Monopoles at the LHC

Philippe Mermod (for the MoEDAL Collaboration)

Workshop of the LHC LLP Community, Trieste, 20 October 2017

Illustration: Corinne Mucha

Long-lived particles

In general-purpose detectors, potential issues with:

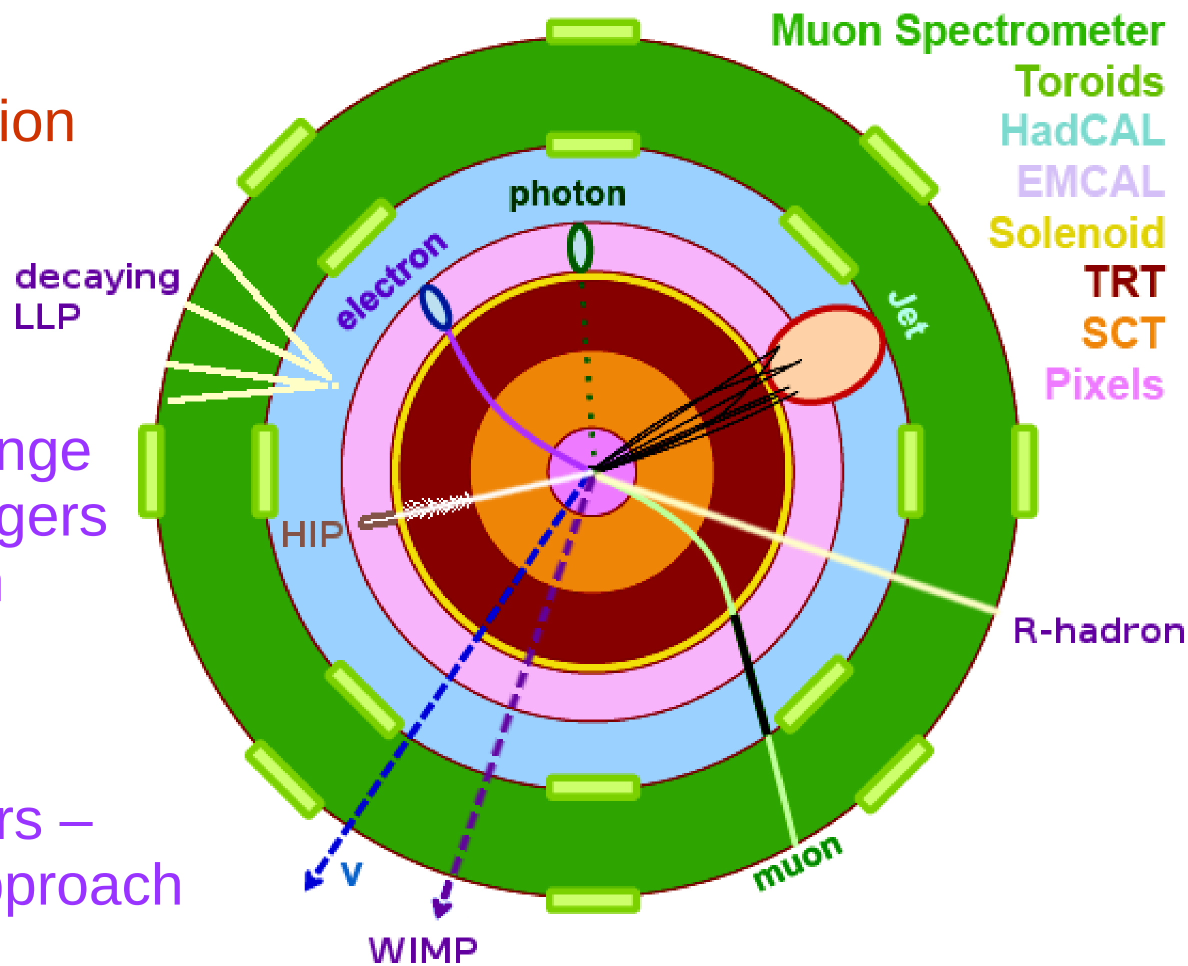
- Electronics (eg saturation, timing)
- Triggers
- Object reconstruction
- Acceptance

Solution 1:

- Take up the challenge with dedicated triggers and reconstruction

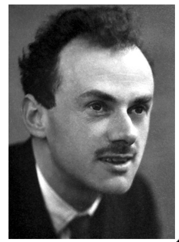
Solution 2:

- Dedicated detectors – complementary approach

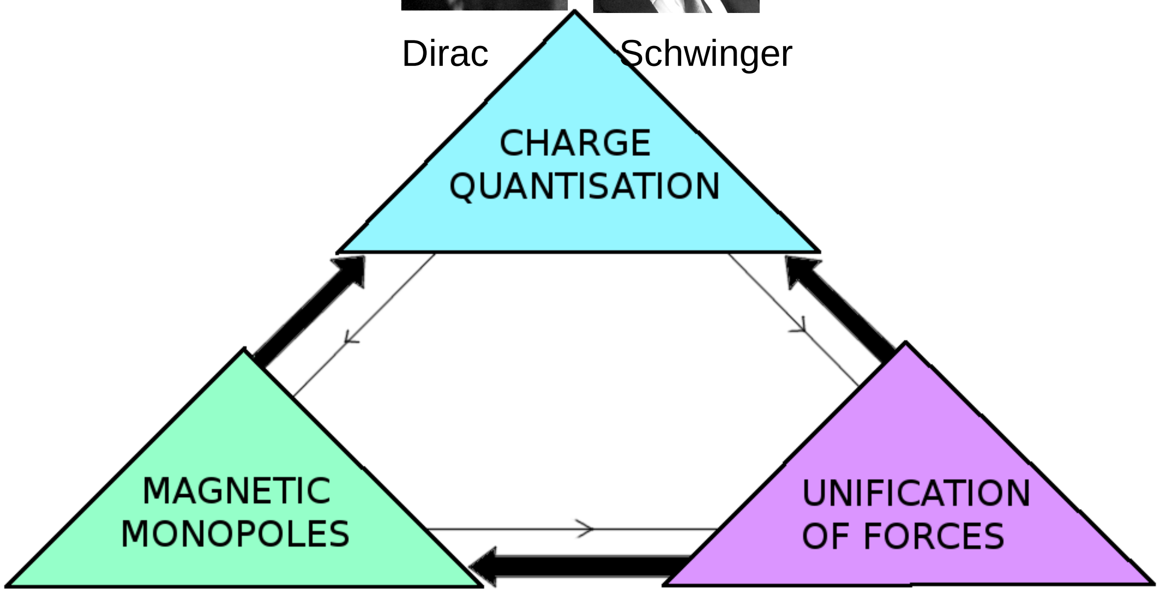


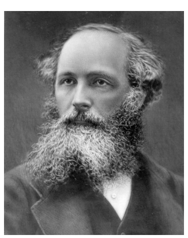
$$g = n \cdot g_D \approx \; n \cdot 68.5$$

(1931)

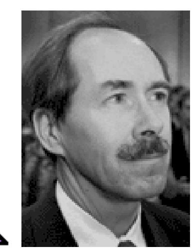


Dirac Schwinger





Maxwell



't Hooft Polyakov

Under these circumstances one would be surprised if nature had made no use of it.

(1931)

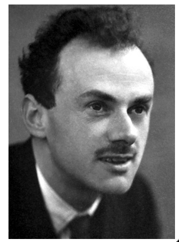
The magnetic monopole is the most venerable member of the mythological bestiary of physics.

(1986)

Don Groom

The existence of magnetic monopoles seems like one of the safest bets that one can make about physics not yet seen.

(2002)



Dirac

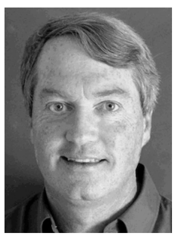
Schwinger

Magnetic monopoles should exist if the Higgs boson exists.

(1986)

Tini Veltman

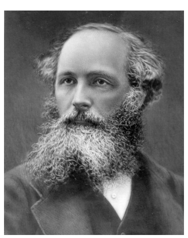
Joe Polchinski



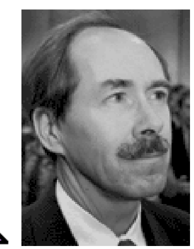
CHARGE QUANTISATION

MAGNETIC MONOPOLES

UNIFICATION OF FORCES



Maxwell



't Hooft

Polyakov

John Preskill

But it is one thing to say that monopoles must exist, and quite another to say that we have a reasonable chance of observing one.

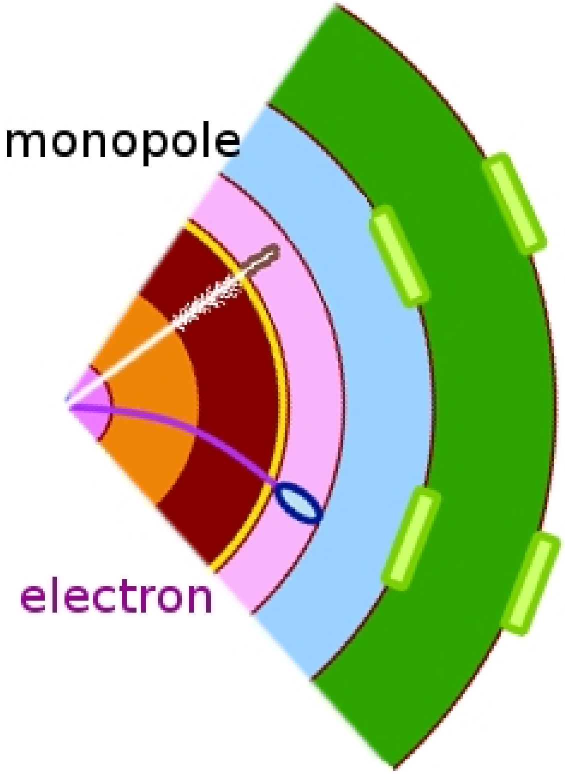
(1984)

Direct HIP/monopole detection at colliders (1)

signature of very highly ionising particle (HIP)

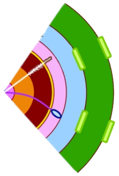
1) General-purpose detectors

- High ionisation
- Narrow energy deposit
- Anomalous bending



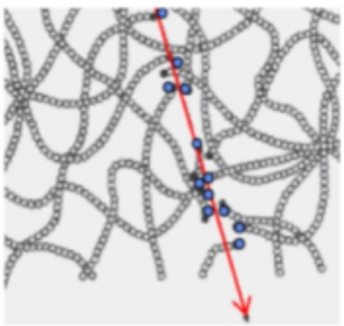
Direct HIP/monopole detection at colliders (2)

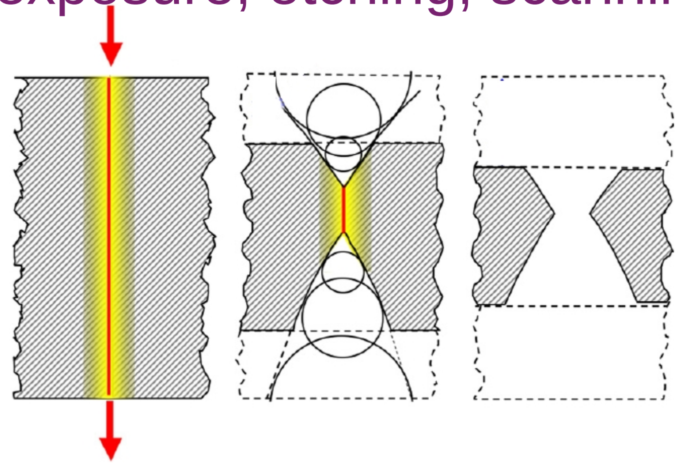
signature of very highly ionising particle (HIP)

1) General-purpose detectors 

2) Nuclear-track detectors

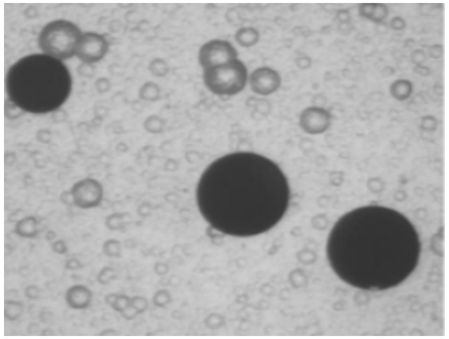
– Plastic NTD foil – exposure, etching, scanning

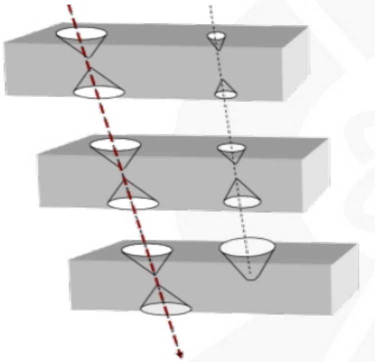




Like a camera (with film)

– Etch-pit cones (~50 μm) in successive sheets





Direct HIP/monopole detection at colliders (3)

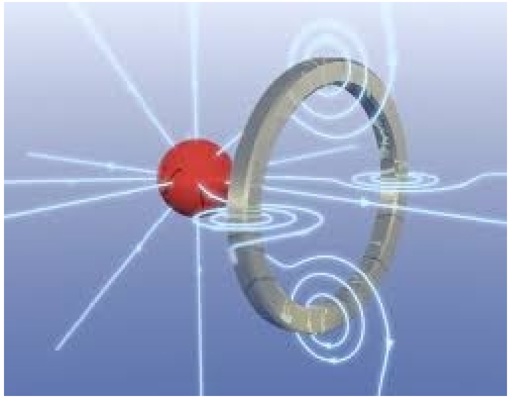
signature of very highly ionising particle (HIP)

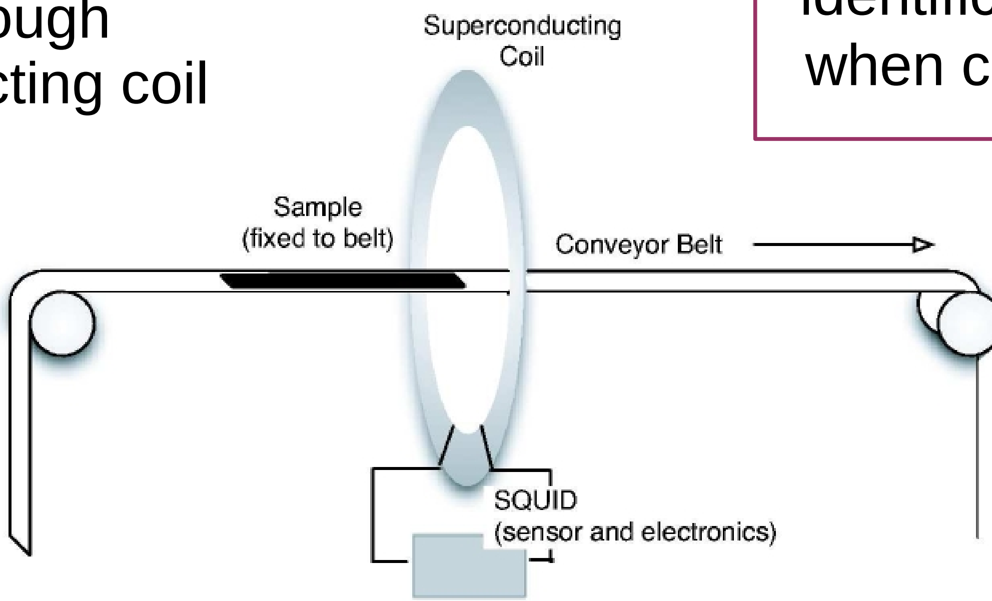
1) General-purpose detectors

2) Nuclear-track detectors

3) Trapping technique
   - Monopole-nucleus binding energy ~100 keV
   - Persistent current after passage through superconducting coil

Unambiguous identification when caught

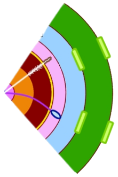




Direct HIP/monopole detection at colliders

signature of very highly ionising particle (HIP)

1) General-purpose detectors
2) Nuclear-track detectors
3) Trapping technique



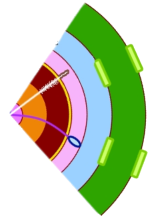
All three techniques are needed
to cover the full parameter space

(see EPJC 72, 1985 (2012), arXiv:1112.2999)

HIP searches at the LHC

(see EPJC 72, 1985 (2012), arXiv:1112.2999)

- ATLAS and CMS
  - ➔ $|g| \leq 2g_D$
  - ➔ $0.3 \leq |z|/\beta \leq 100$

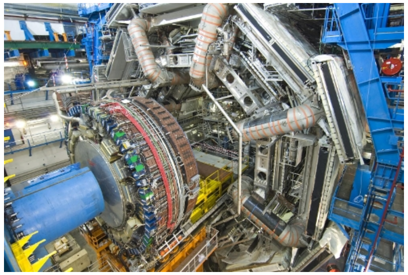


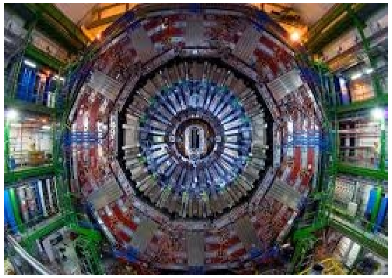
- MoEDAL NTD detectors
  - ➔ $|g| \leq 9g_D$
  - ➔ $5 \leq |z|/\beta \leq 500$

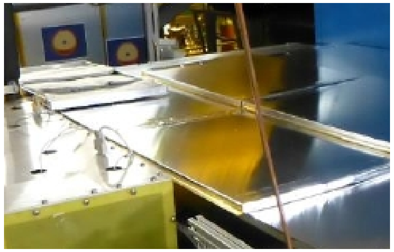
- MoEDAL trapping detector
  - ➔ $|g| \leq 4g_D$

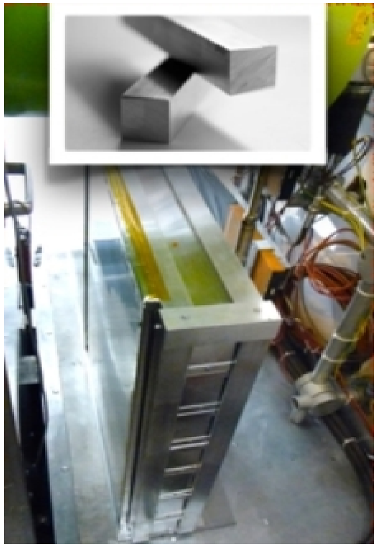
- Trapping in beam pipes
  - ➔ $|g| \geq 4g_D$

Complementary techniques!





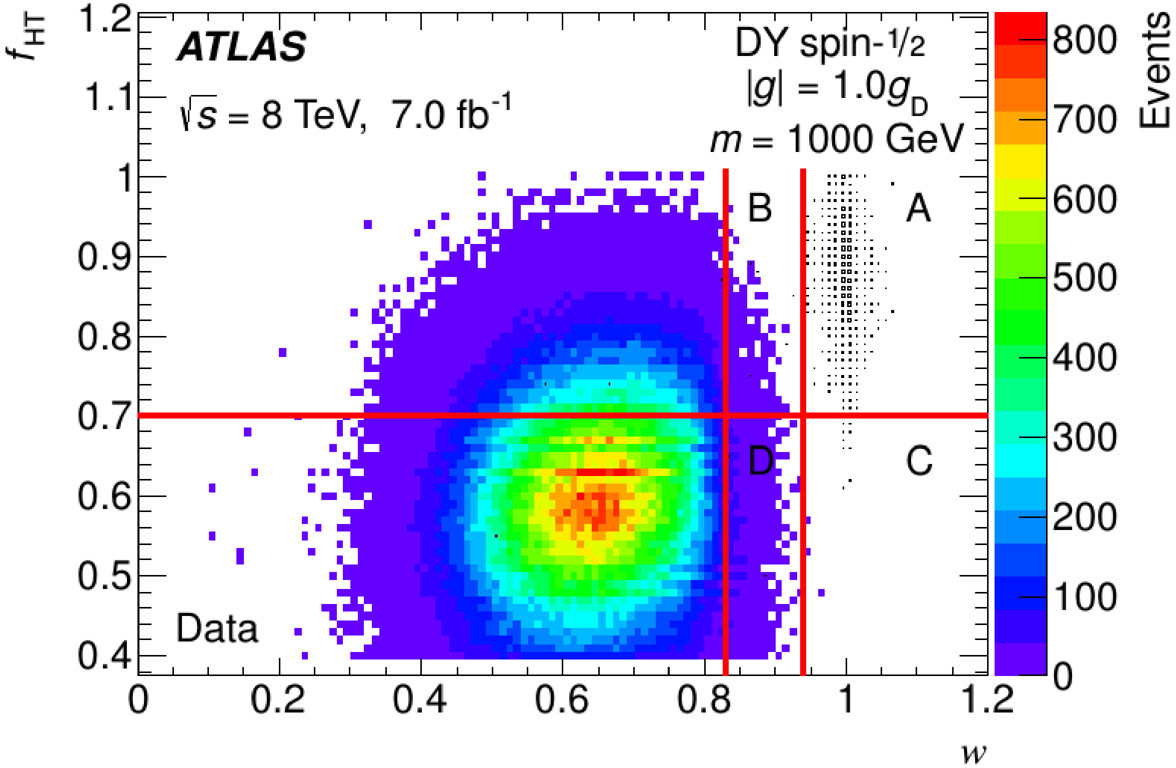


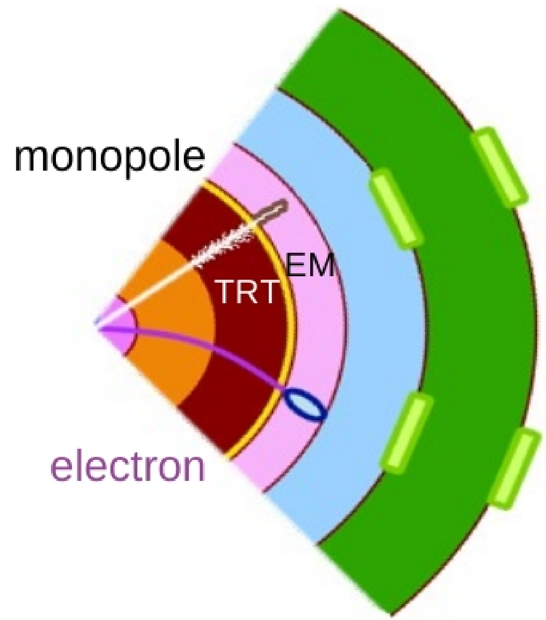


ATLAS search with dedicated trigger

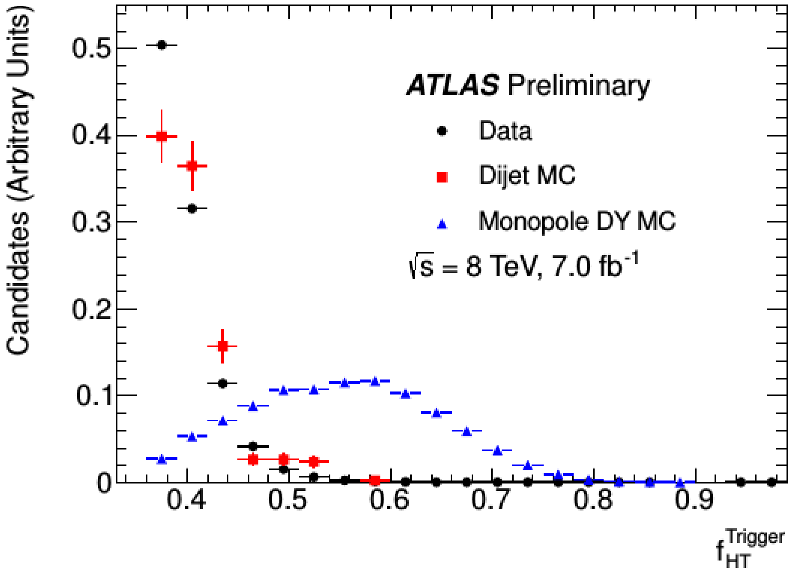
- HIPs stopping in ATLAS EM calorimeter
- Signature of high-ionisation track associated with pencil-like EM deposit – two independent variables

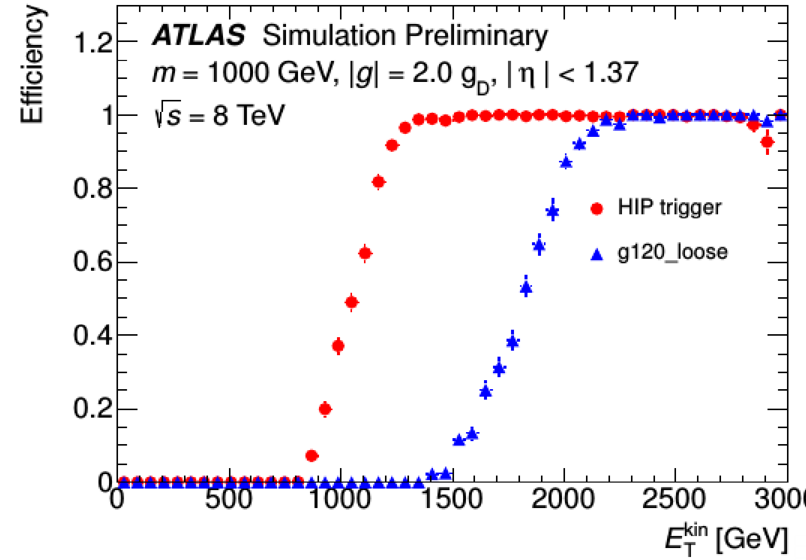
PRD 93, 052009 (2016), arXiv:1509.08059





The ATLAS HIP trigger





- Novel trigger based on TRT developed in 2012
  - Selects high fraction of high-threshold TRT hits
  - Low p_T thresholds, no requirement on second EM layer → large sensitivity enhancement
- Trigger updated and optimised in 2015
- 2016 data analysed, to be published soon
  - ➔ best sensitivity for monopoles with charge up to $2g_D$

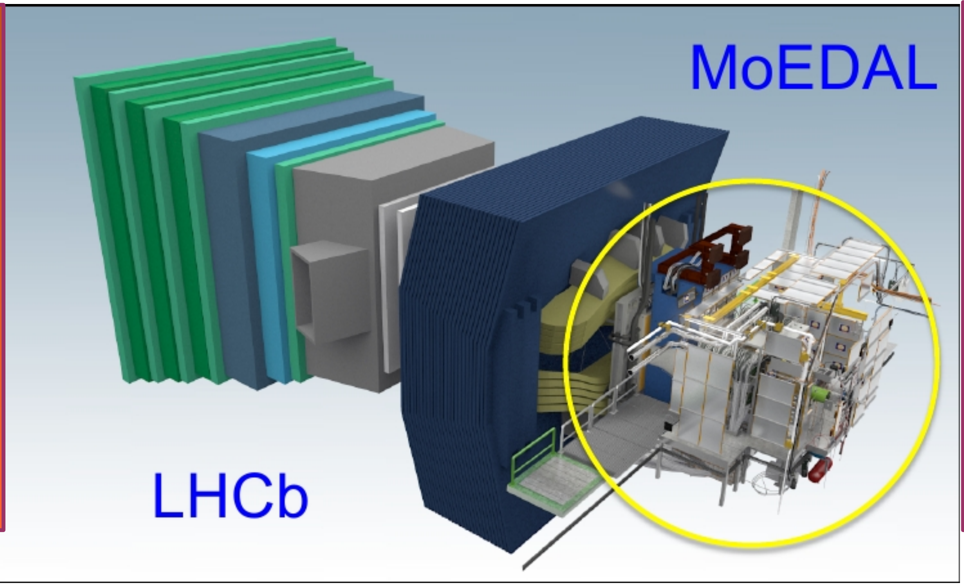
The Monopole & Exotics Detector at the LHC

- Searches for new charged long-lived particles
- The 7th LHC experiment, located at IP8
- ~70 members, 26 institutes

http://moedal.web.cern.ch/

The MoEDAL detector

Probes penomena which are inaccessible to other LHC experiments



No SM backgrounds, permanent physical record of new physics

MoEDAL is largely passive made up of three detector systems

NTD array
(~200 m²)

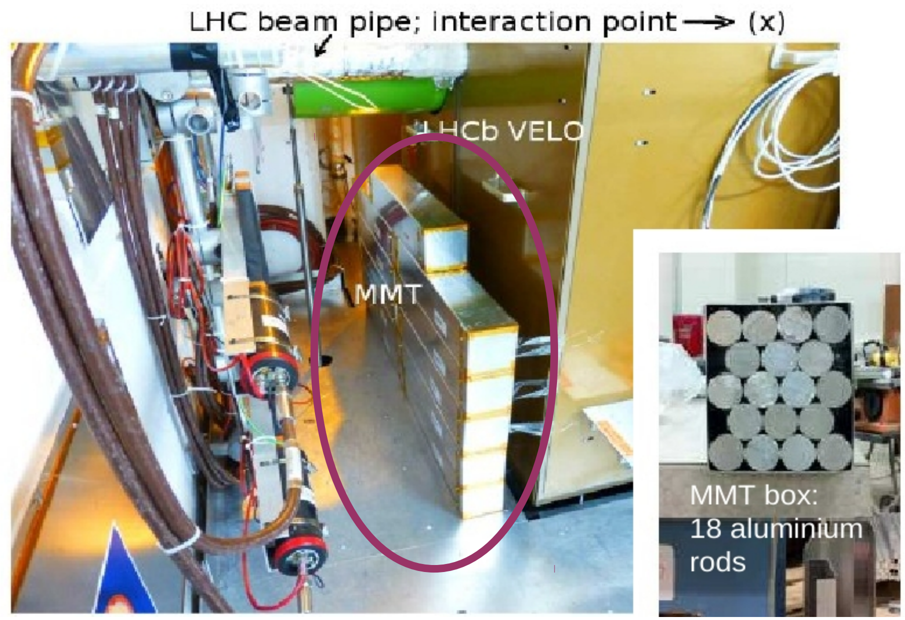
Trapping array
(~1 tonne of Al)

Timepix array
(for real-time monitoring)

MoEDAL in 2012

NTD stacks
on surrounding walls

1 array trapping detector prototype
Below beam pipe opposite to LHCb



Test arrays exposed to 8 TeV *pp* collisions

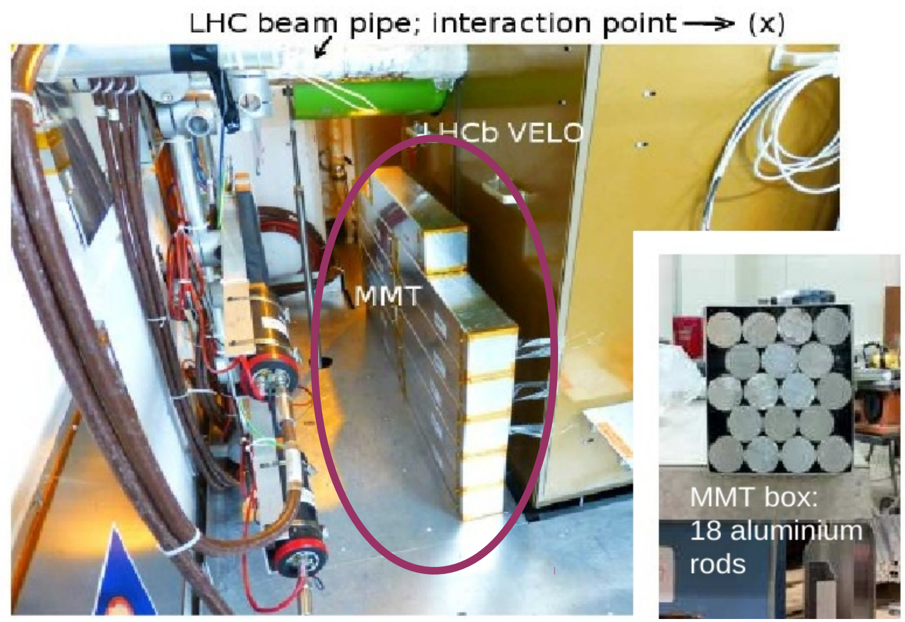
MoEDAL in 2012

NTD stacks
on surrounding walls

First LHC constraints on particles with multiple magnetic charge

JHEP 08, 067 (2016)

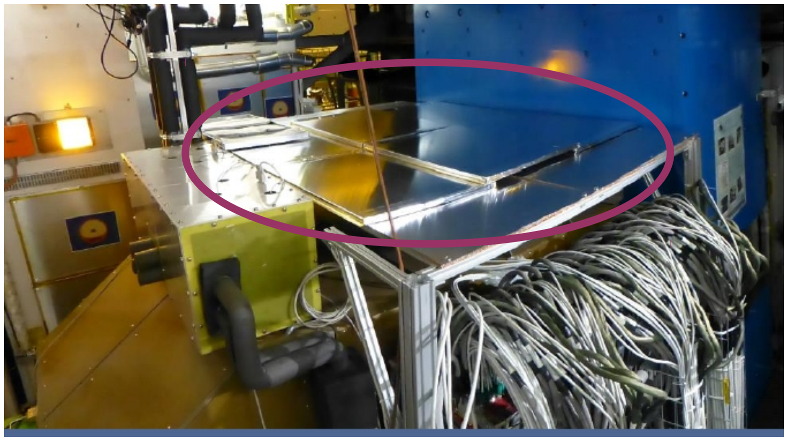
1 array trapping detector prototype
Below beam pipe opposite to LHCb



Test arrays exposed to 8 TeV *pp* collisions

MoEDAL in 2015/2016

NTD stacks on top of VELO, close to IP + on surrounding walls



Thin “shower curtain” NTD within LHCb acceptance

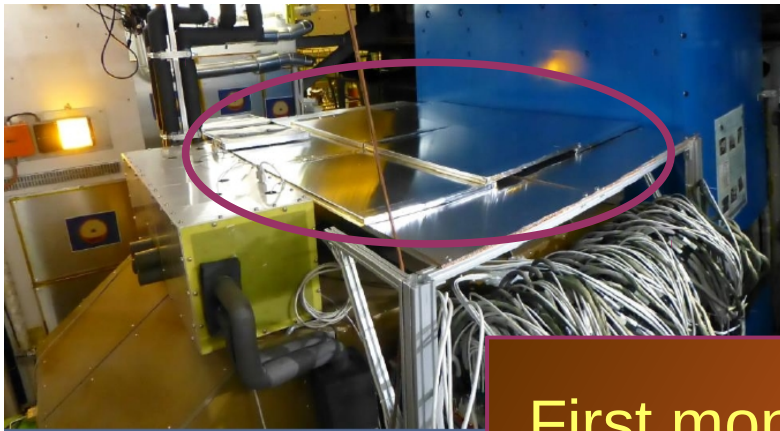
TimePix for online monitoring

3 arrays trapping detectors

Full arrays exposed to 13 TeV *pp* collisions

MoEDAL in 2015/2016

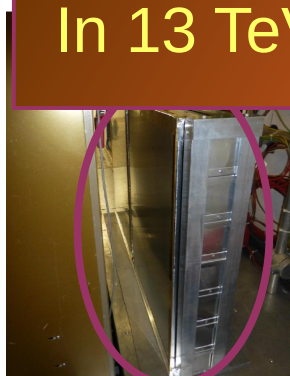
NTD stacks on top of VELO, close to IP + on surrounding walls



PRL 118, 061801 (2017)

Thin “shower curtain” NTD within LHCb acceptance

First monopole constraints
In 13 TeV collisions



3 arrays trapping detectors

Full arrays exposed to 13 TeV *pp* collisions

The beam-pipe initiative

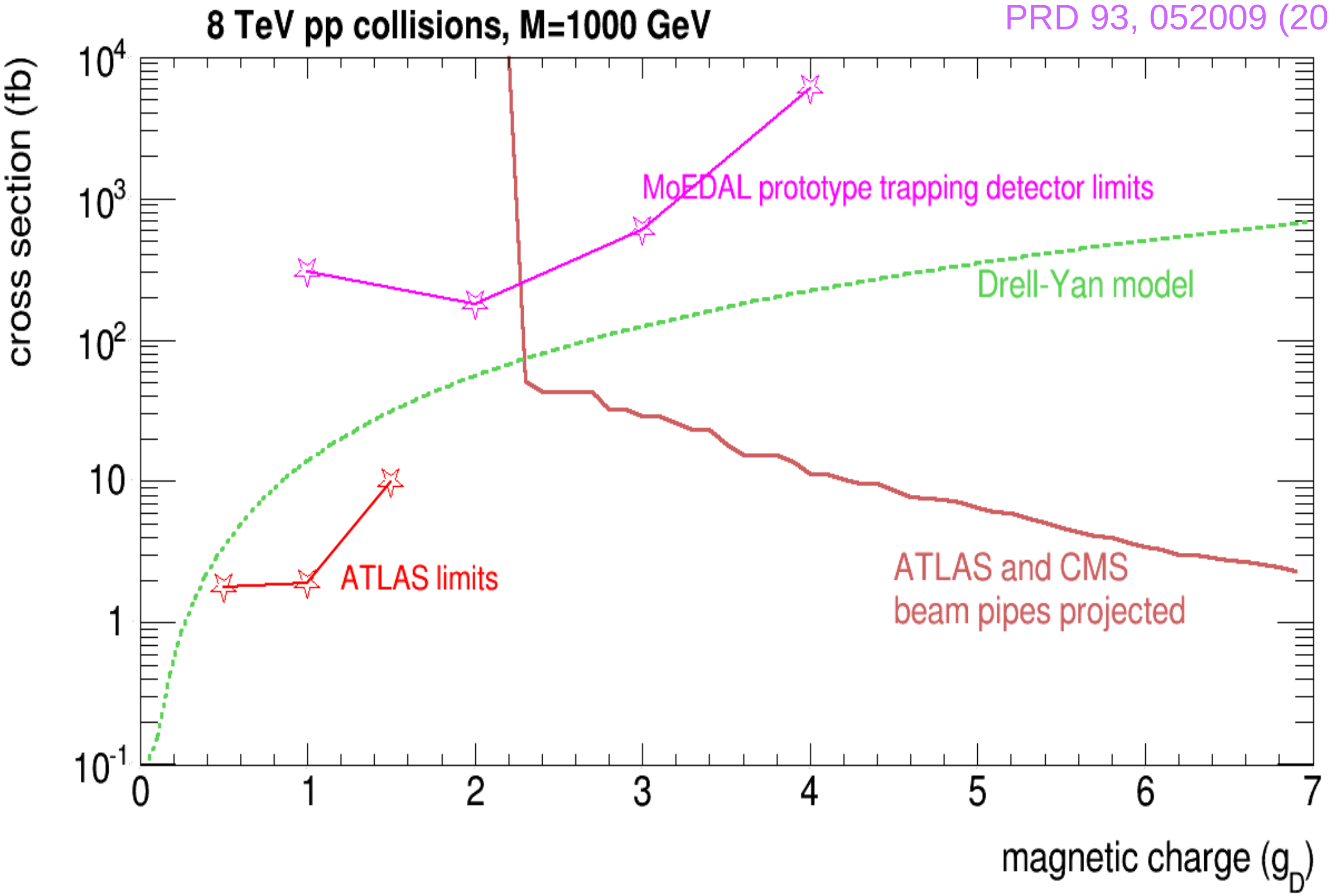
- Scan material exposed to high-energy LHC collisions
  - Beam pipes – sensitivity to very high charges
- LHC beam-pipe consortium made members of MoEDAL, ATLAS and CMS
  - Proposal sent to ATLAS and CMS managements for use of decommissioned run-1 Be pipes https://cds.cern.ch/record/2270165
  - Good chance accessing CMS pipe early 2018
- MoEDAL proposed to serve as a formal platform
  - Sample machining at U. Alberta
  - Magnetometer runs at ETH Zurich
- Search to be performed in 2018
  - Simulations still needed
  - All interested people welcome to join

Near-future prospects (run-1)

EPJC 72, 1985 (2012)

JHEP 08, 067 (2016)

PRD 93, 052009 (2016)

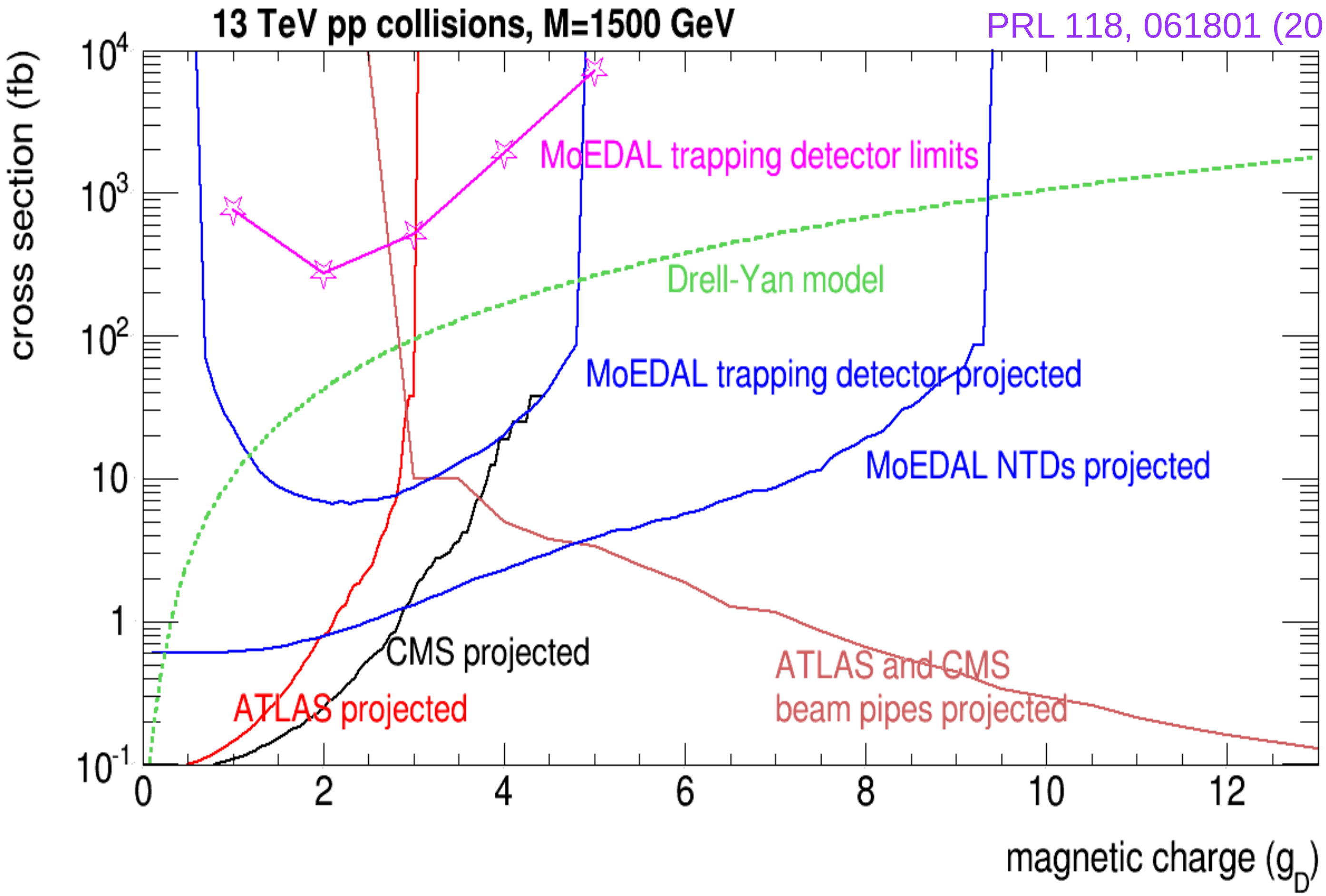


Near-future prospects (run-2)

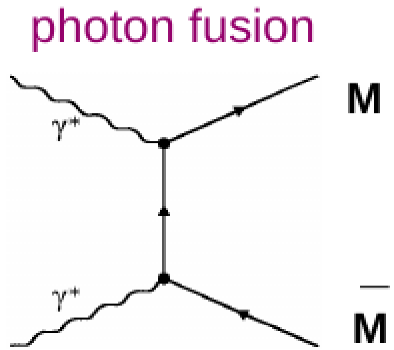
Assuming 0.2 background events in ATLAS/CMS and 0.0 background events in MoEDAL

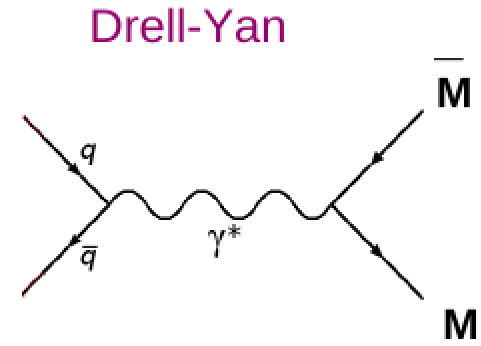
EPJC 72, 1985 (2012)

PRL 118, 061801 (2017)



HIP search interpretation

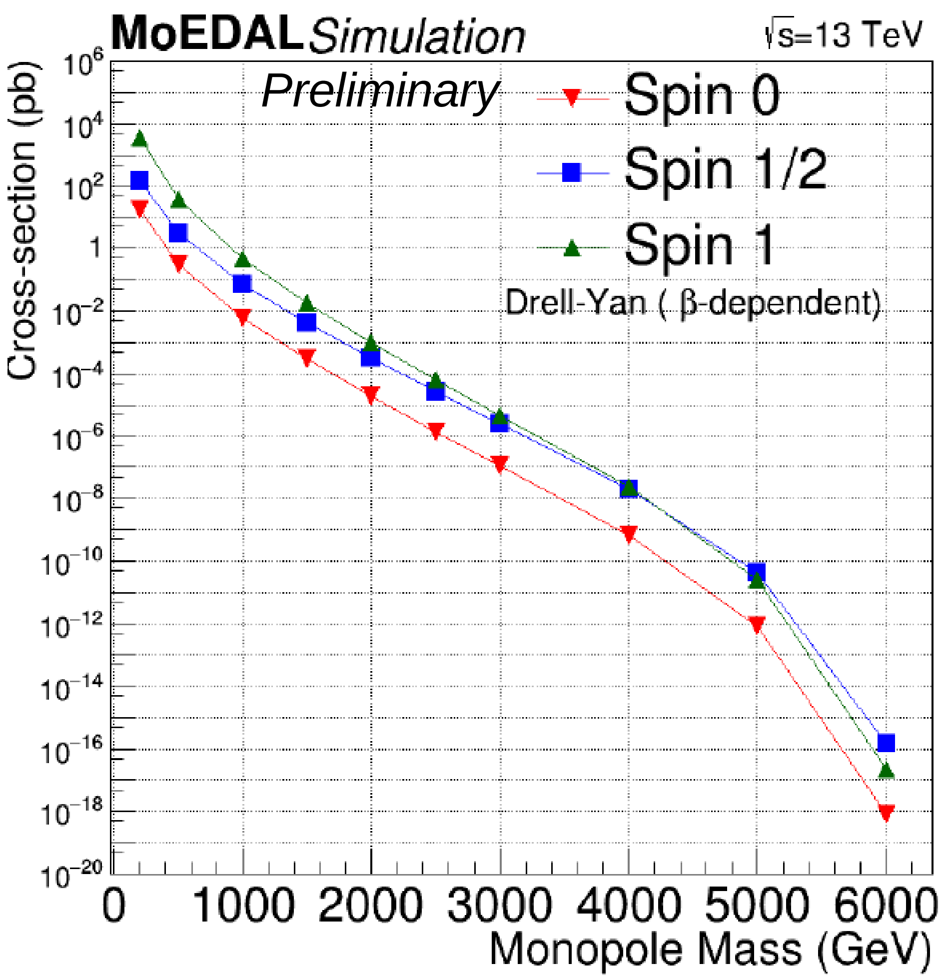




- EM coupling constant for Dirac charge = 34.25
  - non-perturbative, no reliable cross sections and kinematics
- Stategy until now at ATLAS and MoEDAL
  - Simplest pair production – Drell-Yan spin-1/2 and spin-0
  - Also fiducial regions for model-independent results
- Under development
  - Photon fusion, beta-dependent couplings, spin-1...
  - Thermal production in heavy-ion collisions – does not rely on perturbation theory, thus escaping model uncertainties (see arXiv:1705.07052)

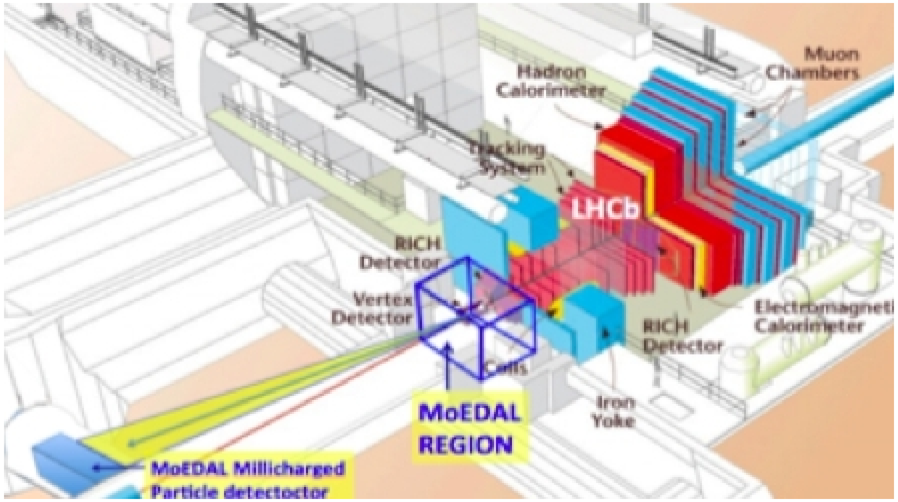
Development and validation of new models

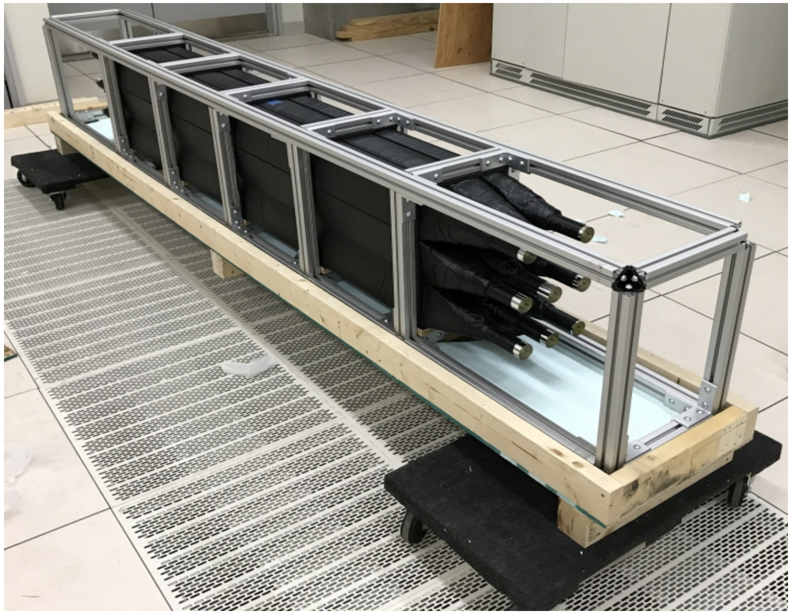
- Madgraph models of DY and photon fusion with spin-0, spin-1/2, spin-1 with β-dependent and β-independent couplings
- Comparisons with calculations found in the literature
- Cross-checks with analytical calculations by theorists (eg spin-1 used for the first time)

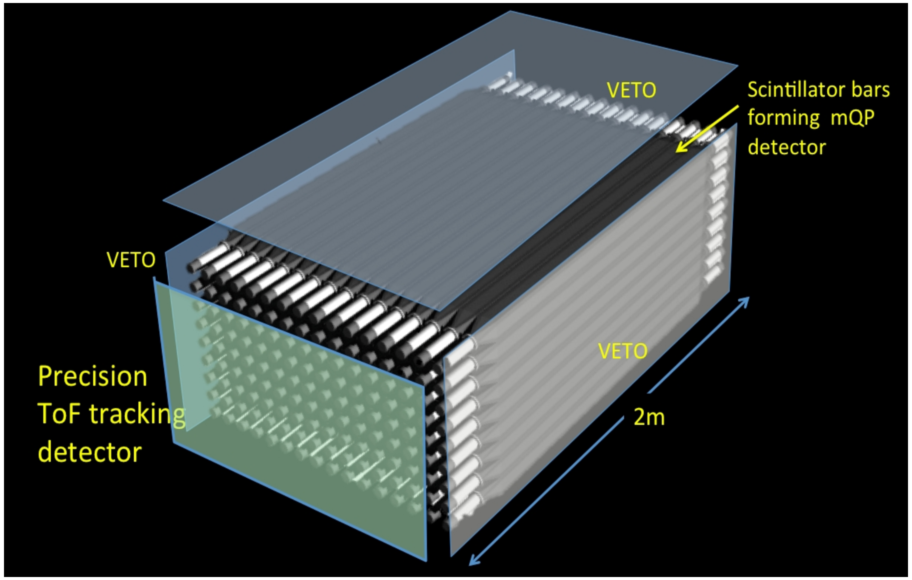


The MoEDAL MAPP detector

- New detector near IP8
- Fractionally charged particles and long-lived decaying neutral particles
- Test prototype shipped to CERN, now being installed







Summary

Wide programme of searches for new charged long-lived particles at ATLAS/CMS and MoEDAL

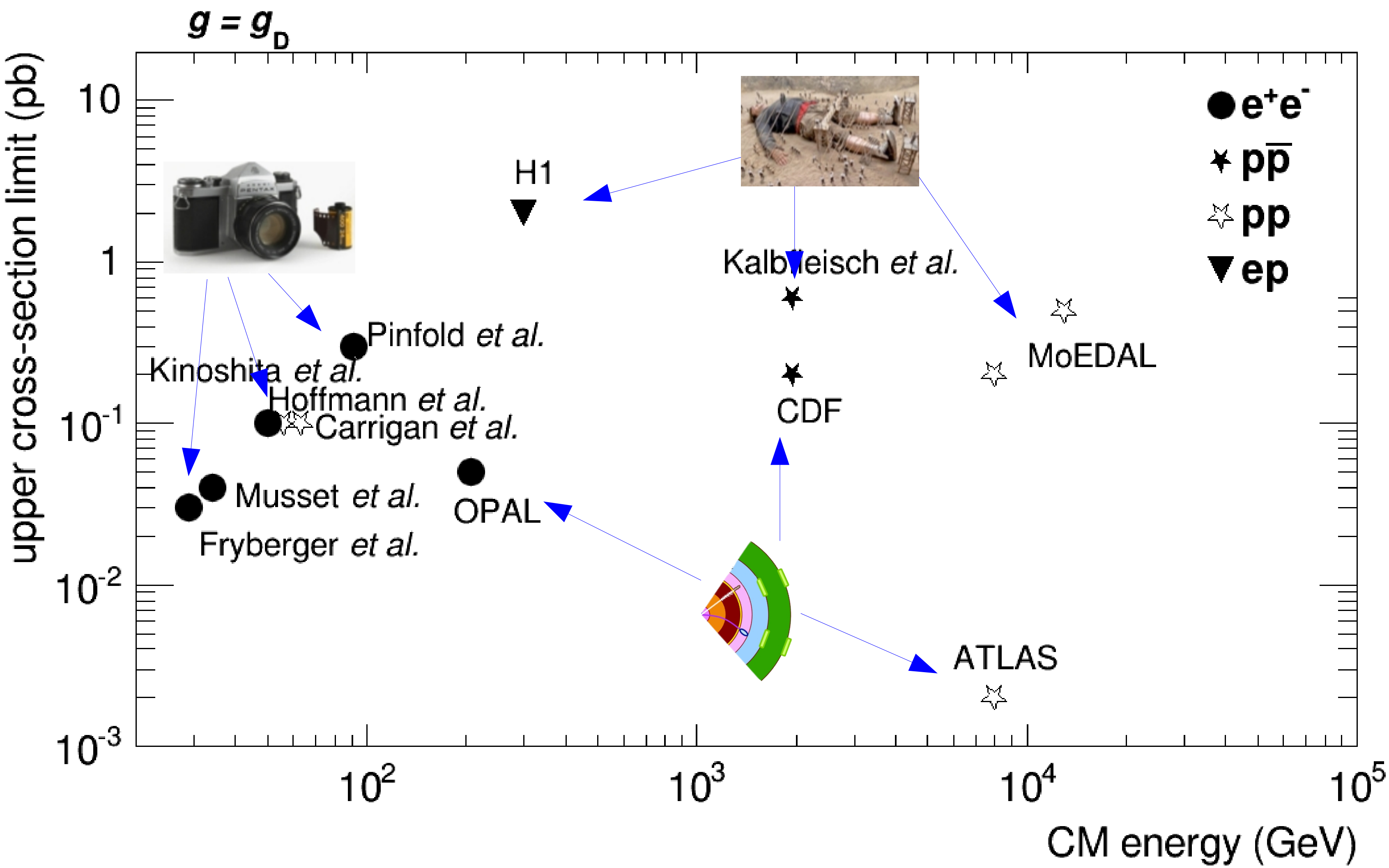
- ATLAS and CMS benefit from high integrated luminosity and developed dedicated triggers
- MoEDAL benefits from dedicated passive detector techniques – robust and complementary design
- Common area: development of a range of pair-production models, facilitate interpretation and comparison between experiments

The hunt continues in 2018

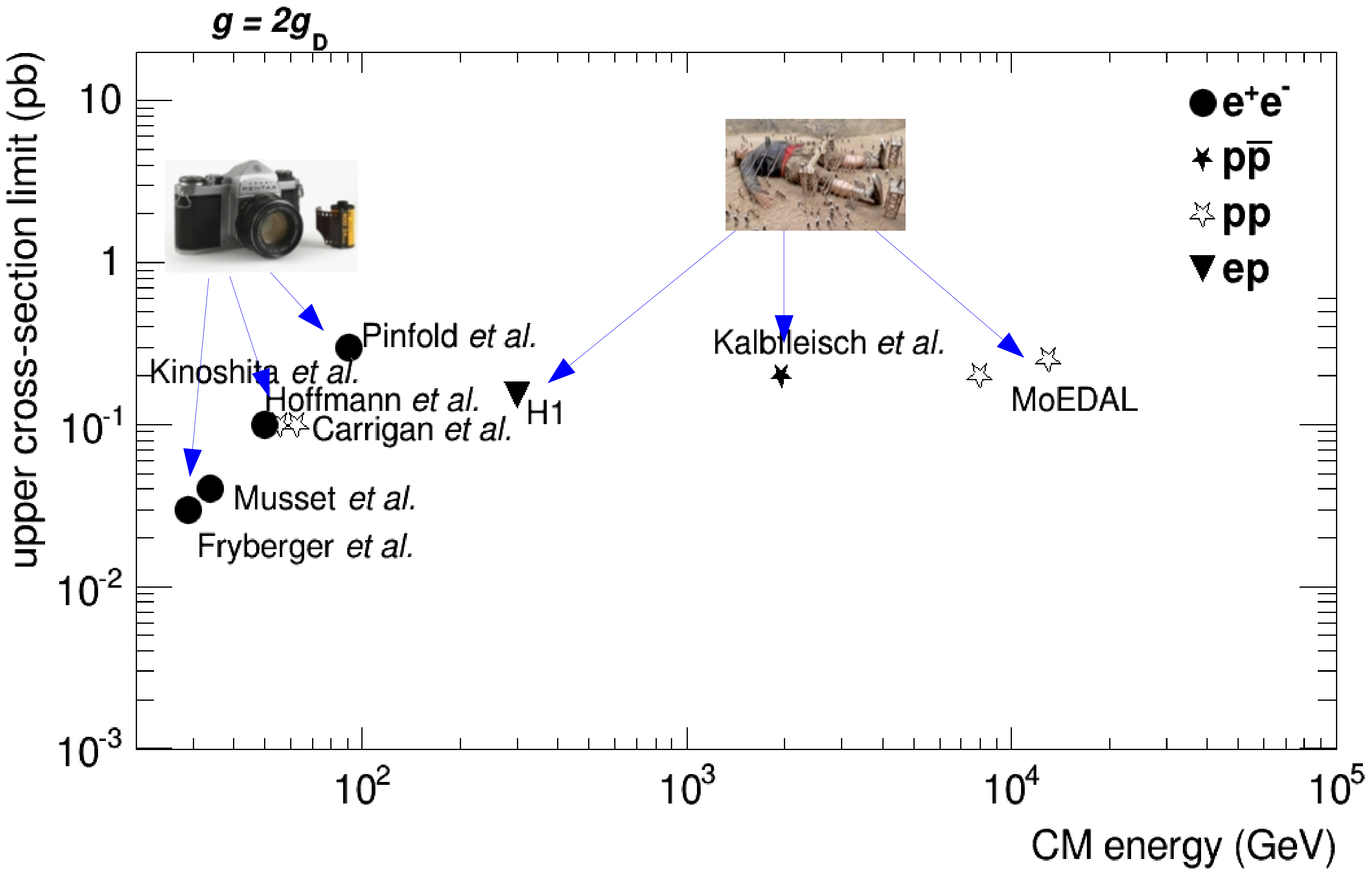
- ATLAS@13 TeV
- MoEDAL NTDs
- Full trapping detector array
- Trapping in beam pipes

extras

Direct collider monopole searches
current limits, assuming Dirac charge g_D



Direct collider monopole searches
current limits, assuming twice the Dirac charge $2g_D$

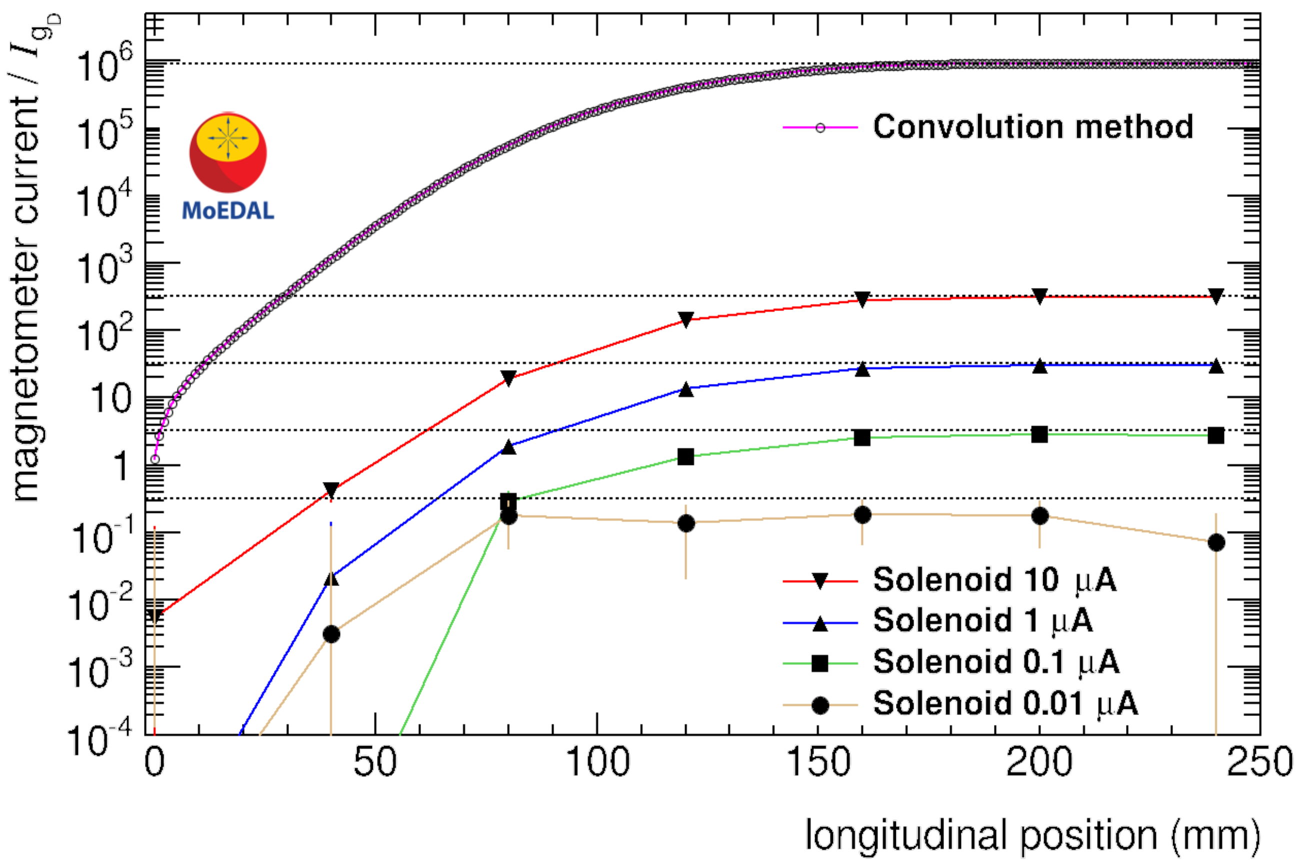


Magnetometer scans

- > 1000 samples
- Persistent current measured for each sample
- Samples with persistent current > 0.25 g_D are set aside as candidates
- Multiple measurements rule out the monopole hypothesis

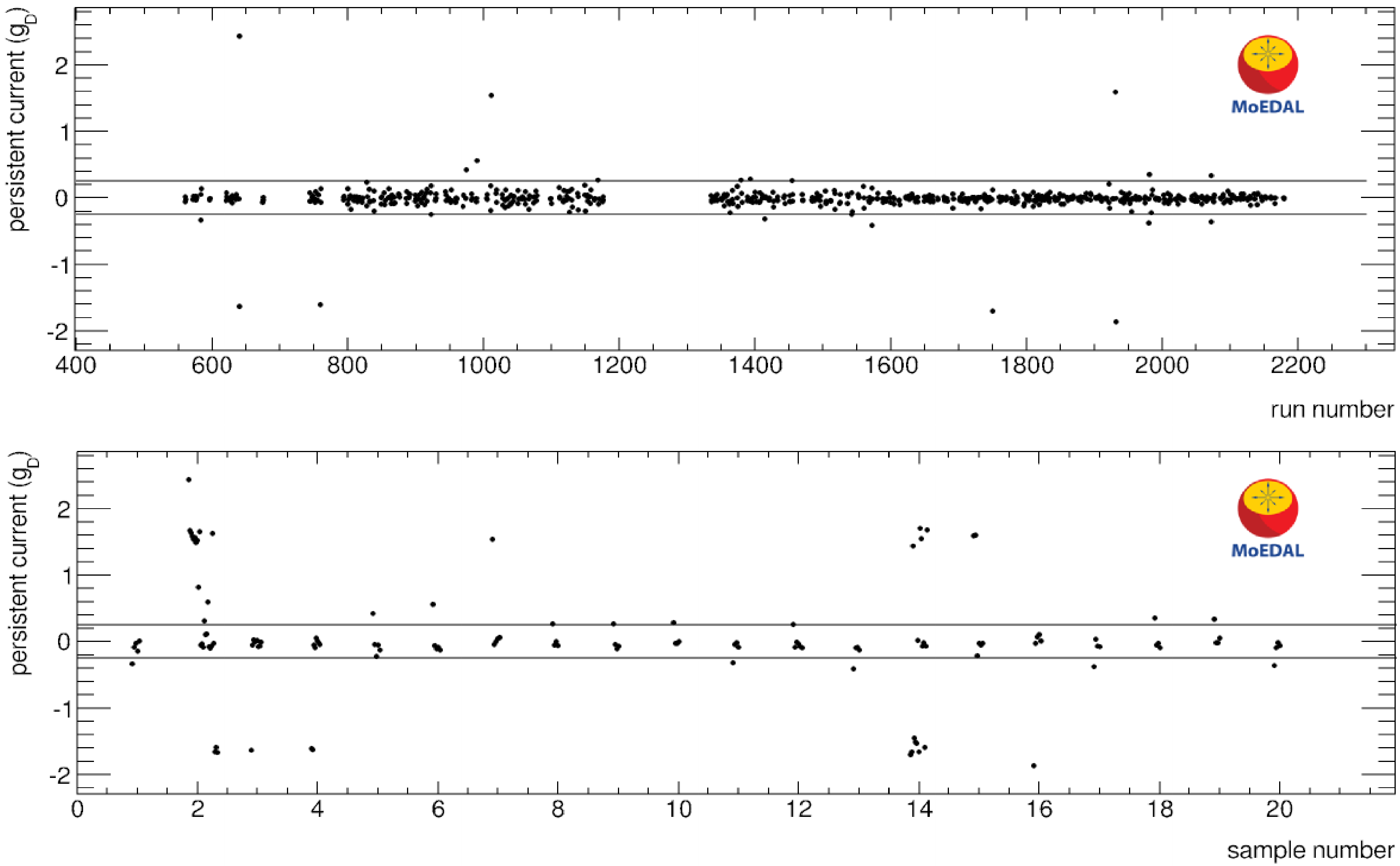
Magnetometer calibration

- Two independent methods: convolution and solenoid
- Very good agreement between the two
- Linearity demonstrated in range 0.3-10^6 g_D



Magnetic charges in samples (13 TeV exposure in 2015)

PRL 118, 061801 (2017)



- Exclude > 0.5 g_D in all samples

Cross-section limits with 2015 exposure

PRL 118, 061801 (2017)

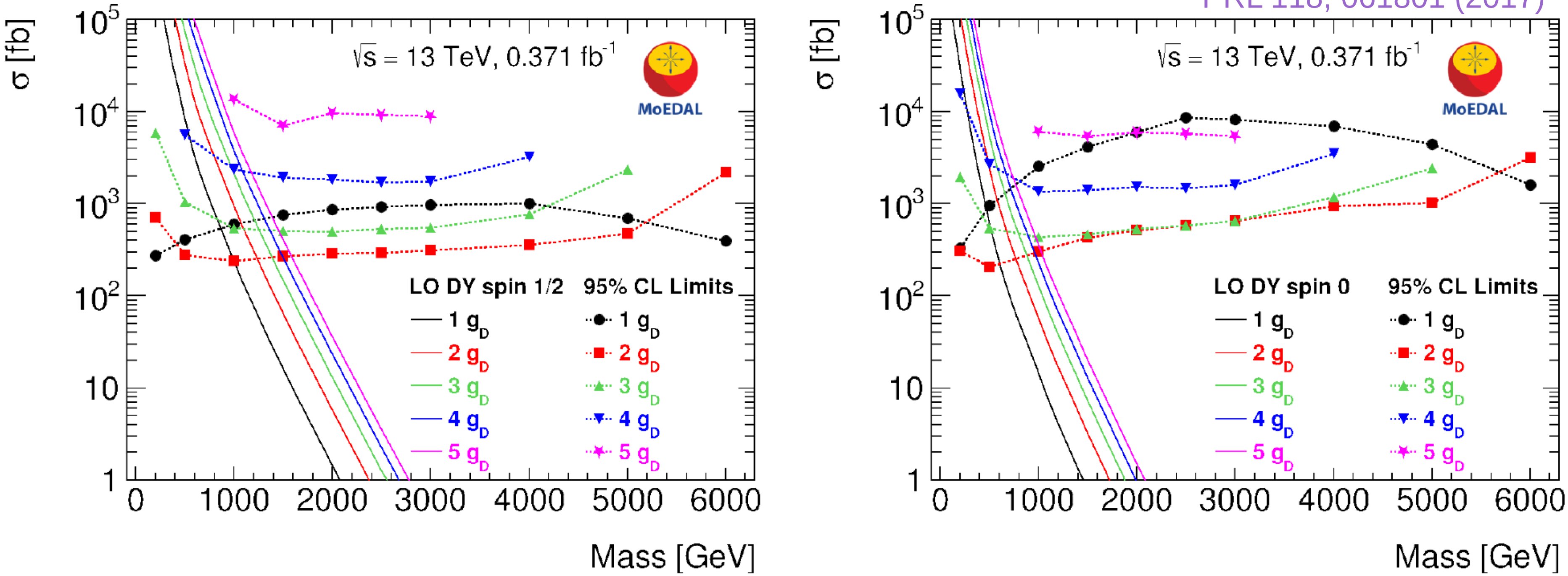


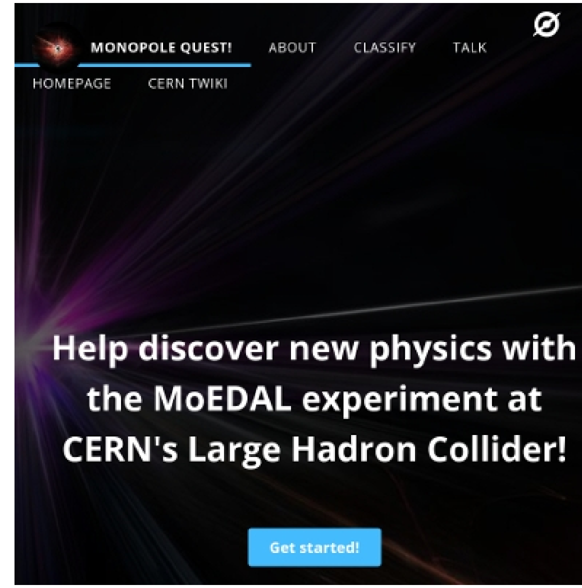
FIG. 2. Cross-section upper limits at 95% confidence level for DY monopole production in 13 TeV *pp* collisions as a function of mass for spin-1/2 (left) and spin-0 (right) monopoles. The colours correspond to different monopole charges. The solid lines are DY cross-section calculations at leading order.

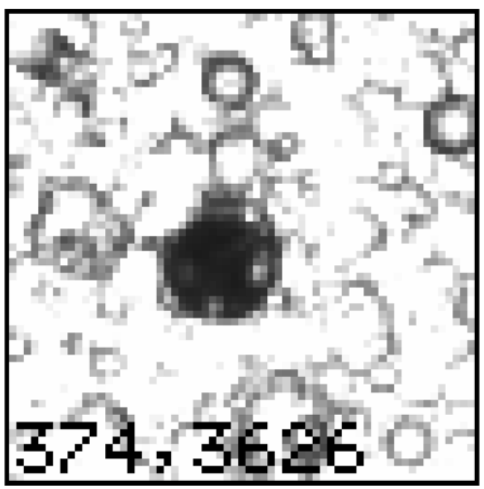
- First monopole constraints in 13 TeV *pp* collisions
- Probe masses in the TeV regime for up to $5g_D$

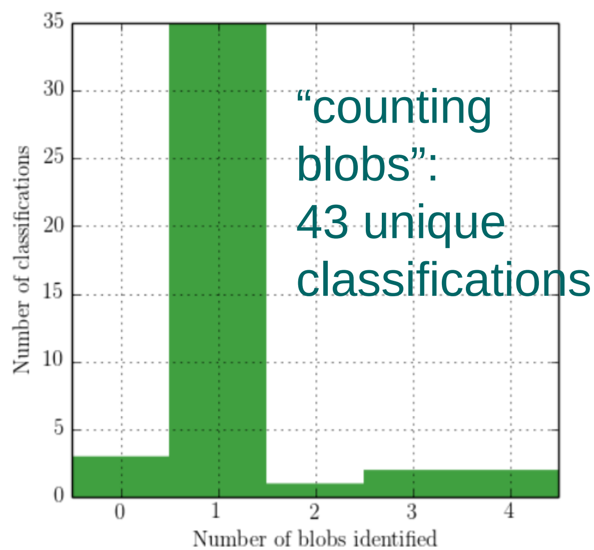
MoEDAL's unique patterns

https://www.zooniverse.org/projects/twhyntie/monopole-quest

- Machine vision
  – Modern fast scanners
  – Automatic pattern recognition
- Citizen science – the Zooniverse
  – Analysis of images from TimePix and NTDs







NTD exposed to collisions and ion beam

Use human brains
- ➜ signal identification in big messy images
- ➜ "anything odd?"