HPQCD

Light meson form factors at high Q^2 from LQCD

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Lattice 2017, Granada, Spain

Outline

- Motivation & experimental status
- Method
- Results
- Summary & future prospects

HPQCD, ArXiv:1701.04250

$F_\pi(Q^2)$ and $F_K(Q^2)$ from experiments

- $F_\pi(Q^2)$ is known up to $Q^2 < 2.45$ GeV^2 (JLAB, 2008)
- Measurements of π and K form factors are key experiments in the new Jefferson Lab 12 GeV upgrade (expt E12-06-101 and E12-09-11)

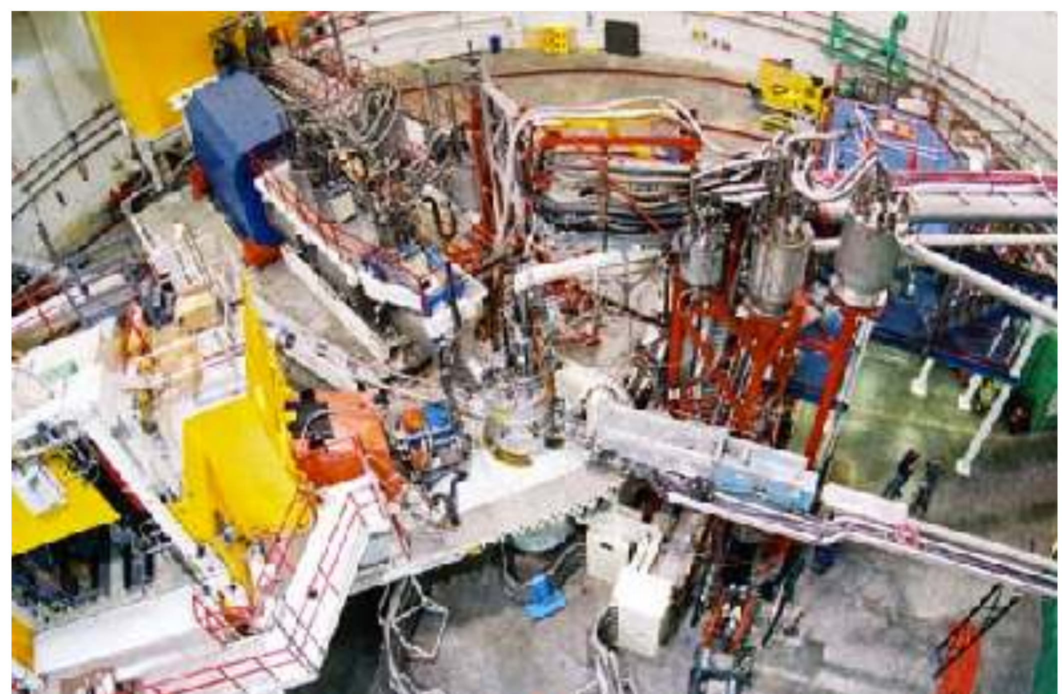
- This will extend the Q^2 range up to 6 GeV^2

Motivation & goal

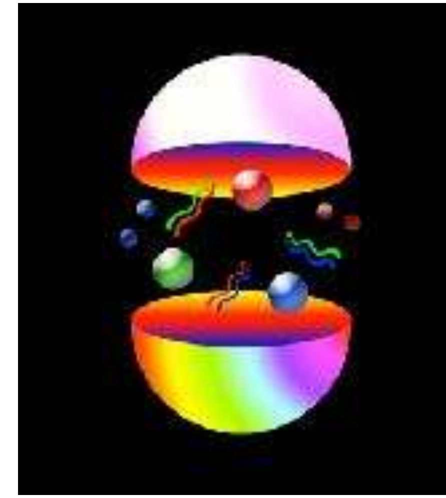
- Calculate the π and K electromagnetic form factors $F(Q^2)$ in the region Q^2 ~ few GeV^2 using lattice QCD

- Provide predictions of the form factors ahead of experiment and test applicability of asymptotic PQCD

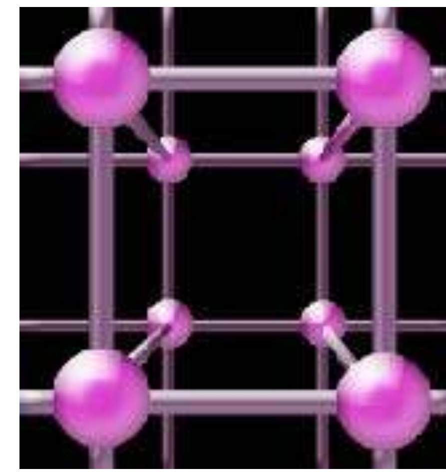
- JLAB experiment's aim is 5% accuracy



Lattice configurations



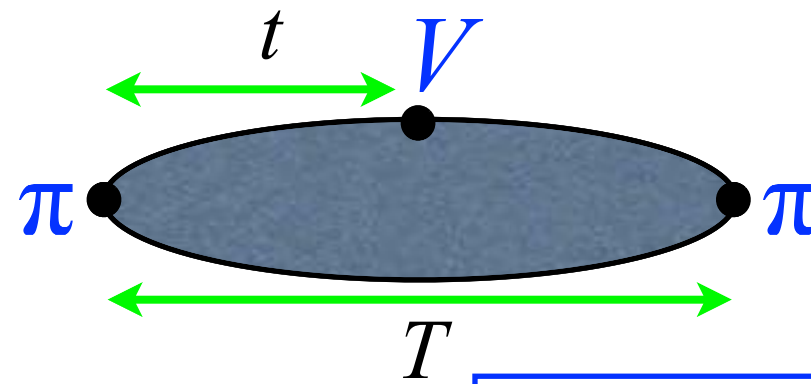
- Use MILC collaboration's lattice configurations
  - u/d, s and c quarks in the sea
  - 3 lattice spacings: a~0.15 fm, 0.12 fm, 0.09 fm
  - different volumes and am_l available



- Highly Improved Staggered Quark action for both sea and valence quarks

Set	β	w_0/a	am_l	am_s	am_c	$L_s/a \times L_t/a$	M_π	n_{cfg}
1	5.8	1.1119(10)	0.0130	0.0650	0.838	16×48	300 MeV	1020
2	6.0	1.3826(11)	0.0102	0.0509	0.635	24×64	300 MeV	1053
3	6.0	1.4029(9)	0.00507	0.0507	0.628	32×64	220 MeV	1000
4	6.3	1.9006(20)	0.0074	0.037	0.44	32×96	310 MeV	1008

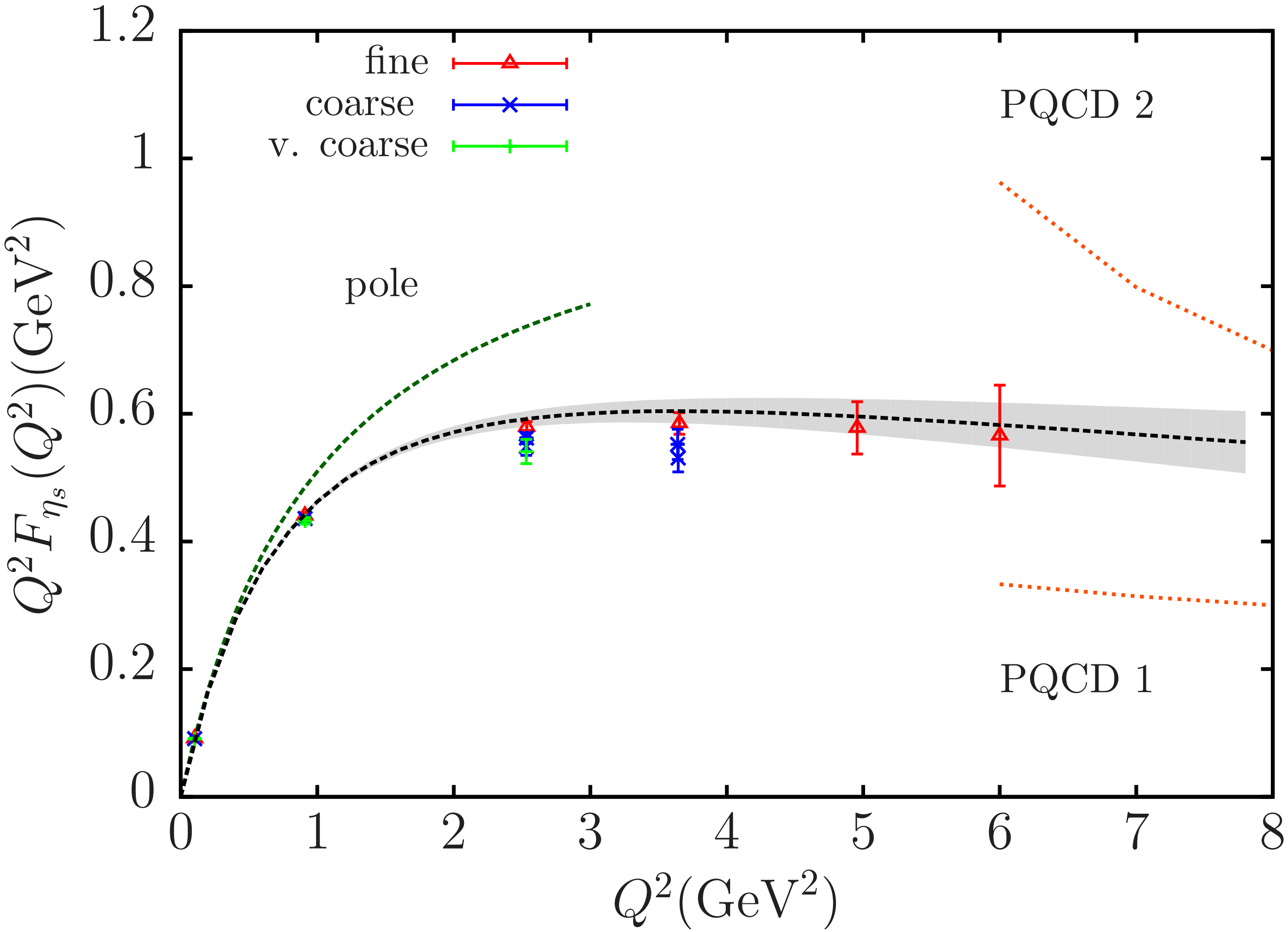
Form factors



Multiple T values

- 3-point correlation function
  $\langle P(p_f)|V_\mu|P(p_i)\rangle = F_P \cdot (p_i + p_f)_\mu$
- Using Breit frame $\vec{p}_i = -\vec{p}_f$ maximises momentum transfer for a given (pa), $Q^2 = |2\vec{p}_i|^2$
- Choose V in the time direction, normalise by requiring $F_P(0) = 1$
- Fit 2pt and 3pt correlators together using multiple exponentials and Bayesian techniques: extract ground state, but including excited states improves systematic error

η_s form factor

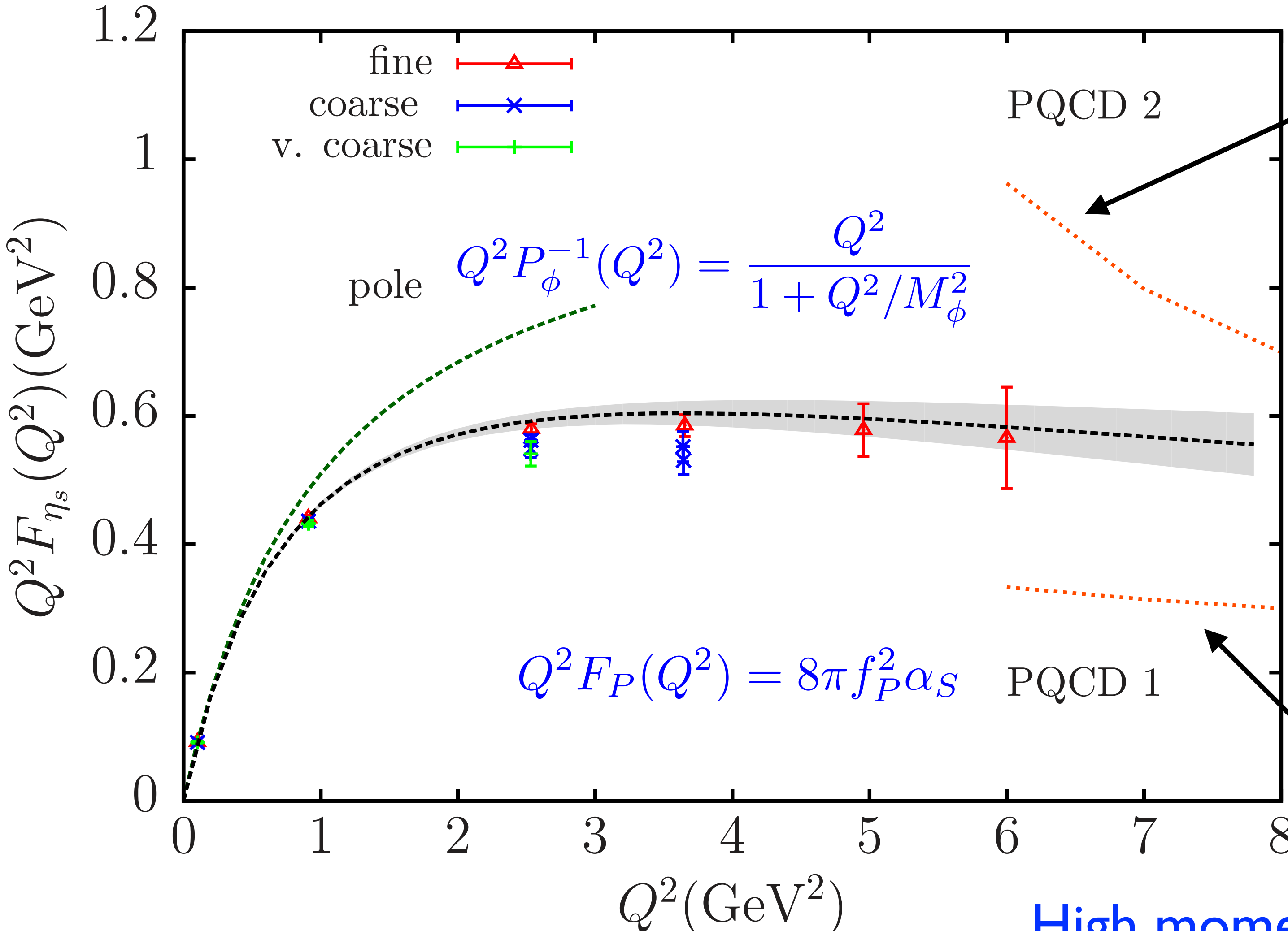


HPQCD, ArXiv:1701.04250

Useful test case:

- pseudoscalar meson made of s quarks, mass and f_{η_s} known from LQCD
- relatively cheap
- strange quark is light compared to QCD scales → asymptotic qualities similar to K and π

η_s form factor

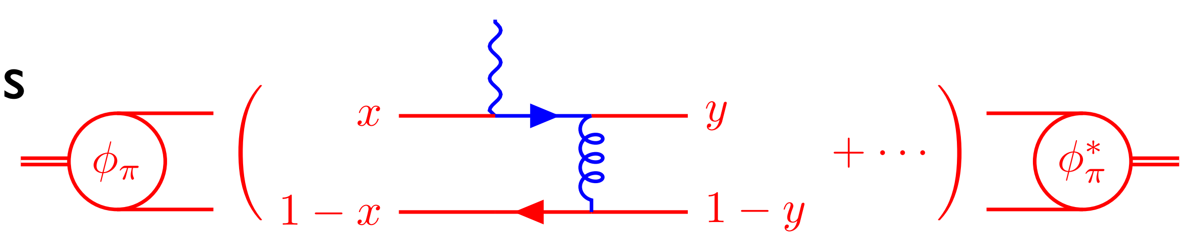


Add corrections to asymptotic PQCD
Calculated on lattice
Braun et al. ArXiv: 1503.03656
Curve PQCD2 uses

$\phi_P(2\ \mathrm{GeV}) = [x(1-x)]^{0.52}$

Asymptotic pert. QCD

High momentum photon & gluon



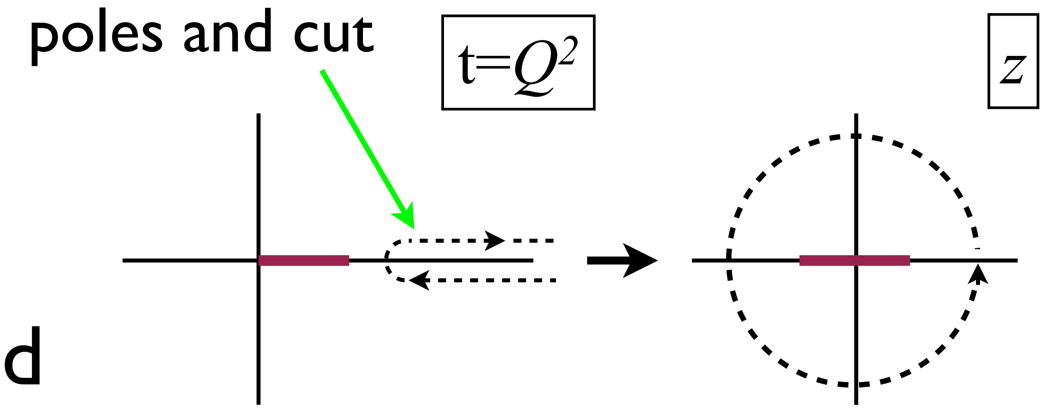
Hard scattering process factorises
Distribution amplitude ϕ_P
Use f_P to normalise

Continuum & chiral extrapolation

- Remove the pole

$$P_\phi(Q^2) = 1 + \frac{Q^2}{M_\phi^2}$$

- Convert to z variable and fit as power series in z, allowing for discretisation effects and mistuning in quark mass



Maps t region into -1 < z < 1

$$z(t, t_{\text{cut}}) = \frac{\sqrt{t_{\text{cut}} - t} - \sqrt{t_{\text{cut}}}}{\sqrt{t_{\text{cut}} - t} + \sqrt{t_{\text{cut}}}}$$

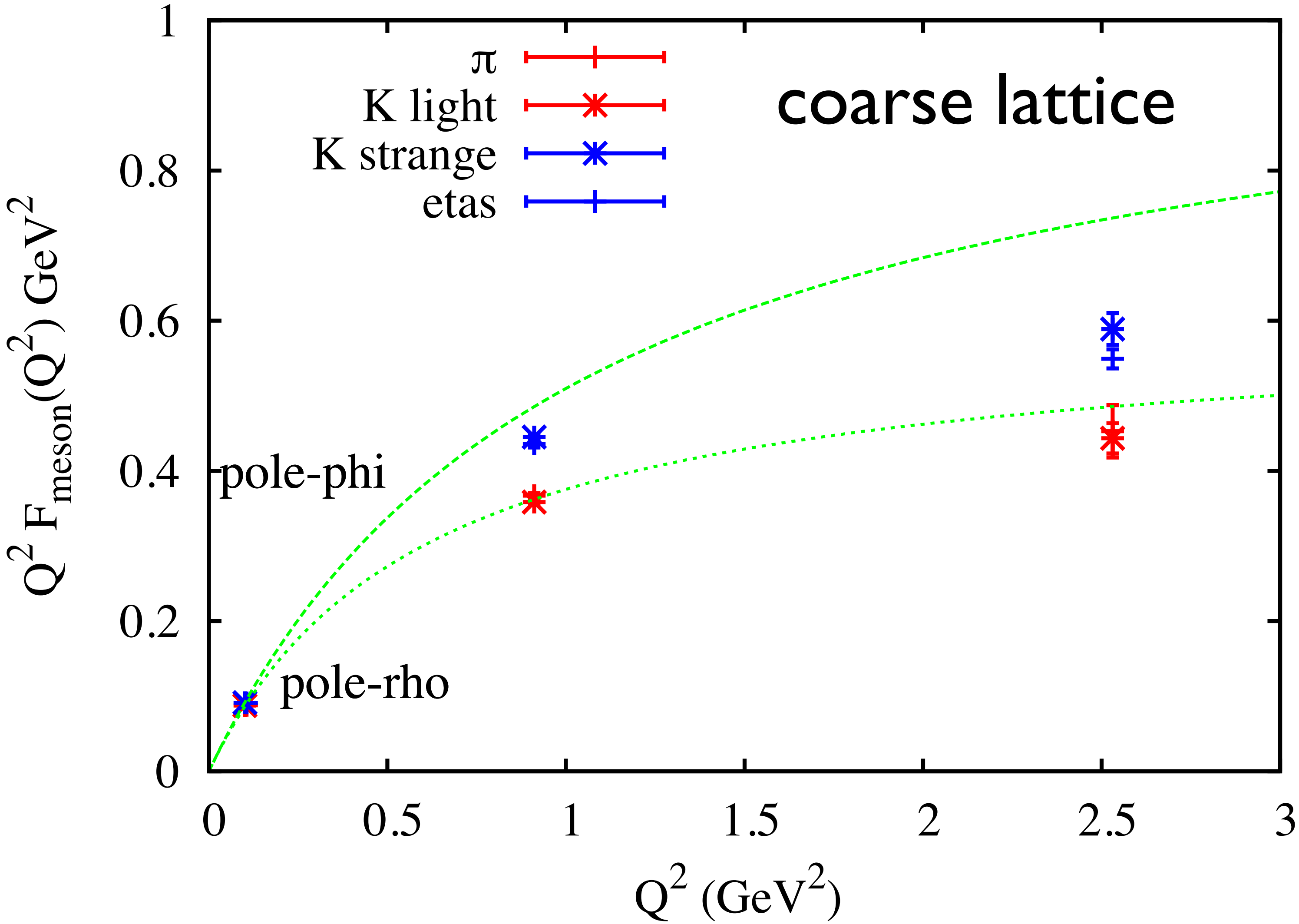
$$t_{\text{cut}} = 4M_K^2$$

$$P_\phi F(z, a, m_{\text{sea}}) = 1 + \sum_i z^i A_i \left[1 + B_i (a\Lambda)^2 + C_i (a\Lambda)^4 + D_i \frac{\delta m}{10}\right]$$

$$\delta m = \sum_{u,d,s} (m_q - m_q^{\text{tuned}})/m_s^{\text{tuned}}, \;\; \Lambda = 0.5 \text{ GeV}$$

π and K form factors

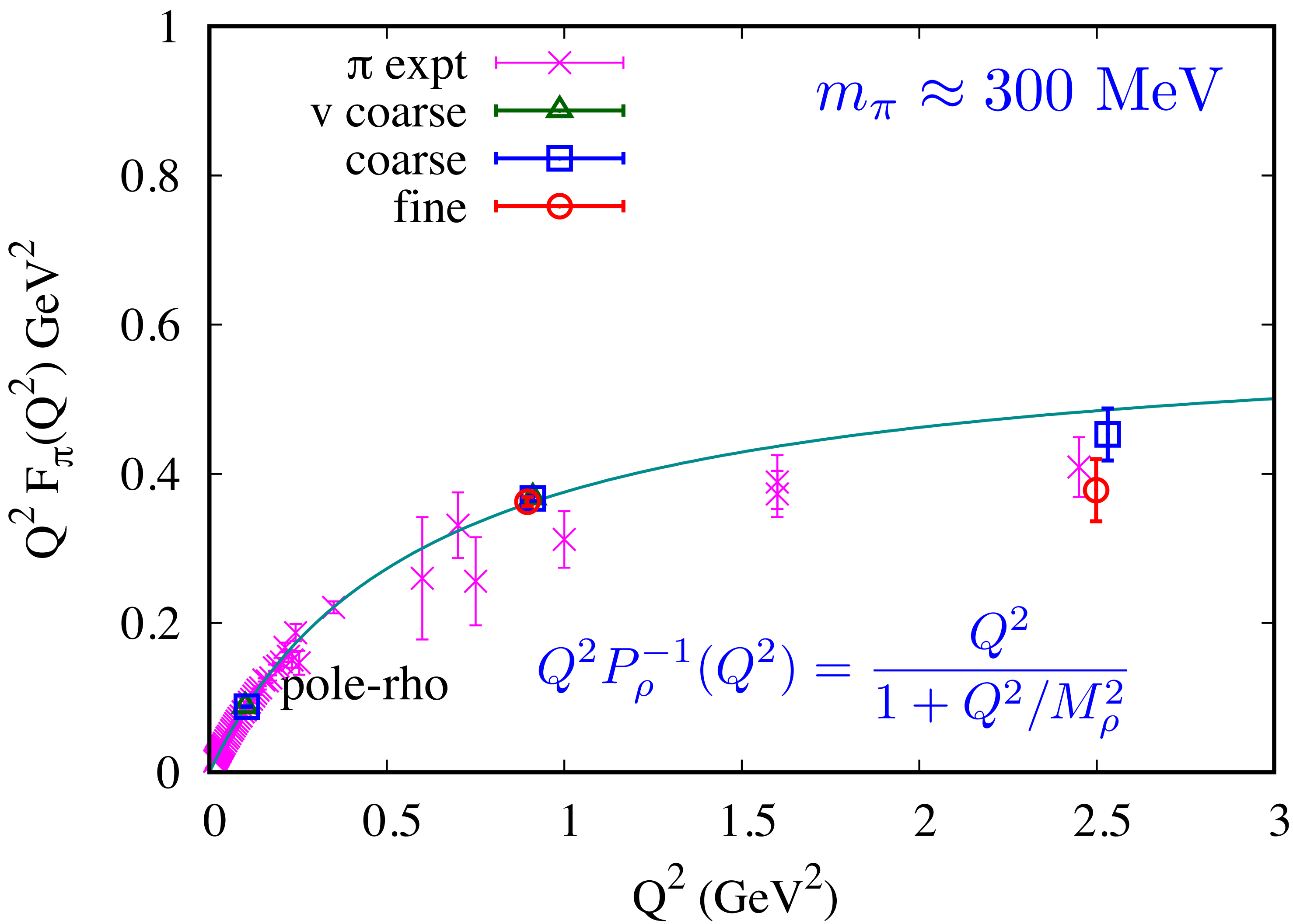
PRELIMINARY



- Note that the light current form factors match and so do strange
- Pole masses M_ϕ and M_ρ for strange and light current respectively

π form factor

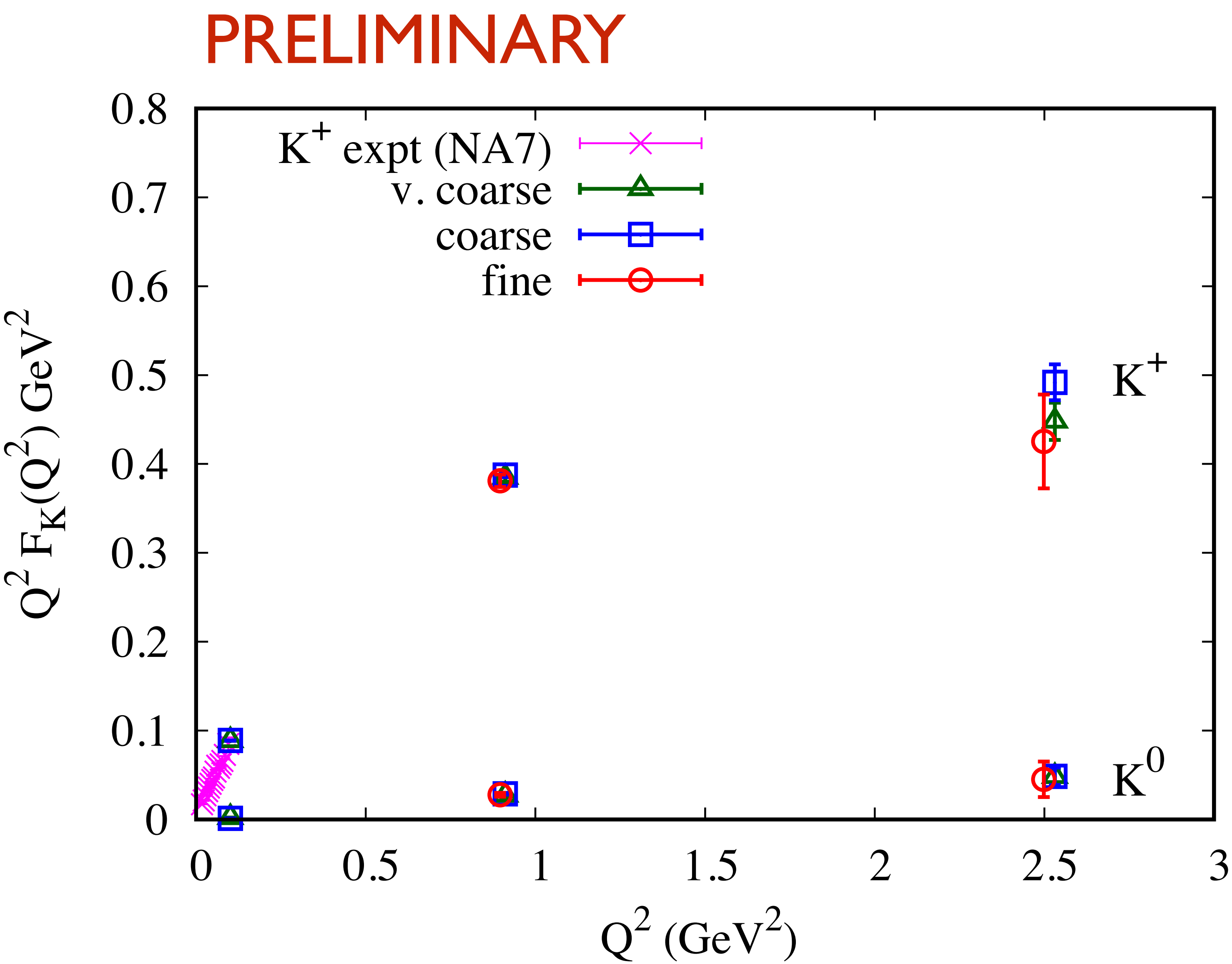
PRELIMINARY



- Can improve statistics on the fine lattice - higher Q^2 possible?
- Need smaller m_π for chiral extrapolation

Expt. results: NA7, Nucl. Phys. B277 (1986) 168 and JLAB, Phys. Rev. C 78 (2008) 045202

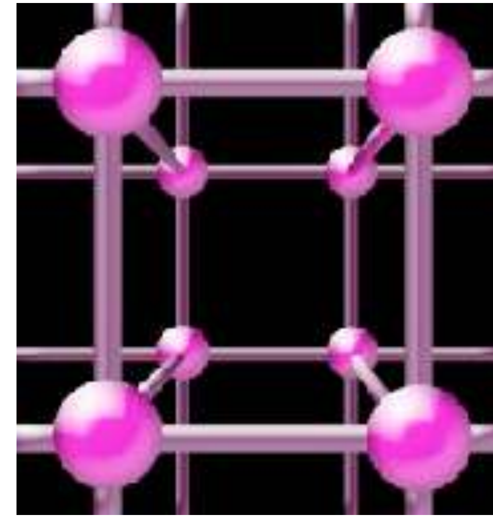
K form factor



- First predictions of K form factor for JLAB
- Combine strange and light current with electric charges to get K^+, K^0

Expt. results: NA7, Phys. Lett. B178 (1986) 435

Summary and outlook



- Light meson (η_s) form factor calculated up to $Q^2 \sim 6$ GeV^2 with high precision
- η_s form factor does not agree with asymptotic PQCD at $Q^2 \sim 6$ GeV^2
- First prediction of K form factor ahead of the JLAB experiment
- Still a lot to do:
  - lighter pion masses
  - can we push to higher Q^2?

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Thank you!

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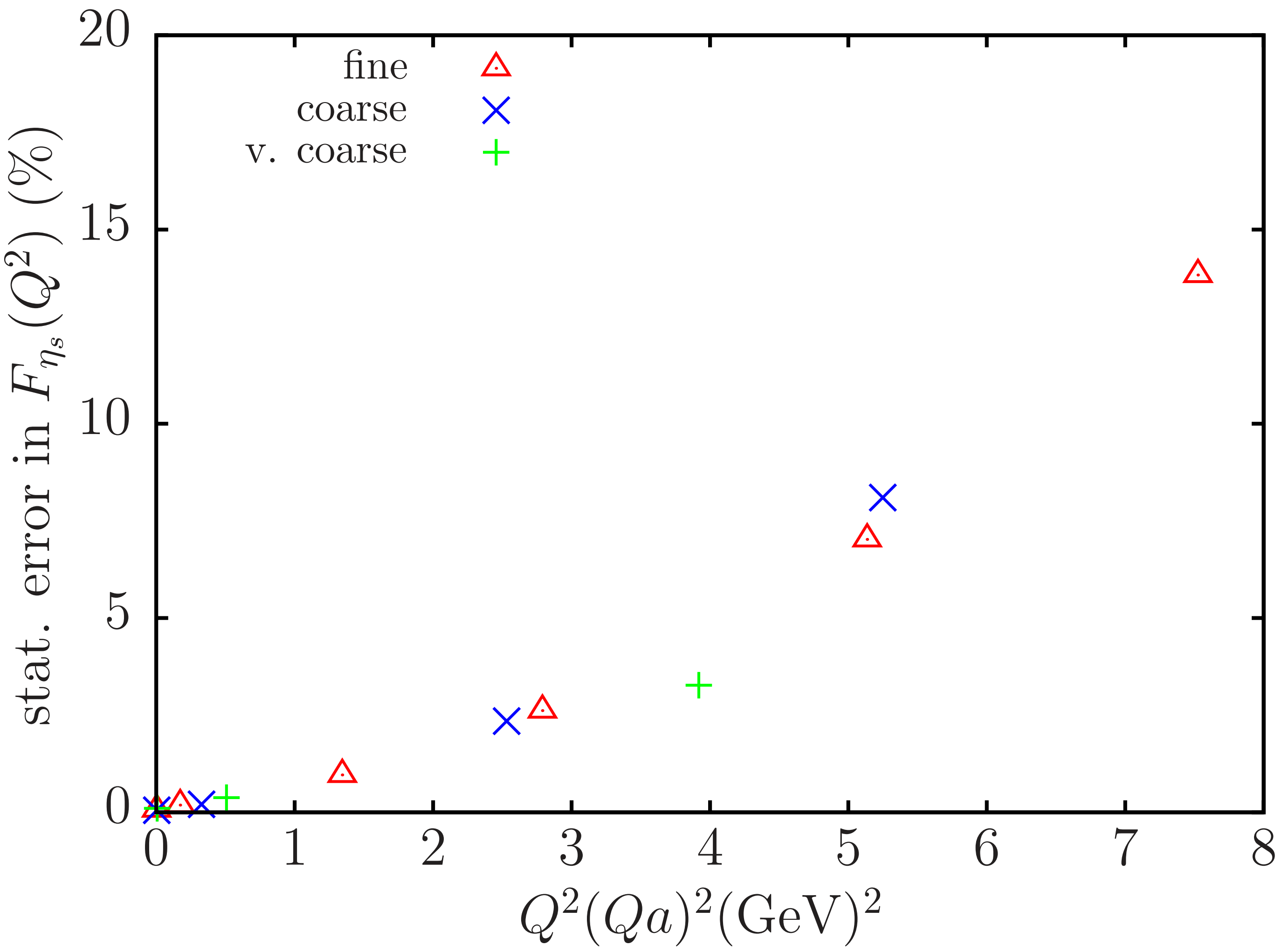
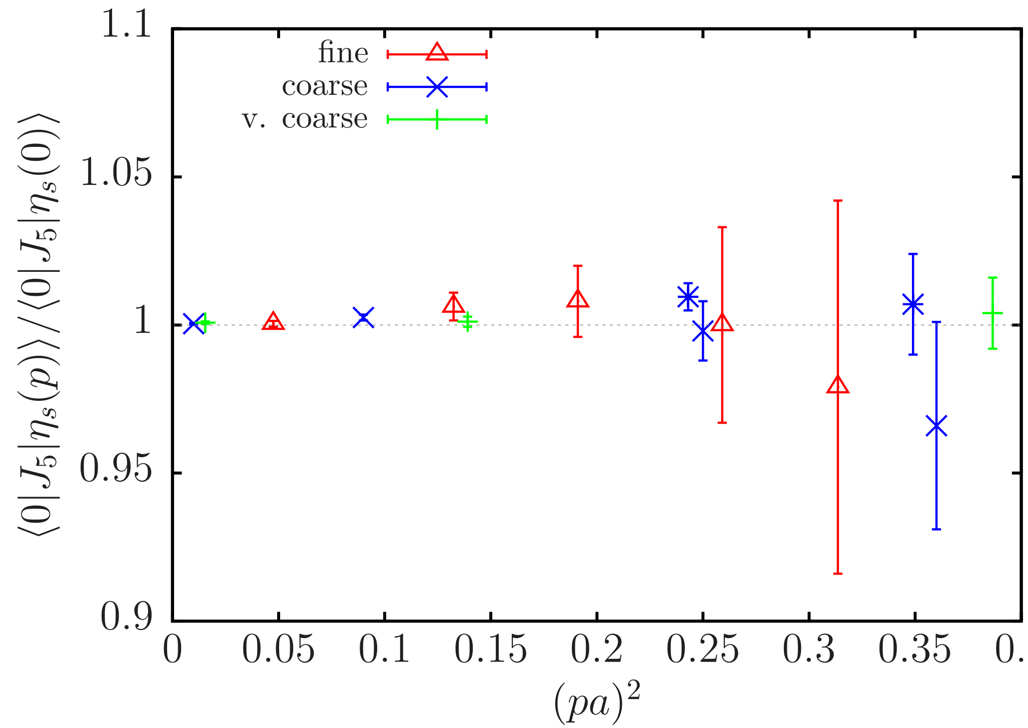
Spare slides

Error budget: statistics

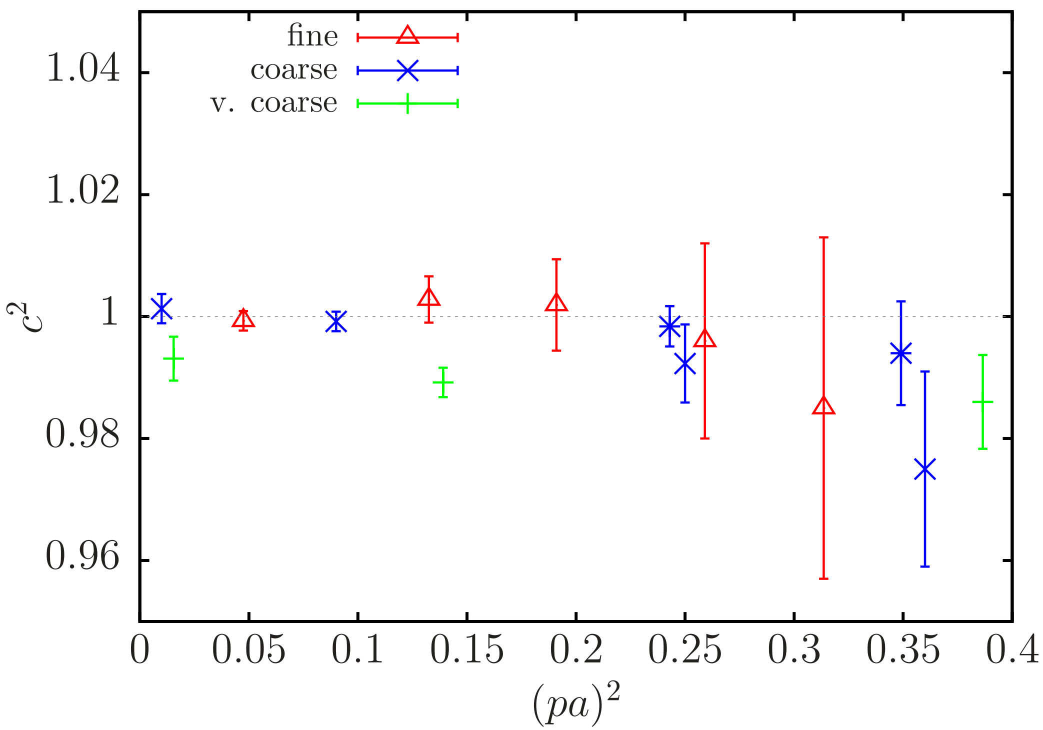


Testing discretisation effects

- Small discretisation effects even at our highest (pa)



Speed of light $c^2 = \frac{E^2 - M^2}{\vec{p}^2}$



Amplitudes

$$\frac{\langle 0|J_5|\eta_s(p)\rangle}{\langle 0|J_5|\eta_s(0)\rangle} = \frac{A_0(p)}{A_0(0)}\sqrt{\frac{E_0(p)}{E_0(0)}}$$