First 13 TeV results from CMS

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ISMD 2015, Wildbad Kreuth

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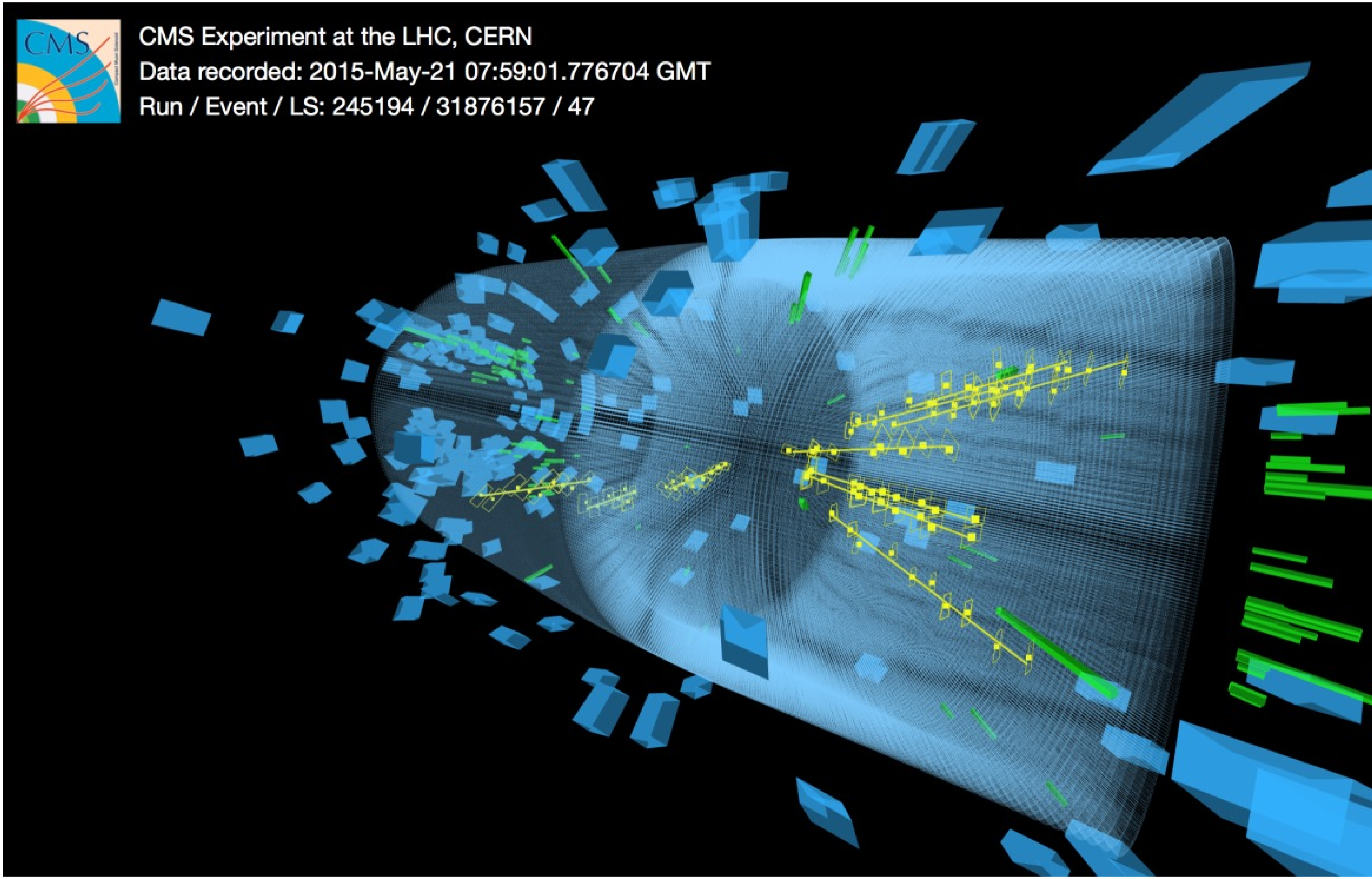
Introduction – pp at $\sqrt{s} = 13$ TeV

- First physics – basics, QCD
  - $\mathrm{d}N/\mathrm{d}\eta$ of charged hadrons — 55 k and 170 k events
  - two-particle angular correlations, ridge — 270 nb^{-1}
- Top physics – very first look
  - $\mathrm{t\bar{t}}$ and single top production — 42 pb^{-1}
    dilepton or lepton+jet
    inclusive and/or differential
- New physics? – very first look
  - search for narrow resonances using dijets — 42 pb^{-1}

⇒ All new! ⇐

First physics – basics, QCD



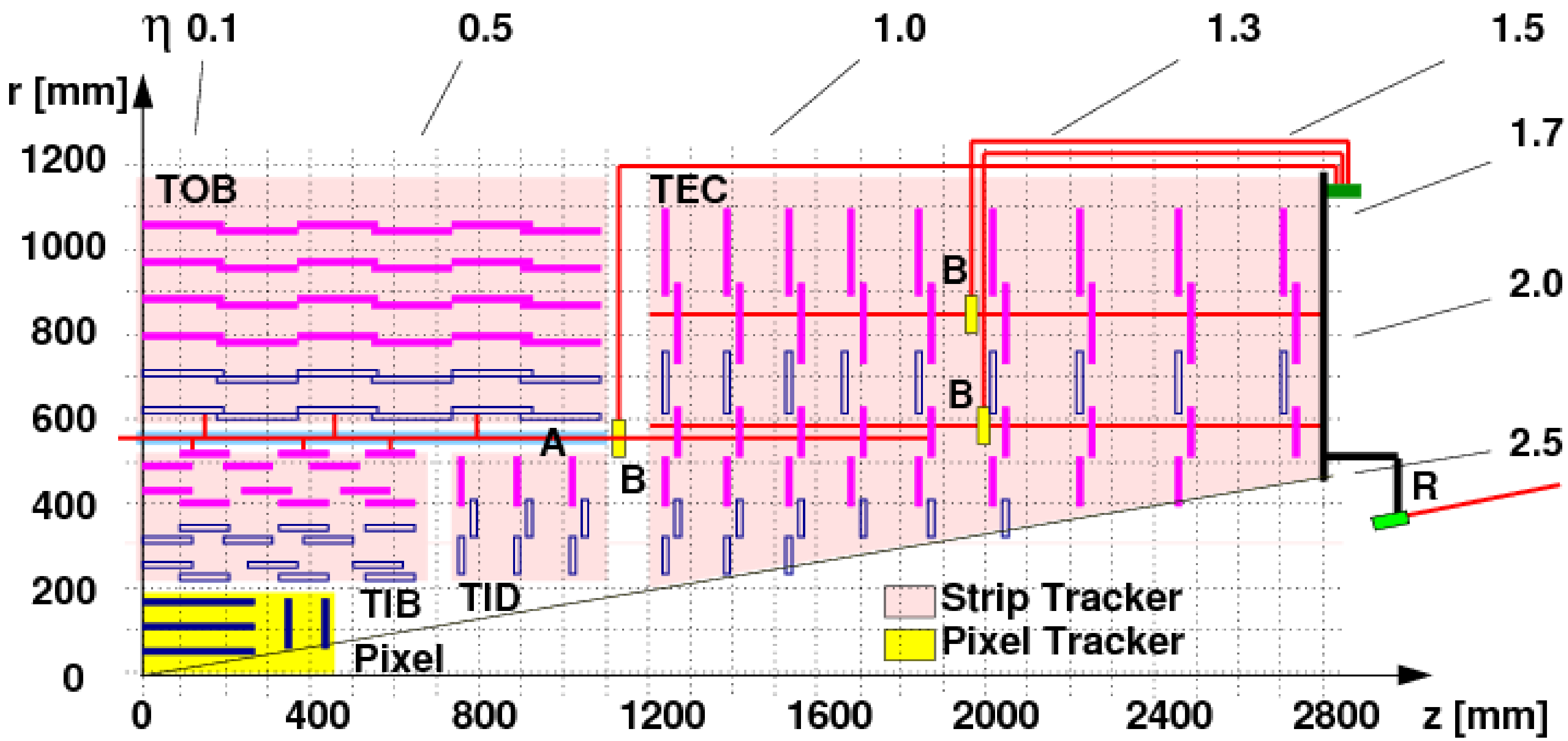
Charged hadrons – dN/dη

- Why?
  - most basic physical observables in high-energy particle collisions
  - essential first step in exploring the physics of a new energy regime
  - combination of perturbative and nonperturbative QCD: saturation of parton densities, multiparton interactions, parton hadronization, and soft diffractive scattering

- How to measure?
  - special circumstances: **no magnetic field** (cryo problem at CMS)
  - trigger on incoming proton bunches from LHC (**inelastic**)
  - use 3D hits in the silicon tracker
  - look for **hit pairs** at different radii (tracklets)
  - look for **hits on straight lines** (tracking)

Unusual conditions – technically challenging measurement

Charged hadrons – the silicon tracker



- Layers with 3D hits

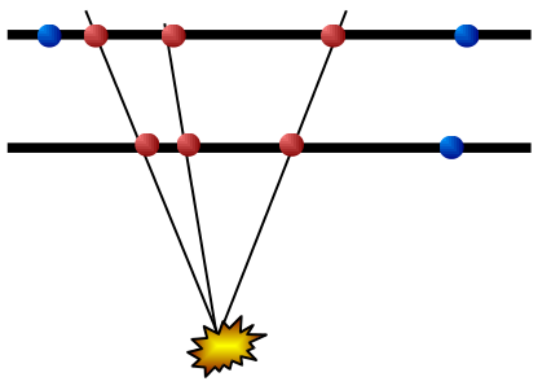
  double-sided strip modules ⇒ very preliminary

  21 May: quiet beams, **pixel detector off**, low pile-up

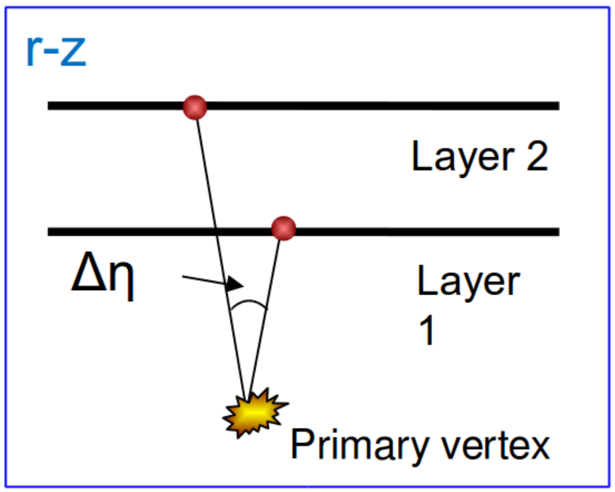
  pixel modules ⇒ final result

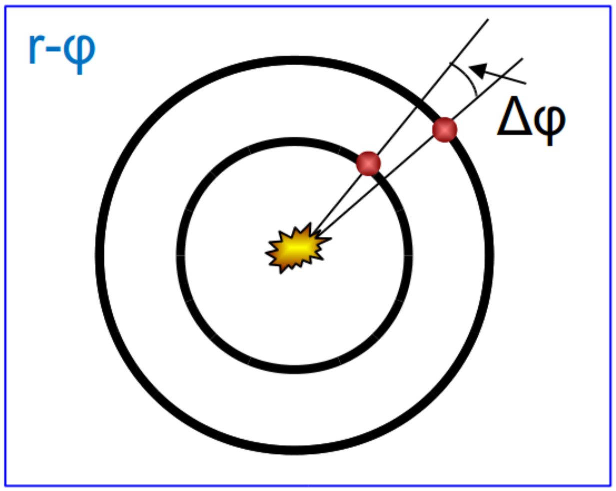
  7 June: $\pm 3\sigma$ beam separation, very low pile-up

Charged hadrons – strip hits – hit pairs



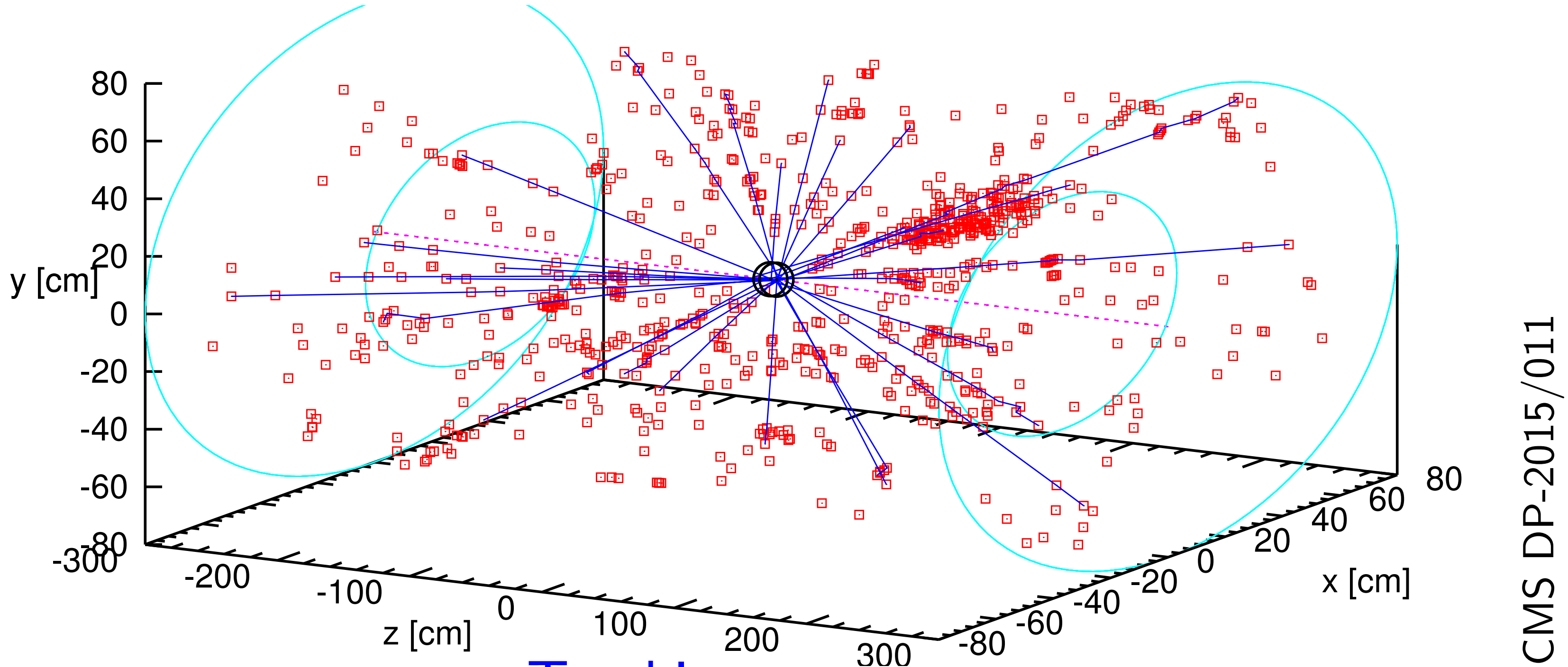
- Tracklets
  - they are used to reconstruct the position of the primary vertex
  - combinatorial background estimated from the sideband region ($1 < |\Delta\phi| < 2$)
  - efficiency down to 50 MeV/c in p_T
  - charged particle multiplicity from the height of the $(\Delta\eta, \Delta\phi)$ correlation peak

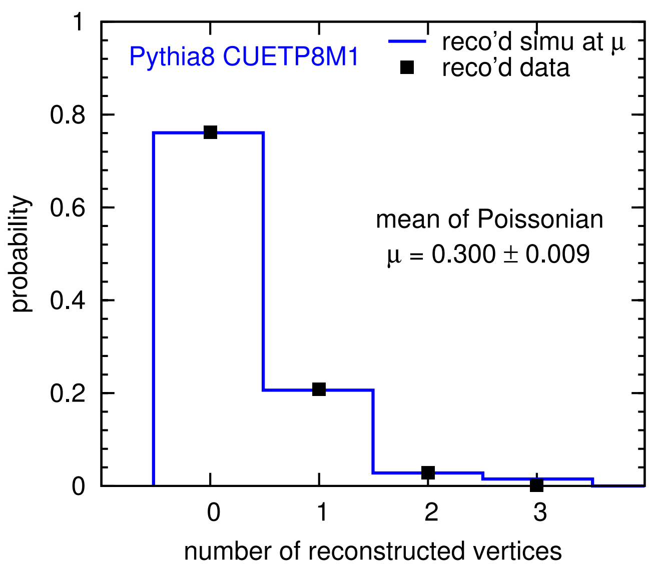




CMS DP-2015/011

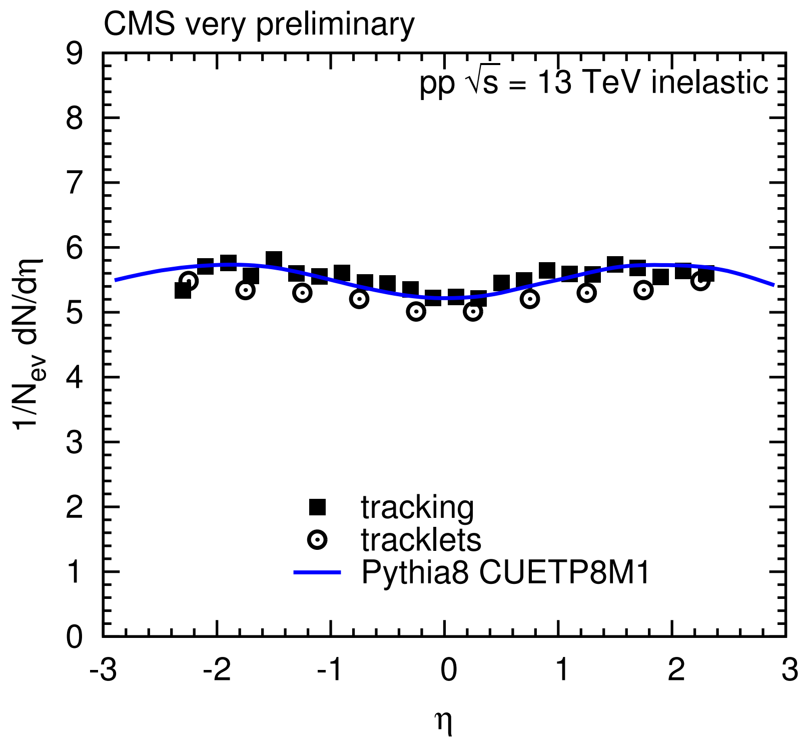
Charged hadrons – strip hits – straight lines

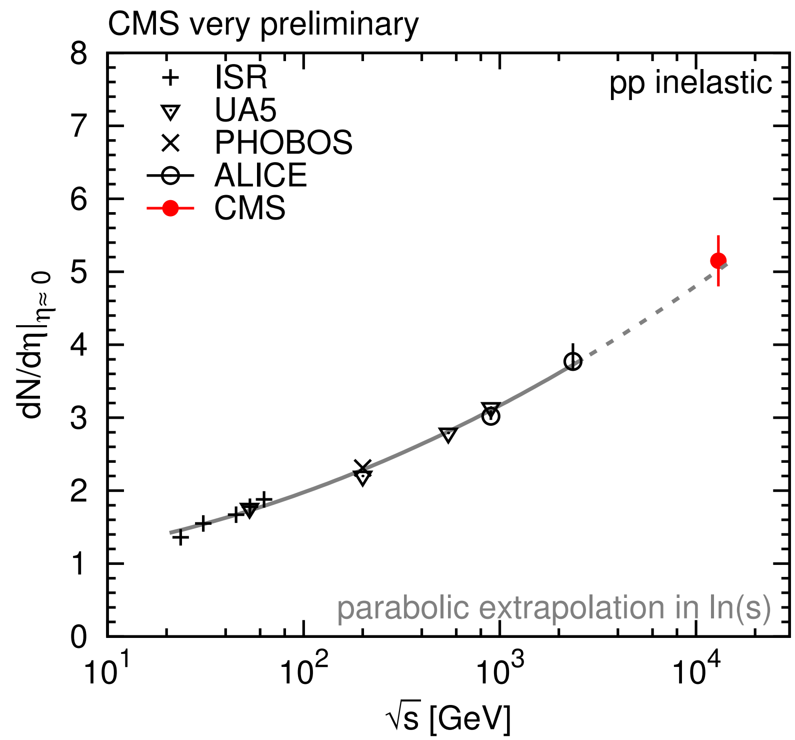




- Tracking
  - transform (x, y, z) coordinates to (η, ϕ)
  - agglomerative clustering with fPNN search
  - fit them to a straight-line model
  - vertexing: cluster tracks using fitted (z_0, σ_z)
  - estimate pile-up from data, with help of simulated response

Charged hadrons – strip hits – very preliminary





CMS DP-2015/011

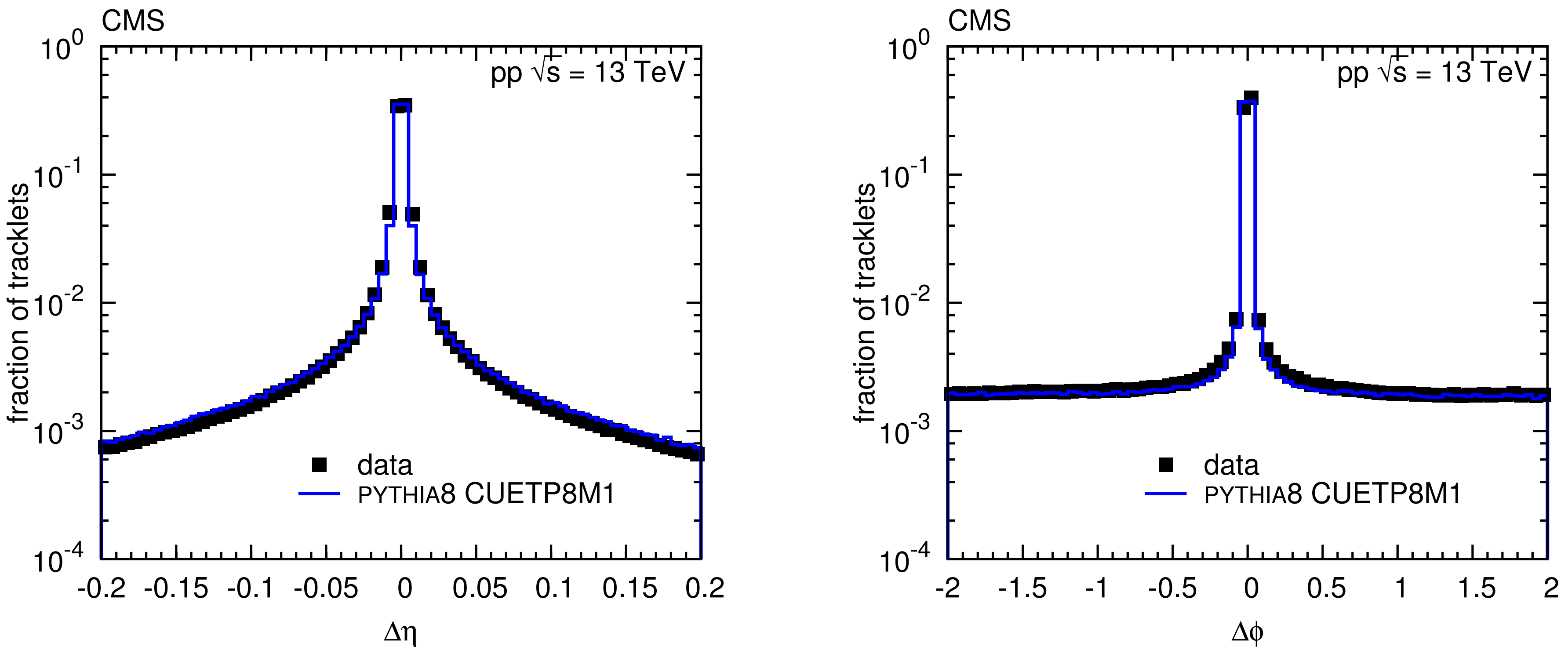
The raw dN/dη is corrected using a Pythia8 tune, bin-by-bin

The typical size of the correction at midrapidity is 20-30%

Averaged inelastic dN/dη from tracklet and tracking

Estimated 7% systematic uncertainty

Charged hadrons – pixel hits – hit pairs



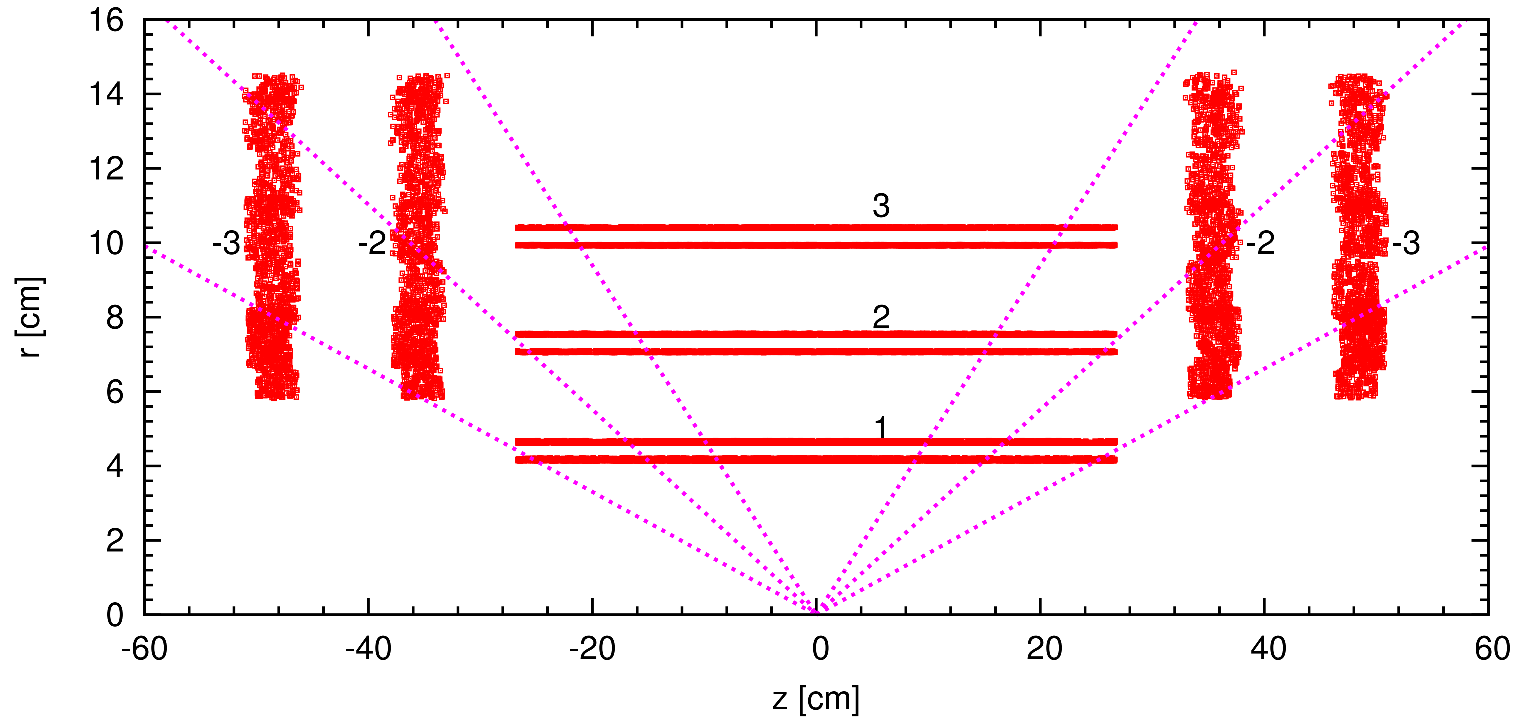
CMS arXiv:1507.05915, PLB accepted

Pixel hits on three barrel layers: much better position resolution, close

Sharp correlation peak at $(\Delta\eta, \Delta\phi) = 0$, nice match with simulation

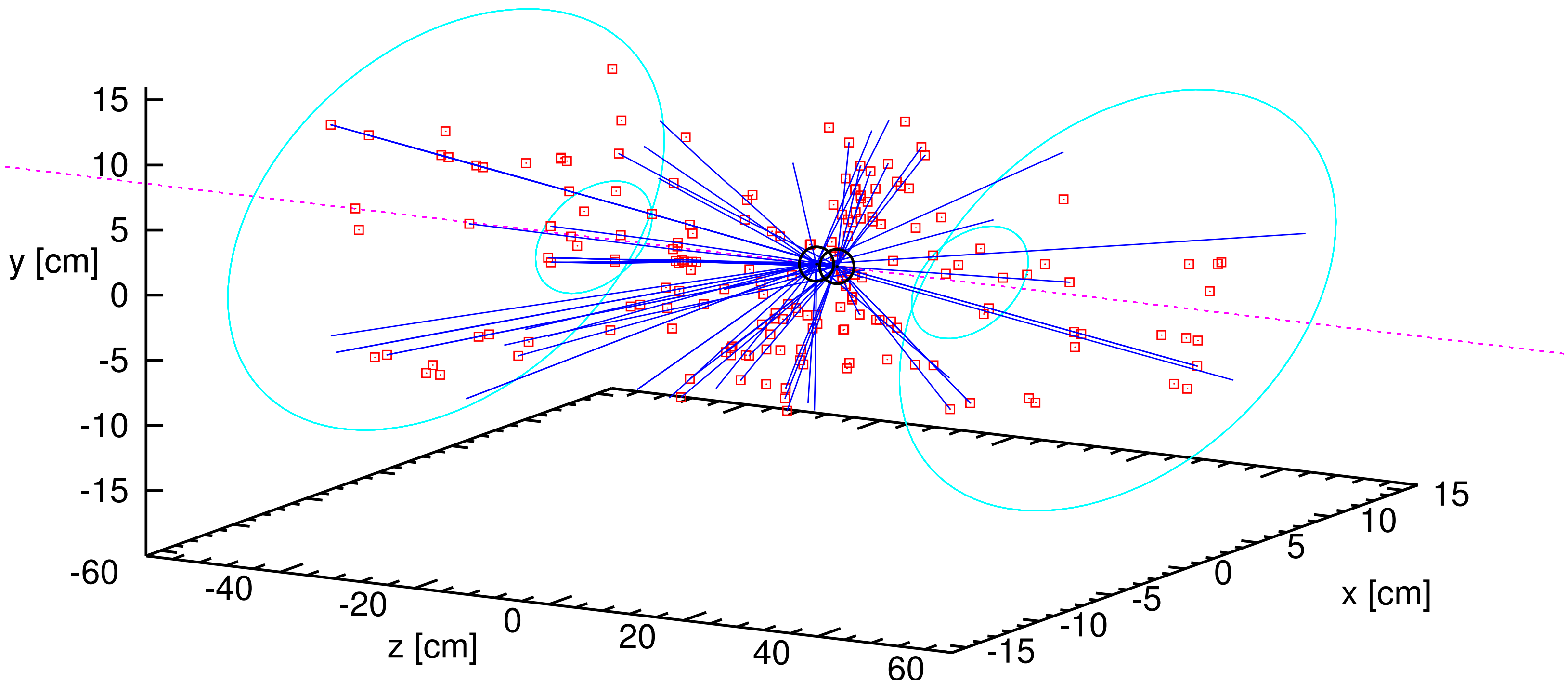
Combinatorial background estimated from the sideband region $(1 < |\Delta\phi| < 2)$

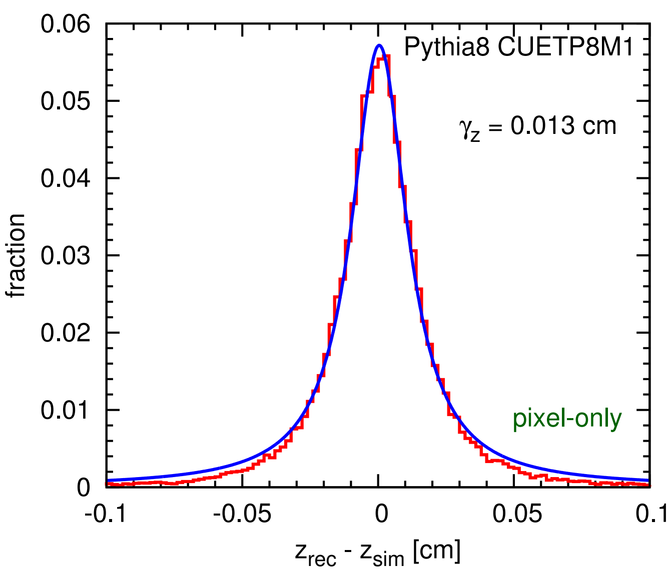
Charged hadrons – pixel hits – tracking



- Tracking
  - only barrel layers are used
  - search for hit pairs from layers 1 and 2, with $|\Delta\phi_{12}| < 0.02$
  - search for another hit from layer 3, with $|\Delta\phi_{23}| < 0.02$
  - select triplets on a straight line, with $|\Delta\theta_{12,23}| < 0.02$
  - clean them

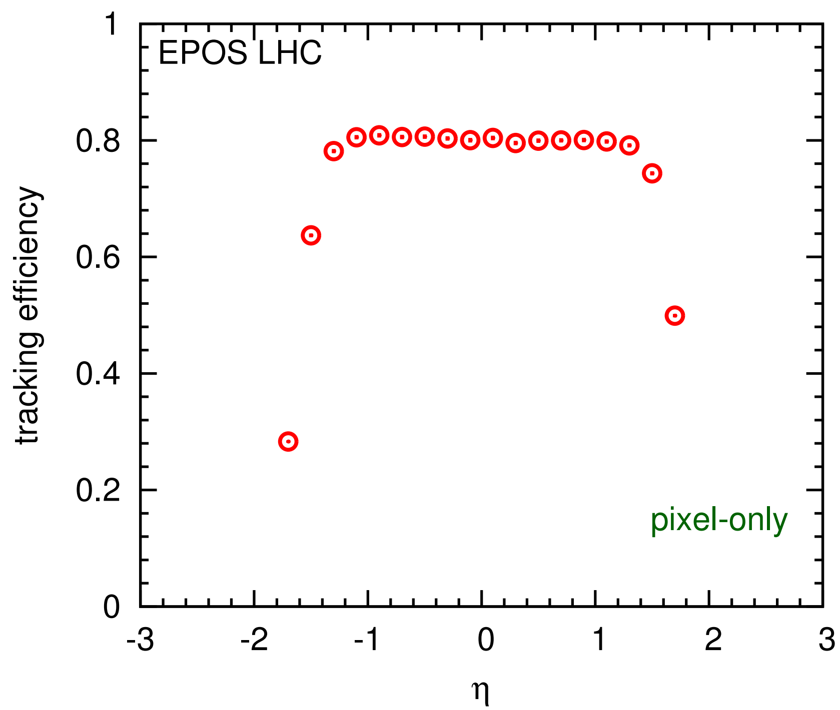
Charged hadrons – pixel hits – tracking

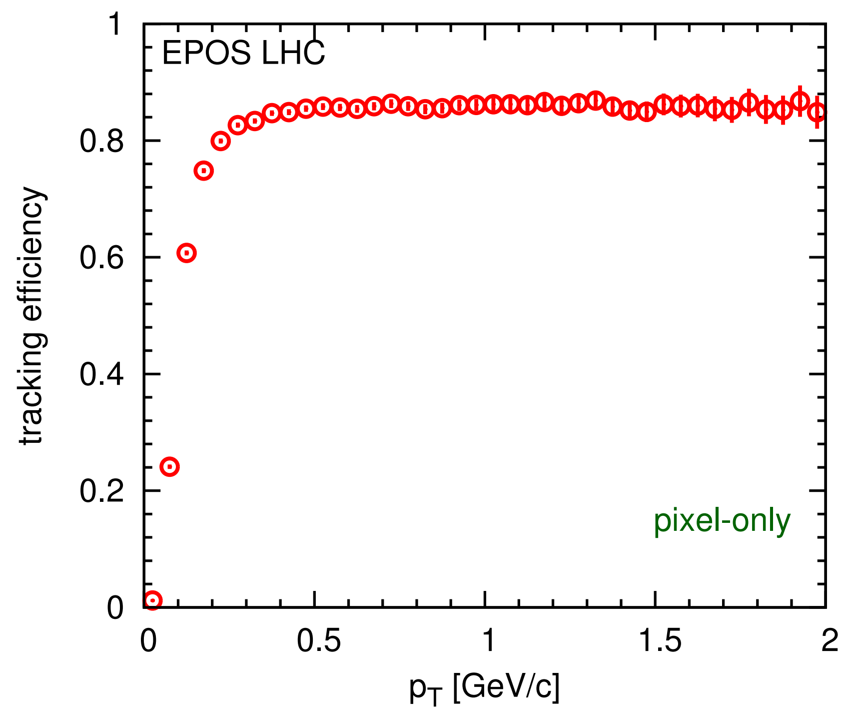




- Straight lines
  - excellent track-pointing
  - very good vertex position resolution
  - we are able to resolve multiple pp collisions within a bunch crossing

Charged hadrons – pixel hits – tracking

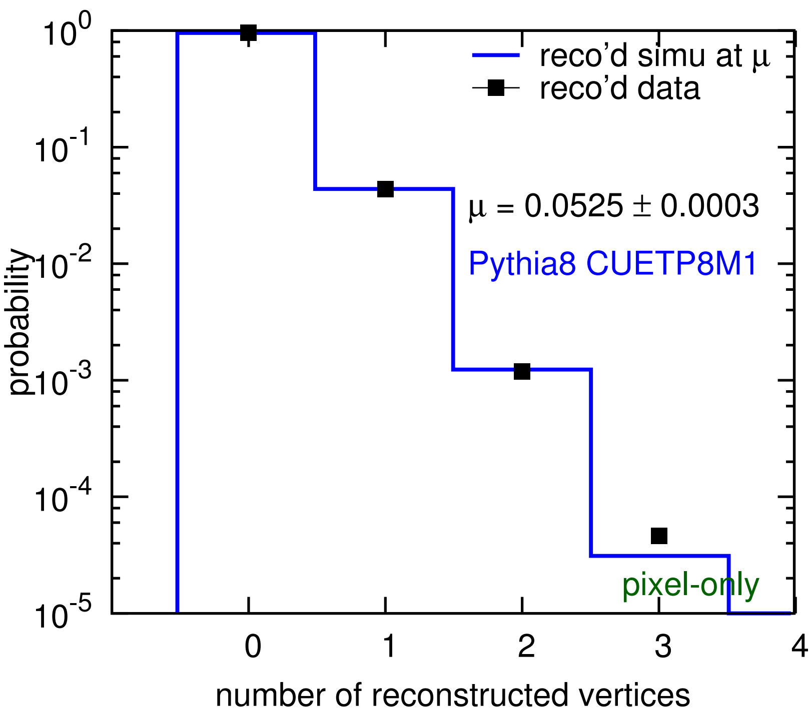


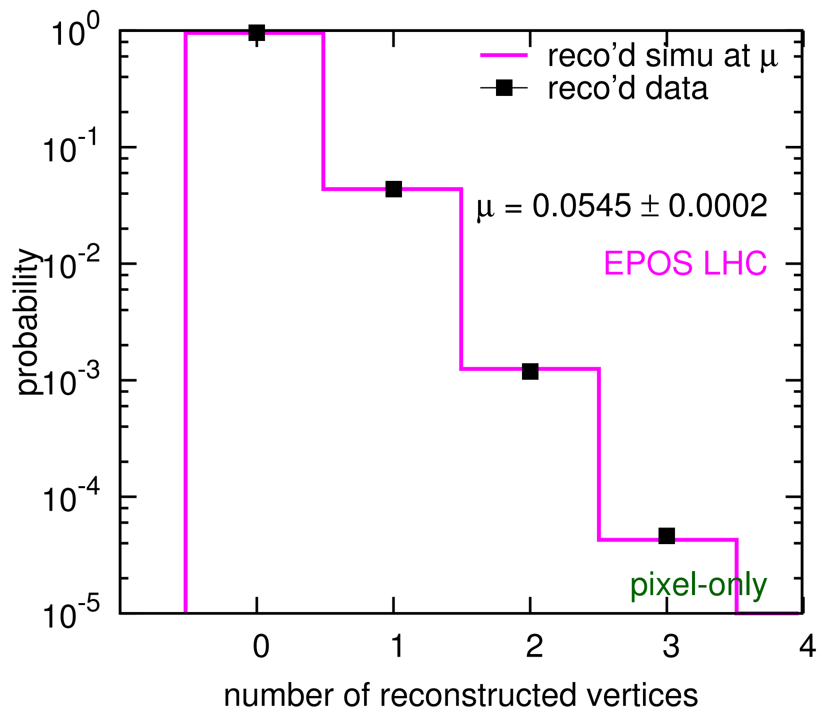


Very few duplicate tracks (1-2%), small number of fakes (3-6%)
Checked both with Pythia8 and EPOS LHC

How to estimate the number of inelastic collisions?
Measured pile-up using detector response and a Poissonian model

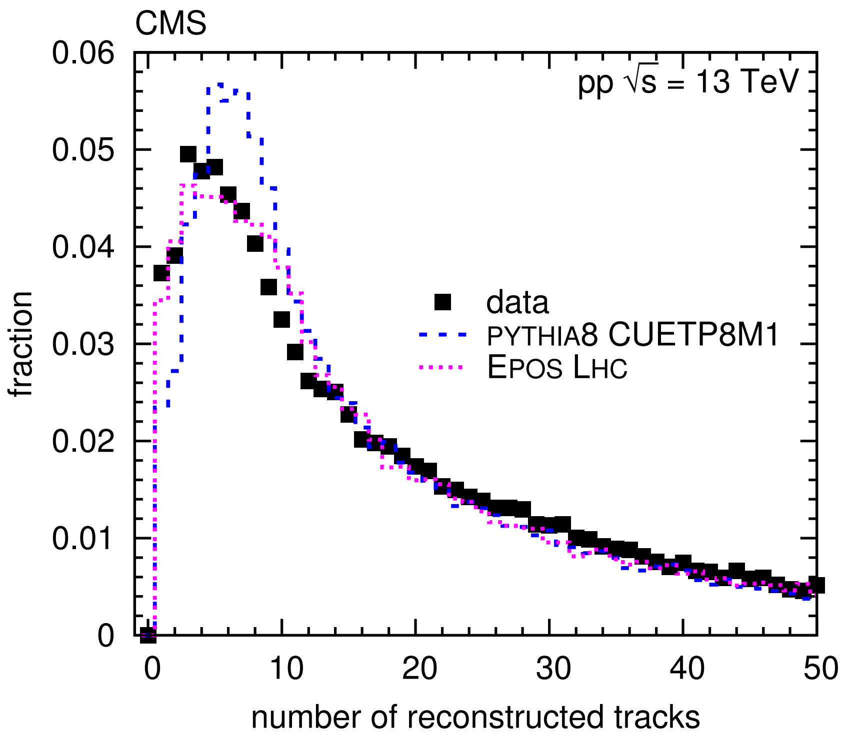
Charged hadrons – pixel hits – pile-up

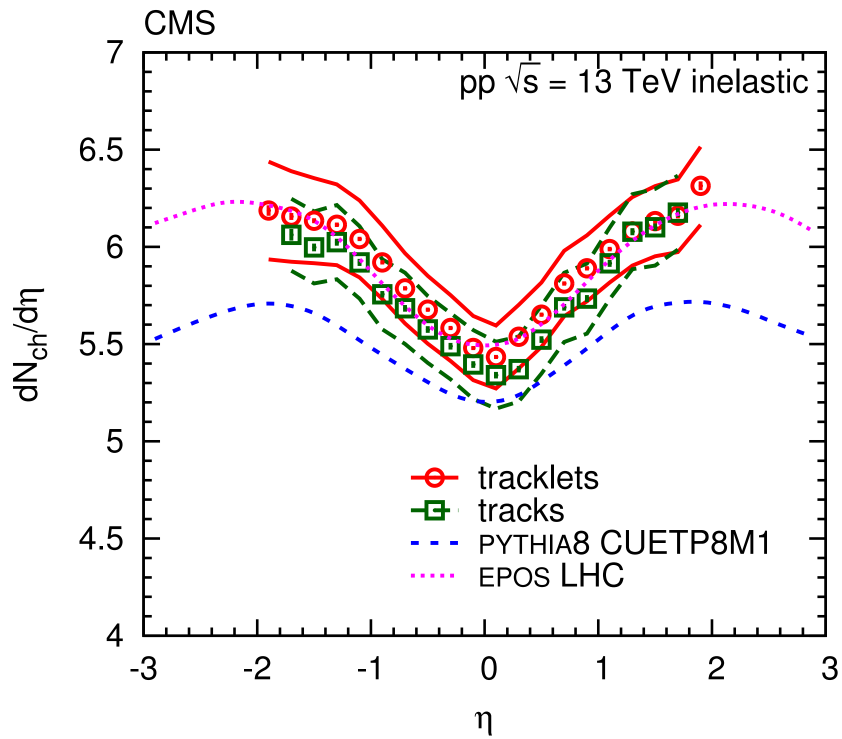




Input	*Reconstructed* 0	1	2	3	4
reco'd Pythia8, one coll	12.35%	86.92%	0.72%	0.01%	0.00%
reco'd Pythia8, two colls	1.57%	30.80%	66.36%	1.23%	0.04%
reco'd Pythia8, three colls	0.17%	8.59%	37.35%	52.14%	1.65%
reco'd EPOS LHC, one coll	15.61%	83.54%	0.82%	0.02%	0.00%
reco'd EPOS LHC, two colls	2.30%	38.18%	58.02%	1.44%	0.05%
reco'd EPOS LHC, three colls	0.39%	12.61%	42.21%	42.73%	1.87%
reco'd data	95.50%	4.37%	0.12%	0.00%	0.00%

Charged hadrons – pixel hits





CMS arXiv:1507.05915, PLB accepted

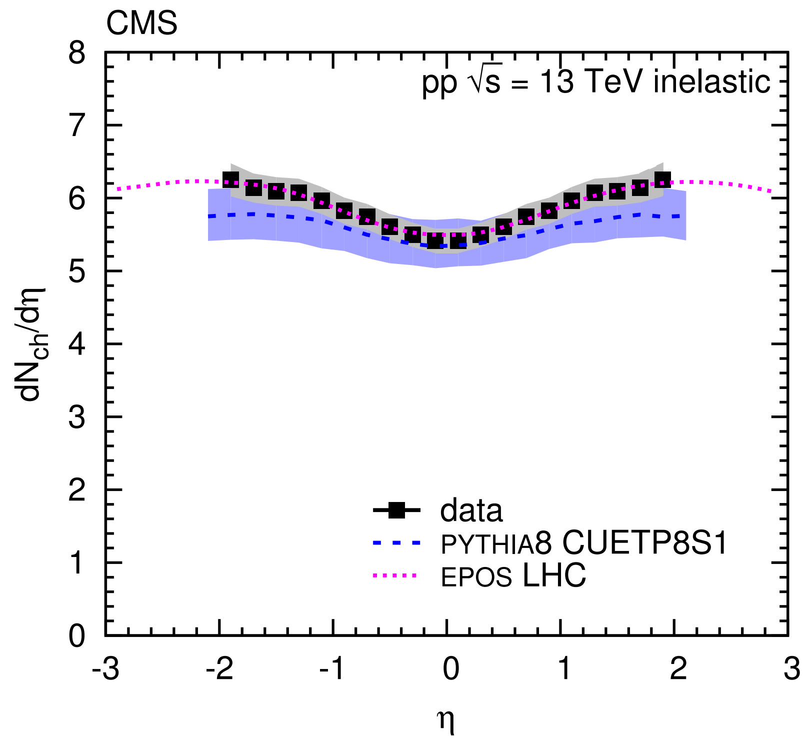
Detailed studies on systematics:

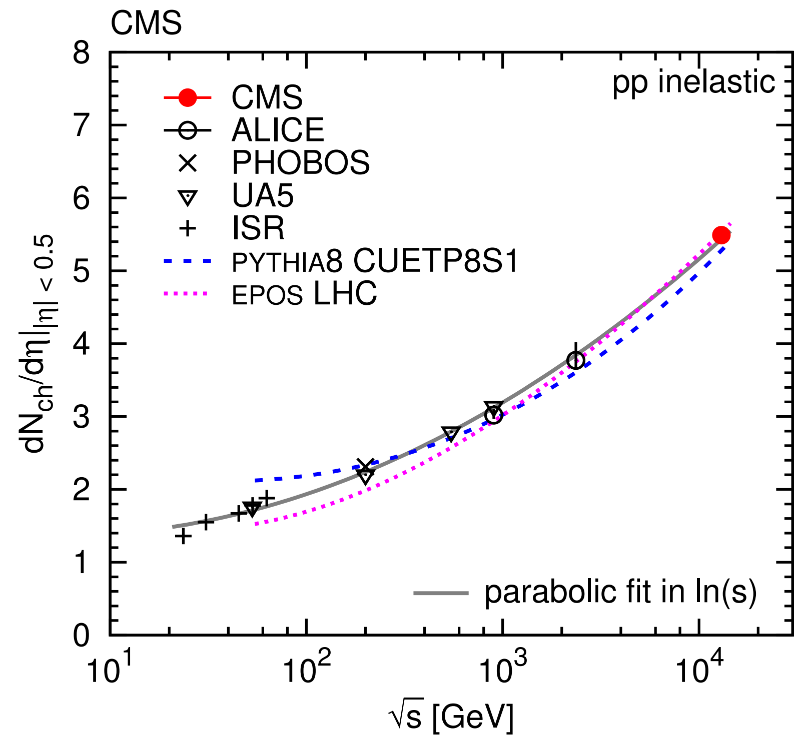
MC-dependence, mostly on the fraction of unseen events (diffraction)

Multiplicity distribution – closer to EPOS LHC

Tracklet and tracking methods are compatible, they are averaged

Charged hadrons – dN/dη – result



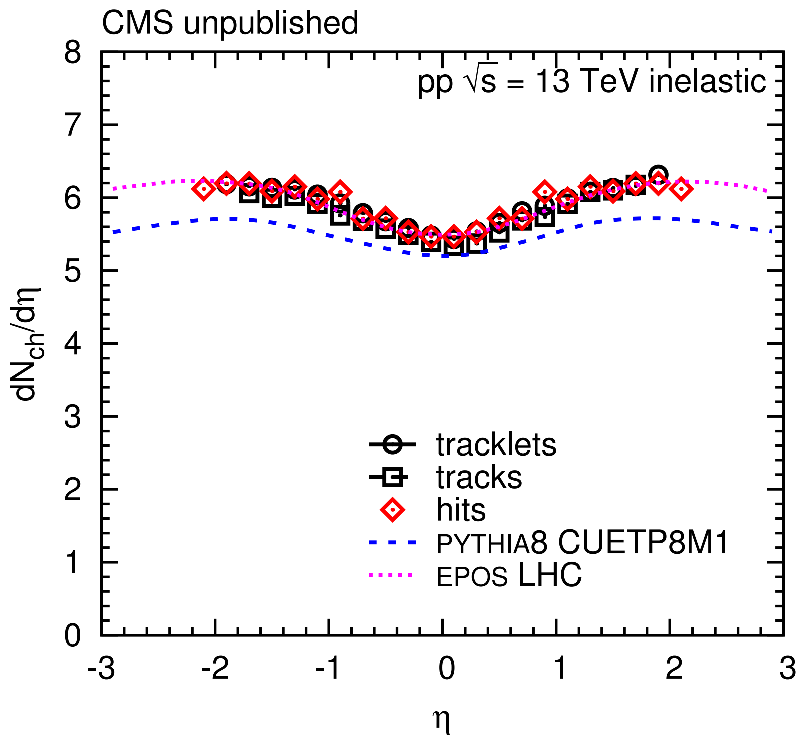


CMS arXiv:1507.05915, PLB accepted

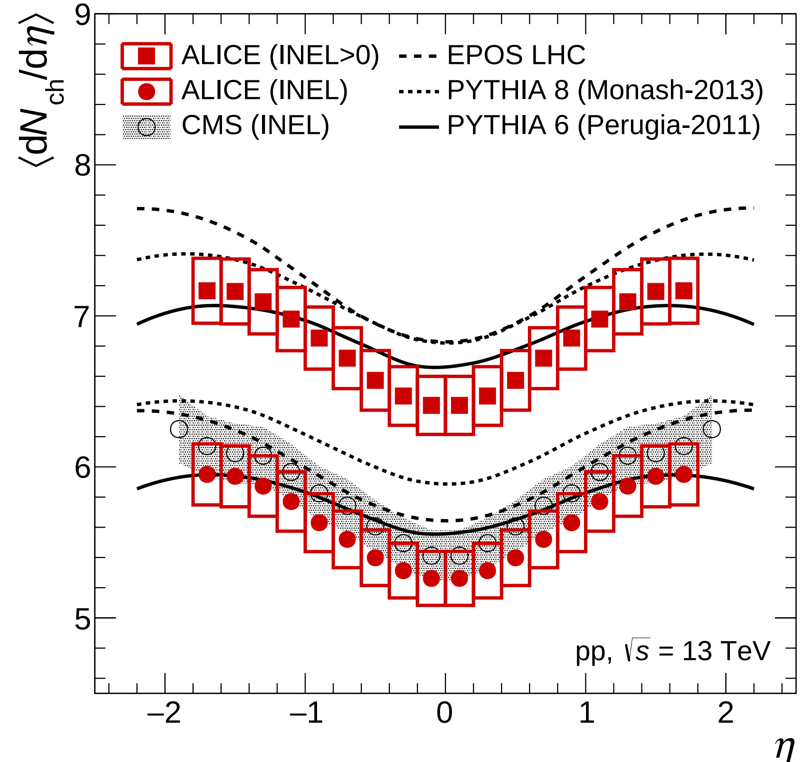
$$\text{Inelastic pp: } dN/d\eta|_{|\eta|<0.5} = 5.49 \pm 0.01(\text{stat}) \pm 0.17(\text{syst})$$

It is consistent with Pythia8 (with tunes CUETP8S1 and CUETP8M1), while for the full η range EPOS LHC gives a better description

Charged hadrons – dN/dη – comparisons



CMS with hit counting



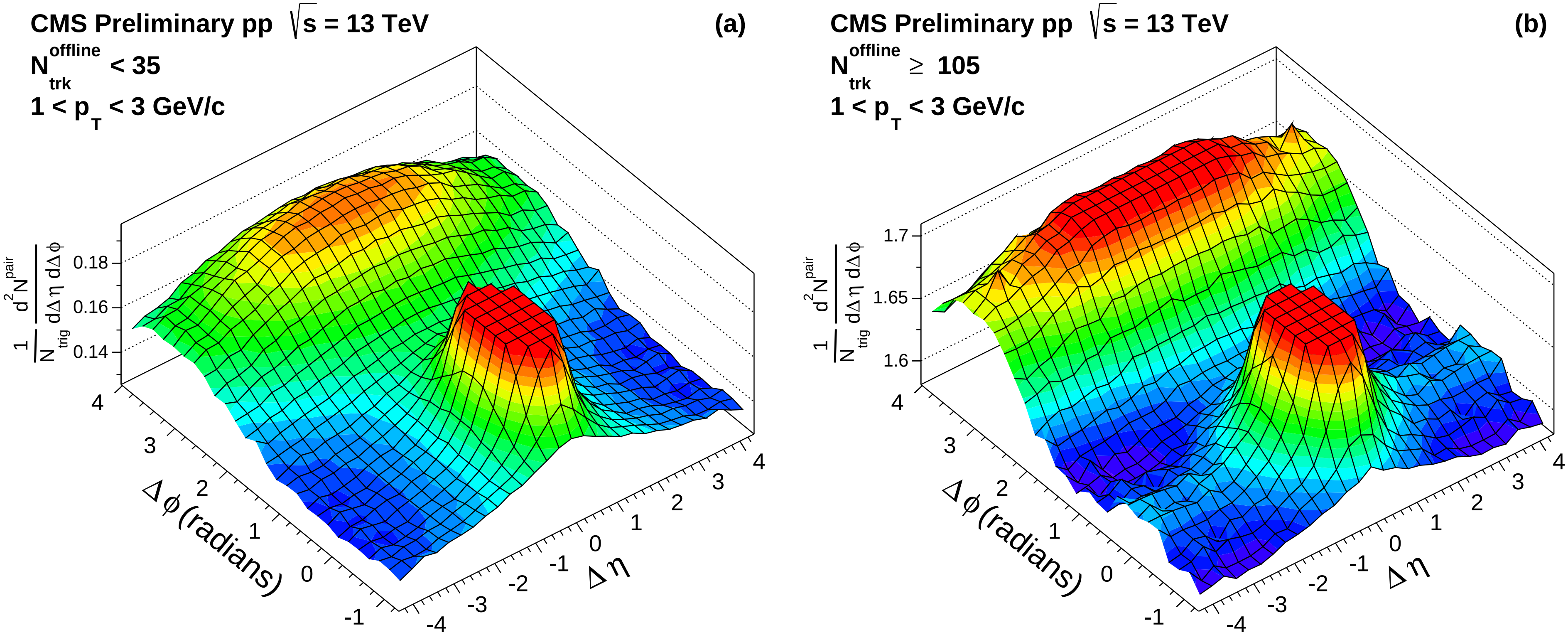
ALICE arXiv:1509.08734

Consistent with other alternative method (hit counting)

Also compatible with measurement from others

Charged hadrons – angular correlations

low multi high multi



CMS PAS FSQ-15-002

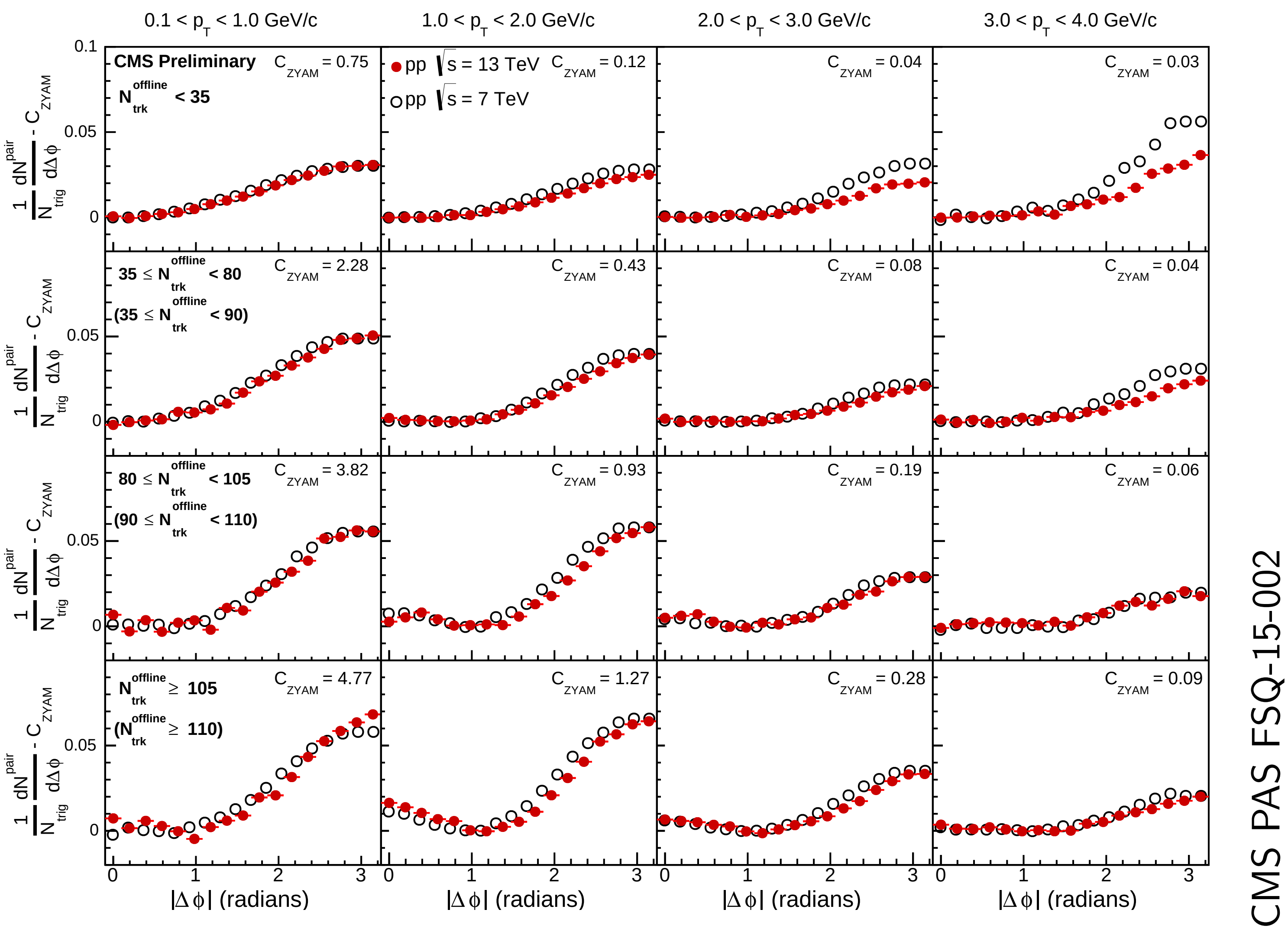
Why and how?

Various structures: jet peak, backward jet, and . . . the ridge

Long range $|\Delta\eta| > 2$

Near side $\Delta\phi \approx 0$

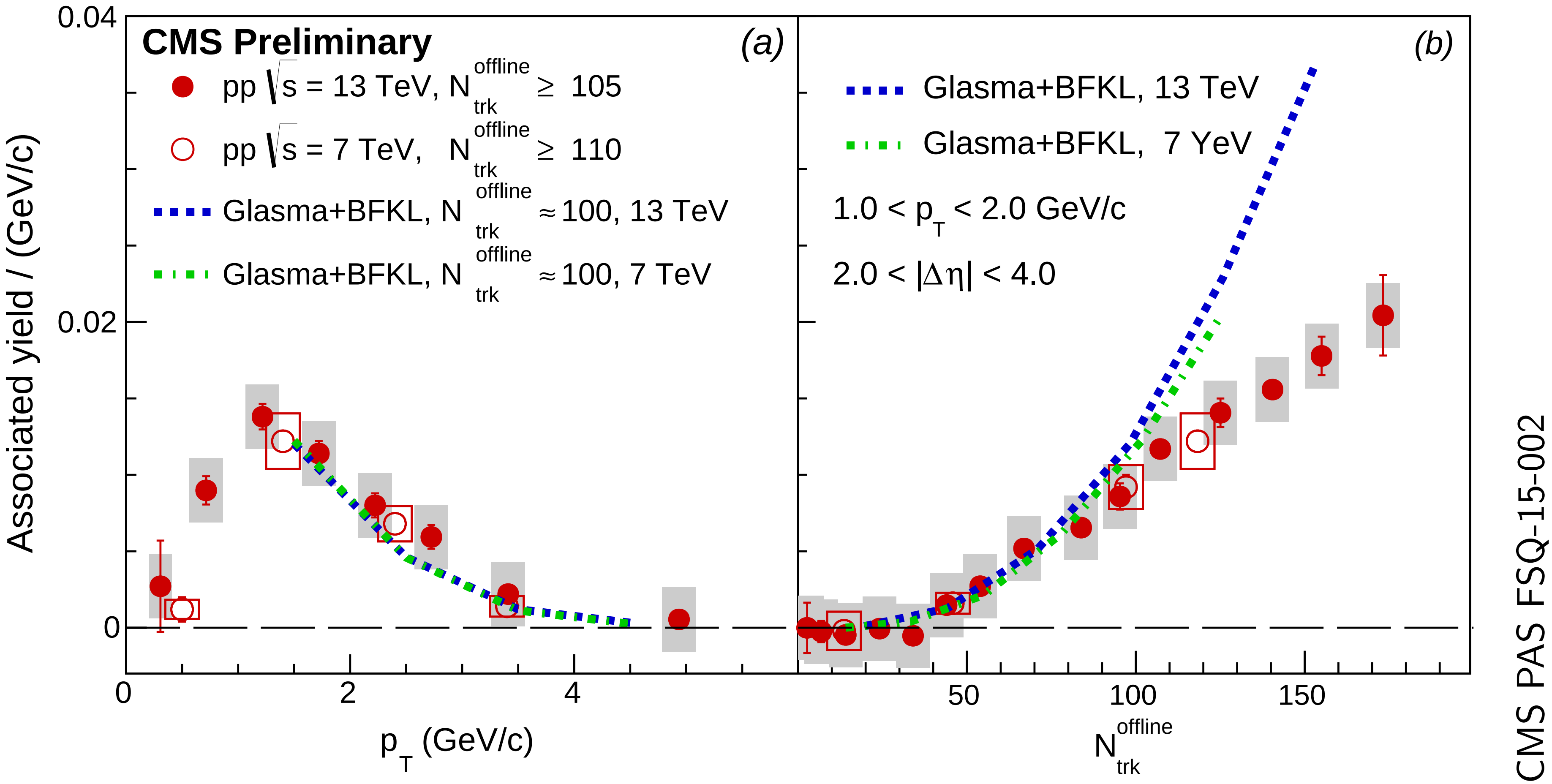
Charged hadrons – angular correlations



Correlation function vs $|\Delta\phi|$, for several p_T and $N_{trk}^{offline}$ settings

Extract "ridge yield" with zero-yield-at-minimum procedure

Charged hadrons – angular correlations

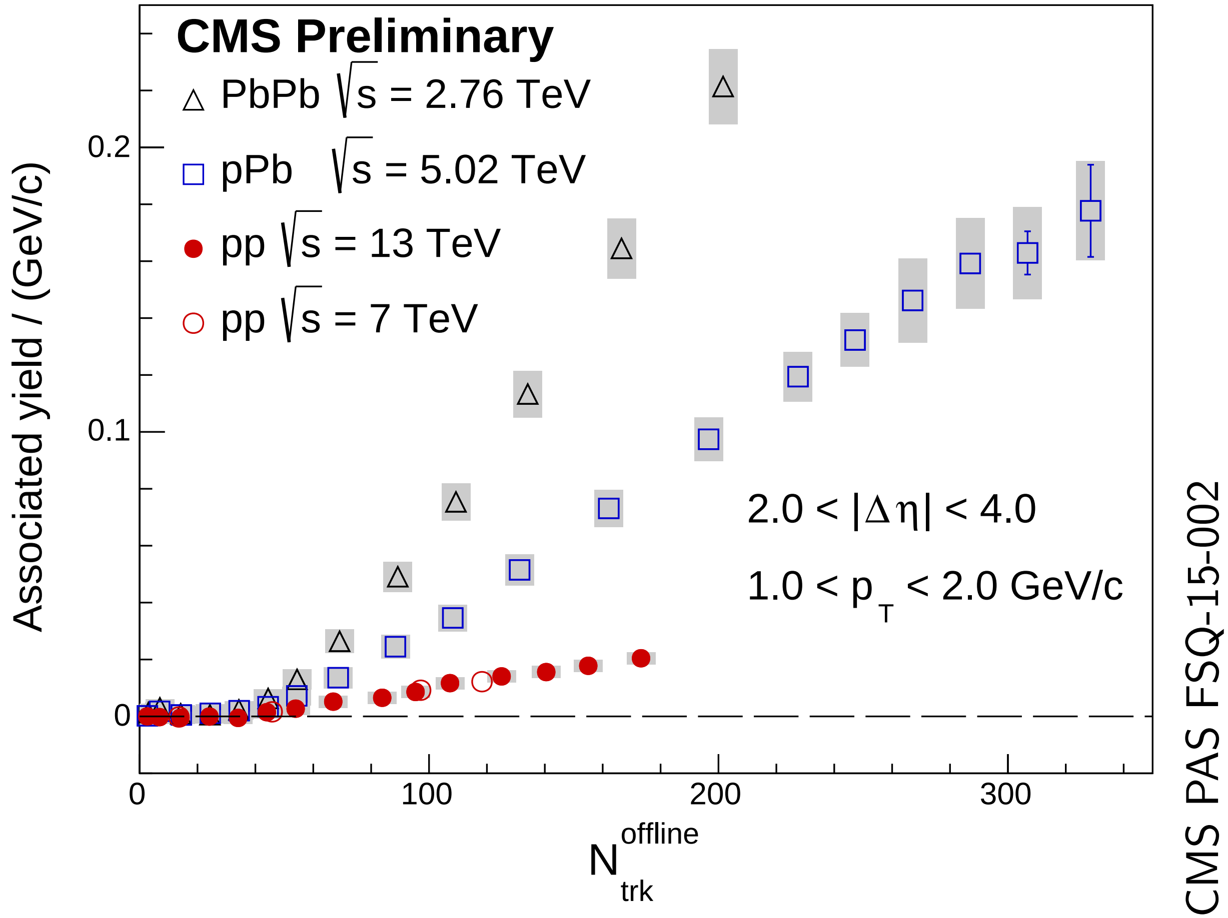


Associated yield shows maximum in the range $1 < p_T < 2$ GeV/c

Approximately linear increase with multiplicity for $N_{trk}^{offline} \geq 40$

Gluon saturation models: these arise from initial collimated gluon emissions

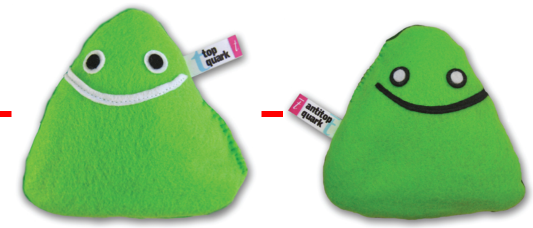
Charged hadrons – angular correlations



Correlation strength is similar to that found in lower energy pp data, but is measured up to much higher multiplicity values

Strong collision system size dependence (pp vs pPb vs PbPb)

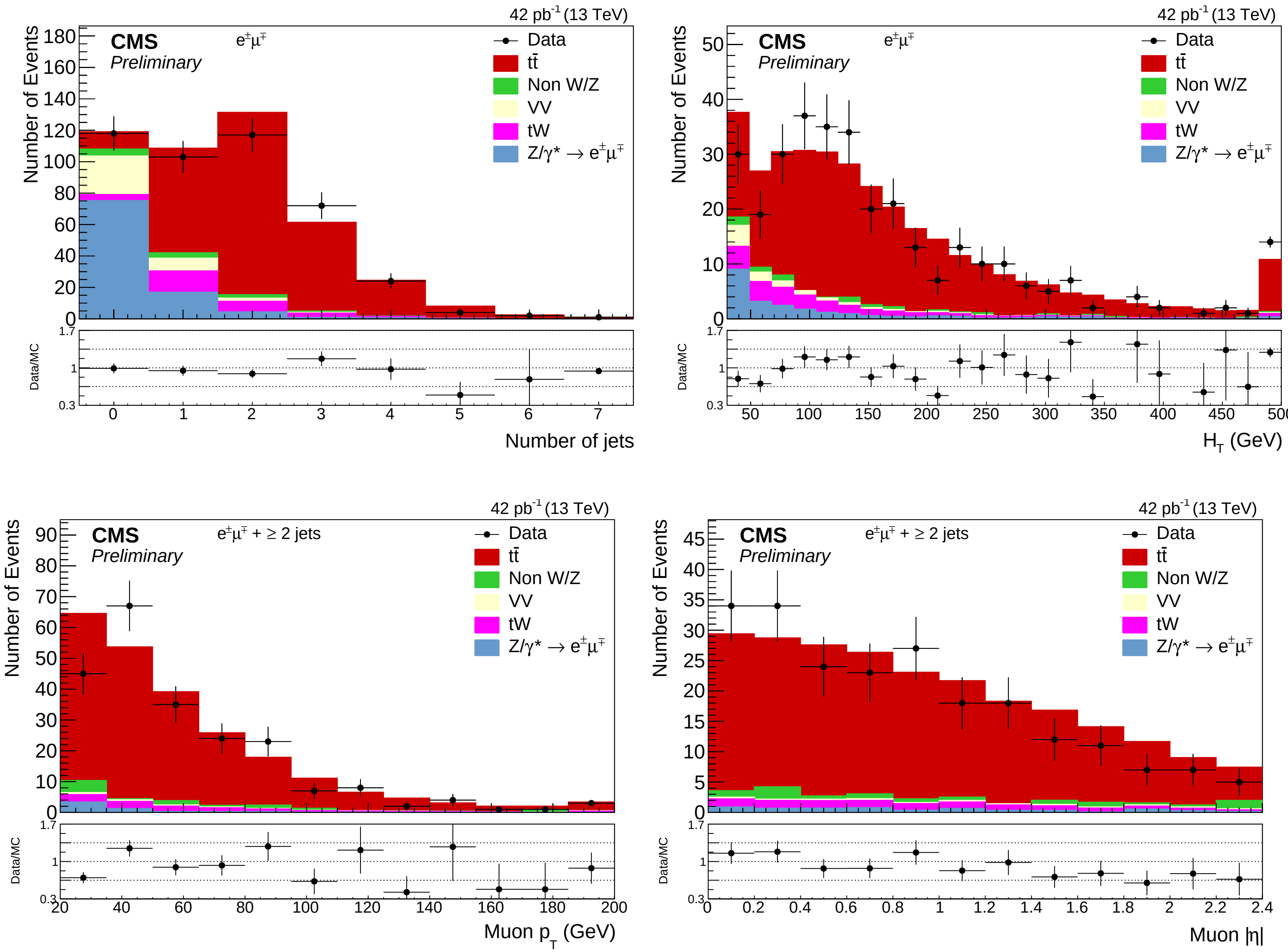
Top production – $t\bar{t}$



- Why?
  - great discovery potential for physics beyond the SM
  - test of the production mechanism, dominated by gg fusion
  - check the validity of QCD
  - important source of background in searches for beyond the SM

- How to measure?
  - t can decay leptonically: $t \to W\ b \to (l\ \nu)$ (b-jet)
    hadronically: $t \to$ hadrons (two jets)
  - both leptonic: one electron **and** one muon of opposite charge, and at least **two** jets in the final state
  - leptonic+hadronic: one electron **or** one muon, and at least **four** jets in the final state

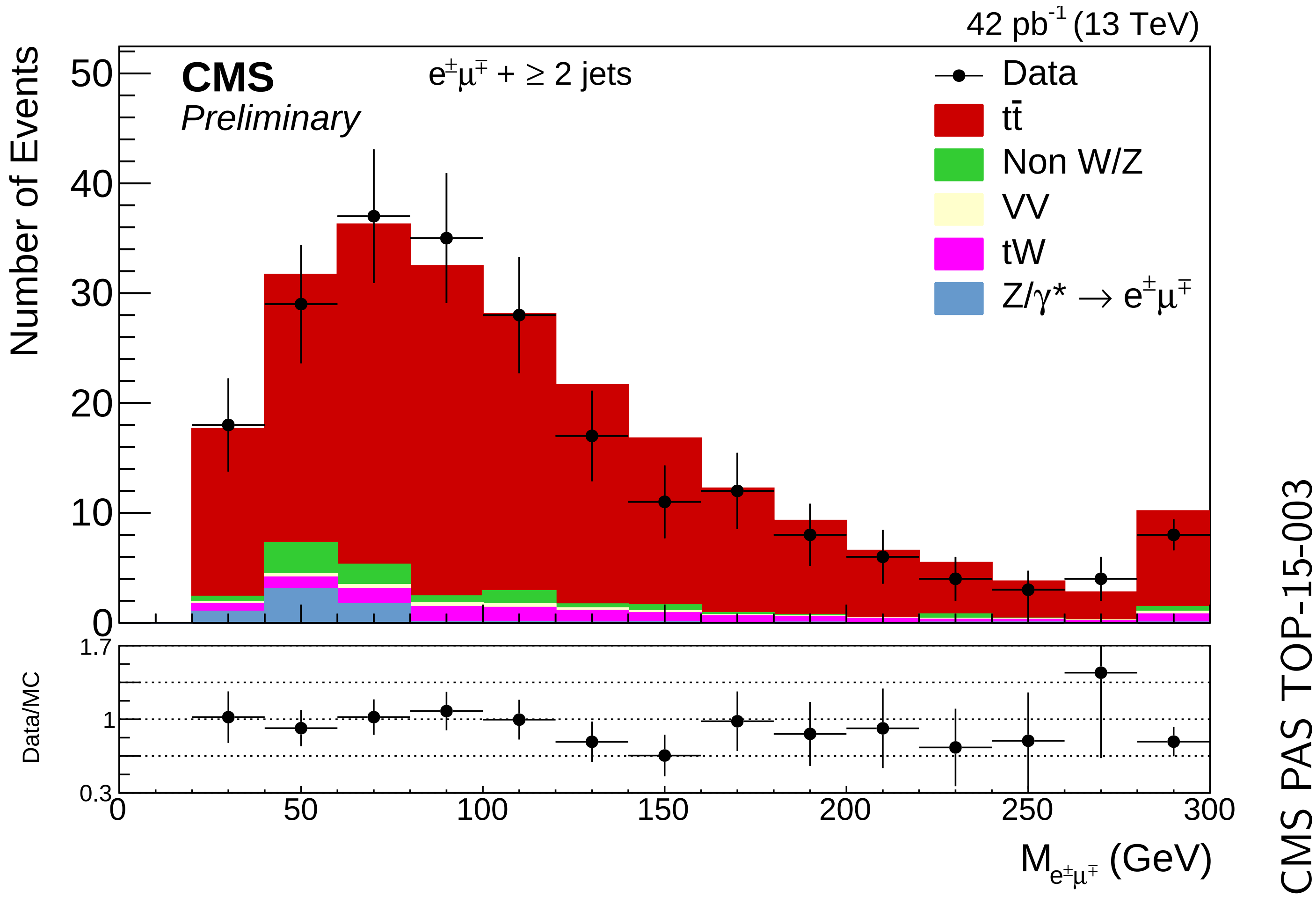
Top production – $t\bar{t} \rightarrow$ both leptonic



CMS PAS TOP-15-003

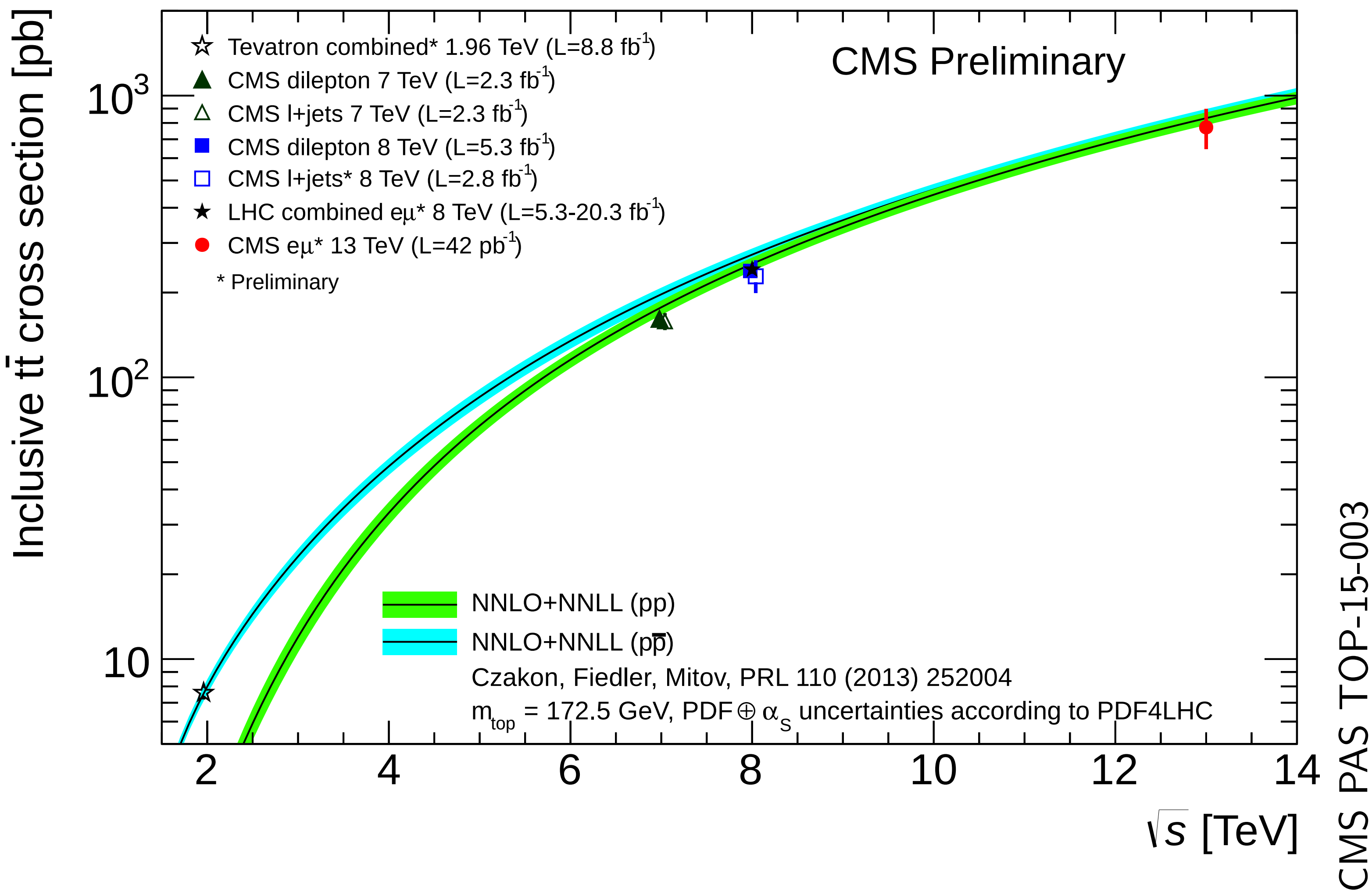
Nice significance

Top production – $t\bar{t} \rightarrow$ both leptonic



$e^{\pm}\mu^{\mp}$ probes the existence of a new heavy object decaying into a top quark pair

Top production – $t\bar{t} \to$ both leptonic

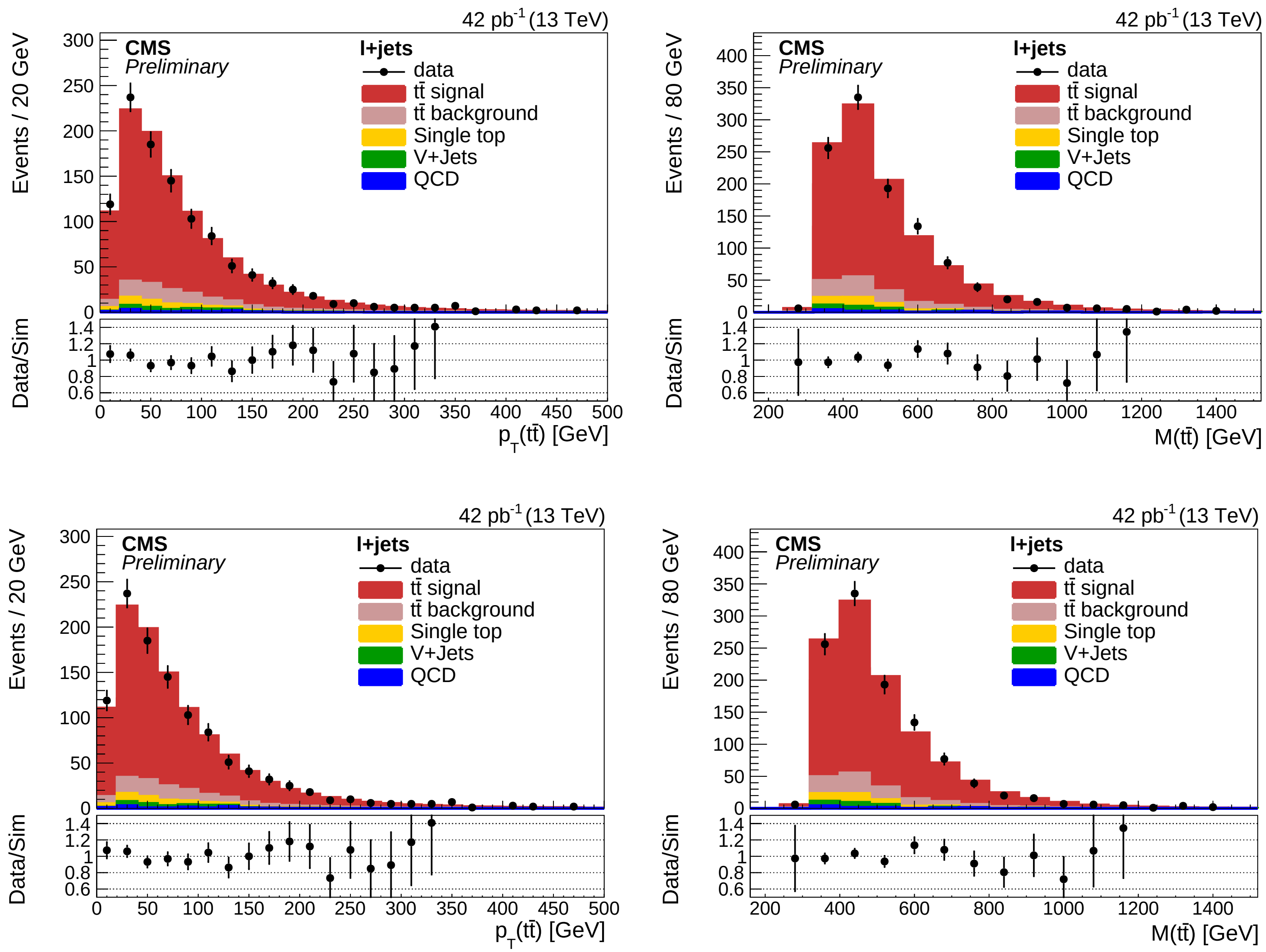


$$\sigma_{t\bar{t}} = 772 \pm 60(\mathrm{stat}) \pm 62(\mathrm{syst}) \pm 93(\mathrm{lumi})\ \mathrm{pb}$$

In agreement with the expectations from the standard model

$$\sigma_{t\bar{t}}^{\mathrm{NNLO+NNLL}} = 832 \pm 46\ \mathrm{pb}$$

Top production – $t\bar{t} \to$ leptonic+hadronic

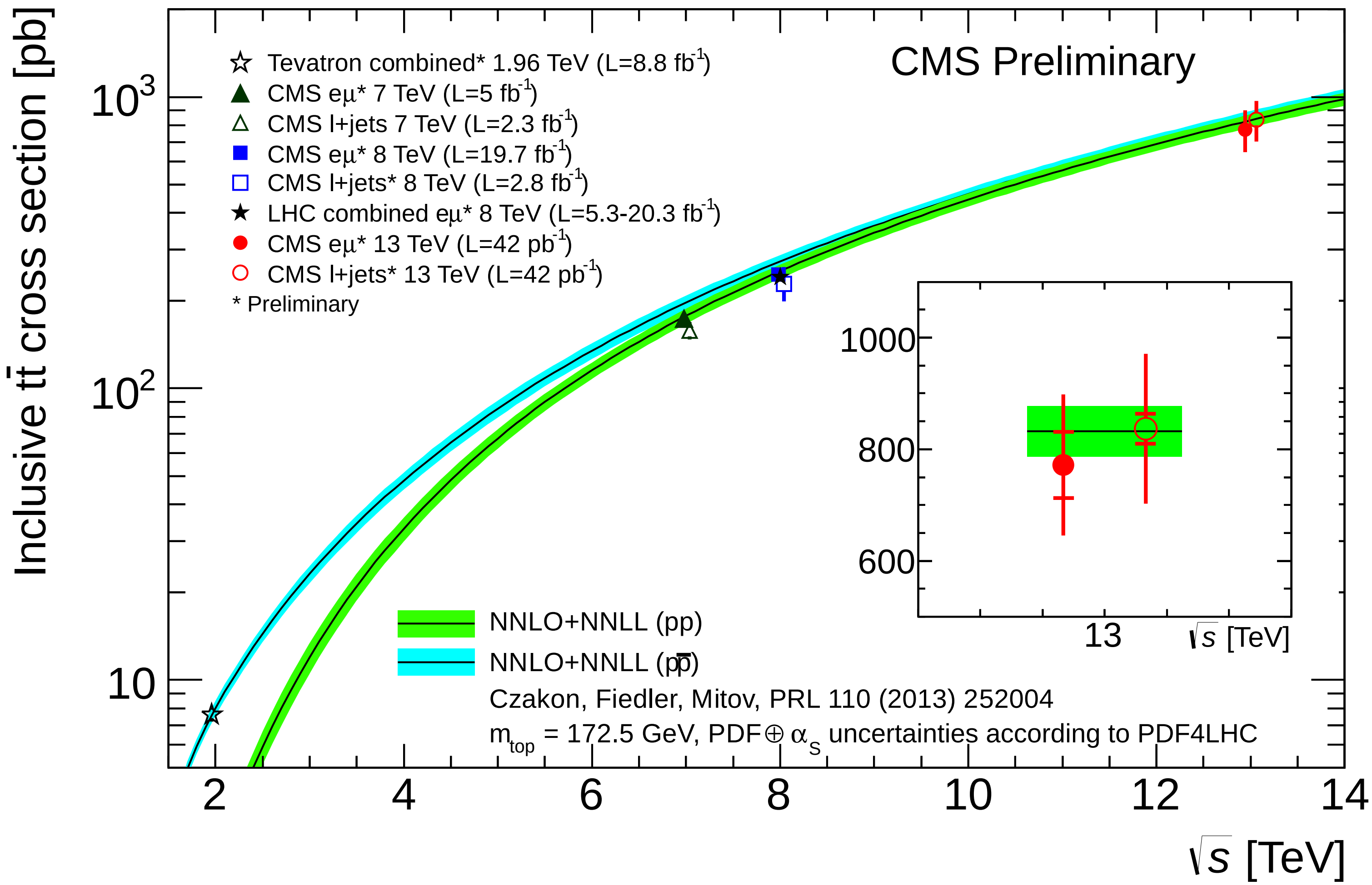


CMS PAS TOP-15-005

$$\sigma_{t\bar{t}} = 836 \pm 27(\text{stat}) \pm 84(\text{syst}) \pm 100(\text{lumi})\ \text{pb}$$

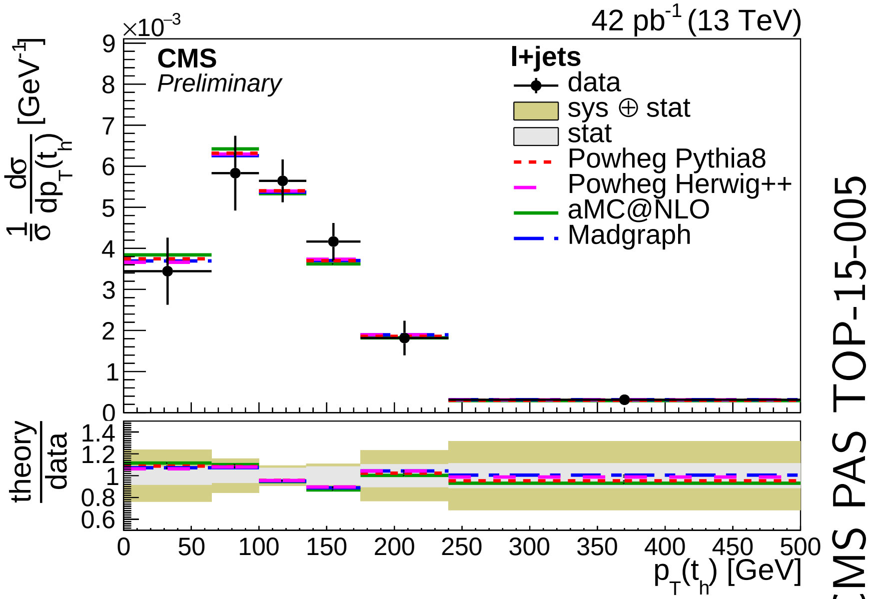
In good agreement with the theoretical expectation

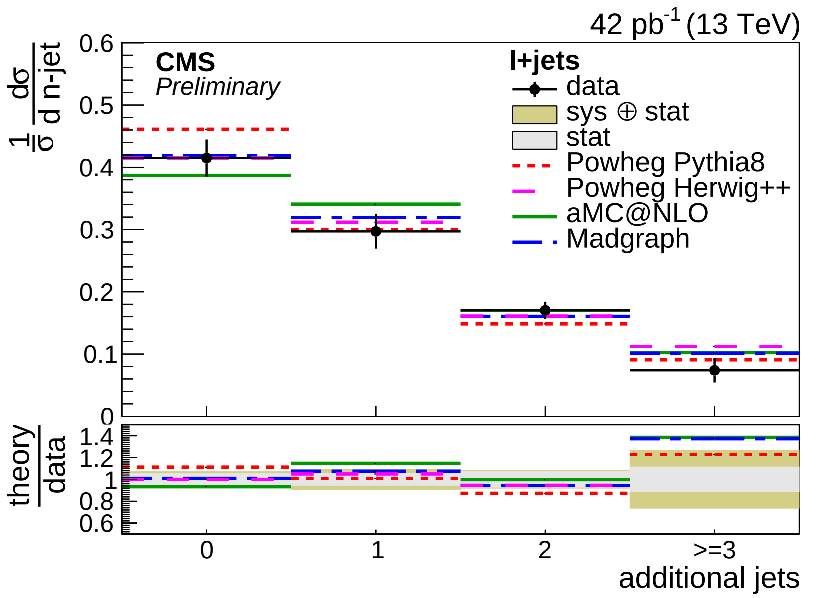
Top production – $t\bar{t}$

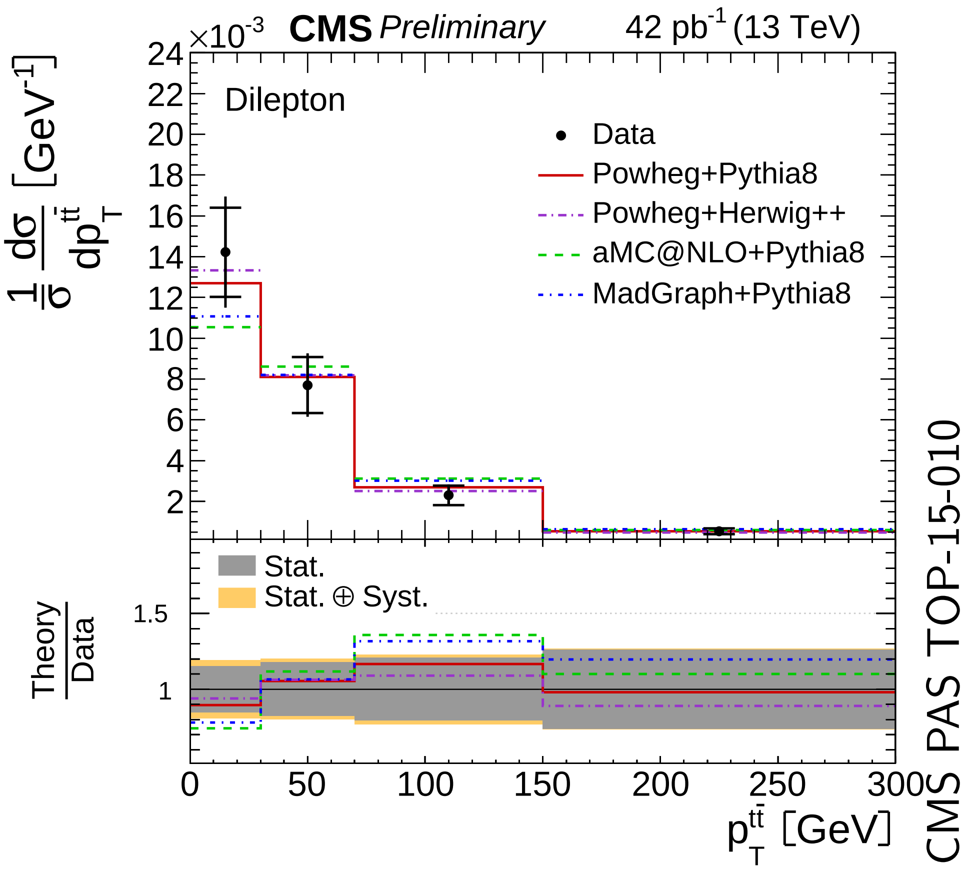


Plotting both dilepton and lepton+jets channels

Top production – differential

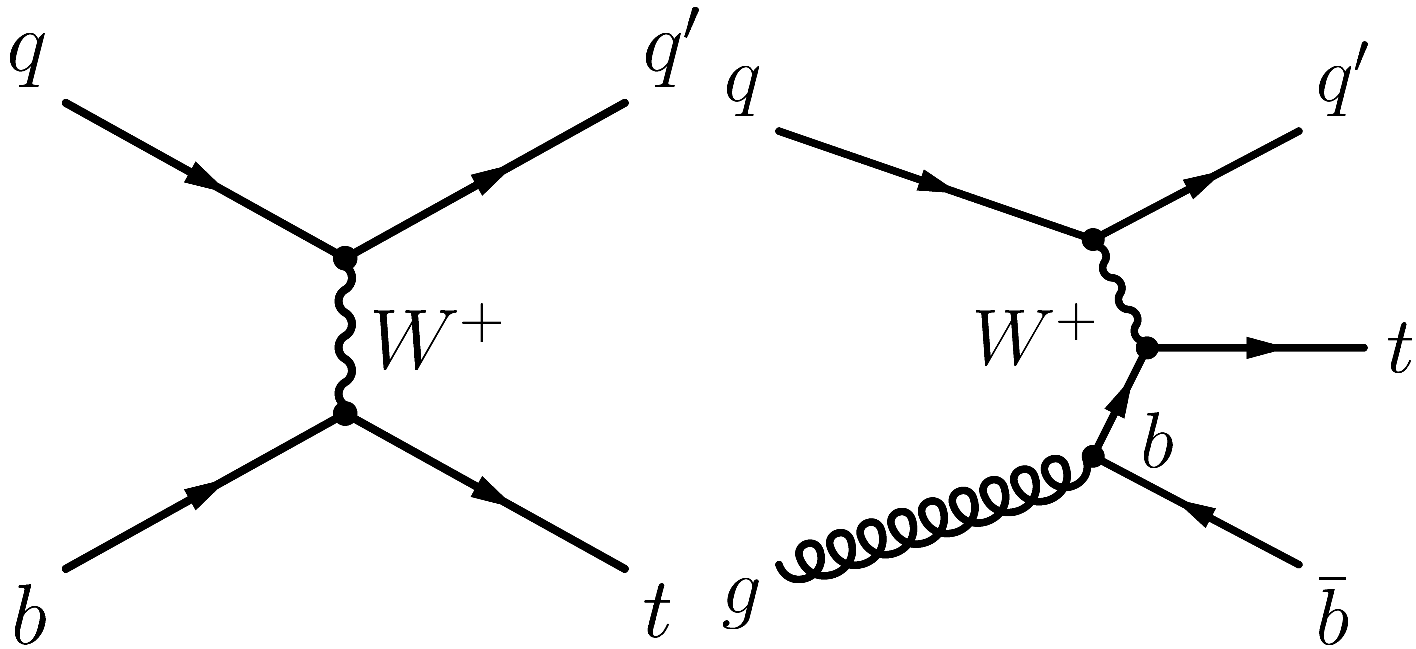






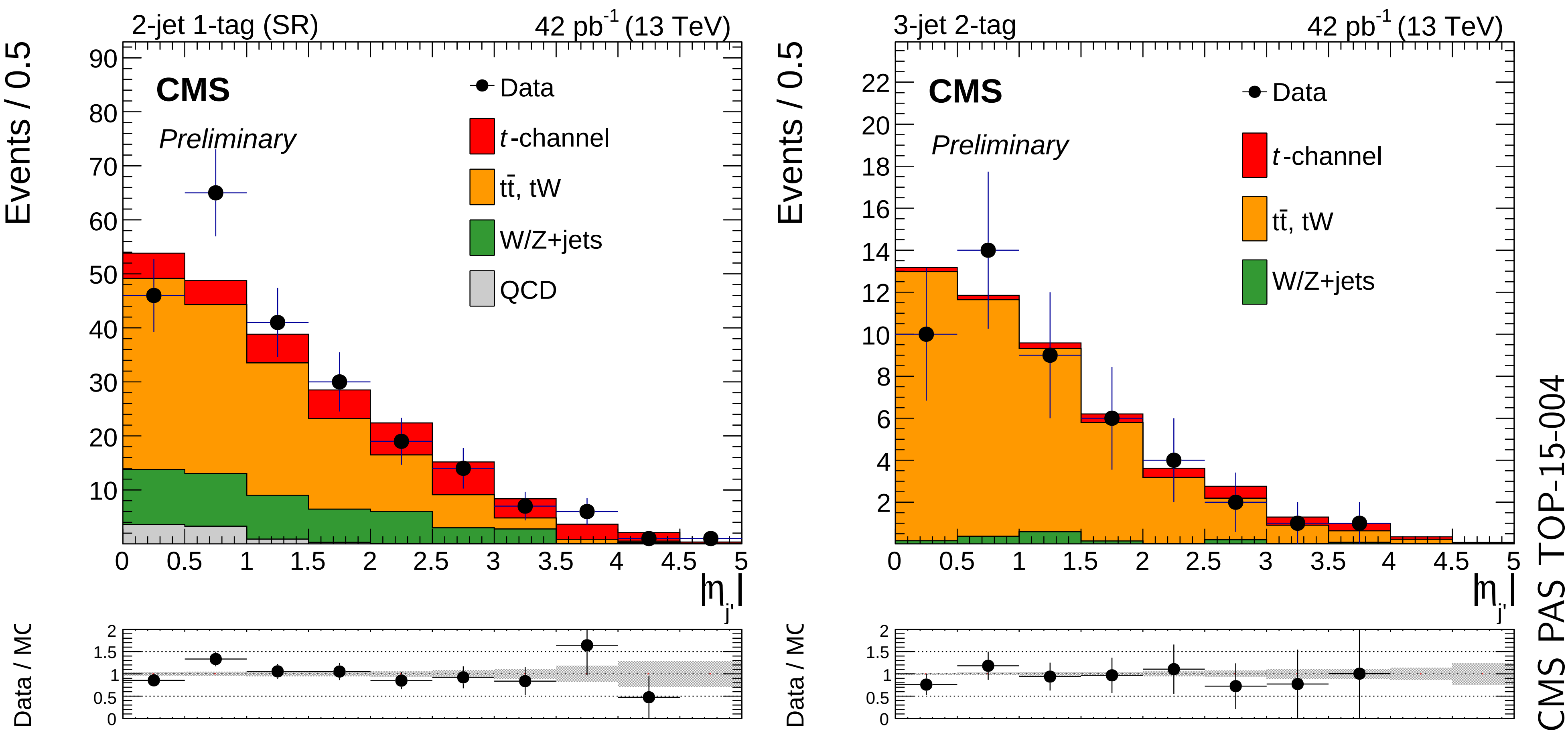
Plots in several variables, agreement with theory

Top production – t-channel single top



- Why and how?
  - testing QCD and electroweak processes, specifically the tWb vertex, and the CKM matrix element V_{tb}
  - select events with one muon in the final state (from t $\to$ W $\to$ μ or via t $\to$ W $\to$ τ $\to$ μ decays)
  - get signal from a fit to the η distribution of the (light) recoil jet

Top production – t-channel single top

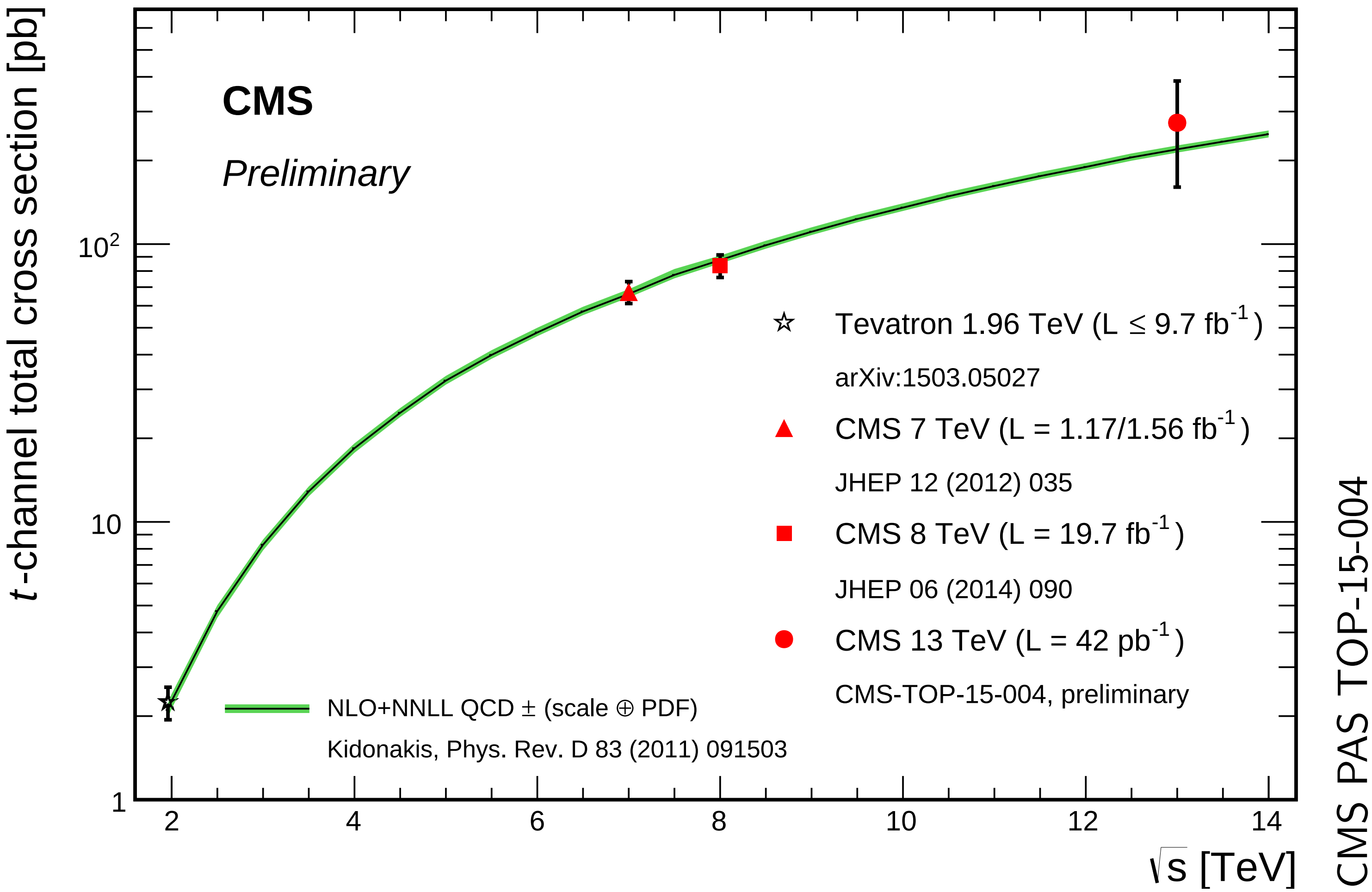


Maximum likelihood fits

Templates from simulation, normalized by data

3.5 σ observed significance, while 2.7 σ is expected

Top production – t-channel single top

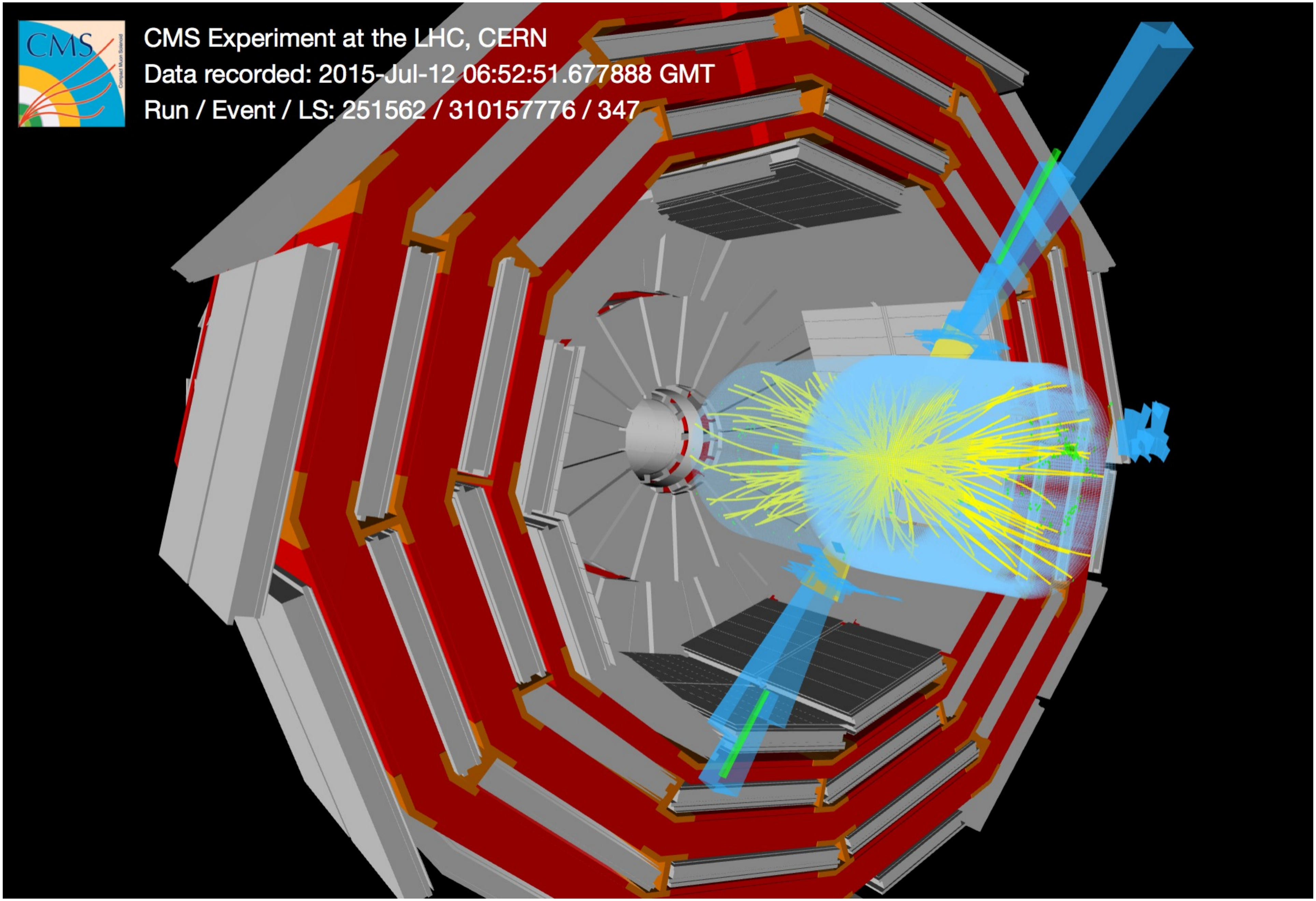


$$\sigma_{\mathrm{t-ch}} = 274 \pm 98(\mathrm{stat}) \pm 52(\mathrm{syst}) \pm 33(\mathrm{lumi})\ \mathrm{pb}$$

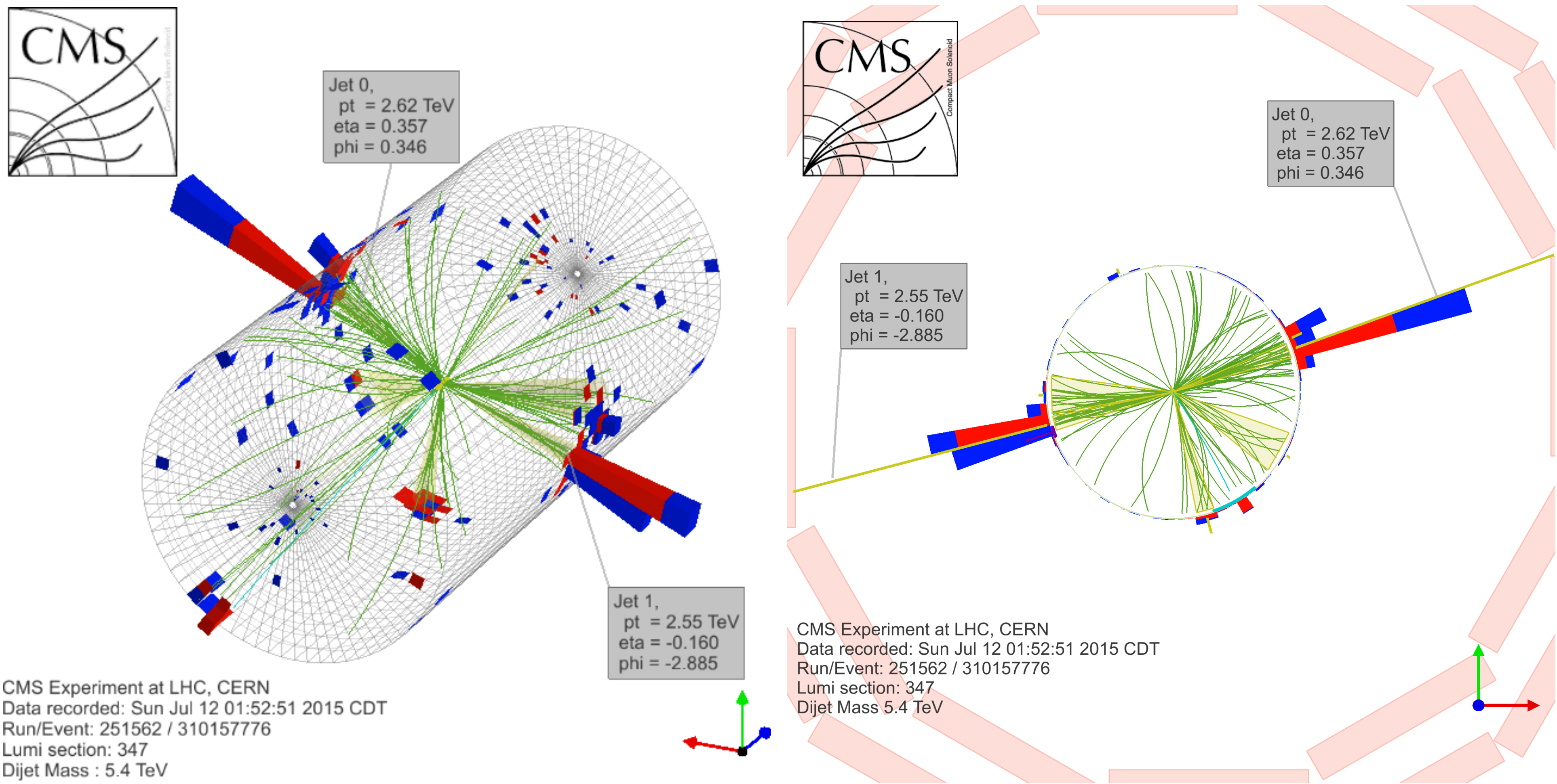
$$|V_{\mathrm{tb}}| = 1.12 \pm 0.24(\mathrm{exp}) \pm 0.02(\mathrm{theo})$$

In agreement with SM

New physics? – very first look



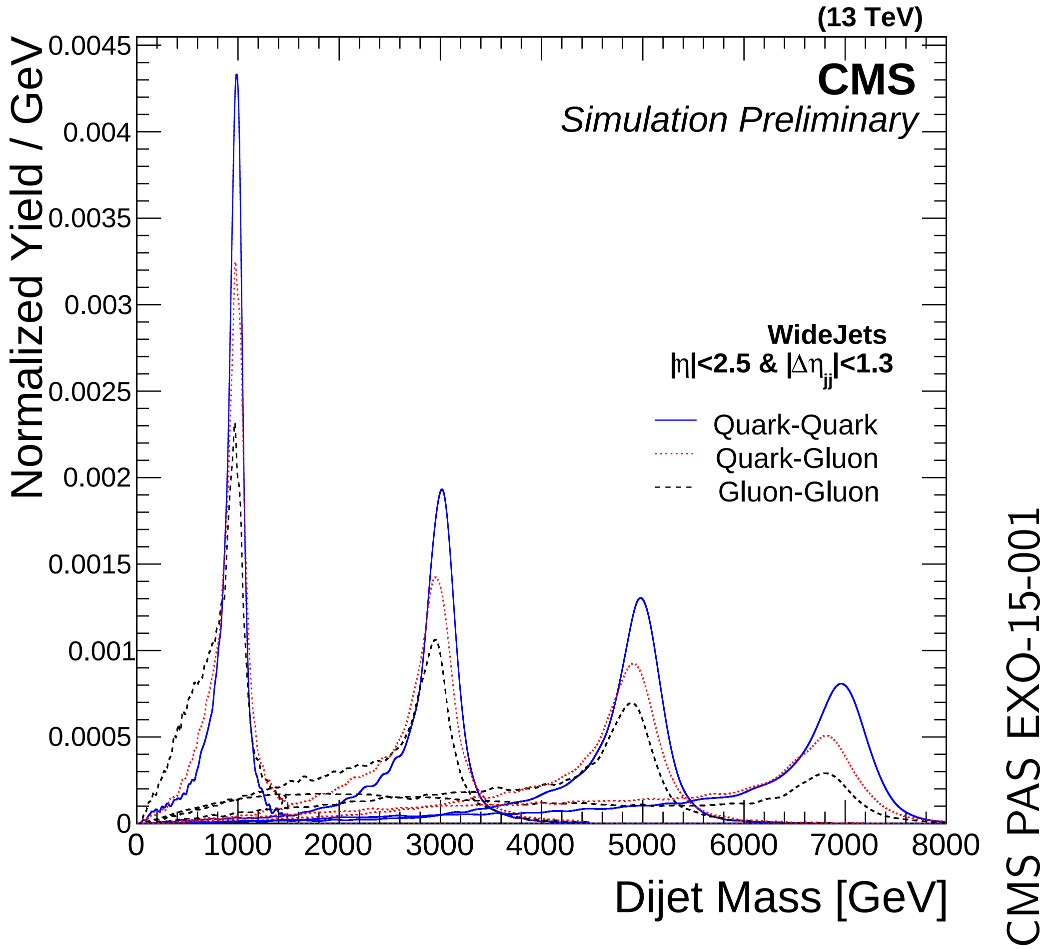
Exotica – search for narrow resonances using dijets



CMS PAS EXO-15-001

Event with a dijet mass of 5.4 TeV

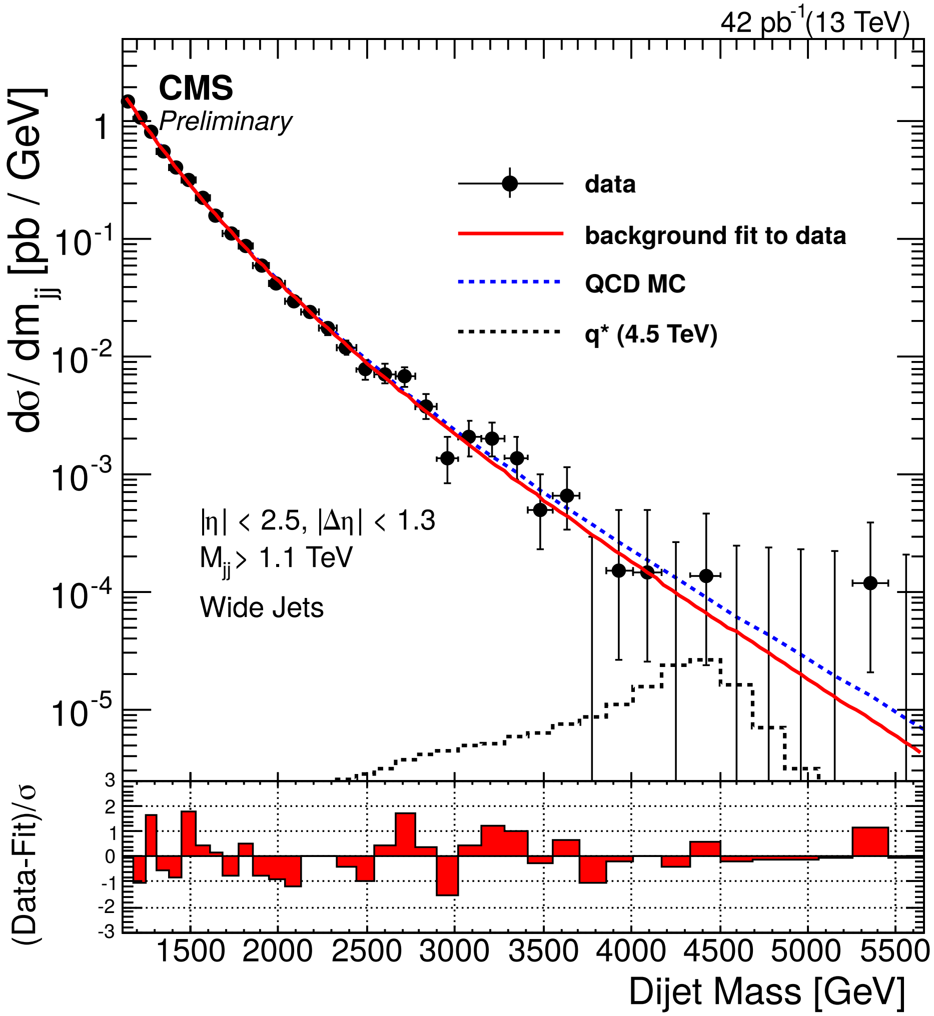
Exotica – search for narrow resonances using dijets



Expected mass spectra for qq, qg, and gg resonances (simulation)

For resonance masses greater than 5 TeV this search is more sensitive than those done at $\sqrt{s} = 8$ TeV

Exotica – search for narrow resonances using dijets

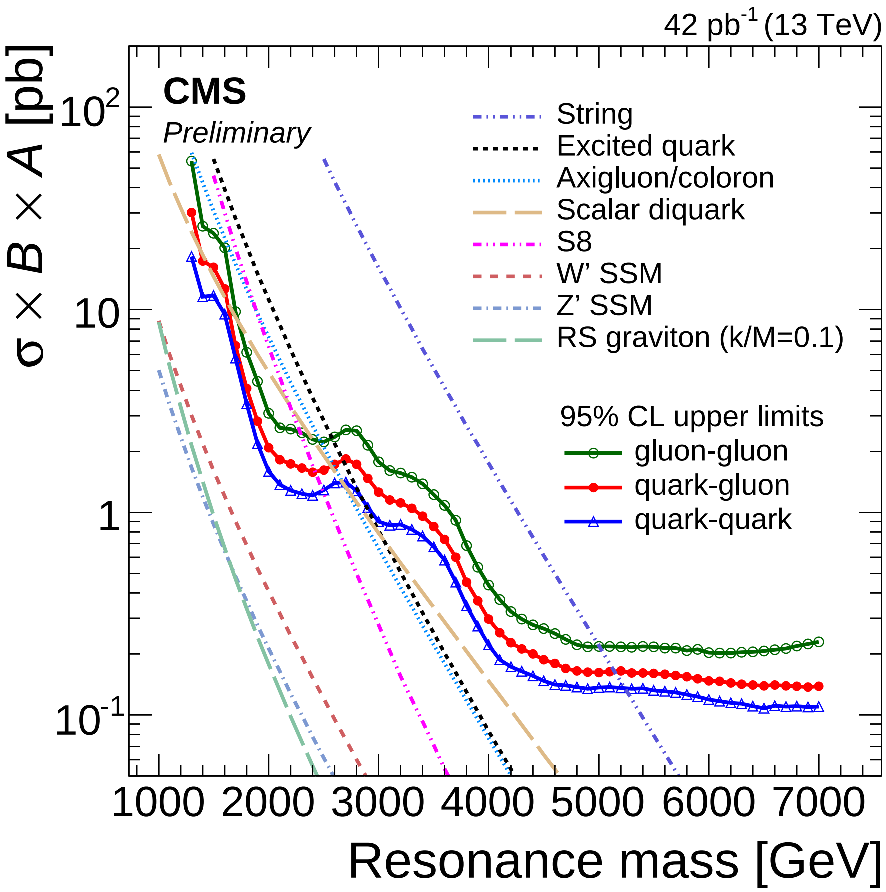


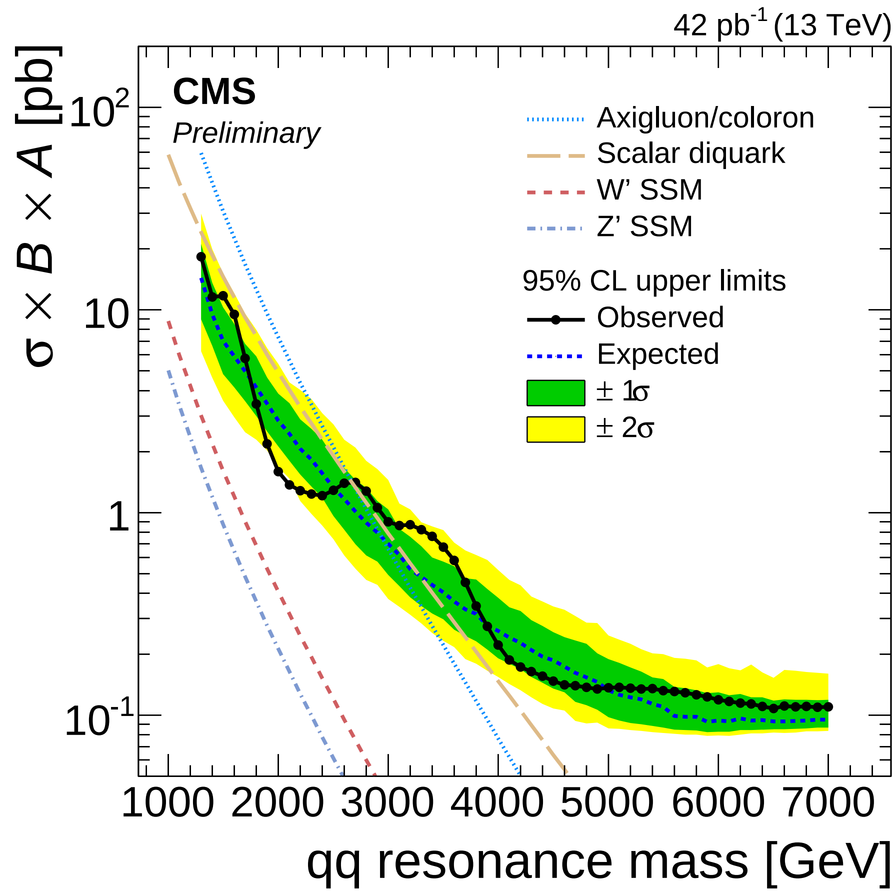
CMS PAS EXO-15-001

Spectrum is well described by a smooth parameterization

No evidence for new particle production

Exotica – search for narrow resonances using dijets





CMS PAS EXO-15-001

Lower limits are set on the mass of string resonances, excited quarks, axigluons, colorons, scalar diquarks and color octet scalars

CMS final and preliminary results – 13 TeV

- The full list

pseudorapidity distribution	arXiv:1507.05915, PLB
two-particle angular correlations	CMS PAS FSQ-15-002
$t\bar{t}$ production, to e+μ+jets, incl	CMS PAS TOP-15-003
$t\bar{t}$ production, to lepton+jets, incl+diff	CMS PAS TOP-15-005
$t\bar{t}$ production, to dilepton+jets, diff	CMS PAS TOP-15-010
t-channel single top-quark, incl	CMS PAS TOP-15-004
narrow resonances using dijets	CMS PAS EXO-15-001

More to come: spectra, correlations,
search for new physics (already > 1 fb^{-1})

Thank you for your attention!