Shane Sweetman

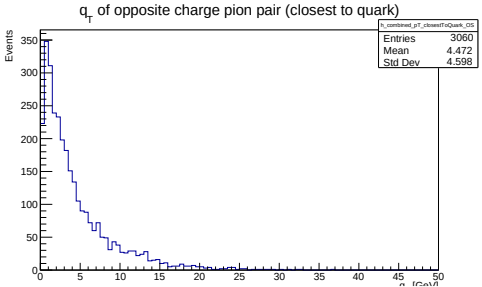
Project update meeting
Week 3

A TMD-oriented analysis of $\pi^+\pi^-$ pairs in e^+e^- collisions

Outline

- Make OS/SS selection **exclusive per event** (pick the 2 highest-momentum pions, then classify as OS or SS).
- Investigate large-q_T events ($q_T \sim 20$ GeV) with the event logger (print 4-vectors and topology).
- Read more papers to identify the **right TMD observable**.

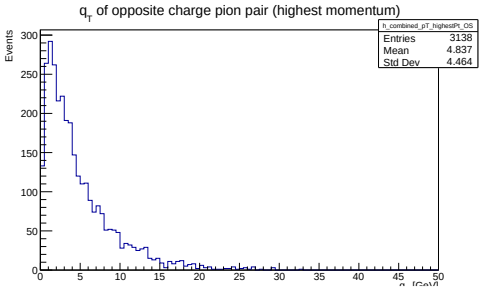
Closest to Quark (after OS/SS filter)



Closest-to-quark: quick read

- OS vs SS totals are roughly **50/50**.
- The q_T **shape** is essentially unchanged after the OS/SS split.

Highest-q_T (after OS/SS filter)



Highest-p_T: quick read

- OS vs SS totals are roughly **50/50**.
- The q_T **shape** appears to have some slight differences after the OS/SS split.

$q_T \sim 20$ GeV: counts in probe window

```
---- Counts in qT window around 20 GeV
Window: [19.000, 21.000] GeV
Closest OS in window:                20
Closest SS in window:                9
Highest-pT OS in window:             19
Highest-pT SS in window:             11
=======================================
```

Setup (this week)

15k $e^+e^- \to Z^0 \to q\bar{q}$ at $\sqrt{s} = 91.2$ GeV; thrust > 0.8; exactly 2 jets; $|\Delta\phi| > 2.8$. Beam-axis transverse q_T from one charged pion per jet (closest-to-quark / highest-p_T).

What this shows

- Probe window: $19 < q_T < 21$ GeV. Only $\mathcal{O}(10)$ events per category (rare in the full sample).
- Appears in both OS and SS, but **OS is roughly twice as common as SS** in this window (for both selection modes shown).

$q_T \sim 20$ GeV: focused view (selected pair)

```
--- FOCUSED VIEW: selected pion pair only ---
pair pion0 row:
idx=26 id=211 st=83 m1=21 m2=25 d1=0 d2=0 px=-5.812 py=3.811 pz=-2.393 E=7.352
pair pion1 row:
idx=43 id=-211 st=91 m1=35 m2=0 d1=0 d2=0 px=21.099 py=-16.000 pz=7.563 E=27.539
Focus [Enter=continue, a=ancestry, t=table, q=quit]: t
```

What is being printed

"Focused view" shows only the two selected pions (one per jet) with their 4-vectors and record indices.

Beam-axis transverse check (from (p_x, p_y))

$$p_{x,\mathrm{sum}} \approx 15.287, \qquad p_{y,\mathrm{sum}} \approx -12.189, \qquad q_T \approx 19.6 \text{ GeV}.$$

Takeaway

A single pion with large beam-p_T is enough to generate $q_T \sim 20$ GeV when the partner does not cancel it in (x, y).

Closer look into ancestry (rows 26 & 43)

=== EVENT 3919 (table) ===

row	event	size	no	id	name	st	m1	m2	d1	d2	px	py	pz	E
0	3919	60	0	90	system	-11	0	0	0	0	0.000	0.000	0.000	91.200
1	3919	60	1	-11	e+	-12	0	0	3	0	0.000	0.000	45.600	45.600
2	3919	60	2	11	e-	-12	0	0	4	0	0.000	0.000	-45.600	45.600
3	3919	60	3	-11	e+	-21	1	0	5	0	0.000	0.000	45.600	45.600
4	3919	60	4	11	e-	-21	2	0	5	0	0.000	0.000	-45.600	45.600
5	3919	60	5	23	Z0	-22	3	4	6	7	0.000	0.000	0.000	91.200
6	3919	60	6	2	id2	-23	5	0	8	9	-34.777	26.674	-12.582	45.600
7	3919	60	7	-2	id-2	-23	5	0	10	10	34.777	-26.674	12.582	45.600
8	3919	60	8	2	id2	-51	6	0	21	21	-29.748	23.196	-10.063	39.043
9	3919	60	9	21	g	-51	6	0	11	12	-5.008	3.461	-2.511	6.585
10	3919	60	10	-2	id-2	-52	7	7	13	13	34.755	-26.658	12.574	45.572
11	3919	60	11	21	g	-51	9	0	14	15	-4.935	3.665	-2.210	6.532
12	3919	60	12	21	g	-51	9	0	16	16	0.642	-0.751	-0.042	0.989
13	3919	60	13	-2	id-2	-52	10	10	19	19	34.041	-26.110	12.315	44.635
14	3919	60	14	21	g	-51	11	0	22	22	-4.748	3.028	-2.252	6.065
15	3919	60	15	21	g	-51	11	0	23	23	-0.120	0.558	0.038	0.572
16	3919	60	16	21	g	-52	12	12	17	18	0.575	-0.672	-0.038	0.885
17	3919	60	17	21	g	-51	16	0	24	24	0.558	-0.236	-0.053	0.608
18	3919	60	18	21	g	-51	16	0	20	0	9.493	-7.702	3.446	12.701
19	3919	60	19	-2	id-2	-52	13	13	20	0	24.564	-18.844	8.884	32.211
20	3919	60	20	-2	id-2	-73	19	18	25	25	34.058	-26.546	12.330	44.912
21	3919	60	21	2	id2	-71	8	8	26	35	-29.748	23.196	-10.063	39.043
22	3919	60	22	21	g	-71	14	14	26	35	-4.748	3.028	-2.252	6.065
23	3919	60	23	21	g	-71	15	15	26	35	-0.120	0.558	0.038	0.572
24	3919	60	24	21	g	-71	17	17	26	35	0.558	-0.236	-0.053	0.608

(showing rows 0 to 24 of 60 total)
More [Enter=continue, n=next event, q=quit]:

=== EVENT 3919 (table) ===

row	event	size	no	id	name	st	m1	m2	d1	d2	px	py	pz	E
25	3919	60	25	-2	id-2	-71	20	20	26	35	34.058	-26.546	12.330	44.912
26	3919	60	26	211	pi+	83	21	25	0	0	-5.812	3.811	-2.393	7.352
27	3919	60	27	311	id311	-83	21	25	36	36	-19.611	15.368	-6.055	25.646
28	3919	60	28	-313	id-313	-83	21	25	37	38	-3.904	3.842	-1.250	5.678
29	3919	60	29	-211	pi-	83	21	25	0	0	-5.087	2.824	-2.399	6.295
30	3919	60	30	213	rho+	-83	21	25	39	40	0.803	0.157	-0.067	1.082
31	3919	60	31	-211	pi-	83	21	25	0	0	-0.005	0.300	-0.126	0.354
32	3919	60	32	211	pi+	84	21	25	0	0	3.874	-3.220	1.459	5.246
33	3919	60	33	-211	pi-	84	21	25	0	0	0.286	-0.386	0.854	0.990
34	3919	60	34	213	rho+	-84	21	25	41	42	7.689	-6.208	2.223	10.157
35	3919	60	35	-213	rho-	-84	21	25	43	44	21.767	-16.490	7.754	28.400
36	3919	60	36	310	id310	-91	27	27	46	47	-19.611	15.368	-6.055	25.646
37	3919	60	37	-311	id-311	-91	28	0	45	45	-2.297	1.959	-0.671	3.132
38	3919	60	38	111	pi0	-91	28	0	48	49	-1.607	1.883	-0.579	2.546
39	3919	60	39	211	pi+	91	30	0	0	0	0.716	0.306	0.113	0.799
40	3919	60	40	111	pi0	-91	30	0	50	51	0.086	-0.148	-0.180	0.283
41	3919	60	41	211	pi+	91	34	0	0	0	4.907	-4.165	1.741	6.669
42	3919	60	42	111	pi0	-91	34	0	52	53	2.782	-2.043	0.482	3.488
43	3919	60	43	-211	pi-	91	35	0	0	0	21.099	-16.000	7.563	27.539
44	3919	60	44	111	pi0	-91	35	0	54	55	0.668	-0.489	0.191	0.861
45	3919	60	45	130	id130	91	37	37	0	0	-2.297	1.959	-0.671	3.132
46	3919	60	46	111	pi0	-91	36	0	56	57	-9.863	7.667	-2.827	12.810
47	3919	60	47	111	pi0	-91	36	0	58	59	-9.748	7.701	-3.228	12.836
48	3919	60	48	22	gamma	91	38	0	0	0	-0.999	1.265	-0.355	1.650
49	3919	60	49	22	gamma	91	38	0	0	0	-0.608	0.618	-0.224	0.896

(showing rows 25 to 49 of 60 total)

Selected pions in the record

Row 26 (π^+, id=211):
$(p_x, p_y, p_z, E) \approx$
$(-5.812,\ 3.811,\ -2.393,\ 7.352)$
mothers: $m_1 = 21,\ m_2 = 25$

Row 43 (π^-, id=-211):
$(p_x, p_y, p_z, E) \approx$
$(21.099,\ -16.000,\ 7.563,\ 27.539)$
mother: $m_1 = 35$

Point

These rows are the two pions used in the q_T calculation; the mother indices are what I follow to check ancestry.

Paper motivation: use a thrust-axis transverse momentum

Why this paper is relevant to us [1]

- Same collider environment: e^+e^- at high energy (LEP-style).
- Same physics goal: access **TMD-sensitive transverse momentum** in fragmentation.
- Key design choice: define transverse momentum **w.r.t. the thrust (event) axis**, not the beam axis.

Takeaway for our q_T definition

- Beam-axis transverse momentum can be large in e^+e^- (jets are randomly oriented).
- For a TMD-like observable, use an **event axis** (thrust) to define transverse components.

[1] Kang, Shao, Zhao, arXiv:2007.14425.

Questions?