First Results from **CMS** on QCD, Quarkonia, and Heavy-Flavour Physics in proton-proton Collisions at $\sqrt{s}$=7 TeV

ICHEP PARIS 2010

Session 01: Early Experience and Results from LHC

S.Bolognesi (CERN)

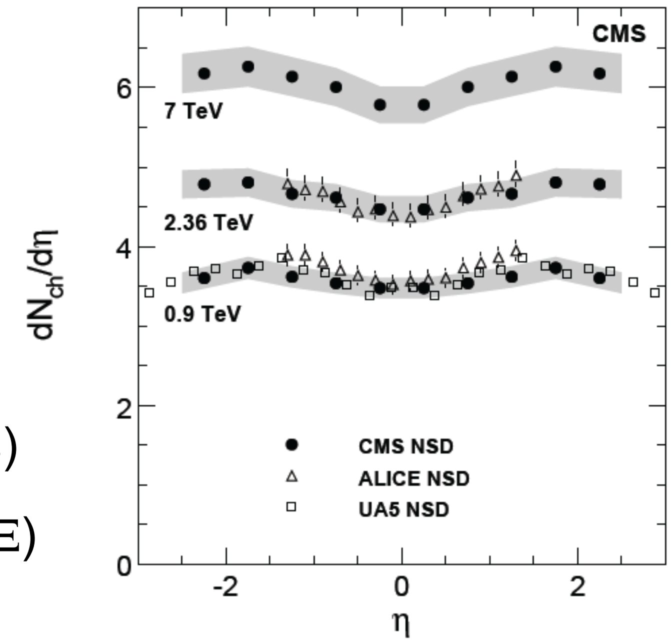
Outline

- **Soft and hard QCD results**
  - track multiplicity, Underlying Event (jet area)
  - *jets performance*
    - ⇒ inclusive jet p_T spectrum, decorrelations, event shapes, 3j/2j

- **Inclusive b physics**
  - *b-tagging performances*
    - ⇒ b-jet and $b \to \mu + X$ production xsec

- **Quarkonia, exclusive B-physics**
  - *muon trigger, tracking resolution*
    - ⇒ $J/\psi \to \mu\mu$, $\Upsilon \to \mu\mu$ inclusive xsec and $B \to J/\psi$ fraction
      $B \to J/\psi + X$, (open charm resonances)

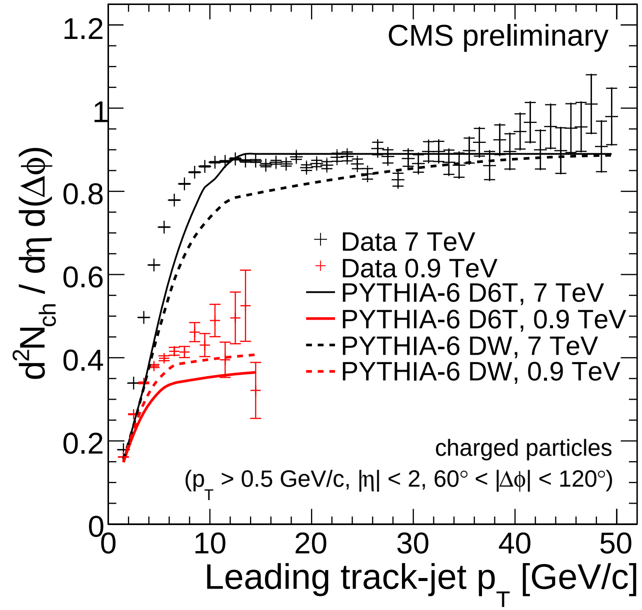
Soft QCD
(p_T track>50 MeV)

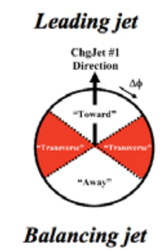


- **dN/dη** at 0.9, 2.36 and 7 TeV
  - correction for NSD (~6% corr. →2.5% syst)
  - 3 methods (pixel clusters, tracklets, tracks)
  - **Multiplicity of strange hadrons** (K_s, Λ_0, Ξ)

→ rate increasing with √s underestimated by MC tunes

- **Underlying event** in transverse region
  - underestimation of track multiplicity at low $p_T^{leading}$
  - rise 0.9→7 TeV described only qualitatively by MC tunes





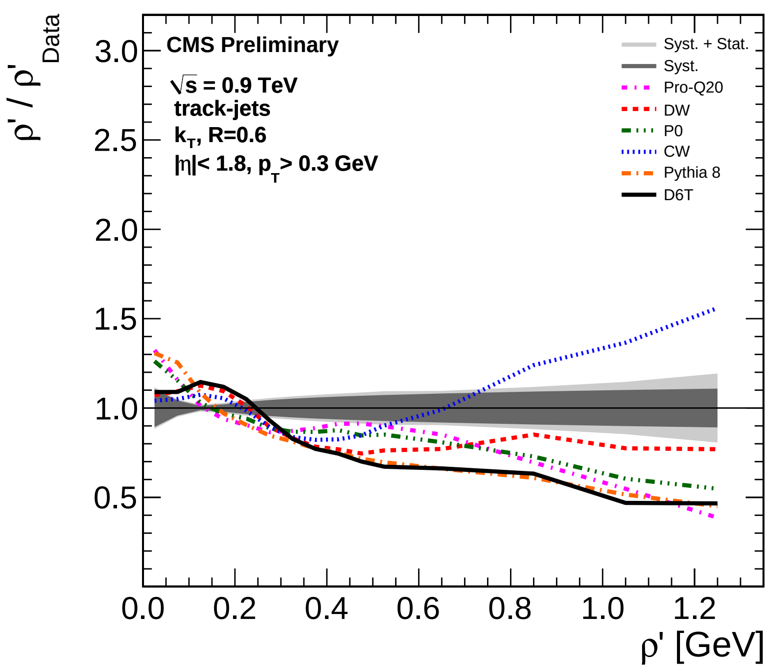
UE from jet area ($\sqrt{s}$=900 GeV)

- $\rho = \underset{j \in \text{jets}}{\text{median}}\left[\left\{\frac{p_{Tj}}{A_j}\right\}\right]$ area (η,φ) estimated from a uniform grid of very soft pseudo-particles* (FASTJET)

→ measurement of total activity in the event

- k_T algo (others force a fixed jet shape) with R=0.6 (where ρ stable)
- $\rho \rightarrow \rho'$ considering only physical jets (at low $\sqrt{s}$→ low occupancy, pseudo-jets dominate)

uncorrected detector-level



- Same pattern of disagreement tunes-data as standard approach but complementary:
  - IR/collinear safe variable
  - look at all the event (not only transverse region)
  - no need of leading object (multi-jets)
- useful technique to remove PU (and UE) contribution at high luminosity

* Cacciari, Salam, Sapeta JHEP **04** (2010) 065

Jet performances

- **4 jet algorithms** with energy corrections from MC (+data cross-checks):
  - **Calorimeter Jets**
    → uncertainty on Jet Energy Scale 10%
  - **Jet-Plus-Tracks**
  - **Track Jets**
  - **Particle-Flow Jets**

    } → uncertainty on Jet Energy Scale 5%
  - η dependence of jet energy : 2% uncertainty, linearly increasing with η
  - Jet Energy Resolution 10% ($\sigma(p_T)$~10±1GeV for p_T~100GeV)

- anti-K_T algorithm with D=0.5 (or 0.7)
- jet quality cuts (100% eff. p_T>50)
- single jet trigger: L1 jet>6 GeV + HLT jet > 15 GeV (uncorrected)

- Rich set of measurements (next slides) → **jet commissioning and test pQCD**

Dijet mass and angular distribution

- Dijet mass (|η|<1.3)
- $\chi_{dijet} = \exp(|y_1 - y_2|)$

probes parton scattering with light dependency on PDF

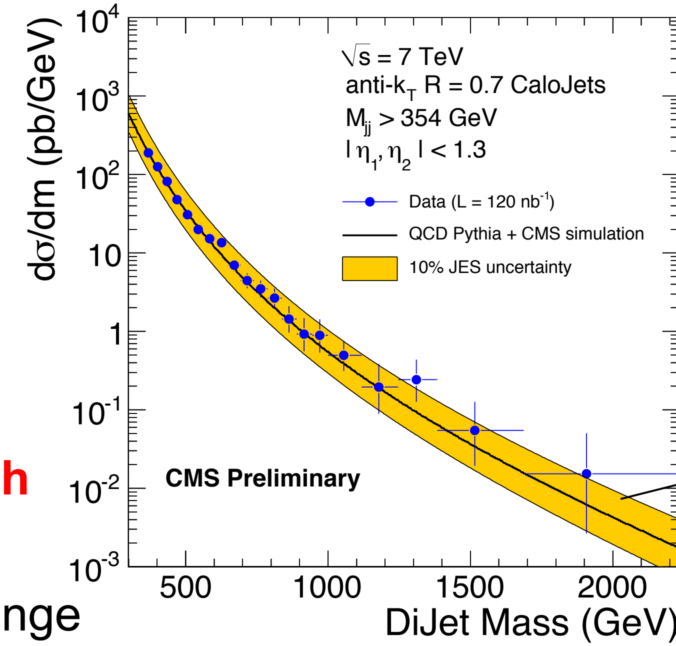
- flat for t-channel gluon exchange
- new physics → excess at low χ

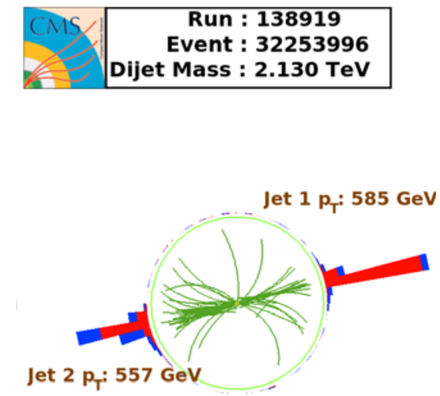
- Comparison with NLO using CTEQ6.6 + non-perturb. from Pythia

μ_f, μ_r set to average dijet pT→ varied from half to twice

PDF uncertainty from CTEQ6.6 uncertainty eigenvectors

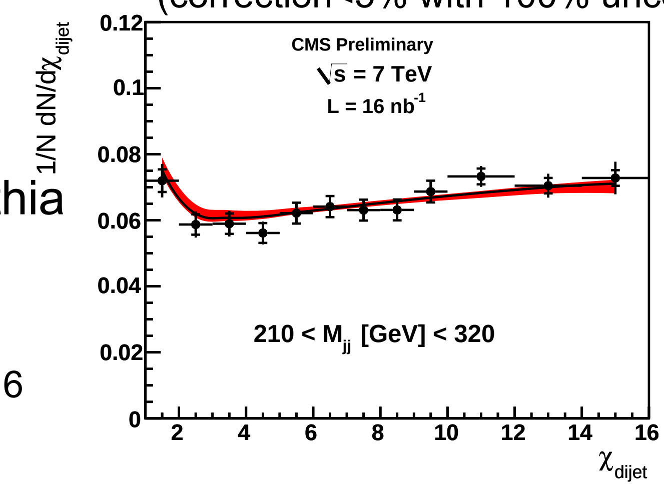
detector level

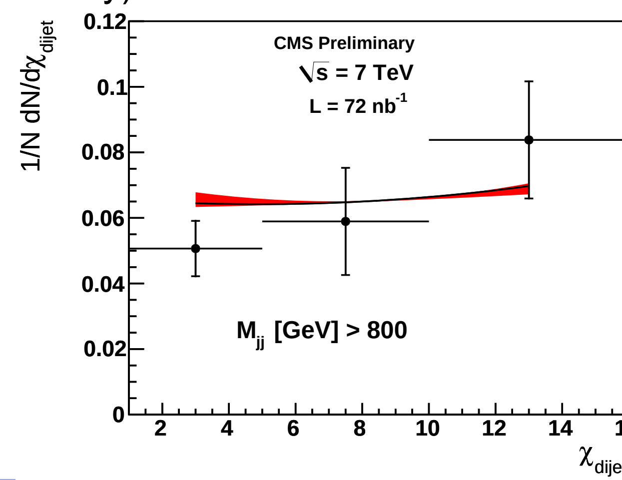




corrected at hadron level (correction<5% with 100% uncertainty)

data
NLO + non-pert.
scale + PDF unc.





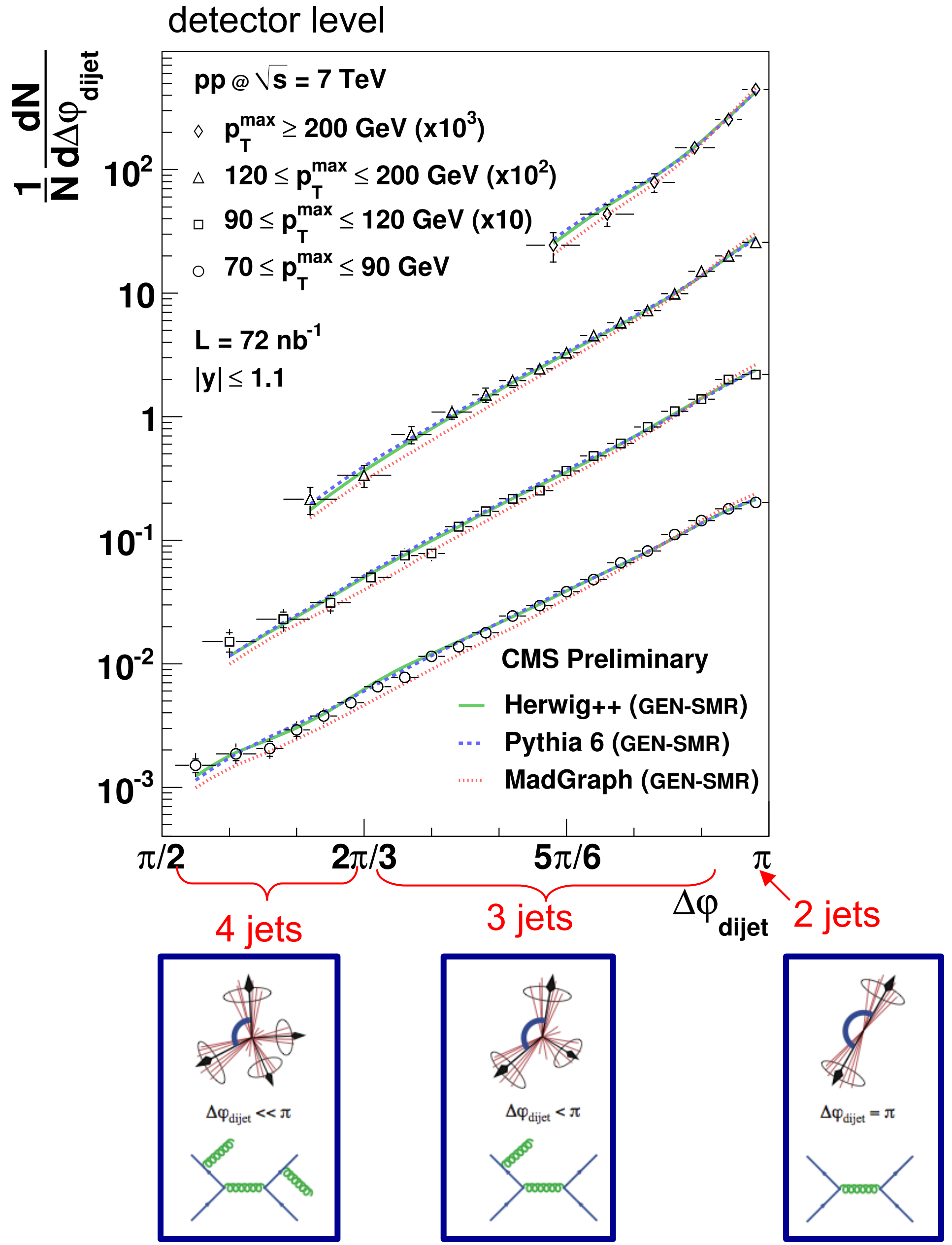
Dijet Azimuthal Decorrelations

❑ $\Delta\varphi_{dijet} = |\varphi_{jet1} - \varphi_{jet2}|$

sensitive to higher order QCD radiation effects

• Madgraph underestimates low Δϕ (multi-jet) region

• High sensitivity to ISR, much less to FSR

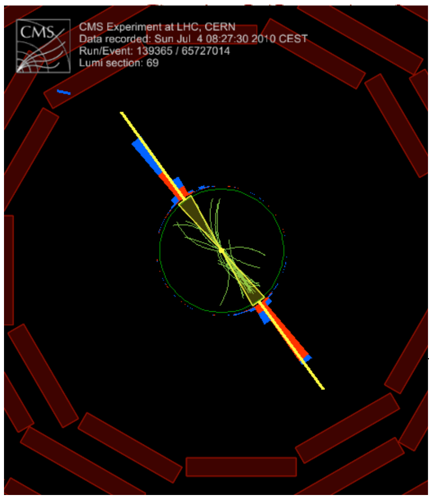


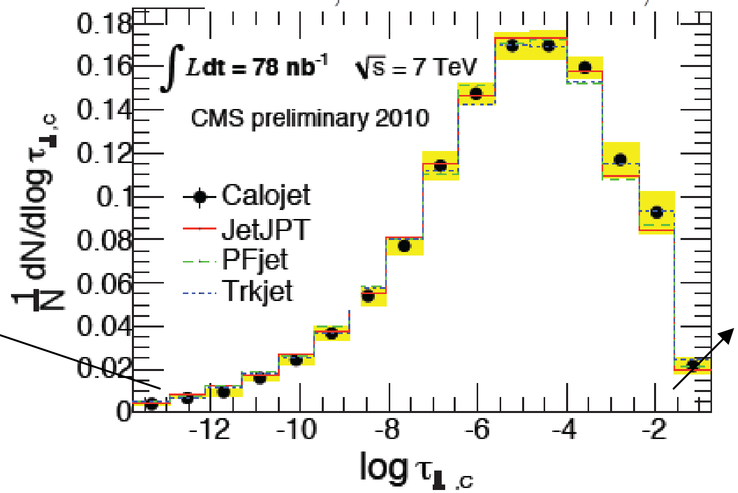
Hadronic Event Shape

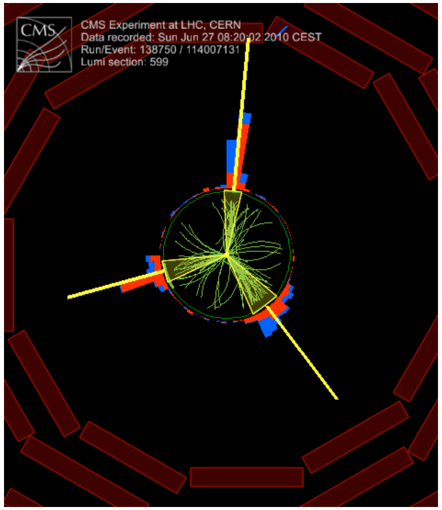
- **Central transverse thrust**

$$T_{\perp,\mathcal{C}} \equiv \max_{\vec{n}_T} \frac{\sum_{i\in\mathcal{C}} |\vec{p}_{\perp,i} \cdot \vec{n}_T|}{\sum_{i\in\mathcal{C}} p_{\perp,i}}$$

$$\log \tau_{\perp,\mathcal{C}} = \log(1 - T_{\perp,\mathcal{C}})$$

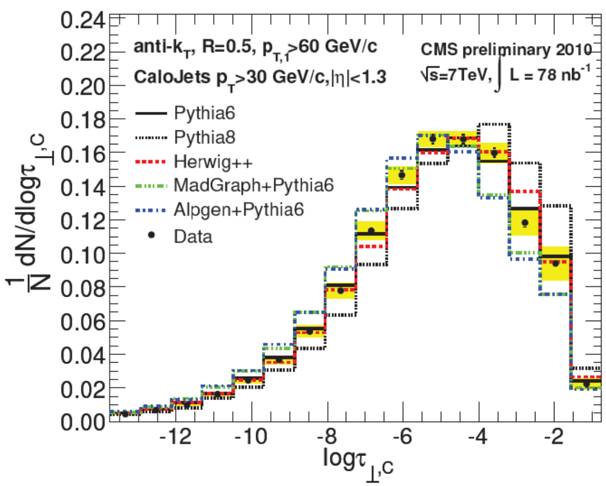






- 4 jet types in very good agreement
- $p_T^{leading}$>60 GeV, $|\eta_{j1j2}|$<1.3, p_T>30 GeV, $|\eta|$<1.3,

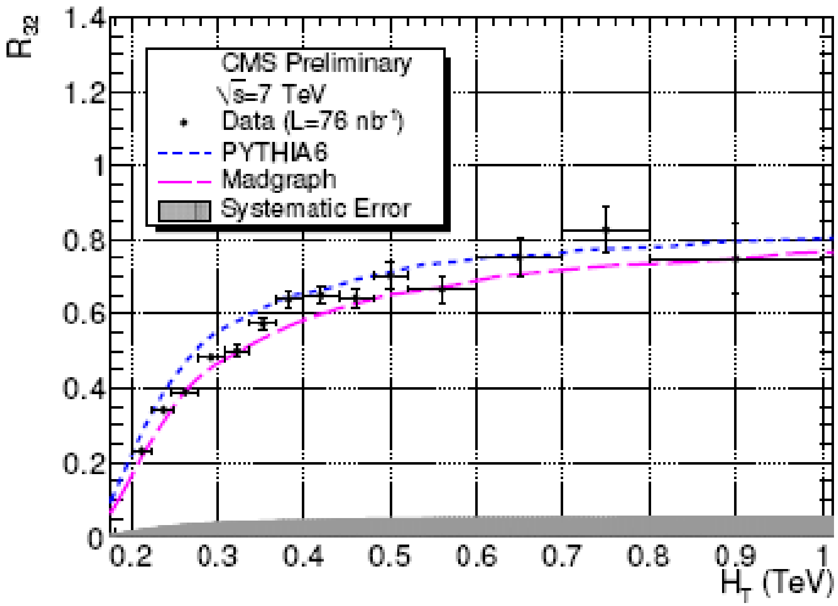
  → JES dominant syst, JER and position resolution (±10%)



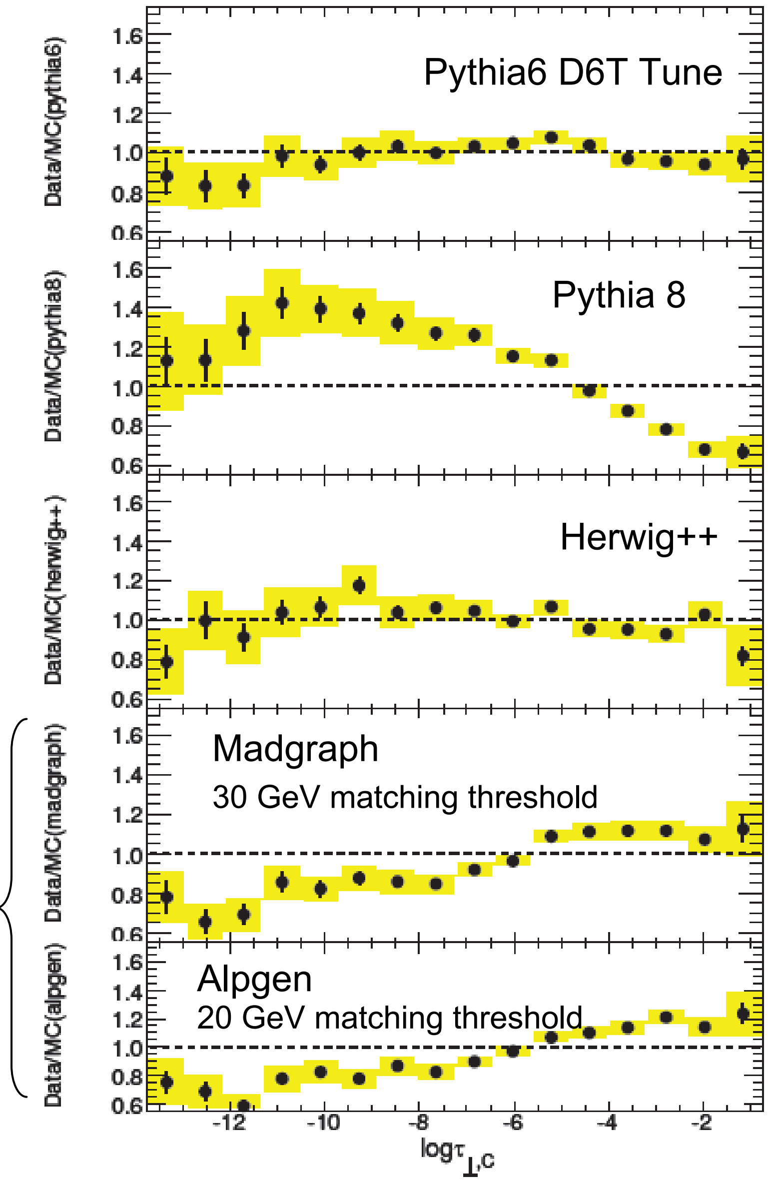
2j → 3j results

- **Hadronic event shape:**
  sensitivity to tune ME MC
  - same behavior for higher $p_T^{leading}$
  - better data-MC agreement for higher jet multiplicity

- **3j / 2j VS H_T:**
  not conclusive yet

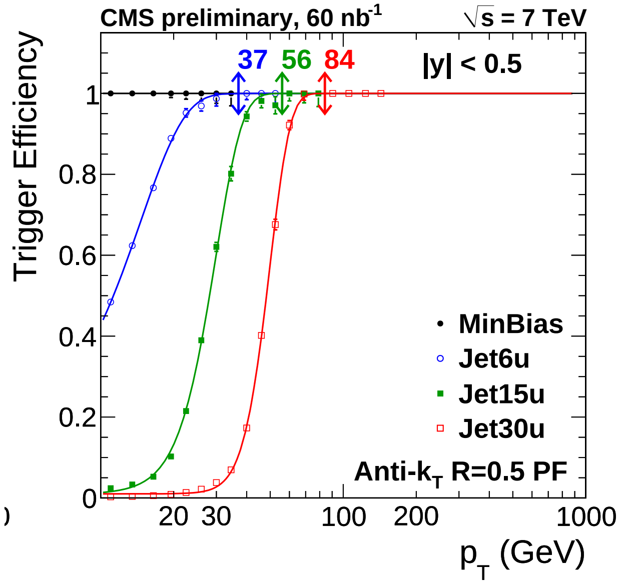


detector level (calo jets)

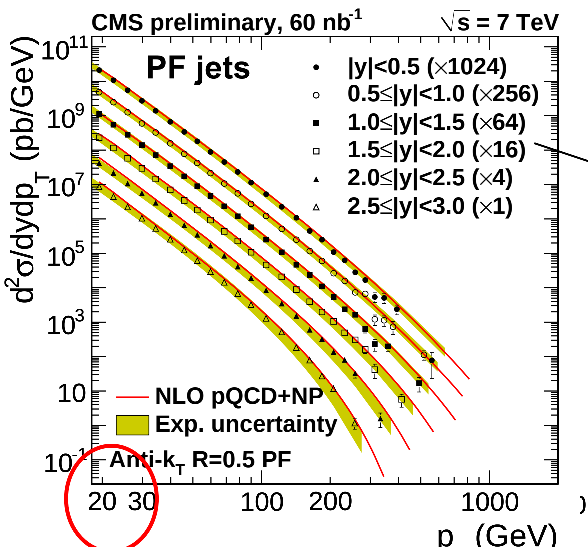


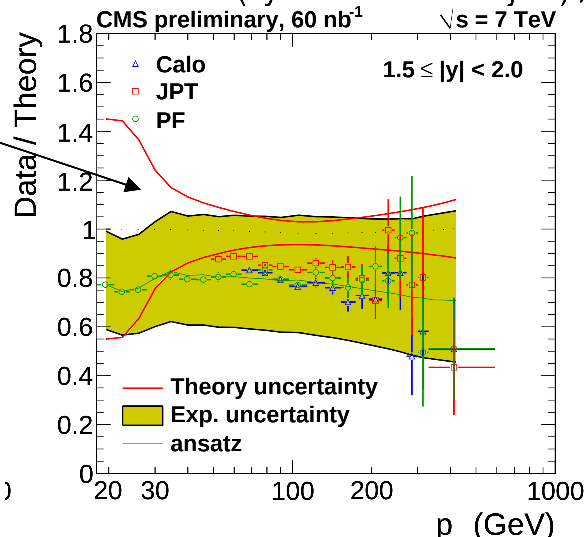
Inclusive Jet $d\sigma/dp_T$

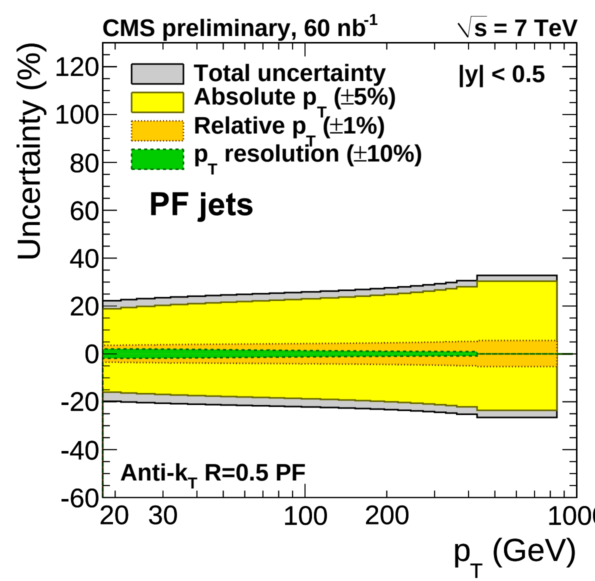
- Triggers: min.bias + single jet > 6,15,30 GeV
  combined exclusively at ~99% turn-on
- Resolution unfolding → hadron level
- Agreement with NLO using CTEQ6.6
  non-perturb. correction from Pythia-Herwig average
  PDF uncertainty comparing different PDF sets
  μ_f, μ_r uncertainty: pT/2 → 2 pT



(systematics of PF jets)





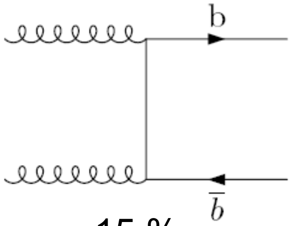


- Few % difference in JES between algos → 10% on the xsec

b production

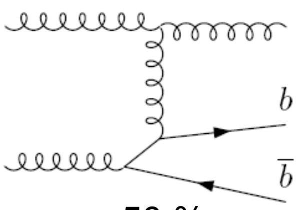
- Understanding and testing b-quark production at 7 TeV

Flavor Creation



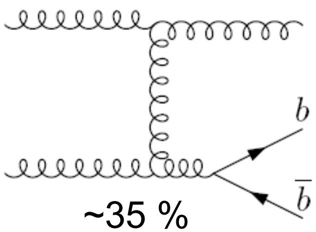
~15 %

Flavor Excitation



~50 %

Gluon Splitting



~35 %

for p_T 20-100 GeV

- FEX, GS are higher order effects but dominate at LHC

With available statistics:

- measurement of inclusive b production cross section with 2 independent methods (next slides)

With more statistics:

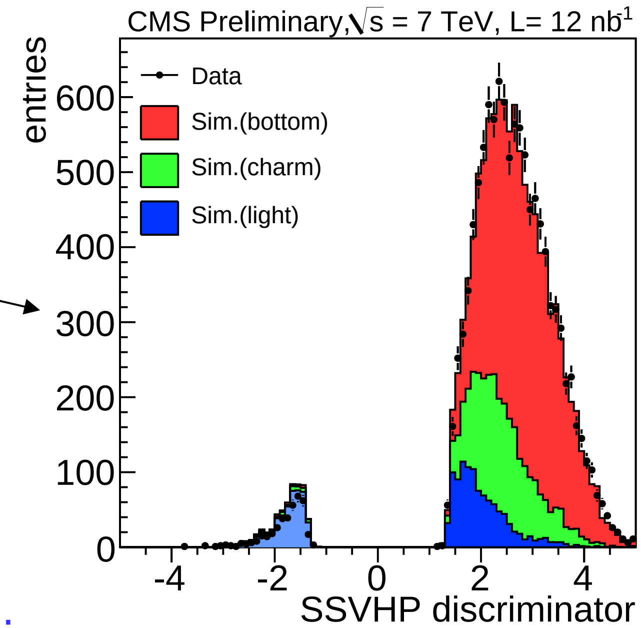
- test the relative fractions of the different production processes
  - 3 muons angular correlation $BB_{bar} \to J/\psi + \mu + X$
  - pixel precision would allow multiple Secondary Vertices reconstruction

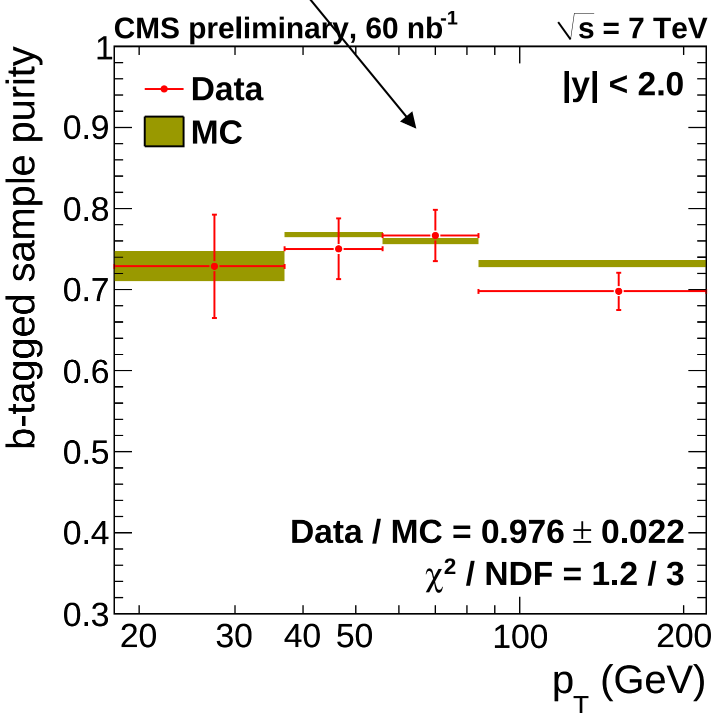
b-tagging

- b-tag **based on Secondary Vertex**

  efficiency, purity from MC but x-check with data:

  - b-tag purity: fit to secondary vertex mass with templates





- b-tag efficiency

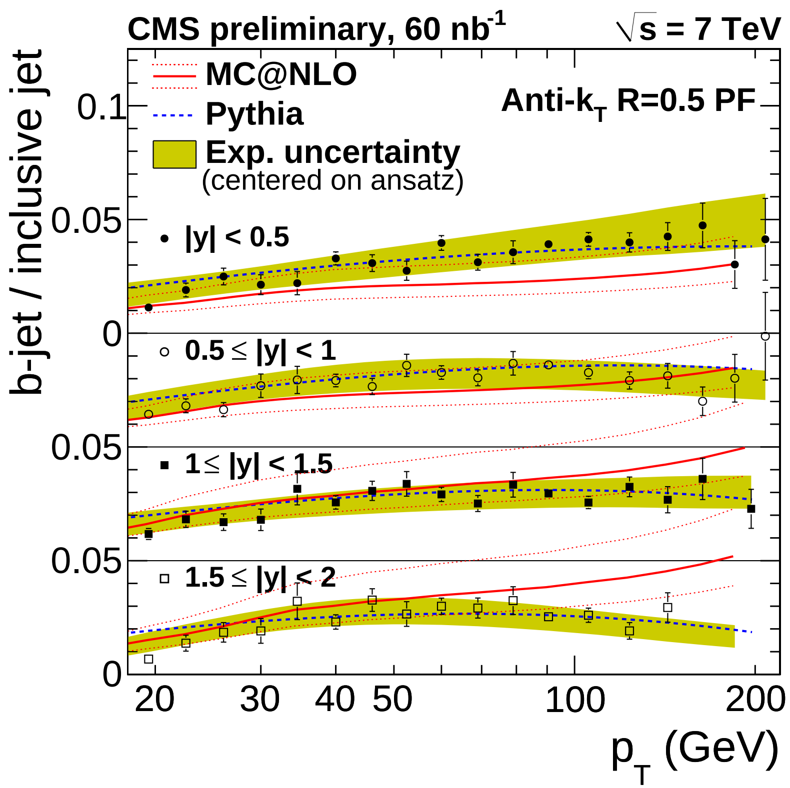
  from fit to muon p_T^{rel} with templates

- mistag rate from negative tag tails

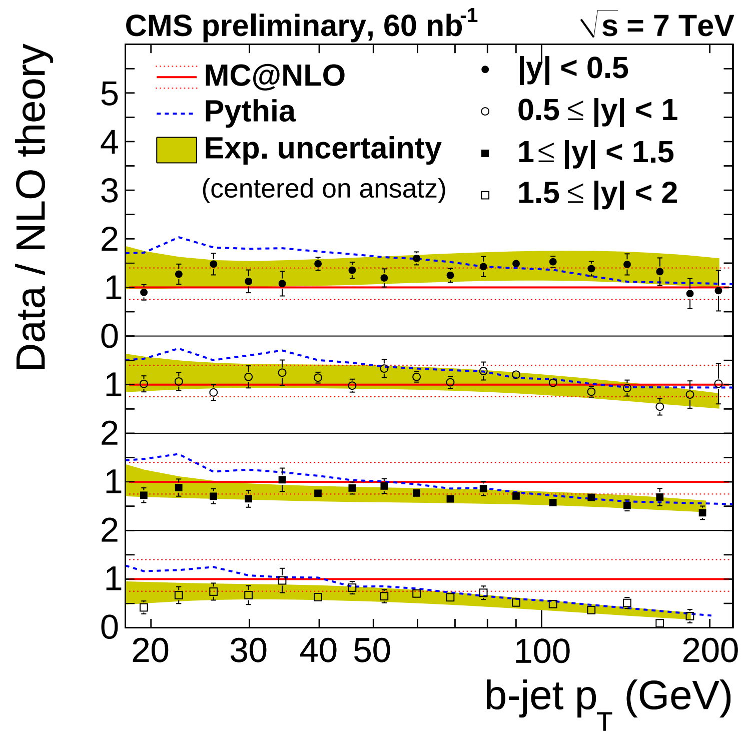
- secondary vertex energy / b-jet energy sensitive to FC+FE (large ratio) versus GS (low ratio)

b-jet dσ/dp_T

- Ratio to inclusive → partial syst cancellation
  - b-tag efficiency syst.~ 20%
  - JES b-jets VS LF jets ~1%



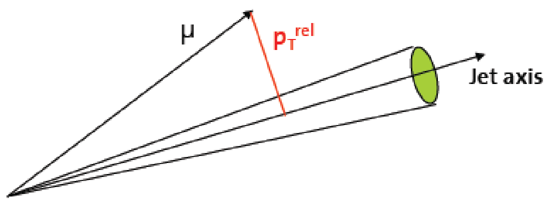
- b-jet xsec



- Comparison to theory:
  - b-jets from MC@NLO (CTEQ6M)
  - inclusive jets from NLO (CTEQ6M)

→ reasonable agreement with NLO **but different p_T, η shapes**

$b \rightarrow \mu + X$

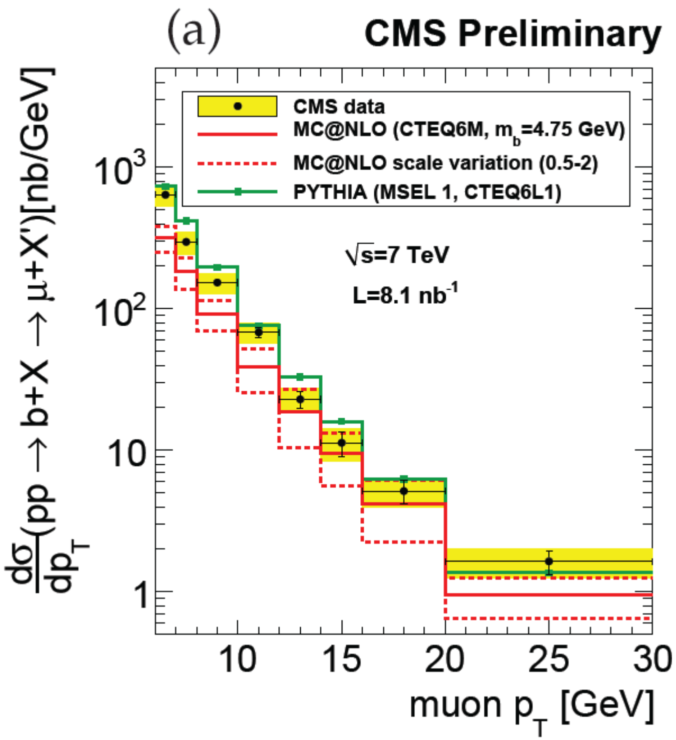


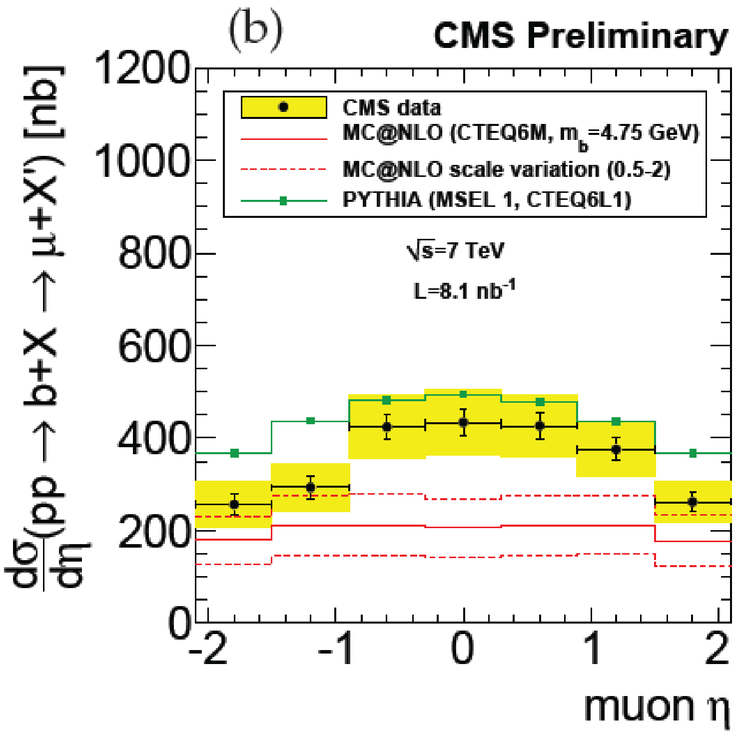
- Measurement from p^T_{rel} distribution fit with b and light-flavors templates

(p_T^μ>6 GeV, $|\eta^\mu|$<2.1)

$$\sigma = (1.48 \pm 0.04_{\rm stat} \pm 0.22_{\rm syst} \pm 0.16_{\rm lumi})\ \mu{\rm b}.$$

$$\sigma_{\rm MC@NLO} = [0.84^{+0.36}_{-0.19}({\rm scale}) \pm 0.08(m_b) \pm 0.04({\rm pdf})]\ \mu{\rm b}.$$



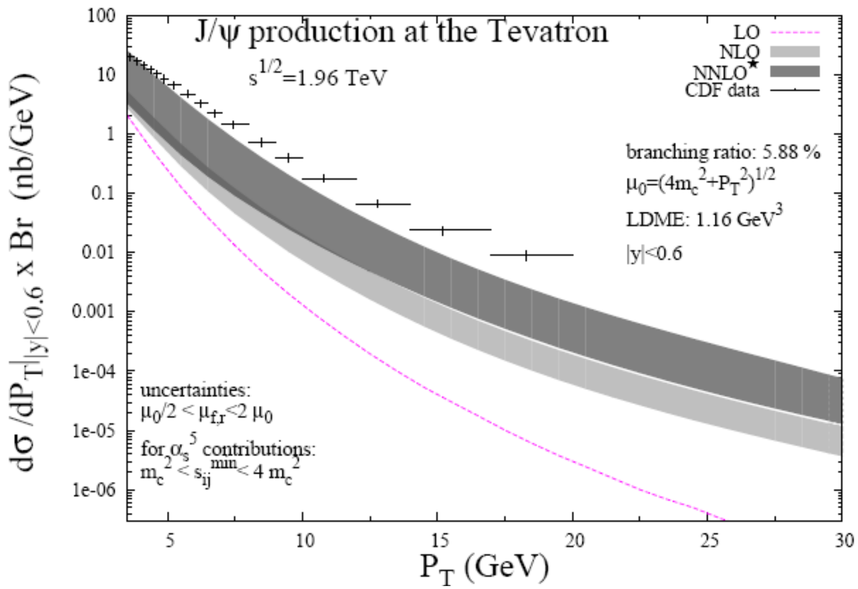


- **NLO underestimates xsec at central η and low p_T (very low p_T!)**

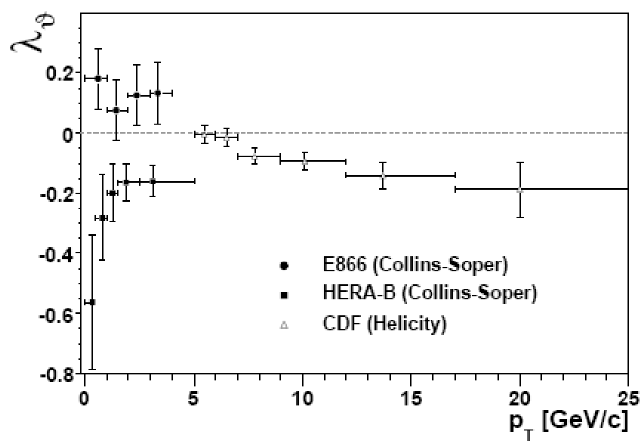
Quarkonia

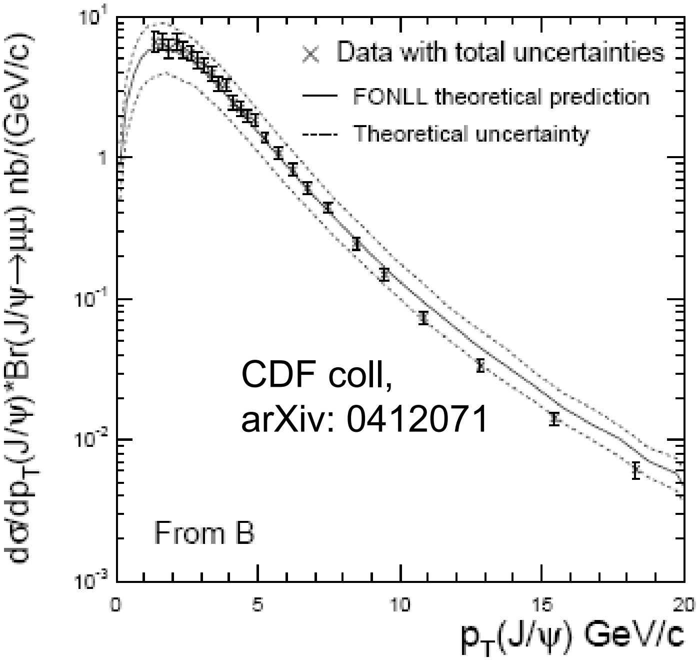
- **Production process** not understood:
  - COM [NRQCD]: long-distance contribution tuned to Tevatron data → check at LHC scale
  - CSM NNLO*

Artoisenet, 2008



- **J/ψ polarization** :
  - transverse polariz. at high p_T in COM
  - longitudinal polariz. in NLO CSM



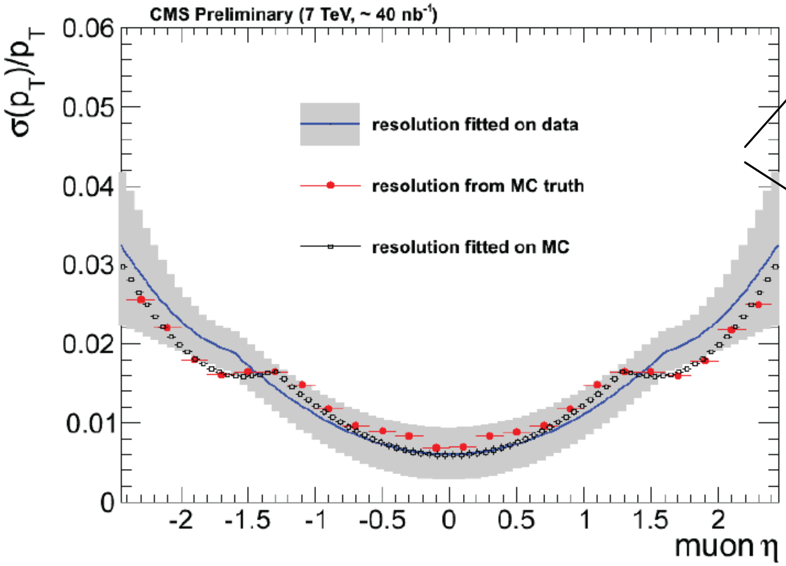


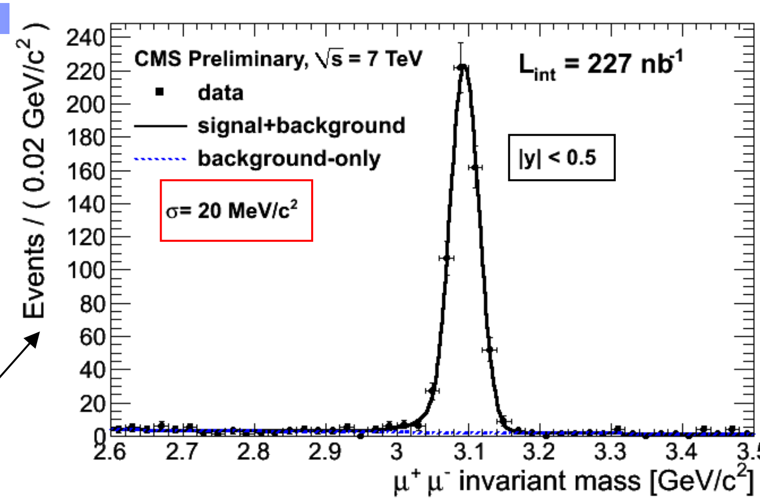
- **Non-prompt J/ψ's for B-cross section**

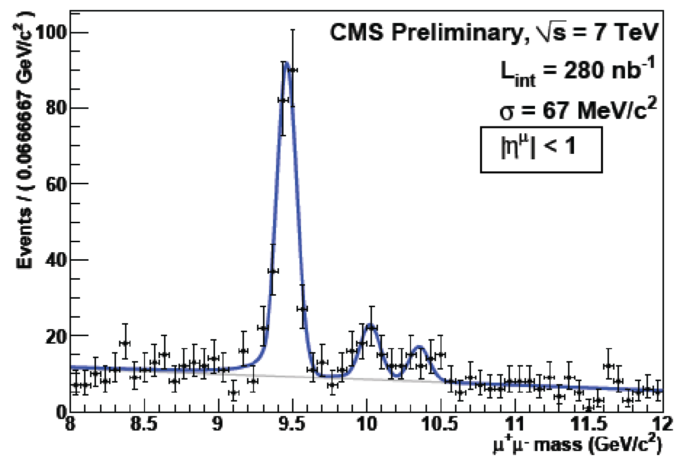
→ CMS can probe wider η and p_T range

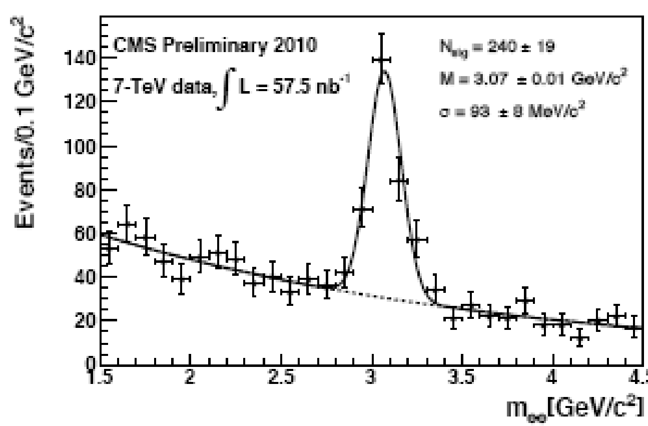
CMS features for J/ψ and Υ

- **Muon final state:**
  - 1%-3% tracking resolution









  - high trigger efficiency up to low p_T

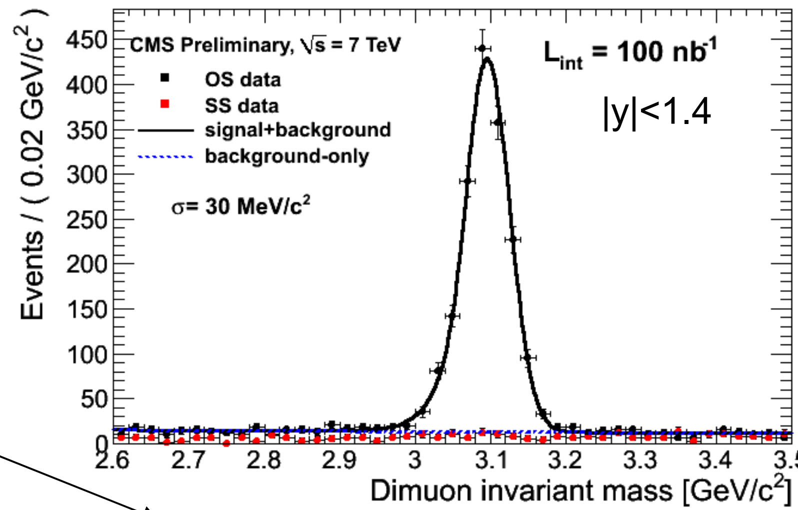
  → ~50k J/ψ per pb^{-1} (up to few E31)

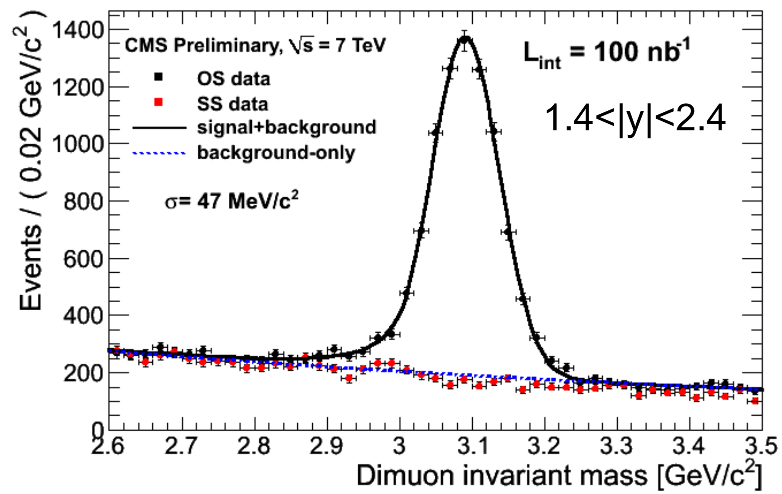
- **Electron final state:**

  MinBias trigger

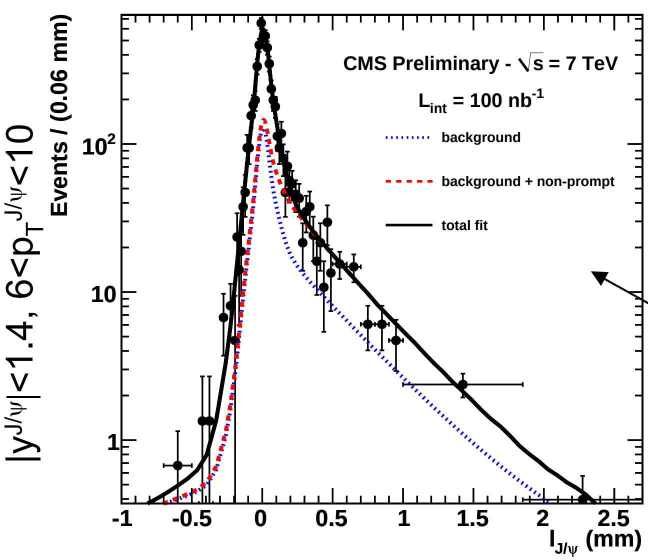
J/ψ analysis

- **Inclusive (same for Υ):**
  - central region with better resolution and low background
  - endcap region down to p_T~0



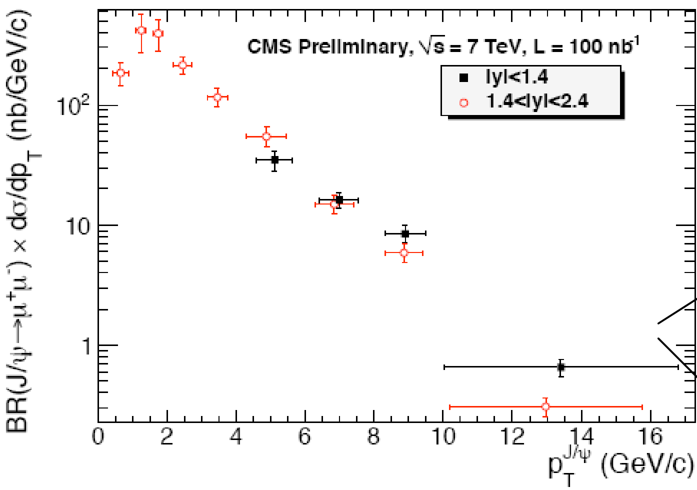


- Largest syst due to stat. uncertainty on efficiency from tag&probe
- Results for 5 polarization hypotheses (difference up to 20%-30% on J/ψ xsec)



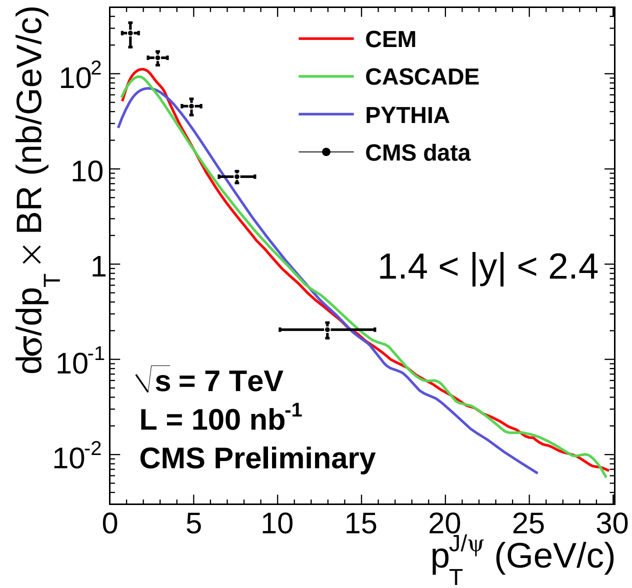
- **Prompt non-prompt separation:**
  - from fit to J/ψ pseudo-decay length
  - (2D fit: mass & decay length)

❑ Inclusive $J/\psi \to \mu\mu$

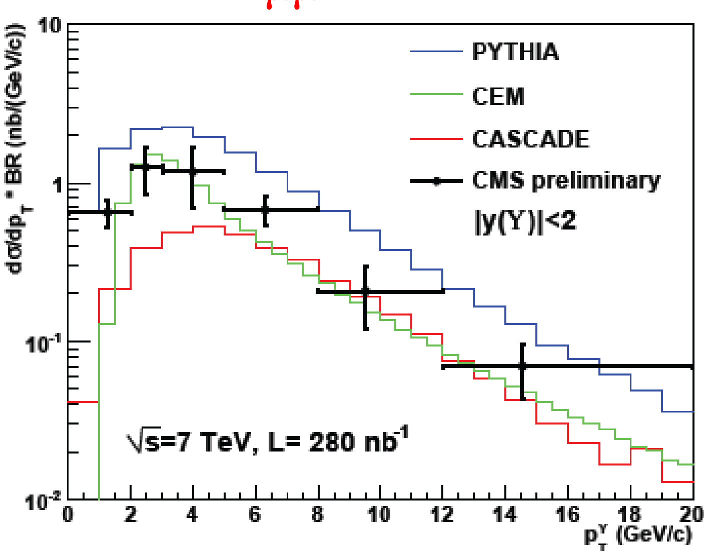


❑ Prompt $J/\psi \to \mu\mu$

(similar behavior in central region)



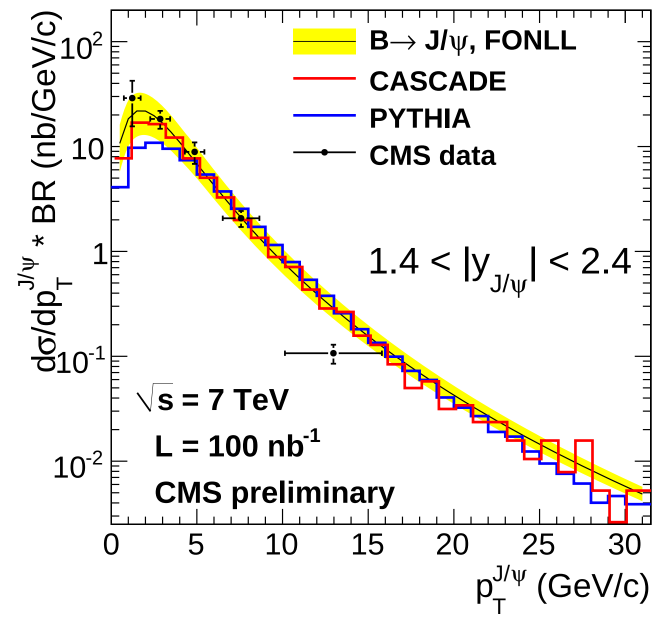
❑ Y1s→μμ



$$[Y(2S)+Y(3S)]/Y(1s) = 0.44 \pm 0.06_{\text{stat}} \pm 0.07_{\text{syst}}$$

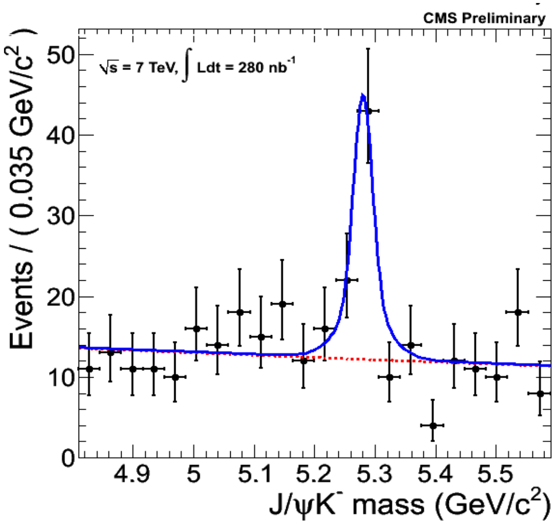
❑ $B \to J/\psi \to \mu\mu$

(good agreement also in central region)

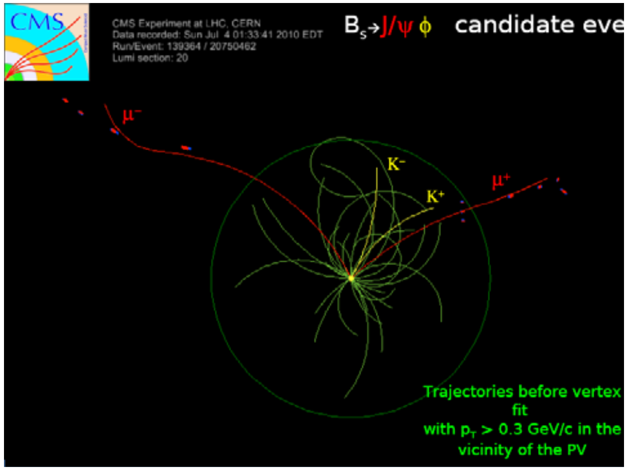


Exclusive B-physics and open charm

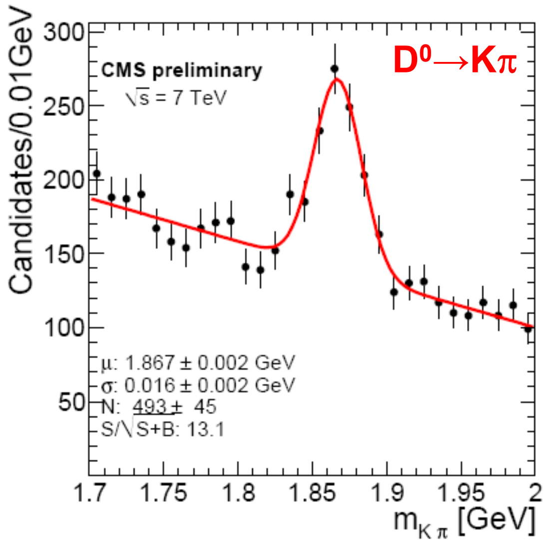
- First mass peak for B→J/ψ K

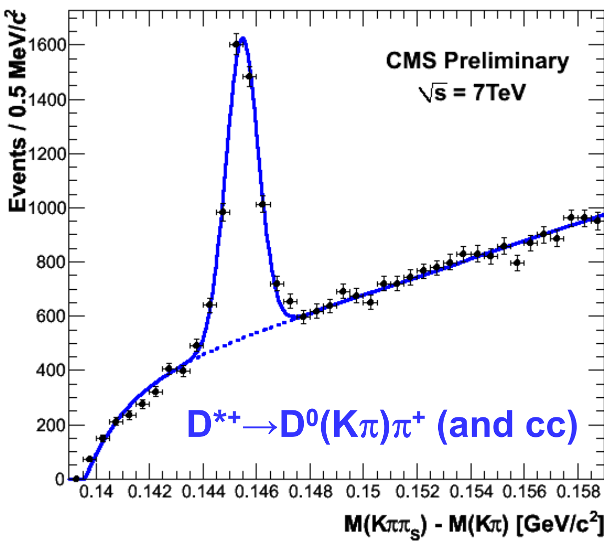


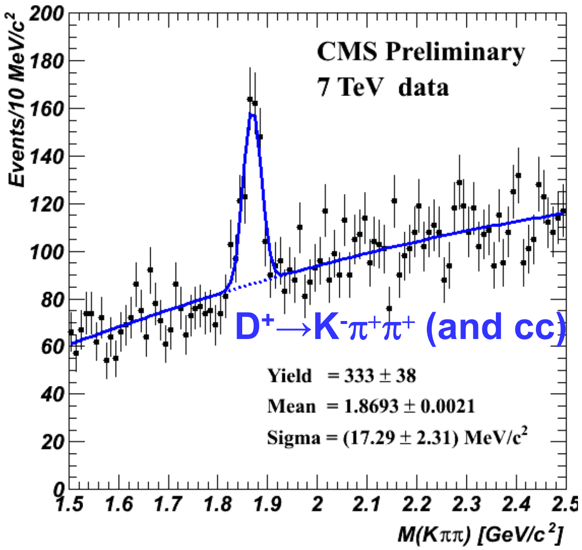
- First candidates for $B_s \to J/\psi\ \phi$



In the meanwhile… we are training with open charm spectroscopy !







Summary

- soft QCD (p_T>50 MeV) for UE tuning
- basic hard QCD measurement for the jet commissioning

  → strategic measurements (2j-3j) to tune non-perturbative component:

  sensitivity to tune Matrix Element MC

- amazing b-tag performance → first b jet measurement

  → **NLO calculation underestimates b xsec at (very!) low p_T and central $|\eta|$**

  GS, FE, FC components under study

- very good trigger efficiency and tracking resolution → rich quarkonia and B-physics program

  → **Y, J/ψ prompt and non-prompt:** first measurement at 7 TeV !

  → first steps into **exclusive B-physics** (training on open-charm)

  $B \rightarrow J/\psi\, K$, $B_s \rightarrow J/\psi\, \phi$ soon!

More details in …

TALKS:

Measurement of the inclusive b production cross section in pp collisions at sqrt(s) = 7 TeV
by L.Caminada in Session 05

Measurement of J/psi, Upsilon and b-hadron production in proton-proton collisions at sqrt(s) = 7 TeV with the CMS experiment
by N.Viegas Guerreiro in Session 05

Studies of QCD jet production with the CMS detector in pp Collisions at sqrt(s) = 7 TeV
by Mikko Voutilainen in Session 03

Underlying Event Studies and Forward Physics at CMS by P.Bartalini in Session 03

POSTERS:

Study of the underlying event with the CMS detector at the LHC
by A.Lucaroni in Session 03

Dijet physics with the CMS detector at LHC
by C.Dragoiu in Session 03

Inclusive b-jet production measurement on early CMS data
by S.M.Honc in Session 01

Study of hadronic event shapes with the CMS detector at LHC
by M.A.Weber in Session 03

Bibliography

QCD-10-005 Measurement of the Underlying Event Activity with the Jet Area/Median Approach at 0.9 TeV

QCD-10-010 Measurement of the Underlying Event Activity at the LHC with $\sqrt{s}$ = 7 TeV and Comparison with $\sqrt{s}$ = 0.9 TeV

QCD-10-006 Transverse-momentum and pseudorapidity distributions of charged hadrons in pp collisions at $\sqrt{s}$ =7 TeV

QCD-10-007 Spectra of identified hadrons in pp collisions at $\sqrt{s}$ = 0.9 and 7 TeV

QCD-10-011 Measurement of the Inclusive Jet Cross Section in pp Collisions at 7 TeV

QCD-10-012 Measurement of the 3-jet to 2-jet Cross Section Ratio in pp Collisions at $\sqrt{s}$ = 7 TeV

QCD-10-015 Dijet Azimuthal Decorrelations and Angular Distributions in pp Collisions at $\sqrt{s}$ = 7 TeV

QCD-10-013 Hadronic Event Shapes in pp Collisions at 7 TeV

EXO-10-001 Search for Dijet Resonances in the Dijet Mass Distribution in pp Collisions at $\sqrt{s}$ = 7 TeV

BPH-10-009 Inclusive b-jet production in pp collisions at $\sqrt{s}$ = 7 TeV

BPH-10-007 Open beauty production cross section with muons in pp collisions at $\sqrt{s}$ = 7 TeV

BPH-10-002 J/ψ prompt and non-prompt cross sections in pp collisions at $\sqrt{s}$ = 7 TeV

BPH-10-003 Inclusive Upsilon production cross section in pp collisions at $\sqrt{s}$ = 7 TeV

BTV-10-001 Commissioning of b-jet identification with pp collisions at $\sqrt{s}$ = 7 TeV

JME-10-003 Jet Performance in pp Collisions at $\sqrt{s}$=7 TeV

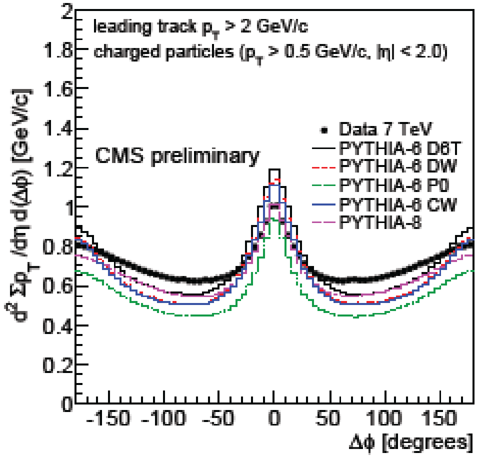
Back-up

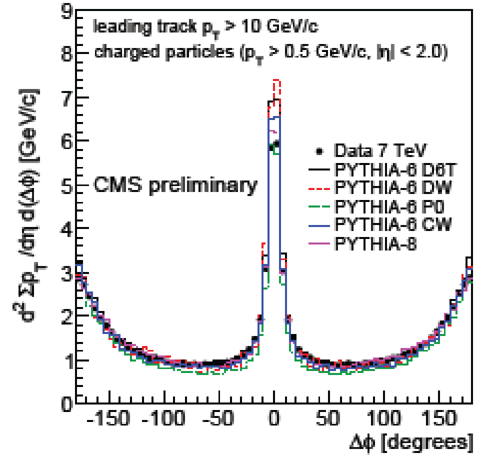
First Results from **CMS** on **QCD, Quarkonia, and Heavy-Flavour Physics** in proton-proton Collisions at $\sqrt{s}$=7 TeV

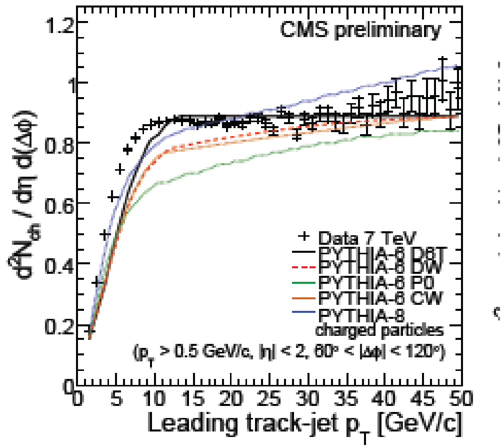
ICHEP PARIS 2010

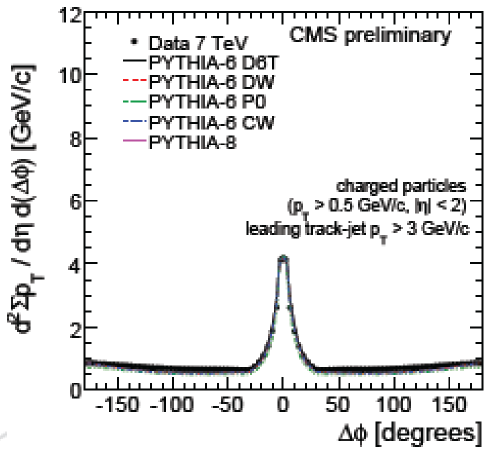
Session 01: Early Experience and Results from LHC

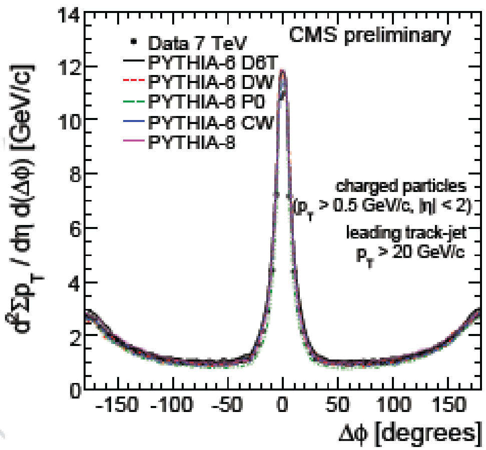
Underlying event: tunes

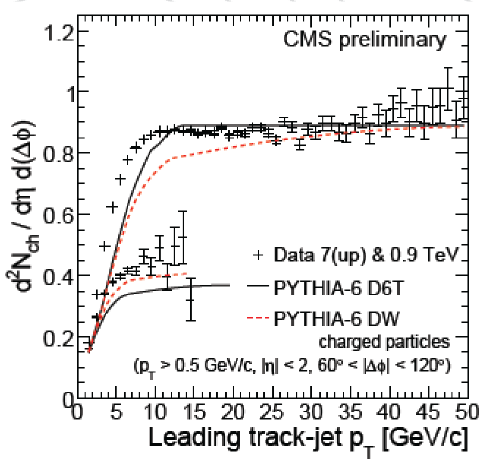


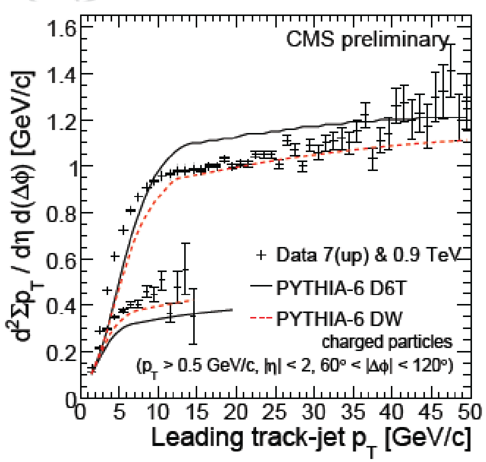












regularization of $1/(p_T)^4$ divergence of the leading order partonic scattering amplitude

$$1/\hat{p}_T^4 \rightarrow 1/(\hat{p}_T^2 + \hat{p}_{T_0}^2)^2$$

p_{T0} cut-off parameterized by

$$\hat{p}_{T_0}(\sqrt{s}) = \hat{p}_{T_0}(\sqrt{s_0}) \cdot (\sqrt{s} / \sqrt{s_0})^{\epsilon}$$

dN/dη and dN/dp$_T$ for NSD

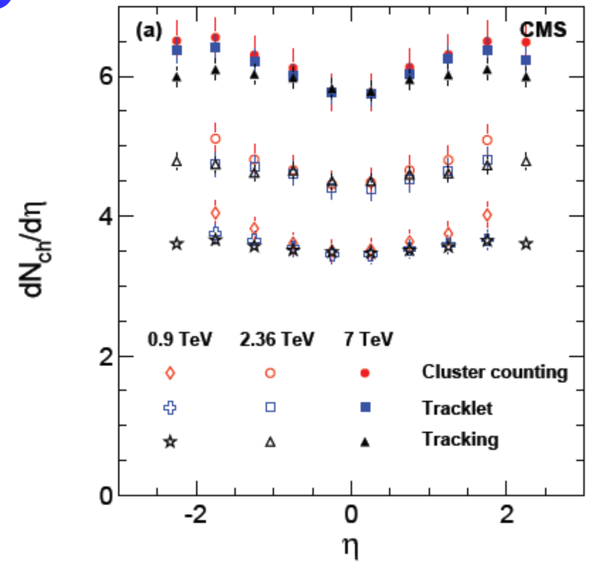
- **Correction for SD and DD**

  → 2.5% uncert.from SD and DD fraction

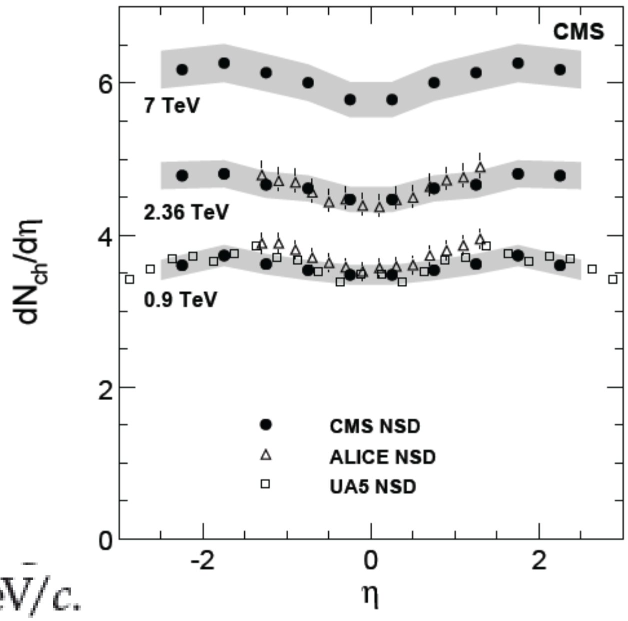
  (3.7% uncert. from ev.selection)

	PYTHIA	
	Frac.	Sel. eff.
SD	19.2%	26.7%
DD	12.9%	33.6%
ND	67.9%	96.4%
NSD	80.8%	86.3%

checked with data with 20% precision (sensitive HF variables)



- 3 methods:
  - pixel cluster counting
    - **pT>30 MeV**
    - **4.4% sys**: 3% from cluster selection
  - pixel tracklets (cluster pairs) counting
    - **pT>50 MeV**
    - **2.9% sys**: 1.9% reco efficiency
  - track counting (pixel+strip)
    - **pT>100 MeV**
    - **2.4% sys**: 2.0% reco efficiency



- dN/dp$_T$ for $|\eta|<2.4$ and $p_T>0.1$

  → extrapolated to 0,inf with Tsallis fit

$$\langle p_T \rangle = 0.545 \pm 0.005\,(\text{stat.}) \pm 0.015\,(\text{syst.})\,\text{GeV}/c.$$

Jet performances

❑ **4 (!) jet reconstruction algorithms with energy corrections from MC:**

- **Calorimeter Jets**

  p0 ECAL mass peak, p0 HCAL response

  → uncertainty JES 10%, JER 10%

- **Jet-Plus-Tracks**
- **Track Jets**

  good precision on B field, tracker material budget and alignm.

- **Particle-Flow Jets**

  particle composition of jets agree with simulation at few %

  fragmentation impact on energy corrections < 3%

  → uncertainty JES 5%, JER 10%

- Relative energy: 2% uncertainty, linearly increasing with η

❑ anti-K_T algorithm with D=0.5

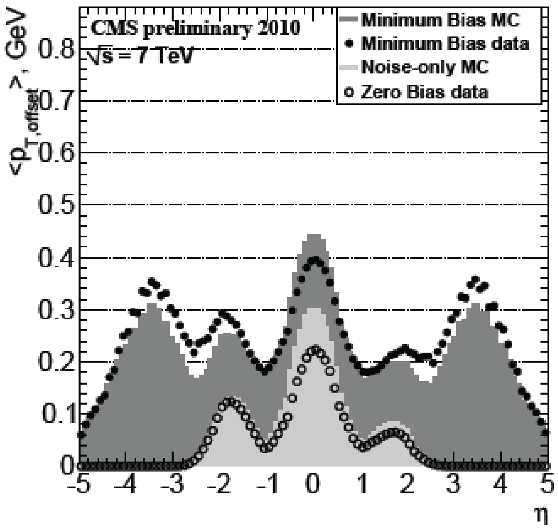
❑ jet quality cuts (100% eff. pT>50)

- EM fraction, more cells or channels combined
- sizable charged component (not only electrons)

❑ single jet trigger:

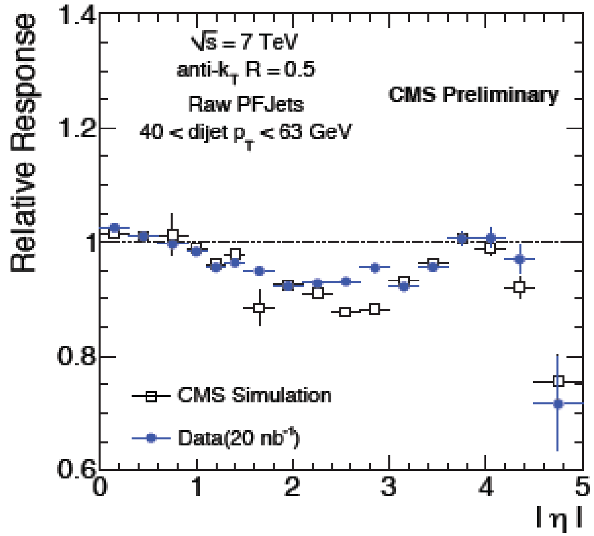
L1 jet>6 GeV + HLT jet > 15 GeV (uncorrected)

JES: cross-checks with data

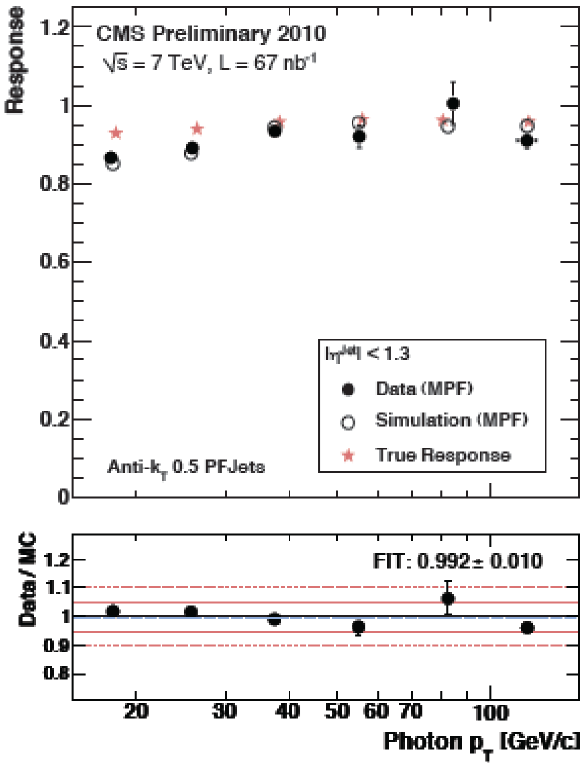


- **Offset correction:**
  - noise + Pile Up

<NPU> ~ 0.001 → 0.5

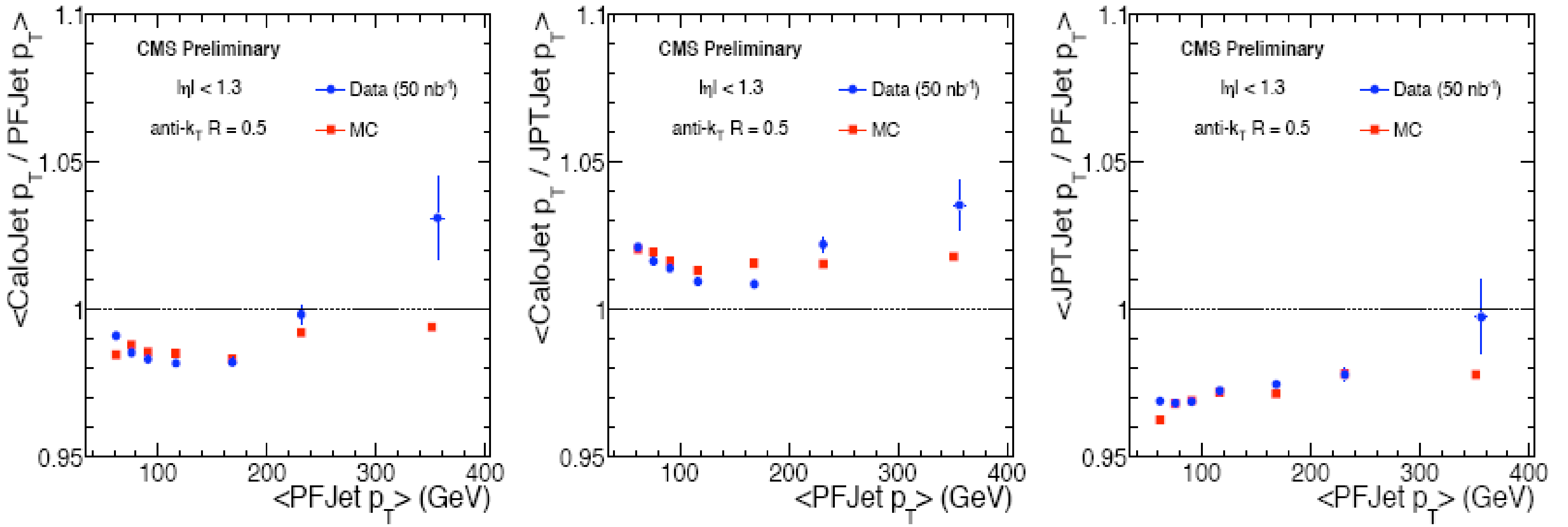


- **Energy scale VS η**
  - dijet p_T balance

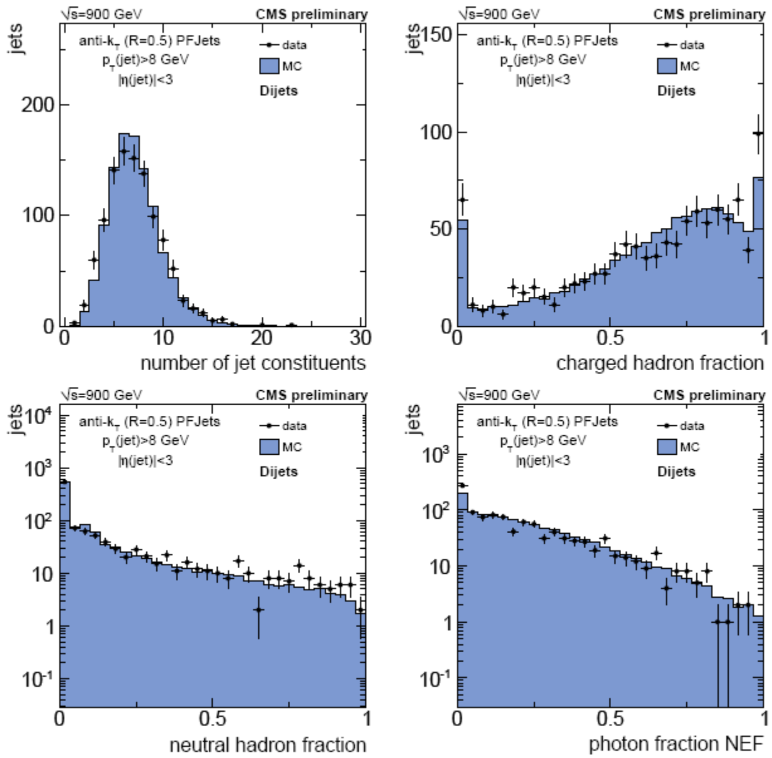


- **Absolute scale**
  - photon+jet

JES: cross-checks between different algorithms

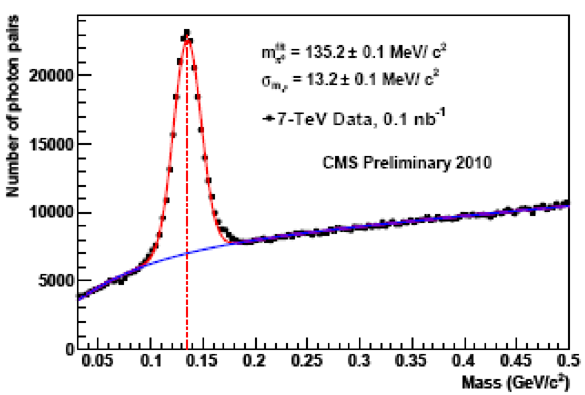


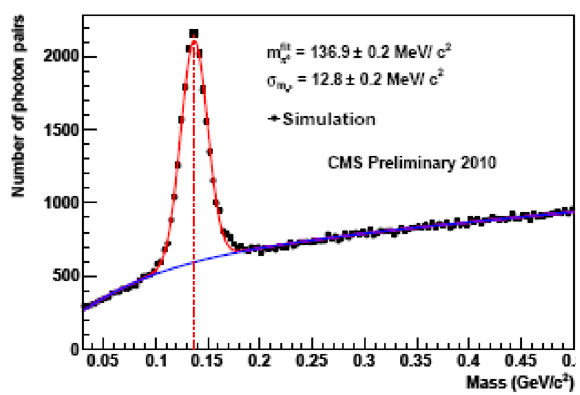
Ingredients of JES for PFJets



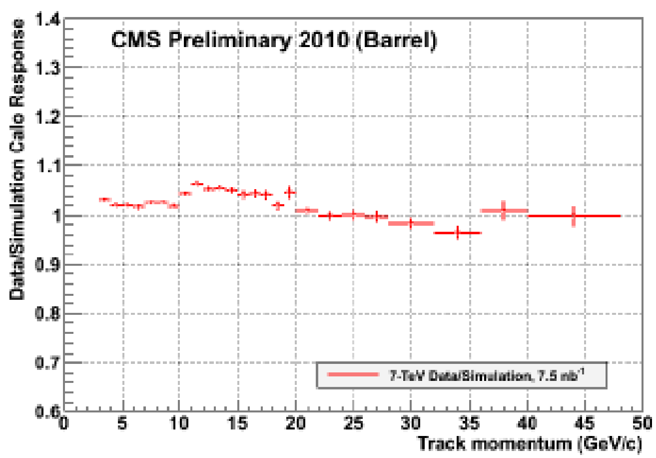
- Jet composition

- Photons





- Hadrons

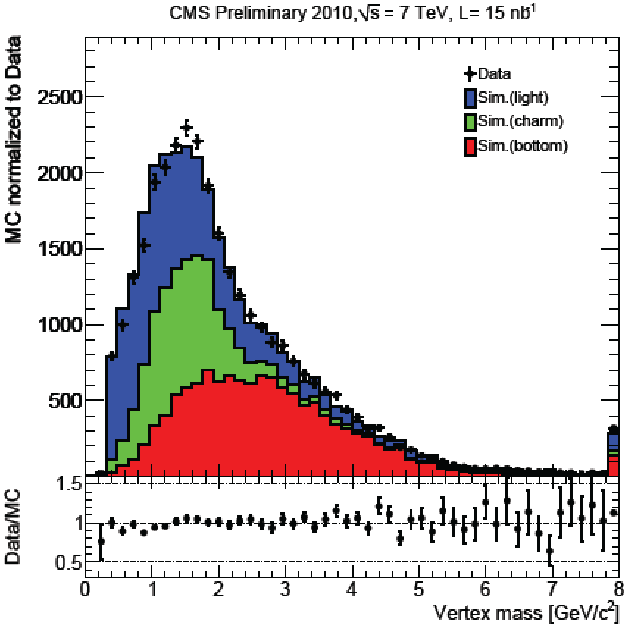


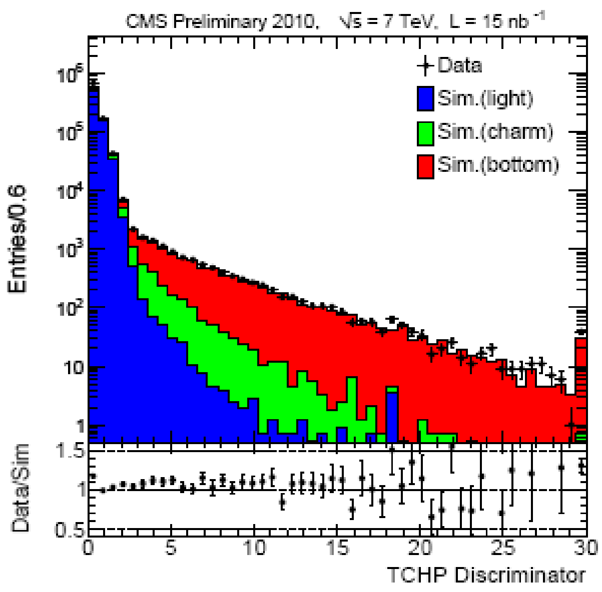
b-tagging

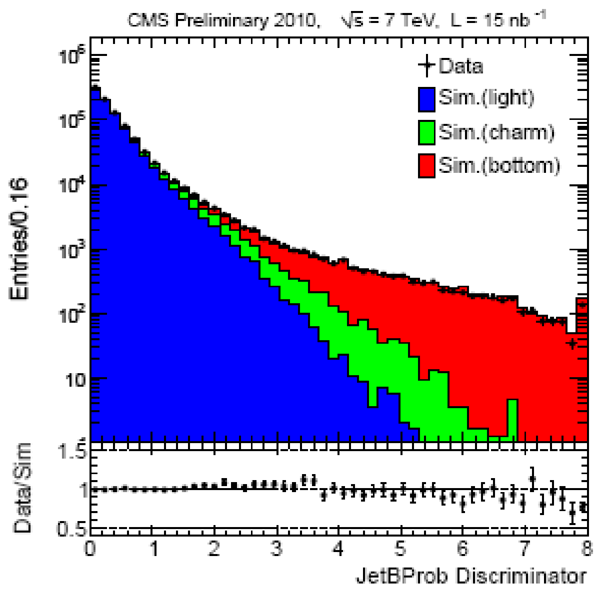
- For all the b-tagging algorithms amazing data-MC agreement for all the involved variable !
  - b-tag efficiency from data: p^T_{rel} fit with MC templates for passing/failing tag requirement

    $\varepsilon_{data}/\varepsilon_{MC}$ >~ 0.85
  - mistag rate from data, assuming mistag/negative rate same in data and MC

    $\varepsilon^{mistag}_{data}/\varepsilon^{mistag}_{MC}$ >~90%

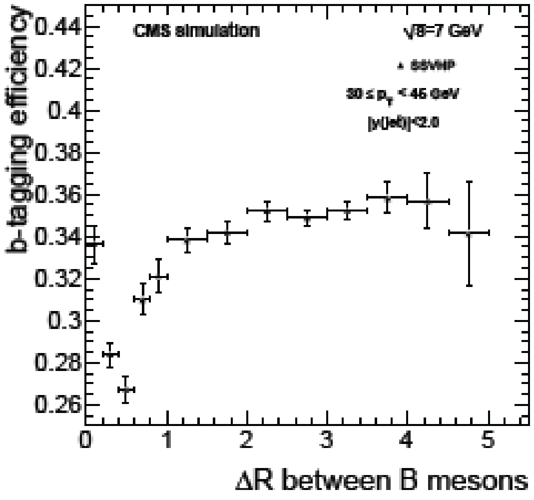




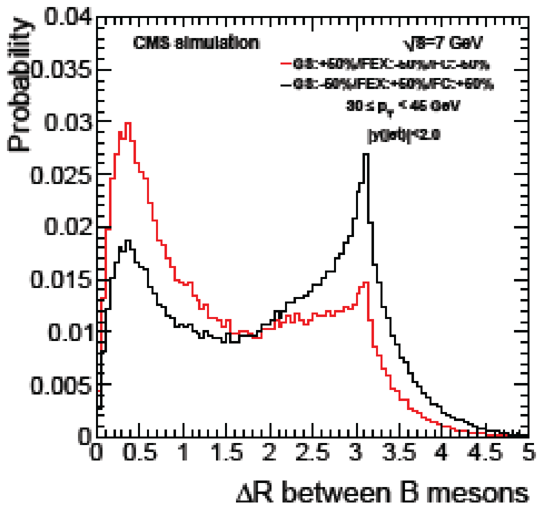


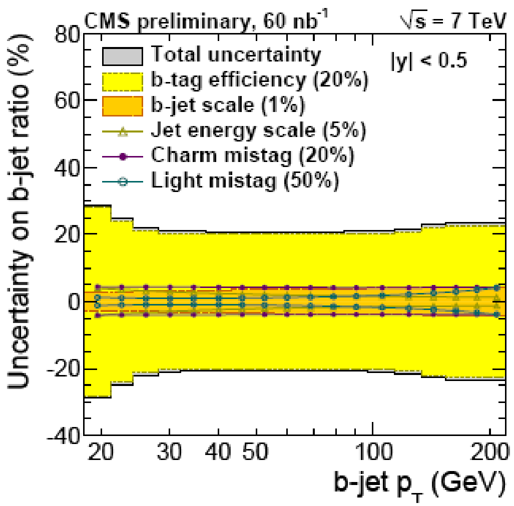
b-jet xsec: systematics

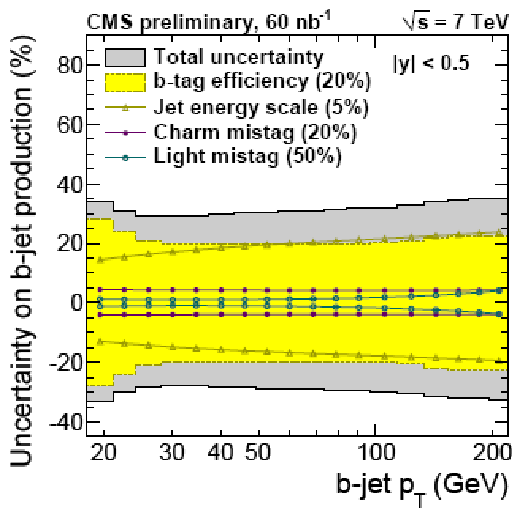
- b-tag efficiency:
  - from data (p_T^{rel}) with **20%** uncertainty
  - from MC, depends on FC,FEX,GS fractions composition checked with p_T^{SV}/p_T^{jet} varied by 50% → **2%** syst.



- mistag rate from MC:
  - **10%** syst. from ±50% LF fraction
  - **3-4%** uncert. from ±20% c mistag rate (constrained from SV mass fit)







$b \rightarrow \mu + X$: systematics

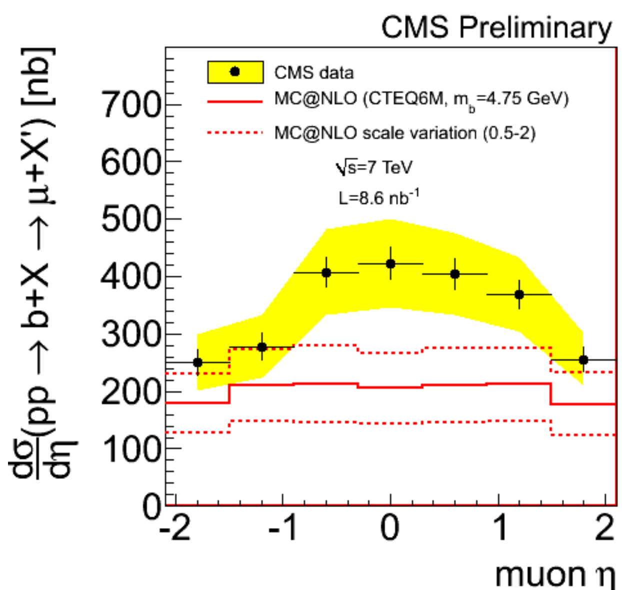
- $p_T^{\mu}>5$ GeV, $|\eta^{\mu}|<2.1$ (track jets, $p_T>1$ GeV)
  - Light Flavors template from data

    reweighting hadron spectrum with muon fake rate probability (from data) and considering p_T^{Rel} for any tracks → **1-14% syst**
  - c template from MC → unique LF template

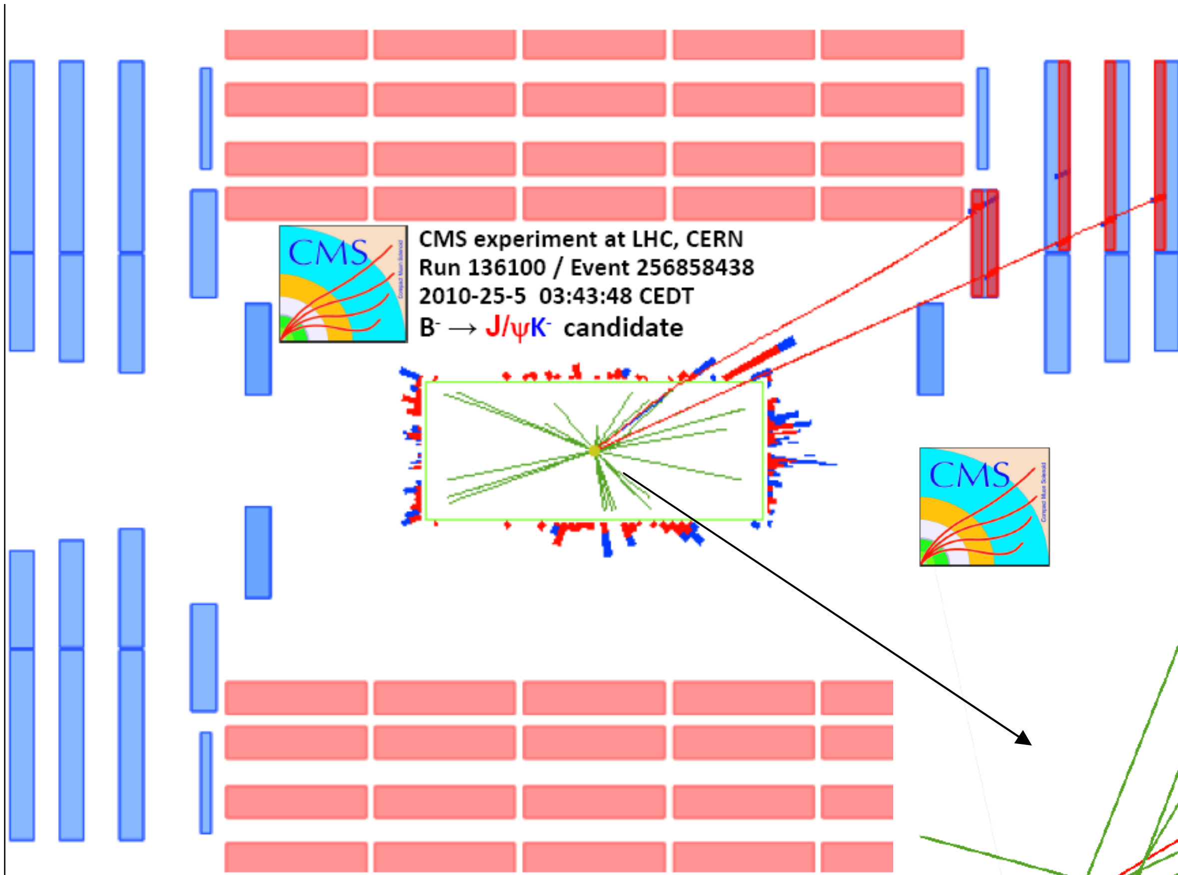
    c VS udsg content → **2-8% syst**
  - b template from MC

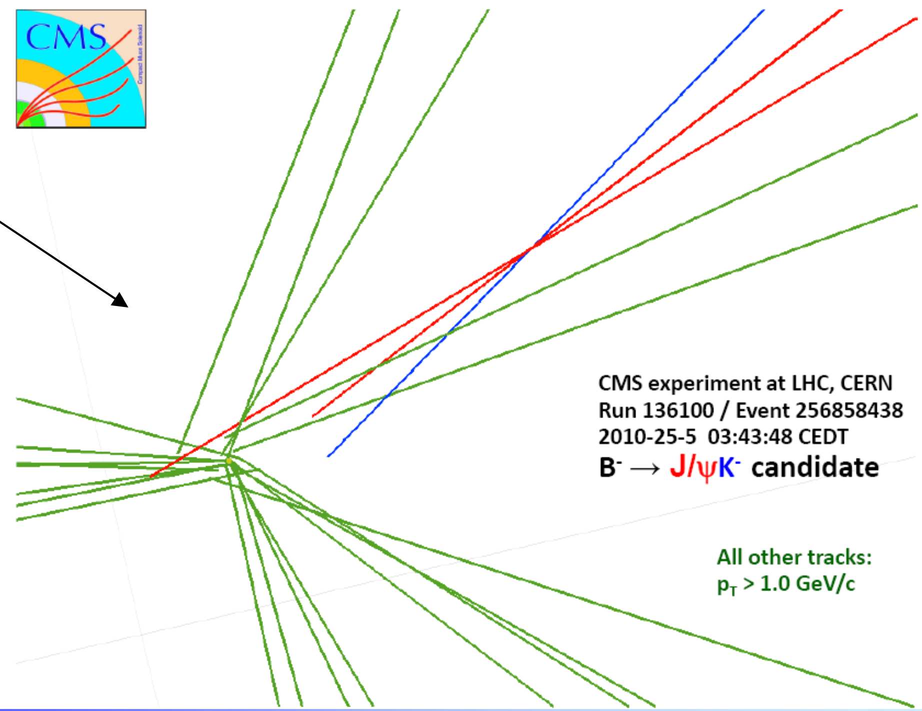
    2-5% syst. from FC, FE, GS (Pythia VS Herwig)
  - UE description has effect on track jet efficiency → 8% syst
  - 11% syst from luminosity

Source	Uncertainty
Luminosity	11 %
Trigger	3–5 %
Production mechanism	2-5 %
b hadron decays	3 %
Fragmentation	1–4 %
Tracking efficiency	2 %
c vs. *udsg* content	2–8 %
udsg template	1–14 %
Underlying event modeling	8 %
MC event statistics	1-4%
Total	18-21%



First step in exclusive B-physics





B^- → J/psi K^- Event Reconstruction in CMS

Contact: cms-pag-conveners-bph@cern.ch

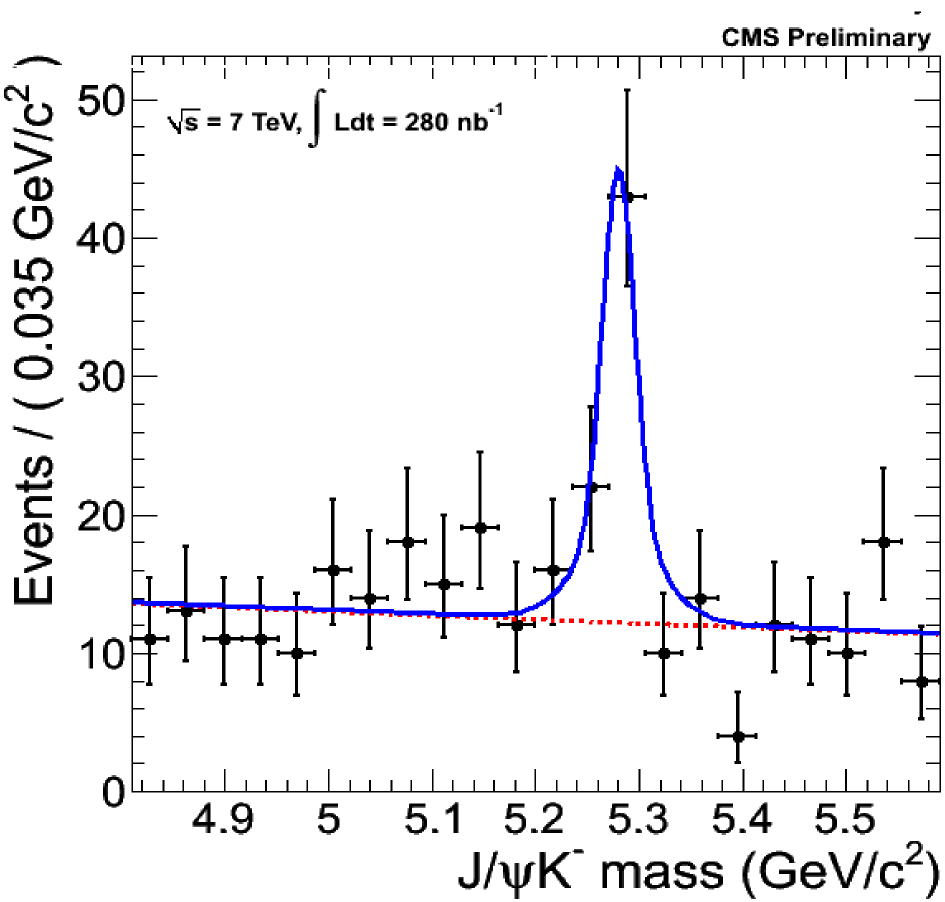
Date: July 20, 2010

- Select opposite sign di-muon combinations,
- Select combination/event with mass closest to the J/psi mass
- Select events with a di-muon vertex Probability >0.1%
- Muons satisfying quality criteria (require a muon chamber segment matching in position and direction with the prediction of the associated track extrapolation)
- At least one muon required to fire the trigger
- Both muons required to have p_T(mu)>3 GeV/c, |eta(mu)|<2.4
- Combine J/psi candidate with tracks (p_T>0.9 GeV/c)
- Kinematic fit with J/psi mass constraint
- Require vertex probability > 0.1%
- If multiple candidates/event, choose highest p_T B^- candidate

J/psi K^- Invariant Mass Plot

Contact: cms-pag-conveners-bph@cern.ch
Date: July 20, 2010

Single Muon trigger
(p_T >3 GeV/c cut at HLT level)
$ct/sigma_{ct}$ >1
ct:transverse decay length of J/psiK^- vertex relative to primary vertex
$sigma_{ct}$=error on transverse decay length



1-d fit to J/psiK^- invariant mass:

- Signal: sum of three Gaussians (means and widths fixed to MC)
- Mean: 5.280 GeV/c^2
- Resolution = 32 MeV/c^2 (weighted sum of gaussian resolutions)
- Background is fitted with exponential function (slope floated in the fit)
- N_sig = 48 ± 8

Inclusive D^0 production

- Information:
  - Contact: Andrey Starodumov
    starodum@mail.cern.ch
  - Presented for approval: May 4
    http://indico.cern.ch/conferenceDisplay.py?confId=93495
- Selection criteria
  - 'good' runs: 132440 - 133038
  - transverse momentum cuts

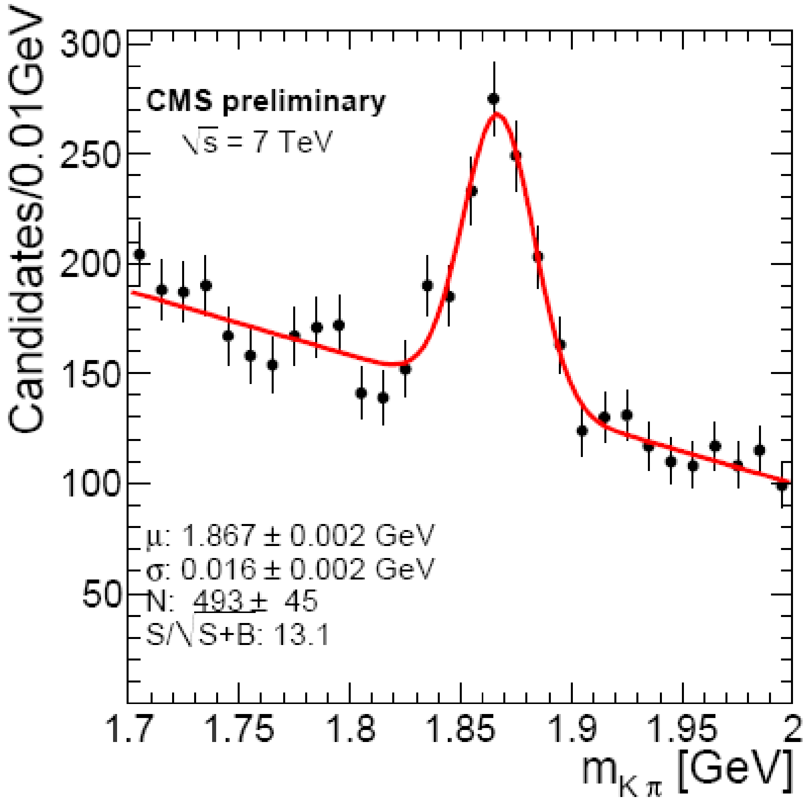
$$p_\perp(K) > 1.25\,\mathrm{GeV}$$
$$p_\perp(\pi) > 1.0\,\mathrm{GeV}$$
$$p_\perp(D^0) > 3.0\,\mathrm{GeV}$$

  - Vertexing cuts

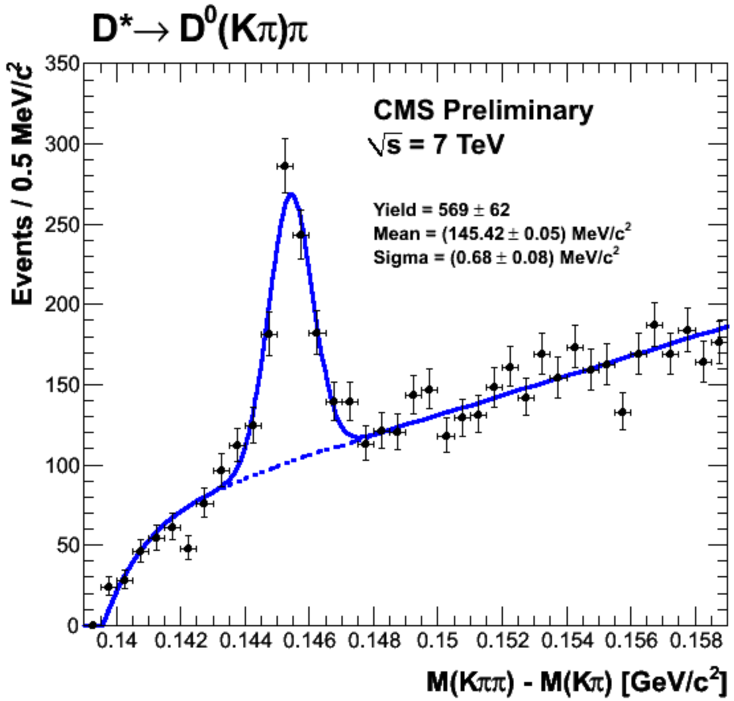
$$d(K,\pi) < 0.025\,\mathrm{cm}$$
$$\chi^2 < 4.5$$
$$3 < l_{xy}/\sigma(l_{xy}) < 20$$
$$\sigma(l_{xy}) < 0.03\,\mathrm{cm}$$

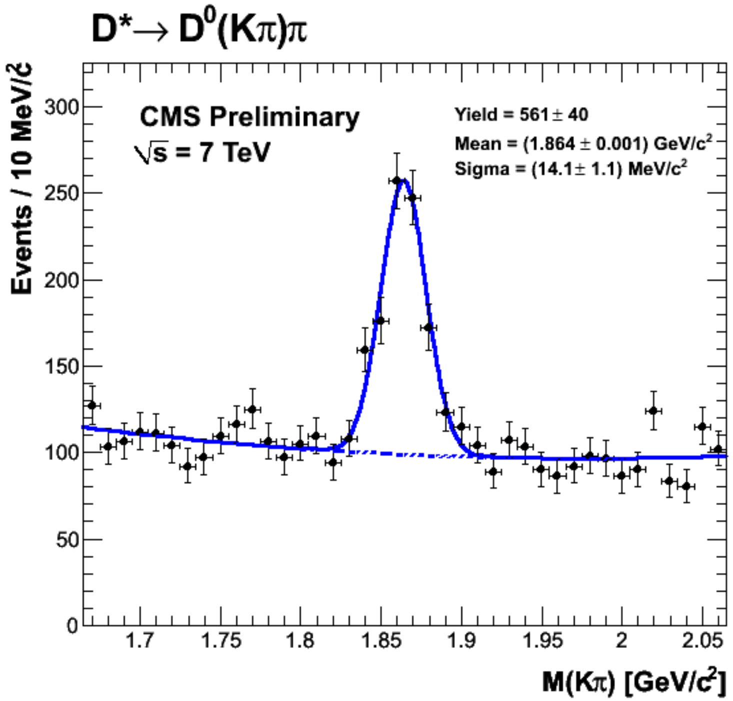
  - D^0 momentum vs. PV-SV direction

$$\angle(\vec{p}_{D^0}, \overline{PV:SV}) < 0.1$$



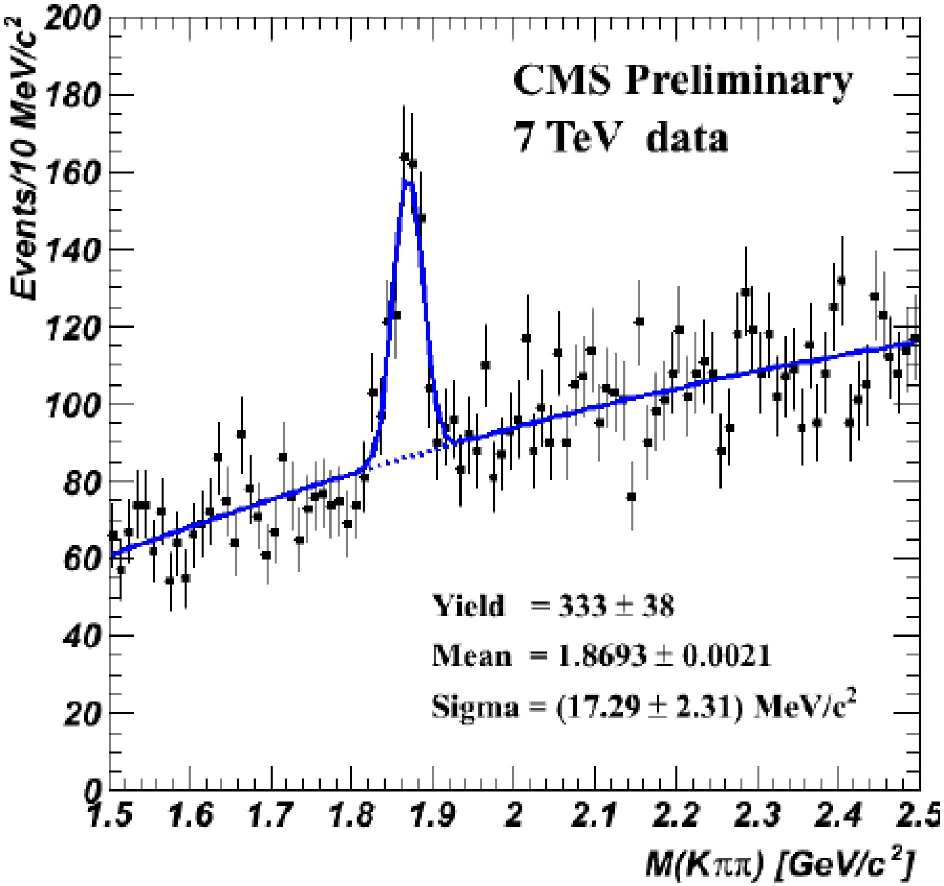
- MC expectations
  - Peak: $1.863 \pm 0.002\,\mathrm{GeV}$
  - Width: $0.014 \pm 0.002\,\mathrm{GeV}$





- Contact: Andrzej Zuranski
  - Andrzej.Zuranski@cern.ch
- Pre-approval talk
- Data: ~37M events in good runs:
  - /MinimumBias/Commissioning10-Apr20Skim_GOODCOLL-v1
  - /MinimumBias/Commissioning10-GOODCOLL-v9
- Reconstruct $D^* \rightarrow D^0\pi_S$, $D^0 \rightarrow K\pi$
  - Kinematic selection:
    - p_T > 600 MeV/c for K and π
    - p_T > 250 MeV/c for π_S
    - p_T > 5.0 GeV/c for D^*
      - Select D^* candidate with highest p_T if there is more than one in an event
  - Track quality:
    - N_{hit} > 5 (except for π_S)
    - χ^2 / ndof < 2.5
    - $|d_{xy}|$ < 1mm; $|\Delta z|$ < 1cm
  - Mass windows (when plotting the other mass variable):
    - $|M(K\pi) - PDG| < 25$ MeV/c²
    - $|M(K\pi\pi) - M(K\pi) - PDG| < 1.2$ MeV/c²
- Unbinned extended ML fit (RooFit)
  - Signal = Gaussian
  - Bkg = threshold function for ΔM and quadratic for $M(K\pi)$
- Date: May 4, 2010

D^+ search



Information

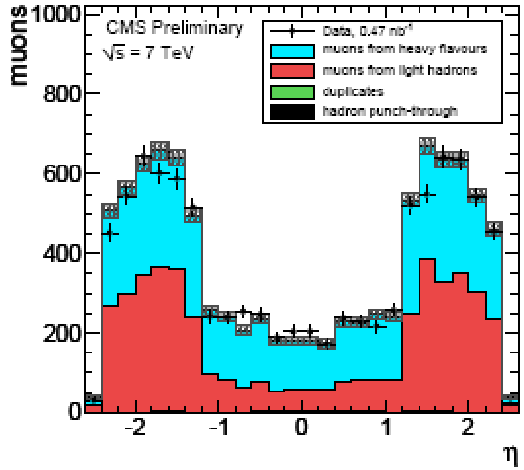
- Contact: Daniele Pedrini
  pedrini@cern.ch
- Preapproval talk at the Tracker DPG - Tracking POG meeting April 29, 2010
  - http://indico.cern.ch/conferenceDisplay.py?confId=82582
- Data: ~24M events from: MinimumBias/Commissioning10-GOODCOLL-v8/RAW-RECO
- Search for $D^+ \to K^- \pi^+ \pi^+$ (and c.c.)
  - secondary vertex formed by 3 tracks with total charge ±1
  - topological approach: L/S and D^+ pointing to the primary
  - Momentum cuts on tracks:
    $p > 1.5$ GeV
    $p_T > 0.1$ GeV
- Binned ML fit (Minuit)
  - Signal = Gaussian
  - Bkg = 2^{nd} order polynomial

More details of the analysis can be found at

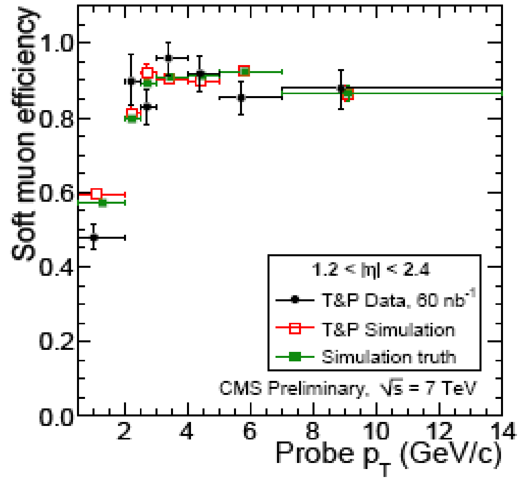
- https://twiki.cern.ch/twiki/bin/viewauth/CMS/DplusAt7TeV

Muons

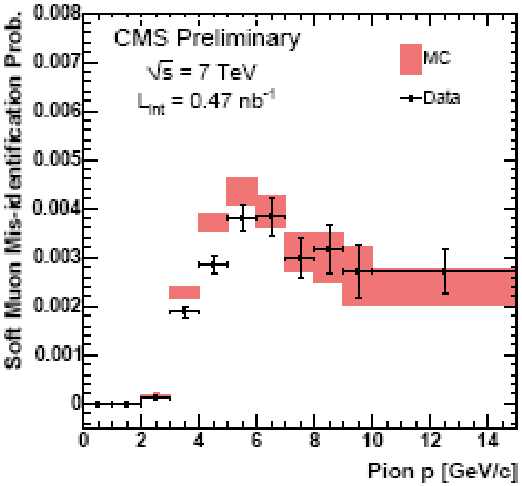
Inclusive muons



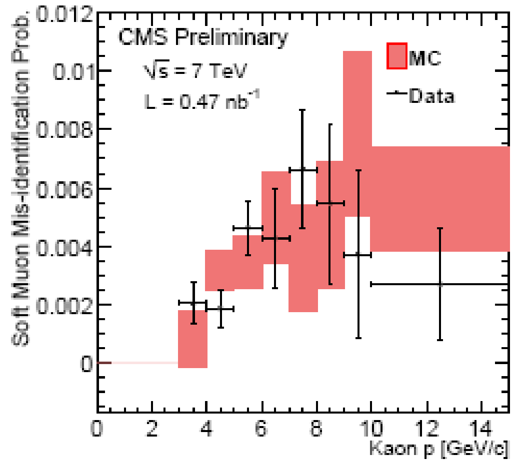
from J/ψ→μμ



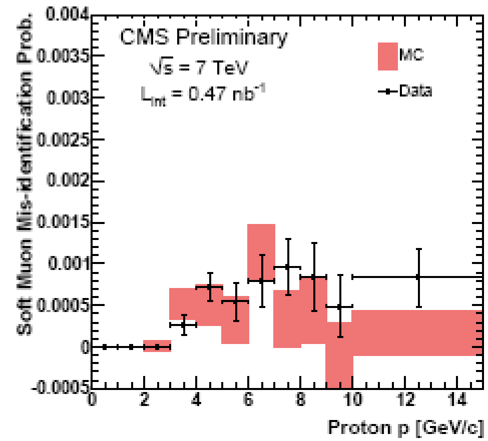
Efficiency and fake rates measured from data (good agreement with MC)



from $K^0_s \rightarrow \pi\pi$



from $\phi \rightarrow KK$



from $\Lambda \rightarrow p\pi$