The top quark
as the gateway to
new physics at the LHC

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DESY and Universität Hamburg
freyablekman

Quantum Universe Mini-Colloquium
30 November 2021

- MSc University of Amsterdam (2000)
- PhD Nikhef based at Fermi National Accelerator Laboratory (2005)
- Postdoc Imperial College 2005-2007
- Postdoc Cornell University 2007-2010

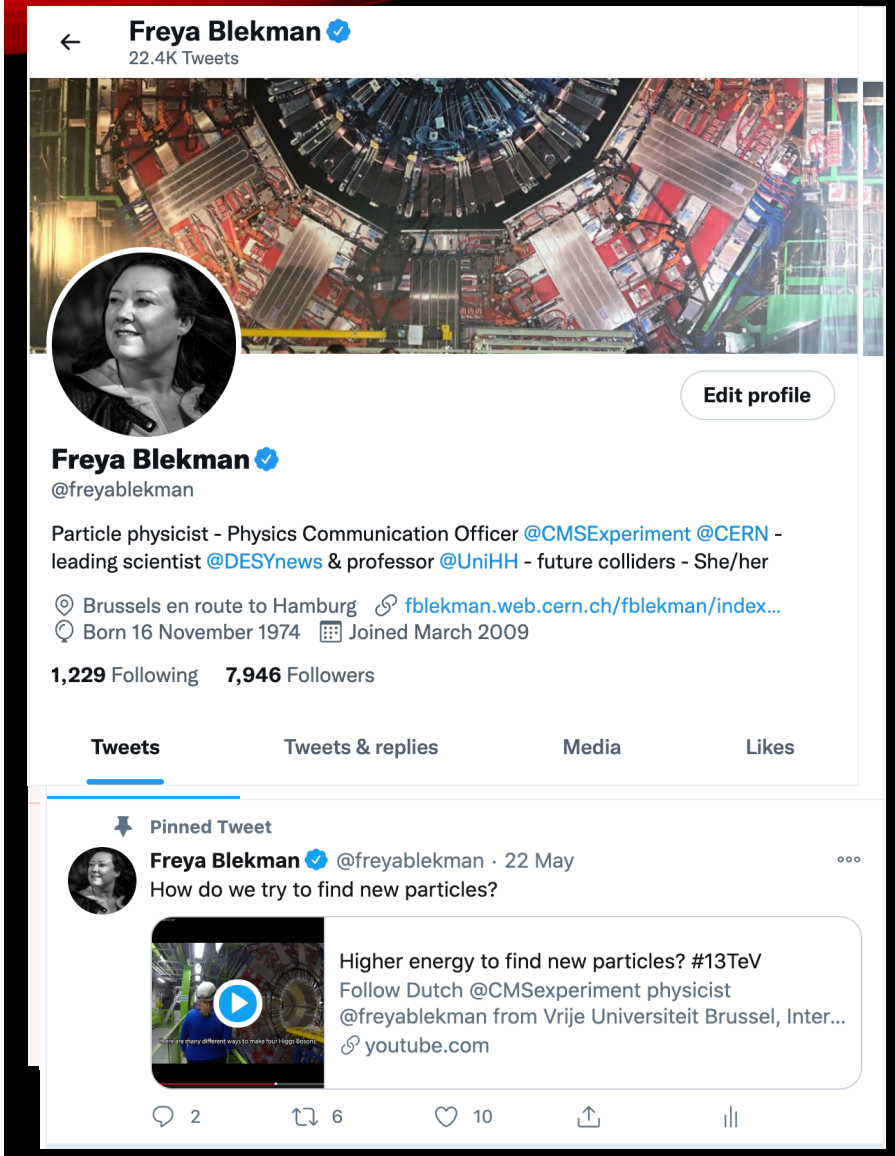
- 2010 Assistant Prof Vrije Universiteit Brussel
- 2015 Associate Prof Vrije Universiteit Brussel
- 2019 Full Prof Vrije Universiteit Brussel

2021: Helmholtz recruitment:

Lead Scientist at DESY and professor at UniHH

international links:

- Visiting professor Oxford
- long standing collaboration with University of Bristol (shared PhDs)
- LPC Distinguished Researcher Fermilab
- Visiting professor at Vrije Univ. Brussel



CMS ever first physics communication officer

- **Responsible /coordinating physics scicomm of CMS**

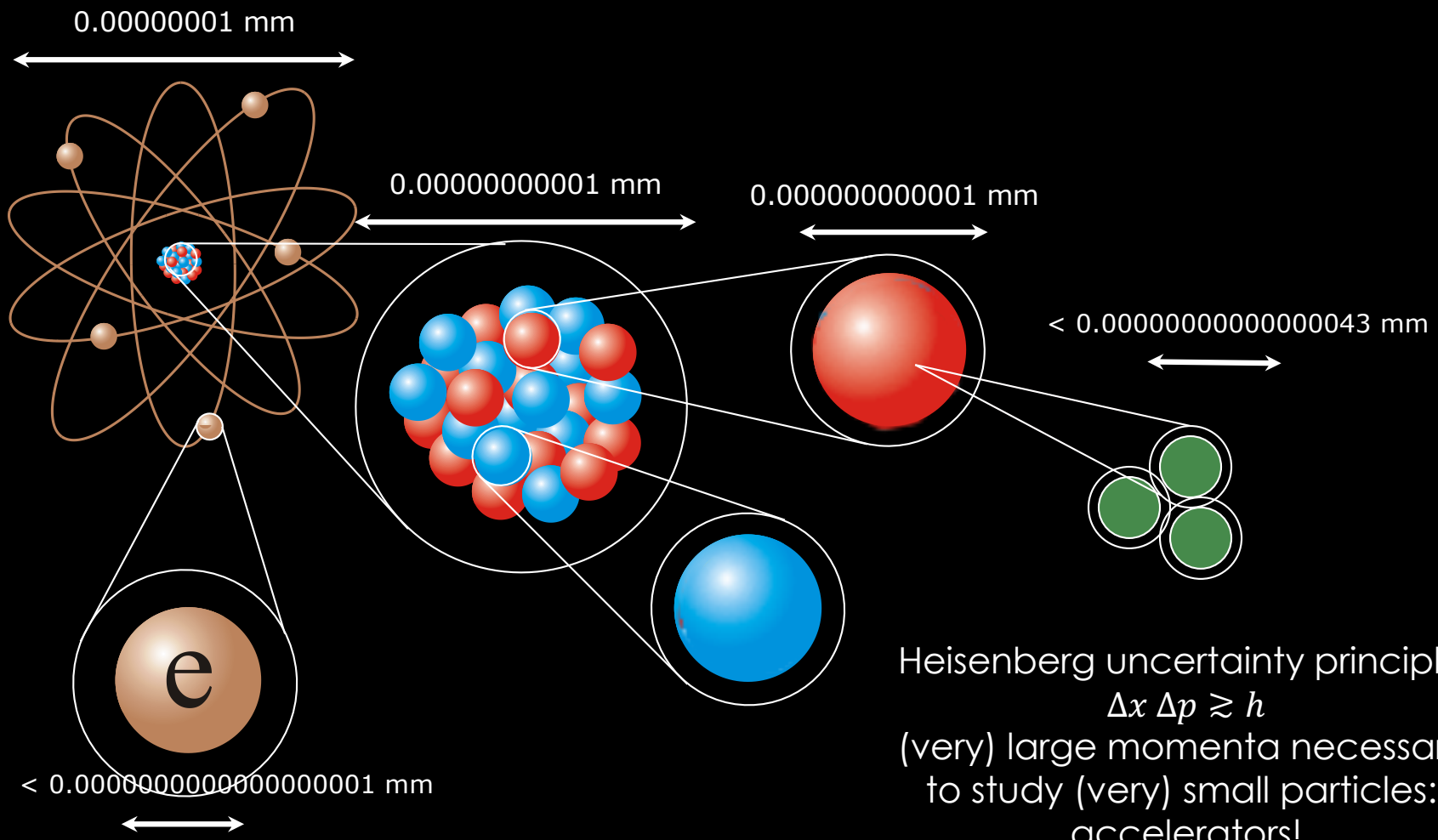
Outreach via social media:

- Personally reaching 150-200k people per month
- **Follow me on twitter for (particle) physics and beyond!**
- Also: Youtube videos with 200k+ views

Good links international media (*Nature* news, *Science* news, New Scientist, Wired, Gizmodo, newspapers USA, UK, BE, NL)

- Since starting: five media appearances already in international, benefit to DESY !

Looking forward to working within DESY outreach activities 🖤❤️💛



Heisenberg uncertainty principle:
$\Delta x \, \Delta p \gtrsim h$
(very) large momenta necessary
to study (very) small particles:
accelerators!

"Physics beyond the standard model"

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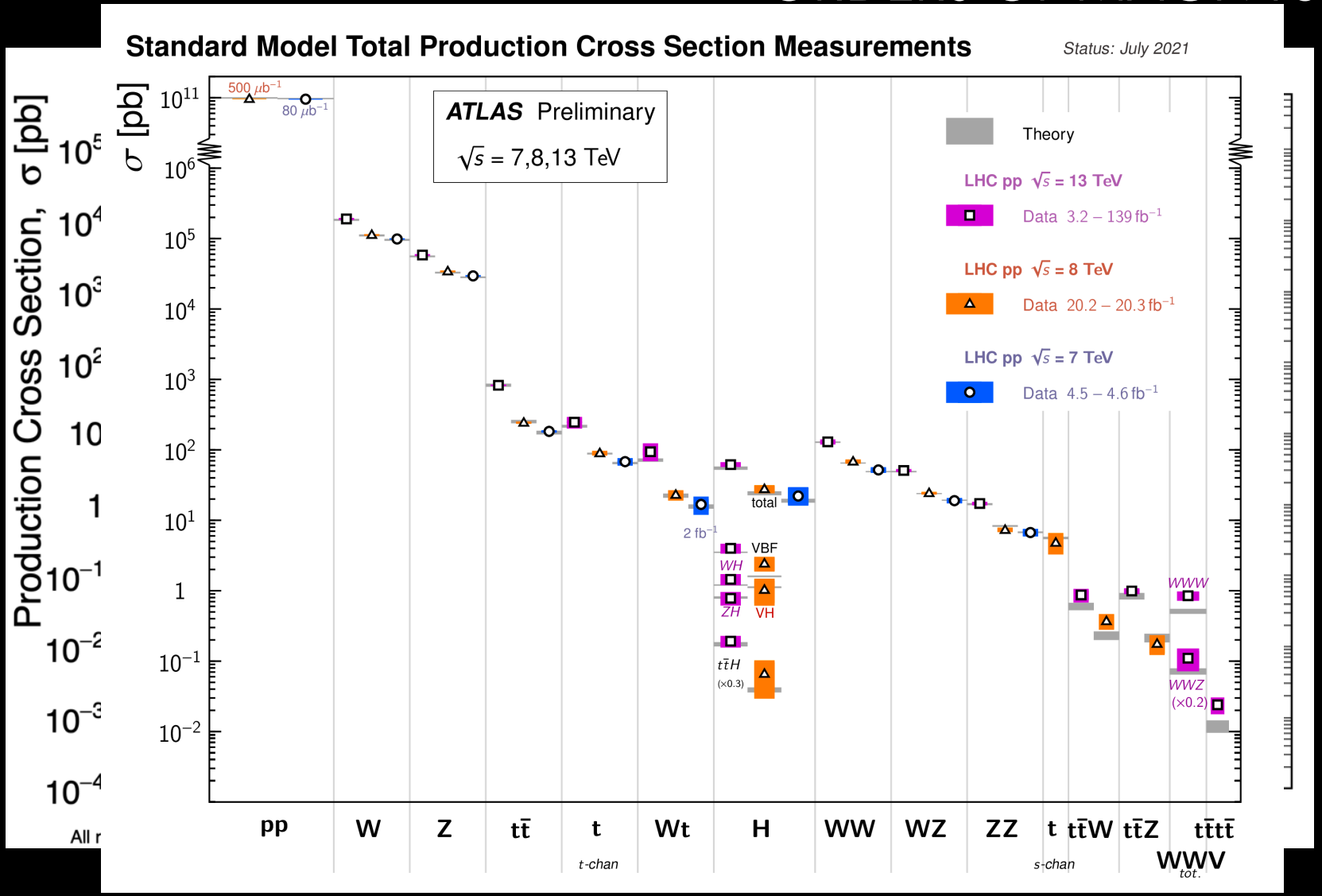
STANDARD MODEL AT THE LHC: ORDERS OF MAGNITUDE

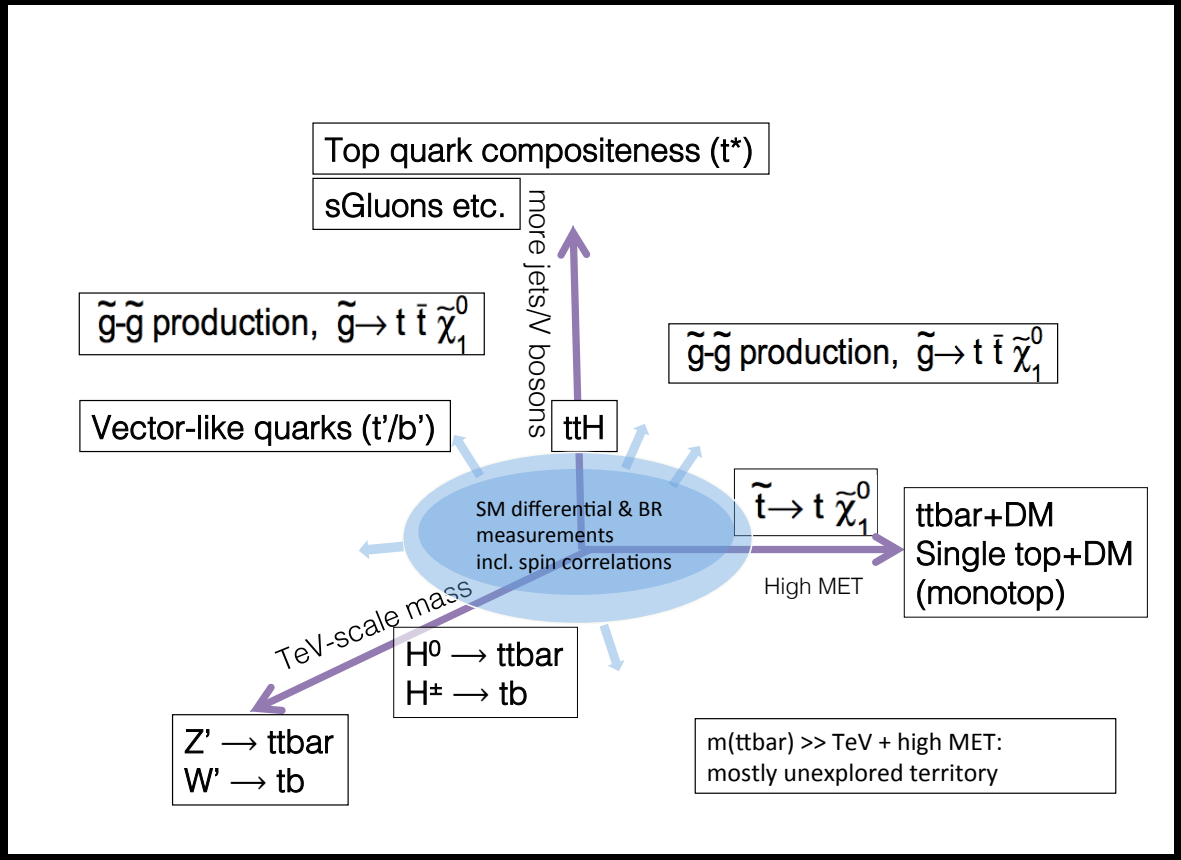


PROBLEMS WITH THE STANDARD MODEL – EXPERIMENTALIST PERSPECTIVE

- No explanation for Higgs sector, hierarchies of force strenghts and general structure
- Matter vs antimatter asymmetry
  - Standard Model cannot provide enough CP violation to explain dominance of matter
- Dark Matter
  - No known physics explanation that covers all observations
  - If DM is a particle, it is very likely not described by the Standard Model
  - Neither is dark energy
- Standard Model neutrinos are massless
  - The 2015 Nobel Prize (Kajita and McDonald) was for neutrino oscillations, directly proving that neutrinos have mass
  - Impossible to incorporate in the standard model without extra other interactions

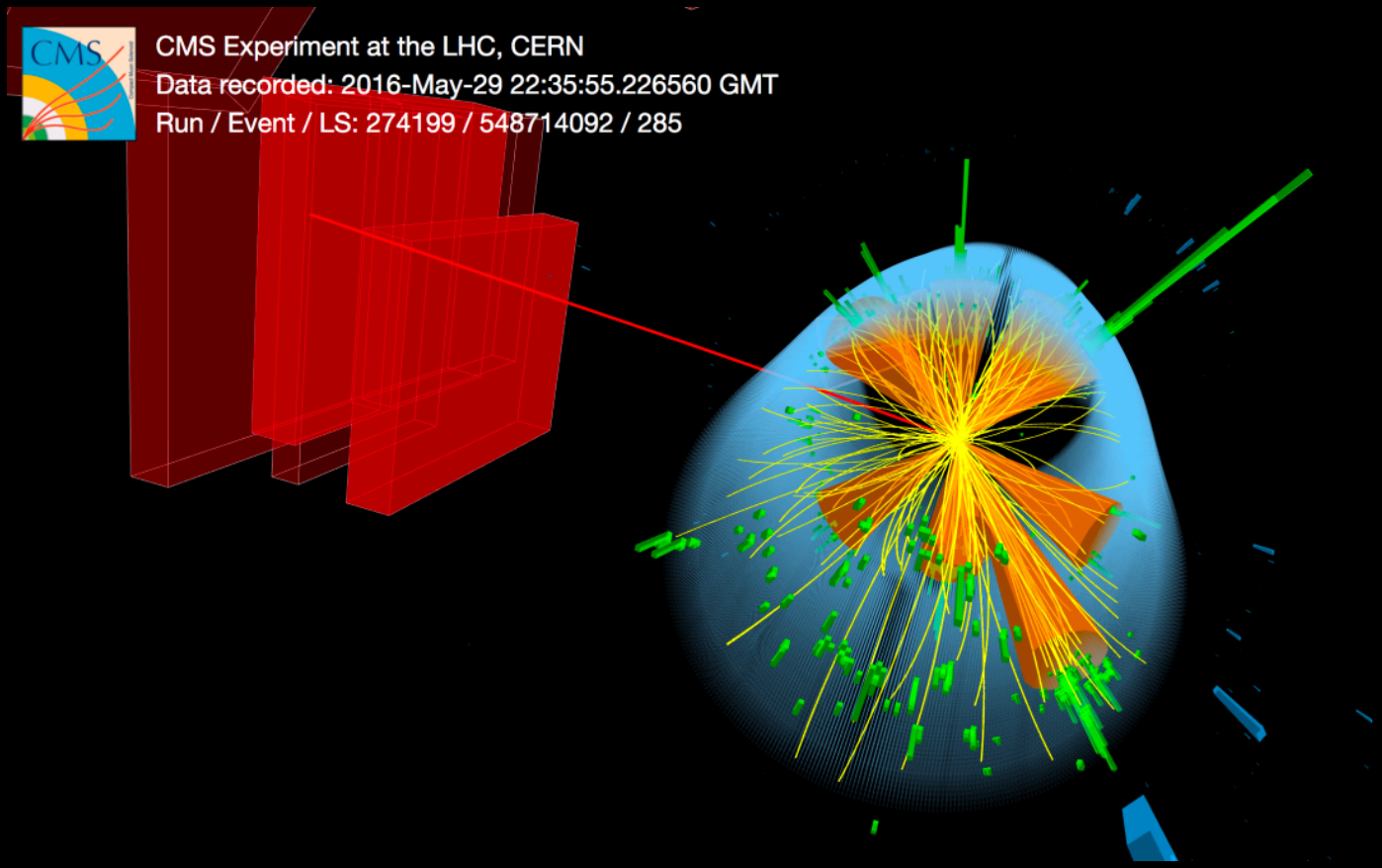
- CHALLENGE:
- WHERE ARE THE NEW PARTICLES???

TOP QUARKS AS TOOL TO COLLECT NEW PARTICLES



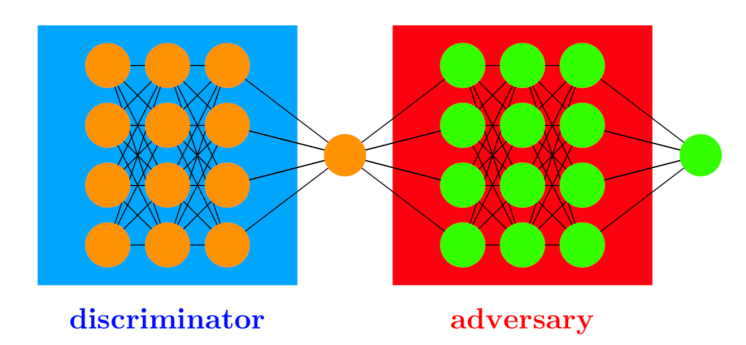
See also: Czakon et al. arXiv:1501.01112

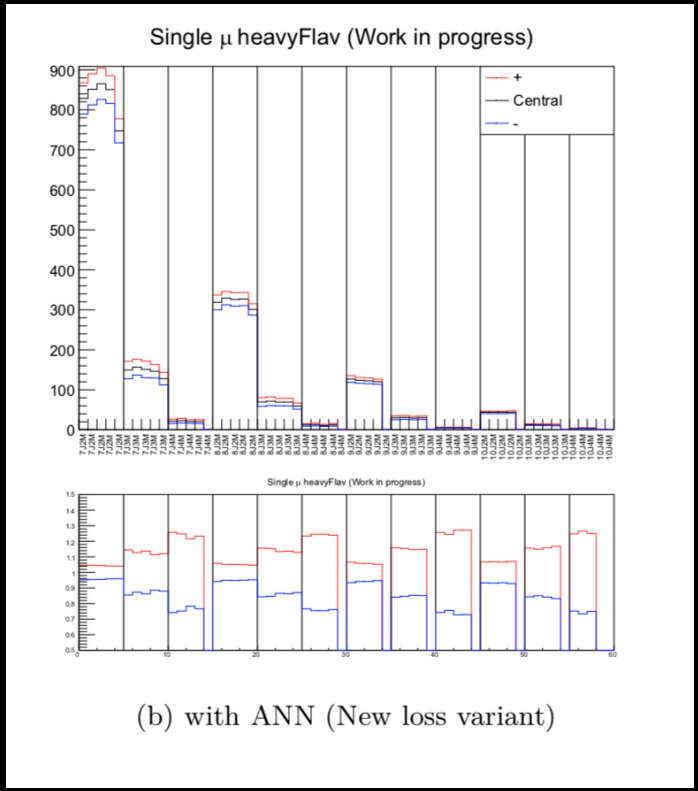
I STUDY VERY BUSY COLLISIONS



SMARTER ANALYSIS TECHNIQUES!

- Smarter Machine Learning
- Ex: Pivoted Adversarial Neural Networks
  - Are trained to reduce sensitivity to systematic uncertainties
  - Louppe et. al, Arxiv:1611.01046 (stat.ML)

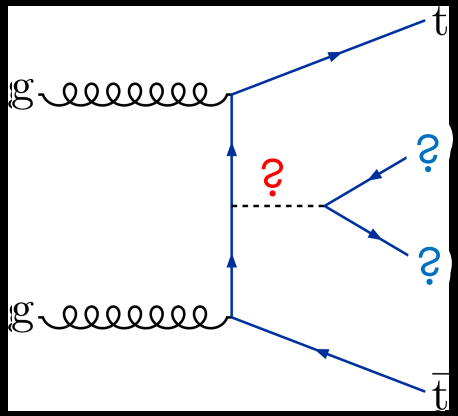




(b) with ANN (New loss variant)

src:
CERN-THESIS-2019-100 MSc. V. Wachirapusitanand,
(winner 2nd place poster prize CMS week)

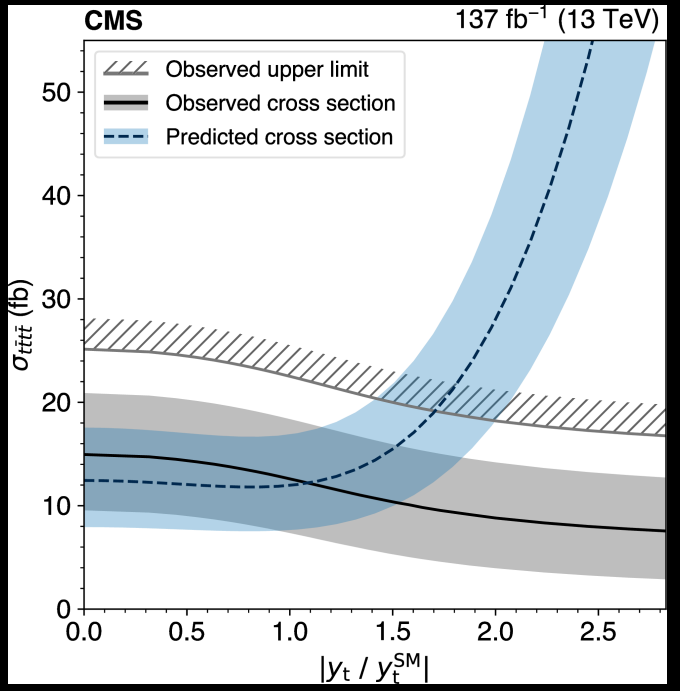
FUNDAMENTAL CONSTANTS FROM BUSY COLLISIONS?



- Many diagrams at lowest order in tttt production
- About 10-20% of the cross section comes from higgs production

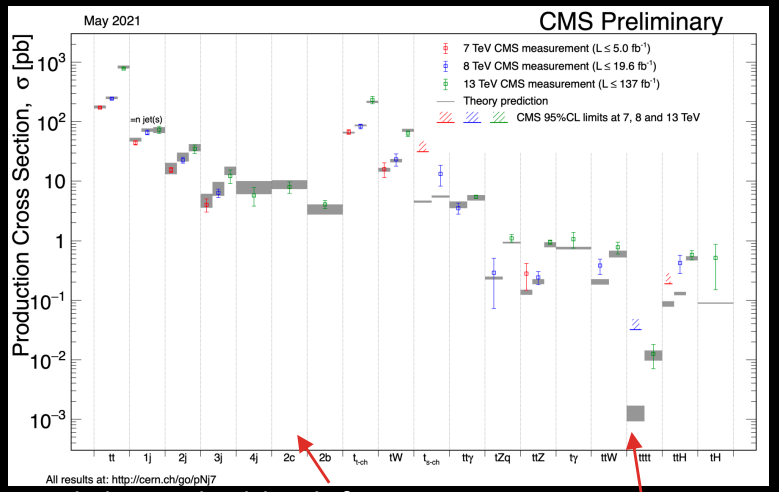
src: TOP-18-003 arxiv:1908.06463 (EJPC)

- tttt is sensitive to the coupling of higgs to top quarks!
- Direct link top yukawa coupling



PLAN: SEARCH FOR NEW PARTICLES PRODUCED TOGETHER WITH TOP QUARKS

- Answer the question are there new particles produced **together with top quarks**?
  - And continue with tttt production until observation
- **Both rely on the very large samples that only now are becoming available**
- Example:
  - DM mediators, VLQ, LQ all enhance tttt and ttbb
  - ALPS
  - And then move to other high multiplicity signatures
  - Plans to also include LLP in such busy topologies



Search here, but look for resonances

(essentially tt+many b/c jets)

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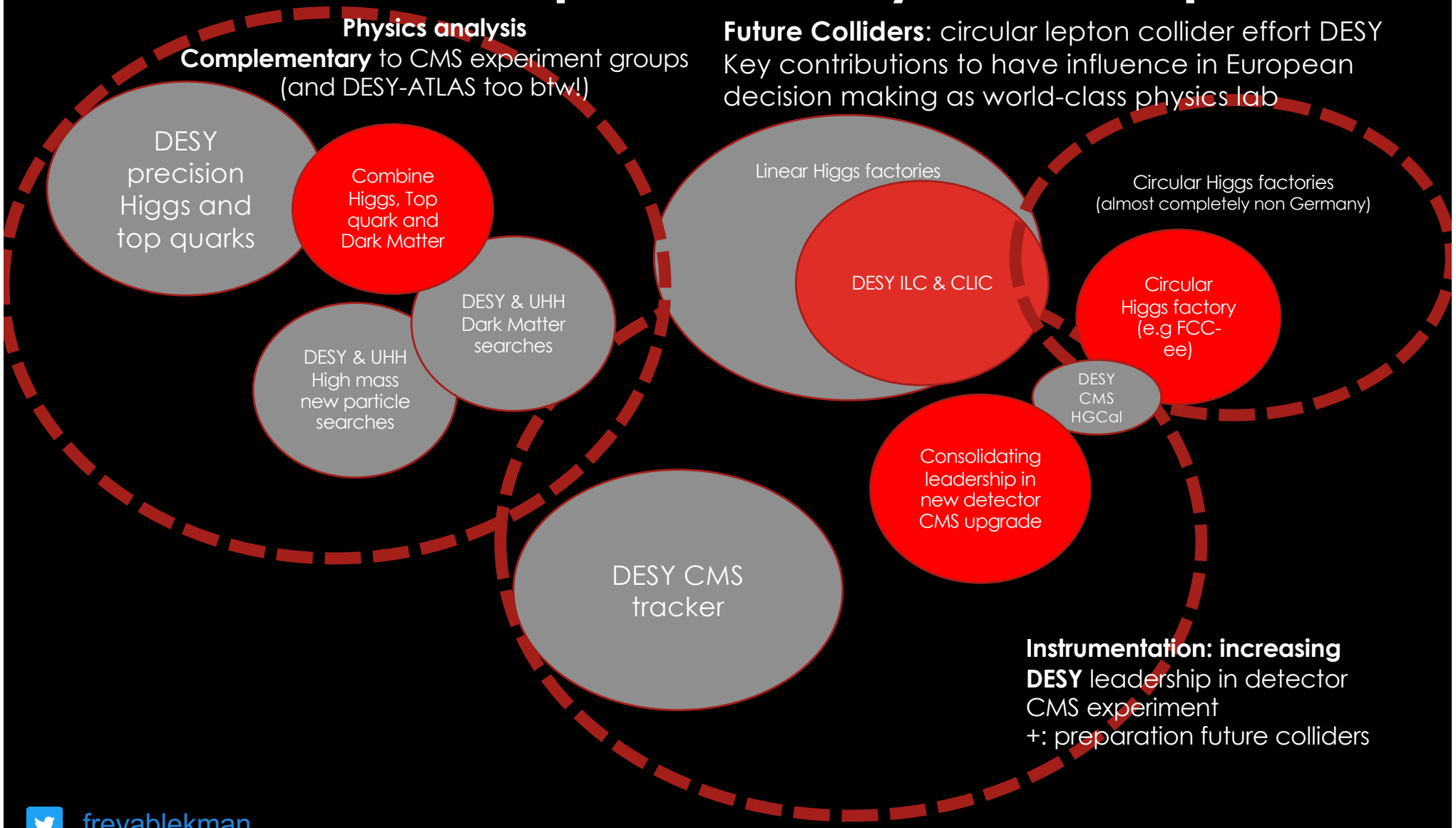
- Many of these models and techniques also relevant for future colliders
- And will start contributing to CMS HGCal for Phase 2 upgrade

Complementarity and uniqueness

Physics analysis
Complementary to CMS experiment groups (and DESY-ATLAS too btw!)

Future Colliders: circular lepton collider effort DESY
Key contributions to have influence in European decision making as world-class physics lab



Instrumentation: increasing
DESY leadership in detector CMS experiment
+: preparation future colliders

Are we done?
NOT EVEN CLOSE!

- There is a long list of problems with the standard model that needs answers
- There is long list of unexplored signatures that need much (high quality) data
  - Leave no stone unturned
  - There are final states mostly unexplored at the LHC
- My detector efforts provide ties LHC experiments and future collider efforts
- Senior FH staff with strong outreach profile will benefit DESY in many aspects
- Broad interest beyond particle physics, including astro-particle, biophysics & fundamental physics in general (e.g. GW)

Medium-term plan:

- Do world-class (and highly visible) physics with CMS
- Strengthen transition ILC to agnostic future collider @DESY
- Contribute local experiment (LUXE?)
- Continue to internationally (eventually locally) promote particle physics

How can DESY directorate help:

- Resources covered (now) by generous Helmholtz funding
- Support with connection to outreach/PR team resources

PHOTO TAKEN IN HAMBURG, 1977

Great to meet everyone and

thanks for your attention

Management (highlights)

On CMS full-time since 2005

- Pixel detector convener during Run 1 LHC startup
- First B2G convener when group started
- SUSY PubComm chair for 4 years
- Currently first CMS physics Communications Officer

CMS papers (highlights):

- First CMS ttbar cross section with b-tagging
- First CMS b-tagging papers
- First displaced lepton search
- First MET paper & MET significance
- Evidence/discovery tW production
- Broad analysis interest: searches for BSM in multijet+MET (with/without substructure) up to ttbar differential cross sections
- Currently working on finding four-top production (both BSM and SM): evidence expected in Run 2