Prospects of $J/\psi \rightarrow \mu^+\mu^-$ measurements in CMS

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on behalf of the CMS collaboration

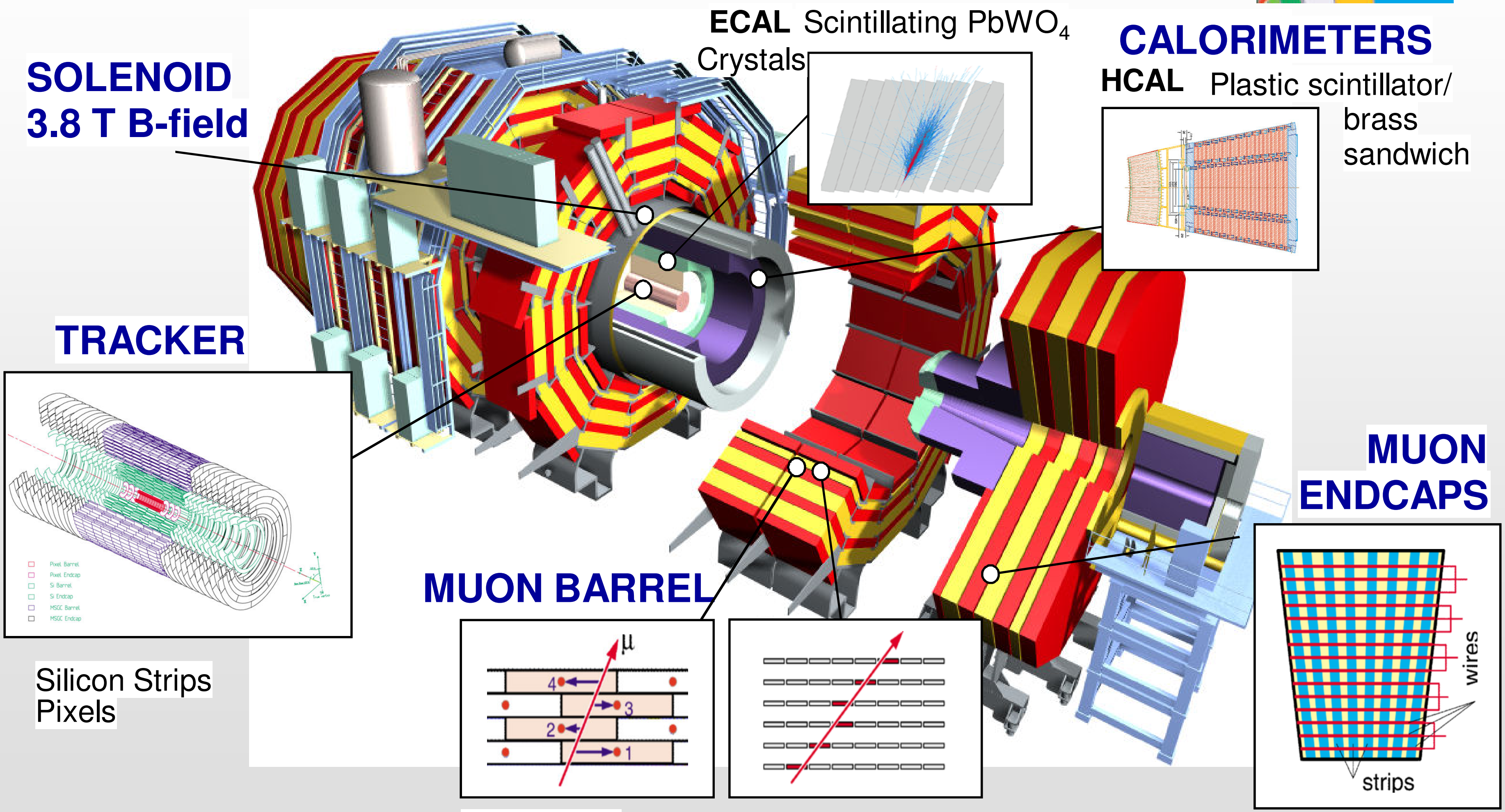
"Quarkonium production at the LHC" workshop

CERN – 19 Feb 2010

Outline

- The CMS detector
- Cross-section measurement prospects in CMS
  - 2007 MC-based analysis (14 TeV)
  - Results for yields and non-prompt J/ψ fraction
- Analysis improvements:
  - Muon reconstruction and selection
  - Triggers for low luminosity
- Perspectives in first data:
  - 2009 MC-based analysis (0.9 and 2.36 TeV)
  - Search in December '09 data
  - Other possible analyses
- Conclusions

The CMS detector



The J/ψ x-section formula

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

- $N^{fit}_{J/\psi}$ = $(1 - f_B) N_{J/\psi}^{tot}$ (prompt) or $f_B N_{J/\psi}^{tot}$ (non-prompt) *
- $\int Ldt$ = integrated luminosity
- A = signal acceptance/efficiency (from MC modeling) *
- $\lambda^{corr}_{trigger} \cdot \lambda^{corr}_{reco}$ = trigger/reconstruction efficiency MC/data correction (to be determined with "tag-and-probe" method) *
- Δp_T = p_T bin size *

Differential x-section in rapidity can be considered, depending on available statistics ← separation of barrel/endcap implies simpler mass description (see next slides)

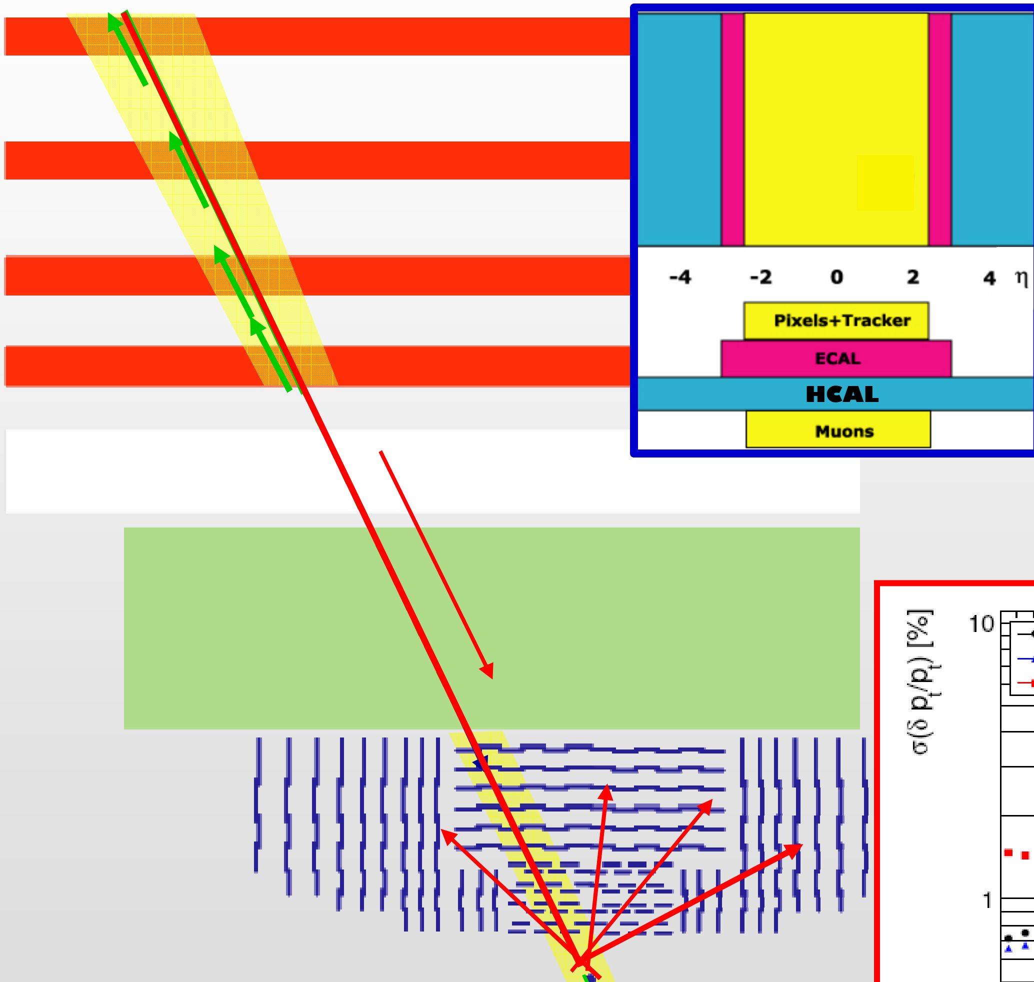
* = function of p_T

MC event generation

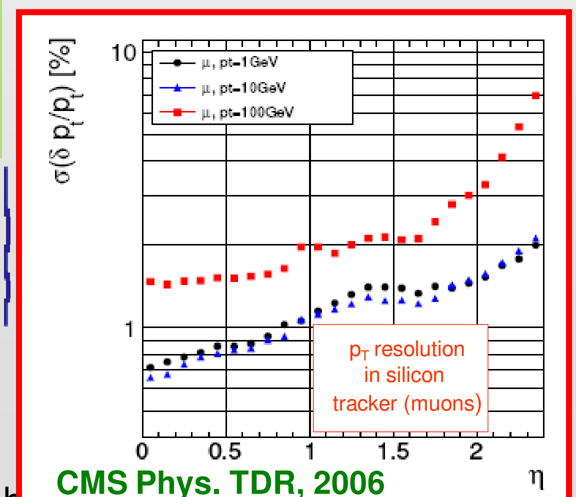
- Signal ($p_T^\mu > 2.5$ GeV/*c*, $|\eta^\mu| < 2.4$)
  - Prompt J/ψ → PYTHIA6
    - Color Singlet + Color Octet model
    - COM non-perturbative factors $<O_n(^{2S+1}L_J)>$ fitted from CDF results
    - Cross-section reweighting with p_{T0}^2 cut-off
    - Fragmentation parameters set to obtain "high" soft-gluon radiation (details in Aafke's talk)
    - uniform polarization
  - Non-prompt J/ψ → PYTHIA6 (no EvtGen!)
- Background ($p_T^\mu > 2.5$ GeV/*c*, $|\eta^\mu| < 2.4$)
  - Muon-enriched QCD events → PYTHIA6

    Main sources of background from MC-truth information:
    - D and B meson decays
    - Decay in flight of π and K
    - Hadron punch-through

Muon reconstruction in CMS



- Large rapidity coverage:
  - $|\eta| < 2.4$
- Excellent muon momentum resolution:
  - matching between μ-chambers and in the silicon tracker (only using the latter for momentum determination at low p_T)
  - strong solenoidal magnetic field (3.8 T)
  - Because of the increasing material thickness traversed and the different lever arm, the resolution changes with pseudo-rapidity



J/ψ yields ($N_{J/\psi}^{tot}$)

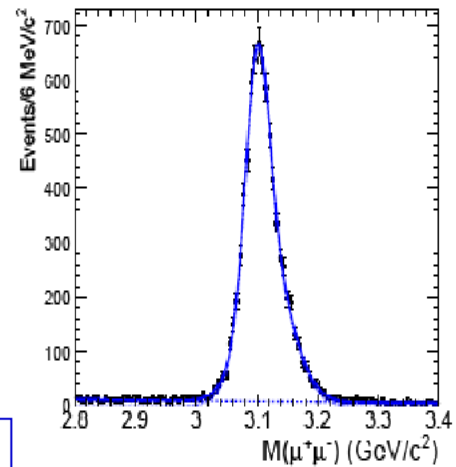
$p_T^{J/\psi}$ bin GeV/c	Yield N_{sig}
5-6	2591±52
6-7	11098±109
7-8	17565±137
8-9	20007±147
9-10	18856±141
10-11	16601±132
11-12	13685±119
12-13	10669±106
13-14	8304±93
14-15	6513±82
15-17	8923±96
17-20	7420±88
20-24	4480±68
24-30	2617±52
30-40	1287±36

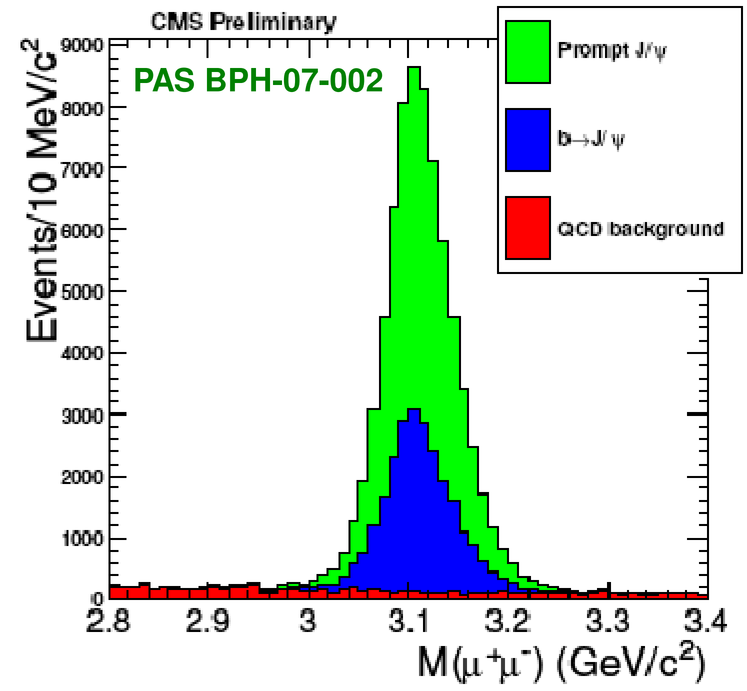
Total	**150 600 ± 380**

Double-muon trigger with $p_T > 3$ GeV/c

3 pb^{-1} integrated luminosity (14 TeV)

Resolution (barrel)
σ ~ 20 MeV/c^2
Resolution (endcap)
σ ~ 37 MeV/c^2





- 2-Gaussian shape due to non optimal muon momentum scale in endcaps → now fixed in MC
- Momentum scale must then be extracted from data

B-fraction (f_B)

- Using a 2D-fit to invariant mass and proper decay length distributions:
  - Proper decay length calculated from decay length in the lab frame
  - Secondary vertex from a Kalman vertex fit to the two muon tracks

$$\ell^{J/\psi} \equiv \frac{L_{xy}^{J/\psi} \cdot M_{J/\psi}}{p_T^{J/\psi}}$$

- For prompt events, expected to be a simple δ-function
- For non-prompt events, it has an exponential shape with λ_B^{eff} [but smearing effects must be considered since in this case we are using the "pseudo"-proper decay length, i.e. $(M/p_T)_{J/\psi}$ instead of $(M/p_T)_B$]
- For background events a generic superposition of different contributions (symmetric + asymmetric with effective lifetimes) is adopted

} Convoluted with 2-Gauss resolution

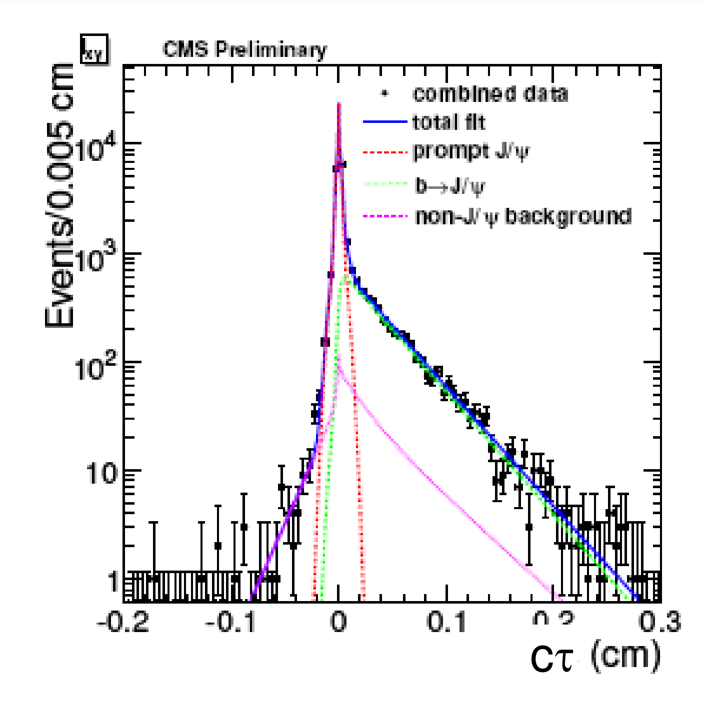
B-fraction (f_B)

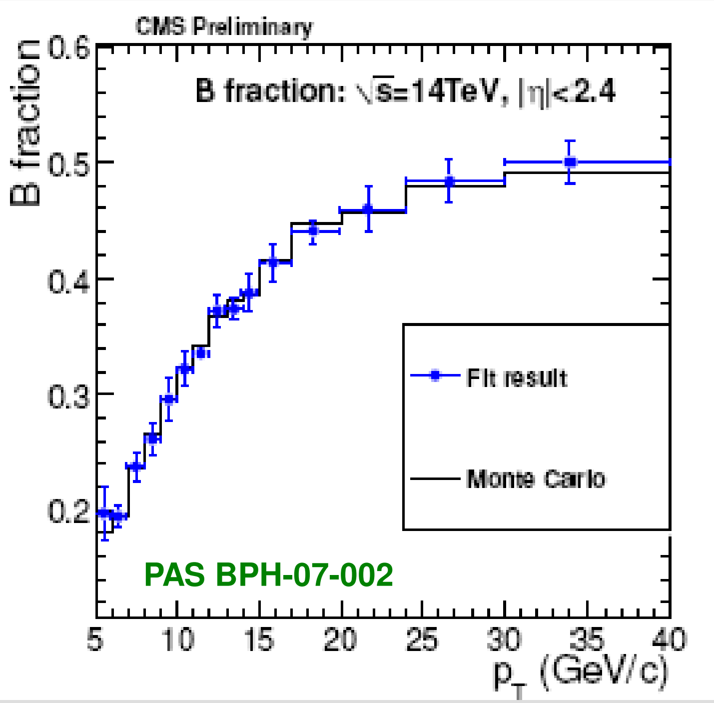
- From 14 TeV result (2007):
  - global-global combinations only
  - 3 pb^{-1} equivalent luminosity
  - 15 bins: 5 < p_T < 40 GeV/*c*
  - 1 bin: |η| < 2.4

NO BIAS OBSERVED FROM FITTING TECHNIQUE

$\sigma_{stat}(N_{J/\psi}^{prompt})$ = 1.8% - 5%

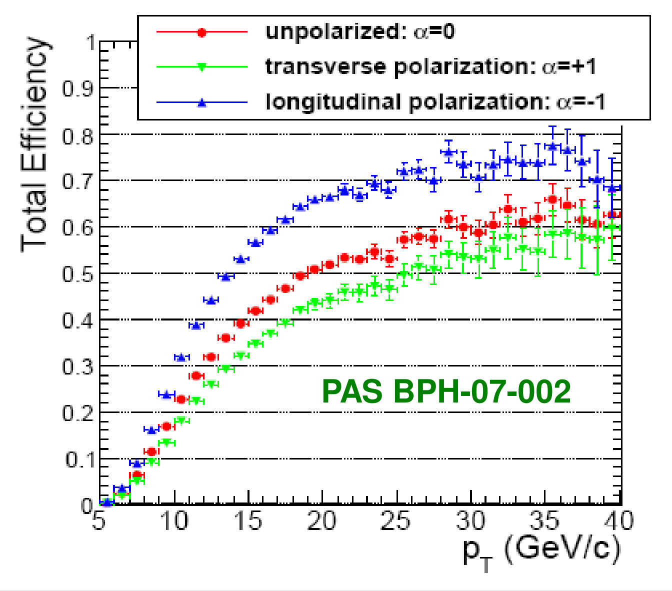
$\sigma_{stat}(N_{J/\psi}^{non\text{-}prompt})$ = 2% - 10%





Acceptance calculation (A)

- Geometrical acceptance and reconstruction efficiency for the signal is first estimated from MonteCarlo
- Main contribution to systematics expected from unknown J/ψ spin alignment
  - In the 2007 work, estimated using differences in acceptance between the unpolarized case and the extreme polarization values in the helicity frame (all longitudinal, all transverse)
  - A more reliable procedure was outlined recently considering both helicity and Collins-Soper frames (details in Pietro's talk)



Efficiency corrections (λ)

- MC efficiency is used in the 2007 analysis ($\lambda = 1$)
- "Tag-and-probe" method:
  - Given a cleanly identified ("tag") muon, estimate number of other muons satisfying or not certain steps of reconstruction ("probes") from a fit to the J/ψ mass vs. p_T, η of the muon ← selection independent
  - Reconstruction:
    - Tag: reconstructed muon with $p_T > 3$ GeV/*c*

$$\varepsilon_{trk} = N_{trk+\mu C} / N_{\mu C}$$

← Limited by muon resolution in μ-chambers and biased

$$\varepsilon_{\mu-ID} = N_{trk+\mu C} / N_{trk}$$

← Well established

  - Trigger:
    - Tag: reconstructed muon matched to a trigger object

$$\varepsilon_{trig} = N_{global-\mu+trig} / N_{global-\mu}$$

- Limitations of the method:
  - Fit precision
  - Correlation between muons (e.g. small ΔR)

Systematic uncertainties

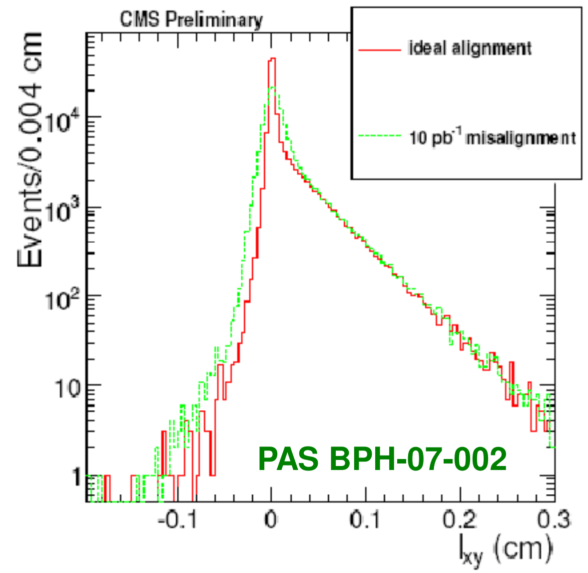
Parameter affected	Source	$\Delta\sigma/\sigma$
Luminosity	Luminosity	$\sim$ 10 %
Number of J/ψ	J/ψ mass fit	1.0 - 6.3 %
Number of J/ψ	Momentum scale	$\sim$ 1 %
Total efficiency	J/ψ polarization	1.8 - 7.0%
Total efficiency	J/ψ p_T binning	0.1 - 10 %
Total efficiency	MC statistics	0.5 - 1.7 %
$\lambda_{reconstruction}$	Non-perfect detector simulation	$\sim$ 5 %
$\lambda_{trigger}$	Non-perfect detector simulation	$\sim$ 5 %
B fraction	ℓ_{xy} resolution model	0. - 1.9 %
B fraction	B-hadron lifetime model	0.01 - 0.05 %
B fraction	Background	0.1 - 3.0 %
B fraction	Misalignment	0.7 - 3.5 %
Total systematic uncertainty 13-19 %		

Effects of misalignment on:

- Lifetime

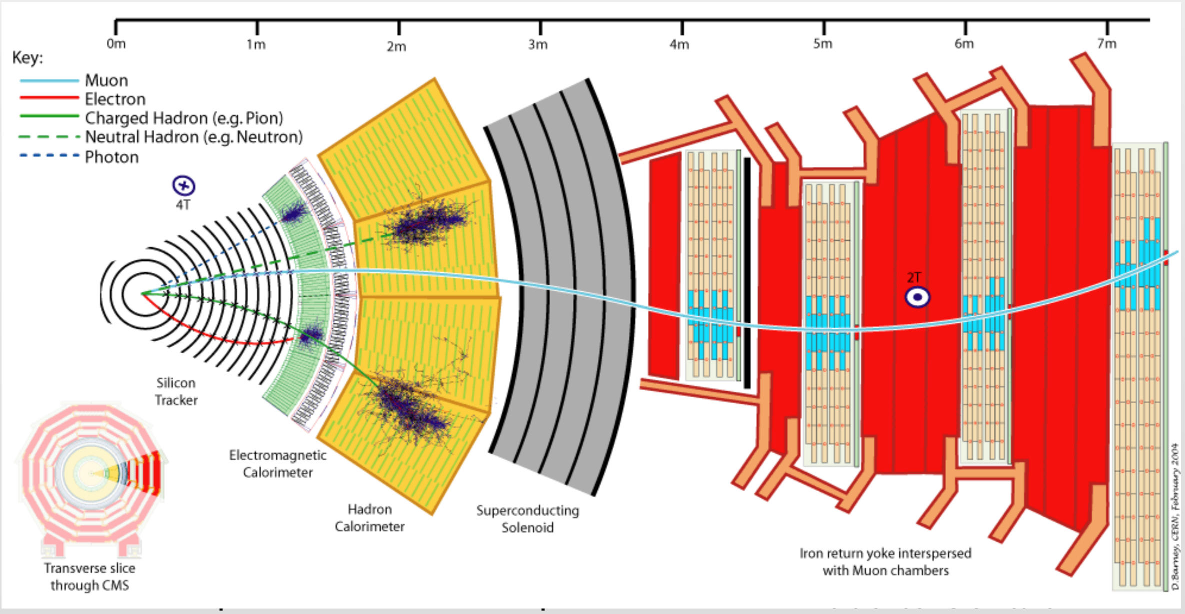
- Invariant mass

	10 pb^{-1}	100 pb^{-1}	ideal
J/ψ mass resolution (MeV/c^2)	34.2	30.5	29.5



Improvements since 2007 (1)

- MC Generators:
  - EvtGen / PHOTOS have now been introduced in CMS and used to simulate properly B → J/ψ X decays / generate FSR
- Muon trigger and reconstruction:
  - A reconstructed muon ("global" muon) in CMS is defined as a μ-chamber "seed", then matched to a track in the tracking devices:



- In order to compute a rough momentum estimate and thus fire the Level-1 trigger, hits must be in at least two stations
- Curvature due to the *B*-field and material crossed limit the p_T acceptance

Improvements since 2007 (2)

- The idea of "tracker muons":
  - Perform the reconstruction inside-out, starting from a silicon track and searching for any possible compatible muon signal in the chambers (even in one station)
  - Tight selections on track-segment matching are required to keep hadron background under control
    - Calorimeters can be also exploited to check compatibility with MIP energy deposits
  - Efficiency is enhanced by a large factor, especially at low p_T
- Problem:
  - This procedure cannot be done at trigger level due to processing-time limitations

but…

Improvements since 2007 (3)

- … trigger strategies can evolve/ be optimized to LHC luminosity
  - Write on tape all minimum-bias triggers (maximum advantage from all types of muons) — $<\sim 10^{28}\ \mathrm{cm^{-2}s^{-1}}$
  - Use single-muon triggers — 10^{29}-$10^{30}\ \mathrm{cm^{-2}s^{-1}}$
  - Use ad-hoc intermediate solutions: — $10^{31}\ \mathrm{cm^{-2}s^{-1}}$
    - Example 1: combining a single-muon trigger with other information, profiting from the CMS High-Level Trigger versatility
  - Use only double-muon triggers (2007 analysis, almost no benefit from tracker muons) — $>\sim 10^{32}\ \mathrm{cm^{-2}s^{-1}}$

MC analysis at 0.9-2.36 TeV

- Event selection:
  - All tracks:
    - N_{hits} (pixels + strips) > 12
    - $|d_0| < 5$ cm, $|d_z| < 20$ cm
  - "Global" muons: normalized global $\chi^2 < 20$
  - "Tracker" muons:
    - normalized track $\chi^2 < 5$
    - tight angular compatibility between track and muon segment directions
  - Probability of the di-muon vertex > 0.001

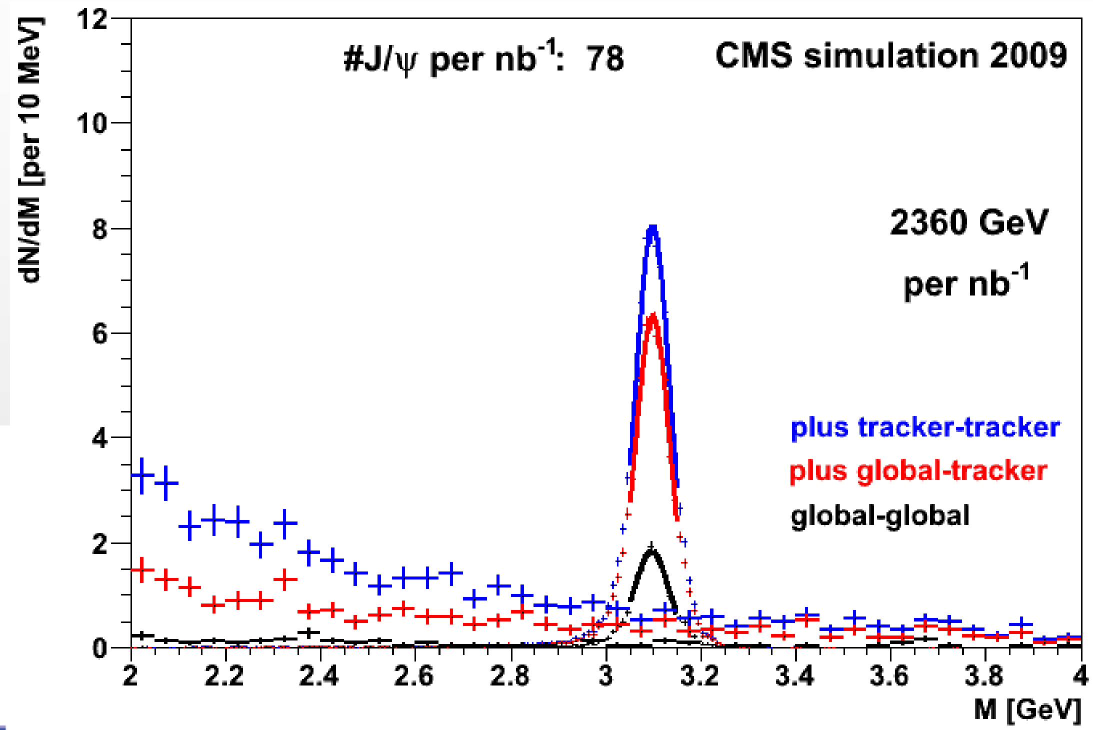
- Here neglecting contributions of $B \to J/\psi X$ decays, expected to be < 10% in total

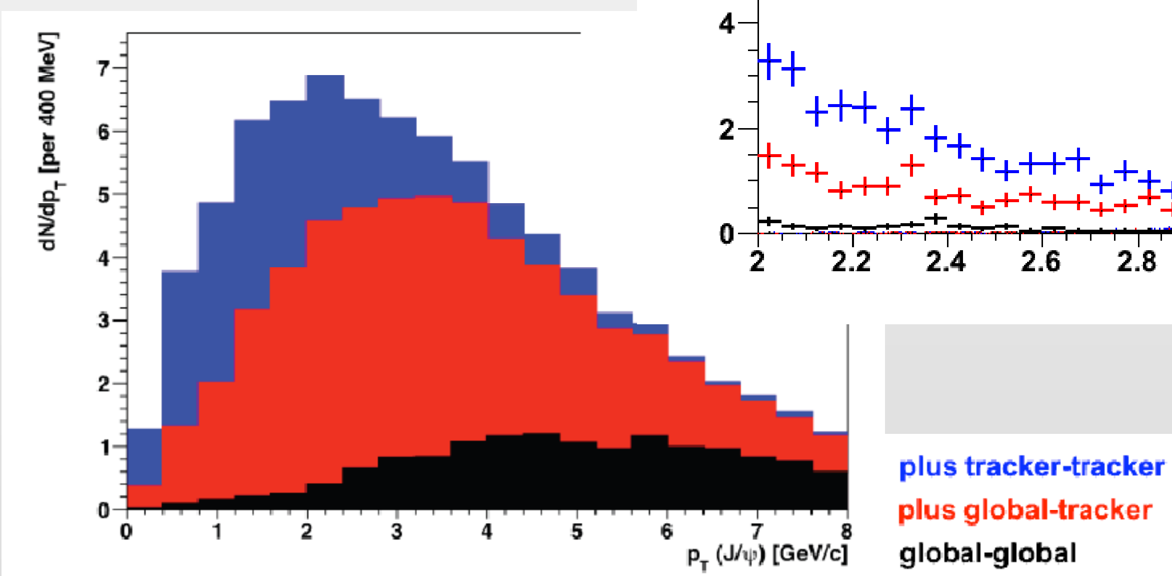
in the mass window 3.0-3.2 GeV, per nb^{-1}

	900 GeV		2.36 TeV	
	prompt J/ψ	background	prompt J/ψ	background
global - global	5.6 ± 0.1	0.3 ± 0.2	17.6 ± 0.3	1.3 ± 0.5
global - tracker	19.1 ± 0.2	1.5 ± 0.5	43.7 ± 0.4	6.4 ± 1.1
tracker - tracker	8.3 ± 0.1	1.3 ± 0.4	16.3 ± 0.2	4.8 ± 0.9

MC results at 0.9-2.36 TeV

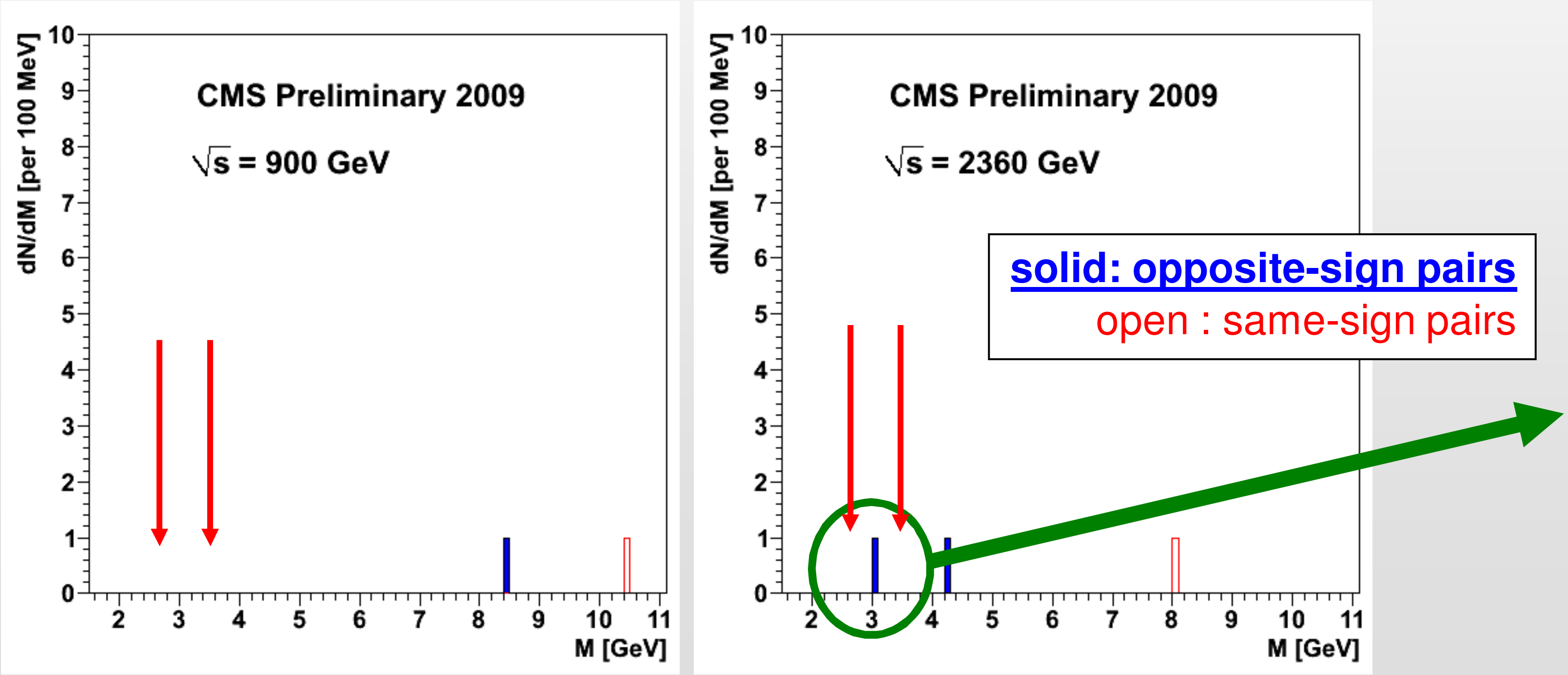
- Using simulation of CMS as close as possible to the expected initial detector conditions



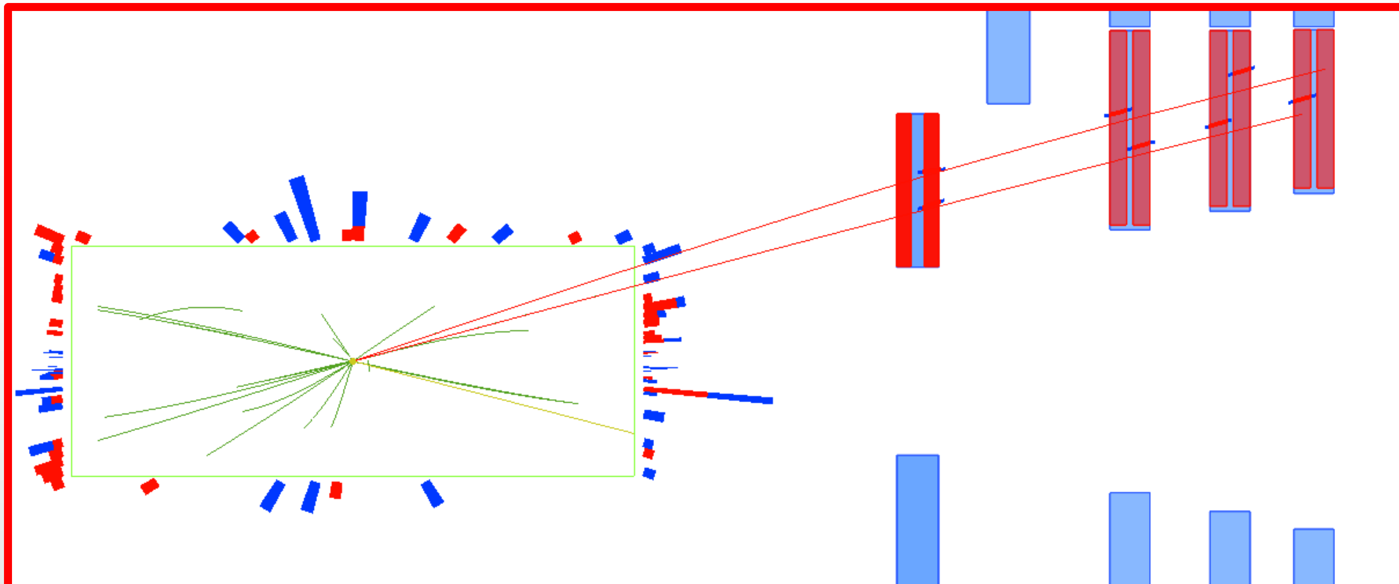


Search for J/ψ in data

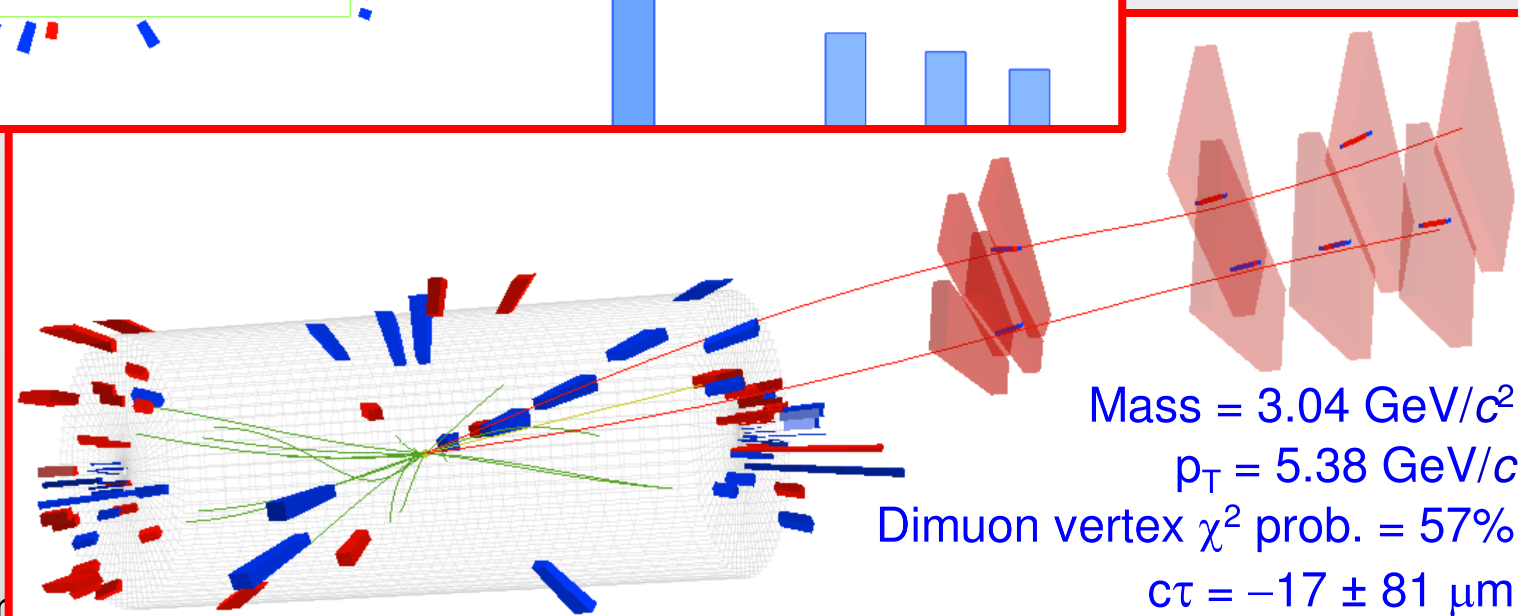
- Minimum-bias events triggered using coincidence of beam scintillators (approximate collected luminosity: 10 μb^{-1} at 900 GeV, 400 mb^{-1} at 2.36 TeV)
- "Good" collision events selected based on generic criteria (tracker/muons in the data-taking, presence of at least a reconstructed primary vertex … etc.), then analysis requirements are applied



The "J/ψ" event display



Run 124120
Event 5686693



Other on-going studies

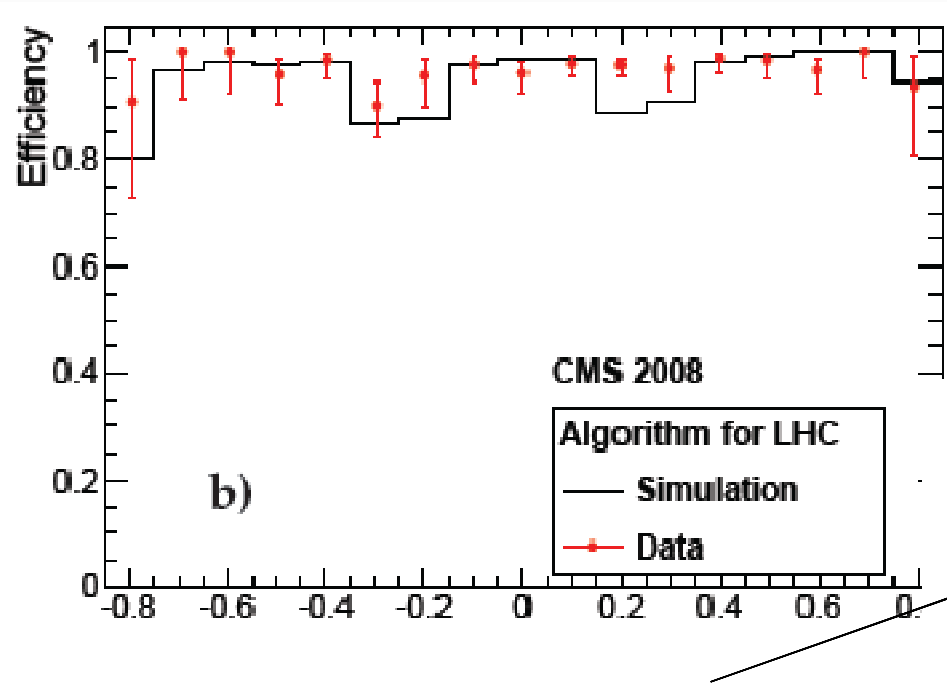
- Wide physics program for quarkonia in CMS:
  - Production cross-section measurement (J/ψ and Υ's)
    - The expected Υ-peak resolution of ~90 MeV/c^2 allows to separate the three states, at least in the muon barrel
  - Spin alignment measurement (J/ψ and Υ's)
    - Depending crucially on detector acceptance: detailed studies ongoing
  - P-wave state (χ_c, χ_b) radiative decays
    - Very useful to extract direct J/ψ / Υ production, but depending on the performance of identifying low-energy photons in data
  - Quarkonia in di-electron channel
    - Depending on the performance of triggering/identifying low-pT electrons in data (huge amount of *bremsstrahlung* in the tracker material): probably adding not so much to the di-muon yields

Conclusions

- Perspectives of $J/\psi \rightarrow \mu^+\mu^-$ measurements with the CMS detector have been presented
- The cross-section measurement prospects have been investigated:
  - with the old nominal LHC energy / luminosity / trigger strategy
  - using 15 p_T bins between 5 and 40 GeV/*c* and the full rapidity range
  - Effective separation of prompt and non-prompt contribution using proper decay length distributions
  - Total uncertainties vary with the p_T bin and are of the order of 5% statistical and 15% systematic with an integrated luminosity of 3 pb^{-1}
- Current analysis of MC and data has large benefits from improvements on muon reconstruction and relaxed trigger criteria, both in terms of yields and lower p_T reach
  - Clean "observation" possible with only 1 nb^{-1} of data
  - One suitable candidate already found in December LHC data

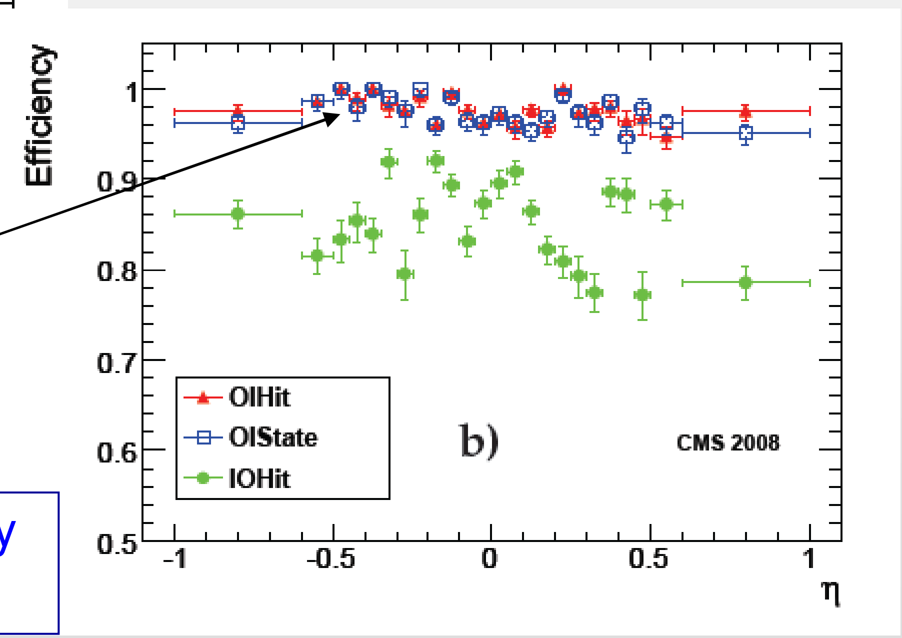
Backup slides

CRAFT results



Reconstruction efficiency
Cosmic data vs. simulation

Currently used in CMS



HLT efficiency
Cosmic data

14 TeV vs. 7 TeV cross-sections

Cross-section x BR	Prompt J/ψ → μμ	QCD
14 TeV	21.0 μb	54.71 mb
10 TeV	15.6 μb	51.60 mb
7 TeV	12.6 μb	48.44 mb