

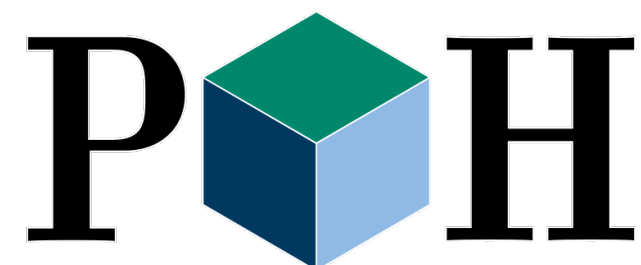
An EFT that should not be:

Collinear Chiral Perturbation Theory

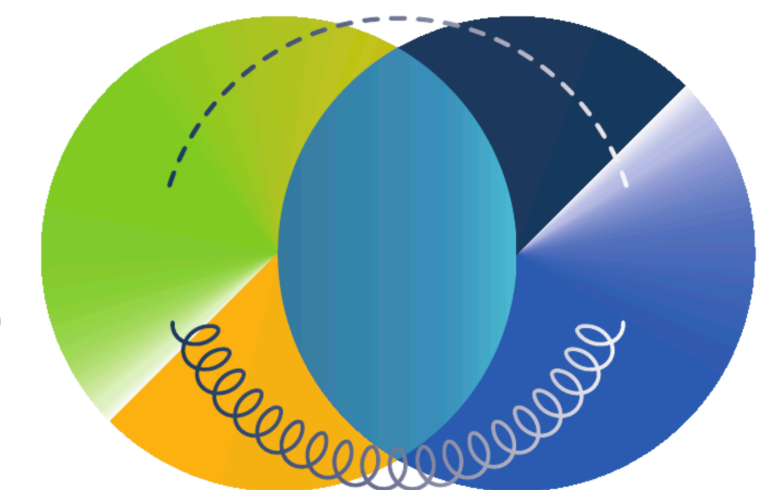
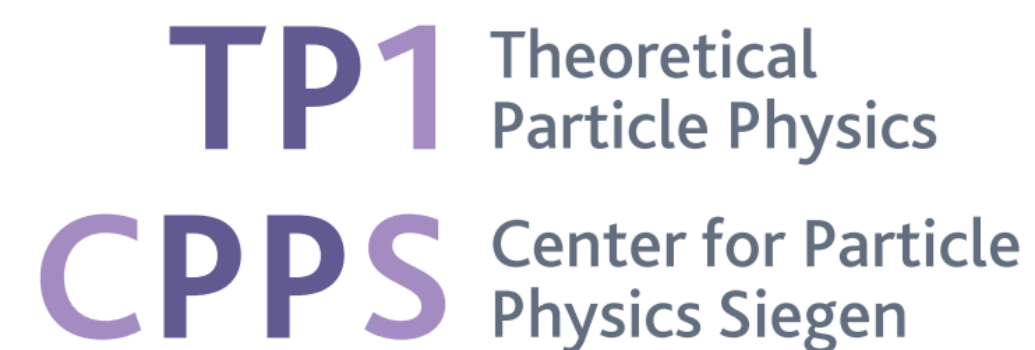
Young Scientists Meeting 2026

Jaime del Palacio Lirola

Collaborative Research Center TRR 257



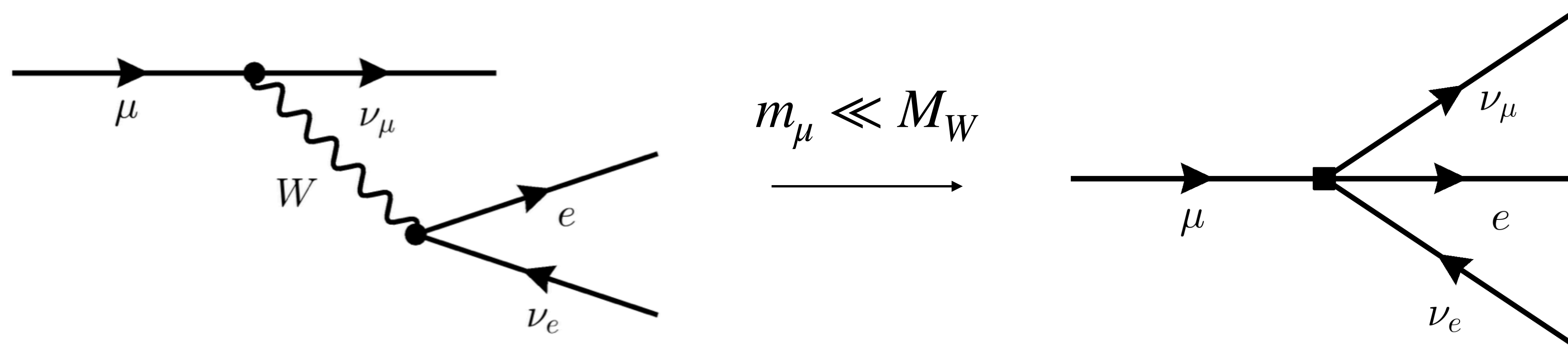
Particle Physics Phenomenology after the Higgs Discovery



color
meets
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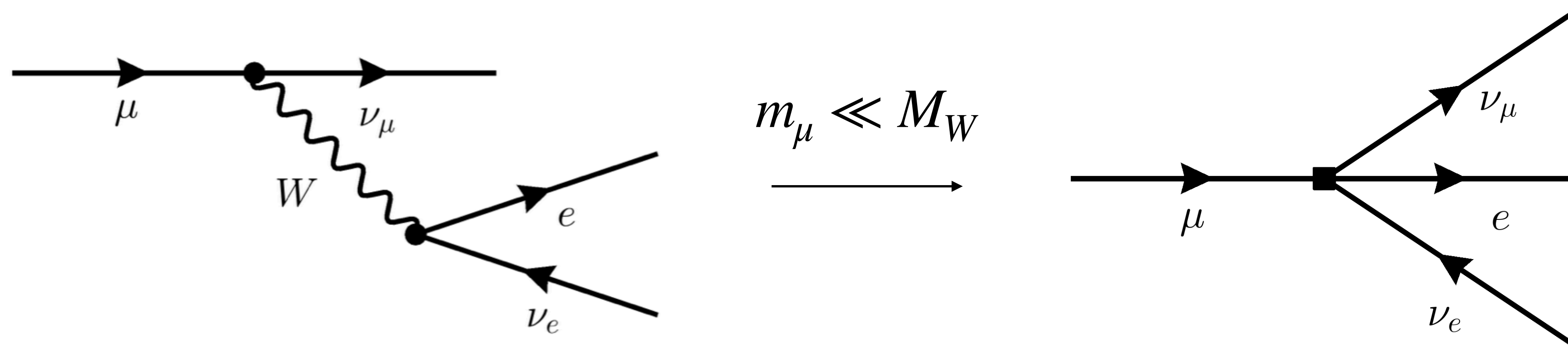
Quick reminder: What is an Effective Field Theory?

- Common examples: Weak Effective Field Theory, SMEFT, ChPT
- Based on hierarchies of scales, expand in small ratios
- New symmetries / power counting simplify the problem



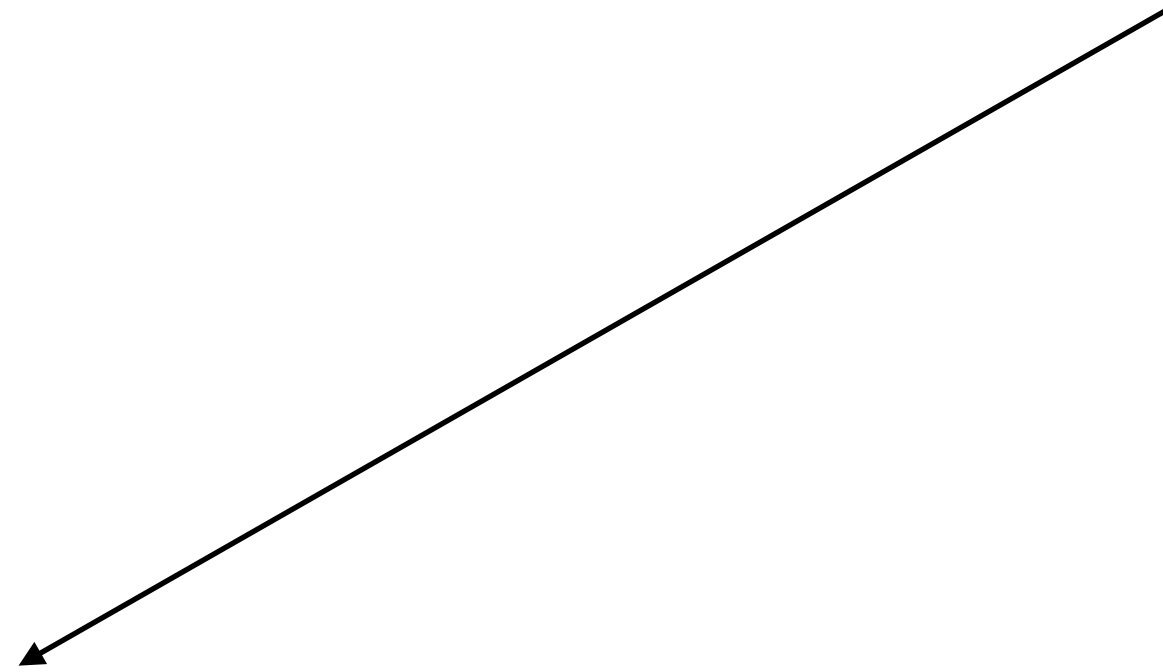
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- Common examples: Weak Effective Field Theory, SMEFT, ChPT
- Based on hierarchies of scales, expand in small ratios
- New symmetries / power counting simplify the problem
- Can be deeper than just “integrating out the heavy particle”



QCD through EFTs

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Chiral Perturbation Theory (π, K, η)

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- $m_q \ll \Lambda_{QCD}$, QCD has approximate chiral symmetry ($m_u = m_d = 0$ ($= m_s$)) in the Lagrangian, but condensate $\langle \bar{q}q \rangle$ is not invariant $\rightarrow$ SSB
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$$\mathcal{L}_{\pi_s}^{(2)} = \frac{f^2}{4} \text{Tr} \left[\partial_\mu \Sigma_s^\dagger \partial^\mu \Sigma_s \right]$$

- Degrees of freedom: **soft** pions (and $SU(N)$ partners), can add mass as a “spurion”

Matching: Chiral Perturbation Theory

$$\mathcal{L}_{\pi_s}^{(2)} = \frac{f^2}{4} \text{Tr} \left[\partial_\mu \Sigma_s^\dagger \partial^\mu \Sigma_s \right]$$

- Matching is what makes EFTs work. In QCD pion decay goes through $j_W = \bar{q}_L \gamma^\mu q_L$ which transforms under chiral symmetry as $j_W \mapsto L j_W L^\dagger$

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$$\langle 0 | j_W | \pi \rangle \stackrel{!}{=} \langle 0 | O_W | \pi \rangle \rightarrow f = f_\pi$$

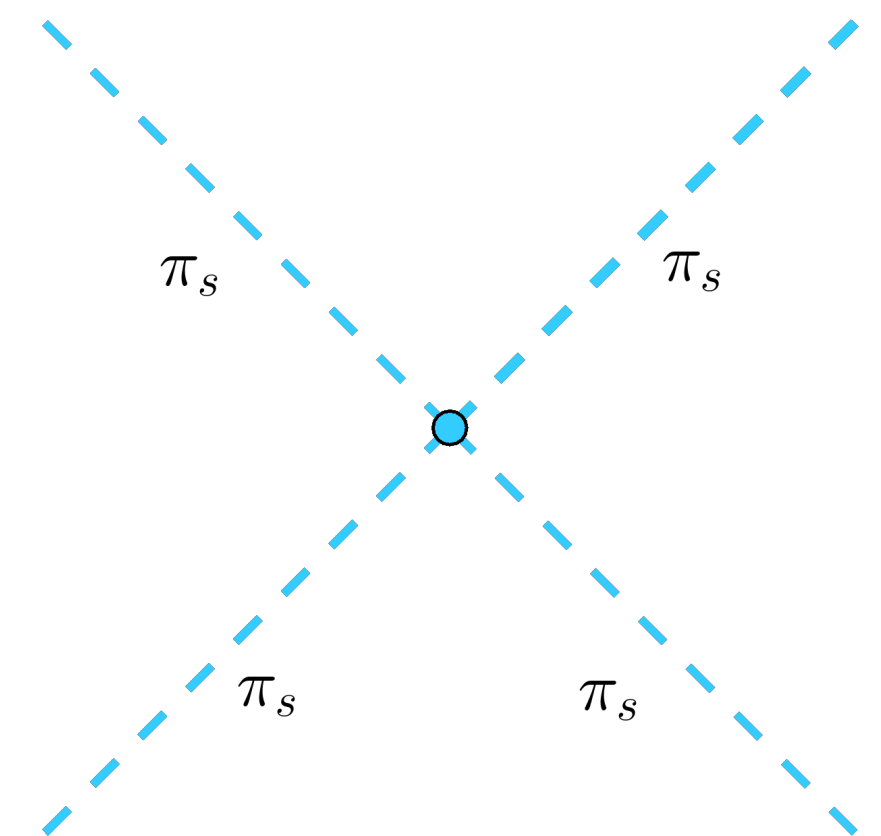
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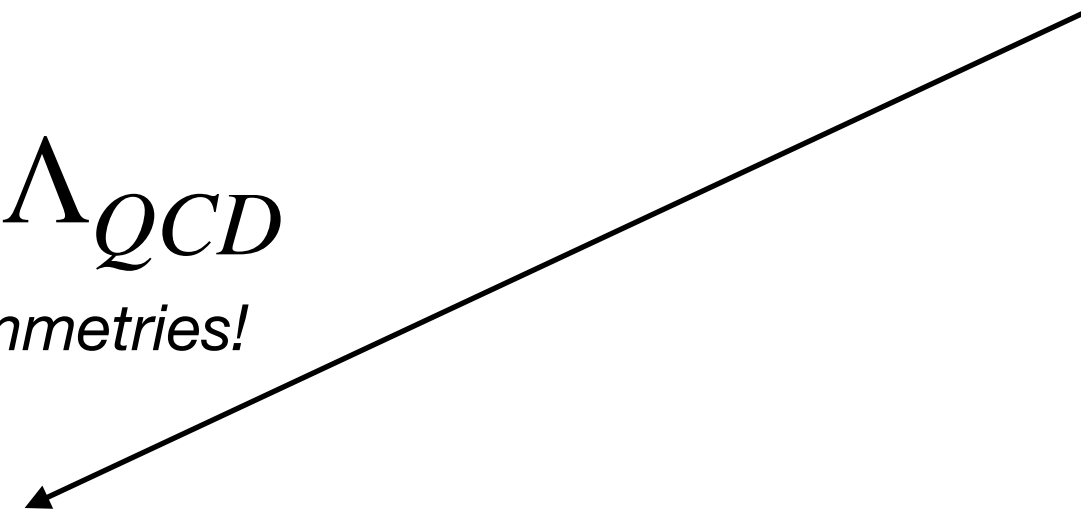
- Now we can calculate some stuff with ChPT!



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$$n^\mu = (1, 0, 0, 1), \quad \bar{n}^\mu = (1, 0, 0, -1), \quad n^2 = \bar{n}^2 = 0, \quad n \cdot \bar{n} = 2 \quad n \cdot k_\perp = \bar{n} \cdot k_\perp = 0$$

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 - In SCET II, the **collinear** fields are a boosted version of the **soft** fields
 - The SCET II LO Lagrangian is two copies of QCD (one **soft**, one **collinear**), decoupled

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It's use is motivated in places where you have relevant soft and collinear hadrons, like in $B \rightarrow \pi_c$

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- Problem: $\mathcal{U}_1 \sim 1$, so $\mathcal{U}_2 = \Sigma_\infty(s_1\bar{n})\Sigma_\infty^\dagger(s_2\bar{n})\Sigma_\infty(s_3\bar{n})\Sigma_\infty^\dagger(s_4\bar{n})$ is allowed

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$$\Sigma_\infty(x)\Sigma_\infty^\dagger(x) = 1$$

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$$\widehat{\mathcal{U}}_1 = \Sigma_\infty(s_1\bar{n})\Sigma_\infty^\dagger(s_2\bar{n}) - 1 = \Sigma_\infty(s_1\bar{n})\Sigma_\infty^\dagger(s_2\bar{n}) - \Sigma_\infty(s_2\bar{n})\Sigma_\infty^\dagger(s_2\bar{n})$$

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$$\mathcal{U}_N = \Sigma_\infty(s_1 \bar{n}) \Sigma_\infty^\dagger(s_2 \bar{n}) \Sigma_\infty(s_3 \bar{n}) \Sigma_\infty^\dagger(s_4 \bar{n}) \cdots \Sigma_\infty(s_{2N-1} \bar{n}) \Sigma_\infty^\dagger(s_{2N} \bar{n})$$

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$$\mathcal{U}_1^\partial = [\bar{n} \cdot \partial \Sigma_\infty(s_1 \bar{n})] \Sigma_\infty^\dagger(s_2 \bar{n})$$

Matching: **Collinear** Chiral Perturbation Theory

$$\widehat{\mathcal{U}}_2 = \left(\Sigma_\infty(s_1 \bar{n}) - \Sigma_\infty(s_2 \bar{n}) \right) \left(\Sigma_\infty^\dagger(s_2 \bar{n}) - \Sigma_\infty^\dagger(s_3 \bar{n}) \right) \left(\Sigma_\infty(s_3 \bar{n}) - \Sigma_\infty(s_4 \bar{n}) \right) \Sigma_\infty^\dagger(s_4 \bar{n})$$

$$\mathcal{U}_2^\partial = [\bar{n} \cdot \partial \Sigma_\infty(s_1 \bar{n})] [\bar{n} \cdot \partial \Sigma_\infty^\dagger(s_2 \bar{n})] [\bar{n} \cdot \partial \Sigma_\infty(s_3 \bar{n})] \Sigma_\infty^\dagger(s_4 \bar{n})$$

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$$\mathcal{U}_2^\partial = [\bar{n} \cdot \partial \Sigma_\infty(s_1 \bar{n})] [\bar{n} \cdot \partial \Sigma_\infty^\dagger(s_2 \bar{n})] [\bar{n} \cdot \partial \Sigma_\infty(s_3 \bar{n})] \Sigma_\infty^\dagger(s_4 \bar{n})$$

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$$\Sigma = \exp(2i\pi^a t^a / f_\pi) \approx 1 + \frac{2i}{f_\pi} \pi^a t^a + \dots \quad \partial^\mu \Sigma \approx \frac{2i}{f_\pi} \partial^\mu \pi^a t^a + \dots$$

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$$\langle 0 | j_\pi | \pi \rangle \stackrel{!}{=} \sum_N C_N \langle 0 | \mathcal{U}_N^\partial | \pi \rangle$$

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- Conclusion: We can compute chiral corrections to LCDAs!
And in principle, any non-local operators

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Solution: Basis subtraction procedure so $\mathcal{U}_N^\partial = \mathcal{O}(\pi_c^{2N-1})$, only one operator contributes at tree (and 1-loop) order!

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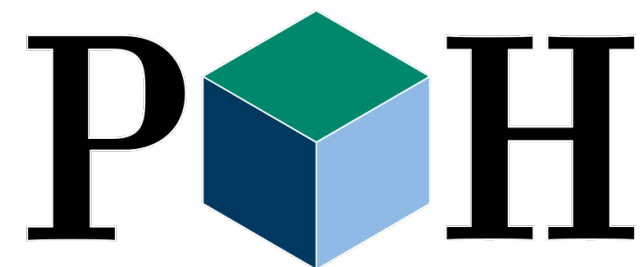
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Conclusions

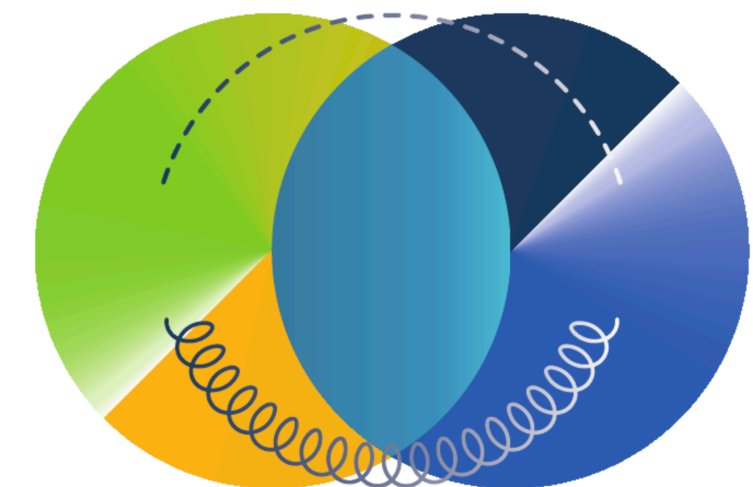
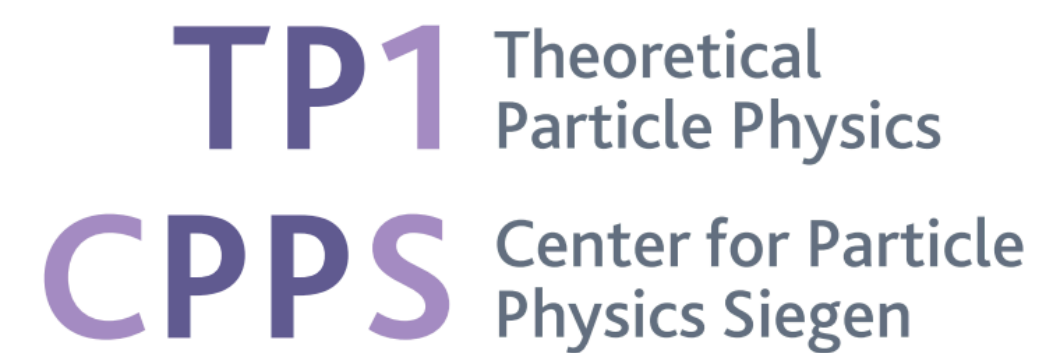
- We built SCET for a hadronic theory: SC-ChPT
- It's use is motivated in places where you have relevant soft and collinear hadrons, like in $B \rightarrow \pi_c$
- The Lagrangian is based on the Lorentz invariance of ChPT and the duplication of Chiral symmetry of SCET II
- The matching procedure for external currents becomes more complicated, but ends in a useful result
- This procedure can be in principle replicated with other operators that may appear in different contexts

Thank you!

Collaborative Research Center TRR 257



Particle Physics Phenomenology after the Higgs Discovery



**color
meets
flavor**

Backup slides

SCET ChPT: Power counting

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Scale hierarchies:

$$p \ll 4\pi f_\pi \qquad p \ll E$$

SCET ChPT: Power counting

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Momentum modes:

$$k_s \sim (p, p, p) \qquad k_c \sim (E, p^2/E, p)$$

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All chiral loops in the effective theory count as $\sim \epsilon^2$.

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$$\mathcal{L}_{\pi_{s/c}}^{(0)} = \frac{f_\pi^2}{4} \text{Tr} \left[\partial_\mu \Sigma_{s/c}^\dagger \partial^\mu \Sigma_{s/c} \right] = f_\pi^2 \text{Tr} [A_{s/c}^\mu A_{s/c\mu}]$$

$$A_c^2 = \frac{1}{2} \{ \bar{n} \cdot A, n \cdot A \} + A_\perp^2 \sim \epsilon^2$$

All chiral loops in the effective theory count as $\sim \epsilon^2$.