Status

What?	Who?	When?
Reco and trigger efficiency: get a number from a common source (or quickly tag-and-probe $Z \to \mu\mu$)	me (probably)	nothing yet
Signal shape: fit resonances and gun	me	done (new)
Background shape: construct physically-meaningful templates and fit them	me	done
The fit: include all systematics and make upper limit plots	Vadim	looks good; improvements in pipeline
Understanding low-mass excess	Aysen	?
Paper: introduction/motivation	me	done (new)
Paper: everything but the fit/limits	me	half-done
Paper: the fit and limits	Alexei	?

Reminder

(a) only one mu-jet per event:

fits with backgrounds (yellow)

(a-1) two muons in the mu-jet with vector-sum $p_T > 80\ \text{GeV}/c$, targeting models with a single high-momentum $m_1 \to \mu\mu$,

(a-2) four muons in the mu-jet, targeting models with a low-mass m_2 decaying via $m_2 \to m_1 m_1 \to 4\mu$,

(a-3) more than four muons in the mu-jet, for more complex models;

(b) two mu-jets per event:

two-dimensional fit (with backgrounds)

(b-1) each mu-jet contains exactly two muons, targeting a model with a heavy particle M decaying to two light particles m_1: $M \to m_1 m_1 \to 4\mu$ (this is the NMSSM signature),

(b-2) one mu-jet contains two muons, the other contains four, targeting $M \to m_1 m_2$ with $m_1 \to \mu\mu$ and $m_2 \to m_1 m_1 \to 4\mu$,

(b-3) both mu-jets contain four muons for $M \to m_2 m_2$,

(b-4) one mu-jet with more than four muons, for more complex models;

the other cases are background-free

(c) more than two mu-jets per event, targeting even more complex models.

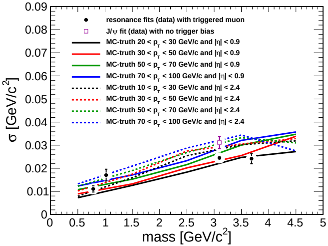
- at least one muon with $p_T > 15\ \text{GeV}/c$ and $|\eta| < 0.9$ per event (muon barrel system trigger plateau);
- all other muons must have $p_T > 5\ \text{GeV}/c$ and $|\eta| < 2.4$ (offline reconstruction plateau).

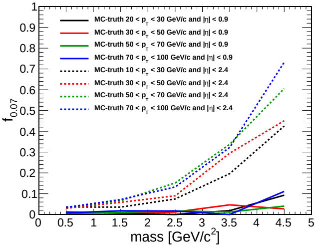
Signal shape

- In writing this up, I noticed that the real shape in the endcap is double-Gaussian (quantified by $f_{0.07}$ below)

$$f(m) = p\Bigg[(1 - f_{0.07}) \begin{cases} \dfrac{1}{\sqrt{2\pi}\,\sigma} \exp\left(-(m-m_0)^2/(2\sigma^2)\right) & \text{if } (m-m_0)/\sigma > -\alpha \\ \dfrac{2}{5\sigma} \exp\left(-\alpha^2/2\right)/(1-\alpha^2-(m-m_0)/\sigma) & \text{otherwise} \end{cases} + f_{0.07}\,\frac{1}{\sqrt{2\pi}\,0.07} \exp\left(-(m-m_0)^2/(2\cdot 0.07^2)\right)\Bigg]. \quad (1)$$

- Core Gaussian same in barrel and endcap, data and MC (left)
- 0.07 GeV$/c^2$ wide second Gaussian is relevant only in endcap (right)



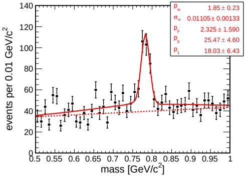


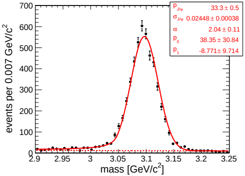
- Only information on Crystal Ball $\alpha = 2.04 \pm 0.11$ from data J/ψ fit

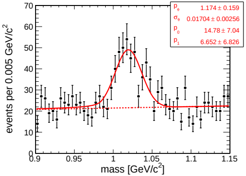
Signal shape

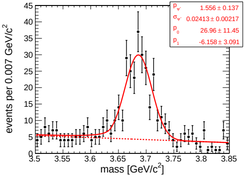
Gallery of peaks in data (fit function on previous page with some parameters fixed and an extra $p_0 + p_1 m$ linear background)

Most apply to the barrel only, since they must satisfy the requirement of at least one $p_T > 15$ GeV/c, $|\eta| < 0.9$ muon

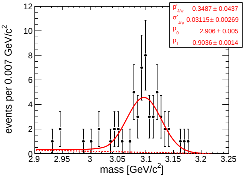








This one (below) is the J/ψ with a third muon to satisfy the trigger. It therefore applies to the whole η range.



For the fitter (signal part)

- For all dimuon signal regions with $|\eta| < 0.9$ (a-1, a-2, triggered dimuon in b-1), the double-Gaussian term is unnecessary ($f_{0.07} = 0$)
- For dimuons that are allowed in the whole range, we should either
  - sample the η distribution and set $f_{0.07}$ appropriately, or
  - simply let $f_{0.07}$ float in the signal-search.
- We don't need to worry about the p_T dependence
- Extremes observed on the plots (page 3):

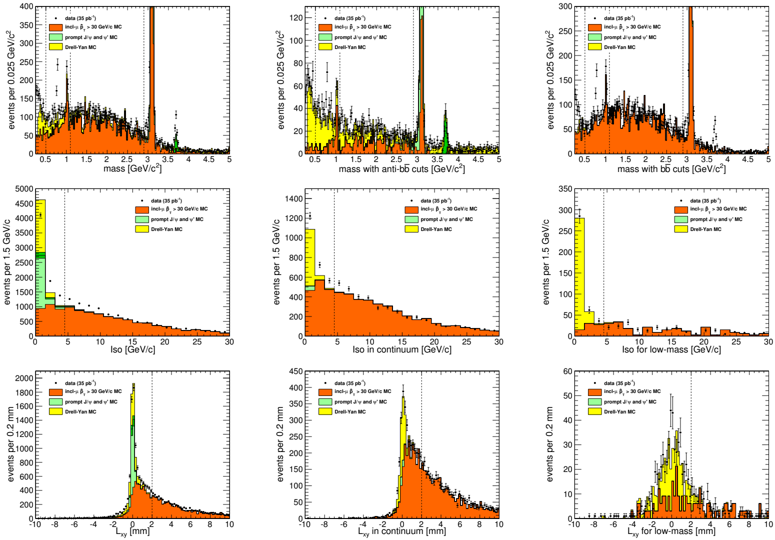
$$0.004 + 0.006m < \sigma(m) < 0.011 + 0.007m \text{ [GeV}/c^2\text{]} \tag{2}$$

$$0 < f_{0.07}(m) < 0.04 + 0.008m^3 \text{ [fraction of area]} \tag{3}$$

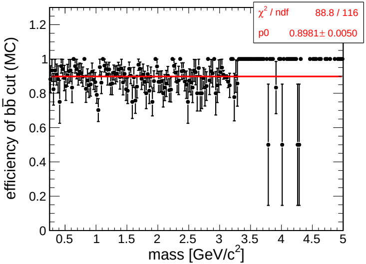
Dimuon studies

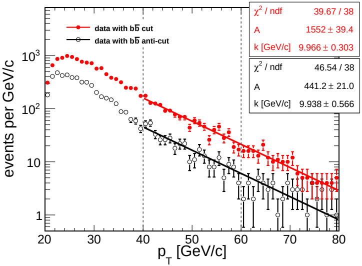
Drell-Yan output from Pythia output, rather than Z-scaling. All plots range 0.25–5 GeV/c^2 in 190 bins.

"Low-mass" is 0.35–0.5 GeV/c^2, "continuum" is 1.1–2.9 GeV/c^2. $b\bar{b}$ cuts are: *Iso* $>$ 4.5 GeV/c **or** L_{xy} $>$ 2 mm.



- Understanding the low-mass region and the $b\bar{b}$ cuts will be important for defining mass templates, but not analyzing signal.
- Scaling Drell-Yan by Pythia output fills in the anti-$b\bar{b}$ cut region (why is Pythia calculation correct for low-mass but not for Z?)
- Low-mass excess in $b\bar{b}$ is still not fully understood: is it possible to find photons in jets? Perhaps identify the $b\bar{b}$ system by tagging the *other* b-quark, then ask for the b with muons to be clean?
- These $b\bar{b}$ cuts are uniformly efficient for MC $b\bar{b}$ (left), and the $b\bar{b}$ and non-$b\bar{b}$ components scale proportionally with p_T (right)





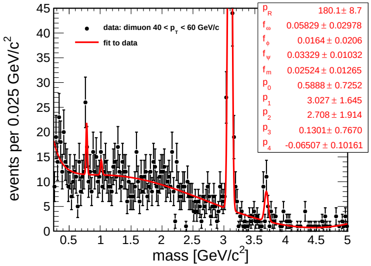
Mass template for (a-1)

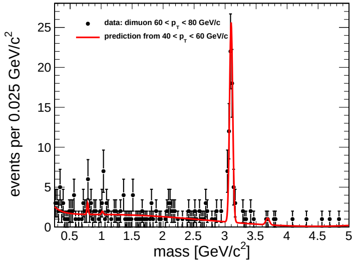
- "Background-enriched" is $40 < p_T < 60$, "control" is 60–80 GeV/c
- Fit to background-enriched sample (left plot; vertical scale zoomed):

$$T(m) = p_R(f_\omega \exp(-(m - 0.78265)^2/2/0.011^2) + f_\phi \exp(-(m - 1.019455)^2/2/0.014^2) + \exp(-(m - 3.096916)^2/2/0.025^2) + f_{\psi'} \exp(-(m - 3.68609)^2/2/0.029^2) + f_m/m) + p_{-1}/m + p_0 + p_1(m-5) + p_2(m-5)^2 + p_3(m-5)^3 + p_4(m-5)^4 \quad (4)$$

(p_{-1} fixed to zero here, used in other templates). Templates will be named $T_a(m)$, $T_b(m)$, etc.

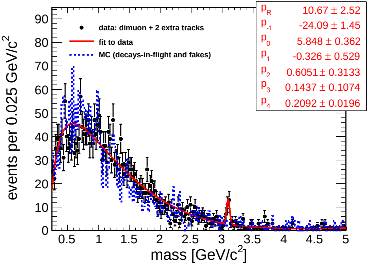
- Overlay on control sample (right plot; vertical scale unzoomed). Ratio of normalization: $T_{60-80}(m) = 0.14\ T_{40-60}(m)$.

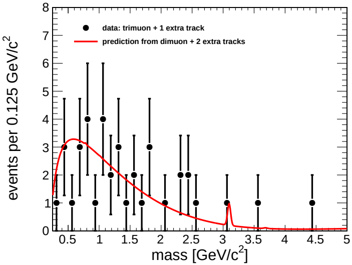




Mass template for (a-2)

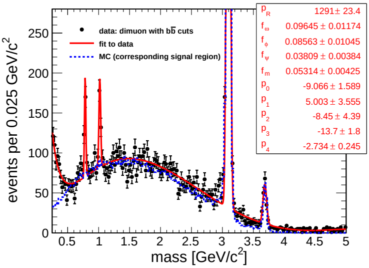
- "Background-enriched" is 2 muons + 2 extra tracks, "control" is 3 muons + 1 extra track. (Extra tracks have the same kinematics as muons, but no associated muon segments.)
- Of the 4 tracks, we plot the most consistent pair of dimuons.
- Left: fit background-enriched to Eqn. 4 with resonance fractions (f_ω, f_ϕ, $f_{\psi'}$) fixed to previous values and p_{-1} released.
- Blue MC: dimuons with decay-in-flight or missing genlevel-match.
- Right: control. Ratio of normalization: $T_{3+1}(m) = 0.014\ T_{2+2}(m)$.

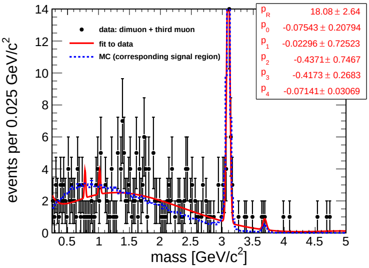




Mass templates for (b-1)

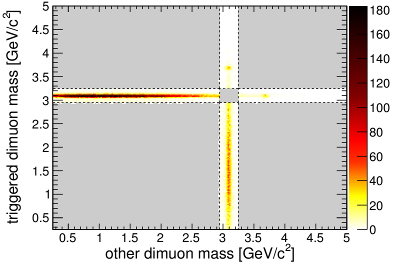
- "Triggered dimuon" contains the $p_T > 15$ GeV$/c$, $|\eta| < 0.9$ muon, "other dimuon" is the other one.
- "Background-enriched" sample for the triggered dimuon is the single-dimuon sample with $b\overline{b}$ cuts, "background-enriched" for the other dimuon is dimuon + third muon satisfying the trigger.
- Left: fit single-dimuon with $b\overline{b}$ cuts to Eqn. 4 (only p_{-1} fixed). Right: fit dimuons + third muon sample with f_ω, f_ϕ, $f_{\psi'}$, p_{-1} fixed.
- Blue MC: $b\overline{b}$ in the *signal* regions— i.e., the difference between data-driven shapes and MC-driven shapes.



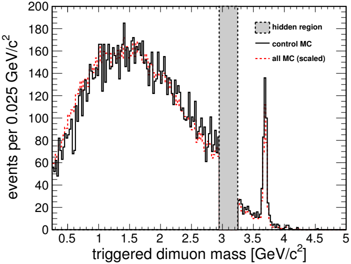


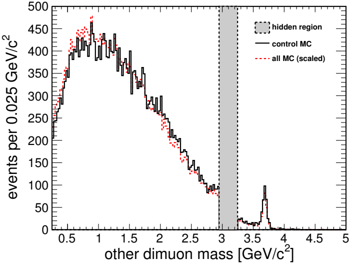
Mass templates for (b-1)

- Control regions for both dimuons: select J/ψ in one coordinate, plot non-J/ψ in the other coordinate (right: $b\bar{b} \to 4\mu$ MC showing controls)



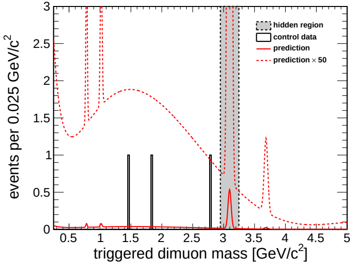
- Bottom: projection of control MC and all MC, demonstrating that the 2-D distribution factorizes

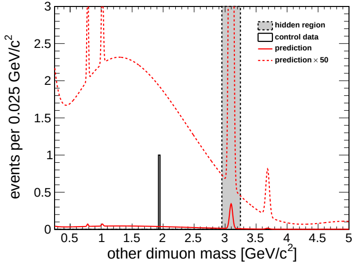




Mass templates for (b-1)

- Control regions for data:





- Normalization of $T_{td}(m)$, $T_{od}(m)$ for control regions:
  - 12 841 single $b \to 2\mu X$ events in background-enriched sample
  - $\times$ 0.2% probability for the other b to go to $2\mu X$ (EvtGen)
  - $\times$ 30% in J/ψ $\times$ 70% not in J/ψ (selected area in the plane)

$=$ 5 events expected in each control region. 3 and 1 observed, respectively.

For the fitter:

- Let the background normalization float!
- Take the parameters from here; statistical errors for resonance fluctuations?
- Late for the meeting...