Measurement of central exclusive $\pi^+\pi^-$ production at $\sqrt{7}$ TeV in CMS

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WG5 Small-x and Diffraction

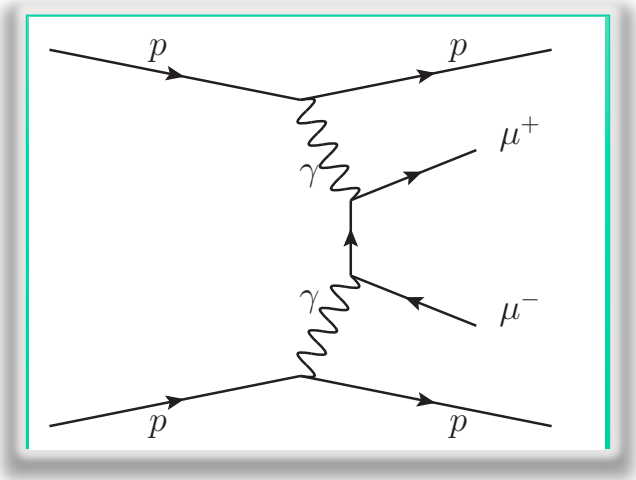
Outline

- Introduction
- Data and MC models
- Data Analysis
  - Event Selection
  - Background Estimation
  - Systematics
- Results
- Summary

Physics motivation

Exclusive production: the protons remain intact (not detected in CMS) after the interaction and escape undetected along the beamline or dissociate into undetected low mass states.

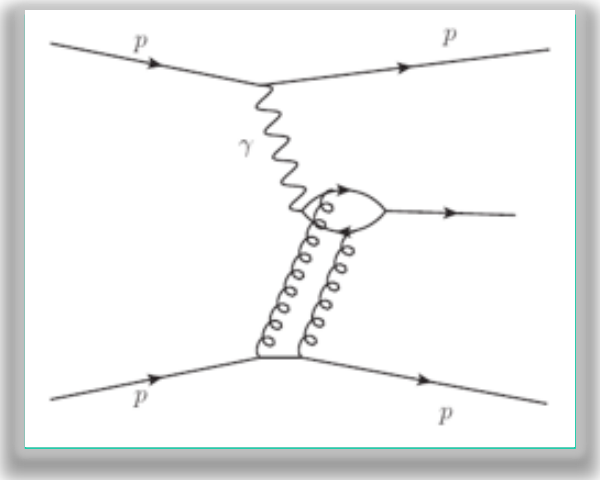
Exclusive Two-Photon



$\mu^+\mu^-$, $e^+ e^-$, $\pi^+\pi^-$, W^+W^-

- ✓ QED lepton pair production is of interest as a check/control of everything (including dissociation probability)

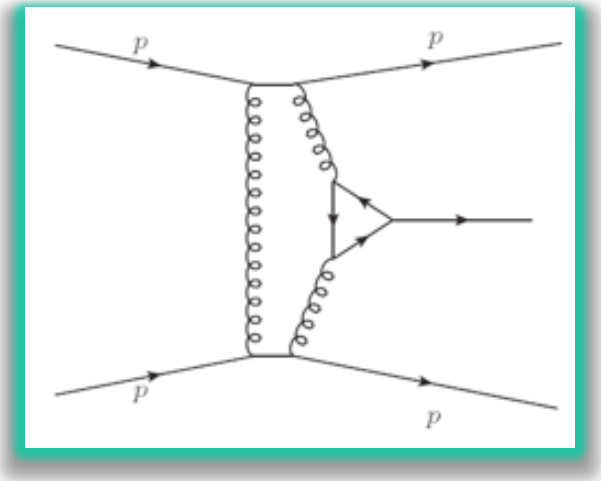
Elastic Photo-Production



ρ, J/ψ, Υ, Z, …

- ✓ Photoproduction of vector mesons tests pomeron coupling to quark (done at HERA with no DPE background)

CEP: central exclusive production



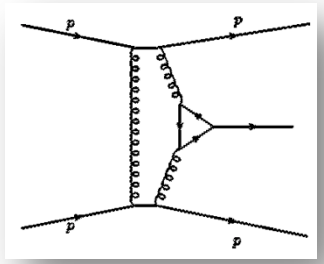
X_c, X_b, $\pi^+\pi^-$, Dijet, gg, …

- ✓ Test the soft pomeron models, and good for hadron spectroscopy
- ✓ glue-rich: so scalar and tensor glueballs produced

Physics motivation …

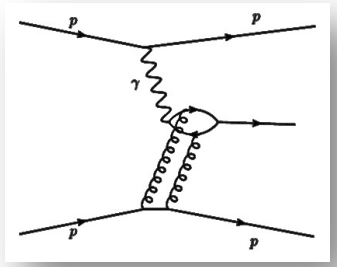
Contribution may come from exclusive sources, with large cross-sections well measured in previous experiments at lower energies:

- **Central Exclusive Production (CEP)**

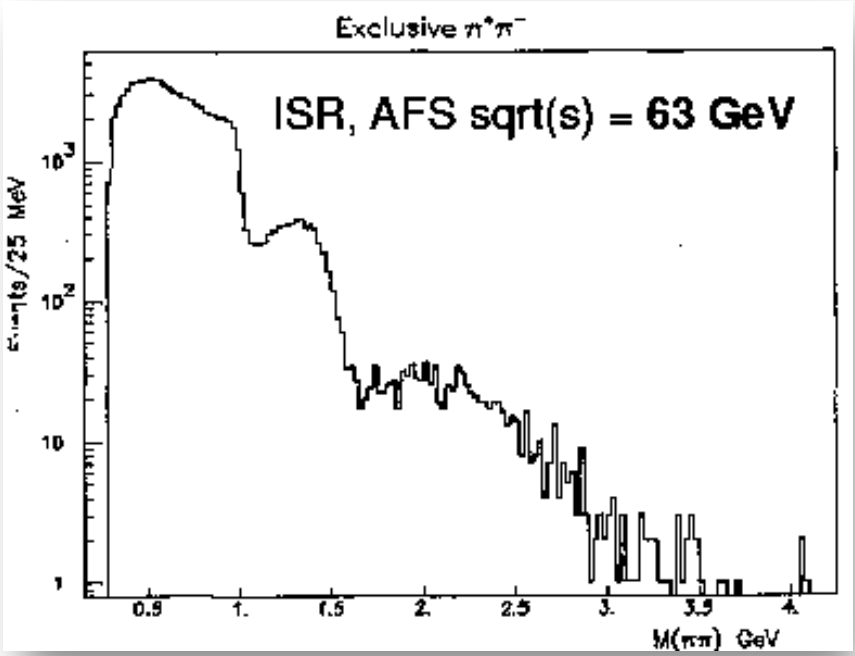


(hadron-hadron)

- **γ p➔ ρ (770)p ➔$\pi^+\pi^-$p Production**



(electron–hadron)
(hadron–hadron)



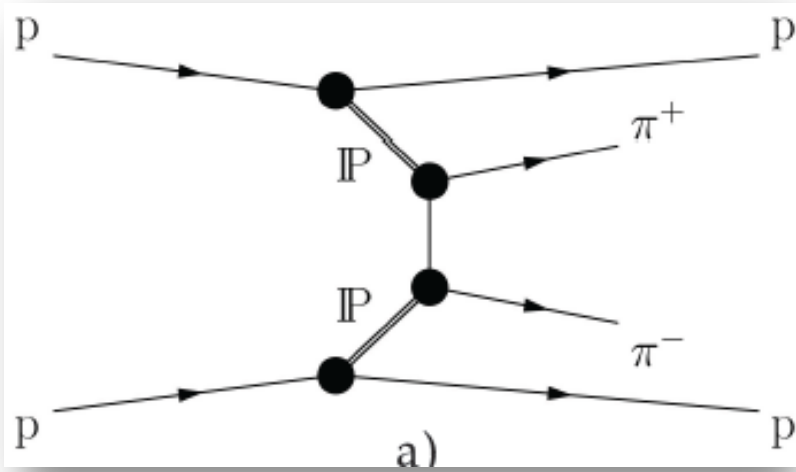
Ref: Nucl. Phys. B264 (1986) p. 154

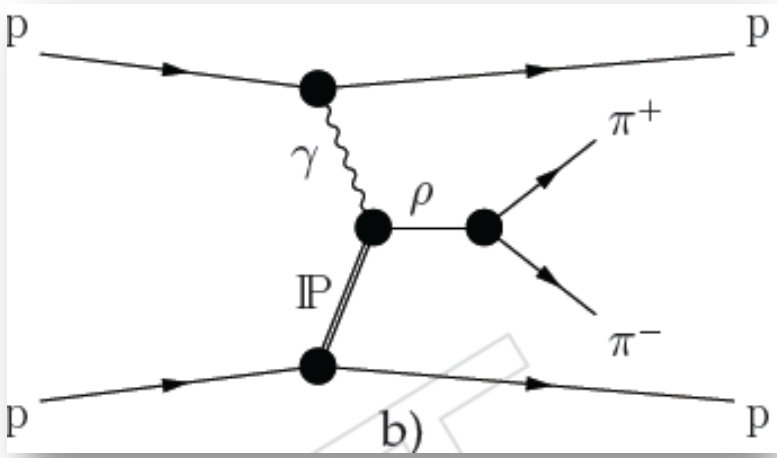
- Spectroscopic study: low-mass scalar resonances
- Different analysis from μμ: larger σ and larger background

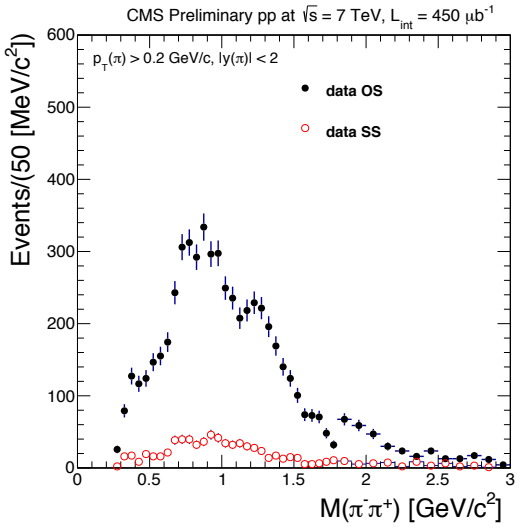
Experimental signature

- **Signal:**
  - **Only two tracks, no other track on vertex**
  - **No additional signals in the calorimeters**
  - **$p_T(\pi) > 200$ MeV/c**
  - **$|y(\pi)| < 2.0$**

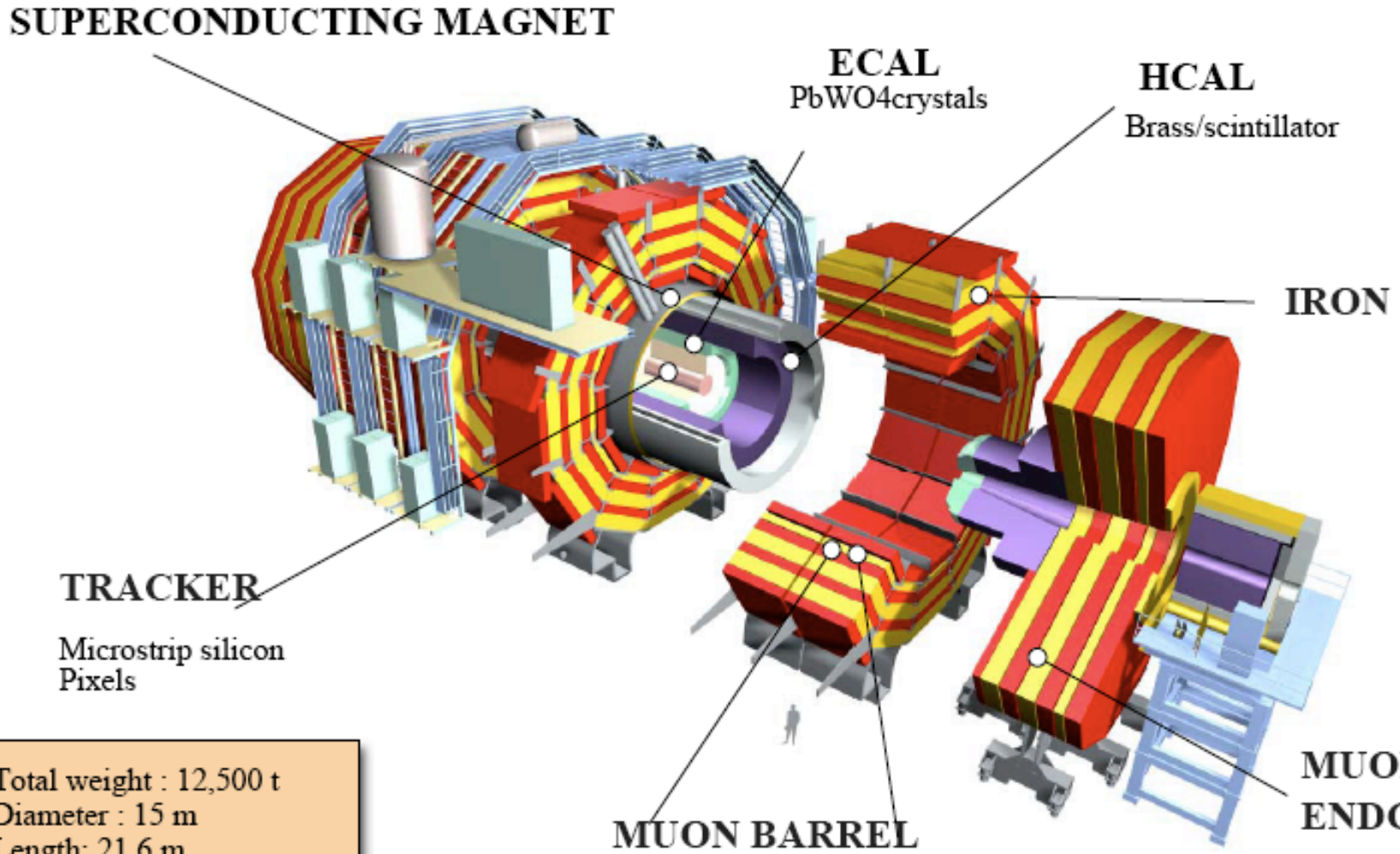
- **Exclusive production of hadrons at central rapidities phenomenologically described in terms of "DPE" Double Pomeron Exchange when the mass of central system is low, or perturbatively in "CEP"**







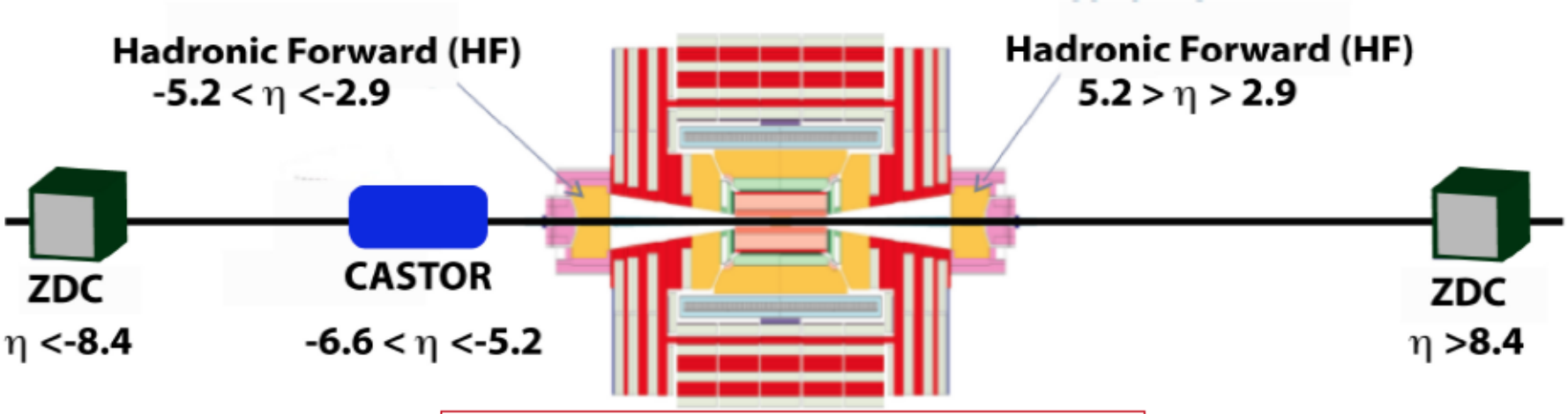
CMS (Compact Muon Solenoid)



Total weight : 12,500 t
Diameter : 15 m
Length: 21.6 m
Magnetic field : 4 Tesla

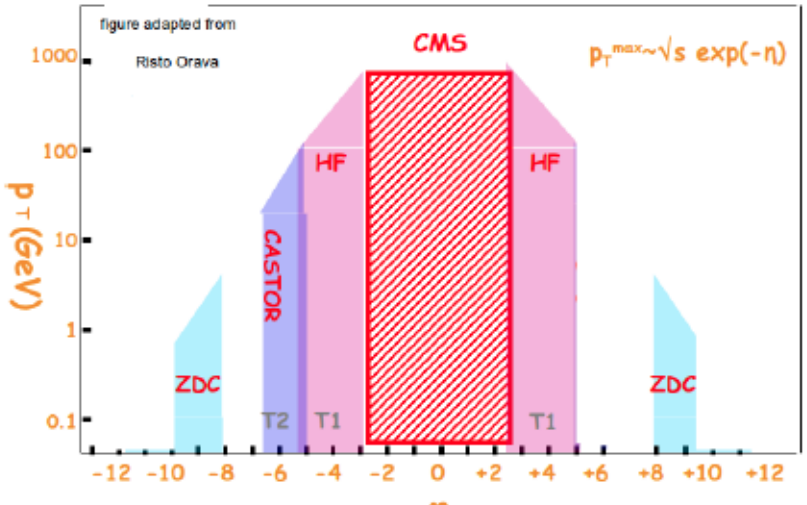
Pseudorapidity: $\eta = -\ln(\tan(\theta/2))$

Forward detectors at CMS



Three cherenkov calorimeters:

- **HF**
  - rapidity coverage: $2.9 < |\eta| < 5.2$
  - at 11.2 m from IP
- **CASTOR**
  - rapidity coverage: $-6.6 < \eta < -5.2$
  - at 14.3 m from IP
- **ZDC**
  - rapidity coverage: $|\eta| > 8.4$
  - at 140 m from IP



Pseudorapidity:

- $\eta = -\ln(\tan(\theta/2))$

Monte Carlo models

- PYTHIA 8: MBR (Minimum Bias Rockefeller) model used to generate pp events with particle production from three diffraction dissociation processes:
  - **Single dissociation (SD)**: one proton dissociates; p + p ➔ Xp,
  - **Double dissociation (DD)**: both protons dissociate; p + p ➔ XY
  - **Double Pomeron Exchange (DPE)**: neither proton dissociates;

  pp ➔ pXp The produced system X is then fragmented into hadrons by PYTHIA. (https://indico.cern.ch/event/195114/contribution/1/material/slides/0.pdf)

- STARLIGHT: The production of vector mesons in exclusive photoproduction γIP, e.g. ρ^0 ➔ $\pi^+\pi^-$. In this MC generator, one of the protons emits a quasi-real photon, that materializes into a vector meson by scattering with the other proton via IP exchange

- Dime MC: The Durham Dime MC model provides theoretical predictions for pp ➔ $p\pi^+\pi^-p$ processes. (continuum contribution – resonances not included)

Data Analysis

Event selection

- 2010 Data sample corresponds to an integrated luminosity of 450 μb^{-1}
- Low pileup beam conditions at $\sqrt{7}$ TeV
- Trigger: HLT_ZeroBias

- Exactly two opposite-sign tracks with $p_T(\pi) > 200$ *MeV/c* and $|y(\pi)| < 2$
- Track-quality cuts (high purity) to remove fake tracks
- Primary vertex with 2 tracks and $|z| < 15$ cm of the nominal center
- No extra calorimeter activity

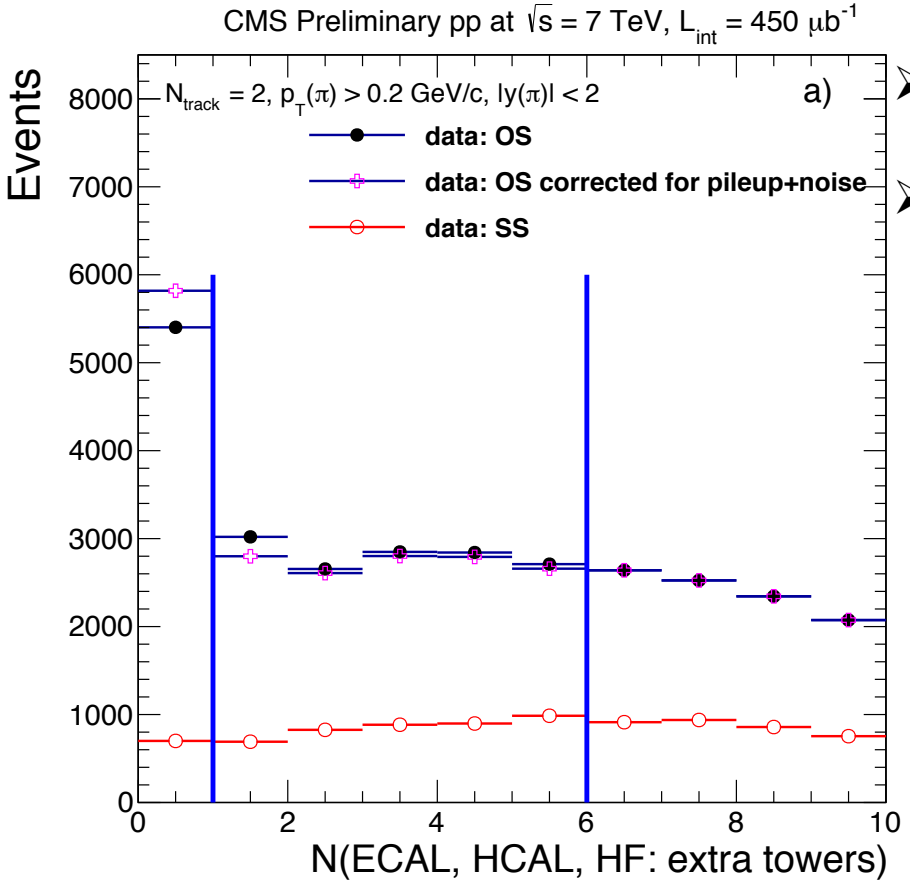
- Noise thresholds on ECAL & HCAL

Selection	Data: events left
High-level trigger zero-bias	33214795
Exactly two tracks	215139
Track purity	170990
$\|y(track)\| < 2$	128375
$p_T(track) > 0.2$ GeV/c	103038
Vertex with 2 tracks	58468
$\|z_{vertex}\| < 15$ cm	57602
$E_{EB} < 0.52$ GeV	49462
$E_{EE} < 2.18$ GeV	42988
$E_{HB} < 1.18$ GeV	41703
$E_{HE} < 1.95$ GeV	32565
$E_{HF+} < 4.0$ GeV	14037
$E_{HF-} < 4.0$ GeV	6102
Opposite-sign	5402
Same-sign	700

Background Estimation

Data-driven estimate of background

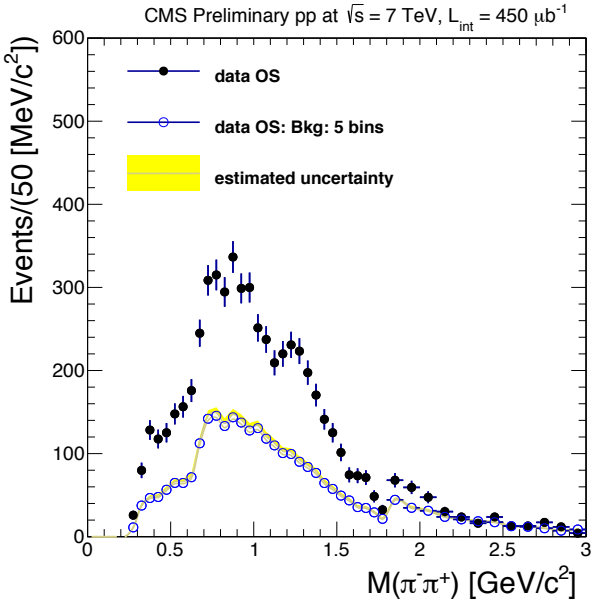
Background Control Region

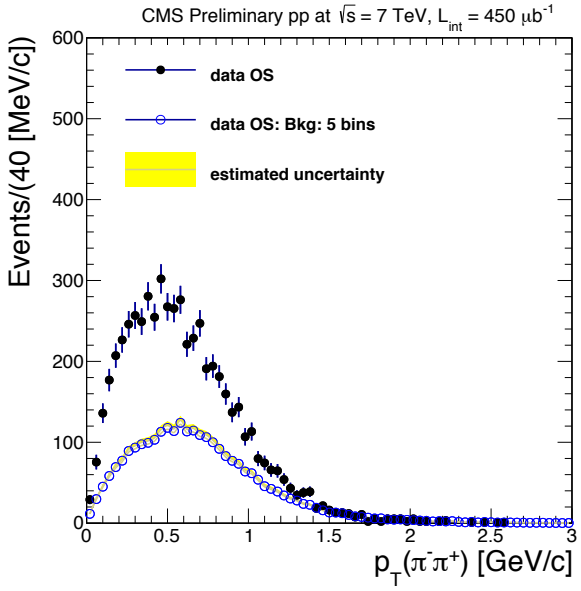


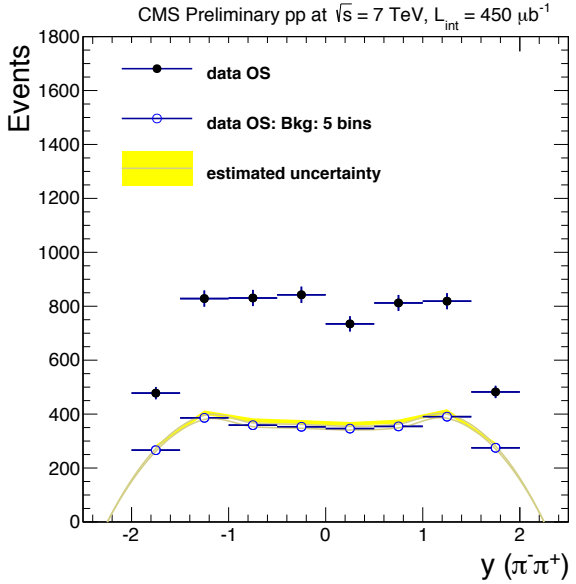
- **Signal**: (Zero-bin with opposite-sign (OS) events)
- **Background**:
  - ✓ Make "data-driven"
  - ✓ Both normalization and shape for different distributions
  - ✓ Use the sample with all cuts applied, but require 1-5 towers above threshold
  - ✓ Take the background normalization from the average of these 5 bins
  - ✓ Take the shapes from events in these 5 bins
- Use the same procedure on same-sign (SS) events (purely background)

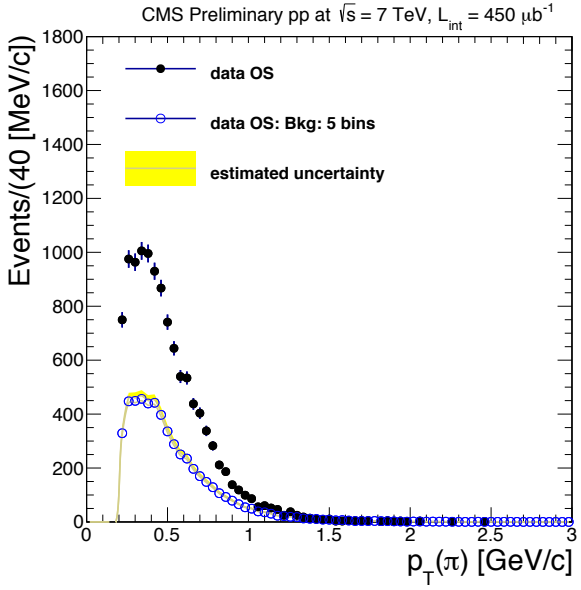
Signal distributions

Signal: Opposite-sign (OS)









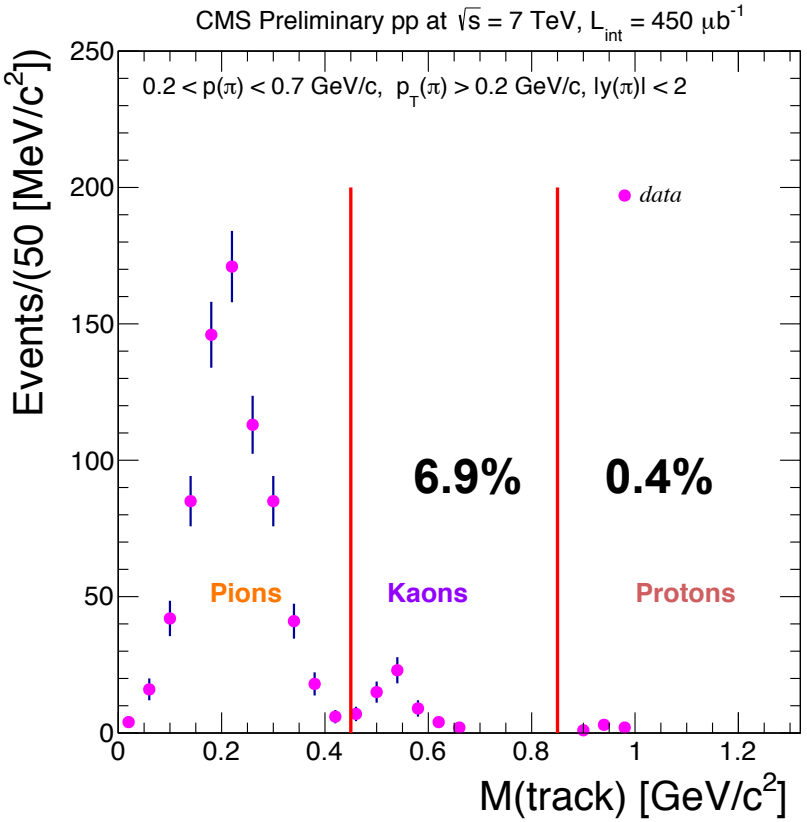
- Using the sideband region in the tower multiplicity distribution
- For the nominal background estimate, use the control sample with 1-5 extra calorimeter towers above threshold, and all other selection criteria applied
- The non-exclusive background shapes obtained from this method are shown, with a normalization given by the average number of events per bin of tower multiplicity

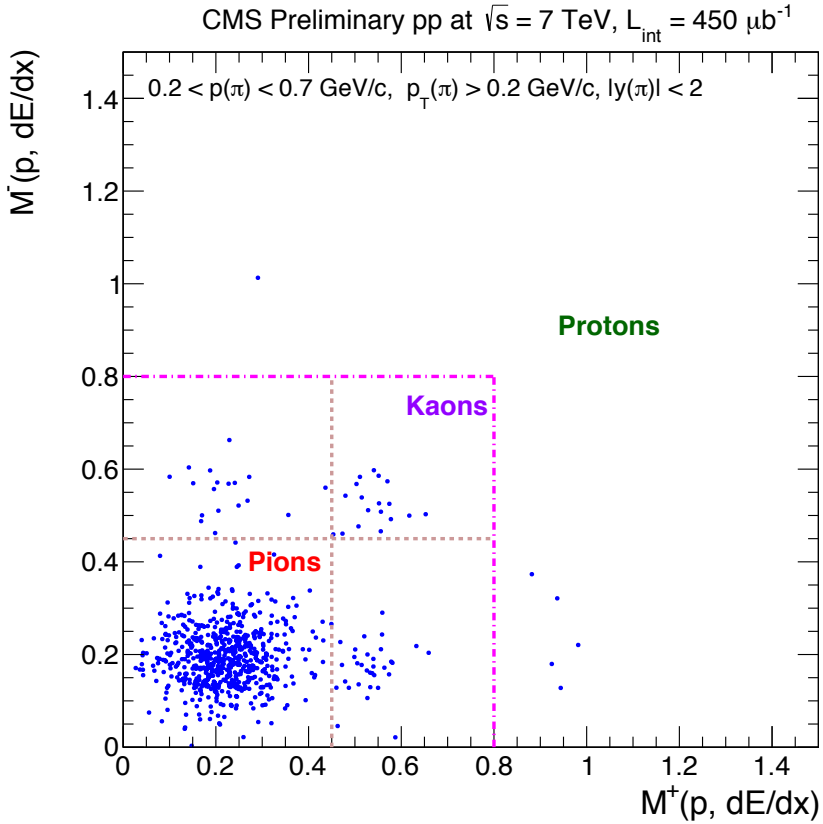
Background is $\pi^+\pi^-$ events but with additional activity

Particle identification

study of non-pion contamination

The identification of charged pions is carried out using measured momentum and isolation energy loss, dE/dx, of the low momentum tracks traversing the silicon tracker





$$M = p\sqrt{(dE/dx - C)/K}$$

- Separation of pions from Kaons and few protons:
- Scatter distribution shows the separation of two tracks
  - ~90% of two tracks are $\pi^-\pi^+$ in the momentum range of 0.2-0.7 GeV/c
  - ~2.5% are K+K-, ~7% are pi-K, ~0.9% are pi-p
- We do not subtract the non-π-π background (efficiency mass dependence)

Systematics

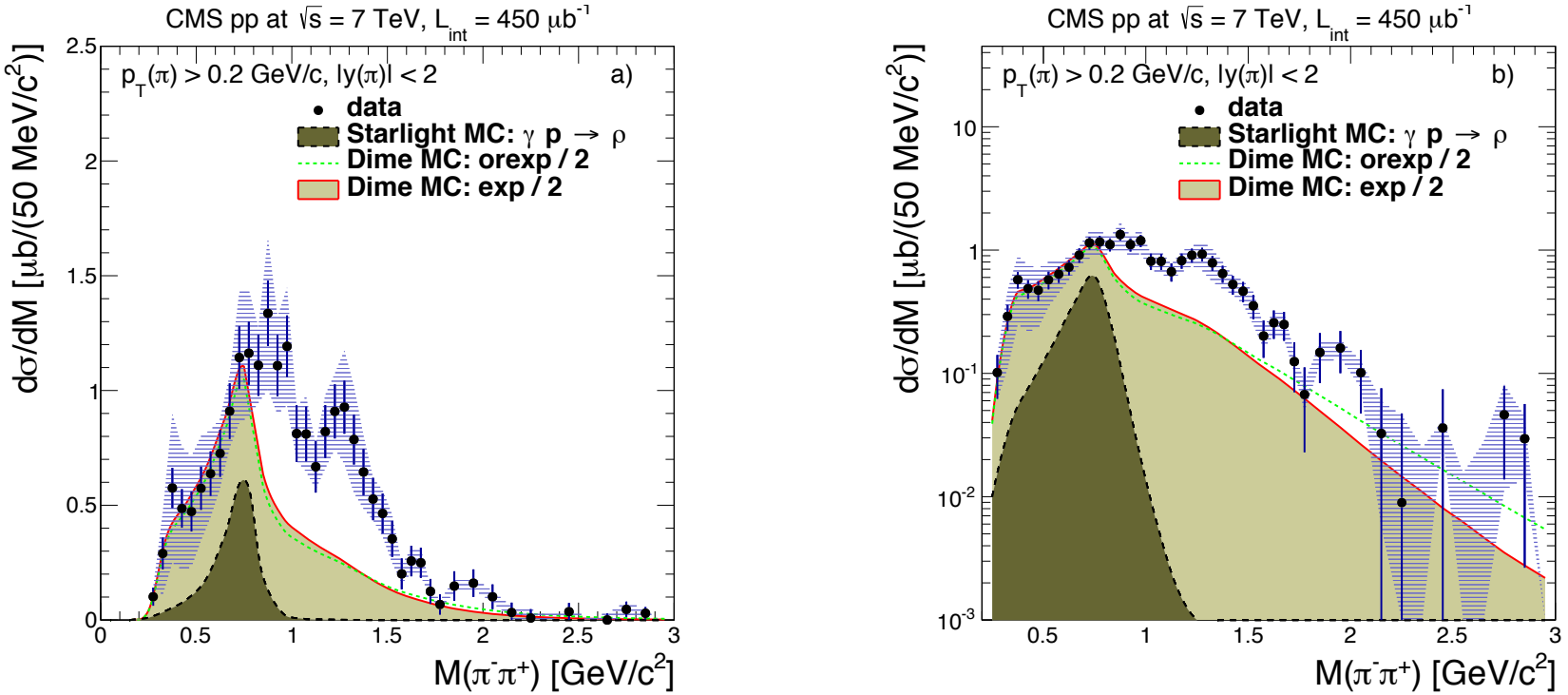
Systematics …

Source	Uncertainty (%)
Background estimation	7.2
Tracking efficiency (pion pair)	7.8
Luminosity measurement	4.0
Unfolding	10.3
HF energy scale	2.0
Barrel, Endcap energy scale	3.9

- **Table above summarizes the sources of total systematic uncertainty on the cross section measurement**
- **The total systematic uncertainties is obtained by adding the individual sources in quadrature**

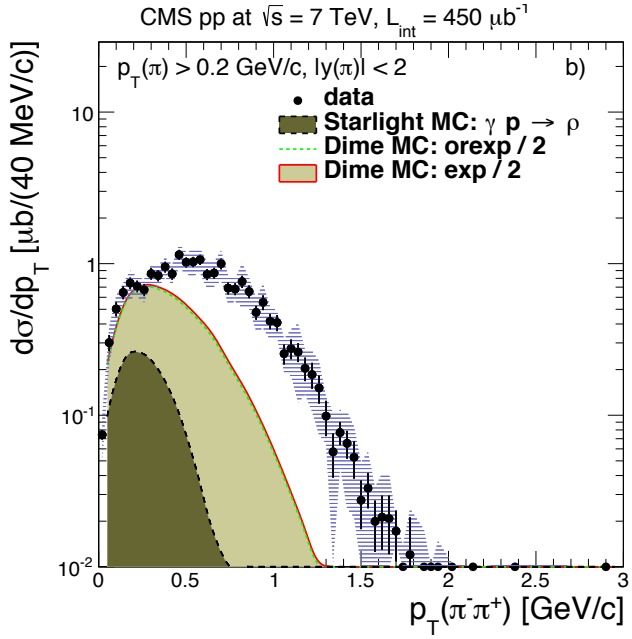
Results

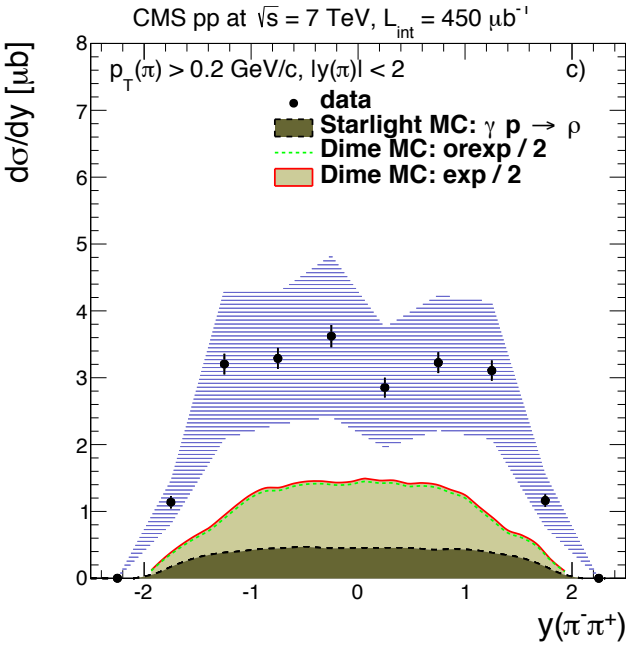
dσ / dM



- **Differential cross section**:
  - with $p_T(\pi) > 0.2$ GeV/c and $|y(\pi)| < 2$
  - compared to the predictions of DPE productions from the Dime MC (red/green-curves), and STARLIGHT (dash). (Here: Dime MC & Starlight are stacked)
  - The shaded blue band shows the overall systematic uncertainty, and the thin error bar indicates the statistical uncertainty
  - The results are plotted on a linear scale (left) and a logarithmic scale (right)

$d\sigma / d [p_T(\pi\pi), y(\pi\pi), p_T(\pi)]$

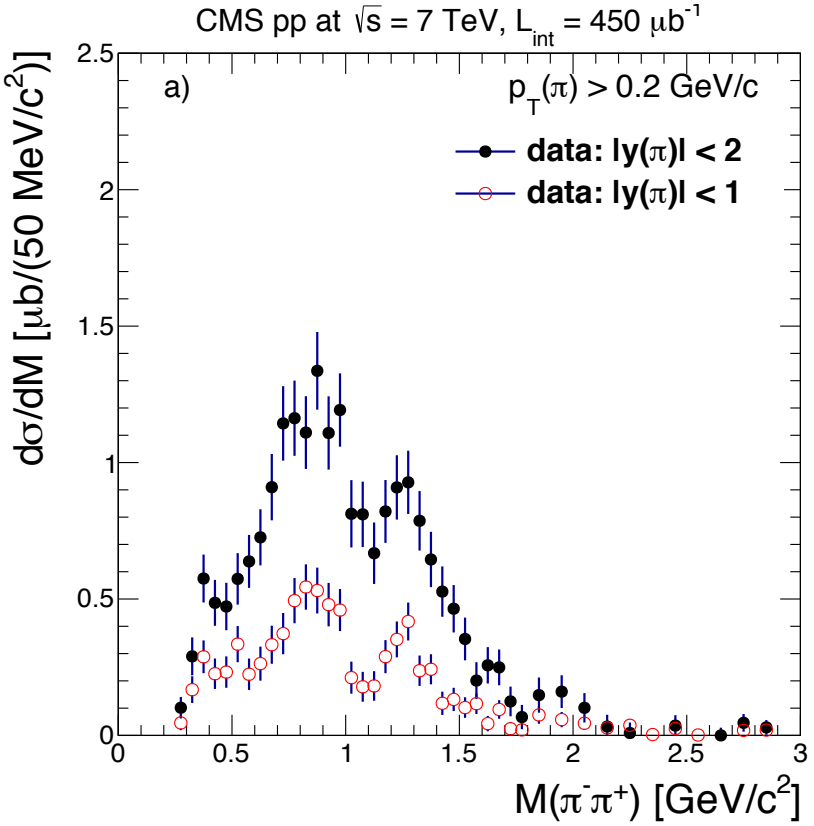


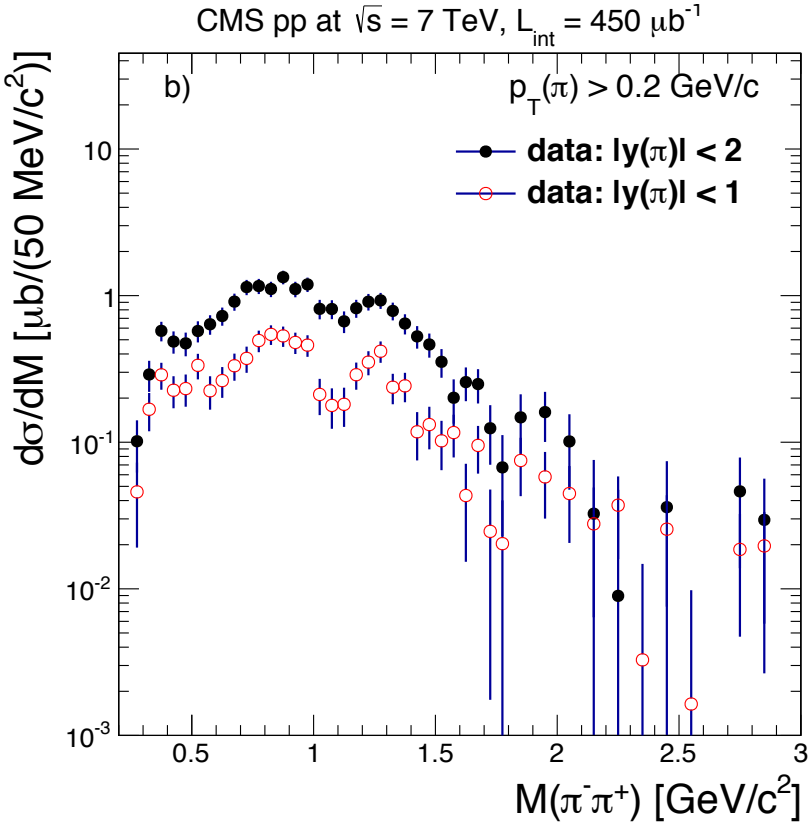


- **Differential cross sections as a function of p_T and Rapidity**:
  - with $p_T(\pi) > 0.2$ GeV/c and $|y(\pi)| < 2$ at $\sqrt{}$**7 TeV**
  - compared to the predictions of DPE production from the Dime MC (red/green-curves), and STARLIGHT (dash). (Here: Dime MC & Starlight are stacked)
  - The shaded blue band shows the overall systematic uncertainty, and the thin error bar indicates the statistical uncertainty
  - The results are plotted on linear and log scale
  - As the rapidity gap still extends to $|\eta| = 4.9$, the minimum gap size in this case is 3.9, a fact that leads to a reduction of the contribution of non-pomeron exchange.

$$\sigma_{Vis} = 20.5 \pm 0.3(stat.) \pm 3.1(sys.) \pm 0.8(lumi)\mu b$$

Restricting y(π) region from <1.0 to < 2.0





- Corrected differential cross section, comparing |y(π)| regions < 1 and 2
- New Mass($\pi^-\pi^+$) plot does have the strong features f0(980) and f2(1270)
- The minimum gap increases to 3.9, which will select purer DPE events and seems to enhance the resonance structures.

$$\sigma_{Vis} = 8.1 \pm 0.2(stat.) \pm 1.2(sys.) \pm 0.3(lumi)\mu b$$

$p_T(\pi) > 0.2$ GeV/c and $|y(\pi)| < 1$ at $\sqrt{7}$ TeV

Summary

- Integrated and differential cross sections of the pion-pair production for the exclusive and semi-exclusive reaction
- Using the proton-proton collisions at √7 TeV with the CMS detector with an integrated luminosity of 450 μb^{-1}
- The integrated cross section in the phase space of $p_T(\pi) > 0.2$ GeV/c and $|y(\pi)| < 2$ with no additional particles above threshold
- The $\pi^+\pi^-$ cross sections as a function of in variant mass, p_T, and y have been compared to model predictions: Dime MC and STARLIGHT
- The integrated measured cross section is larger than the predictions based on exclusive $\pi^+\pi^-$ without proton dissociationation, with most of the excess at $p_T(\pi^+\pi^-) > 0.5$ GeV/c.
- The invariant-mass spectrum shows some features not included in the purely non-resonant predictions
    - Similar to those observed in lower-energy p-pbar [CDF with √1.96 TeV for p_T> 1 GeV/c: **Phys Rev D 91, 091101(R) (2015)]**, and qualitatively reproduced in **Phys. Rev. {D92} (2016) 054015.**

Thank you!