

Systematics affecting Drell-Yan cross-section analysis

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Release: a summary

The Drell-Yan cross-section results were released in September 2023, in 3D (M , q_T , x_F), 2D and 1D, from the three targets: (NH₃+He), Al and W.

In the released results, for Al and W targets a systematic difference between two triggers was seen (taken as 5% for Al and 13% for W). Results were scaled accordingly and combined by simple average.

A mass-dependent systematic uncertainty related to the purity of DY process was considered. Purity factors were obtained from the cocktail fits to mass spectra, while systematic error was taken as the full difference to the simple method (difference from RD data to MC HMDY).

Two systematic uncertainties due to acceptance were considered: the HMDY MC sample size and the sensitivity of the cross section to a variation of trigger efficiencies by 1sigma.

A large variance of the DY cross section from period to period was observed.

In the released cross-section plots, the errors were added in quadrature and assumed fully correlated.

Progress after the release

Since both methods to extract purity have pros and cons, we decided to take the average of purity between the two methods, thus optimizing the systematic error related to purity. The purity affects mostly the low masses and W is more affected than ammonia. Due to the methods used (fit by sigmoid of the purity datapoints), a correlation in mass is introduced.

The systematic related to acceptance is $\delta\sigma(\text{syst-acc}) = \sqrt{(\delta\sigma(\text{syst-MCsize})^2 + \delta\sigma(\text{syst-time})^2}$
The first is uncorrelated, thus it is estimated that $\delta\sigma(\text{syst-acc})$ is 44% uncorrelated and 89% correlated.

[see Vincent talk January 2024](#)

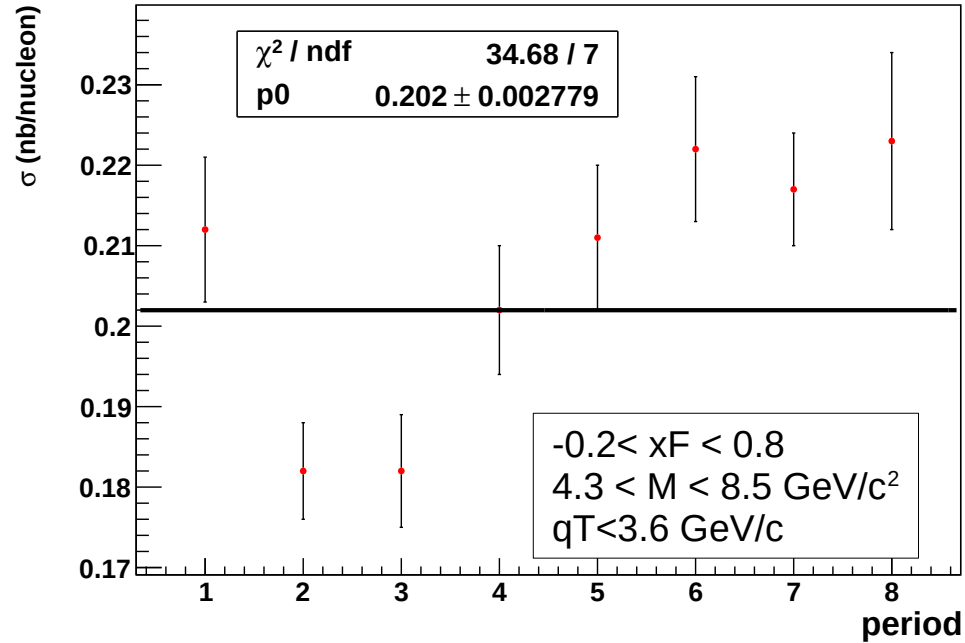
The variations of cross section per period suggest that the only time-dependent systematic, $\delta\sigma(\text{syst-time})$, might be under-estimated.

The acceptance correction was made globally, adding the 8 HMDY MC samples in same proportions as in real data. These proportions are now checked to be correct.

PT1 cross sections per period: compatibility (only statistical errors)

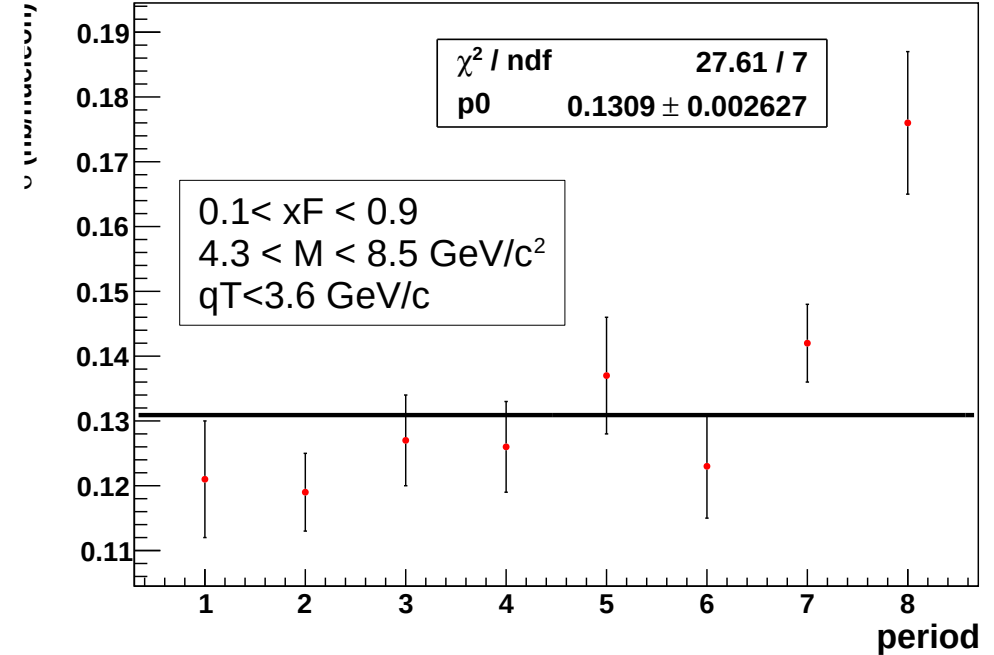
(See Vincent talk, slide 6)

PT1 LL 0D



From global analysis: $\sigma = 0.198 \pm 0.003$ nb/nucleon
Periods weighted mean (beam flux): $\sigma = 0.203 \pm 0.003$ nb/nucleon

PT1 LO 0D

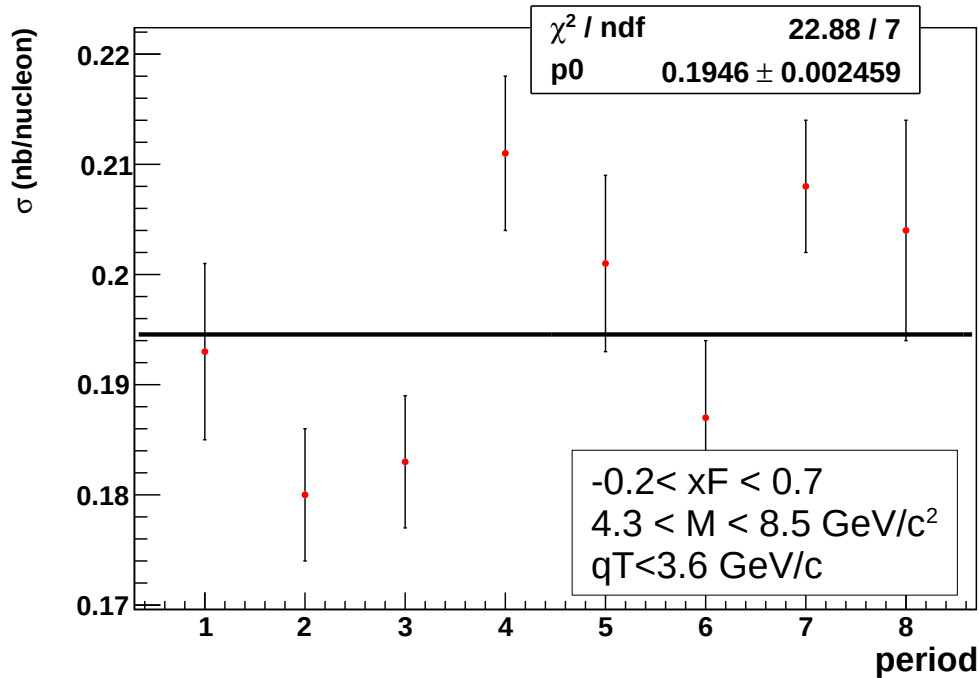


From global analysis: $\sigma = 0.129 \pm 0.003$ nb/nucleon
Periods weighted mean (beam flux): $\sigma = 0.131 \pm 0.003$ nb/nucleon

PT2 cross sections per period: compatibility (only statistical errors)

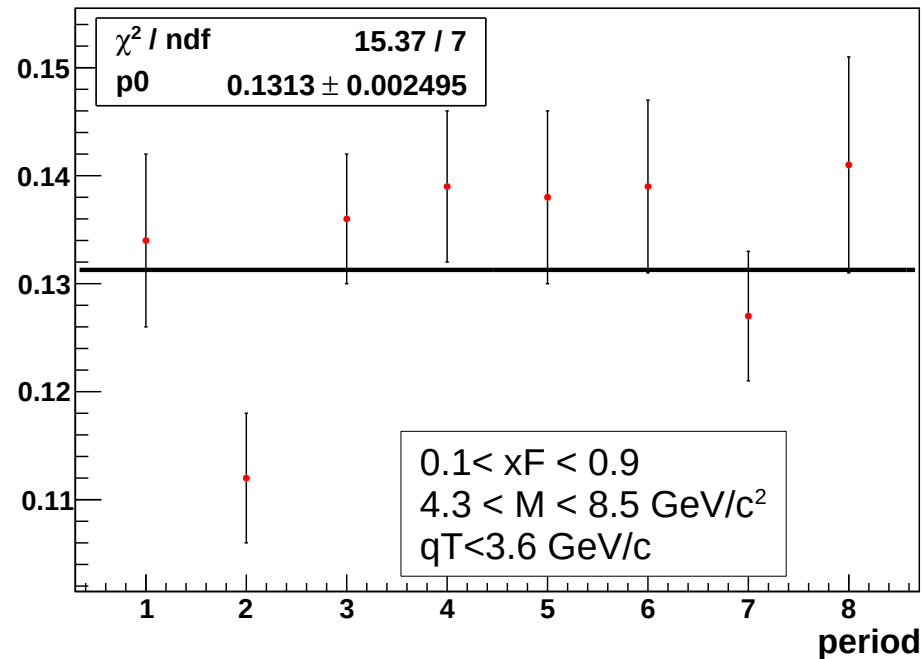
(See Vincent talk, slide 6)

PT2 LL 0D



From global analysis: $\sigma = 0.193 \pm 0.002$ nb/nucleon
 Periods weighted mean (beam flux): $\sigma = 0.195 \pm 0.002$ nb/nucleon

LO 0D

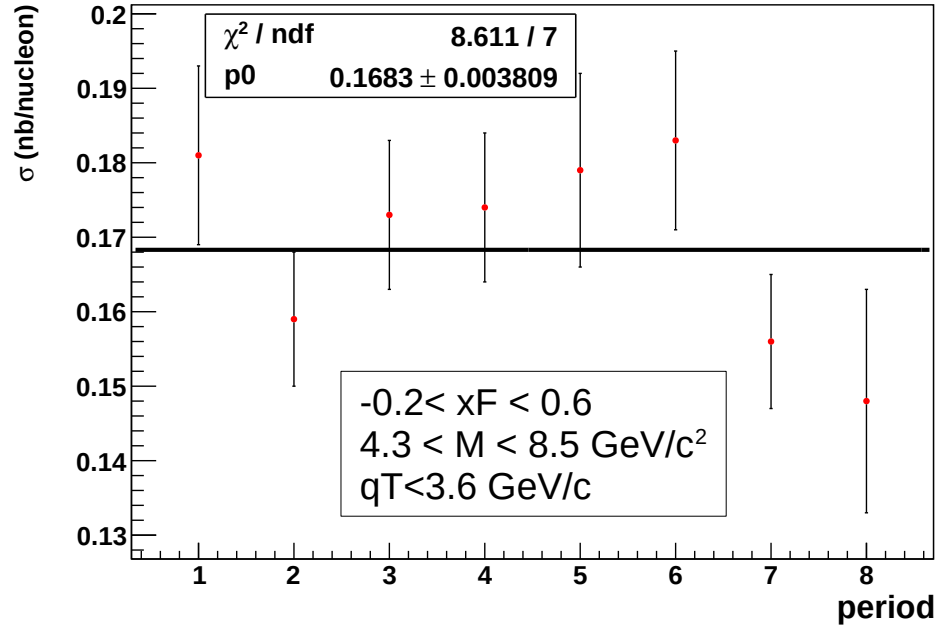


From global analysis: $\sigma = 0.129 \pm 0.002$ nb/nucleon
 Periods weighted mean (beam flux): $\sigma = 0.131 \pm 0.002$ nb/nucleon

Al cross sections per period: compatibility (only statistical errors)

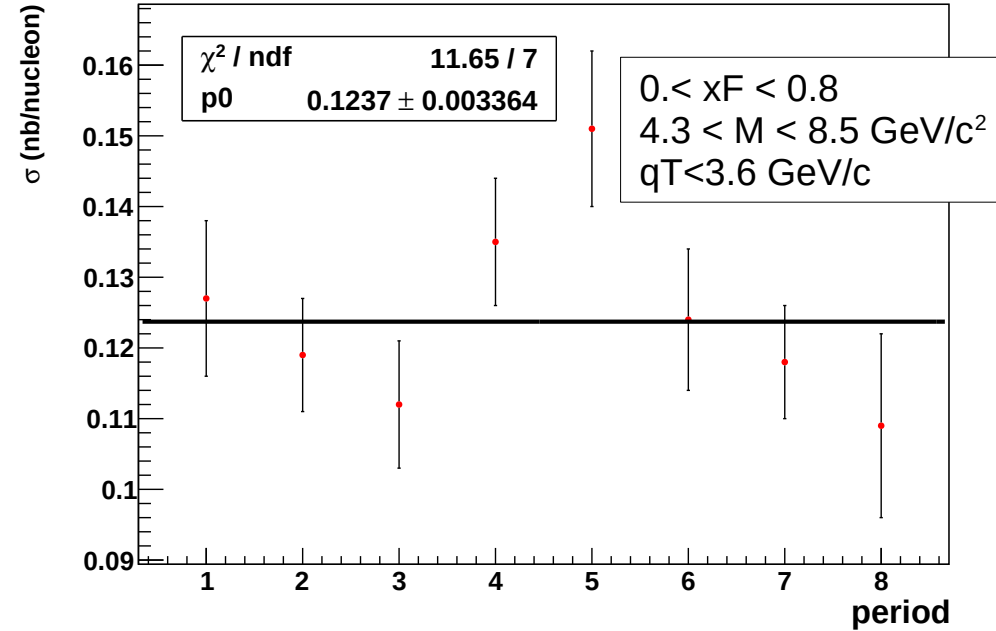
(See Vincent talk, slide 6)

Al LL 0D



From global analysis: $\sigma = 0.167 \pm 0.004 \text{ nb/nucleon}$
Periods weighted mean (beam flux): $\sigma = 0.168 \pm 0.004 \text{ nb/nucleon}$

Al LO 0D

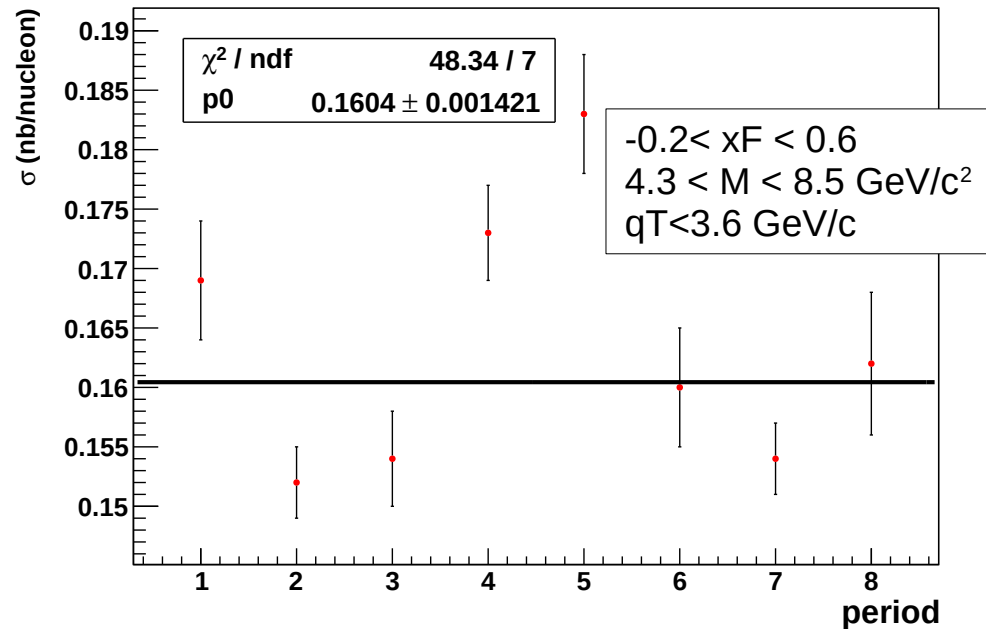


From global analysis: $\sigma = 0.122 \pm 0.003 \text{ nb/nucleon}$
Periods weighted mean (beam flux): $\sigma = 0.123 \pm 0.003 \text{ nb/nucleon}$

W cross sections per period: compatibility (only statistical errors)

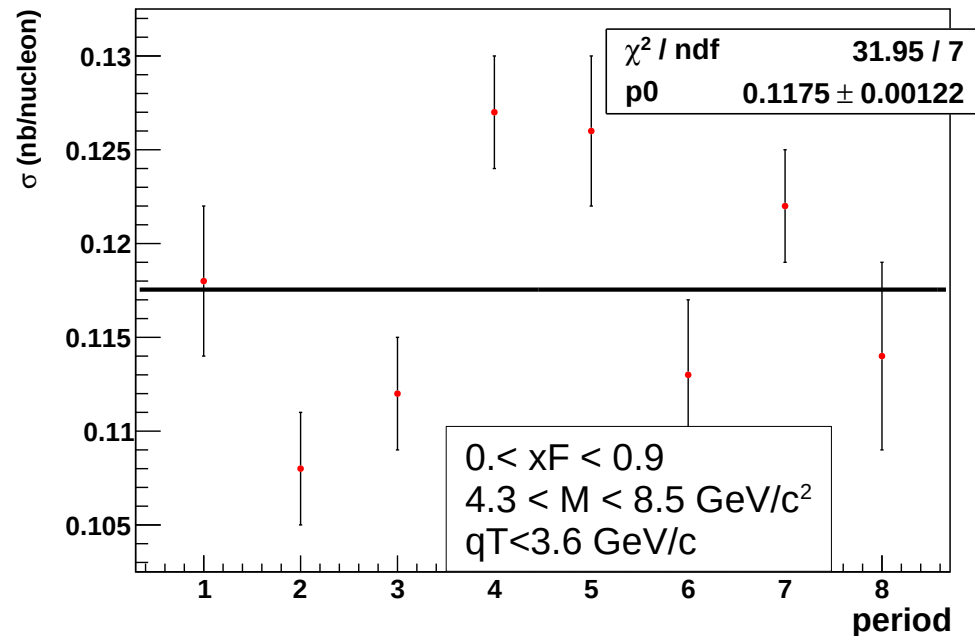
(See Vincent talk, slide 6)

W LL 0D



From global analysis: $\sigma = 0.161 \pm 0.001$ nb/nucleon
Periods weighted mean (beam flux): $\sigma = 0.162 \pm 0.001$ nb/nucleon

W LO 0D



From global analysis: $\sigma = 0.117 \pm 0.001$ nb/nucleon
Periods weighted mean (beam flux): $\sigma = 0.117 \pm 0.001$ nb/nucleon

Pulls of cross section per period in 3D analysis

The variations of cross section per period suggest a time-dependent systematic that can be evaluated from the pulls of cross section per period.

12 pulls are built, per target (PT1 & PT2, Al, W) and per trigger (LAS-LAS, LAS-OT) separately.

Each pull contains:

- 16 points for (NH3+He)
- 8 point for Al
- 8 points for W

Each point (x-section $\sigma \pm \delta\sigma(\text{stat})$, where $\delta\sigma(\text{stat})$ stands for the statistical error only) in the pull is calculated using the usual formula:

$$(\sigma_i - \bar{\sigma}) / \sqrt{(\delta\sigma_i^2 - \delta\bar{\sigma}^2)}$$

where $\bar{\sigma}$ is the average cross section luminosity-weighted

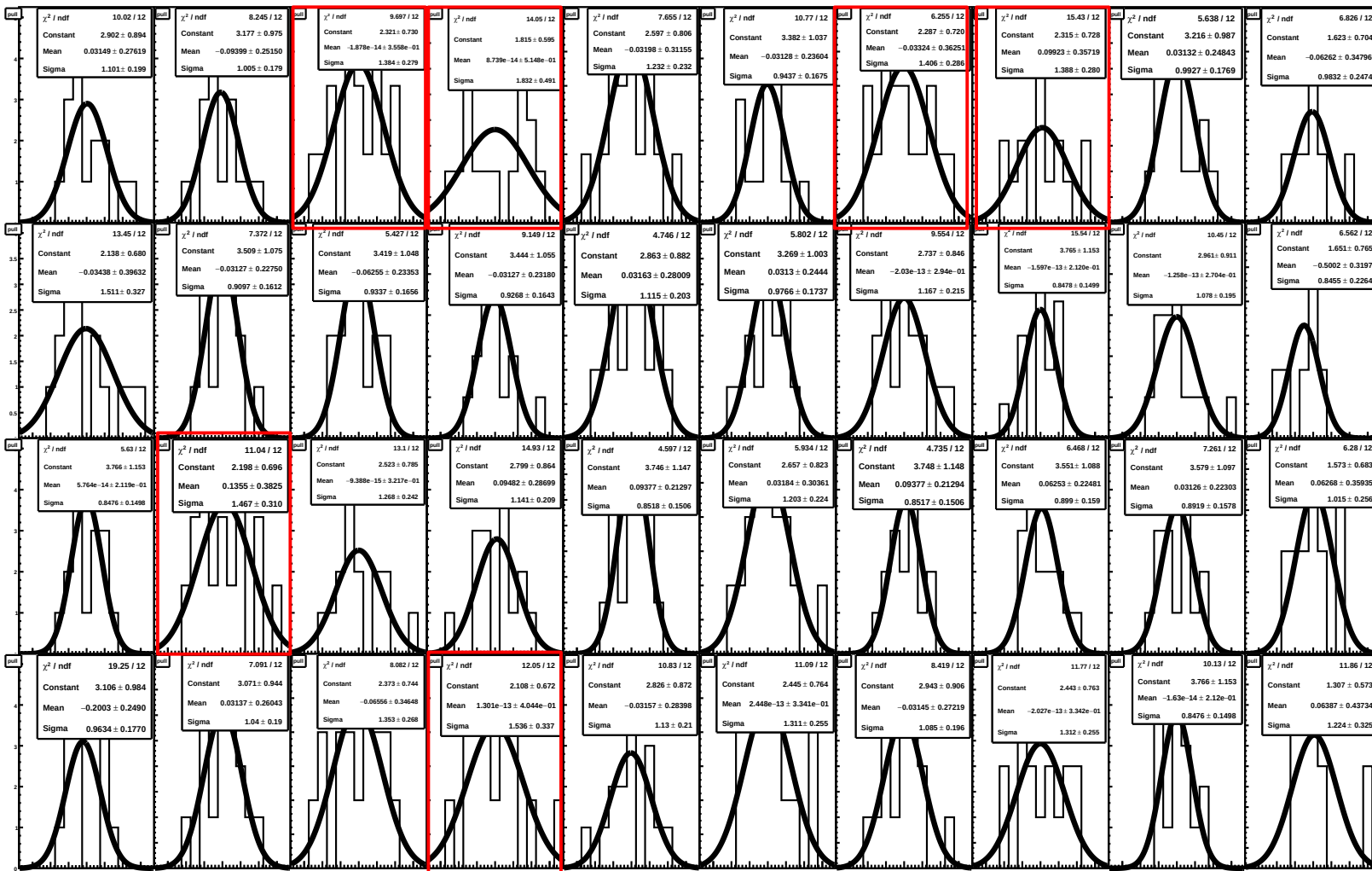
The ideal pull behaves as a normalized gaussian with mean value $\mu_{\text{pull}}=0$ and sigma $\sigma_{\text{pull}}=1$. The spectrometer behaviour varies with time, namely with detectors efficiency, trigger efficiency and global alignment that vary from period to period. The pull is used here to evaluate the compatibility of periods, by resulting in a systematic error in the cross section, due to acceptance variations

$$\delta\sigma(\text{syst-time}) / \delta\sigma(\text{stat}) = \sqrt{(\sigma_{\text{pull}}^2 - 1) + |\mu_{\text{pull}}|}$$

(M,qT,xF) bins

Systematic from “acceptance” variations over time: pulls

Example: (NH3+He) LAS-LAS, 3D, $4.3 < M < 4.7 \text{ GeV}/c^2$



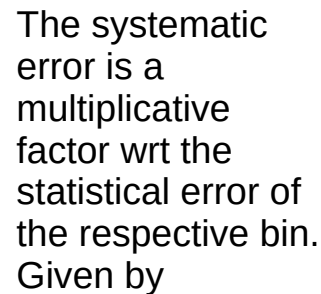
The systematic error is a multiplicative factor wrt the statistical error of the respective bin. Given by

$$\sqrt{(\sigma_{\text{pull}}^2 - 1) + |\mu|}$$

Bins with 0 x-section do not have 0 statistical error!

6/40 pulls slightly non-compatible with sigma=1
→ no systematics?

(qT,xF) bins



$$\sqrt{(\sigma_{\text{pull}}^2 - 1) + |\mu|}$$

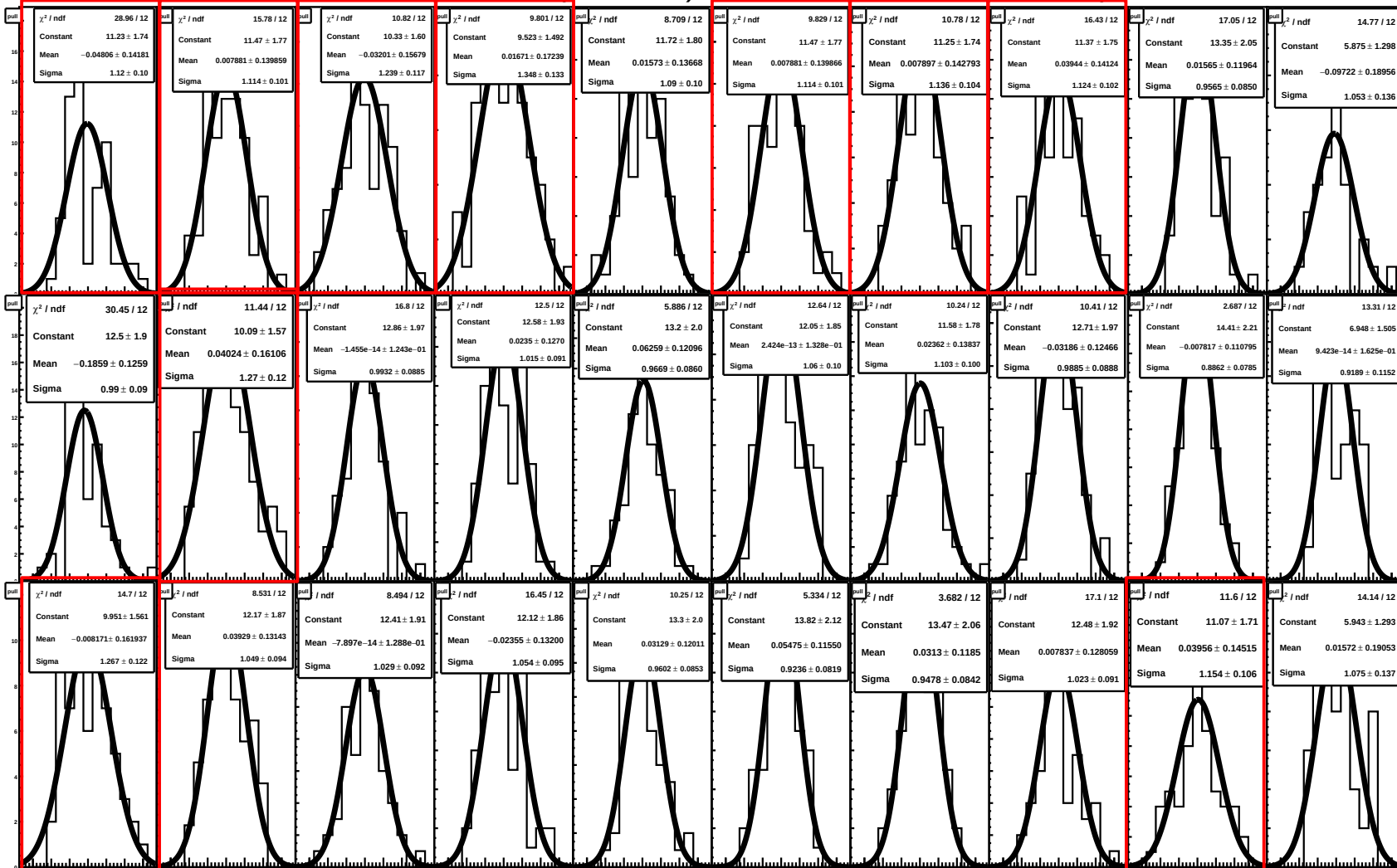
Bins with 0 x-section
do not have 0
statistical error!

Still not enough statistics

Systematic from “acceptance” variations over time: pulls

(M,xF) bins

(NH3+He) LAS-LAS, 3D: variations in qT



The systematic error is a multiplicative factor wrt the statistical error of the respective bin. Given by

$$\sqrt{(\sigma_{\text{pull}}^2 - 1) + |\mu|}$$

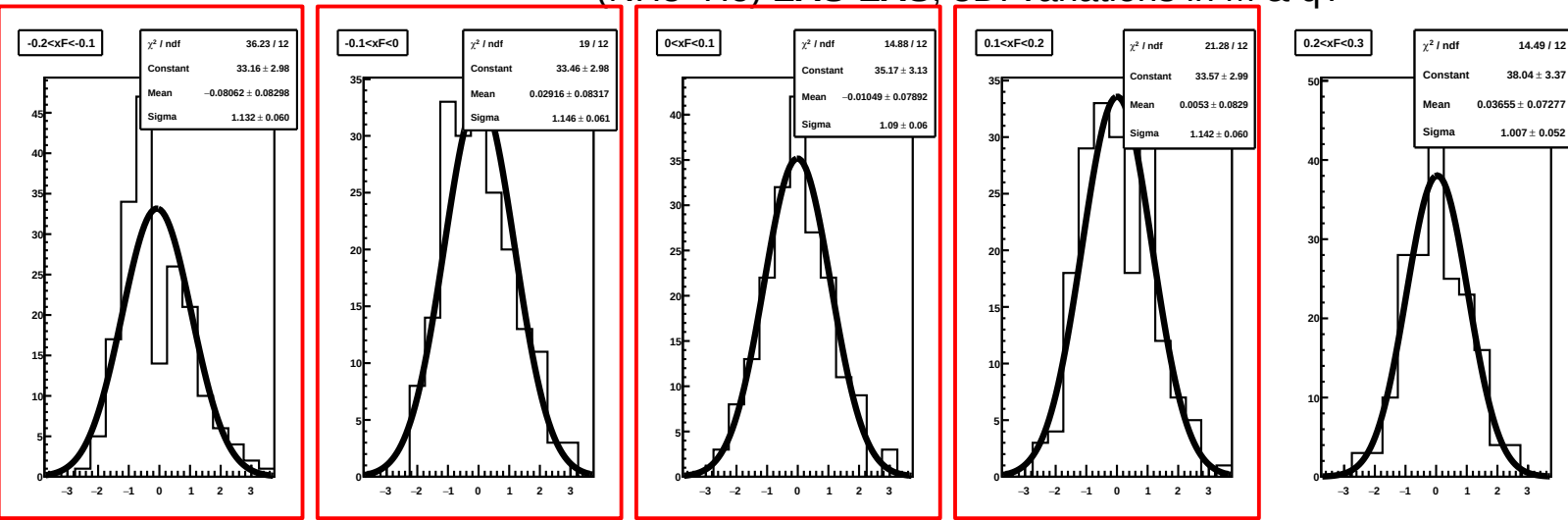
Bins with 0 x-section do not have 0 statistical error!

Still not enough statistics

Systematic from “acceptance” variations over time: pulls

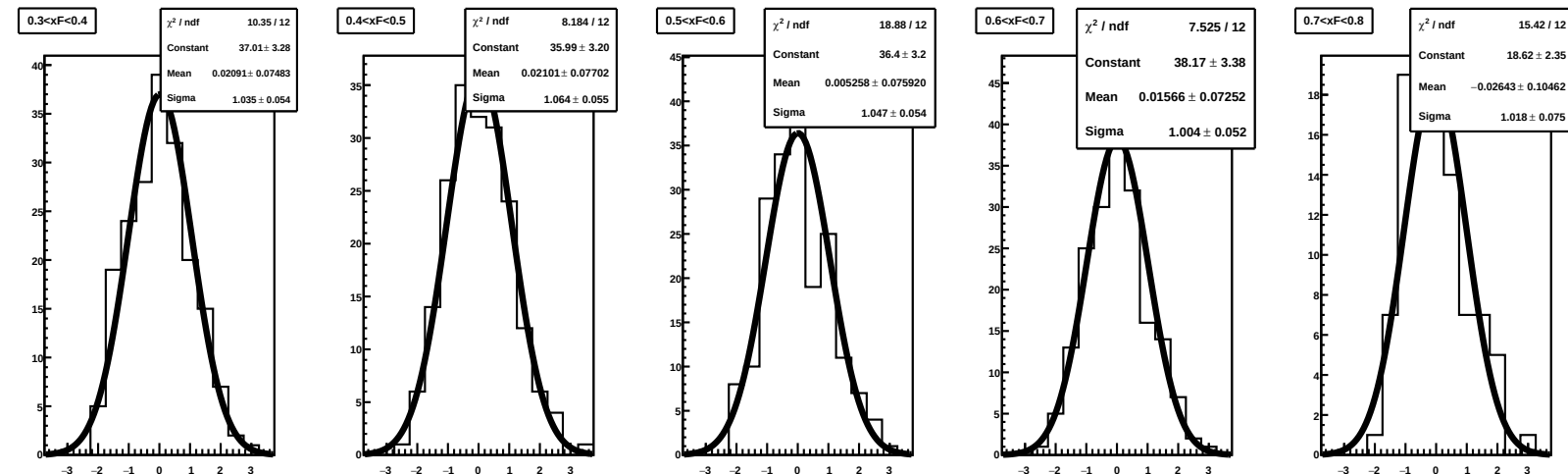
(NH3+He) **LAS-LAS**, 3D: variations in M & qT

xF bins



The systematic error is a multiplicative factor wrt the statistical error of the respective bin. Given by

$$\sqrt{(\sigma_{\text{pull}}^2 - 1) + |\mu|}$$

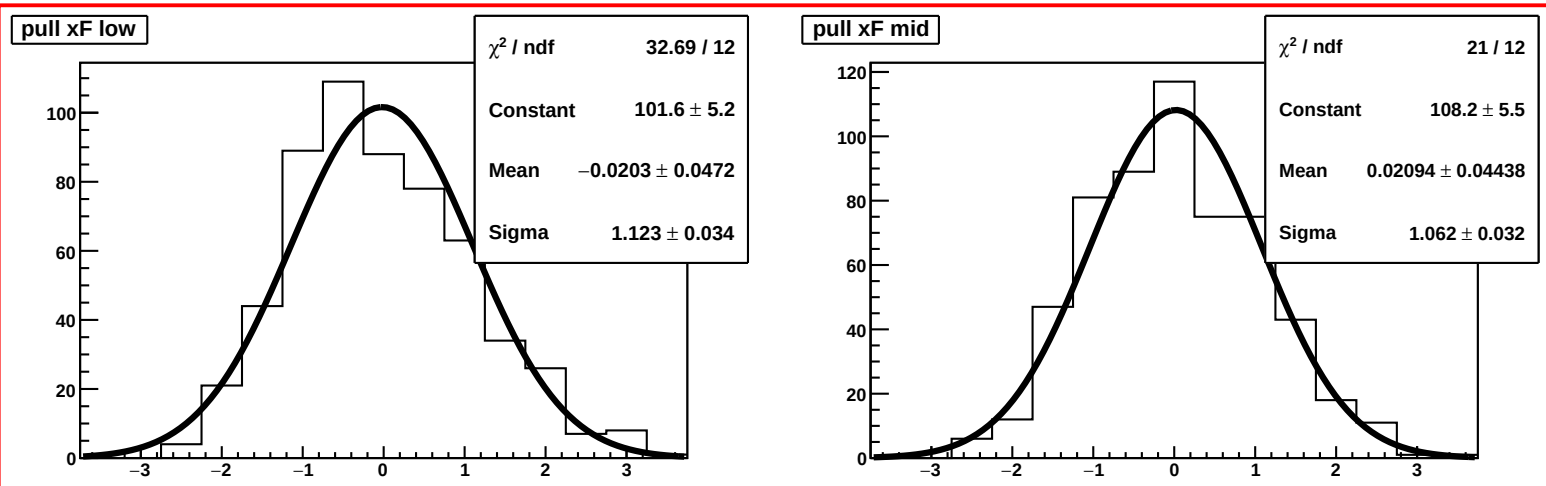


Bins with 0 x-section do not have 0 statistical error!

$\delta\sigma(\text{syst-time})$ seems to depend on xF

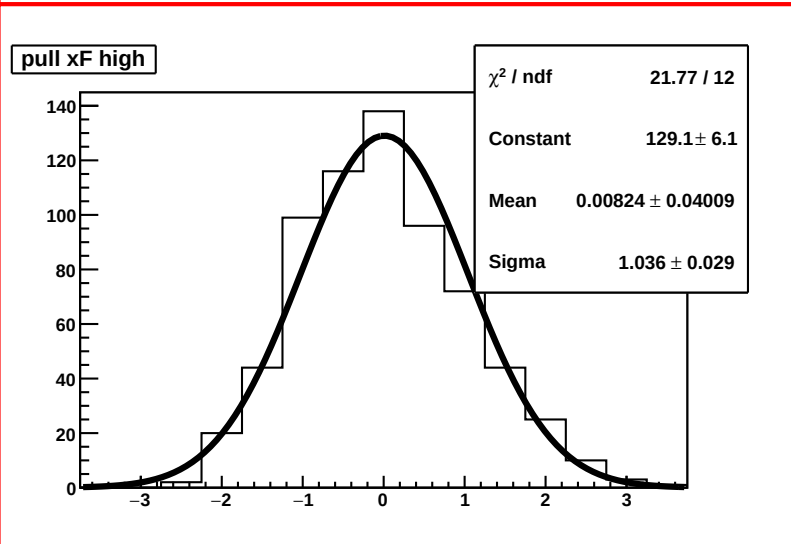
xF bins

Systematic from “acceptance” variations over time: pulls (NH3+He) **LAS-LAS**, 3D: variations in M & qT



The systematic error is a multiplicative factor wrt the statistical error of the respective bin. Given by

$$\sqrt{(\sigma_{\text{pull}}^2 - 1) + |\mu|}$$



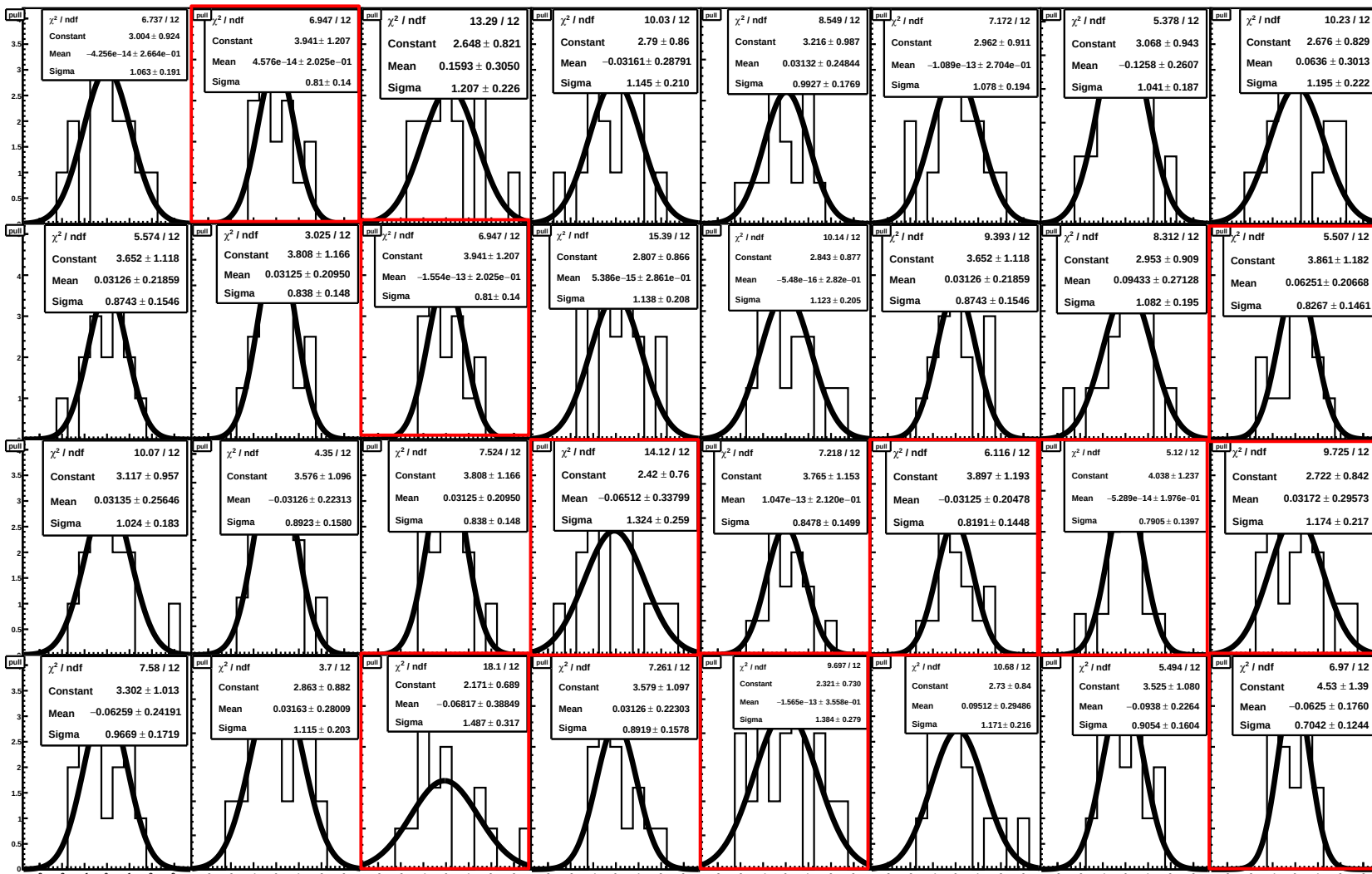
LAS-LAS:
 $\delta\sigma(\text{syst-time})$
decreases with xF

Bins with 0 x-section do not have 0 statistical error!

(M,qT,xF) bins

Systematic from “acceptance” variations over time: pulls

Example: (NH3+He) LAS-OT, 3D, $4.3 < M < 4.7 \text{ GeV}/c^2$



The systematic error is a multiplicative factor wrt the statistical error of the respective bin. Given by

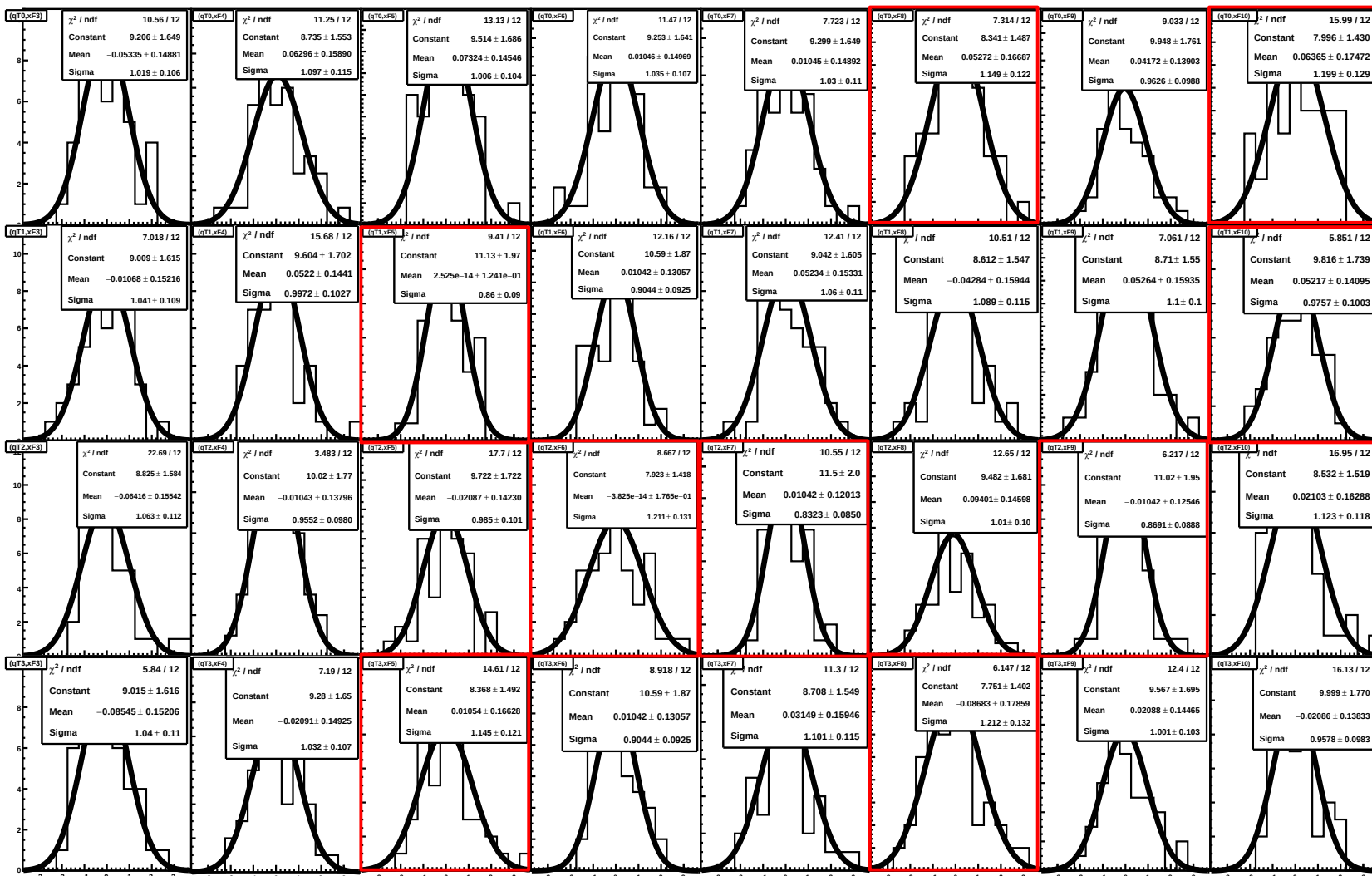
$$\sqrt{(\sigma_{\text{pull}}^2 - 1) + |\mu|}$$

Bins with 0 x-section do not have 0 statistical error!

10/40 pulls slightly non-compatible with sigma=1
→ no systematics?

(qT,xF) bins

Systematic from “acceptance” variations over time: pulls (NH3+He) LAS-OT. 3D variations in mass



The systematic error is a multiplicative factor wrt the statistical error of the respective bin. Given by

$$\sqrt{(\sigma_{\text{pull}}^2 - 1) + |\mu|}$$

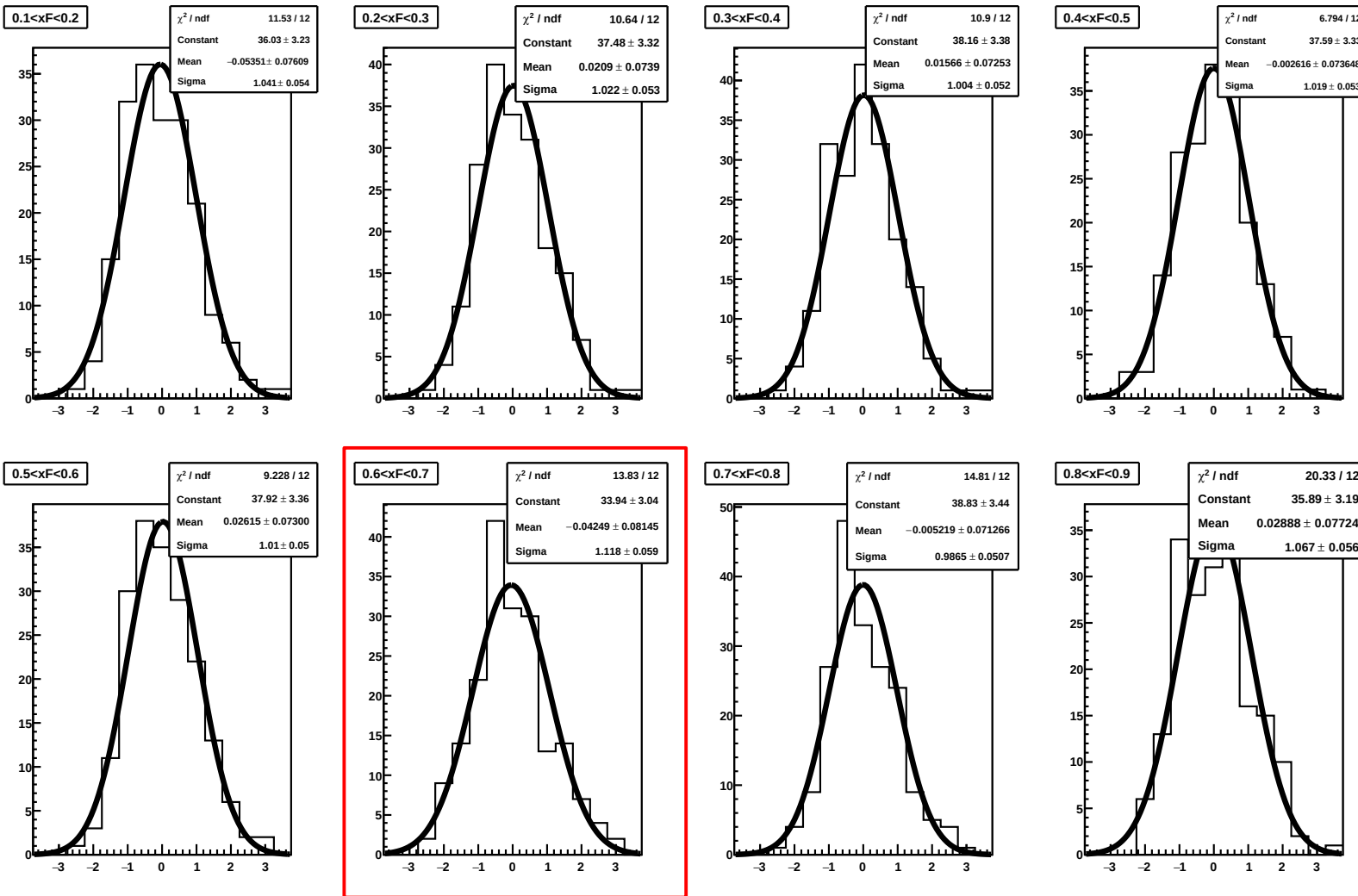
Bins with 0 x-section do not have 0 statistical error!

10/40 pulls slightly non-compatible with sigma=1
→ no systematics?

Systematic from “acceptance” variations over time: pulls

(NH₃+He) **LAS-OT**, 3D: variations in M & qT

xF bins



The systematic error is a multiplicative factor wrt the statistical error of the respective bin. Given by

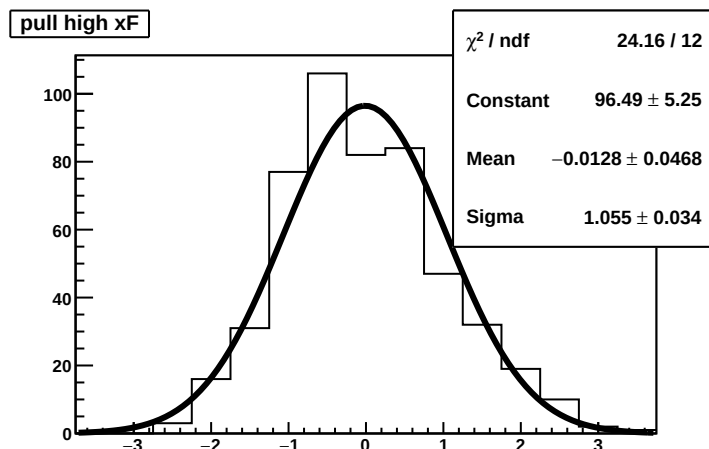
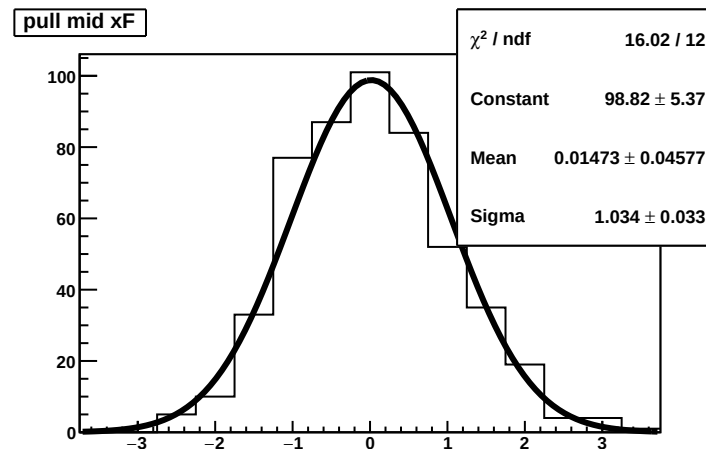
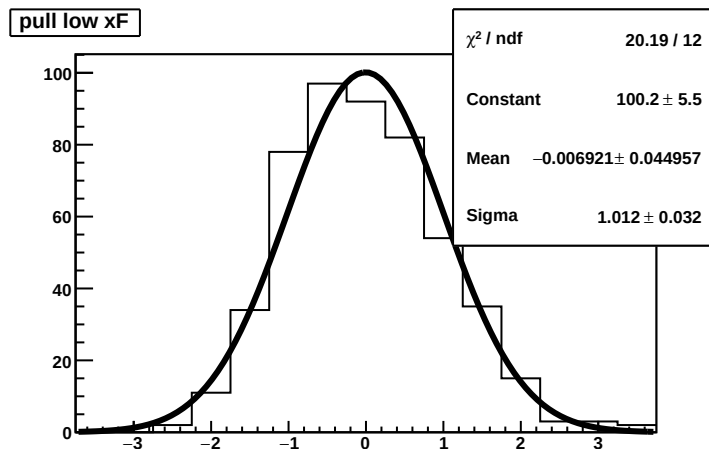
$$\sqrt{(\sigma_{\text{pull}}^2 - 1) + |\mu|}$$

Bins with 0 x-section do not have 0 statistical error!

10/40 pulls slightly non-compatible with sigma=1
→ **no systematics?**

xF bins

Systematic from “acceptance” variations over time: pulls (NH3+He) **LAS-OT**, 3D: variations in M & qT



LAS-OT:
 $\delta\sigma(\text{syst-time})$
increases with xF

The systematic error is a multiplicative factor wrt the statistical error of the respective bin. Given by

$$\sqrt{(\sigma_{\text{pull}}^2 - 1) + |\mu|}$$

Bins with 0 x-section do not have 0 statistical error!

Systematic from “acceptance” variations over time: fit to pulls
 $\delta\sigma(\text{syst-time})$

(NH3+He) LAS-LAS

(NH3+H3) LAS-LAS	mean[608]	sigma[608]	Syst(acc[608])
-0.2 < xF < 0.	-0.02±0.05	1.12±0.03	0.53 * $\delta\sigma(\text{stat})$
0. < xF < 0.3	0.02±0.04	1.06±0.03	0.38 * $\delta\sigma(\text{stat})$
0.3 < xF < 0.8	0.01±0.04	1.04±0.03	0.28 * $\delta\sigma(\text{stat})$

(NH3+He) LAS-OT

(NH3+H3) LAS-LAS	mean[512]	sigma[512]	Syst(acc[512])
0.1 < xF < 0.4	-0.01±0.04	1.01±0.03	0.* $\delta\sigma(\text{stat})$
0.4 < xF < 0.6	0.01±0.04	1.03±0.03	0.28 * $\delta\sigma(\text{stat})$
0.6 < xF < 0.9	-0.01±0.05	1.05±0.03	0.35 * $\delta\sigma(\text{stat})$

Systematic from “acceptance” variations over time: fit to pulls
 $\delta\sigma(\text{syst-time})$

AI LAS-LAS

AI LAS-LAS	mean[256]	sigma[256]	Syst(acc[256])
$-0.2 < x_F < 0.1$	0.01 ± 0.06	0.98 ± 0.04	$0. * \delta\sigma(\text{stat})$
$0.1 < x_F < 0.3$	-0.00 ± 0.07	1.00 ± 0.05	$0. * \delta\sigma(\text{stat})$
$0.3 < x_F < 0.6$	-0.06 ± 0.06	0.97 ± 0.04	$0. * \delta\sigma(\text{stat})$

W LAS - LAS

W LAS-LAS	mean[288]	sigma[288]	Syst(acc[288])
$-0.2 < x_F < 0.1$	0.02 ± 0.07	1.12 ± 0.05	$0.51 * \delta\sigma(\text{stat})$
$0.1 < x_F < 0.4$	0.15 ± 0.09	1.18 ± 0.06	$0.69 * \delta\sigma(\text{stat})$
$0.4 < x_F < 0.6$	-0.02 ± 0.06	1.09 ± 0.05	$0.46 * \delta\sigma(\text{stat})$

AI LAS-OT

AI LAS-OT	mean[256]	sigma[256]	Syst(acc[256])
$0 < x_F < 0.2$	-0.03 ± 0.06	1.00 ± 0.05	$0. * \delta\sigma(\text{stat})$
$0.2 < x_F < 0.5$	0.02 ± 0.06	1.07 ± 0.05	$0.39 * \delta\sigma(\text{stat})$
$0.5 < x_F < 0.8$	0.01 ± 0.06	1.04 ± 0.04	$0. * \delta\sigma(\text{stat})$

W LAS - OT

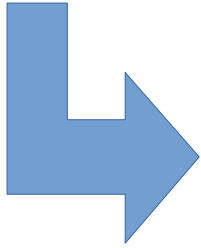
W LAS-OT	mean[288]	sigma[288]	Syst(acc[288])
$0 < x_F < 0.3$	-0.02 ± 0.06	1.09 ± 0.05	$0.45 * \delta\sigma(\text{stat})$
$0.3 < x_F < 0.6$	0.01 ± 0.07	1.14 ± 0.05	$0.55 * \delta\sigma(\text{stat})$
$0.6 < x_F < 0.9$	-0.02 ± 0.07	1.15 ± 0.05	$0.60 * \delta\sigma(\text{stat})$



Not enough statistics for extracting
a systematic from this.

3D Drell-Yan cross sections

Another conclusion that can be drawn from the period-dependence of cross sections is that it is more correct to evaluate them per period



For each period, use the acceptance of that period, instead of the global (combined) acceptance.

Afterwards, combine the cross sections from periods using a weighted-average:

- Weight by the beam flux in each period

x-sections: **global acceptance** versus period-by-period, using **beam flux** as weight

PT1 LAS-LAS

(only statistical errors are shown)

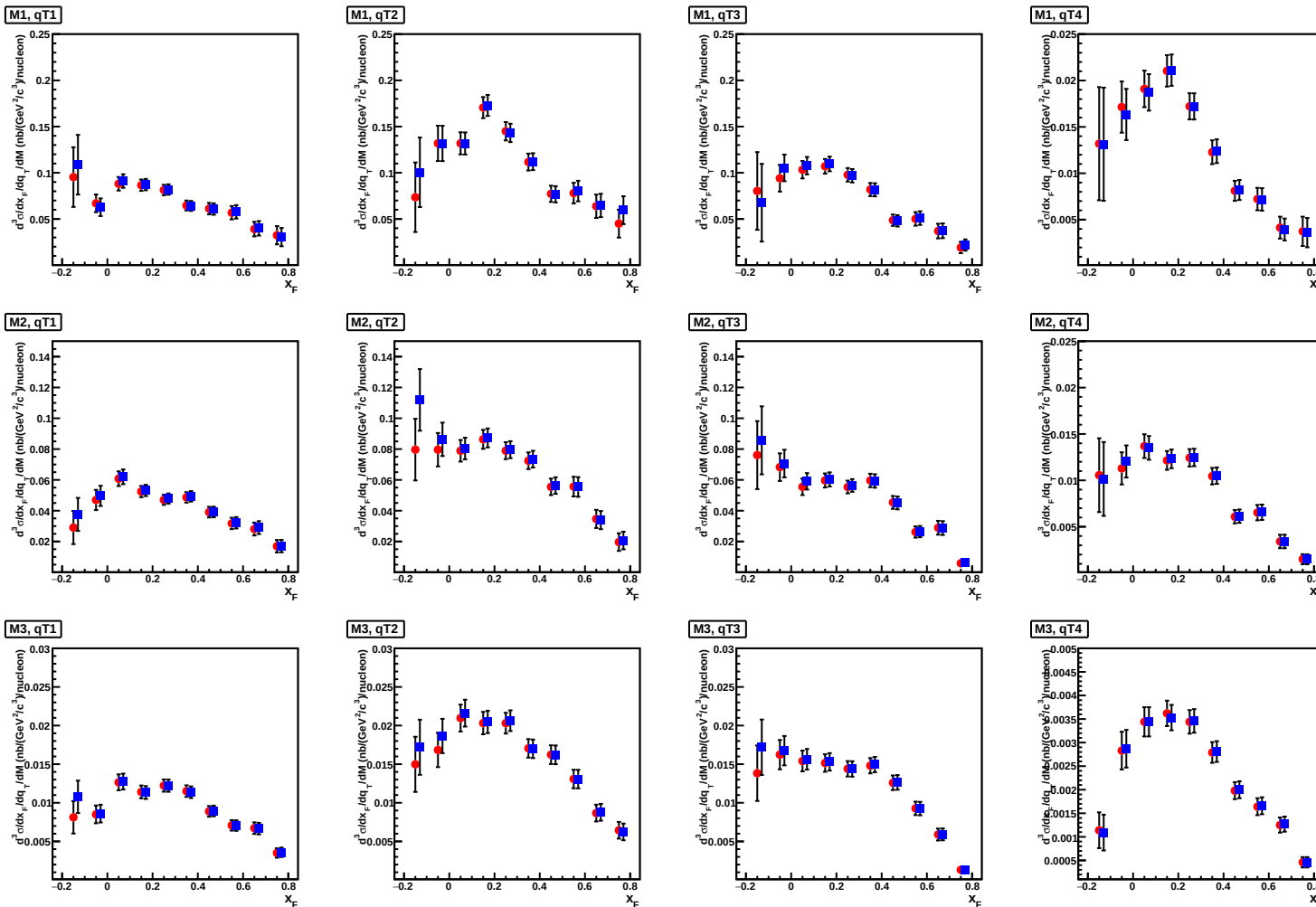
$$\sigma \pm \delta\sigma$$

Larger differences of x-section are visible at the low x_F .

For the x-section with period-by-period acceptance, the weighted-average of x-sections can be done using the **beam flux as weight**:

$$\sigma_{\text{mean}} = \sum(\sigma_i * \mathcal{L}_i) / \mathcal{L}_{\text{tot}}$$

$$\delta\sigma_{\text{mean}} = 1/\mathcal{L}_{\text{tot}} * \sqrt{(\sum \delta\sigma_i^2 * \mathcal{L}_i^2)}$$



x-sections: **global acceptance** versus period-by period, using **beam flux** as weight

PT2 LAS-LAS

(only statistical errors are shown)

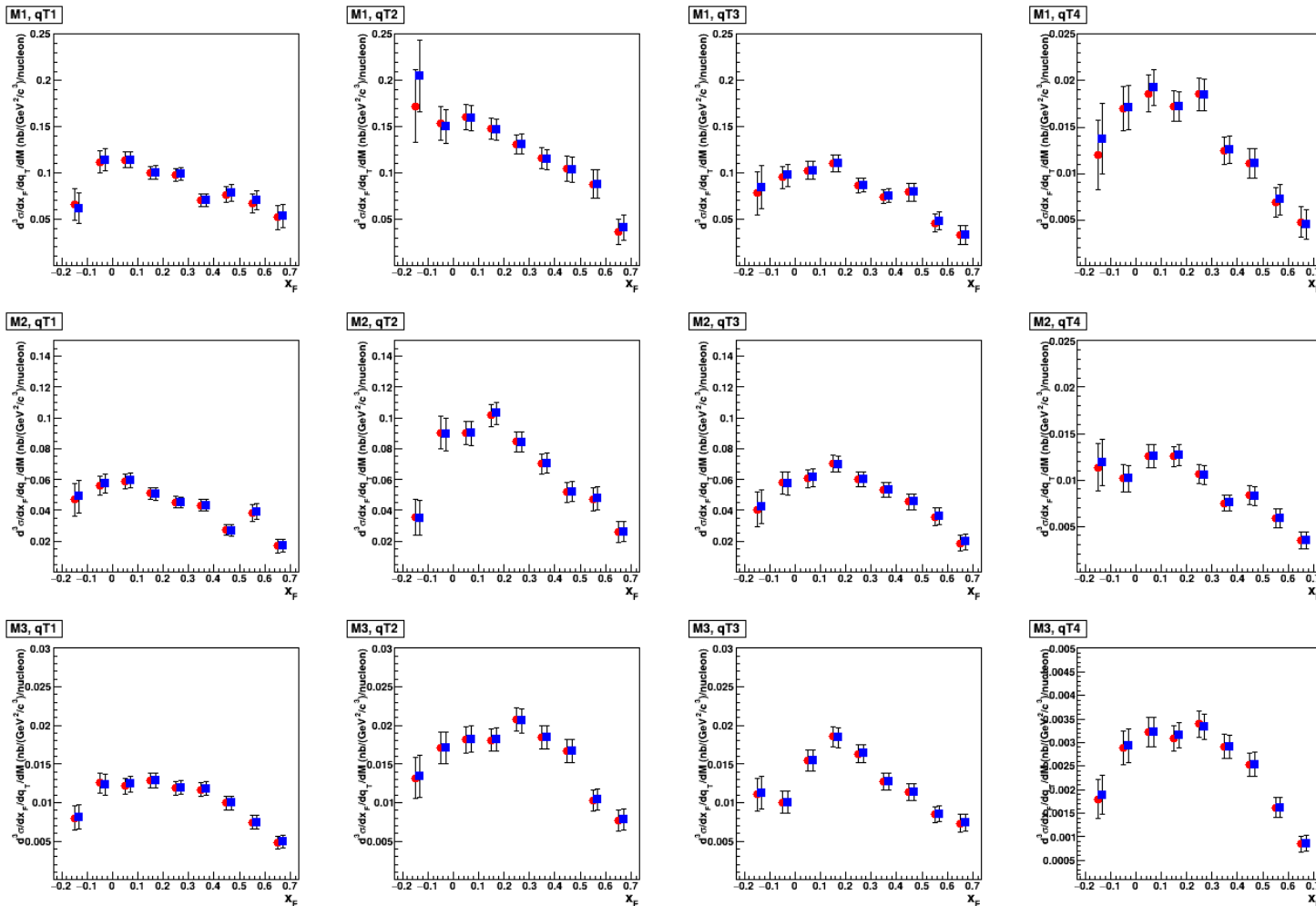
$$\sigma \pm \delta\sigma$$

The two methods show very small differences.

For the x-section with period-by-period acceptance, the weighted-average of x-sections can be done using the **beam flux as weight**:

$$\sigma_{\text{mean}} = \sum (\sigma_i * \mathcal{L}_i) / \mathcal{L}_{\text{tot}}$$

$$\delta\sigma_{\text{mean}} = 1/\mathcal{L}_{\text{tot}} * \sqrt{(\sum \delta\sigma_i^2 * \mathcal{L}_i^2)}$$



x-sections: **global acceptance** versus period-by-period, using **beam flux** as weight

AI LAS-LAS

(only statistical errors are shown)

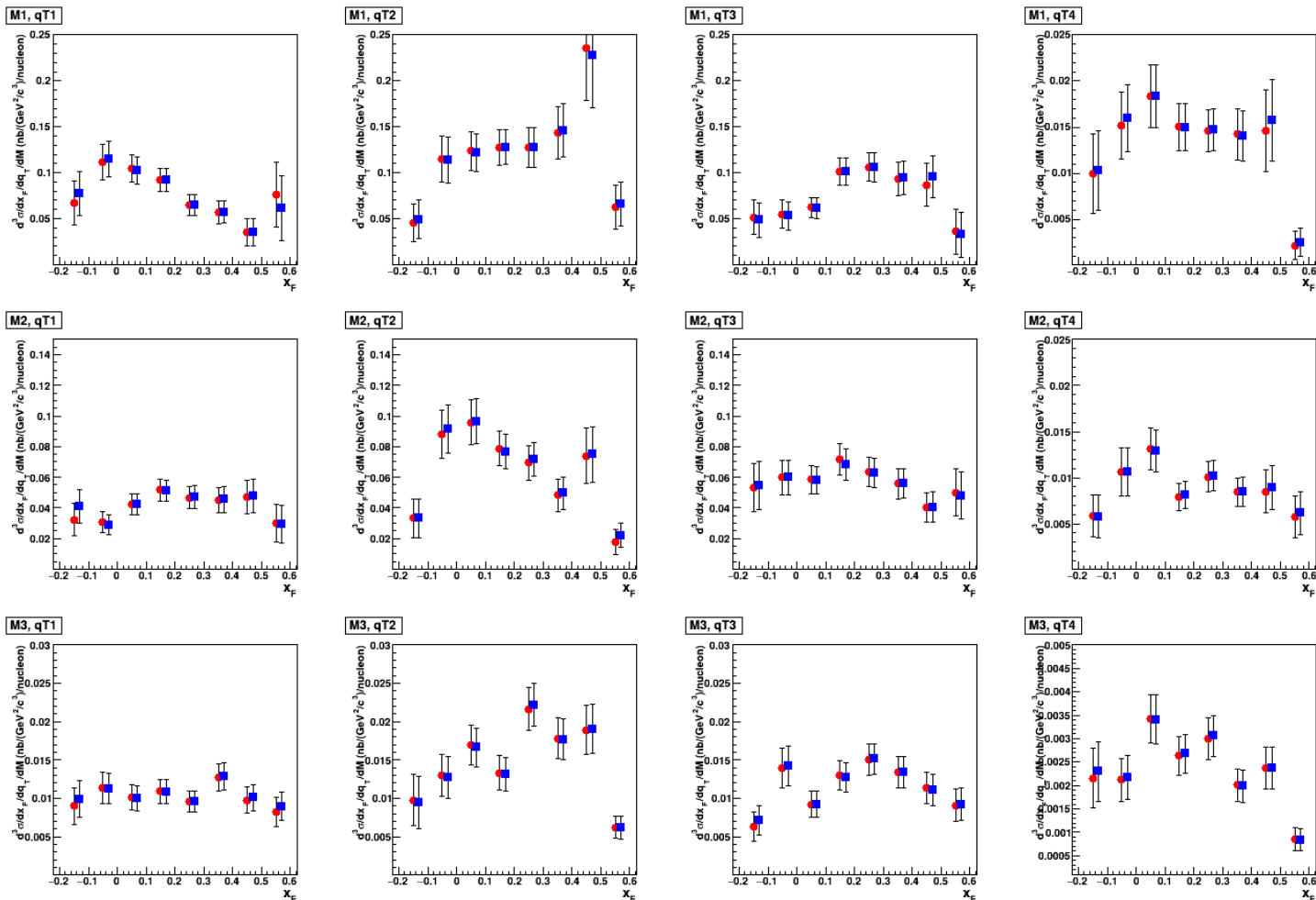
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x-sections: **global acceptance** versus period-by-period, using **beam flux** as weight

W LAS-LAS

(only statistical errors are shown)

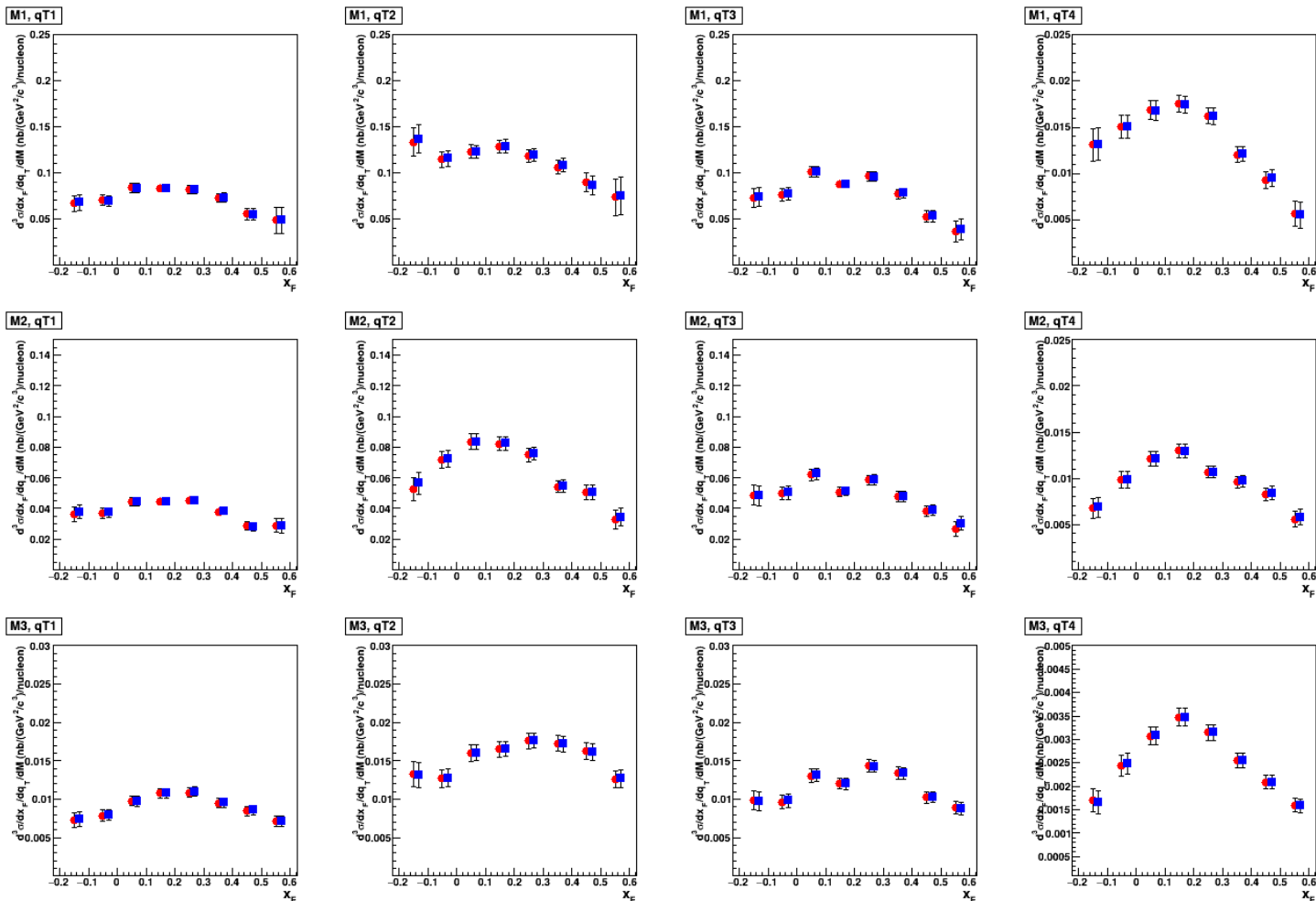
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$$\delta\sigma_{\text{mean}} = 1/\mathcal{L}_{\text{tot}} * \sqrt{(\sum \delta\sigma_i^2 * \mathcal{L}_i^2)}$$



x-sections: global acceptance versus period-by-period, using beam flux as weight

PT1 LAS-OT

(only statistical errors are shown)

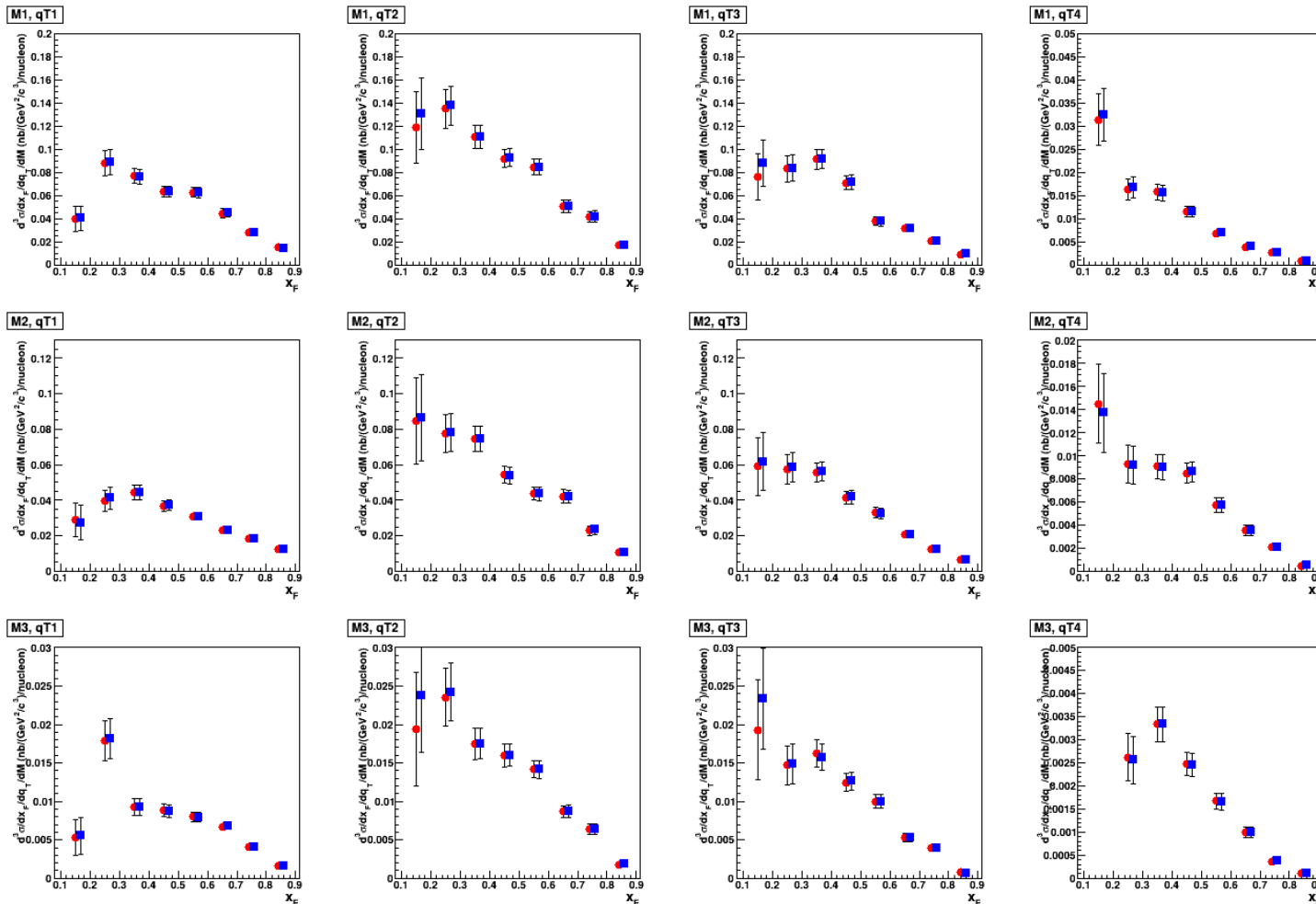
$$\sigma \pm \delta\sigma$$

Larger differences of x-section are visible at the low x_F .

For the x-section with period-by-period acceptance, the weighted-average of x-sections can be done using the beam flux as weight:

$$\sigma_{\text{mean}} = (\sum \sigma_i * \mathcal{L}_i) / \mathcal{L}_{\text{tot}}$$

$$\delta\sigma_{\text{mean}} = 1/\mathcal{L}_{\text{tot}} * \sqrt{(\sum \delta\sigma_i^2 * \mathcal{L}_i^2)}$$



x-sections: **global acceptance** versus periods, using **beam flux** as weight

PT2 LAS-OT

(only statistical errors are shown)

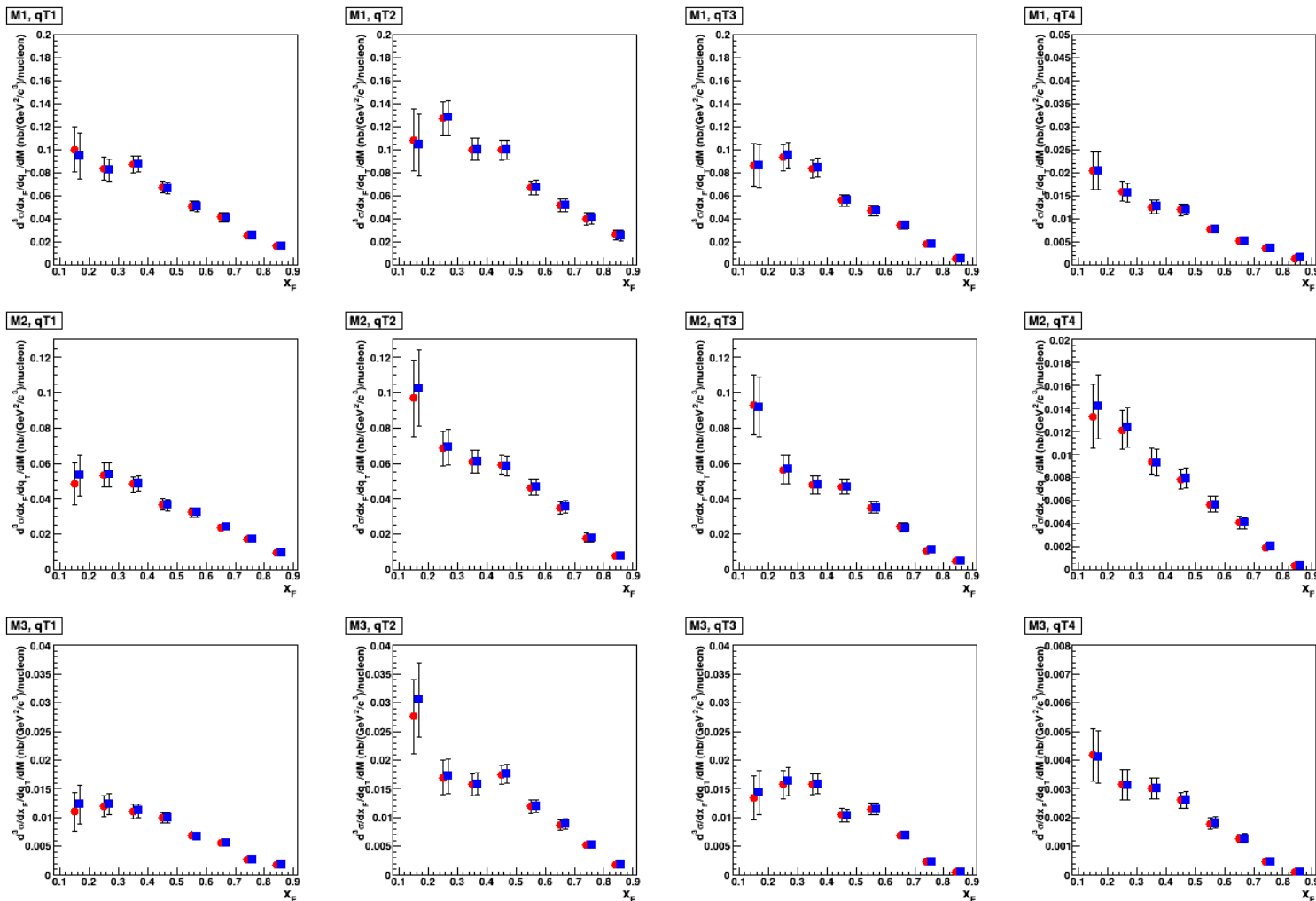
$$\sigma \pm \delta\sigma$$

The two methods show very small differences.

For the x-section with period-by-period acceptance, the weighted-average of x-sections can be done using the **beam flux as weight**:

$$\sigma_{\text{mean}} = \sum(\sigma_i * \mathcal{L}_i) / \mathcal{L}_{\text{tot}}$$

$$\delta\sigma_{\text{mean}} = 1/\mathcal{L}_{\text{tot}} * \sqrt{(\sum \delta\sigma_i^2 * \mathcal{L}_i^2)}$$

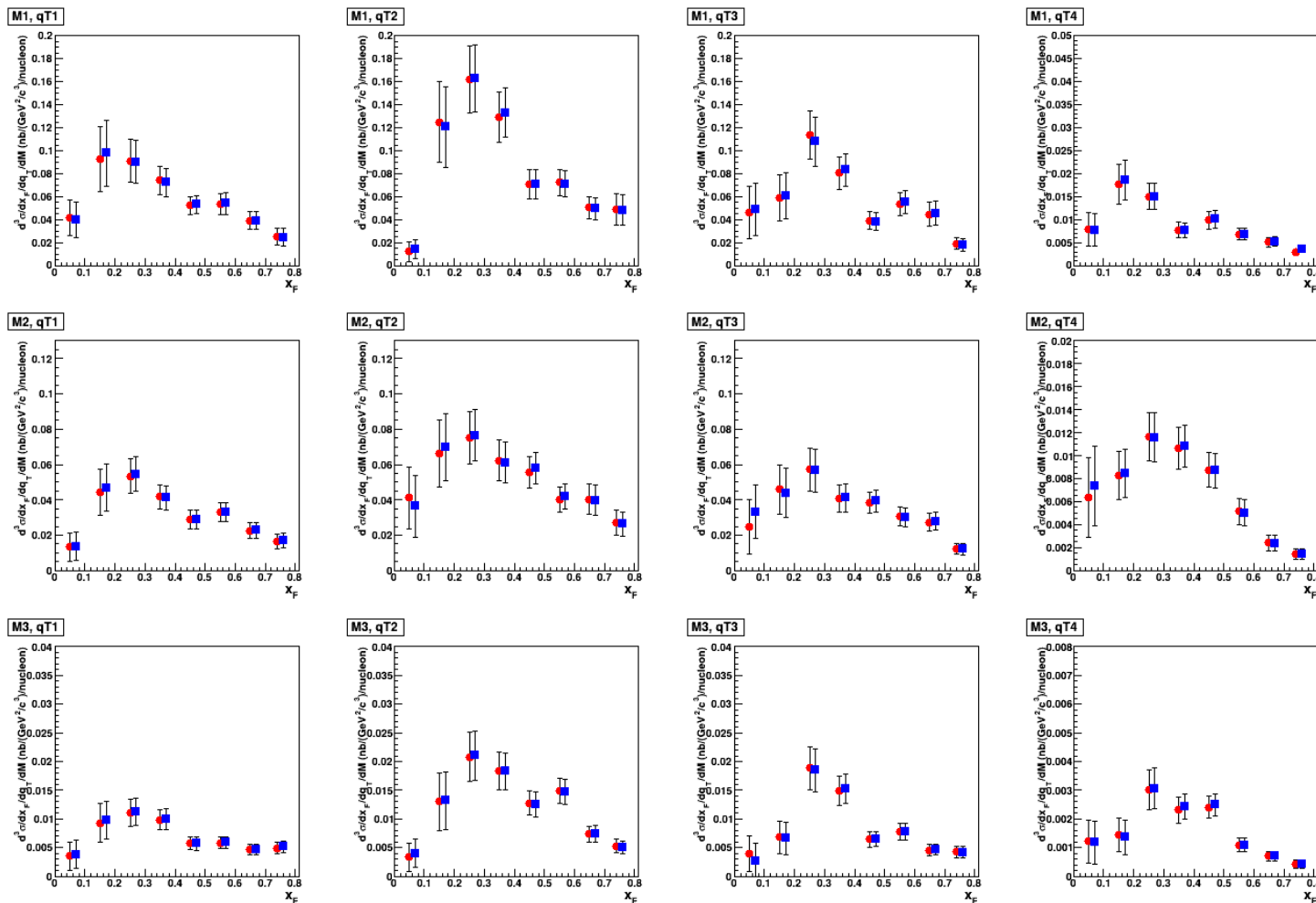


x-sections: **global acceptance** versus period-by-period, using **beam flux** as weight

AI LAS-OT

(only statistical errors are shown)

$\sigma \pm \delta\sigma$



For the x-section with period-by-period acceptance, the weighted-average of x-sections can be done using the **beam flux as weight**:

$$\sigma_{\text{mean}} = (\sum \sigma_i * \mathcal{L}_i) / \mathcal{L}_{\text{tot}}$$

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x-sections: **global acceptance** versus period-by-period, using **beam flux** as weight

W LAS-OT

(only statistical errors are shown)

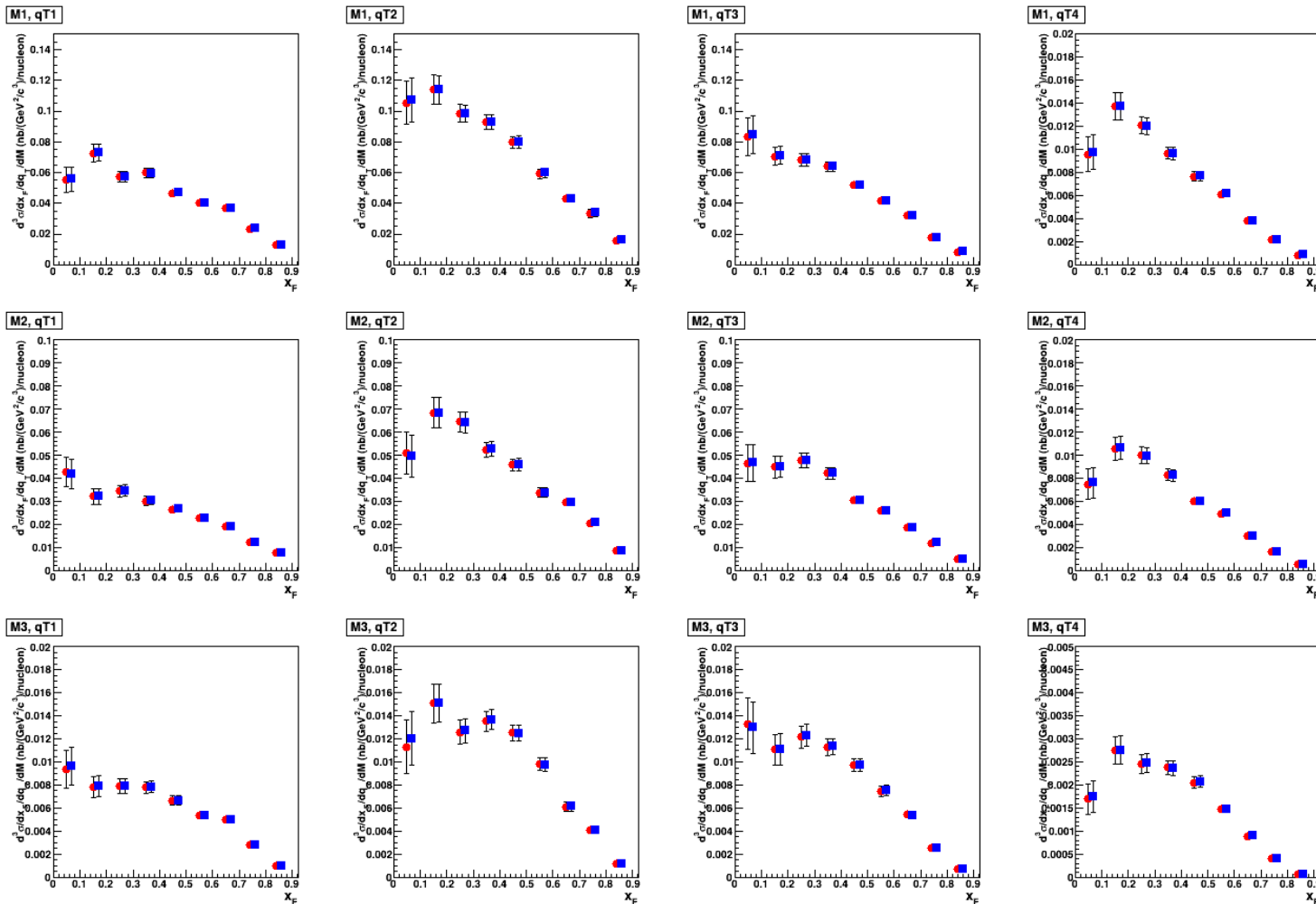
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For the x-section with period-by-period acceptance, the weighted-average of x-sections can be done using the **beam flux as weight**:

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$$\delta\sigma_{\text{mean}} = 1/\mathcal{L}_{\text{tot}} * \sqrt{(\sum \delta\sigma_i^2 * \mathcal{L}_i^2)}$$



There are only small differences between the three methods. But to have each period corrected by its own acceptance (MC with trigger efficiencies per period, beam file per period and detectors efficiency of first or second half of the Run) is more correct. When combining the periods, weighting by the statistical error leads to systematically under-estimated cross sections (due to double counting or to canceling of efficiencies effect?). The best method is the luminosity-weighting, which we propose to adopt as standard.

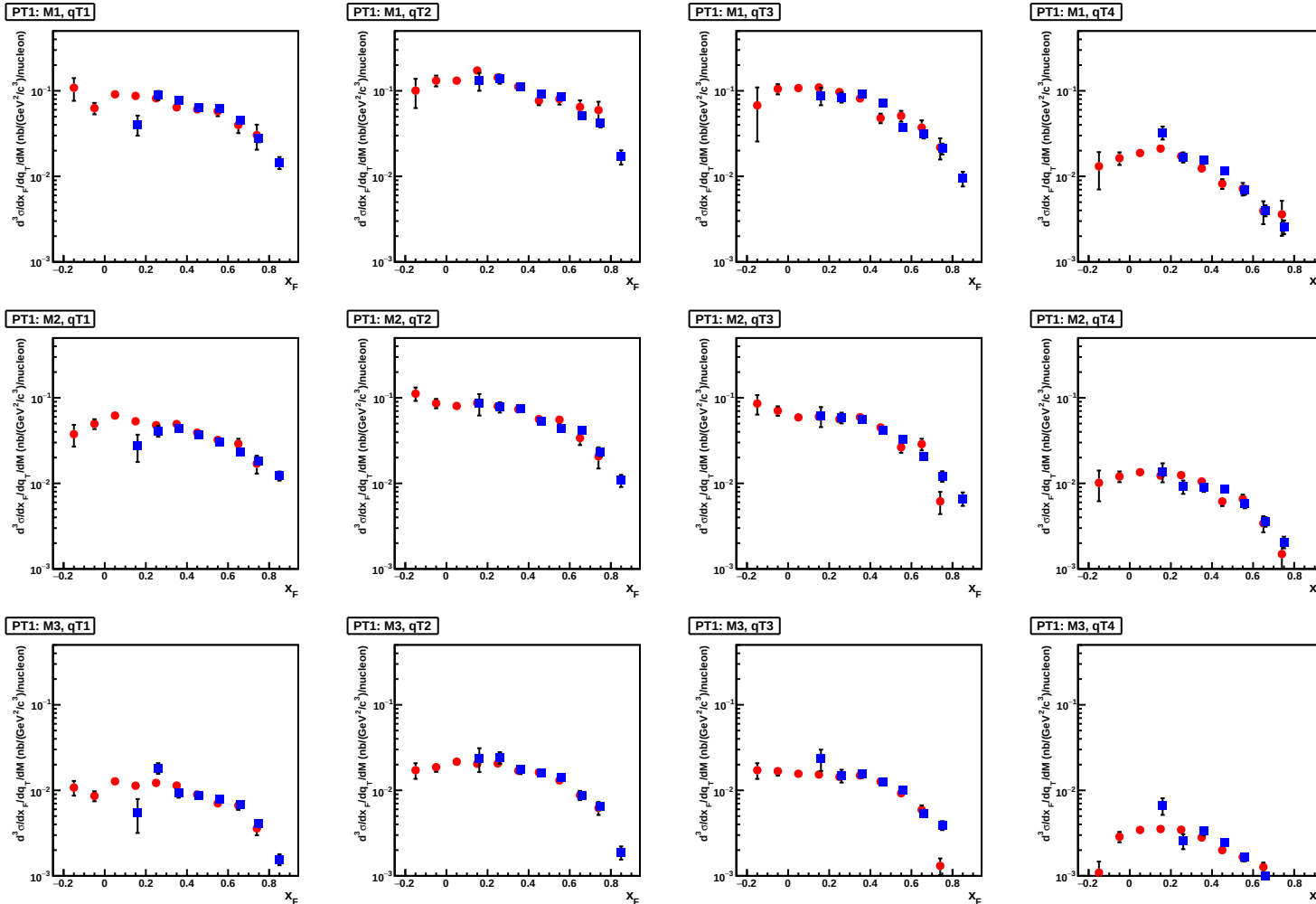
When obtaining the DY cross section in 3D bins, separately per trigger and target, and per period, it happens sometimes to have empty bins, because the binning was optimized for the global analysis (all periods together).

Although a bin with zero event counts means zero cross-section, this **does not** mean that the uncertainty is null. To evaluate the approximate error of such bins, one can use the global (all periods together) cross section statistical error of the bin, divided by the square root of fraction of beam intensity this period represents.

all calculations are in the google sheet at this [link](#)

Triggers comparison: LAS-LAS vs LAS-OT

PT1 (mean from periods luminosity weighted)



The two triggers cover different phase-space in x_F .

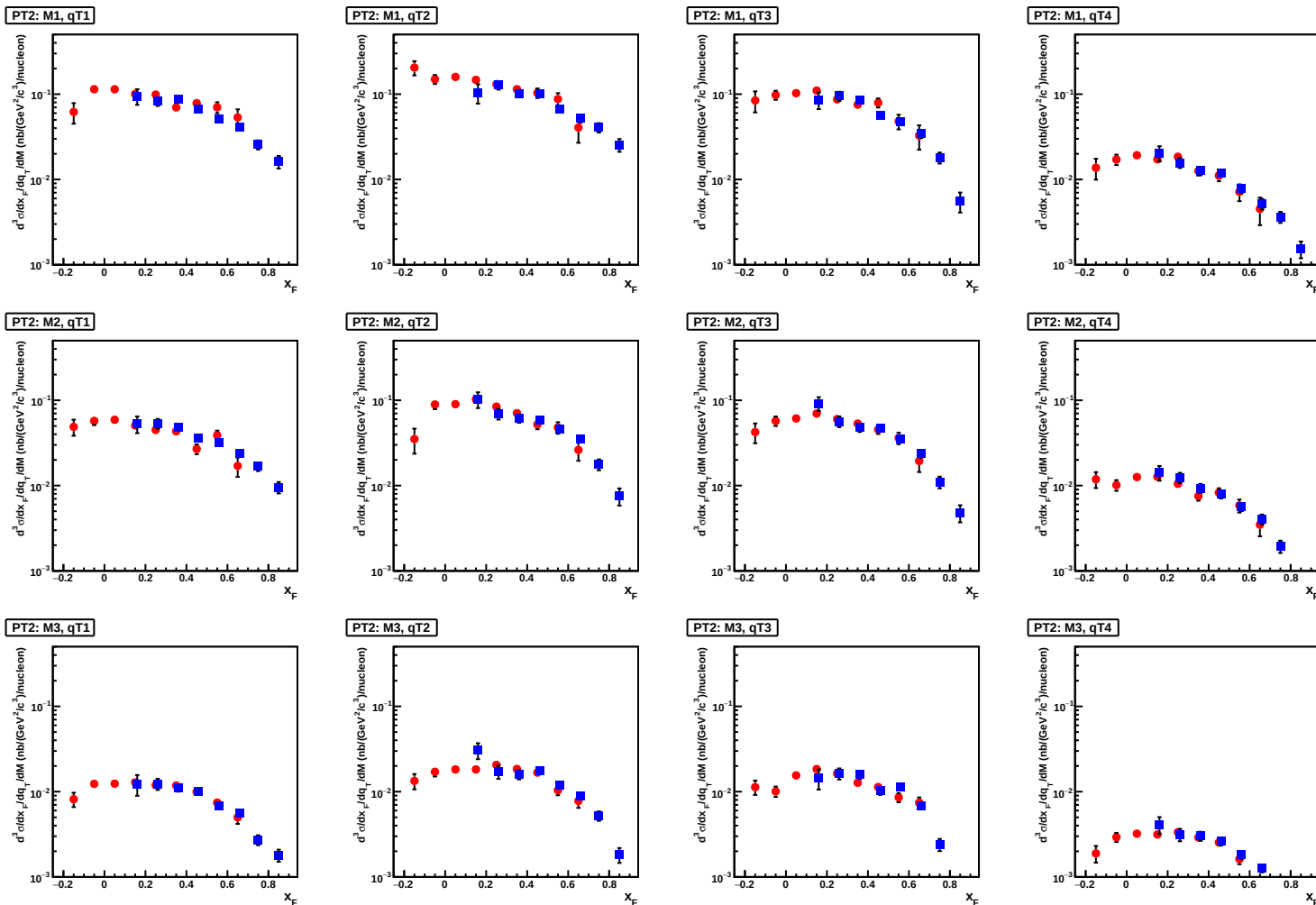
The overlap range is $0.1 < x_F < 0.8$

In the overlap range the results seem to be in agreement.

(only statistical errors shown)

Triggers comparison: LAS-LAS vs LAS-OT

PT2 (mean from periods luminosity-weighted)



The two triggers cover different phase-space in x_F .

The overlap range is $0.1 < x_F < 0.7$

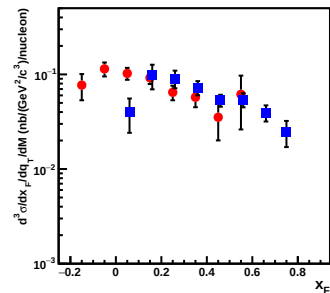
In the overlap range the results seem to be in agreement.

(only statistical errors shown)

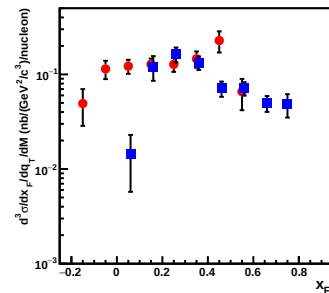
Triggers comparison: LAS-LAS vs LAS-OT

AI (mean from periods luminosity-weighted)

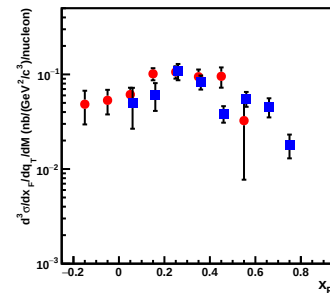
AI: M1, qT1



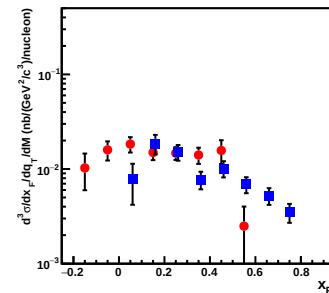
AI: M1, qT2



AI: M1, qT3



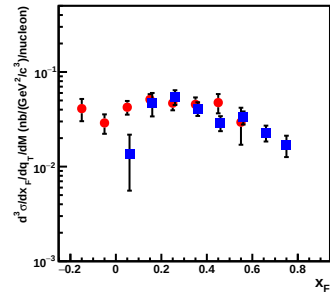
AI: M1, qT4



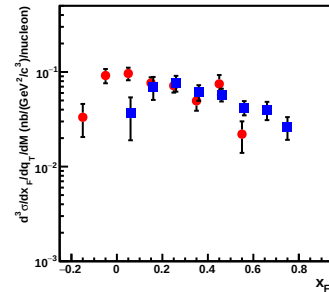
The two triggers cover different phase-space in x_F .

The overlap range is $0 < x_F < 0.6$

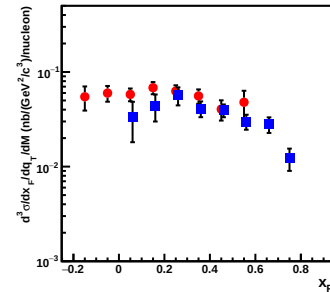
AI: M2, qT1



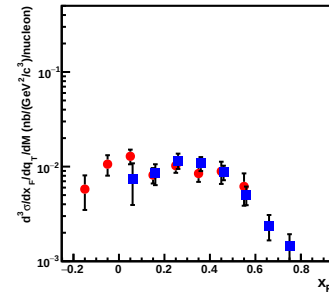
AI: M2, qT2



AI: M2, qT3

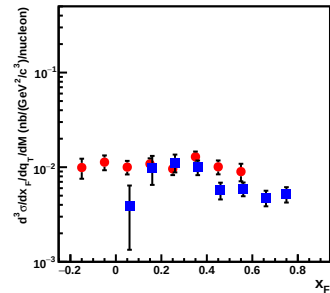


AI: M2, qT4

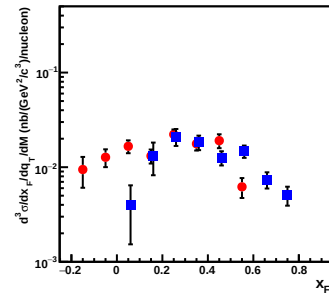


In the overlap range the results seem to be in reasonable agreement.

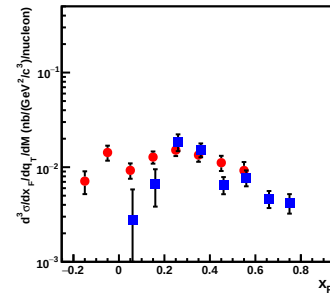
AI: M3, qT1



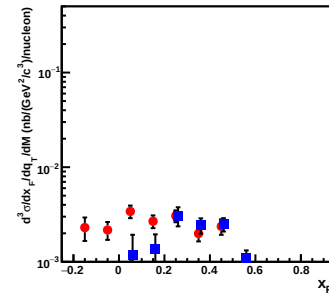
AI: M3, qT2



AI: M3, qT3



AI: M3, qT4

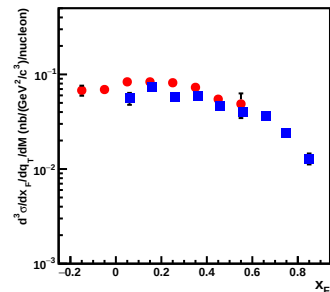


(only statistical errors shown)

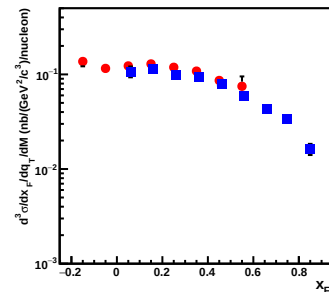
Triggers comparison: LAS-LAS vs LAS-OT

W (mean from periods luminosity-weighted)

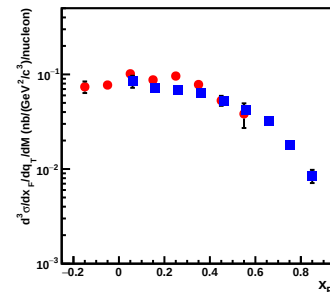
W: M1, qT1



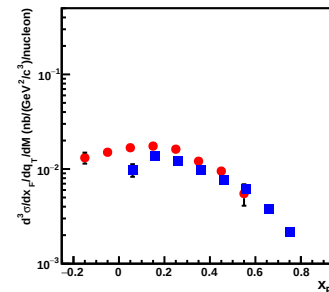
W: M1, qT2



W: M1, qT3



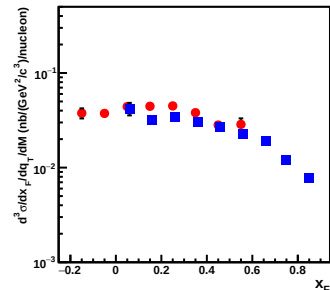
W: M1, qT4



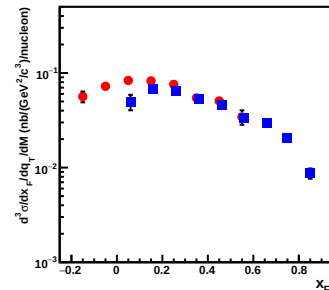
The two triggers cover different phase-space in xF.

The overlap range is $0 < x_F < 0.6$

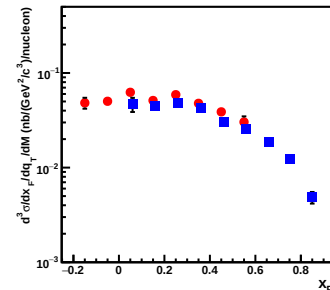
W: M2, qT1



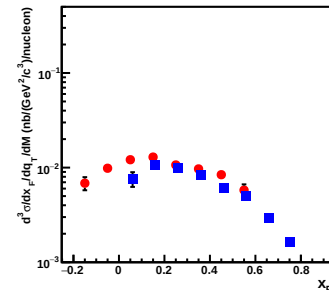
W: M2, qT2



W: M2, qT3

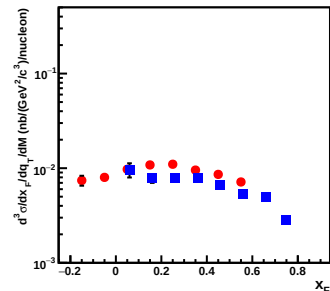


W: M2, qT4

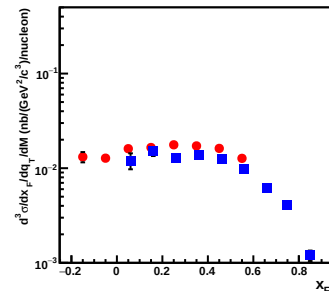


In the overlap range LAS-LAS is systematically higher than LAS-OT.

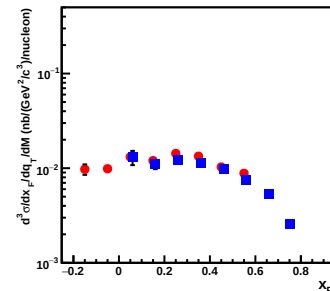
W: M3, qT1



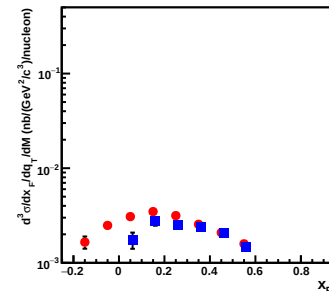
W: M3, qT2



W: M3, qT3



W: M3, qT4



(only statistical errors shown)

<PT>: Combining the cells PT1 and PT2

Just as the mean values of cross section in the two cells were combined by a weighted average, where the weight is given by the inverse statistical variance, the same weight is used also when we combine the **systematic errors** related to **purity** and to the **size of MC sample** (that have no correlation between cells):

$$x = \frac{w_1 x_1 + w_2 x_2}{w_1 + w_2}, \quad w_i = \frac{1}{\sigma_{i,\text{stat}}^2}.$$

For the **statistical uncertainty** of the combined result:

$$\sigma_{\text{stat}} = \sqrt{\frac{1}{w_1 + w_2}}.$$

For the systematic uncertainty, assuming the systematic uncertainties are **independent**, propagate them using the same weights:

$$\sigma_{\text{syst}} = \sqrt{\left(\frac{w_1}{w_1 + w_2} \sigma_{1,\text{syst}} \right)^2 + \left(\frac{w_2}{w_1 + w_2} \sigma_{2,\text{syst}} \right)^2}.$$

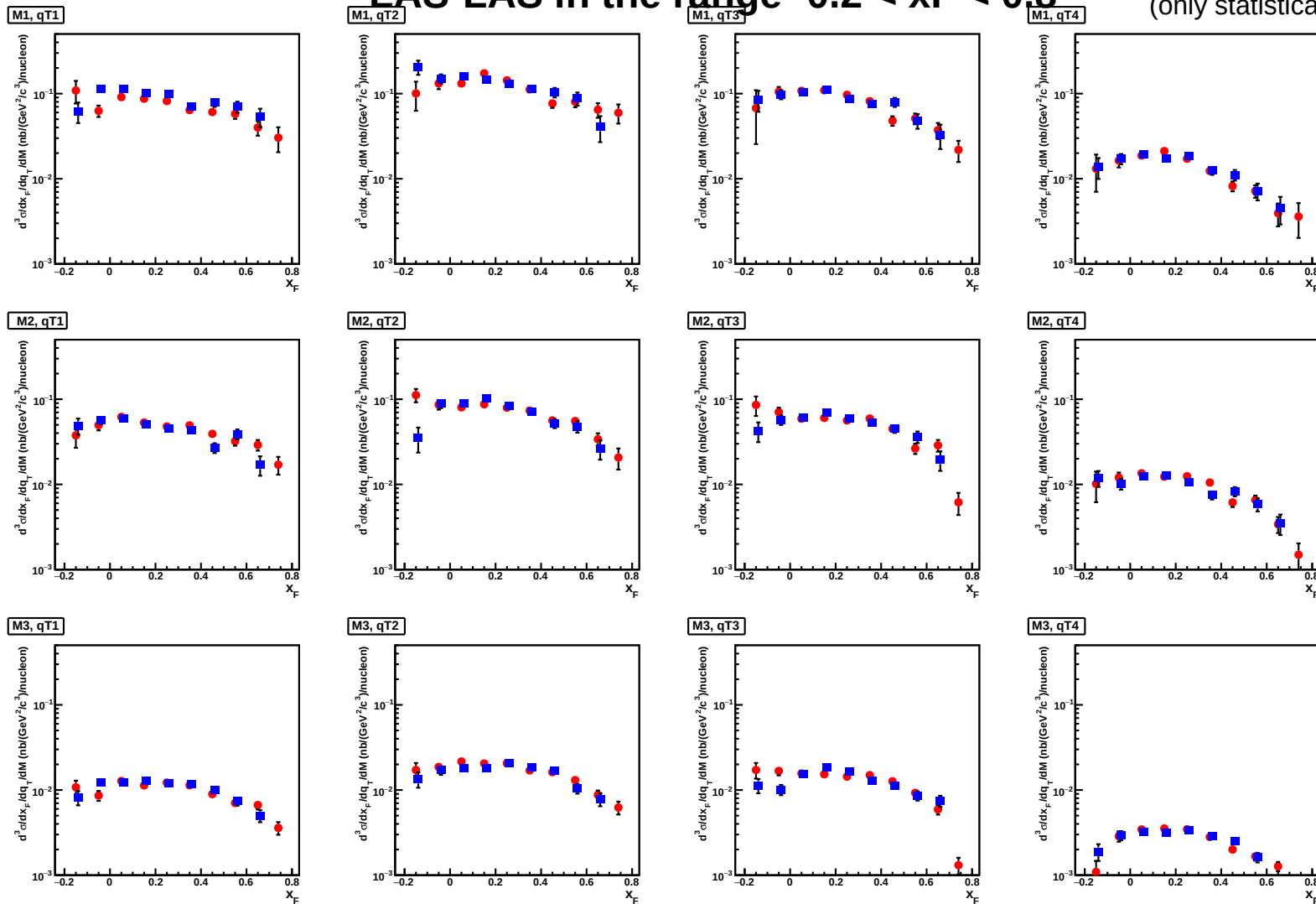
The **systematic error** from **periods-dependence**, calculated from 3D pulls putting together the two ammonia cells, is applied after the cells are combined, in previous slide ($\delta\sigma(\text{syst-time})$).

The **luminosity-related** systematic, a constant evaluated as 3.5% for (NH₃+He), is calculated also after combining cells.

Combining (NH₃+He) cells: **PT1** vs **PT2**

LAS-LAS in the range $-0.2 < x_F < 0.8$

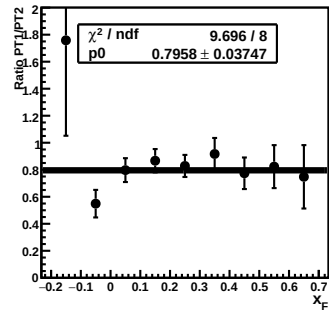
(only statistical errors shown)



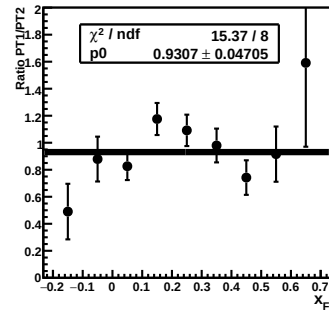
(NH₃+He) cells: **PT1** / **PT2**

LAS-LAS in the range $-0.2 < x_F < 0.8$

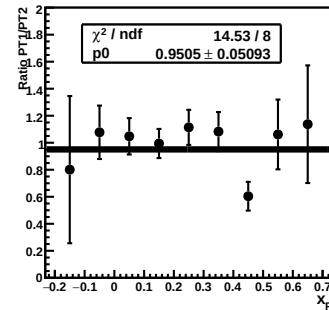
M1, qT1



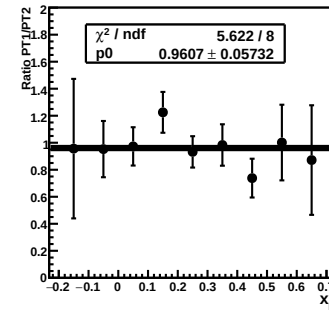
M1, qT2



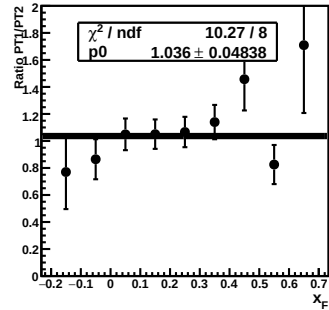
M1, qT3



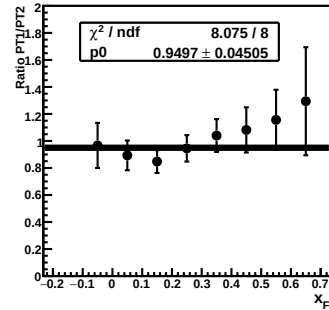
M1, qT4



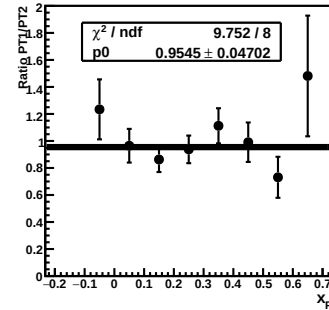
M2, qT1



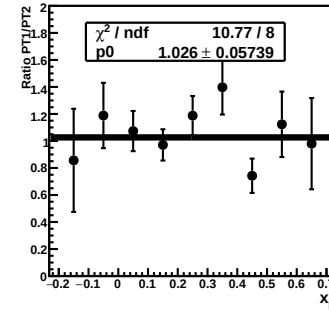
M2, qT2



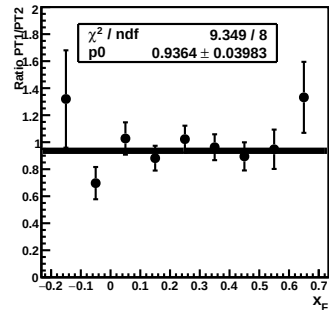
M2, qT3



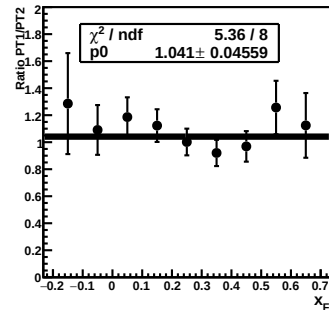
M2, qT4



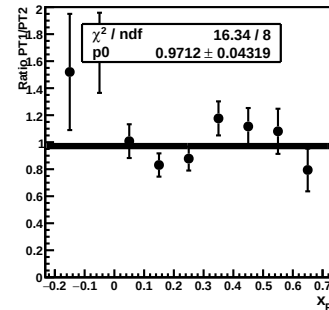
M3, qT1



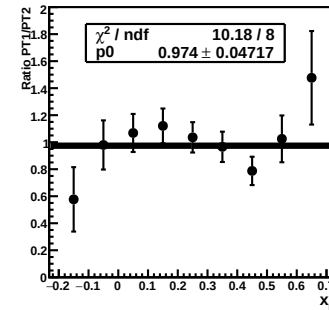
M3, qT2



M3, qT3



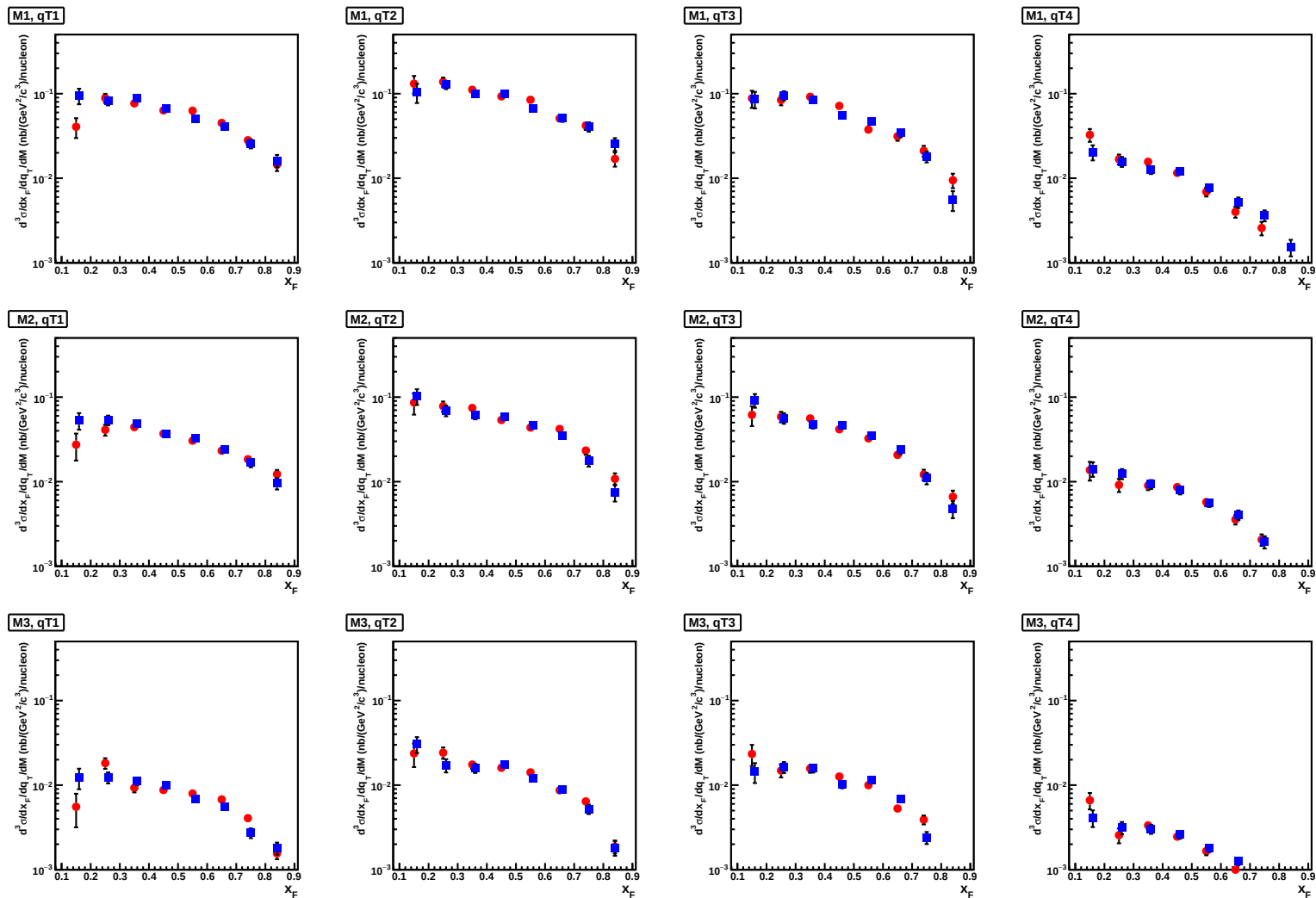
M3, qT4



Combining (NH₃+He) cells: **PT1** vs **PT2**

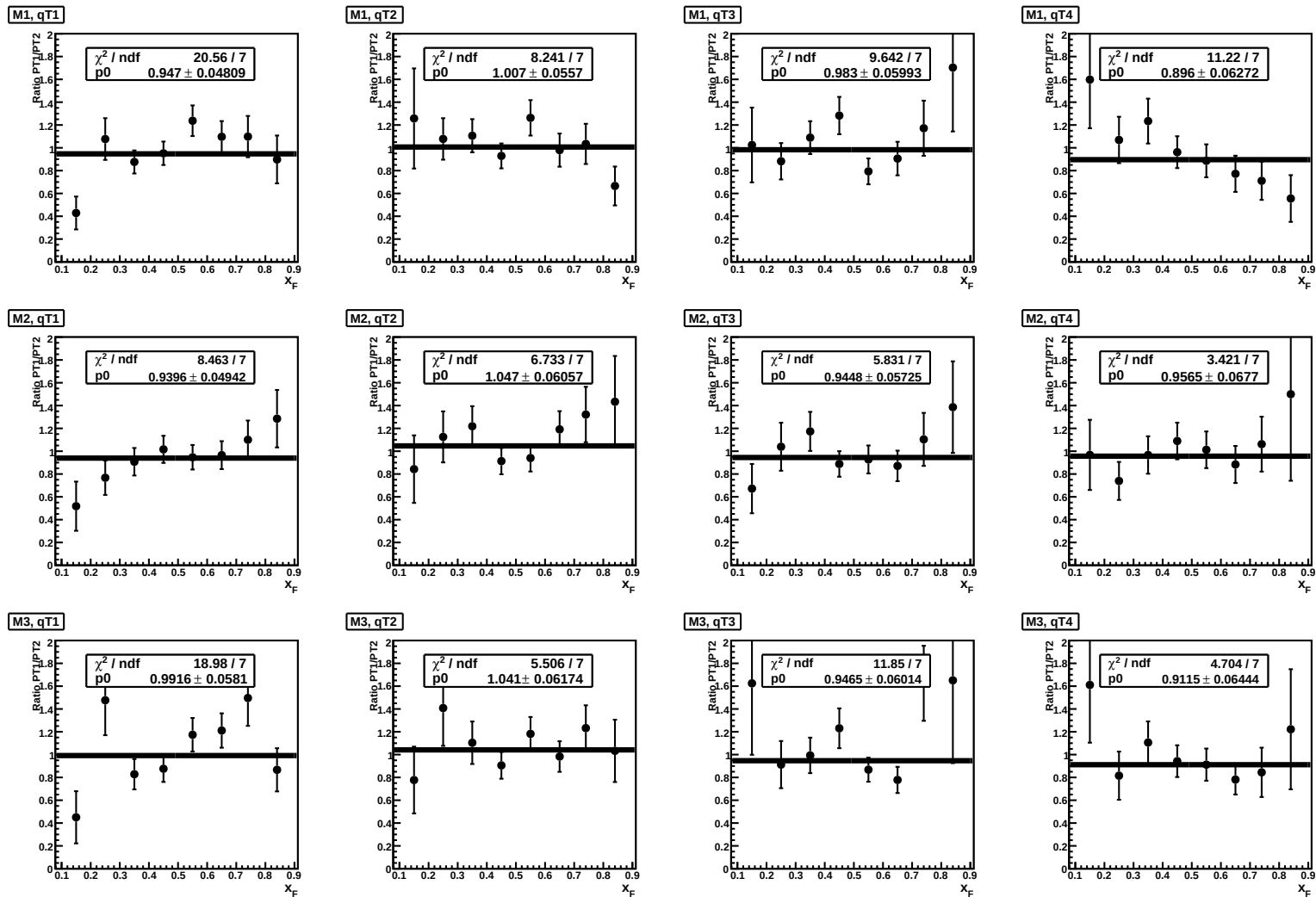
LAS-OT in the range $0.1 < x_F < 0.9$

(only statistical errors shown)



(NH₃+He) cells: **PT1** / **PT2**

LAS-OT in the range $0.1 < x_F < 0.9$



<PT>

Cells combined: LAS-LAS vs LAS-OT in common triggers range $0.1 < x_F < 0.8$

PT1 and PT2 x-sections are combined as a weighted-average, where the inverse statistical variance is used as weight:

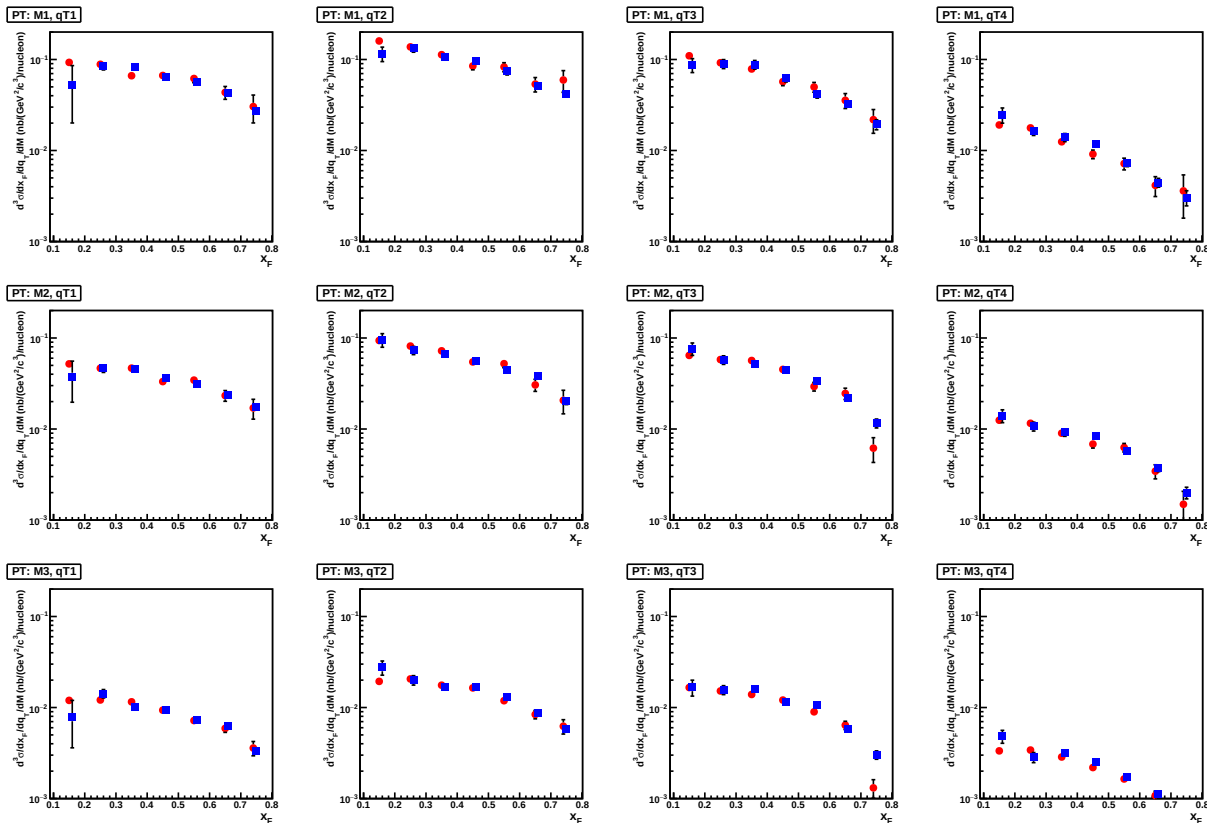
$$\sigma_{\text{mean}} = (\sigma_{\text{PT1}}/\delta\sigma_{\text{PT1}}^2 + \sigma_{\text{PT2}}/\delta\sigma_{\text{PT2}}^2) / \sum (1/\delta\sigma_{\text{PTi}}^2)$$

$$\delta\sigma_{\text{mean}}(\text{stat}) = 1/\sqrt{(\sum 1/\delta\sigma_{\text{PTi}}^2)}$$

$$\sigma \pm \delta\sigma(\text{stat}) \pm \delta\sigma(\text{syst-Mcsize}) \pm \delta\sigma(\text{syst-time}) \pm \delta\sigma(\text{syst-purity}) \pm \delta\sigma(\text{syst-lumi})$$

$\delta\sigma(\text{syst-lumi})$ is fully correlated between the two triggers. But in the ratio of triggers, it cancels.

(errors added quadratically, assuming no correlation between systematics sources. Luminosity error was not included)



<PT>

Cells combined: LAS-LAS / LAS-OT in common triggers range $0.1 < x_F < 0.8$

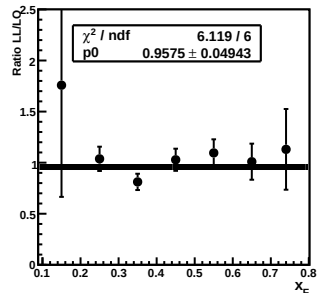
corr=0.

For <PT>, ratios LL/LO in 3D
seem compatible with 1 (or it
tends to be 5 – 10% lower).

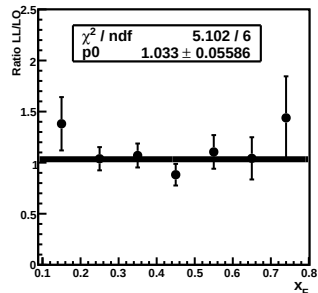
Errors propagation, here
assuming no correlation
between the two triggers.

The error propagation of **ratio**
will **cancel part of the**
systematics.

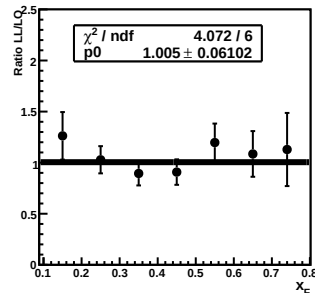
PT: M1, qT1



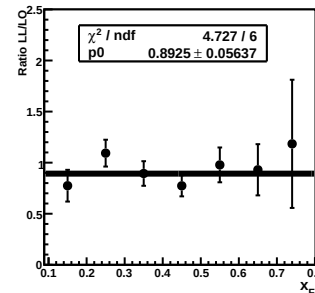
PT: M1, qT2



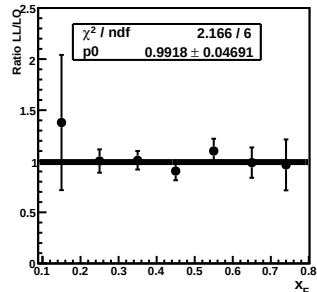
PT: M1, qT3



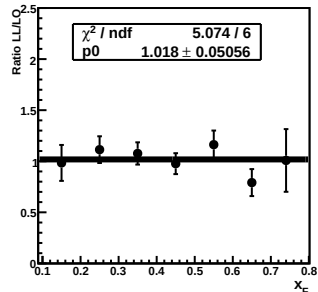
PT: M1, qT4



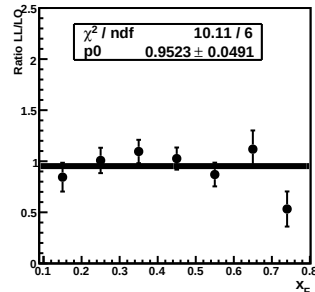
PT: M2, qT1



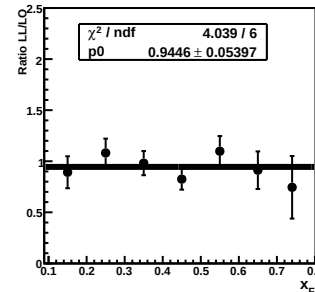
PT: M2, qT2



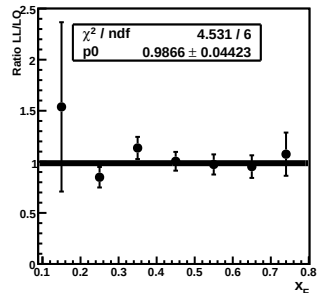
PT: M2, qT3



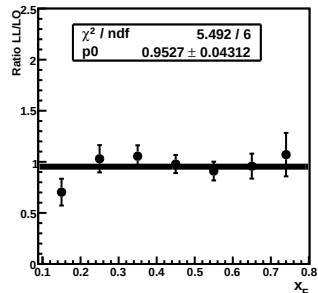
PT: M2, qT4



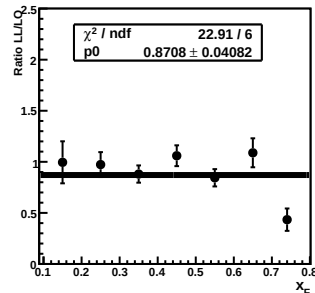
PT: M3, qT1



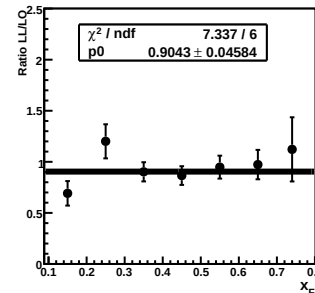
PT: M3, qT2



PT: M3, qT3



PT: M3, qT4



An estimate of the two trigger measurements correlation factor

We can divide the errors in two classes: those for sure uncorrelated and those where we expect a possible correlation:

$$\sigma \pm \delta\sigma(\text{sys_uncorr}) \pm \delta\sigma(\text{sys_corr})$$

where

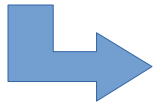
$$\delta\sigma(\text{sys_uncorr}) = \delta\sigma(\text{stat}) \pm \delta\sigma(\text{syst-Mcsize})$$

and

$$\delta\sigma(\text{sys_corr}) = \delta\sigma(\text{syst-purity}) \pm \delta\sigma(\text{sys-time})$$

The two trigger measurements are making partly use of the same detectors and same hodoscopes.

In the 3D analysis, two datapoints at the same (M,qT,xF) from LL or LO share the same physics phase-space -- but not necessarily the same spectrometer phase-space.

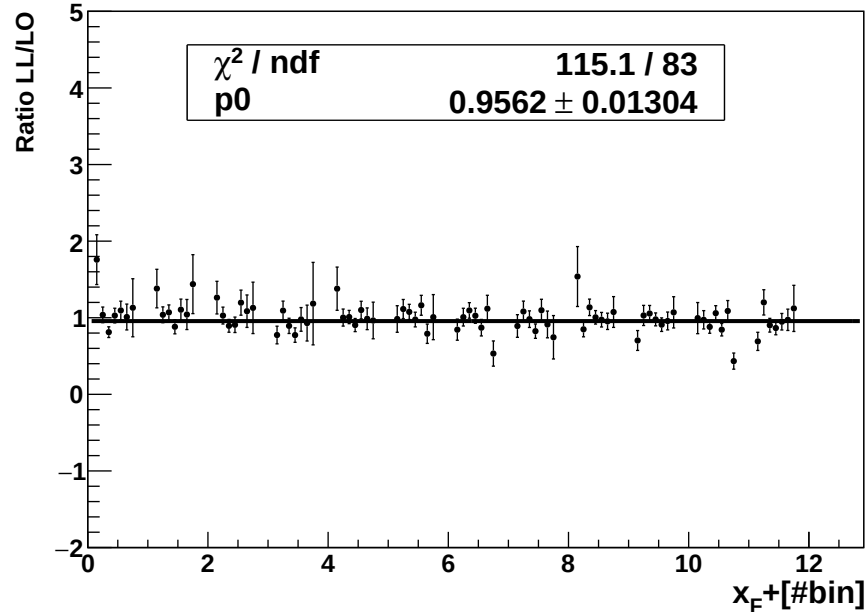


- In the ratio LL/LO, the error propagation of $\delta\sigma(\text{sys_corr})$ may take into account the correlation factor (if $\text{corr} \neq 0$).
- Find **corr** value that leads to global $\chi^2/\text{NDF} = 1$

Triggers ratio: **LAS-LAS** / **LAS-OT** in common range $0.1 < x_F < 0.8$

PT

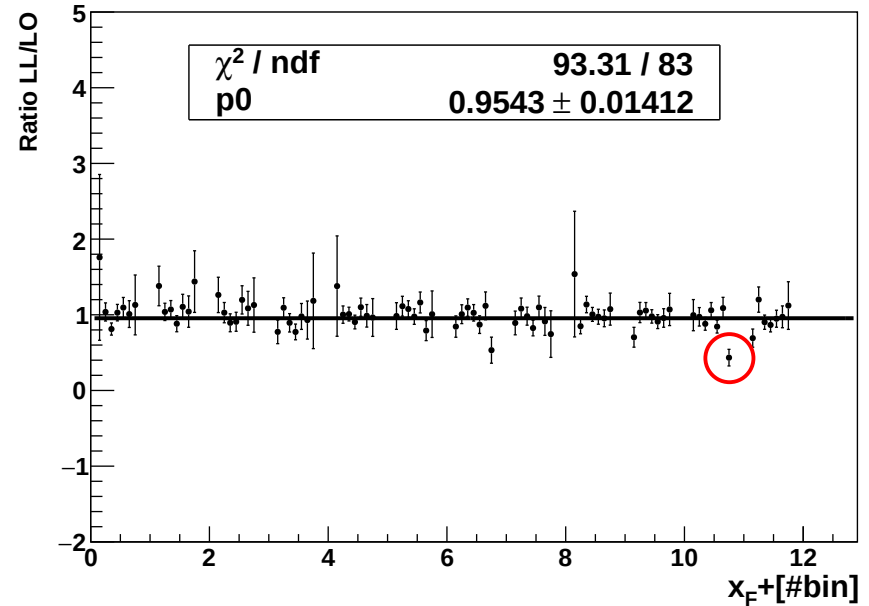
(only statistical errors propagated)



PT

(full error propagation)

corr=0.



The ratio shows that LAS-LAS is $(4 \pm 1)\%$ lower than LAS-OT.

When including systematics, χ^2/ndf goes from 1.39 to 1.12 → Good

The systematic errors seem to be reasonable.

No evidences for under-estimation or for need to take into account trigger correlation (increasing the suspicious point error does not change the mean)

Triggers combined: LAS-LAS and LAS-OT

Scaling factor $R=1.04$, meaning:

LAS-LAS : All cross-section datapoints are scaled up by $(1+R)/2$

LAS-OT: All cross-section datapoints are scaled down by $(1+R)/(2R)$

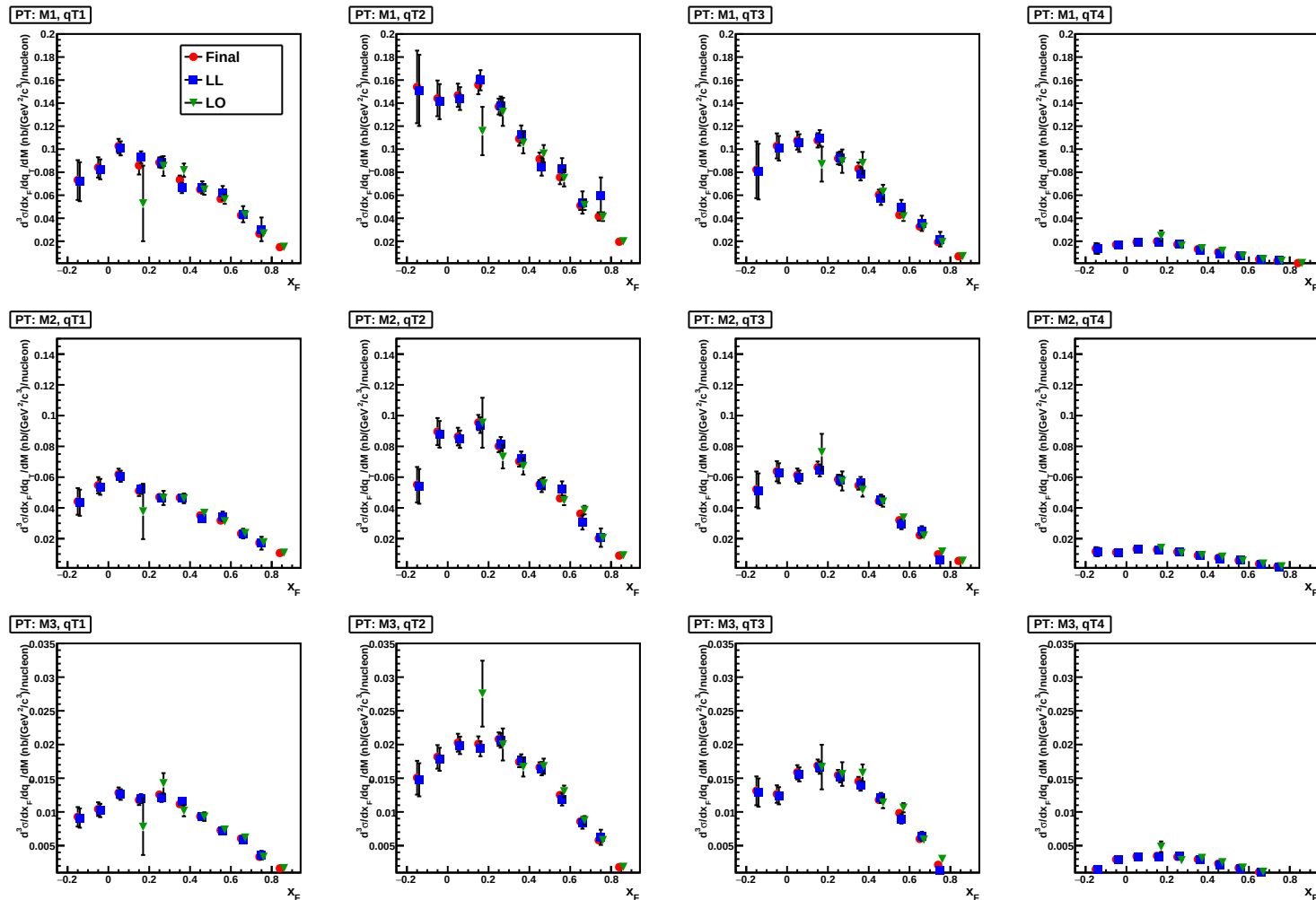
The scaling obtained in the common xF range of the two triggers is applied in all the phase-space

A normalization uncertainty of **2%** is introduced. This uncertainty is fully correlated, just as the luminosity uncertainty.

In the following plots of final results of (NH₃+He), the error bars represent the total error, by adding in quadrature statistical and systematics errors that are kinematic dependent. The **normalization systematic error**, due to luminosity uncertainty (3.5%) and due to trigger scaling (2%), is not represented in the error bars. **It amounts to 4%.**

(NH₃ + He) cross section per nucleon in 3D

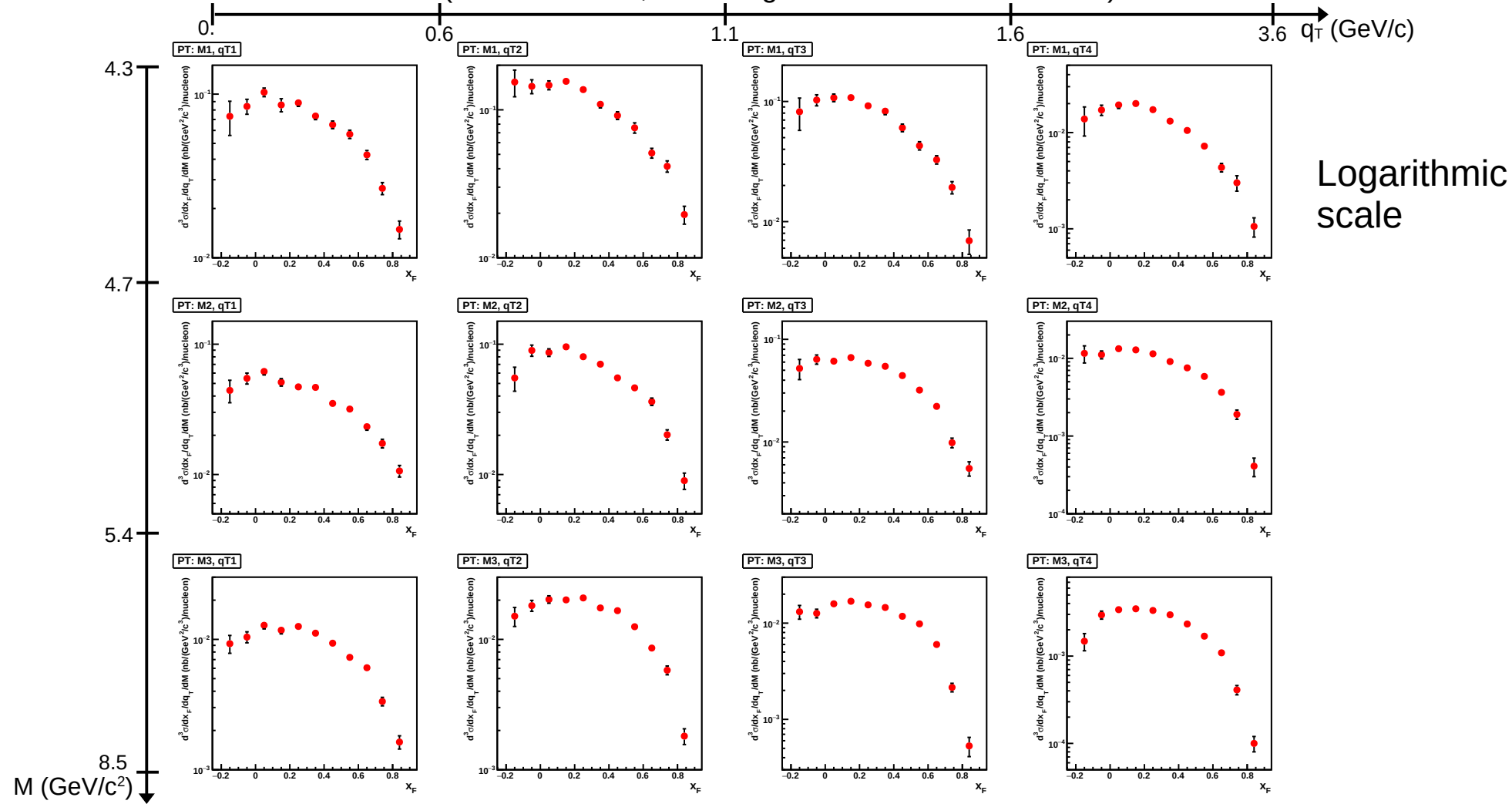
Final combined result versus separated LAS-LAS and LAS-OT
(total error bars, excluding normalization errors)



(NH₃ + He) cross section per nucleon in 3D (M, q_T, x_F)

Final result

(total error bars, excluding normalization error of 4%)



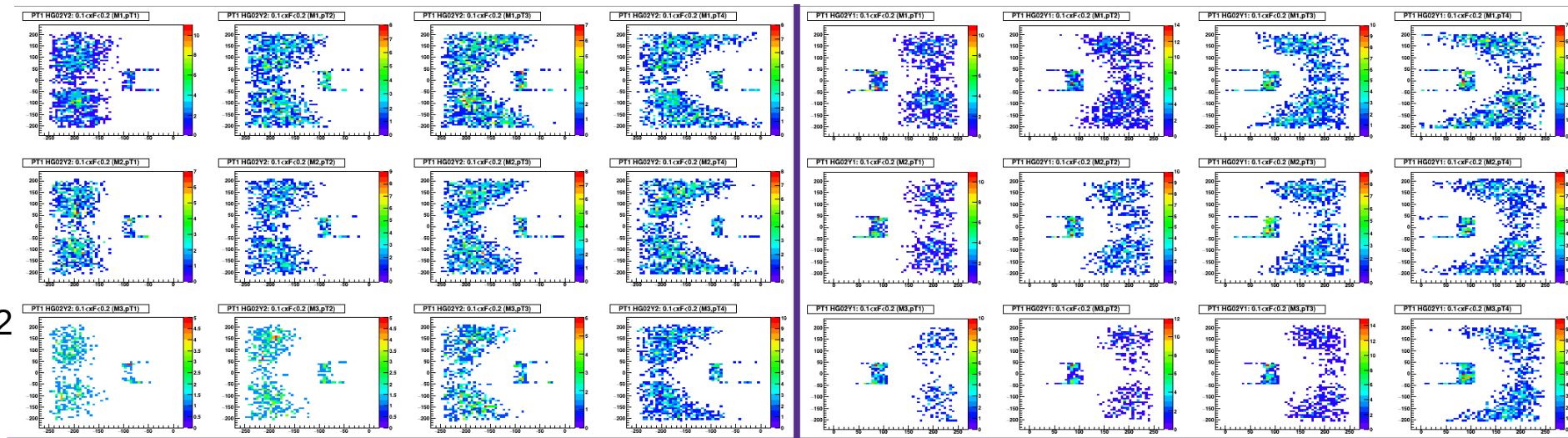
PT1 LAS-OT MC

HG02Y2

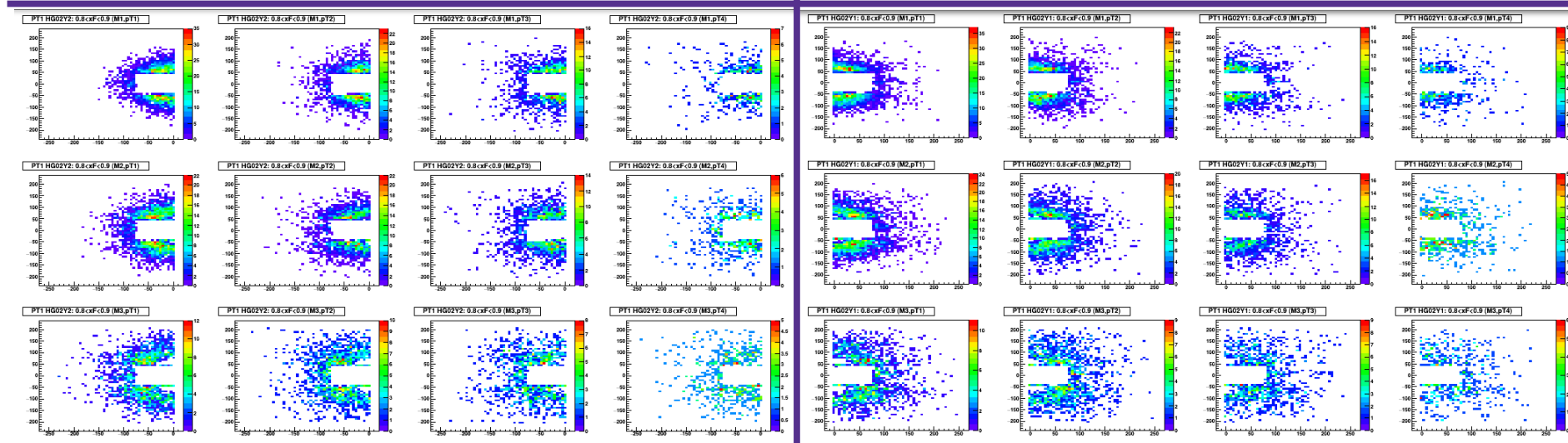
Location of the muon in HG02 (LAS)

HG02Y1

$0.1 < x_F < 0.2$



$0.8 < x_F < 0.9$



PT1 LAS-OT MC

HG02Y2

Location of the muon in HG02, when muon in OT has no LAS hits associated

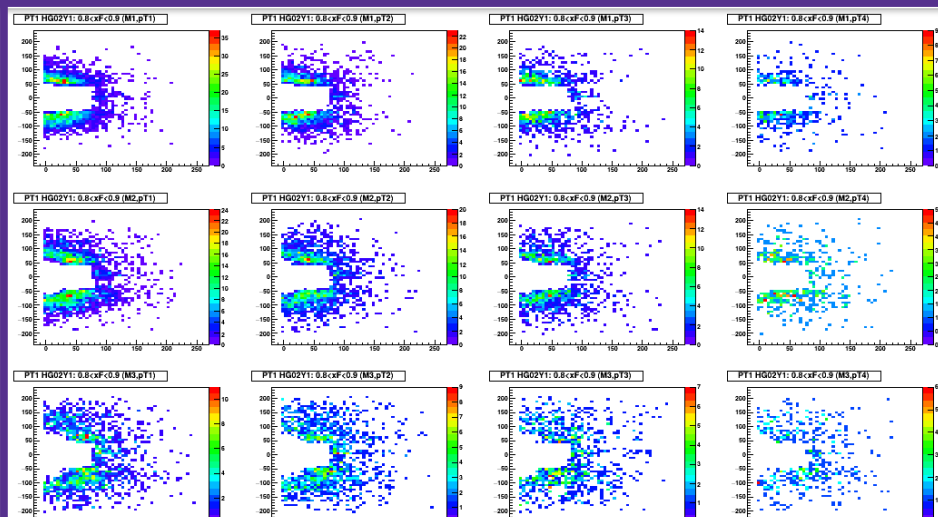
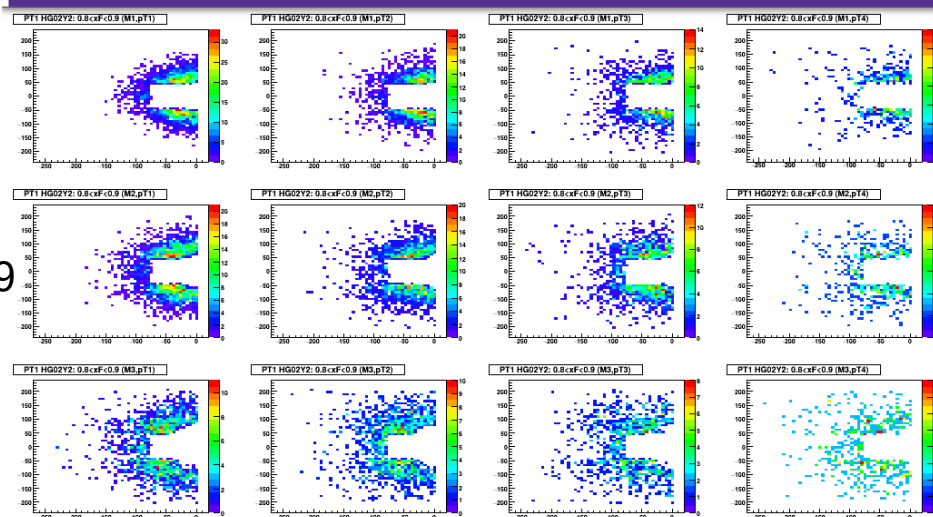
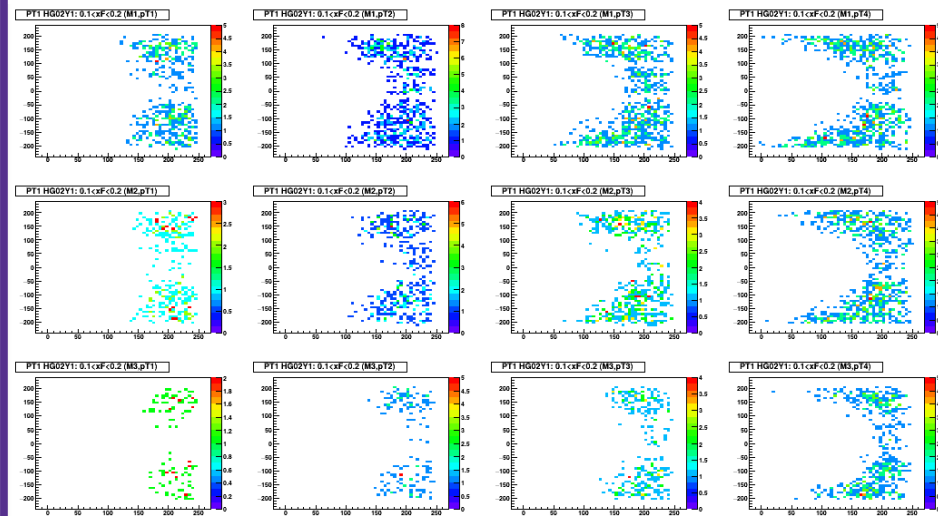
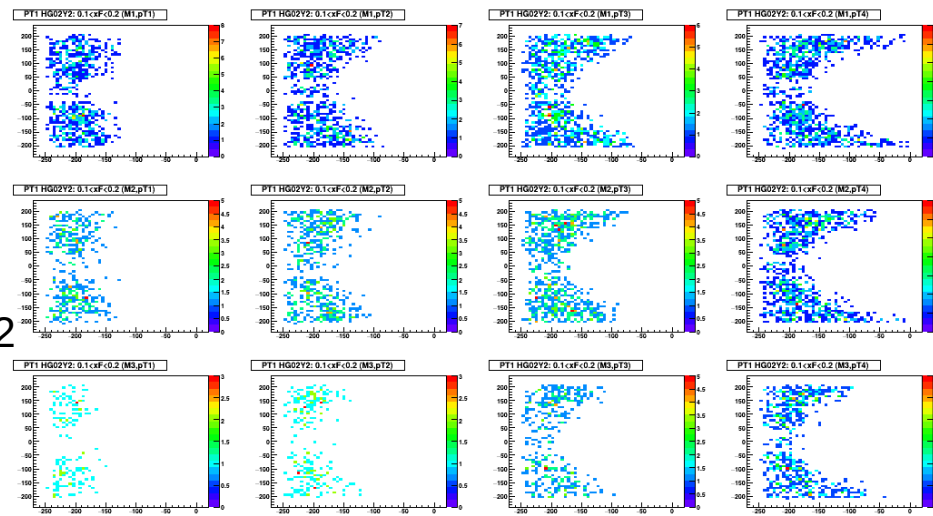
HG02Y1

~50% cut

$0.1 < x_F < 0.2$

~5% cut

$0.8 < x_F < 0.9$



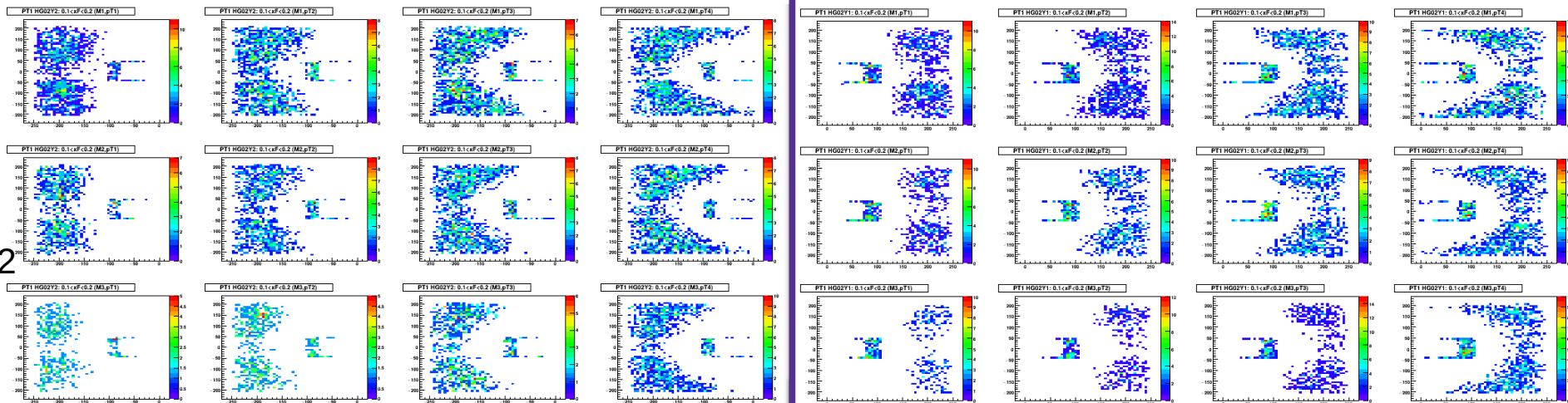
PT1 LAS-OT MC

HG02Y2

Location of the muon in HG02, when muon in LAS has no OT hits associated

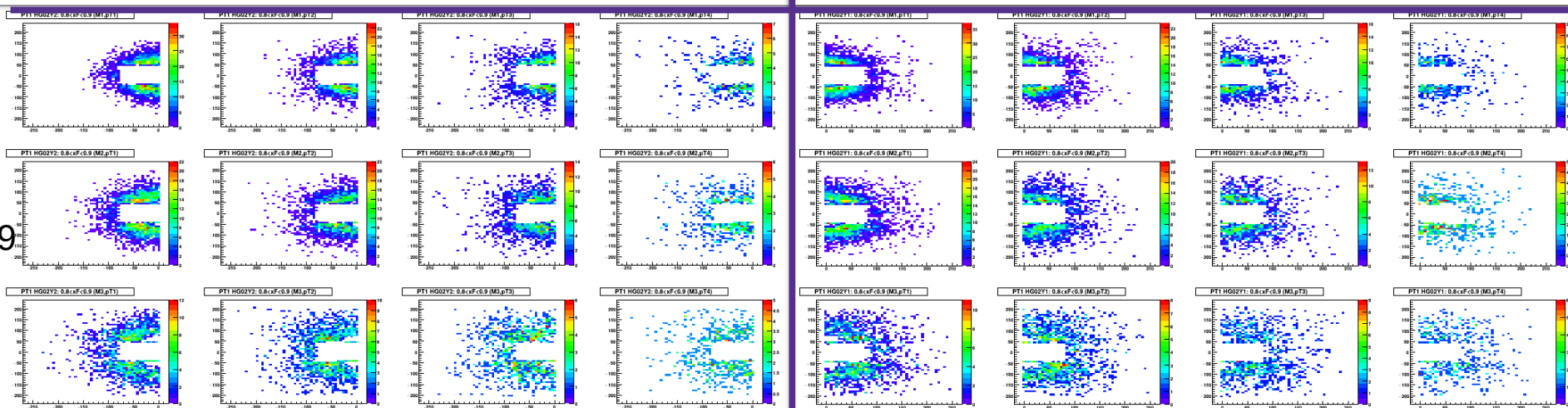
HG02Y1

0% cut



0.1 < xF < 0.2

5% cut



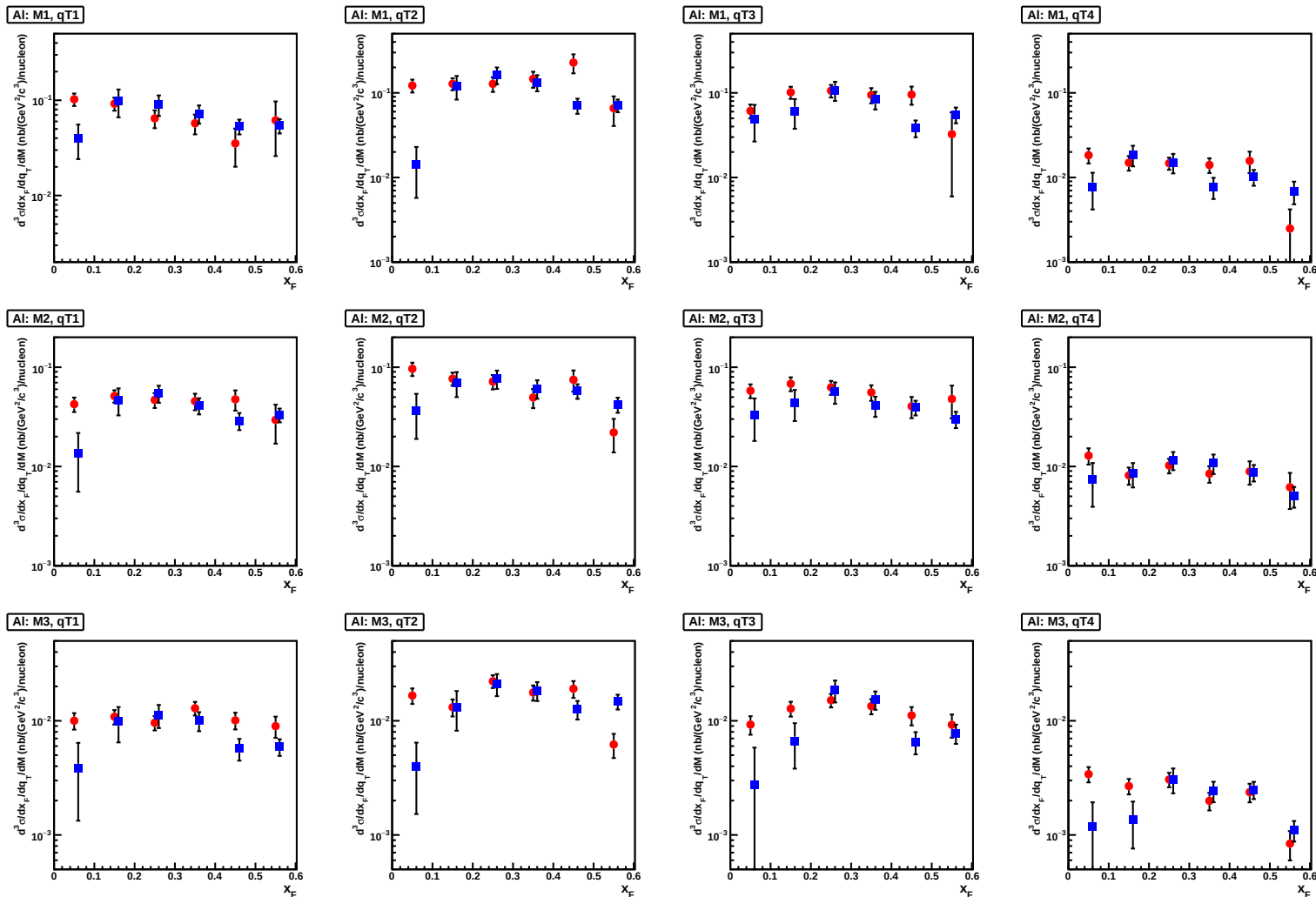
0.8 < xF < 0.9

LAS-OT

This trigger, at the low x_F limit, seems to be contaminated by badly reconstructed events. This is visible in the MC, and leads to too large acceptance, and thus too low x-section.

AI

Triggers combined: LAS-LAS vs LAS-OT in common range $0. < x_F < 0.6$



For AI, the ratios LL/LO in 3D are mostly compatible with 1.

The lowest x_F point seems always too low in LO.

Errors propagation, here assuming no correlation between the two triggers.

(all errors added quadratically, assuming no correlation between systematics sources)

AI

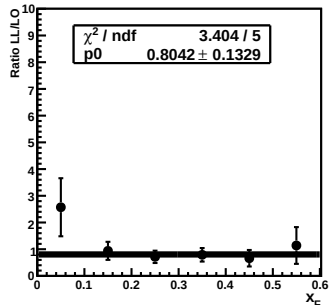
Triggers combined: LAS-LAS / LAS-OT in common range $0. < x_F < 0.6$

corr=0.

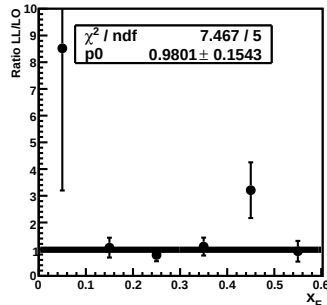
Errors propagation, here
assuming no correlation
between the two triggers.

Most ratios compatible with 1.

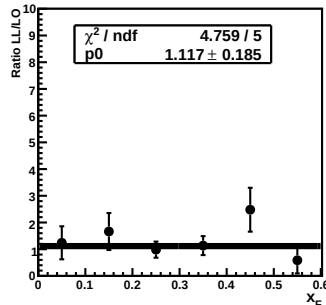
AI: M1, qT1



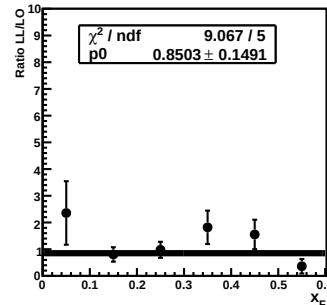
AI: M1, qT2



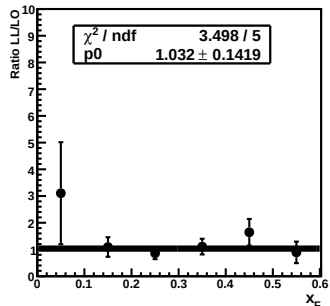
AI: M1, qT3



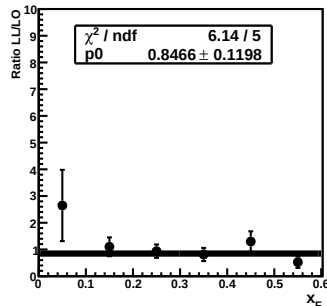
AI: M1, qT4



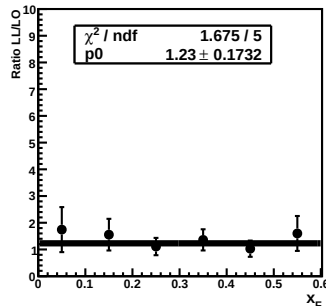
AI: M2, qT1



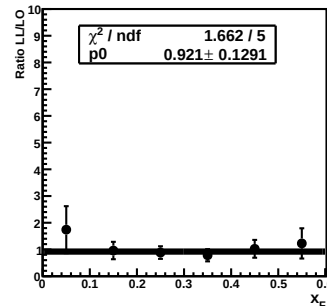
AI: M2, qT2



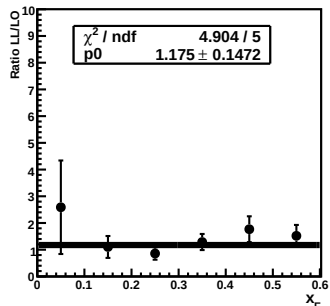
AI: M2, qT3



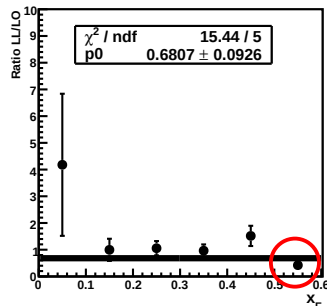
AI: M2, qT4



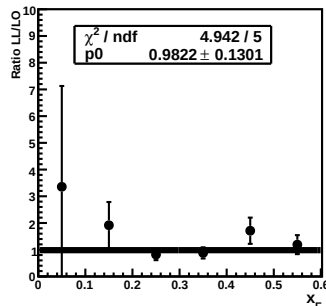
AI: M3, qT1



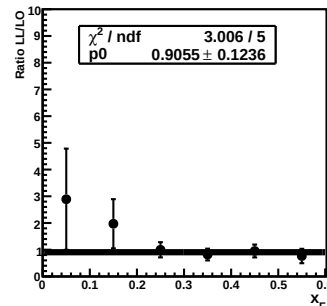
AI: M3, qT2



AI: M3, qT3



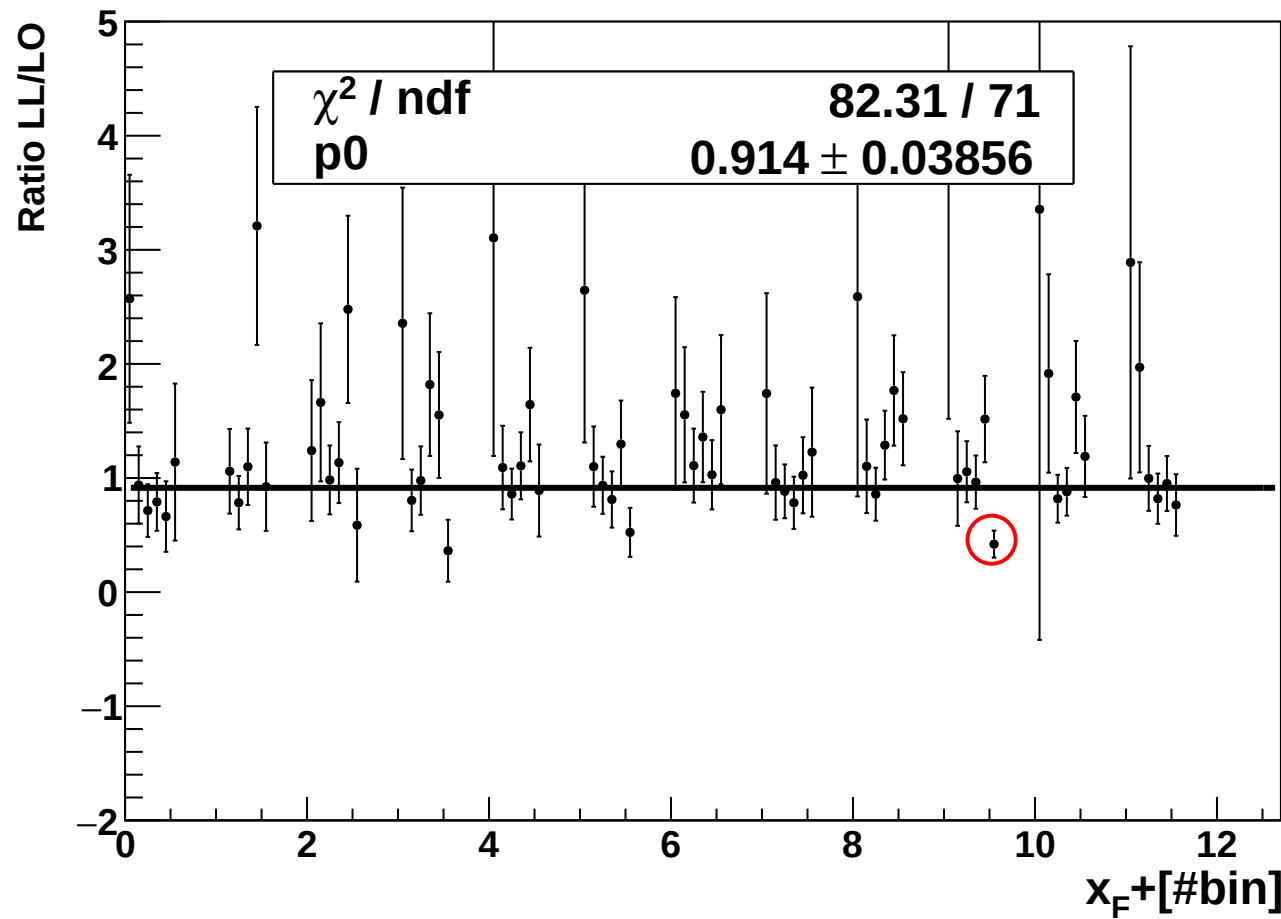
AI: M3, qT4



Triggers combined: **LAS-LAS** / **LAS-OT**
in common range $0. < x_F < 0.6$

AI

corr=0.

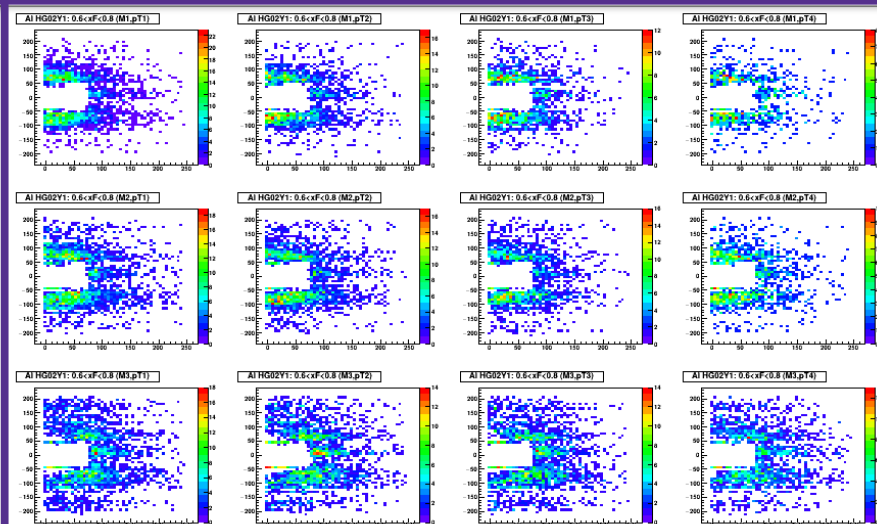
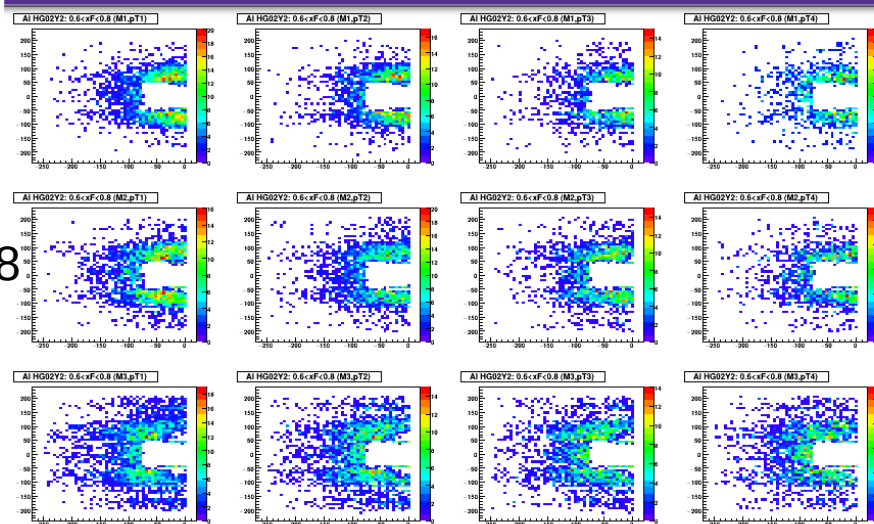
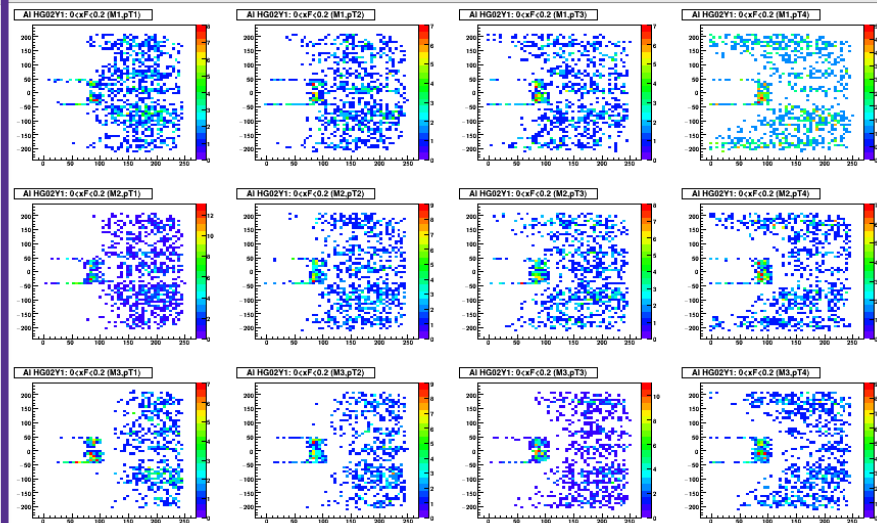
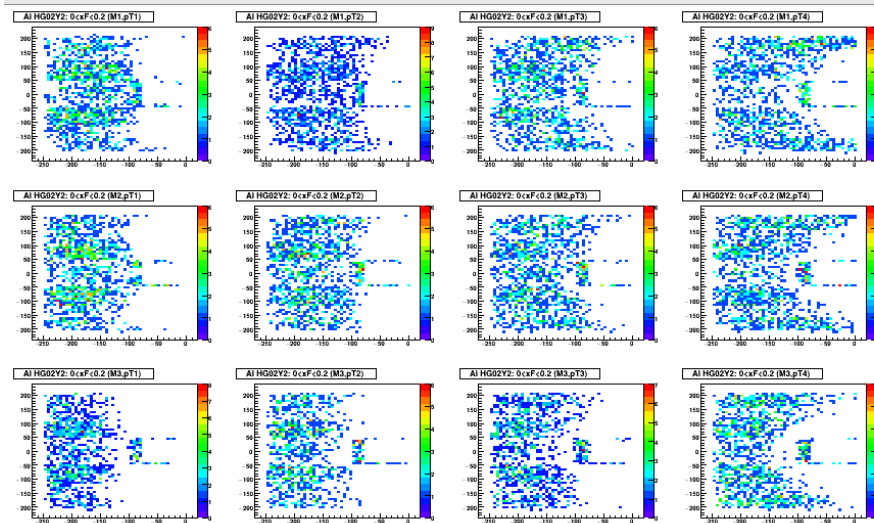


If the error of this single point becomes much larger, the mean gets compatible with 1 ($P0=0.97\pm0.04$, $\chi^2/\text{ndf}=0.89$)

HG02Y2

AI LAS-OT: MC HMDY

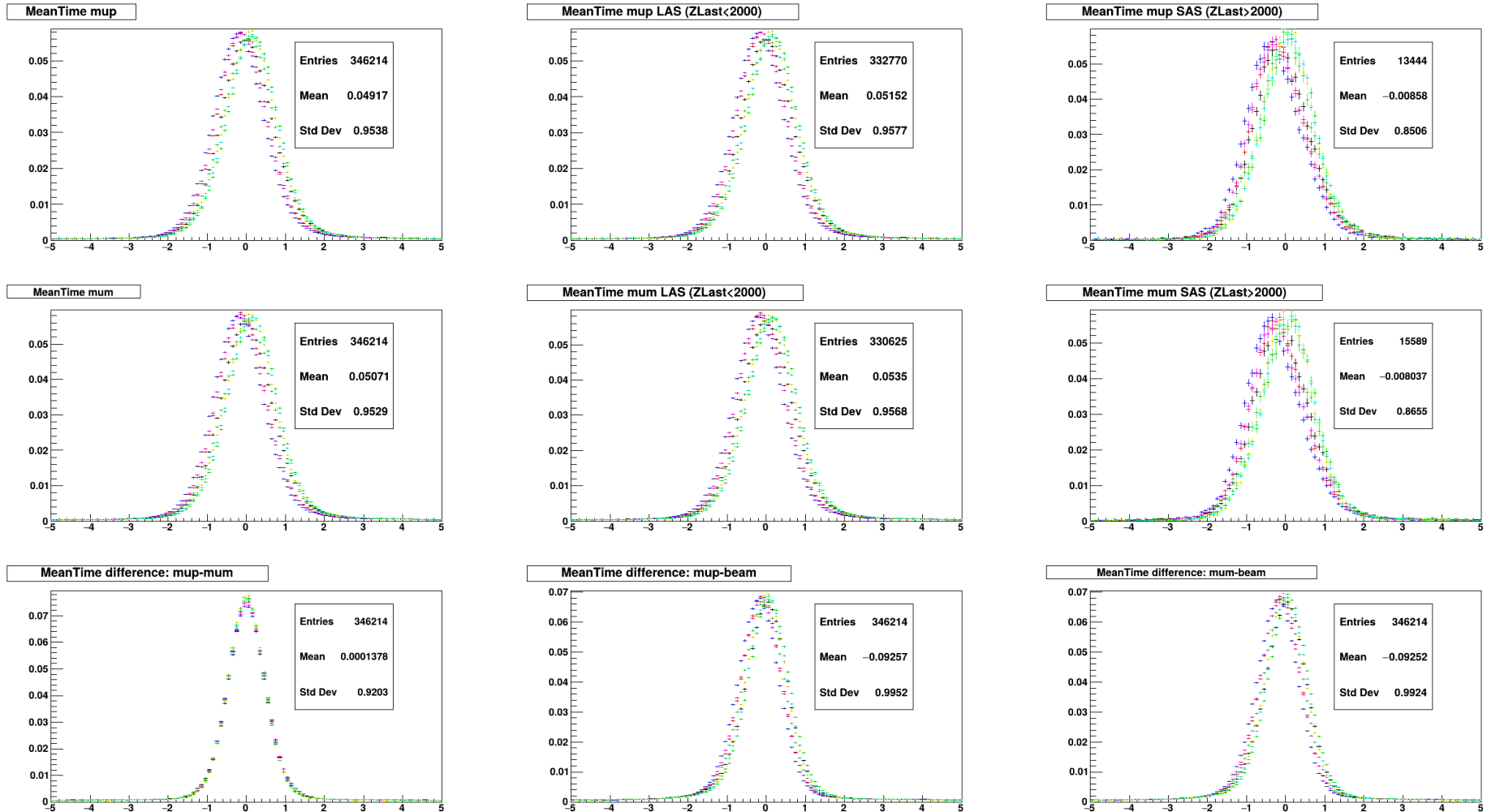
HG02Y1

 $0 < x_F < 0.2$  $0.6 < x_F < 0.8$

SPARES

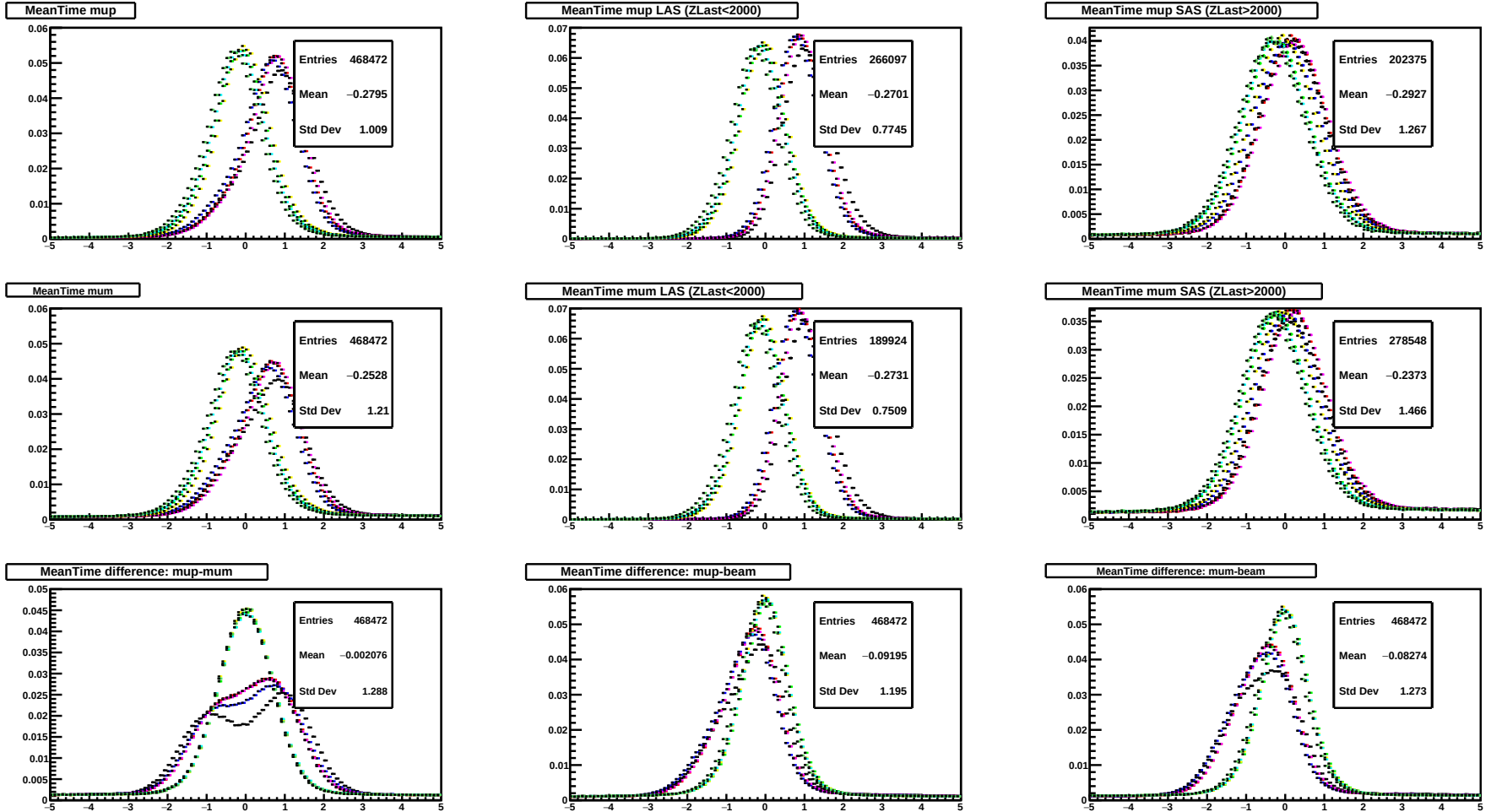
Evidences of differences between periods (RD)

LAS-LAS events $M > 1.5 \text{ GeV}/c^2$



Evidences of differences between periods (RD)

LAS-OT events $M > 1.5 \text{ GeV}/c^2$



In the first 4 periods there is a timing problem affecting the muons (but the window of timing cuts is in principle wide enough to accommodate this: $[-3, 3] \text{ ns}$).

LAS-LAS	P1	P2	P3	P4	P5	P6	P7	P8
PT1: RD fraction that pass time cuts	96%	96%	97%	96%	97%	97%	98%	95%
PT1: MC fraction that pass time cuts	97%	99%	97%	96%	96%	96%	96%	97%
PT1: MC/RD	122	133	148	131	134	123	113	144
W: RD fraction that pass time cuts	96%	96%	96%	96%	95%	96%	95%	95%
W: MC fraction that pass time cuts	97%	99%	97%	96%	97%	96%	96%	96%
W: MC/RD	56	59	66	59	58	60	59	68

MC: HMDY

All other cuts are applied, except time cuts being tested.

$$4.3 < M < 8.5 \text{ GeV}/c^2$$

LAS-OT	P1	P2	P3	P4	P5	P6	P7	P8
PT1: RD fraction that pass time cuts	94%	94%	94%	94%	95%	95%	95%	96%
PT1: MC fraction that pass time cuts	97%	99%	96%	96%	96%	96%	96%	96%
PT1: MC/RD	133	127	143	128	134	127	122	142
W: RD fraction that pass time cuts	92%	94%	93%	92%	94%	95%	94%	95%
W: MC fraction that pass time cuts	97%	99%	96%	96%	96%	96%	96%	96%
W: MC/RD	63	65	70	63	65	64	61	78