Effect of muon alignment on TeV tracks

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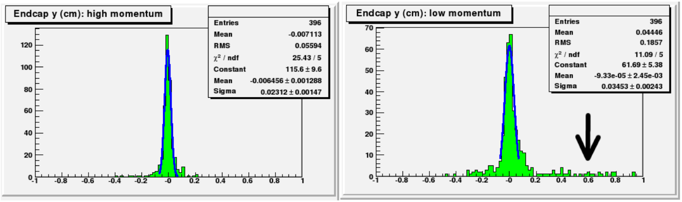
Need for a bottom line

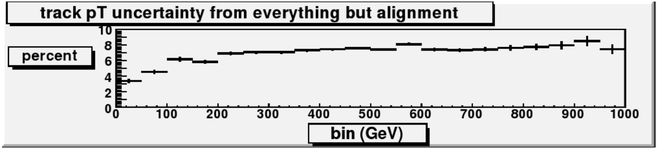
- We have seen that muon alignment needs surprisingly few tracks for 100 μm accuracy RMS in x, but
  - some degrees of freedom better aligned than others
  - some distributions have tails, especially systematics studies



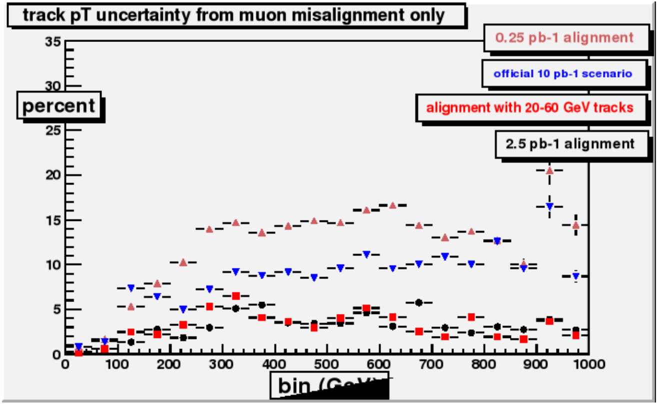
- To assess alignment quality, we can look at its effect on TeV-scale tracks
  - effect on momentum resolution for individual tracks
  - broadening of TeV di-muon resonance (RMS misalignment)
  - smearing of Drell-Yan background (higher moments)

Effect on individual tracks

Fractional widening of momentum distribution, binned



track-by-track RMS of $\dfrac{p_{T\,\text{ideal}}}{p_{T\,\text{generated}}} - 1$

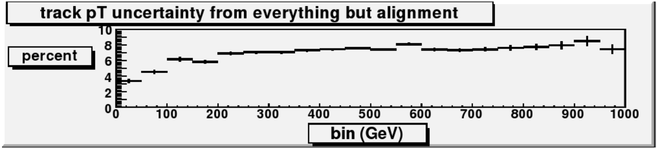


track-by-track RMS of $\dfrac{p_{T\,\text{misaligned}}}{p_{T\,\text{ideal}}} - 1$

$$\left(\frac{\sigma_{p_T}}{p_T}\right) = \left(\frac{\sigma_\kappa}{\kappa}\right)$$

$=$ sum in quadrature of both uncertainties

Fractional widening of momentum distribution, binned



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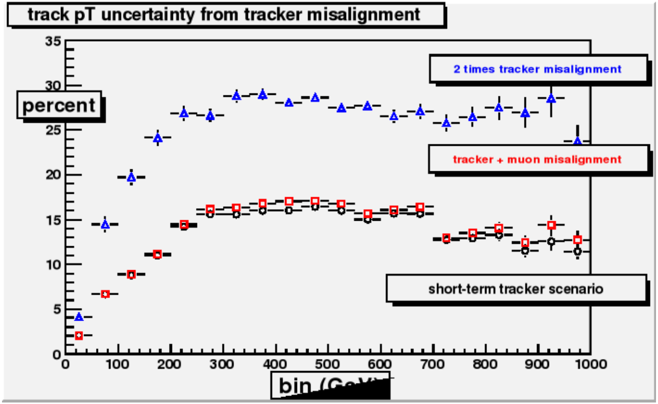


track-by-track RMS of $\dfrac{p_{T\,\text{misaligned}}}{p_{T\,\text{ideal}}} - 1$

$$\left(\frac{\sigma_{p_T}}{p_T}\right) = \left(\frac{\sigma_\kappa}{\kappa}\right)$$

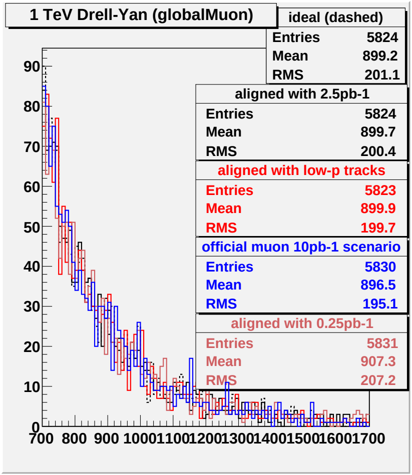
= sum in quadrature of both uncertainties

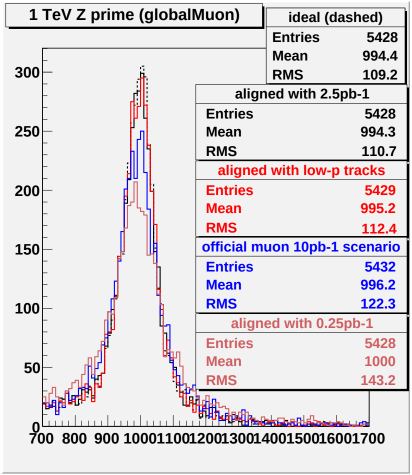
Notes for the previous page (page 5)

- The plots on the previous two slides require explanation, which I hope to give verbally when I present this talk (this page is for archival reference).
  - $p_{T\,\text{generated}}$ is the generator-level p_T
  - $p_{T\,\text{ideal}}$ is the reconstructed p_T with perfect alignment
  - $p_{T\,\text{misaligned}}$ is the reconstructed p_T with realistic alignment
- A single reconstructed muon p_T is $\dfrac{p_{T\,\text{ideal}}}{p_{T\,\text{generated}}} \times \dfrac{p_{T\,\text{misaligned}}}{p_{T\,\text{ideal}}}$
- By plotting the RMS of each distribution, I plot
  - the uncertainty in a track p_T due to detector effects other than alignment
  - the uncertainty in a track p_T due to alignment
- Total uncertainty, $\left(\dfrac{\sigma_{p_T}}{p_T}\right)$, which is $\left(\dfrac{\sigma_\kappa}{\kappa}\right)$, is the sum in quadrature of the uncertainty of the two factors

Effect on di-muon resolution

Overlay of 1 TeV Drell-Yan and Z' resonance

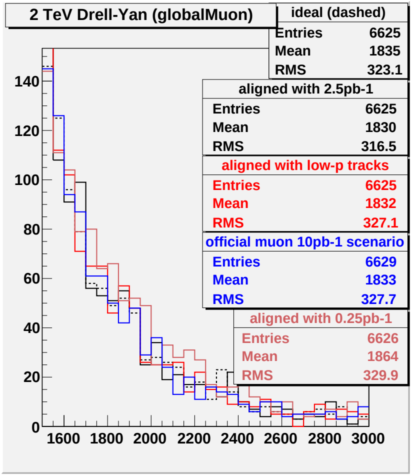


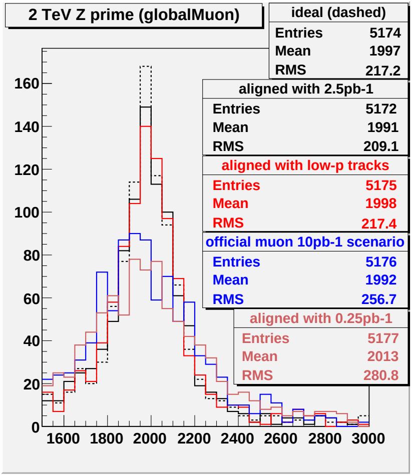


"low-p" means 20-60 GeV $Z \to \mu\mu$

official 10 pb^{-1} scenario is pessimistic

Overlay of 2 TeV Drell-Yan and Z' resonance





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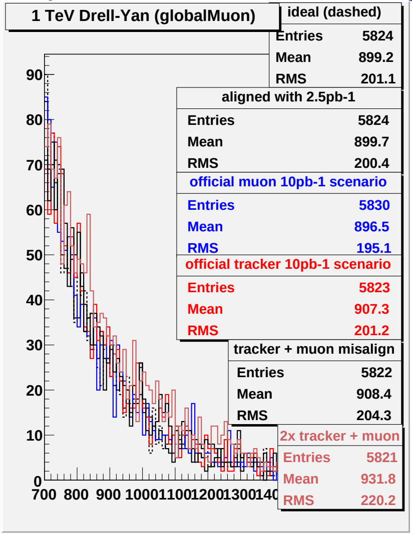
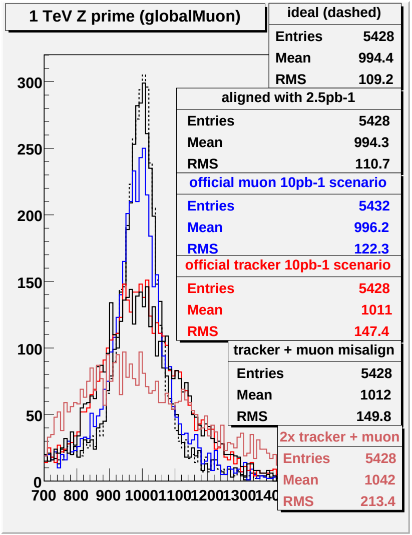
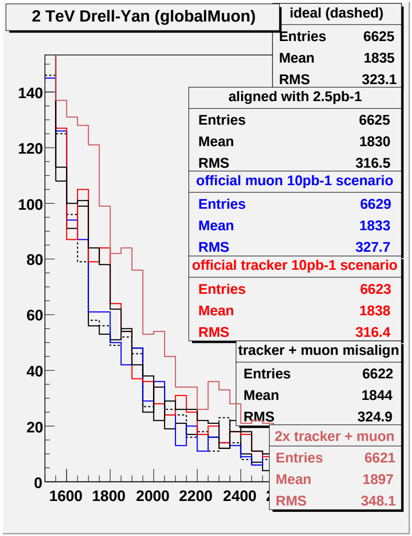
Comparison with tracker alignment scenario

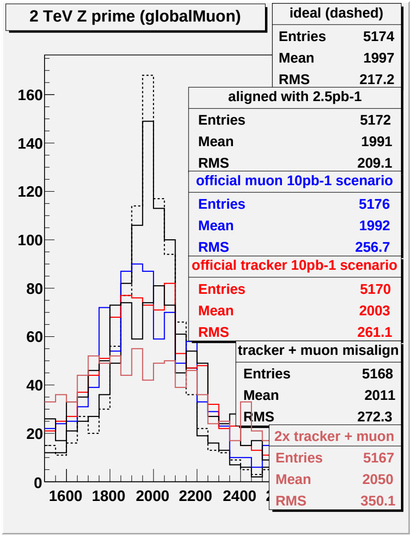




Careful! Tracker alignment scenario might be pessimistic, too

Comparison with tracker alignment scenario





Careful! Tracker alignment scenario might be pessimistic, too

Drell-Yan (not) smearing

Simple model of Drell-Yan smearing

- Drell-Yan is exponentially distributed: $f(x) = e^{-kx}$
- Convoluted: $f(y) = \int f(x) \, \frac{1}{\sqrt{2\pi}\sigma} \exp\left(\frac{-(x-y)^2}{2\sigma^2}\right) \, dx$
- $f(y) = e^{-ky} \, \exp(\sigma^2 k^2/2)$
- Convolution kernel is a series: $A_1 e^{x^2/2/{\sigma_1}^2} + A_2 e^{x^2/2/{\sigma_2}^2} + \ldots$ ("tails" are wide Gaussians with small contribution)
- $f(y) = e^{-ky}(A_1 \exp({\sigma_1}^2 k^2/2) + A_2 \exp({\sigma_2}^2 k^2/2) + \ldots)$
- Depends linearly on A_i and as $e^{{\sigma_i}^2}$ on width: $\boxed{\text{could be big!}}$

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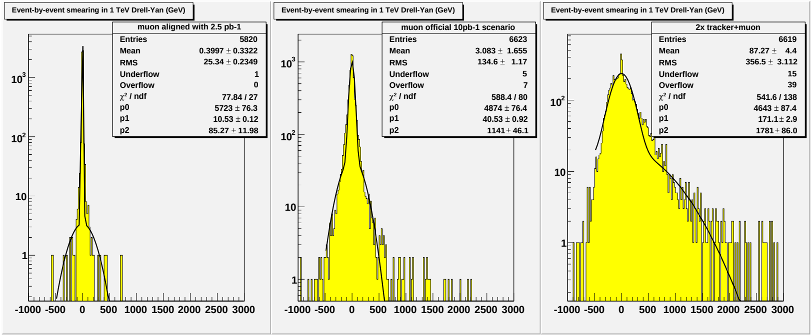
- Depends linearly on A_i and as $e^{{\sigma_i}^2}$ on width: $\boxed{\text{could be big!}}$
- What's k for Drell-Yan? $k = 6{\times}10^{-3}$/GeV (near 1 TeV) and $3.4{\times}10^{-3}$/GeV (near 2 TeV)
- What's σ?

Fit Drell-Yan smearing to multi-Gaussian to quantify tail σs



- Only in $2\times$ tracker misalignment scenario does it become significant: $A_i = 0.07$, $\sigma = 500$ GeV, $A_i\, e^{{\sigma_i}^2 k^2/2} = 7.3$
- But smearing in this scenario is negligible ($\lesssim 1.5$): when $\Delta E \sim 500$ GeV, $\sigma \to \sigma(E)$, less contribution from low-energy
- Exponential is cut off by $\sigma(E)$ before it can explode

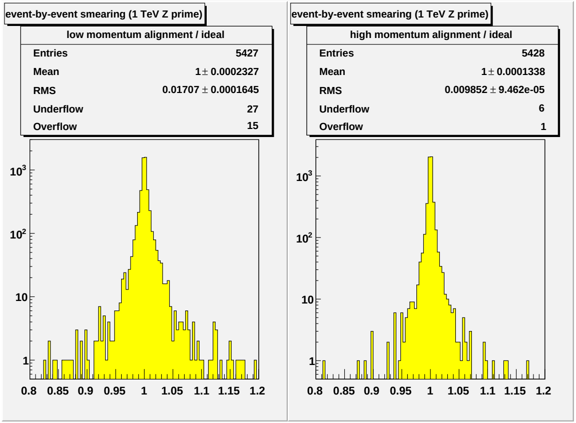
Notes for the previous page (page 14)

- For the record, I need to repeat the argument at the bottom of the last page with more words than would fit.
- The extreme case (2× tracker) illustrates a limitation in the multi-Gaussian model of Drell-Yan convolution.
  - I assumed each Gaussian component had a σ which is constant with respect to energy
  - In reality, the σ of each Gaussian $\to 0$ as $\sqrt{s} \to 0$
  - This effect suppresses the pile-up of low-energy Drell-Yan events in a given di-muon mass bin to such an extent that the calculated value of 7 for "2× tracker" is something less than 1.5 (see page 10).
- What we have learned from this exercise is that Drell-Yan falls off steeply enough (k is small enough) that it will not pile up in the TeV for even the worst alignments
- It was a quantitative question that needed to be asked. . .

So let's concentrate on resonance broadening

How much does a misalignment broaden di-muon mass?

$$\text{RMS of event-by-event } \frac{\text{misaligned di-muon mass}}{\text{ideal di-muon mass}} - 1$$



aligned with: $20 < |\vec{p}| < 60$ GeV $\qquad |\vec{p}| > 60$ GeV

Notes for the previous page (page 16)

- This is the same technique as on pages 4 and 5, but applied to di-muon mass instead of track momentum.
- The *same* di-muon mass is observed in an ideal alignment case and a misaligned case.
- We plot the ratio of these two numbers (minus 1) and take the RMS.

Comparison of alignment scenarios

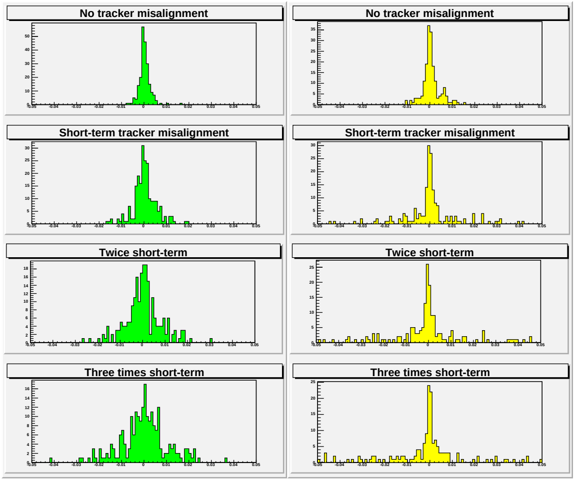
$$\text{RMS of event-by-event } \frac{\text{misaligned di-muon mass}}{\text{ideal di-muon mass}} - 1$$

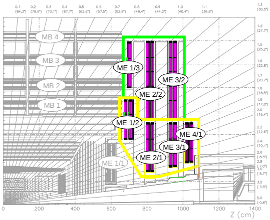
Source of alignment	$Z'(1000)$	$Z'(2000)$	DY(1000)	DY(2000)
1k μ (0.25 pb^{-1})	6.0%	5.5%	4.8%	6.6%
10k μ (2.5 pb^{-1})	1.8%	1.7%	1.6%	2.1%
100k μ (25 pb^{-1})	1.2%	1.1%	1.0%	1.3%
325k μ (82 pb^{-1})	1.0%	1.0%	0.7%	1.2%
$\lvert\vec{p}\rvert > 60$ GeV	1.0%	1.0%	0.8%	1.2%
$20 < \lvert\vec{p}\rvert < 60$ GeV	1.7%	1.7%	1.5%	2.1%

With this as a bottom line, we can make statements like “switching to $|\vec{p}| > 60$ GeV is as good as getting a factor of ten more tracks.”

Tails in accuracy from tracker misalignment at high η

Outer endcap | Inner endcap





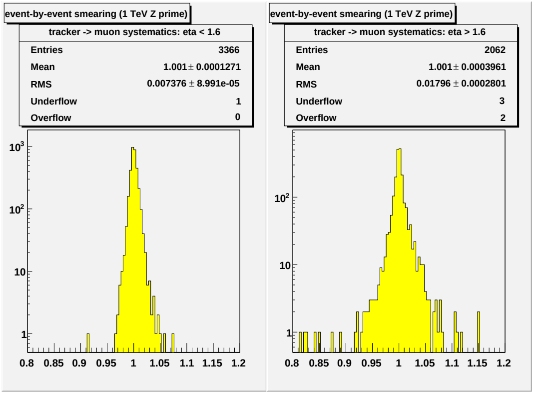
Outer endcap (1/3, 2/2, 3/2) only widens

But inner endcap (1/2, N/1) gets more outliers

Notes for the previous page (page 18)

- This is a subtlety of the effect of tracker misalignment on muon alignment with globalMuons that didn't make it into my EMU talk.
- Presumably, the tracker misalignment scenario assumes more misalignment in the TID and TEC regions, the edge of which is at an η of $\sim$1.6.

Effect on di-muons



$$\text{RMS of } \frac{\text{tracker and muon misaligned di-muon mass}}{\text{tracker misaligned di-muon mass}} - 1$$

	$Z'(1000)$	$Z'(2000)$	DY(1000)	DY(2000)
Both μ's in $\lvert\eta\rvert < 1.6$	0.7%	0.9%	0.5%	1.0%
One in $\lvert\eta\rvert > 1.6$	1.8%	1.5%	1.3%	2.0%

Conclusions

- Resonance broadening is more significant than Drell-Yan smearing
- 10 pb^{-1} tracker misalignment *scenario* has more impact on resonance shape (10%) than 10 pb^{-1} muon alignment *scenario* (6%)
- Effect of muon misalignment scenario is about $4\times$ too pessimistic, including known systematic effects (tracker extrapolation, momentum dependence down to 20 GeV, miscalibration)
- Systematic error from tracker extrapolation is measurably larger in $|\eta| > 1.6$ (2%) than $|\eta| < 1.6$ (1%).