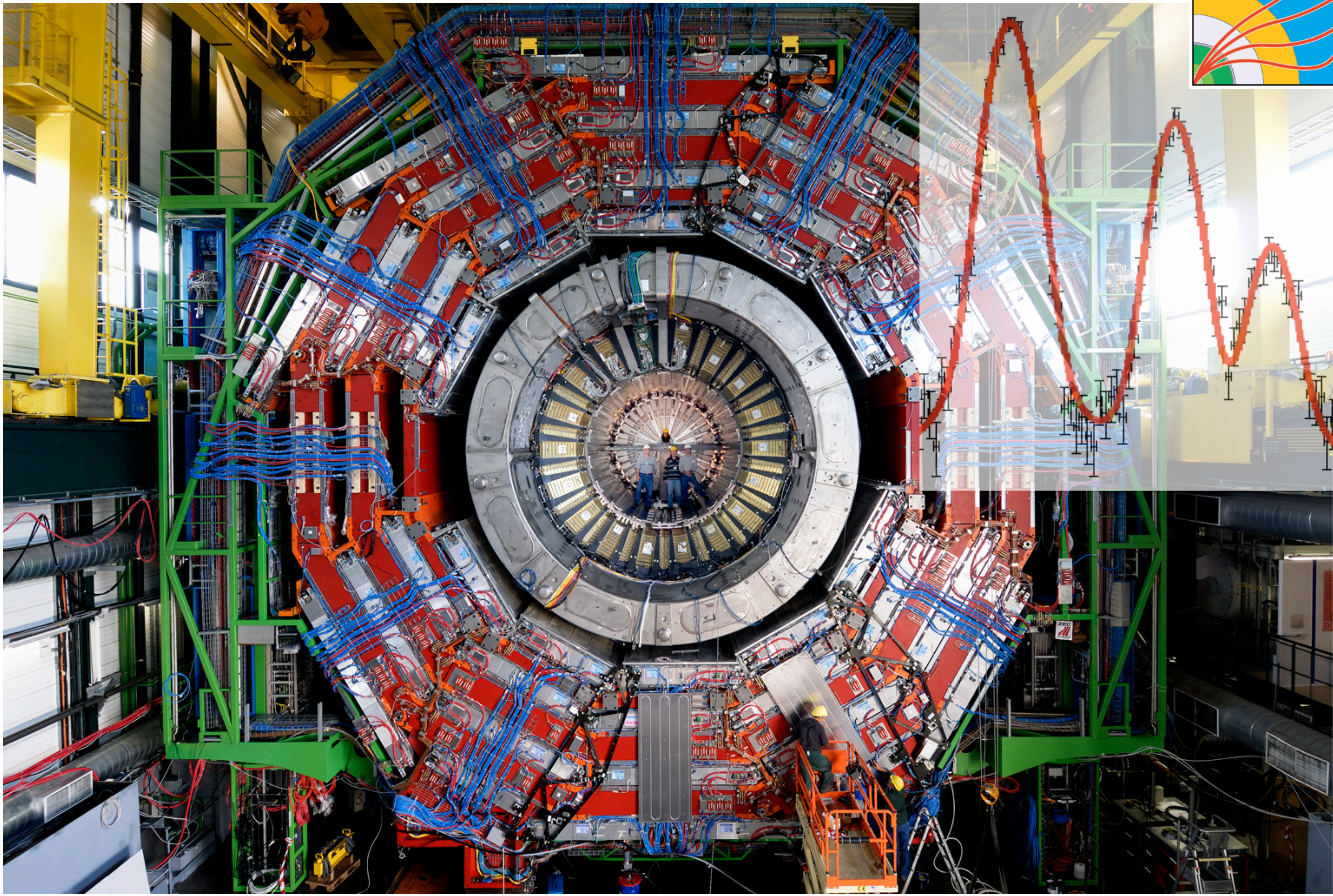
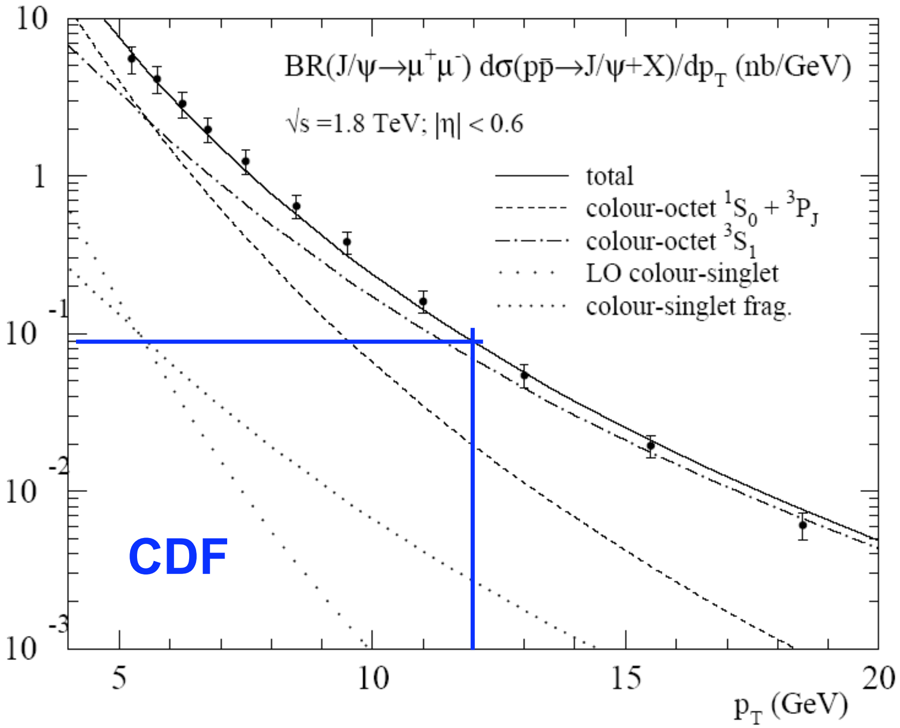
Quarkonium production in CMS

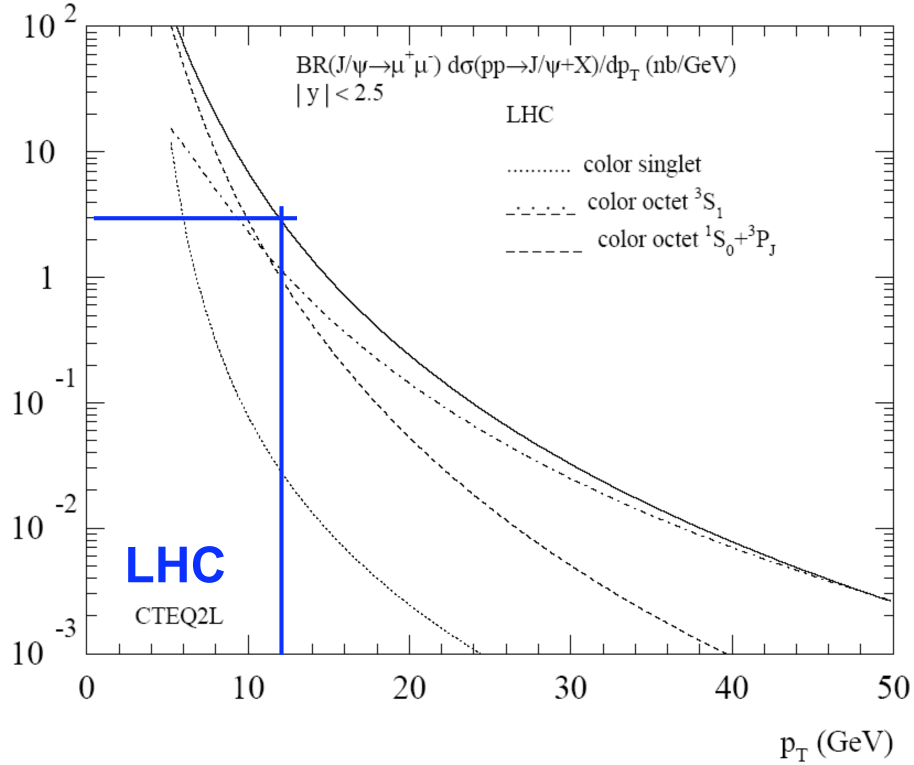


Carlos Lourenço, on behalf of CMS

DIS2009, Madrid, Spain, April 2009

Direct J/ψ production: from CDF to CMS





Extrapolation of singlet and octet contributions to direct J/ψ production from Tevatron to LHC energies (not very sensitive to details of underlying theoretical description) gives:

The J/ψ cross section times branching ratio into dimuons, in the "barrel acceptance", for p_T = 12 GeV/c is 0.09 nb/GeV at CDF and 3 nb/GeV at the LHC : 30 times larger

"Bottom Production", P. Nason et al., hep-ph/0003142
"1999 CERN Workshop on SM physics (and more) at the LHC"

Quarkonium polarization: from CDF to CMS

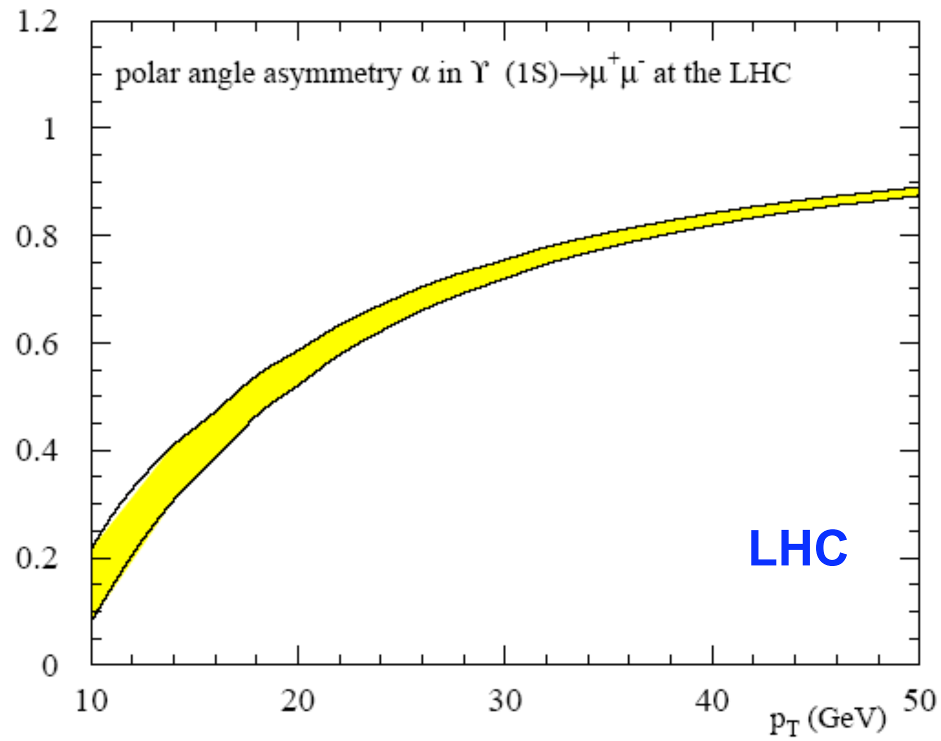
The analysis of the J/ψ, ψ' and Upsilon polarization is a crucial test of NRQCD

NRQCD predicts transverse polarization at high p_T contrary to the CDF observations

Further progress requires measurements extending over large p_T ranges → LHC data

NRQCD should be on safer ground for the bottomonium system, where higher-order terms in the velocity expansion are less relevant than in the charmonia case

If the charmonium states are too light for a reliable non-relativistic expansion, the study of Υ polarization at $p_T \gg M_\Upsilon$ will be the most crucial test of the NRQCD approach



Quarkonium production at LHC energies

- The LHC will provide pp and Pb-Pb collisions

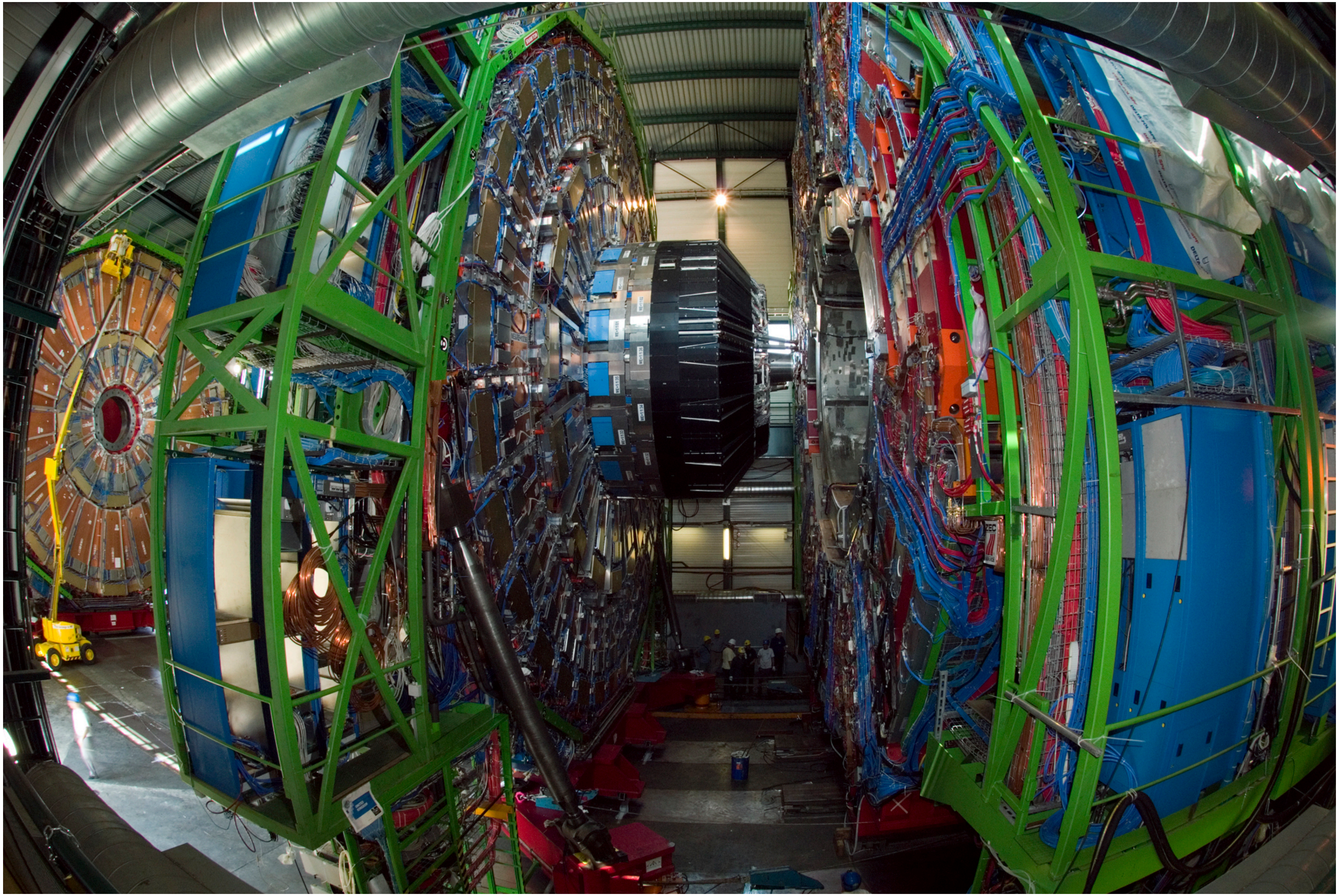
- First runs will be with pp collisions at ≈10 TeV with instantaneous luminosities from less than 10^{30} to more than 10^{31} $cm^{-2}s^{-1}$

- Later on the energy will be increased to 14 TeV and the luminosity to 10^{34} $cm^{-2}s^{-1}$

- A short Pb-Pb run should occur at 4 TeV per NN collision, at the end of 2010

- Quarkonium states will be produced with very high rates

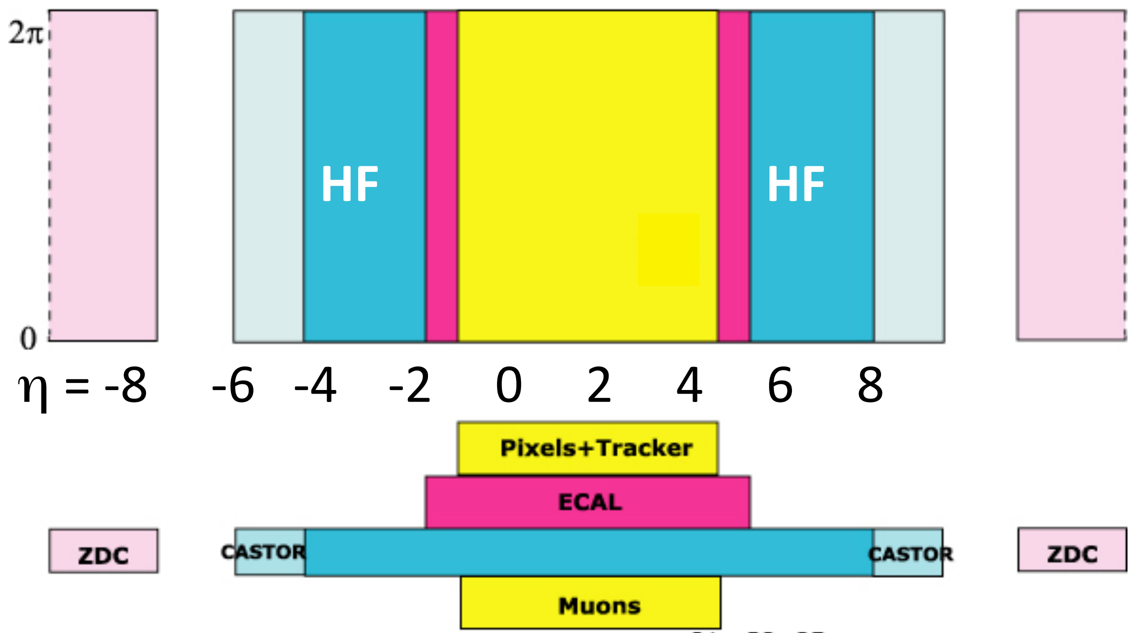
The CMS detector during assembly



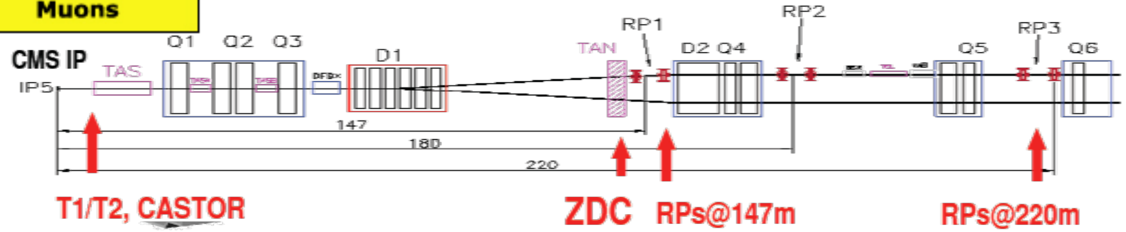
The CMS phase space coverage

CMS + TOTEM: full φ and almost full η acceptance at the LHC

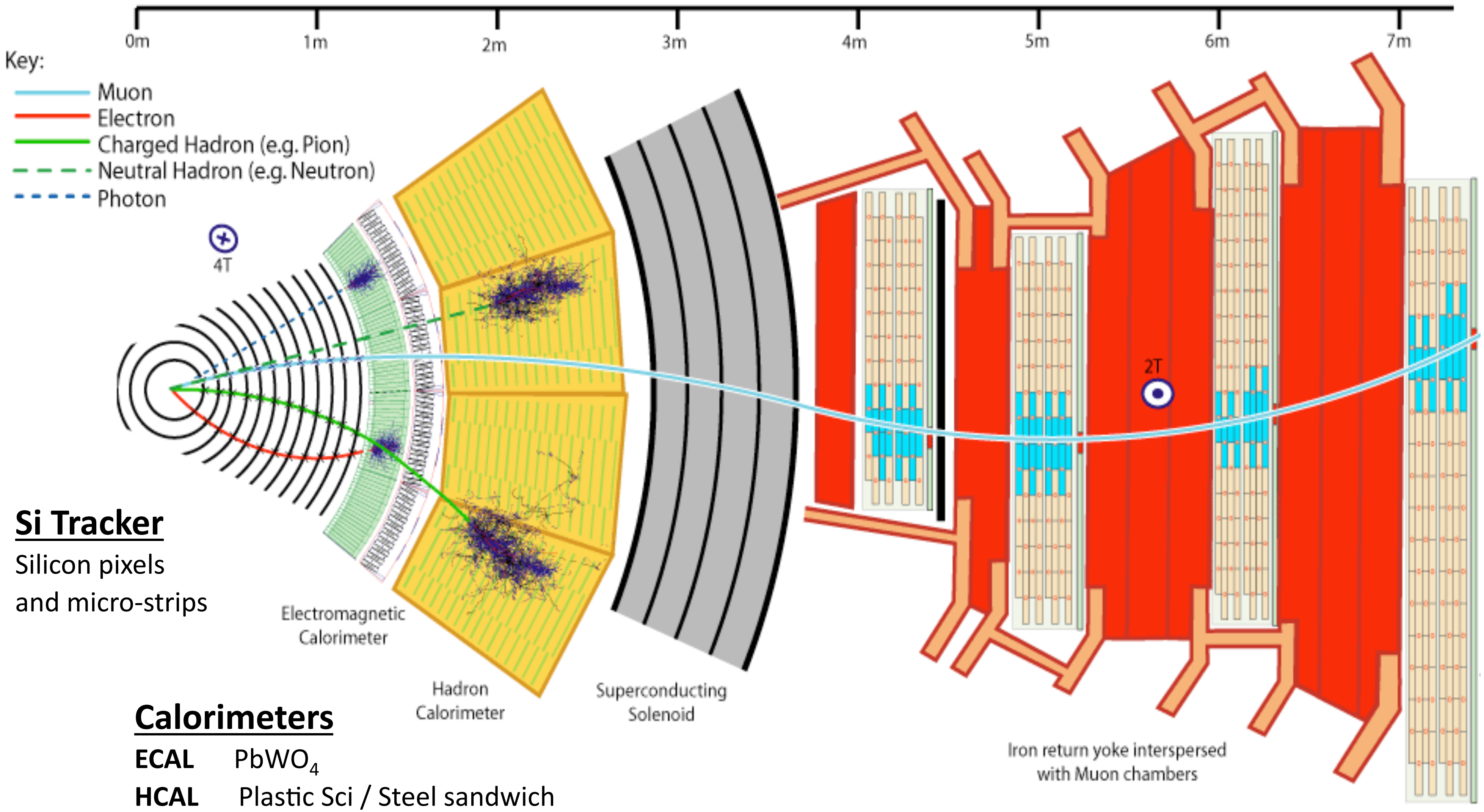
- charged tracks and muons: $|\eta| < 2.5$
- electrons and photons: $|\eta| < 3$
- jets, energy flow: $|\eta| < 6.7$ (plus $\eta > 8.3$ for neutrals, with the ZDC)



- excellent granularity and resolution
- very powerful High-Level-Trigger



A transverse slice through the CMS “barrel”



Si Tracker

Silicon pixels
and micro-strips

Calorimeters

ECAL $PbWO_4$

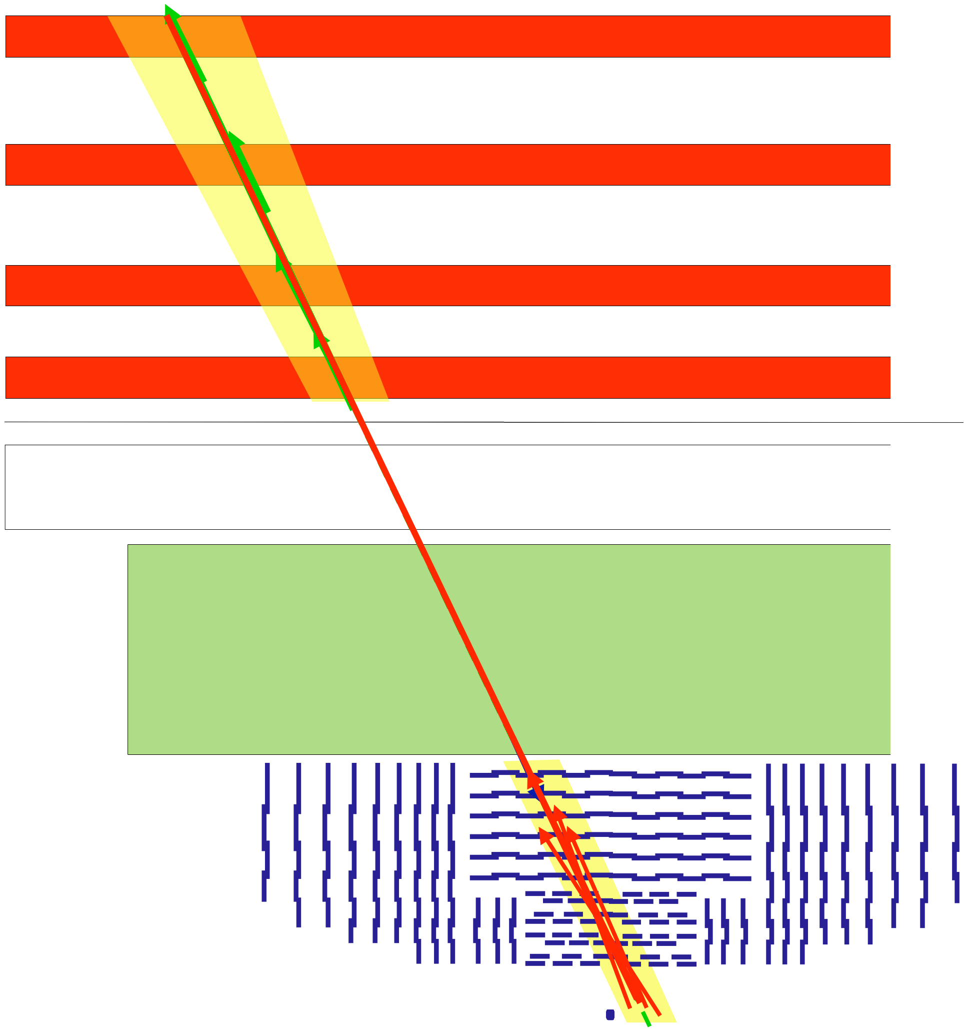
HCAL Plastic Sci / Steel sandwich

Muon Barrel

Drift Tube Chambers
Resistive Plate Chambers

J/ψ detection and dimuon mass resolution in CMS

- CMS is ideally suited to study quarkonium production in the dimuon decay channel:
  - large rapidity coverage ($|\eta| < 2.4$)
  - excellent dimuon mass resolution

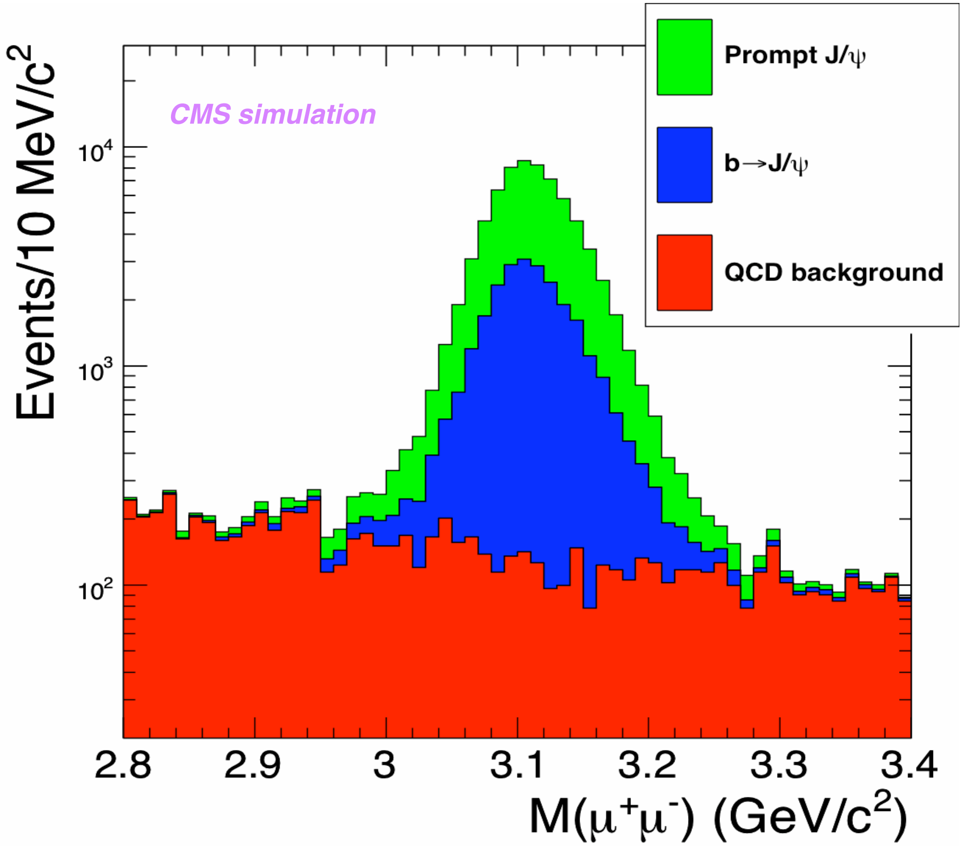


- The good dimuon mass resolution is due to the good muon momentum resolution, which results from the matching between the tracks in the muon chambers and in the silicon tracker

- The dimuon mass resolution changes with pseudo-rapidity; in the J/ψ region, from ≈15 MeV at $\eta\approx0$ to ≈40 MeV at $\eta\approx2.2$

Inclusive differential J/ψ cross section

- The observed J/ψ yield results from:
  - direct production
  - decays from ψ' and χ_c states
  - decays from B hadrons



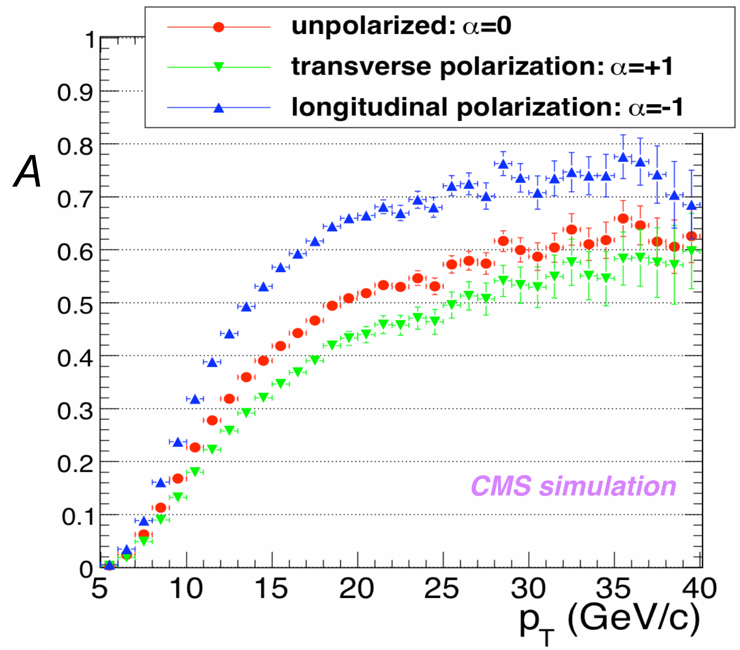
- CMS will measure the inclusive, prompt, and non-prompt (B decays) production cross sections

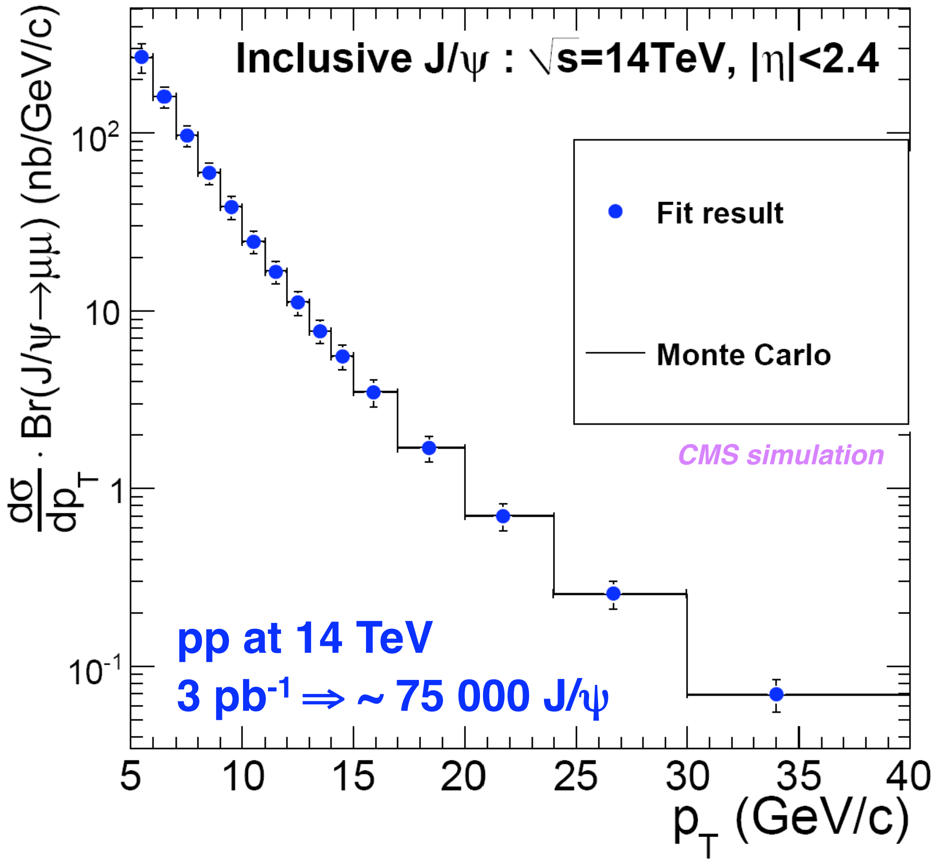
- In the first few weeks of LHC operation, CMS should collect more than 100 000 J/ψ events

- The J/ψ yield is extracted by fitting the dimuon mass distribution, separating the signal peak from the underlying background continuum

Inclusive differential J/ψ cross section

$$\frac{d\sigma}{dp_T^{J/\psi}} \cdot Br(J/\psi \to \mu^+\mu^-) = \frac{N_{J/\psi}^{fit}}{\int Ldt \cdot \Delta p_T^{J/\psi} \cdot A \cdot \lambda^{corr}}$$





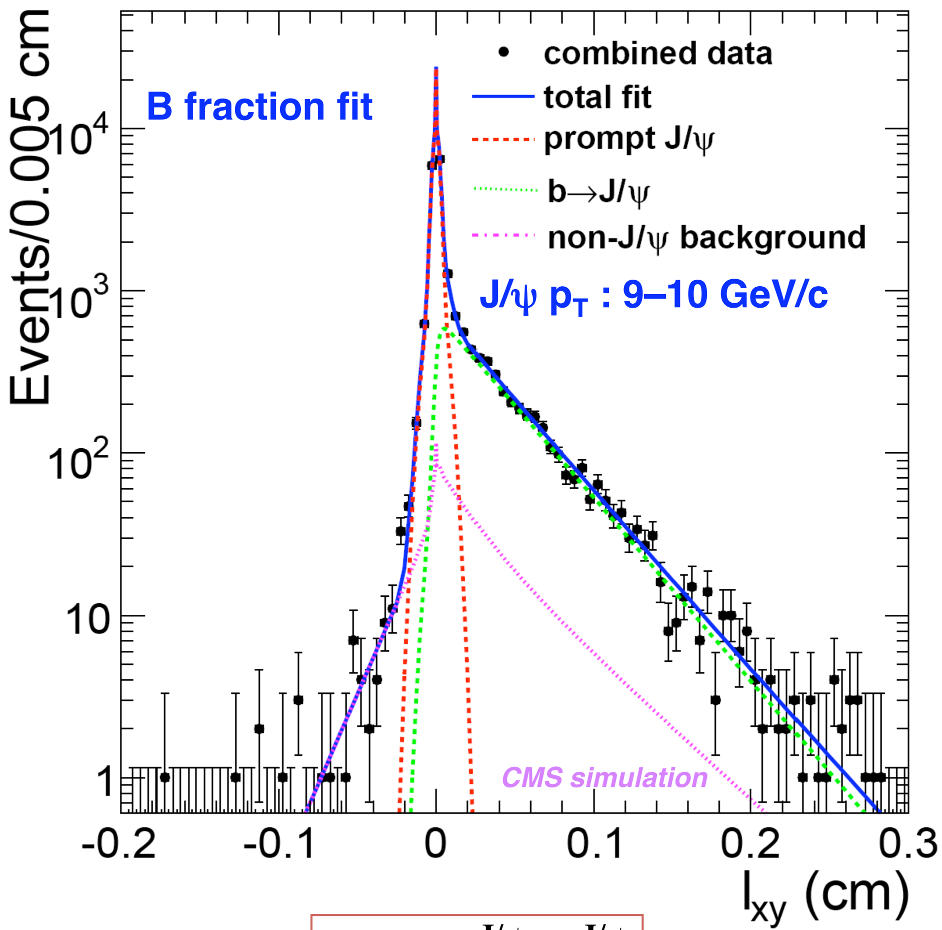
A : convolution between the detector acceptance and the trigger and reconstruction efficiencies, which depend on the assumed polarization

Competitive with Tevatron results after only 3 pb^{-1}

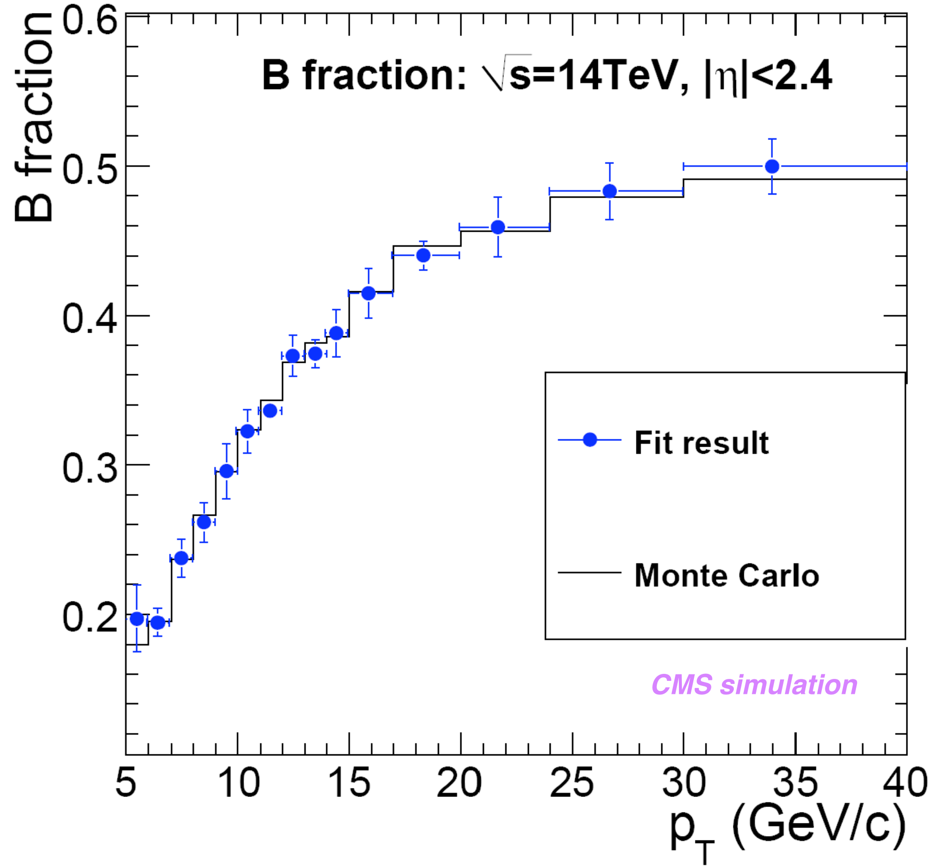
λ^{corr} : needed if MC does not match “reality”

Feed-down from B meson decays

An unbinned maximum likelihood fit is made, in p_T bins, to determine the non-prompt fraction, f_B, using the dimuon mass and the pseudo proper decay length

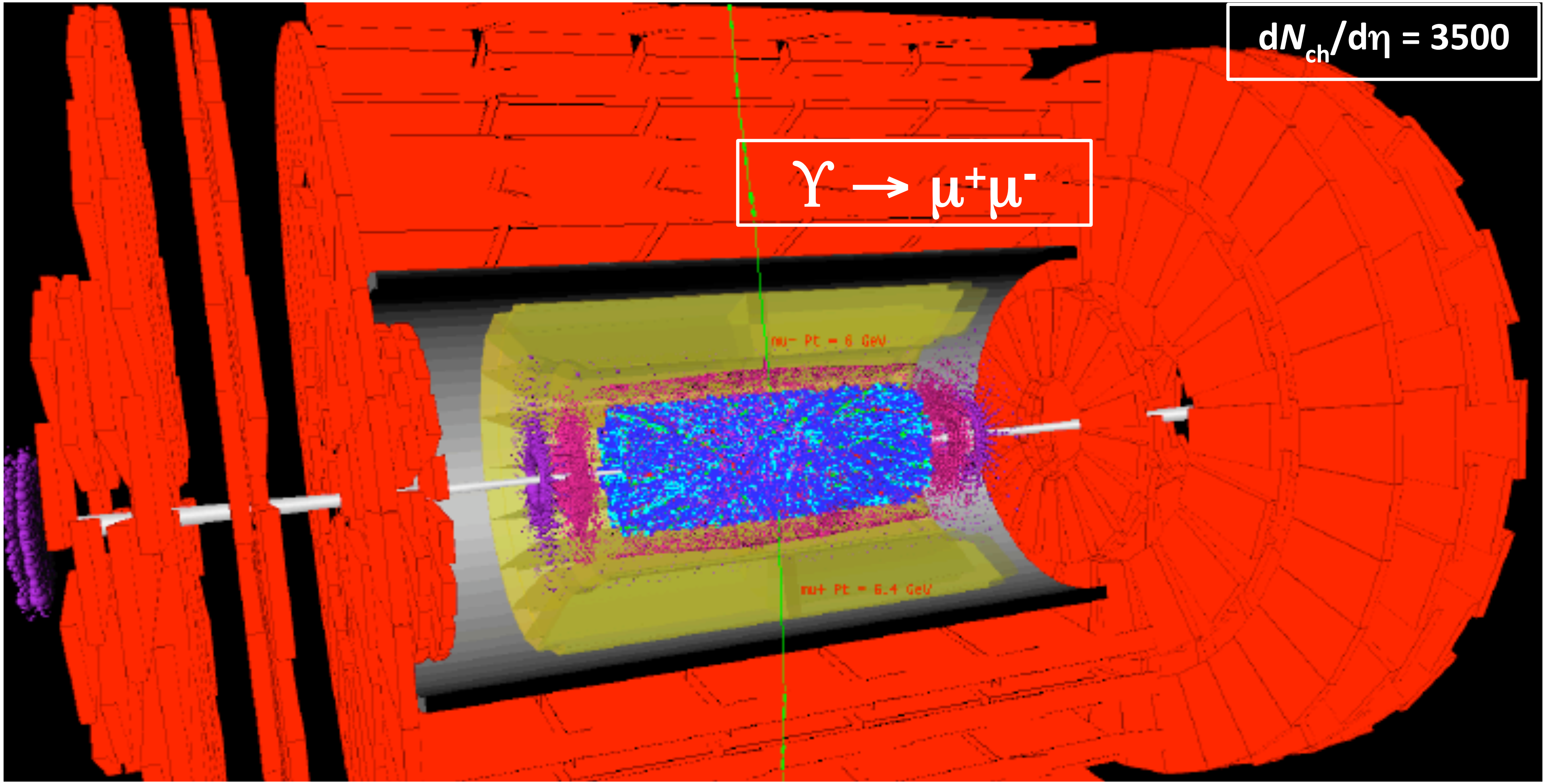


$$\ell_{xy} = \frac{L_{xy}^{J/\psi} M^{J/\psi}}{P_T^{J/\psi}}$$



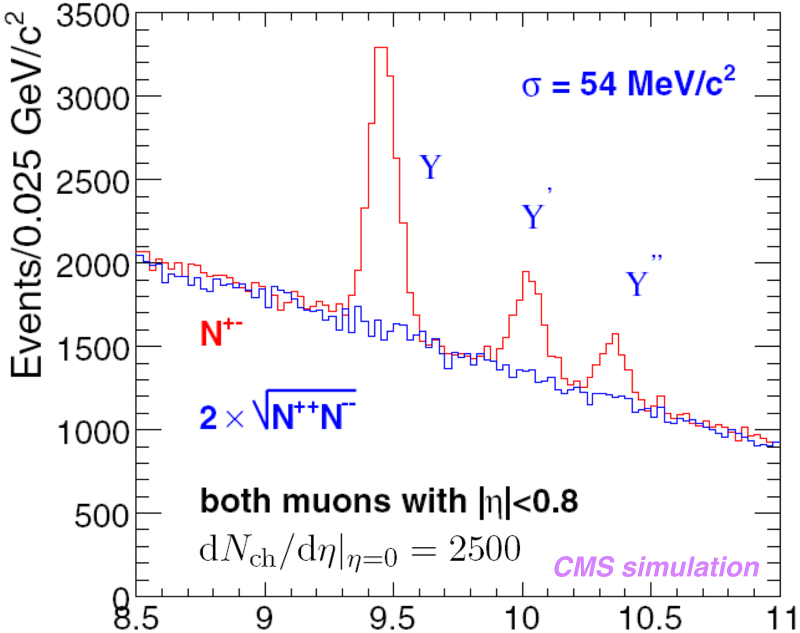
Systematic error dominated by luminosity *and polarization* uncertainties

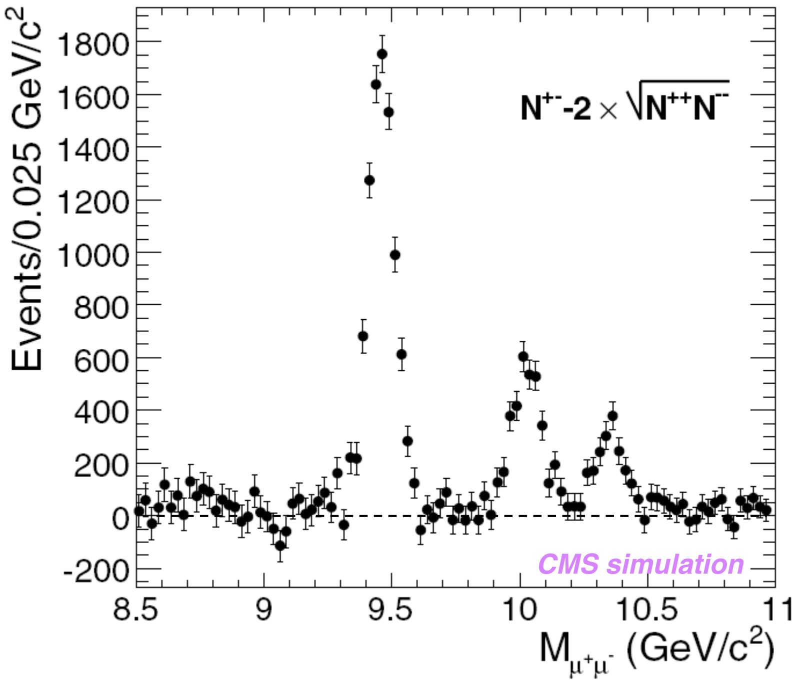
Quarkonium production in Pb-Pb collisions

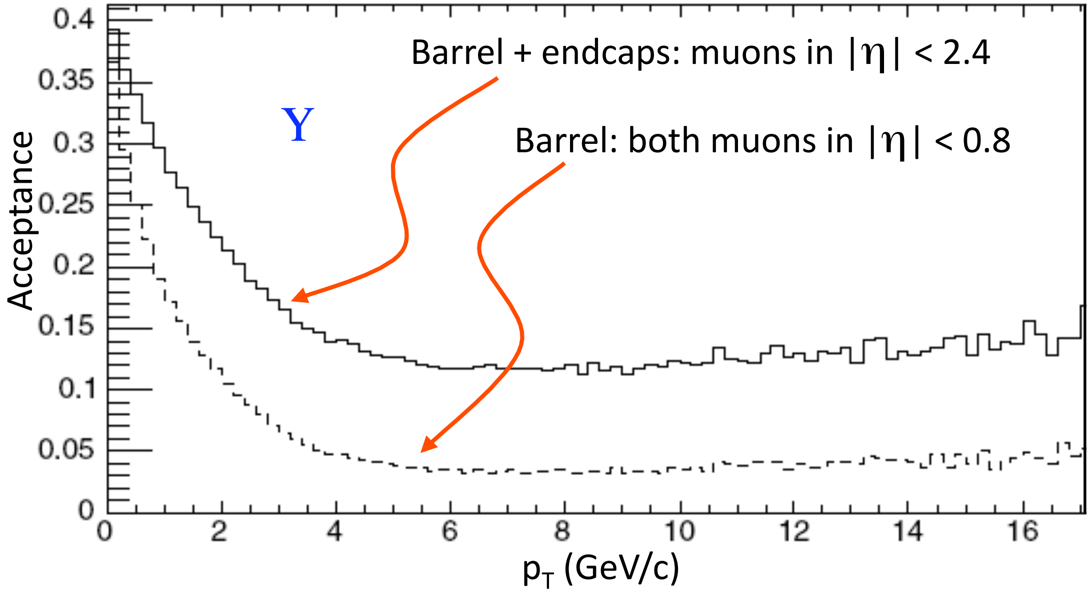


In the context of high-temperature QCD, heavy quarkonia are the best known probes of the formation of a deconfined state of quarks and gluons in heavy-ion collisions, where the $c\bar{c}$ and $b\bar{b}$ states are "dissolved" above successive medium energy density thresholds

Pb-Pb → ϒ → $\mu^+\mu^-$: acceptances and mass resolutions







CMS has a very good dimuon acceptance in the Upsilon mass region

The dimuon mass resolution allows us to separate the 1S, 2S and 3S Upsilon states:
≈ 54 MeV within the barrel and
≈ 86 MeV when including the endcaps

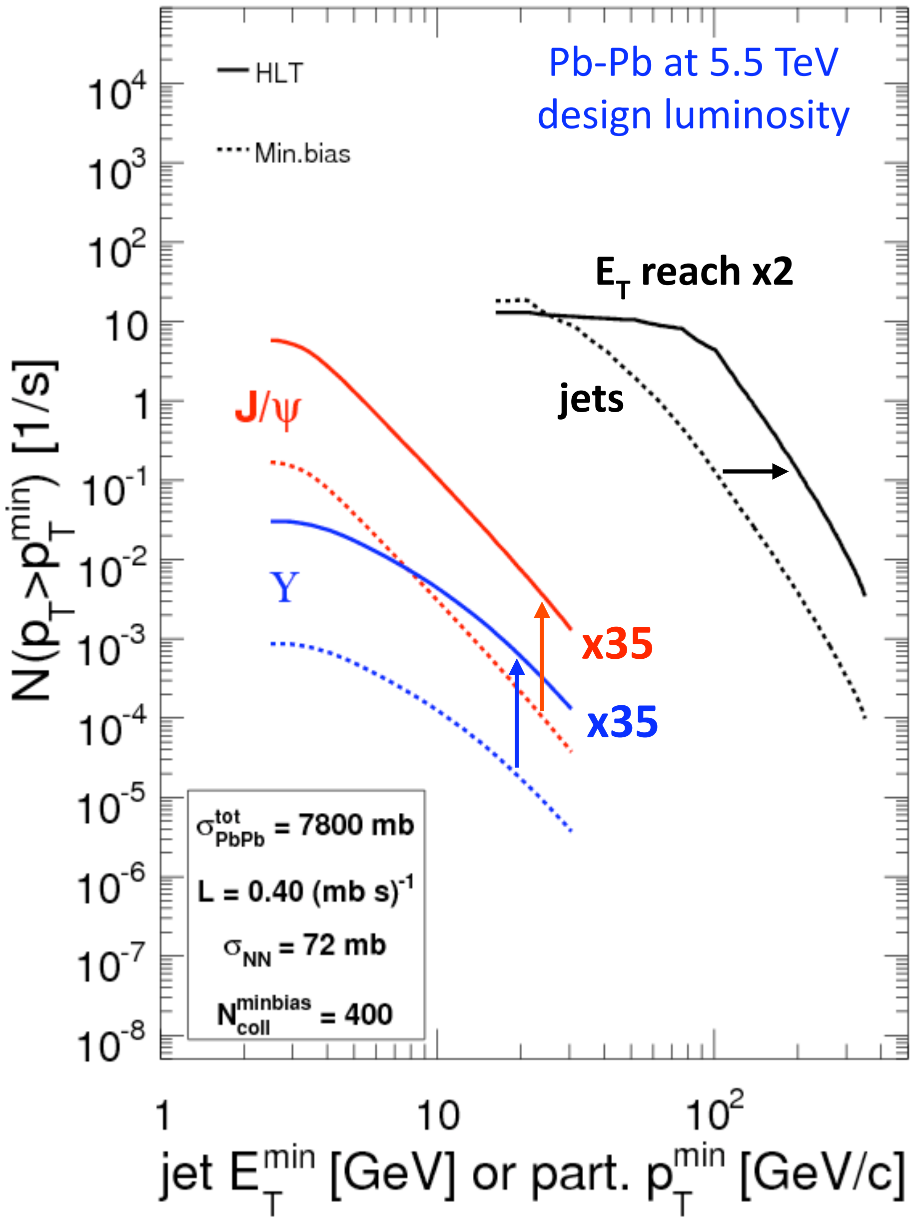
The High Level Trigger in Pb-Pb "design" operation

- CMS High Level Trigger:
  12 000 CPUs of 1.8 GHz ≈ 50 Tflops !
- Executes "offline-like" algorithms

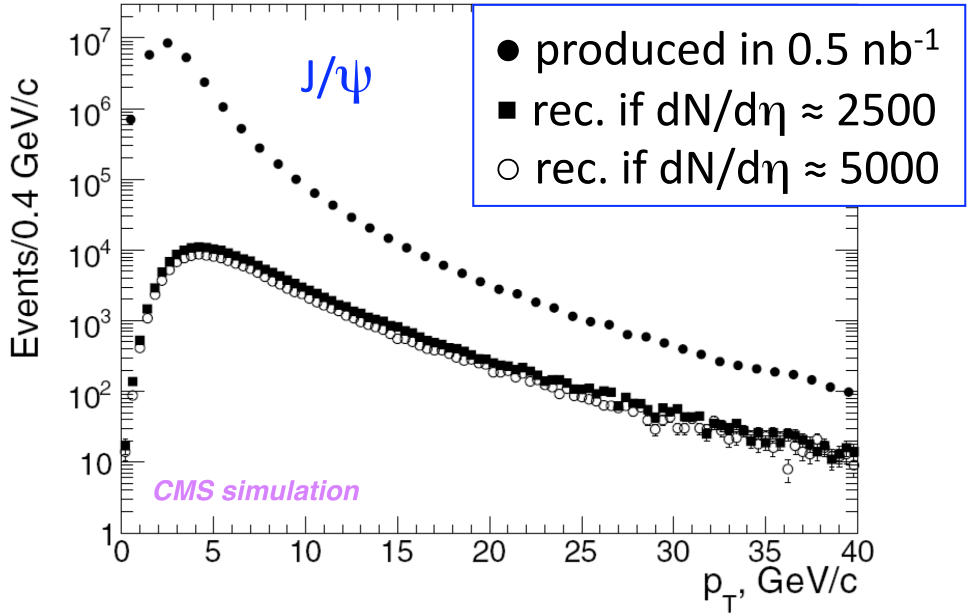
- pp design luminosity L1 trigger rate: 100 kHz
- Pb-Pb collision rate: 8 kHz (peak); 3 kHz (av.)
  ⇒ pp L1 trigger rate > Pb-Pb *collision* rate
  ⇒ run HLT filters on *all* Pb-Pb events

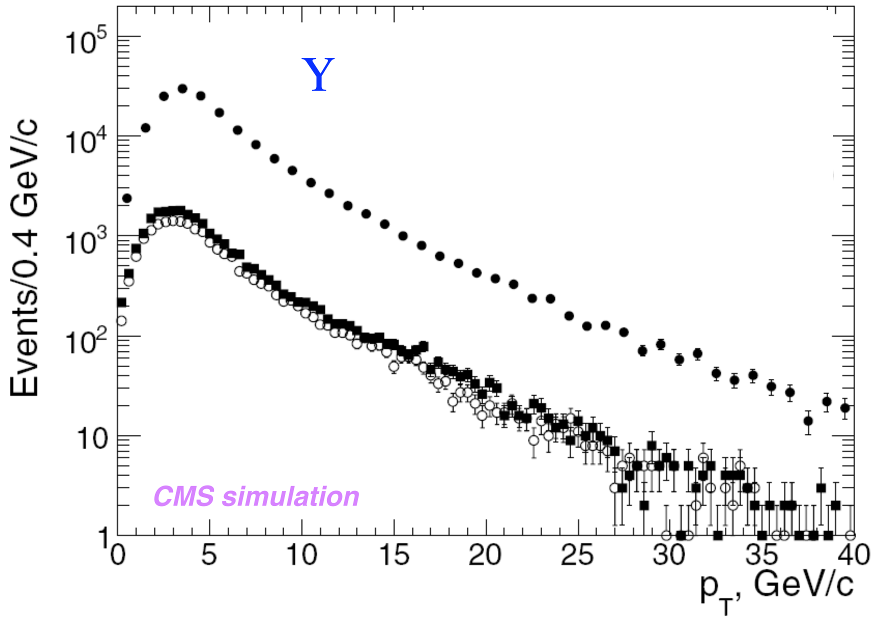
- Pb-Pb event size: ≈2.5 MB (up to ~9 MB)
- Data storage bandwidth: 225 MB/s
  ⇒ 10–100 Pb-Pb events / second
- Average HLT reduction factor: 3 kHz → 100 Hz
- Average HLT time budget per event: ≈4 s

- Thanks to the HLT, the J/ψ and Υ event samples are not affected by DAQ bandwidth limitations



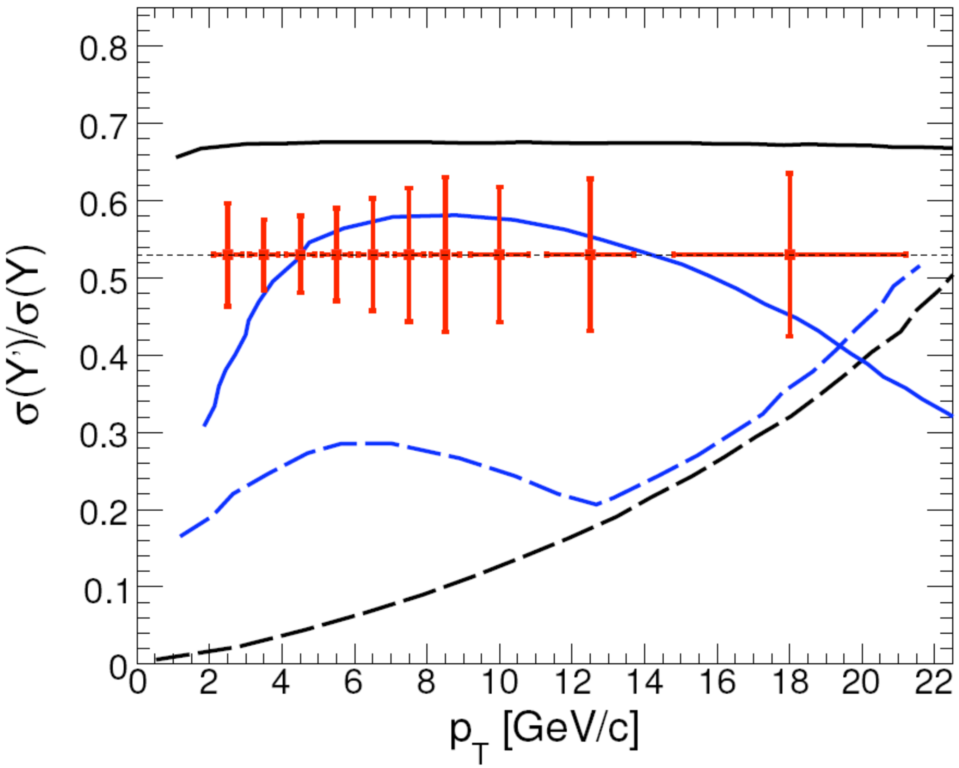
p_T reach of Pb-Pb quarkonium measurements





0.5 nb^{-1} : 1 month at $4x10^{26}$ cm^2s^{-1}
Expected rec. quarkonia yields:
J/ψ : ≈ 180 000 Υ : ≈ 26 000

Statistical accuracy (with HLT) of Υ' / Υ ratio vs. p_T should be good enough to rule out some models

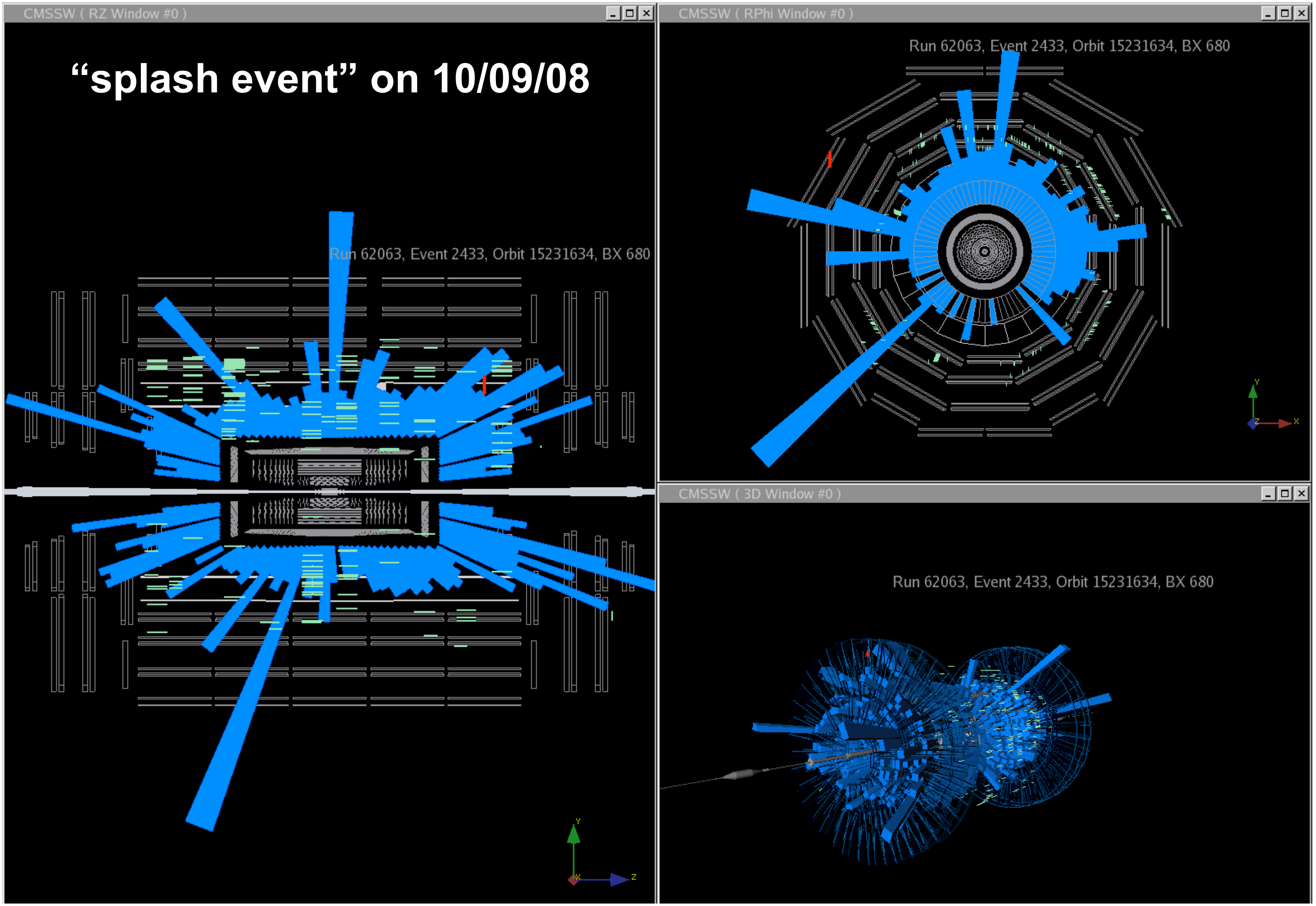


Summary

- CMS has a high granularity silicon tracker, a state-of-the-art ECAL, large muon stations, powerful DAQ and HLT systems, etc.
  - ⇒ Excellent capabilities to study quarkonium production, in pp and Pb-Pb
- Dimuon mass resolutions: ≈30 MeV for the J/ψ; ≈90 MeV for the Υ, over $|\eta| < 2.4$
  - ⇒ Good S/B and separation of $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$
- Expected pp rates: 100'000 J/ψ and 30'000 Υ after first 5 LHC weeks ($L < 10^{31}$ $cm^{-2}s^{-1}$)
  - ⇒ J/ψ and Υ dimuons up to $p_T \approx 40$ GeV/c in the first LHC onia papers
- Expected Pb-Pb rates: 180'000 J/ψ and 25'000 $\Upsilon(1S)$ per 0.5 nb^{-1} (one month)
  - ⇒ Studies of Upsilon suppression as signal of QGP formation
- CMS will also study J/ψ and Υ polarization, and $\chi_c \rightarrow J/\psi + \gamma$ production

Further information can be found in:
http://cms.cern.ch/iCMS/ ("B-physics" and "Heavy-Ions" Physics Analysis Groups)
http://www.slac.stanford.edu/spires/find/hep/www?j=JPHGB,G34,N143
http://www.slac.stanford.edu/spires/find/hep/www?j=JPHGB,G34,2307

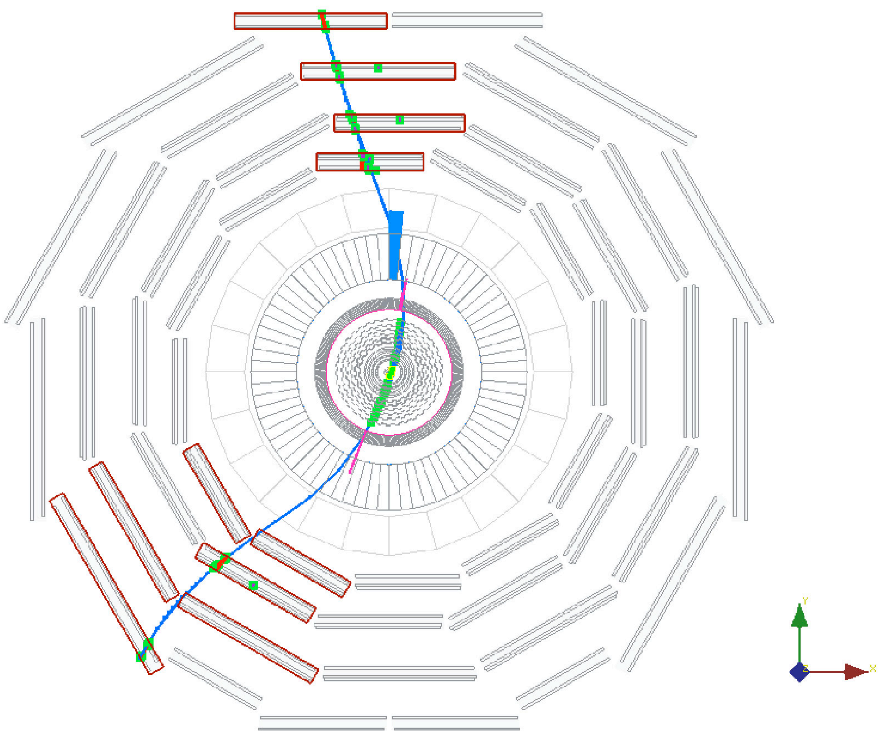
LHC proton beam in CMS



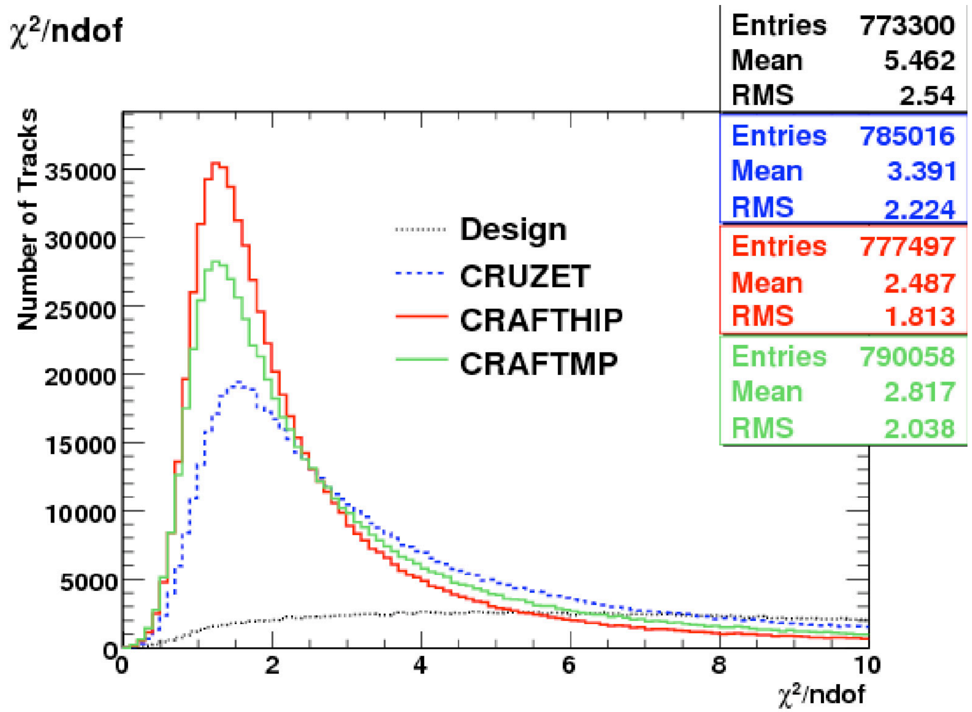
CMS sees a few hundred thousand muons produced when 10^9 protons simultaneously hit a collimator

Cosmic muons in CMS

CMS recorded around 300 million cosmic muons in one month of 24 / 7 running at full magnetic field and with all detectors operational



A cosmic muon that traversed the barrel muon systems, the barrel calorimeters, and the silicon strip and pixel trackers



Improved track quality in the strip tracker as the nominal design geometry is replaced by versions aligned with cosmic muons

See http://www.cern.ch/cms-project-cmsinfo/ for more information