First Italian Workshop on Hadron Physics and Non-Perturbative QCD

Cortona, 20th - 22nd April 2015

60 participants, 27 talks

The idea of this workshop was born within the discussions and the events related to the INFN "What's Next" process and the completion of the White Book of CSN1.

The workshop is meant as an occasion for the Italian community involved in Hadron Physics and non Perturbative QCD to meet, discuss, exchange information and plan its future.

The themes to be discussed can be summarised as:

3-Dimensional nucleon structure
Hadron spectroscopy
p-p cross section, elastic scattering and diffraction physics
Multi Parton Interactions and Underlying Event
Cosmic rays and accelerator physics

Gruppi di lavoro What Next - INFN

7-8 April 2014 - Roma

MATERIA OSCURA

NEUTRINI

RADIAZIONE COSMICA

ONDE GRAVITAZIONALI

FISICA FONDAMENTALE

NEW DIRECTIONS

MISURE DI PRECISIONE SM

FLAVOUR

BEYOND SM

Area Tematica NUOVE TECNOLOGIE

The LTS1 2014 - Workshop on the Long Term Strategy of INFN-CSN1.
The next 10 years of accelerator based experiments

22-24 May 2014, Isola d'Elba

Working groups

BSM: "Direct searches of new physics"

SM: "Precise Standard Model measurements"

FP: "Flavor Physics"

NP-QCD: "Non perturbative QCD"

What Next: White Paper of the CSN1
Long term strategy for accelerator based experiments
Editors: Isidori, Rescigno, Tenchini, Walsh

Hadron Physics and non perturbative QCD: from quark structure to hadronic interactions

partonic structure of nucleons: a 3-D imaging in momentum and coordinate space

partonic structure of hadrons: confinement, glueballs, tetraquark, hybrids, heavy states, ….

nucleon interactions from parton interactions, elastic, total and diffractive cross sections

nucleons and multi parton interactions, MPI

cosmic rays and hadronic interactions

contributions from CSN1, 2, 3, 4: but common scientific goals and theoretical background

3-Dimensional nucleon structure
(Alessandro Bacchetta, Patrizia Rossi)

The 3-D nucleon structure: Barbara Pasquini

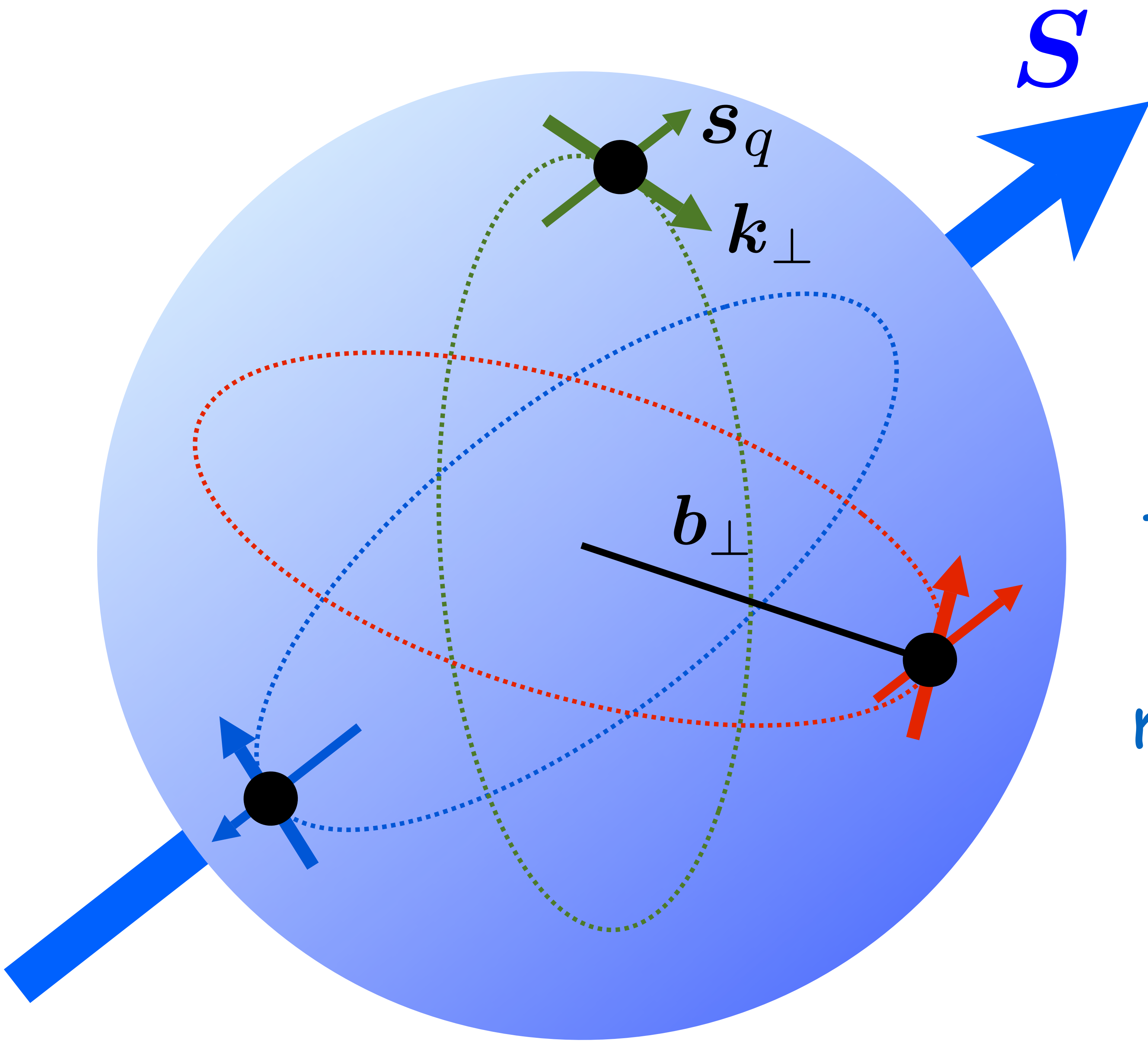
TMDs in experiment: Andrea Bressan

GPDs in experiments: Silvia Pisano

TMD phenomenology: Elena Boglione

GPD phenomenology: Michel Guidal

3-D, future: Marco Contalbrigo

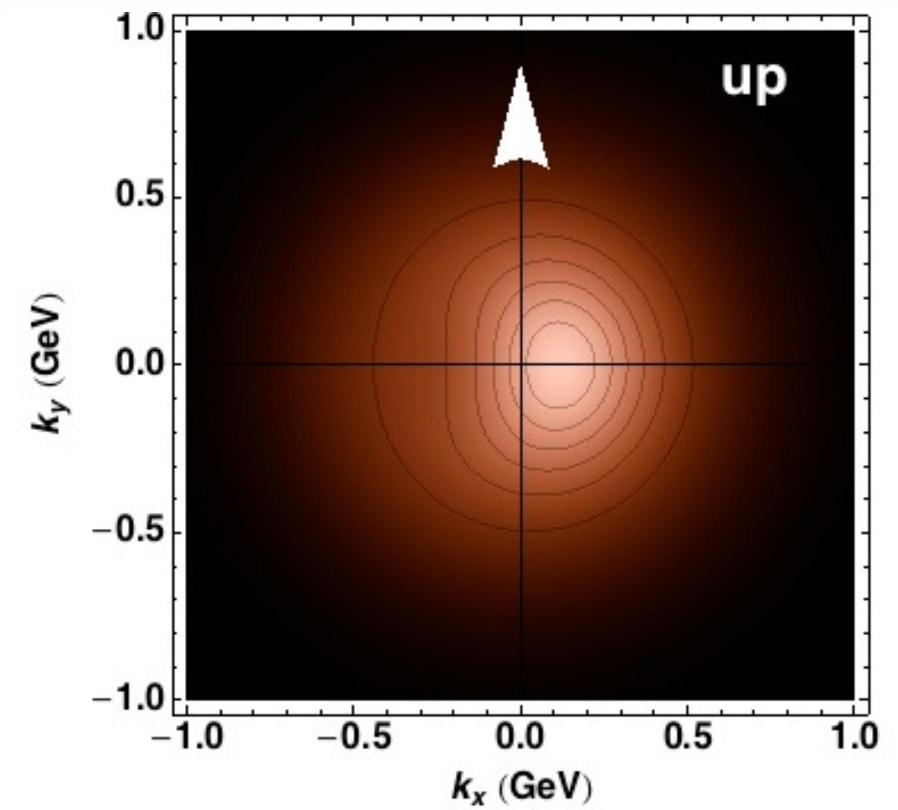


Transverse Momentum Dependent partonic distribution and fragmentation functions (TMD-PDF, TMD-FF - momentum distributions)

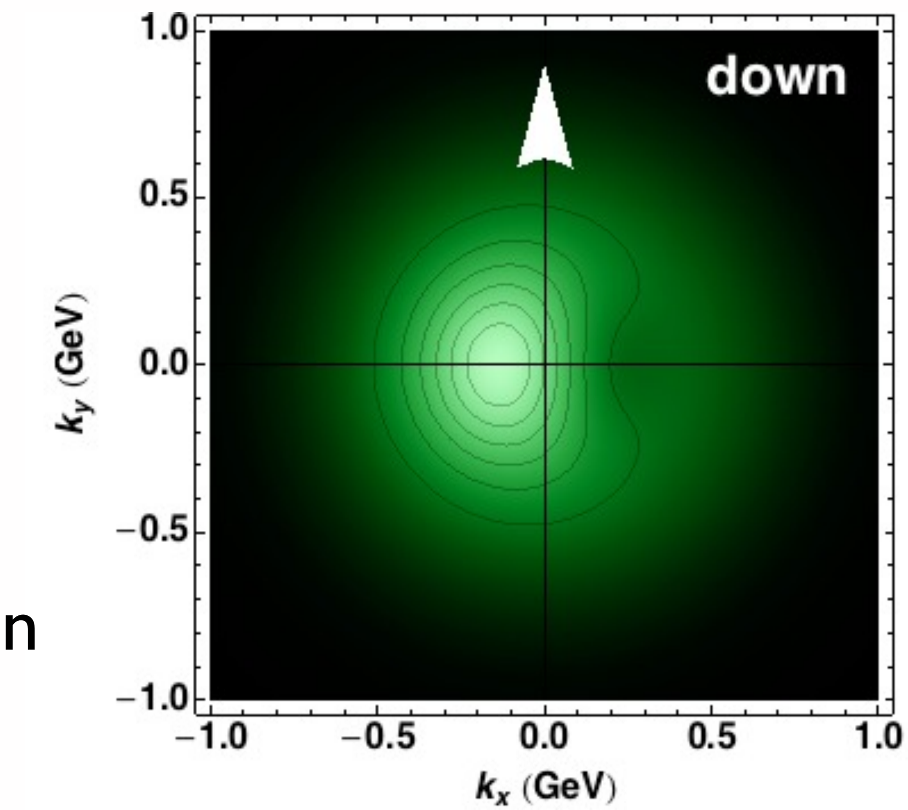
Generalised Partonic Distributions (GPD - space distributions)

distribution of unpolarized q in ⊥ polarized p↑

$$f_{q/p^\uparrow}(x,\mathbf{k}_\perp) = f_1^q(x,\mathbf{k}_\perp^2) - f_{1T}^{\perp q}(x,\mathbf{k}_\perp^2)\,\frac{(\hat{\mathbf{P}}\times\mathbf{k}_\perp)\cdot\mathbf{S}}{M}$$



S_y
polarization

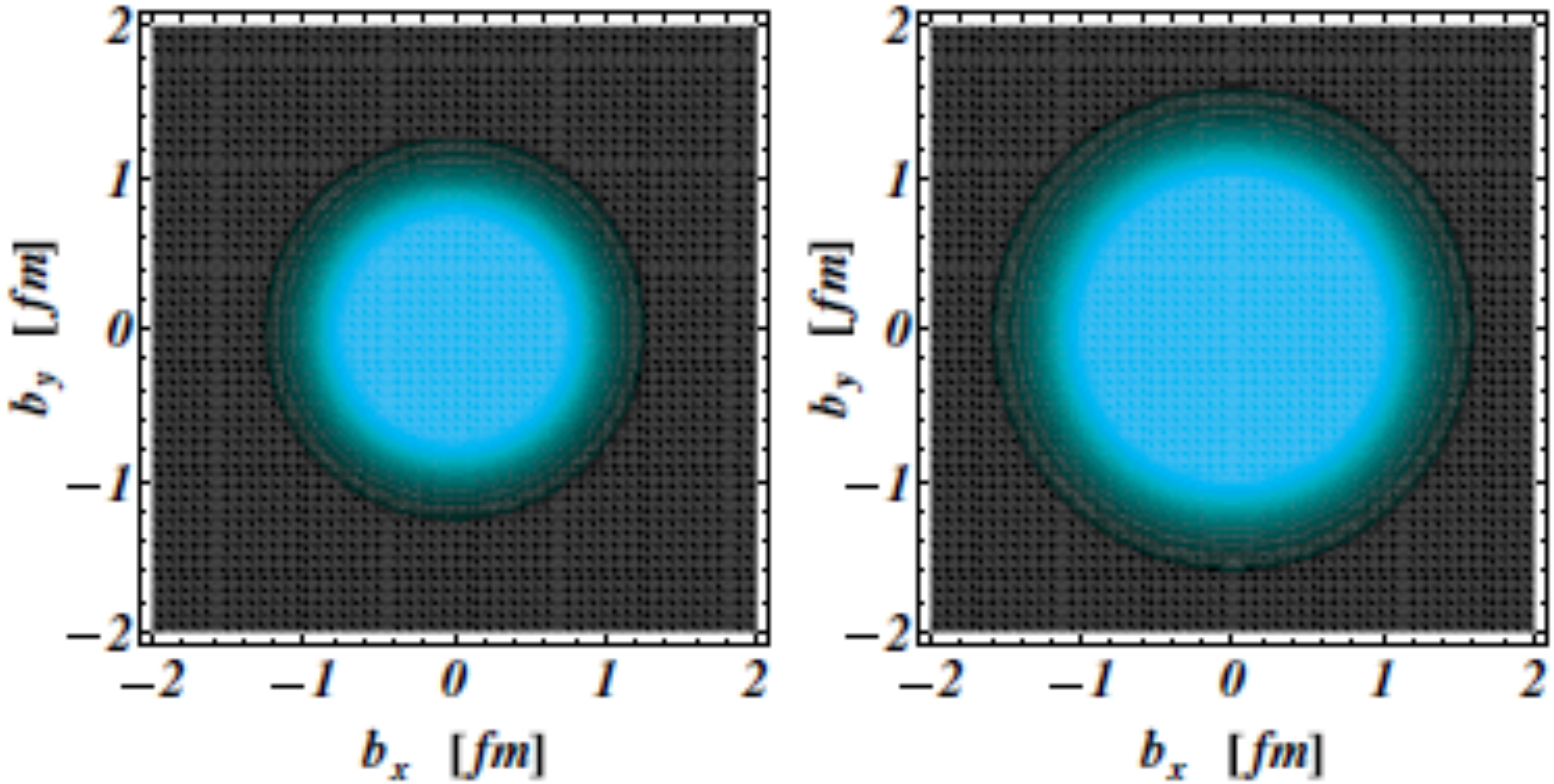


deformation induced by Sivers function

Bacchetta & Contalbrigo, The proton in 3D
Il Nuovo Saggiatore **28** (12) n.1,2

$b_\perp$ distribution at different values of x (nucleon tomography)

x_B=0.25 **x_B=0.09**



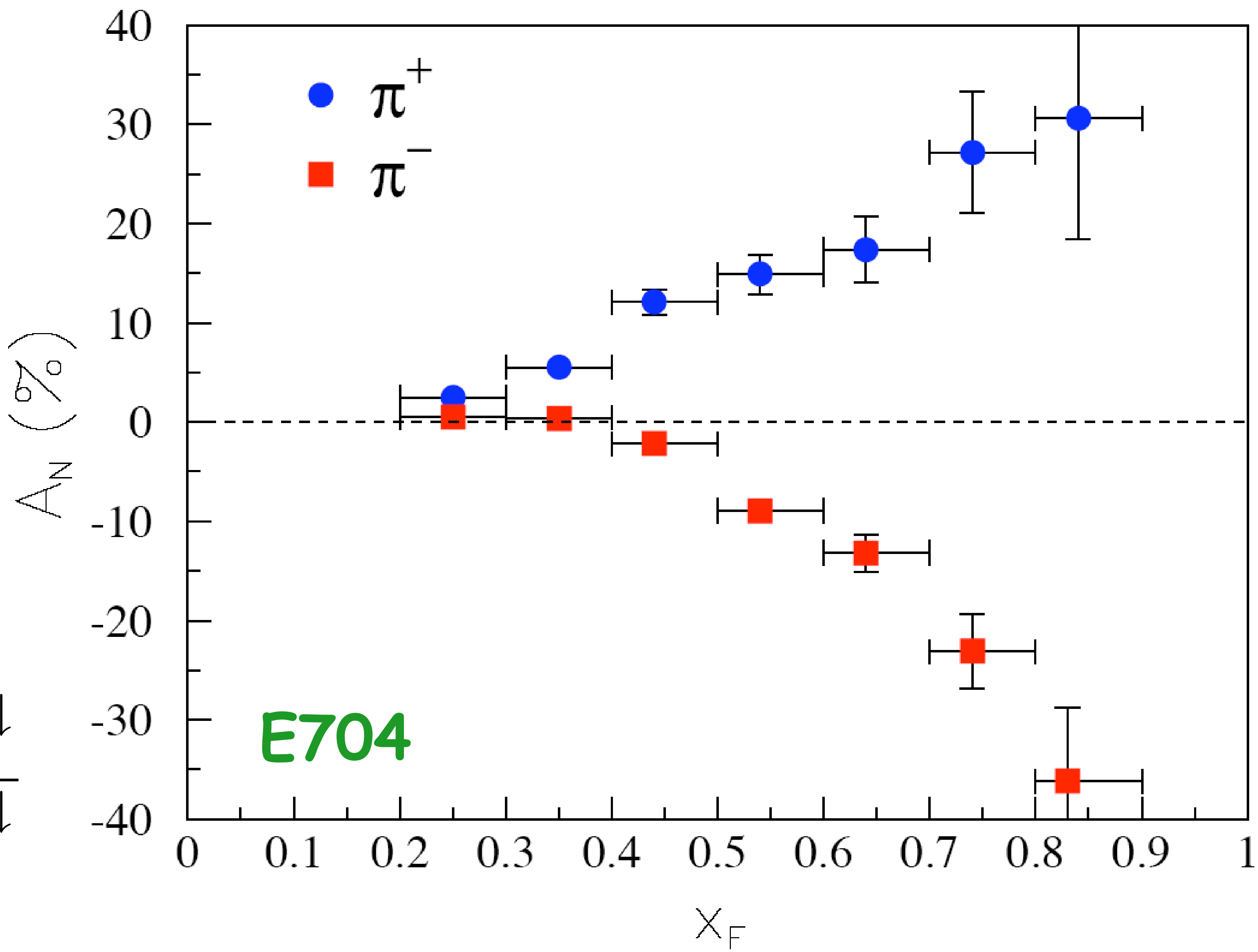
where TMDs started from ... (1991)

large P_T

$$p^\uparrow p \to \pi X$$

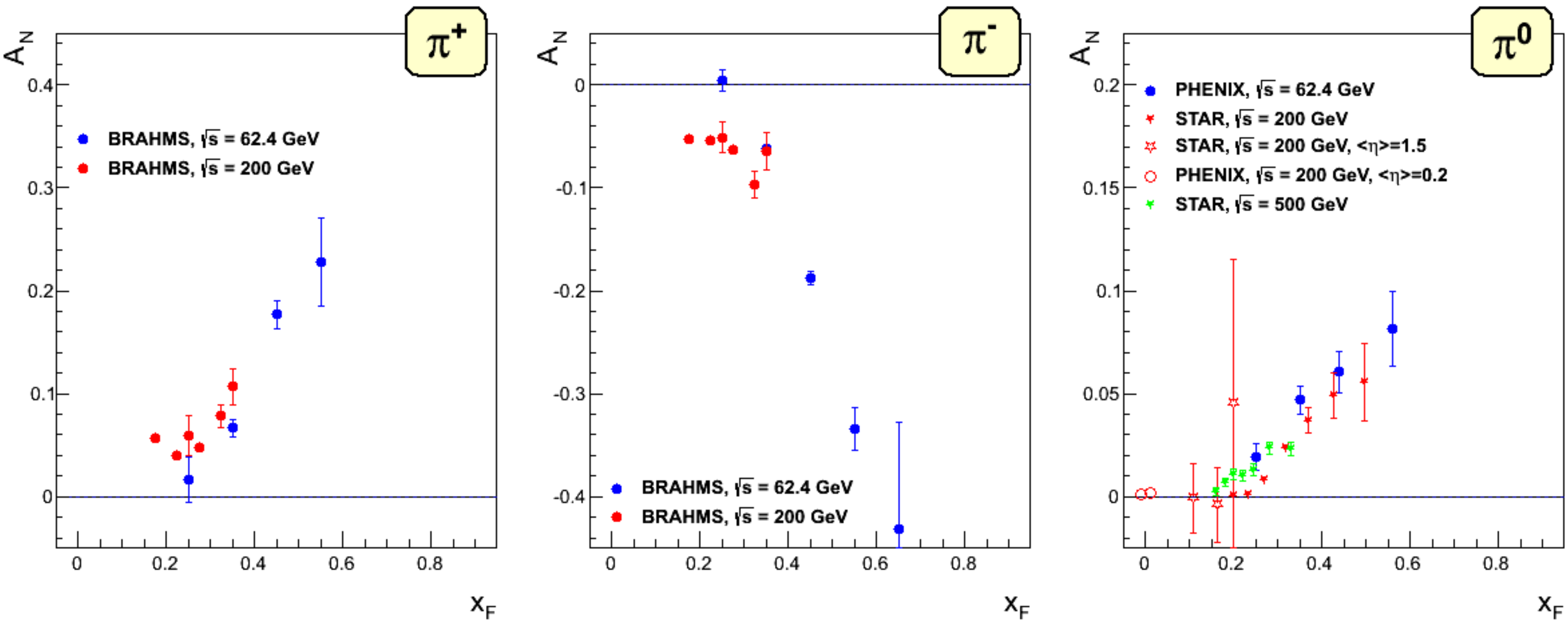
Single Spin Asymmetry

$$A_N = \frac{d\sigma^\uparrow - d\sigma^\downarrow}{d\sigma^\uparrow + d\sigma^\downarrow}$$



E704 $\sqrt{s}$ = 20 GeV $0.7 < p_T < 2.0$

RHIC data on Transverse Single Spin Asymmetries (TSSAs)



TSSAs are zero in pQCD, but not in real life, up to very high energy

possible explanation with TMDs and/or quark-gluon-quark correlations. MPI?

Hadron spectroscopy
(Roberto Mussa, Antonello Polosa)

QCD spectroscopy, problems and new challenges: Pietro Colangelo

Spectroscopy, experiments (conventional): Marco Pappagallo

Spectroscopy, open problems (theory, unconventional): Fulvio Piccinini

Spectroscopy, experiments (unconventional): Alexis Pompili

WHY STUDYING QCD SPECTROSCOPY IN THE LHC ERA?

our knowledge of fundamental interactions
is not complete

confinement and chiral symmetry breaking characterize strong interactions

spectroscopy is a tool to learn about confinement/χsB

ab initio: LQCD, QCDSr
scale hierarchies identified -> effective theories (pert. th. + external input)

long list of poorly (or not) understood issues

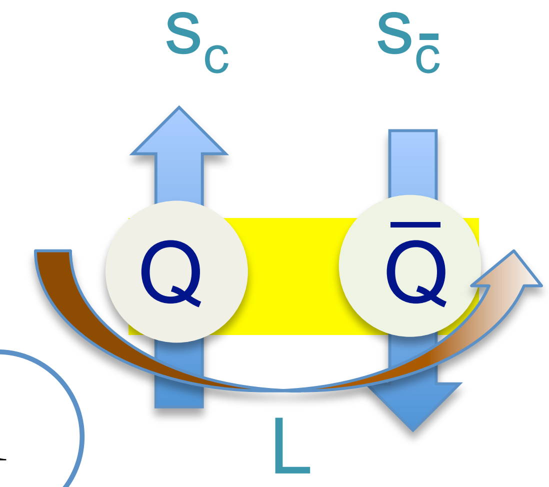
vast investigation programme
results envisaged for curious open-minded researchers

talk by P. Colangelo

quark model color singlets (-> from atomic physics)

mesons $q \otimes \bar{q} = 3 \otimes \bar{3} = 8 \oplus 1$

baryons $q \otimes q \otimes q = 3 \otimes 3 \otimes 3 = 10 \oplus 8 \oplus 8 \oplus 1$



$P=(-1)^{L+1}$
$C=(-1)^{L+S}$
$S=S_c+S_{\bar{c}}$
$J=L+S$

$n^{2S+1}L_J$

non quark model color singlets

hybrids $q \otimes \bar{q} \otimes G = 3 \otimes \bar{3} \otimes 8 = 27 \oplus 10 \oplus \overline{10} \oplus 8 \oplus 8 \oplus 8 \oplus 1$

glueballs $G \otimes G = 8 \otimes 8 = 27 \oplus 10 \oplus \overline{10} \oplus 8 \oplus 8 \oplus 1$

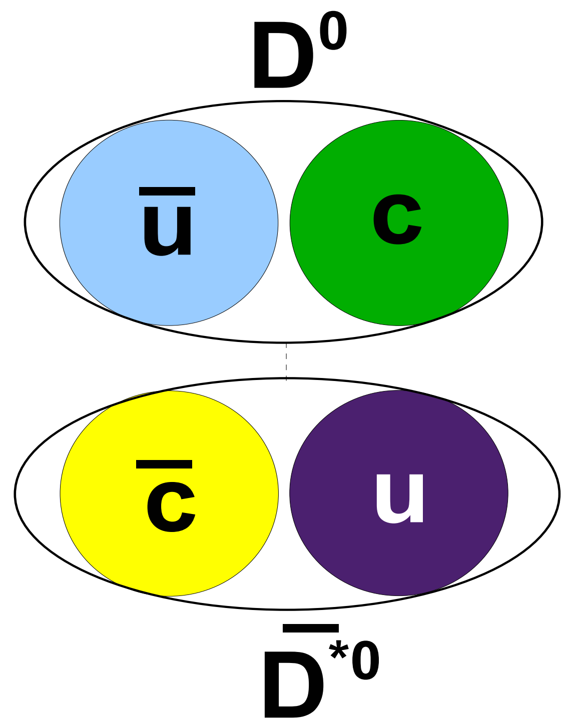
multi quarks, multi gluons, multi quark-gluons …

……….

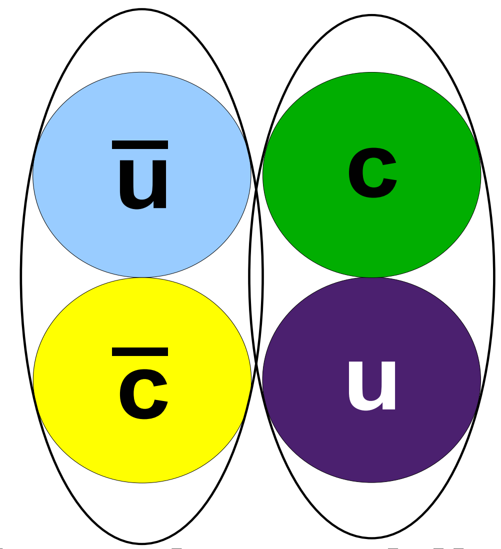
distinction between “CONVENTIONAL” and “EXOTIC” spectrum arbitrary and misleading

hadrons emerge from the full QCD dynamics

Theoretical phenomenological models



D^0-$\bar{D}^{*0}$ “molecule”



diquark - antidiquark

but also other models such as e.g.

- hadrocharmonium
- hybrids
- models including rescattering effects, like cusps, or $c\bar{c}$ dynamically coupled to open charm channels

E. Santopinto and collaborators; F. de Fazio

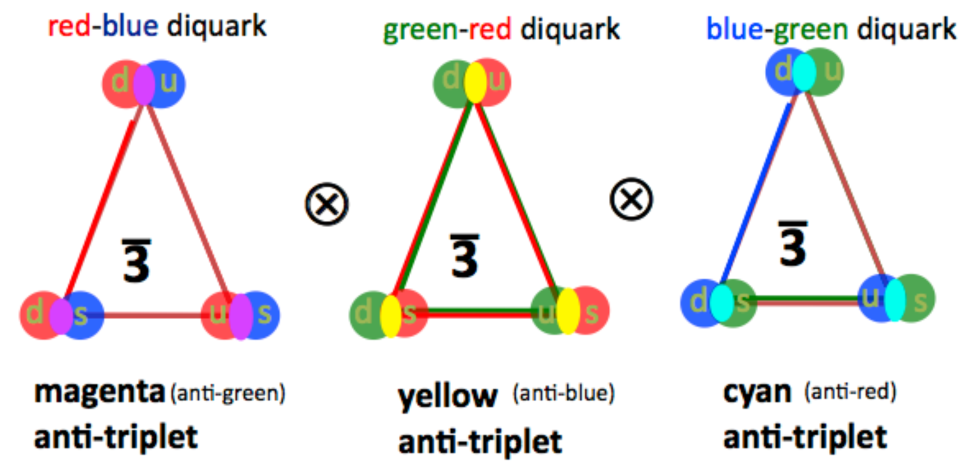
overall picture is still confused

Further multiquarks states : pentaquarks & dibaryons

- Besides building tetraquark mesons with diquarks & anti-diquarks considered respectively as color anti-triplets & triplets …

Designs borrowed by S.L.Olsen

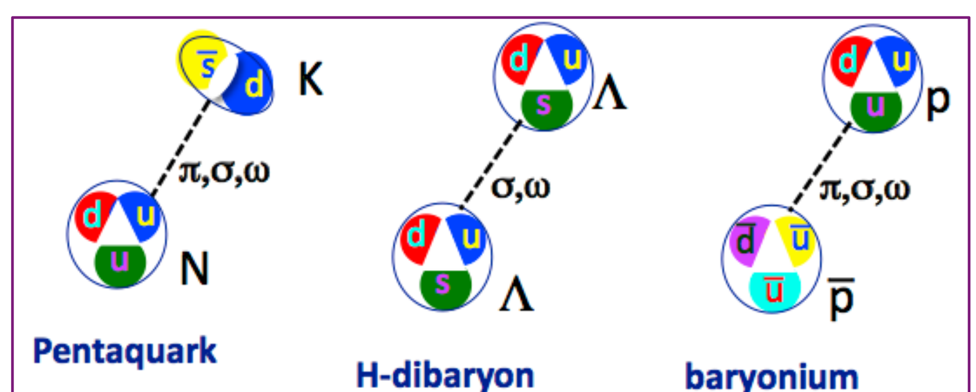
… it is possibile to combine color anti-triplets …



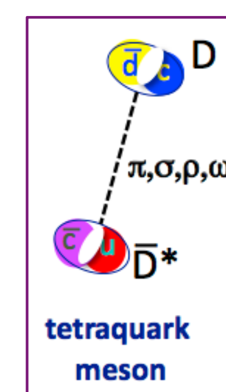
… to build color singlets like

or

- These multiquark states considered as "hadron molecules" would be



just as



p-p cross section, elastic scattering and diffraction physics (Vincenzo Barone, Fabrizio Ferro)

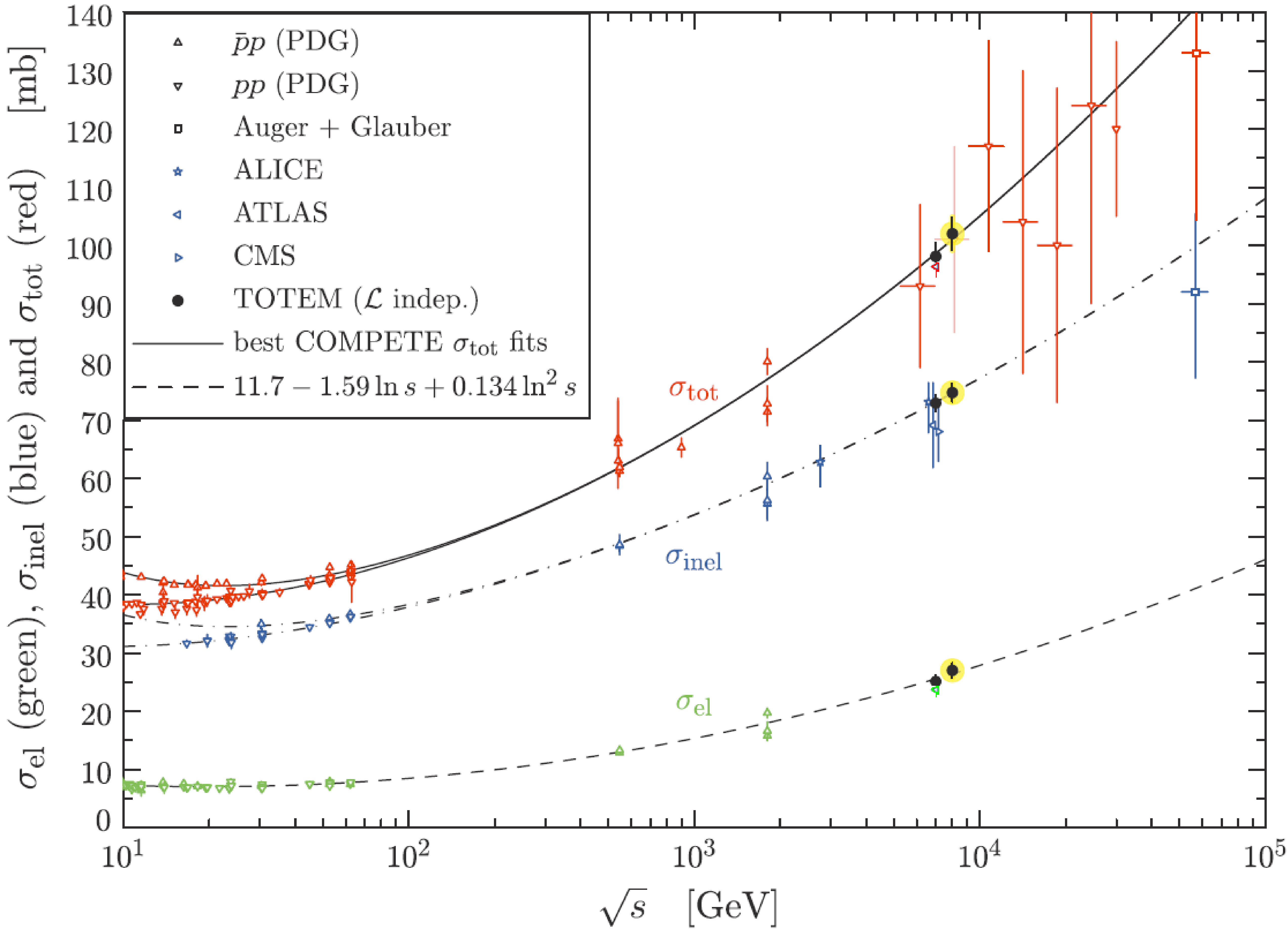
Diffraction from HERA to LHC: Federico Ceccopieri

Diffraction and forward physics at the LHC, experiments: Nicolò Cartiglia

Total, elastic and inelastic pp scattering, experiment: Giuseppe Latino

Models for the total and inelastic pp cross sections at LHC and beyond: Giulia Pancheri

Diffraction: semi-hard processes and BFKL: Alessandro Papa



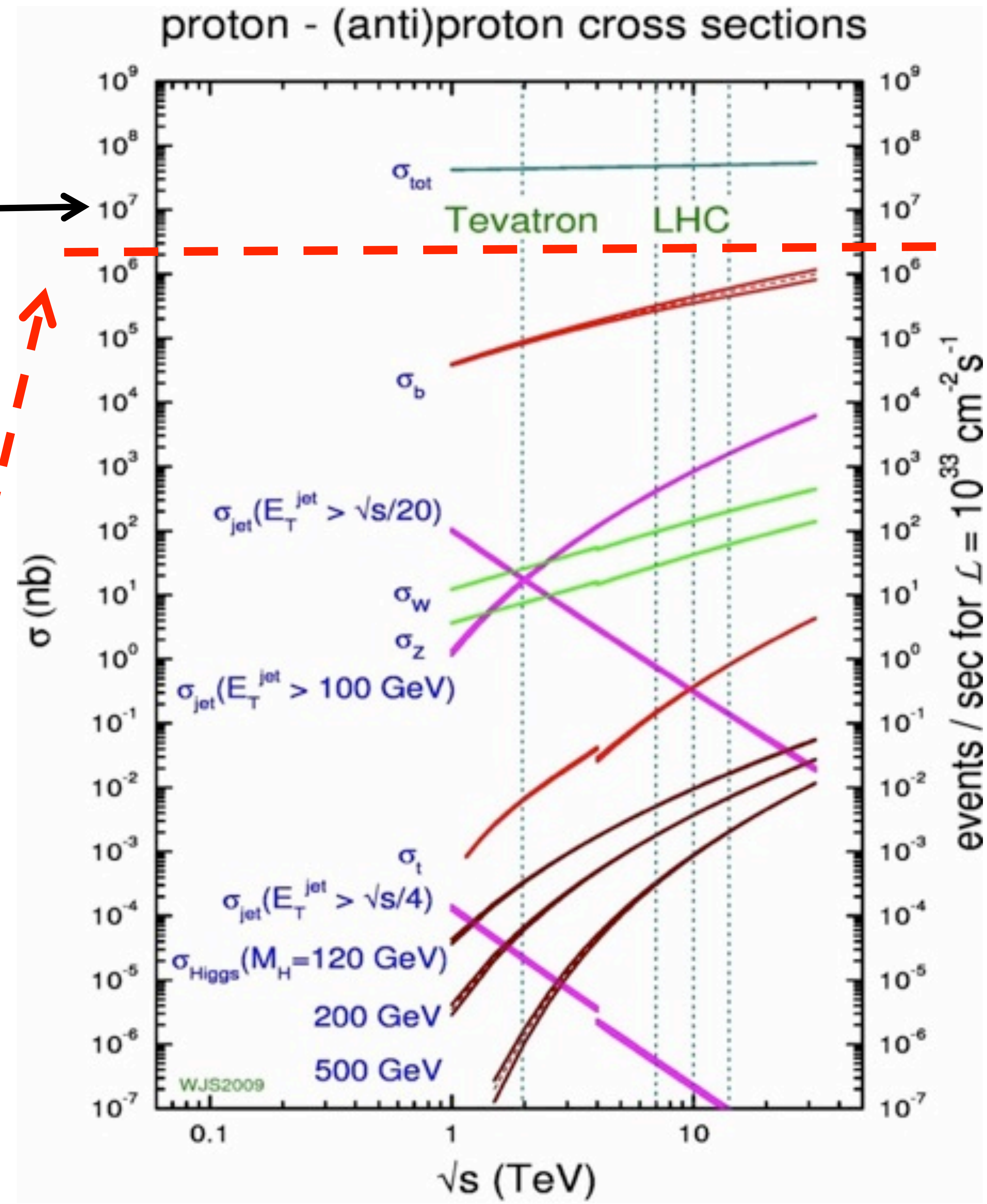
$\bar{p}p$ (PDG)
pp (PDG)
Auger + Glauber
ALICE
ATLAS
CMS
TOTEM ($\mathcal{L}$ indep.)
best COMPETE σ_{tot} fits
$11.7 - 1.59 \ln s + 0.134 \ln^2 s$
σ_{tot}
σ_{inel}
σ_{el}
σ_{el} (green), σ_{inel} (blue) and σ_{tot} (red) [mb]
$\sqrt{s}$ [GeV]
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
10^1
10^2
10^3
10^4
10^5

Let's set the scale

The total cross section is dominated by soft processes.

100 mb

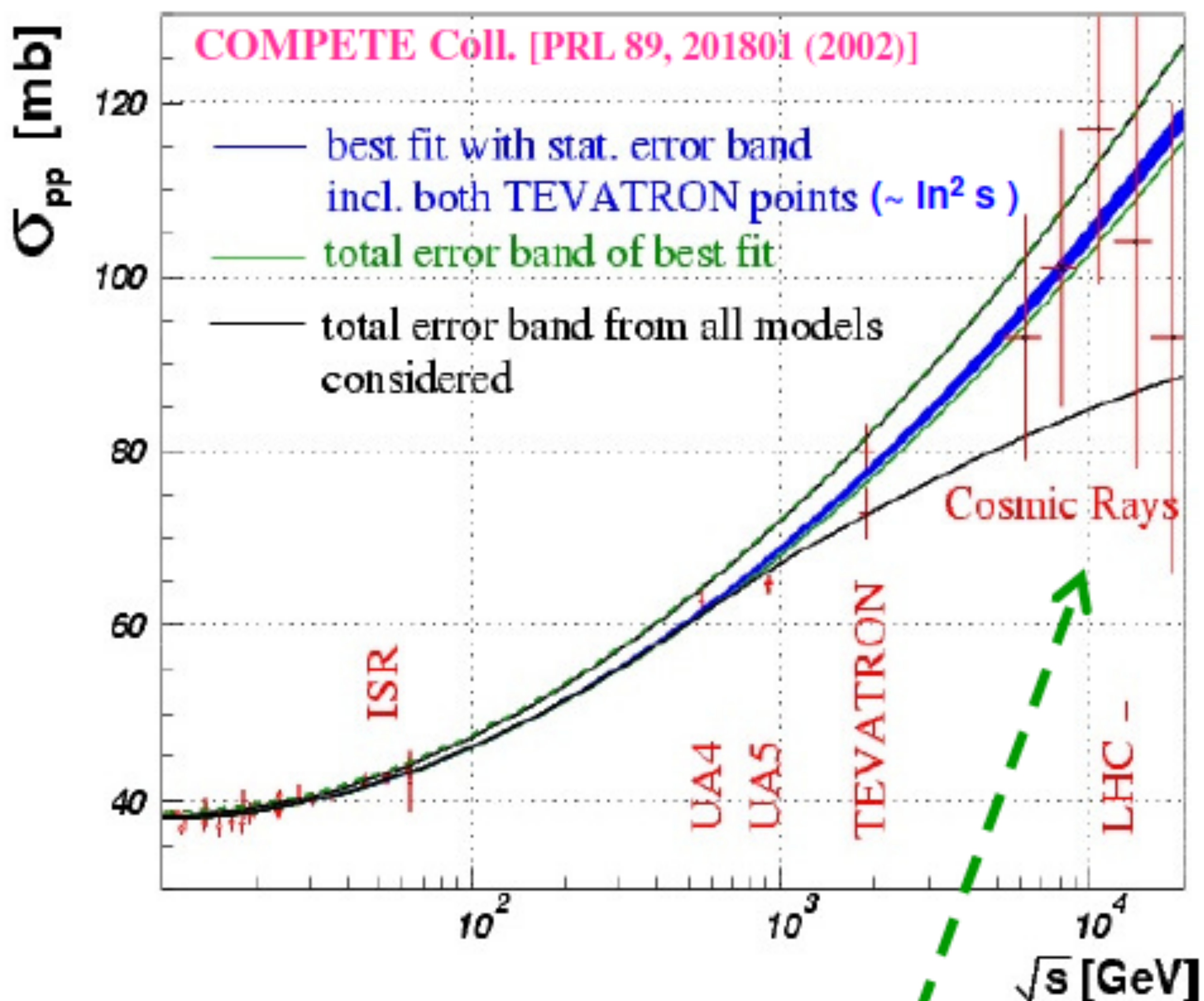
If you were to eliminate every process below the first line (even the Higgs) the value of the total cross section would be the same

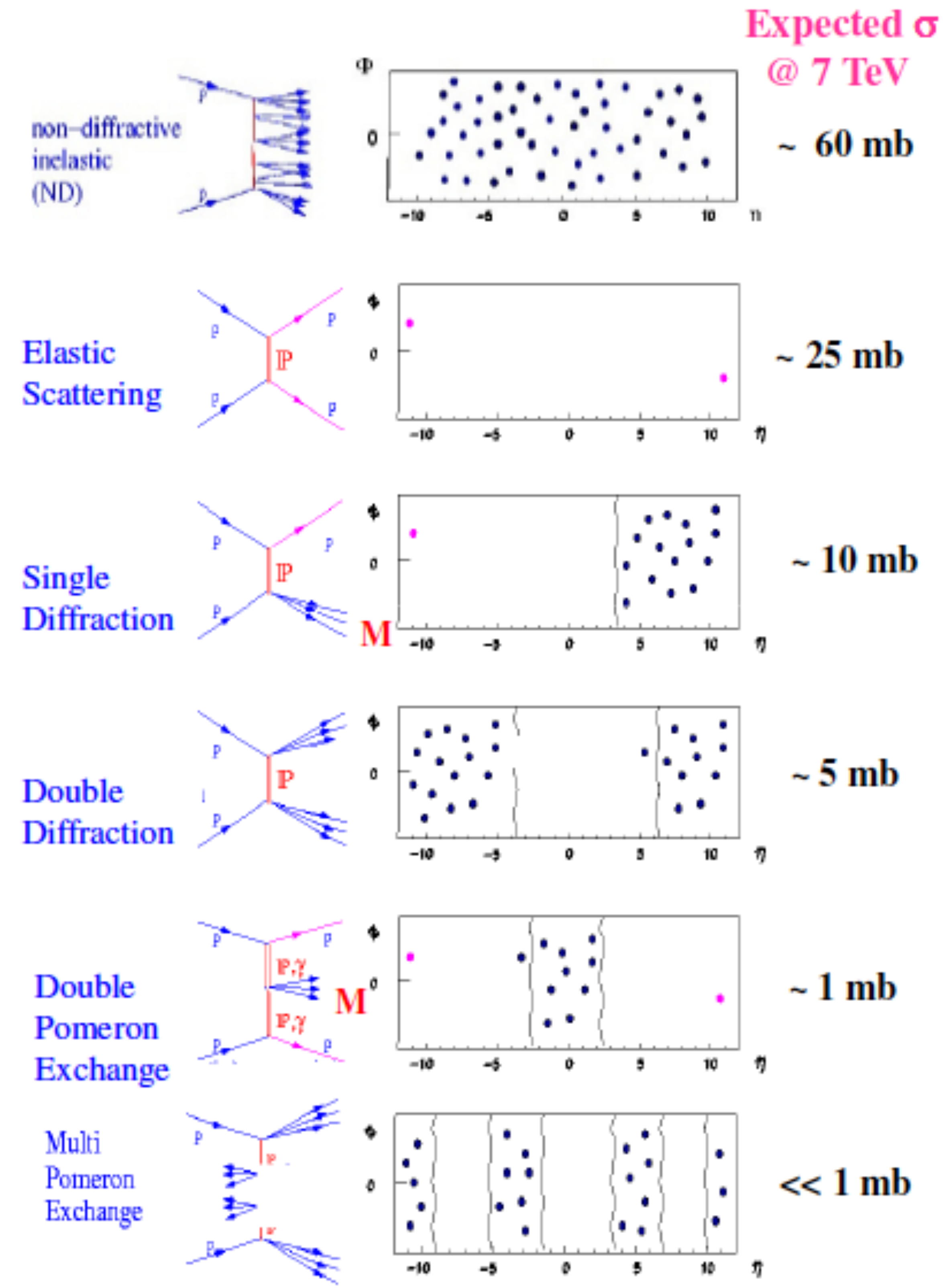


If $R_1 = R_2 = 10^{-13}$ cm (one fermi)

➔ $s \sim 10^{-25}$ cm^2 = 100 mb

Total Cross Section: from ISR to Tevatron

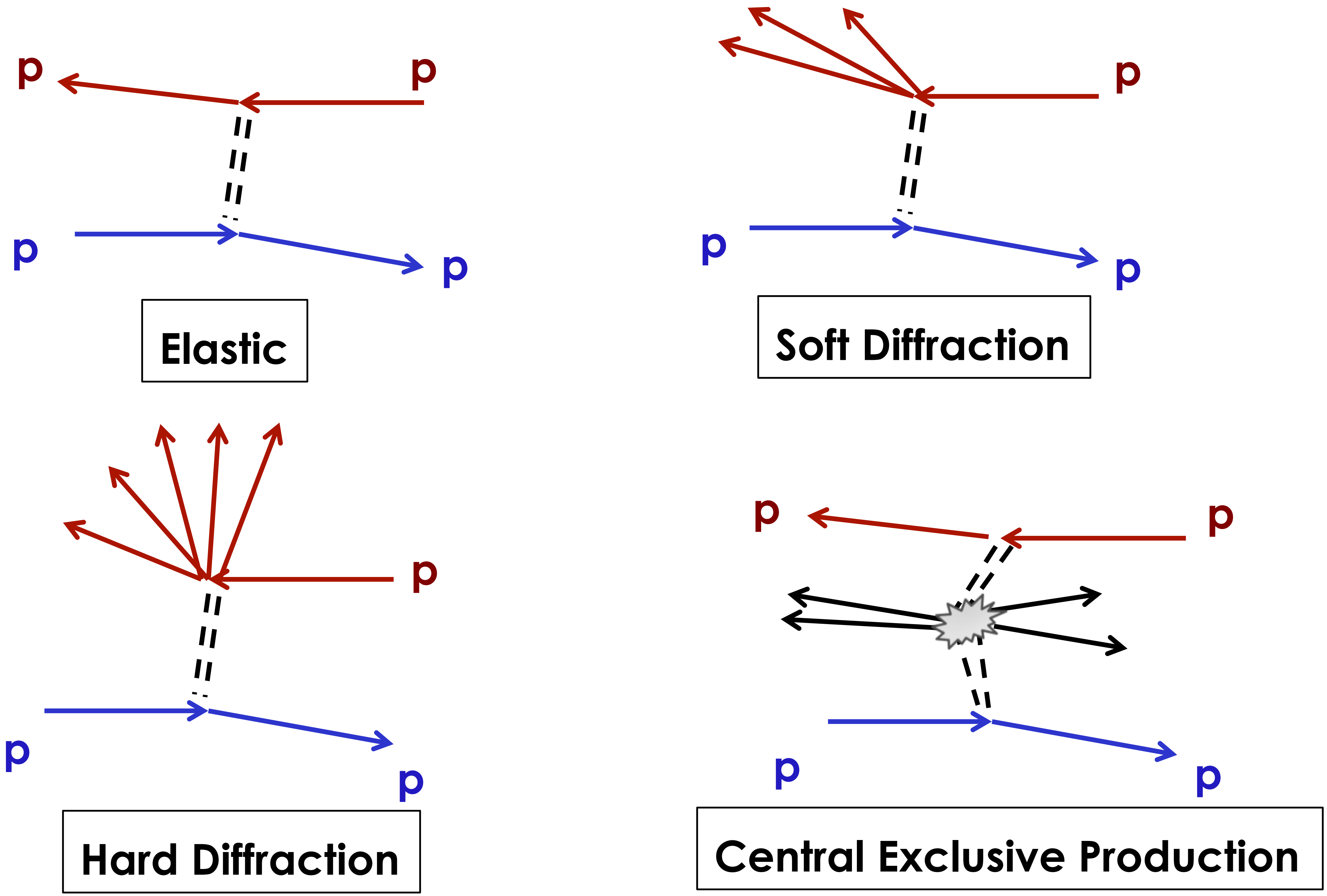




Importance of performing σ_T measurement @ LHC with adequate resolution (abs. error ~ O(1 mb)), allowing to distinguish among different models

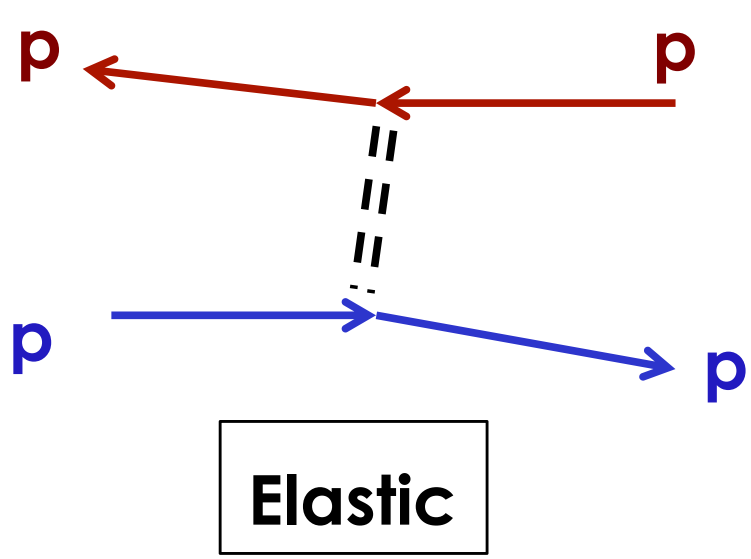
A common origin…

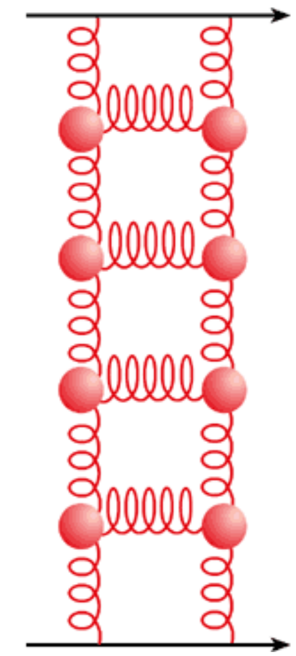
The **Elastic, Soft diffraction, Hard Diffraction, and Central Exclusive production** have in common the **exchange of a color neutral object** between the incoming particles:

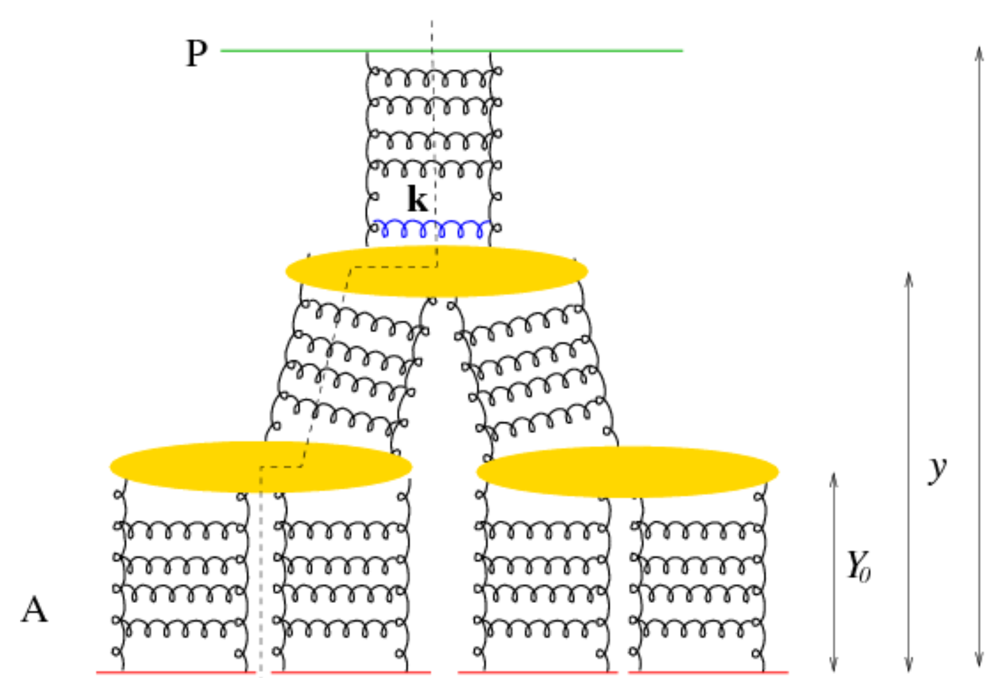


What is exchanged?

The most obvious configuration is the exchange of a 2-gluon state, but it can get very complicated…







As these gluons are soft, calculations use various parameterizations as pQCD cannot be used.

The exchanged colorless object takes the generic name of **Pomeron**

the lowest state glueball?

Multi Parton Interactions and Underlying Event
(Livio Fanò, Matteo Rinaldi)

Multi Parton Interactions, overview: Jonathan Gaunt

Double parton correlations in MPI: Sergio Scopetta

Double parton scattering in high-energy pA collisions:
Daniele Treleani

MPI, experiment: Livio Fanò

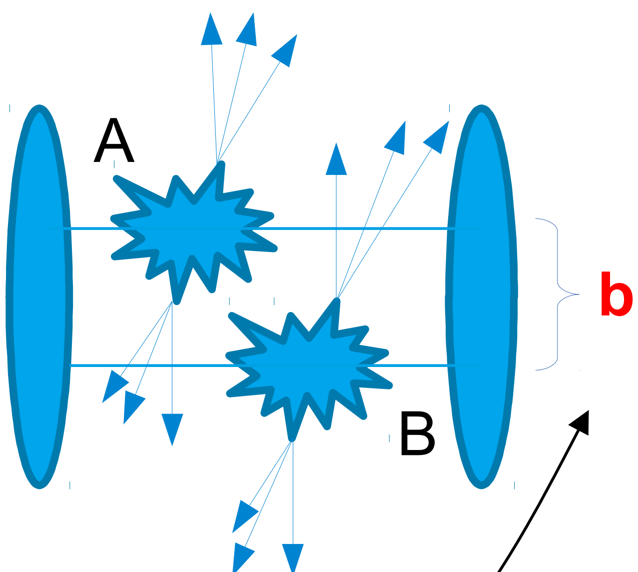
Soft MPI: Stefano Camarda

Hard MPI: Paolo Gunnellini

MPI in nuclei collisions: Fiorella Fionda

Total Cross Section for DPS

How can we describe MPI theoretically? Let's look at DPS:



Assuming the factorisation of the hard processes A and B, the total DPS cross section may be written as:

$$\sigma_D^{(A,B)} = \underbrace{\frac{m}{2}}_{\text{Symmetry factor}} \sum_{i,j,k,l} \int \overbrace{\Gamma_h^{ik}(x_1, x_2, \mathbf{b}; Q_A, Q_B)\Gamma_h^{jl}(x_1', x_2', \mathbf{b}; Q_A, Q_B)}^{\text{Two-parton generalised PDF (2pGPD)}}$$

$$\times \underbrace{\hat{\sigma}_{ij}^{A}(x_1, x_1')\hat{\sigma}_{kl}^{B}(x_2, x_2')}_{\text{Parton level cross sections}} \mathrm{d}x_1 \,\mathrm{d}x_1' \mathrm{d}x_2 \,\mathrm{d}x_2' \mathrm{d}^2\mathbf{b}$$

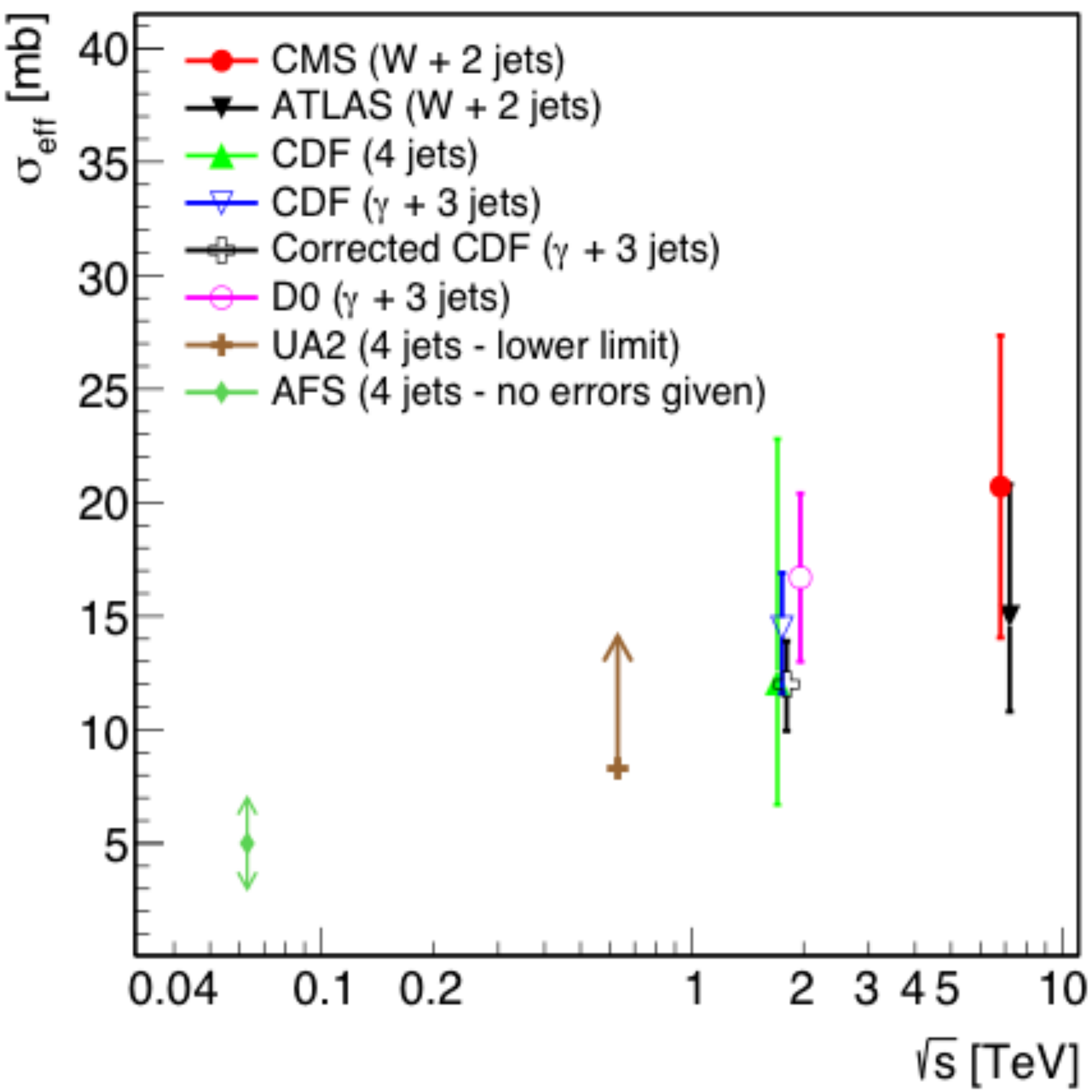
Paver, Treleani, Nuovo Cim. A70 (1982) 215.
Mekhfi, Phys. Rev. D32 (1985) 2371.
Diehl, Ostermeier and Schäfer (JHEP 1203 (2012))

b = separation in transverse space between the two partons

In this formula the two 2pGPDs are integrated over a common **b** – cannot express DPS cross section in terms of parton distributions independently integrated over their impact parameter arguments, as in single scattering case.

Comparison with Experiment

In the "pocket formula" all unknowns are summarized in the value of a single quantity σ_{eff} wich, for the second interaction, plays "effectively" the role of the inelastic cross section.



Different results of the value of σ_{eff}, where the experimental DPI cross section is given by the "pocket formula":

$$\sigma_{double}^{(A,B)} = \frac{m}{2} \frac{\sigma_A \sigma_B}{\sigma_{eff}}$$

First measurement of DPS signal at 7 TeV

New J. Phys. 15 (2013) 033038

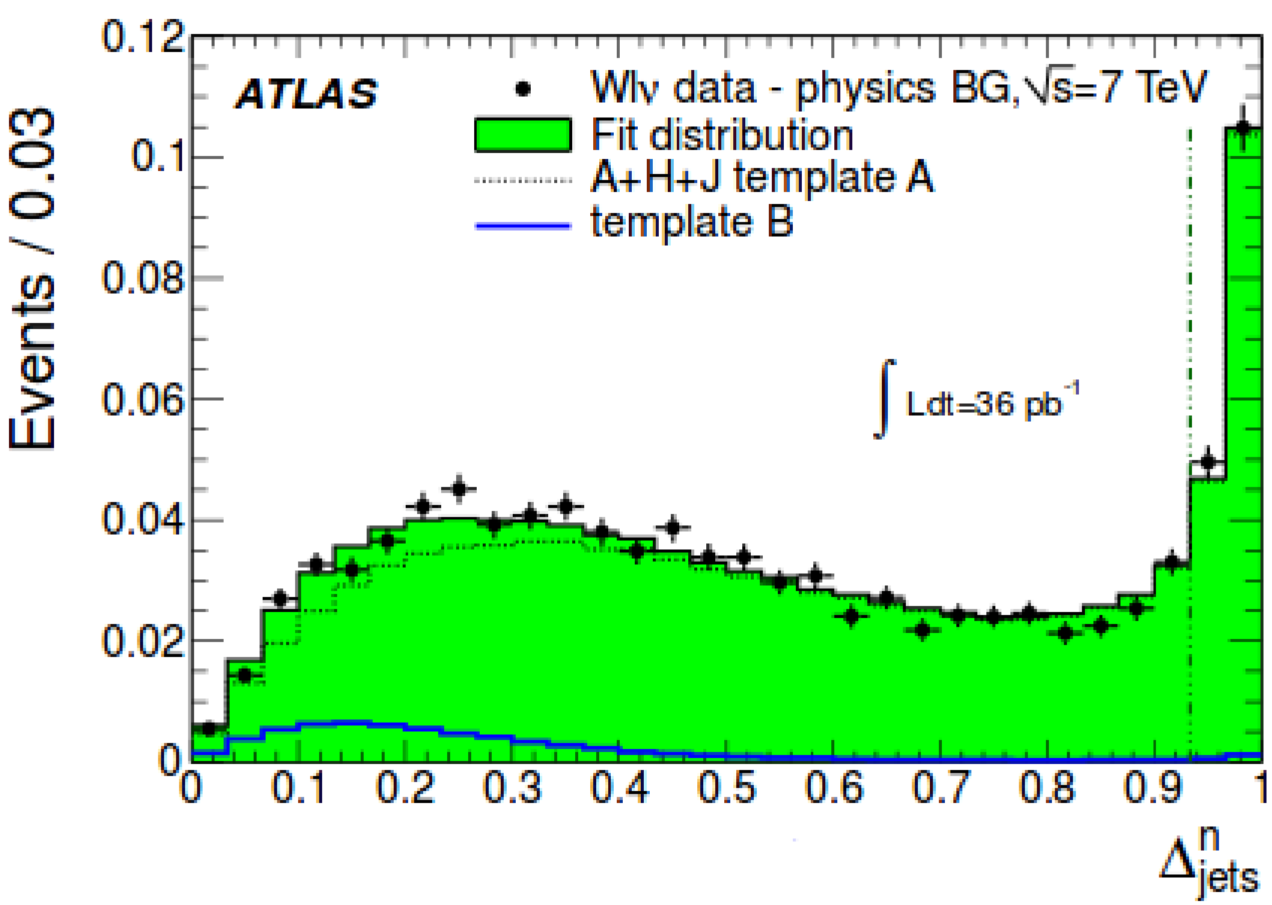
SELECTION: 2j with $p_T > 20$ GeV in $|y| < 2.8$, standard W selection

CONSIDERED OBSERVABLES: normalized $\Delta^n_{jets} = \frac{|\vec{p}_T^{1j} + \vec{p}_T^{2j}|}{|\vec{p}_T^{1j}| + |\vec{p}_T^{2j}|}$

BACKGROUND: ALPGEN+HERWIG+JIMMY with hard MPI excluded

SIGNAL: selection of two independent collisions from data

DRIVING UNCERTAINTY: model dependence



$$\sigma_{eff} = \frac{N_{W+0j}}{f_{DPS} \cdot N_{W+2j}} \cdot \sigma_{2j}$$

with $f_{DPS} = 8.0\%$ and

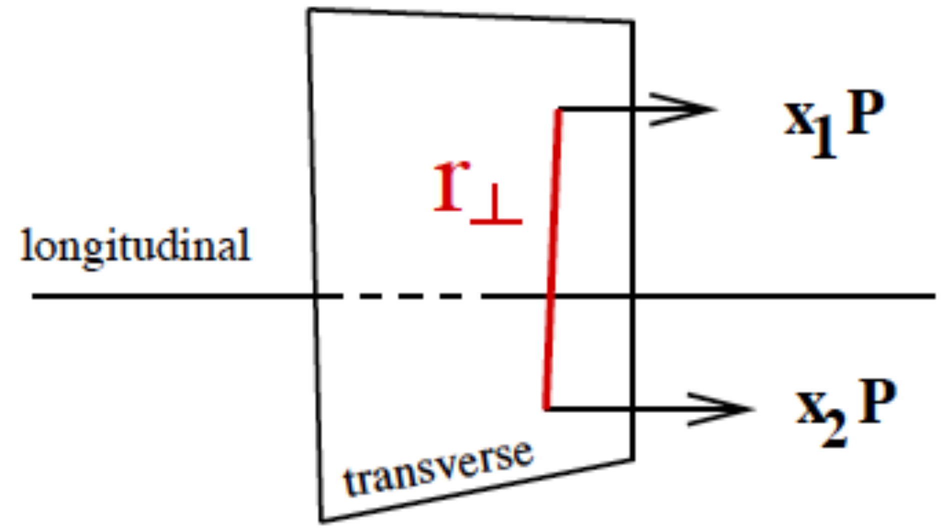
$$\frac{N_{W+0j}}{N_{W+2j}} = 23$$

$$\boxed{\sigma_{eff} = 15.0 \pm 3 \text{ (st.) } {}^{+5}_{-3} \text{ (sys.) mb}}$$

Nucleon 3D structure from dPDFs?

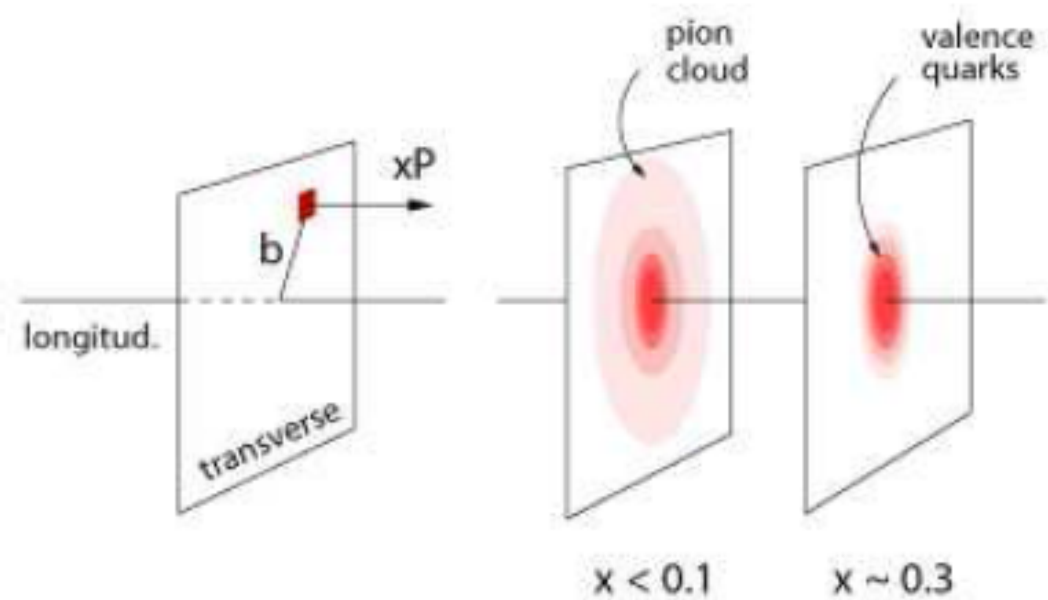
$F_{ij}(x_1, \mu_A, x_2, \mu_B, r_\perp)$ is a 2-body density

- It is dimensioned;
- Its F.T. wrt $r_\perp$, dimensionless, is NOT a density (sometimes it is called ${}_2GPD$)



Nucleon tomography proposed through GPDs (in Impact parameter space)

- $H(x, \xi = 0, b_\perp, \mu)$ is a 1-body density
- Its F.T. wrt $b_\perp$, dimensionless, is NOT a density (standard GPD)



Nucleon tomography

F_{ij} is very interesting: 2-body quantities are always theoretically intriguing (their measurement, challenging). The difference between a 2-body quantity and the product of two 1-body quantities is a measurement of CORRELATIONS

Cosmic rays and accelerator physics
(Alessia Tricomi, Paolo Lipari)

Overview on cosmic rays and accelerators: Ralph Engel

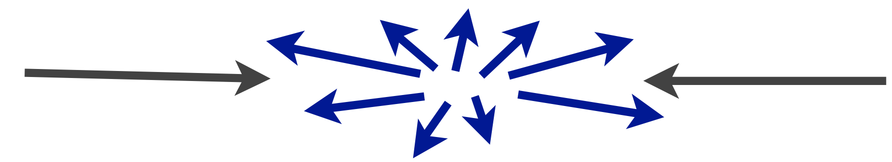
Cosmic ray phenomenology - low energy: Fiorenza Donato

Cosmic ray phenomenology - high energy: Andrea Chiavassa

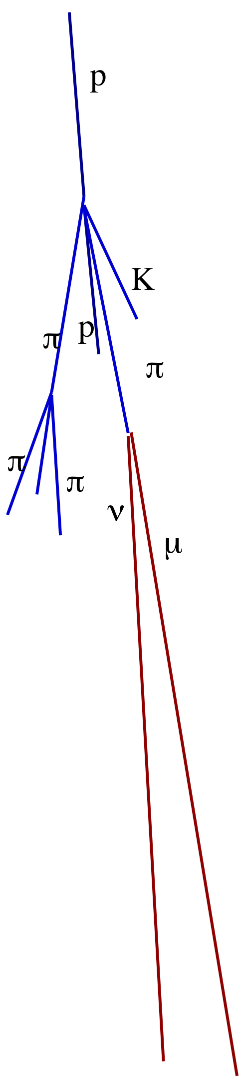
Cosmic ray and accelerators, experiment: Lorenzo Bonechi

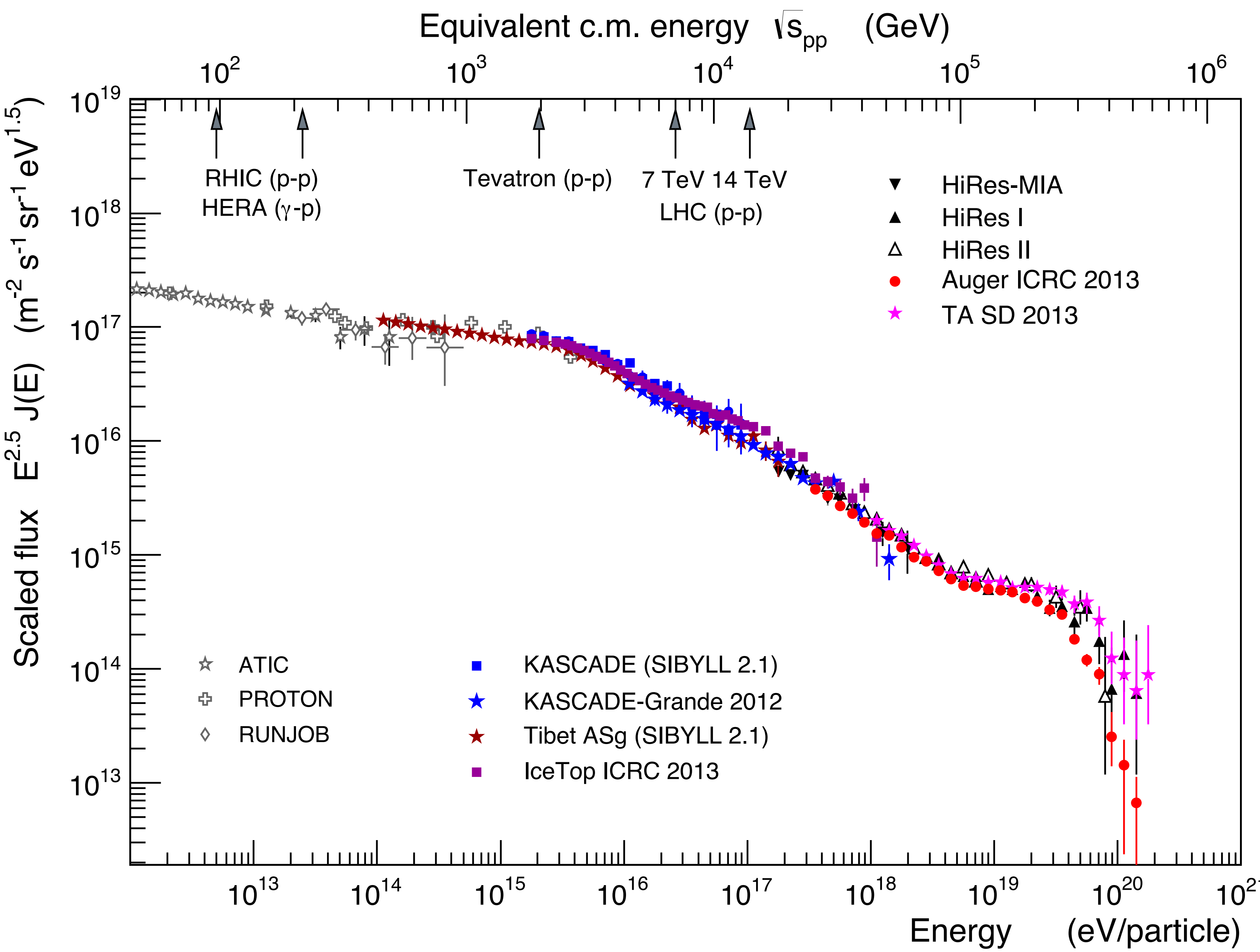
Cosmic ray, future: Oscar Adriani

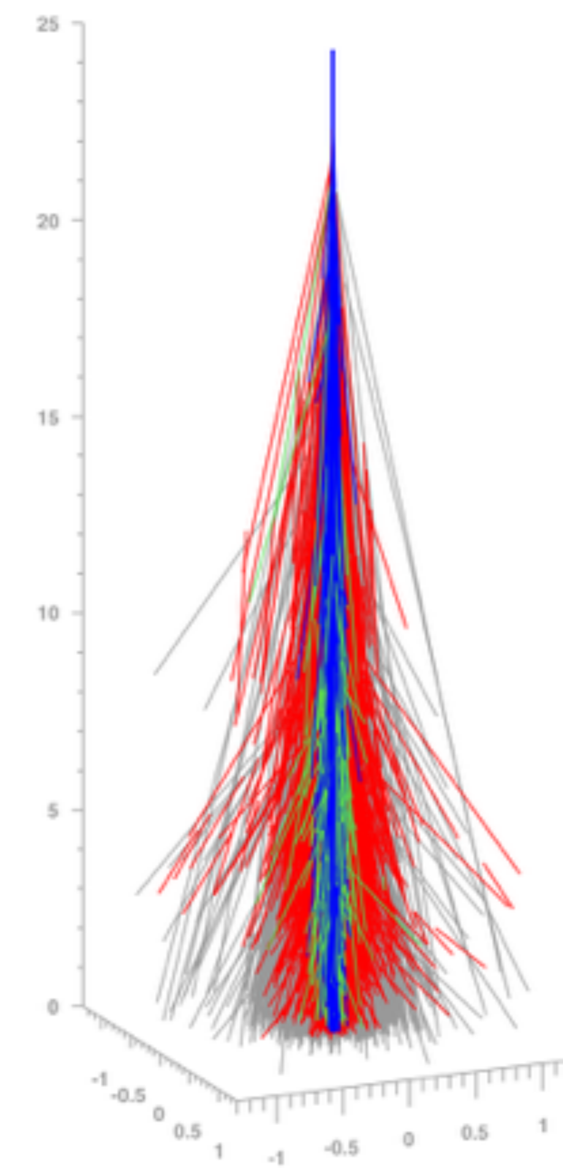
Cosmic ray flux and interaction energies

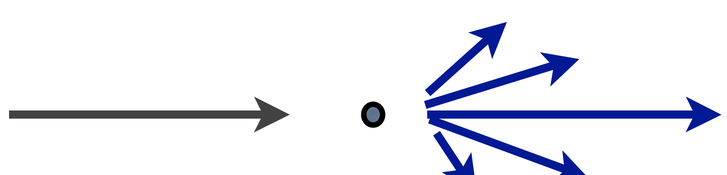


Center-of-mass energy



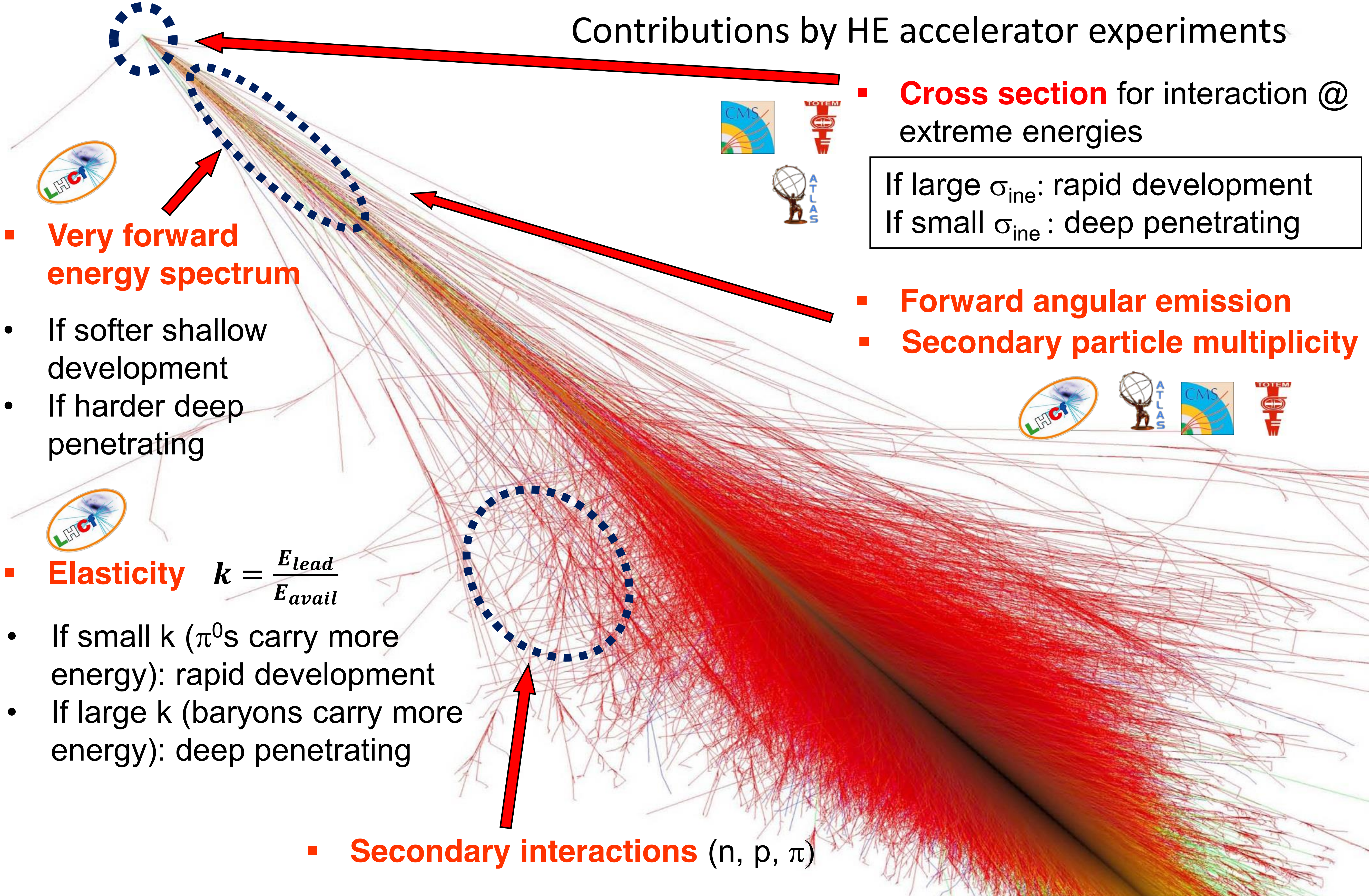






Laboratory energy

Study of Very High Energy Cosmic Rays



Contributions by HE accelerator experiments

- **Cross section** for interaction @ extreme energies

If large σ_{ine}: rapid development If small σ_{ine} : deep penetrating

- **Forward angular emission**
- **Secondary particle multiplicity**

- **Very forward energy spectrum**

• If softer shallow development
• If harder deep penetrating

- **Elasticity** $k = \frac{E_{lead}}{E_{avail}}$

• If small k (π^0s carry more energy): rapid development
• If large k (baryons carry more energy): deep penetrating

- **Secondary interactions** (n, p, π)

Few final remarks

Fiorenza Donato

The astrophysics of cosmic rays is entering an era of remarkable **precision** (AMS-02/ISS)

ANTIMATTER is a key element for testing galactic models and searching for DARK MATTER signals

Propagation uncertainties confined to less than 20%, close to be < 10%

The (production, total inelastic, inelastic non-annihilating, …) cross sections from Fe down, including isotopes and antimatter, rely on very few or (often) NO lab data!!

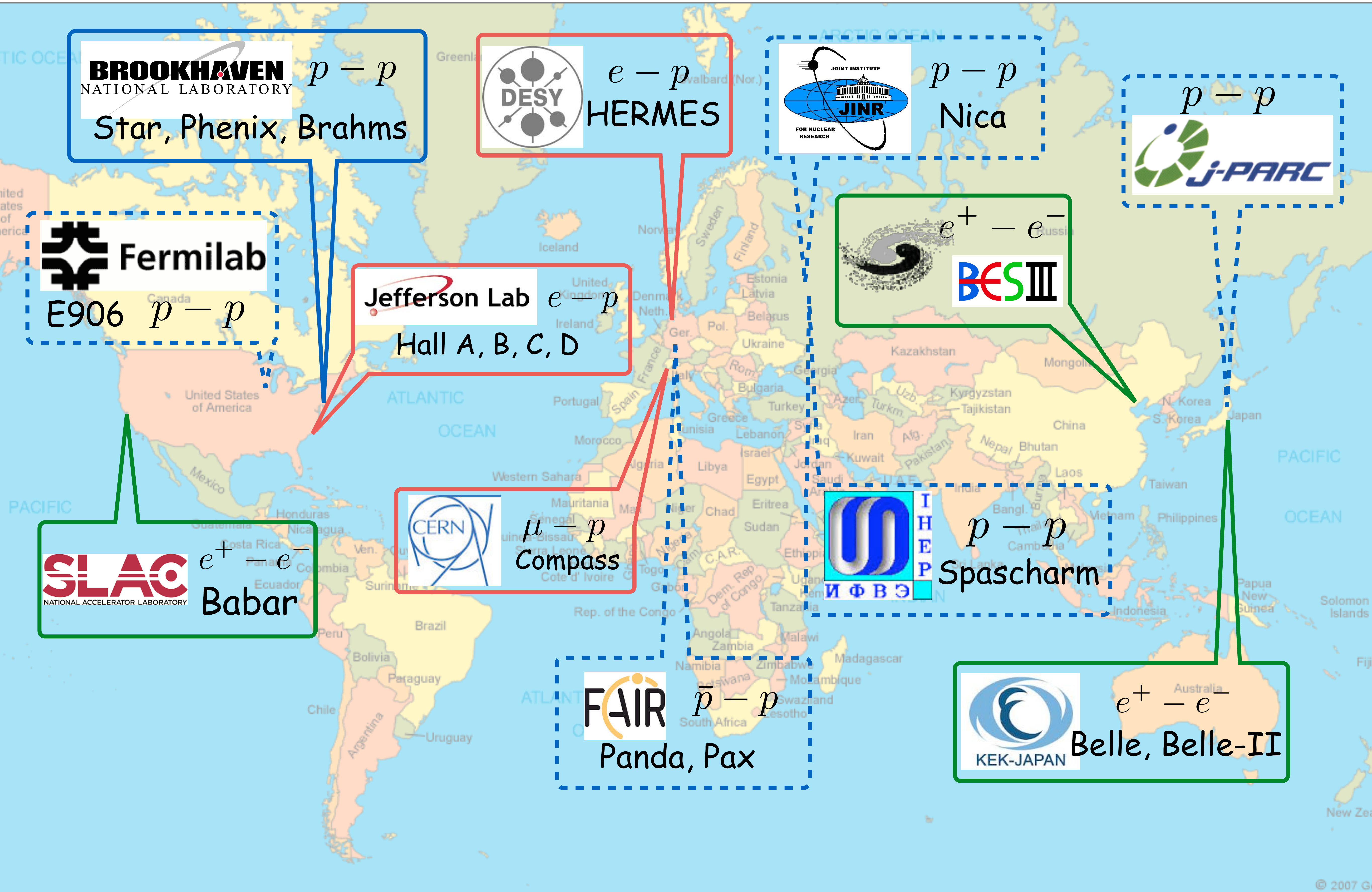
→ A HUGE EXPERIMENTAL PROGRAM IS REQUIRED FOR A SIGNIFICANT REDUCTION OF UNCERTAINTIES

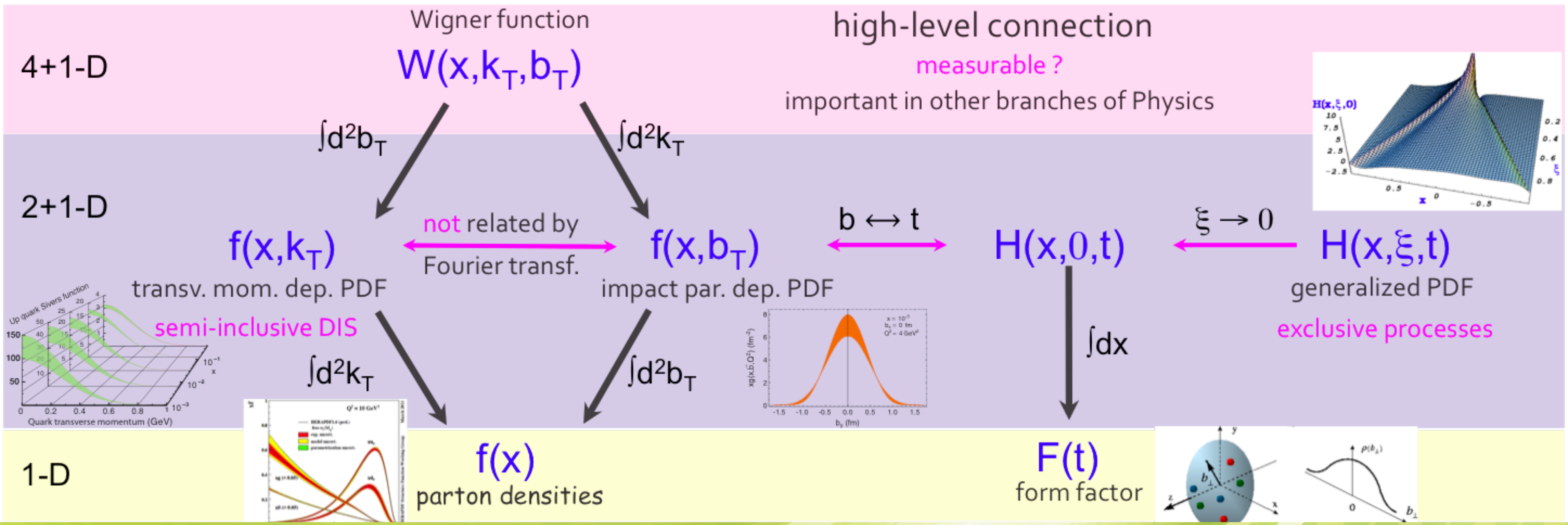
Proton-helium→ antiproton + X looks the most urgent case (contextually, measure of → e+, γ, D-)

A new idea!

- After the talk of F. Donato yesterday a new idea came to my mind
- The SMOG system has already been tested in 2012 in LHCb
  - Injection of noble gas atoms inside the beam pipe to:
    - Measure the beam profile
    - Measure the luminosity
- Why don't use SMOG to measure cross section relevant for Cosmic Ray Physics???
  - P-He→Antiprotons+X
- We could make use of 'perfect' Particle Identification Detectors
- We could make use of the highest possible energies
  - Direct access to protons in the most interesting energy region

some hadron physics in the world



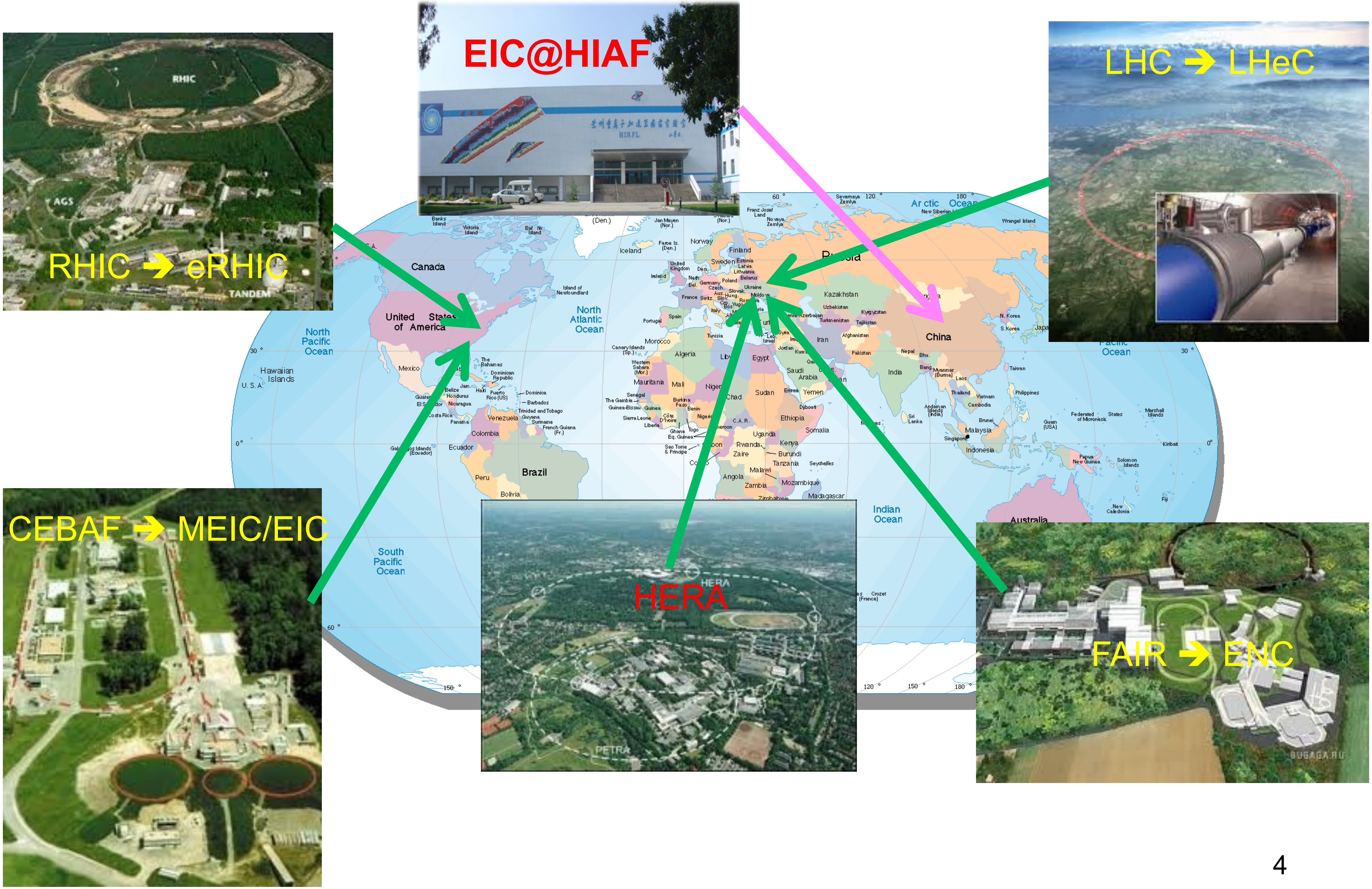


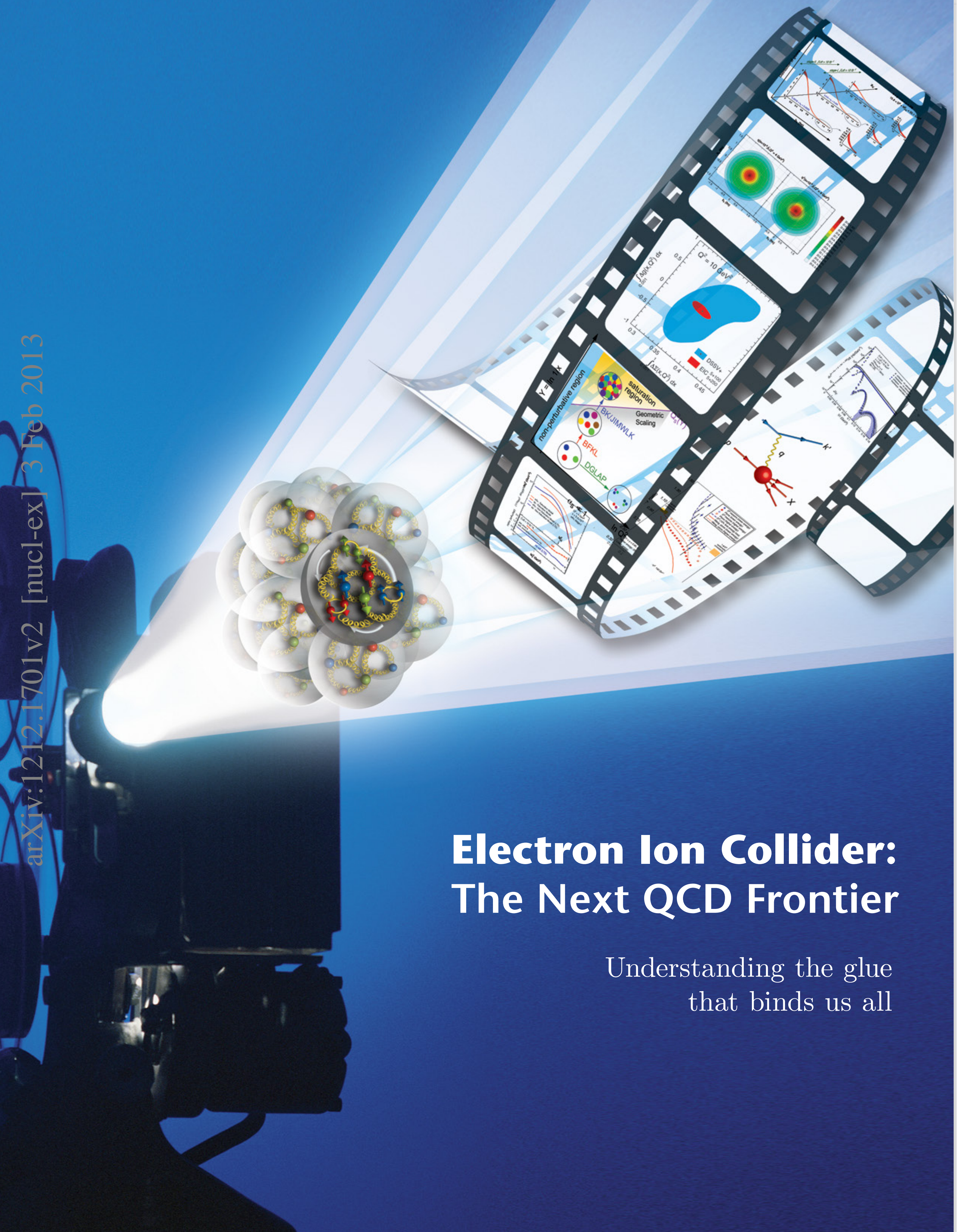
The RHIC SPIN Program

Achievements and Future Opportunities

Elke-Caroline Aschenauer (BNL), Alexander Bazilevsky (BNL), James Drachenberg (Valparaiso U.), Kjeld Oleg Eyser (BNL), Renee Fatemi (Kentucky U.) ,
Carl Gagliardi (Texas A&M), John Lajoie (Iowa U.), Ralf Seidl (Riken), Ernst Sichtermann (LBNL), Berndt Surrow (Temple U.), Marco Stratmann (Uni-Tuebingen),
Werner Vogelsang (Uni-Tuebingen), and Anselm Vossen (Indiana U.)

Main EIC plans in the world





future facilities
and experiments:

D-Y @ COMPASS

JLAB 12 GeV

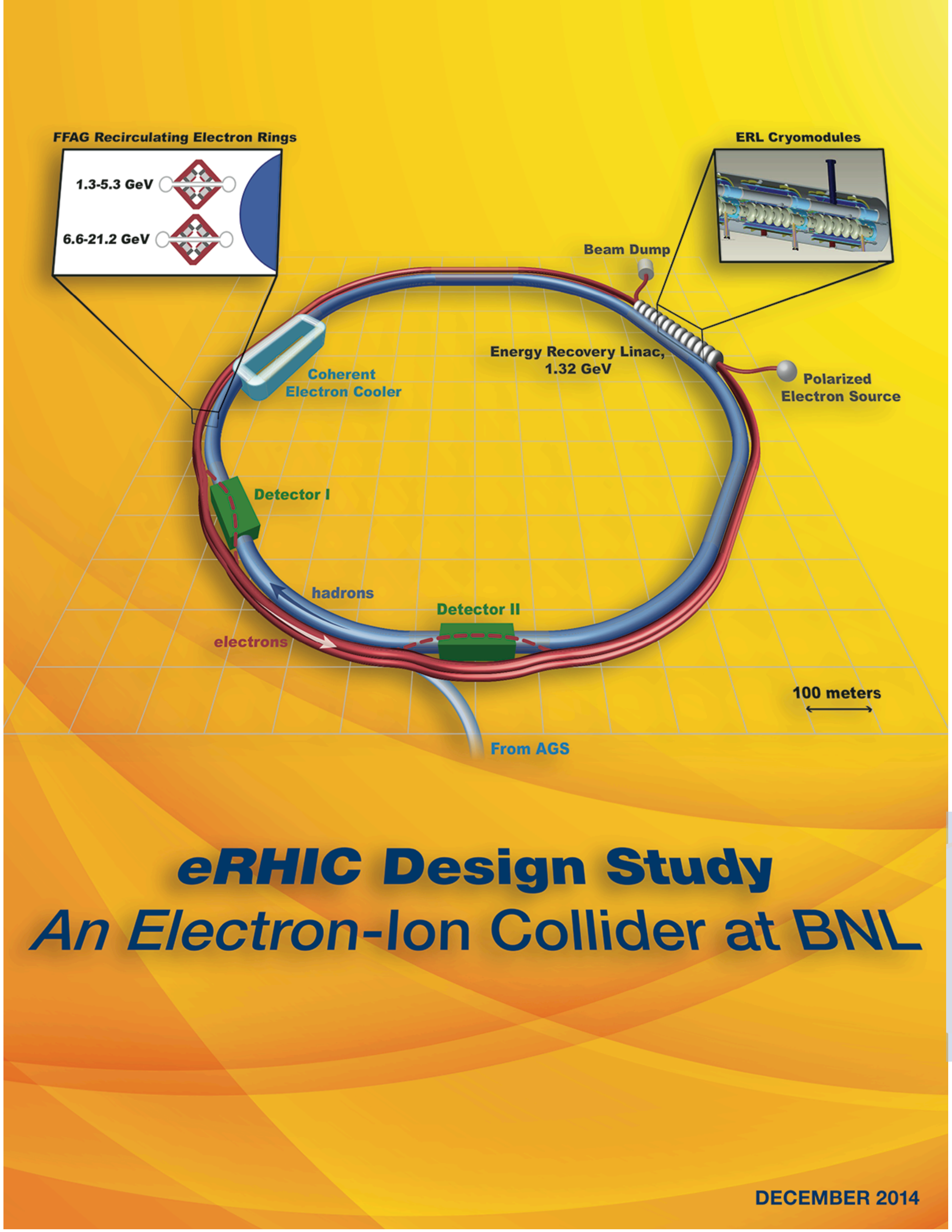
EIC

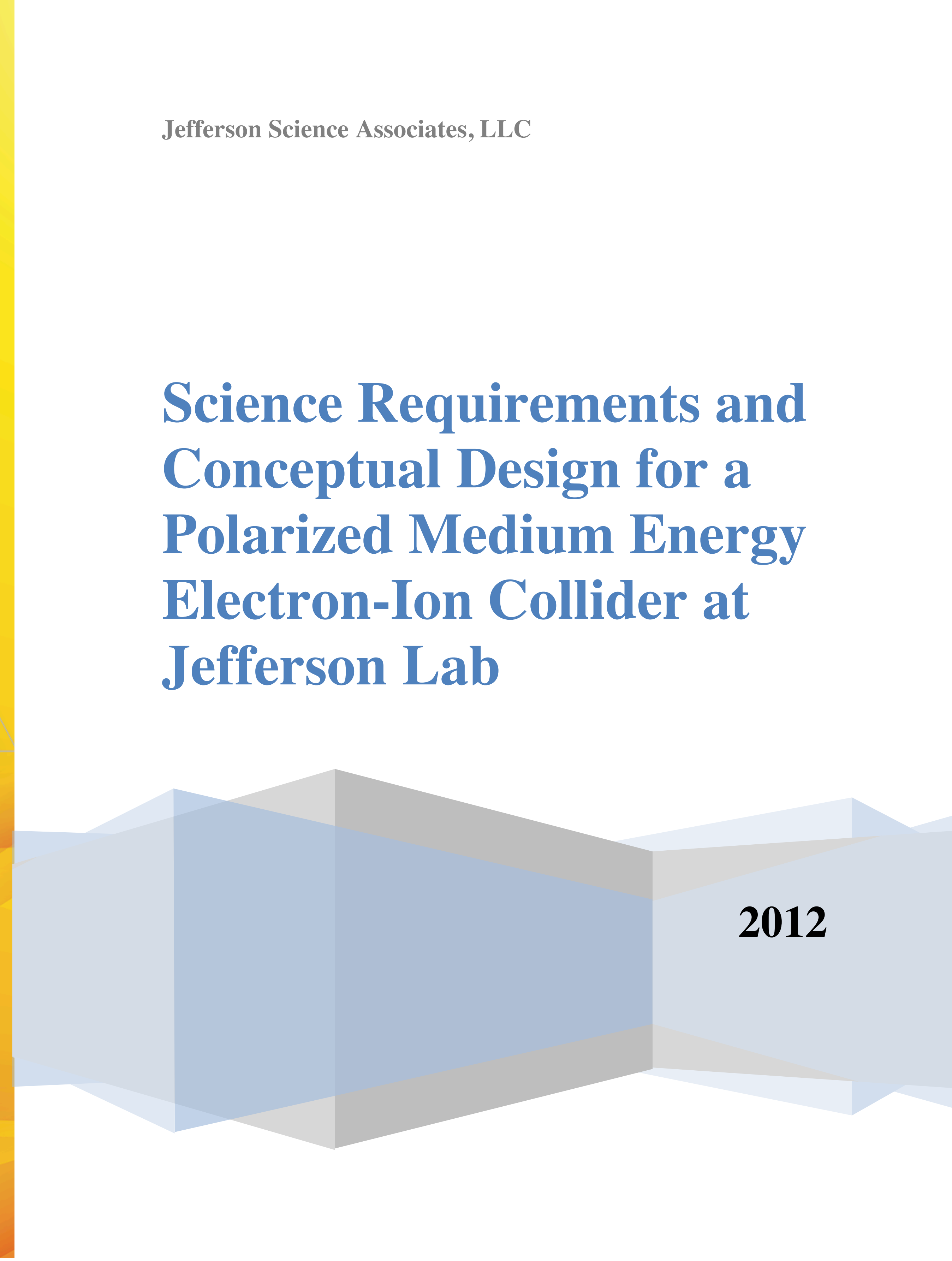
BESIII

AFTER

NICA-SPD

....




Jefferson Science Associates, LLC

Science Requirements and Conceptual Design for a Polarized Medium Energy Electron-Ion Collider at Jefferson Lab

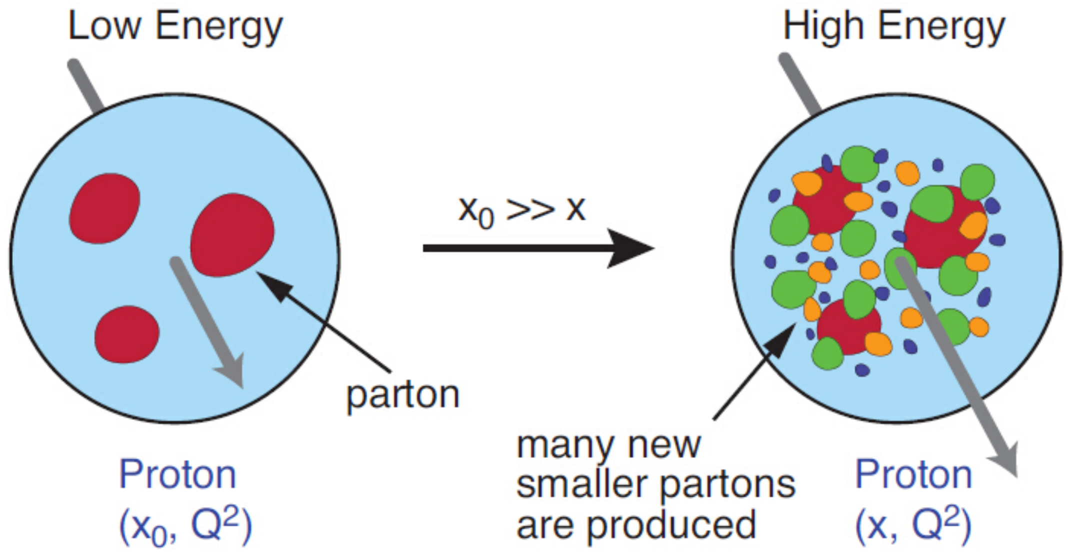
2012

eRHIC and MEIC-JLab

Physics Programs at EIC@HIAF

Six golden experiments

1. Nucleon spin-flavor structure (polarized sea, Δs)
2. GPDs (Deep-Virtual Meson Production, pion/Kaon)
3. TMD in "sea quark" region and significant increase in Q^2 / P_T range for valence region
4. Pion/Kaon structure functions in the high-x (valence) region
5. e-A to study hadronization
6. EMC-SRC in e-A



2014

QCD and Hadron Physics

Summary of the DNP Town Meeting
Temple University, 13-15 September 2014

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many thanks to the conveners and all participants

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3-dimensional nucleon structure

hadron spectroscopy

pp-cross section, elastic scattering and diffraction physics

cosmic rays and accelerator physics

multi parton interactions and underlying event