Saturation and Diffraction at the LHC and the EIC

29 June 2021 to 1 July 2021

Results from the LHC on diffraction and hadron physics

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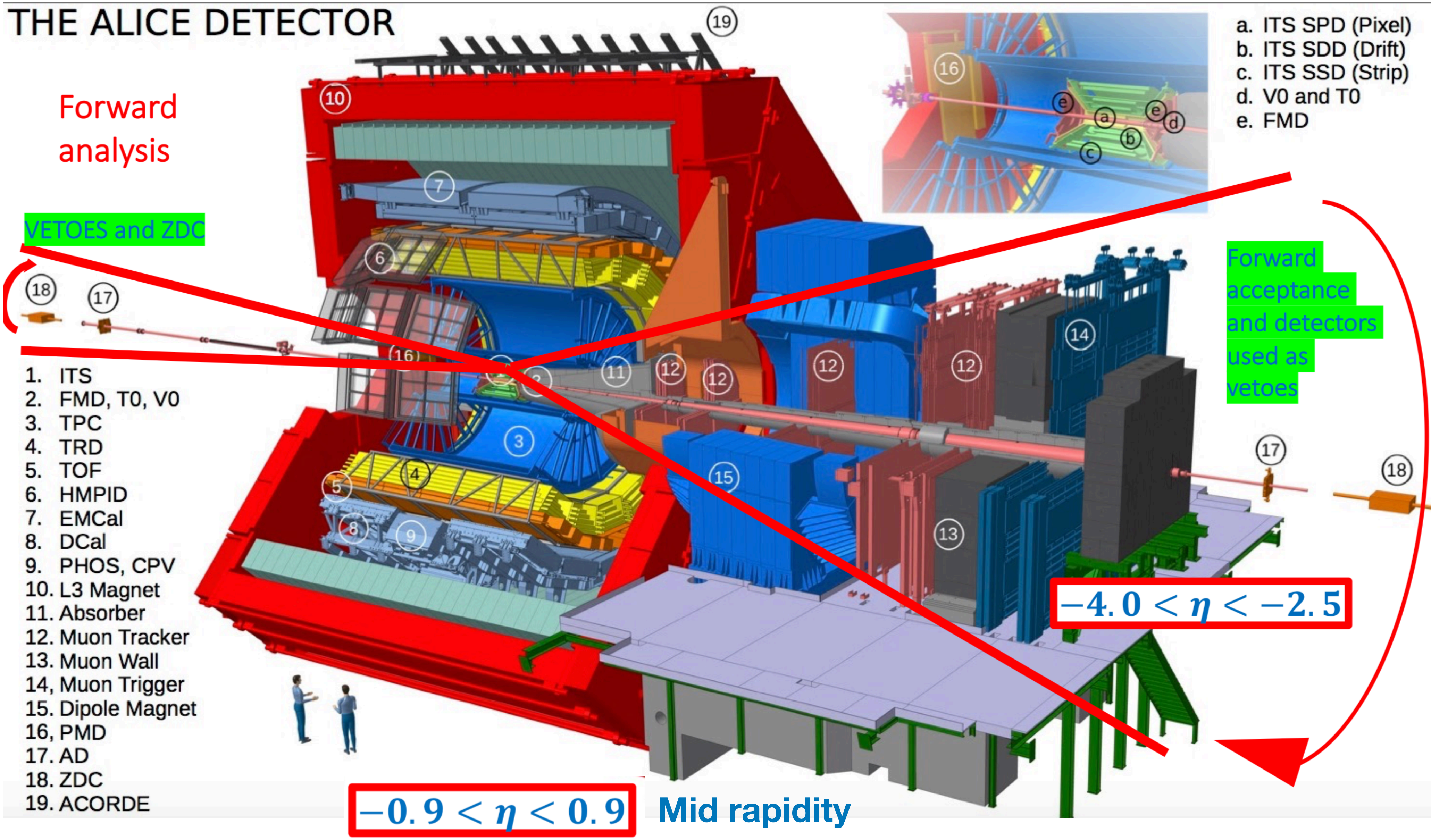
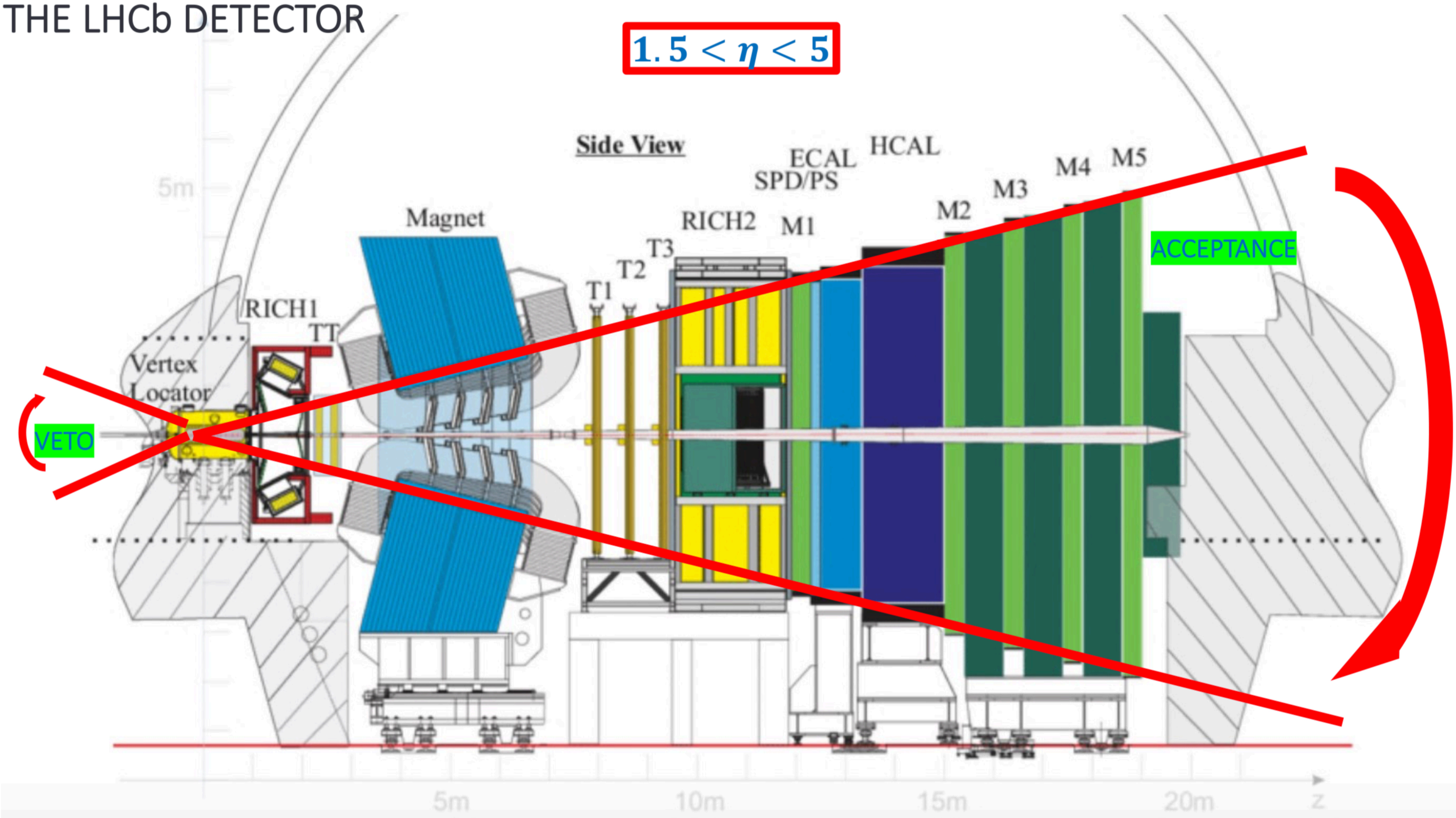
Cinvestav CONACYT

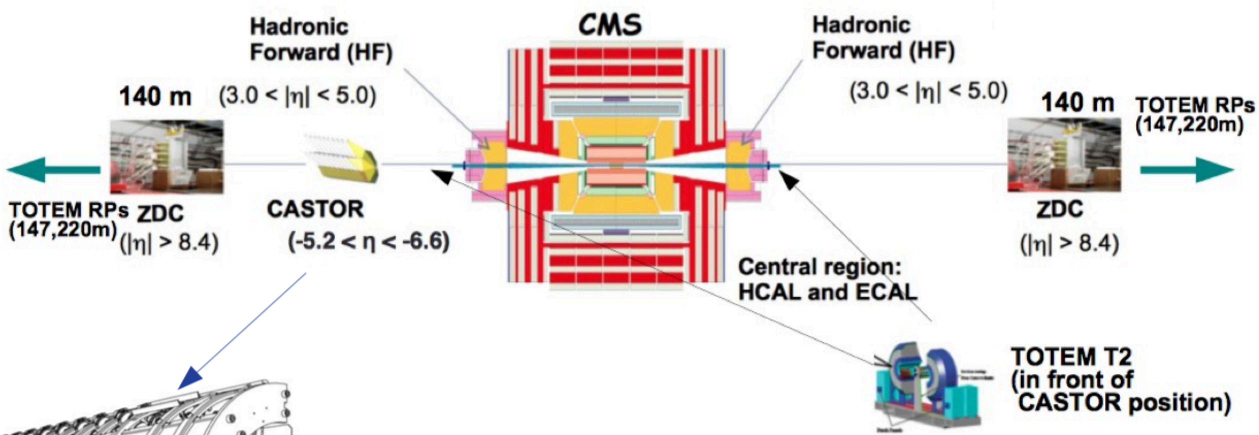

THE ALICE DETECTOR
Forward analysis
VETOES and ZDC
1. ITS
2. FMD, T0, V0
3. TPC
4. TRD
5. TOF
6. HMPID
7. EMCal
8. DCal
9. PHOS, CPV
10. L3 Magnet
11. Absorber
12. Muon Tracker
13. Muon Wall
14, Muon Trigger
15. Dipole Magnet
16, PMD
17. AD
18. ZDC
19. ACORDE
a. ITS SPD (Pixel)
b. ITS SDD (Drift)
c. ITS SSD (Strip)
d. V0 and T0
e. FMD
Forward acceptance and detectors used as vetoes
$-4.0 < \eta < -2.5$
$-0.9 < \eta < 0.9$
Mid rapidity

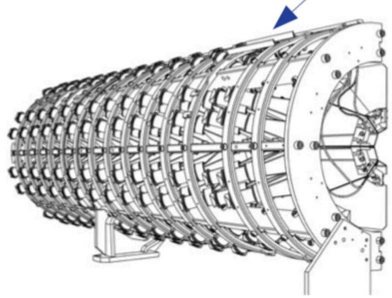
THE LHCb DETECTOR

$1.5 < \eta < 5$



Forward detectors at CMS



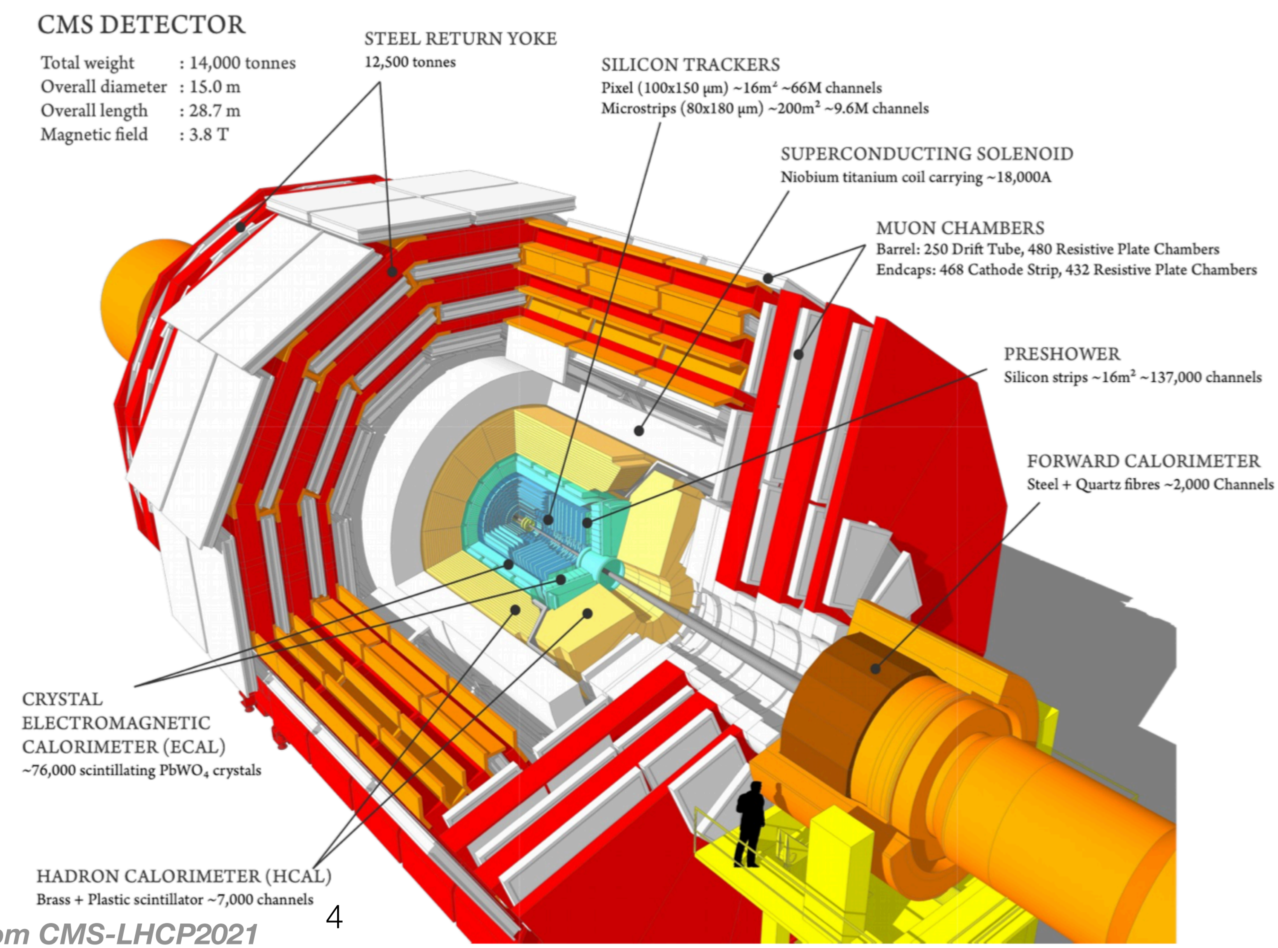


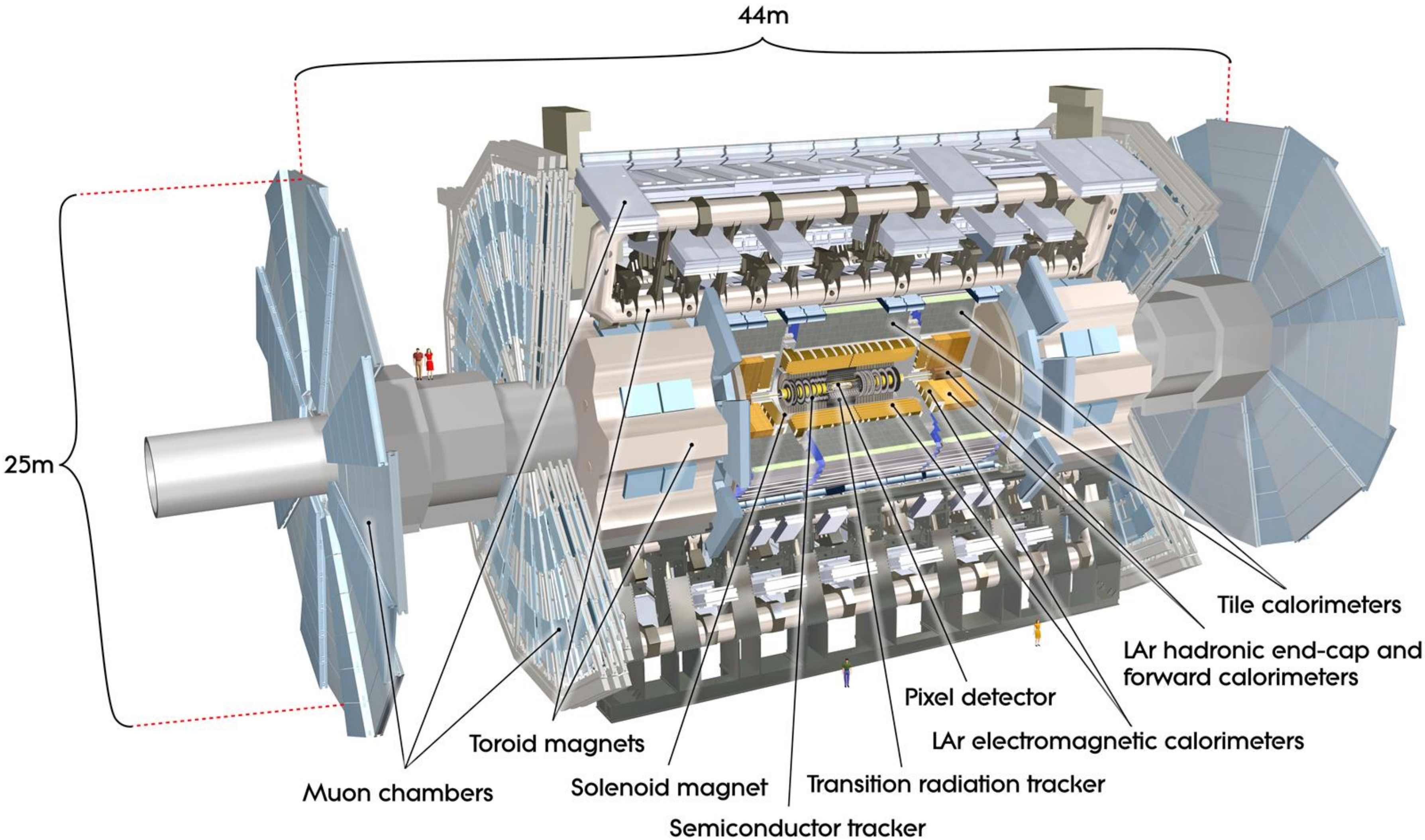
TOTal and Elastic Measurement (TOTEM)

- Dedicated for measuring total pp cross-section and understanding proton structure by elastic scattering
- Acceptance: $3.1 \leq |\eta| \leq 5$
- Consist of 2 near-beam telescopes: Roman Pot
- Leading protons measured at 147 m and 220 m from IP

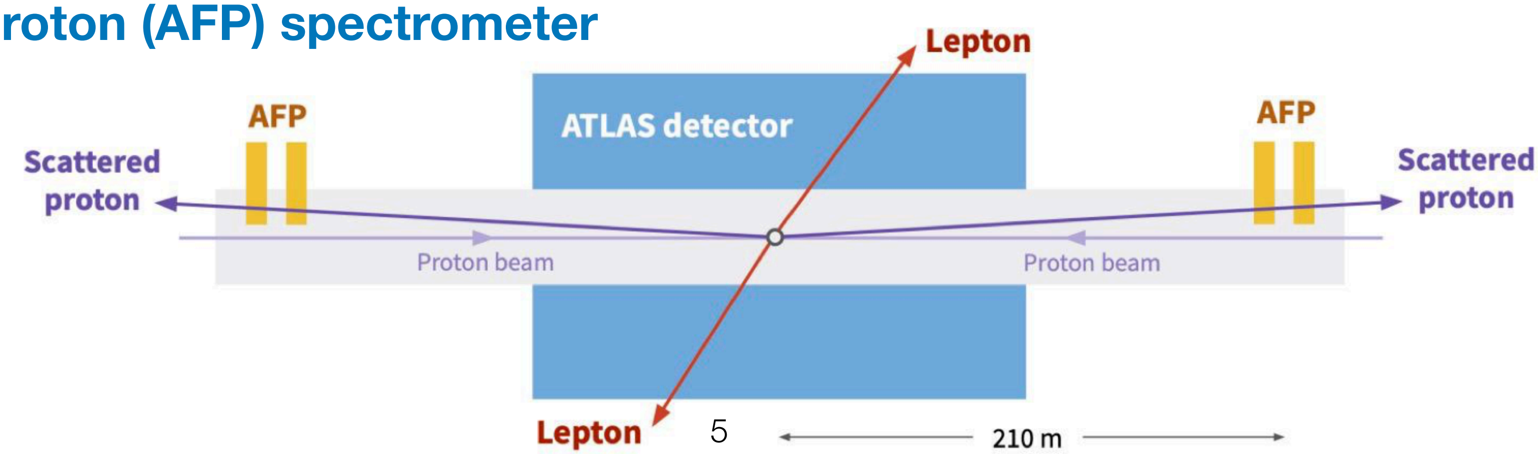
CASTOR at CMS

- CASTOR: EM-hadronic tungsten-quartz calorimeter at CMS
- Most forward conventional calorimeter deployed at the LHC, at 14 m from interaction point. Acceptance: $-6.6 \leq \eta \leq -5.2$
- Longitudinally 14-fold segmentation
- Transversally 16-fold segmentation
- CASTOR has no η segmentation! Consequence: measure energy of jets instead of p_T within its acceptance





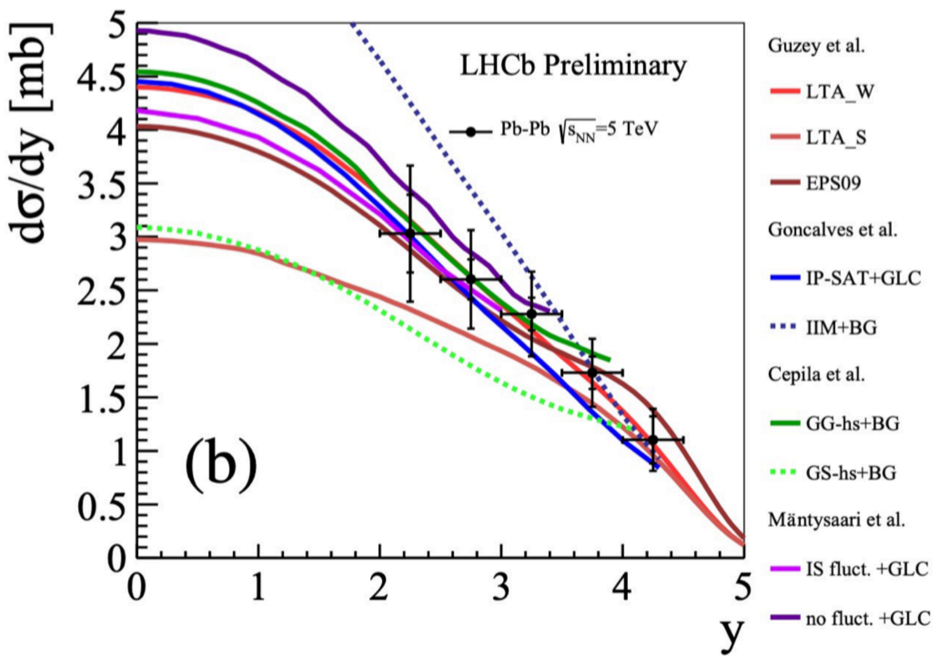
Forward Proton (AFP) spectrometer

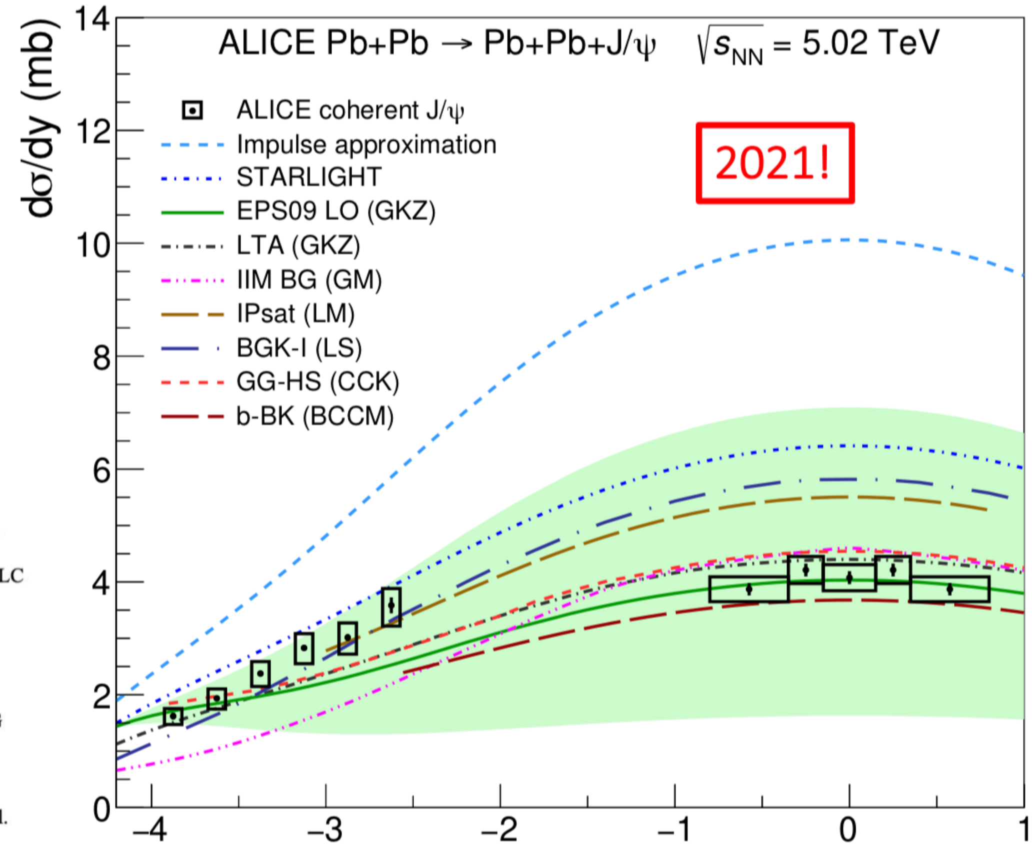


Coherent J/ψ cross section

ALICE, arxiv: 2101.04577 [nucl-ex]

- ALICE in tension with EPS09 at semi-forward rapidity, while LHCb agrees with it





LHCb, Nucl.Phys.A 1005 (2021) 121902, LHCb-CONF-2018-003

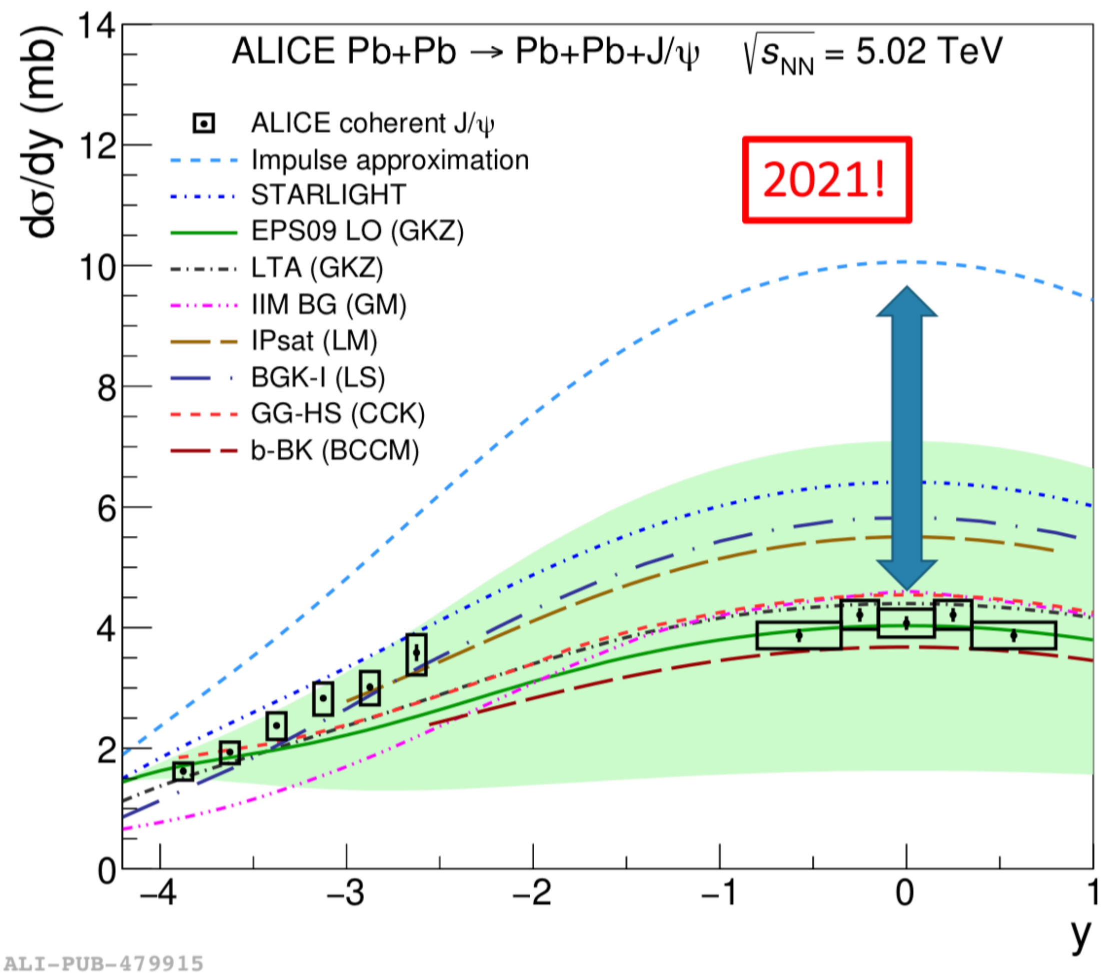
Coherent J/ψ cross section

- Nuclear suppression factor (easier at midrapidity)

$$S_{\mathrm{Pb}} = \sqrt{\frac{d\sigma}{dy}_{\mathrm{data}} \Big/ \frac{d\sigma}{dy}_{\mathrm{IA}}} \sim 0.63$$

- IA = Impulse Approximation (no nuclear effects)
- $S(W_{\gamma p})$ - Nuclear Suppression Factor - provides a way to test the consistency of the data with the available nuclear and nucleon PDFs and to measure the gluon shadowing factor

ALICE, arxiv: 2101.04577 [nucl-ex]



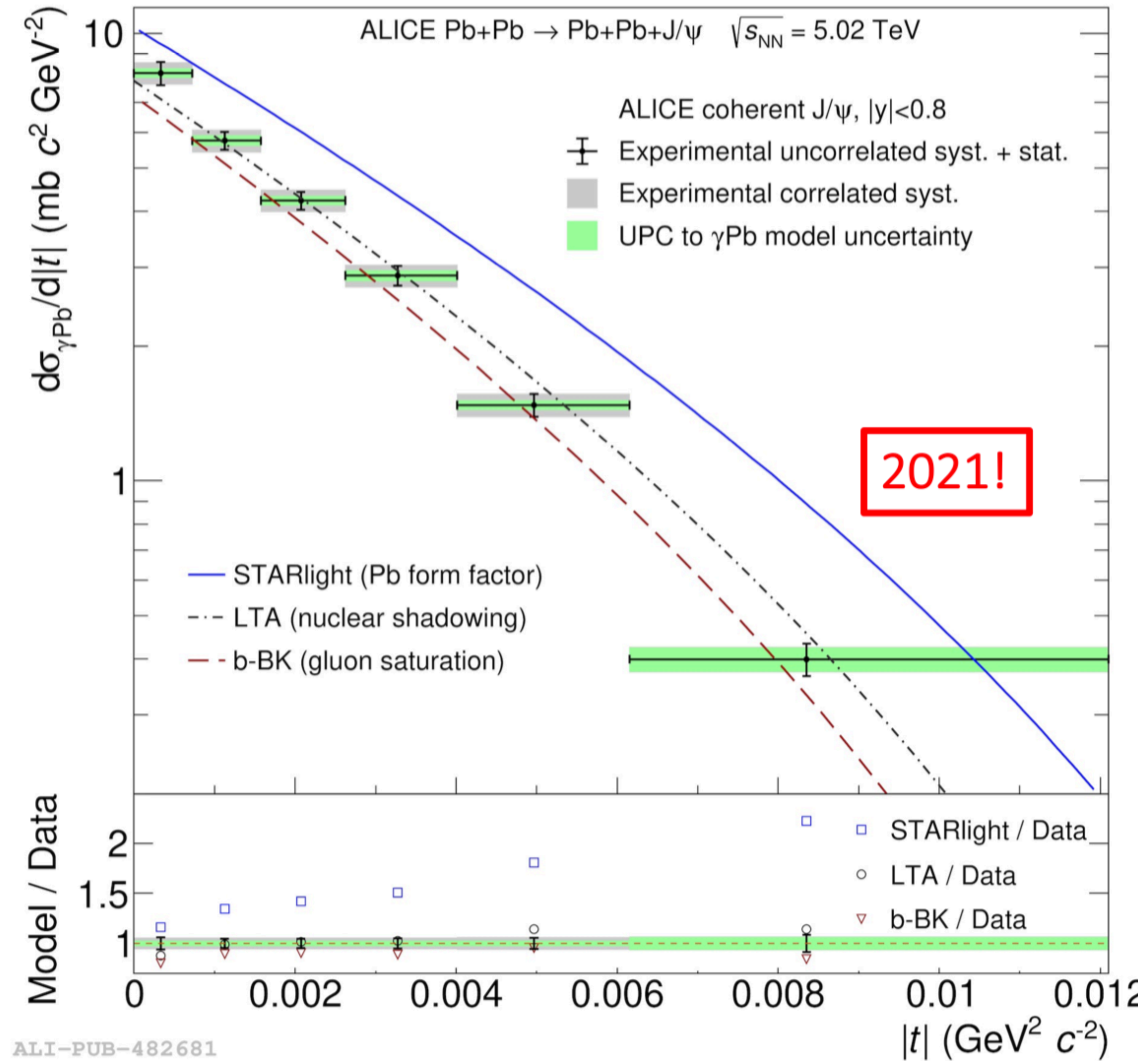
Coherent J/ψ t-dependence

- From p_T^2-dependent photoproduction to $|t|$-dependent photonuclear production

$$\left.\frac{d^2\sigma^{coh}_{J/\psi}}{dy\,dp_T^2}\right|_{y=0} = 2n_{\gamma Pb}(y=0)\frac{d\sigma_{\gamma Pb}}{d|t|}$$

- Probing the transverse gluonic structure of the nucleus at low x

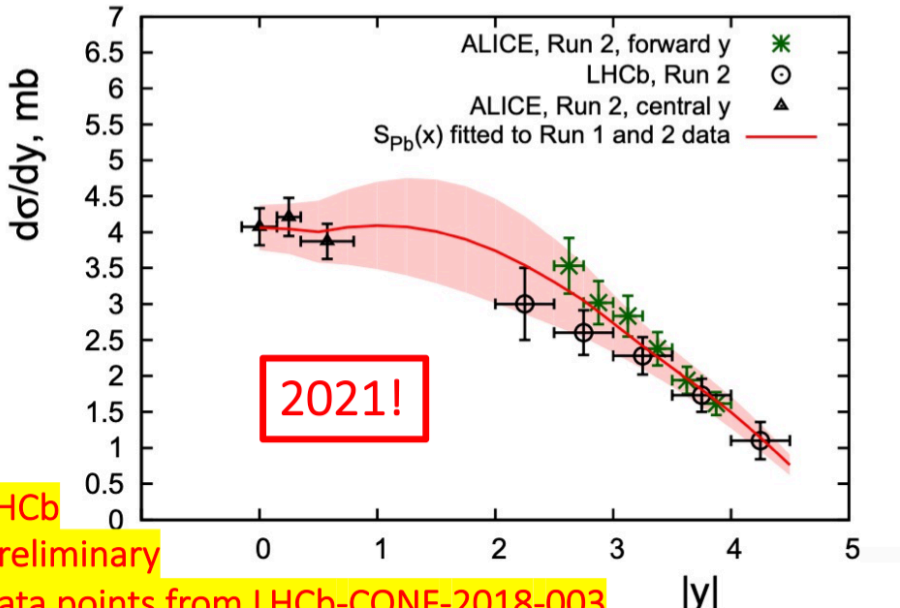
ALICE, Phys.Lett.B 817 (2021) 13628



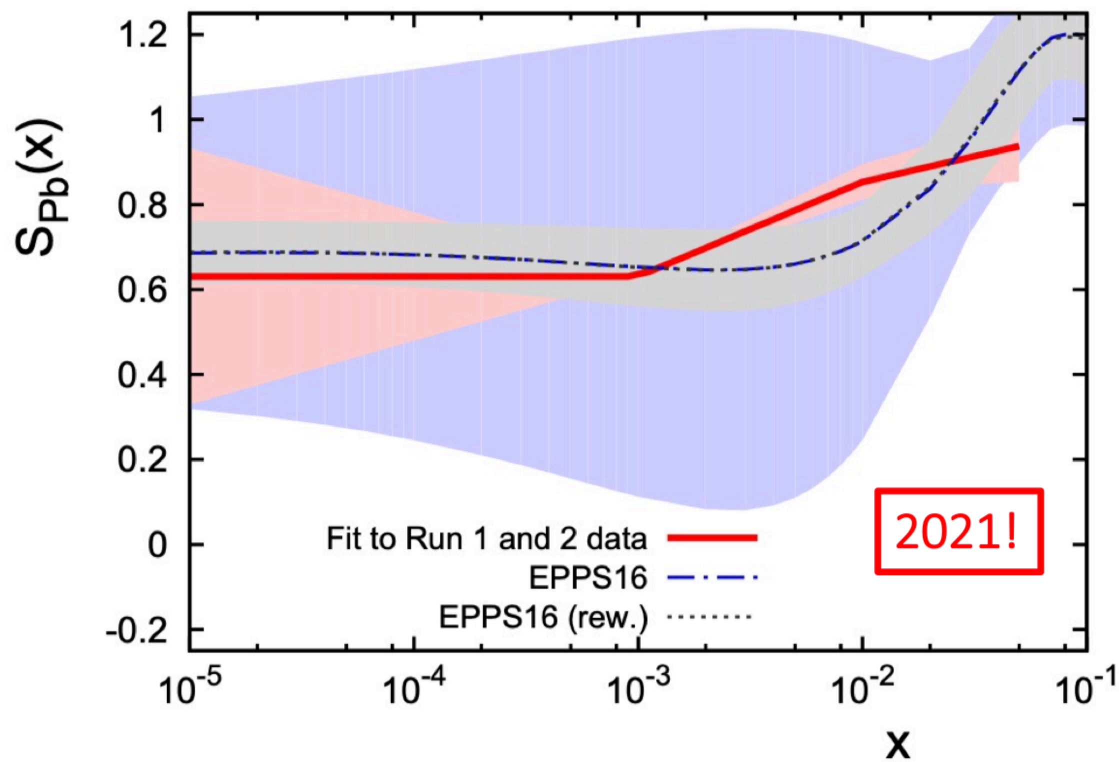
2021!

Guzey, Kryshen, Strikman, Zhalov, Phys.Lett.B 816 (2021) 136202

$$S(W_{\gamma p}) = \left[\frac{\sigma^{\rm exp}_{\gamma Pb \to J/\psi Pb}(W_{\gamma p})}{\sigma^{\rm IA}_{\gamma Pb \to J/\psi Pb}((W_{\gamma p})} \right]^{1/2}$$

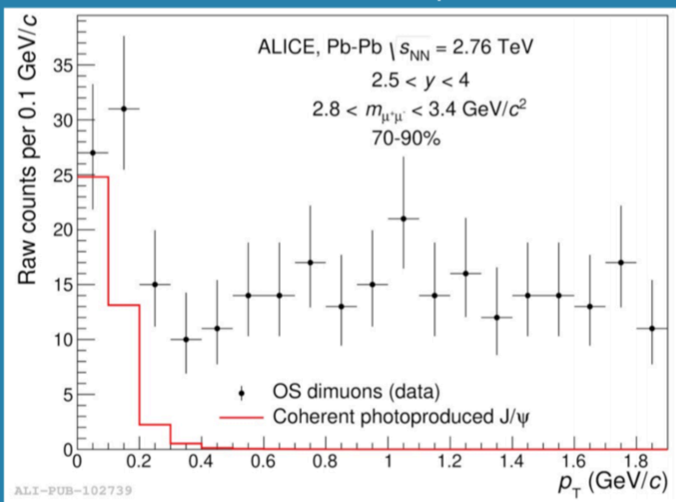


LHCb preliminary
data points from LHCb-CONF-2018-003

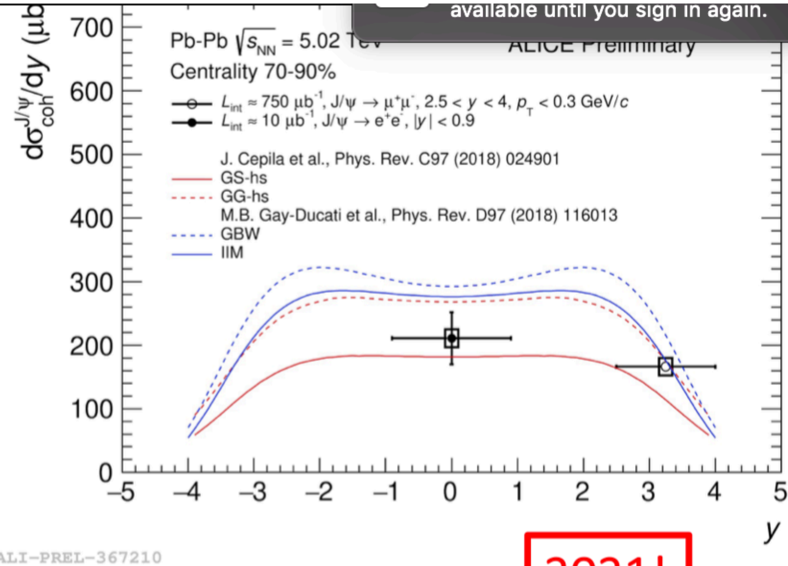


Peripheral J/ψ photoproduction

- First observed with Run 1 data by ALICE
- Now confirmed with Run 2 statistics by both ALICE and LHCb. STAR also reports this

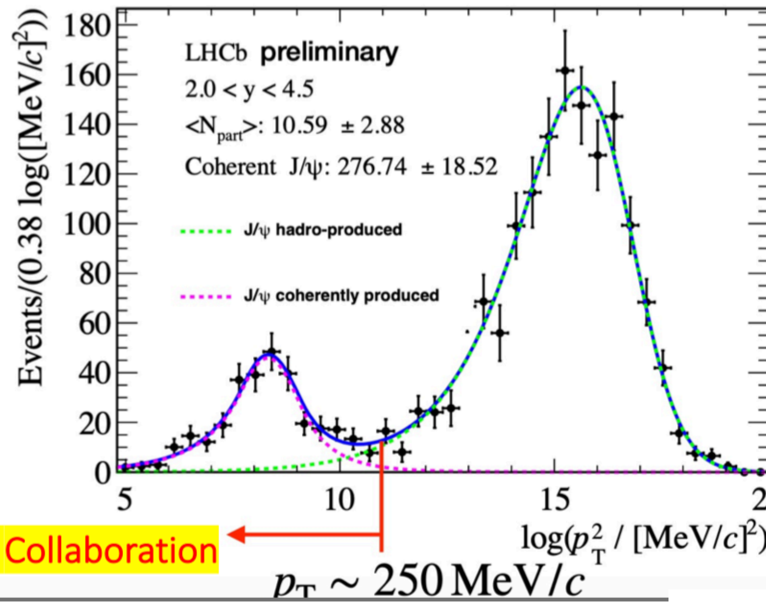


ALICE, EPL (Europhysics Letters), Volume 129, Number 4



STAR Collaboration, PRL 123, 132302 (2019)

2021!



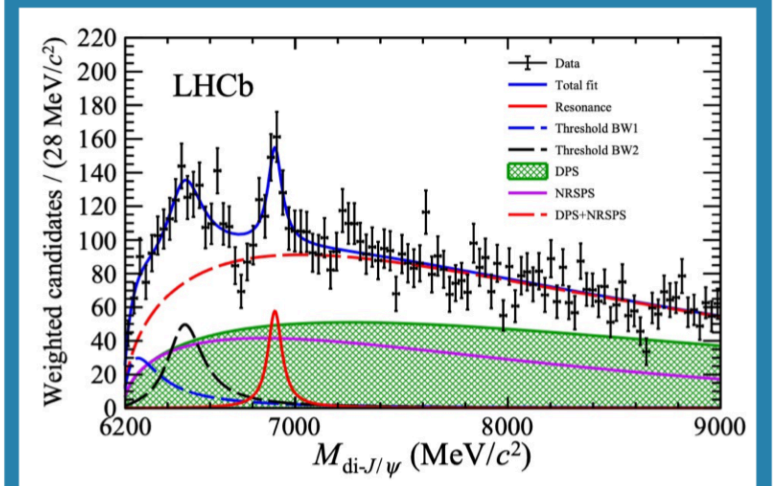
2021!

LHCb-PAPER-2020-043 in preparation

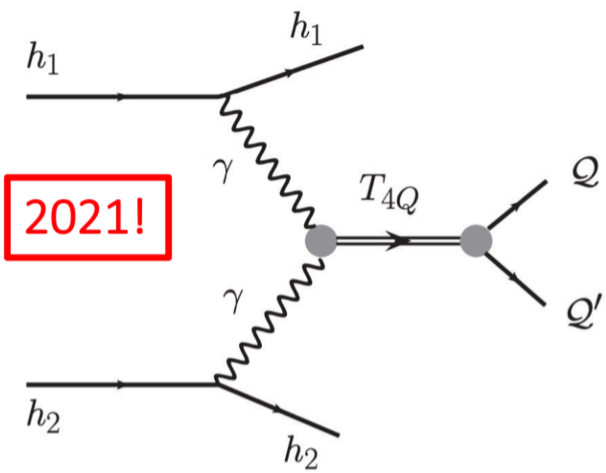
DIS talk by Óscar Boente García on behalf of the LHCb Collaboration

UPC potential for tetraquark discoveries

- LHCb has observed a state interpreted as a tetraquark state $T_{cc\bar{c}\bar{c}}$ in inclusive sample



LHCb, arxiv: 2006.16957[hep-ex]



2021!

V. Gonçalves, B. Moreira, Phys. Lett. B 816 (2021) 136249:

UPC potential for tetraquark searches in ALICE and LHCb!

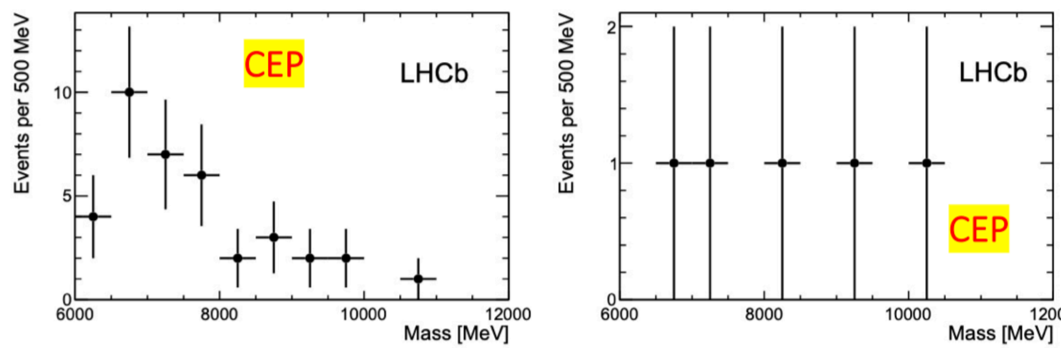
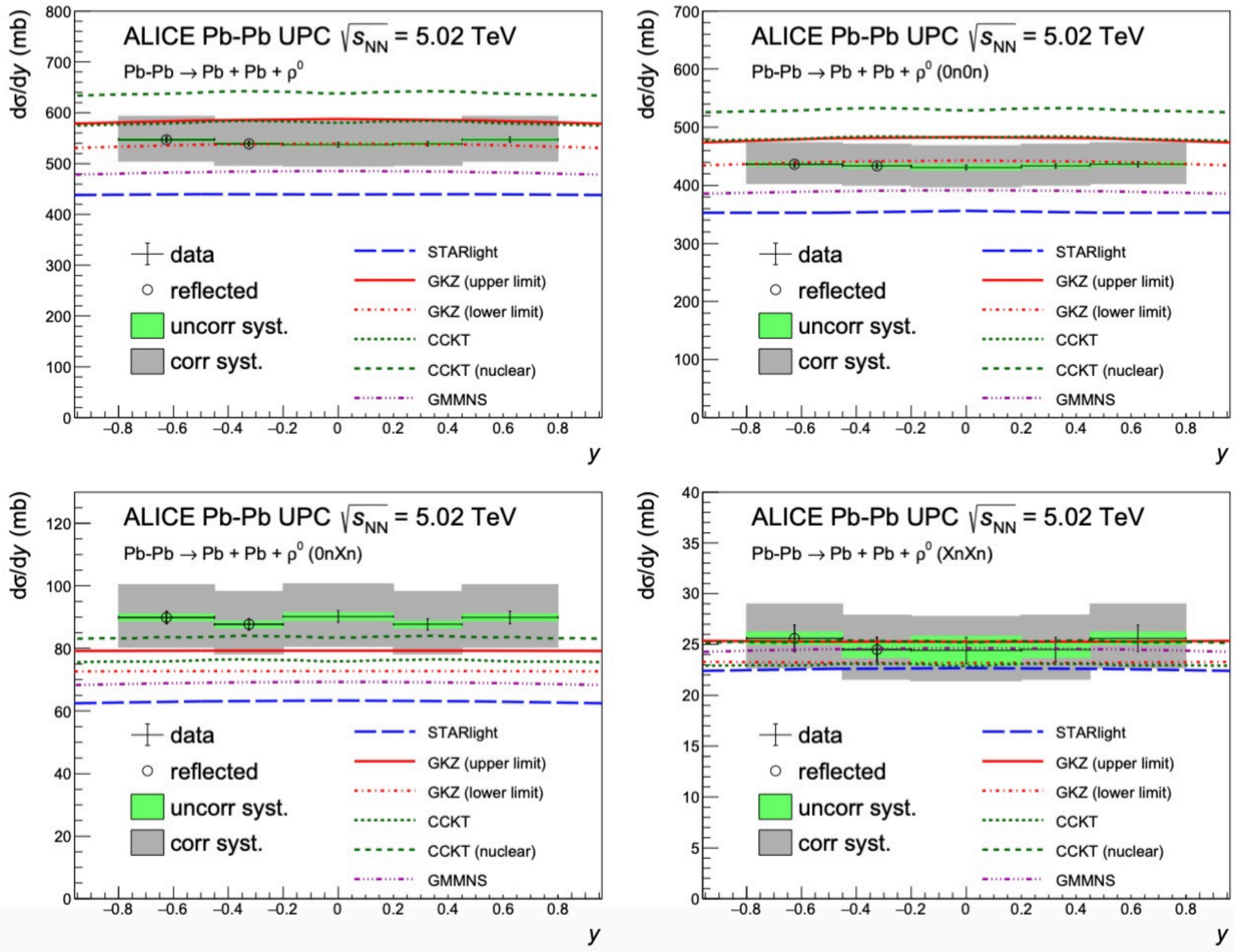


Figure 3: Invariant mass of the four-muon system in (left) $J/\psi\, J/\psi$ and (right) $J/\psi\, \psi(2S)$ events.

LHCb, J. Phys. G: Nucl. Part. Phys. 41 (2014) 115002

Coherent ρ^0 in Pb-Pb

- Generally good agreement with models on the market
- A good proof-of-principle while waiting for reduced uncertainties and better agreement between models
- Different neutron emission classes = different impact parameters
- $\langle b_{XNXN} \rangle < \langle b_{XN0N} \rangle < \langle b_{0N0N} \rangle$
- Factorization holds

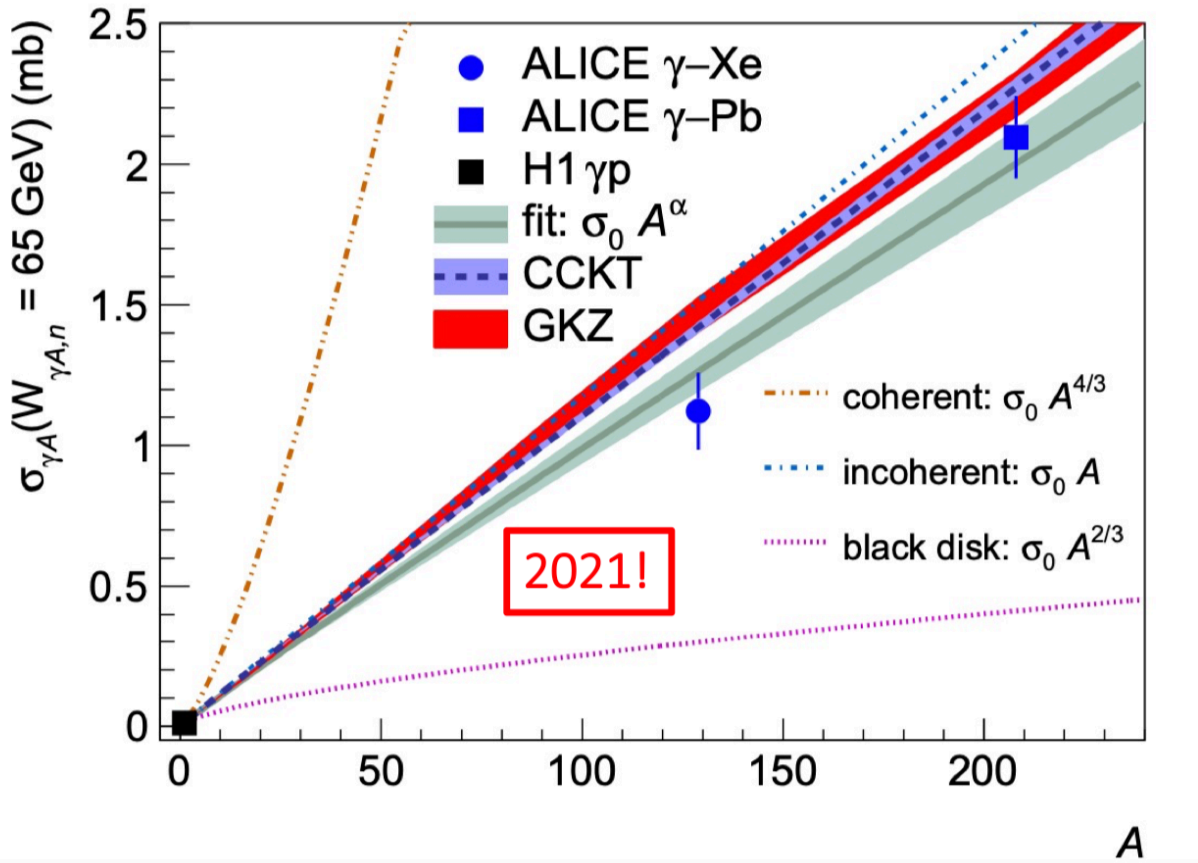


ALICE, JHEP06 (2020) 35

Coherent ρ^0 and BDR

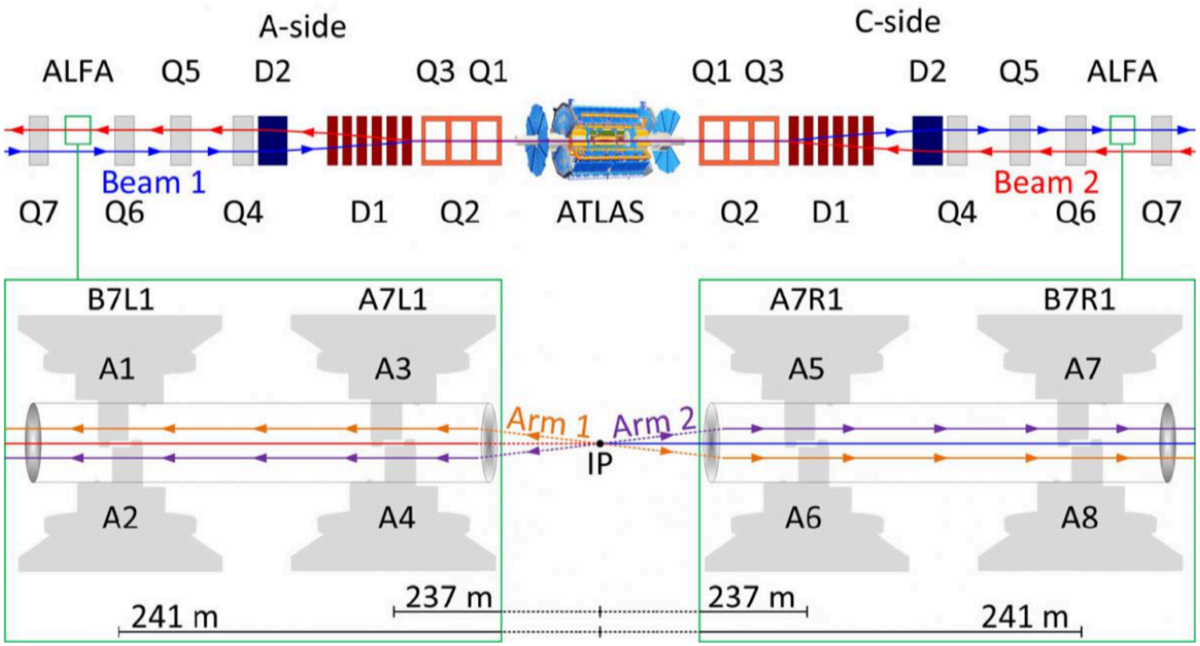
- Three collision systems available now (p, Pb, Xe)
- First fit to obtain the A dependence!
- Black disk regime (BDR) quite far away
- Models based on Gribov-Glauber shadowing (GKZ) or hot-spots (CCKT) describe the data reasonably well

ALICE, 2101.02581 [nucl-ex]

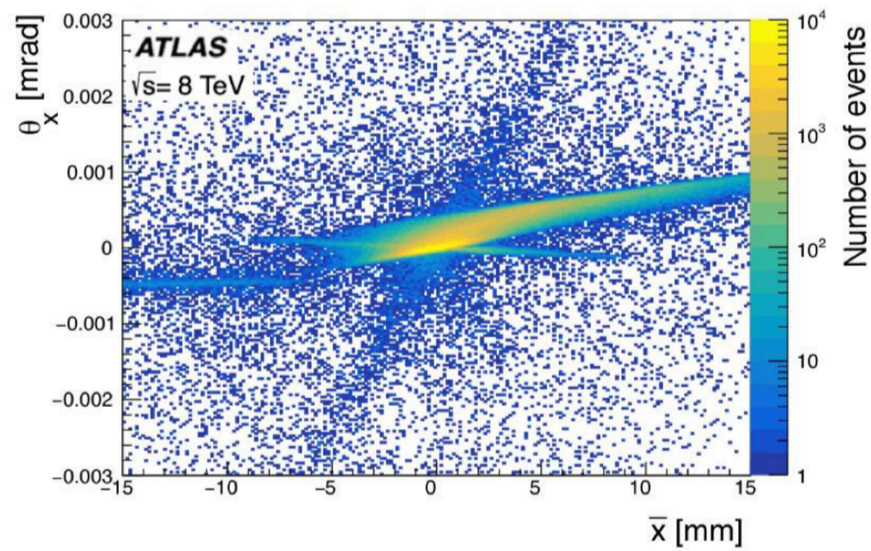


Inclusive single diffractive dissociation cross-section of pp collisions at 8 TeV, JHEP 02 (2020) 042, 24.11 nb^{-1}

- ALFA Roman Pot stations in the outgoing LHC beams
- Data from special run: $\beta^* = 90$ m, L = 1.67 nb^{-1}, $\mu < 0.08$



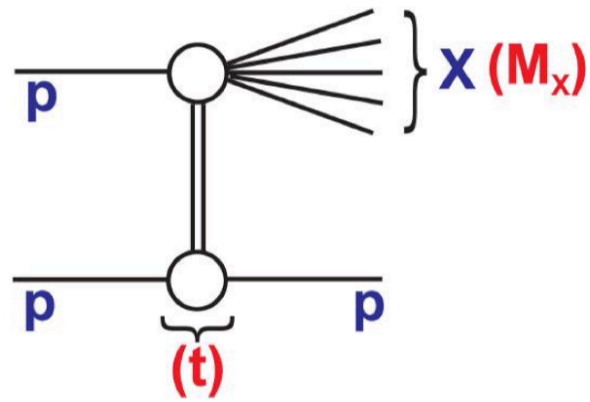
Average scattered proton x position in ALFA versus angle in the x-z plane



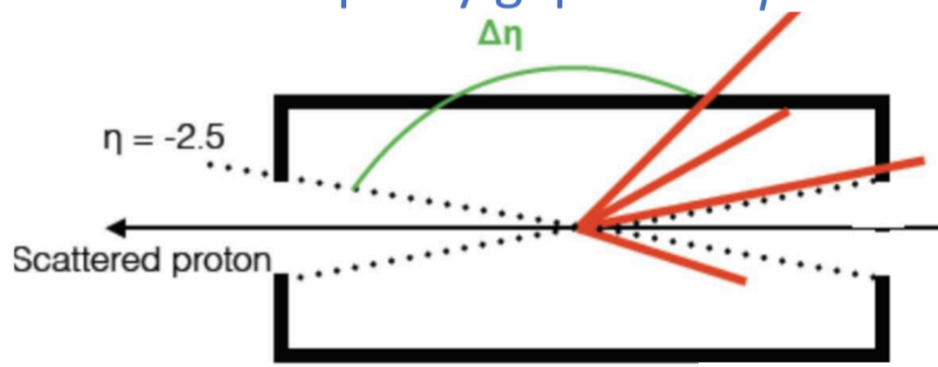
Taken from LHCP 2021, A. Sopczack

Inclusive single diffractive dissociation cross-section of pp collisions at 8 TeV, JHEP 02 (2020) 042, 24.11 nb^{-1}

- Single diffractive dissociation (SD), kinematics: squared four-momentum transfer, t, mass, M_X, of the dissociated system X, proton energy loss $\xi = 1 - E_p/E_{beam}$
- Hadron-level cross-sections: σ versus t, ξ, Δη
- Background from non-SD pp collisions
  - Correlated signals in ALFA and the Inner Detector (estimated from MC)
  - Overlay background: coincidences of a signal in ALFA with an uncorrelated signal in the Inner Detector (data-driven estimate, contributes the largest uncertainty)



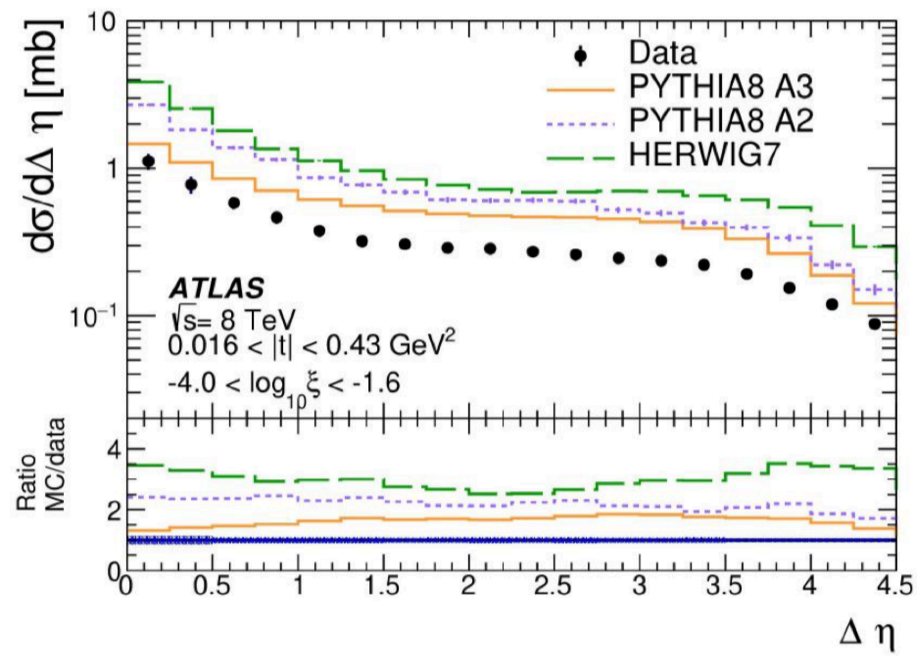
Rapidity gap size $\Delta\eta$



Taken from LHCP 2021, A. Sopczack

Inclusive single diffractive dissociation cross-section of pp collisions at 8 TeV, JHEP 02 (2020) 042, 24.11 nb^{-1}

- Hadron-level differential SD cross section as a function of $\Delta\eta$
- Diffractive plateau is visible
- Increase at small rapidity gaps: restricted rapidity region corresponding to the ATLAS tracker acceptance
- Decrease at large rapidity gaps: fiducial range restriction (loss of small-ξ events close to the ξ-edge)
- Generators describe the shape reasonably, but overestimate the cross-section

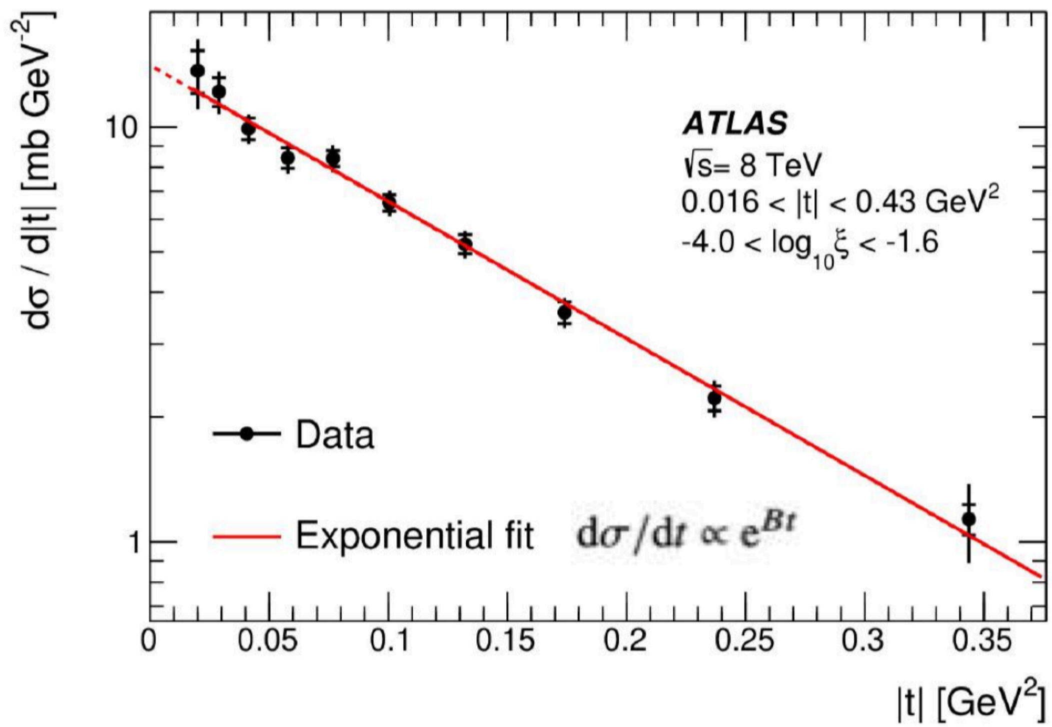


Distribution	$\sigma_{SD}^{fiducial(\xi,t)}$ [mb]	$\sigma_{SD}^{t\text{-extrap}}$ [mb]
Data	1.59 ± 0.13	1.88 ± 0.15
PYTHIA8 A2 (Schuler–Sjöstrand)	3.69	4.35
PYTHIA8 A3 (Donnachie–Landshoff)	2.52	2.98
HERWIG7	4.96	6.11

Taken from LHCP 2021, A. Sopczack

Inclusive single diffractive dissociation cross-section of pp collisions at 8 TeV, JHEP 02 (2020) 042, 24.11 nb^{-1}

- Differential cross-section as function of |t|
- Inner error bars stat. uncertainties and outer error bars stat. and syst.
- Generator predictions
  PHYS-PUB-2016-017
  Pythia8 A2: B = 7.82 GeV^{-2}
  Pythia8 A3: B = 7.10 GeV^{-2}
- Measurement
  B=7.65±0.26(stat.)±0.22(syst.) GeV^{-2}
  Systematics dominated by proton overlay backgrounds

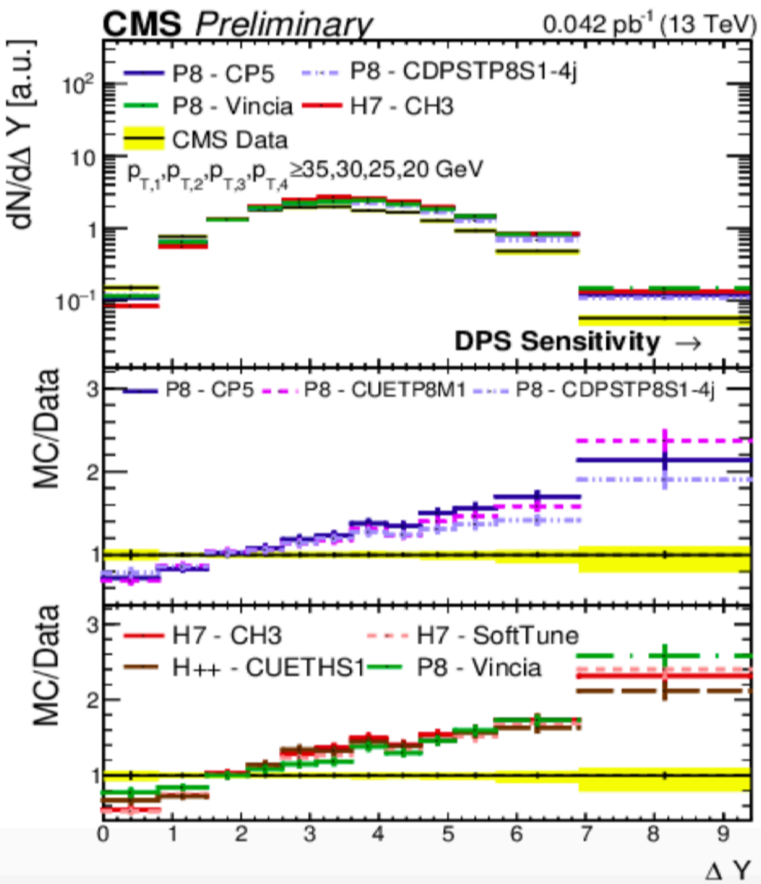


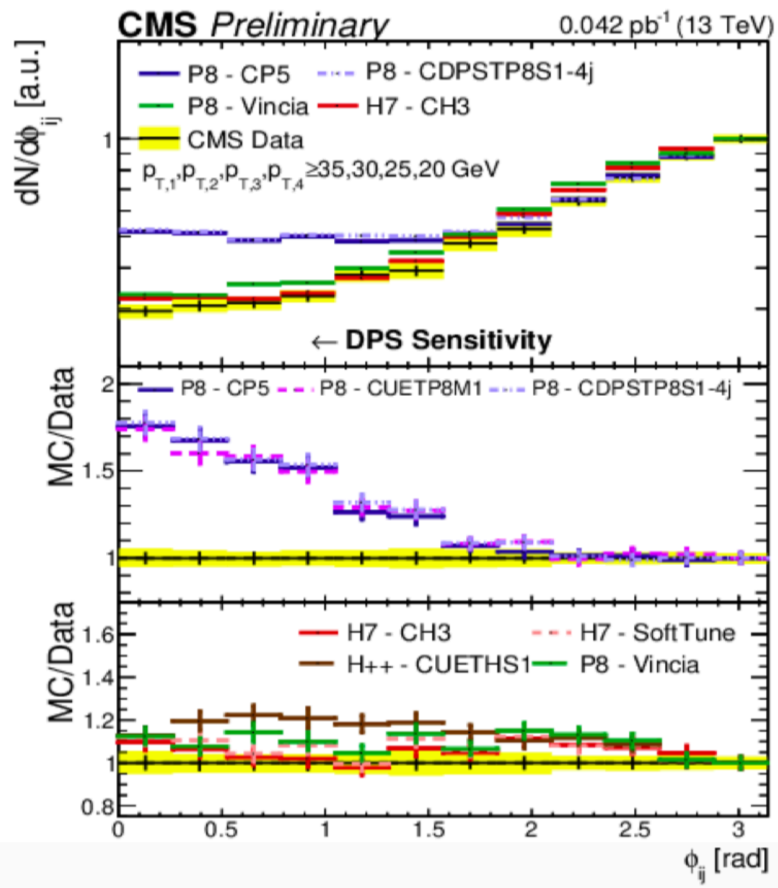
Taken from LHCP 2021, A. Sopczack

DPS studies in 4-jets with low p_T at 13 TeV (CMS-PAS-20-007)

NEW

- ΔY (left) and Φ_{ij} (right)
  - Normalization to first four bins for ΔY and the last bin for Φ_{ij}
- LO Models overshoot the data due to excess of forward/backward low p_T jets.
- Abs. cross-section prediction improves with NLO or high multiplicity ME (not true for all models)
- Φ_{ij} favor angular ordered/dipole antenna PS models over p_T-ordered showers.





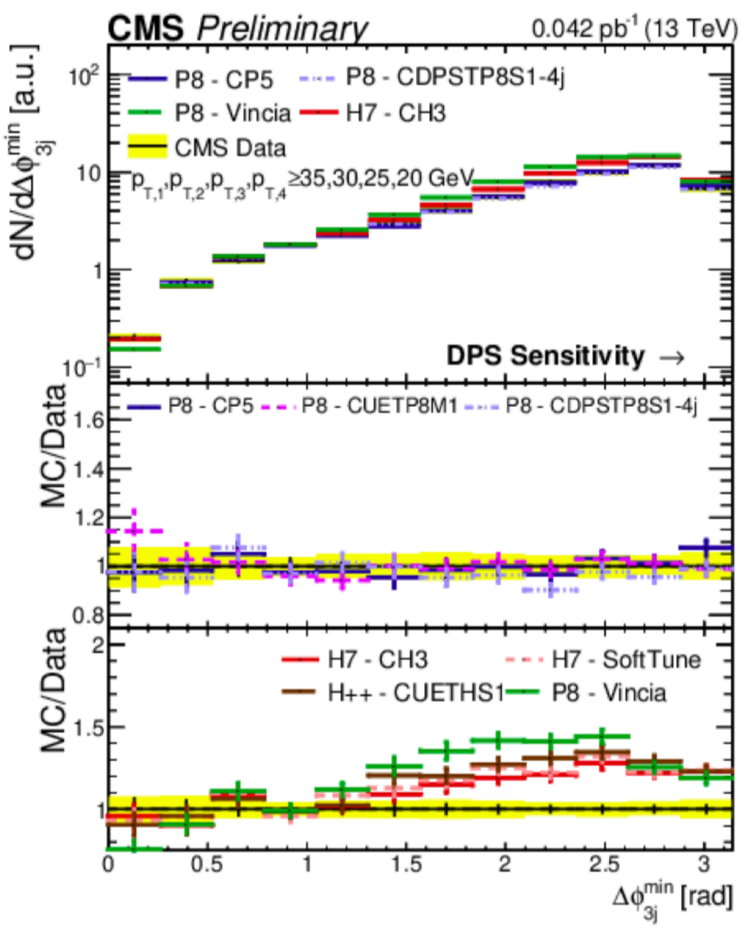
DPS studies in 4-jets with low p_T at 13 TeV (CMS-PAS-20-007)

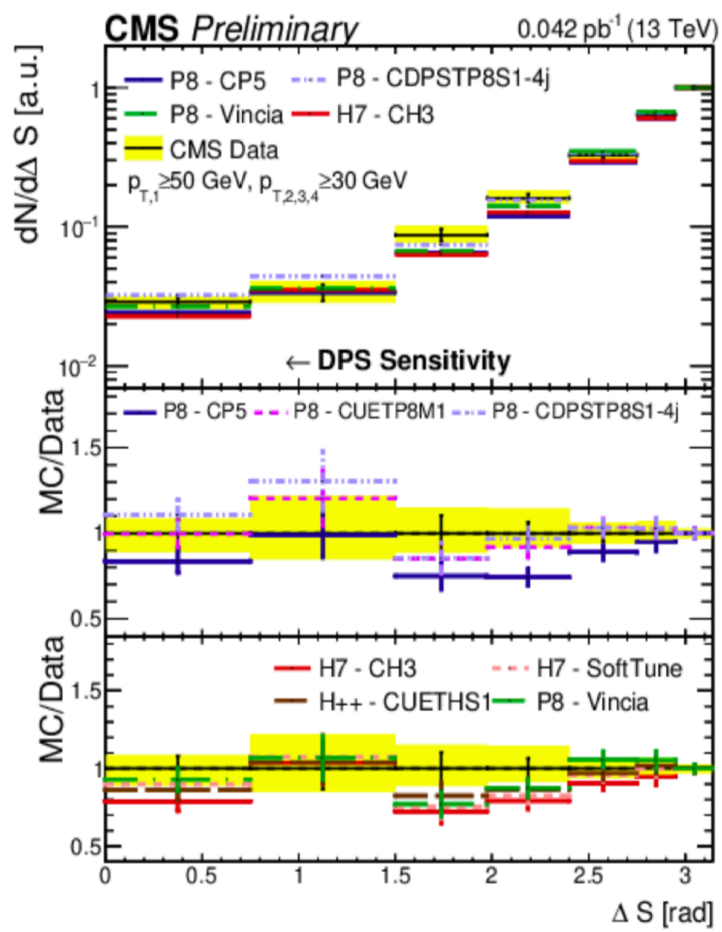
NEW

- $\Delta\Phi_{3j}$ (left) and ΔS (right)
  - Normalization to first four bins for $\Delta\Phi_{3j}$ and the last bin for ΔS_j

- Data favour p_T-ordered showers for LO models
- Less conclusive for NLO and/or higher-multiplicity ME

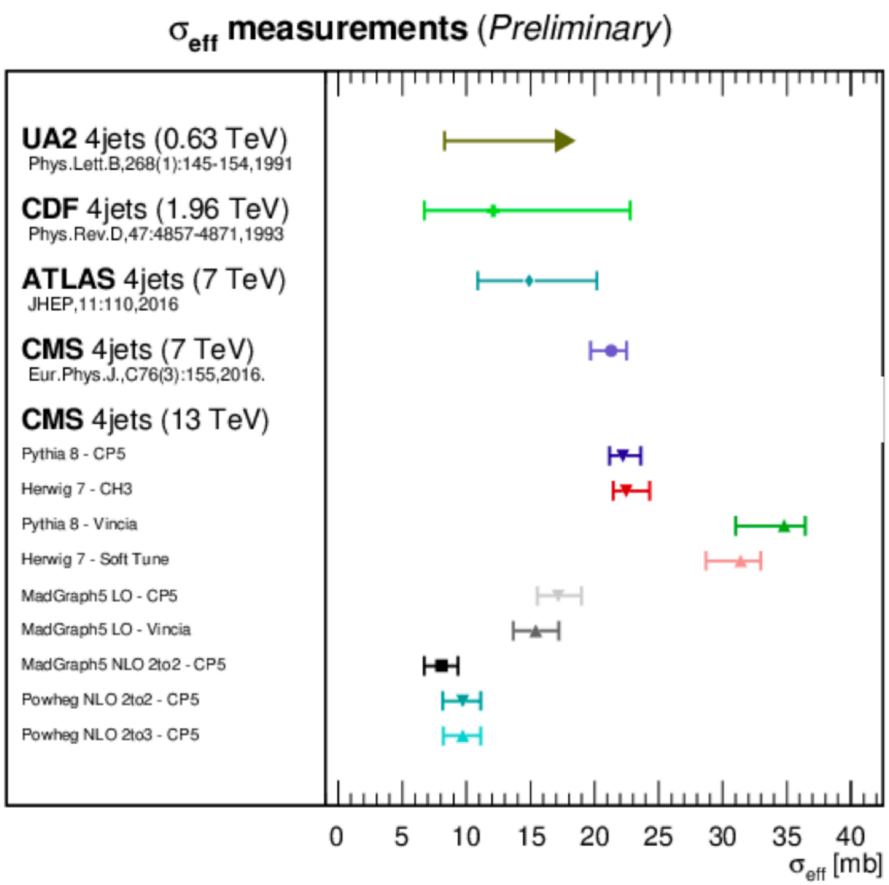
- Only distribution insensitive to PS modelling -- hence used for σ_{eff} extraction





DPS studies in 4-jets with low p_T at 13 TeV (CMS-PAS-20-007)

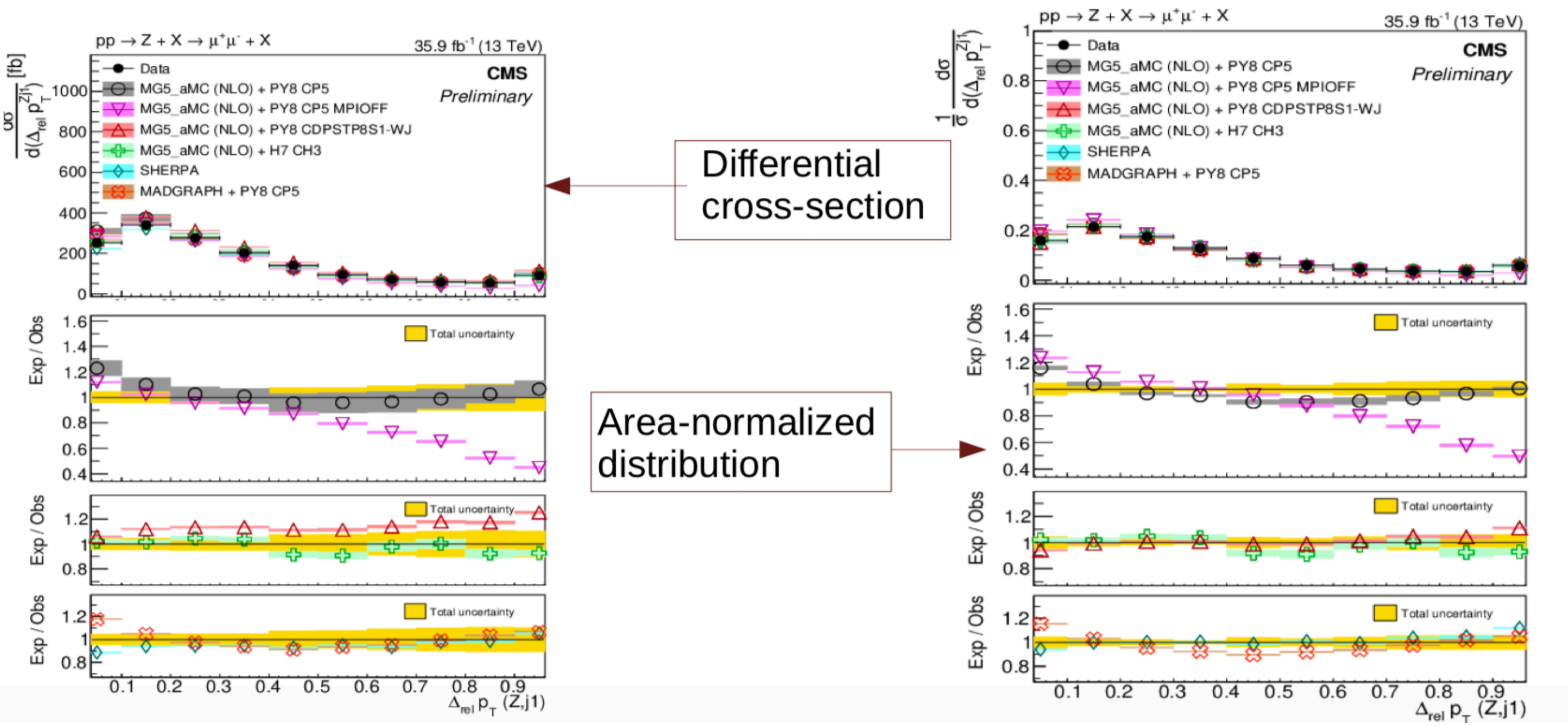
NEW



- Strong dependence of extracted value of σ_{eff} on the model to describe SPS contribution.
- NLO models with 2→2 and 2→3 ME yield smallest σ_{eff} (~10 mb) implying greater need of DPS contribution
- Including 4 partons in ME of SPS models introduce DPS-like correlat-ions in observables with σ_{eff} ~ 15 mb.
- Largest value of σ_{eff} (>~ 20 mb) found for LO models with 2→2 ME

DPS studies using Z+jets process at 13 TeV (CMS-PAS-20-009)

- MC@NLO+P8 (MPI-OFF) is lower than measurement (by 50%) in lower ΔΦ and high $\Delta_{rel}p_T$ region.
- MC@NLO+P8 (MPI-OFF), MC@NLO+H7 and SHERPA: behave similar while describing differential and area normalized distributions.
- MC@NLO+P8 CP5 (with MPI) describes diff. cross-section within uncertainty (except lower region of $\Delta_{rel}p_T$ (SPS dominated), but underestimates measurement in case of area-normalized distributions (except lower $\Delta_{rel}p_{T\ region}$).
- MC@NLO+P8 (CDPSTP8S1-WJ) fails to describe differential cross-section but describe shape of distribution within uncertainty) --> well modelled collision energy dependence of MPI parameters in tune



Hard color-singlet exchange in dijet events at 13 TeV (arxiV:2102.06945)

Accepted by PRD

Event Selection

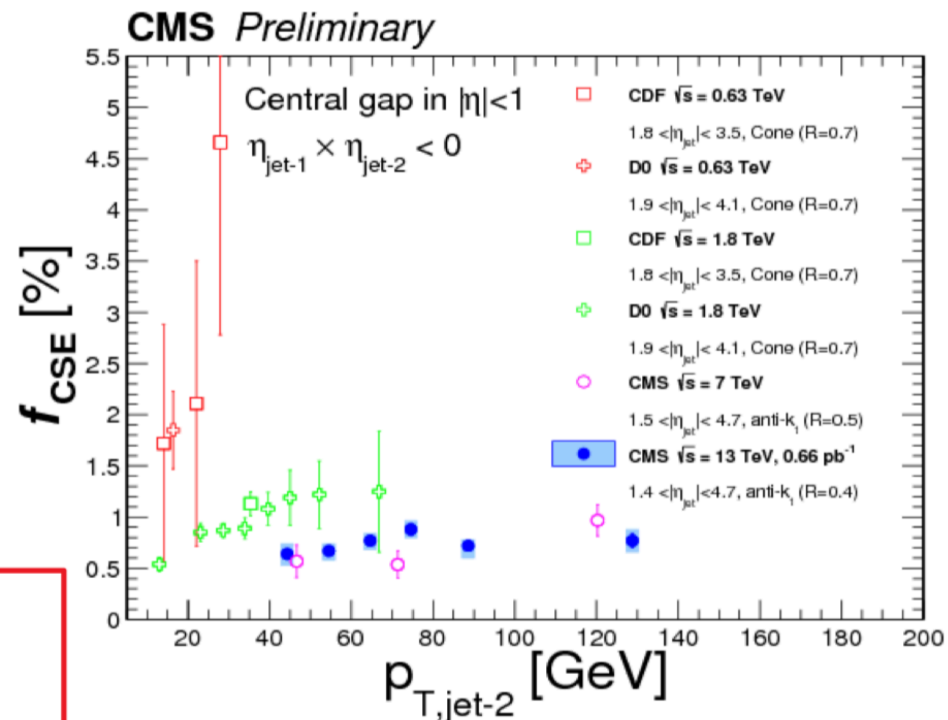
- Particle-flow anti-k_T jets R=0.4
- 2 leading jets p_T > 40 GeV each
- Leading jet $1.4<|\eta_{jet}|<4.7$, and $\eta_{jet-1} \times \eta_{jet-2} < 0$ --> favours t-channel exchange

- Pseudorapidity gap: charged particle multiplicity b/w leading 2 jets (p_T>200 MeV, $|\eta|<1$)

Fraction of dijet events produced by color-singlet exchange f_{CSE}:

$$f_{CSE} = \frac{N(N_{tracks}<3) - N_{bkg}(N_{tracks}<3)}{N_{all}} = \frac{colour\ singlet\ exchange\ dijet\ events}{all\ dijet\ events}$$

f_{CSE} is measured as a function of $\Delta\eta_{jj}$, $p_{T,jet-2}$, $\Delta\phi_{jj}$



- Gap survival probability $|S^2|$ is expected to decrease with increasing COM, due to increase in spectator parton activity with COM.

- Within uncertainties, gap fractions stop decreasing with COM (7 TeV to 13 TeV), in contrast to trend observed at lower energies 0.63 TeV --> 1.8 TeV --> 7 TeV

Summary

- Coherent J/ψ the state of art is shown, with Nuclear suppression factor and how LHCb and ALICE have help to understand it.
- Ways to extract $x \sim 10^{-5}$ neutron emission and peripheral photo-production
- Coherent ρ' missing the black disk regime. Inclusive single diffractive dissociation cross-section and comparison with event generator predictions
- LHC has a rich physics program which is perfect testing ground for QCD models.
- An overview of some representative soft QCD and diffractive measurements has been presented. LHC has provided access to a large phase space as well as a new energy scale for understanding various aspects of QCD.
- Improve our picture of nucleon structure and hadron collision, as well as its universality Energy measurements in the very forward rapidity regions indicate some interesting potential to further improve the underlying event model predictions

Thank you!!