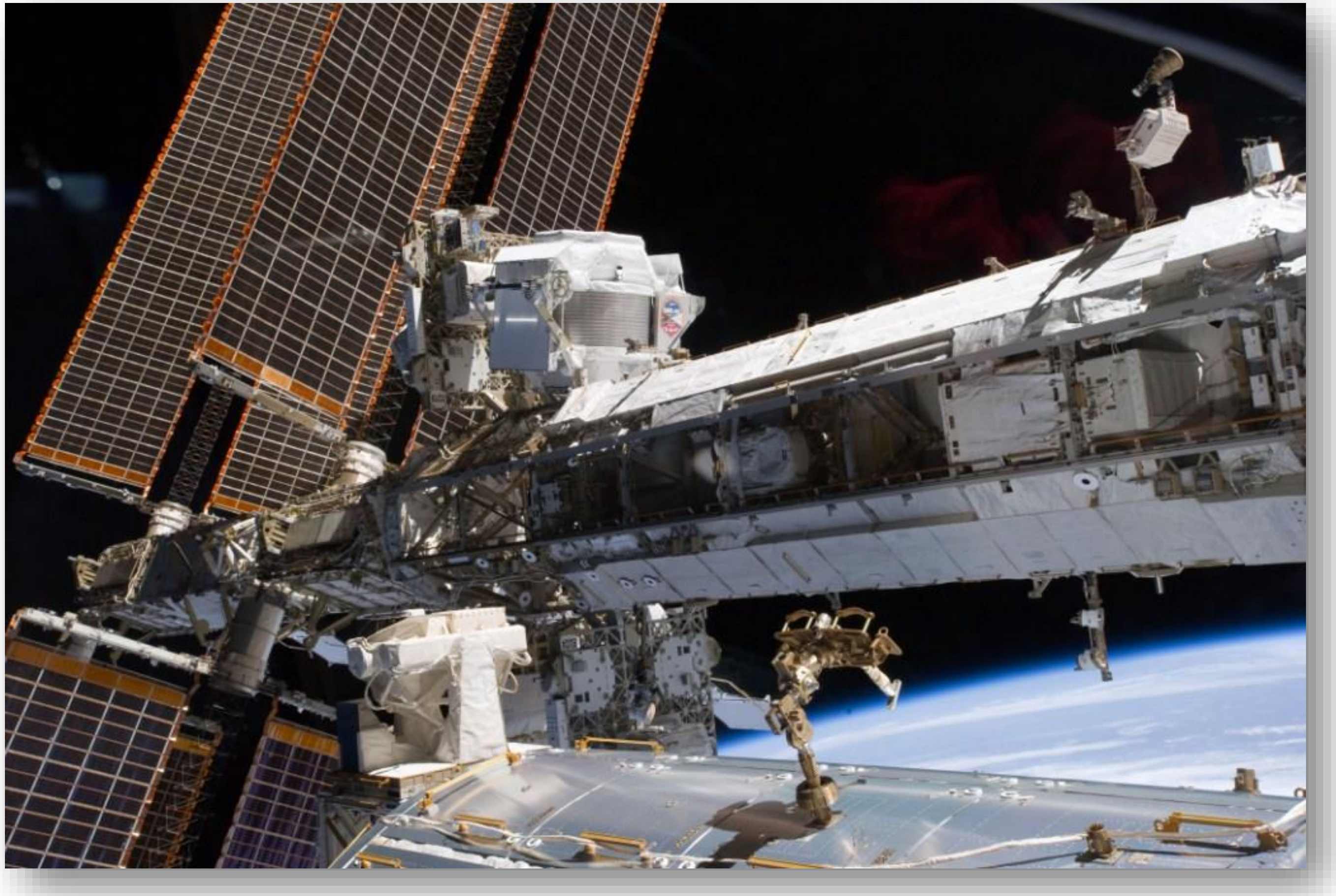
Indirect DM search status with AMS-02

(and collider limits)



Dr. Nicolò Masi

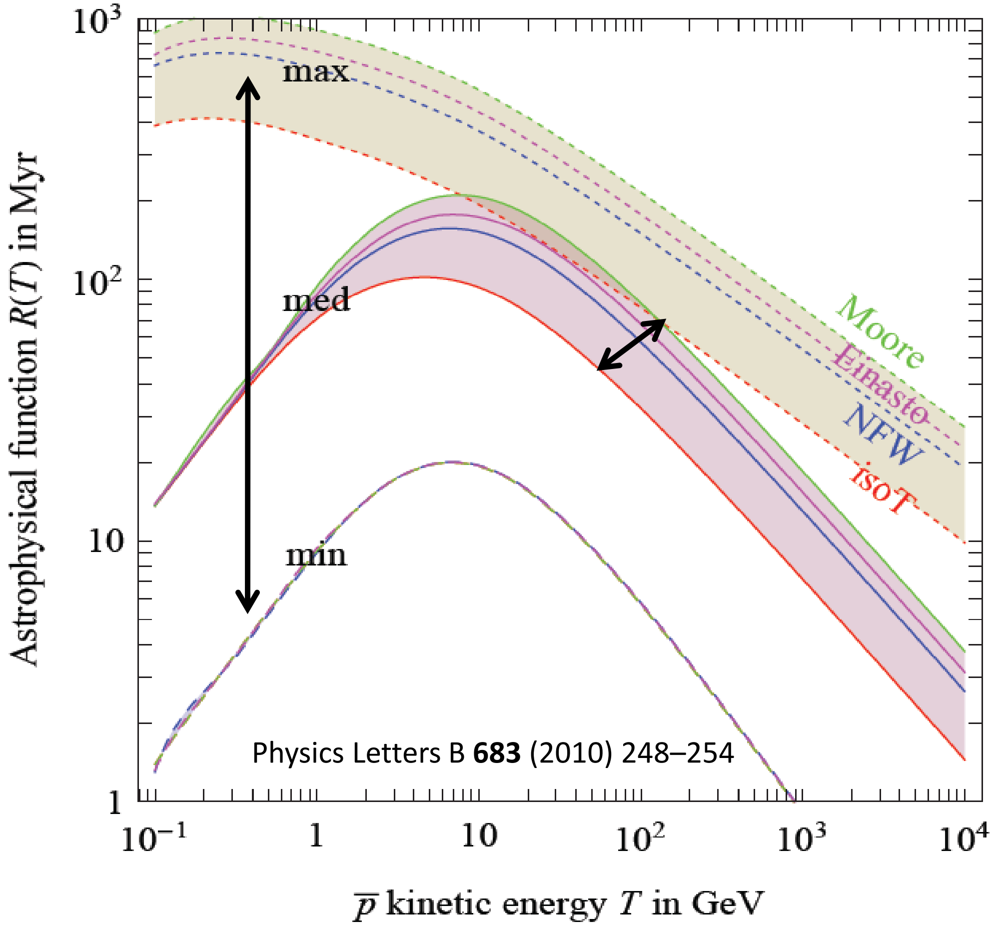
Bologna University
and INFN –

20th Sepetember 2017

Topics

- *CR description uncertainties*
- *Hints of new physics with AMS-02 electrons*
- *Astrophysical uncertainties in the AMS-02 era*
- *The antiprotons channel after AMS-02*
- *Collider search status*

Fluxes uncertainties: astrophysics vs dark halo



Physics Letters B **683** (2010) 248–254

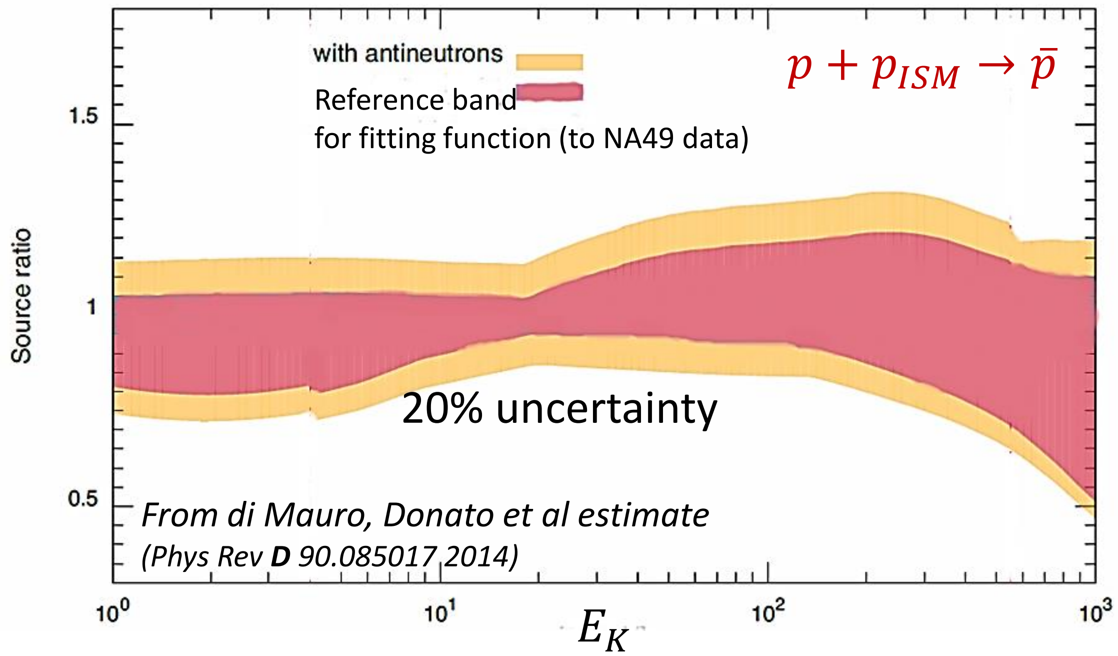
1. **Propagation models**: almost two orders of magnitude, one above one below the MED set
2. **Radial distribution of the halo:** modulates spectra in a less significant way, even if *higher DM density regions* in the inner Galaxy or the introduction of a *cohorotating Dark Disk* (Lisa Randall proposal) could induce a greater annihilation cross section.

Nuclear Uncertainties in the antiproton channel

$$p + ISM \to \bar{p} \ldots \begin{cases} p + p_{ISM} \to \bar{p} \ldots \\ p + He_{ISM} \to \bar{p} \ldots \end{cases}$$

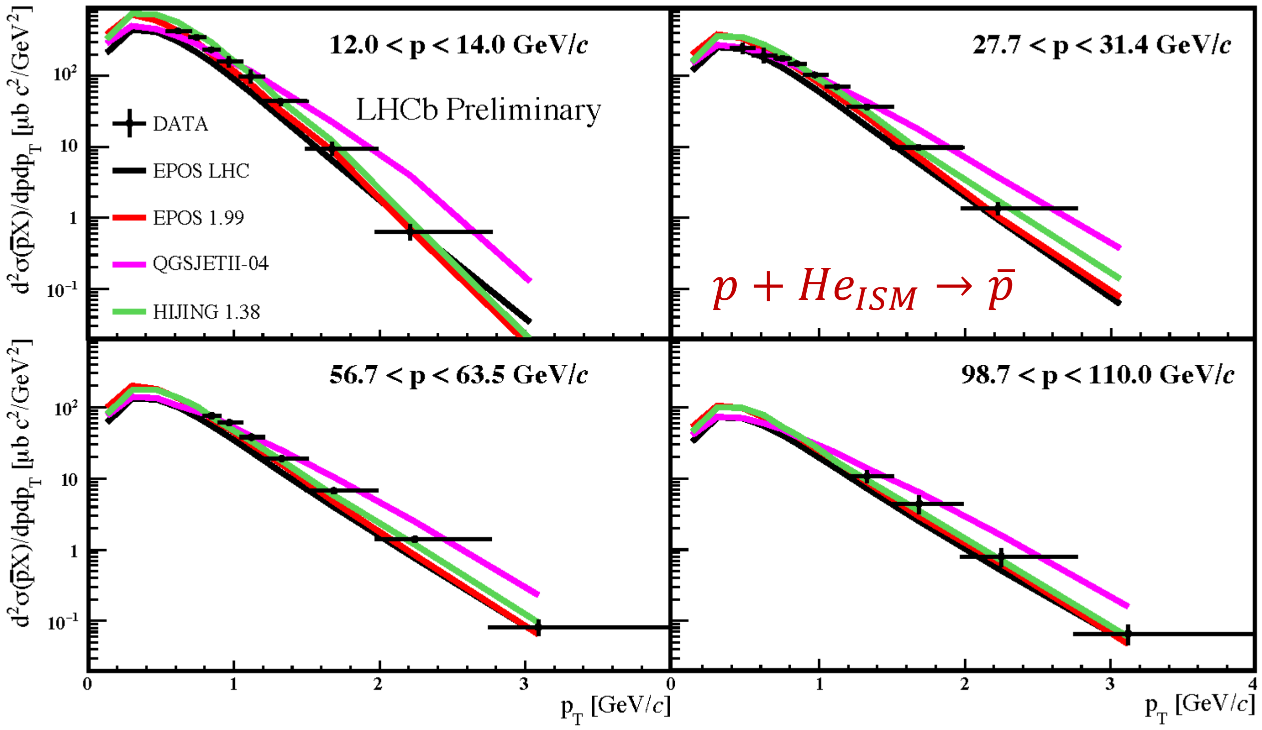
Poor measurements (forthcoming COMPASS and SHINE data)

No direct measurements until 2017 (SMOG)



From di Mauro, Donato et al estimate

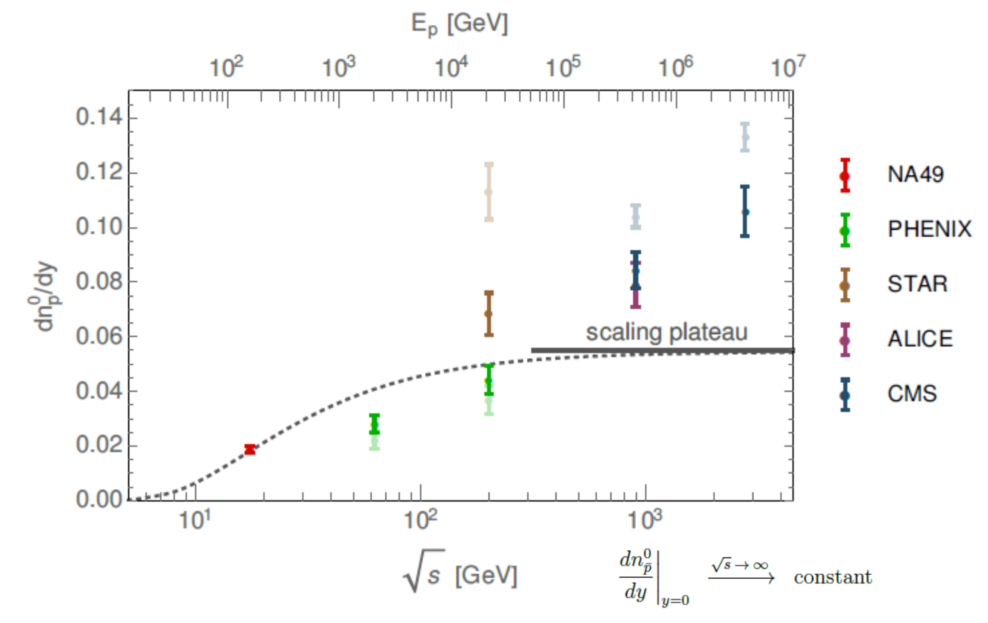
*(Phys Rev **D** 90.085017 2014)*

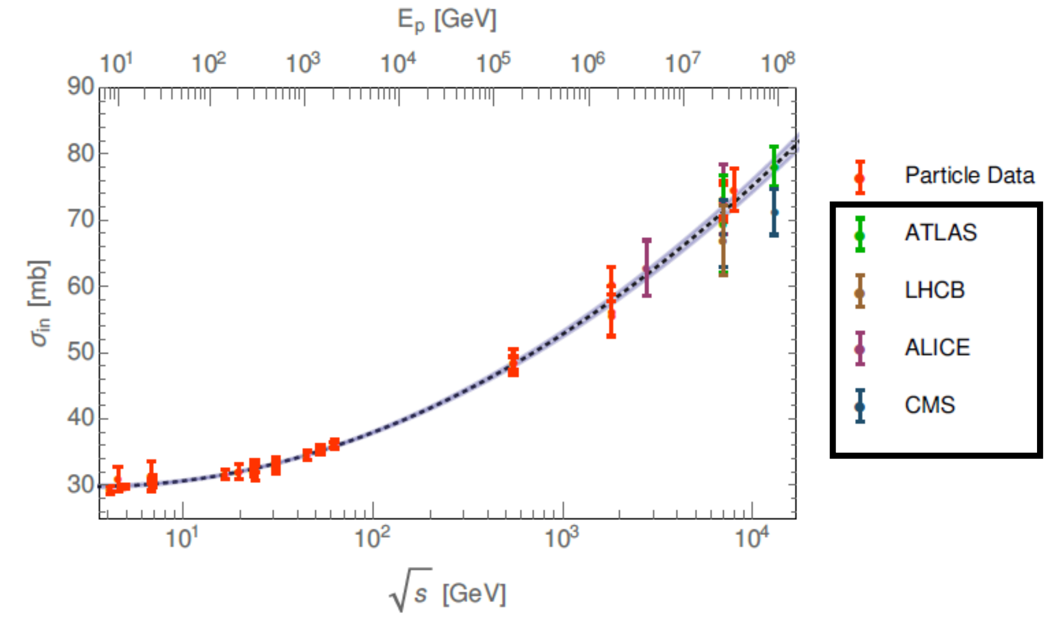


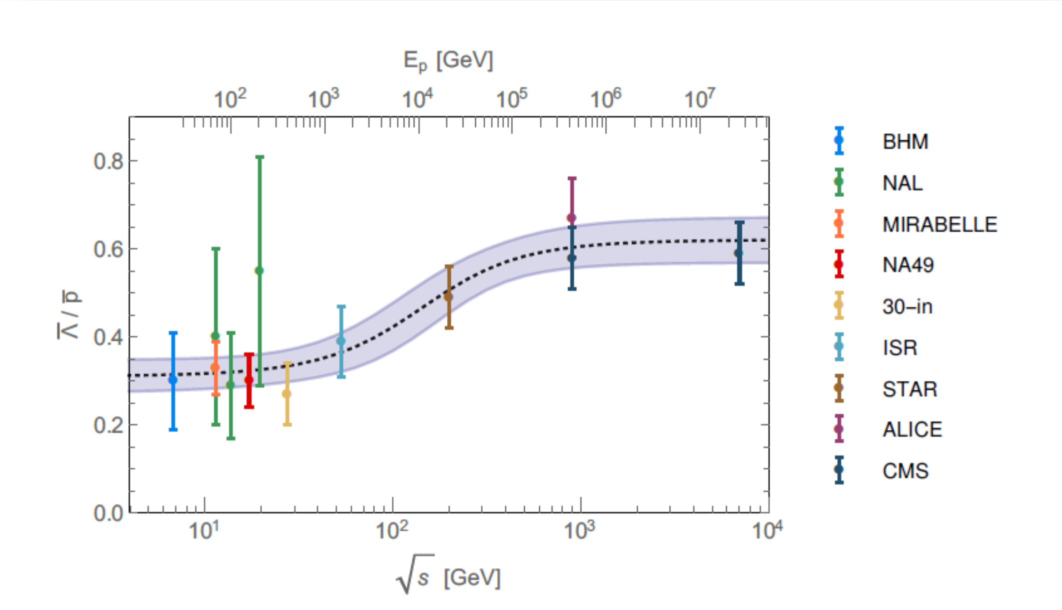
- Uncertainties in the pbar production spectrum are at least 10%.
- **Below 100 GeV the uncertainties for $pp \to \bar{p}$ are about 10-20%**
- **Above 100 GeV extrapolations lead to errors larger than 30%**

In March LHCb has performed the first measurement of the antiproton cross-section in p-He collisions at 6.5 TeV using fixed He target @ SMOG. A precision of around 10% is attained

Compilation of Measurements: LHC contributions







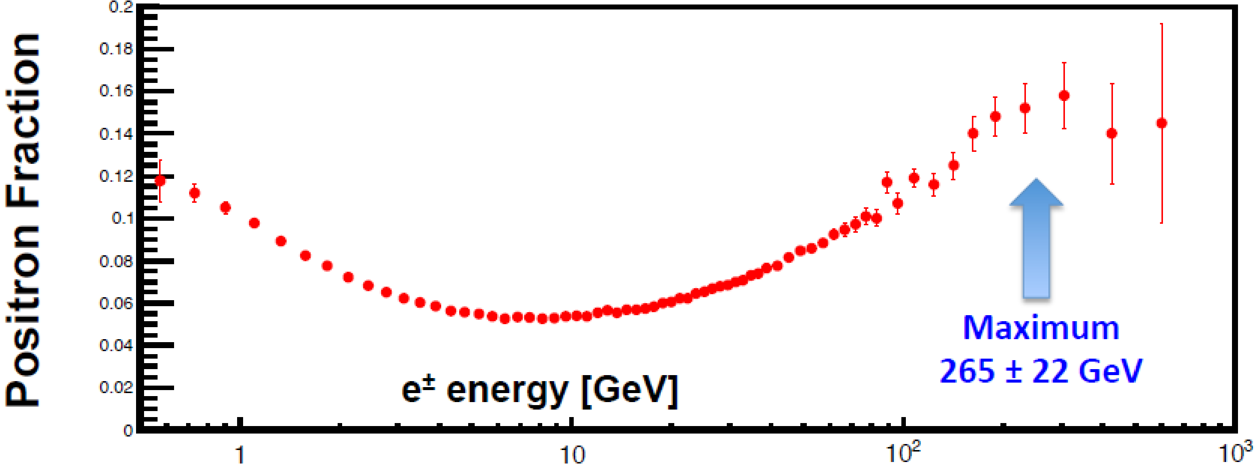
Winkler, JCAP **02**(2017)048

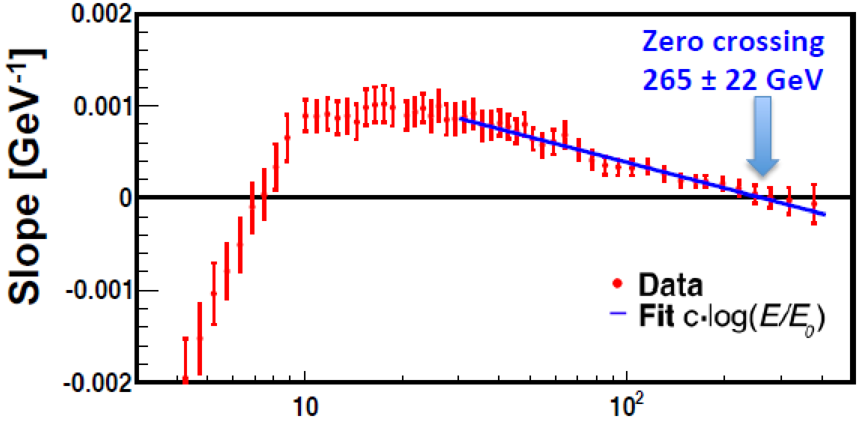
- There are new improved calculation of secondary antiproton production, with a particular focus on the high energy regime, **employing the most recent collider data**.
- A substantial **increase of antiproton cross sections with energy, driven by the violation of Feynman scaling as well as by an enhanced strange hyperon production**.
- **This violation could lead to more antiprotons than expected at high energies**

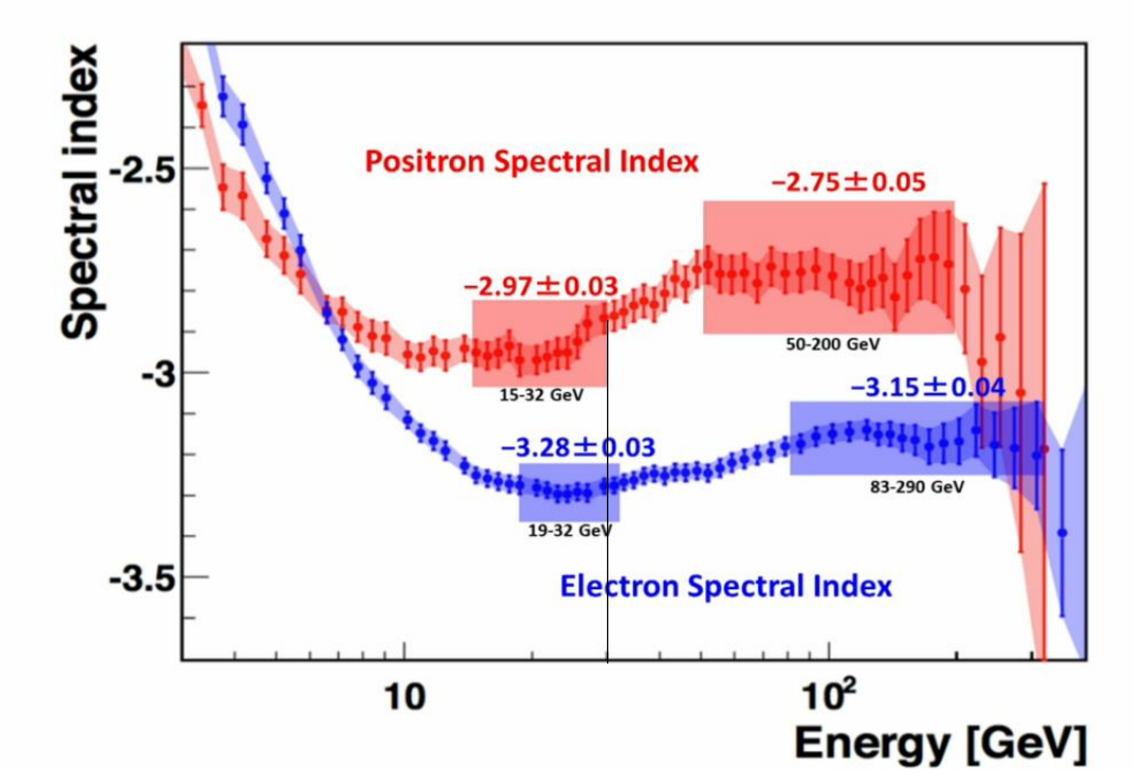
Leptons physics with AMS-02:

what we have to clarify

Positron Fraction: 5 years data







1. Sum of a diffuse spectrum and a **single power law source**

2. **No** clear sign of **substructures**

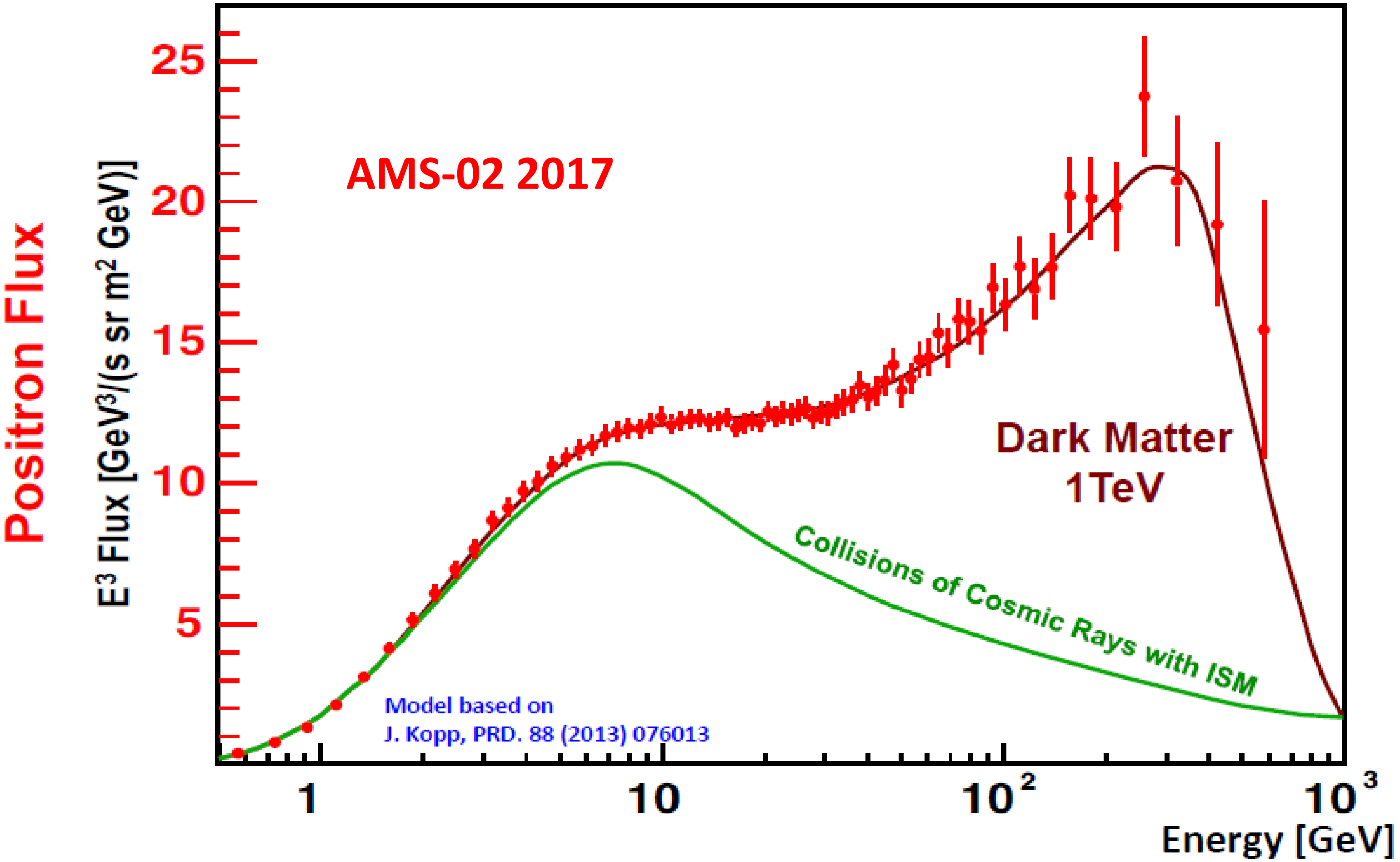
3. **Isotropy:** $\delta \leq 0.020$

4. **Above** $\sim 260\ GeV$ the positron fraction no longer exhibits a remarkable increase with energy

- Standard simulations with pure secondaries are not capable of reproducing positrons, without introducing primary DM or/and astrophysical components
- Positrons spectrum hardening above 30 GeV is not expected within the standard paradigms
- The change of slope is very similar for electrons and positrons, with an approximately conserved $\Delta\gamma_{e^+-e^-}$

Models to explain the AMS Positron Fraction and Flux

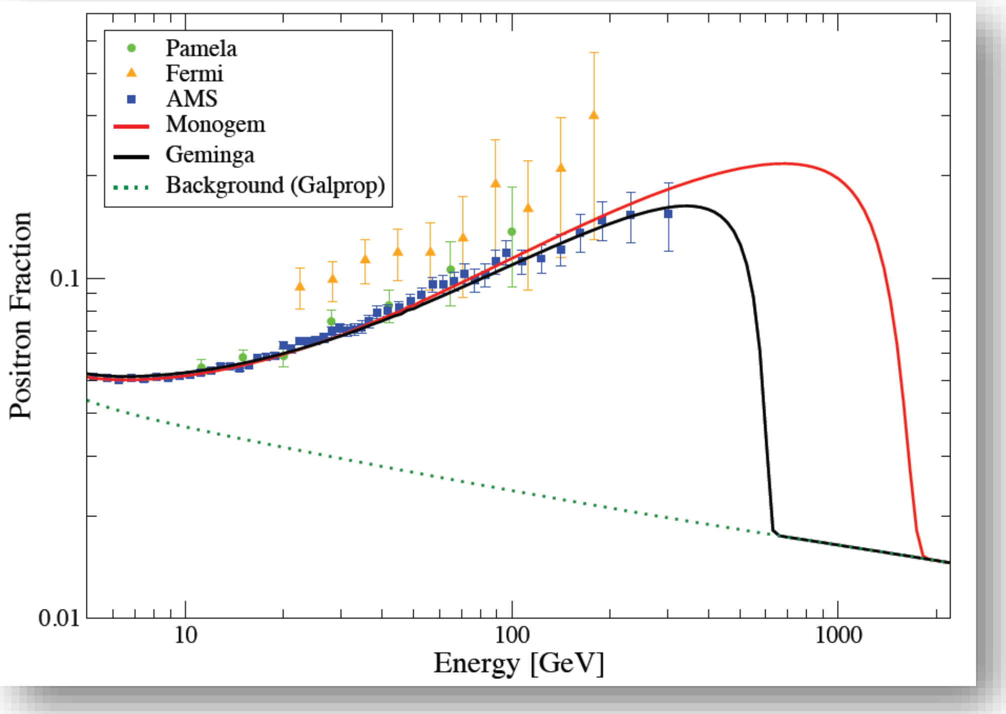
1) Particle origin: Dark Matter
2) Modified Propagation of Cosmic Rays
3) Astrophysics origin: Pulsars, SNRs

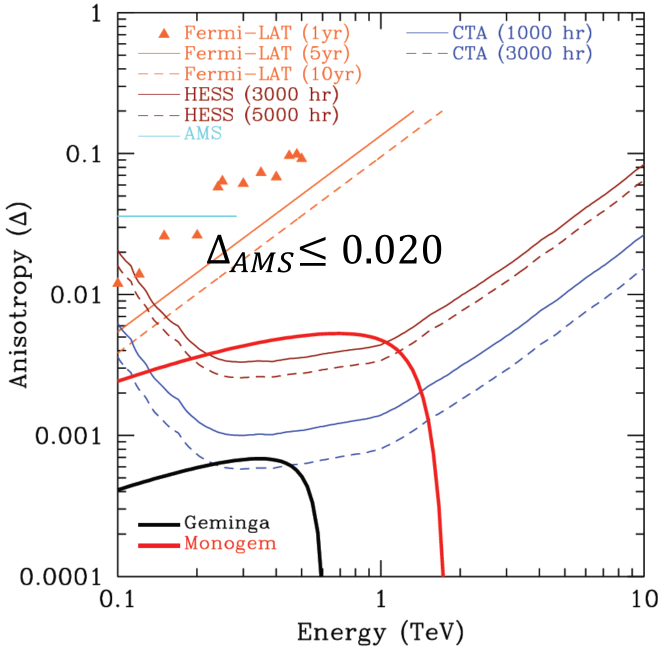


The AMS results are in excellent agreement with some Dark Matter Model

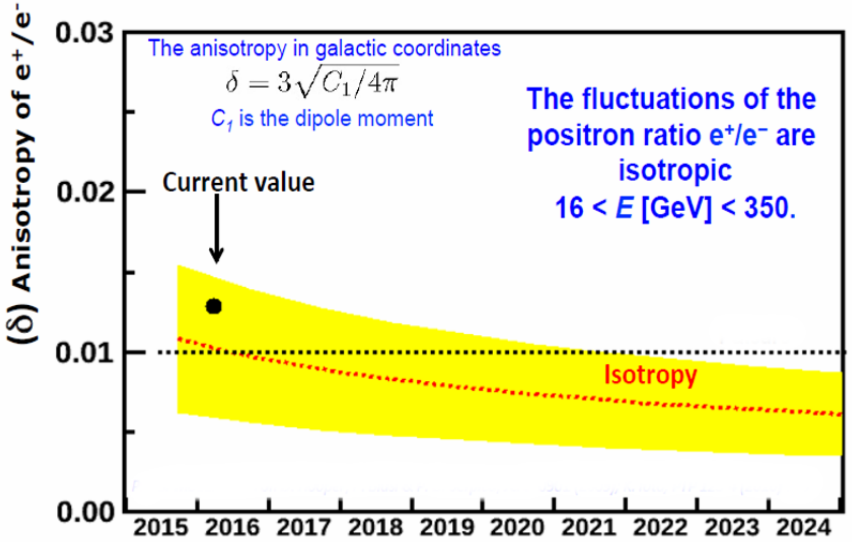
Pulsars Problem

Anyone of two well-known nearby pulsars, Geminga and Monogem, can satisfactorily provide enough positrons to reproduce AMS-02 observations:





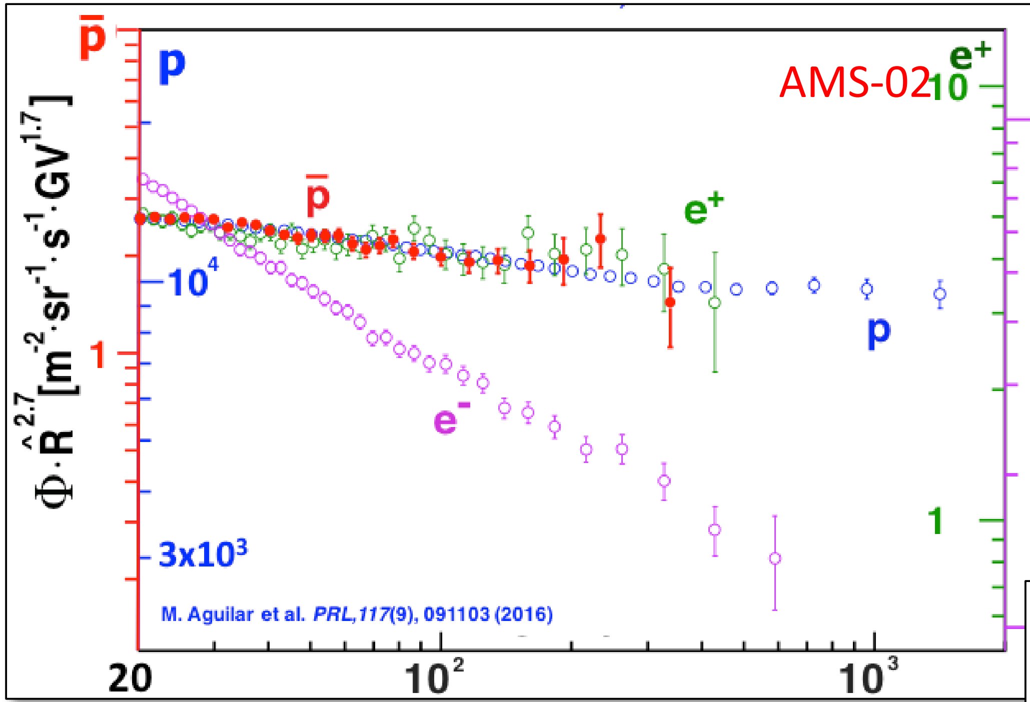
$\Delta_{AMS} \leq 0.020$



The fluctuations of the positron ratio e^+/e^- are isotropic
$16 < E$ [GeV] < 350.

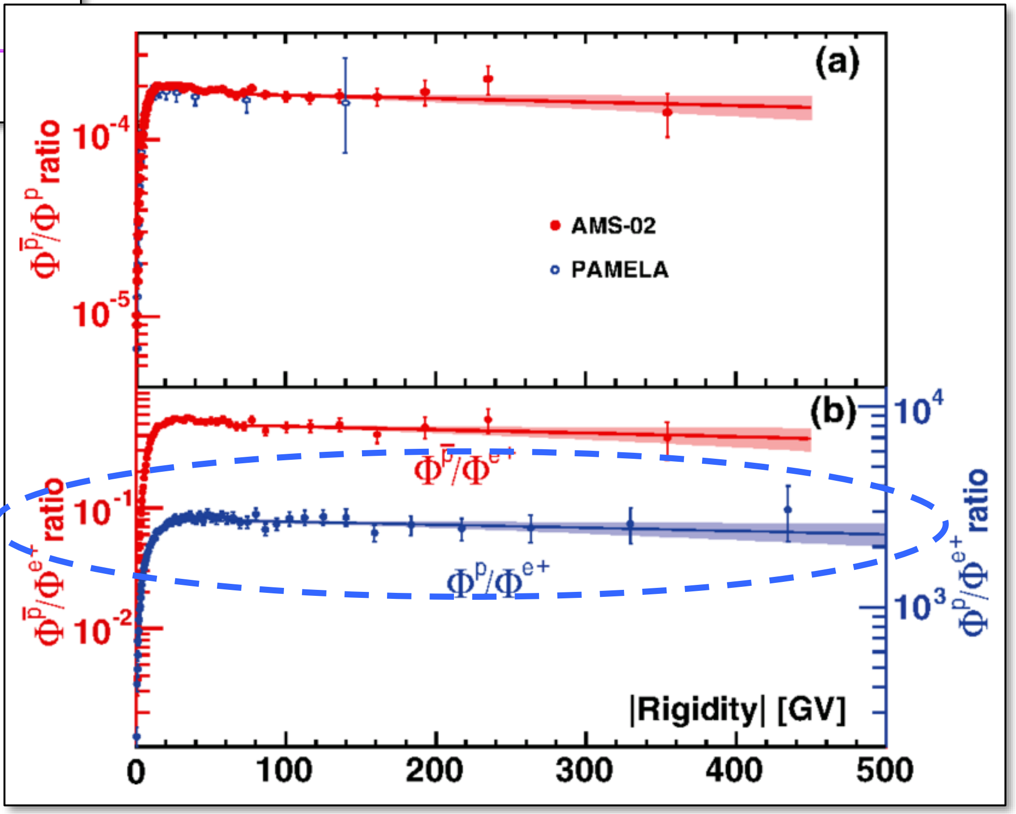
The predicted anisotropy level is, at present, consistent with limits from Fermi-LAT and AMS-02

AMS-02: intriguing new measurements of CRs features



M. Aguilar et al. *PRL,117*(9), 091103 (2016)

- If excess positrons are produced in pulsars or DM annihilation why the p/e$^+$ ratio is flat?
- **The flat p/e$^+$ ratio perhaps indicates a common origin of p and e$^+$!**



Our CRs production and propagation model based on AMS-02 data

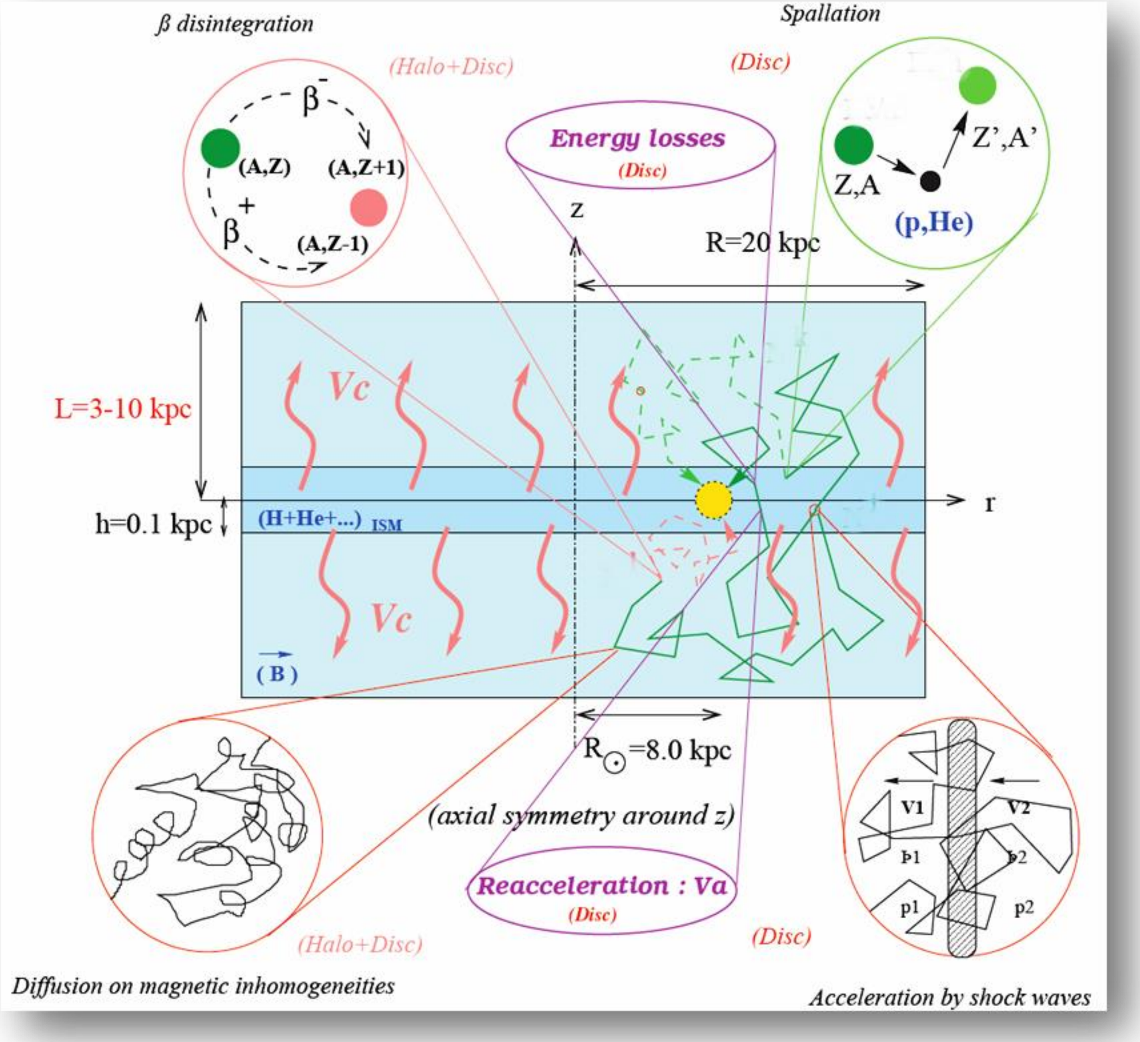
The Astrophysical Journal ***840****:115 No 2, 2017,*
arXiv:1704.06337

The Propagation Scheme in the Milky Way

Diffusion Reacceleration Energy Loss in ISM Fragmentation

$$\frac{\partial \psi}{\partial t} = q(\vec{r}, p) + \vec{\nabla} \cdot (D_{xx} \vec{\nabla} \psi - \vec{V} \psi) + \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{1}{p^2} \psi - \frac{\partial}{\partial p} \left[\dot{p} \psi - \frac{p}{3} (\vec{\nabla} \cdot \vec{V}) \psi \right] - \frac{1}{\tau_f} \psi - \frac{1}{\tau_r} \psi$$

Source Convection Adiabatic Expansion Decay

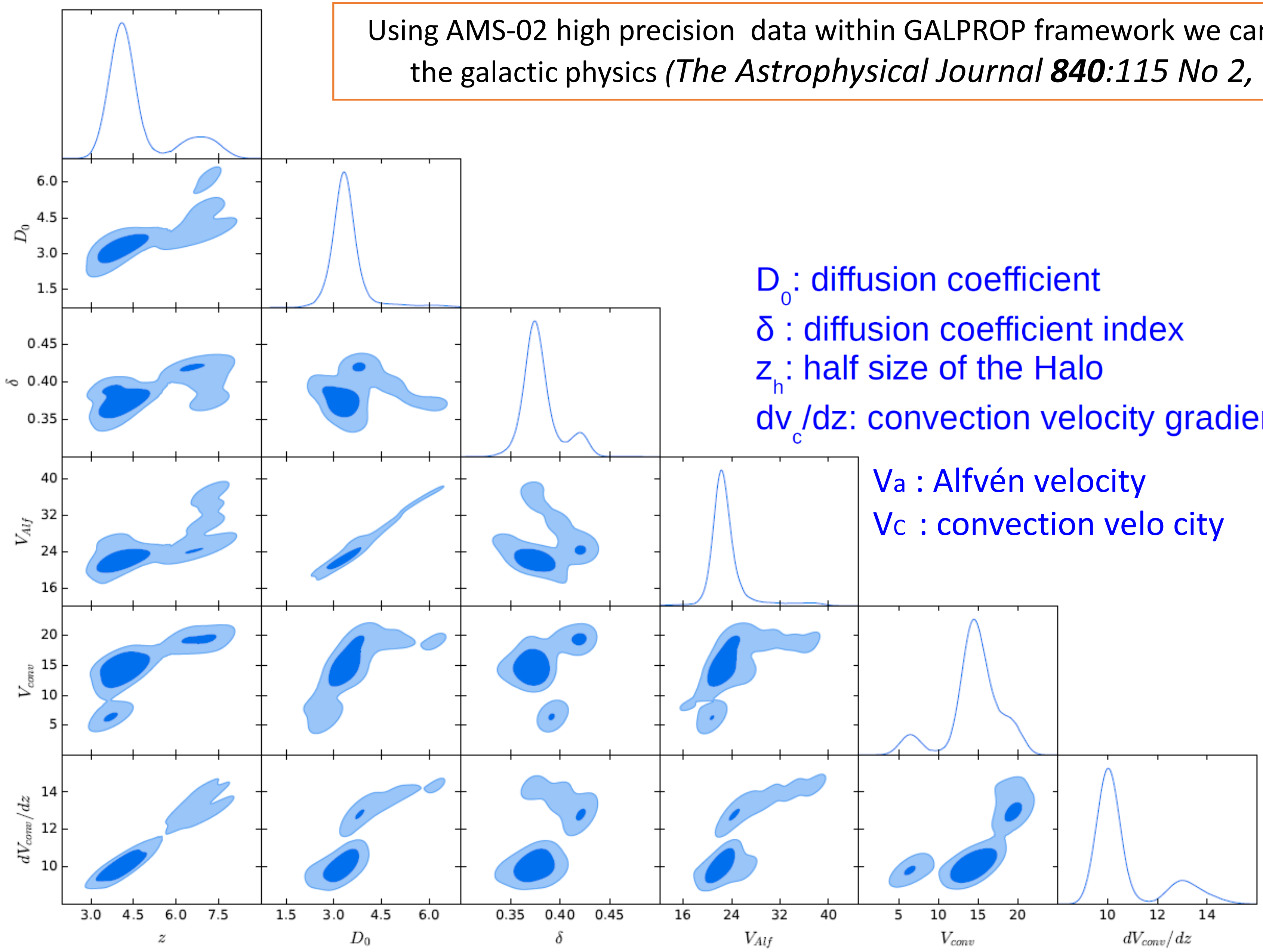


- **Geometry**: halo of thickness z
- **Diffusion**: diffusion in the galactic magnetic field inhomogeneities, propagating through the ISM (D_0, δ)
- **Convection**: galactic wind with velocity V_c and gradient dV_c/dz
- **Reacceleration**: interstellar turbulence with Alfvén velocity V_A
- **Sources**: SNe shocks produce power law spectra in energy ($\gamma_{1,2}$ indices)

6 fundamental parameters space to fix CR propagation + N specific injection indices

MCMC Matrix

Using AMS-02 high precision data within GALPROP framework we can constrain CR propagation and the galactic physics *(The Astrophysical Journal **840**:115 No 2, 2017, arXiv:1704.06337)*



D_0: diffusion coefficient

δ : diffusion coefficient index

z_h: half size of the Halo

dv_c/dz: convection velocity gradient

V_a : Alfvén velocity

V_C : convection velo city

1. A Monte-Carlo-Markov-Chain interface to **GALPROP v55**;
2. The solar modulation is made using **HelMod**;
3. The experimental observables used in the MCMC scan include all published AMS-02 data on **protons, Helium, B/C ratio and electrons**, while positrons and antiprotons are excluded.

CR Physics Improvements

Before AMS-02

	Unit	Error (%)
z	kpc	60%
$D_0/10\text{^}28$	$\mathrm{cm}^2\mathrm{s}^{-1}$	100%
δ		60%
V_{Alfven}	$\mathrm{km\ s}^{-1}$	90%
V_{0conv}	$\mathrm{km\ s}^{-1}$	100%
dV_C/dz	$\mathrm{km\ s}^{-1} kpc^{-1}$	100%

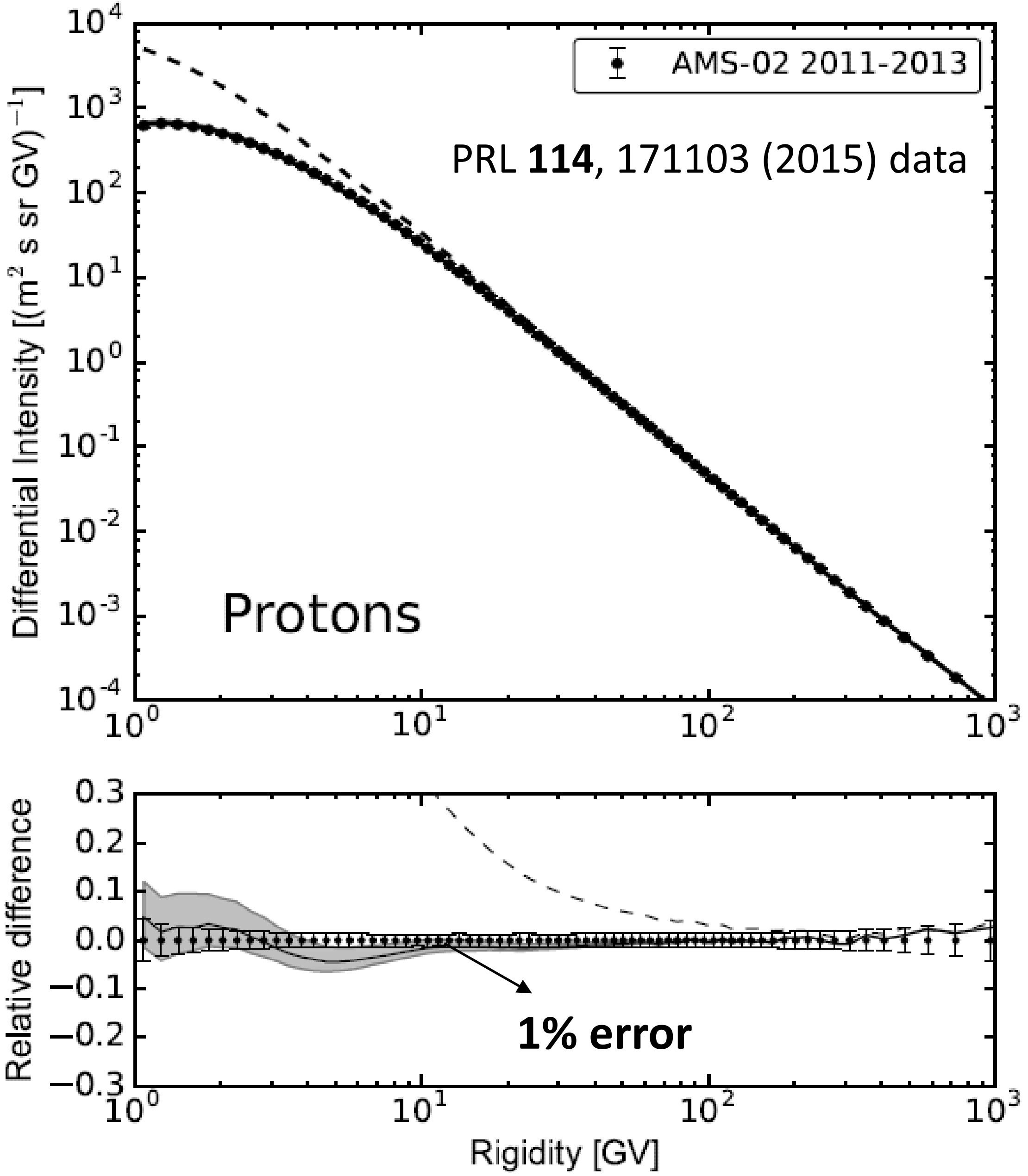
After AMS-02

Error (%)	Improvement factor $\varepsilon_{before}/\varepsilon_{after}$
18%	3
12%	8
6%	10
10%	9
6%	16
7%	14

- Before AMS-02 we were not able to fix the CR propagation physics: **the parameters lied in very wide ranges**.
- With AMS-02 data is finally possible to achive a consistent best fit: the **errors associated to the fundamental propagation parameters z, D_{0xx}, $\delta_{1,2}$ are greatly reduced.**

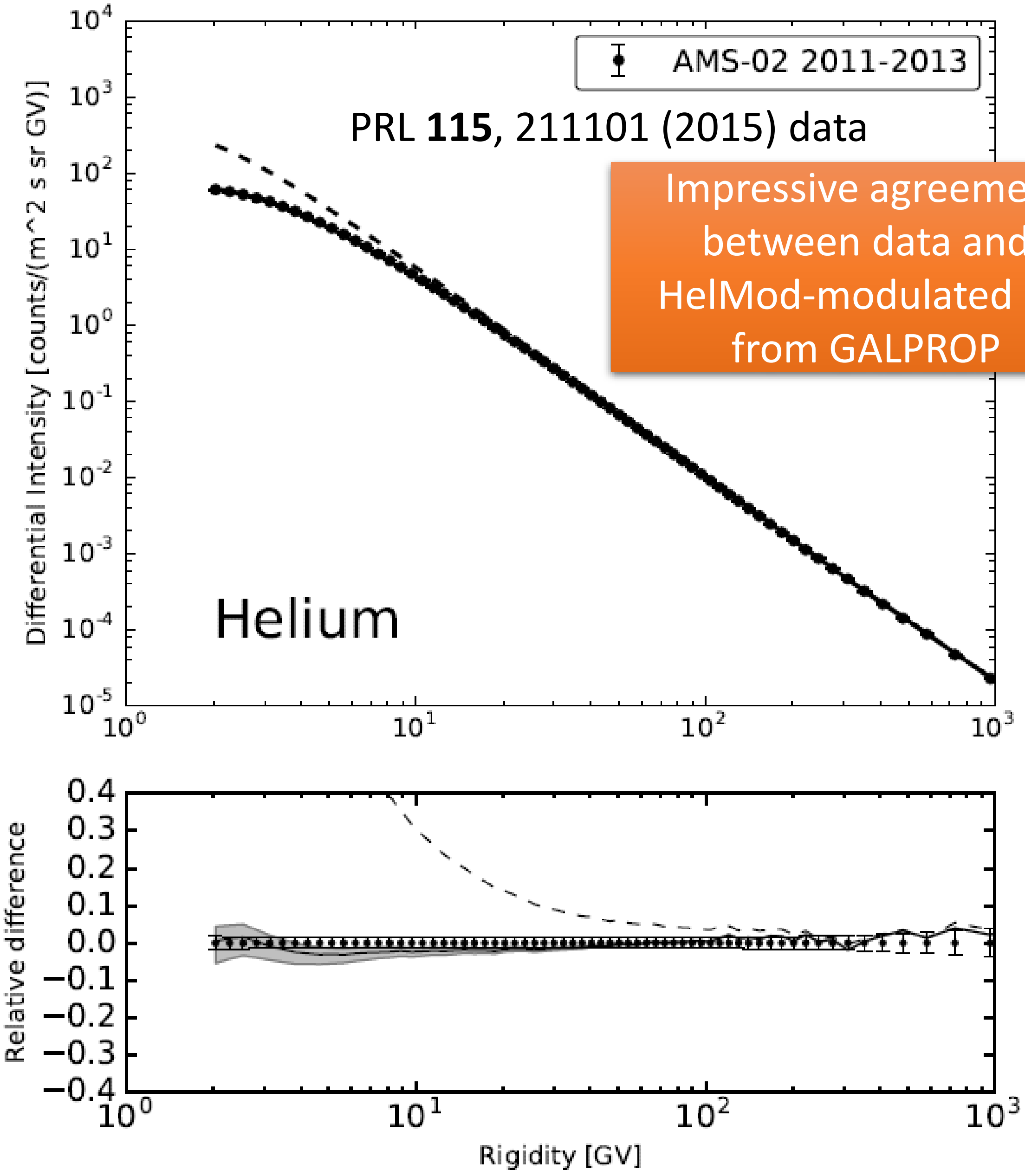
One order of magnitude of improvement for fundamental parameters

Proton and Helium High Solar Activity



PRL **114**, 171103 (2015) data

1% error



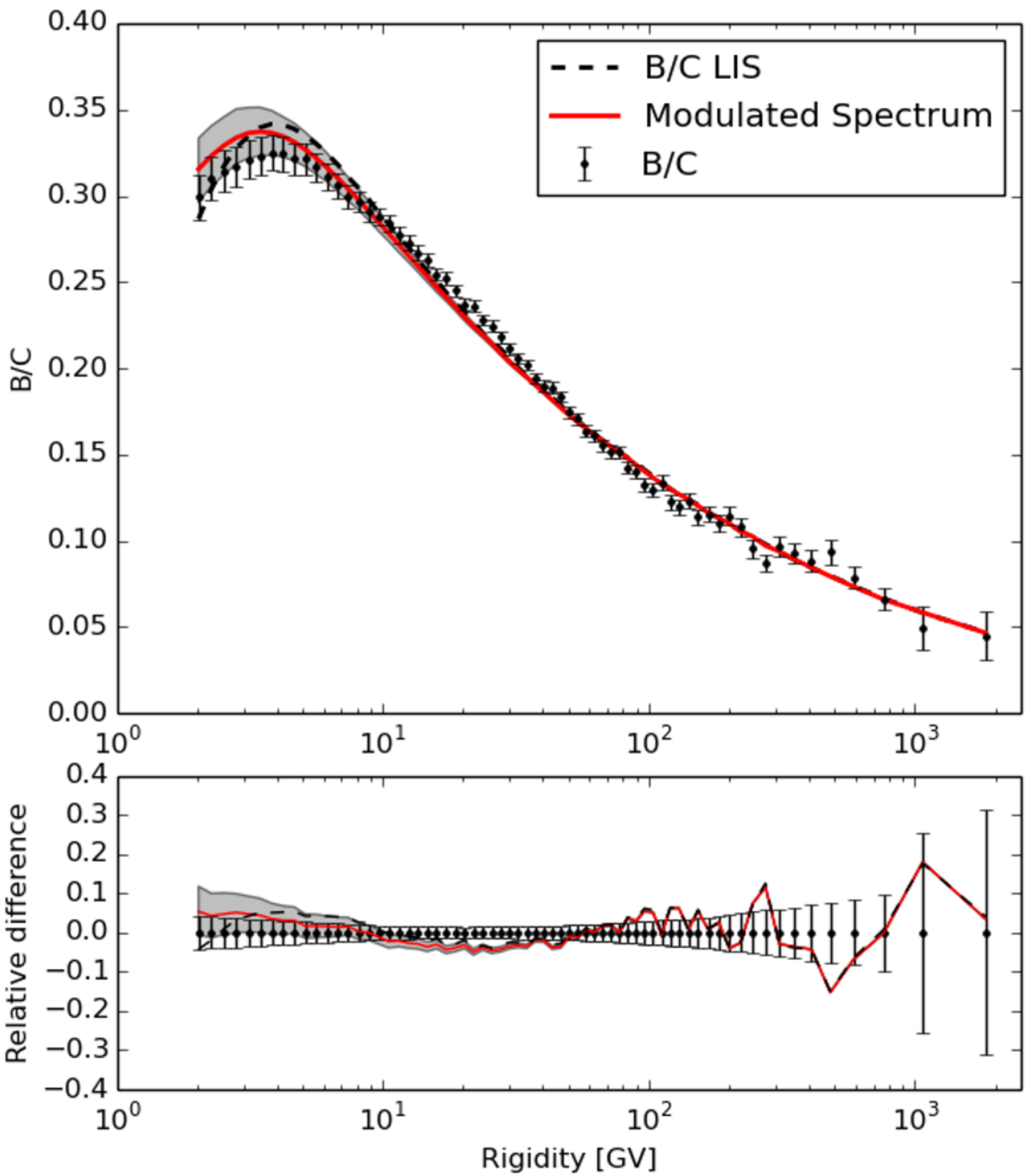
PRL **115**, 211101 (2015) data

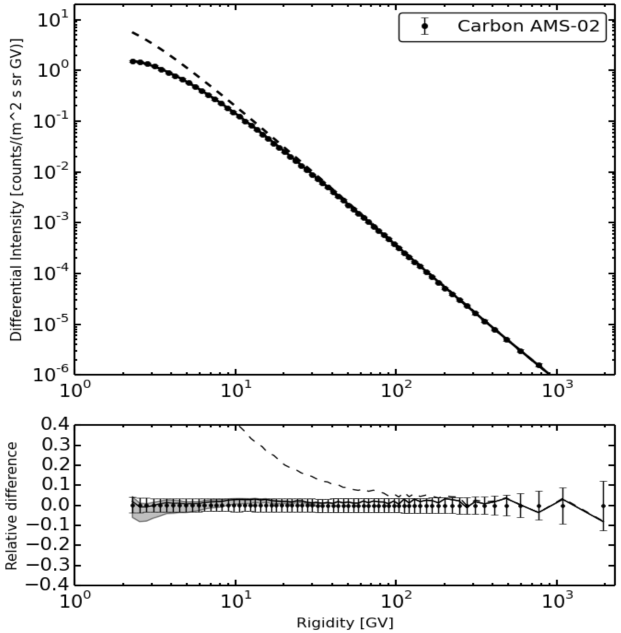
Impressive agreement between data and HelMod-modulated LIS from GALPROP

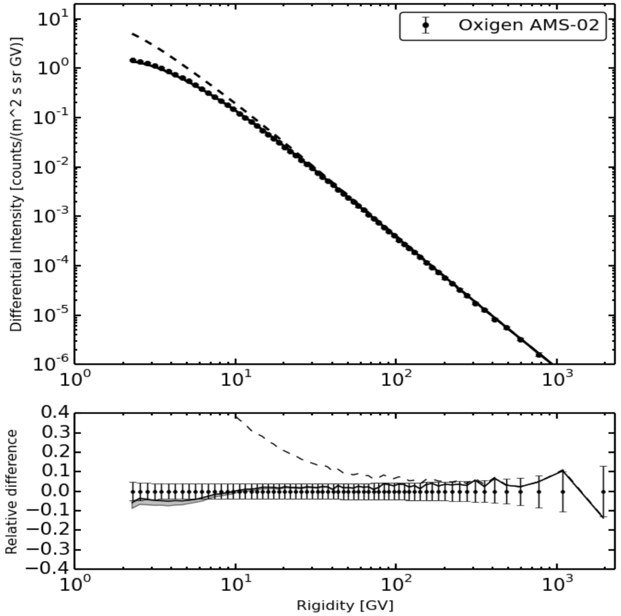
Forthcoming nuclei analysis

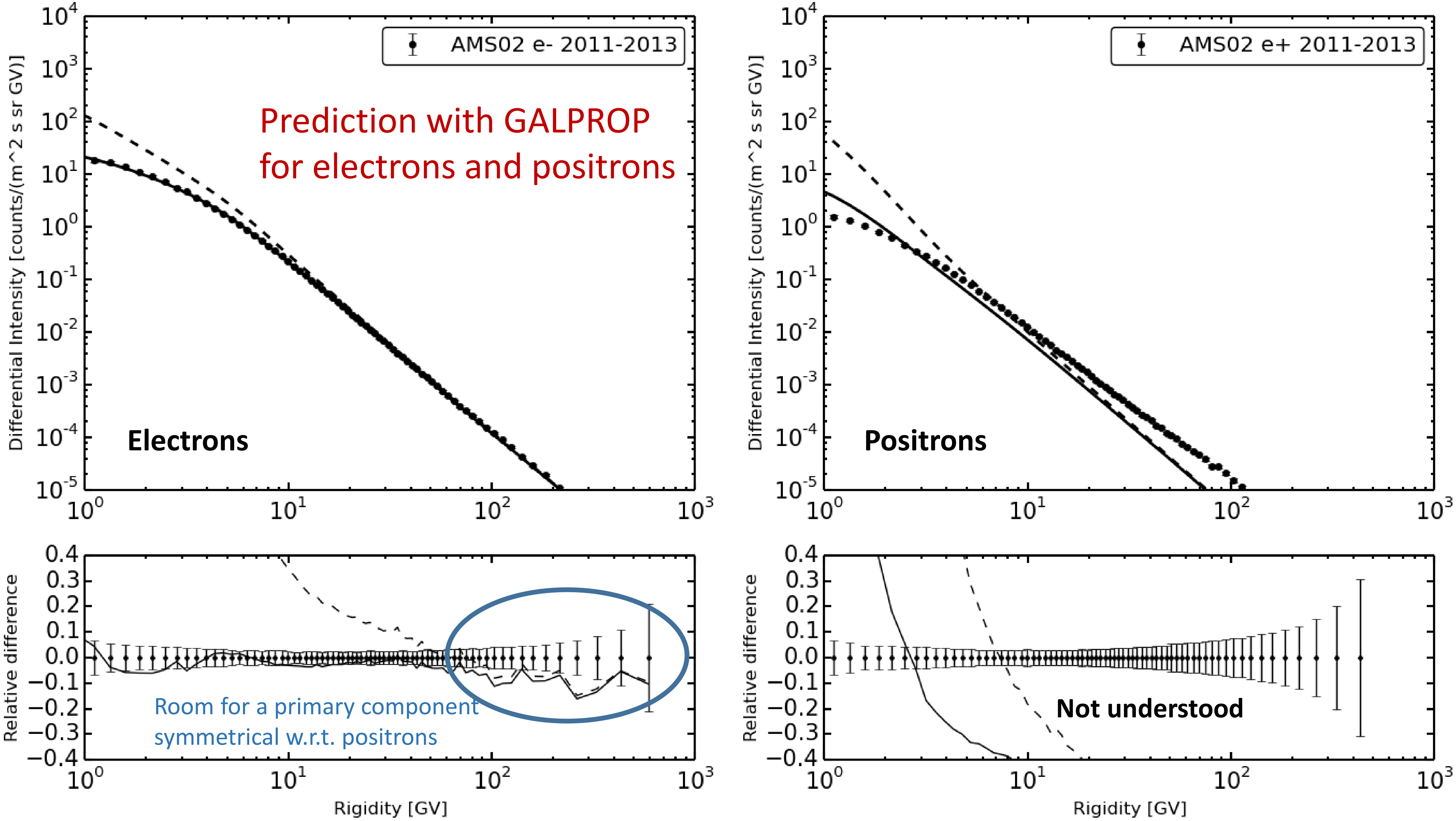
B/C

Good agreement between data and HelMod-modulated LIS from GALPROP, within nuclear and propagation uncertainties









Prediction with GALPROP for electrons and positrons

Electrons

Positrons

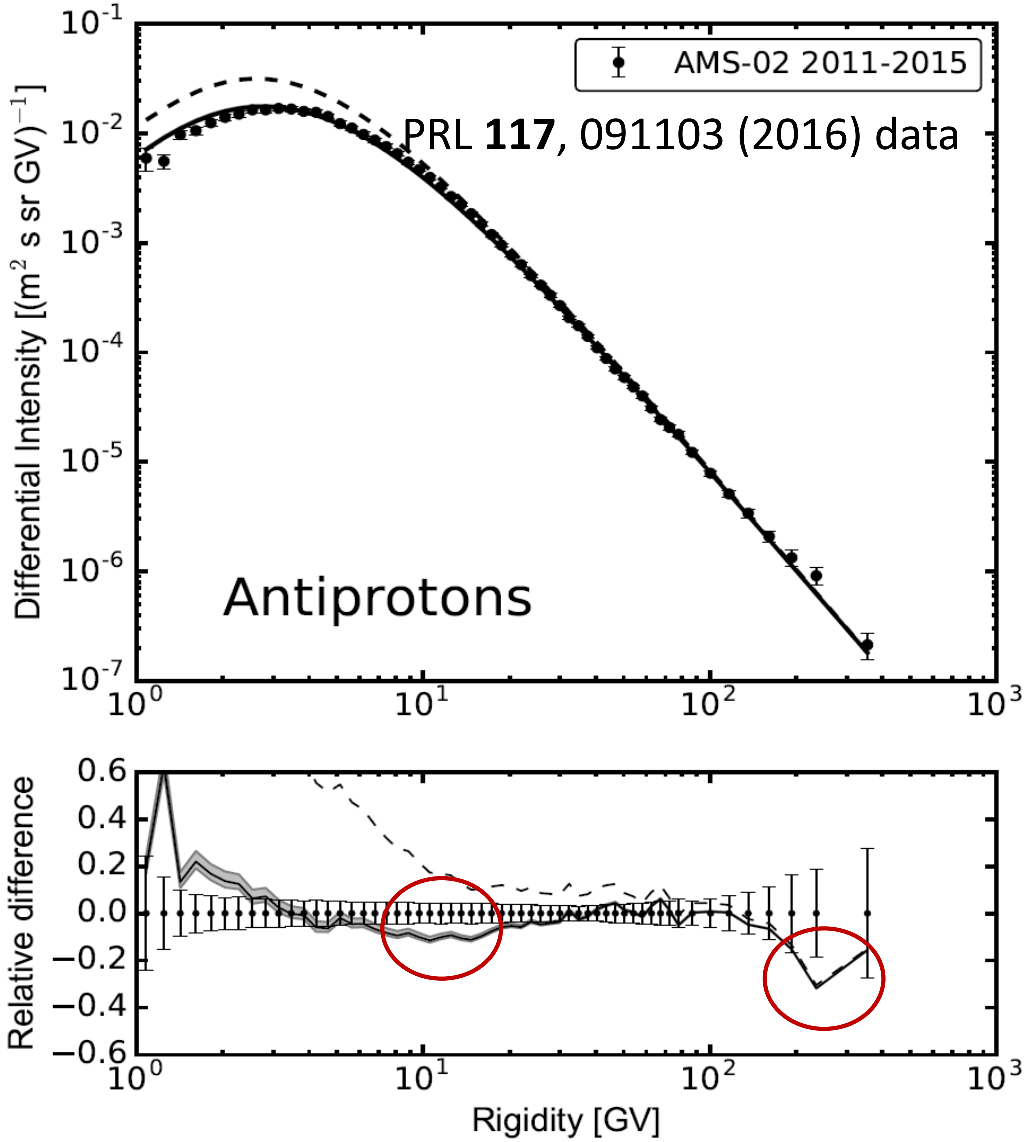
Room for a primary component symmetrical w.r.t. positrons

Not understood

The antiproton channel

The Astrophysical Journal ***840****:115 No 2, 2017,*
arXiv:1704.06337

Antiprotons



PRL **117**, 091103 (2016) data

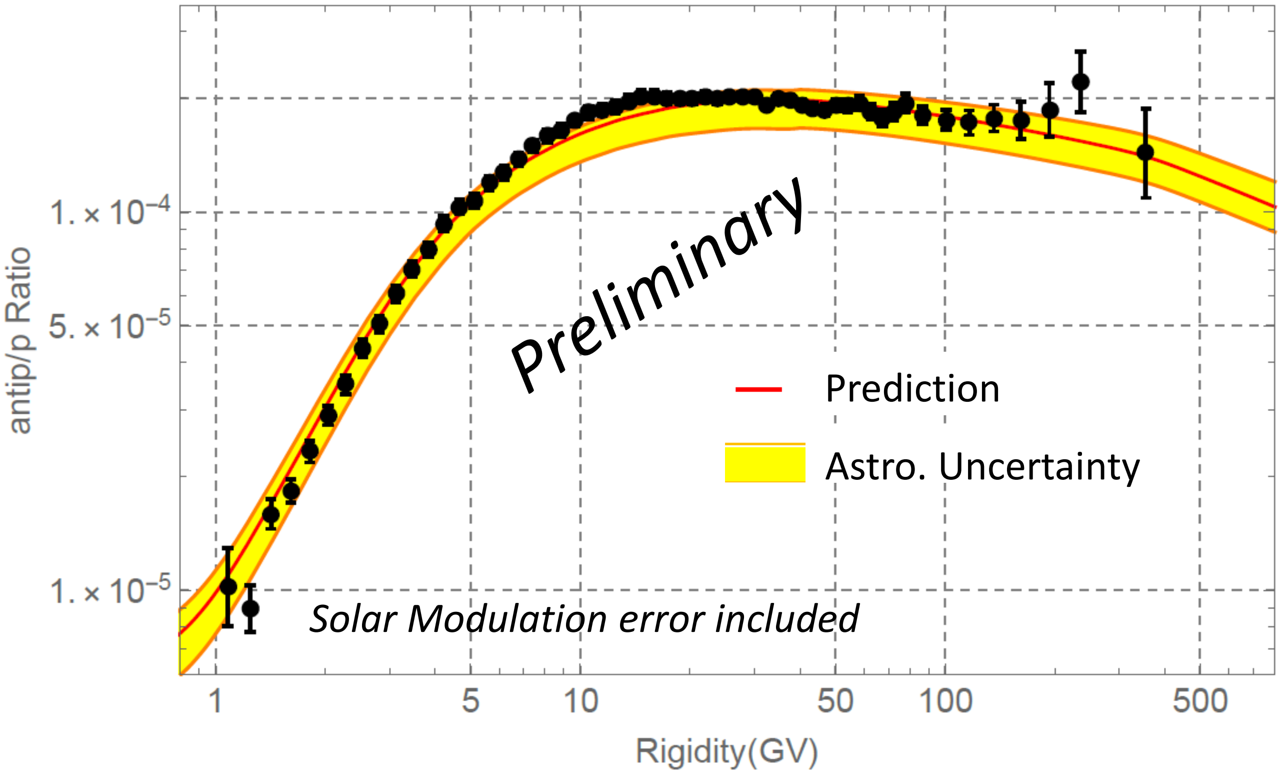
The Antiproton LIS is substantially compatible with AMS-02 within few %

Tiny discrepancies w.r.t. AMS-02 high precision data could be due to:

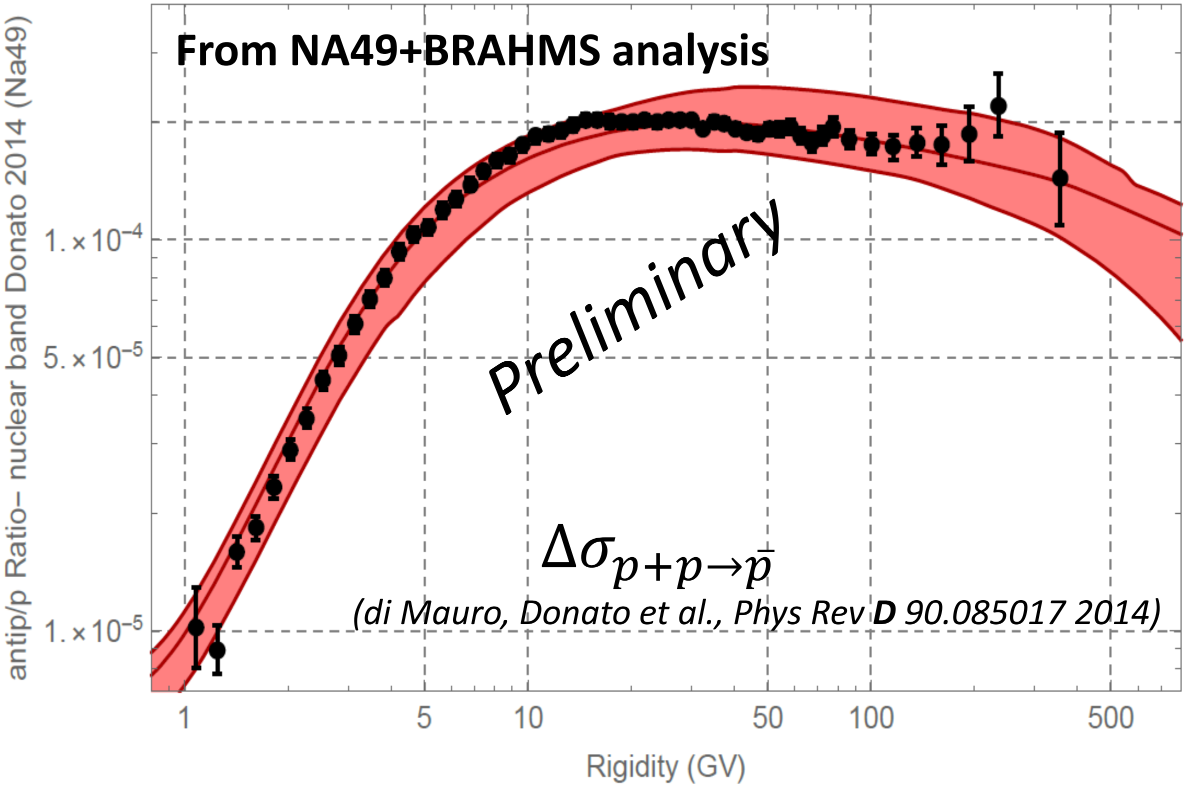
- nuclear cross section uncertainties
- peculiar propagation effects or variation of primary p and He spectra in the Galaxy

- In standard GALPROP: analytic **parameterizations from Tan & Ng based on 70's data**: PRD **26** (1982) 1179; J.Phys.G:Nucl Phys **9** (1983) 227
- In our study: recalculated $\bar{p}$ production in pp/pA/AA-interactions using **EPOS-LHC and QGSJET-II-04 MC generators**, tuned to accelerator data (ApJ, 803:54, 2015)

Antip/p: astrophysical uncertainty vs nuclear uncertainty



Solar Modulation error included

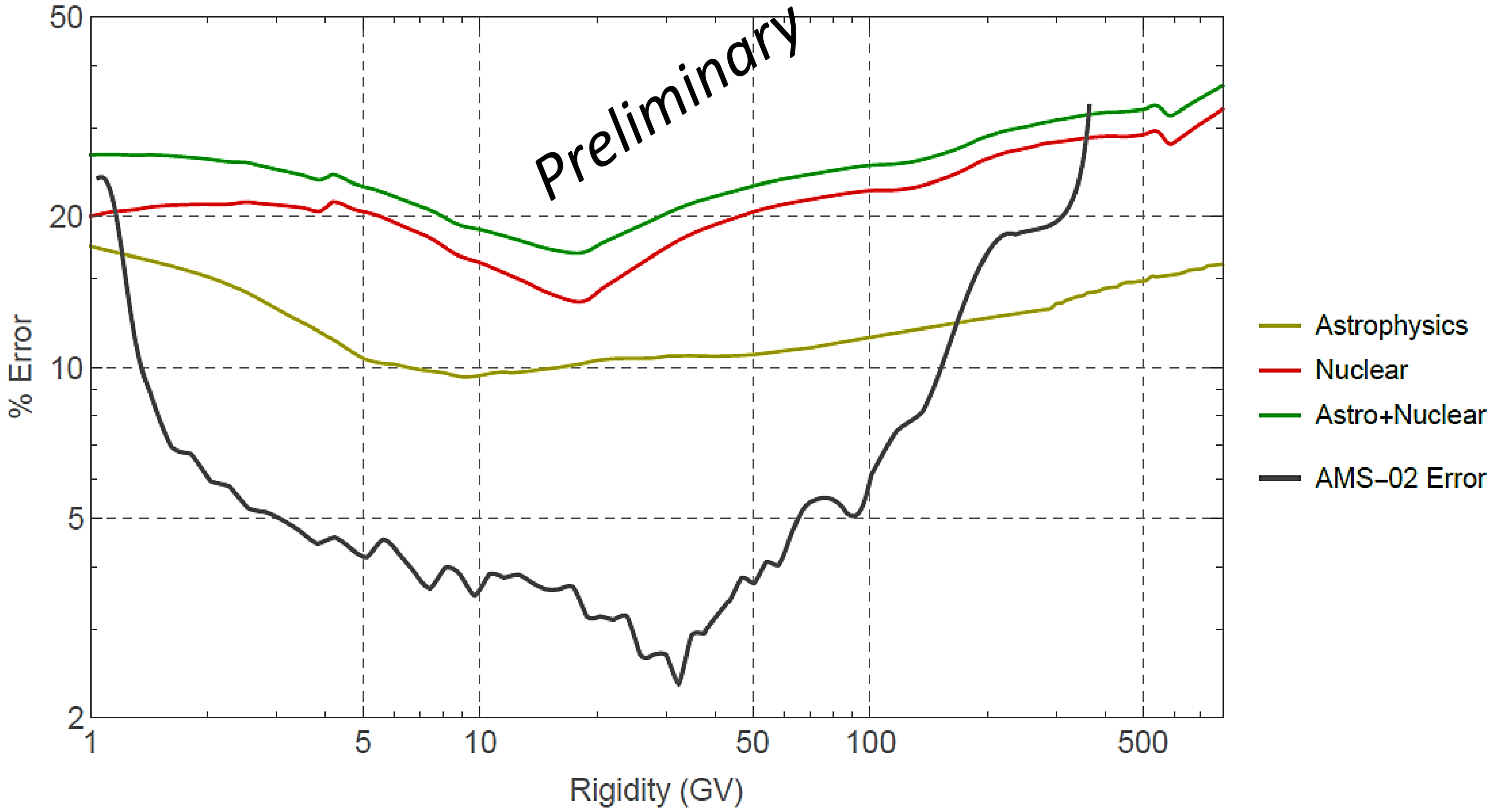


From NA49+BRAHMS analysis

$\Delta\sigma_{p+p\rightarrow\bar{p}}$

*(di Mauro, Donato et al., Phys Rev **D** 90.085017 2014)*

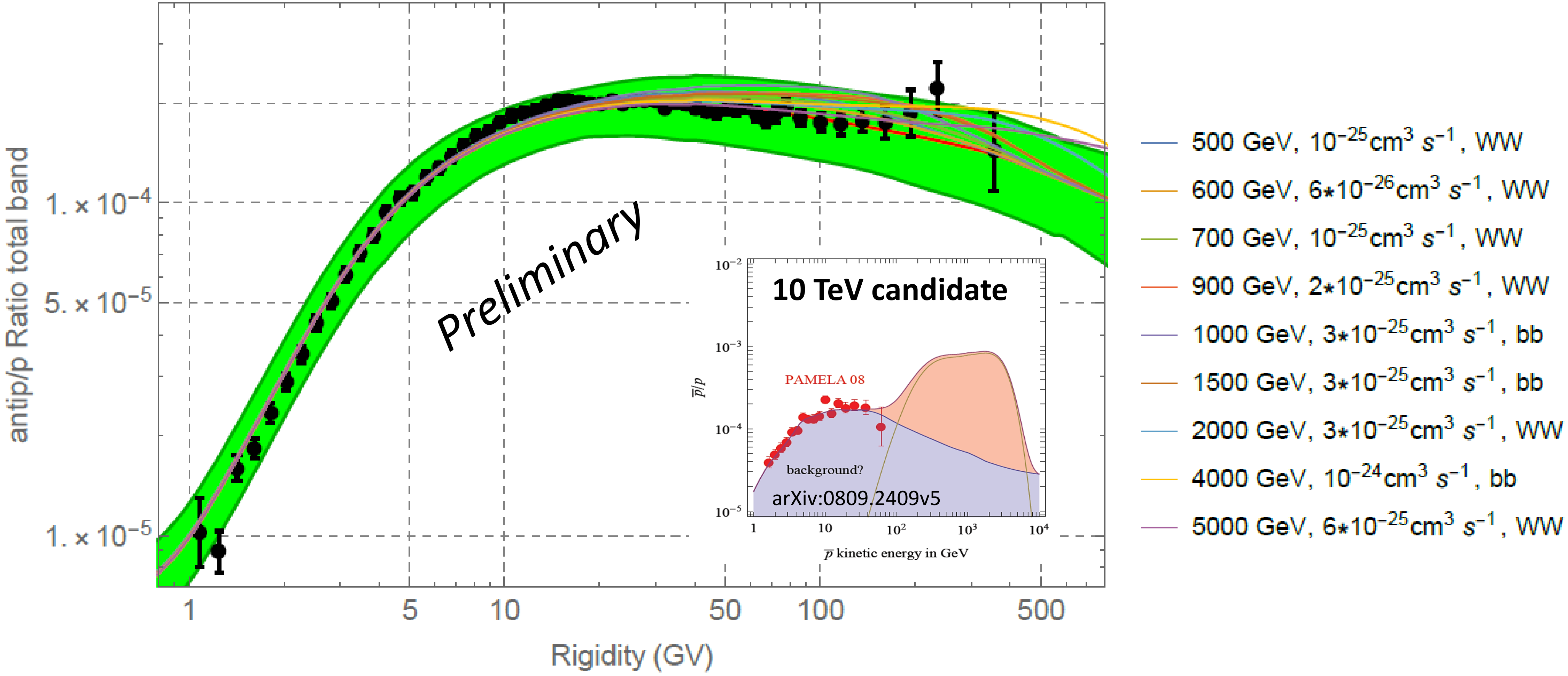
Error Bands: Astrophysics vs Nuclear physics



- Propagation uncertainties are lower than nuclear one.
- Adding further AMS-02 data set to the analysis (C, O, Li, Be, B) the propagation error will be reduced.

Total uncertainty band + DM DarkSUSY simulations

BETTER CANDIDATES: m > 1 TeV, 0.6 TeV < m < 1 TeV and $\langle\boldsymbol{\sigma v}\rangle < \mathbf{10^{-25} cm^3/s}$



- TeV scale candidates are favored by LHC, direct, indirect and astrophysical searches.
- **DM signals could in principle still hide within the overall error band.**

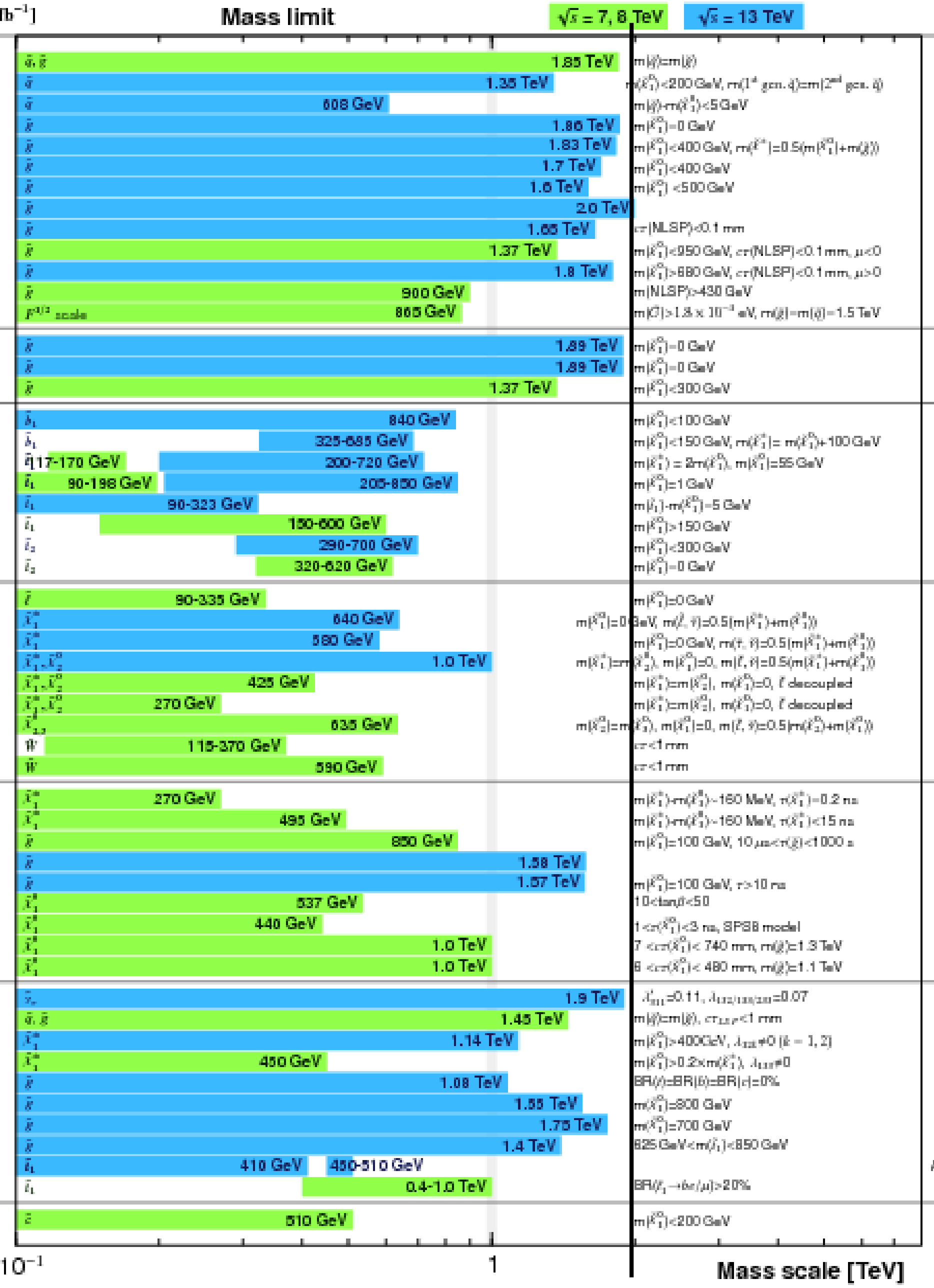
DM search status @ Colliders

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: August 2016

ATLAS Preliminary

$\sqrt{s}$ = 7, 8, 13 TeV



	Model	e,μ,τ,γ	Jets	E_T^{miss}	$\int\mathcal{L}\,dt[fb^{-1}]$	Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0-3 e,μ/1-2 τ	2-10 jets/3 b	Yes	20.3	🟩 $\tilde{q},\tilde{g}$ 1.85 TeV	$m(\tilde{q})=m(\tilde{g})$	1507.05525
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	13.3	🟦 $\tilde{q}$ 1.35 TeV	$m(\tilde{\chi}_1^0)<200$ GeV, $m(1^{st}$ gen. $\tilde{q})=m(2^{nd}$ gen. $\tilde{q})$	ATLAS-CONF-2016-078
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$ (compressed)	mono-jet	1-3 jets	Yes	3.2	🟦 $\tilde{q}$ 608 GeV	$m(\tilde{q})-m(\tilde{\chi}_1^0)<5$ GeV	1604.07773
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	13.3	🟦 $\tilde{g}$ 1.86 TeV	$m(\tilde{\chi}_1^0)=0$ GeV	ATLAS-CONF-2016-078
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^\pm\to qqW^\pm\tilde{\chi}_1^0$	0	2-6 jets	Yes	13.3	🟦 $\tilde{g}$ 1.83 TeV	$m(\tilde{\chi}_1^0)<400$ GeV, $m(\tilde{\chi}^\pm)=0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$	ATLAS-CONF-2016-078
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq(\ell\ell/\nu\nu)\tilde{\chi}_1^0$	3 e,μ	4 jets	-	13.2	🟦 $\tilde{g}$ 1.7 TeV	$m(\tilde{\chi}_1^0)<400$ GeV	ATLAS-CONF-2016-037
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqWZ\tilde{\chi}_1^0$	2 e,μ (SS)	0-3 jets	Yes	13.2	🟦 $\tilde{g}$ 1.6 TeV	$m(\tilde{\chi}_1^0)<500$ GeV	ATLAS-CONF-2016-037
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	3.2	🟦 $\tilde{g}$ 2.0 TeV		1607.05979
	GGM (bino NLSP)	2 γ	-	Yes	3.2	🟦 $\tilde{g}$ 1.65 TeV	$c\tau$(NLSP)<0.1 mm	1606.09150
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	20.3	🟩 $\tilde{g}$ 1.37 TeV	$m(\tilde{\chi}_1^0)<950$ GeV, $c\tau$(NLSP)<0.1 mm, $\mu<0$	1507.05493
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	13.3	🟦 $\tilde{g}$ 1.8 TeV	$m(\tilde{\chi}_1^0)>680$ GeV, $c\tau$(NLSP)<0.1 mm, $\mu>0$	ATLAS-CONF-2016-066
	GGM (higgsino NLSP)	2 e,μ (Z)	2 jets	Yes	20.3	🟩 $\tilde{g}$ 900 GeV	m(NLSP)>430 GeV	1503.03290
	Gravitino LSP	0	mono-jet	Yes	20.3	🟩 $F^{1/2}$ scale 865 GeV	$m(\tilde{G})>1.8\times10^{-4}$ eV, $m(\tilde{g})=m(\tilde{q})=1.5$ TeV	1502.01518
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	14.8	🟦 $\tilde{g}$ 1.89 TeV	$m(\tilde{\chi}_1^0)=0$ GeV	ATLAS-CONF-2016-052
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	Yes	14.8	🟦 $\tilde{g}$ 1.89 TeV	$m(\tilde{\chi}_1^0)=0$ GeV	ATLAS-CONF-2016-052
	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e,μ	3 b	Yes	20.1	🟩 $\tilde{g}$ 1.37 TeV	$m(\tilde{\chi}_1^0)<300$ GeV	1407.0600
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	3.2	🟦 $\tilde{b}_1$ 840 GeV	$m(\tilde{\chi}_1^0)<100$ GeV	1606.08772
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to t\tilde{\chi}_1^\pm$	2 e,μ (SS)	1 b	Yes	13.2	🟦 $\tilde{b}_1$ 325-685 GeV	$m(\tilde{\chi}_1^0)<150$ GeV, $m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_1^0)+100$ GeV	ATLAS-CONF-2016-037
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	0-2 e,μ	1-2 b	Yes	4.7/13.3	$\tilde{t}_1$ 🟩 117-170 GeV 🟦 200-720 GeV	$m(\tilde{\chi}_1^\pm)=2m(\tilde{\chi}_1^0)$, $m(\tilde{\chi}_1^0)=55$ GeV	1209.2102, ATLAS-CONF-2016-077
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e,μ	0-2 jets/1-2 b	Yes	4.7/13.3	$\tilde{t}_1$ 🟩 90-198 GeV 🟦 205-850 GeV	$m(\tilde{\chi}_1^0)=1$ GeV	1506.08616, ATLAS-CONF-2016-077
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet	Yes	3.2	🟦 $\tilde{t}_1$ 90-323 GeV	$m(\tilde{t}_1)-m(\tilde{\chi}_1^0)=5$ GeV	1604.07773
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	🟩 $\tilde{t}_1$ 150-600 GeV	$m(\tilde{\chi}_1^0)>150$ GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ (Z)	1 b	Yes	13.3	🟦 $\tilde{t}_2$ 290-700 GeV	$m(\tilde{\chi}_1^0)<300$ GeV	ATLAS-CONF-2016-038
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+h$	1 e,μ	6 jets + 2 b	Yes	20.3	🟩 $\tilde{t}_2$ 320-620 GeV	$m(\tilde{\chi}_1^0)=0$ GeV	1506.08616
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	20.3	🟩 $\tilde{\ell}$ 90-335 GeV	$m(\tilde{\chi}_1^0)=0$ GeV	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	13.3	🟦 $\tilde{\chi}_1^\pm$ 640 GeV	$m(\tilde{\chi}_1^0)=0$ GeV, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	ATLAS-CONF-2016-096
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	14.8	🟦 $\tilde{\chi}_1^\pm$ 580 GeV	$m(\tilde{\chi}_1^0)=0$ GeV, $m(\tilde{\tau},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	ATLAS-CONF-2016-093
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu),\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	13.3	🟦 $\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ 1.0 TeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)=0$, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	ATLAS-CONF-2016-096
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0Z\tilde{\chi}_1^0$	2-3 e,μ	0-2 jets	Yes	20.3	🟩 $\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ 425 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)=0$, $\tilde{\ell}$ decoupled	1403.5294, 1402.7029
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0h\tilde{\chi}_1^0$, $h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e,μ,γ	0-2 b	Yes	20.3	🟩 $\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ 270 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)=0$, $\tilde{\ell}$ decoupled	1501.07110
	$\tilde{\chi}_2^0\tilde{\chi}_3^0$, $\tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	🟩 $\tilde{\chi}_{2,3}^0$ 635 GeV	$m(\tilde{\chi}_2^0)=m(\tilde{\chi}_3^0)$, $m(\tilde{\chi}_1^0)=0$, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_2^0)+m(\tilde{\chi}_1^0))$	1405.5086
	GGM (wino NLSP) weak prod.	1 e,μ + γ	-	Yes	20.3	🟩 $\tilde{W}$ 115-370 GeV	$c\tau<1$ mm	1507.05493
	GGM (bino NLSP) weak prod.	2 γ	-	Yes	20.3	🟩 $\tilde{W}$ 590 GeV	$c\tau<1$ mm	1507.05493
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	20.3	🟩 $\tilde{\chi}_1^\pm$ 270 GeV	$m(\tilde{\chi}_1^\pm)-m(\tilde{\chi}_1^0)\sim160$ MeV, $\tau(\tilde{\chi}_1^\pm)=0.2$ ns	1310.3675
	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	dE/dx trk	-	Yes	18.4	🟩 $\tilde{\chi}_1^\pm$ 495 GeV	$m(\tilde{\chi}_1^\pm)-m(\tilde{\chi}_1^0)\sim160$ MeV, $\tau(\tilde{\chi}_1^\pm)<15$ ns	1506.05332
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	🟩 $\tilde{g}$ 850 GeV	$m(\tilde{\chi}_1^0)=100$ GeV, 10 $\mu s<\tau(\tilde{g})<1000$ s	1310.6584
	Stable $\tilde{g}$ R-hadron	trk	-	-	3.2	🟦 $\tilde{g}$ 1.58 TeV		1606.05129
	Metastable $\tilde{g}$ R-hadron	dE/dx trk	-	-	3.2	🟦 $\tilde{g}$ 1.57 TeV	$m(\tilde{\chi}_1^0)=100$ GeV, $\tau>10$ ns	1604.04520
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	🟩 $\tilde{\chi}_1^0$ 537 GeV	$10<\tan\beta<50$	1411.6795
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	🟩 $\tilde{\chi}_1^0$ 440 GeV	$1<\tau(\tilde{\chi}_1^0)<3$ ns, SPS8 model	1409.5542
	$\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\to ee\nu/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	🟩 $\tilde{\chi}_1^0$ 1.0 TeV	$7<c\tau(\tilde{\chi}_1^0)<740$ mm, $m(\tilde{g})=1.3$ TeV	1504.05162
	GGM $\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\to Z\tilde{G}$	displ. vtx + jets	-	-	20.3	🟩 $\tilde{\chi}_1^0$ 1.0 TeV	$6<c\tau(\tilde{\chi}_1^0)<480$ mm, $m(\tilde{g})=1.1$ TeV	1504.05162
RPV	LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu,e\tau,\mu\tau$	-	-	3.2	🟦 $\tilde{\nu}_\tau$ 1.9 TeV	$\lambda'_{311}=0.11$, $\lambda_{132/133/233}=0.07$	1607.08079
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	🟩 $\tilde{q},\tilde{g}$ 1.45 TeV	$m(\tilde{q})=m(\tilde{g})$, $c\tau_{LSP}<1$ mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to ee\nu,e\mu\nu,\mu\mu\nu$	4 e,μ	-	Yes	13.3	🟦 $\tilde{\chi}_1^\pm$ 1.14 TeV	$m(\tilde{\chi}_1^0)>400$GeV, $\lambda_{12k}\neq0$ ($k=1,2$)	ATLAS-CONF-2016-075
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to\tau\tau\nu_e,e\tau\nu_\tau$	3 e,μ + τ	-	Yes	20.3	🟩 $\tilde{\chi}_1^\pm$ 450 GeV	$m(\tilde{\chi}_1^0)>0.2\times m(\tilde{\chi}_1^\pm)$, $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqq$	0	4-5 large-R jets	-	14.8	🟦 $\tilde{g}$ 1.08 TeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$	0	4-5 large-R jets	-	14.8	🟦 $\tilde{g}$ 1.55 TeV	$m(\tilde{\chi}_1^0)=800$ GeV	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$	1 e,μ	8-10 jets/0-4 b	-	14.8	🟦 $\tilde{g}$ 1.75 TeV	$m(\tilde{\chi}_1^0)=700$ GeV	ATLAS-CONF-2016-094
	$\tilde{g}\tilde{g}$, $\tilde{g}\to\tilde{t}_1t$, $\tilde{t}_1\to bs$	1 e,μ	8-10 jets/0-4 b	-	14.8	🟦 $\tilde{g}$ 1.4 TeV	625 GeV$<m(\tilde{t}_1)<$850 GeV	ATLAS-CONF-2016-094
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to bs$	0	2 jets + 2 b	-	15.4	🟦 $\tilde{t}_1$ 410 GeV 🟦 450-510 GeV		ATLAS-CONF-2016-022, ATLAS-CONF-2016-084
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\ell$	2 e,μ	2 b	-	20.3	🟩 $\tilde{t}_1$ 0.4-1.0 TeV	BR($\tilde{t}_1\to be/\mu$)>20%	ATLAS-CONF-2015-015
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	🟩 $\tilde{c}$ 510 GeV	$m(\tilde{\chi}_1^0)<200$ GeV	1501.01325

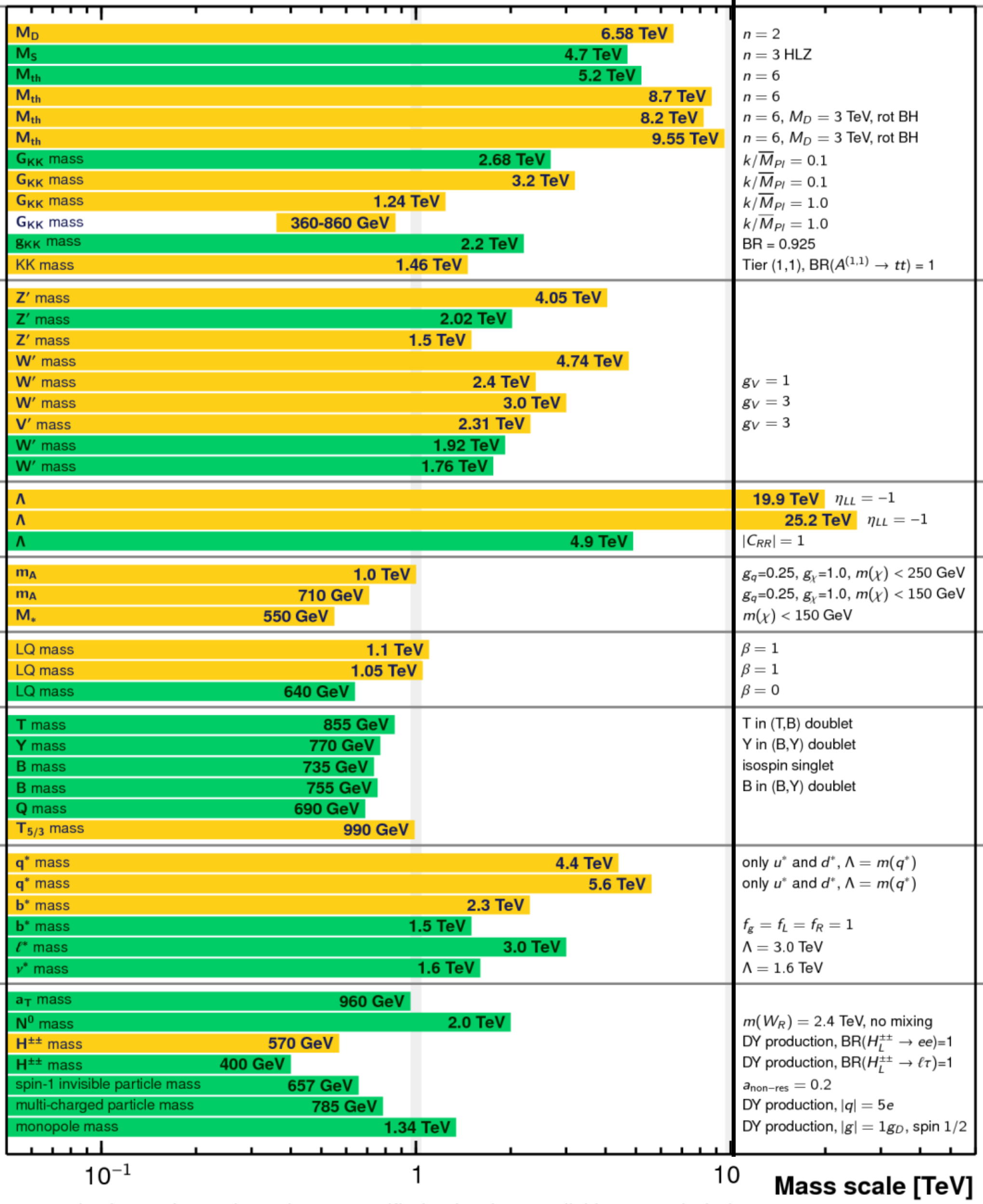
*Only a selection of the available mass limits on new states or phenomena is shown.

ATLAS Exotics Searches* - 95% CL Exclusion

Status: August 2016

ATLAS Preliminary

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



	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	–	≥ 1 j	Yes	3.2	🟨 M_D 6.58 TeV	$n = 2$	1604.07773
	ADD non-resonant $\ell\ell$	2 e, μ	–	–	20.3	🟩 M_S 4.7 TeV	$n = 3$ HLZ	1407.2410
	ADD QBH $\rightarrow \ell q$	1 e, μ	1 j	–	20.3	🟩 M_{th} 5.2 TeV	$n = 6$	1311.2006
	ADD QBH	–	2 j	–	15.7	🟨 M_{th} 8.7 TeV	$n = 6$	ATLAS-CONF-2016-069
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	3.2	🟨 M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	🟨 M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \rightarrow \ell\ell$	2 e, μ	–	–	20.3	🟩 G_{KK} mass 2.68 TeV	$k/\overline{M}_{Pl} = 0.1$	1405.4123
	RS1 $G_{KK} \rightarrow \gamma\gamma$	2 γ	–	–	3.2	🟨 G_{KK} mass 3.2 TeV	$k/\overline{M}_{Pl} = 0.1$	1606.03833
	Bulk RS $G_{KK} \rightarrow WW \rightarrow qq\ell\nu$	1 e, μ	1 J	Yes	13.2	🟨 G_{KK} mass 1.24 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2016-062
	Bulk RS $G_{KK} \rightarrow HH \rightarrow bbbb$	–	4 b	–	13.3	G_{KK} mass 🟨 360-860 GeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2016-049
	Bulk RS $g_{KK} \rightarrow tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	20.3	🟩 g_{KK} mass 2.2 TeV	BR = 0.925	1505.07018
	2UED / RPP	1 e, μ	≥ 2 b, ≥ 4 j	Yes	3.2	🟨 KK mass 1.46 TeV	Tier (1,1), BR($A^{(1,1)} \rightarrow tt$) = 1	ATLAS-CONF-2016-013
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	2 e, μ	–	–	13.3	🟨 Z' mass 4.05 TeV		ATLAS-CONF-2016-045
	SSM $Z' \rightarrow \tau\tau$	2 τ	–	–	19.5	🟩 Z' mass 2.02 TeV		1502.07177
	Leptophobic $Z' \rightarrow bb$	–	2 b	–	3.2	🟨 Z' mass 1.5 TeV		1603.08791
	SSM $W' \rightarrow \ell\nu$	1 e, μ	–	Yes	13.3	🟨 W' mass 4.74 TeV		ATLAS-CONF-2016-061
	HVT $W' \rightarrow WZ \rightarrow qq\nu\nu$ model A	0 e, μ	1 J	Yes	13.2	🟨 W' mass 2.4 TeV	$g_V = 1$	ATLAS-CONF-2016-082
	HVT $W' \rightarrow WZ \rightarrow qqqq$ model B	–	2 J	–	15.5	🟨 W' mass 3.0 TeV	$g_V = 3$	ATLAS-CONF-2016-055
	HVT $V' \rightarrow WH/ZH$ model B	multi-channel			3.2	🟨 V' mass 2.31 TeV	$g_V = 3$	1607.05621
	LRSM $W'_R \rightarrow tb$	1 e, μ	2 b, 0-1 j	Yes	20.3	🟩 W' mass 1.92 TeV		1410.4103
	LRSM $W'_R \rightarrow tb$	0 e, μ	≥ 1 b, 1 J	–	20.3	🟩 W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	15.7	🟨 Λ 19.9 TeV	$\eta_{LL} = -1$	ATLAS-CONF-2016-069
	CI $\ell\ell qq$	2 e, μ	–	–	3.2	🟨 Λ 25.2 TeV	$\eta_{LL} = -1$	1607.03669
	CI $uutt$	2(SS)/≥3 e,μ	≥1 b, ≥1 j	Yes	20.3	🟩 Λ 4.9 TeV	$\lvert C_{RR} \rvert = 1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	0 e, μ	≥ 1 j	Yes	3.2	🟨 m_A 1.0 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 250$ GeV	1604.07773
	Axial-vector mediator (Dirac DM)	0 e, μ, 1 γ	1 j	Yes	3.2	🟨 m_A 710 GeV	g_q=0.25, g_χ=1.0, $m(\chi) < 150$ GeV	1604.01306
	$ZZ\chi\chi$ EFT (Dirac DM)	0 e, μ	1 J, ≤ 1 j	Yes	3.2	🟨 M_* 550 GeV	$m(\chi) < 150$ GeV	ATLAS-CONF-2015-080
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	3.2	🟨 LQ mass 1.1 TeV	$\beta = 1$	1605.06035
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	3.2	🟨 LQ mass 1.05 TeV	$\beta = 1$	1605.06035
	Scalar LQ 3rd gen	1 e, μ	≥1 b, ≥3 j	Yes	20.3	🟩 LQ mass 640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \rightarrow Ht + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	🟩 T mass 855 GeV	T in (T,B) doublet	1505.04306
	VLQ $YY \rightarrow Wb + X$	1 e, μ	≥ 1 b, ≥ 3 j	Yes	20.3	🟩 Y mass 770 GeV	Y in (B,Y) doublet	1505.04306
	VLQ $BB \rightarrow Hb + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	🟩 B mass 735 GeV	isospin singlet	1505.04306
	VLQ $BB \rightarrow Zb + X$	2/≥3 e, μ	≥2/≥1 b	–	20.3	🟩 B mass 755 GeV	B in (B,Y) doublet	1409.5500
	VLQ $QQ \rightarrow WqWq$	1 e, μ	≥ 4 j	Yes	20.3	🟩 Q mass 690 GeV		1509.04261
	VLQ $T_{5/3} T_{5/3} \rightarrow WtWt$	2(SS)/≥3 e,μ	≥1 b, ≥1 j	Yes	3.2	🟨 $T_{5/3}$ mass 990 GeV		ATLAS-CONF-2016-032
Excited fermions	Excited quark $q^* \rightarrow q\gamma$	1 γ	1 j	–	3.2	🟨 q^* mass 4.4 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1512.05910
	Excited quark $q^* \rightarrow qg$	–	2 j	–	15.7	🟨 q^* mass 5.6 TeV	only u^* and d^*, $\Lambda = m(q^*)$	ATLAS-CONF-2016-069
	Excited quark $b^* \rightarrow bg$	–	1 b, 1 j	–	8.8	🟨 b^* mass 2.3 TeV		ATLAS-CONF-2016-060
	Excited quark $b^* \rightarrow Wt$	1 or 2 e, μ	1 b, 2-0 j	Yes	20.3	🟩 b^* mass 1.5 TeV	$f_g = f_L = f_R = 1$	1510.02664
	Excited lepton ℓ^*	3 e, μ	–	–	20.3	🟩 ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	–	–	20.3	🟩 ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	LSTC $a_T \rightarrow W\gamma$	1 e, μ, 1 γ	–	Yes	20.3	🟩 a_T mass 960 GeV		1407.8150
	LRSM Majorana ν	2 e, μ	2 j	–	20.3	🟩 N^0 mass 2.0 TeV	$m(W_R) = 2.4$ TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm} \rightarrow ee$	2 e (SS)	–	–	13.9	🟨 $H^{\pm\pm}$ mass 570 GeV	DY production, BR($H_L^{\pm\pm} \rightarrow ee$)=1	ATLAS-CONF-2016-051
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$	3 e, μ, τ	–	–	20.3	🟩 $H^{\pm\pm}$ mass 400 GeV	DY production, BR($H_L^{\pm\pm} \rightarrow \ell\tau$)=1	1411.2921
	Monotop (non-res prod)	1 e, μ	1 b	Yes	20.3	🟩 spin-1 invisible particle mass 657 GeV	$a_{\mathrm{non-res}} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	🟩 multi-charged particle mass 785 GeV	DY production, $\lvert q \rvert = 5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	🟩 monopole mass 1.34 TeV	DY production, $\lvert g \rvert = 1 g_D$, spin 1/2	1509.08059

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

**Only a selection of the available mass limits on new states or phenomena is shown. Lower bounds are specified only when explicitly not excluded.*

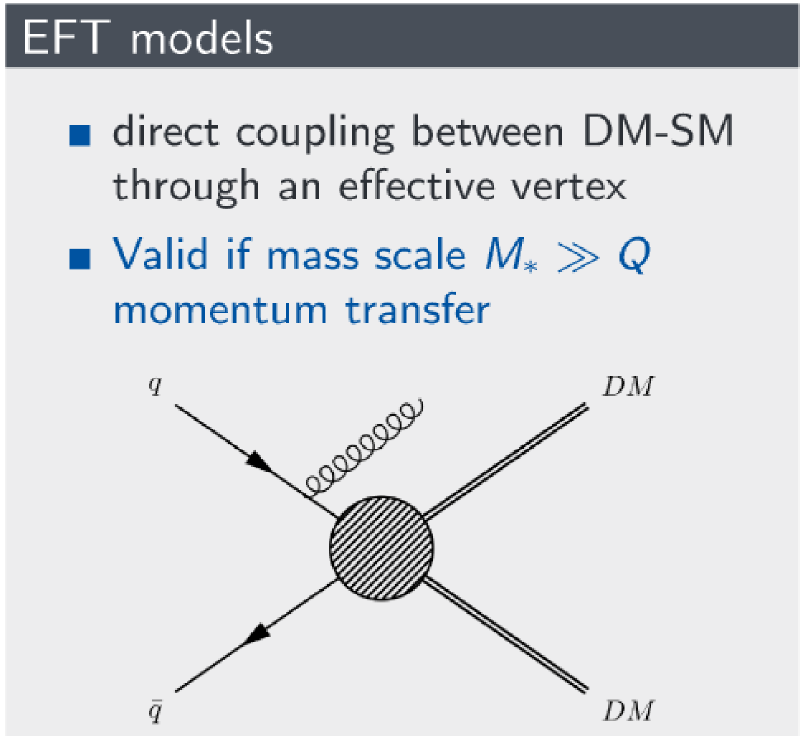
†Small-radius (large-radius) jets are denoted by the letter j (J).

The main idea

Two main production mechanisms, affecting the experimental strategies:

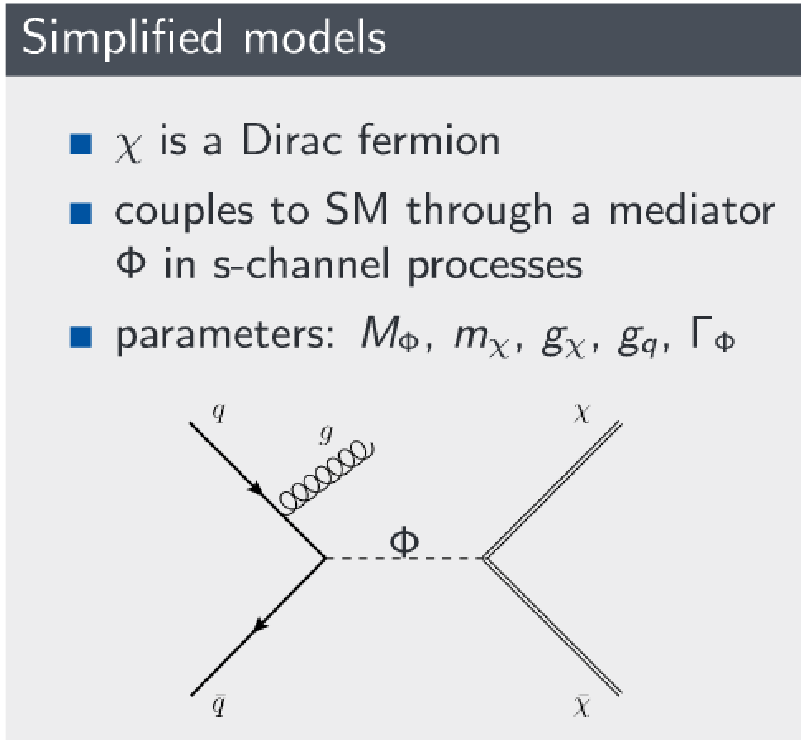
1) Effective interactions with quarks and gluons if no new resonances accessible

2) Decays of other resonances - new mediators - when the latter can be produced on-shell



EFT models

- direct coupling between DM-SM through an effective vertex
- Valid if mass scale $M_* \gg Q$ momentum transfer

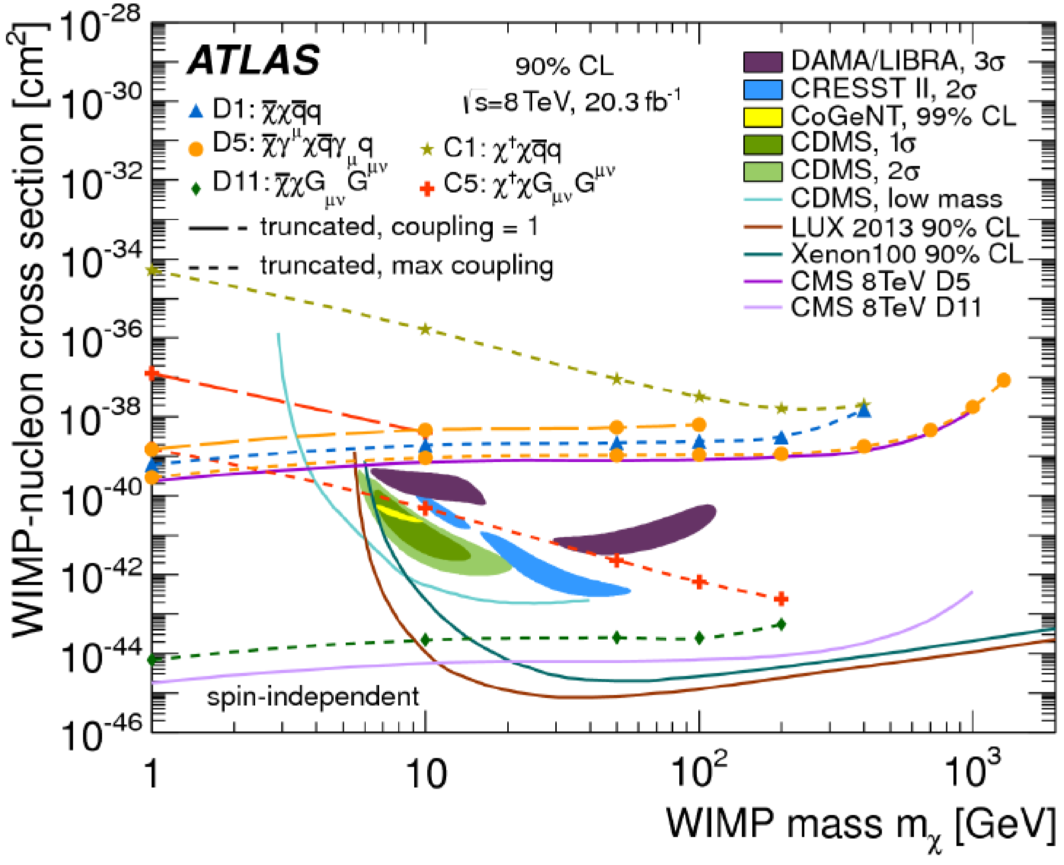


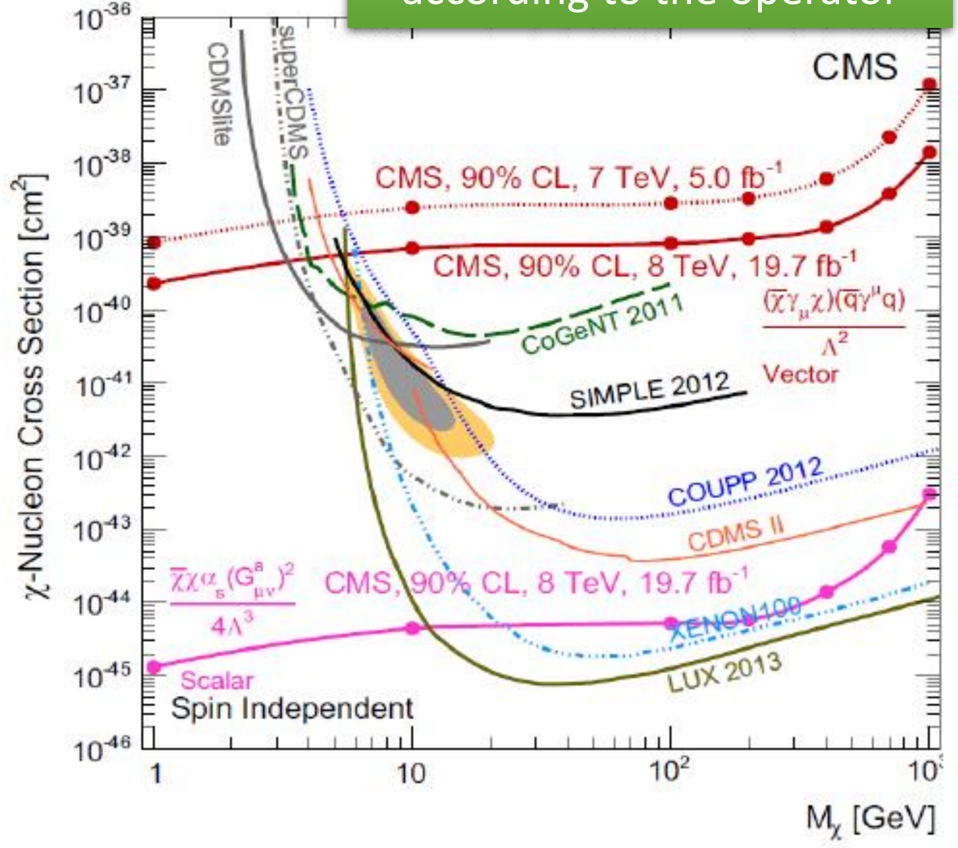
Simplified models

- χ is a Dirac fermion
- couples to SM through a mediator Φ in s-channel processes
- parameters: M_Φ, m_χ, g_χ, g_q, Γ_Φ

Effective Field Model

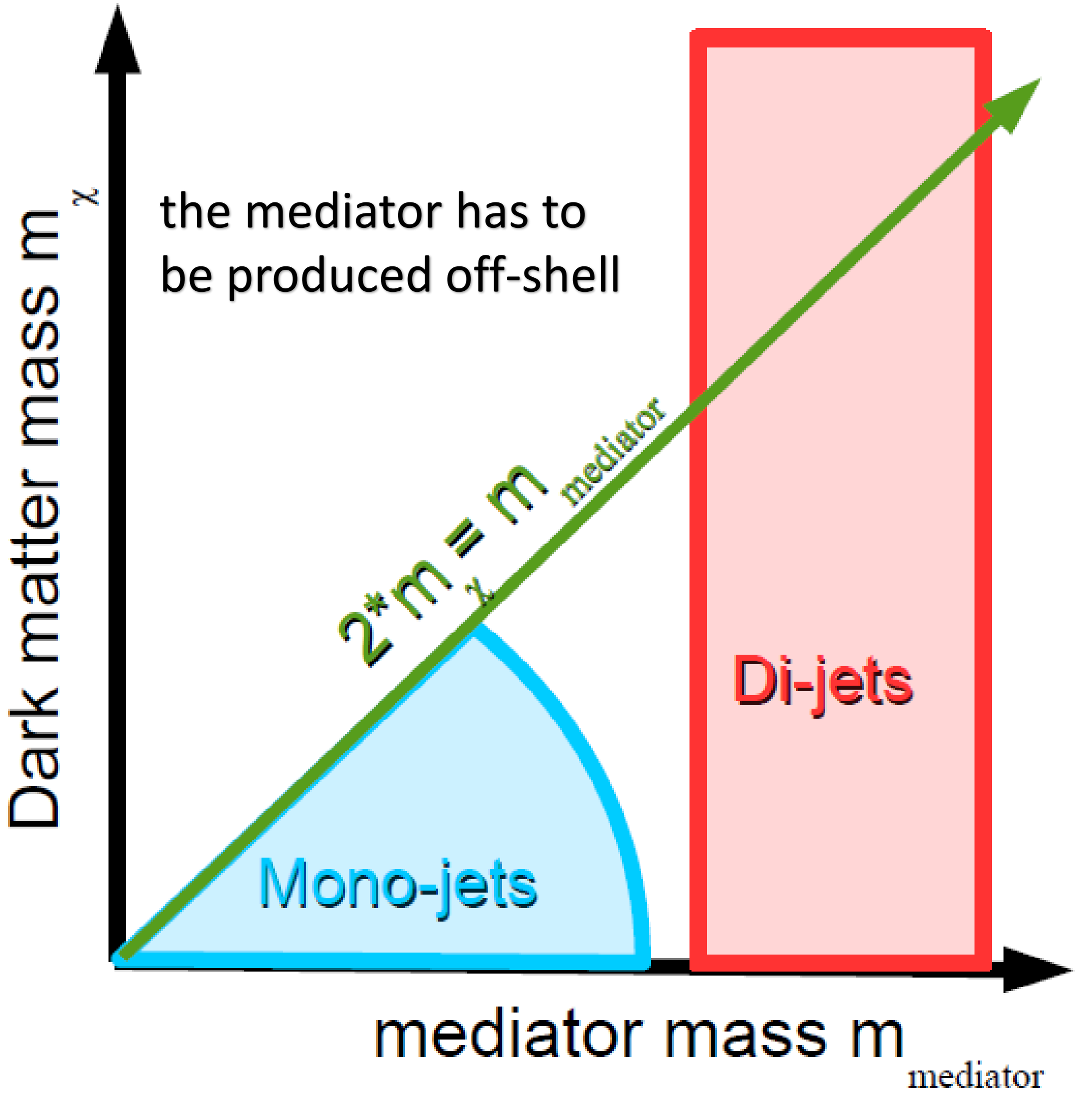
The contraint grandly varies according to the operator



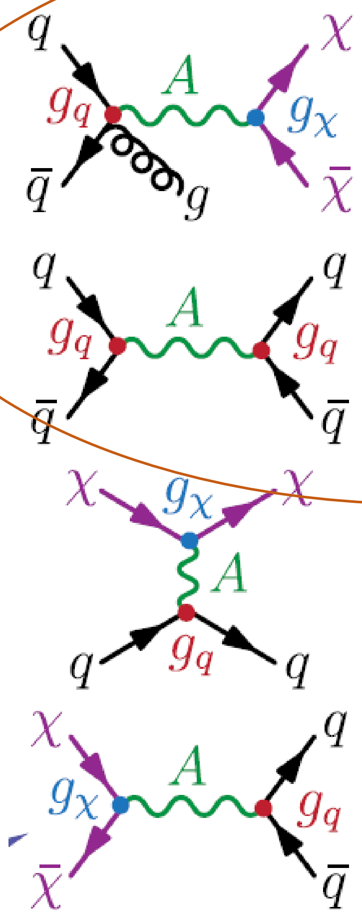


The exclusion capability is competitive with direct search experiment in the DM mass region below 10 GeV

Simplifies model approach



the mediator has to be produced off-shell

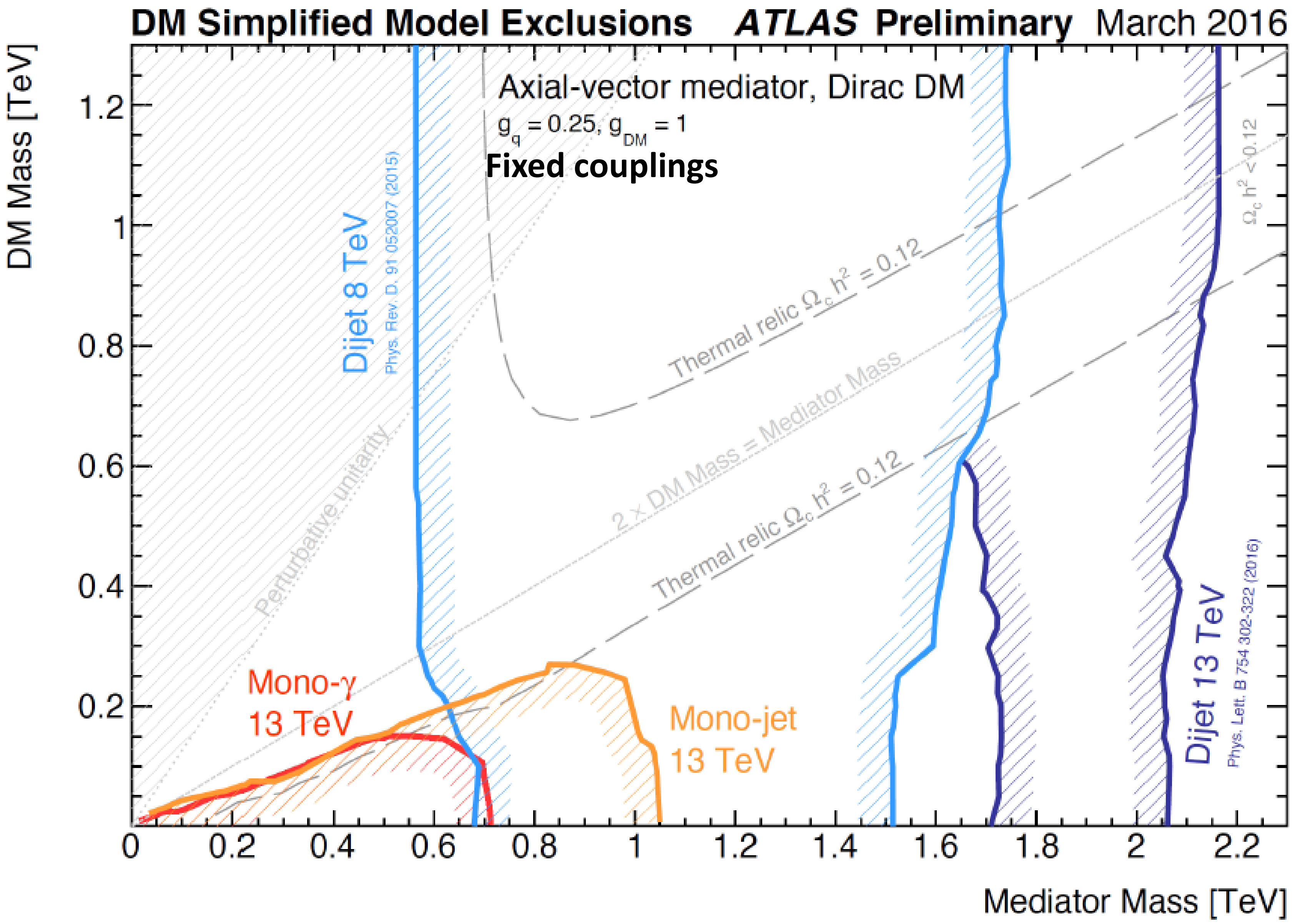


Monojet Final State
DM production at the LHC with initial-state radiation of a gluon

Dijet Resonance
Mediator decay to quarks at the LHC

Direct Detection
Interactions between DM and nuclei

Indirect Detection
DM annihilation

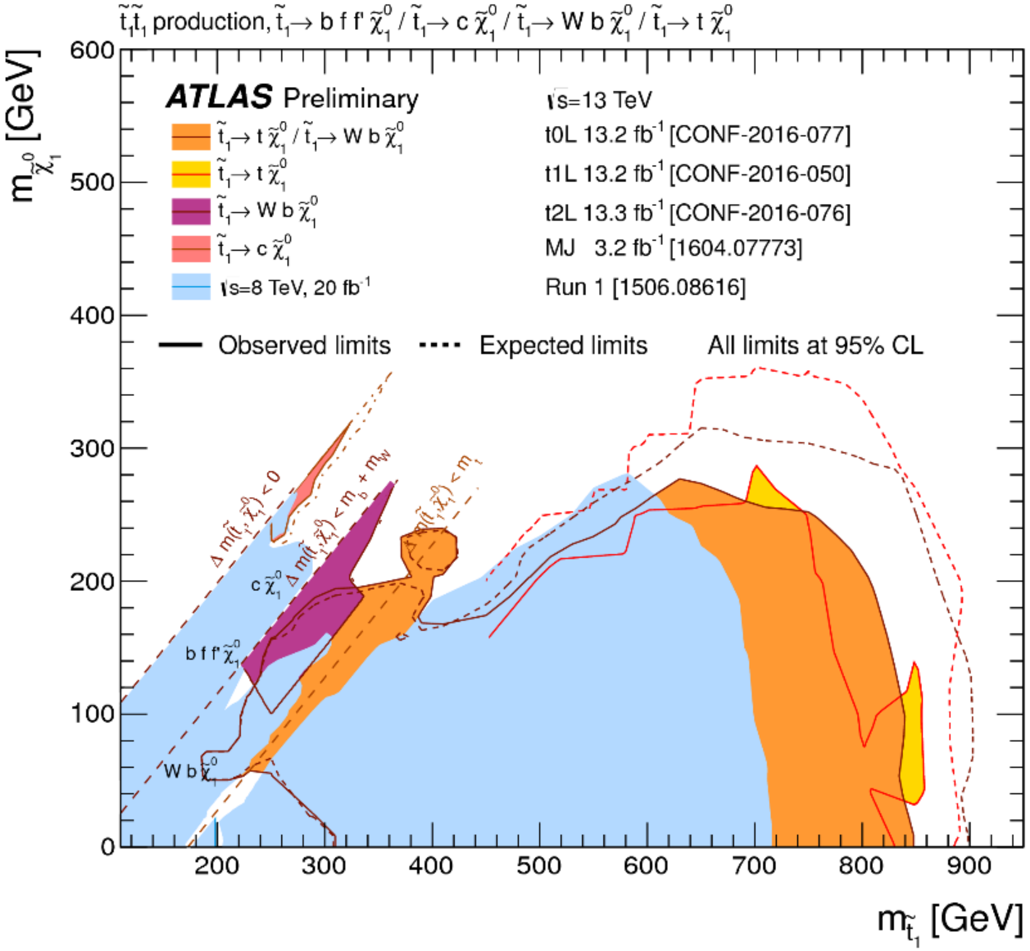


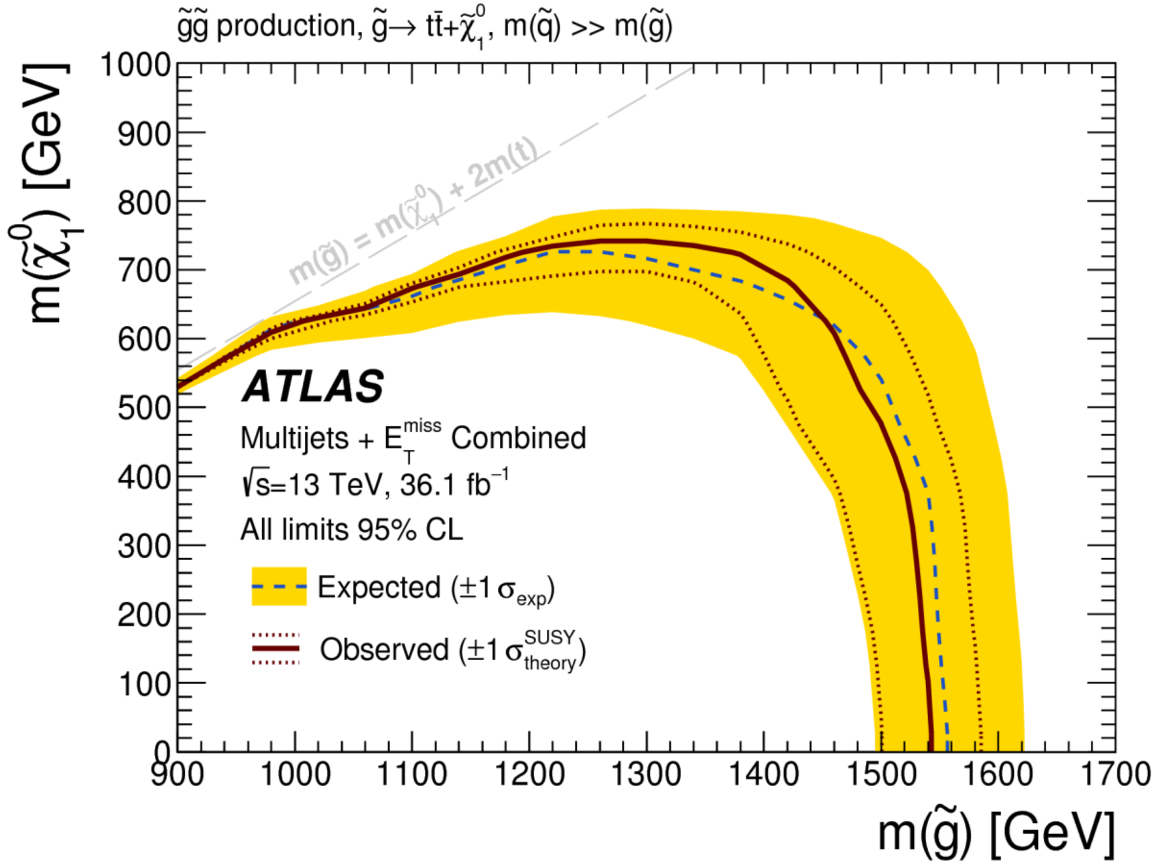
ATLAS dijet results exclude the existence of mediating particles with masses from about **600 GeV to 2 TeV**.

The mono-jet and mono-photon channels **exclude the parameter space at lower mediator and dark-matter masses**, below the off-shell region

Only **TeV-ish** DM candidates and mediators are free to sweep the parameters space and in agreement with thermal relic density

SUSY

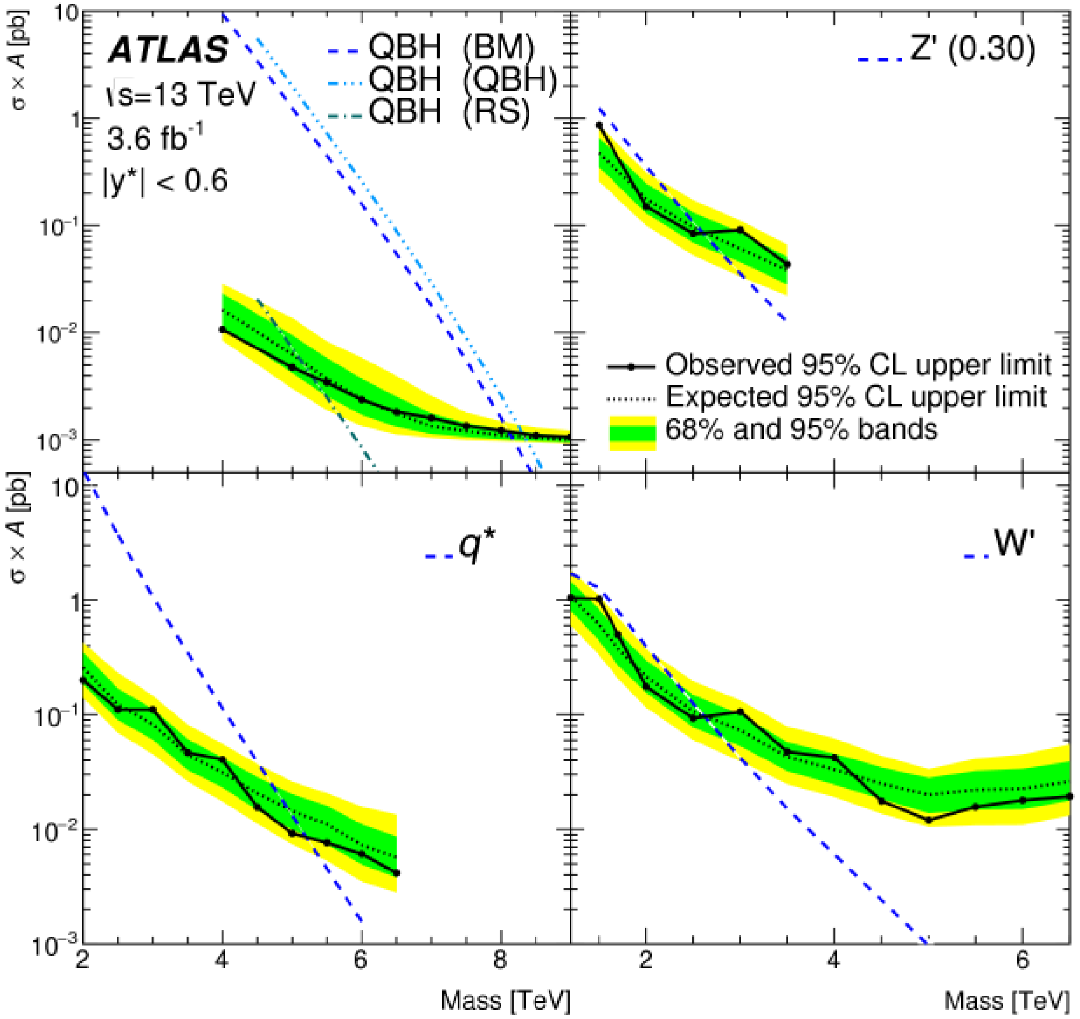




We are learning that:

- Minimal SUSY parameter space is narrowing
- The masses scale for DM, NLSP and exotic mediators is increasing up to the TeV scale

Limits on Dijet resonances



- Limits on benchmark models
  - Excited quarks q* (5.2 TeV)
  - Extra Gauge Bosons
    - Z' -Boson
    - W'-Boson (2.6 TeV)
- Quantum Black Holes (QBH)
  - Randall-Sundrum
    - QBH generator (5.3 TeV)
  - Arkani-Hamed-Dimopoulous-Dvali
    - QBH generator (8.3 TeV)
    - BlackMax generator (8.1 TeV)

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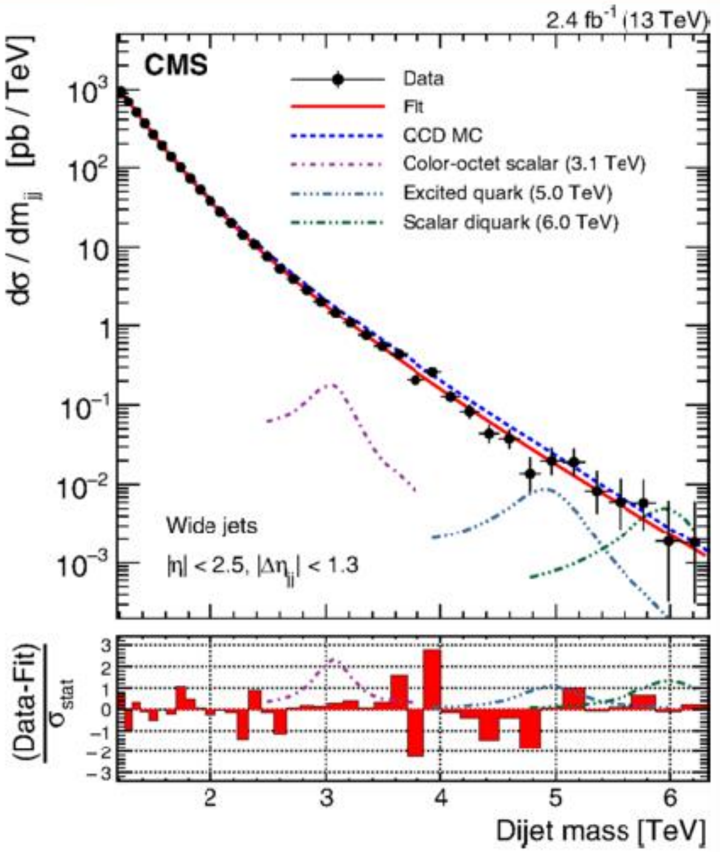
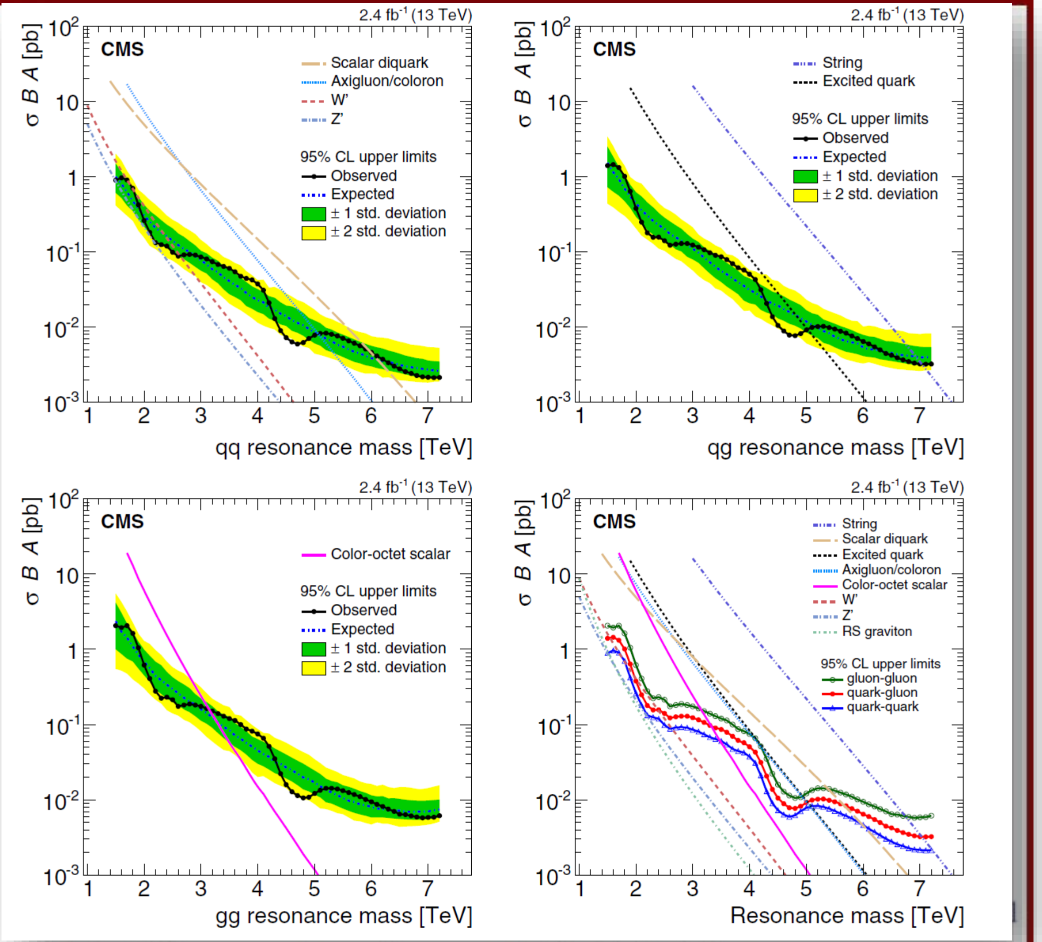
Limits on Dijet resonances





- Excluded masses: String resonance (7.0 TeV) , scalar di-quark (6.0 TeV), axigluon (5.1 TeV), excited quark q* (5.0 TeV), Heavy W' (2.6 TeV)

A new era for astroparticle physics

- AMS-02 data allow a deeper understanding of the «High Energy Universe» and do put the models to the test, highlightning theoretical inaccuracies and driving the models to a precision astroparticle physics;
- Fitting AMS-02 data with the latest **GALPROP** framework together with the **HelMod** Model of Heliosphere, a precise and almost univocal propagation scheme was achieved, granting a unitary description of CR physics at the % level;
- This model is fully consistent and capable of reproducing all CRs observations (except for positrons, but the work is still in progress);
- Once fixed the CR propagation parameters, the secondary background for **DM searches** (and anomalies in general) is removed;
- The indirect dark matter search is moving through a **TeV-ish DM paradigm**, which is substained by recent astrophysical and colliders observations.