Title: Colliding light, tau gâ€“2, and broadband axion detection

Speakers: Jesse Liu

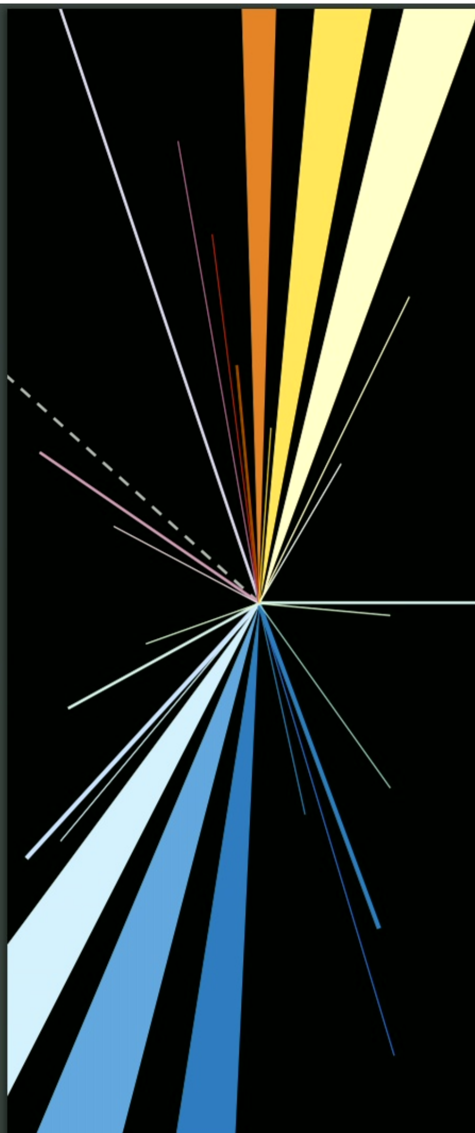
Series: Particle Physics

Date: May 03, 2022 - 1:00 PM

URL: https://pirsa.org/22050000

Abstract: Muons are the archetypal 'who ordered that?' surprise discovered in cosmic rays and fittingly, recent muon measurements including g-2 could be challenging standard paradigms again. Remarkably, tau g-2 remains poorly constrained but can be 280 times more sensitive to new physics than the muon. Recently, ATLAS and CMS announced groundbreaking measurements of tau g-2 using the landmark observation of tau pairs created via photon collisions in LHC heavy-ion data. Beyond colliders, quantum sensing progress enables next-generation haloscopes to illuminate axion-like origins of dark matter above microwave frequencies. This motivates the Broadband Reflector Experiment for Axion Detection (BREAD) proposal at Fermilab and its interdisciplinary science program bridging astronomy, particle physics, and quantum technology.

Zoom Link: https://pitp.zoom.us/j/95937524952?pwd=eFVaTXVXOHBiNE9TZk9oMGNxRUwyQT09



Colliding light to measure tau $g - 2$

Perimeter Institute for Theoretical Physics
Particle Physics Seminar
3 May 2022

Jesse Liu
University of Cambridge

TRINITY COLLEGE CAMBRIDGE
UNIVERSITY OF CAMBRIDGE

Chrome File Edit View History Bookmarks Profiles Tab Window Help Tue 3 May 13:04

It's great to be back! 🎉

HOW IT STARTED...

Natalia Toro & Mariana Carrillo González

Field theory for continuous-spin particles

Perimeter Scholars International Essay

Jesse Liu
George Leibbrandt Library
Perimeter Institute for Theoretical Physics
Waterloo, Ontario N2L 2Y5, Canada

Friday 29th May, 2015

ABSTRACT: Continuous-spin particles are the most general massless particle allowed by special relativity and quantum theory. We review the construction of a free field action describing a single bosonic continuous-spin particle, before proposing an extension to the fermionic variety. We follow the Schuster–Toro vector superspace formalism, which generalises the Schwinger–Fang–Fronsdal prescription of classical fields with arbitrary integer and half-integer helicity.

SUPERVISOR: Natalia Toro

PSI Class 2014–15

... HOW IT'S GOING

POST-PSI SCIENCE MONTAGE

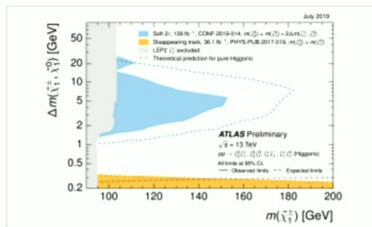
physics.ins-det	hep-ex	hep-ph	

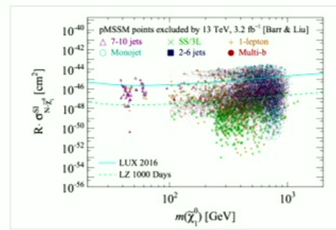
ATLAS silicon trackers
Dawson, ..., JL et al
JINST (2019)

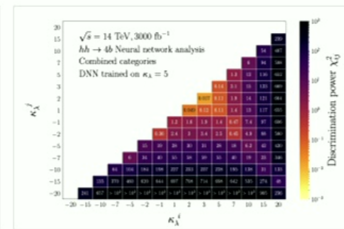
Higgsinos & sleptons
ATLAS (JL Editor)
1712.08119, 1911.12606 (PRD)

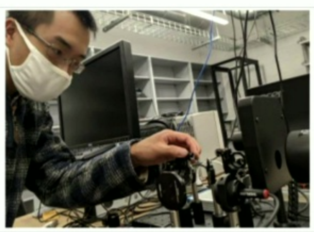
Supersymmetry pheno
Barr & JL
1605.09502, 1608.05379 (EPJC)

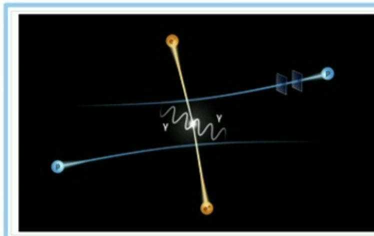
Higgs self-interaction
Amacker, ..., JL et al
2004.04240 (JHEP)

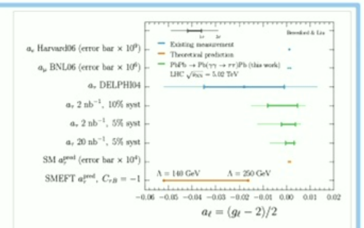


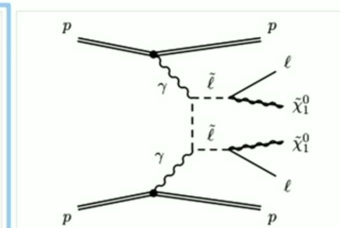












Axion dark matter
BREAD Collaboration
JL et al 2111.12103 (PRL)

Colliding light at LHC
ATLAS (JL Editor)
2009.14537 (PRL), 2204.13478

Tau g – 2 in Pb+Pb
Beresford & JL
1908.05180 (PRD)

Turn light → dark matter
Beresford & JL
1811.06465 (PRL)

TODAY'S FOCUS

April 2021: $g - 2$ recaptures international attention

The New York Times

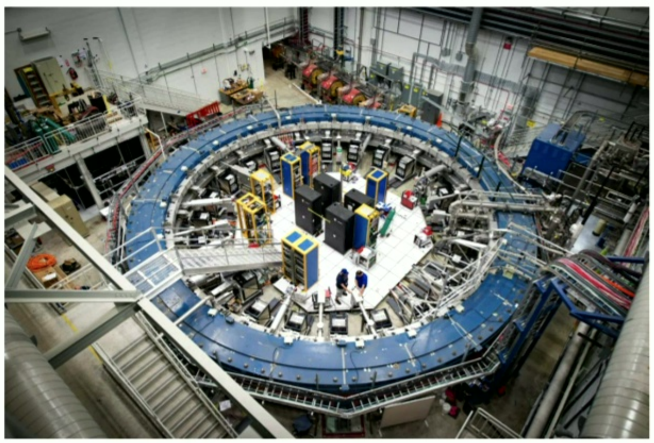
SUBSCRIBE FOR £0.5/WEEK LOG IN

OUT THERE

A Tiny Particle's Wobble Could Upend the Known Laws of Physics

Experiments with particles known as muons suggest that there are forms of matter and energy vital to the nature and evolution of the cosmos that are not yet known to science.

535



The Muon g-2 ring, at the Fermi National Accelerator Laboratory in Batavia, Ill., operates at minus 450 degrees Fahrenheit and studies the wobble of muons as they travel through the magnetic field. Reidar Hahn/Fermilab, via U.S. Department of Energy

nytimes.com

nature

Explore content · About the journal · Publish with us · Subscribe

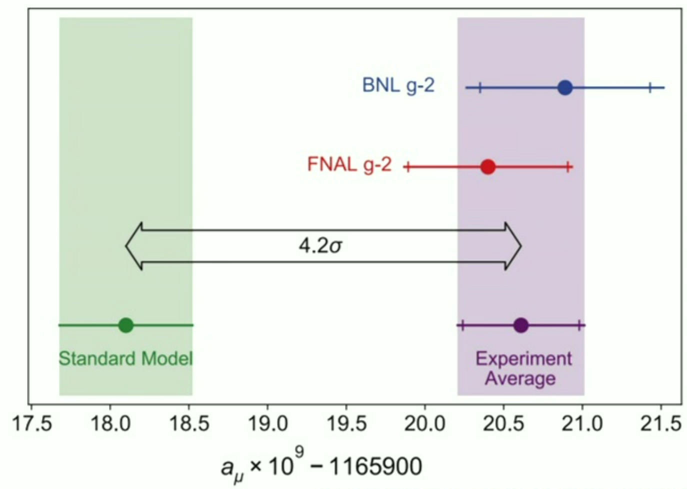
nature > news > article

nature.com

NEWS | 07 April 2021

Is the standard model broken? Physicists cheer major muon result

The muon's magnetic moment is larger than expected – a hint that new elementary particles are waiting to be discovered.



Muon g–2 Experiment [PRL 2021]

TODAY'S FOCUS

Colliding light to measure tau $g - 2$

FROM PHENO PROPOSAL

High Energy Physics – Phenomenology

[Submitted on 14 Aug 2019]

New physics and tau $g - 2$ using LHC heavy ion collisions

Lydia Beresford, Jesse Liu

The anomalous magnetic moment of the tau lepton $a_\tau = (g_\tau - 2)/2$ strikingly evades measurement, but is highly sensitive to new physics such as compositeness or supersymmetry. We propose using ultraperipheral heavy ion collisions at the LHC to probe modified magnetic δa_τ and electric dipole moments δd_τ. We introduce a suite of one electron/muon plus track(s) analyses, leveraging the exceptionally clean photon fusion $\gamma\gamma \to \tau\tau$ events to reconstruct both leptonic and hadronic tau decays sensitive to $\delta a_\tau, \delta d_\tau$. Assuming 10% systematic uncertainties, the current 2 nb^{-1} lead-lead dataset could already provide constraints of $-0.0080 < a_\tau < 0.0046$ at 68% CL. This surpasses 15 year old lepton collider precision by a factor of three while opening novel avenues to new physics.

2019: Propose innovative idea

Lydia Beresford & JL [1908.05180]

TO EXPERIMENTAL REALITY

High Energy Physics – Experiment

[Submitted on 28 Apr 2022]

Observation of the $\gamma\gamma \to \tau\tau$ process in Pb+Pb collisions and constraints on the τ-lepton anomalous magnetic moment with the ATLAS detector

ATLAS Collaboration

This Letter reports the observation of τ-lepton pair production in ultraperipheral lead-lead collisions, $\mathrm{Pb{+}Pb} \to \mathrm{Pb}(\gamma\gamma \to \tau\tau)\mathrm{Pb}$, and constraints on the τ-lepton anomalous magnetic moment, a_τ. The dataset corresponds to an integrated luminosity of 1.44 nb^{-1} of LHC Pb+Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV recorded by the ATLAS experiment in 2018. Selected events contain one muon from a τ-lepton decay, an electron or charged-particle track(s) from the other τ-lepton decay, little additional central-detector activity, and no forward neutrons. The $\gamma\gamma \to \tau\tau$ process is observed in Pb+Pb collisions with a significance exceeding 5 standard deviations, and a signal strength of $\mu_{\tau\tau} = 1.04^{+0.06}_{-0.05}$ assuming the Standard Model value for a_τ. To measure a_τ, a template fit to the muon transverse-momentum distribution from τ-lepton candidates is performed, using a dimuon ($\gamma\gamma \to \mu\mu$) control sample to constrain systematic uncertainties. The observed 95% confidence-level intervals for a_τ are $a_\tau \in (-0.058, -0.012) \cup (-0.006, 0.025)$.

🥳 **Hot off the press last week!** 🎉

ATLAS Collaboration 2204.13478

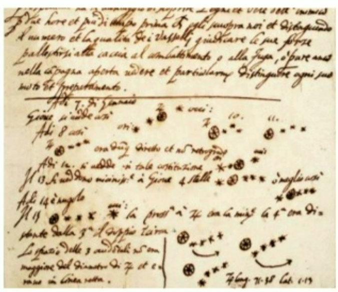
(Lydia Beresford, Mateusz Dyndal, Jakub Kremer, JL Editors)

PROLOGUE

Light historically transforms science

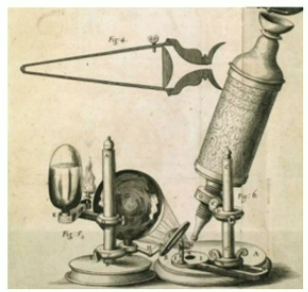
NEW UNDERSTANDING → INSTRUMENTS → DISCOVERIES

RAY OPTICS | WAVE OPTICS



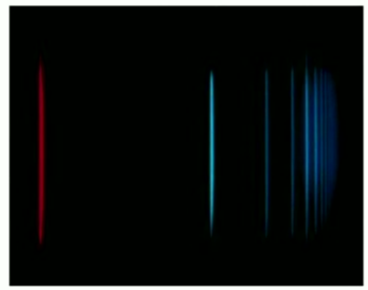
U. Michigan Library Special Collections

TELESCOPE
Modern astronomy
Lippershey c. 1604
Galileo 1610, Newton 1668



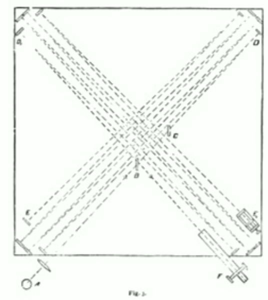
Micrographia British Library

MICROSCOPE
Cell biology
Drebbel c. 1621, Hooke 1665
van Leeuwenhoek 1678



Encyclopædia Britannica

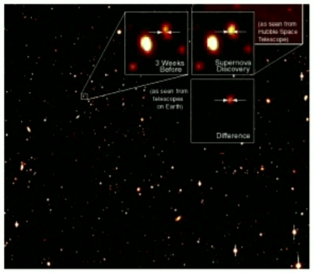
DIFFRACTION
Quantum theory
Fraunhofer 1815, Fresnel 1815
Balmer 1885



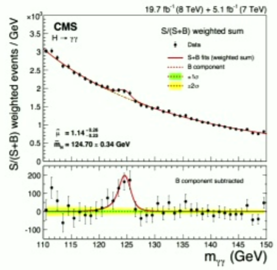
Am J Sci (1887) Series 3 Vol. 34:333-345

INTERFEROMETER
Special relativity
Young 1801, Lloyd 1834
Michelson–Morley 1887

Precisely controlling light still transforming science

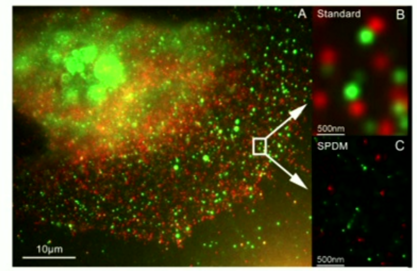


Dark energy
Physics Nobel (2011)
Supernovae redshift



Higgs boson
Physics Nobel (2013)
Diphoton bump hunt

Blue LED
Physics Nobel (2014)
Computers & phones



Super-resolution microscopy
Chemistry Nobel (2014)
Overcome diffraction limit

Gravitational waves
Physics Nobel (2017)
Laser interferometry

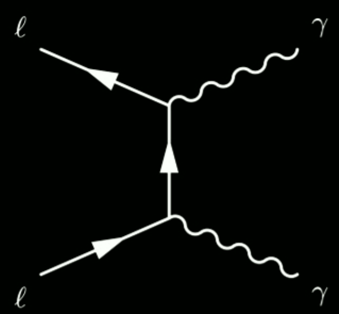
Optical tweezers
Physics Nobel (2018)
Manipulate nanoparticles

Extrasolar planets
Physics Nobel (2019)
Stellar Doppler shift

Galactic centre black hole
Physics Nobel (2020)
Adaptive optics

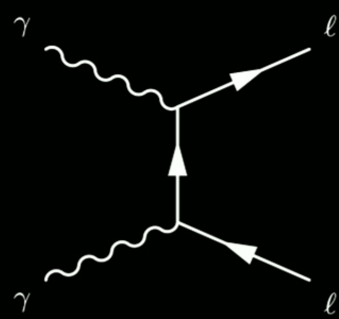
What happens when we collide light at the most extreme laboratory energies?

QUANTUM ELECTRODYNAMICS



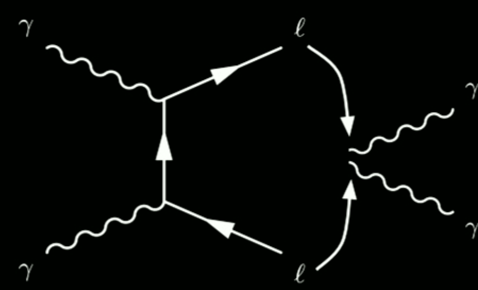
Matter turns into light

MEDICAL IMAGING
Positron–emission tomography



Light turns into matter

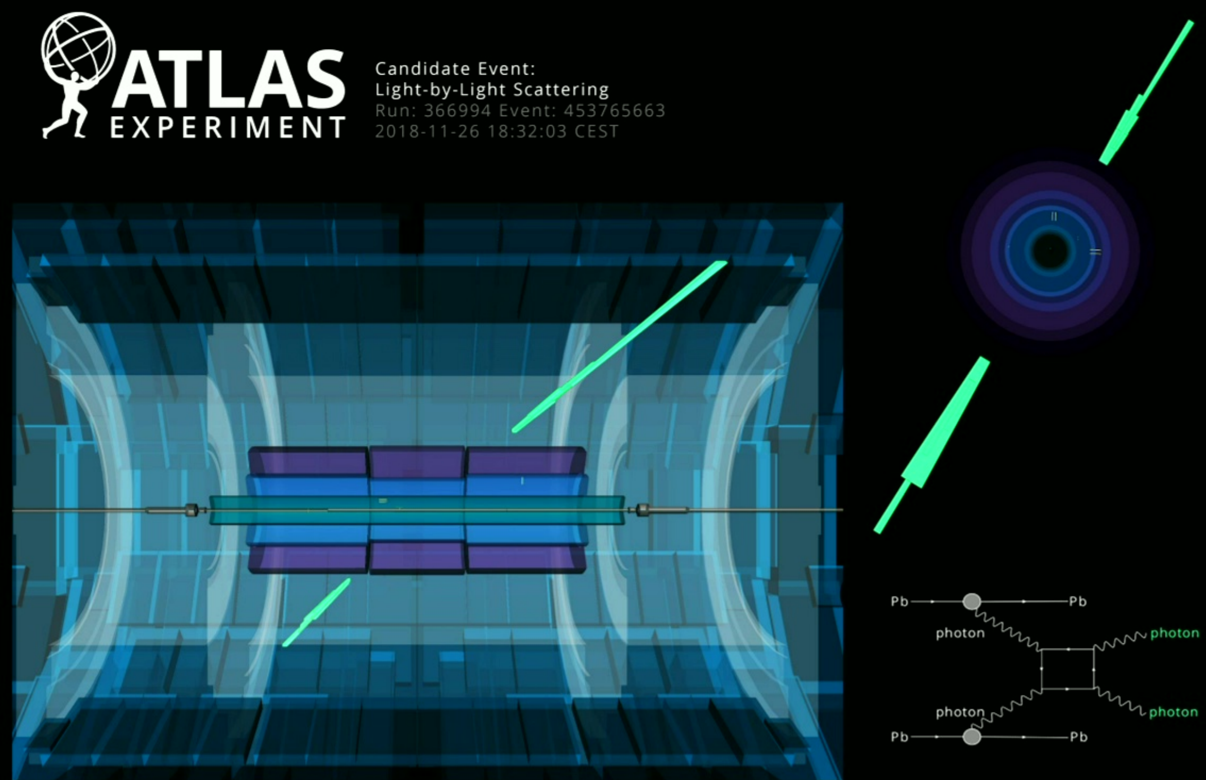
ASTROPHYSICS
Cosmic gamma ray opacity



Light scatters off light

BSM SEARCHES
Axion-like particle searches

Recent experimental breakthroughs ⇒ renaissance of interest



BREAKTHROUGH 1

"All charged-particle tracks with p_T > 100 MeV are shown"

Observation of light-by-light scattering $\gamma\gamma \to \gamma\gamma$

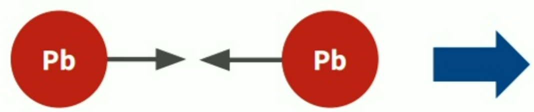
8.2σ (6.2σ) obs (exp) significance

ATLAS [1702.01625, 1904.03536, 2008.05355], CMS [1810.04602]; proposed by d'Enterria & da Silveira [1305.7142]

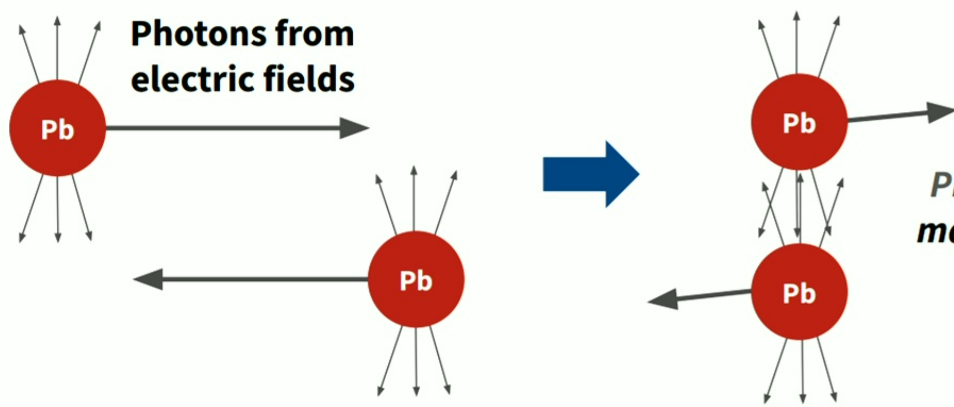
$\gamma\gamma \to$ ALP $\to \gamma\gamma$ search proposed by Knapen, Lin, Lou, Melia [1607.06083]

Colliding light @ LHC

Head-on Pb–Pb collisions



***Partons* collide to make new particles**

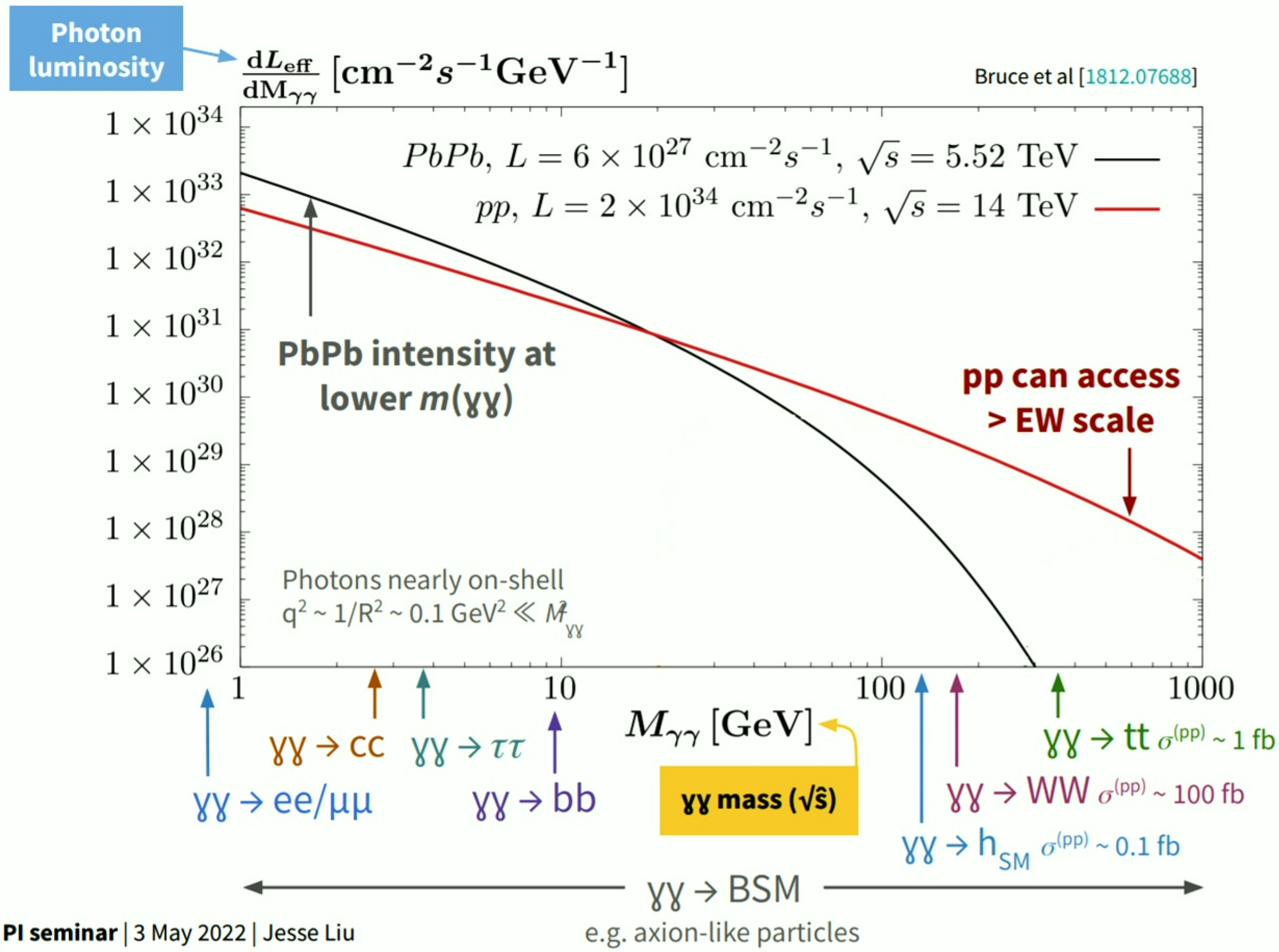


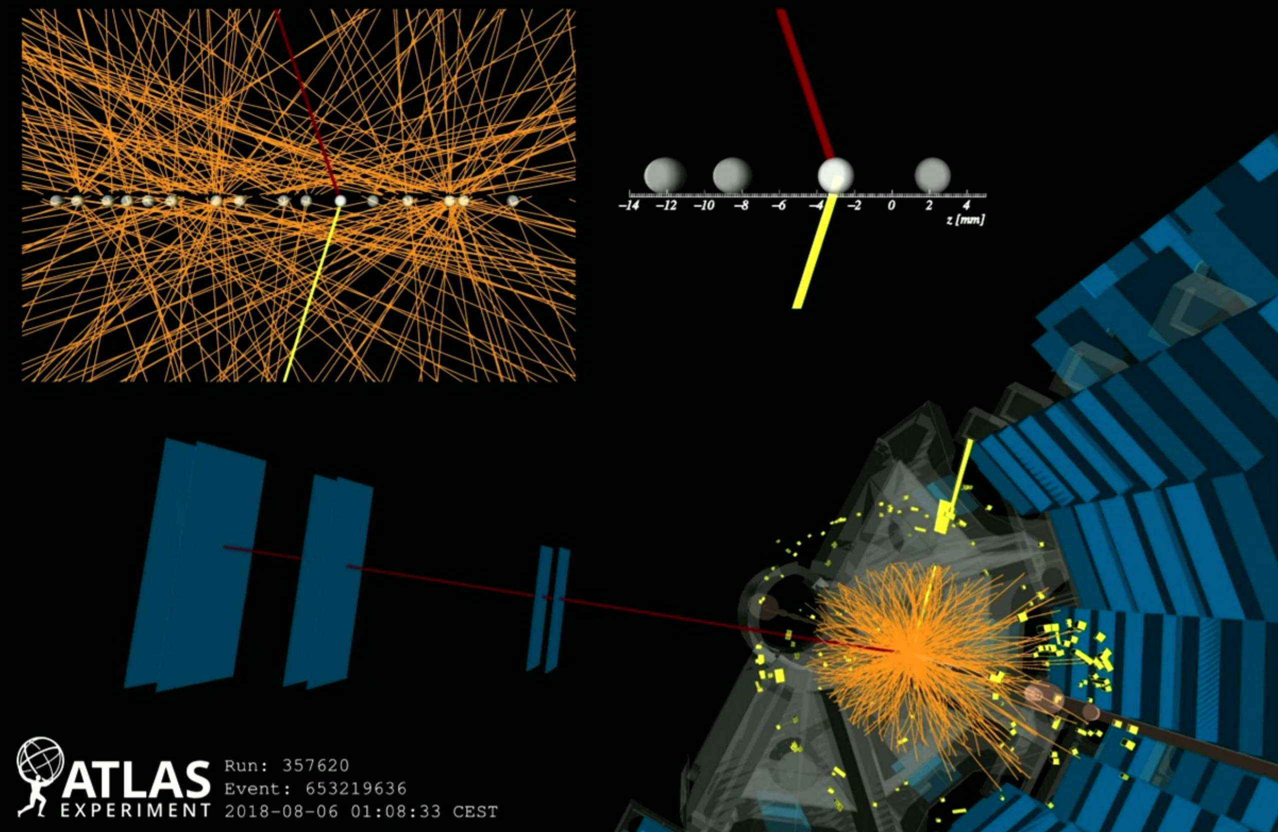
***Photons* collide to make new particles**

EQUIVALENT PHOTON APPROXIMATION

Fermi (1925) [hep-th/0205086], Weizsäcker (1934), Williams (1934), Schwinger (1952), Budnev, Ginzburg, Meledin, Serbo (1975)
ATLAS [ATLAS HION Event Display], Bruce et al [1812.07688]

Colliding γγ spectrum





BREAKTHROUGH 2

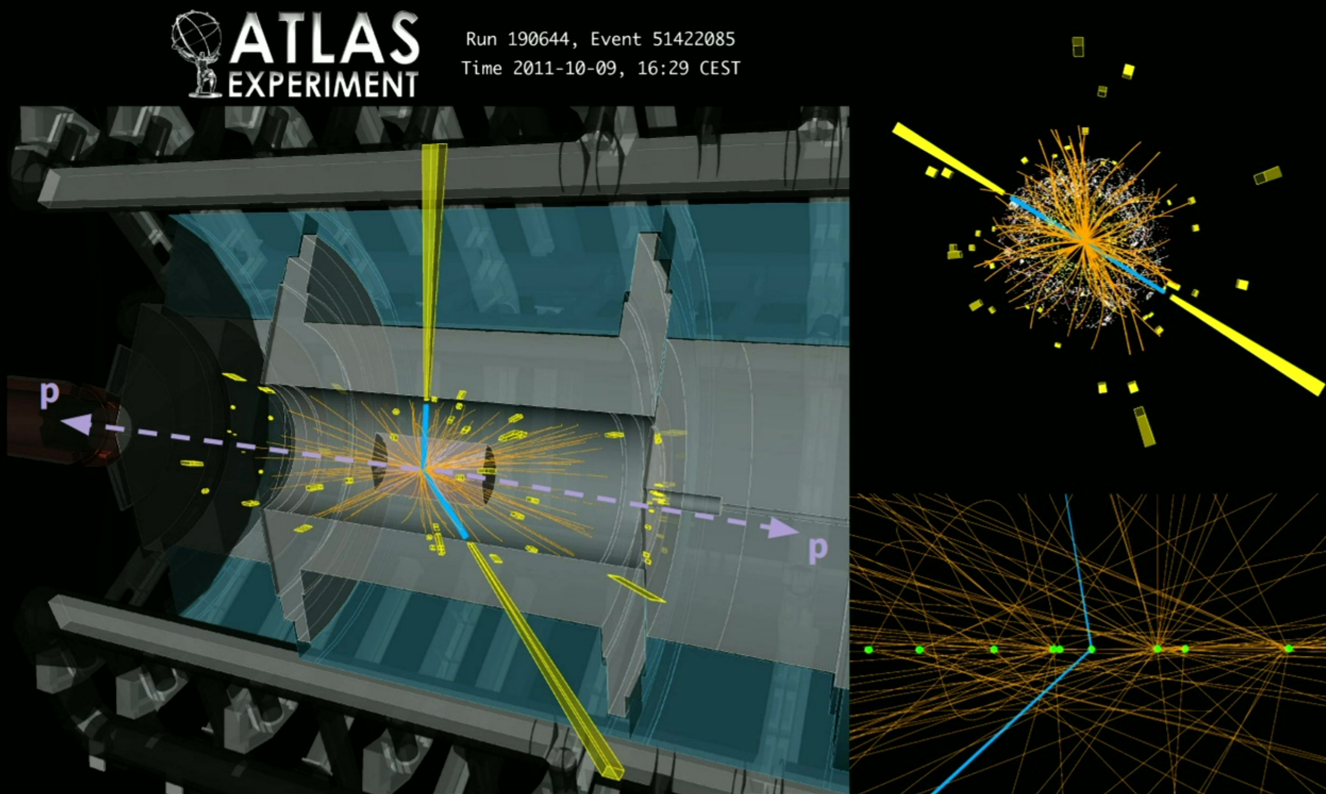
Observation of $\gamma\gamma \rightarrow WW \rightarrow e\nu\mu\nu$

8.4σ obs (6.6σ exp) significance

Run 1: ATLAS [1607.03745]
CMS [1305.5596, 1604.04464]

Run 2: ATLAS [2010.04019]

Fun fact: m(W boson) / m(Bromine) ≅ 1.006



$\gamma\gamma \to ee$ @ 7 TeV event display [1506.07098]

BREAKTHROUGH 3

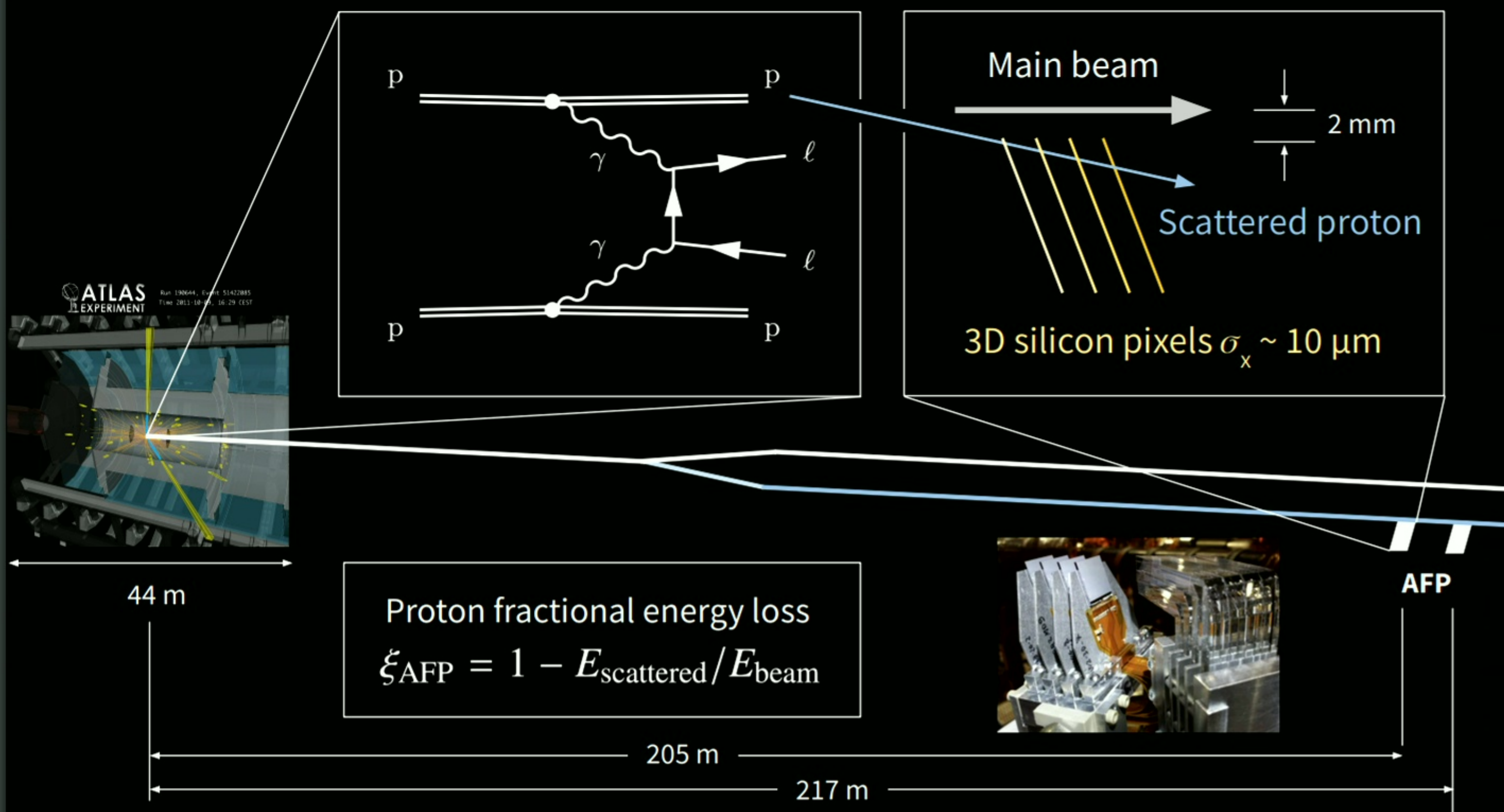
Observation of proton scattering in $pp \to p + (\gamma\gamma \to ee/\mu\mu) + p^{(*)}$

New: see scattered protons stay intact

Without proton tagging can only see this

ATLAS Forward Proton (AFP)

Installed detectors on both sides in 2017 for standard pp data daking



Also CMS–TOTEM PPS @ Point 5

Landmark first physics publication with AFP

PHYSICAL REVIEW LETTERS

Highlights Recent Accepted Collections Authors Referees Search Press About Staff

Open Access

Observation and Measurement of Forward Proton Scattering in Association with Lepton Pairs Produced via the Photon Fusion Mechanism at ATLAS

G. Aad *et al.* (ATLAS Collaboration)

Phys. Rev. Lett. **125**, 261801 – Published 23 December 2020

ATLAS (Lydia Beresford, JL Editors) [2009.14537]

Team: Peter Bussey, **Krzysztof Cieśla***, **Savannah Clawson***, Vlasios Petousis, André Sopczak, Rafał Staszewski, Marek Taševský

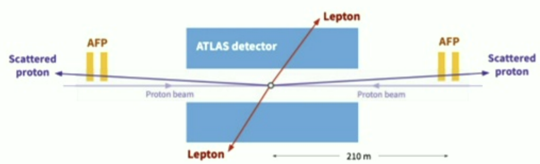
* **Graduate students**

Looking forward: ATLAS measures proton scattering when light turns into matter

[ATLAS Physics Briefing]

By ATLAS Collaboration, 30th July 2020

Today, at the International Conference for High Energy Physics (ICHEP 2020), the ATLAS Collaboration announced first results using the ATLAS Forward Proton (AFP) spectrometer (Figure 1). With this instrument, physicists directly observed and measured the long sought-after prediction of proton scattering when particles of light turn into matter.



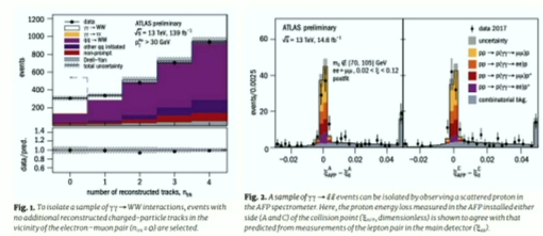
ENERGY FRONTIERS

[CERN Courier Sep/Oct 2020]

Reports from the Large Hadron Collider experiments

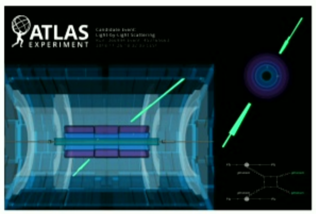
ATLAS

The LHC as a photon collider



INTERLUDE

*"Haven't we already tested **matter–light interactions**?"*
*"What more is there to learn about **photon couplings**?"*



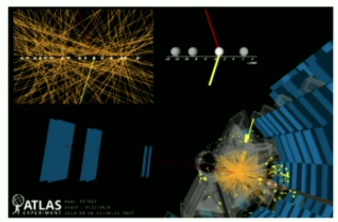
$\gamma\gamma \to \gamma\gamma$

Light couples with itself

2.2 nb^{-1} 2015+18 data

5.02 TeV PbPb

JHEP 03 (2021) 243



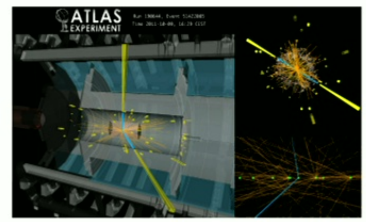
$\gamma\gamma \to WW \to e\nu\mu\nu$

Light fuses into EWK states

139 fb^{-1} 2015–18 data

13 TeV pp

PLB 816 (2021) 136190



$(\gamma\gamma \to ee/\mu\mu) + p$

Directly see forward proton

14.6 fb^{-1} 2017 data

13 TeV pp with AFP

PRL 125 (2020) 261801

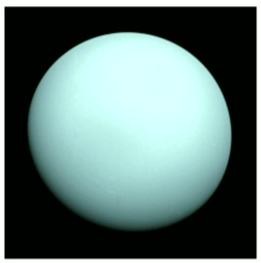
See also STAR [1910.12400], CMS–TOTEM [1803.04496] LHCb [CONF-2018-003], CMS [1604.04464], ALICE [1406.7819], PHENIX [0903.2041]

Just the tip of the iceberg, but let's entertain these questions…

HISTORY

*"Haven't we already tested **Kepler–Newtonian dynamics**?"*
*"What more is there to learn about **Mercury's orbit**?"*

Self-consistency tests	**Spectacular predictive power**	**Transformative precision**



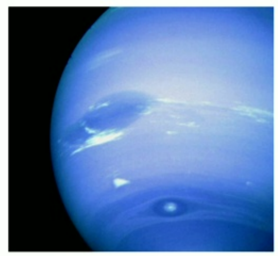
Credits: NASA/JPL-Caltech

Uranus

Herschel 1781

Planet never seen before
65 years of measuring

[Precision electroweak]



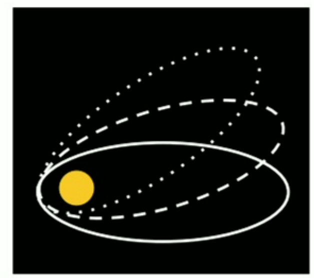
Credits: NASA/JPL-Caltech

Neptune

Le Verrier, Galle, d'Arrest 1846

Discover on same night
within 1° of prediction

[Higgs boson discovery]



General Relativity

Le Verrier 1859, Einstein 1915

43 arcseconds/century deviation
Null search for Planet Vulcan

[Witnessing this today?]

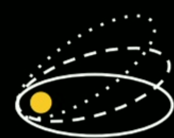
LESSON

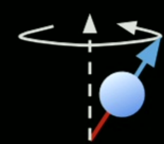
Precision measurements revolutionise science

GR: SPACETIME IS DYNAMICAL

Discover new planets: unchanged physical laws

But planet known since antiquity transformative





QFT: VACUUM IS DYNAMICAL

Per mille precession of electron: no new particles

But groundbreaking evidence of physical loops

The ordinary harboured extraordinary surprises

LHC creativity: collide light for BSM physics

PHYSICAL REVIEW LETTERS

Highlights Recent Accepted Collections Authors Referees About Staff

Open Access | Access by Cambridge

Search Strategy for Sleptons and Dark Matter Using the LHC as a Photon Collider

Lydia Beresford and Jesse Liu
Phys. Rev. Lett. **123**, 141801 – Published 3 October 2019

1811.06465

PHYSICAL REVIEW D

covering particles, fields, gravitation, and cosmology

Highlights Recent Accepted Collections Authors Referees About Staff

Open Access | Access by Cambridge

New physics and tau $g-2$ using LHC heavy ion collisions

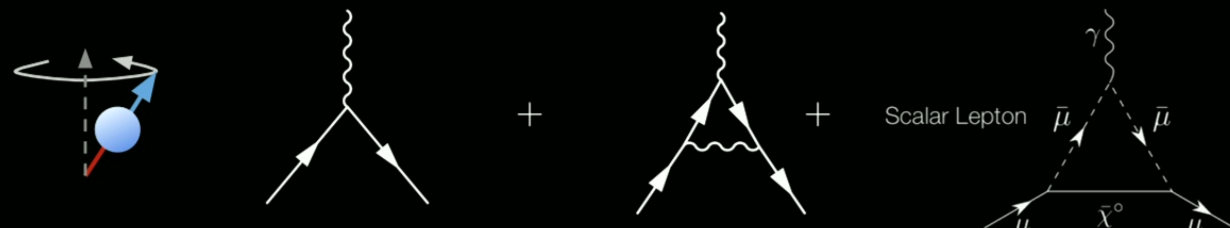
Lydia Beresford and Jesse Liu
Phys. Rev. D **102**, 113008 – Published 22 December 2020

1908.05180

Origin of dark matter?	**Hot topic** Central to particle physics	Origin of muon $g-2$ tension?
p_{miss} 4-vector immeasurable	**Critical problem** dismissed as hopeless	Tau $g-2$ immeasurable
Collide light AFP tag protons	**Creative solution** from recent breakthroughs	*Collide light* Use heavy ions

g – 2: foundational test of QFT

"How does light interact with matter?"

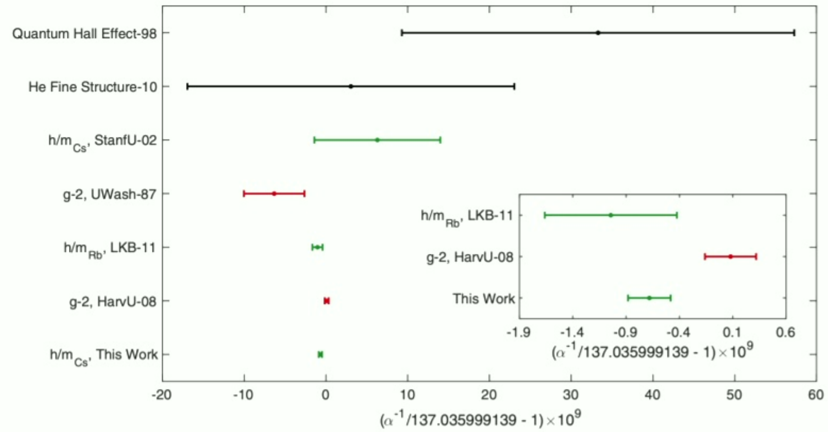


$$g = 2 + \frac{\alpha}{\pi} + \ldots$$

Dirac (1928) **Schwinger (1948)** **BSM?**

$$\boldsymbol{\mu}_f \cdot \mathbf{B} = \frac{g_f e}{2m_f} \mathbf{S} \cdot \mathbf{B}$$

Today: cracks at the heart of Standard Model?



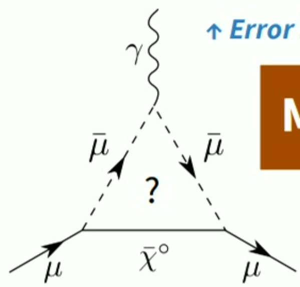
Electron $g - 2$ (−2.5σ?)

Odom, Hanneke, D'Urso, Gabrielse [PRL (2006)]
Bouchendira et al [PRL (2011)]
Aoyama, Hayakawa, Kinoshita, Nio [1205.5368]
Parker, Yu, Zhong, Estey, Müller [Science (2018)]

0.2 parts per billion

"Triumph of quantum electrodynamics"

↑ Error bars width of atom if drawn to scale!

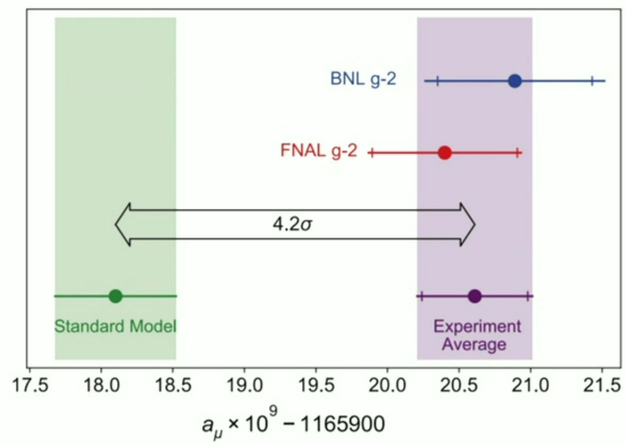


Muon $g - 2$ (+4.2σ?)

BNL E821 [hep-ex/0602035]
Fermilab E989 [1501.06858]
J-PARC [1901.03047]
Keshavarzi, Nomura, Teubner [1802.02995]
Davier, Hoecker, Malaescu, Zhang [1908.00921]
Muon g–2 theory initiative [2006.04822]
FNAL Muon g–2 [2104.03281]

0.5 parts per million

"Hadronic ignorance or harbinger of new physics?"



What about tau *g* – 2?

SHOCKING EXPERIMENTAL IGNORANCE!

Current PDG value is by DELPHI 2004

$$a_\tau^{\text{exp}} = -0.018\,(17)$$

$$a_{\tau,\,\text{SM}}^{\text{pred}} = 0.001\,177\,21\,(5)$$

DELPHI [hep-ex/0406010], Eidelman, Passera [hep-ph/0701260]

Pressing problem: barely measured!

Not even testing 70 year old 1-loop QED!

$$\alpha/2\pi = 0.001162$$

QED: lepton–photon universality at tree-level *AND* 1-loop [Schwinger 1948]

Pressing & *interesting* open problem

Huge uncertainty
⇒ huge room for new physics

$$\delta a_\ell \sim m_\ell^2 / M_{\rm SUSY}^2$$

$$m_\tau^2 / m_\mu^2 \sim 280$$

Martin, Wells [hep-ph/0103067]

280× more sensitive to new physics than muon *g* – 2

e & μ *g* – 2: no model shortage pre-FNAL:

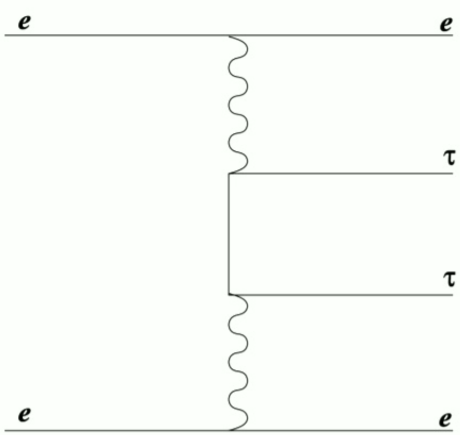
Martin, Wells [hep-ph/0103067]
Czarnecki, Marciano [hep-ph/0102122]
Pospelov [0811.1030]
Cahill-Rowley, Hewett, Ismail, Rizzo [1407.4130]
Ajaib, Dutta, Ghosh, Gogoladze, Shafi [1505.05896]
Allanach, Queiroz, Strumia, Sun [1511.07447]
Han, Kang, Sayre [1511.05162]
Batell, Lange, McKeen, Pospelov, Ritz [1606.04943]
Di Chiara, Fowlie, Fraser, Marzo, Marzola, Raidal, Spethmann [1704.06200]
Poh, Raby [1705.07007]
Cherchiglia, Stöckinger, Stöckinger-Kim [1711.11567]
Davoudiasl, Marciano [1806.10252]
Crivellin, Hoferichter, Schmidt-Wellenburg [1807.11484]
Li, Li, Yang [1808.02424]
Liu, Wagner, Wang [1810.11028]
Dutta, Mimura [1811.10209]
Mohlabeng [1902.05075]
Endo, Wen [1906.08768]
Badziak, Sakurai [1908.03607]
Bauer, Neubert, Renner, Schnubel, Thamm [1908.00008]
...

How can we measure tau *g* – 2?

Belle-II/CLIC/ILC/FCC-ee:
Eidelman, Epifanov, Fael, Mercolli, Passera [1601.07987]
Chen, Wu [1803.00501]
Köksal, Billur, Gutierrez-Rodriguez, Hernandez-Ruiz [1804.02373]
Howard, Rajaraman, Riley, Tait [1810.09570]
Köksal [2104.01003]
Crivellin, Hoferichter, Michael Roney [2111.10378]
LHeC/FCC-eh:
Köksal [1809.01963],
Gutiérrez-Rodríguez, Köksal, Billur, Hernández-Ruíz [1903.04135]
Proton fixed target & bent crystals:
Fomin, Korchin, Stocchi, Barsuk, Robbe [1810.06699]
Fu et al [1901.04003]

Think different: invent new heavy-ion analysis

PDG constraint of tau *g*– 2



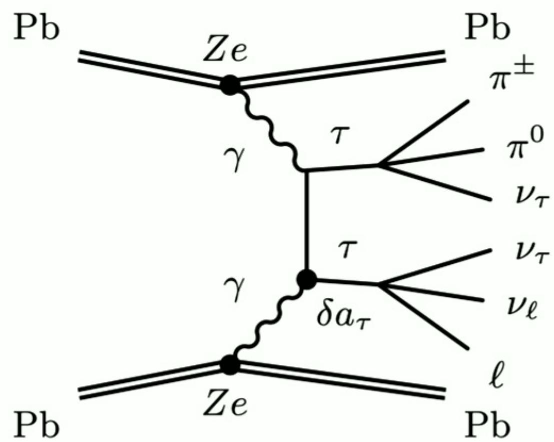
LEP photon collisions

σ ~ 400 pb

⇒ 200k events all years

DELPHI [EPJC 35 (2004) 159-170]

Proceed analogously @ LHC?



Never measured at LHC

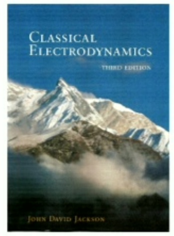
σ ~ Z^4 ~ 500 000 nb (Z_{Pb} = 82)

⇒ 1 million events *already*

Beresford, JL [1908.05180]
Also de Aguila et al [PLB 1991], Dyndal et al [2002.05503]

Photon collisions using MadGraph & SMEFTsim

Follow MadGraph EPA factorised prescription
d'Enterria, Lansberg [0909.3047]
Knapen, Lin, Lo, Melia [1607.06083]
Superchic 3
Harland-Lang, Khoze, Ryskin [1810.06567]

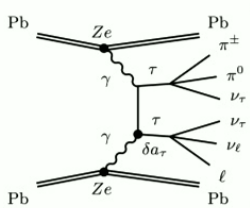


Photon flux: classical field theory

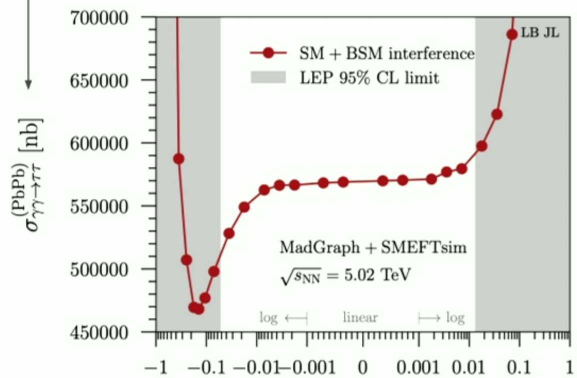
Add Chapter 15 §4 into MadGraph 2.6.5 with Fortran77

$$n(x) = \frac{2Z^2\alpha}{x\pi}\left\{\bar{x}K_0(\bar{x})K_1(\bar{x}) - \frac{\bar{x}^2}{2}\left[K_1^2(\bar{x}) - K_0^2(\bar{x})\right]\right\}$$

MadGraph **Jackson** **SMEFTsim**



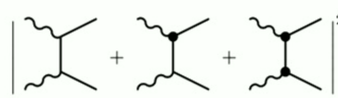
$$\sigma^{(\mathrm{PbPb})}_{\gamma\gamma\to XX}\left(\ \cdots\ \right) = \int \mathrm{d}x_1 \mathrm{d}x_2\, n(x_1) n(x_2)\, \sigma_{\gamma\gamma\to XX}$$



SMEFTsim: implement dim-6 in Feynrules

Grzadkowski, Iskrzyński, M. Misiak, Rosiek [1008.4884]
Alloul, Christensen, Degrande, Duhr, Fuks [1310.1921]
Brivio, Jiang, Trott [1709.06492]

Include interference up to 2 BSM couplings



$$\delta a_\tau \sim \frac{C}{\Lambda^2}\left(\bar{L}_\ell \sigma^{\mu\nu}\ell_R\right) H \left(\partial_\mu A_\nu\right)$$

Beresford, JL [1908.05180]

🥳 CMS and ATLAS breakthroughs realizing our idea 🎉

Available on the CERN CDS information server **CMS PAS HIN-21-009**

CMS Physics Analysis Summary

Contact: cms-pag-conveners-heavyions@cern.ch 2022/03/17

Observation of τ lepton pair production in ultraperipheral nucleus-nucleus collisions

The CMS Collaboration

Abstract

The first observation of τ lepton pair production in ultraperipheral nucleus-nucleus collisions, a pure quantum electrodynamics (QED) process, is presented. The measurement is based on a data sample collected by the CMS experiment at a per nucleon center-of-mass energy of 5.02 TeV, and corresponding to an integrated luminosity of 404 μb^{-1}. The photon-induced $\gamma\gamma \to \tau^+\tau^-$ production is observed with a statistical significance of at least five standard deviations for $\tau^+\tau^-$ events with a muon and three charged hadrons in the final state. The cross section is measured in a fiducial phase space region, and is found to be $\sigma(\gamma\gamma \to \tau^+\tau^-) = 4.8 \pm 0.6(\text{stat}) \pm 0.5(\text{syst})\ \mu b$, in agreement with leading-order QED predictions. The measurement, produced with a fraction of the expected integrated luminosity of the LHC program, establishes the potential for a substantially more precise determination of the anomalous magnetic moment of the τ lepton, which is currently poorly constrained.

↑ Announced Moriond EWK 2022

CMS-PAS-HIN-21-009

arXiv:2204.13478v1 [hep-ex] 28 Apr 2022

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

ATLAS EXPERIMENT

Submitted to: Phys. Rev. Lett.

CERN-EP-2022-079
April 29, 2022

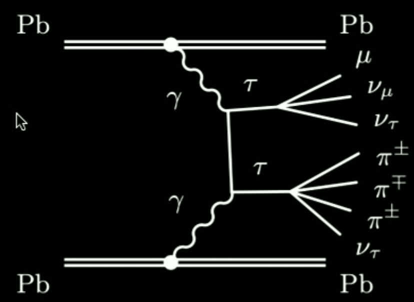
Observation of the $\gamma\gamma \to \tau\tau$ process in Pb+Pb collisions and constraints on the τ-lepton anomalous magnetic moment with the ATLAS detector

The ATLAS Collaboration

This Letter reports the observation of τ-lepton pair production in ultraperipheral lead–lead collisions, Pb+Pb $\to$ Pb($\gamma\gamma \to \tau\tau$)Pb, and constraints on the τ-lepton anomalous magnetic moment, a_τ. The dataset corresponds to an integrated luminosity of 1.44 nb^{-1} of LHC Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV recorded by the ATLAS experiment in 2018. Selected events contain one muon from a τ-lepton decay, an electron or charged-particle track(s) from the other τ-lepton decay, little additional central-detector activity, and no forward neutrons. The $\gamma\gamma \to \tau\tau$ process is observed in Pb+Pb collisions with a significance exceeding 5 standard deviations, and a signal strength of $\mu_{\tau\tau} = 1.04^{+0.06}_{-0.05}$ assuming the Standard Model value for a_τ. To measure a_τ, a template fit to the muon transverse-momentum distribution from τ-lepton candidates is performed, using a dimuon ($\gamma\gamma \to \mu\mu$) control sample to constrain systematic uncertainties. The observed 95% confidence-level intervals for a_τ are $a_\tau \in (-0.058, -0.012) \cup (-0.006, 0.025)$.

↑ Hot off the press last week!

ATLAS (JL Editor) 2204.13478



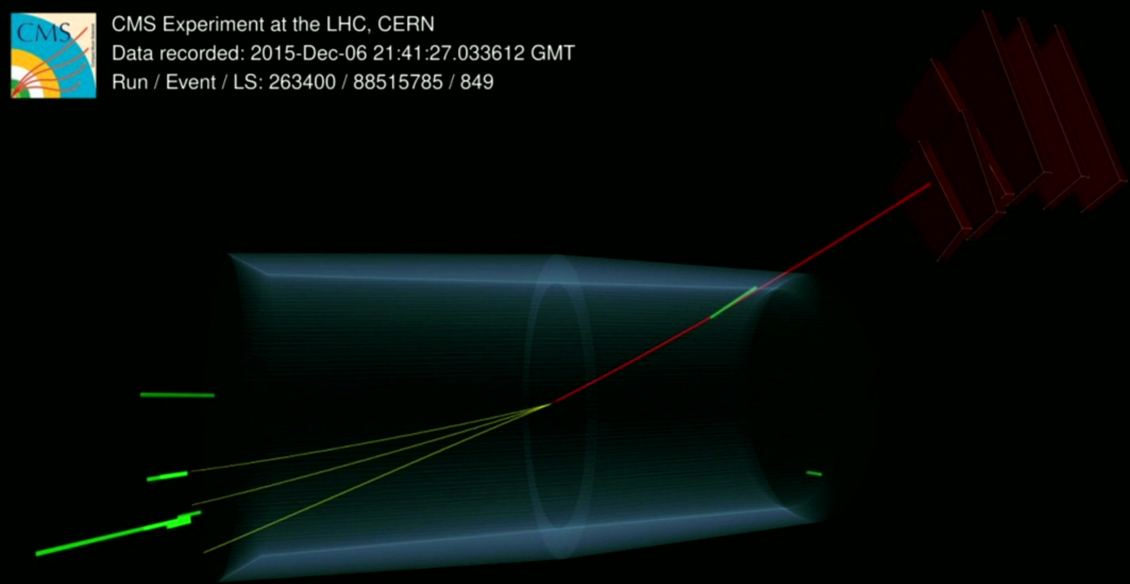
STUNNING TRIDENT EVENT

PbPb → Pb (γγ → ττ) Pb

1 month to collect ~ few nb^{-1}

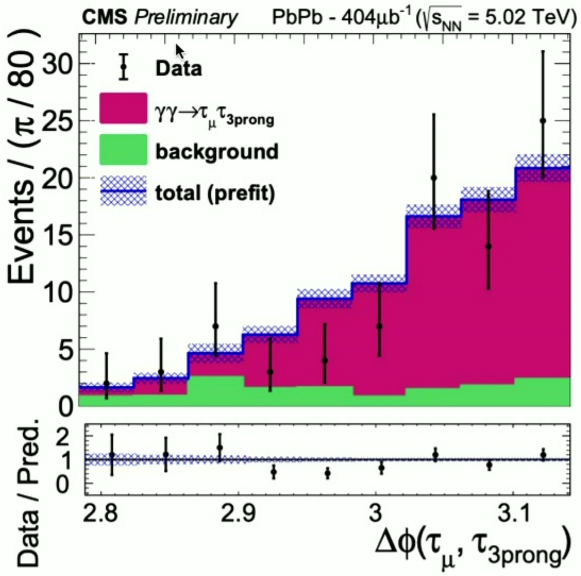
Negligible pileup μ ~ per mille

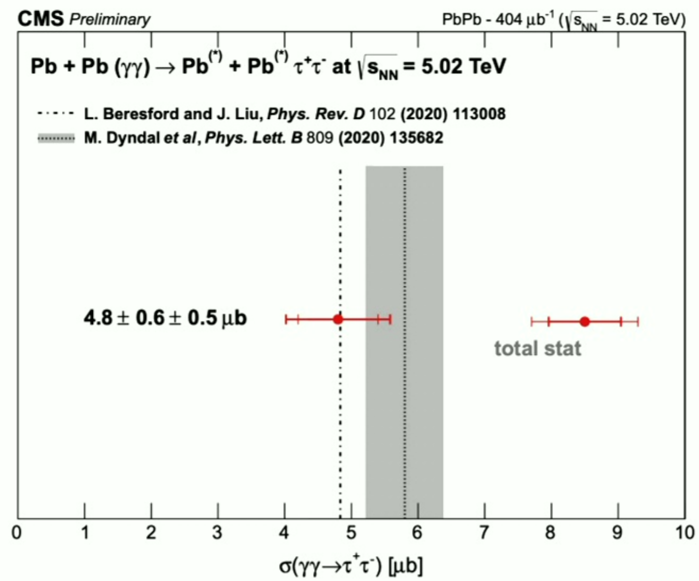
Loose triggers pT ~ few GeV



"Using light to make cousins of the electron" [CMS Physics Briefing]

CMS successfully follows our 1μ + 3-track proposal





Back-to-back distribution

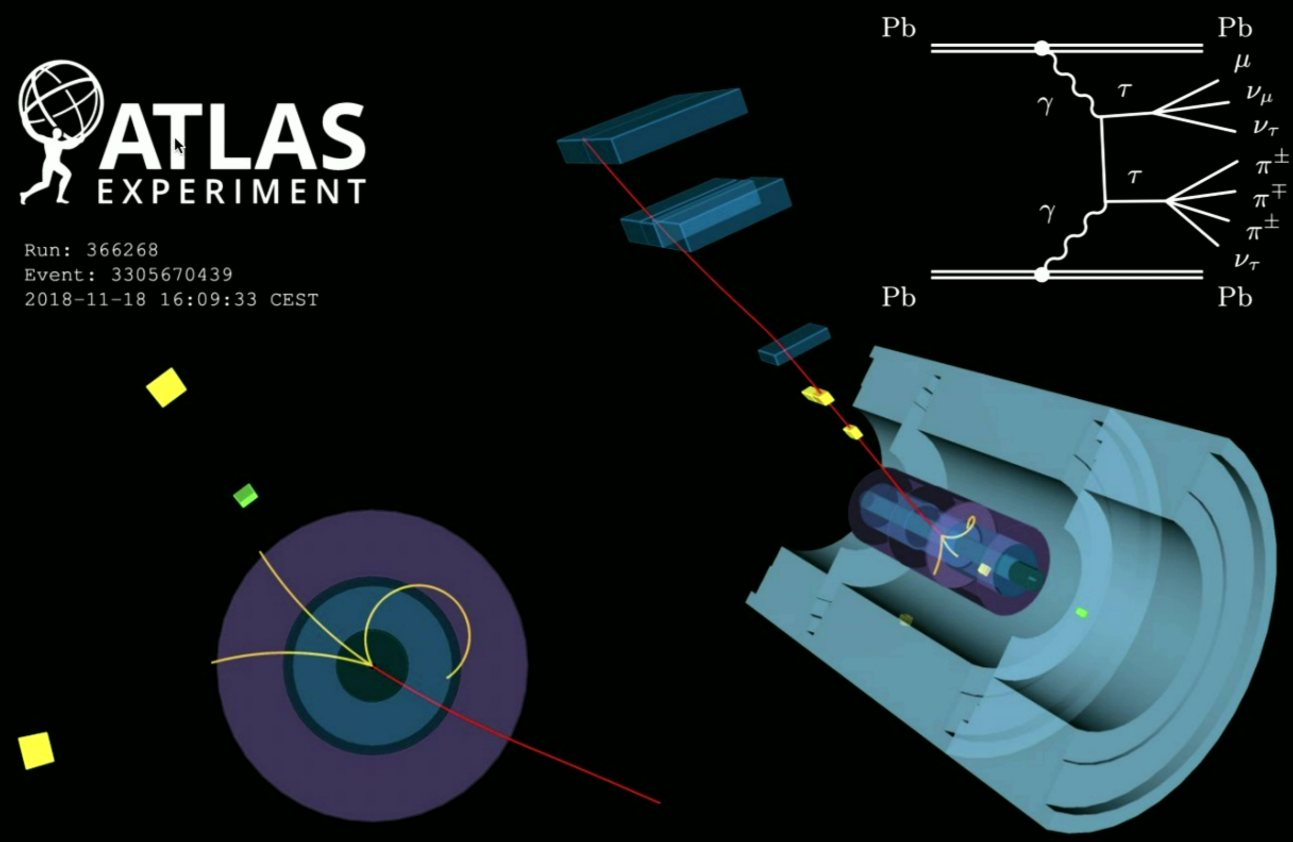
1st cross-section measurement

Remarkable result 🤩 …and just getting started!

CMS uses 2015 PbPb data [CMS-PAS-HIN-21-009]

Muons down to pT > 2.5–3 GeV, compare fiducial cross-section with theory

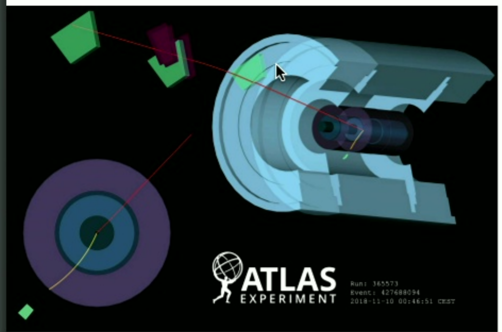
After background subtraction: $N_{sig} = 77 \pm 12$

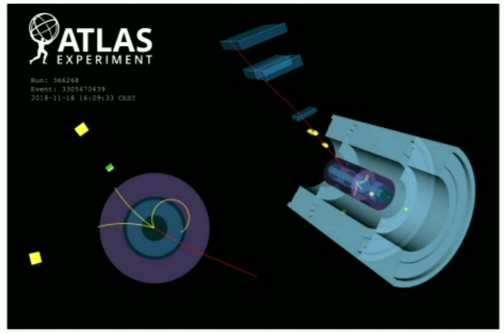


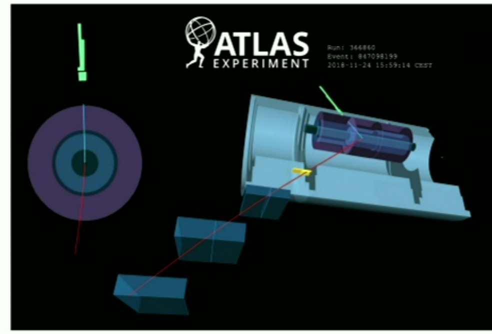
↑ *All charged-particle tracks above 100 MeV are shown; muon trigger pT > 4 GeV*

ATLAS (JL Editor) 2204.13478

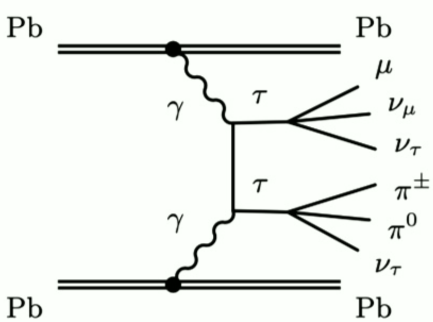
ATLAS considers 2018 data in our 3 proposed channels

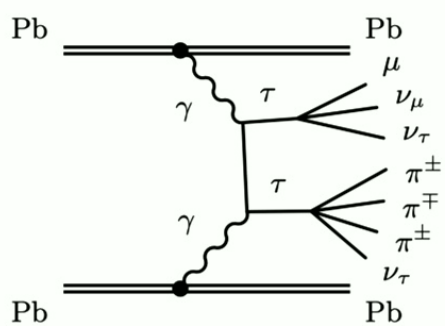


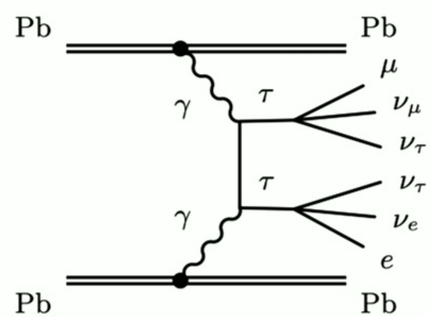




1 muon + 1 track (μ1T-SR) | **1 muon + 3 tracks** (μ3T-SR) | **1 muon + 1 electron** (μe-SR)







$N_{obs} = 532$, $N_{bkg} = 84 \pm 19$

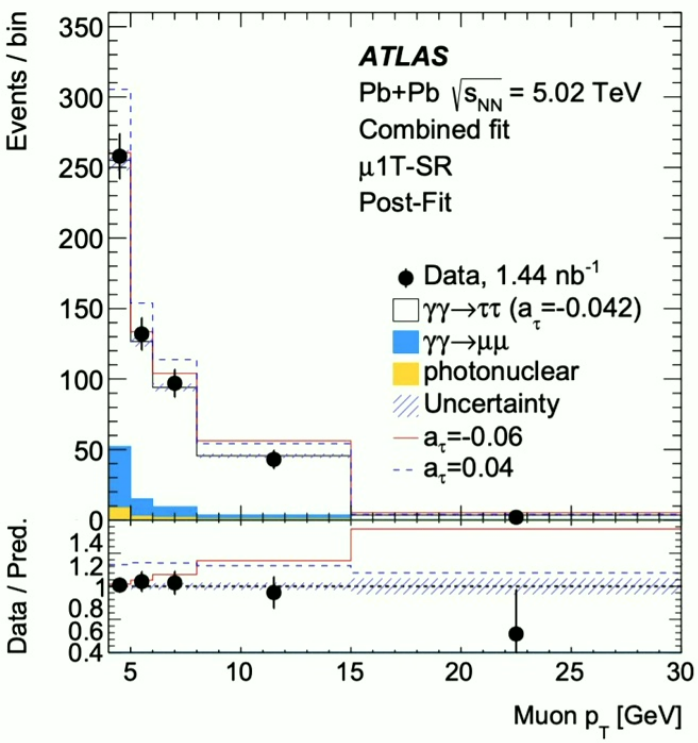
$N_{obs} = 85$, $N_{bkg} = 10 \pm 3$

$N_{obs} = 39$, $N_{bkg} = 2.8 \pm 0.7$

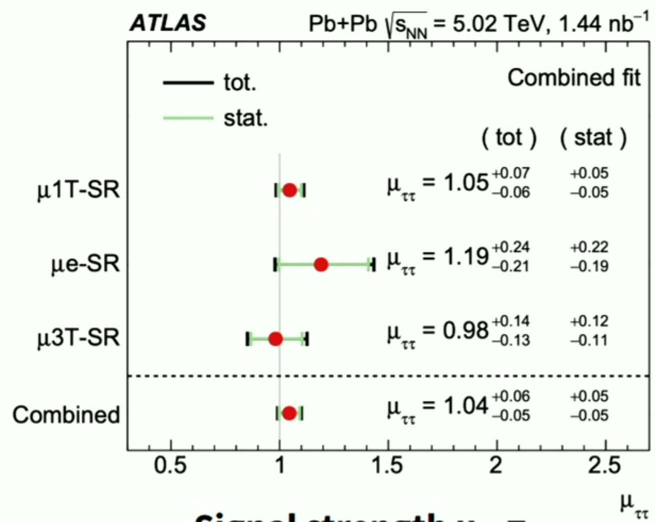
ATLAS (JL Editor) 2204.13478

Example distribution & signal strengths

DOWN TO LOWEST MUON P_T IN ATLAS



STATISTICS LIMITED MEASUREMENTS



Signal strength $\mu_{\tau\tau}$ = observed rate / expected SM rate

$$\mathcal{B}(\tau^\pm \to \ell^\pm \nu_\ell \nu_\tau) = 35\%,$$
$$\mathcal{B}(\tau^\pm \to \pi^\pm \nu_\tau + \text{neutral pions}) = 45.6\%,$$
$$\mathcal{B}(\tau^\pm \to \pi^\pm \pi^\mp \pi^\pm \nu_\tau + \text{neutral pions}) = 19.4\%.$$

ATLAS (JL Editor) 2204.13478

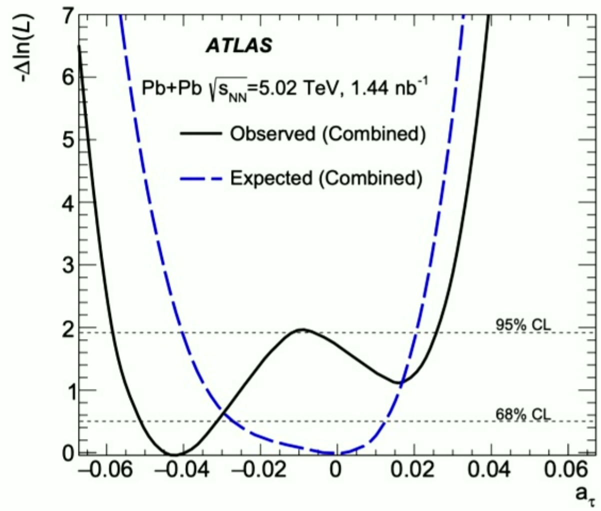
Groundbreaking results competitive with LEP

First laboratory probe of tau *g* – 2 in 2 decades

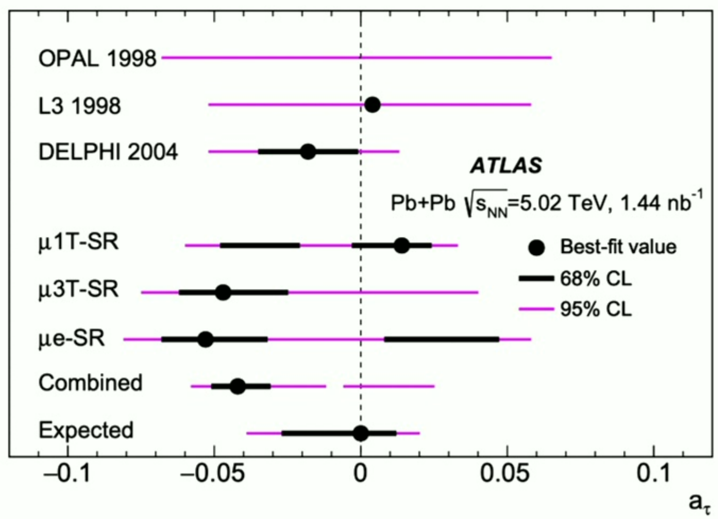
First time taus analysed in heavy ion collisions

Heavy ions enabled 5% measurement of QED g_τ

$a_\tau = (g_\tau - 2)/2$ LIKELIHOOD SCAN



SUMMARY OF MEASUREMENTS



Use µµ events to control photon flux systematics; result is statistically limited

Double-dip structure likelihood due to non-trivial SM-BSM interference, fit to pT distribution, and mild excess

ATLAS (JL Editor) 2204.13478

LET'S REFLECT FOR A MOMENT

Foundational O(mb) cross-section SM process
was not observed at the LHC until last month

Consider severe implication for BSM searches…

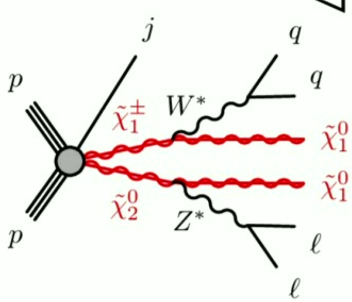
DEEPEST SCIENTIFIC TRAGEDY

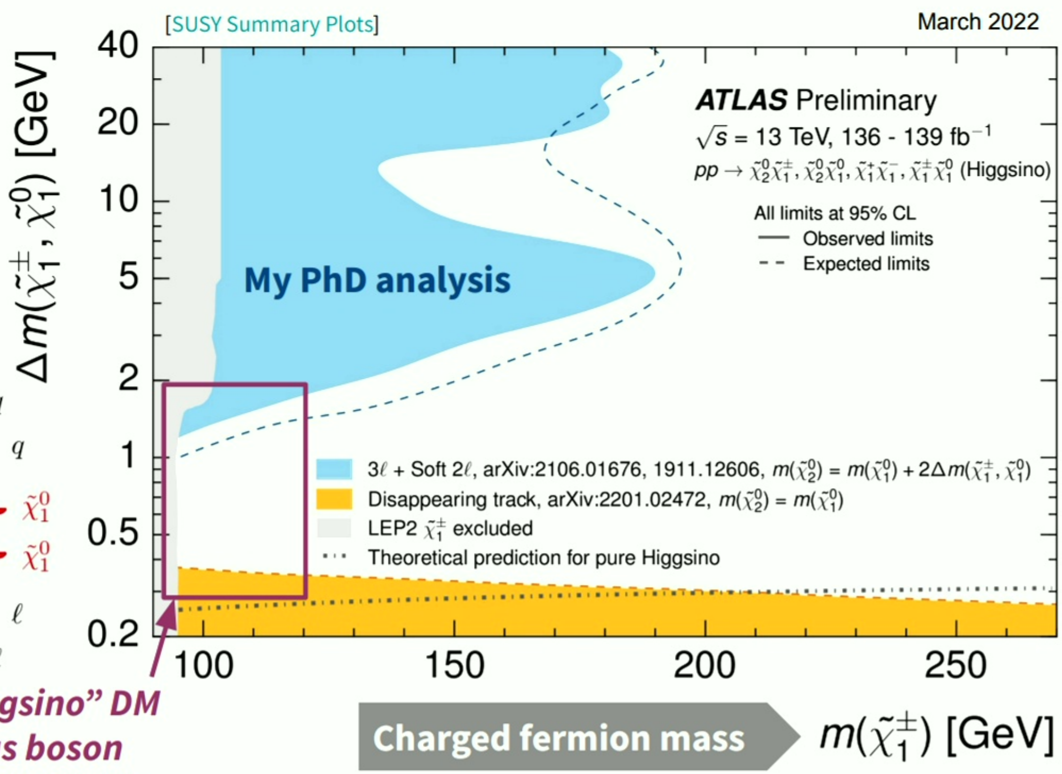
is not if new physics were absent at the weak scale

It's if we were **capable of making** new physics
but **incapable of seeing** it

E.g. LHC could be Higgsino DM factory & we'd have no idea!

Charged-DM mass splitting





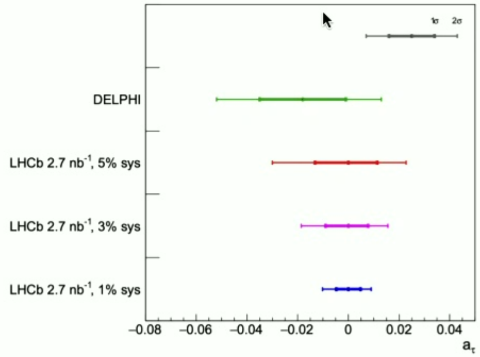
Higgs fermion "Higgsino" DM lighter than Higgs boson STILL experimentally viable

Charged fermion mass

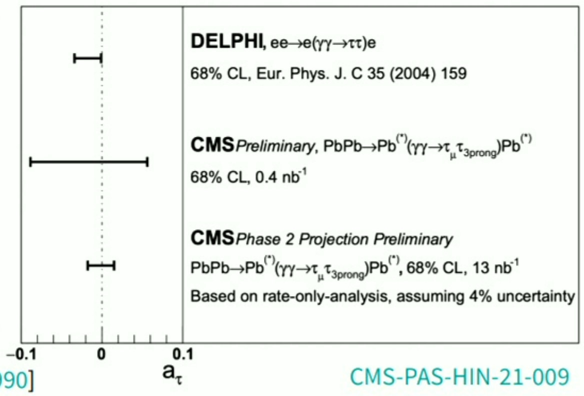
$m(\chi) \sim 100$ GeV: $\sigma(pp \to \chi\chi) \times \mathcal{L} \sim 16800$ fb $\times$ 140 fb^{-1} ~ 2.4 million events

Fuks et al [1304.0790, LHC SUSY cross-sections], Thomas & Wells [hep-ph/9804359]
See also Egana-Ugrinovic, Low, Ruderman [1801.05432]

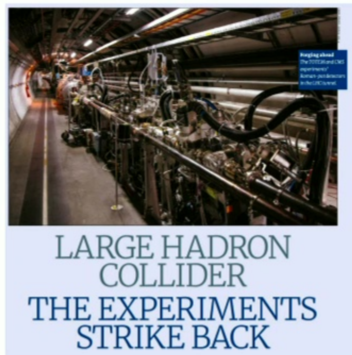
Every innovative idea strengthens HL-LHC science

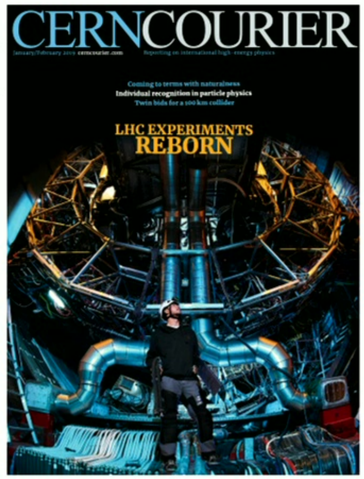


LHCb+ALICE too! Burmasov et al [2203.00990]



CMS-PAS-HIN-21-009

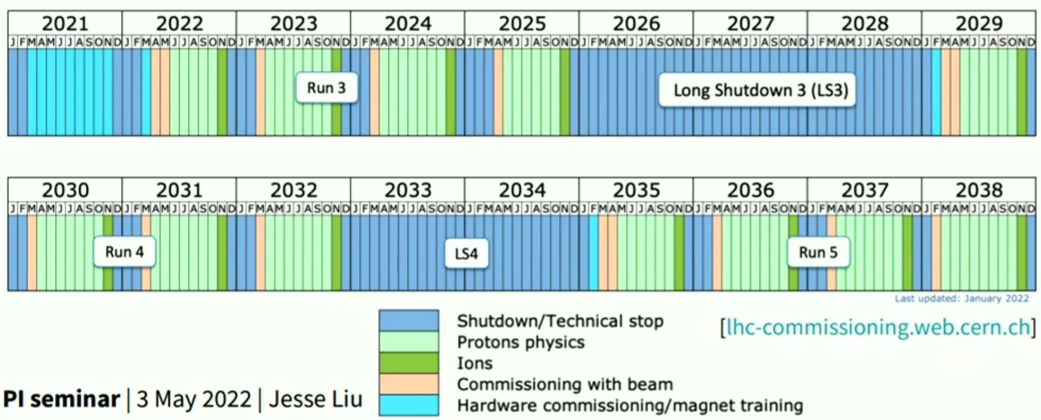




[CERN Courier Jan/Feb 2019]

d'Enterria et al [2203.05939]

Pb-Pb runtime	ATLAS/CMS	ALICE	LHCb
1 month	2.1–2.5 nb^{-1}	2.5–2.8 nb^{-1}	< 0.5 nb^{-1}
5 months	10.5–12.5 nb^{-1}	12.5–14.0 nb^{-1}	< 2.5 nb^{-1}



[lhc-commissioning.web.cern.ch]

Build next-gen ATLAS silicon camera (ITk) at Cambridge

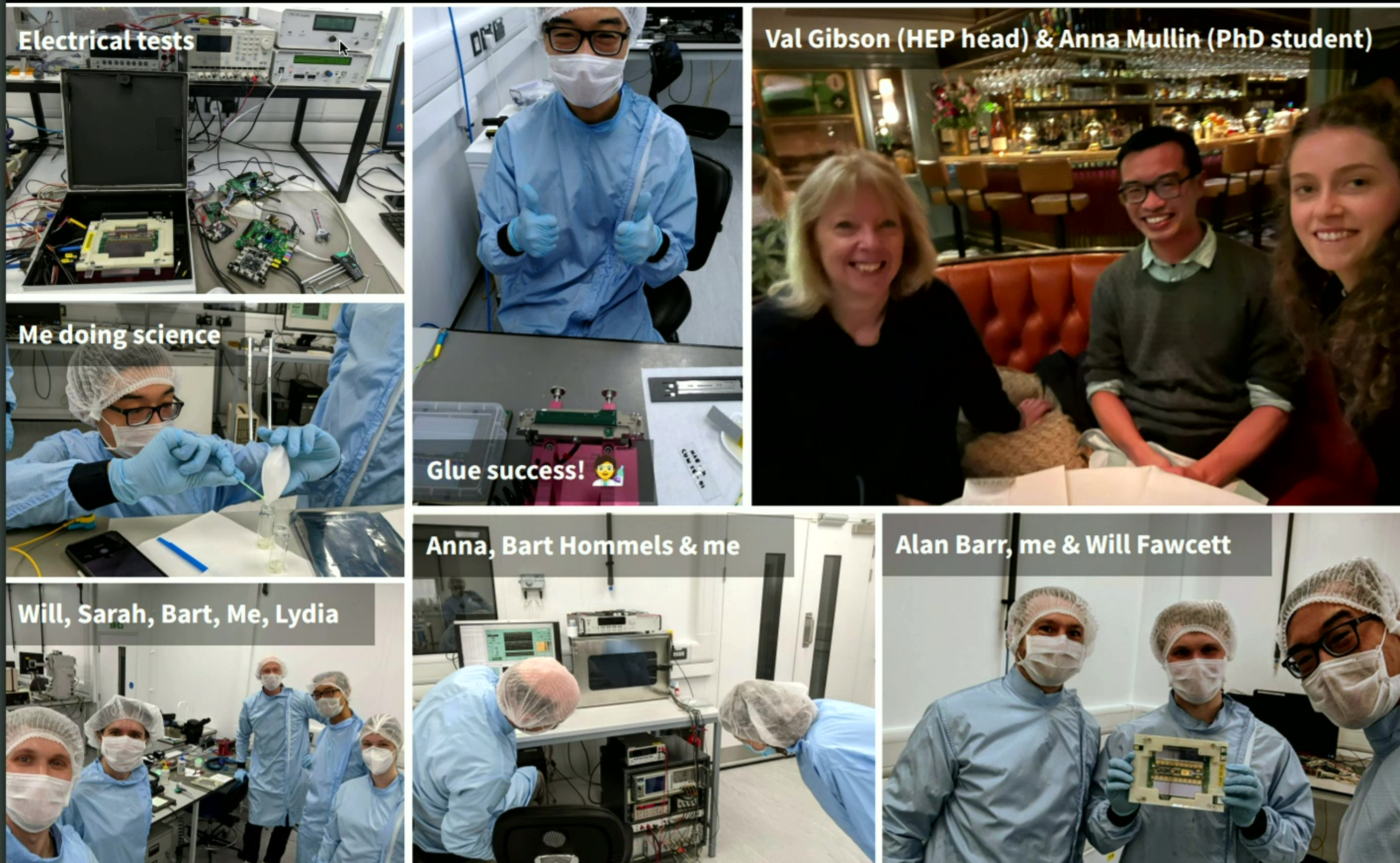


Photo credits: Bart Hommels, Val Gibson, Will Fawcett

3-SLIDE PREVIEW: NEXT TIME…

Broadband Reflector Experiment for Axion Detection

BREAD COLLABORATION

SLAC NIST Lawrence Livermore National Laboratory THE UNIVERSITY OF CHICAGO UNIVERSITY OF CAMBRIDGE

Argonne NATIONAL LABORATORY Fermilab MIT NASA Goddard SPACE FLIGHT CENTER ILLINOIS TECH

PHYSICAL REVIEW LETTERS JL, Dona et al [2111.12103]

Highlights Recent Accepted Collections Authors Referees Search Press

ON THE COVER

Broadband Solenoidal Haloscope for Terahertz Axion Detection

March 28, 2022

Simulation of the full electric field inside the conceptual design of the Broadband Reflector Experiment for Axion Detection (BREAD). Selected for an Editors' Suggestion.

Jesse Liu *et al.*

Phys. Rev. Lett. **128**, 131801 (2022)

Issue 13 Table of Contents | More Covers

Jesse Liu, Kristin Dona, Gabe Hoshino, Stefan Knirck, Noah Kurinsky, Matthew Malaker, David W. Miller, Andrew Sonnenschein, Mohamed H. Awida, Peter S. Barry, Karl K. Berggren, Daniel Bowring, Gianpaolo Carosi, Clarence Chang, Aaron Chou, Rakshya Khatiwada, Samantha Lewis, Juliang Li, Sae Woo Nam, Omid Noroozian, and Tony X. Zhou (BREAD Collaboration)

🥳 **On the cover of PRL & Editors' Suggestion** 🎉

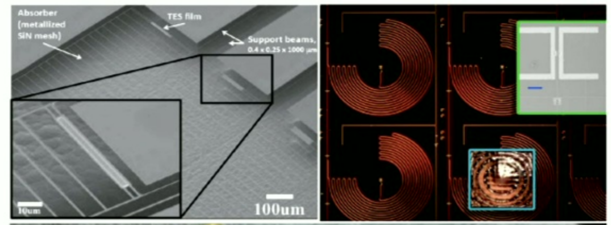
BREAD ~ 0 layer limit of dielectric horoscopes e.g. LAMPOST (Chiles et al) [2110.01582]

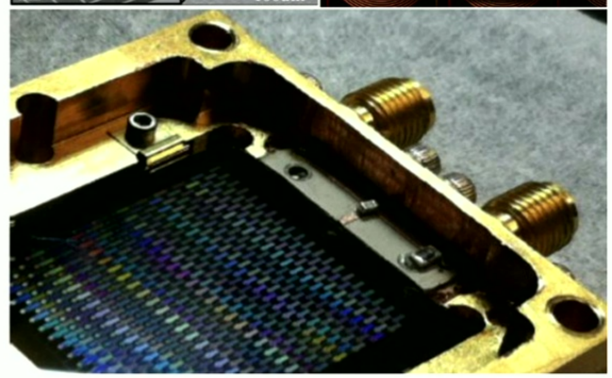
Innovation at interdisciplinary interfaces

ASTRONOMY
Origins of habitability & life

↔ **BREAD** COLLABORATION ↔

QUANTUM TECHNOLOGY
Information & sensing



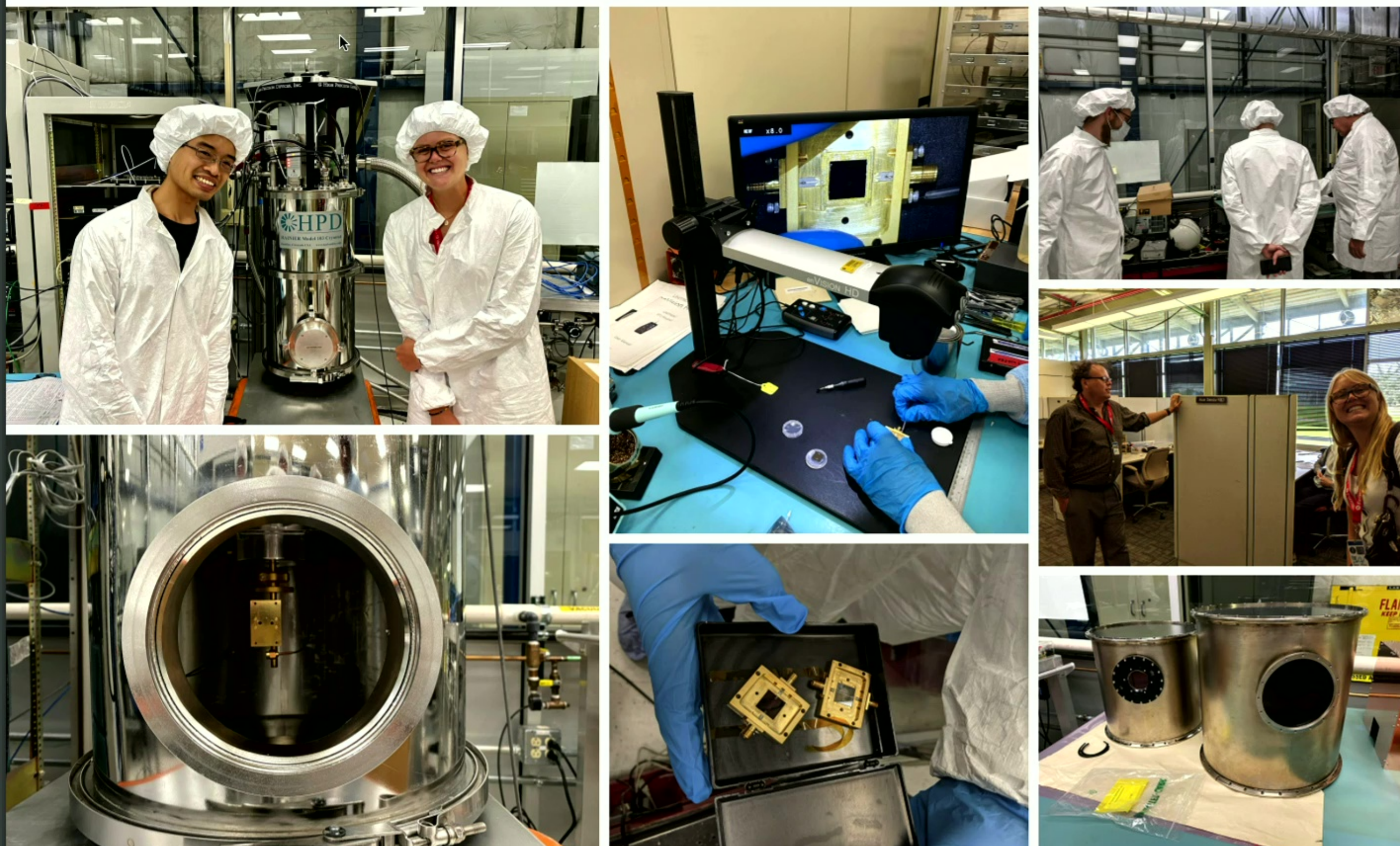


"Think *Inside*, Think *Outside* the box. Make connections to other fields"
NSF Program Director at Snowmass Oct 2020

"Synergies between particle and astroparticle physics should be strengthened"
European Strategy Update Jun 2020

Images: origins.ipac.caltech.edu
Space-based far-IR mission recommended in US Astro 2020 Decadal Survey

Hands on science: sensor testing for BREAD pilot @ FNAL



Kristin Dona, Stefan Knirck, JL, Andrew Sonnenschein pictured;
thanks to Israel Hernandez, David Miller, Tony Zhou et al

EPILOGUE

Neutron magnetic moment

When nature laughed in our 1930s faces

***Theory*: zero as it's neutral & pointlike**

***Nature*: large *AND* negative haha ($g - 2 = -5.8$)**

Chadwick (1932), Bacher (1933), Tamm & Altshuler (1934), Rabi (1934), Alvarez & Bloch (1940), CODATA (2018)

Completely confounded expectation!

TRANSFORMATIVE

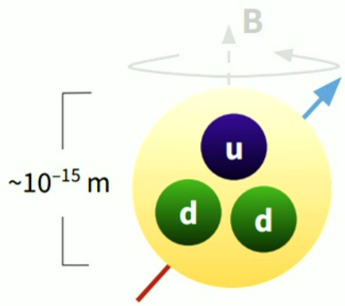
Neutron magnetic moment

When nature laughed in our 1930s faces

Theory: zero as it's neutral & pointlike

Nature: large ***AND*** negative haha ($g - 2 = -5.8$)

Chadwick (1932), Bacher (1933), Tamm & Altshuler (1934), Rabi (1934), Alvarez & Bloch (1940), CODATA (2018)



NUCLEAR SUBSTRUCTURE

New confining strong force

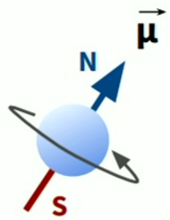
hopkinsmedicine.org

Today nuclear moments save lives with MRI medical imaging

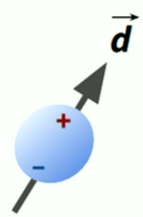
Nobel prize in Physiology or Medicine 2003

However, solution for neutron MDM
opens new problem with EDM

MAGNETIC DIPOLE MOMENT (MDM)
Expectation: $g - 2 = 0$ (Dirac theory)
Reality: huge & negative! :O
Solved: new physics → QCD ✔



ELECTRIC DIPOLE MOMENT (EDM)
Expectation: large (strong CP violation)
Reality: 0 to 1 part per billion! :O
Solution: new physics → axions…?



THANK YOU

We must keep looking at Nature in unprecedented ways
Even if – especially if – it completely defies expectation