CHEP Working Month 2014, 26th May 2014

LHC Results on Charmonium Production, Pixel Luminosity Telescope (PLT)

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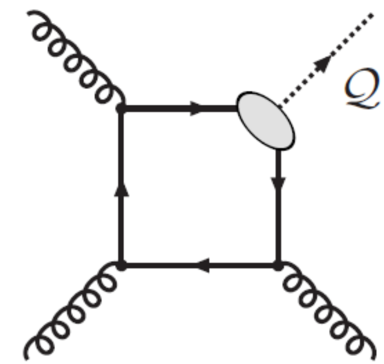
Outline

- ATLAS, CMS and LHCb
- Prompt J/ψ and $\psi(2S)$ cross section, CMS, ATLAS, LHCb
- Non-prompt J/ψ and $\psi(2S)$ cross section, CMS, ATLAS, LHCb
- P-wave states ($\chi_{c1,c2}$) cross-section ratio measurements, CMS, ATLAS, LHCb
- Prompt J/ψ and $\psi(2S)$ polarization, CMS, LHCb
- J/ψ as a probe for Double Parton Scattering (DPS), CMS, ATLAS, LHCb
- Pixel Luminosity Telescope (PLT) for CMS upgrade

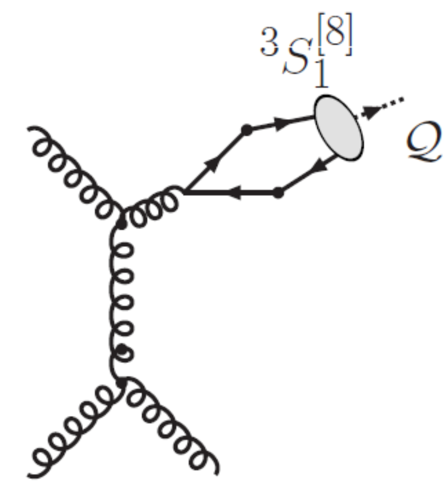
Motivations

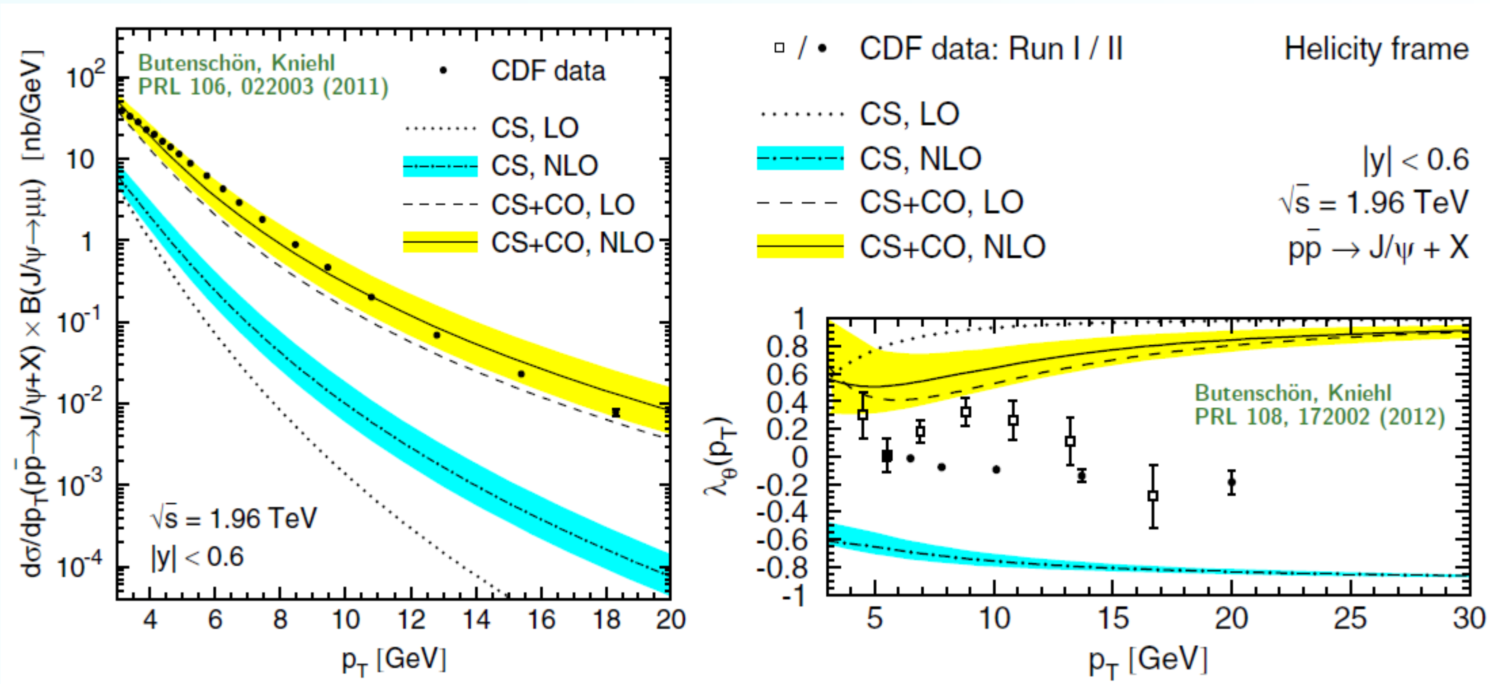
- Quarkonium production has the potential to clarify (non-perturbative) hadron formation and other QCD features.
- However, after decades of theoretical and experimental research, quarkonium production remains a mystery.
- Best theory candidate – NRQCD: effective field theory, treats quakonia as non-relativistic systems (heavy mass).

Color Singlet production

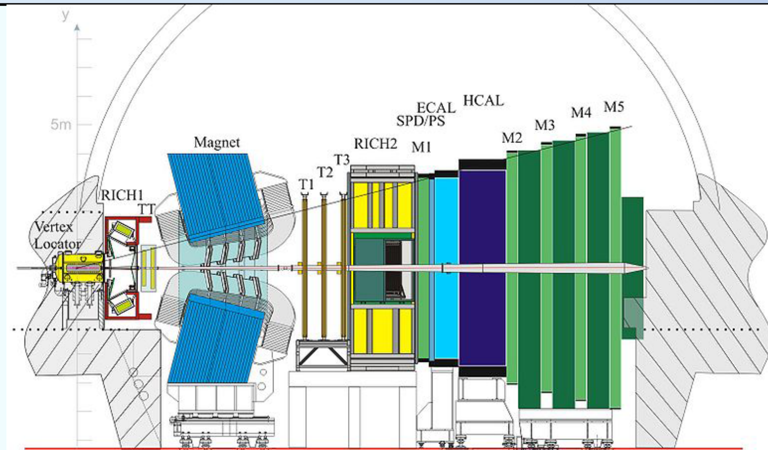


Color Octet production

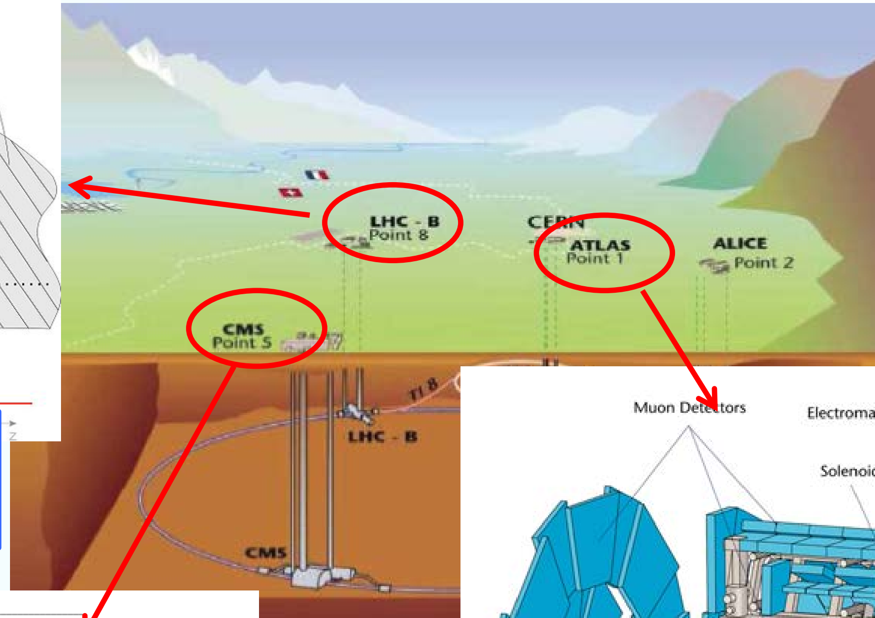


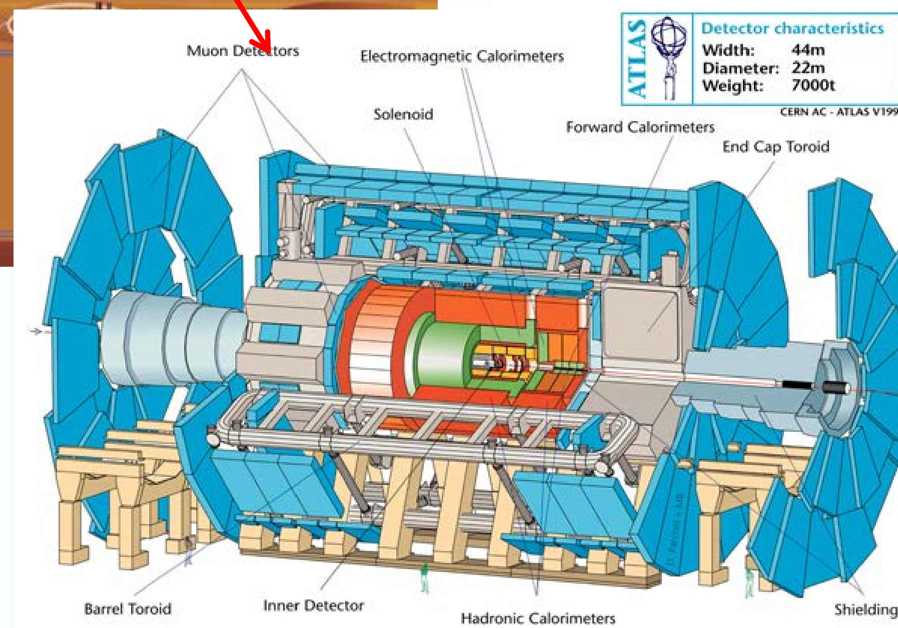


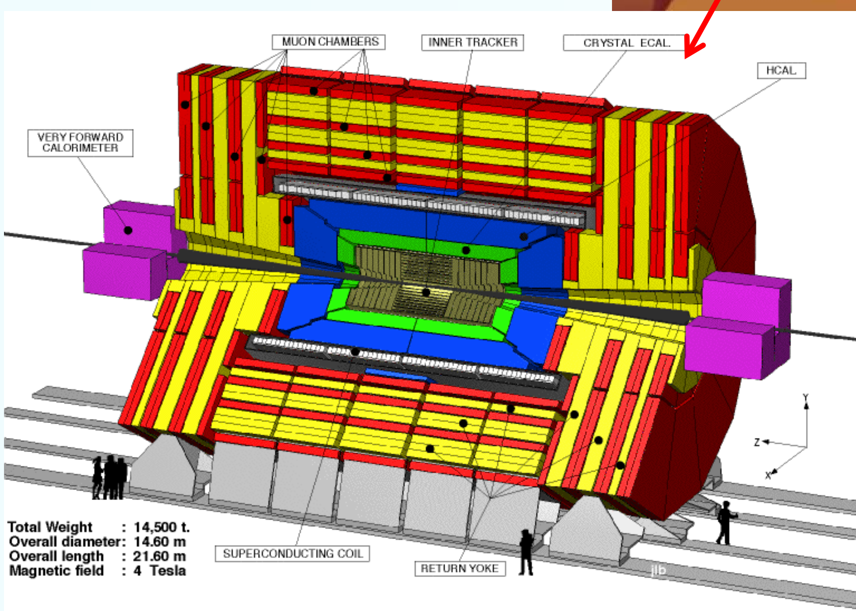
LHC and ATLAS, CMS, LHCb



dedicated experiment for Heavy Flavor physics

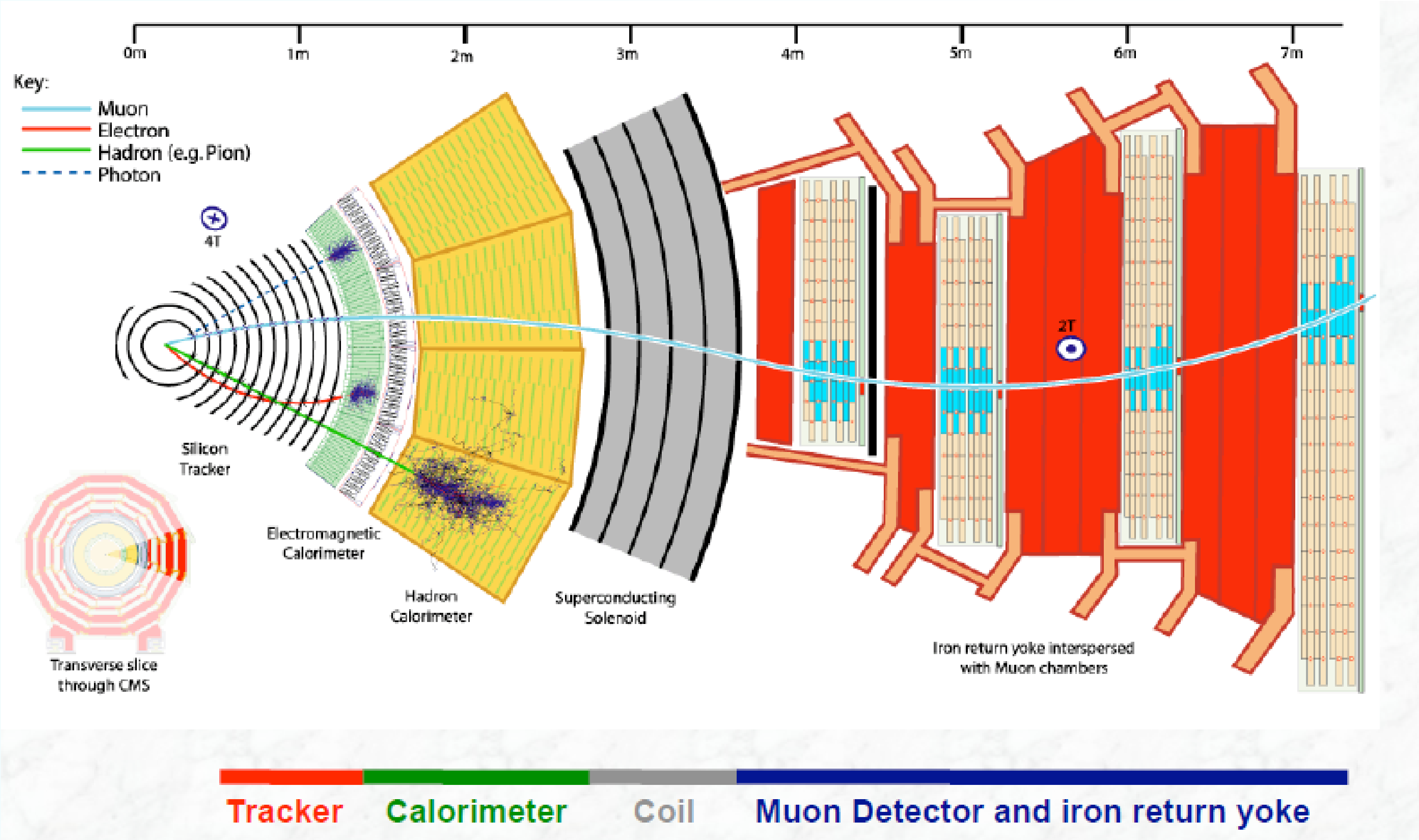






General purpose experiments

CMS Detector Concept



Detector Performance

- Muon coverage:
  - ATLAS/CMS: $|\eta| < 2.4$
  - LHCb: $2.0 < \eta < 4.5$
- High p_T only accessible at ATLAS/CMS.
- Precise tracking allows separation of decays displaced from the production vertex:
  - Separation between prompt and non-prompt (b hadron decays) production.

•mass resolutions (in MeV/c²):

	$J/\psi \rightarrow \mu\mu$	$\chi_c \rightarrow J/\psi\ \gamma$
LHCb	12	~15 ($\gamma \to ee$) 18.3 (non-converted)
CMS	20-71	9.6 ($\gamma \to ee$)
ATLAS	46-111	~10 ($\gamma \to ee$)

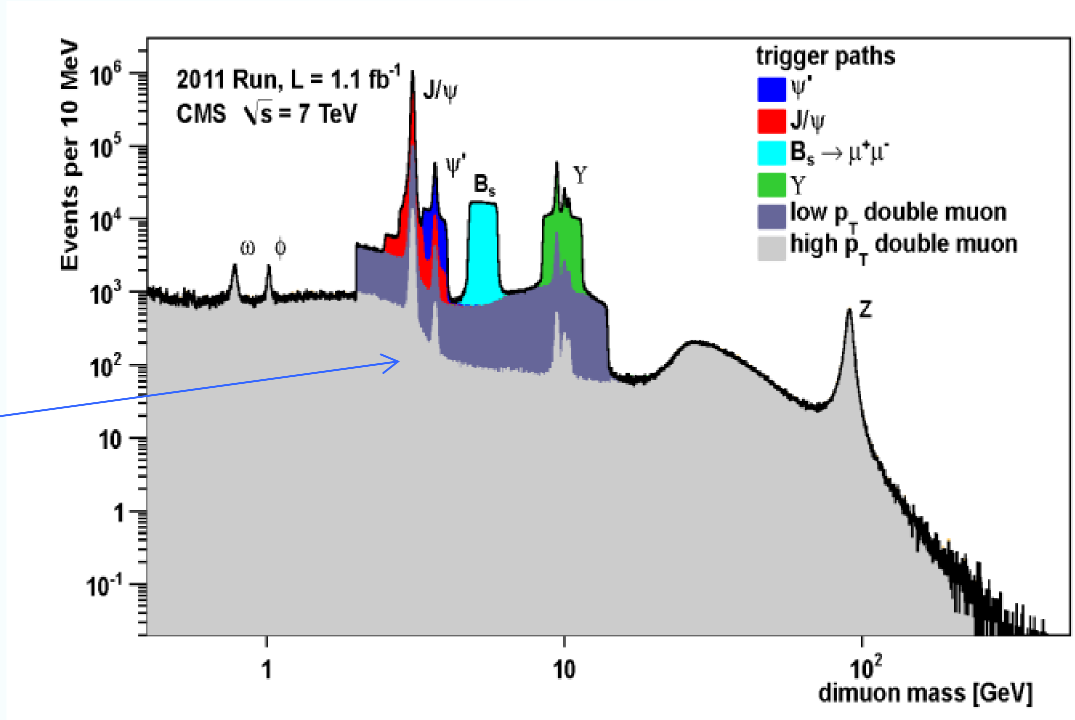
	ATLAS/CMS	LHCb
Triggers	Challenging	Not a problem
Resolution	Better for $\gamma \to ee$ (best in CMS)	Better for dimuons/vertices
p_T -y coverage	$|y| < 2.4$, access to very high p_T	Forward rapidity, low p_T

Data taking and Trigger

- **Collected data:**
  - **Similar integrated luminosity in 2010**
  - **In 2011 LHCb already reached design instantaneous luminosity ($2x10^{32}$ $cm^{-2}s^{-1}$)**
  - **No luminosity leveling in CMS/ATLAS.**

	CMS/ATLAS	LHCb
2010, 7 TeV	40 pb^{-1}	37 pb^{-1}
2011, 7 TeV	~5 fb^{-1}	~1 fb^{-1}
2012, 8 TeV	~20 fb^{-1}	~2 fb^{-1}

- **Low p_T dimuon triggers:**
  - **“High-priority” in LHCb**
  - **Must be kept at reasonable rates in ATLAS/CMS.**
  - **In ATLAS/CMS, special triggers are developed for different analysis.**



Analysis Strategy

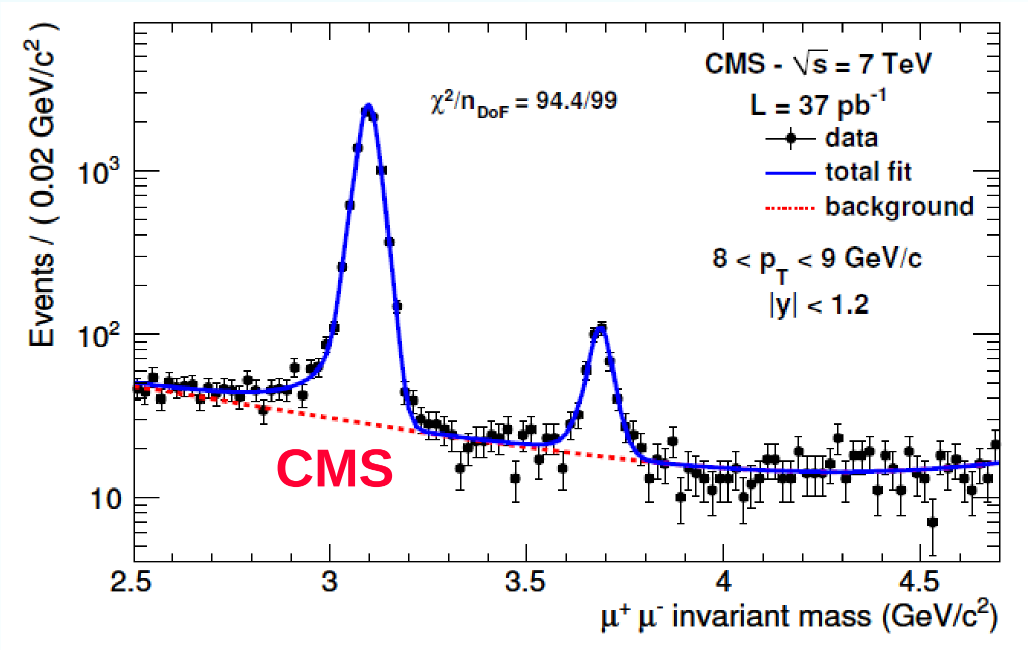
- **The differential cross section:**

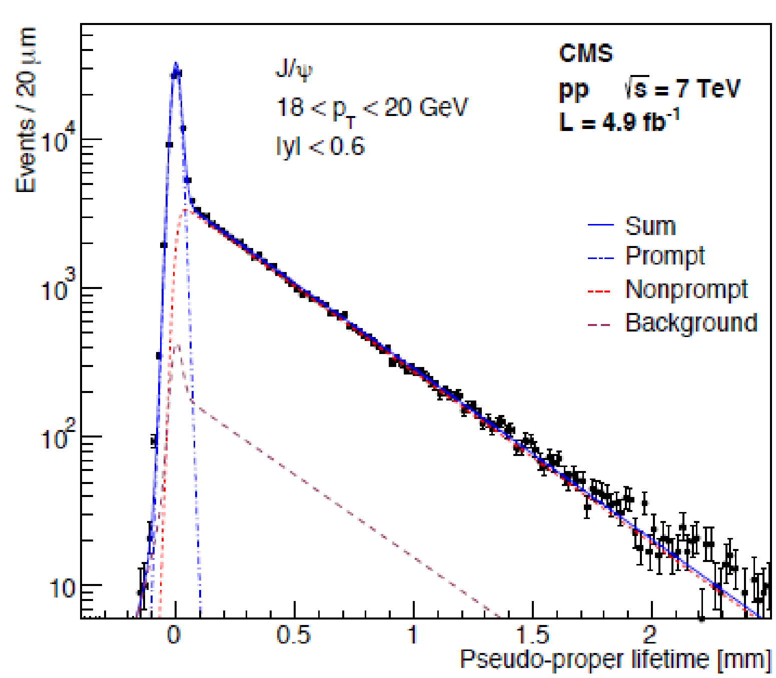
$$\frac{d^2\sigma}{dp_T dy}(Q\overline{Q})Br(Q\overline{Q} \to \mu^+\mu^-) = \frac{N_{fit}(Q\overline{Q})}{\int Ldt \cdot A \cdot \varepsilon \cdot \Delta p_T \Delta y}$$

$$N_{fit}(J/\psi, \psi(2S)) = \begin{cases} (1 - f_B) N_{total} & \text{(prompt)} \\ f_B N_{total} & \text{(non-prompt)} \end{cases}$$

f_B : the fraction of B decays, from simultaneous fits to mass and quarkonium lifetime (using vertex information)

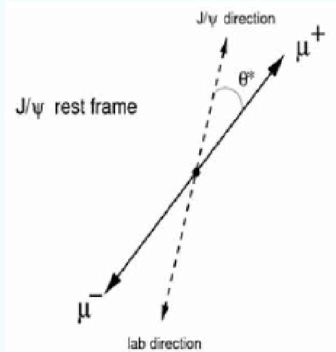
- **N_{fit} from mass fits**





Analysis Strategy

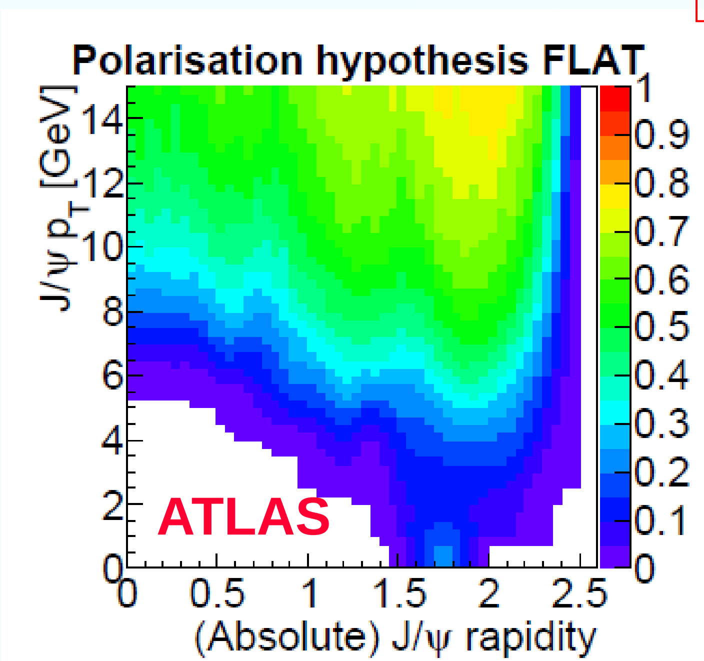
- **Acceptance → from simulation using unpolarized production as a default.**
- **Maximum possible variations are given based on "extreme" polarization scenarios.**

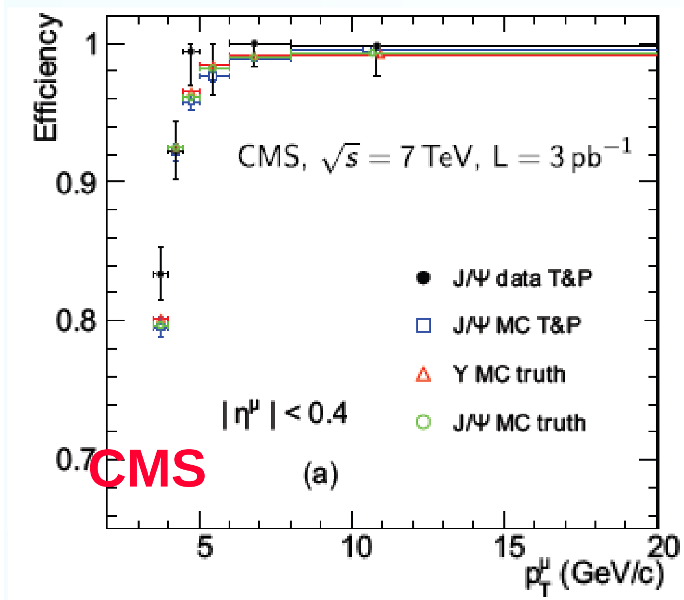


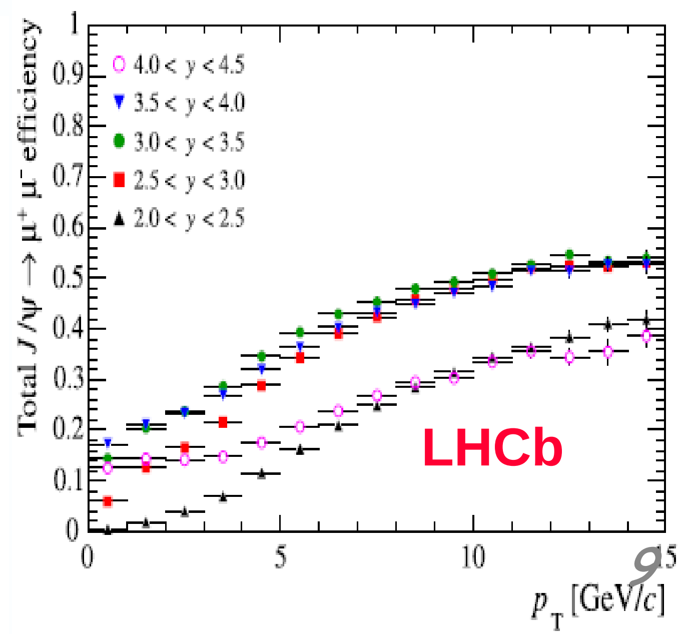
$$I(\cos\theta) = \frac{3}{2(\alpha+3)}(1+\alpha\cdot\cos^2\theta)$$

α=0: upolarized
α=+1: fully transverse polarization
α=-1: fully longitudinal polarization

- **Efficiency: ATLAS/CMS use data-driven measurements of the muon efficiency ("tag-and-probe" method) on independent trigger streams**
- **LHCb determined the total efficiency from simulation of unpolarized sample.**



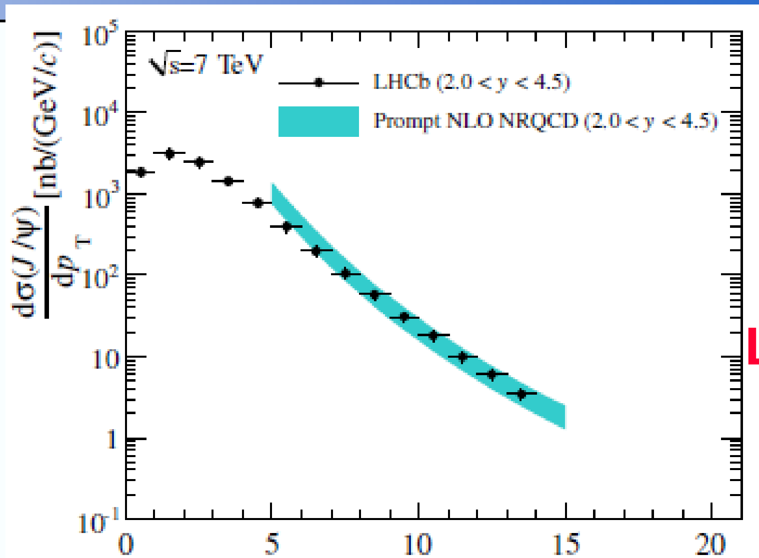




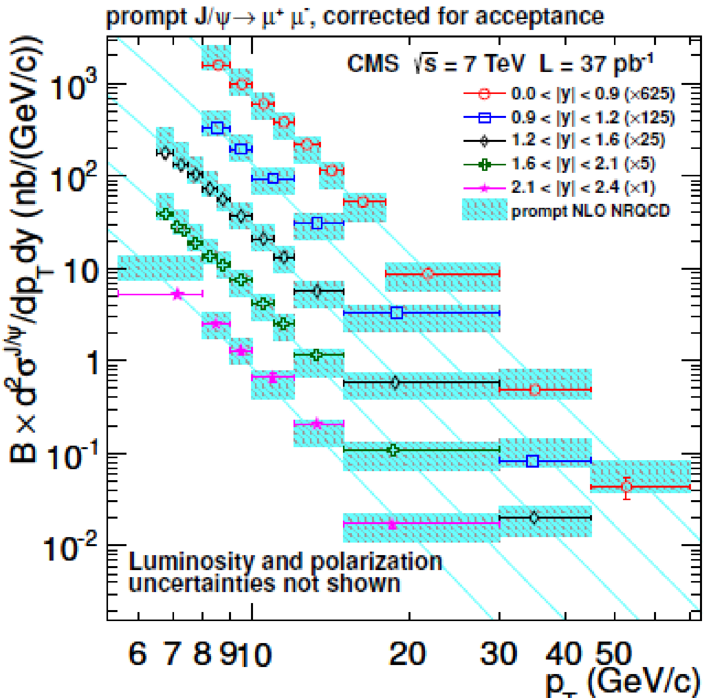
Prompt J/ψ cross-section

- **The differential cross-section of prompt J/ψ in LHCb, CMS and ATLAS(next slide)**
- **Good agreement between experiments and theory:**
  - **the NLO NRQCD calculation here refers to:**

    Yan-Qing Ma, Kai Wang, Kuang-Ta Chao, Phys. Rev. D84 (2011) 114001
  - **LDMEs from CDF data, no global fit.**
- **In general largest uncertainties from unknown polarizations (affecting detector acceptances)**
  - **The measurements of polarization at LHC will improve the uncertainty.**



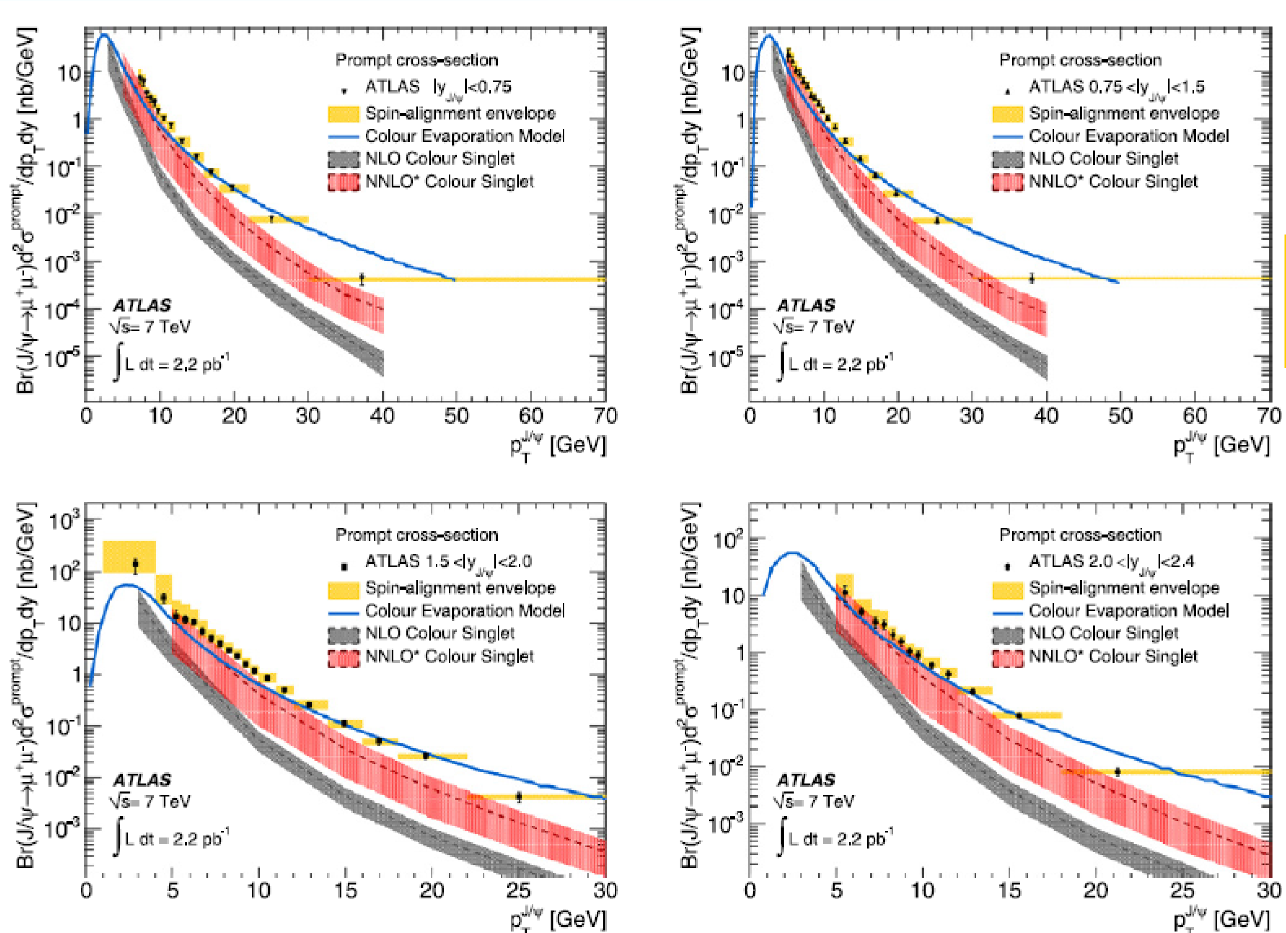
LHCb



CMS

Prompt J/ψ cross-section

- **CEM:**
  - **wrong shape**
  - **ok-ish scale**
- **CSM@NLO:**
  - **ok-ish shape**
  - **wrong scale**
- **CSM@NNLO*:**
  - **ok-ish shape and scale!**



ATLAS

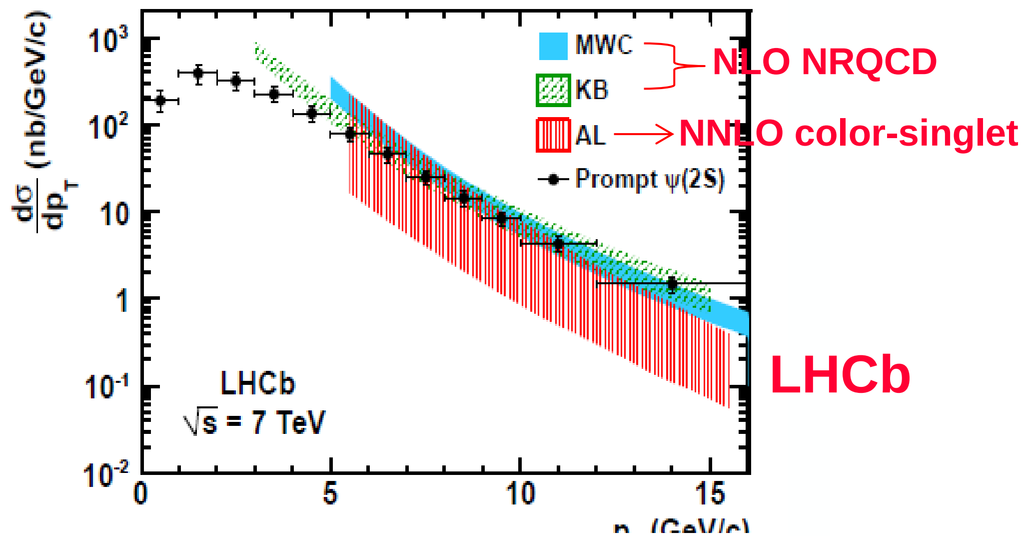
Polarization uncertainty

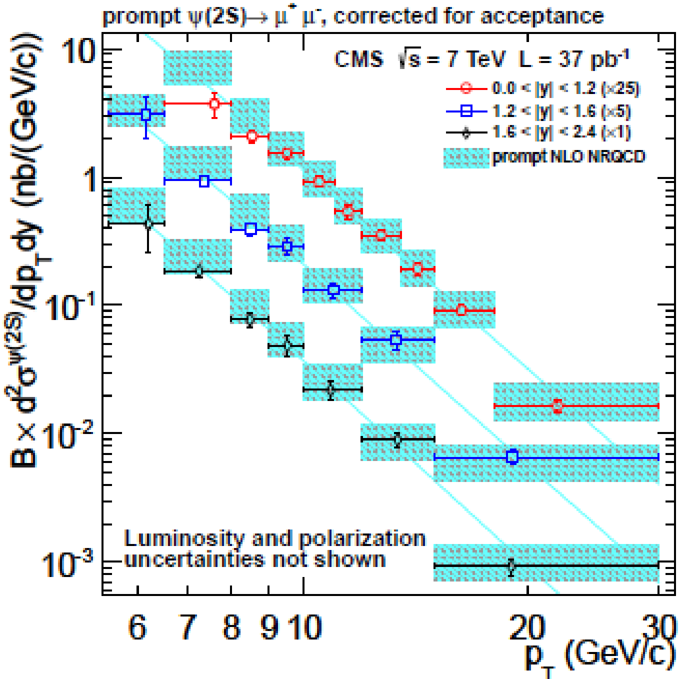
- **Prompt J/ψ production cross-section as a function of J/ψ transverse momentum in the four rapidity bins.**
- **Comparison with NLO and NNLO* Color Singlet calculations, and the Color Evaporation Model.**

Prompt ψ(2S) cross-section

- **The differential cross-section of prompt ψ(2S) in LHCb and CMS**

- **Good agreement with NLO NRQCD calculations. In LHCb plot:**
  - **MWC :**
    Yan-Qing Ma, Kai Wang, Kuang-Ta Chao, Phys. Rev. D84 (2011) 114001
  - **KB:**
    B. Kniehl and M. Butensch
    Phys. Rev. Lett. 106 (2011) 022003
  - **AL:**
    P. Artoisenet Phys. Rev. Lett. 101 (2008) 152001
    J.-P. Lansberg, Eur. Phys. J. C61 (2009) 693

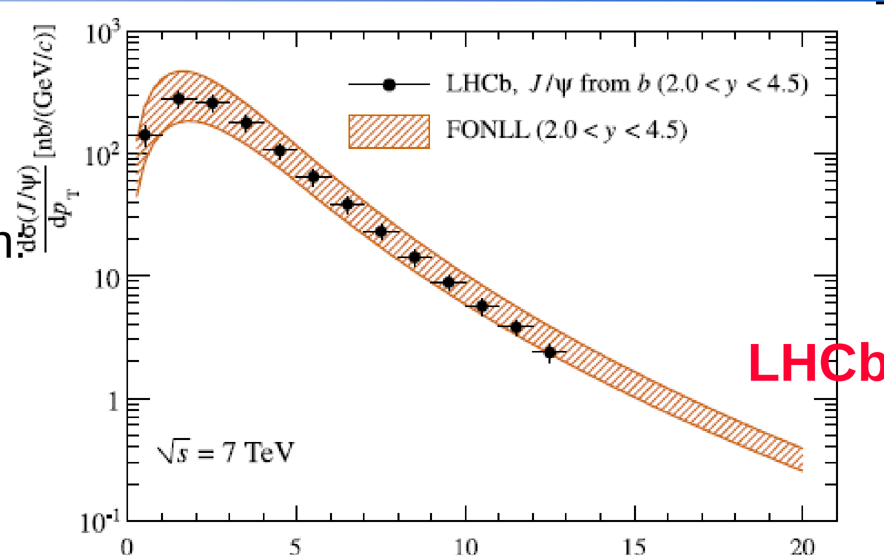


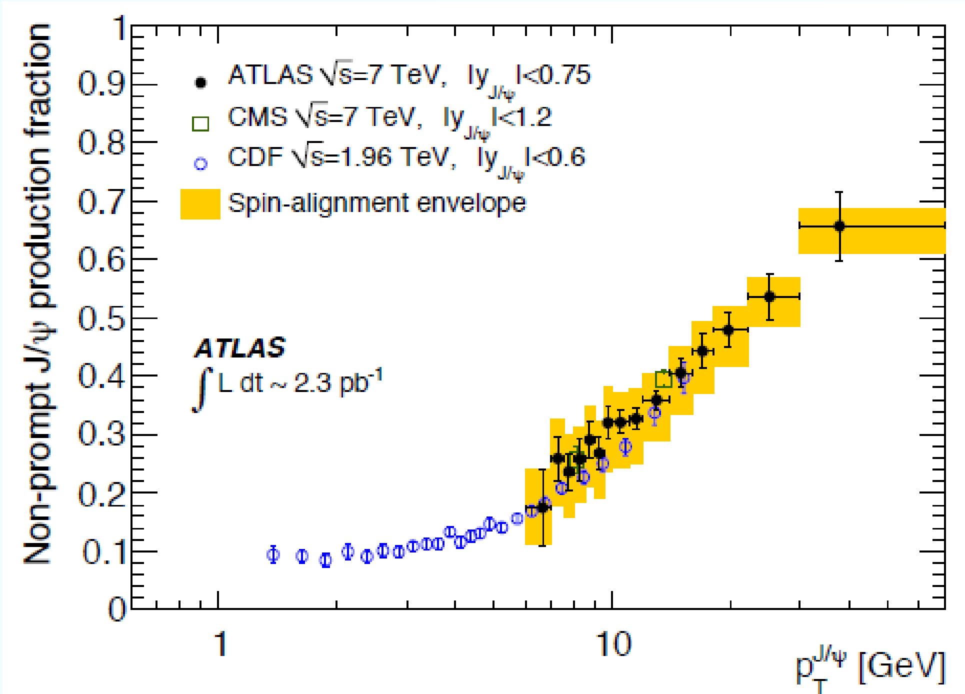


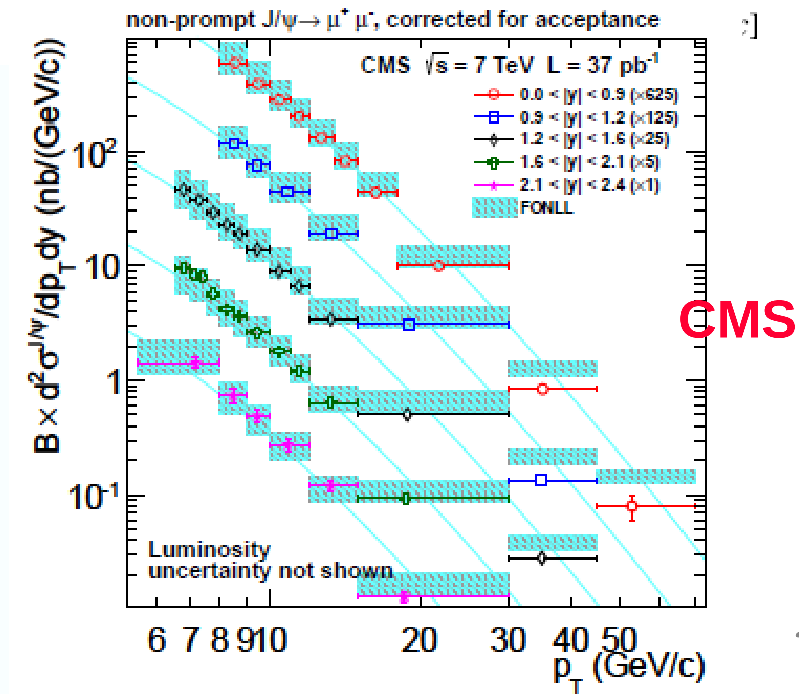
Non-prompt J/ψ cross-section

- The differential cross-section of non-prompt J/ψ in LHCb, CMS and ATLAS(next slide).
  - Good agreement with prediction of bb production cross-section in FONLL approach.

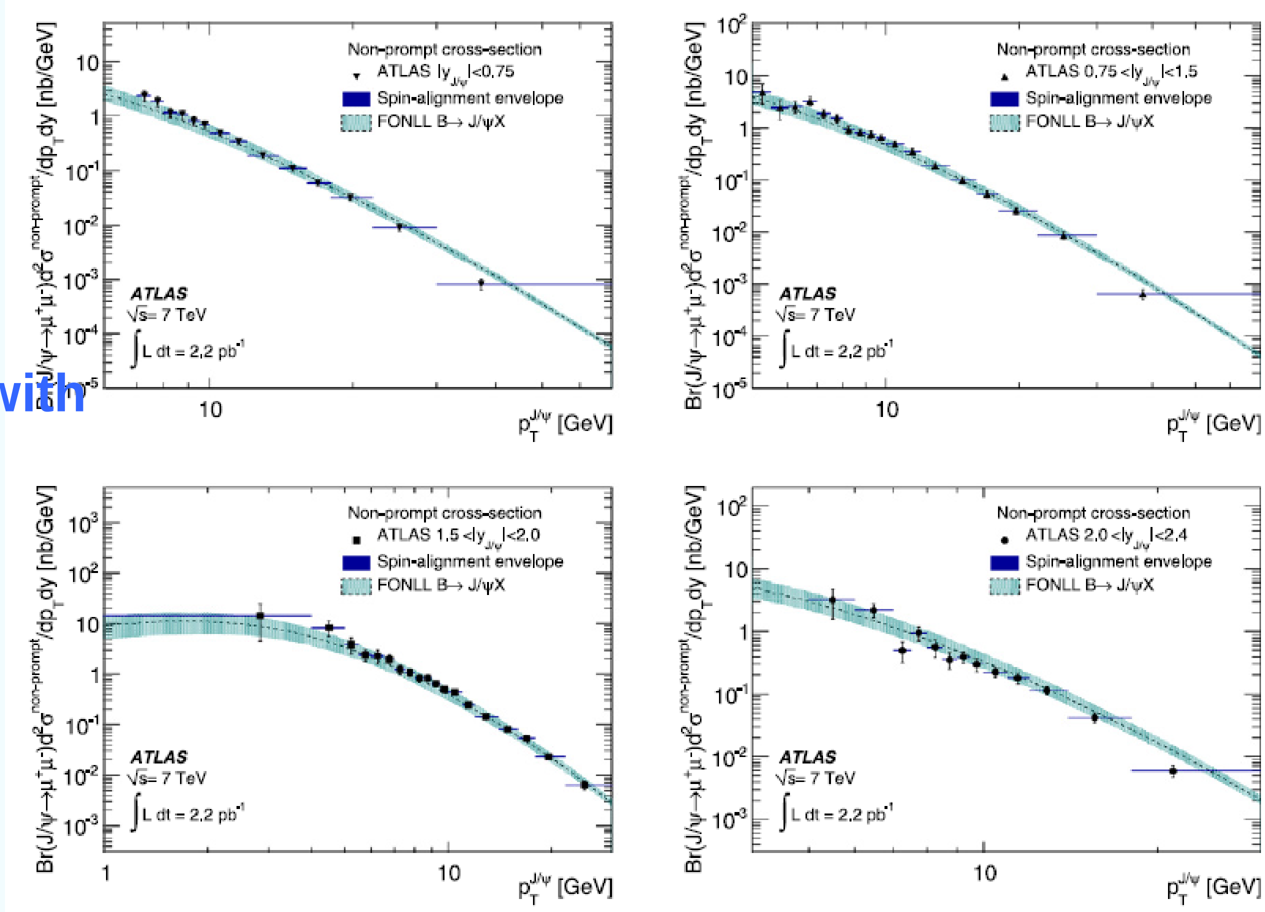
    M.Cacciari et al. JHEP 0103 (2001) 006
- Fraction of non-prompt as a function of p_T in CDF, CMS and ATLAS.
  - Seems to be energy independent.







Non-prompt J/ψ cross-section



Good agreement with theory prediction.

ATLAS

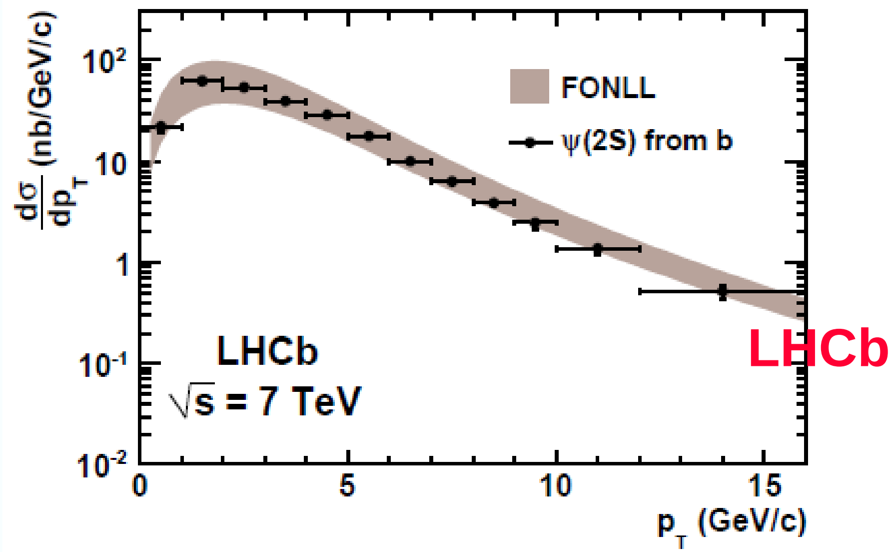
Polarization uncertainty

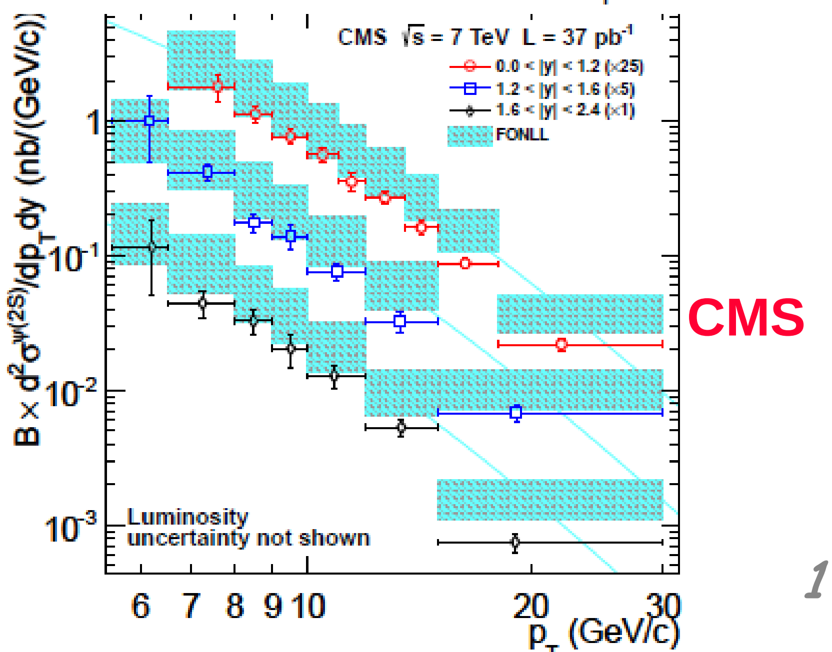
- **Non-prompt J/ψ production cross-section as a function of J/ψ p_T.**
- **Comparison with bb production cross-section in FONLL approach.**

Non-prompt ψ(2S) cross-section

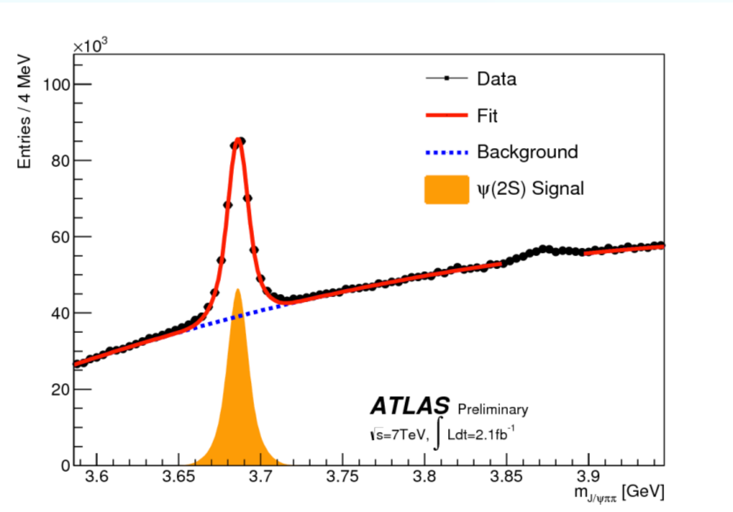
- **The differential cross-section of non-prompt ψ(2S) in LHCb and CMS**

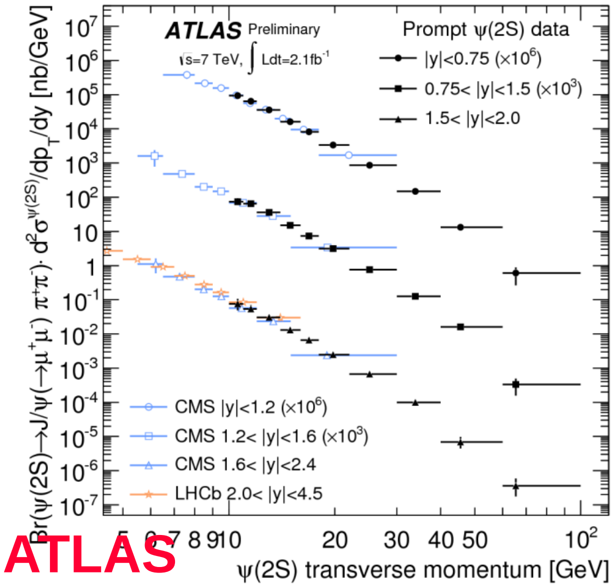
- **Good agreement with prediction of bb production cross-section in FONLL approach.**

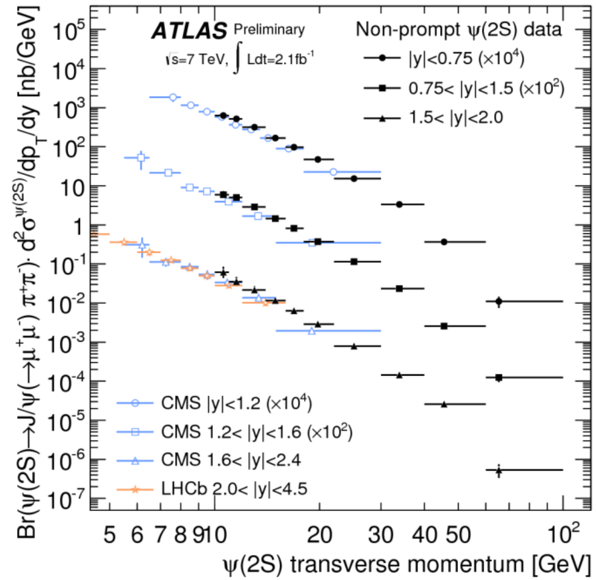




$\psi(2S) \rightarrow J/\psi\pi^+\pi^-$ production cross section in ATLAS

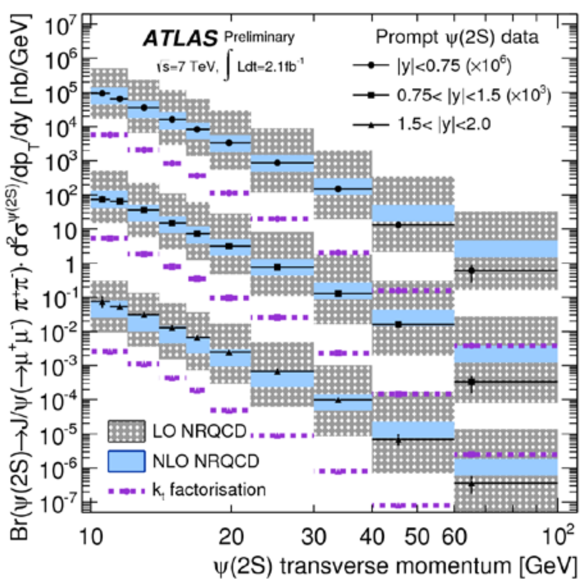


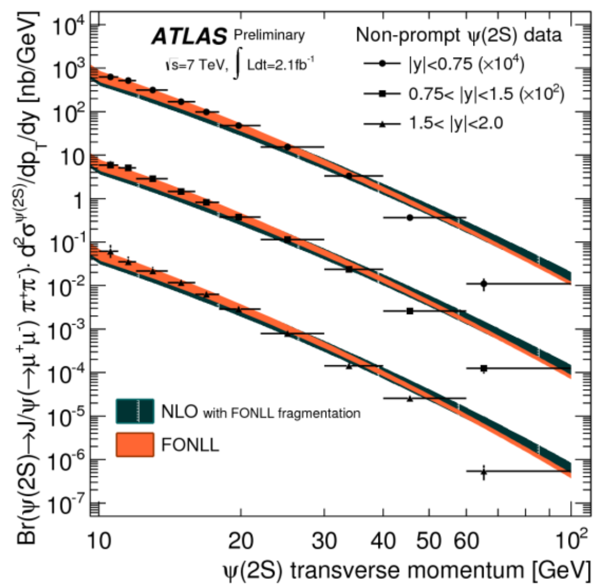




ATLAS

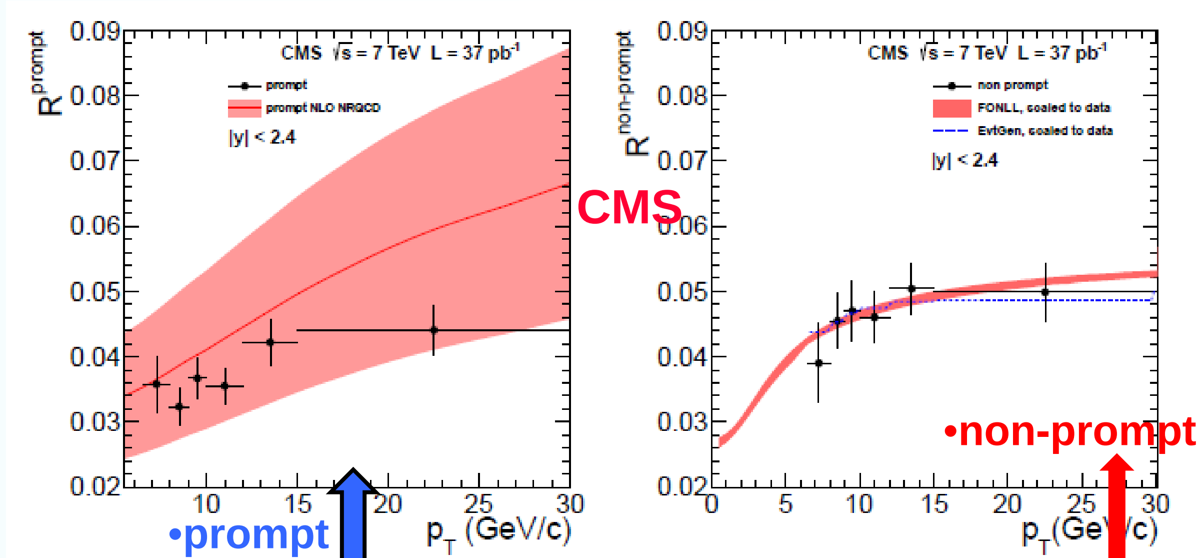
- **2.1 fb^{-1} at 7 TeV. Prompt and non-prompt.**
- **p_T: 10-100 GeV; |y|<2.0**
- **Compared to LHCb and CMS.**
- **Compared to theory calculations.**





σ(ψ(2S))/ σ(J/ψ)

- The ψ(2S) to J/ψ differential cross-section ratio for prompt and non-prompt production.
  - No significant dependence of R on rapidity is observed.
  - NRQCD prediction for prompt.
  - FONLL approach for non-prompt.



•Measurement of inclusive B→ψ(2S)+X branching ratio :

CMS:

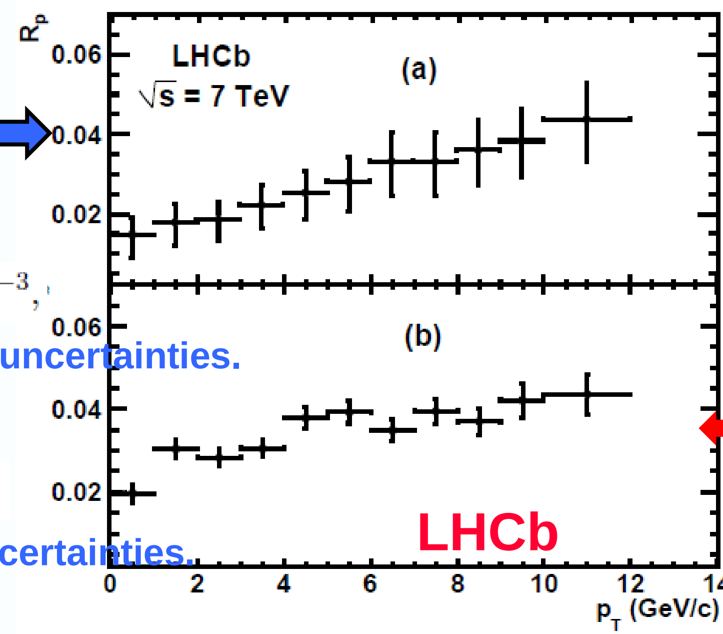
$$\mathcal{B}(\mathrm{B} \to \psi(2\mathrm{S})X) = (3.08 \pm 0.12\,(\mathrm{stat.{+}syst.}) \pm 0.13\,(\mathrm{theor.}) \pm 0.42\,(\mathcal{B}_{\mathrm{PDG}})) \times 10^{-3},$$

0.42(B_{PDG}): sum of the B(b→J/ψX), B(J/ψ→$\mu^+\mu^-$) and B(ψ(2S)→ $\mu^+\mu^-$) uncertainties.

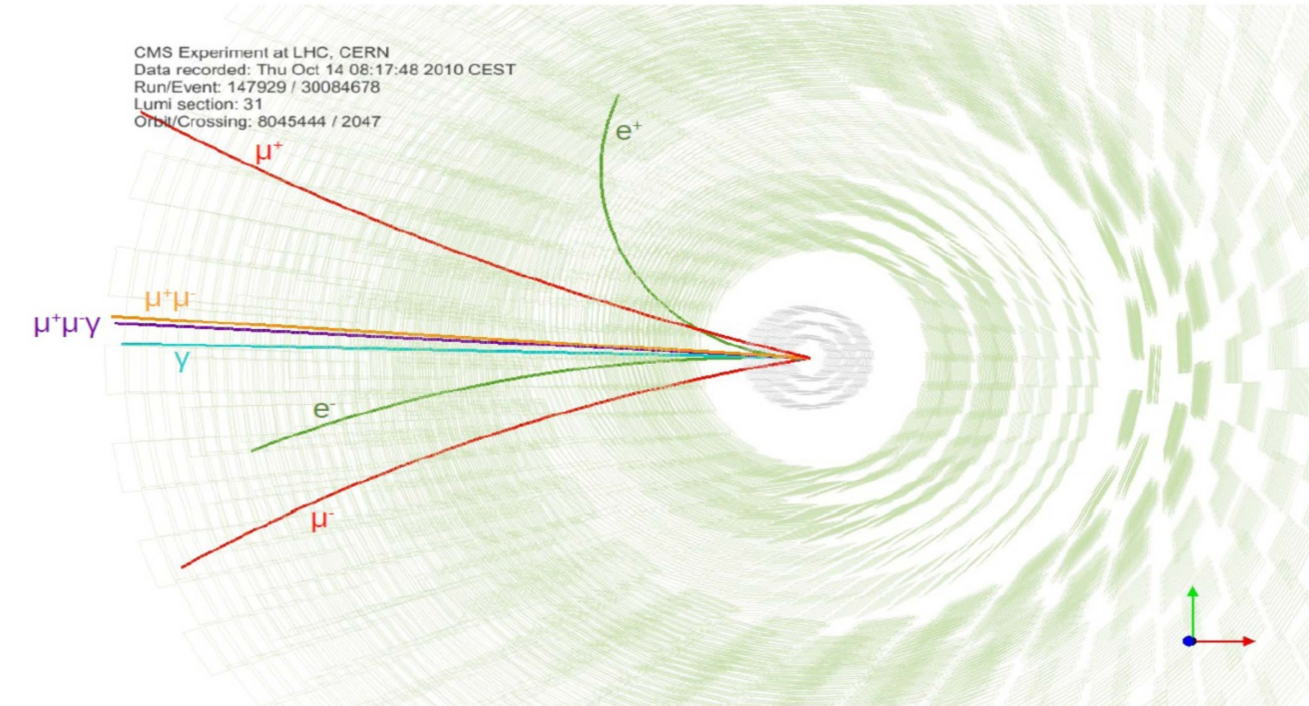
LHCb:

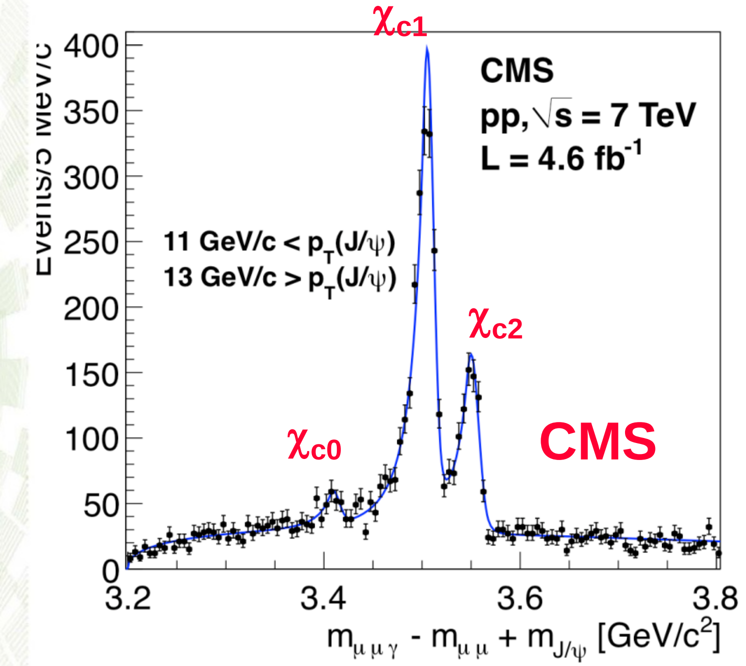
$$\mathcal{B}(b \to \psi(2S)X) = (2.73 \pm 0.06\ (\mathrm{stat}) \pm 0.16\ (\mathrm{syst}) \pm 0.24\ (\mathrm{BF})) \times 10^{-3},$$

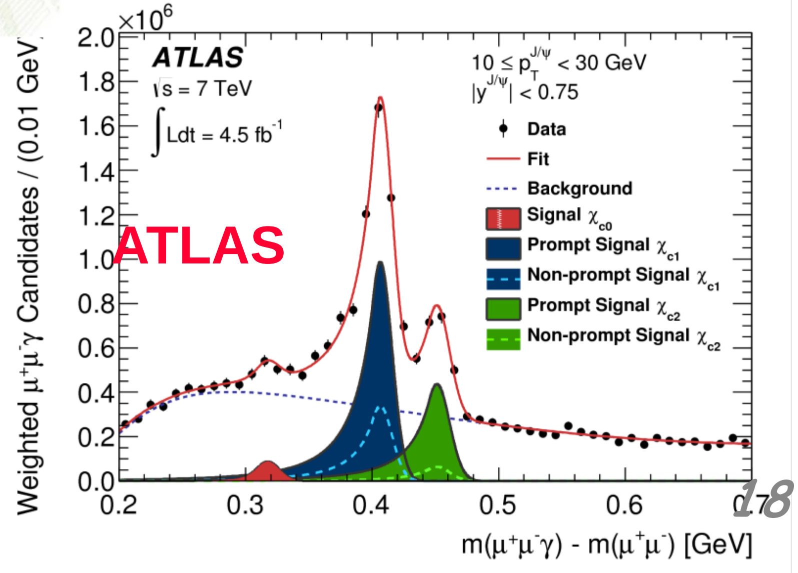
0.24(BF): sum of the B(b→J/ψX), B(J/ψ→$\mu^+\mu^-$) and B(ψ(2S)→e^+e^-) uncertainties.



P-wave states

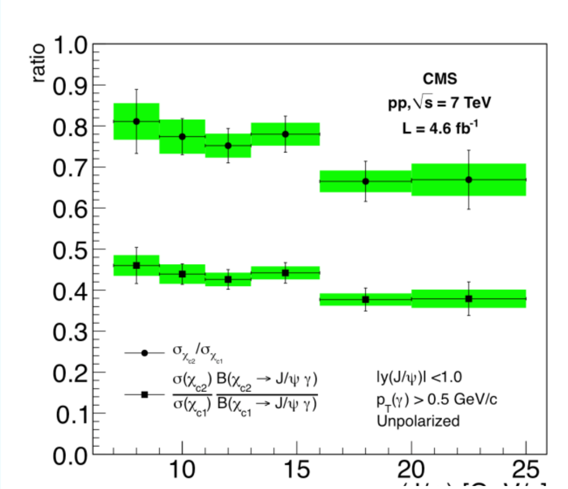


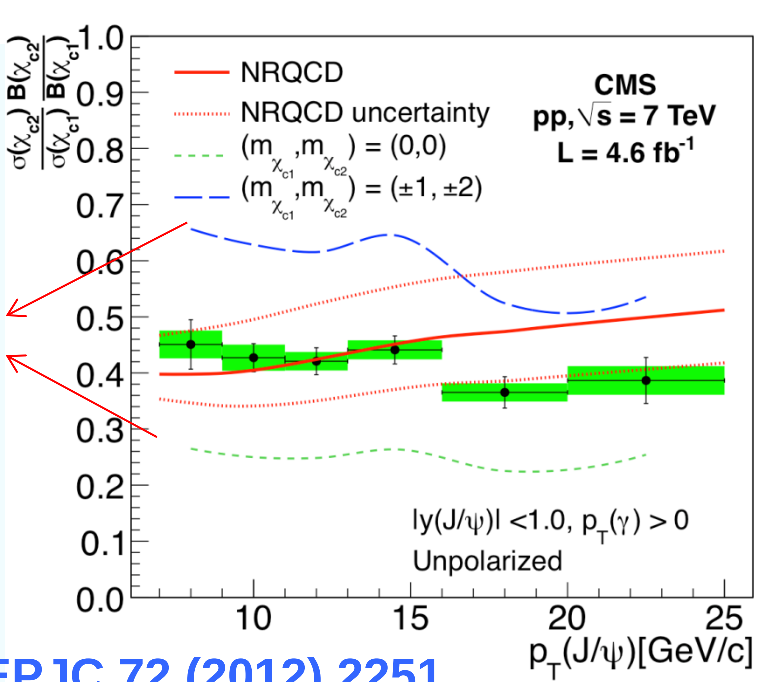




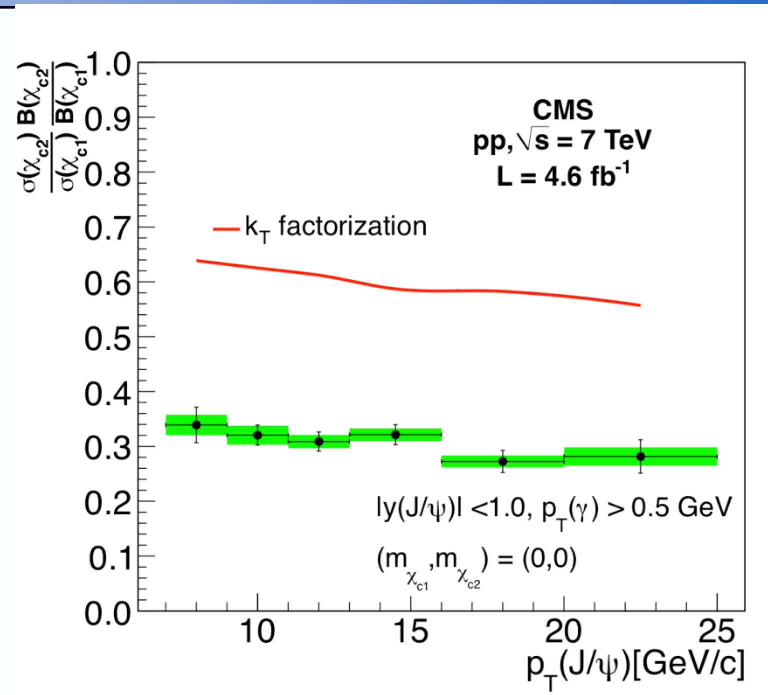
- **Excellent resolution (~10 MeV/c^2) for converted photons in CMS and ATLAS**
  - **χ_{c1} and χ_{c2} peaks resolved.**
  - **Small bump for χ_{c0}, but not measured.**

$\chi_{c1,c2}$ production in CMS





Extreme polarization



- **Compatible with NRQCD, not with k_T factorization.**
- **Compatible with ATLAS (next slide).**

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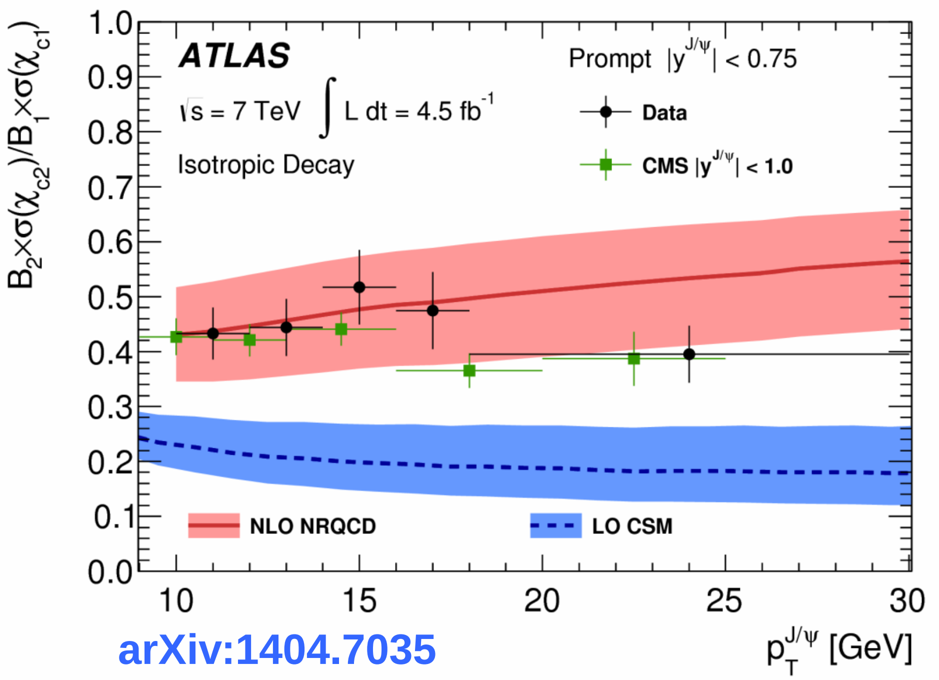
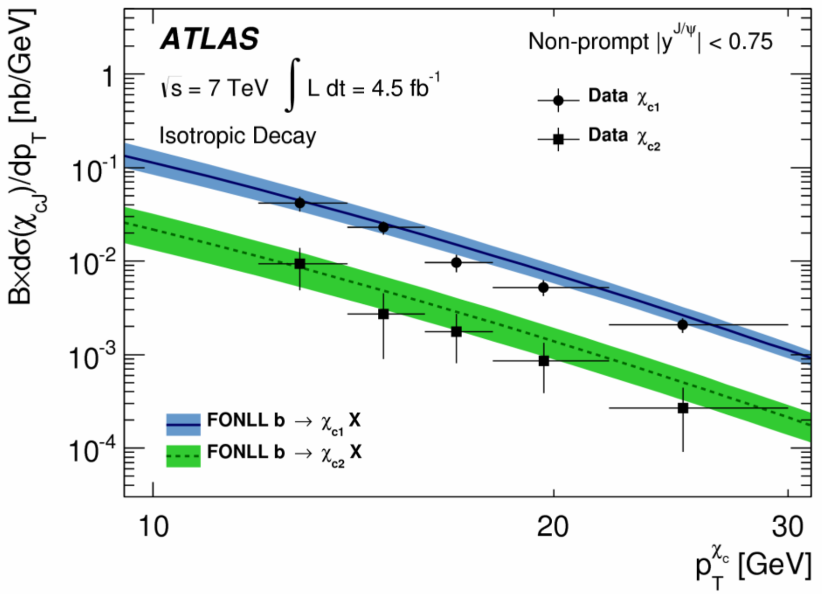
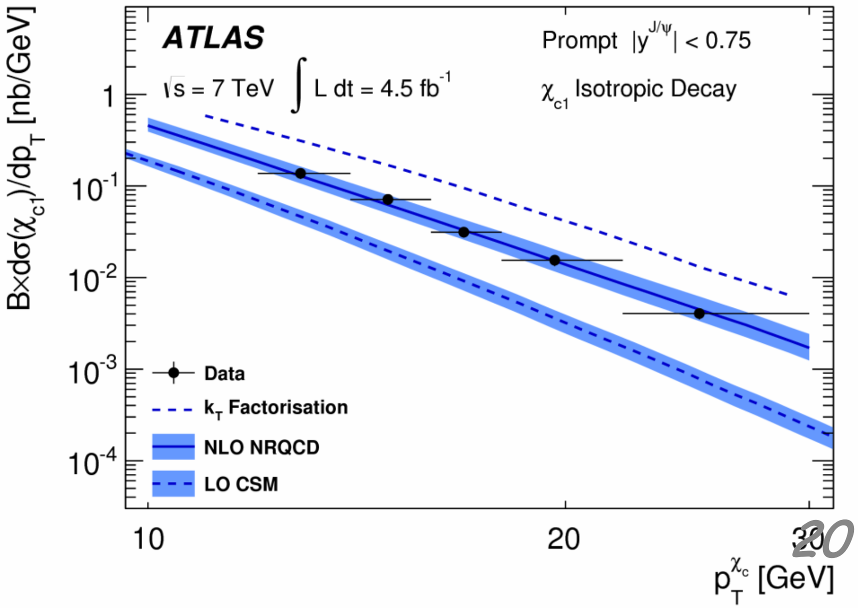
$\chi_{c1,c2}$ production in ATLAS



arXiv:1404.7035

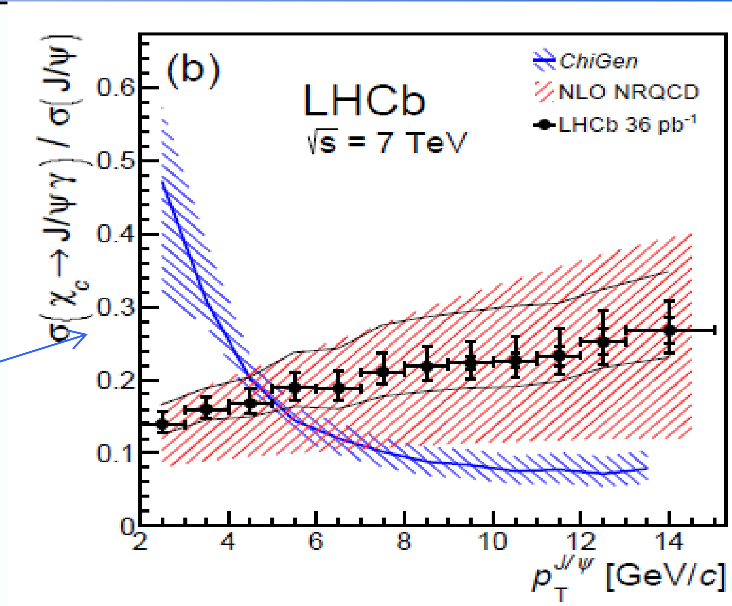




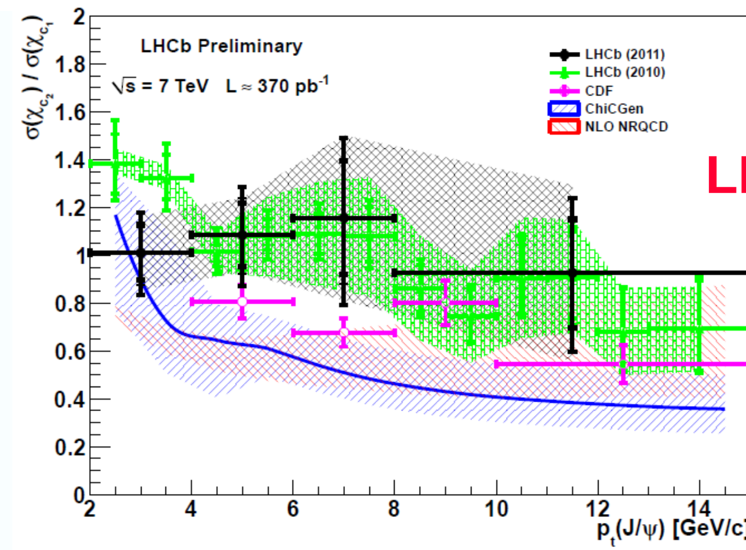
- Prompt X compatible with NLO NRQCD, but not with kT factorization and LO CSM.
- Ratio of prompt compared to CMS.
- Non-prompt X compatible with FONLL.

$\chi_{c1,c2}$ production in LHCb

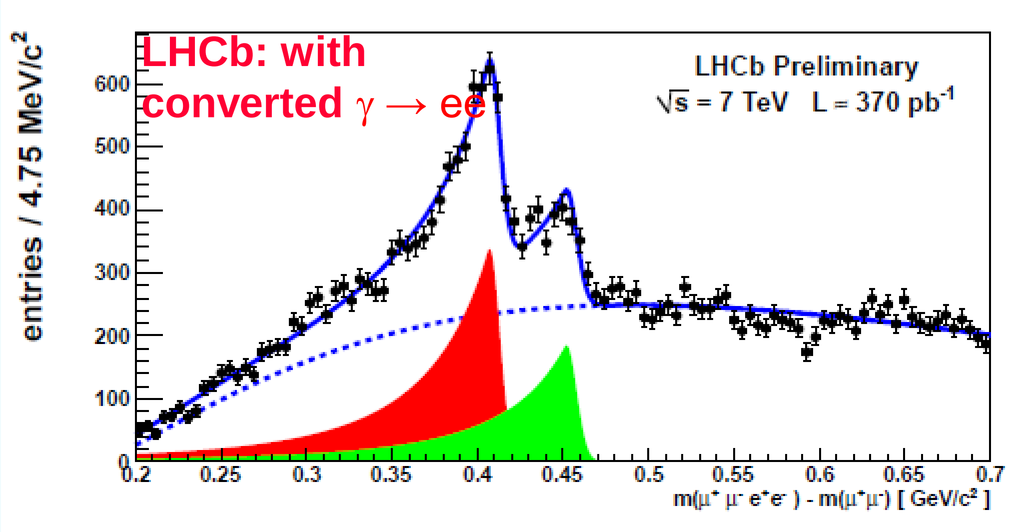
- **LHCb measured χ_c production using the $\chi_c \rightarrow J/\psi\ \gamma$ channel with both converted and non-converted photons:**
  - **$\sigma(\chi_c)/\sigma(J/\psi)$ clearly favors NRQCD over simple LO Color Singlet Model (ChiCGen in the plots)**
  - **The $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ also agrees with the predicted behaviour**



LHCb



LHCb



Charmonium polarization

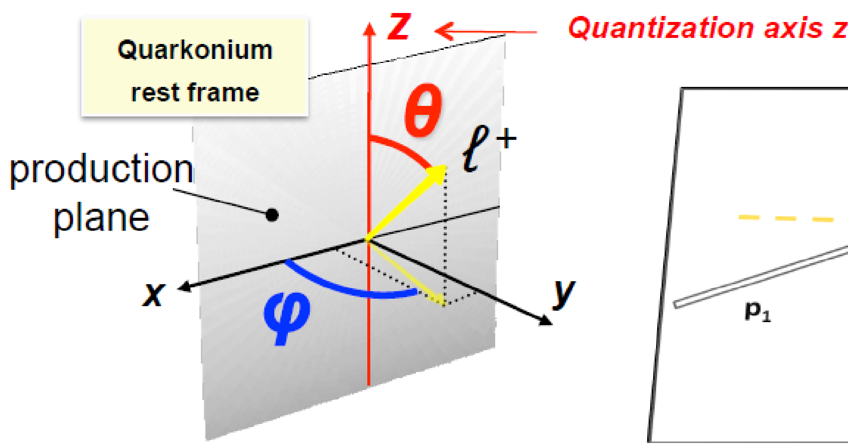
- Polarization is measured through the average angular decay distribution:

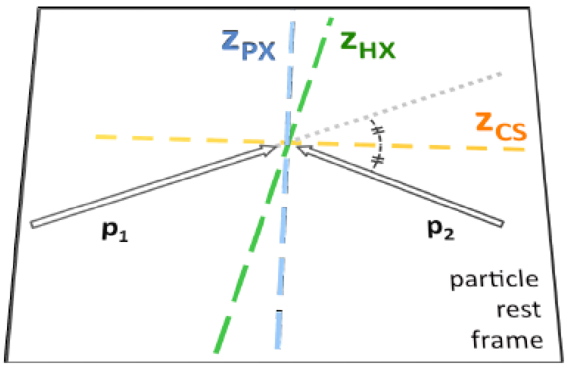
$$W(\cos\vartheta, \varphi|\vec{\lambda}) = \frac{3/(4\pi)}{(3+\lambda_\vartheta)}(1 + \lambda_\vartheta \cos^2\vartheta + \lambda_\varphi \sin^2\vartheta \cos 2\varphi + \lambda_{\vartheta\varphi} \sin 2\vartheta \cos\varphi)$$

θ: polar angle

φ: azimuthal angle

λ_θ, λ_φ, $\lambda_{\theta\varphi}$ are the polarization parameters.



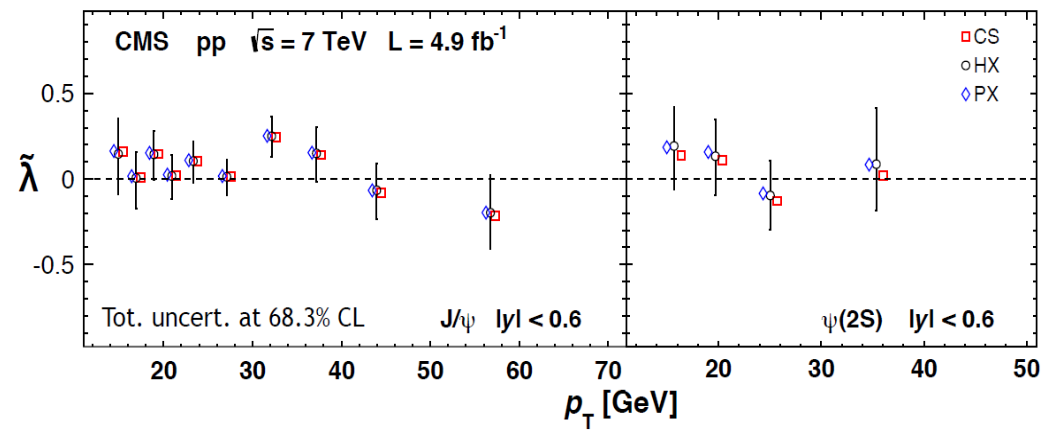


- CMS measured λ_θ, λ_φ, $\lambda_{\theta\varphi}$ and the frame invariant parameter $\tilde{\lambda}$

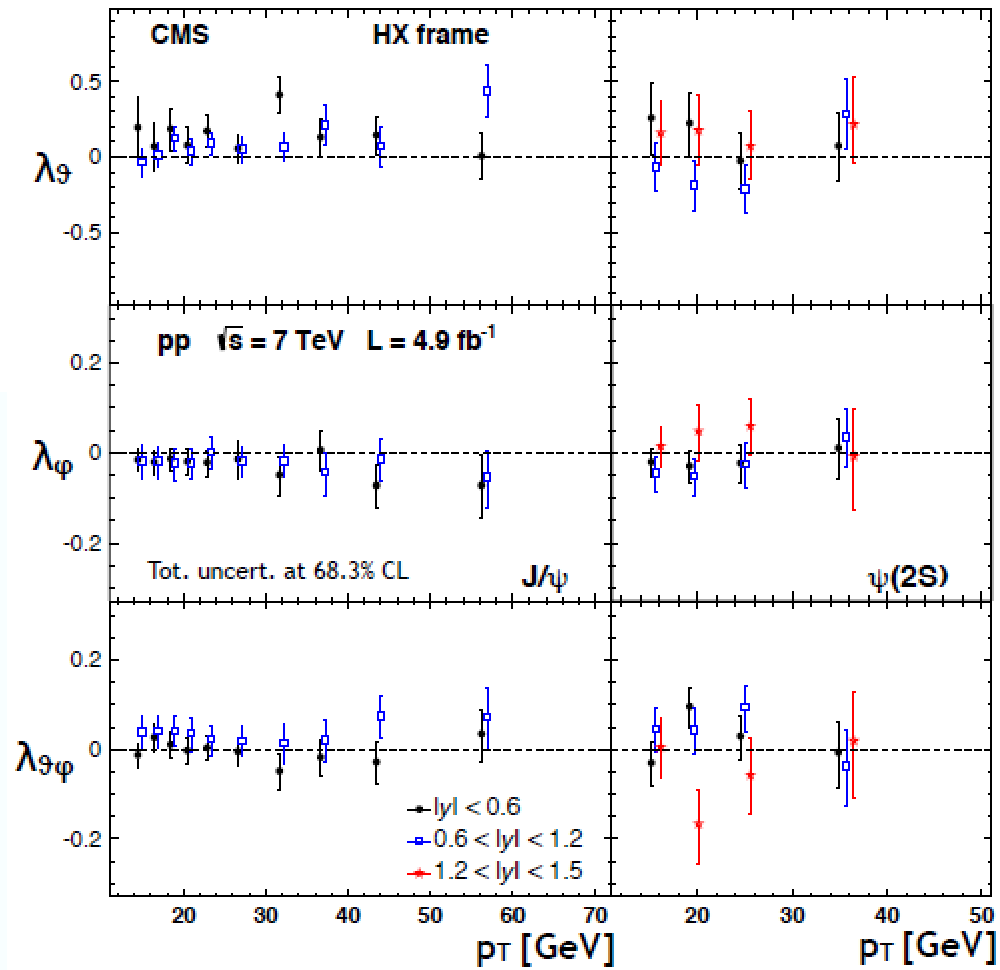
$$\tilde{\lambda} = \frac{\lambda_\theta + 3\lambda_\varphi}{1 - \lambda_\varphi}$$

- Center-of-mass helicity axis (HX): Z_{HX} = direction of quarkonium momentum.
- Collins-Soper axis (CS) : Z_{CS} = direction of relative velocity of colliding particles.
- Perpendicular helicity (PX) : $Z_{PX} \perp Z_{CS}$

Prompt J/ψ and ψ(2S) polarization, CMS



- Good agreement between the $\tilde{\lambda}$ parameters in the three reference frames shows that the results are consistent.
- ψ(2S) is not affected by feed-down decays from higher states.
- No sign of strong polarization.



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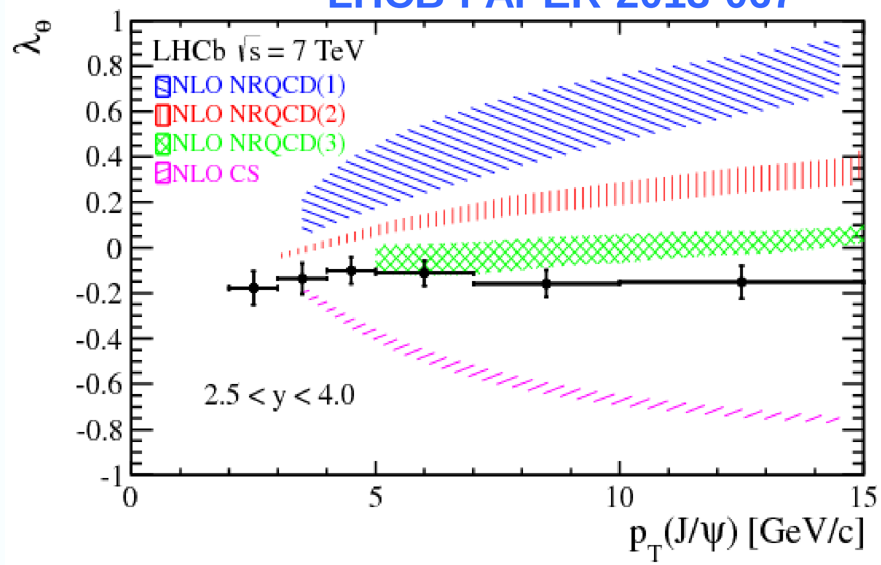
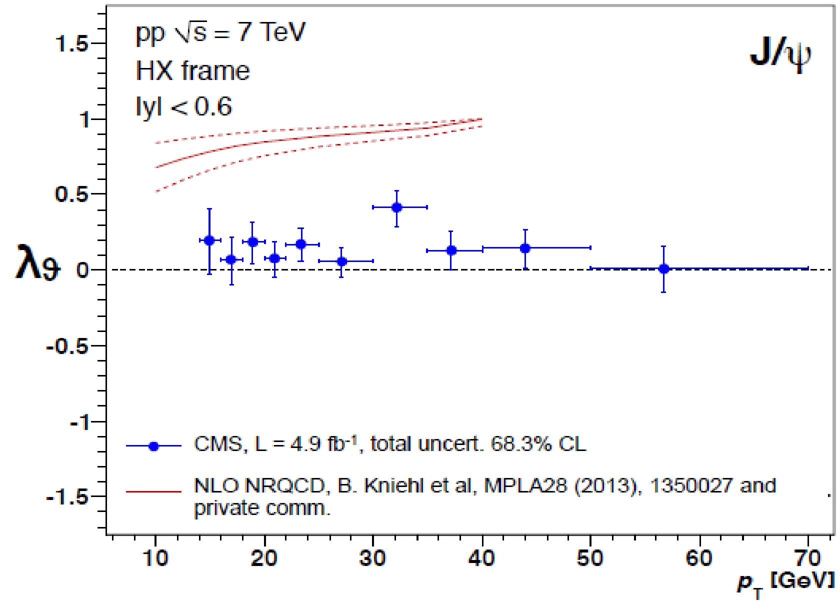
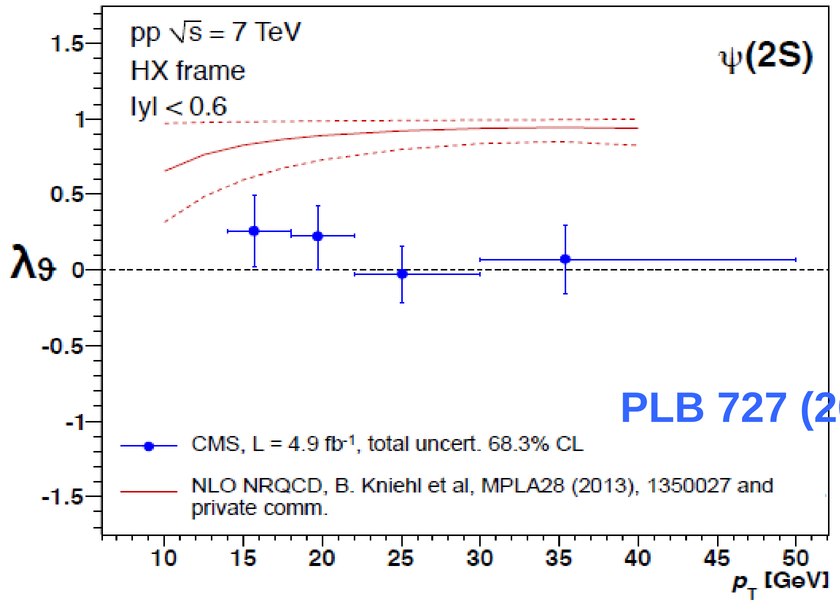
Comparison to NRQCD, CMS, LHCb

- Calculations use a global fit of color octet matrix elements to photo- as well as hadro-production data, excluding polarization results.
- NLO NRQCD calculations fail to describe CMS results.
- Theory predictions didn't consider feed-down decays in J/ψ, while ψ(2S) result can be directly compared to theory.

LHCB-PAPER-2013-067







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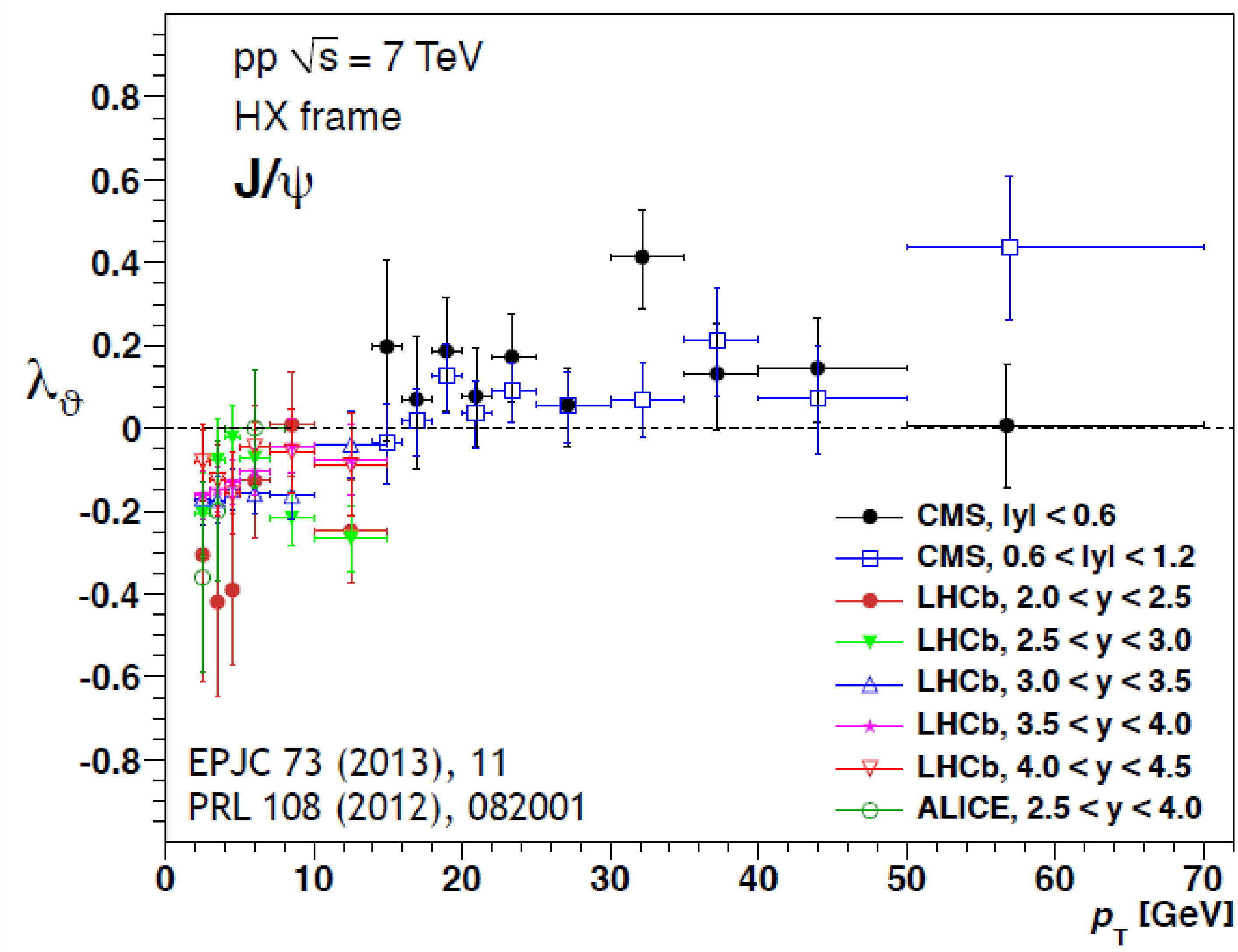
Comparison between LHC experiments

All LHC results are compatible with each other.



Double Parton Scattering

Double parton scattering (double chain process)

- x-section for two processes:

$$\sigma_{DPS} = \sigma_X \cdot \frac{\sigma_Y}{\sigma_{eff}}$$

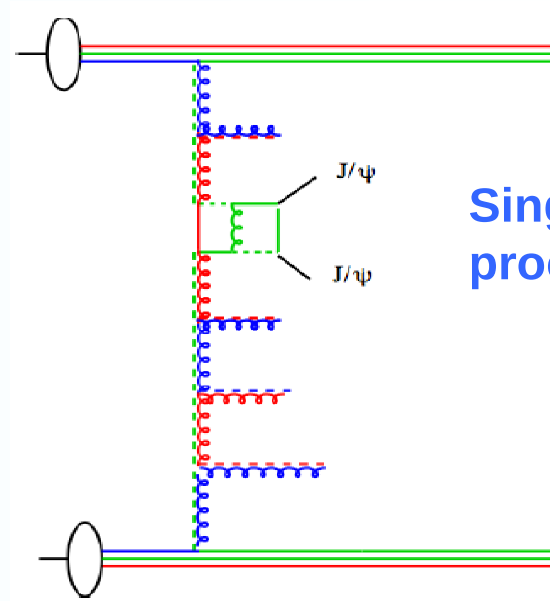
- In terms of probabilities:

$$P(X \wedge Y) = P(X) \times P(Y \mid X)$$

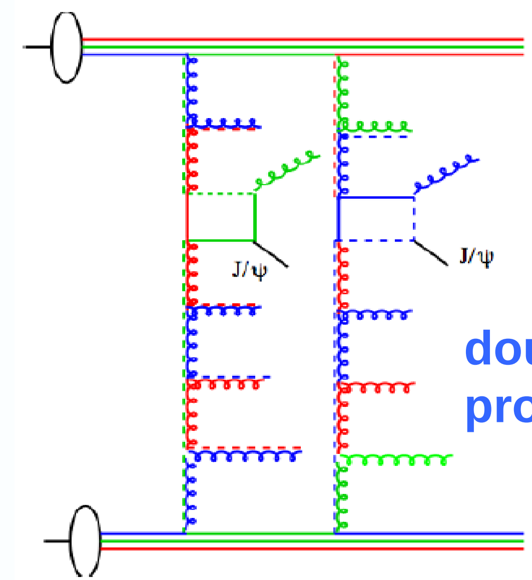
- No correlation: $\sigma_{eff} = \sigma_{inel}$
- Previous measurement of $\sigma_{eff} \sim 15\,mb$.

Special J/ψ+muon HLT trigger was developed for this study in CMS.

- Pile-up and non-prompt events have to be considered as background.

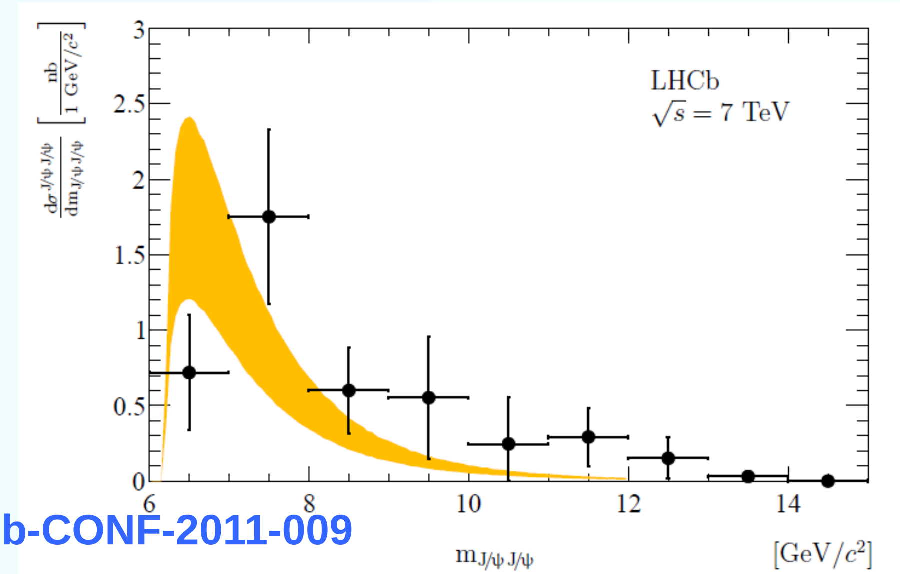


Single chain process



double chain process

Double J/ψ production, LHCb



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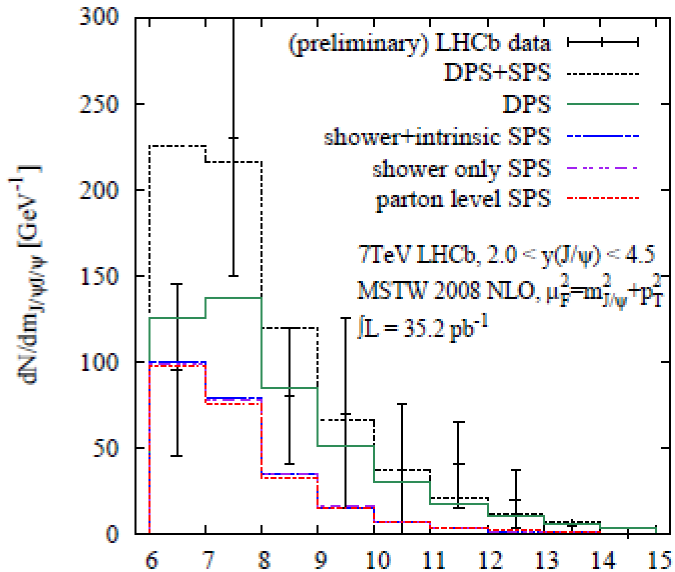
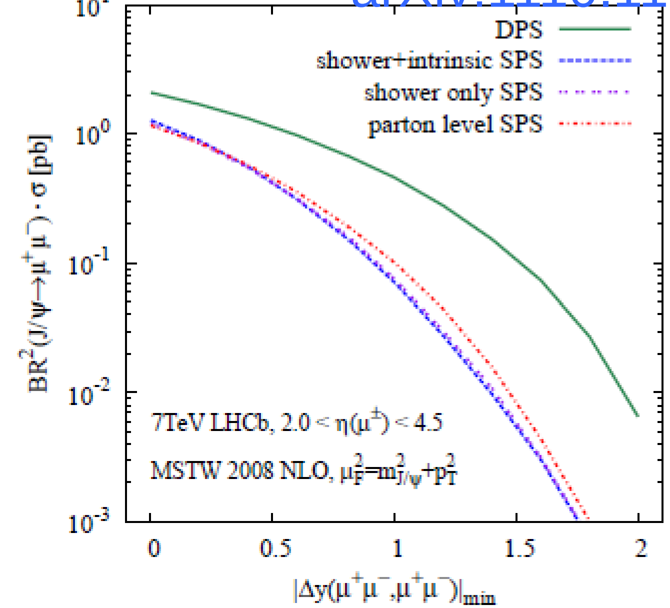


arXiv:1110.1174

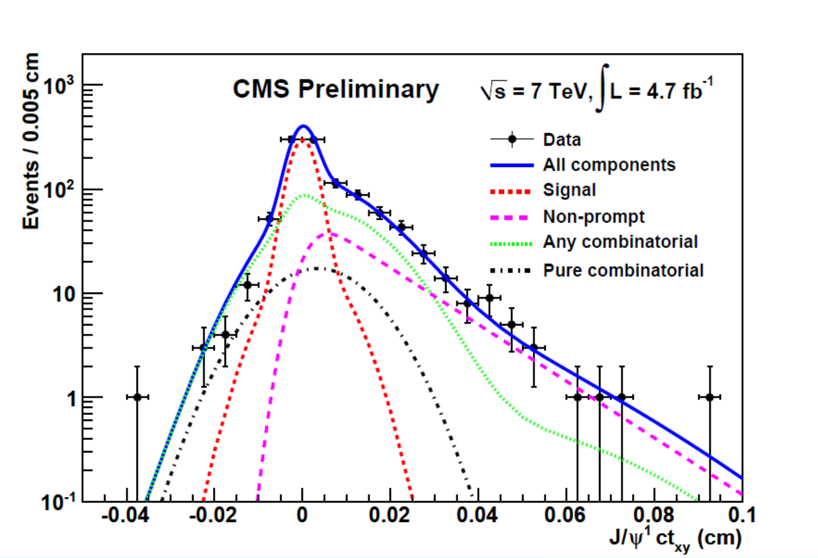


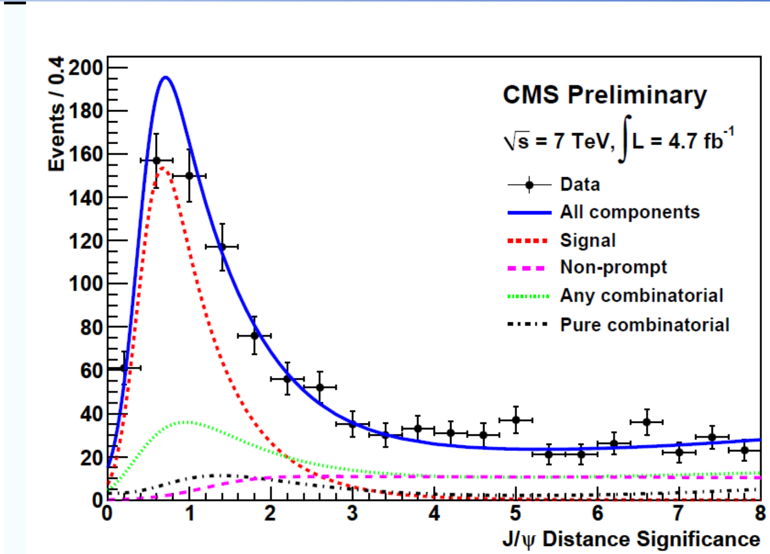
- 4-D likelihood fit: $m_{J/\psi 1}$, $m_{J/\psi 2}$, $\tau_{J/\psi 1}$, $\tau_{J/\psi 2}$
- LHCb measurement of double J/ψ production:

$$\sigma^{J/\psi J/\psi} = 5.1 \pm 1.0 \pm 1.1 \text{ nb}$$

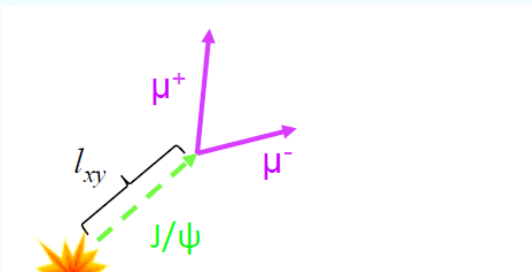
- The difference between two J/ψ's rapidity has more discrimination power.

Double J/ψ production, CMS

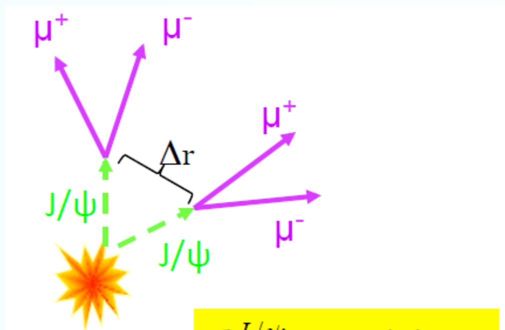




CMS-PAS-BPH-11-021



$$c\tau_{xy} = \frac{m}{|p_T|} \cdot l_{xy}$$



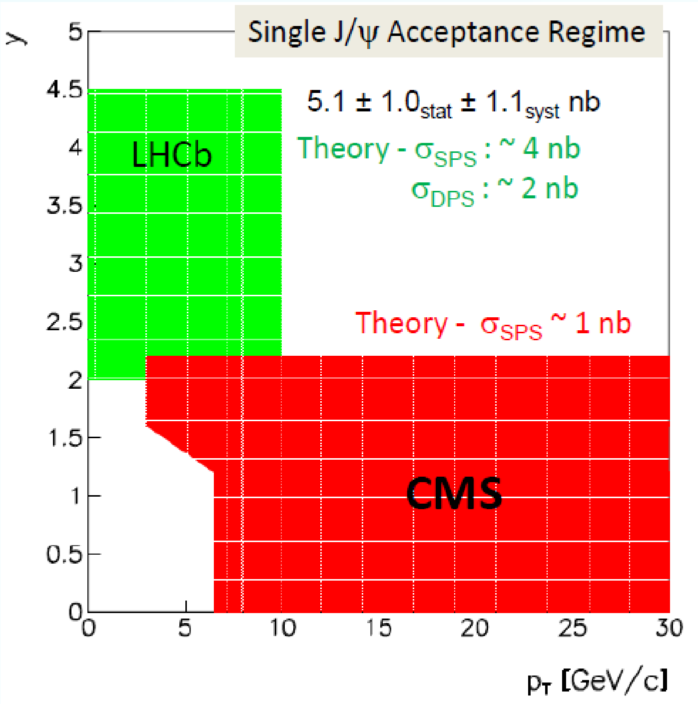
$$d^{J/\psi} = \Delta\vec{r} / \sigma_{\Delta\vec{r}}$$

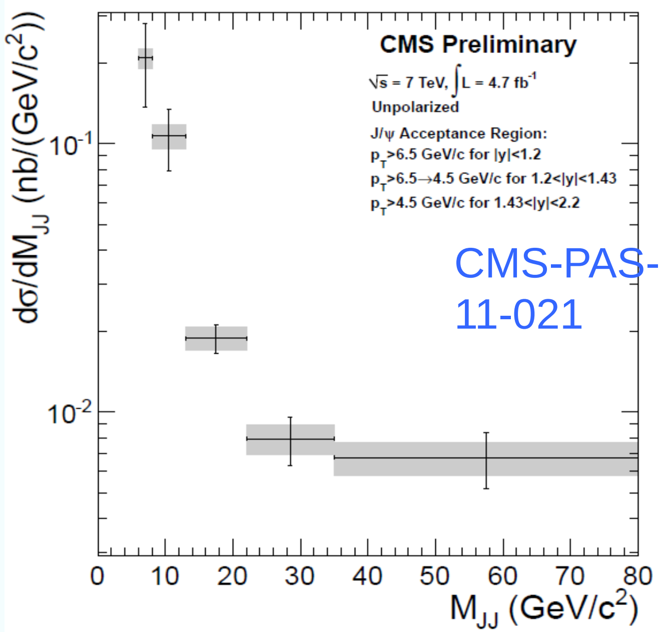
	Yield
Signal	446 ± 23
Non-prompt	182 ± 18
Total Combinatorial	415 ± 32

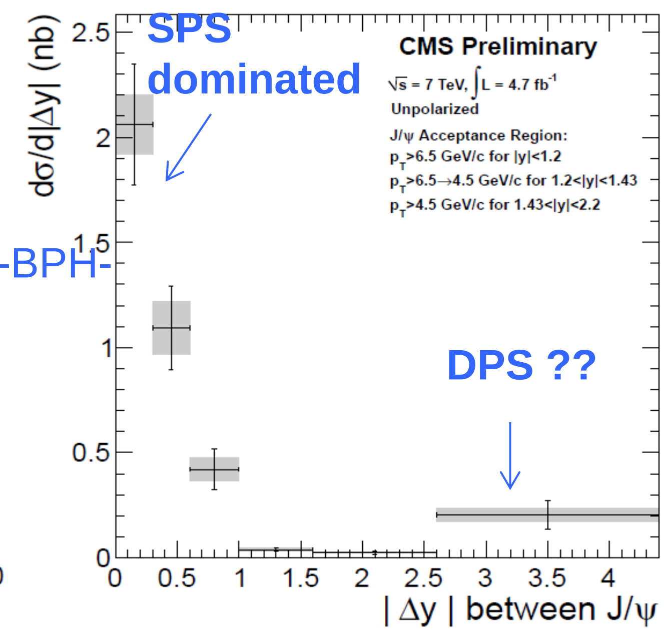
- Distance significance cut on <8. Remove most of the pile-up events.
- 4-D likelihood fit: $m_{J/\psi 1}$, $m_{J/\psi 2}$, $\tau_{J/\psi 1}$, distance significance.
- Efficiency from data-driven method.

Double J/ψ Production, CMS

- LHCb and CMS have very different acceptance region.





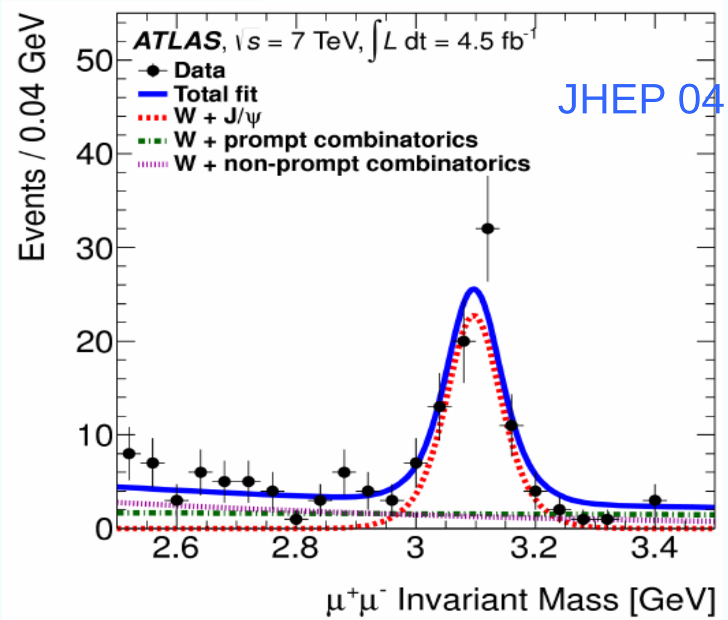


- **CMS measured the differential cross-section of prompt double J/ψ as functions of two J/ψ invariant mass and absolute rapidity difference.**
- **The total cross section assuming unpolarized prompt double production:**

$$\sigma = 1.49 \pm 0.07_{stat.} \pm 0.014_{syst.} \text{ nb}$$

- **Evidence of excess at |Δy|>2.6 which is predicted to have large Double Parton Scattering contribution.**

W + prompt J/ψ associated production, ATLAS



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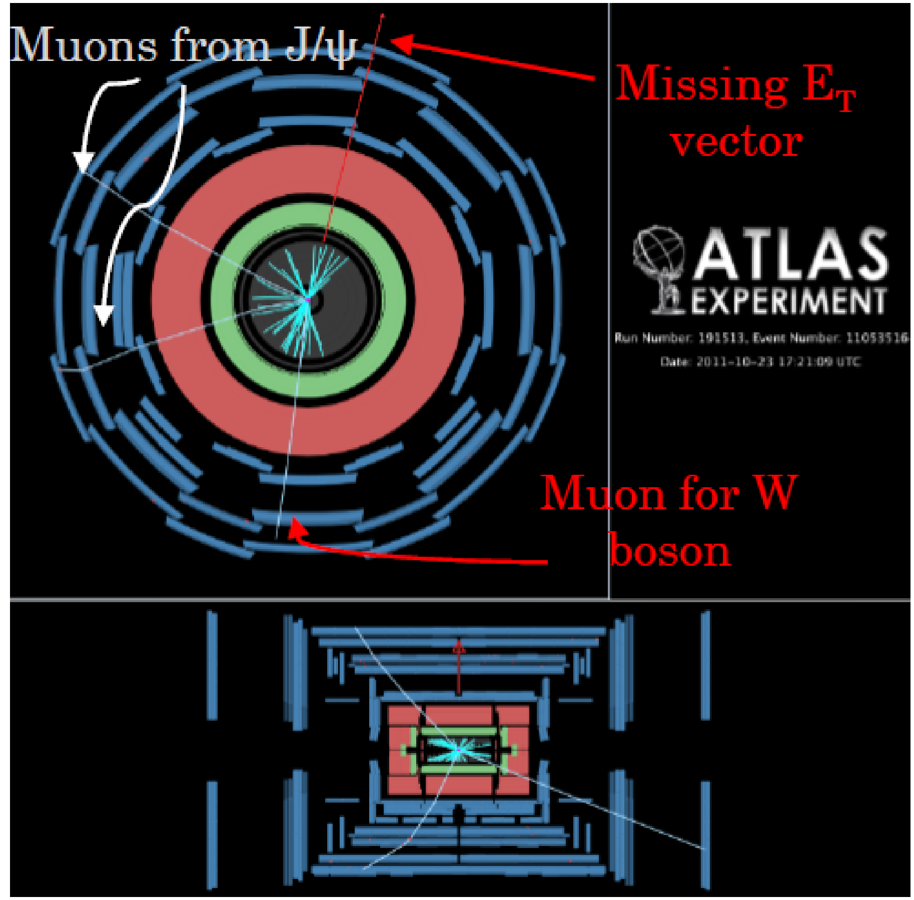
W + prompt J/ψ candidate



- First observation with 4.5 fb-1 at 7 TeV.
- Yield of $27.4^{+7.5}_{-6.5}$ events. Significance>5σ.
- Important test to distinguish between Color Singlet and Color Octet QCD predictions for quarkonium production.
- The production rate as a ratio to the inclusive W rate is measured, and the DPS contribution to the cross section is estimated.

W + prompt J/ψ associated production, ATLAS

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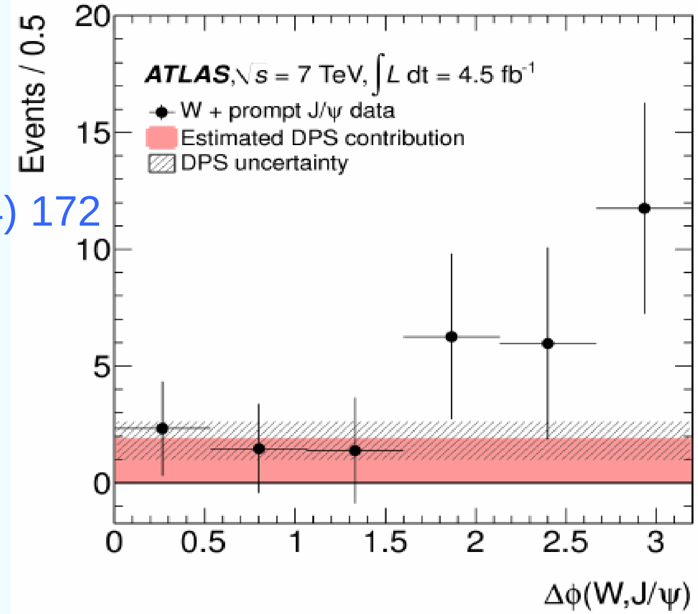
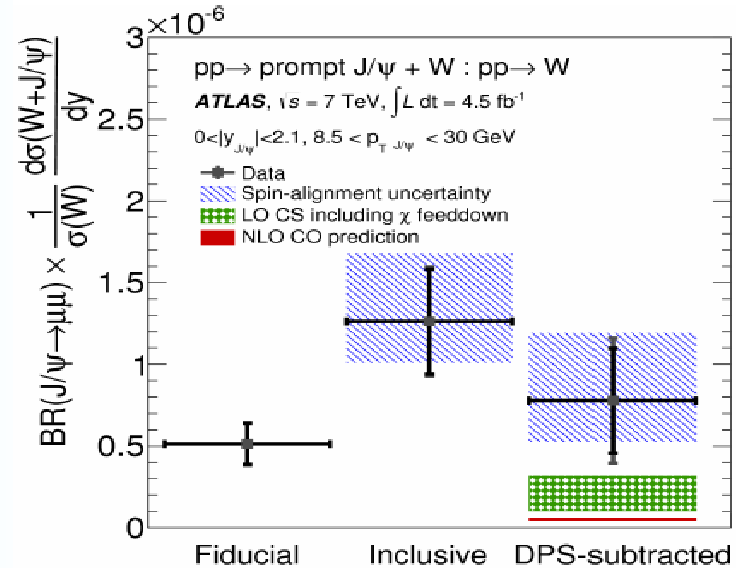
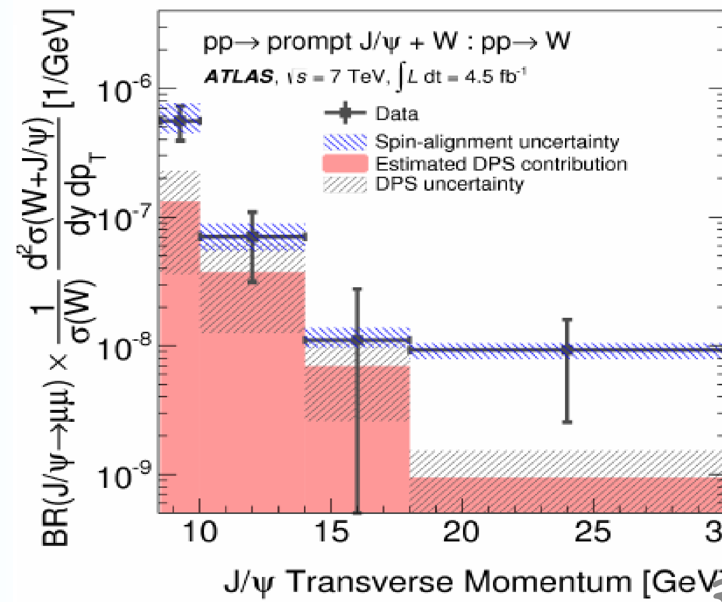






- Both DPS and SPS in data.
- Ratio to the inclusive W production rate:

$$R_{fid}(\psi) = (51\pm13_{stat.}\pm4_{syst.})\times10^{-8}$$

$$R_{incl}(\psi) = (126\pm39_{stat.}\pm9_{syst.}{}^{+41}_{-25})\times10^{-8}$$

$$R_{DPS\_sub}(\psi) = (78\pm32_{stat.}\pm22_{syst.}{}^{+41}_{-25})\times10^{-8}$$

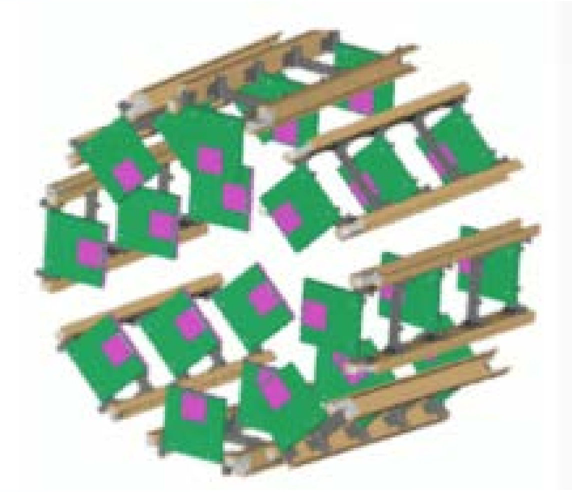
- Third error is due to the J/ψ spin alignment.
- Data suggest that SPS is the dominant at low J/ψ p_T.

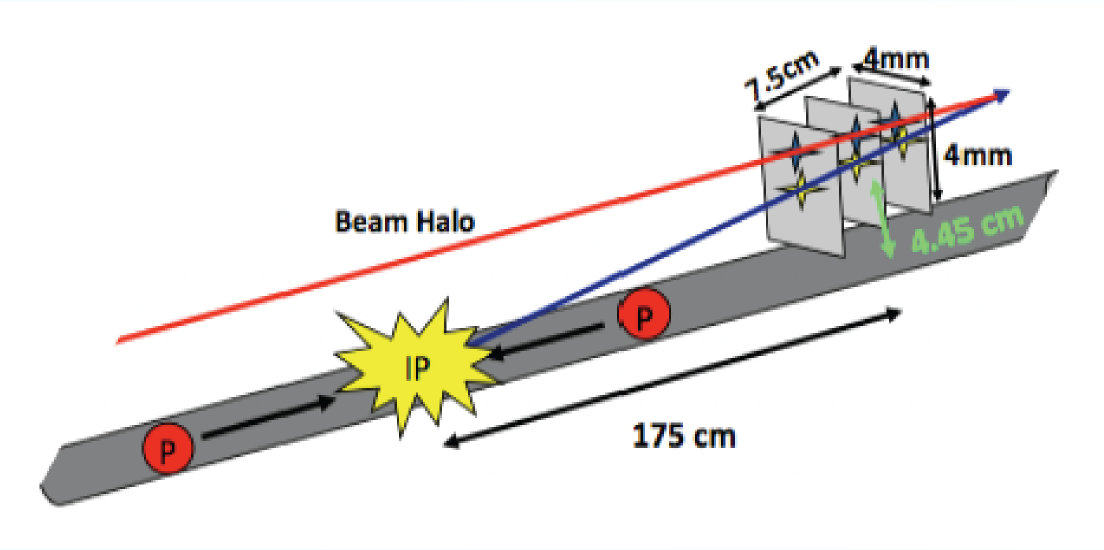
Pixel
Luminosity
Telescope

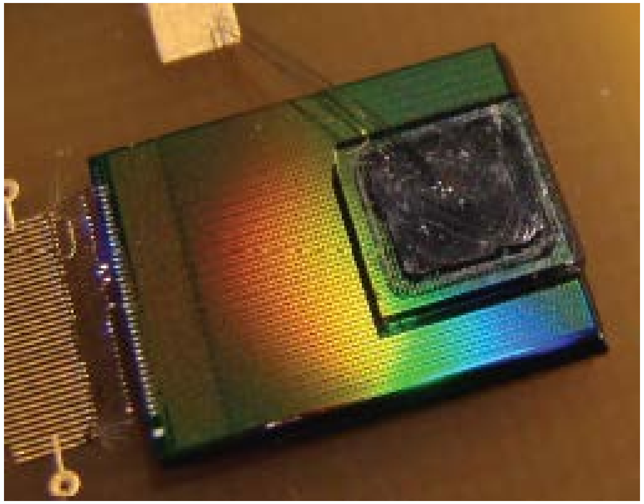
PLT Overview

Pixel luminosity Telescope

- Dedicated stand-alone luminosity monitor for CMS
- High precision bunch-by-bunch luminosity
  - ~1% uncertainty on relative bunch luminosity for $10^{34}/cm^2/s$
- Array of 3-plane telescopes each end of CMS
- Single-crystal diamond pixel sensors
- Measure bunch-by-bunch 3-fold coincidence rate
- Pixel readout for tracking and diagnostics..
  - Will allow online beamspot measurement.







PLT Design

- **From simulation expect**
  - **0.005 tracks per pp collision per telescope**

- **For 10^{34} $cm^{-2}s^{-1}$**
  - **1.6 tracks in PLT per bunch crossing**
  - **or >18000 tracks for each of 2835 filled bunches**

  ⇒ **1% statistical precision on relative bunch luminosity in < 1 second.**

- **Additionally, pixel tracking will allow online beamspot measurement.**

Why Diamond

Material properties	Silicon	Diamond
Band gap [eV]	1.12	5.45
Electron mobility [cm^2/Vs]	1450	2200
Hole mobility [cm^2/Vs]	500	1600
Saturation velocity [cm/s]	0.8*107	2*107
Breakdown field [V/m]	3*105	2.2*107
Resistivity [Ωcm]	2*105	>1013
Dielectric constant	11.9	5.7
Displacement energy [eV]	13-20	43
e-h creation energy [eV]	3.6	13
Ave e-h pairs per MIP per μm	89	36
Charge collection distance [μm]	Full	~250
Thermal conductivity [W/cm*K]	1.5	22

Low Ileakage, shot noise

Faster signal

Low capacitance, noise

High radiation hardness

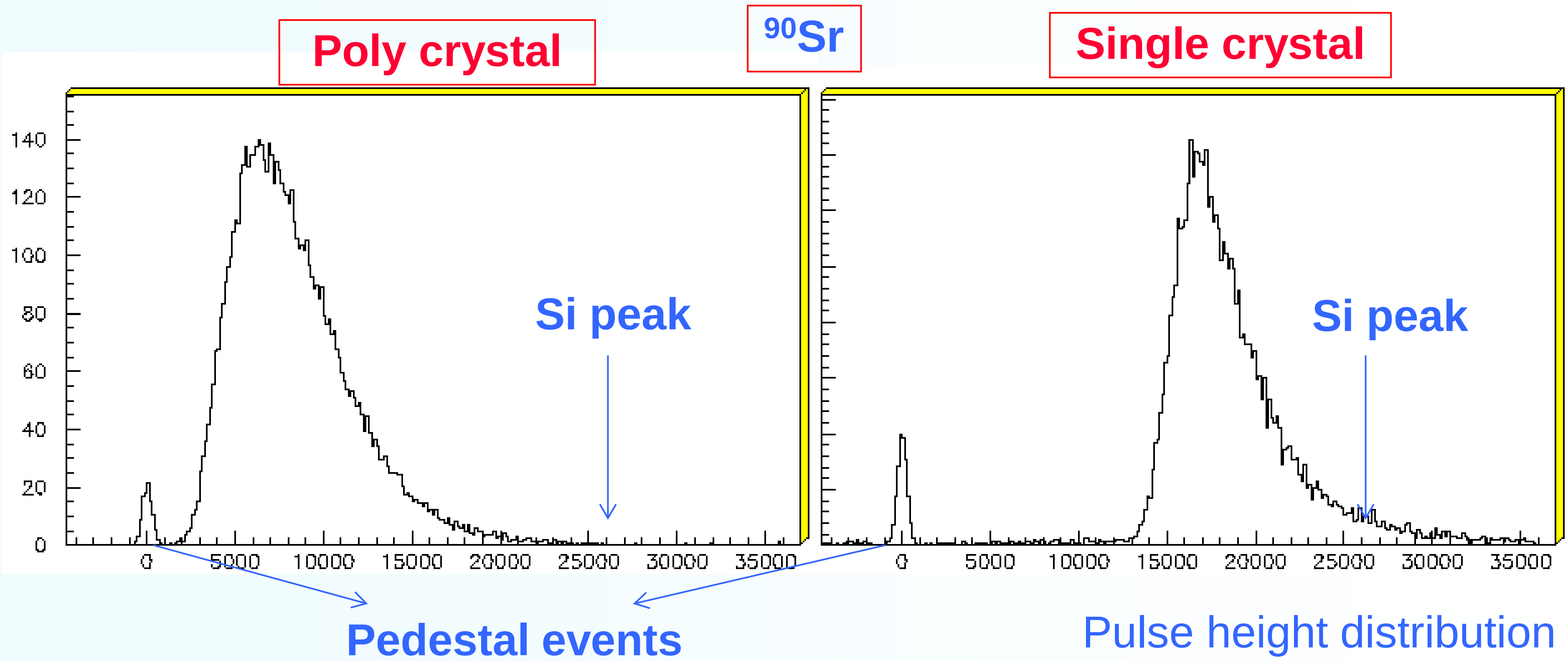
Small signal

Full in sCVD, no localized hot spots

No need for cooling

Poly vs. Single crystal Diamond (500 μm)

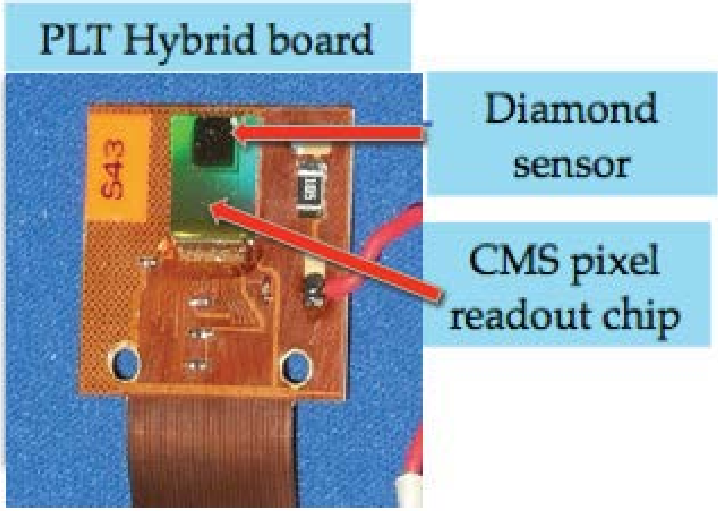
Poly	Single
Suitable for large scale production	1 cm2 largest so far
Less expensive than single crystal	Full charge collection
Stable flux measurement	Charge distribution narrower than poly
Might be less radiation hard	Excellent signal seperation

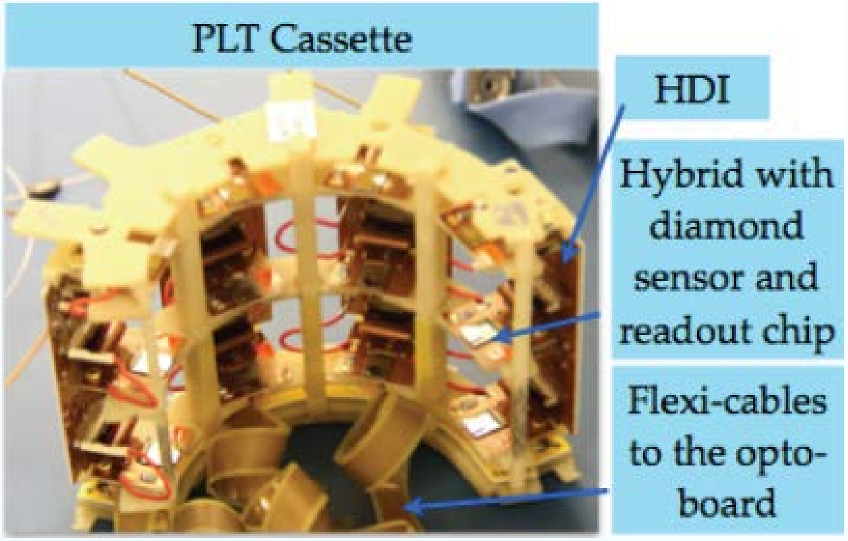


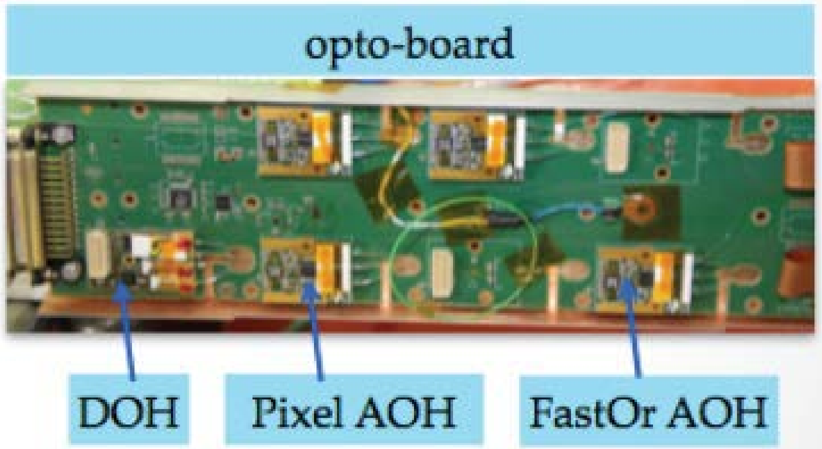
Pulse height distribution

PLT Hardware

- **Telescope**
  - **Made from 3 Hybrid boards (diamond detectors)**
- **Cassette**
  - **Self-contained quarter-detector**
- **Opto-board**
  - **Control and readout of full cassette**

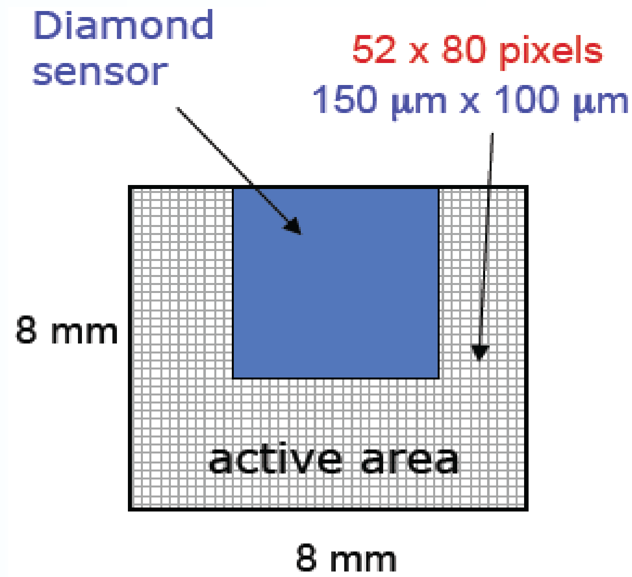


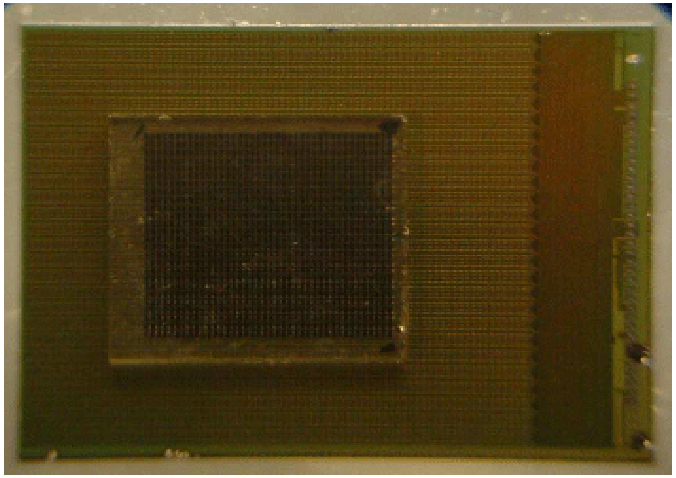




Readout

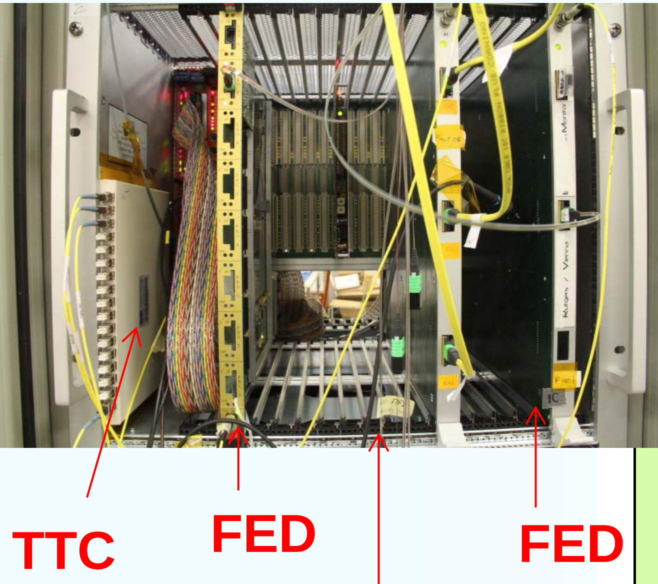
- CMS Pixel chip (PSI46) bump-bonded to sCVD
- Has fast cluster counting in double-columns built in
- Individual pixel thresholds adjustable
- Individual pixels can be masked
- Self-triggered by Fast Or readout
- Full analog readout of
  - Hit address
  - Charge deposit
- Standard pixel readout (FEC, FED [ADC])
- FED has custom firmware for Fast Or

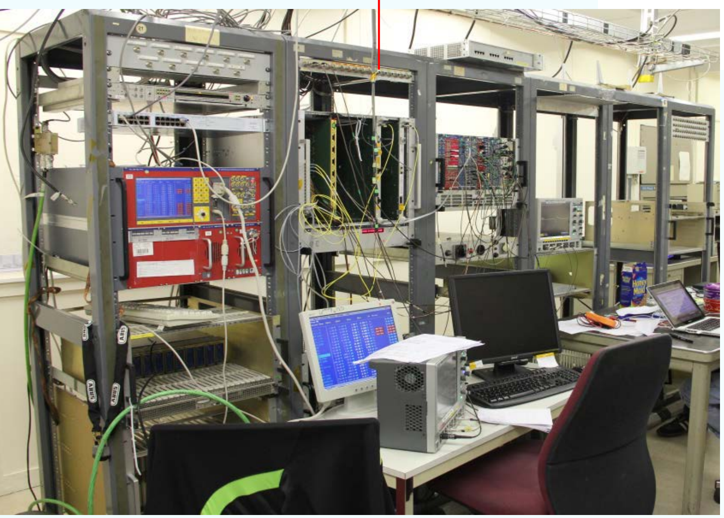


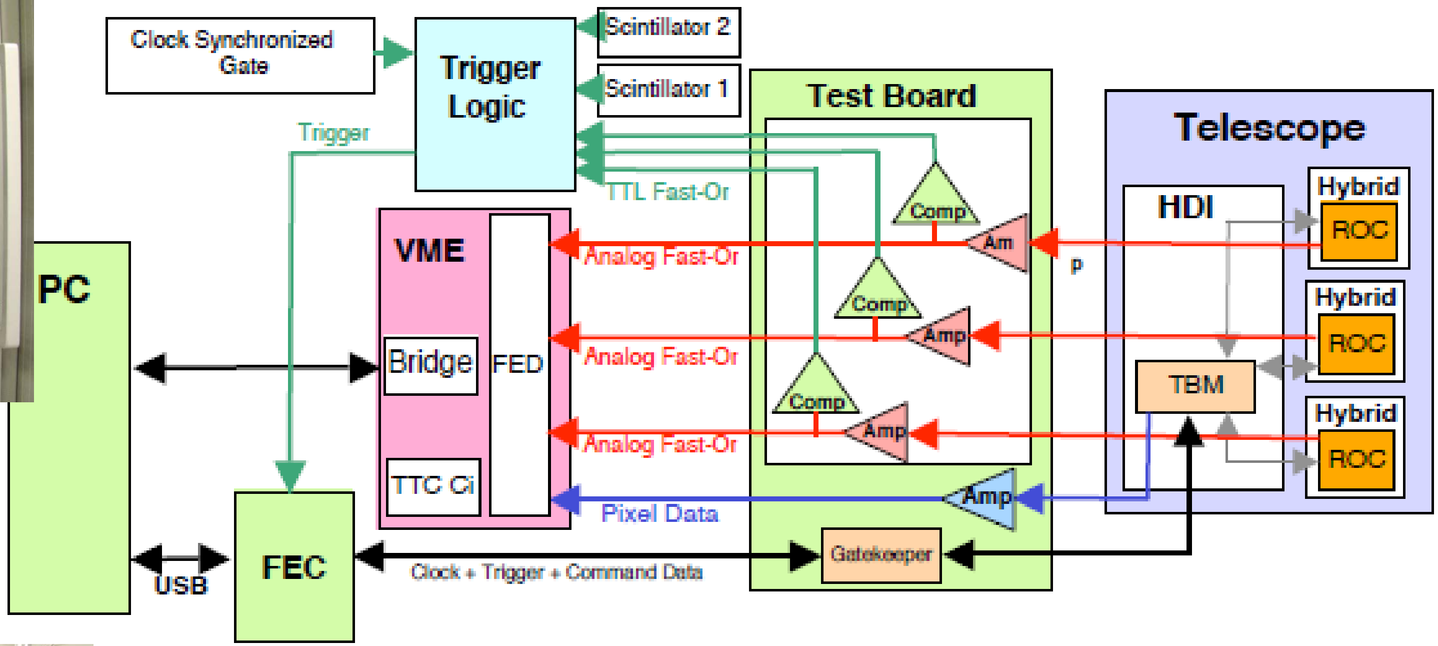


•Bump bonded at Princeton micro-fab lab

DAQ chain



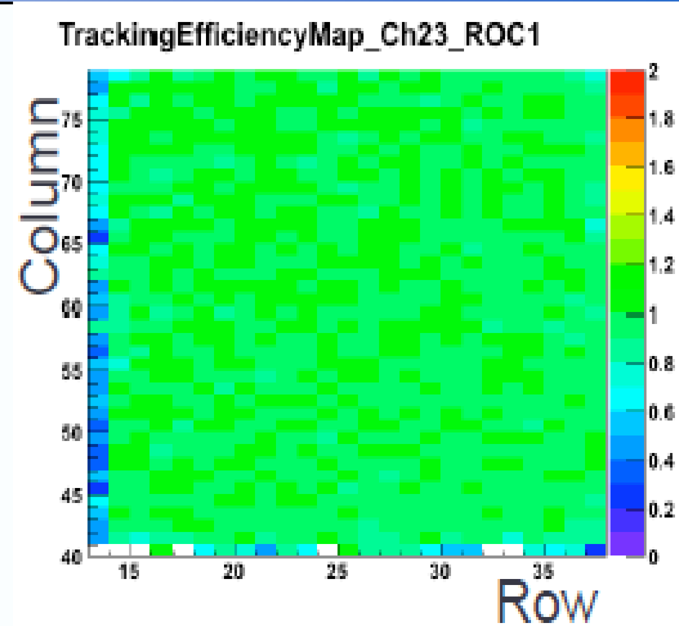


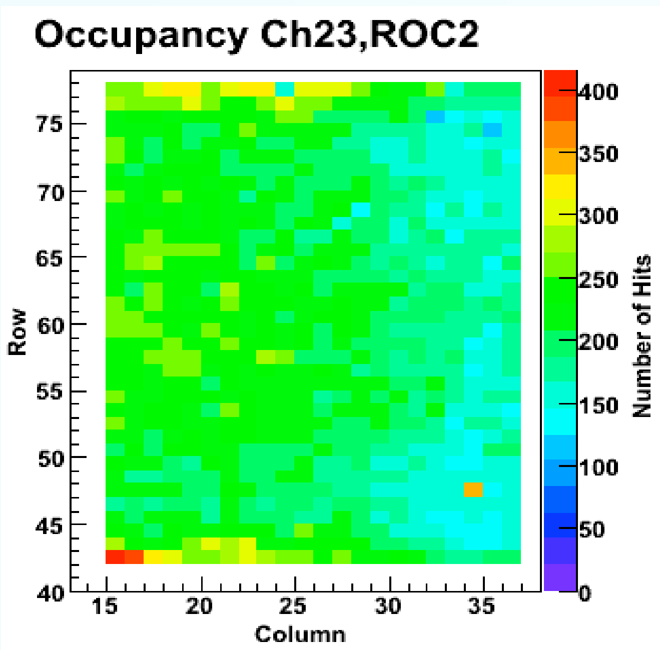


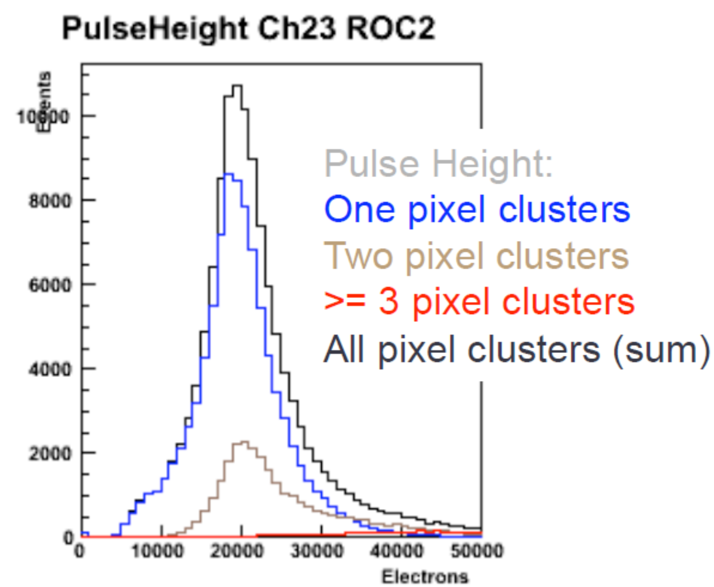
- Similar to CMS pixel DAQ system:
  - FED: pixel Front End Drivers
  - FEC: Front End Controller
  - TTCci: Timing Trigger and Control Interface

Testbeams

- Several successful testbeams in 2009-2013:
  - CERN PS, SPS and Zurich PSI.
- Measure charge collection, study tracking, test DAQ.
- Uniform hit efficiencies.

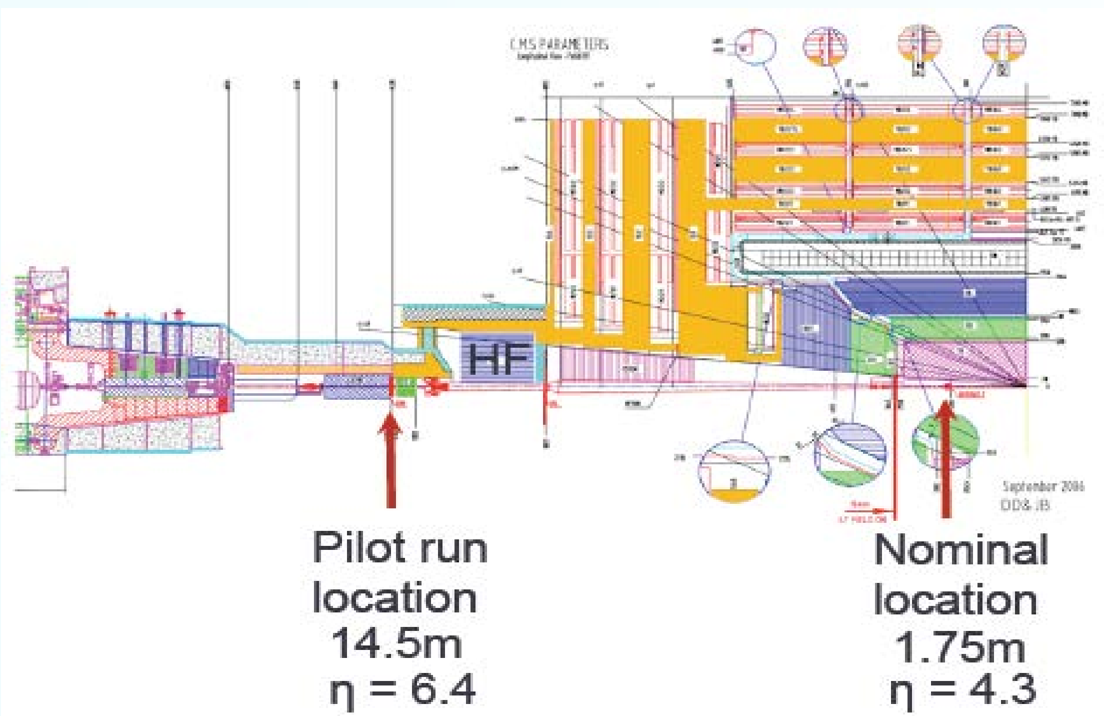




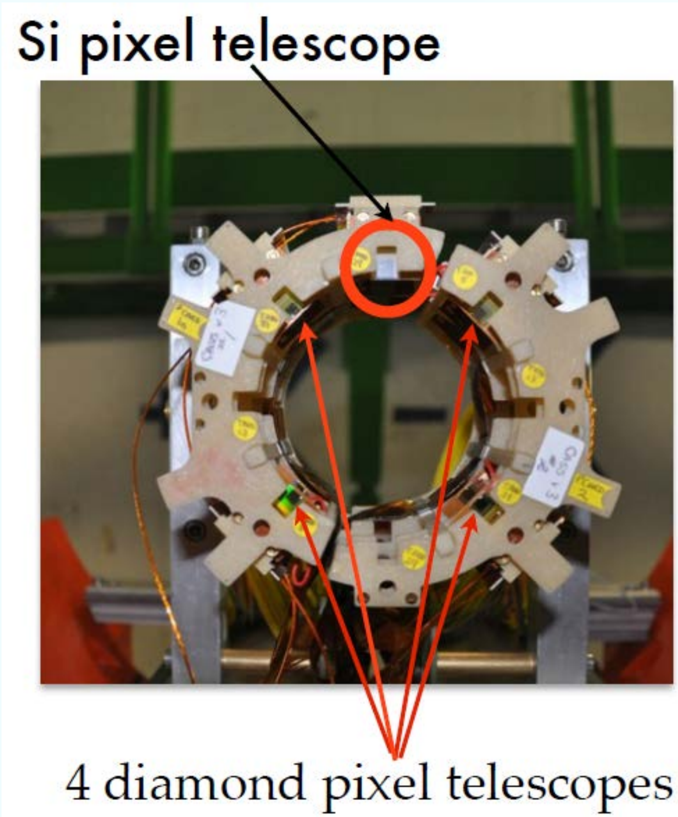


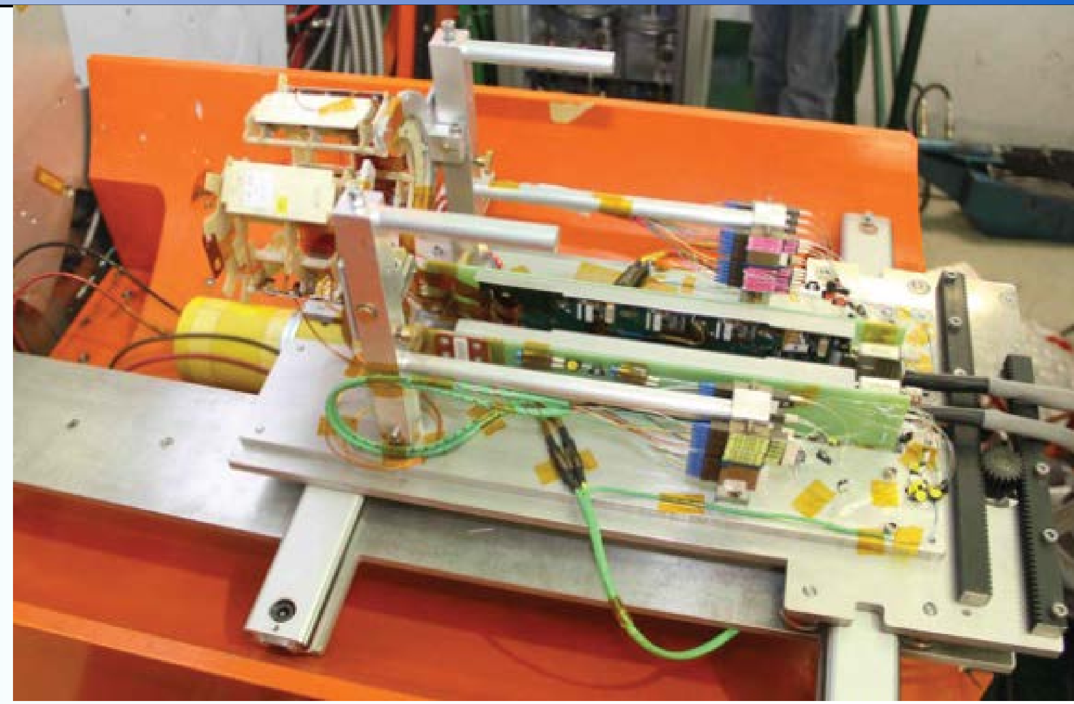
PLT pilot installation

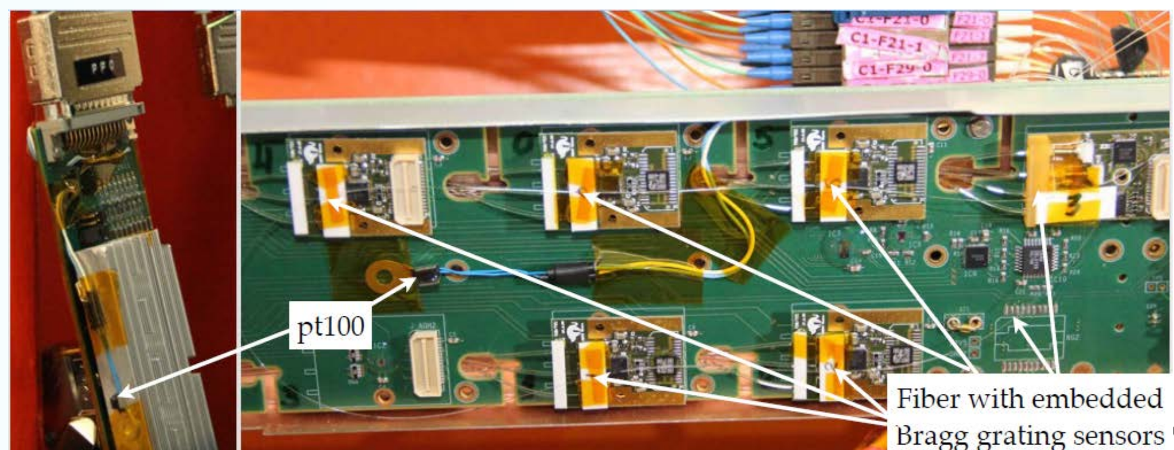
- **2012 pilot installation:**
  - **In January 2012, we installed 4 diamond telescopes and one with silicon on the +Z castor table in CMS (14.5m from collision point).**
  - **Check out of full PLT system.**
  - **Determine if there is any aging of sensors or electronics with radiation**



PLT pilot installation



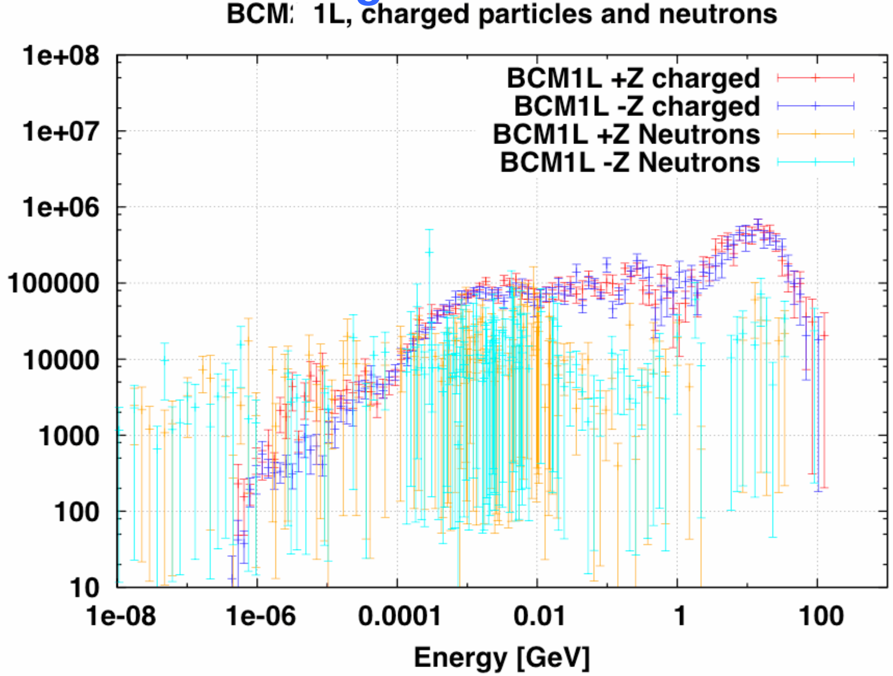




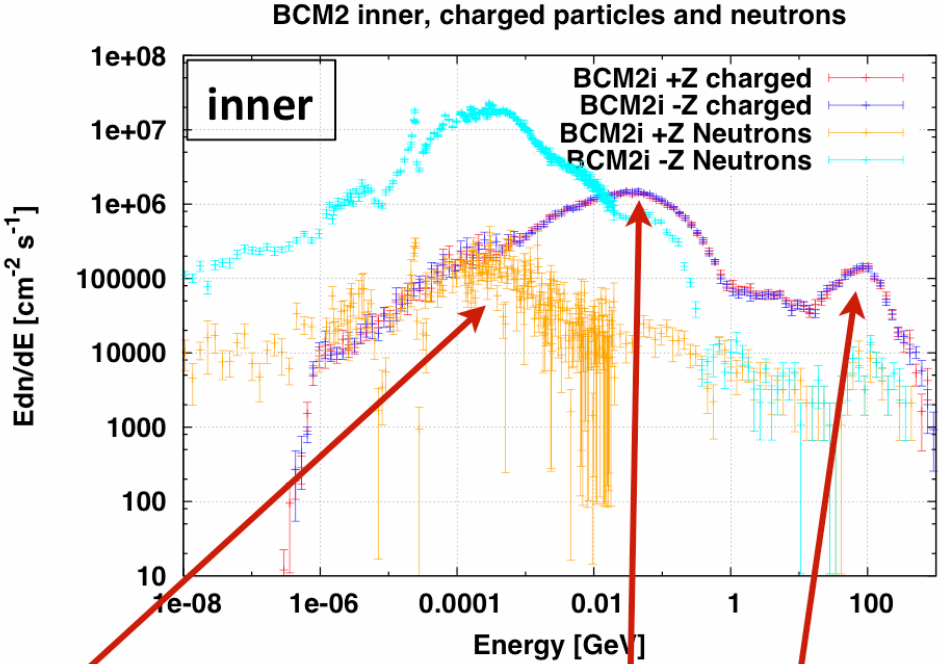
Temperature
measurement

Pilot Run Radiation Environment

Final region



Castor region



- Order of magnitude more neutrons

  peaked at about 200 keV

- Large number of e^+e^- from showering in beam pipe

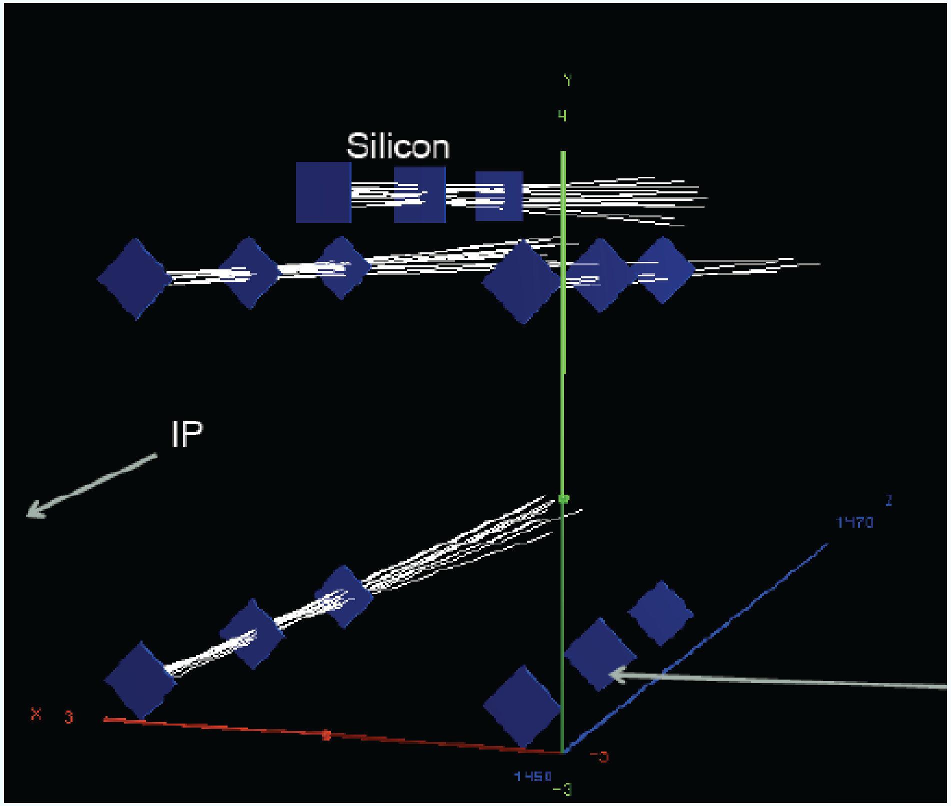
  peaked at about 20 MeV

- About 5 times fewer particles form IP

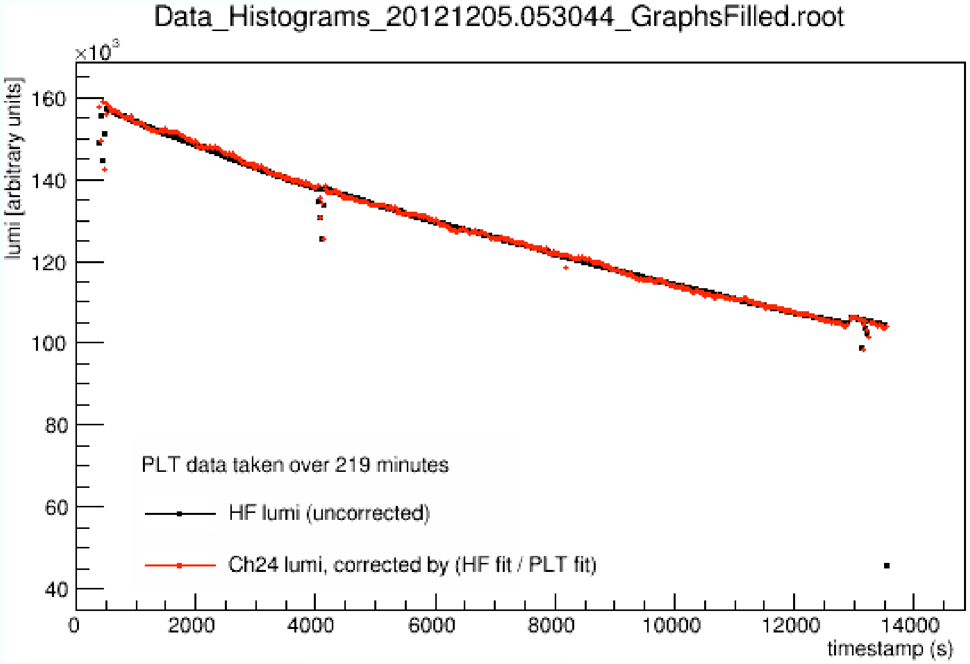
Radiation environment in pilot location is more severe than in the final installation location.

First tracks and measurements

First Tracks seen with the PLT from LHC beam



Luminosity: PLT raw vs HF uncorrected (within 1%)

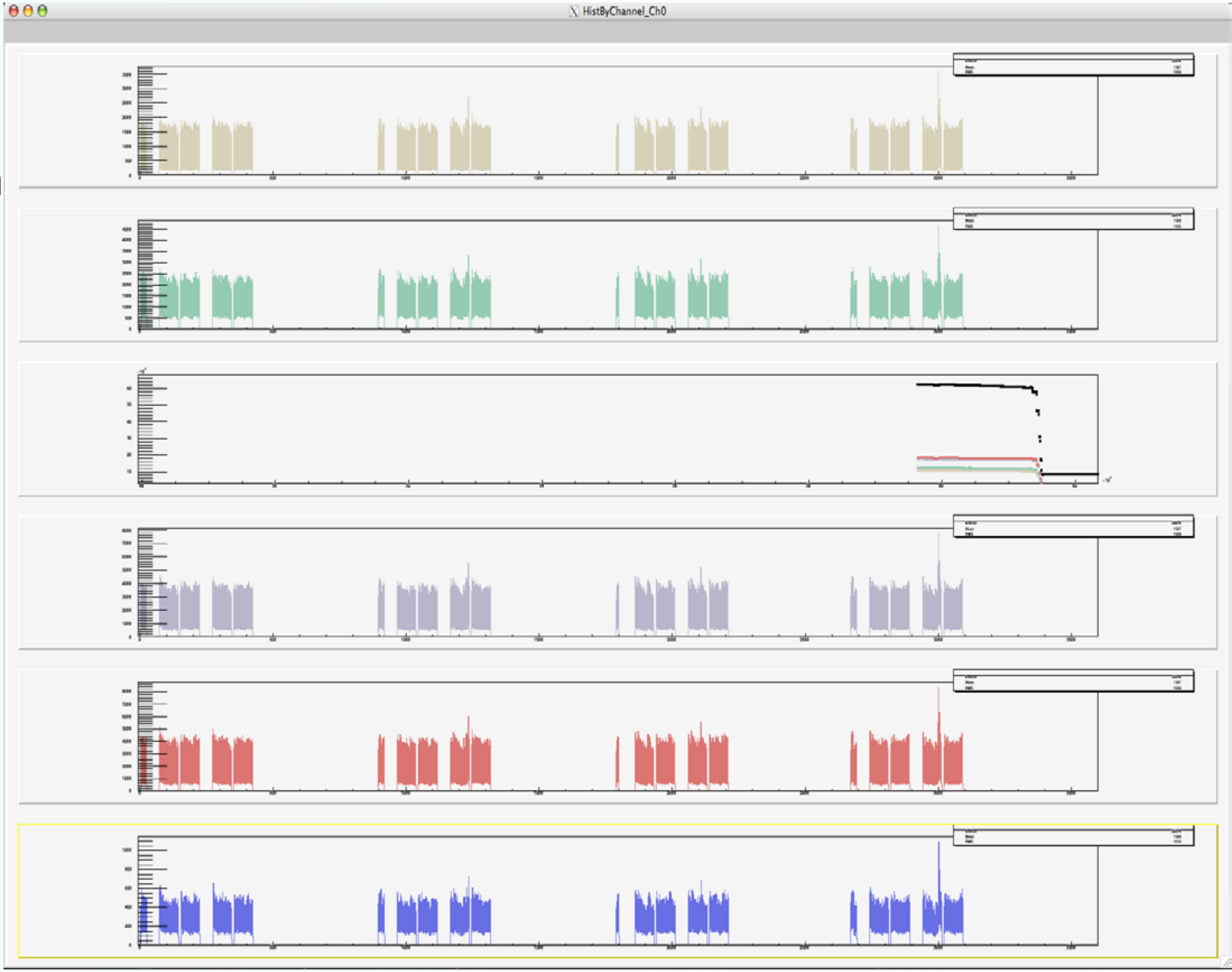


LHC Bunch structure as seen with PLT

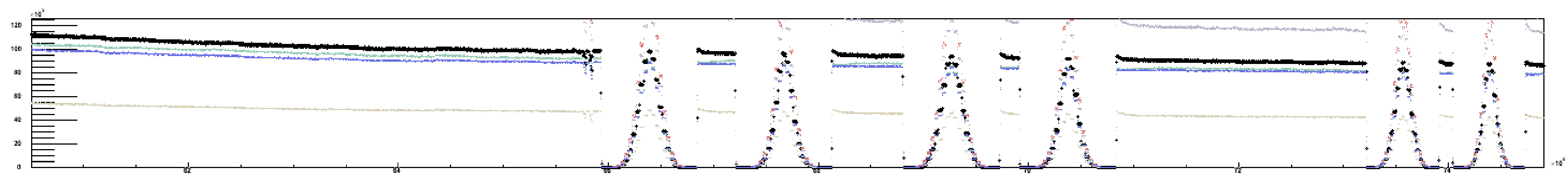
"Histograms" of 3-fold coincidences allow us to measure the luminosity in each 25ns LHC bucket.

Sum "total" used to visualize instantaneous luminosity.

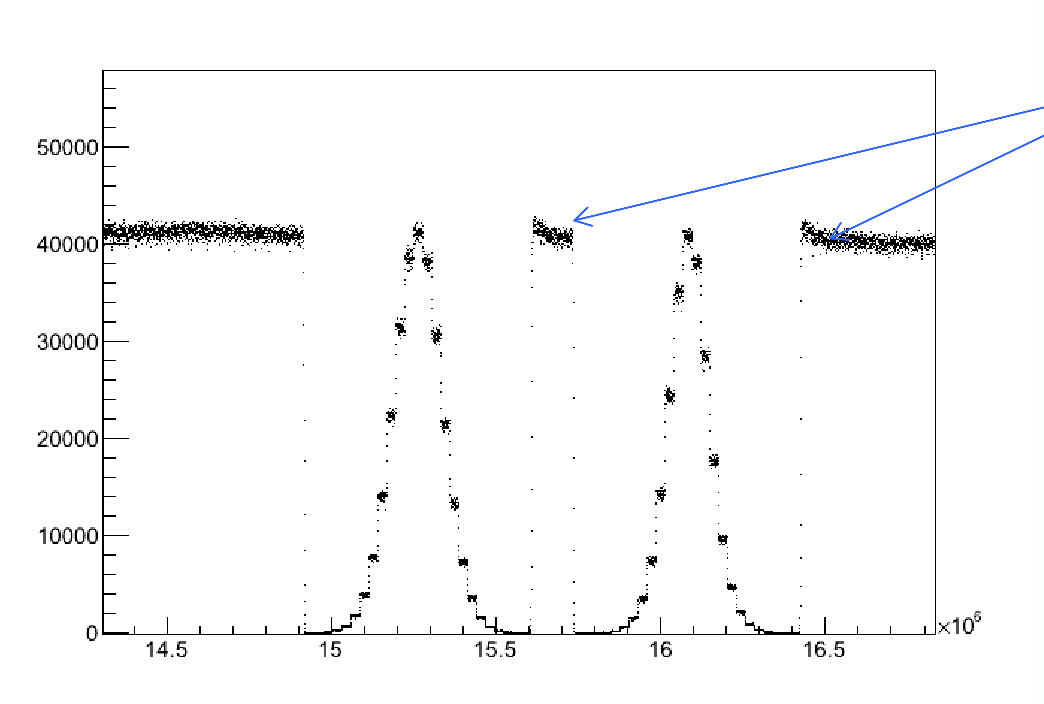
Installed one silicon telescope (without cooling).



VdM Scan - Luminosity



- •Beams are "scanned" across each other in X and in Y
- •We measure the rate as a function of beam separation
    - •For us this is "counts" in our "fast-or" (3-fold coincidence) histograms



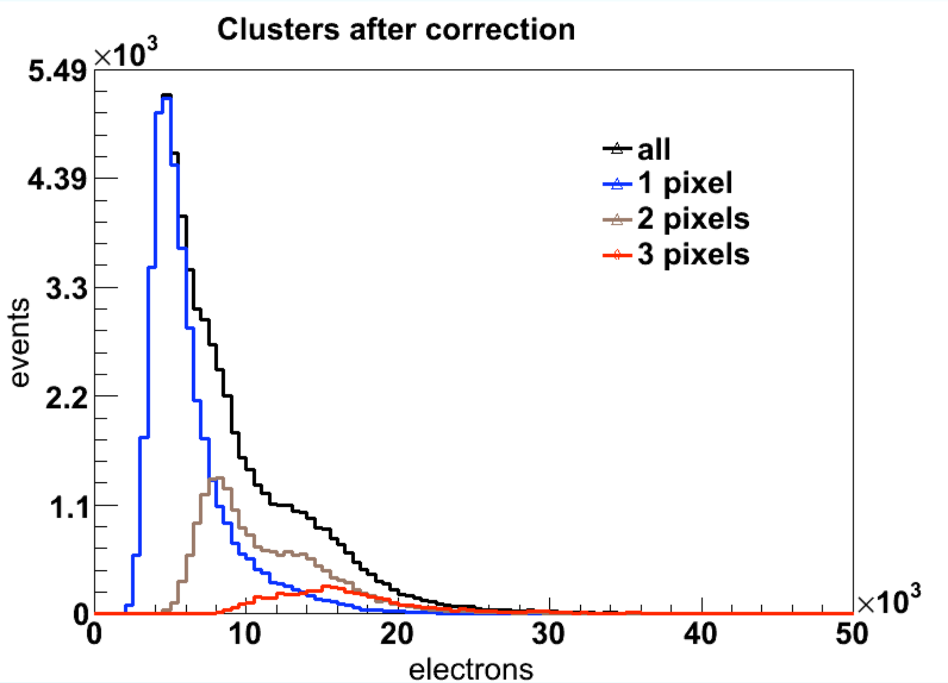
See detector effects

Fit of "counts" vs beam separation give us the luminosity calibration.

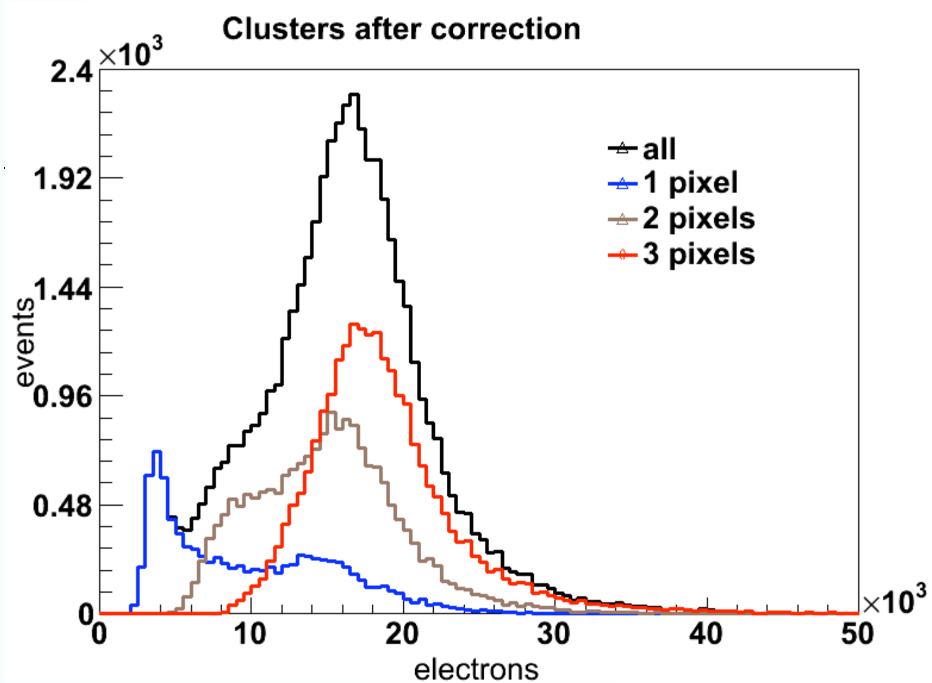
Testing removed planes

- 3 diamonds were removed from pilot installation after 7.5 fb of LHC collisions, and tested at PS test beam.
- Study the charge collection, study tracking and efficiency.

•Charge collection at 300V



•Charge collection at 1020V



•Higher voltage dramatically increases charge collection.

Results from May PSI Beam Test

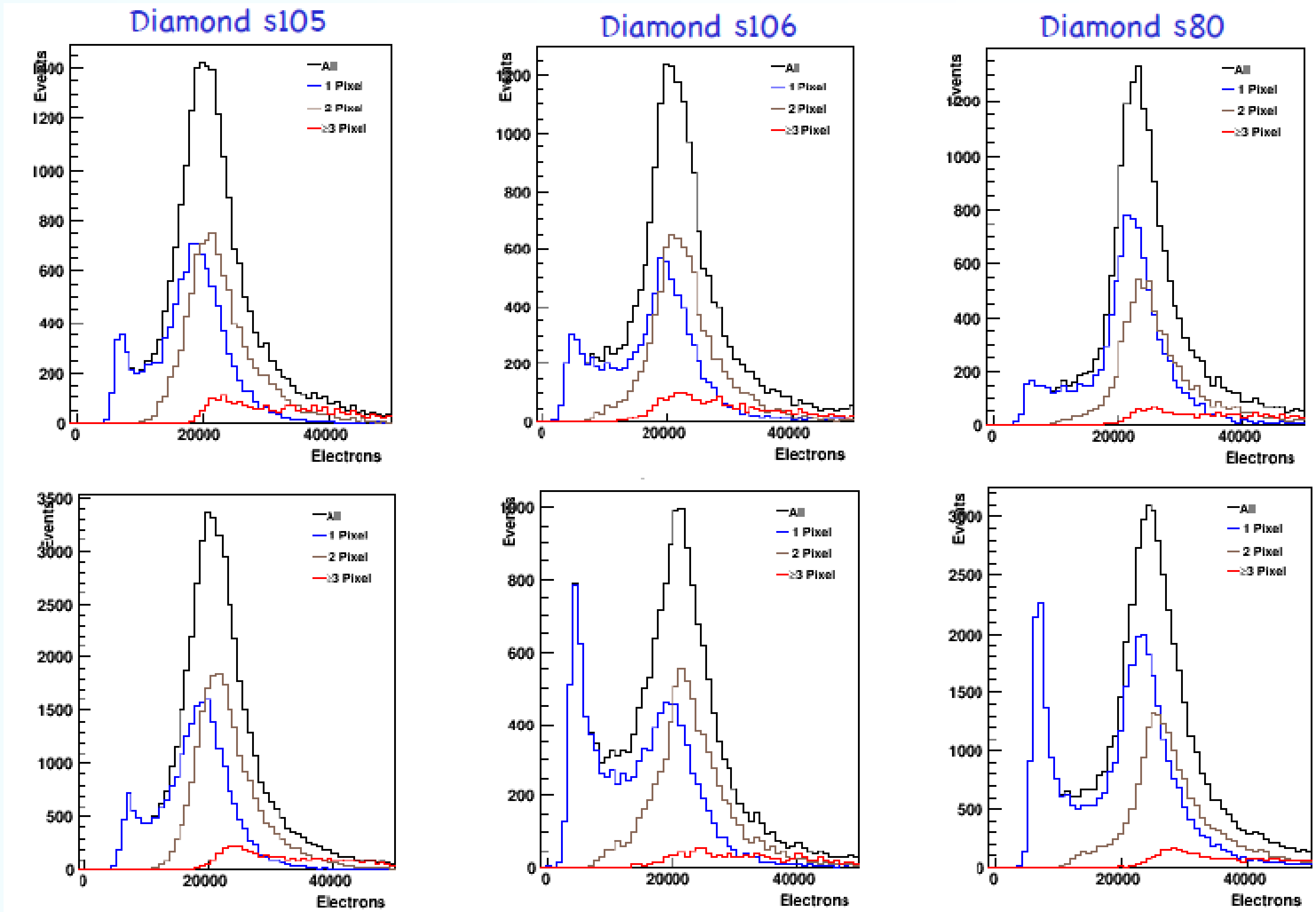
- Diamonds before exposure

Low flux

10 kHz

High flux

2 MHz

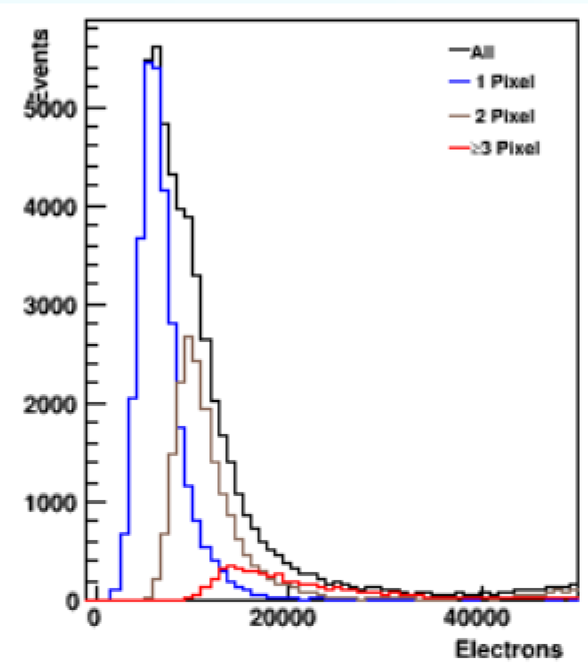


Full charge collection at MHz rates

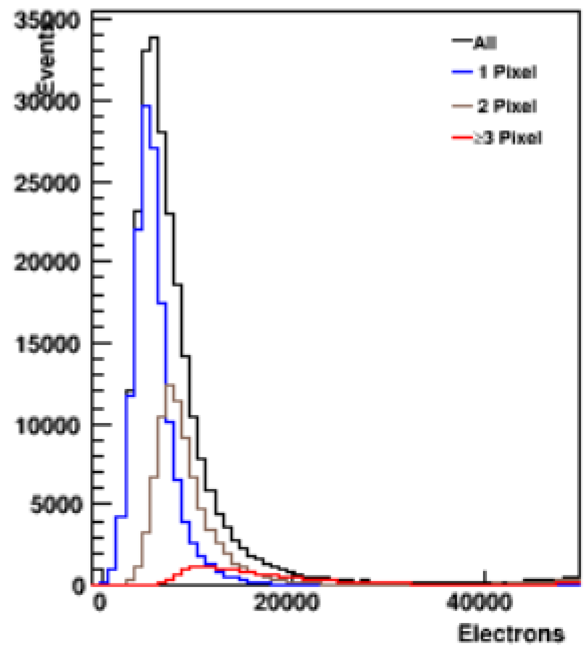
Results from May PSI Beam Test

- Diamonds in CASTOR for 20 fb^{-1}

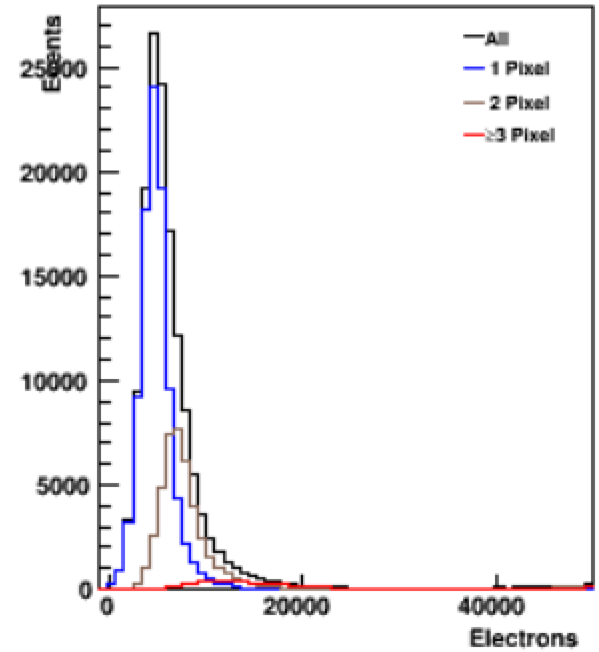
Low flux: 10 kHz



Med flux: 300 kHz



High flux: 2 MHz



- Low charge collection even at low flux.
- Decrease in charge collection with increasing flux.
- Consistent with what was observed during operation in pilot run.

PLT Summary

- Successfully built a full detector system.
- Promising results from testbeams.
- Installation of PLT for pilot run in CMS:
  - monitor and investigate the degradation in charge collection.
- Full installation in the long shutdown.

Thank you!

Backup

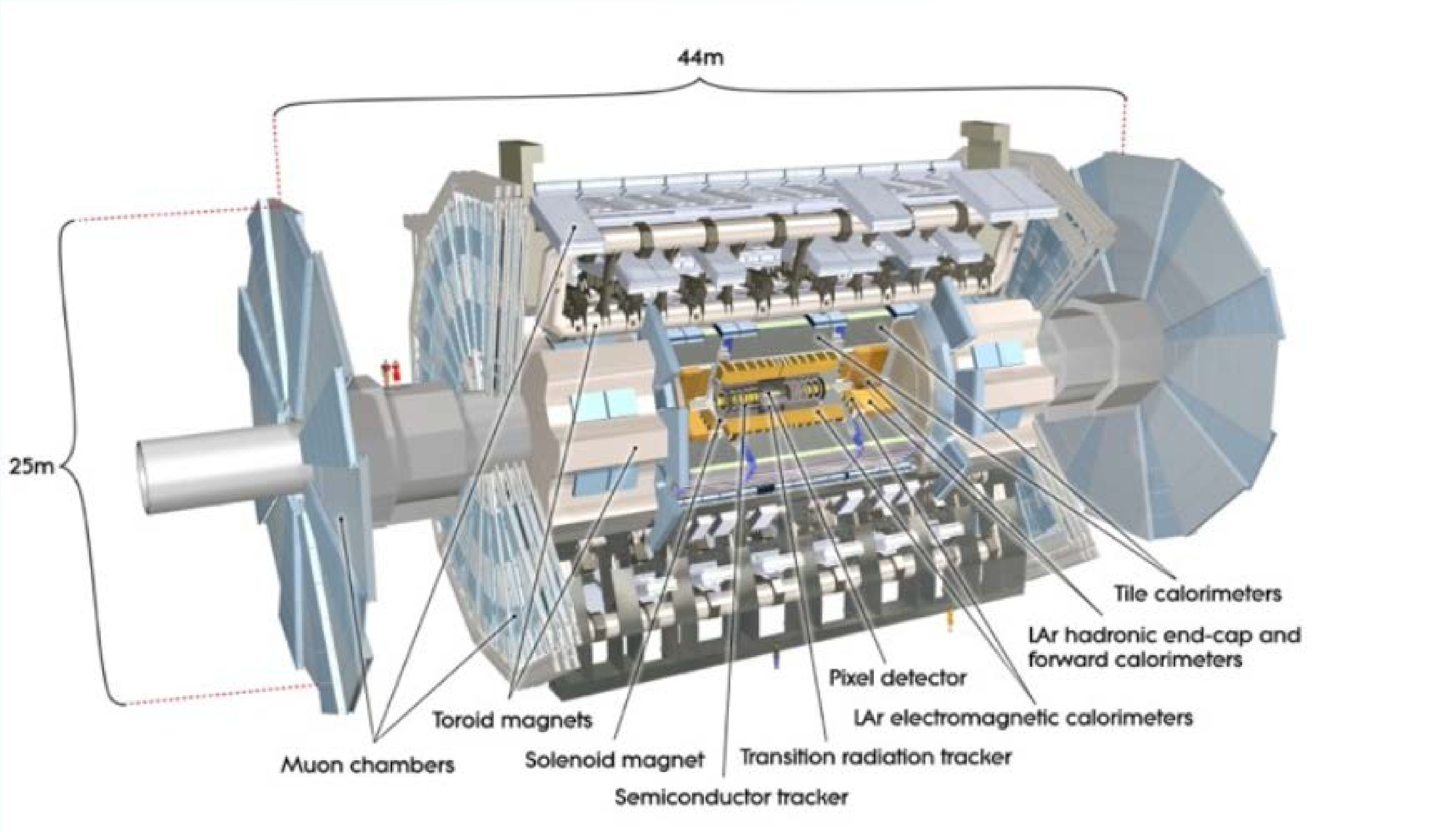
Charmonium production results

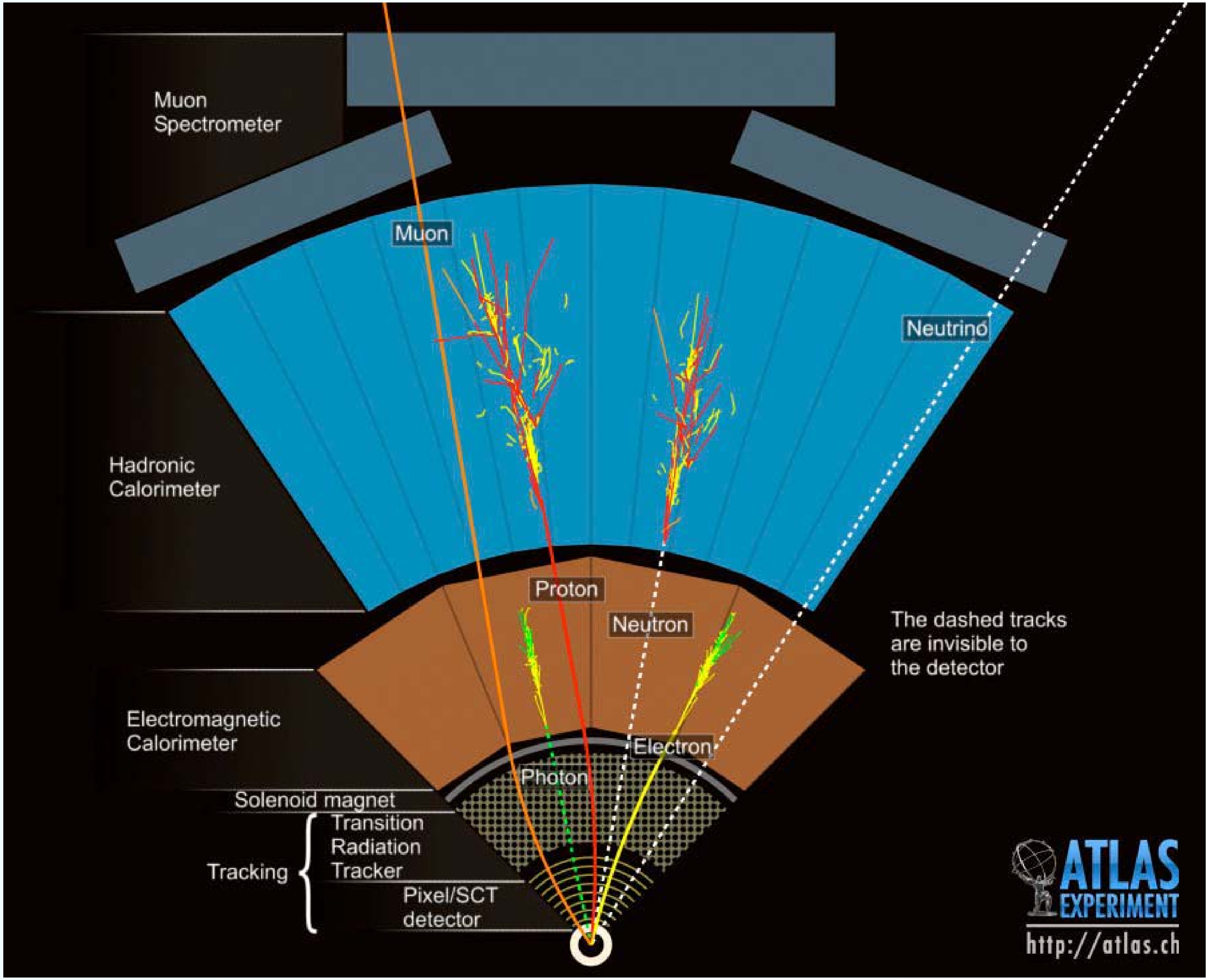
- **CMS**
  - **$J/\psi \to \mu\mu$ (0.3 pb^{-1} and update to 37 pb^{-1})** **Eur. Phys. J. C71 (2011) 1575**
  - **$\psi(2S) \to \mu\mu$ (37 pb^{-1})** **JHEP 1202 (2012) 11**
  - **$\chi_c \rightarrow J/\psi\ \gamma$ (1.1 fb^{-1})** **CMS DPS -2011/011**

- **ATLAS**
  - **$J/\psi \to \mu\mu$ (2.2 pb^{-1})** **Nucl. Phys. B850 (2011) 387**
  - **$\chi_c \rightarrow J/\psi\ \gamma$ (39 pb^{-1})** **ATLAS-CONF-2011-136**

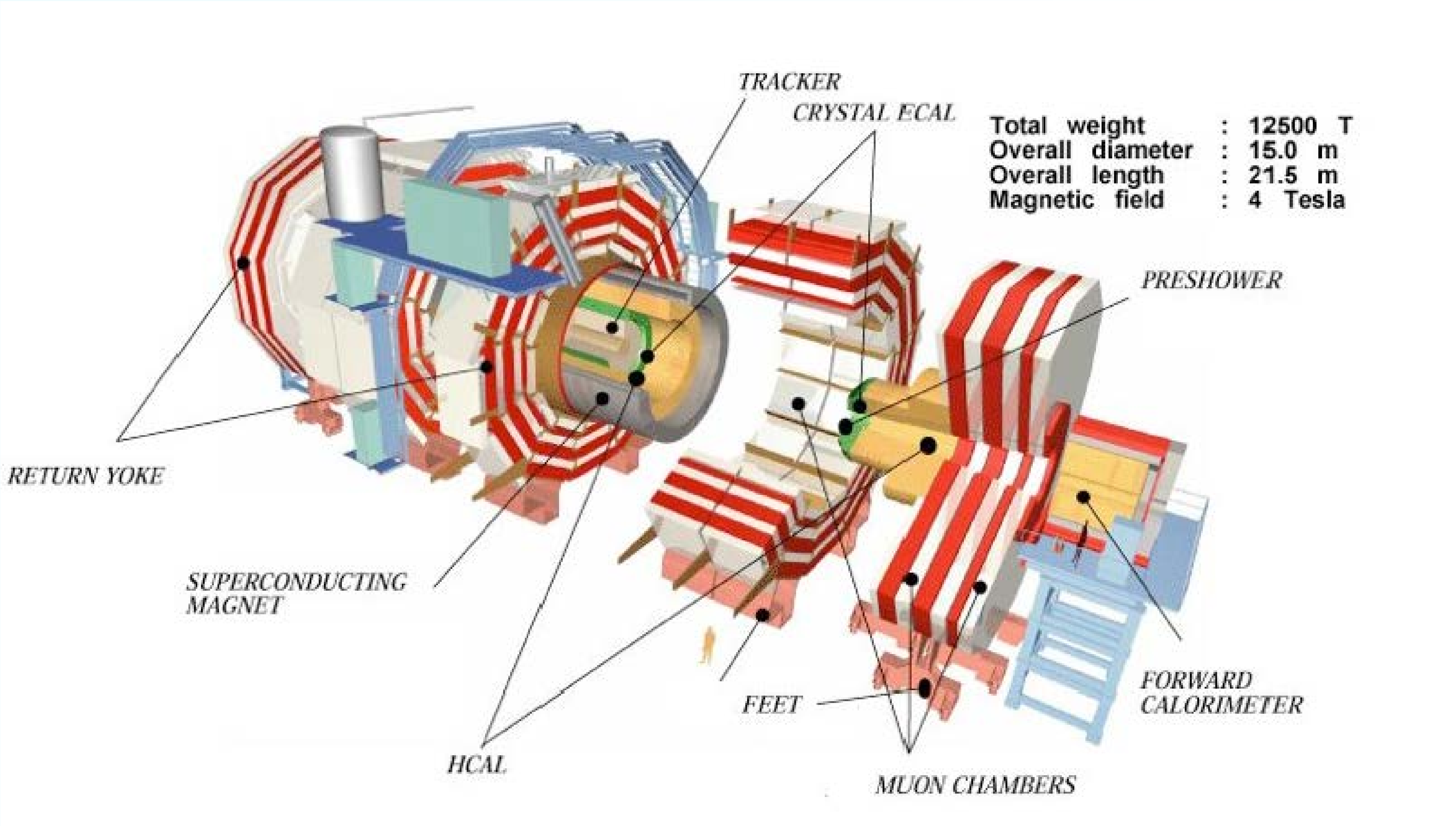
- **LHCb**
  - **$J/\psi \to \mu\mu$ (5.2 pb^{-1})** **Eur. Phys. J. C71 (2011) 1645**
  - **$\psi(2S) \to \mu\mu$ and $\to J/\psi\ \pi\pi$ (36 pb^{-1})** **arXiv:1204.1258**
  - **$\chi_{c1,2}$ cross-section ratio (36 pb^{-1})** **arXiv:1202.1080v1**
  - **χ_c to J/ψ cross-section ratio (36 pb^{-1})** **arXiv:1204.1462**
  - **$\chi_{c1,2}$ cross-section ratio (370 pb^{-1})** **LHCb-CONF-2011-062**

ATLAS Detector

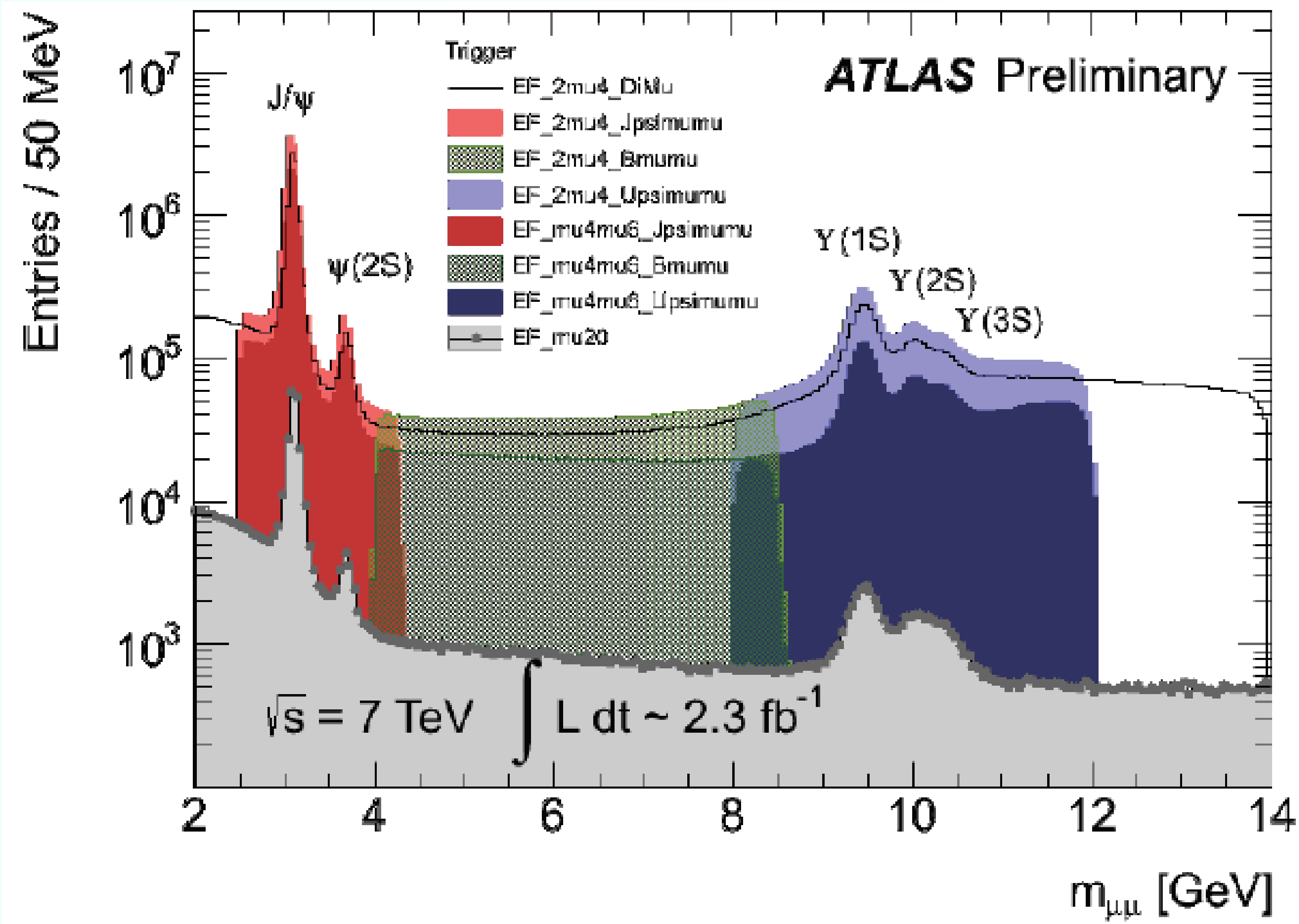



Muon Spectrometer
Muon
Neutrino
Hadronic Calorimeter
Proton
Neutron
The dashed tracks are invisible to the detector
Electromagnetic Calorimeter
Electron
Photon
Solenoid magnet
Transition Radiation Tracker
Tracking
Pixel/SCT detector
ATLAS EXPERIMENT
http://atlas.ch

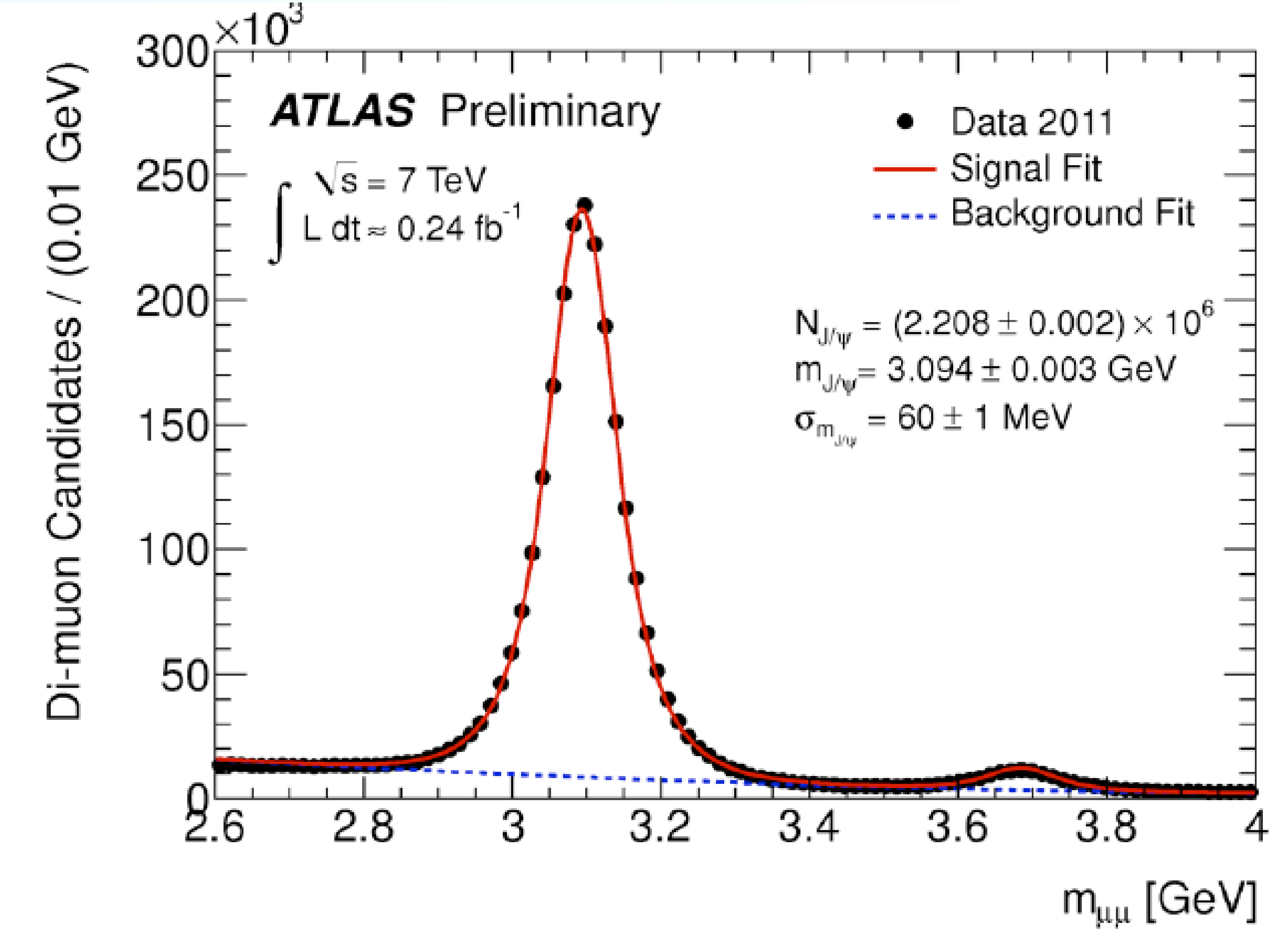
CMS Detector



ATLAS Dimuon Trigger



ATLAS 2011 data



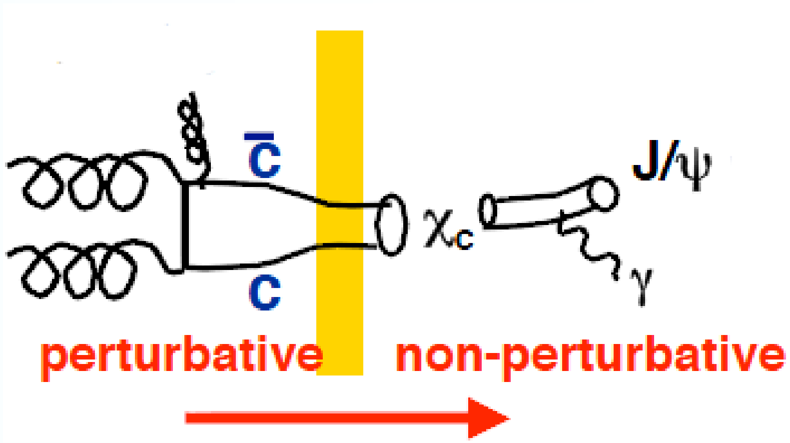
Motivations

- **Long history cross-section/polarization measurements and theoretical calculations, still not so satisfactory:**
  - **cross section results support NRQCD COM**
  - **disagreement in polarization measurement**

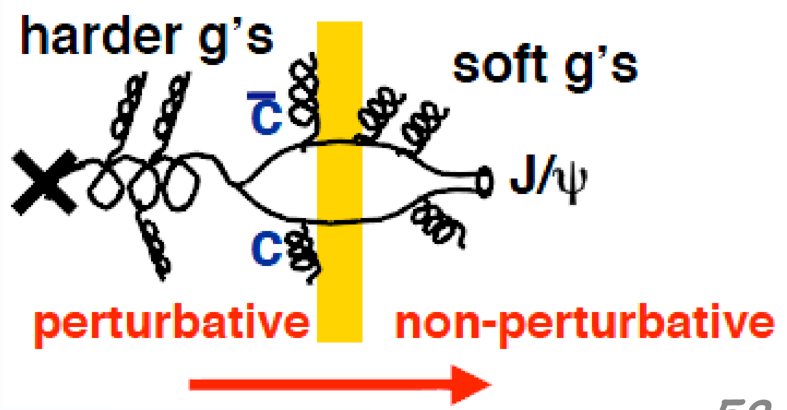
- **Heavy quarkonia are an excellent laboratory for understanding QCD:**
  - **non-relativistic due to the high mass**
  - **non-perturbative effects can be simplified and constrained**

- **In the last decade, significant progress for production mechanisms:**
  - **new experimental results**
  - **improved theoretical descriptions**

Color Singlet production



Color Octet production



P-wave states

- **Ratios of $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ and $\sigma(\chi_c)/\sigma(J/\psi)$ are important for theoretical model builders.**
- **$\chi_c \rightarrow J/\psi\ \gamma$ channel is a challenge to reconstruct low p_T photons.**
- **Good mass resolution to resolve the small mass difference between χ_{c1} and χ_{c2}.**
- **Photon reconstructed by**
  - **CMS/ATLAS: converted e^+e^- pair**
  - **LHCb: converted e^+e^- pair + ECAL**

Van der Meer Scan

- Assuming factorizable gaussian for the beam density function (not too bad as approximation)

$$\rho(x,y) = \rho(x)\rho(y) \propto \exp(-\frac{x^2}{2\sigma_x^2})\exp(-\frac{x^2}{2\sigma_y^2}) \Rightarrow F(\Delta_x, \Delta_y) \propto \exp(-\frac{\Delta_x^2}{2\Sigma_x^2})\exp(-\frac{\Delta_y^2}{2\Sigma_y^2})$$

- The resulting "effective area" is then just:

$$\Sigma_x\Sigma_y = \sqrt{\sigma_{x,1}^2 + \sigma_{x,2}^2}\sqrt{\sigma_{y,1}^2 + \sigma_{y,2}^2}$$