Postcards from the High Energy Frontier

What's New and Synergistic in Collider and Astroparticle Physics

DIFFRACTION 2012

James L Pinfold
University of Alberta

MENU

Starter

Introduction – the synergy between LHC & Astroparticle Physics

Main Course

1. *Colliders and Cosmic Rays*
   a. *LHC results & UHECR rays*
   b. *The LHC as a cosmic ray detector*
2. *Dark Matters*
   a. *Direct and Indirect DM search Experiments*
   b. *The LHC perspective*

MENU

Side Dish

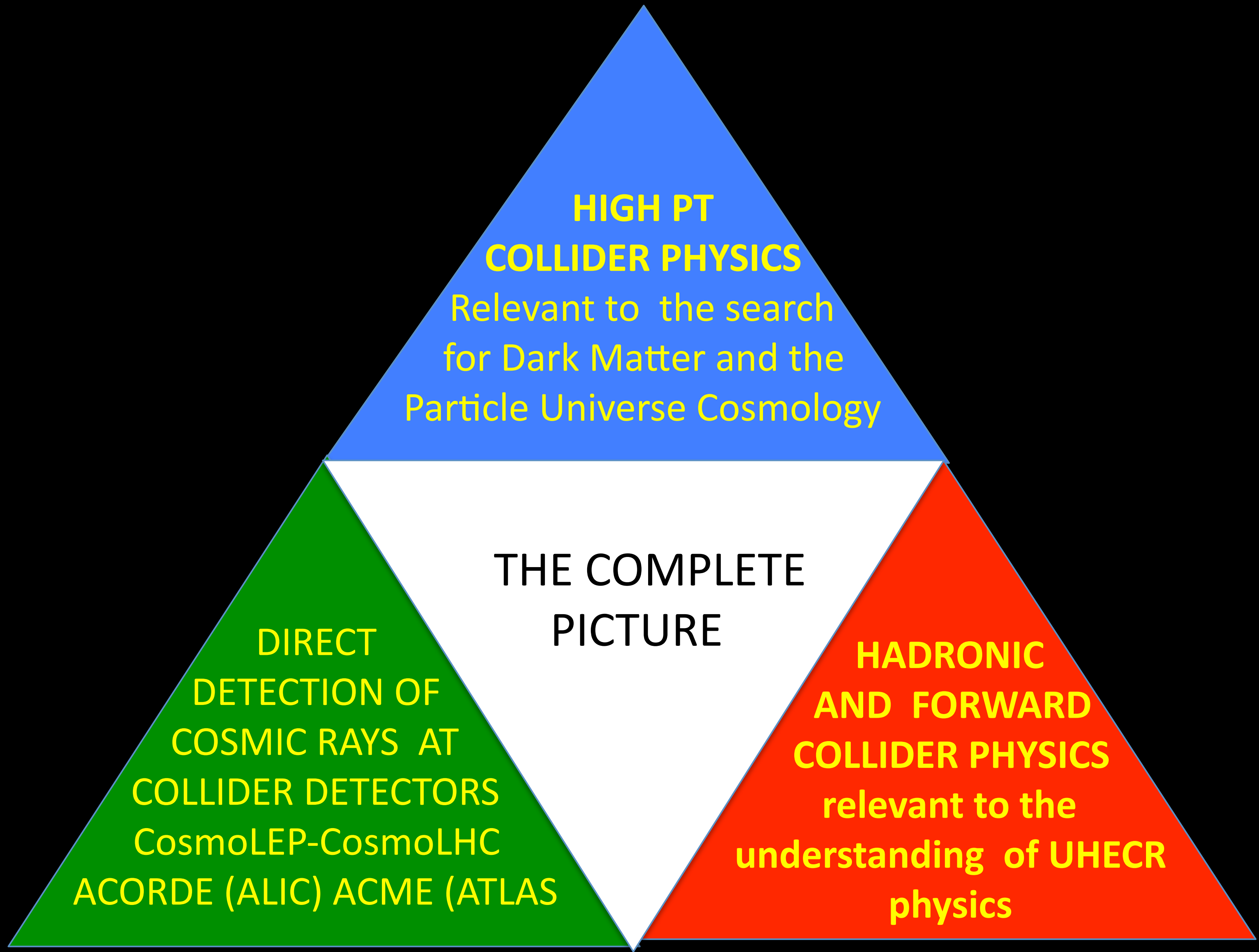
3. *Making the LHC a $\gamma\gamma$, γ-IP and IP-IP Collider*

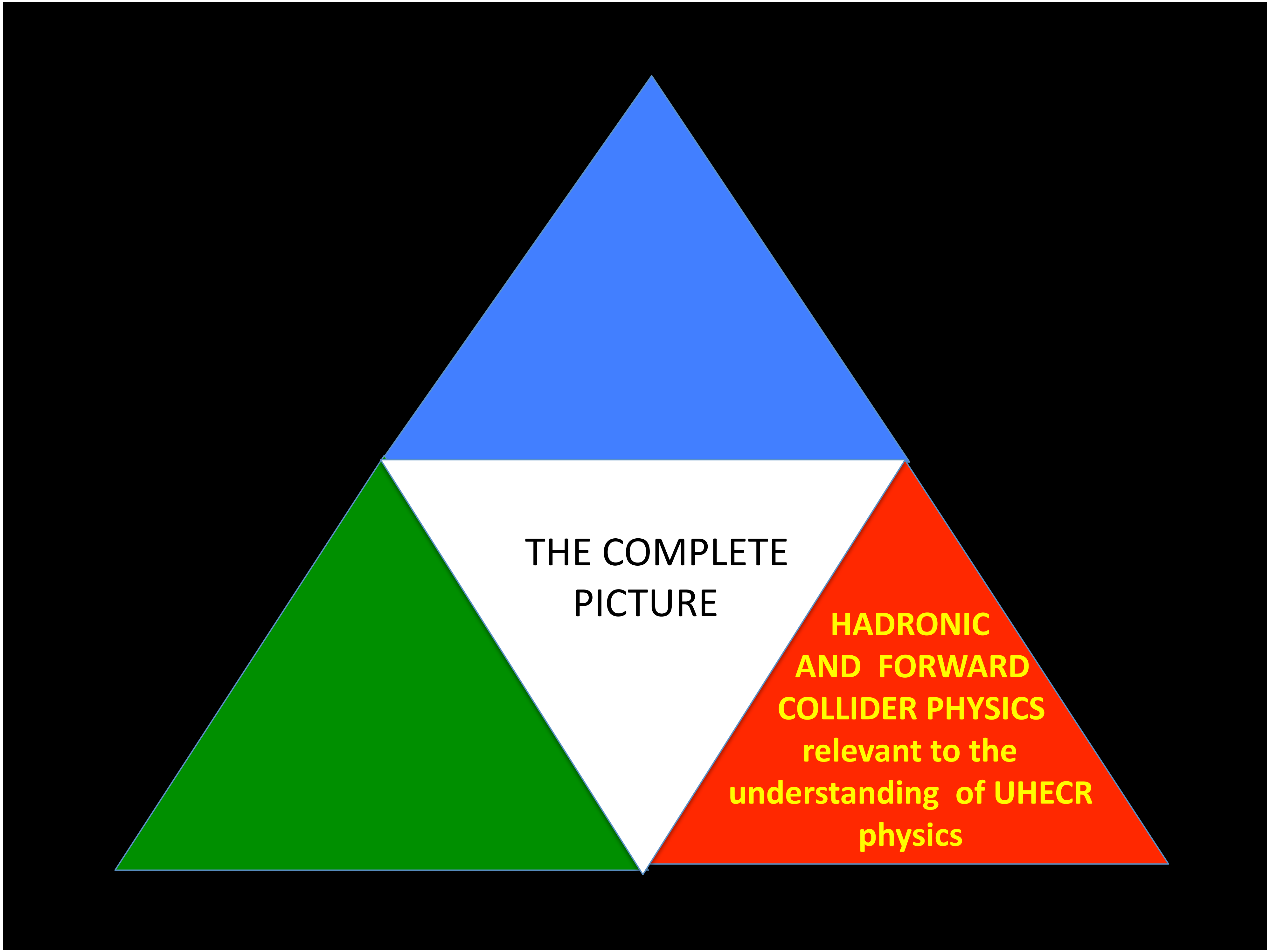
Dessert

4. *MoEDAL the newest LHC Experiment*

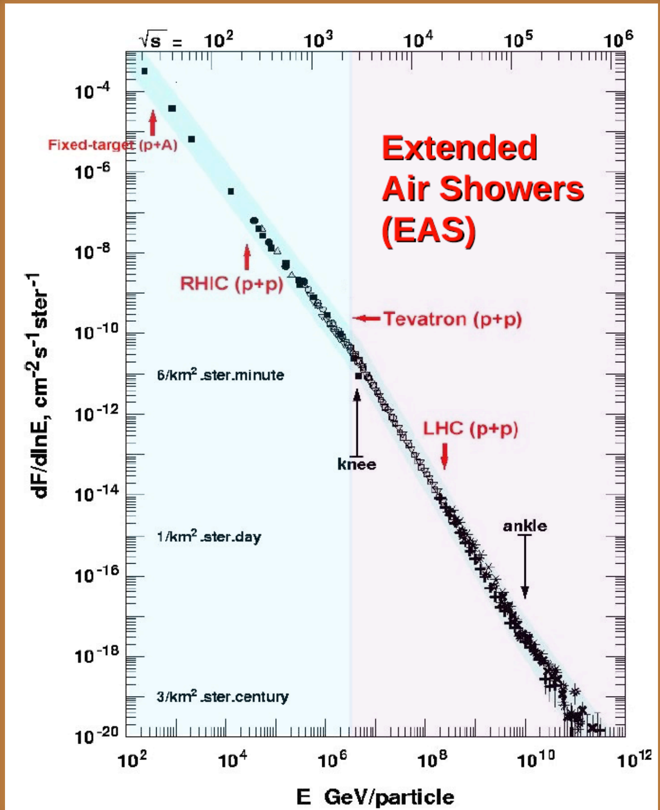
LAST WORDS

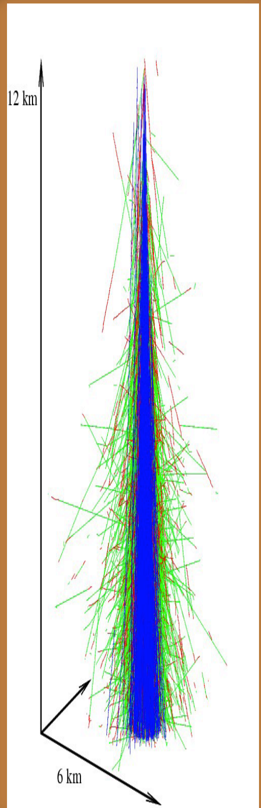
The Collider - Astroparticle Physics Synergy

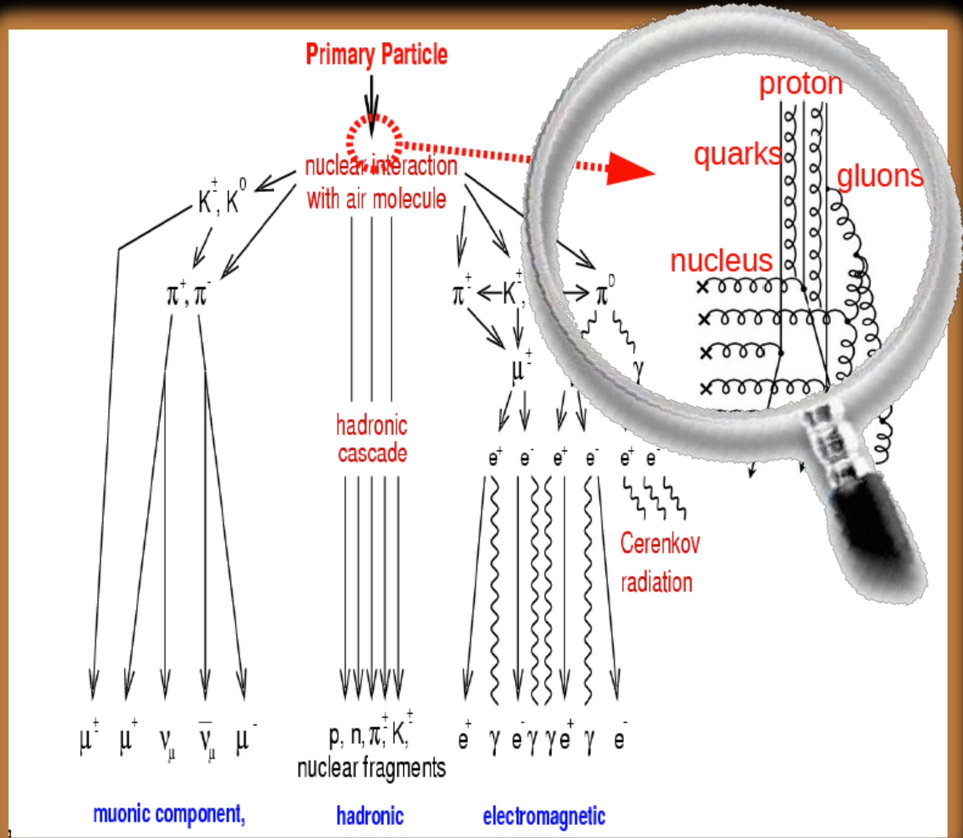



THE COMPLETE PICTURE
HADRONIC AND FORWARD COLLIDER PHYSICS relevant to the understanding of UHECR physics

Ultra High Energy Cosmic Rays & QCD

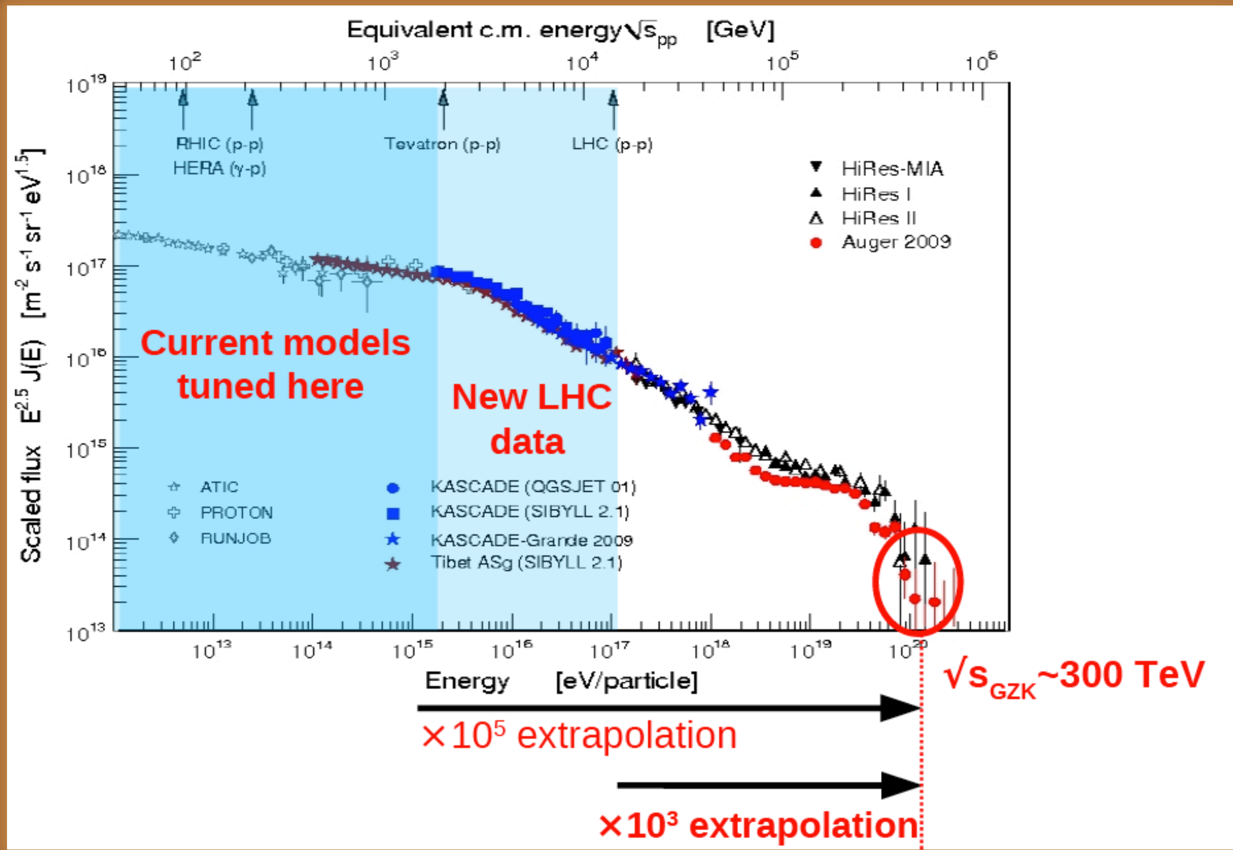






- *Above ~10^{15} eV CR energy & ID determined via hadronic MCs*
  - *p-N collisions: QCD interactions at E_{cm} up to $\sqrt{s}_{GZK}$~300TeV*
- *Many questions: origin of the structures in the energy spectrum? What is the sources & composition of UHECRs?*

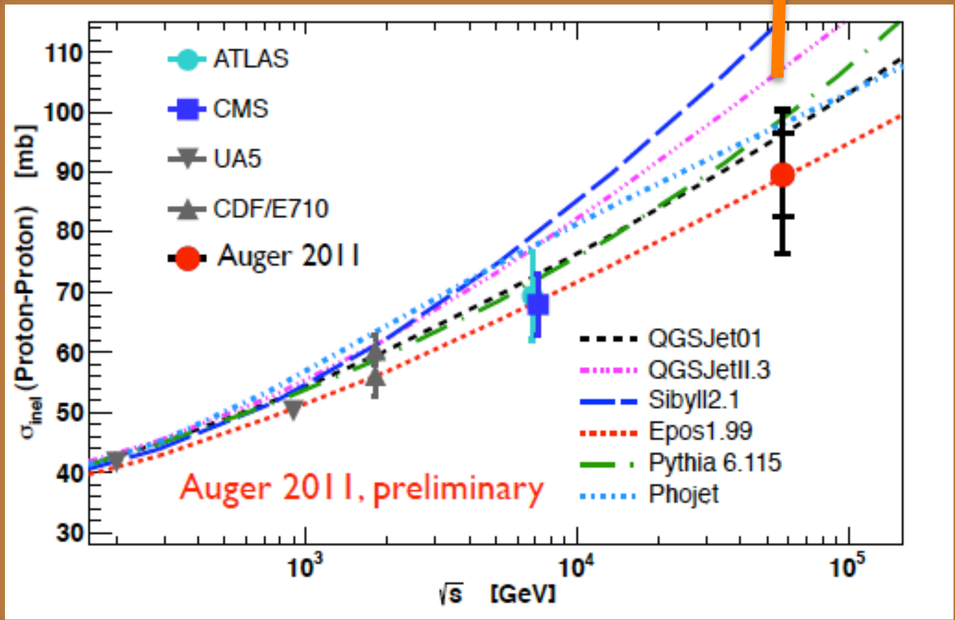
Tuning UHECR MCs with Collider Data

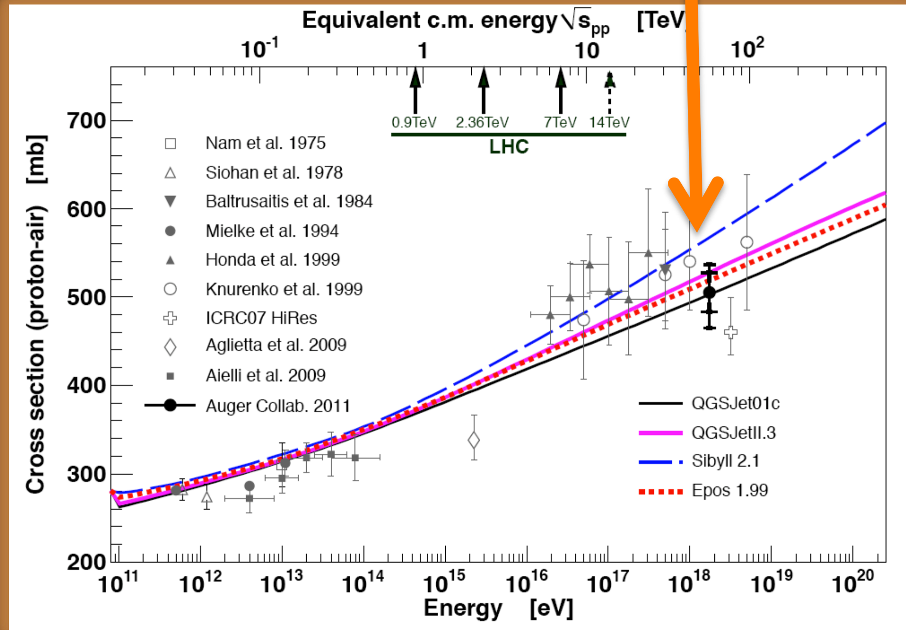


- *Cosmic ray p-N collisions in the atmosphere above "knee" at ~10^8 GeV/particle can be probed in p-p collisions at the LHC*
- *The LHC provides a significant lever-arm in providing constraints for hadronic Monte Carlos for UHECR*

The Inelastic Cross-section Results

Model dependent p-N → p-p (Glauber Model)





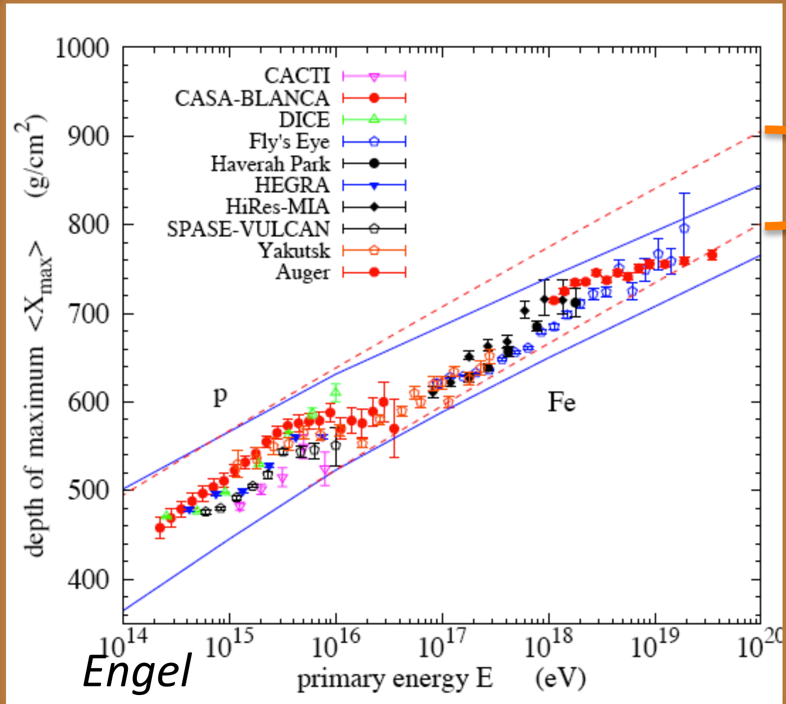
- *ATLAS and CMS crosssection slightly lowers than TOTEM's*

  $$\sigma_{inel}\ (\xi > 5 \times 10^{-6}) = 60.3 \pm 0.05(stat.) \pm 2.1(lumi.)\ mb.$$

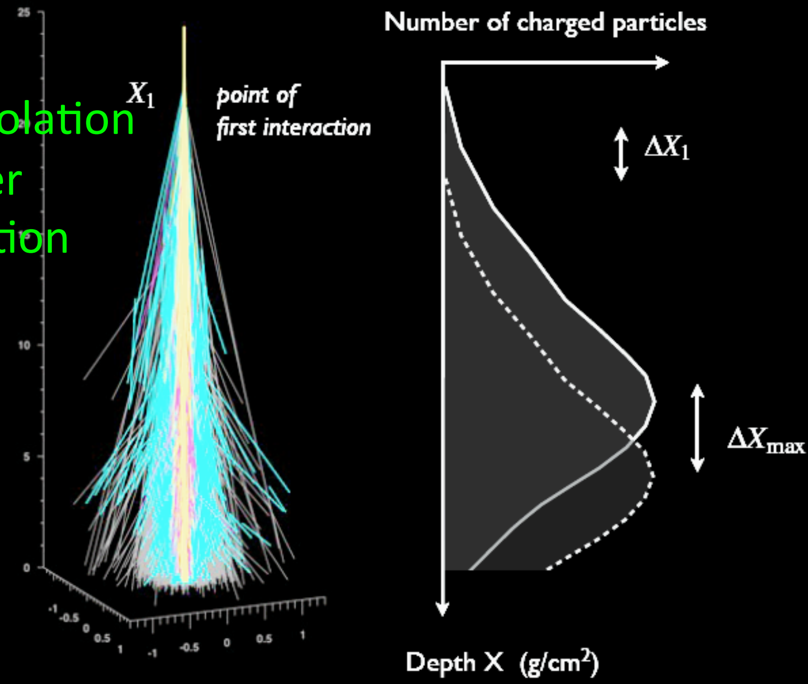
  $$\sigma_{inel} = 69.1 \pm 2.4(exp.) \pm 6.9(extrap.)\ mb.\ (ATLAS)$$

- *The EPOS1.99 model describes the rise in the total cross-section out to 60 TeV (Auger)*

LHC Cross-sections & HECR Composition

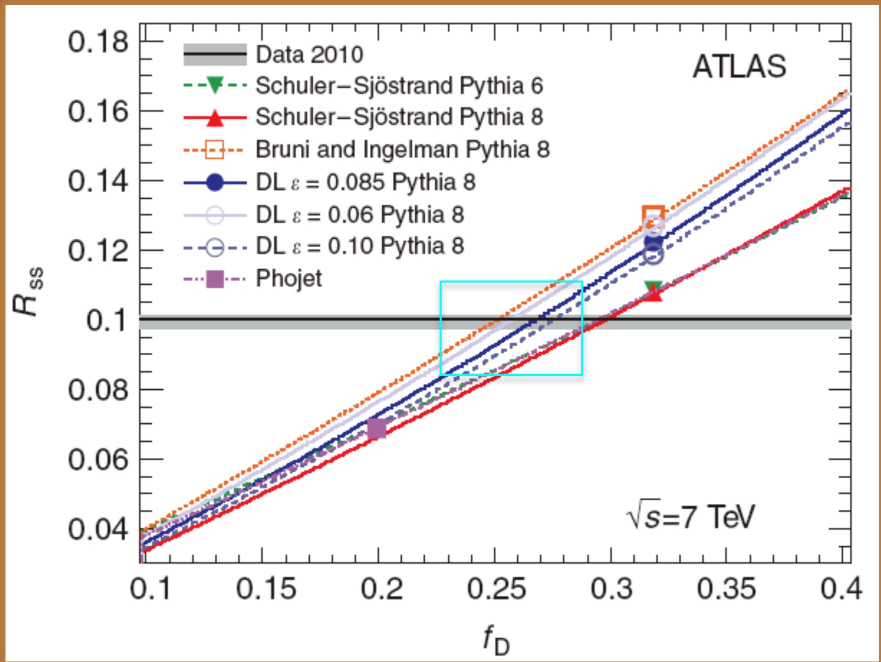


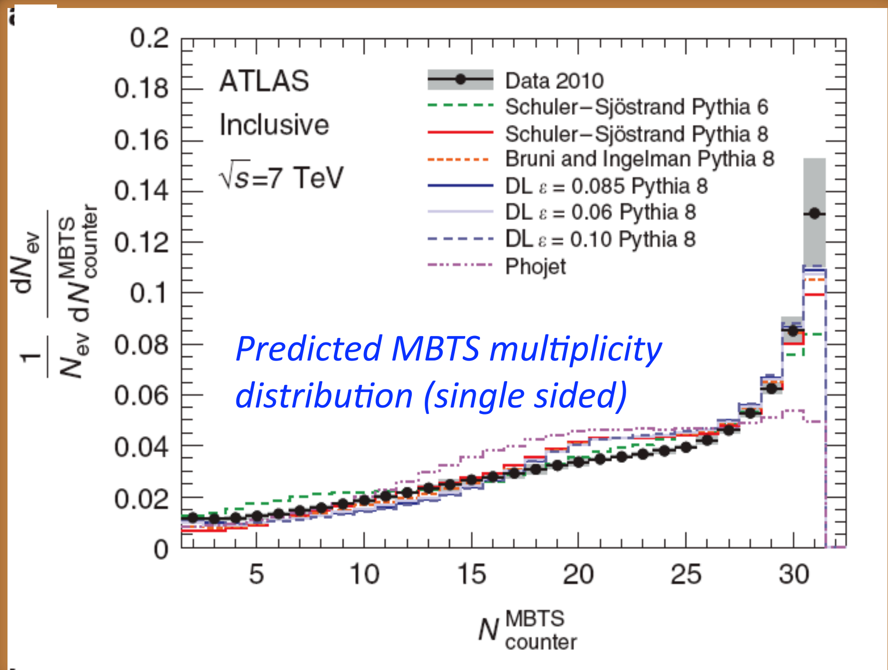
Eg Extrapolation with lower cross-section



- *ATLAS data indicates a slower energy rise of σ_{inel} (pp) than was predicted by a number of models.*
  - *This leads to a reduction of the predicted proton-air cross section and on average a deeper shower max. position*
- *Eg: with this slower rise in σ_{inel} (pp) SIBYLL interpretation would move towards heavier elements (QGSJET same trend)*

The Diffractive Fraction





- *SD selection ≥ 2 hits on one side only → 122,490 events*

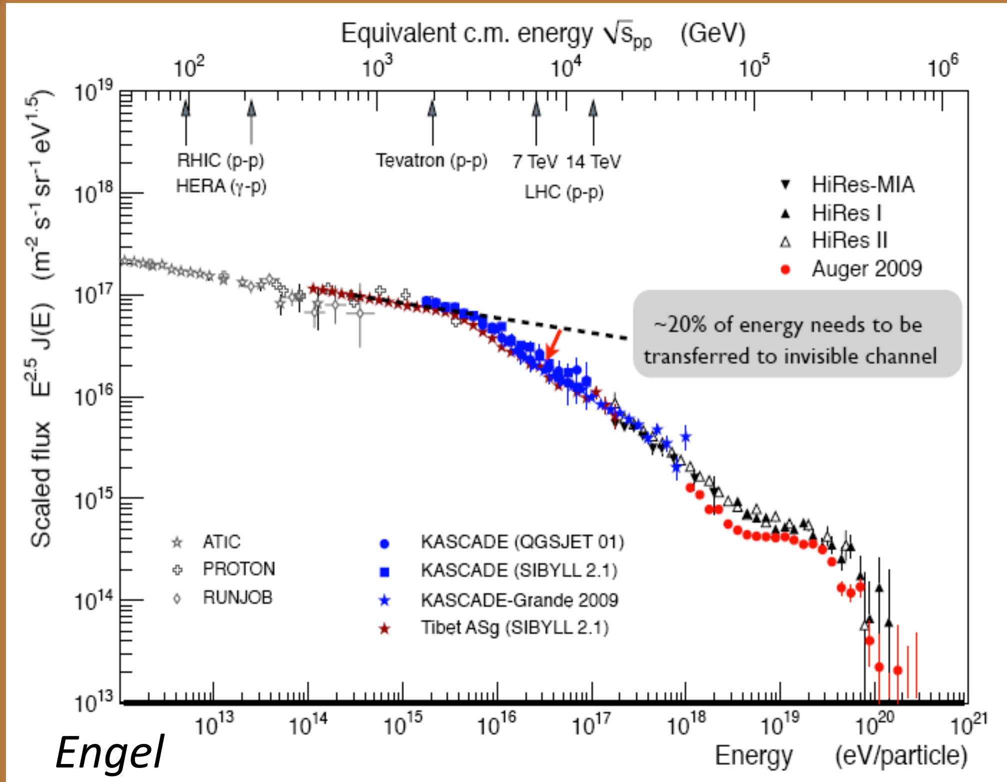
$$R_{SS}(f_D) = \frac{N_{SS}}{Ninc} = \frac{A^D_{SS} f_D + A^{ND}_{SS}(1 - f_D)}{A^D_{inc} f_D + A^{ND}_{inc}(1 - f_D)}$$

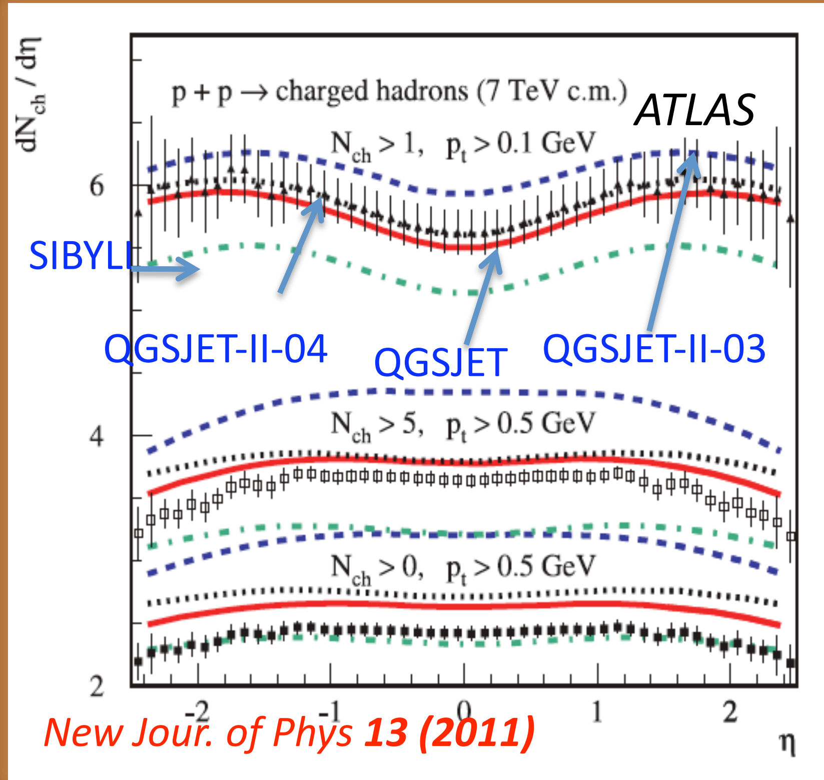
← Diffractive fraction

- *Default model (Pythia8 + D & L.) - $f_D = 26.9^{+2.5}_{-1.0}\%$*

$R_{ss} = [10.02 \pm 0.03(stat.)^{+0.1}_{-0.4}(syst.)]\ \%$

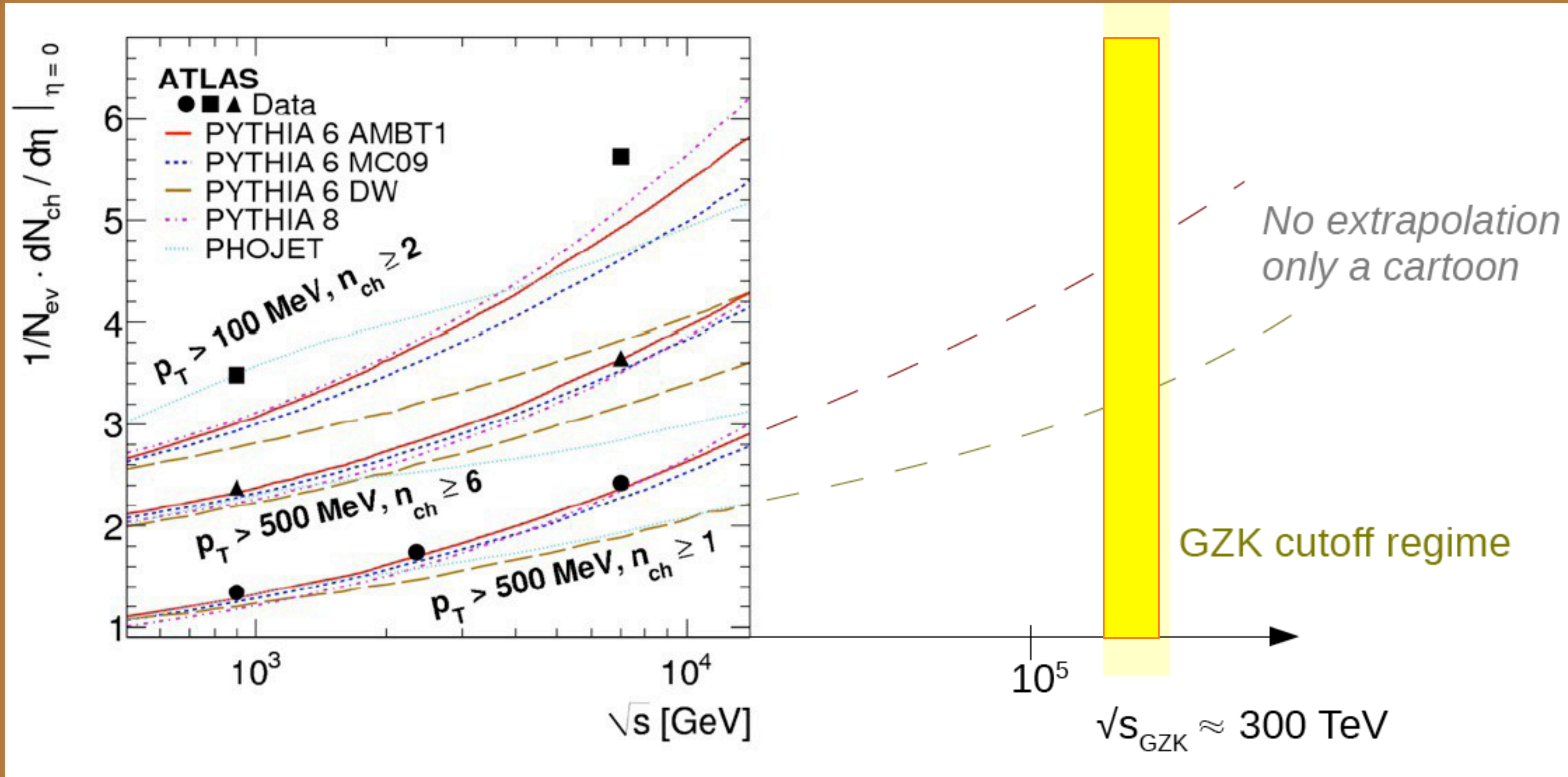
New Physics at the Knee?





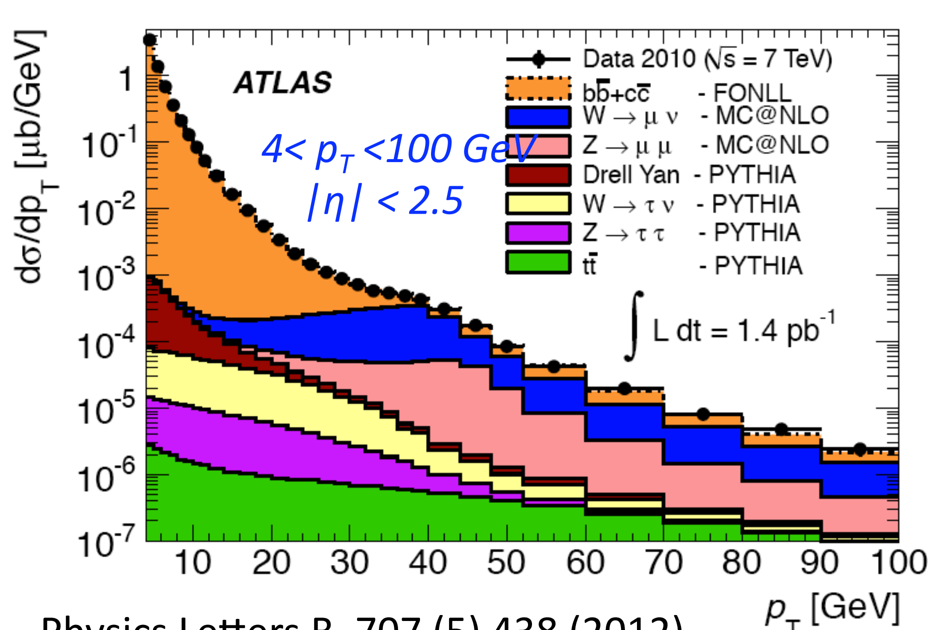
- *Model predictions nicely bracket ATLAS data on particle multiplicity*
  - *LHC E_{cm} = 7 TeV → p_{LAB} of 3 x 10^{16} eV*
- *Thus, ATLAS results indicate that New Physics Scenarios for the knee are unlikely*

Energy Evolution of Particle Density

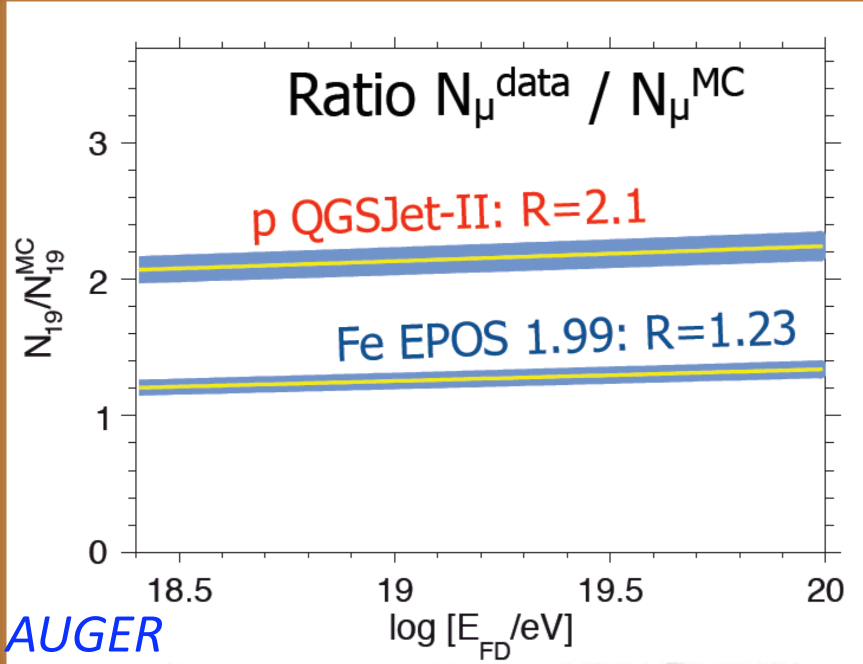


- *Minimum Bias mid-η energy evolution strongly model dep.*
- *Extrapolations to the UHE GZK cutoff region: E_{cm} ~ 40 x E_{cm}(LHC) – large uncertainties need 14 TeV data*

The Auger Muon Excess

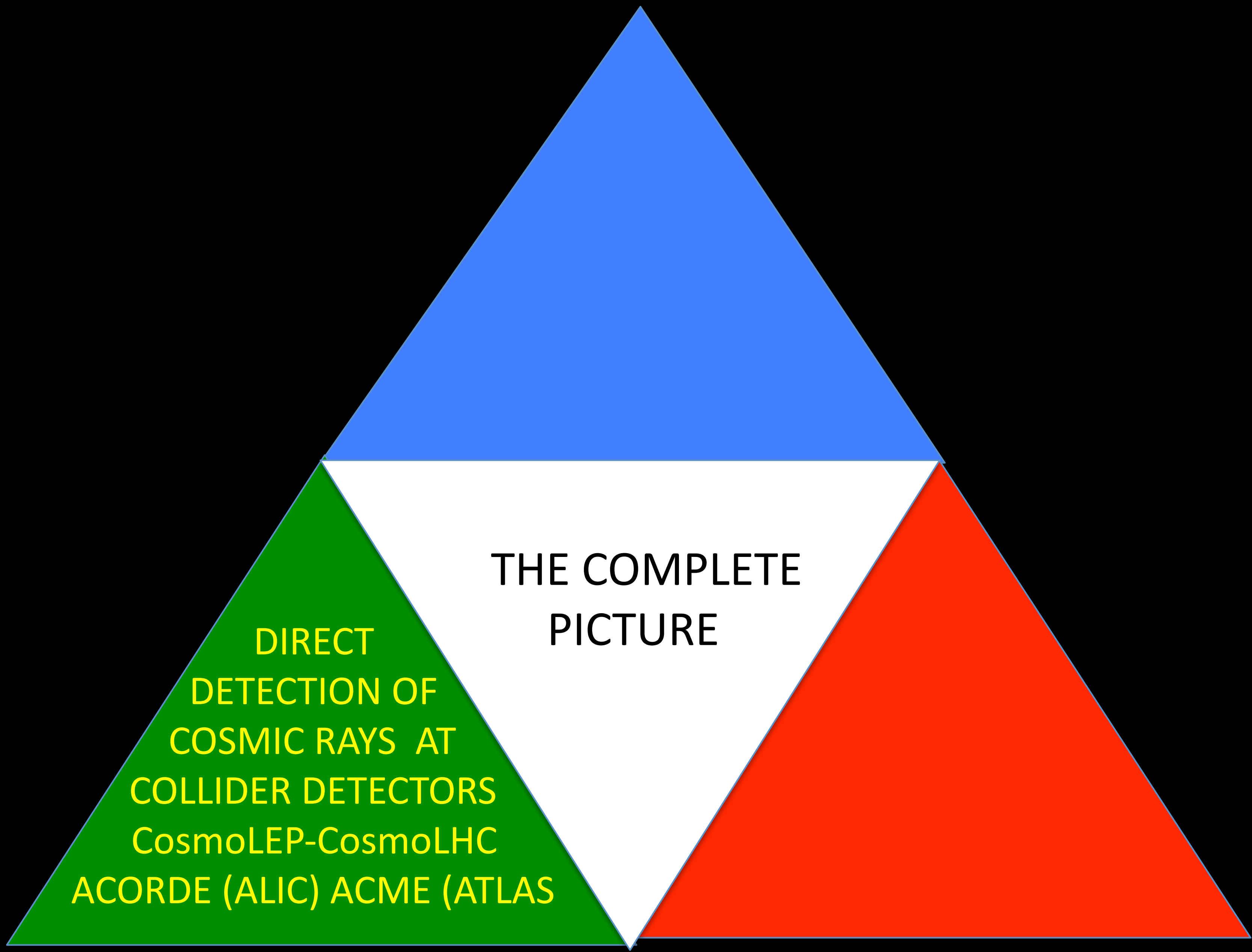


Physics Letters B, 707 (5) 438 (2012)

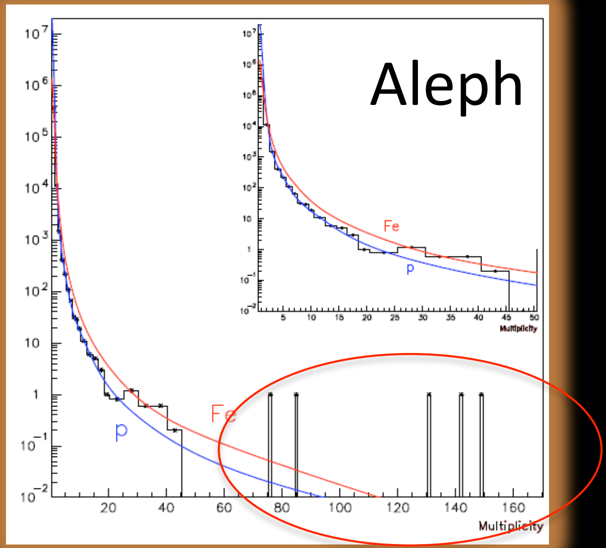


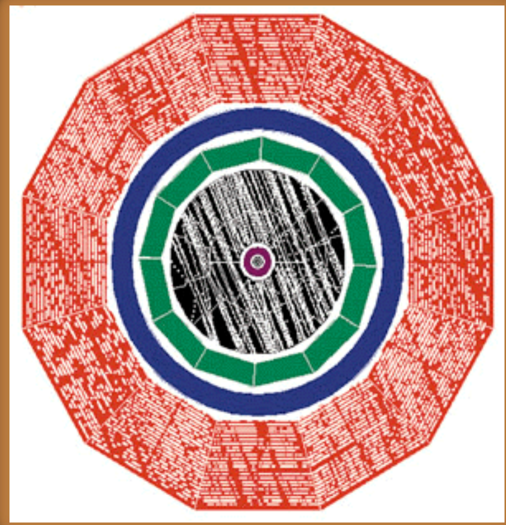
- *Inclined Showers: models underestimate the number of muons*
  - *By 25% if the data is pure Fe*
  - *By 100% if the data is pure p*
- *ATLAS data on multiplicity & muons x p_T shows no corresponding surprises*

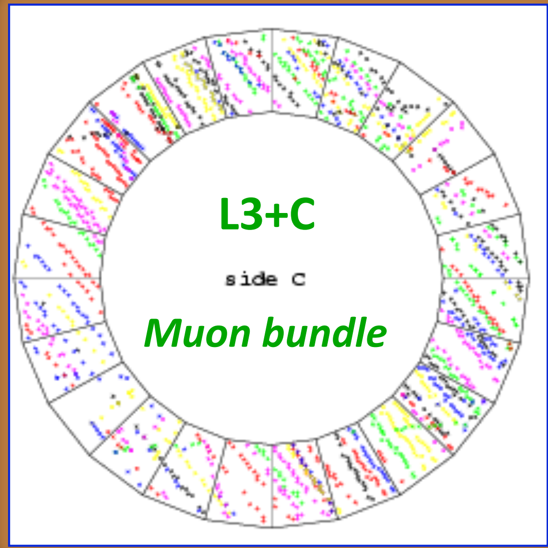
The Collider - Astroparticle Physics Synergy



LEP Discovers Muon Bundles



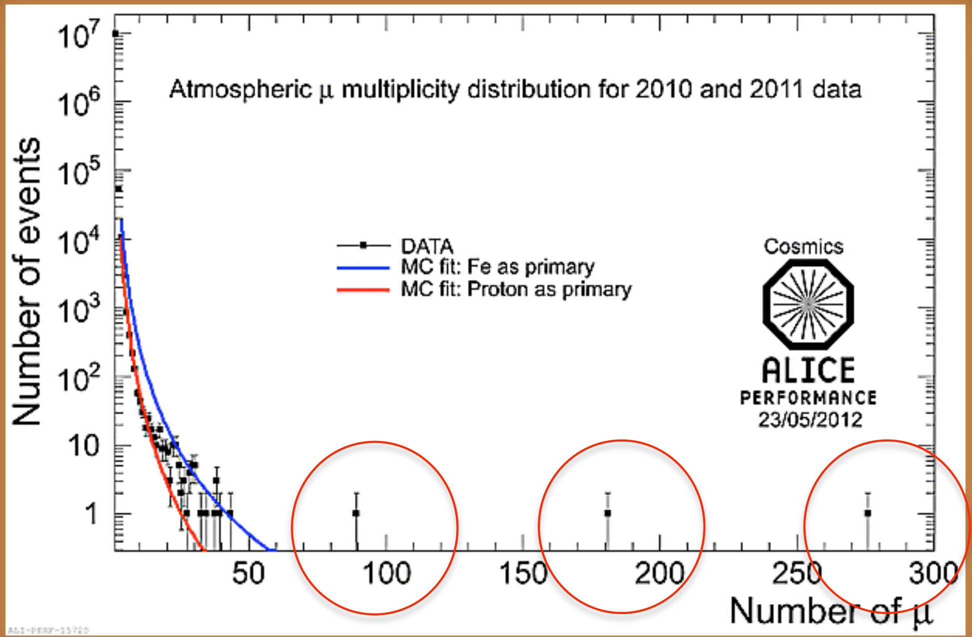


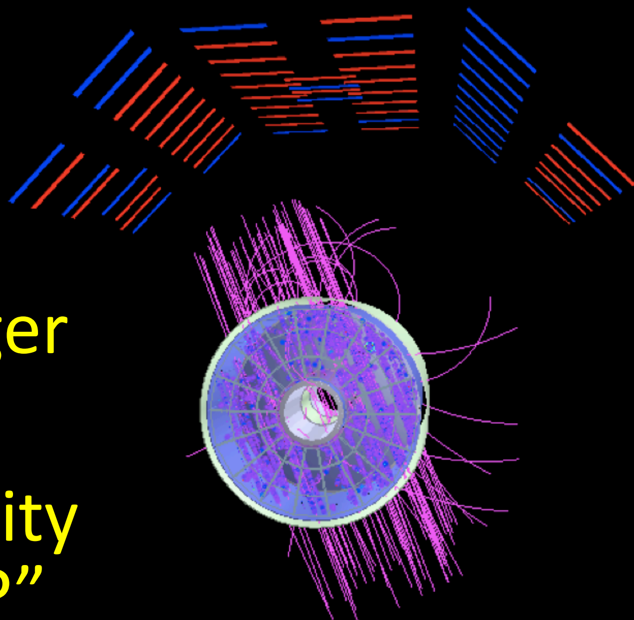


Muon multiplicity Aleph *Muon bundle observed in ALEPH* *Muon bundle observed in L3+3*

- *CosmoLEP experiments observed an excess of high multiplicity muon bundle events compared to simulations by CORSIKA*
- *The Rate depends on: primary energy, composition and the Interaction details*
- *Shallow experiments are sensitive to the knee*
- ***The only LEP result not consistent with the SM!!!***

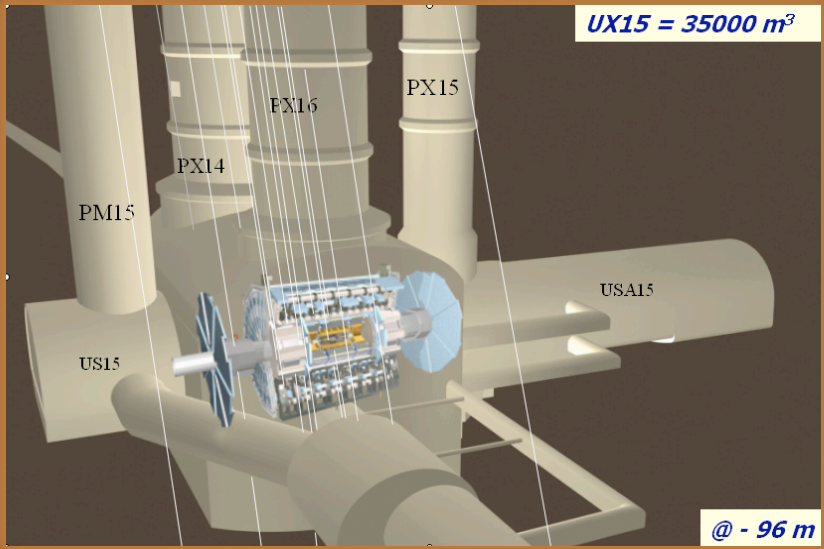
ACORDE- Cosmic Muon Physics in ALICE





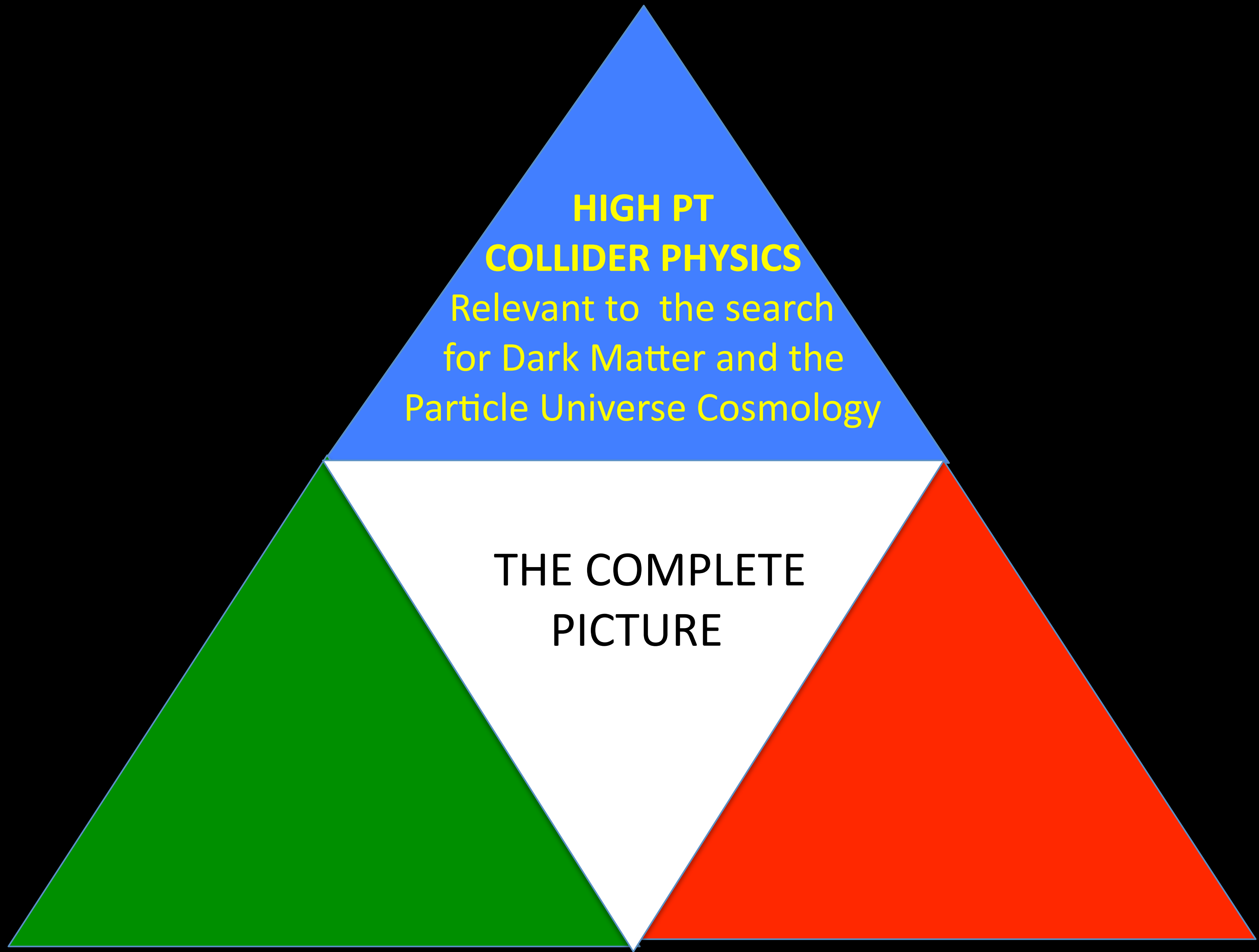
- ALICE has deployed the ACORDE detector to trigger on cosmic rays
- With a 4-fold coincidence they trigger on muon showers
- They see an excess of high multiplicity muon "bundles" as did "CosmoLEP"

ACME- ATLAS Cosmic Muons & Exotics Detector



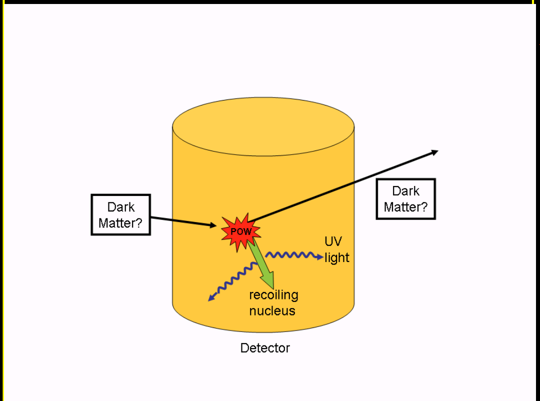
- *ATLAS would measure CR muons using unprecedented areas of precision μ-tracking ~80m underground*
  - *ATLAS triggered by surface array and internal cosmic ray trigger*
- *ACME – ATLAS + Surface Array – will provide precise information on cosmic rays with primary energies around $10^{15} \div 10^{17}$ eV.*

The Collider - Astroparticle Physics Synergy



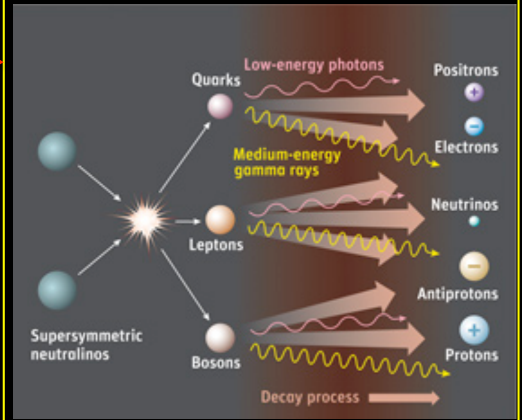
Dark Matter Searches – the Trinity

DIRECT SEARCHES



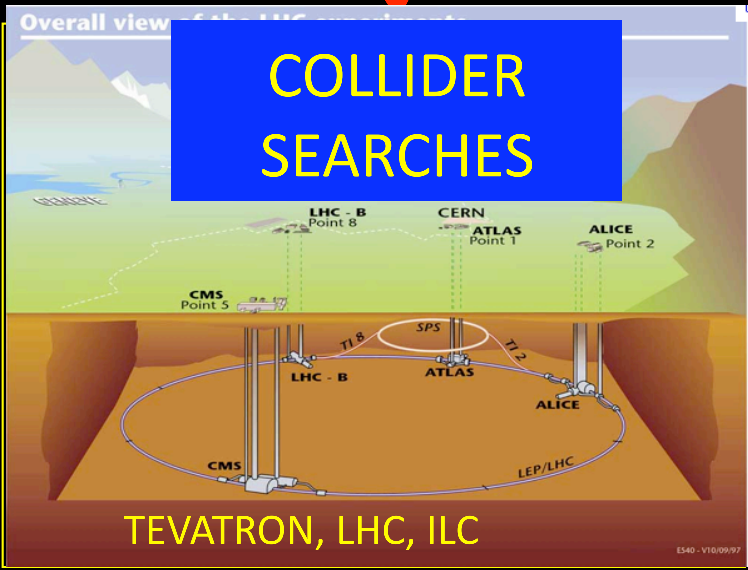
DAMA/LIBRA
XENON
CDMS
CRESST
KIMS
ZEPLIN
COGENT
COUPP
PICASSO

INDIRECT SEARCHES



PAMELA
GLAST
MAGIC
FERMI
HESS
AMS
ANTARES
ICECUBE

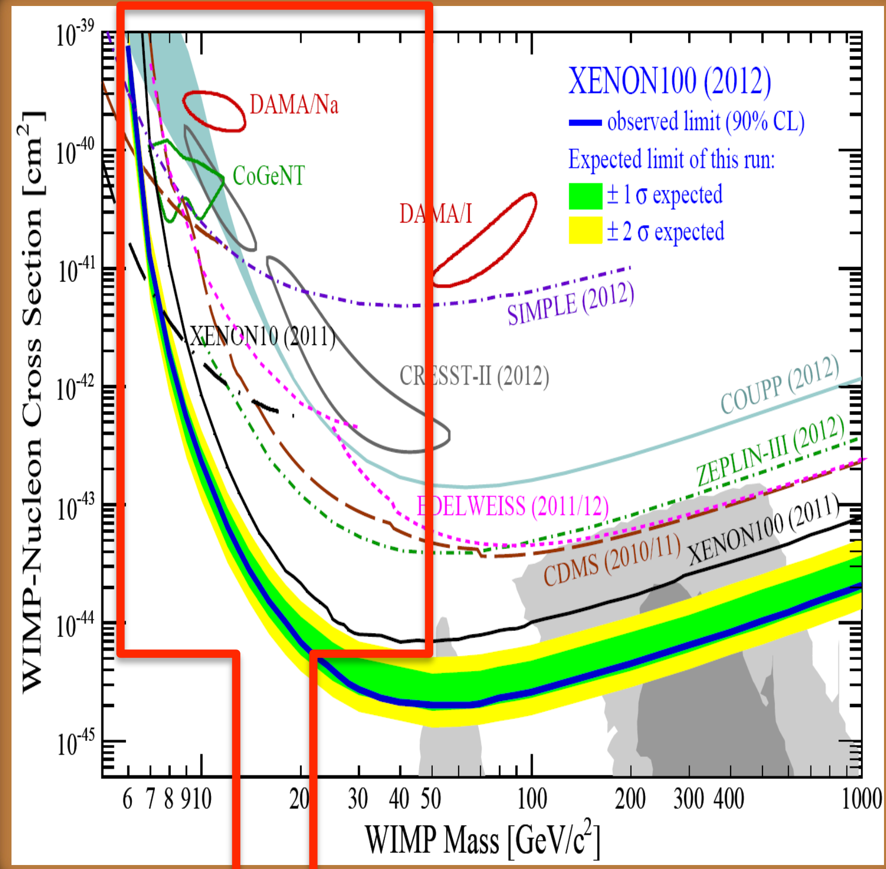
COLLIDER SEARCHES



TEVATRON, LHC, ILC

Status of Direct Dark Matter Searches

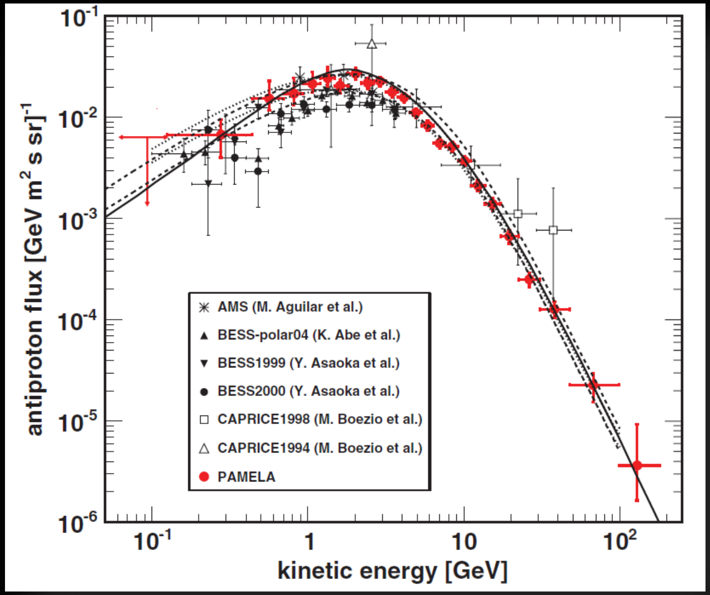
- *DAMA, COGENT & CRESST low threshold detectors are seeing something !*
  - *DAMA (N)aI crystals)*
  - *COGENT (Ge cooled with LN_2)*
  - *CRESST (CaWO4 crystal calo.)*
- *DAMA&COGENT see a consistent annual modulation signal*
  - *No alternative SM explanation has been found for the mod.*
- *However, the latest XENON results have completely excluded the DAMA, COGENT CRESST signals!*
  - *XENON has a high pressure XeTPC*

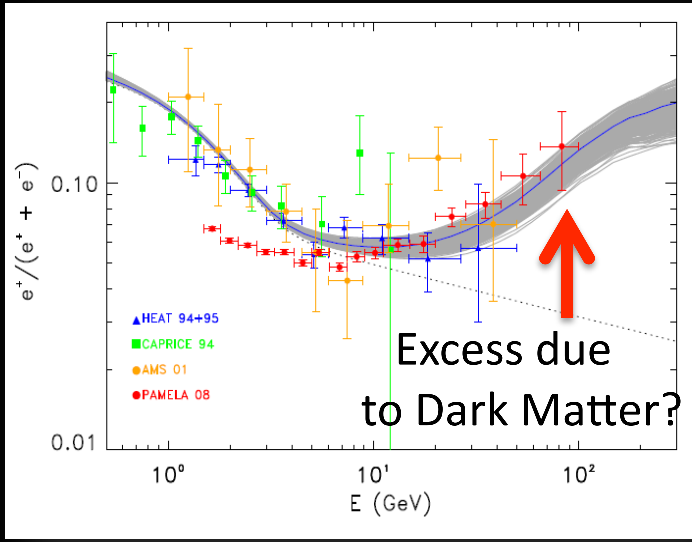


LOW MASS DARK MATTER?

Indirect Dark Matter Searches

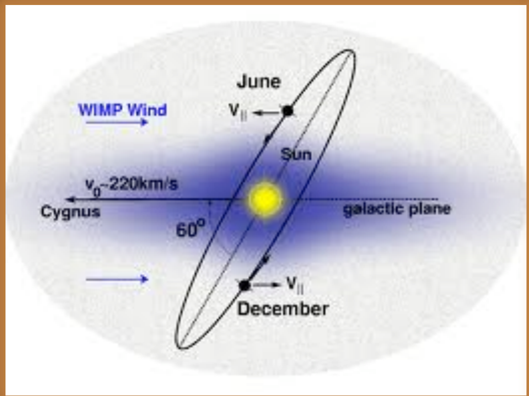
- *No Evidence in the data for dark matter in the antiproton flux measurement by AMS, PAMELA,etc*
- *But there was excitement about the positron excess seen by PAMELA, FERMI-LAT etc*
  - *The shape of the energy spectrum is consistent with KK- WIMPs;*
  - *Unfortunately, the flux is a factor of 100-1000 too big for a thermal relic*
- *At this point, pulsars are a more likely explanation*

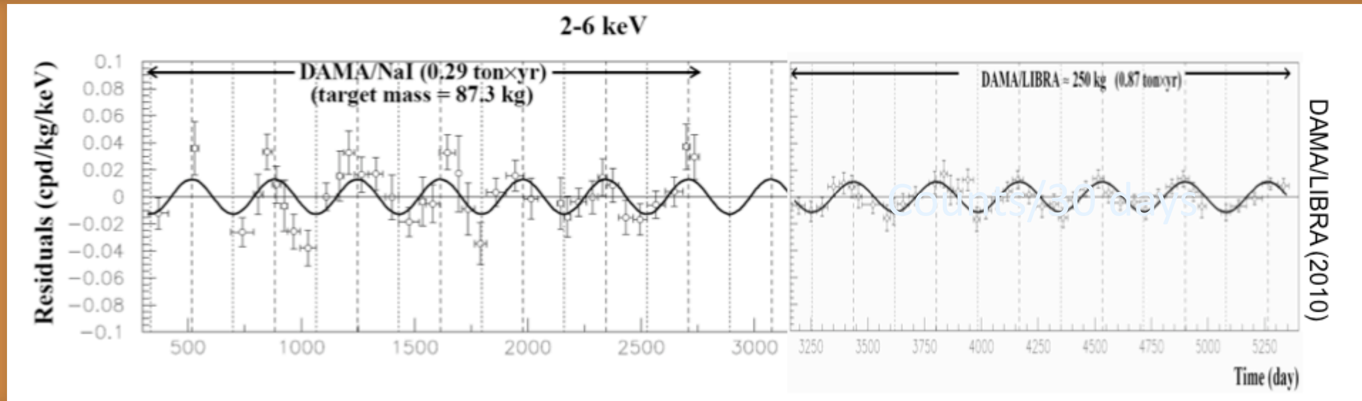




The Annual Modulation of the Signal

- *Collision rate should vary as Earth's moves with or against the WIMP wind.*

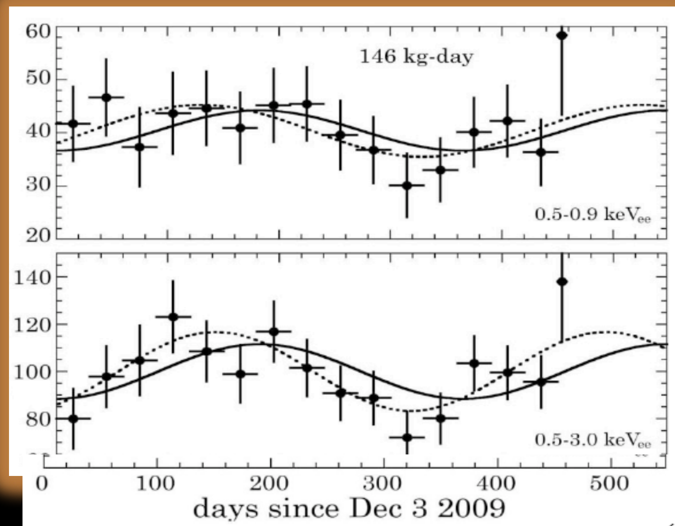




DAMA/LIBRA: 8.9σ signal with T ≈ 1 year, maximum ≈ June 2

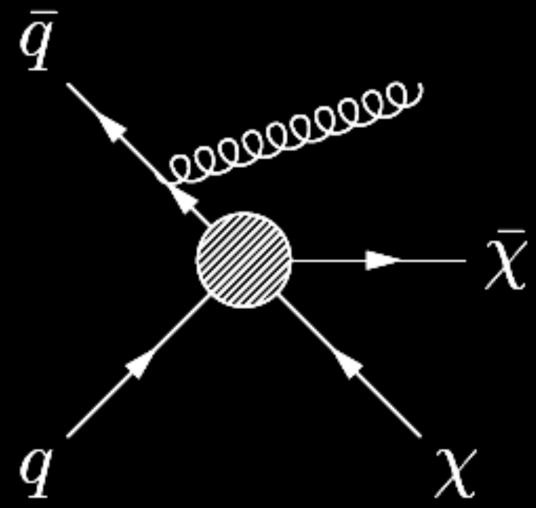
- *Cogent also see signs of an annual modulation → that is consistent with that of DAMA'S*

Counts/30 days



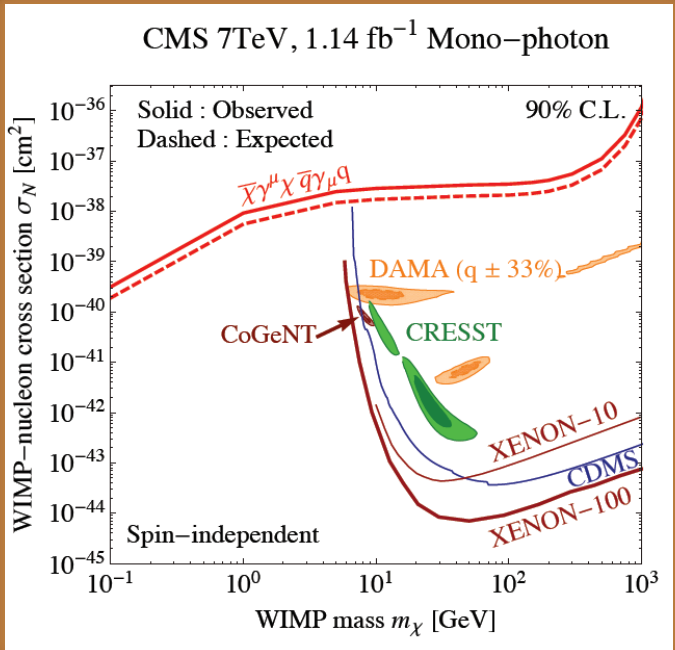
The Collider Connection

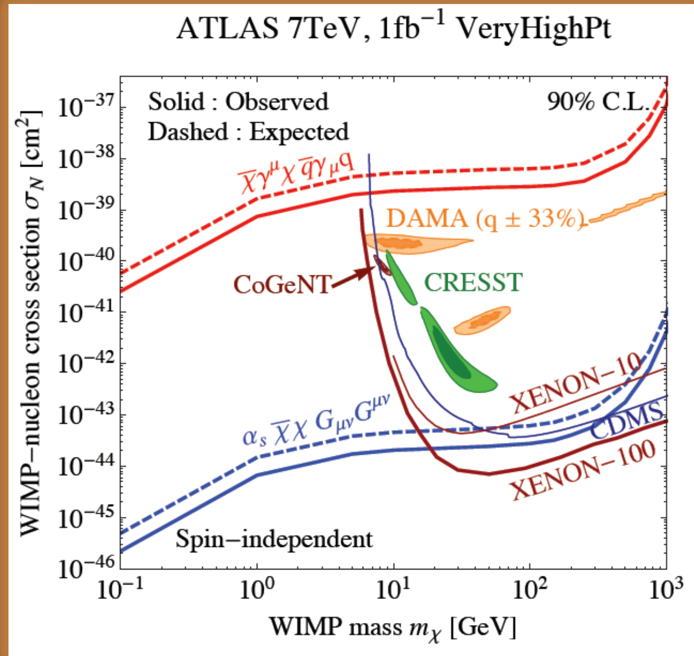
- *At the LHC missing energy signatures eg monojet & monophoton channels, are sensitive to dark matter signals*



- *I collider constraints do not suffer from astrophysical uncertainties - abundance of DM near Earth or its velocity dist.*
- *Use effective field theory to provide a description of dark matter production at the LHC:*
  - *Assume here that the particles that mediate DM-SM interactions are much heavier than typical momentum exchanged in monojet events*
  - *Well approximated by a contact operator*
  - *Assume DM particle is a Dirac fermion*
- *If the DM-SM coupling involves a light mediator then the collider bounds are considerably weakened*

Spin Independent DM Couplings

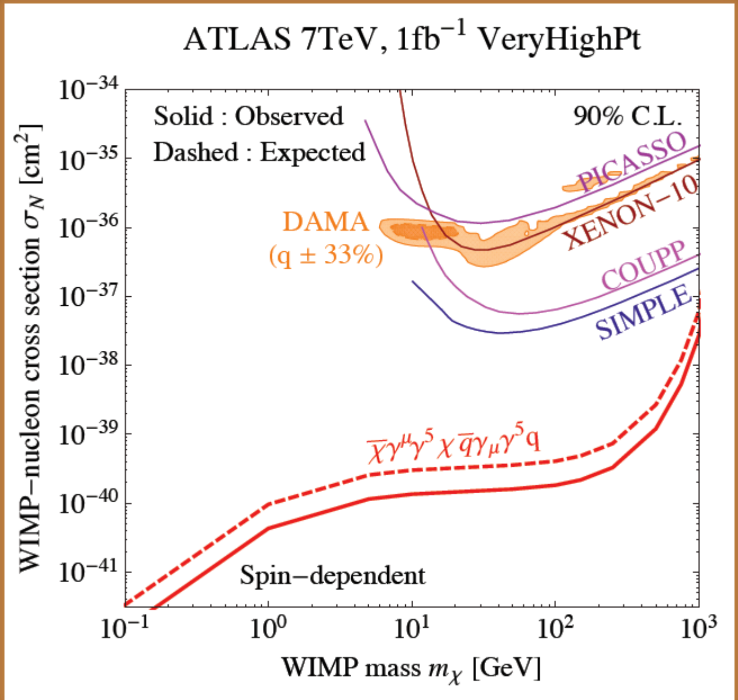




arXiv:1109.4398v1 [hep-ph] 20 Sep 2011. Lumis at 7 TeV Ecm 1.14 fb^{-1} ATLAS & 36pb^{-1} CMS

- *For spin-independent (SI) dark matter couplings, the LHC bounds constraint m_χ to be below about 5 GeV for the scalar and vector operators and below 10 GeV for the gluon operator.*
- *At higher masses, direct detection experiments have the advantage*

Spin Dependent DM Couplings



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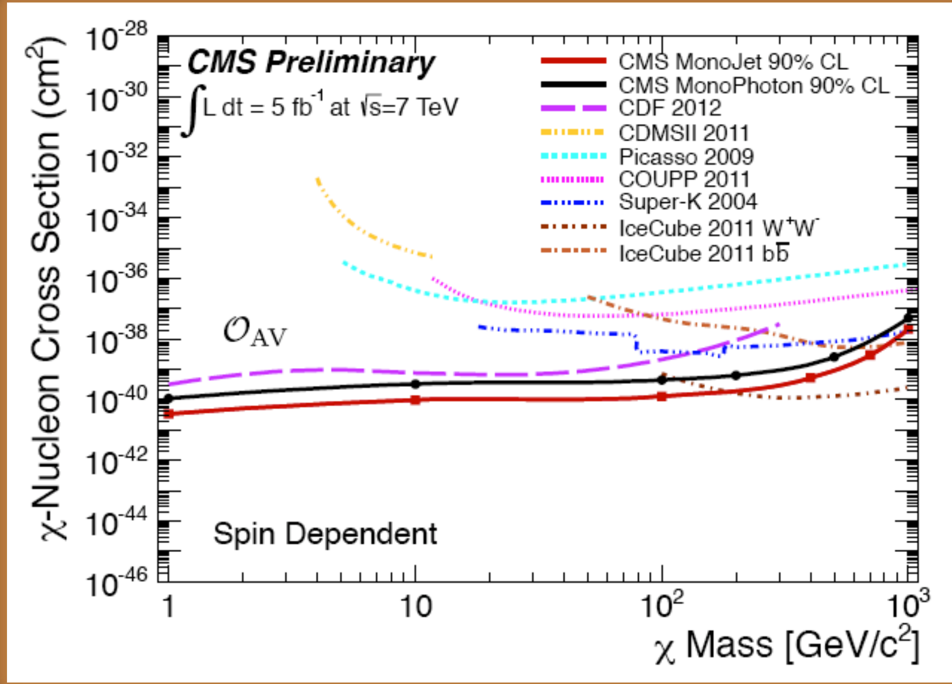
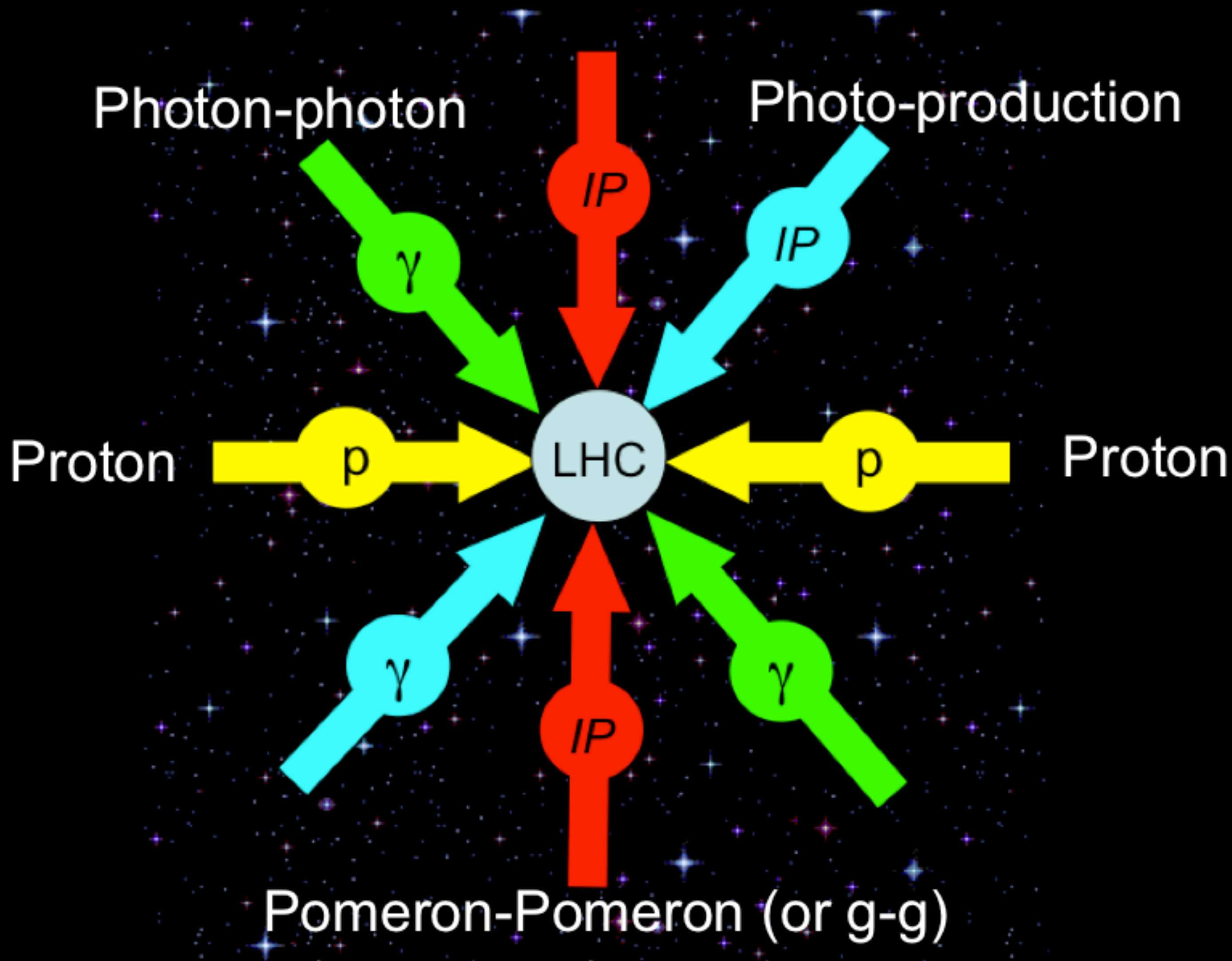
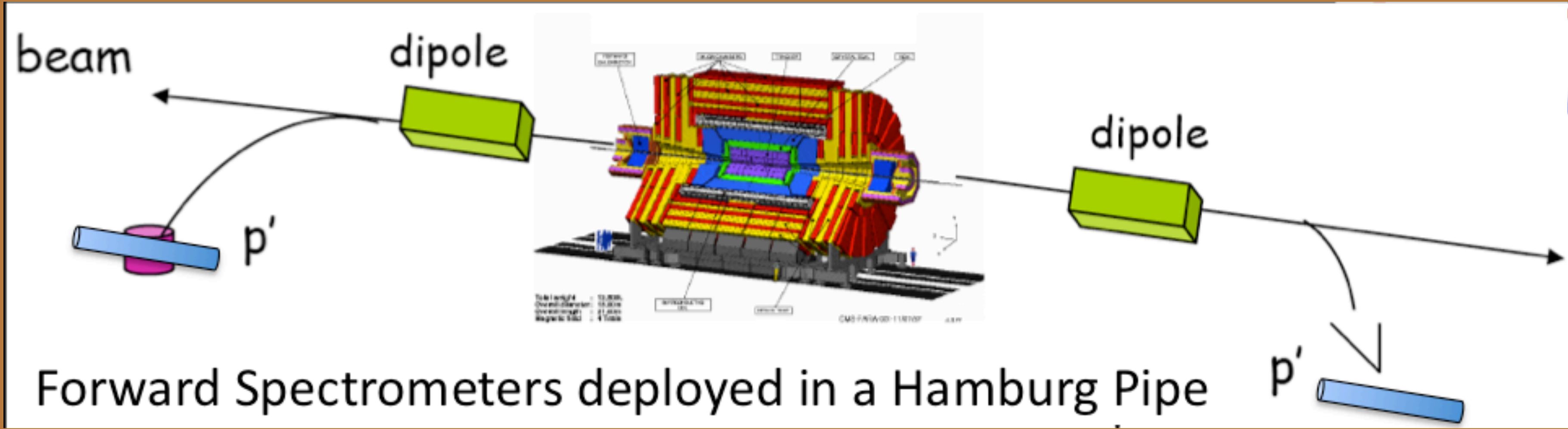


- *The LHC provides the strongest bound on spin dependent dark matter-nucleon scattering, by about two orders of magnitude.*
- *The LHC bound becomes less powerful than current direct detection experiments for $m_\chi >\sim 1 \rightarrow 2$ TeV.*

MAKING THE LHC A γγ, γ-IP, IP-IP COLLIDER



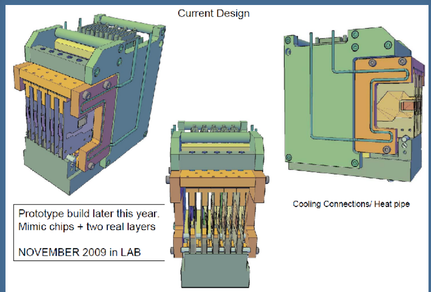
Making the LHC a γ-γ, γ-p & IP-IP Collider

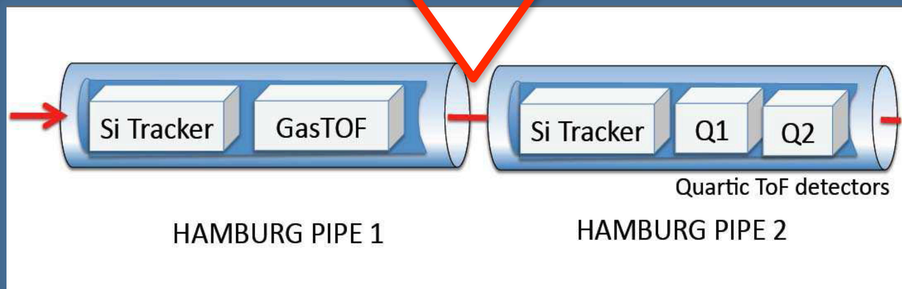


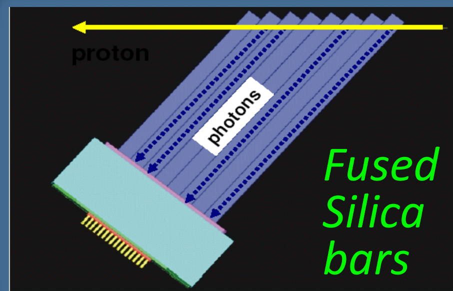
- *Both ATLAS (AFP) and CMS (HPS) are planning to deploy forward spectrometers at ± 220m (Ph-0/1) & ± 420m (Ph-2)*
  - *Measurement of the momentum of the unbroken protons allow us to precisely reconstruct the mass of the central system*
- *Pileup background severely reduced by a fast timing detector with temporal resolution ~10ps → a few mms vertex resolution*
- *AFP is on track to install a Phase-0 detector in 2013-2014*

The Experimental Challenge

Acceptance	Tagged proton momentum loss ξ Typical di-photon mass acceptance	$0.02<\xi<0.2$ $300<\sqrt{(\xi_1\xi_2 s)}<1200$ (GeV)
Si Tracker	Spatial Resolution Angular Resolution Reconstructed Mass Resolution	$\sim 15\ \mu$m $\sim 1\ \mu$rad ~ 5 GeV
QUARTIC	Time resolution	<10 ps

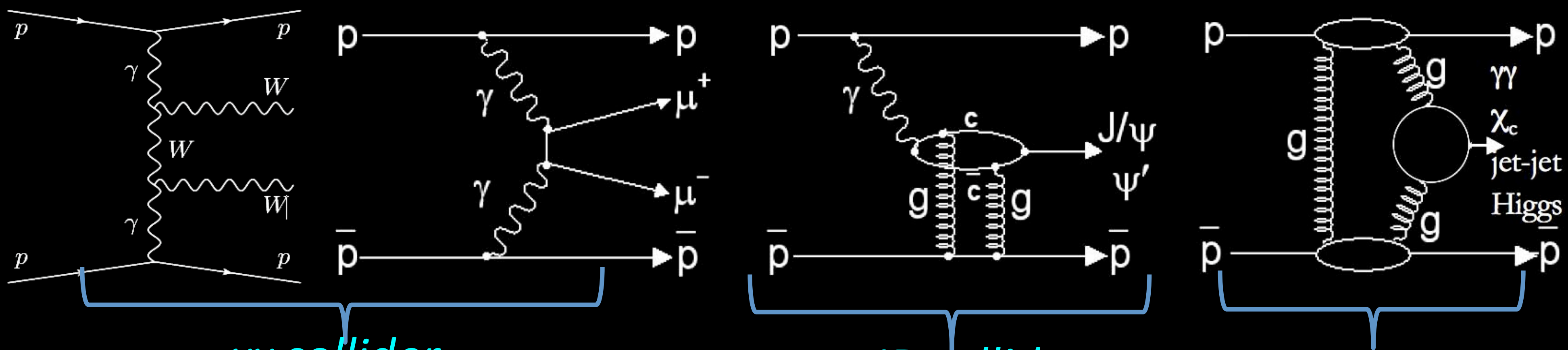






- *We use edgeless 3-D Si technology for the proton spectrometer*
- *Fast timing detector based on fused silica Cerenkov radiators (4 x 8 bars) with x-dependent segmentation*

The AFP/HPS Physics Program



γγ collider *γIP collider* *IP–IP collider*

- *EXPLORATORY PHYSICS, EG: anomalous couplings between γ & W/Z bosons, Higgs production allowing spin and precision mass determination; monopole production, etc.*
- *QCD PHYSICS EG:*
  - *Double Pomeron exchange (DPE) measurements in the jet, Z, W channels, and the search of exclusive production in the jet channel.*
  - *At LHC energy, very high gluon densities are reached and non-linear QCD effects and new phenomena such as saturation should appear.*

DESSERT

First MoEDAL Physics Workshop

Highly Ionizing Particles & New Physics at the LHC

The CERN Globe (Open Workshop) June 20th 2012
(MoEDAL Collaboration meeting on the 21st of June 2012)

Gerard 't Hooft (Utrecht University)
Magnetic Monopoles Since Dirac

Artu Rajantie (Imperial College London)
Monopoles in the Cosmos and at the LHC

John Ellis (King's College London)
Highly Ionizing Particles at the LHC (SUSY Scenarios)

Nikolaos Mavromatos (King's College London)
Highly Ionizing Particles at the LHC (Non SUSY Scenarios)

Albert de Roeck (CERN)
Searching for Highly Ionizing Particles at the LHC with CMS

Philippe Mermod (University of Geneva)
Searching for Highly Ionizing Particles at the LHC with ATLAS

James Pinfold (University of Alberta)
The Physics Program of the MoEDAL Experiment

Laura Patrizii (INFN Bologna)
The Quest for Cosmic Monopoles

David Milstead (Stockholm University)
Monopole Trapping at the LHC

Vicente Vento (Universidad de Valencia)
The Search for Monopolium at the LHC

For more information go to the website: http://web.me.com/jamespinfold/MoEDAL_Workshop/Welcome.html

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Laura Patrizii (INFN Bologna)
The Quest for Cosmic Monopoles
David Milstead (Stockholm University)
Monopole Trapping at the LHC
Vicente Vento (Universidad de Valencia)
The Search for Monopolium at the LHC
For more information go to the website: http://web.me.com/jamespinfold/MoEDAL_Workshop/Welcome.html
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MoEDAL – The 7th LHC Experiment

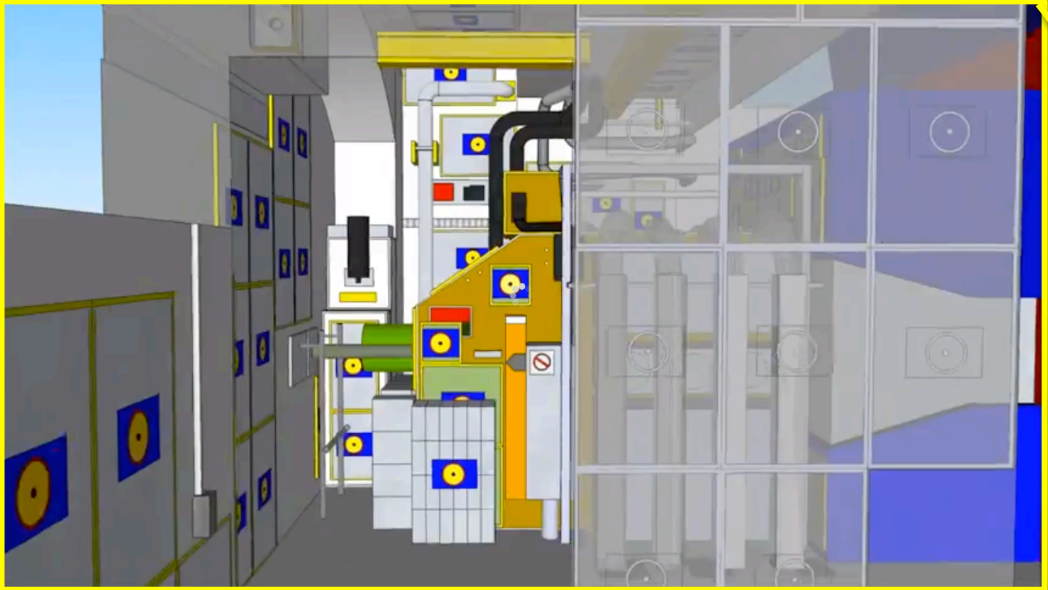
The Continuing Search for the Magnetic Monopole and Other Highly Ionizing Particle avatars of new physics at the LHC

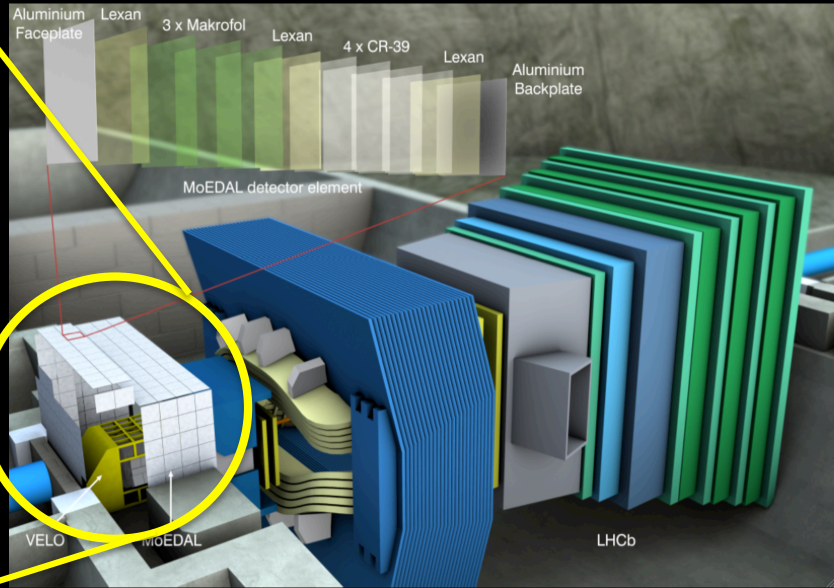
Official startup at 14 TeV after the long LHC shutdown – but test detectors already in place. First results in 2013.

The MoEDAL Physics Program

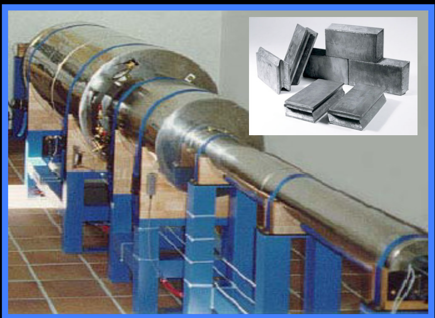
- *Search for magnetic Monopole (a singly charged relativistic monopole has ionization ~4700n x MIP) - with mass ≤ ~7 TeV & magnetic charge (ng) ≤ n=8-9*
- *Search for exotic, massive (pseudo-)stable, single or multiply charged particles (SMPs) with $Z/\beta \geq 5$,with mass up to 7 TeV and charge as high as ~400, for example:*
    - *Charged black hole remnants from ADD models of LEDs*
    - *Universal Extra dimensions - KK-particles*
    - *Higgs bosons: H^{++} (L-R symmetric models) & H^{o} → N-Nbar*
    - *R-hadrons (Split SUSY, GMSB, SUSY5D)*
    - *Very heavy stable SUSY particles (sleptons, etc.)*
    - *Technibaryons & Mirror fermions*
    - *Q-balls (extended balls of electric charge), Quirks, etc*

MoEDAL – The 7th LHC Experiment

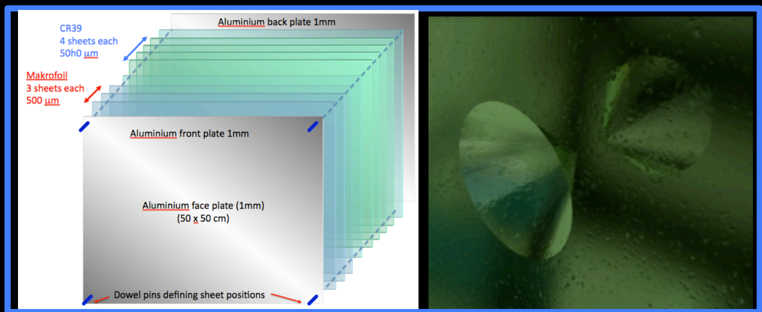




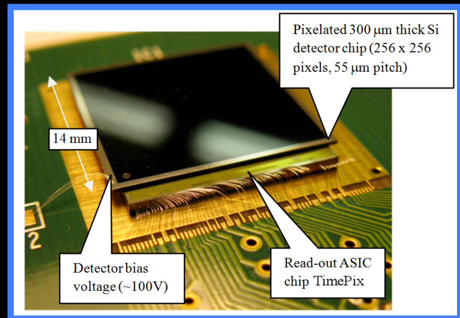
- *MoEDAL is the largest array of passive detectors ever deployed at an accelerator – it has 3 basic types of detector:*



Trapping Detector



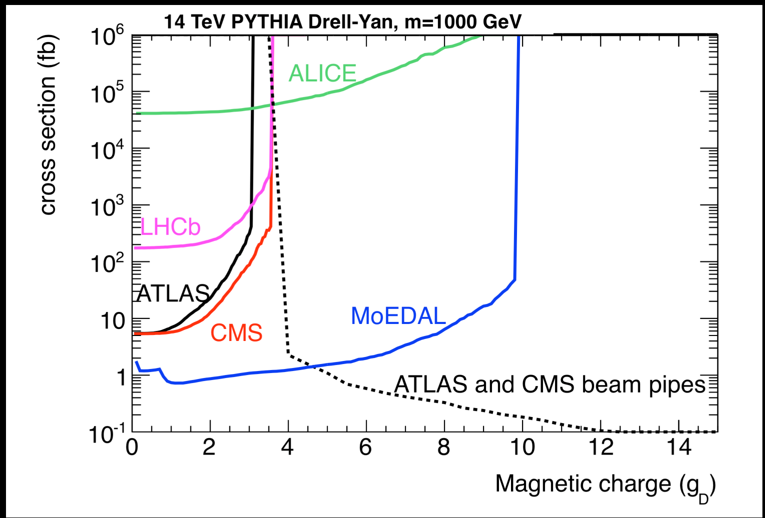
Plastic Nuclear Track Detectors

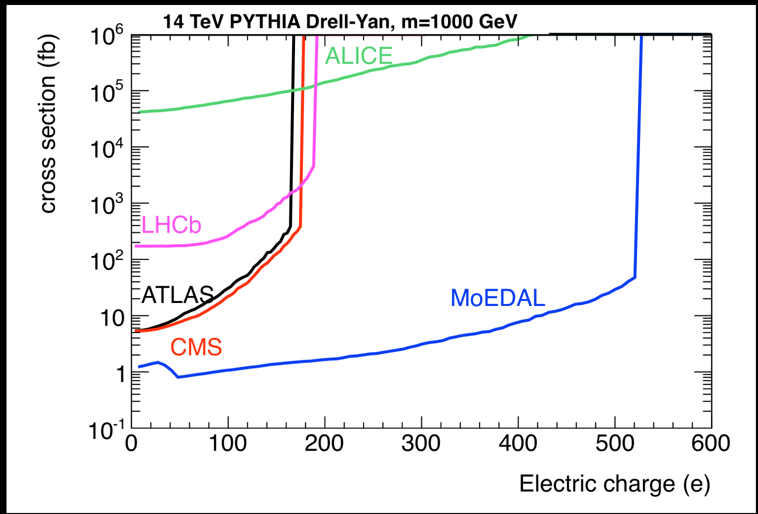


TimePix Pixel chip array

MoEDAL Sensitivity

detector	energy threshold	angular coverage	luminosity	robust against timing	robust efficiency
ATLAS	medium	central	high	no	no
CMS	relatively low	central	high	no	no
ALICE	very low	very central	low	yes	no
LHCb	medium	forward	medium	no	no
MoEDAL	low ✔	full ✔	medium ✔	yes ✔	yes ✔





- *Cross-section limits for magnetic (LEFT) and electric charge (RIGHT) (**arXiv:1112.2999V2** [hep-ph]) assuming:*
  - *Only one MoEDAL event is required for discovery and ~ 100 events in the other (active) LHC detectors*

Last Words

- *Lots of future developments in the synergy between LHC collider results and high energy cosmic ray physics:*
  - *The results from ALFA in the coming months*
  - *We will have p-N running this year (although p-Pb not nitrogen!)*
- *Another important recent development in this area is the creation of an official ATLAS "Astroparticle Physics Forum"*

co-conveners and meeting of ATLAS Astroparticles Forum — Inbox

Richard Hawkings via ualberta.ca — Jul 26 (5 days ago)
to atlas-current-.

Dear All,

As discussed in the OpenEB meeting of Tuesday 22nd May:

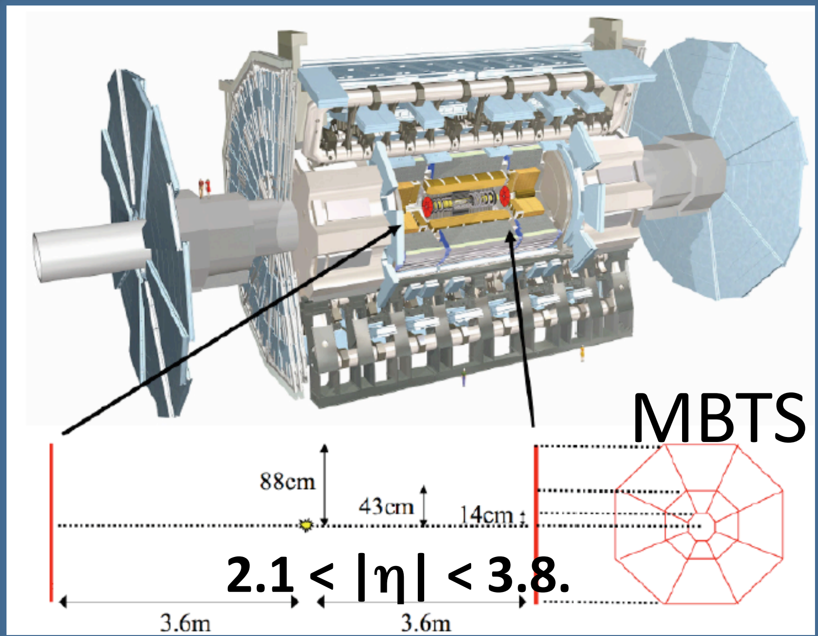
https://indico.cern.ch/conferenceDisplay.py?confId=156299

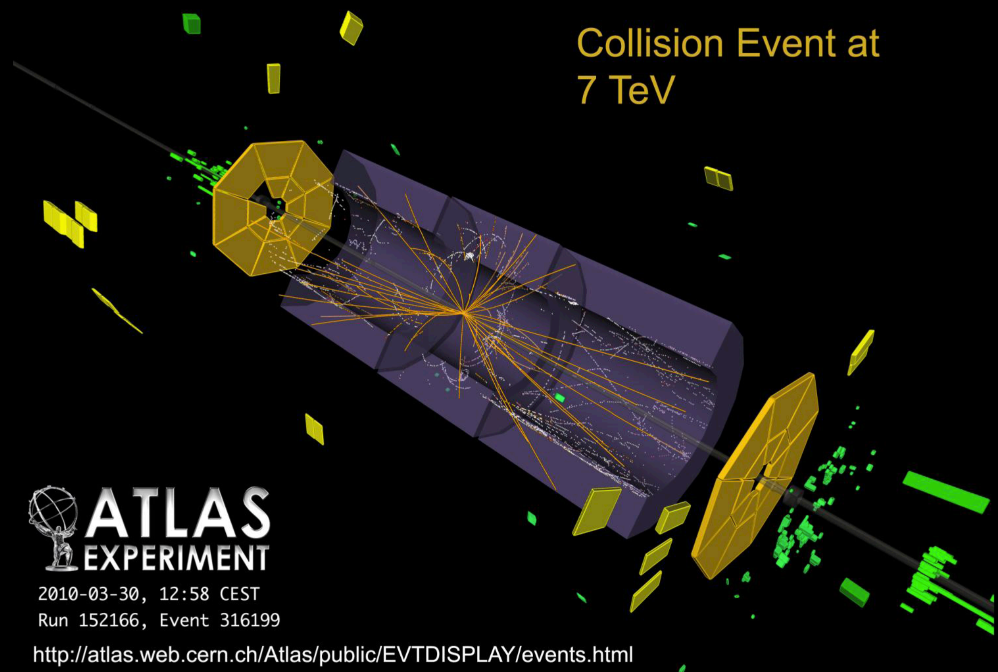
we have established a new 'ATLAS Astroparticle Forum' to provide a focus for Astroparticle physics-related efforts within ATLAS, and serve as a channel of communication to the astrophysics and cosmology communities.

- *After the long shutdown in 2013-2014 we will install AFP Phase-0 – opening up a new era of high luminosity diffractive physics*
- *Last, but not least we will then be running at 14 TeV E_{cm}!*

ADDITIONAL SLIDES

Determining the Inelastic Cross-section





- *The ATLAS analysis uses MBTS to tag inelastic collisions.*
  - *Acceptance $\xi = M_x^2/s > 5 \times 10^{-6} \rightarrow M_x = 15.7$ GeV for $\sqrt{s} = 7$ TeV*
  - *The data collected on the 31 March 2010, corresponding to $L = 20.3 \pm 0.7\ \mu b^{-1}$ - peak instantaneous $L = 1.2\times10^{27}\ cm^{-2}\ s^{-1}$*
  - *Requires at ≥ 2 MBTs hits → 1,220,743 data events*