The inclusive differential cross section of $p\bar{p} \to \Upsilon(1S)$ at $\sqrt{s} = 1.96$ TeV

Freya Blekman
for the DØ collaboration

Outline:

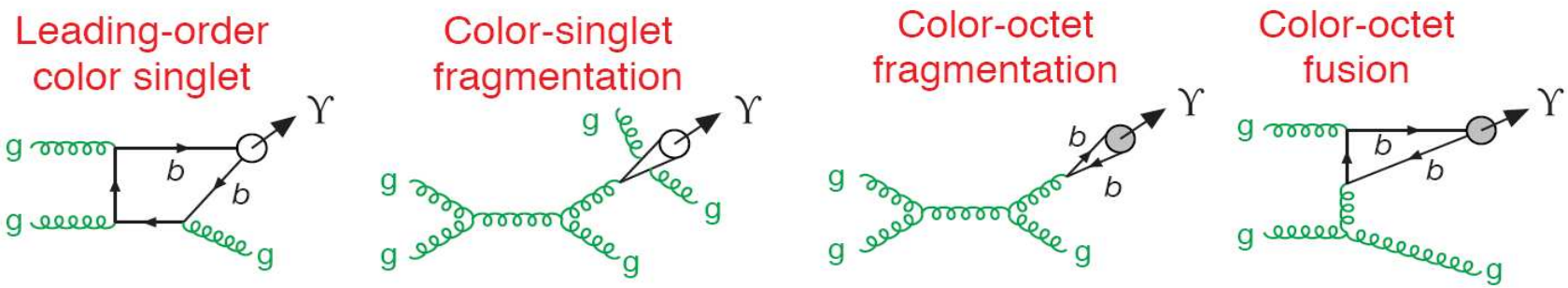
- Context
- Experimental setup
- Muons
- Efficiencies
- Results

Reference: PRL 94, 232001 (2005), hep-ex/0502030

Context

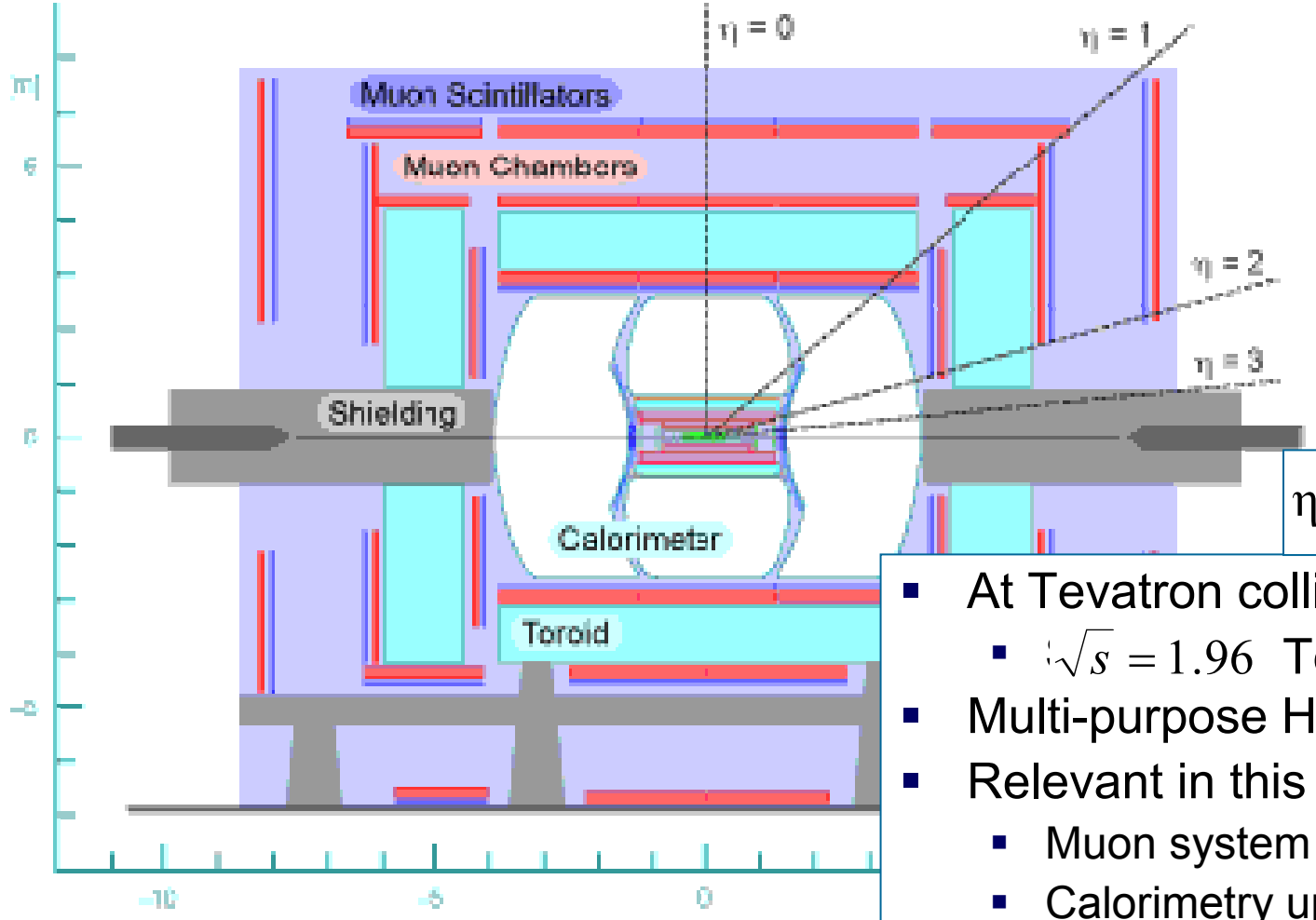
- $\Upsilon(1S) = b\bar{b}$ bound state
- First measurement at 1.96 TeV
  - Rapidity range:
    - Up to |y|<1.8
- CDF measured in Tevatron run 1 (1.8 TeV)
  - Limited rapidity range:
    - |y|<0.4
- Perturbative QCD:
  - Only works at large momenta of Υ
  - Typical Tevatron events:
    - pQCD not valid due to initial state gluons
- Plethora of non-pertubative phenomenological models

Υ production models



- Υ production ideal testing ground for heavy quark production mechanisms
- These models predict shape of Υ differential cross section distribution vs p_T and rapidity y

The DØ detector



$$\eta = -\ln\left(\tan\left[\theta/2\right]\right)$$

- At Tevatron collider
  - $\sqrt{s} = 1.96$ TeV
- Multi-purpose HEP detector
- Relevant in this presentation:
  - Muon system up to |η|<2
  - Calorimetry up to |η|<3
  - Tracking up to |η|<2

Detector: Details

Silicon Tracker

- R<10 cm
- Silicon microstrips
  - Pitch 50-80 μm
  - Barrels and disks

Fibre Tracker

- R<52 cm
- Scintillating fibers
  - Barrel only

Central magnet

- 2T solenoid

Calorimeter

- Liquid argon + Uranium

Muon system

- Drift tubes
  - Three layers
- Scintillating counters
  - Between drift tube layers
- 1,8T toroid

Trigger

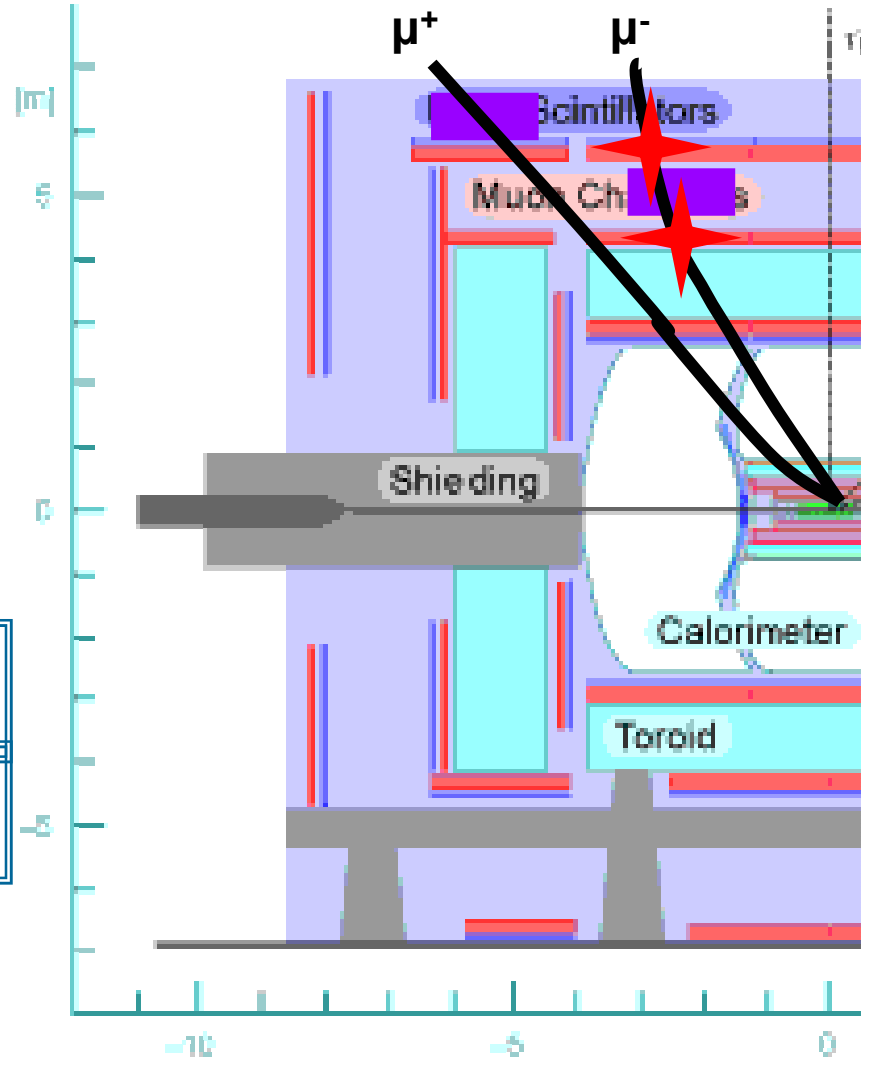
- Three-level trigger. Reduction from 1.7MHz to 50 Hz

Dataset

- Use small subset of data, collected in 2002-2003
- Integrated luminosity:

  $L = 159 \pm 10\ \text{pb}^{-1}$

  - Measurement systematics limited
- Trigger:
  - Di-muon triggers
    - L1: two scintillator triggers (eff=100%)
    - L2: at least one μ confirmed (eff >97%)
  - 100% efficiency after offline cuts for 2 μ final state



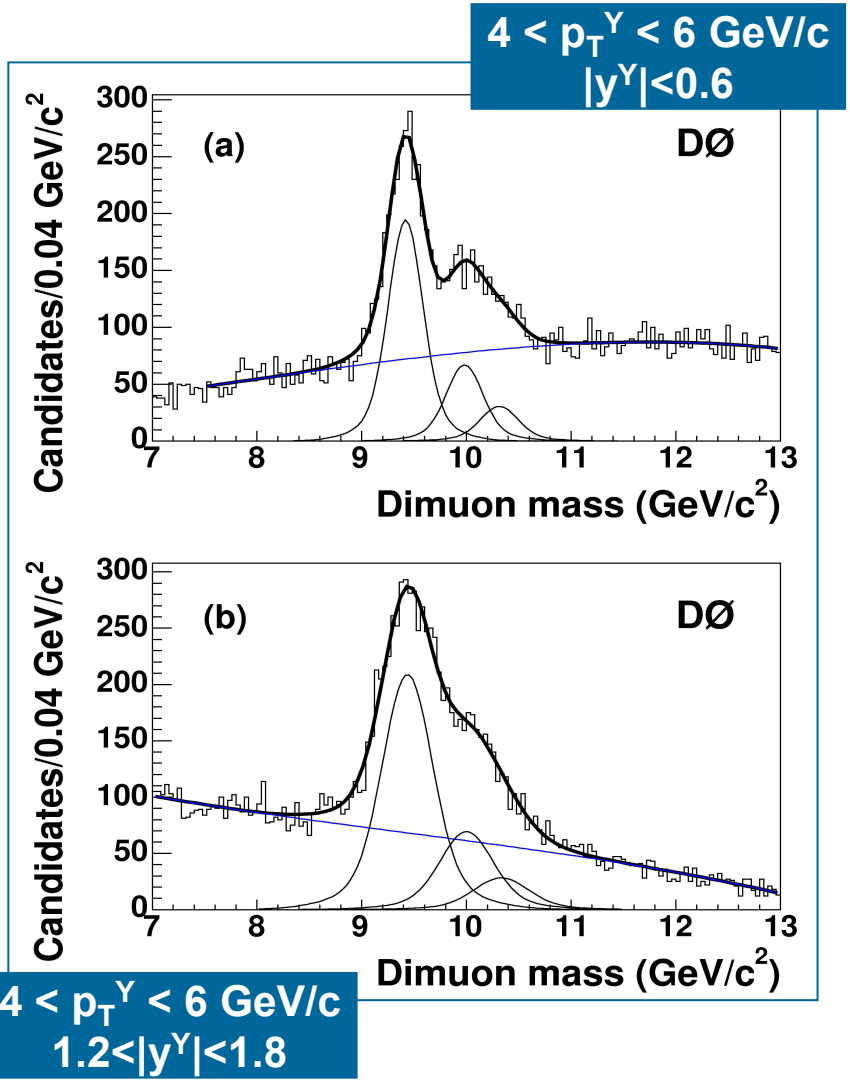
Muons

- Muons:
  - $p_T^{\mu} > 3$ GeV/c
  - $|y^{\mu}| < 2.2, \; y = \frac{1}{2}\ln\frac{E+p_z}{E-p_z}$
  - Central track match
    $\Rightarrow$ with one silicon hit
  - No cosmics (timing)
  - Isolation ($p_T^{R<0.5} < 1$GeV/c)
    $\Rightarrow p_T^{R<0.5}$:tracking or calorimeter
    Only applied to one μ

- Reconstruct Υ :
  - Two muons, opp. sign
  - Mass range in bins of y and p_T
  - Fit $\Upsilon(1S)$ candidates for each bin
  - Free parameters in fit:
    - mass $\Upsilon(1S)$
    - Number of
      - $\Upsilon(1S)$
      - $\Upsilon(2S)/\Upsilon(1S)$
      - $\Upsilon(3S)/\Upsilon(2S)$
    - Width $\Upsilon(1S)$

Fit procedure: details

- Mass distribution of Υ :
  - Fit Υ(1S,2S,3S) with three double Gaussians
    - Mass difference fixed (PDG)
    - Width of Υ(2S,3S) fixed to width Υ(1S)
    - 7.0-7.8 < M_Υ < 13 GeV/c^2 , depends on p_T and y
  - Background: Polynomial (3D)
  - Only use Υ(1S) for cross section
    - Three bins in y, many in p_T
    - Count number of Υ per bin: ***N(Υ(1S))***
- Limited mass resolution:
  - Υ(2S) and Υ(3S) difficult to separate



Cross section

$\lvert y_{\Upsilon} \rvert$	$d\sigma(\Upsilon(1S))/dy$ [pb]
0.0 – 0.6	732 ± 19 (stat) ± 73 (syst) ± 48 (lum)
0.6 – 1.2	762 ± 20 (stat) ± 76 (syst) ± 50 (lum)
1.2 – 1.8	600 ± 19 (stat) ± 56 (syst) ± 39 (lum)
0.0 – 1.8	695 ± 14 (stat) ± 68 (syst) ± 45 (lum)

Cross sections normalized per unit of rapidity

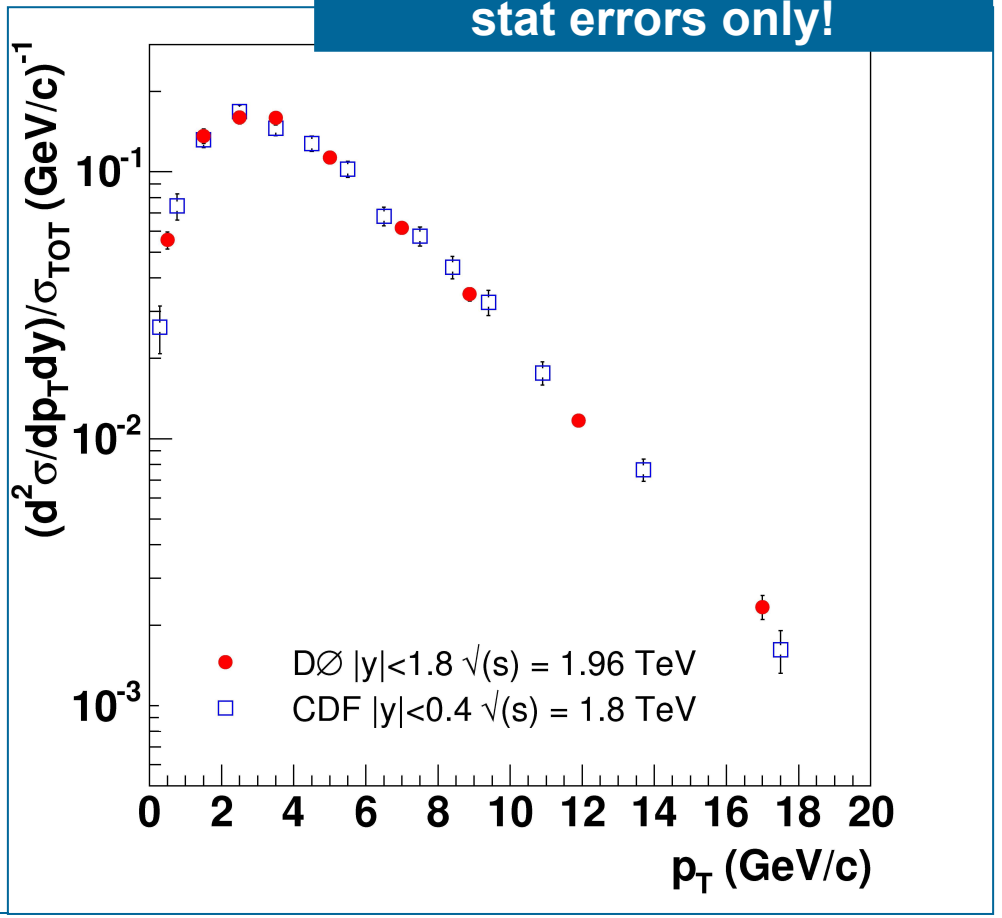
- Statistical uncertainty:
  - Includes fit uncertainty on $N(\Upsilon(1S))/N(\Upsilon(2S))$
- Systematic uncertainties:
  - Typical: total 10%
  - Main contributions:
    - Fit procedure
    - Difference MC/data
  - Luminosity: 6.5%

Previous results: Comparison

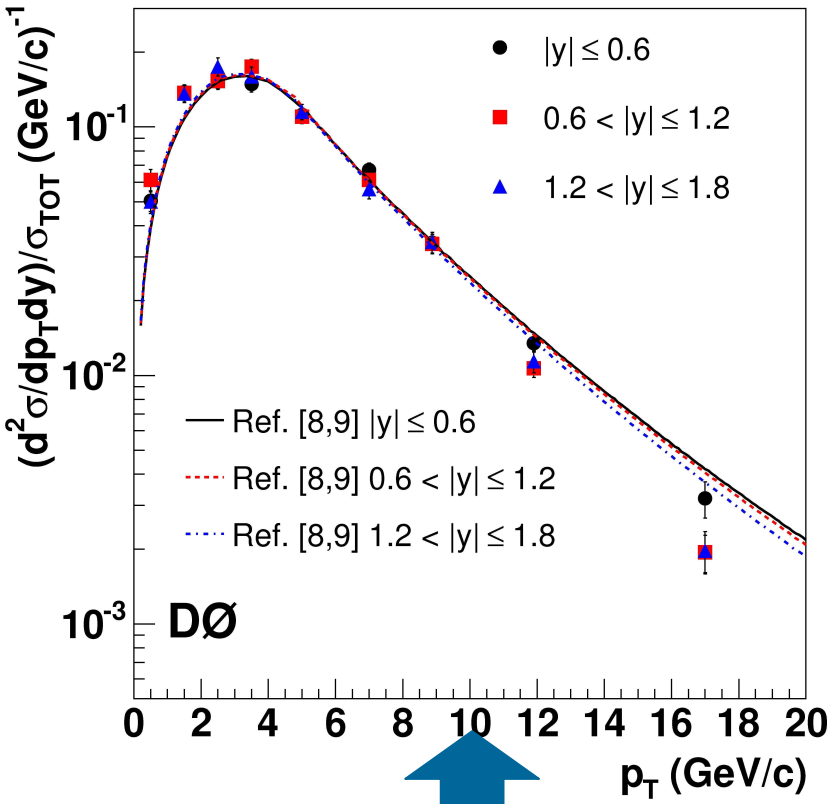
- CDF Run 1 measurement almost compared to DØ Run 2 first rapidity bin
- After correction for $\sqrt{s} = 1.8 \rightarrow 1.96$ TeV

  results are consistent

Comparison to CDF Run 1
680±15(stat) ±18(syst)±26(lum)
[Phys.Rev.Lett. **88**, 2094(2002)]
stat errors only!



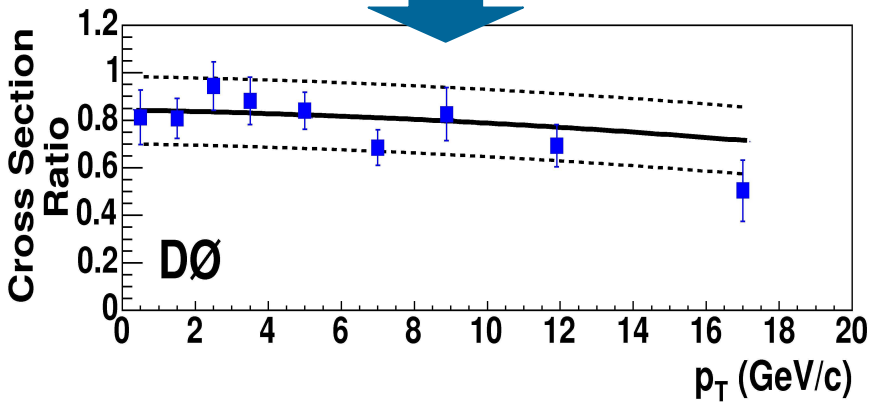
Comparison to theory



Comparison to Theory (COM) [hep-ph/0411026,0404158]

- No polarization of Υ considered
  - $\alpha = -0.12 \pm 0.22$ [CDF, see p8]
  - Variation of α (± 0.15, ± 0.30), changes result by 4%, 15%
    - Independent of p_T

Only change in cross section amplitude versus y, no significant pT dependence. agrees with PYTHIA (line, CSM)



Conclusions

- The DØ collaboration has measured the differential cross section of $\Upsilon(1S)$ bottomonium at $\sqrt{s} = 1.96$ TeV in three rapidity bins
  - 0<|y|<1.8: Much improvement in rapidity range
- The distribution agrees with previous results from CDF Run 1
- The distribution agrees with current theoretical models
- DØ is working on $\Upsilon(1S)$ polarization measurements

Backup slide: numbers

p_T^Υ (GeV/c)	$0.0 < \lvert y^\Upsilon \rvert \leq 0.6$	$0.6 < \lvert y^\Upsilon \rvert \leq 1.2$
0 – 1	0.051 ± 0.005	0.061 ± 0.006
1 – 2	0.138 ± 0.010	0.137 ± 0.010
2 – 3	0.152 ± 0.010	0.153 ± 0.010
3 – 4	0.149 ± 0.011	0.175 ± 0.012
4 – 6	0.112 ± 0.006	0.110 ± 0.007
6 – 8	0.067 ± 0.005	0.061 ± 0.004
8 – 10	0.034 ± 0.003	0.034 ± 0.003
10 – 15	0.014 ± 0.001	0.011 ± 0.001
15 – 20	0.0032 ± 0.0005	0.0019 ± 0.0003

$1.2 < \lvert y^\Upsilon \rvert \leq 1.8$	$0.0 < \lvert y^\Upsilon \rvert \leq 1.8$
0.050 ± 0.005	0.056 ± 0.004
0.136 ± 0.011	0.136 ± 0.008
0.175 ± 0.015	0.160 ± 0.009
0.160 ± 0.014	0.159 ± 0.009
0.115 ± 0.008	0.113 ± 0.005
0.056 ± 0.005	0.062 ± 0.003
0.034 ± 0.003	0.035 ± 0.002
0.011 ± 0.001	0.012 ± 0.001
0.0019 ± 0.0004	0.0023 ± 0.0002

Backup: events to cross section

$$\frac{d^2\sigma(Y(1S))}{dp_T dy} \times BR(Y(1S) \to \mu^+\mu^-) = \frac{N(Y(1S))}{L \cdot \Delta p_T \cdot \Delta y \cdot \varepsilon_{acc} \cdot \varepsilon_{trig} \cdot k_{qual} \cdot k_{trk} \cdot k_{di-mu}}$$

PDG: (2.48±0.06)%

$\lvert y^{\Upsilon}\rvert$:	0.0 - 0.6	0.6 - 1.2	1.2 - 1.8
ε (acceptance)	0.15 - 0.26	0.19 - 0.28	0.20 - 0.27
ε (trigger)	0.70	0.73	0.82
k (quality cuts)	0.85	0.85	0.93
k (track match)	0.99	0.99	0.95
k (di-muons)	0.85	0.88	0.95