Study of the Ratio of Indirect to Prompt J/ψ in e +e- mode in the ATLAS experiment

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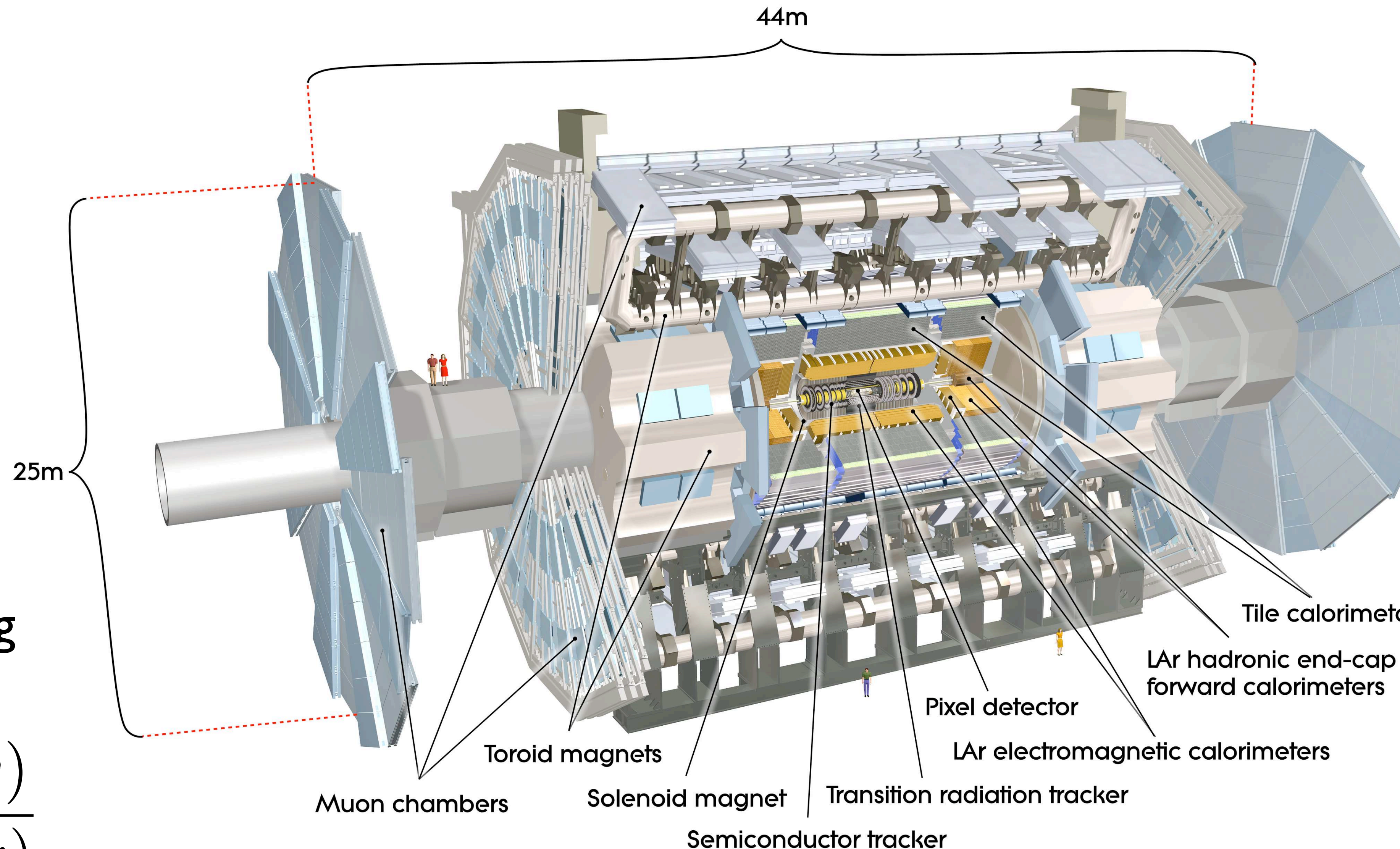
Outline

- Bremsstrahlung
- ATLAS Inner Detector
- L_{xy} and Pseudo-proper time
- Feasibility study of measuring

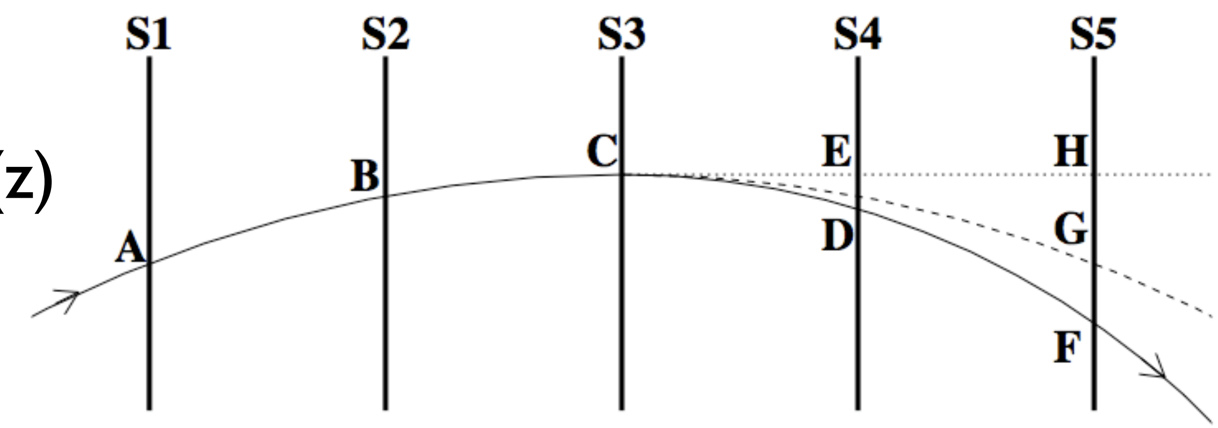
$$\mathcal{R} = \frac{d\sigma(bb \rightarrow J\psi)}{d\sigma(pp \rightarrow J\psi)}$$



- Improvement in ratio measurement by consideration of electron kinematics.

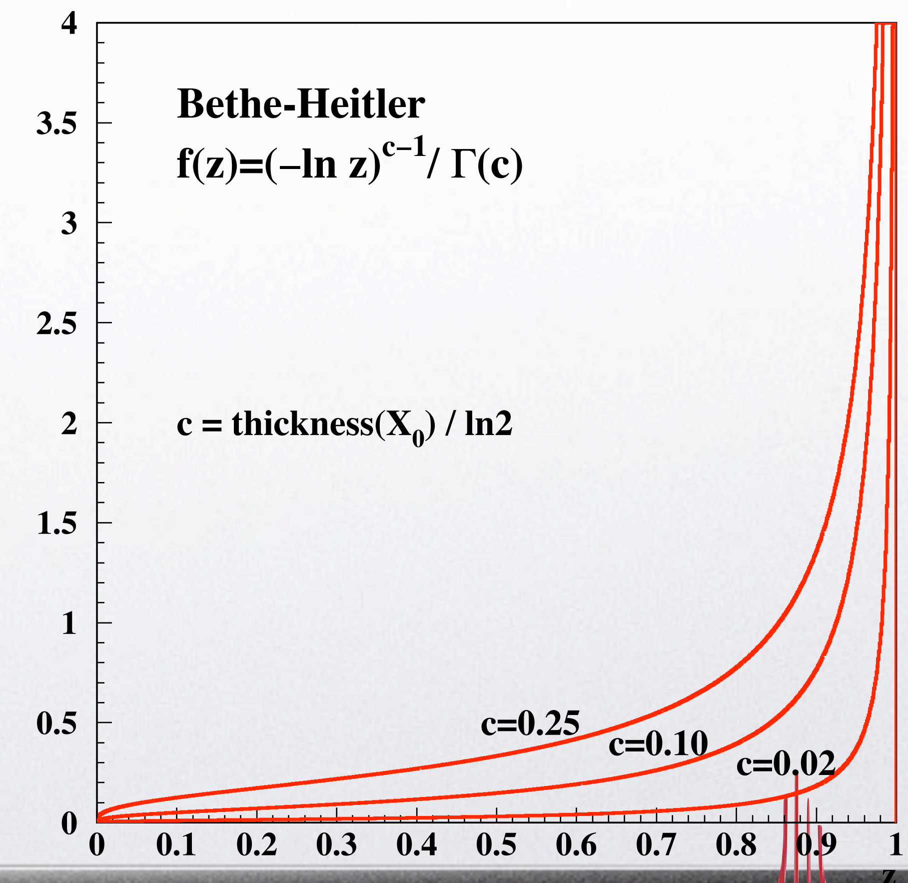
Bremsstrahlung

An electron retains
- its direction of propagation and
- a fraction z of its energy with probability density f(z)



The Bethe-Heitler function describes the energy distribution for electrons undergoing brem
- highly asymmetric
- long tailed
- dependent on the amount of material traversed

In ATLAS we have developed a fast and efficient method of brem recovery which is based on the dynamical adjustment of the 'system noise' term in the Kalman covariance matrix once a brem-like behaviour of the track is detected.
Kalman Dynamic Noise Adjustment Fitter (DNA)
This can be run aggressively on already identified electrons (AggDNA).



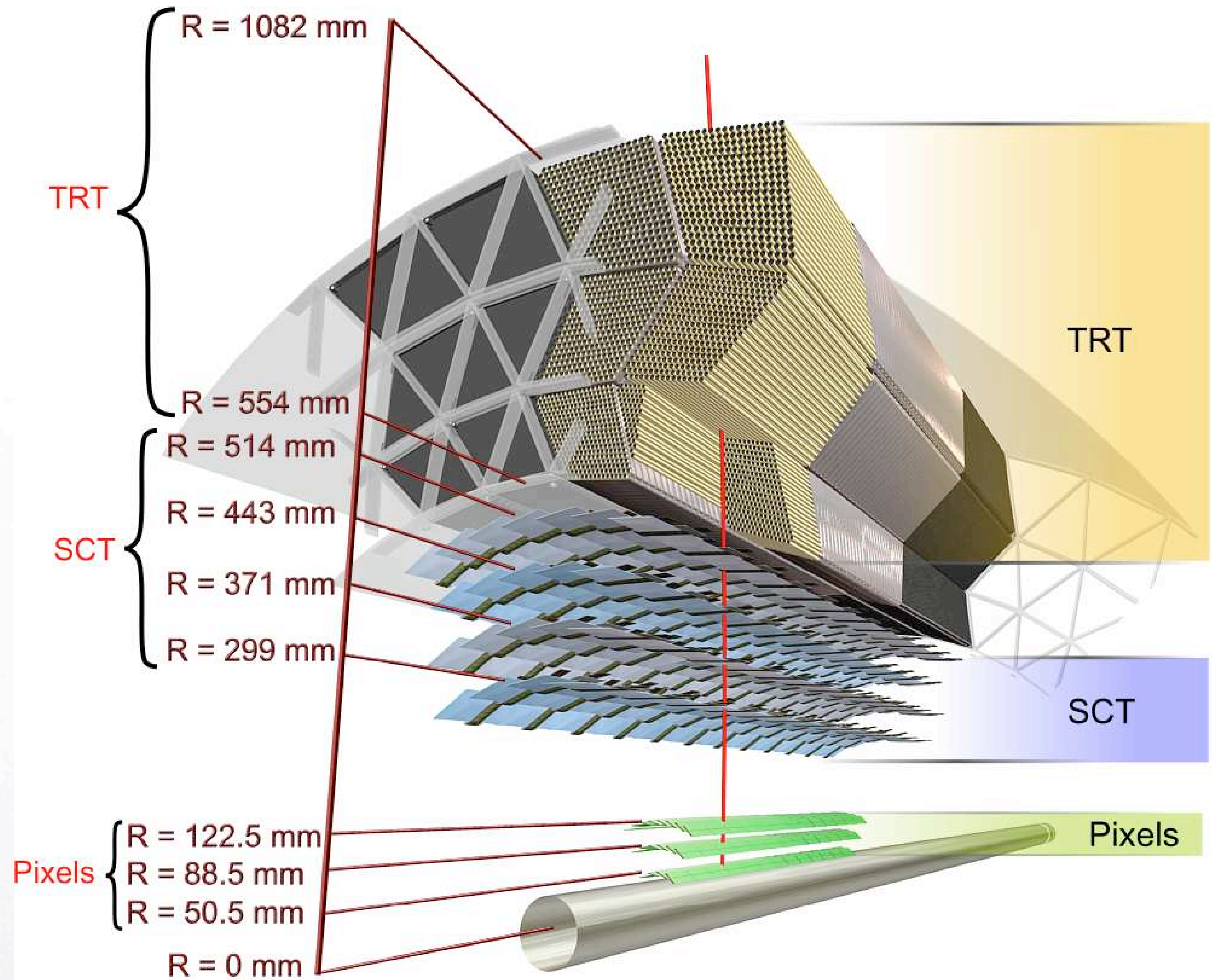
ATLAS Inner Detector

Particles go through quite a lot of material

e.g in the barrel region, where |η|<1
- the beam pipe
- 3 layers of Pixel detector
- 4 layers of Semi Conductor Tracker
- 73 layers of Transition Radiation Detector

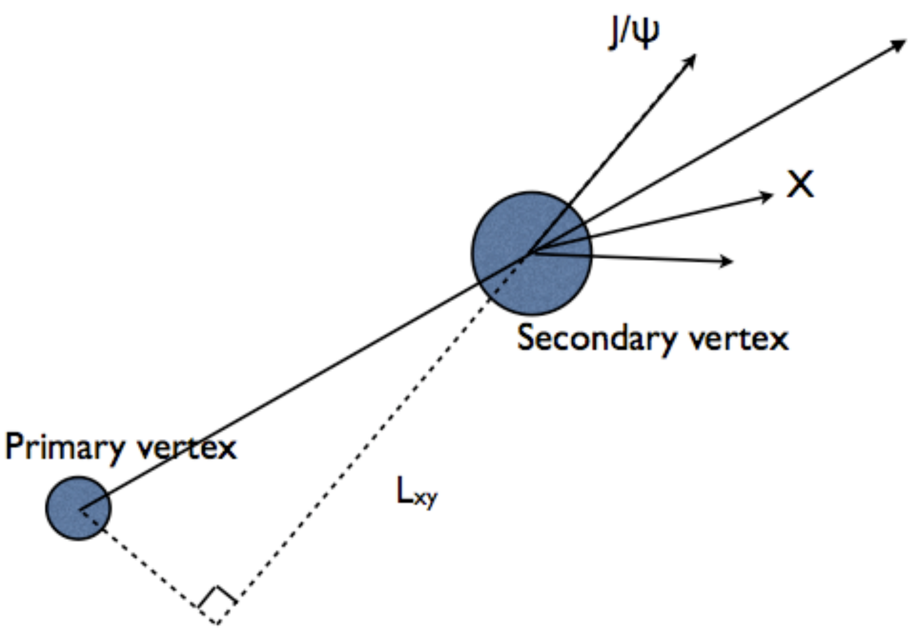
High probability of significant bremsstrahlung.

The default ATLAS track fitter, Global χ^2 (GXF), is not bremsstrahlung-aware



The azimuthal angle, ϕ, which is measured around the beam axis, combined with the pseudorapidity, η, are used to define a position within the detector.

Pseudo-proper time



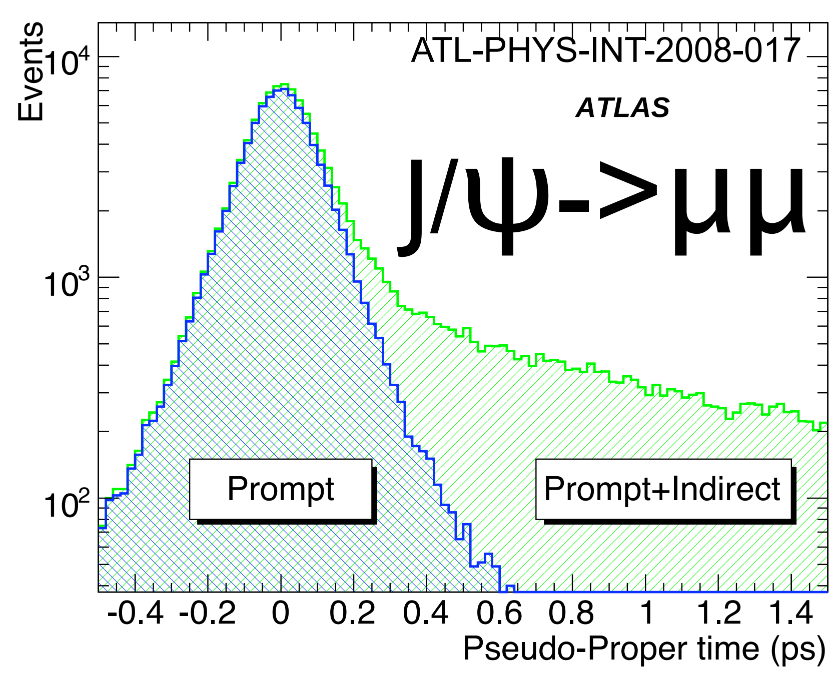
L_{xy} is the distance of the secondary vertex from the primary vertex in the transverse plane projected onto the J/ψ momentum direction.

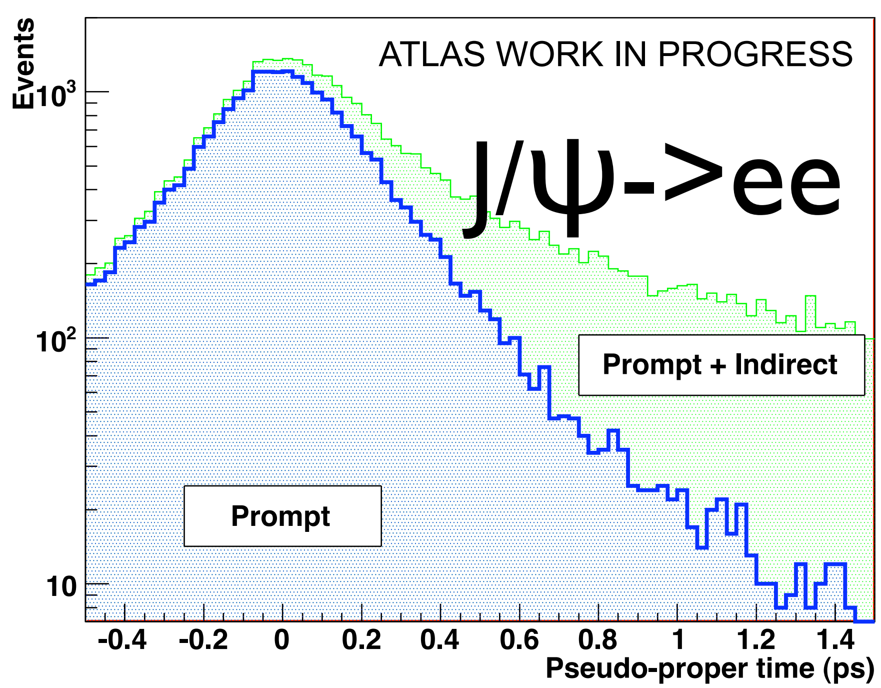
It can be used to distinguish between prompt and indirect J/ψ:
- Prompt J/ψ have a true zero L_{xy}
- B-hadron decays into J/ψ +X have an exponentially decaying L_{xy} distribution due to the non-zero lifetime of the parent.

Pseudo-proper time =

$$\frac{L_{xy} \cdot M_{J\psi}}{p_{T(J\psi)} \cdot c}$$

where
$M_{J\psi}$ and $p_{T(J\psi)}$ represent the mass and p_T of the J/ψ meson





Ratio indirect to prompt J/ψ

$$\mathcal{R} = \frac{d\sigma(bb \to J/\psi(ee))}{d\sigma(pp \to J/\psi(ee))}$$

A function representing the true proper time distribution must include
- a delta function to describe the prompt contribution and
- an exponential term, with slope Γ, to describe the indirect contribution

$$f(t) = C_1 \cdot r(t) \otimes [\delta(t) + \mathcal{R} \cdot \Gamma \cdot \exp(-\Gamma t)]$$

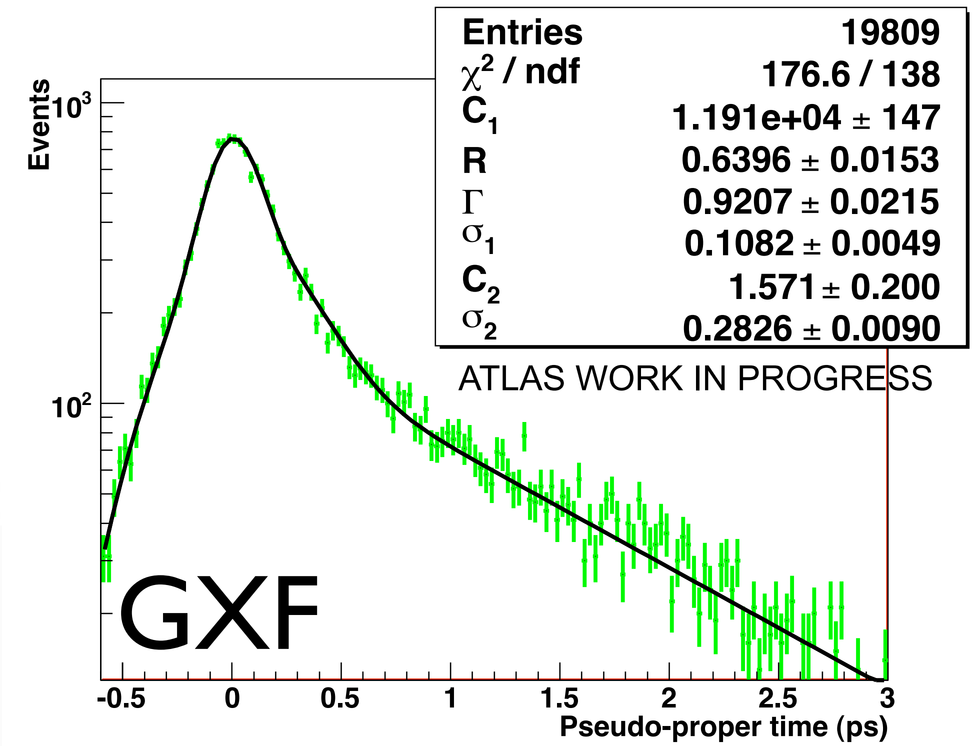
The resolution function can be treated as a normalised sum of two gaussians

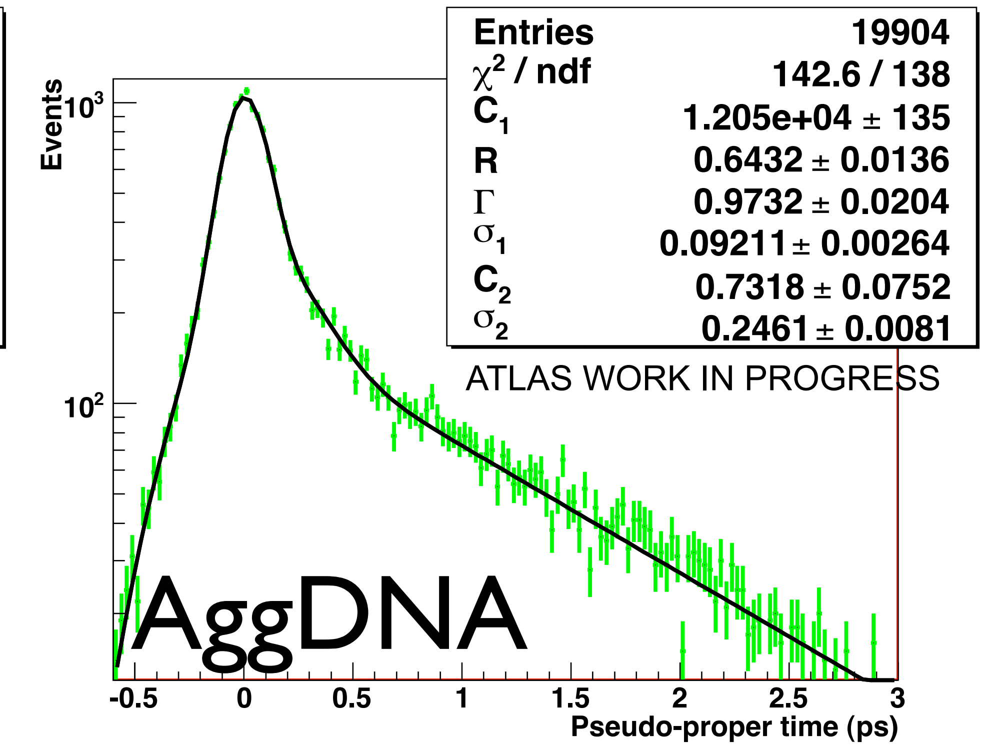
$$r(t) = \frac{1}{\sqrt{2\pi}(1 + C_2)} \left[\frac{1}{\sigma_1} \cdot \exp\left(\frac{-t^2}{2\sigma_1^2}\right) + \frac{C_2}{\sigma_2} \cdot \exp\left(\frac{-t^2}{2\sigma_2^2}\right)\right]$$

Overall normalisation coefficient C_1 estimates the number of prompt J/ψ.
Coefficient C_2 required to describe reconstructed L_{xy} tail due to bremsstrahlung.

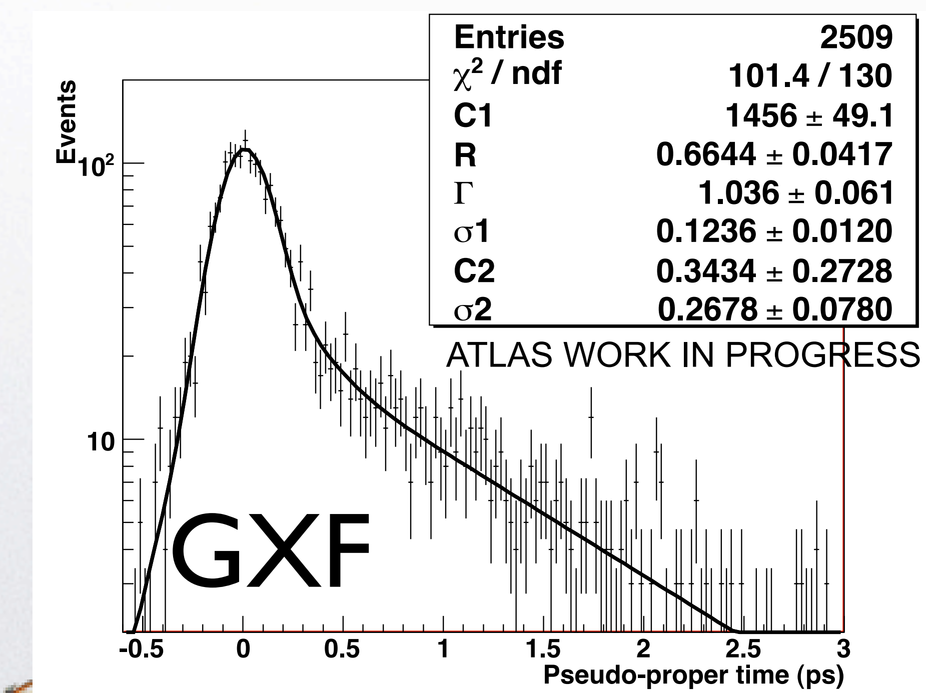
This study only considers events in the barrel (|η|<1) where electrons from J/ψ candidates pass ATLAS `Medium' electron quality cuts (significantly reduce background from jets).

Ratio indirect to prompt J/ψ





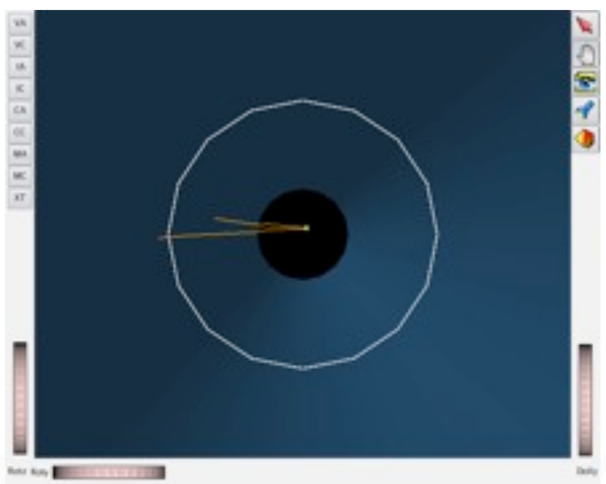
As expected, the resolution is improved by using a bremsstrahlung-aware fitter.
Values of σ_1 and σ_2 reduced with AggDNA.
Values of Γ and *R* remain stable.



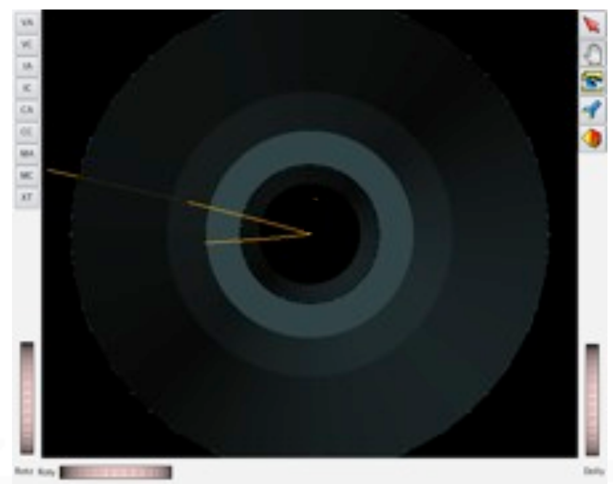
Events selected where both electrons retain more than 80% of their initial energy i.e. little bremsstrahlung.
Value of C_2 returned by fit much reduced.
Coefficient C_2 required to describe reconstructed L_{xy} tail due to bremsstrahlung.

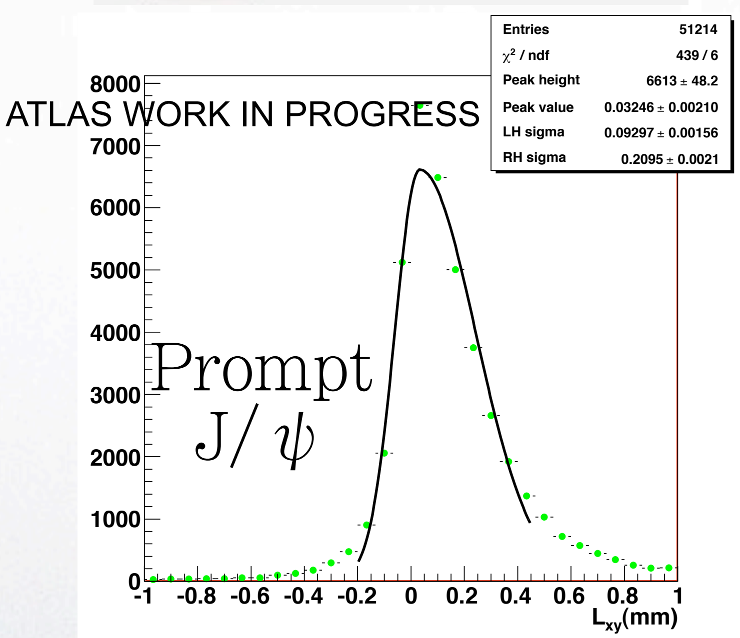
Cowboys and Sailors

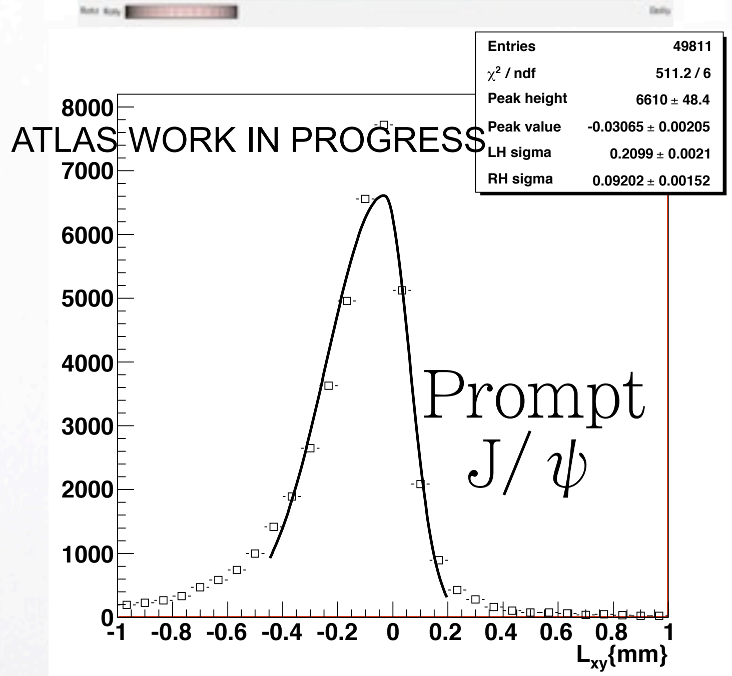
Sailor: $\sin(\phi_{+}-\phi_{-})>0$



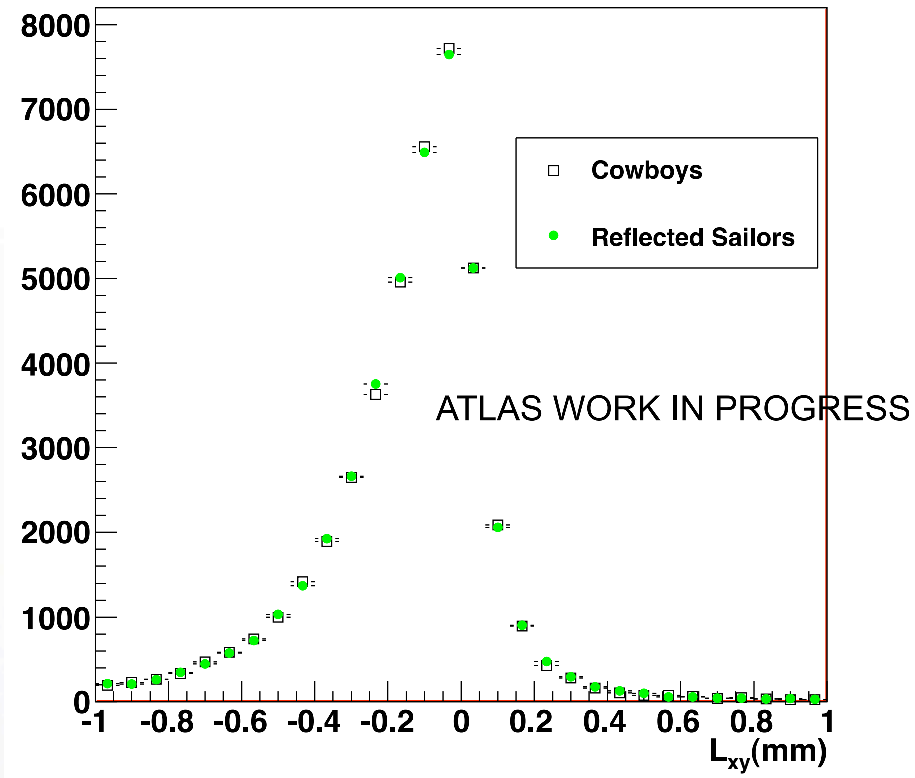
Cowboy: $\sin(\phi_{+}-\phi_{-})<0$

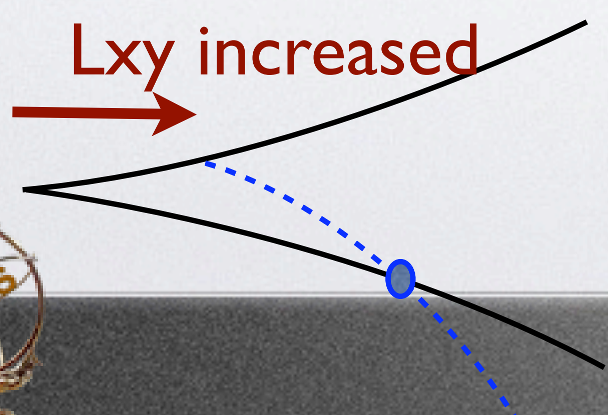


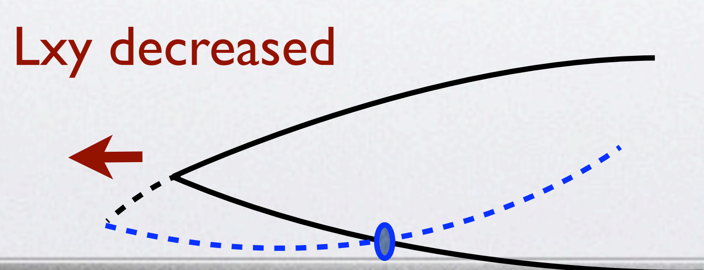




Reconstructed Lxy depends upon track kinematics:
Sailors tend to increase Lxy.
Cowboys tend to reduce Lxy.







$$\sigma_L^{Cowboy} = \sigma_R^{Sailor}$$

$$\sigma_R^{Cowboy} = \sigma_L^{Sailor}$$

Peak shift from zero,m:

$$m^{Sailor} = -m^{Cowboy}$$

New Resolution Function

If the events are to be separated into cowboys and sailors,
the resolution function needs to be modified to take into account for asymmetric gaussians (left and right hand resolutions, σ_L and σ_R) and peak position shift from zero, m.

$$r(t) = \frac{2}{\sqrt{2\pi}\,(\sigma_L + \sigma_R)} \cdot \exp\left(\frac{-(t-m)^2}{2\sigma^2}\right) \qquad \begin{array}{lll} \sigma = \sigma_L & \text{if} & t < m \\ \sigma = \sigma_R & \text{if} & t > m \end{array}$$

The resulting function with two asymmetric gaussians has ten parameters

$$\sigma_{L1}, \sigma_{R1}, m_1, \sigma_{L2}, \sigma_{R2}, m_2, C_1, C_2, \Gamma, R$$

A simultaneous fit of cowboys and sailors permits
six parameters to be cross-fed:

- Left hand cowboy resolutions set to be equal to right hand sailor resolutions (& vice versa)
- Peak positions of the asymmetric gaussians treated as equal but opposite.

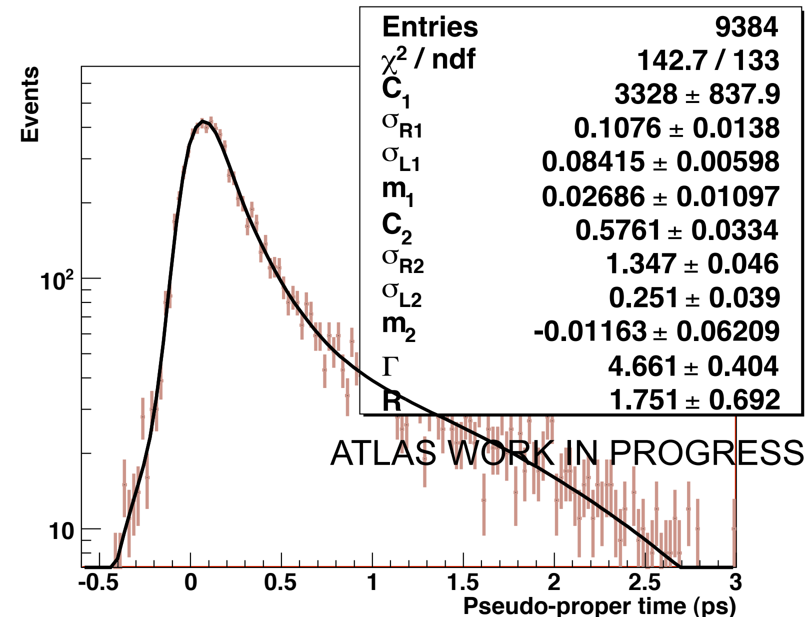
two parameters to be shared:

- Slope of exponential, Γ, and weight of second gaussian, C_2.

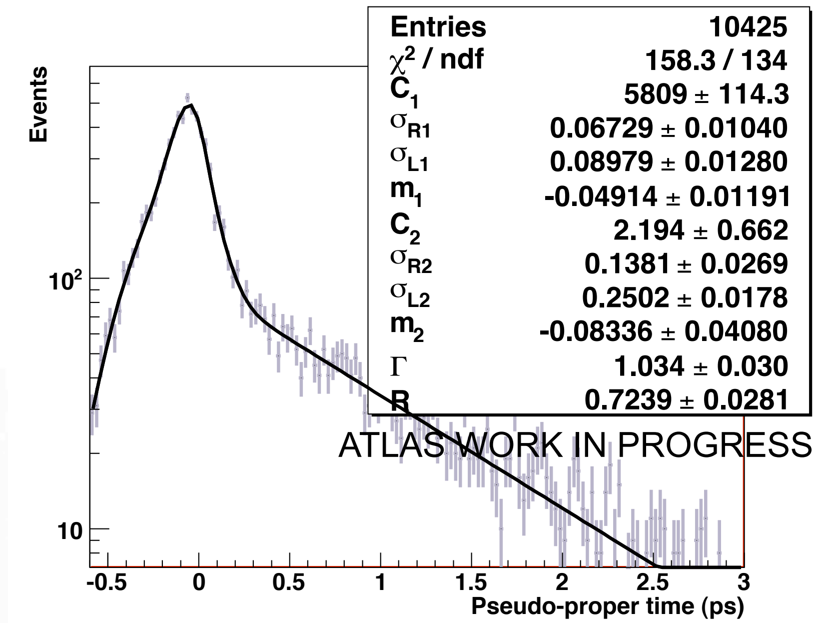
separate normalisation coefficients, C_{1C} and C_{1S}, and separate values of the ratio, R_C and R_S.

Separate Fit

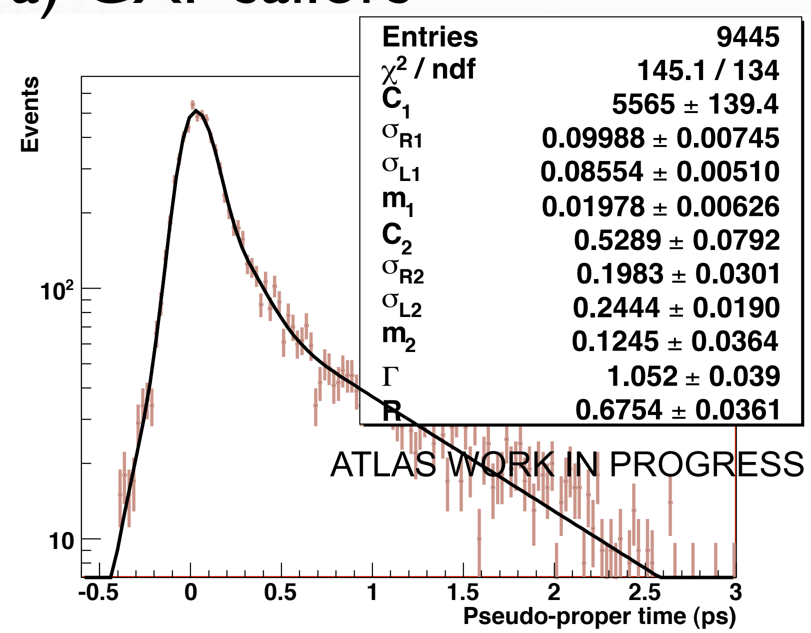
Separate fit of cowboy and sailor distributions



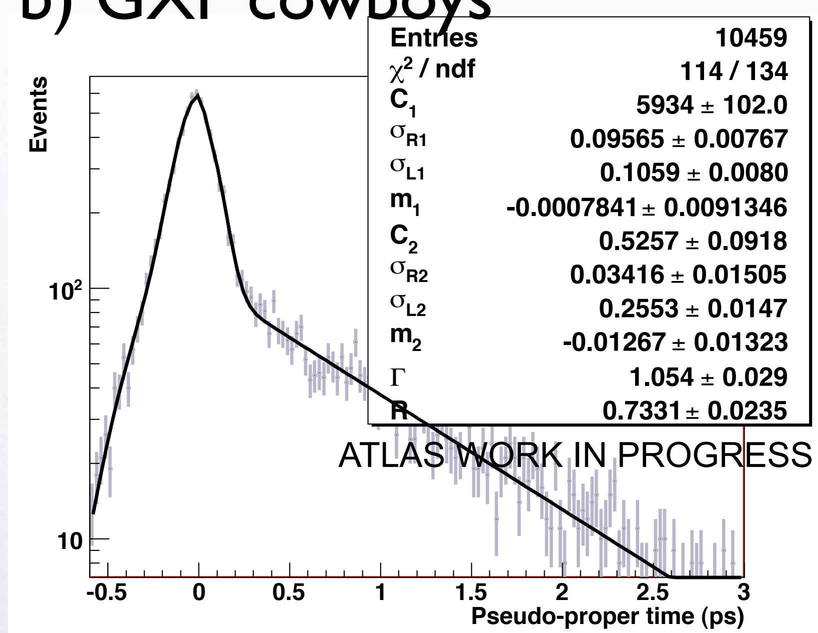
a) GXF sailors



b) GXF cowboys



c) AggDNA sailors



d) AggDNA cowboys

Resolution function used is the sum of two asymmetric gaussians.

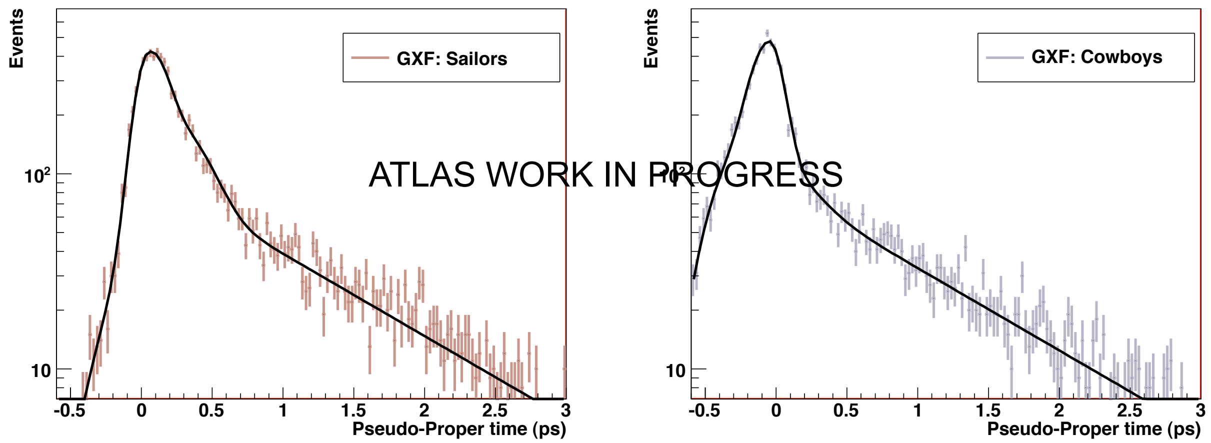
Sailors a) and c)
GXF does not fit a reasonable exponential tail and returns too large Γ value

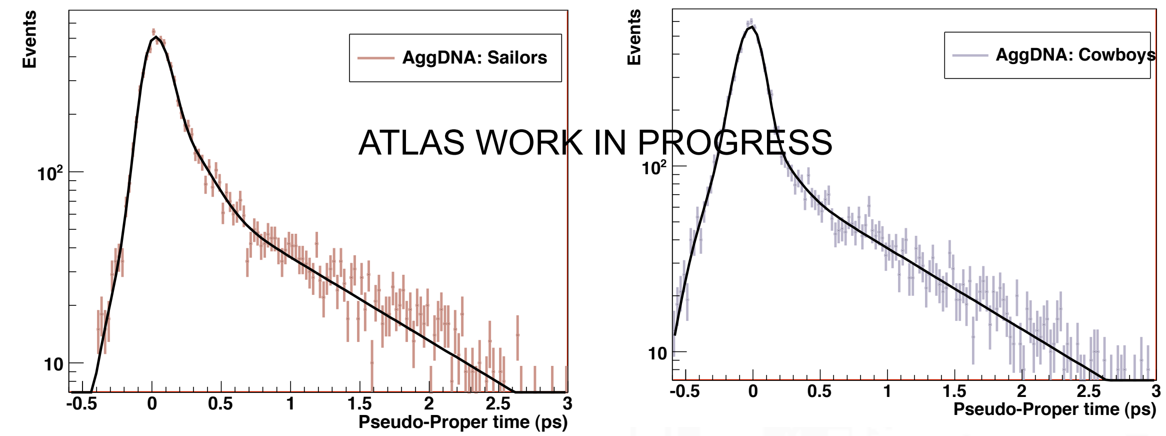
Cowboys b) and d)
GXF left hand tail much reduced by AggDNA.

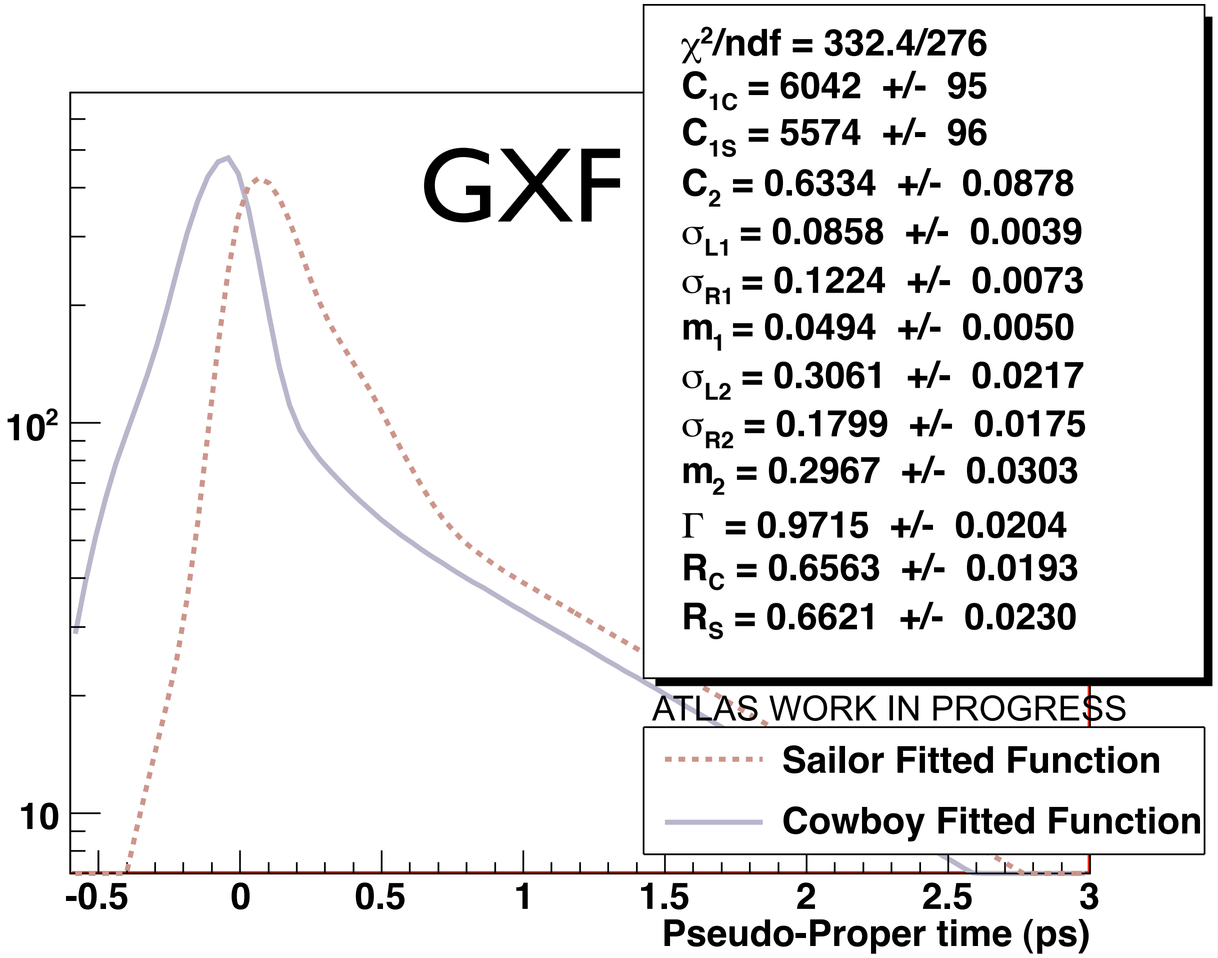
Separate fits of cowboys and sailors therefore unsatisfactory and should be improved by simultaneous fit

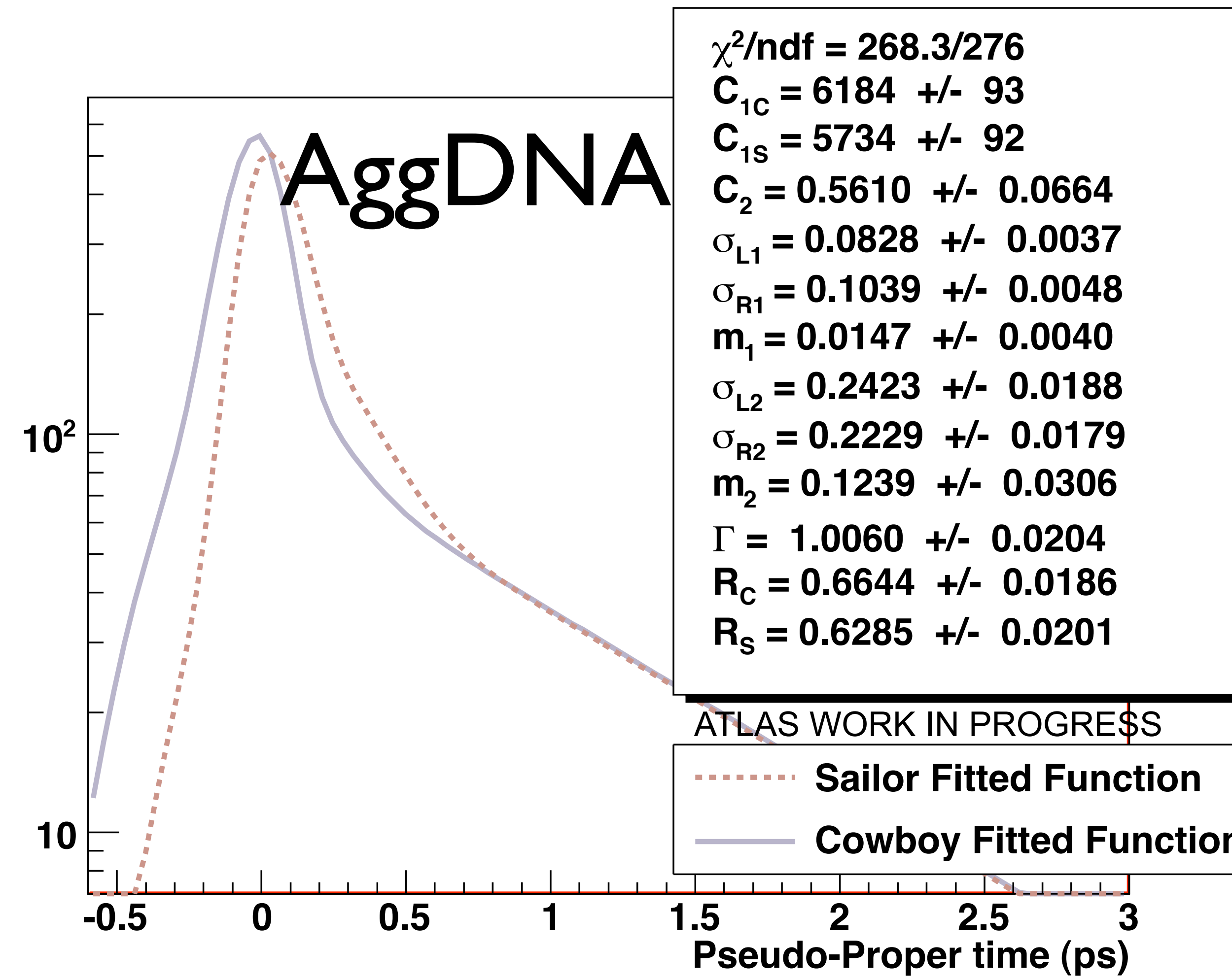
Simultaneous Fit

Simultaneous fit of cowboy and sailor distributions







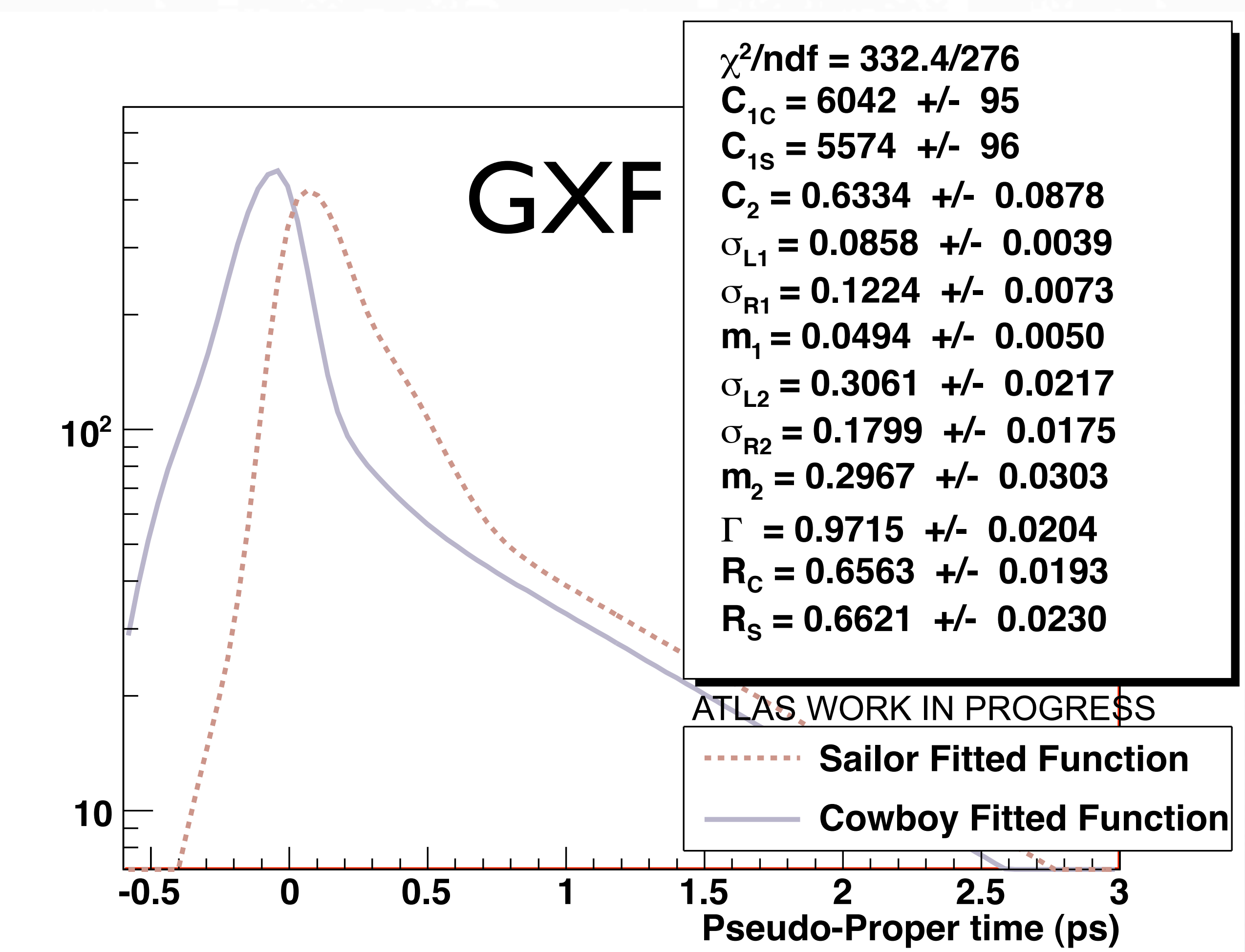


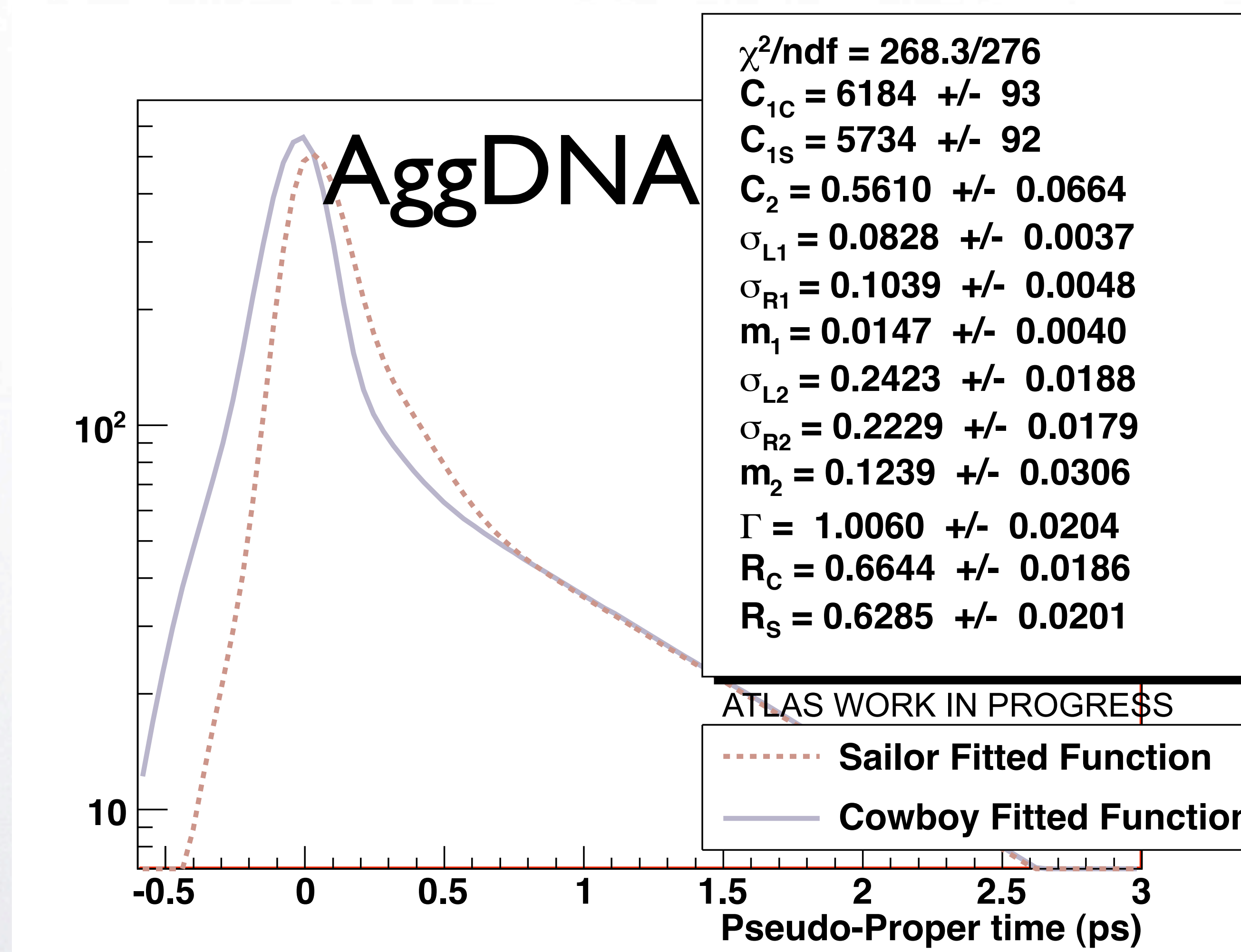
Simultaneous Fit

Simultaneous fit of cowboy and sailor distributions

AggDNA results in

- improved resolutions for both gaussian contributions
- closer peaks for cowboys and sailors
- Matching exponential tail for cowboys and sailors





Ratio indirect to prompt J/ψ

Normalisation coefficient, C_1, estimates the number of prompt J/ψ.
The value obtained from the fit is an underestimate in all cases.
AggDNA simultaneous fit of cowboys and sailors returns closest estimate to input.

	All	Cowboys	Sailors
GXF	11910 ± 147	6042 ± 95	5574 ± 96
GXF input	12380 ± 111	6414 ± 80	5966 ± 77
AggDNA	12050 ± 135	6184 ± 93	5734 ± 92
AggDNA input	12416 ± 111	6437 ± 80	5979 ± 77

Results for C_1 are shown from fitting all J/ψ candidates in the barrel and from simultaneously fitting cowboys and sailors.

The ratio of indirect to prompt J/ψ, *R, is* much improved by using AggDNA and fitting cowboys and sailors simultaneously.

	All	Cowboys	Sailors
GXF	0.640 ± 0.015	0.656 ± 0.019	0.662 ± 0.023
GXF Input	0.600 ± 0.009	0.625 ± 0.013	0.573 ± 0.012
AggDNA	0.643 ± 0.014	0.664 ± 0.019	0.629 ± 0.020
AggDNA Input	0.603 ± 0.009	0.625 ± 0.013	0.580 ± 0.012

Results for *R*.

The input values are slightly different for the two fitters since AggDNA reconstructs slightly more high-quality electron candidates compared with GXF.

Summary

Reconstructed L_{xy} depends on track kinematics.
Sailors, having $\sin(\phi_+ - \phi_-) > 0$, have a tendency of increasing L_{xy}.
Cowboys, having $\sin(\phi_+ - \phi_-) < 0$, have a tendency of reducing L_{xy}.
This effect is due to bremsstrahlung.

Measurement of the ratio $$\mathcal{R} = \frac{d\sigma(bb \rightarrow J/\psi(ee))}{d\sigma(pp \rightarrow J/\psi(ee))}$$

is shown to be possible using a resolution function with two gaussians.
Once the events are separated into cowboys and sailors the fitting function needs to be modified to take into account the asymmetry of the gaussians and their peak shift from zero.
A simultaneous fit of the pseudo-proper time distributions for cowboys and sailors results in a 12 parameter function with 6 parameters cross-fed.

This results in some improvement in determination of the ratio and an important improvement in understanding some electron-specific systematic effects.

Back-up Slides

Ratio function

A function to describe the pseudo-proper time distribution of prompt and indirect J/ψ.

$$f(t) = C_1 \cdot r(t) \otimes \left[\delta(t) + \mathcal{R} \cdot \Gamma \cdot \exp\left(-\Gamma t\right)\right]$$

with a resolution function of a single symmetric gaussian

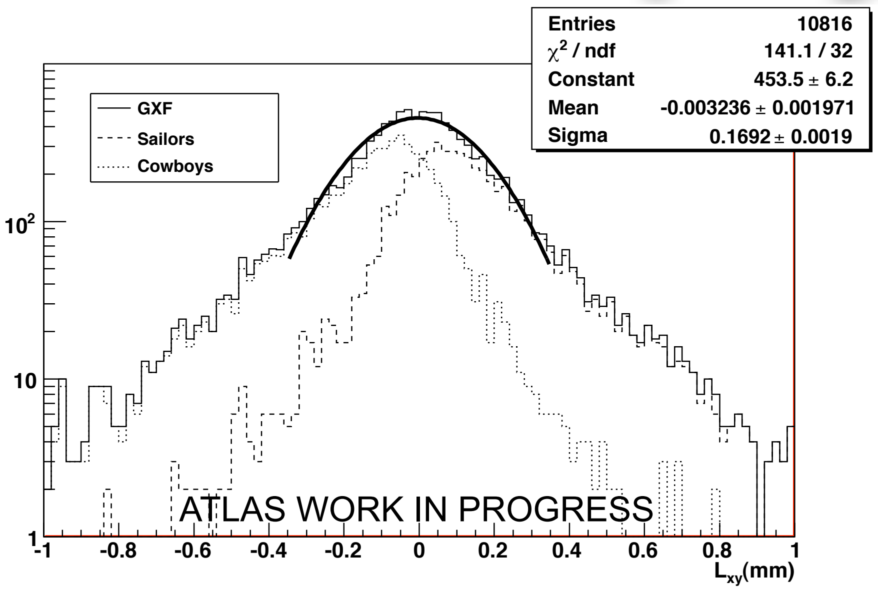
$$r(t) = \frac{1}{\sqrt{2\pi}\sigma} \cdot \exp\left(\frac{-t^2}{2\sigma^2}\right)$$

Results in the following function

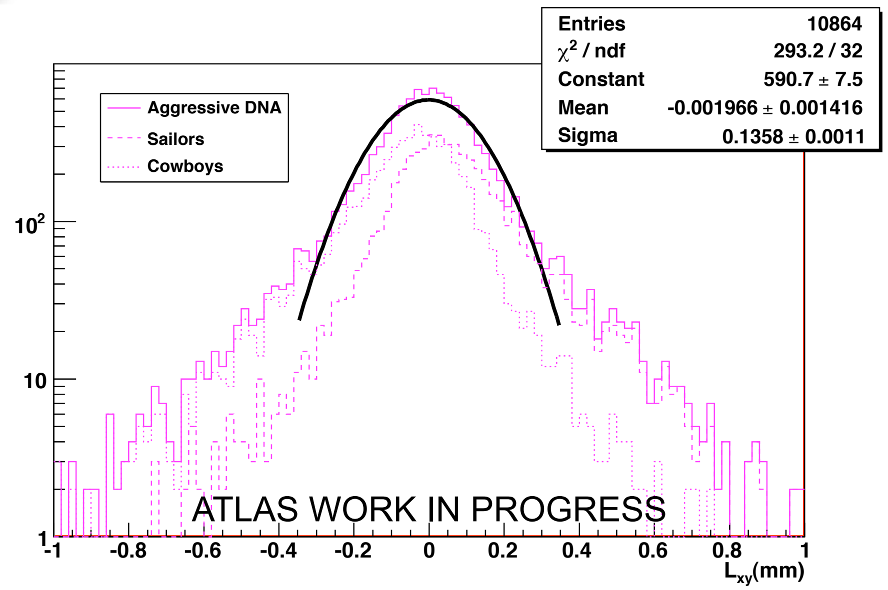
$$\begin{aligned} f(t) &= \frac{C_1}{\sqrt{2\pi}\sigma} \cdot \exp\left(-\frac{t^2}{2\sigma^2}\right) \\ &+ \mathcal{R} \cdot C_1 \cdot \Gamma \cdot \exp\left(\frac{\Gamma^2\sigma^2}{2} - \Gamma t\right)\frac{1}{2}\left[1 + \mathrm{erf}\left(\frac{t - \Gamma\sigma^2}{\sqrt{2}\sigma}\right)\right] \end{aligned}$$

where erf is the error function,
C_1 is the overall normalisation coefficient which estimates the number of prompt J/ψ,
σ is the resolution of the gaussian prompt contribution,
Γ is the slope of the exponential from the indirect contribution.

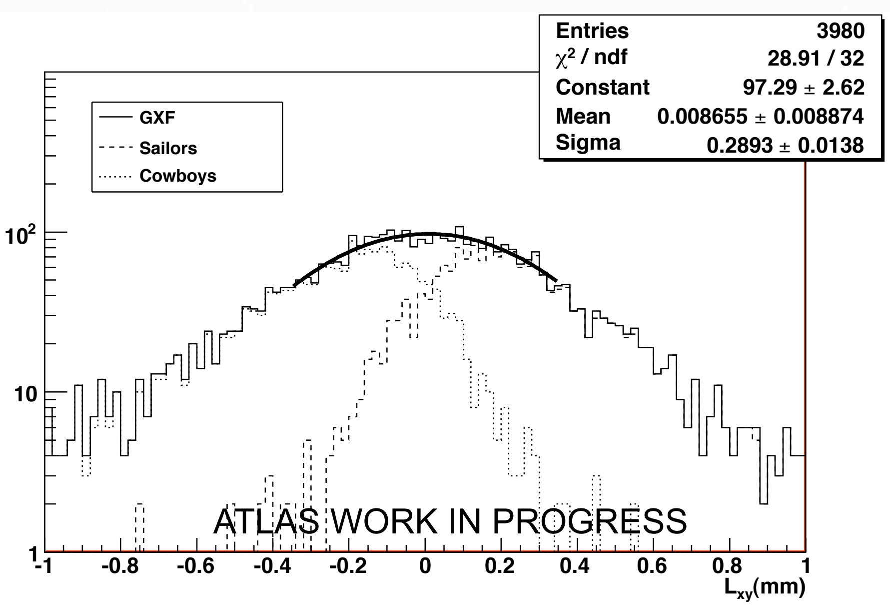
Prompt Jpsi resolutions



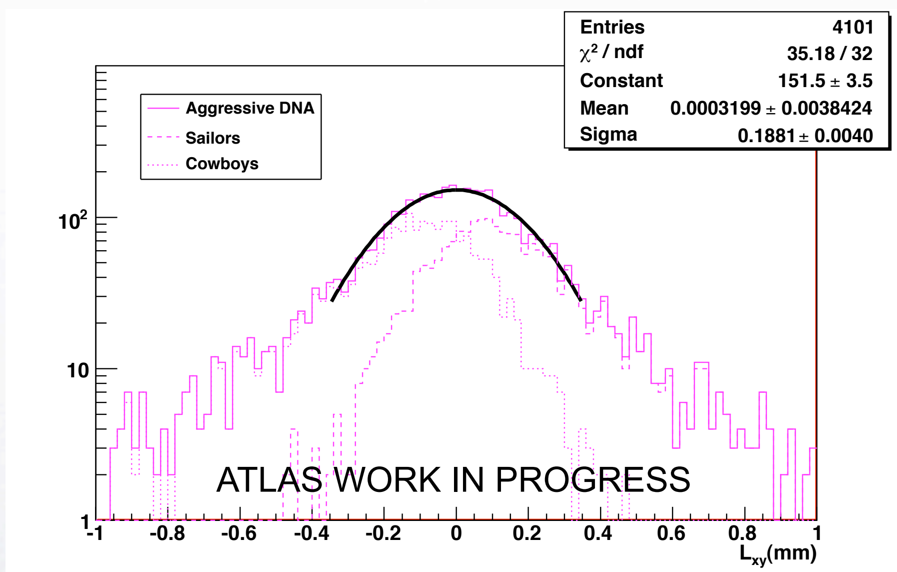
a) GXF barrel (|η|<1)



b) AggDNA barrel (|η|<1)



c) GXF |η|>1



d) AggDNA |η|>1

Prompt J/ψ.

L_{xy} distributions for events in the barrel where electrons from J/ψ candidates pass ATLAS `Medium' electron quality cuts.

Resolution better in barrel (|η|<1) than at large η and improved by using AggDNA.