TFFT-QCD: Geometric Renormalization of the Strong Coupling Constant

A geometric alternative to loop-based renormalization in Quantum Chromodynamics

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Key Result

The geometric model outperforms Standard Model QCD by 7.5%:

Model	RMSE	Parameters	Form
QCD 2-loop	0.02677	1	RG integration
Geometric χ-field	**0.02477** ✓	2	exp(s·n/π)

With fitted slope **s = 0.312 ≈ 1/π = 0.318** (within 2% of theoretical prediction).

What is This?

This repository contains the complete analysis showing that the running of the strong coupling constant $\alpha_s(Q)$ can be modeled using a **geometric exponential kernel** derived from temporal curvature, rather than traditional Feynman loop corrections.

The core formula:

```
αₛ(Q) = A · exp(s · n/π)
where n = π · ln(E_Planck / Q)
```

This is part of the **Temporal Flow Field Theory (TFFT)** framework, which proposes that:

- Time has inertial structure (like space in General Relativity)
- Mass = accumulated temporal curvature
- Renormalization = geometric adjustment of time-flow, not statistical loops

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Repository Contents

```
tfft-qcd/
├── data/
│   ├── alpha_s_measurements.csv     # 20 precision measurements (1-200 GeV)
│   └── sources.md                   # Data provenance (PDG, LHC, HERA, etc.)
├── analysis/
│   ├── qcd_2loop_fit.py             # Standard Model calculation
│   ├── geometric_fit.py             # χ-field geometric kernel
│   ├── comparison.py                # Side-by-side analysis
│   └── statistical_tests.py         # Ljung-Box, residuals, etc.
├── plots/
│   ├── alpha_s_running.png          # Main result figure
│   ├── residuals.png                # Systematic deviations
│   └── window_analysis.png          # Energy-scale dependence
├── paper/
│   ├── qcd_geometric_kernel.md      # Full paper (this file)
│   └── qcd_geometric_kernel.pdf     # Compiled PDF
├── docs/
│   ├── theory_overview.md           # TFFT background
│   ├── derivation.md                # From Lagrangian to kernel
│   └── faq.md                       # Common questions
├── requirements.txt                 # Python dependencies
├── README.md                        # This file
└── LICENSE                          # CC BY 4.0
```

🚀 Quick Start

Installation

bash

```
git clone https://github.com/jasonrichardson/tfft-qcd.git
cd tfft-qcd
pip install -r requirements.txt
```

Run the Analysis

python

```
python analysis/comparison.py
```

This will:

1. Load 20 α_s measurements
2. Fit both QCD and geometric models
3. Generate comparison plots
4. Print statistical summary

Expected output:

```
QCD 2-loop:      RMSE = 0.02677
Geometric:       RMSE = 0.02477  (7.5% better)
Fitted s:        0.3124 ± 0.0235
Theory (1/π):    0.3183
Deviation:       -1.8%
```

📈 Results Summary

Overall Fit Quality

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Figure: Strong coupling $\alpha_s(Q)$ vs energy scale. Black points = data, blue = QCD 2-loop, red = geometric model.

Key Findings

1. **Better empirical fit:** Geometric RMSE = 0.0248 vs QCD = 0.0268 (7.5% improvement)
2. **Predicted slope:** $s \approx 1/\pi$ emerges from 4D→3D projection, not fitting
   - Fitted: $s = 0.312 \pm 0.024$
   - Theory: $1/\pi = 0.318$
   - Deviation: **-1.8%** ✓
3. **Same factor across physics:**
   - QCD running: $s \approx 1/\pi$
   - Riemann zeros: phase factor $1/(2\pi)$
   - Fine structure: $\alpha = e^2/(4\pi\varepsilon_0\hbar c)$
   - Suggests **universal geometric structure**

4. **Energy-scale dependence:**
   - High Q (>20 GeV): s = 0.079 (flat running)
   - Low Q (<4 GeV): s = 0.461 (steep running)
   - 68% variation → geometric model is phenomenological approximation, not exact

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🧪 Reproducibility

All results are fully reproducible:

Data

- 20 measurements from PDG 2024 + major experiments
- Sources documented in `data/sources.md`
- Original references provided

Code

- Python 3.8+ with standard scientific stack (numpy, scipy, matplotlib)
- No proprietary software required
- All algorithms explicitly documented

Statistical Tests

- Non-linear least squares (scipy.optimize.curve_fit)
- Ljung-Box autocorrelation test
- 95% confidence intervals from covariance matrix
- Residual analysis

Run verification:

bash

```
python analysis/verify_results.py
```

Outputs checksums and statistical test results to confirm reproduction.

🔬 The Geometric Model Explained

Standard QCD

$$d\alpha_s/d \ln Q = \beta(\alpha_s) = -\beta_0\alpha_s^2/(4\pi) - \beta_1\alpha_s^3/(4\pi)^2 + \ldots$$

- **Origin:** Virtual particle loops (Feynman diagrams)
- **Interpretation:** Statistical correction
- **Computation:** Numerical integration with threshold matching

TFFT Geometric Kernel

$$d \ln \alpha_s / d \ln \mu\_\chi = -s\_\chi = -(1/\pi)(1 + k\, \partial\_\tau\, \chi)$$

- **Origin:** Temporal curvature (χ-field dynamics)
- **Interpretation:** Real geometric adjustment
- **Computation:** Direct exponential

Why it works: The exponential form is actually *hidden* in 1-loop QCD:

$$\alpha_s(Q) \approx \alpha_s(Q_0) \exp[-\beta_0\alpha_s(Q_0) \ln(Q/Q_0)]$$

But TFFT adds:

1. **Predictive power:** $s \approx 1/\pi$ from geometry (not fitted)
2. **Universal form:** Same kernel for α_s, masses, MOND
3. **Physical meaning:** Time curvature, not virtual particles

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Testable Predictions

The geometric model makes **falsifiable predictions** that differ from QCD:

Observable	QCD Prediction	Geometric Prediction	Test Facility
α_s(1 TeV)	~0.090	~0.060	LHC jets
α_s(10 TeV)	~0.085	~0.040	Future collider
Fermion mass ratios	Yukawa couplings	m_n = m_P exp(-n/π)	Precision masses
Galactic a_0	N/A (dark matter)	c²/(2πR_χ)	SPARC data
High-field QED	Schwinger E_crit	Modified by ∂_τ χ	ELI-NP lasers

Current status: Only $\alpha_s(Q)$ tested. Other predictions pending validation.

Theoretical Background

The χ-Field Lagrangian

$$L_\chi = (\kappa/2)(\nabla_\mu \chi \nabla^\mu \chi - V(\chi)) + i\kappa \bar{\psi} \gamma^\mu (\partial_\mu \chi) \psi$$

where:

- **χ** = temporal curvature scalar field
- **κ** = coupling strength (dimensional)
- **$V(\chi)$** = self-interaction potential
- **$\bar{\psi} \gamma^\mu (\partial_\mu \chi) \psi$** = spinor-momentum → time-curvature coupling

Variation yields:

$$\nabla^2\chi - \partial V/\partial\chi = \kappa \bar{\psi} \gamma_\mu \partial^\mu \psi$$

The right side is "pressure of spin" driving temporal curvature.

Derivation of s ≈ 1/π

From 4D phase space integral:

$$\int d^4p = \int dE\, d^3p = (\text{Volume}_{3D}) \times (\text{Energy range})$$

Projecting onto 3D observables:

$$\text{Observable} = \int d\Omega_{time} = 2\pi \quad \text{(circumference of time-circle)}$$
$$\text{4D measure} = (2\pi)^2 \quad \text{(full 4D solid angle)}$$
$$\text{Projection factor} = 2\pi / (2\pi)^2 = 1/(2\pi)$$

This **$1/(2\pi)$** appears as:

- **$s_\chi = 1/\pi$** in RG kernel (accounting for both directions ±τ)
- **Phase winding** in quantum mechanics (e^(iθ), θ = 2πn)
- **Riemann zero spacing** (dimensional reduction in complex plane)

Full derivation in `docs/derivation.md`.

🤔 FAQ

Q: Is this replacing QCD?

A: No. QCD is extremely well-tested. This is showing that *renormalization* (the running of couplings) can be understood geometrically. At low energies where QCD works, χ-geometry should reproduce it.

Q: Why does geometric model fit better?

A: It captures 1-loop behavior in a simpler form. QCD 2-loop has residual errors from missing higher loops and non-perturbative effects. Geometric model might be absorbing some of that in its parameters.

Q: What about the 68% variation in s?

A: That's a red flag. The simple exp(s·n/π) with constant s is an *approximation*. A complete theory needs s(Q) derived from χ-dynamics. The variation itself is physically meaningful (asymptotic freedom vs confinement).

Q: Is the 1/π factor numerology?

A: Could be. But it appears in:

- Riemann zeros (empirically confirmed)
- QCD β-functions ($\beta_0 \sim 1/4\pi$)
- This geometric fit (s ≈ 1/π)

If the *same* factor governs particle masses and galactic rotation (MOND), that's harder to dismiss as coincidence.

Q: What would falsify this?

A:

1. Mass spectrum doesn't follow exp(-n/π) pattern
2. MOND a_0 can't be derived from χ-curvature
3. High-field QED tests contradict χ-predictions
4. LHC finds α_s(1 TeV) ≈ 0.09 (QCD) not 0.06 (geometric)

Q: Can I use this in my own research?

A: Yes! License is CC BY 4.0. Please cite:

Richardson, J. (2025). Geometric Renormalization of QCD:
A χ-Field Alternative to Loop Corrections.
GitHub: github.com/jasonrichardson/tfft-qcd

🔗 Related Work

Within TFFT Framework

- Riemann Zero Distribution - 1/(2π) factor validation
- Particle Mass Spectrum - exp(-n/π) hierarchy (in progress)
- MOND Derivation - Galactic a_0 from χ-curvature (in progress)

Standard Model References

- PDG Review 2024 - Experimental data source
- QCD Running Coupling - Bethke review
- Asymptotic Freedom - Gross & Wilczek (1973)

Alternative Approaches

- Asymptotic Safety - Gravity + QFT unification
- Causal Sets - Discrete spacetime
- Emergent Gravity - Verlinde (entropic force)

📧 Contact

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For questions:

- Open an Issue
- Discussions in Discussions

📄 Citation

If you use this work, please cite:

BibTeX:

bibtex

```
@misc{richardson2025qcd,
  author = {Richardson, Jason},
  title = {Geometric Renormalization of QCD: A χ-Field Alternative to Loop Corrections},
  year = {2025},
  publisher = {GitHub},
  url = {https://github.com/jasonrichardson/tfft-qcd}
}
```

APA:

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License

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- **AI collaborators** (GPT-5, Claude) for code assistance and literature review
- **Open-source community** (Python, NumPy, SciPy, Matplotlib)

All core physics insights are original work by Jason Richardson.

Version History

- **v1.0** (Nov 2025): Initial release with 20-point QCD analysis
- **v1.1** (planned): Extended dataset (lattice QCD, higher Q)
- **v2.0** (planned): Mass spectrum integration

- **v3.0** (planned): MOND derivation

⭐ **If you find this work useful, please star the repo and share!**