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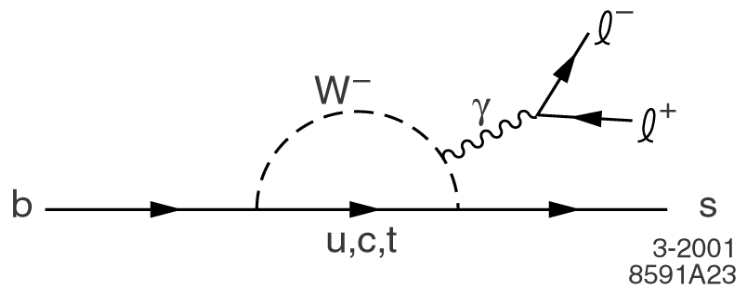
$B_d \to K^{*0}\mu^+\mu^-$ selection and analysis in LHCb

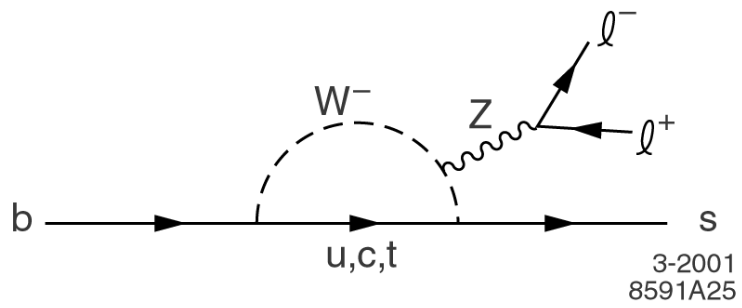
Ulrik Egede
on behalf of LHCb collaboration

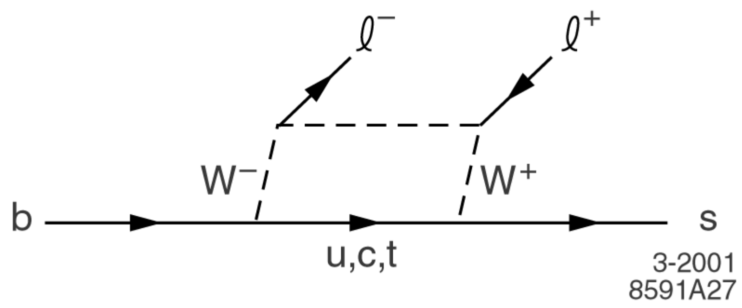
Flavour in the era of LHC workshop

$b \rightarrow s\ \mu^+\mu^-$

- From theoretical point of view inclusive process is far preferable.
  - But at least initially we have to limit ourselves to
    - $B_d \rightarrow K^{*0}\mu^+\mu^-$;
    - $B^+ \rightarrow K^+\mu^+\mu^-$;
    - $\Lambda_b \rightarrow \Lambda\mu^+\mu^-$;
    - $B_s \rightarrow \varphi\mu^+\mu^-$;
- Will today look at $B_d \rightarrow K^{*0}\mu^+\mu^-$ selection and subsequent fits.
- Deviations from SM by
  - SUSY, graviton exchanges, extra dimensions ...



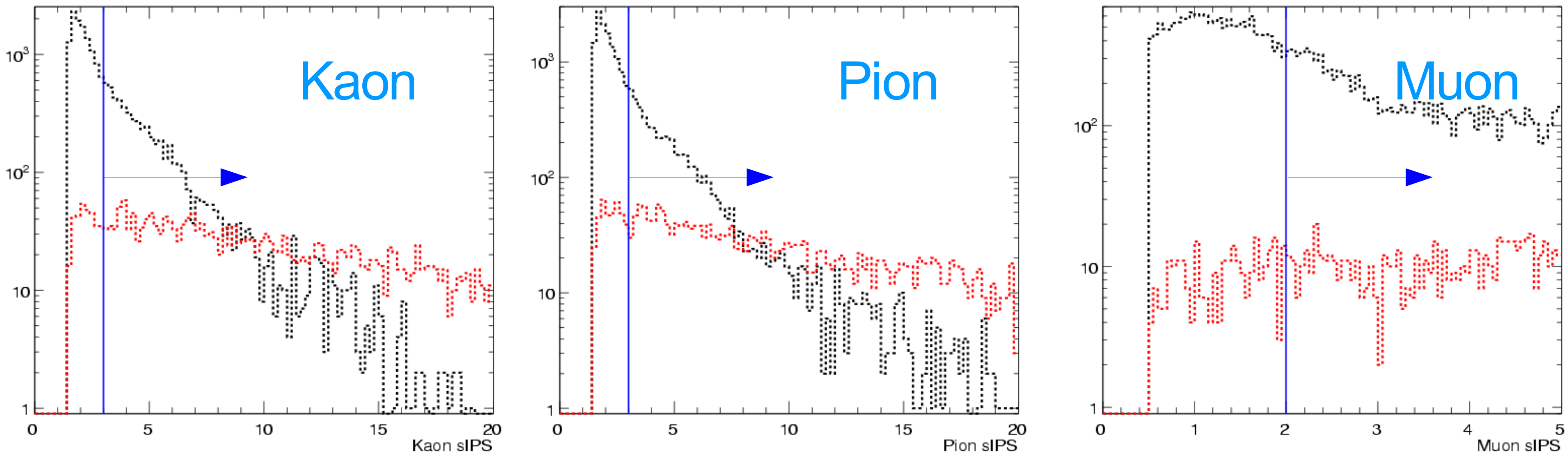




$B_d \rightarrow K^{*0}\mu^+\mu^-$ selection

Update on offline selection for $B_d \rightarrow K^{*0}\mu^+\mu^-$

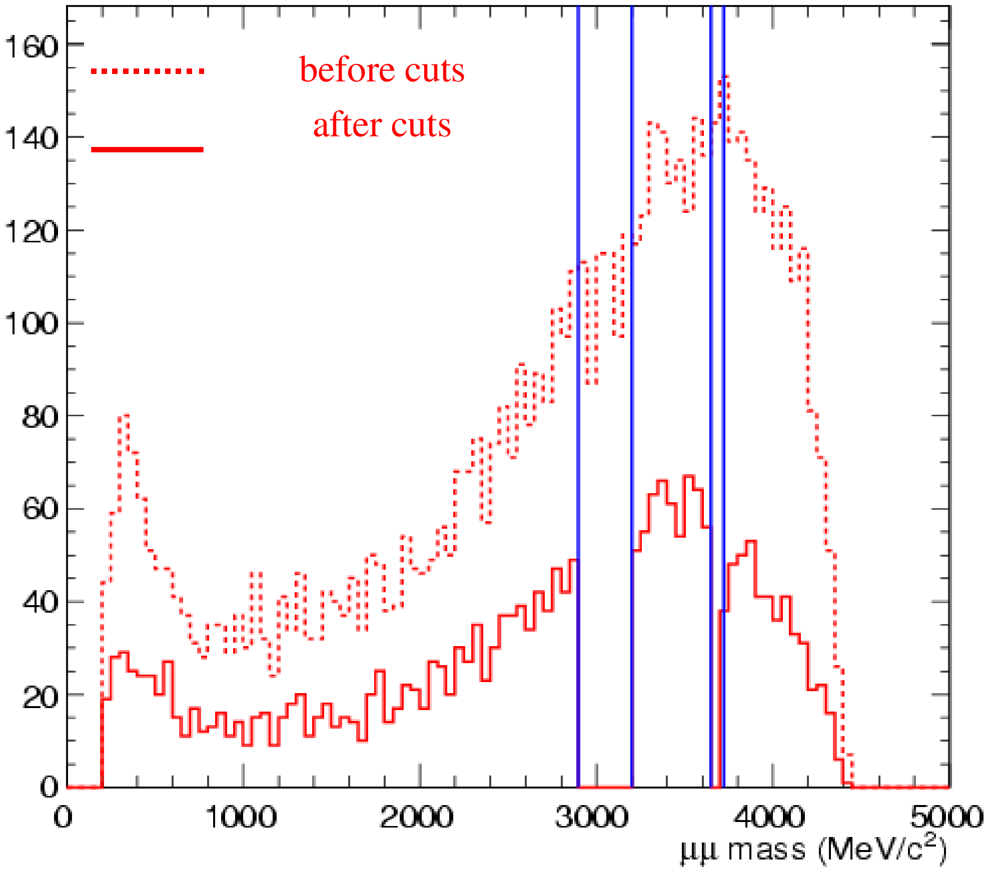
- Looked at 53k fully reconstructed signal events
  - Resolution in B mass is 14.3 MeV
- Have tried to avoid cuts that bias the $\mu\mu$ mass-spectrum
  - Achieved by cutting looser on the muon kinematics
  - For example, the impact parameter significance cut
    - Plots show signal and inclusive b events (after a loose pre-selection)

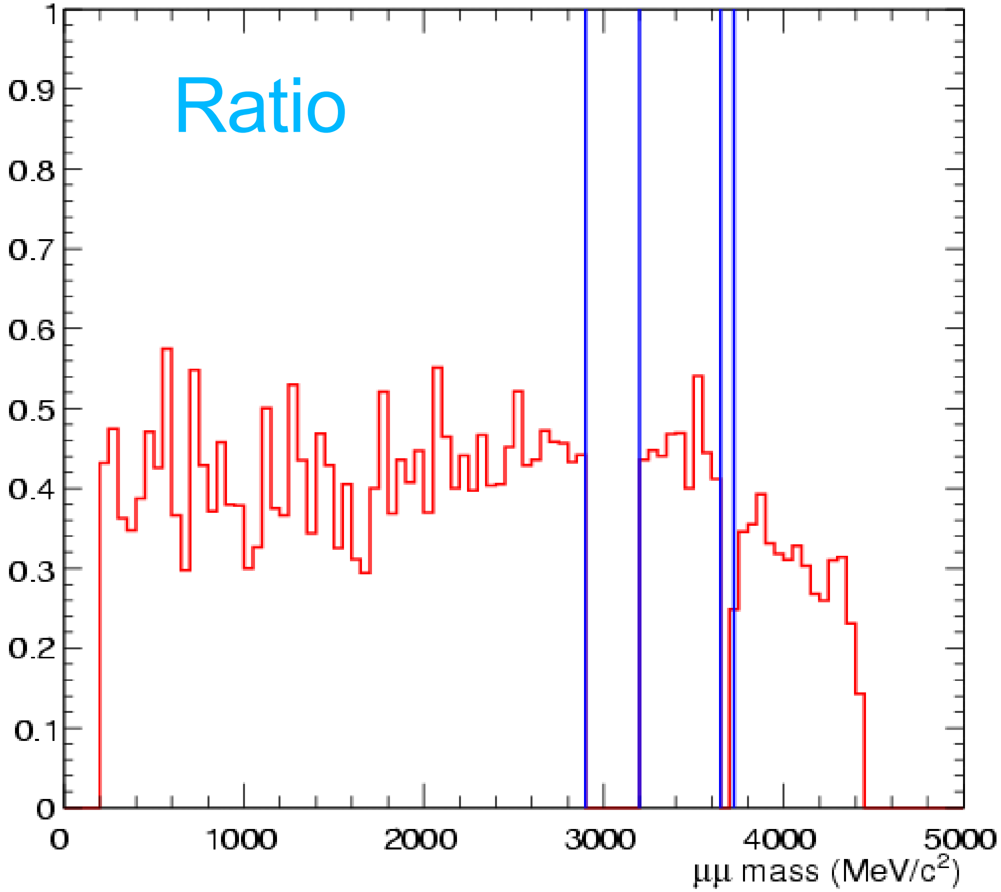


μμ mass distribution

Selection slightly favours low μμ mass

- This is good as the theoretical errors in general are much smaller in the region below the J/Ψ resonance.
- J/Ψ and Ψ(2S) mass regions excluded.





Background

6 events from ~24M inclusive b events survive the selection cuts

- Loose B_d mass window (± 500 MeV/c^2)
  - 2 low-mass events (missing pion, missing photon)
  - 1 irreducible event (non-resonant $B_d \to K\pi\mu\mu$ event)
  - 3 combinatoric events (two muons taken from separate B-decays)

Run on higher significance background samples:

- $B_d \to s\mu\mu$ (includes the non-resonant $B_d \to K\pi\mu\mu$ events)
  - 136,500 events with Br = 4 x 10^{-6} (≅ 1900 x inclusive b sample)
- $B_u \to s\mu\mu$
- $b\to\mu$, $b\to\mu$
  - 8.85M events with Br = 0.012 (≅ 31 x inclusive b sample)
- B_d, B_u, B_s, $\Lambda_b \to \mu$ c ($\to\mu$)

Summary of yields after trigger

Sample		Trigger eff (#evt trg / #evt sel)	Yield in 2 fb^{-1} (tight mass window)
$B_d \rightarrow s\,\mu\,\mu$	Non-resonant $K\pi\mu\mu$	86%	4394±184
	All other	68%	13±5
$B_u \rightarrow s\,\mu\,\mu$		71%	12±5
$b \rightarrow \mu$, $b \rightarrow \mu$		79%	1413±258
$B_d \rightarrow \mu\, c(\mu)$		60%	408±146
$B_u \rightarrow \mu\, c(\mu)$		68%	657±173
$B_s \rightarrow \mu\, c(\mu)$		-	<94 @ 90% CL
$\Lambda_b \rightarrow \mu\, c(\mu)$		75%	255±85
TOTAL		84%	7152
SIGNAL ($K^*\mu\mu$)		88%	7345±174

B/S is in the range [0.86 - 1.10] @90%CL

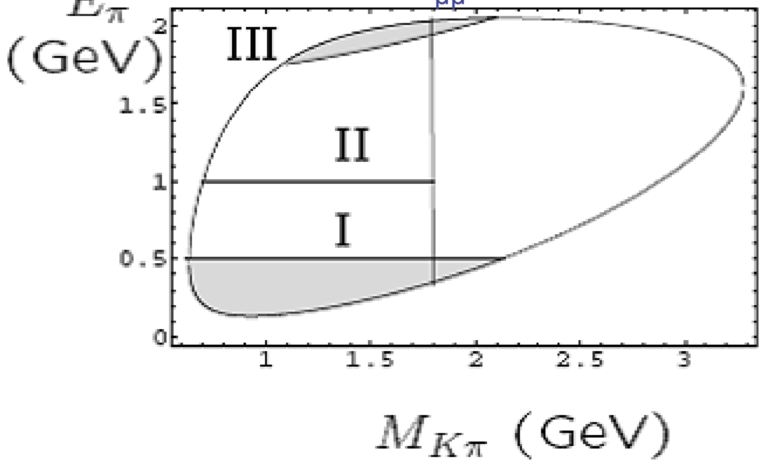
for ±50 Mev B mass window, ±100 MeV K*0 mass window

Non-resonant Kπμμ events

The non-resonant Kπμμ dominate the background

- Simulation of these events is currently just Jetset fragmentation
  - Spectra and rate are very uncertain!
  - BR($B_d \rightarrow K\pi\mu\mu$) (non-res) is 1×10^{-6} in LHCb simulation
    - Seems to be an overestimate; eventually we will measure this.
- Identical from a selection point of view, but without the K* mass constraint
  - Concerning FB asymmetry can be treated as signal, under certain conditions…

Drawn for $M_{\mu\mu}$= 2 GeV



Region I: soft pion, energetic kaon

- Shifts zero of FBA and has larger uncertainties

Region II: energetic Kπ pair

- Can be treated as $B\rightarrow X\mu\mu$ and $X\rightarrow K\pi$

Region III: soft kaon, energetic pion

- Amplitude suppressed so very few events…

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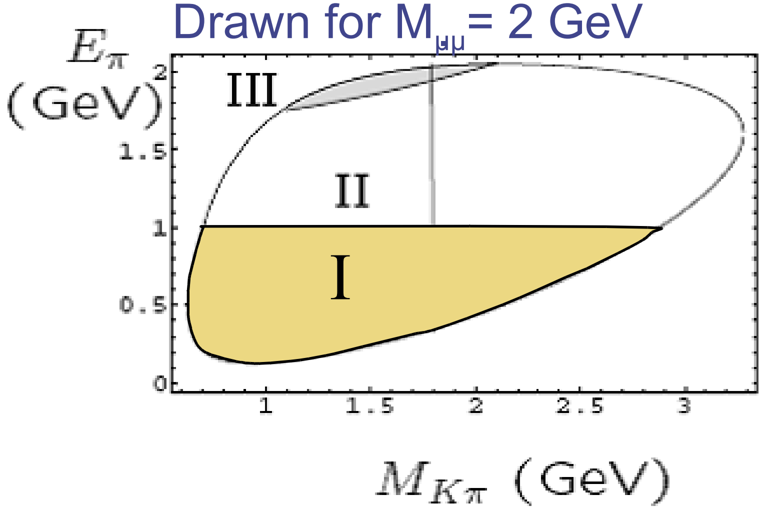

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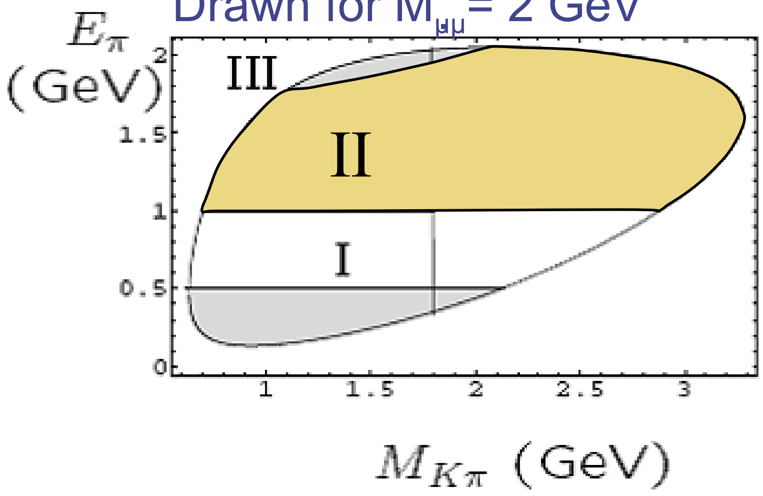

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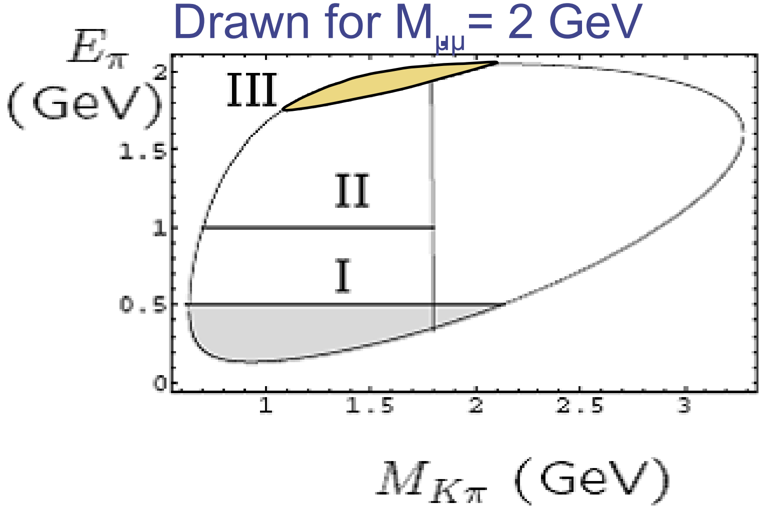

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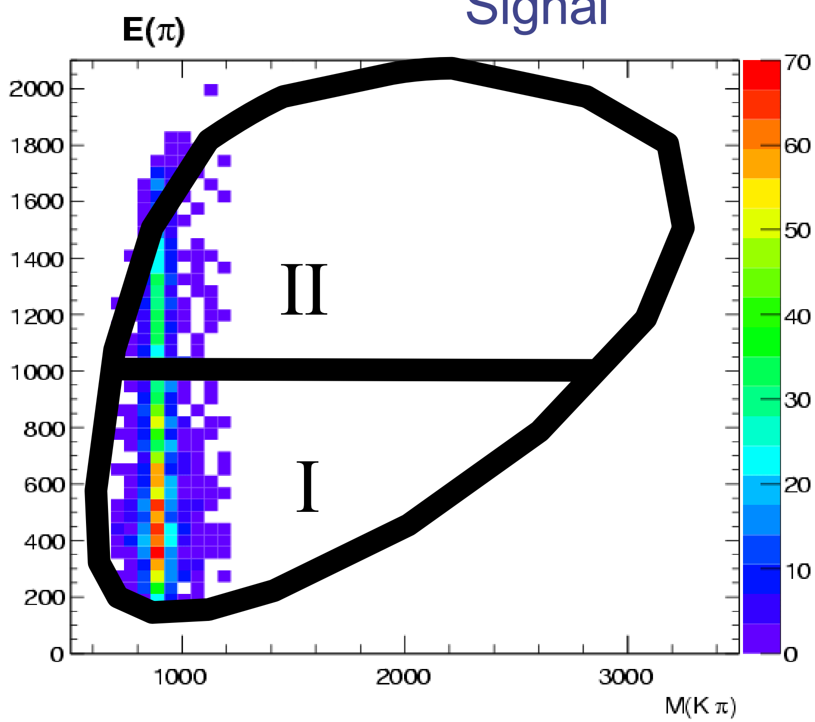
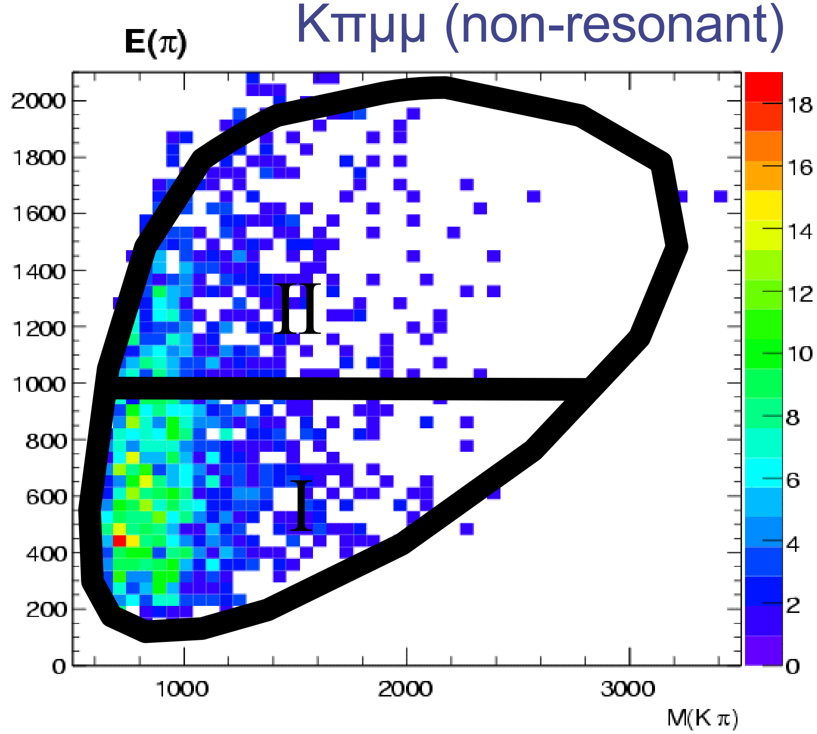
Non-resonant Kπμμ events

Have relaxed the K* mass cut for signal and NR events

Signal



Kπμμ (non-resonant)



For the smallest theory error, we want just those events in region II

- Most of the $K^{*0}\mu\mu$ events are at pion-energies lower than region II

Theory predicts that the $K^{*0}\mu\mu$ FBA will be shifted in region I

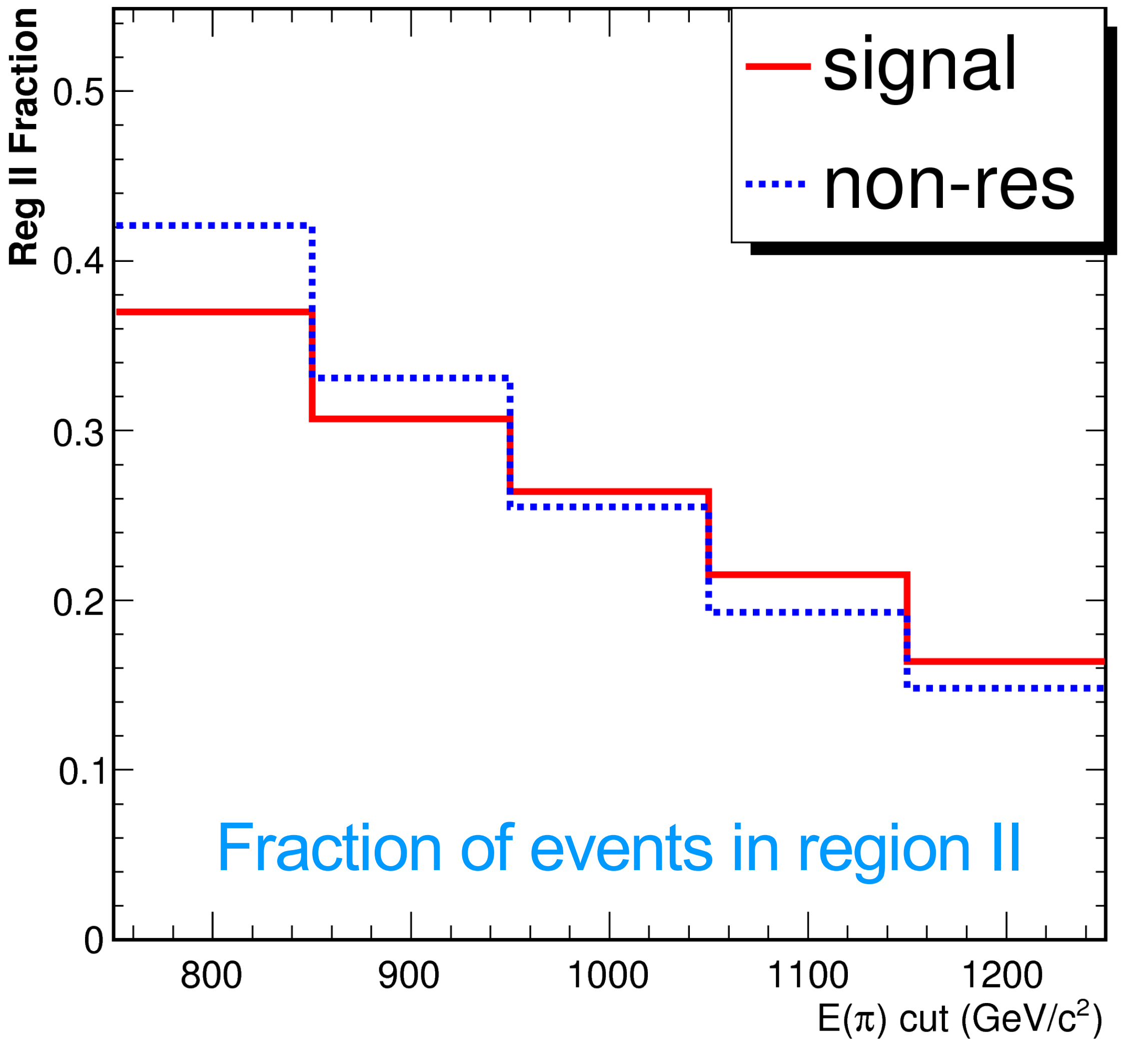
Non-resonant Kπμμ events

Fraction of events in Region II depends strongly on where we place the cut on the pion energy

$E_{\pi} > 800$ MeV → 37%

$E_{\pi} > 1000$ MeV → 25%!

How low can we bring this cut and still feel safe?



$B_d \to K^{*0}\mu^+\mu^-$ angular analysis

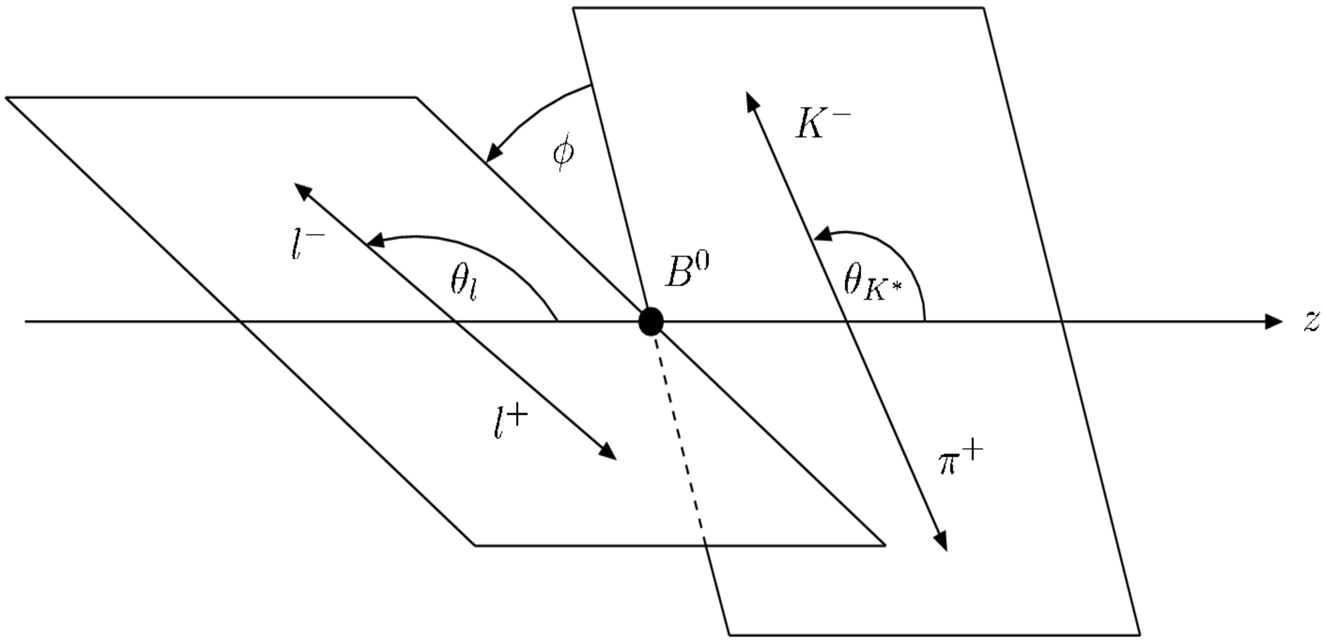
Kinematic measurables in $B \rightarrow K^{*0}\mu^{+}\mu^{-}$

q^2 : The invariant mass squared of the dilepton system

θ_l : The angle of the positive lepton in the dimuon rest frame wrt the B flight direction.

θ_K : The angle of the Kaon in the Kπ rest frame wrt the B flight direction.

φ : The angle between the dilepton and the Kπ decay planes in the B rest frame.



Variables in B → $K^{*0}\mu^+\mu^-$

Look at decay in terms of transversity amplitudes $A_\perp, A_\parallel, A_0$ for left and right handed currents.

Good variables with small theoretical error in the Standard Model are:

Transverse asymmetries (insignificant error at *q*<3 GeV):

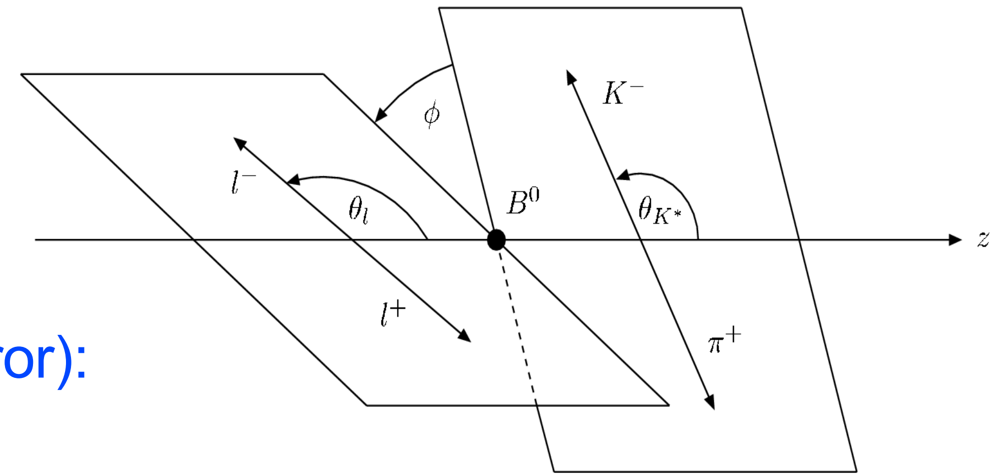
$$A_T^{(1)}(s) = \frac{-2\mathrm{Re}(A_\parallel A_\perp^*)}{|A_\perp|^2 + |A_\parallel|^2}, \quad A_T^{(2)}(s) = \frac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2}.$$

Fraction of K* polarization (small error):

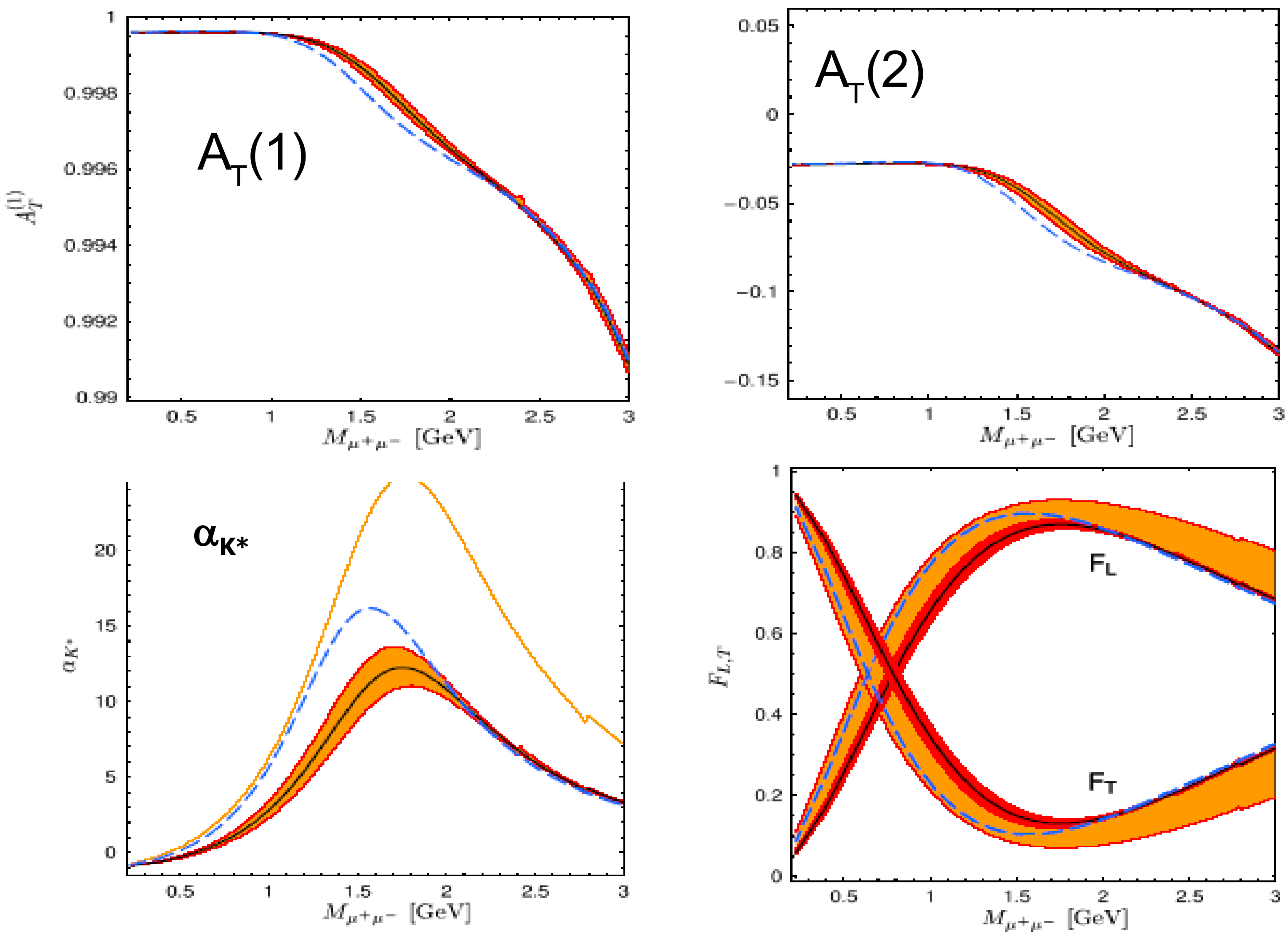
$$F_L(s) = \frac{|A_0|^2}{|A_0|^2+|A_\parallel|^2+|A_\perp|^2} \qquad F_T(s) = \frac{|A_\perp|^2+|A_\parallel|^2}{|A_0|^2+|A_\parallel|^2+|A_\perp|^2}$$

K* polarization parameter (significant error):

$$\alpha_{K^*}(s) = \frac{2|A_0|^2}{|A_\parallel|^2+|A_\perp|^2} - 1$$



Standard Model predictions including uncertainties

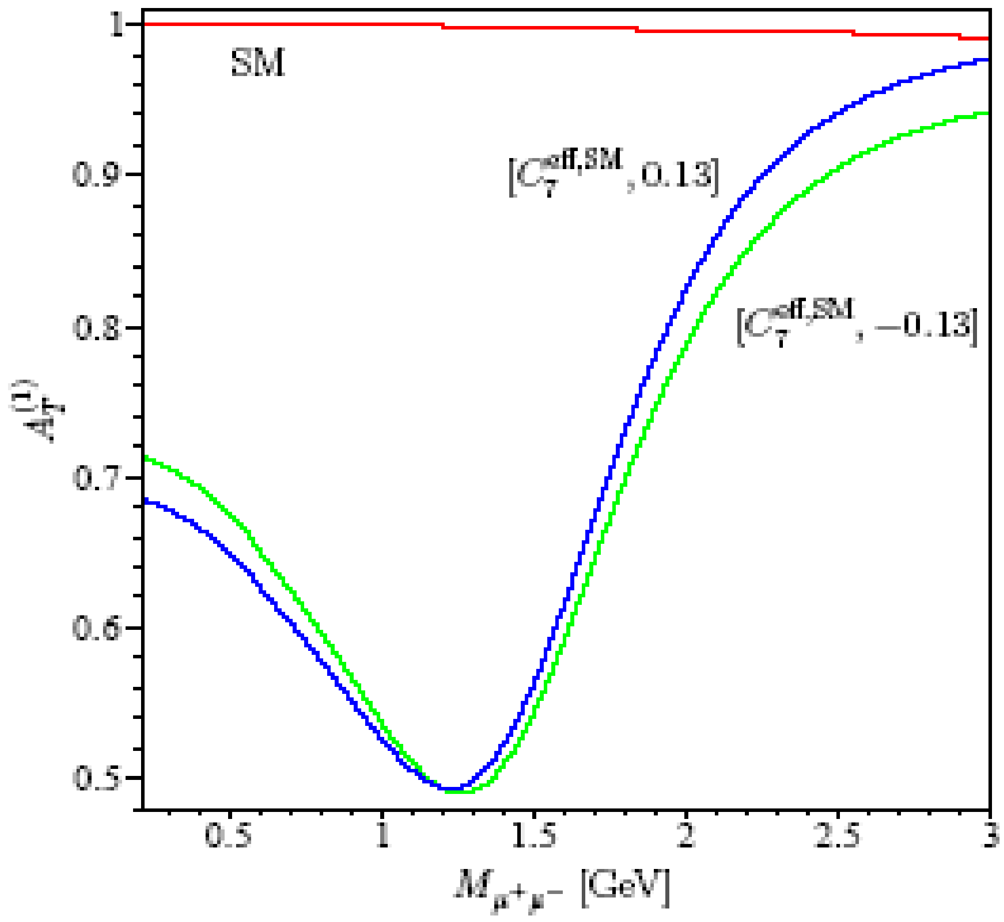


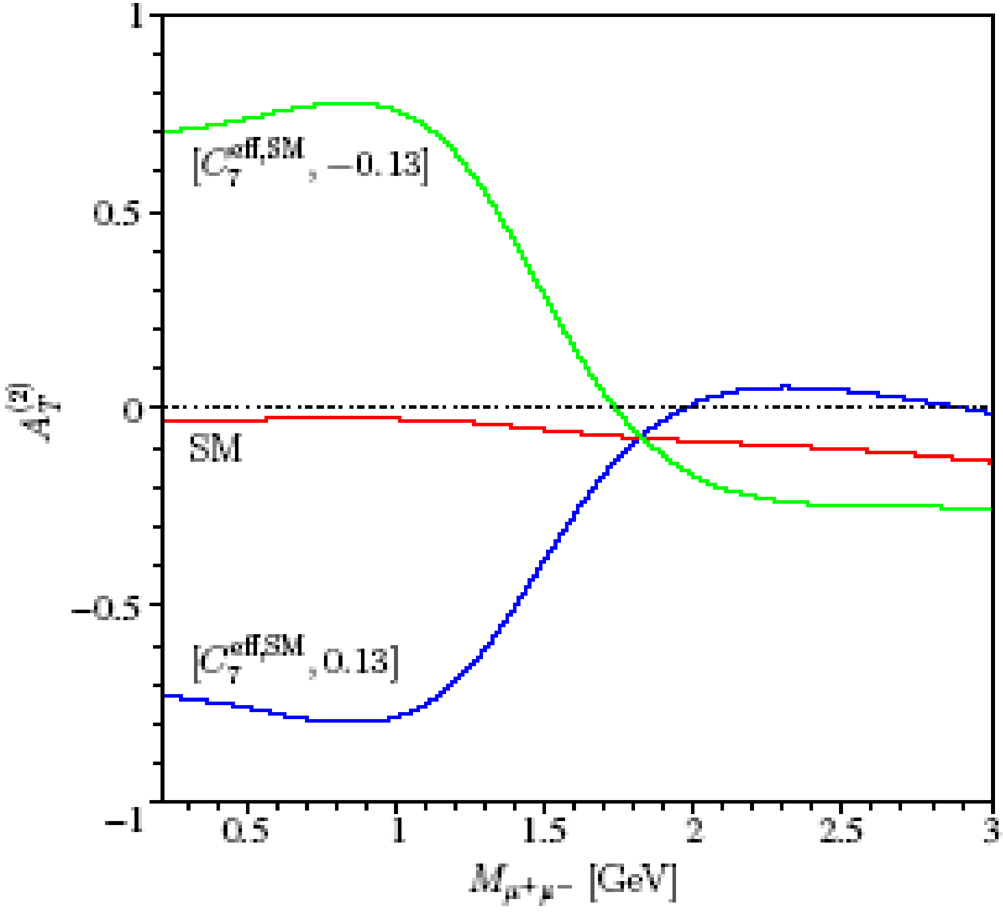
J Matias, EPS 2005

New physics predictions

Small RH contribution in C'_7 produce big effect.

Sensitive to sign of C'_7 as well.





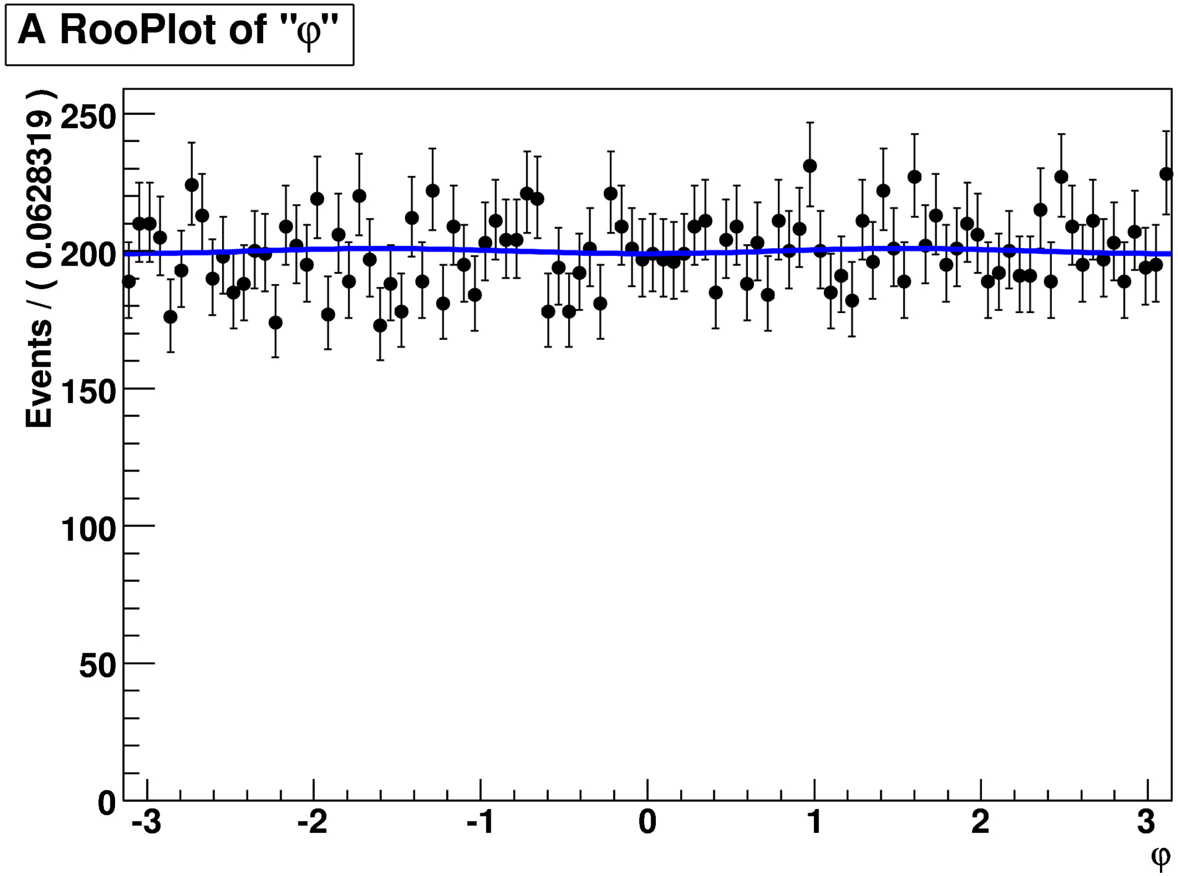
φ distribution

All angular distributions simplify if we ignore m_l^2/q^2 terms,

$$\frac{d^2\Gamma}{dq^2\,d\varphi}=\frac{1}{2\pi}\left(e\cos 2\varphi+m\sin 2\varphi\right)+\frac{1}{2\pi}\frac{d\Gamma}{dq^2}$$

The φ distribution carries information about A_T^2 in the amplitude of the oscillation.

$$A_T^2=\frac{8e}{\left(1-F_L\right)\frac{d\Gamma}{dq^2}}$$



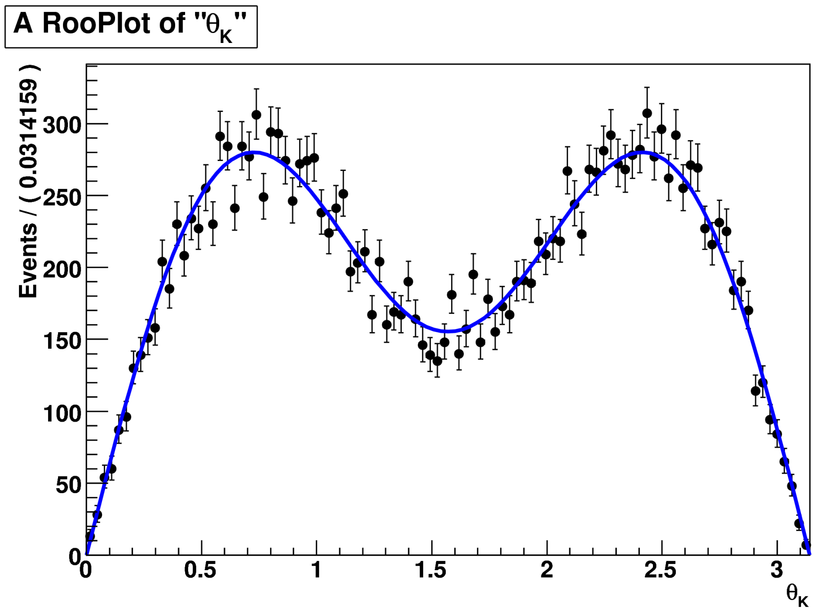
Clearly hard to distinguish from zero in SM but can we see the difference compared to New Physics scenarios?

Θ distributions

For K* angle

Normalisation of A_T^2 is extracted from Θ_{K^*} distribution.

Also determinate the K* polarisation.



$$\frac{d^2\Gamma}{dq^2\,d\theta_K}=\frac{3}{4}\sin\theta_K\left(2F_L\cos^2\theta_K+(1-F_L)\sin^2\theta_K\right)\frac{d\Gamma}{dq^2}$$

For lepton angle

$$\frac{d^2\Gamma}{dq^2\,d\theta_l}=\sin\theta_l\left[\frac{3}{4}F_L\sin^2\theta_l+\frac{3}{8}F_T(1+\cos^2\theta_l)+A_{FB}\cos\theta_l\right]\frac{d\Gamma}{dq^2}$$

Has information on forward backward asymmetry as well as F_L

Toy model

A toy model has been created in RooFit to describe the φ, Θ_{K*} and Θ_l distributions.

Standard model predictions are used for the input of all parameters

- Analysis is performed in 4 bins of q^2 for $0.05\ \text{GeV}^2 < q^2 < 8.95\ \text{GeV}^2$

Background is added according to selection study

- Non resonant $K\pi$ contribution left out at the moment.
  - Will update statistics when we understand Region I/II issue
- Background assumed perfectly known in amount and shape of variables.

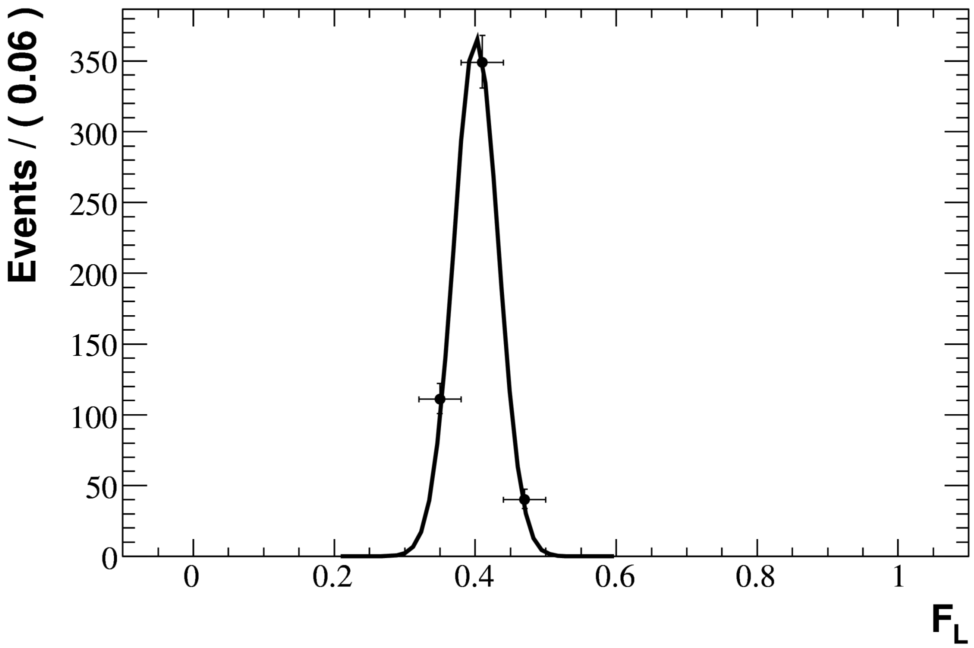
Sample	Events
Signal	7345
Background	2733

Fit for K* longitudinal polarisation F_L

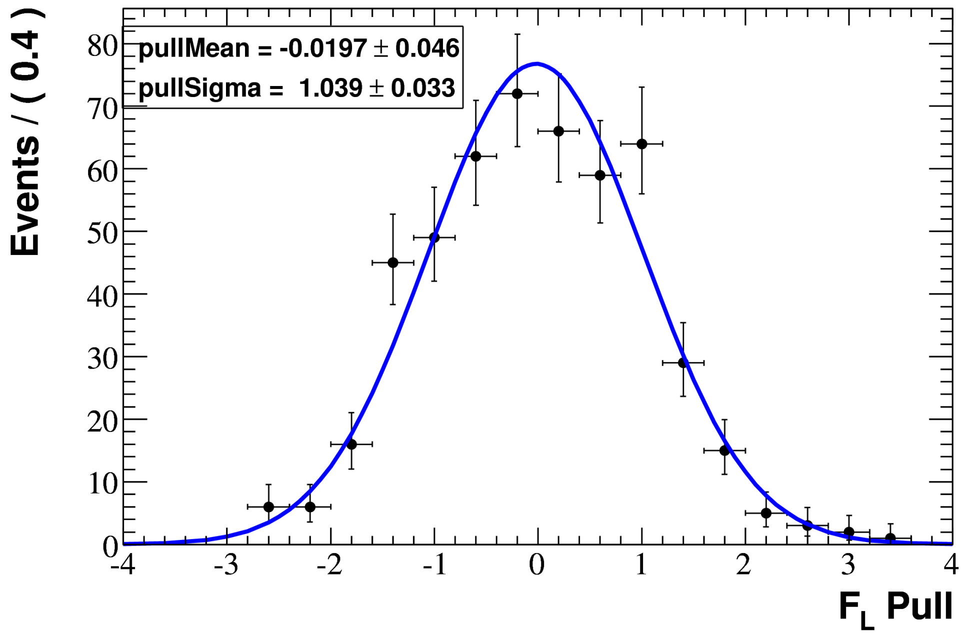
Fits are well behaved.

- Resolution is good and the same in each bin.
- All pull distributions are centred at zero with unit width.

Central value of fits



Pulls



Fits to other angles are well behaved as well.

Summary of resolutions

For each variable the average resolution in a large set of toy simulations is given.

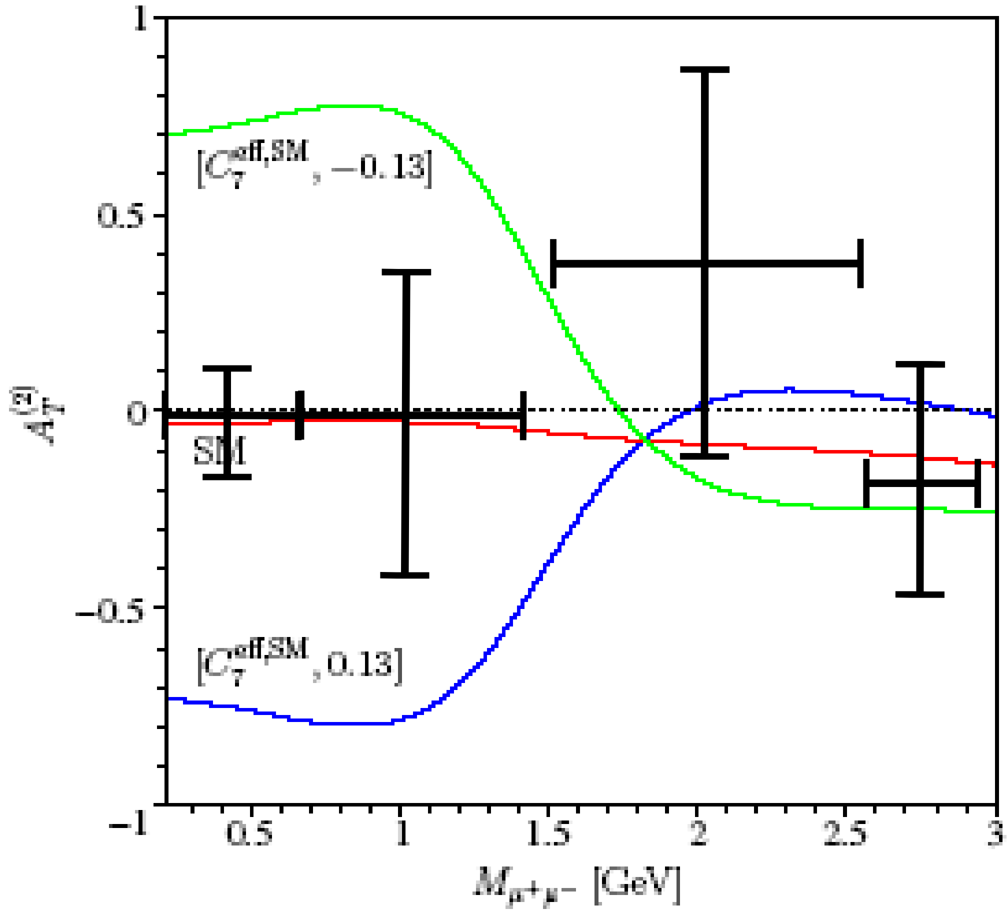
Bin	Range in q^2	A_T^2	A_{FB}	F_L
1	0.05 – 0.49	0.180	0.050	0.037
2	0.49 – 1.96	0.400	0.042	0.033
3	1.96 – 6.25	0.470	0.025	0.018
4	6.25 – 9.0	0.31	0.026	0.020

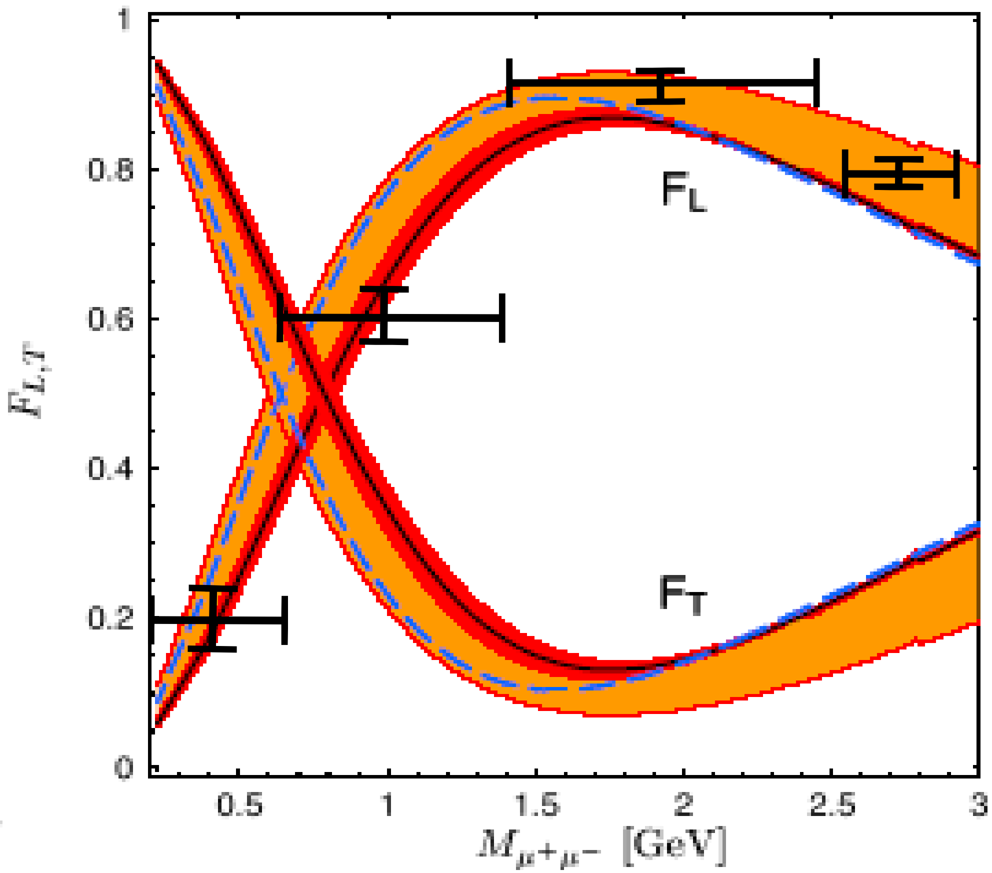
All resolutions are for a 2 fb^{-1} sample

There is a weak correlation between A_T^2 and F_L due to $1-F_L$ normalising A_T^2.

Possible measurement with 2 fb^{-1}

Results from a single toy Monte Carlo fit.





Measurements we can do

- Differential width
  - As function of q^2 in K^{*0} resonance region
  - As function of $(K\pi)$ invariant mass
    - Maybe even in a few q^2 bins
- Forward backward asymmetry
- K^{*0} polarisation with higher precision than current SM theory errors
- Transversity asymmetry A_T^2 with reasonable precision
- Look at the $B \rightarrow K^*_2 \mu^+ \mu^-$ channel.
  - Width a factor 2 larger, $BR(K^*_2 \rightarrow K\pi)$ factor 2 smaller, $BR(B \rightarrow K^*_2 \mu\mu)$ similar.
  - More or less problematic regarding non-resonant background?
  - Spin 2 state so we have new variables in this system.
    - Choudhury, Cornell, Joshi, McKellar [Phys.Rev.D74:054031,2006]

Unresolved issues

- What is the limit we should place on the π energy to get a theoretical error on the zero point below our statistical error.
  - Is it correct that we can treat resonant and non-resonant contributions together in this region II?
- How are the angular correlations affected by the non resonant background?
  - Can we use the same region II or are we in further trouble?
- Can we get any estimate for the non-resonant contribution or should we just wait and measure it?
- Can we agree on some standard binning in q^2 for the report?
  - How low in q^2 should we go? How close to the J/Ψ resonance?

Conclusion

- Updated study of selection points to 7.3k events in 2 fb^{-1} (previously 4.4k)
  - B/S ratio kept at same level and much better understood.
  - A need to understand how to deal with non-resonant Kπ background
- Resolution in measurables
  - First estimate for precision in transversity asymmetry and K* polarisation available with 2 fb^{-1} of data.
    - Polarisation measurement resolution very good.
    - A_T^2 asymmetry resolution more marginal but still interesting.
  - Progress in updated resolution numbers for A_{FB} and zero point,
  - Treatment of background still very simplistic
  - No estimates of systematics yet