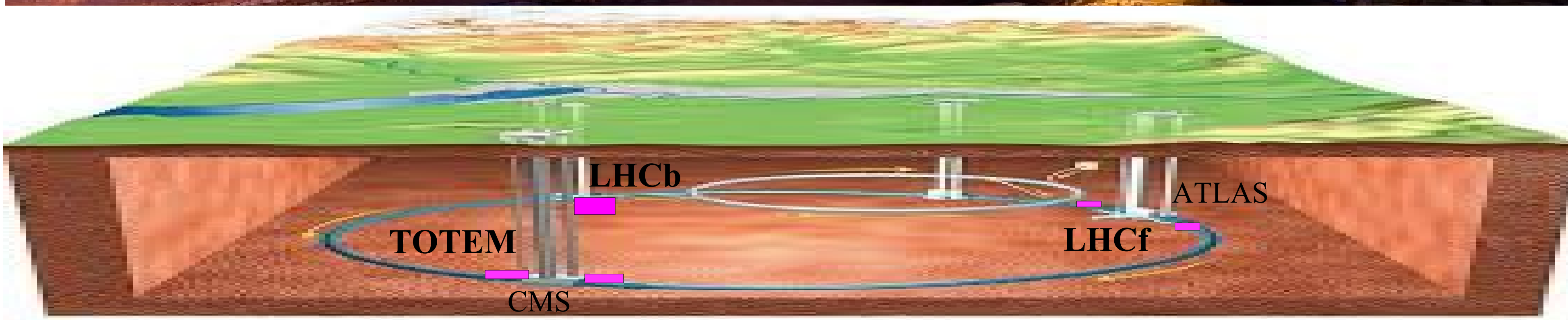
LHCb/LHCf/TOTEM inputs for astrophysics



Valery Zhukov
on behalf of the LHCb collaboration

LHC & Astrophysics

Physics:

LHC:

BSM (DM)
LFV,CPV...
SM (QCD)

Astro(CosmicRays):

DMA (BSM)
CR spectra, composition, gamma, neutrino
Sources,...

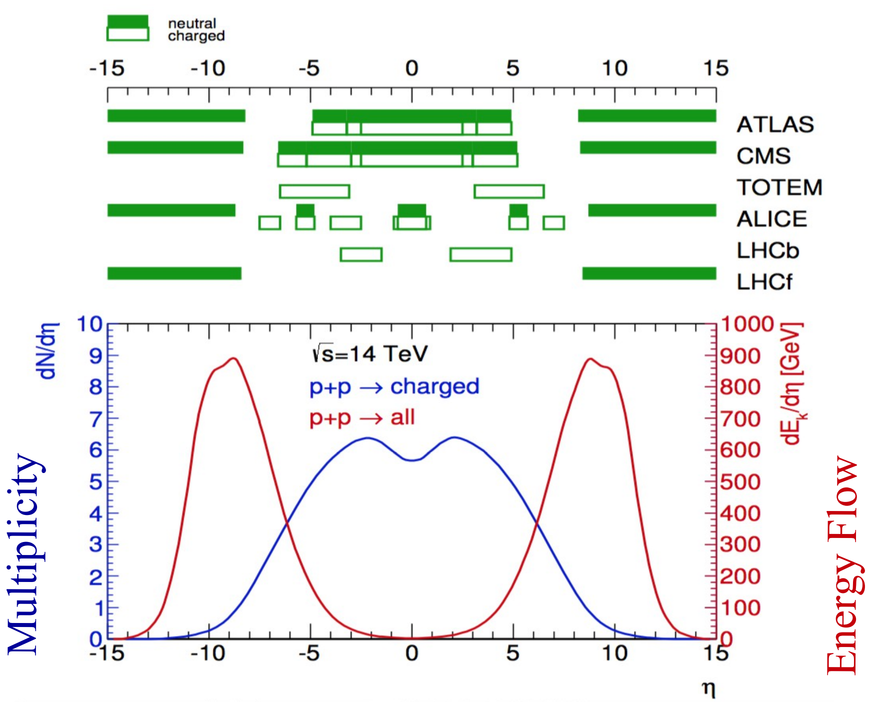
Experiments:

ATLAS, CMS, LHCb, ALICE
LHCf, TOTEM, SMOG
ZDC+ALFA, Castor

→ models →
← models ←

Space: **AMS02, FERMI, PAMELA, DAMPE, CALET,...**
EASground: **Auger, TA, HAWC, HiRes, Yakutsk,..**
CherenkovArrays(CA): **Hess, Magic, Veritas, ...**
Neutrino: **IceCube, Antares, ...**

Others: SPS(NA49,58,61..), RHIC, HERA, Tevatron,...



<u>CR interactions = forward physics</u>

- soft : low Q^2, non pQCD contributions
- diffractions: large x_F i.e. low-x(saturation) and large-x(gPDF)
- scalings violations: Bjorken, Feynman, KNO
- nuclear collective effects

↓

1. Data parameterization.
with some assumptions on factorization and scalings

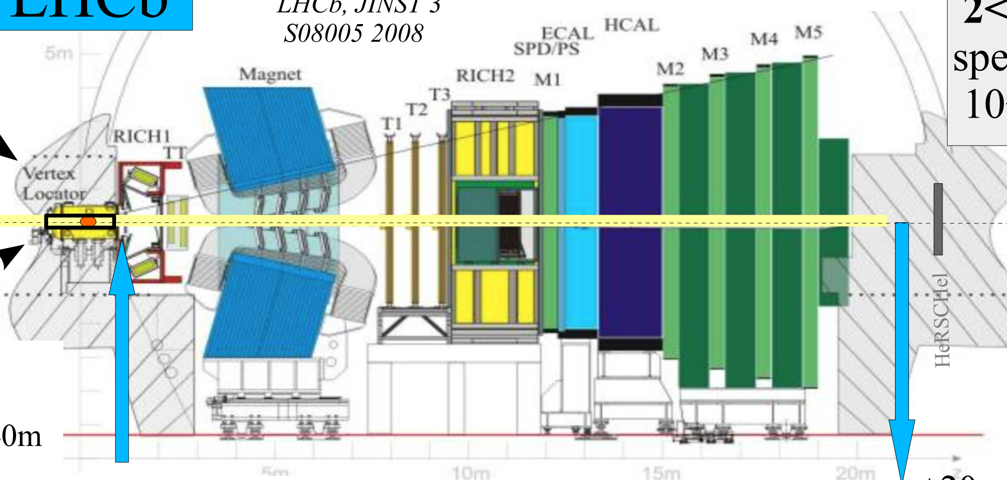
2. Reggeon Field Theory(RFT)+pQDC
EPOS, QGSJET, SYBILL, DPMJET,...
more solid theory motivations and predictions
Check parameterizations with RFT models that are verified with the LHC data

Experiments: LHCb

LHCb

IP8
pp collisions
region z ~50mm

LHCb, JINST 3 S08005 2008



$2 < \eta < 5$ (+HeRSChel η[5,10] , [-10,-3.5])
spectrometer+rich(p,π,K)+calo+muon
$10 < p < 120$ GeV/c $p_T > 0.4$ GeV/c

Beam1 **Beam2** z

fixed-target
fiducial~800mm
whole gas region~40m

not all bunches are colliding
$\mathcal{L}$: ~ 0.5 mb $^{-1}$s^{-1} per non coll. bunch

-20m
gas out

gas in the beam pipe ~2×10^{-7} (from 10^{-9}) mbar of He,Ne,Ar,..

+20m
gas pumped out

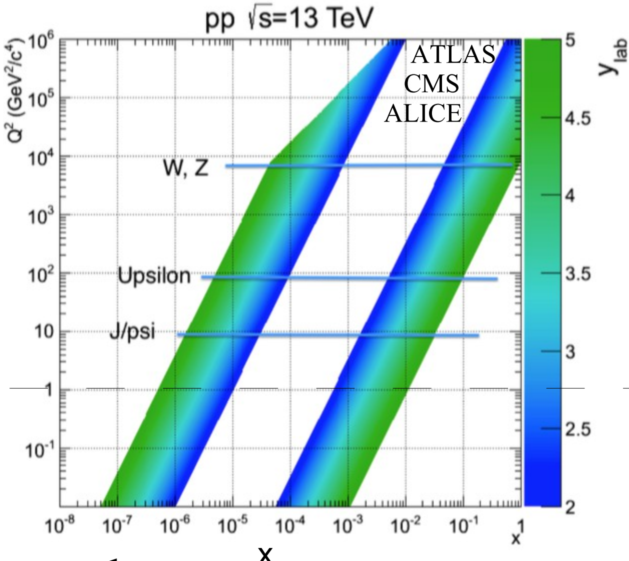
Systemfor
Measuringthe
Overlapwith
Gas

Two modes of operation:

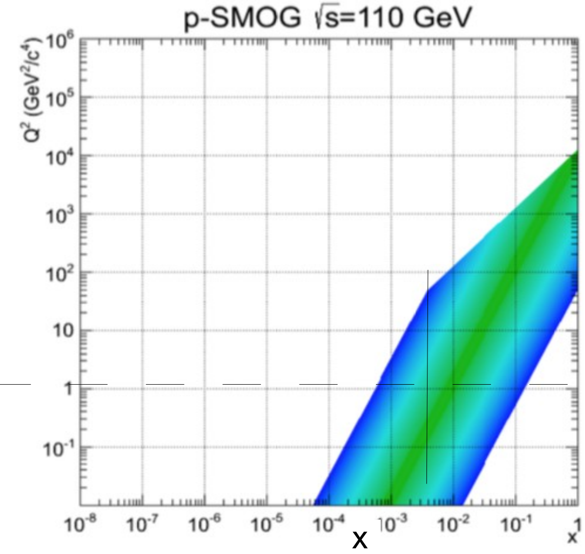
I. Collisions: pp(√s=0.9,7,13TeV), pPb(5TeV)

II. FixedTarget (LHCbSMOG) p(2.5,4,6.5TeV) or Pb(2.5TeV) beams: pHe(√s=87, 110GeV), pNe(69,110), pAr(110), PbAr(69)

Collisions:

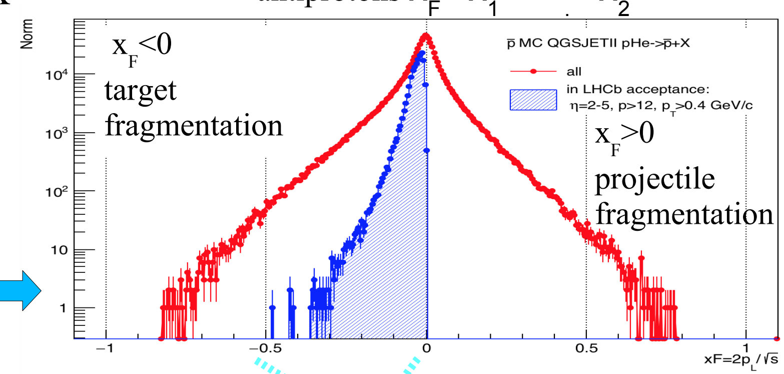


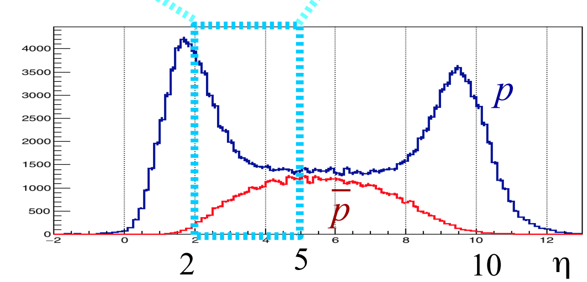
FixedTarget:



pHe → $\bar{p}$X

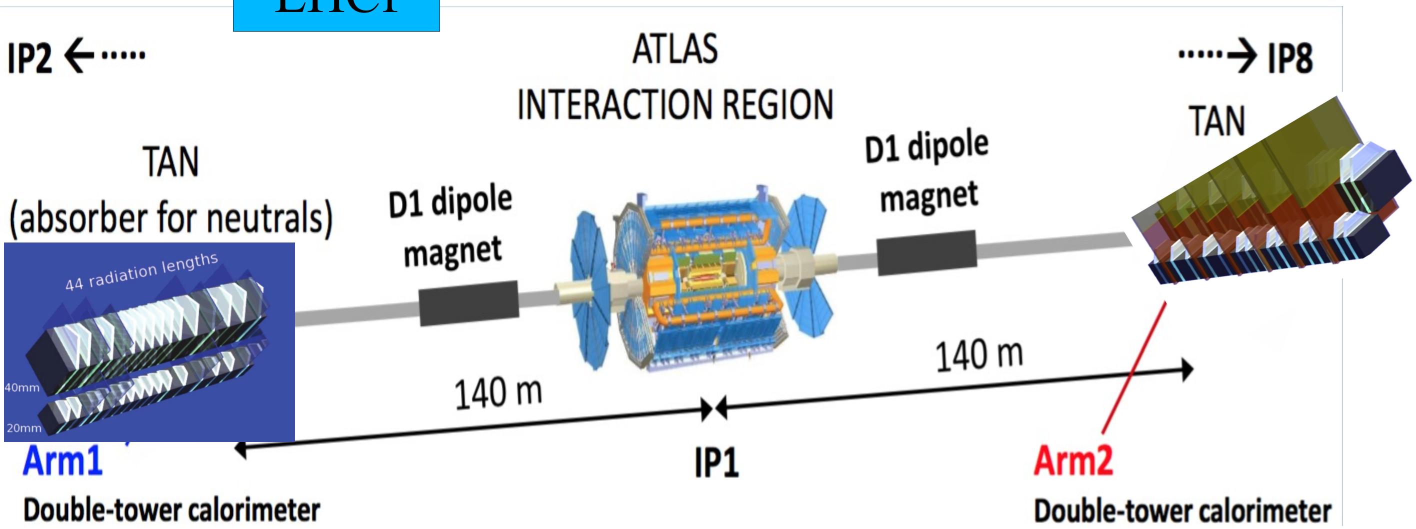
antiprotons $x_F = x_1^{project} - x_2^{target}$





Experiments: LHCf/TOTEM

LHCf 2 arms



tungsten+GSO $44X_o$, 1.6 λ
4 tracking layers (200μm)

tungsten+GSO $44X_o$, 1.6 λ
4 Si tracking layers (20μm)

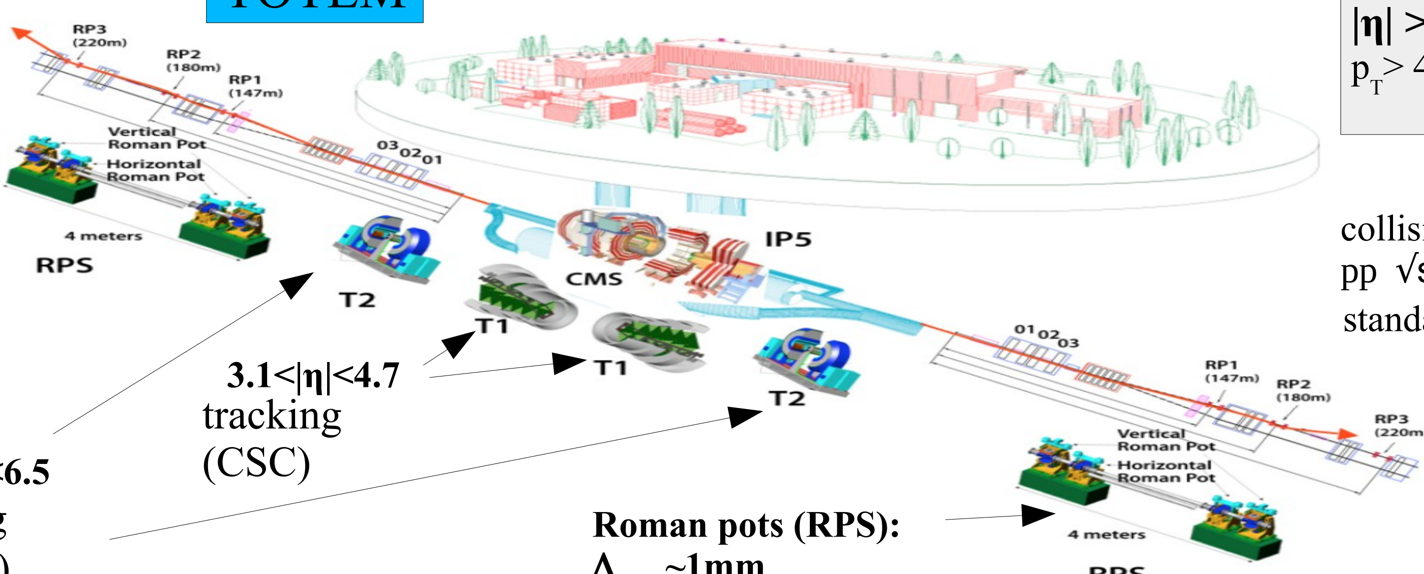
|η| > 8.4 neutral calorimetry and tracking:

γ :	p_γ > 100 GeV/c
π0 (2γ):	$p_{\pi 0}$ > 200 GeV/c
n :	p_n > 500 GeV/c

collisions:
pp √s= 0.9, 2.8,7,13 TeV
pPb √s= 5, 8 TeV
standalone and with ATLAS

CERN-LHCC-2006-004

TOTEM 2 arms



3.1<|η|<4.7
tracking
(CSC)

5.3<|η|<6.5
tracking
(GEM)

Roman pots (RPS):
Δ_{beam}~1mm
(Silicon)

|η| > 3.1 tracking:
p_T> 40 MeV/c (T2)

collisions:
pp √s=2.8, 7, 8,13 TeV
standalone and with CMS

CERN-LHCC-2014-021

Indirect Dark Matter searches

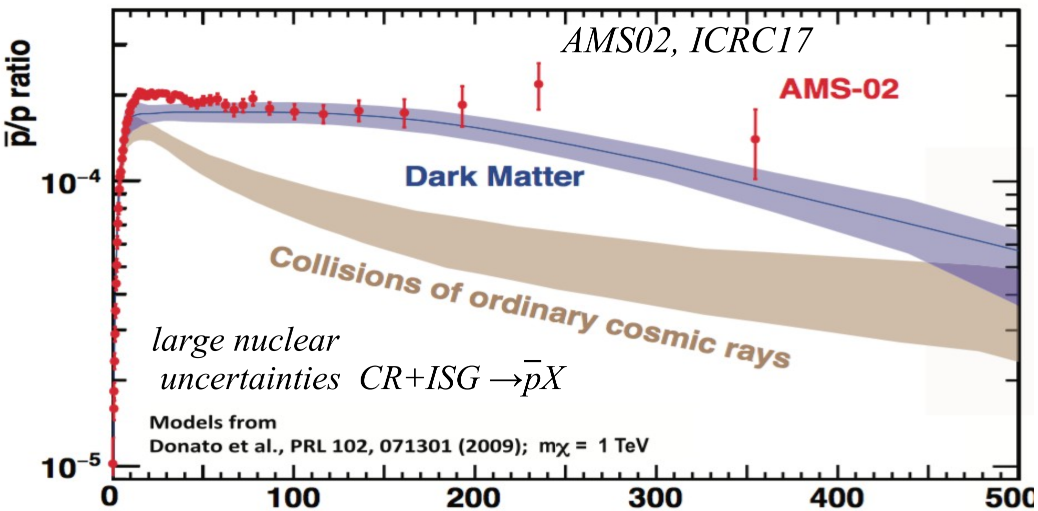
DM Annihilations:

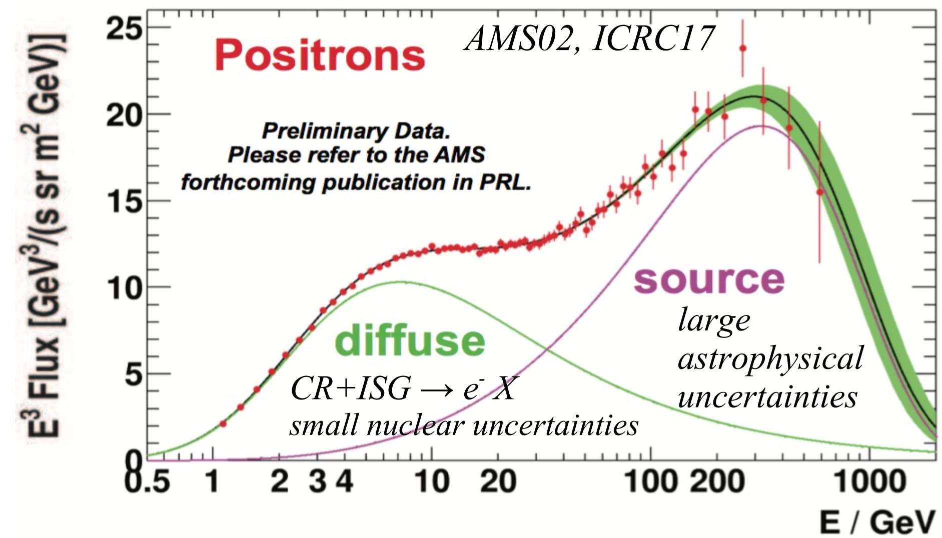
$\chi\chi \rightarrow b\bar{b}, t\bar{t}, e^+e^-, \mu^+\mu^-, \tau^+\tau^-, \nu\bar{\nu}, \gamma\gamma, W^+W^-, ZZ, Z\gamma$ ...

Fluxes of secondary CR from AMS02:

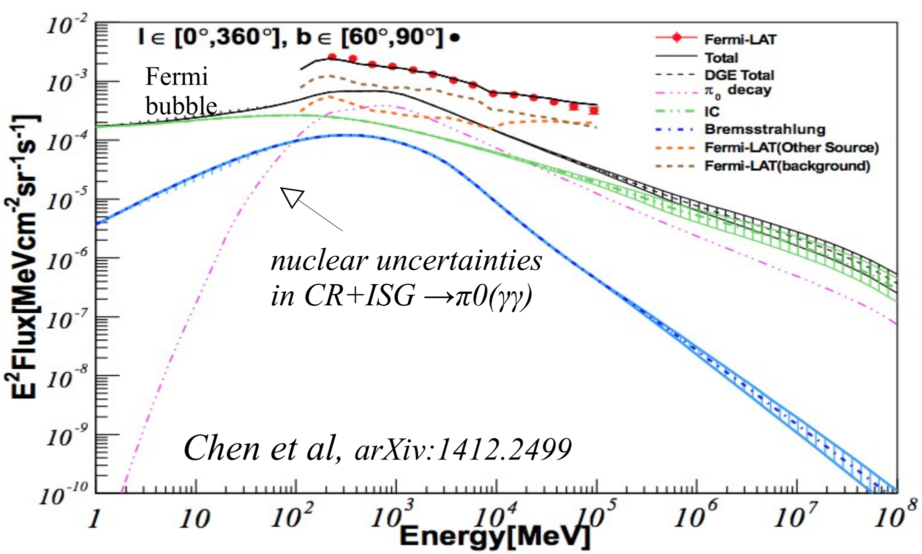
DMA excess in secondary CR: $\bar{p}$, e^- and γ, ν

- monopeaks for $\nu\bar{\nu}, \gamma\gamma, Z\gamma$
- also antideuterons $\bar{d}$ from DMA, via coalescence $\bar{p}+\bar{n}$





Diffusive Gamma FermiLAT:



Uncertainties in secondary CR fluxes, γ,ν:

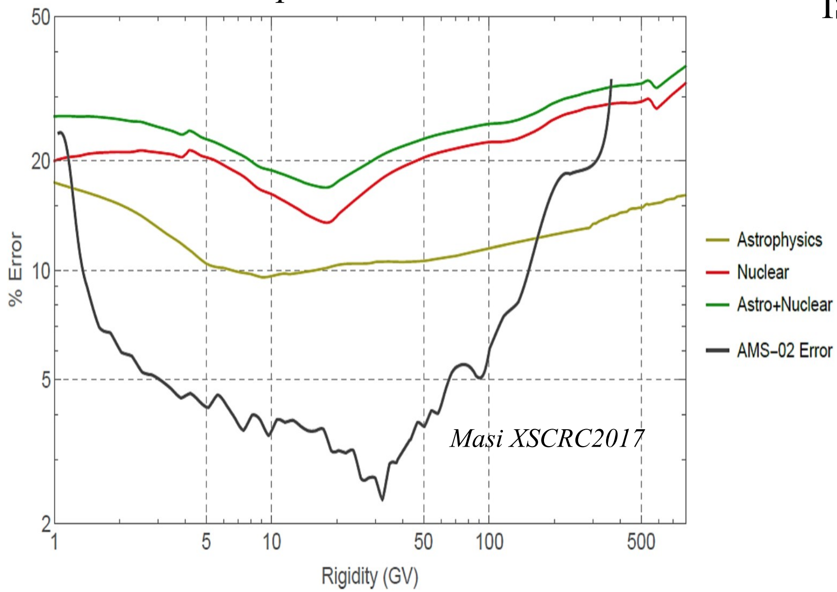
- **nuclear interactions**

- CR source spectra
- Propagation
- InterStellarMedia: InterStellarGas(ISG)+ InterStellarRadiationField(ISRF)

Astrophysical uncertainties can be constrained by using other CR fluxes and astro data (+nuclear uncertainties for propagation and Elosses)

Antiprotons in CR:
nuclear uncertainties

Model uncertainties and AMS02 errors in antiproton measurements



Interaction of CR(p,He,C,...) with ISG(H1,HII,H2+ 10% He):

$$CR+ISG \rightarrow \bar{p}+X$$

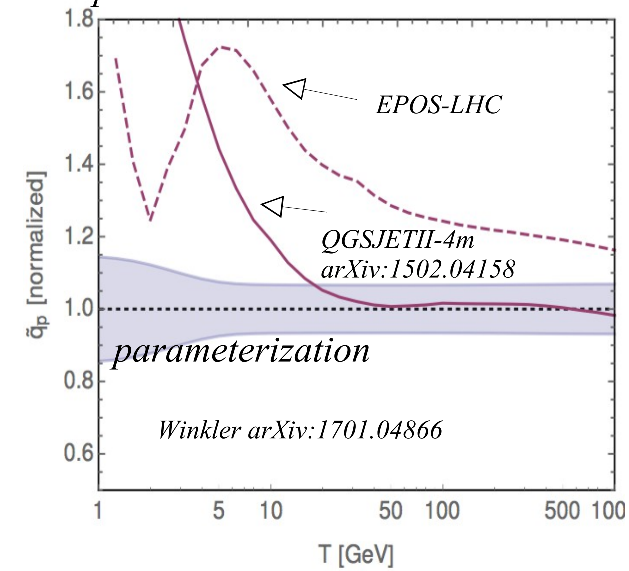
Many parameterizations of $\sigma_{pp(\bar{p}X)}$:

Tan and Ng 1983 (Galprop)
Duperray et al., 2003
Di Mario et al, 2014
Tomassetti, Oliva 2017
Winkler 2017

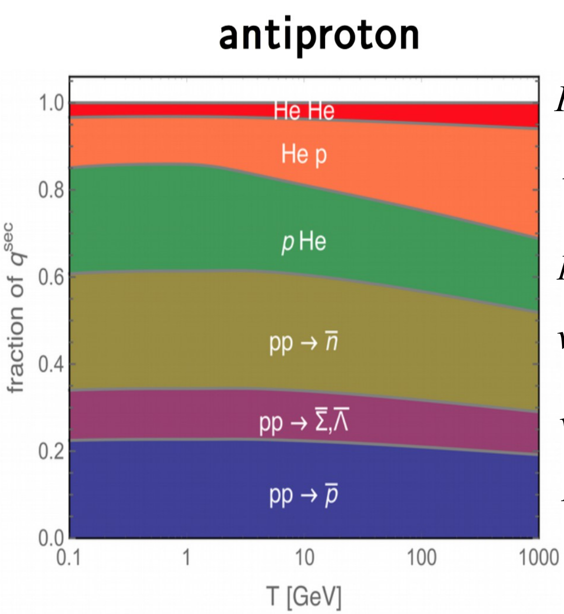
or MC RFT, eg. QGSJET, EPOS:
Kacherliess et al, 2015

using mostly ISR data at $\sqrt{s}\sim17$ GeV

Cross section $\sigma_{\bar{p}}$ with parametrization and RFT models



resonance production <10GeV not well simulated in RFT models



He+ISG(He)
He+ISG(H)
p+ISG(He)
via $\bar{n}(\bar{p}ev)$
via hyperons $\bar{\Lambda}(\bar{p}\pi),\bar{\Sigma}(\bar{p}\pi_0)$
prompt p+H

Assumptions in parameterizations:

- scaling violations (σ_{inel}, $n_{\bar{p}}$, p_T)
- $\bar{p}$ from hyperons $\bar{\Lambda}$,$\bar{\Sigma}$ (hyperon/prompt ~0.3)
- $\bar{n}$ production, isospin invariance ($\bar{n}/\bar{p}$ ~1) ….

correlations in parameterization can be missed...

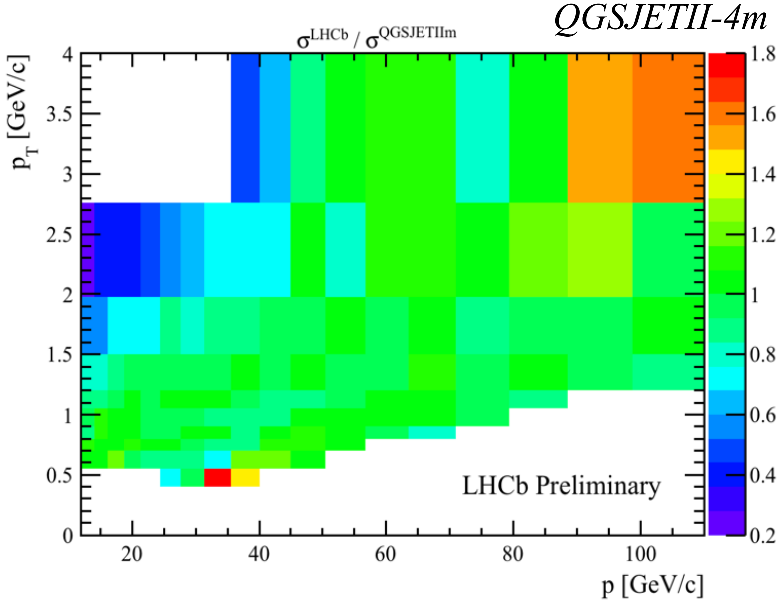
Need validation of parametrization and RFT models with data at high energies

Prompt antiprotons LHCbSMOG
in pHe→$\bar{p}$+X at √s=110.4 GeV

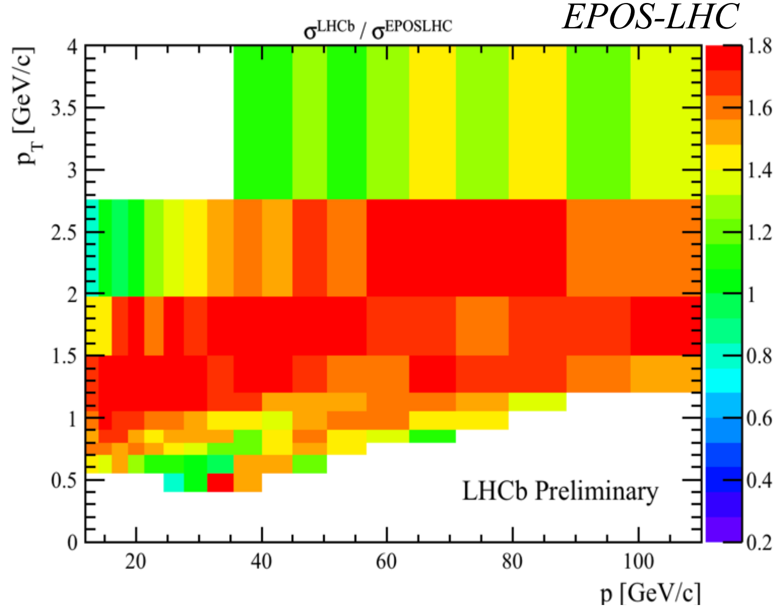
Ratio of LHCb data to different model predictions for prompt $\bar{p}$ in p_T-p plane

LHCb-CONF-2017-002

QGSJETII-4m



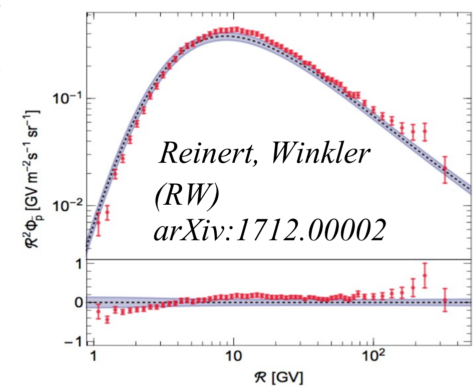
EPOS-LHC



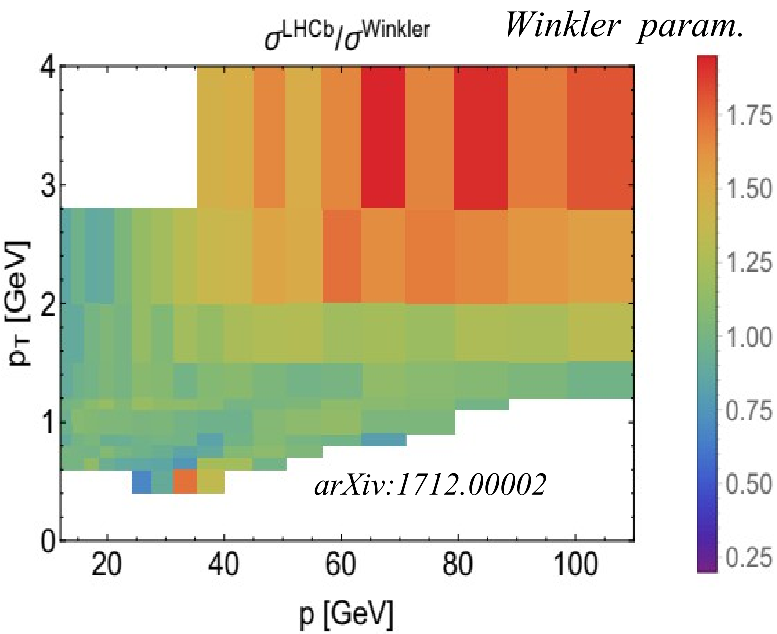
Underestimation of prompt $\bar{p}$ production in EPOS-LHC, but overall higher CR $\bar{p}$ flux due to isospin violation

eg., see Feng, et al arXiv:1701.02263

AMS02 CR antiprotons and RW parameterization with the fit to B/C for propagation No DMA.



Winkler param.



$$\sigma_{\text{inel}}^{\text{LHCb}}(p\text{He}, \sqrt{s_{\text{NN}}} = 110\,\text{GeV}) = (140 \pm 10)\ \text{mb}$$

EPOS-LHC = 118 mb

QGSJETIIm = 127 mb

- Increase of $\bar{p}$ production and reduction of nuclear uncertainties to ~10% , little room for DM
- Good agreement between QGSJETII-4m and RW parametrization

Only prompt is measured, still need: pHe→$\bar{\Lambda}$

Isospin symmetry violation $\Delta_{IS}=\bar{n}/\bar{p}$-1, need Deuterium target

big uncertainties; 0.1(NA49), 0.4(Fermilab), in EPOS-LHC (0.5) ?

Diffusive galactic gamma rays:
nuclear uncertainties

$CR+ISG \rightarrow \pi_0(\gamma\gamma)+X$

dominant contribution for galactic plane region $|b|<10^o$ and $E_\gamma < 10^9$eV

Inverse Compton for larger b and E

$e^{\pm}+ISRF \rightarrow e^{\pm}+ \gamma$

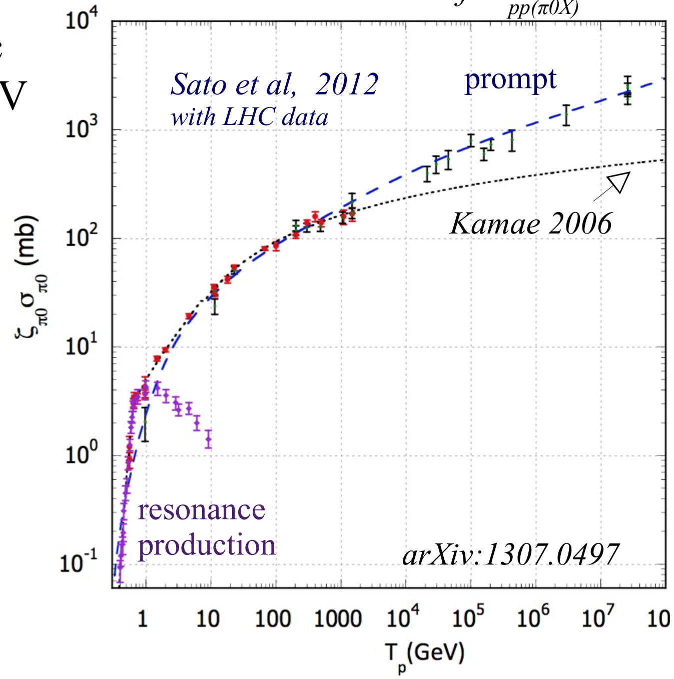
Parameterizations of $\sigma_{pp(\gamma X)}$:

Stephens, Badhwar 1980 (Galprop)
Dermer 1986
Kamae et al., 2006 (used in Fermi)
Huang et al, 2007
Sato et al, 2012 (with LHC data)
Kafexhiu et al 2016

or MC, eg. QGSJET:

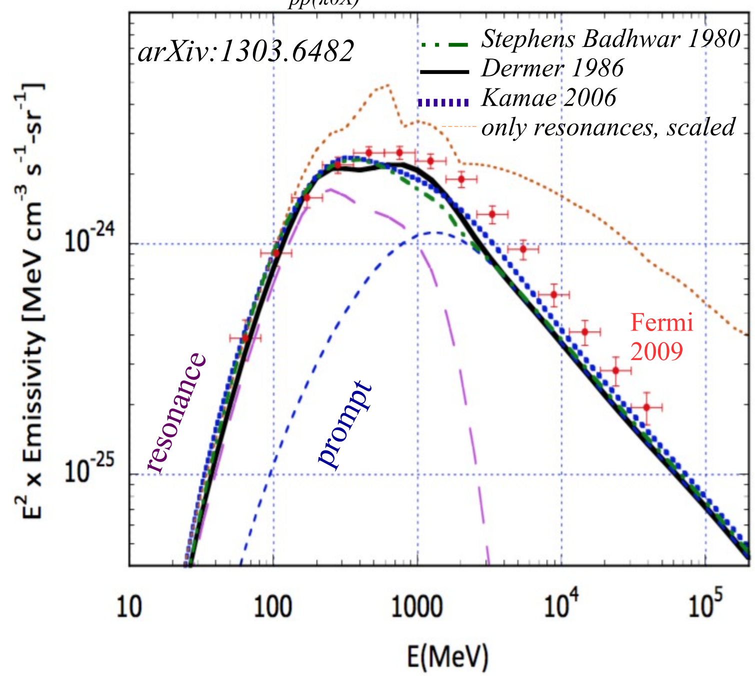
Kacherliess, Ostapchenko 2014

Parameterizations of $\sigma_{pp(\pi 0X)}$



Emissivity $I=\sigma_{pp(\gamma X)} \otimes ISG$

for different $\sigma_{pp(\pi 0X)}$ parameterizations



$\Delta(1232)$
$\Delta(1600)$
N(1440)...

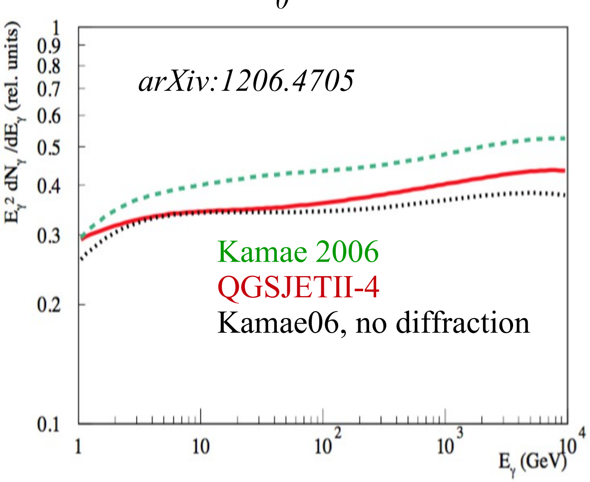
RFT models are not reliable in resonance region <10 GeV, parameterization is better

hadronization of diffraction(~20%) is not well parameterized, RFT models should be better

>30% uncertainties in $pp(\pi_0)$ in emissivity

The uncertainties in $F_\gamma = F_{CR} \otimes I$ are large due to uncertainties in the F_{CR} galactic CR (p,e,..) spectral shapes

Gamma from π_0 in different models

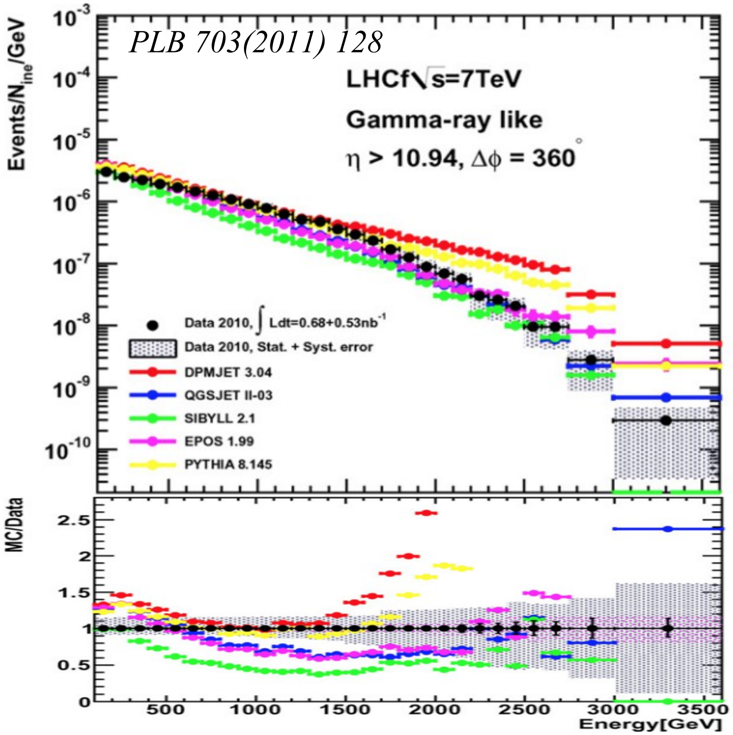


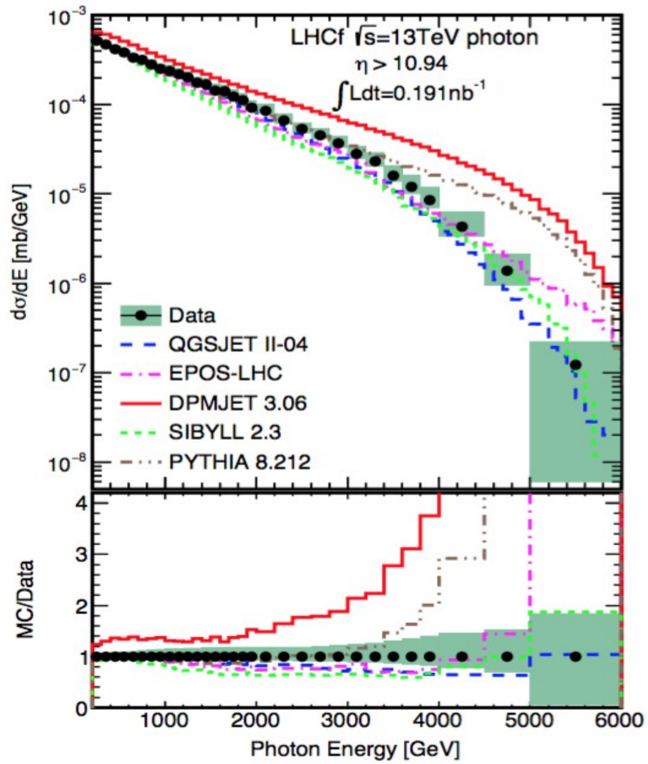
Fermi excess(bubble) hard to explain with $\pi_0(\gamma\gamma)$ uncertainties... But:

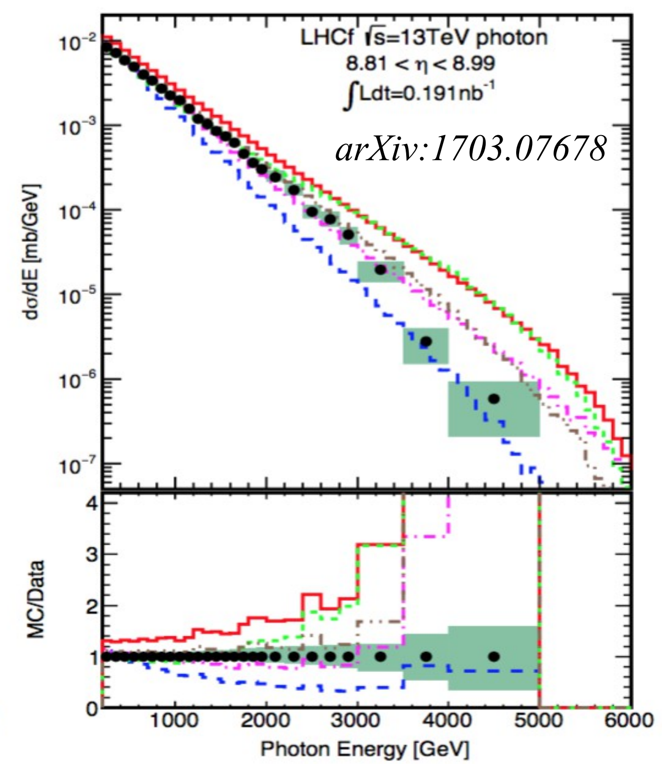
- The $\sigma_{\pi 0}$ is important for $E\gamma$=0.1-1000 GeV in dense ISG regions.
- Check of galactic model: can constrain remote galactic F_{CR}: $F_\gamma = F_{CR} \otimes \sigma_\gamma \otimes ISM$ and compare with local F^{LIS}_{CR}

Gamma with LHCf

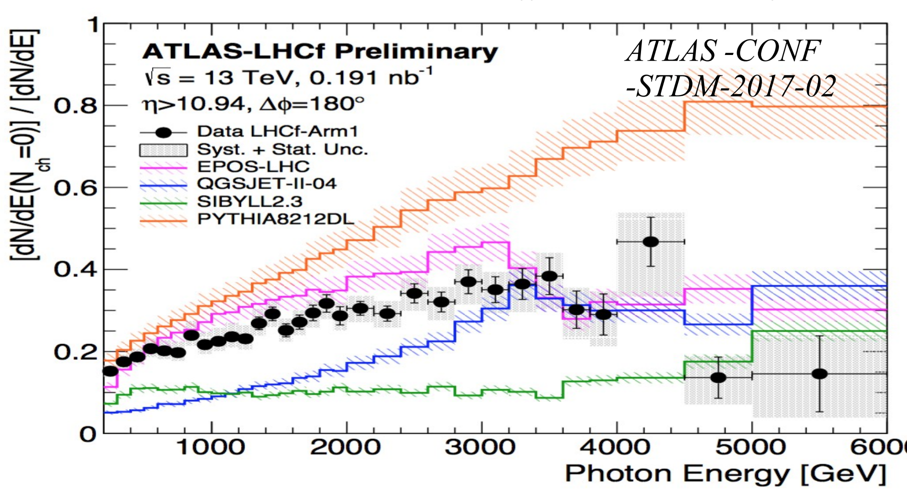
pp →γX at 7 and 13 TeV, and different models

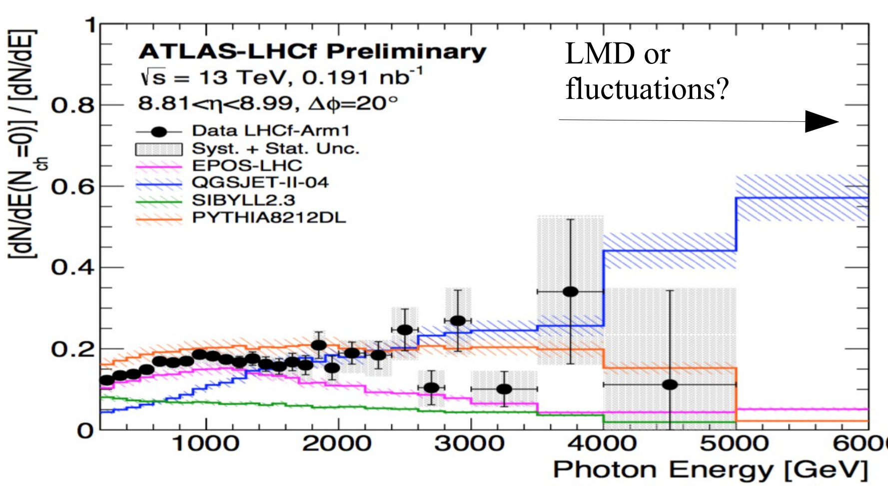






Diffraction: ratio of Gamma with ATLAS charged veto(|η|<2.5)/all

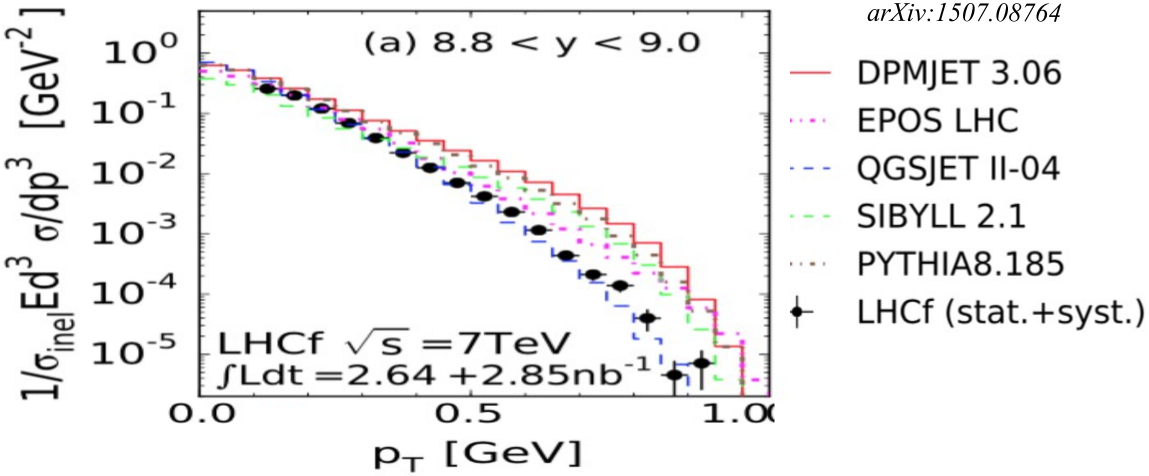




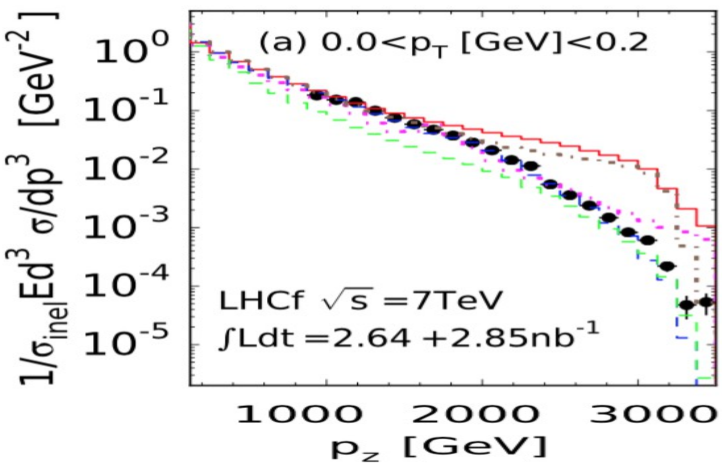
pp →π_0X with LHCf

$\pi_0(\gamma\gamma)$ p_T at 7TeV

LHCf, arXiv:1507.08764

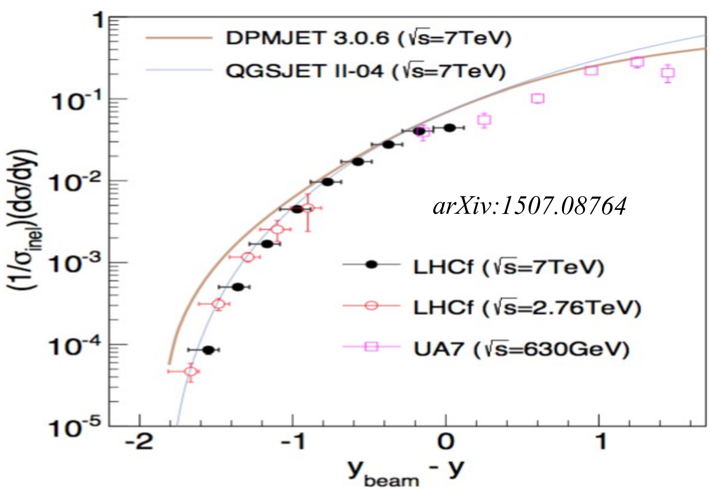


$\pi_0(\gamma\gamma)$ p_Z at 7TeV

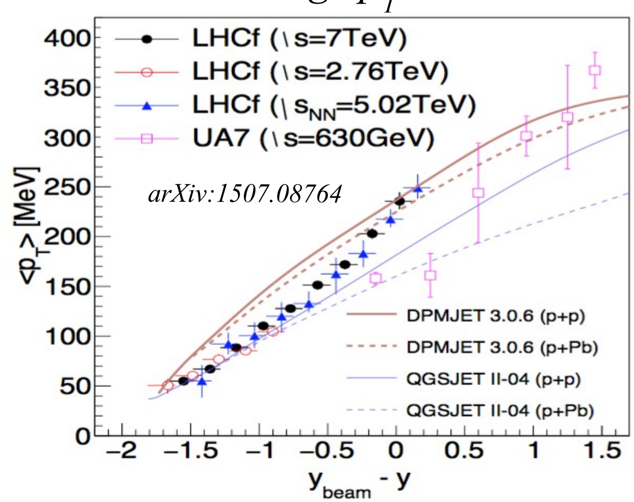


<u>Scalings of π_0 production in forward region</u>

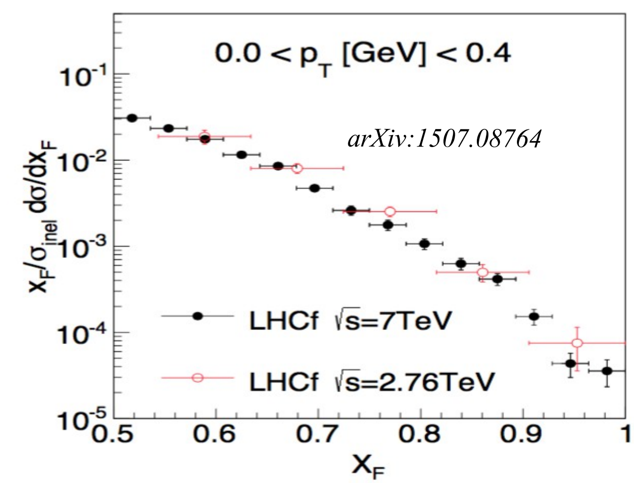
Limiting fragmentation



Average p_T



Feynman scaling



- Good agreement of forward pp →γX spectra and π0 distributions with QGSJETII and EPOS-LHC

  some deviations for diffractive contribution, important for γ emissivity, QGSJETII4 looks underestimated (unexpected)

  Large uncertainties for harder γ and more central regions, more data needed.
- Forward scaling holds at ~20% accuracy in 0.6-7TeV range

  compatible with QGSJETII and EPOS-LHC evolutions

Atmospheric Neutrino:
nuclear uncertainties

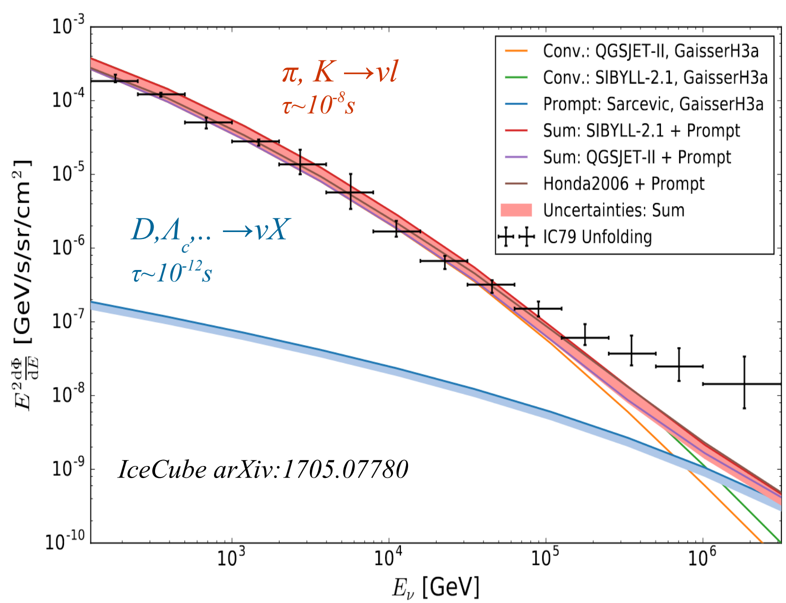
DMA ν :
- in Galaxy and beyond
- gravitationally trapped in Sun and Earth center

Astrophysical ν :
similar to γ: $CR+ISG \rightarrow \nu+l+X$

Atmospheric ν as background:
- nuclear uncertainties
- CR fluxes uncertainties

$CR+air \rightarrow \nu + X$

IceCube neutrino flux and atmospheric ν calculations



At high energy open charm production is the main source of uncertainties (>50%)

Intrinsic Charm (IC)

non pQCD charm contribution to PDF at large **x>0.1**, eg.:

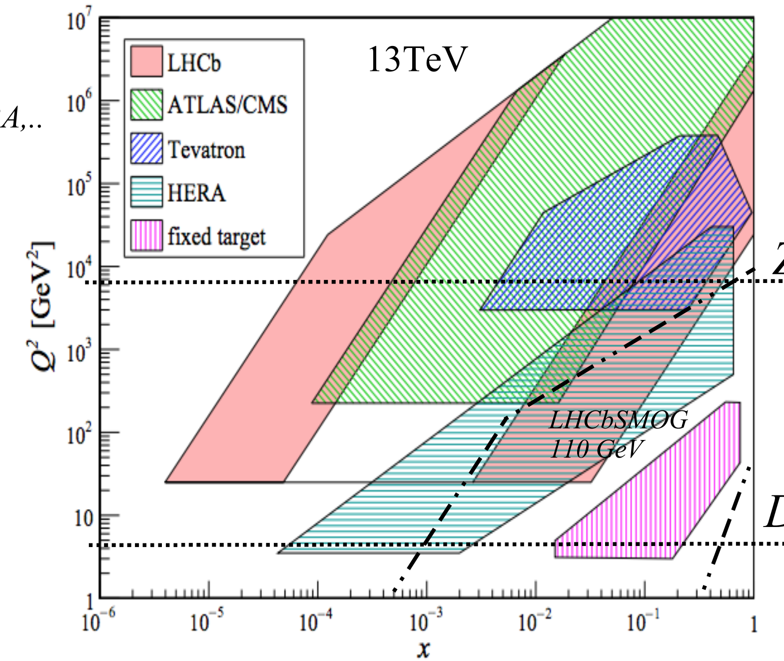
BHPS model *Brodsky et al, 1980*

SEA model *Dulat et al, 2013*

Observations: EMC, ISR, Tevatron,HERA,..
EMC, NPB461, 181, 1996
D0, PLB719,354, 2013
CDF, PRL111, 2013....

but no clear evidence

Low-x with charm in pp collisions at LHCb
Large-x at LHC, two possibilities:
- *in pp collisions via Z/W+c (ongoing)*
- *in LHCbSMOG via open charm D, Λ_c*

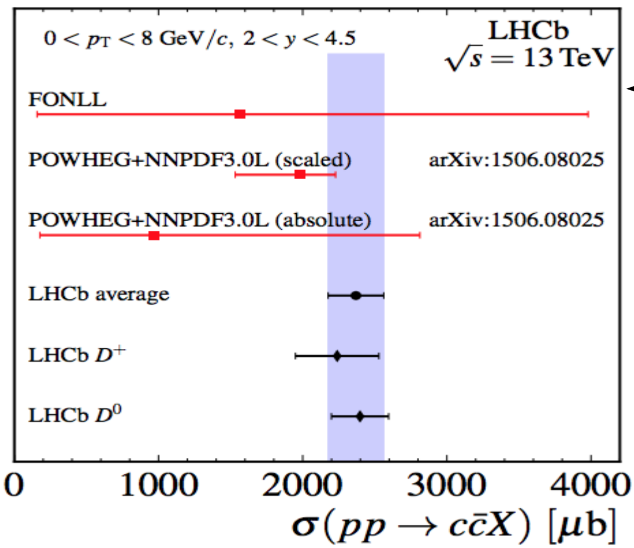


- Update of atmospheric ν flux calculations
  (using LHCb charm and bottom production)
- Interactions of astrophysical ν with ISG
  (low-x gPDF improvement, with LHCb)
- Intrinsic Charm contribution in atmospheric ν
  (disentangle IC and CNM effects by simultaneous observation of the charmonium J/Ψ and open charm D, Λc)

Neutrino and low-x physics with LHCb

Update atmospheric ν production using LHCb charm and bottom production

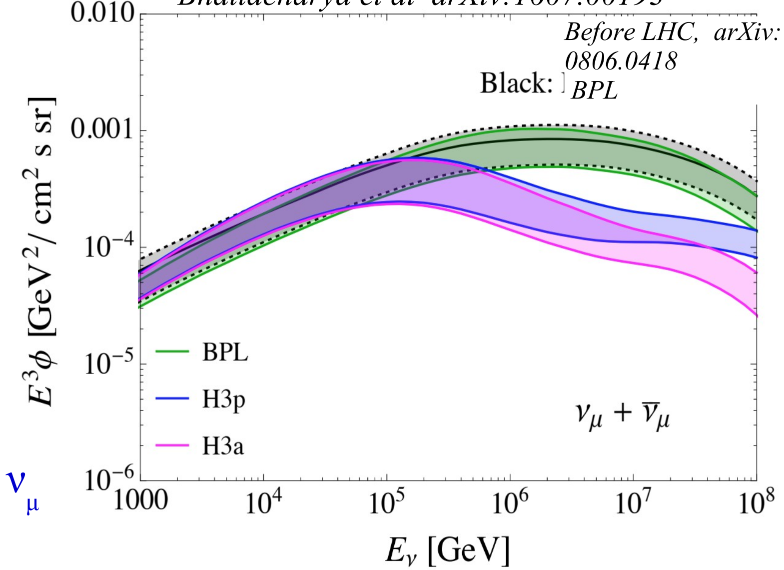
LHCb, arXiv:1510.01707



Open charm LHCb measurements 13TeV

Atmospheric neutrino flux at NLO QCD (color dipole, BFKL,nPDF) using LHCb charm production
(with different CR spectra)

Bhattacharya et al arXiv:1607.00193

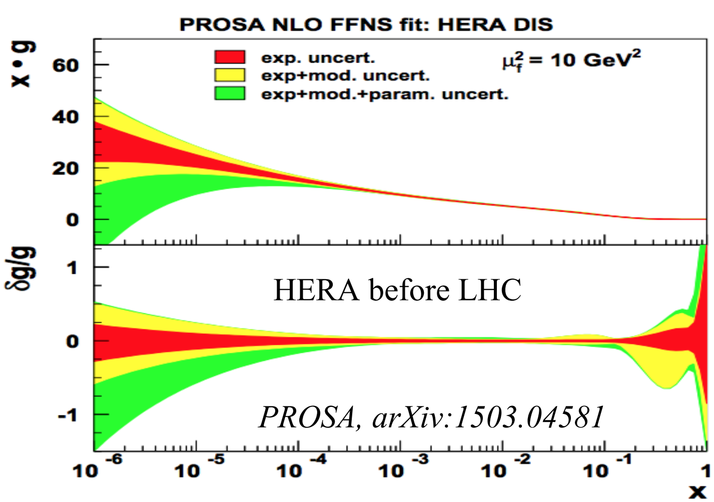


30% reduction of atmospheric ν_μ
(i.e larger astro ν_μ signal)

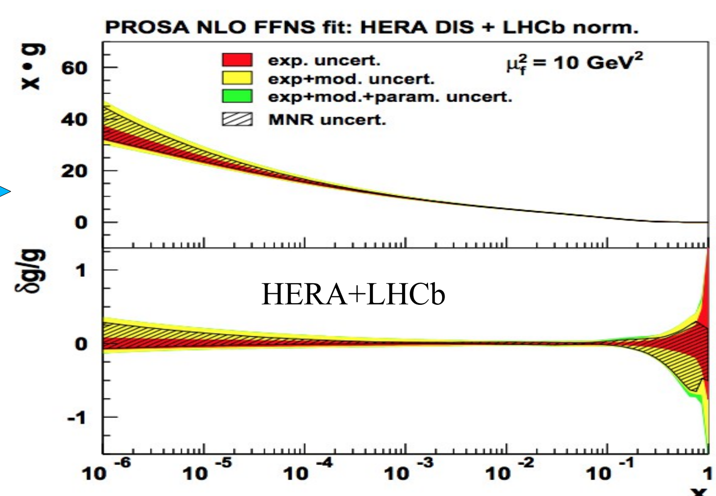
Interactions of UHE CR ν: ***ν+ISG→lX:*** $x \sim M_W^2/m_p E_\nu$, i.e. low-x PDF

above ~10 TeV gamma are absorbed and γ+*ISRF* → e^+e^- only ν remains to trace sources

gPDF (HERAPDF) fit with HERA data and with D,B mesons LHCb 7-13TeV



recombination gg →g saturation ⟷ splitting g →gg



Similar for NNPDF, arxXiv:1610.09373

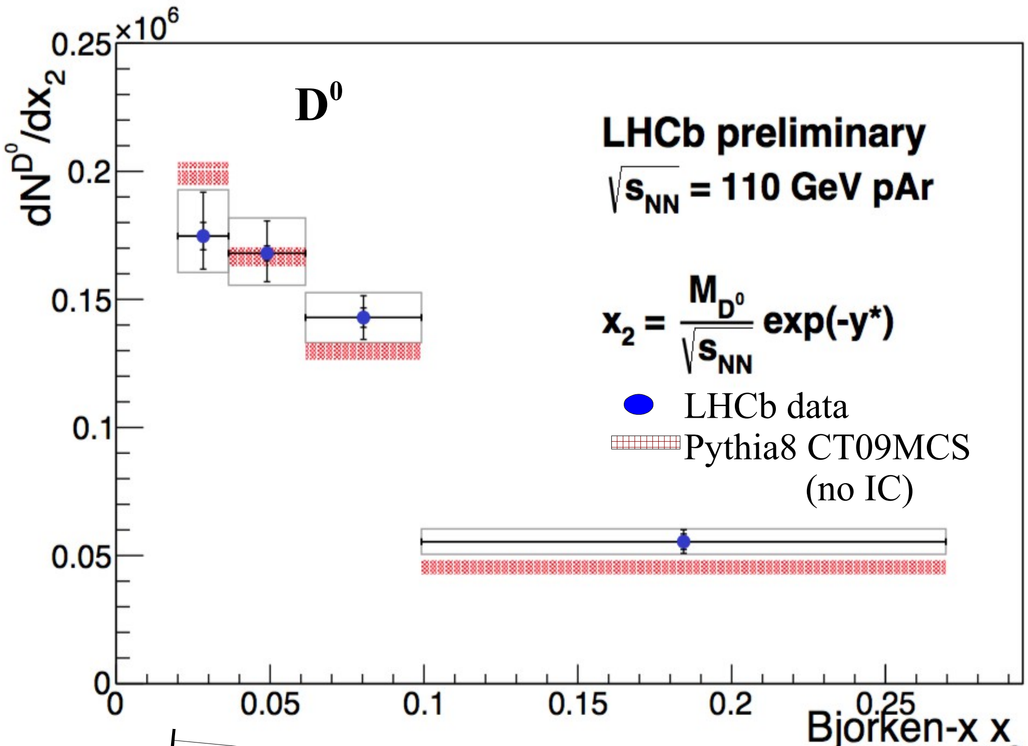
LHCb:
Charm, Bottom production in pp
$x \sim M_c^2/s < 10^{-5}$

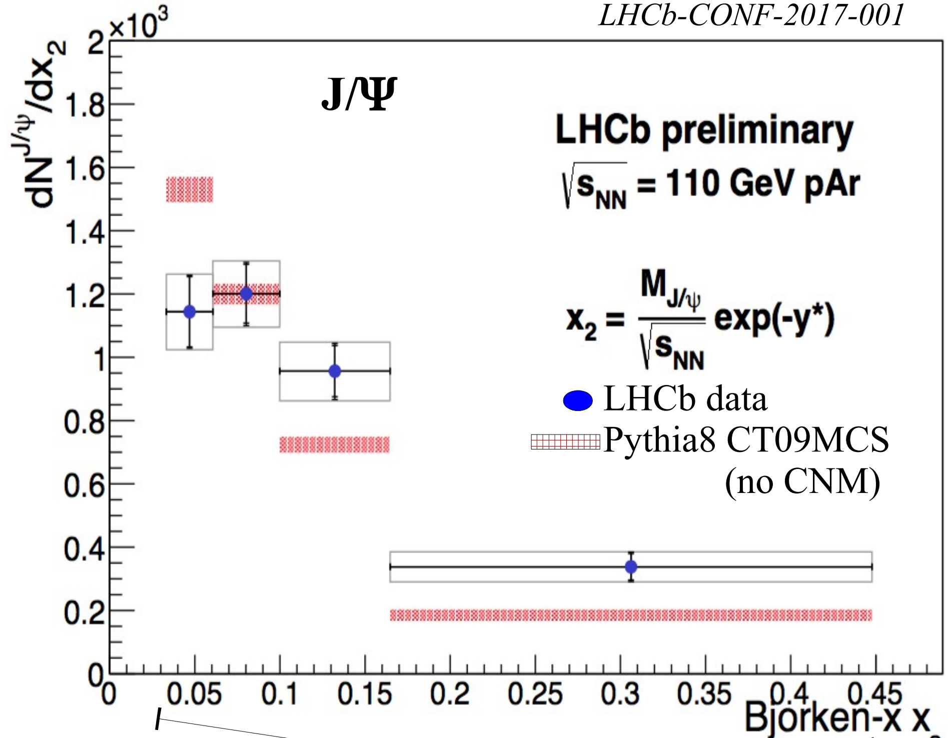
Still to be included:
Low mass DY (*LHCb, arXiv:1511.07302*)
CentralExclusiveProduction (*LHCb-CONF-2012-013*)
also see arXiv:1409.4785 for CEP

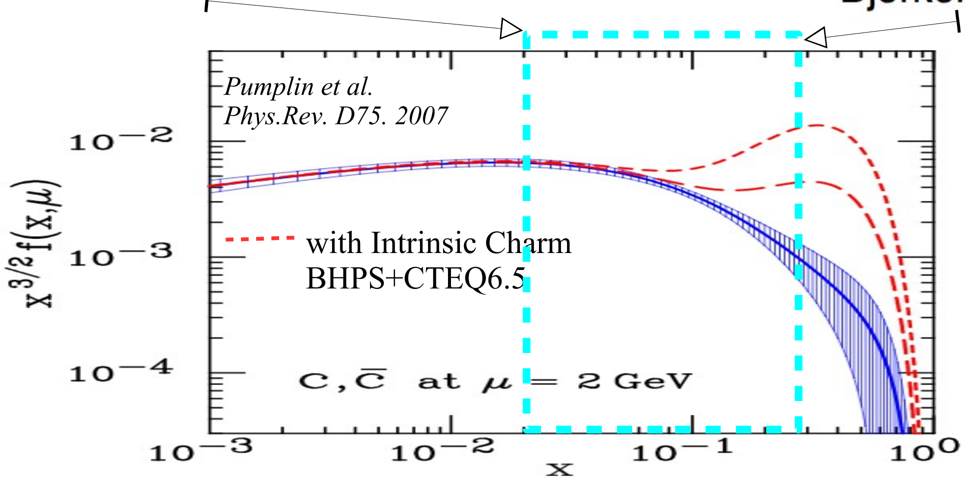
Uncertainties for gPDF $x < 10^{-5}$ are down to ~10%

Intrinsic Charm with LHCbSMOG in pAr at √s=110.4 GeV

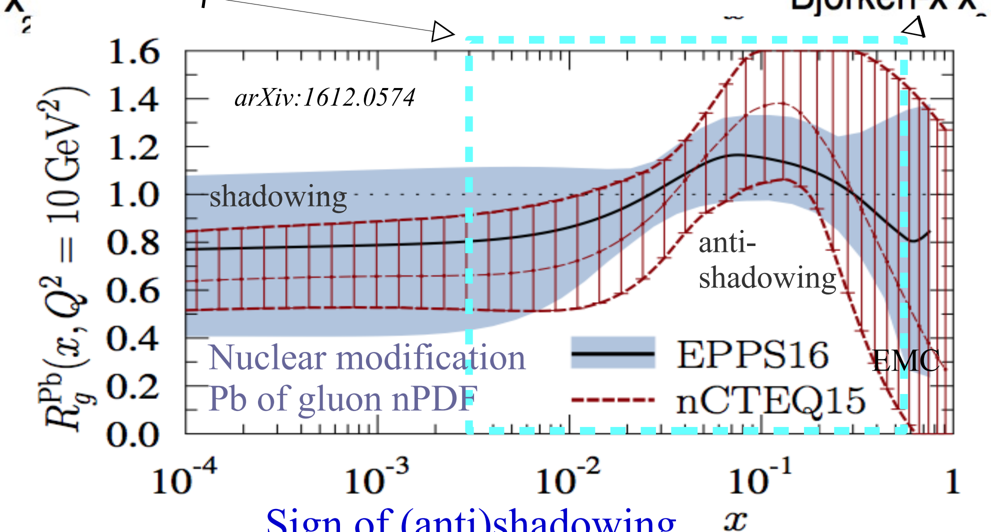
LHCb-CONF-2017-001







No significant IC contribution



Sign of (anti)shadowing

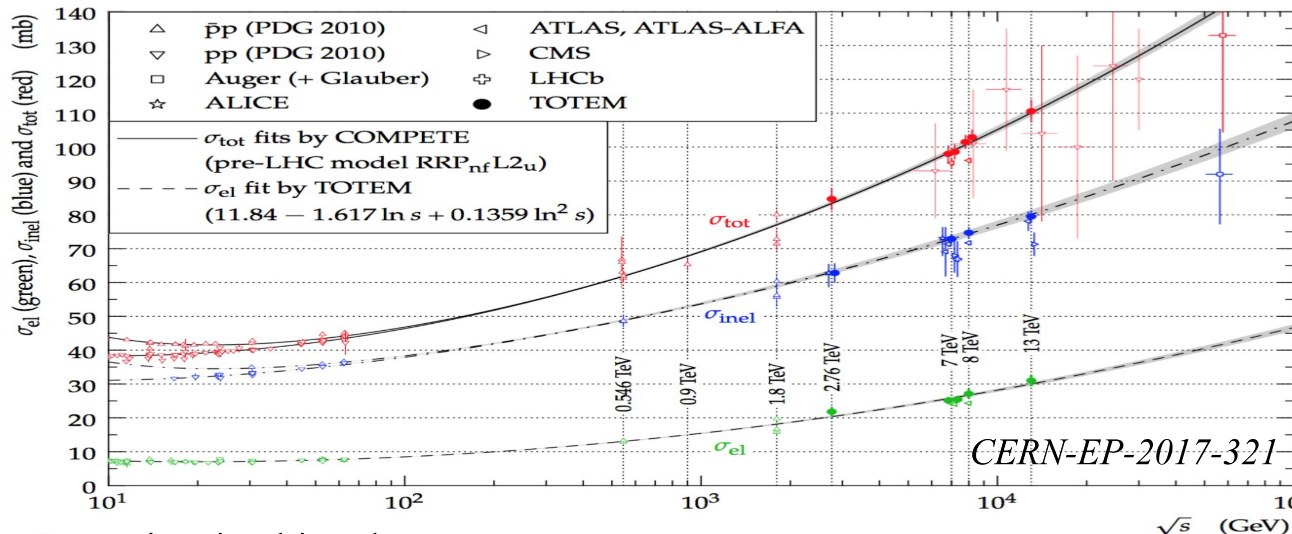
ongoing comparison with theory

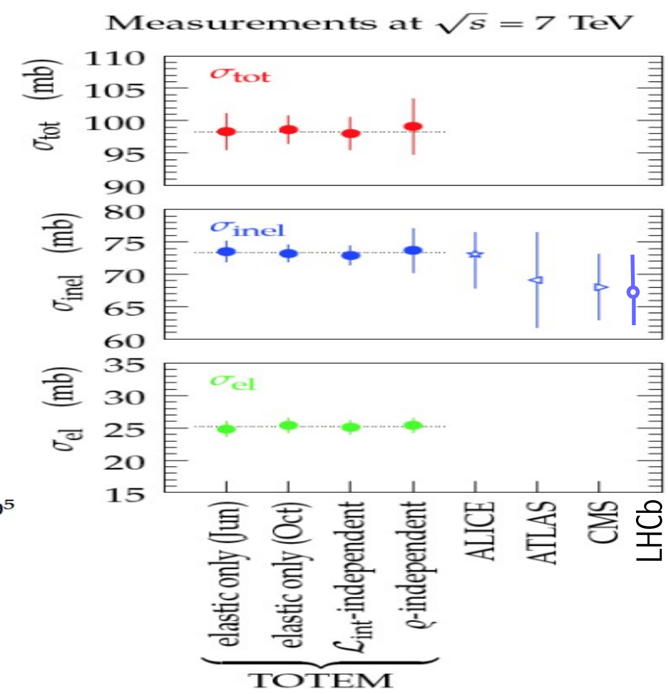
Cross sections with TOTEM

$\sigma_{tot} = \sigma_{el} + \sigma_{inel}$ $\{\sigma_{diff}(SD+DD+CD)+\sigma_{NonDiff}\}$

***TOTEM** decisive measurements with 3 methods*

see TOTEM talk..



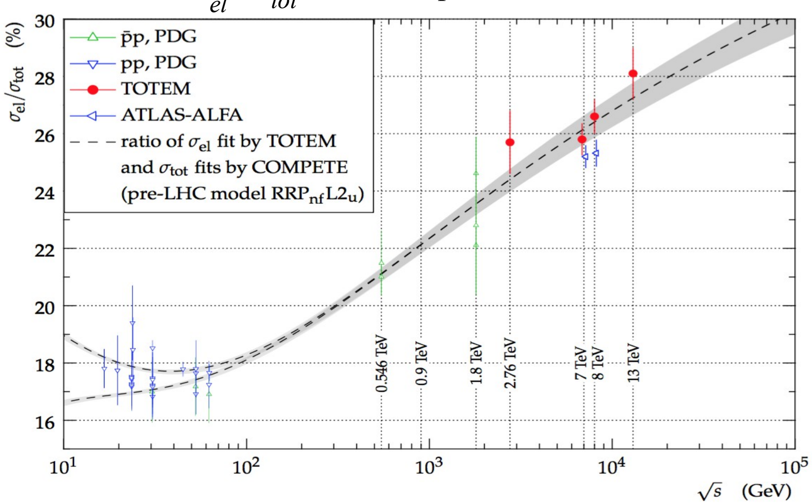


Increasing rise driven by pomeron $\varepsilon =$ 0.08 (1TeV) → ~ 0.12 (10TeV)

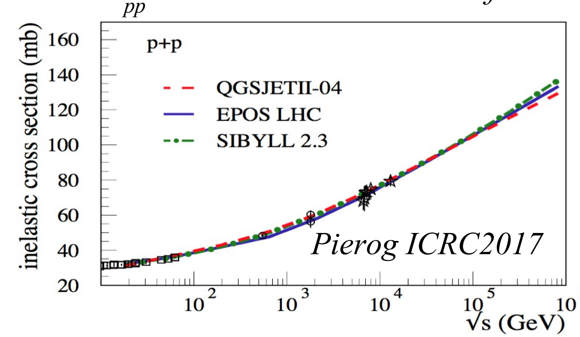
$\sigma_{tot} \sim \sigma_r s^{-0.5} + \sigma_0 s^{\varepsilon}$ *Donnachie,Landshoff,1992*

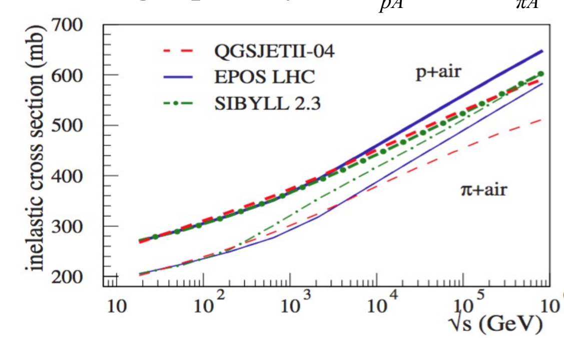
$\sigma_{tot} = c + a\, s^{-0.5} + b\, \ln^2(s)$ *COMPETE fit triplepole RRP, and more...*

σ_{el}/σ_{tot} *will at stop at black disk ½ limit?*



σ_{pp} all models are tuned after LHC, but large spread for σ_{pA} and $\sigma_{\pi A}$





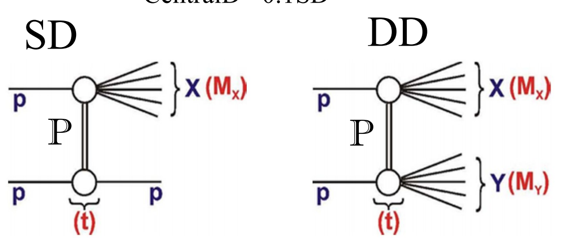
- Big improvement for all models after TOTEM σ tot, inel, el important for all exclusive productions in all models, increase secondary CR yields

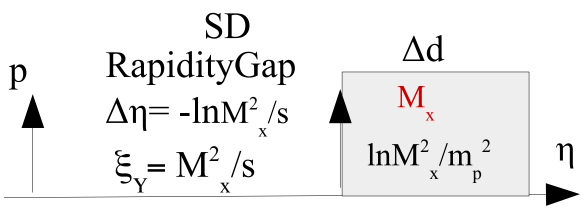
  baryons/mesons inelasticity, nuclear effects

Diffraction with TOTEM

Diffraction contributes ~50% for $x_F \to 1$ in CR interactions, important hard to simulate, important source of models uncertainties.

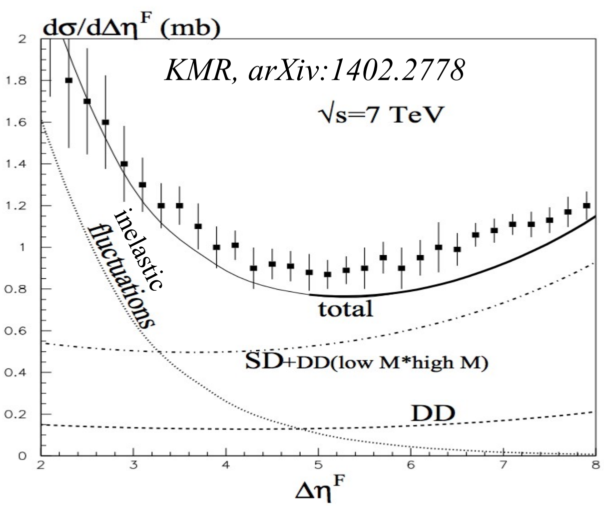
CentralD ~0.1SD





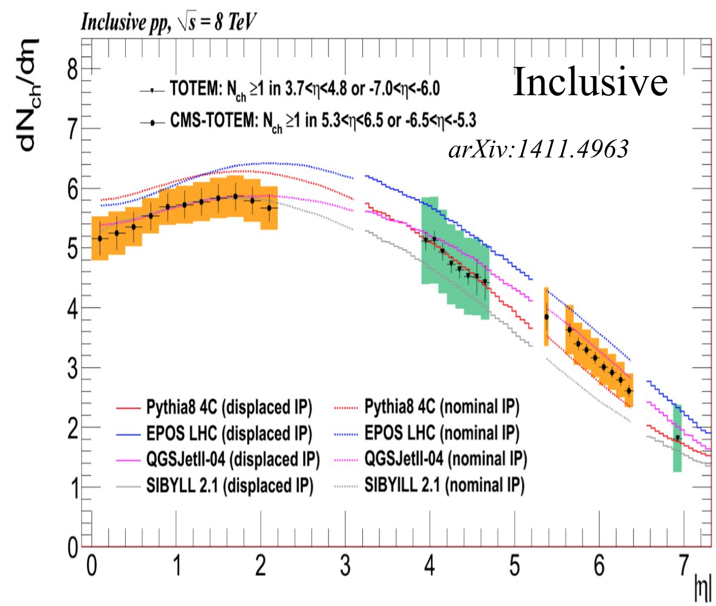
M_x GeV	3	12	394	1100
lgξ	-6.7	-5.5	-2.5	-1.6
Δd	2.7	5	11	14

Diffraction versus forward RG $\Delta\eta^F$ ATLAS(arXiv:1201.2808) and model



RG survival can be affected by fluctuations contamination from inclusive up to Δη<5

Pseudorapidity: Inclusive and SD enhanced in TOTEM+CMS



Diffraction extrapolated by Pythia8-MBR from visible $\lg\xi_Y$ [-5.5,-2.5] to larger mass range:

CMS, *arXiv:1503.08689* $\xi_Y<0.05$:

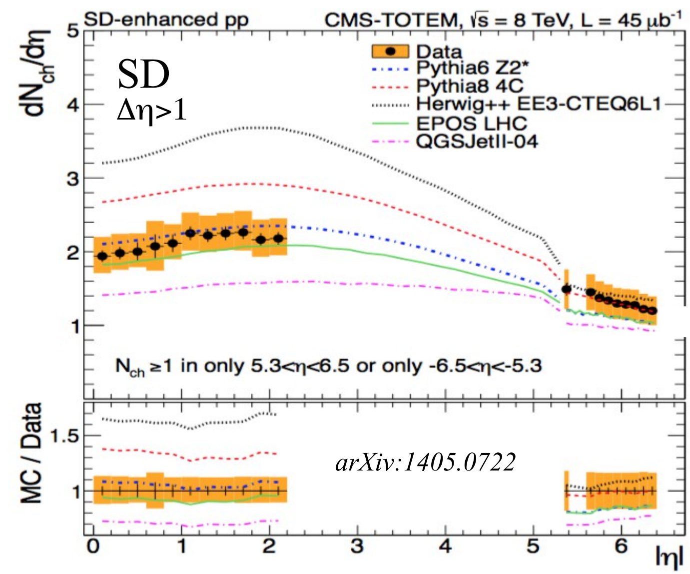
$$\sigma^{DD} = 5.17 \pm 0.08\,(\text{stat})^{+0.55}_{-0.57}\,(\text{syst})^{+1.62}_{-0.51}\,(\text{extrap})\,\text{mb},$$

$$\sigma^{SD} = 8.84 \pm 0.08\,(\text{stat})^{+1.49}_{-1.38}\,(\text{syst})^{+1.17}_{-0.37}\,(\text{extrap})\,\text{mb}$$

TOTEM(*preliminary Kaspar, ISMD17*) $\xi_Y<0.02$:

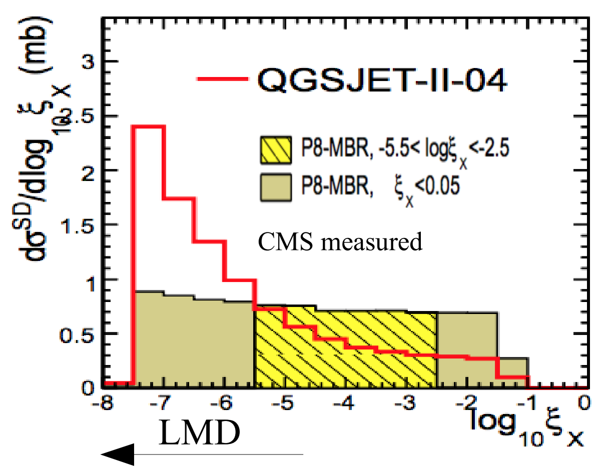
$$\sigma_{SD} = (9.1 \pm 2.9)\,\text{mb}.$$

agreement on SD in extrapolated mass range, but low-mass diffraction(LMD) is neglected in P8MBR



Large underestimation of $d\sigma_{SD}/d\eta$ for QGSJETII or RG contamination?

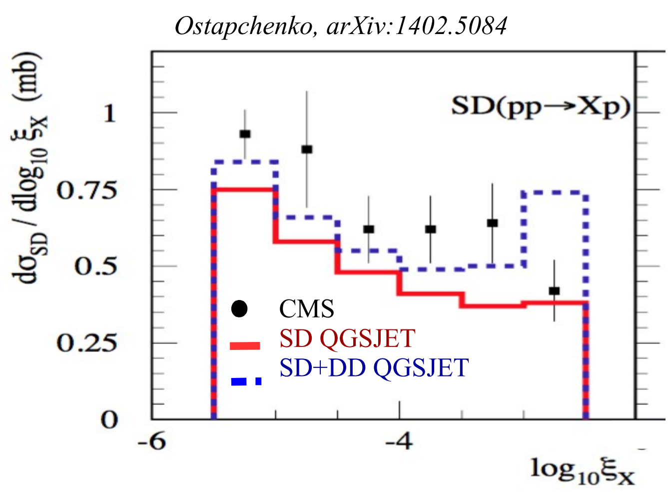
Extrapolation with P8-MBR and QGSJET



More diffraction

Comparison of CMS SD and QGSJETII SD and SD+DD in the visible mass range

Ostapchenko, arXiv:1402.5084

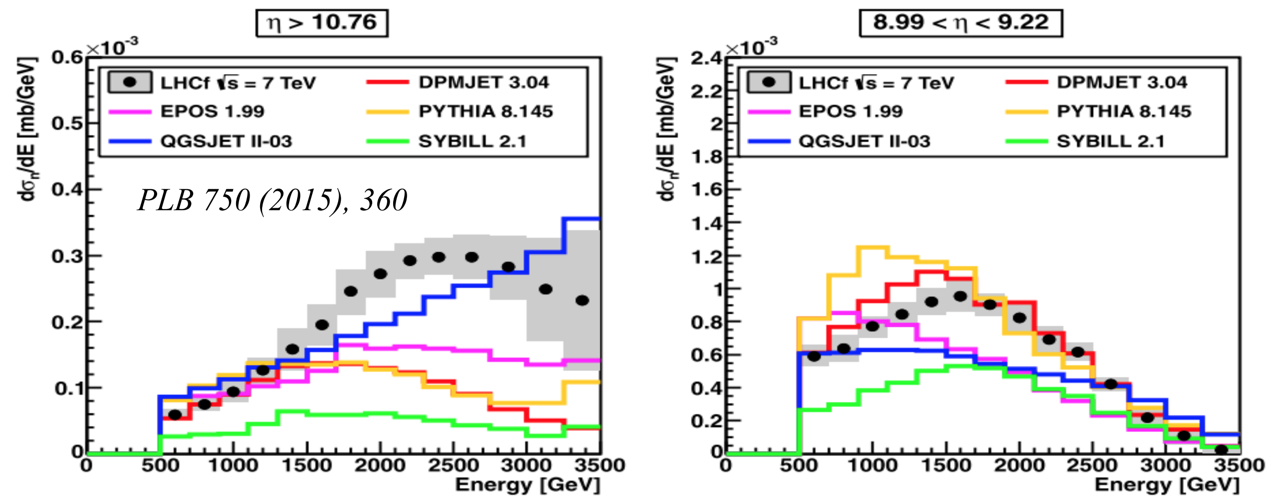


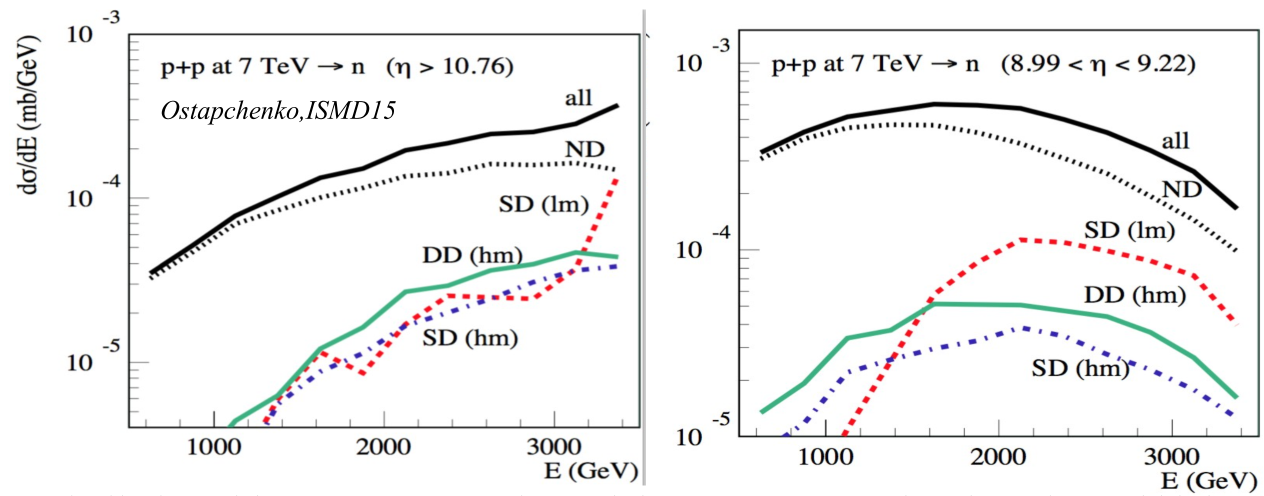
KMR, arXiv:1402.2778

Mass interval (GeV)	(3.4, 8)	(8, 350)	(350, 1100)
Prelim. TOTEM data	1.8	3.3	1.4
CMS data		4.3	
Present model	2.3	4.0	1.4

Tension between CMS, TOTEM and models on SD in the measured mass range

LHCf: Neutrons





Similarity with gamma, overestimated low-mass SD and underestimated high-mass

S.Ostapchenko, ISMD15

- LHCf and CMSTOTEM results on diffraction are important for CR interaction and EAS modeling, but diffractive mass distribution is puzzling.

more measurements on SD, DD, especially in the low mass range are very needed, decomposition of different contributions using vetos

Nucleus interactions in CR

see M.Schmelling talk on ions...

projectile target

CR: p,He,C,..,e,γ,ν EAS: p,π,K,...	+	Space:H, He,... EAS: air(N, O,...) Detector: C, Si, Al,...

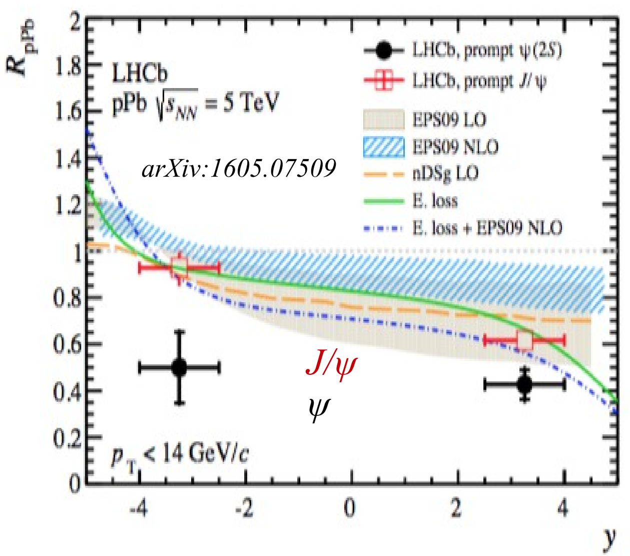
CR: peripheral interactions(high b, low centrality, low Q^2), forward (low-x/high-x), light targets
LHC: central collisions, heavy ions(Pb), high density, good for QGP

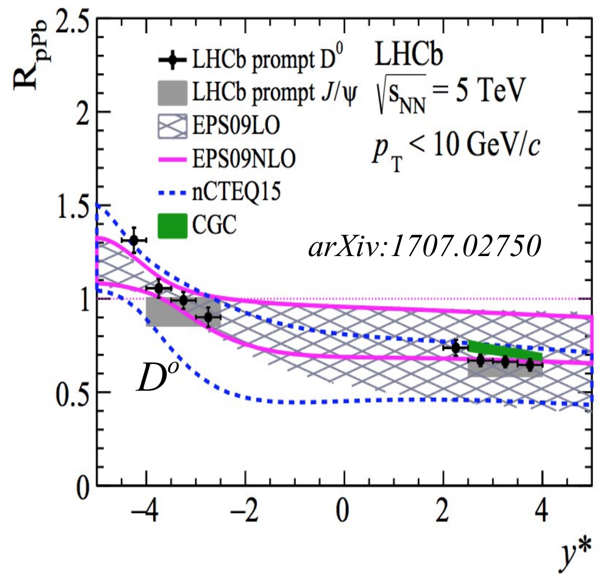
Cold NuclearMatter effects:
→initial state energy losses
k_T spread ('Cronin' effect)
→final state interactions
→ **collective effects**
shadowing, antishadowing, EMC, Fermi motion

losses and density saturation are not so important in peripheral CR interactions

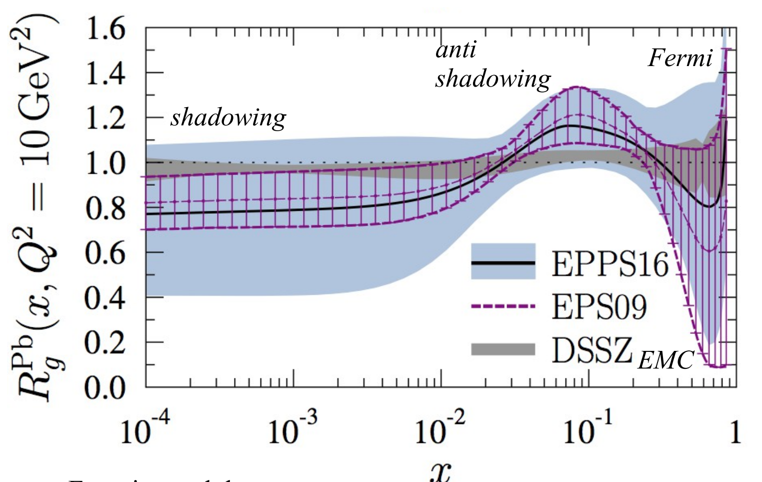
→ nPDF *Paukkunen, arXiv:1704.04036*
or rather nGPD (x,b) *Frankfurt et al arXiv:1106.2091*

***LHCb** modification factors vs y for prompt J/ψ,ψ and D° in pPb(Pbp)*





Comparison g nPDF of preLHC EPPS09 (arXiv:0902.4154) with afterLHC EPPS16(arXiv:1612.05741) and DSSZ(arXiv:1112.6324) fits



Experimental data:
DIS and DY in p,l,ν+A (NMC,SLAC,FNAL,RHIC) →EPPS09
W,Z, dijets in pPb (CMS,ATLAS,ALICE) →EPPS16
Charms in pPb, pA FT (LHCb, SMOG) →?

more data, more uncertainties....

- Some advance in nPDF for heavy ions
  but not much data on low centrality and light targets, large uncertainties
- Collective effects in RFT models: some are included (EPOS-LHC)

Summary

Forward measurements in LHCb/LHCf/TOTEM are used to largely reduce uncertainties in antiprotons, gamma and neutrino production in CR interactions, relevant for indirect (and direct) DM searches, and Cosmic Ray physics.
Mostly used to improve exclusion DMA limits in antiprotons and gamma.

- reduced uncertainties in prompt pA $\rightarrow\bar{p}X$
- improvement of pA $\rightarrow\pi_0X$ prediction
- improvement of pA $\rightarrow\nu X$ calculations
- verification of forward scaling
- constrained intrinsic charm contribution
- improved low-x gPDF fit
- constrained diffraction contribution at high energies
- improvement of RFT models for EAS simulations
- ....

ongoing:

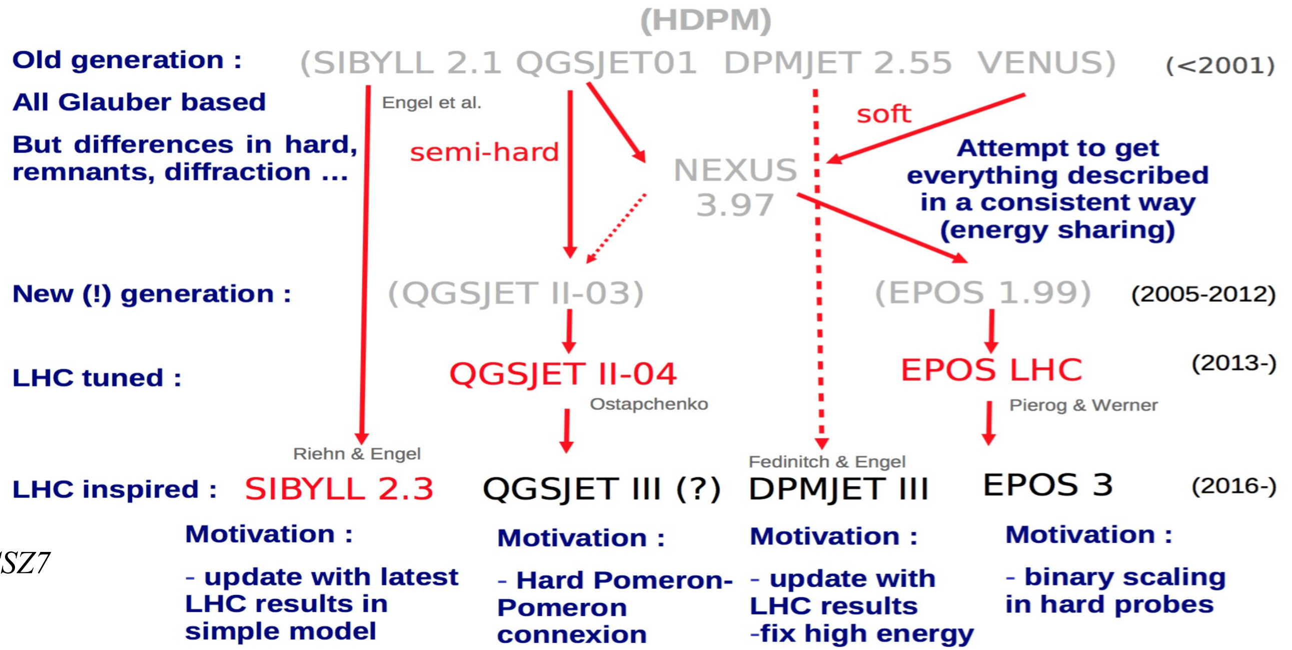
- $\bar{p}$ from hyperons
- isospin n/p asymmetry
- (anti)baryons/mesons ratios
- charm production in diffraction
- diffraction puzzle
- nuclear effects on lighter targets

…..

More measurements on diffraction and light ions can be expected with:
LHCbSMOG+HeRSHCeL and TOTEM with Run2 data.

Backups

Models



Pierog HESSZ7

EPOS

Werner, Liu & Pierog, PRC74 (2006) 044902

QGSJET-II

Ostapchenko, PRD83 (2011) 0114018

Gribov-Regge based models for hard and soft(Pomeron) parts
DGLAP for hard part, own PDF
Enhanced diagramms, multipomeron interactions, screenings
Can be used to simulate soft and hard up to high energies in central and forward regions

EPOS:
Tuning to data, parameterizations
MPI with energy conservation
Collective effects for nucleus
Special treatment for diffraction and nonlinear effects
Resonance production included

QGSJET-II:
Theory motivated, almost no parameters (Q_o cutoff scale)
Diffraction, elastic and inelastic unified approach
High and low mass diffractions
Not(many) resonance production

SIBYLL

Ahn, Engel, Gaisser, Lipari & Stanev, PRD80 (2009)

RFT based for cross sections, used for EAS.
Separate hard and soft treatment,
String fragmentation (similar to Pythia), external PDF,
Only high mass diffraction,
Non linear effects via running Q(s),
Mostly for central production ,
Limited to light ions

DPMJET

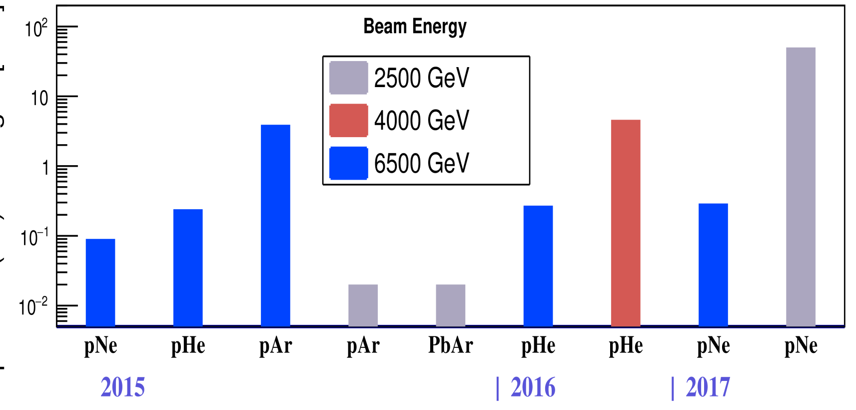
S. Roesler, R. Engel, J. Ranft
arXiv:hep-ph/0012252

RFT based,
Separate hard-soft,
external PDF,
Limited collective effects,
used in GEANT, and HI

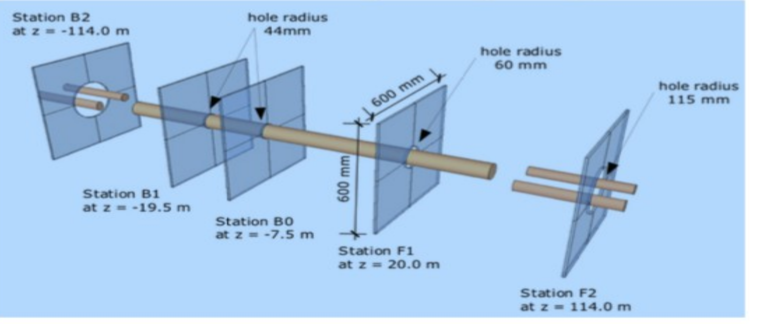
complimentary approaches and cross checks

LHCbSMOG

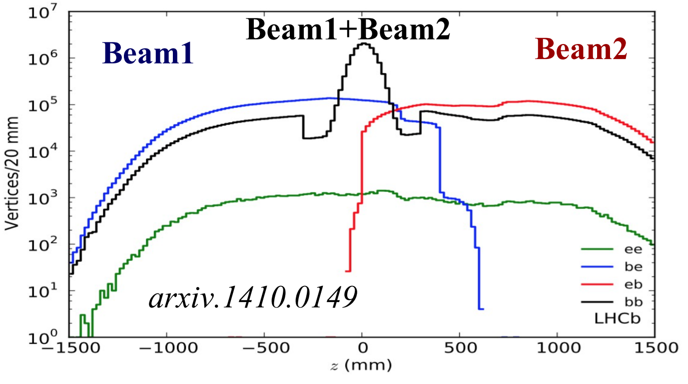
LHCbSMOG runs

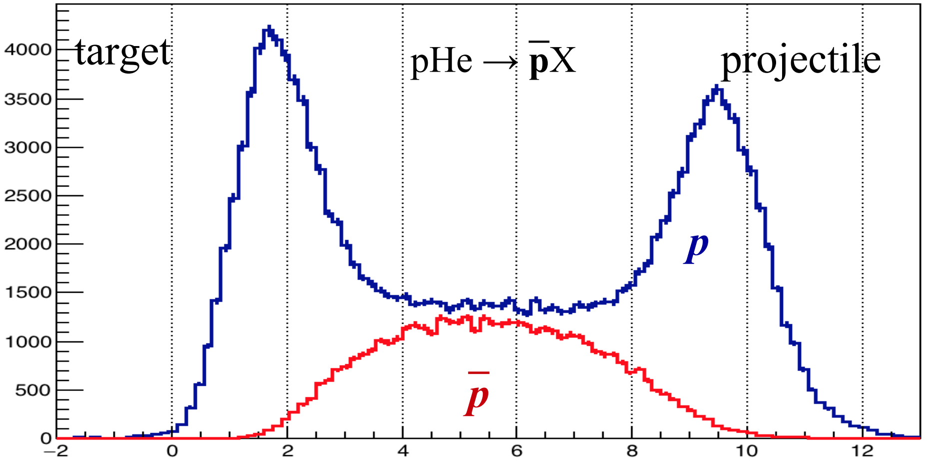


LHCbSMOG+HeRSCheL
HighRapidityShowerCounterforLHCb
up/downstream veto scintillators



Primary vertex z reconstructed with Beam1(be), Beam2(eb), Collisions(bb), and without beams(ee)

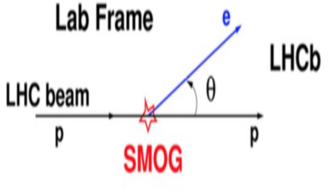




LHCb PID | HeRSCHeL veto

SD high-mass on light targets at ~110 GeV

LHCbSMOG luminosity measurements



Rosenbluth pe- elastic scattering cross section (<1% accuracy):

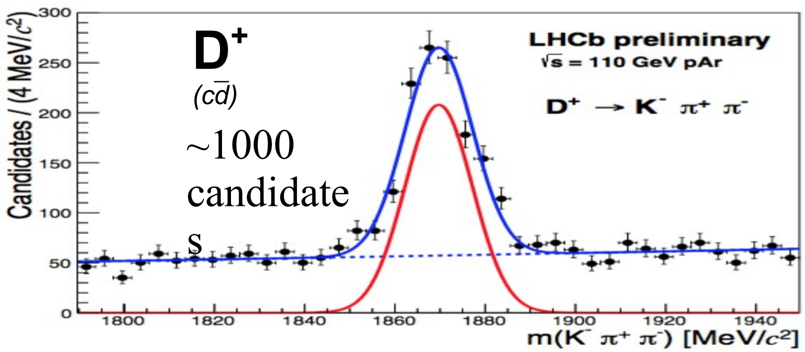
$$\mathcal{L} = \frac{N_e}{Z_{He} \times \sigma_{p-e^-} \times \epsilon}$$

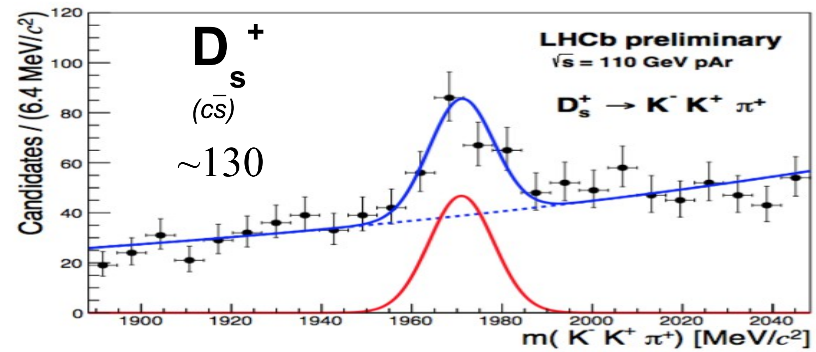
~6% accuracy in absolute Lumi

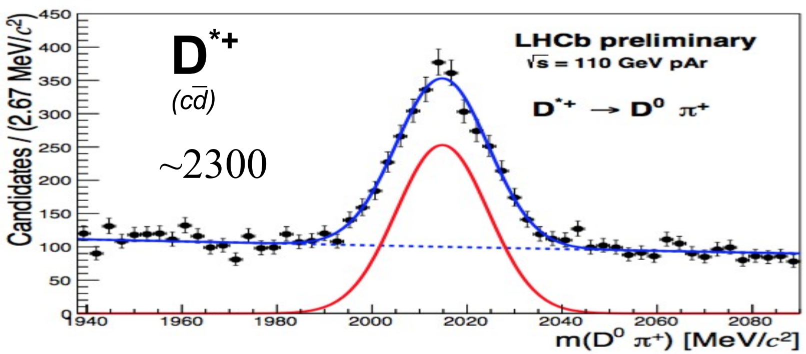
Charm with LHCbSMOG and IC in ν

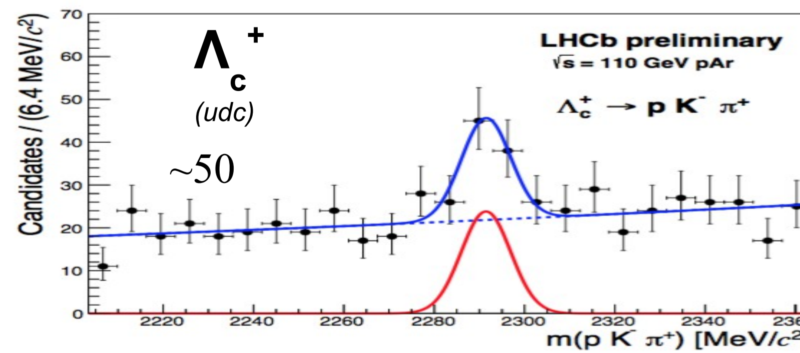
Other charm resonances in the pAr SMOG data sample (data17h)

LHCb-CONF-2017-001

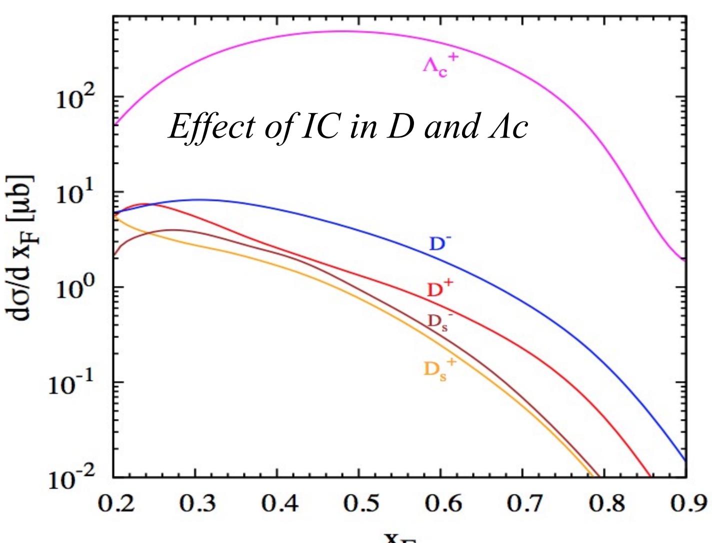


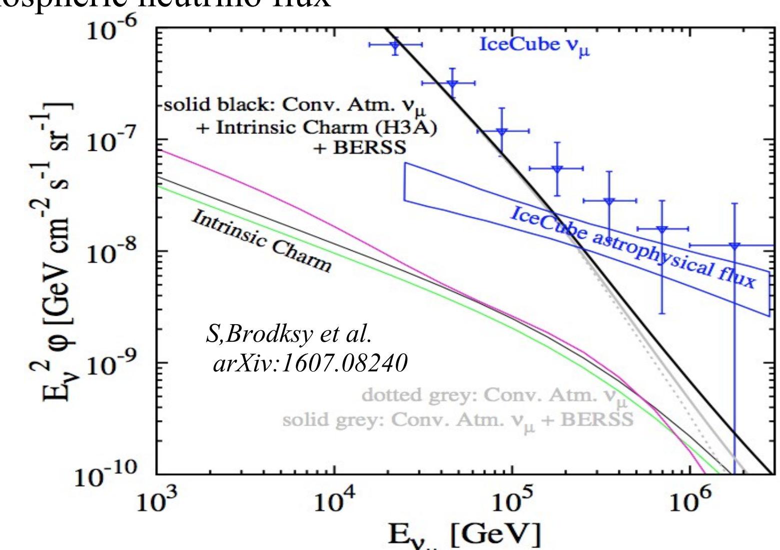






Effect of IC on atmospheric neutrino flux

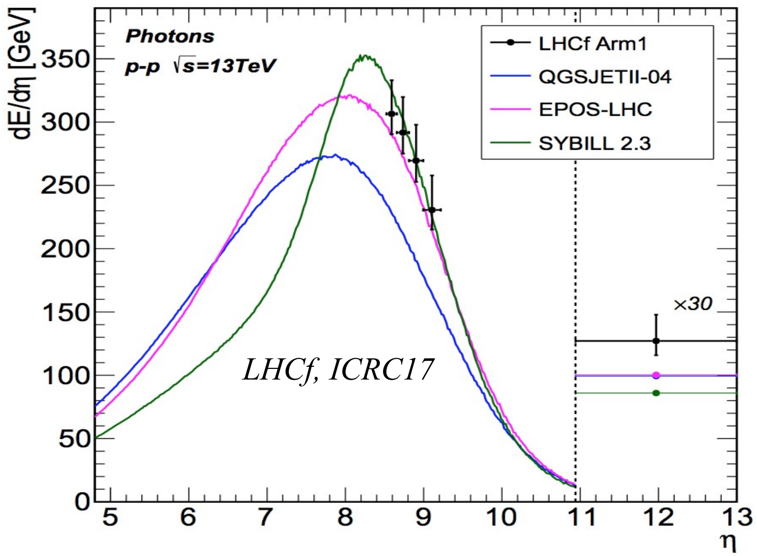




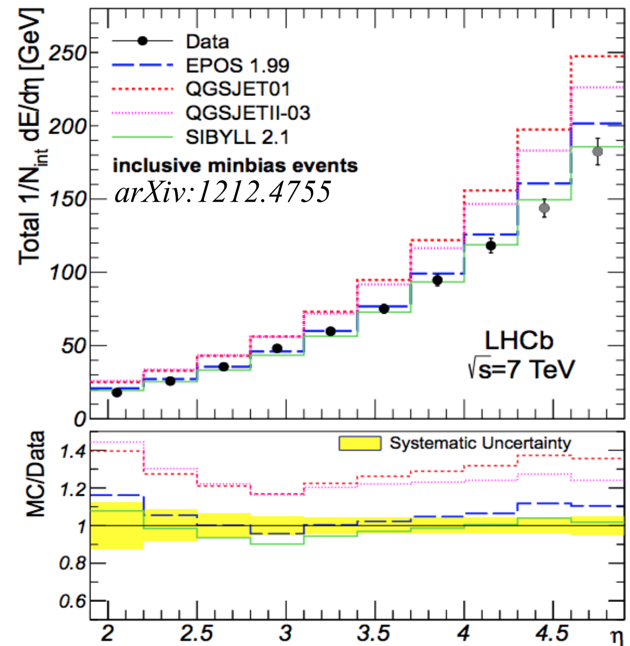
IceCube
HE neutrino cant be explained by IC of Atmospheric contribution

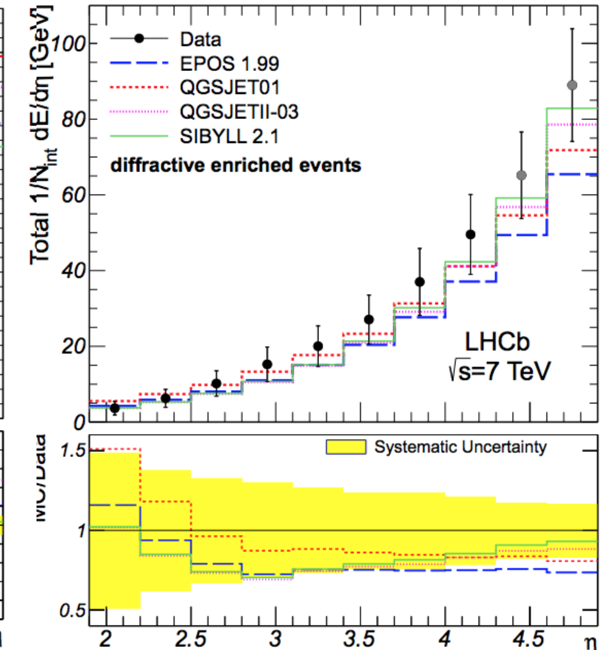
Energy Flow with LHCf and LHCb

Energy flow *gamma* LHCf pp 13TeV

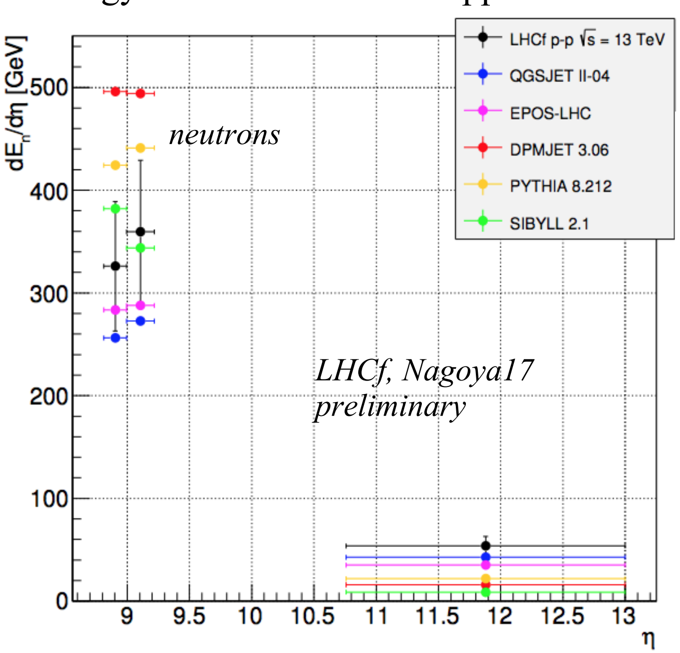


Energy flow *charged* LHCb pp 7TeV and preLHC models

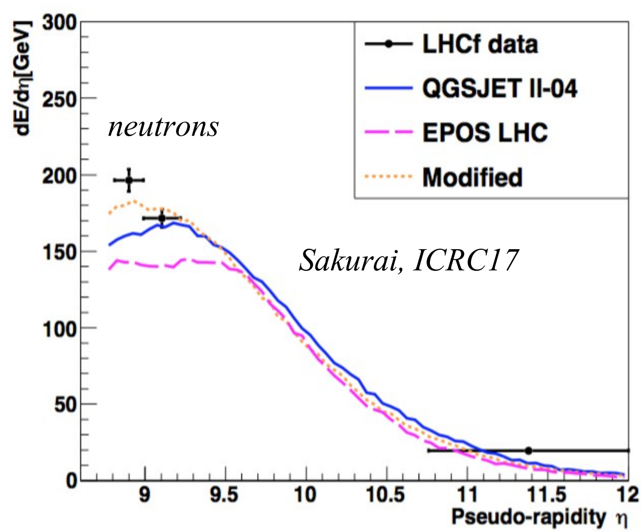


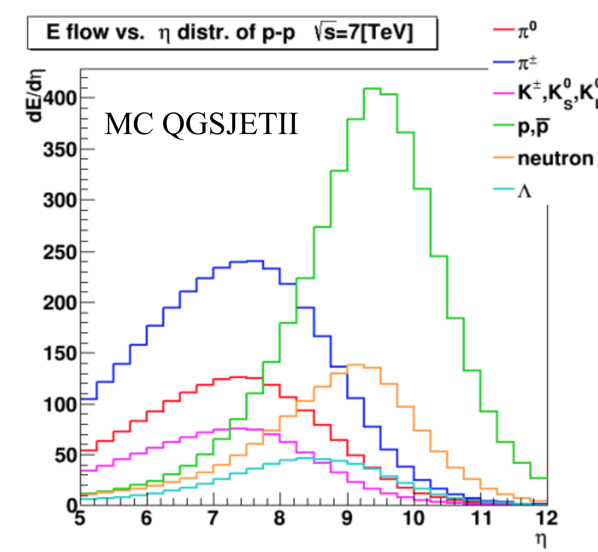


Energy flow *neutrons* LHCf pp13TeV



Energy flow *neutrons* LHCf pp 7TeV

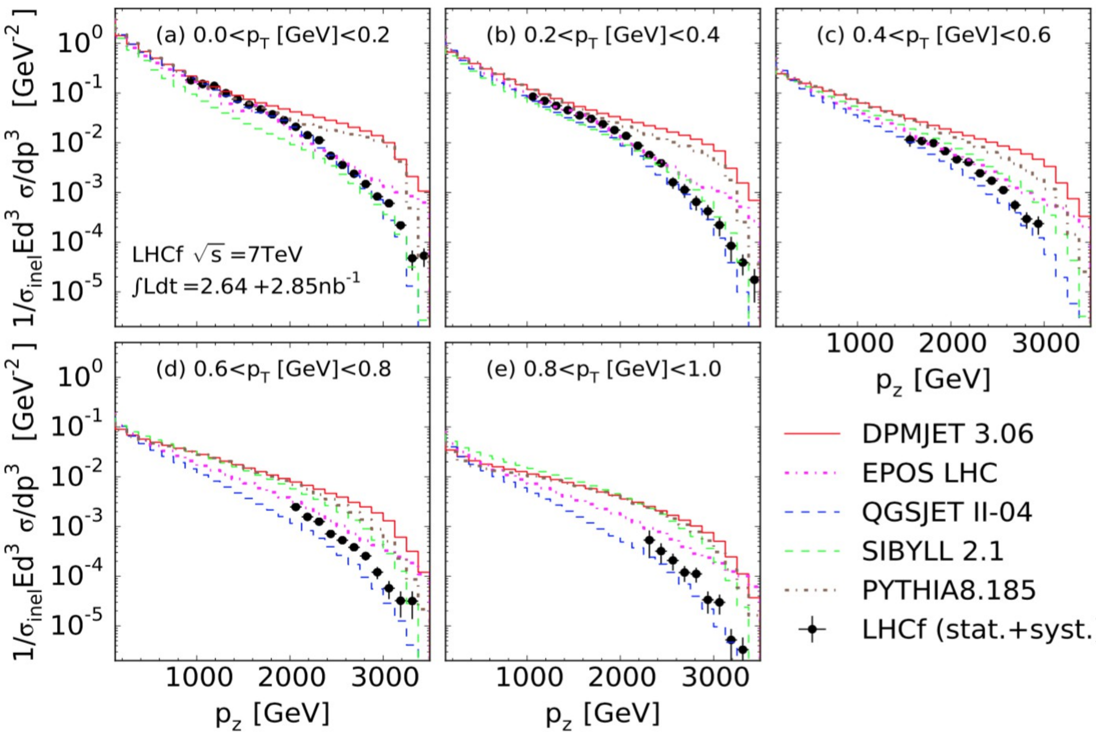


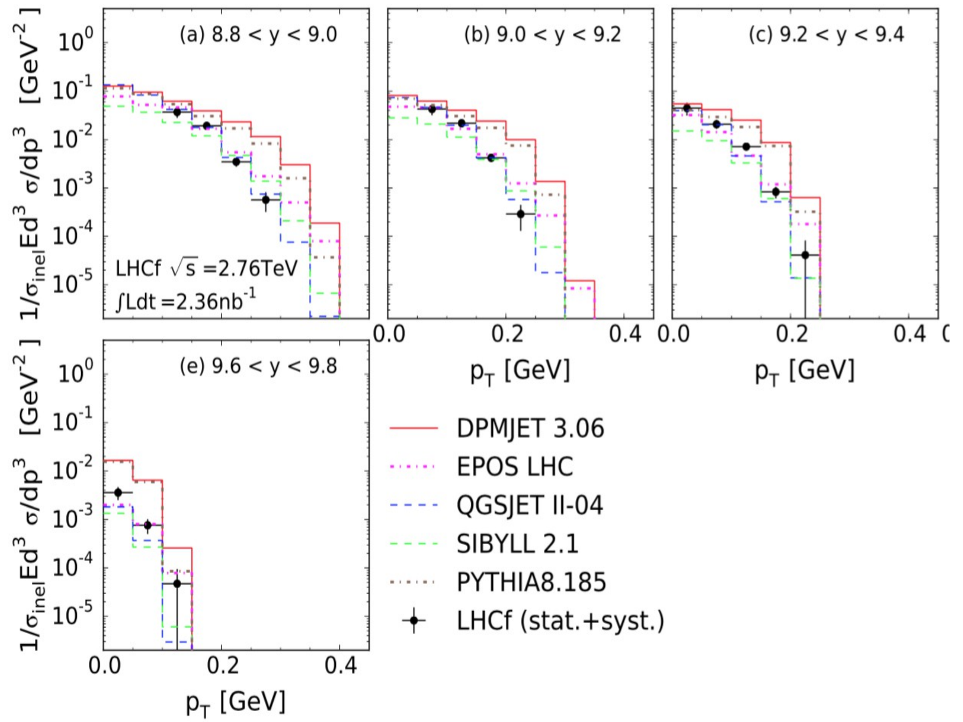


LHCf pions spectra and cross sections

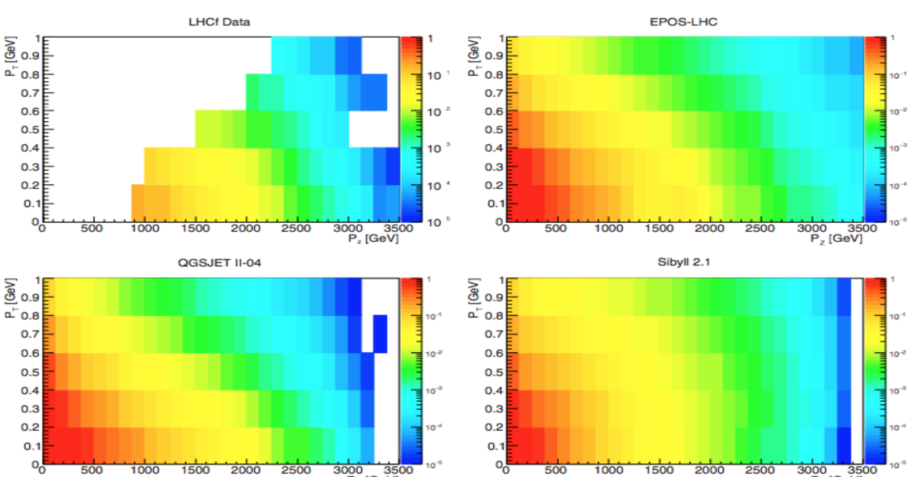
Forward $\pi 0$ Pz and P_T LHCf pp 7TeV

LHCf, arXiv1507.08764





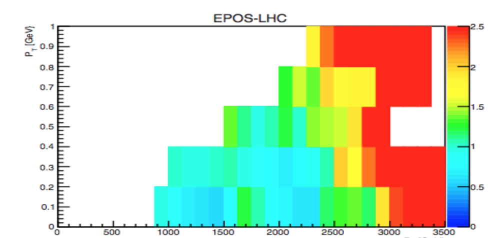
Cross sections $\pi 0$ in P_T-P_Z LHCf pp 7 TeV and EPOS-LHC, QGSJETII4, and SYBILL2.1

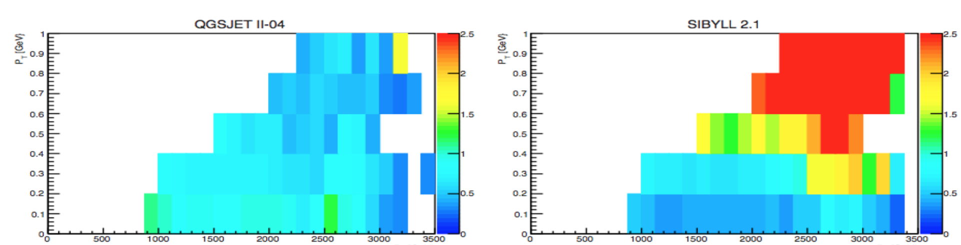


Ratios MC/Data

LHCf, T.Sako, ISVHECRI2016

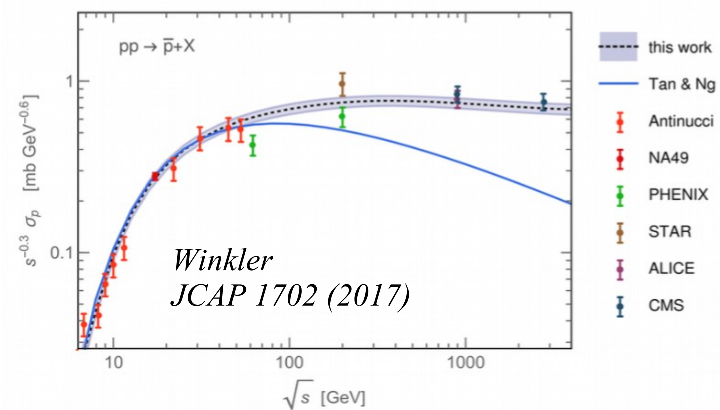
Good agreement for QGSJETII-4

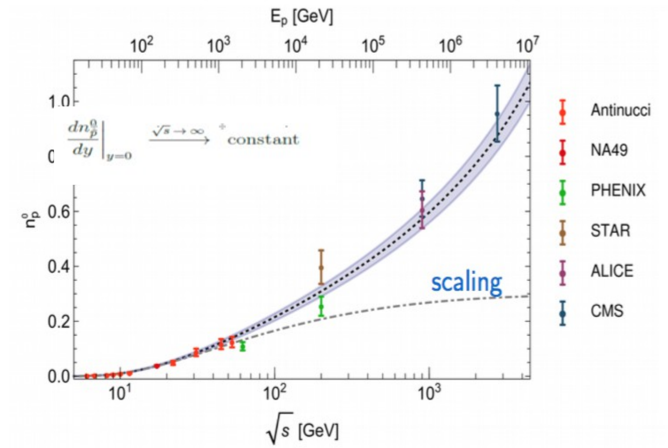




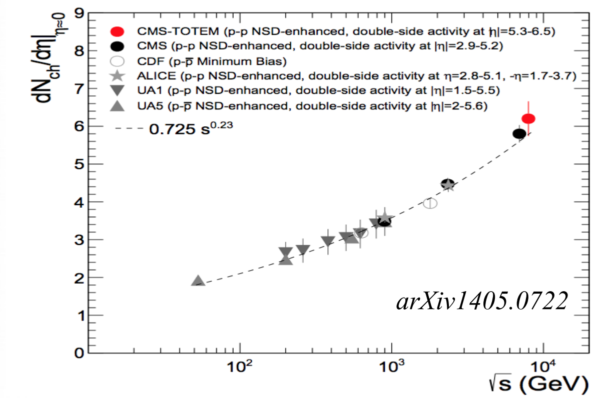
Antiprotons: $\sigma_{pp(\bar{p}X)}$ parameterizations and DMA

Scaling violations for $\bar{p}$ in RW parameterization

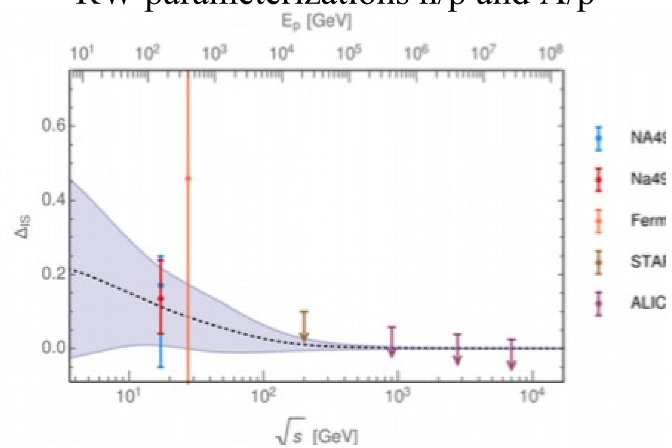


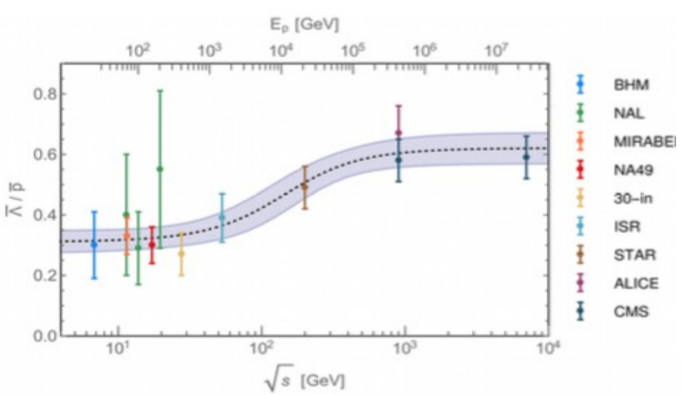


CMS TOTEM

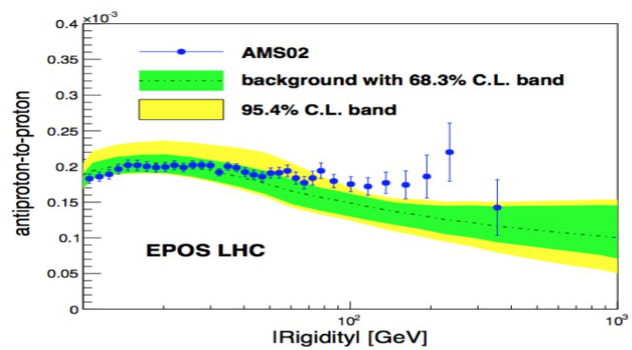


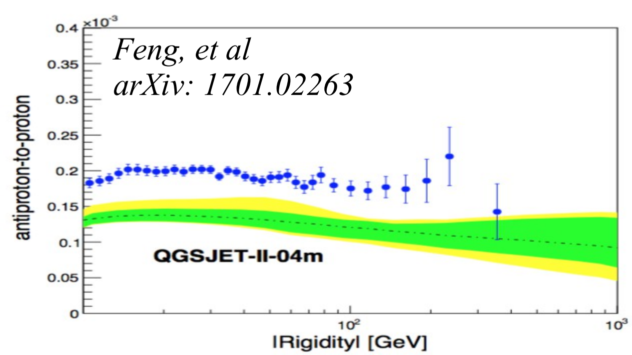
RW parameterizations n/p and Λ/p



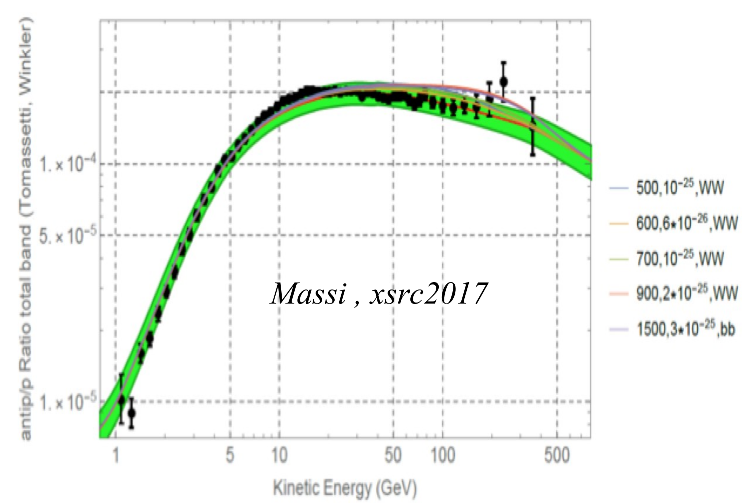


EPOS and QGSJET for p CR prediction



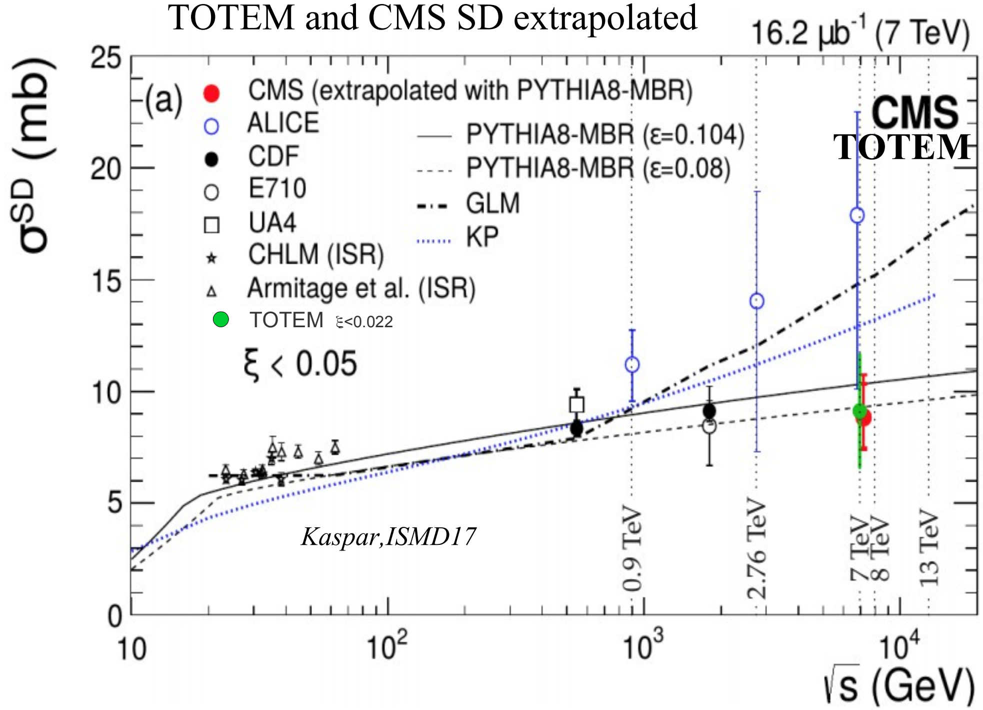


AMS02 $\bar{p}$/p total uncertainties and different DMA mass hypothesis M_{dm}=500-1500 GeV



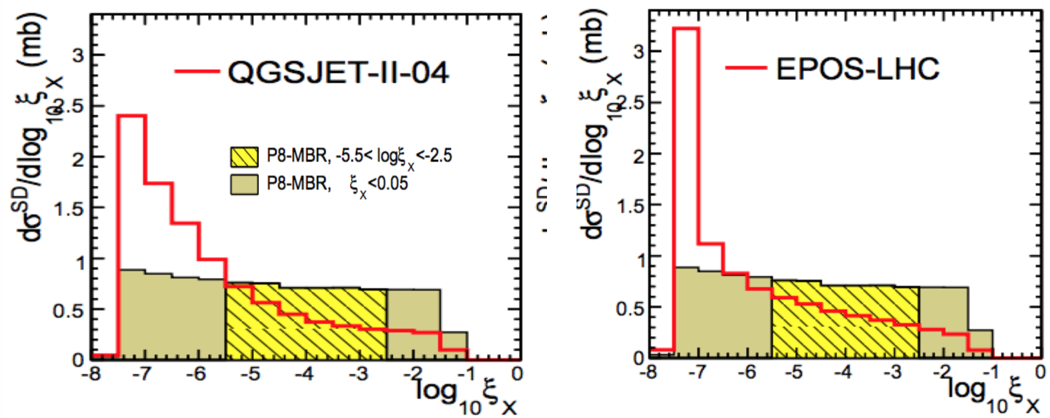
Diffraction

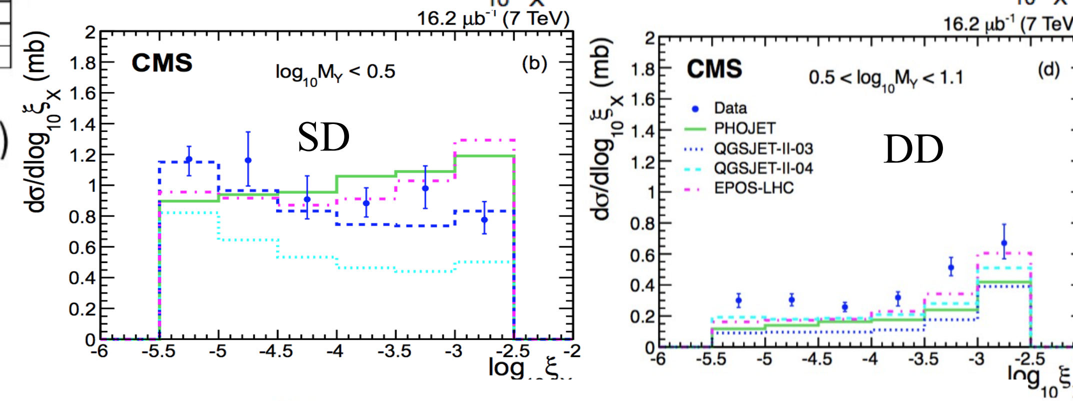
TOTEM and CMS SD extrapolated



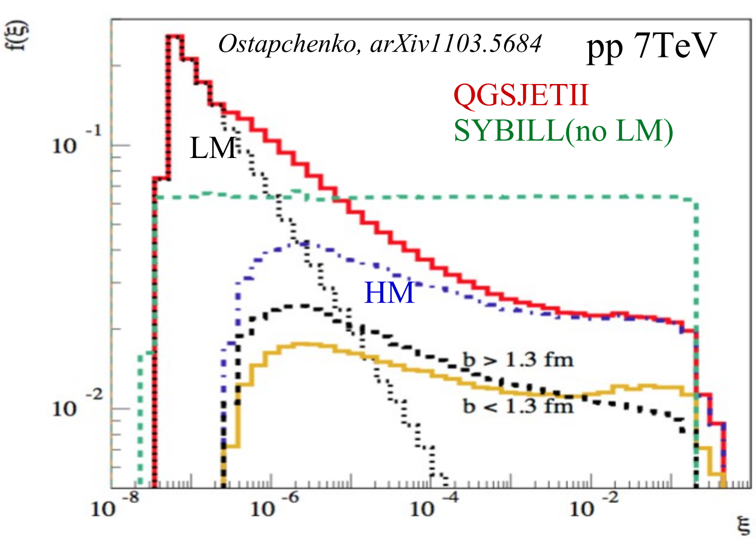
How to extrapolate to different mass regions?

Comparison of QGSJETII-04, EPOS-LHC and PYTHIA8-MBR (tuned to CMS data no LMD)

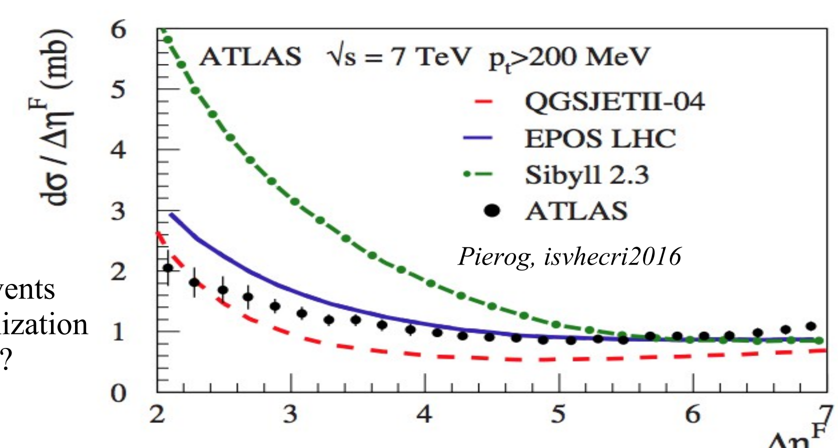




Mass distribution M_x^2/s for low and high mass SD



RG in minimum bias events or fluctuation of hadronization in inelastic production ?

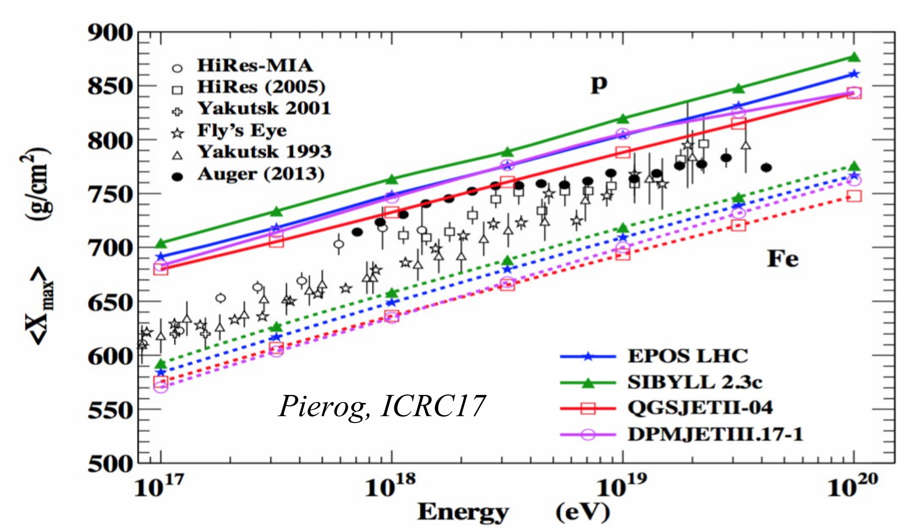


EAS models

EAS simulations:

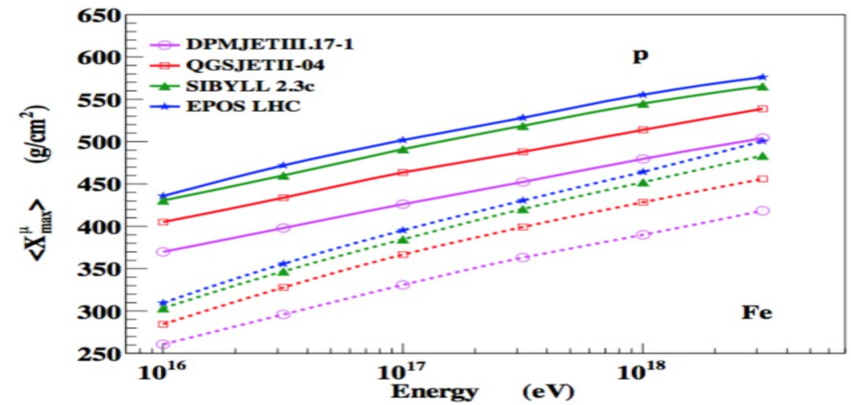
- CR spectra and composition for $E>10^{12}$eV important for CR model and DMA search
- Test of interaction models: $\overline{X}_{max}$, $\overline{X}^{\mu}_{max}$, $\sigma(X_{max})$ degeneracy of interactions and composition

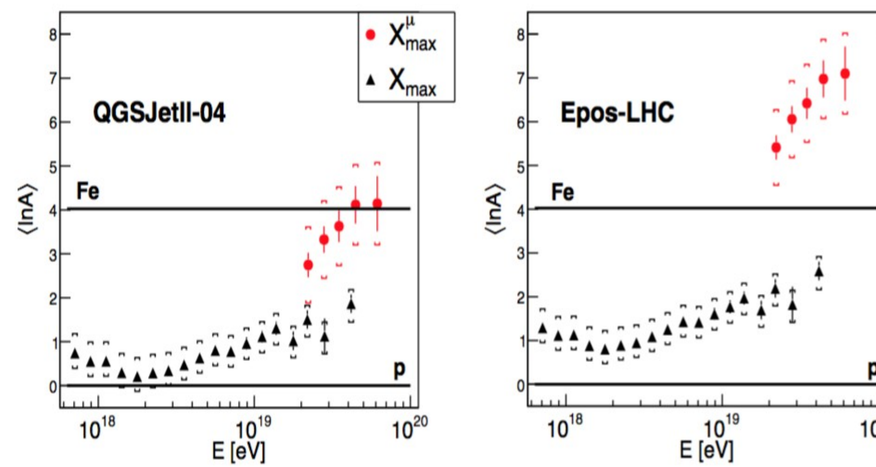
$\overline{X}_{max}$ data and prediction for p and Fe CR composition



large improvement on σ_{inel} and less for σ_{diffr}, K_{inel}, and pp to pA recalculations

Muon excess in EAS >10^{17} eV





X_{max} deeper than X^{μ}_{max} (heavier composition with X^{μ}_{max}) can be due to large p/n production and/or larger π-air diffraction.
Larger inelasticity, i.e. smaller diffraction for pions would shift X^{μ}_{max} to heavier component.

Pierog, ICRC17
Ostapchenko, EDS17

Cross sections

arXiv:1610.100038