HEAVY FLAVOR RESULTS FROM CMS

DIS 2016, DESY, Hamburg

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On behalf of CMS Collaboration

FLAVOUR PHYSICS PROGRAM @ CMS

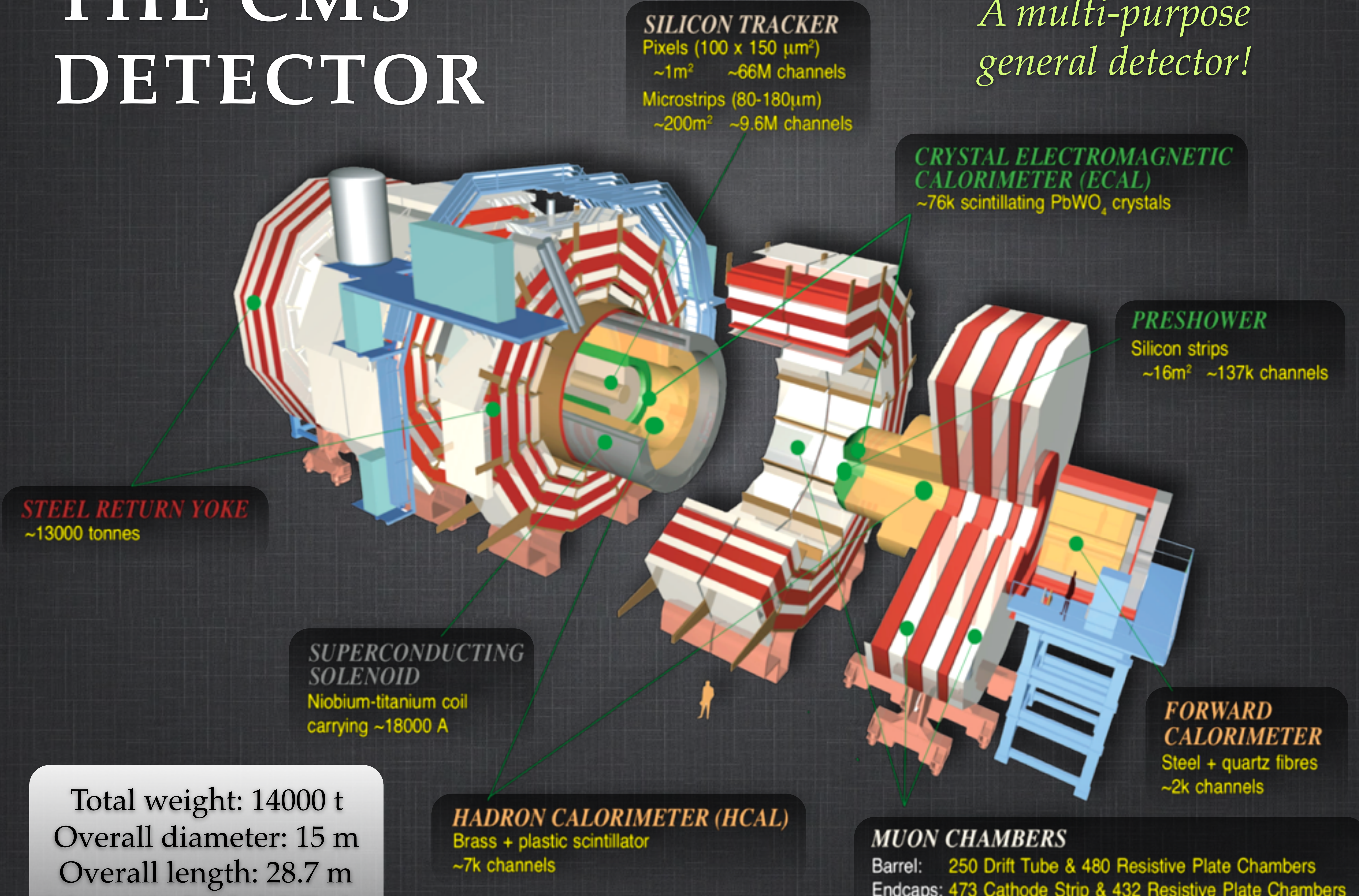
"CMS is an unique test bench for flavour physics predictions!"

High luminosity ×
Large production cross section =
ONE OF THE BIGGEST B HADRON DATA SETS!

- **CMS flavour physics objectives:**
  - Understand the underlying QCD processes: measure the spectrum of quarkonia production & polarization; look for new exotic quarkonia states and new baryons.
  - Test the Standard Model with high precision measurements: study the decay rates, lifetime, and properties of B hadrons.
  - Look for new physics in the rare decays.
- **Several recent results to be covered today:**
  - **BPH-13-010:** Angular analysis in $B^0 \to K^{*0}\mu^+\mu^-$ at 8 TeV
  - **BPH-15-004:** B^+ production cross section at 13 TeV
  - **BPH-15-005:** Quarkonia production cross sections at 13 TeV

THE CMS DETECTOR

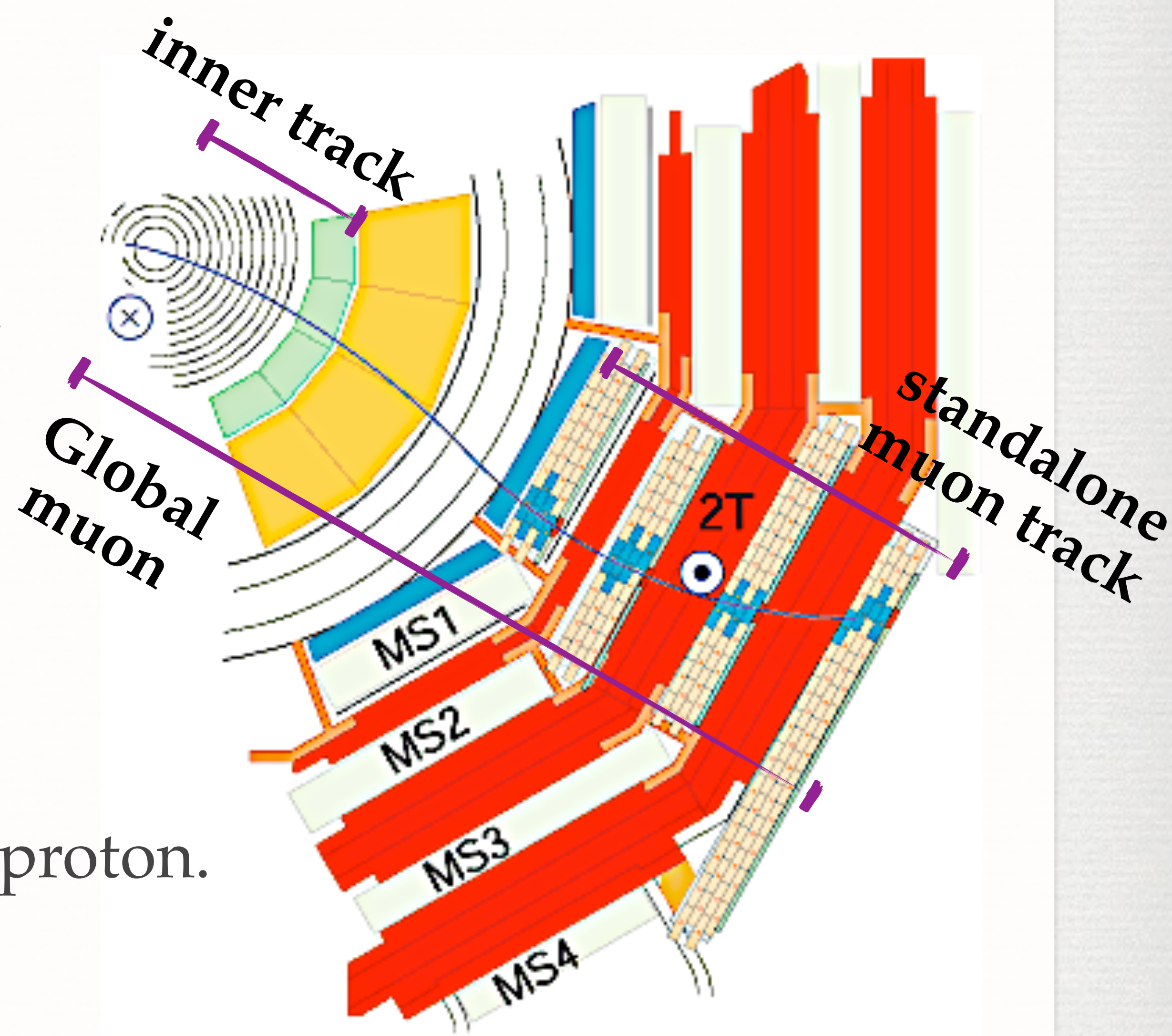
A multi-purpose general detector!



Total weight: 14000 t
Overall diameter: 15 m
Overall length: 28.7 m
Magnetic field: 3.8 Tesla

CMS MUON RECONSTRUCTION

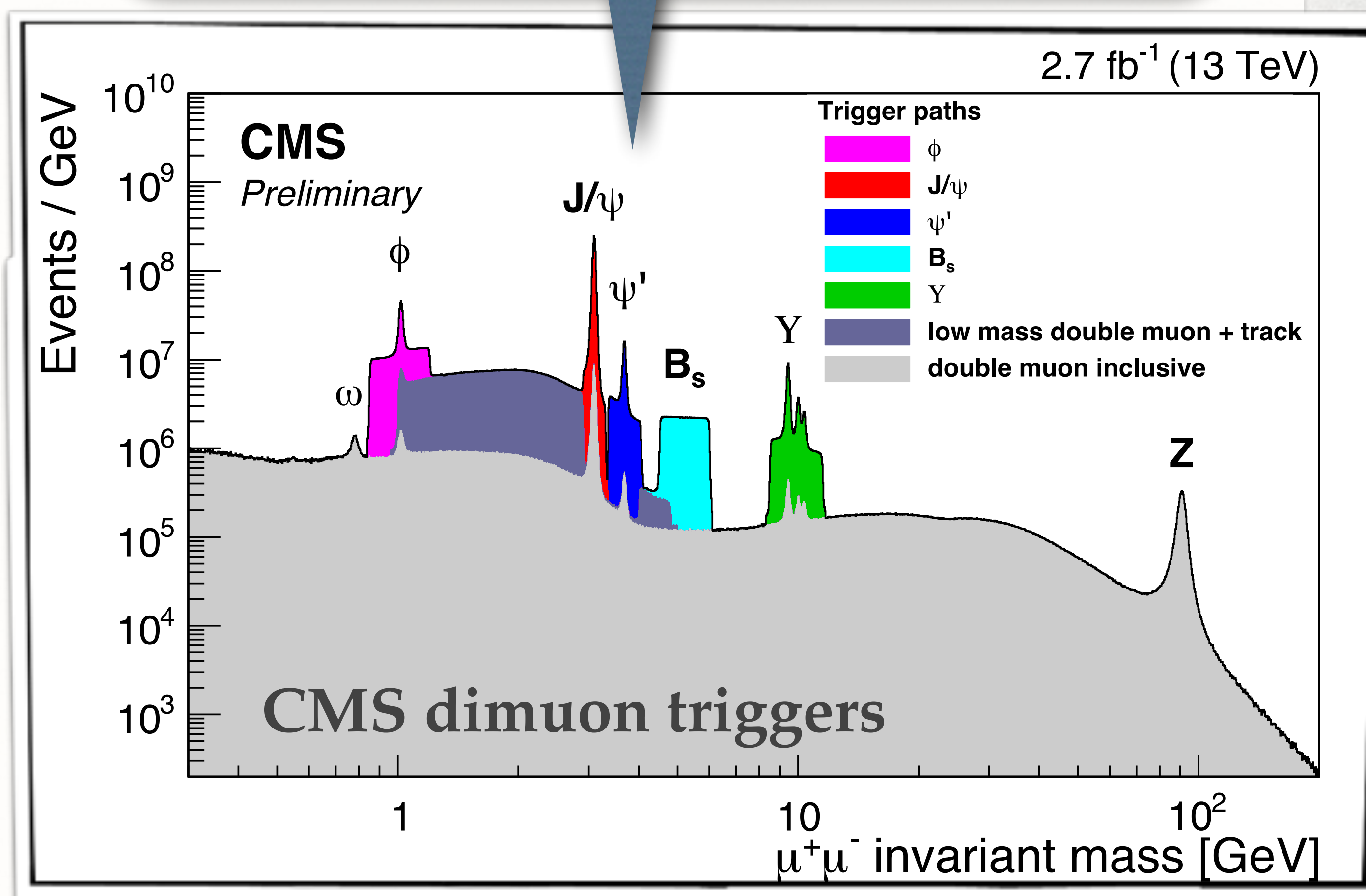
- **The muon system:**
  - 3 different devices installed, with a large coverage up to |η|<2.4.
  - Good dimuon mass resolution
    ~0.6-1.5% (depending on |y|).
- **Reconstruction algorithms:**
  - **standalone muon**:
    reconstructed in muon system only
  - **global muon**:
    standalone muon ⇒ inner track
  - **tracker muon**:
    inner track ⇒ muon system
- **Excellent muon identification**
  - Fake rate ≤0.1% for π,K; ≤0.05%for proton.
  - MVA-based ID for B→μμ analysis.



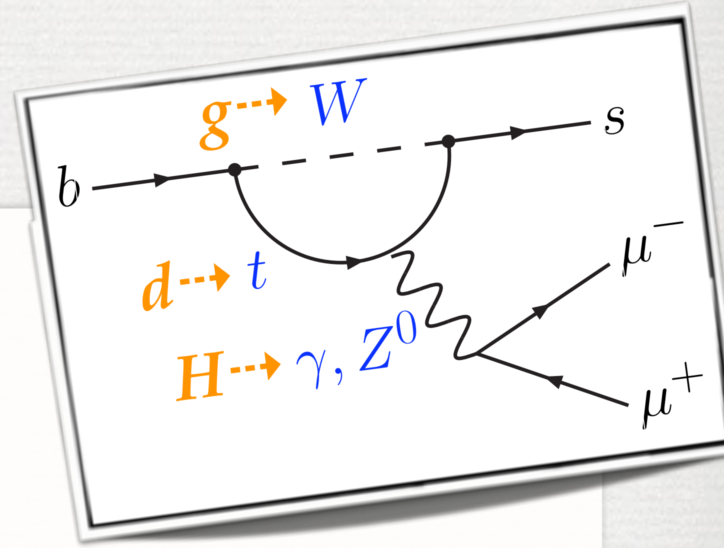
CMS DIMUON TRIGGERS

- **CMS trigger system:**
  - **Fast hardware trigger (L1)**
  - **Software trigger with full tracking & vertex reconstruction (HLT).**
  - Specific triggers were developed for various analyses.
  - Trigger requirements tightened with the increased luminosity.
  - ~10% of CMS bandwidth is reserved for flavor physics.

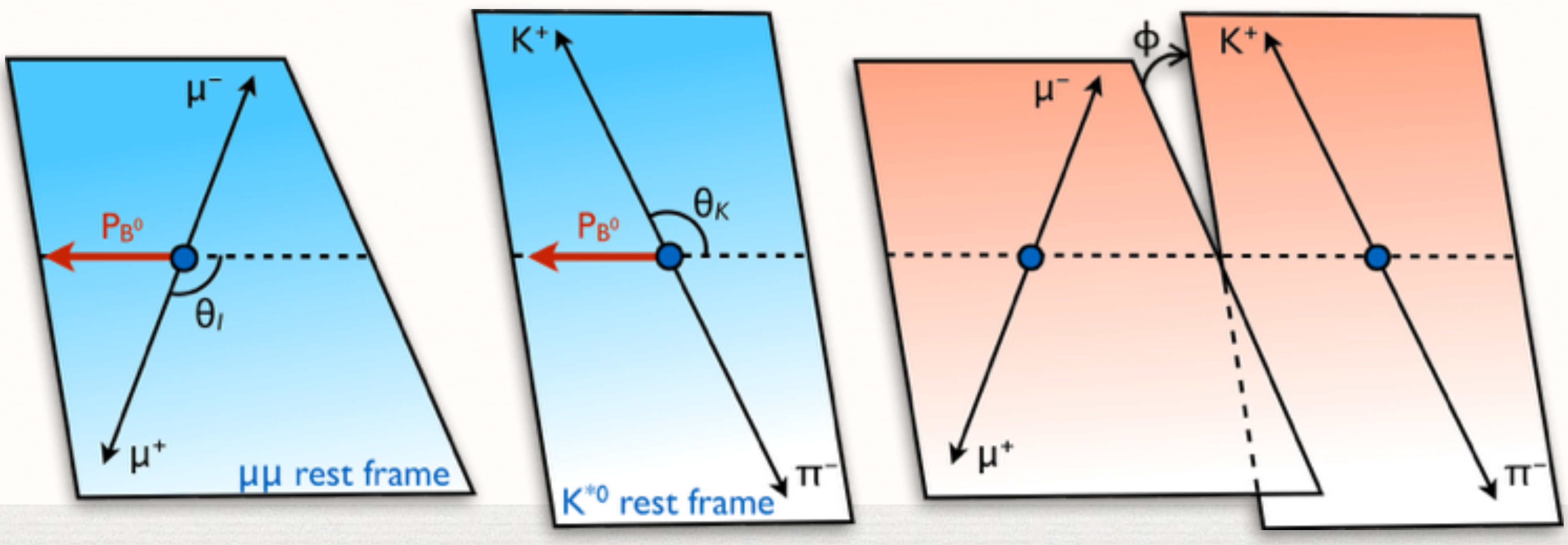
Flavor physics analyses rely on displaced/non-displaced quarkonia (ϕ, J/ψ, ψ' & Υ), $B_{(s)}$, and non-resonant **DIMUON** triggers.



ANGULAR ANALYSIS OF $B^0 \to K^{*0} \mu^+ \mu^-$



- The B→K*μμ decay is proceed via a **FCNC** process, **sensitive to new physics beyond the SM**.
- Robust theoretical calculations.
- Single channel with many measurements [and as a function of q^2=M^2(μμ)]: branching fractions, A_{FB}, polarization,... etc.
- Four-particle final states lead to 3 angular observables **(θ_K, θ_l, ϕ)**, while ϕ is integrated out in the current analysis.



ANALYSIS KEY FEATURES

- Measure the forward-backward asymmetry (***A_{FB}***), longitudinal polarisation of K^{*0} (***F_L***), and differential branching fraction (***dB/dq^2***) in bins of q^2.
- Analyzed data: 20.5 fb^{-1} at 8 TeV
- Control channels: $B^0 \to J/\psi\ K^{*0}$ (also used as normalization) & $\psi(2S)\ K^{*0}$.
- Unbinned extended maximum likelihood fits to three variables: ***$m(K\pi\mu\mu)$***, angular variables ***θ_K*** and ***θ_l*** for each q^2 bin:

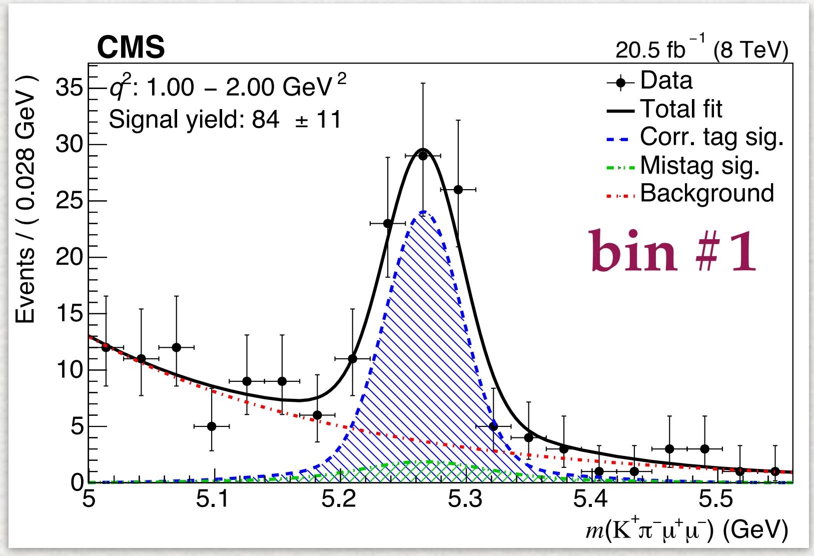
$$\frac{1}{\Gamma}\frac{d^3\Gamma}{d\cos\theta_K d\cos\theta_l dq^2} = \frac{9}{16}\left\{\frac{2}{3}\left[F_S + A_S\cos\theta_K\right](1-\cos^2\theta_l) + (1-F_S)\left[2F_L\cos^2\theta_K(1-cos^2\theta_l) + \frac{1}{2}(1-F_L)(1-\cos^2\theta_K)(1+\cos^2\theta_l) + \frac{4}{3}A_{FB}(1-\cos^2\theta_K)\cos\theta_l\right]\right\}$$

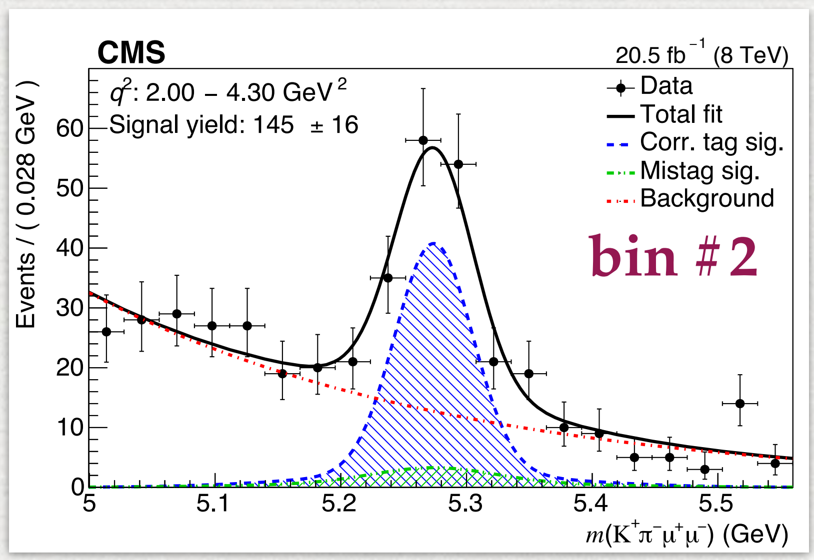
F_S: fraction of S-wave (~few %)
A_S: interference amplitude

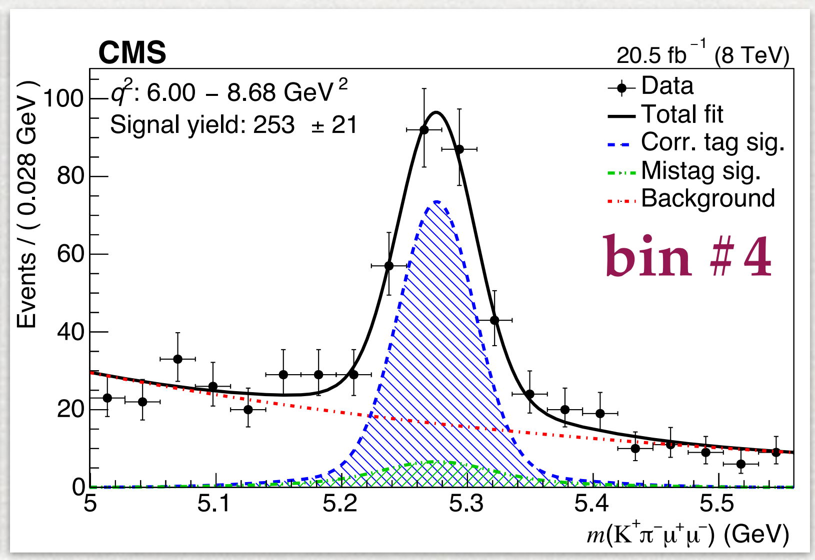
A_{FB} and F_L do not depend on ϕ, efficiency nearly constant.

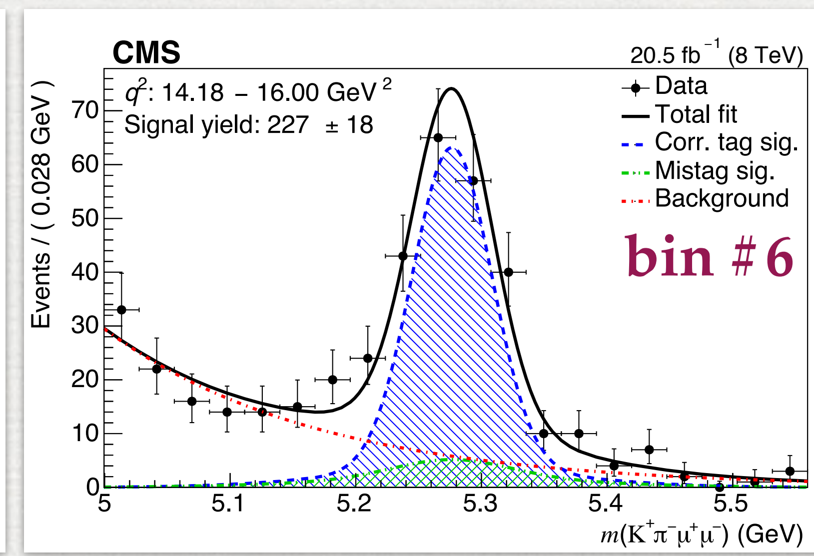
SIGNAL EVENTS

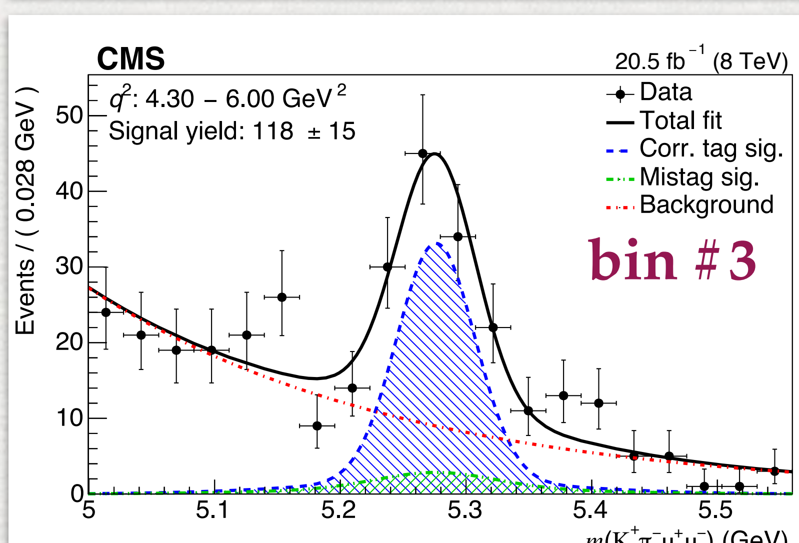
- Reconstruct the events in **7 q^2 bins**, excluding J/ψ & ψ' regions, total ~1426 signal events seen.
- Signal CP-tagged by the best $K\pi$ invariant mass.

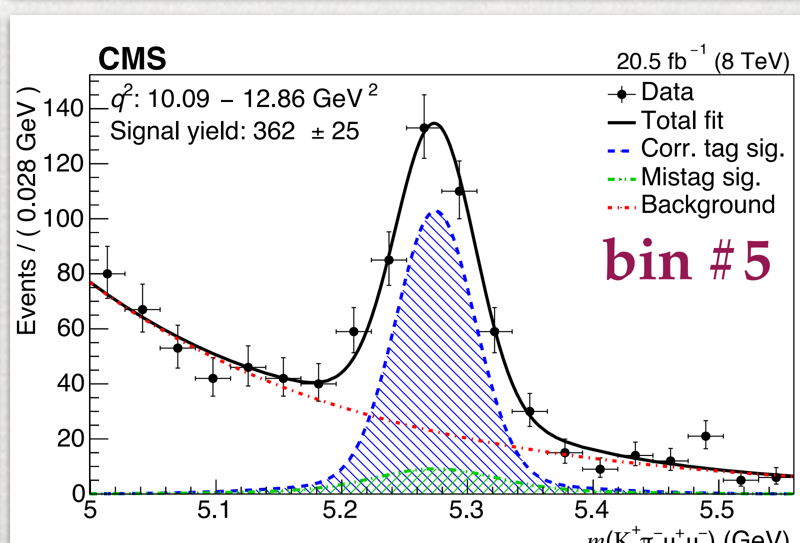


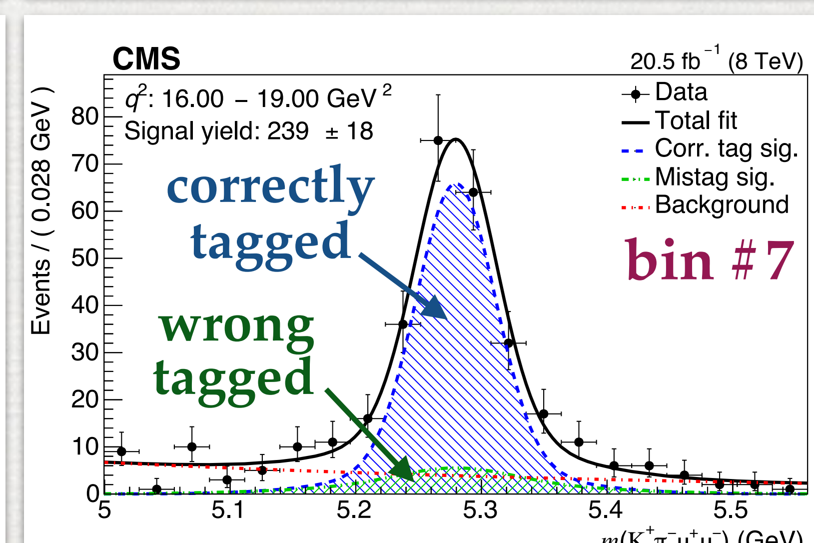






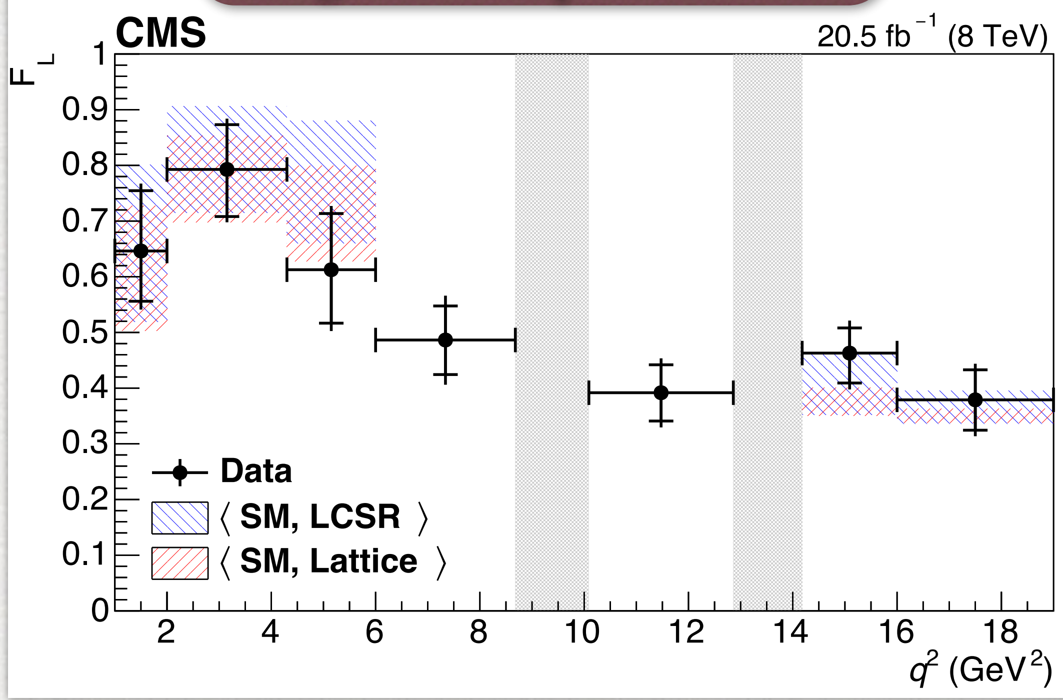




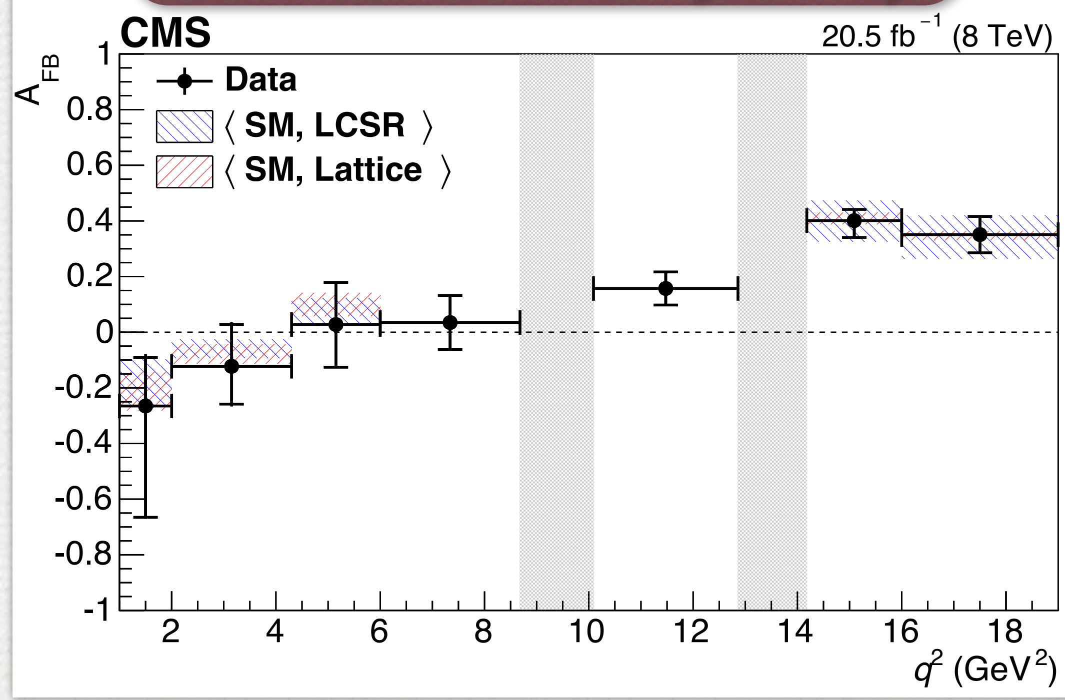


ANGULAR ANALYSIS

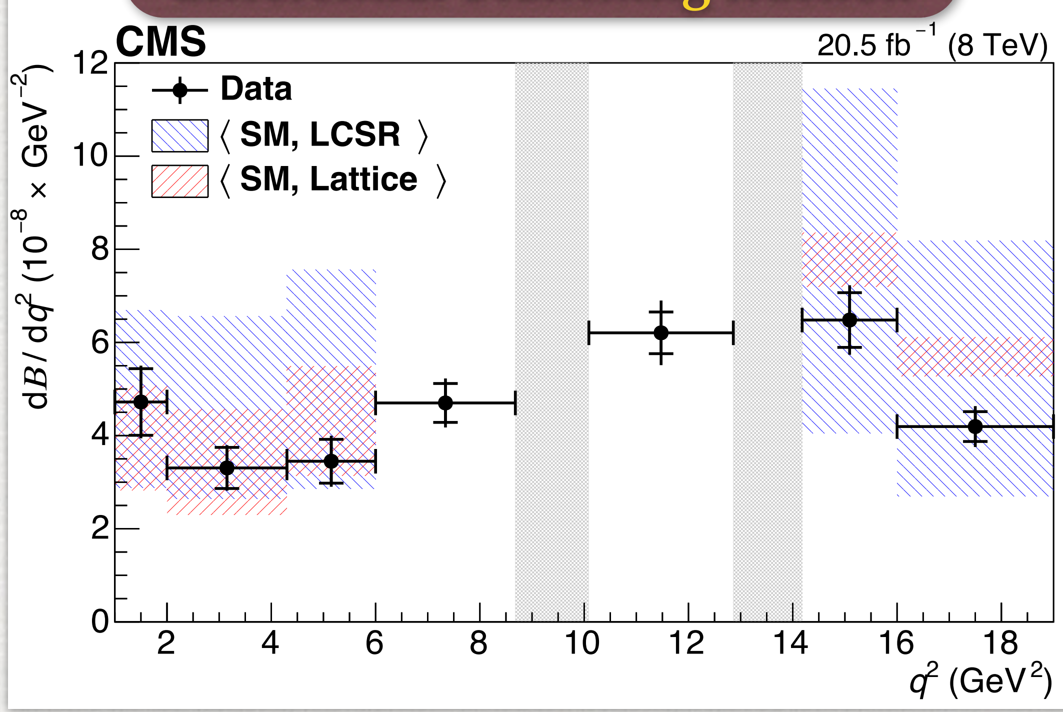
longitudinal polarisation



forward-backward asymmetry



differential branching fraction

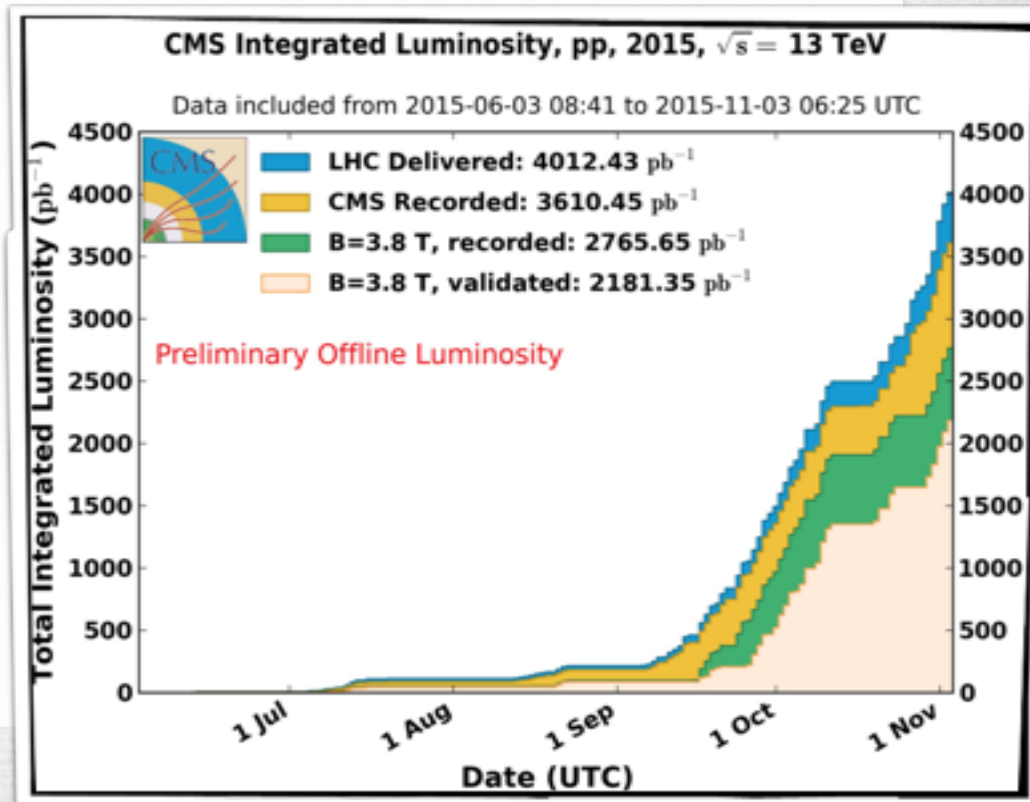


Ref. CMS BPH-13-010; Phys. Lett. B 753 (2016) 424

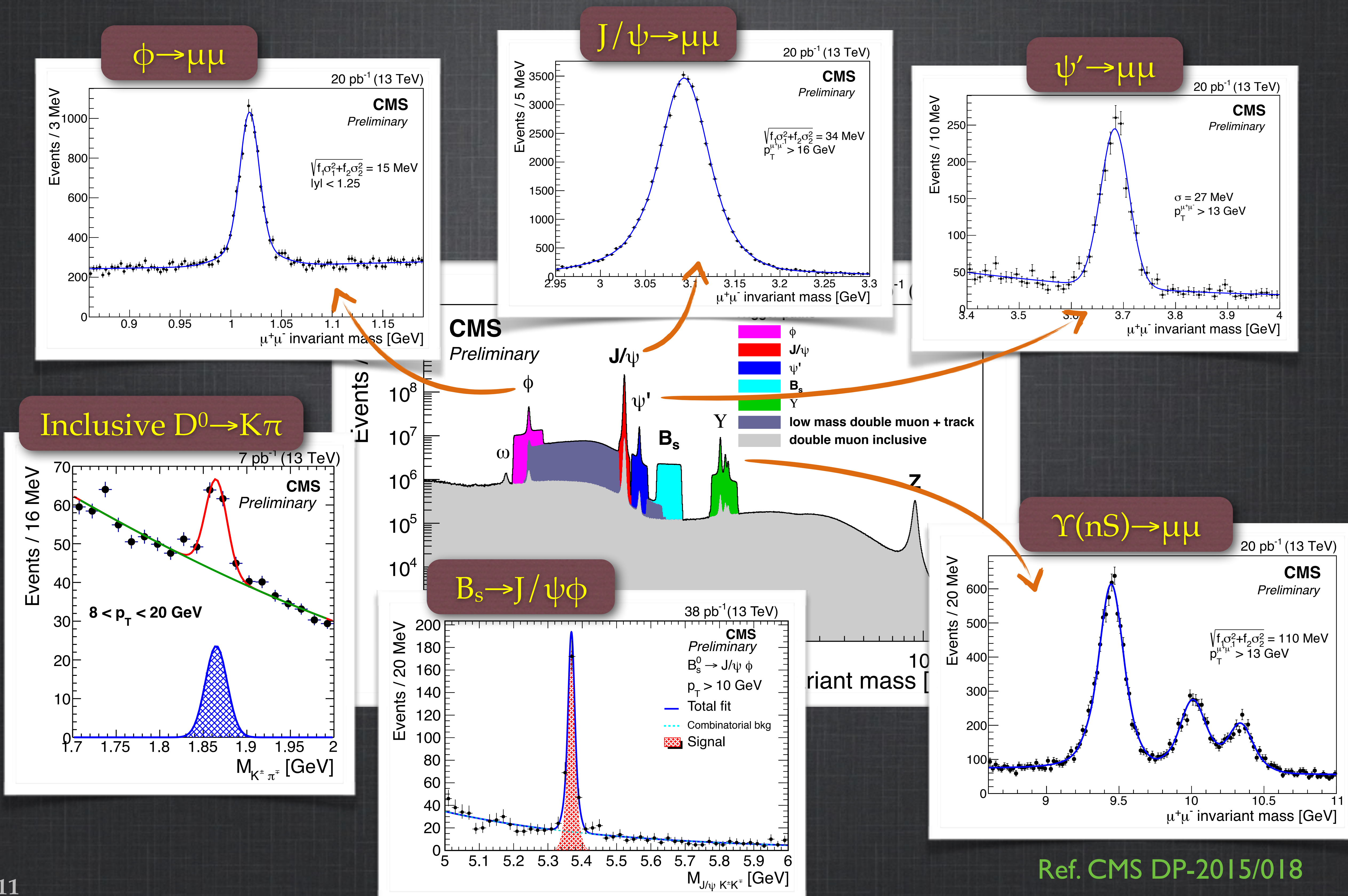
- Results consistent with SM predictions and previous measurements.
- Measurement of A_{FB} and F_L with good precision at high q^2.
- Next: analysis with more angular variables (P'5, etc)!

CMS @ LHC RUN-II

- **LHC resumed in 2015 with energy 13 TeV and 50/25 ns bunch spacing.**
- CMS has went through a series of detector and trigger improvements during the LS1 shutdown:
  - Sub-detectors operating with active channel fraction higher than Run-I.
  - Re-commissioning of the physics objects.
  - New challenge of 25 ns operations.
- **CMS data sets at 13 TeV:**
  2.2 fb^{-1} "golden";
  2.6 fb^{-1} "silver", good for most searches;
  2.7 fb^{-1} for muons
- ~25% luminosity collected by CMS so far was taken without B field due to a problem with cryogenic supply feeding liquid He.

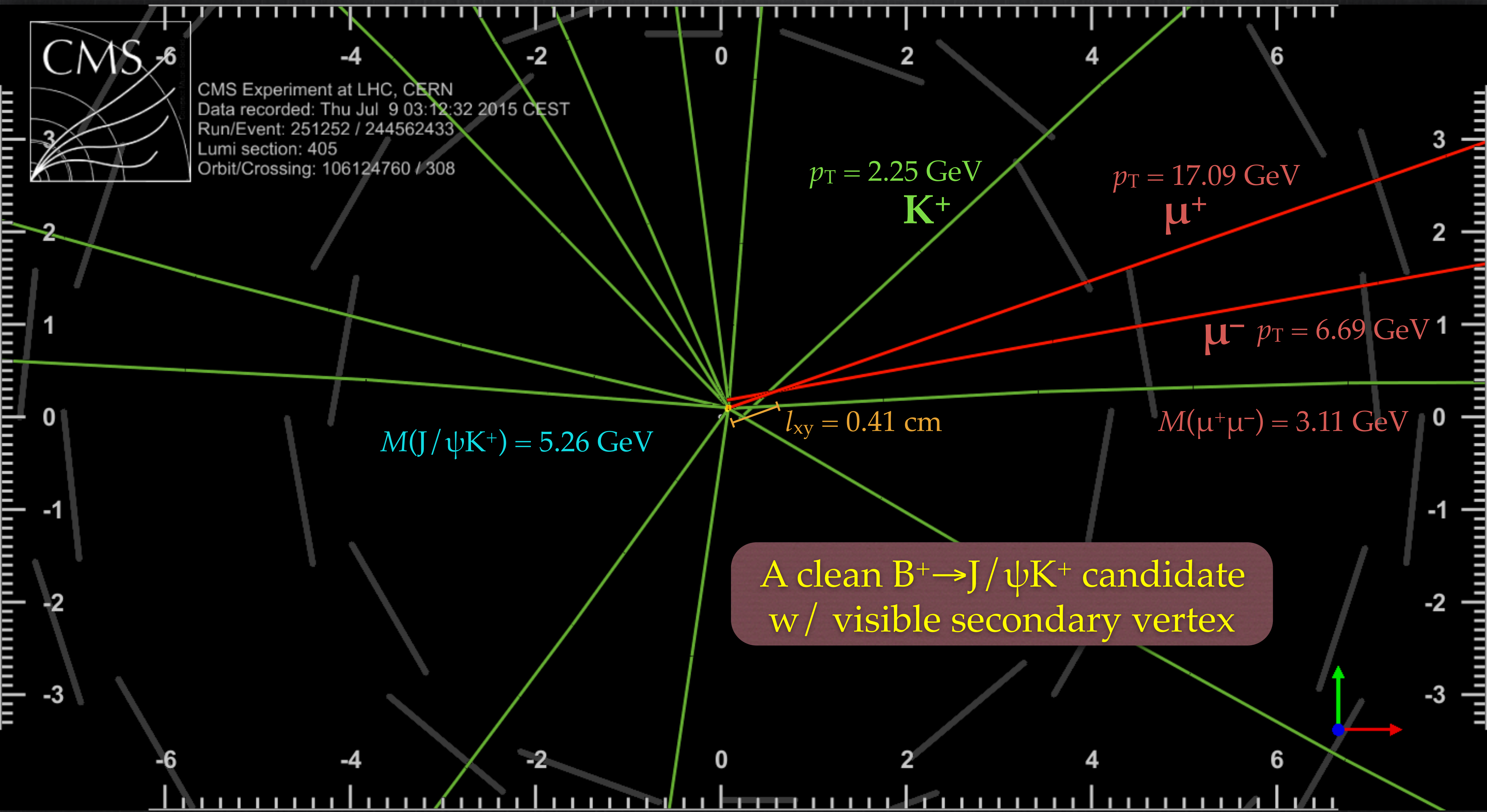


SOME NICE "PEAKS"



Ref. CMS DP-2015/018

A $B^+ \to J/\psi K^+$ CANDIDATE



A clean $B^+ \to J/\psi K^+$ candidate
w/ visible secondary vertex

B^+ PRODUCTION CROSS SECTION

- Measurements of b-hadron production cross sections provide essential information to understand QCD.
- Studies of b-hadron production at the higher energies provide a new important test of theoretical calculations.
- **First 13 TeV B^+ production cross section measurement**, based on the exclusive decay of $B^+ \to J/\psi(\to \mu^+\mu^-)K^+$.
- Differential cross sections as functions of B transverse momentum and B rapidity are measured:

Signal yields

$$\frac{d\sigma(pp \to B^+X)}{dp_T^B} = \frac{n_{sig}(p_T^B)}{2\, A\cdot\epsilon(p_T^B)\, \mathcal{B}\, \mathcal{L}\, \Delta p_T^B}, \quad \frac{d\sigma(pp \to B^+X)}{dy^B} = \frac{n_{sig}(|y^B|)}{2\, A\cdot\epsilon(|y^B|)\, \mathcal{B}\, \mathcal{L}\, \Delta y^B}$$

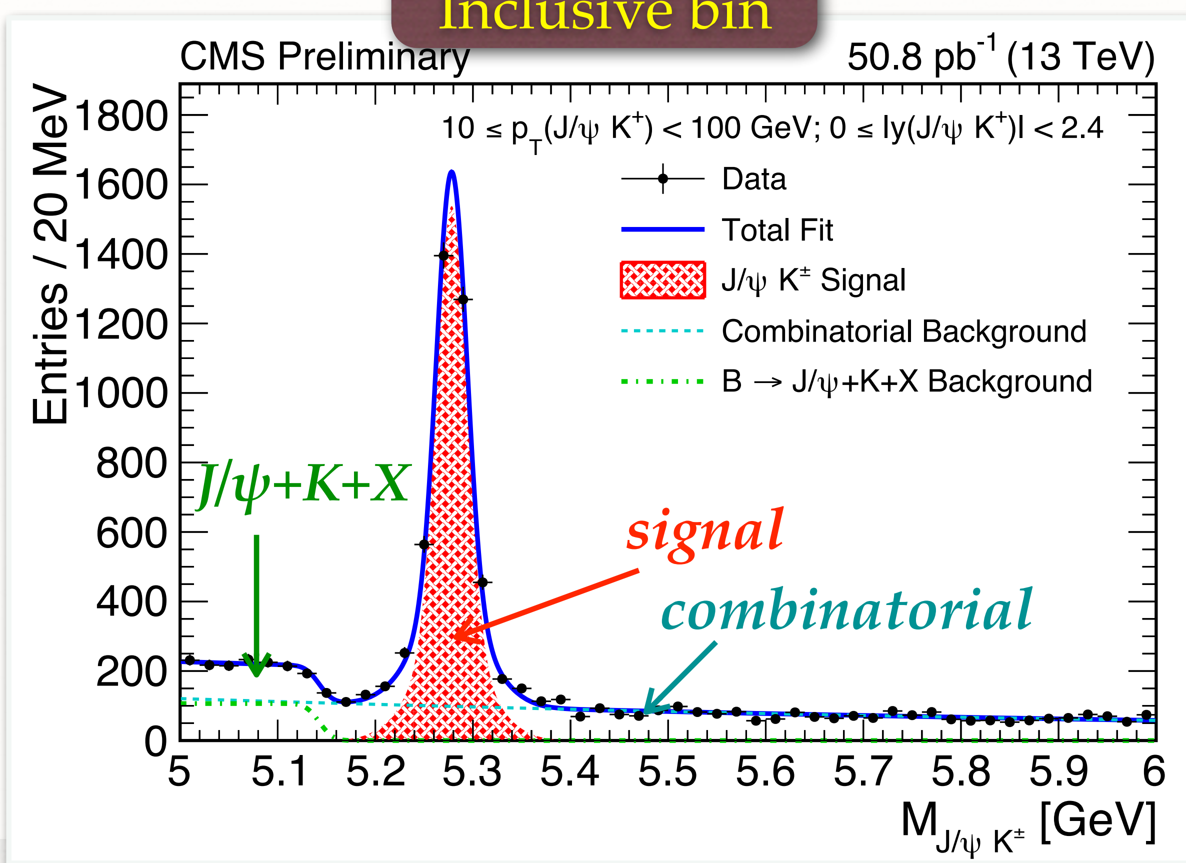
Acceptance × efficiency *bin width*

Defined in the phase-space:
$|y|<2.4$; 10 GeV $<p_T<$ 100 GeV

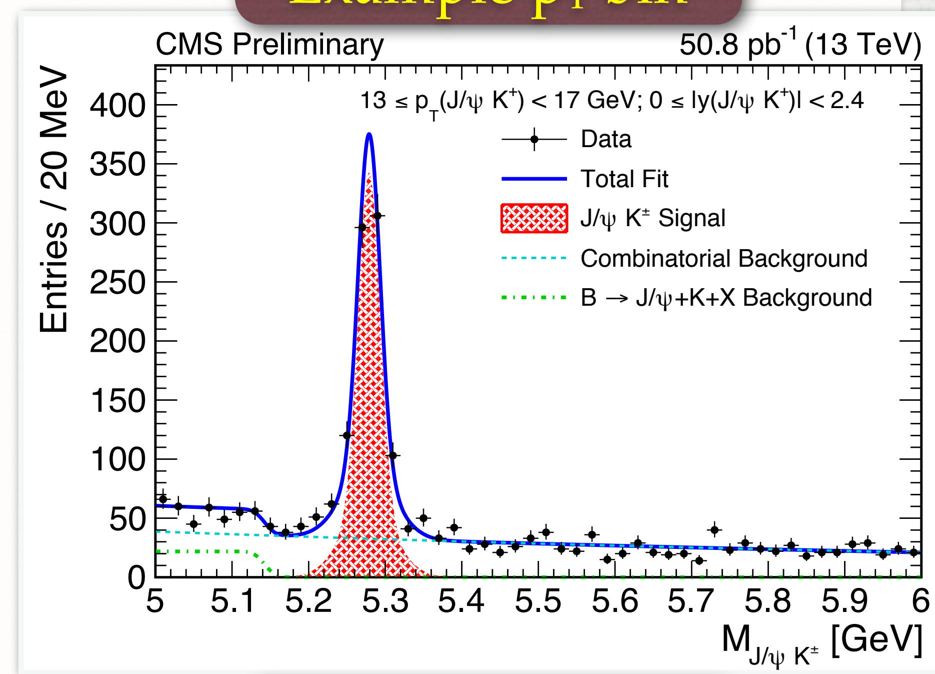
B^+ YIELD EXTRACTION

- Based on 13 TeV data, 50 ns spacing. Luminosity ~50.8 pb^{-1}.
- Signal yields are extracted by unbinned maximum likelihood fits to the invariant mass of B^+ candidates in bins of p_T & |y|.

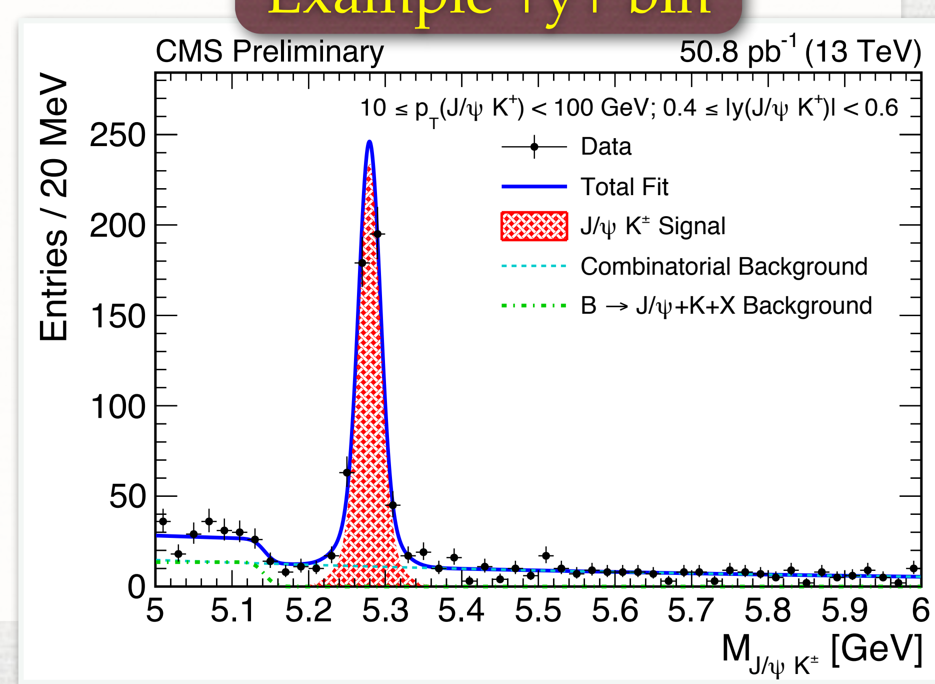
Inclusive bin



Example p_T bin

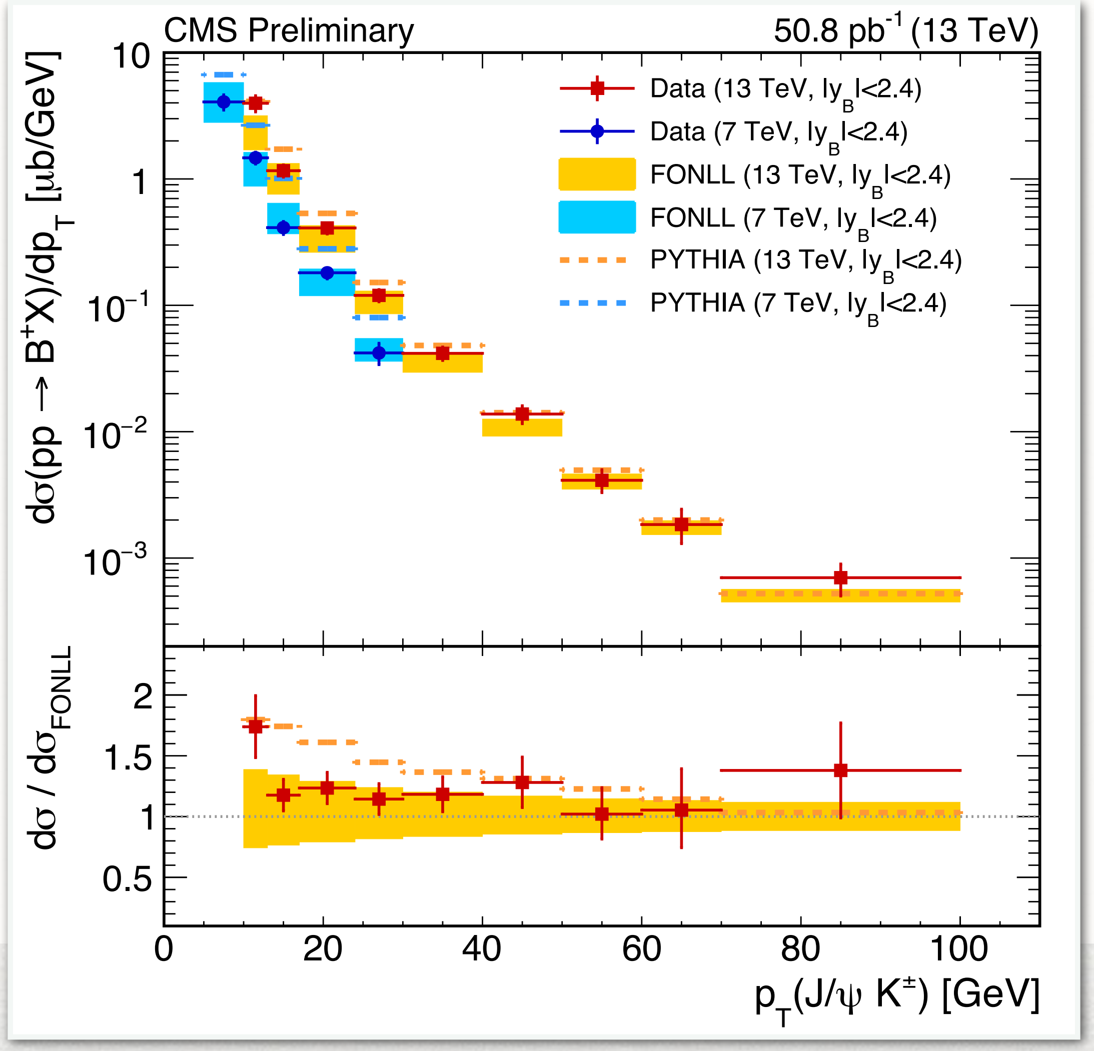


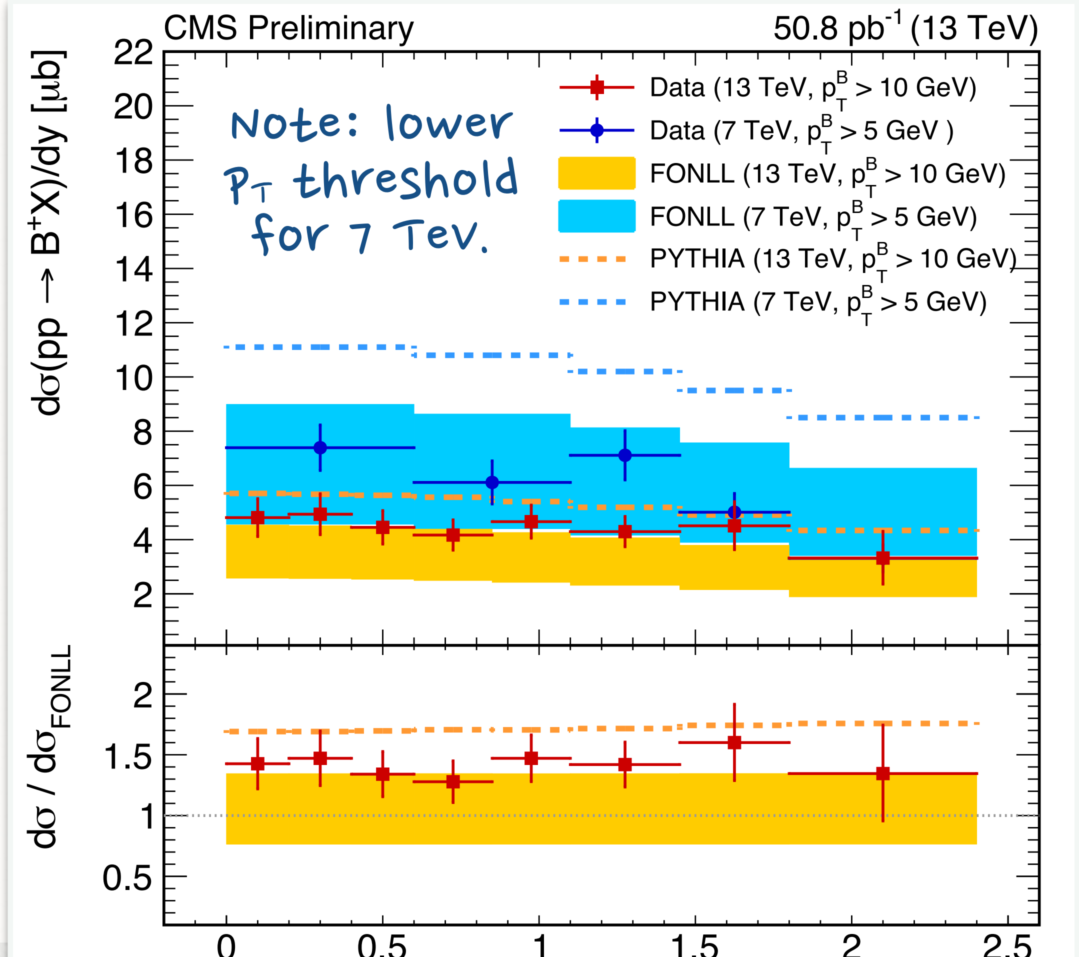
Example |y| bin



DIFFERENTIAL CROSS SECTIONS

- Differential cross sections in bins of pT and |y|.
- Systematics dominant by muon efficiencies and sig/bkg modeling.
- The measured values show a reasonable agreement, both in terms of shape and of normalization, with FONNL and PYTHIA.





Ref. CMS BPH-15-004

NEW

QUARKONIUM PRODUCTION @ 13 TeV

- **Quarkonia — an ideal probe of hadron formation!**
- Comparison of the productions at 13 and 7 TeV provides a good opportunity to test the factorization hypotheses of NRQCD.
- Measure the double-differential prompt production cross sections of J/ψ & ψ(2S) and the production cross sections of Υ(1S)/Υ(2S)/Υ(3S) in the kinematical range of **p_T > 20 GeV, |y|<1.2**:

Signal yields

$$\mathcal{B}(q\bar{q} \to \mu^+\mu^-) \times \frac{d^2\sigma^{q\bar{q}}}{dp_T dy} = \frac{N^{q\bar{q}}(p_T, y)}{\mathcal{L}\Delta y \Delta p_T} \cdot \left\langle \frac{1}{\epsilon(p_T, y)\mathcal{A}(p_T, y)} \right\rangle$$

bin width

average of the inverse acceptance × efficiency

Acceptance from particle-gun MC; Efficiencies from data-driven tag-and-probe studies.

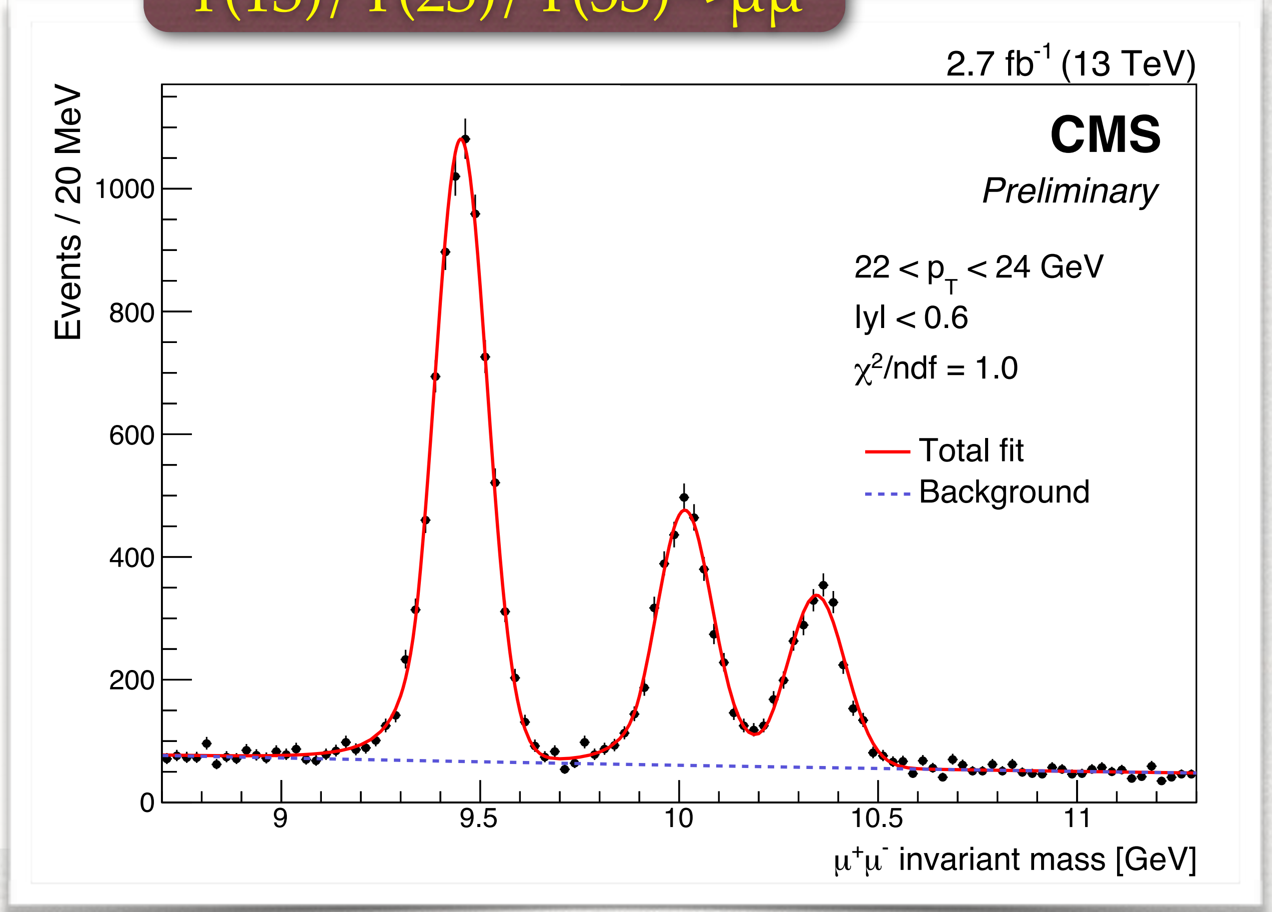
SIGNAL EXTRACTION

- **2.4~2.7 fb^{-1} of data at 13 TeV is included in the analysis.**
- Based on dimuon triggers, requiring two muons with requirements on p_T, invariant mass and vertexing.
- In order to perform the measurement in a kinematical region where muon acceptance is high, the following requirements are applied to muon itself:

$p_T(\mu) > 4.5$ GeV if $0.0 < |\eta(\mu)| < 0.3$;
$p_T(\mu) > 4.0$ GeV if $0.3 < |\eta(\mu)| < 1.4$

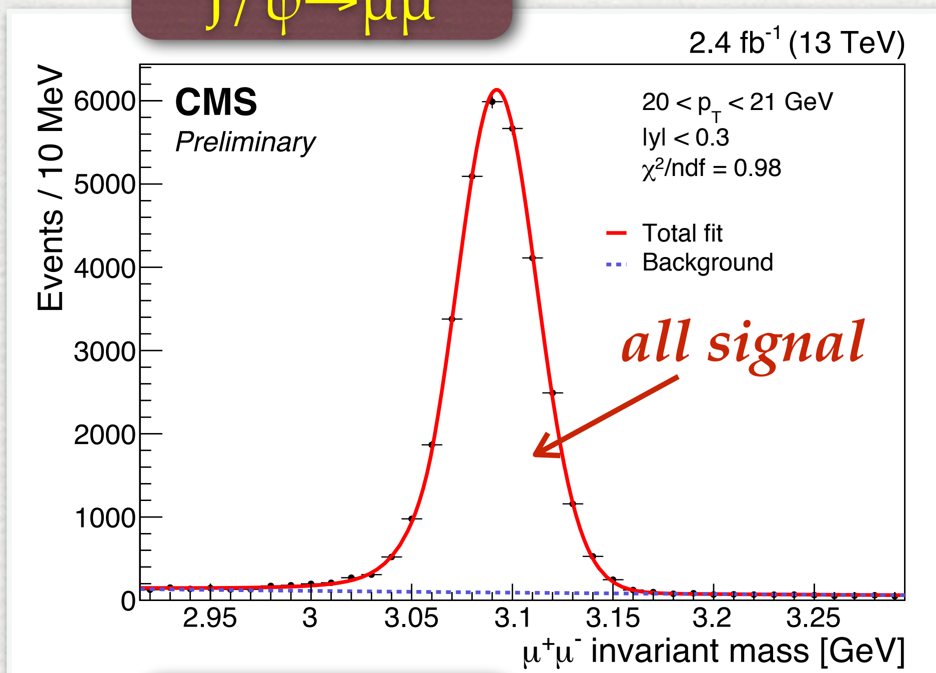
- Yields are extracted by maximum likelihood fits to the invariant mass spectra:

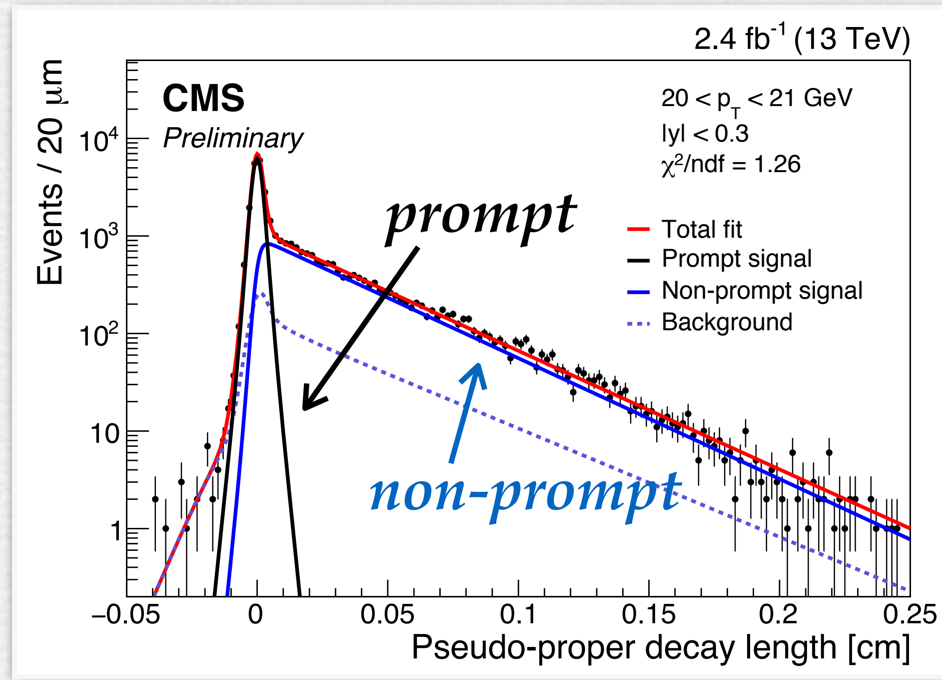
Υ(1S)/Υ(2S)/Υ(3S)→μμ



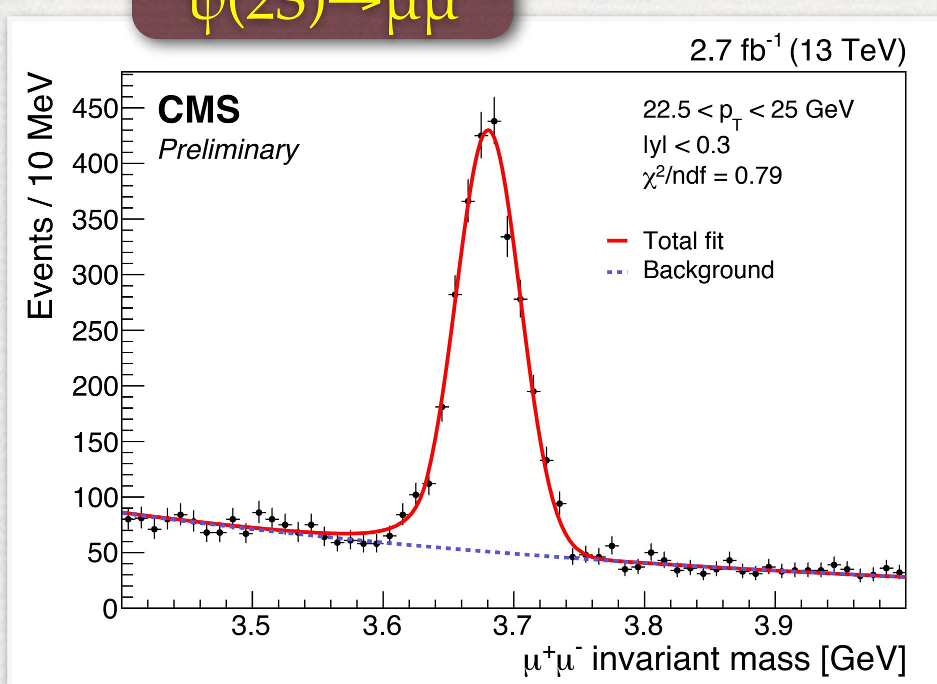
SIGNAL EXTRACTION (CONT.)

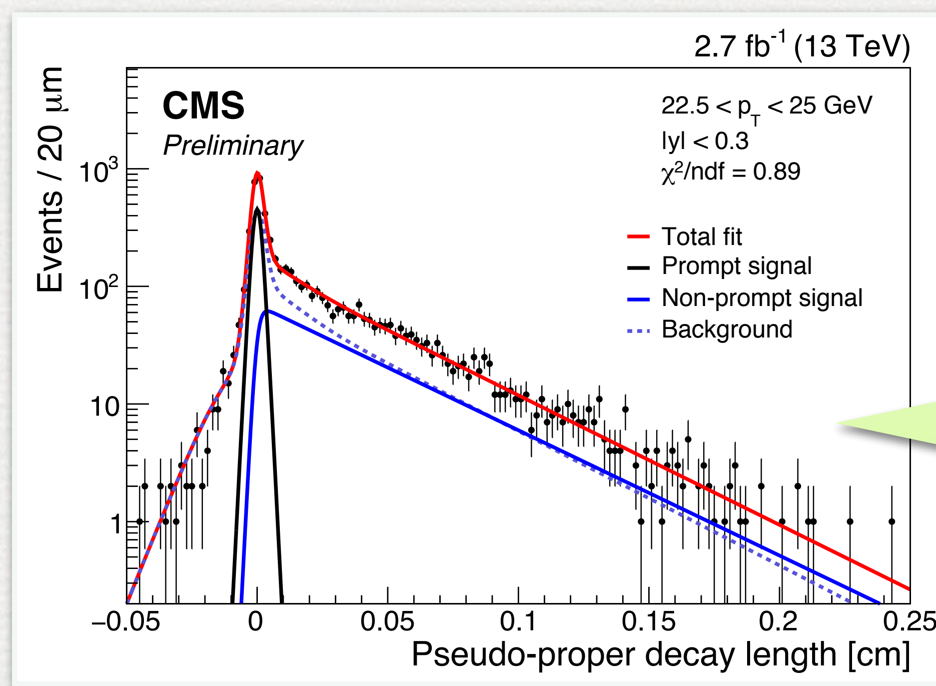
$J/\psi \to \mu\mu$





$\psi(2S) \to \mu\mu$





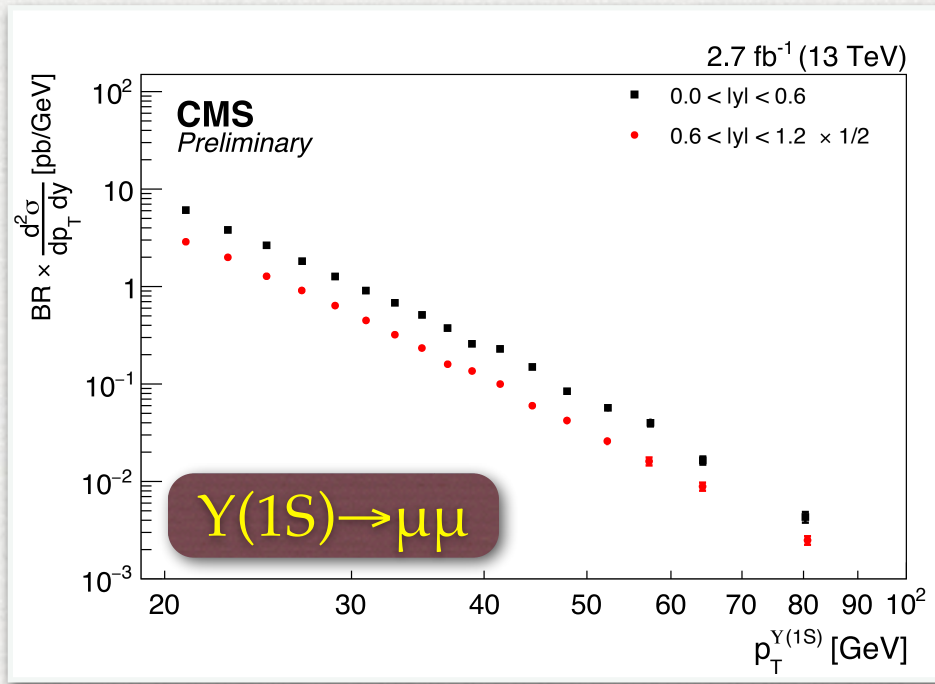
Charmonium: 2D fits to **invariant mass** and **decay length** are used to obtain the ***signal yields*** and ***non-prompt fractions*** together.

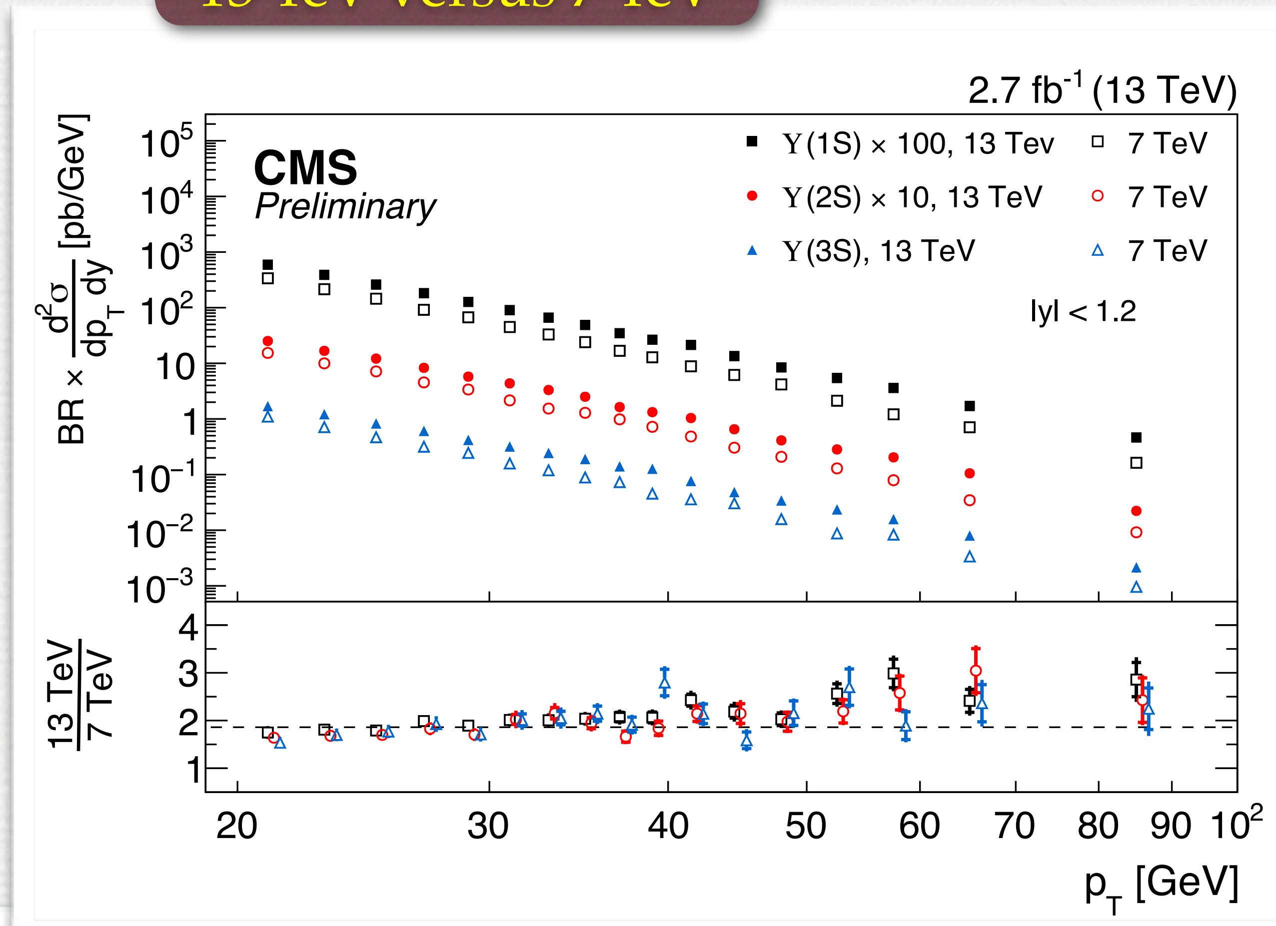
RESULTS: ϒ(nS)

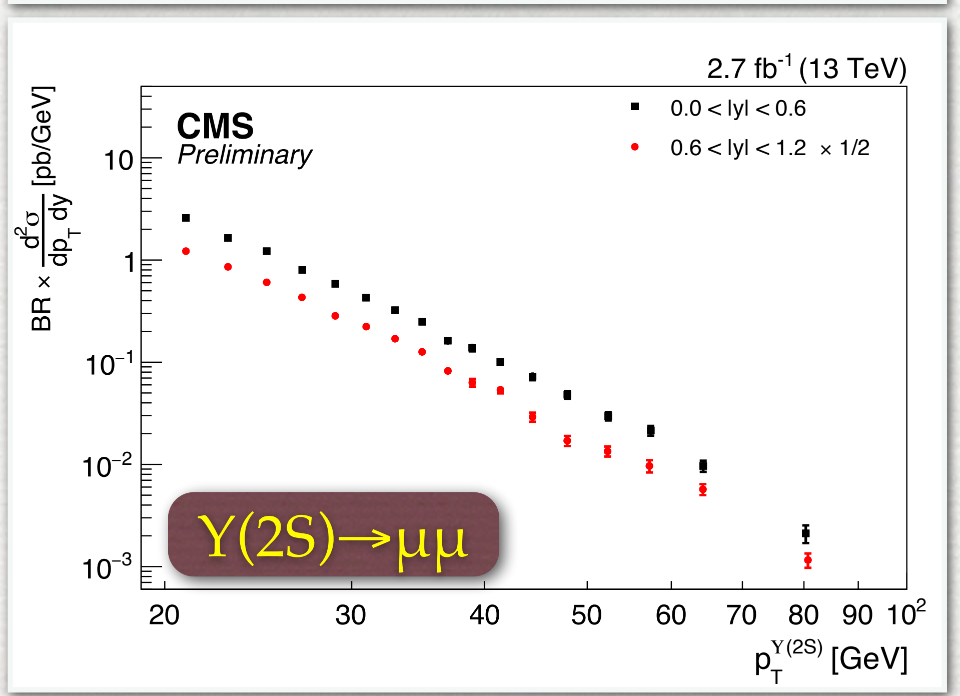
Ref. CMS BPH-15-005

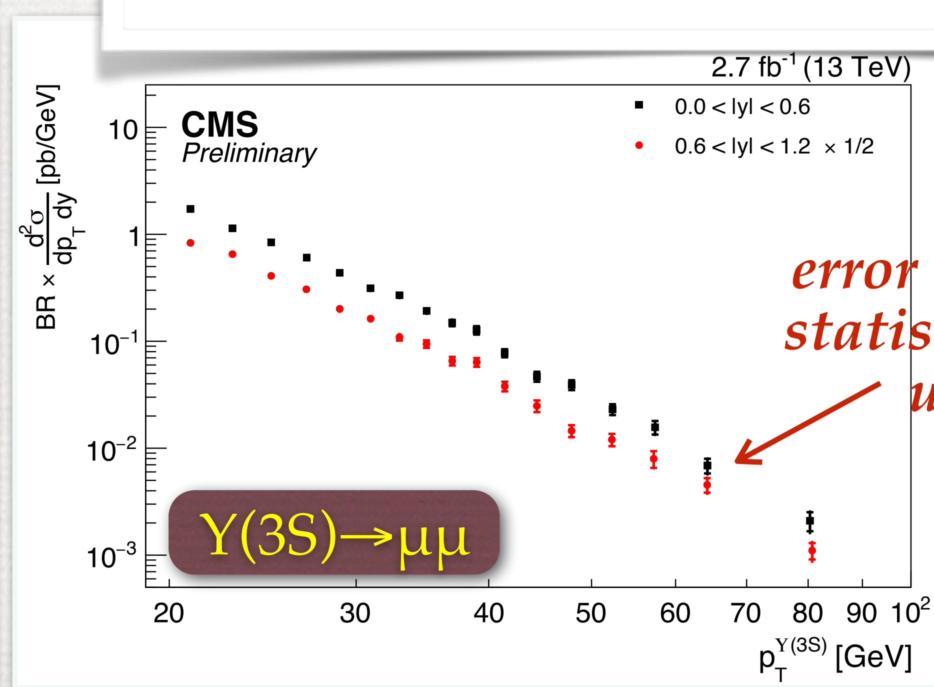
- Differential cross sections measured in 2 rapidity bins.

13 TeV versus 7 TeV



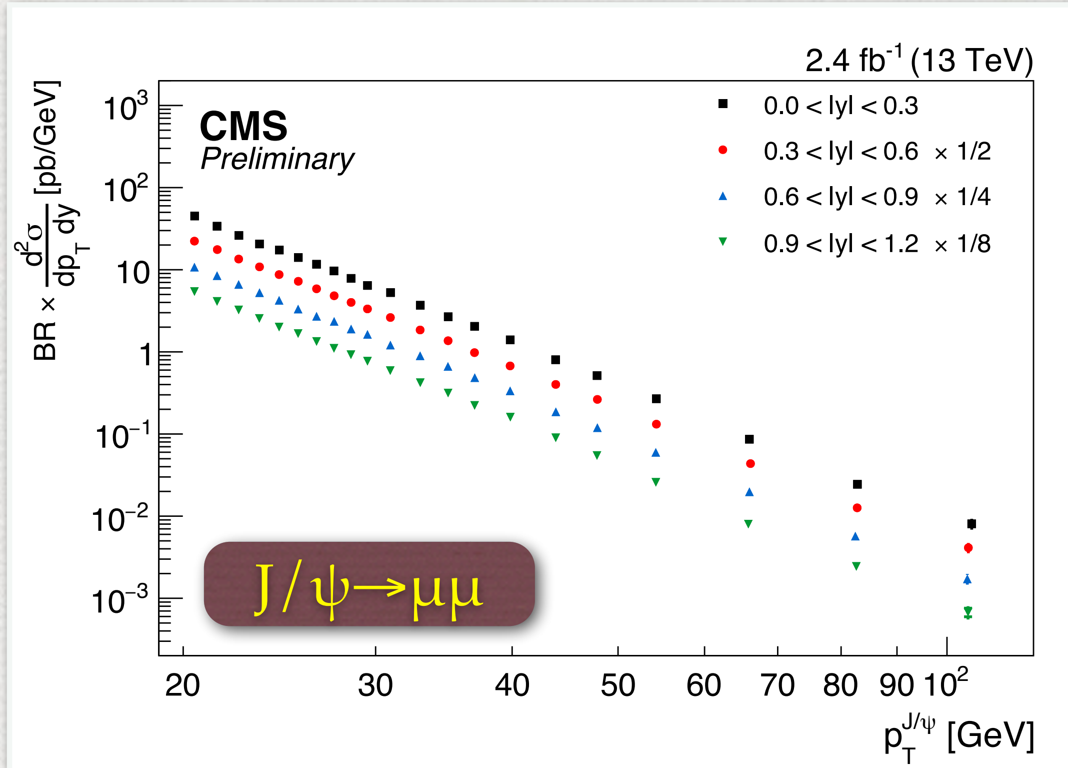


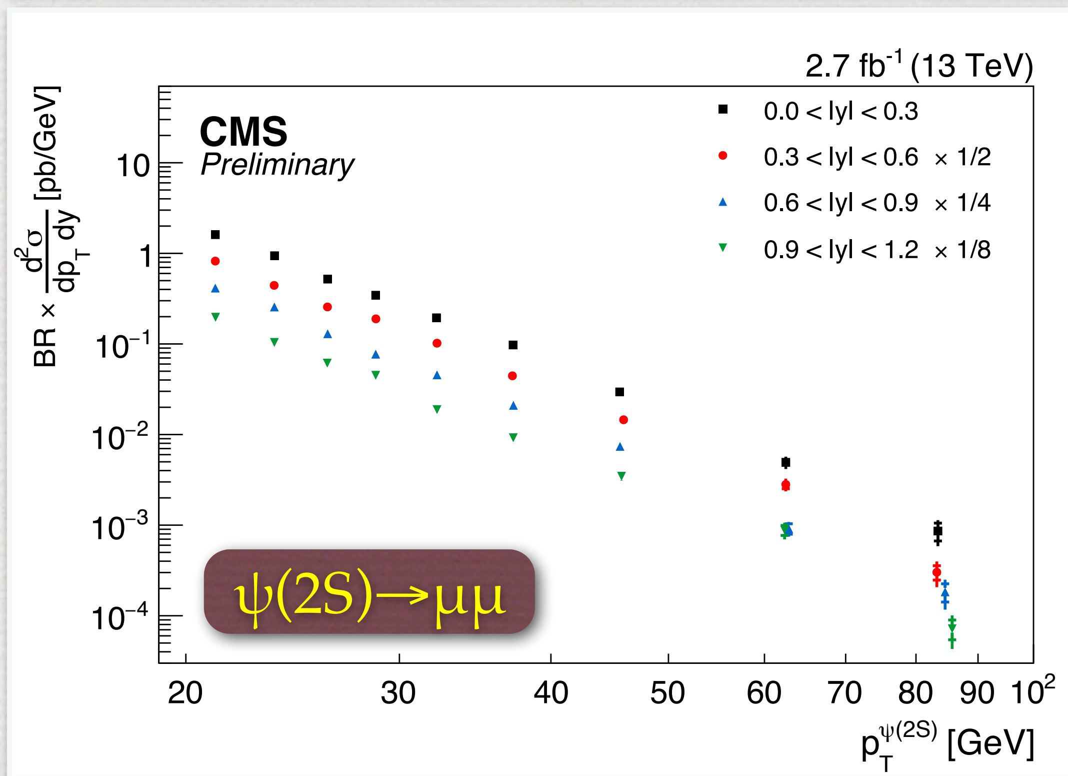




error bar includes both statistics & systematic uncertainties.

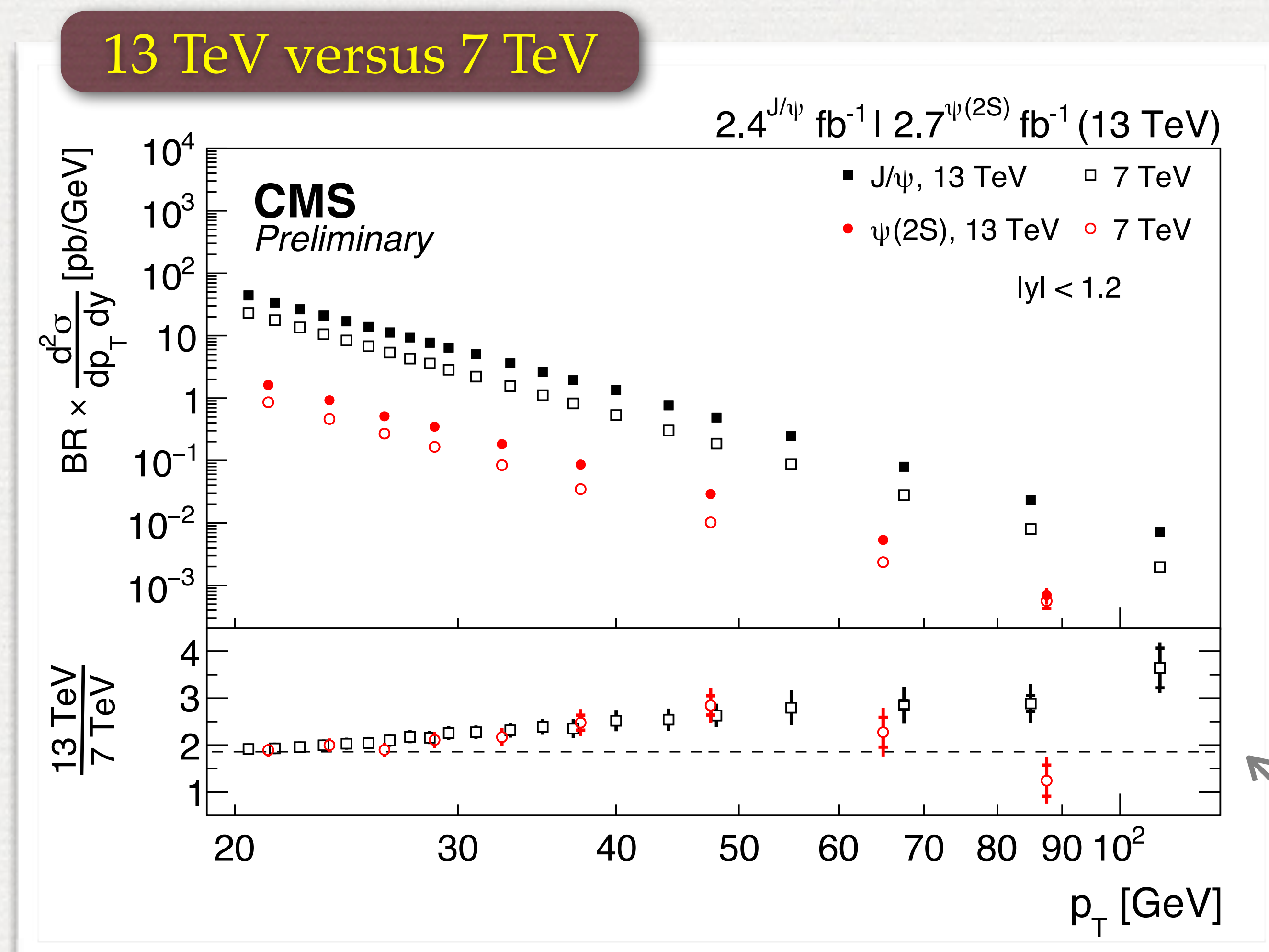
RESULTS: J/ψ & ψ(2S)





- Differential cross sections measured in 4 rapidity bins.
- Extending up to 120 GeV in pT for J/ψ, and up to 100 GeV for ψ(2S).

13 TeV versus 7 TeV

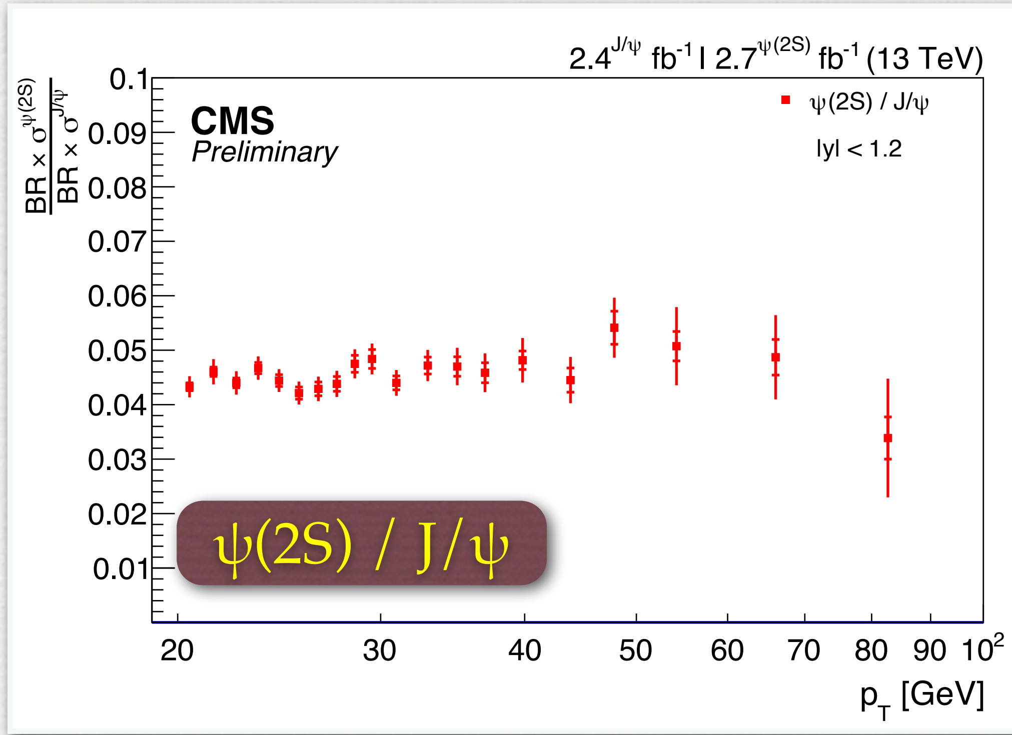


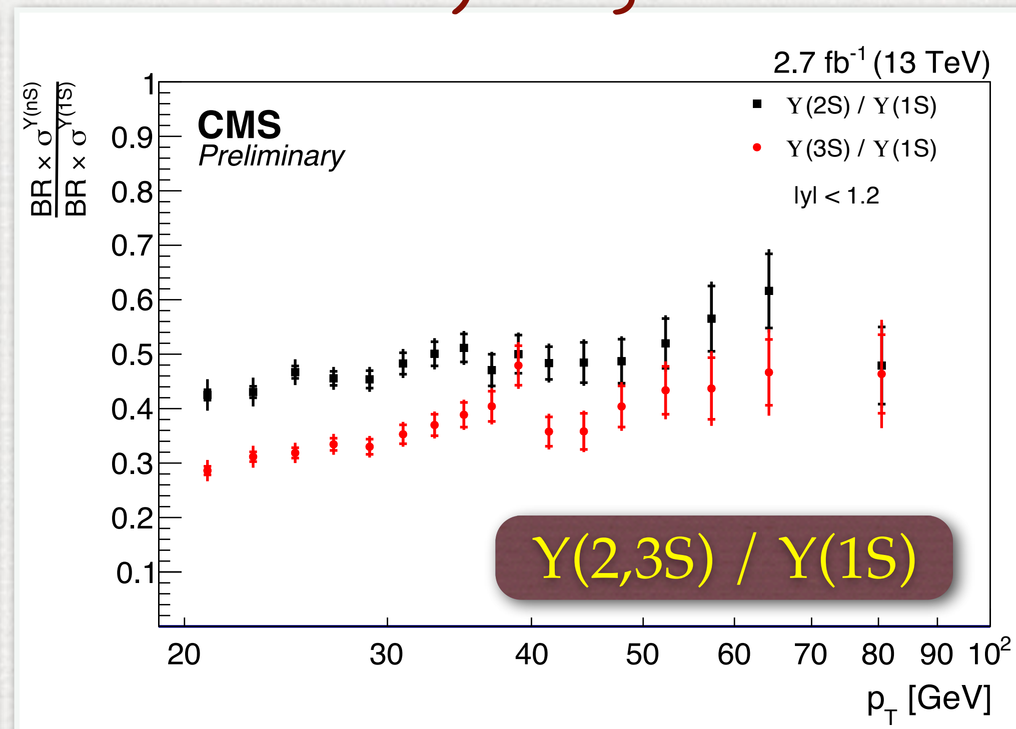
ratio of $\sqrt{s}$

RESULTS: MORE!

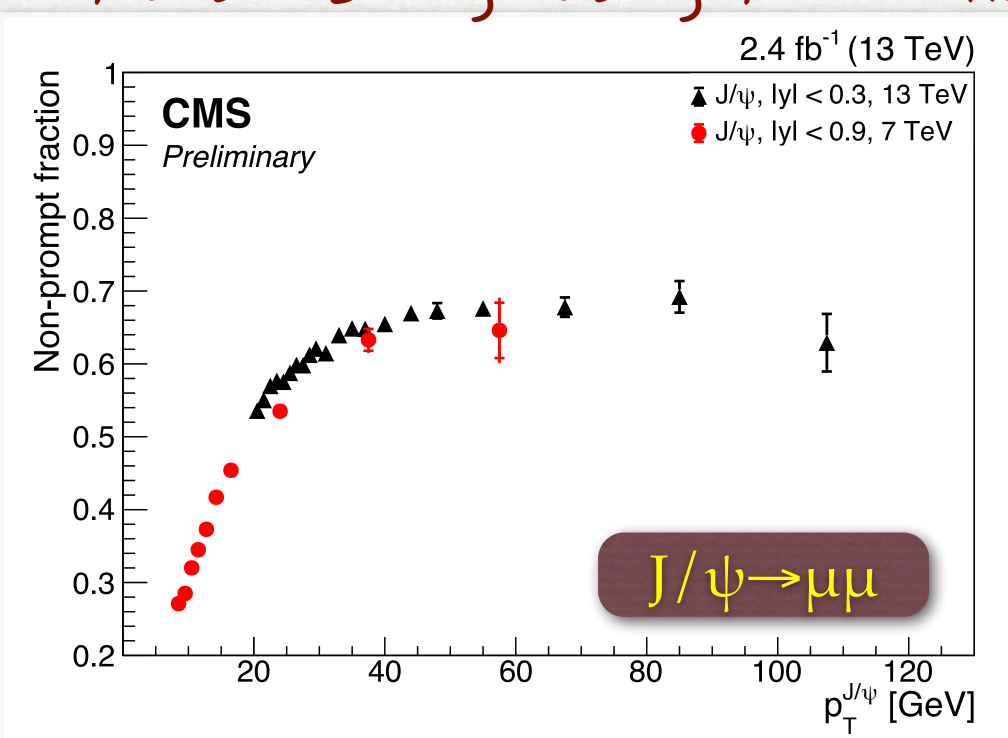
Differential Cross Sections Ratios

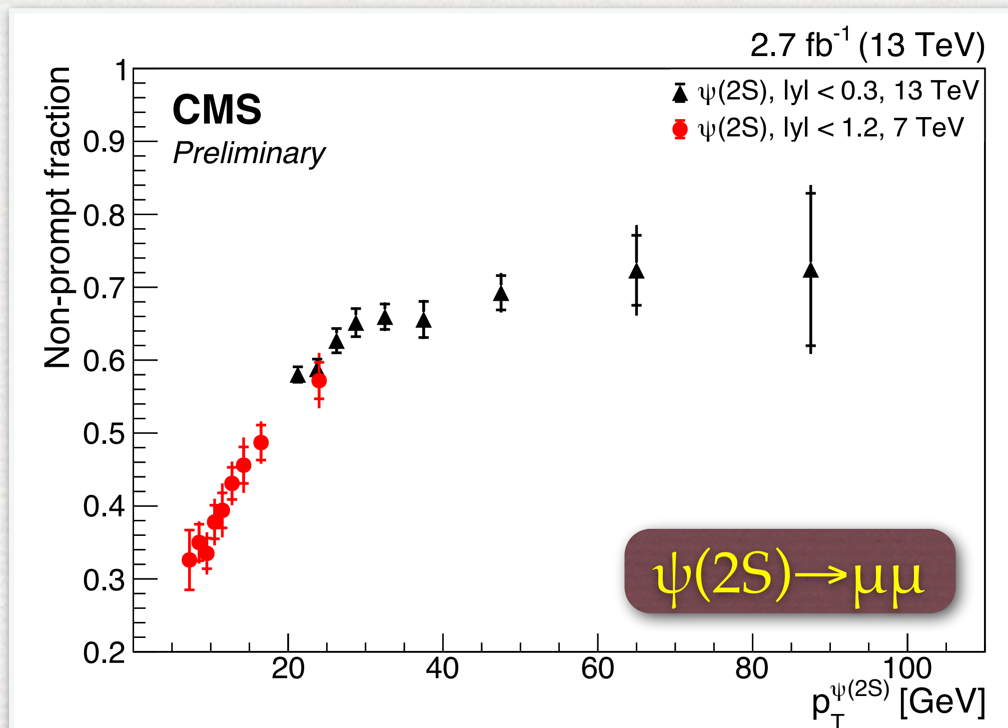
Normalized by its ground state





fractions originating from b-hadrons





Charmonium Non-prompt Fractions

SUMMARY

- Angular analyses have been carried out for $B^0 \to K^{*0}\mu\mu$ decays with full CMS 8 TeV data. The measured physics parameters (F_L, A_{FB}) are found to be consistent with the TH calculations. Analyses with additional variables are coming soon.
- Differential cross section for B^+ production at 13 TeV has been measured up to 100 GeV in p_T. The values show a reasonable agreement with FONNL calculations and with PYTHIA.
- The double differential production cross sections at 13 TeV for J/ψ, ψ(2S), ϒ(nS) have been measured. Our results shall contribute to consolidate the underlying hypotheses of NRQCD and provide further input to constrain the theory parameters.

Stay tuned – more results to be expected!

See https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsBPH for more!