Upsilon Production Cross Section Measurement at CMS

3PY
the Peking + Princeton + Purdue Upsilon Analysis team

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Upsilon Analysis Group

- the three groups had produced three analyses independently
  - AN-2009/066, AN-2009/118, AN-2009/119(+AN-2009/064)
- were invited by the B Physics Analysis Group and Quakonia Task Force conveners to merge
- and produce a reference analysis to become the first $\Upsilon(nS) \to \mu\mu$ cross section measurement with early data
- having several groups doing the same analysis independently is a real strength, allowing many cross checks and division of labor
- the groups are working very well together
- and 'naturally' converging in common criteria and results
- paper draft is advancing at good pace
- Completed first attempt at draft 1 (end of July 2009), draft 2 is due end of August 2009.

Motivation

1. Large cross section of Upsilon production allows its measurement in early data at a new energy scale of 10TeV
2. Production mechanism of Upsilons is not understood
3. LHC with high luminosity and large p_T Upsilons has the potential to discriminate between the theoretical models
4. Upsilons are also used for calibration and alignment of the detector

Strategy of Υ Cross Section Measurement

The differential cross section multiplied by the branching fraction for $\Upsilon \to \mu^+\mu^-$ is calculated in each bin of transverse momentum and rapidity using the equation

$$\frac{d^2\sigma}{dp_T dy}\mathrm{Br}(\Upsilon \to \mu^+\mu^-) = \frac{N_{\mathrm{corrected}}(p_T, y)}{(\int \mathscr{L} dt) \cdot \varepsilon_{\mathrm{rec}} \Delta p_T \Delta y} \quad (1)$$

- $N_{\mathrm{corrected}}(p_T, y)$ is the corrected yield (see details on next slide)
- $\varepsilon_{\mathrm{rec}}$ is the $\Upsilon \to \mu^+\mu^-$ reconstruction efficiency, which contains contributions from those effects that do not depend on the transverse momentum or rapidity of the individual muons.

$$\varepsilon_{\mathrm{rec}} = \varepsilon_{\mathrm{hit}}^2 \varepsilon_{\mathrm{rad}} \varepsilon_{z_0} \varepsilon_{\Delta z} \quad (2)$$

  - $\varepsilon_{\mathrm{hit}}$: efficiency with which tracks contained in the detector acceptance are found by the tracking algorithms
  - $\varepsilon_{\mathrm{rad}}$: inefficiency due to events migrating out of the Υ peak due to internal final state radiation in the Υ decay
  - ε_{z_0}: efficiency of the restriction on the position of the primary vertex along the z axis
  - $\varepsilon_{\Delta z}$: efficiency with which the two muons satisfy the requirement on Δz.
- $\int Ldt$ is the integrated luminosity.
- Δp_T and Δy are the transverse momentum and rapidity bin widths, respectively.

ready,still in study

How to Extract Corrected Yield ($N_{corrected}$)

$N_{\text{corrected}}(p_T, y)$ is determined by fitting the $\mu^+\mu^-$ invariant mass distribution that is obtained by weighting individual events by p_T and rapidity-dependent factors:

$$N_{\text{corrected}}(p_T, y) = \sum_{i=1}^{N_s} \frac{1}{w_i}$$

$$w_i = \varepsilon_{\text{HLT\_Mu3}} \varepsilon_{\text{Id}}(p_T^{\mu^+}, \eta^{\mu^+}) \varepsilon_{\text{Id}}(p_T^{\mu^-}, \eta^{\mu^-}) \mathscr{A}(p_T^{\Upsilon}, y^{\Upsilon}, \alpha).$$

- ε_{Id}: efficiency with which a muon in the fiducial acceptance of the tracker is reconstructed as a tracker muon
- $\varepsilon_{\text{HLT\_Mu3}}$: efficiency with which the event is selected by the `HLT_Mu3` trigger

$$\varepsilon_{\text{HLT\_Mu3}} = \varepsilon_{\text{HLT\_Mu3}}(p_T^{\mu^+}, \eta^{\mu^+}) + \varepsilon_{\text{HLT\_Mu3}}(p_T^{\mu^-}, \eta^{\mu^-}) - \varepsilon_{\text{HLT\_Mu3}}(p_T^{\mu^+}, \eta^{\mu^+}) \cdot \varepsilon_{\text{HLT\_Mu3}}(p_T^{\mu^-}, \eta^{\mu^-})$$

- $\mathscr{A}(p_T, y, \alpha)$ is defined as the detector acceptance: (<u>in backup slides</u>)

$$\mathscr{A}(p_T, y, \alpha) = \frac{N_{\text{rec}}(p_T, y)}{N_{\text{gen}}(p'_T, y', \alpha)}$$

Event Selection

- Offline Selection Cuts
  - Low Pt Muon ID:
    - muon p_T > 3.0 GeV
    - muon |eta| < 2.1
    - number of valid silicon track hits > 10
    - silicon track chi2/ndof < 5
    - |d0|<0.5cm, |Z0|<25cm, |Dz0|<2cm
    - pass the TMOneStationTight Muon Id algorithm
  - Υ(nS) Selection
    - event passes the single muon HLT with p_T > 3GeV
    - both muons pass low p_T muon ID criteria
    - both muons with opposite charge
    - upsilon mass: 8-12 GeV

Z.Gecse, N.Adam, A.Hunt

Calculating Efficiencies(ε_{HLT_Mu3}, ε_{Id})

- We use Tag and Probe(TnP), a data driven method, to determine efficiencies from physics processes.
  - one of the muons is defined as "Tag" using tight identification criteria
  - the other muon, referred to as a "Probe", is used to measure the efficiency.

	Muon-Id	**Trigger**
Tag	Muon-id Matched to HLT_Mu3 $p_T > 3.0$ GeV/c $\|\eta\| < 2.1$	Muon-id Matched to HLT_Mu3 $p_T > 3.0$ GeV/c $\|\eta\| < 2.1$
Probe	General-track $p_T > 3.0$ GeV/c $\|\eta\| < 2.1$	Muon-id $p_T > 3.0$ GeV/c $\|\eta\| < 2.1$
Passing-Probe	Muon-id	Matched to HLT_Mu3

TnP Muon-Id & Trigger Efficiency

TnP probe binning

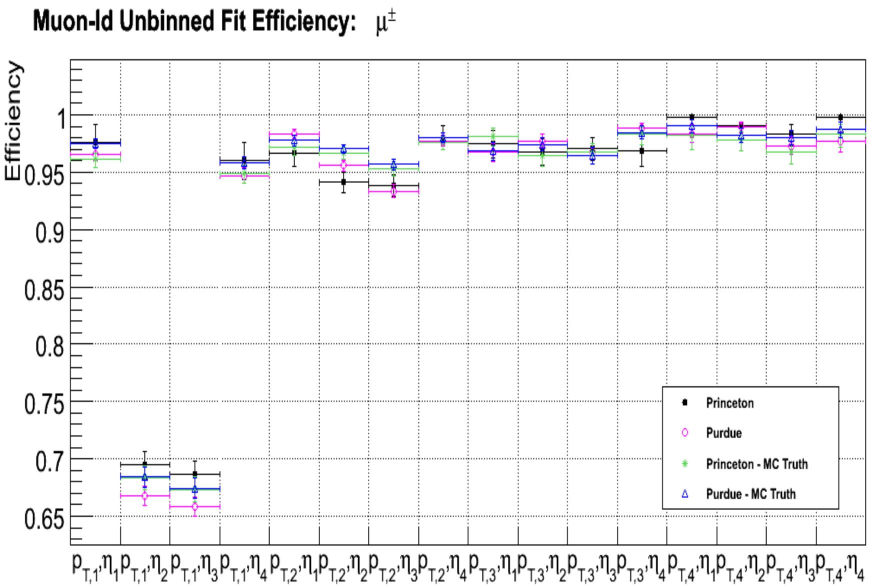
pt (4 bins): 3.0-4.5, 4.5-6.0, 6.0-8.0, 8.0-infty

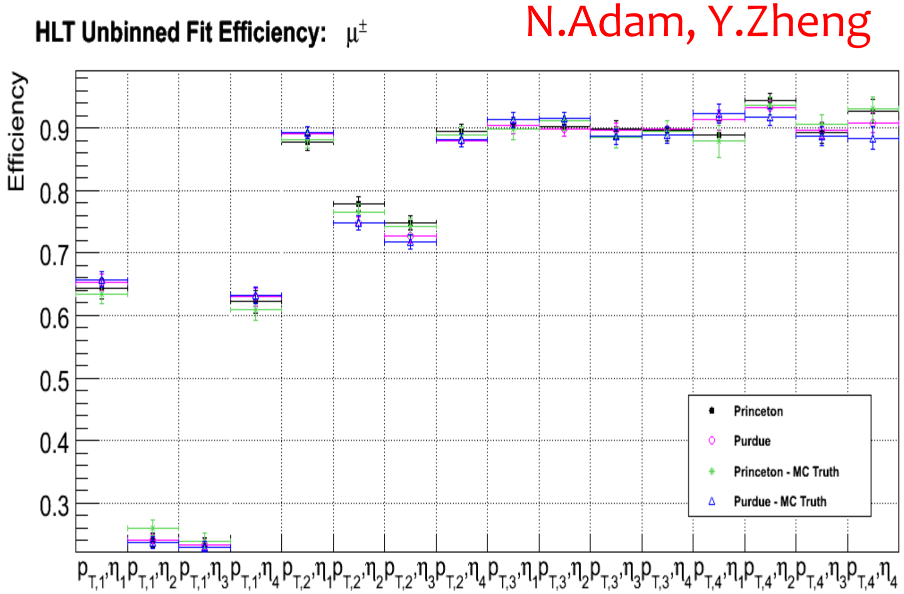
eta (4 bins): -2.1--1.2, -1.2-0.0, 0.0-1.2, 1.2-2.1

Detailed comparison of tag and probe efficiency results by two independent analysis (Purdue/Princeton)

- observe rather good agreement
- slightly different criteria for tag-probe pair selection
- plan to take (small) difference as the systematic uncertainty associated with tag and probe algorithm implementation

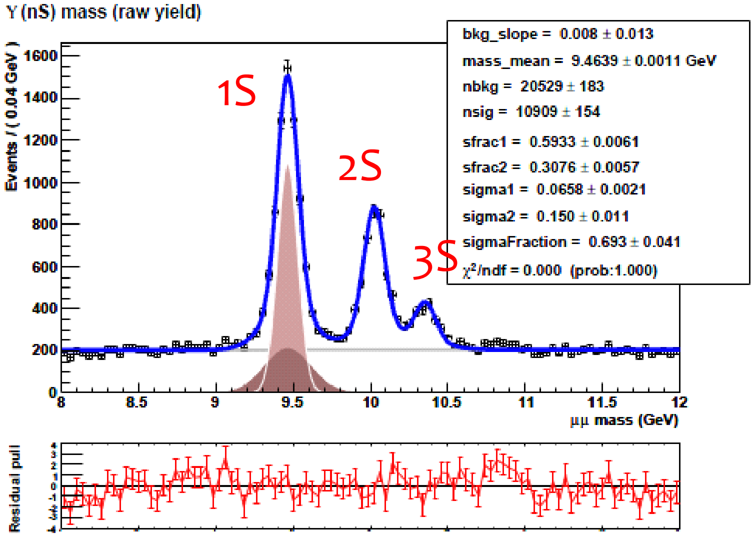
N.Adam, Y.Zheng



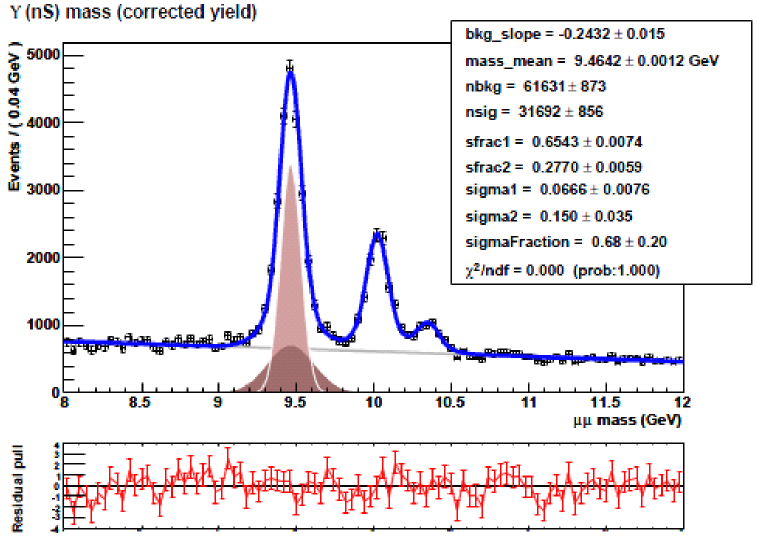


Cross Section Measurement (1)

- Corrected Yield with 1pb^{-1} sample($N_{corrected}$)



(a) Unweighted yield



(b) Yield after per event weighting

From CMS AN-2009/118 by Purdue, 3PY final results in preparation

Cross Section Measurement (2)

- Sources of Systematic Uncertainty
  - Luminosity: determined by the CMS luminosity monitoring group.
  - Statistical uncertainties: assessed by varying the weights used in the mass fit coherently by ±1σ (stat.)
  - Tag and Probe bias: the deviation between the fitted and the MC matching results measured in 15 pb^{-1} sample
  - binning in efficiency: determined by varing the bin size and repeating the measurement
  - Polarization and choice of pdf: from CMS-AN 2009-066

Source	Reference	Υ(1S)	Υ(2S)	Υ(3S)
Luminosity	[16]	10%	10%	10%
Acc. and Eff.	AN-2009/118	4.7%	3.7%	3.5%
Tag and Probe bias	AN-2009/118	4.1%	3.9%	3.1%
Polarization	AN-2009/066	1.5%	1.4%	0.7%
Choice of pdf	AN-2009/066	4.1%	4.1%	3.2%

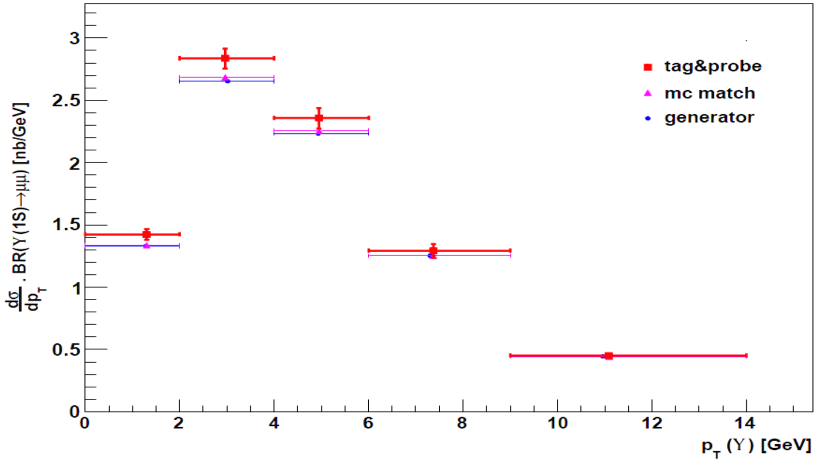
Table from CMS AN-2009/118 by Purdue, 3PY final results in preparation

Cross Section Measurement (3)

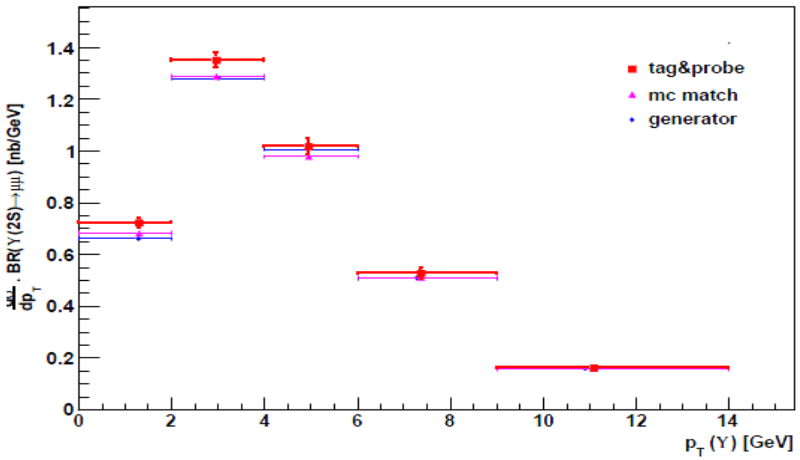
- Validation using large MC samples 15 pb^{-1}

Measurement of the differential Upsilon(1S) production cross section using the Tag and probe technique in 15 pb^{-1} sample

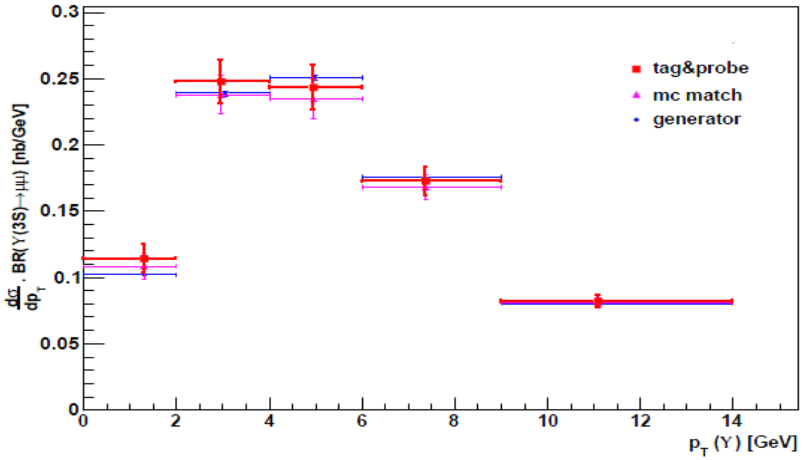
From CMS AN-2009/118 by Purdue, 3PY final results in preparation



(a) Υ(1S) differential cross section.

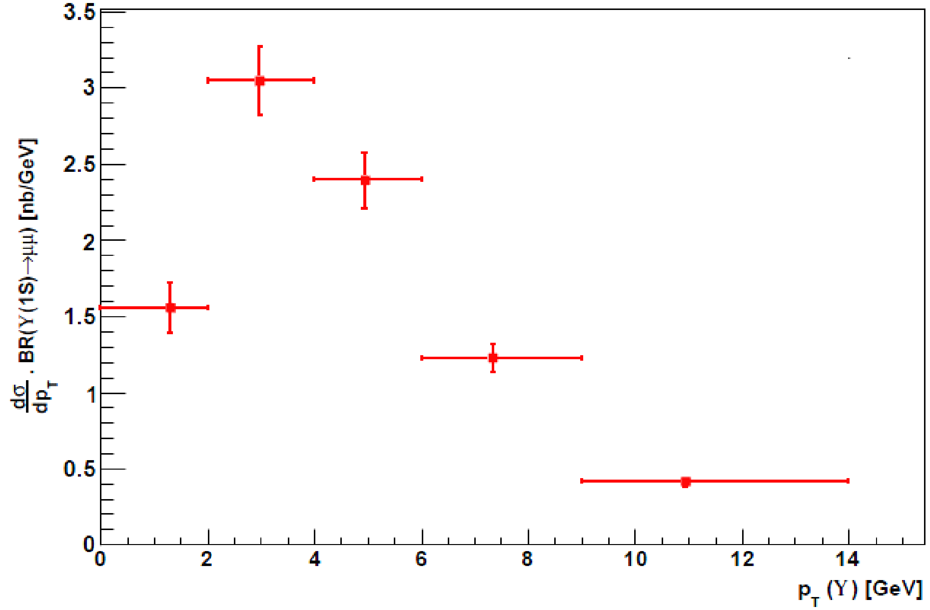


(b) Υ(2S) differential cross section.



(c) Υ(3S) differential cross section.

Upsilon(1S) Differential X-section with 1pb-1 sample



From CMS AN-2009/118 by Purdue, 3PY final results in preparation

Results for Υ(2s), Υ(3s) in backup slides

p_T^{Υ} (GeV)	cross-section (nb)	statistical uncertainty	systematic uncertainty			other syst. sources	total uncertainty
			acc. & effic.	t&p bias	combined		
$0-2$	3.112	0.255 (8.2%)	+0.116 / -0.128	0.174	6.9%	10.9%	15.3%
$2-4$	6.092	0.222 (3.6%)	+0.224 / -0.248	0.306	6.5%	11.5%	13.7%
$4-6$	4.791	0.213 (4.4%)	+0.200 / -0.224	0.207	6.4%	11.3%	13.7%
$6-9$	3.679	0.173 (4.7%)	+0.181 / -0.208	0.124	6.6%	10.1%	12.9%
$9-14$	2.075	0.094 (4.5%)	+0.094 / -0.111	0.039	5.7%	10.8%	13.0%
>14	0.969	0.063 (6.6%)	+0.051 / -0.064	0.004	6.6%	12.7%	15.7%
$0-\infty$	20.737	0.607 (2.9%)	+0.867 / -0.982	0.855	6.3%	11.0%	13.0%

Results with 1pb^{-1} sample

- From the weighted fit the integrated Upsilon(nS) production cross section is determined to be

$$\begin{aligned}
\sigma_{\Upsilon(1S)} &= \left(20.74 \pm 0.61^{+2.59}_{-2.63}\right) \text{ nb}\,, \\
\sigma_{\Upsilon(2S)} &= \left(\ 8.78 \pm 0.30^{+1.05}_{-1.06}\right) \text{ nb}\,, \\
\sigma_{\Upsilon(3S)} &= \left(\ 2.18 \pm 0.30^{+0.24}_{-0.24}\right) \text{ nb}\,,
\end{aligned}$$

with a total precision of 13%, 13%, 18%, which are in good agreements with the generator level values: 19.37 ± 0.02, 8.51 ± 0.02, and 2.35 ± 0.01 (nb), respectively for ϒ(1S), ϒ(2S), and ϒ(3S).

From CMS AN-2009/118 by Purdue, 3PY final results in preparation

Summary

- We studies the feasibility of the Upsilon cross section measurement:
  - TnP study of Muon-Id and trigger efficiencies
  - Cross section calculation with per-event weighting
  - Unbinned maximum likelihood fit of invariant mass with double Gaussians and linear background
  - Systematics due to statistical uncertainties and binning of efficiencies
  - validated in 15/pb, demonstrated in 1/pb sample
  - Completed Draft 1 (reference BPH-09-003)
- Next step:
  - Rerun all the analysis with common criteria.
  - Systematics study due to polarization and other sources.
  - Many cross checks within the whole group.
  - Completing draft 2 by the end of August.

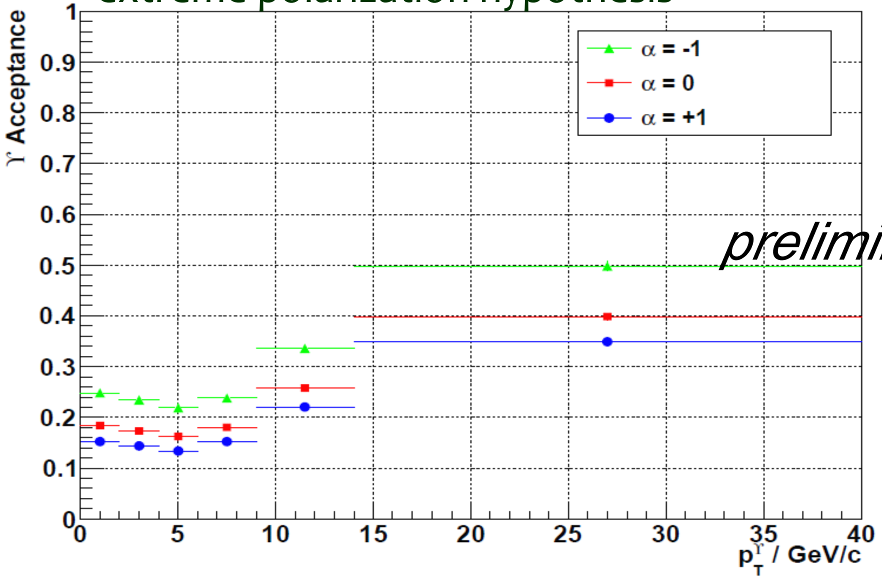
BACK UP

Acceptance and Polarization($A(p_T,y,\alpha)$)

- Currently the acceptance is computed assuming no net polarization of the Υ.
- proposal for estimating systematic effect due to the unknown ϒ polarization (P.Faccioli, C.Lourenco et al)
  - calculate acceptance as function of polar and azimuthal angles in two different frames
  - choose frame with largest variation in acceptance
  - evaluate systematic uncertainty by extreme polarization hypothesis

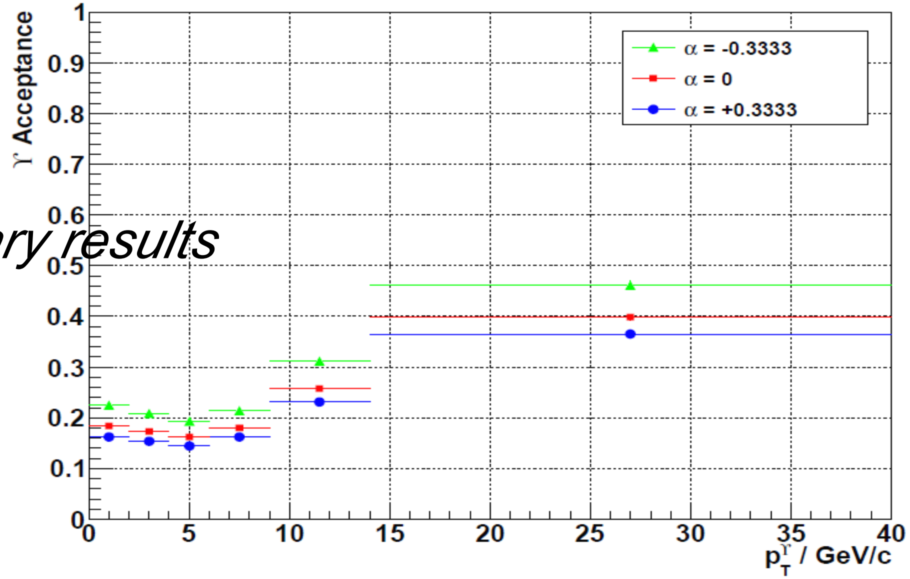
S.Guo, Z.Hu

Acceptance as a function of p_T for three extreme polarization hypothesis

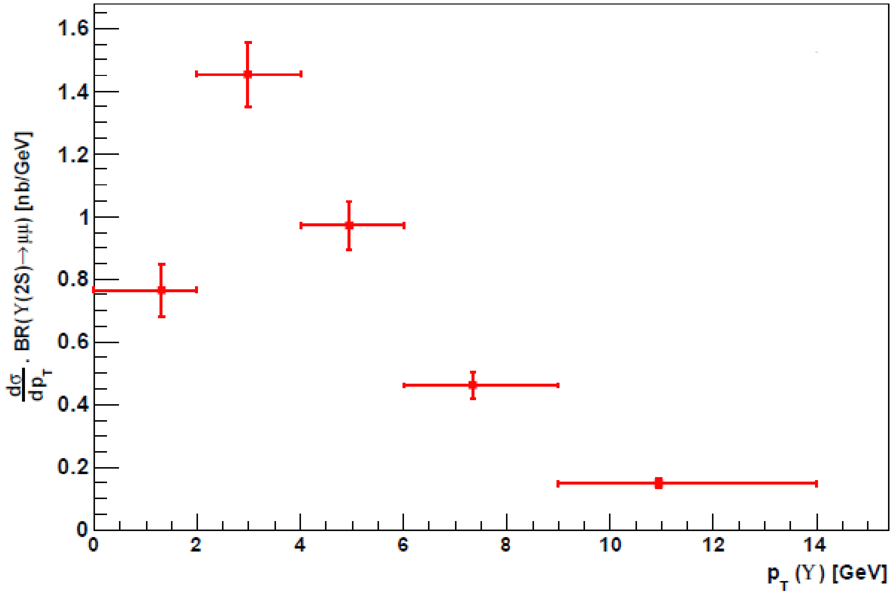


preliminary results

When the input α = ±1/3, the uncertainty band is narrowed down

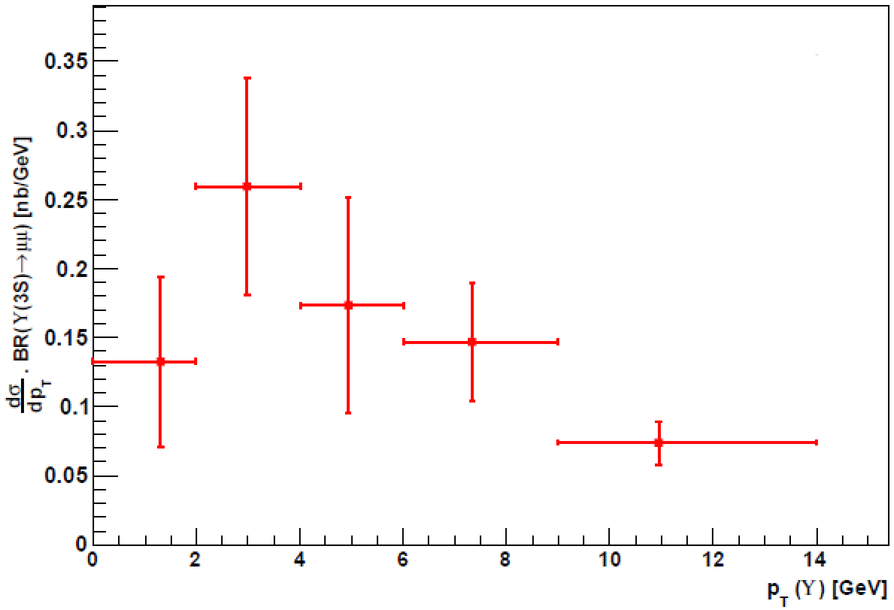


Upsilon(2S) Differential X-section with 1pb-1 sample



p_T^{Υ} (GeV)	cross-section (nb)	statistical uncertainty	systematic uncertainty acc. & effic.	t&p bias	combined	other syst. sources	total uncertainty
$0-2$	1.529	0.135 (8.8%)	+0.042 / -0.046	0.080	6.1%	10.9%	15.3%
$2-4$	2.905	0.135 (4.7%)	+0.077 / -0.086	0.125	5.2%	11.5%	13.5%
$4-6$	1.943	0.123 (6.3%)	+0.061 / -0.068	0.075	5.2%	11.3%	13.9%
$6-9$	1.386	0.097 (7.0%)	+0.053 / -0.060	0.046	5.4%	10.1%	13.4%
$9-14$	0.743	0.056 (7.5%)	+0.035 / -0.041	0.013	5.8%	10.8%	14.4%
> 14	0.310	0.034 (11.0%)	+0.018 / -0.023	0.001	7.4%	12.7%	18.4%
$0-\infty$	8.779	0.301 (3.4%)	+0.286 / -0.324	0.341	5.4%	10.9%	12.6%

Upsilon(3S) Differential X-section with 1pb-1 sample



p_T^{Υ} (GeV)	cross-section (nb)	statistical uncertainty	systematic uncertainty acc. & effic.	t&p bias	combined	other syst. sources	total uncertainty
$0-2$	0.265	0.123 (46.2%)	+0.008 / -0.008	0.011	5.4%	10.9%	47.8%
$2-4$	0.519	0.155 (29.9%)	+0.015 / -0.017	0.020	5.0%	11.5%	32.5%
$4-6$	0.347	0.155 (44.7%)	+0.010 / -0.011	0.017	5.8%	11.3%	46.5%
$6-9$	0.440	0.127 (28.8%)	+0.015 / -0.017	0.013	4.9%	10.1%	30.9%
$9-14$	0.369	0.076 (20.6%)	+0.013 / -0.015	0.006	4.3%	10.8%	23.6%
>14	0.214	0.048 (22.4%)	+0.008 / -0.009	0.001	4.4%	12.7%	26.1%
$0-\infty$	2.177	0.304 (14.0%)	+0.067 / -0.076	0.067	4.7%	10.2%	17.9%