



# Review of recent forward physics results from the CMS experiment

ISVHECRI 2018, Nagoya

Ralf Ulrich

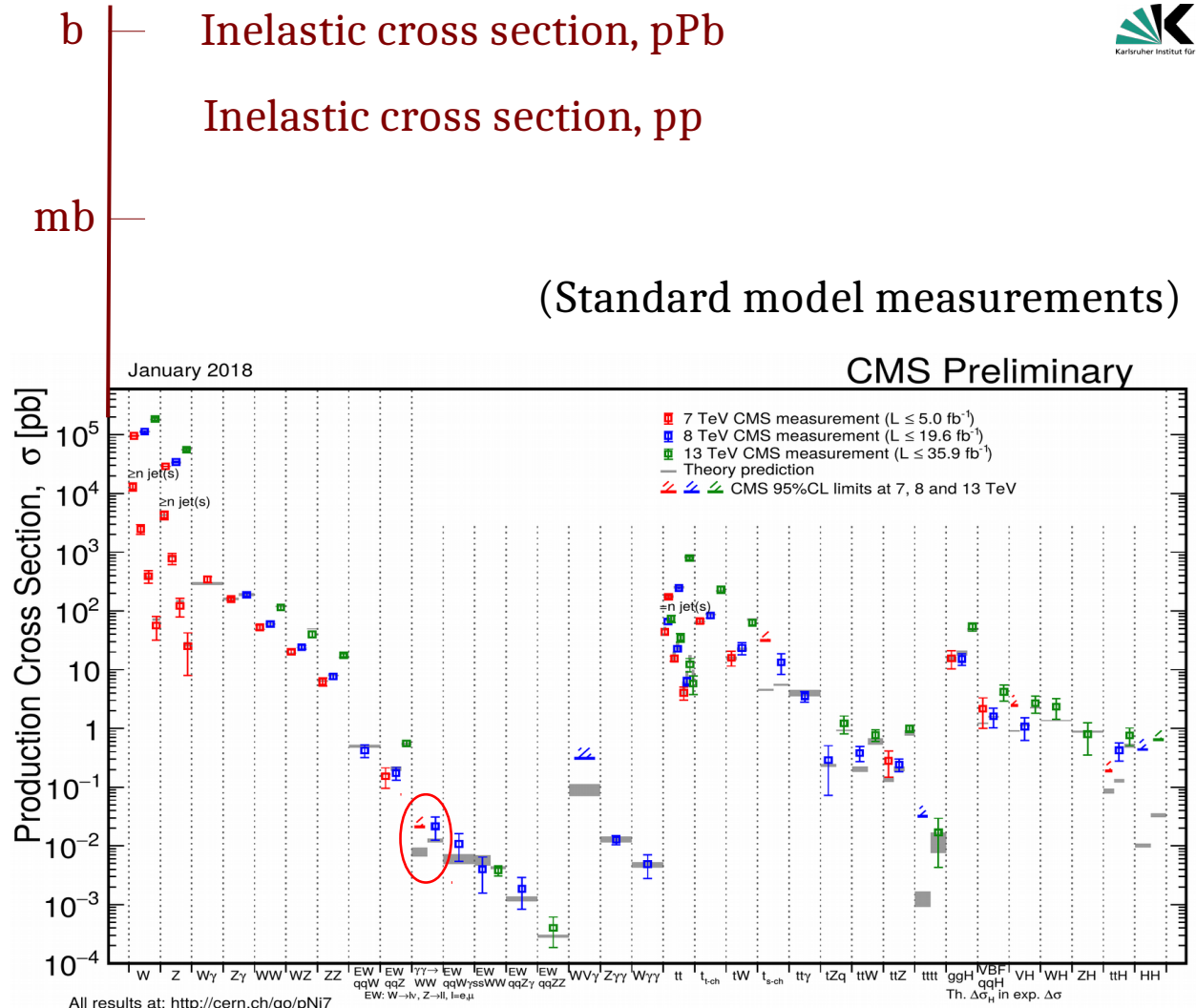
All information at: <http://cms-results.web.cern.ch/cms-results/public-results/publications/FSQ>  
(FSQ: Forward physics and small-x QCD)

# Overview

## Forward physics in CMS:

- Exclusive production
- Diffraction
- Inclusive cross sections
- Multi-parton interactions
- Double-parton scattering
- Underlying event
- Minimum bias, spectra
- Correlations

15 orders of magnitude in cross section

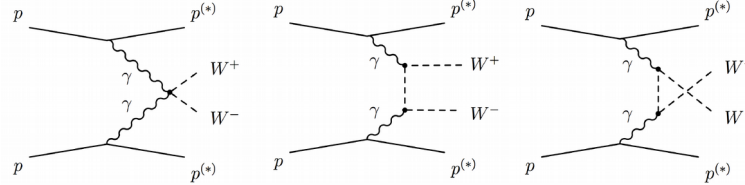


# Exclusive final states

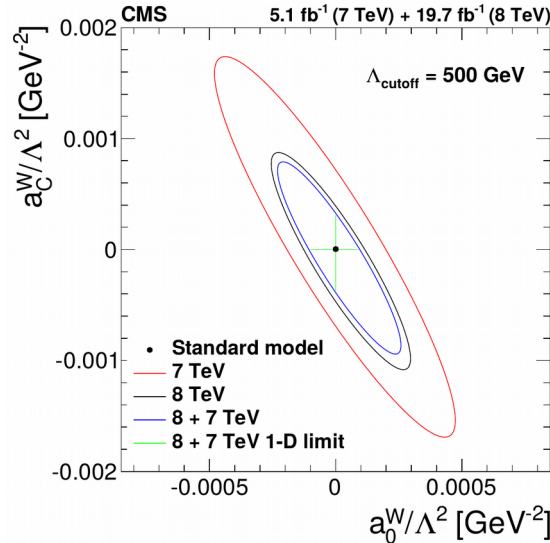
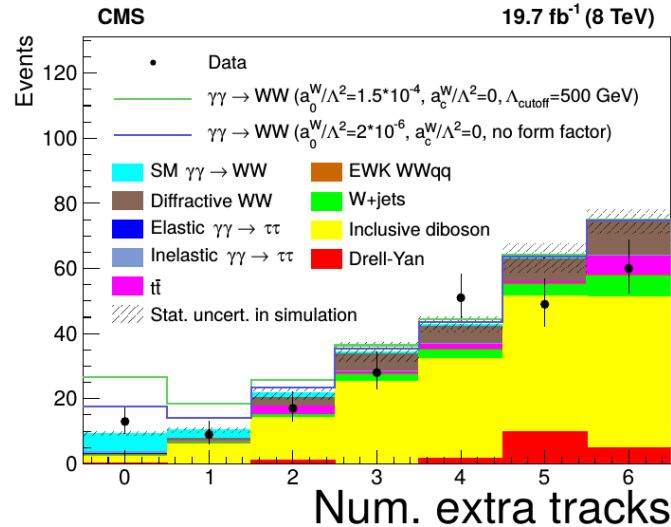
# Exclusive $\gamma\gamma \rightarrow W^+W^-$

JHEP 08 (2016) 119

## Standard model



## Beyond standard model: anomalous quartic gauge couplings



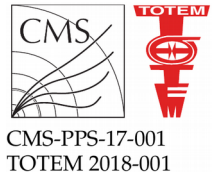
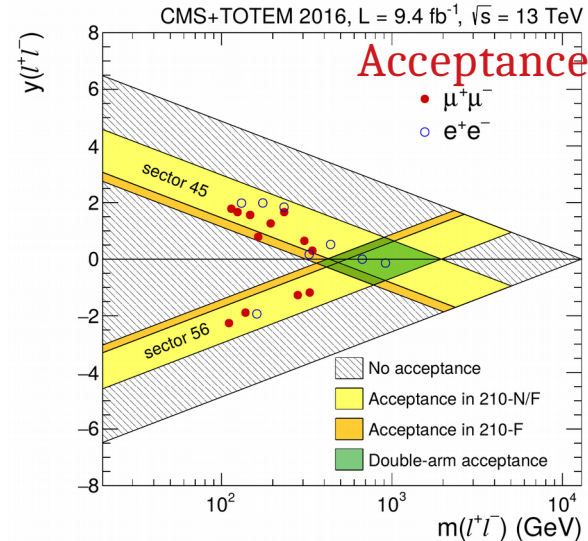
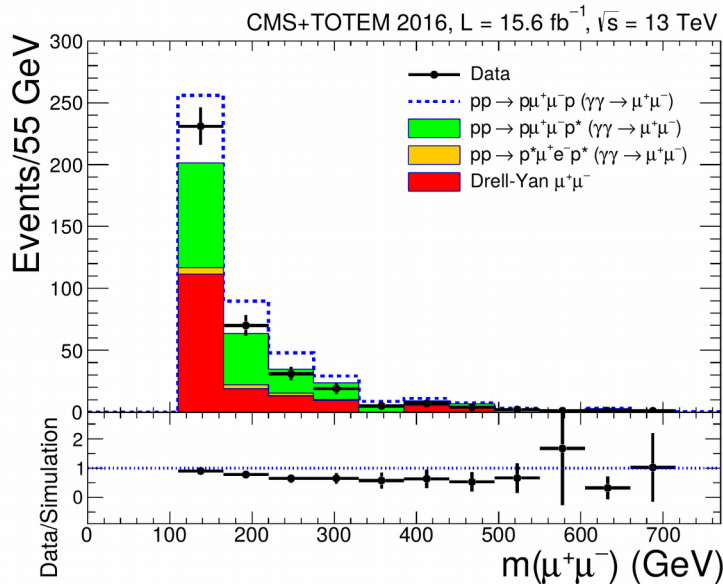
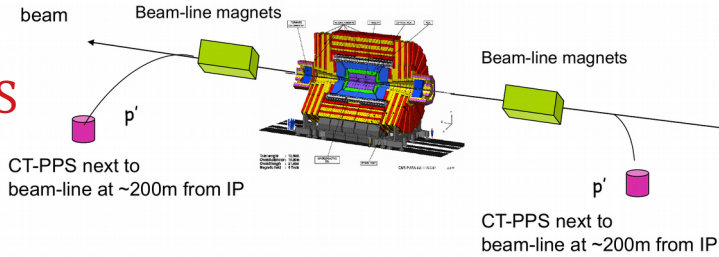
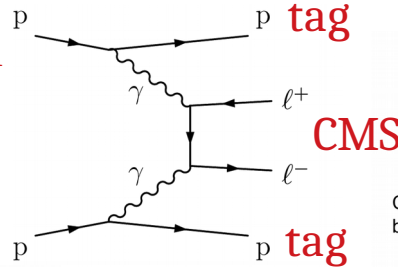
Very clean channel to search for anomalous couplings

So far no signal found

# Exclusive high-mass lepton pairs

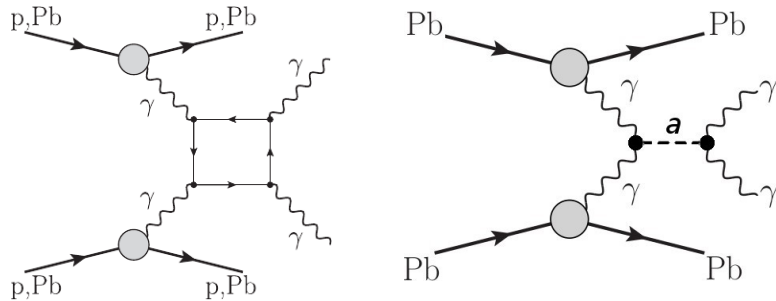
First high-luminosity measurement with CT-PPS proton tags.

Roman pots at 210...220 m from IP



# Light by Light scattering in PbPb

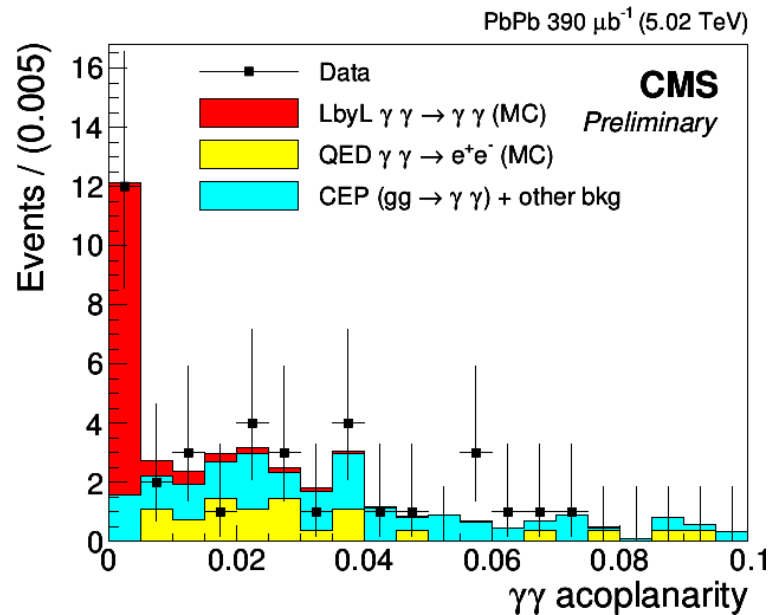
CMS-PAS-FSQ-16-012



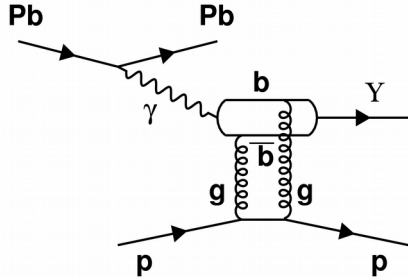
Exploit huge enhancement due to Pb charge, factor  $82^2=6724$

Very clean signature: two photons, nothing else

Search for new physics in loop, or also axions



# Exclusive Y

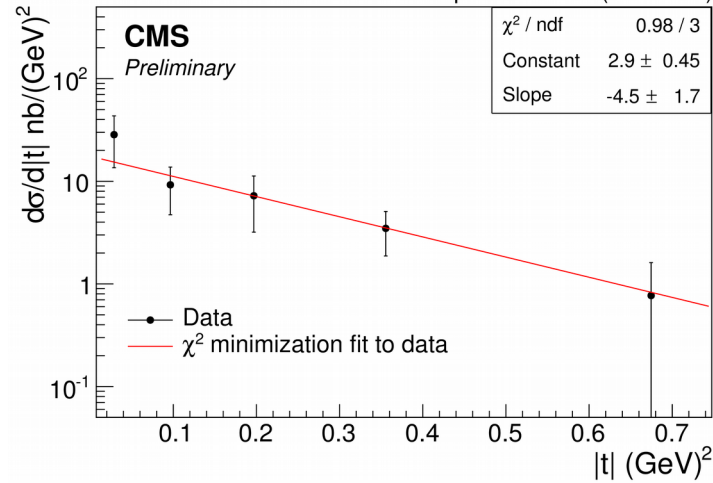
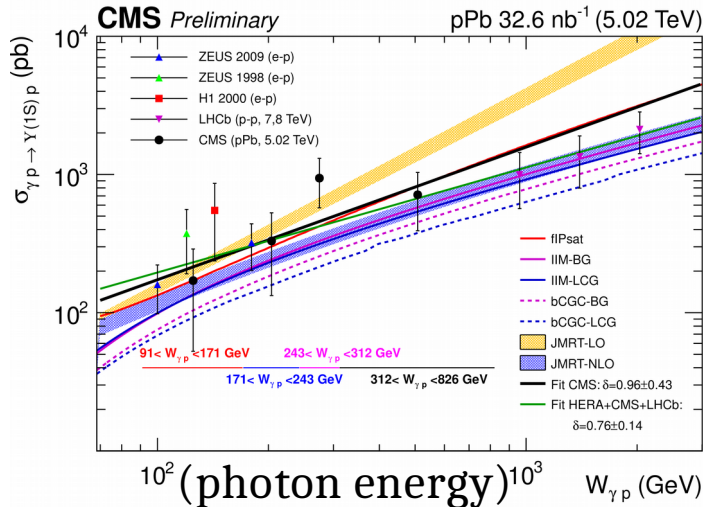
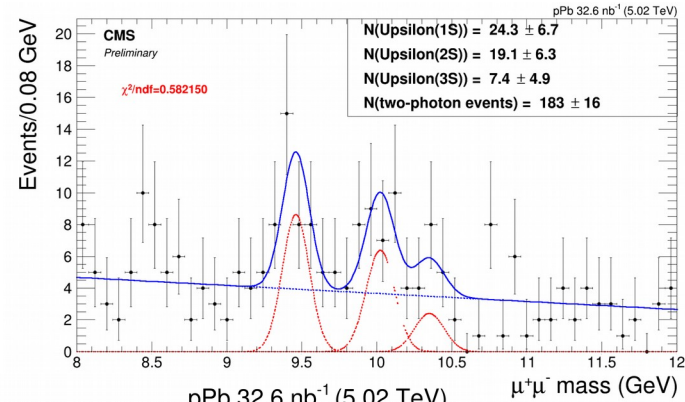


Exclusive vector meson production sensitive to proton gluon PDFs

Proton-lead collisions are ideal system at LHC

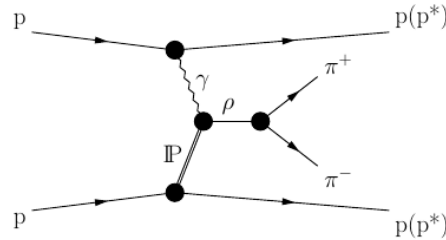
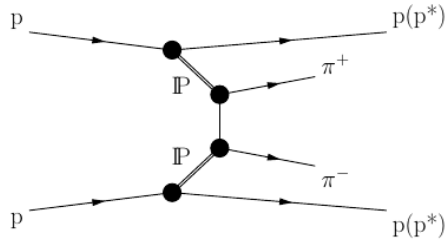
Gluons down to  $x \sim 10^{-4}$

CMS-PAS-FSQ-13-009

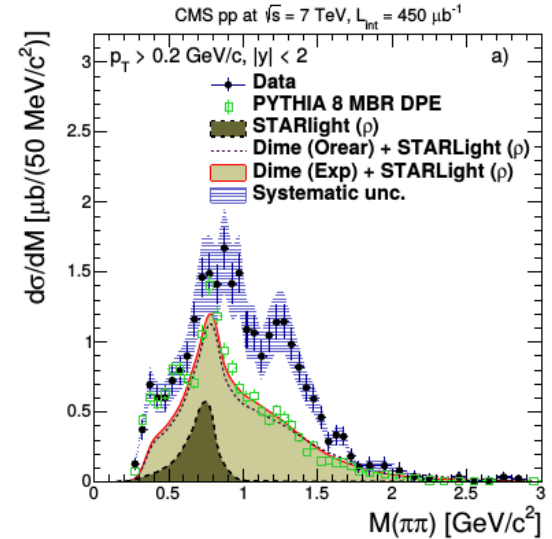
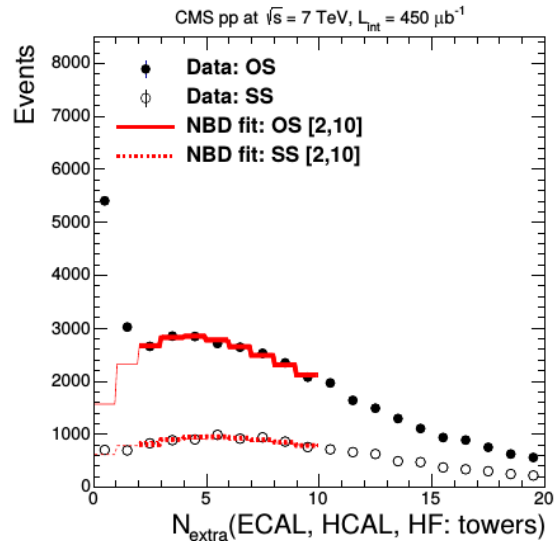


# Exclusive $\pi^+\pi^-$

arXiv:1706.08310, subm. to PRD



Double pomeron exchange creates unique gluon-rich environment for meson spectroscopy and search for glueballs



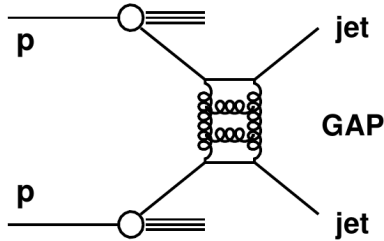
Stay tuned: New result with TOTEM+CMS data in last approval stages!



# Diffraction, and inclusive cross sections

# Di-jets with rapidity gap (jet-gap-jet)

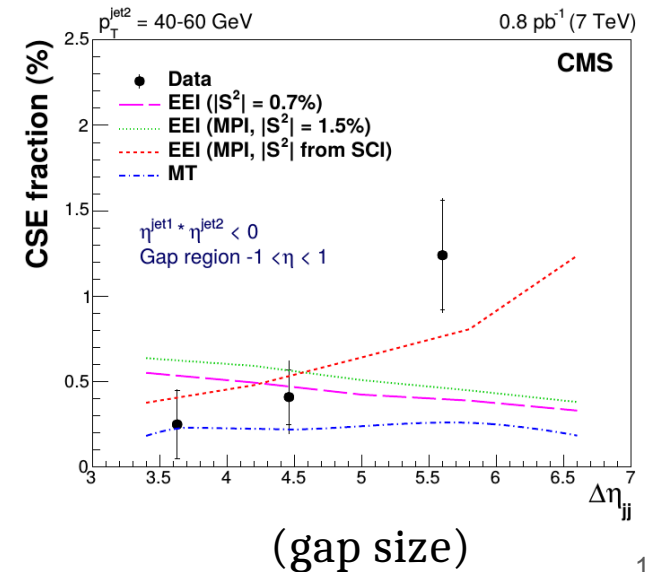
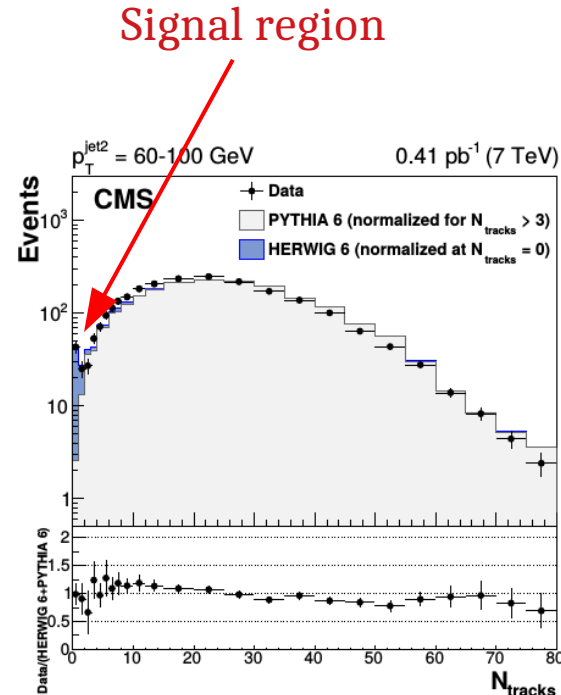
Eur. Phys. J. C 78 (2018) 242



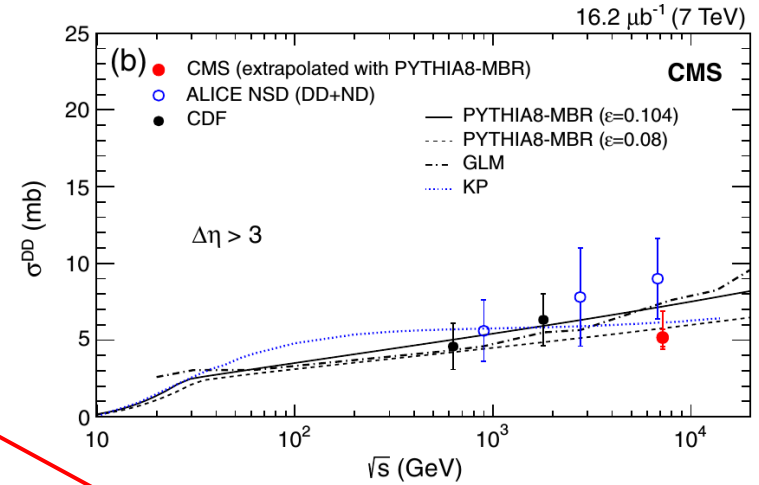
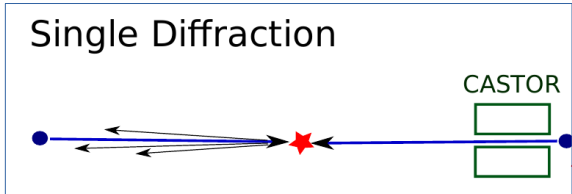
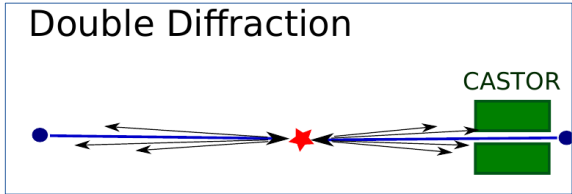
Difficult background estimation.

Measure gap survival probability.

Search for BFKL effects.

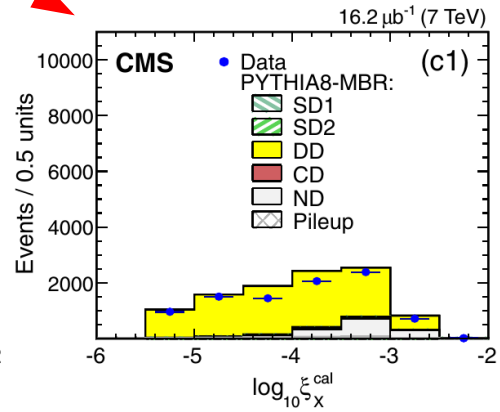
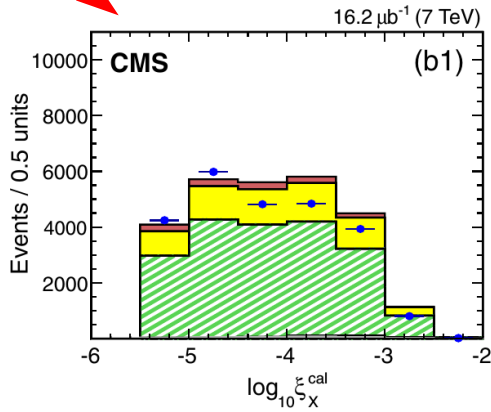
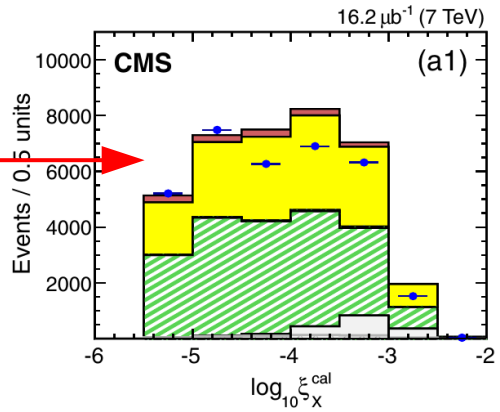


# Single diffractive dissociation



PRD 92 (2015) 012003

events with forward gap



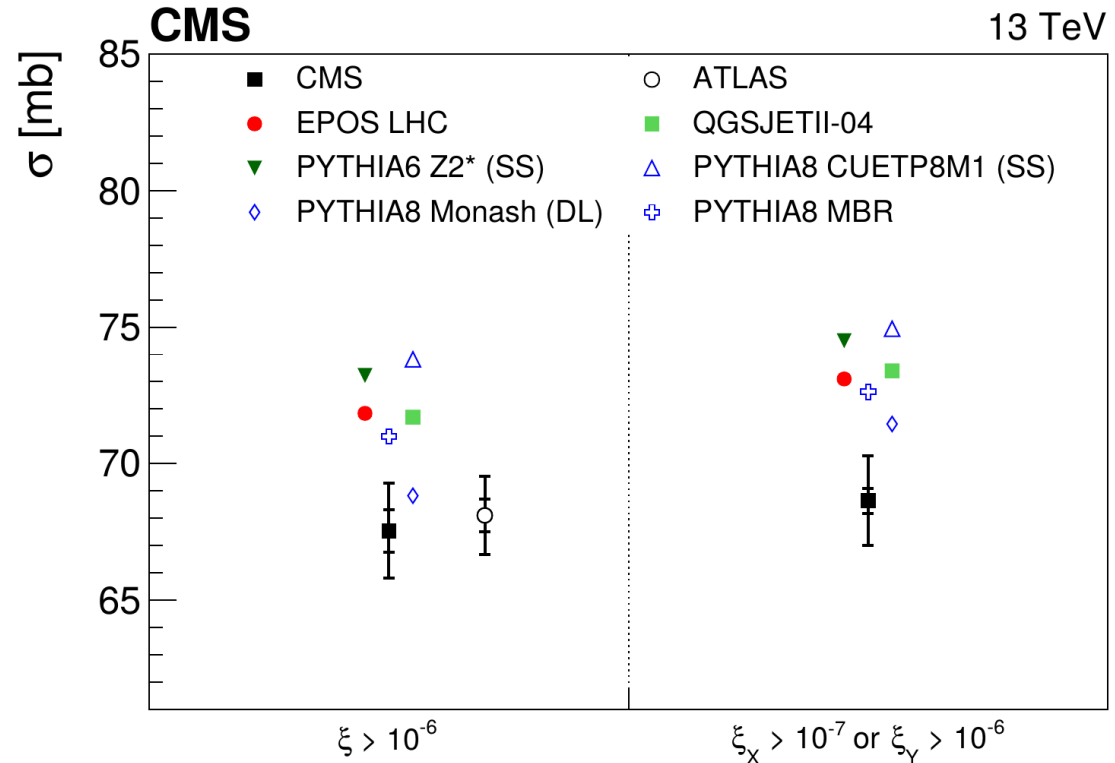
# Inelastic cross section

arXiv:1802.02613, subm. to JHEP

Excellent acceptance  
due to CASTOR.

Data below most  
models.

$\xi$ -dependence in data  
and models very  
similar.



# Inclusive jets

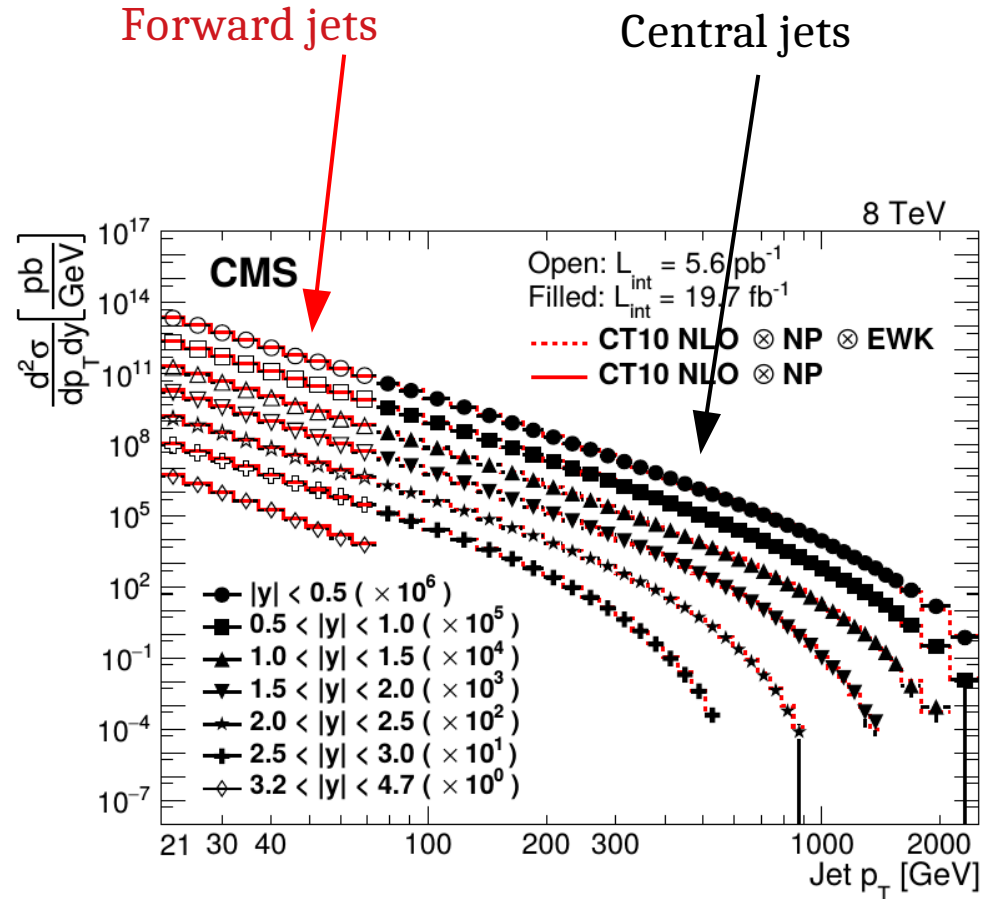
Jets from 21 to 2000 GeV

Conclusion:

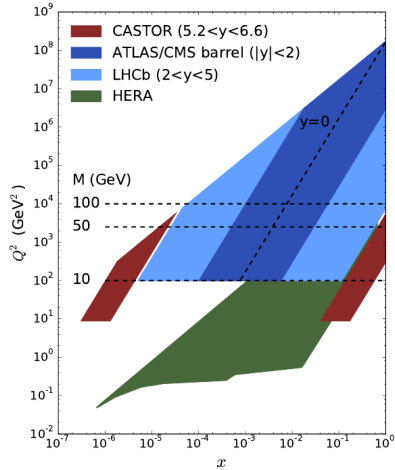
Inclusive spectra over a wide range in  $\Delta y$  and  $p_T$  can be described by NLO with small non-perturbative and EW corrections.

→  $\alpha_s$

→ PDF improvements



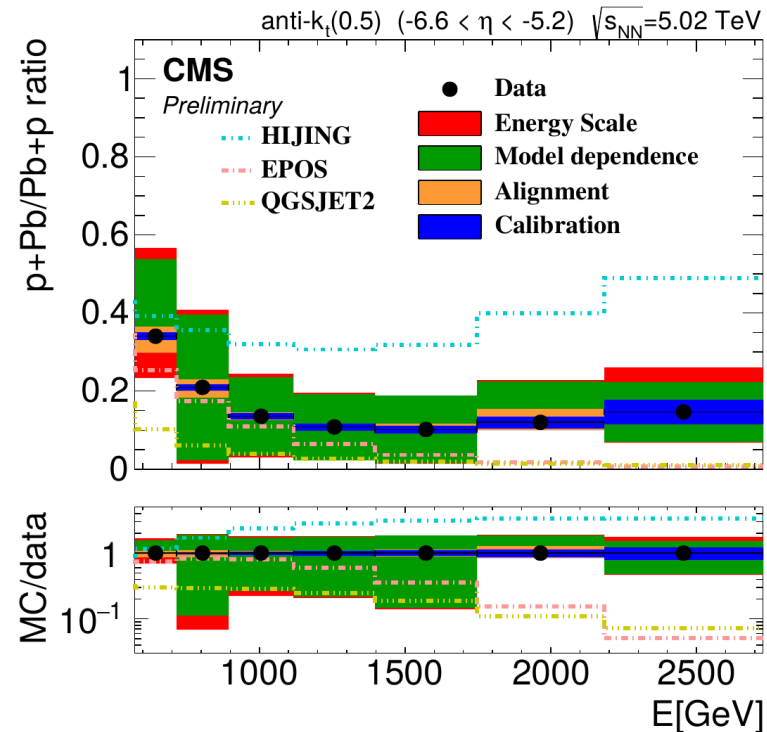
# Small-x QCD, very-forward ( $5.2 < \eta < 6.6$ ) jets



Inclusive jets going very-forward are more affected by non pQCD effects.

First results encouraging but huge potential for improvements in experiment and theory.

PDF at  $x \sim 10^{-6}$ , gluon density, saturation, MPI, non-perturbative modelling, jet structure, ...

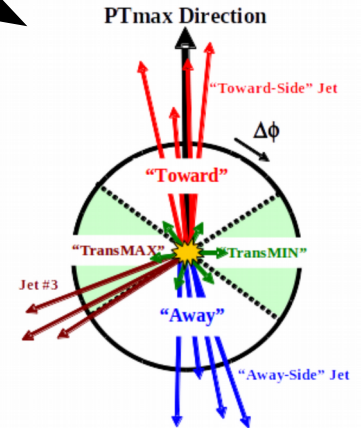
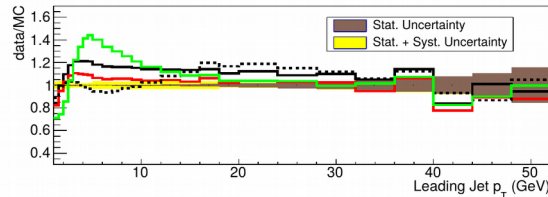
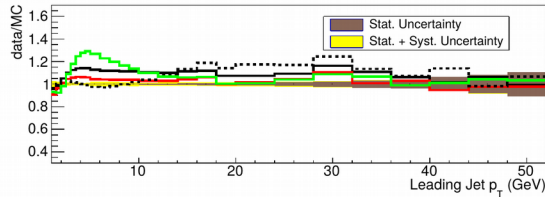
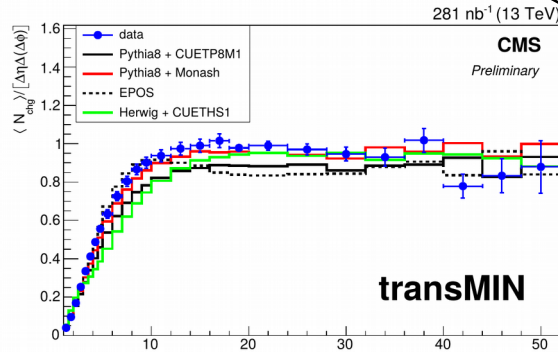
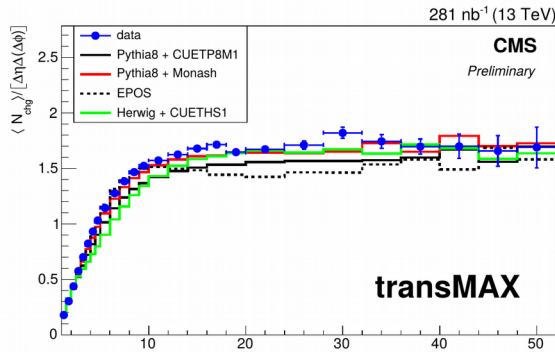
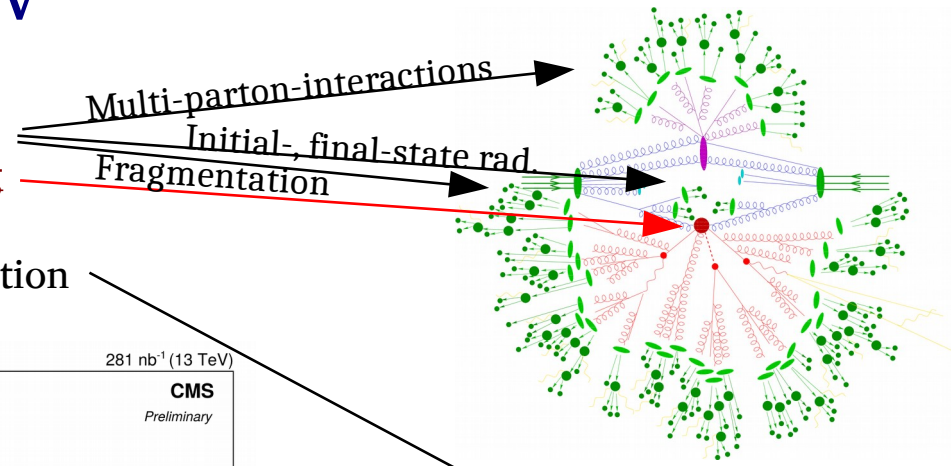


CMS-PAS-FSQ-17-001  
to be submitted to JHEP

Underlying Event,  
Multi-Parton-Interaction,  
Double Parton Scattering

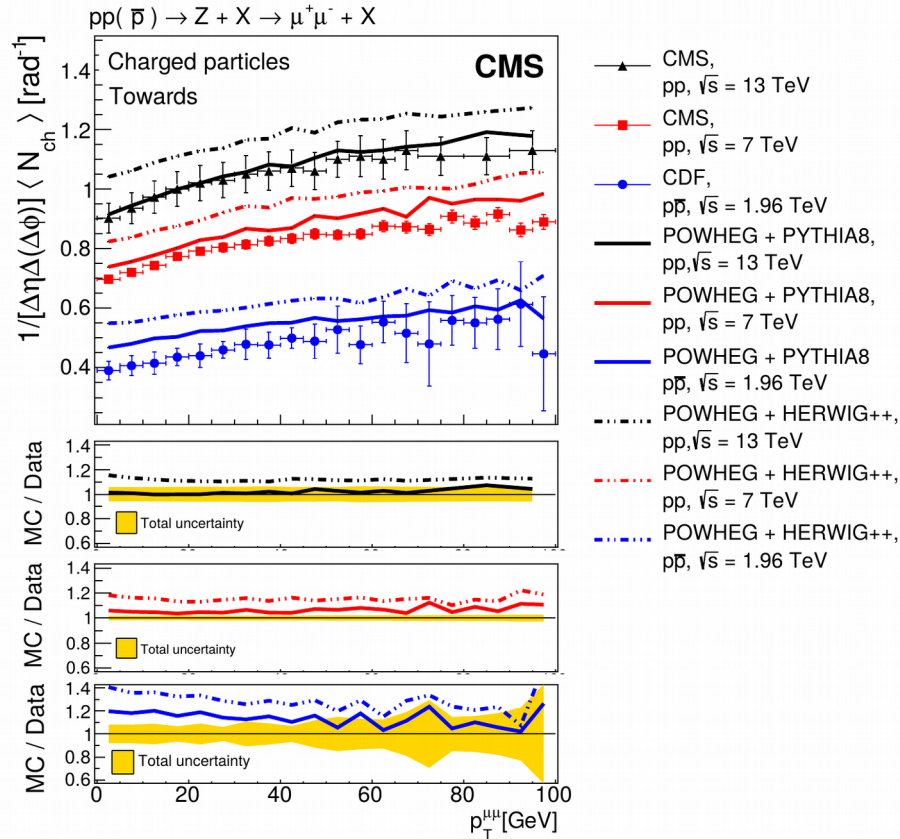
# Underlying event at 13TeV

- Extra particle production relative to hard scattering
- New scheme for classification





# Underlying event in Z events

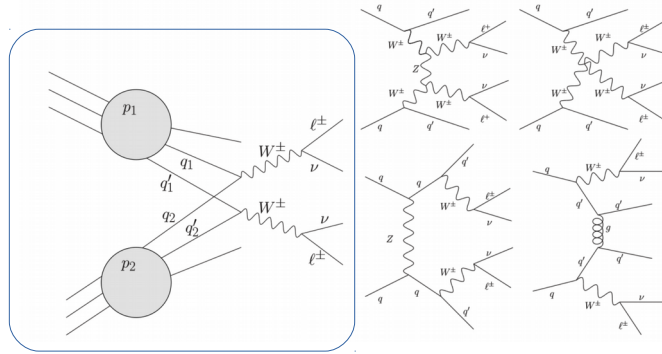


arXiv:1711.04299, subm. to JHEP

Underlying event almost independent of details of central system and center-of-mass energy

# Double parton scattering, same-sign WW

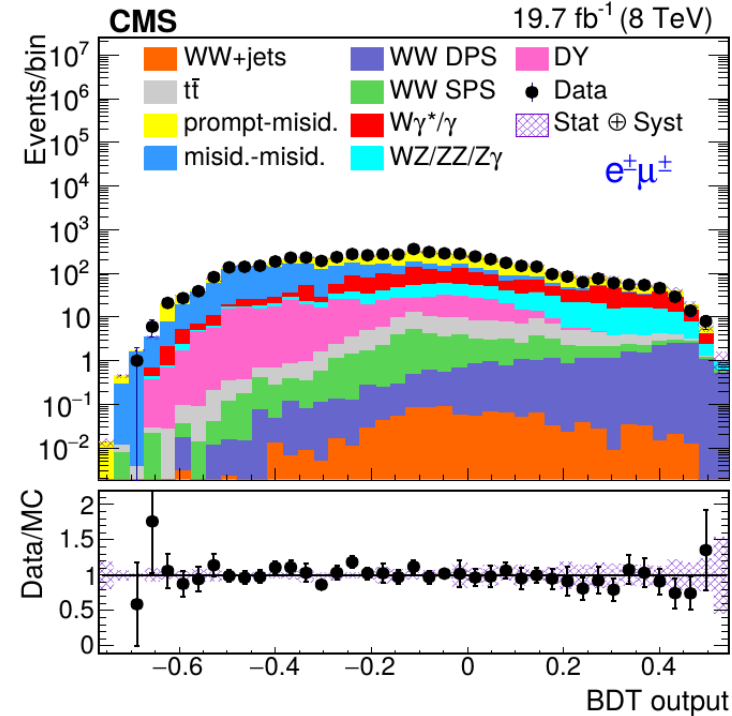
JHEP 02 (2018) 032



Search for two independent simultaneous scatterings  $\sigma_{AB}^{DPS} = \frac{m}{2} \frac{\sigma_A \sigma_B}{\sigma_{eff}}$

Difficult:

- cross section small
- various background possibilities



# Correlations

# Two particle correlations

One of the few discoveries at LHC

Near-side long-range correlations

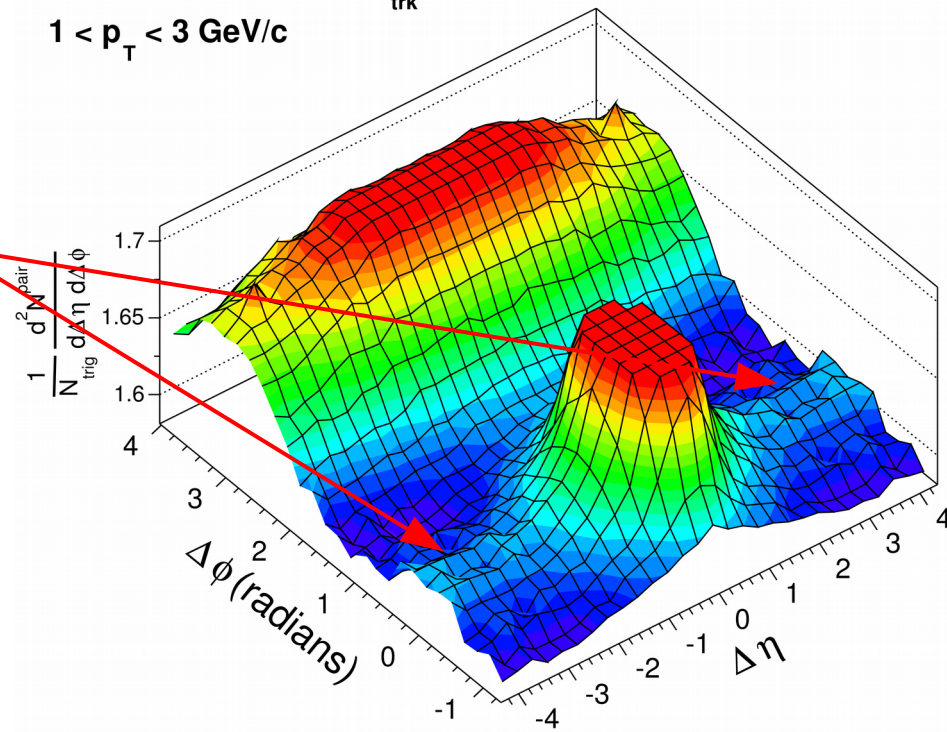
→ Ridge

Sign of hydrodynamical evolution?

PRL 116 (2016) 172302 [100 cites]  
 JHEP 1009 (2010) 091 [676 cites]  
 PLB 718 (2013) 795 [513 cites]

CMS pp  $\sqrt{s} = 13 \text{ TeV}$ ,  $N_{\text{trk}}^{\text{offline}} \geq 105$   
 $1 < p_T < 3 \text{ GeV}/c$

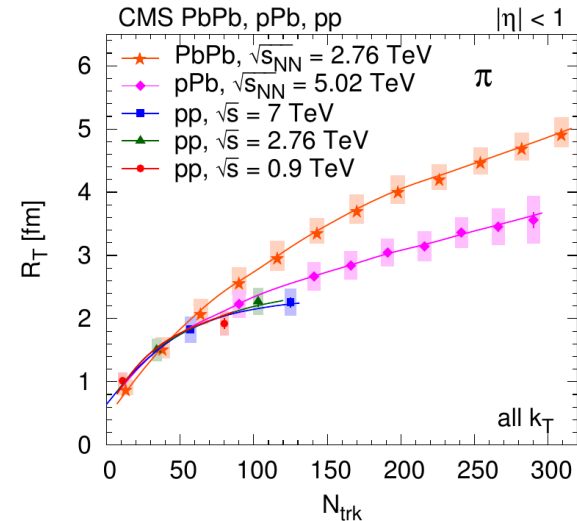
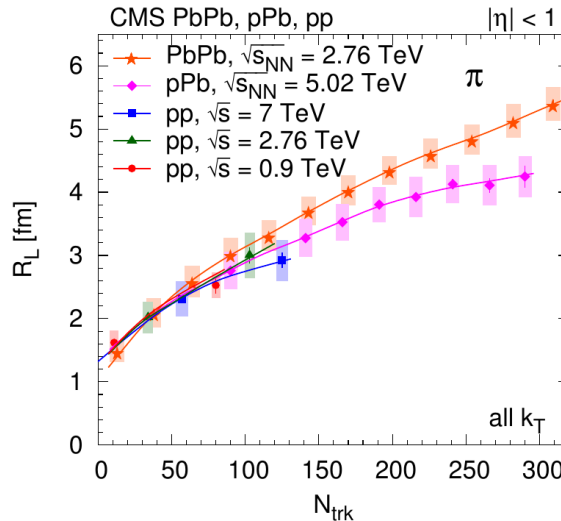
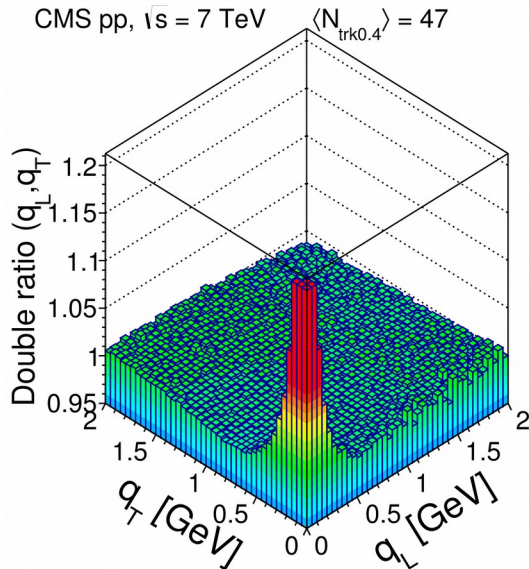
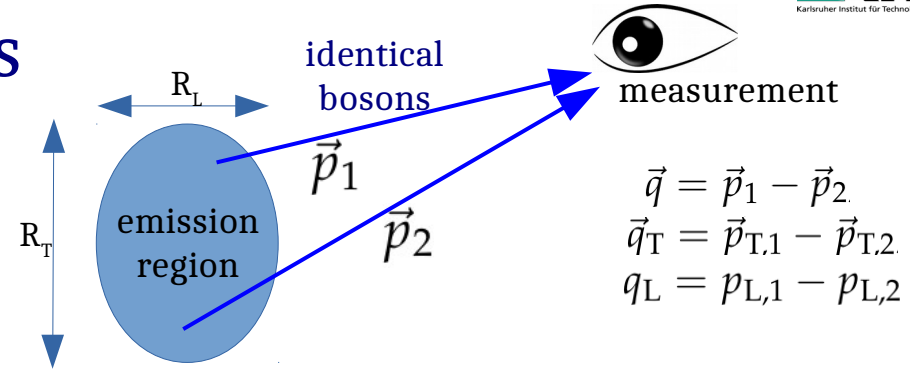
(b)



**4<sup>th</sup> most cited CMS physics paper!**

# Bose-Einstein-Correlations

- Interferences observed in boson measurements allow femtoscopy
- Corrections for Coulomb, min-jets, decays, resonances

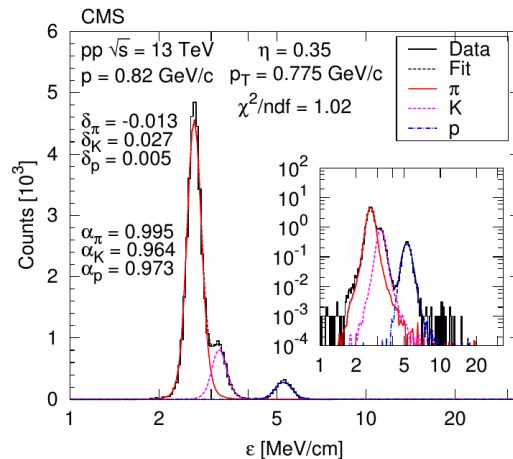
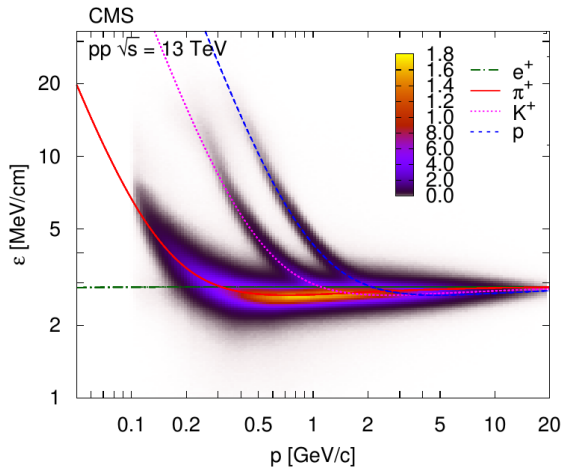


# Minimum Bias

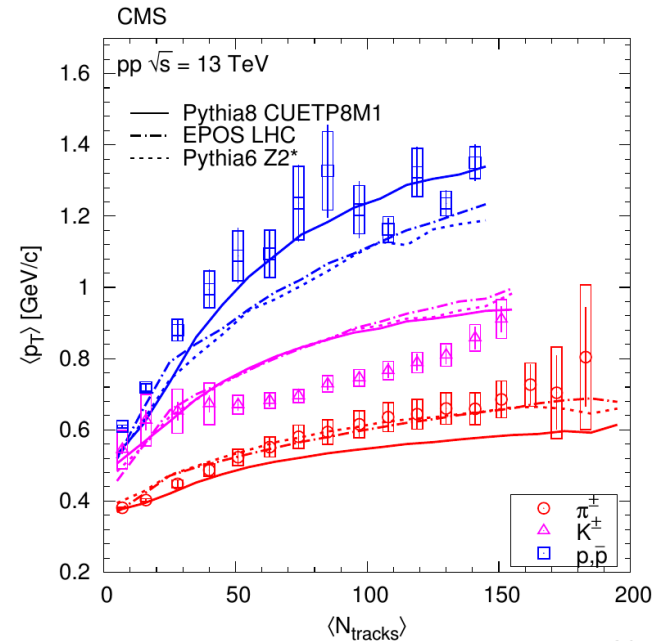
(tons of results, see also talk by S. Baur after coffee break)

# Identified particles

- Exploit particle identification with  $dE/dX$  in CMS silicon tracker
- Relevant for baryon production, charge ratios, etc.



PRD 96 (2017) 112003



# Summary

- Forward physics is more than just “small angles”
- Very rich program in extremely wide field of physics.
- Exciting options in pp, pPb, PbPb,  $\gamma\gamma$ , Pomerons, etc.
- Room for discoveries!
- At same time: many results directly relevant for our community
- More ideas+opportunities than manpower at LHC...





# CMS

Total weight: :  
 Overall diameter: 15m  
 Acceptance:  $-6.6 < \eta < 5.2, |\eta| > 8.2$

