Status of $\psi(2S)/J/\psi(1S)$ analysis in PHP channel

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ZEUS Analysis Forum, DESY, 2-Feb-2016

Outlook

- Selection for 2PR and 4PR channels
- Muon corrections: **Yes, we can.**
  - methodology: TAG and PROBE using exclusive di-muon sample
  - separate treatment of trigger levels and off-line corrections
  - correlations between trigger levels and off-line reconstruction
  - BRMUO TLT ambiguity resolving (TLT MUO03 bit)
  - problem of FMUON FLT over-corrections in MC
- Control plots: 2PR and 4PR channels
- Extracting of number of events:
  Gaussian fits and event counting with BG subtraction
- Conclusions/Plans

DATA Sample: full HERA II statistic

- process under study:
  $ep \to ep + \psi(2S)$,
  $\psi(2S) \to \mu + \mu-$ or
  $\psi(2S) \to \mu + \mu - \pi + \pi-$
- "benchmark" process:
  $ep \to ep + J/\psi$,
  $J/\psi \to \mu + \mu-$
- PHP: both selections (including triggers) driven by muons
- the same muon efficiency corrections should work
  for 2- and 4-prongs final state

2PR: Selection cuts

- trigger chains:
  $(BRMUO : FLT\ and\ SLT\ and\ TLT)\ or$
  $(FMUO : FLT\ and\ SLT\ and\ TLT)\ or\ \ (BAC : FLT\ and\ SLT\ and\ TLT)$
- $N_{trk} = 2$, both tracks from primary vertex, opposite charge
- vertex cuts: $|Z_{VTX}| < 30$ cm and $\rho_{VTX} < 0.5$ cm (w.r.t. beam-spot)
- COSMIC rejection: $cos(\vec{p^{+}}, \vec{p^{-}}) > -0.9$
- DIS rejection: no Sinistra cand. with $prob > 0.9$ and $E_e > 5$ GeV
- elasticity cut on ZUFOS:
  no zufo unmatched to track with $E^{CAL}_{ZUFO} > 0.5$ GeV
- anti-p.diss cut: $E_{FCALin1^{st}IR} < 1.0$ GeV

2PR: Selection cuts (cont.)

- track length: for muon tracks $N_{SL} >= 3$
  $\rightarrow$ limits η range to approx. $(-2, 2)$
- muon tracks $p_T^\mu > 1.0$ GeV
- (muon tracks $p^\mu > 1.0$ GeV) consistency with MV finder
- muon identification using GMUON:
  Quality > 0, ZTT track match
  both muons identified by CAL MV finder
  (enhanced by Prob. cut $p_{MV} > 0.7$ and isolation cuts)
  and at least one muon found in MUON chambers
  (BRMUO or FMUO) or in BAC
- W cut: $30 < W < 180$ GeV
- $|t| < 5$ GeV

4PR: differences w.r.t. the 2-prongs channel

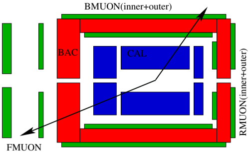
- $N_{trk} = 4$, all tracks from primary vertex
- two highest momentum tracks are muon candidates (the pions are really SLOW)
- opposite charge of muon and pion candidates
- both pion tracks: $p_T^{\pi} > 0.12$ GeV
- $M(\mu^+, \mu^-)$ in J/ψ window (2.8 – 3.4) GeV
- $M(\mu^+, \mu^-, \pi^+, \pi^-) - M(\mu^+, \mu^-)$ in window (0.5 – 0.7) GeV

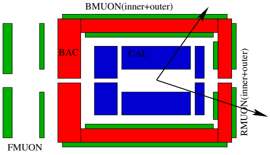
Principles of muon efficiency extraction from DATA

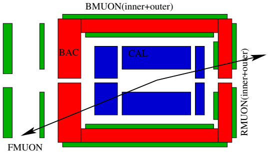
- TAG and PROBE method using exclusive di-muon sample: Tagging muon should be "taken" at all trigger levels and reconstructed off-line (ensures "pass-through" condition to study the unbiased decisions related to PROBE)
- efficiencies are calculated in (η, p_t) bins for Barrel and (η, p_z) bins for Endcaps
  p_t, p_z grid size 0.25 GeV for $p_t, p_z < 3$ GeV
- efficiency corrections extracted for each trigger level and off-line (F/SLT, TLT and REC) $\rightarrow$ to account for "cross-triggers"
- decisions for various trigger levels are correlated
  $\rightarrow$ efficiency should be expressed as conditional probability
- the same investigation should be performed for MC
  $\rightarrow$ the DATA/MC ratio delivers the correction factor
- ... and repeated for each data taking periods: (03p, 04p, 05e, 06e, 06p, 07p)

Di-Muon configurations for efficiency extraction

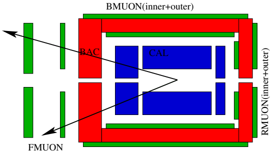
- (almost) non ambiguous: 1F1B, 1B1R, 1F1R (used)

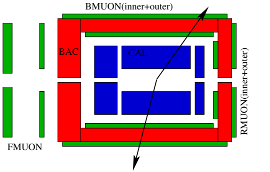


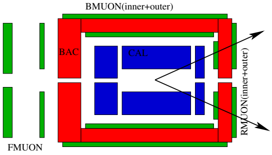




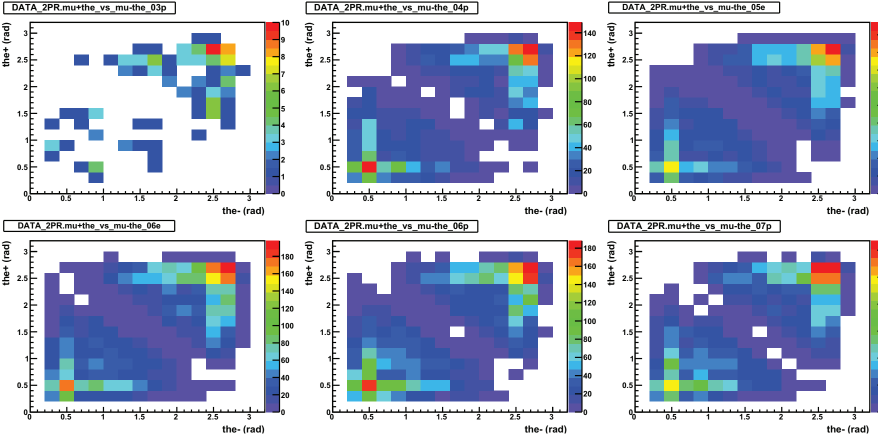
- ambiguous: 2F, 2B, 2R (not used)







DATA sample for efficiency calculations: θ_{μ^+} vs. θ_{μ^-}



- use only events with not more than one muon in FMUON / BMUON / RMUON region: 1F1B or 1B1R (1F1R configurations are very rare)

Trigger slots

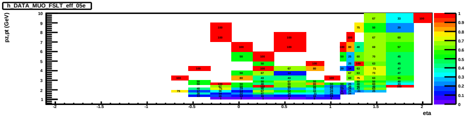
- FMUON
  - FLT: (FLT0 || FLT6 || FLT18)
  - SLT: (MUO03 || MUO04 || MUO05)
  - TLT: (TLTMUO01 || TLTMUO02 || TLTMUO04)
- BMUON
  - FLT: (FLT10 || FLT14)
  - SLT: (MUO01 || MUO02) for runs < 51246 else (MUO02 || GTT05)
  - TLT: (TLTMUO03 || TLTHFL16)
- RMUON
  - FLT: (FLT9 || FLT15)
  - SLT: (MUO01 || MUO02) for runs < 51246 else (MUO02 || GTT05)
  - TLT: (TLTMUO03 || TLTEXO12 || TLTHFL16)

- FLT and SLT are very correlated $\rightarrow$ treat them as one “super-level” FSLT
- BRMUO TLT is ambiguous $\rightarrow$ use GLOMU info together with TLT tracking to resolve this ambiguity (work in progress: still some room for improvement here...)

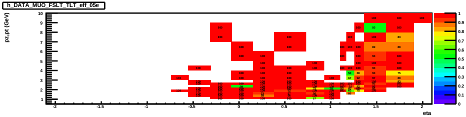
Offline muon identification algorithms from GMUON

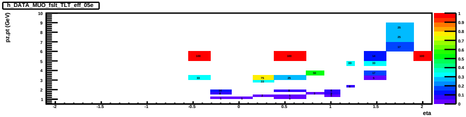
- FMUON: MAMMA or MPMATCH
  (with GMUON Quality > 0 and ZTT track match)
- B/RMUON: GLOMU or BREMAT
  (with GMUON Quality > 0 and ZTT track match)
- CAL: MV NN finder $\rightarrow$ CAL MIP Islands
  TAG and PROBE muons are required to have CAL MIP match
  to avoid double corrections
  (MUON chambers at TLT and REC are also using CAL MIP match)
- no ambiguity (known position/angles of each muon)

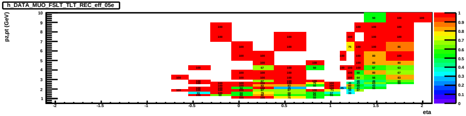
Unambiguous case: 1F1B (example for DATA 05e)

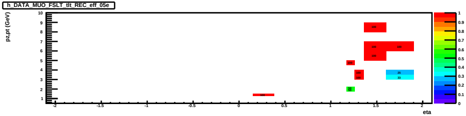


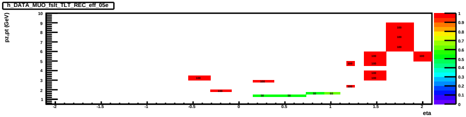
$\leftarrow P(FSLT)$ (unconditional !)

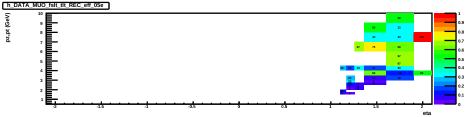












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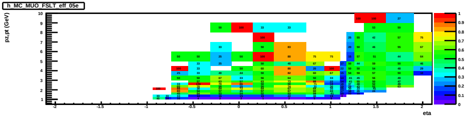
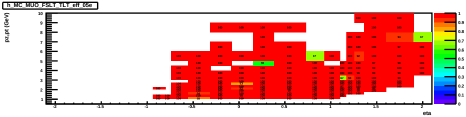
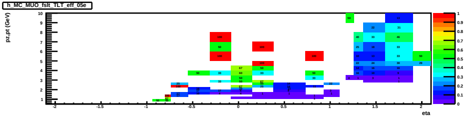
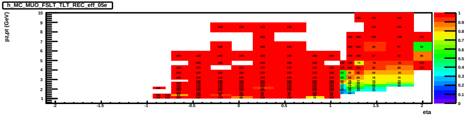
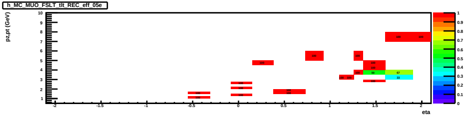


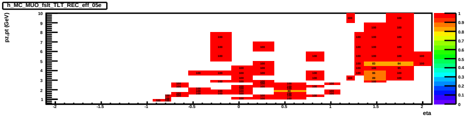
$\leftarrow P(FSLT)$ (unconditional !)

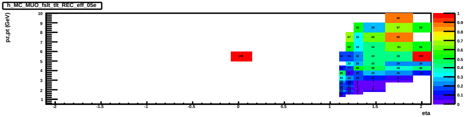












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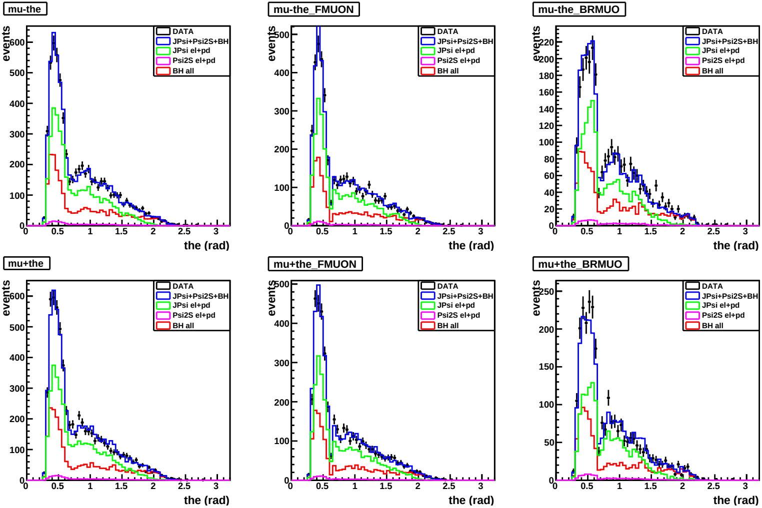
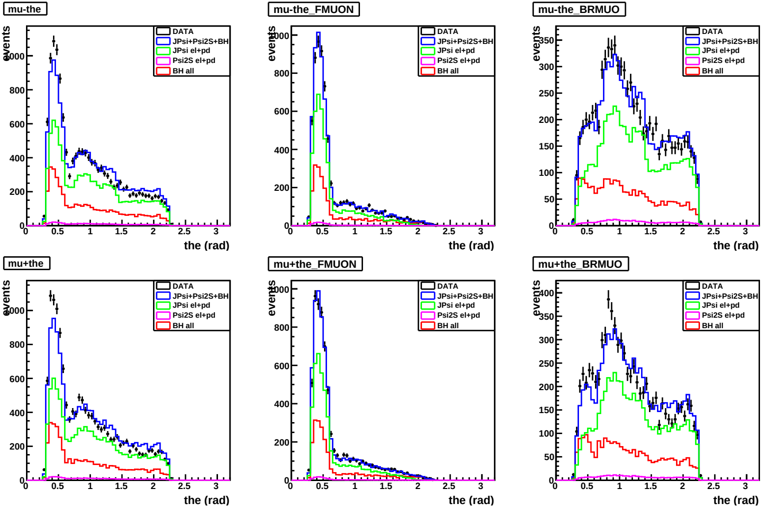
Distributions for θ_{μ^-} and θ_{μ^+}: 1F1B case



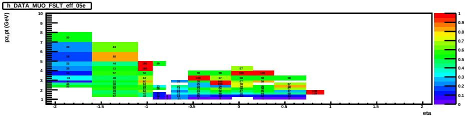
- events selected by FMUON, BMUON or both of them (left plots)
- correction factor for single muon: $\epsilon_{DATA} = \epsilon_X \cdot \epsilon_{MC}$

Distributions for θ_{μ^-} and θ_{μ^+}: 1F1B or 2F0B or 0F2B

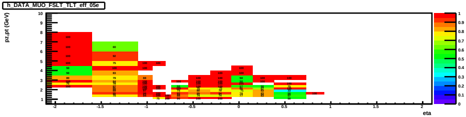


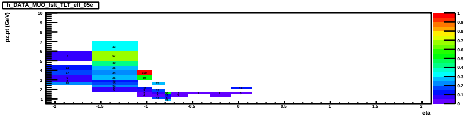
- correction for pair: $(\epsilon^+_{DATA} + \epsilon^-_{DATA} - \epsilon^+_{DATA} \cdot \epsilon^-_{DATA})/(\epsilon^+_{MC} + \epsilon^-_{MC} - \epsilon^+_{MC} \cdot \epsilon^-_{MC})$
- irreducible ambiguity in 2F or 2B case at APPLICATION level !

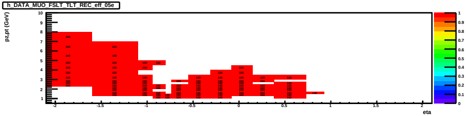
Ambiguous case: 1B1R (example for DATA 05e)

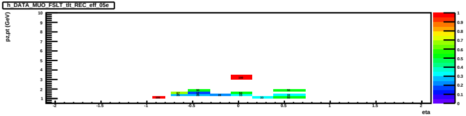


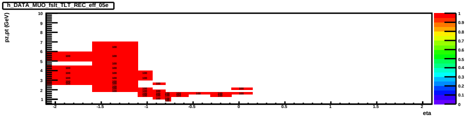
$\leftarrow P(FSLT)$ (unconditional !)

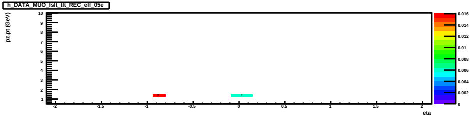












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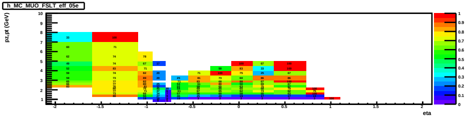
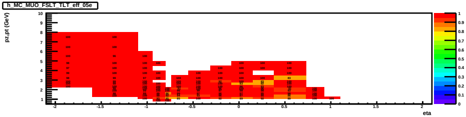
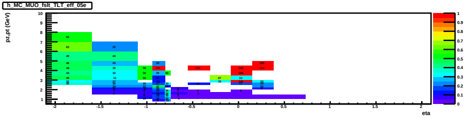
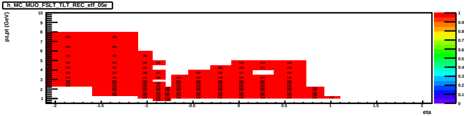
Ambiguous case: 1B1R (example for MC 05e)

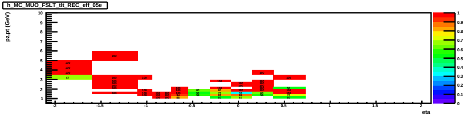


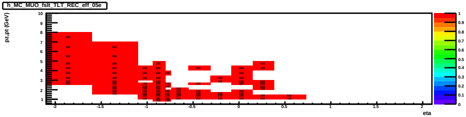
$\leftarrow P(FSLT)$ (unconditional !)

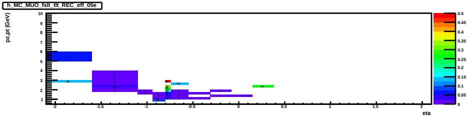












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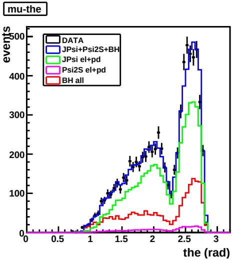
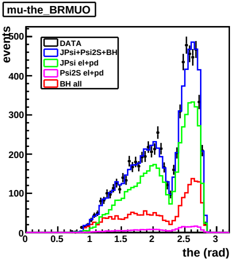
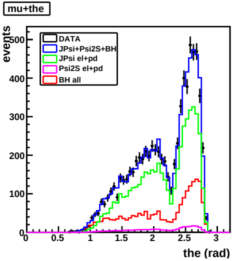
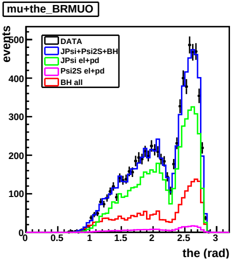
Distributions for θ_{μ^-} and θ_{μ^+}: 1B1R case



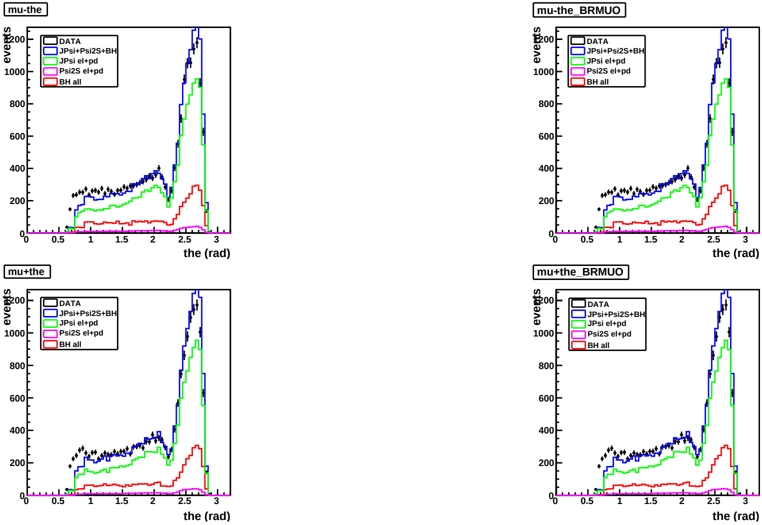






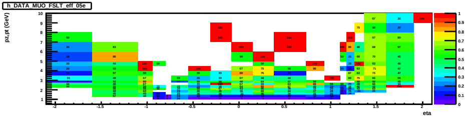
- despite ambiguity the shapes are well described $\rightarrow$ distortion due to the ambiguity has uniform angular distribution $\rightarrow$ this will be further exploited

Distributions for θ_{μ^-} and θ_{μ^+}: 1B1R or 2B0R or 0B2R

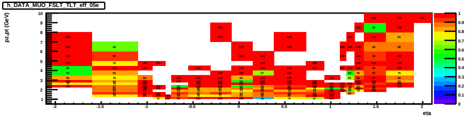


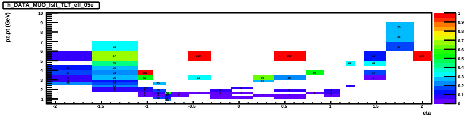
- some effect at the edge of the phase space visible (not enough stat. of 1B1R events comparing to 2B0R) $\rightarrow$ effect is smaller when using efficiency maps extracted in (1F1B or 1B1R) phase space

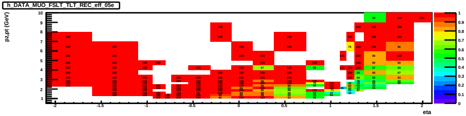
Combination: 1F1B or 1B1R (example for DATA 05e)

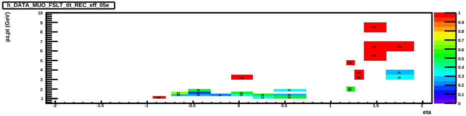


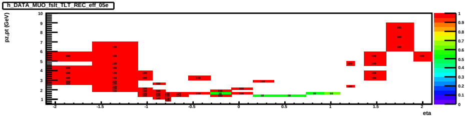
$\leftarrow P(FSLT)$ (unconditional !)

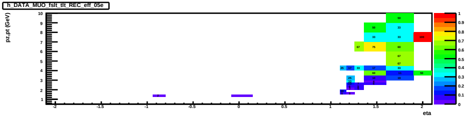






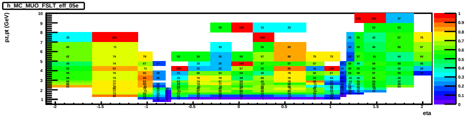




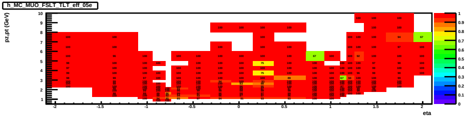


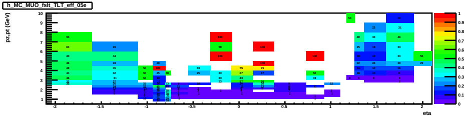
- Notation: 1F1B or 1B1R = 1F1B1R (at most one muon in each trigger region)

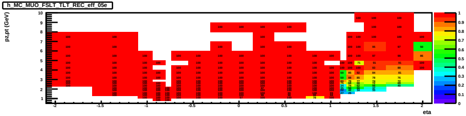
Combination: 1F1B or 1B1R (example for MC 05e)

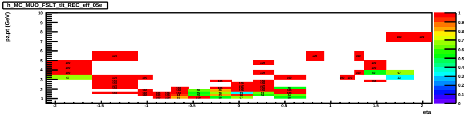


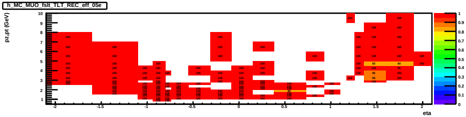
$\leftarrow P(FSLT)$ (unconditional !)

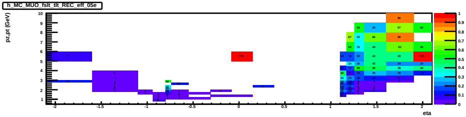






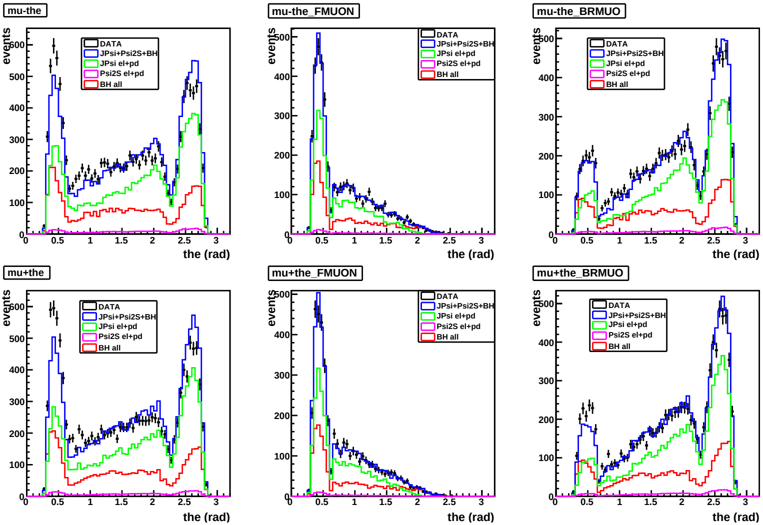






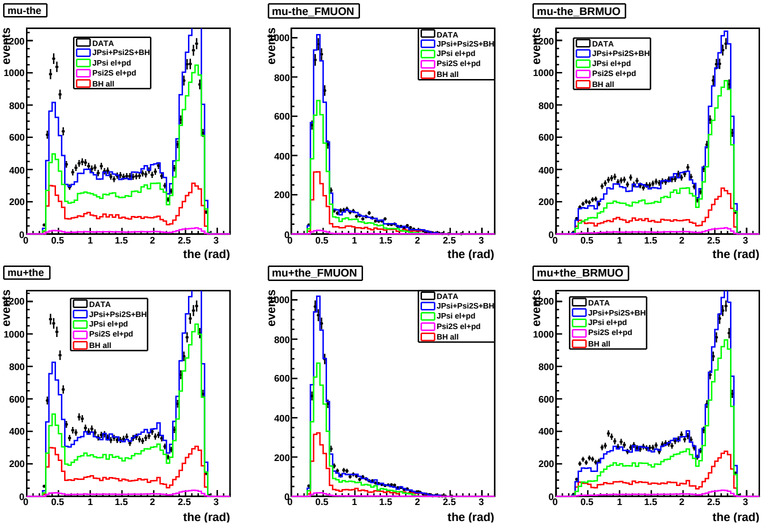
- Notation: 1F1B or 1B1R = 1F1B1R (at most one muon in each trigger region)

Distributions for θ_{μ^-} and θ_{μ^+}: 1F1B1R case



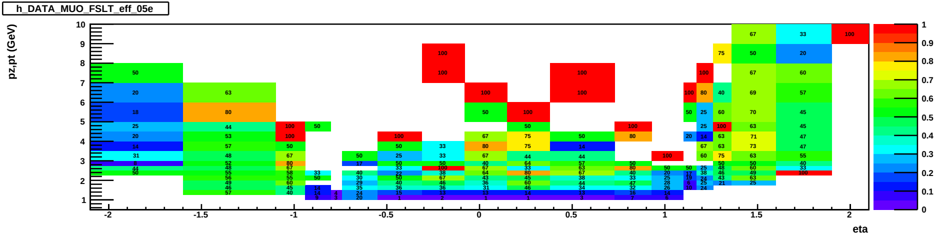
- FMUON and BRMUON have different normalization !
- two sources: BRMUO TLT ambiguity and FMUON over-corrected at MC

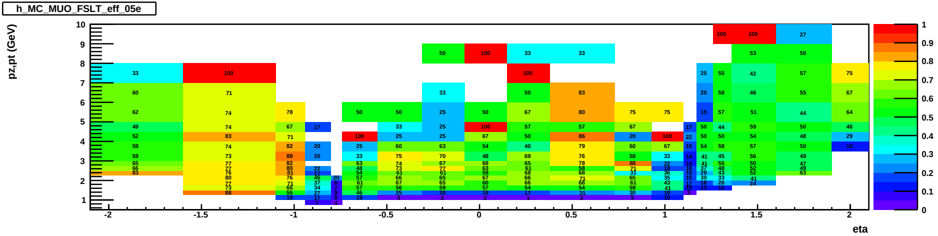
Distributions for θ_{μ^-} and θ_{μ^+}: 1F1B1R or 2F2B2R



- again: FMUON and BRMUON separately perform well, but when combined, reveal different normalization...

FSLT effic: closer look DATA vs. MC



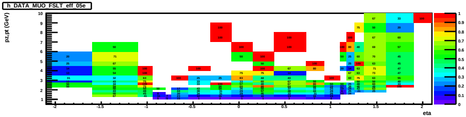


- FMUON has bigger effic in DATA than MC !?
  (overcorrection already at ZGANA MC level ? Noises in DATA ?)

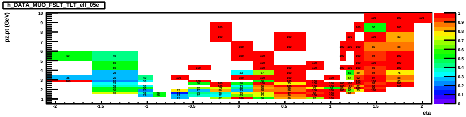
Possible solutions

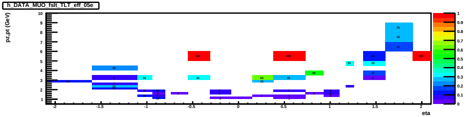
- increase FMUON MC FLT efficiency by “resimulating” trigger decision $\rightarrow$ based on off-line (REC) and TLT decision (access to hits) and then correct it to the level observed in DATA $\rightarrow$ work in progress
- improve BRMUO TLT ambiguity resolving $\rightarrow$ more realistic match between GLOMU candidates and TLT tracks and CAL MIPS (reproducing TLT on-line conditions)
  - use unambiguous BRMUO FLT bits to help to resolve TLT ambiguity (?)
- ad-hoc solution: degrade in an uniform way the BRMUO TLT efficiency to make it more realistic $\rightarrow$ it is overestimated due to the ambiguity $\rightarrow$ should work as “effective” solution to calculate the acceptance corrections

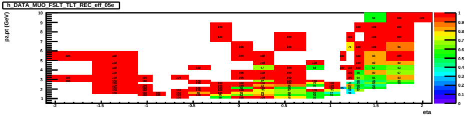
Corrected: 1F1B or 1B1R (example for DATA 05e)

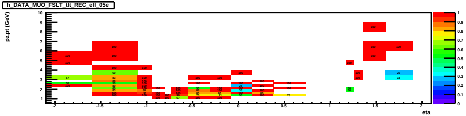


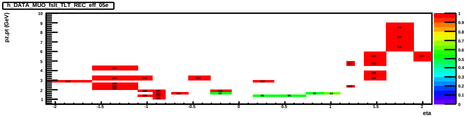
$\leftarrow P(FSLT)$ (unconditional !)

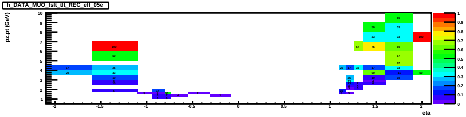






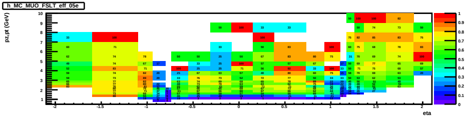




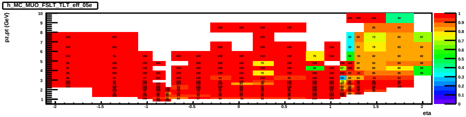


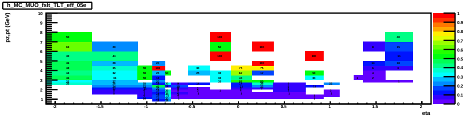
- Notation: 1F1B or 1B1R = 1F1B1R (at most one muon in each trigger region)

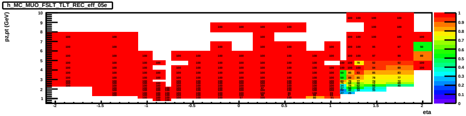
Corrected: 1F1B or 1B1R (example for MC 05e)

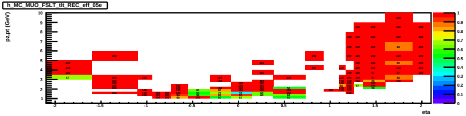


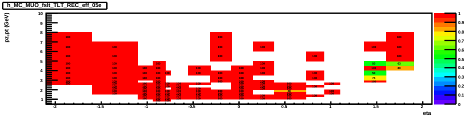
$\leftarrow P(FSLT)$ (unconditional !)

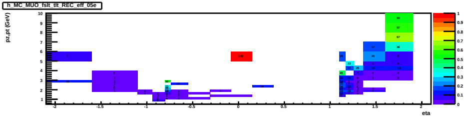






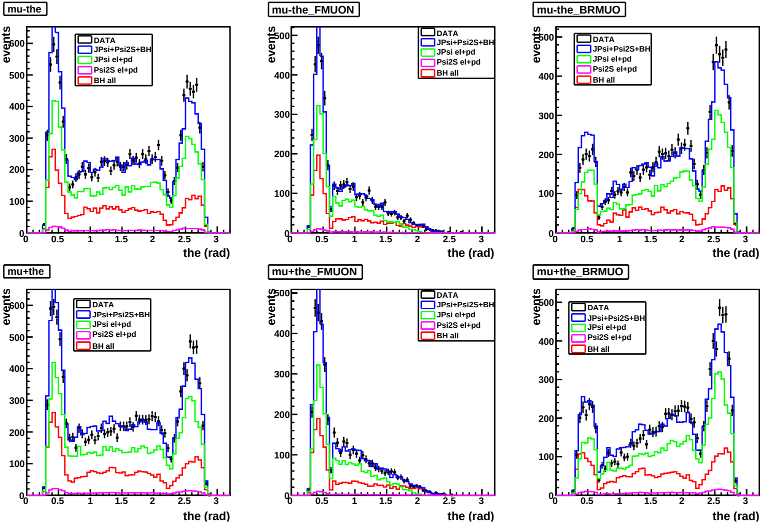






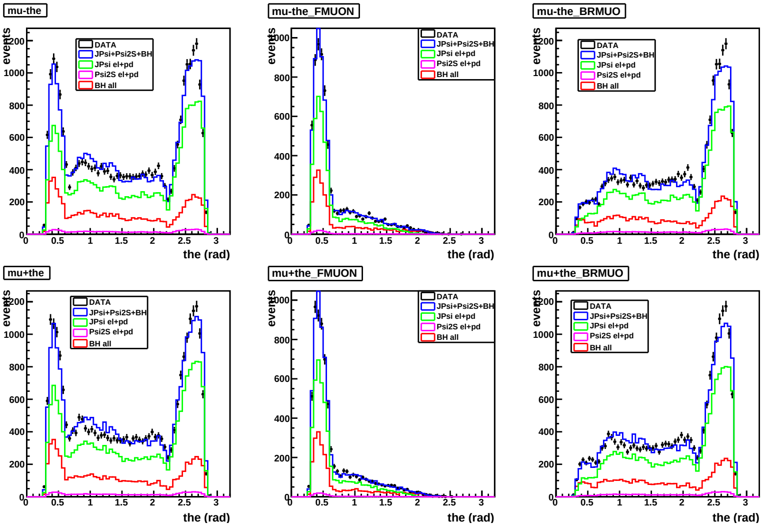
- Notation: 1F1B or 1B1R = 1F1B1R (at most one muon in each trigger region)

Distributions corr. for θ_{μ^-} and θ_{μ^+}: 1F1B1R case



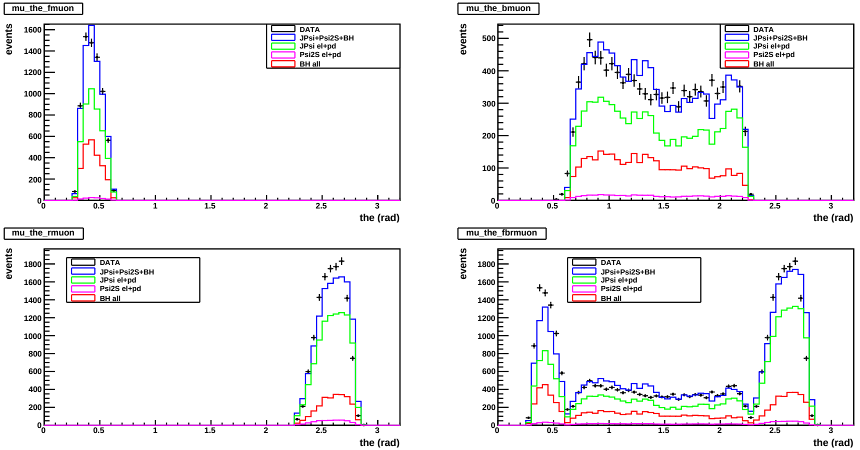
- first attempt over-corrects FMUON effic for 1F1B1R case

Distributions corr. for θ_{μ^-} and θ_{μ^+}: 1F1B1R or 2F2B2R



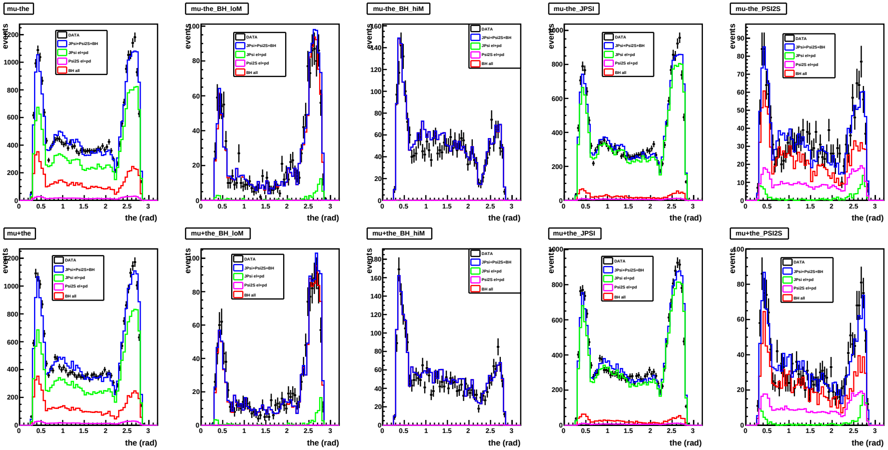
- 2F2B2R case: a compromise between FMUON and BRMUON
- shapes not ideal but for MC acceptance corrections should be OK

$\theta_{\mu^\pm}$: only muons REC and Triggered by F/B/R



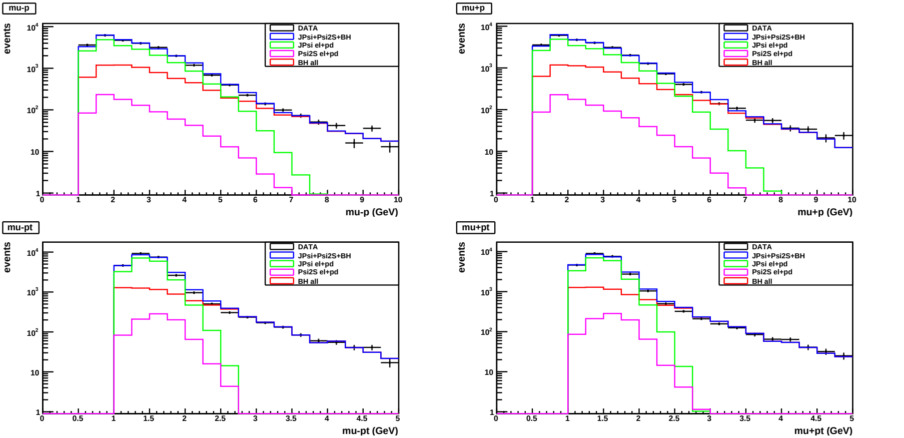
- here: geometrical acceptance of muon detectors is better visible

θ_{μ^-} and θ_{μ^+} in Mass bins



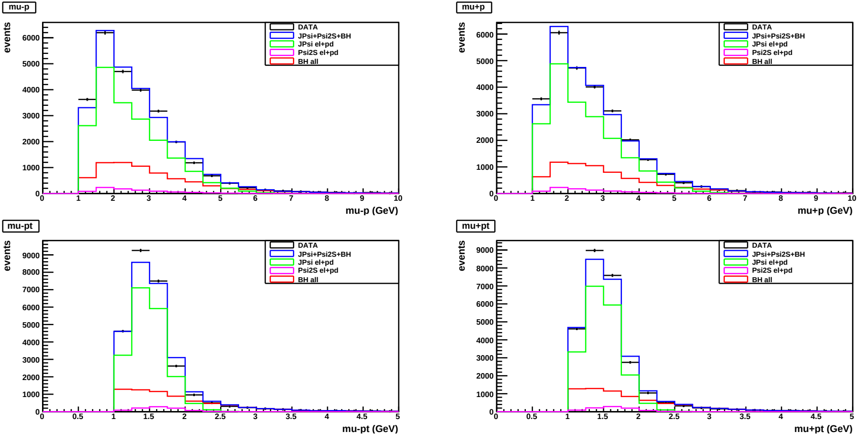
- sample splitted for BH-low-mass, BH-hi-mass, JPSI and PSI' mass peak

More control plots: μ^-, μ^+ muons p and p_T, log scale



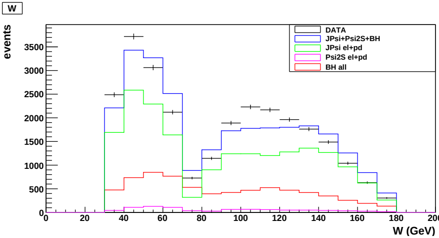
- good agreement

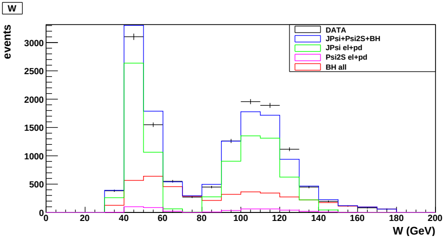
More control plots: μ^-, μ^+ muons p and p_T, lin scale



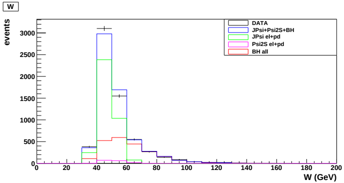
- good agreement

W distribution: 2F2B2R and 1F1B1R case

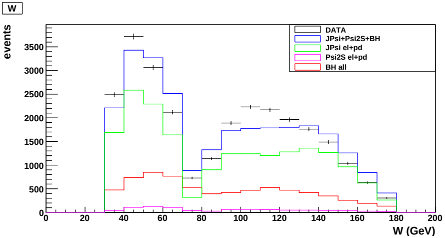


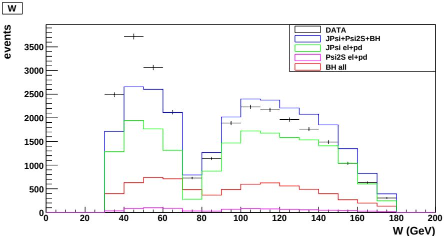


- W distribution is very sensitive to the corrections scheme
- discrepancy inherited from the θ distribution: underestimated BRMUO after 'ad-hoc' corrections $\rightarrow$ requires more precise treatment
- right-bottom: W for 1F1B0R selction (good agreement)



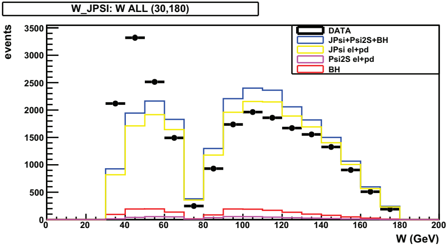
W distribution (cont.)

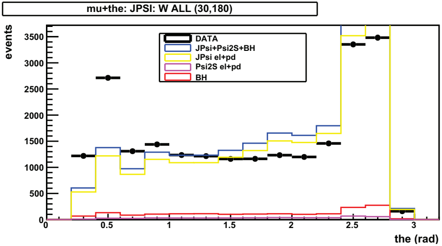




- W distrib. with 'ad-hoc' tuning of corrections and taking them 'as they are'
- in the 'ad-hoc' tuning BRMUO TLT effic was too much degraded in order to increase relative contribution from FMUON
  $\rightarrow$ FMUON MC FLT effic. should be increased directly
- a proper balance between FMUON and BRMUO is needed
  $\rightarrow$ next version of tuning

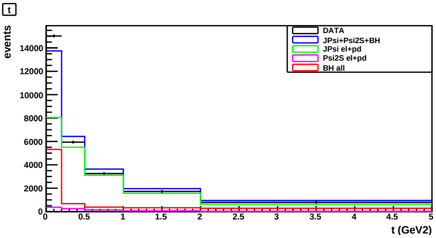
Results from previous status report

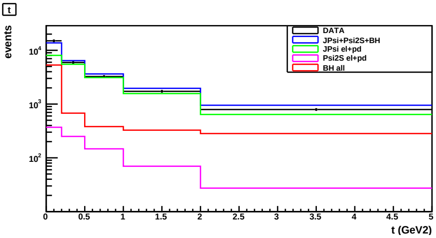




- Obtained using previous version of muon efficiency corrections: single correction for each muon, not splitted for trigger levels
- Progress on description of the FMUON region using current version $\rightarrow$ compare current agreement of θ_μ distribution

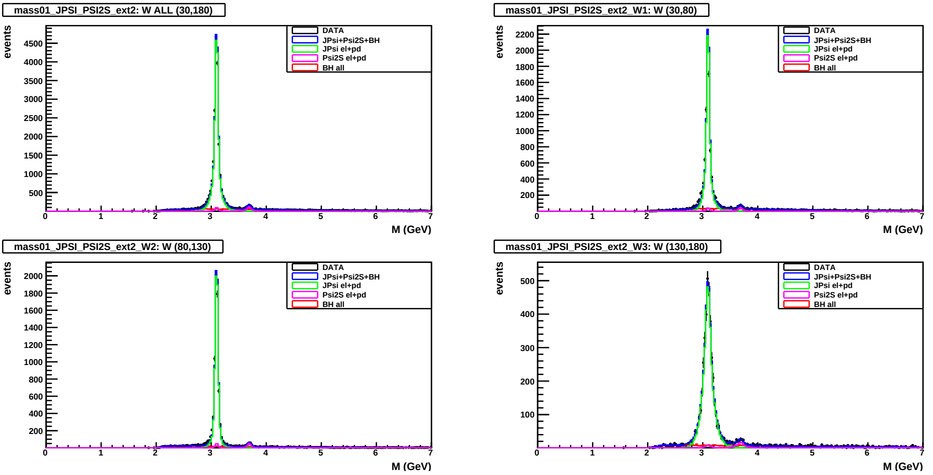
$|t|$ distribution





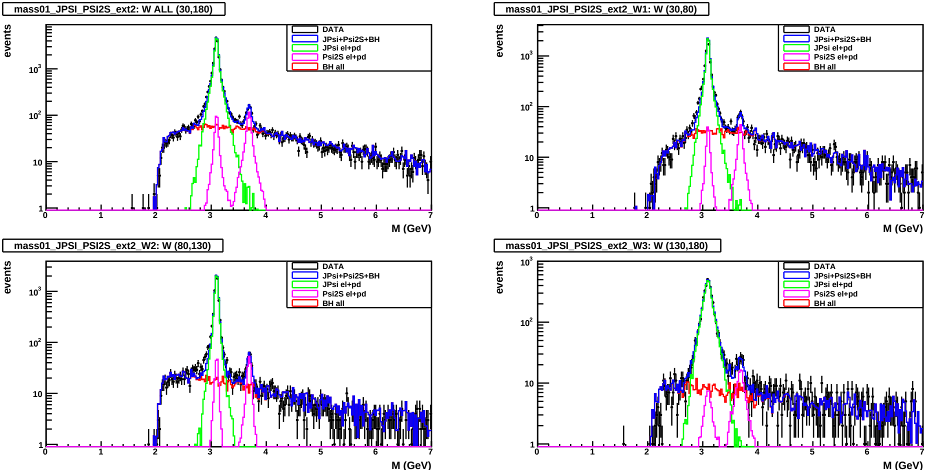
- first bin underestimated in MC (also before 'ad-hoc' tuning...)
- for control plots $f_{p.diss} = 0.25$ (for J/ψ and ψ') (not fitted)

Di-muon Mass distribution lin scale



- All W (upper-left) and W1(30-80), W2(80-130), W3(130-180) GeV bins

Di-muon Mass distribution log scale

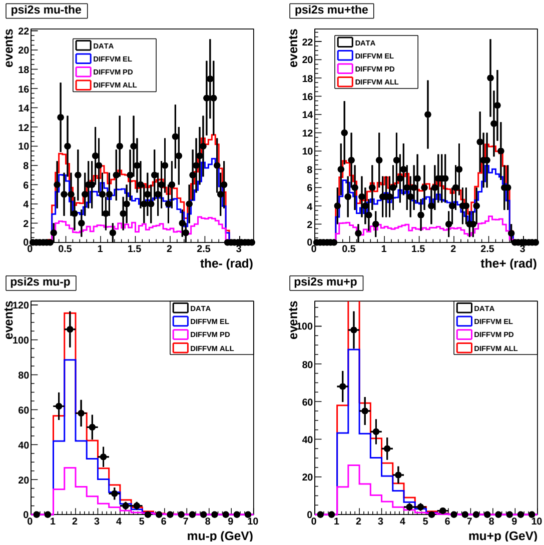


- All W (upper-left) and W1(30-80), W2(80-130), W3(130-180) GeV bins
- BG shape and mass resolution are reasonable well described by MC
- relative contribution of all processes from TFracFitter

Control plots for 4PR channel

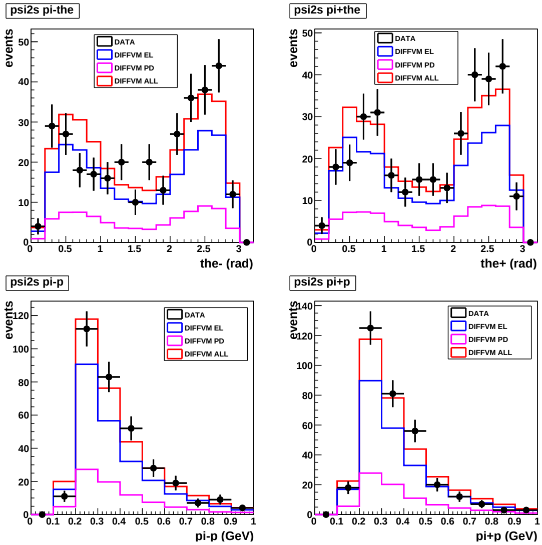
- $\psi(2S) \to \mu^+\mu^-\pi^+\pi^-$
- using the same muon corrections as for 2PR channel

4PR: muon polar angle θ_{μ^-}, θ_{μ^+}, and p_{μ^-}, p_{μ^+}



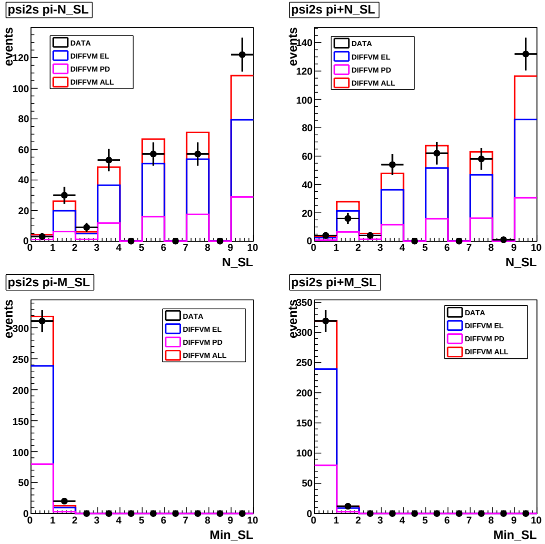
- θ_μ distribution reveals the same tendency as for 2PR case, p_μ looks OK

4PR: pion polar angle θ_{π^-}, θ_{π^+}, and p_{π^-}, p_{π^+}



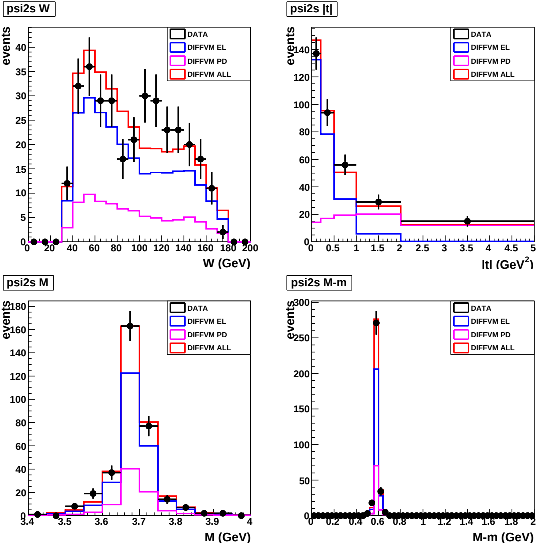
- good agreement (we cut on pion $p_T > 0.12$ GeV)

4PR: last and first SL (Super Layer) of (slow) π^-, π^+



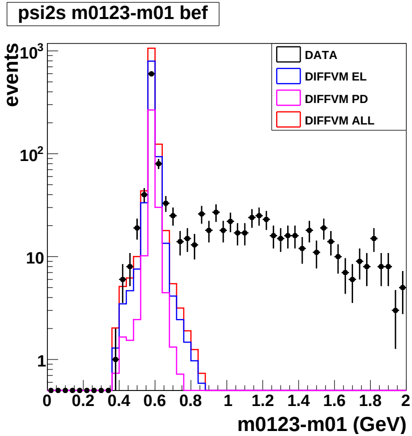
- good agreement (we do not cut on outer layer number for pions)

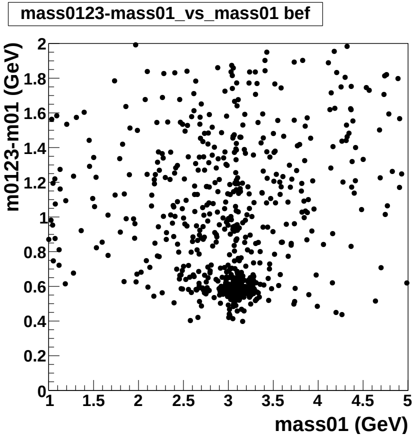
4PR: W, $|t|$ and Mass distribution



- W distr. similar tendency as in 2PR case (MC over-corrected for high W – populated by BRMUON events)

4PR: Mass difference cuts





- before final clean-up on $M(\mu^+,\mu^-) - M(J/\psi)$ and $M(\mu^+,\mu^-,\pi^+,\pi^-) - M(\mu^+,\mu^-)$ cuts

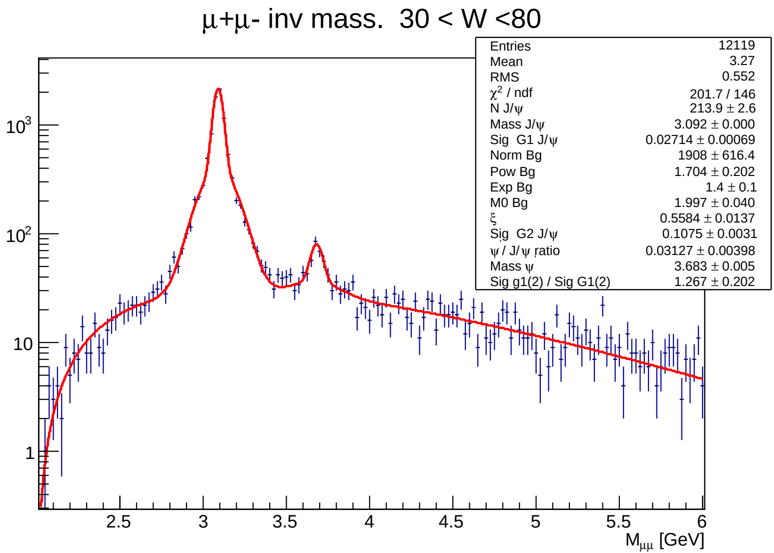
2PR: Signal extraction: fit parametrisation

- Gaussian shape: $G(x)$ or $g(x) = N \cdot \Delta \cdot \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(x-m)^2}{2\sigma^2}\right)$
  where: N – number of events, Δ – mass bin width,
  m – mean value, σ – RMS
- for J/ψ: $N_1 \cdot G_1(x) + N_2 \cdot G_2(x)$
- for ψ': $N_1' \cdot g_1(x) + N_2' \cdot g_2(x)$
- introducing: $N = N_1 + N_2$, $N' = N_1' + N_2'$, $R = \frac{N'}{N}$
- with additional constrains: $m_1 = m_2$, $m_1' = m_2'$,
  $\frac{\sigma_1'}{\sigma_1} = \frac{\sigma_2'}{\sigma_2} = \alpha$, $\xi = \frac{N_1}{N} = \frac{N_1'}{N'}$
- final formulae:

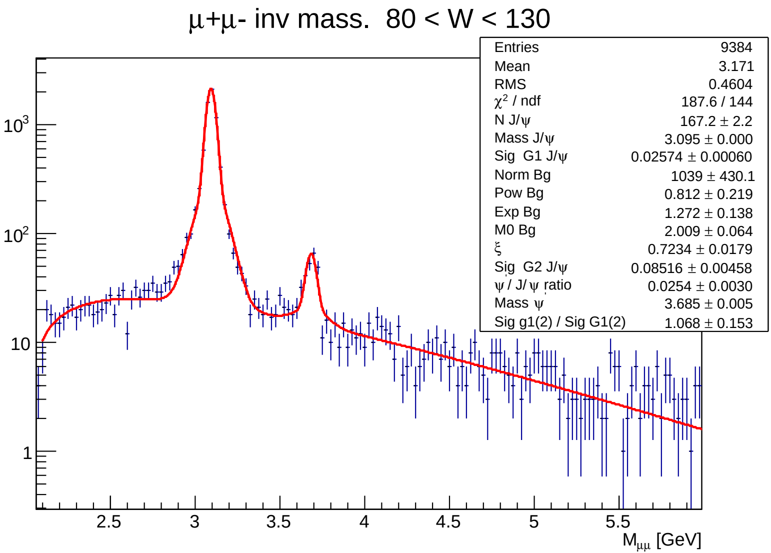
$$F(x) = N \cdot ((\xi \cdot G_1(x) + (1-\xi) \cdot G_2(x)) + R \cdot (\xi \cdot g_1(x) + (1-\xi) \cdot g_2(x))) + BG(x)$$

- background function: $BG(x) = A \cdot (x - B)^C \cdot \exp(-Dx)$
  where A, B, C, D are fit parameters

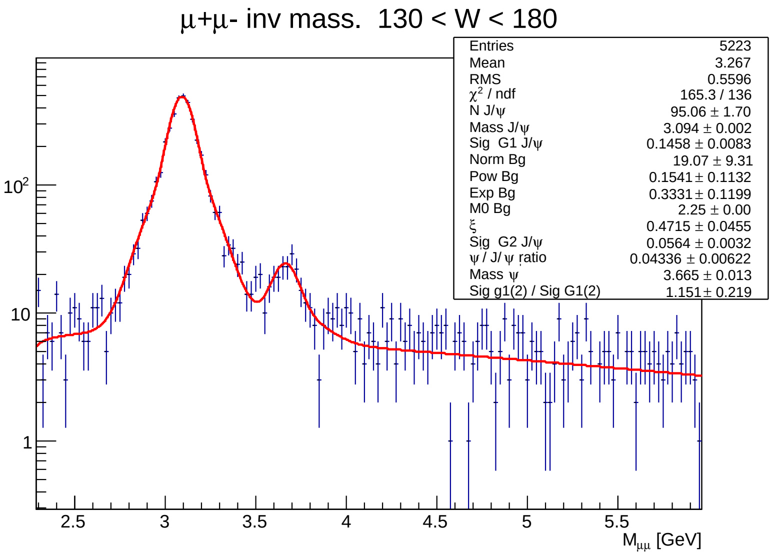
2PR: Signal fit: W1 bin (30-80) GeV



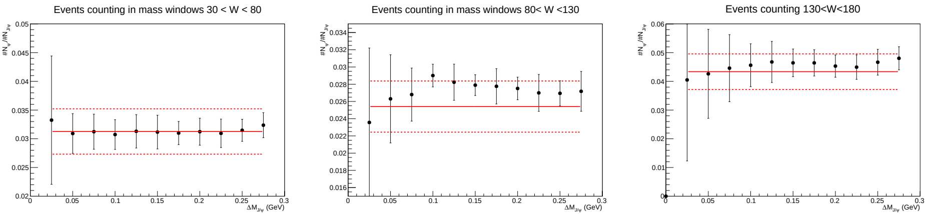
2PR: Signal fit: W2 bin (80-130) GeV



2PR: Signal fit: W3 bin (130-180) GeV

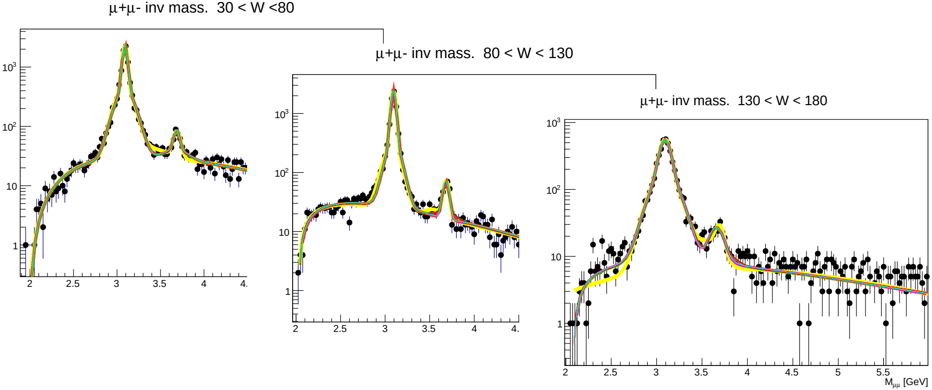


Independent cross-check of signal extraction in W bins



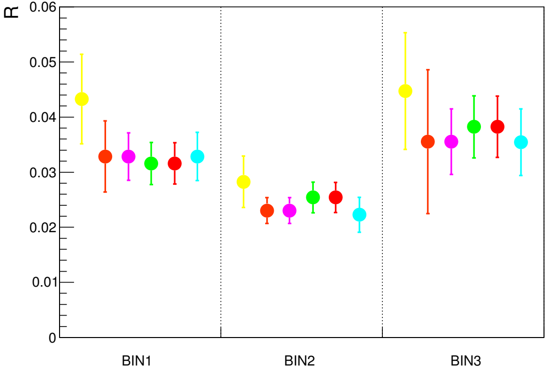
- event counting w/o Gaussian fits, (only BG fit used for BG subtraction)
- Ratio $R = \frac{N'}{N}$ obtained counting events in mass windows around J/ψ and ψ' peaks is plotted as a function of the window width $\Delta M_{J/\psi}$
- ratio of the windows width $\Delta M_{\psi'}/\Delta M_{J/\psi}$ fixed according to detector resolution obtained from Gaussian fits: $\alpha = \frac{\sigma_1'}{\sigma_1} = \frac{\sigma_2'}{\sigma_2}$
- for comparison red lines are $R \pm err$ values from the Gaussian fits

Double Gaussian mass fits: systematics checks



- various fit schemes were compared:
  relaxing mass constrains: $m_1 \neq m_2$, $m'_1 \neq m'_2$, (yellow curve)
  no constrains on $\alpha = \frac{\sigma'_1}{\sigma_1} = \frac{\sigma'_2}{\sigma_2}$, or $\xi = \frac{N_1}{N} = \frac{N'_1}{N'}$, etc.

Mass fits: systematics checks: summary



- $R = \frac{N'}{N}$ values in W bins, various fit schemes were compared: relaxing mass constrains: $m_1 \neq m_2$, $m'_1 \neq m'_2$, (yellow point) no constrains on $\alpha = \frac{\sigma'_1}{\sigma_1} = \frac{\sigma'_2}{\sigma_2}$, or $\xi = \frac{N_1}{N} = \frac{N'_1}{N'}$, etc.

Conclusions/Plans:

- a new scheme of muons efficiency corrections developed
- first consistent treatment of ZEUS muon corrections incl. trigger for HERA II exclusive di-muon data
- good performance for 2PR and 4PR channels
- still requires some tuning (better agreement on W distribution)
- add BAC to this scheme (efficiency splitted for trigger levels)
- progress on extracting the number of signal events (ratio of ψ' to J/ψ events as fit parameter, proper treatment of errors propagation incl. correlations), fit systematics

- calculate acceptance, convert numbers of events into cross-section ratio in W bins for 2PR and 4PR channels
- request for preliminary for DIS2016, draft (almost) ready
- longer term: BRMUO ambiguity resolving reproducing GLOMU TLT conditions
- more elaborate systematics

Backup plots

- Backup plots follow...

BRMUO FLT: splitting for B/RMUO slots in 2004

```
===========================================
GFLT Sub-trigger information ---- Run 49916
===========================================
From slot 0 to 31 id == vvvssstt, vvv:version, sss:slot, ttt:trigger type
id         sub-trigger                             pre-scale   taken  rate  |.0123|

FLT09: CALreg3*RMUI*vldgTRK*02i                         1    8659  2.72+1|###  |
FLT10: CALreg3*BMUI*vldgTRK*96i                         1    5509  1.77+1|###  |

FLT14: CAL_E*BMU*vldgTRK*96a(464)                       1    1744  6.02+0|##   |
FLT15: RCAL_E*RMU*vldgTRK*02i(464)                      1    4575  1.43+1|###  |

===========================================
GFLT Sub-trigger information ---- Run 47544
===========================================
From slot 0 to 31 id == vvvssstt, vvv:version, sss:slot, ttt:trigger type
id         sub-trigger                             pre-scale   taken  rate  |.0123|

FLT09: BACmu_r                                          -     649  1.97+2|#### |
FLT10: CALreg3*BRMUI*vldgTRK*02h                        1  122267  6.73+1|###  |

FLT14: CAL_E*BMU*vldgTRK*02h(464)                       1    8274  4.91+0|##   |
FLT15: RCAL_E*RMU*vldgTRK*02h(464)                      1   39071  2.10+1|###  |
```