Quarkonia in ATLAS

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on behalf of the ATLAS collaboration

ReteQuarkonii Thematic Day
Orsay, February 9th , 2010

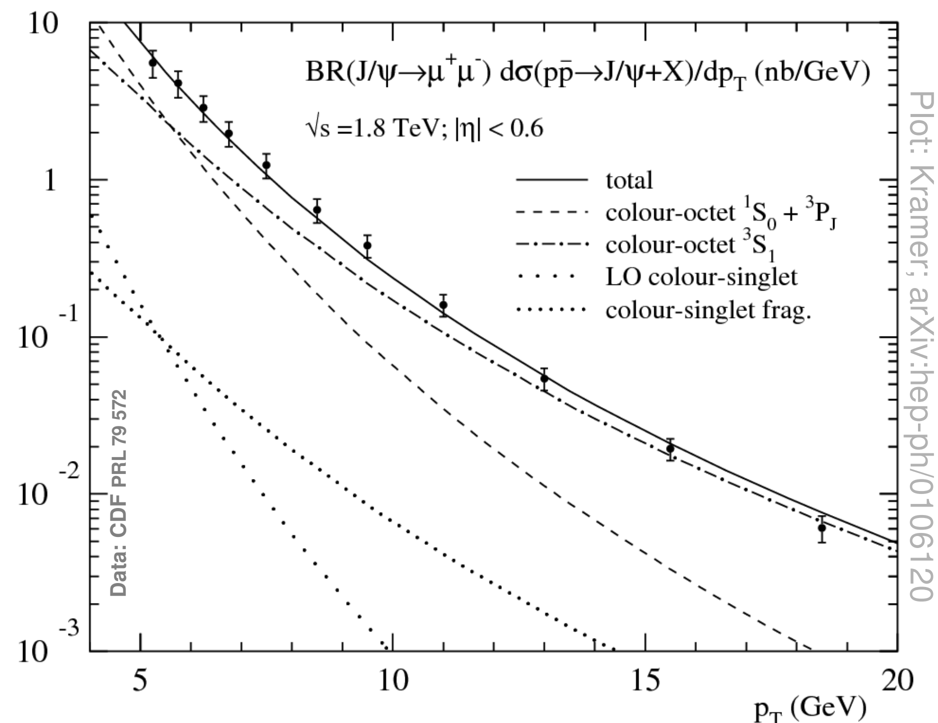
Outline of talk

- Introduction
  - Motivation for studying production
  - Introduction to ATLAS detector and measurement capability
- Onia reconstruction at ATLAS
  - Predicted quarkonium cross-sections at ATLAS
  - Reconstruction performance
- Physics studies
  - Spin-alignment studies
  - Analysis of χ_c ,χ_b production

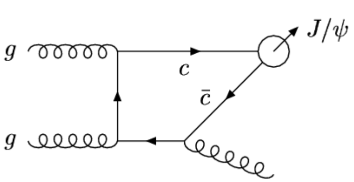
Motivation for study

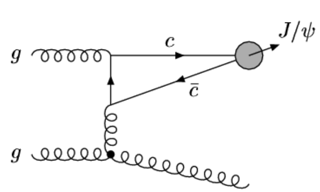
- **Detector commissioning**
  - Narrow resonances (J/ψ, ϒ) with clean signature (in muon channel) make them invaluable for calibration of the trigger, tracking and muon systems

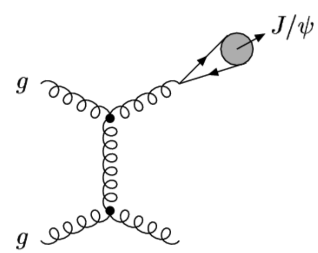
- **Theoretical interest**
  - Production mechanism of quarkonium unexplained
    - Important as testbed for QCD in both perturbative and non-perturbative regimes
    - Once understood, quarkonium production is the perfect probe for determining low x gluon PDFs
  - Quarkonia forms an important background for many other B-physics processes at LHC



Colour Octet Model provides excellent agreement with p_T cross-section shape and normalisation, but there are problems...





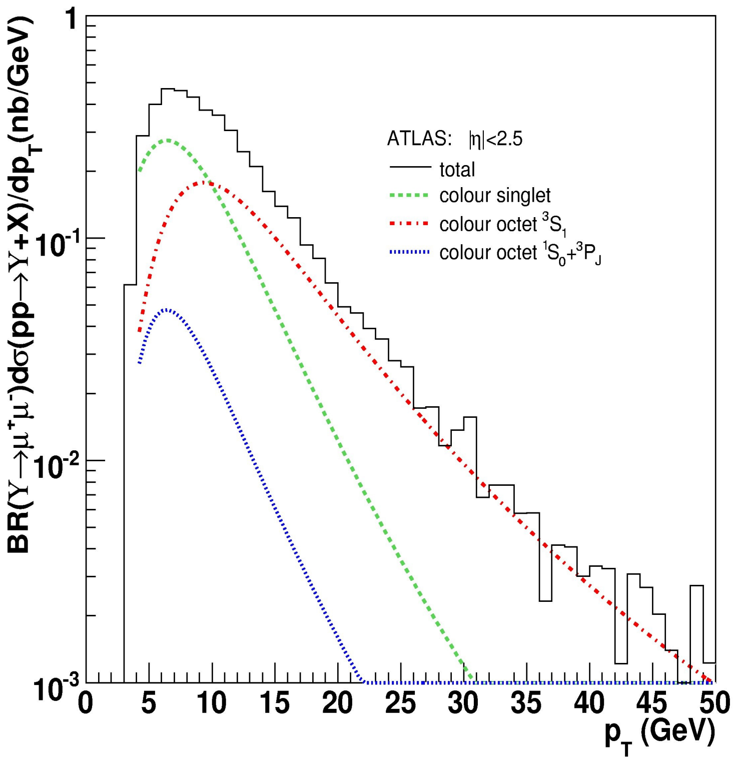


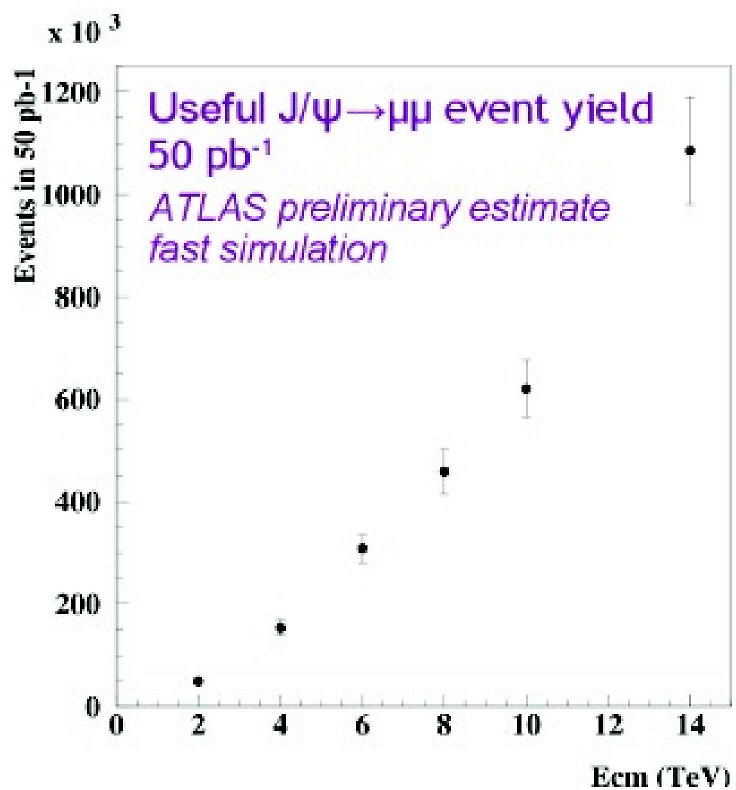
Quarkonium spin-alignment as a probe

- Earlier alluded to the unknown quarkonium polarisation
- Different models of quarkonium production predict differing p_T dependencies of quarkonium spin-alignment
  - Makes measurement of this a key factor in determining production model
  - A difficult measurement due to correlation between polarisation state and efficiency
- Theory predicts high p_T data important for discrimination
  - CDF/D0 suffer from statistics in this regard
  - ATLAS has complementary coverage, can provide high stats from 9 GeV+
- Current techniques at Tevatron use fits to MC template polarisation samples
  - Rely heavily on fidelity of MC templates run through detector simulation
  - Detector acceptance across cos θ^* very variable -- high |cos θ^*| suppressed at Tevatron due to trigger requirements

Monte Carlo samples

- Currently basing our studies on Colour Octet Mechanism implemented in Pythia and fully simulated through ATLAS reconstruction in GEANT
- Produced samples look at muon channel: include χ feed down
- Colour octet NRQCD matrix elements describe non-perturbative quarkonium evolution
  - Matrix elements set to values derived from Tevatron data
- Both low and high p_T regions important for measuring contributions from singlet and octet production





10 TeV

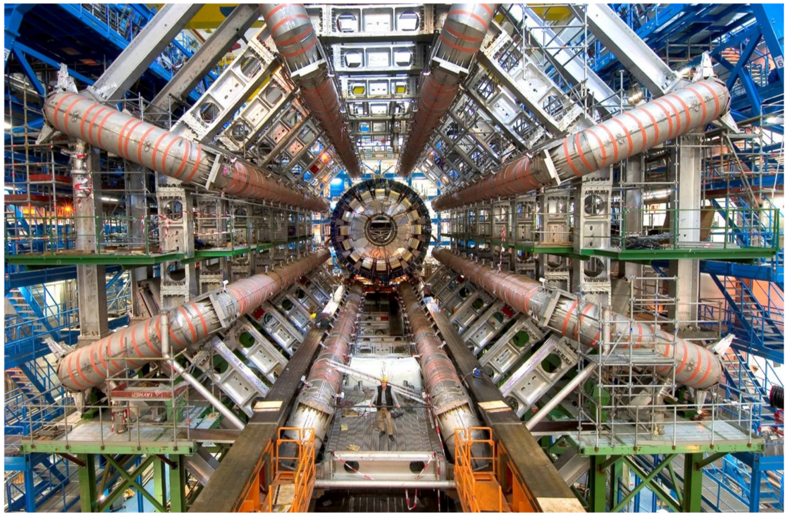
Process	Cross-section
$pp \to J/\psi \to \mu2.5\mu2.5$	245 nb
$bb \to \mu2.5\mu2.5$	545 nb
$bb \to J/\psi \to \mu2.5\mu2.5$	45 nb
$pp \to \psi(2S) \to \mu2.5\mu2.5$	7.5 nb
$pp \to \Upsilon(1S) \to \mu2.5\mu2.5$	90 nb
$pp \to \Upsilon(2S) \to \mu2.5\mu2.5$	26 nb
$pp \to \Upsilon(3S) \to \mu2.5\mu2.5$	21 nb
$cc \to \mu2.5\mu2.5$ (no $bb+cc \to J/\psi$)	261 nb
$pp \to \gamma^* \to \mu2.5\mu2.5$ (DY)	3 nb
Minimum bias	50 mb

Studies presented in this talk are based on 14 TeV c.m.s energy, using muon p_T thresholds of $\mu6\mu4$

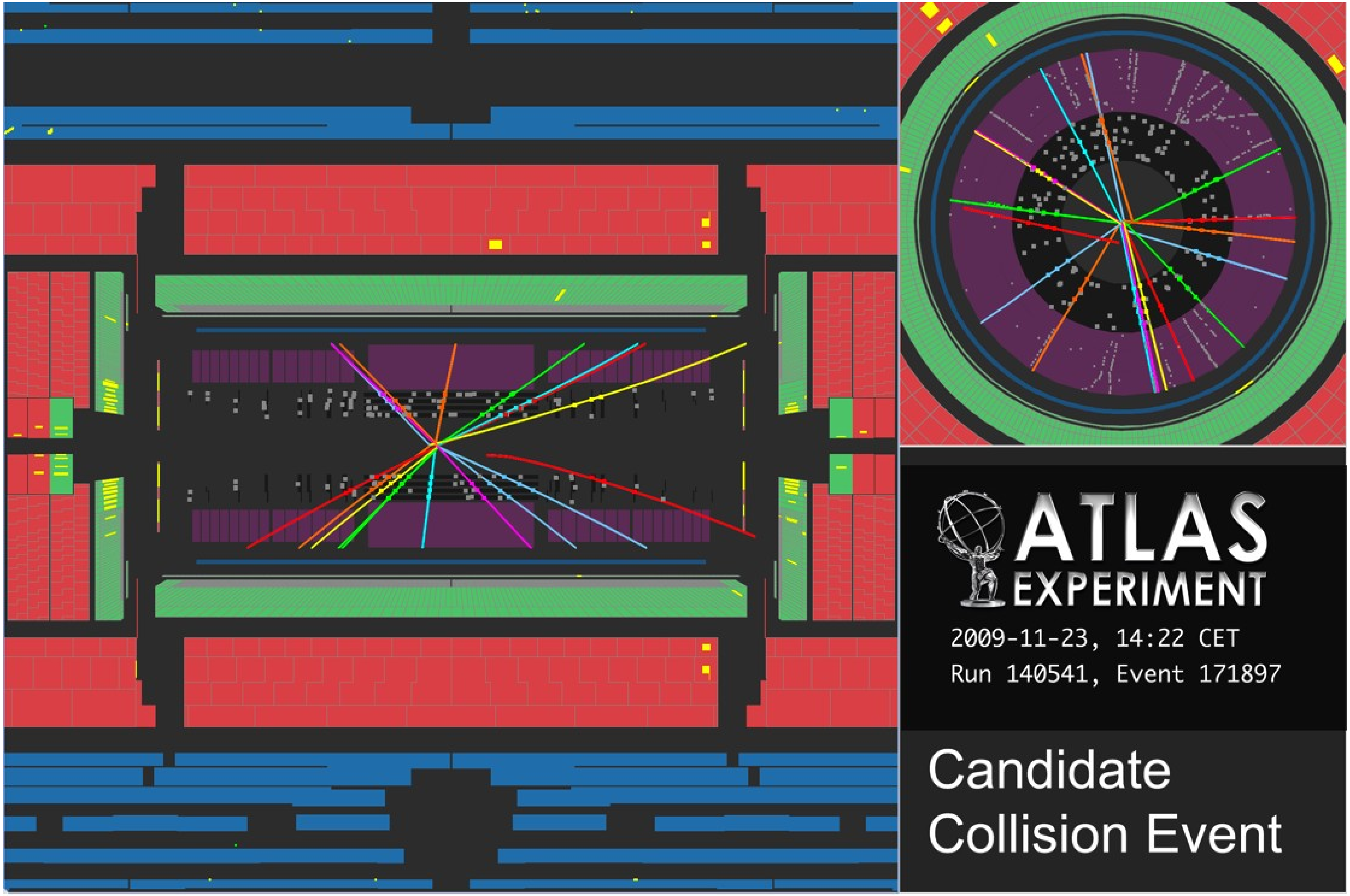
20 years history before the beginning

1989: R&D starts
1992: ATLAS LoI
1996: approval
1997:construction starts
Until 2004: several Test-Beam campaigns
2003: underground installation starts
2008 : installation completed
Combined cosmics data taking
Sept 2008: first single beam data

20 Nov 2009: single beam splash
23 Nov 2009: First collisions @ 900 GeV
6 Dec 2009: First collisions with stable beam
Full detector switched on
8 Dec 2009: First collisions at 2.36 TeV
16 Dec 2009: end of 2009 data taking



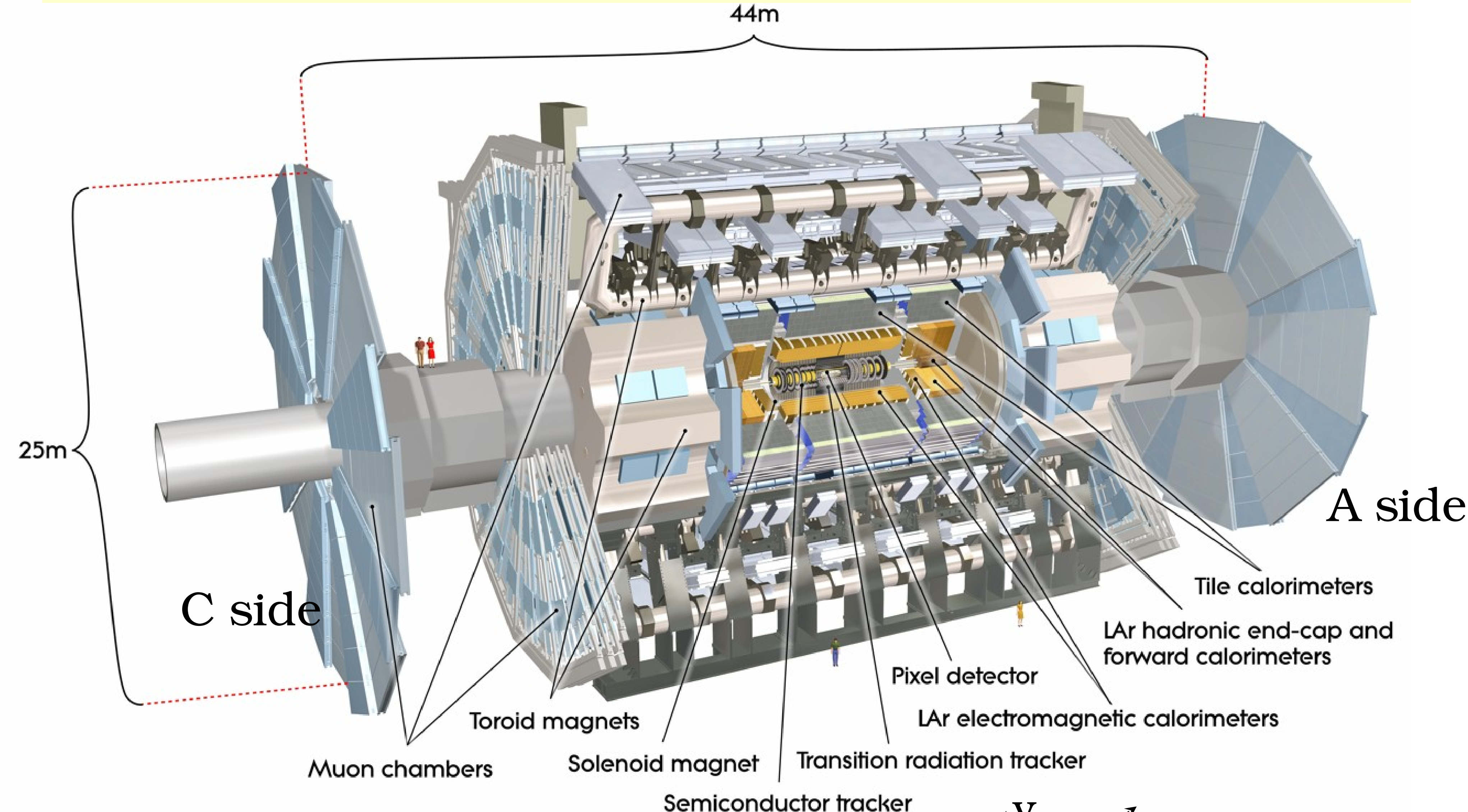
First observed collision candidate at 900 GeV, Nov 23 2009



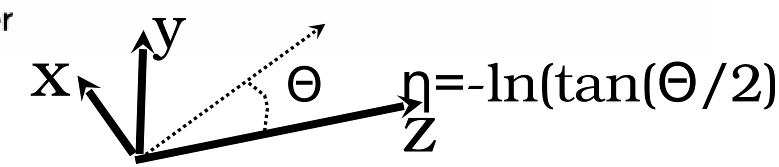
http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html

Note: Solenoid off and Si detectors off or at reduced voltage (no stable beam)

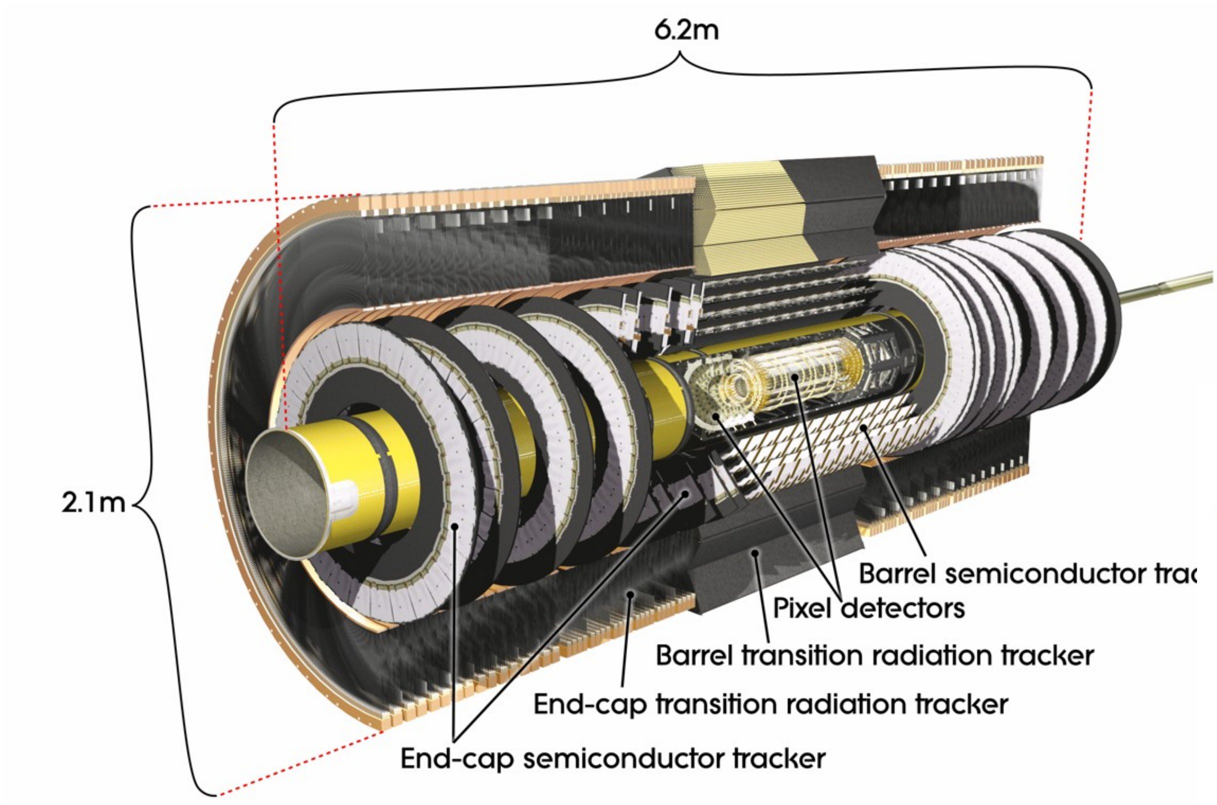
ATLAS Detector



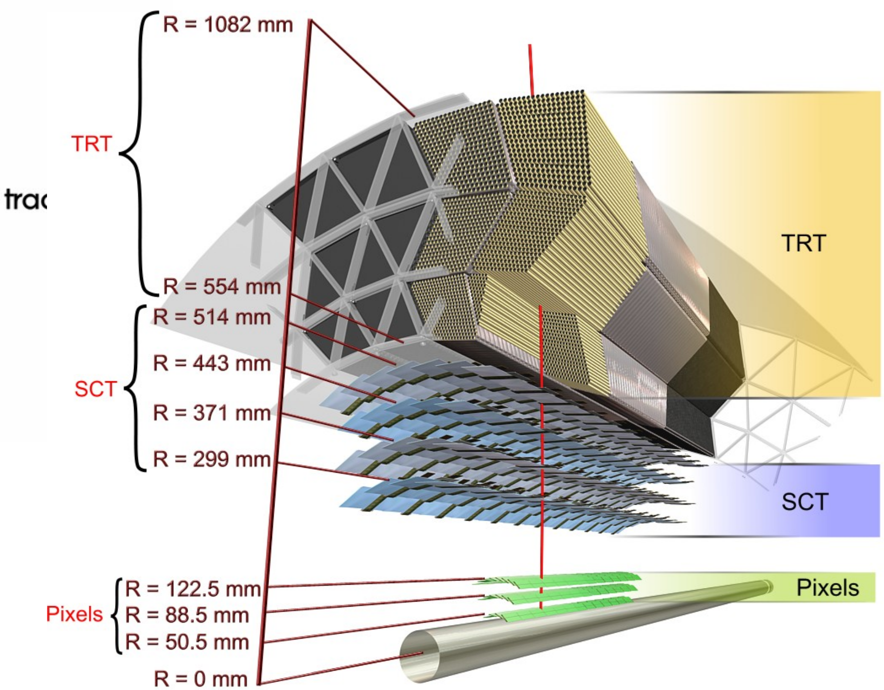
weight ~7000 tons



Inner Detector



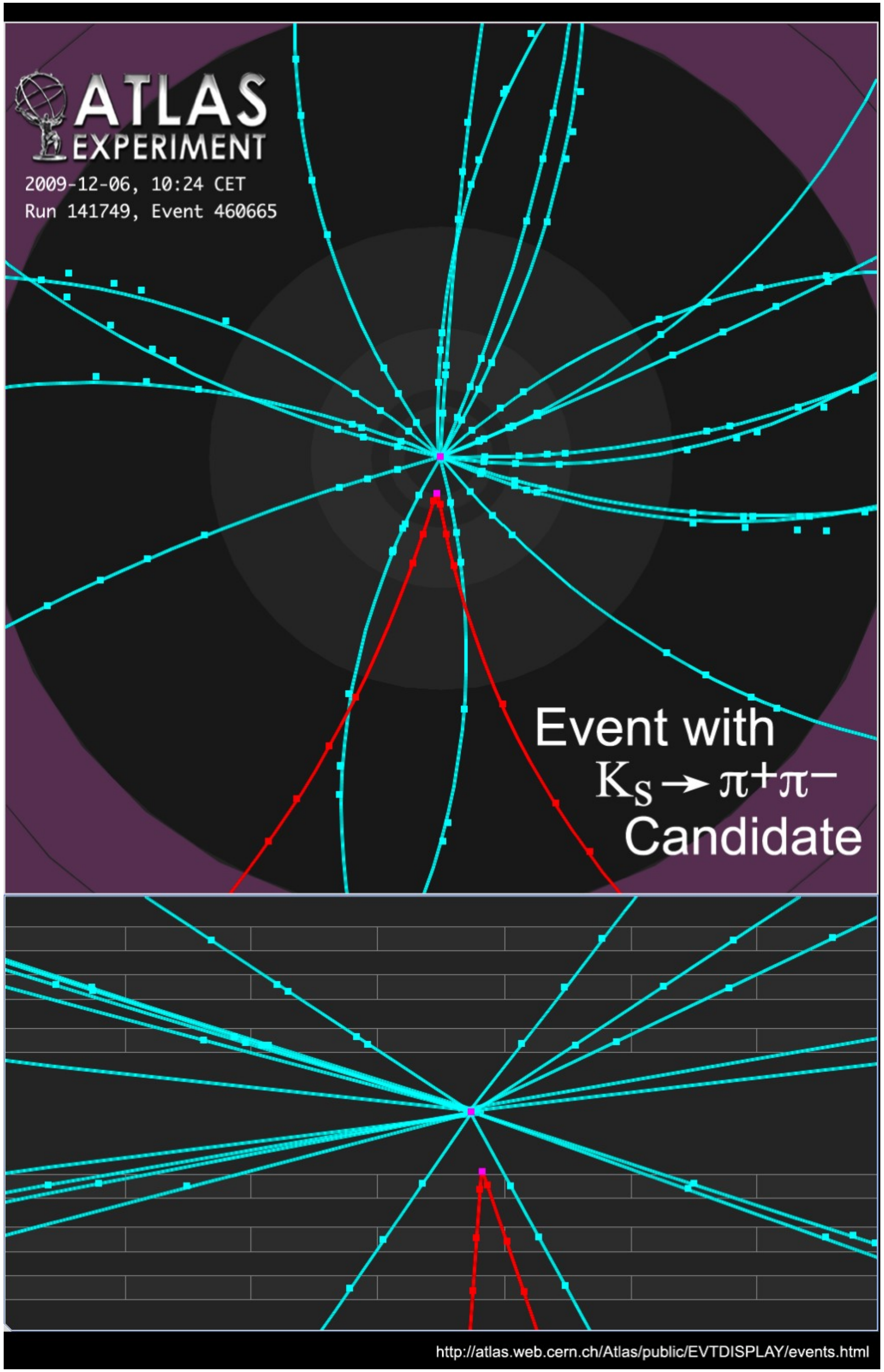
in 2T solenoid field



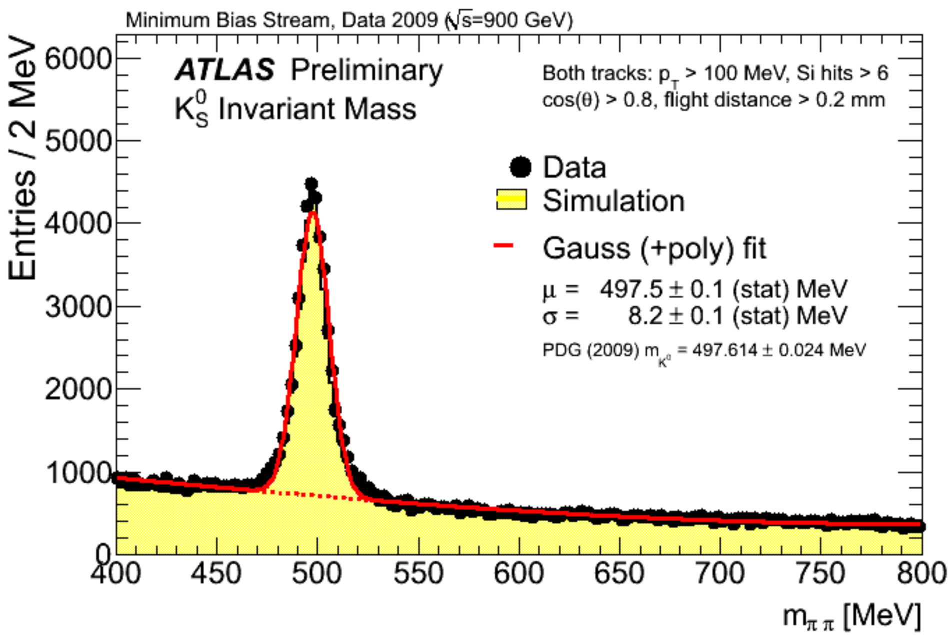
Nominal performances in barrel region:

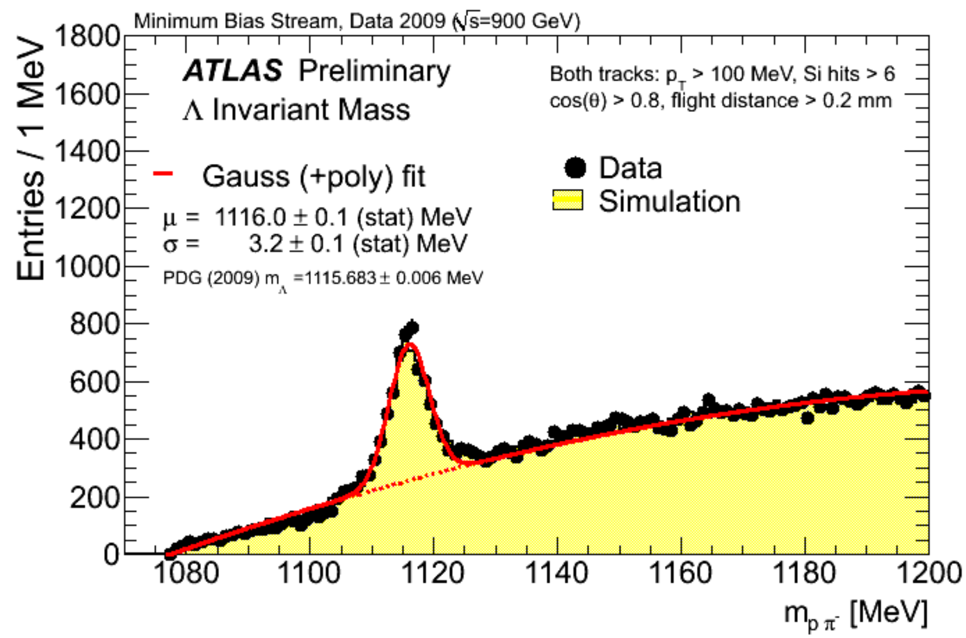
$\sigma(p_T)/p_T \sim 3.4\text{x}10^{-4}\ \text{x}(p_T/\text{GeV}) \oplus 0.015$

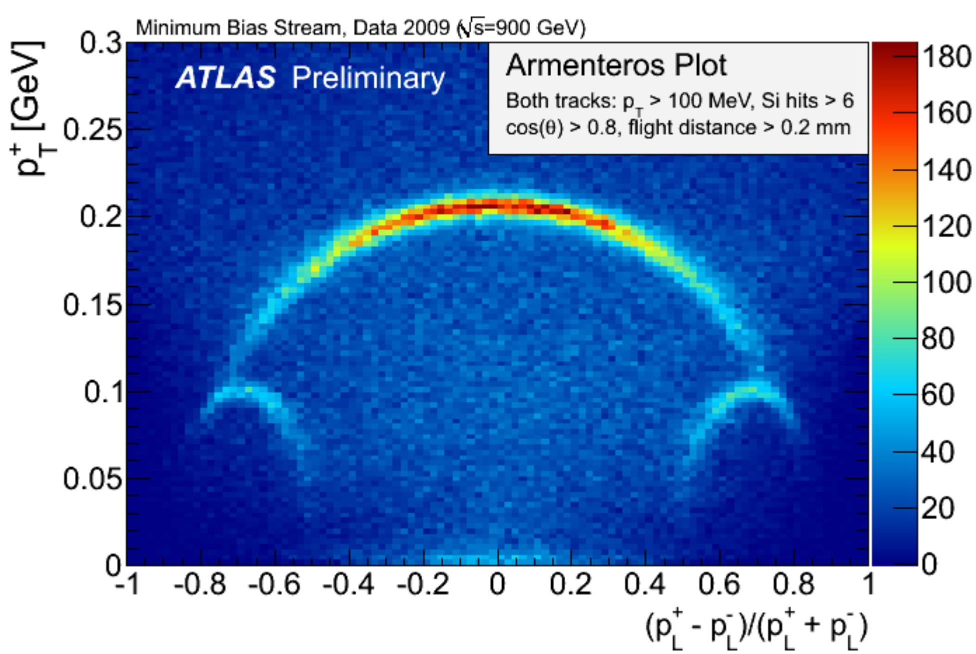
$\sigma(d_0) \quad \sim 10 \oplus 140/(p_T/\text{GeV})\ \mu m$

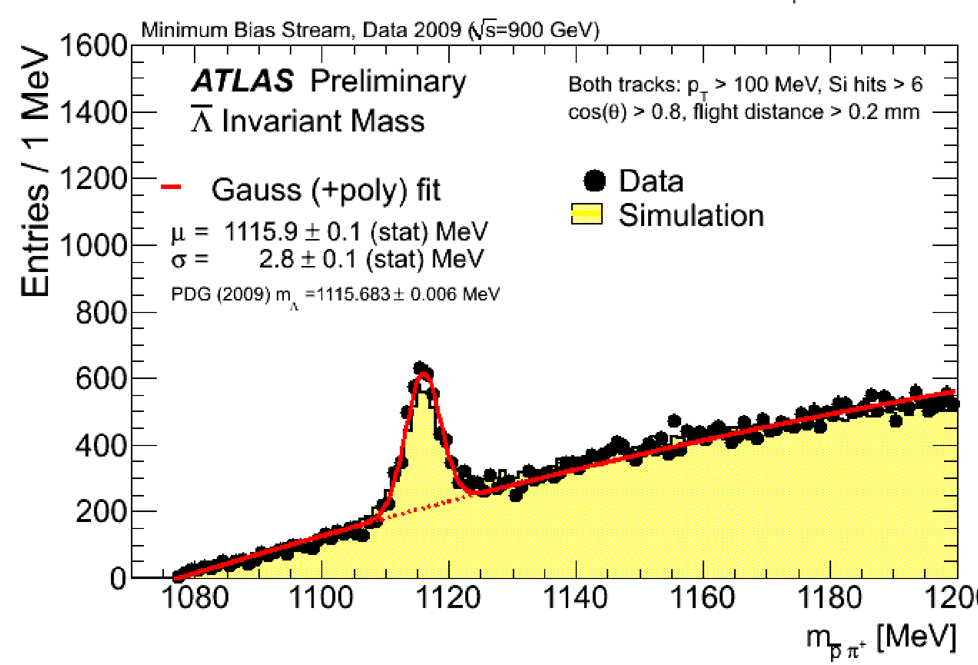

ATLAS
EXPERIMENT
2009-12-06, 10:24 CET
Run 141749, Event 460665
Event with
$K_S \rightarrow \pi^+\pi^-$
Candidate
http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html

Masses of Ks and Λ agree well with PDG
Resolutions (multiple scattering limited) agree with expectations

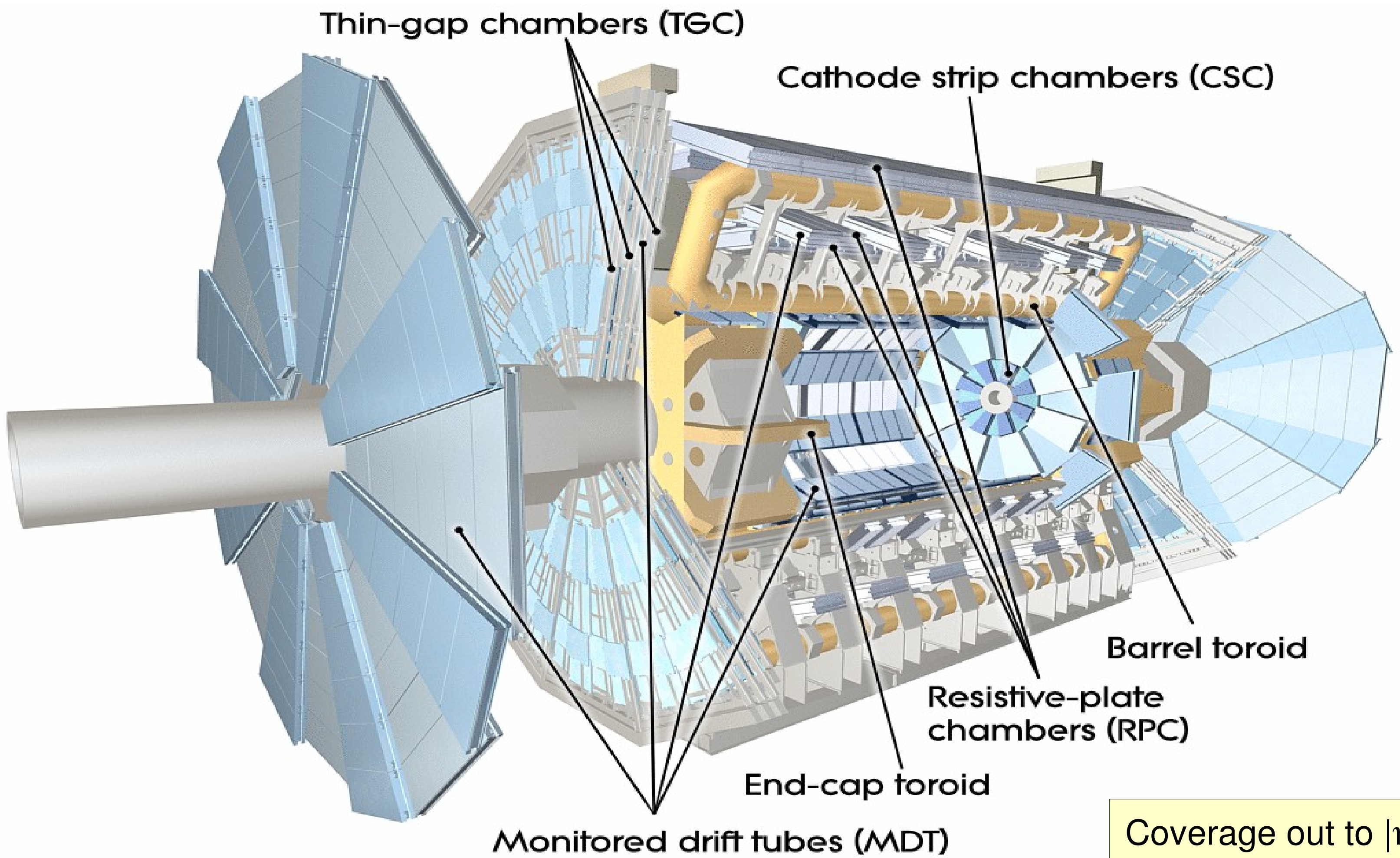








Muon Spectrometer

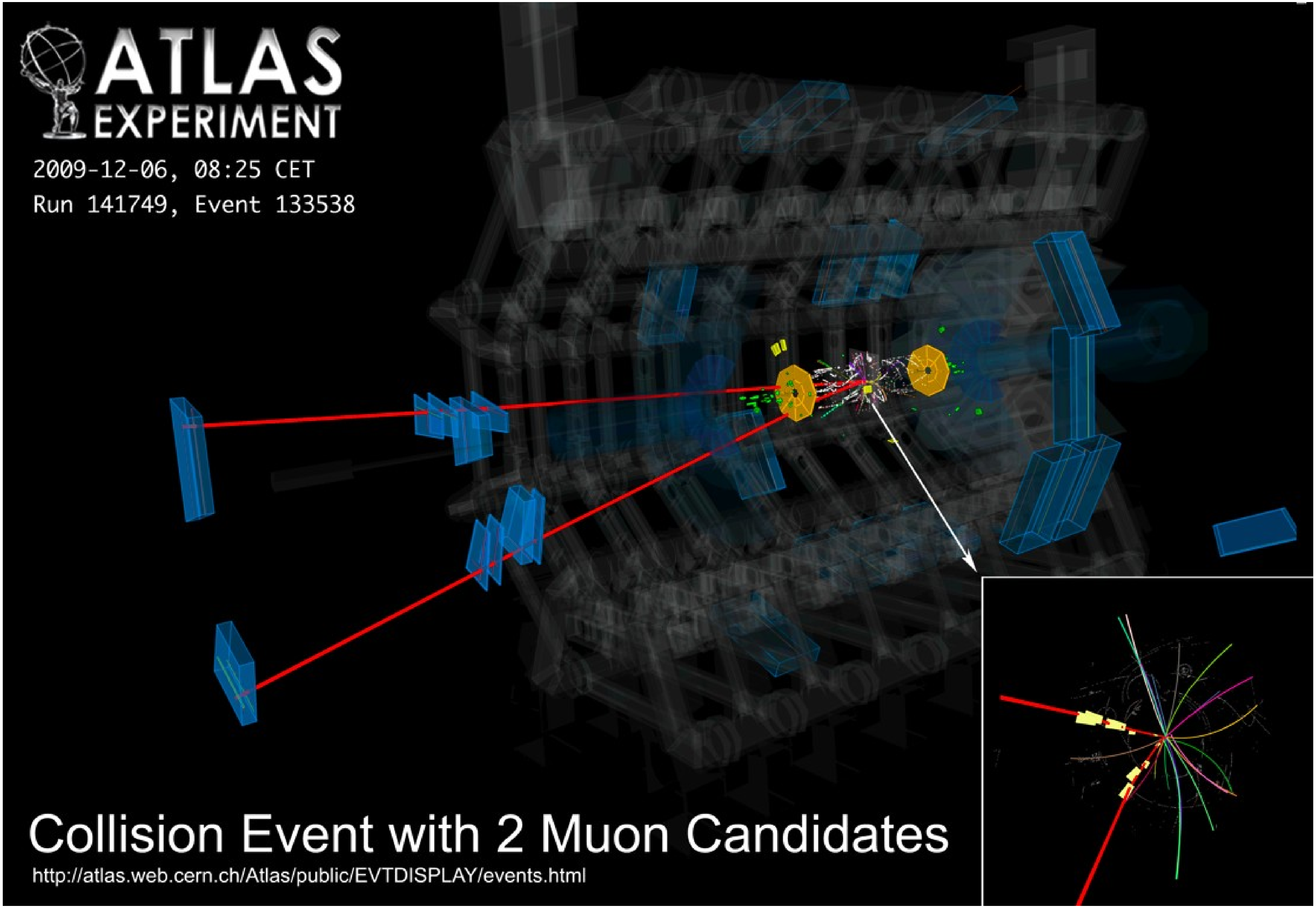


Coverage out to $|\eta|<2.7$

Drift chambers and trigger chambers in an air-core toroid : Field integral:
2-6 Tm $|\eta|<1.3$, 4-8 Tm $1.6<|\eta|<2.7$

Good standalone performance:
σ/p_T <10% up to 1 TeV

$\sqrt{s} = 900\ GeV$



ATLAS trigger

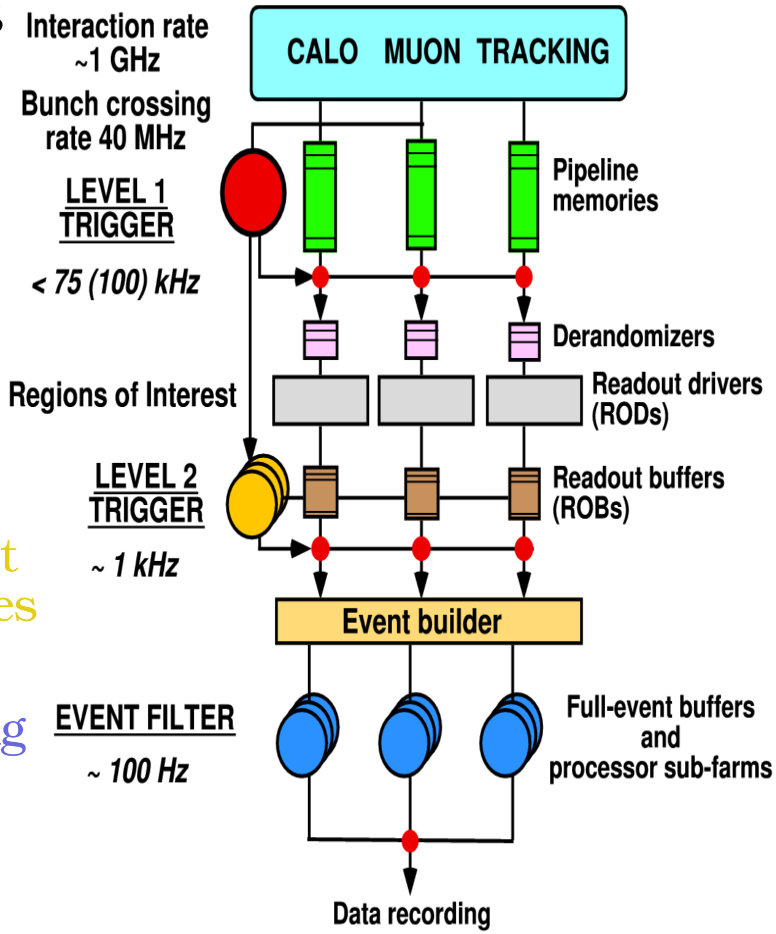
- Due to the bunch crossing rate and multiple interactions, need to reduce events written to tape to small fraction: **challenge is to keep the interesting ones**

- **Trigger system at ATLAS has three levels:**
  - Level 1 (Hardware, Online)

    Define region-of-interest in small area of detector, coarse measurements of 'interesting' features -- high p_T muons etc.
  - Level 2 (Software, Online)

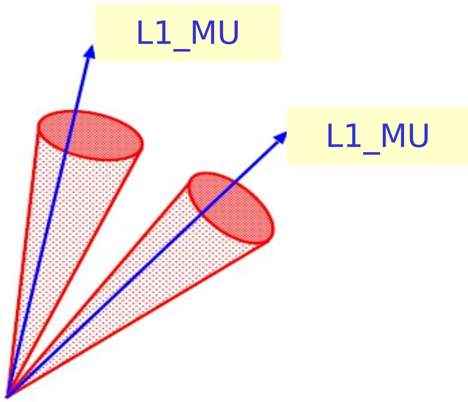
    Confirm LVL1 result, refine the physics object measurements and look for additional features
  - Event Filter (Software, Offline)

    Offline algorithms do further refinement using all relevant detector information at full granularity



J/ψ–>μμ and Υ–>μμ trigger

Di-muon Trigger



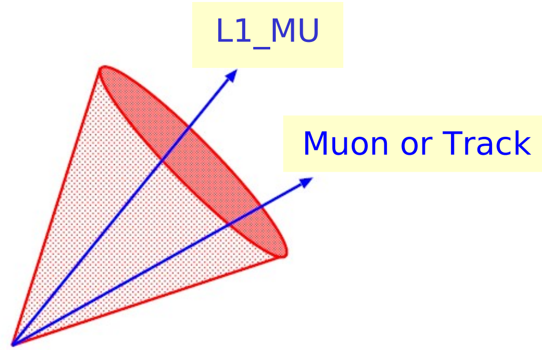
<u>Two L1 muons</u>

confirm muon at L2

Tracking in small RoI

Mass & vertex cuts

Single μ Trigger



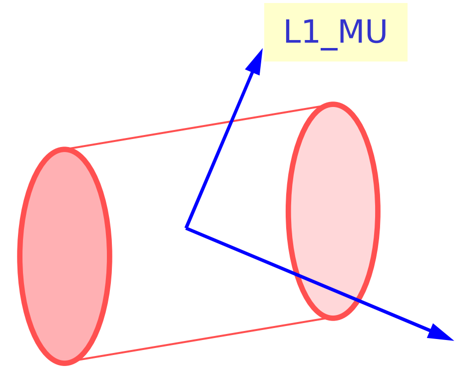
<u>One L1 muon</u>

confirm muon at L2

Tracking in one large RoI,search for the 2nd muon

Mass & vertex cuts

FullScan Trigger



<u>One L1 muon</u>

confirm muon at L2

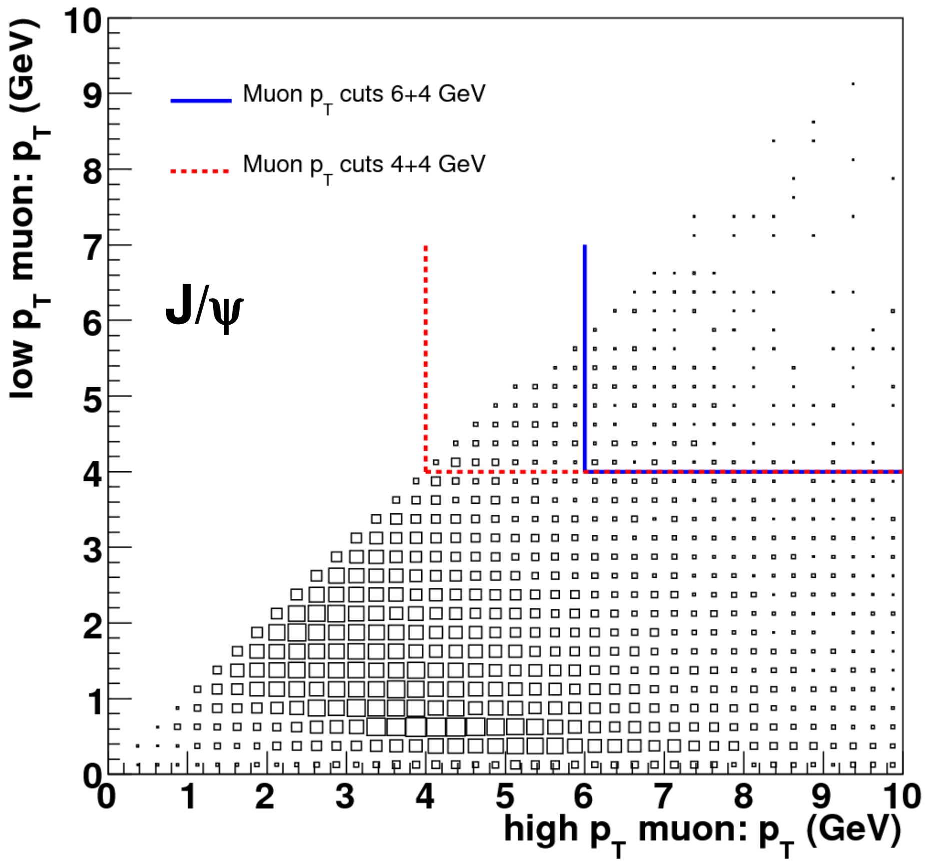
Tracking in entire detector, search for the 2nd muon

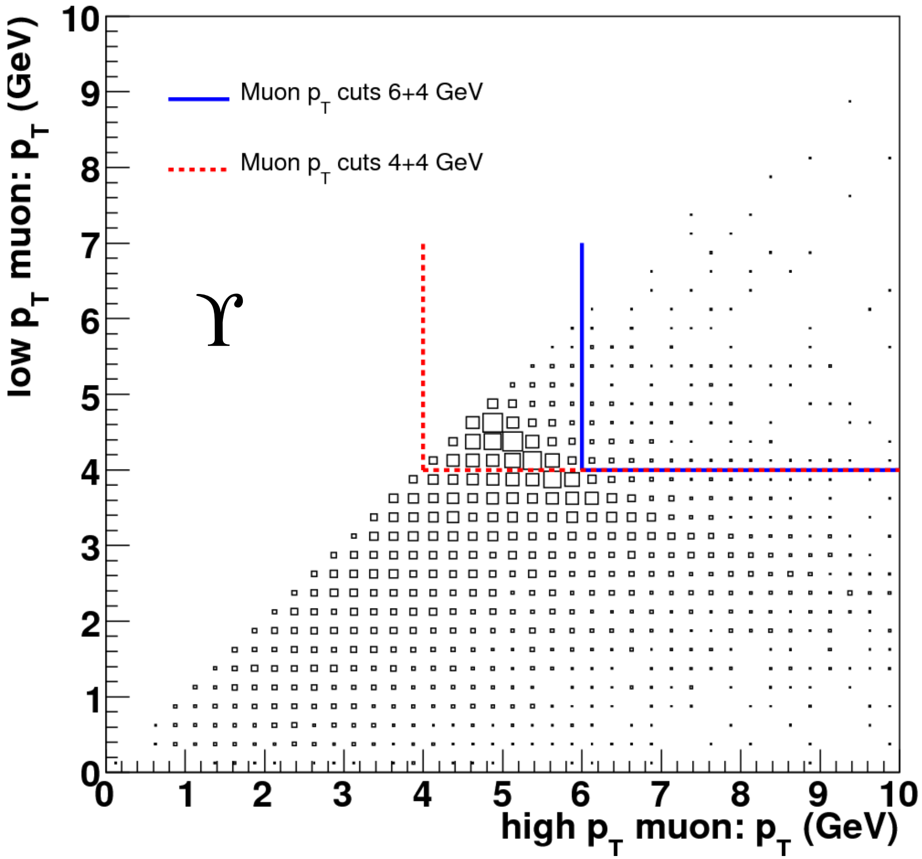
Mass & vertex cuts

The lowest level 1 muon trigger threshold are 4 GeV, 6 GeV

- Single L1 muon triggers:
  - Use lowest muon pT threshold and FullScan(time consuming) to give highest efficiency at startup
- L1 di-muon triggers:
  - Use lowest muon pT threshold (MU4)
  - Reduce the background and will be needed at higher luminosity.

Lowering p_T triggers





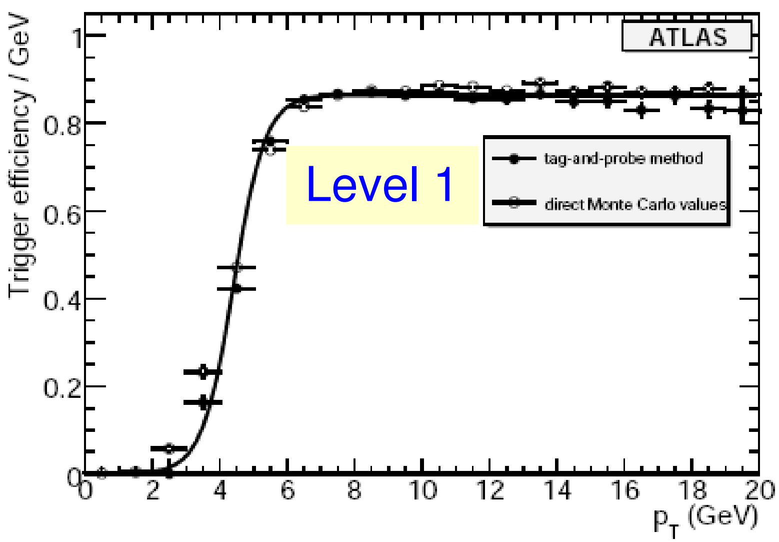
- Lowering of muon p_T requirements from $\mu6\mu4$ to $\mu4\mu4$ increases J/ψ and substantially increases ϒ cross-section
- By lowering cuts to 4+4 GeV we accept the bulk of the ϒ production, due to the high mass of the ϒ

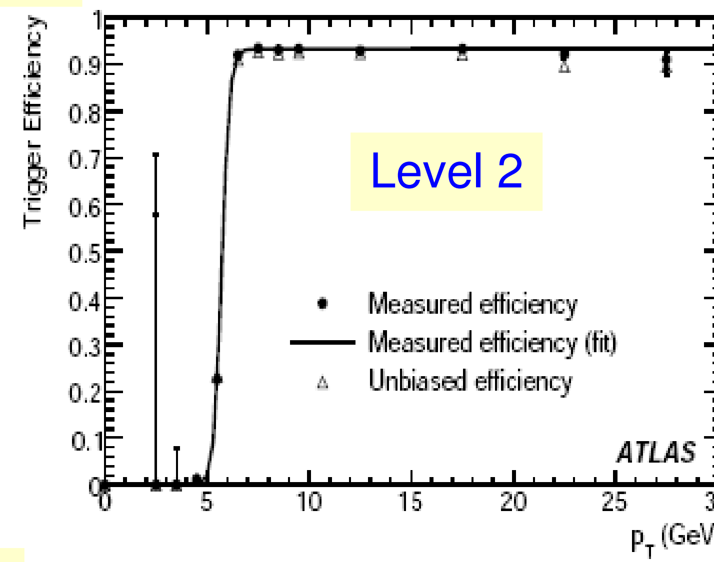
Trigger cuts	6+4 GeV	4+4 GeV
σ(J/ψ)	22 nb	27 nb
σ(ϒ)	4.6 nb	43 nb

Trigger efficiency measurement

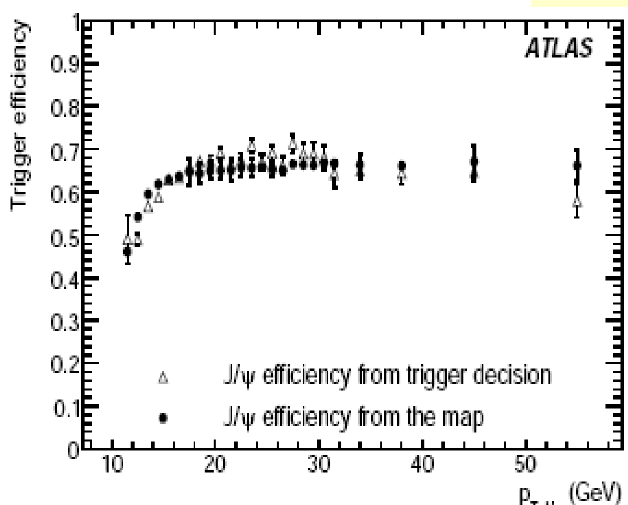
- Use Tag & Probe with J/ψ resonance collected using an unbiased trigger (single μ or μ +track) trigger in order to measure the trigger efficiencies at Level 1,2,3

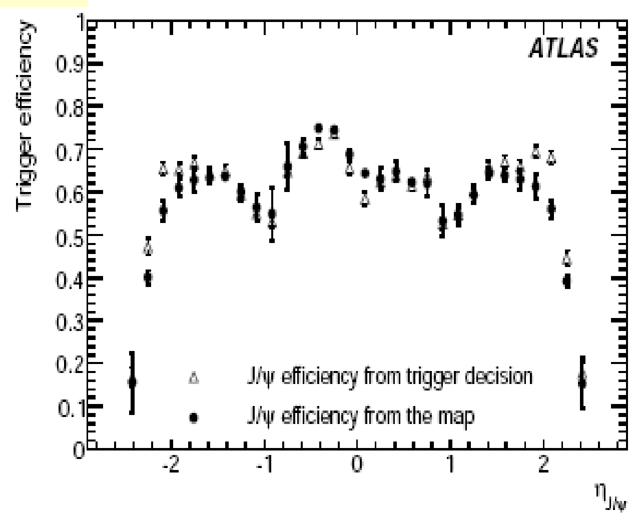
Single-muon





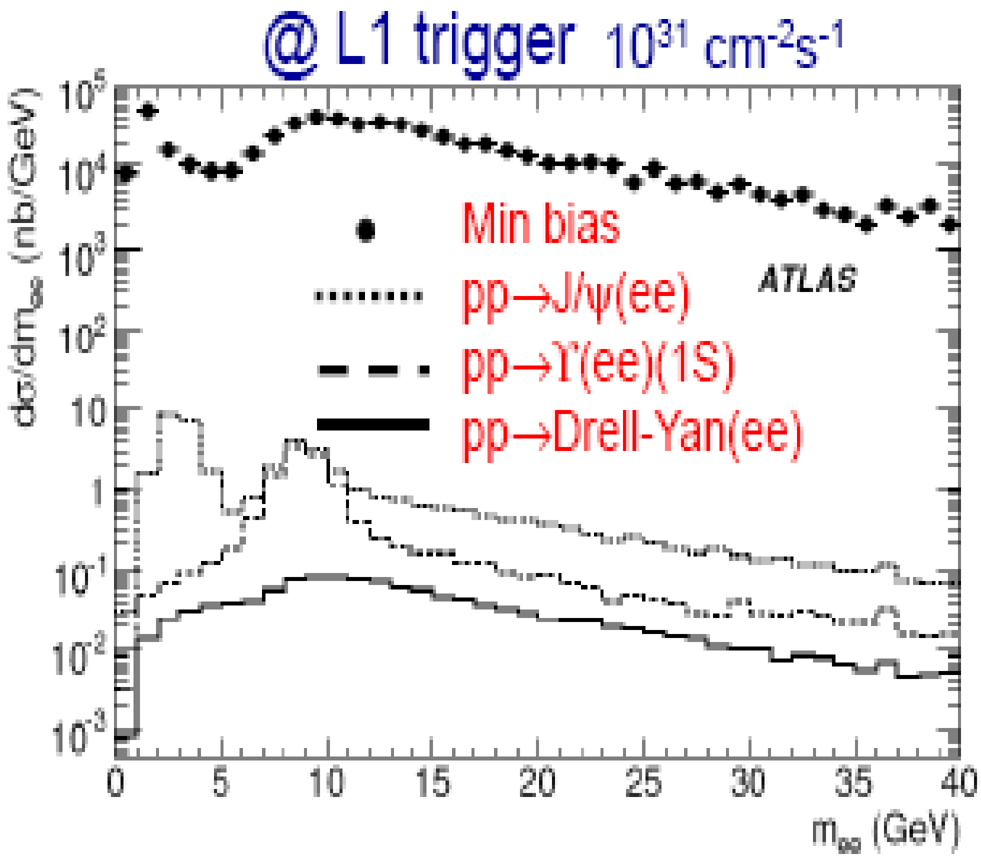
di-muon

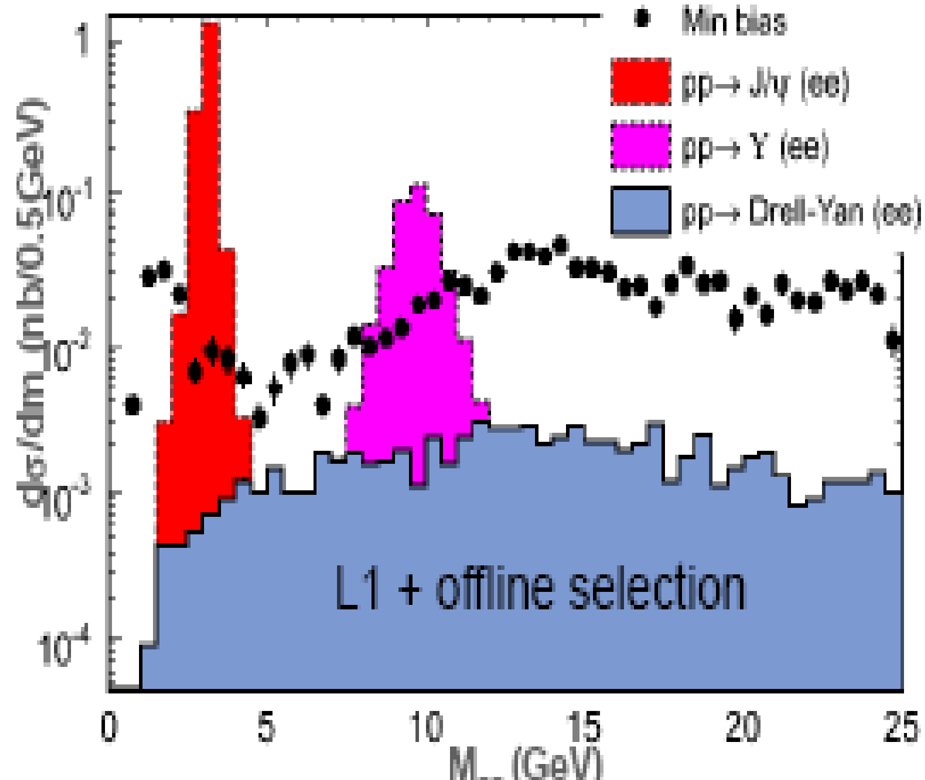




J/ψ–>*ee* and Υ–>*ee* trigger

- Two complementary ways of triggering on J/ψ->ee
  - Use calorimeter only 2E3, 2E5 during the first data taking
  - Use single muon trigger (bb->μ J/ψ(->ee)) : the advantage is the reduction of the background, the disadvantage is the restriction to b-> J/ψ->ee





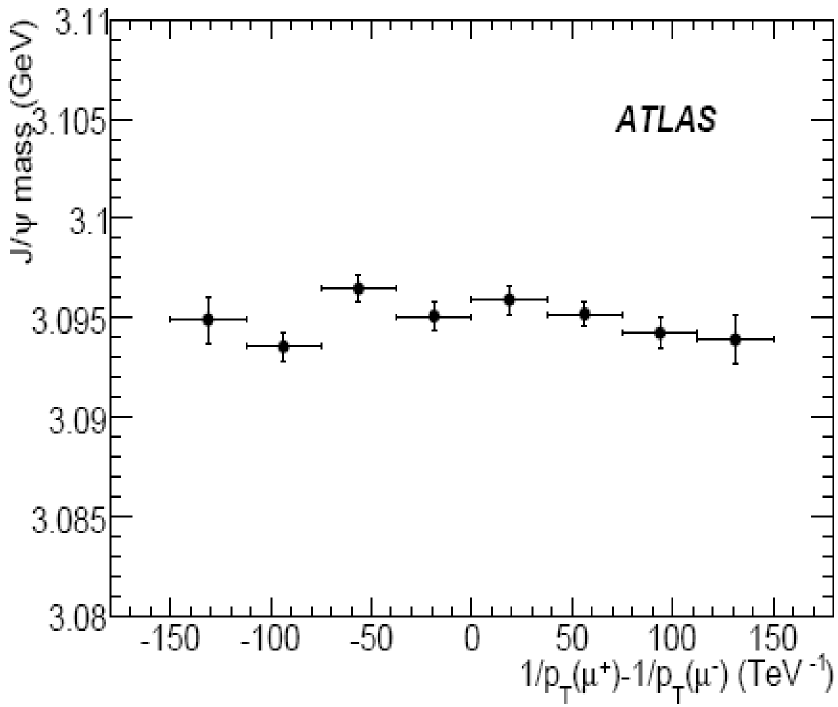
L1 **ε**(trig) ~ 27%

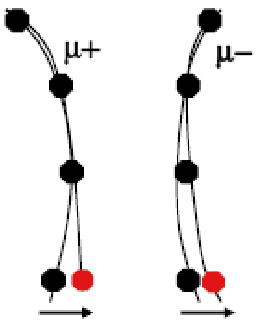
After offline selection 100 pb^{-1}:
~230k J/ψ's and ~43k ϒ's
Expect to measure m(J/ψ) to
~0.6%

Quarkonia as a monitoring tool

- **Detector commissioning**
  - By looking at mass shifts in onia with a number of variables, can disentangle various causes of detector effects
    - **p_T:** momentum scale, energy loss
    - **Curvature difference:** detector misalignments
    - **η and φ:** magnetic field, material effects

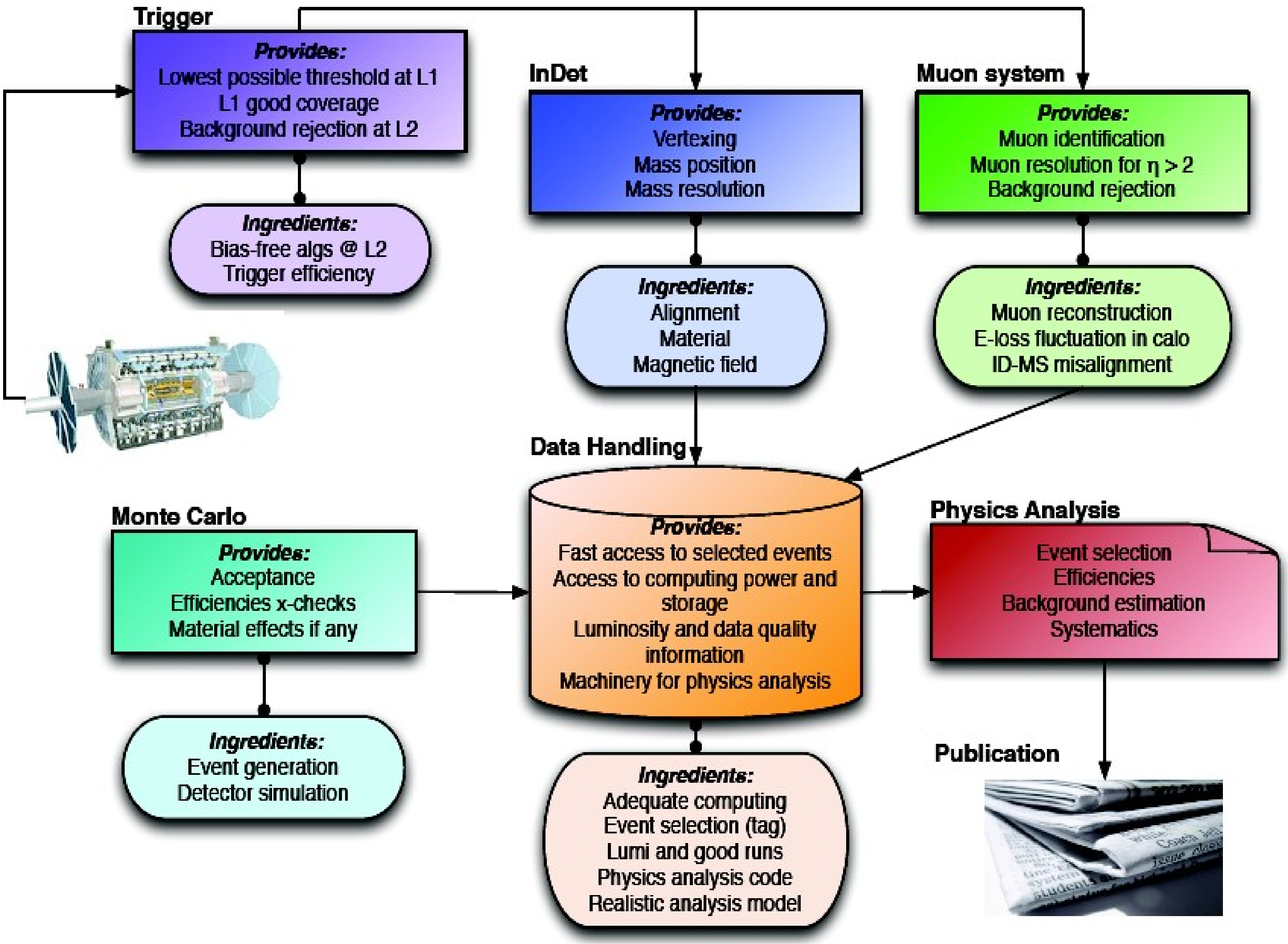
Perfect alignment, 6 pb^{-1}





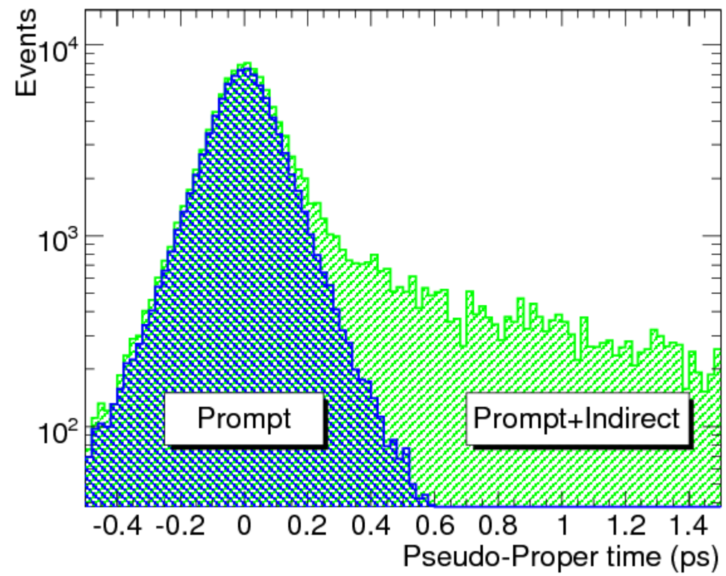
In this example, a misalignment means a negative track has a higher assigned curvature, whilst a positive track has a lower asssigned curvature

Analysis Roadmap



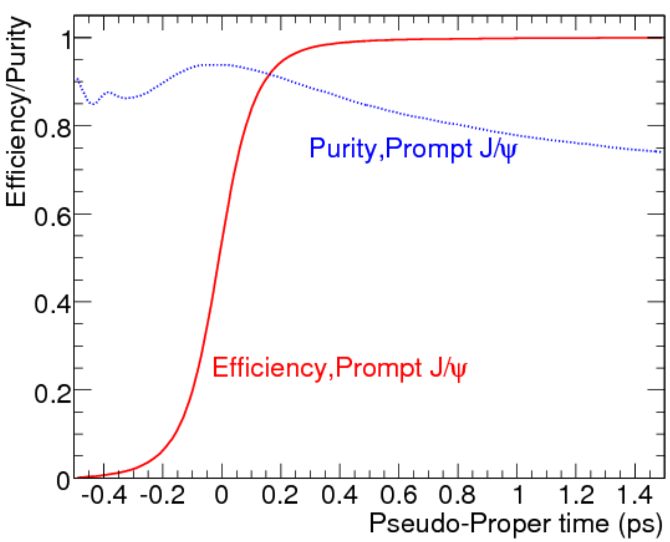
Proper time resolution for background separation

- J/ψ from B-decays form significant background to prompt J/ψ, in addition to muons from b-quark decays



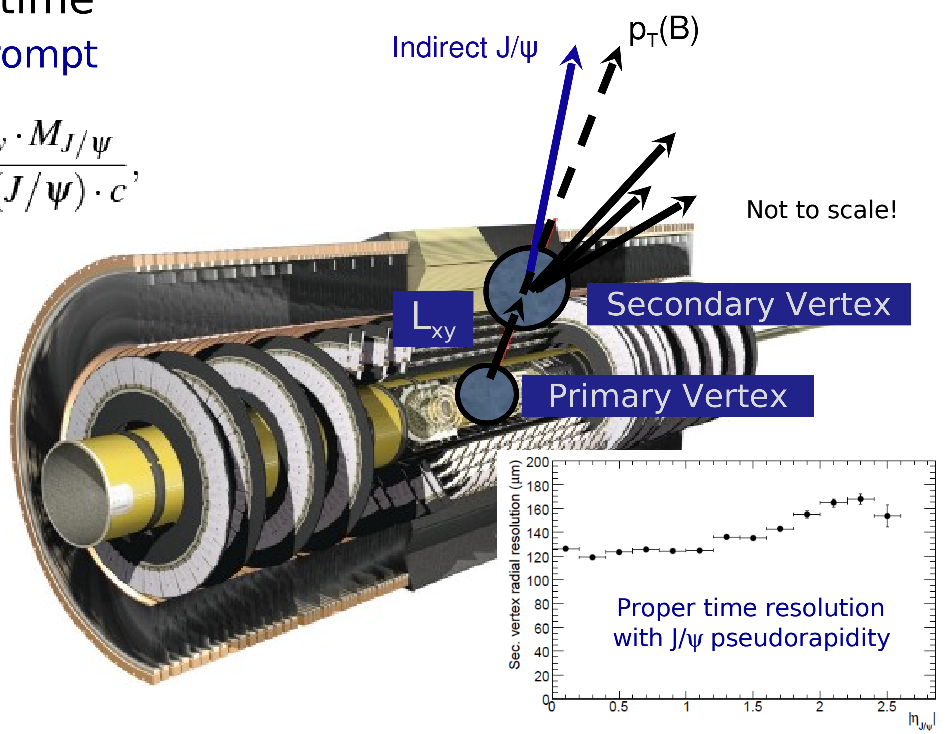
- Measurement of prompt J/ψ to indirect cross-section relies on separation (and understanding of separation) of these two processes

- Proper time of zero characteristic of prompt J/ψ, while those from B-decays have positive proper-time
  - Cut on pseudo-proper time to separate indirect/prompt



$$\text{Pseudo-proper time} = \frac{L_{xy} \cdot M_{J/\psi}}{p_T(J/\psi) \cdot c},$$

Prompt J/ψ
purity/efficiency



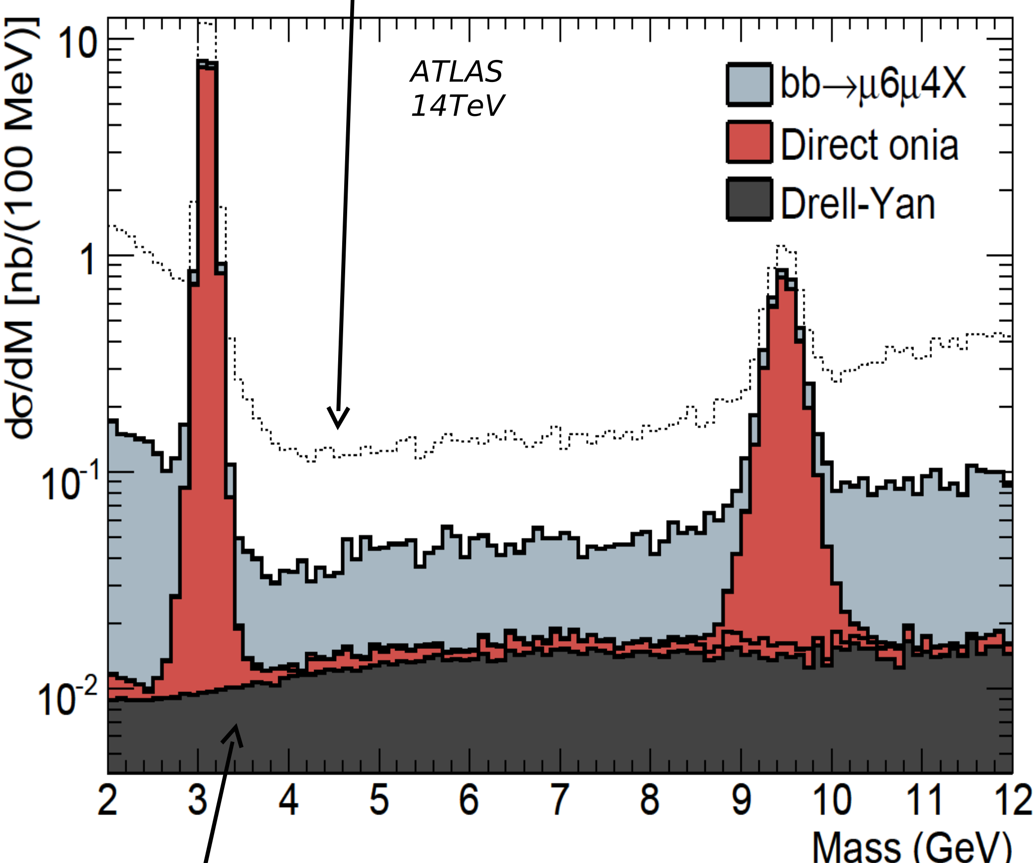
Quarkonium invariant mass distributions

AFTER TRIGGERING AND RECONSTRUCTION [DI-MUON CASE]

1. At least two oppositely charged, identified muons in event
2. Refit associated ID tracks to common vertex (+apply cuts on tracks and refit quality)

Height of background + signal before transverse decay length and vertexing cuts

Statistics equivalent to approx. ~8 pb^{-1} integrated luminosity

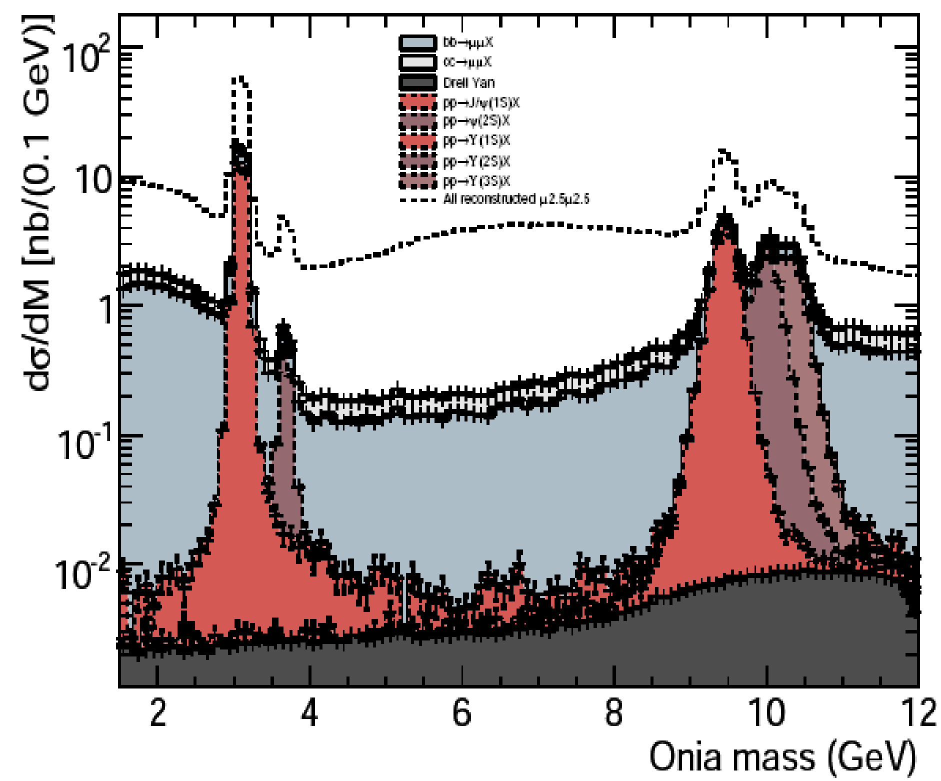


No simulation of ψ(2S), Υ(2s,3s) included here!

MASS RESOLUTIONS AFTER TRIGGER (μ4μ4)

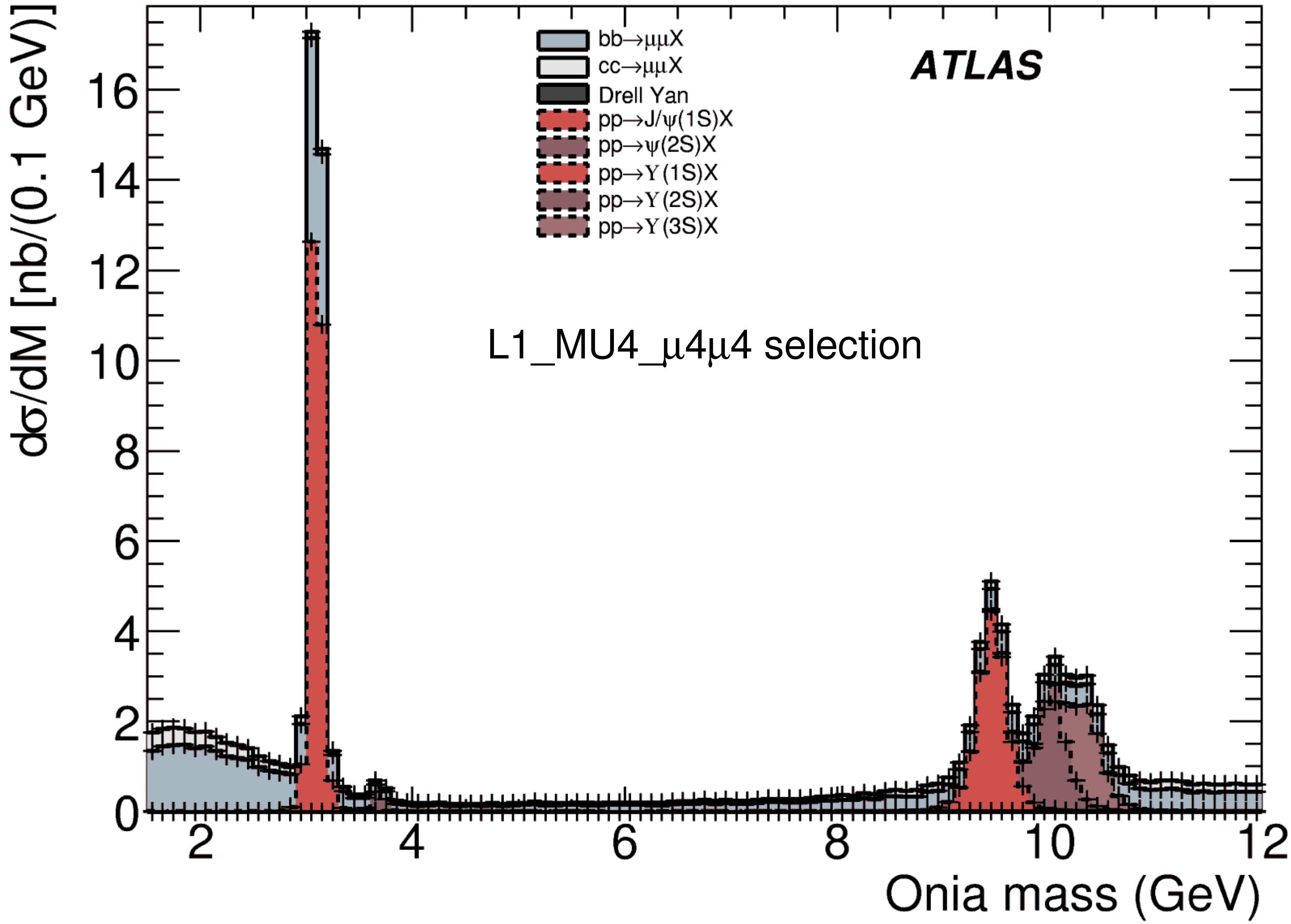
	J/ψ	Υ(1-3S)
Resolution (MeV)	53	160±5

10 TeV



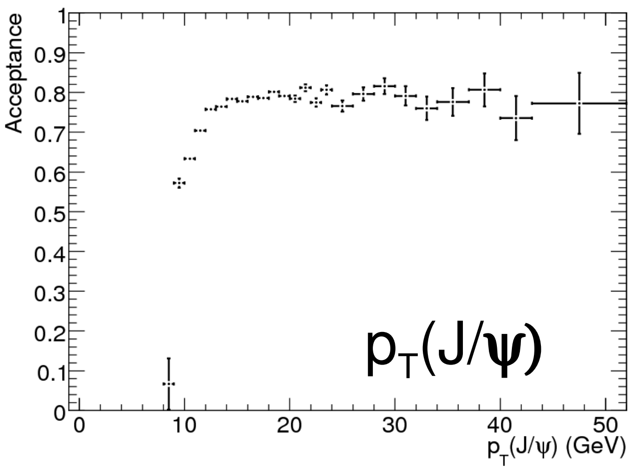
Mass on linear scale

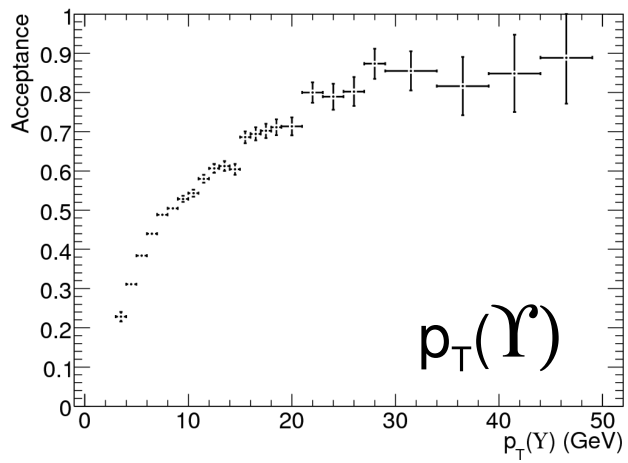
A reminder of how things look on a linear scale!



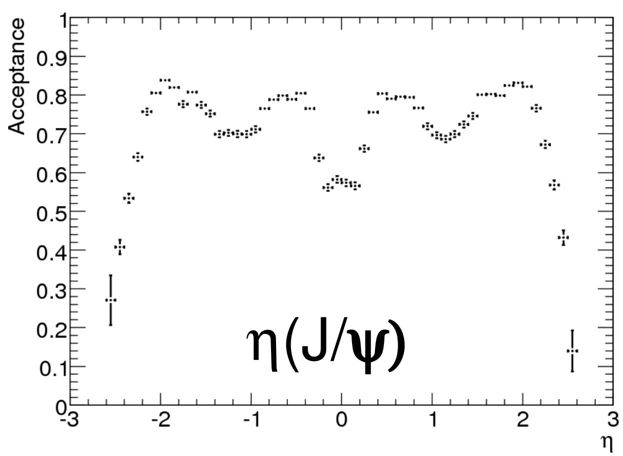
Acceptance and efficiencies

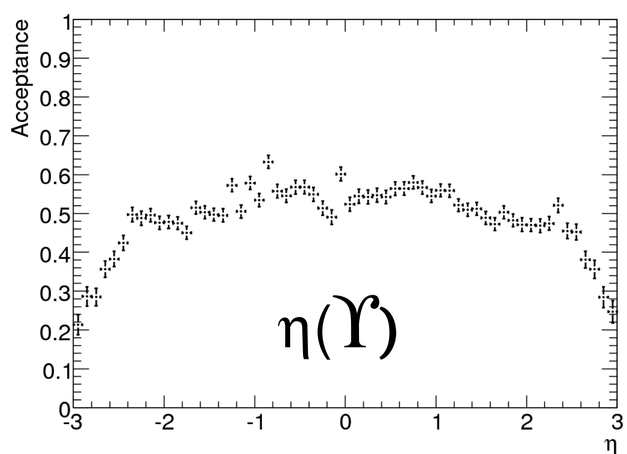
- Plots below show trigger efficiency and geometric acceptance of reconstructed quarkonium candidates in p_T and η
- High p_T reach (50 GeV) and relatively flat and broad η acceptance



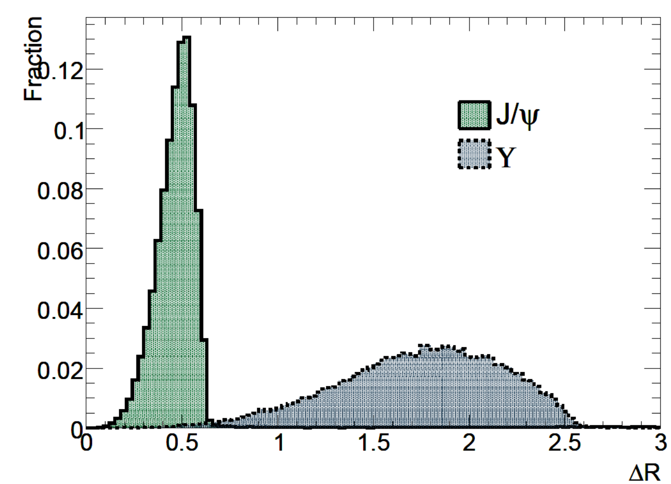


Stark differences in p_T and η for J/ψ and Υ are due to kinematic configurations imposed by di-muon trigger





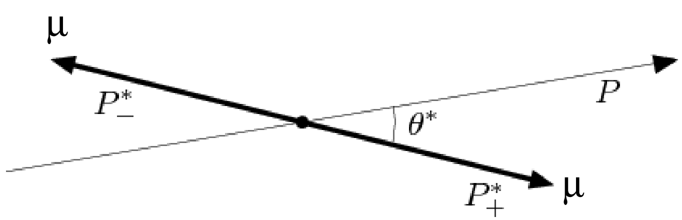
$\Delta R = (\Delta\eta^2 + \Delta\phi^2)^{1/2}$



Quarkonium spin-alignment/polarisation

- Theoretical calculations such as NRQCD and higher order (NLO+NNLO) singlet contributions offer clear predictions for polarisation of produced quarkonium states

- Different models/calculations offer differing predictions of polarisation (amongst other things) which ATLAS can measure as a way of determining the underlying production mechanism



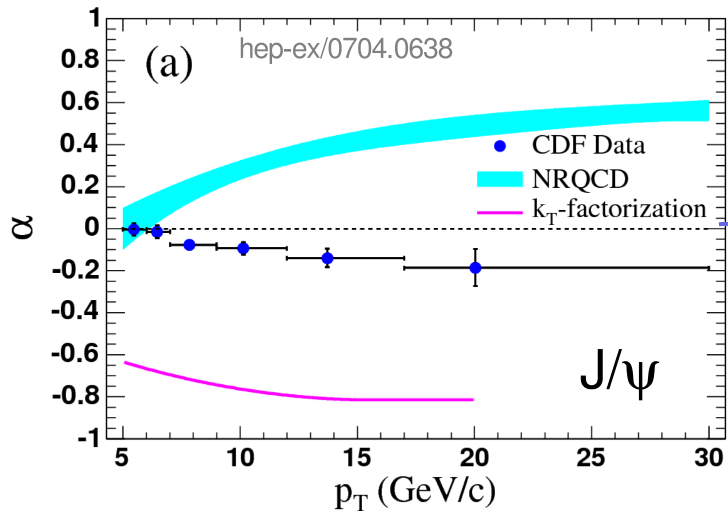
Angle defined between positive muon direction in quarkonium rest frame and quarkonium direction in lab frame, distribution given by:

$$\frac{d\Gamma}{d\cos\theta} \propto \left(1 + \alpha \cos^2\theta \right)$$

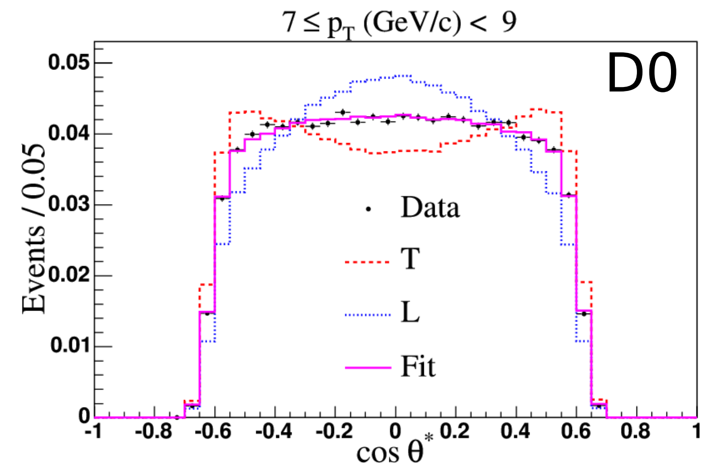
- Polarisation parameter α=0 corresponds to unpolarised mesons, whilst α=+1 and α=–1 correspond to 100% transverse and longitudinal polarised mesons respectively

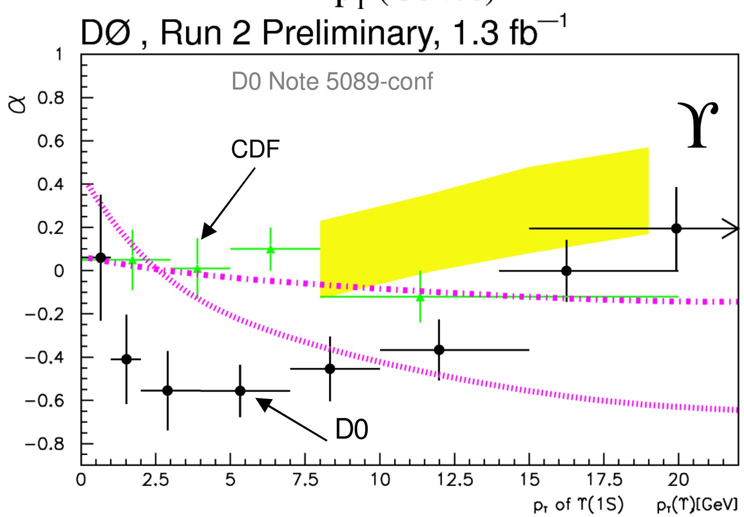
- Polarisation of quarkonium may vary with p_T, and different polarisation states have significant effects on overall acceptance (and thus cross-section)
  - Correlations between measured efficiencies and polarisation state an important consideration!

The problem of limited cosθ acceptance*



D0 Run II measurements disagree with theoretical models *and* CDF Run I results!





Restricted cos θ* acceptance causes problems for discrimination of different polarisation regimes

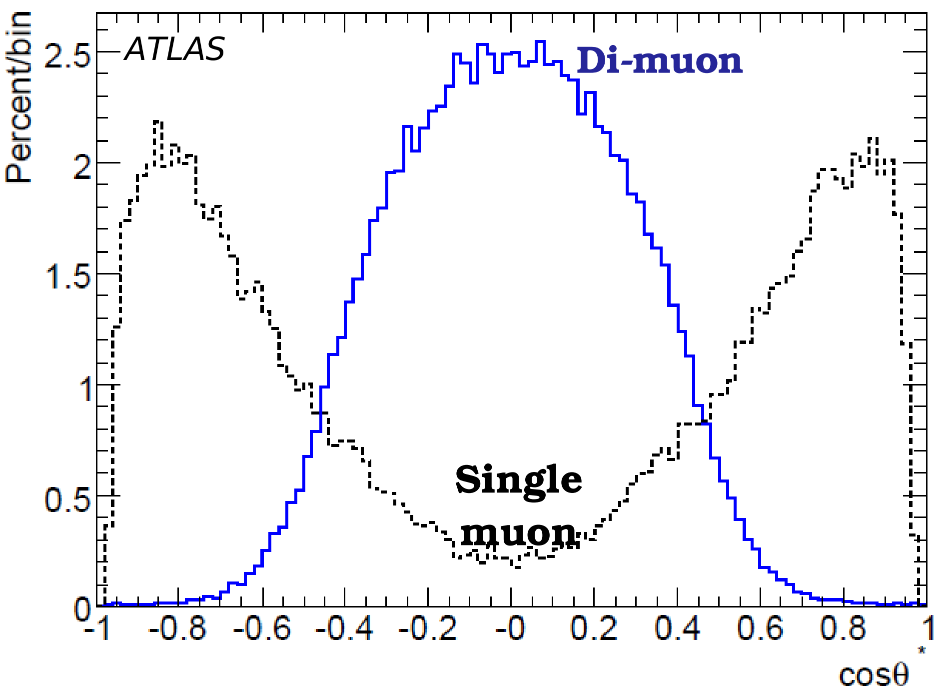
A difference in polarisation looks very much like a modification to trigger efficiency in this variable!

Without full range of cos θ*, hard to disentangle these effects: could incorrectly assign a polarisation effect to a trigger effect

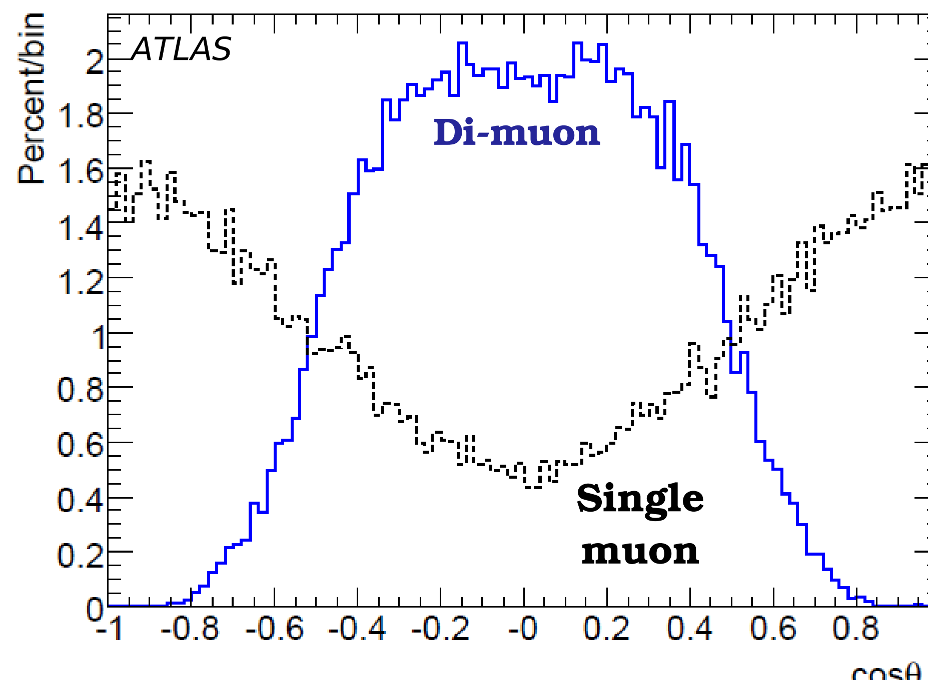
- With di-muon trigger cuts, we see similar acceptance issues at ATLAS
- Would like to have a complementary, independent, high cos θ* sample of quarkonia to give better discrimination and provide cross-check for efficiencies

Single muon μ10 trigger to the rescue

- We can achieve exactly what we want by using a single μ10 trigger:
  - ✓ Second muon can be reconstructed offline from track (>0.5 GeV p_T)
  - ✓ |cos θ*| ~ 1 corresponds to a configuration where one muon is fast, the other slow
  - ✓ Provides similar p_T range of onia to the di-muon configuration and similar rates!
- Go from a distribution in μ6μ4 (blue curve) to that in μ10 (black curve)



J/ψ acceptance

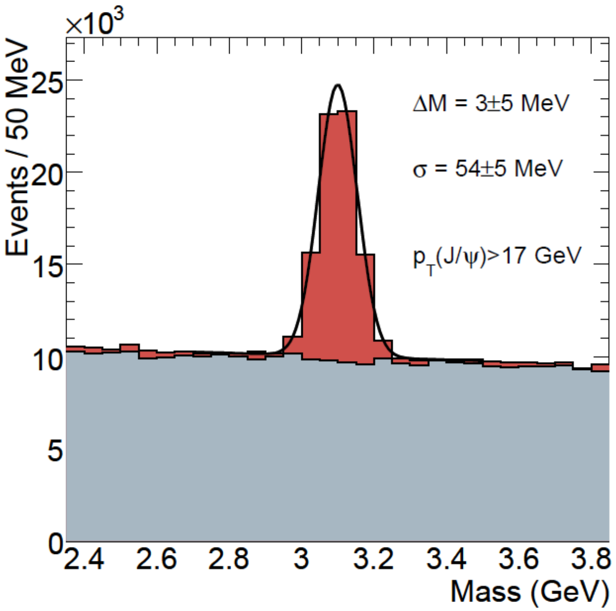


ϒ acceptance

Quarkonium invariant mass distributions
AFTER TRIGGERING AND RECONSTRUCTION [SINGLE-MUON CASE]

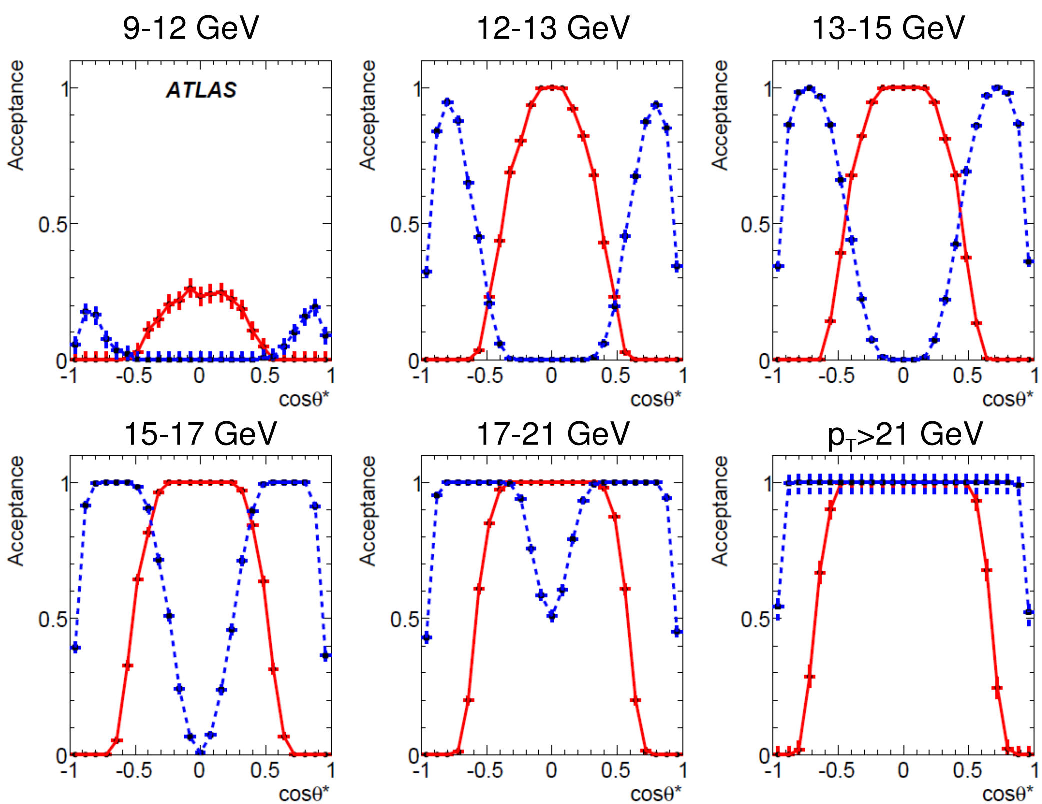
- Single muon selection similar to di-muon analysis but this time…
  - Pair one identified muon with p_T>10 GeV with all Inner Detector tracks in the event fulfilling certain selection criteria (down to p_T of 0.5 GeV)
- Kinematics are such that we expect similar numbers of J/ψ (and ϒ) in both the di-muon and single-muon channels after efficiencies and cuts
- Invariant mass distributions in μ10 suffer from larger, but manageable, backgrounds (and remember this is with just 10 pb^{-1} data equivalent)

J/ψ signal in μ+track selection



  - Lower signal-to-background in Upsilon μ10 case means we will likely need higher integrated luminosities (~100-200 pb^{-1}) to make use of single-muon sample
  - Larger ϒ mass means range of accessible cos θ* in di-muon case is larger than in J/ψ case anyway, so problem is somewhat reduced

Spin-alignment measurement at ATLAS



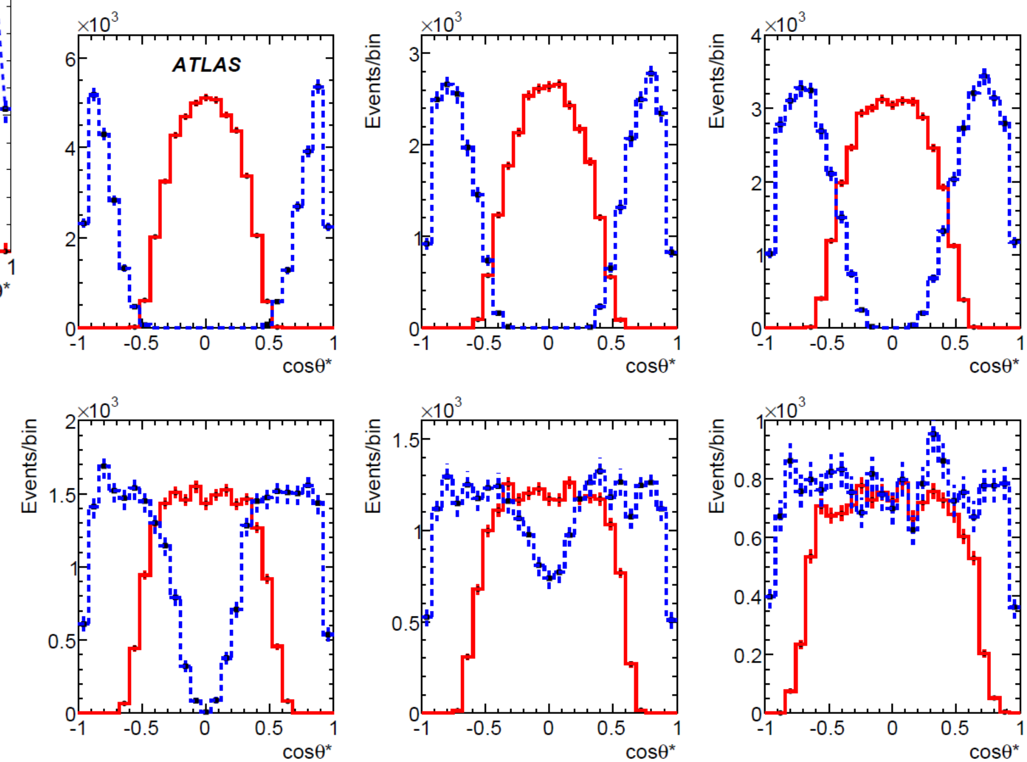
ACCEPTANCE AND EFFICIENCY
(from geometric considerations
+ data-driven efficiency studies)

di-muon sample in red

single muon sample in blue

- We start with an unpolarised (α=0), simulated 10 pb^{-1} sample of J/ψ
- Split into six bins of transverse momenta
- Measure reconstructed distributions

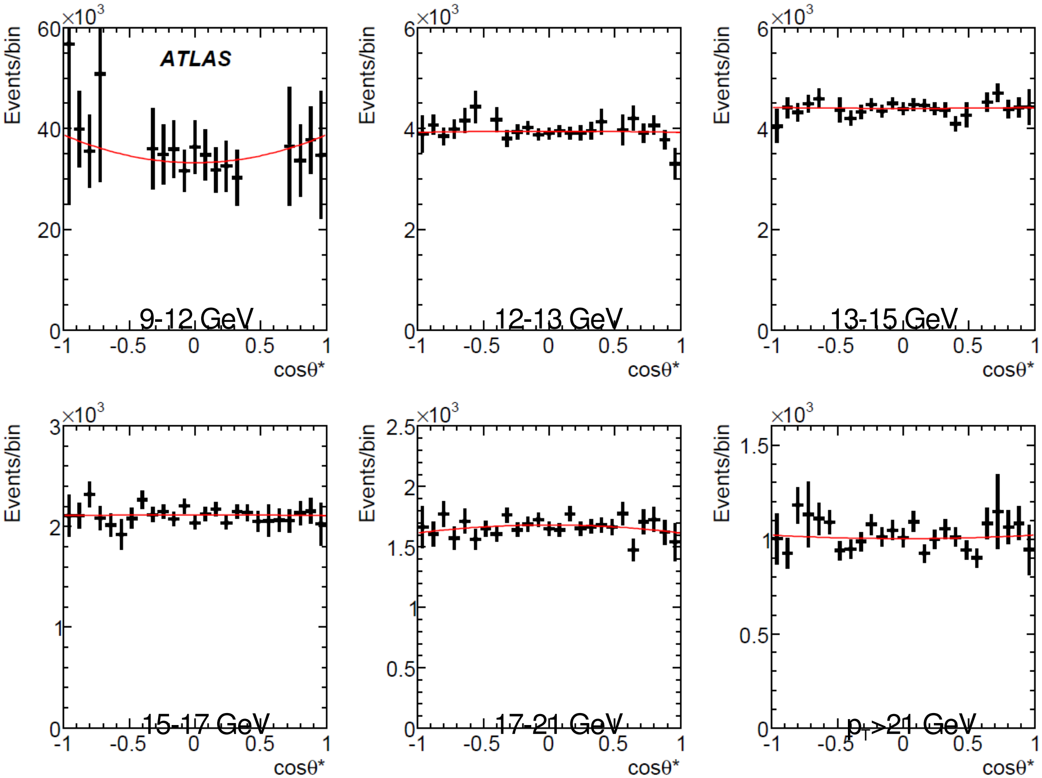
'MEASURED' DISTRIBUTIONS



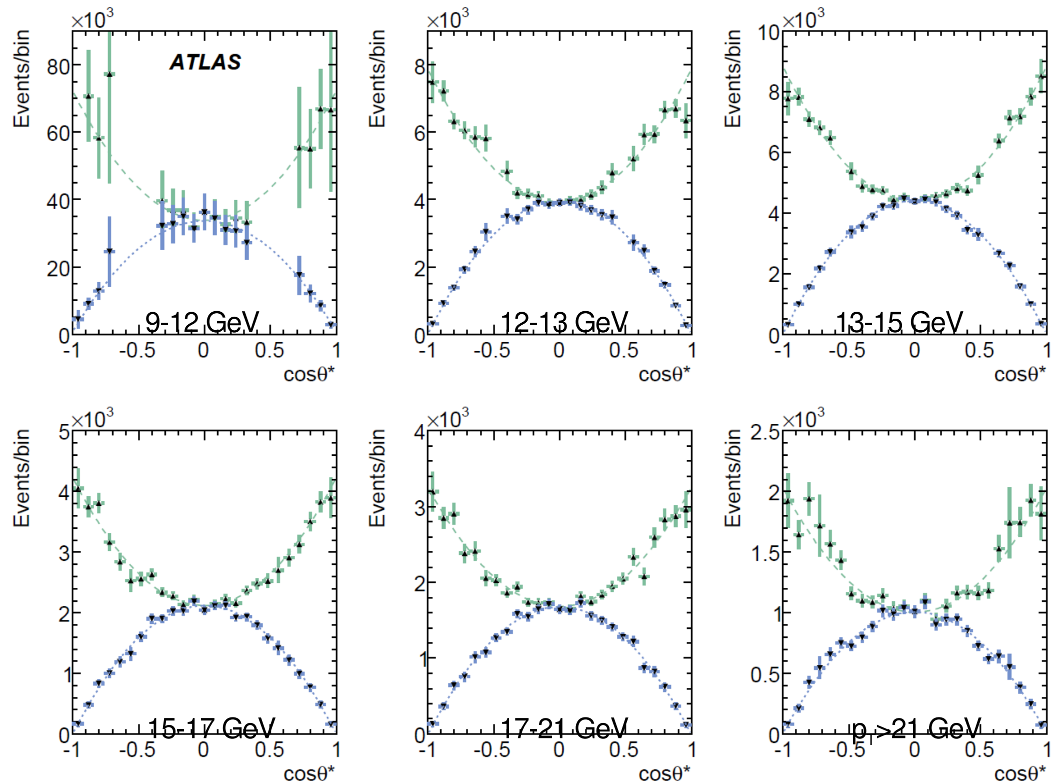
Spin-alignment measurement at ATLAS

- Measured distributions from di-muon and single muon are corrected for their individual acceptances and efficiencies

- The existence of overlapping regions at higher p_T's allows for a cross-check of cross-normalisation of the two samples
- Use pre-defined acceptance mask to combine the two (now non-overlapping) datasets and make a fit to the corrected distributions (shown below)



UNPOLARISED SAMPLE



LONGITUDINAL AND TRANSVERSE SAMPLE

Measurement sensitivity at 10 pb^{-1}

- With 10 pb^{-1} of data (taking into account quarkonium polarisation state and resultant systematics in the corrections) can expect cross-section measurement precision in bins of p_T of the order of 1% (dependent on the polarisation)

- By taking data with μ10 sample and combining them in the way outlined:
  - Increase our acceptance in the important high cos θ* area
  - Increase our quarkonia yield in partially overlapping kinematic region
  - Significantly reduce systematic errors on polarisation measurement

Sample	p_T, GeV	$9-12$	$12-13$	$13-15$	$15-17$	$17-21$	>21
J/ψ, $\alpha_{\text{gen}} = 0$	α	0.156 ±0.166	−0.006 ±0.032	0.004 ±0.029	−0.003 ±0.037	−0.039 ±0.038	0.019 ±0.057
	σ, nb	87.45 ±4.35	9.85 ±0.09	11.02 ±0.09	5.29 ±0.05	4.15 ±0.04	2.52 ±0.04
J/ψ, $\alpha_{\text{gen}} = +1$	α	1.268 ±0.290	0.998 ±0.049	1.008 ±0.044	0.9964 ±0.054	0.9320 ±0.056	1.0217 ±0.088
	σ, nb	117.96 ±6.51	13.14 ±0.12	14.71 ±0.12	7.06 ±0.07	5.52 ±0.05	3.36 ±0.05
J/ψ, $\alpha_{\text{gen}} = -1$	α	−0.978 ±0.027	−1.003 ±0.010	−1.000 ±0.010	−1.001 ±0.013	−1.007 ±0.014	−0.996 ±0.018
	σ, nb	56.74 ±2.58	6.58 ±0.06	7.34 ±0.06	3.53 ±0.04	2.78 ±0.03	1.68 ±0.02
Υ, $\alpha_{\text{gen}} = 0$	α	−0.42 ±0.17	−0.38 ±0.22	−0.20 ±0.20	0.08 ±0.22	−0.15 ±0.18	0.47 ±0.22
	σ, nb	2.523 ±0.127	0.444 ±0.027	0.584 ±0.029	0.330 ±0.016	0.329 ±0.015	0.284 ±0.012

J/ψ polarisation

J/ψ cross-section

Results at extrema of polarisation states

ϒ polarisation

ϒ cross-section

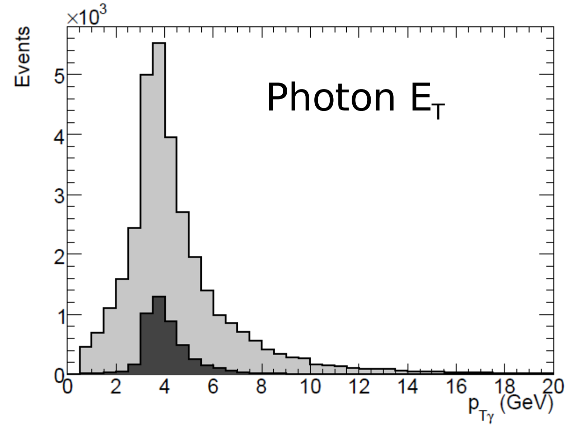
$\chi_c \to J/\psi\ \gamma$ *reconstruction with calorimetry*

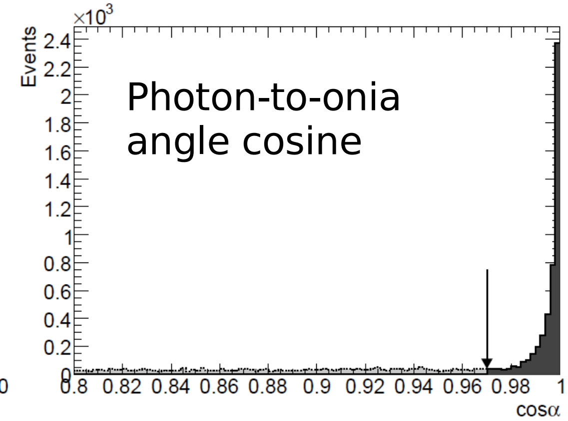
- For J/ψ, ~30% of total prompt cross-section comes from $\chi_c \to J/\psi\ \gamma$ feed-down, and we would like to study this contribution

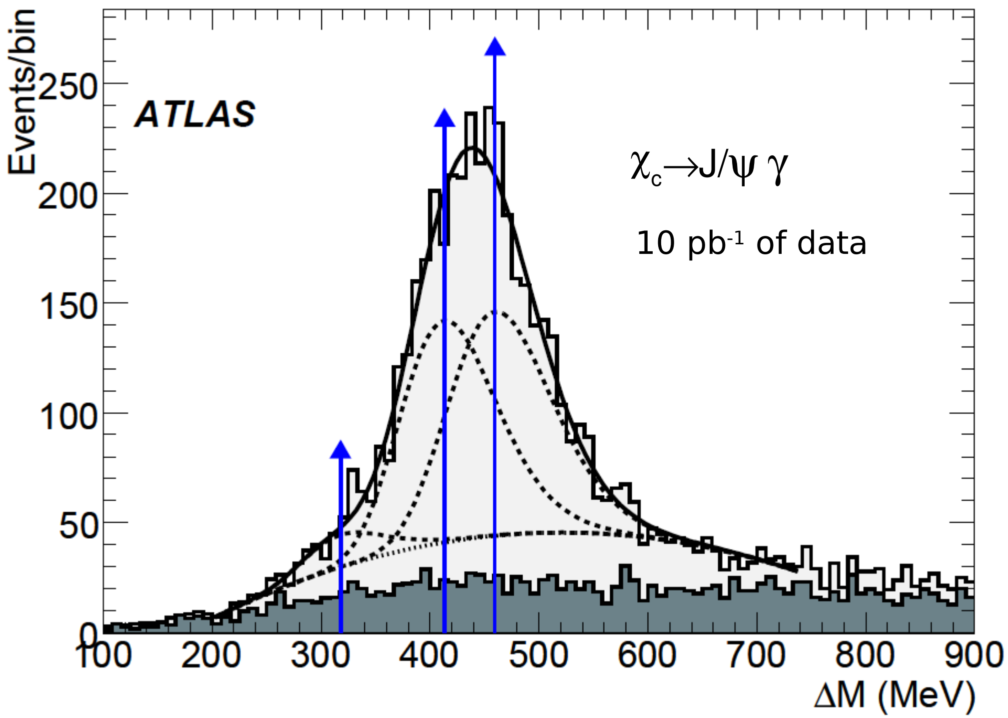
  1. Have a J/ψ candidate
  2. Look in narrow cone ($\cos\alpha > 0.98$) around quarkonium momentum direction for photon (reduces combinatorics)
  3. $\mu\mu\gamma - \mu\mu$ invariant mass difference shows peaks where χ_{c0}, χ_{c1} or χ_{c2} was reconstructed

- Fixing the mass differences of the signals in a simultaneous fit of three Gaussians and quadratic background, can find the three peaks with a typical resolution of 40 MeV

- Only ~4% of χ_c decays into $J/\psi\ \gamma$ have the right kinematics for photons to be reliably reconstructed and identified in ECAL
- Studies on-going to include photon conversions using ID tracks, which should have better resolution, at the price of much reduced efficiency.



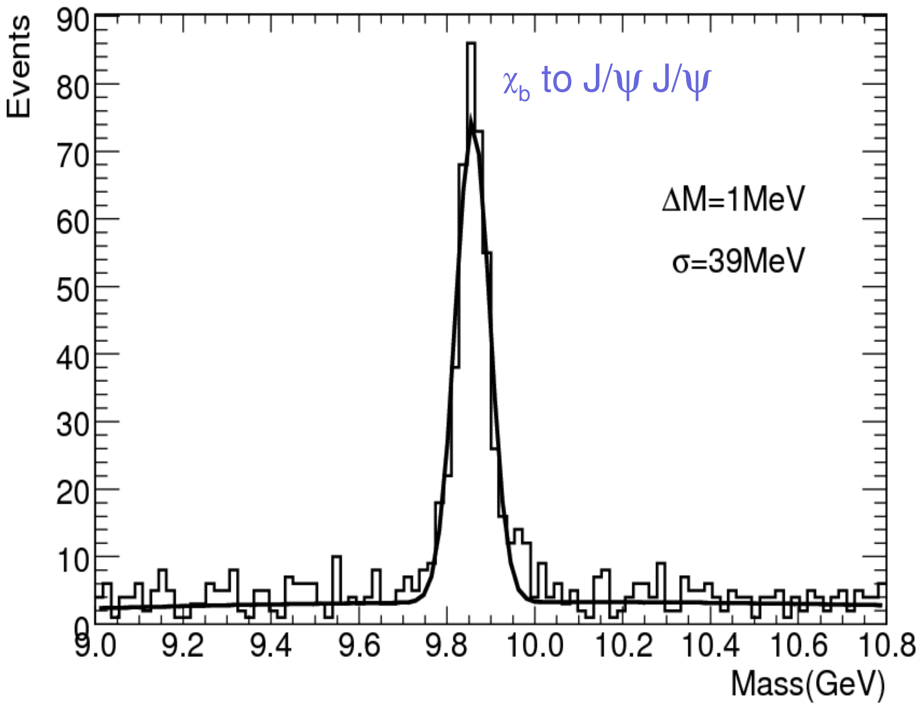




χ_b *reconstruction and searches*

- A related decay under study is χ_b to J/ψ J/ψ for which a signal is expected to be seen within few years of data-taking, with similar mass resolution

- This decay mode also tests the feasibility of the discovery channel η_b to J/ψ J/ψ, which should be seen using the same analysis



Summary & conclusions

Complete chain of analysis is well-developed and well tested.

Expect to make number of measurements with early data, in a number of epochs as our understanding of the data improves

Likely first measurement will be ratio of cross-section of indirect/prompt J/ψ production with p_T in both previously and never-before explored kinematic regions

As we begin to reduce detector-associated systematics, we can start making definitive statements on production models, and test theories at momenta where new mechanisms are expected to become important

Number of studies will require additional Monte Carlo / simulation of:
decays in flight, Min Bias, pile up, multiple interactions

Understanding production of J/ψ will also set the scene for a rich programme of B-Physics at ATLAS, as well as test QCD & our detector!

Additional slides

Summary of planned early measurements

With very early data, beyond detector/performance studies, plan to measure ratios (allow us to cancel many uncertainties & efficiency dependencies), for insight into quarkonium production models

1-Indirect-to-direct J/ψ ratio

- Production mechanism of quark-antiquark bound states not well-understood
- Comparison of charmonium B-decay (b→ccs) vs. prompt [gluon-gluon fusion (gg→ ccg) for example] can give early insight for theoretical models
- Will immediately be probing high1er p_T region than before: particularly interesting for higher order corrections & expected high p_T effects

2-Indirect-to-direct ψ(2S) ratio

- Analysis similar to J/ψ, but smaller statistics and higher backgrounds: still a possibility
- MC studies will require generation of some new samples

3-Ratio of prompt production cross-sections:

Υ(1S) : Υ(2S) : Υ(3S) and J/ψ:ψ(2S)

- Relative efficiency corrections can, to some extent, be assessed directly from data
- Large number of theoretical uncertainties also cancel, can test production models

4-Differential production cross-sections and spin-alignment measurements

- Will require good understanding of trigger efficiencies, luminosity, muon reconstruction
- Likely will need to combine data from single muon and di-muon selections
- Expect to be able to definitively probe production models and provide world-leading measurements

Implementation of NRQCD in ATLAS

- ATLAS studies currently based on Colour Octet Mechanism as implemented in Pythia and fully simulated through ATLAS reconstruction in GEANT 4

- NRQCD matrix elements describe non-perturbative quarkonium evolution
  - Matrix elements tuned within ATLAS to values derived from Tevatron data and tested at Tevatron settings in the ATLAS framework.
  - Values for J/ψ and Upsilon are now Pythia defaults as standard

PYTHIA parameter	J/ψ	Matrix element
PARP(141)	1.16	$\langle \mathcal{O}(J/\psi)[^3S_1^{(1)}]\rangle$
PARP(142)	0.0119	$\langle \mathcal{O}(J/\psi)[^3S_1^{(8)}]\rangle$
PARP(143)	0.01	$\langle \mathcal{O}(J/\psi)[^1S_0^{(8)}]\rangle$
PARP(144)	0.01	$\langle \mathcal{O}(J/\psi)[^3P_0^{(8)}]\rangle/m_c^2$
PARP(145)	0.05	$\langle \mathcal{O}(\chi_{c0})[^3P_0^{(1)}]\rangle/m_c^2$

PYTHIA parameter	NRQCD matrix element	$\psi(2S)$
PARP(141)	$\langle \mathcal{O}(\psi(XS))[^3S_1^{(1)}]\rangle$	0.76
PARP(142)	$\langle \mathcal{O}(\psi(XS))[^3S_1^{(8)}]\rangle$	0.005
PARP(143)	$\langle \mathcal{O}(\psi(XS))[^1S_0^{(8)}]\rangle$	0.0088
PARP(144)	$\langle \mathcal{O}(\psi(XS))[^3P_0^{(8)}]\rangle/m_c^2$	0.0039
PARP(145)	$\langle \mathcal{O}(\chi_{c0}(XP))[^3P_1^{(1)}]\rangle/m_c^2$	0.0

$$d\sigma(pp \to H + X) = \sum_{n_i} d\hat{\sigma}\left(pp \to Q\bar{Q}[n_i] + x\right) \langle \mathcal{O}^H[n_i]\rangle$$

total cross-section — short distance heavy quark production — matrix element

- Note that despite Monte Carlo samples being for the NRQCD hypothesis, ATLAS quarkonium analysis predictions do not depend a priori on this production model!

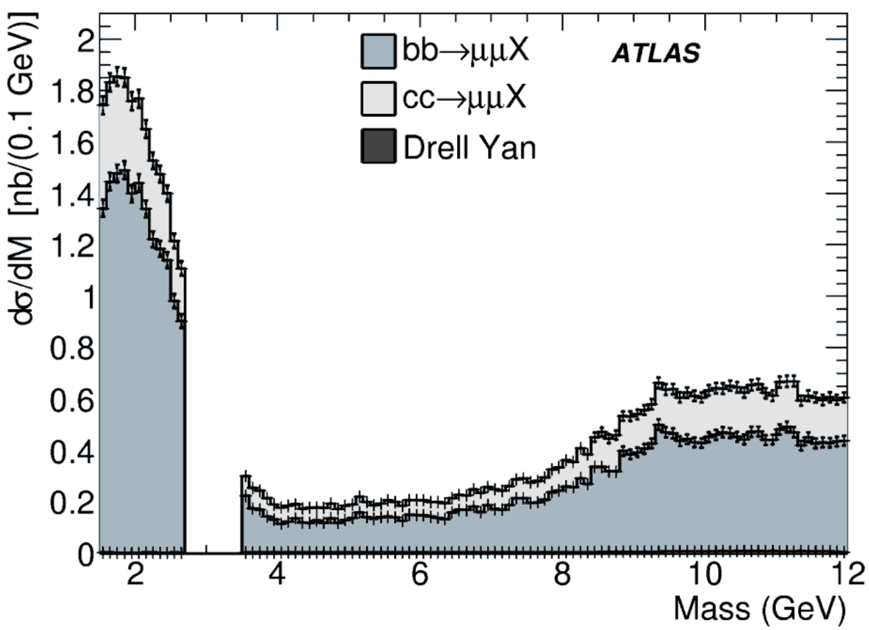
PYTHIA parameter	NRQCD matrix element	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
PARP(146)	$\langle \mathcal{O}(\Upsilon(XS))[^3S_1^{(1)}]\rangle$	9.28	4.63	3.54
PARP(147)	$\langle \mathcal{O}(\Upsilon(XS))[^3S_1^{(8)}]\rangle$	0.150	0.055	0.039
PARP(148)	$\langle \mathcal{O}(\Upsilon(XS))[^1S_0^{(8)}]\rangle$	0.020	0.008	0.005
PARP(149)	$\langle \mathcal{O}(\Upsilon(XS))[^3P_0^{(8)}]\rangle/m_b^2$	0.020	0.008	0.005
PARP(150)	$\langle \mathcal{O}(\chi_{b0}(XP))[^3P_0^{(1)}]\rangle/m_b^2$	0.085	0.103	0.110

Background continuum considerations

SOURCES AND EFFECTS

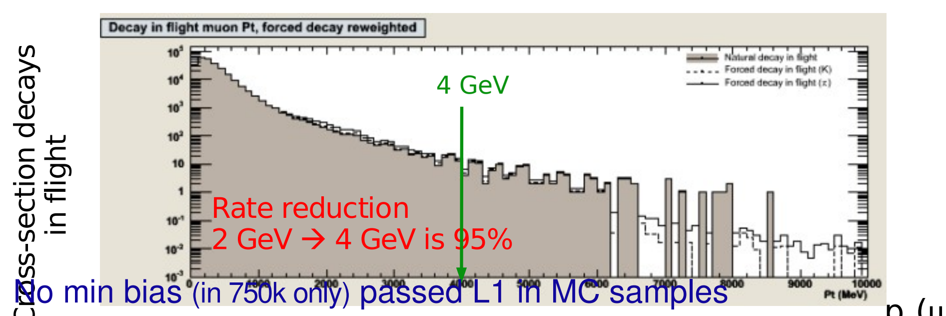
Several sources of continuum background to quarkonium

1. beauty production: non-resonant bb $\rightarrow \mu\mu$
2. charm production: non-resonant cc $\rightarrow \mu\mu$
3. Drell-Yan
4. decays in flight/instrumental backgrounds
5. minimum bias



Continuum backgrounds (linear scale) with resonances removed for clearer picture of background behaviour
(L1_MU4_μ4μ4 selection)

- Charm has softer muon p_T spectrum
  - Despite larger theoretical cross-section, charm contribution ~20% of beauty at masses we consider
- Drell-Yan is 1—2 orders of magnitude below heavy flavour
- Decays in flight ($\pi^{\pm}$, $K^{\pm}$) have been previously studied
  - expect to see fast fall off with Mass/p_T



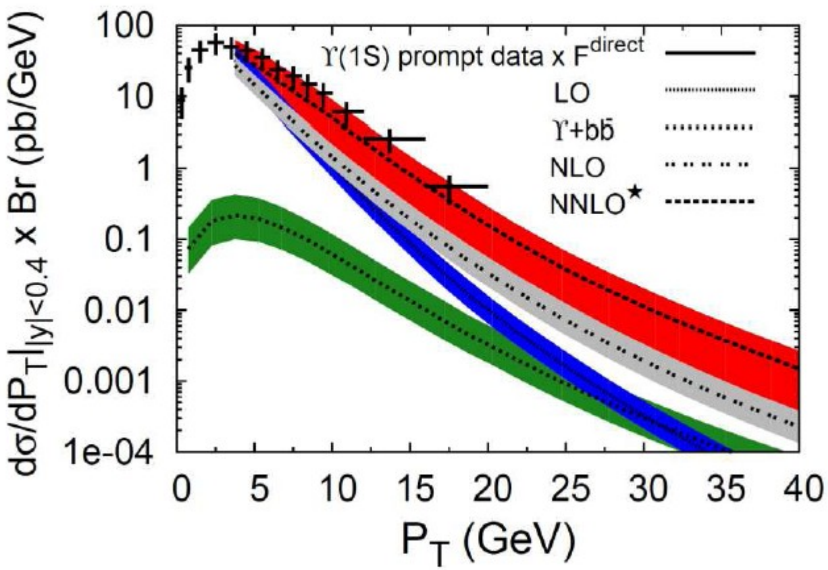
- No min bias (in 750k only) passed L1 in MC samples
  - For both, expect similar behaviour to charm (high cross-section, concentrated at low mass) after L1

Results of selection in μ6μ4 and μ10 samples

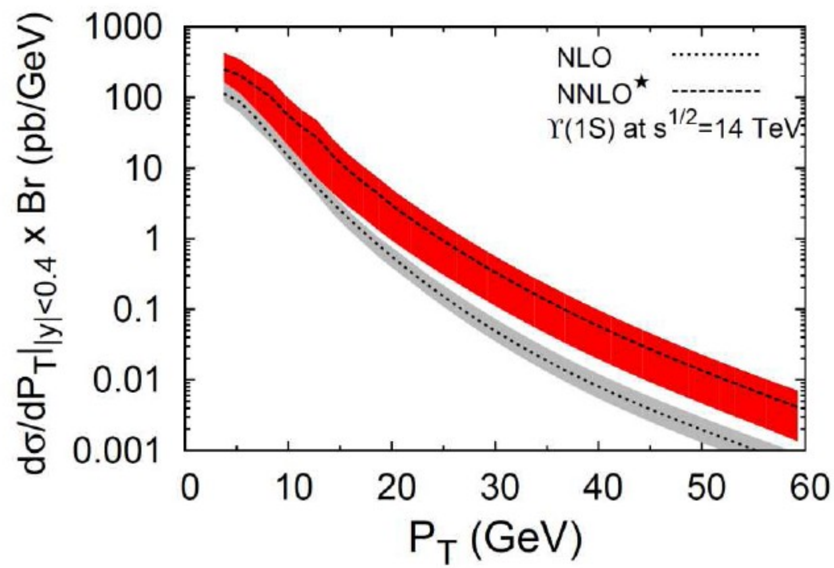
	Quarkonium Trigger type	J/ψ $\mu6\mu4$	J/ψ $\mu10$	Υ $\mu6\mu4$	Υ $\mu10$
	MC cross-section	23 nb	23 nb	5.2 nb	2.8 nb
ε_{L1}	Level-1 trigger	87%	*96%*	84%	*96%*
ε_{L2}	Level-2 trigger	97%	*>99%*	66%	*>99%*
ε_{Rec}	Reconstruction	89%	*96%*	93%	*96%*
ε_{Vtx}	Vertex fit	99%	*99%*	99%	*99%*
ε_1	$\varepsilon_{L1} \cdot \varepsilon_{L2} \cdot \varepsilon_{Rec} \cdot \varepsilon_{Vtx}$	75%	*90%*	51%	*90%*
ε_{t0}	Pseudo-proper time cut	93%	*93%*	n/a	n/a
ε_{Flg}	Only primary vertex tracks	96%	92%	95%	*92%*
$\varepsilon_{\Delta R}$	Second track inside cone	n/a	99%	n/a	91%
ε_{d0}	Impact parameter cut	n/a	90%	n/a	90%
ε_2	$\varepsilon_{t0} \cdot \varepsilon_{Flg} \cdot \varepsilon_{\Delta R} \cdot \varepsilon_{d0}$	90%	76%	95%	75%
ε	Overall efficiency $\varepsilon_1 \cdot \varepsilon_2$	67%	69%	49%	68%
	Observed signal cross-section	15 nb	16 nb	2.5 nb	2.0 nb
	N_S for 10 pb^{-1}	150 000	160 000	25 000	20 000
	N_B in mass window for 10 pb^{-1}	7000	700 000	16 000	2 000 000
	Signal/Background at peak	60	1.2	10	0.05

Additional avenues for polarisation study

HIGHER STATE (NLO & NNLO) SINGLET CONTRIBUTIONS

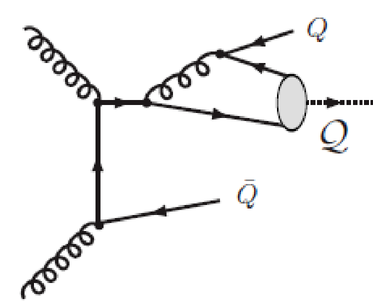


$p\bar{p} \to \Upsilon(1S)X$ at CDF



$pp \to \Upsilon(1S)X$ prediction for LHC

- New calculations show that higher order terms are important: p_T sca



- Higher order corrections give rise to predictions of significant associated hadroproduction at high p_T

- This, along with spin-alignment analysis will provide sensitive tests of production at ATLAS