ICHEP2016CHICAGO

38th INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS

AUGUST 3 - 10, 2016

CHICAGO

Phenomenology on Strong Interactions and Hadron Physics

M. Nielsen

Instituto de Física
USP - Brazil

Rio2016


Rio2016
Fooora
Temer!!!

Big Questions

What are the degrees of freedom and mechanisms responsible for confinement?

Big Questions

Big Questions

What are the degrees of freedom and mechanisms responsible for confinement?

What are the degrees of freedom and mechanisms responsible for chiral symmetry breaking?

Big Questions

What are the degrees of freedom and mechanisms responsible for confinement?

What are the degrees of freedom and mechanisms responsible for chiral symmetry breaking?

for U(1) symmetry breaking?

Big Questions

What are the degrees of freedom and mechanisms responsible for confinement?

What is the structure of hadrons in terms of quarks and gluons?

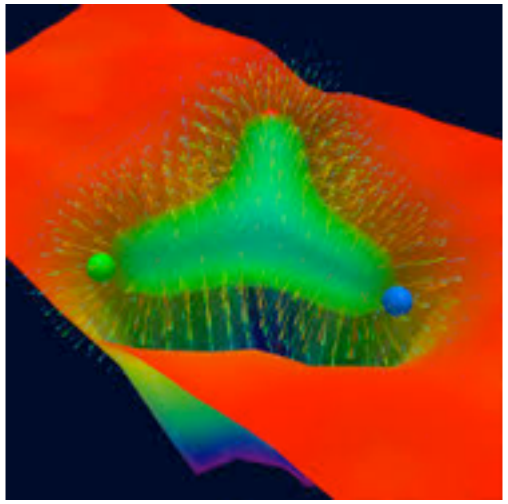
for U(1) symmetry breaking?

What are the degrees of freedom and mechanisms responsible for chiral symmetry breaking?

Fundamental Problems in Strong Interactions and Hadron Physics

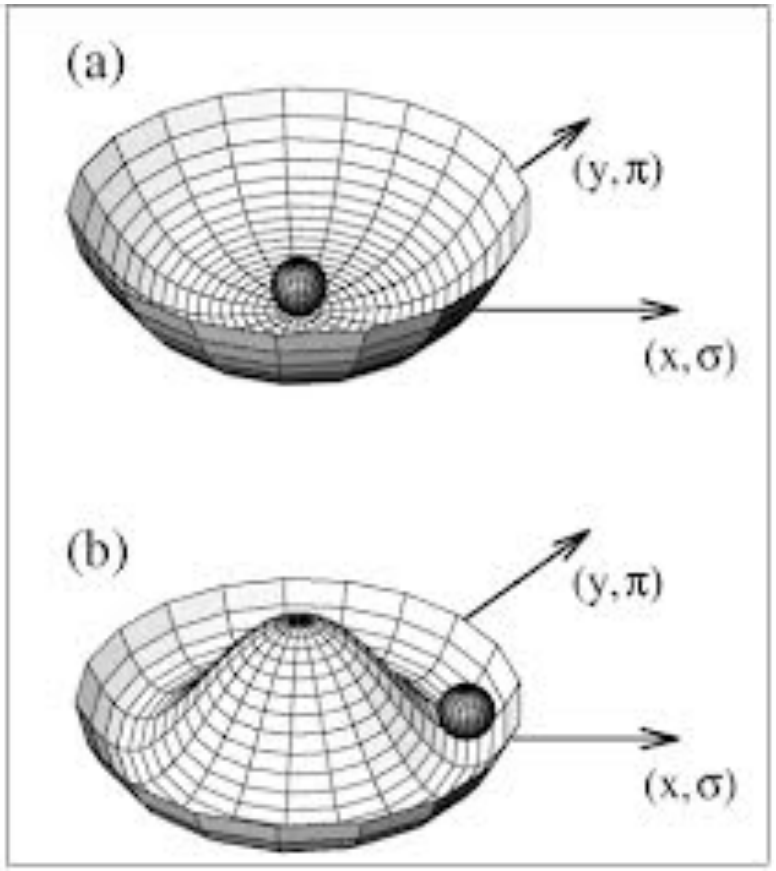
- **Accurate determination of the parameters of QCD:**
- Λ_{QCD}, or α_s, which sets the scale for all strong interaction phenomena;
- the QCD vaccum Θ parameter, controlling the violation of CP symmetry;
- masses of quarks, in particular the ratio $(m_d-m_u)/(m_d+m_u)$, which ultimately control details of hadron spectroscopy

- **Understand the origin and dynamics of confinement. Whereas lattice calculations clearly indicate the formation of tubes of gluonic fields connecting colored charges, we need to understand:**



- why flux tubes are formed;
- how they relate to the confinement of color charges;
- what is the role that they play in the structure and dynamics of hadrons

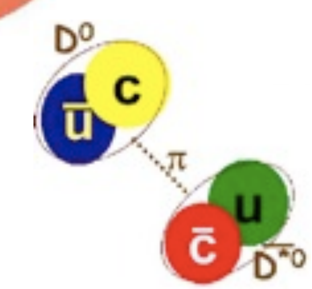
- **Understand the origin and dynamics of chiral symmetry breaking, responsible for the existence of light pions, in particular:**



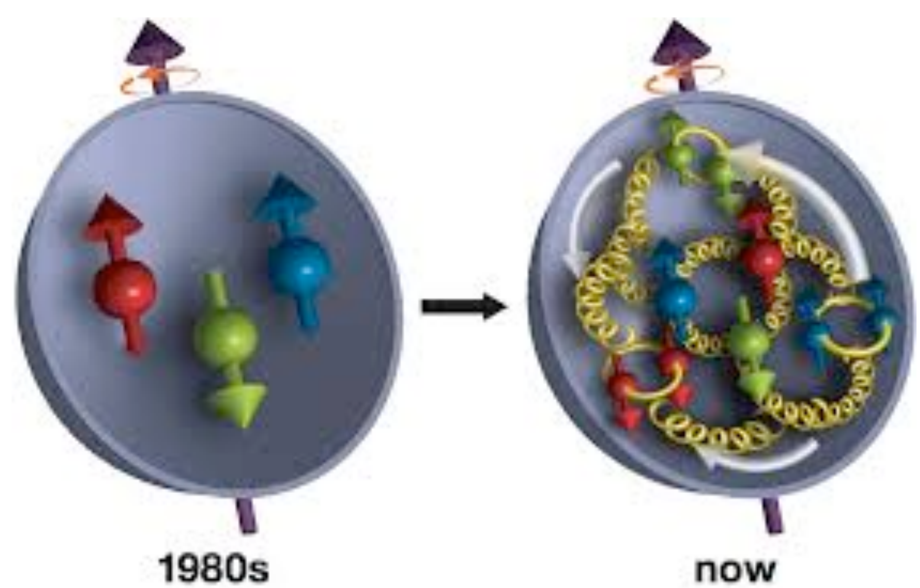
- we need to understand the physical origin of the quark zero modes generating the chiral condensate;
- we need to understand the relationship between the deconfinement and chiral phase transitions at finite temperature

- **Understand the quark and gluon structure of hadrons based on QCD. We need to develop a quantitative understanding of how quarks and gluons provide:**

- the binding of hadrons; mesons, baryons and exotic states



- the spin of the nucleon

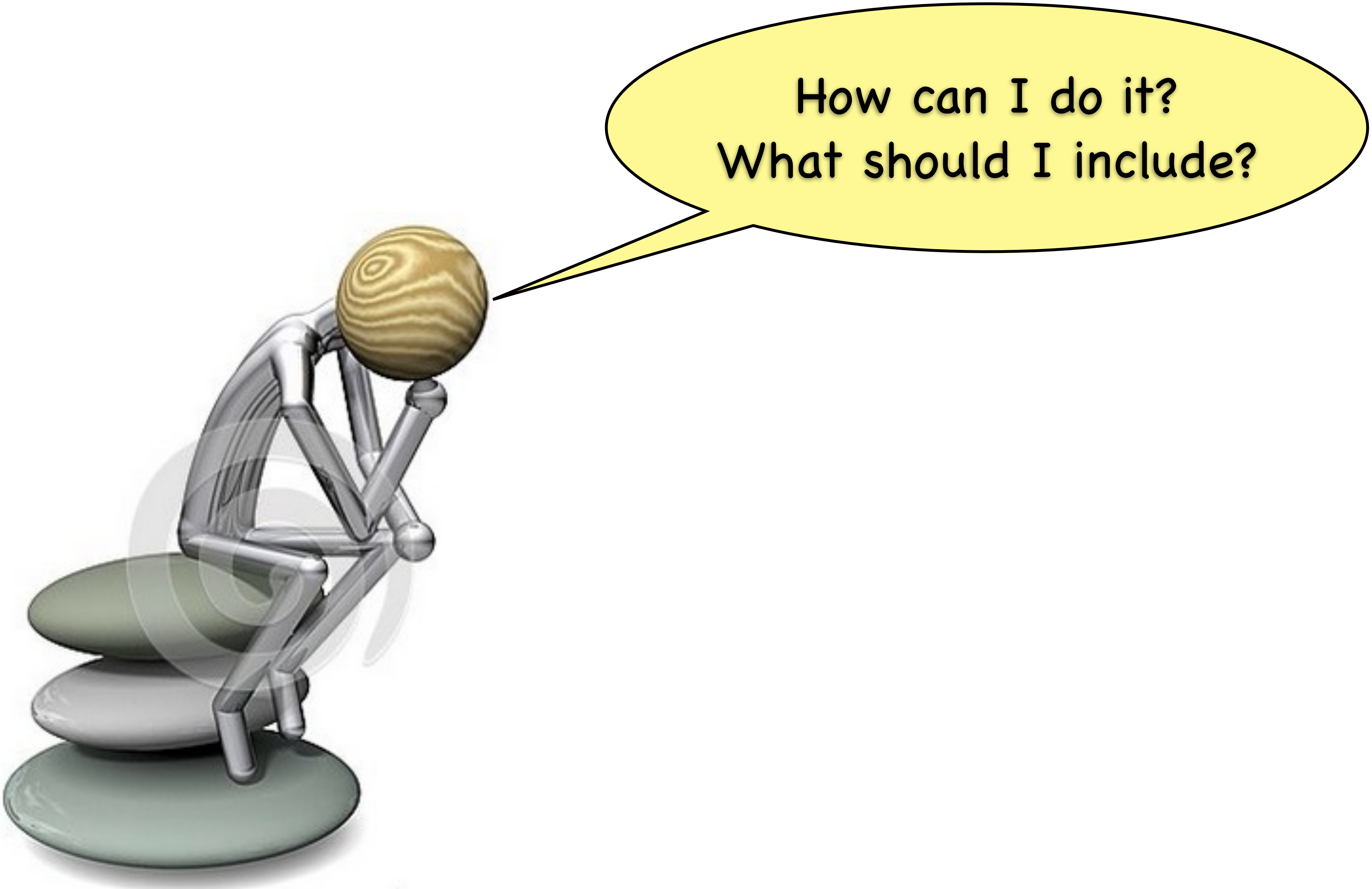


- **Understand the relation between parton degrees of freedom in the infinite momentum frame and the structure of hadrons in the rest frame:**
- deeply inelastic scattering experiments measure correlation functions along the light cone and determine probability distribution of partons in the infinite momentum frame;
- we need to develop physical insight and quantitative tools to relate parton distributions to the structure of hadrons in their rest frame

Strong Interactions and Hadron Physics Session

experimental talks	theoretical talks	posters
36	19	~40

Hadron structure
QCD parameters
Parton distribution functions
Single/Double parton scattering
Strangeness in the nucleon
Nucleon form factor
QCD under extreme conditions


How can I do it?
What should I include?

How can I do it?
What should I include?

This is my personal view
I apologize for not including some contributions that are as important as the ones I have included

all figures were taken from the oral presentations in the SIHP session


I will try not to fall!!!

Hadron Structure: exotics

tetraquark ?

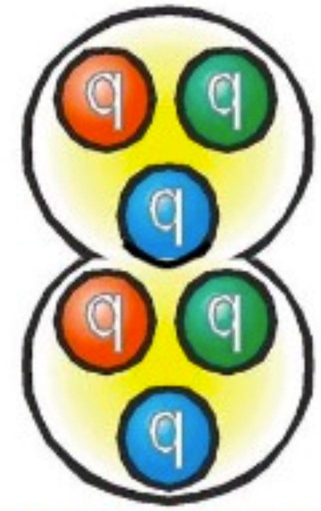
meson

from L. Zhang talk

baryon

normal hadrons

mesonic molecule ?



e.g. deuteron

pentaquark ?

$X^+(5568)$, $Z^-(4430)$, $P_c^+(4380)$, $P_c^+(4450)$, $X(4140)$, $X(1835)$, $Y(4260)$, $X(3872)$, $Z_c^+(3900)$, $Z_c^+(4020)$, $Z_b^+(10610)$, $Z_b^+(10650)$ ...

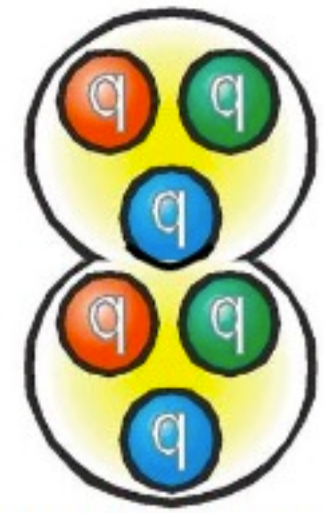
Hadron Structure: exotics

tetraquark ?

meson

from L. Zhang talk

mesonic molecule ?



e.g. deuteron

pentaquark ?

baryon

normal hadrons

$X^+(5568)$, $Z^-(4430)$, $P_c^+(4380)$, $P_c^+(4450)$, $X(4140)$, $X(1835)$, $Y(4260)$, $X(3872)$, $Z_c^+(3900)$, $Z_c^+(4020)$, $Z_b^+(10610)$, $Z_b^+(10650)$ ...

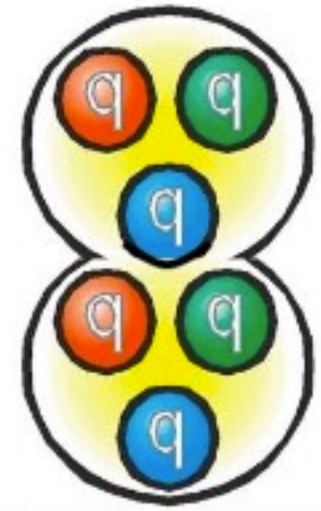
charged states are necessarily 4(5) quark states

Hadron Structure: exotics

tetraquark ?

meson

from L. Zhang talk



normal hadrons

baryon

mesonic molecule ?

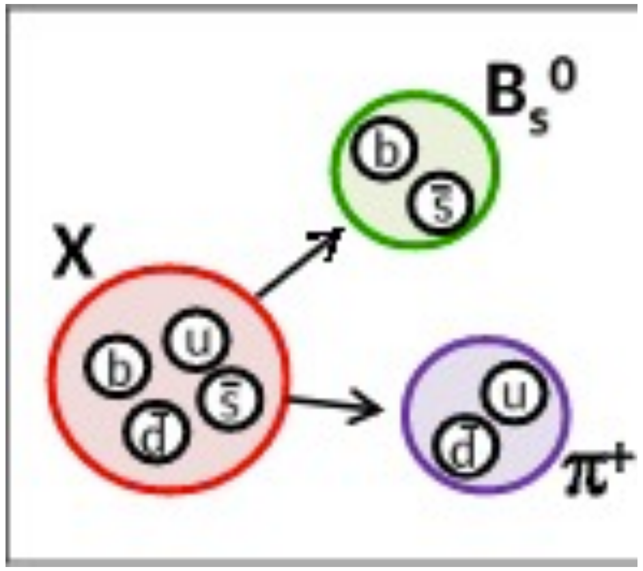
e.g. deuteron

pentaquark ?

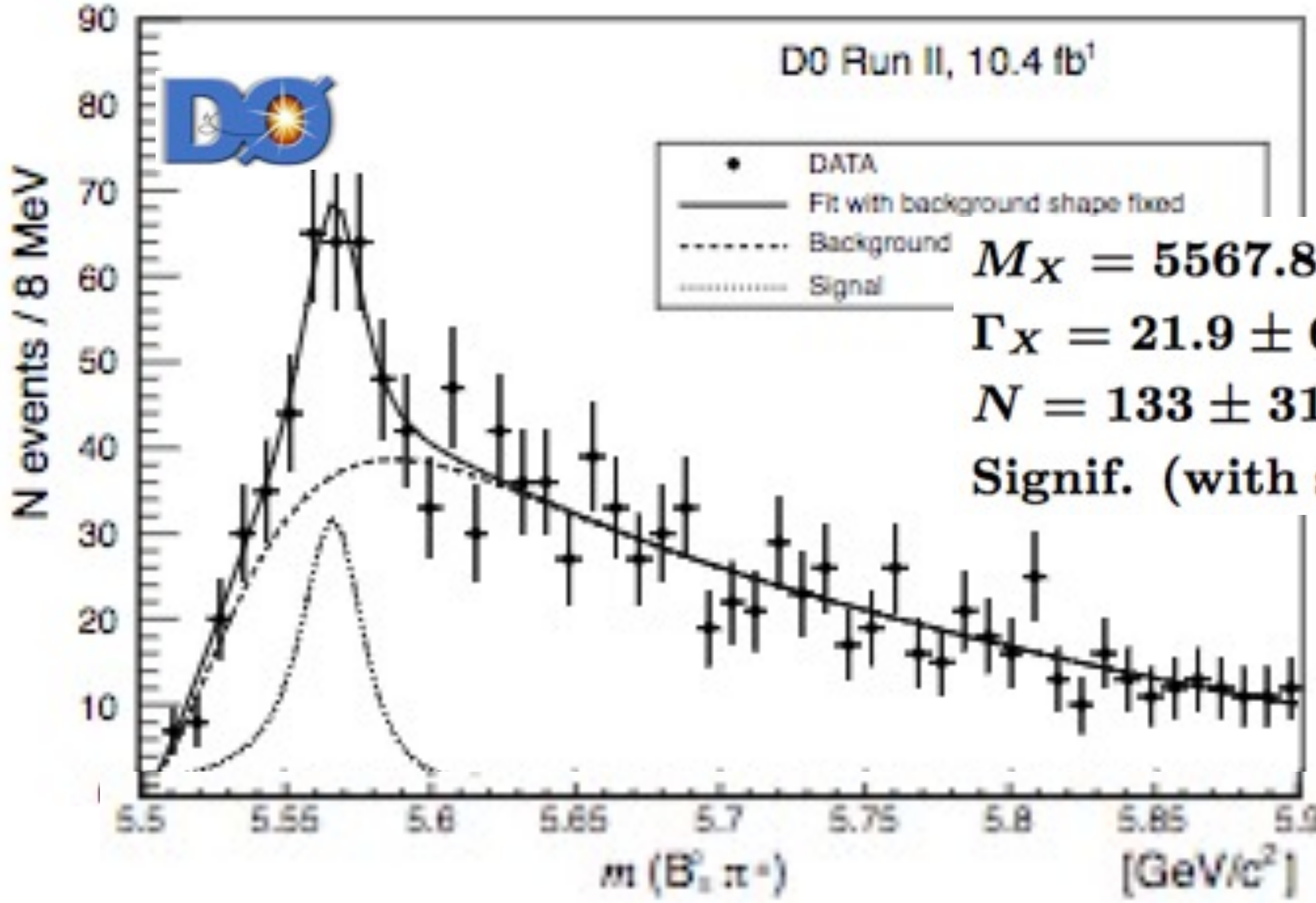
$X^+(5568)$, $Z^-(4430)$, $P_c^+(4380)$, $P_c^+(4450)$, $X(4140)$, $X(1835)$, $Y(4260)$, $X(3872)$, $Z_c^+(3900)$, $Z_c^+(4020)$, $Z_b^+(10610)$, $Z_b^+(10650)$ ...

charged states are necessarily 4(5) quark states

$X^+(5568)$



from D. Zieminska talk



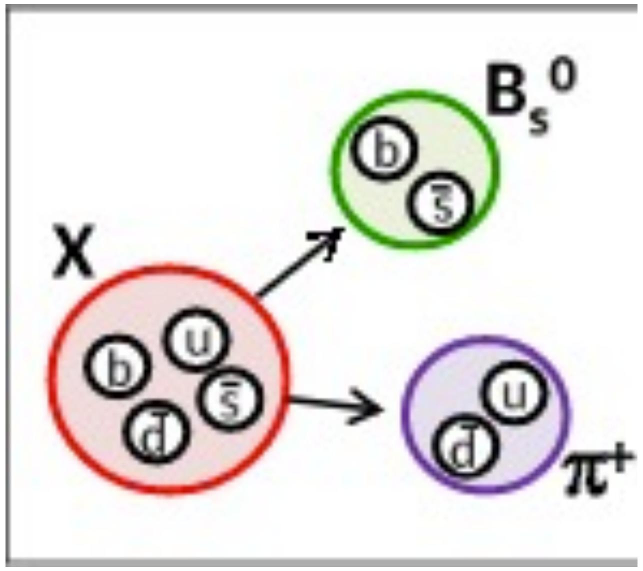
$M_X = 5567.8 \pm 2.9$ MeV

$\Gamma_X = 21.9 \pm 6.4$ MeV

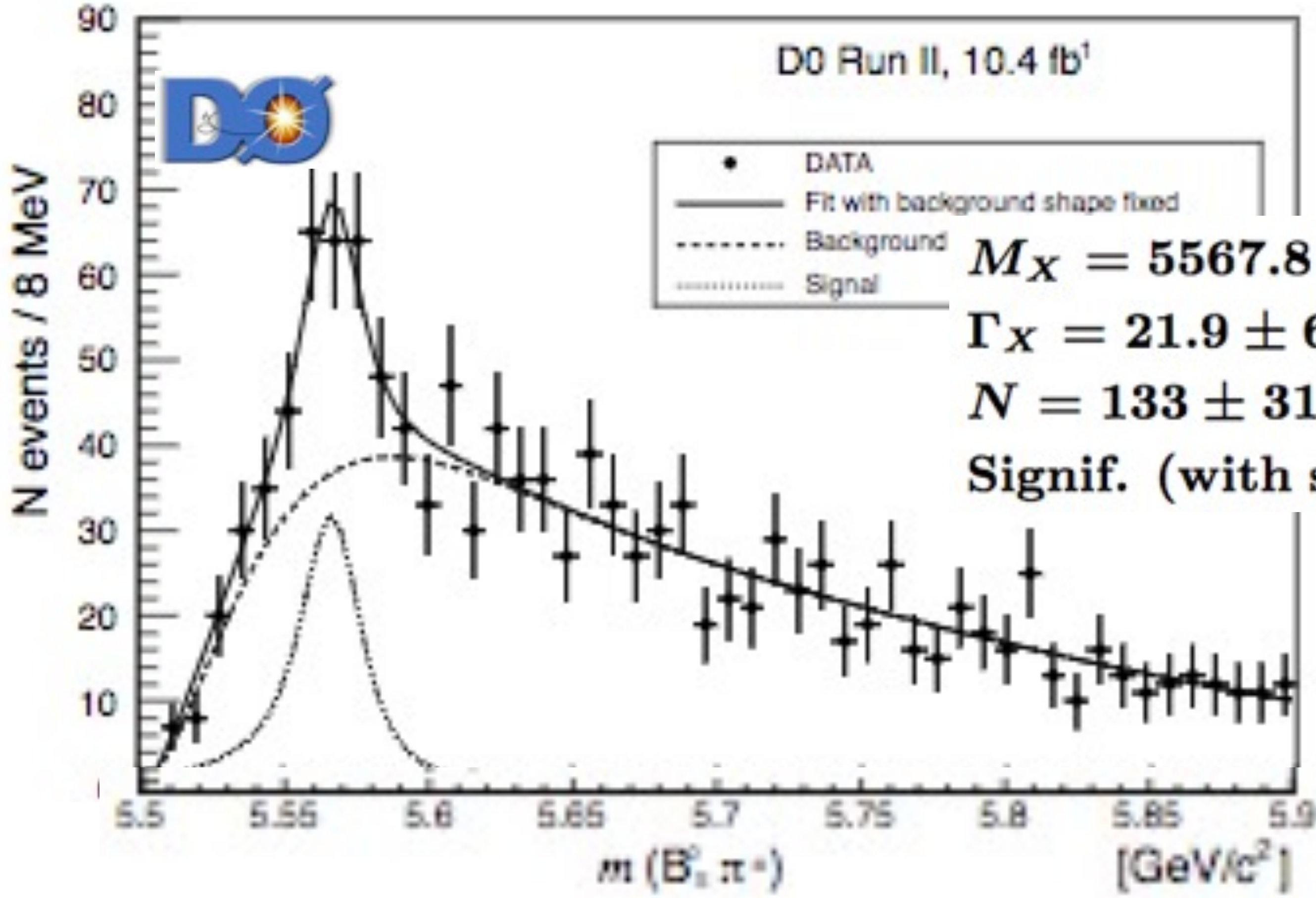
$N = 133 \pm 31$

Signif. (with syst and LEE) $S = 5.1\sigma$

$X^+(5568)$



from D. Zieminska talk

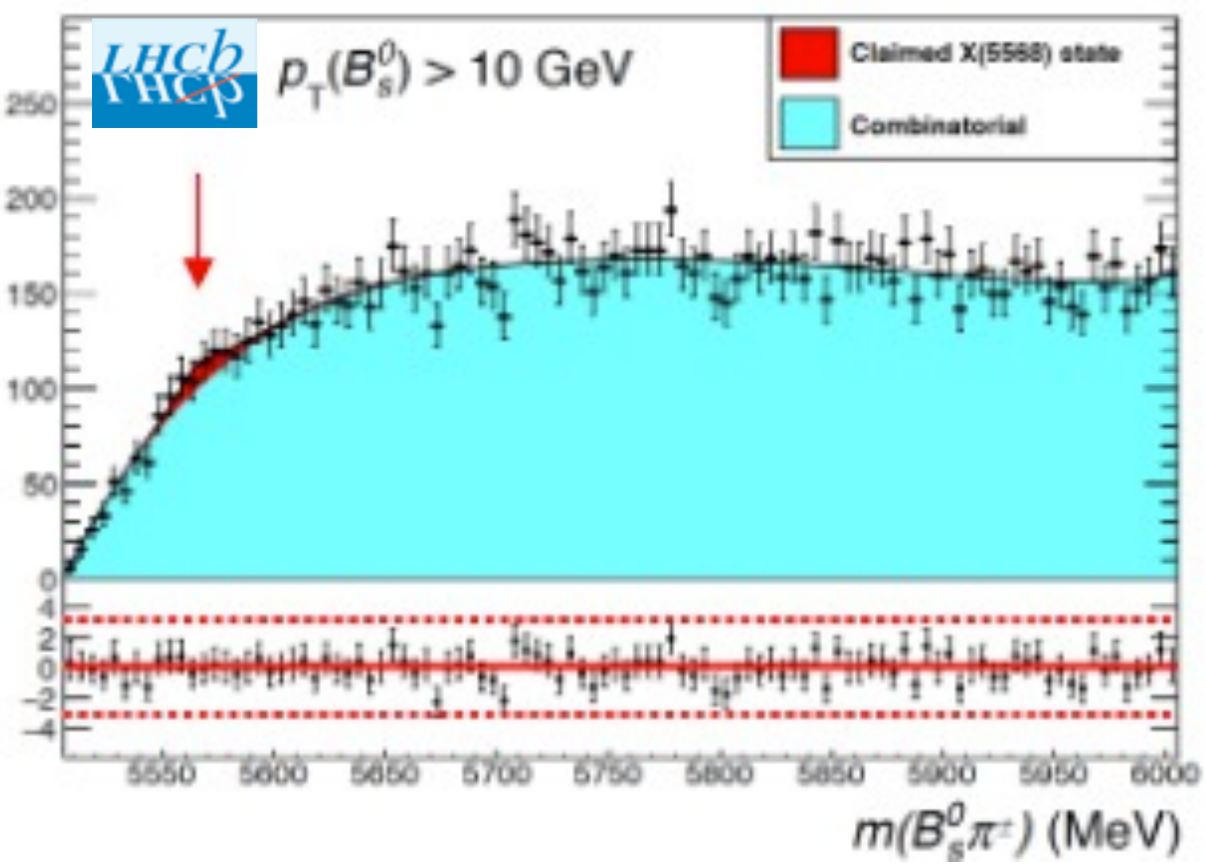


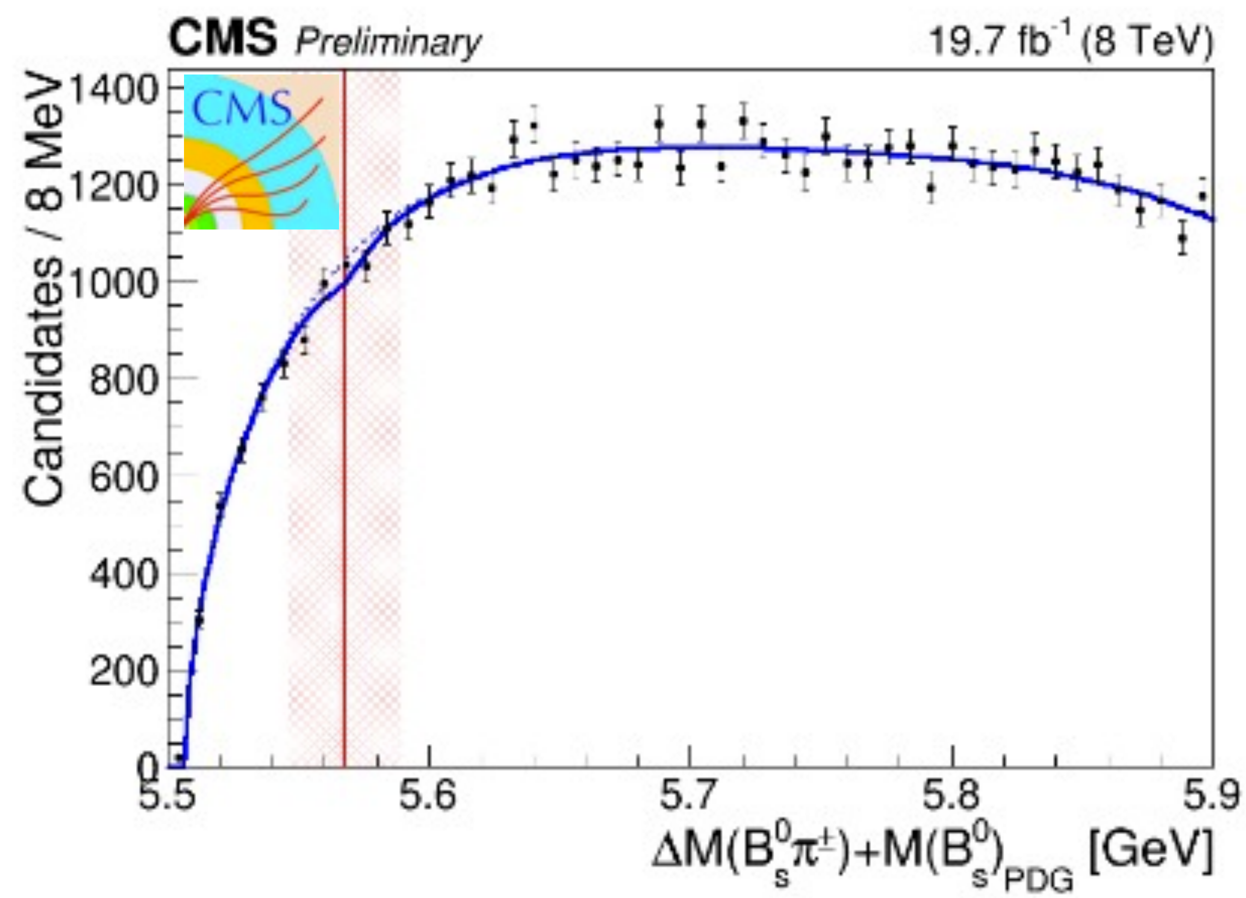
$M_X = 5567.8 \pm 2.9$ MeV

$\Gamma_X = 21.9 \pm 6.4$ MeV

$N = 133 \pm 31$

Signif. (with syst and LEE) $S = 5.1\sigma$

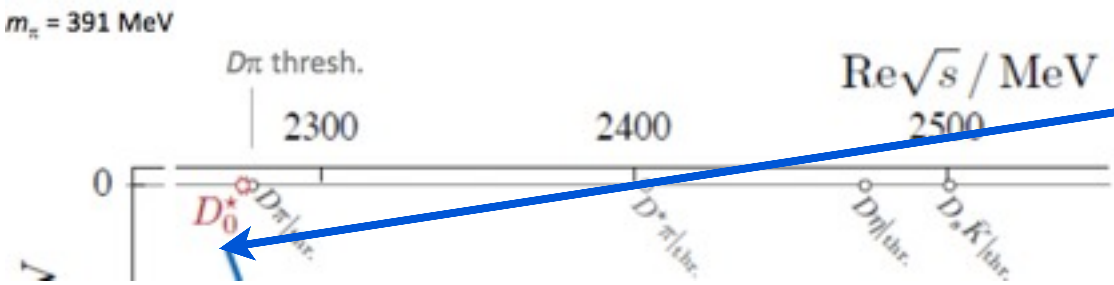


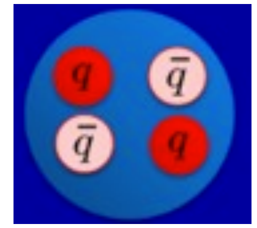


Excited heavy mesons from lattice QCD

ChristopherThomas

Dπ, Dη, $D_s\bar{K}$ (I=½): poles of *t*-matrix



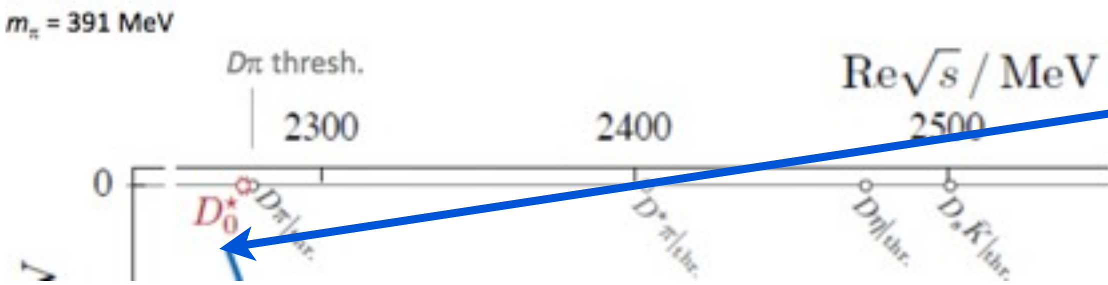


0^+ **bound state** just below thresh.
m = (2275.9 ± 0.9) MeV
c.f. Dπ thr. = (2276.4 ± 0.9) MeV

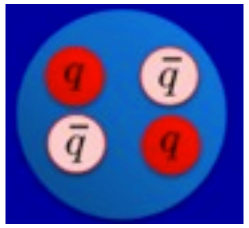
c.f. D_0^*(2400)

Excited heavy mesons from lattice QCD

ChristopherThomas



$D\pi$, $D\eta$, $D_s\bar{K}$ (I=½): poles of *t*-matrix



0^+ bound state just below thresh.
m = (2275.9 ± 0.9) MeV
c.f. $D\pi$ thr. = (2276.4 ± 0.9) MeV
c.f. $D_0^*(2400)$

Resonances in Coupled-Channel Scattering from Lattice QCD

David Wilson

ρ resonance : $\pi\pi$

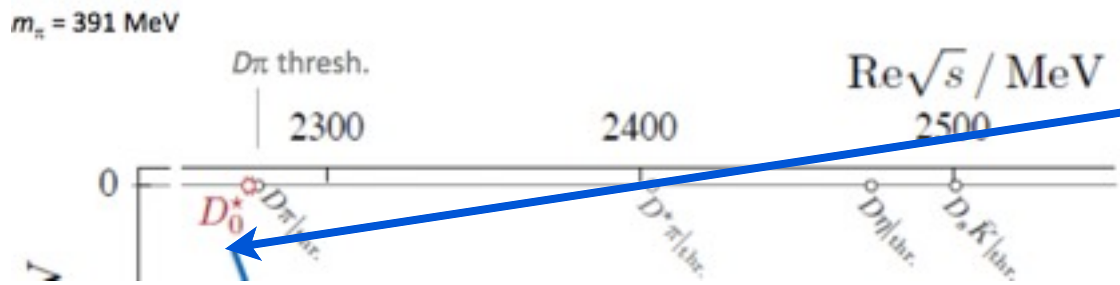
a_0 resonance $\pi\eta$-$K\bar{K}$

$f_0(500)/\sigma$ **resonance** $\pi\pi$

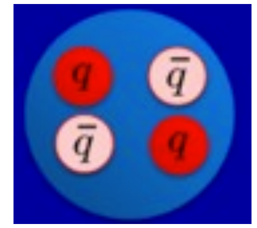
also did a coupled channel analysis looking for poles of t-matrix

Excited heavy mesons from lattice QCD

ChristopherThomas



$D\pi$, $D\eta$, $D_s\bar{K}$ (I=½): poles of *t*-matrix



0^+ bound state just below thresh.
m = (2275.9 ± 0.9) MeV
c.f. $D\pi$ thr. = (2276.4 ± 0.9) MeV
c.f. D_0^*(2400)

Resonances in Coupled-Channel Scattering from Lattice QCD

David Wilson

also did a coupled channel analysis looking for poles of t-matrix

ρ resonance : $\pi\pi$

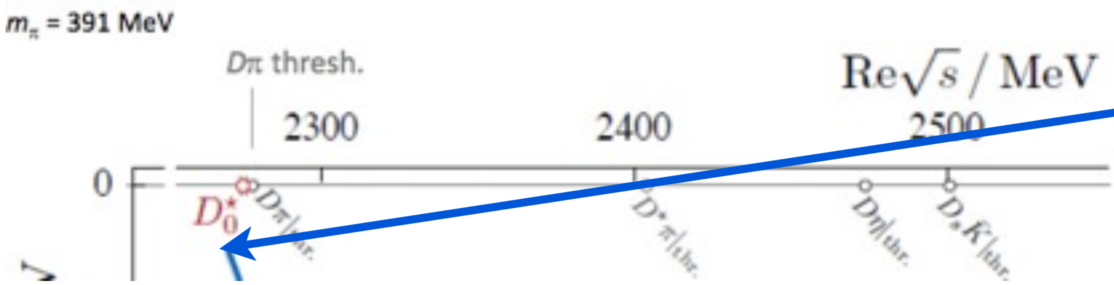
a_0 resonance $\pi\eta$-$K\bar{K}$

$f_0(500)/\sigma$ **resonance** $\pi\pi$

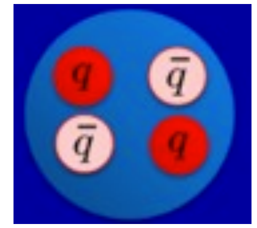
} scalars as 4-quark states

Excited heavy mesons from lattice QCD

ChristopherThomas



Dπ, Dη, $D_s\bar{K}$ (I=½): poles of *t*-matrix



0^+ bound state just below thresh.
m = (2275.9 ± 0.9) MeV
c.f. Dπ thr. = (2276.4 ± 0.9) MeV

c.f. $D_0^*(2400)$

Resonances in Coupled-Channel Scattering from Lattice QCD

David Wilson

ρ resonance $\pi\pi$

a_0 resonance $\pi\eta$-$K\bar{K}$

$f_0(500)/\sigma$ **resonance** $\pi\pi$

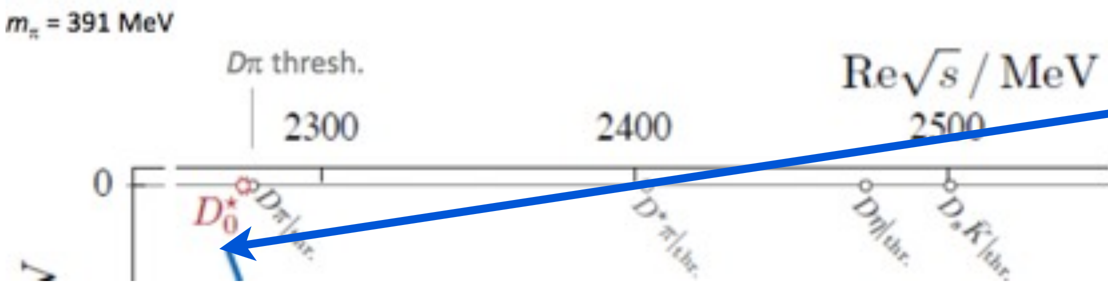
also did a coupled channel analysis looking for poles of t-matrix

not a q-qbar state? It has a q-qbar component, but also a ππ component

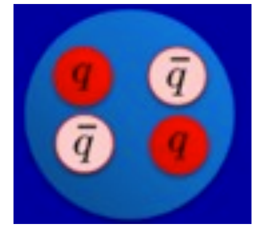
} scalars as 4-quark states

Excited heavy mesons from lattice QCD

ChristopherThomas



Dπ, Dη, $D_s\bar{K}$ (I=½): poles of *t*-matrix



0^+ bound state just below thresh.
m = (2275.9 ± 0.9) MeV
c.f. Dπ thr. = (2276.4 ± 0.9) MeV

c.f. D_0^*(2400)

Resonances in Coupled-Channel Scattering from Lattice QCD

David Wilson

ρ resonance $\pi\pi$
a_0 resonance $\pi\eta$-$K\bar{K}$
$f_0(500)/\sigma$ **resonance** $\pi\pi$

also did a coupled channel analysis looking for poles of t-matrix

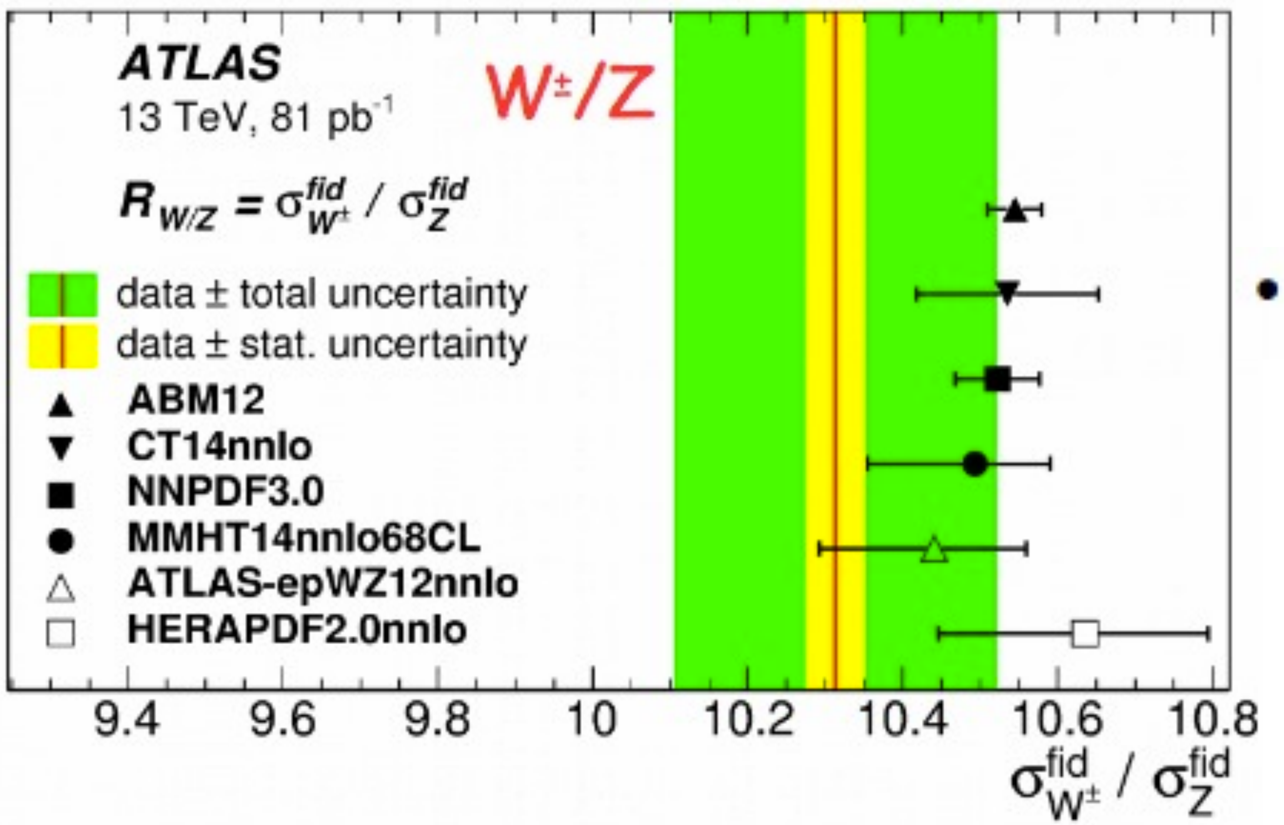
not a q-qbar state? It has a q-qbar component, but also a ππ component

} scalars as 4-quark states

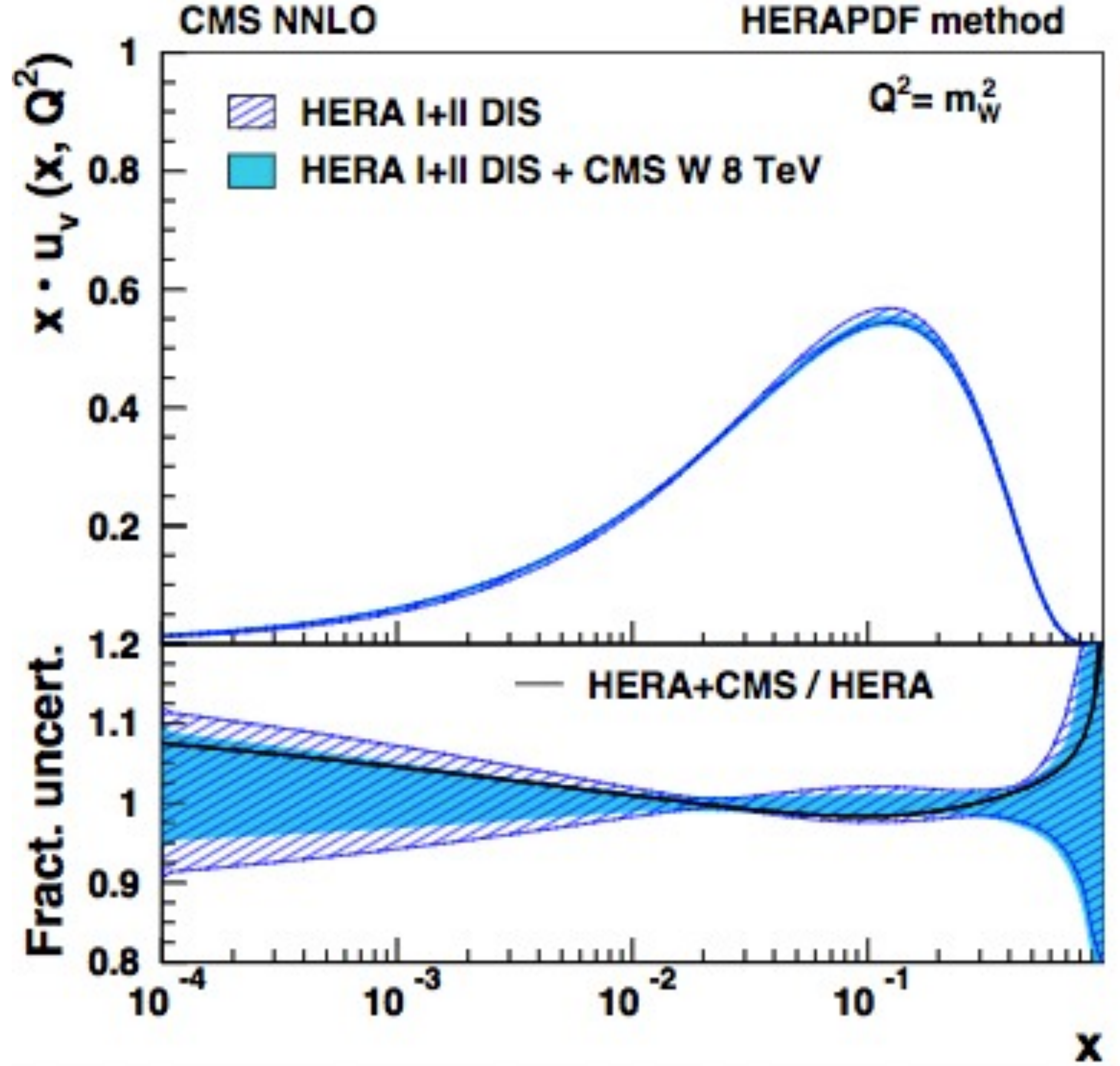
in LQCD all non stable (in QCD) states will mix!
Real question: how big are the components?

Hadronic Structure

PDF, vector boson production,
Z + jets



- Cross sections will constrain PDFs!



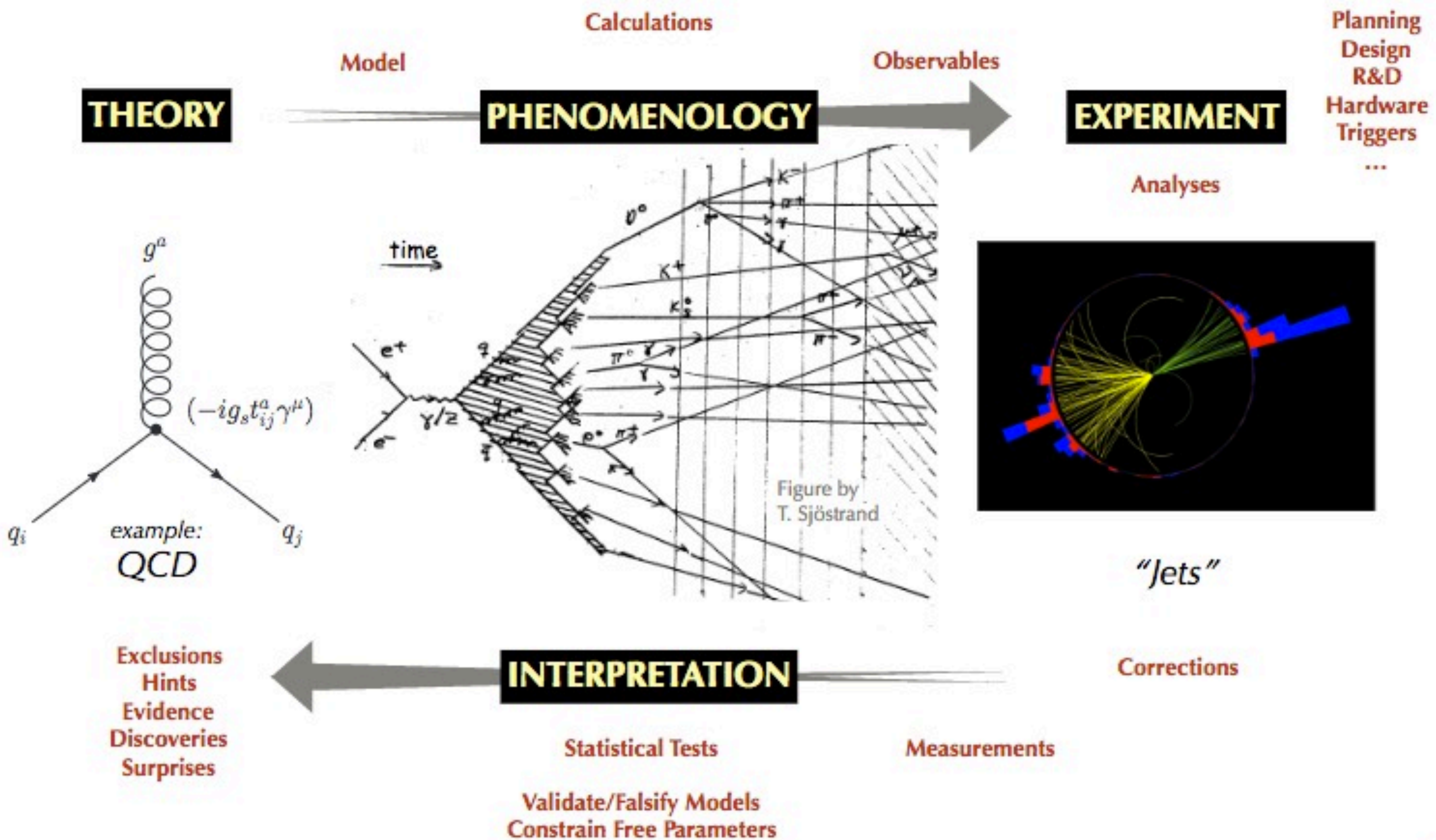
- W and Z production at LHC proceeds at the hard scattering level and first order via collisions of a valence quark (u,d) and a sea anti-quark ($Q \approx 100$ GeV):

$$u + \bar{d}(\bar{s}) \rightarrow W^{+} \qquad u + \bar{u} \rightarrow Z$$

$$d + \bar{u}(\bar{c}) \rightarrow W^{-} \qquad d + \bar{d} \rightarrow Z$$

– CMS results provide constraints in PDFs

from N. Neumeister talk

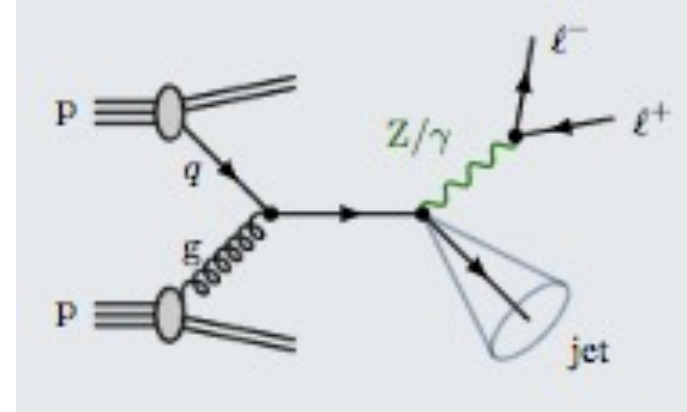


from Peter Skands talk

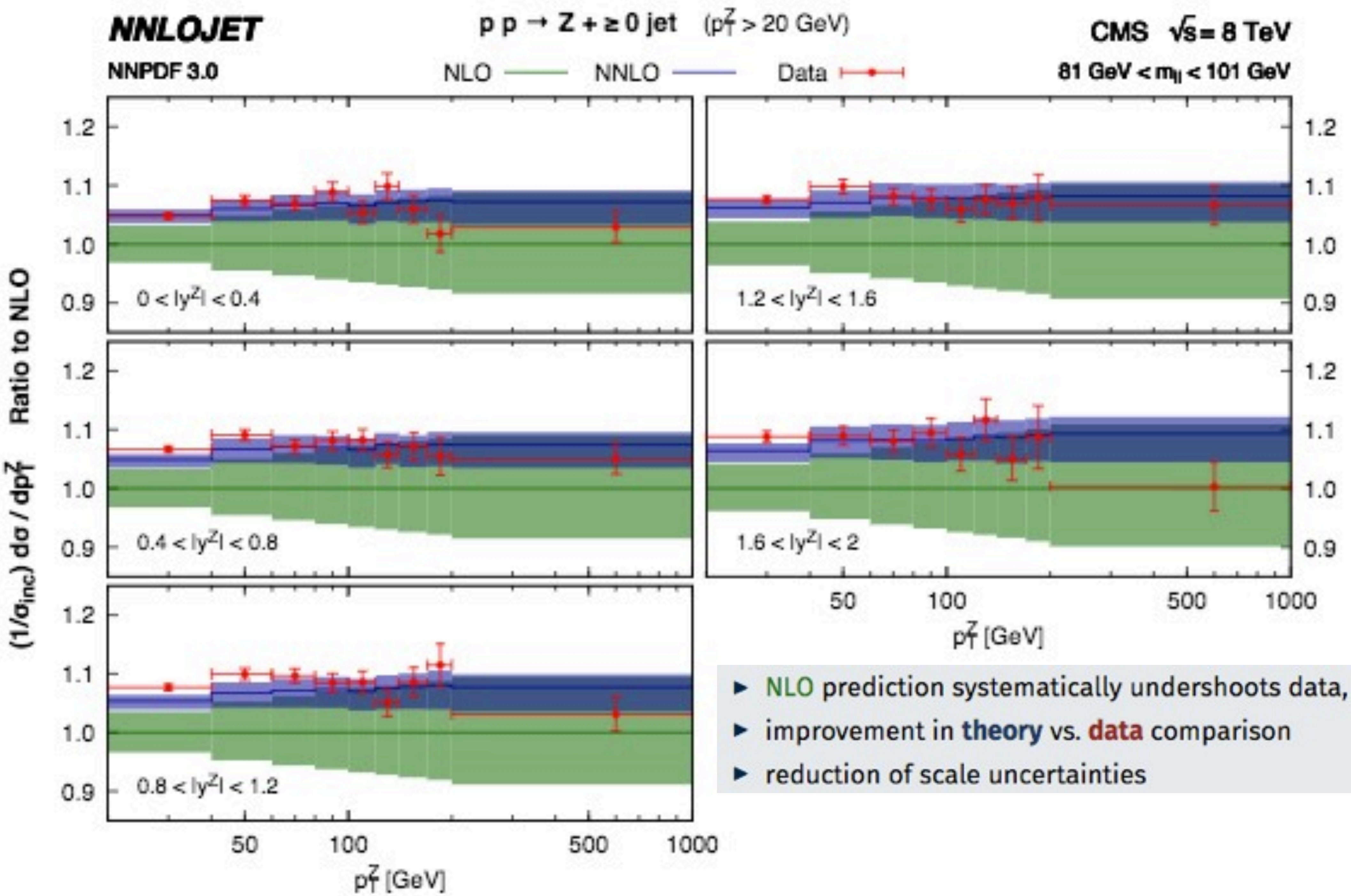
$Z + \text{jet}$ production at NNLO

Alexander Huss

▸ NNLO QCD ....
↪ Antenna subtraction .



Double-differential: $d\sigma/dp_T^Z$ binned in y^Z — CMS

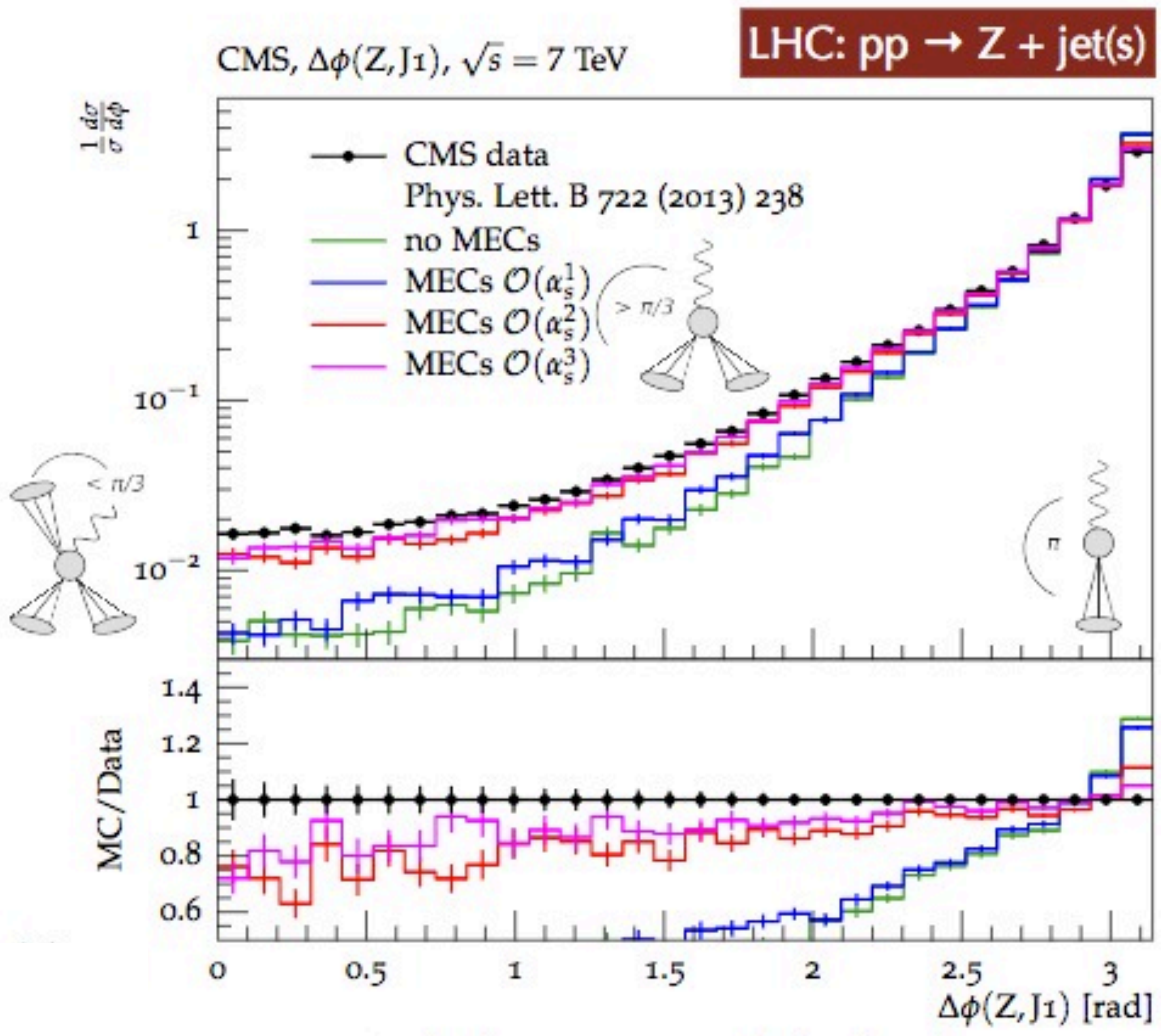


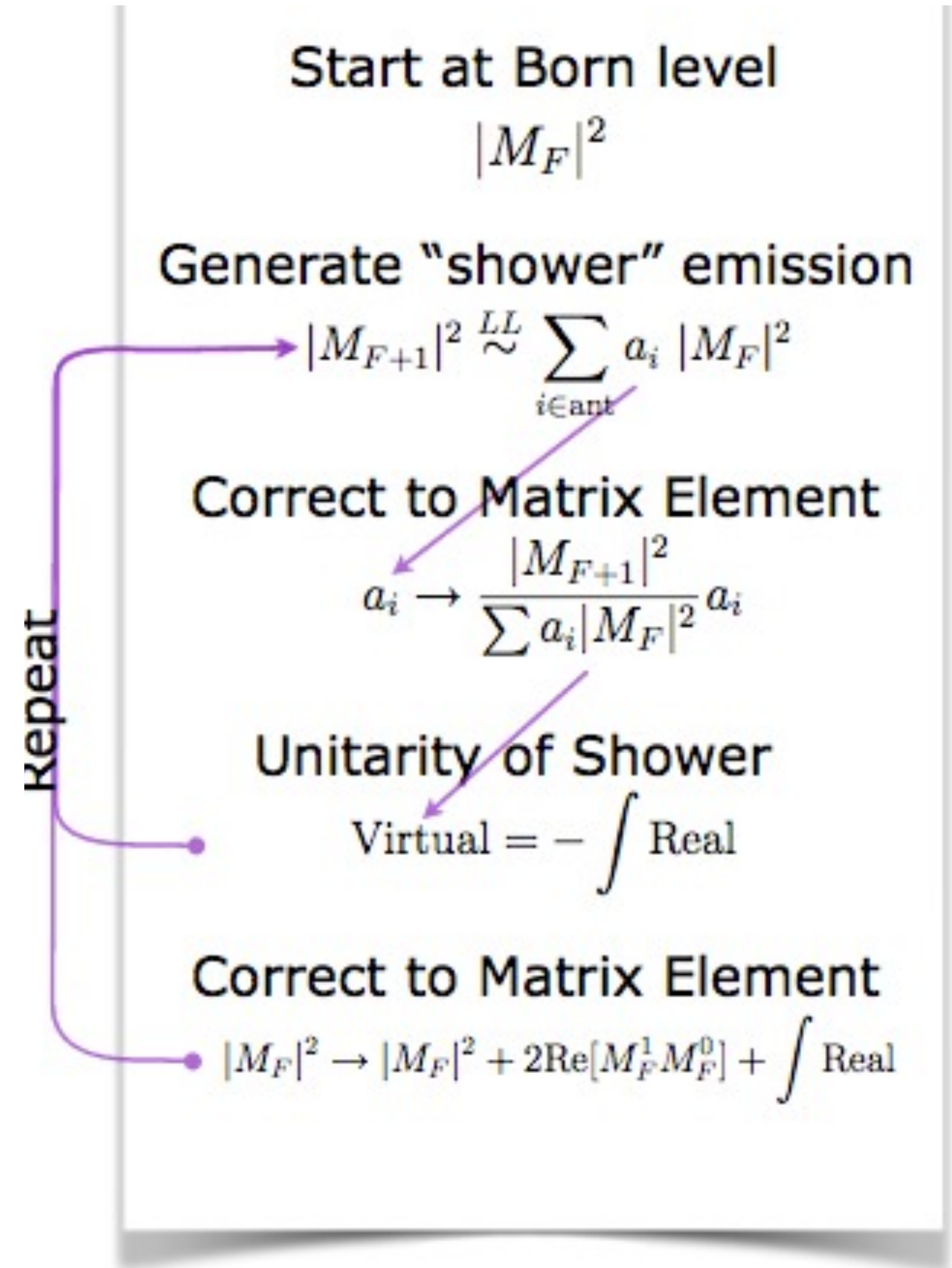
- NLO prediction systematically undershoots data, NNLO corrections $\sim$ 5–10%
- improvement in **theory** vs. **data** comparison
- reduction of scale uncertainties

VINCIA for Hadron Colliders

Peter Skands

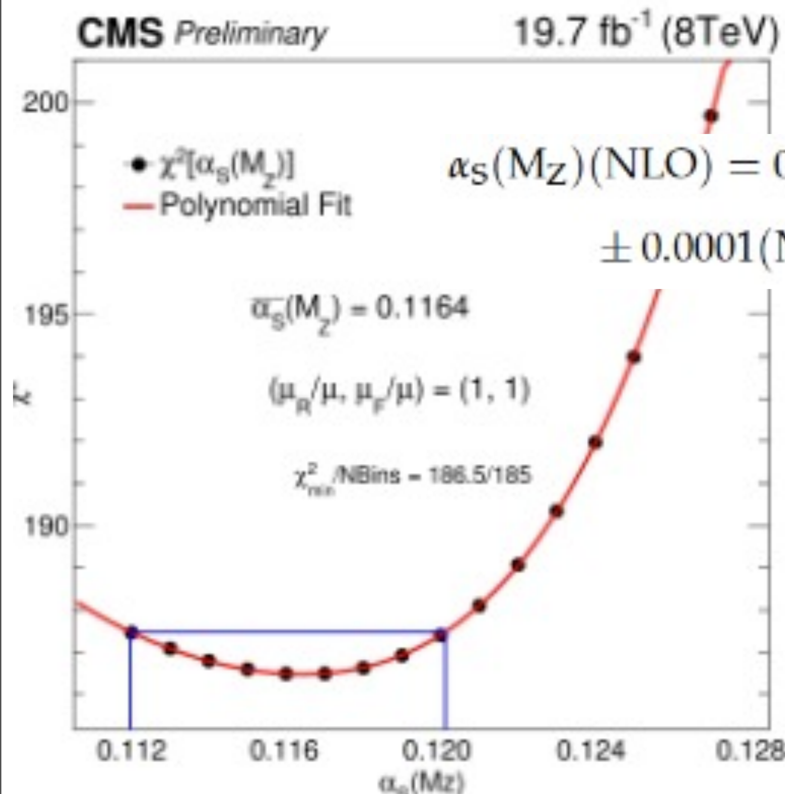
QCD showers based on 2 → 3 antenna patterns



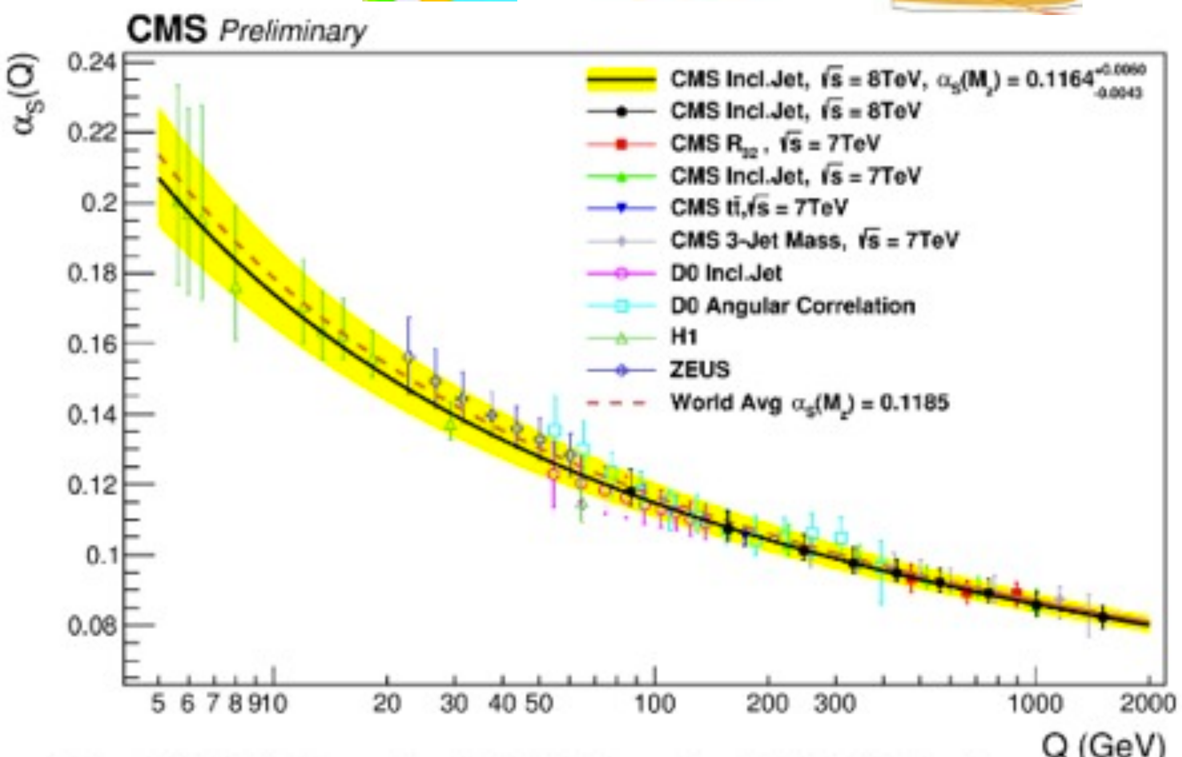


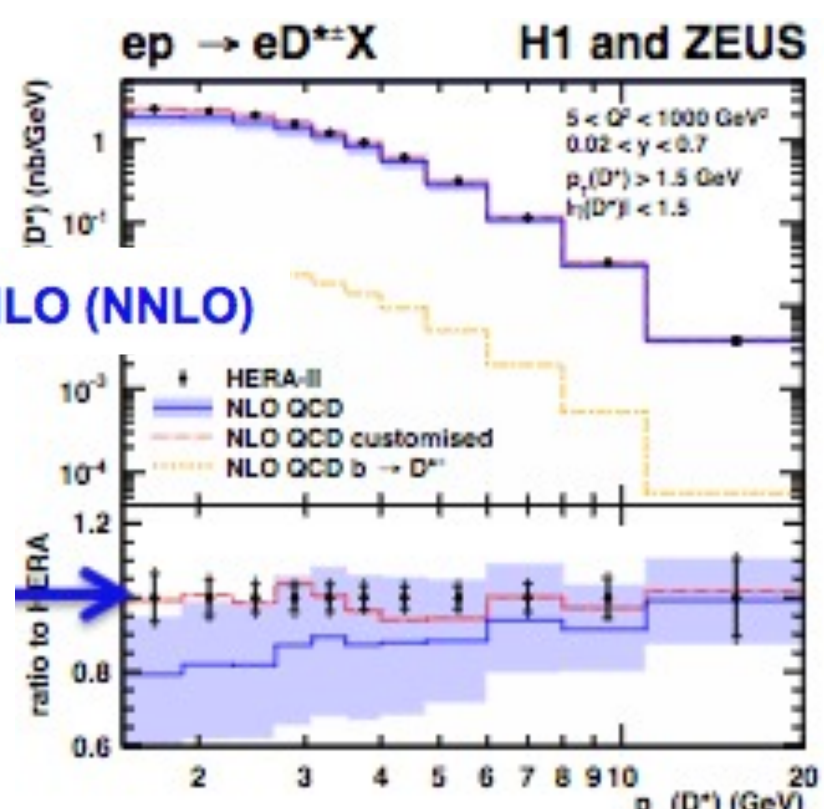
QCD parameters

α_S, m_Q

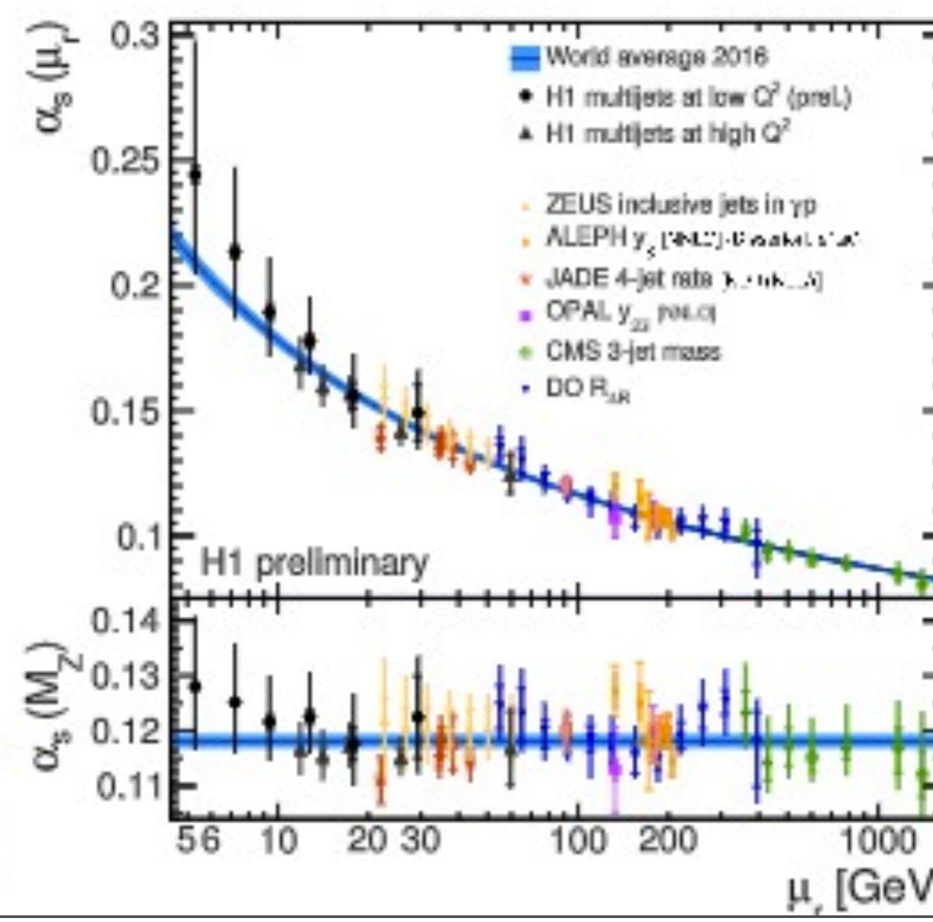


$$\alpha_S(M_Z)(\text{NLO}) = 0.1164^{+0.0025}_{-0.0029}(\text{PDF})^{+0.0053}_{-0.0028}(\text{Scale})$$
$$\pm 0.0001(\text{NP})^{+0.0014}_{-0.0015}(\text{Exp}) = 0.1164^{+0.0060}_{-0.0043}$$





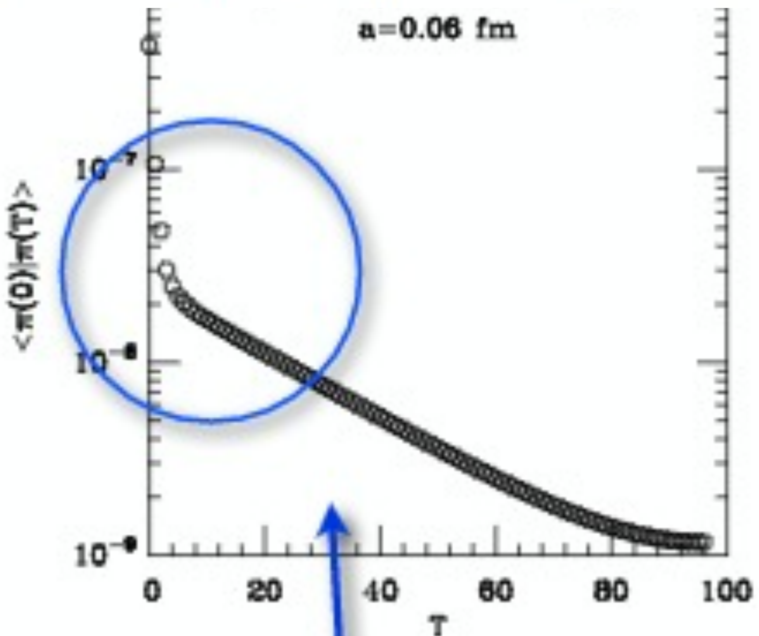
M_c = 1.47 (1.43) GeV at NLO (NNLO)



m_c, m_b, and α_s Lattice status and prospects

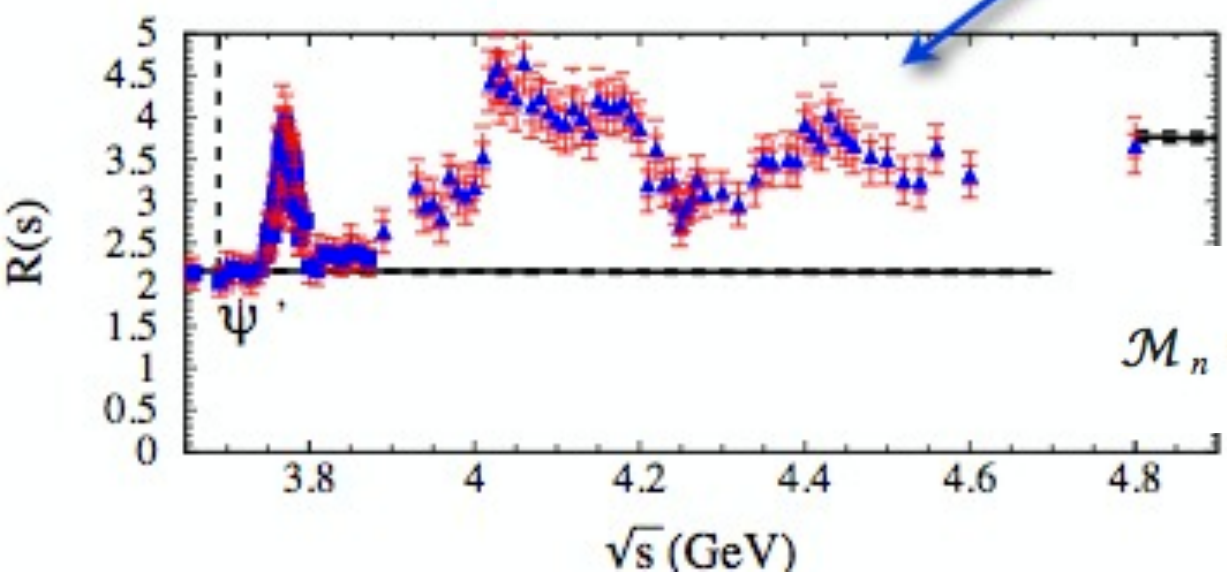
Paul Mackenzie

$$\langle \bar{\psi}\gamma_5\psi(t=0) \mid \bar{\psi}\gamma_5\psi(t) \rangle = C\exp(-Mt) + \text{excited states.}$$

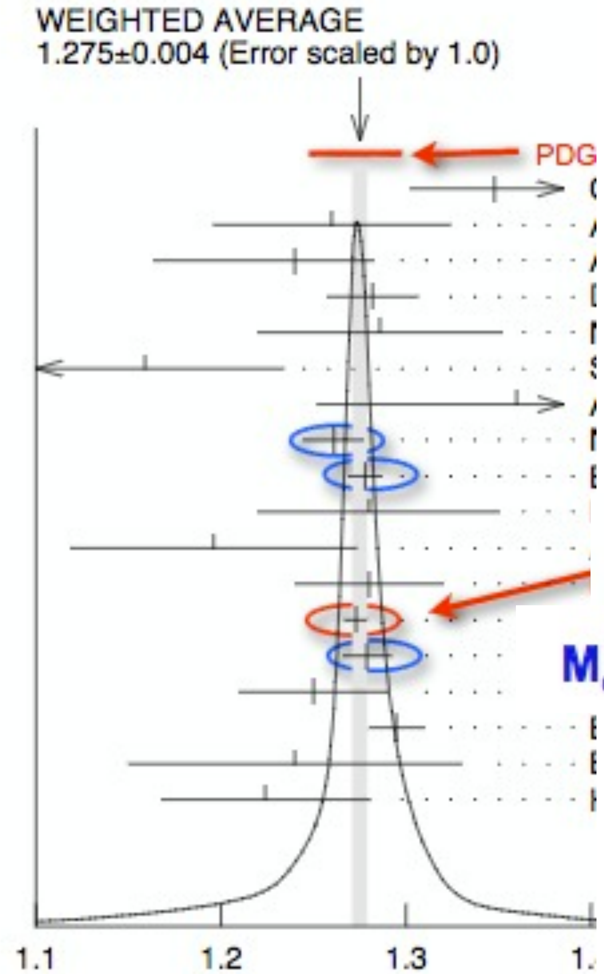


Because this is cleaner data than this.

$e+e- \rightarrow m_c$

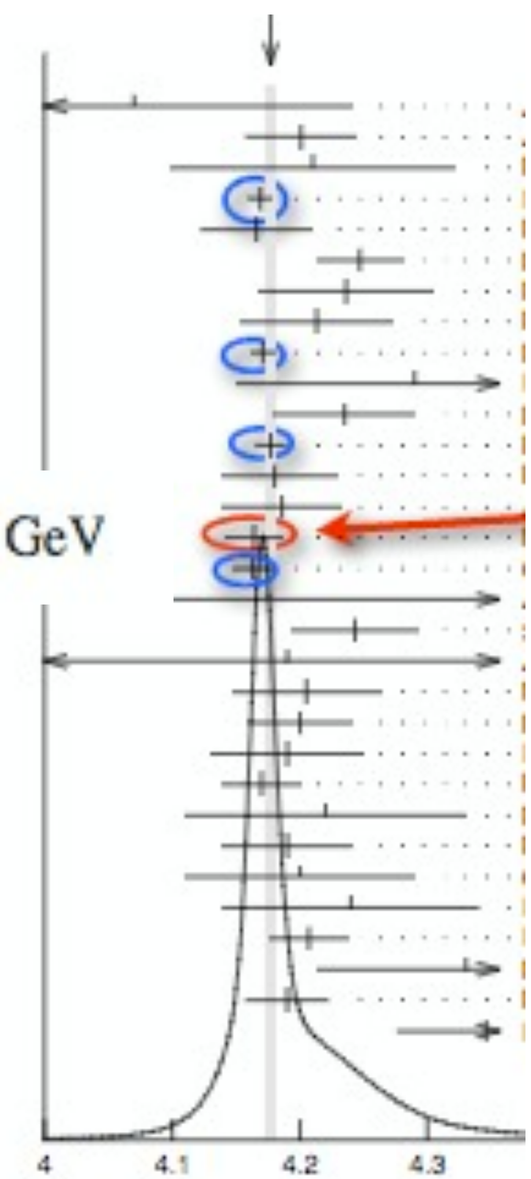


$$\mathcal{M}_n \equiv \int \frac{ds}{s^{n+1}} R_Q(s)$$

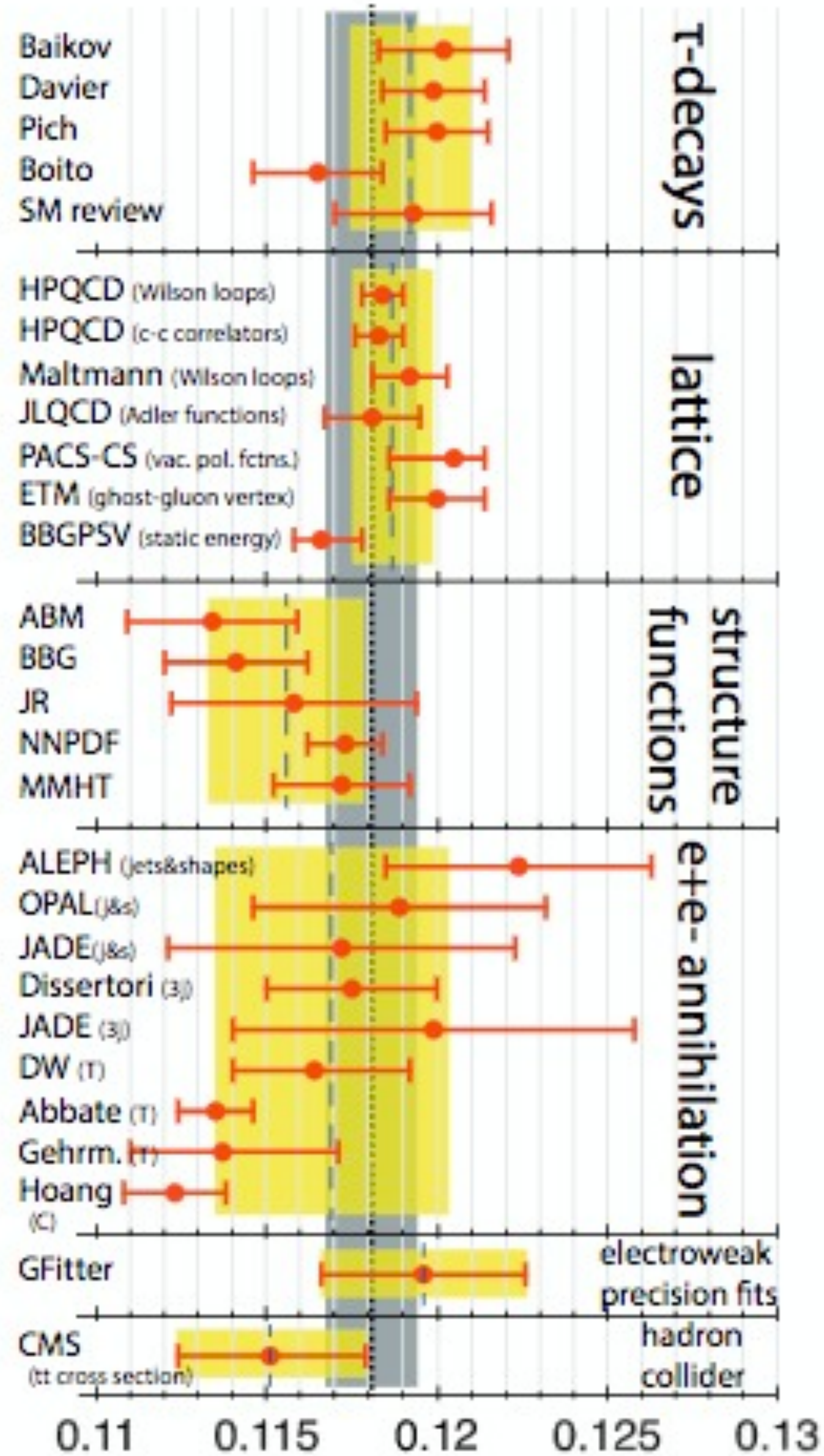


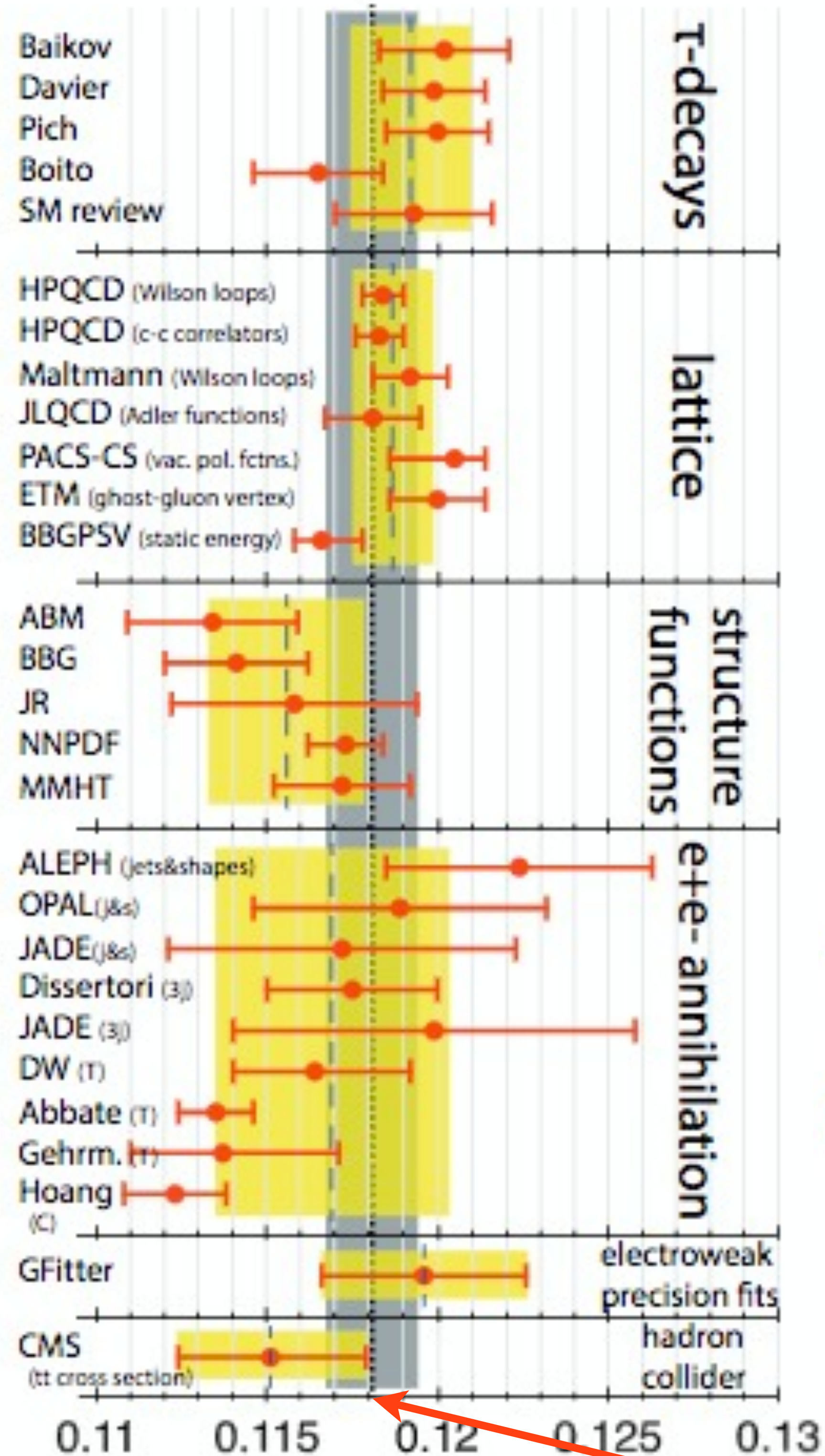
$$m_c(m_c, n_f = 4) = 1.273(6)\ \text{GeV}$$

M_c = 1.47 (1.43) GeV at NLO (NNLO)



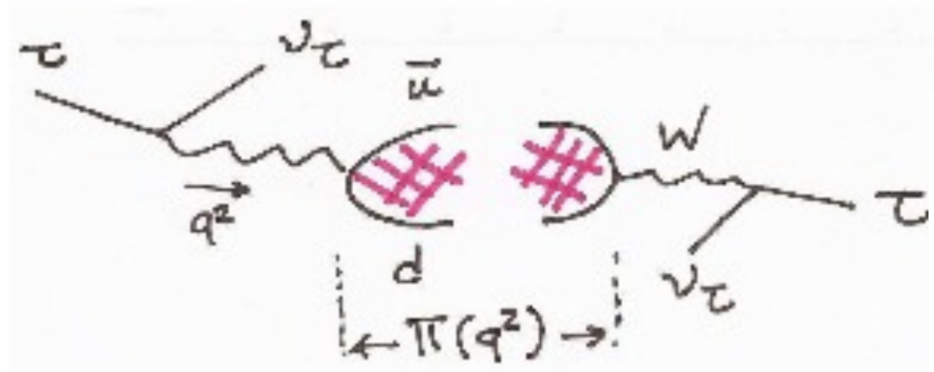
$$m_b(m_b, n_f = 5) = 4.164(23)\ \text{GeV}$$

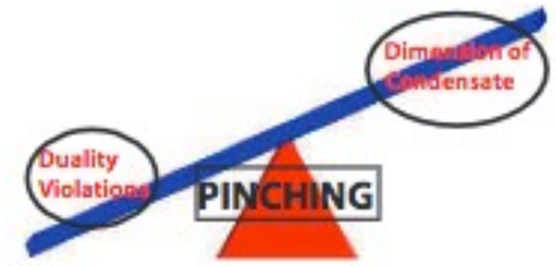

Baikov
Davier
Pich
Boito
SM review
τ-decays
HPQCD (Wilson loops)
HPQCD (c-c correlators)
Maltmann (Wilson loops)
JLQCD (Adler functions)
PACS-CS (vac. pol. fctns.)
ETM (ghost-gluon vertex)
BBGPSV (static energy)
lattice
ABM
BBG
JR
NNPDF
MMHT
structure functions
ALEPH (jets&shapes)
OPAL(j&s)
JADE(j&s)
Dissertori (3j)
JADE (3j)
DW (T)
Abbate (T)
Gehrm. (T)
Hoang (C)
e+e- annihilation
GFitter
electroweak precision fits
CMS (tt cross section)
hadron collider
0.11
0.115
0.12
0.125
0.13



α_s *from the (revised) Aleph data for* τ *decay*

Santiago Peris





- Pinching does not allow a simultaneous reduction of DVs **and** higher-dim condensates

- We have introduced a new strategy based on an educated guess for DVs which allows the data to determine both the contribution from DVs and condensates.

- Using **Aleph + Opal** data, we get:

$$\alpha_s(m_Z) = 0.1165 \pm 0.0012 \text{ (FOPT)}$$

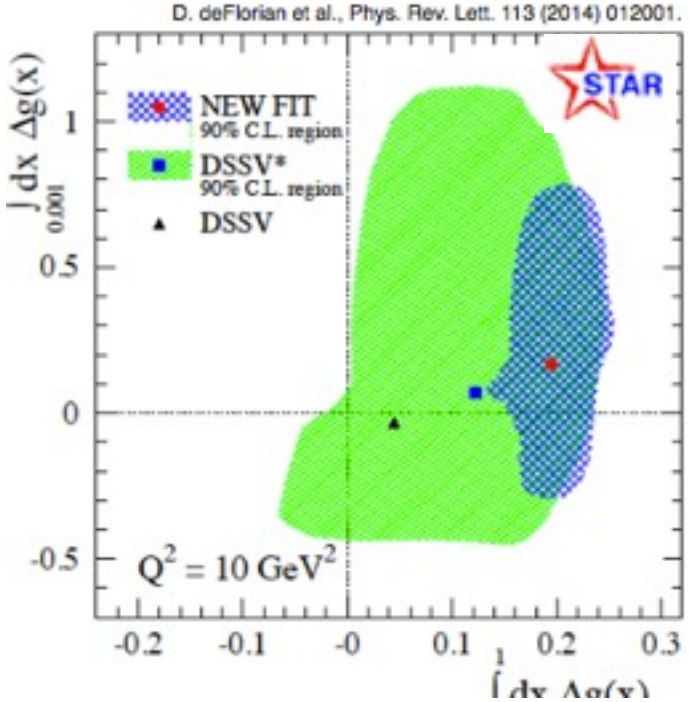
$$\alpha_s(m_Z) = 0.1188 \pm 0.0015 \text{ (CIPT)}$$

(Current PDG world average: $\alpha_s(m_Z) = 0.1181 \pm 0.0013$)

Hadronic Structure

spin of the nucleon,
strangeness in nucleon

D. deFlorian et al., Phys. Rev. Lett. 113 (2014) 012001.



from B. Surrow talk

o DSSV - NEW FIT: Strong impact on $\Delta g(x)$ with RHIC

run 9 results: $0.20^{+0.06}_{-0.07}$ 90% C.L. for $0.05 < x$

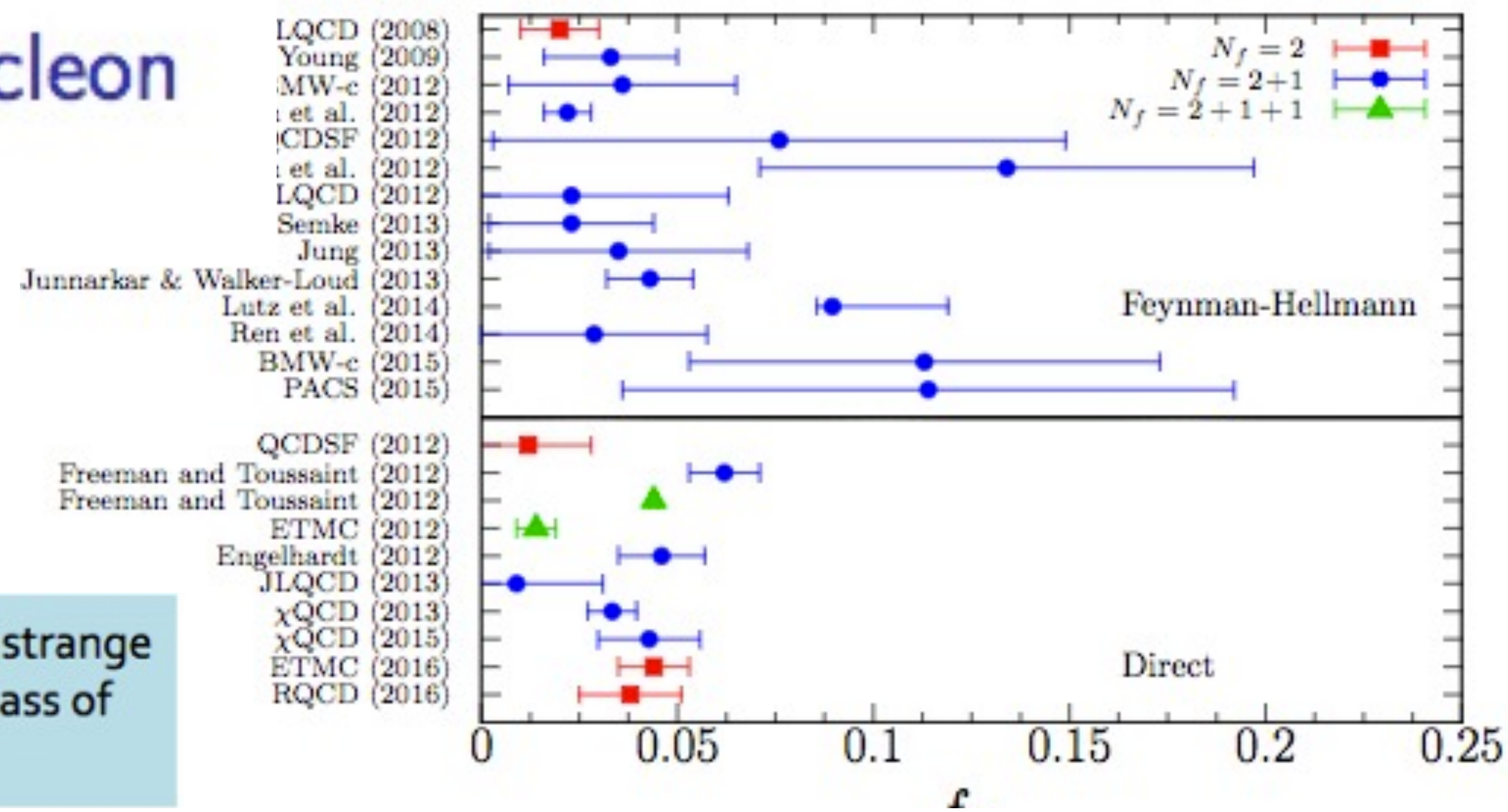
contributes to the spin of the nucleon

Strange Quarks in the Nucleon from Lattice QCD

Phiala Shanahan

$$\mathcal{M} \sim \sum_q C_q \langle N | m_q \bar{q} q | N \rangle = \sum_q C_q \sigma_q$$

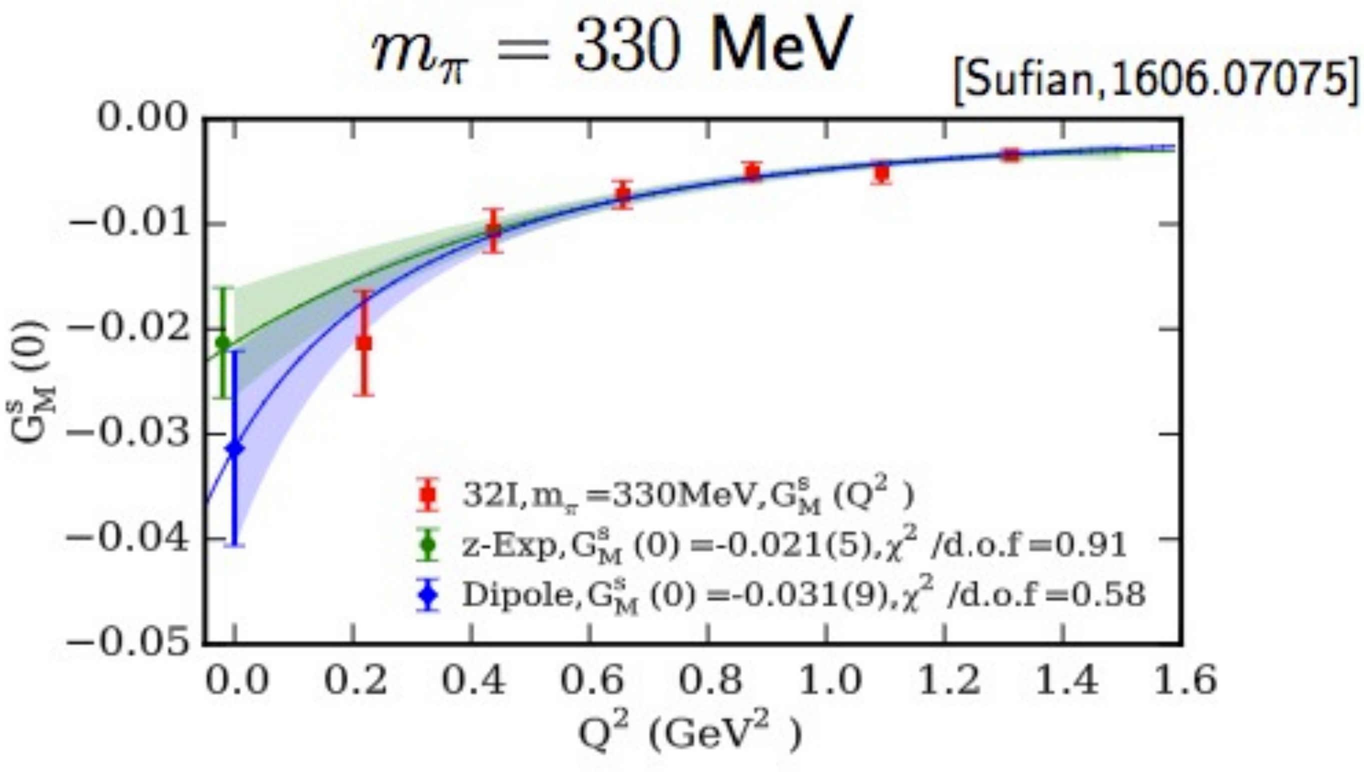
Strange sigma term σ_s ⟷ Contribution of strange quarks to the mass of the proton

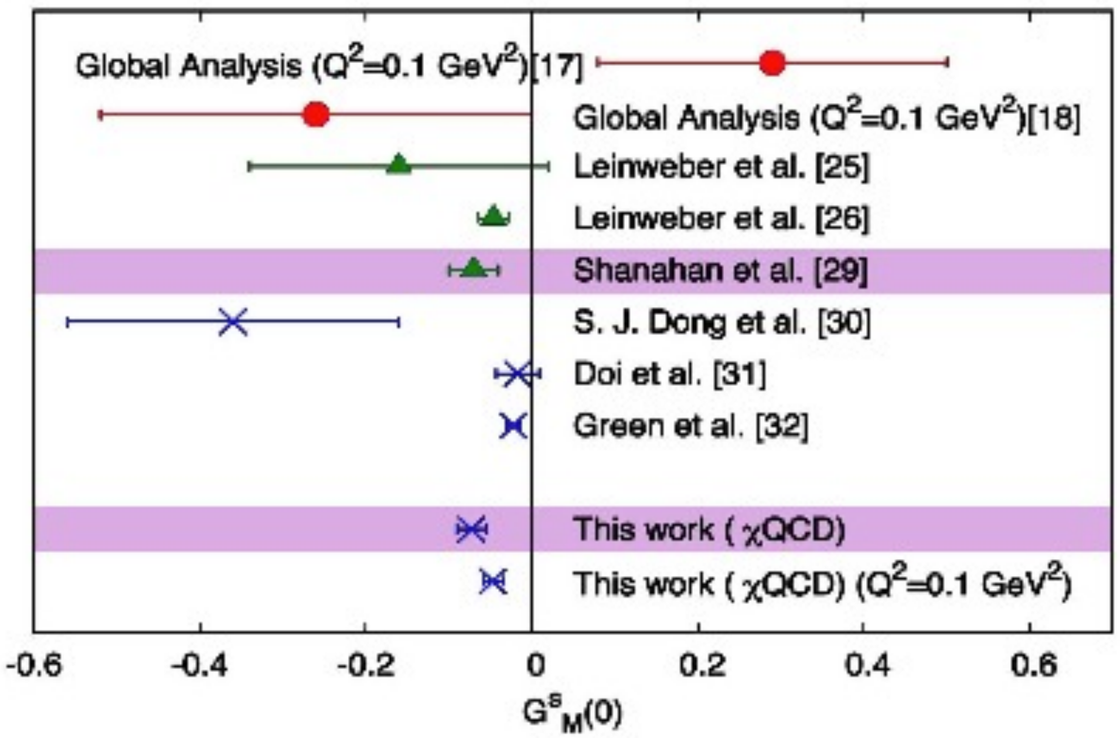


Precise, small values of $f_{T_s} = \sigma_s / M_N$: $\approx 2\%$ nucleon mass from s quarks

quarta-feira, 10 de agosto de 16

Strange form factors on the lattice:





Consistent picture: strange quarks contribute

- $\sim$ 1-5% to the mass of the nucleon
  Direct calculations strange sigma term are consistent and precise
  $\rightarrow$ new level of precision for DM searches

Strange sigma term
$\sigma_s = 10$ - 50 MeV

- $\sim$ 1% to the nucleon magnetic moment
  $\rightarrow$ new benchmark for experiment

Strange magnetic moment
$G^s_M(Q^2 = 0) = -0.07 \pm 0.03\mu_N$

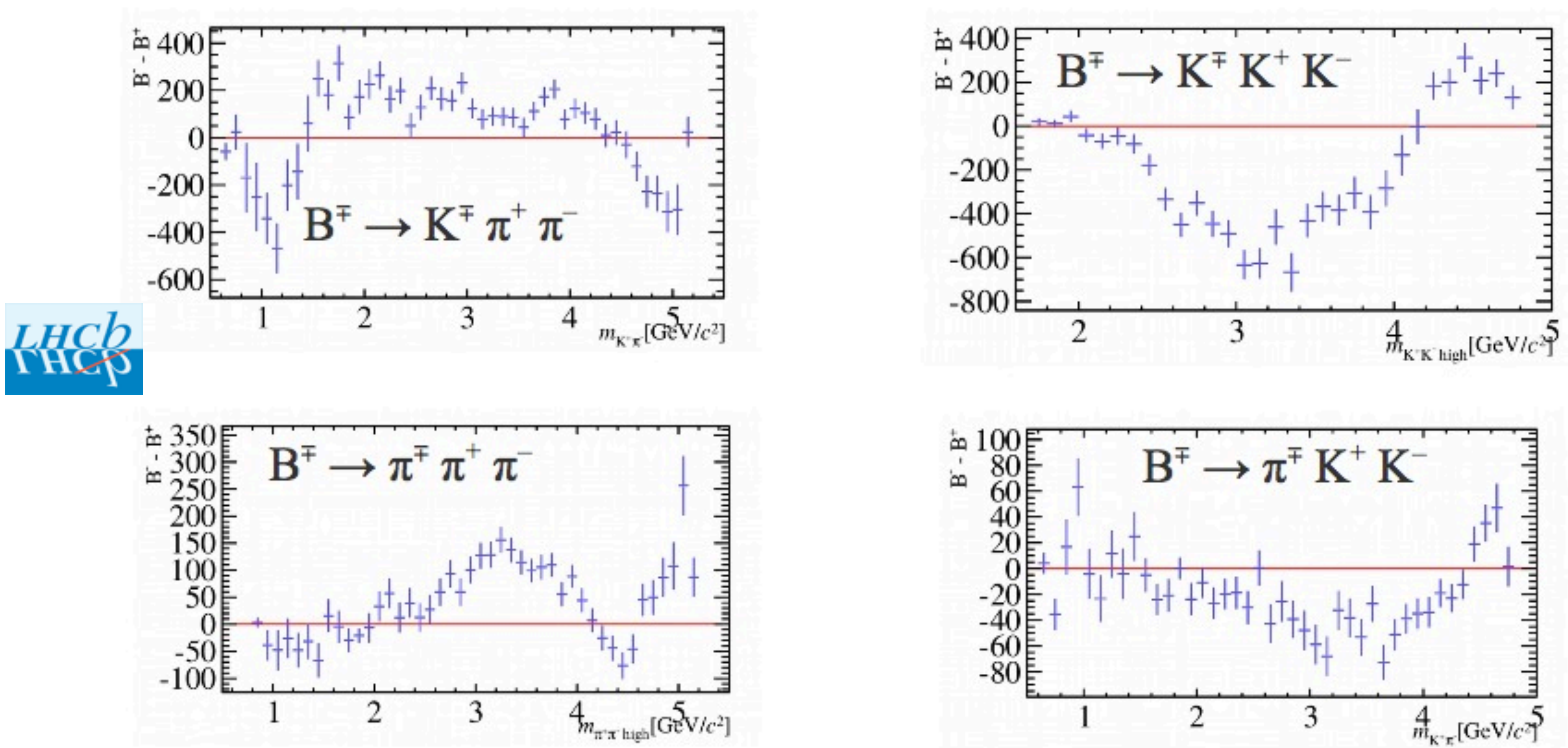
QCD parameters

CP violation

CP violation in the three-body $B^{\pm}$ phase-space

Jorge A. Nogueira

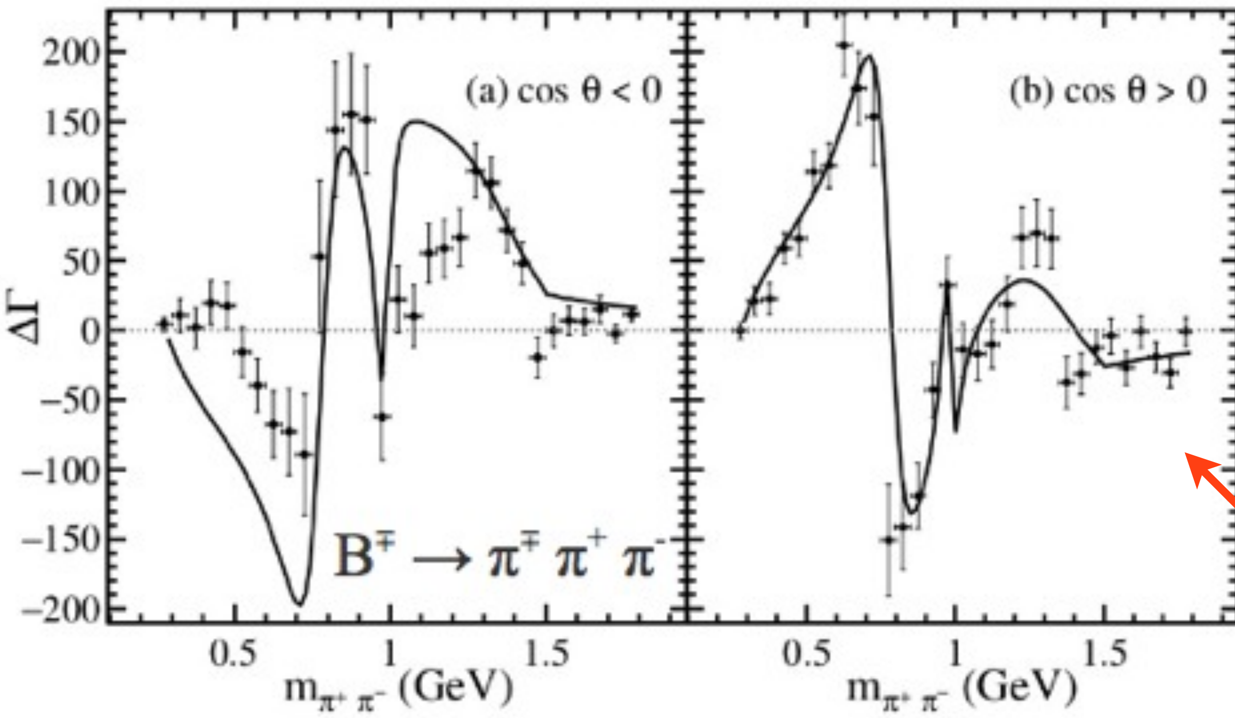
The decay channels $B^{\mp} \rightarrow \pi^{\mp} \pi^{+} \pi^{-}$ and $B^{\mp} \rightarrow \pi^{\mp} K^{+} K^{-}$ (also $B^{\mp} \rightarrow K^{\mp} \pi^{+} \pi^{-}$ and $B^{\mp} \rightarrow K^{\mp} K^{+} K^{-}$) presents asymmetries that seems to be related by the CPT constraint;



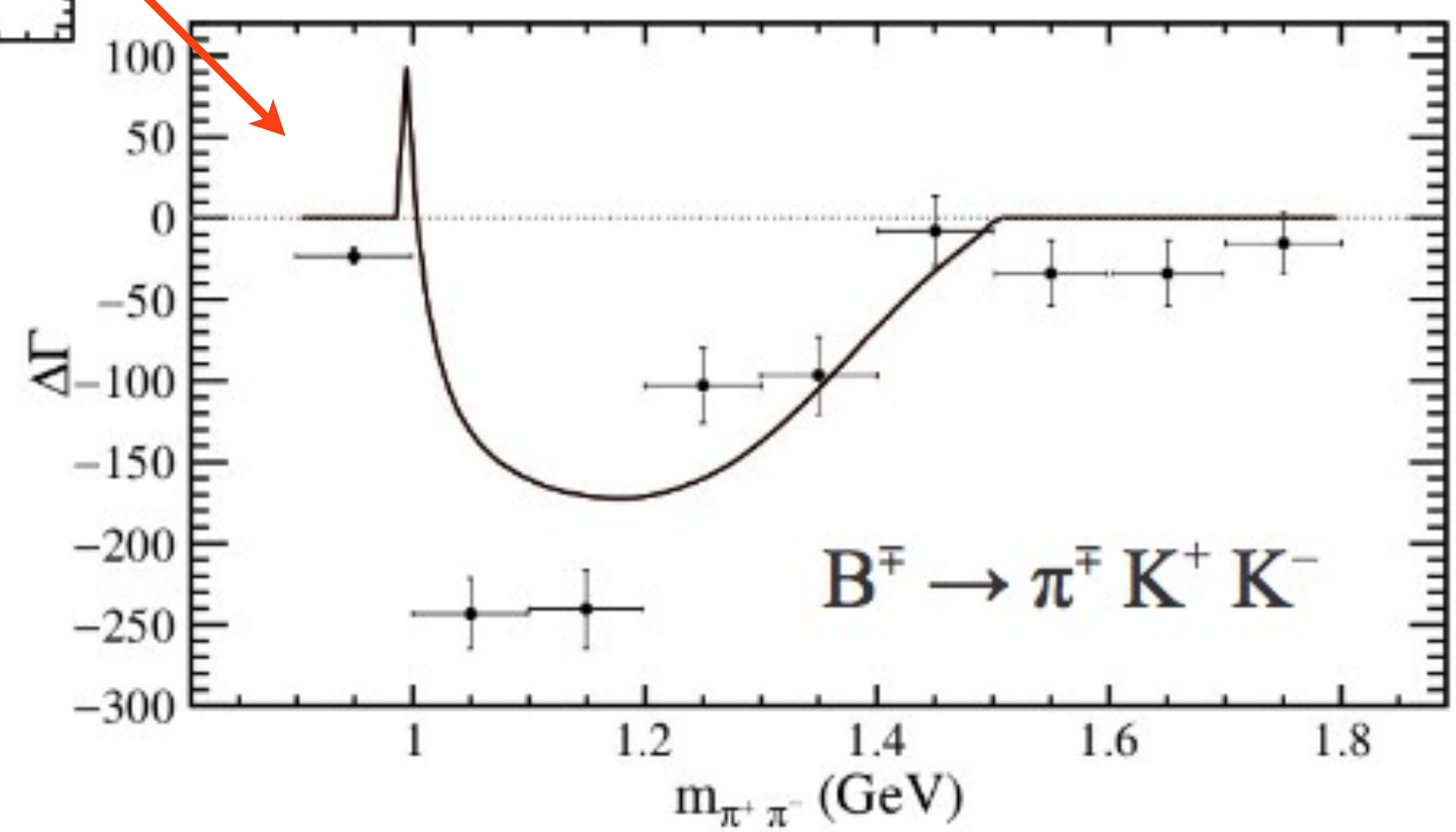
Soft final state interactions

Soft FSI should have an important effect for CPT ; Important strong phase effect in B decays;
Depends on how probable the state is as a final state;
Hadronic FSI replace the absorptive part of the penguin graph;

Fitting the data



Resonant interferences (ρ(770) and f_0(980) resonances)
+ hadronic inelastic rescattering



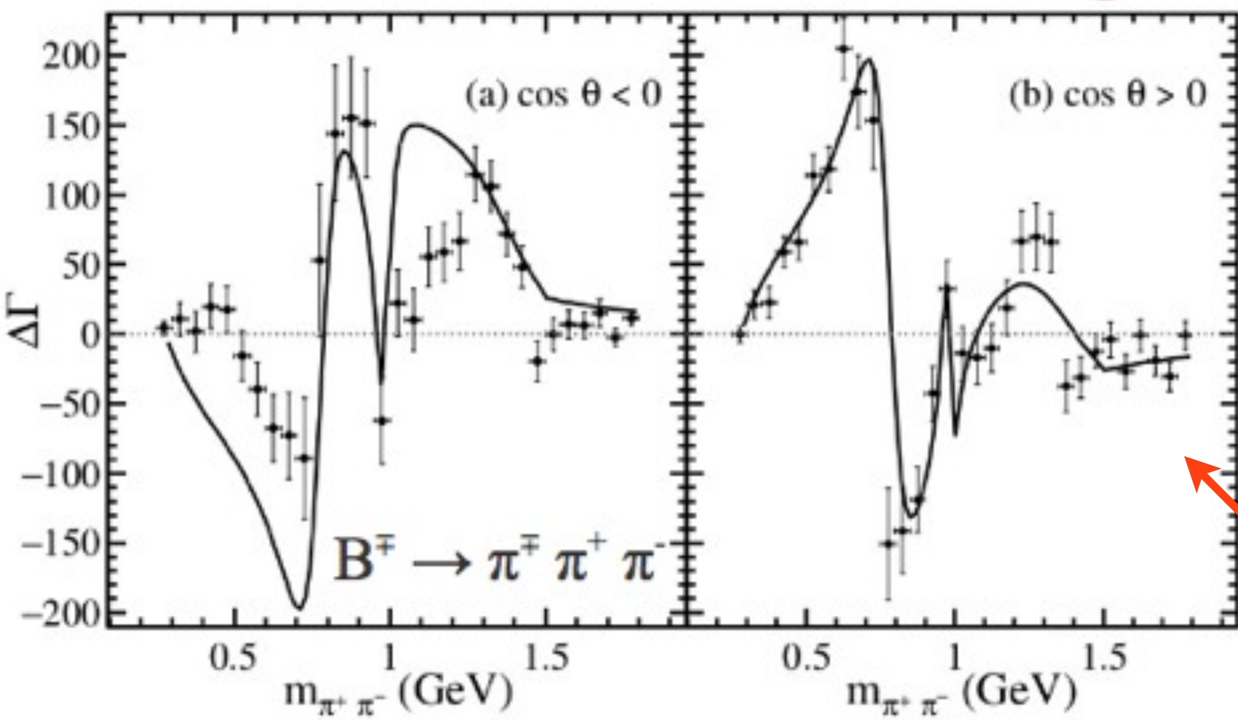
Soft final state interactions

Soft FSI should have an important effect for CPT ; Important strong phase effect in B decays;

Depends on how probable the state is as a final state;

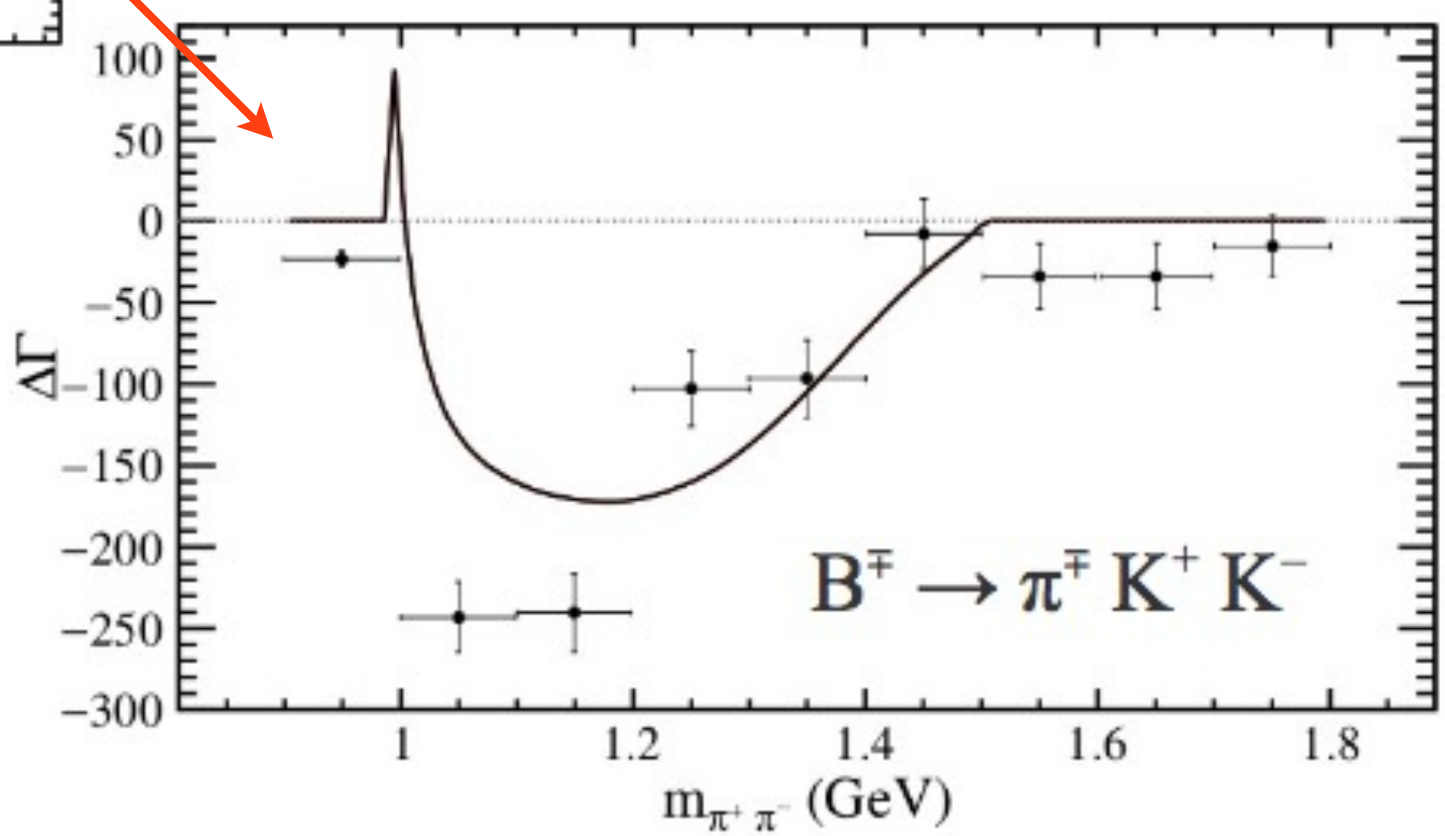
Hadronic FSI replace the absorptive part of the penguin graph;

Fitting the data



Resonant interferences ($\rho(770)$ and $f_0(980)$ resonances)

+ hadronic inelastic rescattering



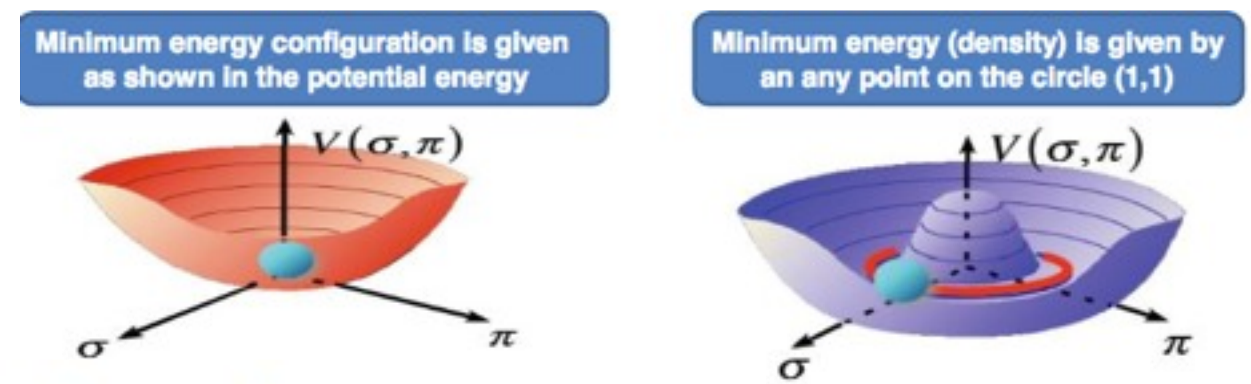
Hadron Physics working!

Chiral Symmetry

2+1+1 Polyakov Linear-Sigma Model at finite Temperature and Density

Abdel N. Tawfik

Spontaneous symmetry breaking

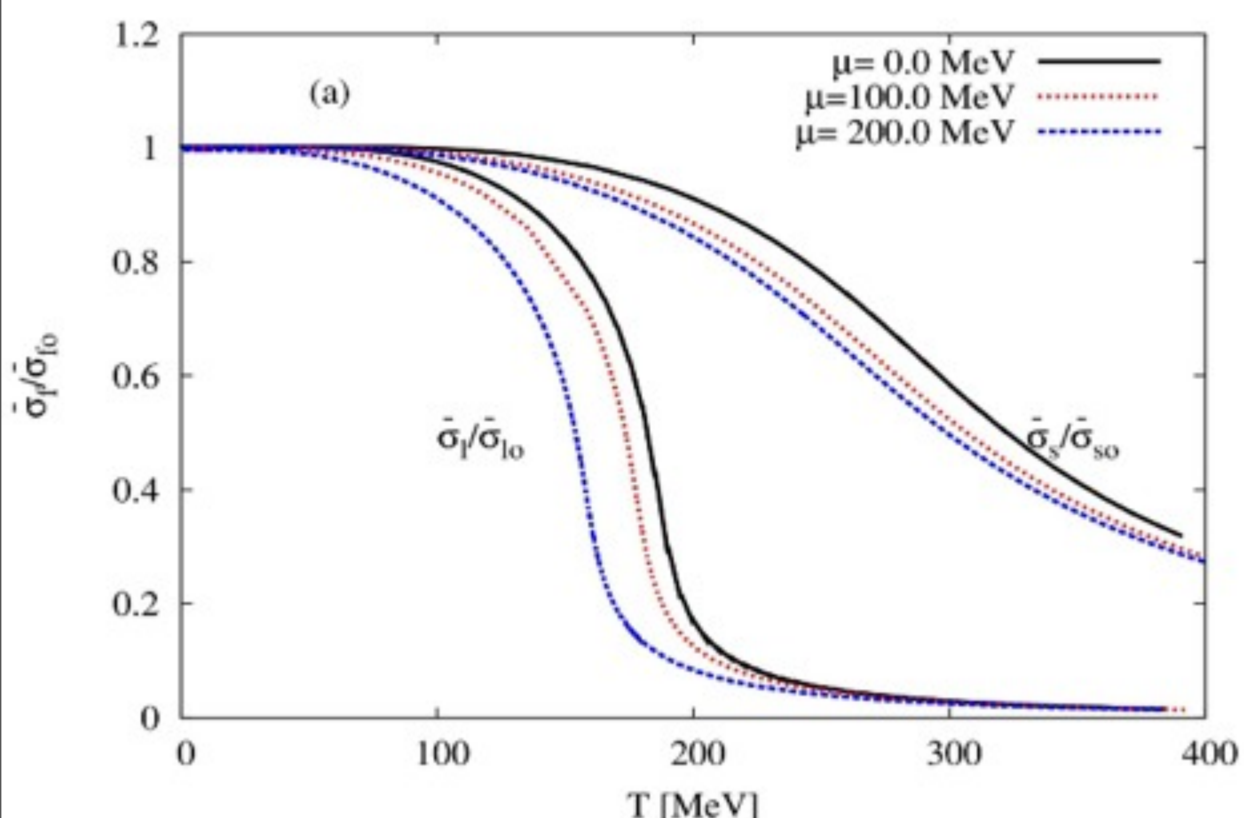


Quarks-antiquarks potential

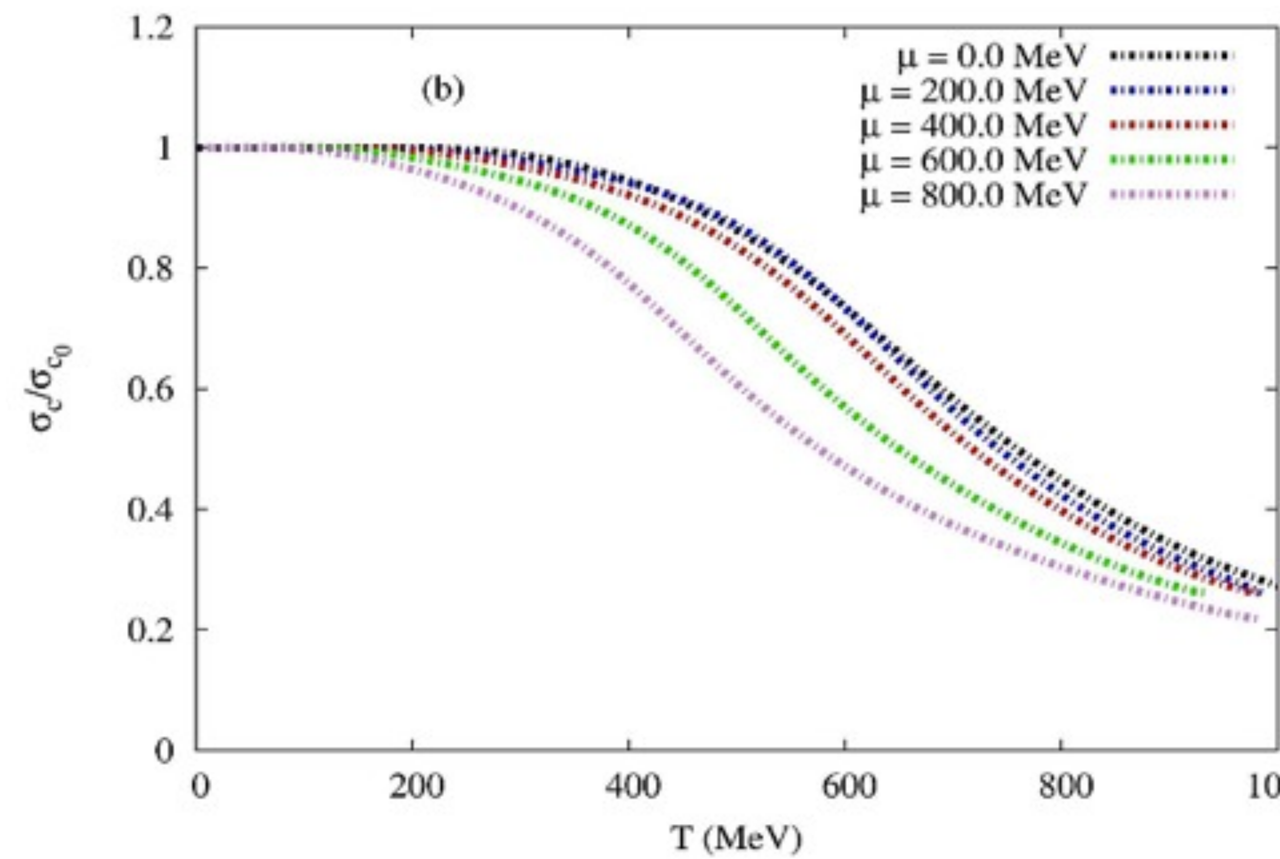
Polyakov-loop Potential

For $N_f = 4$ f = u, d, s, and c

Results of l and s condensates at finite mu



Results of c condensates and finite mu



Modeling

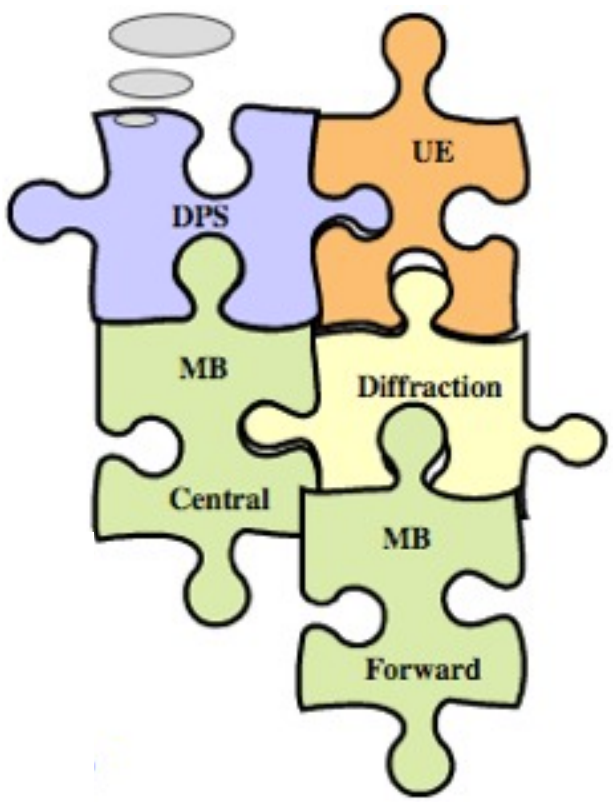
No model describes all the features of the LHC UE, MB, and DPS data!

Probing The Extremes of the Underlying Event

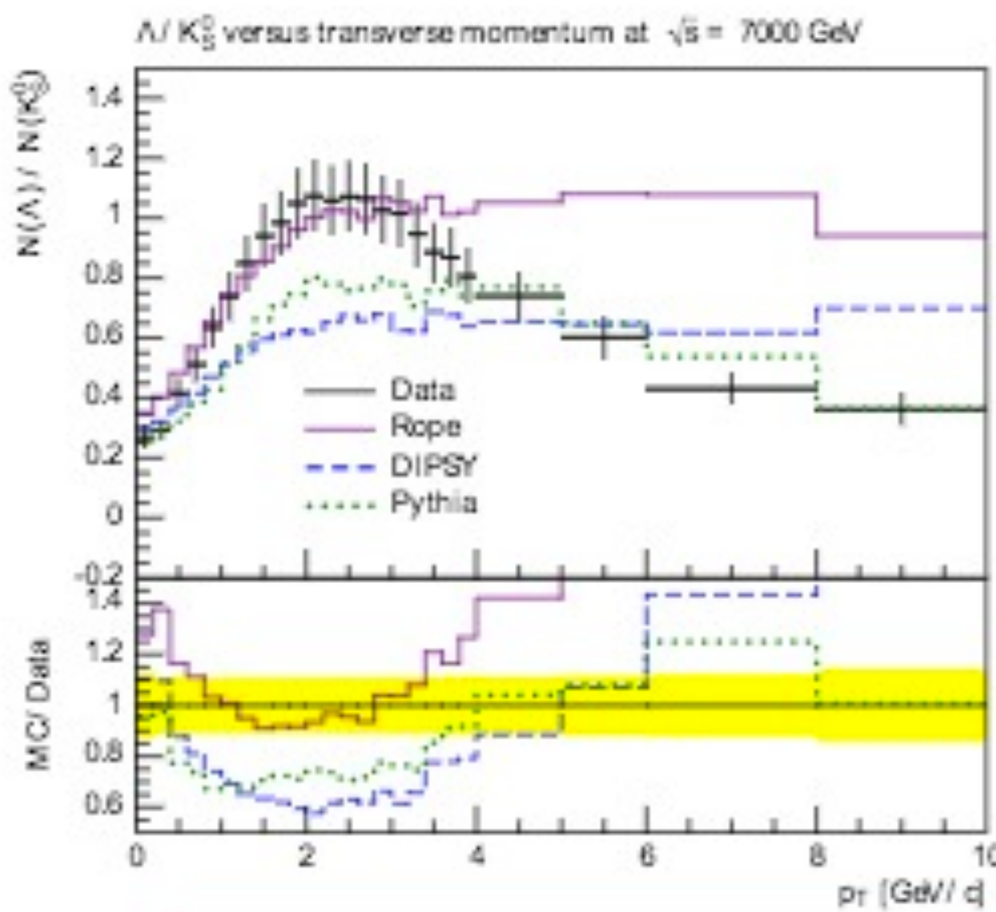
Tim Martin

Improved Predictions [CMS JHEP 1105(2011)064]

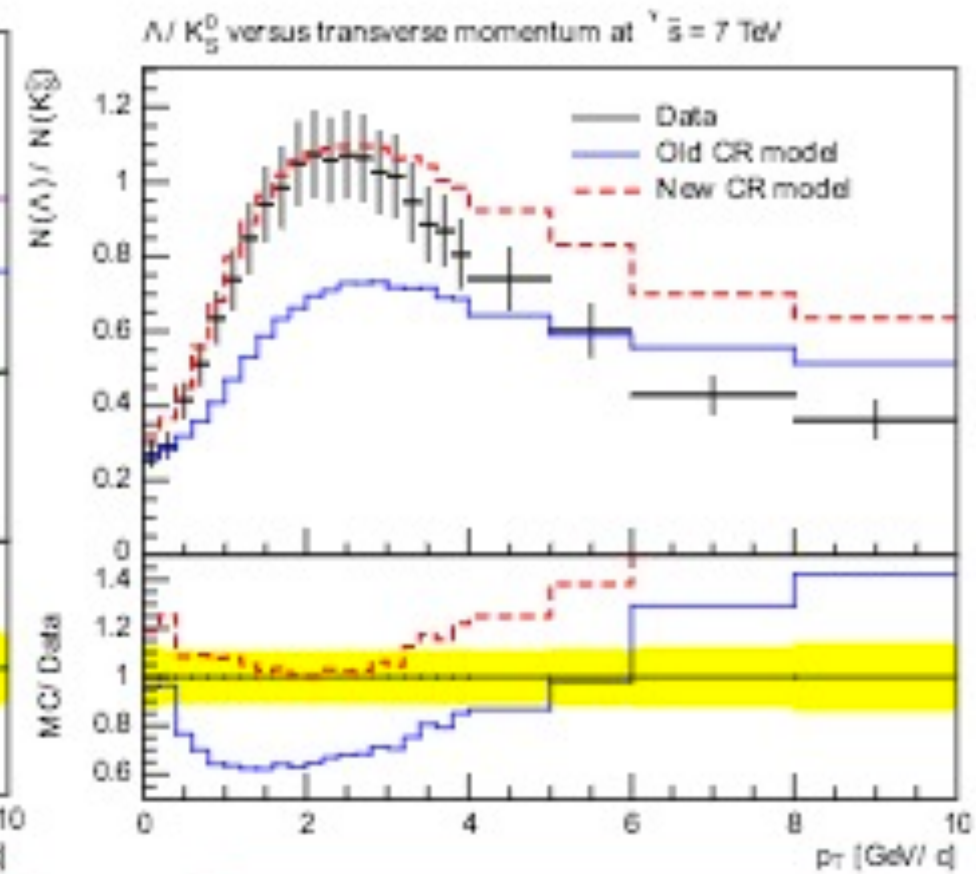
For DIPSY-ROPE and PYTHIA 8 with new Colour Reconnection



from R. Field

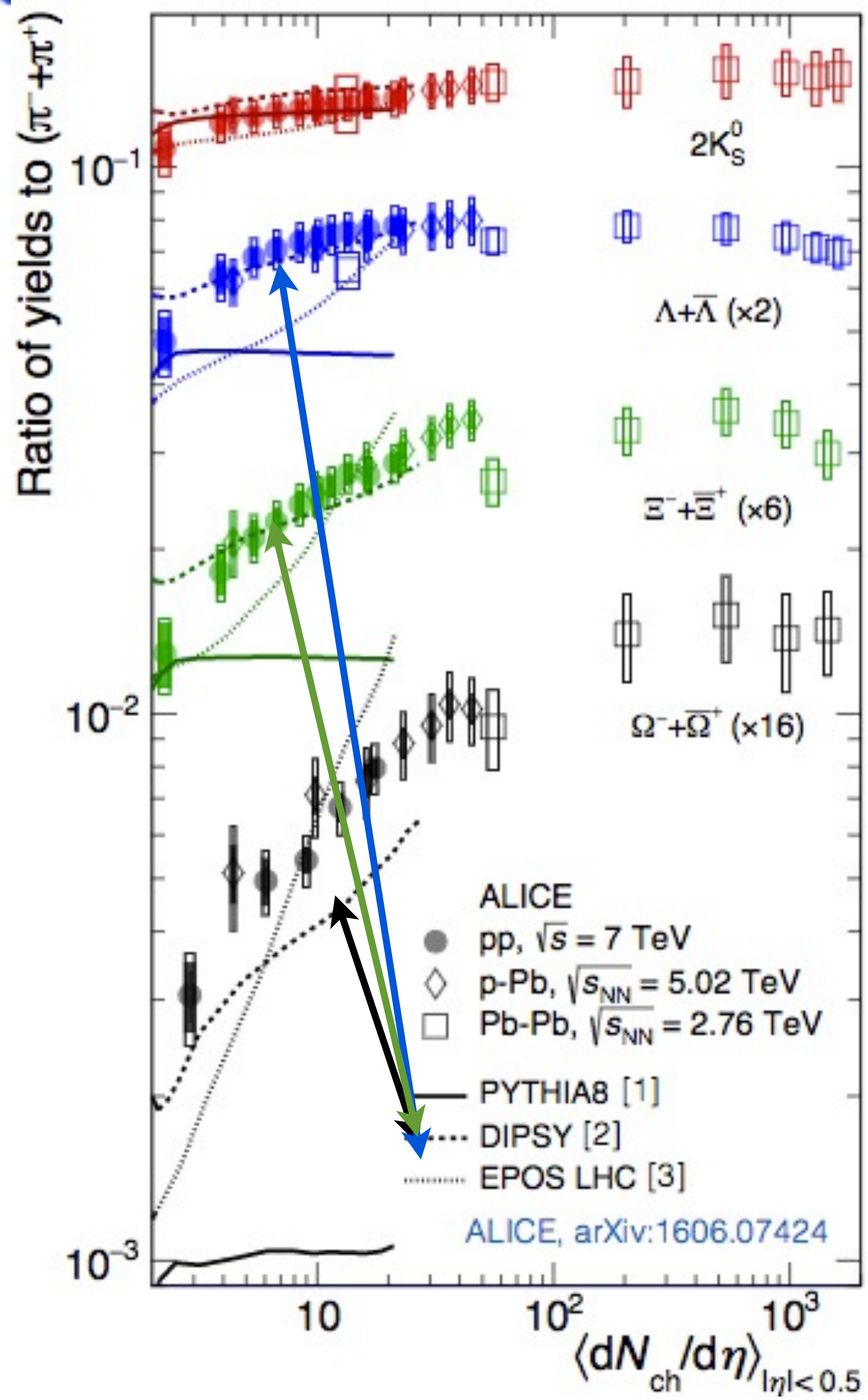


Tuned DIPSY-ROPE



Tuned PYTHIA-8 new CR

Recent result from ALICE favour DIPSY's ROPE model overall, with EPOS-LHC performing well for p/π and K_S^0/π



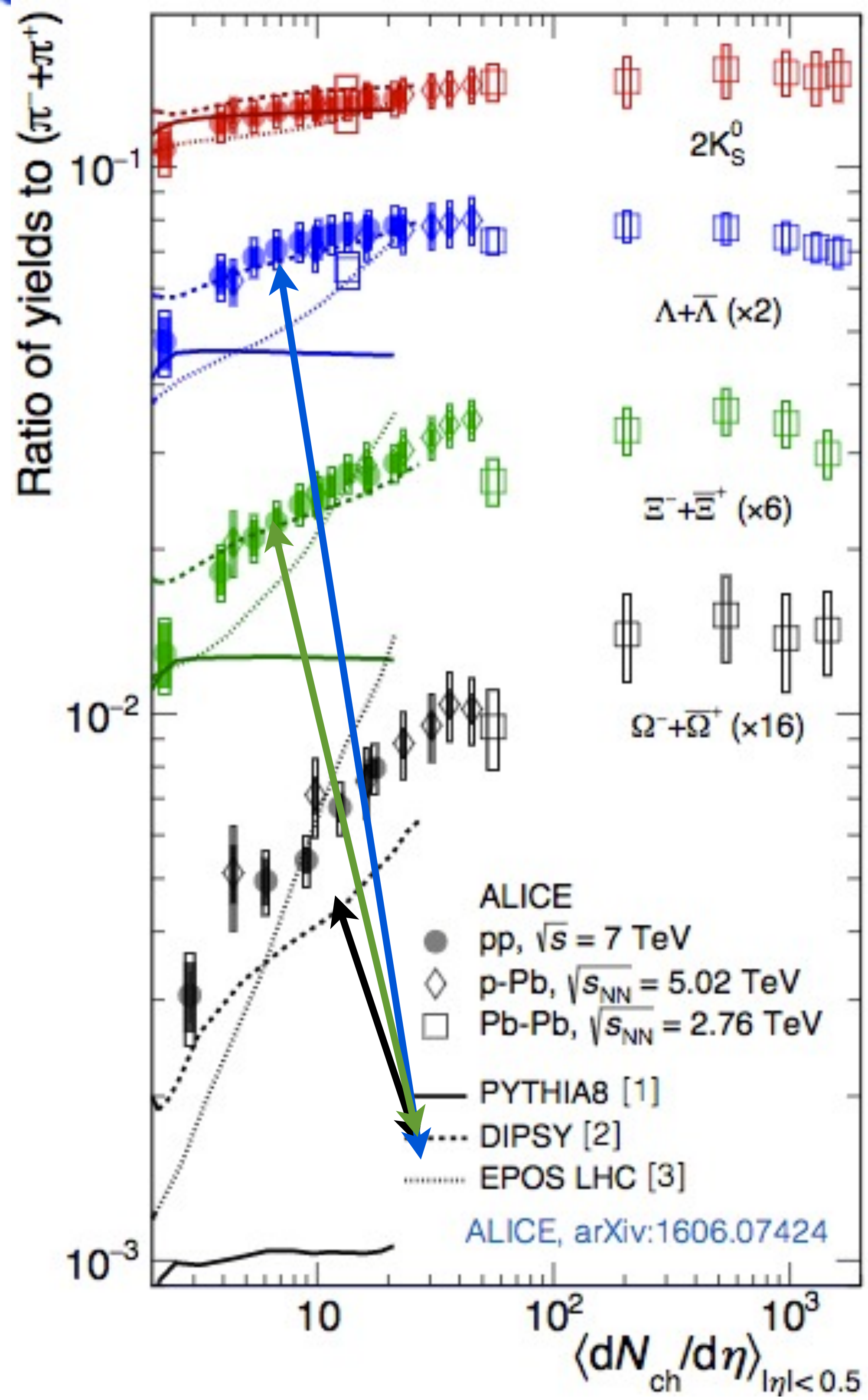
EPOS hydrodynamic modelling not only for *PbPb* and *pPb*, EPOS-LHC tune also describes *pp*

DIPSY Dipole cascade model in transverse coordinate space. Hadronised via Pythia8.

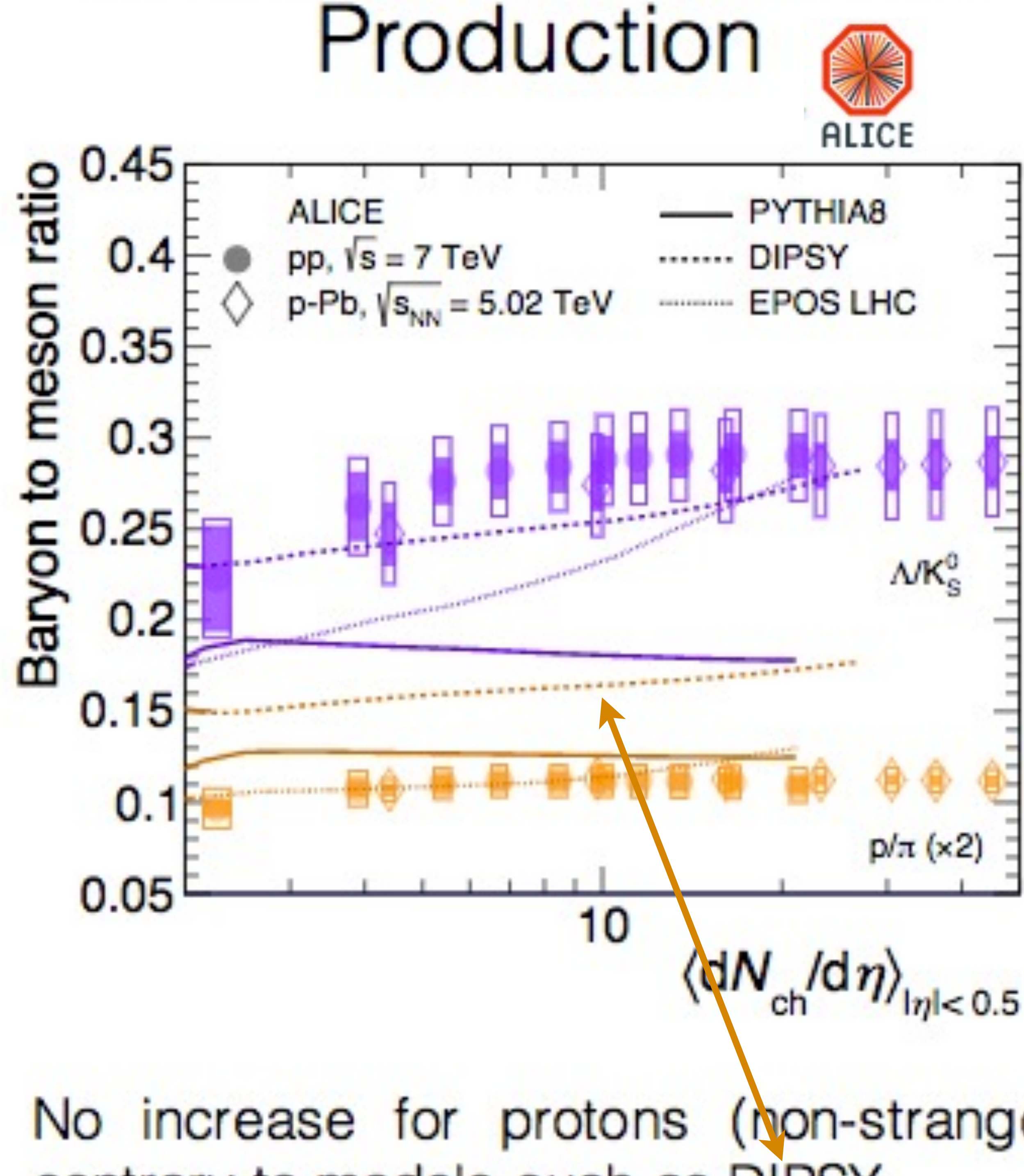
Recent result from ALICE favour DIPSY's ROPE model overall, with EPOS-LHC performing well for p/π and K^0_S/π

EPOS hydrodynamic modelling not only for *PbPb* and *pPb*, EPOS-LHC tune also describes *pp*

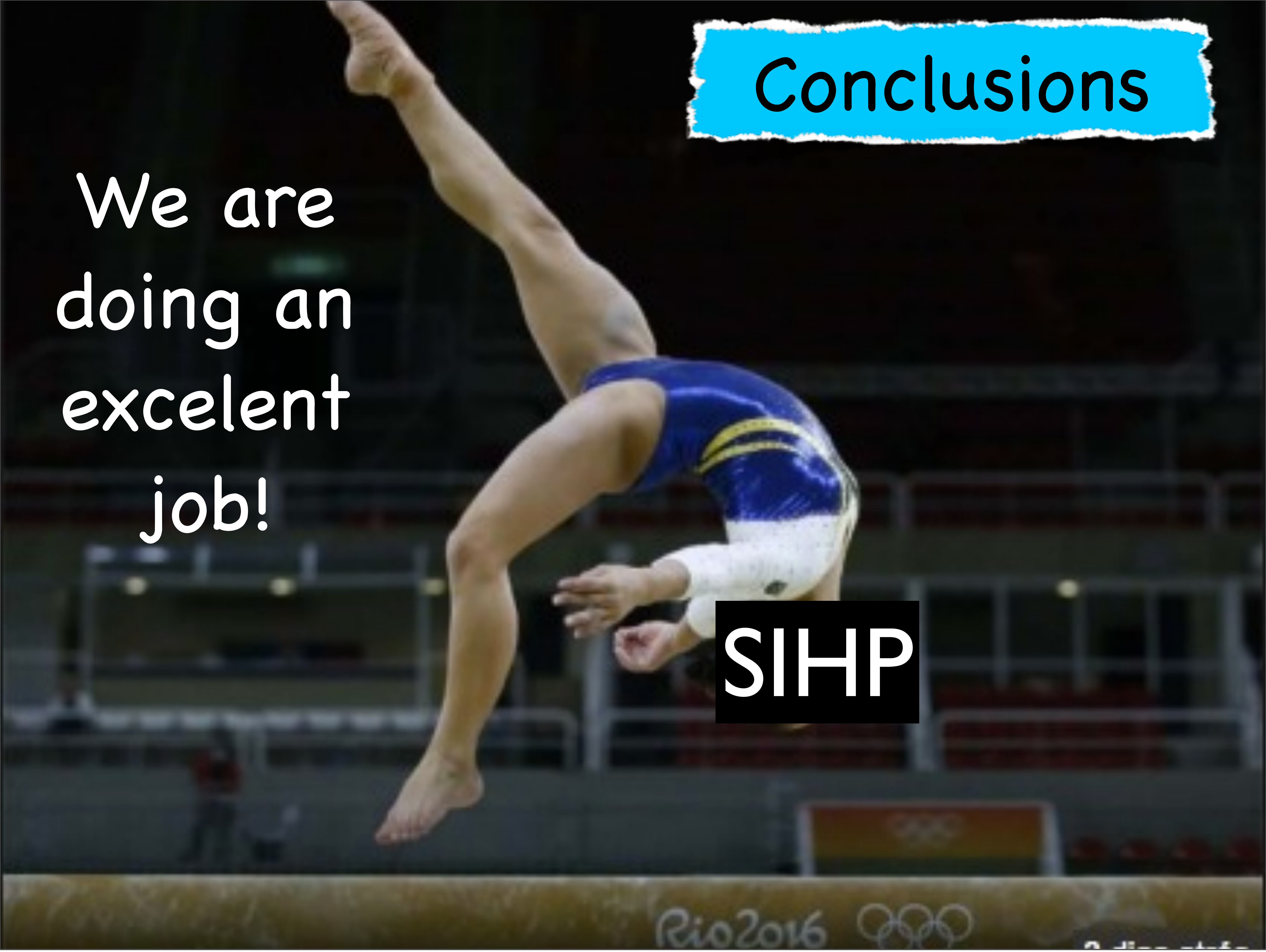
DIPSY Dipole cascade model in transverse coordinate space. Hadronised via Pythia8.



Relative Strangeness Production



No increase for protons (non-strange), contrary to models such as DIPSY


Conclusions
We are doing an excelent job!
SIHP
Rio2016


Questions?