Transverse momentum broadening of DIS multiple-pion events

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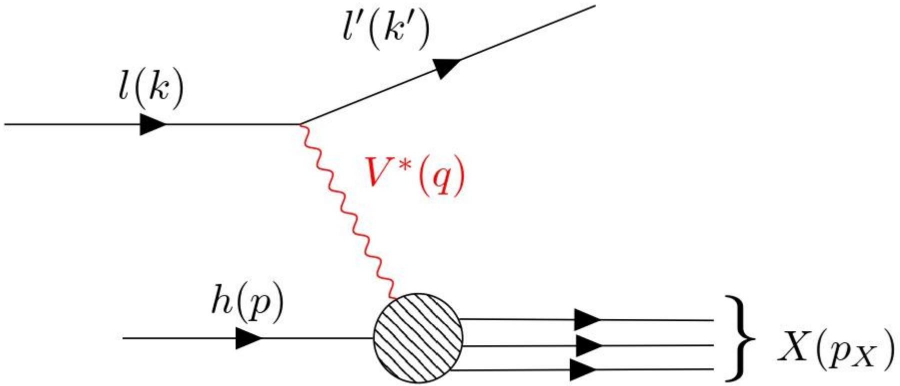
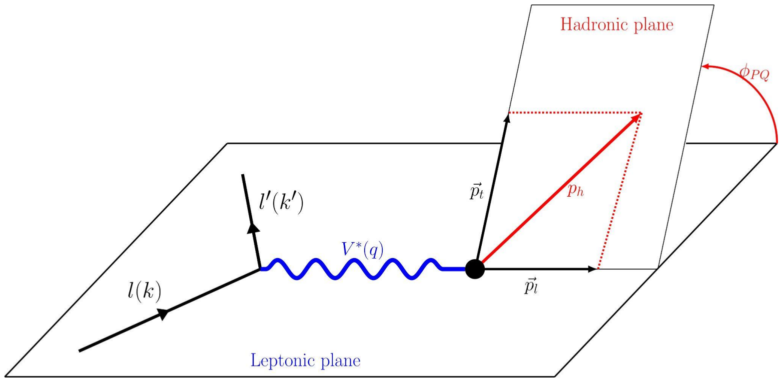
March, 2024

Outlook

- Physics motivation.
- Experimental setup.
- Data analysis.
  - Simulations.
  - Acceptance corrections.
  - Radiative corrections.
  - Systematics Errors.
- Results.

DIS and SIDIS variables





- Some important variables:

$$Q^2 = -(q \cdot q) \overset{lab}{\approx} 4EE' \sin^2\left(\frac{\theta}{2}\right)$$

$$\nu \equiv \frac{p \cdot q}{M} \overset{lab}{=} E_k - E_{k'}$$

- Some important variables:

$$Z_h \equiv \frac{p \cdot p_h}{p \cdot q} \overset{lab}{=} \frac{E_h}{\nu}$$

$$\cos(\phi_{PQ}) = \frac{\vec{q} \cdot \vec{p_h}}{|\vec{q}||\vec{p_h}|}$$

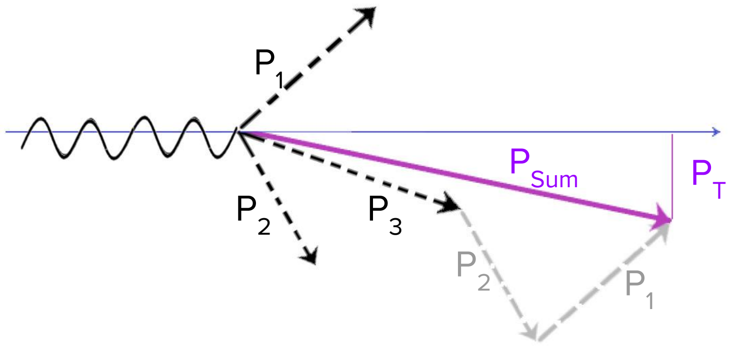
$$P_t^2 = |\vec{p_h}|^2(1 - \cos^2(\theta_{PQ}))$$

Observable definition

- Transverse momentum broadening is defined as the difference between the mean of the square transverse momentum (P_T^2) for events produced in a nuclear media (A) and deuterium (D).

$$\Delta P_t^2 = \langle P_t^2 \rangle_A - \langle P_t^2 \rangle_D$$

- We defined the transverse momentum of the event by taking the vector sum of the positive pion's momentum and then calculating the transverse component of this vector in relation to the virtual photon.



Kinematical variables definition

- For events with multiple pions in the final state:

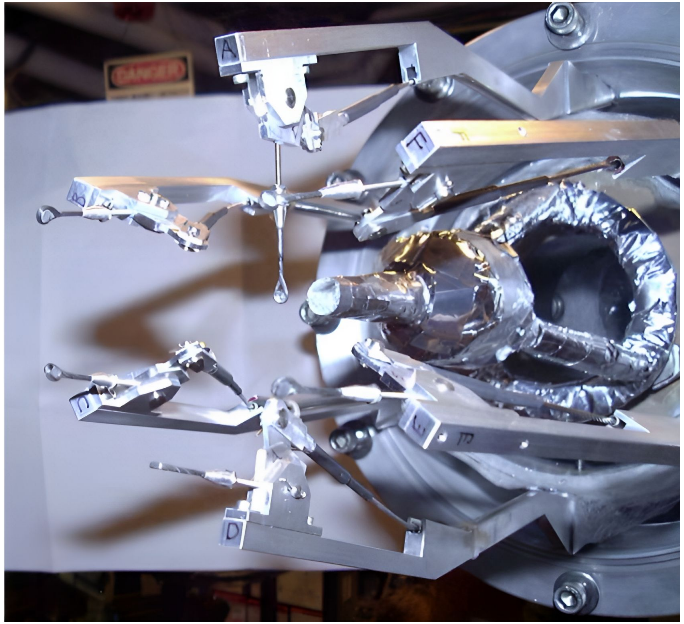
$$Z_h^+ \equiv \sum_i Z_{hi}$$

$$P_t^{+2} \equiv tranverse\left(\sum_i \vec{p_i}\right)^2$$

$Q^2, \nu \rightarrow$ Do not depend on the hadronic final state.

Double Target Experiment

- The EG-2 experiment consisted on one liquid target (Deuterium) and one solid target exposed to the beam at the same time.
- The solid targets analyzed were carbon, iron, and lead.
- Exposed both targets at the same time reduces time-based systematic uncertainties in ratios.



Acceptance correction

- The simulation consist of two parts
  - A simulation of the DIS interaction, this was done using a montecarlo model (PYTHIA).
  - A simulation of the CLAS detector and how it interacts with the particles (Geant 3).
- Around 2.5 x 10E8 pions were generated.

Acceptance correction

Two factors were combined to take into account the events which were not reconstructed and the false positives.

N^i_{gen} : Numbers of events where i pions were generated in the simulation.

N^i_{rec} : Numbers of events where i pions were reconstructed in the simulation.

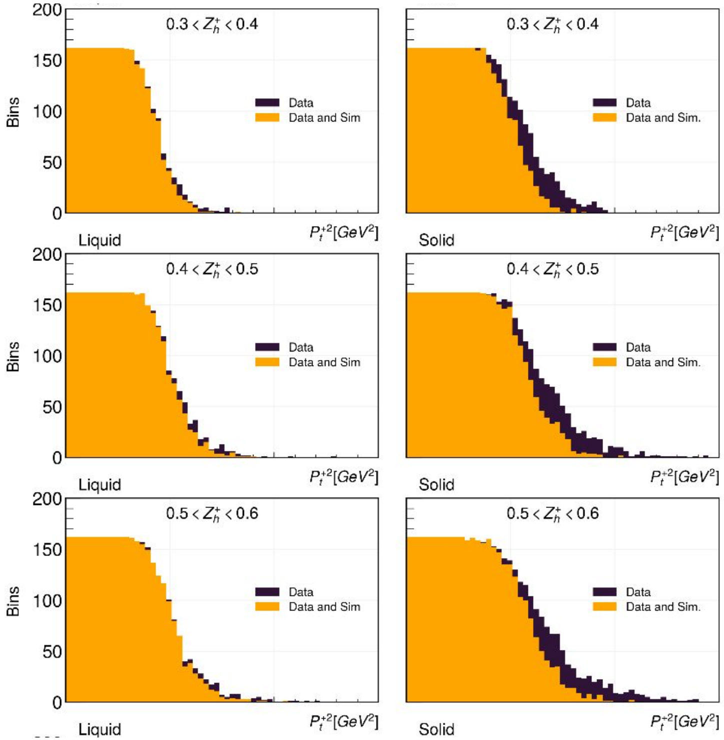
$N^i_{gen=rec}$: Number of events where i pions were generated and reconstructed in the simulation (Well reconstructed events.)

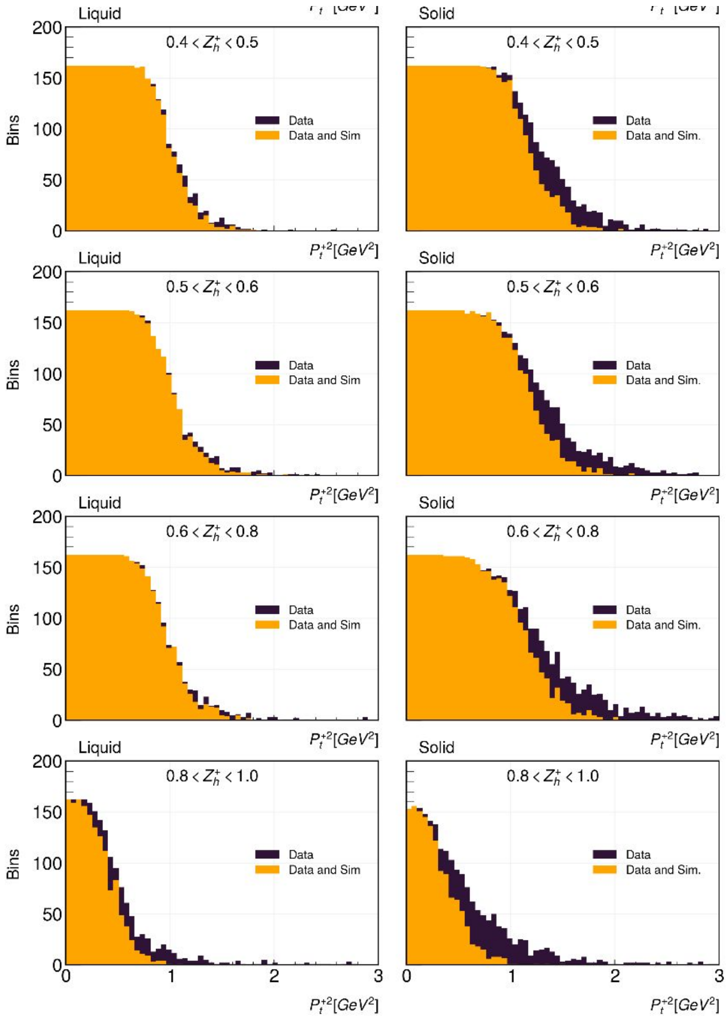
$$Acc^i_1 = \frac{N^i_{gen=rec}}{N^i_{gen}} \qquad Acc^i_2 = \frac{N^i_{gen=rec}}{N^i_{rec}}$$

$$\text{Corr. data events}_i(5dim) = \text{data events}_i(5dim) \times \frac{Acc^i_2(5dim)}{Acc^i_1(5dim)}$$

$$\mathrm{Acc}^i = \frac{Acc^i_2}{Acc^i_1} = \frac{N^i_{gen}}{N^i_{rec}} \qquad N^i_{gen=rec} \geq 1$$

Simulation vs Data: Empty Bins





	Liquid Target	Solids Targets
Zh_{Sum}	Lost events(%)	Lost events(%)
0.1 - 0.2	0.062	0.319
0.2 - 0.3	0.029	0.282
0.3 - 0.4	0.022	0.358
0.4 - 0.5	0.036	0.506
0.5 - 0.6	0.044	0.773
0.6 - 0.8	0.063	1.116
0.8 - 1.0	4.496	15.202
Total	0.083	0.591

Table 3: Percentage of the two pion events in bins where there is no reconstructed events in the simulation

- To correct this, the factors that could not be calculated were interpolated.

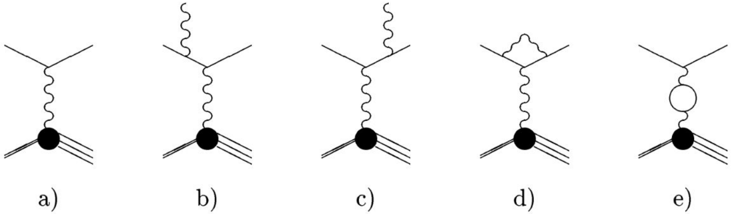
Binning

Variable	Binning
$Q^2[GeV^2]$	$[1, 1.32, 1.74, 4.00]$
$\nu[GeV]$	$[2.2, 3.36, 3.82, 4.26]$
Zh	$[0.0,\ 0.1,\ 0.2,\ 0.3,\ 0.4,\ 0.5,\ 0.6,\ 0.8,\ 1.0]$
$P_t^2[GeV^2]$	60 bins equally spaced between 0 and 3
$\phi_{PQ}[Deg]$	6 bins equally spaced between -180 and 180

Table 3: Binning used in the acceptance correction

Radiative correction

- Remove the contributions of the radiation of photons by the incoming or outgoing electron.
- Remove the contributions of higher order electrodynamics contributions to the electron-photon vertex and the photon propagator.

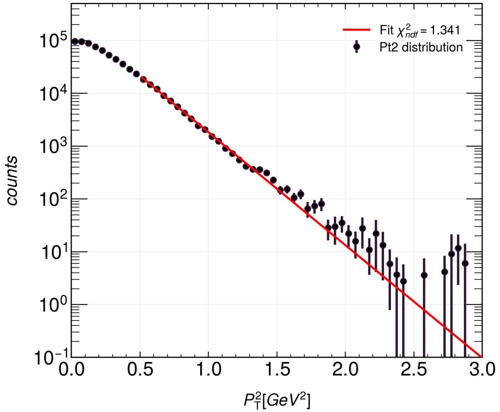


- The corrections was done with HAPRAD. Even if the software was done for SIDIS also works for two pions events because RC only depends on the leptonic branch on the interaction.

Background subtraction

- The procedure consisted of two parts. The first consisted of removing the events with P_t^2 bigger than a cutoff value. Then, the empty bins in P_t^2 distributions below the cutoff value were interpolated.
- The cutoff values differed for each Zh bin and were selected to dismiss the events at high P_t^2 , which does not follow an exponential behavior.
- The cutoff values were calculated fitting exponential functions starting from a different bin.

$$f_{fit}(P_t^2) = CExp(-P_t^2/\alpha)$$



Background subtraction

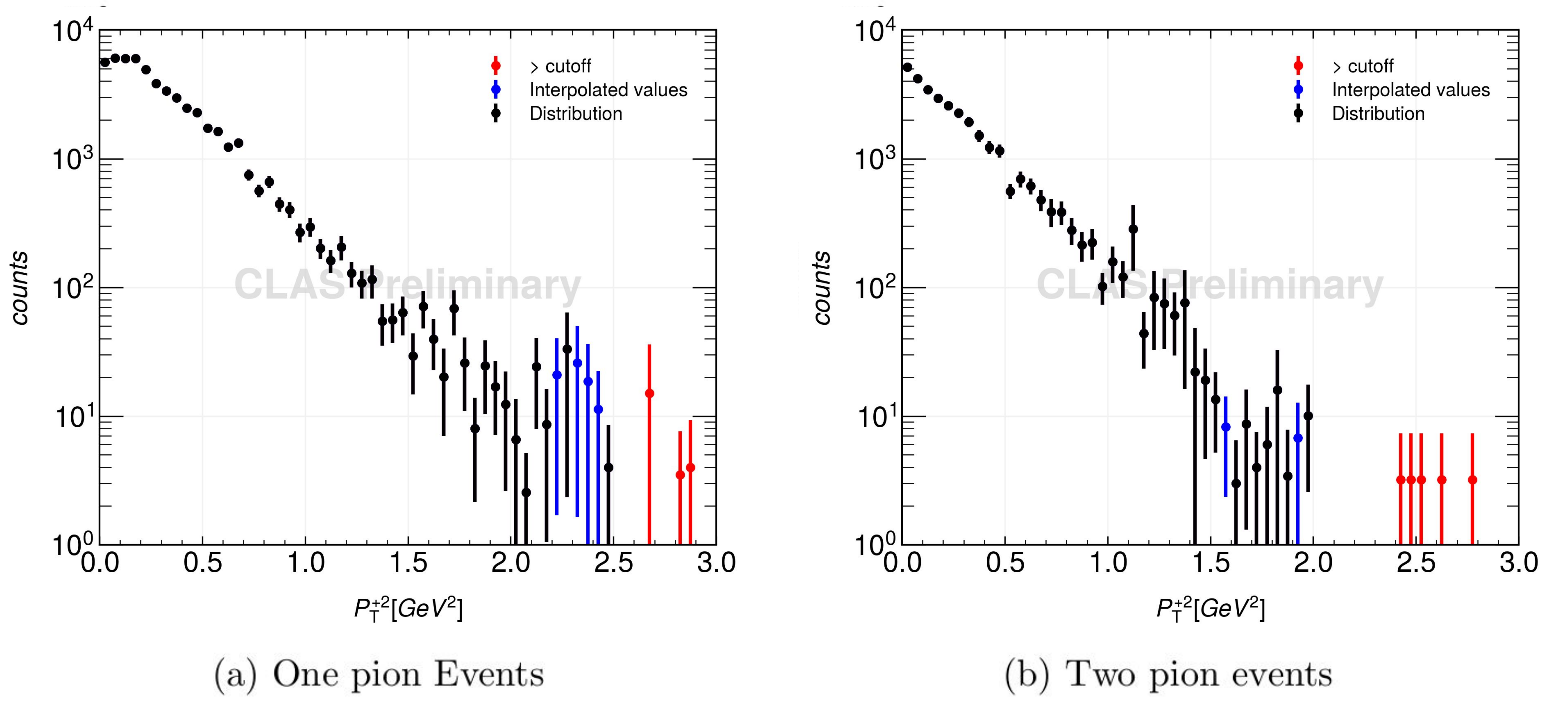


Fig 4: $P^{+}_{t}{}^{2}$ distribution after the background subtraction for Fe target with Z^{+}_{h} between 0.4 and 0.5. In black, the original point in the distribution; in red, events with $P^{+}_{t}{}^{2}$ bigger than the cutoff value; and in blue, the interpolated points

Systematic uncertainties sources

- Positive Pion identification cuts.
- Vertex identification.
- Delta Z Cut.
- Background subtraction procedure.
- Number of bins.
- $N^{i}_{a=t}$ cut.
- Acc minimum value.
- Closure test.
- Acceptance factor interpolation.
- Radiative correction.

Results as a function of $A^{\frac{1}{3}}$.

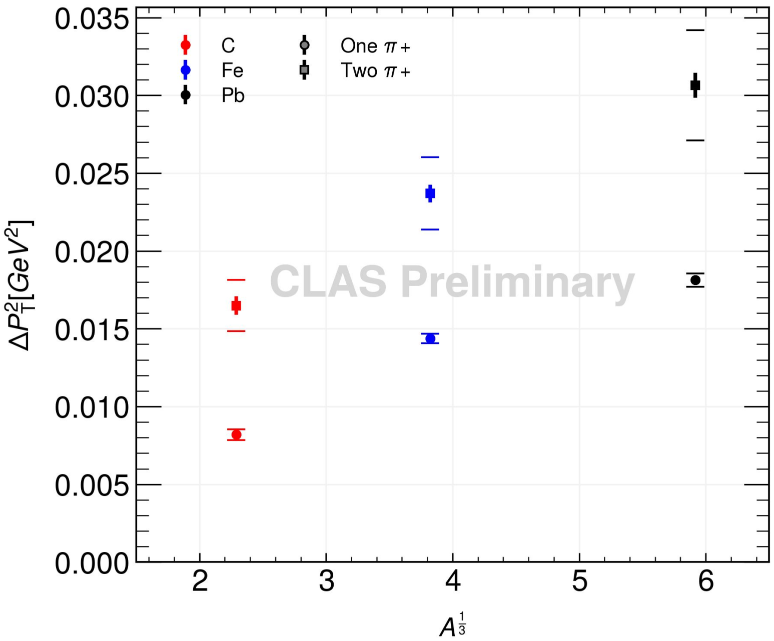


Fig 7: Transverse momentum broadening in function of $A^{1/3}$, all the other variables are integrated. The circles are one pions events, and the squares are two pions events.

Results as a function of Zh

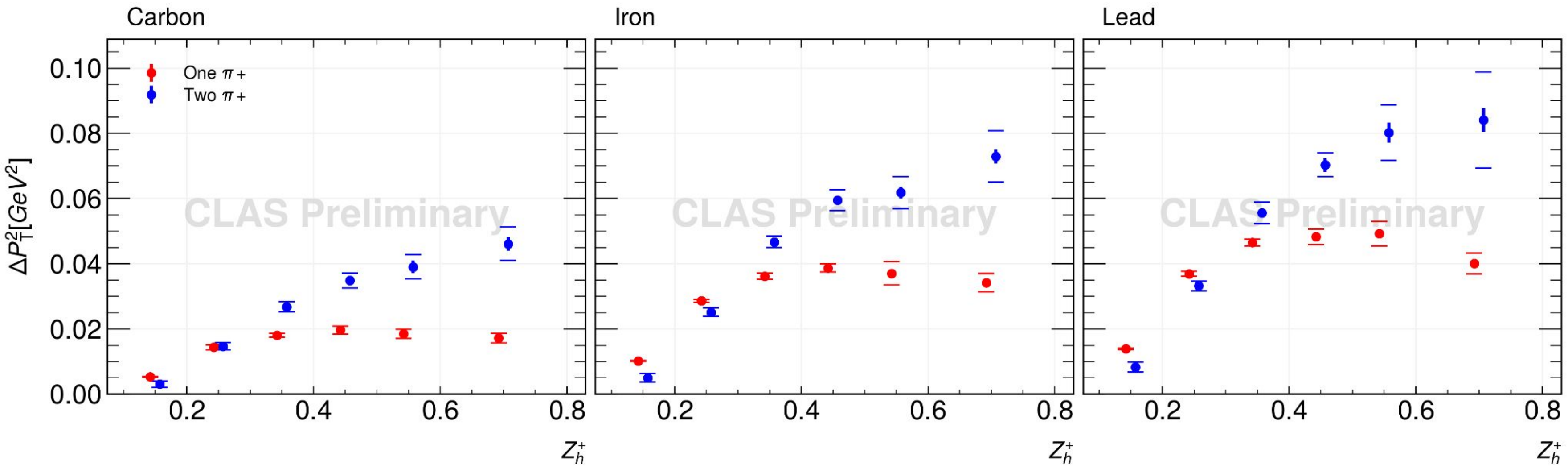


Fig 8: Transverse momentum broadening in function of Z_h (all the other variables are integrated). Each box represent a different target

Results as a function of Q^2

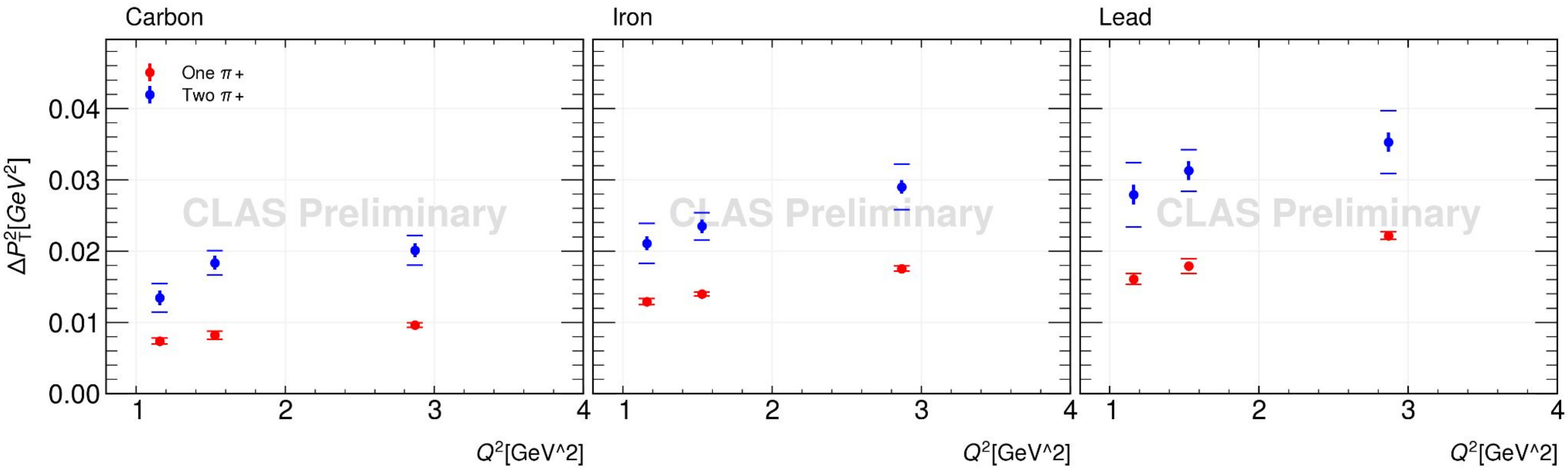


Fig 9: Transverse momentum broadening in function of Q^2 (all the other variables are integrated). Each box represent a different target

Results as a function of ν

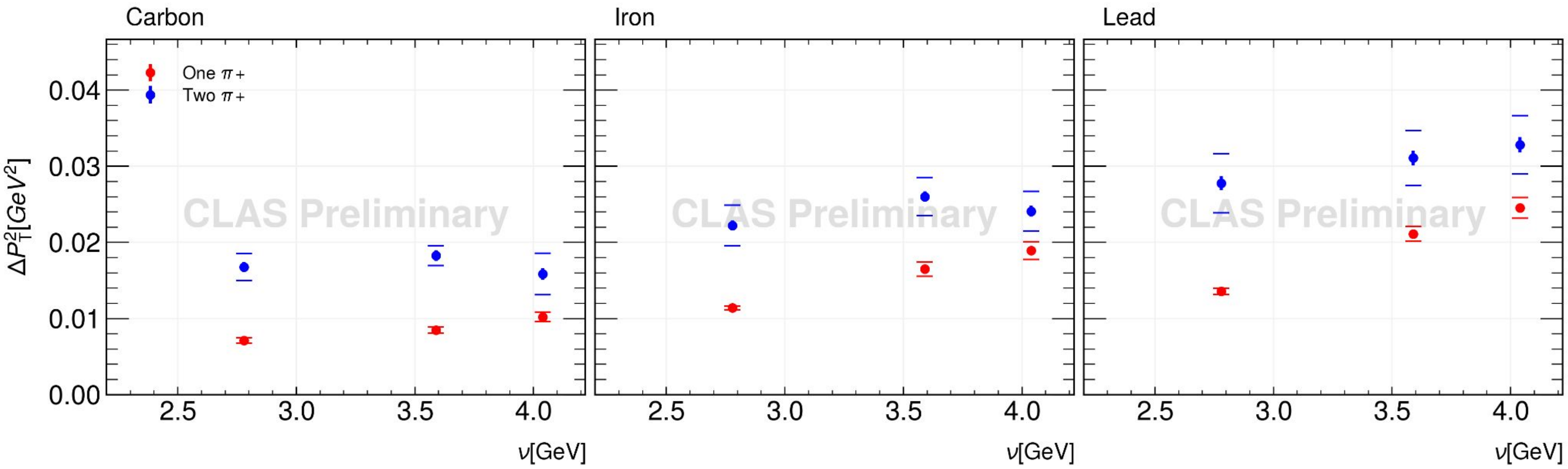


Fig 10: Transverse momentum broadening in function of ν (all the other variables are integrated). Each box represent a different target

Conclusions

- We studied the transverse momentum broadening as a function of the number of pions in the final state and different kinematical variables, applying all the necessary corrections.

- The results present a strong dependence on $A^{1/3}$ and Z_h.

- We proved that the broadening is bigger for two pions events for $Z_h > 0.3$ and the difference increases with Z_h.

- There was not enough statistics to obtain a solid result for $Z_h > 0.8$.

Backup

Systematics uncertainty

- The value for the systematic error was obtained under the assumption that the nominal value is in the center of a uniform distribution with a length of 2Δ, where Δ is the biggest variation with respect to the nominal value.
- This assumption was made because no predilection is expected for the selected nominal values.

$$f_{uniform} = \frac{1}{2\Delta} = \frac{1}{2\sigma\sqrt{3}} \rightarrow \sigma_{sou} = \pm\frac{\Delta}{\sqrt{3}}$$

- The total systematic uncertainty reads:

$$\sigma_{sys}^2 = \sum_{Sources} \sigma_{sou}^2$$

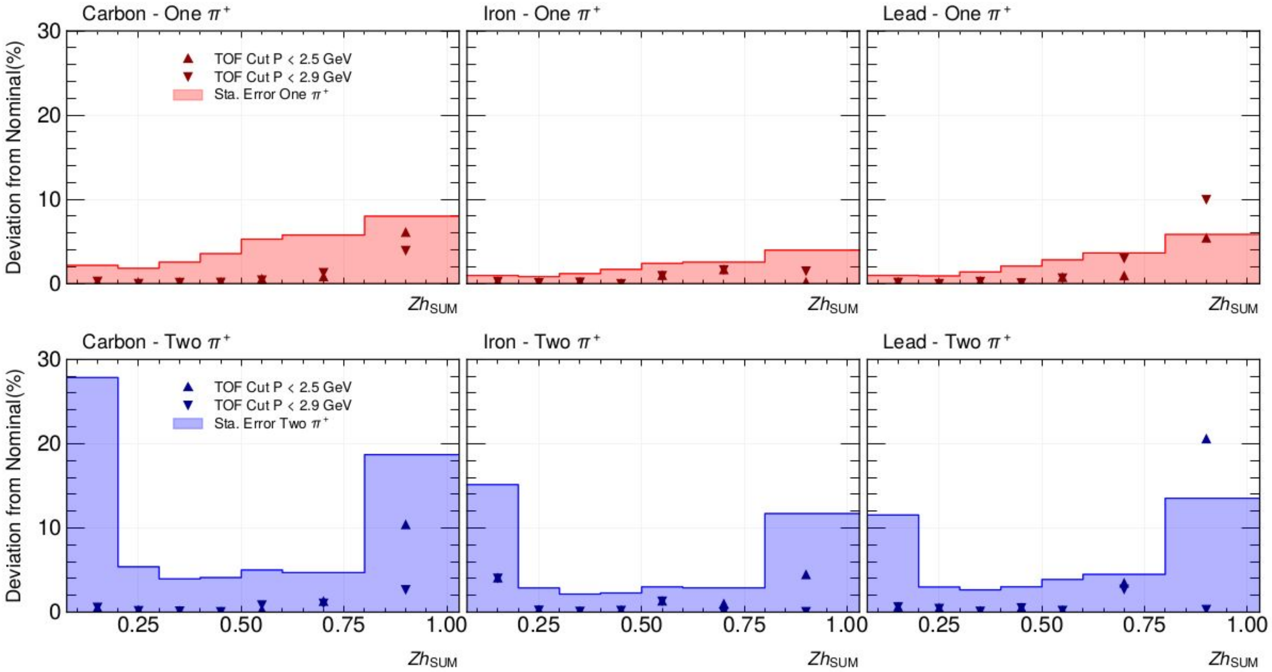


Figure 3.31: Deviation from the nominal ΔP_t^2 value due the variation in the positive pion identification.

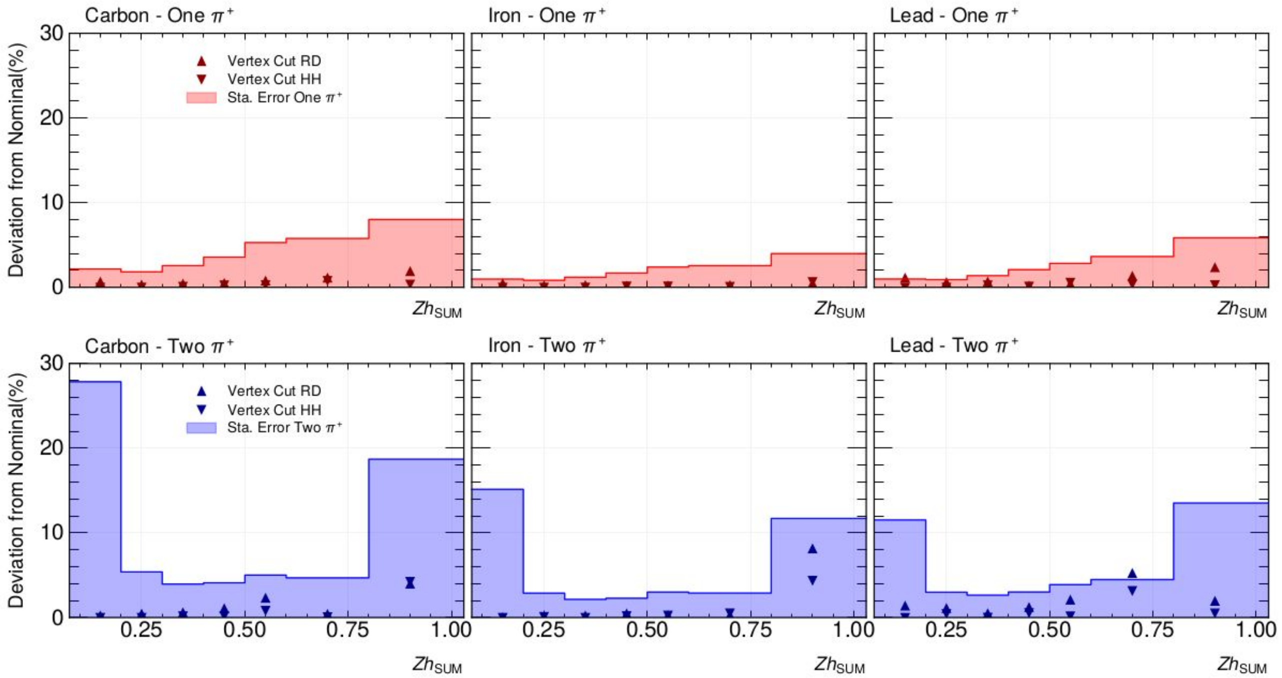


Figure 3.32: Deviation from the nominal ΔP_t^2 value due the variation in the method used to select the vertex of interaction.

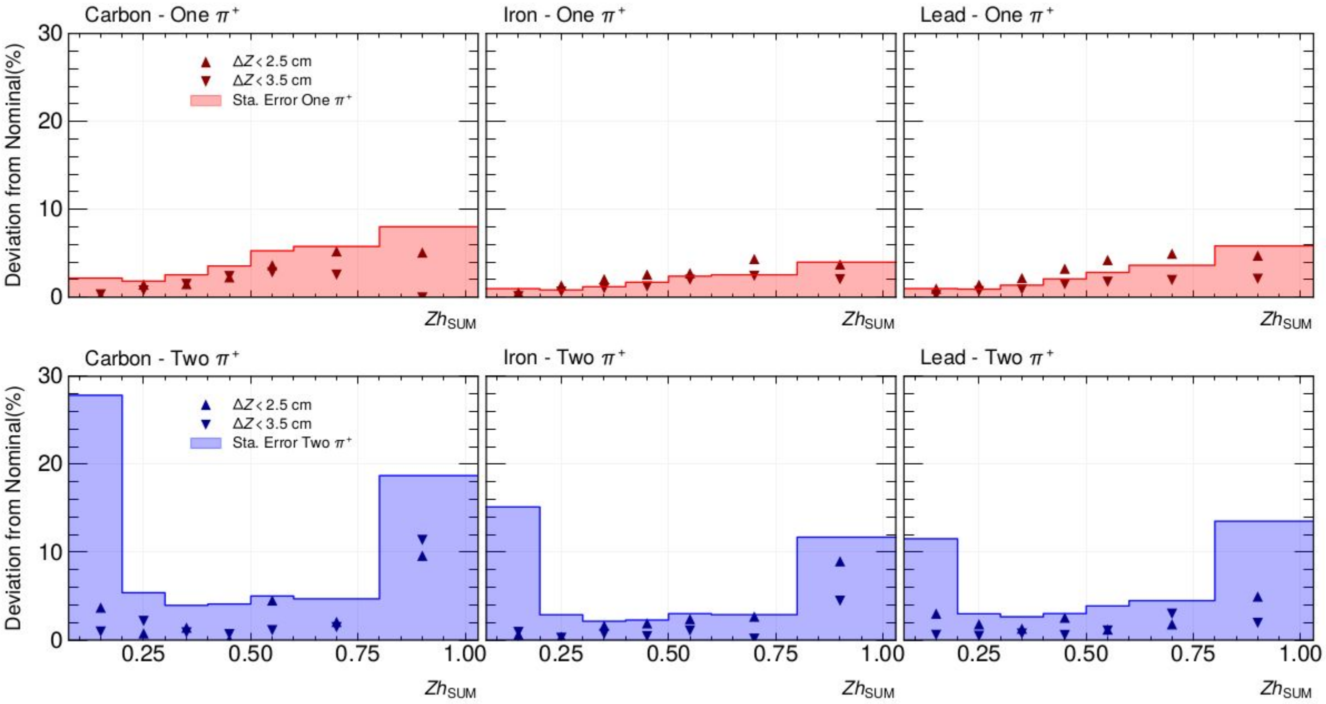


Figure 3.33: Deviation from the nominal ΔP_t^2 value due the variation in the ΔZ cut.

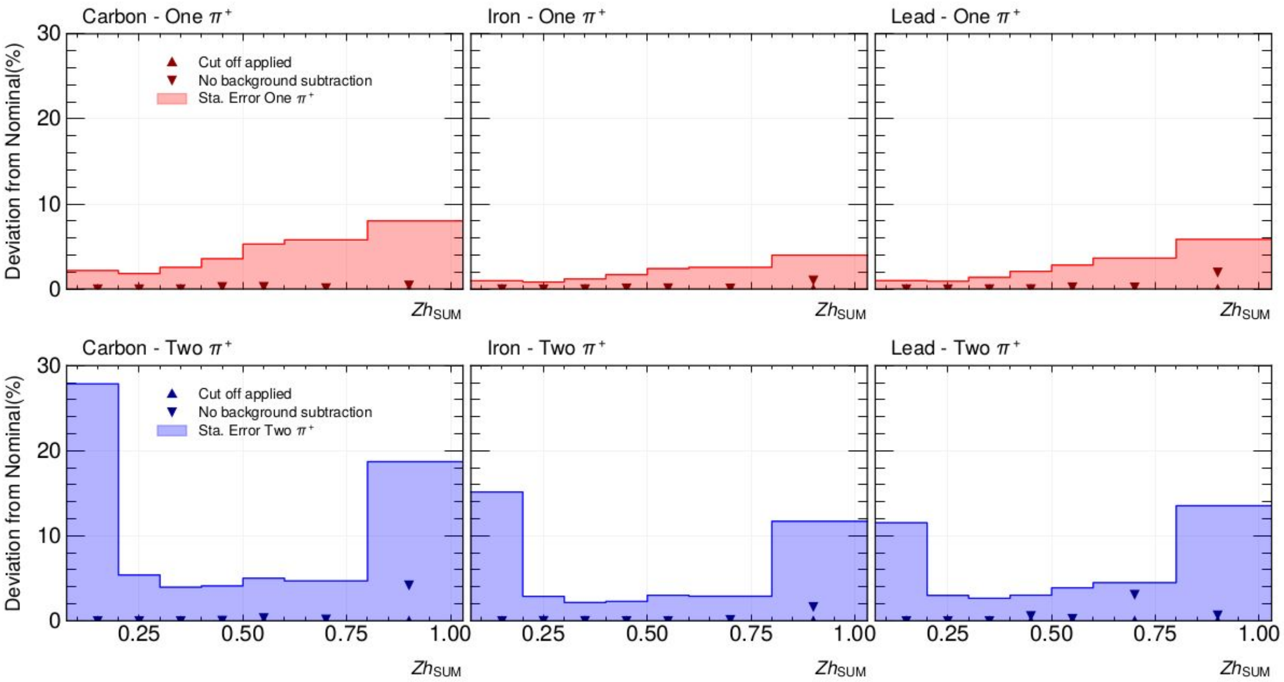


Figure 3.34: Deviation from the nominal ΔP_t^2 value due the variation in the background subtraction procedure.

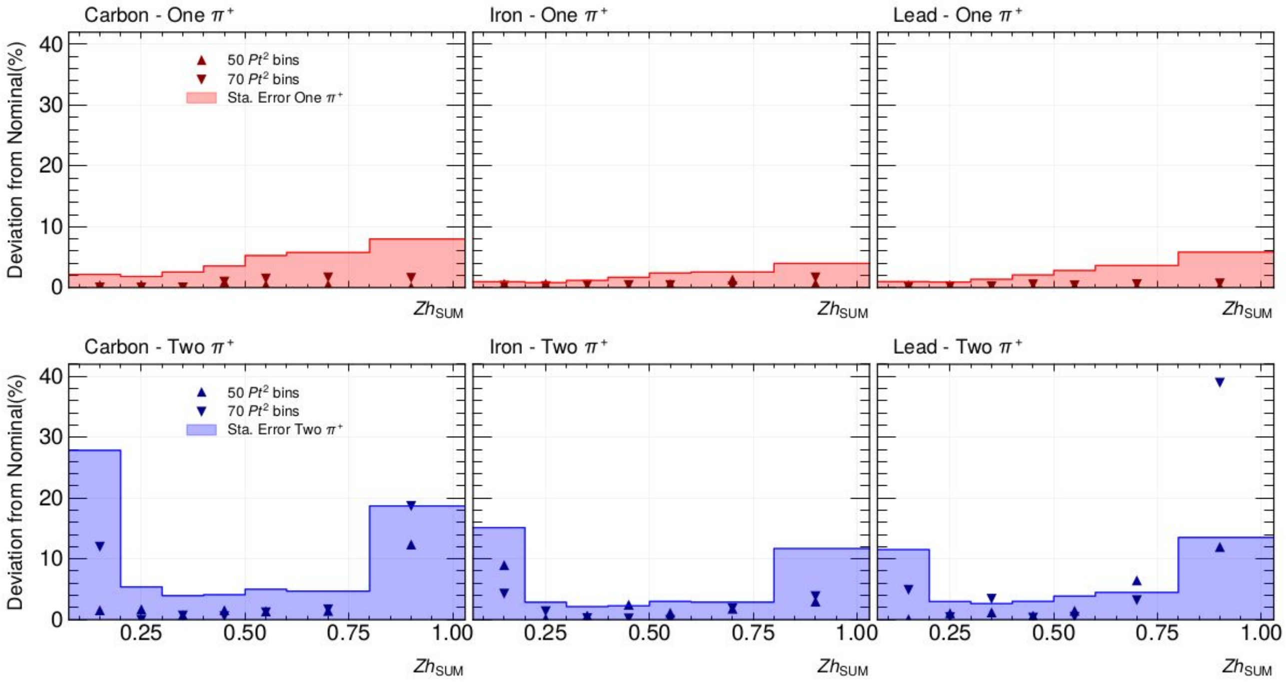


Figure 3.35: Deviation from the nominal ΔP_t^2 value due the variation in numbers of P_t^2 bins in the acceptance correction.

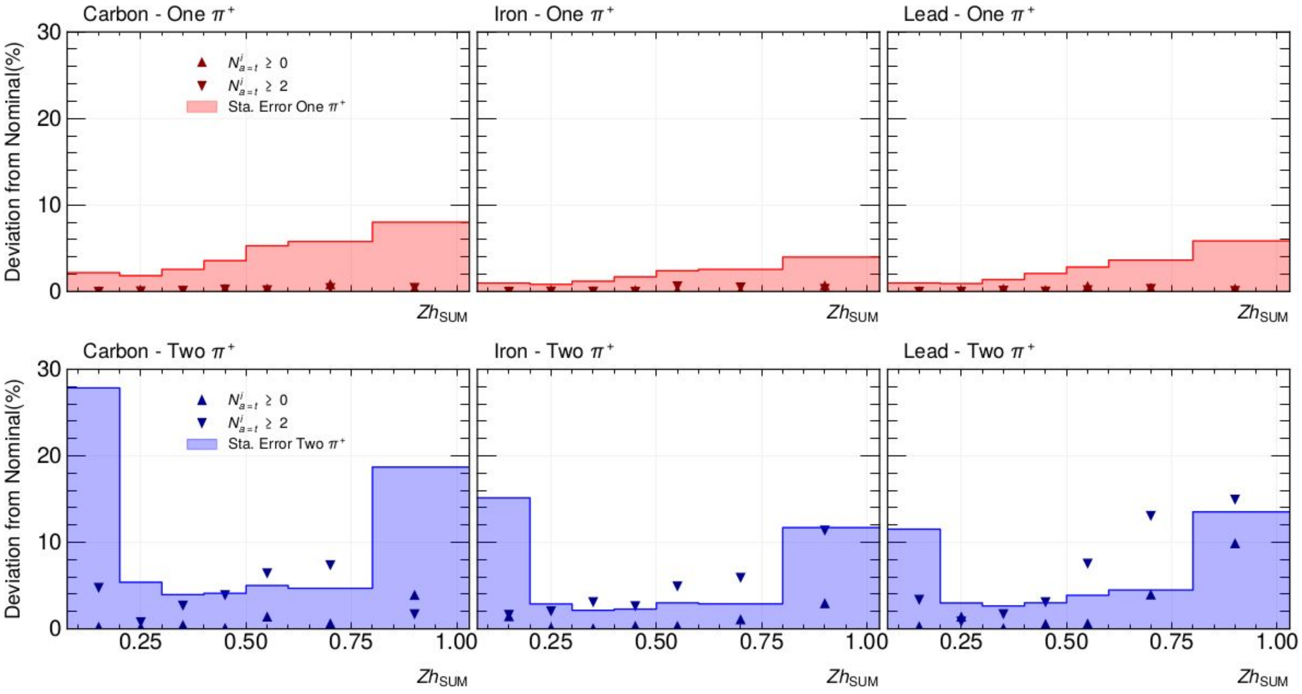


Figure 3.36: Deviation from the nominal ΔP_t^2 value due the variation in $N^i_{a=t}$ cut.

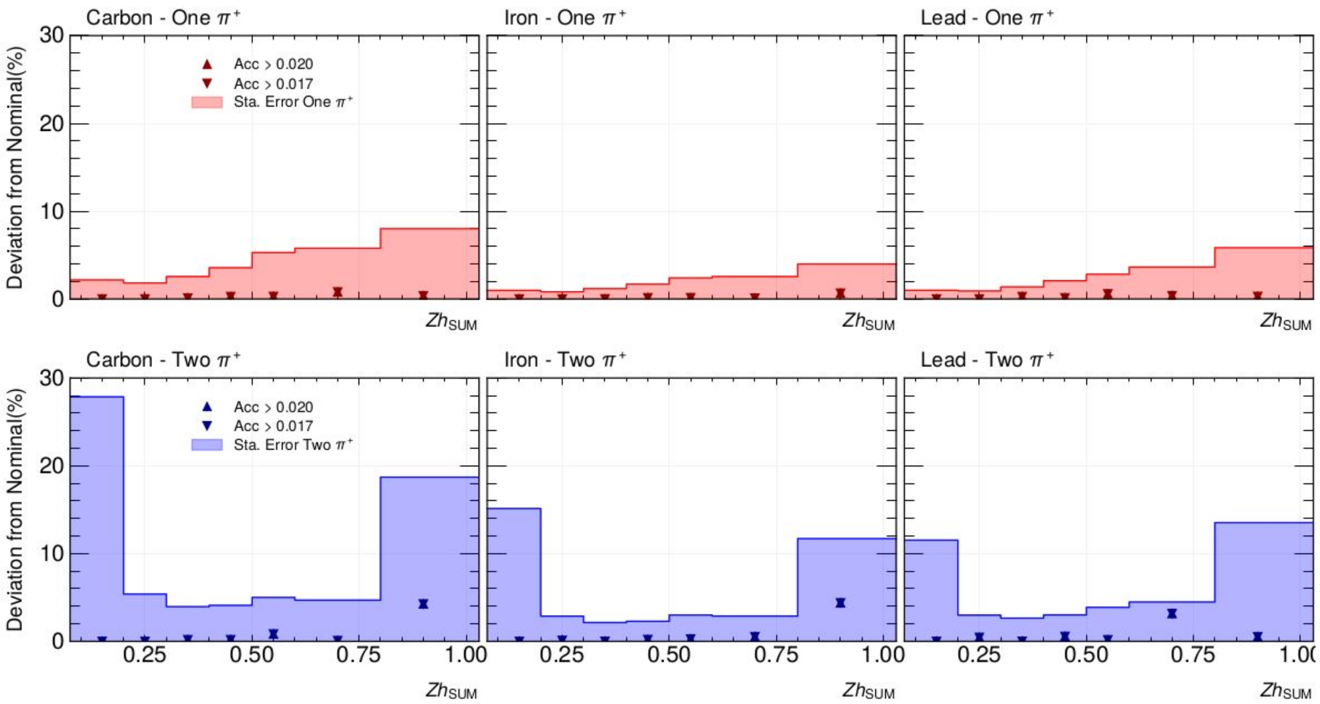


Figure 3.37: Deviation from the nominal ΔP_t^2 value due to applied a cut in Acc^i.

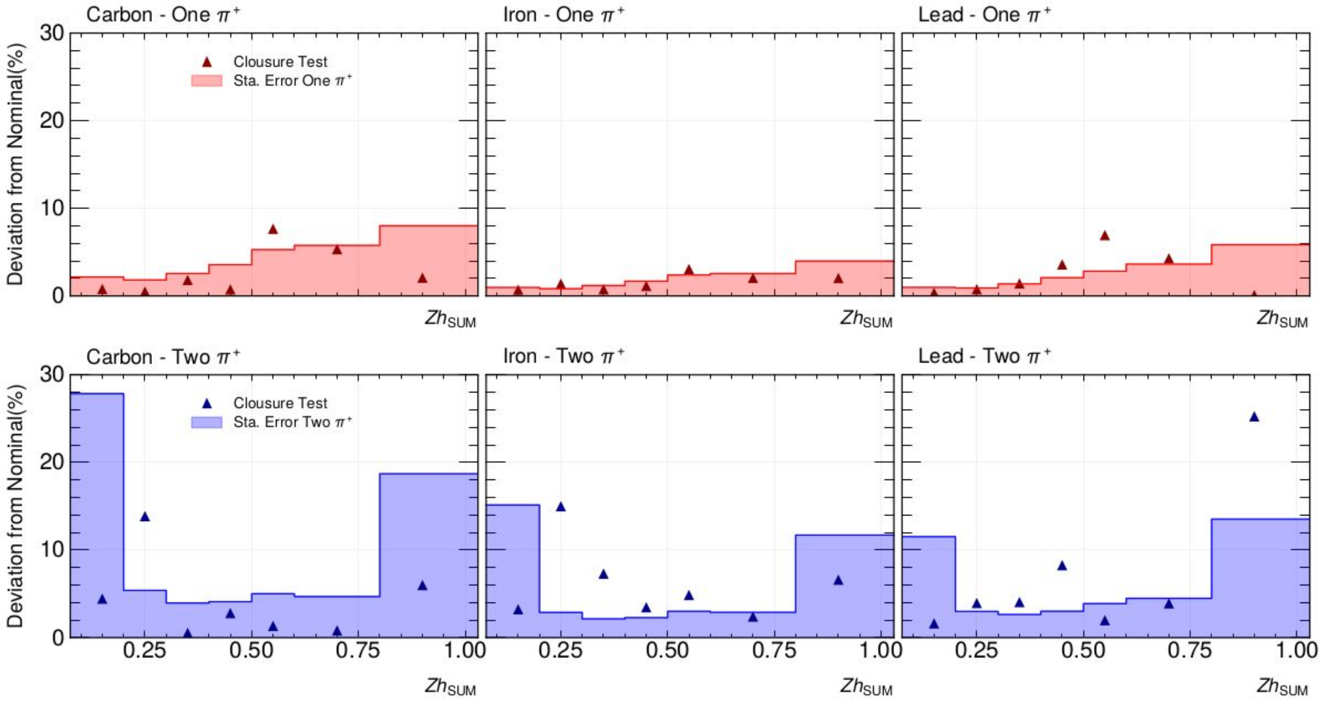


Figure 3.38: Deviation from the nominal ΔP_t^2 value due to apply the CT factor.

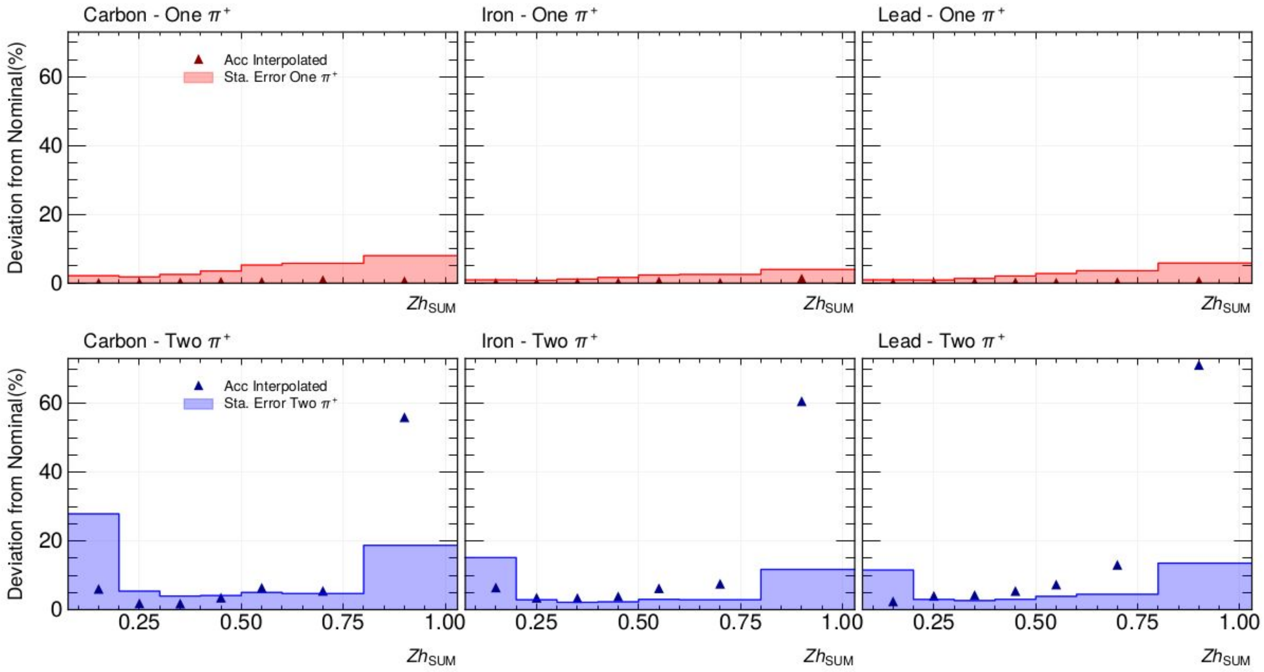


Figure 3.39: Deviation from the nominal ΔP_t^2 value due to do not interpolated the acceptance factors.

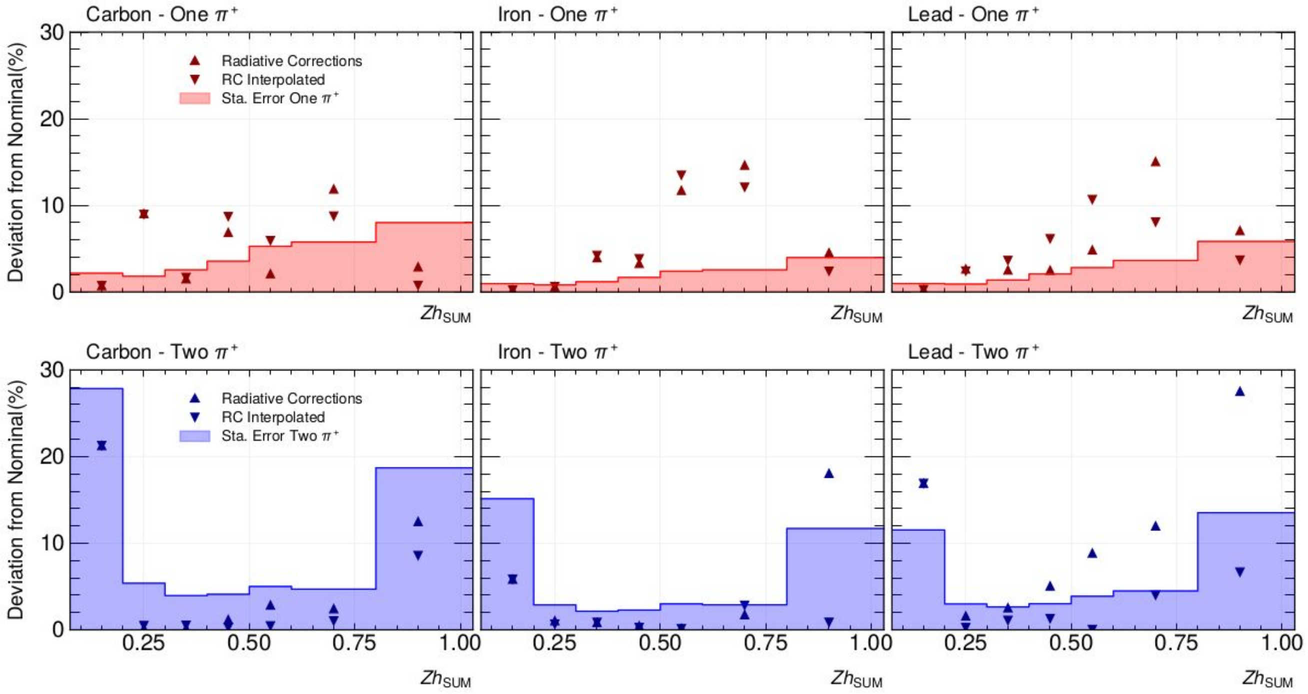


Figure 3.40: Deviation from the nominal ΔP_t^2 value due the radiative correction.

Broadening Table Carbon

	One pion events				Two pion events			
Zh_{Sum}	ΔP_t^2	σ_{tot}	σ_{sta}	σ_{sys}	ΔP_t^2	σ_{tot}	σ_{sta}	σ_{sys}
0.1 - 0.2	0.0052	0.0001	0.0001	0.0	0.003	0.001	0.0008	0.0005
0.2 - 0.3	0.0143	0.0008	0.0003	0.0008	0.0147	0.0014	0.0008	0.0012
0.3 - 0.4	0.018	0.0005	0.0005	0.0003	0.0266	0.0012	0.0011	0.0006
0.4 - 0.5	0.0197	0.0011	0.0007	0.0008	0.0347	0.0019	0.0014	0.0013
0.5 - 0.6	0.0184	0.0014	0.001	0.0009	0.0384	0.0031	0.0019	0.0024
0.6 - 0.8	0.0172	0.0017	0.001	0.0014	0.0455	0.0034	0.0021	0.0026
0.8 - 1.0	0.0216	0.0021	0.0017	0.0011	0.0518	0.0212	0.0097	0.0188

Table 4.1: Transverse momentum broadening for carbon. The results are in GeV^2

Broadening Table Iron

	One pion events				Two pion events			
Zh_{Sum}	ΔP_t^2	σ_{tot}	σ_{sta}	σ_{sys}	ΔP_t^2	σ_{tot}	σ_{sta}	σ_{sys}
0.1 - 0.2	0.0102	0.0001	0.0001	0.0001	0.0049	0.0008	0.0007	0.0004
0.2 - 0.3	0.0285	0.0004	0.0002	0.0003	0.0252	0.0024	0.0007	0.0023
0.3 - 0.4	0.036	0.001	0.0004	0.0009	0.0468	0.0026	0.001	0.0024
0.4 - 0.5	0.0386	0.0012	0.0007	0.001	0.0596	0.0026	0.0014	0.0022
0.5 - 0.6	0.0373	0.0028	0.0009	0.0027	0.0615	0.0039	0.0018	0.0034
0.6 - 0.8	0.0341	0.0032	0.0009	0.0031	0.0735	0.005	0.0021	0.0045
0.8 - 1.0	0.0331	0.0019	0.0013	0.0013	0.0778	0.031	0.0091	0.0297

Table 4.2: Transverse momentum broadening for iron. The results are in GeV^2

Broadening table lead

	One pion events				Two pion events			
Zh_{Sum}	ΔP_t^2	σ_{tot}	σ_{sta}	σ_{sys}	ΔP_t^2	σ_{tot}	σ_{sta}	σ_{sys}
0.1 - 0.2	0.0138	0.0002	0.0001	0.0001	0.0082	0.0013	0.0009	0.0009
0.2 - 0.3	0.0369	0.0008	0.0003	0.0007	0.0332	0.0016	0.001	0.0012
0.3 - 0.4	0.0463	0.0012	0.0006	0.001	0.0554	0.0028	0.0015	0.0024
0.4 - 0.5	0.0484	0.0018	0.001	0.0015	0.0701	0.0052	0.0021	0.0048
0.5 - 0.6	0.0492	0.003	0.0014	0.0027	0.0784	0.0071	0.003	0.0064
0.6 - 0.8	0.04	0.0041	0.0015	0.0039	0.0836	0.0125	0.0038	0.0119
0.8 - 1.0	0.0386	0.0038	0.0023	0.003	0.1127	0.0624	0.0152	0.0605

Table 4.3: Transverse momentum broadening for lead. The results are in GeV^2