ATLAS
Heavy Quark Measurements and future plans

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(Università di Napoli "Federico II" and INFN)

On behalf of the ATLAS Collaboration

"Heavy Flavor-11 Workshop"

International Workshop on Heavy Quark Production in Heavy-ion Collisions

Purdue University, January 4-6, 2011

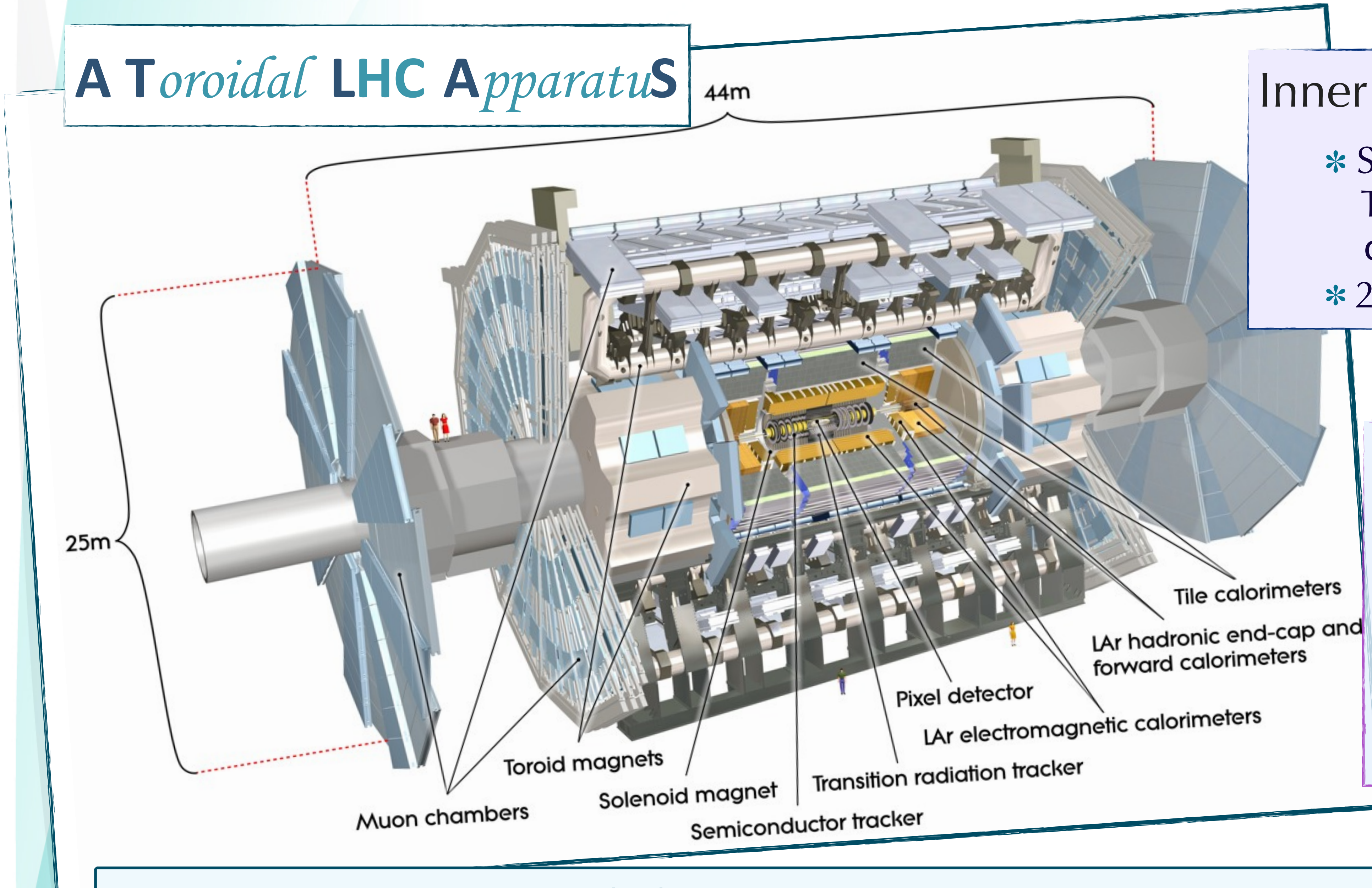
Outline

- The ATLAS detector performance
- The ATLAS Heavy Flavor Physics
- 2010 data:
  - p-p runs:
    - Charmonium: J/ψ & ψ' observation, measurements of inclusive production, differential cross section and non-prompt to prompt ratio
    - Observation of Υ system
    - Observation of D^*, D^+, D_s
    - Observation of $B^{+/-} \rightarrow J/\psi\, K^{+/-}$
  - Pb-Pb runs results
- Plans for future

About ATLAS

The ATLAS detector at LHC

A T_oroidal_ **LHC A**_pparatu_**S**



Inner detector ($|\eta| < 2.5$):

- Silicon pixel and strip, Transition Radiation Tracker (TRT) $\sigma/p_T \approx 5 \cdot 10^{-4} p_T \oplus 0.001$
- 2T Solenoidal field

Calorimeters ($|\eta|<5$):

- EM : Pb-LAr $\sigma/E \approx 10\%/\sqrt{E(GeV)} \oplus 0.7\%$
- HADRONIC: Iron Scintillator Tiles $\sigma/E \approx 50\%/\sqrt{E(GeV)} \oplus 3\%$
- Forward (FCal) :$3.2<|\eta|<5$

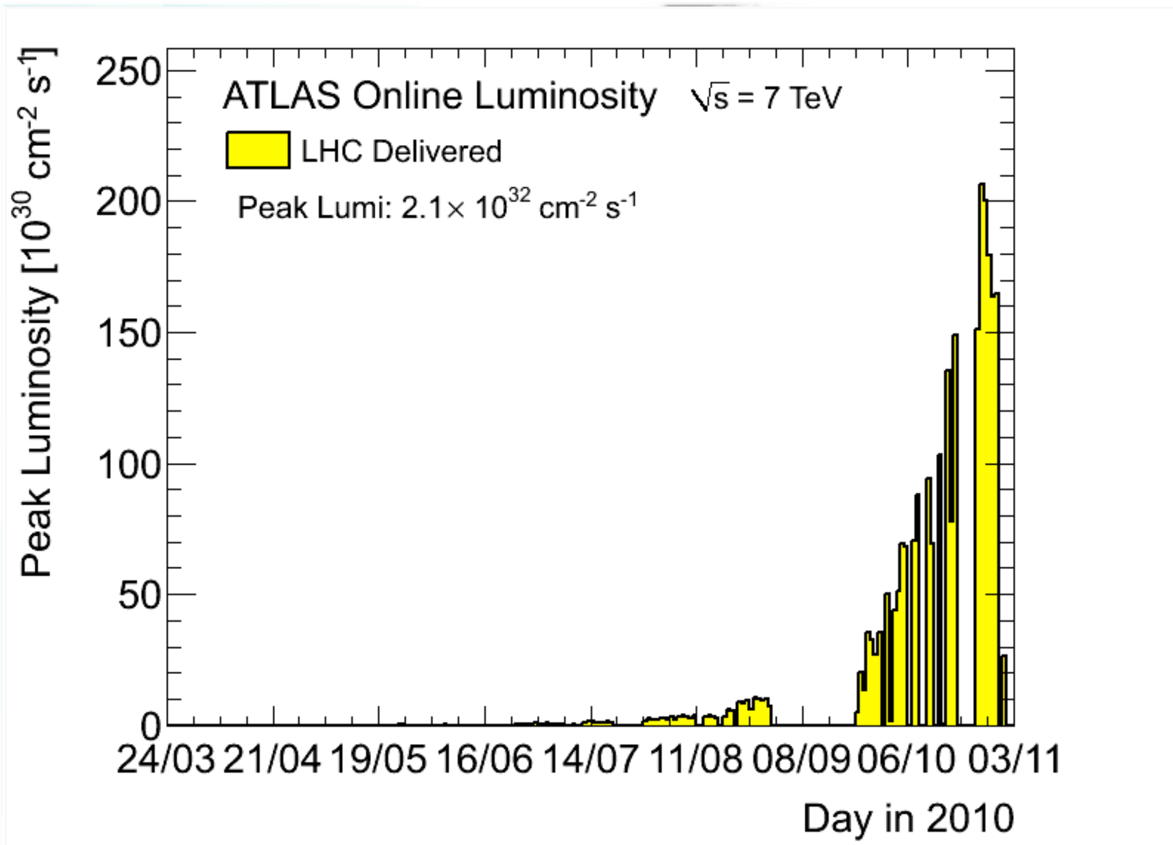
Muon Spectrometer ($|\eta| < 2.7$):

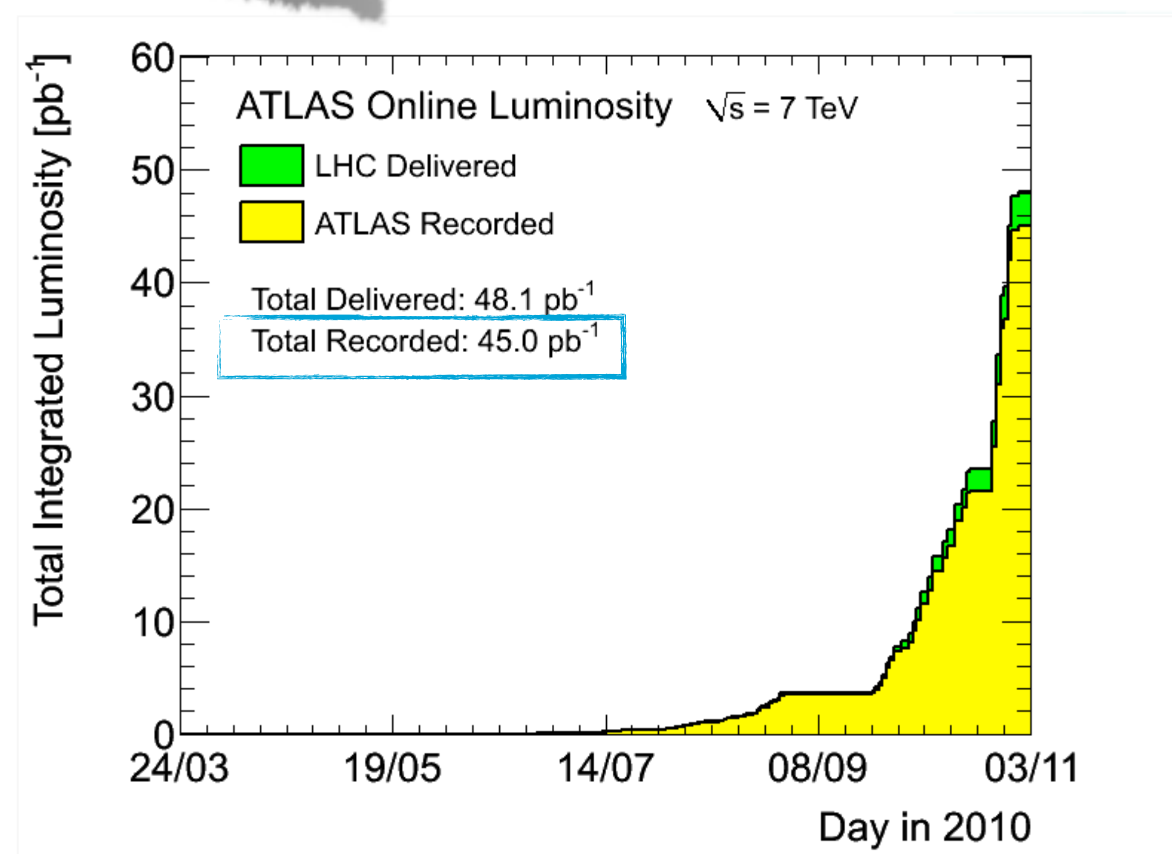
- Trigger chambers: Resistive Plate Chambers (RPC) & Thin Gap Chambers (TGC) - $\sigma_t \sim$ ns
- 0.5 T Toroidal field
- Coordinate Measurements Chambers: Monitored Drift Tubes (MDT) & Cathode Strip Chambers (CSC) $\sigma/p_T \approx 10\%$ (for $p_T = 1$ TeV/c)

2010 data-taking

(https://twiki.cern.ch/twiki/bin/view/AtlasPublic/RunStatsPublicResults2010)

p-p collisions@√s =7 TeV
March 2010 ->November 2010





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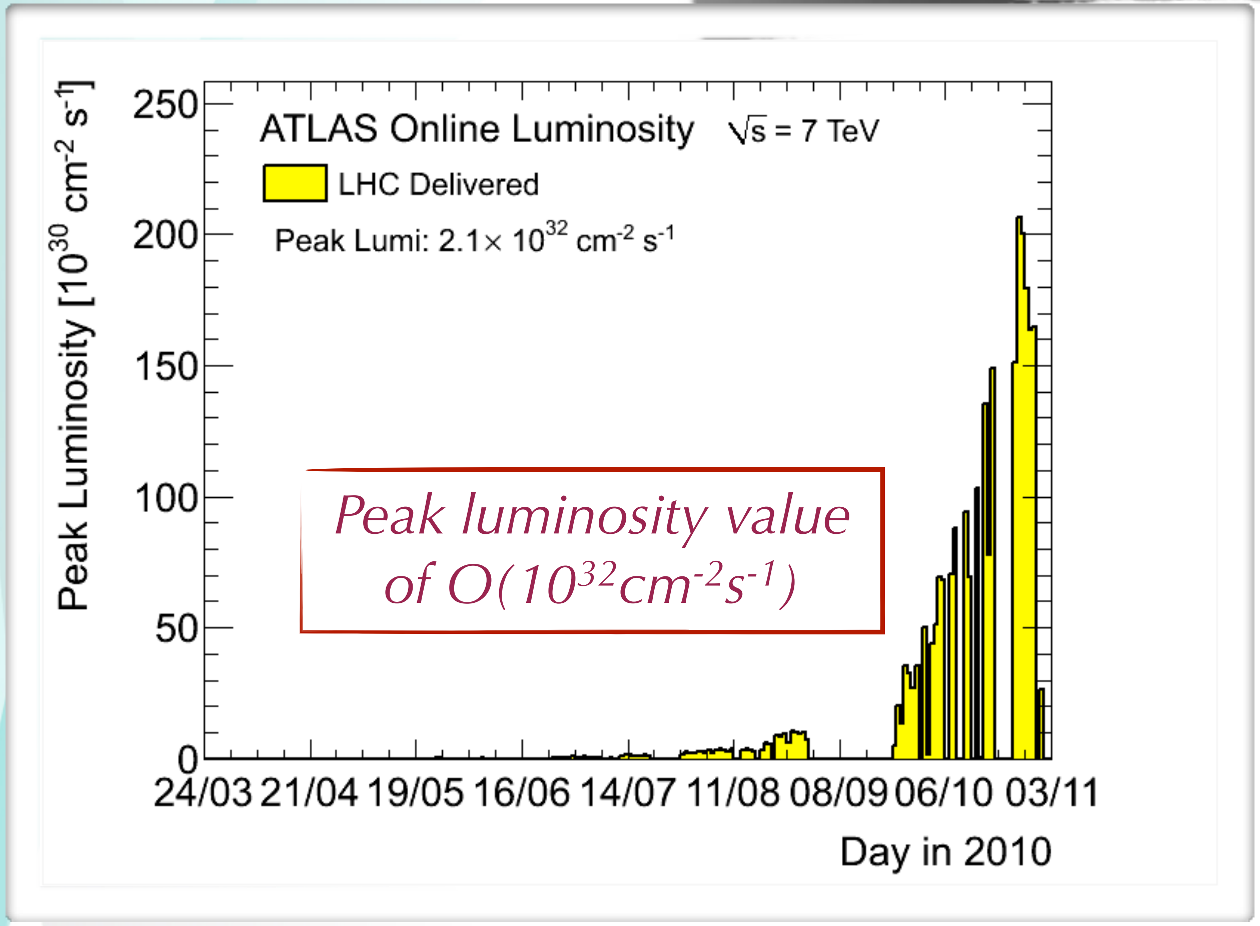

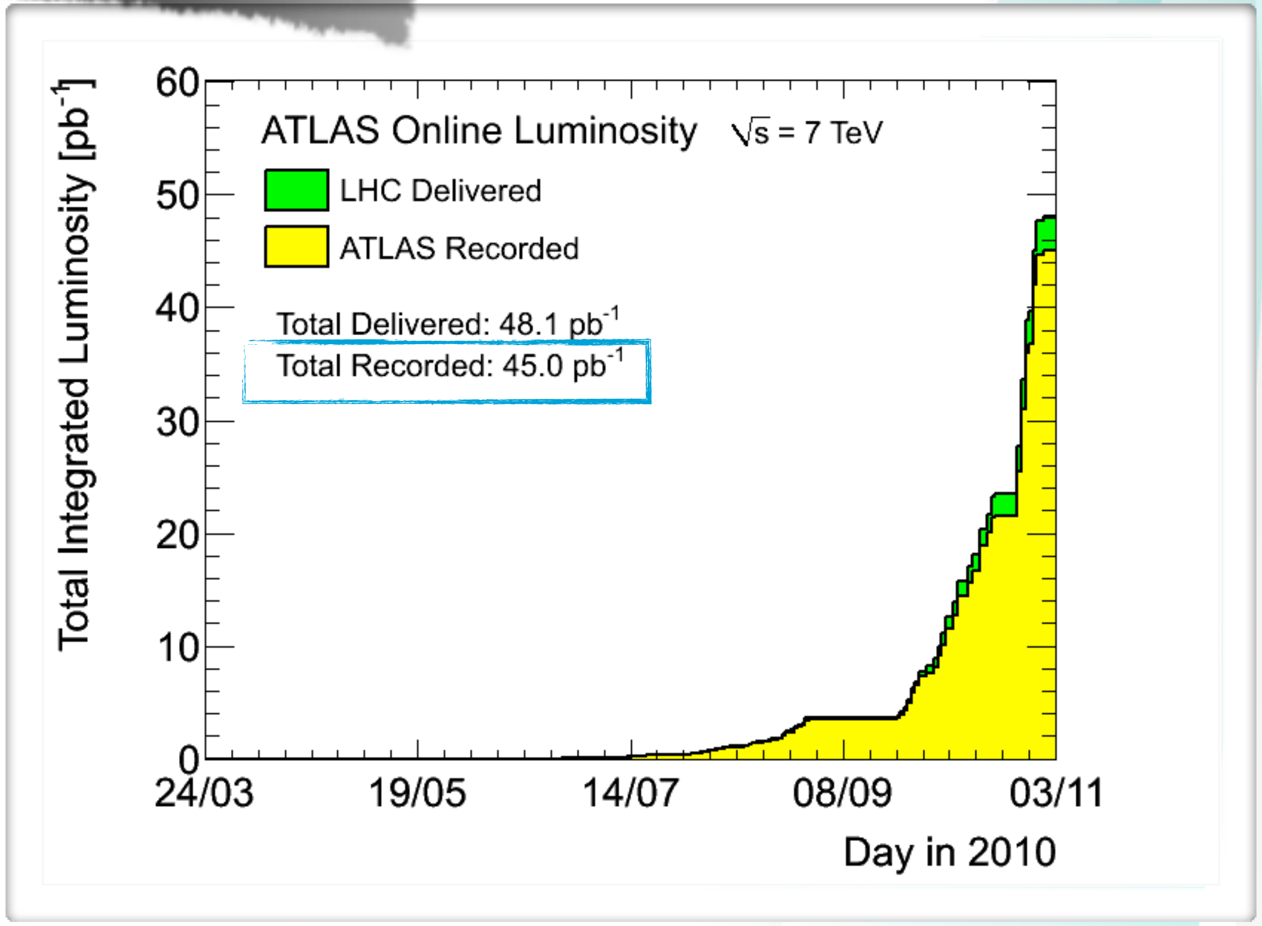

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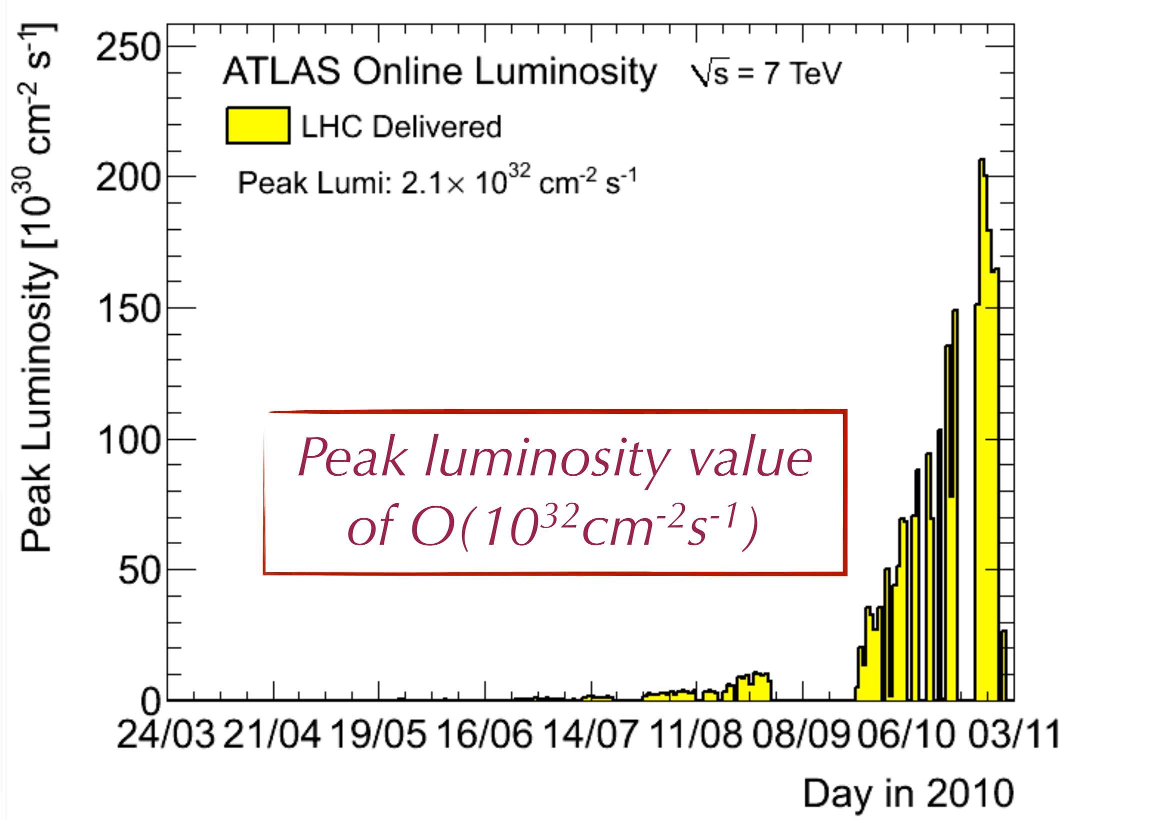
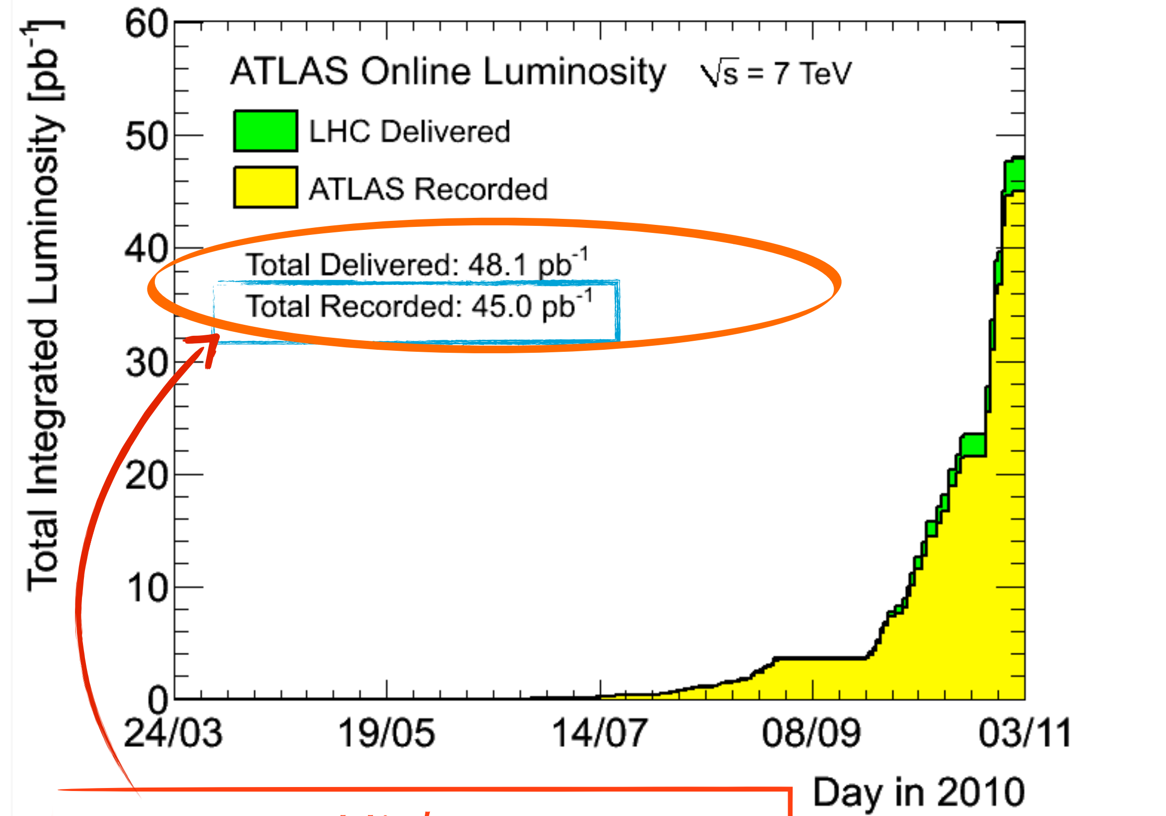


Peak luminosity value of $O(10^{32}cm^{-2}s^{-1})$



Highest
(wrt other LHC experiments)
data taking efficiency: ~94%

Performance

ATLAS Detector Status

Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	97.3%
SCT Silicon Strips	6.3 M	99.2%
TRT Transition Radiation Tracker	350 k	97.1%
LAr EM Calorimeter	170 k	97.9%
Tile calorimeter	9800	96.8%
Hadronic endcap LAr calorimeter	5600	99.9%
Forward LAr calorimeter	3500	100%
LVL1 Calo trigger	7160	99.9%
LVL1 Muon RPC trigger	370 k	99.5%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.5%
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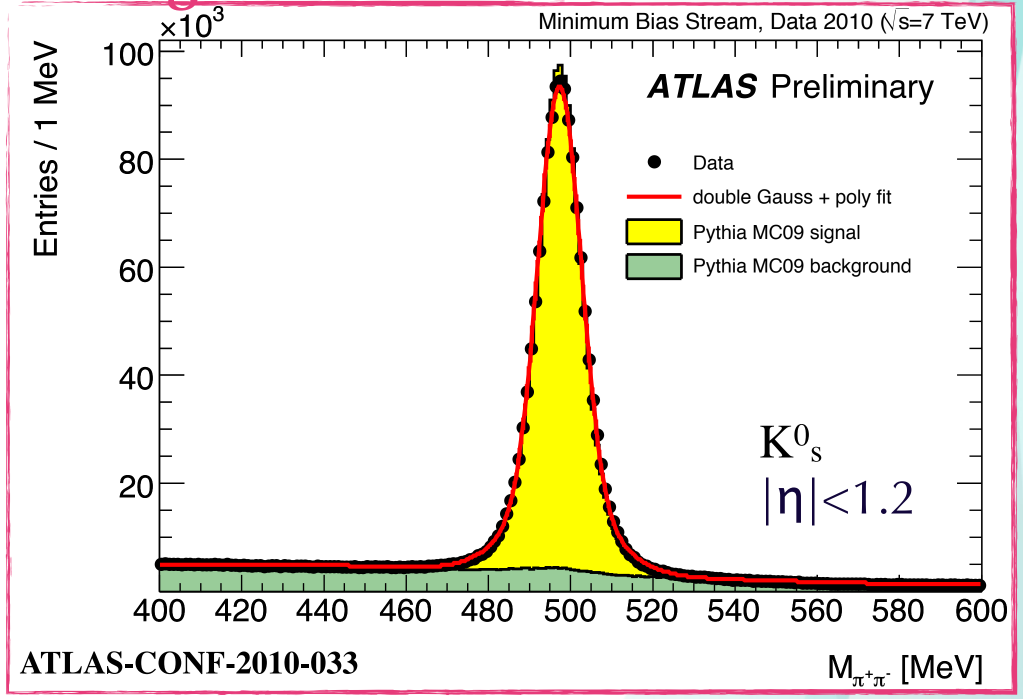
Tracking



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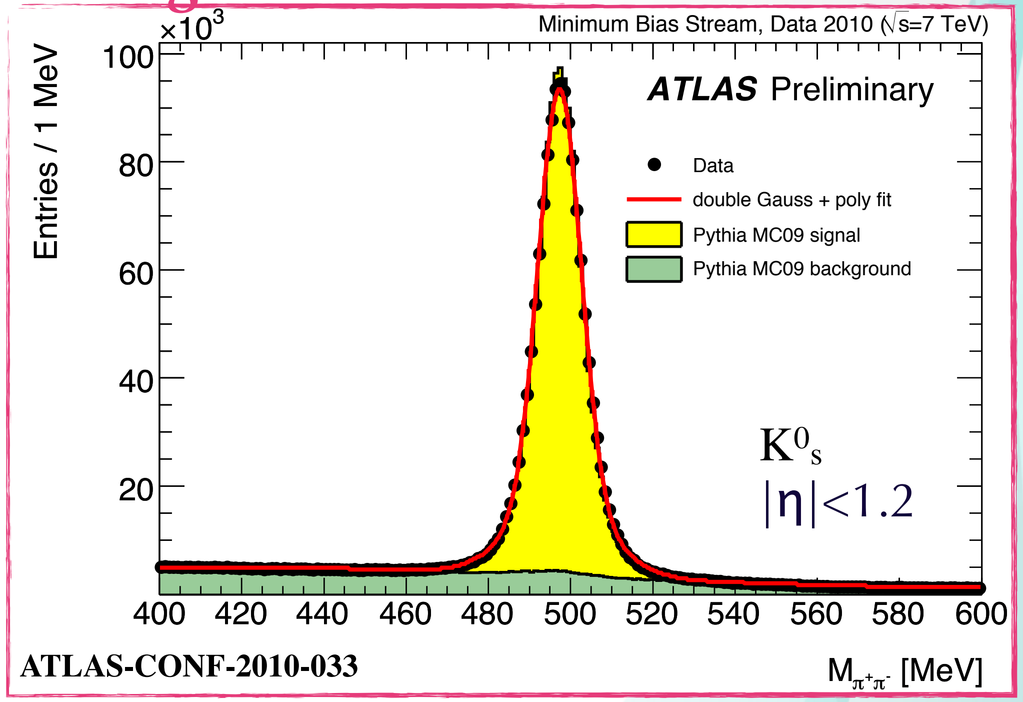
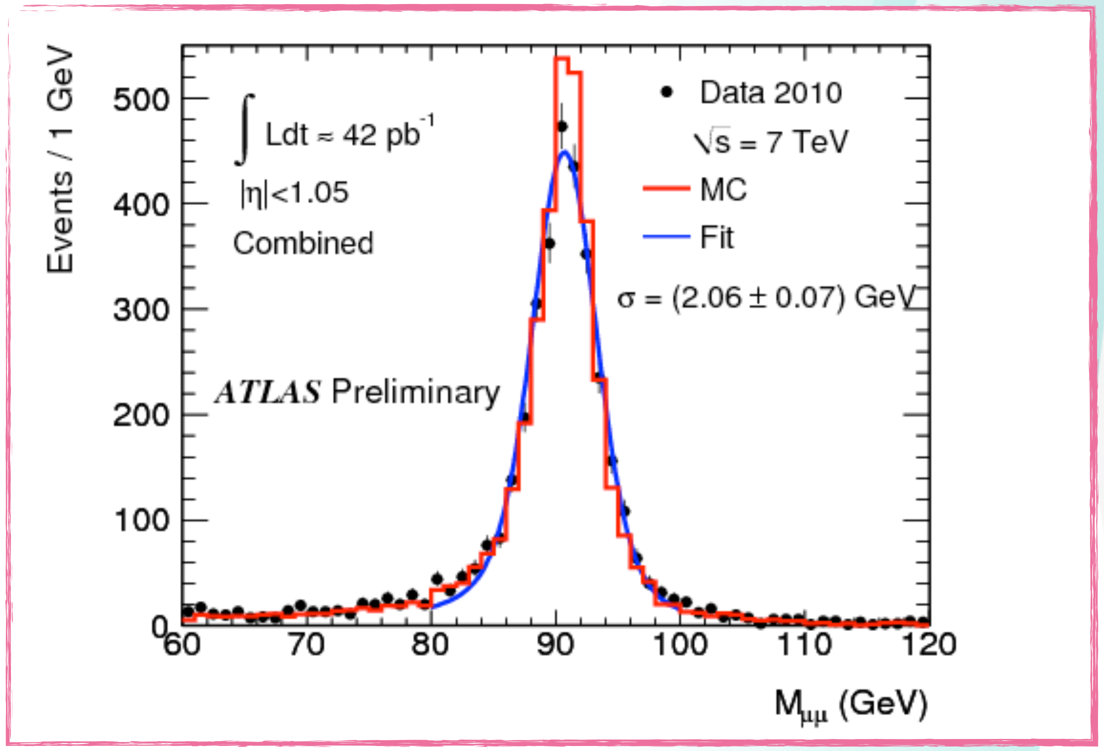


Muon System



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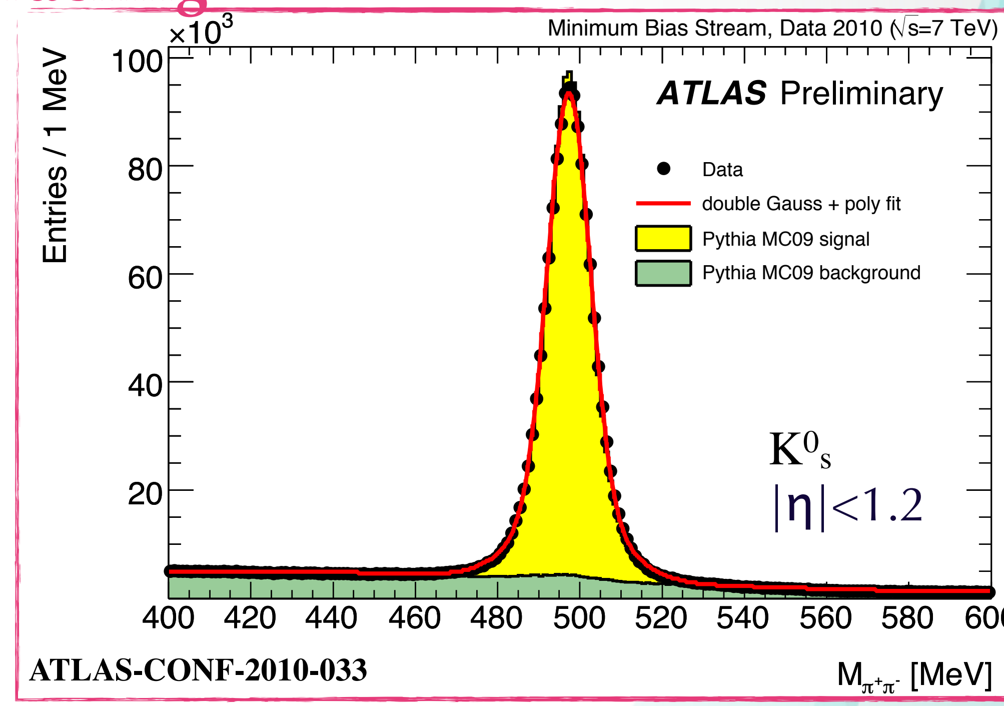

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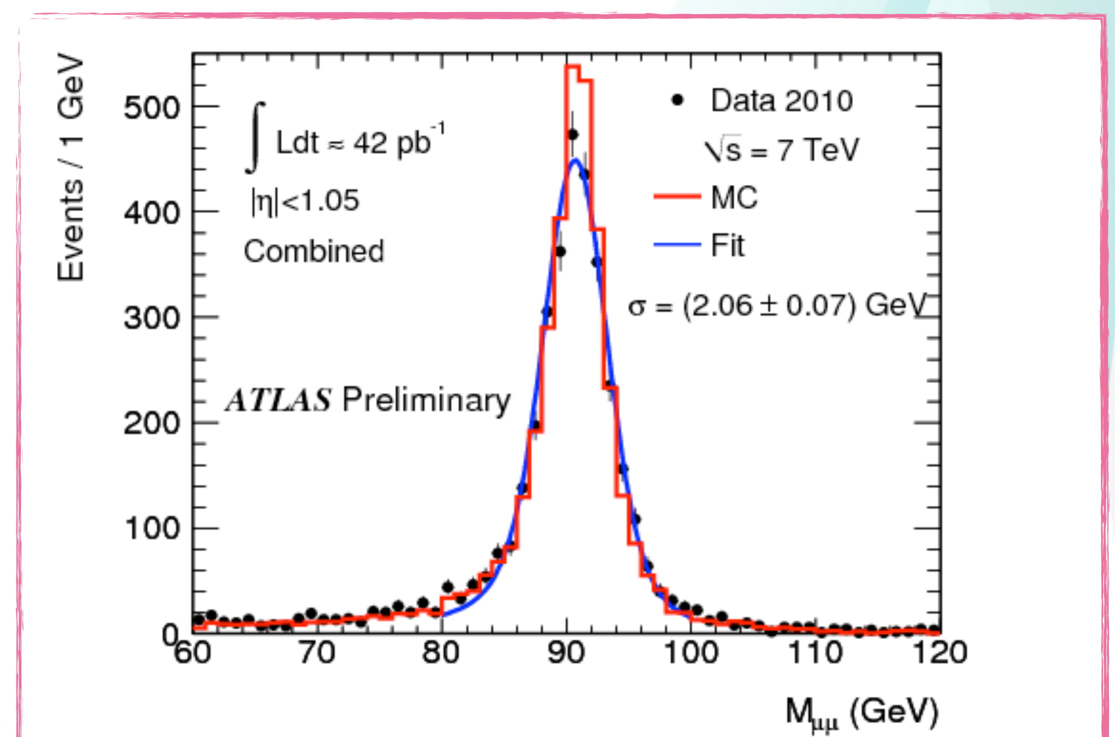
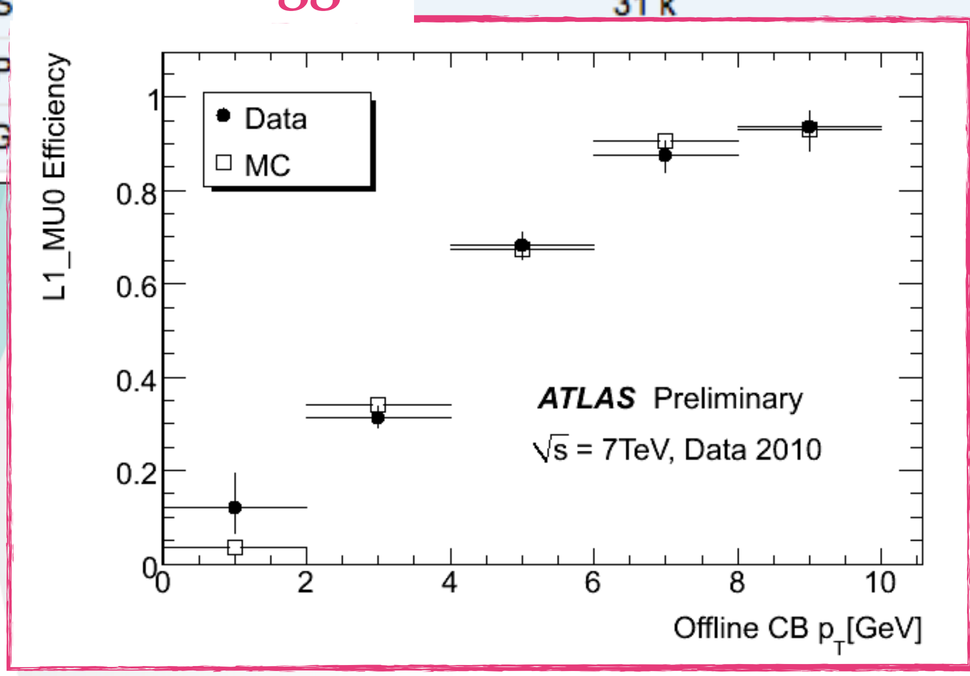


Muon Trigger



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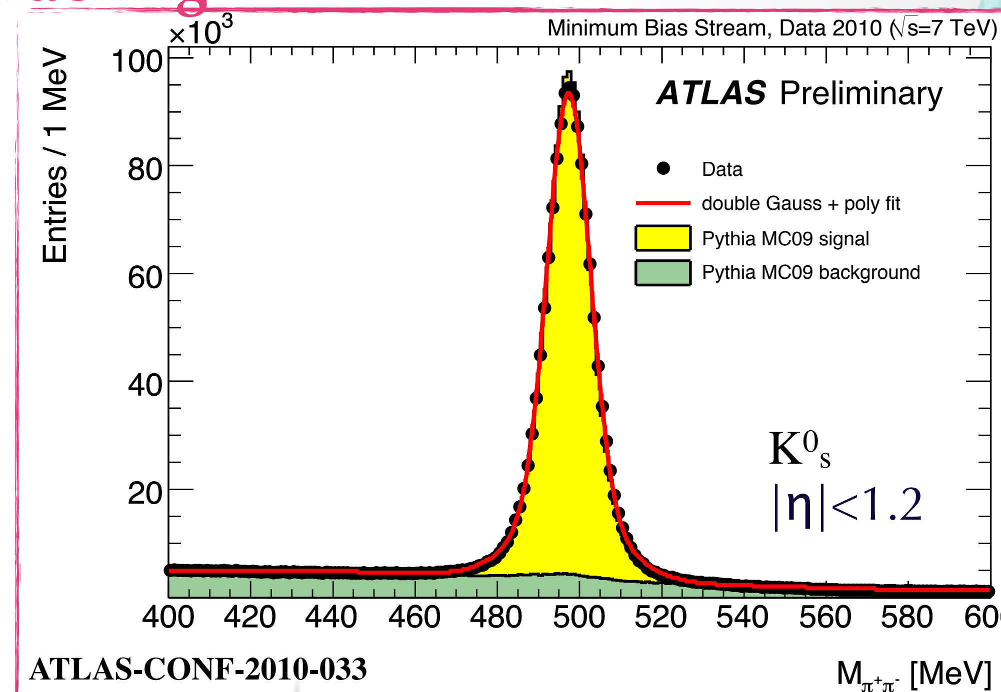
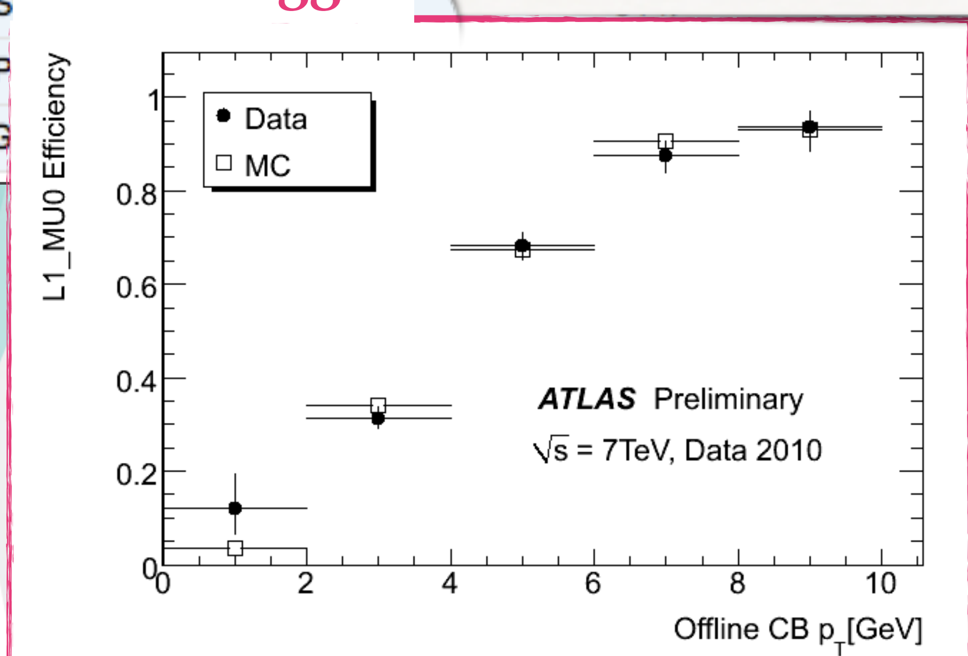
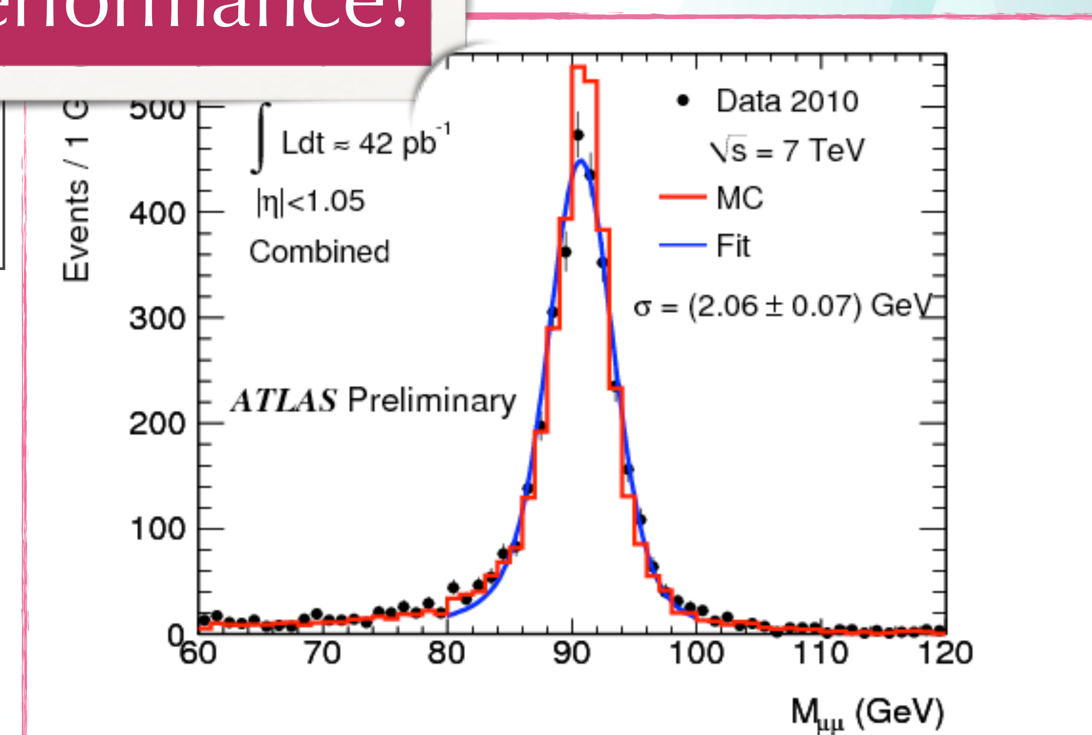


Lot of work! Very good performance!

Muon Trigger





Heavy Flavor in ATLAS

The main *motivations* for these studies are:

- QCD physics understanding: prompt onia production ,hadron-production mechanism, quarkonia polarization state
- background for rare/interesting processes understanding
- detector understanding

First *results*:

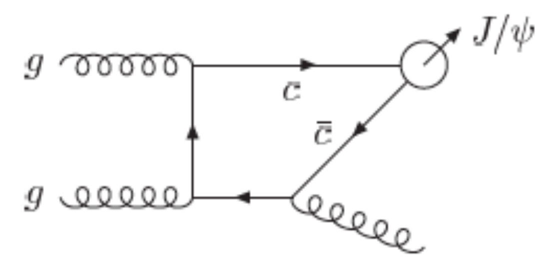
- $D^{(*)}$mesons reconstruction: ATLAS-CONF-2010-034
- J/ψ observation: ATLAS-CONF-2010-045
- J/ψ differential cross section and fraction from B decays: ATLASCONF-2010-062
- Observation of $B^{\pm}\rightarrow J/\psi(\mu^{+}\mu^{-})K^{\pm}$ decay: ATLAS-CONF-2010-098
- J/ψ yield suppression in Pb-Pb collisions: **CERN-PH-EP-2010-090**

About the theory

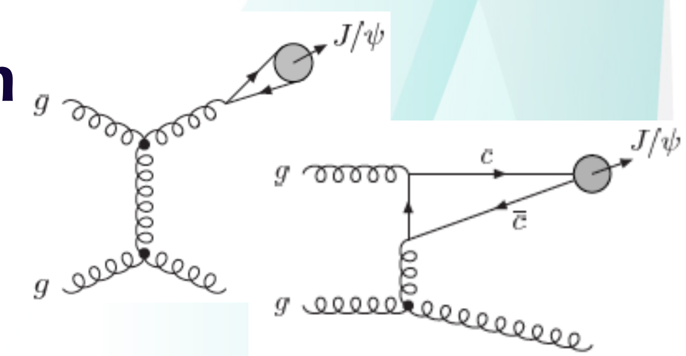
A bit of history

Different models developed in more than 30 years:

- **Color Singlet Model: quarkonium quantum numbers = final meson quantum numbers**
  - ✦ LO seemed predictive before CDF run1
  - ✦ After introduction of quark and gluon fragmentation processes still data far above theory prediction (factor 30-100)
  - ✦ Adding other contributions at LO, NLO, NLO+ and NNLO* mechanism revived



- **Color Octet Model: allows for gluon content of the quarkonium**
  - ✦ NLO $d\sigma/dp_T$ predictions at low p_T overshoot data
  - ✦ predictions challenged also from B-factories results



- **Color Evaporation Model: charmonium production dependent on the invariant mass of $q\bar{q}$ produced**

....

...but still no very predictive theory!

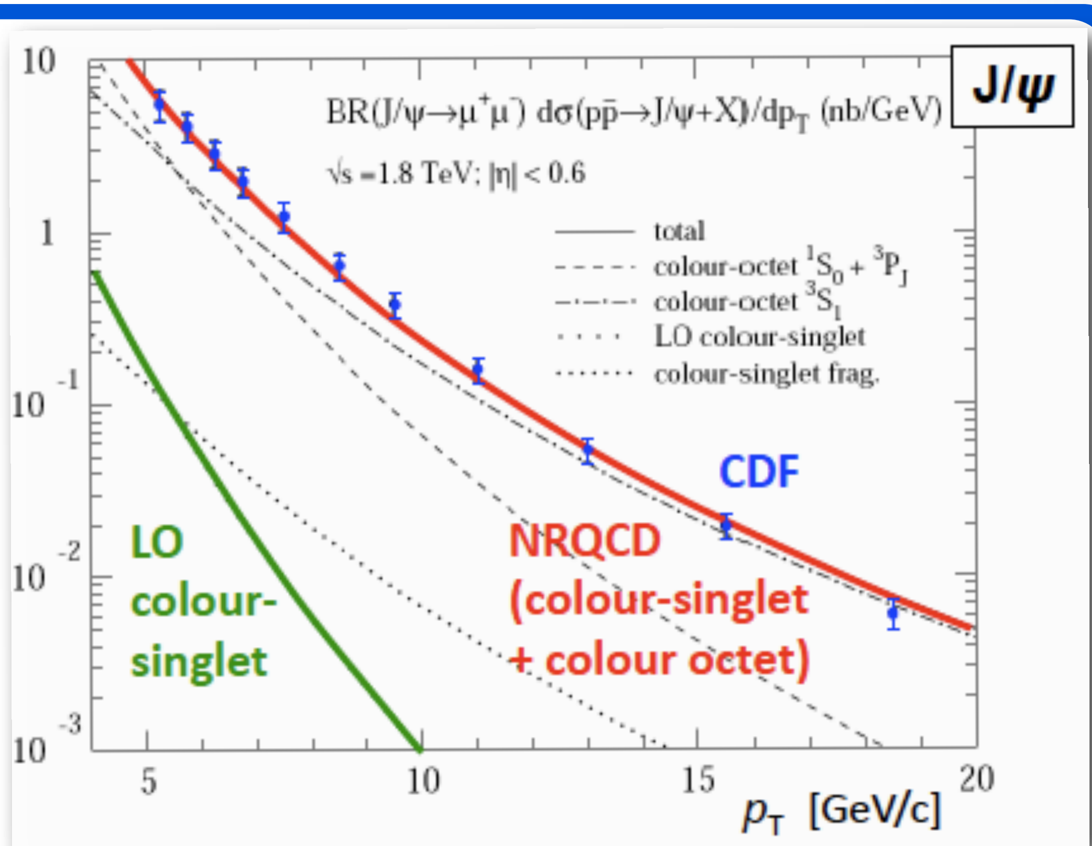
Charmonium Cross sections

Non Relativistic QCD approach

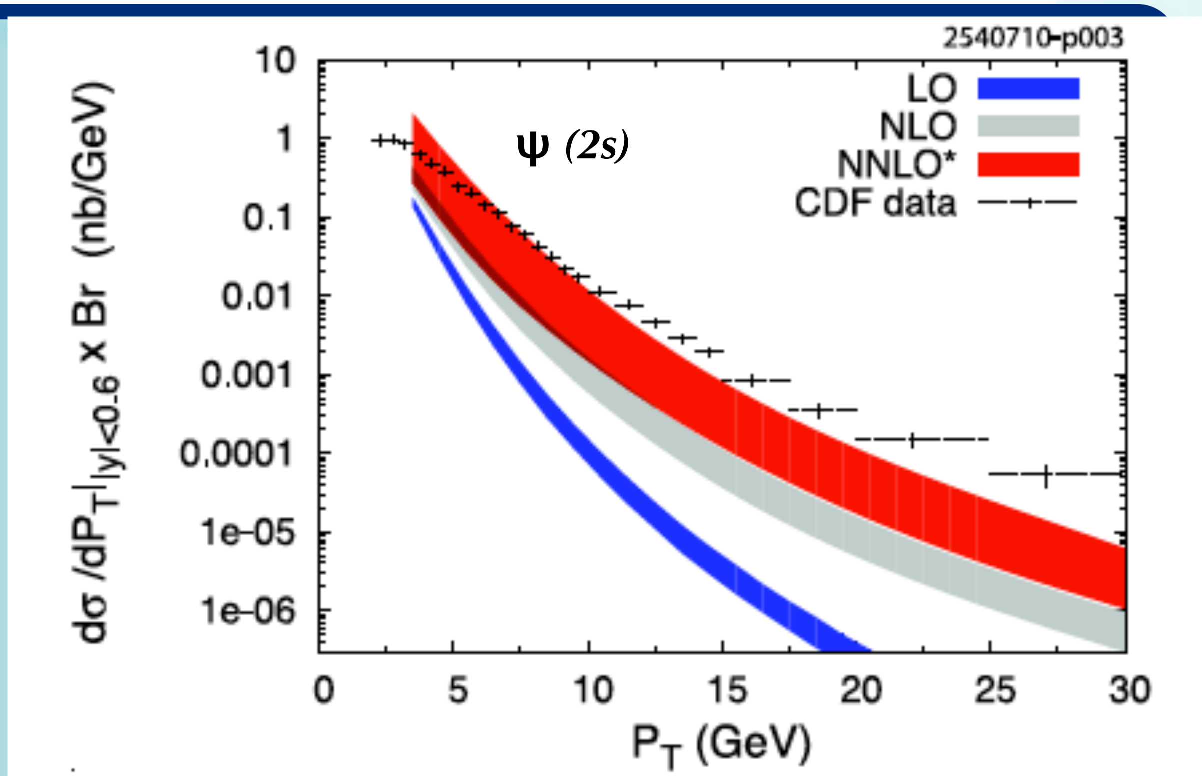
$$\mathcal{L}_{\mathrm{NRQCD}} = \sum_n \frac{c_n(\alpha_s(m),\mu)}{m^n} \times O_n(\mu, mv, mv^2, \ldots)$$

- O_n: operators corresponding to effective vertices" at μ energy scale
- C_n: Wilson coefficients containing information on energy scales > m

Seems to be in good agreement with data!



CSM + pQCD at improved NLO (NNLO*) describes the p_T trend of the production cross section in the low and intermediate range



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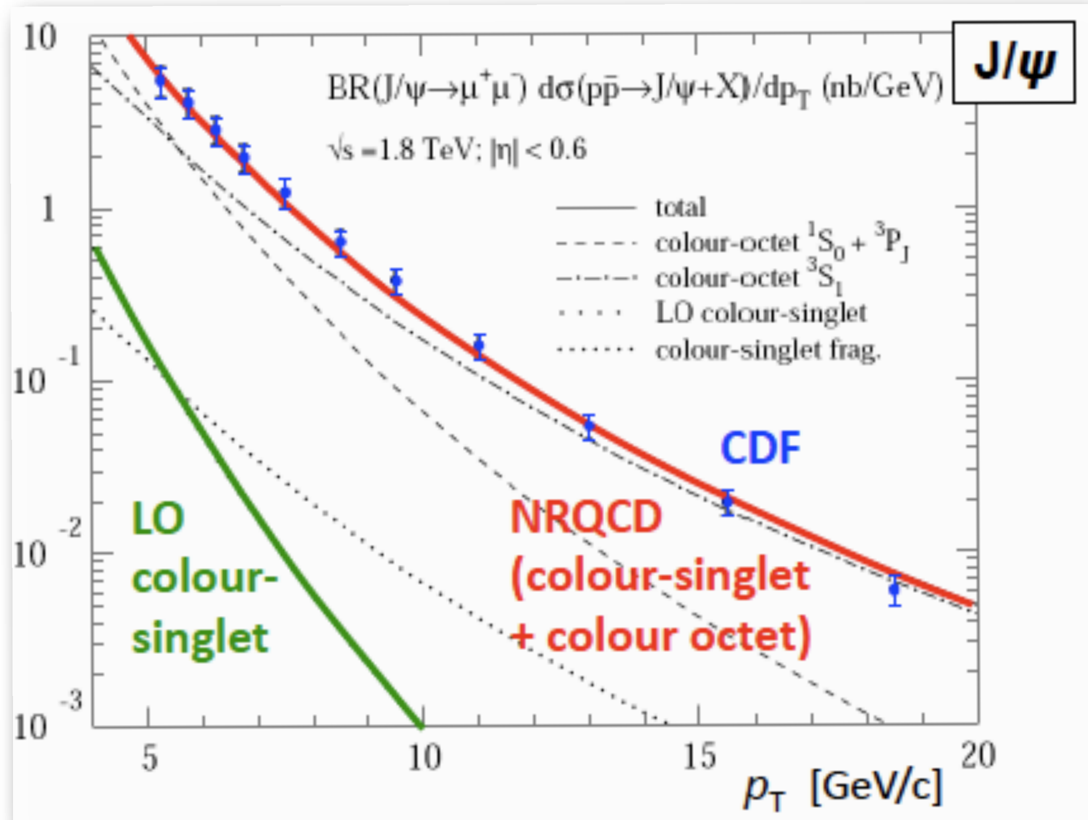

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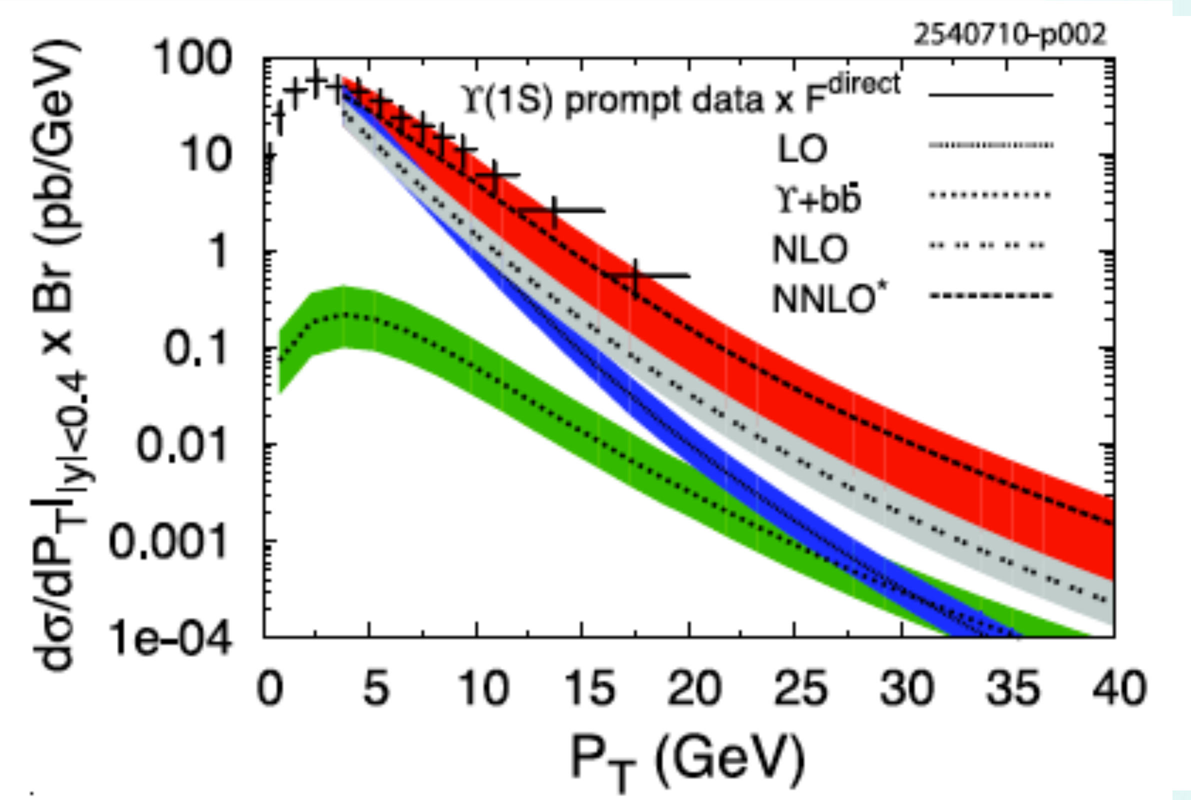
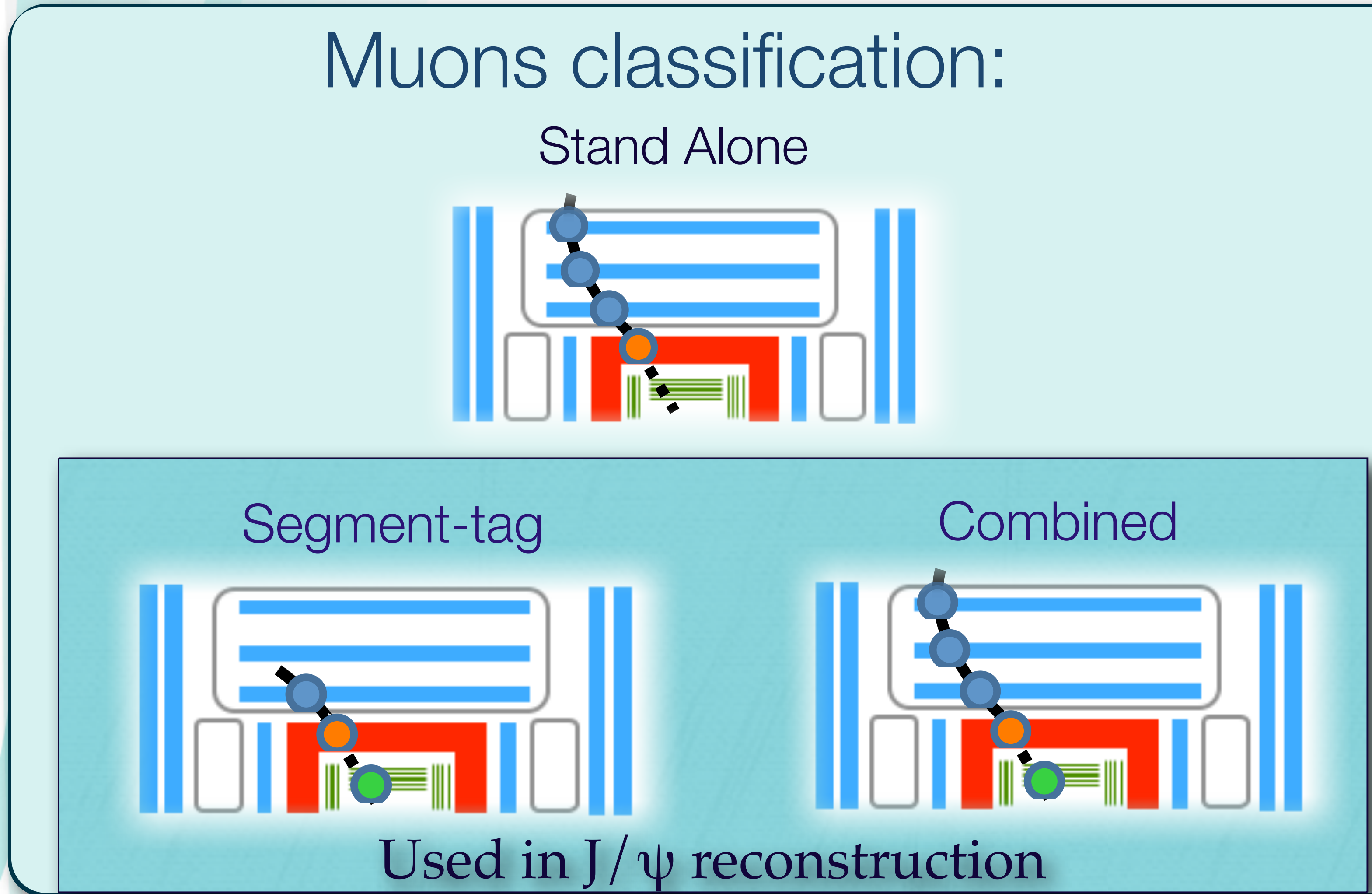


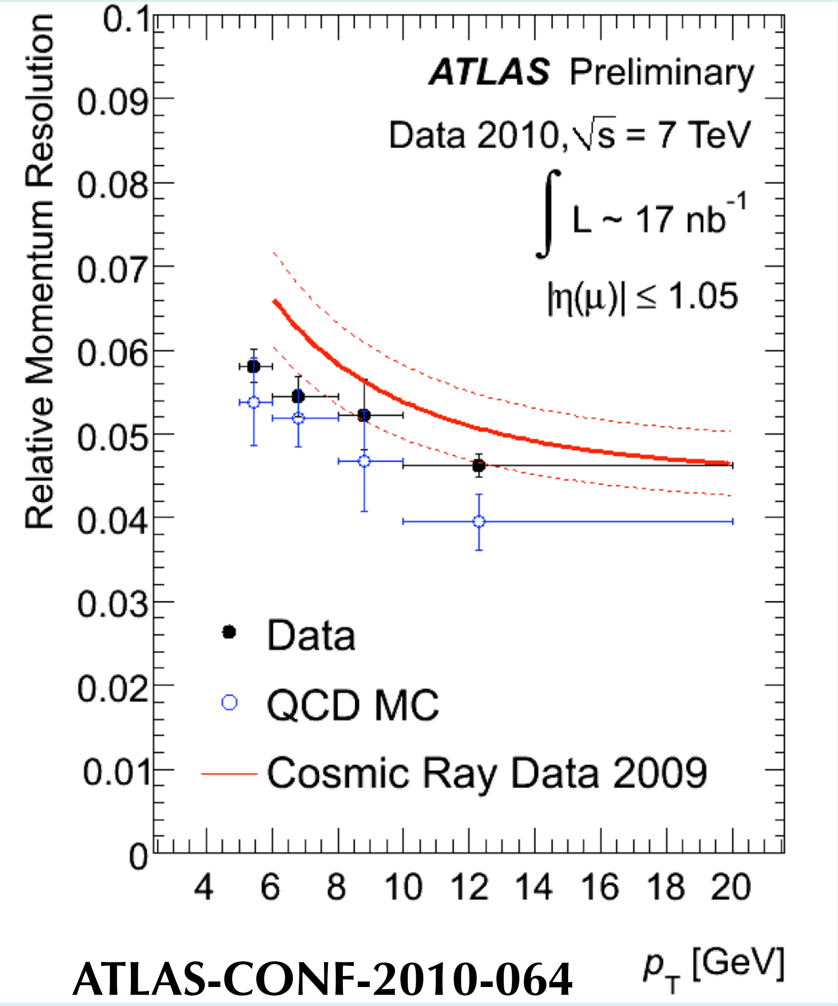
About ATLAS results

Muon reconstruction

Charmonium detection requires good muon reconstruction

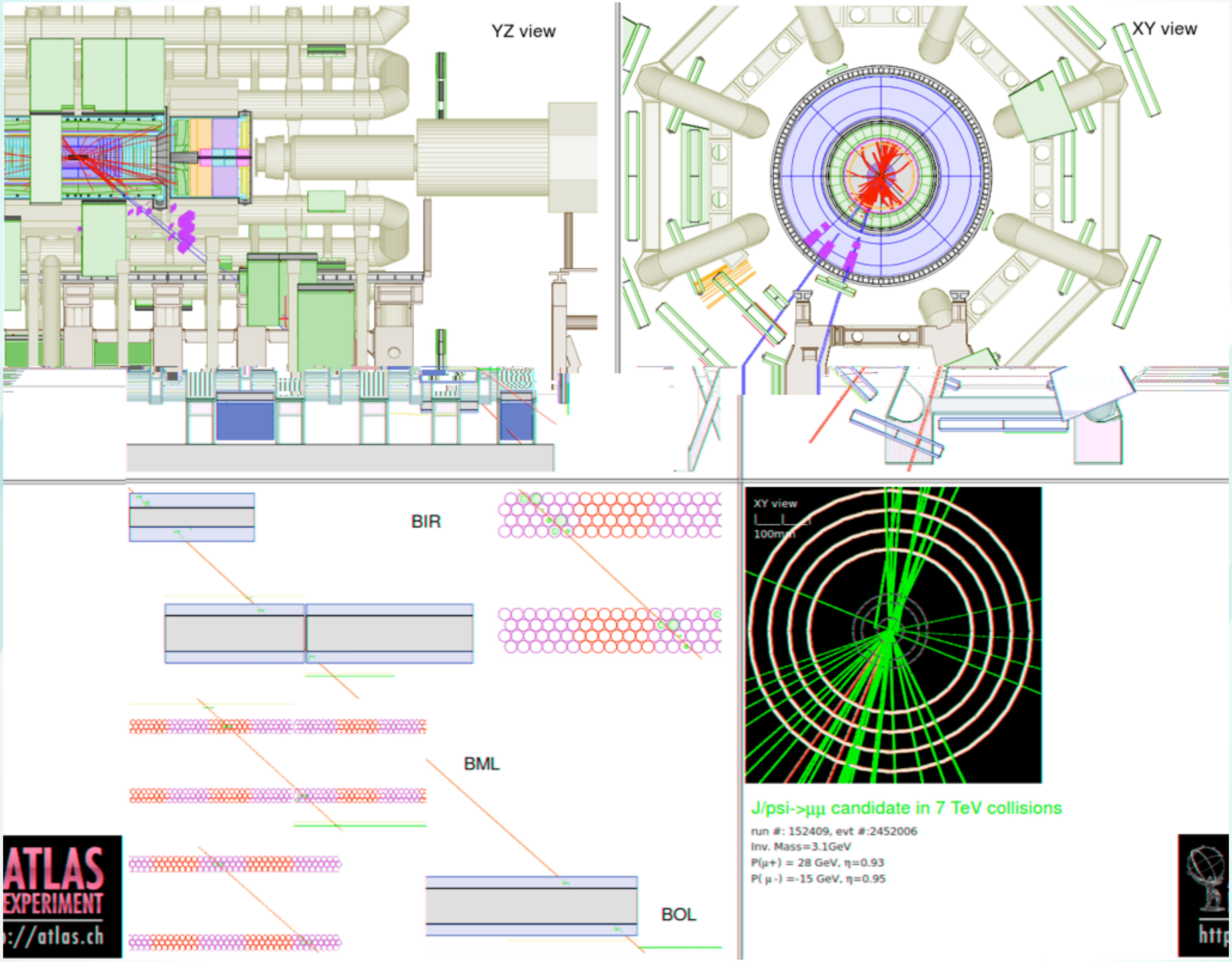
- ✦ **good Inner Detector Tracking performance(since at the typical J/ψ momentum the ID momentum resolution dominates)**
- ❖ **good Muon Spectrometer performance (for muon trigger and identification)**





ATLAS-CONF-2010-064

$J/\psi \rightarrow \mu^+\mu^-$ ATLAS Event



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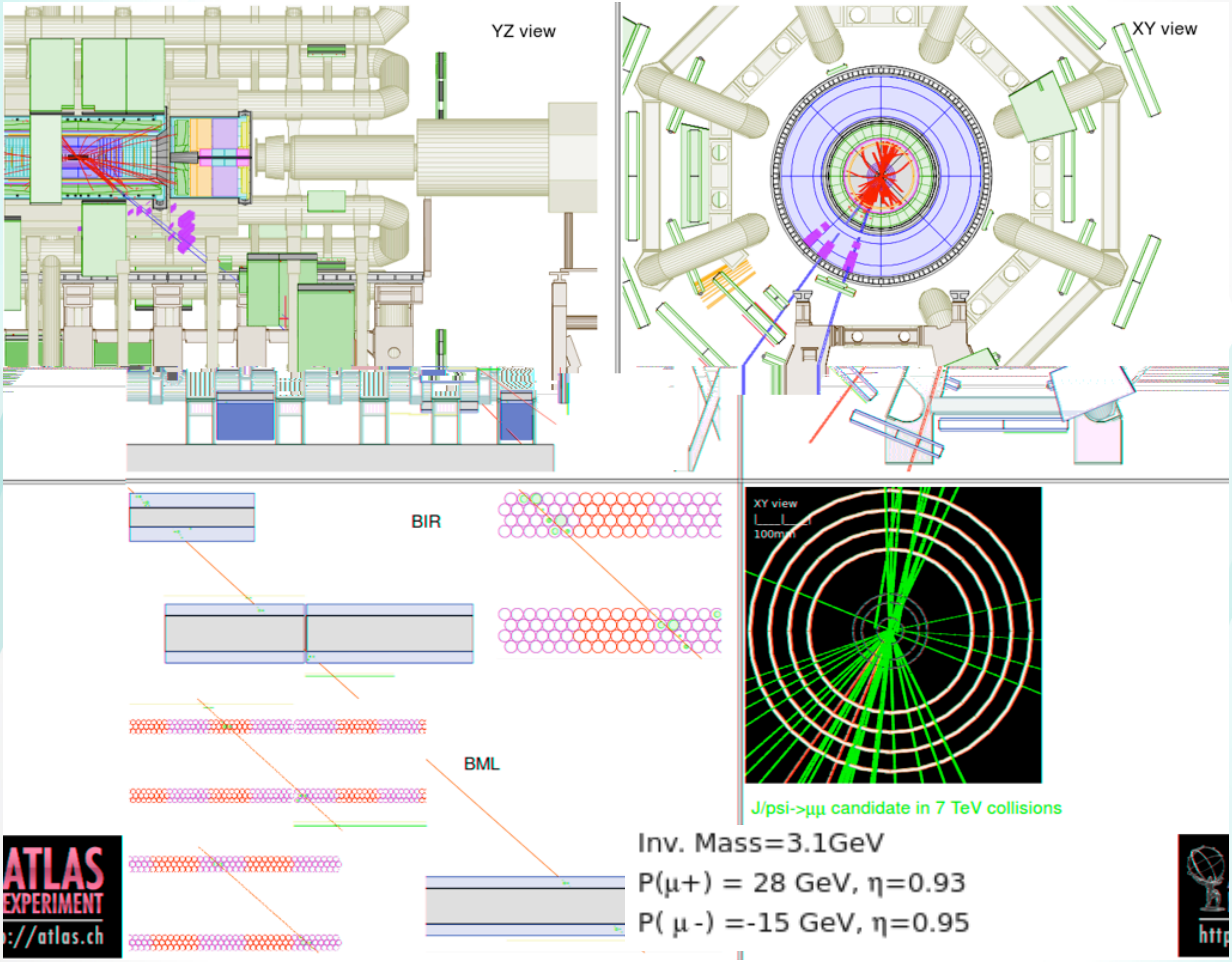


Inv. Mass=3.1GeV

P(μ+) = 28 GeV, η=0.93

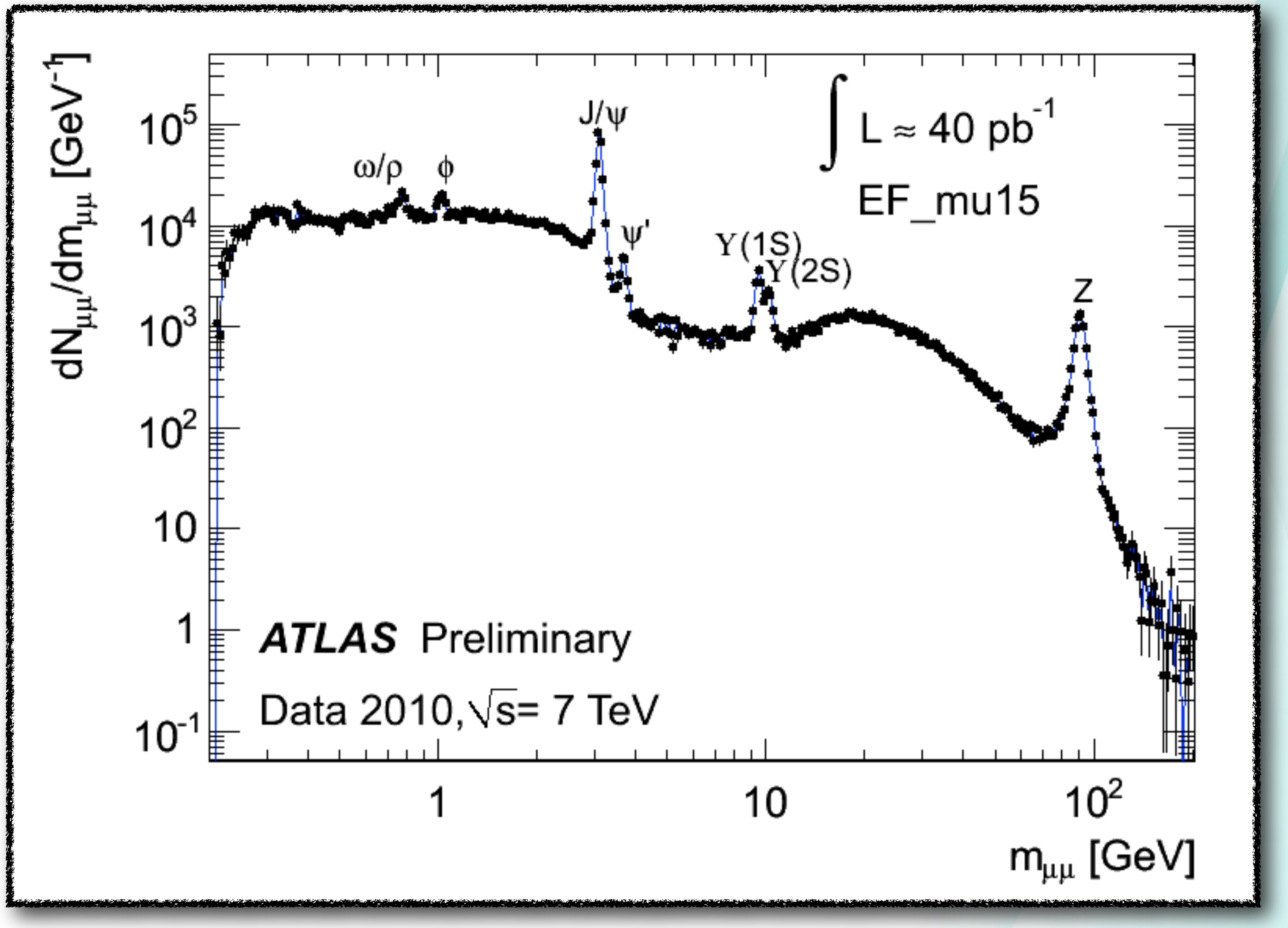
P(μ -) =-15 GeV, η=0.95

$\mu^+\mu^-$: invariant mass spectrum

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/MuonPerformancePublicPlots

Fully combined
opposite sign muons with:

- $p_T(\mu_1) > 15$ GeV/c
- $p_T(\mu_2) > 2.5$ GeV/c
- High Level Trigger (EF), p_T threshold > of 15 GeV



Note: following public results will use much less statistics and a very different trigger!

$\mu^+\mu^-$: invariant mass spectrum

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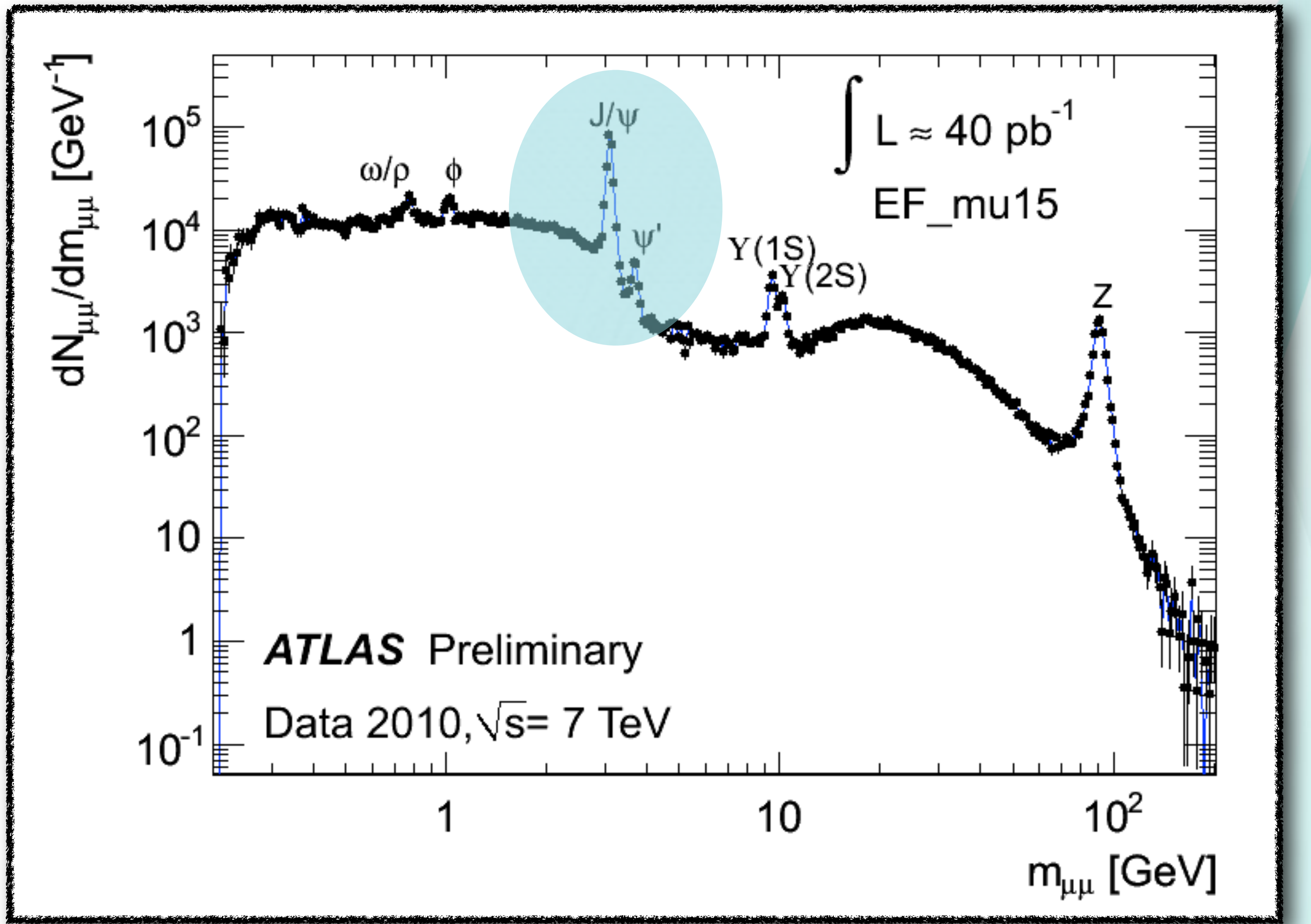

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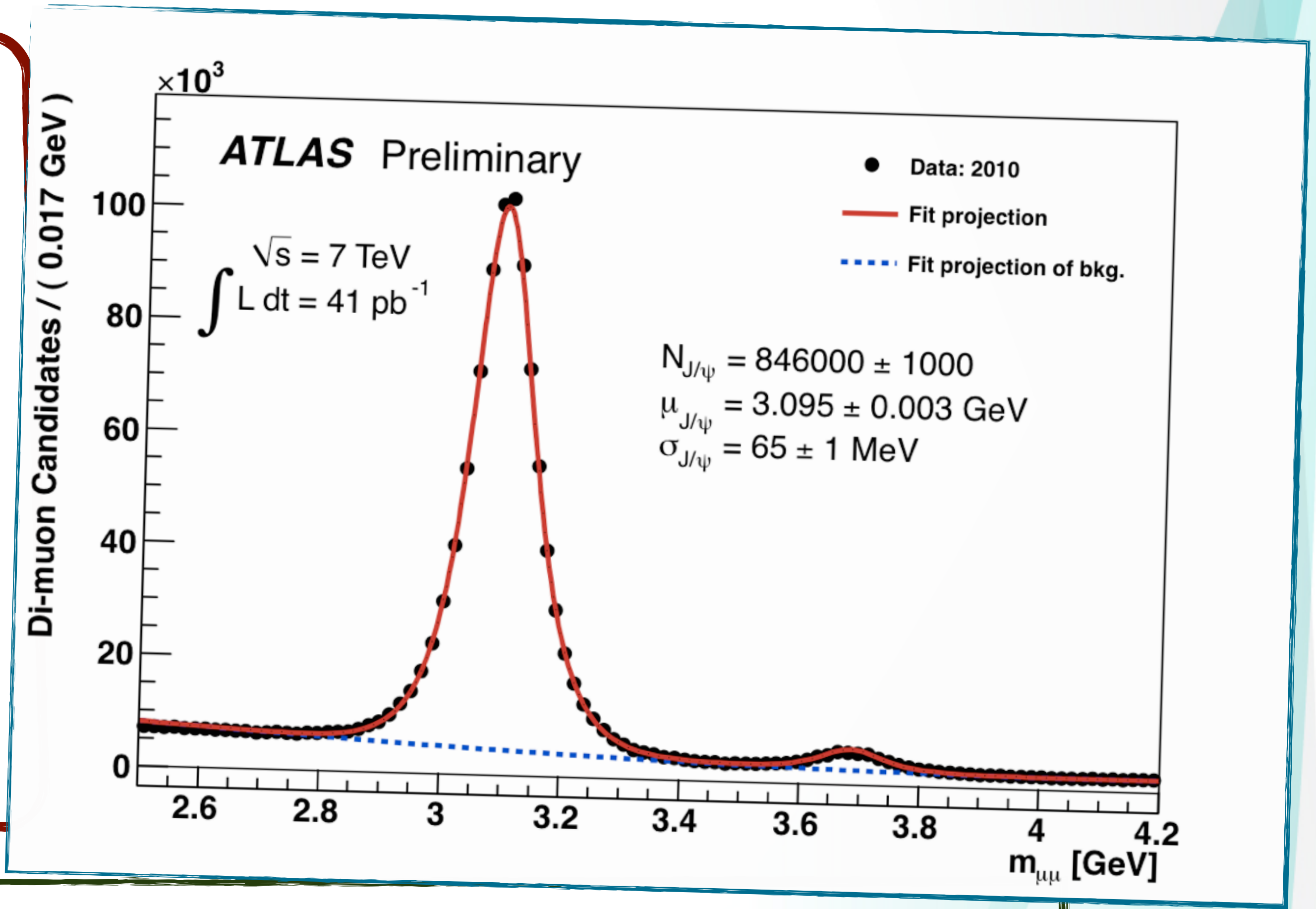
J/ψ and ψ(2S) candidates

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/BPhysPublicResults#Stand_alone_plots

Event selection:

- At least 1 primary vertex with 3 tracks associated
- Quality cuts on the Inner Detector tracks
- Opposite charge muon pairs with successful vertex fit
  - at least one combined muon in the pair
  - invariant masses between 2.5 and 4.2 GeV
- $|\eta(\mu)| < 2.5$
- Transverse momentum Cut:
  - $p_T(\mu_1) > 4$ GeV
  - $p_T(\mu_2) > 2.5$ GeV



Trigger:

- L1 muon confirmed at HLT with 4,6 or 10 GeV threshold
- L1 muon confirmed at HLT with 4 GeV threshold + HLT muon in the same RoI as the L1 muon. $0.5<M_{\mu\mu}<12.0$ GeV or $2.4<M_{\mu\mu}<4.2$ GeV
- 2 L1 muon confirmed at HLT with (4,4) or (4,6) GeV threshold. $0.5<M_{\mu\mu}<12.0$ GeV

The signal lineshape fits are both Gaussian with a third-order polynomial to model the background

$J/\psi \rightarrow \mu\mu$: differential cross section and non-prompt to prompt J/ψ cross section ratio

ATLAS-CONF-2010-062

The two topics use different statistics:

- 9.5 nb^{-1} in the case of cross section
- 17.5 nb^{-1} in the prompt/non prompt ratio

In both measurement maximum likelihood fitting techniques are used to extract results

Differential cross section measurement for the $J/\psi \to \mu\mu$

- *For the determination of the J/ψ yield a maximum likelihood fit of the di-muon invariant mass in p_T and y bins has been performed*

- *To recover the true number of $J/\psi \to \mu^+\mu^-$ events, each event in given "analysis bin" is assigned a weight w :*

$$w^{-1} = \mathcal{A}(p_T, y, \lambda_i) \times \mathcal{E}_\mu(\vec{p}_1) \times \mathcal{E}_\mu(\vec{p}_2) \times \mathcal{E}_{\text{trig}}(\vec{p}_1, \vec{p}_2)$$

Detector acceptance

Reconstruction efficiency from Monte Carlo

Trigger efficiency calculated using minimum bias data

Particular spin-alignment scenario

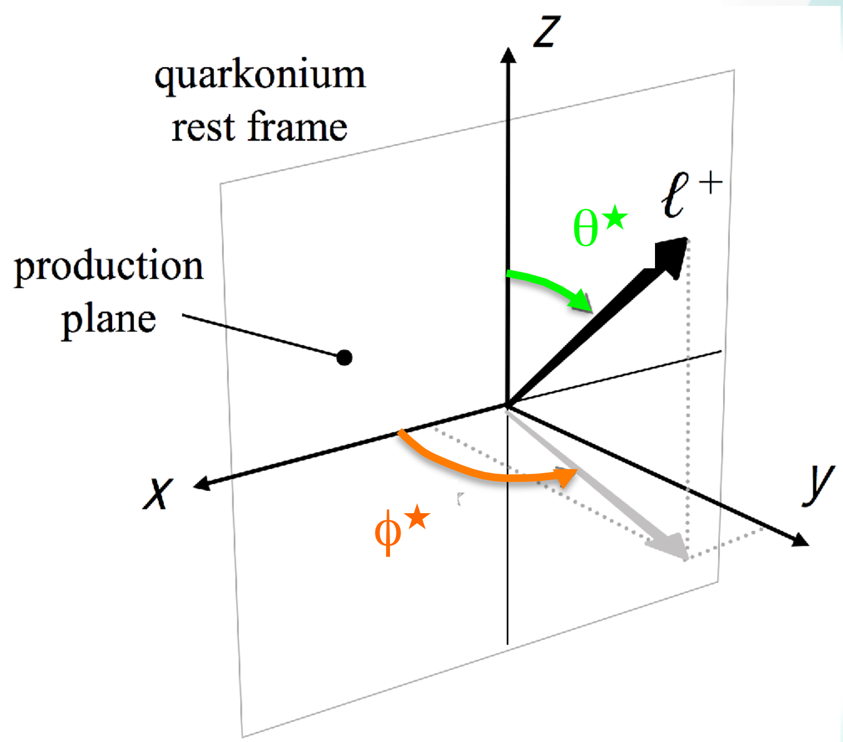
- *The acceptance has been parametrized by independent 5 vars:*
  - *J/ψ: p_T , y, φ*
  - *J/ψ decay in its rest frame: angles θ^* and φ^**

J/ψ→μμ : polarization

Polarization dependence of the cross section parametrized by:

$$\frac{d^2N}{d\cos\theta^\star d\phi^\star} \propto 1 + \lambda_\theta \cos^2\theta^\star + \lambda_\phi \sin^2\theta^\star \cos 2\phi^\star + \lambda_{\theta\phi} \sin 2\theta^\star \cos\phi^\star$$

- $\theta^\star$ (angle between μ^+ momentum in the J/ψ rest frame and J/ψ momentum)
- $\varphi^\star$ (angle between J/ψ production and decay planes)



λ_θ, λ_φ, $\lambda_{\theta\varphi}$ related to the spin density matrix elements of the J/ψ spin wave function

As we have not measured the polarization, it is not known and causes a systematic on the acceptance

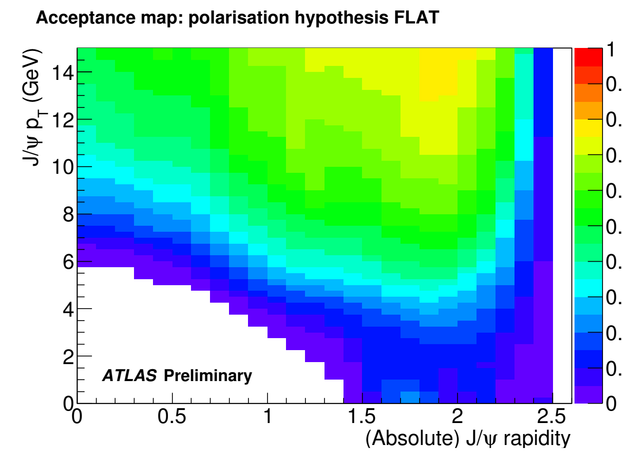
Polarization & acceptance

Acceptance dependance on the spin-alignment of J/ψ

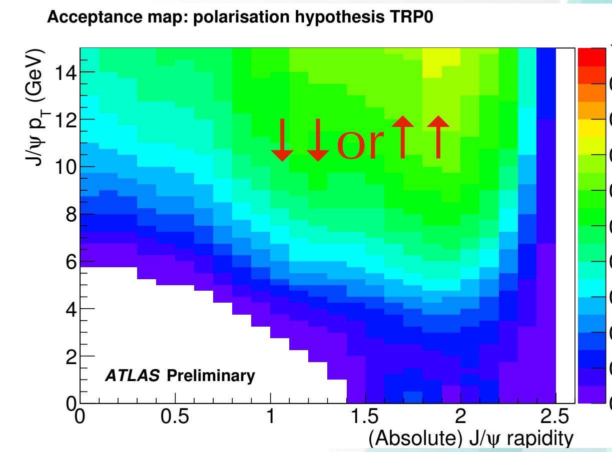
5 scenarios considered:

- FLAT:
  - a) $\lambda_\theta=0$, $\lambda_\varphi=0$, $\lambda_{\theta\varphi}=0$
- LONGITUDINAL:
  - c) $\lambda_\theta=-1$, $\lambda_\varphi=\lambda_{\theta\varphi}=0$ ←→
- TRANSVERSE:
  - b) $\lambda_\theta=+1$, $\lambda_\varphi=\lambda_{\theta\varphi}=0$ ↓↓or↑↑
  - d) $\lambda_\theta=\lambda_\varphi=+1$, $\lambda_{\theta\varphi}=0$ ↓↓+↑↑
  - e) $\lambda_\theta=+1$, $\lambda_\varphi=-1$, $\lambda_{\theta\varphi}=0$ ↓↓-↑↑

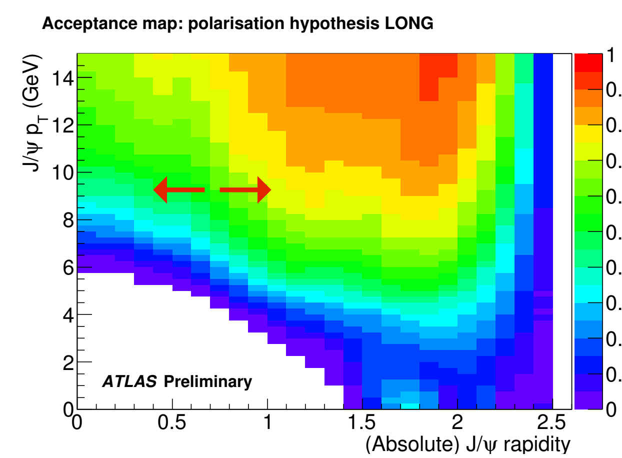
Differences in acceptance behaviors particularly at low p_T



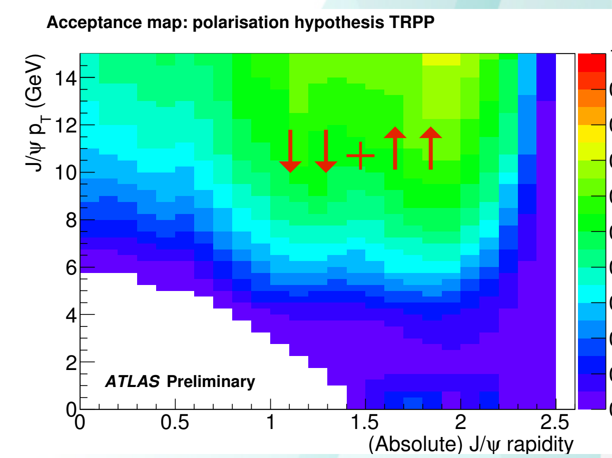
(a) $\lambda_\theta = \lambda_\phi = \lambda_{\theta\phi} = 0$



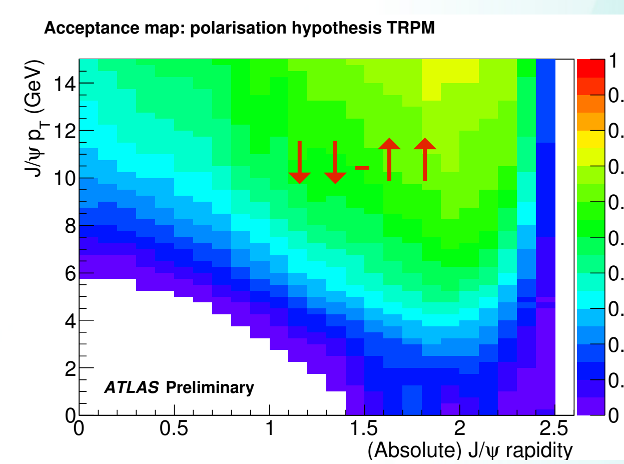
(b) $\lambda_\theta = +1, \lambda_\phi = \lambda_{\theta\phi} = 0$



(c) $\lambda_\theta = -1, \lambda_\phi = \lambda_{\theta\phi} = 0$



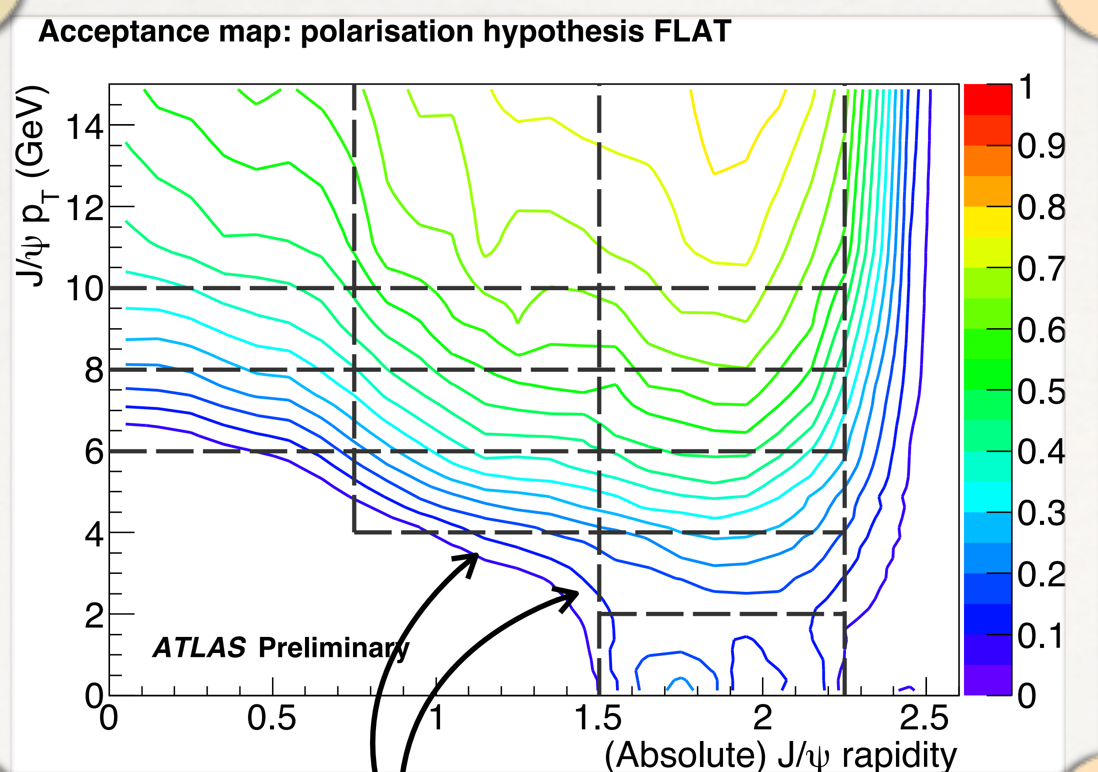
(d) $\lambda_\theta = +1, \lambda_\phi = +1, \lambda_{\theta\phi} = 0$



(e) $\lambda_\theta = +1, \lambda_\phi = -1, \lambda_{\theta\phi} = 0$

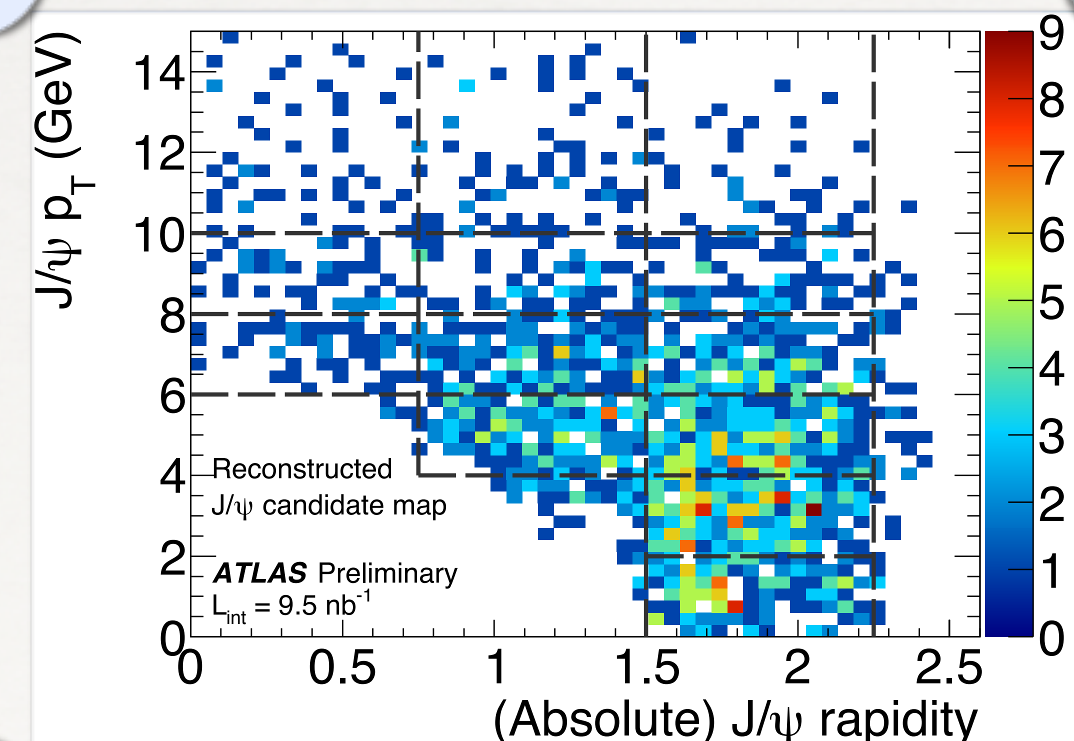
Correction maps

Constant Acceptance Contours for the flat polarization hypothesis in the p_T - y space (6x3 bins)



bin boundaries

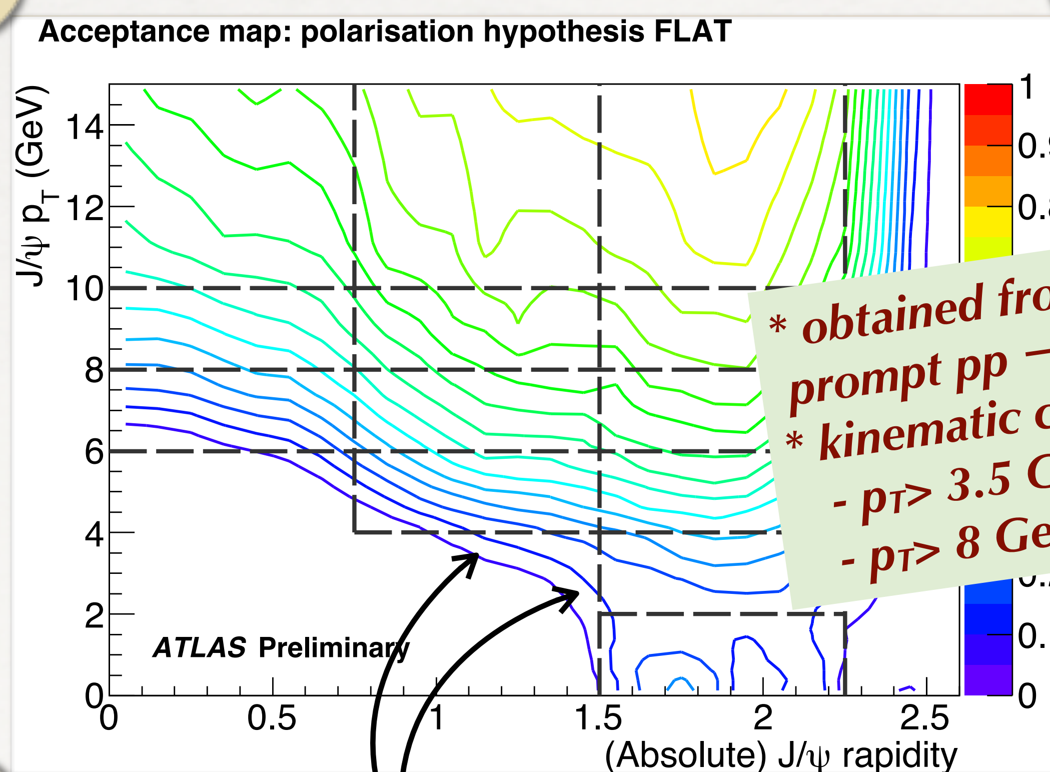
Reconstructed J/ψ candidates in the signal mass region ($m_{J/\psi} \pm 3\ \sigma$) in the p_T - y space (6x3 bins)



Data-driven trigger efficiency, from minimum-bias stream data: Determined for candidate events from J/ψ single-muon trigger efficiencies, separately for fully combined and tagged muons

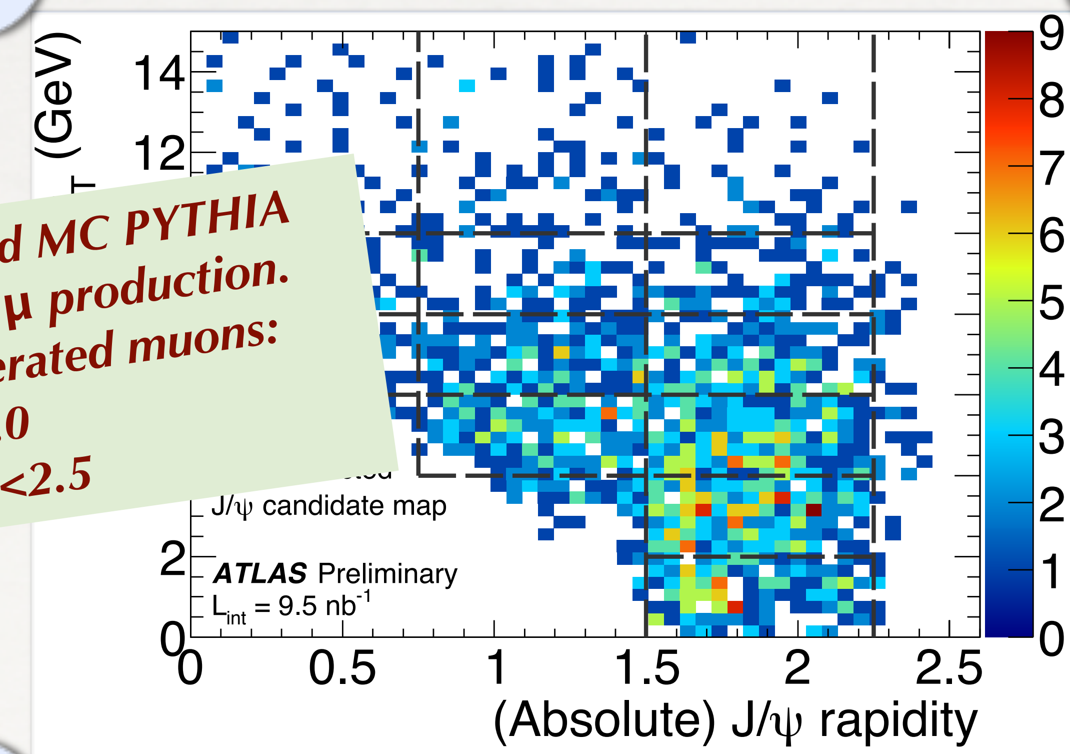
Correction maps

Constant Acceptance Contours
for the flat polarization hypothesis
in the p_T - y space (6x3 bins)



bin boundaries

Reconstructed J/ψ candidates in
the signal mass region ($m_{J/\psi}$ ± 3 σ)
in the p_T - y space (6x3 bins)



***** obtained from simulated MC PYTHIA prompt pp → J/ψX → μμ production.**
***** kinematic cuts on generated muons:**
- p_T> 3.5 GeV if |η|<2.0
- p_T> 8 GeV if 2.0<|η|<2.5

Data-driven trigger efficiency, from minimum-bias stream data:
Determined for candidate events from J/ψ single-muon trigger efficiencies, separately for fully combined and tagged muons

Invariant mass fitting

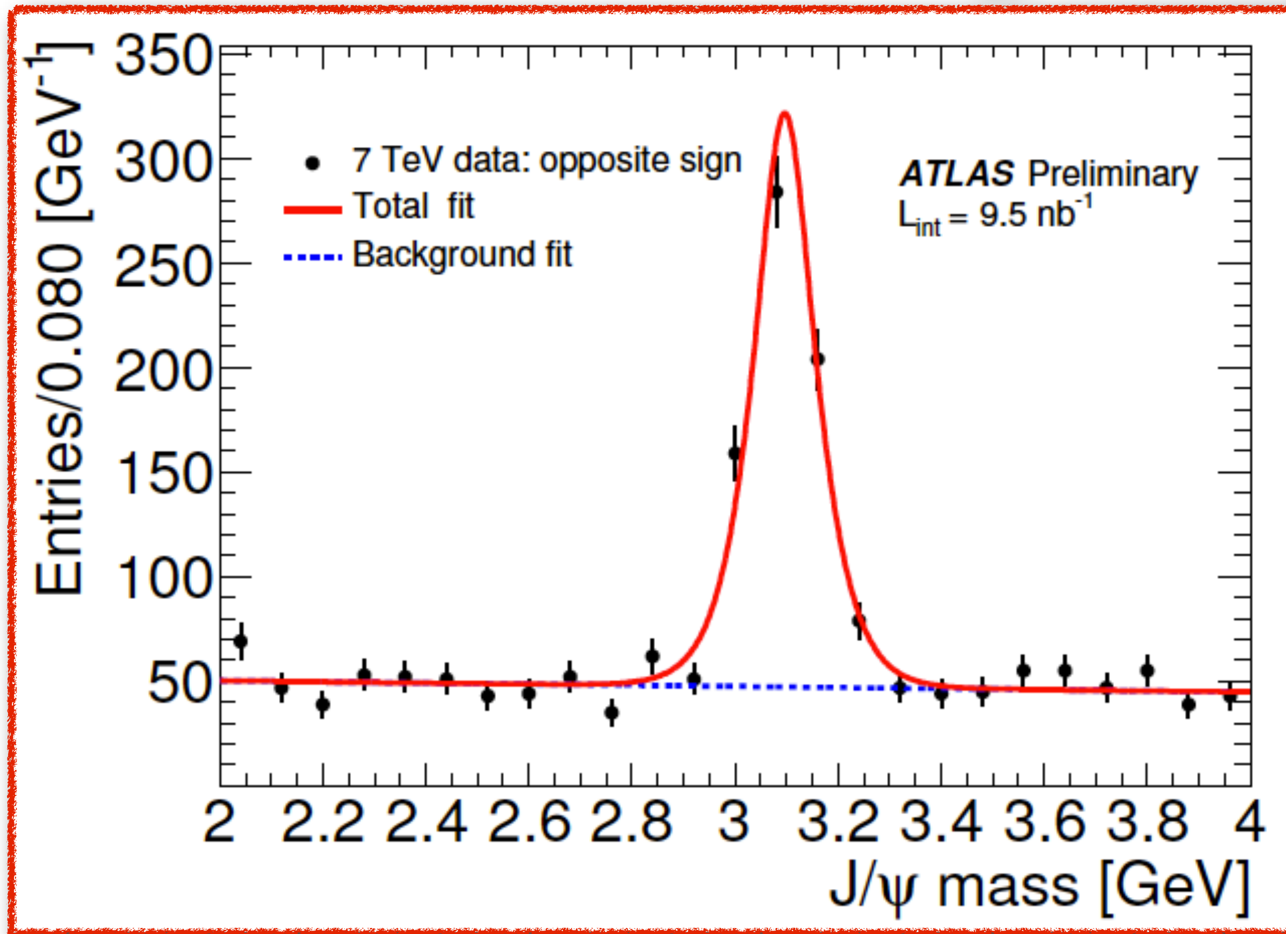
Maximum likelihood fit:

$$\ln \mathcal{L} = \sum_{i=1}^{N} w_i \cdot \ln\left[f_{signal}(m^i_{\mu\mu}) + f_{bkg}(m^i_{\mu\mu})\right]$$

$$f_{signal}(m_{\mu\mu}, \delta m_{\mu\mu}) \equiv a_0 \frac{1}{\sqrt{2\pi}\, S\, \delta m_{\mu\mu}} e^{\frac{-(m_{\mu\mu}-m_{J/\psi})^2}{2(S\,\delta m_{\mu\mu})^2}}$$

$$f_{bkg}(m_{\mu\mu}) \equiv (1 - a_0) + b_0 m_{\mu\mu}$$

N = total number of pairs of oppositely-charged muons in the invariant mass range [2,4] GeV



4 free parameters:

- $m_{J/\psi}$
- *S:scaling factor for the mass resolution*
- a_0*:fraction of signal events*
- b_0*:background slope*

Fit results:
$m_{J/\psi}$: (3.096 ± 0.003)GeV
σ_m (calculated using the covariance matrices of the fittedvertices):
(0.070 ± 0.003) GeV
In the range $m_{J/\psi} \pm 3\sigma_m$:
- N_{bck} = 373 ± 10 (mainly from c/b)
- N_{sig} = 710±34

Invariant mass fitting

Maximum likelihood f

$$\ln \mathcal{L} = \sum_{i=1}^{N} w_i \cdot \ln \left[f_{signal}(m^i_{\mu\mu}) + f \right.$$

$$f_{signal}(m_{\mu\mu}, \delta m_{\mu\mu}) \equiv a_0 \frac{1}{\sqrt{2\pi}\, S\, \delta m_{\mu}}$$

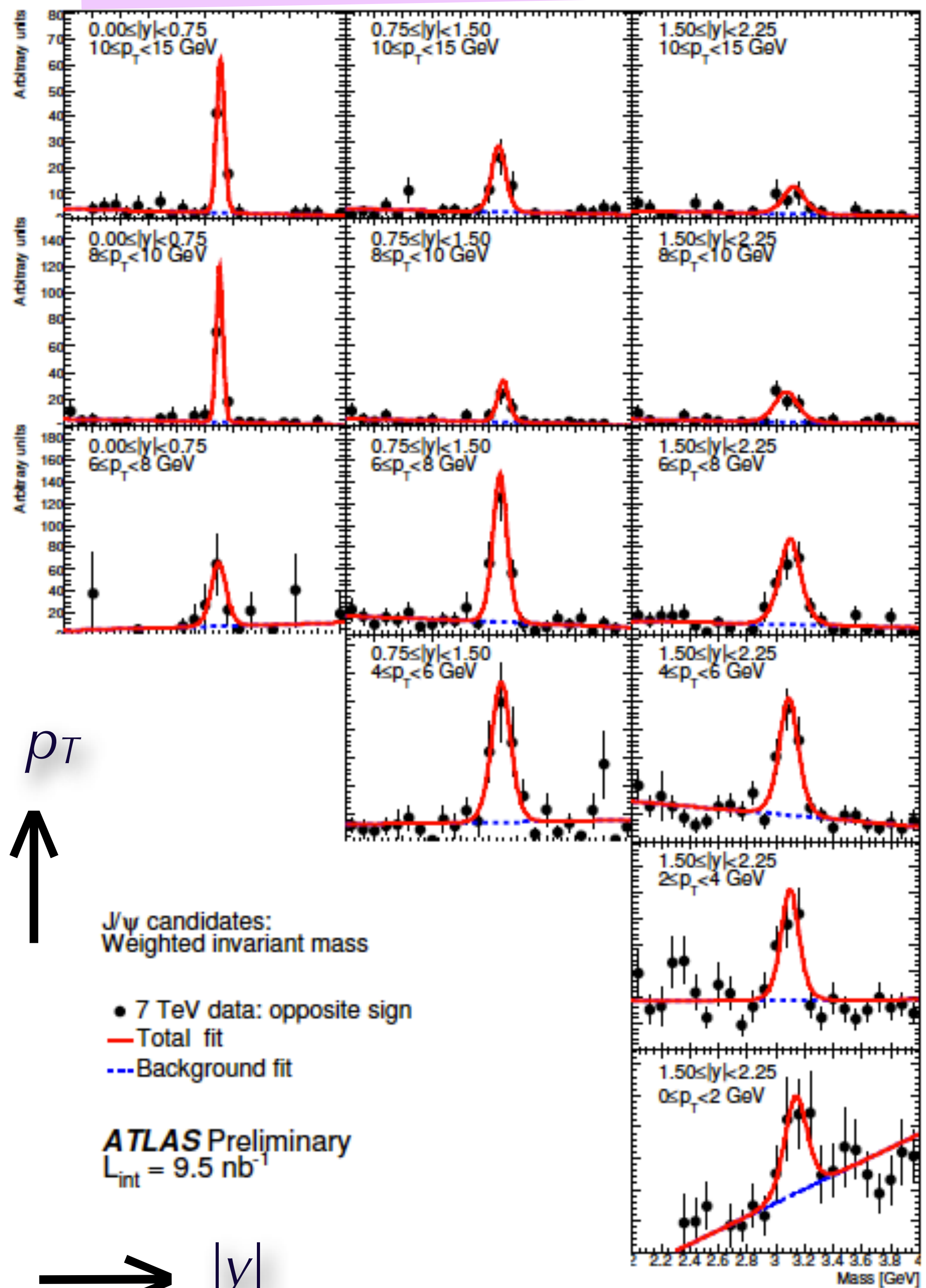
$$f_{bkg}(m_{\mu\mu}) \equiv (1 - a_0) + b_0 m_{\mu}$$

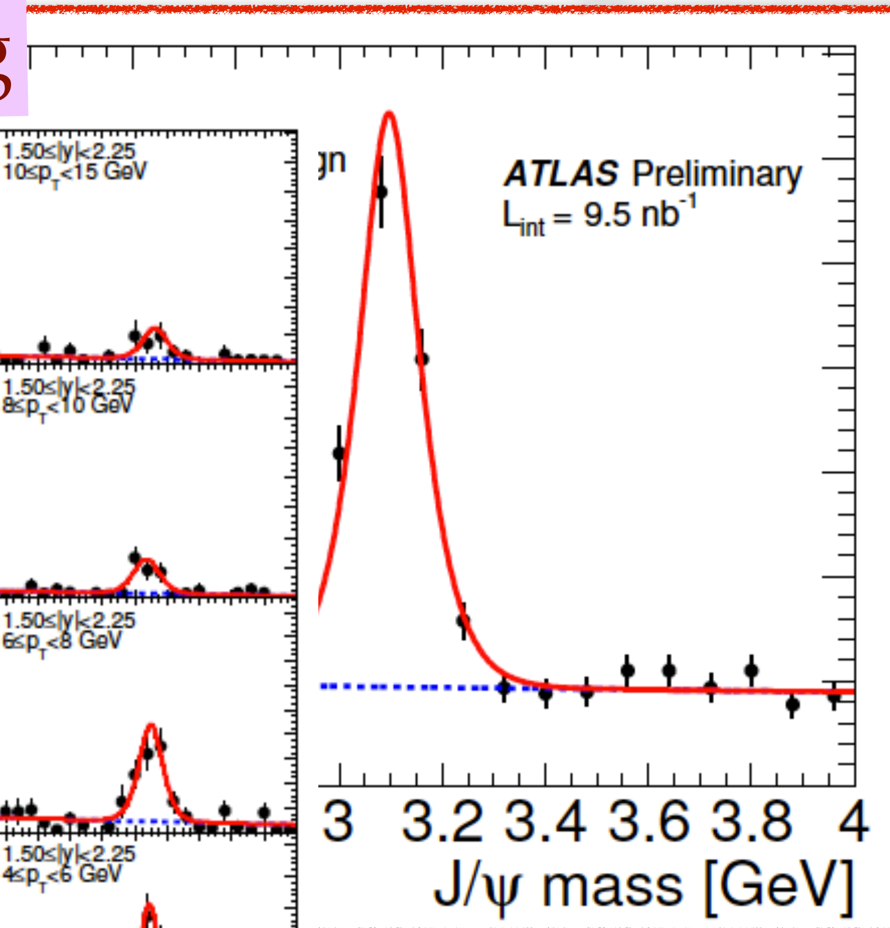
N = total number of pairs of opposi
muons in the invariant mass range

4 free parameters:

- $m_{J/\psi}$
- S:scaling factor for t
- a_0:fraction of signal
- b_0:background slop

after re-weighting





Fit results:
(3.096 ± 0.003)GeV
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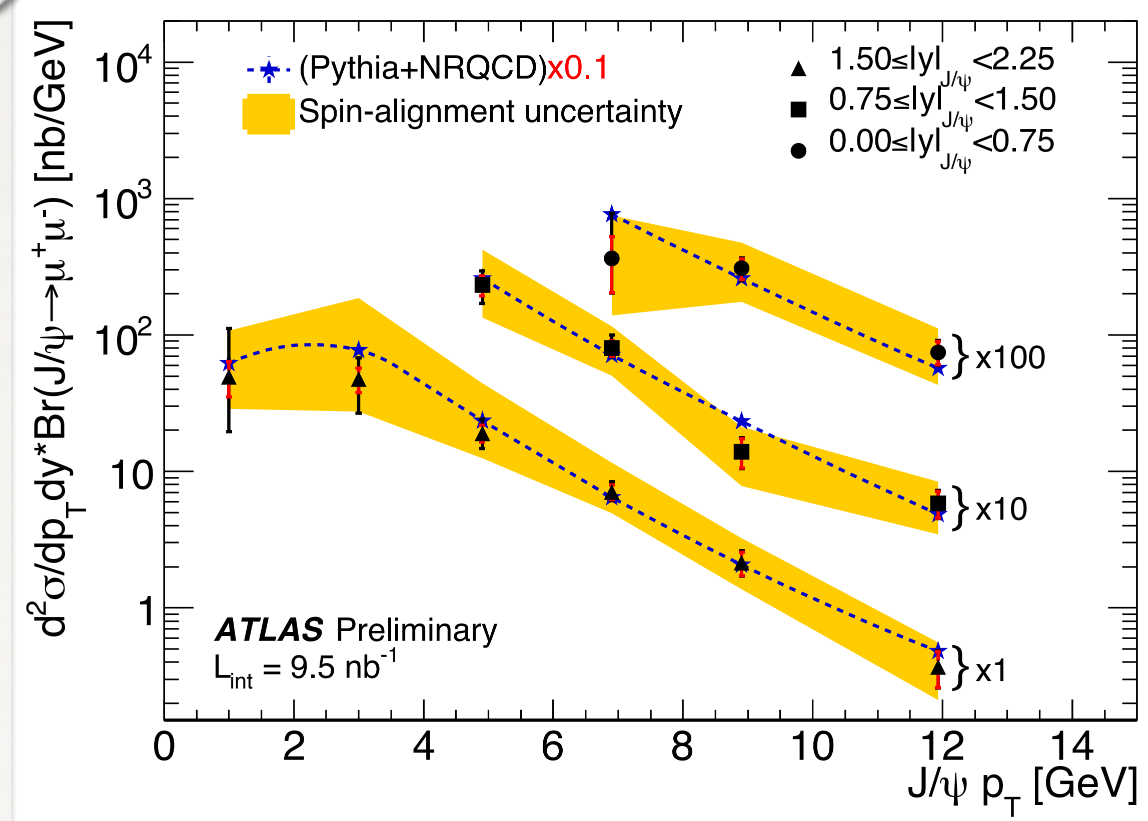
es of the fittedvertices):
.070 ± 0.003) GeV
he range $m_{J/\psi} \pm 3\sigma_m$:
73 ± 10 (mainly from c/b)
- N_{sig} = 710±34

Differential cross section measurement for the J/ψ→μμ

Cross-Section versus J/ψ p_T, each curve is a y bin



- Shape in good agreement with the Pythia NRQCD expectations
- ATLAS Pythia re-tuning ongoing to correct the factor 10 discrepancy
- Dominant systematics: trigger efficiency, reconstruction, selection will decrease by increasing statistics

Using most populated bins concentrated in the high-η region, disregarding spin alignment correction one has:

$$d\sigma/dy \times \mathrm{Br}(J/\psi \to \mu\mu)|_{\langle y\rangle \simeq 1.85} = \left(250^{+130}_{-80}\right)\mathrm{nb}$$

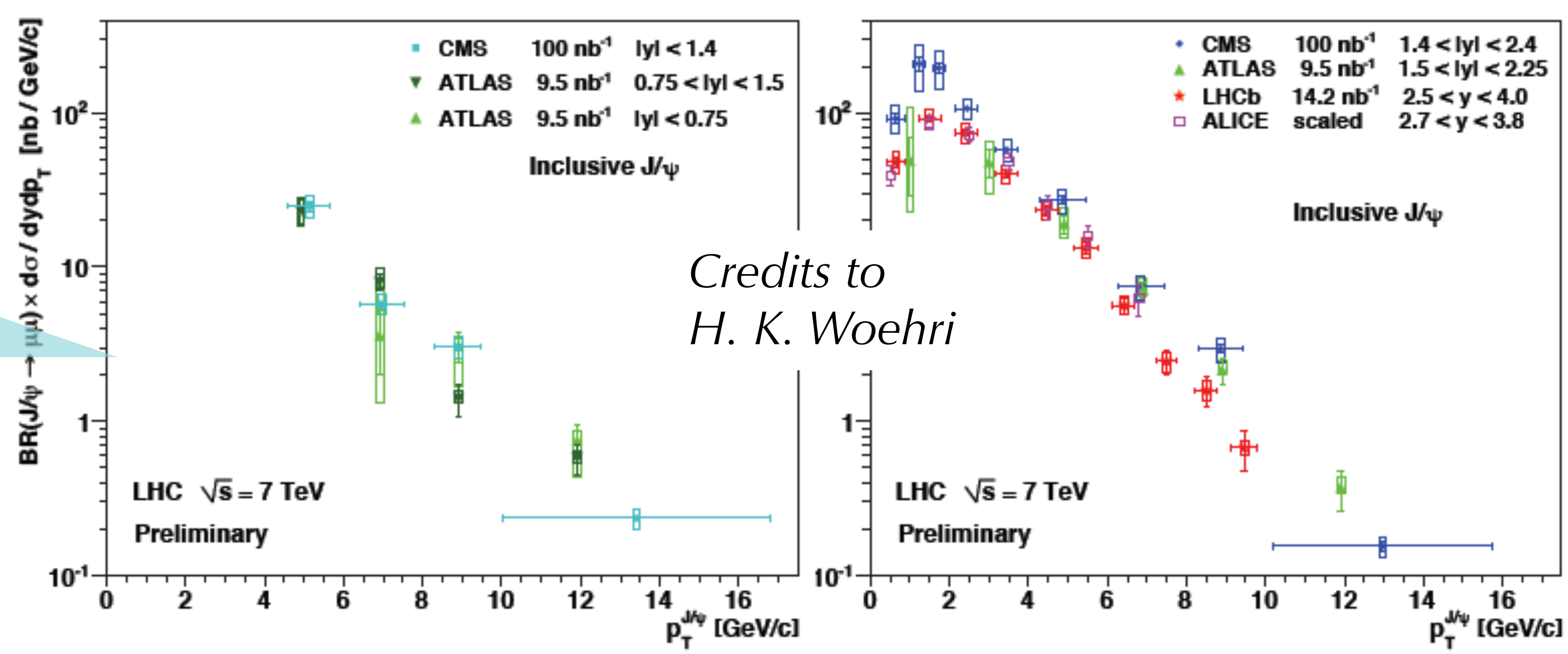
Current theory predictions are in the range 140-250 nb with uncertainties as large as 3 x prediction in either directions (Brodsky, Lansberg PRD81(2010)051502)

- Statistical and systematic uncertainty (trigger and reconstruction efficiencies, binning)shown in RED
-Theoretical uncertainty due to spin alignment (via acceptance) shown separately (yellow)
-Luminosity correction (~11%) to add

Comparison of results...

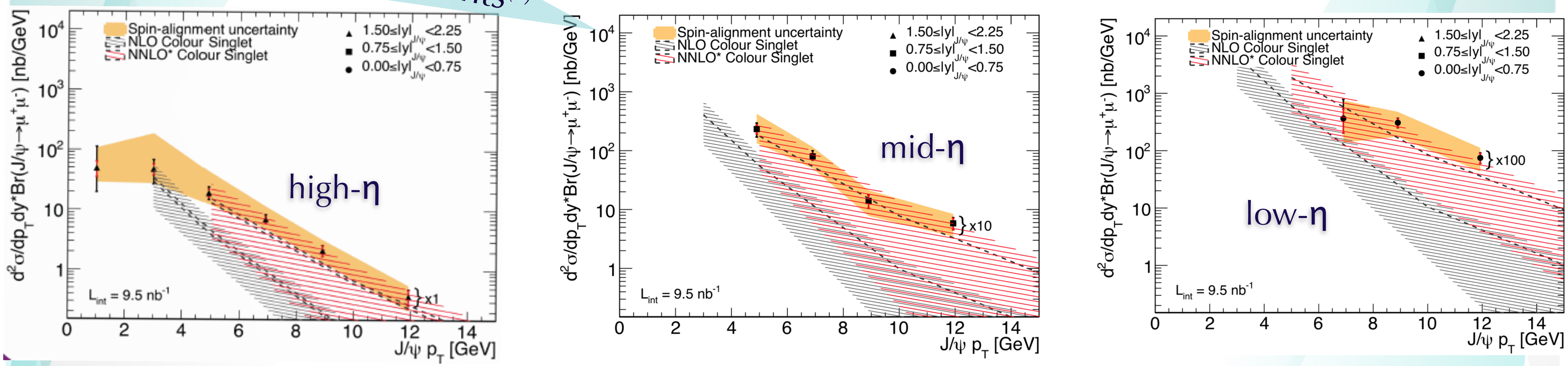
....with
other LHC
experiment shows
a very good agreement!

central region   forward region



Credits to H. K. Woehri

....with
theory needed
some further improvements(*)



(*) 1. Used correction factor (from CDF) to account for

- non prompt B->J/ψ contribution (also measured by ATLAS)

- ψ(2S) and χc feed-down (P. Faccioli et al JHEP10(2008)004)

2. χc corrections not available to NLO accuracy

Non-prompt to prompt J/ψ cross section ratio

- J/ψ can be produced either via the decay of long lived particles such as B-hadrons ("non-prompt"), or from short-lived sources such as QCD-related subprocesses ("prompt"). The ratio between these components:

$$\mathcal{F} \equiv \frac{d\sigma(pp \to b\bar{b}X \to J/\psi\, X')}{d\sigma(pp \to J/\psi\, X'')_{\mathrm{All}}}$$

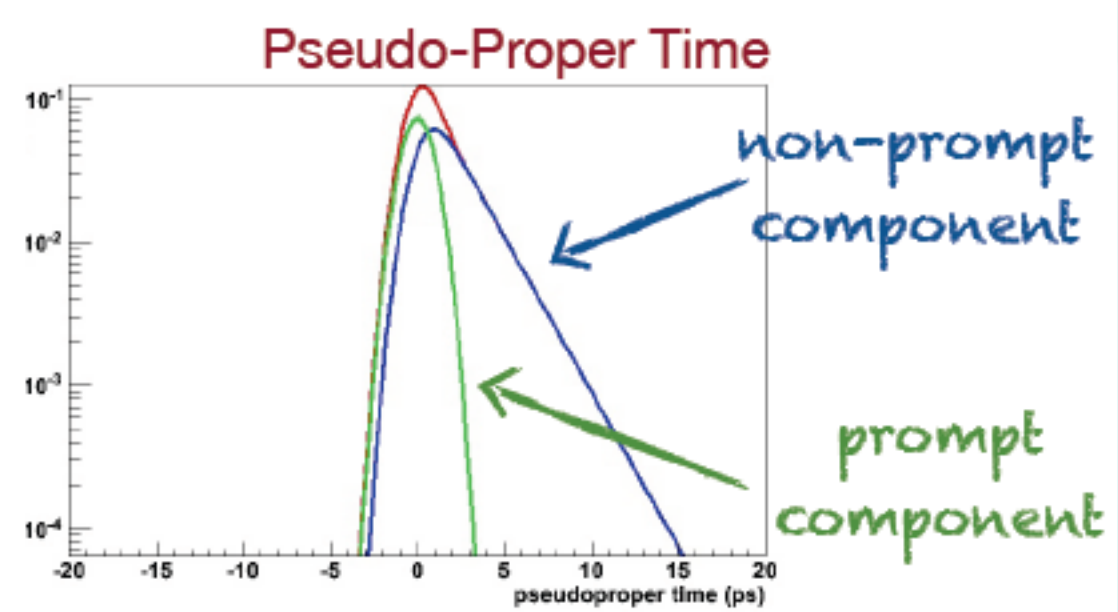
is very attractive because in the ratio the acceptances and efficiencies should cancel.

- The main discriminating variable between the two components is the pseudo-proper time:

$$\tau = L_T\, M^{\mu\mu}/P^{\mu\mu}_T$$

$$\simeq L_T\, M^B/P^B_T \propto e^{-\tau/\tau(B)}$$

L_T → decay length wrt the primary vertex in the xy projection



J/ψ→μμ lifetime measurement

Maximum Likelihood Simultaneous fit of:

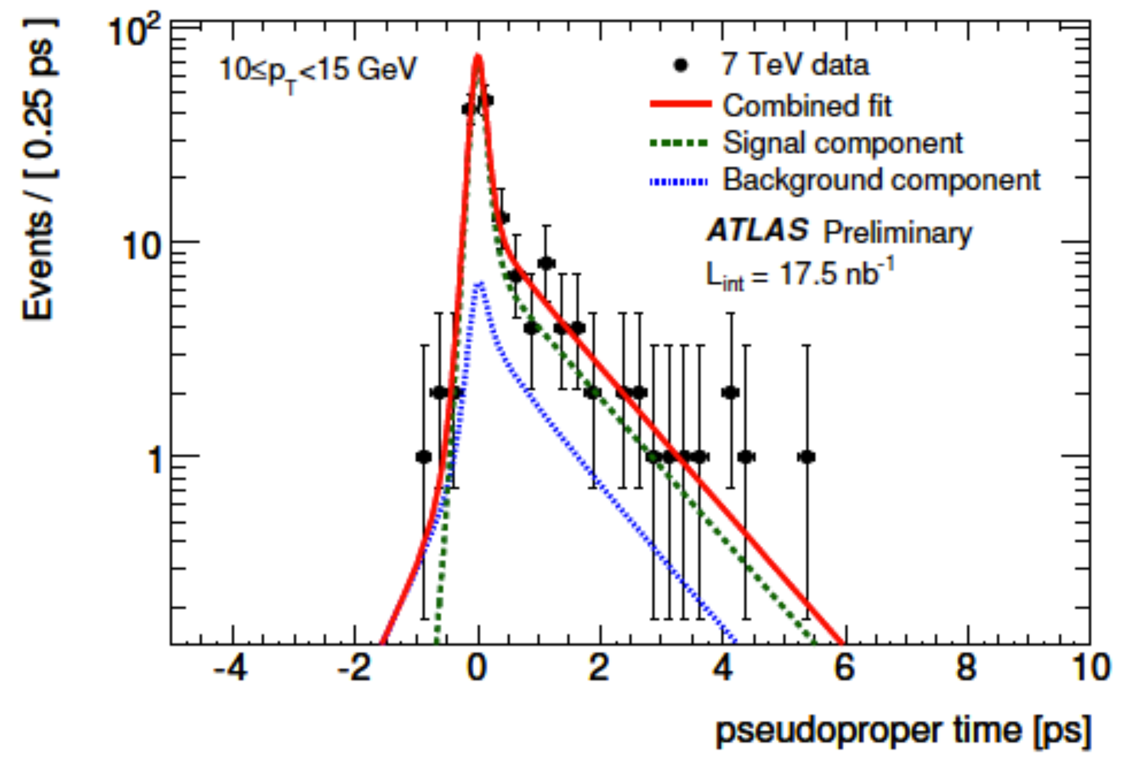
- invariant mass → signal/background separation, modeled by gaussian/linear function
  Signal model estimated by fitting data in the range $m_{J/\psi} \pm 3\sigma_m$,
  background from sidebands
- pseudo-proper time → prompt/non-prompt separation

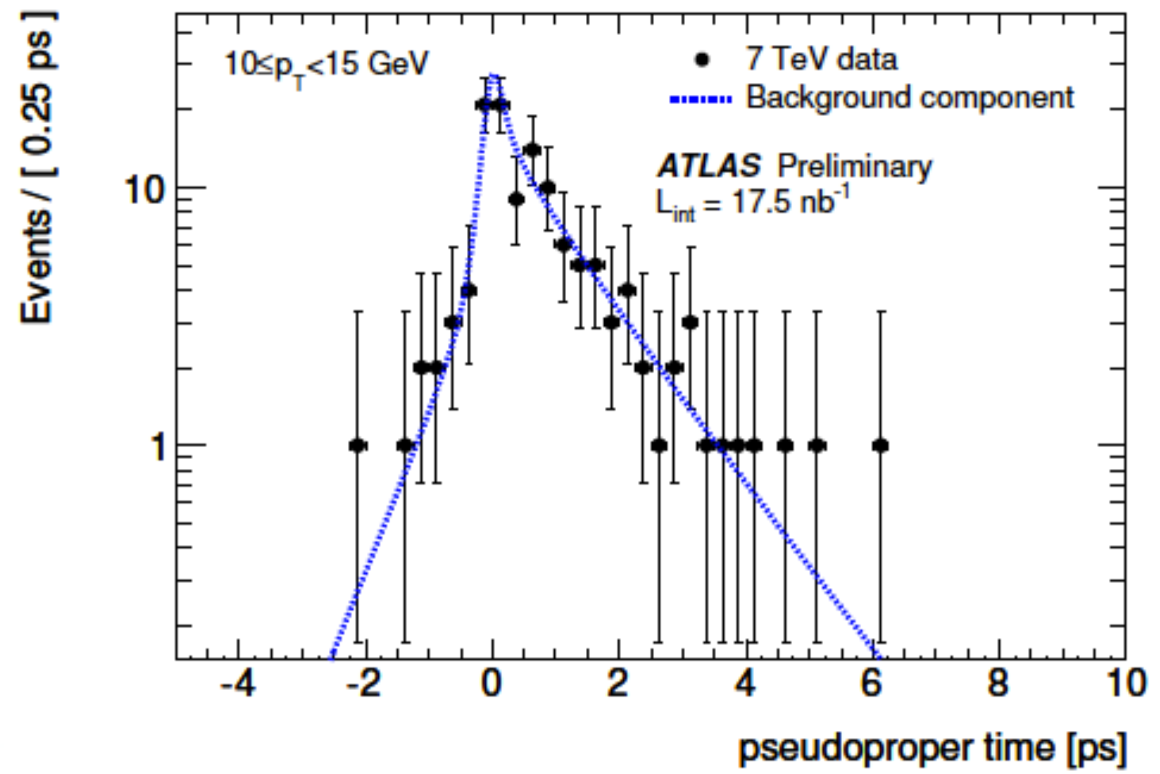
Simultaneous mass-time fit in invariant mass range [2,4]GeV

Fit Performed in five p_T bins (GeV): 1-4, 4-6, 6-8, 8-10, 10-15

Good agreement with modeling function

Sidebands dominated by a gaussian resolution term with mean 0

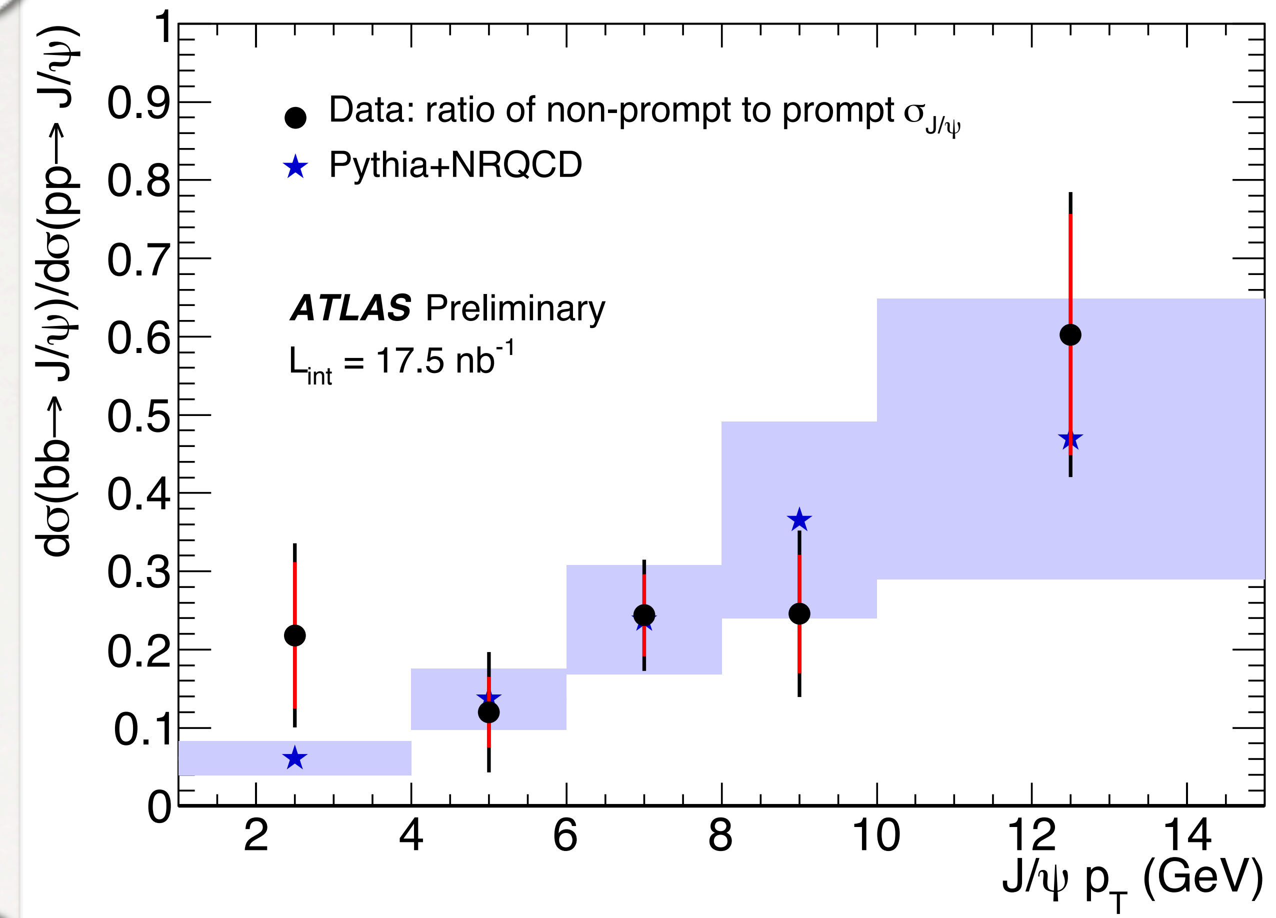




Non-prompt to prompt ratio

Pythia predictions in good agreement with ATLAS data

normalization discrepancy due to Pythia used in ATLAS equally affect prompt and indirect J/Ψ production



Systematics estimated from fraction f_B of non-prompt stability vs various fit options:

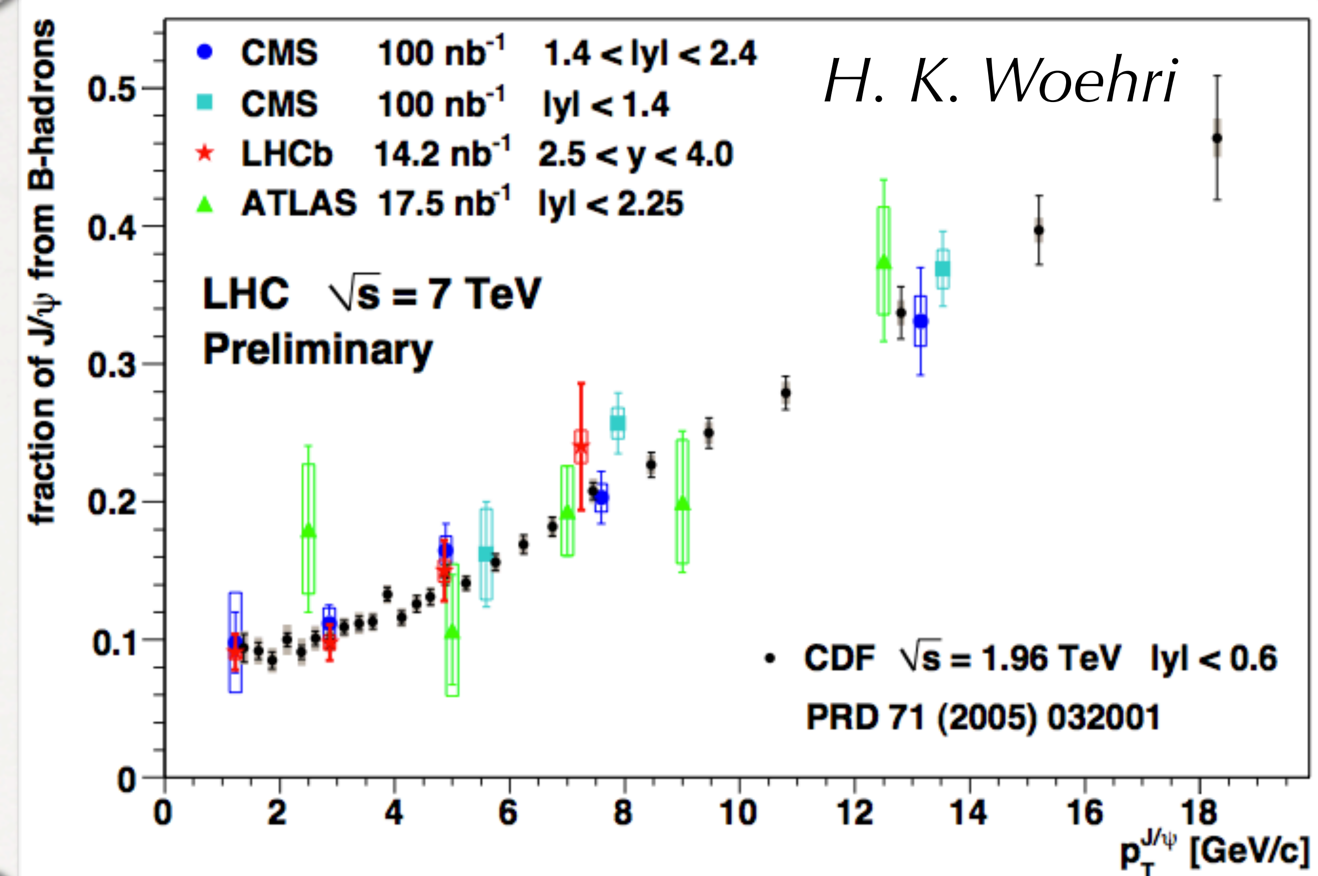
- different τ resolution model (double gaussian)
- polynomial background model vs linear
- background τ pdf parameters fixed from sideband fit vs simultaneous fit with signal τ pdf

In progress: assessment of uncertainty due to spin-alignment differences for non-prompt and prompt J/Ψ

Non-prompt to prompt ratio

Pythia predictions in good agreement with ATLAS data

Good agreement with other LHC experiments and also with CDF results



Systematics estimated from fraction f_B of non-prompt stability vs various fit options:

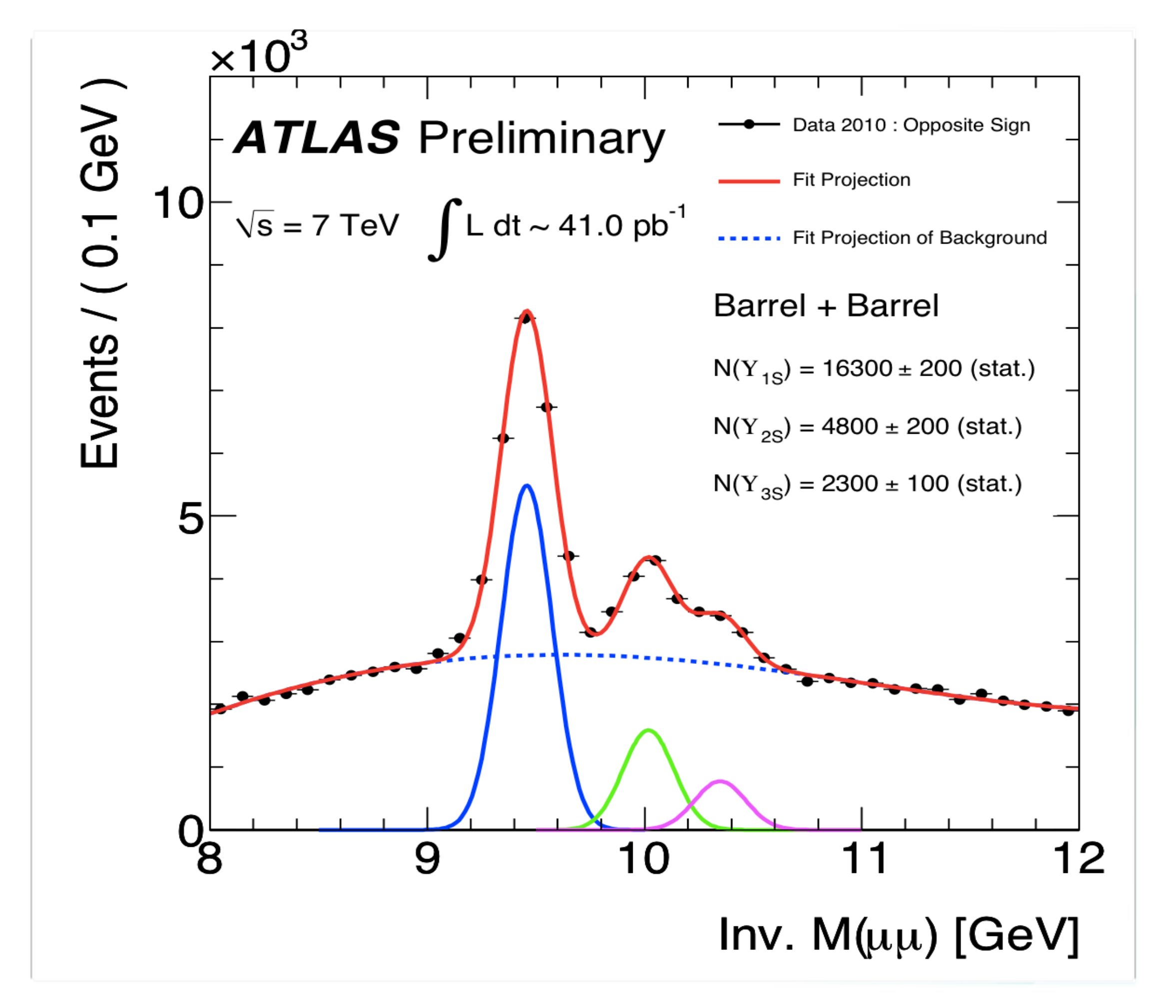
- different τ resolution model (double gaussian)
- polynomial background model vs linear
- background τ pdf parameters fixed from sideband fit vs simultaneous fit with signal τ pdf

In progress: assessment of uncertainty due to spin-alignment differences for non-prompt and prompt J/ψ

Y meson families: Y(1s,2s,3s)

FIT model:

- *Background: 4th degree Chebyshev polynomial*
- *Signal:3 Gaussians are fixed to the same width with spacings fixed to the pdg values*



Predominance of candidates in the endcap-endcap case, but better resolution in the barrel-barrel case

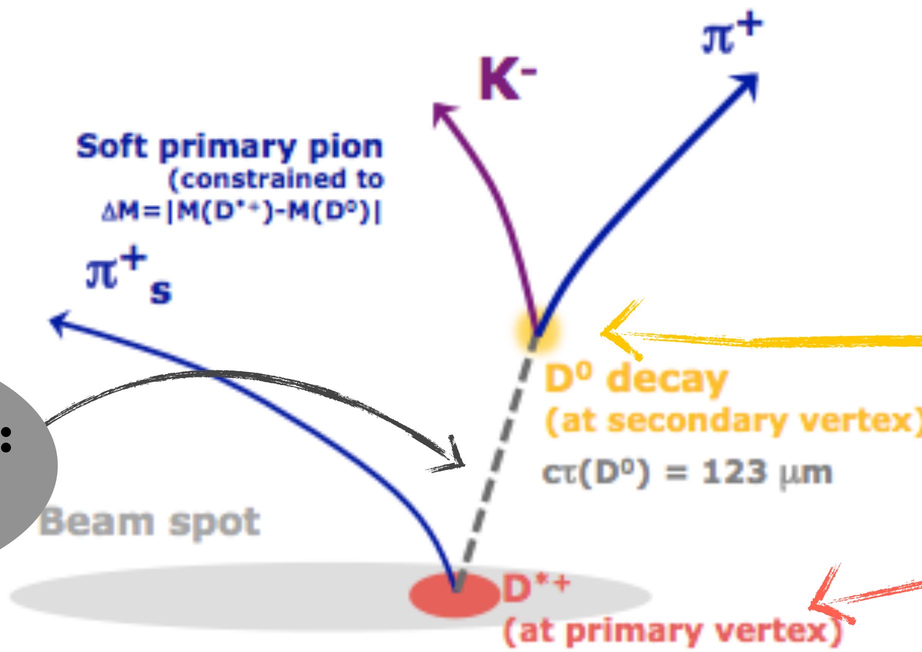
$D^{(*)}$ mesons reconstruction

ATLAS-CONF-2010-034

- First ATLAS B-Phys public result obtained with data sample collected at up to May 2010 using the minimum-bias triggers(99.5% efficiency): only 1.4 nb^{-1} of integrated luminosity used!
- Total cross section predicted at $\sqrt{s}$ =7 TeV :
    - $c\bar{c}$ ~4.4mb
    - $b\bar{b}$~0.24mb
- Theoretical calculations available till NLO+NLL level but still large uncertainties (scales, multiple interactions)-> huge statistics allows to verify MC predictions and proton structure functions
- Key elements for observation:ID track reconstruction (->quality cuts applied) and vertexing of the D^0
- Common cuts:
    - $|\eta(D^{(*)})| < 2.1$
    - $p_T\ (D^{(*)}) > 3.5$ GeV
- Combinatorial background significantly reduced by requiring (hard fragmentation):
    - $p_T\ (D^{*\pm}, D^{\pm})/E_T > 0.02$
    - $p_T\ (D^{\pm}_s)/E_T > 0.04$

$D^{*+} \rightarrow D^0(K^-\pi^+)\pi^+$ (+c.c.)

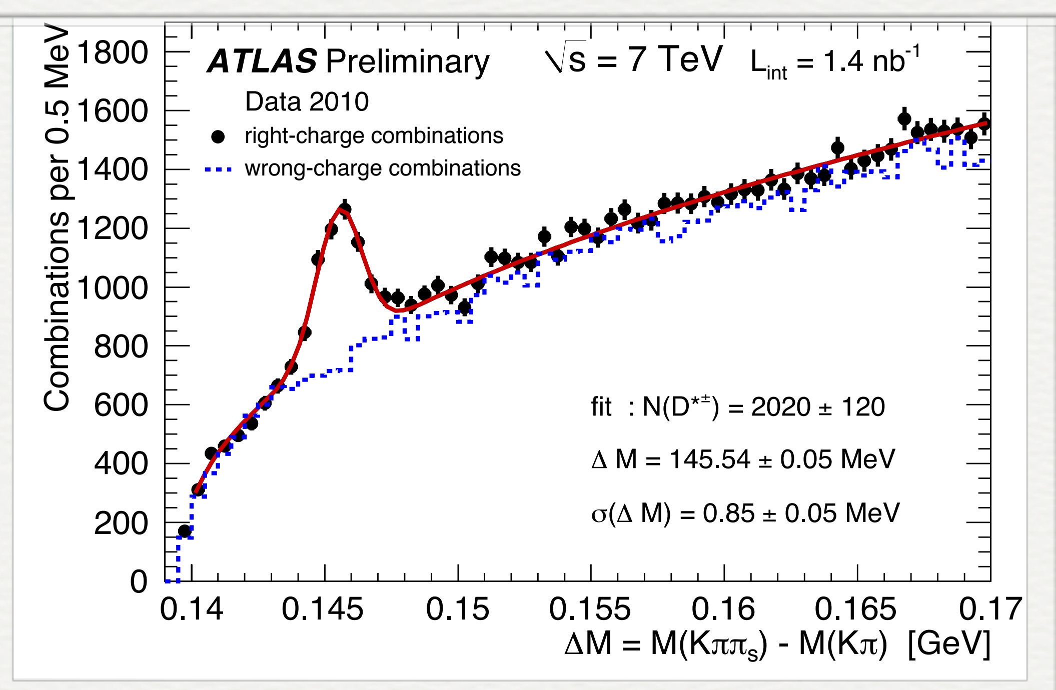
long lifetime:
$L_{xy} > 0$



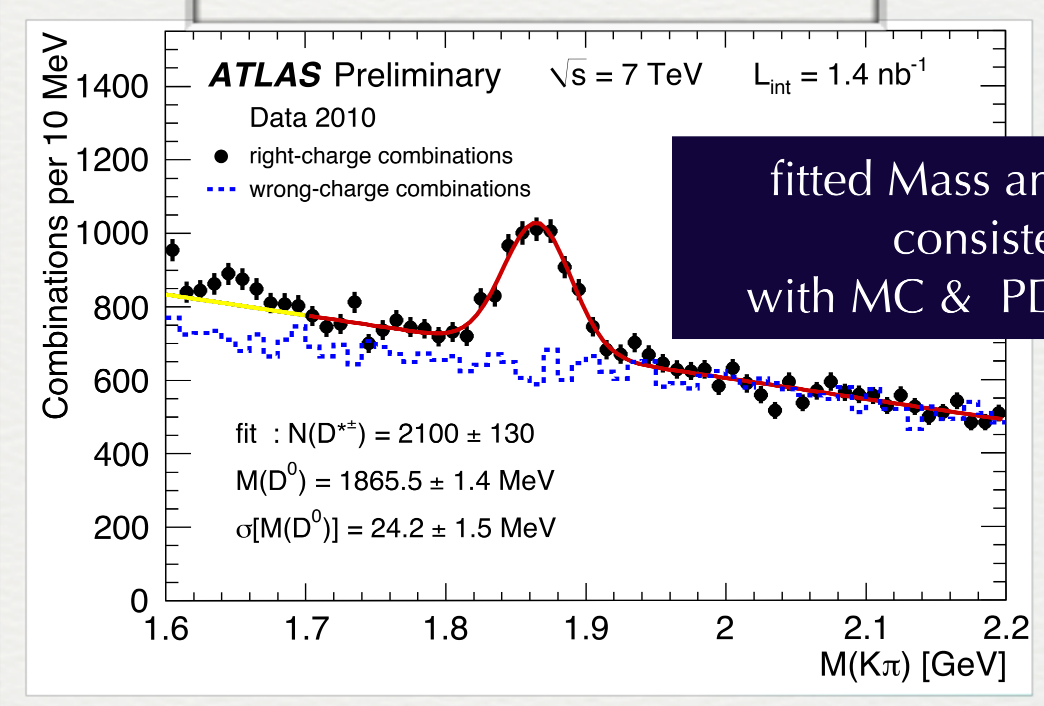
2 OS tracks,
$p_T > 1.0$ GeV
each assigned a K/π mass hypo fitted to a common vertex

Third track
$p_T > 0.25$ GeV
assigned a π^+_s mass hypo fitted to a common vertex

$\Delta M = M(K\pi\pi_s) - M(K\pi)$ for $1.83\text{GeV} < M(K\pi) < 1.90$ GeV

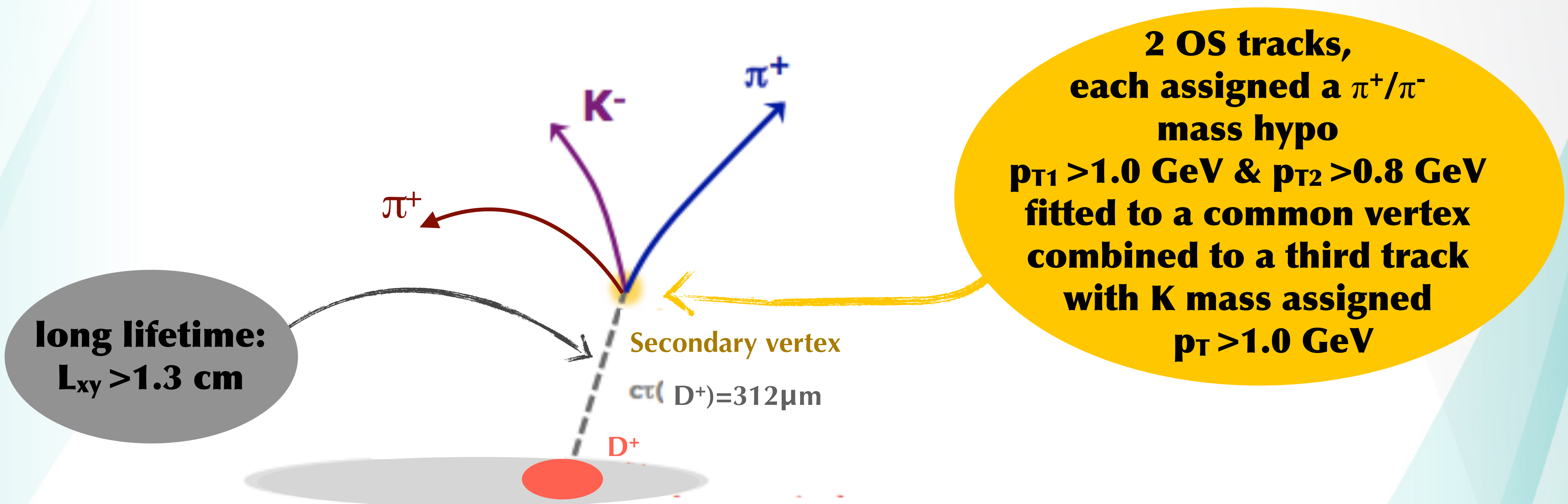


$D^{*\pm}$ for $144 < \Delta M < 147$ MeV



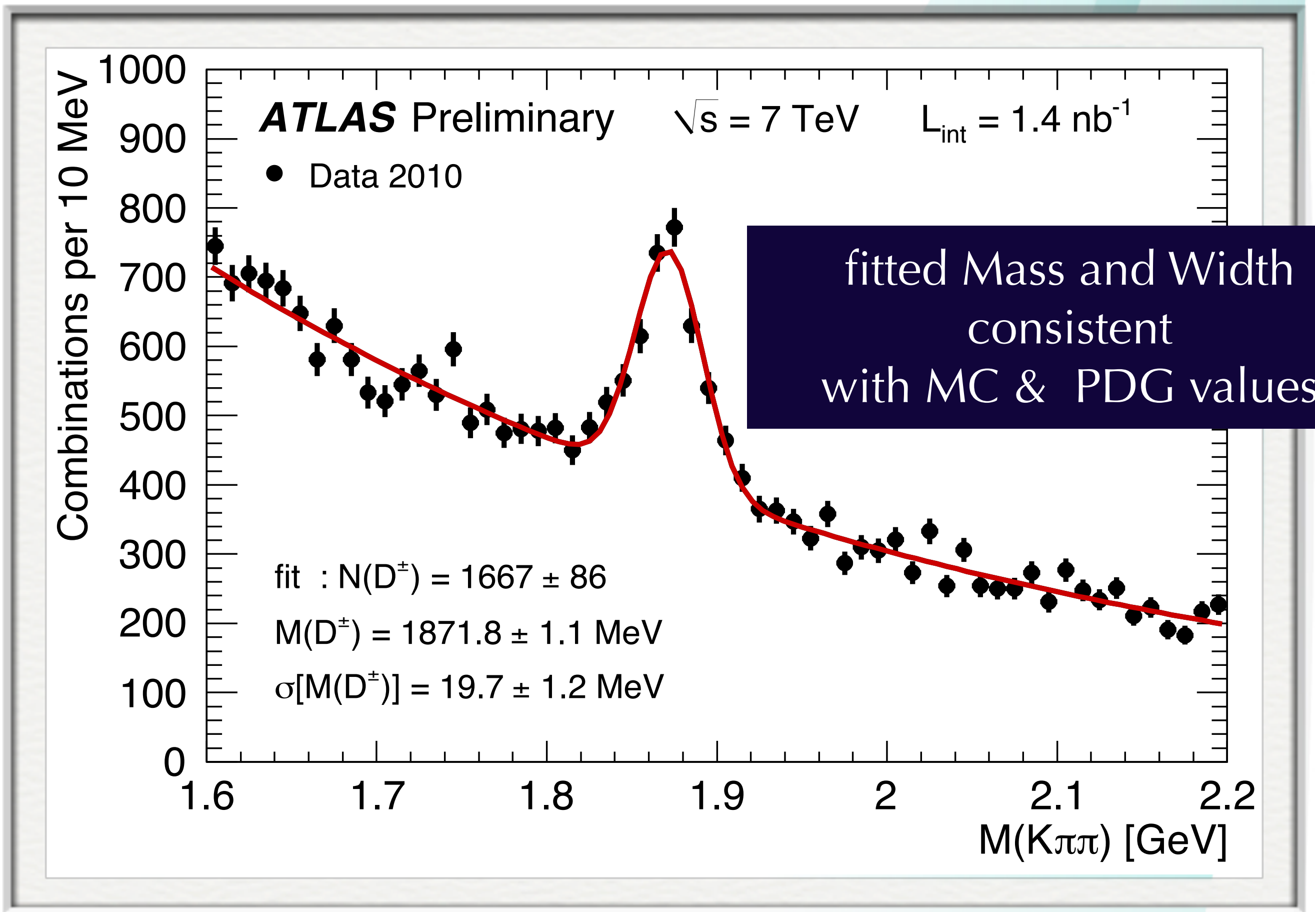
fitted Mass and Width consistent with MC & PDG values

$D^+ \rightarrow K^-\pi^+\pi^+$ (+c.c.)

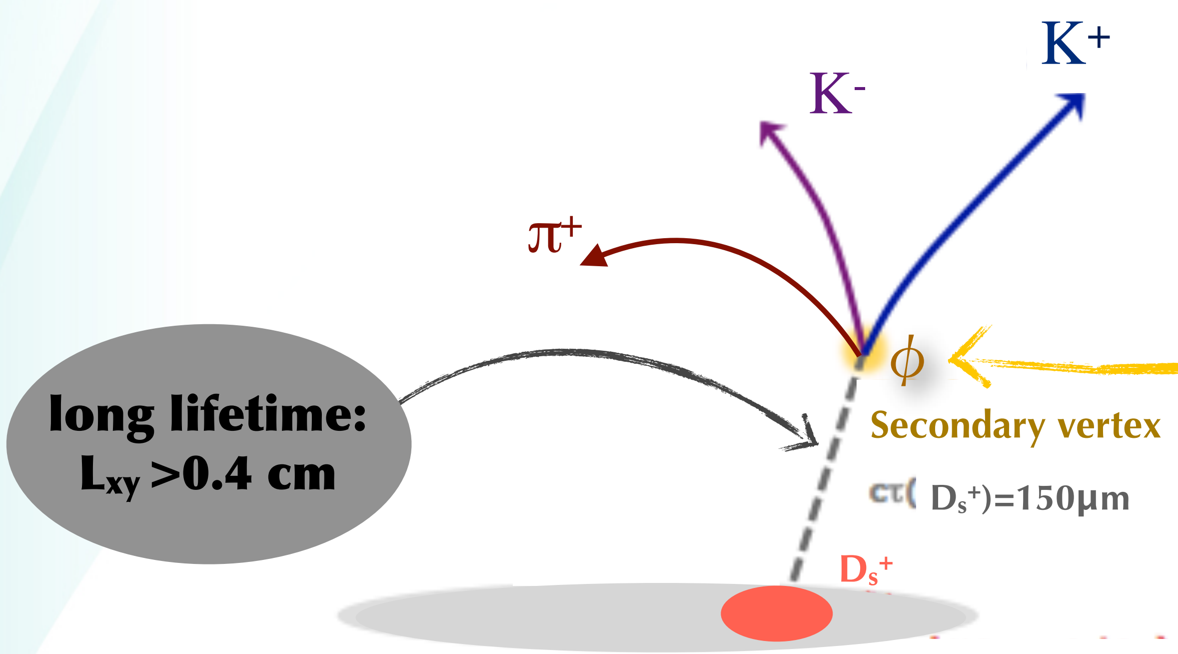


Further cuts:
- *$M(K\pi\pi)-M(K\pi)>150$ MeV (to suppress D^{*+})*
- *$|M(K^-K^+)-M(\phi)|_{PDG}>8$ MeV (to suppress D_s^+)*

Combinatorial background reduced using cut on angle θ^* between kaon p_T in D^+ rest frame and D^+ p_T in the lab frame: $\cos(\theta^*)>-0.8$

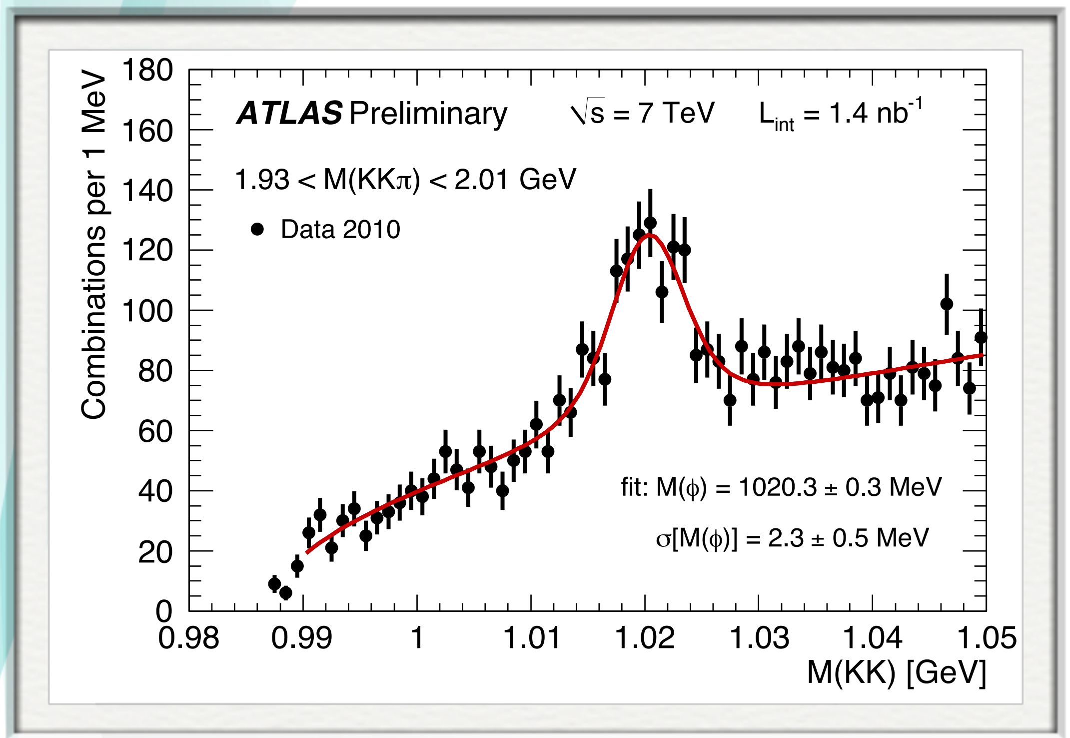


$D_s^+ \to \phi\,(K^-K^+)\,\pi^+$ (+c.c.)

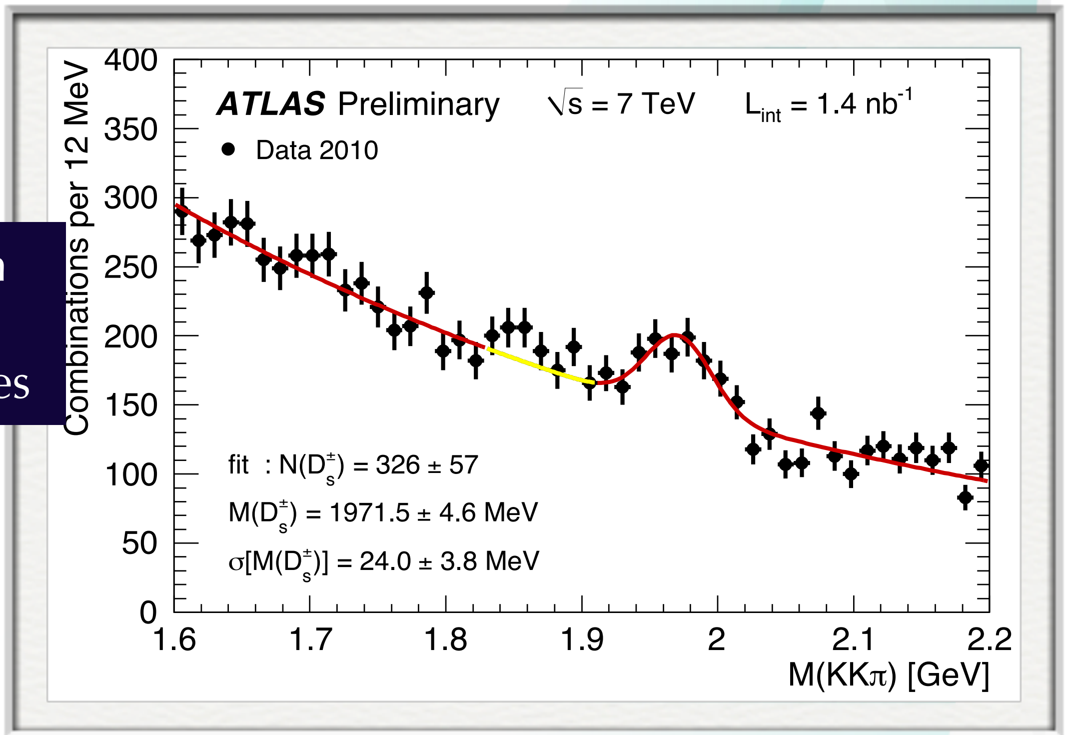


2 OS tracks,
each assigned
kaon mass assigned
p_T >0.7
fitted to a common vertex
fixing M ϕ ± 3 GeV combined to a third track
with π mass assigned
p_T >0.8 GeV

Further cuts on polarization angles applied to reduce combinatorial background



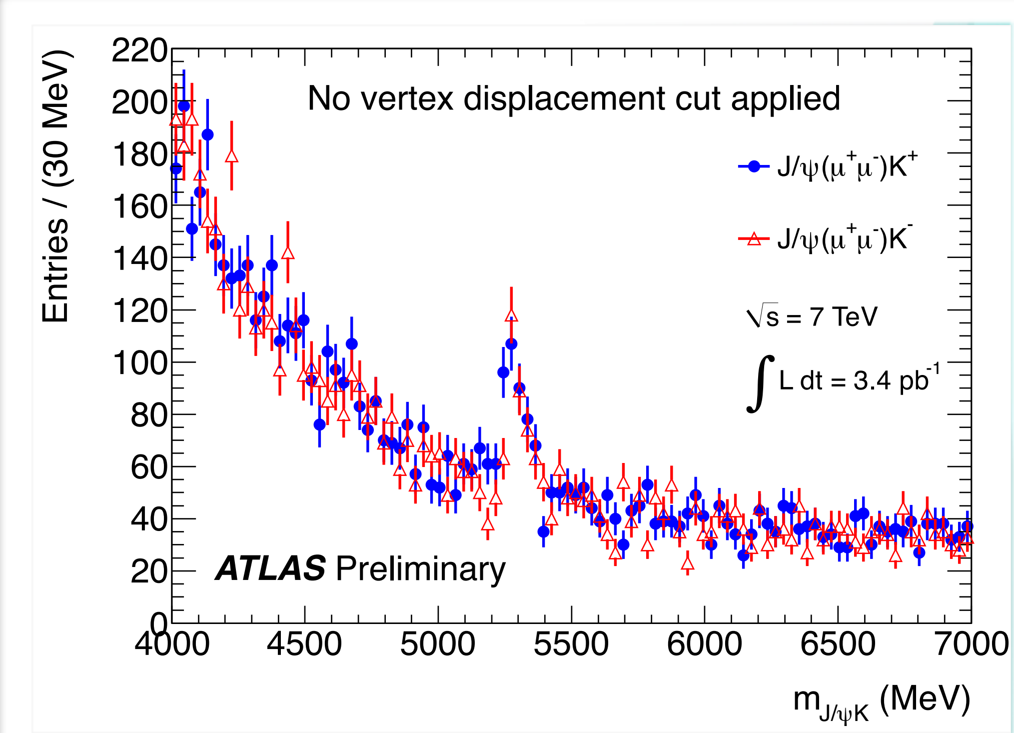
fitted Mass and Width consistent with MC & PDG values

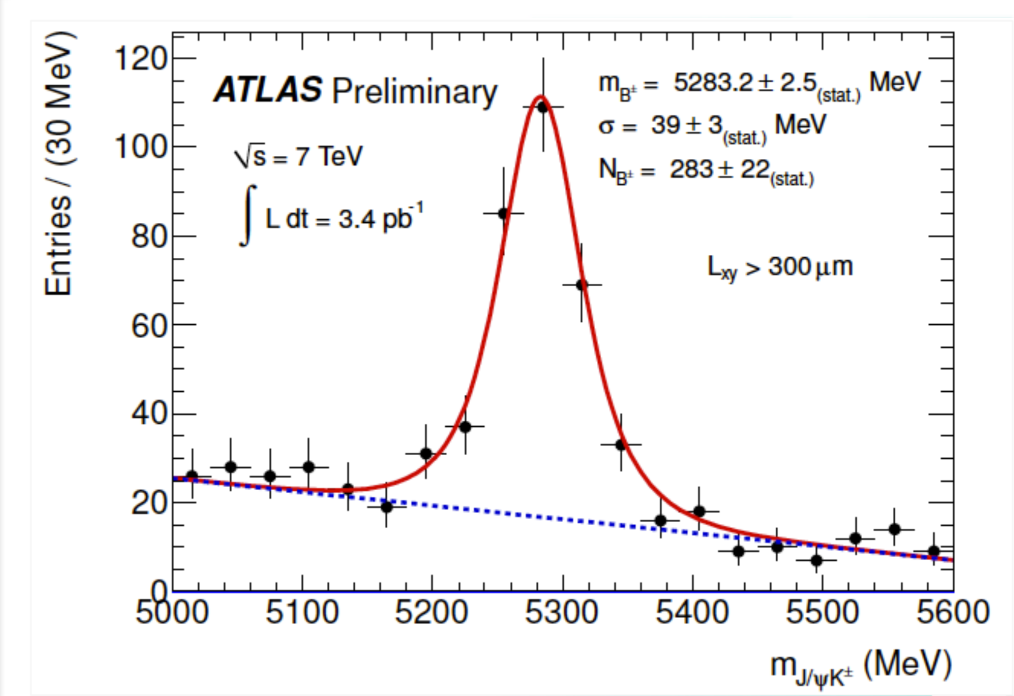


$B^{\pm}$ meson decay in $J/\psi(\mu^+\mu^-)K^{\pm}$

(ATLAS-CONF-2010-098)

- ATLAS recent observation, 3.4 pb^{-1} used
- Di-muon in the J/ψ mass range combined with a third track (kaon mass assigned)
- Fitted to a common vertex, with J/ψ mass constraint on di-muons
- Background suppression by applying a cut on transverse decay length $L_{xy} > 0.3$ mm
- *The value of the mass found* (unbinned maximum likelihood fit applied)*: (5283.2 ± 2.5) MeV is compatible with PDG value ((5279.17±0.29) MeV) and with the values obtained by fitting separately* $B^- \to J/\psi K^-$ and $B^- \to J/\psi K^+$ distributions
- A well knowledge of this channel allows rare B-physics decays branching ratio measurement





About Pb-Pb results

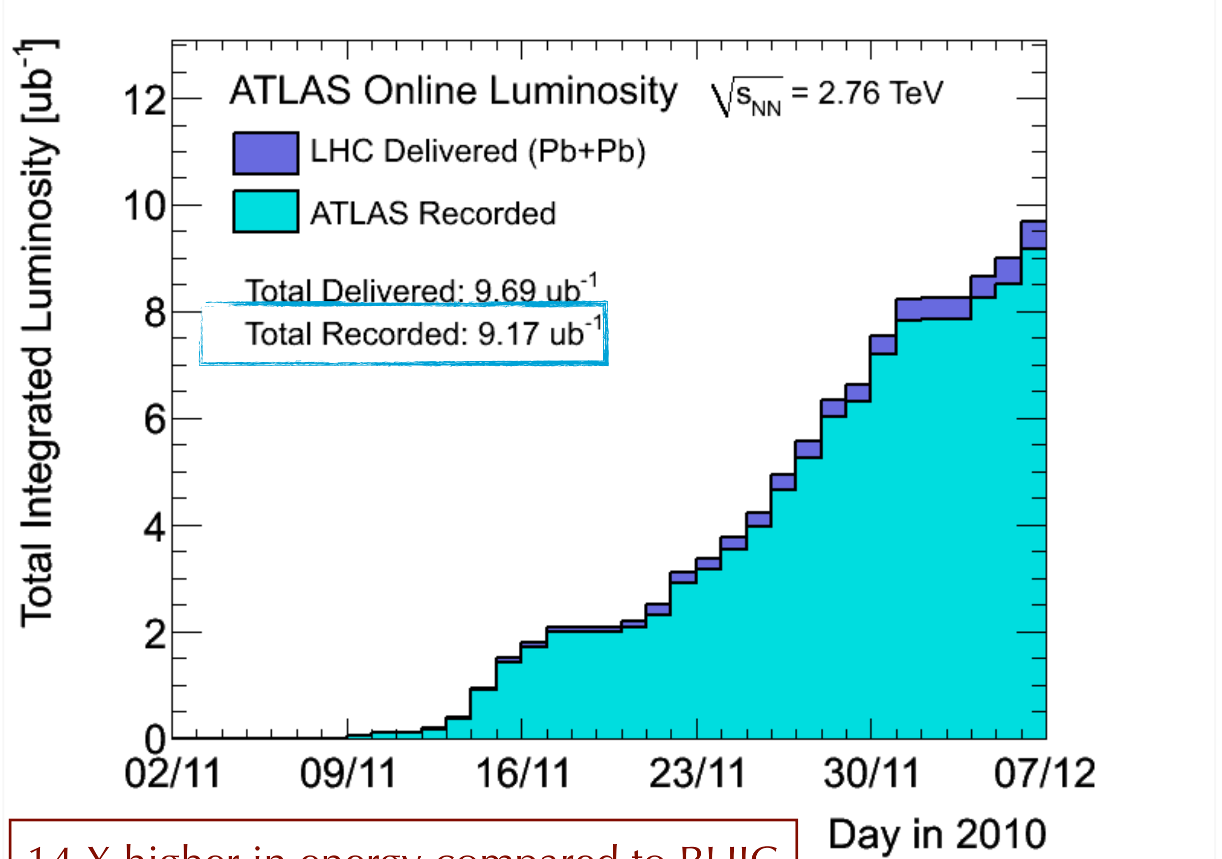
Motivations

- Nuclear collisions provide a laboratory for studying QCD also in non perturbative regimes and LHC is the new frontier of heavy-ion collisions
- Matter produced in relativistic high-energy nuclear collisions is very hot ($T \sim 10^{12}$K), dense (~ 1 GeV/fm^3) and strongly interacting -> phase transition to QGP, were quark-antiquark pairs condense and show collective properties like in superconductors
- In the QGP (the time scale being big wrt strong interaction) it is expected that:

  - fragmentation in the medium differs from the vacuum->asymmetric jet quenching due to energy losses in the medium **(J.D. Bjorken, FERMILAB-PUB-82-059-T)**
  - the QCD binding potential is color-screened, the screening level increasing with the energy density of the created system-> quarks de-confinement, suppression of the strongly bound states of charmonium and bottomonium **(A. Mocsy and P. Petreczky, Phys. Rev. Lett. 99 (2007) 211602)**

ATLAS 2010 Pb-Pb collisions

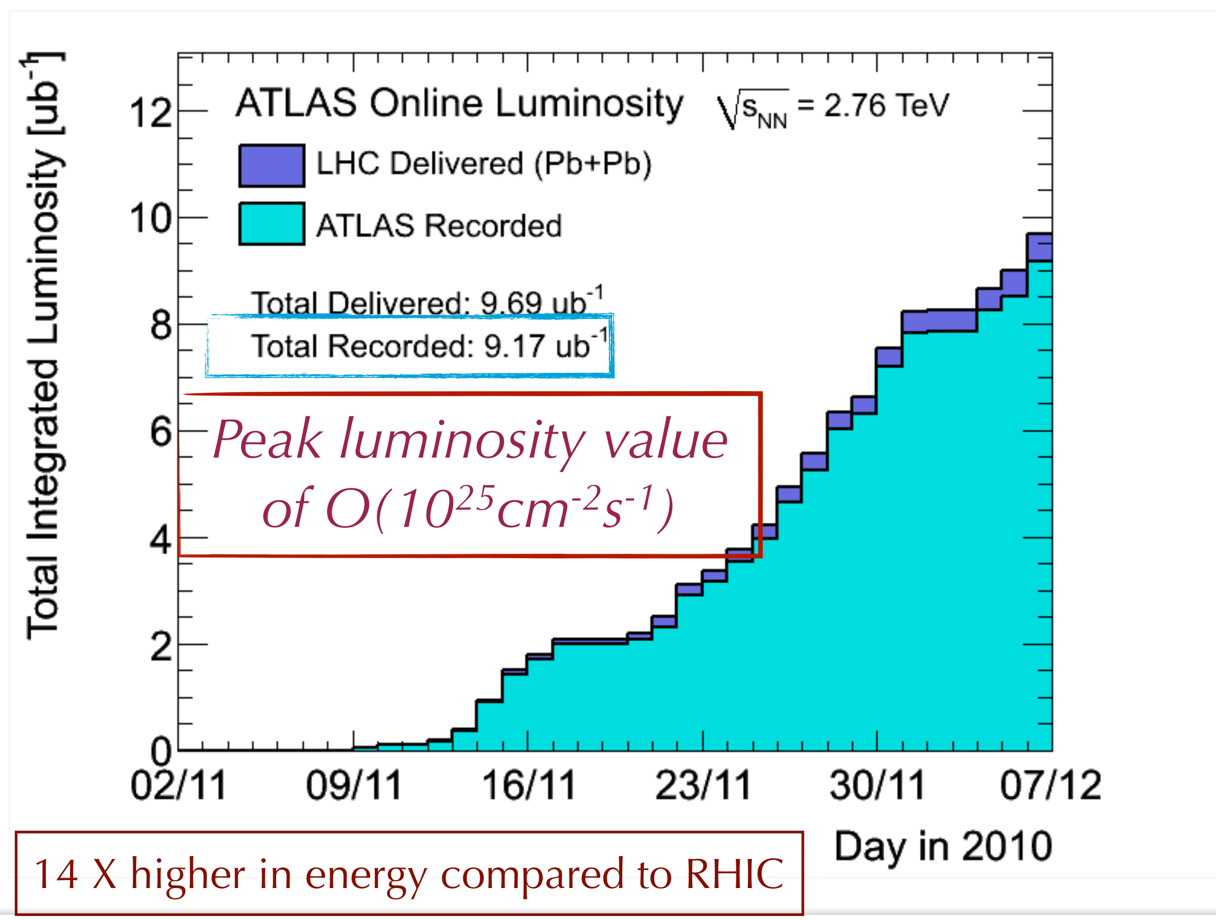
Pb-Pb collisions@$\sqrt{s_{NN}}$ =2.76 TeV
November 2010 ->December 2010



14 X higher in energy compared to RHIC

ATLAS 2010 Pb-Pb collisions

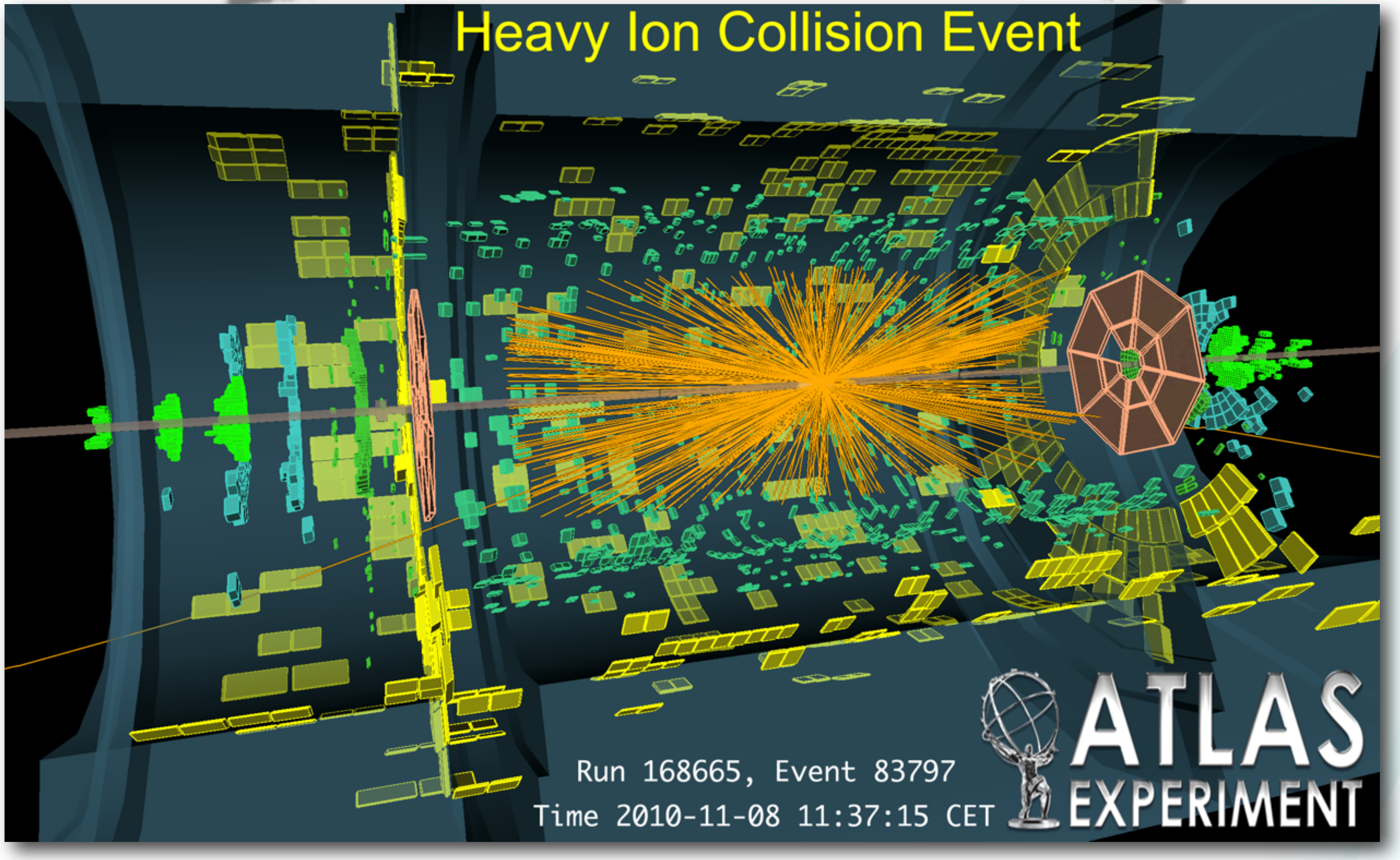
Pb-Pb collisions@$\sqrt{s_{NN}}$ =2.76 TeV
November 2010 ->December 2010



ATLAS 2010 Pb-Pb collisions

Pb-Pb collisions@$\sqrt{s_{NN}}$ =2.76 TeV
November 2010 ->December 2010

Raw number of reconstructed tracks with p_T > 1 GeV is 1115!



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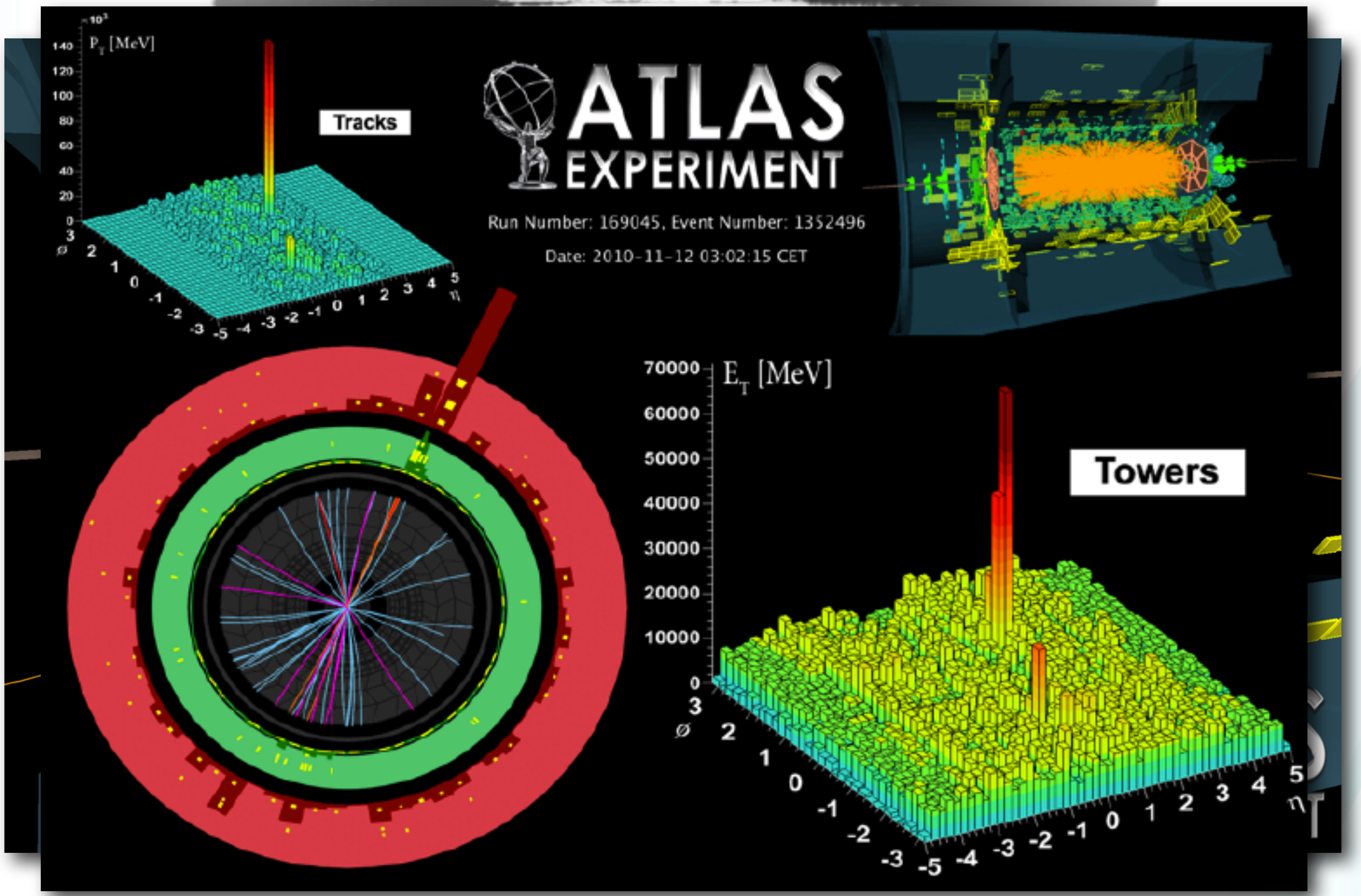
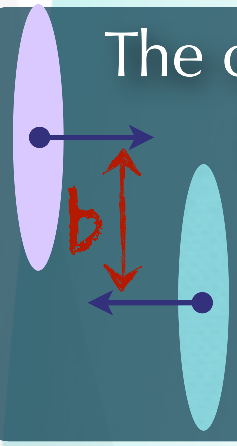


First physics results submitted to PRL during Thanksgiving day (jet quenching):
Phys. Rev. Lett. (25 Nov 2010) CERN-PH-EP-2010-062

Centrality

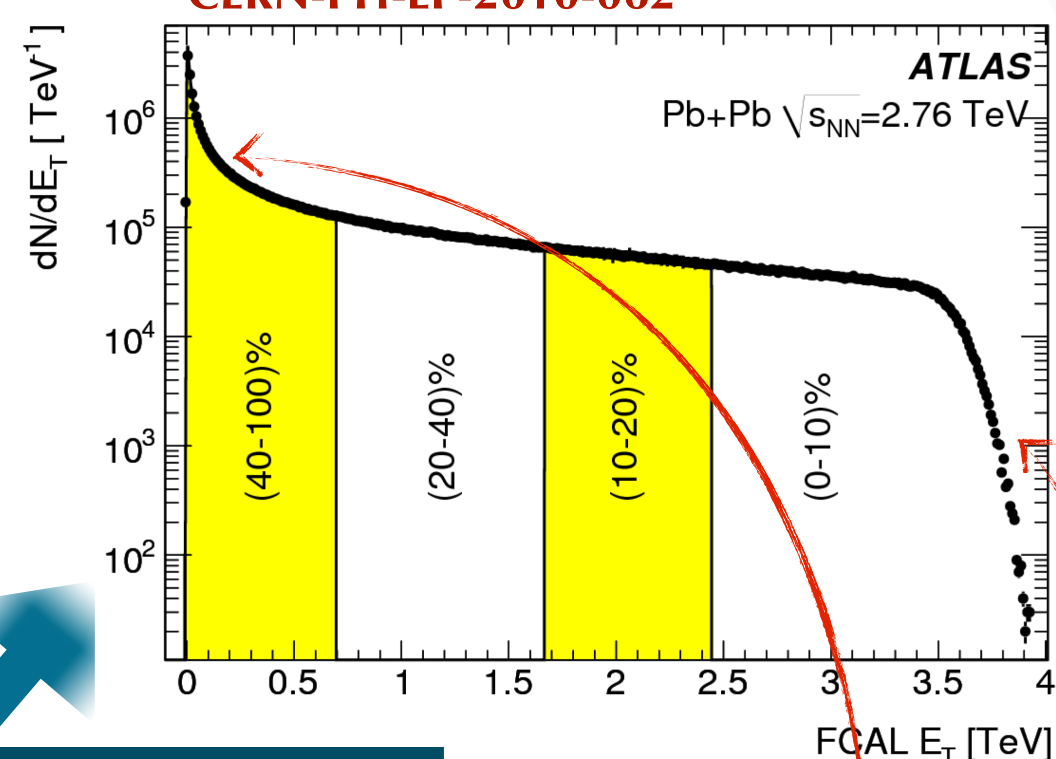


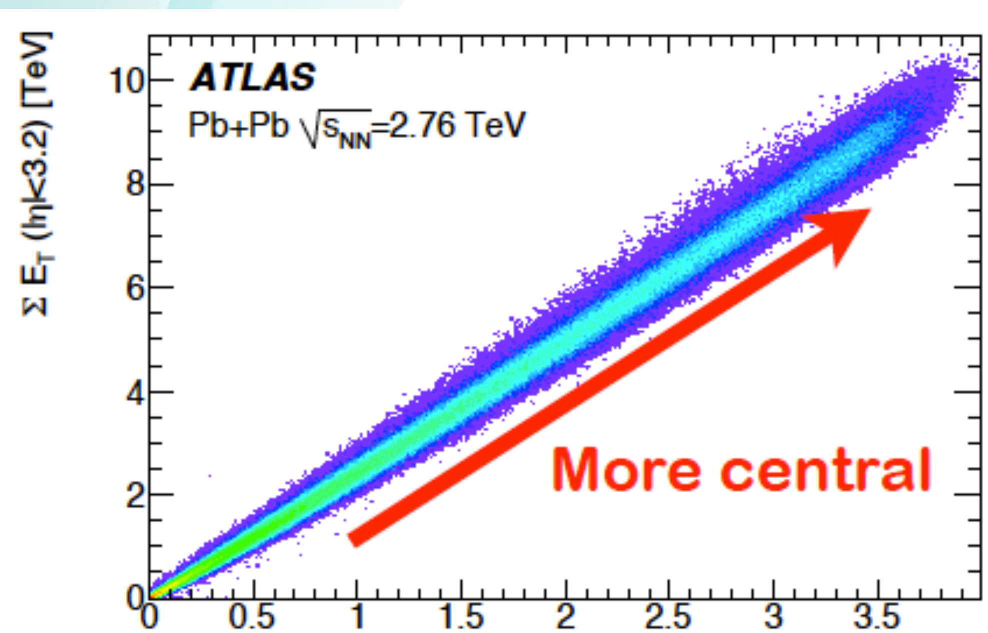
The classical impact parameter can help in understanding heavy-ion collisions dynamics but it's not directly measurable

- check multiplicity of 'participant' nucleons to inelastic collisions, N_{part} (that increases monotonically as b decreases), and of binary collisions N_{coll}

- characterize distribution of observables into bins by fraction of cross section

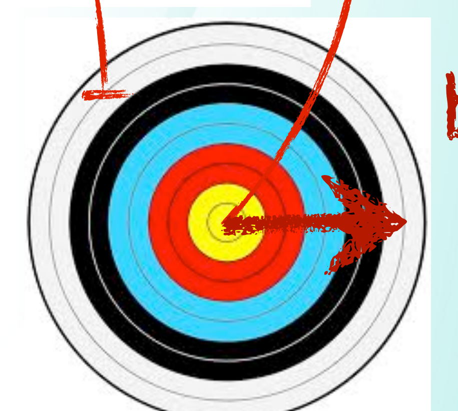
CERN-PH-EP-2010-062





CERN-PH-EP-2010-062

Centrality by percentiles of total cross-section using FCAL E_T



The J/ψ yield

Second physics results submitted to PRL some hours before Xmas:

Phys. Rev. Lett. (24 Dec 2010) CERN-PH-EP-2010-090

Goal: measure how J/ψ yield depends on centrality @ $\sqrt{S_{NN}}$ =2.76 TeV in a defined kinematic region: $p_T(\mu)$> 3 GeV and $|\eta|<2.5$

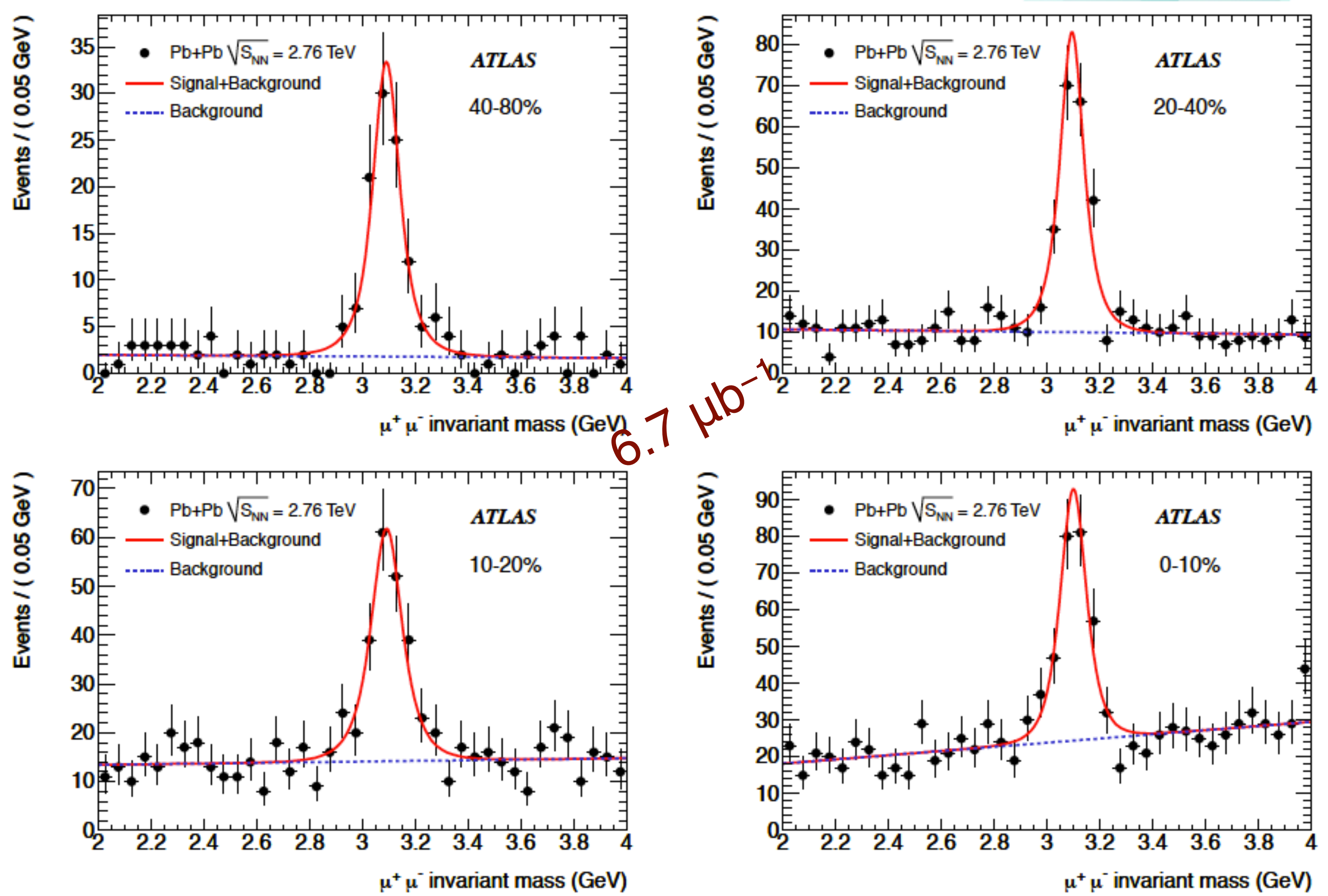
Two methods:

1. Signal vs side-band windows counting, background linearly extrapolated:
   - S: [2.95 , 3.15]GeV;
   - B: [2.4 , 2.8]GeV + [3.4 , 3.6] GeV;

2. Un-binned maximum-likelihood fit:
   - S:Gaussian, B: Polynomial (I degree)

   with event by event mass error (form error matrix) x FREE Scale Factor (resolution)-> just cross check

Fully combined opposite sign muons



The J/ψ yield suppression

Measured J/ψ yield are corrected:

$$N_c^{\rm corr}(J/\psi \to \mu^+\mu^-) = \frac{N^{\rm meas}(J/\psi \to \mu^+\mu^-)_c}{\epsilon(J/\psi)_c \cdot W_c}$$

detection efficiency from MC

centrality bin width

expressed wrt the yield found in the most peripheral 40-80% centrality bin(*):

$$R_c = N_c^{\rm corr}/N_{40-80\%}^{\rm corr}$$

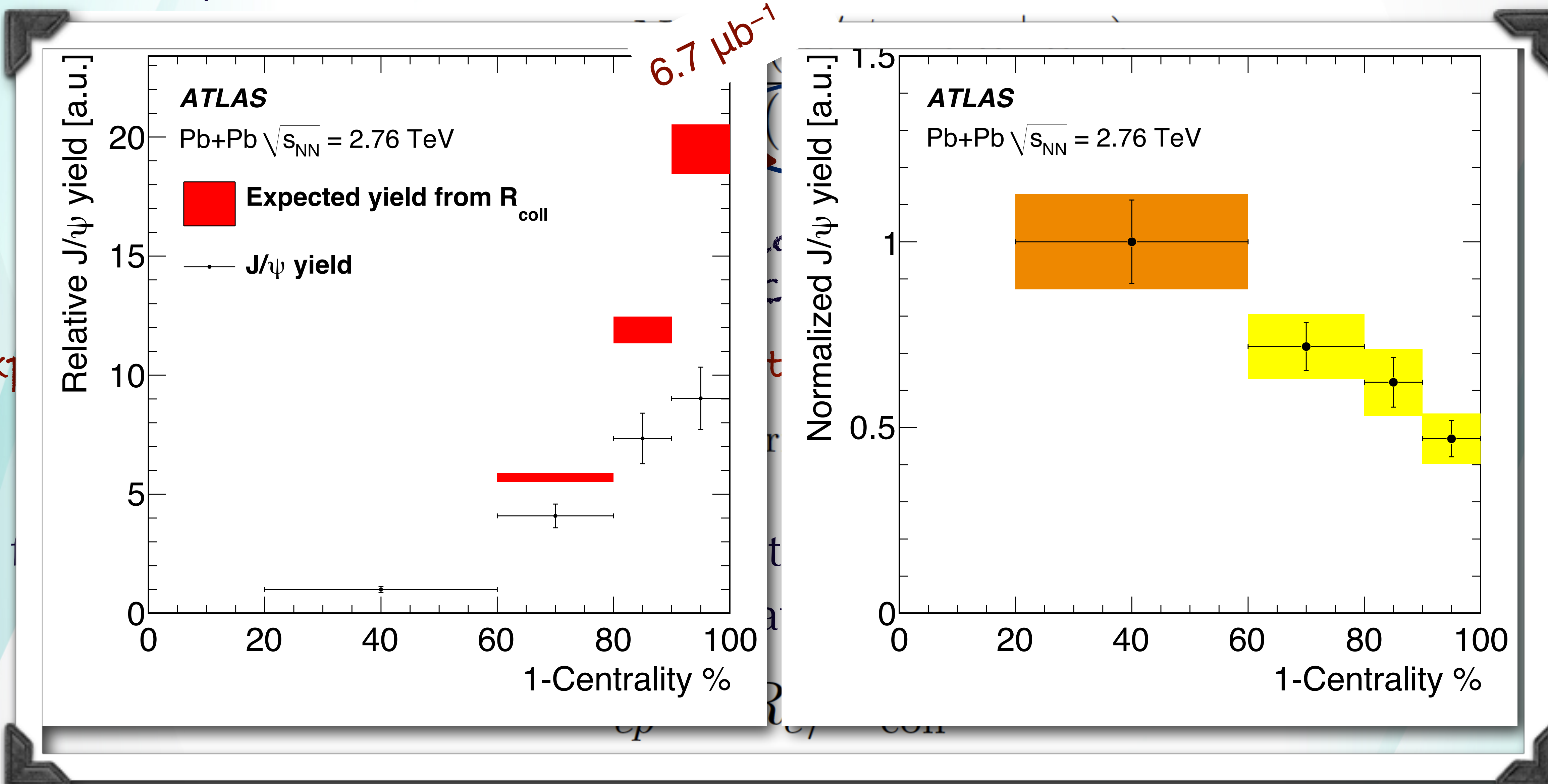
and finally normalized to the ratio R_{coll} of the mean number of binary collisions N_{coll} (*) in each centrality bin to that for the most peripheral bin:

$$R_{cp} = R_c/R_{\rm coll}$$

(*) In the ratio ONLY efficiency effects wrt to centrality do not cancel!
(**) From Glauber MC

The J/ψ yield suppression

Measured J/ψ yield are *corrected:*



exp

and t

coll

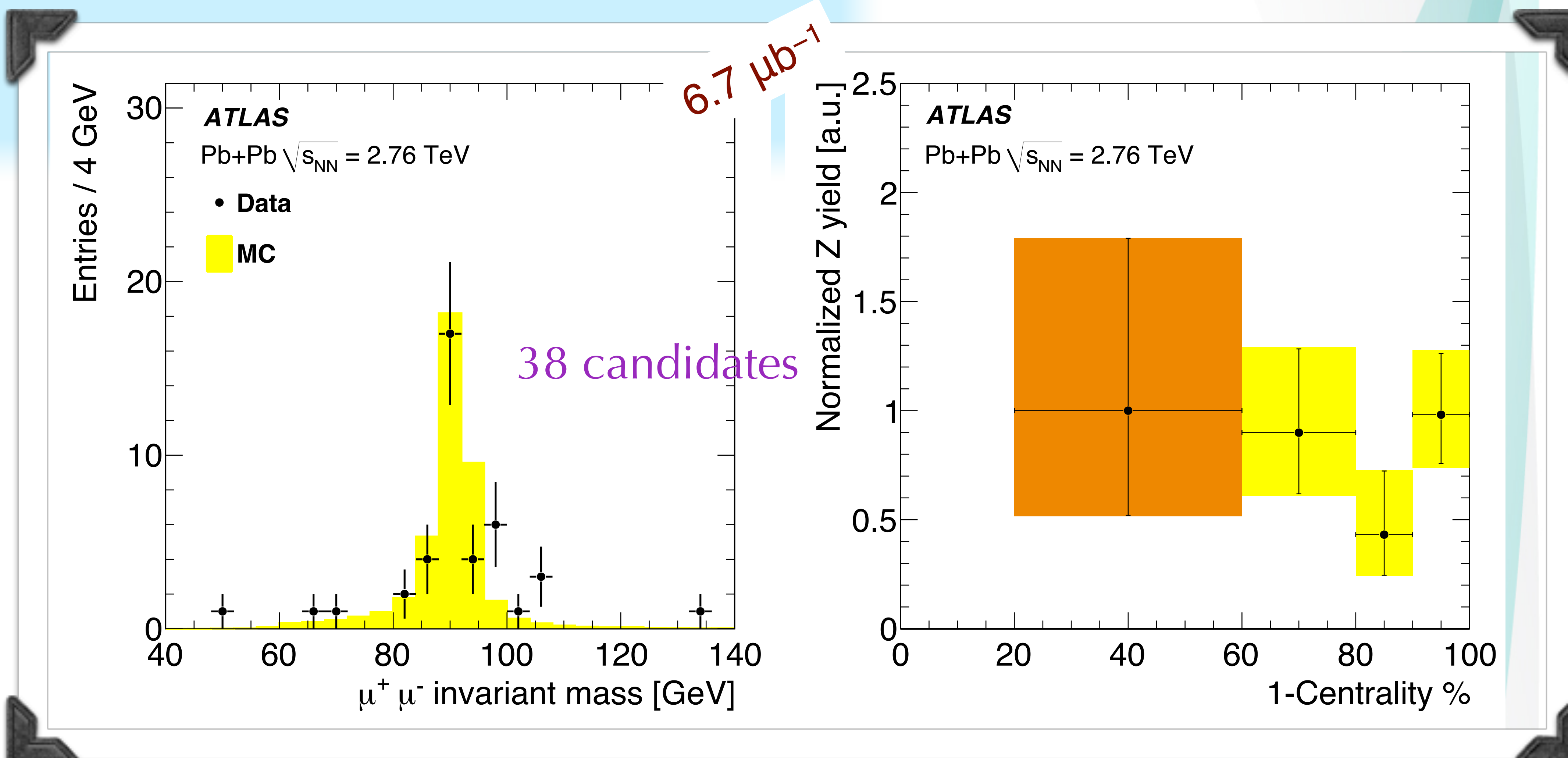
(*) **In the ratio ONLY efficiency effects wrt to centrality do not cancel!**

(**) **From Glauber MC**

Further checks: $Z \rightarrow \mu^+\mu^-$

Event selections:

- Invariant Mass window [66,116] GeV,
- fully combined muons
- $p_T > 20$ GeV,
- $|\eta| < 2.5$
- $|\eta_1 + \eta_2| > 0.01$



within statistics yield independent of centrality

Summary

- First ATLAS J/ψ production cross section result used 9.5 nb^{-1} data:
  - have good agreement with PYTHIA in shape.
  - new tuning for ATLAS MC is ongoing
  - have good agreement with other LHC experiments
- First results on J/ψ production & prompt to non prompt ratio
- The Upsilon family has been found in ATLAS detector
- Observation of $D^{*\pm}$, $D^{\pm}$, $D_s^{\pm}$ in hadronic decay modes
- Observation of $B^{\pm}$ decay into $J/\psi\ K^{\pm}$
- Heavy Ion collisions results

Plans for 2011

Proton-Proton up to few fb^{-1}:

- Extend J/ψ, Υ measurements: higher p_T and polarization, full stat cross section
- $\psi(2s)$, $\chi_c \rightarrow J/\psi\ \gamma$: observation and cross section measurements
- Observation of $X(3872) \rightarrow J/\psi\pi\pi$, cross section
- Observation of $B_c \rightarrow J/\psi\pi$ and $\Lambda_b \rightarrow J/\psi\ \Lambda_0$
- Insight into production mechanism:
  - Associated production of J/ψ with jets, open charm and non resonant photons
  - Cross section measurements for exclusive beauty decays
- Rare decays: $B_s \rightarrow \mu\mu$ sensitivity curves & confidence limits
- CP violation: B_s lifetime, mixing

Heavy Ion:

- Measurements of open charm cross sections, for all observed charmed mesons
- J/ψ and Z inclusive cross section and ratio
- $\Upsilon(1s)$ production cross section and relative fraction of Υ states

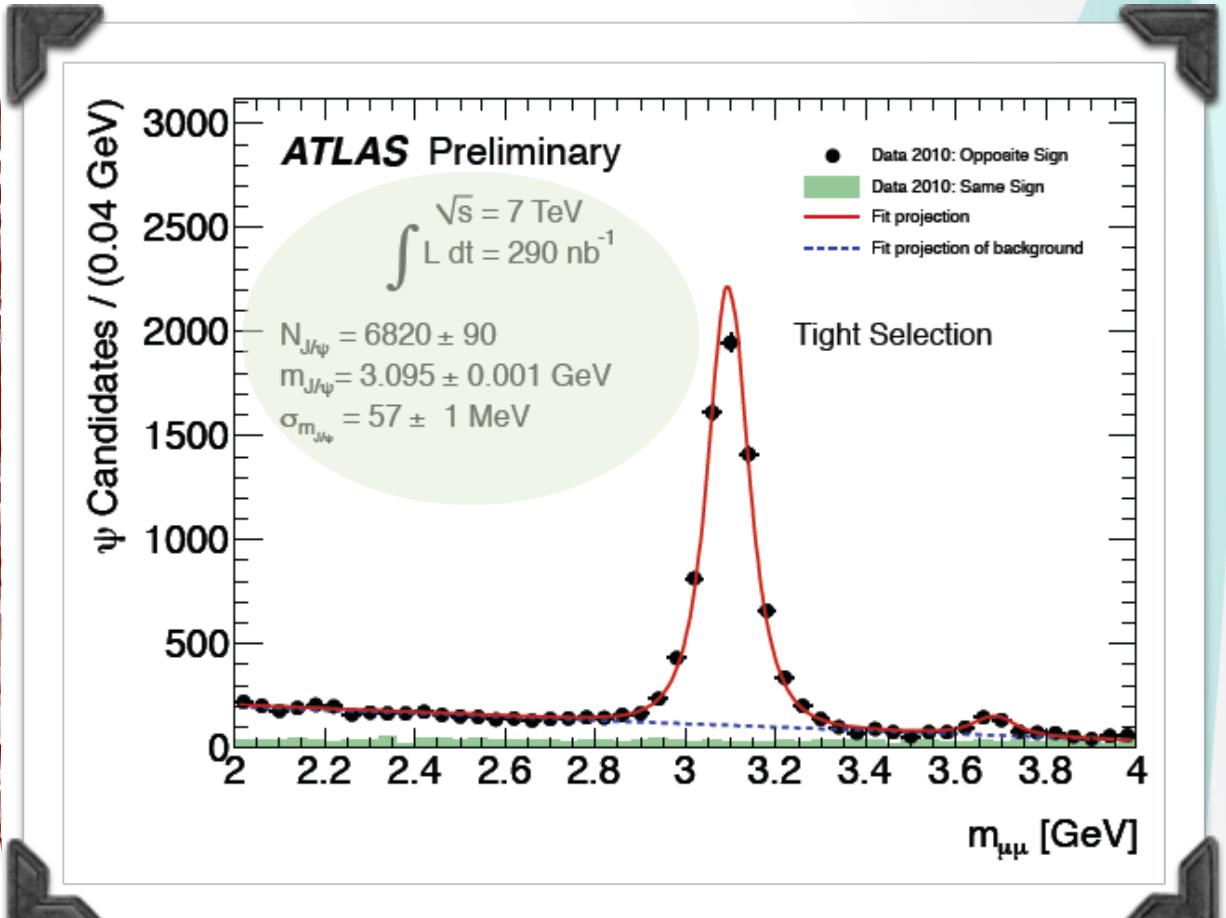
Backup slides

$J/\psi \rightarrow \mu^+\mu^-$ observation

First J/ψ observation with 6.4 nb^{-1} ATLAS-CONF-2010-045

Event selection:

- At least 1 primary vertex with 3 tracks associated
- Quality cuts on the Inner Detector tracks
- Opposite charge muon pairs with successful vertex fit
    - at least one combined muon in the pair
- $|\eta(\mu)| < 2.5$
- Transverse momentum Cut:
    - $p_T(\mu_1) > 4$ GeV
    - $p_T(\mu_2) > 2.5$ GeV



Trigger:

- L1 minimum bias trigger.
- Muon L1 threshold confirmed by HLT with 4 GeV threshold

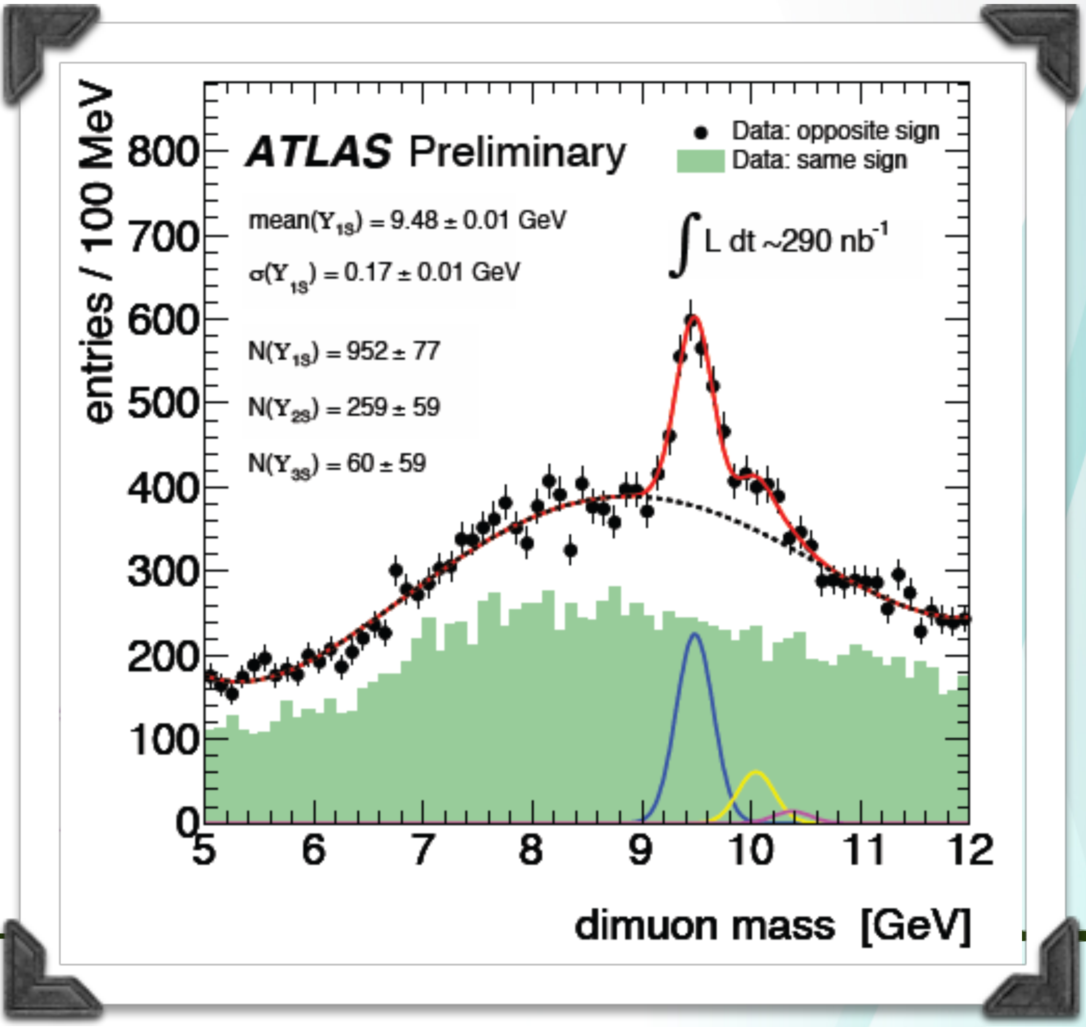
Maximum likelihood fit results:

- $m_{J/\psi}$: (3.095 ± 0.004) GeV
- σ_m: (82 ±7) MeV
- N_{sig} = 612 ± 34
- N_{bck} (in $m_{J/\psi} \pm 3\sigma_m$) = 332 ± 9

Υ meson families: Υ(1S,2S,3S)

Event selection:

- At least 1 primary vertex with 3 tracks associated
- Quality cuts on the Inner Detector tracks
- Opposite charge muon pairs with successful vertex fit
  - at least one combined muon in the pair
  - invariant masses between 8 and 12 GeV
- $|\eta(\mu)| < 2.5$
- Transverse momentum Cut:
  - $p_T(\mu_1) > 4$ GeV
  - $p_T(\mu_2) > 2.5$ GeV



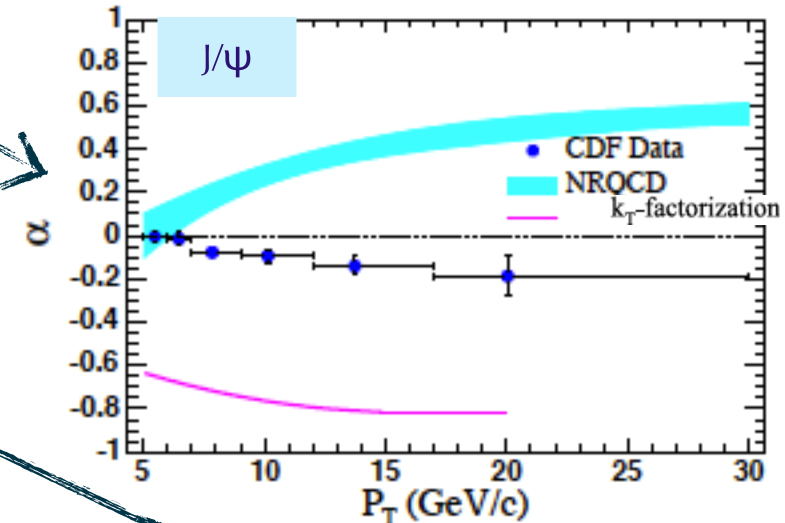
Trigger:

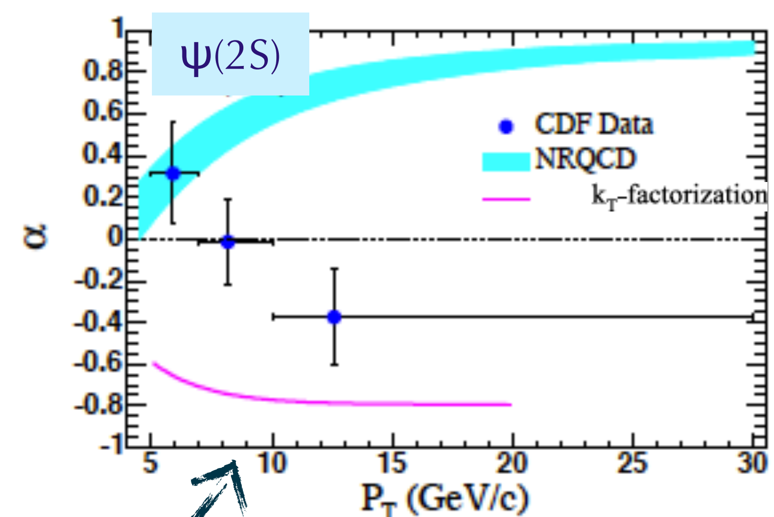
- L1 muon trigger
- L1 muon confirmed at HLT with 4 or 6 GeV threshold
- L1 muon confirmed at HLT with 4 or 6 GeV threshold + HLT muon in the same RoI as the L1 muon. $0.5<M_{\mu\mu}<12.0$ GeV (+ $08<M_{\mu\mu}<12.0$ GeV)
- 2 L1 muon confirmed at HLT with (4,4) or (4,6) GeV threshold. $0.5<M_{\mu\mu}<12.0$ GeV or $08<M_{\mu\mu}<12.0$ GeV

Polarization puzzle

Discrepancy between Tevatron data and "theoretical prediction"

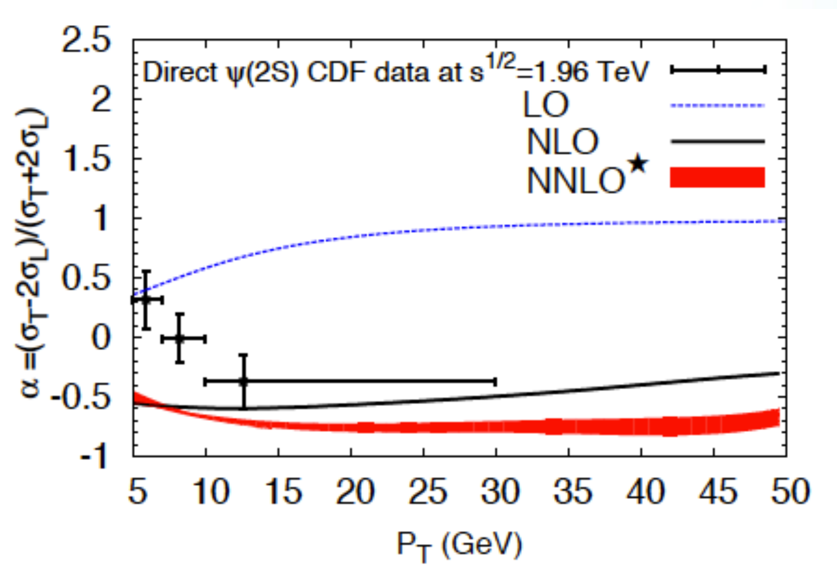
NRQCD@LO
opposite wrt data behavior





α= +1 , Transverse
α= 0 , Unpolarized
α= −1 , Longitudinal

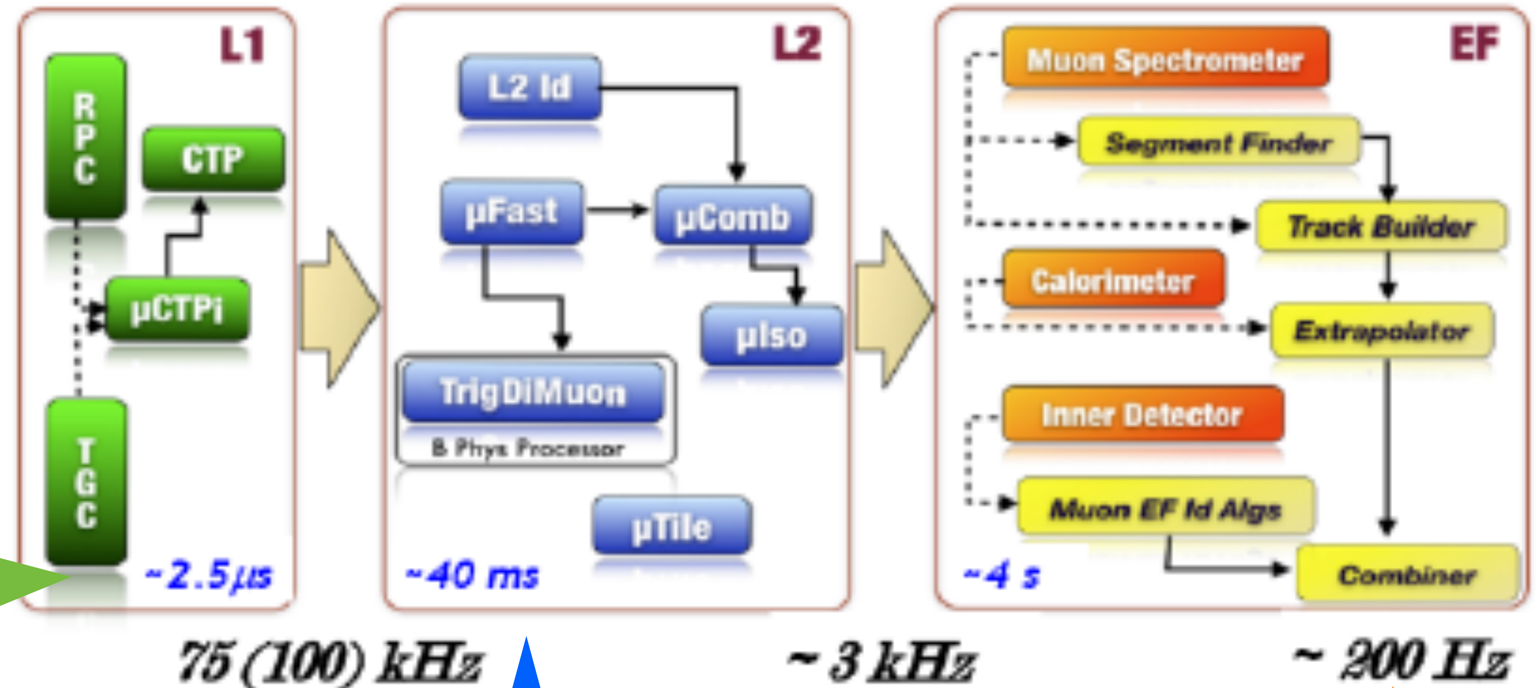
CSM +pQCD @NLO
opposite prediction
wrt LO!



Online muon trigger

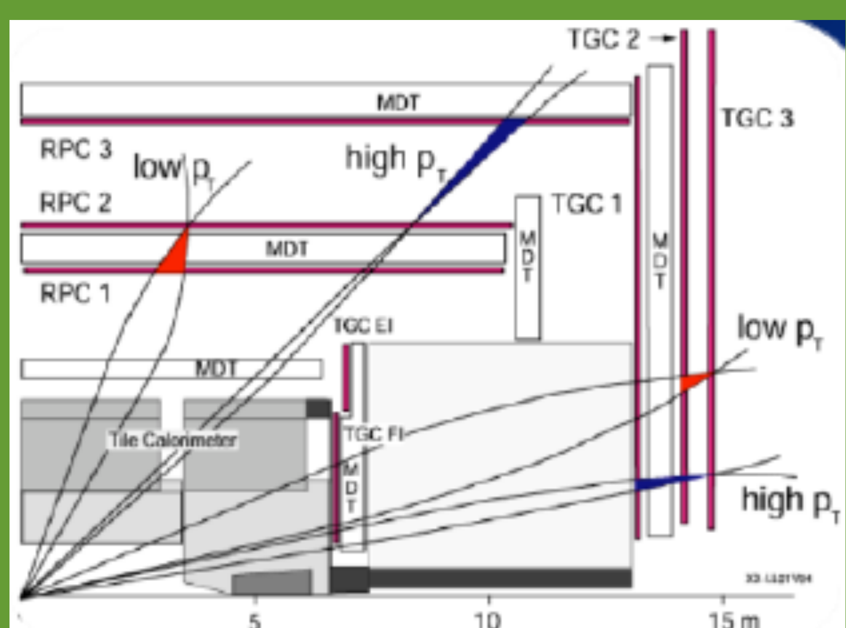
Three levels reduce LHC interaction rate of ~1 GHz to ~200Hz:

- Level1 (L1), hardware-based;
- High Level Trigger (HLT):
  Level2(L2)+Event Filter (EF),
  software based



Level 1 (L1)

- **Hardware (RPC+TGC)**
- **'Prompt' muons from interaction point (IP), p_T > threshold**
- **RoI (Region of Interest) id :p_T, η, φ**



Level 2 (L2)

- **RoIs in parallel,**
- **Several algorithms:**
  1. **'Fast' Muon Spectrometer(MS), 'Stand Alone'**
  2. **'Combined' reconstruction**
  3. **Isolation**

Event Filter (EF)

- **Full event data available**
- **'Offline' reconstruction adapted to the 'on-line' environment**
- **Two main strategies:**
  1. **Inside-Out (MS->IP) Outside-In (ID ->MS)**
  2. **Combined reconstruction**

Pseudo-proper time fitting

Maximum Likelihood Simultaneous fit of:

- invariant mass → signal/background separation, modeled by gaussian/linear function
  Signal model estimated by fitting data in the range $m_{J/\psi} \pm 3\sigma_m$,
  background from sidebands
- pseudo-proper time → prompt/non-prompt separation

$$\ln \mathcal{L} = \sum_{i=1}^{N} \ln \mathcal{F}(\tau, \delta_\tau, m_{\mu\mu}, \delta_m)$$

N = number of pairs of OS muons in the invariant mass range [2,4] GeV

$$\mathcal{F}(\tau, \delta_\tau, m_{\mu\mu}, \delta_m) = \mathcal{F}_{\rm sig}(\tau, \delta_\tau) f_{signal}(m_{\mu\mu}, \delta m_{\mu\mu}) + \mathcal{F}_{\rm bkg}(\tau, \delta_\tau) f_{bkg}(m_{\mu\mu})$$

pseudo-proper time pdfs

$$\mathcal{F}_{\rm sig}(\tau, \delta_\tau) = f_B \mathcal{F}_B(\tau, \delta_\tau) + (1 - f_B)\mathcal{F}_P(\tau, \delta_\tau)$$

$$\mathcal{F}_{\rm bkg}(\tau, \delta_\tau) = R_{\rm bkg}(\tau, \delta_\tau) + \exp\left(\frac{-\tau'}{\tau_{\rm eff1}}\right) \otimes R_{\rm bkg}(\tau' - \tau, \delta_\tau) + \exp\left(\frac{-|\tau'|}{\tau_{\rm eff2}}\right) \otimes R_{\rm bkg}(\tau' - \tau, \delta_\tau)$$

exponential(non prompt)
convolved with a gaussian

δ function(prompt)
convolved with a gaussian

δ function
convolved with a gaussian

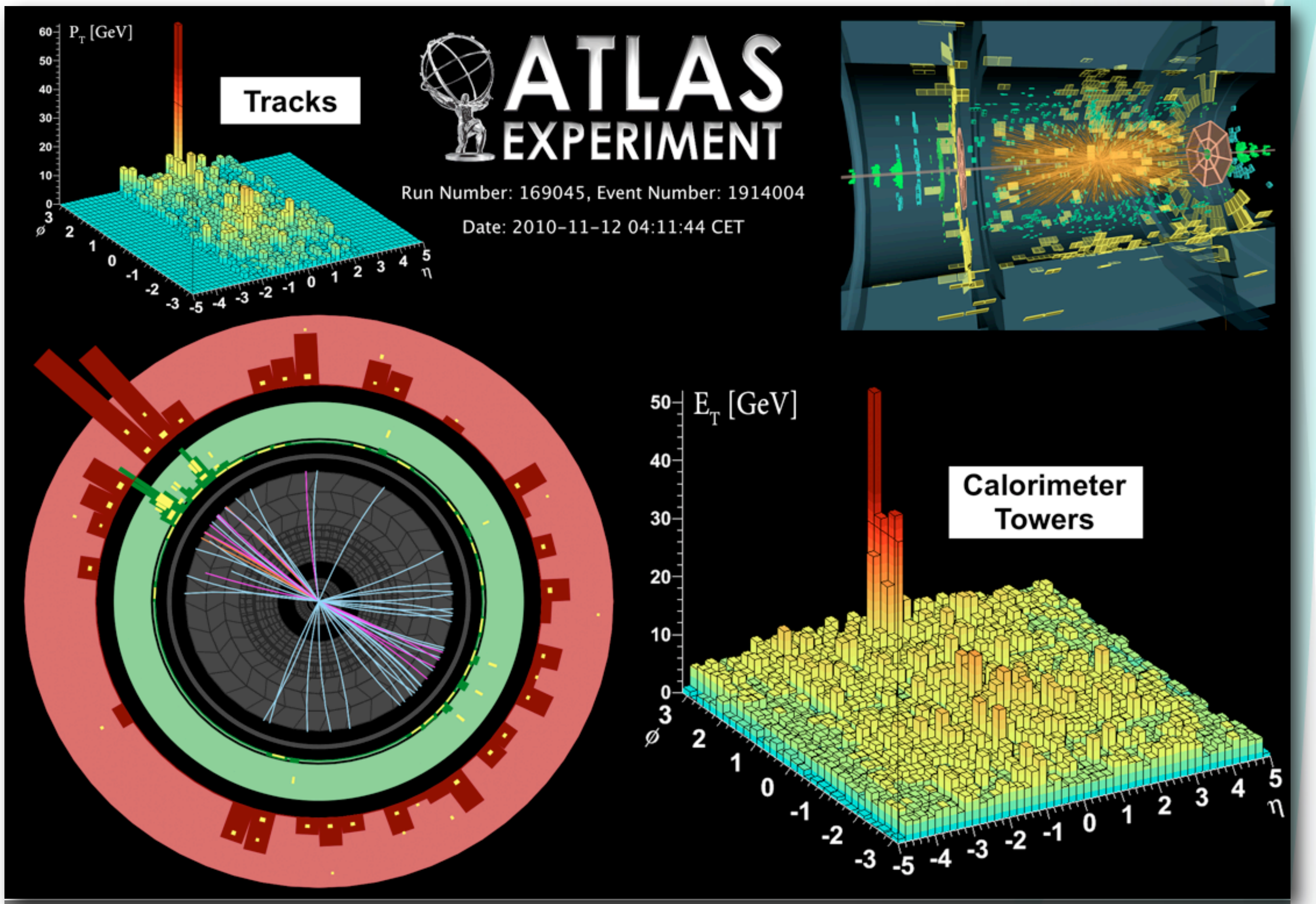
positive and a negative exponential
convolved with a gaussian

The di-jet asymmetry

Event Selection:

- Anti-kT of cone size R=0.4. Underlying event subtraction per cell layer dependent, η dependent with 0.1granularity
- Leading jet with:
  - ✓Et>100 GeV
  - ✓|η| < 2.8

  Plateau ~100% eff. at all centralities
  In 1.7 μb^{-1} → 1693 events.
- Second jet:
  - ✓Et>25 GeV
  - ✓Δφ > π/2 (opposite hemisphere)



Only tracks with p_T > 2.6 GeV are shown,
E_T > 700 MeV in the ECal
E > 1 GeV in the HCal

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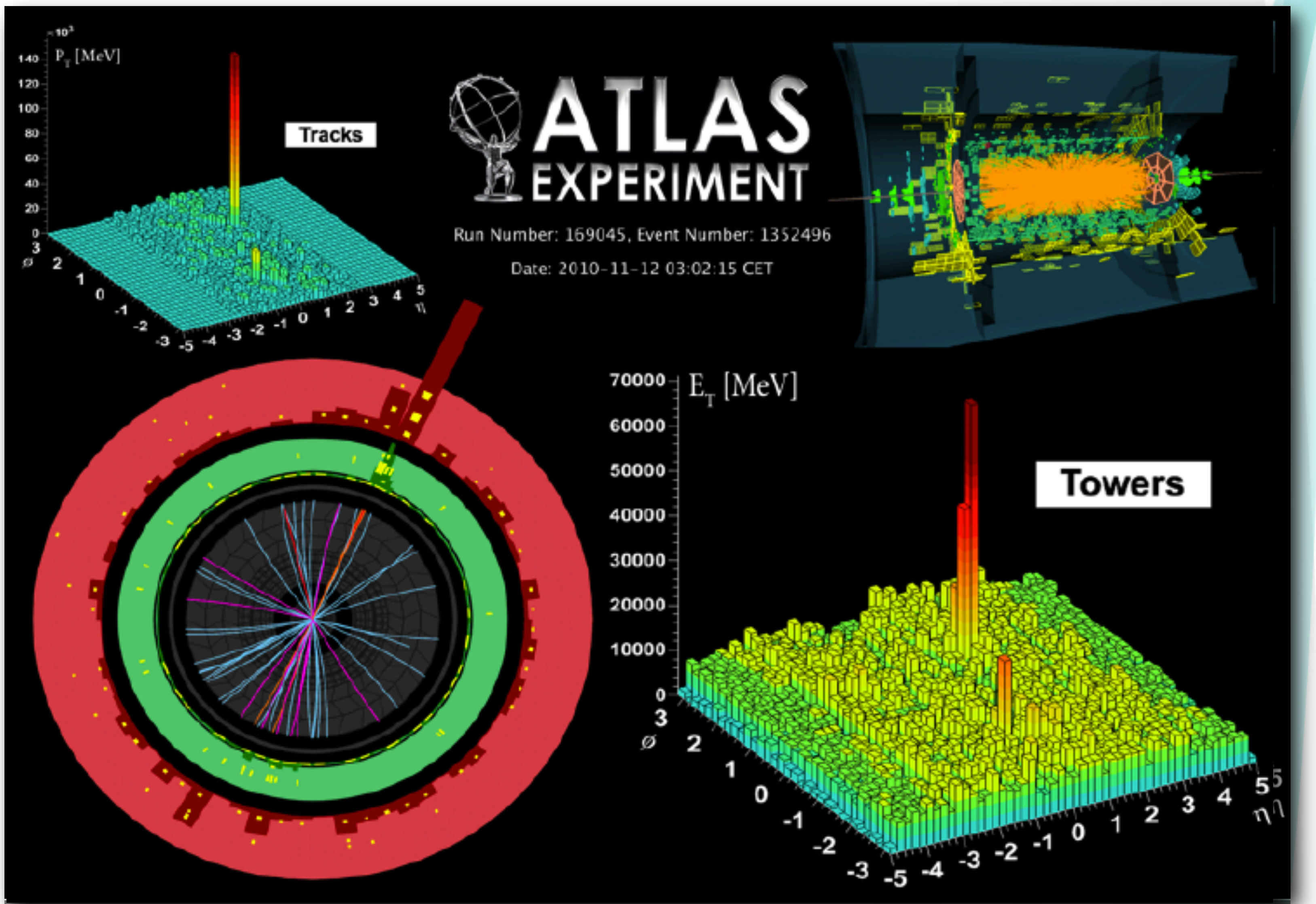

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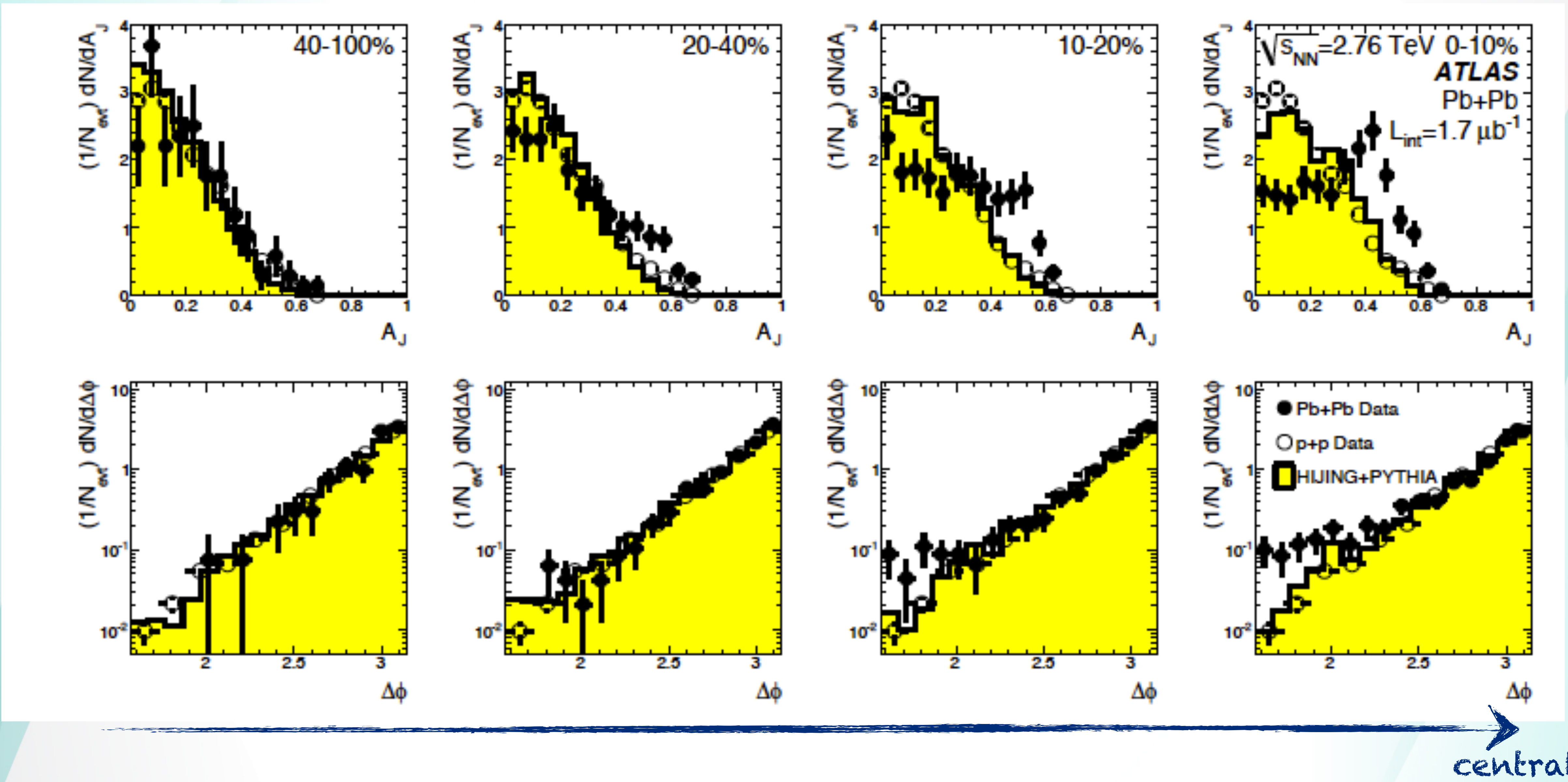
The di-jet asymmetry

$$A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}, \Delta\phi > \frac{\pi}{2}$$



Asymmetry in peripheral events similar to proton-proton and simulated events; as the event centrality increases, the rate of highly asymmetric di-jet events increases

→ strong energy loss in the hot and dense medium