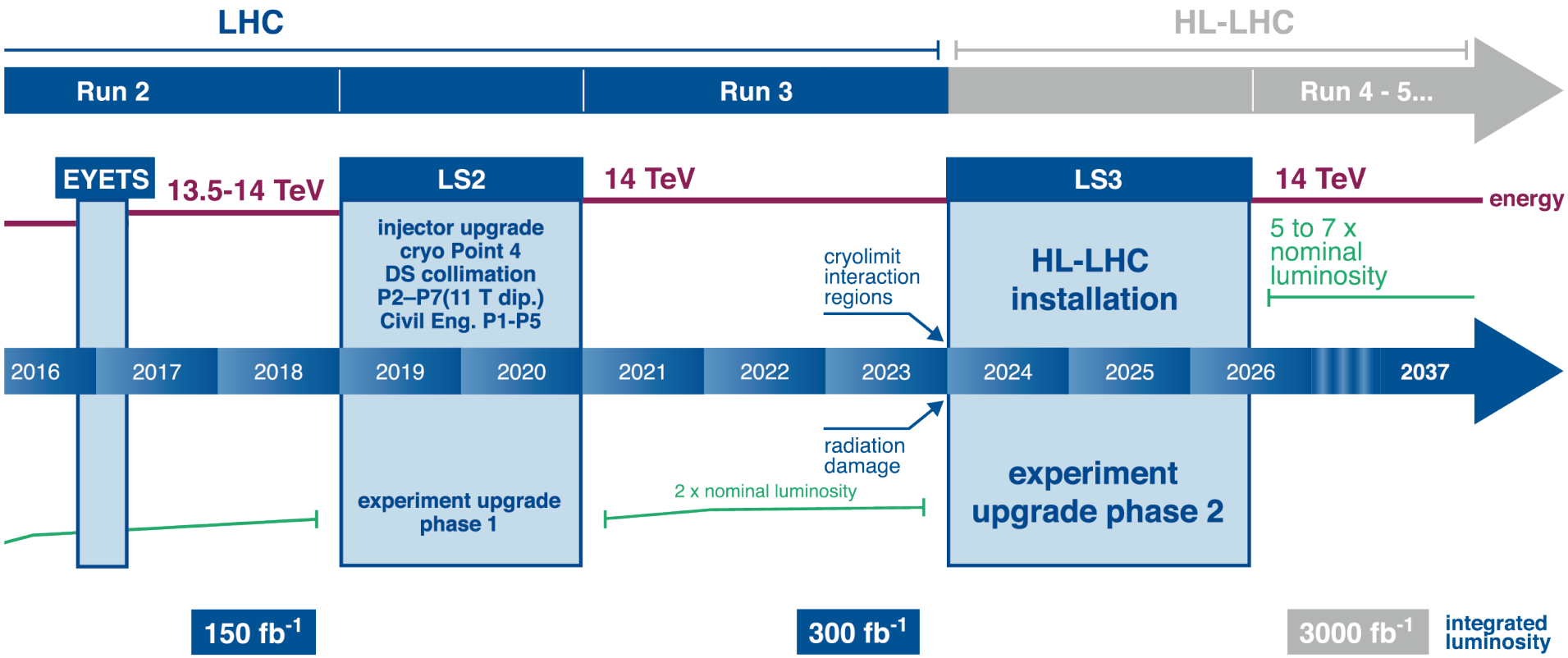
6700 $\Lambda_b \to p\pi\pi\pi\pi$ Zerfälle

Messung der CP-Asymmetrie in Phasenraum-Bins

→ CPV mit Signifikanz 3.3σ

[eingereicht bei Nature Physics]

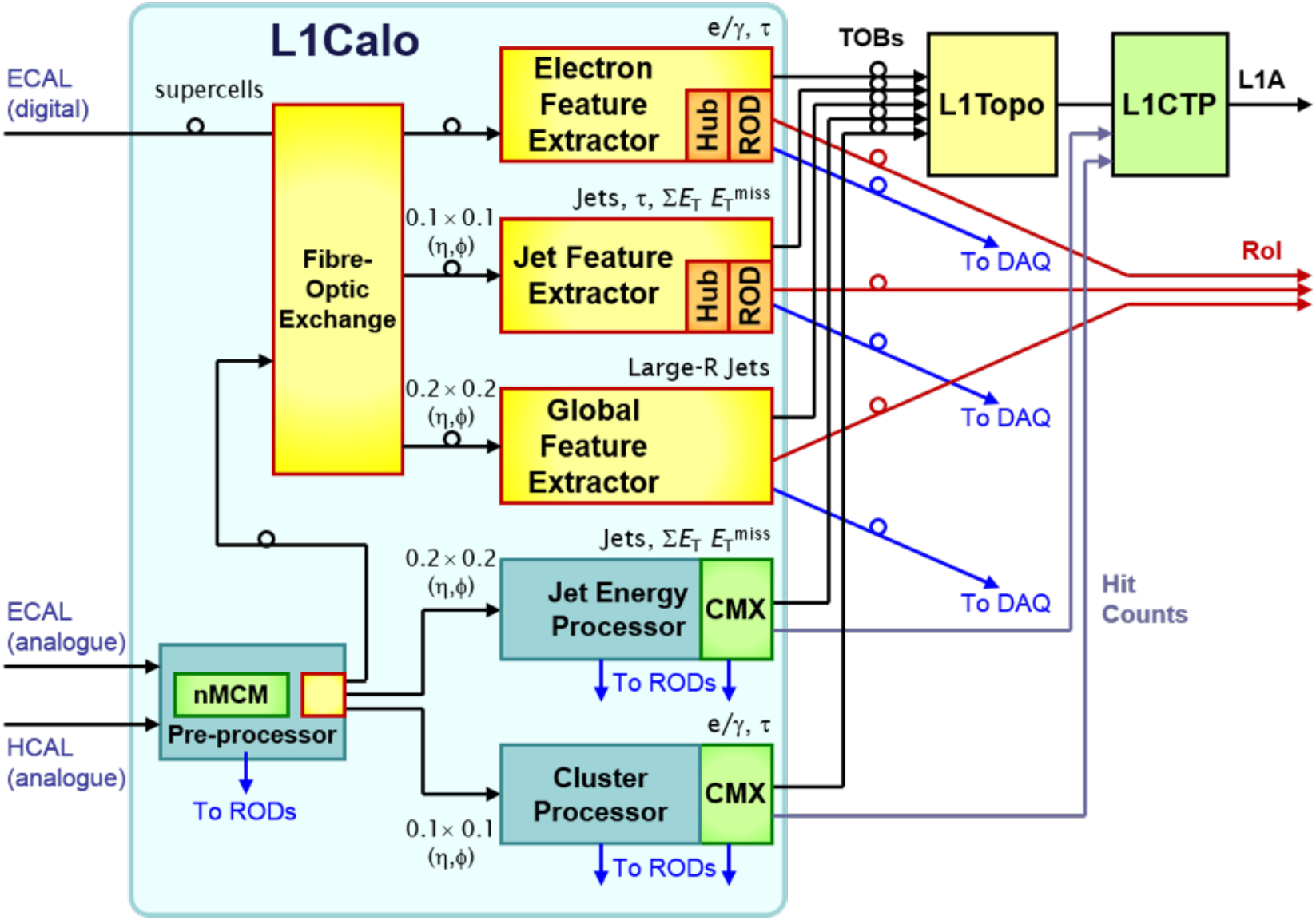
LHC Langfristige Planung



Starke deutsche Beteiligung an Phase 1 und Phase 2 Upgrades

Beispiel Upgrade Phase 1: ATLAS Level 1 Trigger

Vielzahl der Komponenten von deutschen Instituten entwickelt und gebaut



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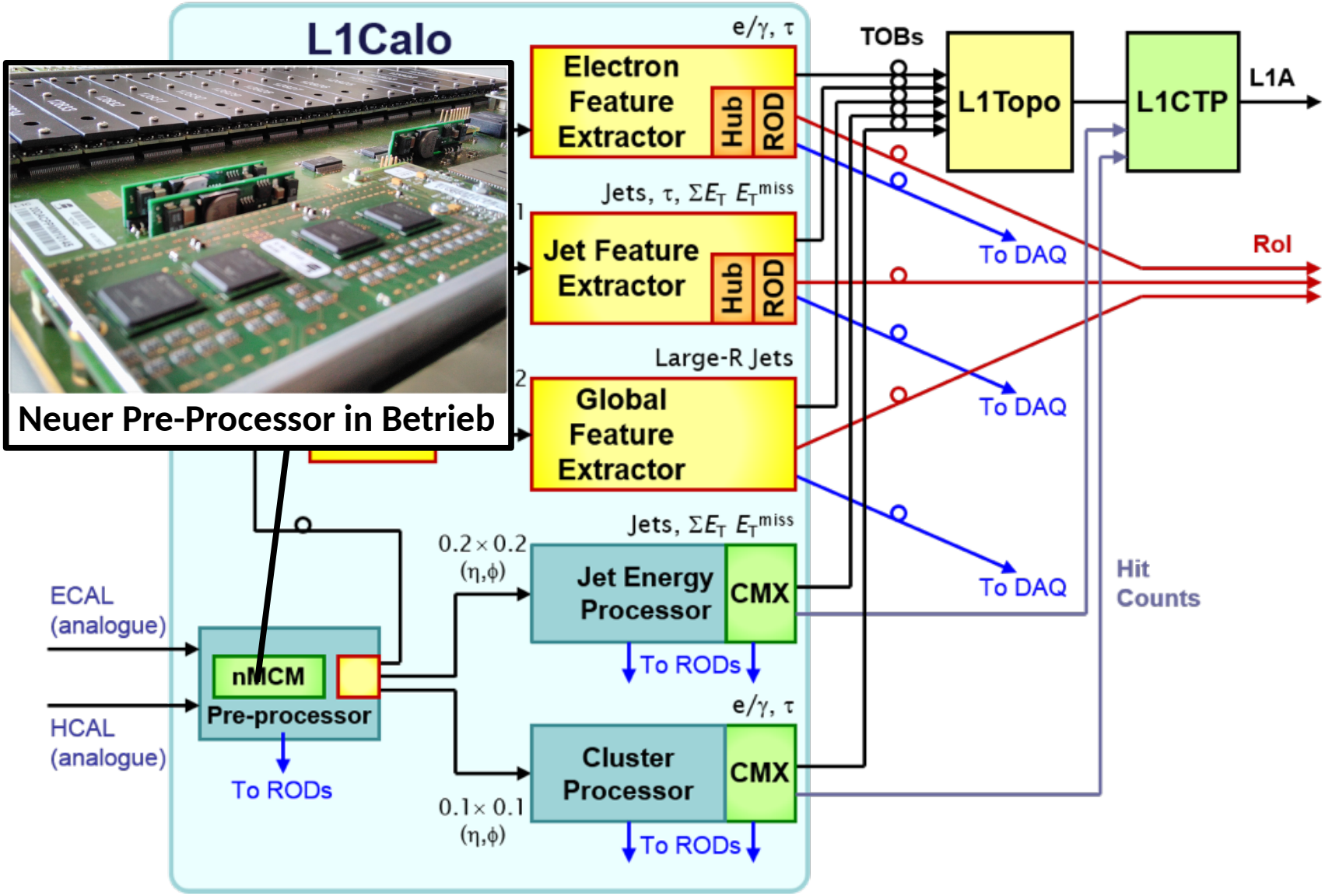

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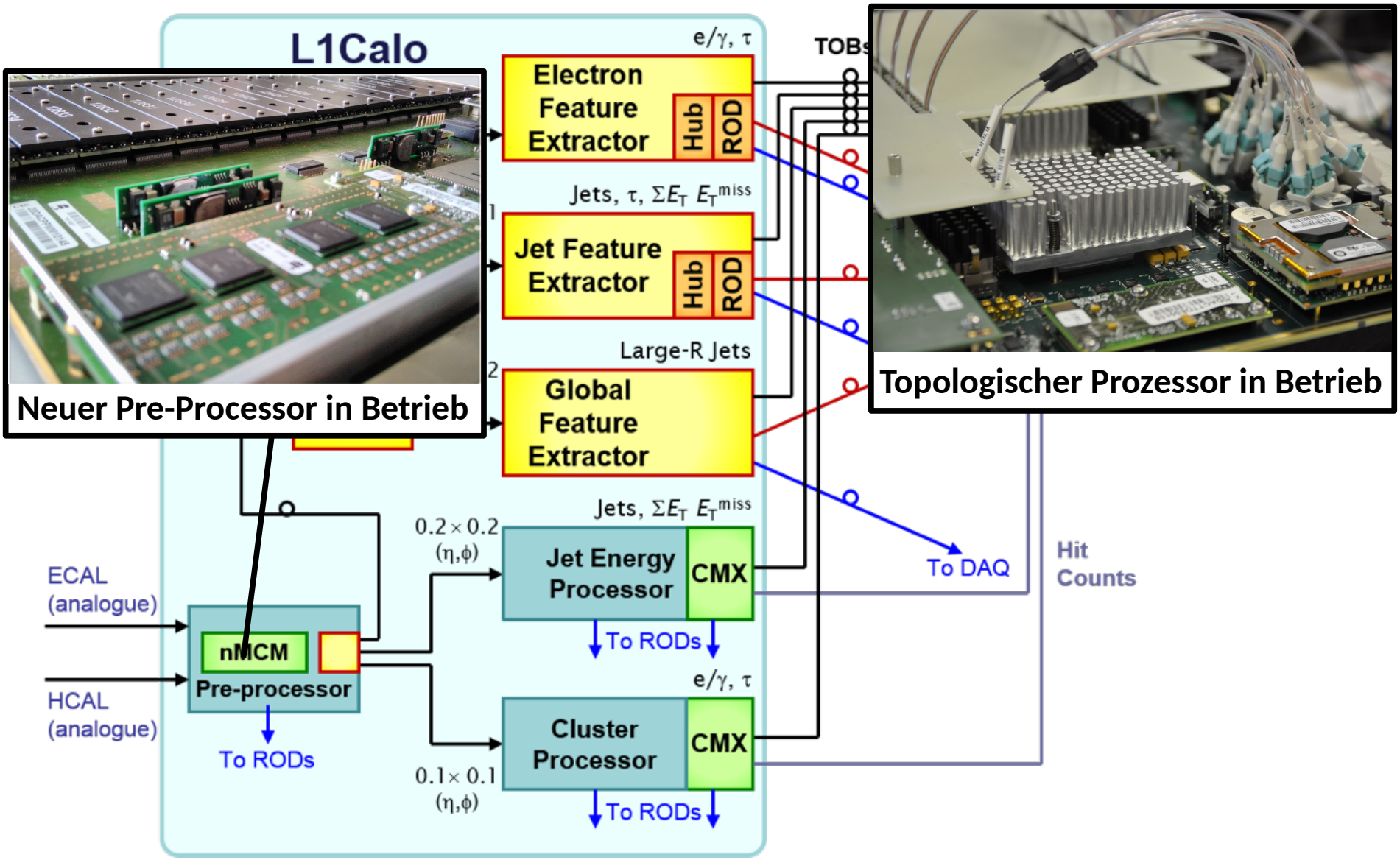
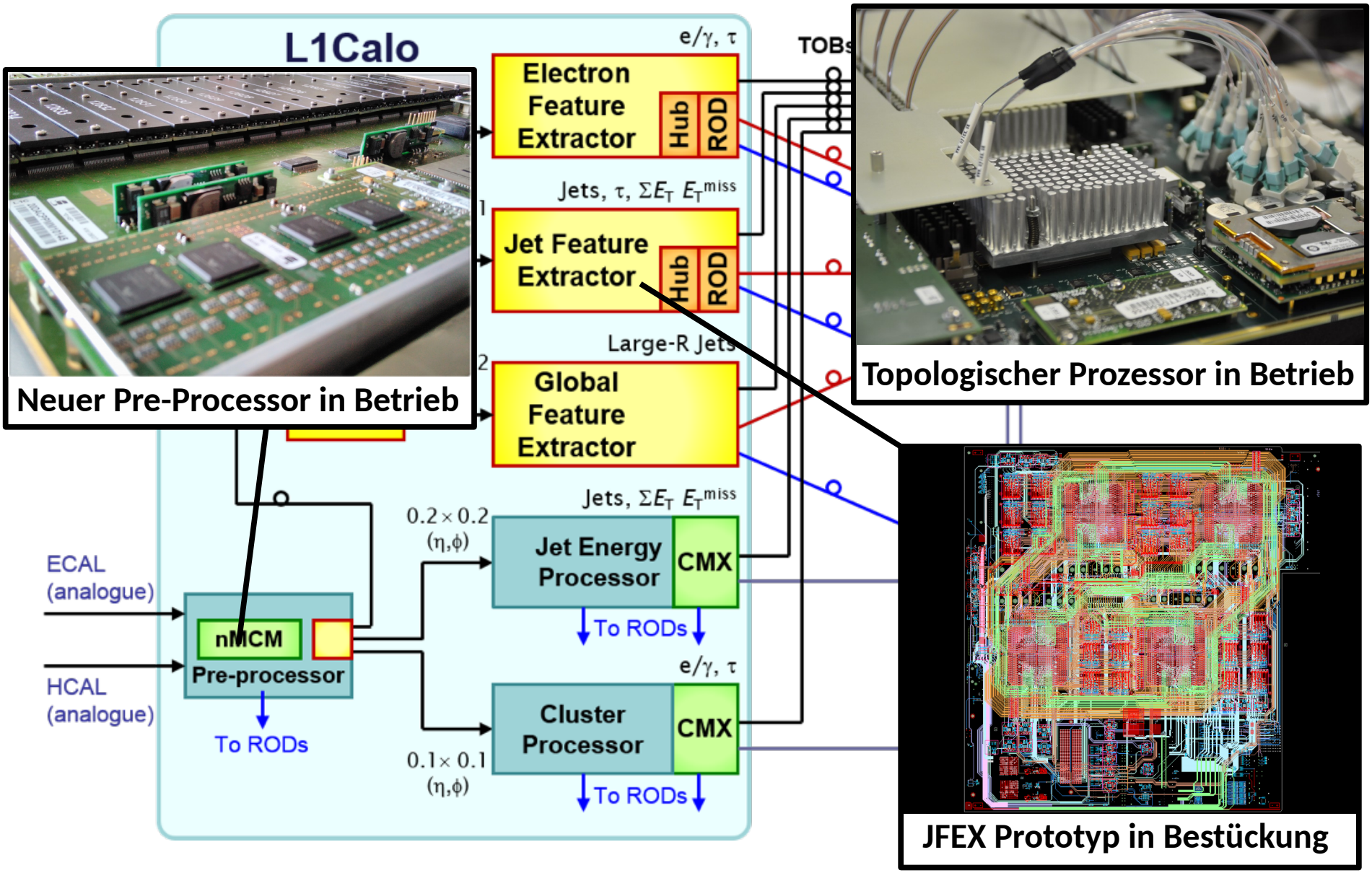


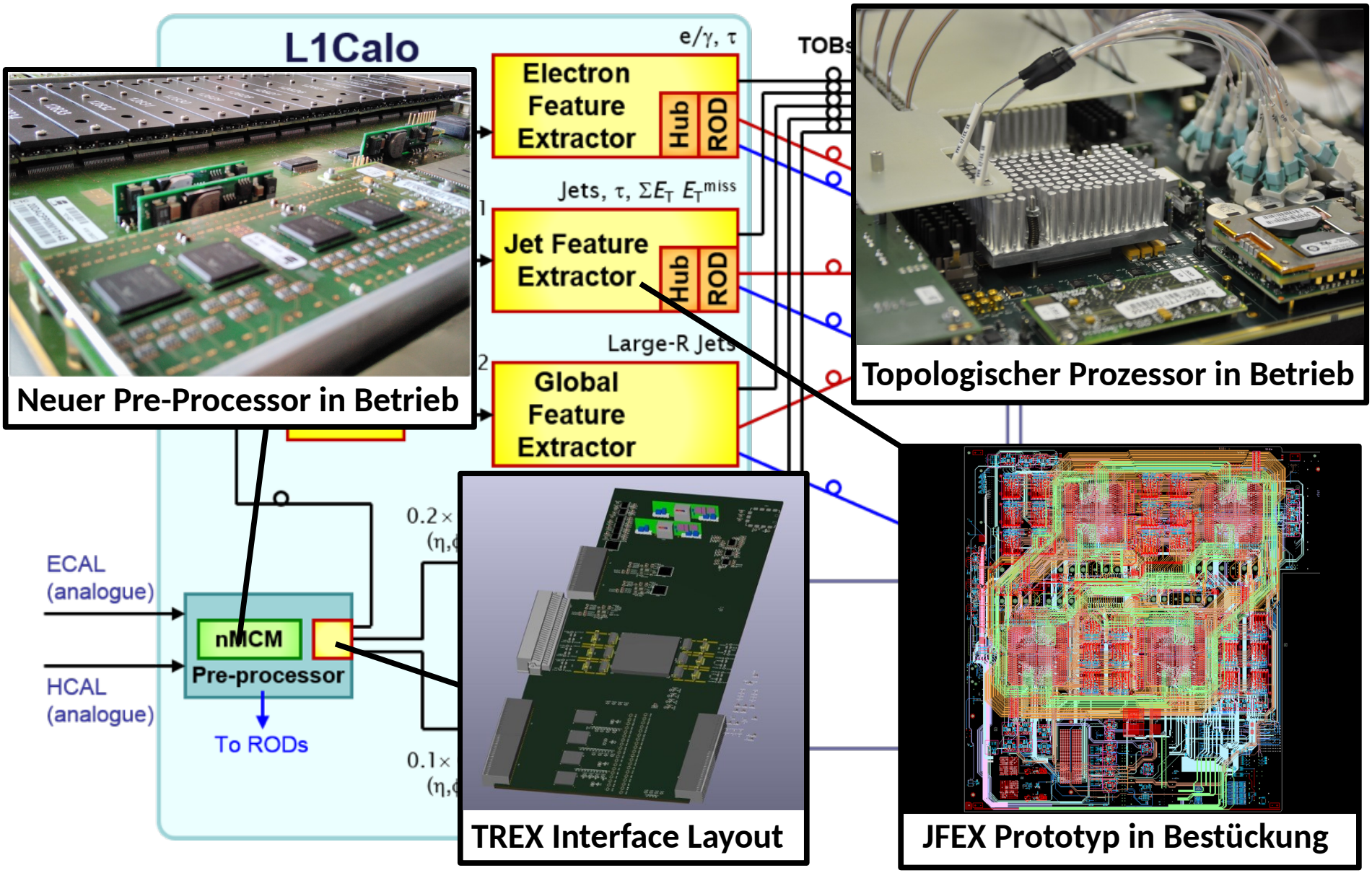
Beispiel Upgrade Phase 1: ATLAS Level 1 Trigger

Vielzahl der Komponenten von deutschen Instituten entwickelt und gebaut



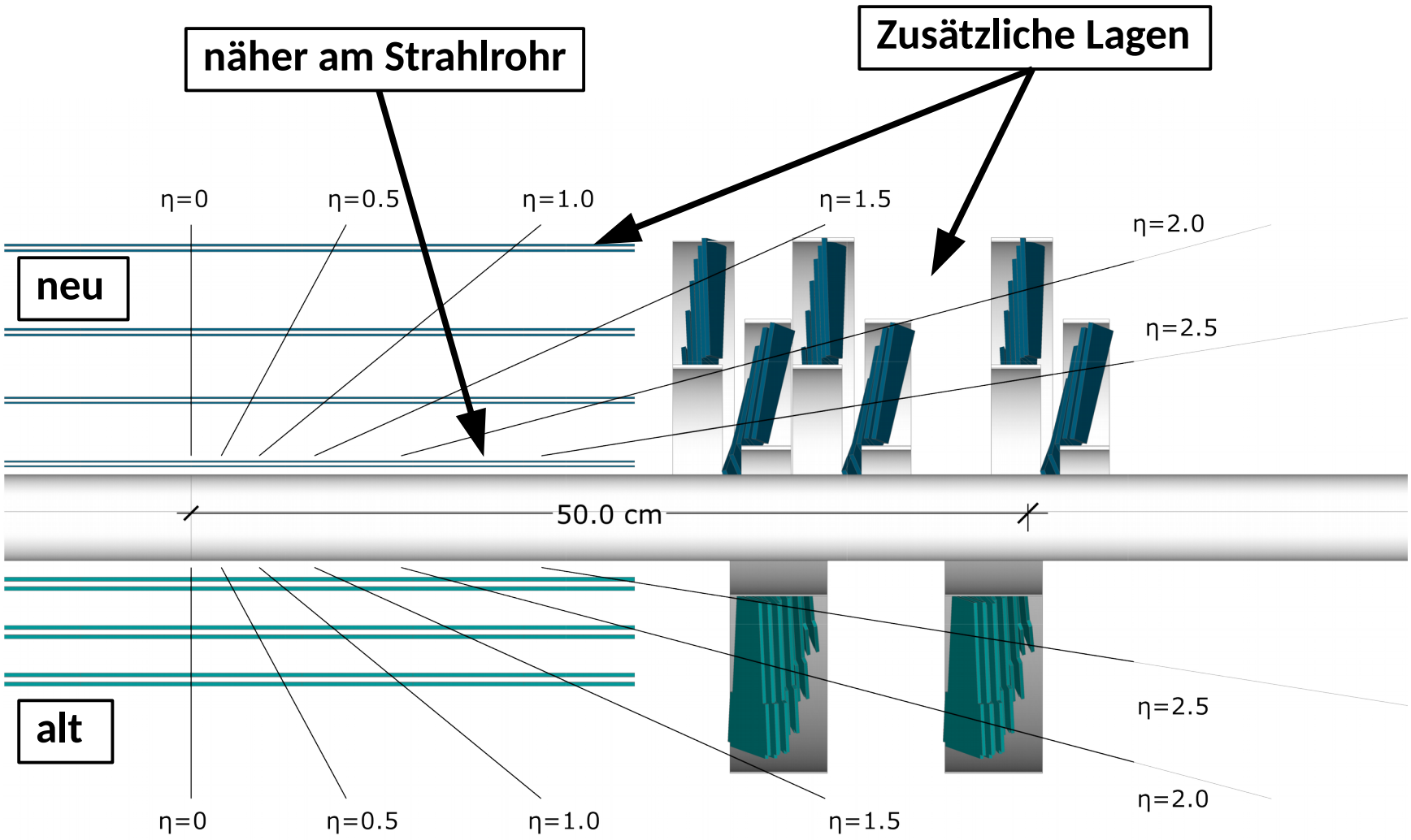
Beispiel Upgrade Phase 1: ATLAS Level 1 Trigger

Vielzahl der Komponenten von deutschen Instituten entwickelt und gebaut



Beispiel Upgrade Phase 1: CMS Pixel Detektor

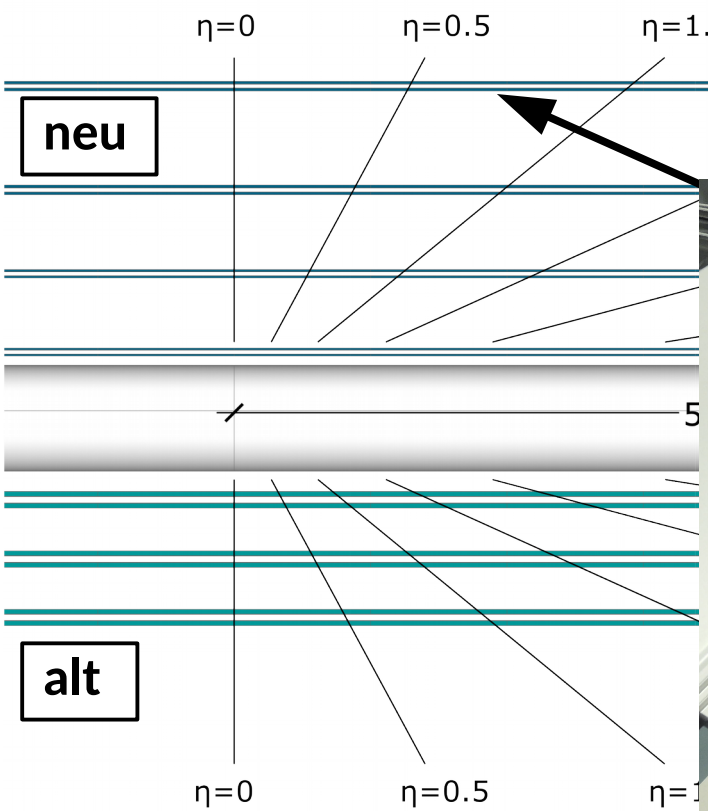
CMS Pixeldetektor wird komplett ersetzt

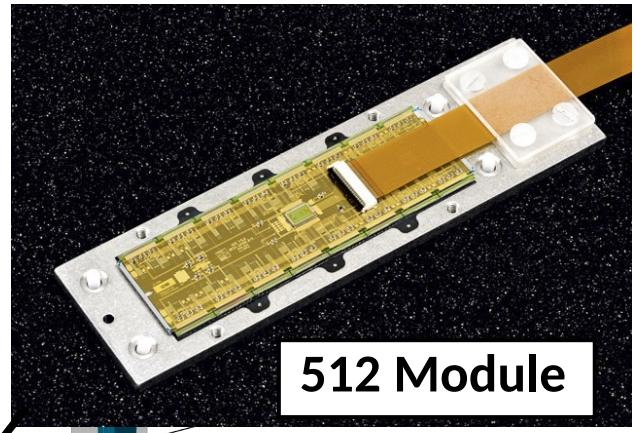


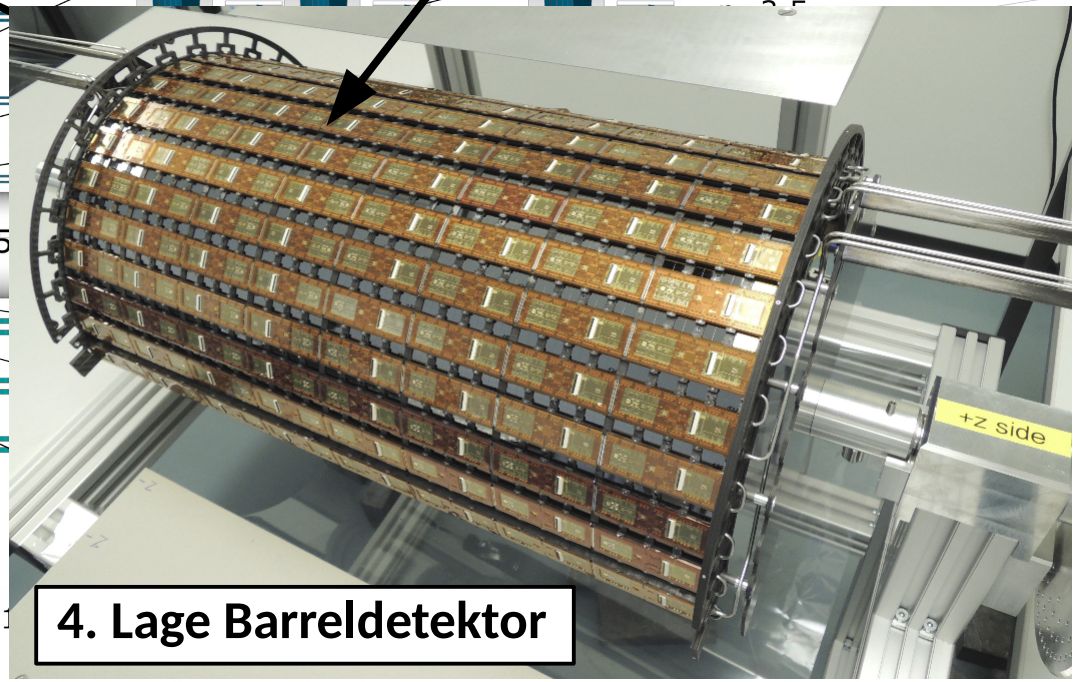
Beispiel Upgrade Phase 1: CMS Pixel Detektor

CMS Pixeldetektor wird komplett ersetzt

- 4. Barrel-Lage von deutschen Gruppen gebaut
- Modulproduktion erfolgreich abgeschlossen
- Detektor zur Zeit in Endmontage
- Einbau Februar 2017

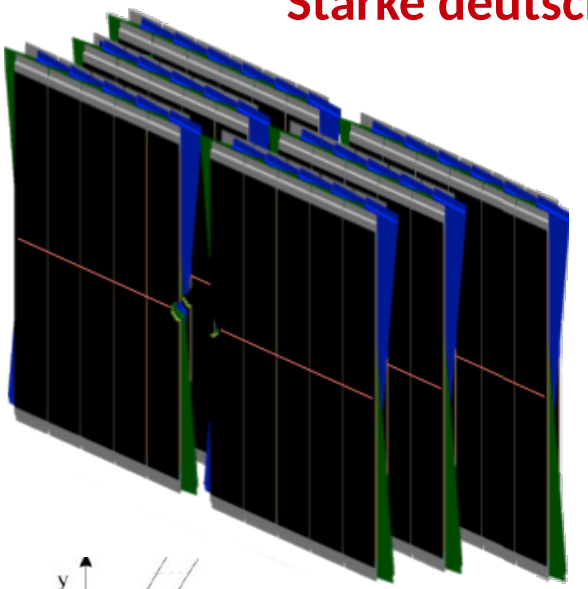




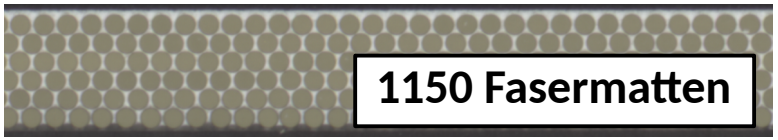


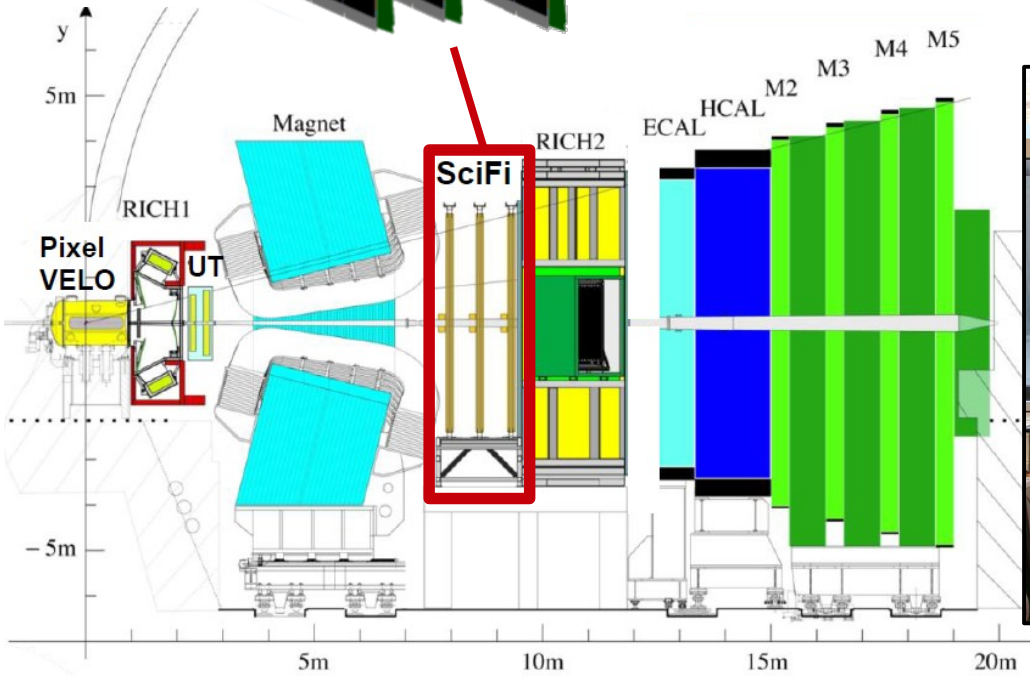
Beispiel Upgrade Phase 1: LHCb Scintillating Fibre Tracker

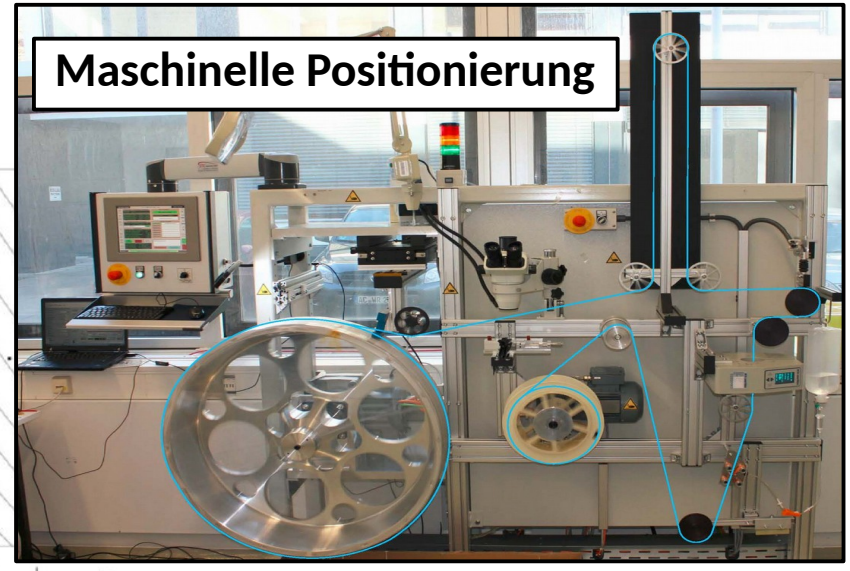
Starke deutsche Beteiligung am Bau des neuen SciFi Trackers



- 360 m^2 sensitive Fläche, Ortsauflösung <80µm
- 11.000 km Fasern, SiPM-Auslese
- Serienproduktion hat begonnen







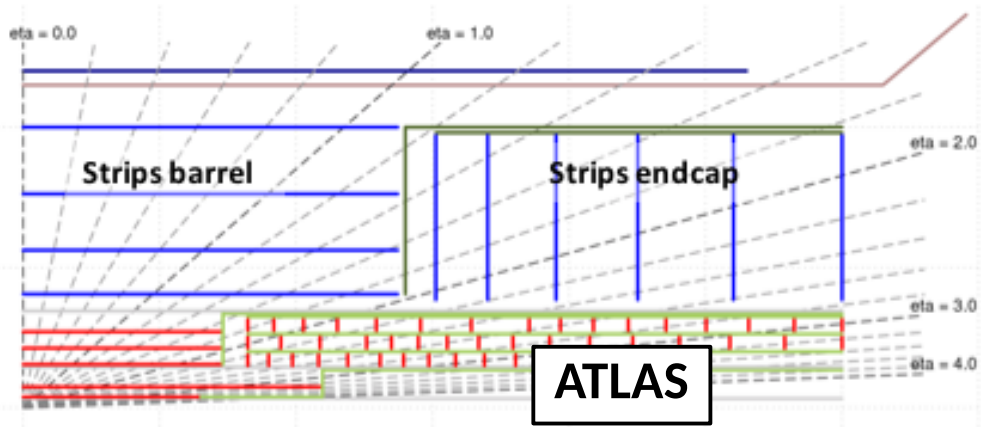
Upgrade Phase 2

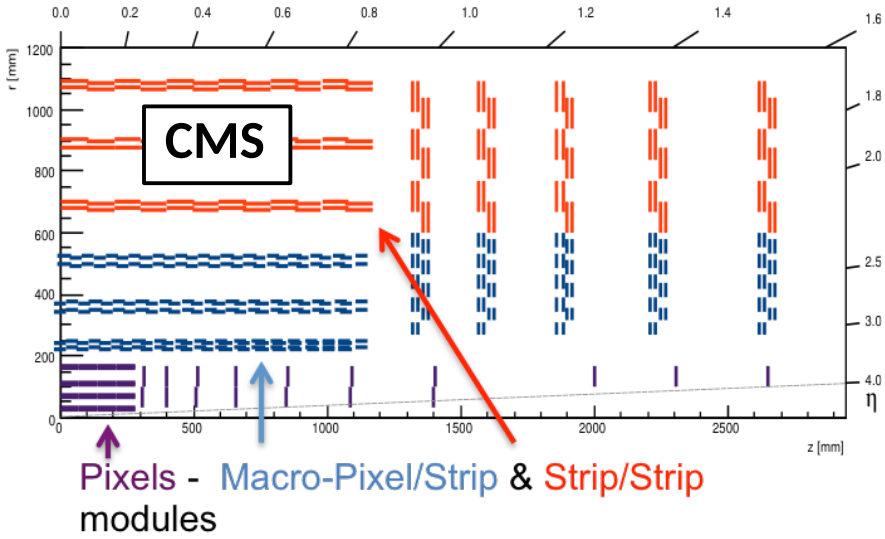
Alle Projekte: TDRs in 2017, MoU gegen Ende 2017

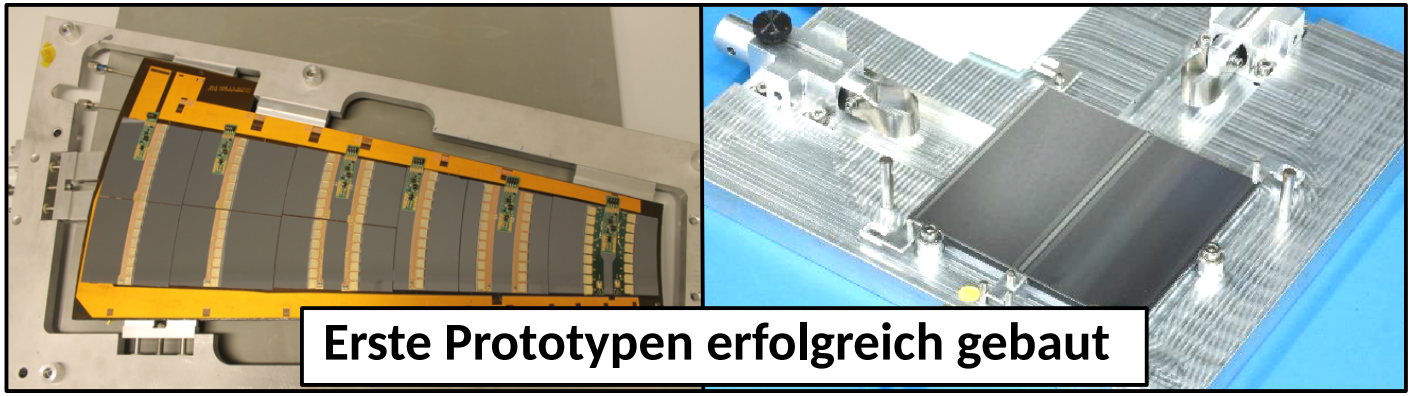
BMBF-Funding aus FIS-Projekt: zur Zeit R&D, erste core-Mittel in nächster FP

Beispiel ATLAS und CMS Siliziumstreifendetektoren:

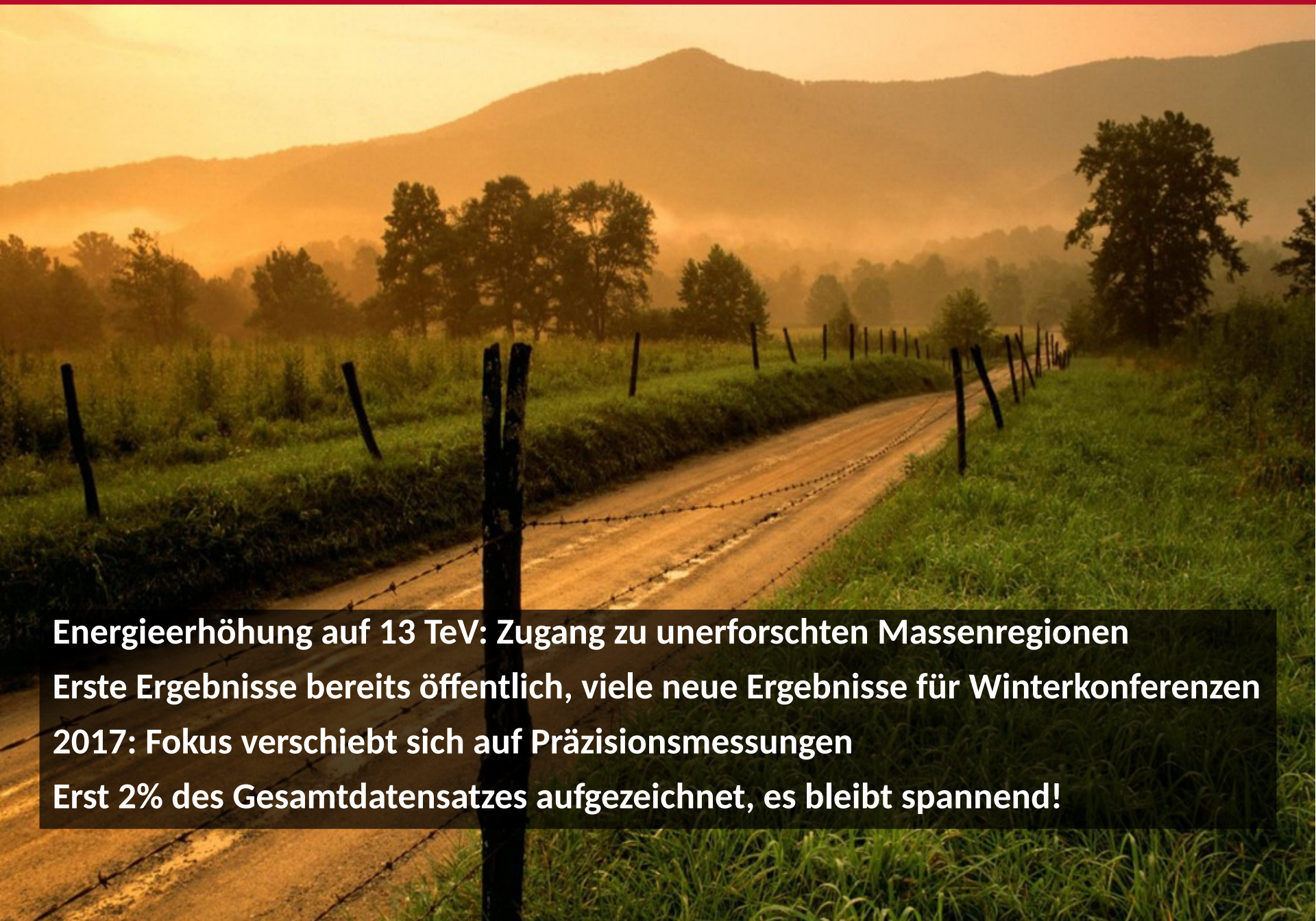
Bau jeweils einer Endkappe in Zusammenarbeit deutscher Universitäten und DESY







Zusammenfassung



Energieerhöhung auf 13 TeV: Zugang zu unerforschten Massenregionen

Erste Ergebnisse bereits öffentlich, viele neue Ergebnisse für Winterkonferenzen

2017: Fokus verschiebt sich auf Präzisionsmessungen

Erst 2% des Gesamtdatensatzes aufgezeichnet, es bleibt spannend!