QCD -Instantons – Lattice Results and Deep Inelastic Scattering

F. Schrempp, DESY

in collaboration with

A. Ringwald

1. **Introduction**
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– Theory Seminar, DESY, July 13th, 1999 –

1. Introduction

♣ Rich vacuum structure of non-abelian gauge theories like QCD ⇐ TOPOLOGY!

- Gauge fields $A_\mu(x)$ with finite action carry an integer topological charge Q
- Simplest building blocks of topological structure

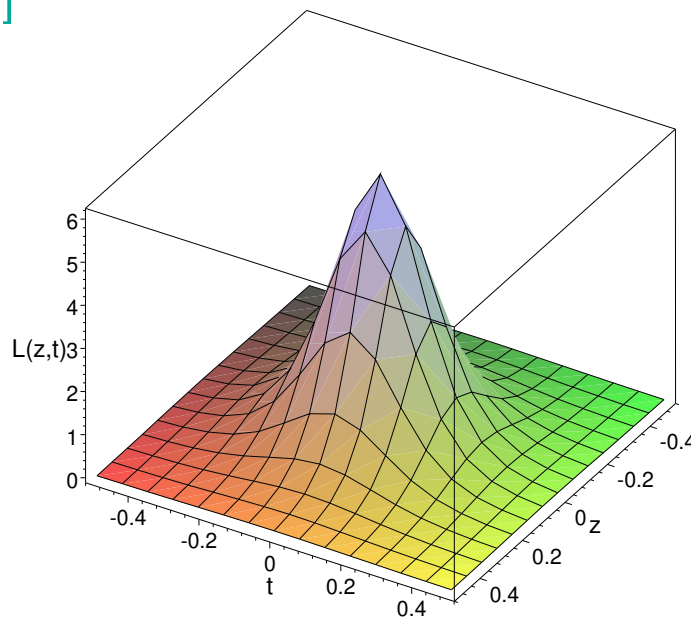
Instantons (Q=+1) and **anti-instantons (Q=-1)**:

♢ Explicitly known solutions of classical 4d Euclidean field equations ⇔ minimize classical action for $|Q| = 1$:
[Belavin *et al.* '75, 't Hooft '76]

$(\boldsymbol{I} - \text{size } \rho)$:

$$\mathcal{L}\left(A_\mu^{(I)}(x;\rho)\right) = \frac{12}{\pi\alpha}\cdot\frac{\rho^4}{(x^2+\rho^2)^4}$$

$$\Rightarrow \quad S\left[A_\mu^{(I)}\right] = \frac{2\pi}{\alpha}$$



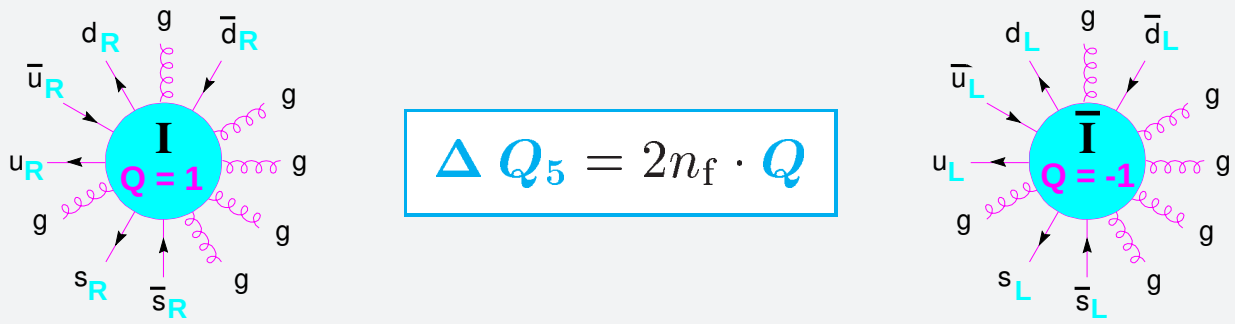
♢ Non-perturbative fluctuations of gauge-fields, localized ("instantaneous") in time and space.

♢ Tunnelling transitions between adjacent, topologically inequivalent vacua

- Instantons widely believed to play an important rôle in various long-distance aspects of QCD :
  - axial "U(1) problem" (why $m_{\eta'} \gg m_{\eta}$?)
  - breaking of chiral symmetry [Diakonov '96 (review)]
  - hadron and glueball spectrum [Schaefer, Shuryak '96 (review)]

- Also very important short-distance implications of instantons:

induce processes violating "chirality" $Q_5 = \#(q_{\rm R}) - \#(q_{\rm L})$ in QCD with $\approx$ massless quarks ['t Hooft '76]



$$\Delta\, Q_5 = 2n_{\rm f} \cdot Q$$

- in accord with general Adler-Bell-Jackiw ANOMALY
- forbidden in ordinary perturbation theory ($Q = 0$!)

♣ An experimental discovery of **instantons** through these anomalous processes would be of basic significance $\Leftarrow$ **HERA !**.

♣ **DIS** regime at **HERA** offers unique discovery window for events induced by QCD -instantons, through

♢ their characteristic final-state signature
[Ringwald & F. Sch. '94 - '99,
Carli, Gerigk, Ringwald & F. Sch., hep-ph/9906441 & in prep]

♢ a sizable rate, calculable within I-perturbation theory
[Ringwald & F. Sch., Phys. Lett **B438** (1998) 217,
Moch, Ringwald & F. Sch., Nucl. Phys. **B507** (1997) 134 & in prep]

Key feature: hard generic **DIS** scale $\mathcal{Q}$ cuts off instantons with large size $\rho \gtrsim \mathcal{Q}^{-1}$, over which we have no control!

♣ Lattice simulations: Much recent activity the measure topological fluctuations in the (quenched) QCD vacuum

- **Central issues in this talk:**
  - Link I-observables in **DIS** and on the lattice
  - Exploit recent high-quality lattice investigation [UKQCD, Smith & Teper], to gain information on crucial building blocks of I-perturbation theory
  - Lattice$\Rightarrow$ important support for basic prerequisites of our calculations in **DIS**, "fiducial" kinematical region. . .

2. Instanton Perturbation Theory in DIS

[Ringwald & F. Sch., Phys. Lett **B438** (1998) 217,
Moch, Ringwald & F. Sch., Nucl. Phys. **B507** (1997) 134 & in prep]

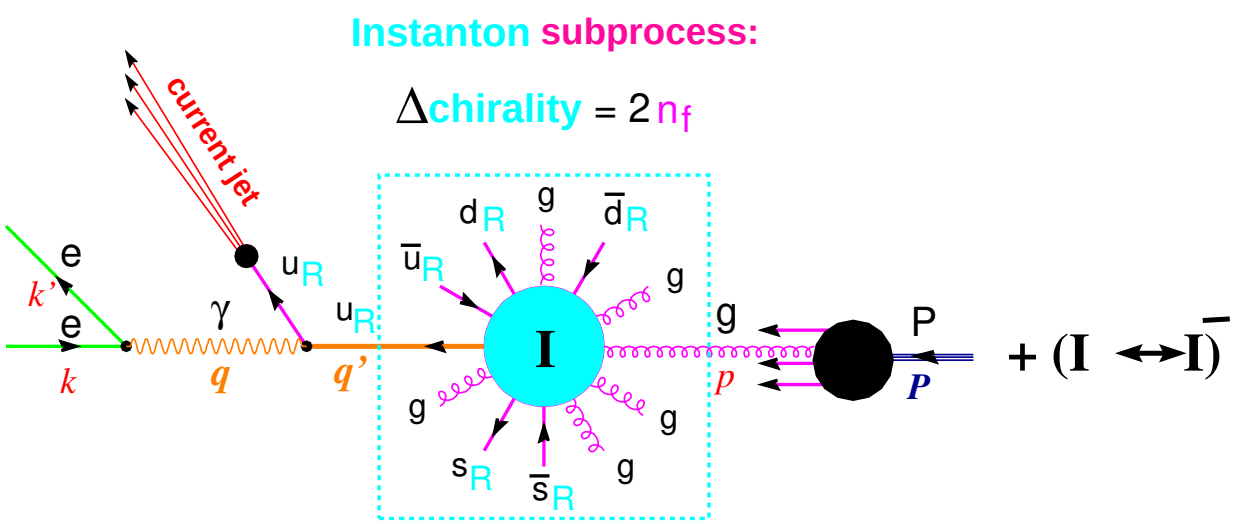
- I-perturbation theory for dilute gas of I's and $\overline{I}$'s light quarks with $\mathrm{m}_q \cdot \rho_{\mathrm{eff}} < 1$

  – Expand Euclidean path integral for generating functional of Green's functions about known, classical I-solution $A_\mu(x) = A_\mu^{(I)}(x) + \cdots$ for small α

  – derive (modified) Feynman rules in momentum space

  – LSZ-amputation along with (careful!) analytic continuation to DIS-kinematics

- Leading I-induced, chirality violating process in DIS regime of $e^{\pm}P$ scattering:



- I-subprocess with own **Bjorken**-variables, (x', Q'^2):

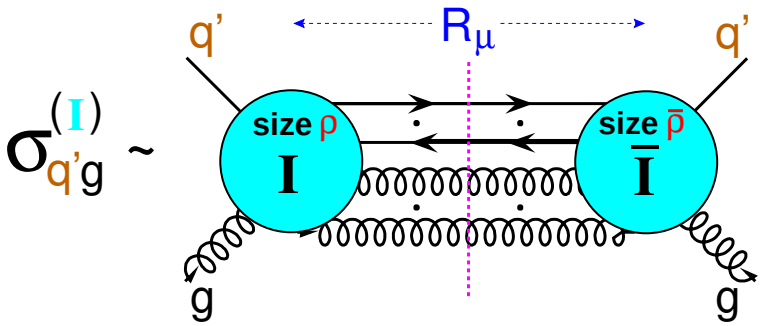
$$\text{large} \quad Q'^2 = -q'^2 > 0; \quad x' = \frac{Q'^2}{2p\cdot q'} \leq 1 \quad \text{fixed}$$

- Show within I-perturbation theory (Bjorken limit):

$$\frac{\mathrm{d}\sigma_{\mathrm{HERA}}{}^{(I)}}{\mathrm{d}x'\mathrm{d}Q'^2} \simeq \frac{\mathrm{d}\mathcal{L}^{(I)}_{q'g}}{\mathrm{d}x'\mathrm{d}Q'^2} \cdot \sigma^{(I)}_{q'g}(Q', x')$$

- Differential luminosity, $\mathrm{d}\mathcal{L}^{(I)}_{q'g}$: number of $q'g$ collisions per eP collision; integrations over gluon density, γ^*-flux P_{γ^*} and known q'-flux $\mathrm{P}_{q'}{}^{(I)}$ in I-background.

- Crucial I-dynamics in total cross-section $\sigma^{(I)}_{q'g}(Q', x')$ of I-subprocess $q'g \overset{I}{\Rightarrow} X$!



- Being an observable, $\sigma^{(I)}_{q'g}(Q', x')$ involves **integrations** over all I and $\overline{I}$-"collective coordinates",

$$I\text{-size } \rho,\ \overline{I}\text{-size } \overline{\rho},\ I\overline{I}\text{-distance 4-vector } R_\mu,$$
$$\text{and} \quad U{=}I\overline{I} \text{ relative color orientation}$$

$$\sigma^{(\boldsymbol{I})}_{q'\,p} = \int d^4\boldsymbol{R}\; \mathrm{e}^{\mathrm{i}\,(p+q')\cdot R} \int_0^\infty d\rho \int_0^\infty d\overline{\rho}\; \mathrm{e}^{-(\rho+\overline{\rho})Q'}$$

$$\times\; D(\rho)\, D(\overline{\rho}) \int dU\; \mathrm{e}^{-\frac{4\pi}{\alpha}\,\Omega\left(U,\frac{R^2}{\rho\overline{\rho}},\frac{\overline{\rho}}{\rho}\right)} \{\ldots\}$$

Two crucial quantities of $\boldsymbol{I}$-calculus:

$D(\rho) =$ (reduced) $\boldsymbol{I}$-size distribution , $\Omega\left(U,\frac{R^2}{\rho\overline{\rho}},\frac{\overline{\rho}}{\rho}\right) = I\overline{I}$-interaction

♢ $D(\rho)$ known in $\boldsymbol{I}$-pert. theory, for $\alpha(\mu_r)\ln(\mu_r\rho) \ll 1$
(μ_r = renormalization scale)

$$D(\rho) = d\left(\frac{2\pi}{\alpha(\mu_r)}\right)^6 \exp\left(-\frac{2\pi}{\alpha(\mu_r)}\right)\frac{(\boldsymbol{\rho}\,\mu_r)^{\boldsymbol{b}}}{\boldsymbol{\rho}^5}$$

d = known, scheme dependent constant

b	$\frac{1}{D}\frac{\mathrm{d}D}{\mathrm{d}\mu_r}$	Ref.
β_0	$\mathcal{O}(\alpha)$	't Hooft '76, Bernard '79
$\beta_0 + \frac{\alpha(\mu_r)}{4\pi}(\beta_1 - 12\beta_0)$	$\mathcal{O}(\alpha^2)$	Morris, Ross & Sachrajda '85

β-function coefficients: $\beta_0 = 11 - \frac{2}{3}\mathrm{n_f}$; $\beta_1 = 102 - \frac{38}{3}\mathrm{n_f}$

Note:

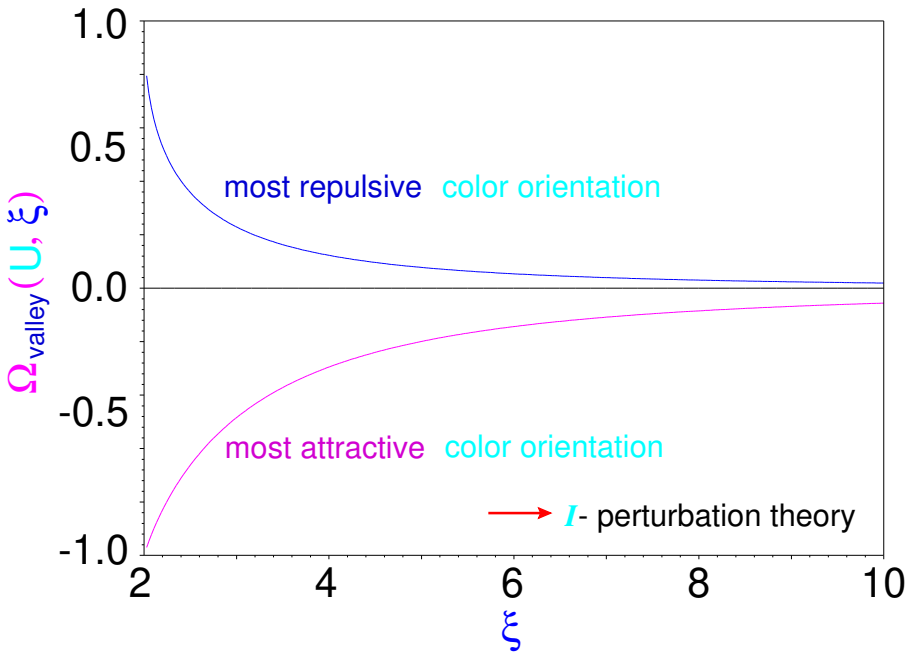
- For $n_f = 0$ (lattice), $D(\rho)$ equals the proper size distribution (in dilute gas approx.), i. e. $D(\rho) \simeq d\,n_I/d^4x\,d\rho$
- Power-law behaviour $D(\rho) \propto \rho^{6-2/3n_f+\mathcal{O}(\alpha)}$ generically spoils applicability of I-perturbation theory, since I-size integrals diverge for large ρ (infrared)
- Exception in **DIS**, where "form factor" $\exp(-Q'(\rho+\overline{\rho}))$ insures $\rho, \overline{\rho} \lesssim 1/Q'$

$\diamondsuit$ $\Omega\left(U, \frac{R^2}{\rho\overline{\rho}}, \frac{\overline{\rho}}{\rho}\right)$

- known as series for $R^2/\rho\overline{\rho} \gg 1$
- analytically known within "$I\overline{I}$-valley" approximation [Yung '88, Khoze & Ringwald '91, Verbaarschot '91]

conformal $I\overline{I}$-distance

$\xi = \frac{R^2}{\rho\overline{\rho}} + \frac{\rho}{\overline{\rho}} + \frac{\overline{\rho}}{\rho}$



♣ For (large) $Q' \neq 0$, all collective coordinate integrations in $\sigma^{(I)}_{q'g}$ in terms of unique saddle point:

$U^* \Leftrightarrow$ most attractive color orientation

$$\rho^* = \overline{\rho}^* \sim \frac{4\pi}{\alpha(\frac{1}{\rho^*})}\frac{1}{Q'}; \qquad \xi^* - 2 \equiv \frac{R^{*\,2}}{\rho^{*\,2}} \overset{Q' \text{ large}}{\sim} 4\frac{x'}{1-x'}$$

$$\sigma^{(I)}_{q'g}(Q', x') \simeq D(\rho^*)^2 \; \mathrm{e}^{-\frac{4\pi}{\alpha(\frac{1}{\rho^*})}\Omega_{\text{valley}}(U^*,\xi^*)} \; \frac{\underbrace{H(\xi^*,\rho^*)}}{1/\sqrt{\det(\text{Hessian})},\ldots}$$

⇒ formally, for large Q' and small $(1-x')$:
dilute gas $(R/\rho \gg 1)$ of small I's and $\overline{I}$'s $(\rho \sim 1/Q')$!

$D(\rho)$ and $\Omega\left(U, \frac{R^2}{\rho\overline{\rho}}, \frac{\overline{\rho}}{\rho}\right)$: Link between **DIS** and **lattice** observables!

♢ **Lattice** ⇒ Independent, non-perturbative information on range of validity of their predicted form in (ρ, R)

♢ Due to crucial one-to-one saddle-point correspondence of effective I-coordinates

⇒ "fiducial" (Q', x') region for our predictions in **DIS**!

3. Implications of Lattice Results

[Ringwald & F. Sch., Phys. Lett. **B 438** (1998) 217,
hep-lat/9903039 and Phys. Lett. **B 459** (1999) 249]

- **Lattice**: "Snapshots" of the QCD -vacuum in (Euclidean) space-time, including all non-perturbative, topological features like instantons

- Recent high-quality lattice simulation of quenched QCD ($n_f = 0$) [UKQCD, Smith & Teper, '98,. . .]

$\beta \equiv 6/g_0^2(a)$:	$=$	6.4	6.2	6.0	
i. e. lattice spacing a :	$\simeq$	0.055	0.072	0.10	fm
volume $V = (n_s^3\, n_t)\, a^4$:	$=$	$32^3\, 64$	$24^3\, 48$	$16^3\, 48$	a^4
	$\simeq$	18.6	18.0	18.2	fm^4

- **Throughout**: use Sommer scale r_0: $2\, r_0 \simeq 1$ fm
rather than string tension σ to convert to physical units
($r_0 \Leftrightarrow$ force $F_{\overline{q}q}$ between static quarks: $r_0^2 F_{\overline{q}q}(r_0) = 1.65$) .

♣ Topological structure over fairly wide range of sizes
$a \ll \rho \ll V^{1/4}$ accessible.

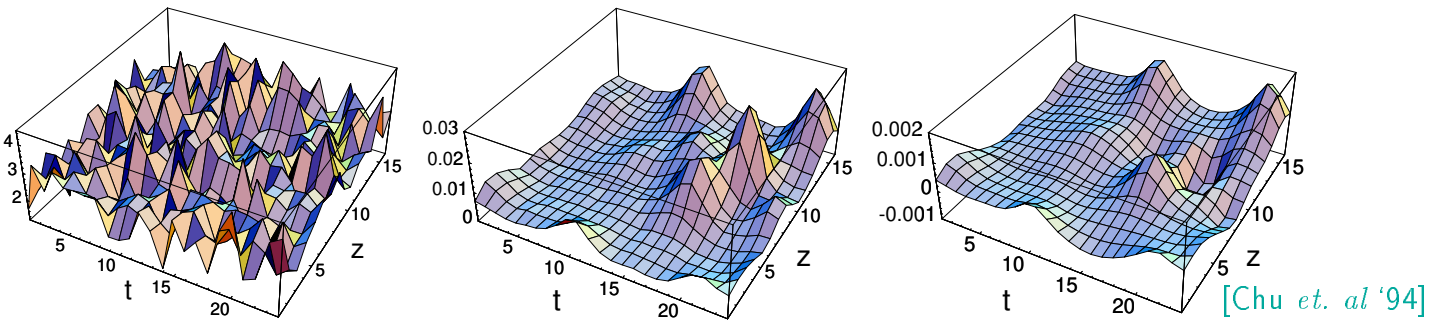
♣ Range of validity of I-perturbation theory?

– Crucial: $\Rightarrow$ "fiducial" $(Q',\ x')$ region for **DIS** predictions!
– Interesting question by itself. . .

Cooling

- Designed to filter out (dominating) fluctuations of short wavelength $\mathcal{O}(a)$, while affecting topological fluctuations of size $\rho \gg a$ comparatively little.

Lagrange Density **Topological Charge Density**



[Chu *et. al* '94]

Before Cooling **After** Cooling

- **In practice**: n_{cool} sweeps trough the lattice links replacing existing link matrices $\Rightarrow$ new ones, locally minimizing (or reducing) the action

- $\Rightarrow$ Sequence of increasingly smooth or 'cold' lattice fields. May then study local topological structures (I, $\overline{I}$) via pattern recognition algorithms (c. f. Fig.)

- Cooling also removes I's and $\overline{I}$'s, e.g. via $I\overline{I}$ annihilation $\Rightarrow$ **UKQCD**: "under-relaxed" (i. e. slow) cooling

- No objective criterium available yet, on quantitative amount of "vacuum damage" introduced by cooling. . .

- Various proposals to approach physics of uncooled vacuum:

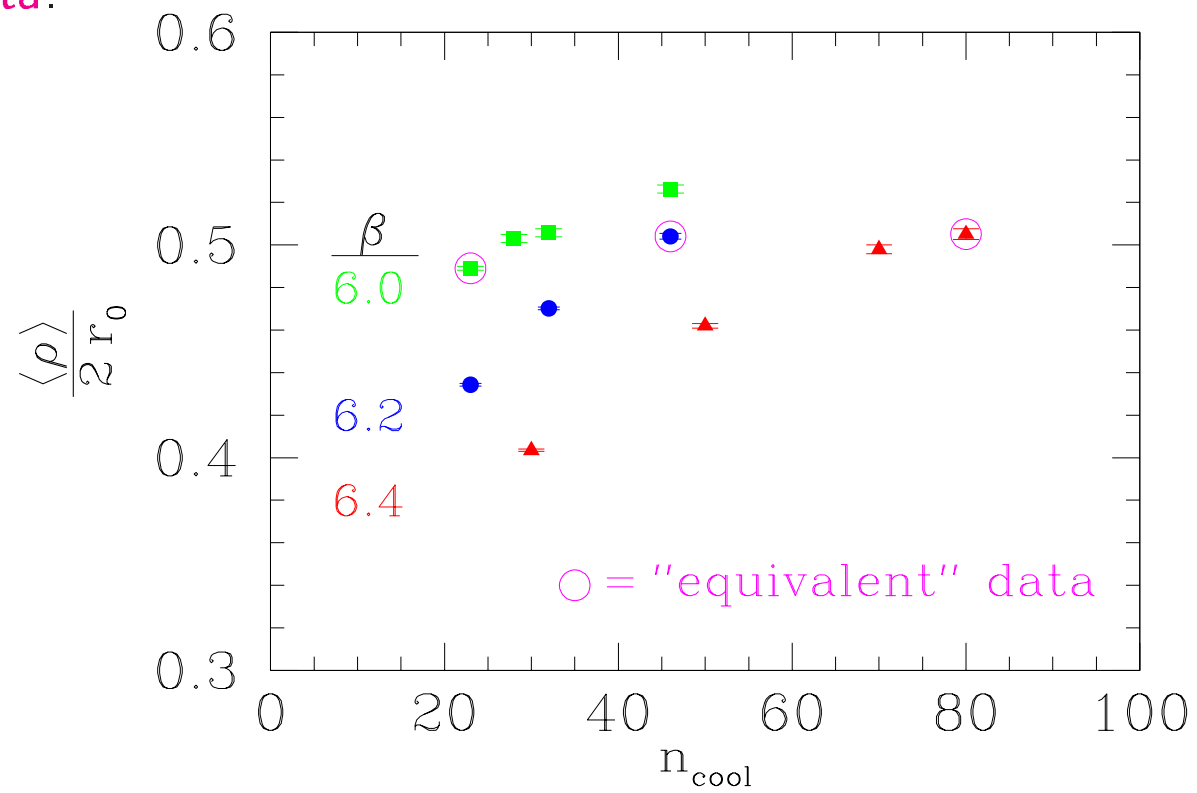
  $\Rightarrow$ **UKQCD:** Starting from smallest reliable $n_{\rm cool} \simeq 23$ at $\beta = 6.0$, say, find further "equivalent" pairs $(\beta, n_{\rm cool})$ giving $\sim$ same shape & normalization of distributions.

  $\diamondsuit$ **Result:** pairs $(\beta, n_{\rm cool}) = (6.0, 23),\ (6.2, 46),\ (6.4, 80)$ used for continuum limit, $a \to 0$!

  ? Crucial question remains: Why $(\beta, n_{\rm cool}) = (6.0, 23)$ as "starting pair" distinguished? (c. f. below!)

- **Illustration**: average I-size $\langle \rho \rangle$

- Fixed β: strong dependence on $n_{\rm cool}$, unlike "equivalent" data.



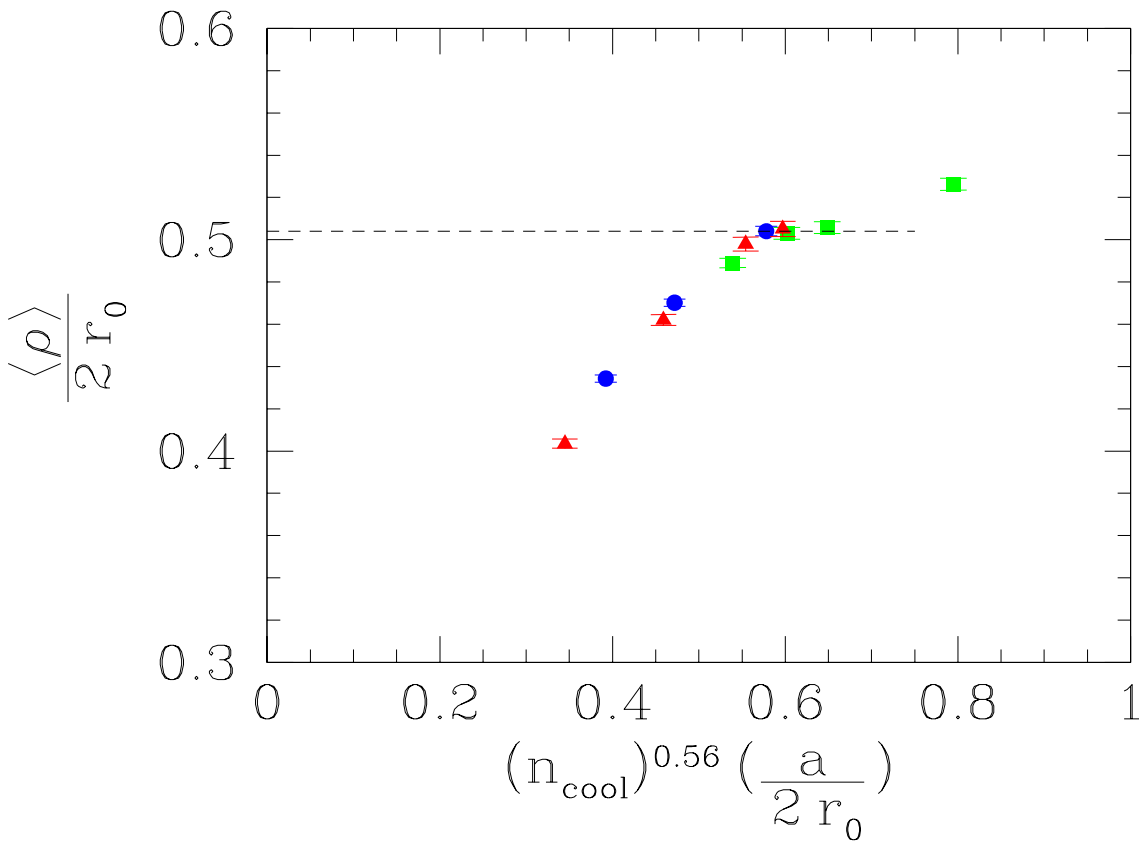
- Striking observation: [Ringwald & F. Sch., Phys. Lett. **B 459** '99]

  Cooling is kind of "diffusion process": length scale up to which it smoothes configurations grows with $n_{\rm cool}$.

- $\Rightarrow$ random walk argument:

  "cooling radius": $\frac{r_{\rm cool}}{2\,r_0} = \text{const.}(\sqrt{n_{\rm cool}})^{1+\delta}\frac{a}{2\,r_0}$; δ small

- **Fig.:** $\frac{\langle\rho\rangle}{2r_0}$ vs. $\frac{r_{\rm cool}}{2\,r_0}$ for all $(\beta, n_{\rm cool})$ on a single smooth curve, exhibiting a clear plateau $\Leftrightarrow$ "equivalent" data!



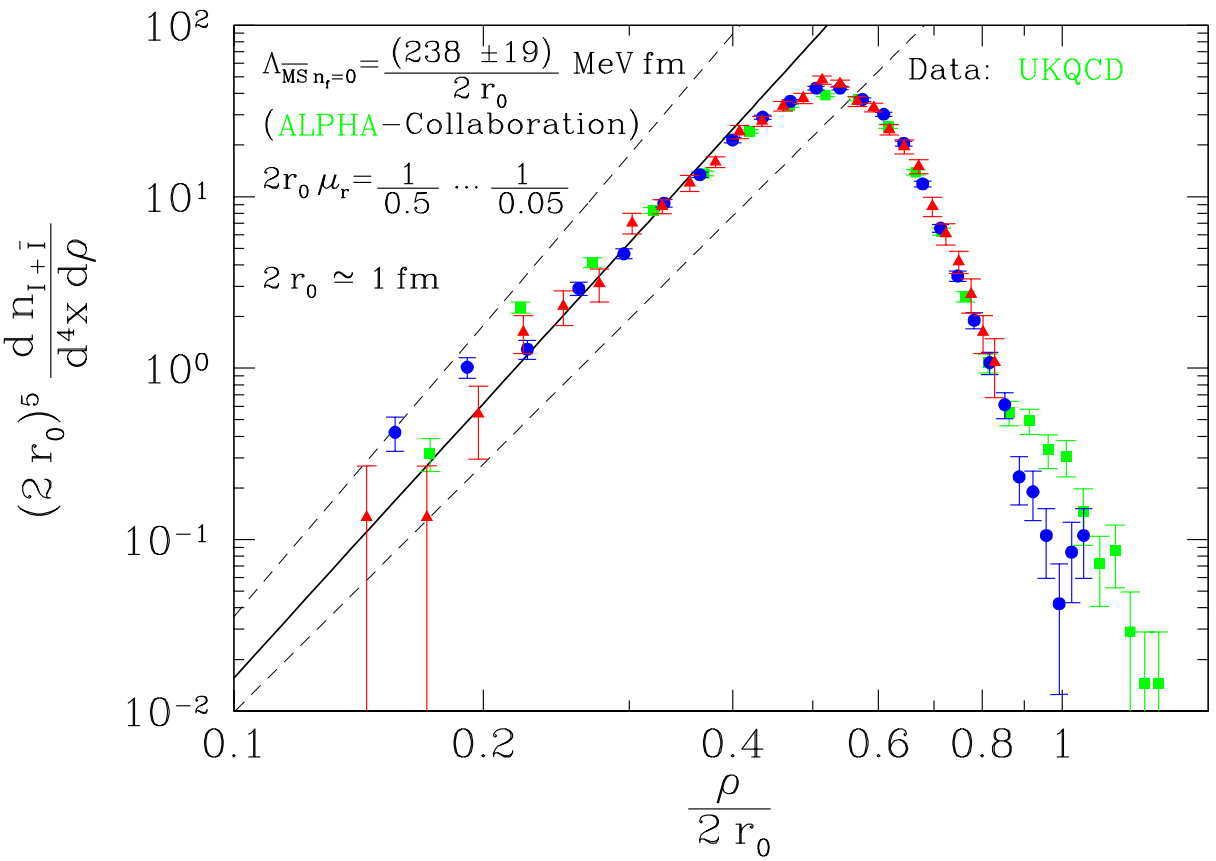
- In summary: plateau region = correct regime for extracting physical information about instantons!

I-Size Distribution $\frac{d\,n_{I+\bar{I}}}{d^4x\,d\rho}$

- Perform continuum limit of "equivalent" data via ansatz

$$(2r_0)^5 \frac{d\,n_{I+\bar{I}}}{d^4x\,d\rho} = \mathrm{f}\left(\frac{\rho}{\langle\rho(a)\rangle}\right) \qquad \begin{cases} \langle\rho(a)\rangle & \approx & \langle\rho(0)\rangle + \mathcal{O}(a^2) \\ \rho & \Rightarrow & \frac{\langle\rho(0)\rangle}{\langle\rho(a)\rangle}\cdot\rho \end{cases}$$

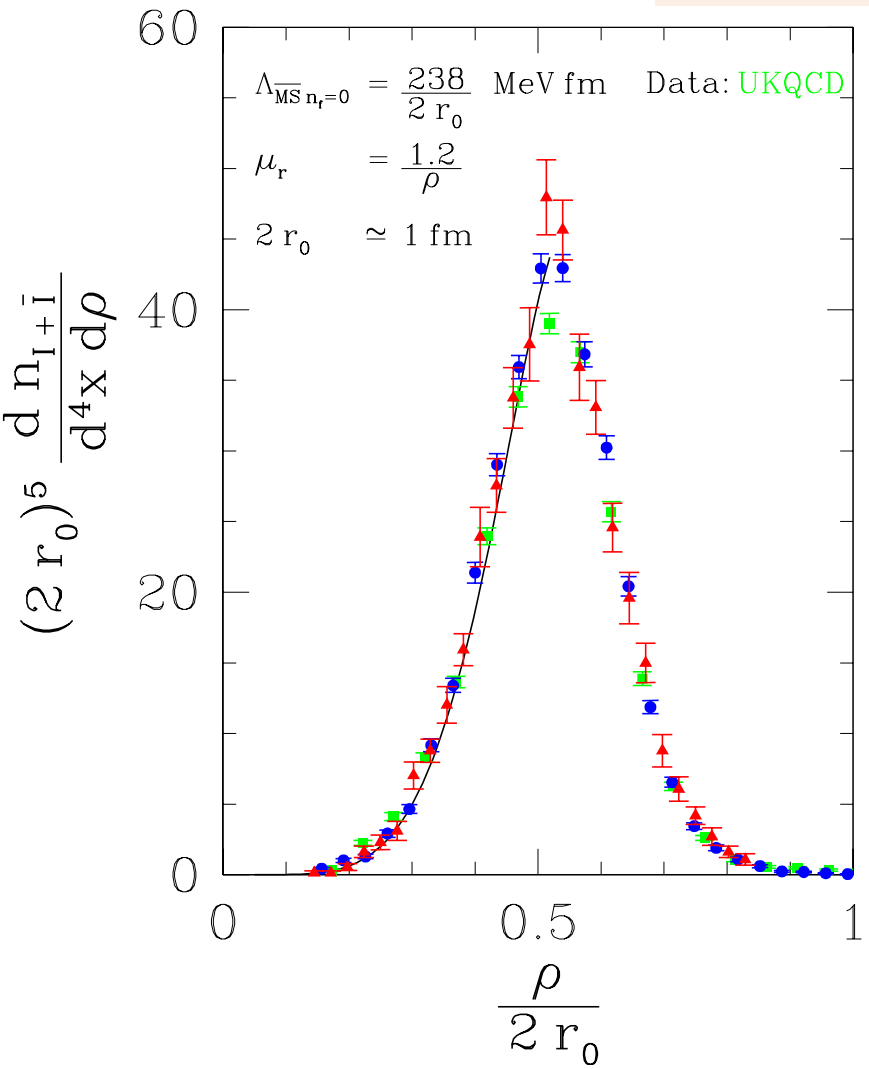
$$(2r_0)^5 \frac{d\,n_{I+\bar{I}}}{d^4x\,d\rho}\Big|_{\mathbf{UKQCD}} \stackrel{?}{\simeq} 2\,D(\rho)\Big|_{I-\text{perturbation theory}}$$



- Parameter-free **agreement** in shape and normalization,

for $\rho \lesssim 0.3 - 0.4$ fm

- Error band $\Leftrightarrow$ error of $2r_0\Lambda_{\overline{\rm MS}\,n_f=0} = (238\pm19)$ MeV fm [ALPHA-Collaboration, Nucl. Phys **B 544** (1999) 669]
- Almost independent of μ_r for large range $0.5 \lesssim \mu_r \lesssim 5$ GeV.
- Improved choice: $\mu_r\rho = \mathcal{O}(1)$, to minimize $\ln(\mu_r\rho)$-corrections $\Rightarrow$ **agreement** up to the peak, $\rho \lesssim 0.5$ fm !



- **Note:** As function of α, $D[\alpha]$ has a peak structure like lattice data! Maximum around $\alpha_{\rm peak} \approx \pi/N_c \simeq 1$ for $N_c = 3$

- Define non-perturbative "instanton-scheme" for α, by requiring exact validity of I-perturbative form for $D[\alpha_{\rm I}(1/\rho)]$,

$$\rho^5 \frac{d\, n_{I+\overline{I}}}{d^4x\, d\rho} \equiv 2\, d_{\overline{\rm MS}} \left(\frac{2\pi}{\alpha_{\rm I}(\frac{1}{\rho})}\right)^6 \exp\left(-\frac{2\pi}{\alpha_{\rm I}(\frac{1}{\rho})}\right) s_{\rm I}{}^{\beta_0 + \frac{\alpha_{\rm I}(\frac{1}{\rho})}{4\pi}(\beta_1 - 12\beta_0)}$$

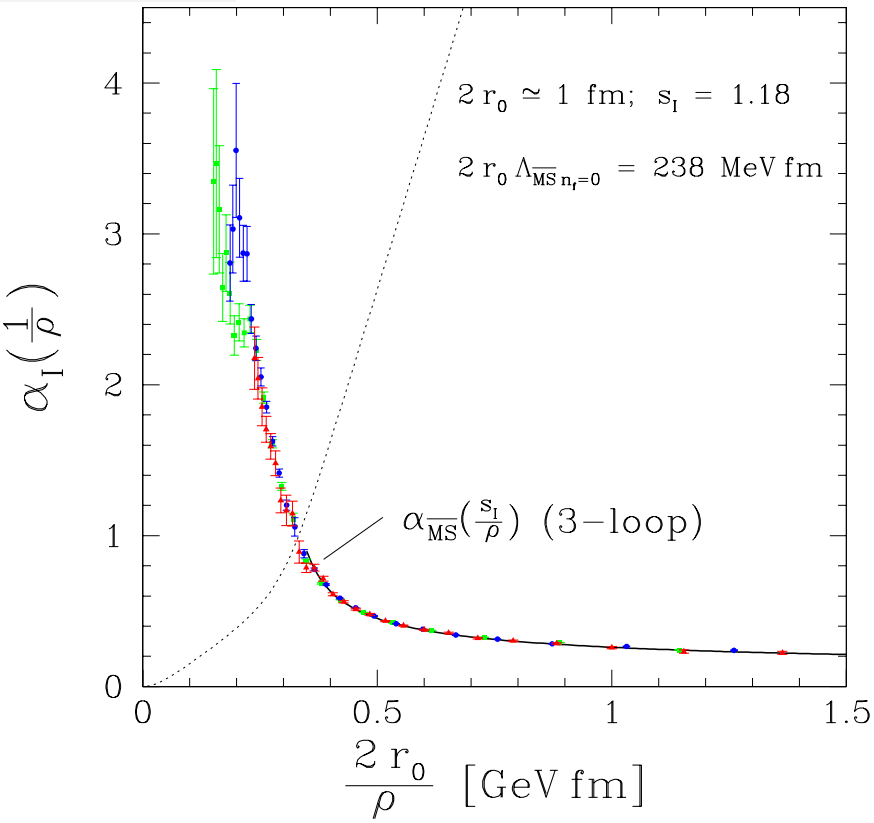
- In perturbative regime: compare with $\overline{\rm MS}$-form for $D(\rho)$, put $\mu_r = \frac{s}{\rho}$ $\Rightarrow$ standard 2-loop scheme conversion formula:

$$\alpha_{\overline{\rm MS}}(\tfrac{s}{\rho}) = \alpha_{\rm I}(\tfrac{1}{\rho}) - \frac{\beta_0}{2\pi} \ln(\tfrac{s}{s_{\rm I}})\, \alpha_{\rm I}(\tfrac{1}{\rho})^2 + \mathcal{O}(\alpha_{\rm I}(\tfrac{1}{\rho})^3); \quad s_I = \frac{\Lambda_{\overline{\rm MS}}}{\Lambda_I},$$

hence $\boxed{\alpha_{\overline{\rm MS}}(\frac{s_I}{\rho}) \simeq \alpha_I(\frac{1}{\rho})}$

- From peak-region: $s_I \approx 1.18$ $\Rightarrow$ at short distances, I-scheme close to $\overline{\rm MS}$-scheme.

Extract $\alpha_I(\frac{1}{\rho})$ for each data point of $(I + \overline{I})$-size distribution:



- second solution $\alpha_I^{(2)}$, vanishing in IR-limit (dotted line), with monopole-like relation in peak-region, $\alpha_I^{(2)} \cdot \alpha_I \approx 1$,

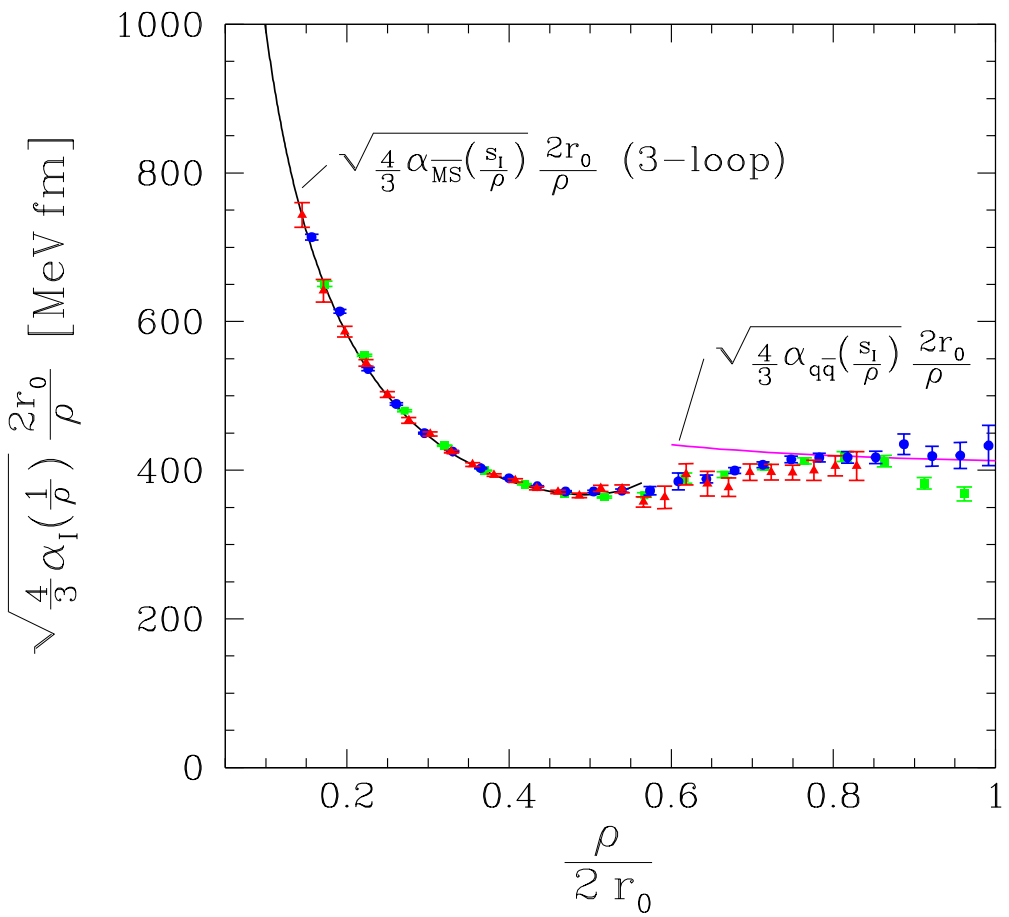
superstrong coupling $\alpha_I^{(2)}(\mu) \propto (\mu/\Lambda_I)^{\beta_0/2N_c}$ in UV limit.

Analoguous to [I. Kogan & M. Shifman '95]: two (dual) phases in SUSY Yang Mills (exact NSVZ β-function) ?

- **Remarkable:** In non-perturbative long-distance regime, $\alpha_I(\frac{1}{\rho})$ approaches $\alpha_{\mathrm{q\overline{q}}}(\frac{s_I}{\rho})$ $\Leftrightarrow$ static $\mathrm{q\overline{q}}$-potential $V_{\mathrm{q\overline{q}}}$

$$\frac{4}{3}\frac{\alpha_{\mathrm{q\overline{q}}}(1/r)}{r^2} \equiv \frac{dV_{\mathrm{q\overline{q}}}(r)}{dr} \simeq \sigma + \frac{\pi}{12}\frac{1}{r^2} \overset{r\to\infty}{\Rightarrow} \sigma,$$

with string tension σ, $2r_0\sqrt{\sigma} = (472.4 \pm 4.3)$ MeVfm [M. Guagnelli *et al.* '98]



- Transition between perturbative and confinement sensitive physics seems rather sharp, located around peak of $\frac{d\,n_{I+\overline{I}}}{d^4x\,d\rho}$

$I\overline{I}$-Distance Distribution $\frac{d(n_{I\overline{I}})}{d^4x\, d^4R}$ = number of unlike charges in the spherical shell of width δR a distance R away from each charge, normalized by shell volume ($\Leftarrow$ **UKQCD**)

- First direct test of $I\overline{I}$-valley form for $I\overline{I}$-interaction Ω!

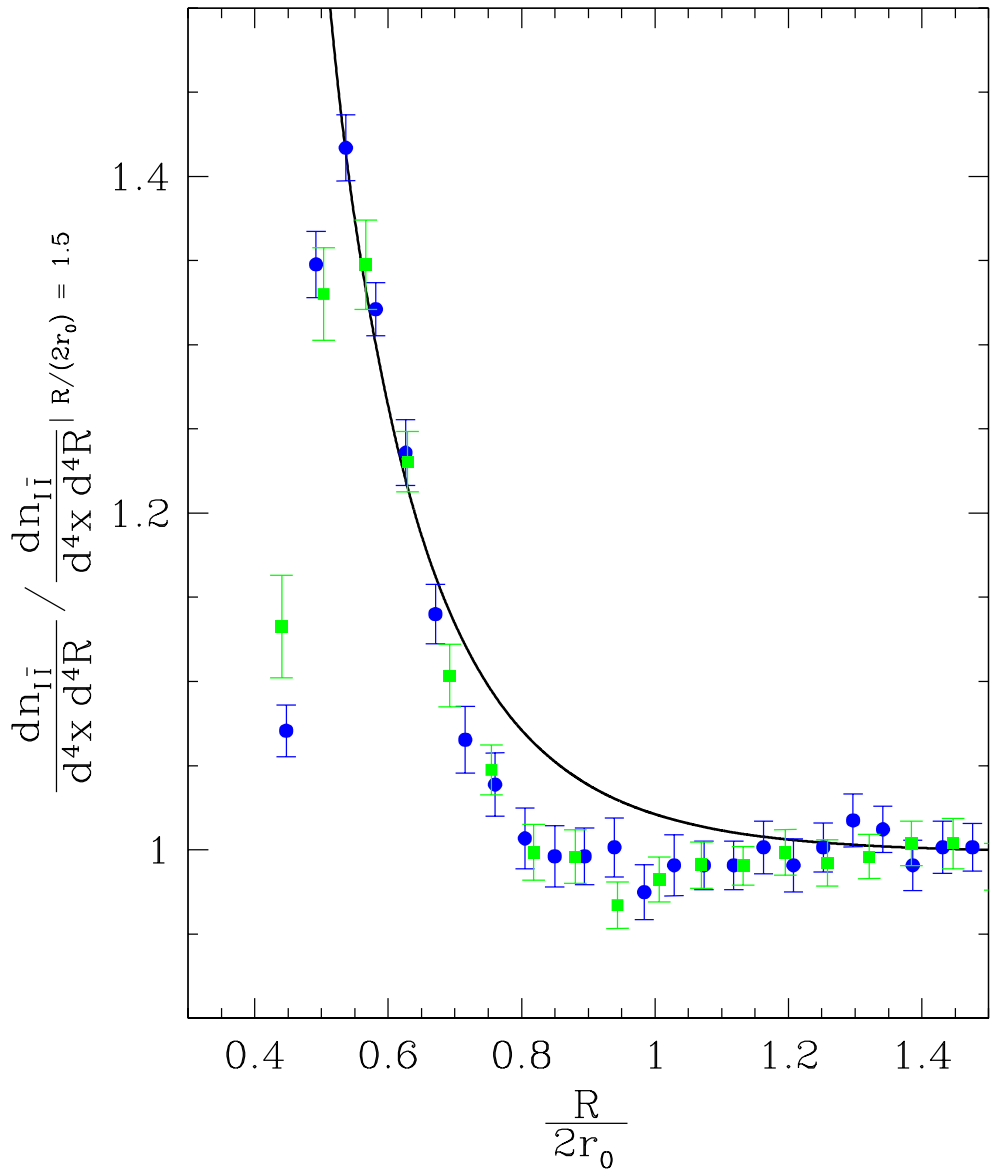
$$\frac{d\, n_{I\overline{I}}}{d^4x\, d^4R}_{|\,\mathbf{UKQCD}} \stackrel{?}{\simeq}$$

$$N \int_0^\infty d\rho \int_0^\infty d\overline{\rho}\;\; D(\rho)\, D(\overline{\rho}) \int dU\, \mathrm{e}^{-\frac{4\pi}{\alpha}}\;\; \Omega_{\mathrm{valley}}\left(U, \frac{R^2}{\rho\overline{\rho}}, \frac{\overline{\rho}}{\rho}\right)$$

- Substitute $D(\rho)$ and $\alpha = \alpha_I(\frac{s_{I\overline{I}}}{\sqrt{\rho\overline{\rho}}})$ by lattice results, perform 4 integrations numerically. 1 parameter: $s_{I\overline{I}} \simeq 0.7 = \mathcal{O}(1)$

- Continuum limit of "equivalent" data analogously to I-size distribution (too bad, $\beta = 6.4$ data missing!):

$$(2r_0)^8 \frac{d\, n_{I\overline{I}}}{d^4x\, d^4R} = \mathrm{f}\left(\frac{R}{r(a)}\right) \qquad \begin{cases} r(a) & \approx & r(0) + \mathcal{O}(a^2) \\ R & \Rightarrow & \frac{r(0)}{r(a)} \cdot R \end{cases}$$



- Continuum distributions from rescaling of the "equivalent" data at $\beta = 6.0$ and $\beta = 6.2$ are nicely consistent.

- Good **agreement** with $\Omega_{\rm valley}$ for $R \gtrsim 0.5$ fm, i. e. $R/\rho \gtrsim 1$

♣ In summary:

♢ Good **agreement** of lattice results with I-perturbation theory very interesting by itself.

♢ Lattice constraints translate via saddle point into "fiducial" kinem. region in **DIS**:

$$\left.\begin{array}{lcl} \rho & \lesssim & 0.35 \text{ fm} \\ R/\rho & \gtrsim & 1 \end{array}\right\} \Rightarrow \left\{\begin{array}{lcl} Q' & \gtrsim & 10 \text{ GeV} \\ x' & \gtrsim & 0.35. \end{array}\right.$$

implying $\Omega_{\text{valley}}(U^*, \xi^*) \gtrsim -0.5$ which should be reliable

♢ Promising: Try replacing $D(\rho)$ and $I\bar{I}$-interaction Ω by the actual form measured on the lattice! $\Rightarrow$ **DIS**-cuts may be much relaxed, high-E_T fireballs in photoproduction. . .

4. Status of Searches at HERA

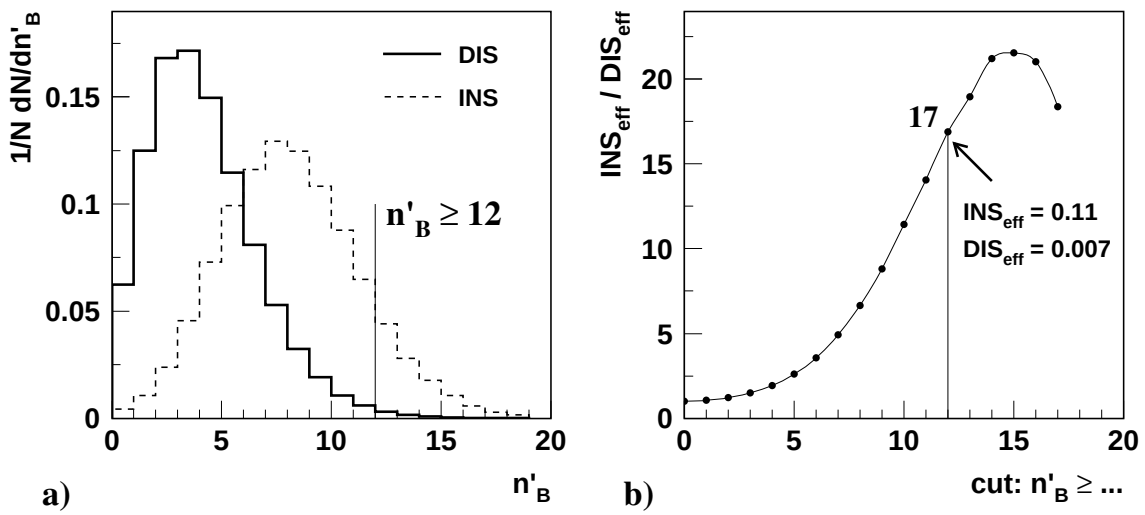
Indispensable Tool: QCDINS

Monte-Carlo generator for I-induced DIS-events:
[Gibbs, Ringwald & F. Sch. '95, Ringwald & F. Sch, '99, to appear,
http://www.desy.de/~t00fri/qcdins/qcdins.html]

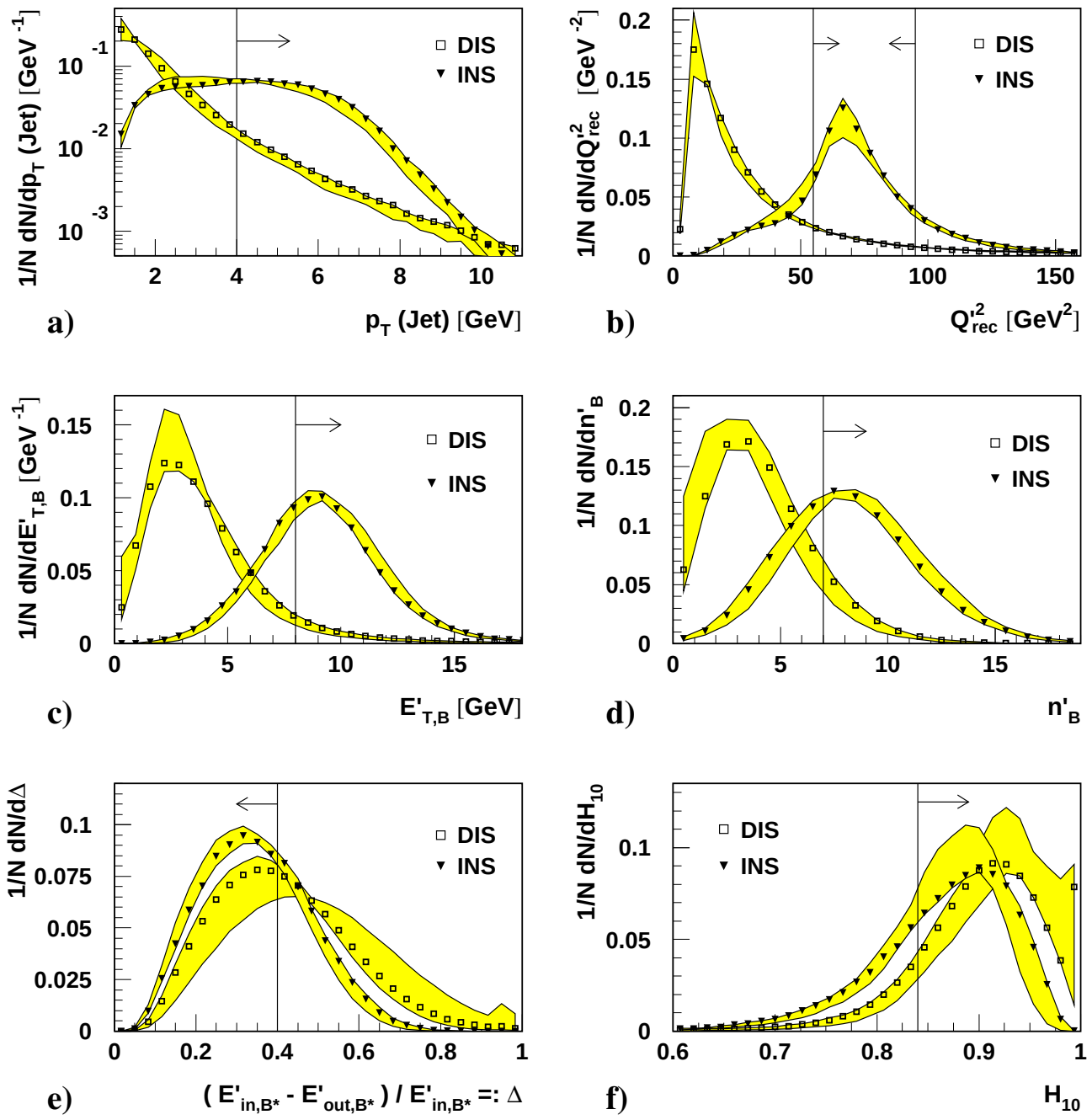
New Search Strategies

[T. Carli, J. Gerigk, A. Ringwald & F. Sch., hep-ph/9906441
T. Carli, J. Gerigk, B. Koblitz, A. Ringwald & F. Sch., to appear]

- Goal: Isolate I-enriched data sample by means of optimized cuts to a set of I-sensitive DIS-observables.
- Optimize I-separation power:$=\frac{\mathrm{INS}_{\mathrm{eff}}}{\mathrm{DIS}_{\mathrm{eff}}}$, $\mathrm{INS}_{\mathrm{eff}} \gtrsim 0.1$
- For **single** observables $\Rightarrow$ separation power $\lesssim \mathcal{O}(20)$



- Set of 6 "best" observables (among ~ 30) enhance I-separation power to $\mathcal{O}(130)$:

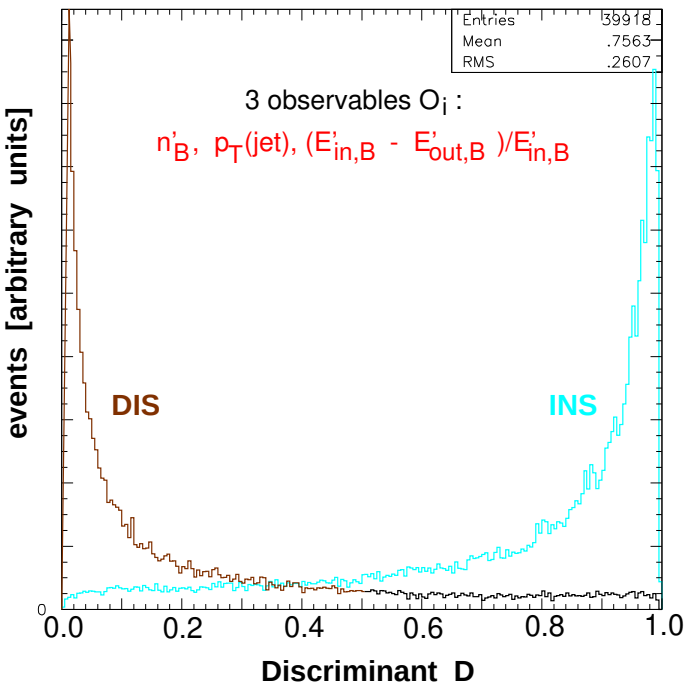


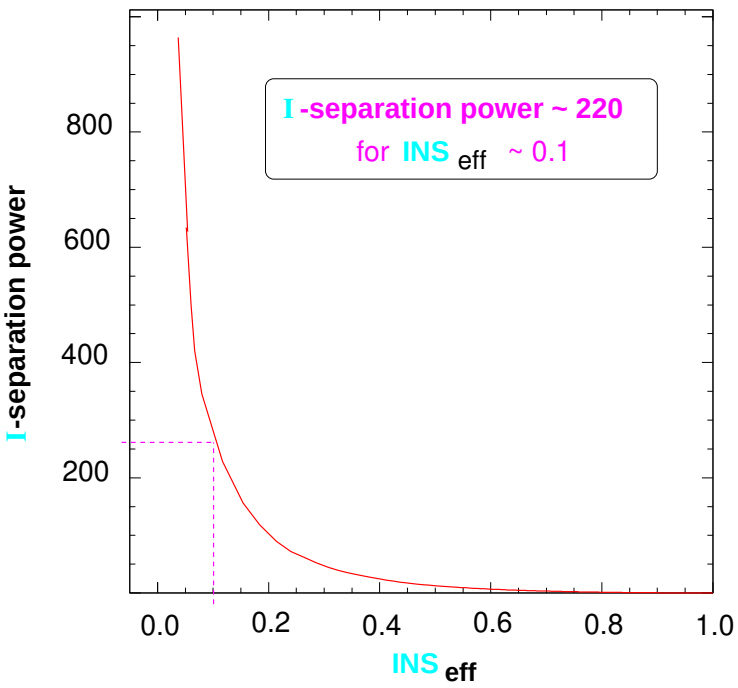
Note: Quite strongly dependent on (Monte-Carlo $\oplus$ parameters) used for DIS-"background". Better understanding of the tails of distributions for normal DIS events desirable!

I-Discriminants, a Better Way?

[suggested by Dave Soper, DIS 99 ; also D0 Collab., hep-ex/9801025
T. Carli, J. Gerigk, B. Koblitz, A. Ringwald & F. Sch., to appear]

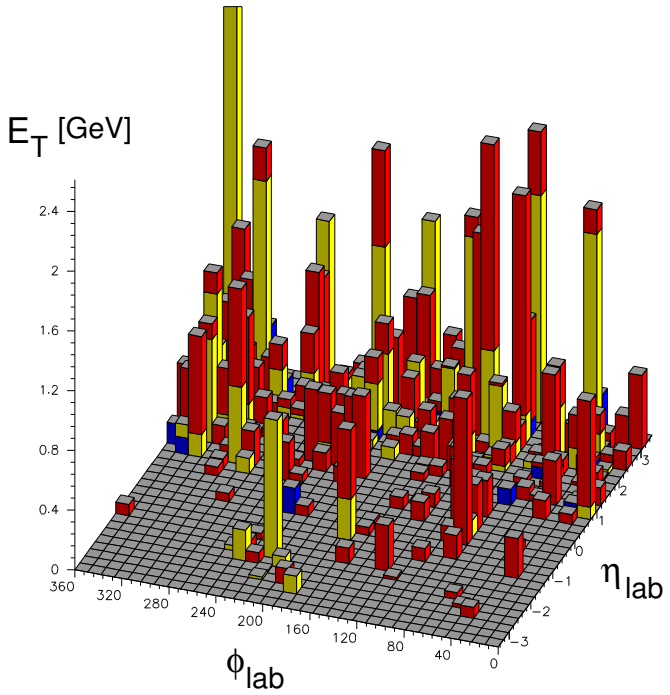
- **Desirable**: I-discriminating variable, whose distribution peaks if there is an I-signal
- **Multivariate approach:** Encode each event as a point in n-dim space of ($\sim$ uncorrelated) I-sensitive observables $\vec{O} = [O_1 \ldots O_n]$
- Map to 1-dim "Discriminant" D, such that background and signal vectors are mapped to $D \sim 0$ and $D \sim 1$, respectively
- Increase sensitivity, by treating observables $\vec{O}$ collectively rather than cutting on each separately! $\mathrm{INS}_{\mathrm{eff}} \Leftrightarrow$ cut on D.



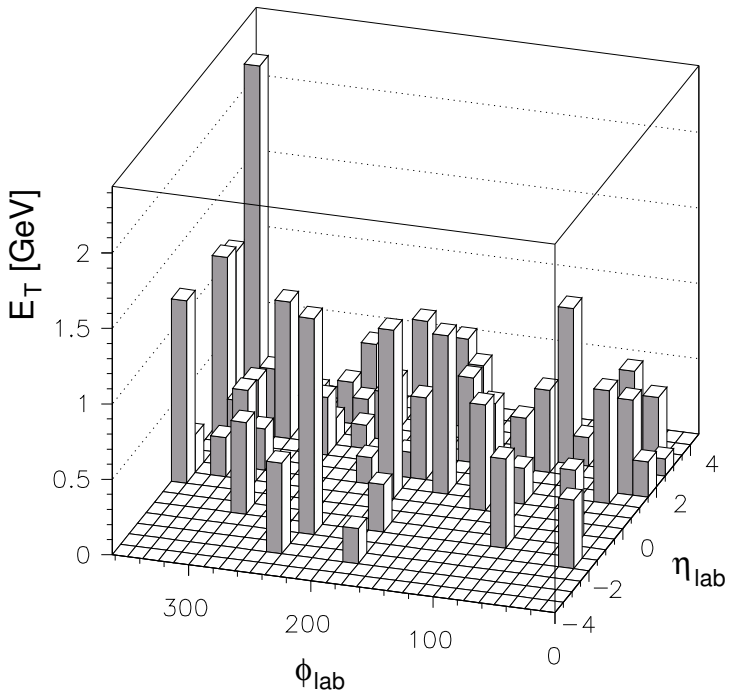


I-Induced Processes at small Q^2 (Photoproduction)?

- At small Q^2, a number of spectacular "fireball" events with large $(E_T)_{\text{total}}$ were reported [Y. Yamazaki (ZEUS), Durham '98]



ZEUS-home page, DESY



QCDINS

♣ Seem to exhibit all characteristics of I-induced processes

- Analysis just startet [PhD Thesis C. Nath (Oxford) '98]

♣ Look for strangeness, muons (from charm) in fireball events!

- Can we extend our calculations to $Q^2 \Rightarrow 0,\ E_t$ large?

5. Conclusions

- Exploited high-quality QCD lattice results [UKQCD] for information on crucial building blocks of I-perturbation theory

- New scaling variable for cooled lattice data: "cooling radius $r_{\rm cool}$", helps to extract information on uncooled distributions

♢ Surprising **agreement** of lattice results with I-perturbation theory very interesting by itself

  – I-size distribution $D(\rho)$ for $\rho \leq 0.3 - 0.4$ fm
  – support for $I\overline{I}$-valley form of $I\overline{I}$-interaction Ω for $R/\rho \gtrsim 1$!

♢ Lattice⇒ crucial support for basic prerequisites of our calculation of I-rate in **DIS**, "fiducial" kinematical region. . .

♢ I-Searches at **HERA**

  – unique window to detect I-induced events through their final-state signature and high expected rate, $\mathcal{O}(100\ \mathrm{pb})$
  – **H1:** Optimized search strategies are being applied to $\mathcal{O}(10^5)$ **DIS** events from '97 in $x_{\rm Bj} \gtrsim 10^{-3}, y_{\rm Bj} \gtrsim 0.1$.
  – **ZEUS:** "fireball" events in photo-production look "inspiring" and are under study. . .

Hope for definite results until end of '99