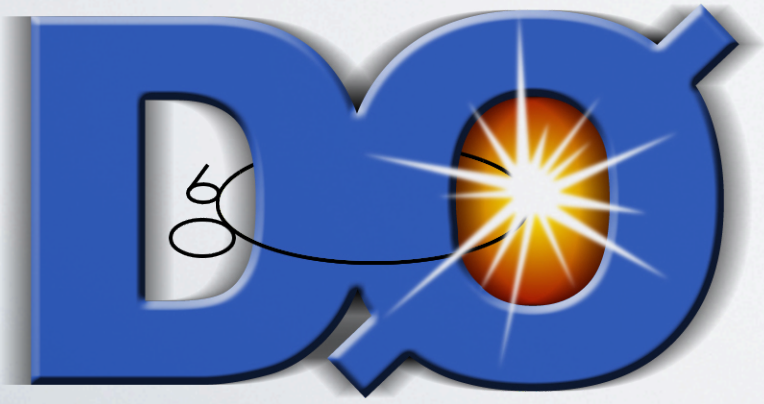
Observation of a Narrow Structure Decaying to $\Upsilon\gamma$

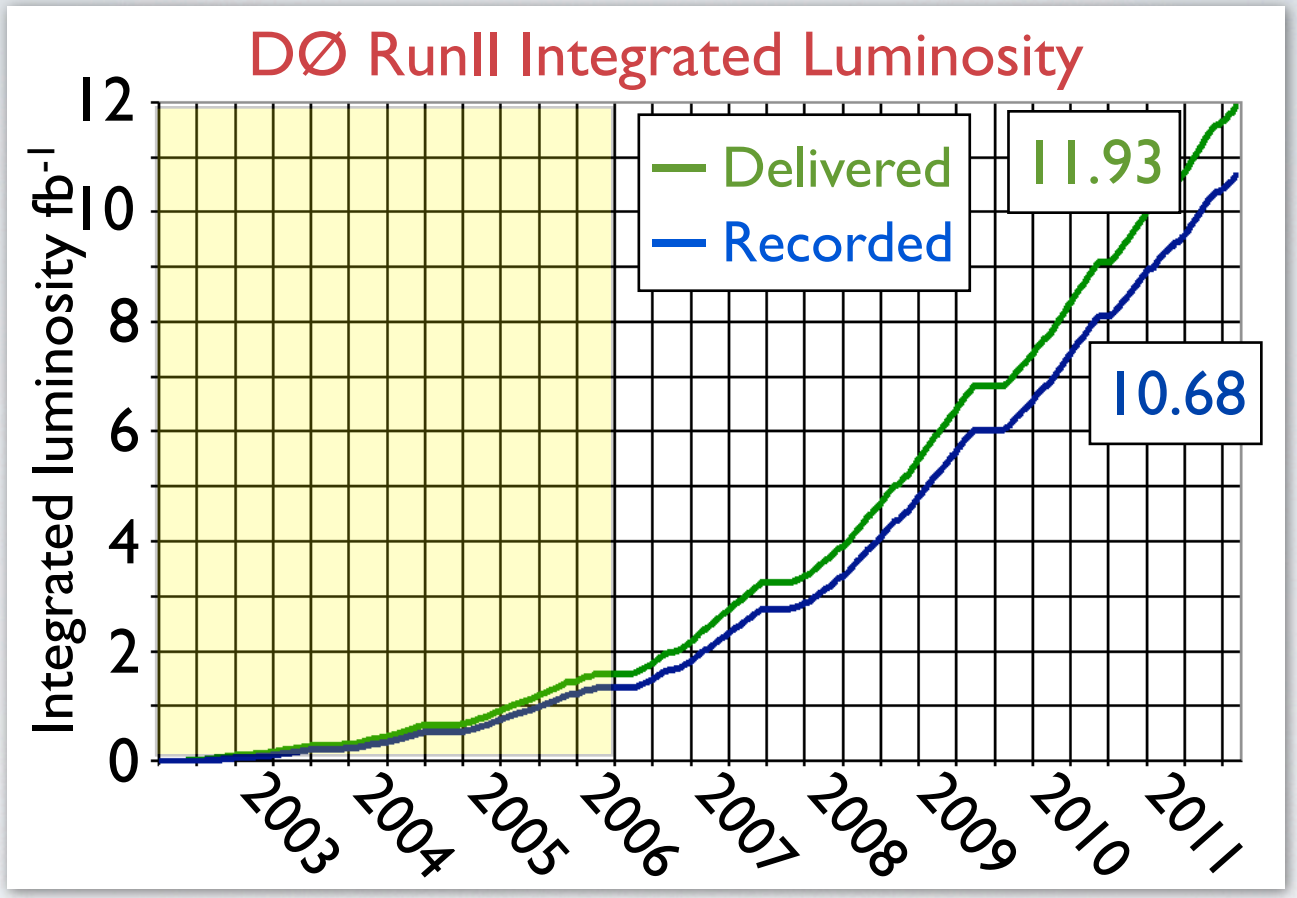
Claus Buszello for the DØ Collaboration

QWG 2013, Beijing



Tevatron

Data Set



Recorded luminosity: Run IIa : 1.3 fb^{-1}

Run IIb : 9.3 fb^{-1}

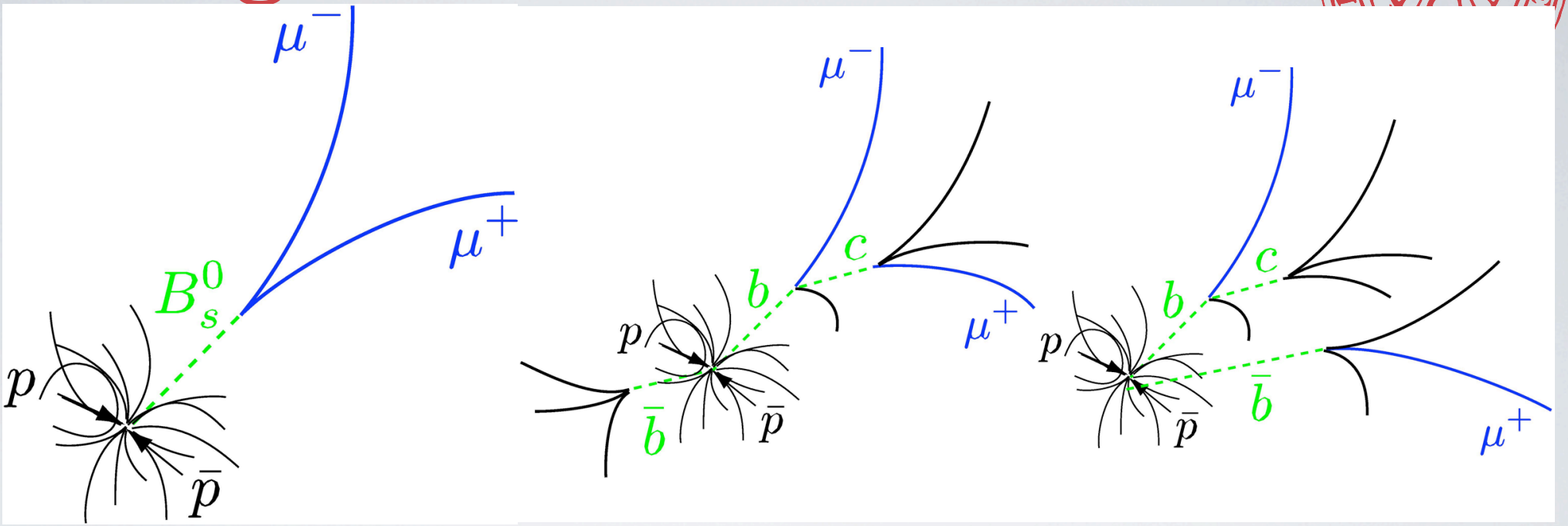
Run IIa had lowest instantaneous luminosity

$\Rightarrow$ Low p_T tracking, low multiplicity, best resolution

$B_s \rightarrow \mu\mu$

- Improved SM prediction (incl. $\Delta\Gamma_s > 0$)
  - $\mathcal{BR}(B_s \rightarrow \mu\mu) = 3.5 \pm 0.2 \times 10^{-9}$
  - Beyond SM prediction: change BR significantly
- Previous DØ limit using 6.1 fb^{-1}:
  - Bayesian NN based selection
  - ➡ $\mathcal{BR}(B_s \rightarrow \mu\mu) < 5.1 \times 10\text{-}8$
- New limit using $10.4\ fb^{-1}$
  - blind analysis
  - Expected yield derived from $B^{\pm} \rightarrow J/\psi\ K$ as normalisation channel

Backgrounds

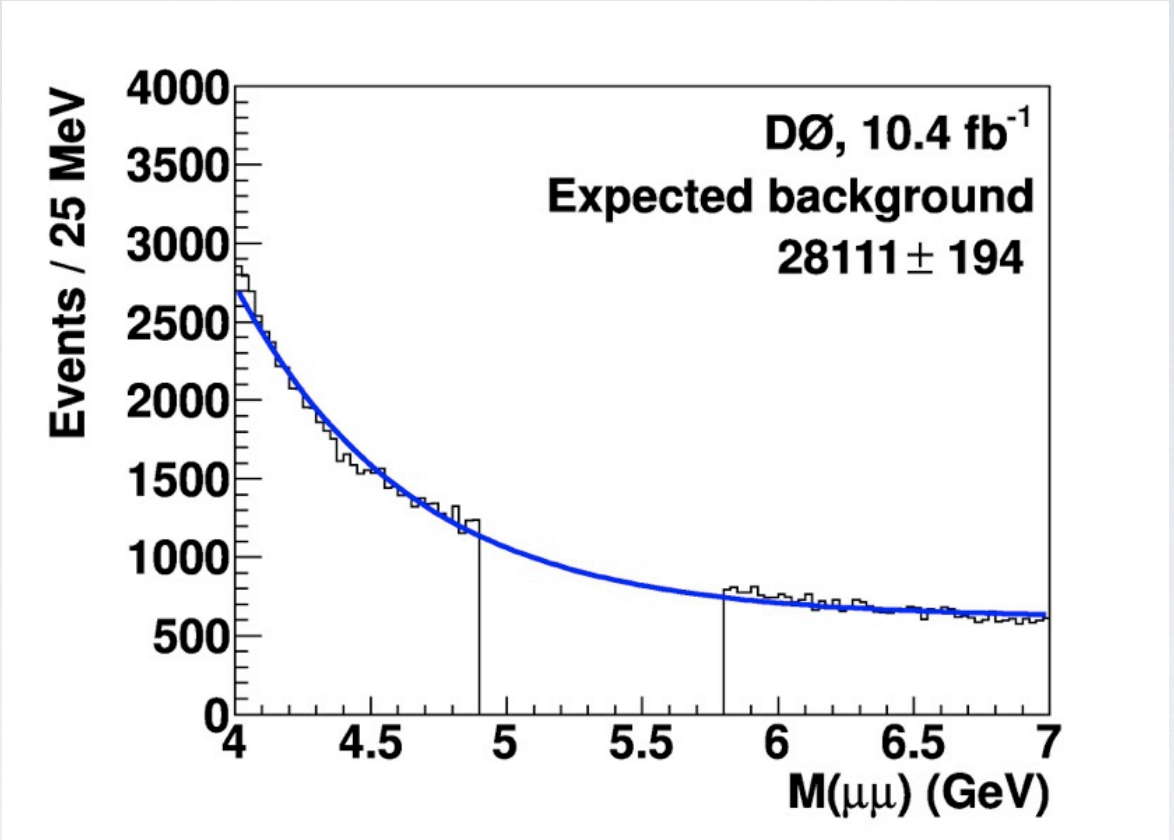


Signal differs from background by:

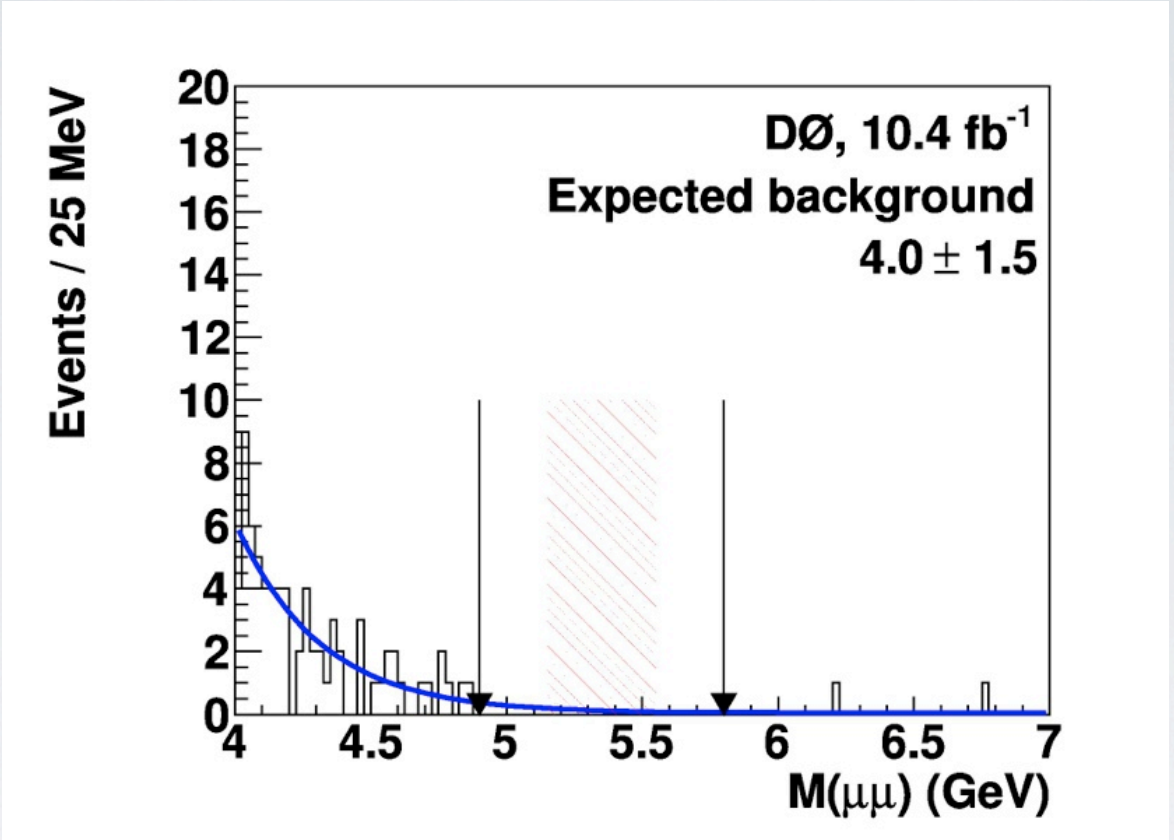
- dimuon system points back to PV
- IPS of individual muons
- the environment around dimuon candidate

→ use two separate BDT to suppress BG using 30 input variables each

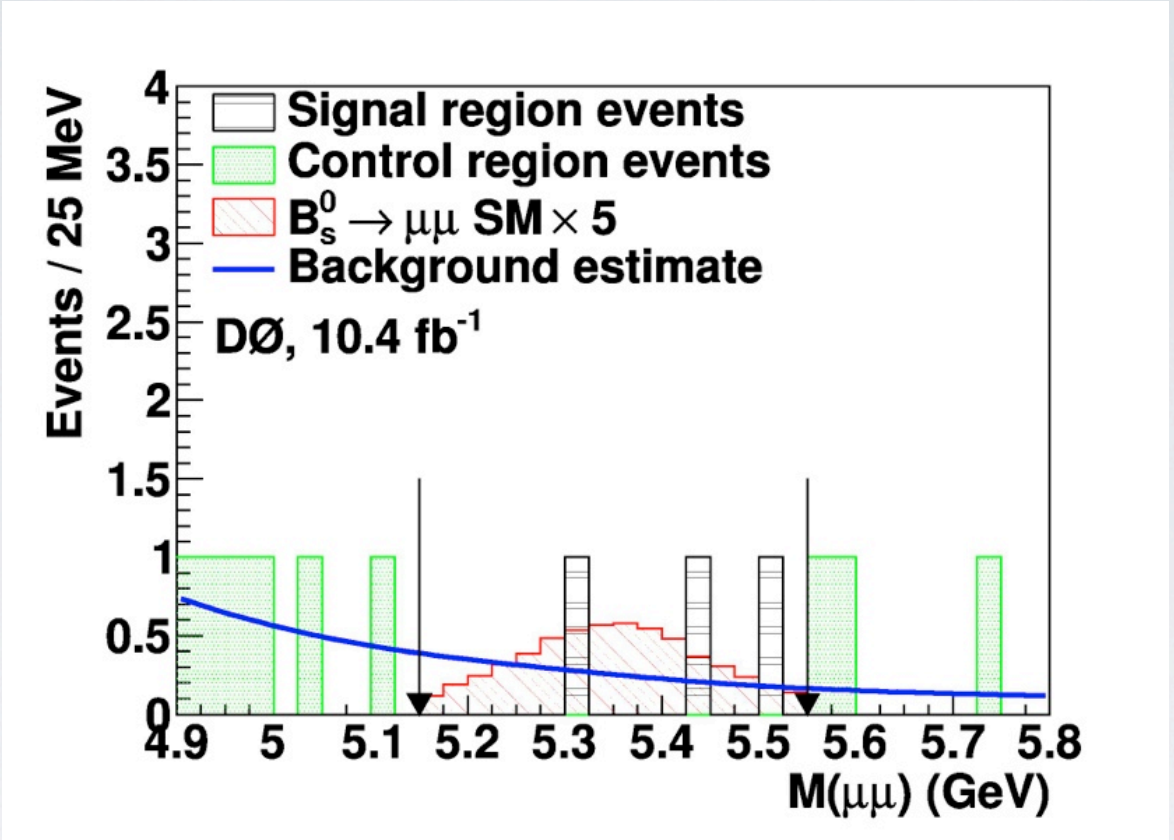
Before BDT


DØ, 10.4 fb^{-1}
Expected background
28111 ± 194
Events / 25 MeV
4000
3500
3000
2500
2000
1500
1000
500
0
4
4.5
5
5.5
6
6.5
7
M(μμ) (GeV)

After BDT


Events / 25 MeV
20
18
16
14
12
10
8
6
4
2
0
4
4.5
5
5.5
6
6.5
7
M(μμ) (GeV)
DØ, 10.4 fb-1
Expected background
4.0 ± 1.5

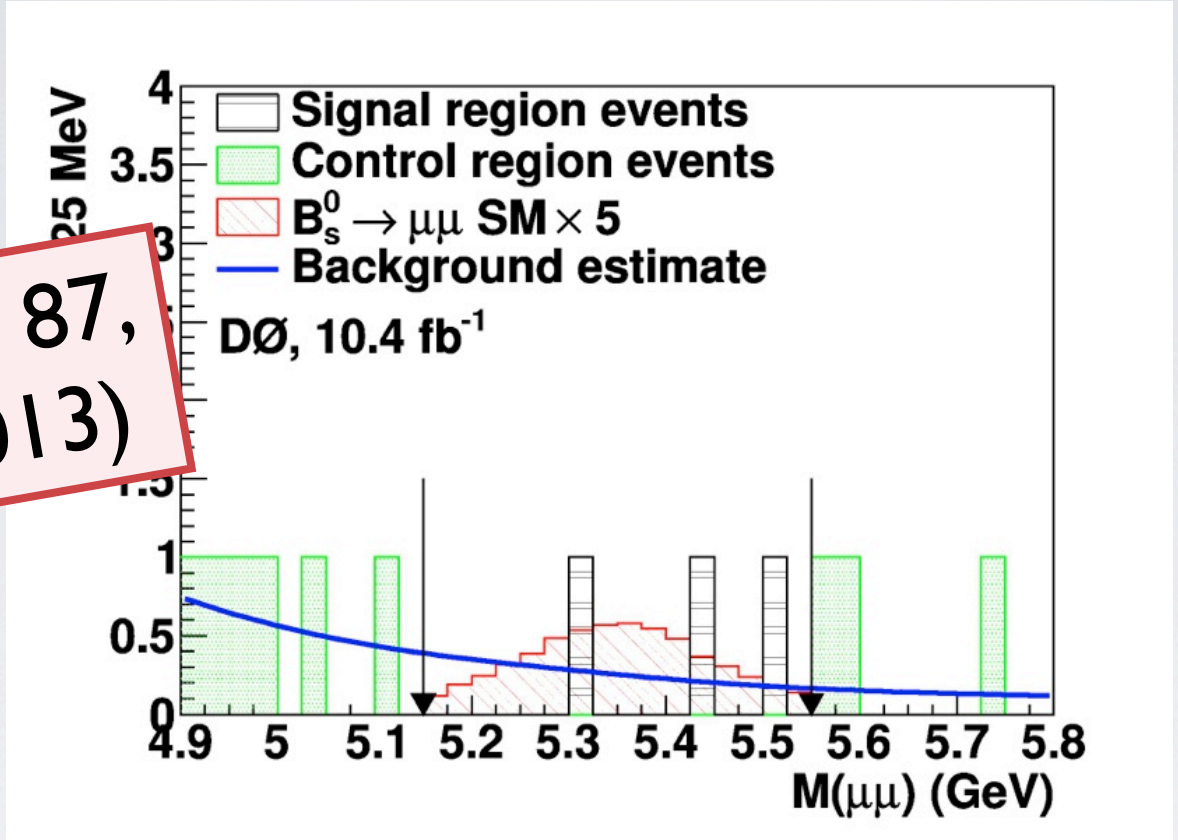
Limit



- $\mathcal{BR}(B_s \to \mu\mu) < 15 \times 10^{-9}$ (at 95% CL)

  (previous limit: $\mathcal{BR} < 5 \times 10^{-8}$ using 6.1 fb^{-1})

Limit



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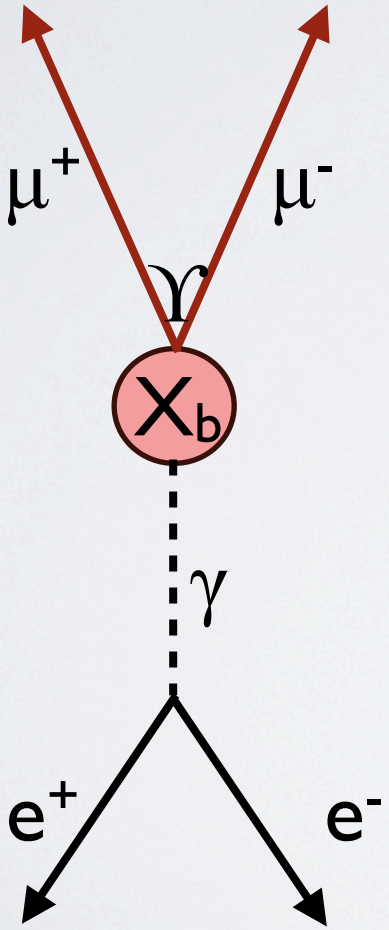
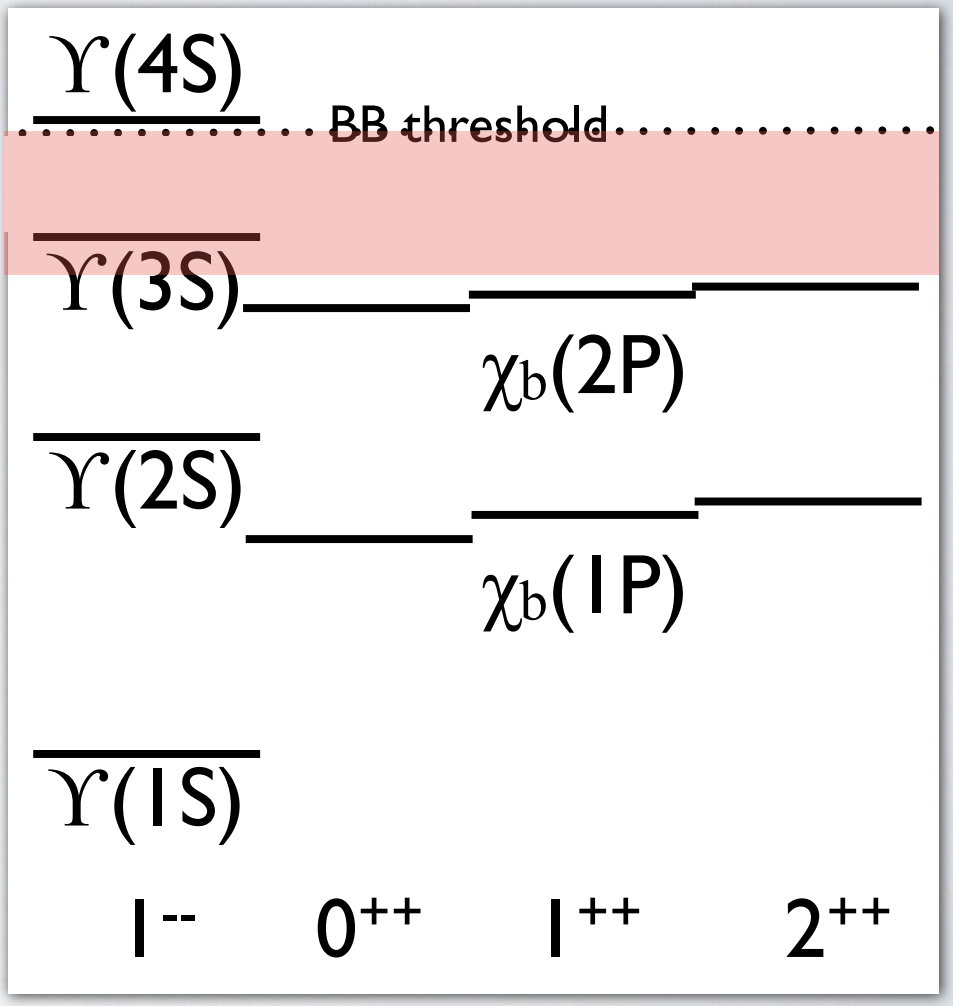
- $\mathcal{BR}(B_s \to \mu\mu) < 15 \times 10^{-9}$ (at 95% CL)

  expected: $\mathcal{BR}(B_s \to \mu\mu) < 23 \times 10^{-9}$

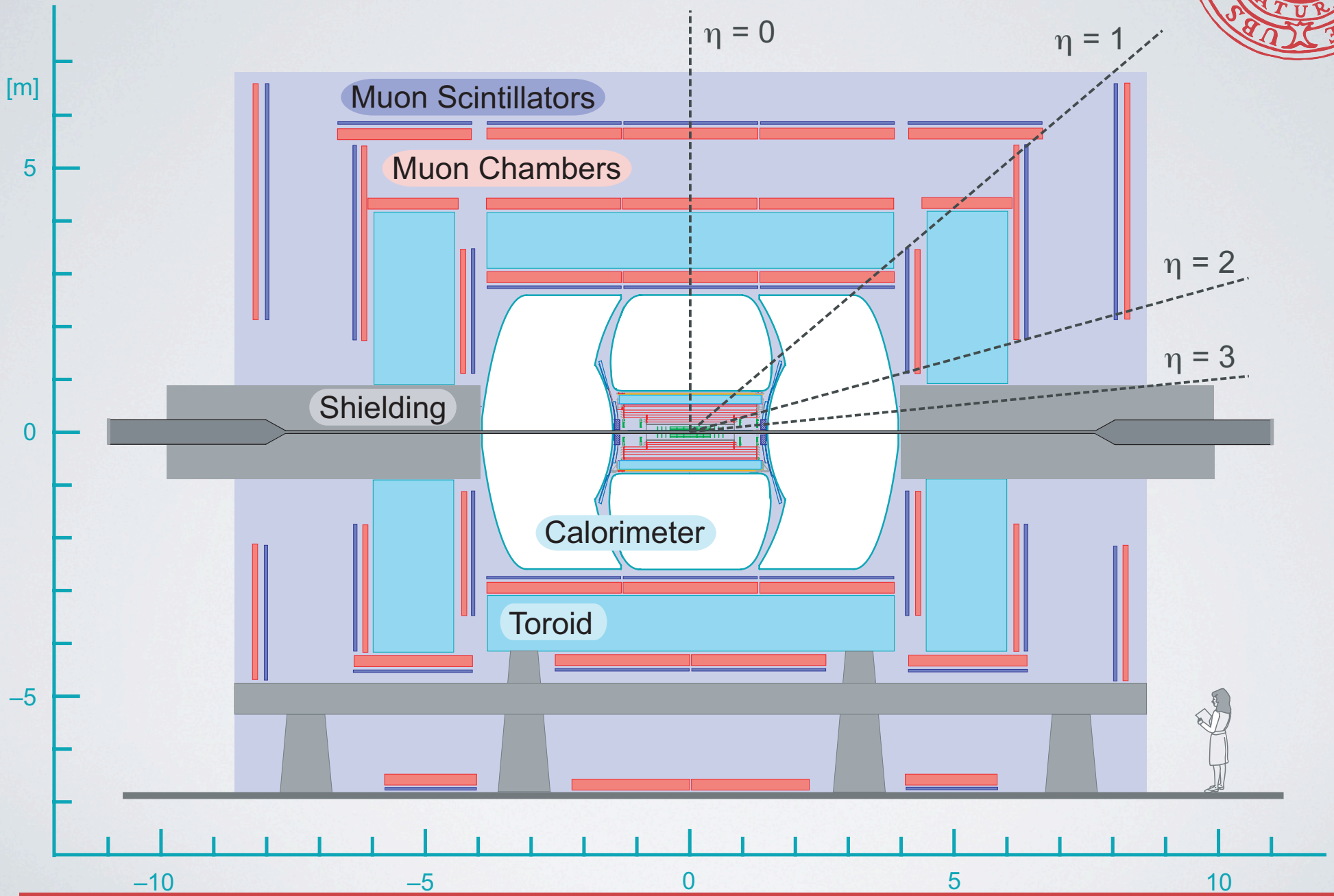
X_b search

- Search for particles decaying to $\Upsilon(1S)\gamma$
- Between $\chi_b(2P)$ and the BB threshold

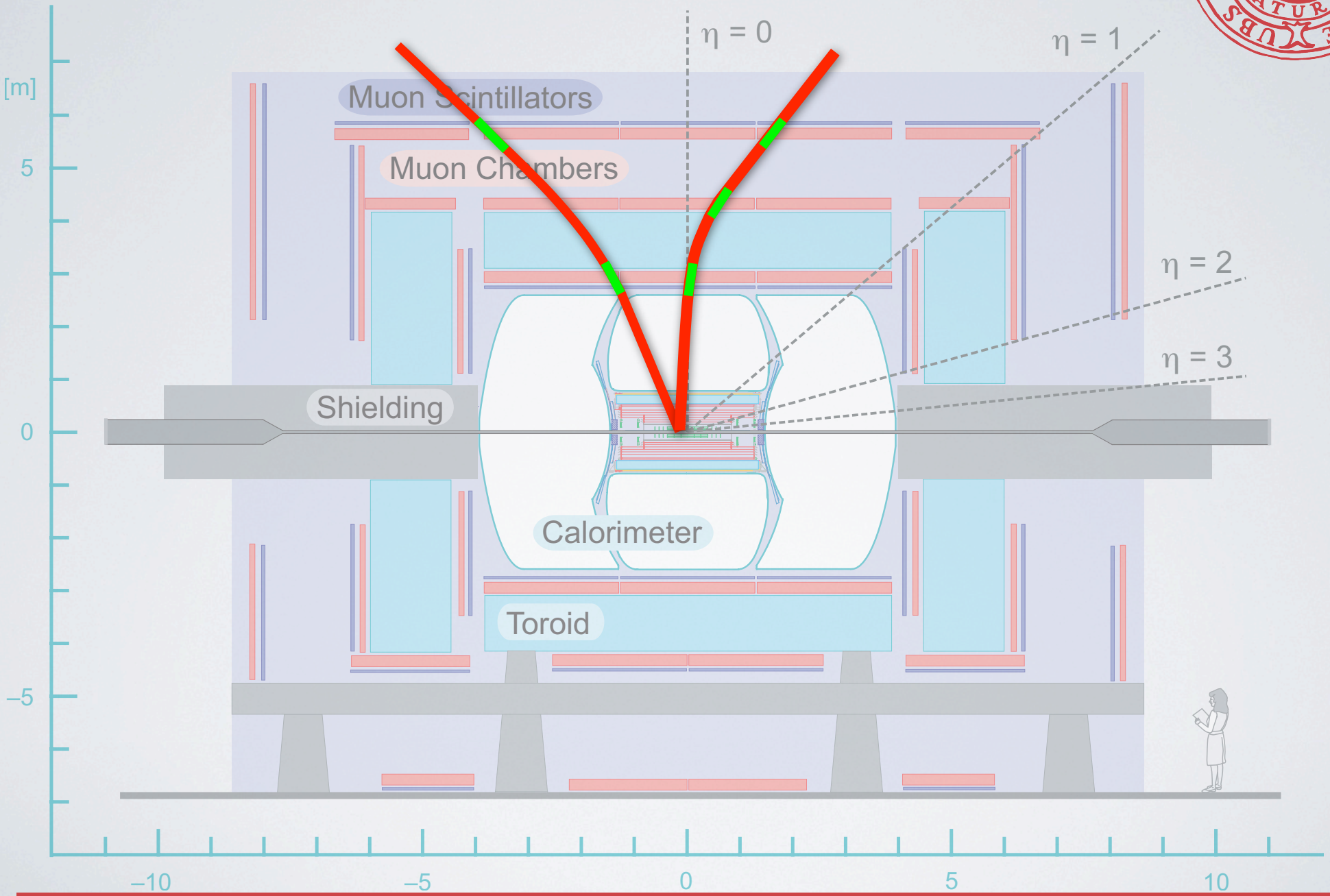




DØ Detector


η = 0
η = 1
η = 2
η = 3
Muon Scintillators
Muon Chambers
Shielding
Calorimeter
Toroid
[m]
5
0
–5
–10
–5
0
5
10

DØ Detector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Muon Scintillators
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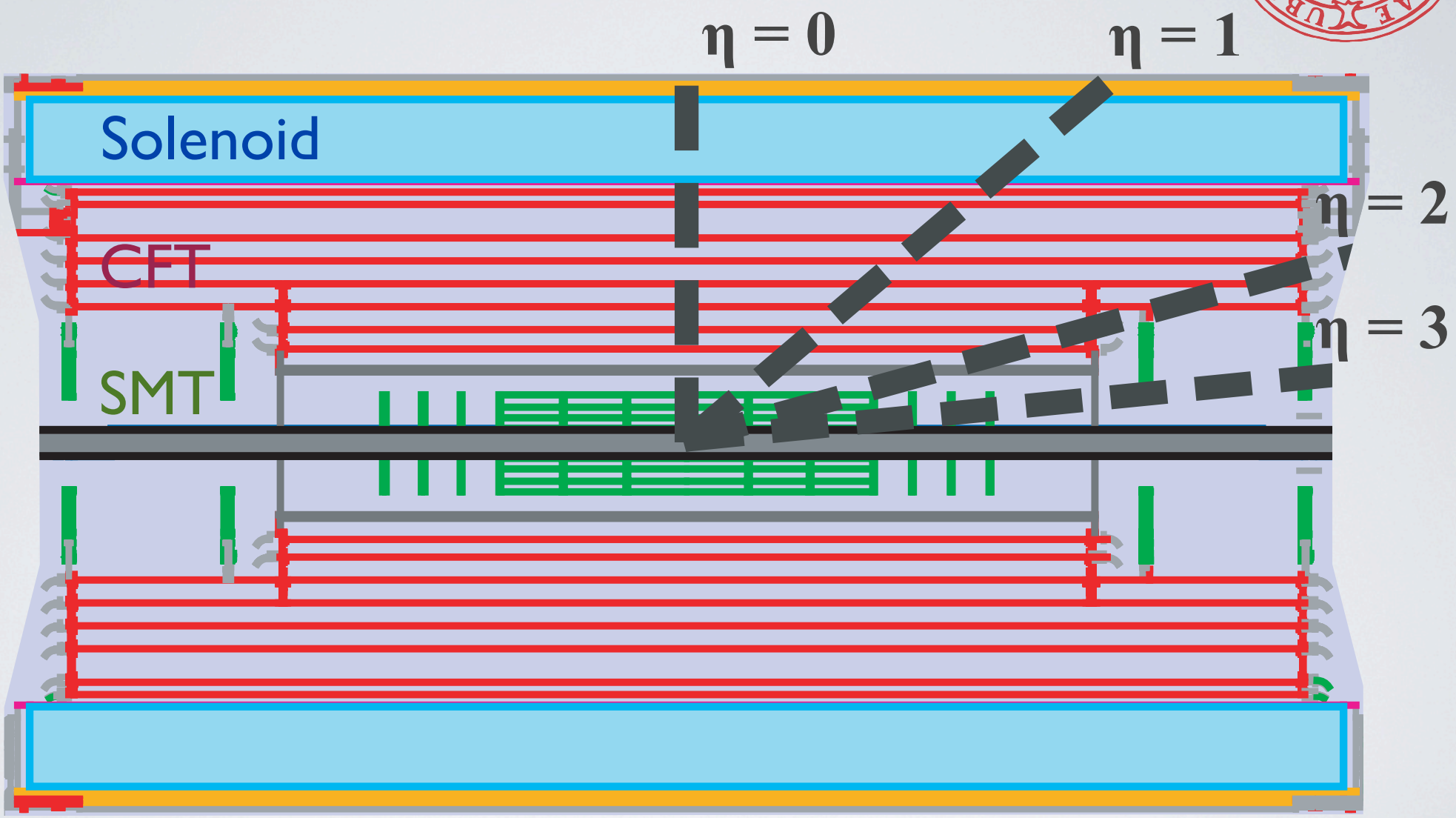
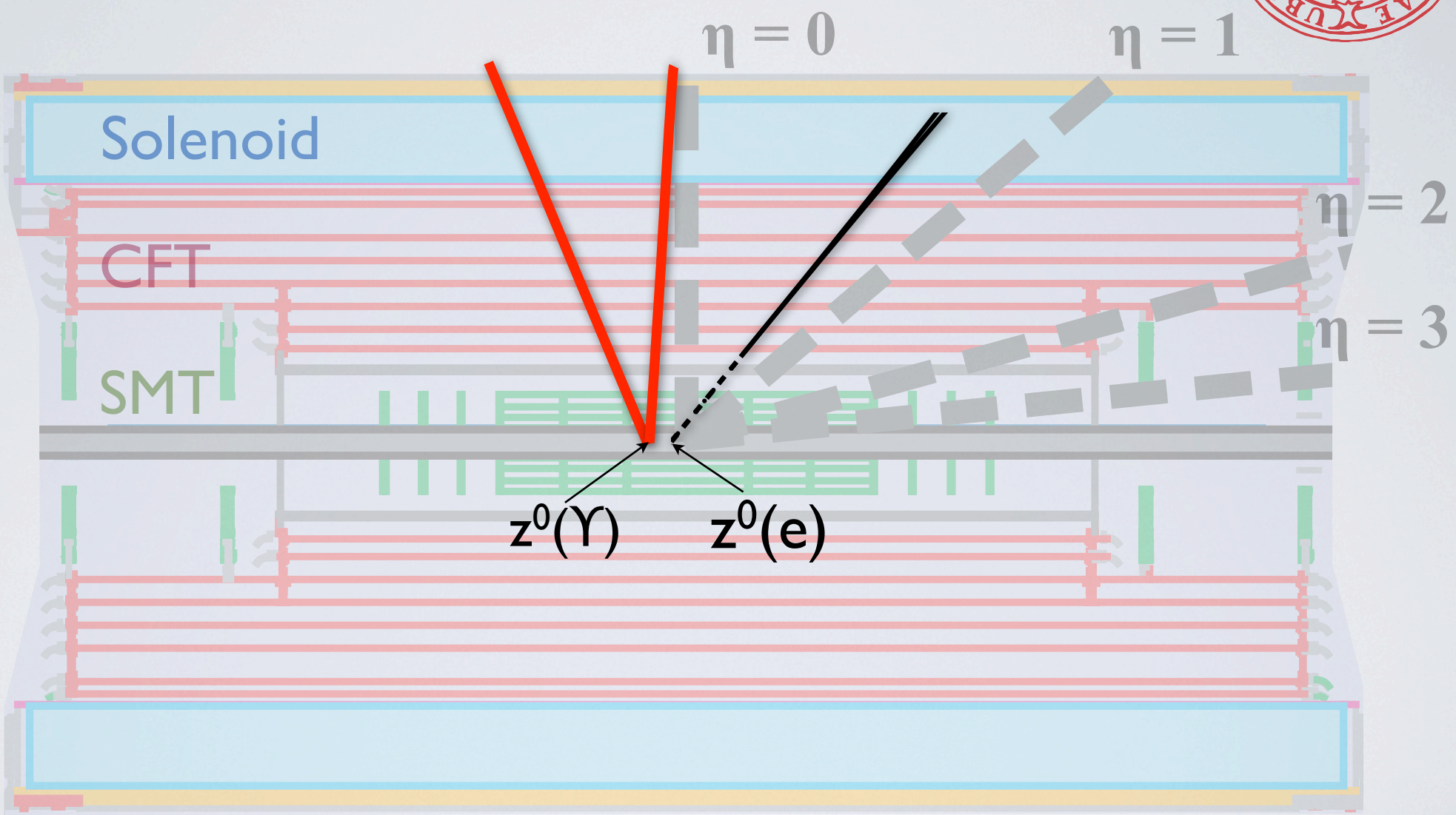
[m]
5
0
–5
–10
–5
0
5
10

Tracking



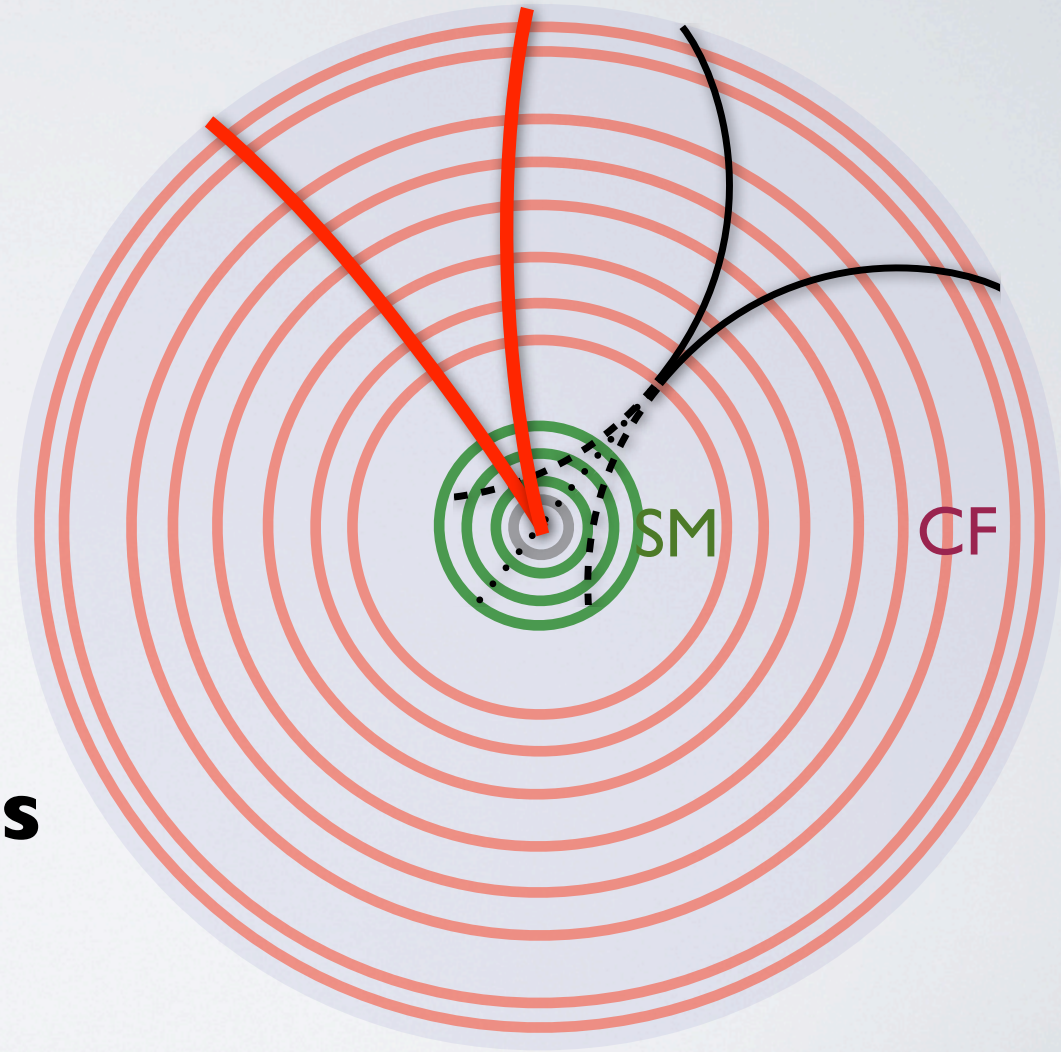
Tracking



Differences Δz^0 used to remove background

Vertexing

- Transverse IPS: S_T
  - $S_T(\mu)$ small
  - $S_T(e)$ large
  - $S_T(\mu) < S_T(e)$
  - $S_T(\gamma)$ small
- gamma conversion in the "right" direction
  - $\cos_{xy}(\theta) > .8$
- **All vertexing Cuts optimised on χ_c**



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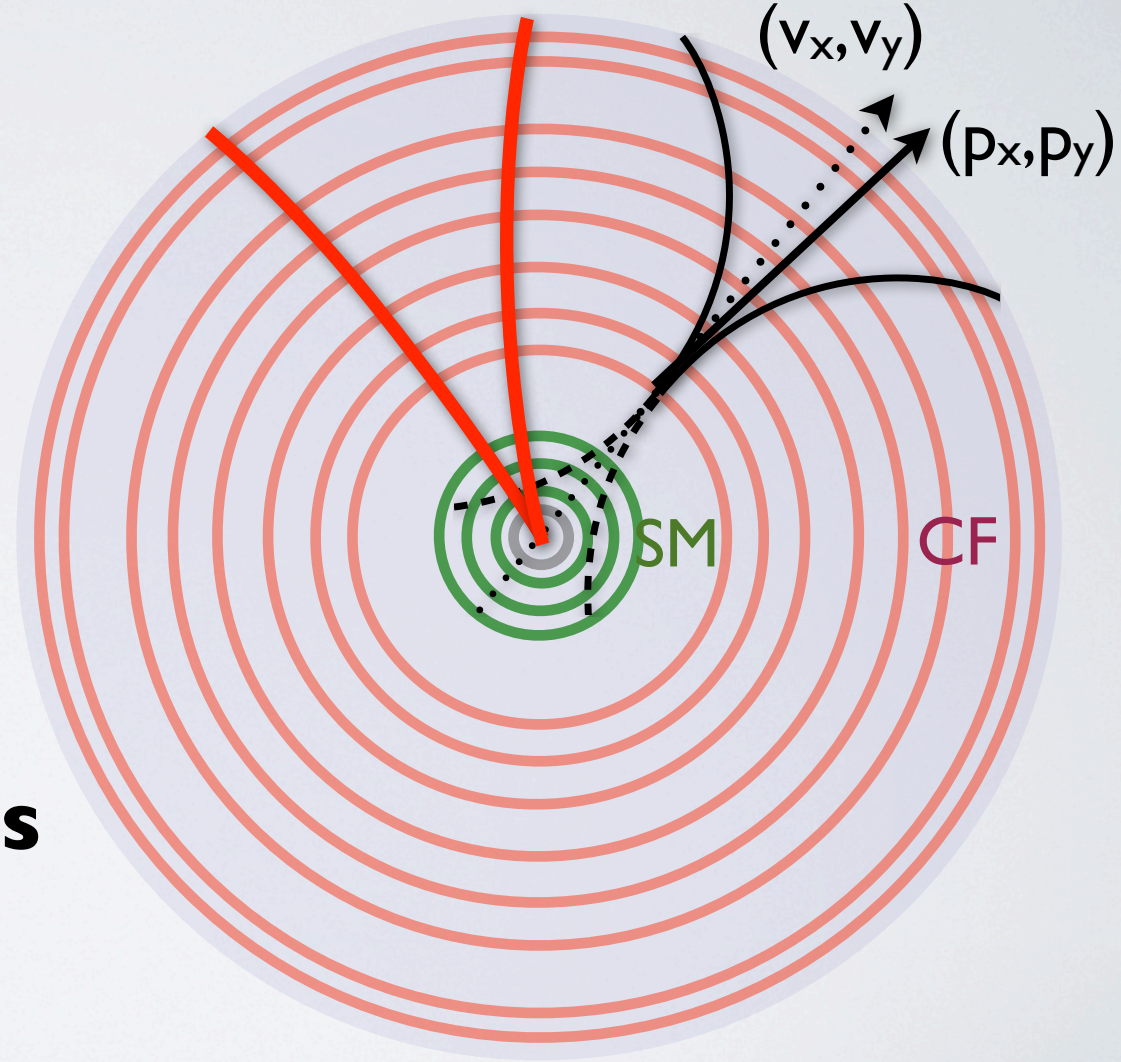
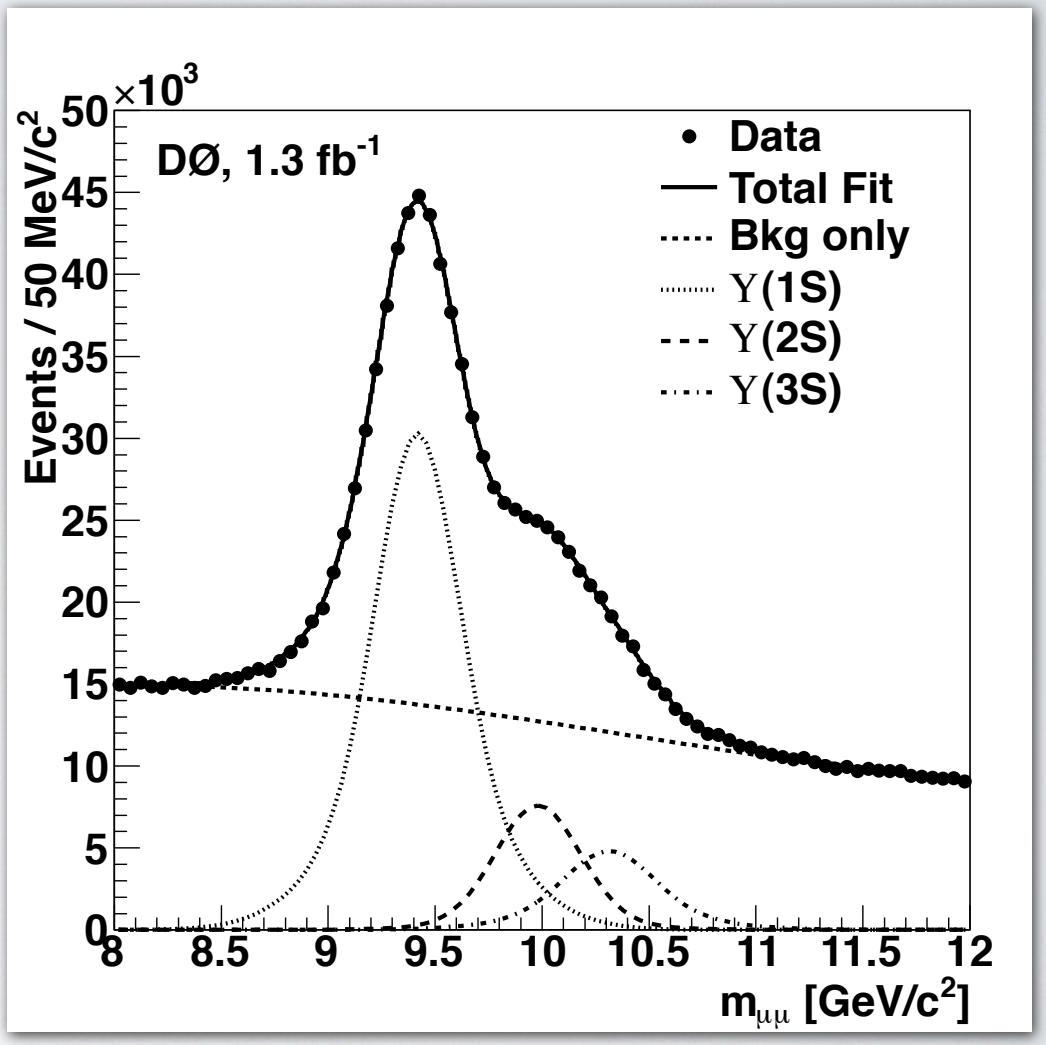


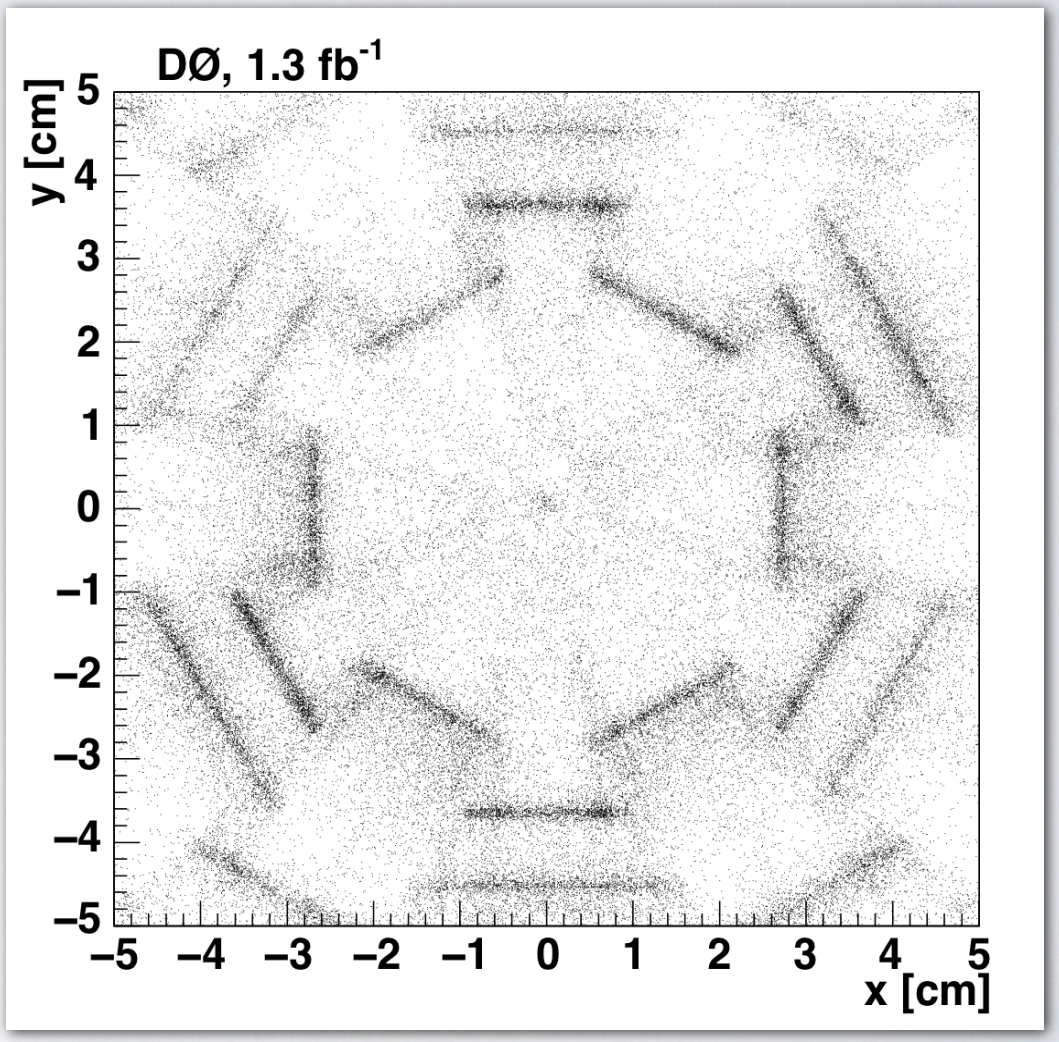
Υ Selection

- Two track matched muons
  - Segments in- and outside of Toroid
  - Opposite Sign
  - p_T > 1.5 GeV
  - S_T < 7
- Di-muon Vertex
  - χ^2 < 14
  - 9.1<$m_{\mu\mu}$/GeV<9.7

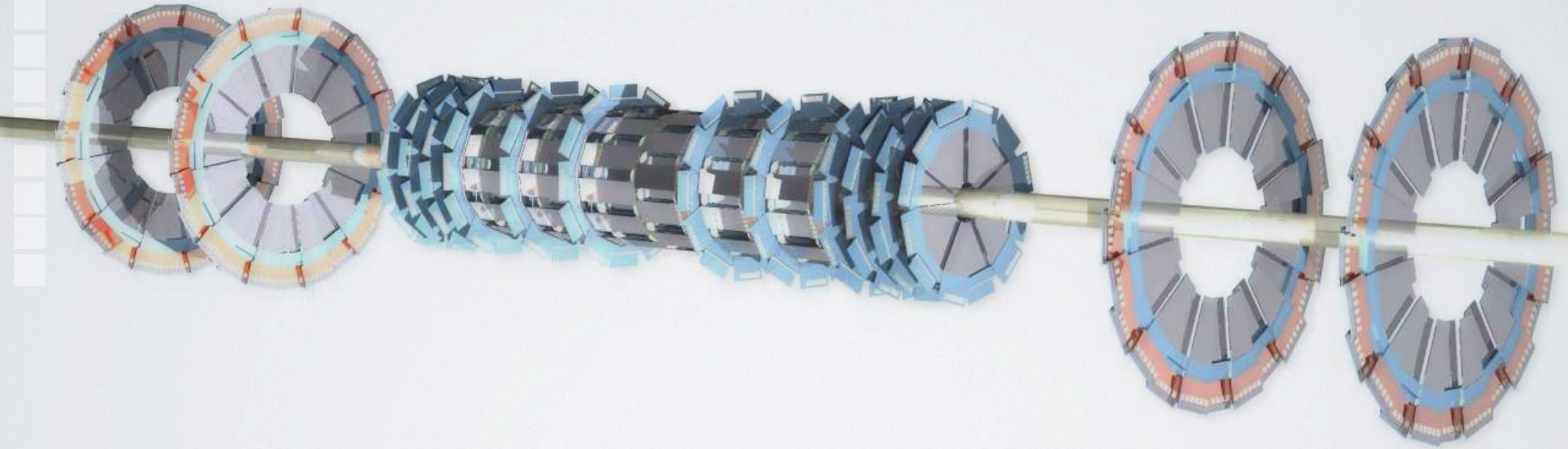


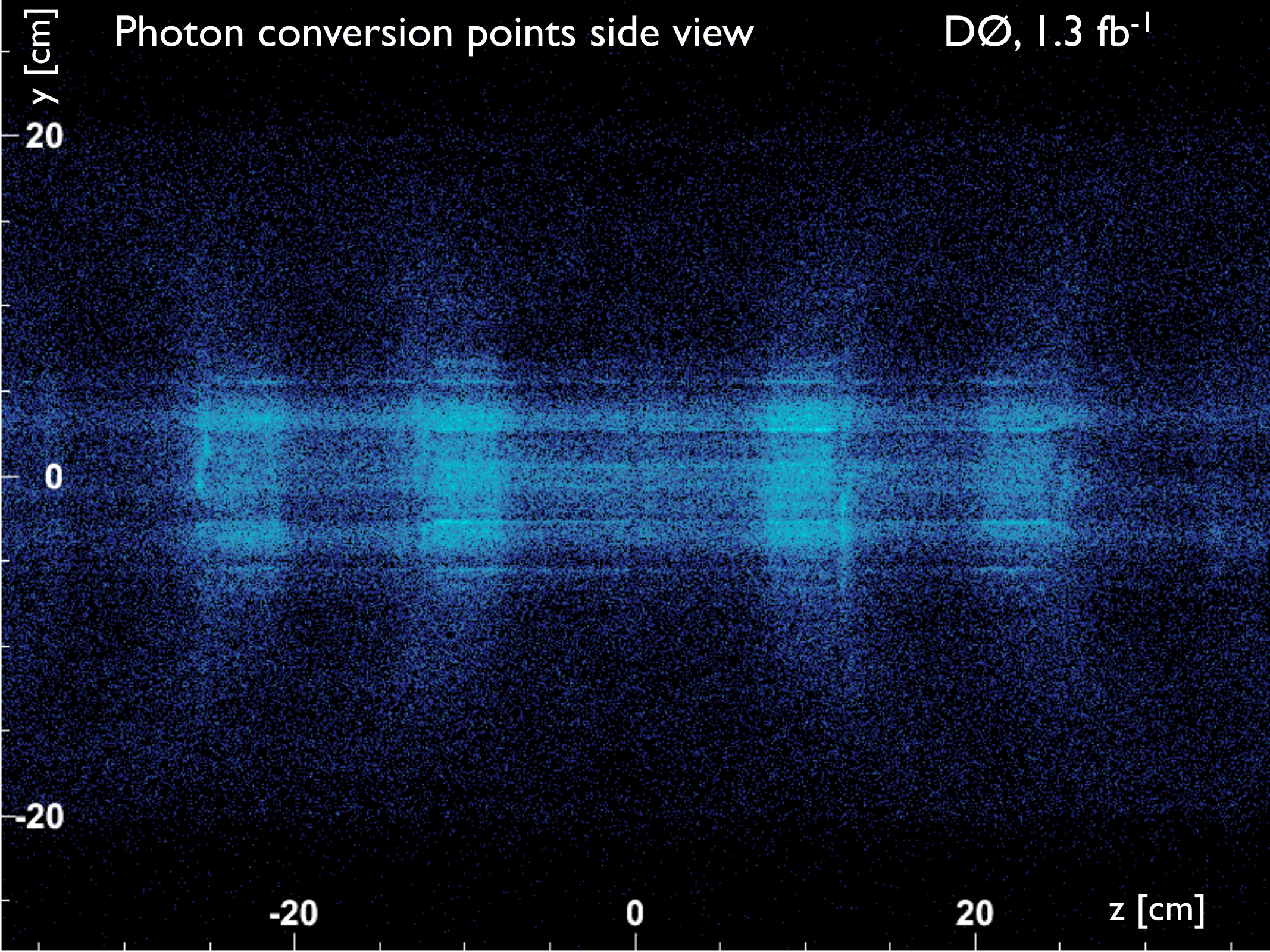
γ Selection

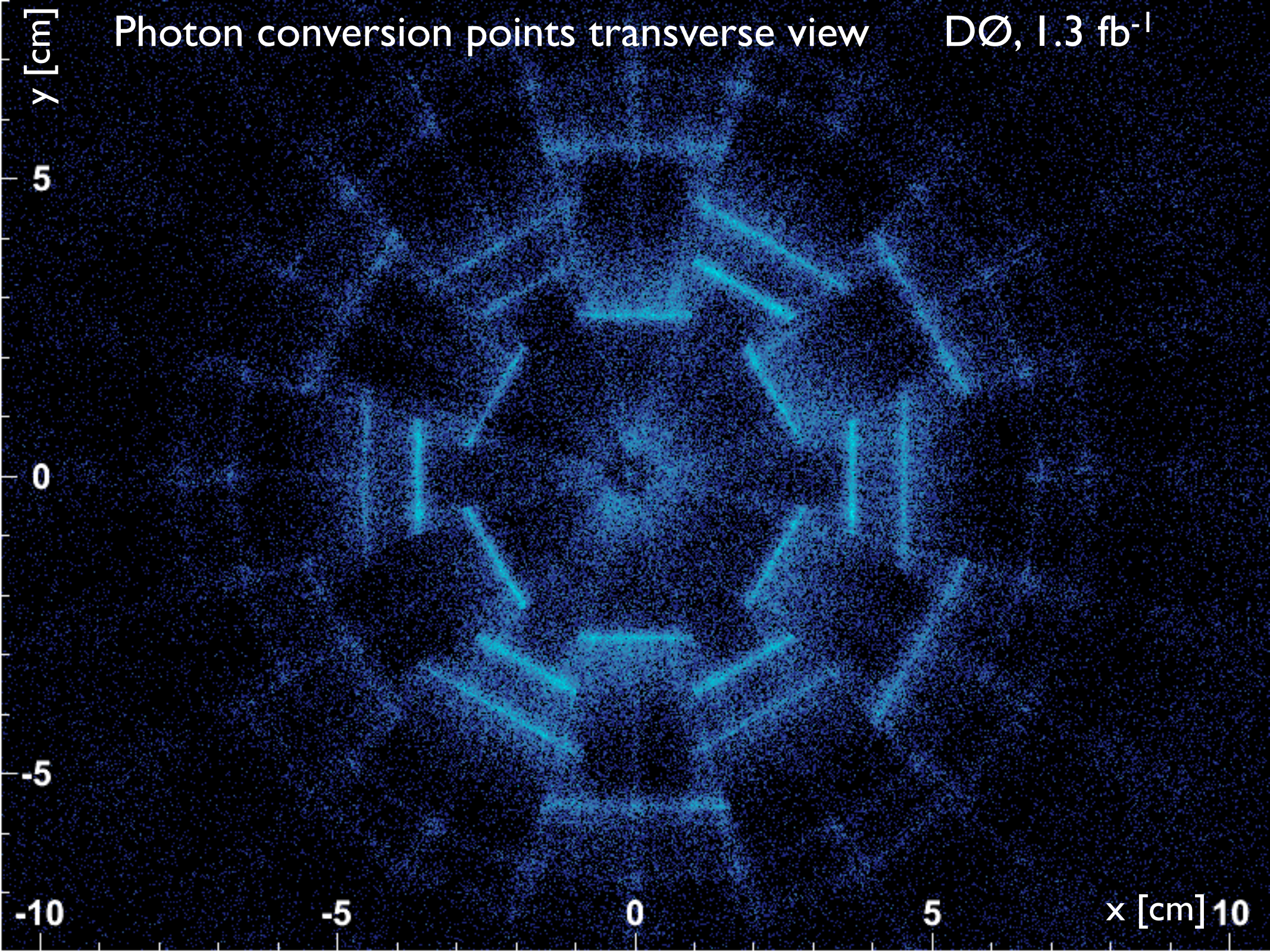
- Pair of well measured tracks
  - Associated to same PV
  - Opposite Sign
  - p_T > 180 MeV
  - S_T > 7
- Di-electron Vertex
  - χ^2 < 14
  - S_T < 16
  - m_{ee} < 80 MeV



SMT Layout

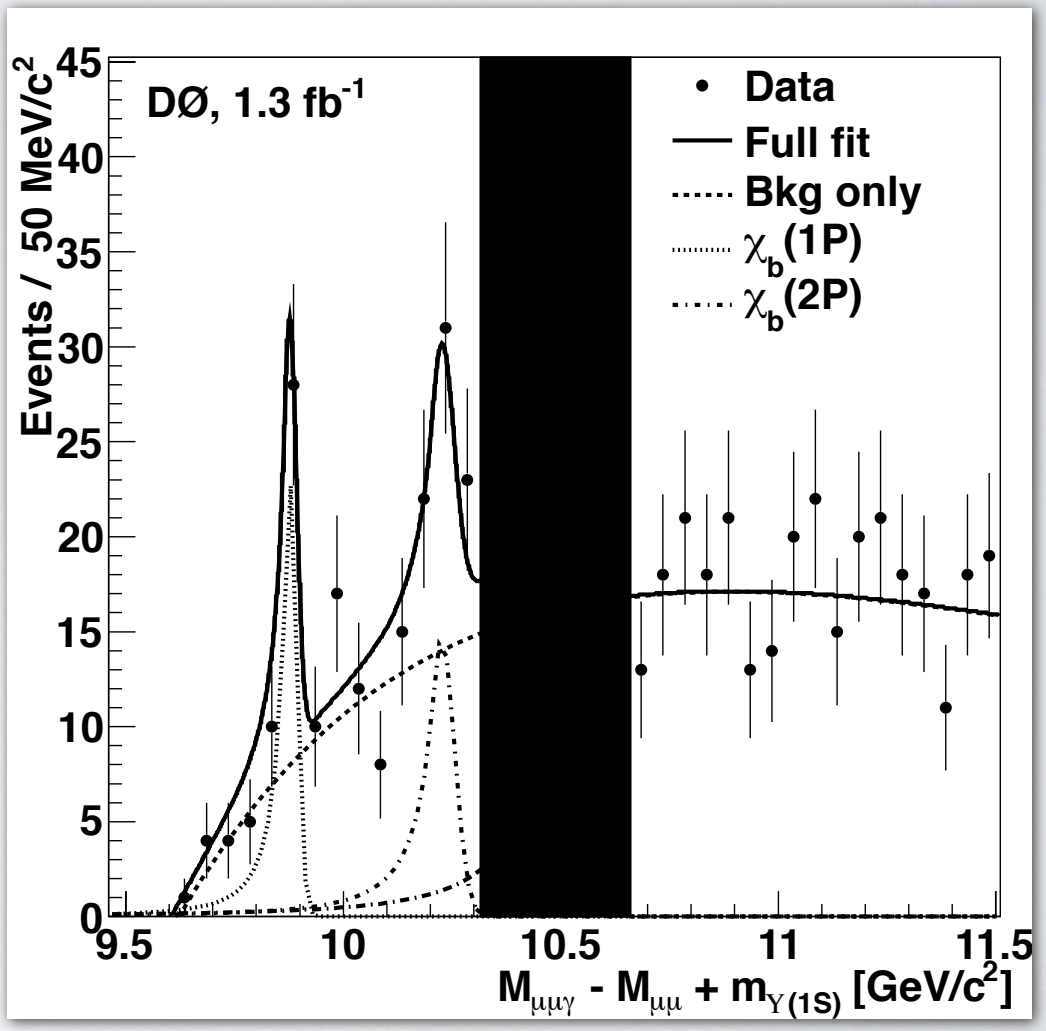



Photon conversion points side view
DØ, 1.3 fb-1
y [cm]
20
0
-20
-20
0
20
z [cm]


Photon conversion points transverse view
DØ, 1.3 fb-1
y [cm]
5
0
-5
-10
-5
0
5
x [cm]
10

$\Upsilon\gamma$ Selection

- All particles, tracks associated to the same PV
- Good $\mu\mu\gamma$ Vertex
  - $\chi^2 < 16$
- Tracks close in z
  - $\Delta z(e, \gamma) < 0.8$ cm
  - $\Delta z(e, \Upsilon) < 1.2$ cm
- $p_T(\mu\mu\gamma) > 5$ GeV



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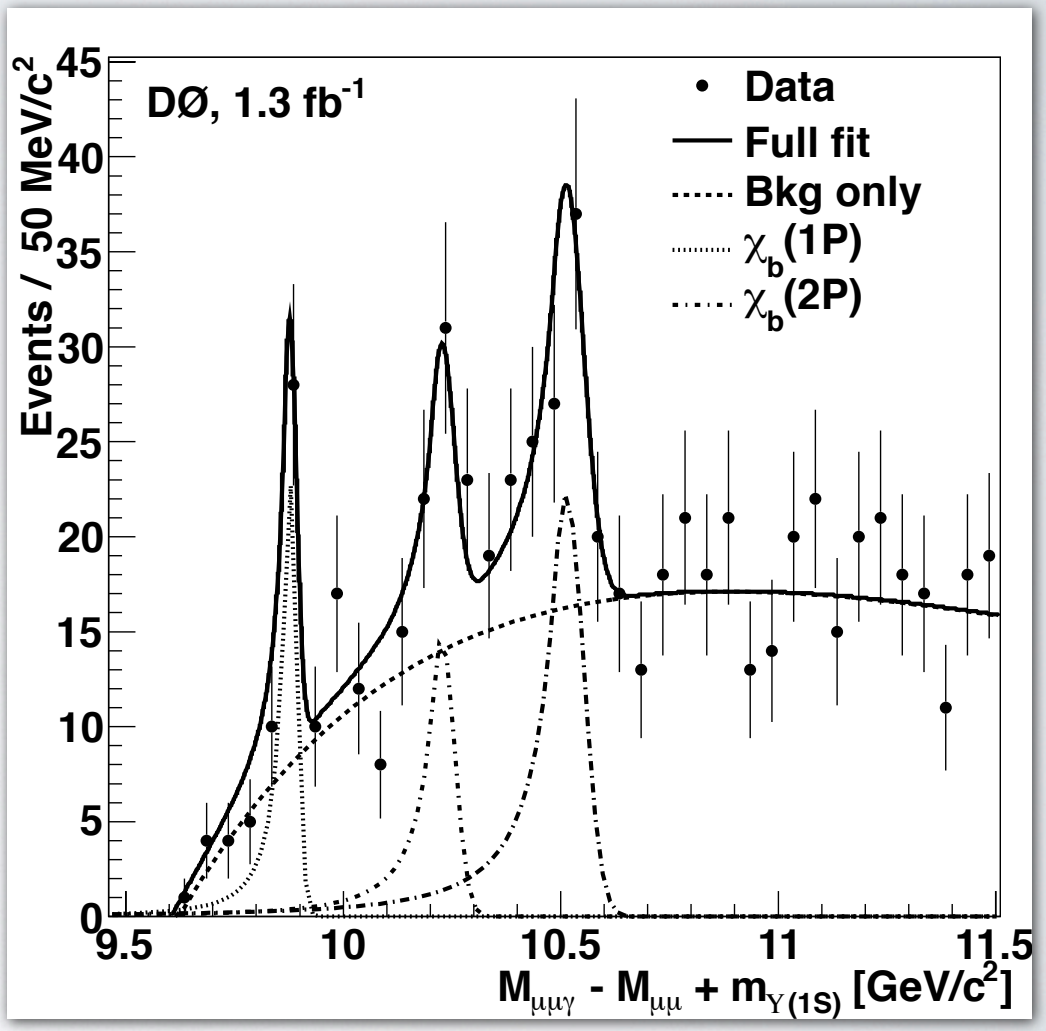
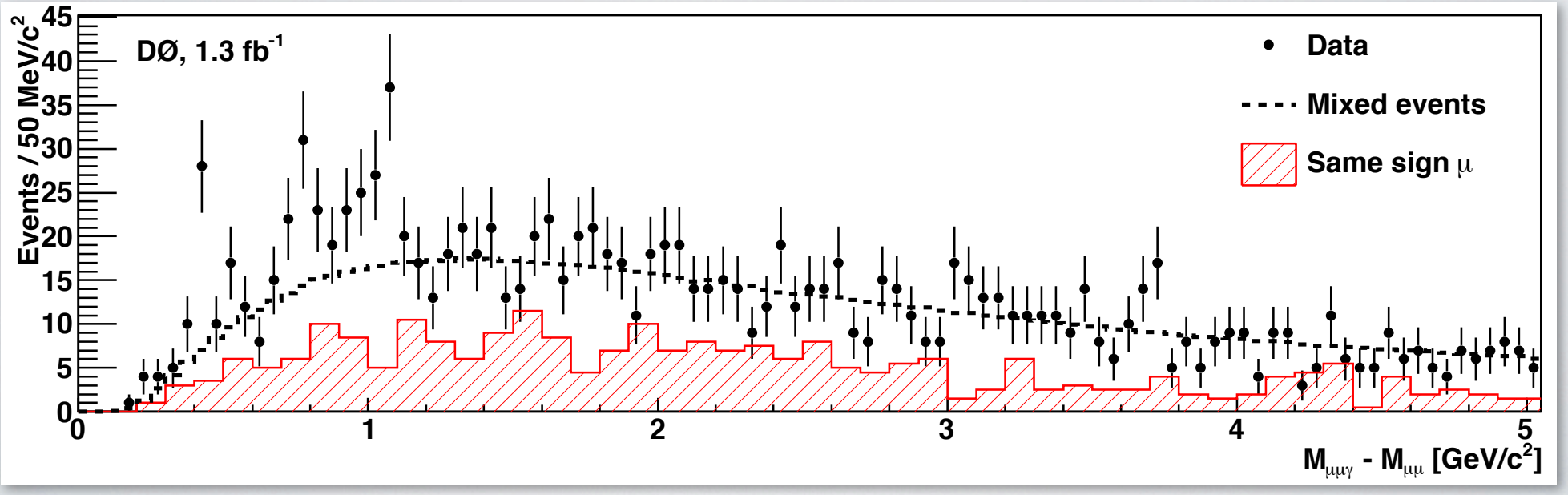
  - $\Delta z(e, \Upsilon) < 1.2$ cm
- $p_T(\mu\mu\gamma) > 5$ GeV

$\Rightarrow$ Third peak near threshold



Background

- Using mass difference $M_{\mu\mu\gamma} - M_{\mu\mu}$ (+ $m_{\Upsilon(1S)}$)
- Mix events: one Υ and one γ from different events
  $\Rightarrow$ Good description of combinatoric BKG
- Υ sidebands and same sign muons show no sign of excess anywhere



X_b Mass

- Unbinned extended likelihood fit
  - Signals: Crystal Ball Functions (N,μ,σ,α,k)

    Gaussian (N,μ,σ) from $\mu-\alpha\sigma$ to $+\infty$

    Power law (k) from $-\infty$ to $\mu-\alpha\sigma$
  - Background: exponential with turn-on

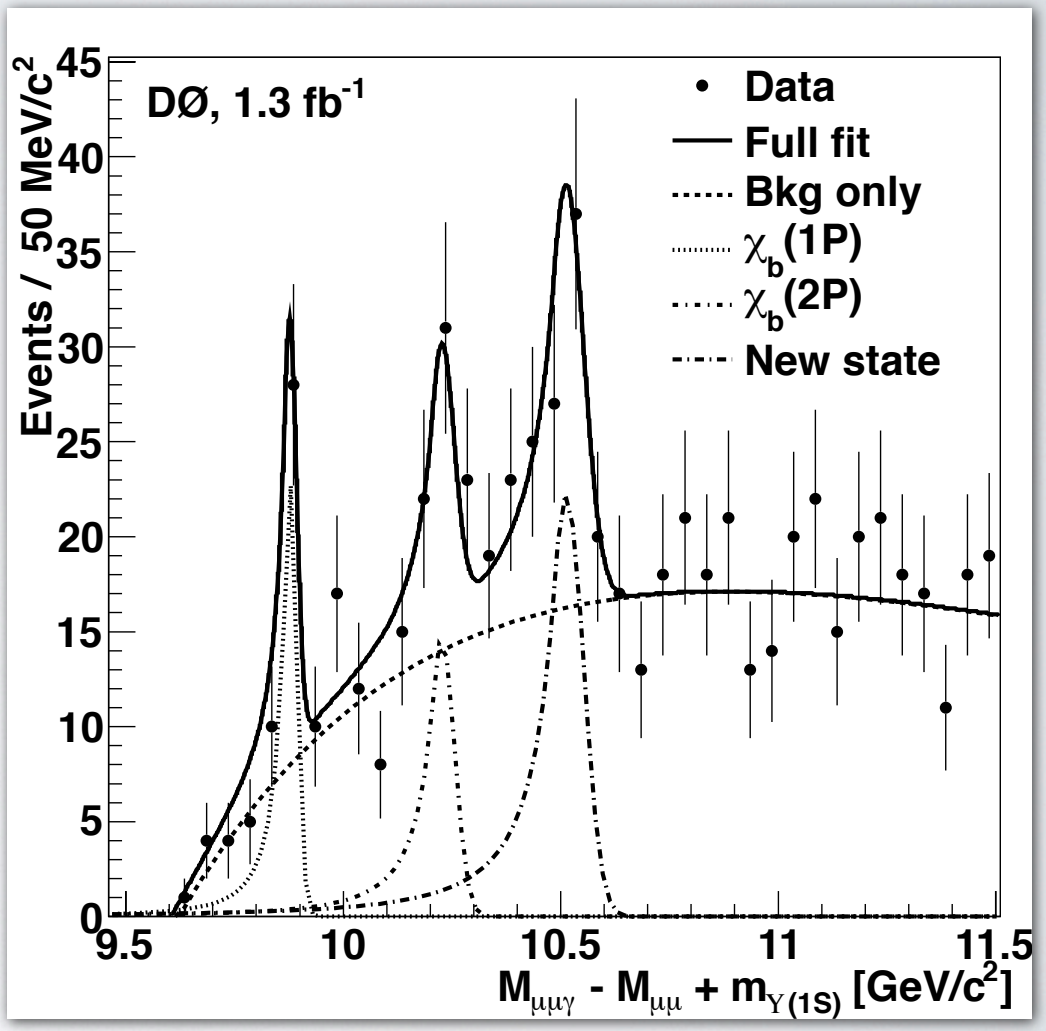
    $$B \cdot (1 - 1./(s \cdot x + s_0)) \cdot e^{-\tau x} + o$$
  - Masses of known χ_b states linked: $s_m \cdot m(\chi_b(1P,2P))$
  - Widths of gaussians scaled linearly

$$M = M_{\mu\mu\gamma} - M_{\mu\mu} + m(\Upsilon(1S))$$
$$= \mathbf{10.551\ GeV}$$
$$\mathbf{\pm .014(stat.)\ GeV}$$
$$\mathbf{\pm .017(syst.)\ GeV}$$

Main systematics	
$\chi_{b1,2,3}$ mixture	0.013 GeV
mass scale s_m	0.010 GeV
Bkg model	0.005 GeV

Significance

- Using the same fit
  - Likelihood ratio of fit with and without 3rd peak
  - p-value from χ^2 distribution ($NDF\chi^2 = \Delta NDF_{LL}$)
  - ➡ Local significance: 6.1 σ
  - ➡ Look elsewhere effect: -0.3 σ

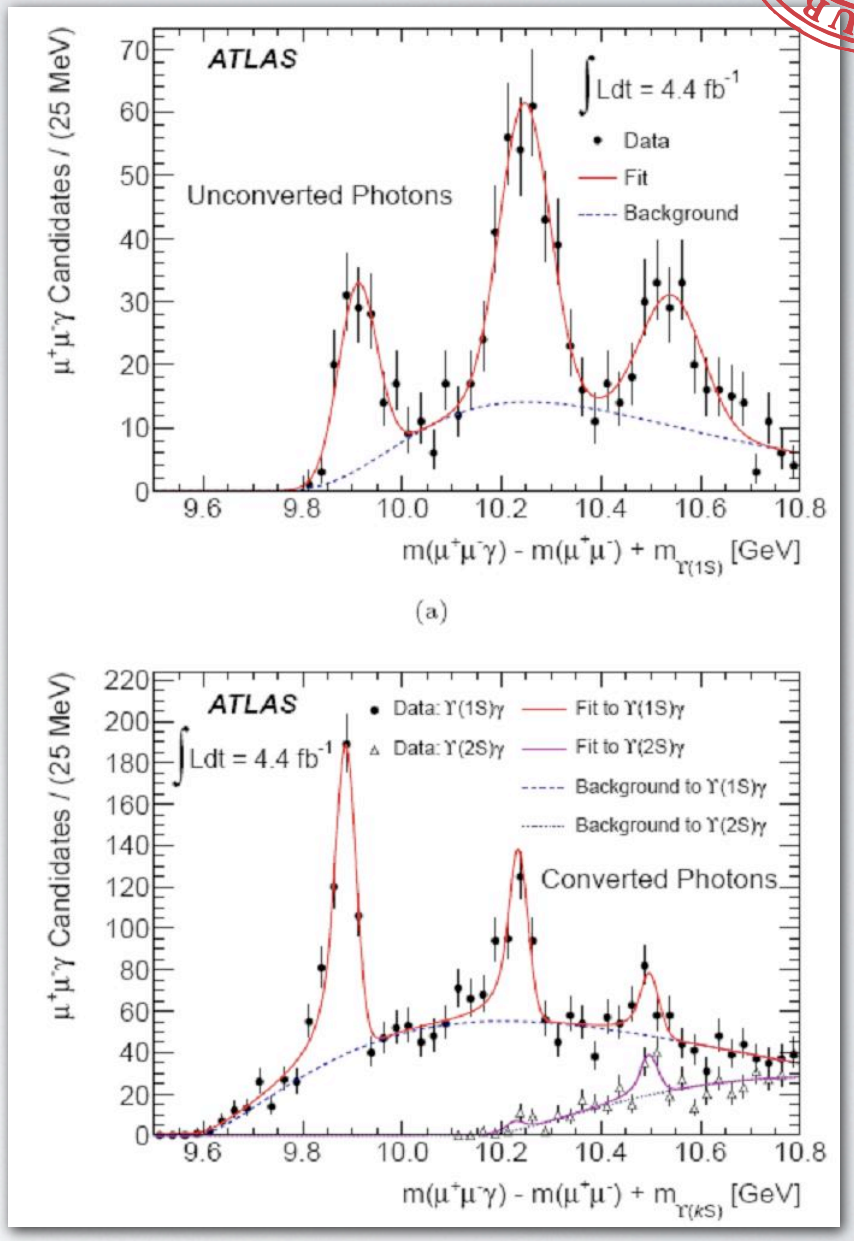


Comparison

- ATLAS also sees decay to $\Upsilon(2S)$
- ... interprets it as: $\chi_b(3P)$

- ATLAS' mass:

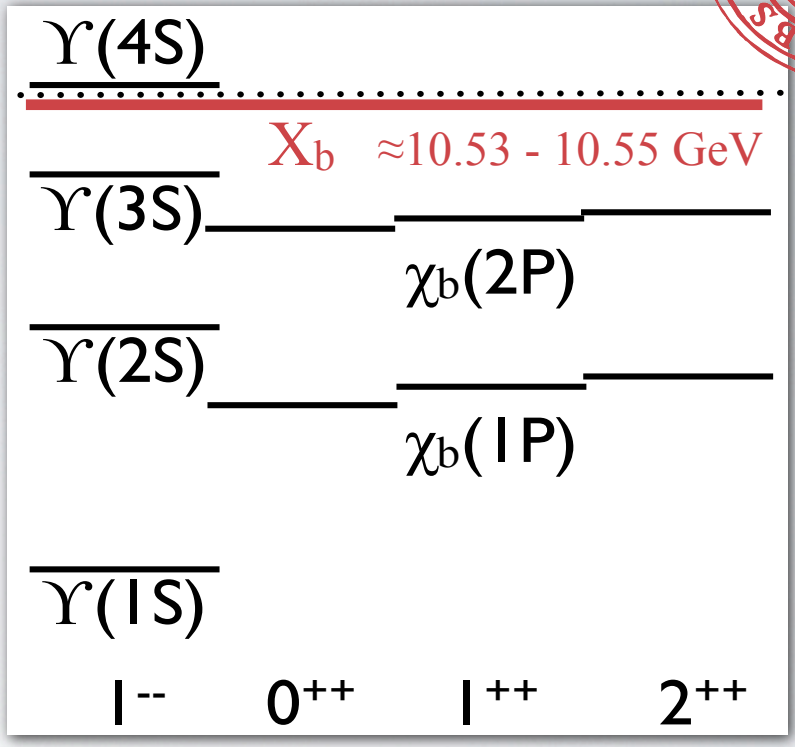
  10.530 GeV
  ±0.005 GeV (stat.)
  ±0.009 GeV (syst.)



Interpretation

- DØ currently only sees decay to $\Upsilon(1S)$
- ... calls it a narrow structure (X_b)
  - Branching ratios?
  - Spin structure?
  - Just one state?
- DØ's mass:

  10.551 GeV
  ±0.009 GeV (stat.)
  ±0.017 GeV (syst.)



Kwong, Rosner
Phys.Rev.D38:279,1988
$m(\chi_b(3P)) \approx 10.520$ GeV

Törnqvist
Phys.Lett.B590:209-215,2004
$m(B\bar{B}^*) \approx 10.545$ GeV

Summary

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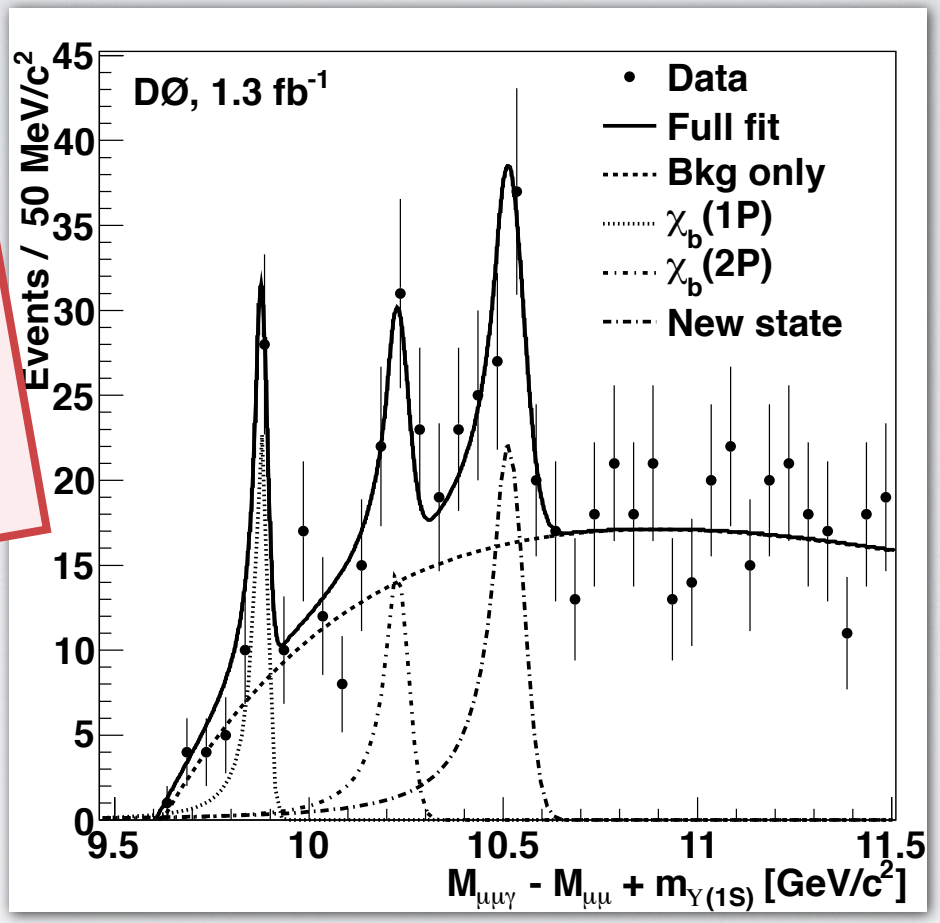
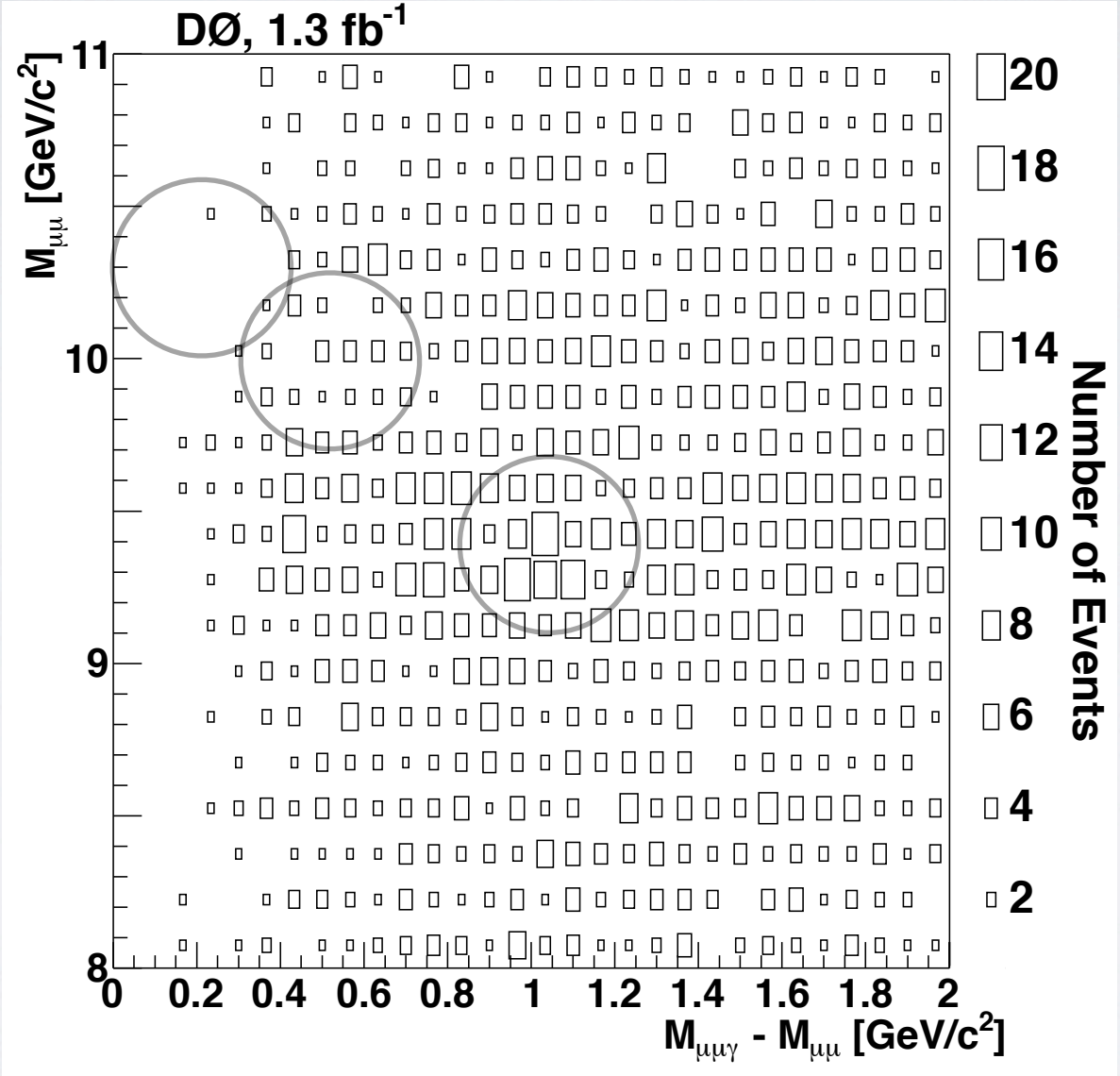
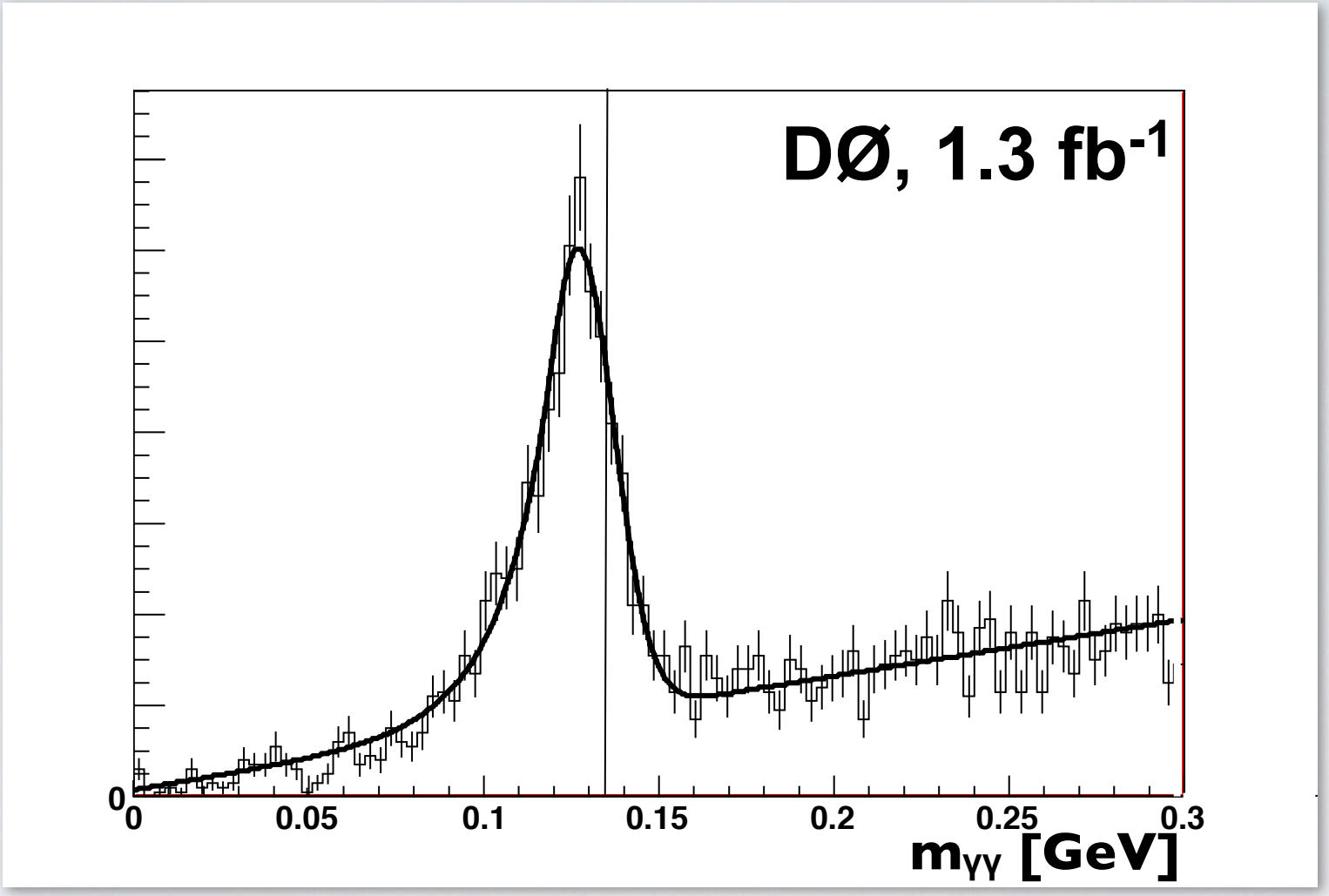


- 6 σ observation of narrow structure $X_b \rightarrow \Upsilon(1S)\gamma$
- m(X_b) = 10.551 ± 0.009 (stat.) ± 0.017 (syst.) GeV

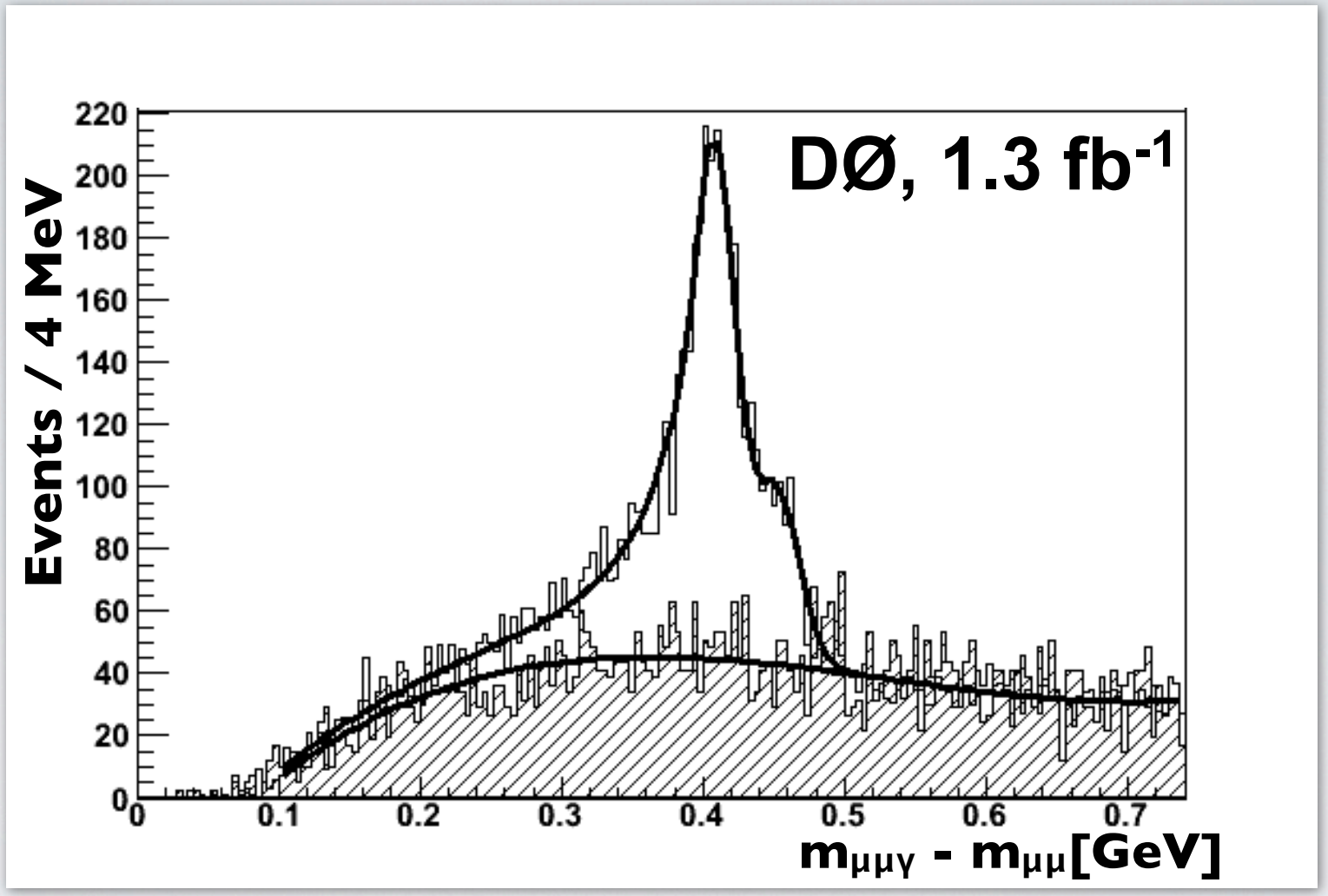
Correlation



$\pi^0 \longrightarrow \gamma\gamma$



χ_c Signal


DØ, 1.3 fb-1
Events / 4 MeV
220
200
180
160
140
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
mμμγ - mμμ[GeV]