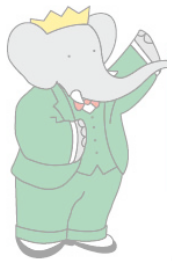
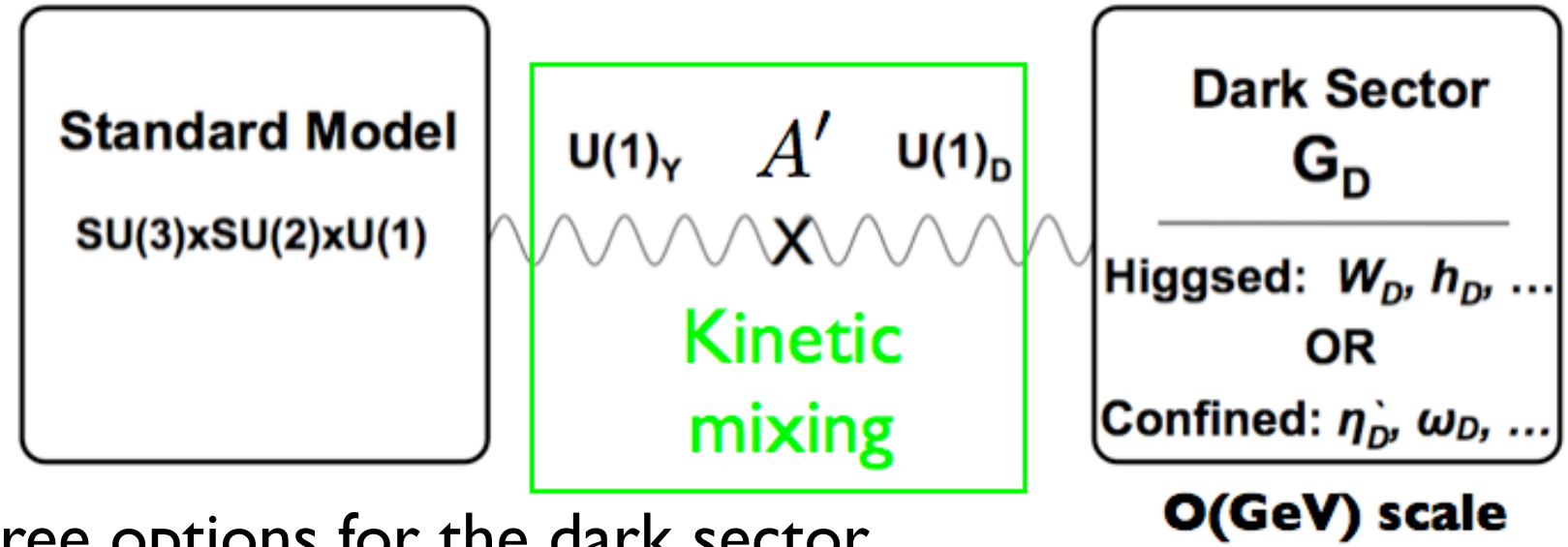
Search for narrow resonance pairs in $e^+e^- \rightarrow 4$ lepton @ BaBar

Matt Graham, SLAC
September 25, 2009

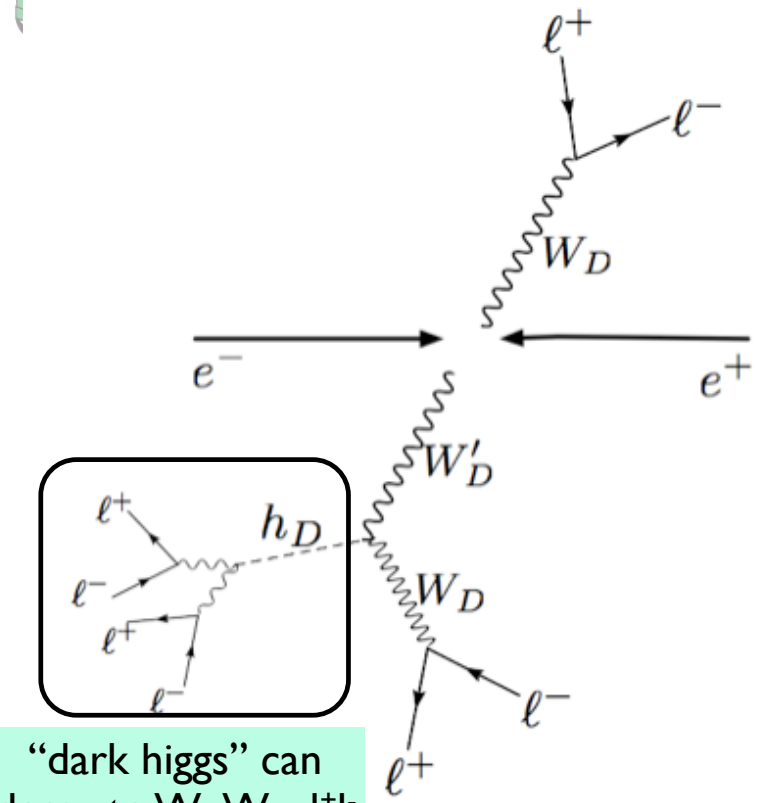


Structure of the dark sector



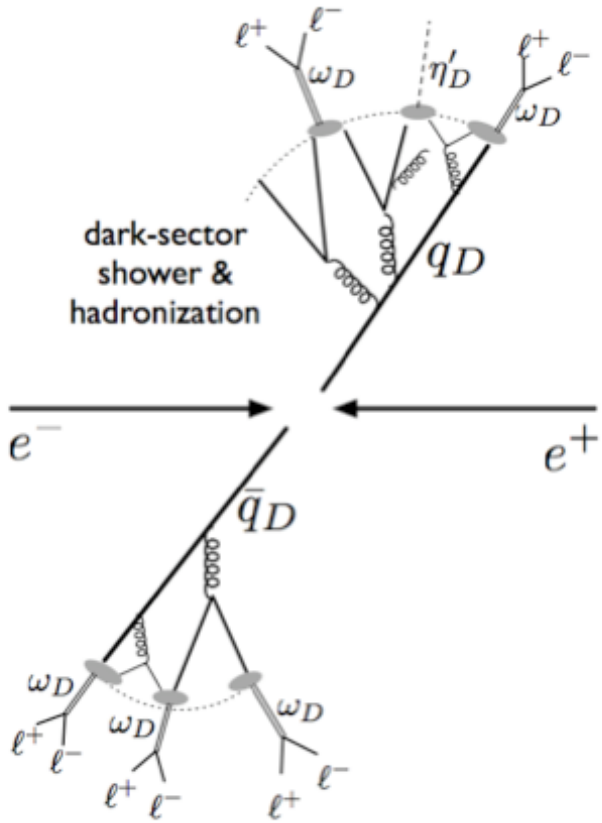
- Three options for the dark sector...
- Abelian: "dark EM"
- Higgsed non-abelian: "dark EW"
  - Arkani-Hamed, Finkbeiner, Slatyer, Weiner (hep-ph/0810.0713)
- Confined non-abelian: "dark color"
  - Alves, Behbahani, Schuster, Wacker (hep-ph/0903.3945)
- "Dark photon" talks to SM photon through kinetic mixing

Non-Abelian dark sector...

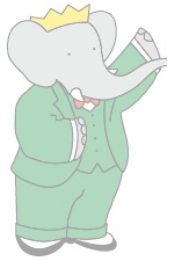


"dark higgs" can decay to $W_D W_D$, l^+l^- or escape detector!

"Higgsed": 4-8 leptons; possibly missing mass



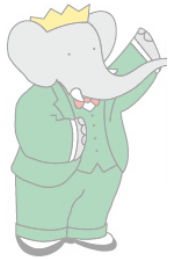
Confined: 4 leptons and up; possibly missing mass depending on lifetimes..



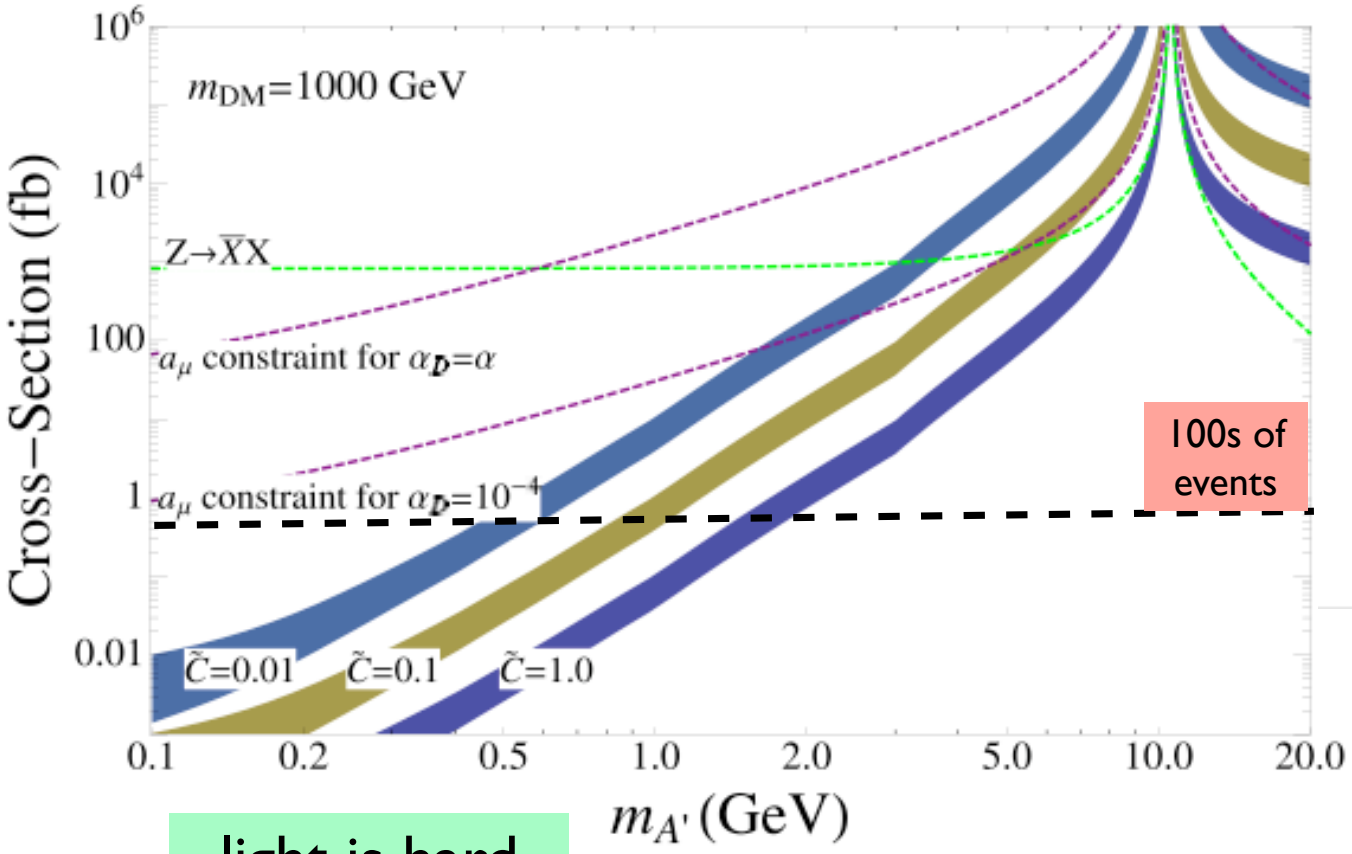
Signatures in the B-Factories

- A number of different searches...
  - exclusive 4-lepton (+photon): $W_D W_D$, $\gamma A'$
    - $W_D \to l^+l^-; A' \to W_D W_D$
  - exclusive 4-lepton + missing particle
  - inclusive 6-or-more-lepton (+photon)
  - displaced vertex $\to l^+l^-$
- In this talk, focusing on the exclusive $e^+e^- \to 4$ lepton case

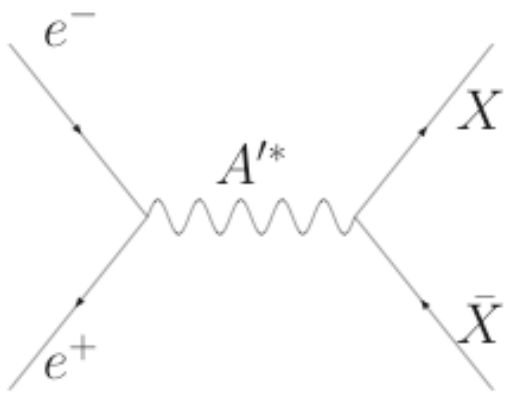
Essig, Schuster, Toro
hep-ph/0903.3941



What to expect...



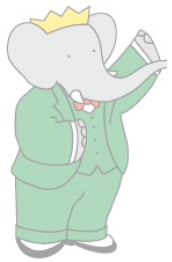
100s of events



...light is hard...

model parameters tuned to DAMA modulation result

Essig, Schuster, Toro
hep-ph/0903.3941



Event Selection etc.

- We look for $e^+e^- \rightarrow W_D W_D \rightarrow (l^+l^-)(l^+l^-)'$ from ~$2\times m_\mu$ - $\sqrt{s}/2$
  - three combos: (e^+e^-) (e^+e^-), $(e^+e^-)(\mu^+\mu^-)$, and $(\mu^+\mu^-)(\mu^+\mu^-)$
- We've got some handles to reduce background...
  - PID: electrons look like electrons, muons like muons...
  - 4-lepton invariant mass ~ E_{cm} (nothing missing)

Event Selection etc.

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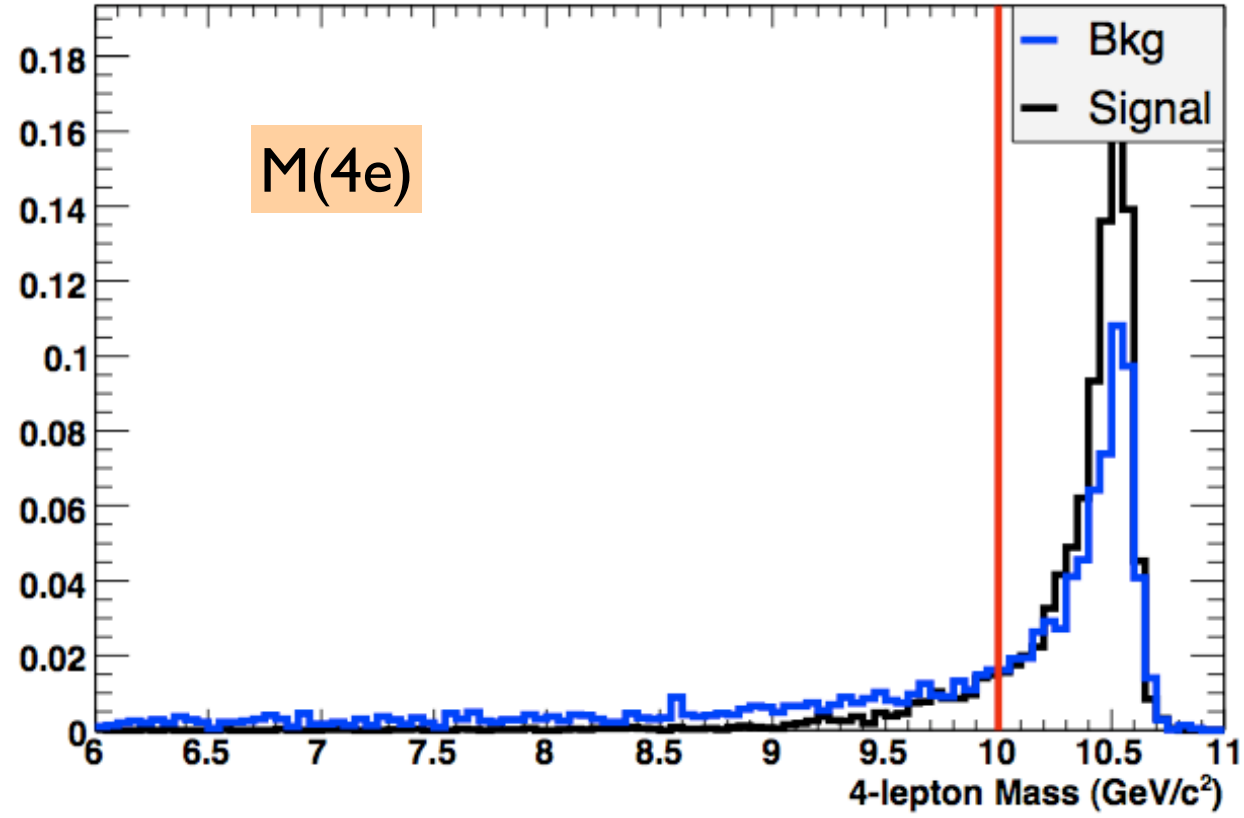
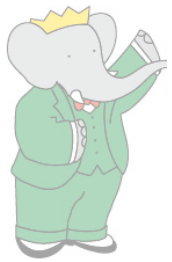
  -





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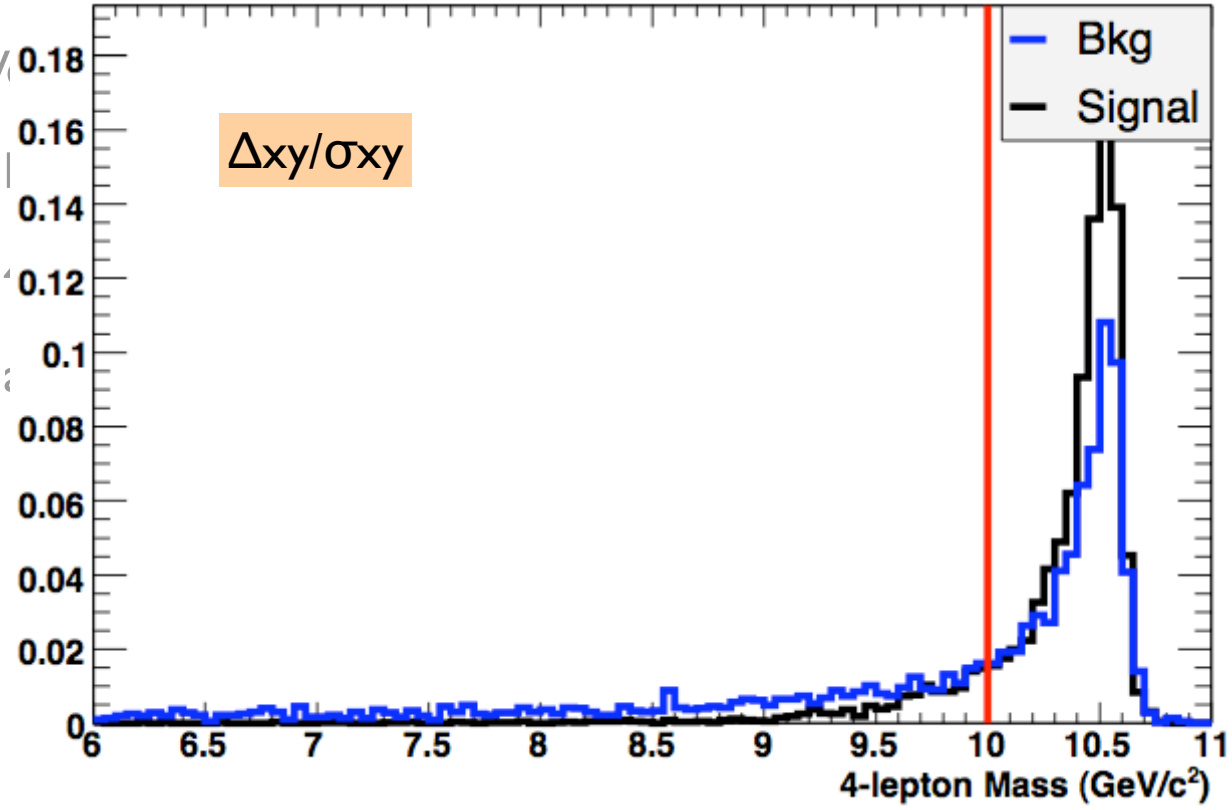

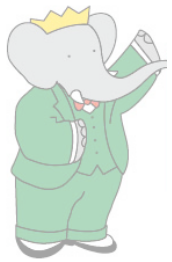

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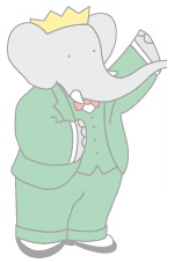
  - all tracks come from IP (i.e. remove conversions)
  - other kinematics: helicity and angle between decay planes



Event Selection etc.

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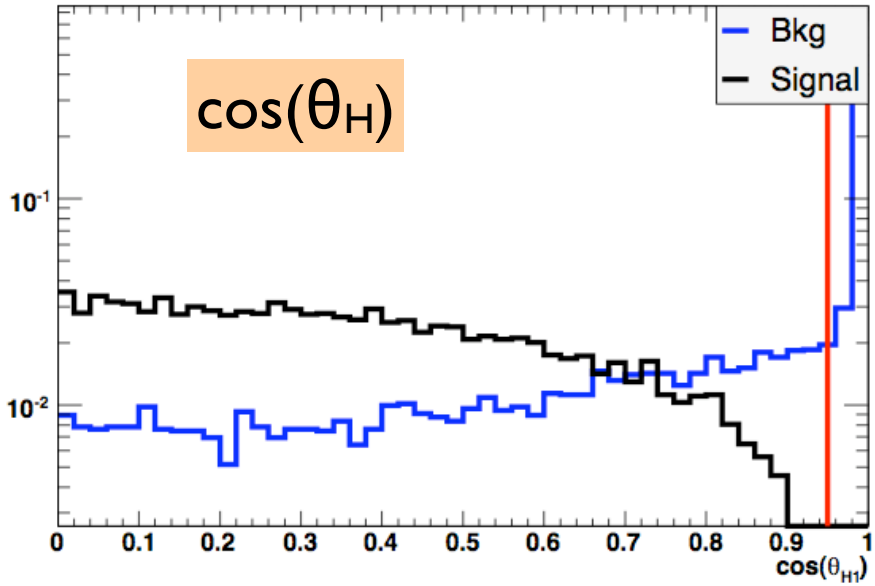


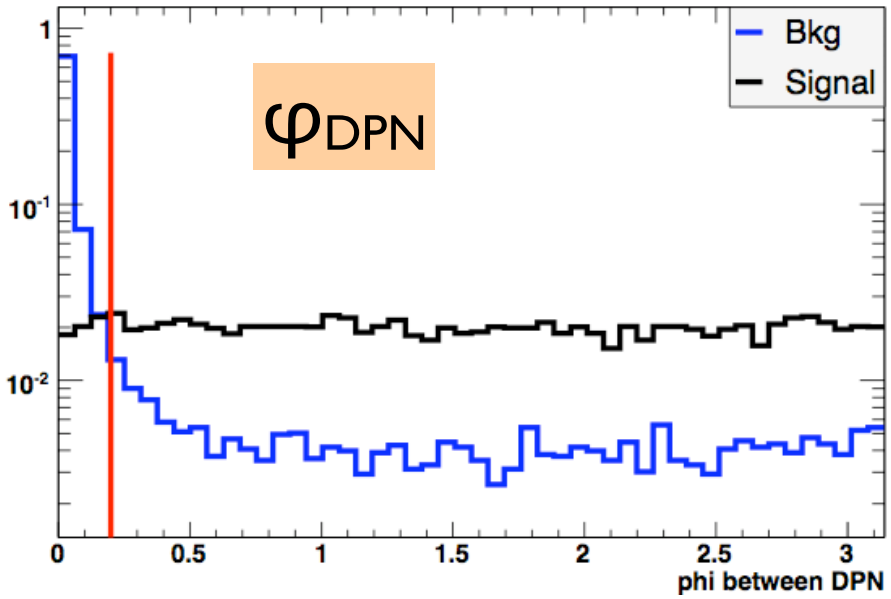
$(e^+e^-)(\mu^+\mu^-)$, and $(\mu^+\mu^-)(\mu^+\mu^-)$

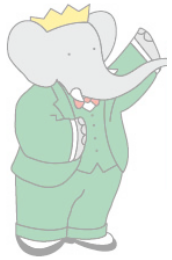
ce background...

ons, muons like muons...

(nothing missing)

- other kinematics: helicity and





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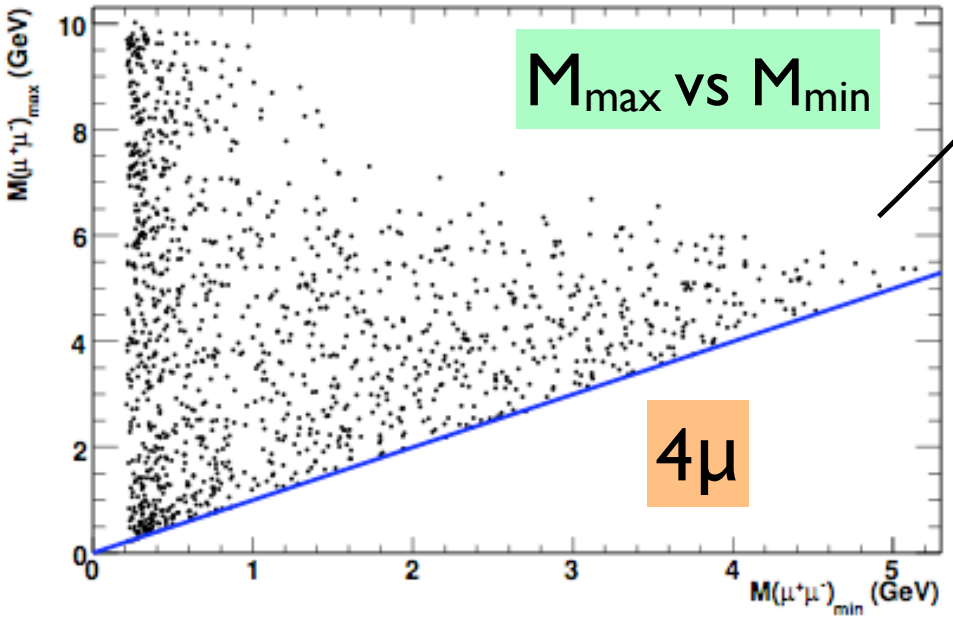
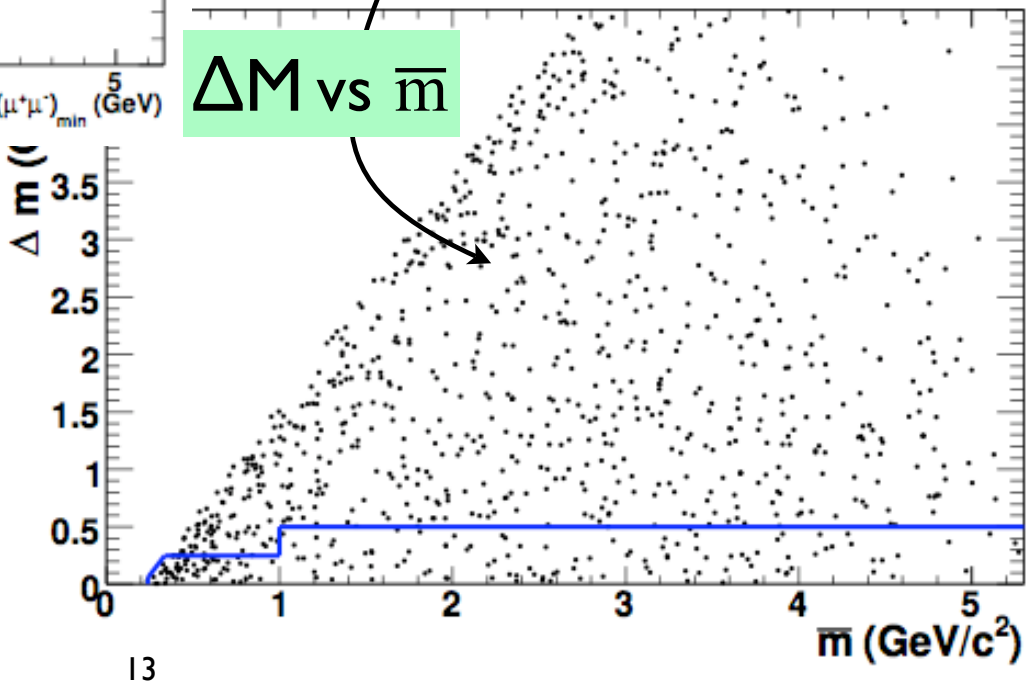
- We've got some handles to reduce background...
  - PID: electrons look like electrons, muons like muons...
  - 4-lepton invariant mass ~ E_{cm} (nothing missing)
  - all tracks come from IP (i.e. remove conversions)
  - other kinematics: helicity and angle between decay planes
  - both invariant mass pairs ~ same
- Efficiency of these cuts ~ 25-45% depending on W_D mass
- We use the full runs 1-7 data set! 536 fb^{-1}

Background Mass Distributions



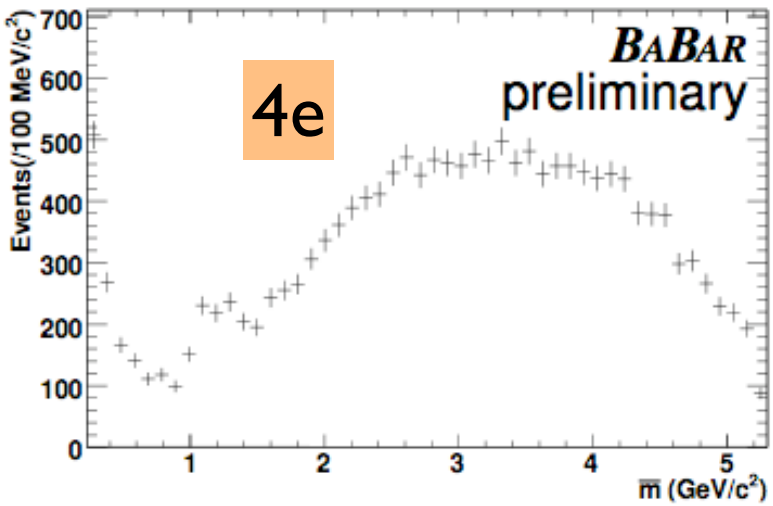
$$\overline{m} = \frac{M_{max} + M_{min}}{2}$$

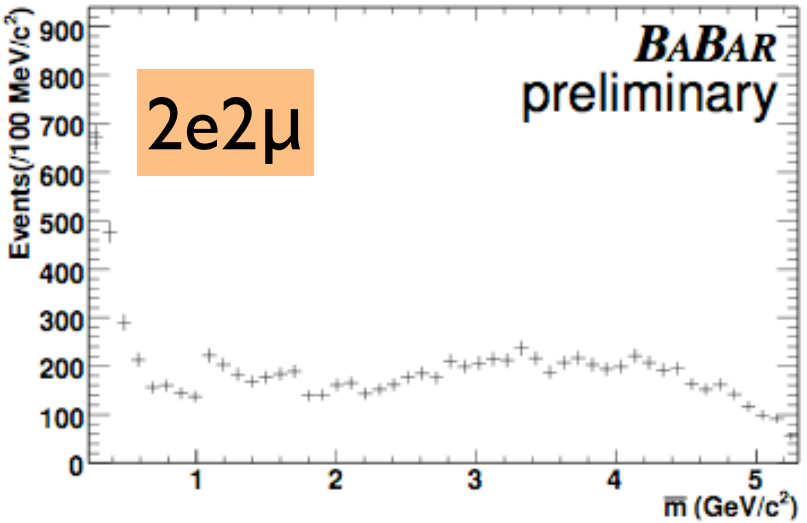
$$\Delta M = M_{max} - M_{min}$$



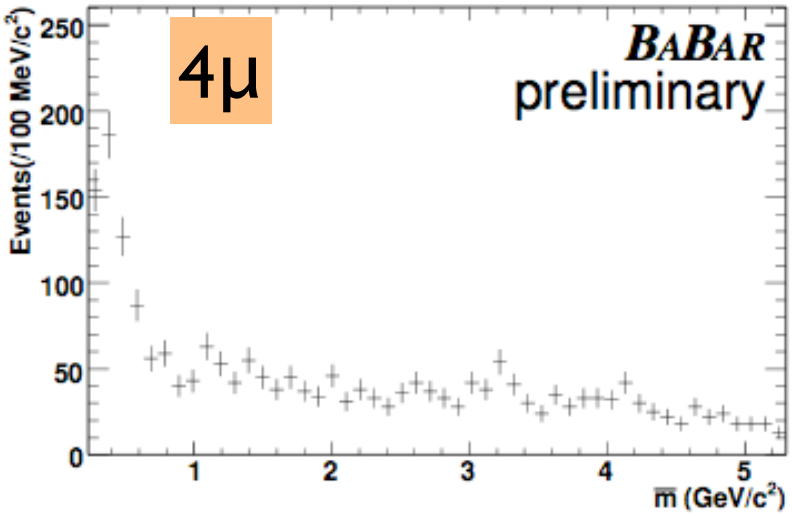
Cut on ΔM:
<0.25 for $\overline{m}$<1.0 GeV
<0.50 for $\overline{m}$>1.0 GeV
...still very loose...

Background $\bar{m}$ distributions



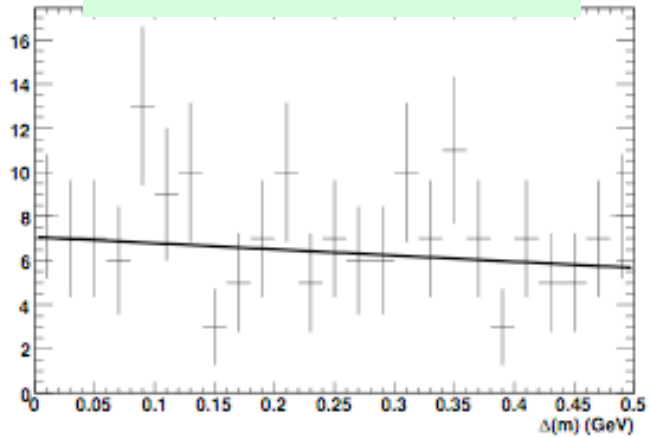


Somewhat peaking at low mass
~ 45, 20, 5 events/20MeV for 4e, 2e2μ, and 4μ respectively
...the shapes and scales are consistent with $e^+e^- \rightarrow 4l$

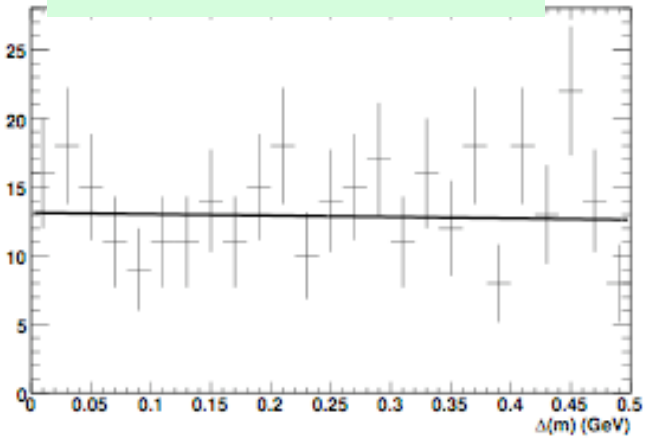


Background Δm distributions

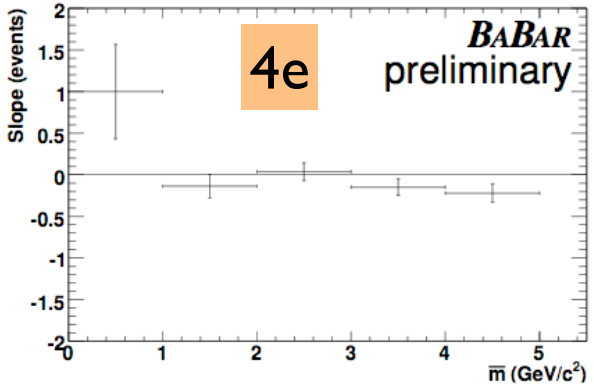
4e: 2.0>$\overline{m}$>3.0 GeV

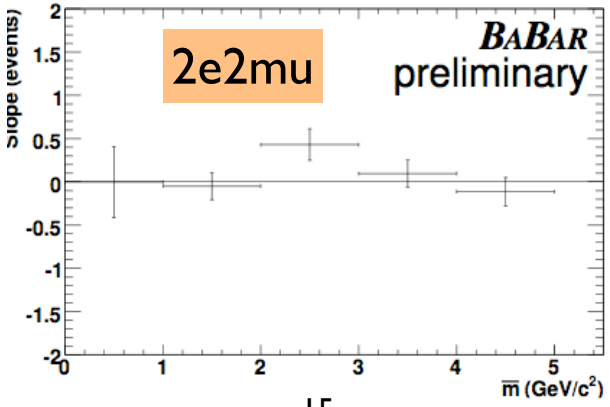


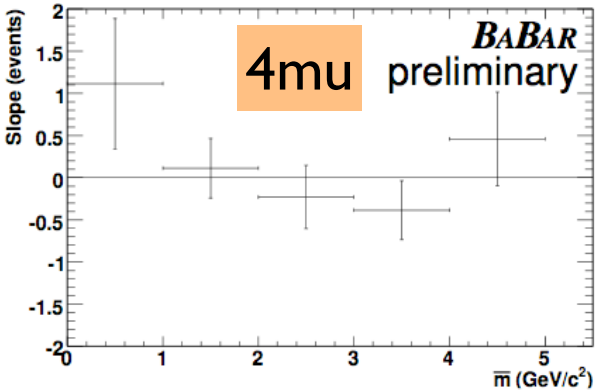
4e: 3.0>$\overline{m}$>4.0 GeV



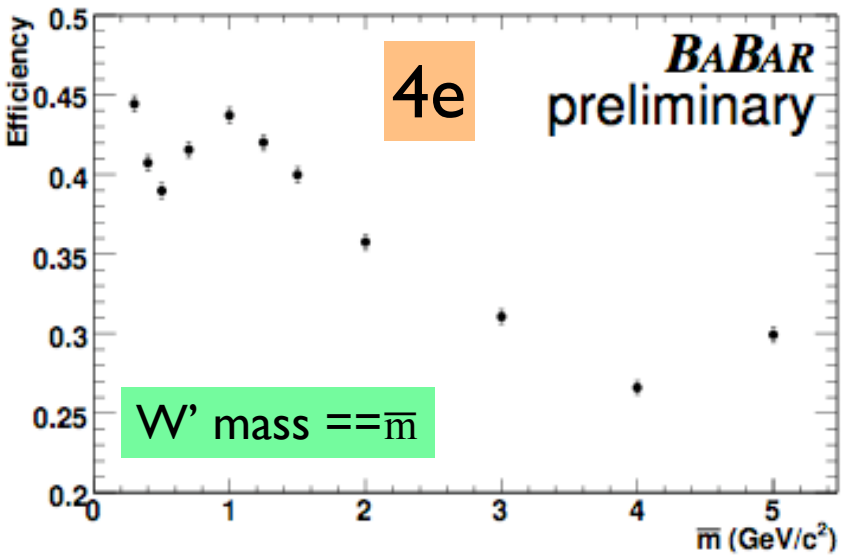
...slope of Δm in bins of $\overline{m}$ consistent with 0.

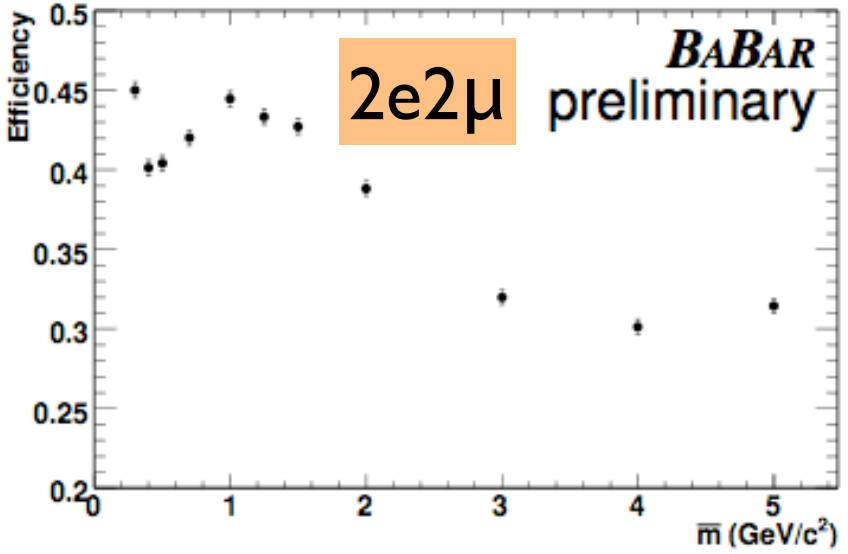


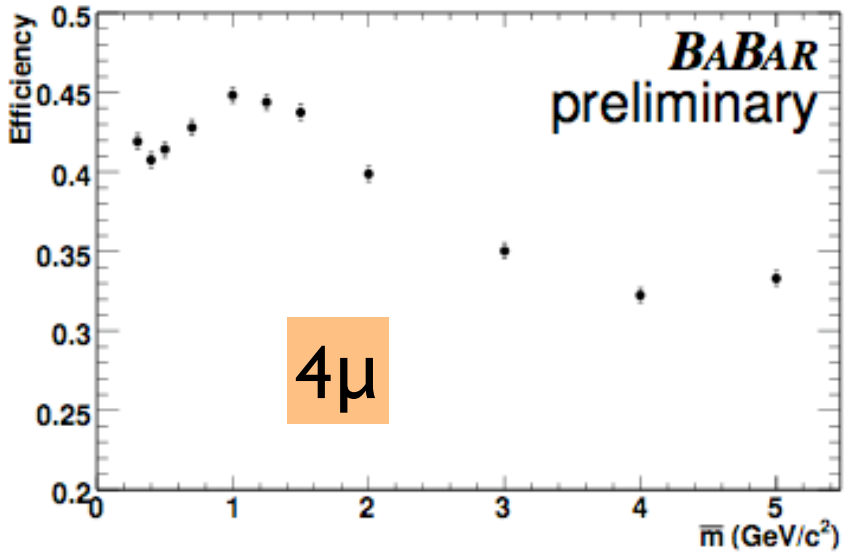




W´ mass dependence...efficiency



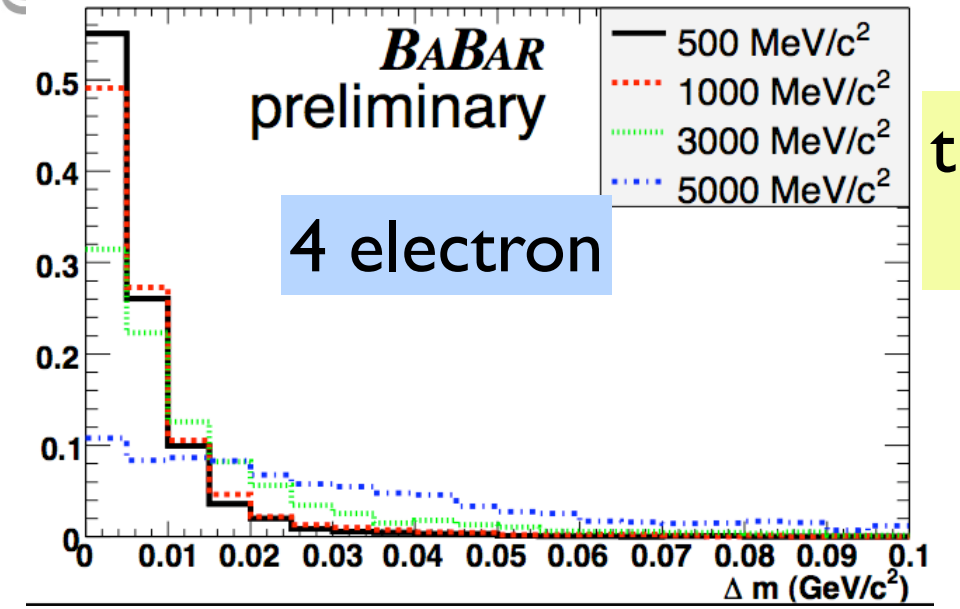




The total efficiency is somewhat dependent on the mass...interpolate (linearly) between MC points to correct event yields

The dip ~500MeV is due to the opening angle ≈ bending angle at the EMC

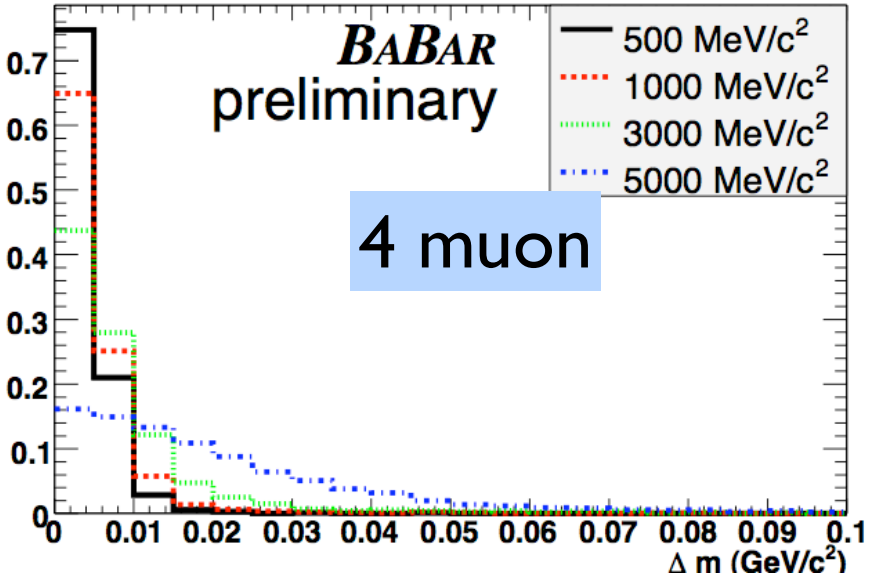
W´ mass dependence...Δm



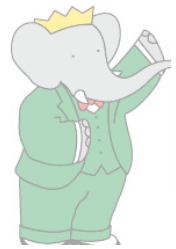
4 electron

the Δm resolution is worse for 4e than for 4μ...

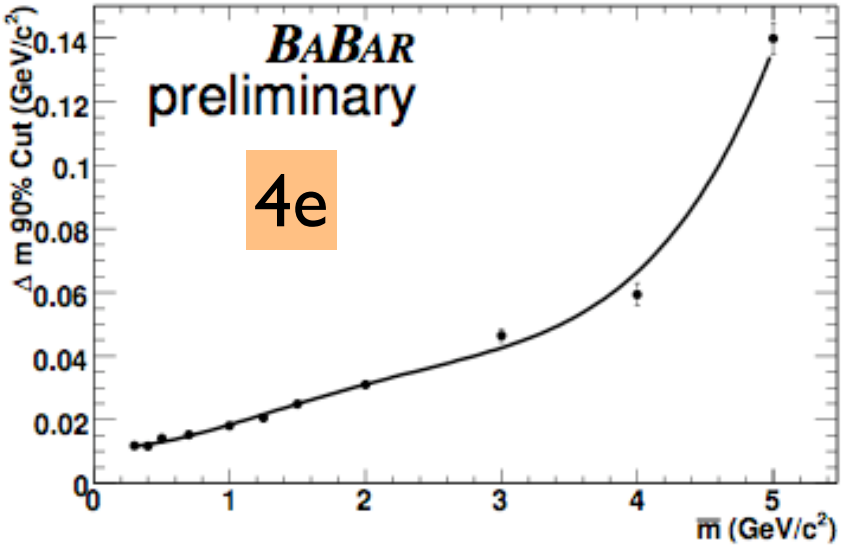
...and it degrades with increasing mass.

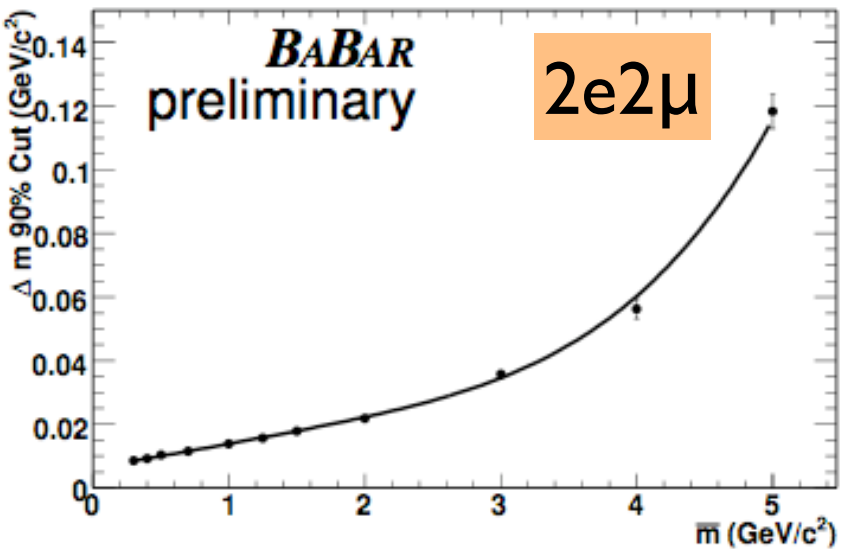


4 muon



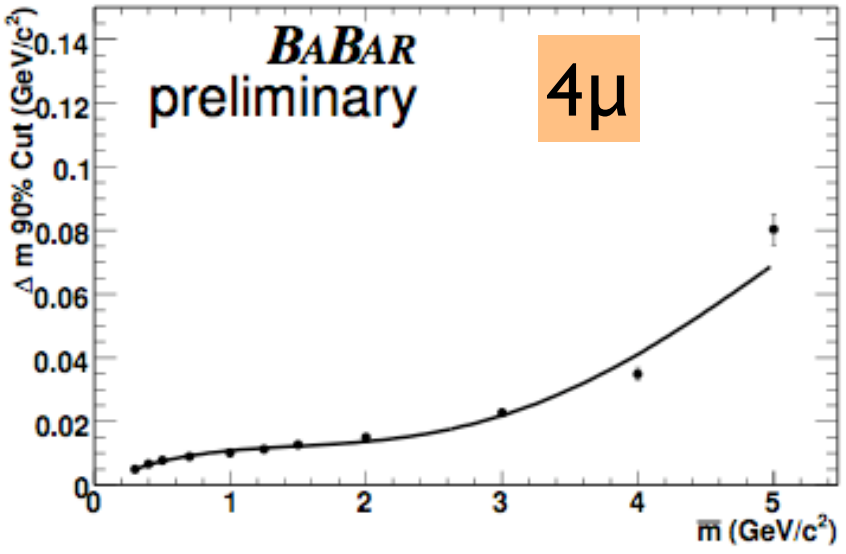
W´ mass dependence...Δm

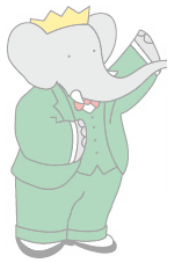




...these show the 90% efficiency cut value of Δm at different W´ masses

we use these values (from fit) to define the signal/background regions.

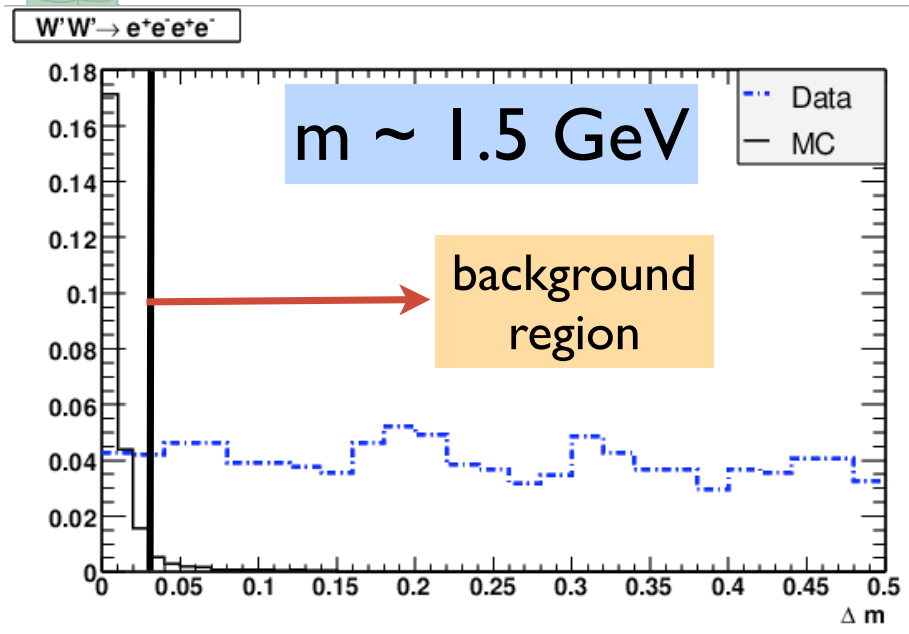




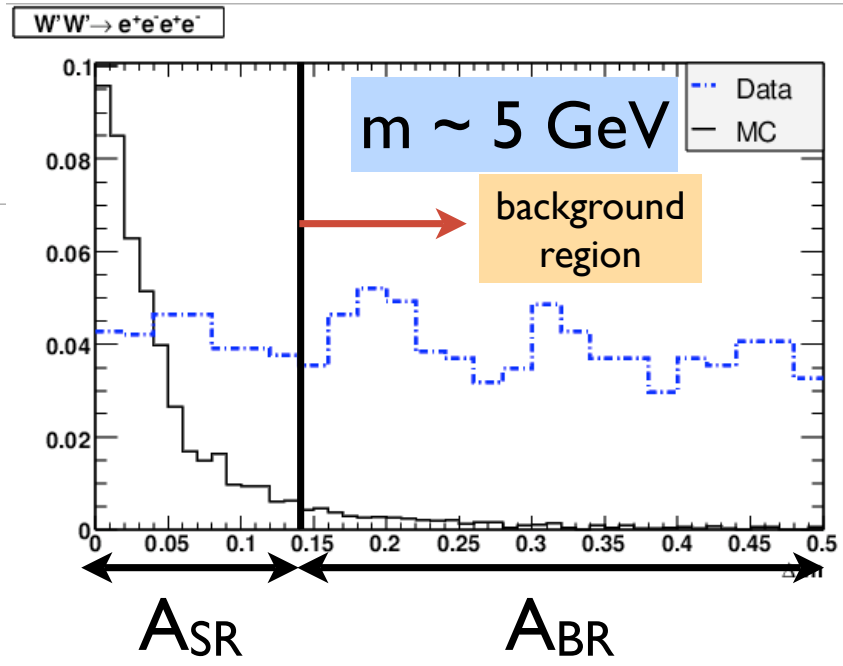
Signal Extraction & Limit Setting

- Goal: search for a narrow resonance in $\overline{m}=m(W_D)$ between 240 MeV and $\sqrt{s}/2$...if nothing is seen, set a limit
- We do this by scanning in $\overline{m}$ bins 20 MeV wide (resolution is ~2-8MeV), stepping every 10 MeV so that there is 50% overlap between the bins before and after
- perform cut-and-count analysis in each bin defining signal/background region in Δm
- Calculate # of observed signal events
  - $N_{obs} = N_{SR} - N_{BR} \times (A_{SR}/A_{BR})$
- Use the Rolke class to set limits ("**Limits and Confidence Intervals in the Presence of Nuisance Parameters", arxiv:physics/0403059**).
  - uses profile likelihood method to set asymmetric limits
  - takes into account (poisson) uncertainty in the background region event yield
  - coverage is pretty good (I've checked)
- For observation criteria, need to account for "trials factor"...done using toy MC

ΔM cut examples...

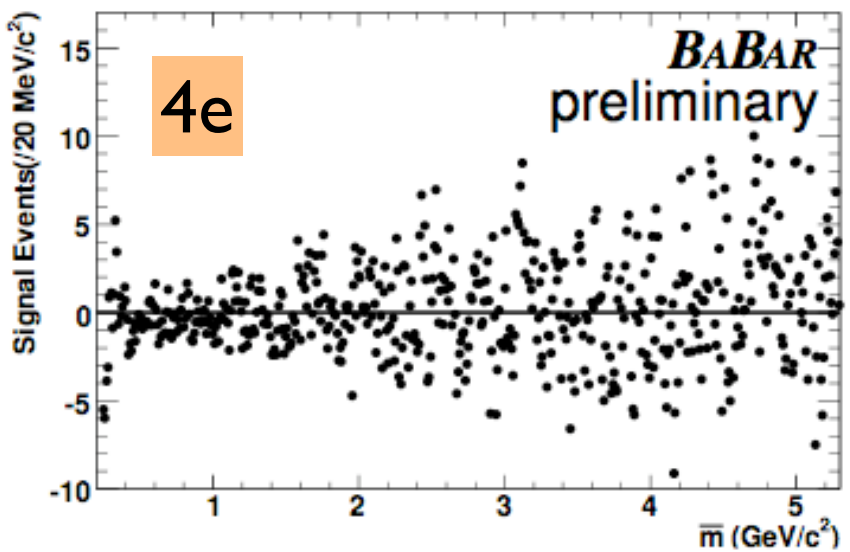


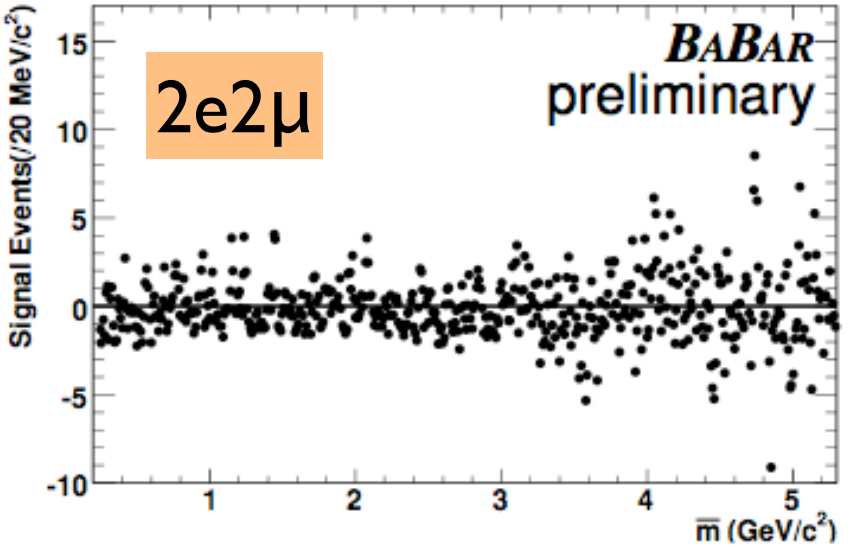
$N_{obs} = N_{SR} - N_{BR} \times (A_{SR}/A_{BR})$

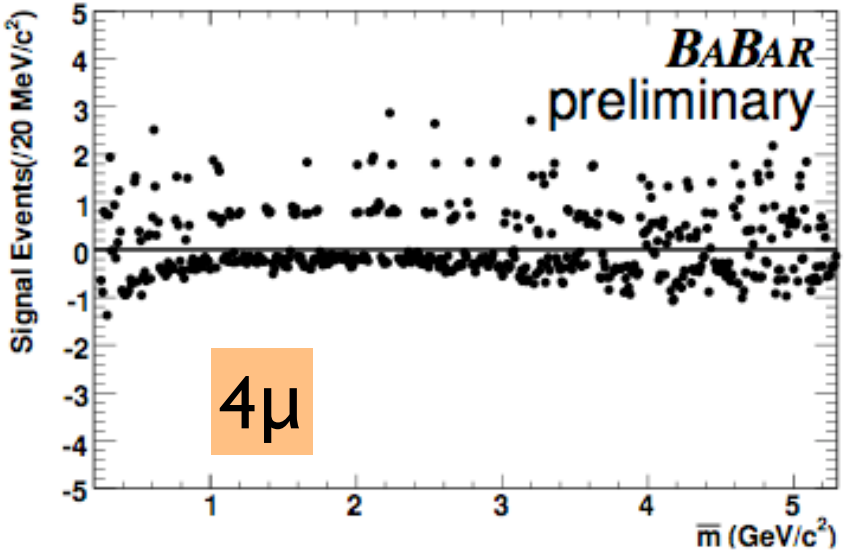


Higher mass → poorer $S/\sqrt{B}$

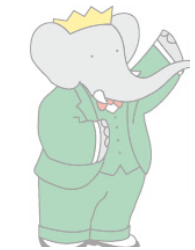
Results: Event Yields



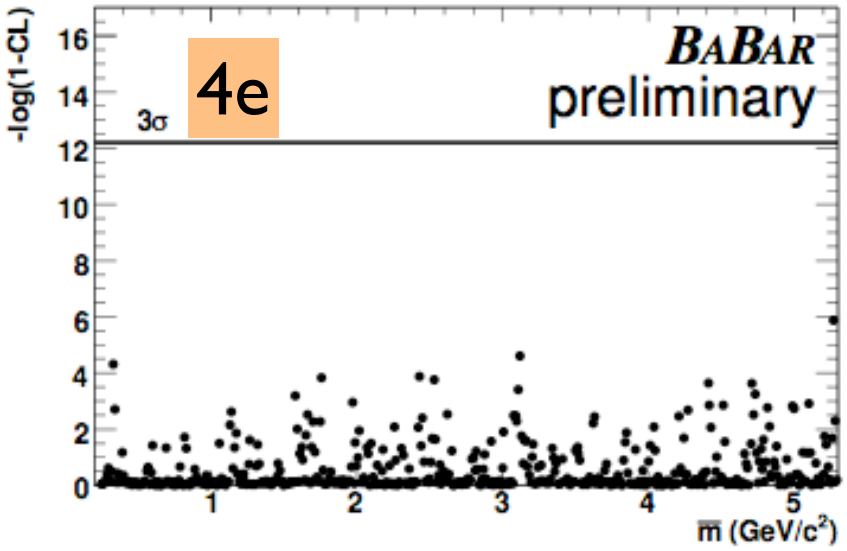


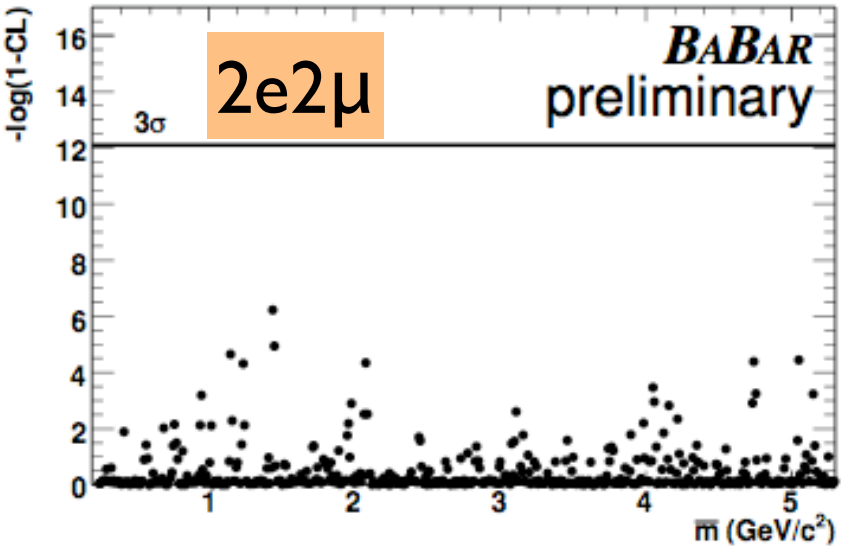


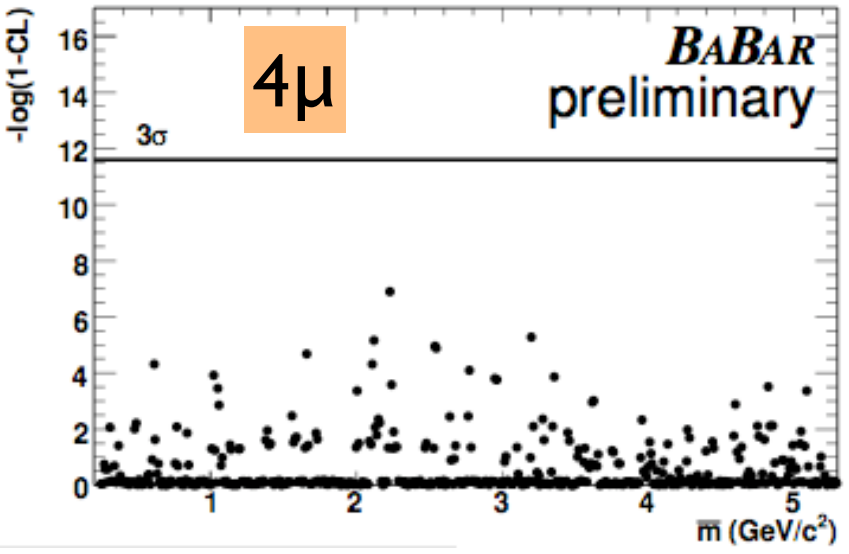
- these plots show bkg-subtracted event yield
- just by eye, nothing significant
- band structure in 4μ is due to the low number events in both the background and signal regions



Results: -log(1-CL) vs mass



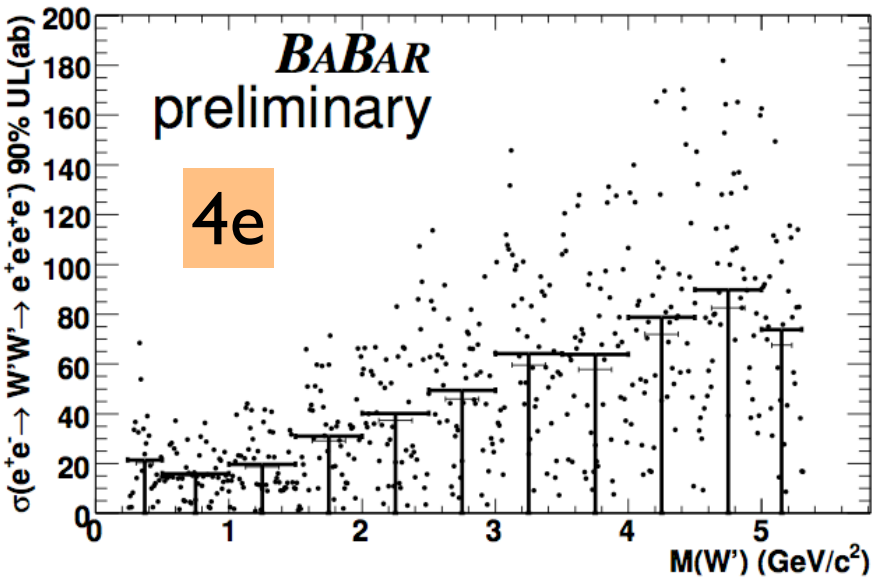


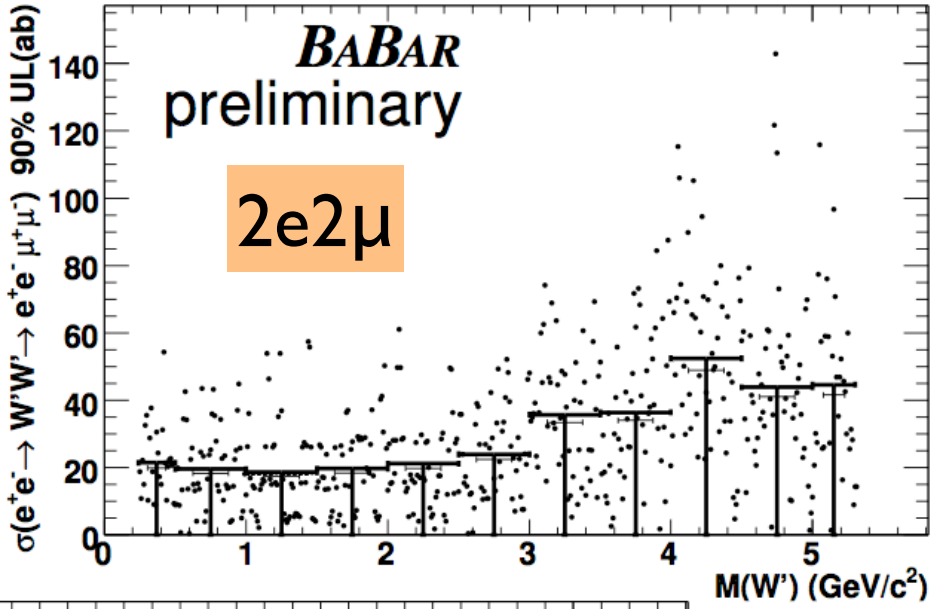


	$-ln(1-CL_{max})$	$\overline{m}_{max}$ (GeV)
$e^+e^-e^+e^-$	5.88	5.27
$e^+e^-\mu^+\mu^-$	6.26	1.44
$\mu^+\mu^-\mu^+\mu^-$	6.94	2.23
Combined	7.15	1.66

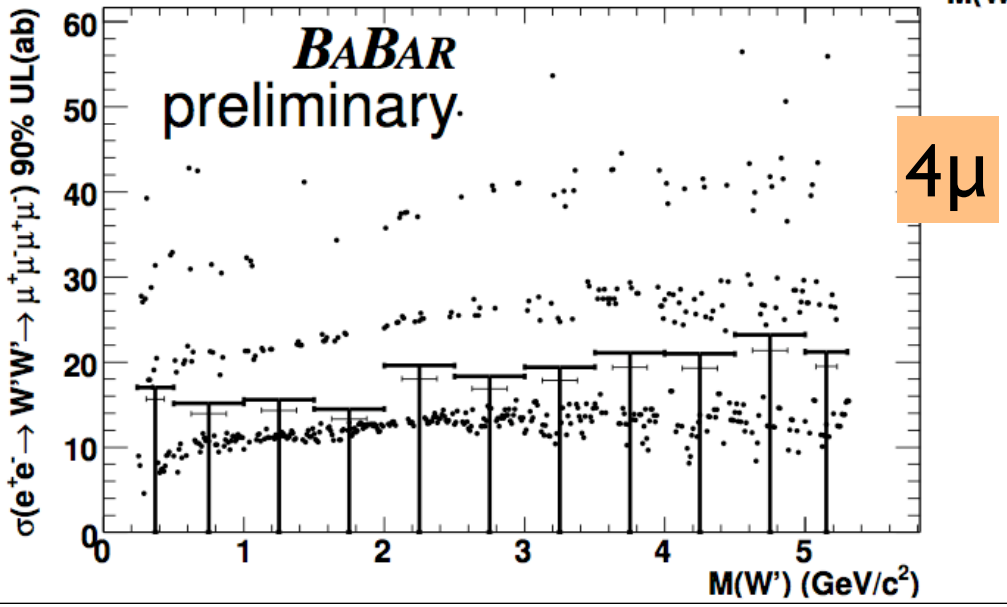
...nothing significant...and the largest CLs are at different masses for the 3 modes

Cross Section Upper Limits

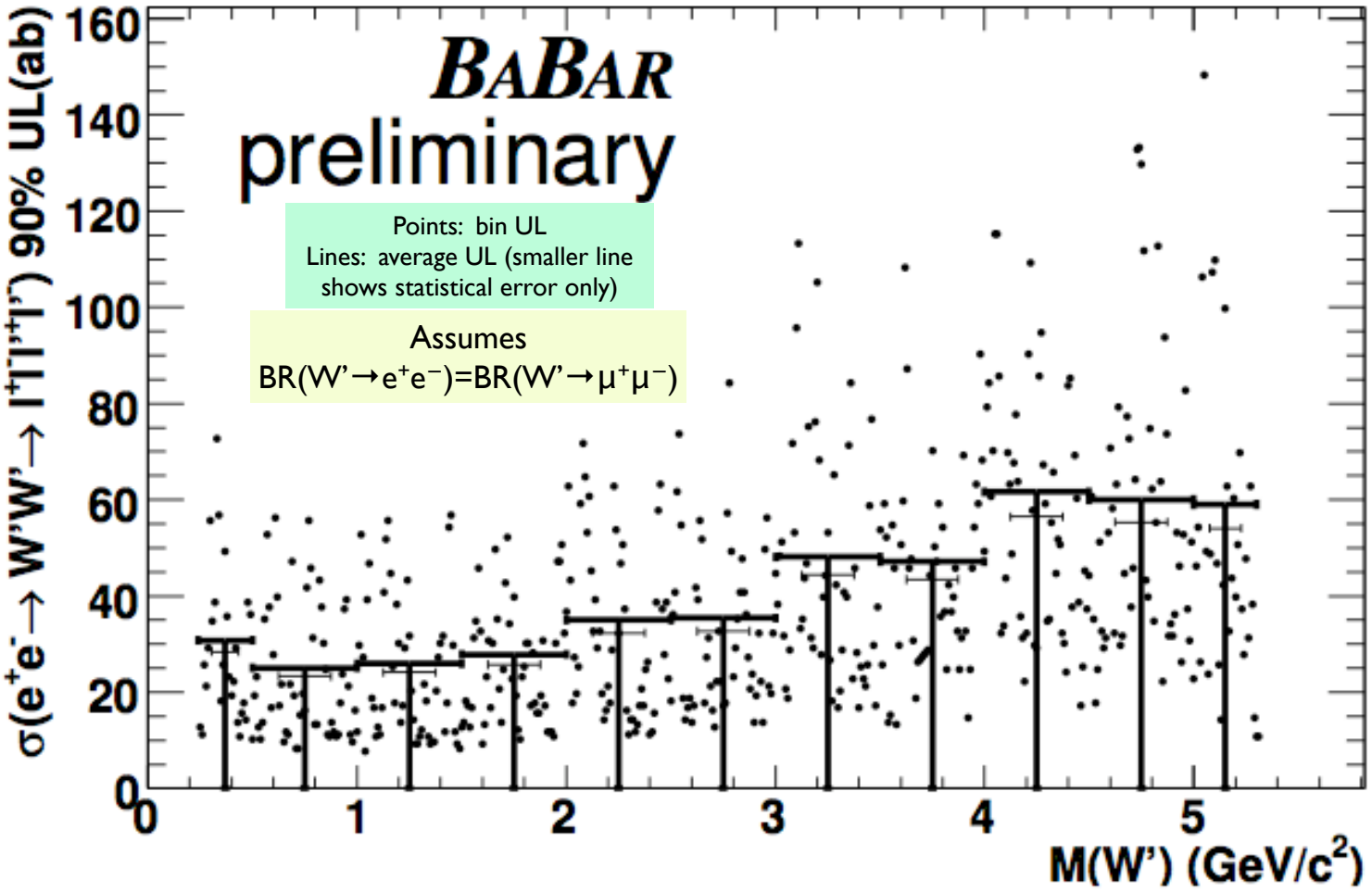




Points: bin UL
Lines: average UL
(smaller line shows statistical error only)



Combined Upper Limits

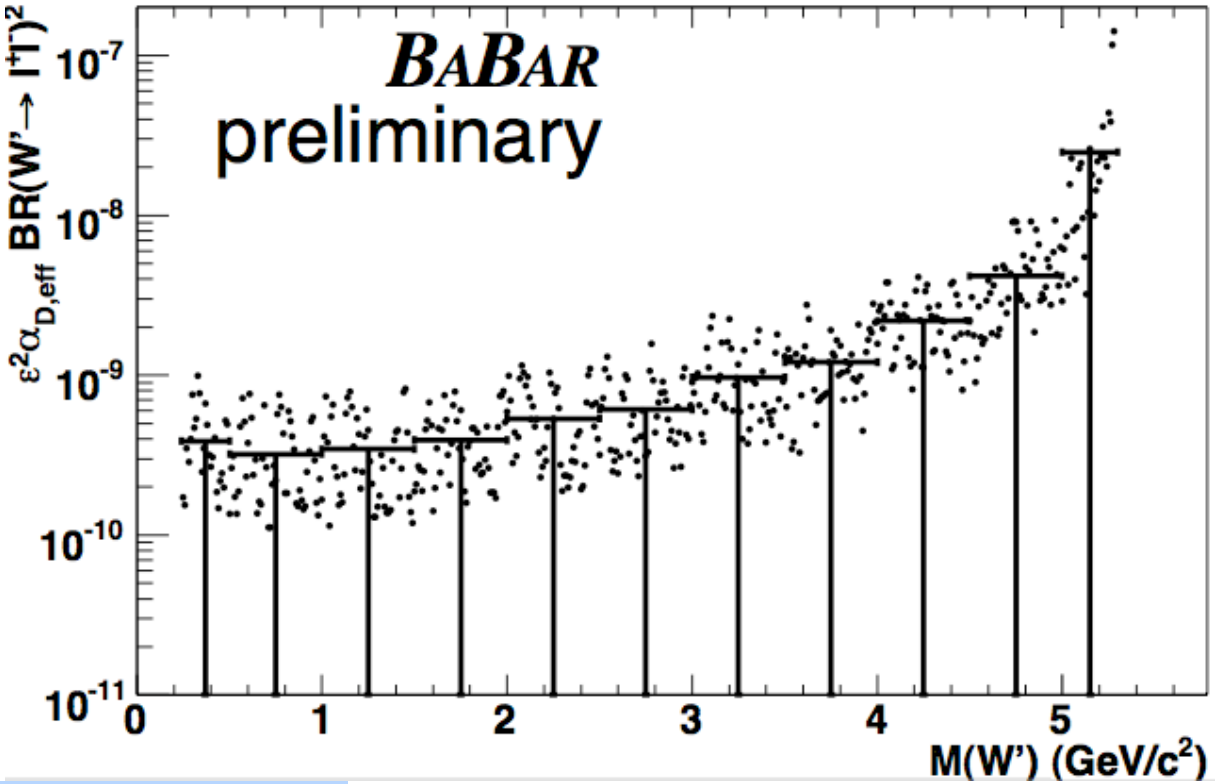


to obtain combined UL, we add the profile NLL vs CS from the 3 modes

Limits on Coupling to Dark Sector

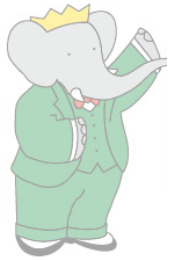
$$\sigma(e^+e^- \to W_D W_D) \sim \frac{\pi\varepsilon\alpha\alpha_{D,eff}}{E_{cm}^2}\left(1-\frac{4m_{W_D}^2}{E_{cm}^2}\right)^{3/2}$$

...some O(1) s dependence absorbed into definition of $\alpha_{D,eff}$



Remove BR(W→ll)^2 by dividing (2+R)^2

Note: this figure has been corrected from hep-ex/0908.2821.v1



Conclusions and Outlook

- we've looked at the exclusive $e^+e^- \to W'W' \to (l^+l^-)(l^+l^-)'$ and see no evidence for signal and set some nice upper limits on the product of SM/dark sector mixing and the dark coupling in the case a Higgsed non-Abelian dark sector
  - see hep-ex/0908.2821 for ***much*** more detail
  - This is the first result from the e^+e^- colliders on this particular mode
    - the $\Upsilon(3S) \to \gamma\mu\mu$ search also constrains these models
- still more searches to do: 4-lepton+photon, >5 leptons (+X pions), displaced vertex...
- expect more interesting results in the near future!