Prospettive per misure di QCD con i primi dati di CMS

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per la collaborazione CMS

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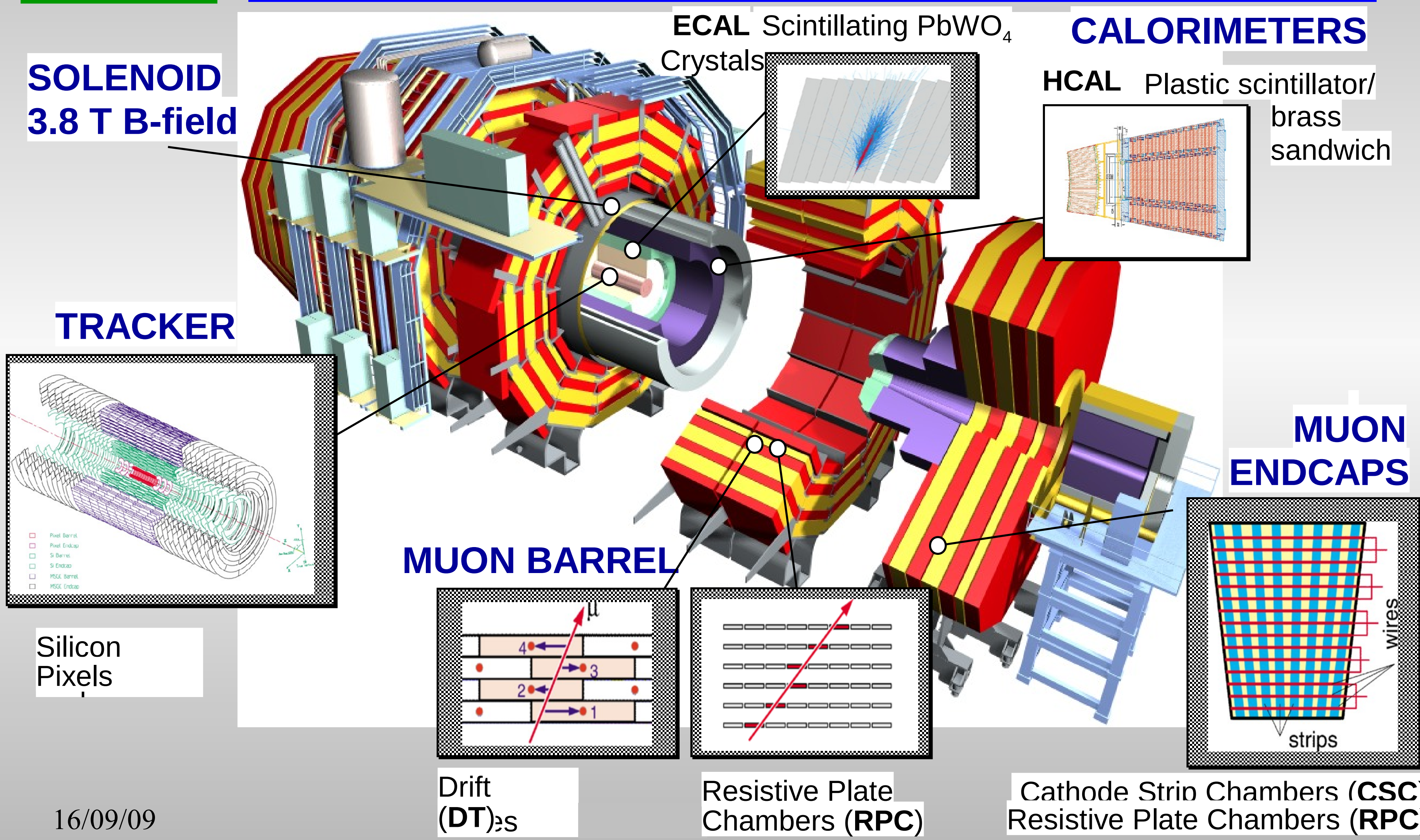
Outline and references

- The talk will be mainly based on 2007-2009 Physics Analysis Summaries available on the CMS server (https://twiki.cern.ch/twiki/bin/view/CMS/PhysicsResults):
  - Charged hadron spectra with pixel “tracklets” (PAS-QCD-09-002)
  - Charged hadron spectra with full tracking (PAS-QCD-07-001)
  - Study of underlying event (PAS-QCD-07-003)
  - Measurement of prompt and non-prompt $J/\psi \rightarrow \mu\mu$ cross-section (PAS-BPH-07-002)

plus some news on recent additions and developments of the analyses

The CMS detector



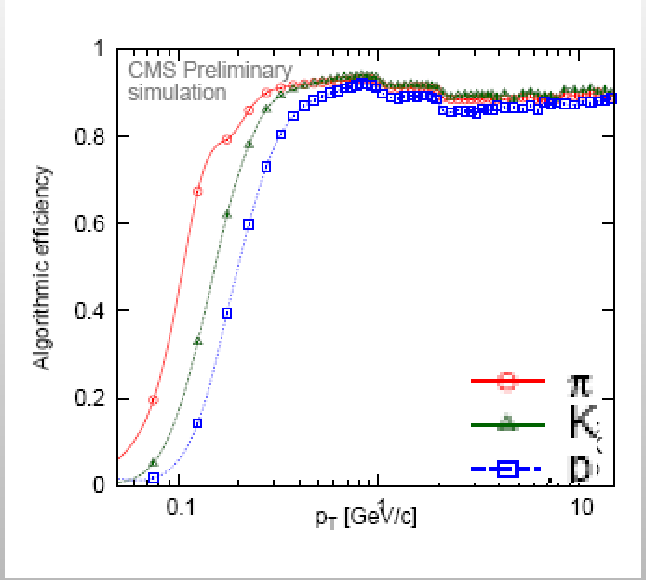
CMS and the LHC schedule

- CMS: a detector optimized for high-p_T physics (Higgs, top, SUSY, high-mass vector bosons… etc.)
- New LHC schedule, both in terms of energy and instantaneous luminosity, increased interest in exploring also low-p_T CMS capabilities

Production cross-section	$\sqrt{s}$ = 14 TeV	$\sqrt{s}$ = 10 TeV	$\sqrt{s}$ = 7 TeV
Total inelastic	55 mb	51 mb	48 mb
Prompt J/ψ (COM)	320 μb	260 μb	210 μb
$b\bar{b}$ (NLO)	480 μb	340 μb	230 μb
$W \rightarrow l\nu$	53 nb	35 nb	23 nb
$t\bar{t}$	550 pb	250 pb	90 pb
$gg \rightarrow H^0$ (NLO, m_H = 200 GeV)	14 pb	8 pb	1.5 pb

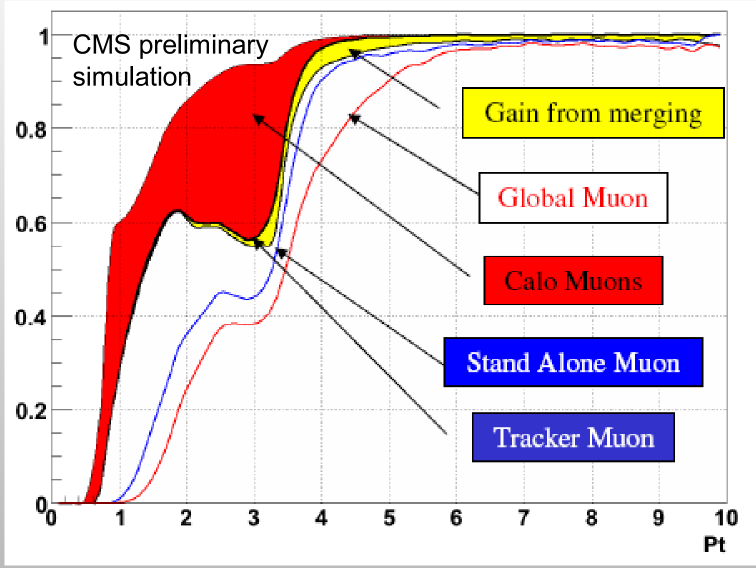
Low p_T: MB and tracking

- <u>Trigger:</u> Two start-up High-Level Trigger (HLT) menus have been defined → "8e29" and "1e31", according to the instantaneous luminosities where they are expected to be effective:
  - Zero-bias trigger
  - Minimum-bias triggers (tuned by just changing pre-scale factors):
    - minimal activity in the EM or hadronic calorimeter
    - 2 short tracks above a given p_T threshold in the pixel detector
- <u>Reconstructed tracks</u>: Standard tracking down to 900 MeV/*c*. For QCD analyses pushed to lower values → keeping fake rates to o(%) needs:
  - Use of pixel hit triplets only for seeding
  - Cluster shape and measured width-trajectory compatibility requirements
  - Primary vertex finding and re-fit of tracks using determined vertex(es) → d_0, d_z cuts



Low p_T: muons

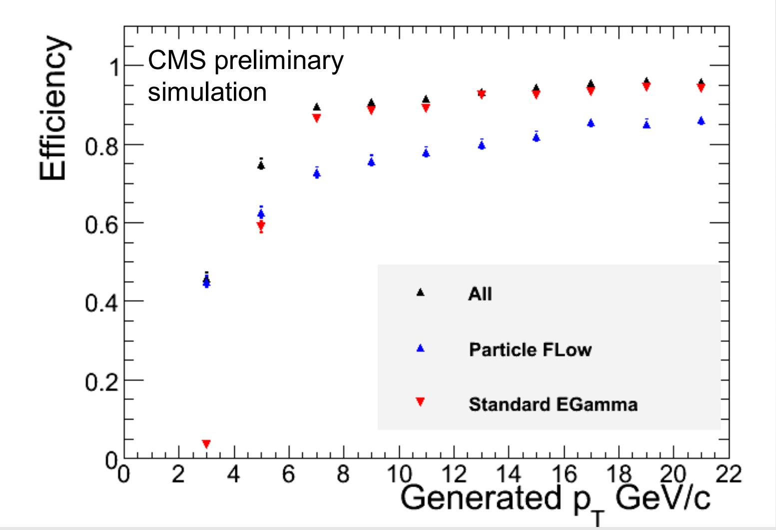
- Triggers:
  - 8e29: HLT_Mu3 and HLT_DoubleMu0, all others have 100% overlap
  - 1e31: HLT_Mu5 (prescale: 20), HLT_Mu9 (unprescaled) and HLT_DoubleMu3 (unprescaled): not completely overlapping
- Reconstructed muons: besides the standard "global muons" (seeded by multiple signals in the muon chambers) two more categories used to recover the efficiency loss at low p_T:



  - "Tracker muons" (one segment in μC)
  - "Calo muons" (only requiring minimum calorimeter compatibility)
- Up to 6 di-muon "categories", 3 of which can be efficiently selected online (HLT requires Level-1 seeding from the μC, so at least one of the muons has high probability to be global)

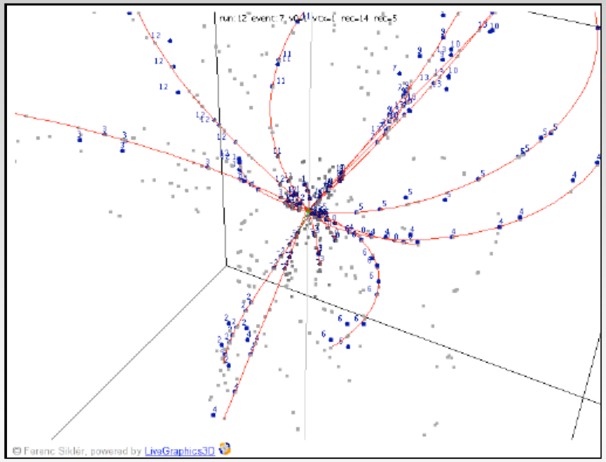
Low p_T: electrons

- Reconstructed electrons: Standard reconstruction (starting from "super-clusters" in the EM calorimeter) not effective below 4 GeV.
  - Particle flow electrons are seeded by short tracks in the first layers of the tracker, then follow and recover bremsstrahlung emission along the tangent up to ECAL → significant improvement in low-pT efficiency



- Triggers:
  - Work on-going: not trivial
  - HLT timing requirements make tracker seeding difficult
  - Super-cluster reconstruction criteria can be loosened, but other trigger requirements being studied to control background rate and timing

$h^{\pm}$ spectra: techniques in CMS



ADVANTAGES / DISADVANTAGES

Main contributions:
- “loopers”
- secondary beam particle interactions
- V^0’s

Low p_T reach	Dependence on silicon response simulation	Dependence on tracker alignment	Background characterization

1) HIT COUNTING

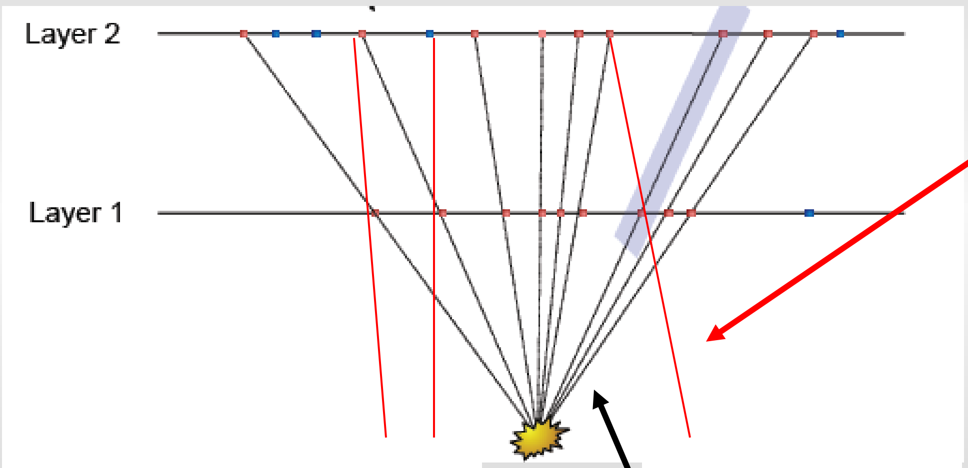
1) PIXEL “TRACKLETS”

2) FULL TRACKS

I will show in detail methods 2) and 3)

$h^{\pm}$ spectra: "tracklets" (1)

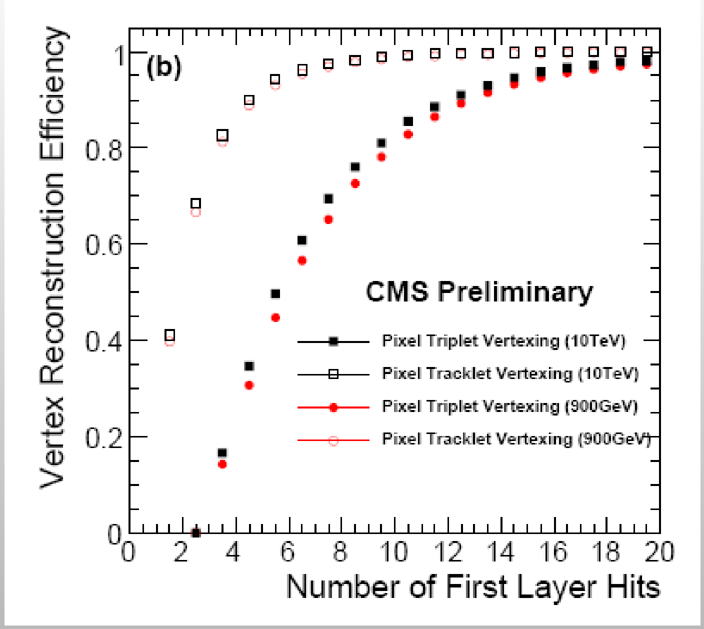
- Based on reconstruction of hit pairs in the 2 innermost pixel layers ($p_T > 60$ MeV/c) and constraint to primary vertex



1) Build combinations of hit pairs and extrapolate to compute z of candidate vertex

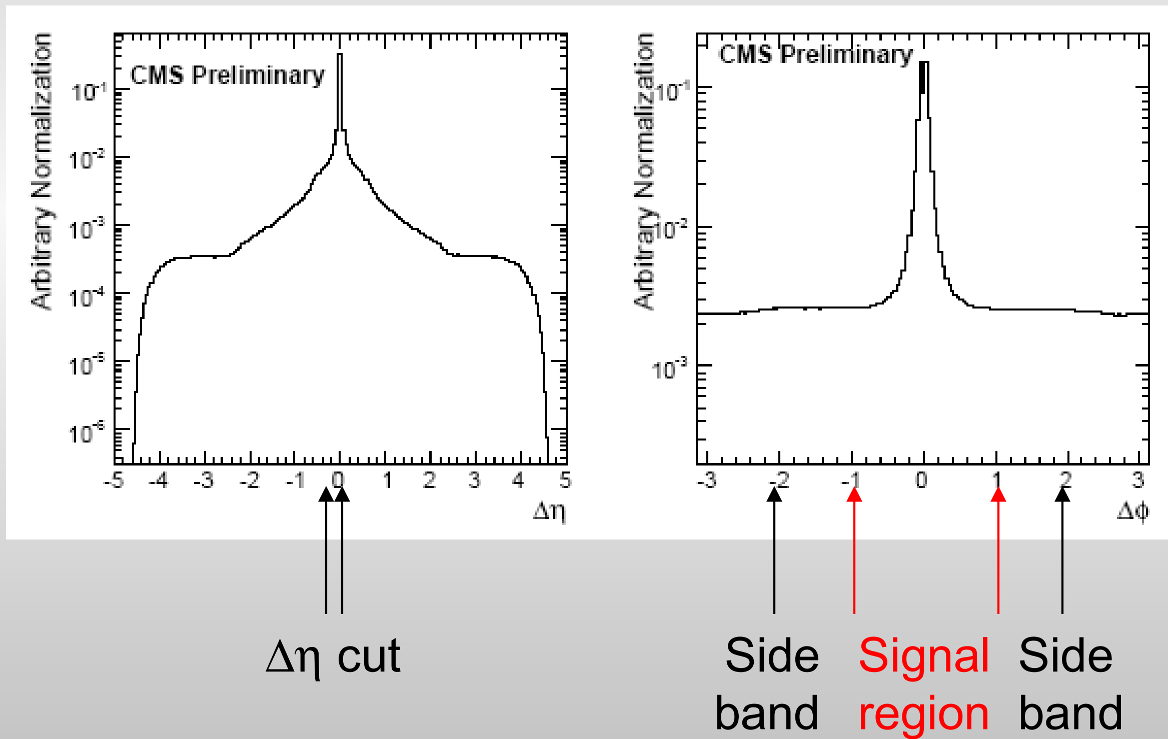
2) the candidate vertex with the highest number of compatible combinations is taken as the PV

3) "Tracklets" are fitted using PV information



$h^{\pm}$ spectra: “tracklets” (2)

1) Use of $\Delta\eta = \eta_1 - \eta_2$ to select good tracklets and and $\Delta\phi = \phi_1 - \phi_2$ to perform sideband subtraction on “data” (50 mb^{-1} equivalent MC sample)

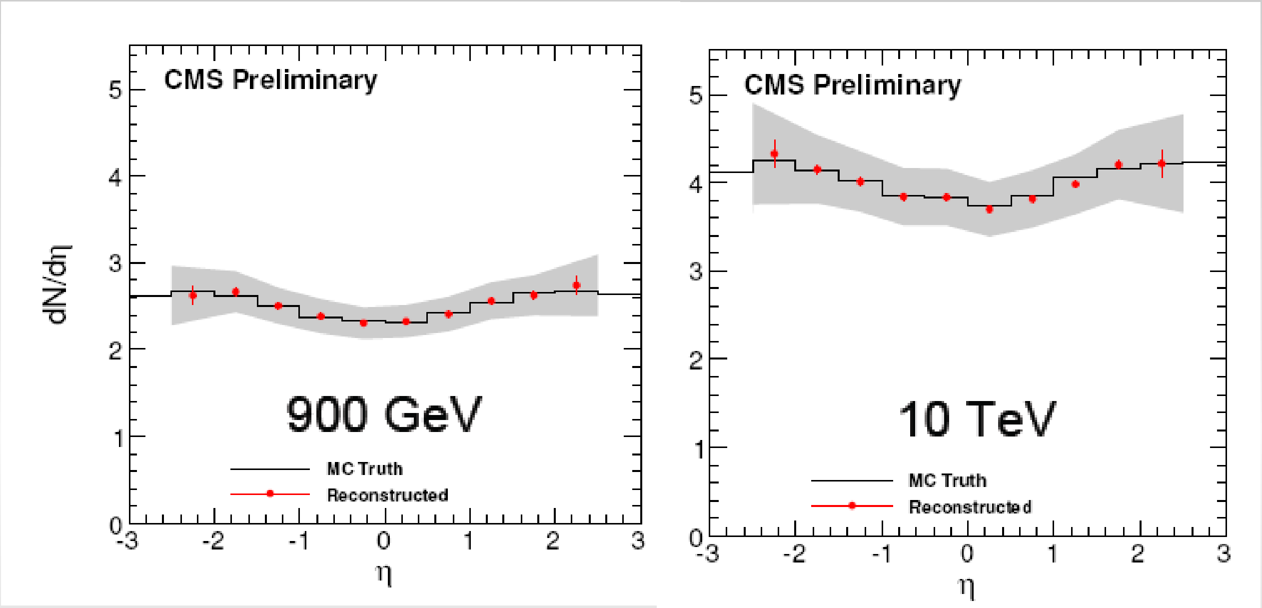


2) Acceptance calculated from a large number of independent simulated events (“MC”)

- Both 1) and 2) in bins of:
  - Hit multiplicity
  - η_1
  - z_{vtx}

$h^{\pm}$ spectra: "tracklets" (3)

- Results: $dN^{\pm}/d\eta$ after MC acceptance correction



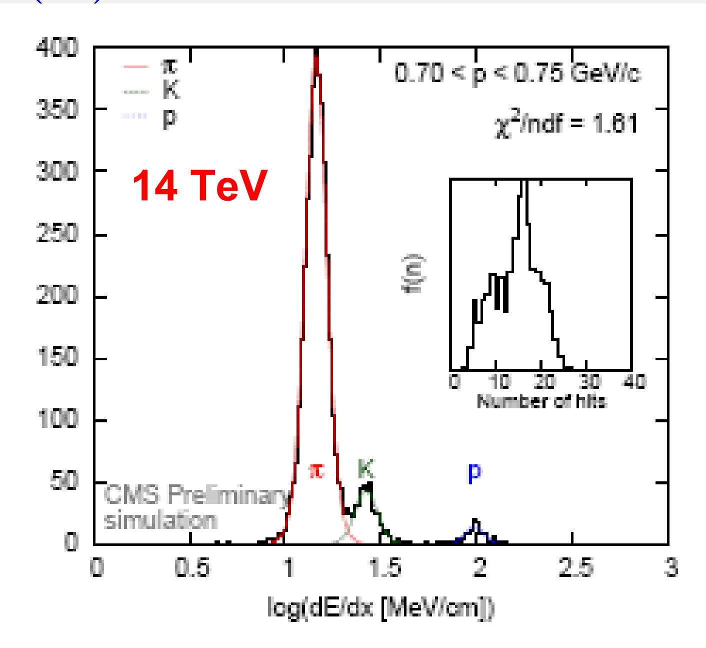
- Estimation of main systematic sources

SOURCE	900 GeV	10 TeV
Acceptance correction	5-10%	5-10%
Pixel hit reconstruction efficiency	5.0%	5.5%
Pixel hit splitting	1.5-3.5%	1.0-2.0%
Background subtraction	0.5-1.5%	0.5-2.0%
Misalignment	1.0%	2.0%
TOTAL	**7.5-13.5%**	**8.5-13.5%**

$h^{\pm}$ spectra: full tracks (1)

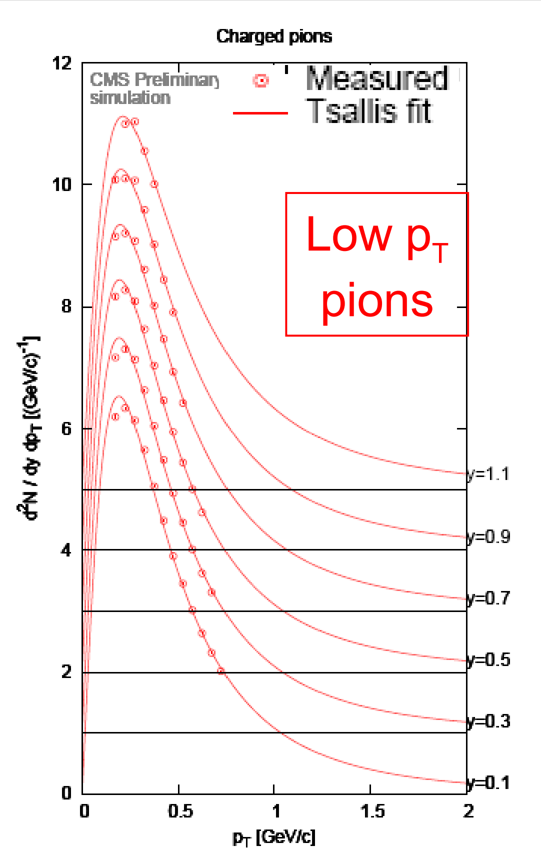
- Using low-p_T tracking (all tracker, pixel + strips) and primary vertex finding technique:
  - $p_T > 100$ MeV/c (π), 200 MeV/c (K), 300 MeV/c (p)
  - background from fake tracks down to o(%)

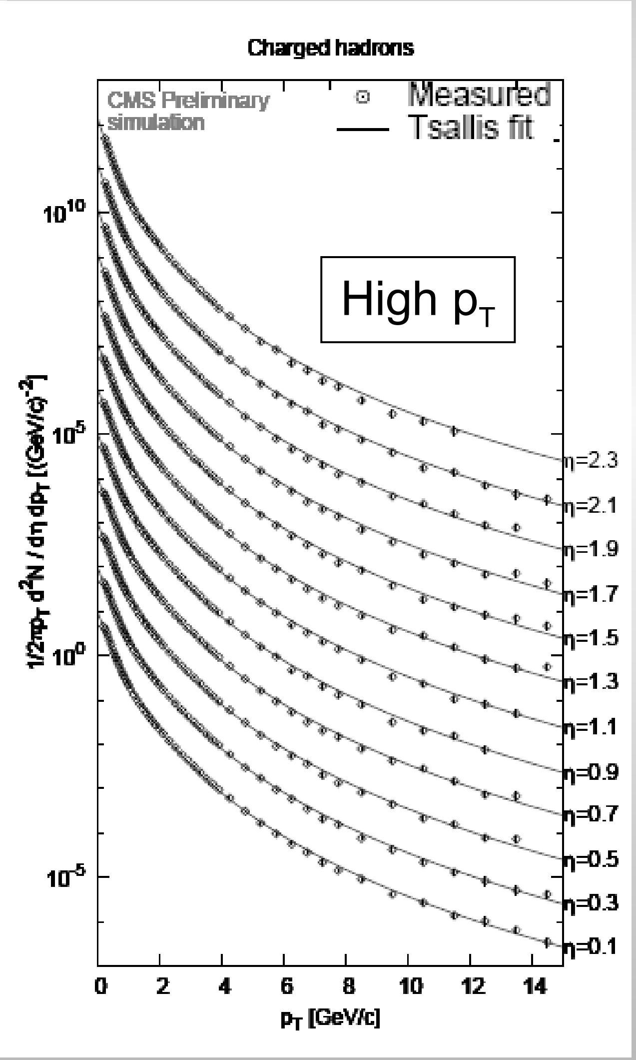
- V^0 vertex finding after tracking rejects K_S's, Λ's
- Measured dE/dx in silicon allows π/K/p separation power depending on the p_T range considered



$h^{\pm}$ spectra: full tracks (2)

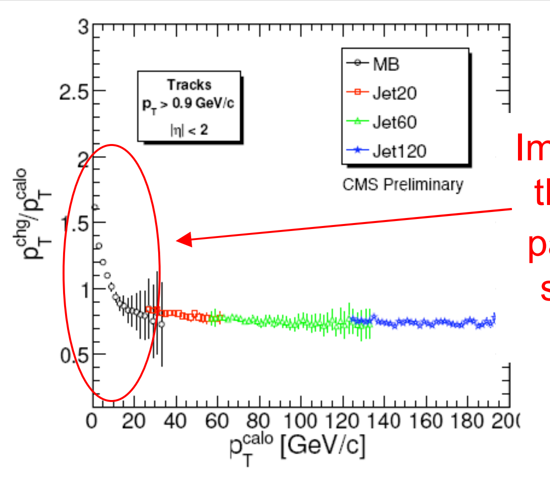
- Results: $dN^{\pm}/dp_T d\eta$ after MC acceptance correction (fitted by a Tsallis function)
- Estimation of main systematic sources is of the order of 7-9% (but see next slides)



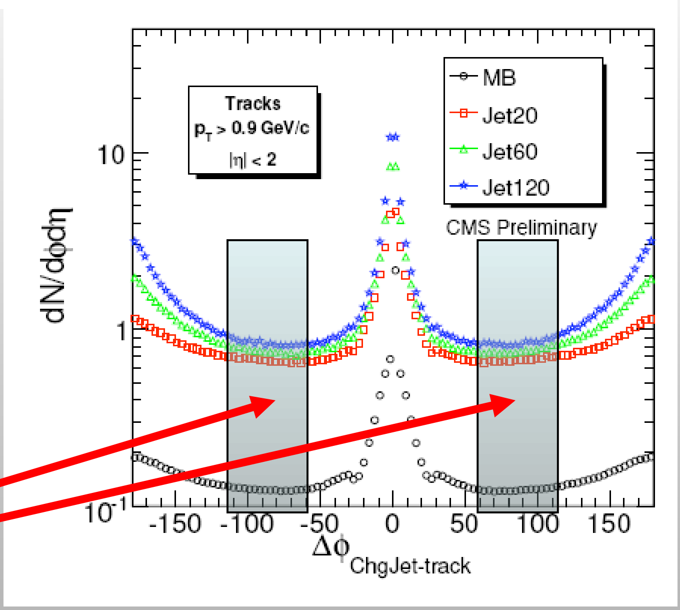


Underlying event (1)

- Study of underlying event:
  - Triggers: MB + Jet20, 60, 120
  - Reconstruction of "charged jets" (using only track information, no calorimeters) ← tracking down to 500 MeV/c
  - Observables: $dN^{\pm}/d\phi d\eta$ and $d\Sigma p_T/d\phi d\eta$ vs. p_T of the charged jet in the "transverse" region defined by the direction of the leading jet in the event (hard scattering contribution is minimized)



Improving in the low-p_T part due to soft track recovery

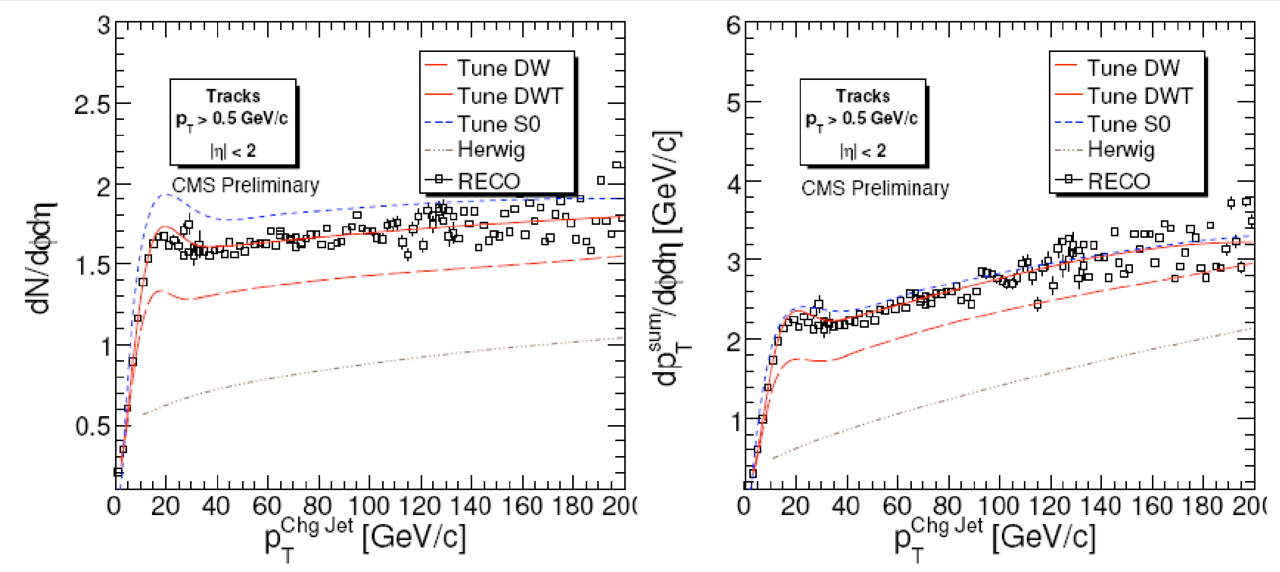


Transverse region

Underlying event (2)

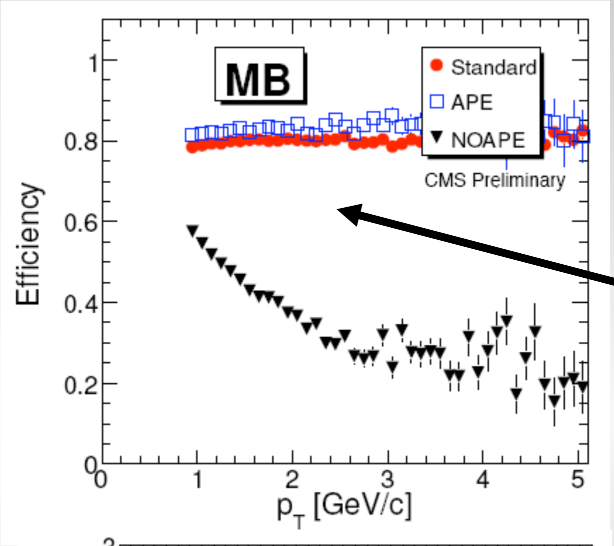
- Results:

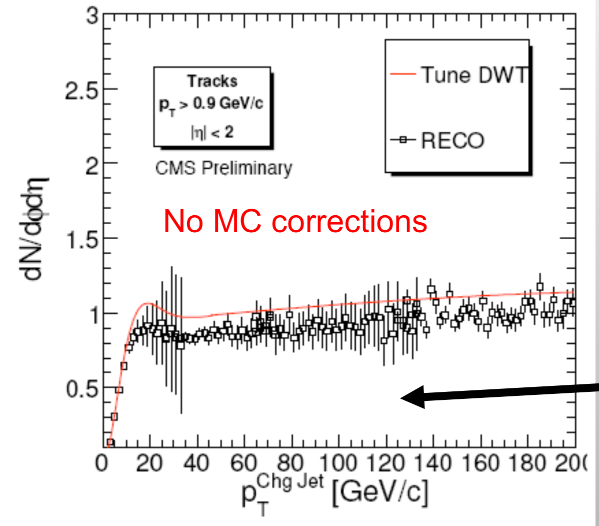
(700 mb^{-1} to 2 pb^{-1})



- Comparison between different MC generators:
  - Herwig: does not include Multiple Parton Interactions
  - PYTHIA using different "tunes", i.e. parameterizations of UE structure (all including MPI)
  - DWT tune = Default used in reconstruction → MC acceptance corrections found to be independent of the model used

Low-p_T tracking: alignment





- Systematic errors for analyses using low-p_T tracking are expected to be dominated by tracker alignment
- Tracking efficiency re-estimated with a "start-up" alignment scenario (pessimistic, no cosmic data)
- Adding ad-hoc alignment position errors to MS estimation in pattern recognition recovers efficiency, while keeping fake rates below 5%
- Effect shown on UE analysis

$Q\bar{Q}$ resonances in CMS

- J/ψ, Υ(1S), Υ(2S), Υ(3S), B_c^+: topics of studies completed/ongoing in CMS
- Quarkonia in di-muon channel → wide physics program:
  - Physics analysis:
    - production cross-section measurements
    - spin alignment
    - P-wave states (χ_c, χ_b): radiative decays …
  - Detector studies:
    - Momentum scale calibration
    - Measurement of muon trigger/reconstruction efficiencies using one well-reconstructed muon and checking requirements on a candidate compatible with QQ mass ("tag-and-probe" method) …
- Quarkonia in di-electron channel: feasibility still under study, due to the detector limitations of low-p_T electron identification

The J/ψ x-section measurement

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

- $N^{fit}_{J/\psi}$ = $(1-f_B)N_{J/\psi}^{tot}$ (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) *
- Δp_T = p_T bin size *

* = function of p_T

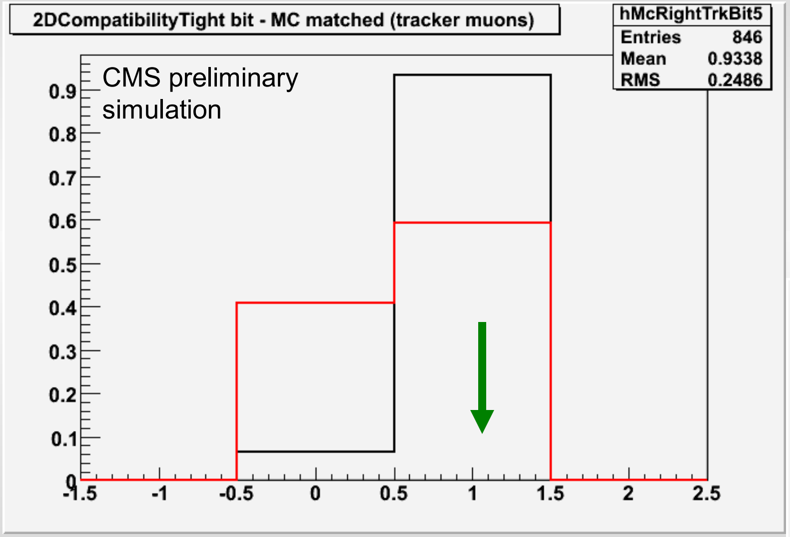
- For non-prompt J/ψ, unfolding (to obtain $d\sigma/dp_T(b)$) is recommended for comparison with theoretical predictions

Event generation and samples

- Signal ($|\eta_\mu| < 2.4$)
  - Prompt J/ψ (~2M events) → PYTHIA6 Color Singlet + Color Octet model with matrix elements tuning from CDF results, uniform polarization
  - Non-prompt J/ψ (~1M events)→ EvtGen
- Backgrounds
  - Generic Drell-Yan events (~2M events)
  - Muon-enriched QCD events (~20M events). Main sources from MC-truth information:
    - D and B meson decays
    - Decay in flight of π and K
    - Hadron punch-through

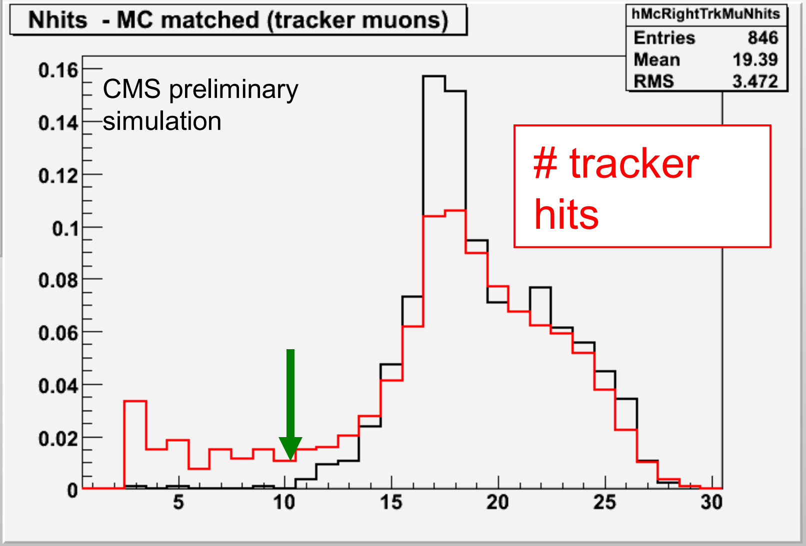
Muon selection

- Global muons (very high signal purity) → all selected
- Tracker muons (lower purity)



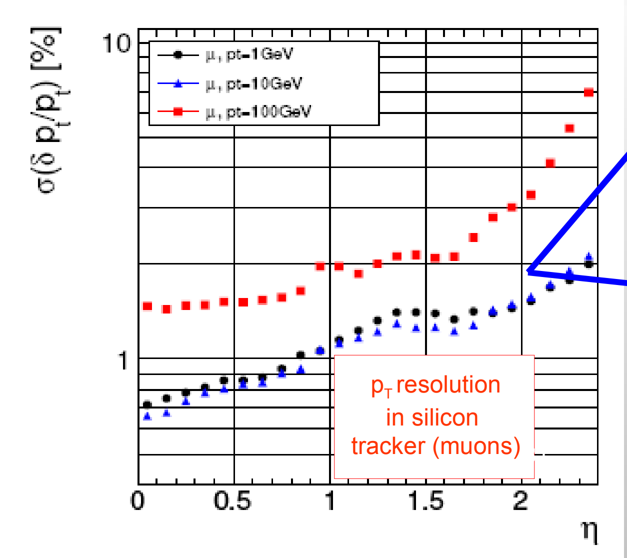
Likelihood-based selector on track- muon segment compatibility

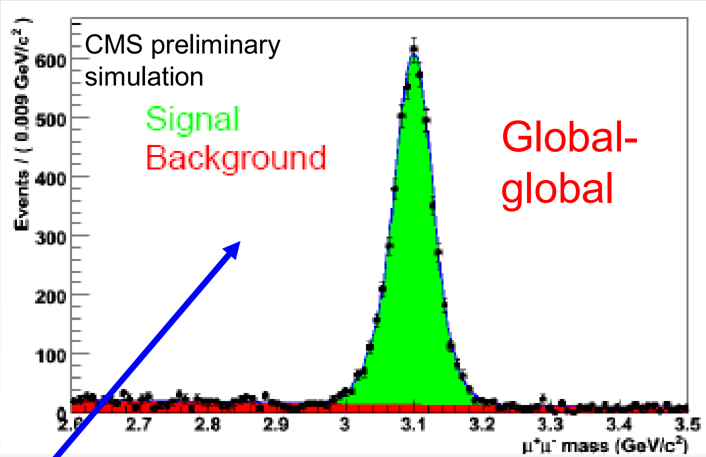
- Signal: MC-truth matched
- Signal: Not MC-truth matched + QCD single-muon enriched background

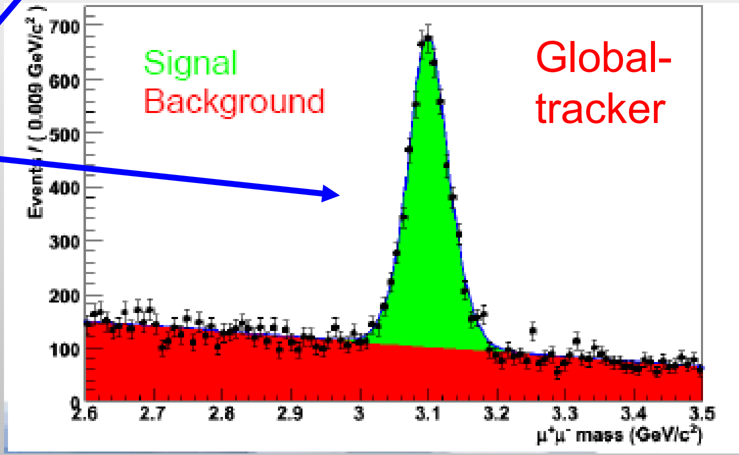


J/ψ yield ($N_{J/\psi}^{tot}$)

- L = 100 nb^{-1}
- Here integrated in p_T, η
- Invariant mass form muon track momenta





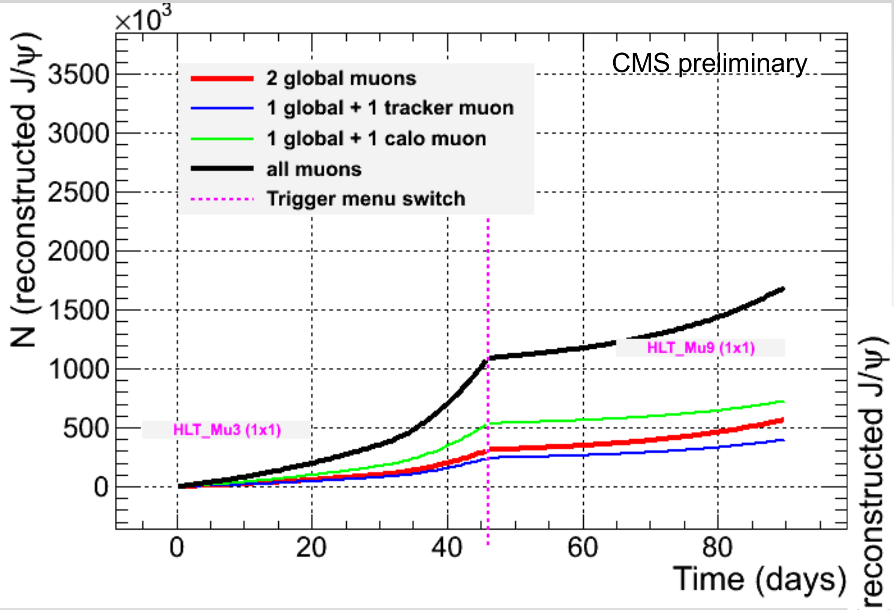


$N_{J/\psi}$ = 4970 ± 70
σ_{mass} = (34 ± 2) MeV

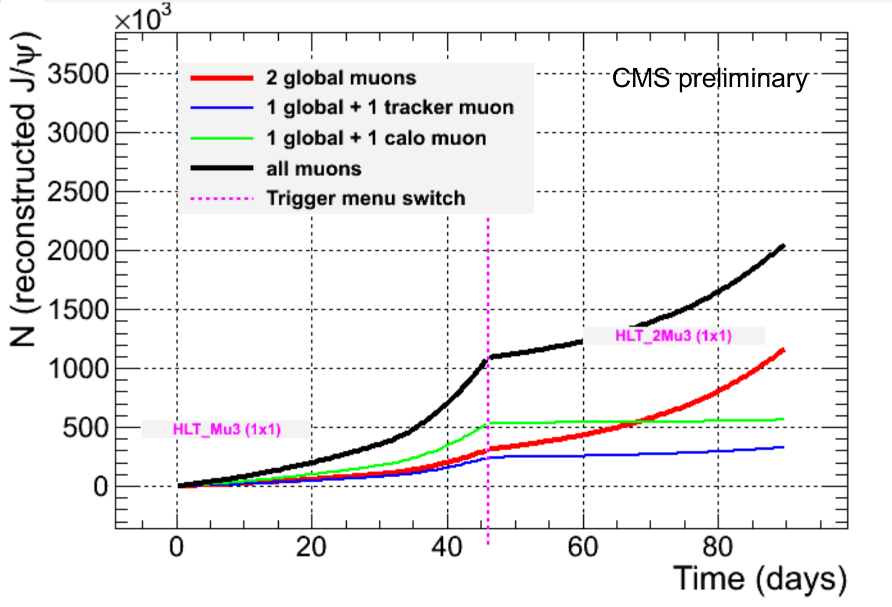
- $\sqrt{s}$ = 10 TeV
- 3 GeV single-muon trigger

$N_{J/\psi}$ = 4750 ± 90
σ_{mass} = (32 ± 3) MeV

J/ψ yields in data: expectations



- Updated to the new 7 TeV luminosity delivery scenario provided by LHC people



- If we believe in it, data statistics seems not a problem

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. $\gamma_{J/\psi}$ instead of γ_B)
- For background events a generic superposition of different contributions (symmetric + asymmetric with effective lifetimes) is adopted

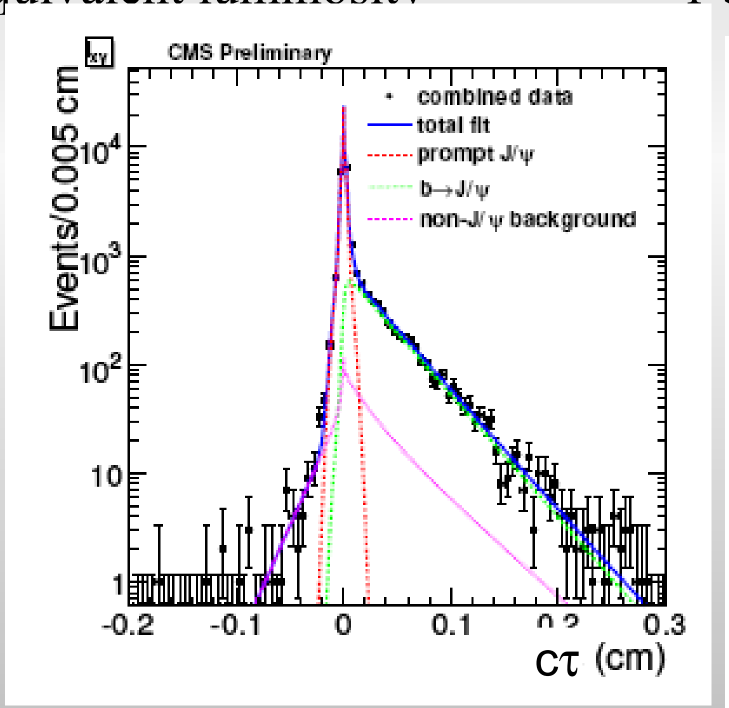
Convoluted with 2-Gauss resolution

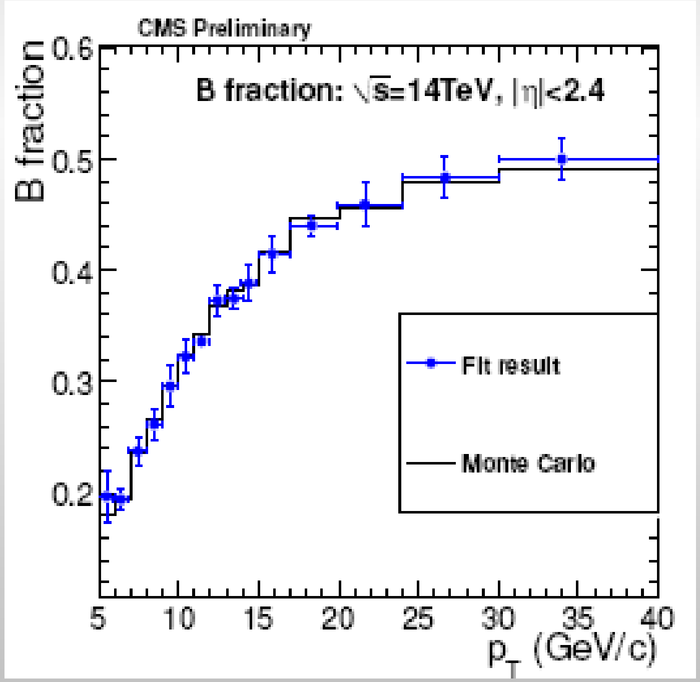
B-fraction (f_B)

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

NO BIAS OBSERVED FROM FITTING TECHNIQUE

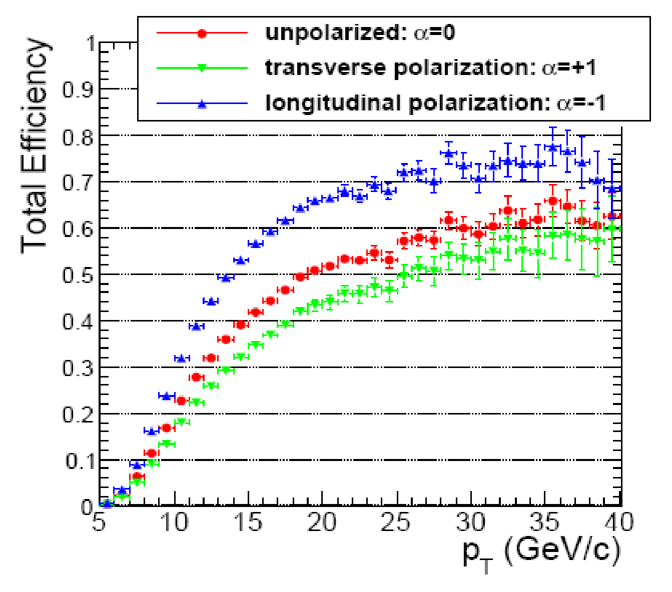
$\sigma(N_{J/\psi}^{prompt}) = \sigma(N_{J/\psi}^{non\text{-}prompt}) = 1.6\% - 7\%$





Acceptance correction (*A*)

- This has to be 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



Efficiency measurements (λ)

- Tag-and-probe method:
  - Given a cleanly identified ("tag") muon, estimate number of other muons satisfying certain steps of reconstruction ("probes") from a fit to the QQ mass vs. p_T, η of the muon ← selection independent
  - Reconstruction:
    - Tag: global muon with p_T > 3 GeV/*c*

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

Limited by muon resolution in μC and biased

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

Well established

  - Trigger:
    - Tag: global muon matched to an HLT object

$$\varepsilon_{HLT} = N_{global-\mu \quad HLT} / N_{global}$$

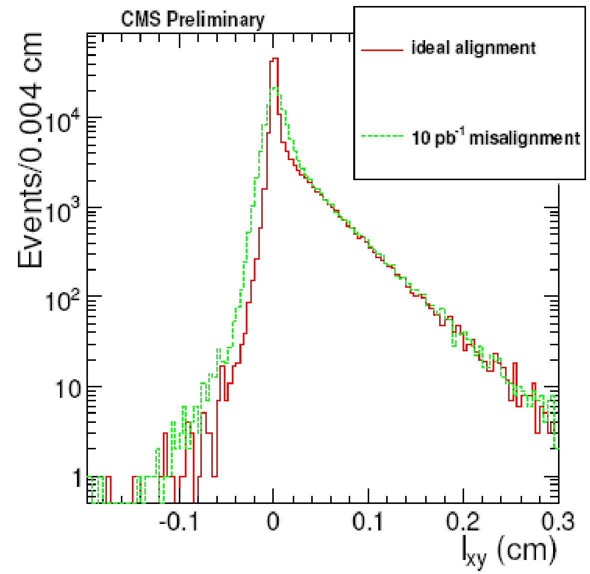
- Limitations of the method:
  - Fit precision
  - Correlation between muons (e.g. small ΔR)

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

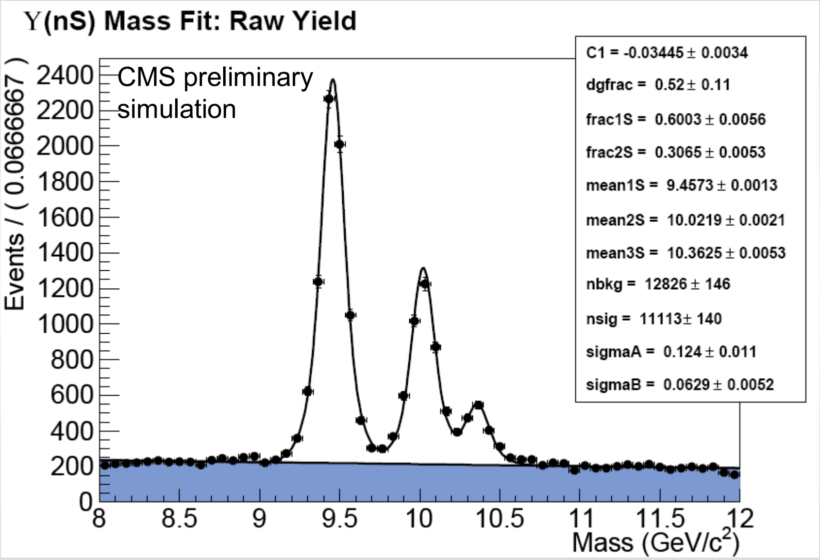


- Invariant mass

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

Υ(nS) analysis: sketch

- Cross-section measurement method along the lines of J/ψ (no need for lifetime fit)
- Analysis in progess:
  - $\sqrt{s}$ = 10 TeV
  - 3 GeV single-muon trigger



- Expected o(10K) events/pb^{-1}
- Achieved mass resolution allows separation of the 3 states
- Tag-and-probe expected to be more precise (larger average ΔR between the muons)

Conclusions

- CMS will be performing a variety of QCD-related measurements which in general:
  - are not statistically limited, so depend slightly on integrated luminosity
  - take advantage from running at different values of $\sqrt{s}$
  - Need optimization of detector performances at low p_T
- Several methods for charged hadron spectra measurement with increasing object complexity (from pixel hit counting to full tracking)
  - Need a few Kevents
  - Depend differently on detector conditions (typical systematic errors of ~10%)
- Underlying event study shows that it is possible to discriminate QCD "tunes" and estimate amount of MPIs with $< 2\ pb^{-1}$
- Rich physics program with quarkonia in di-muons:
  - Use of low-purity muons increases statistics and allows lower $p_T(J/\psi)$ reach
  - Good S/B and very good mass resolution (~30 MeV) are obtained
  - Total yield of about 100K J/ψ / pb^{-1} (including tracker muons)
  - A differential J/ψ cross-section measurement, separated by prompt/non-prompt contributions, in $5 < p_T < 40$ GeV/c, $|\eta| < 2.4$, is possible with 3 pb^{-1}