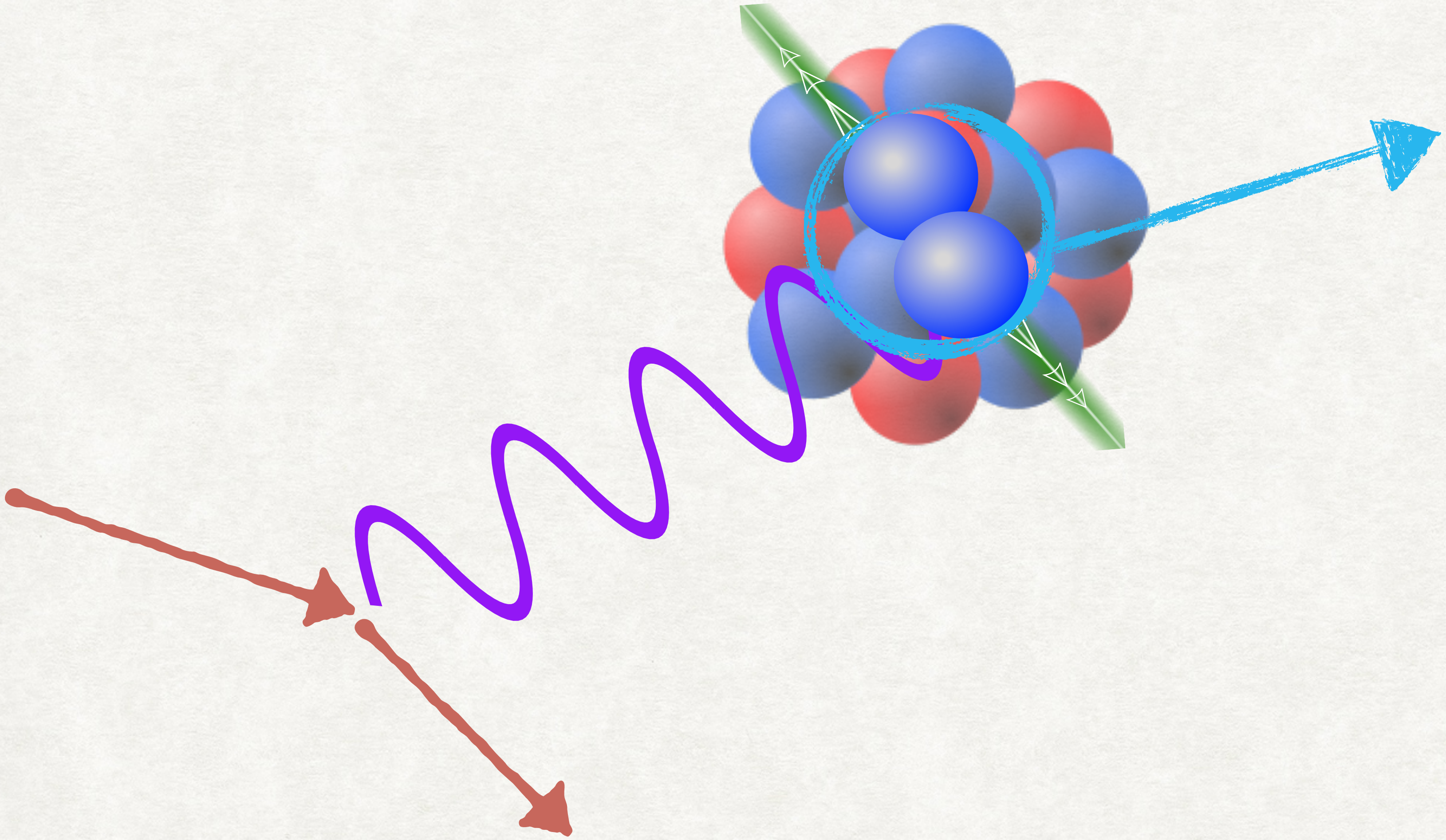
2N-SRC c.m. momentum distribution extracted from A(e,e'pp)



Erez. O. Cohen

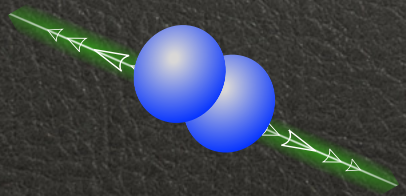
Tel Aviv University

EG2 data-mining

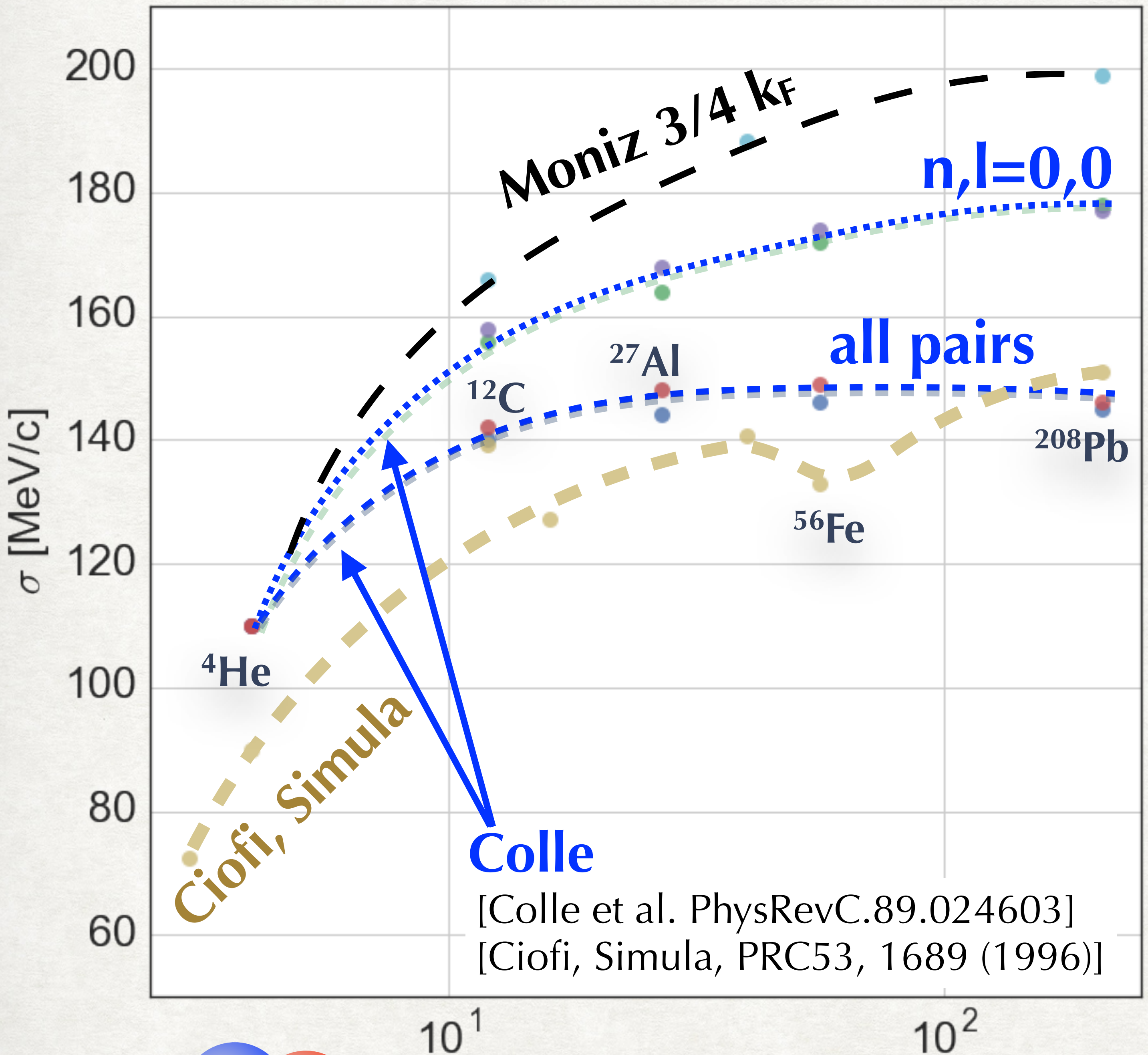
Outline

- Introduction and Motivation.
- Previous results.
- EG-2 (CLAS) analysis of pp-SRC.
- Preliminary results.

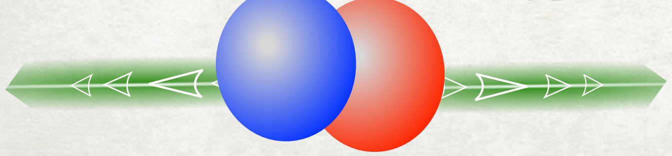
Introduction and Motivation

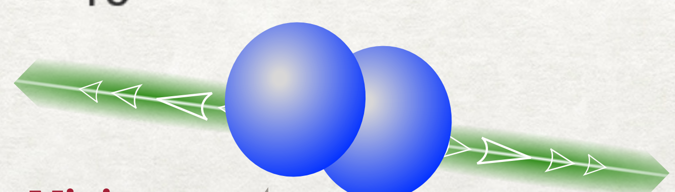


2N-SRC c.m. momentum



- **Important feature** of an SRC pair.
- Described by a **3D Gaussian**.
- **pp/np ratio** varies with p_{cm}.
- Width sensitive to **pair quantum numbers**.
- Distribution is **less sensitive to FSI in (e,e'pp)**.
- **Hall-A data** ⇨ $p_{cm} \lesssim p_F$.
- $p_{cm} > p_F$ **not necessarily** ⇨ **SRC**.





How do we extract p_{cm} from data

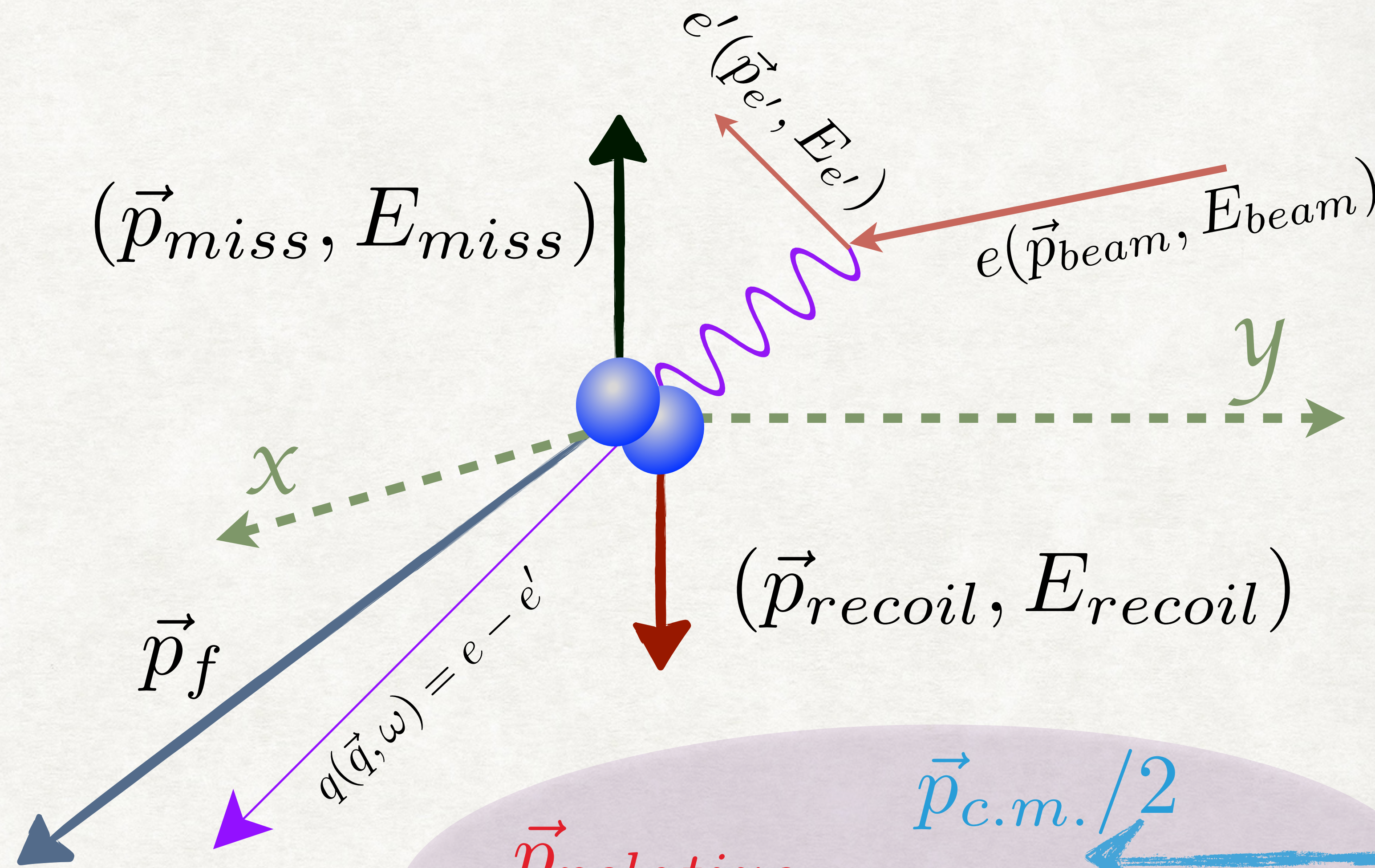
Measured:

$\vec{p}_{e'}$ $\vec{p}_f$ $\vec{p}_{recoil}$

Extracted:

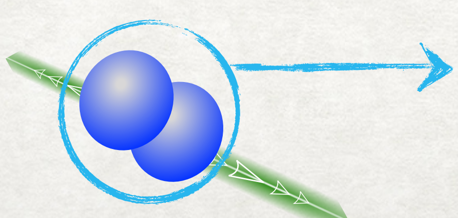
$\vec{p}_{miss} = \vec{p}_f - \vec{q}$

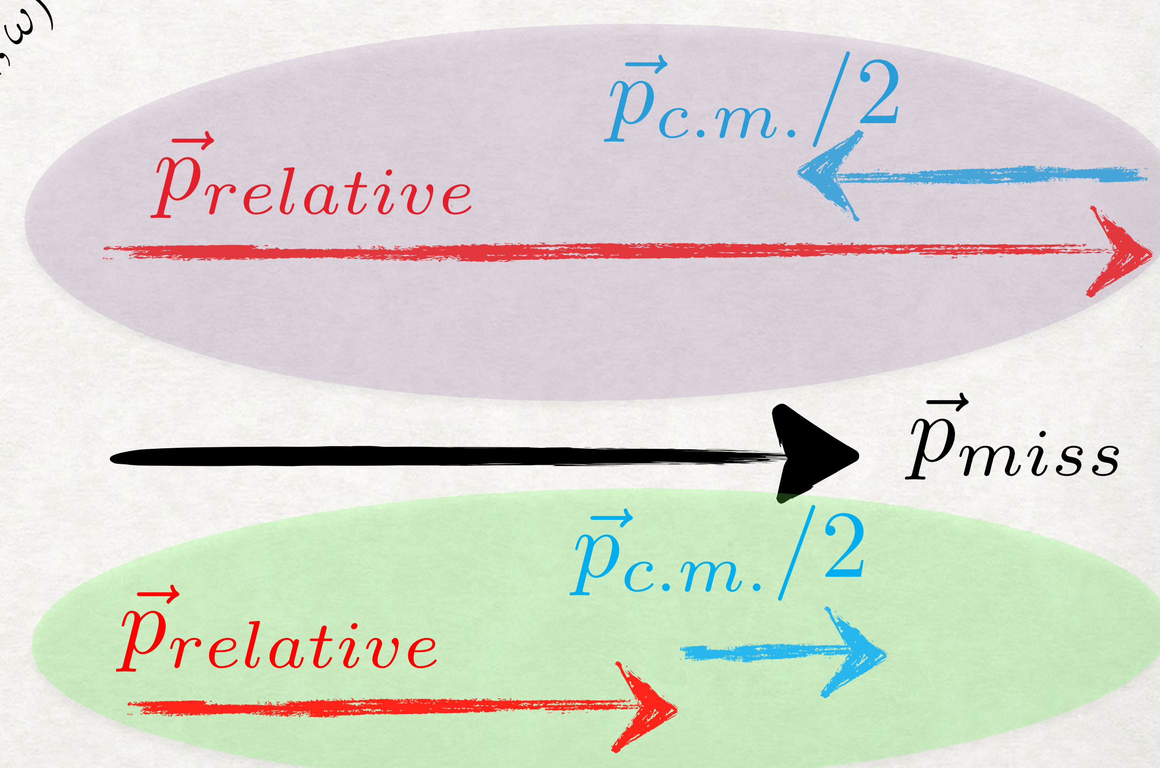
$\vec{p}_{c.m.} = \vec{p}_{miss} + \vec{p}_{recoil}$



For high $\mathbf{p}_{\mathbf{miss}}$,

- More likely to find $\mathbf{p}_{\mathbf{cm}}$ biased in the $\mathbf{p}_{\mathbf{miss}}$ direction.





Previous results

c.m. motion of an SRC pair ('old' data)

BNL ^{12}C

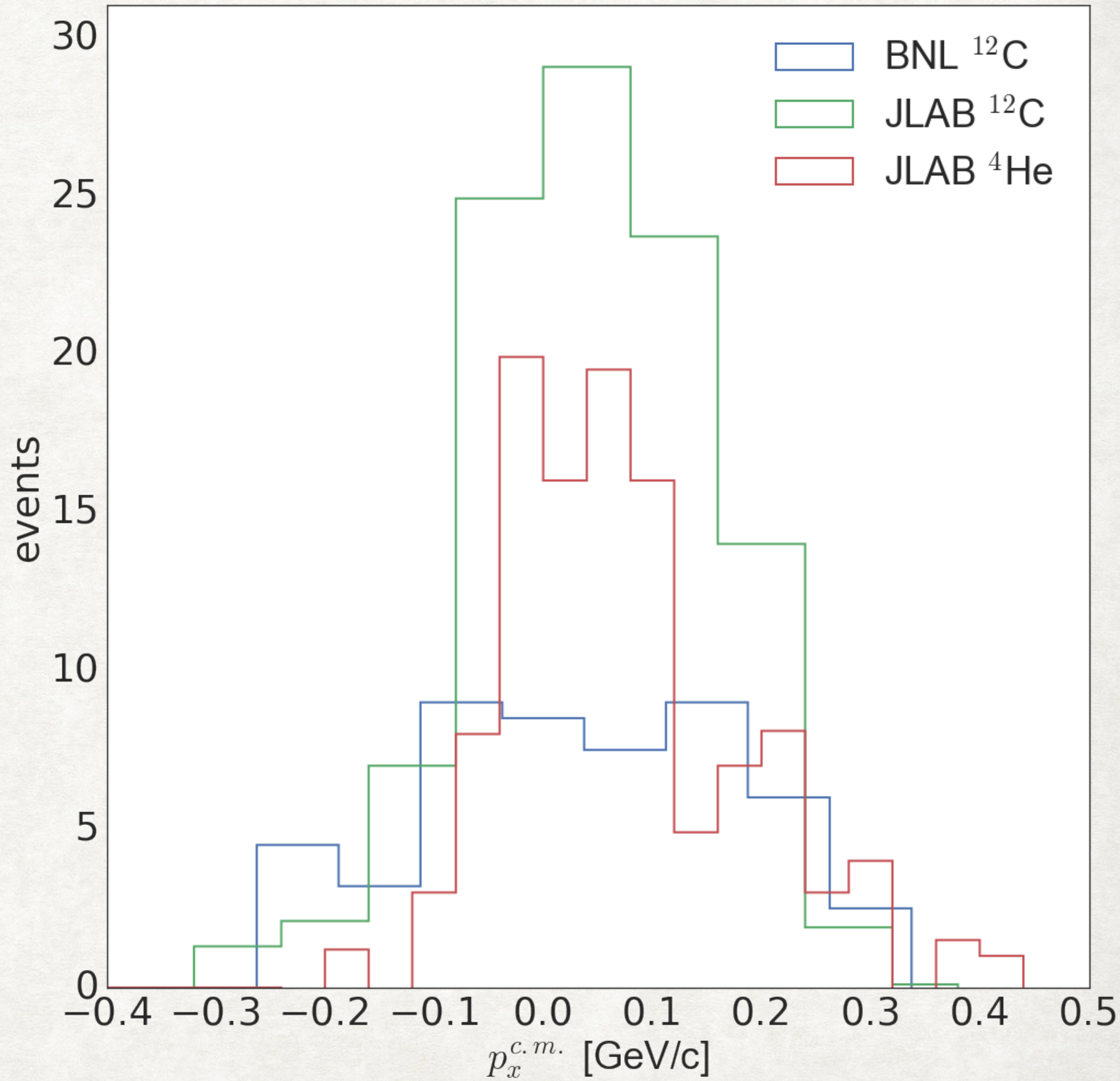
$$\sigma_{c.m.} = 143 \pm 7 \text{ MeV/c}$$

JLab ^{12}C

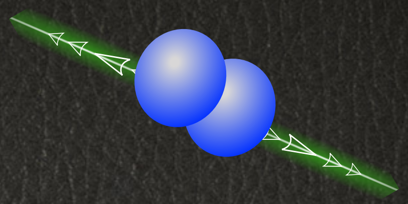
$$\sigma_{c.m.} = 136 \pm 20 \text{ MeV/c}$$

JLab ^{4}He

$$\sigma_{c.m.} = 100 \pm 20 \text{ MeV/c}$$



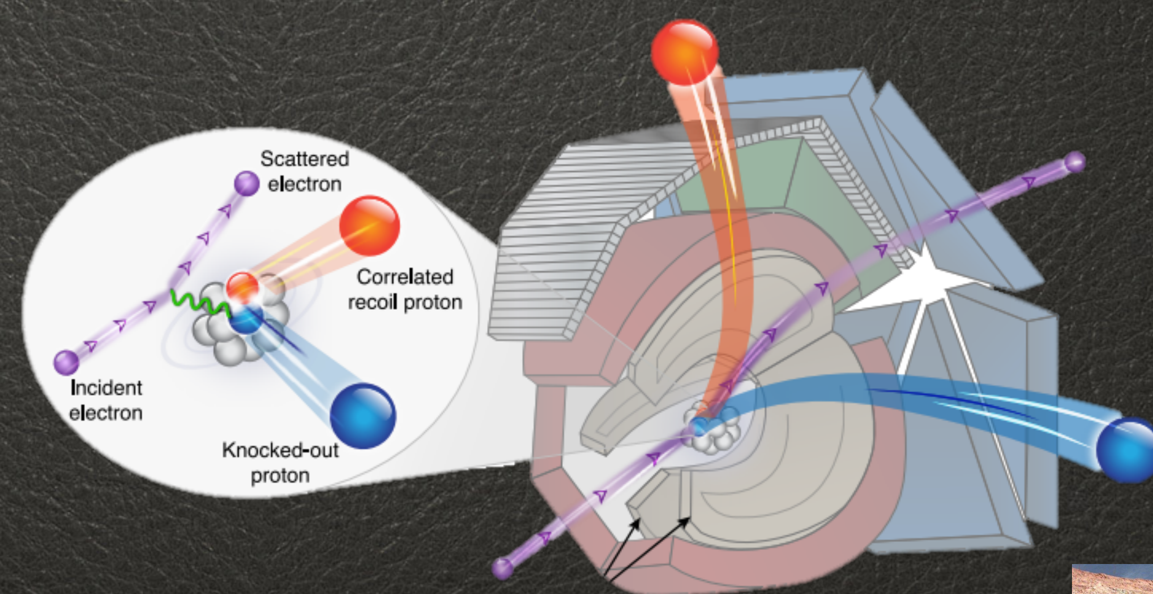
[Tang et al., PRL 90 ,042301 (2003)]
[Shneor et al., PRL 99, 072501 (2007)]
[Korover et al., PRL 113,022501(2014)]



EG2 Analysis of pp-SRC

- Data-mining
- 2004 at Hall-B, JLAB.
- 5 GeV e-beam.
- Targets:

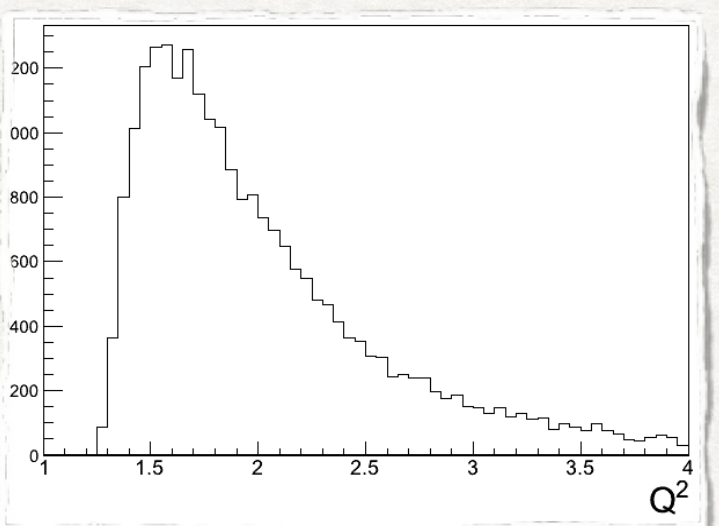
$^{2}\mathbf{H} + {}^{12}C/{}^{27}Al/{}^{56}Fe/{}^{208}Pb.$



pp-SRC events selection

(e,e'p) Kinematics

- $x_B > 1.2$
- $1 > |\mathbf{p}_{miss}| > 0.3$ GeV/c
- $M_{miss} < M_p + M_\pi$

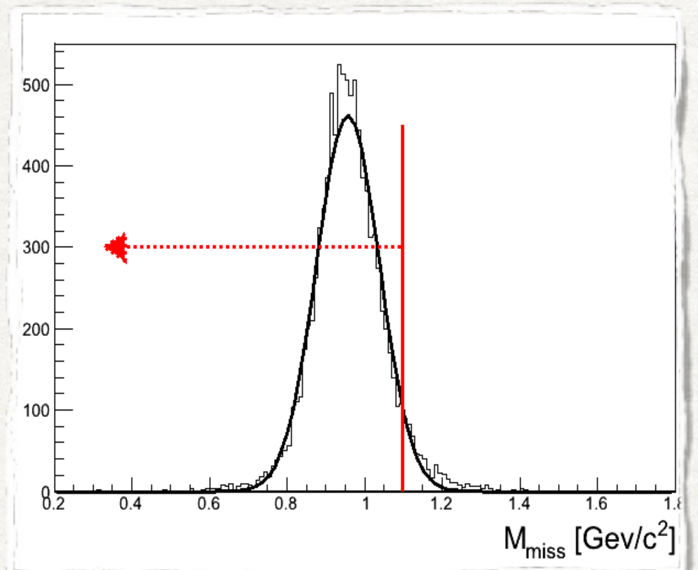


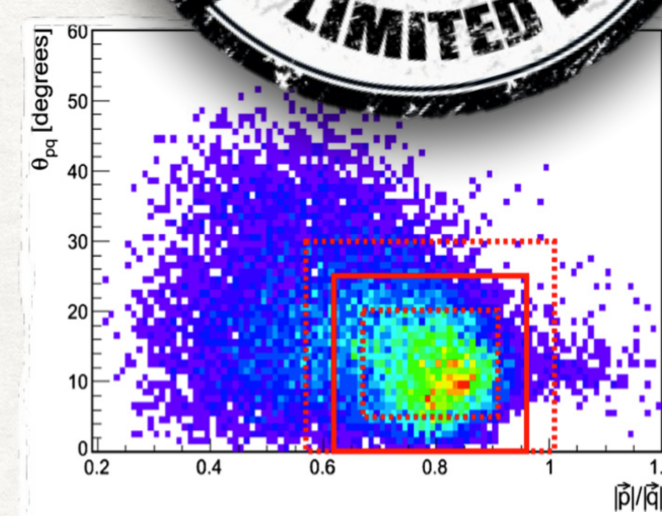
[O. Hen et al., Science, 346:614 (2014)]

[PRL 108, 092502 (2012) , PRL 113, 022501 (2014)]

(e,e'p) Leading proton

- $\theta_{pq} < 25^0$
- $0.62 < |\mathbf{p}|/|\mathbf{q}| < 0.96$

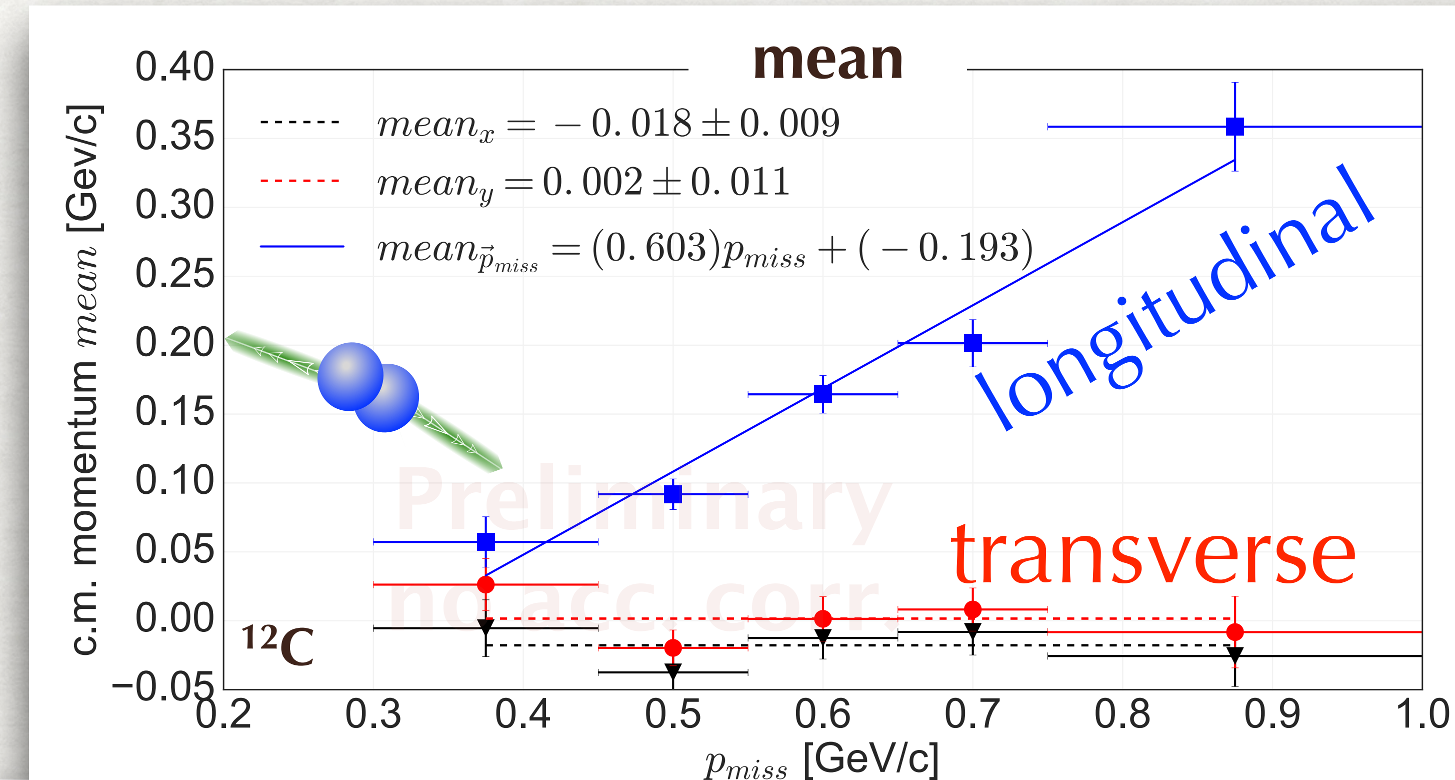


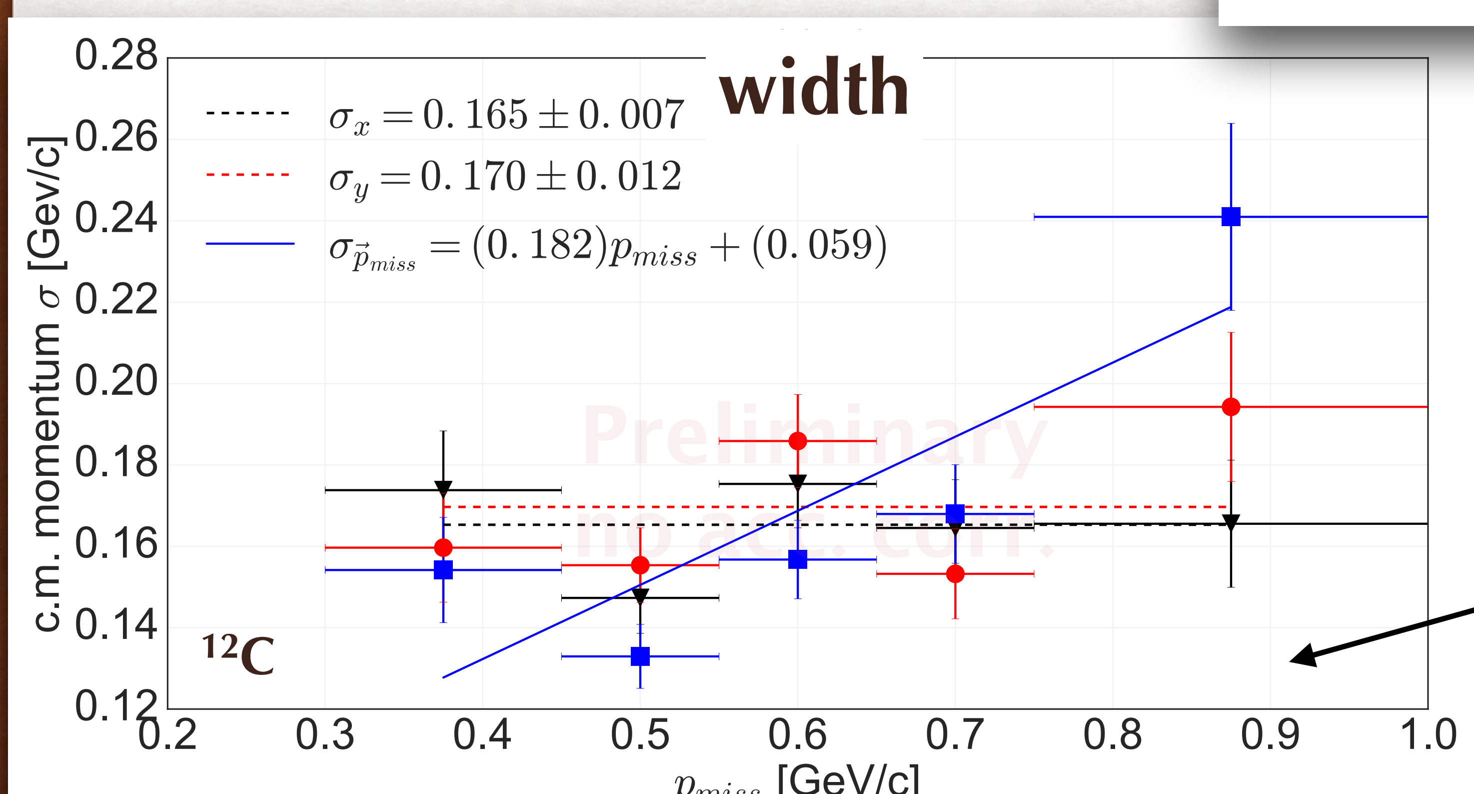


(e,e'pp) : (e,e'p) events, in which a recoil proton is detected w/ momentum > 350 MeV/c

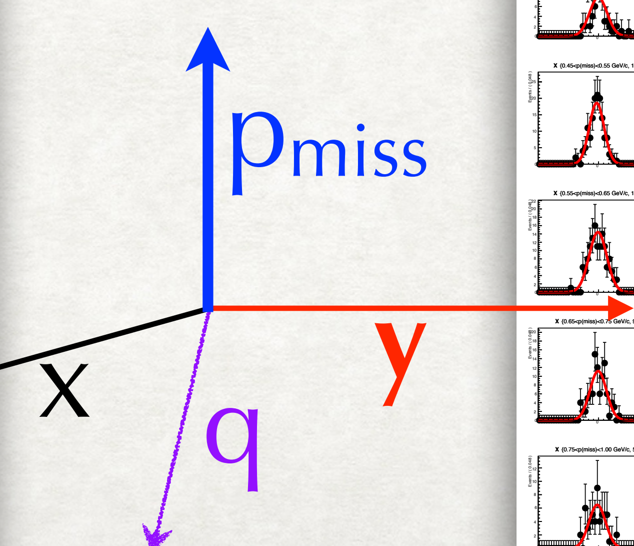
EG2 analysis - p_{cm} of a pp pair

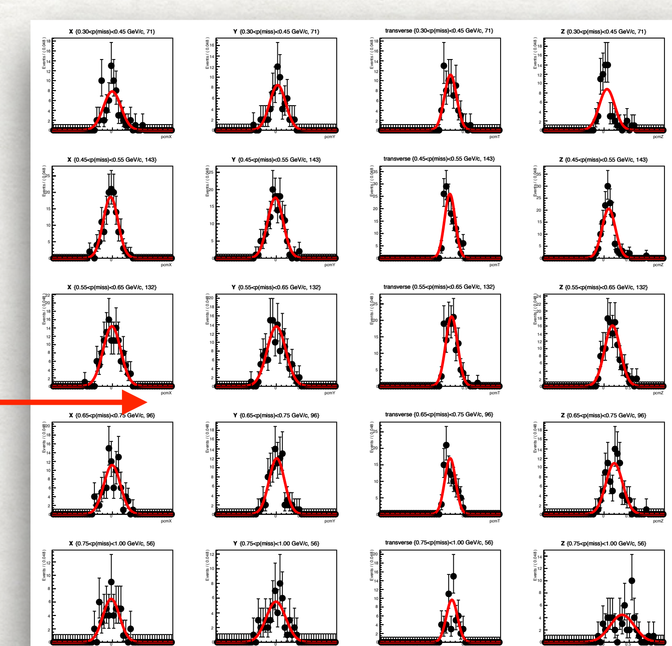
- **Fit p_{cm} distribution in each direction** to a Gaussian, extract its mean and width.
- Data un-corrected for CLAS acceptance.





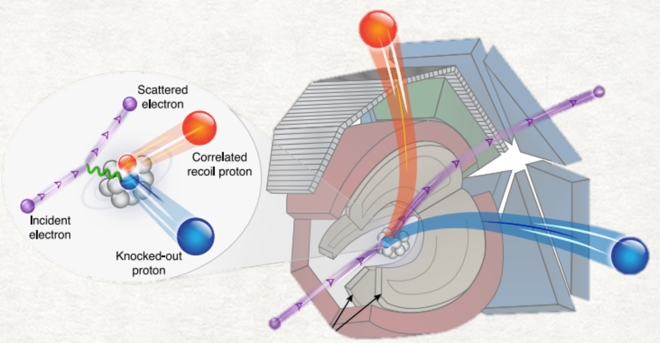
498 events after fiducial cuts



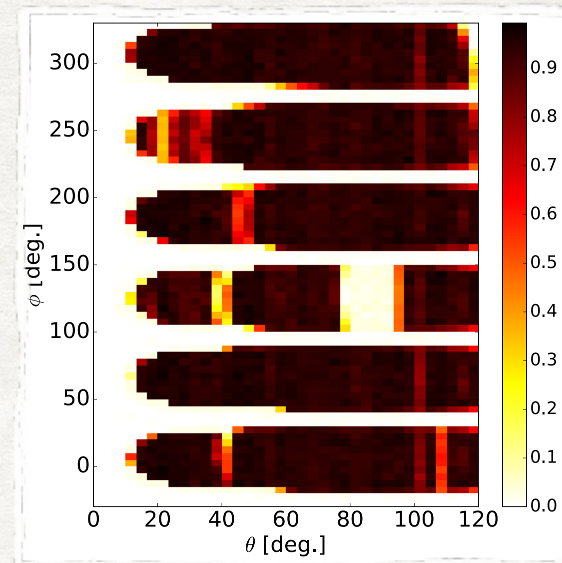


How do we extract p_{cm} distributions from the data?

- To get the momentum distribution we need to correct for **CLAS** phase-space and cuts biasing.



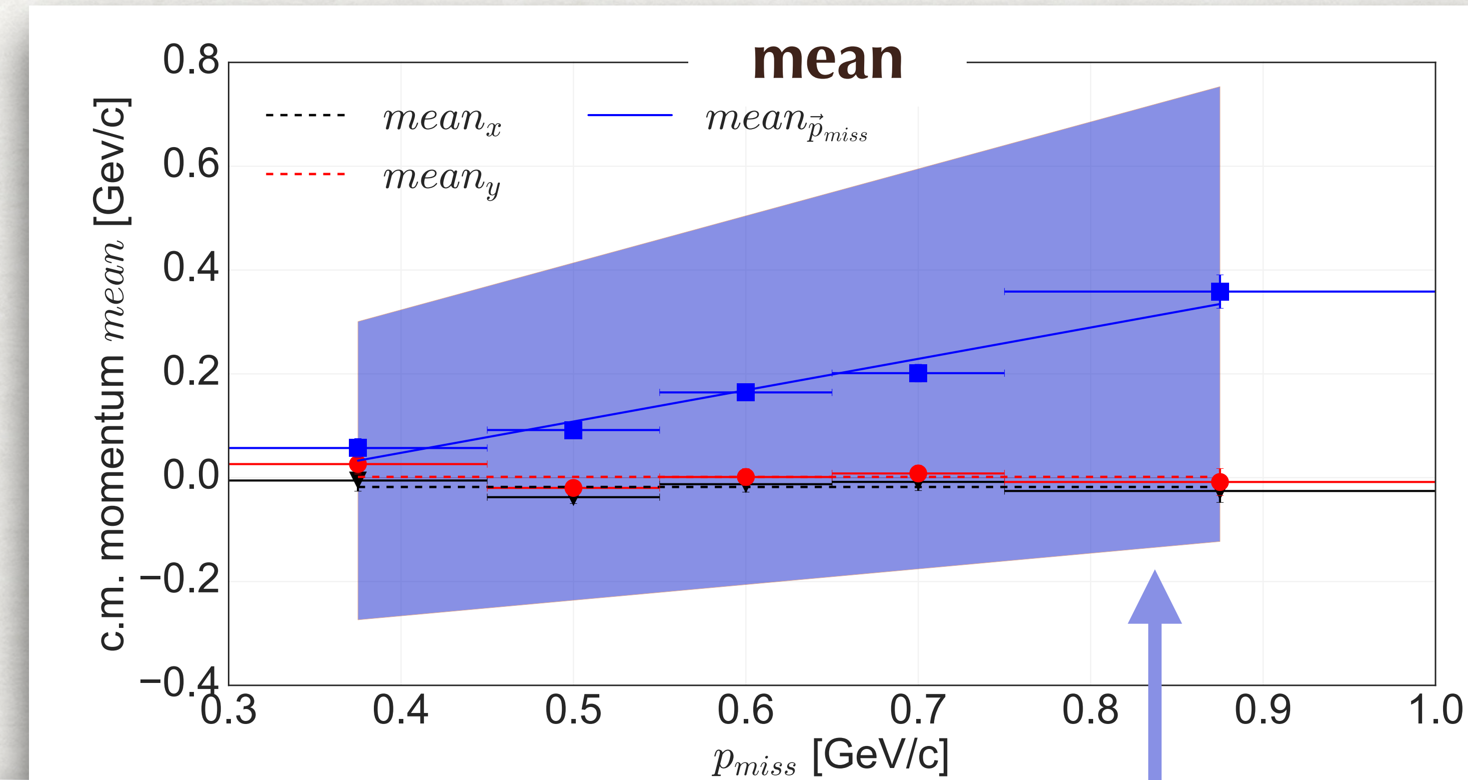
- Create **5-parameter model**
  - width of transverse distribution ($\sigma_x = \sigma_y = \boldsymbol{\sigma}$)
  - (vanishing transverse mean, $\mu_x = \mu_y = 0$)
  - width of longitudinal distribution ($\sigma_z = \mathbf{a_\sigma} + \mathbf{b_\sigma}\, p_{miss}$)
  - mean of longitudinal distribution ($\mu_z = \mathbf{a_\mu} + \mathbf{b_\mu}\, p_{miss}$)

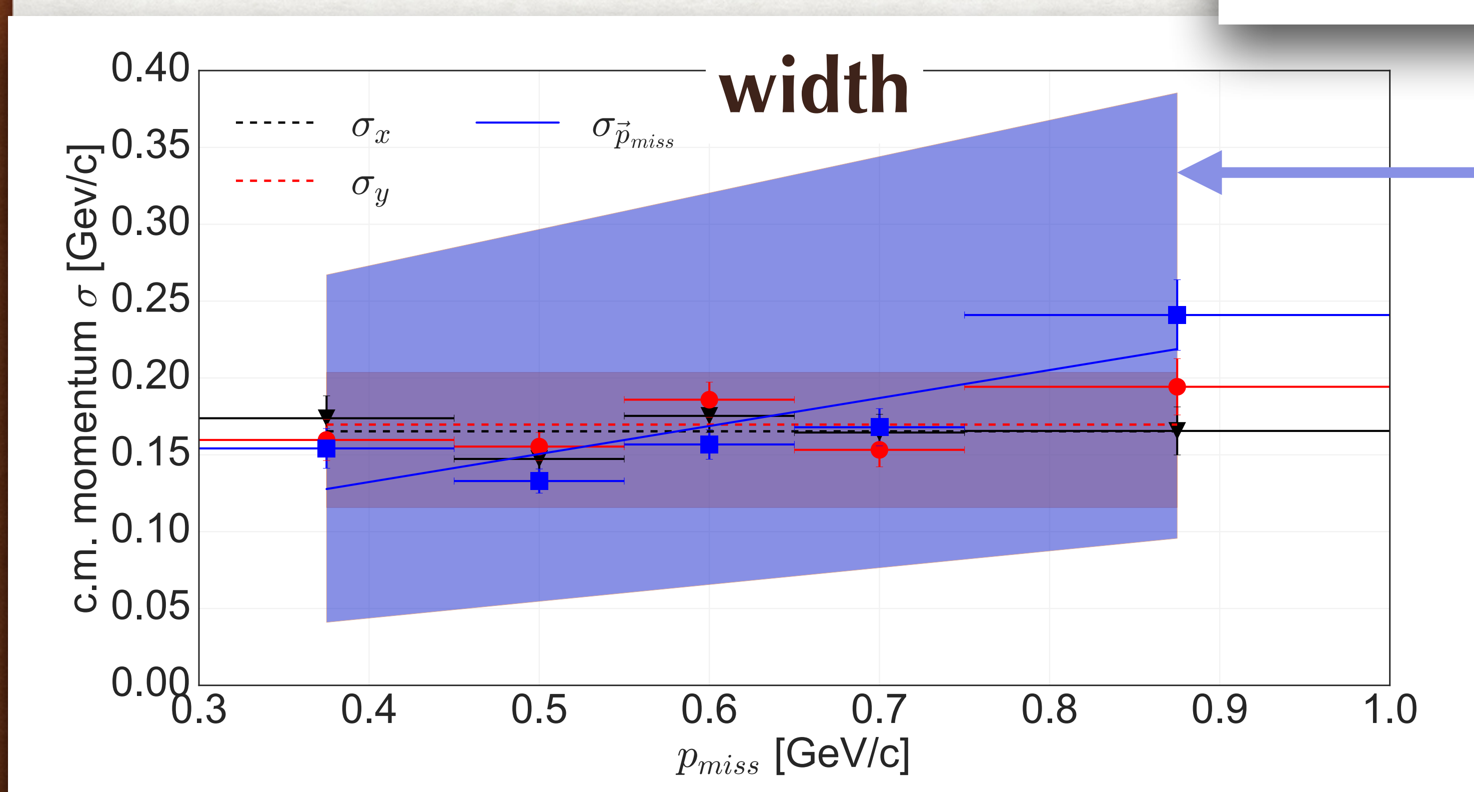


- **Generate a set of simulated events for each combination of model parameters, and compare resulting accepted (e,e'pp) events to measured data.**

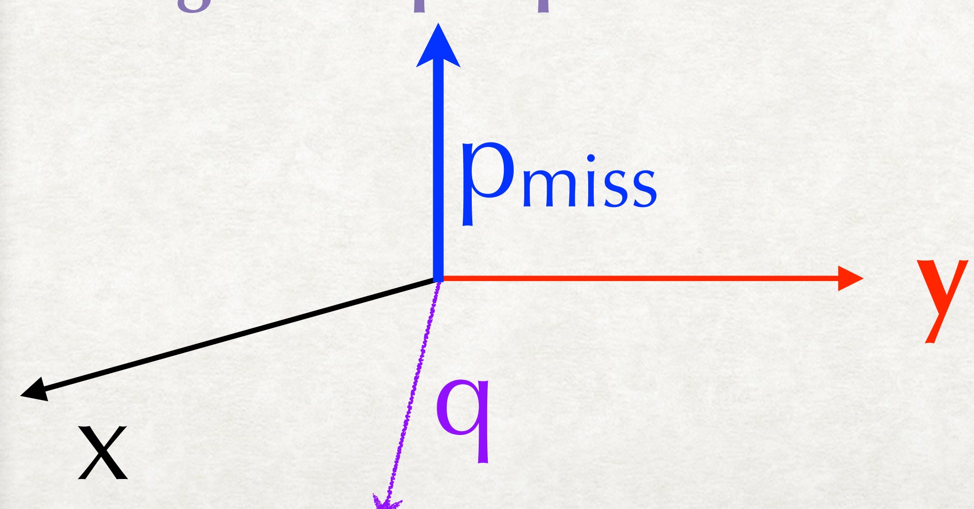
How do we extract p_{cm} ? (continue)

- Consider realistic parameters - bands around nominal values,
- Generate synthetic EG2-data, ran through the virtual CLAS and analyzed similarly to data.
- Find the parameters that best correspond with the data.

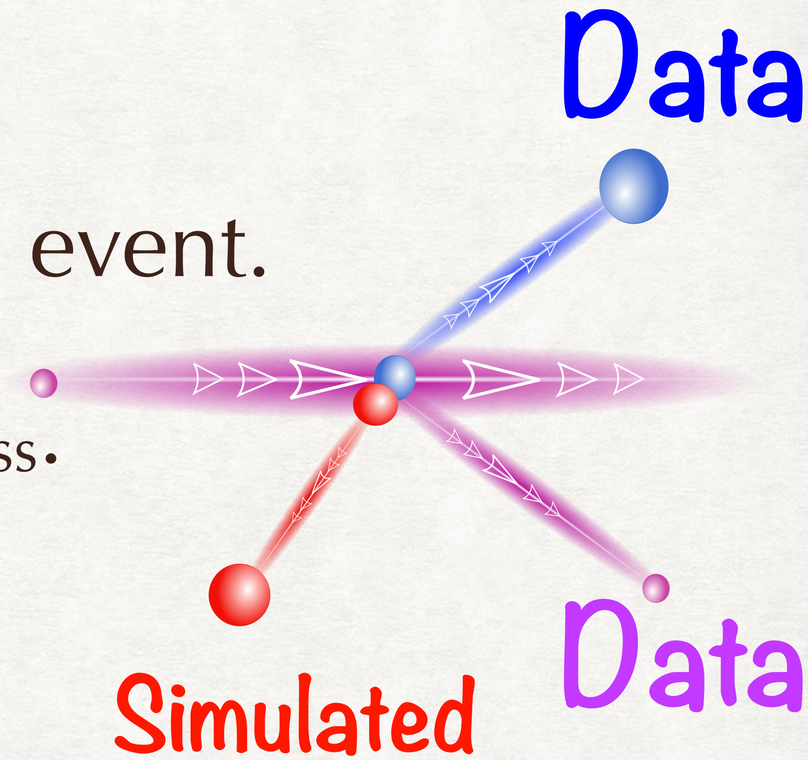




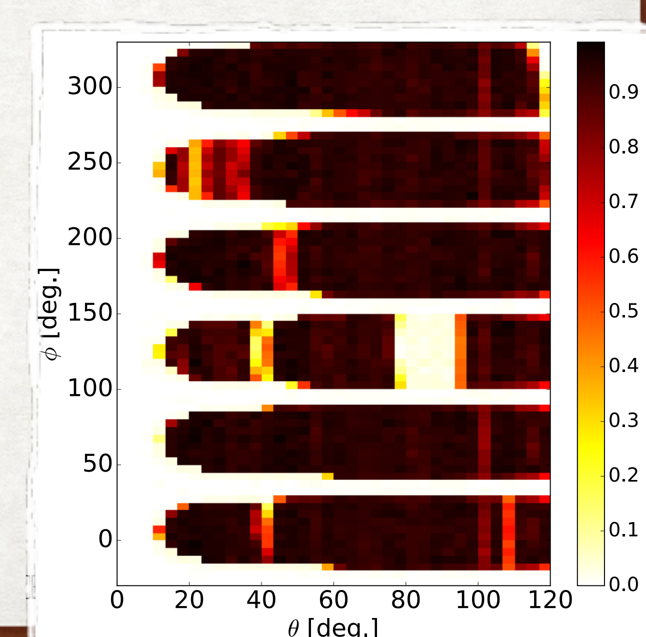
Purple and orange bands show range of input parameters.



How do we extract p_{cm}? (continue)

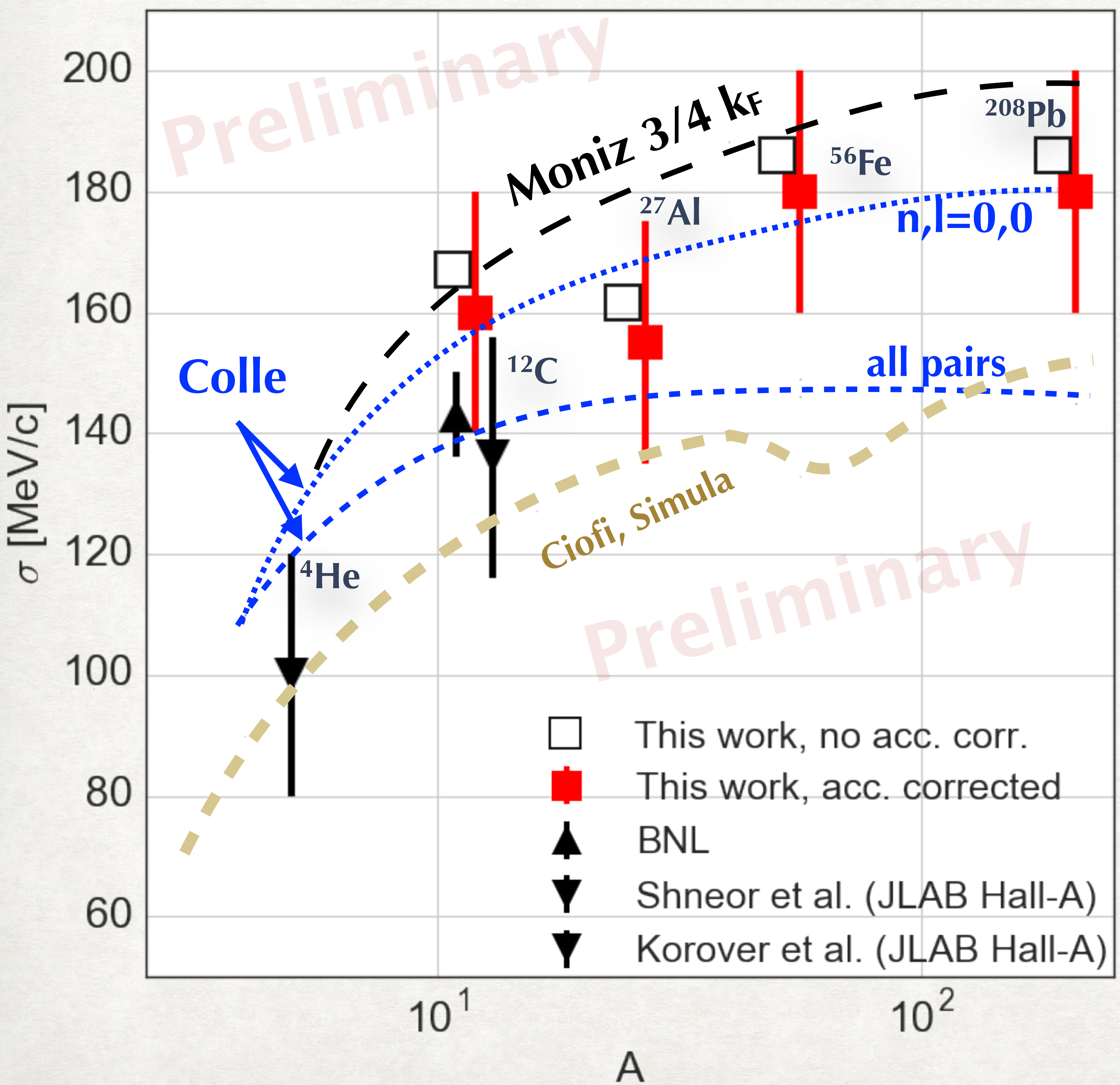


- Randomly select measured an SRC (e,e'p) event.
- Generate $\mathbf{p}_{cm}$ and define $\mathbf{p}_{recoil} = \mathbf{p}_{cm} - \mathbf{p}_{miss}$.
- Apply CLAS acceptance and fiducial cuts
- Weight recoil proton with CLAS detection efficiency.
- **Compare resulting accepted (e,e'pp) events to measured data, and assign a P-value.**

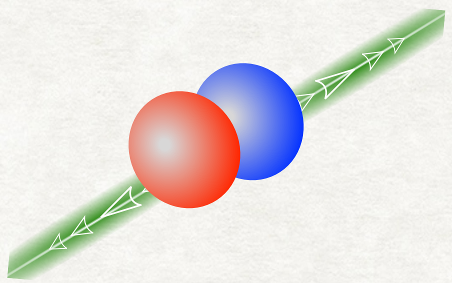


Preliminary Results

Pcm (Transverse)



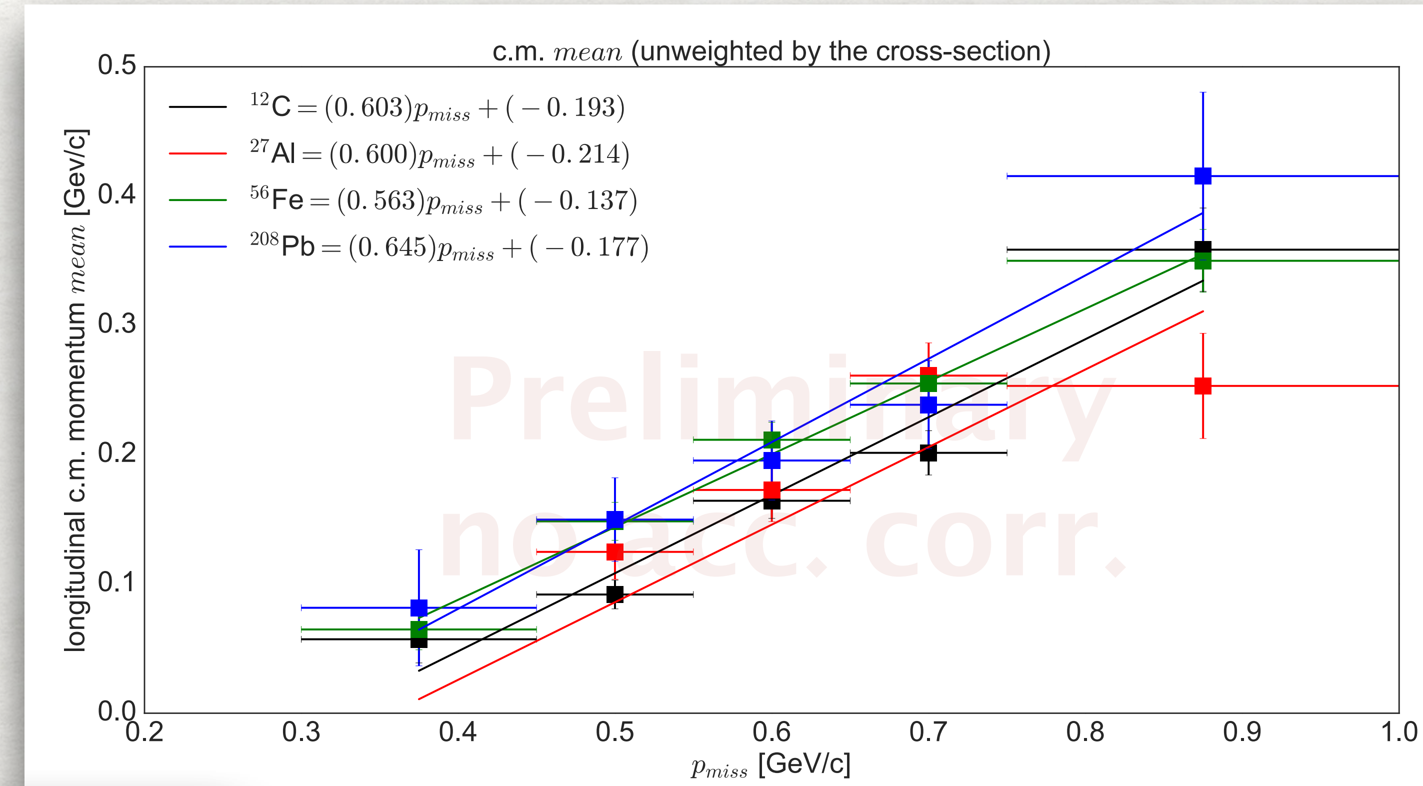
- Low SRC-pair **c.m. momentum** width.
- **Consistent with the n,l=0,0** prediction.

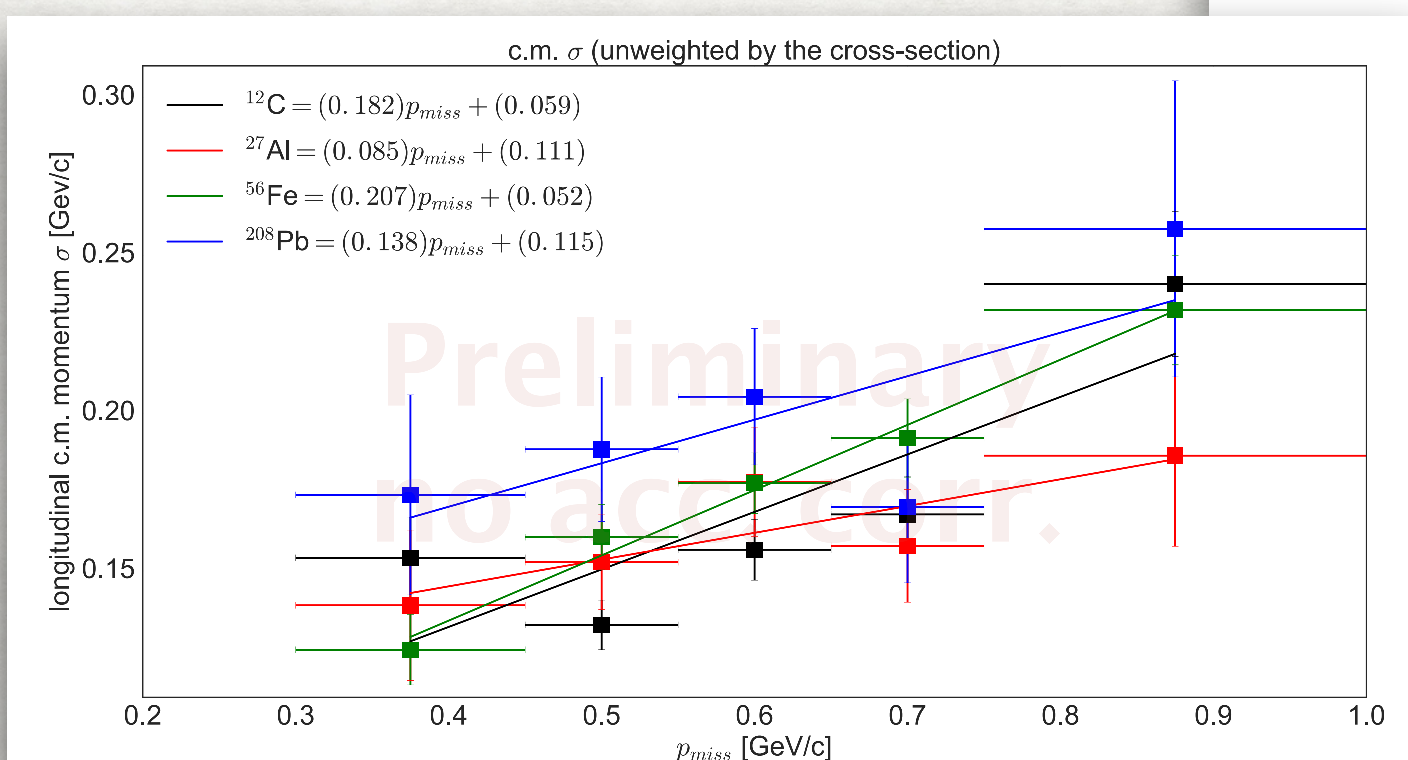


[Colle et al. PhysRevC.89.024603]
[Ciofi, Simula, PRC53, 1689 (1996)]
[Korover et al., PRL 113,022501(2014)]
[Shneor et al., PRL 99, 072501 (2007)]
[Tang et al., PRL 90 ,042301 (2003)]

p_{cm} (Longitudinal)

- Next step: extract information on the **relative momentum** from $p_{cm}(p_{miss})$.





- **Acceptance corrections:**
  - expected to be small.
  - are under study.

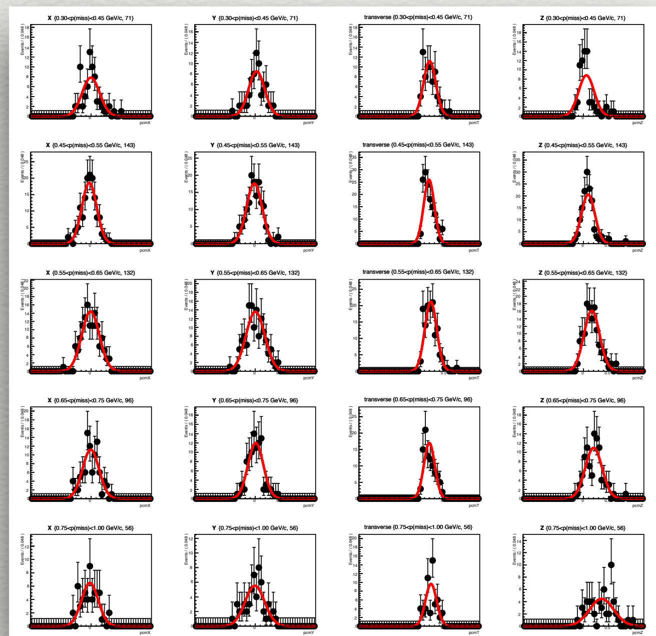
Thank you for your time…

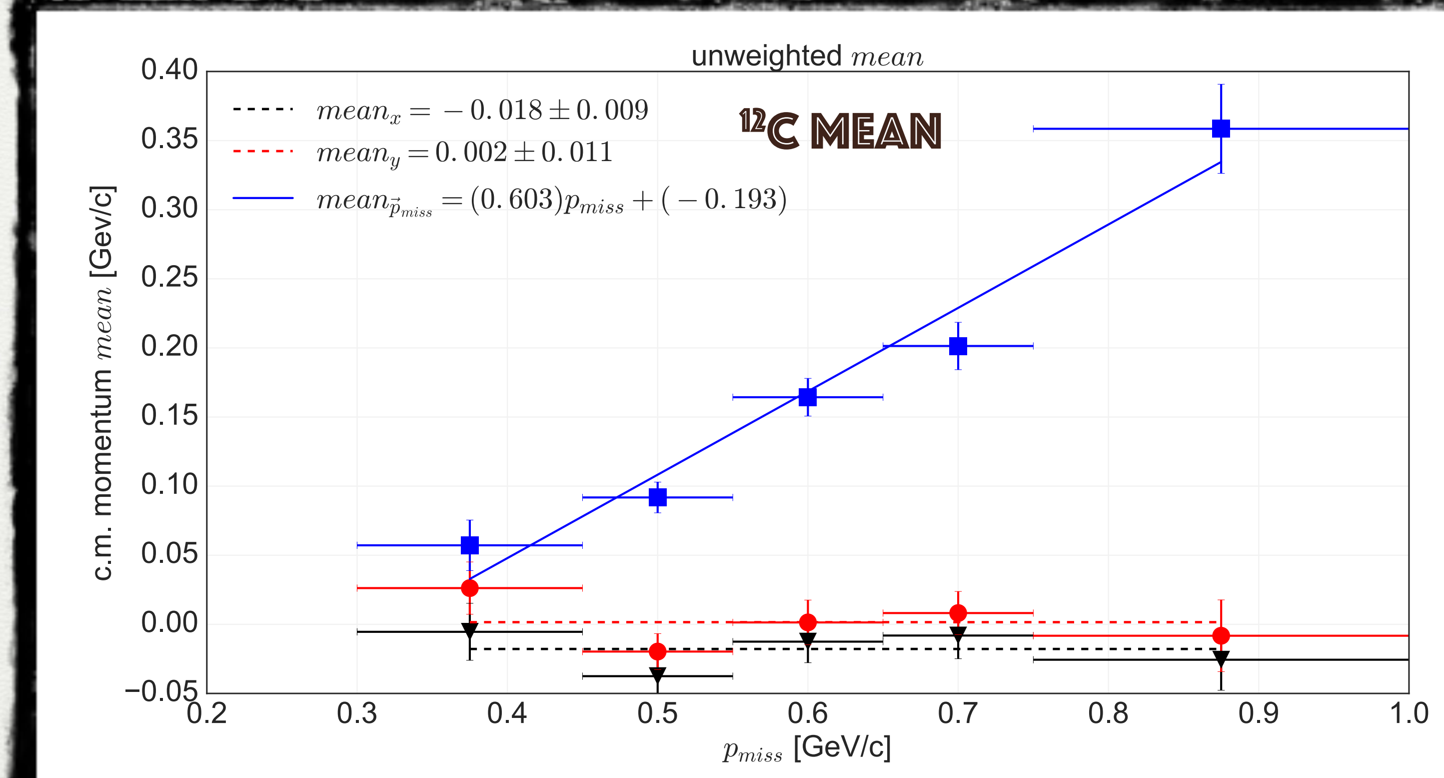
Comments/Suggestions/Questions:
cohen.erez7@gmail.com

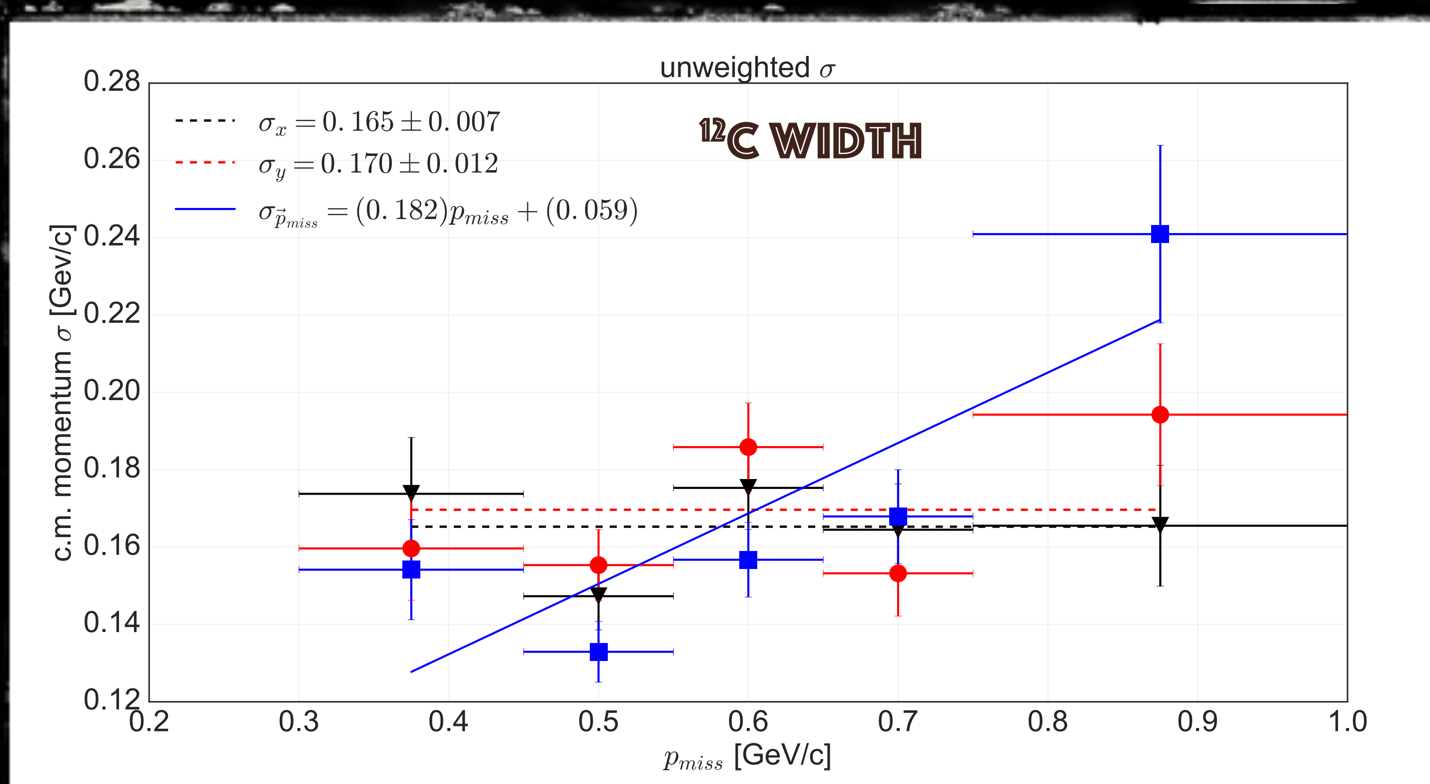
Backup Slides

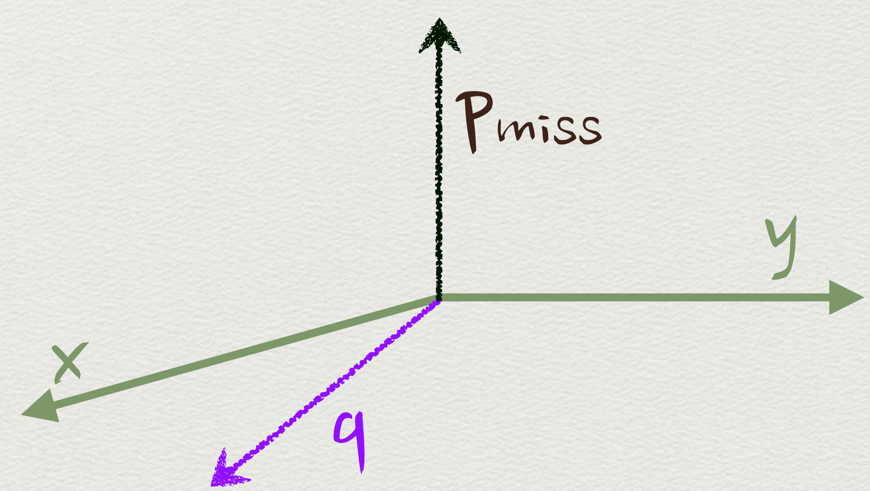
unweighted EG2 analysis - no acc. corr.

498 events after fiducial cuts



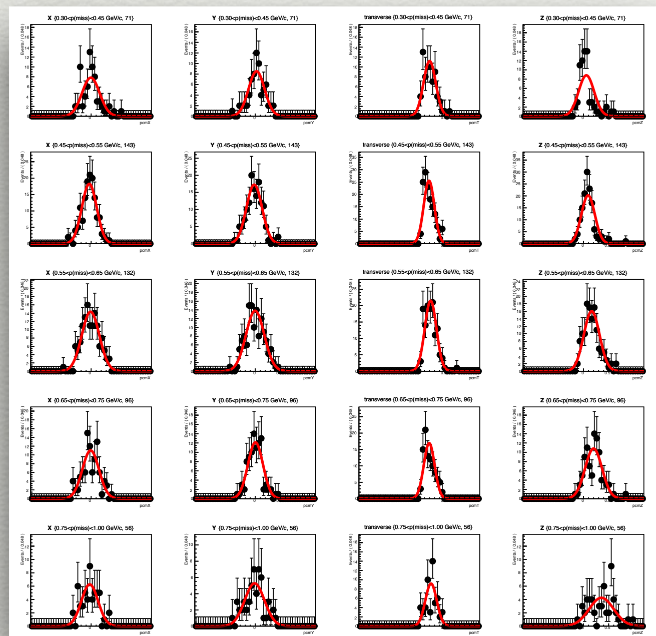


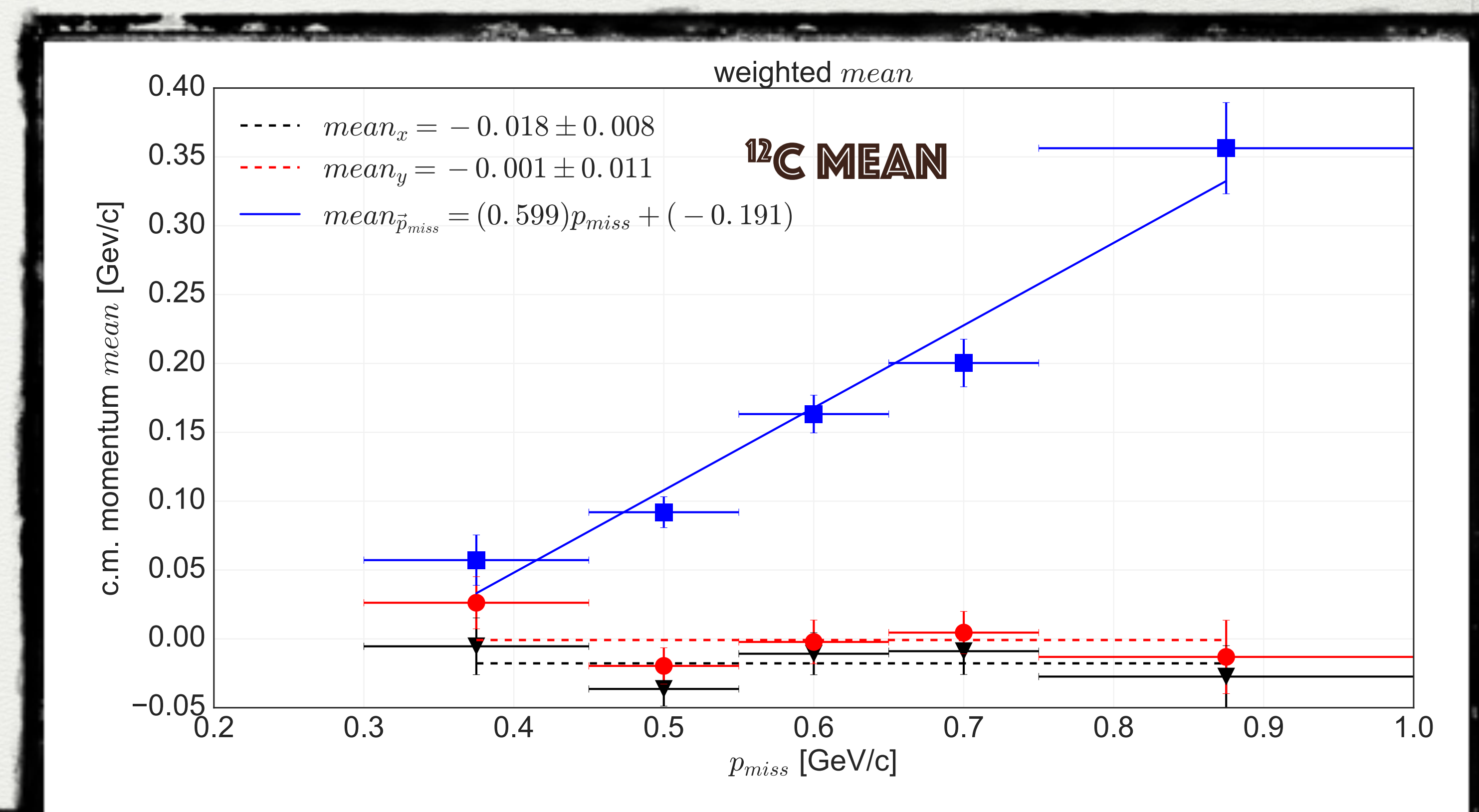


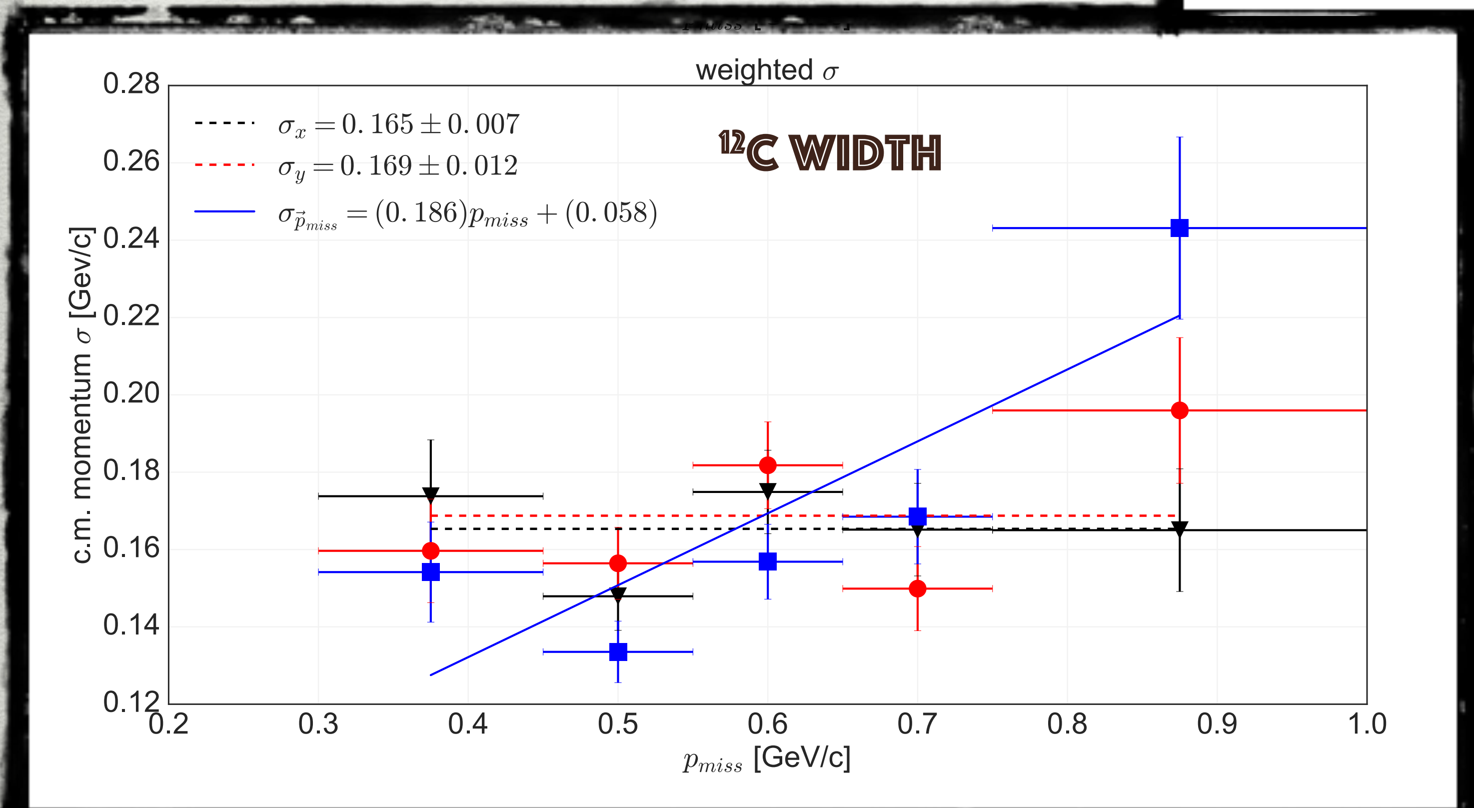


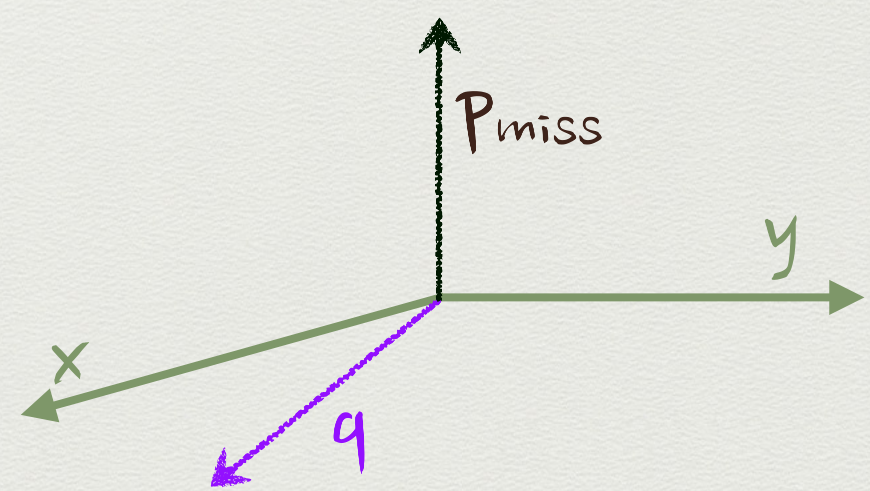
weighted EG2 analysis - no acc. corr.

498 events after fiducial cuts



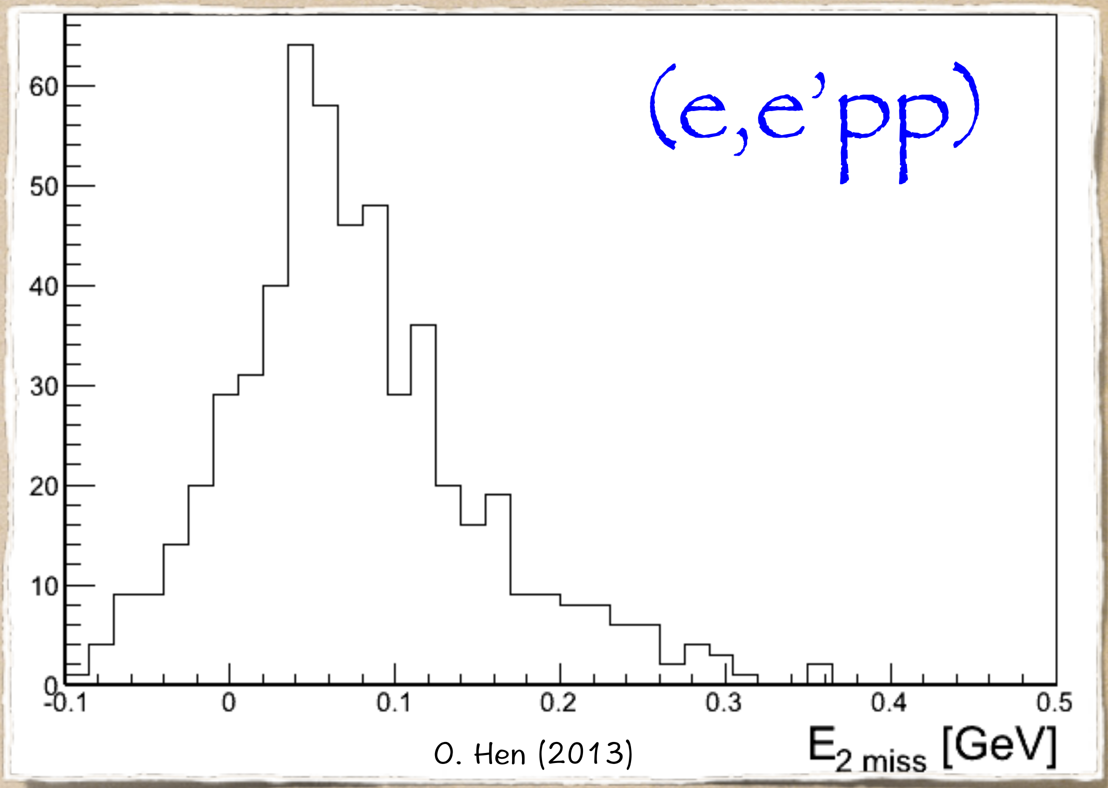




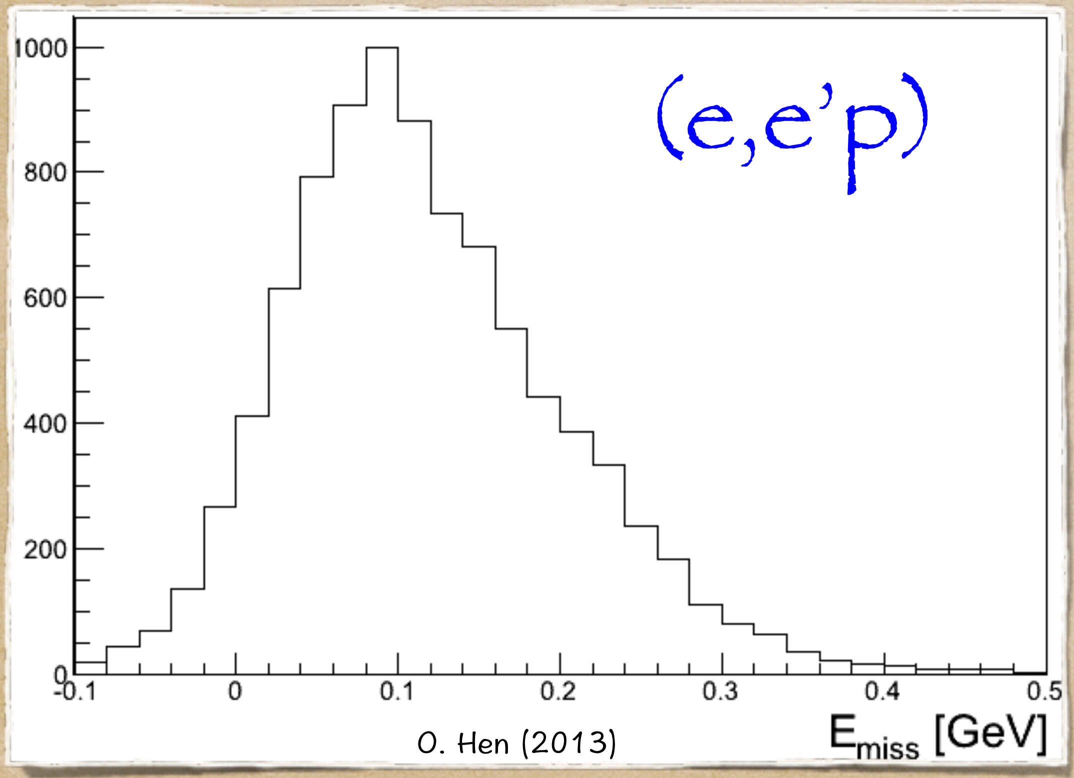


EXCITATION ENERGIES

Excitation energies



$$E_{miss} = \omega - T_p - T_{A-1}$$

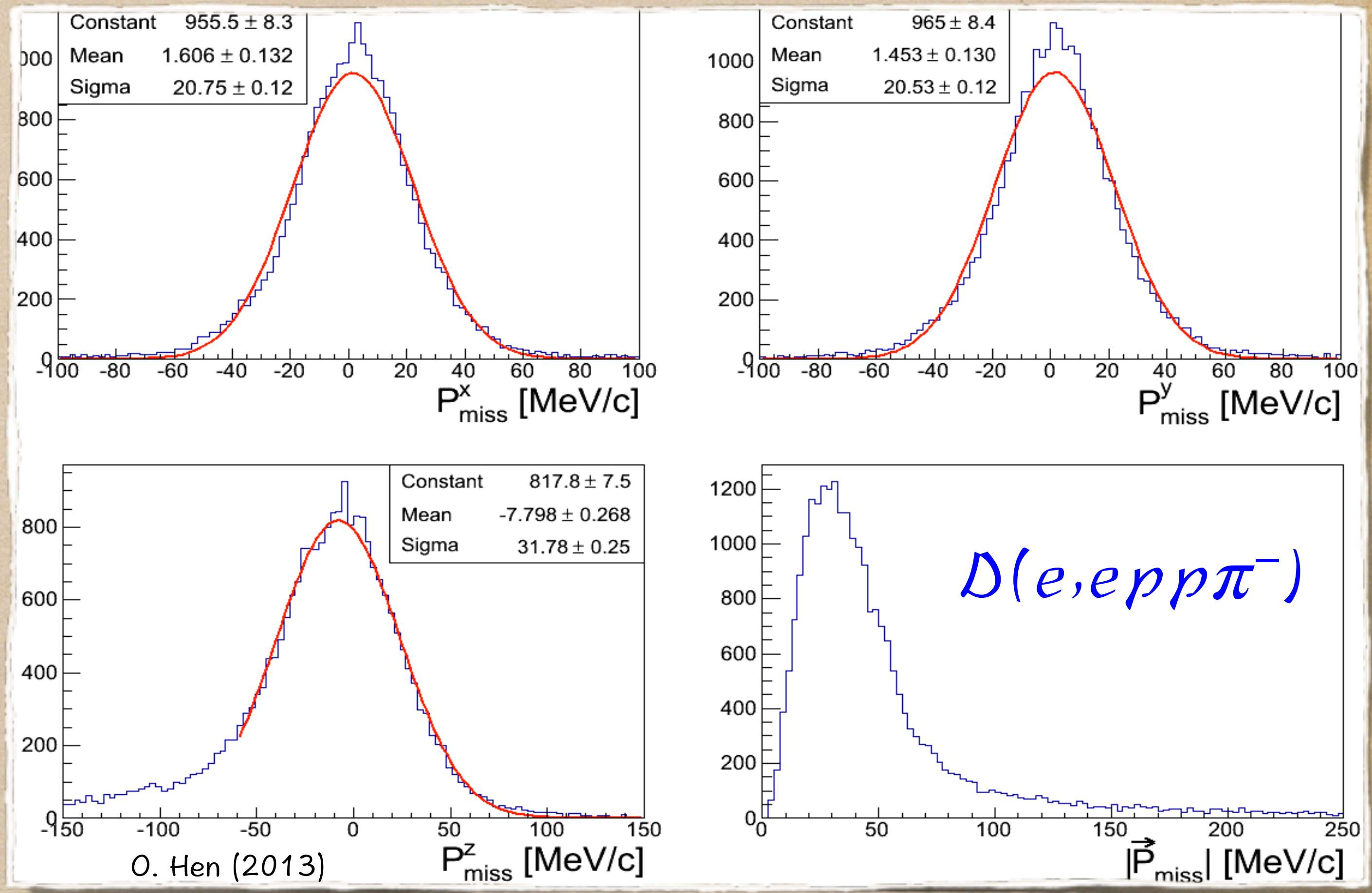


$$E_{2-miss} = \omega - T_{lead} - T_{recoil} - T_{A-2}$$

CLAS RESOLUTION CONTRIBUTION TO WIDTH OF C.M.

CLAS resolution contribution to width of c.m.

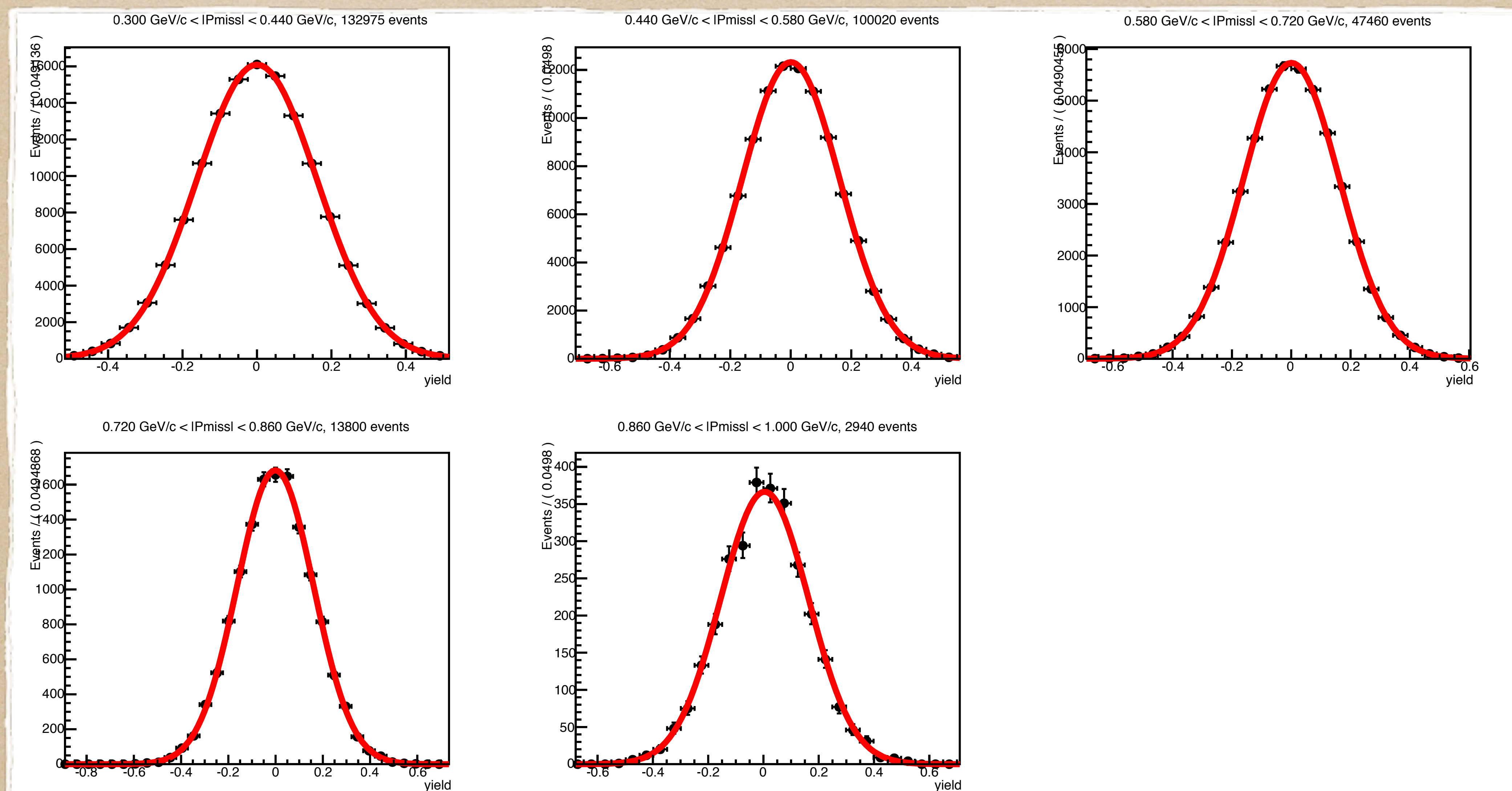
$$\sigma_{c.m.} = \sqrt{\sigma_{exp}^2 - \sigma_{res}^2}$$



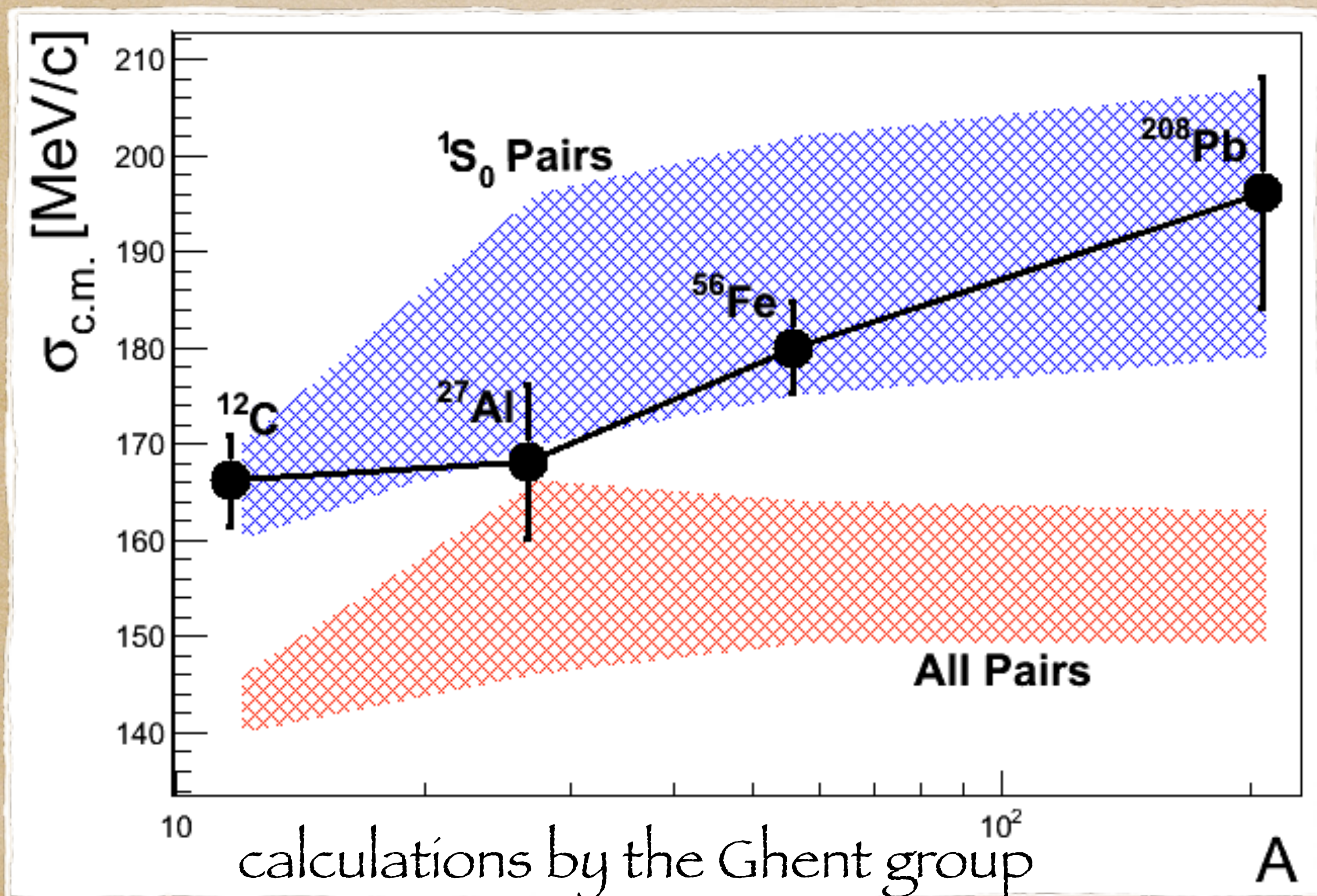
$\sigma_{res} \sim 20$ MeV/c

☞ Correction ~ 3 MeV/c for $\sigma_{exp} \sim 160$ MeV/c

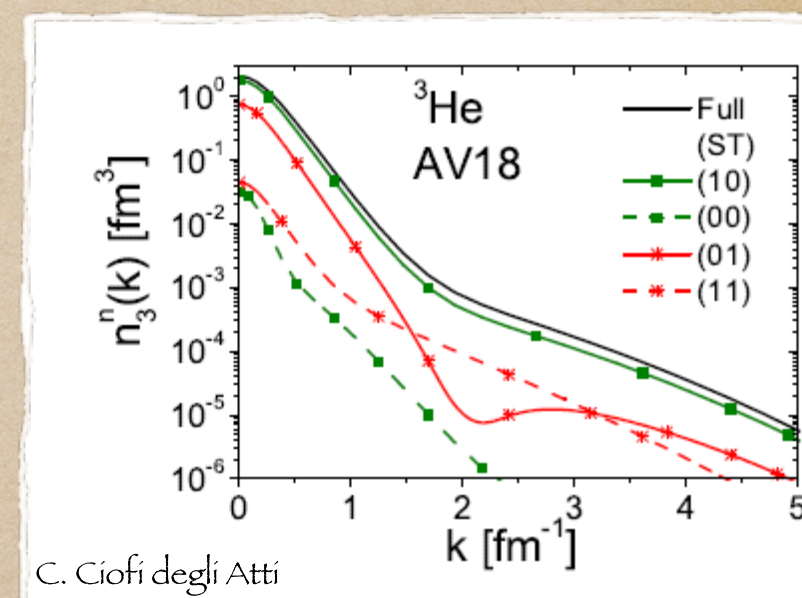
Using RooFit for un-binned fitting



C.M. motion width



calculations by the Ghent group



C. Ciofi degli Atti

nucleus	σ_x [MeV/c]	σ_y [MeV/c]
^{12}C	169±7	164±6
^{27}Al	162±10	180±13
^{56}Fe	179±6	182±7
^{208}Pb	208±18	186±16

The spin-Isospin contribution to the momentum distribution

Light cone

Light-cone fraction study

$$\alpha = A\frac{E_p - p_z}{m_A}$$

- The Light-Cone fraction has less sensitivity to FSI.
- Goes together with the transverse momentum

flux calculated for the moving nucleon

$$\frac{d\sigma}{dE'_e d\Omega'_e d^3p_f d^3p_{rec}} = \frac{j_N}{j_A} A \sum_N \sigma_{eN}(p_f, k_e, k'_e) D^N(\vec{p}_m, E_m, \vec{p}_{rec})$$

Sargsian, Abrahamyan, Strikman and Frankfurt), Phys. Rev. C 71, 044615

electron - off-shell eN scattering

2N-SRC Decay function formalism

$$\frac{d\sigma}{dE'_e d\Omega'_e d^3p_f d^3p_{rec}} = \frac{j_N}{j_A} A \sum_N \sigma_{eN}(p_f, k_e, k'_e \ldots) \, D^N(\ldots, E_m, \vec{p}_{rec})$$

The decay function is a convolution of two density matrices representing the relative and c.m. momentum distribution

$$D = \rho_{rel} \cdot \rho_{c.m.} \frac{\alpha_{rec}}{\alpha_{c.m.}} \times \delta\left(P_{R+} - \frac{m^2 - (p_{rec})^2_T}{m\alpha_{rec}} - \frac{M^2_{A-2} + (p_{c.m.})^2_T)}{m(A - \alpha_{c.m.})}\right)$$

E. Piasetzky et al., Phys.Rev.Lett. 97 (2006) 162504

LC componenet of the residual A-1 nuclear state

Light-cone fraction study

$$\alpha = A\frac{E_p - p_z}{m_A}$$

- Define the equivalents of detected, missing, c.m. and recoil light cone fraction of momenta

$$\alpha_{miss} = \alpha_{initial} = \alpha_{lead} - \alpha_q$$

$$\alpha_{c.m.} = \alpha_{miss} + \alpha_{rec}$$

Where $\alpha_q = \dfrac{\omega - |q|}{m}$

$$(p_{c.m.})_T = (p_{miss})_T + (p_{rec})_T$$

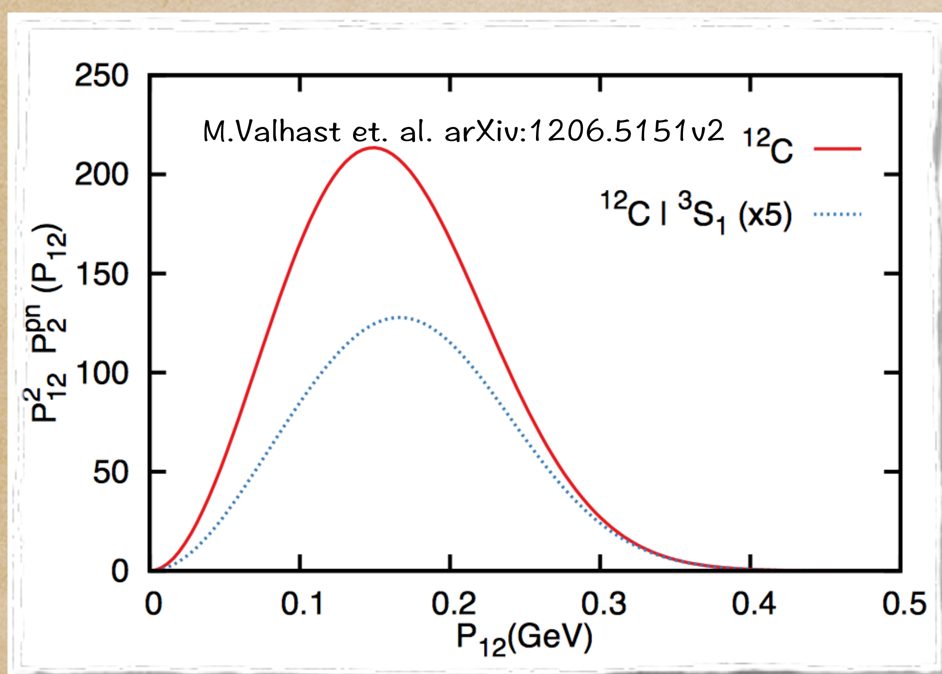
$$(p_{rel})_T = (p_{rec})_T - \frac{\alpha_{rec}}{\alpha_{c.m.}}(p_{c.m.})_T$$

2N-SRC Decay function formalism

$$\frac{d\sigma}{dE'_e d\Omega'_e d^3p_f d^3p_{rec}} = \frac{j_N}{j_A} A \sum_N \sigma_{eN}(p_f, k_e, k' \; D^N \; , E_m, \vec{p}_{rec})$$

E. Piasetzky et al., Phys.Rev.Lett. 97 (2006) 162504

$$D = \rho_{c.m.} \cdot \times \delta\left(P_{R+} - \frac{m^2 - (p_{rec})_T^2}{m\alpha_{rec}} - \frac{M_{A-2}^2 + (p_{c.m.})_T^2)}{m(A - \alpha_{c.m.})}\right)$$



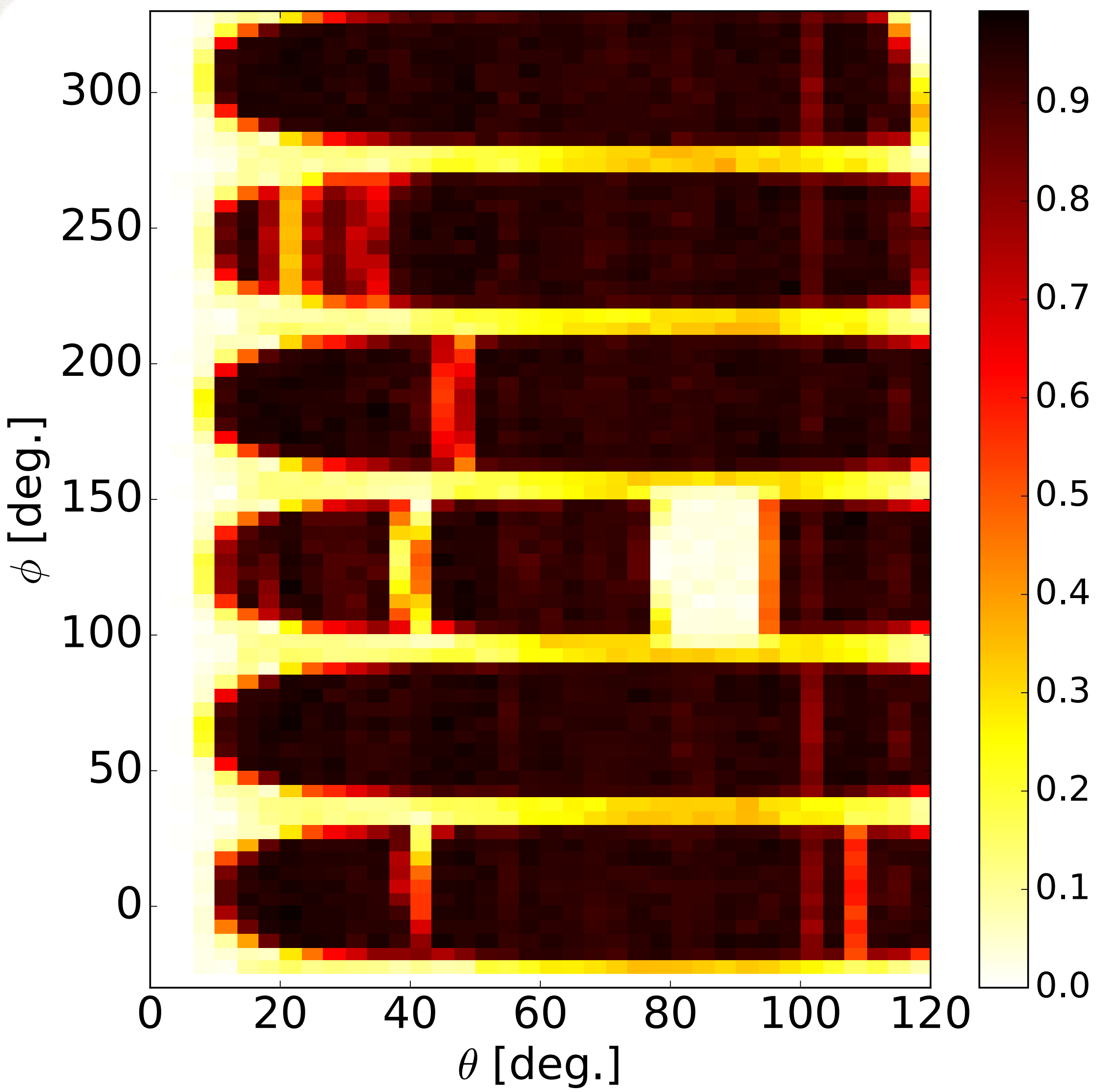
- The 2-body c.m. momentum distribution can be parametrized in terms of Gaussian distribution.

$$\rho_{rel}(\alpha_{rel}, (p_{rel})_T) = a_2(A/d)\frac{\psi_D^2(k_{rel})}{2 - \alpha_{rel}}\sqrt{m^2 + k_{rel}^2}$$

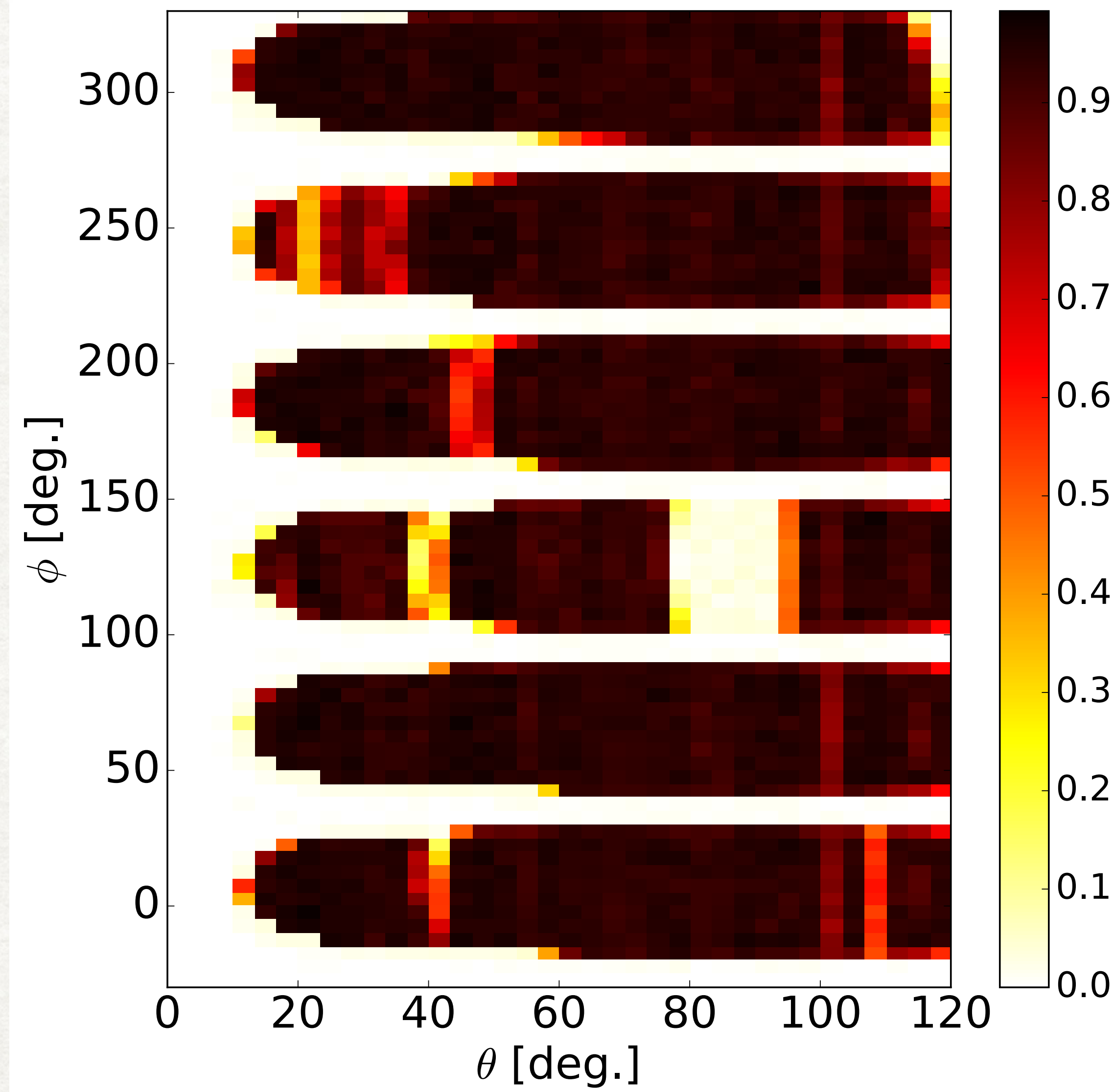
$$\rho_{c.m.}(\alpha_{c.m.}, (p_{c.m.})_T) = \frac{2m}{(2\pi\sigma_{c.m.}^2)} e^{-\frac{m^2(2-\alpha_{c.m.})^2 + (p_{c.m.})_T^2}{2\sigma_{c.m.}^2}}$$

Recoil proton Acceptance

Full detector



Fiducial region

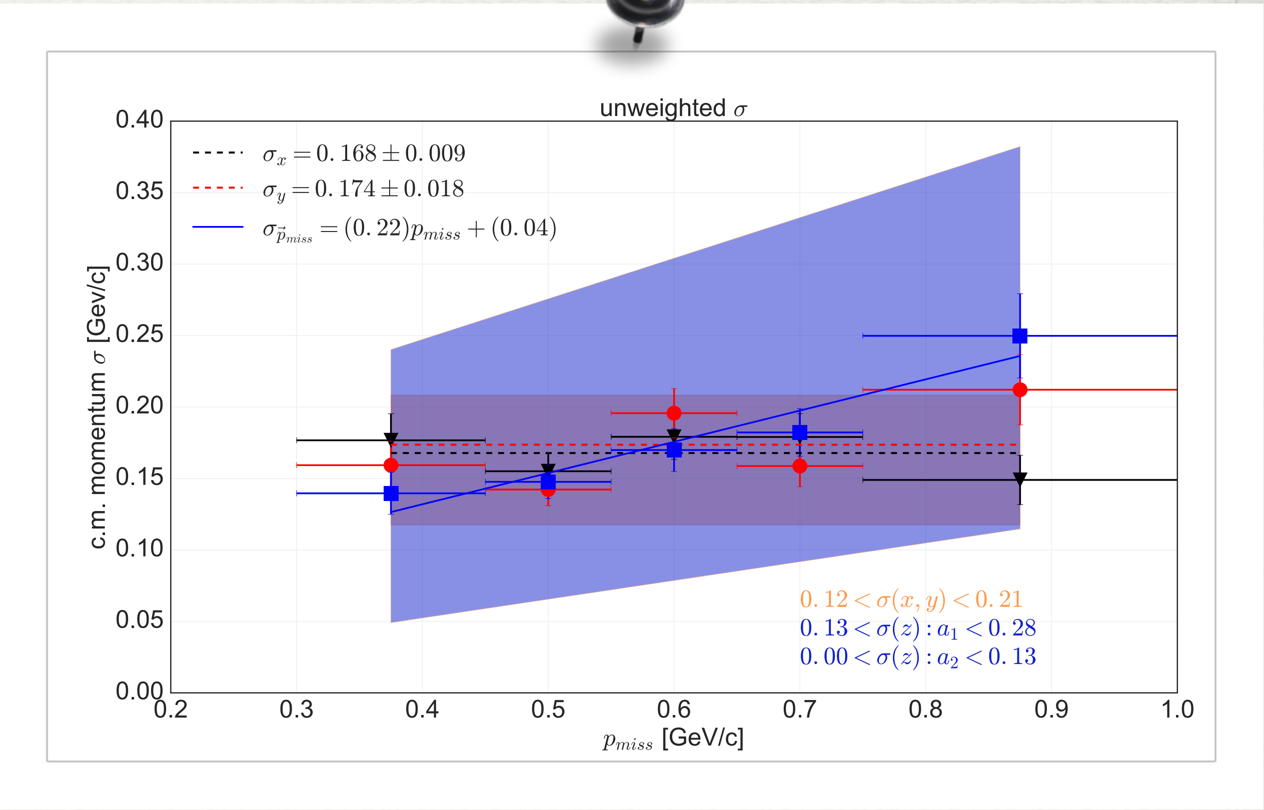


First Step

Fix all parameters except transverse momentum width

Varying Transverse c.m. width

Transverse c.m. width

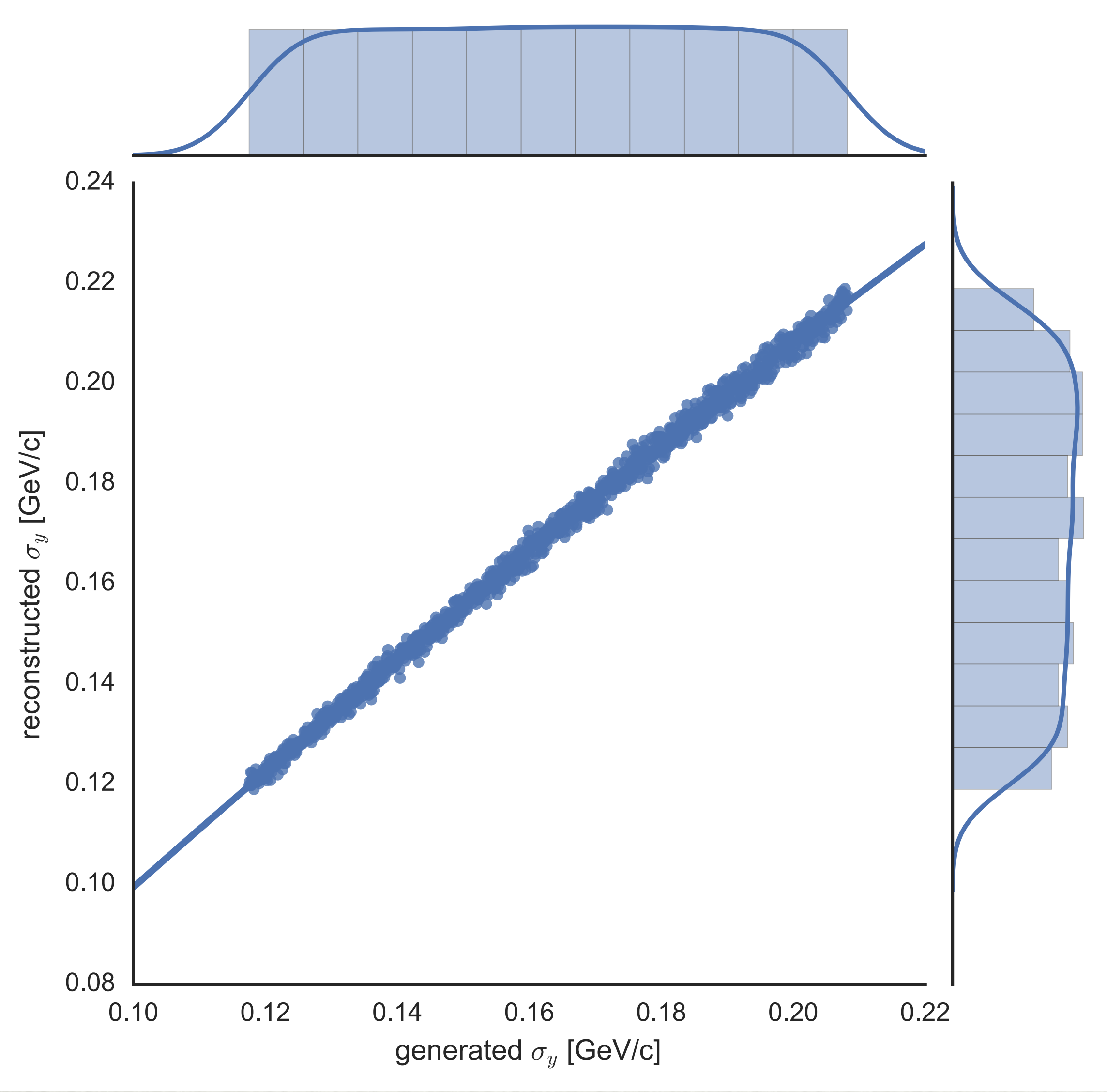


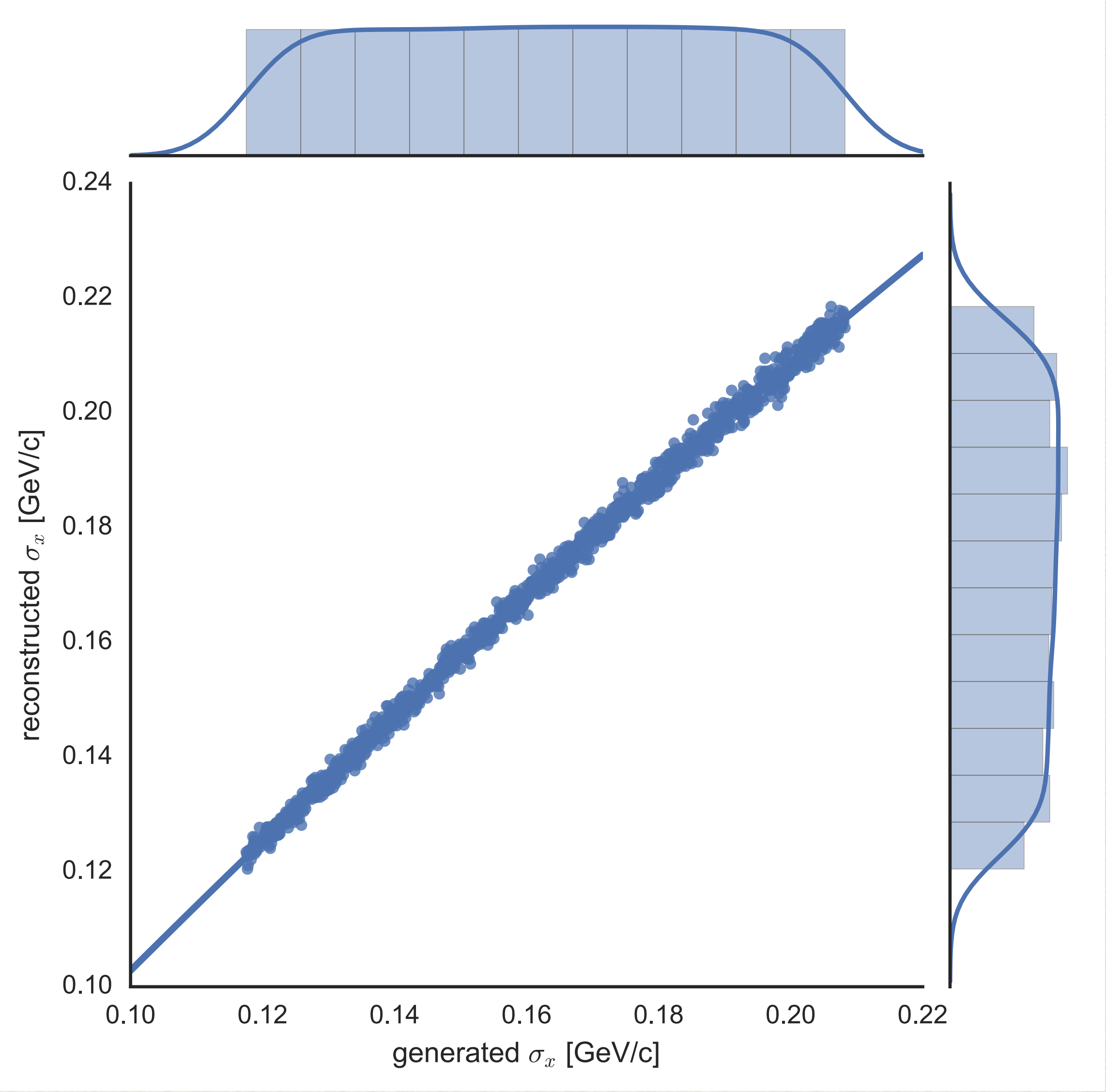
- σ_z, μ_z fixed on their nominal values.
- $\mu_x = \mu_y = 0$
- $0.11 < \sigma_x = \sigma_y < 0.21$ GeV/c
- 1200 event-generator runs (1200 points in band), ea with a few thousand events.

ev.gen. runs 1-1200, Oct. 16

/Users/erezcohen/Desktop/DataMining/Analysis_DATA/ppSRCcm/final_simulation_results/VaryOnlySigmaT

Transverse c.m. width

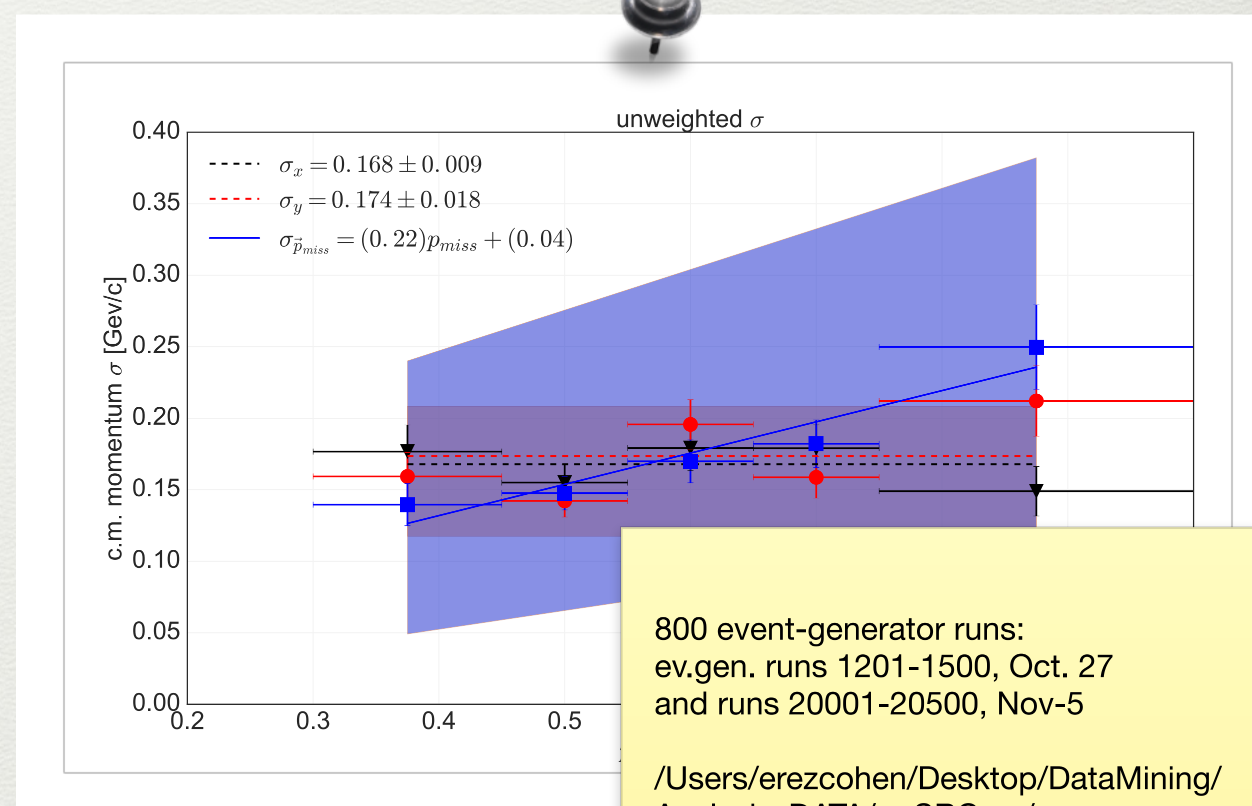




Varying Longitudinal c.m. width a_l

Longitudinal c.m. width

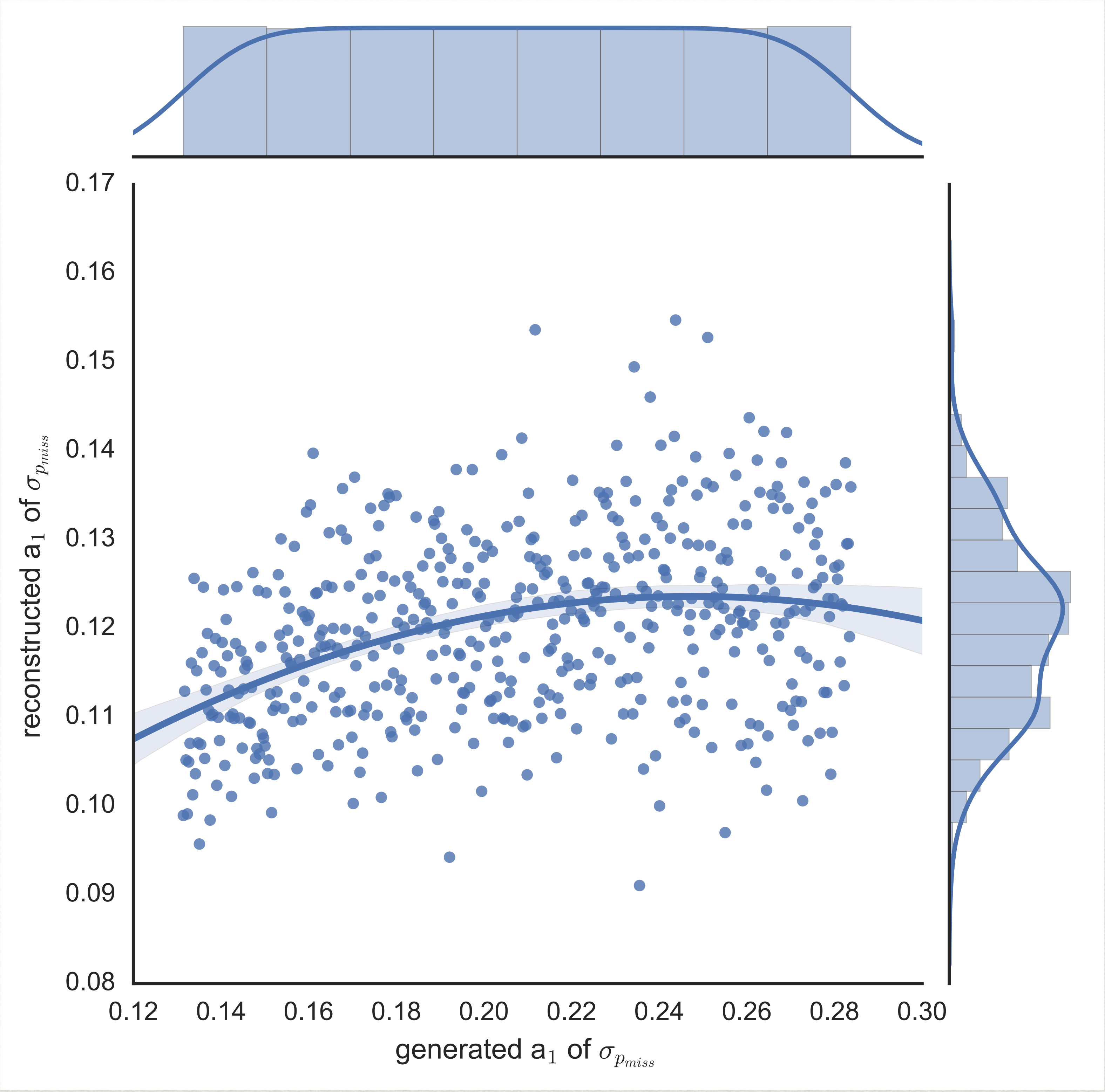
- $\mu_z, \sigma_x, \sigma_y$ fixed on their nominal values.
- $\mu_x = \mu_y = 0$
- $\sigma_z = a_1 p_{miss} + a_2$
  - a_2 fixed at its nominal value
  - $0.13 < a_1 < 0.28$
- 500 pts. in range.



800 event-generator runs:
ev.gen. runs 1201-1500, Oct. 27
and runs 20001-20500, Nov-5

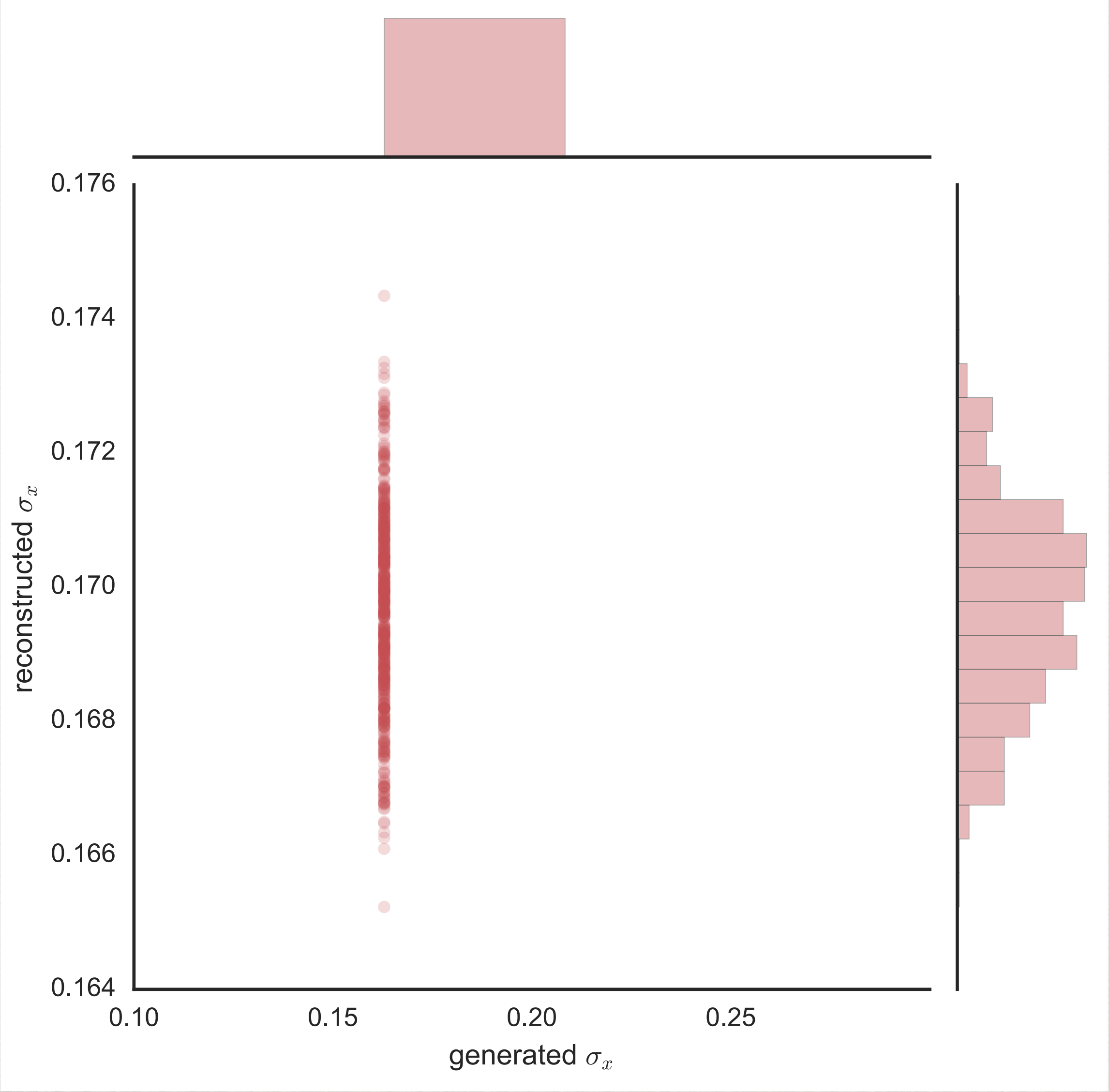
/Users/erezcohen/Desktop/DataMining/Analysis_DATA/ppSRCcm/final_simulation_results/VaryOnlySigmaZa1

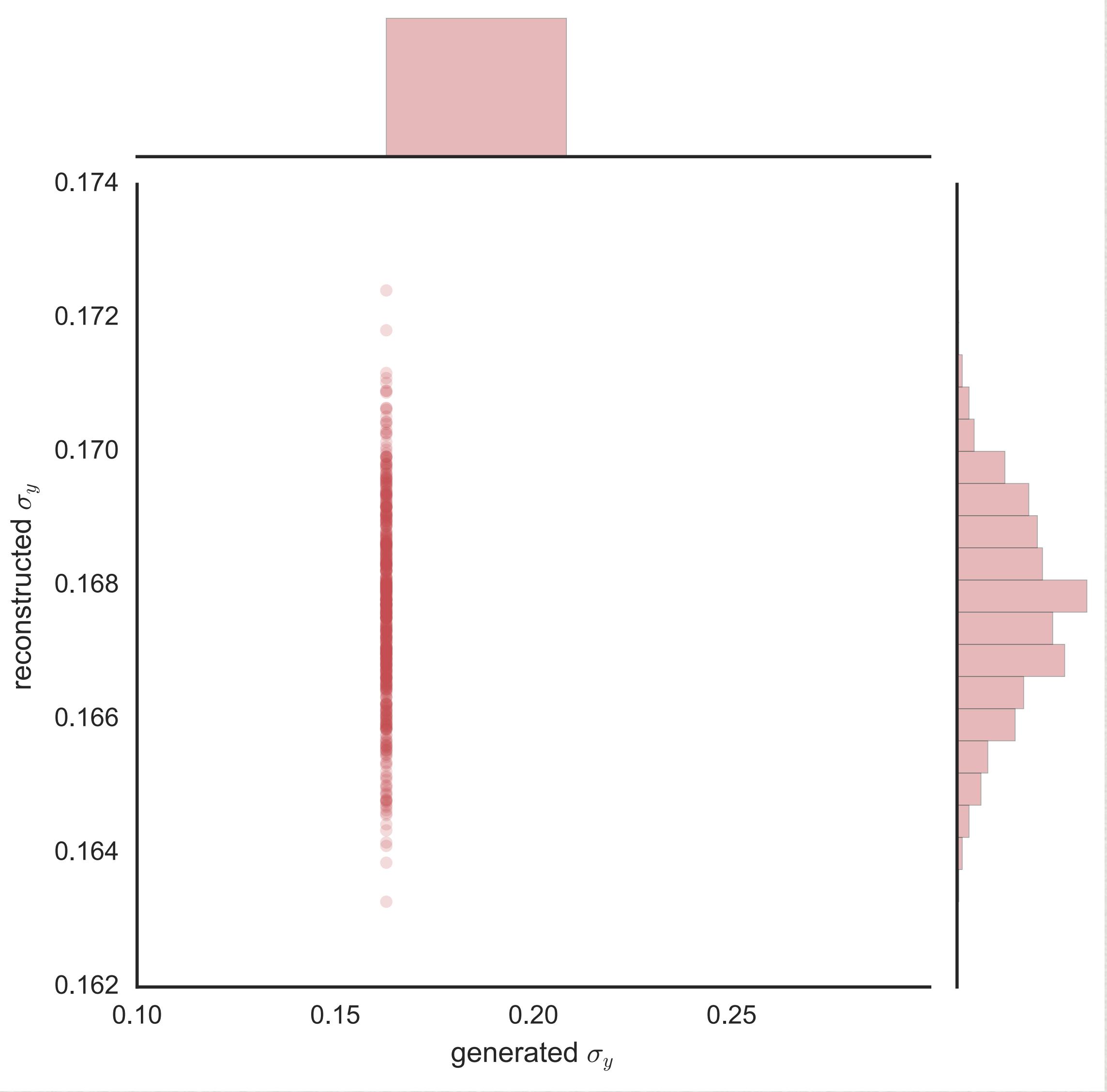
impact on Longitudinal c.m. width



Cross-correlation: The impact on transverse c.m

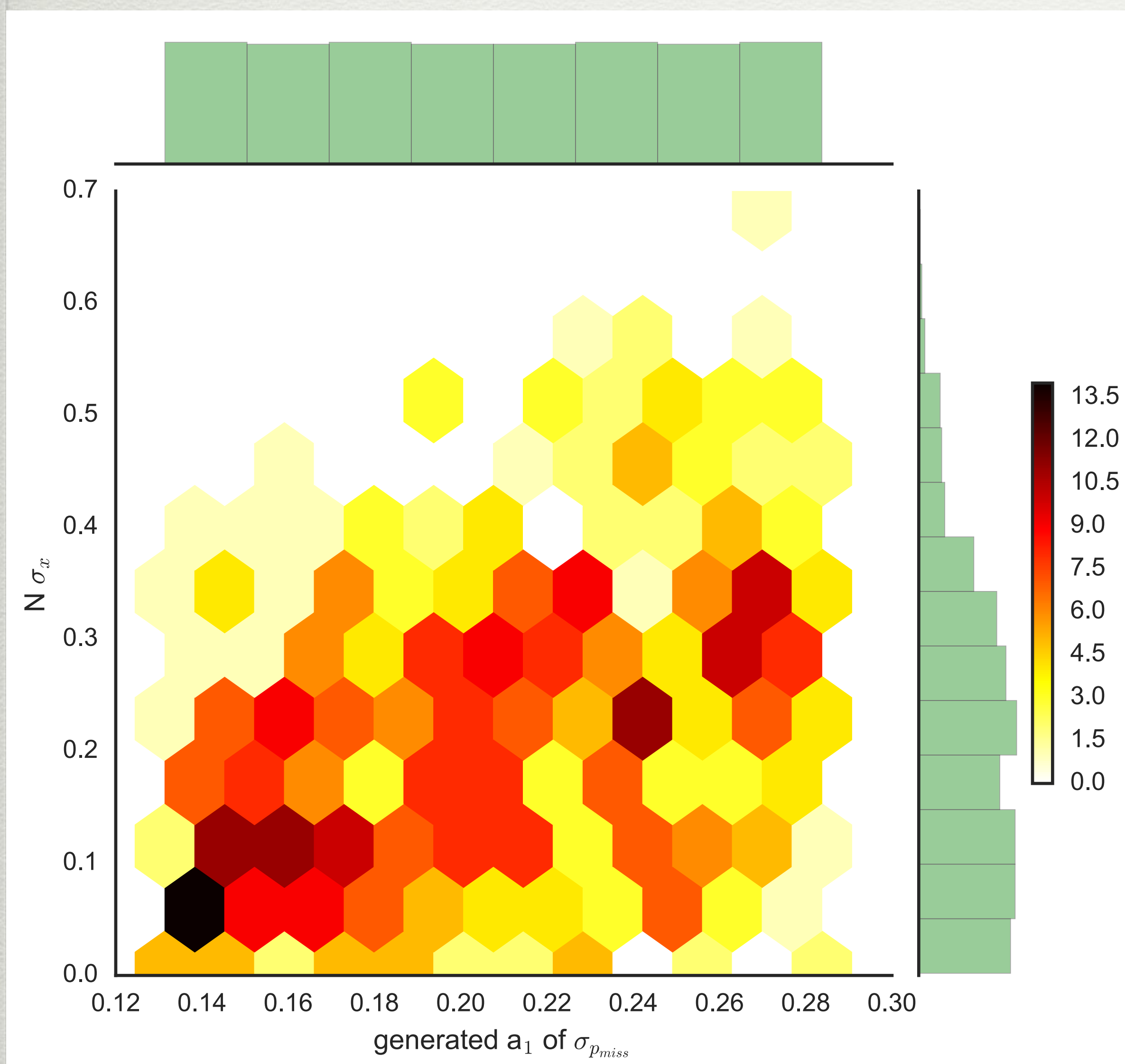
Opening $0.13 < \sigma_z(a_1) < 0.28$ (nominal value 0.22) results in a broadening of ~ 10 MeV/c in the transverse direction width

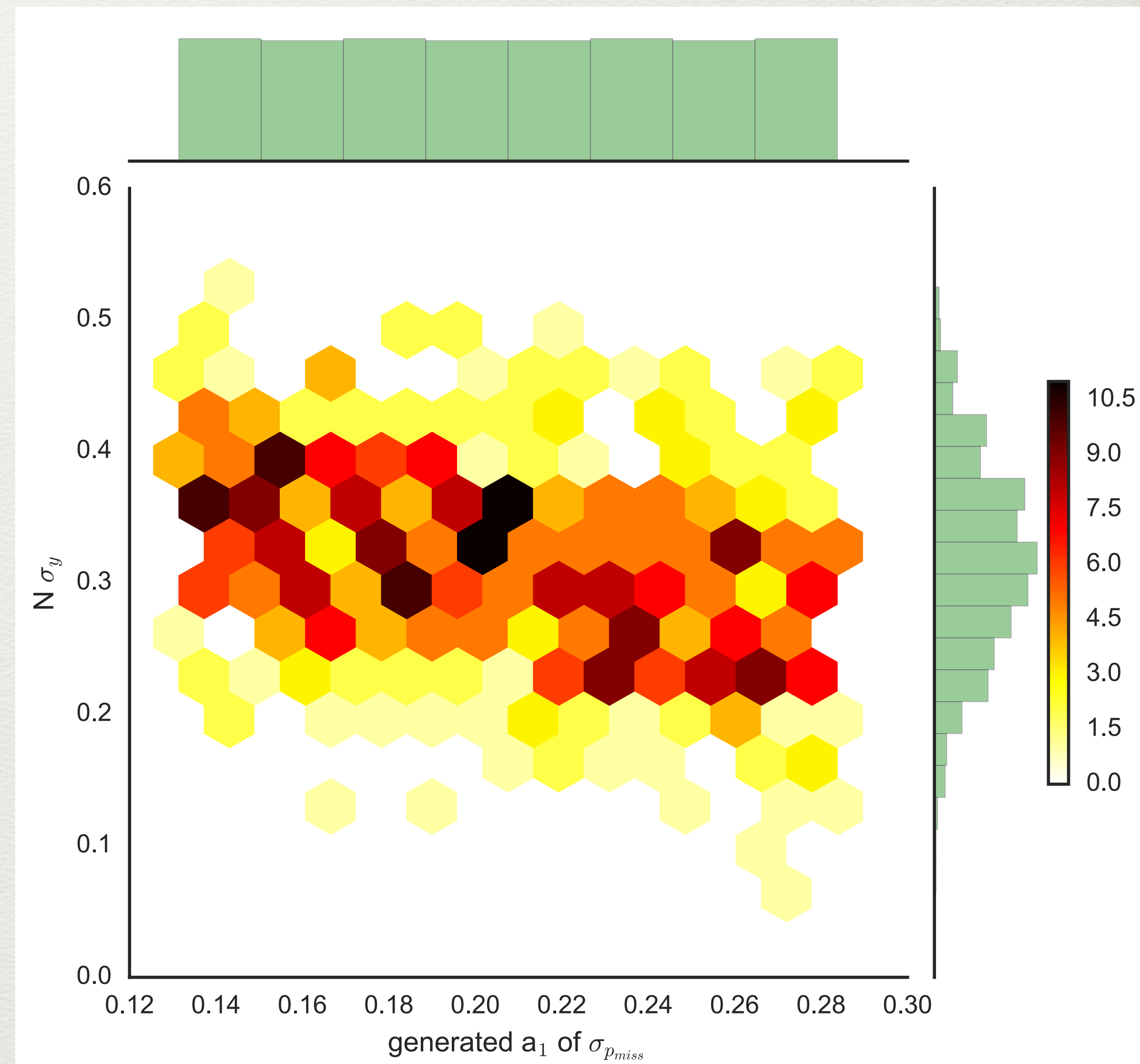




Cross-correlation: Where is the best correspondence?

Considering the generated $\sigma_z(a_1)$ vs. N_σ for the c.m. width (correspondence with data), is it clear which is the best parameter?

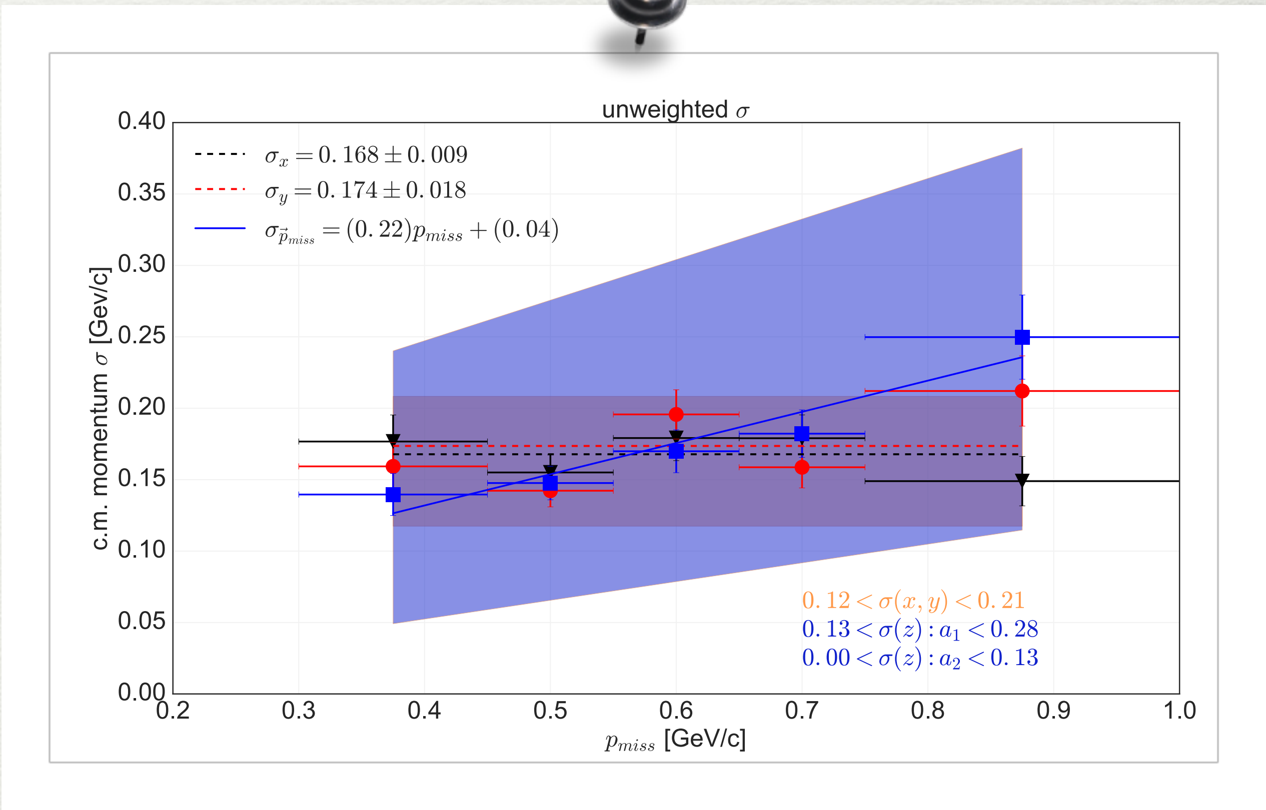




Varying Longitudinal c.m. width a_2

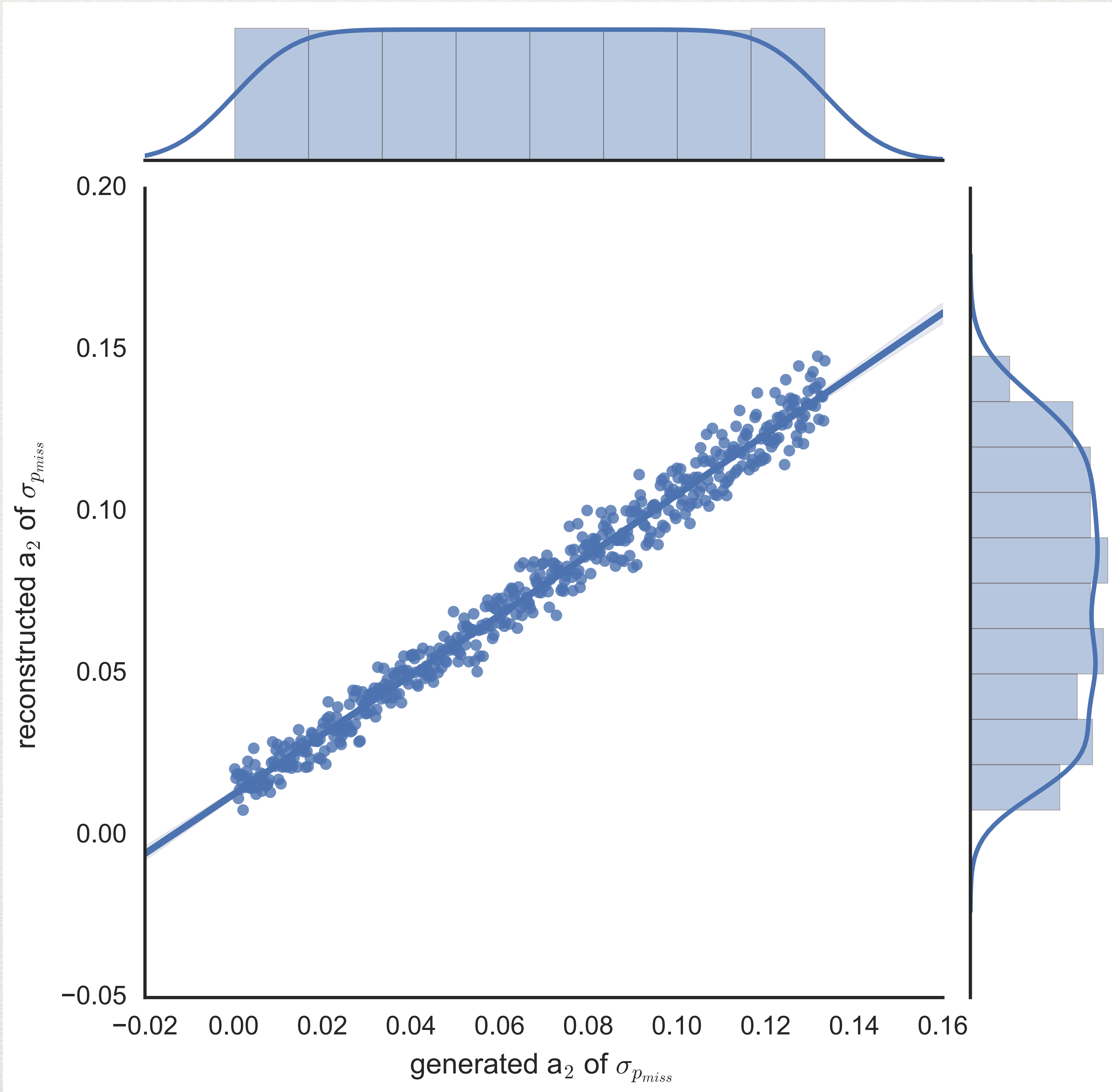
Longitudinal c.m. width

- $\mu_z, \sigma_x, \sigma_y$ fixed on their nominal values.
- $\mu_x = \mu_y = 0$
- $\sigma_z = a_1 p_{miss} + a_2$
  - a_1 fixed at its nominal value
  - $0 < a_2 < 0.13$ GeV/c
- 500 event-generator runs.



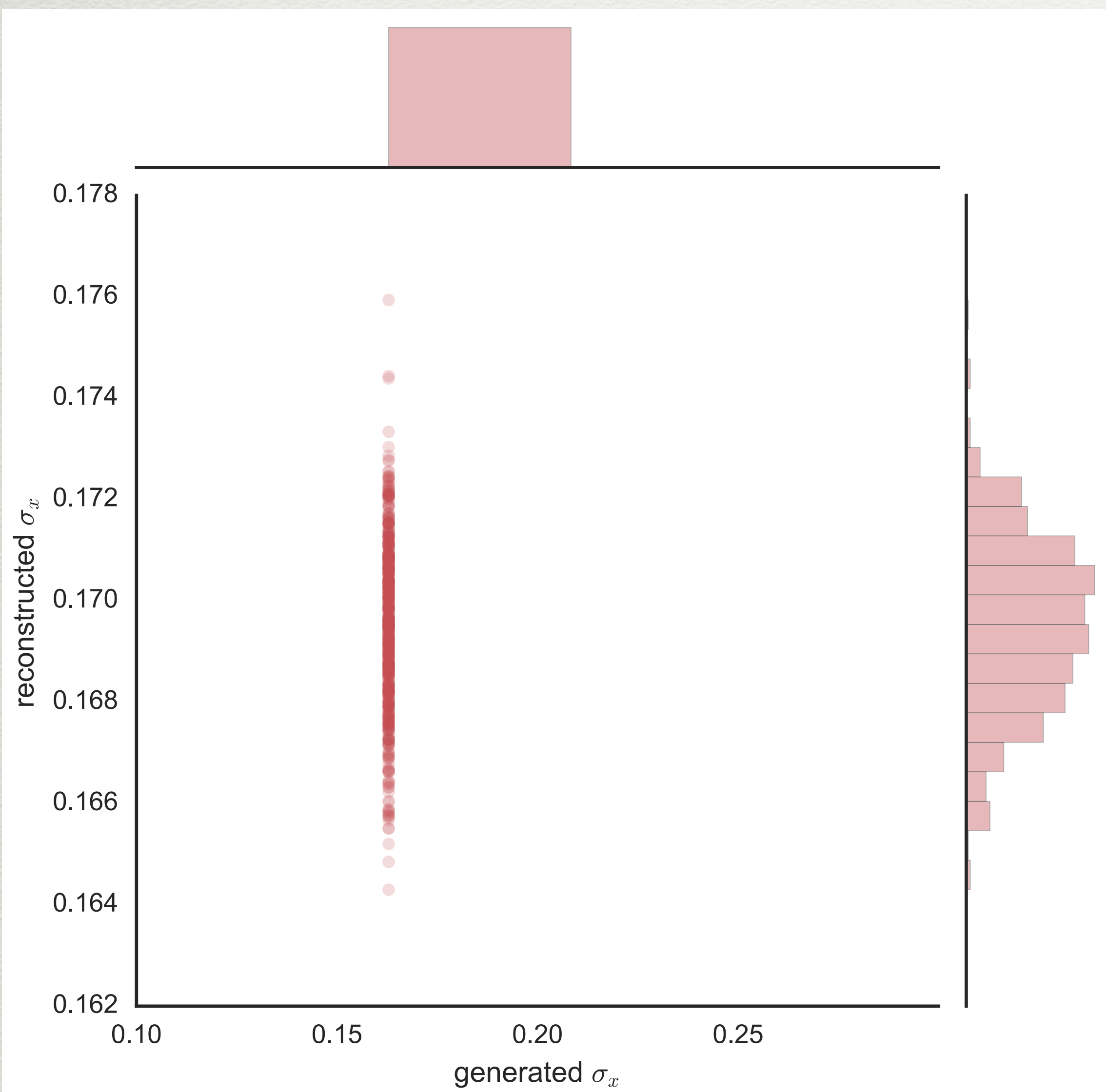
/
final_simulation_results/
VaryOnlySigmaZa2

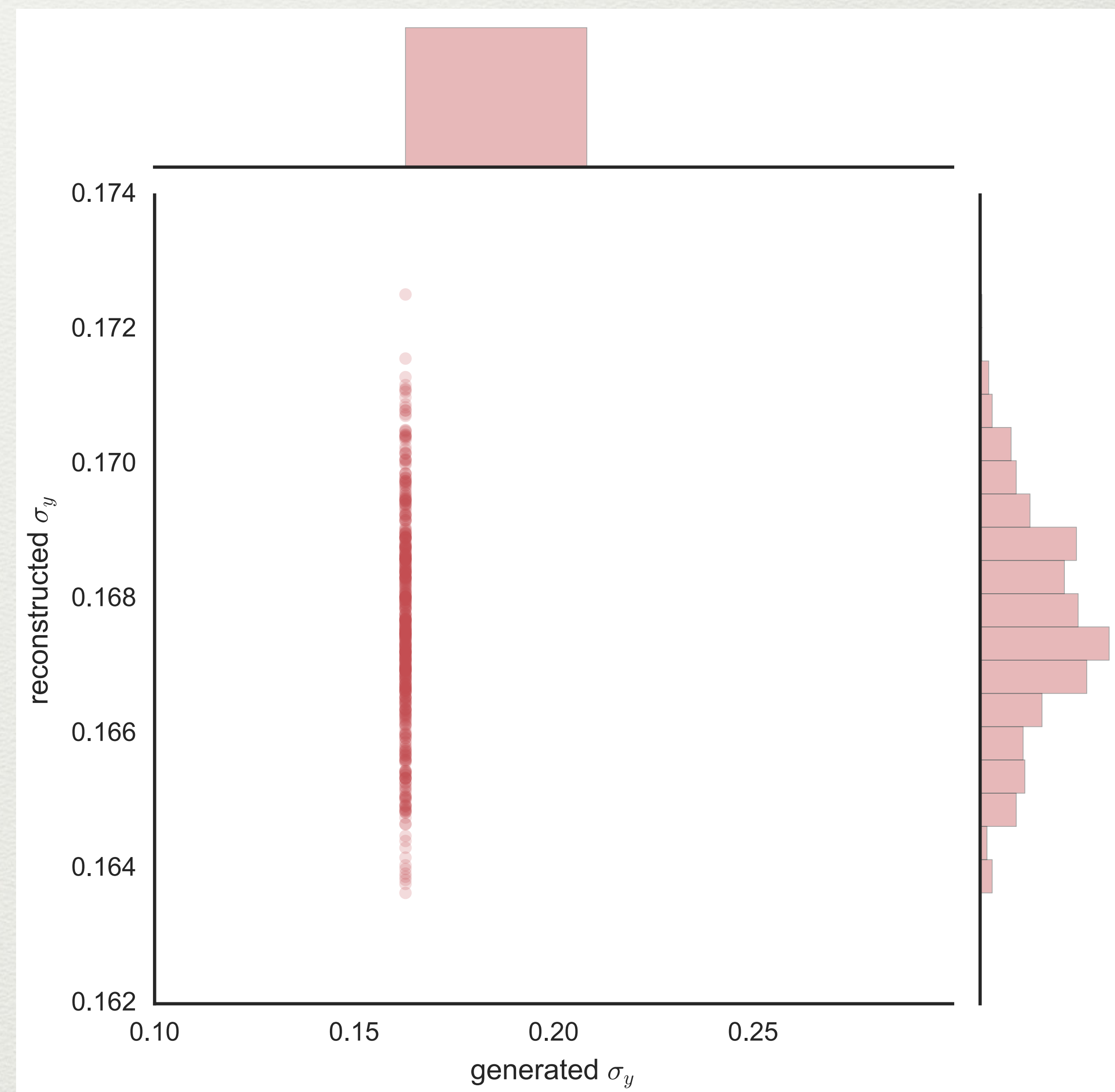
impact on Longitudinal c.m. width



Cross-correlation: The impact on transverse c.m

Opening $0 < \sigma_z(a_2) < 0.13$ GeV/c (nominal value 0.04) results in a broadening of ~ 8 MeV/c in the transverse dir. width





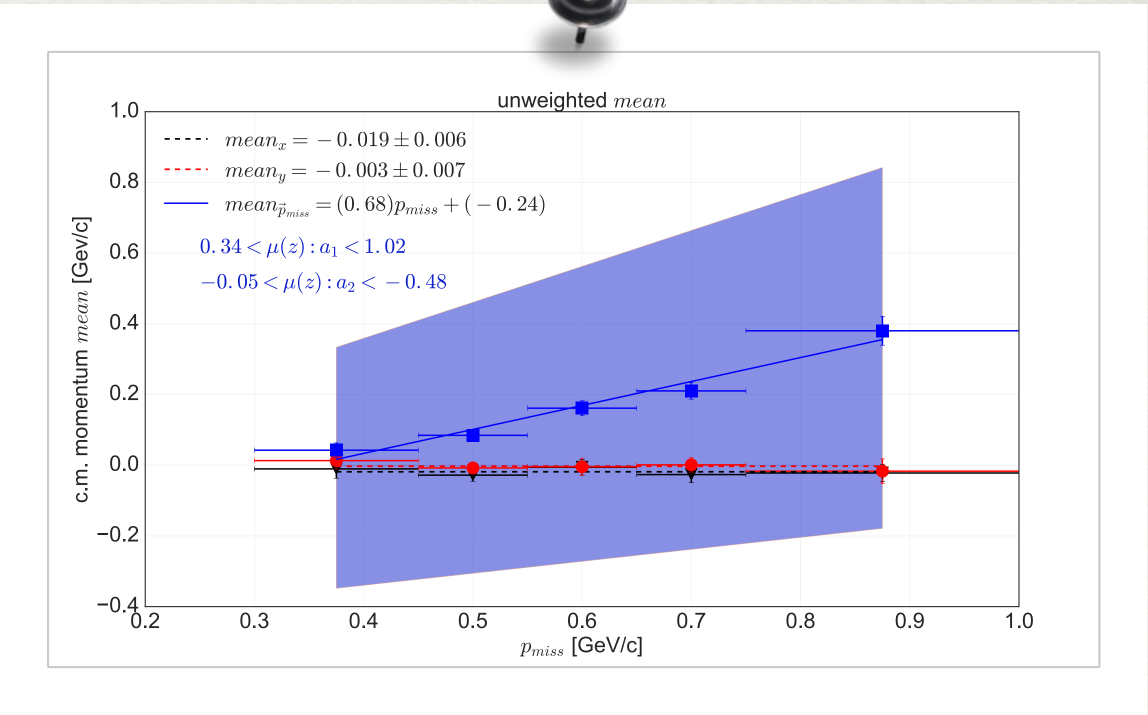
Varying Longitudinal c.m.
Mean a_l

Longitudinal c.m. mean

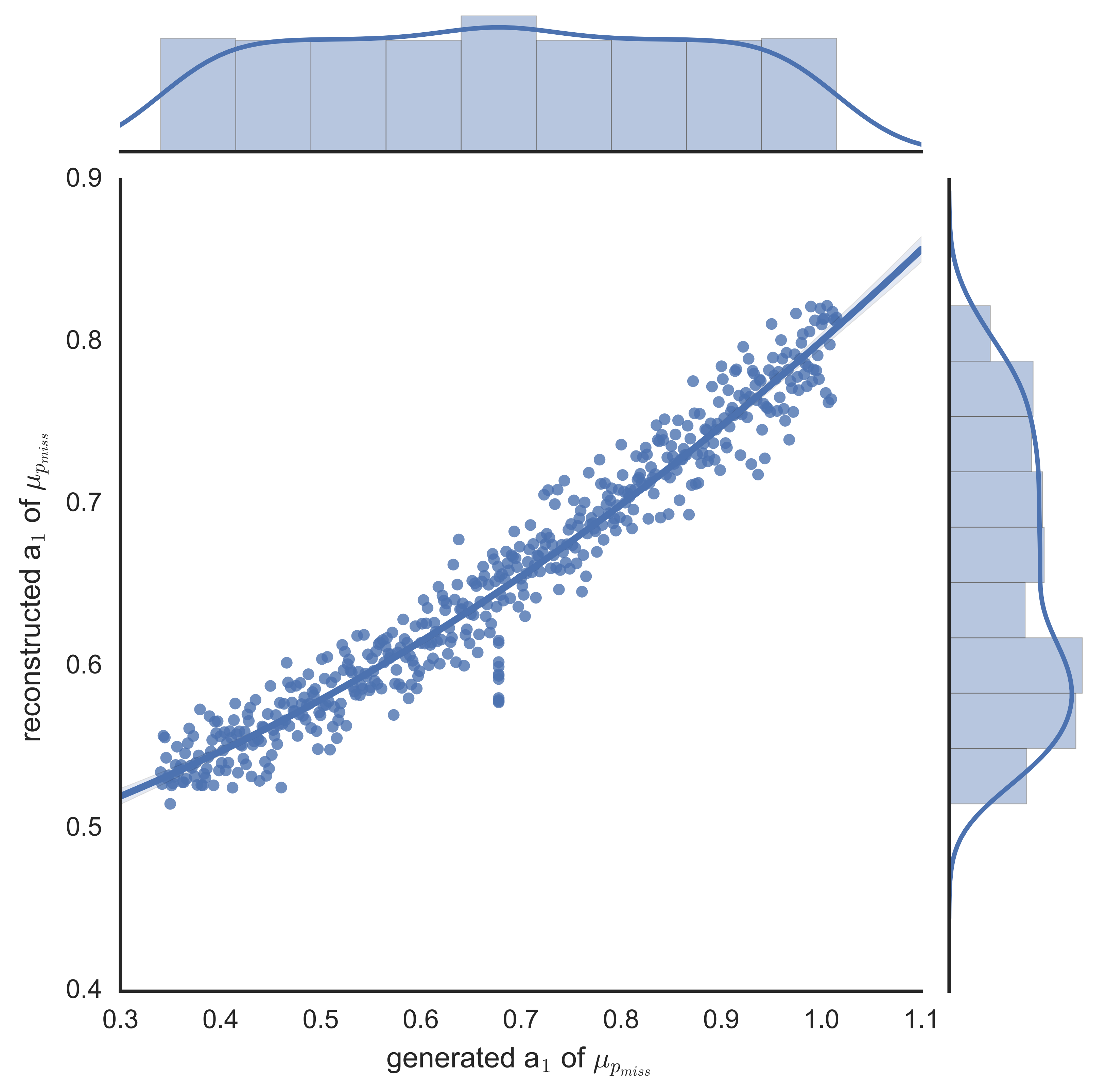
- σ_z, σ_x fixed on their nominal values.
- $\mu_x = \mu_y = 0$
- $\mu_z = a_1 p_{miss} + a_2$
  - a_2 fixed at its nominal value
  - $0.34 < a_1 < 1.02$
- 500 event-generator runs.

ev.gen. runs 1801-2100, Oct. 27
runs 21001-21500, Nov-5

/Users/erezcohen/Desktop/DataMining/Analysis_DATA/ppSRCcm/final_simulation_results/VaryOnlyMeanZa1

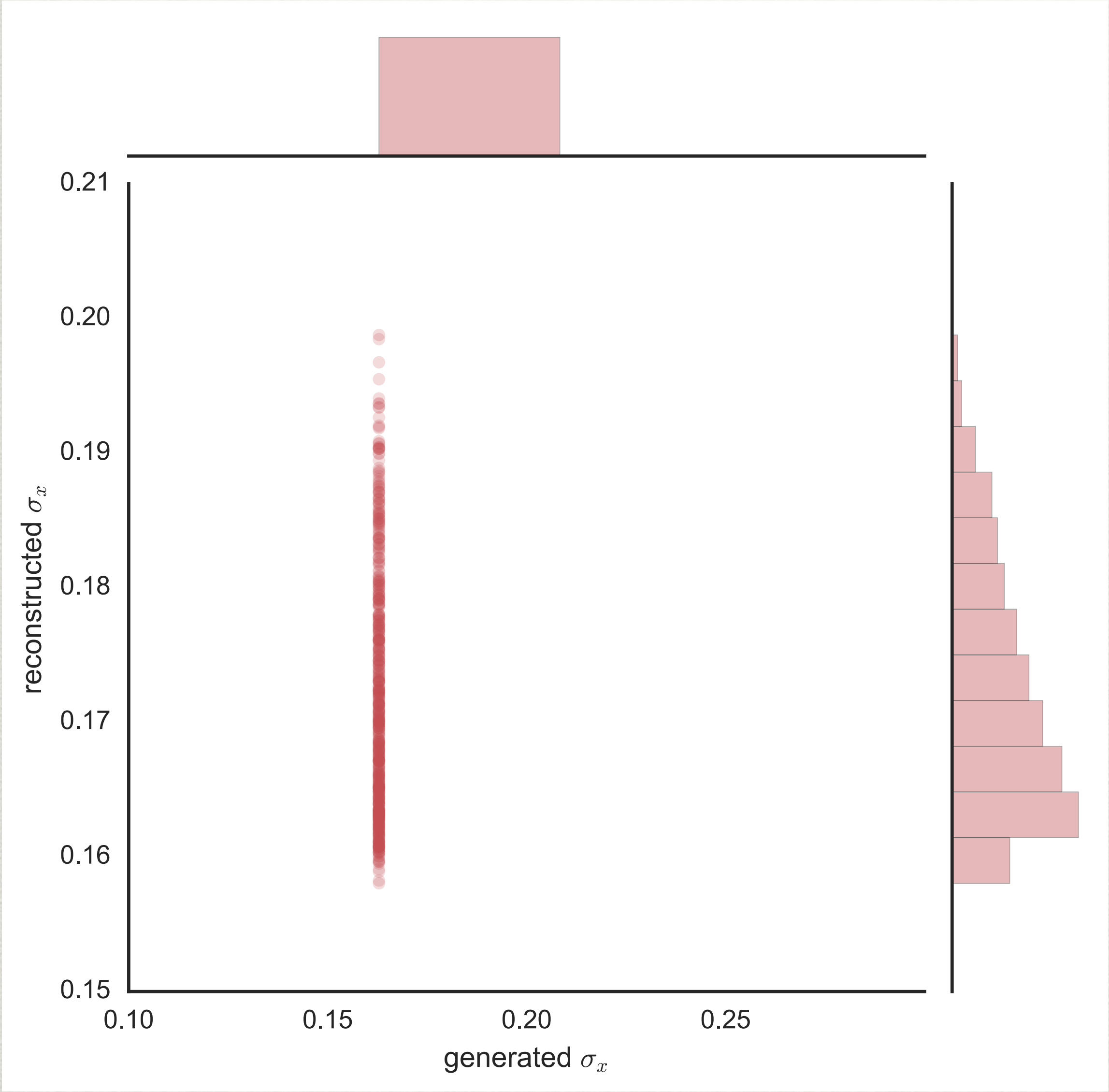


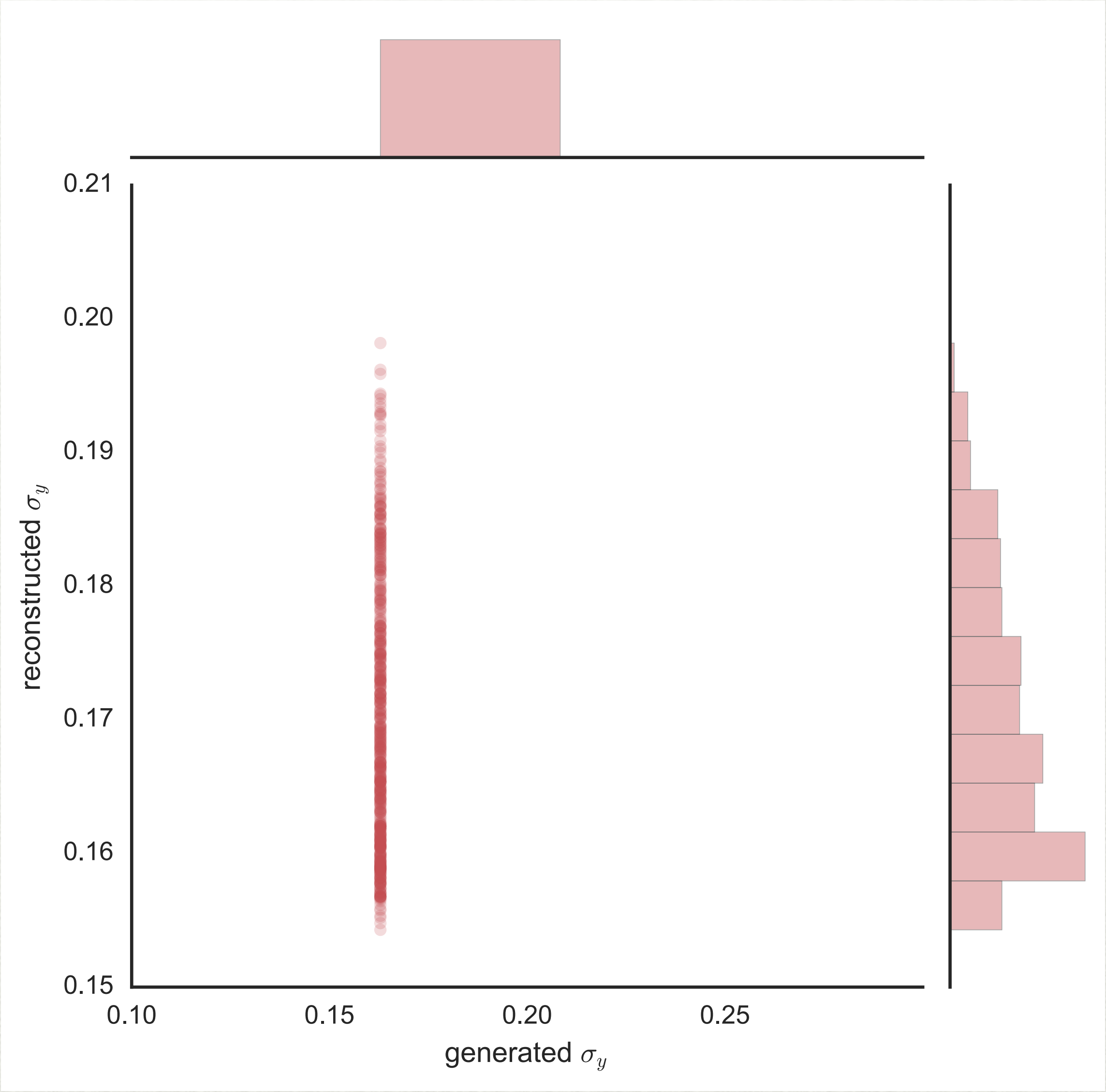
impact on Longitudinal c.m. mean



Cross-correlation: The impact on transverse c.m

Opening $0.34 < \mu_z(a_1) < 1.02$ (nominal value 0.68) results in a broadening of ~50 MeV/c in the transverse direction width, with a peak at 160 MeV/c and a tail to 200 MeV/c





Varying Longitudinal c.m.

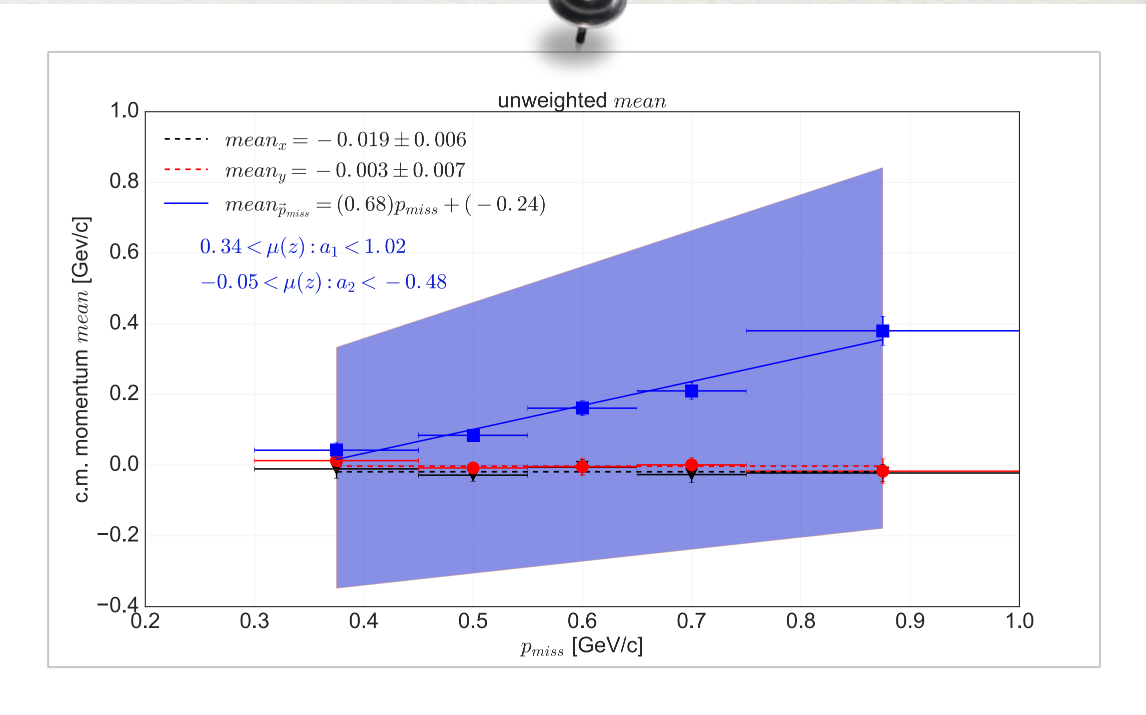
Mean a_2

Longitudinal c.m. mean

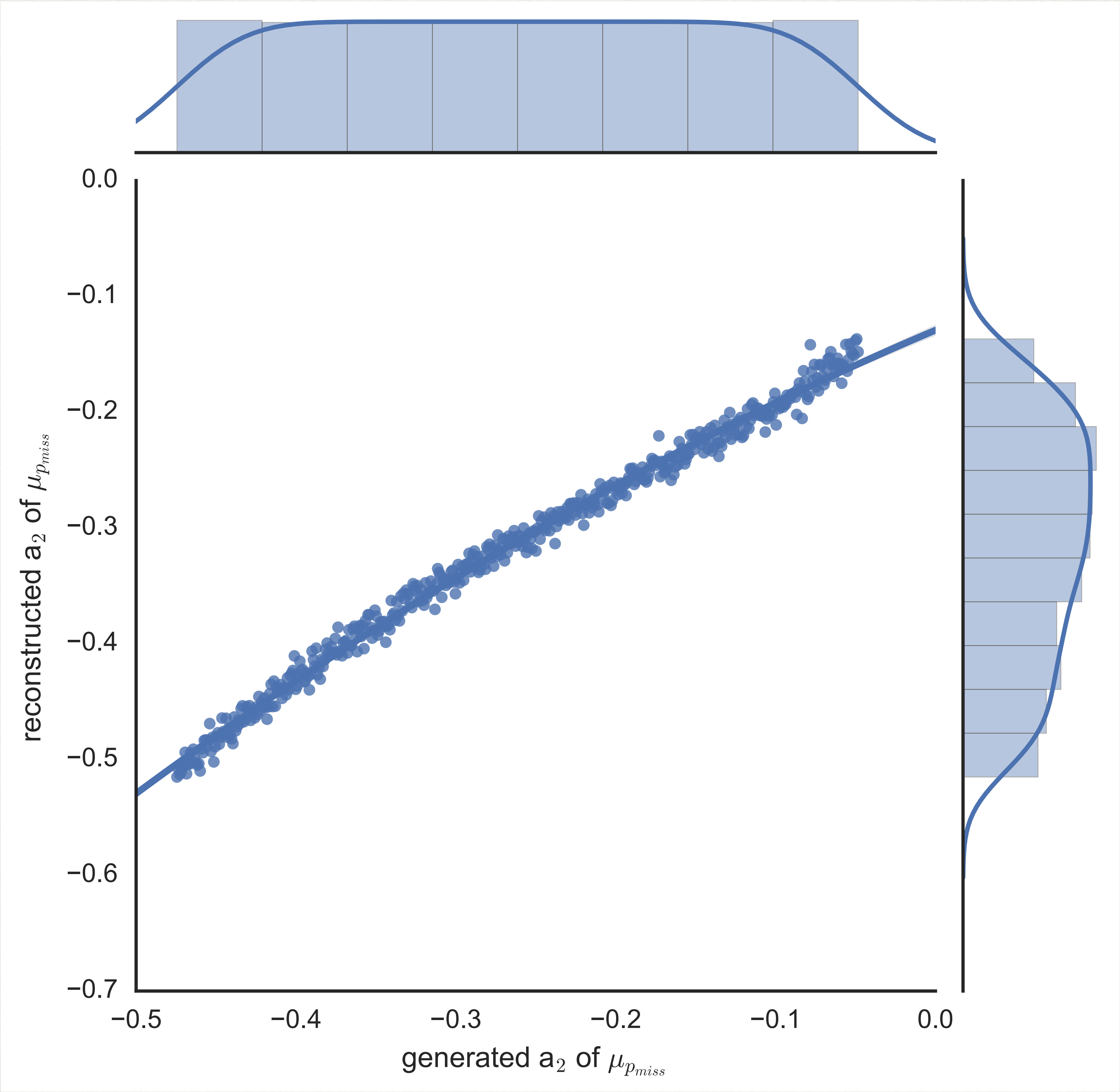
- σ_z, σ_x fixed on their nominal values.
- $\mu_x = \mu_y = 0$
- $\mu_z = a_1 p_{miss} + a_2$
  - a_1 fixed at its nominal value
  - $-0.48 < a_2 < -0.05$
- 500 event-generator runs.

ev.gen. runs 2101-2400, Oct. 27
runs 21501-22000

/Users/erezcohen/Desktop/DataMining/Analysis_DATA/ppSRCcm/final_simulation_results/VaryOnlyMeanZa2

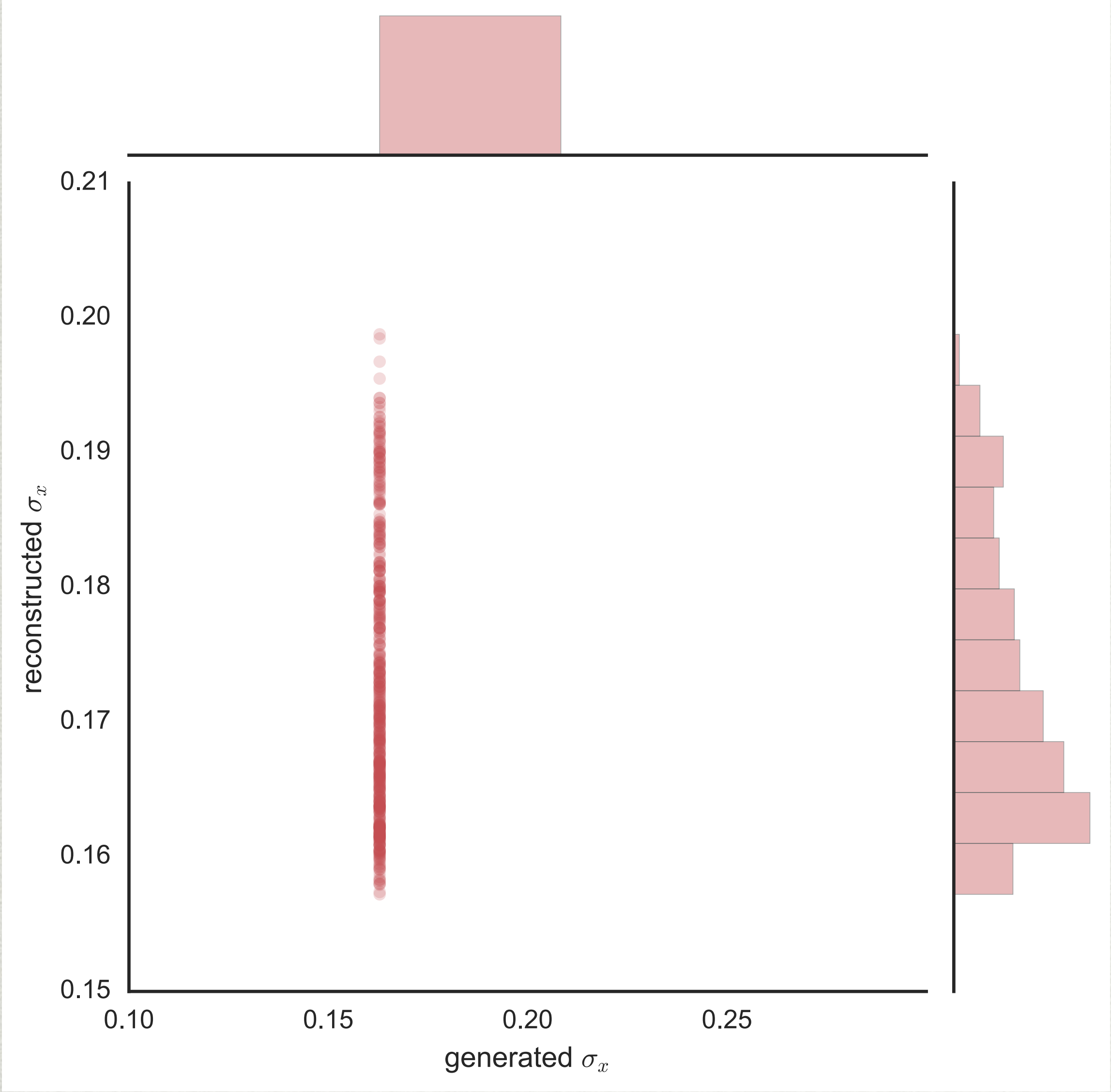


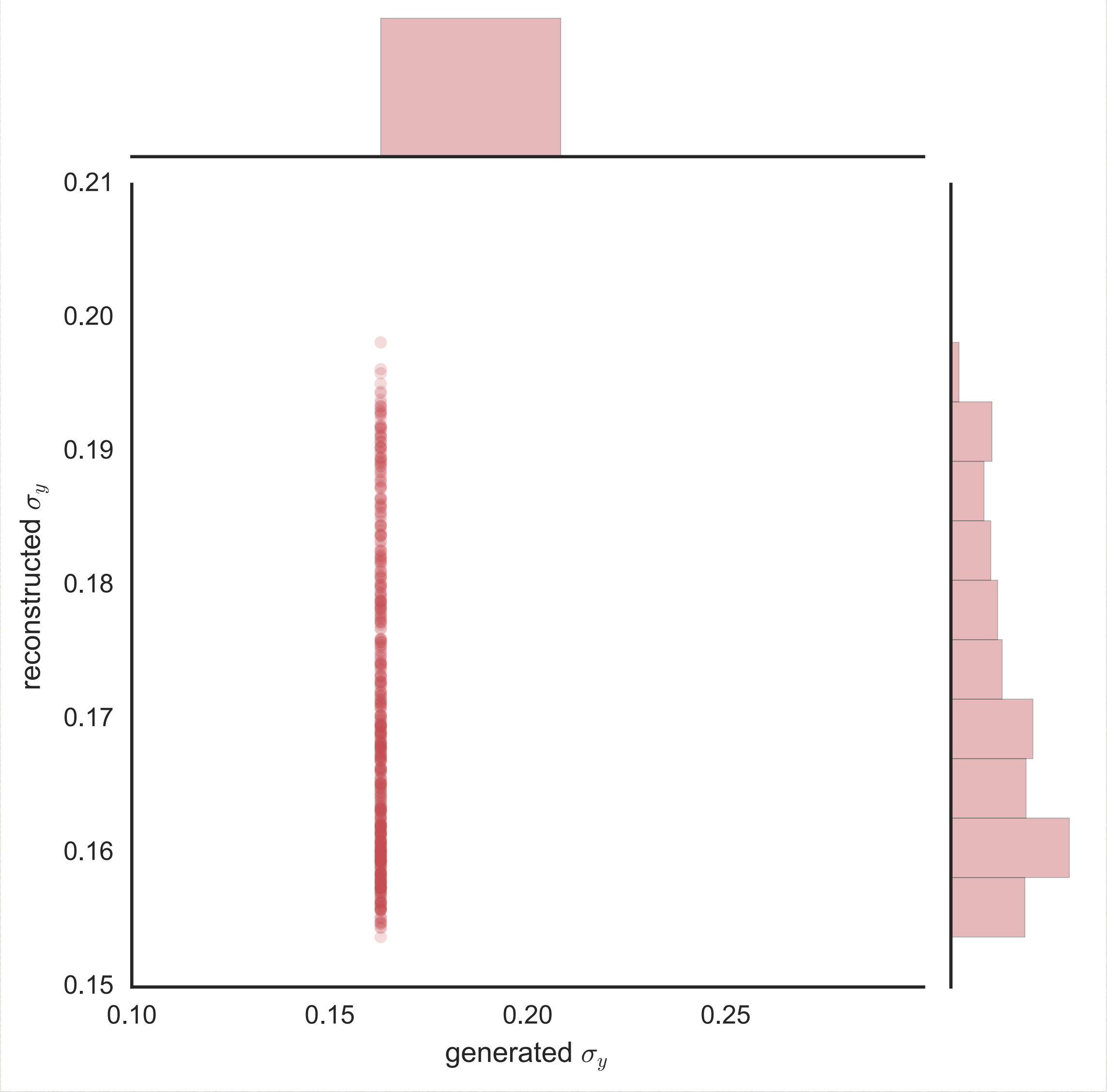
impact on Longitudinal c.m. mean



Cross-correlation: The impact on transverse c.m

Opening $-0.48 < \mu_z(a_2) < -0.05$ (nominal -0.24 GeV/c) results in a broadening of ~50 MeV/c in the transverse direction width, with a peak at 160 MeV/c and a tail to 200 MeV/c





SMALL EFFECT OF FSI

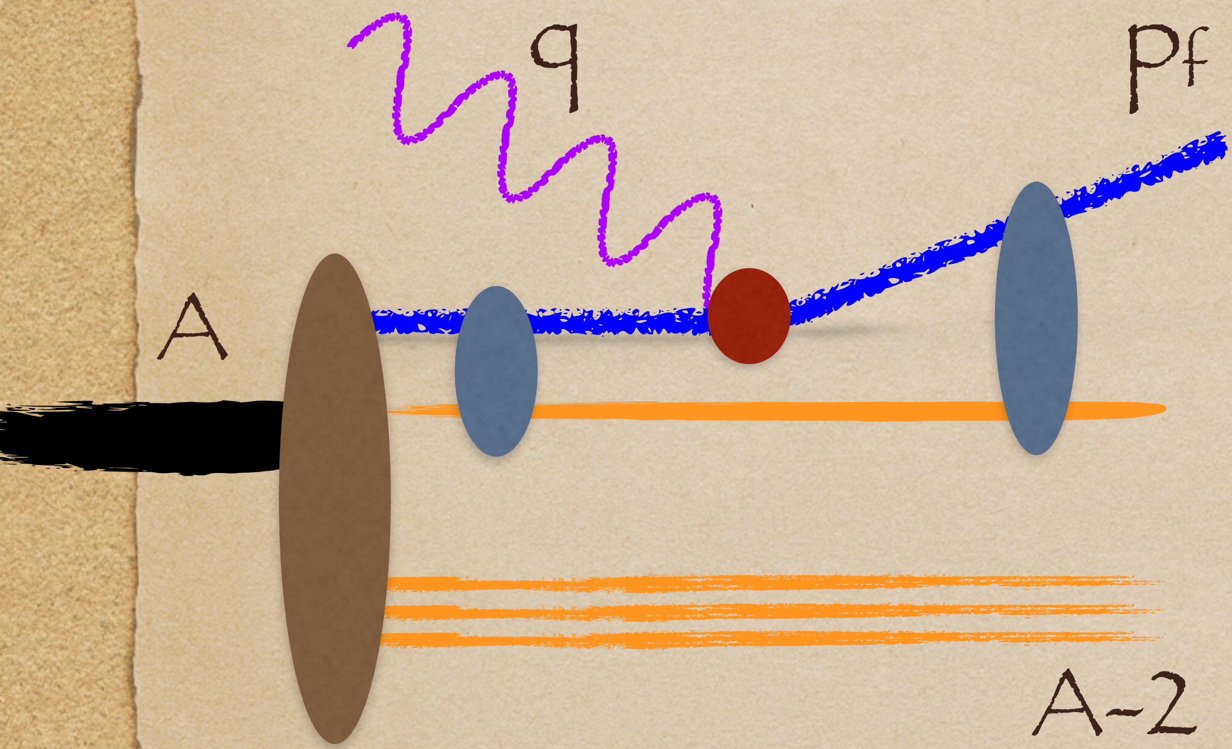
Small effect of FSI

- PWIA assumption (neglecting FSI) is supported by calculations and even the data itself:
  - The Gent group showed using relativistic multiple scattering Glauber approximation (RMSGA) that the width of the c.m distributions under similar condition to this measurement are effected by FSI by less than 10%. Similar results from Sargasian and Ciofi.
  - The data also indicate small contribution of FSI: the measured widths are small compare to that expected from FSI, the widths change very little between small and large nuclei, and they are about equal parallel and perpendicular to the momentum transfer (including LC).

The reason for small effect of FSI

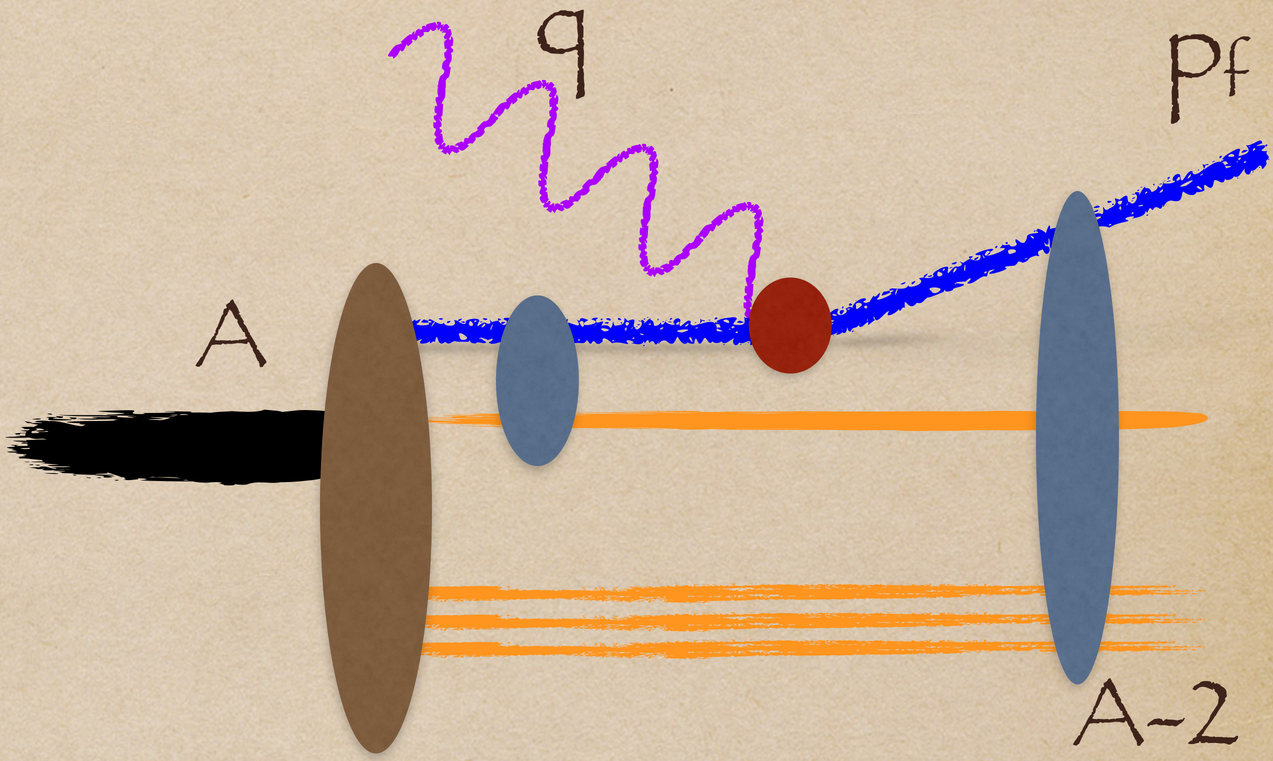
- The strong FSI between the close nucleons in the pair do not affect the c.m momentum of the pair.
- Attenuation of the incident and outgoing fluxes of particles only change the overall normalization and not the shape of the distributions.

Small effect of FSI



FSI in the SRC pair:

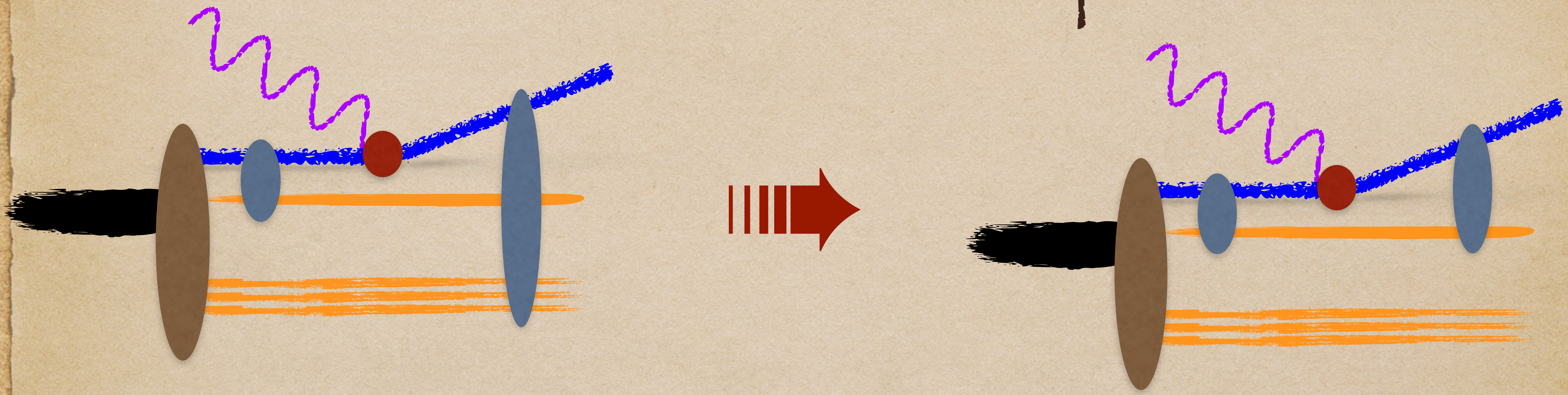
- These are not necessarily small, BUT: Conserve the CM momentum of the pair.



FSI with the A-2 system::

- Small (?)
- Leading proton with a large component of p_{miss} in the virtual photon direction.
- Pauli blocking for the recoil particle.
- Can be treated in Glauber approximation.

For large Q^2 and x>1, FSI is confined to within the SRC pair



Distances that highly virtual struck nucleon propagates

$$\Delta E = -q_0 - M_A + \sqrt{m^2 + (p_i + q)^2} + \sqrt{M_{A-1}^2 + p_i^2}$$

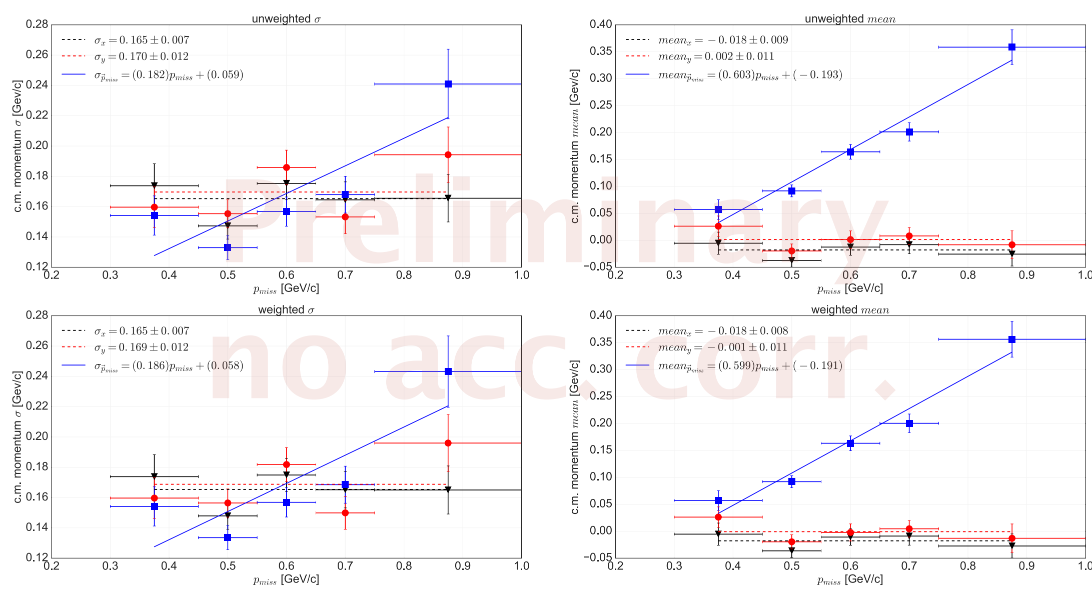
For x > 1.3

$$r \sim \frac{1}{\Delta E v} \lesssim 1 \text{ fm}$$

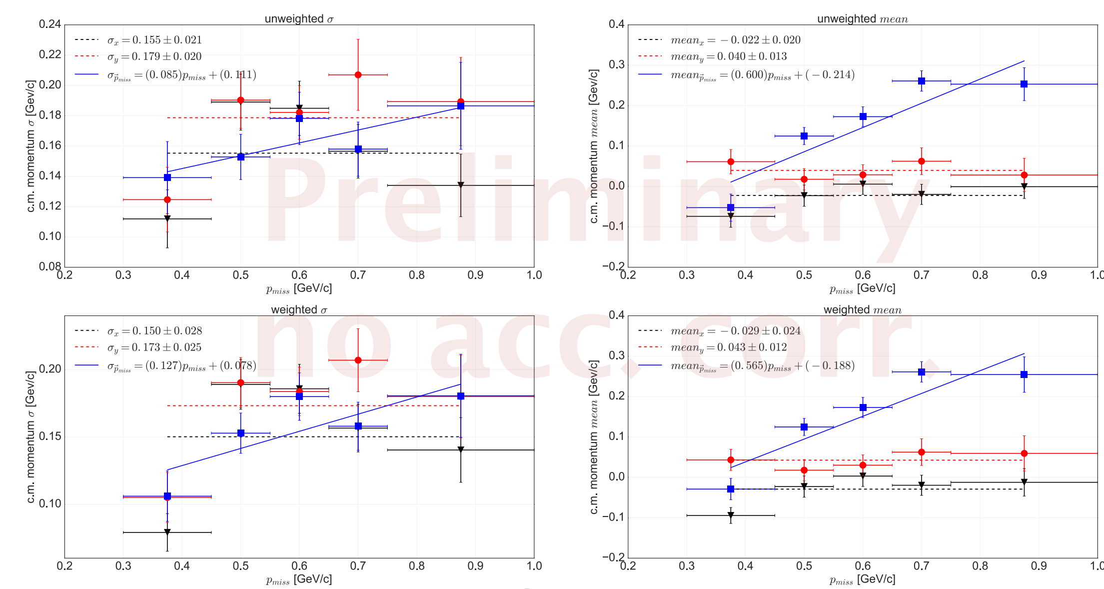
FSI in the SRC pair:

- conserve the Isospin structure.
- conserve the c.m. momentum of the pair.

EG2 analysis - pp c.m. all nuclei

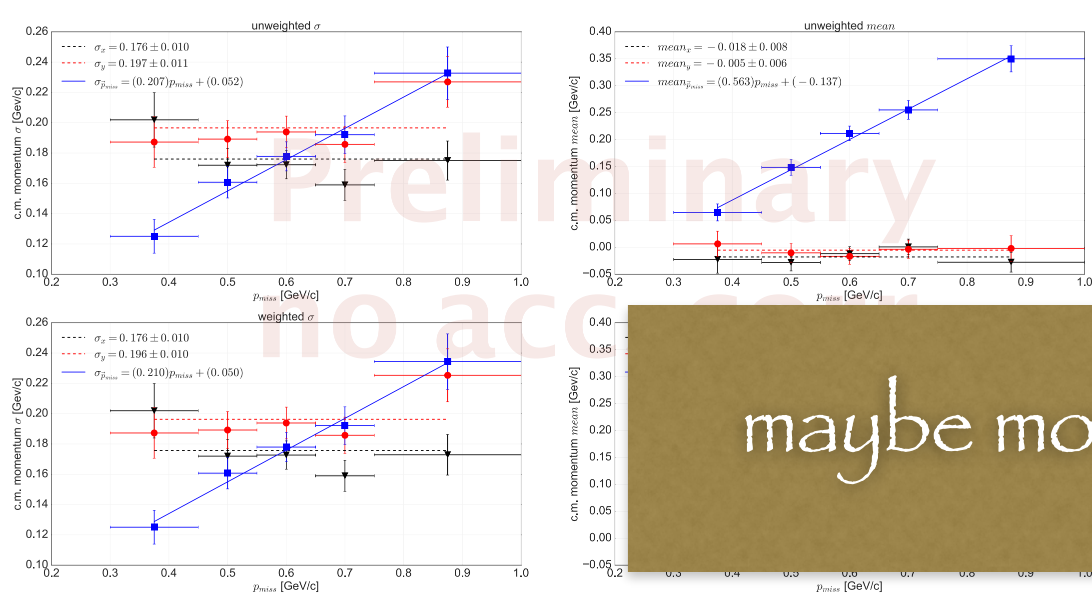


^{12}C

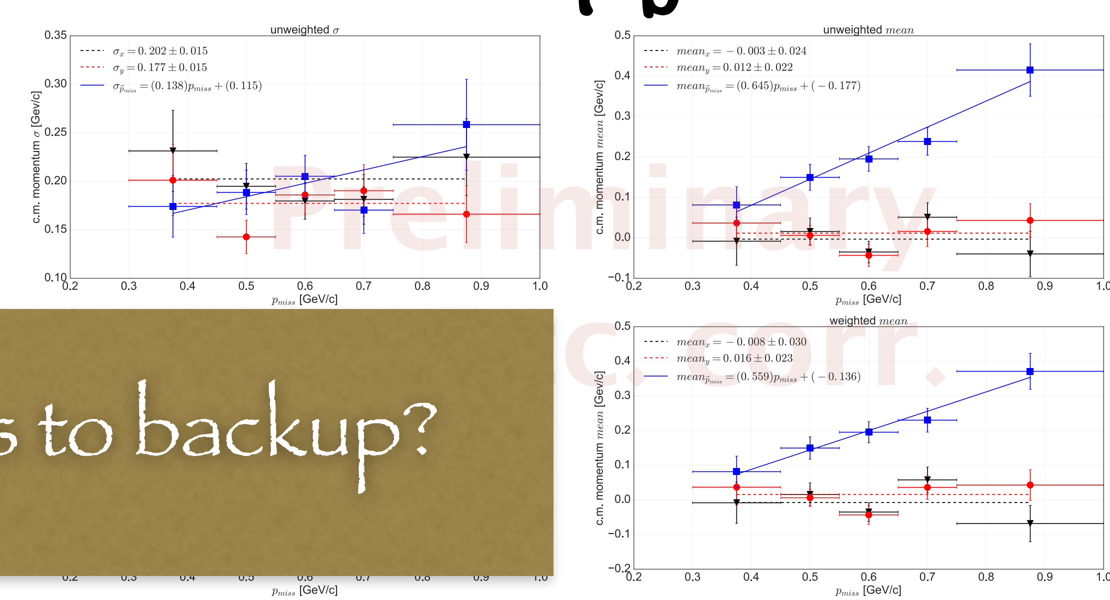


^{27}Al

^{56}Fe



^{208}Pb



maybe move this to backup?