# Magnetic Monopole Production Cross Section Limits (Update)

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Monopole Group Meeting

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# RHIC Collider Projections (FY2007 – FY2008)

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This note discusses in Part I possible modes for the RHIC Run-7 (FY2007) operating period including constraints from cryogenic cool-down, machine set-up and beam commissioning. In Part II a 2-year projection is given for gold-gold and polarized proton collisions. This latest update is based on the experience gained during the Run-6 polarized proton operation.

**In the following all quoted luminosities are delivered luminosities. Recorded luminosities are smaller due to vertex cuts, detector uptime, and other considerations. An estimate of how much of the delivered luminosity can be recorded must be made by every experiment individually.**

**http://www.agsrhichome.bnl.gov/RHIC/Runs/**

**http://www.agsrhichome.bnl.gov/RHIC/Runs/RhicProjections.pdf**

# RHIC Collider Projections (FY2007 – FY2008)

**Table 1: Achieved beam parameters and luminosities for Au-Au (Run-4), Cu-Cu (Run-5), d-Au (Run-3), and p-p (Run-6). All numbers are given for operation at a beam energy of 100 GeV/n.**

| Mode | # bunches | Ions/bunch [$10^9$] | $\beta^*$ [m] | Emittance [μm] | $\mathcal{L}_{peak}$ [$cm^{-2}s^{-1}$] | $\mathcal{L}_{store\ avg}$ [$cm^{-2}s^{-1}$] | $L_{week}$ |
|---|---|---|---|---|---|---|---|
| Au-Au | 45 | 1.1 | 1 | 15-40 | $15\times10^{26}$ | $5\times10^{26}$ | 160 $\mu b^{-1}$ |
| Cu-Cu | 37 | 4.5 | 0.9 | 15-30 | $2\times10^{28}$ | $0.8\times10^{28}$ | 2.4 $nb^{-1}$ |
| d-Au | 55 | 110d / 0.7Au | 2 | 15 | $7\times10^{28}$ | $2\times10^{28}$ | 4.5 $nb^{-1}$ |
| p↑-p↑ * | 111 | 135 | 1 | 18-25 | $30\times10^{30}$ | $20\times10^{30}$ | 7.0 $pb^{-1}$ |

* Blue and Yellow ring average polarization of 65%, in RHIC stores at 100GeV. Both STAR and PHENIX elected to have 9 non-colliding bunches. If either experiment elects to have all 111 bunches colliding in the experiment, the luminosity will be increased by 9%.

**Table 2: Maximum luminosities that can be reached after a sufficiently long running period. All numbers are given for operation at an energy of 100 GeV/n.**

| Mode | No of bunches | Ions/bunch [$10^9$] | $\beta^*$ [m] | Emittance [μm] | $\mathcal{L}_{peak}$ [$cm^{-2}s^{-1}$] | $\mathcal{L}_{store\ avg}$ [$cm^{-2}s^{-1}$] | $L_{week}$ |
|---|---|---|---|---|---|---|---|
| Au-Au | 111 | 1.1 | 0.9 | 15-40 | $36\times10^{26}$ | $8\times10^{26}$ | 290 $\mu b^{-1}$ |
| Cu-Cu | 111 | 6 | 0.9 | 15-30 | $12\times10^{28}$ | $4\times10^{28}$ | 14 $nb^{-1}$ |
| Si-Si | 111 | 12.5 | 0.9 | 15-30 | $50\times10^{28}$ | $17\times10^{28}$ | 60 $nb^{-1}$ |
| d-Au | 111 | 140d/1.1Au | 1.5 | 15-30 | $30\times10^{28}$ | $7.5\times10^{28}$ | 25 $nb^{-1}$ |
| p↑-p↑ * | 111 | 175 | 1.0 | 20-25 | $60\times10^{30}$ | $40\times10^{30}$ | 14 $pb^{-1}$ |

*We expect that an average store polarization of 65% can be reached. If both STAR and PHENIX elect again to have 9 non-colliding bunches, the luminosity is reduced by 9% compared to the numbers stated in the table.

# RHIC Collider Projections (FY2007 – FY2008)

## Part II – 2-Year Projections

In both Au-Au and p-p operation RHIC exceeds the Design Luminosity. The 2-year plan laid out below aims at reaching the RHIC Enhanced Luminosity consisting of

**$\mathcal{L}_{\text{store avg}} = 8\times10^{26}\ \text{cm}^{-2}\text{s}^{-1}$ for Au-Au at 100 GeV/n (4× design)**

**$\mathcal{L}_{\text{store avg}} = 6\times10^{31}\ \text{cm}^{-2}\text{s}^{-1}$ for p-p at 100 GeV,**
**$\mathcal{L}_{\text{store avg}} = 1.5\times10^{32}\ \text{cm}^{-2}\text{s}^{-1}$ for p-p at 250 GeV (16× design)**
**both with 70% polarization**

# RHIC Collider Projections (FY2007 – FY2008)

**Table 4: Projected RHIC Au-Au luminosities.**

| Fiscal year | | 2001A | 2002A | 2004A | 2007E | 2008E |
|---|---|---|---|---|---|---|
| No of bunches | … | 55 | 55 | 45 | 111 | 111 |
| Ions/bunch, initial | $10^9$ | 0.3 | 0.6 | 1.1 | 1.1 | 1.1 |
| Average beam current/ring | mA | 16 | 33 | 49 | 117 | 121 |
| $\beta^*$ | m | 2 | 1.0 | 1.0 | 0.9 | 0.9 |
| Peak luminosity | $10^{26}$ $cm^{-2}s^{-1}$ | 0.3 | 5 | 15 | 36 | 40 |
| Average store luminosity | $10^{26}$ $cm^{-2}s^{-1}$ | 0.2 | 1.5 | 5.0 | 8.0 | 8.0 |
| Time in store | % | | 25 | 53 | 60 | 60 |
| Maximum luminosity/week | $\mu b^{-1}$ | 3 | 25 | 160 | 291 | 289 |
| Minimum luminosity/week | $\mu b^{-1}$ | | | | 160 | 160 |
| Maximum integrated luminosity | $\mu b^{-1}$ | 7 | 89 | 1370 | 3060 | 3040 |
| Minimum integrated luminosity | $\mu b^{-1}$ | | | | 1680 | 1680 |

# RHIC Collider Projections (FY2007 – FY2008)

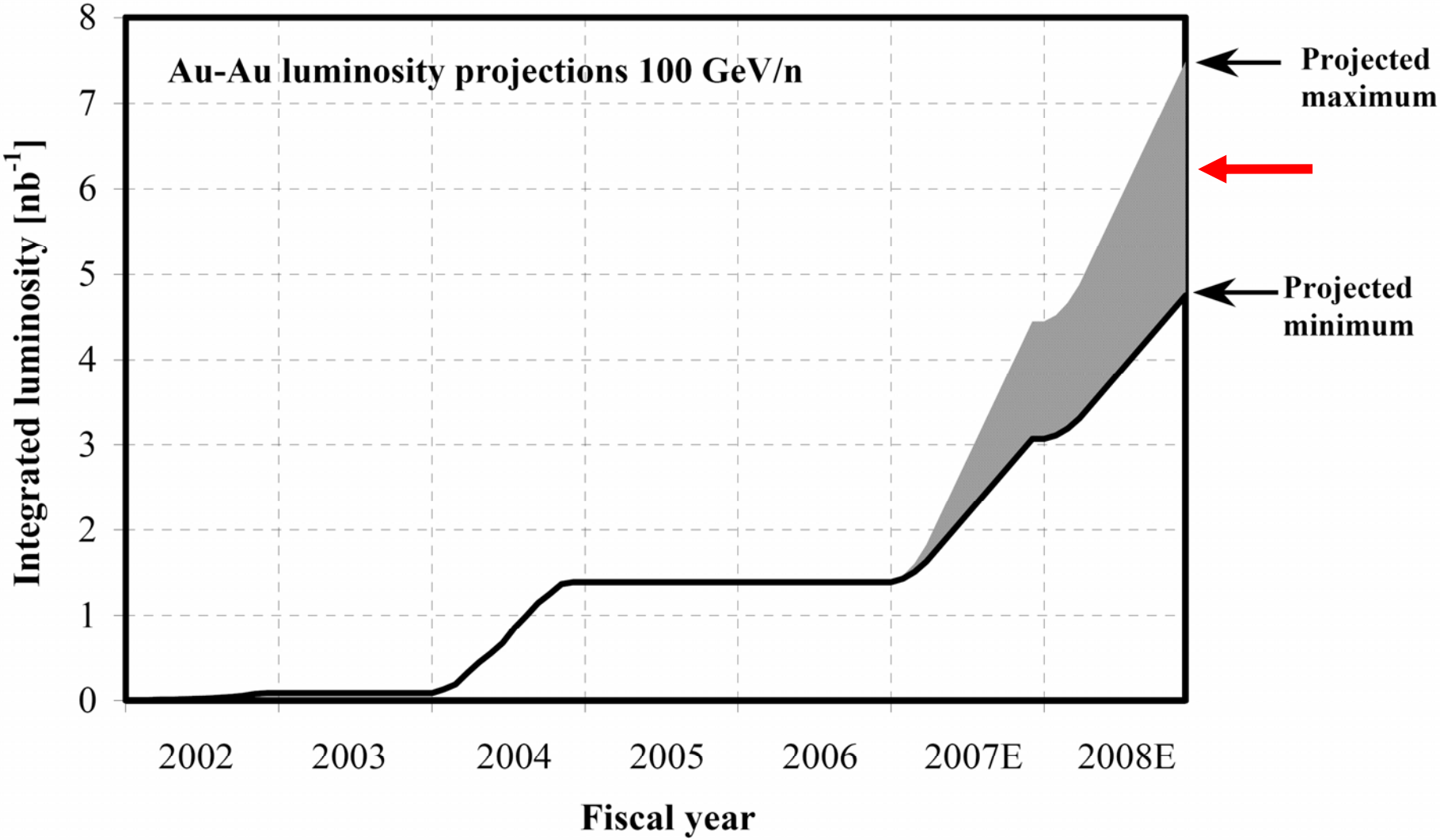



**Figure 5: Minimum and maximum projected integrated luminosity for Au-Au collisions.**

# RHIC Collider Projections (FY2007 – FY2008)

**Table 5: Projected RHIC p-p luminosities and polarization.**

| Fiscal year | | 2002A | 2003A | 2004A | 2005A | 2006E | 2007E | 2008E |
|---|---|---|---|---|---|---|---|---|
| No of bunches | … | 55 | 55 | 56 | 106 | 111 | 111 | 111 |
| Ions/bunch, initial | $10^{11}$ | 0.7 | 0.7 | 0.7 | 0.9 | 1.4 | 1.8 | 2.0 |
| Average beam current/ring | mA | 48 | 48 | 52 | 119 | 187 | 243 | 280 |
| $\beta^*$ | m | 3 | 1 | 1 | 1 | 1 | 1 | 0.9 |
| Peak luminosity | $10^{30}$ $cm^{-2}s^{-1}$ | 2 | 6 | 6 | 10 | 30 | 61 | 90 |
| Average store luminosity | $10^{30}$ $cm^{-2}s^{-1}$ | 1.5 | 3 | 4 | 6 | 20 | 41 | 60 |
| Time in store | % | 30 | 41 | 41 | 56 | 46 | 58 | 60 |
| Maximum luminosity/week | $pb^{-1}$ | 0.2 | 0.6 | 0.9 | 1.9 | 7.0 | 14.3 | 21.9 |
| Minimum luminosity/week | $pb^{-1}$ | | | | | | 7.0 | 7.0 |
| Maximum integrated luminosity | $pb^{-1}$ | 0.5 | 1.6 | 3 | 13 | 41 | 123 | 180 |
| Minimum integrated luminosity | $pb^{-1}$ | | | | | | 63 | 63 |
| AGS polarization at extraction | % | 35 | 45 | 50 | 55 | 65 | 70 | 75 |
| RHIC store polarization, average | % | 15 | 35 | 46 | 47 | 65 | 65 | 70 |
| Maximum $LP^4$/week | $nb^{-1}$ | 0 | 9 | 40 | 90 | 945 | 2550 | 5250 |
| Minimum $LP^4$/week | $nb^{-1}$ | | | | | | 1250 | 1250 |

# RHIC Collider Projections (FY2007 – FY2008)

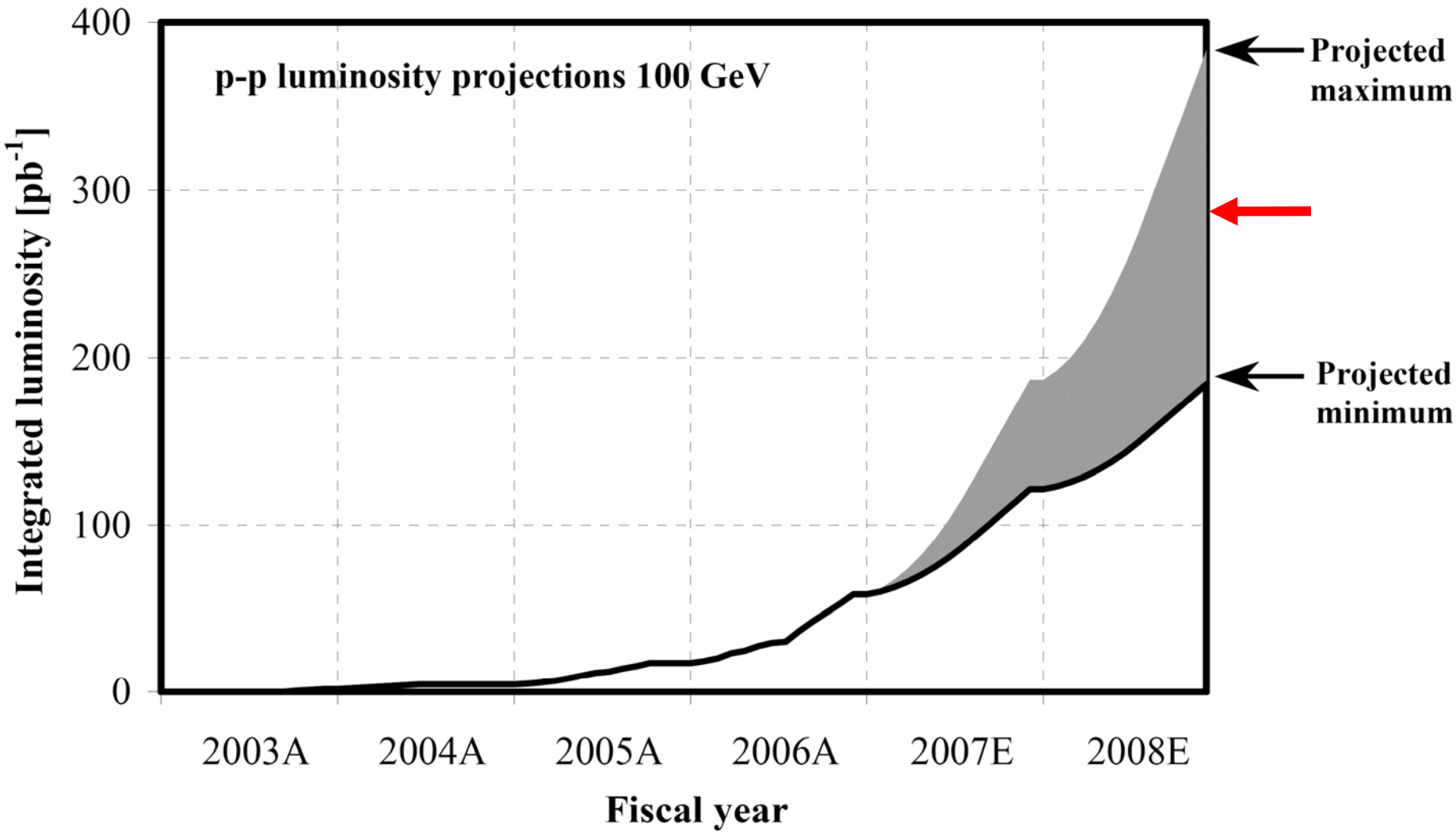



**Figure 6: Minimum and maximum projected integrated luminosity for p-p collisions.**

$$\sigma < \frac{3.0}{\epsilon \int \mathcal{L}\, dt} \equiv \sigma_{\rm lim} \quad (95\%\ \text{C.L.})$$

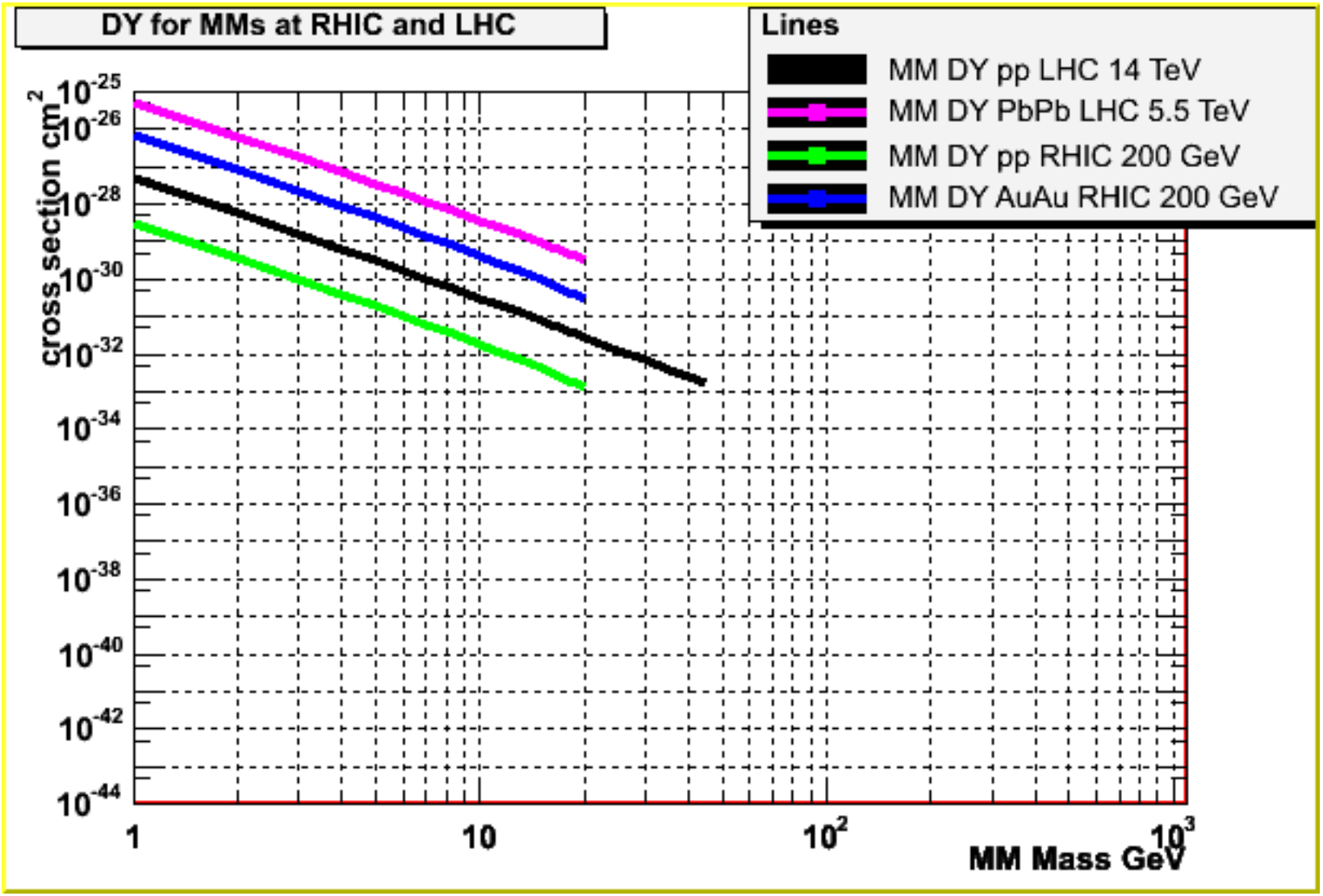
| Energy | Ldt ( $pb^{-1}$) | ε | σ (pb) | |
|---|---|---|---|---|
| 100 | 280 | 0.005 | 2.1 | |
| 100 | 280 | 0.5 | 0.021 | |
| 250 | 1500 | 0.005 | 0.4 | |
| 250 | 1500 | 0.5 | 0.004 | |
| 14000 | 5000 | 0.5 | 0.0012 | $1.2 \times 10^{-39}$ $cm^2$ |
| 14000 | 100000 | 0.5 | 0.00006 | $6.0 \times 10^{-41}$ $cm^2$ |
| 14000 | 1000000 | 0.5 | 0.000006 | $6.0 \times 10^{-42}$ $cm^2$ |

# Cross section calculation, AuAu, PbPb

$$\sigma < \frac{3.0}{\epsilon \int \mathcal{L}\, dt} \equiv \sigma_{\rm lim} \quad (95\%\ \text{C.L.})$$

| Energy | Ldt ($nb^{-1}$) | ε | σ (pb) | |
|---|---|---|---|---|
| 100 | 6.0 | 0.005 | $1000 \times 10^{2}$ | |
| 100 | 6.0 | 0.5 | 1000 | |
| 100 | 6.0 | 0.005 | 0.0026 | $2.6 \times 10^{-39}$ $cm^2$ |
| 100 | 6.0 | 0.5 | 0.000026 | $2.6 \times 10^{-41}$ $cm^2$ |
| 5500 | 10.0 | 0.5 | 600 | |
| 5500 | 10.0 | 0.5 | 0.00013 | $1.3 \times 10^{-41}$ $cm^2$ |

# Drell-Yan Process for MMs at RHIC and LHC



# Future Monopole Search experiment

**Projected Sensitivity of the MOEDAL Monopole Search**

Assuming a Drell-Yan production mechanism for monopole pair production we can extrapolate to LHC energies using results from lower energy scaling studies:

$$\frac{d\sigma}{dmdy}\Big|_{y=0} = \frac{44 \times 10^{-30}}{s^{3/2}} \times e^{-25.3m/\sqrt{s}} \frac{\mathrm{cm}^2}{\mathrm{Gev}/c^2}$$

To obtain the cross-section for monopole pair production with mass $M = x.(s/2)^{1/2}$ we integrate the above expression above m=2M. Assuming no phase space suppression:

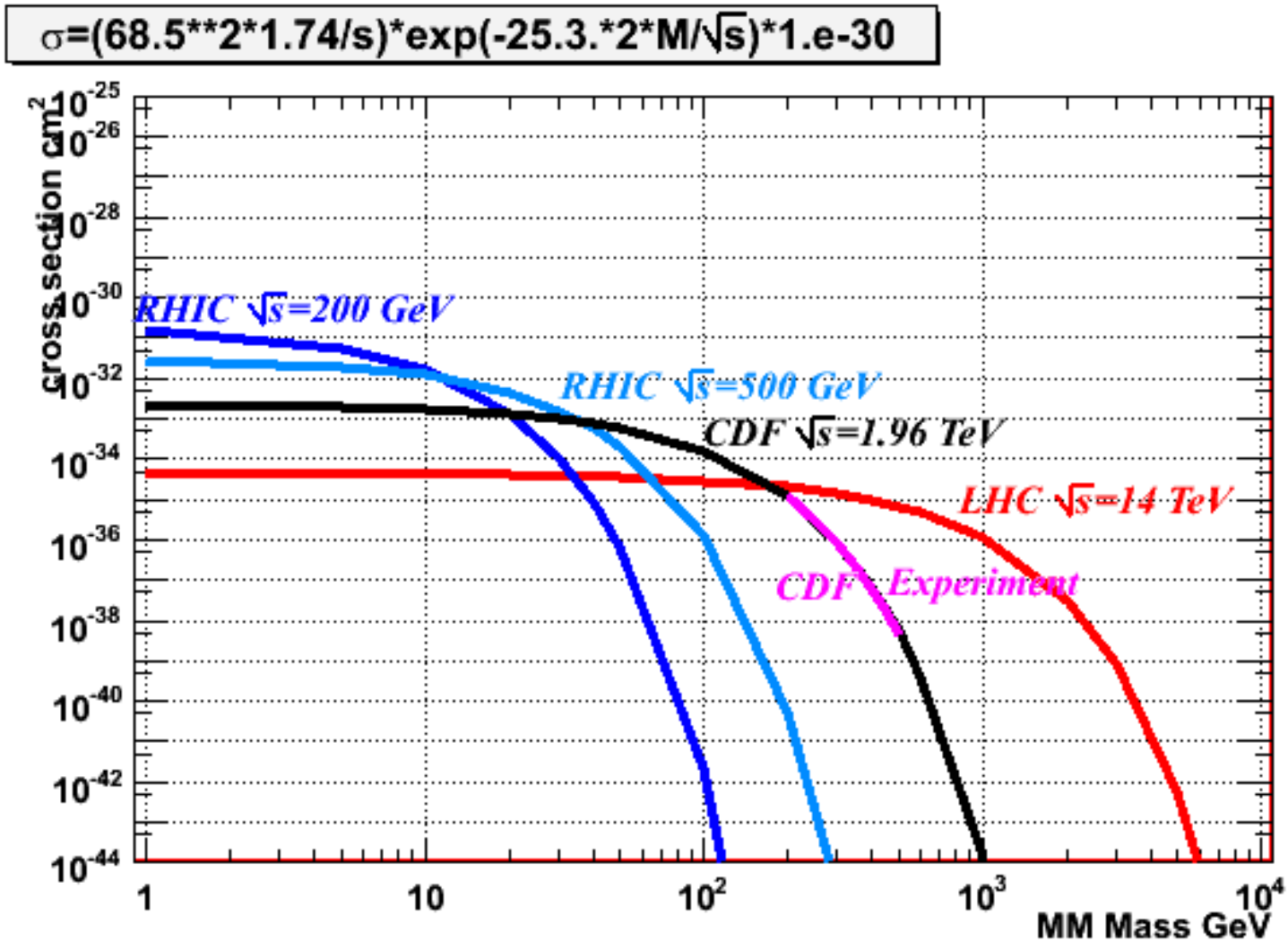
$$\sigma(M) \approx (68.5)^2 \times \frac{1.74 \times 10^{-30}}{s} \times e^{-25.3 \times 2M/\sqrt{s}} \mathrm{cm}^2$$

$$\approx 4.2 \times 10^{-35} \times e^{-25.3 \times 2M/\sqrt{s}} \mathrm{cm}^2$$

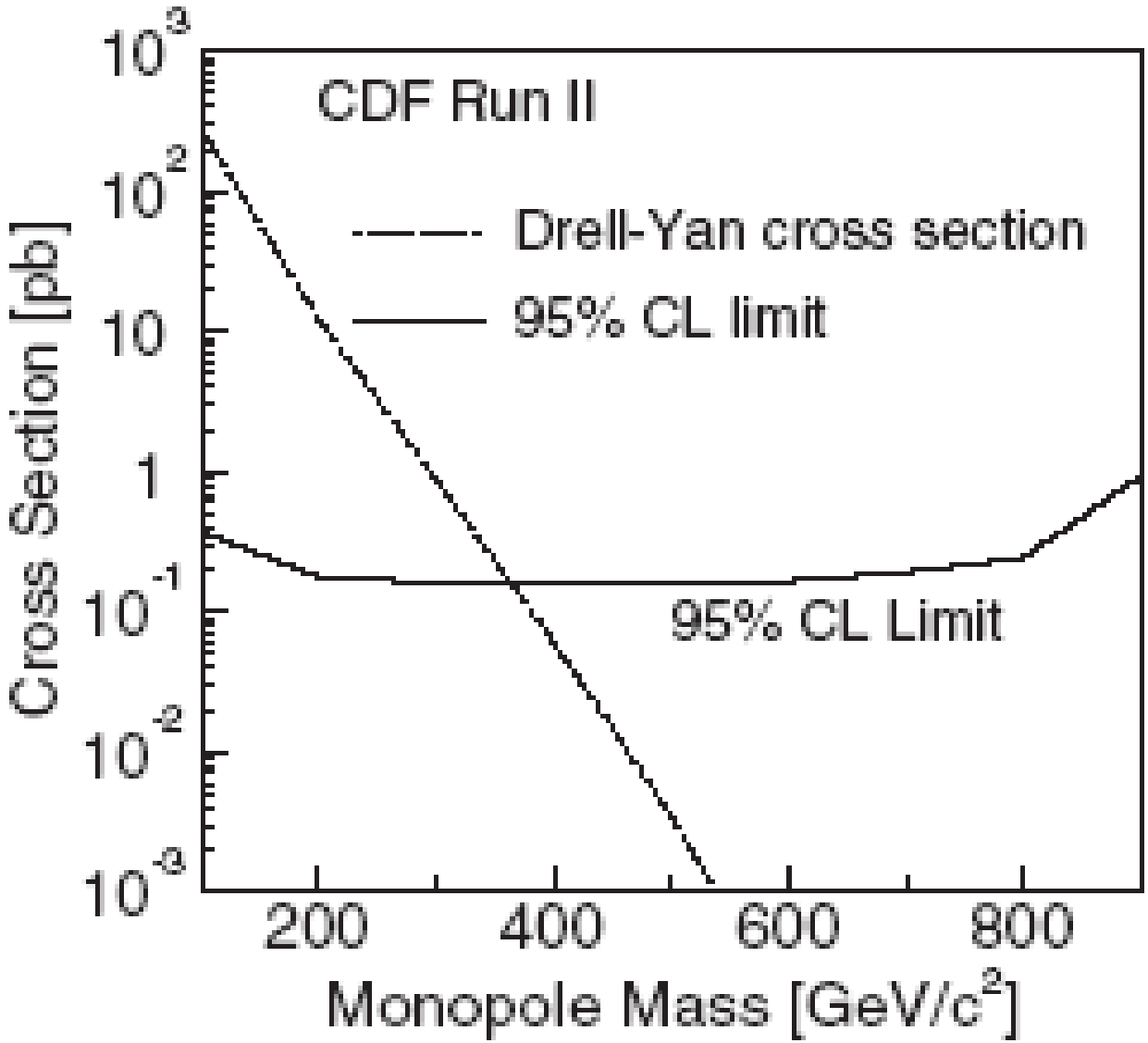
Running for one year ($10^7$ s) at a luminosity of $5 \times 10^{32}$ cm$^2$ s$^{-1}$ the sensitivity of the search is: ~$10^{40}$ cm$^2$ which corresponds to single event production with mass:

$$x = -\frac{1}{25.3} \ln\left(\frac{10^{-40}}{4.2 \times 10^{-35}}\right) = .5 \Rightarrow \boxed{3.5\ \mathrm{TeV}}$$

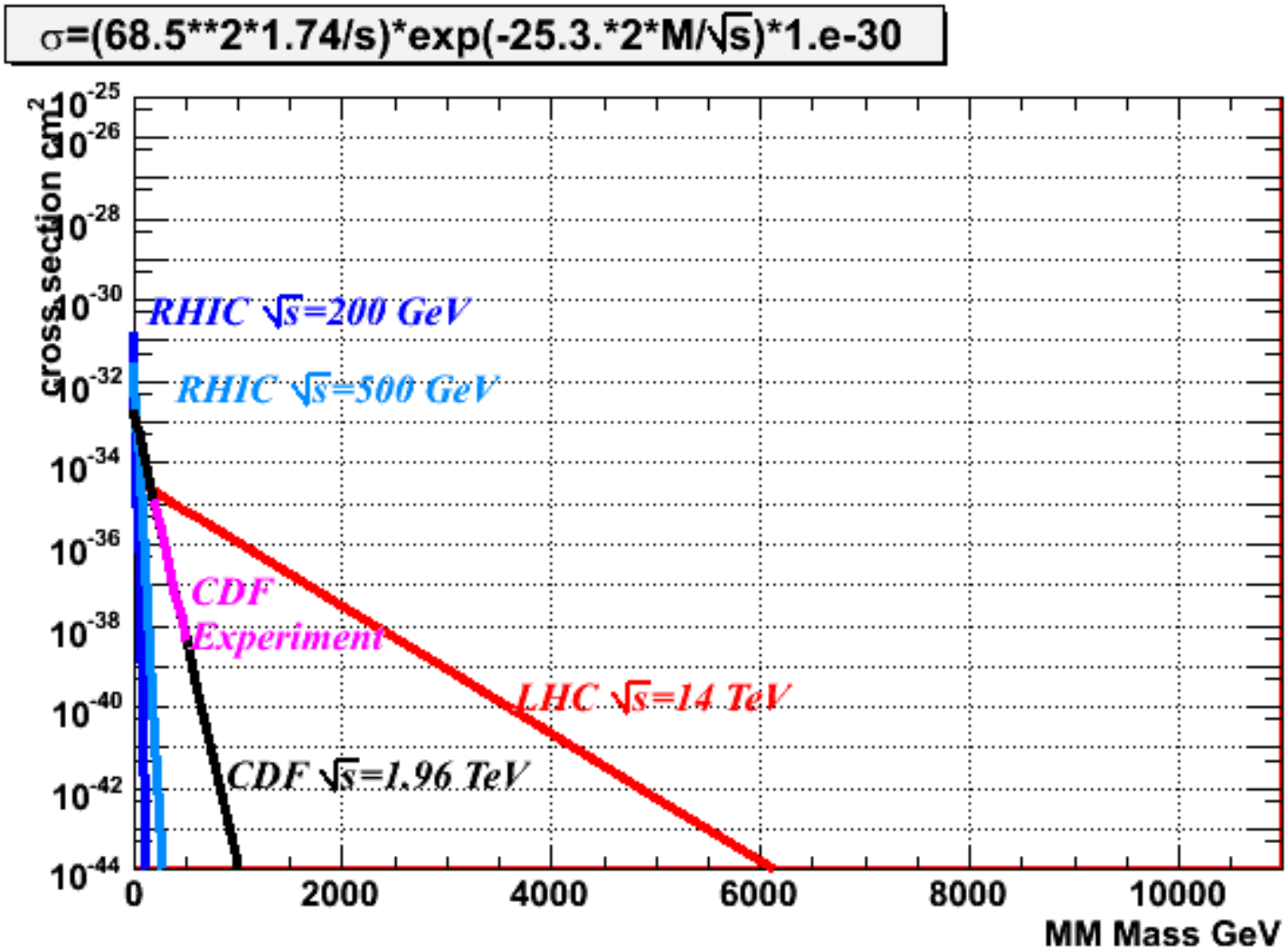
# MM Drell-Yan process at different energies



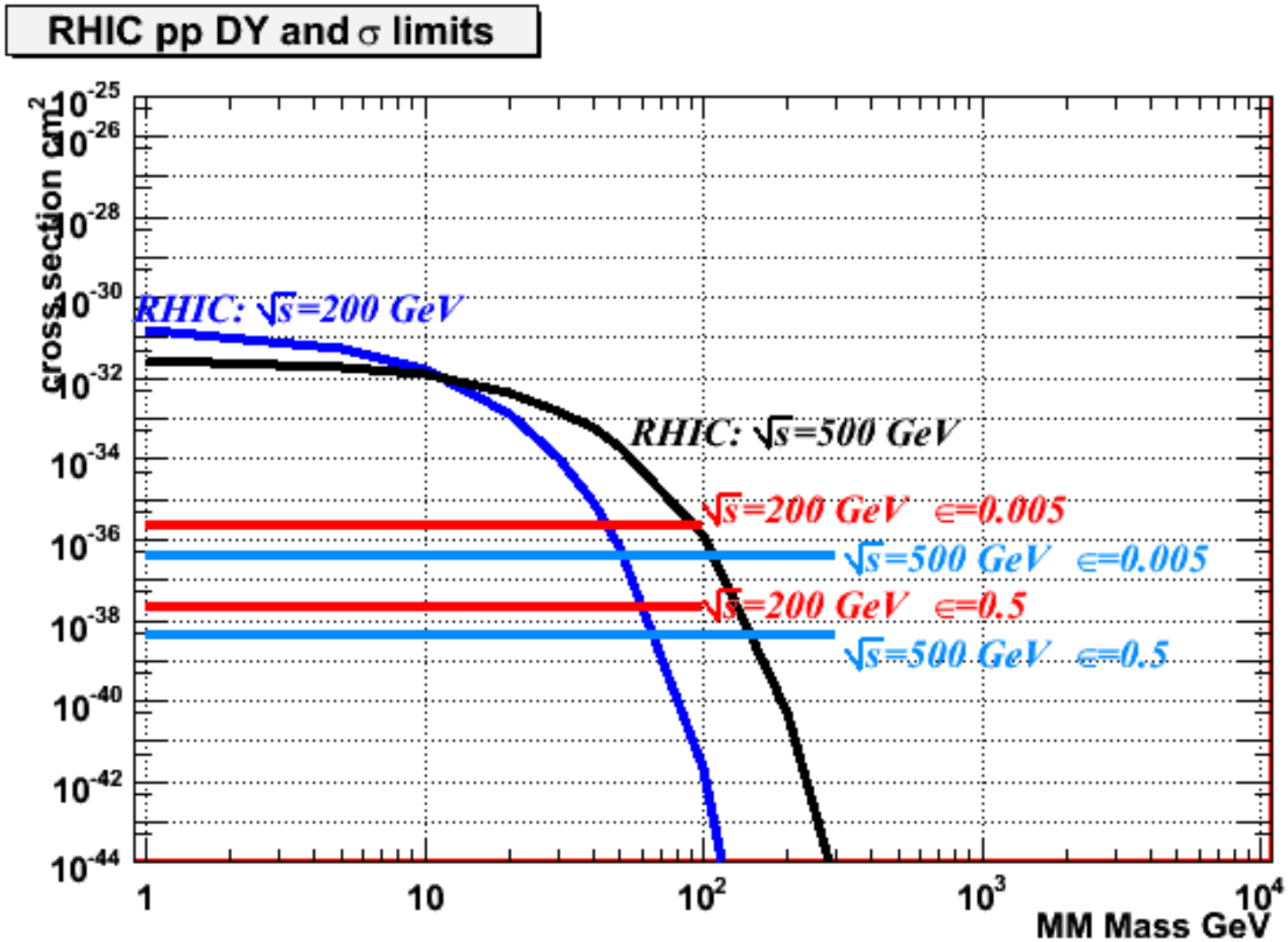
# FNAL CDF Monopole Search experiment, 2006



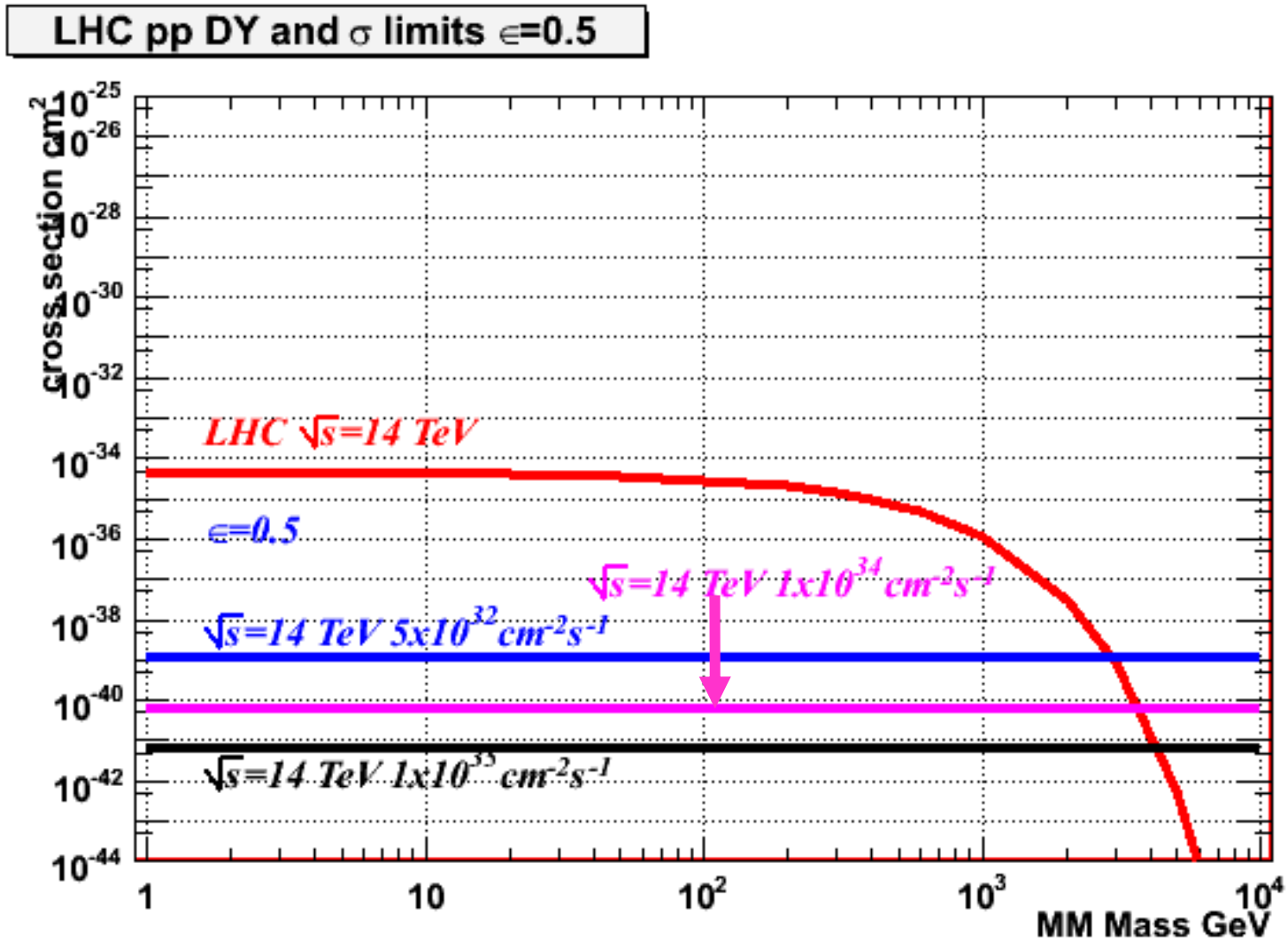
# MM Drell-Yan process at different energies



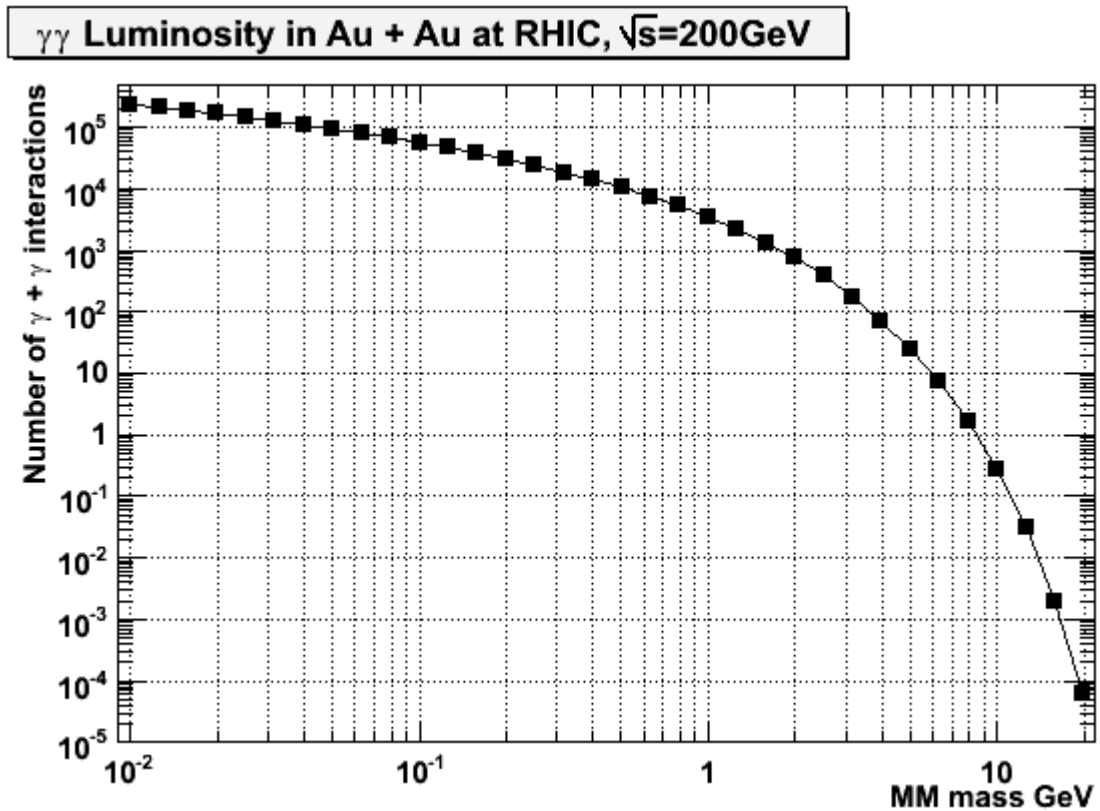
# RHIC pp, 200 and 500 GeV



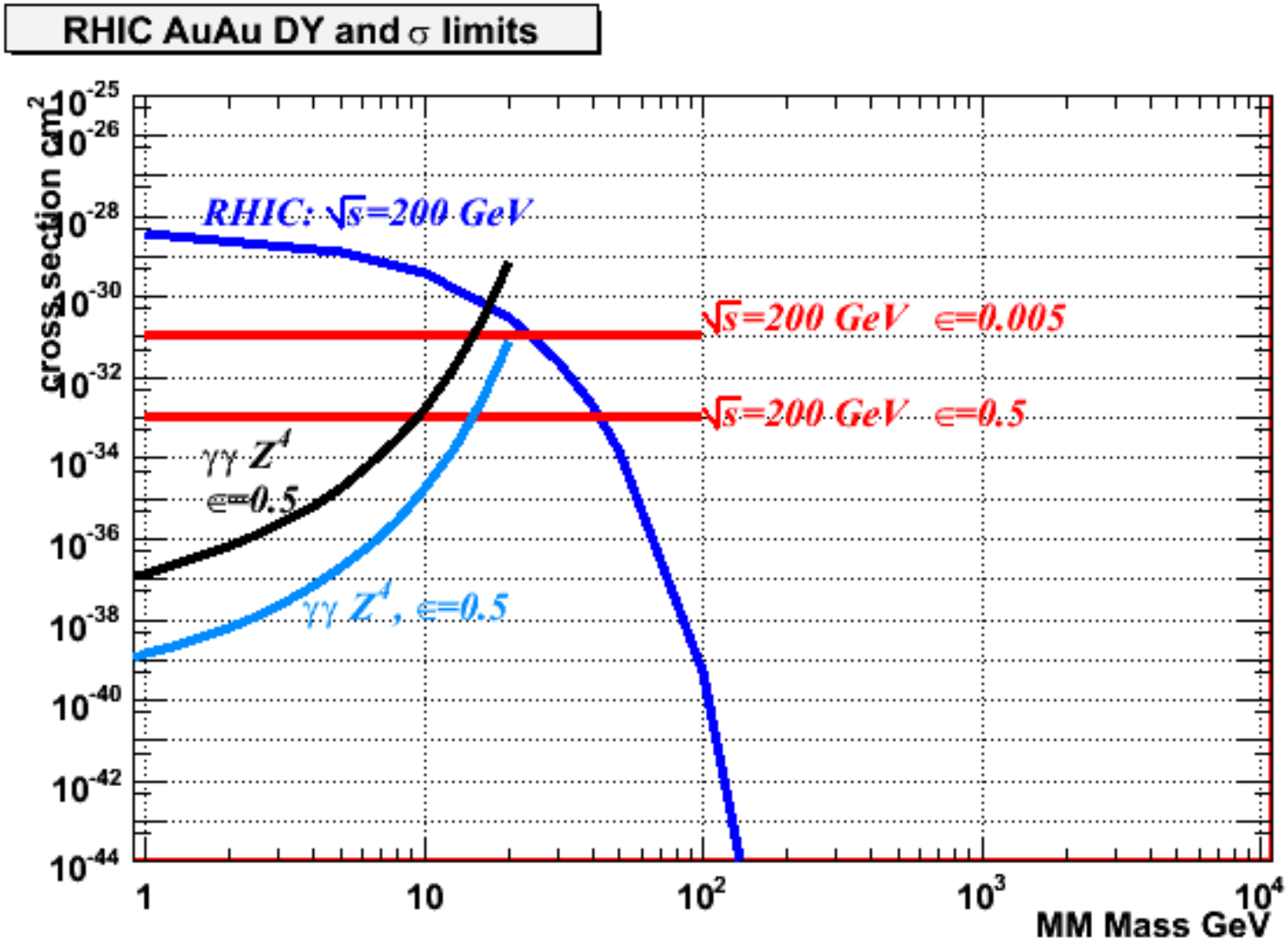
# LHC pp, 14 TeV


LHC pp DY and σ limits ∈=0.5
cross section cm²
10^-25
10^-26
10^-28
10^-30
10^-32
10^-34
10^-36
10^-38
10^-40
10^-42
10^-44
LHC √s=14 TeV
∈=0.5
√s=14 TeV 1x10^34 cm^-2s^-1
√s=14 TeV 5x10^32 cm^-2s^-1
√s=14 TeV 1x10^33 cm^-2s^-1
1
10
10^2
10^3
10^4
MM Mass GeV

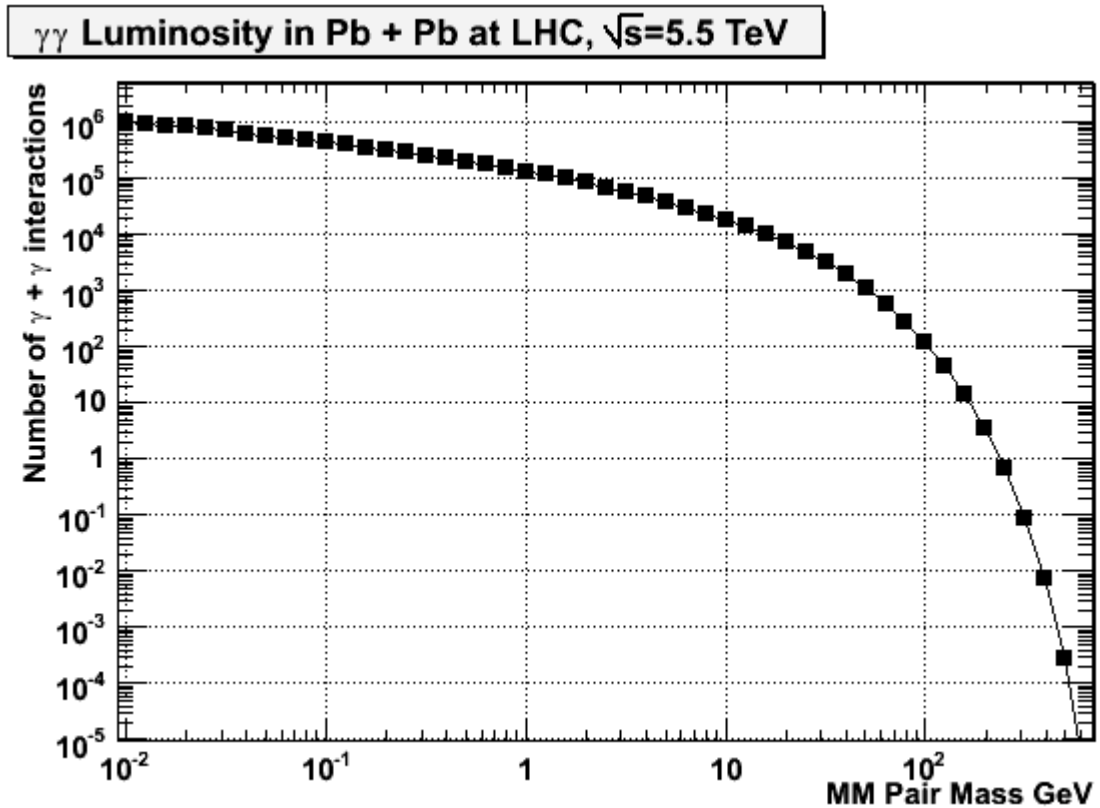
# $\gamma\gamma$ luminosities at RHIC AuAu



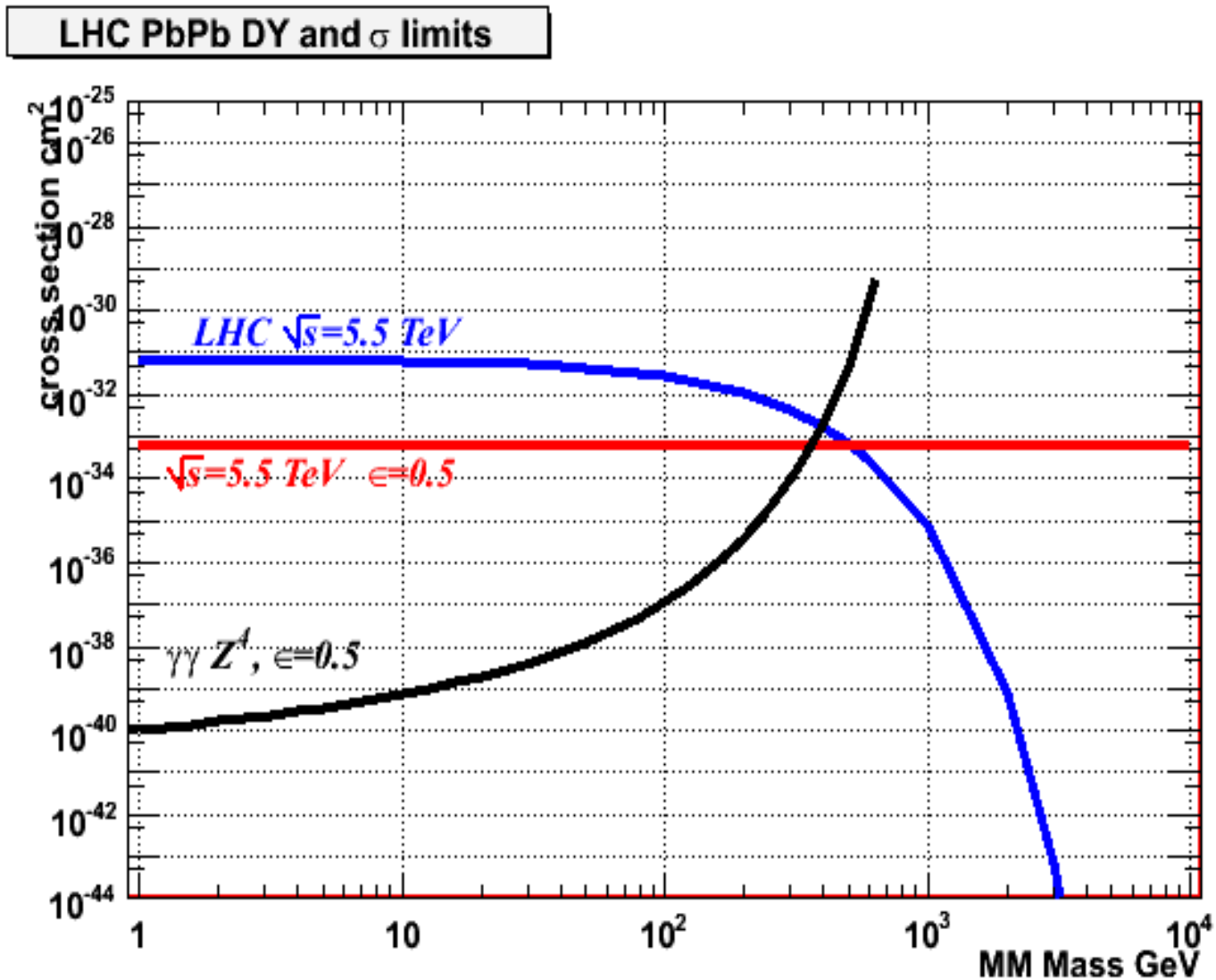
# RHIC AuAu

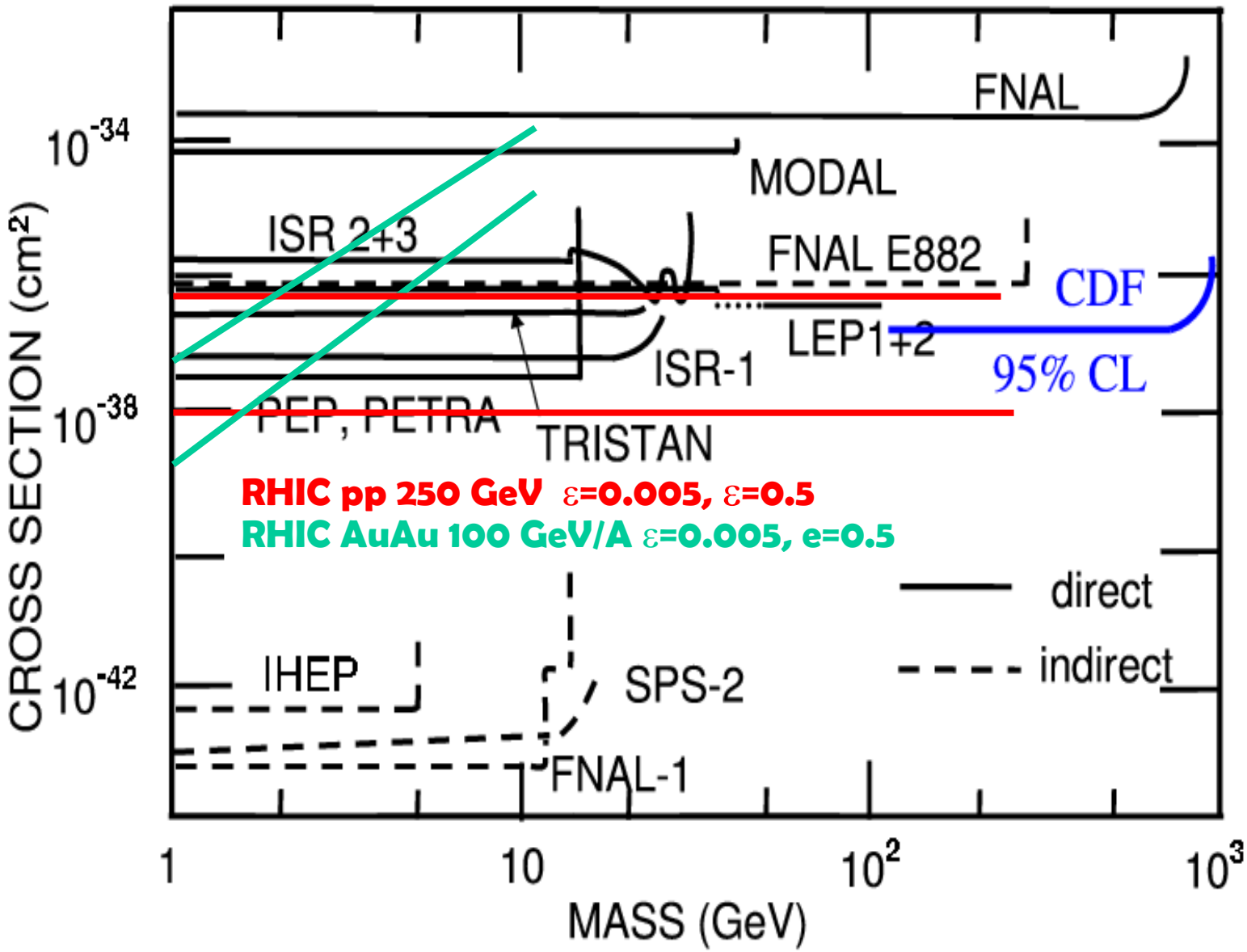

RHIC AuAu DY and σ limits
cross section cm²
RHIC: √s=200 GeV
√s=200 GeV ∈=0.005
√s=200 GeV ∈=0.5
γγ Z^A
∈=0.5
γγ Z^A, ∈=0.5
MM Mass GeV

# LHC PbPb $\gamma\gamma$ luminosities



# LHC PbPb


LHC PbPb DY and σ limits
cross section cm²
10^-25
10^-26
10^-28
10^-30
10^-32
10^-34
10^-36
10^-38
10^-40
10^-42
10^-44
LHC √s=5.5 TeV
√s=5.5 TeV ∈=0.5
γγ Z^4, ∈=0.5
1
10
10^2
10^3
10^4
MM Mass GeV

# MM Search Experiments, Compilation

(Giacomelli and Patrizii, hep-ex/0302011)