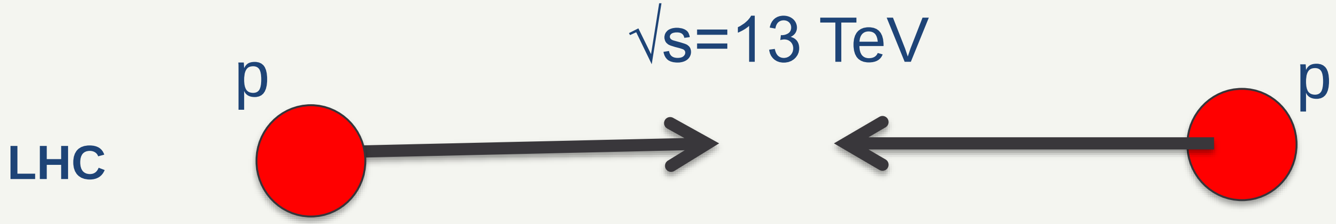
Glueballs at the LHC: experimental possibilities

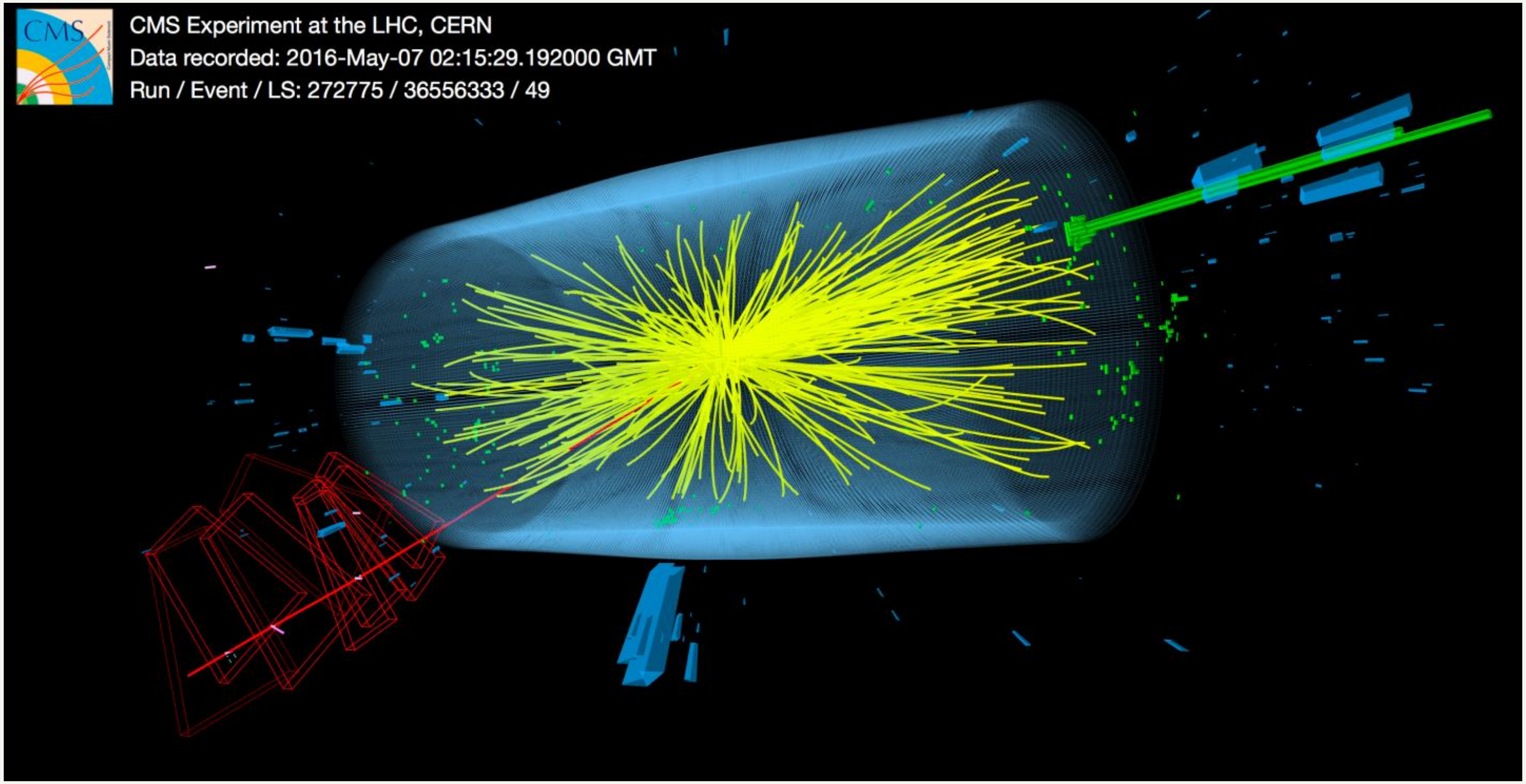
Ronan McNulty

Glueball hunting workshop, 1-2 June 2021

Overview

- Introduction to Ultra-peripheral Collisions
- Brief Experimental Review
  - Omega spectrometer
  - STAR at RHIC
  - LHC experiments
- The glueball filter

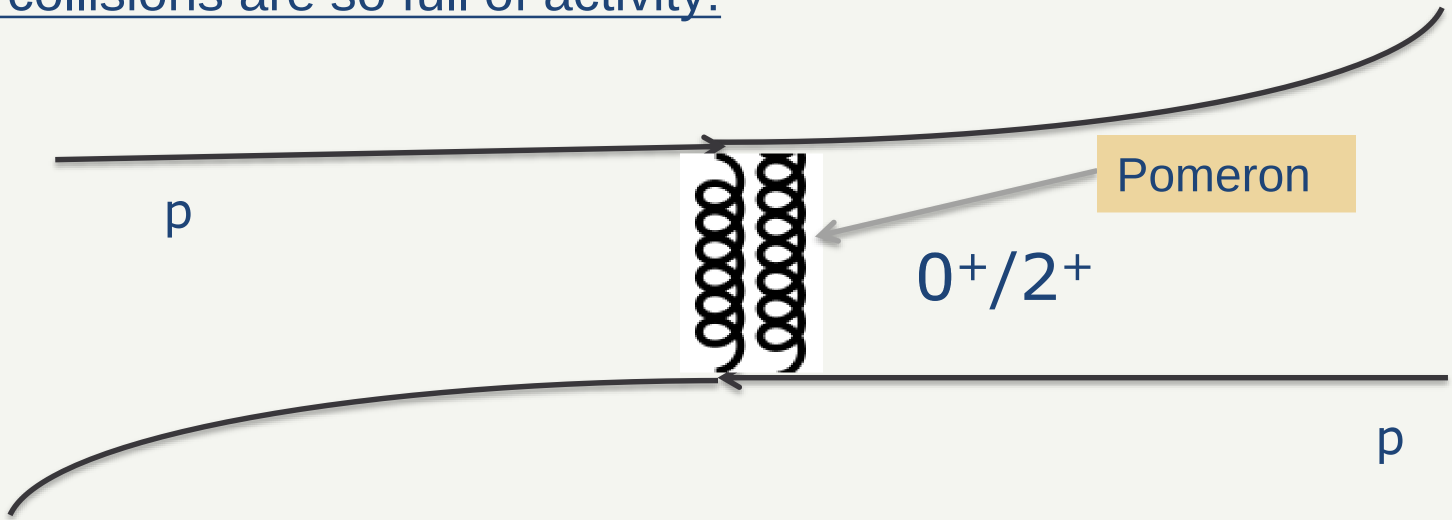




How are you going to identify a glueball here?

Elastic scattering

Not all collisions are so full of activity!



Elastic scattering has strong and EM contributions
but for the protons to remain intact, exchange particle must be colourless.
Thus at least two gluons (**Pomeron**) or three gluons (**Odderon**).

Elastic scattering

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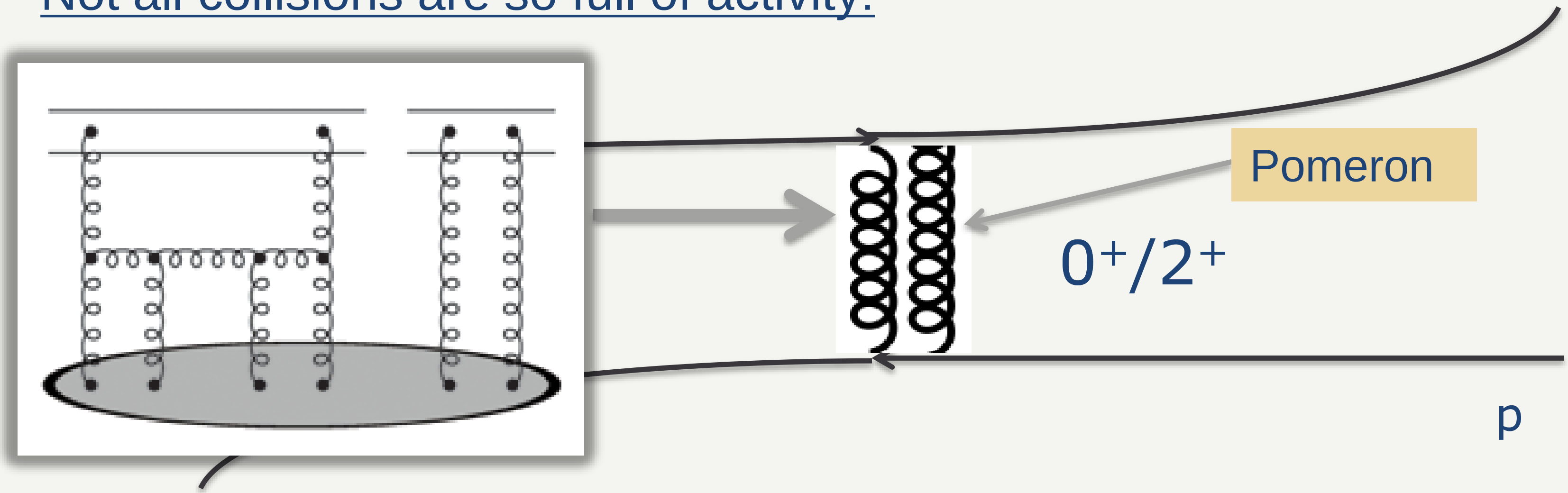

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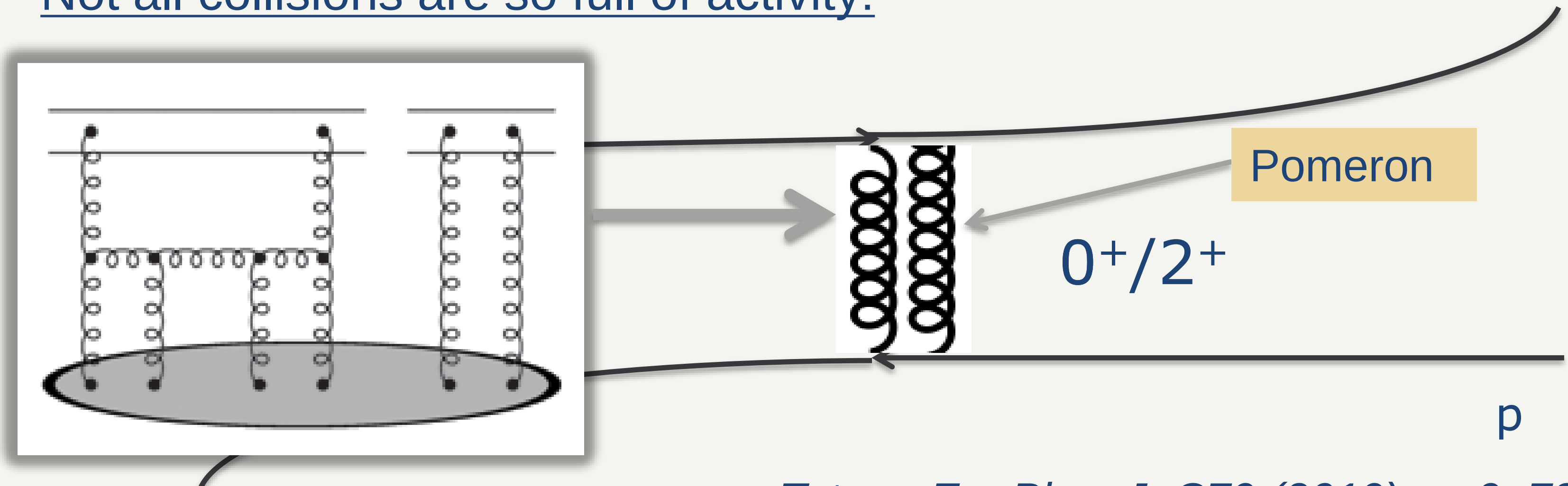
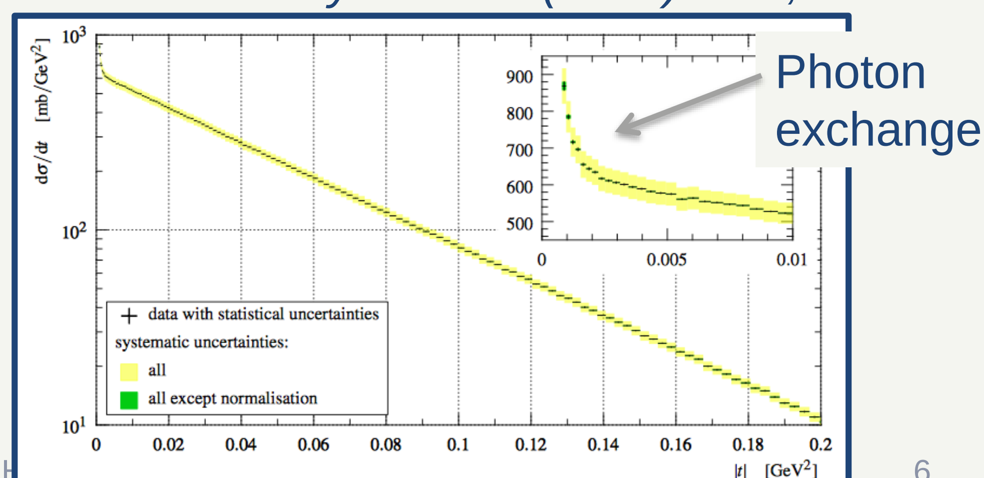


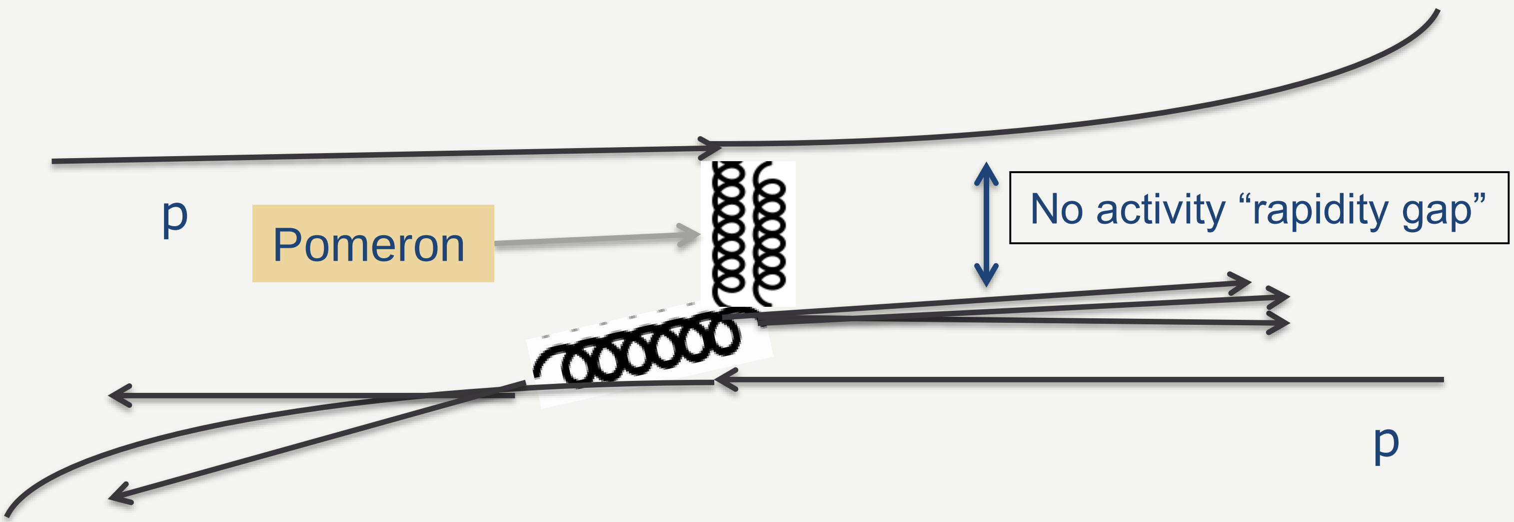
At high energy: $A(s,t)=s^{\alpha(t)}$
$\alpha_P(t)=\alpha_P(0)+\alpha' t$

$\sigma_{elastic}$ ≈ 40mb
$\sigma_{diffractive}$ ≈ 10mb
$\sigma_{inelastic}$ ≈ 60mb

Totem: Eur.Phys.J. C79 (2019) no.9, 785



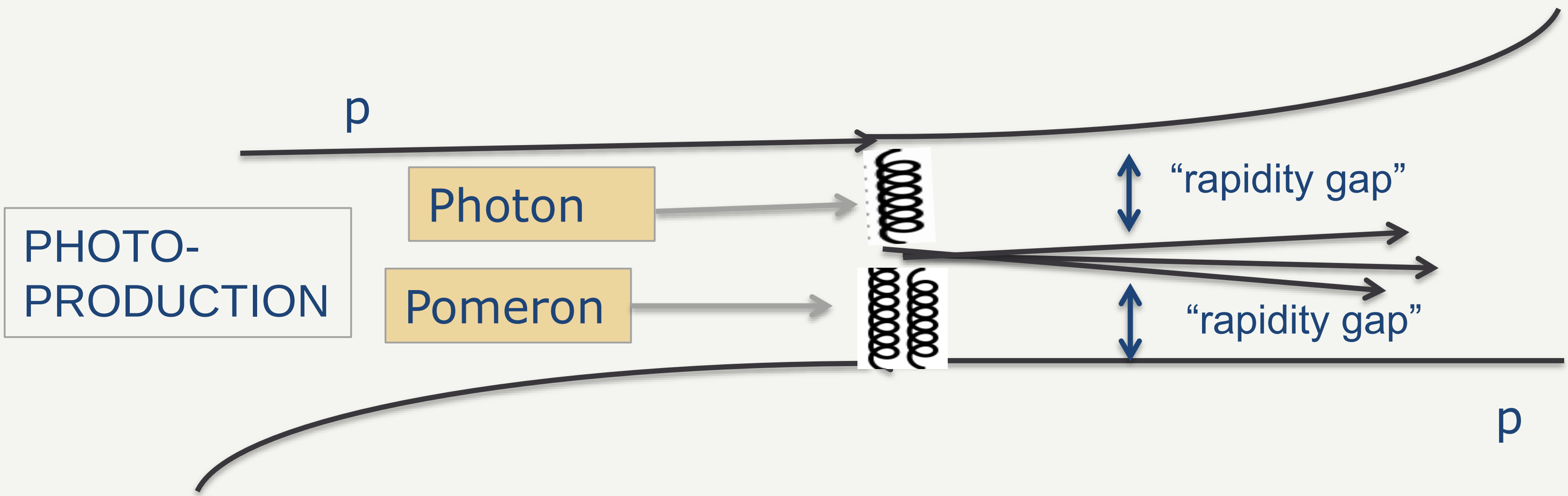
Diffraction



$\sigma_{elastic} \approx 40mb$
$\sigma_{diffractive} \approx 10mb$
$\sigma_{inelastic} \approx 60mb$

Experimentally accessed through identification of **rapidity gap.**

Central Exclusive Production (CEP)



$\sigma_{elastic}$ ≈ 40mb

$\sigma_{diffractive}$ ≈ 10mb

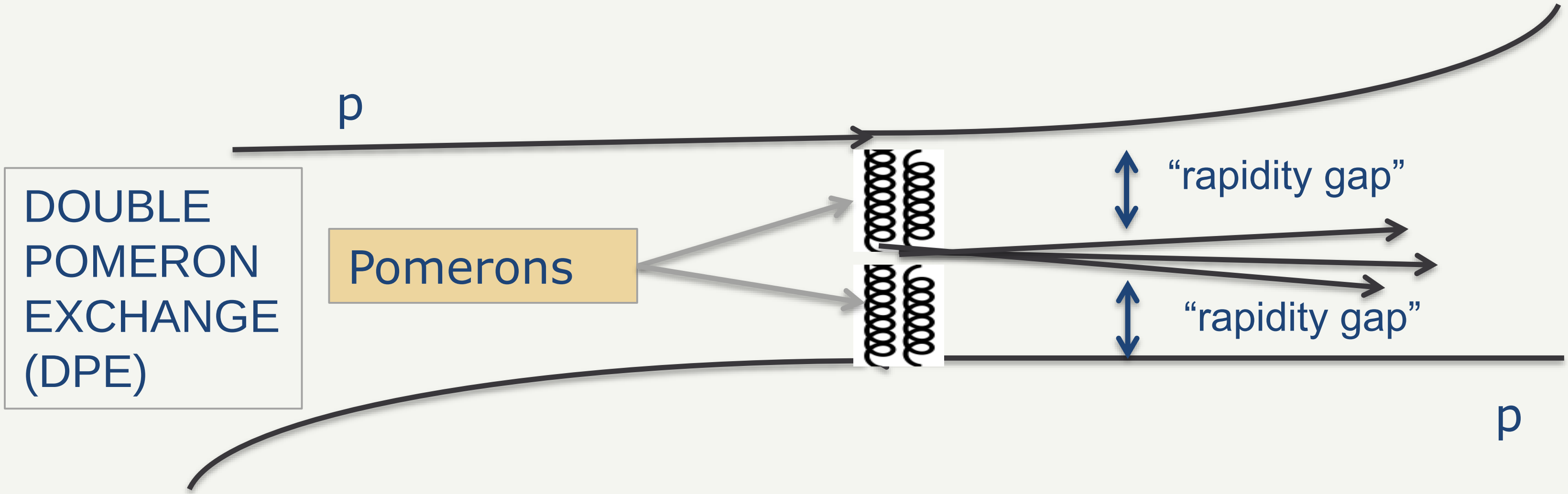
$\sigma_{inelastic}$ ≈ 60mb

100 μb

Two rapidity gaps
Both protons remain intact
Elastic scatter where you produce
a central colour-neutral system

Photoproduction produces odd parity system
(generally vector mesons)

Central Exclusive Production (CEP)



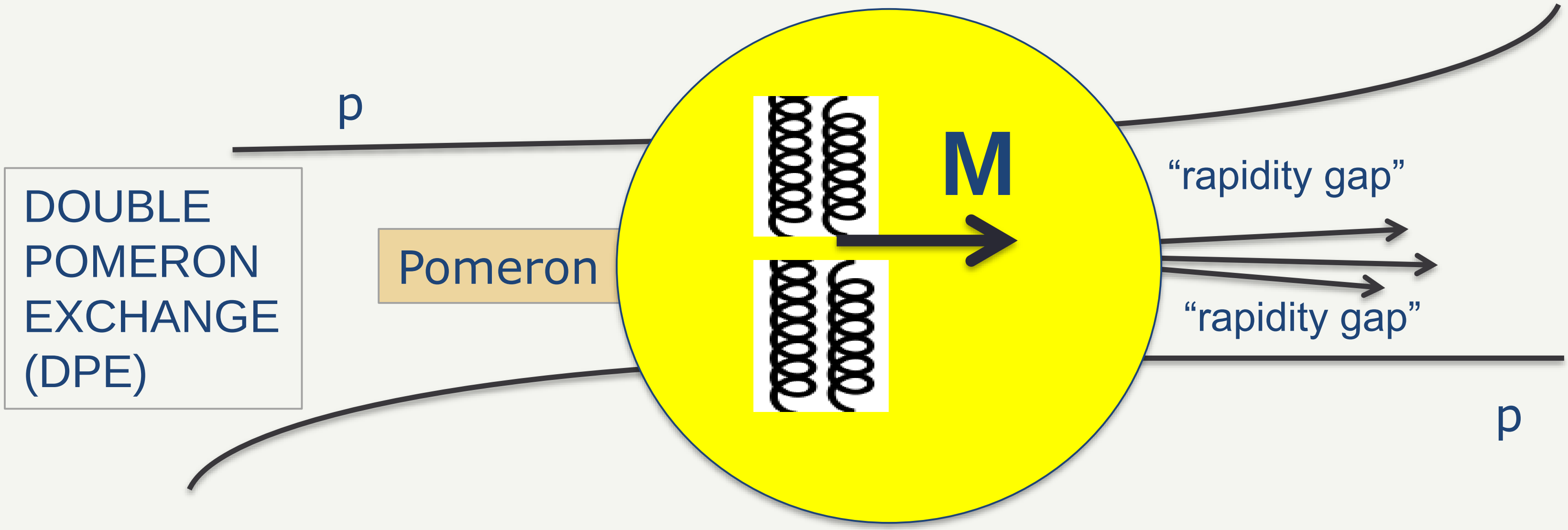
$\sigma_{elastic} \approx 40\text{mb}$

$\sigma_{diffractive} \approx 10\text{mb}$ ⟸ 100 μb

$\sigma_{inelastic} \approx 60\text{mb}$

Double pomeron exchange produces even parity system

Central Exclusive Production (CEP)



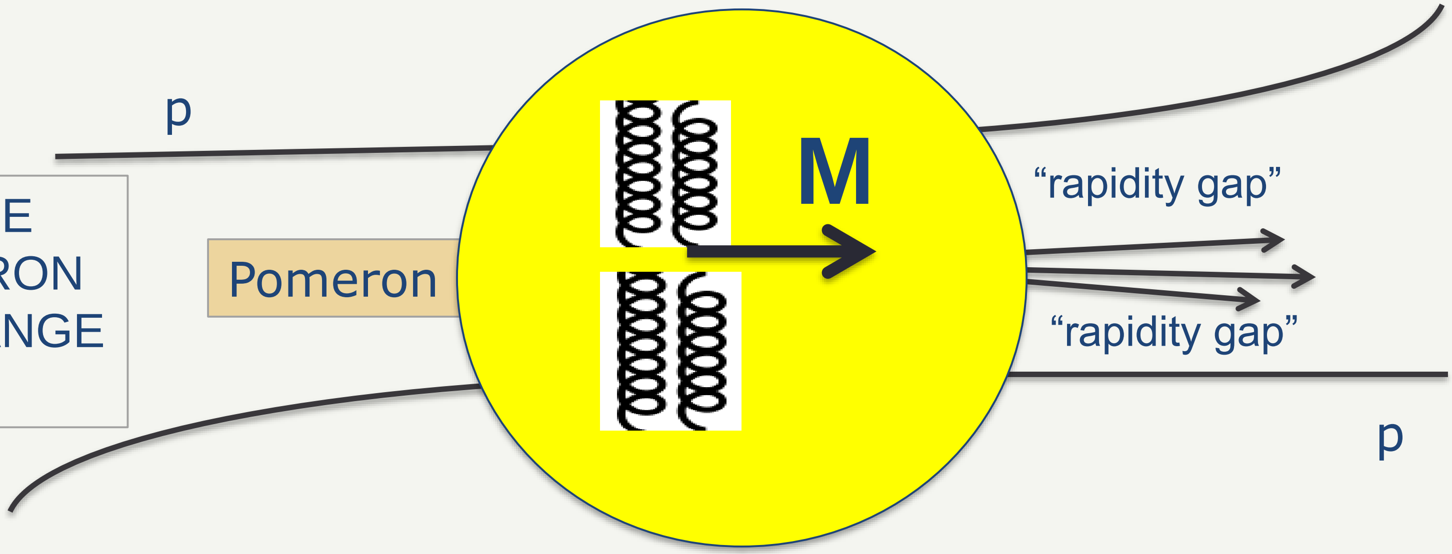
This is a glue-factory.
Surely an ideal environment to produce glueballs.

$\sigma_{elastic}$ ≈ 40mb
$\sigma_{diffractive}$ ≈ 10mb
$\sigma_{inelastic}$ ≈ 60mb

100 μb

Central Exclusive Production (CEP)

DOUBLE POMERON EXCHANGE (DPE)



$\sigma_{elastic} \approx 40mb$
$\sigma_{diffractive} \approx 10mb$
$\sigma_{inelastic} \approx 60mb$

100 μb

1. Experimentally clean
2. Large cross-section
3. Spin analyser

Of course you will also produce 'standard' mesons so how can glueballs be distinguished?

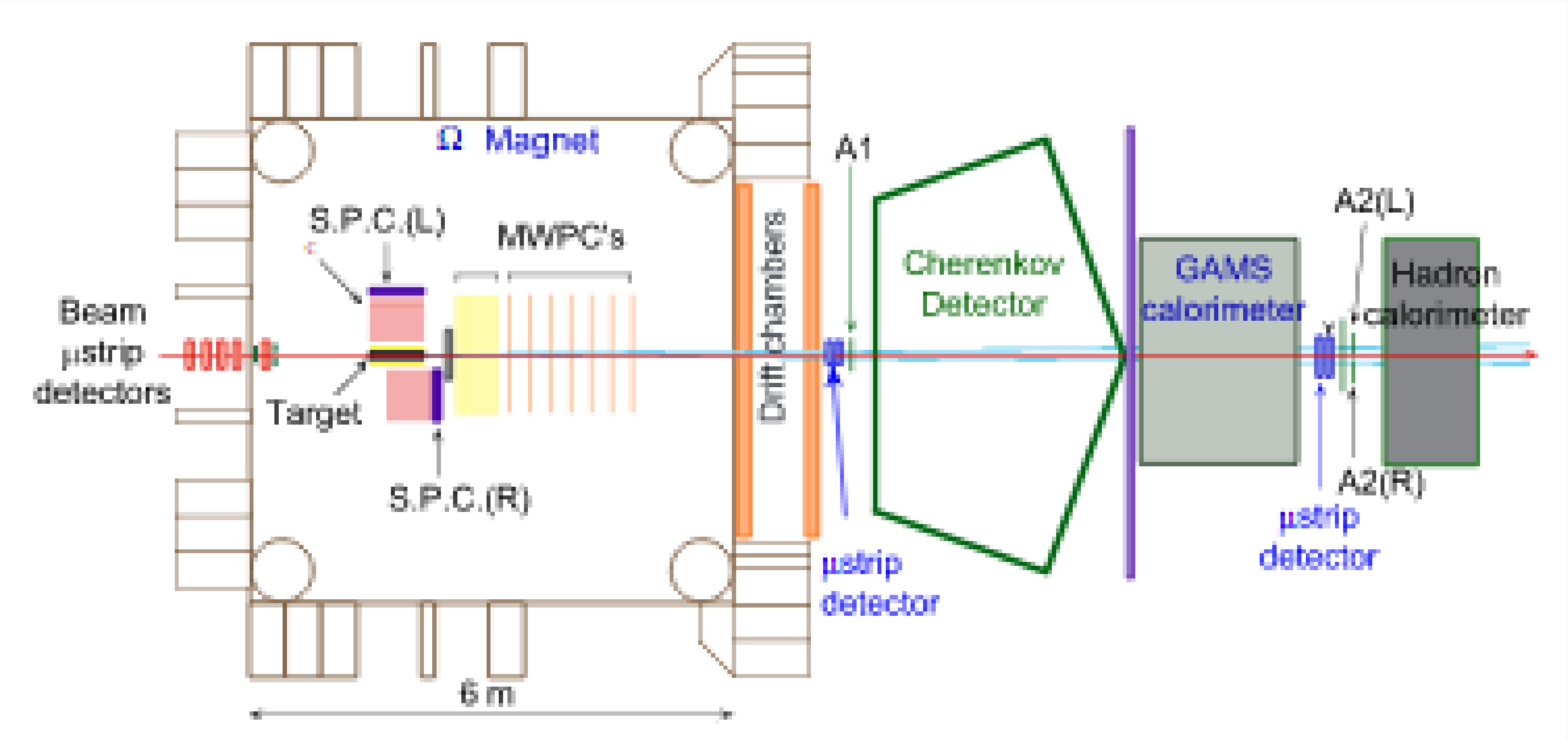
Experiments

- Omega Spectrometer (12 – 30 GeV)
  - Reggeon contributions not insignificant
- STAR at RHIC (200 – 500 GeV)
  - Pure DPE
- LHC (7-13 TeV)

Previous experiments (Omega)

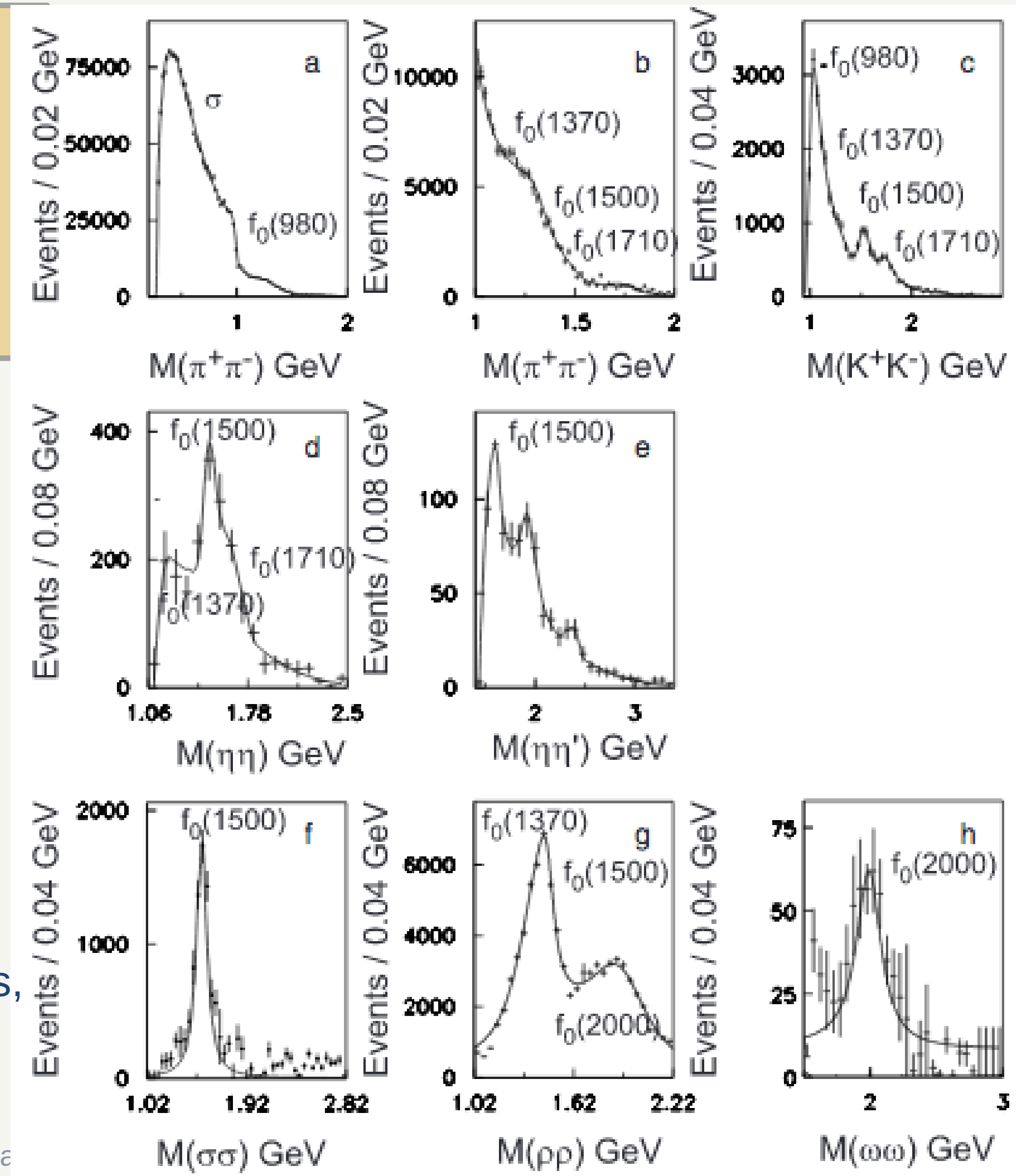
A. Kirk, *Int.J.Mod.Phys.A* 29 (2014) 28, 1446001

$\sqrt{s}$ = 12 – 30 GeV



S-wave for several final states

A. Kirk, *Int.J.Mod.Phys.A* 29 (2014) 28, 1446001



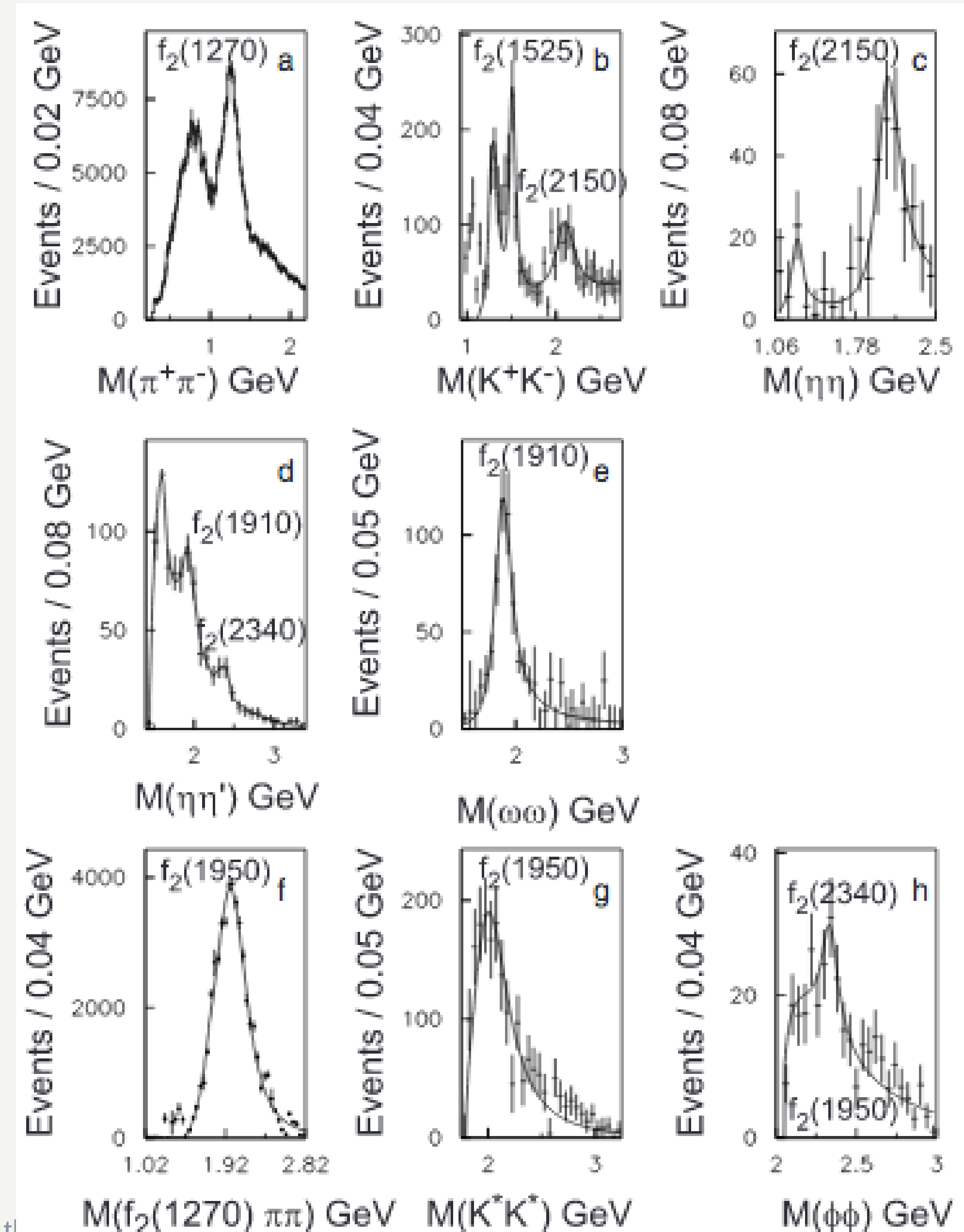
Identify the scalar glueball

(e.g. democratic decay modes, global analysis?)

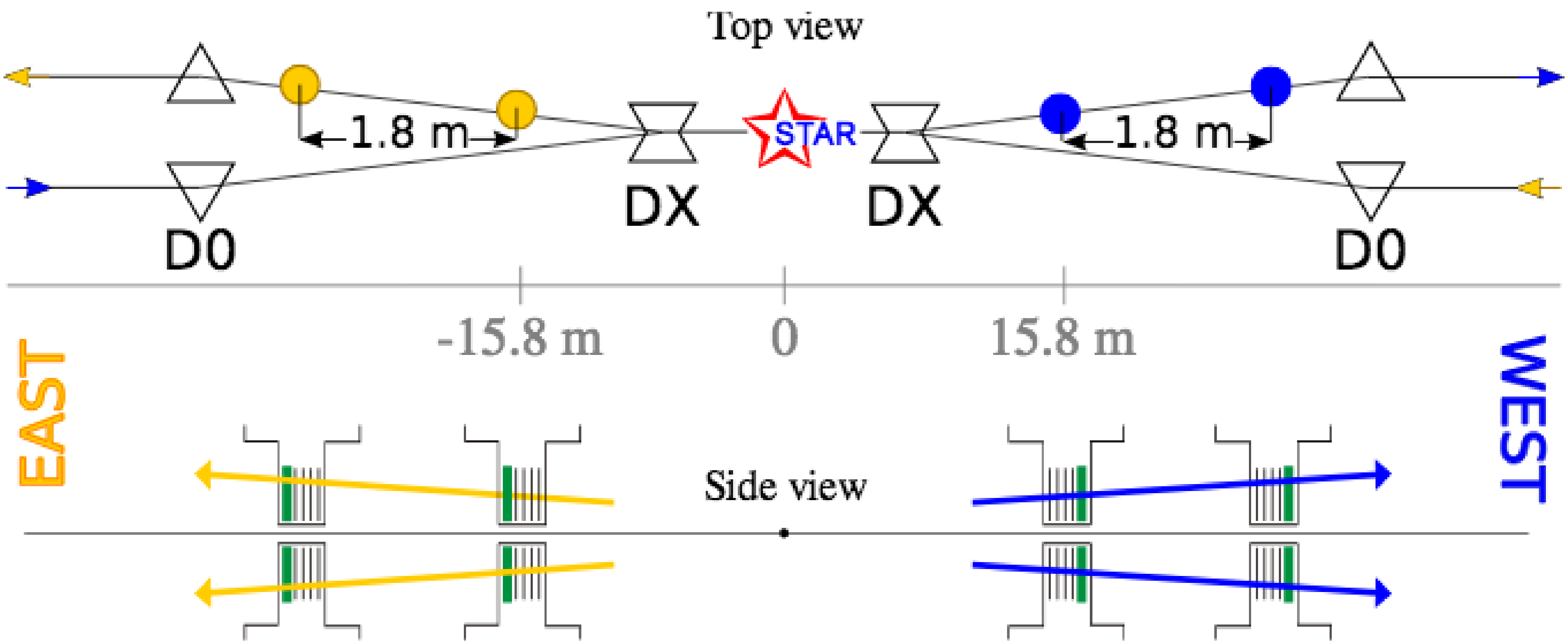
D-wave for several final states

A. Kirk, *Int.J.Mod.Phys.A* 29 (2014) 28, 1446001

Identify the tensor glueball



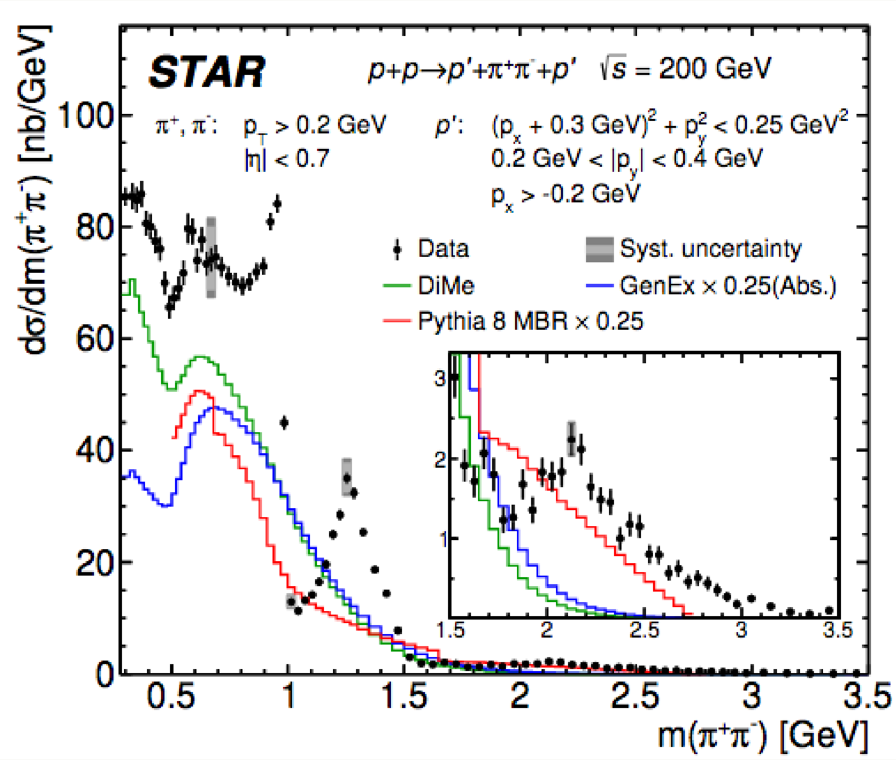
STAR

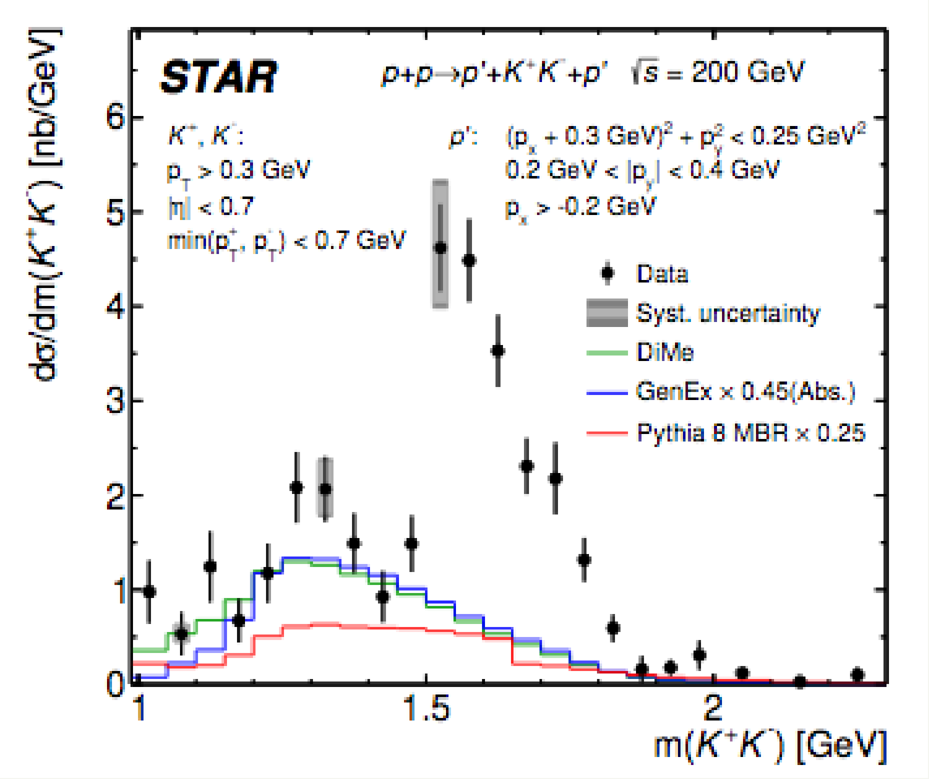


STAR can measure the outgoing protons so complete kinematics can be reconstructed. Also allows angular (azimuthal) correlations to be measured.

STAR: ππ and KK spectra

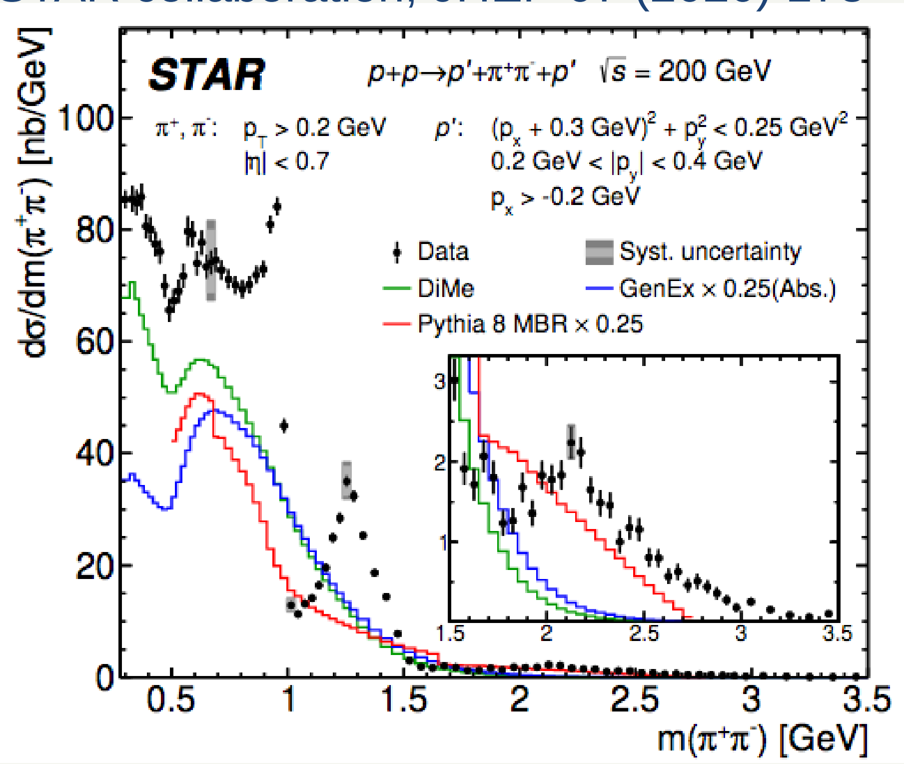
STAR collaboration, JHEP 07 (2020) 178



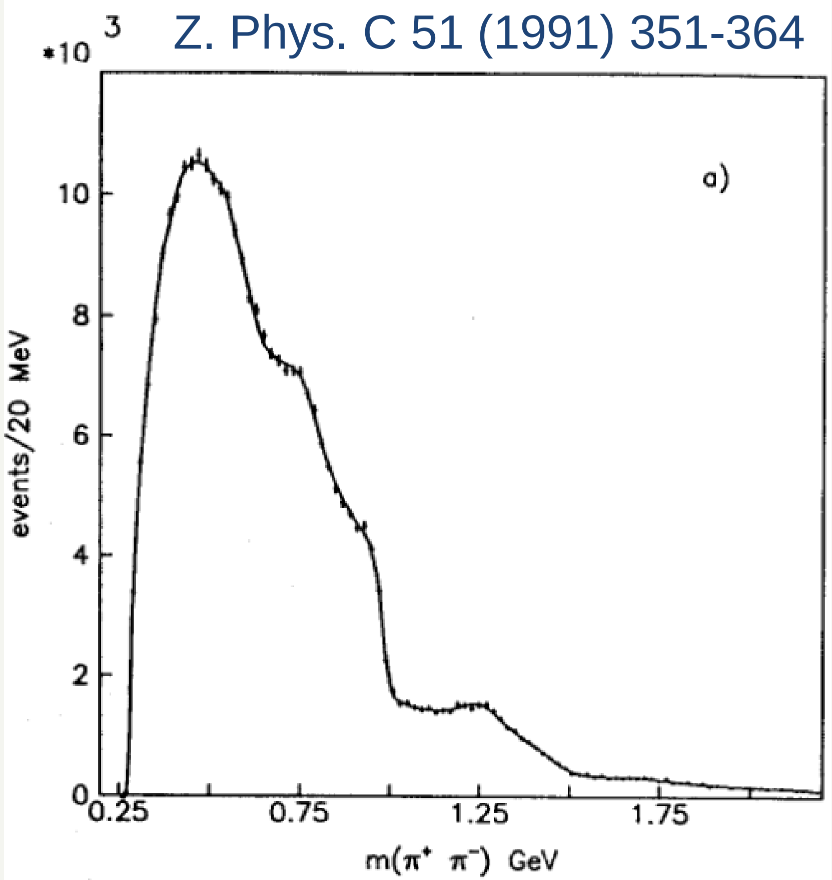


STAR v OMEGA: ππ spectra

STAR collaboration, JHEP 07 (2020) 178



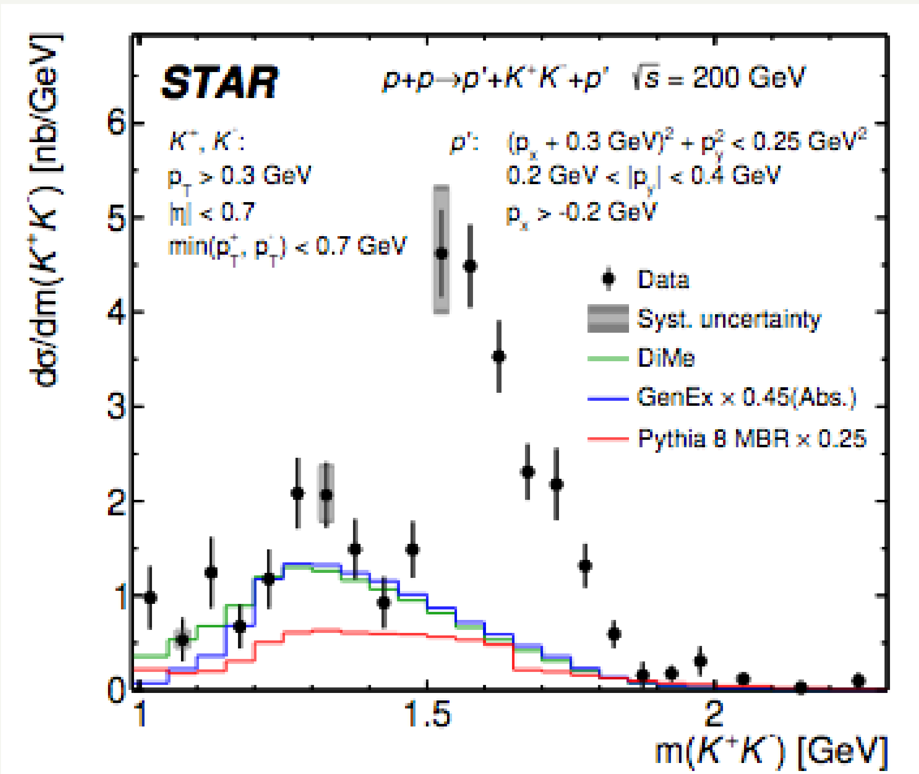
Z. Phys. C 51 (1991) 351-364

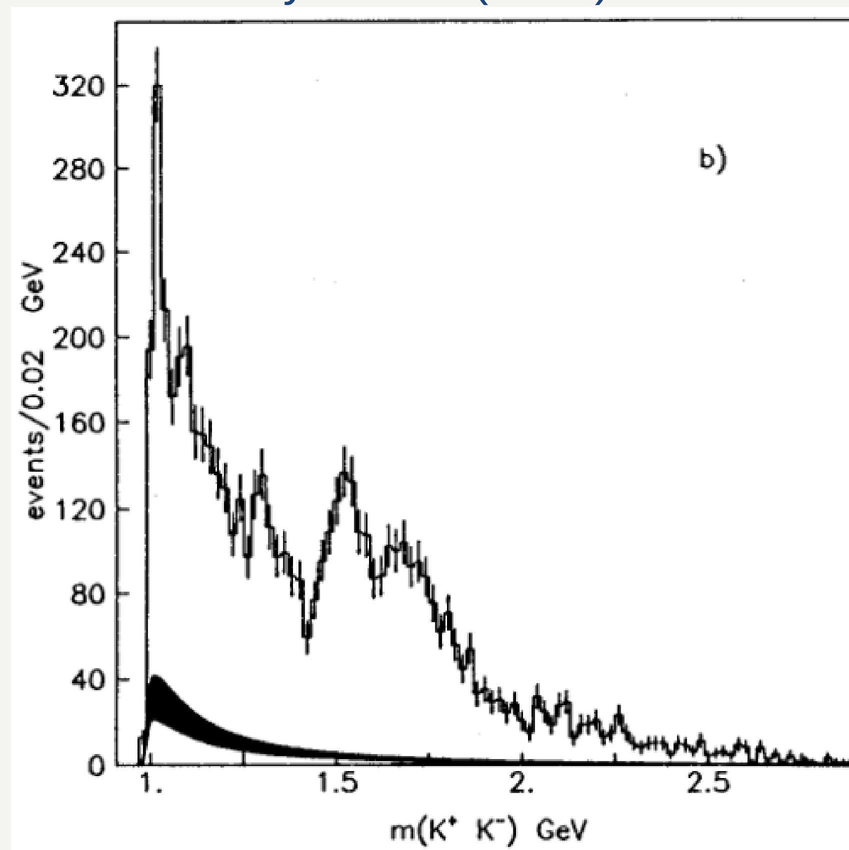


Same resonance features: less reggeon contribution at higher energies
Relative amounts depend on trigger, acceptance, √s

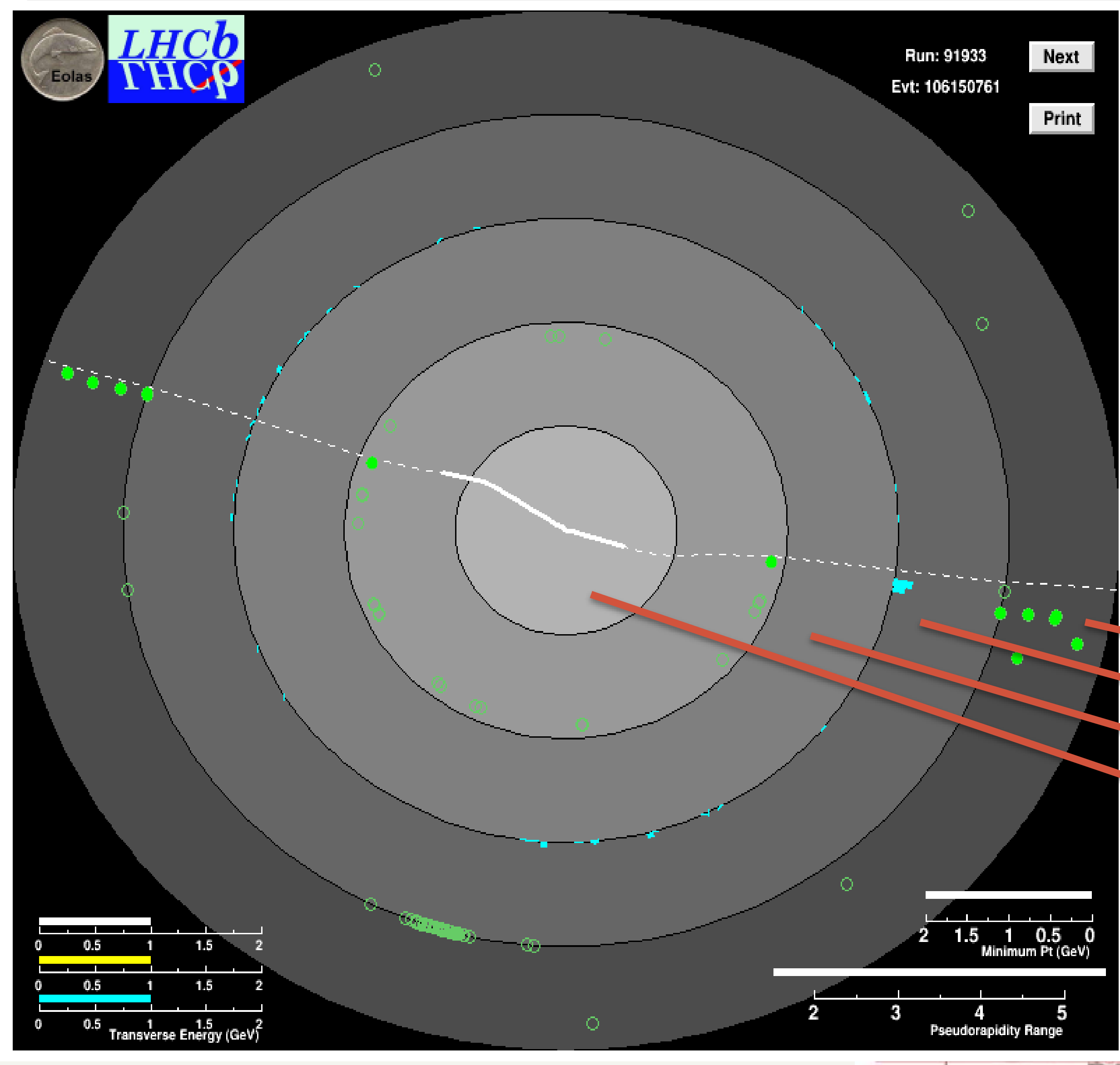
STAR v OMEGA: KK spectra

Z. Phys. C 51 (1991) 351-364

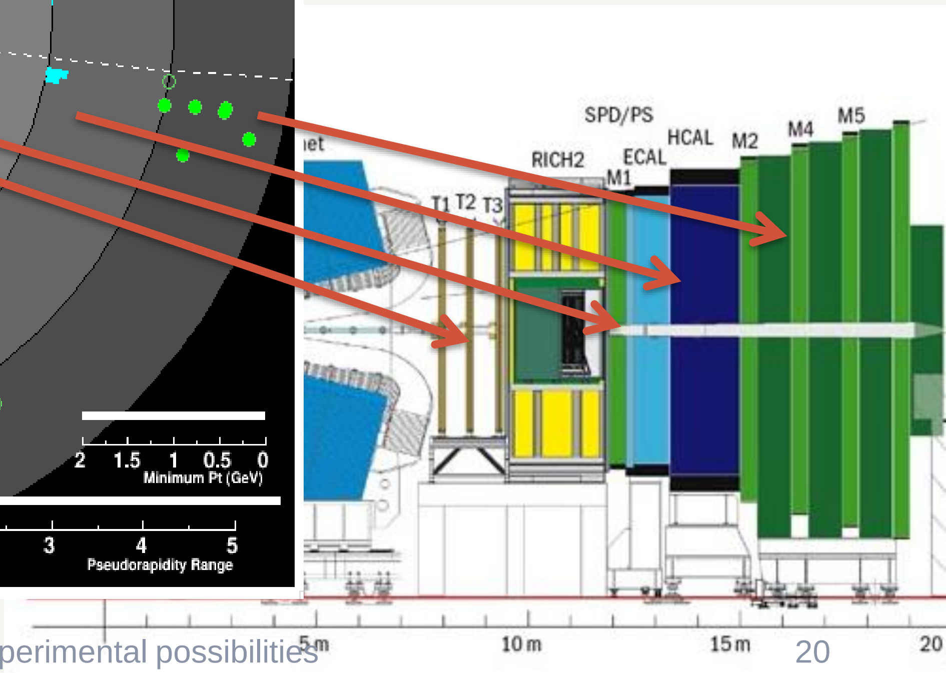




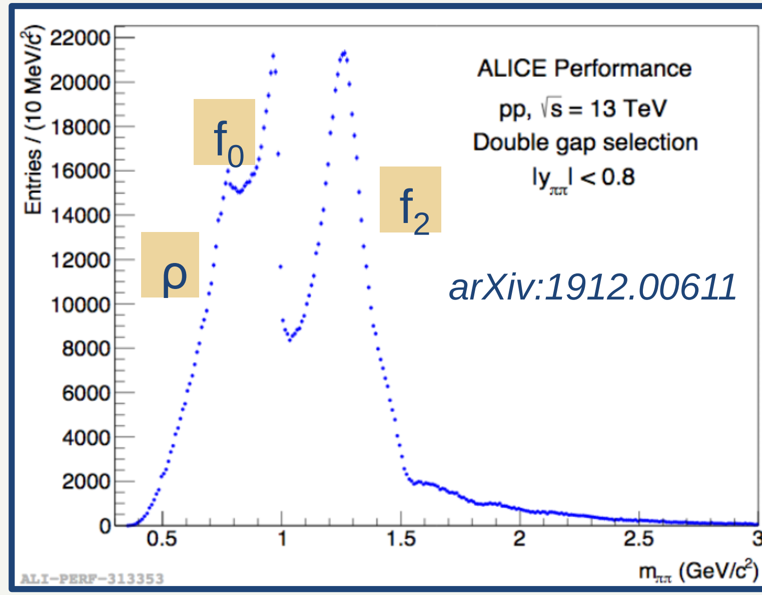
LHC



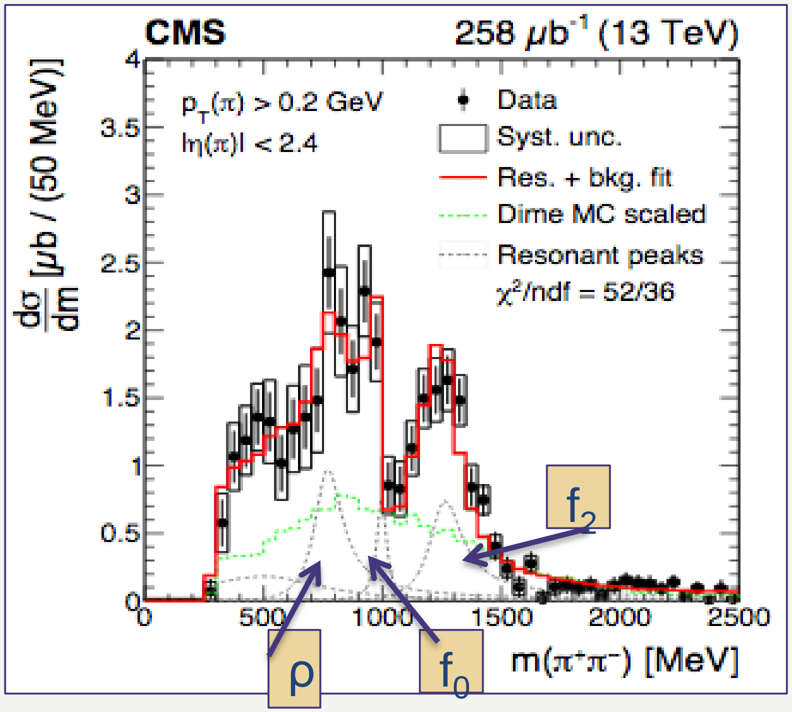
An almost minimal interaction:
Central Exclusive Production (CEP).



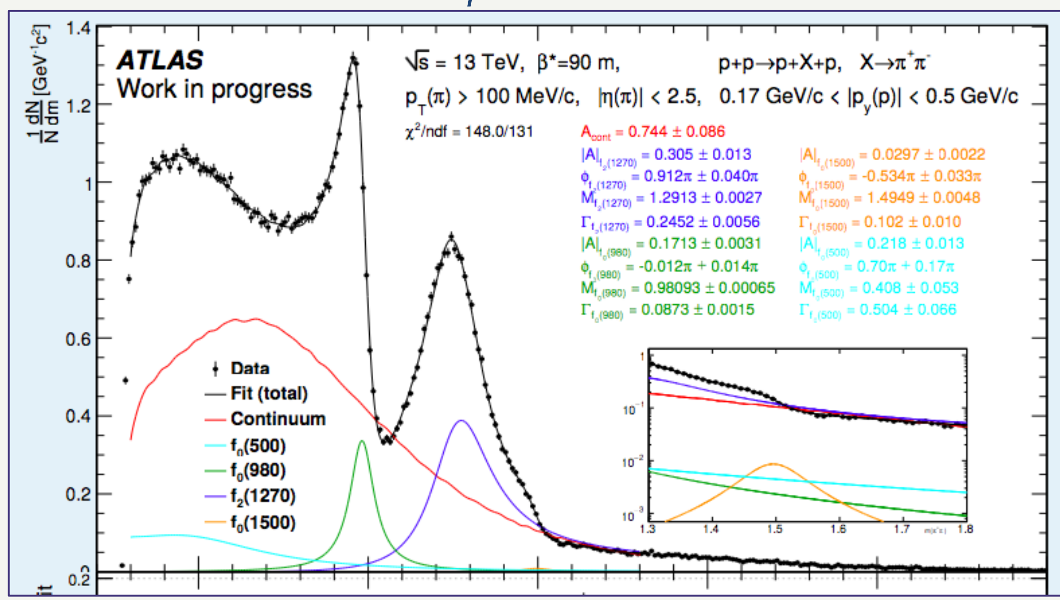
LHC: ππ final state



CMS collab., Eur.Phys.J.C 80 (2020) 8, 718



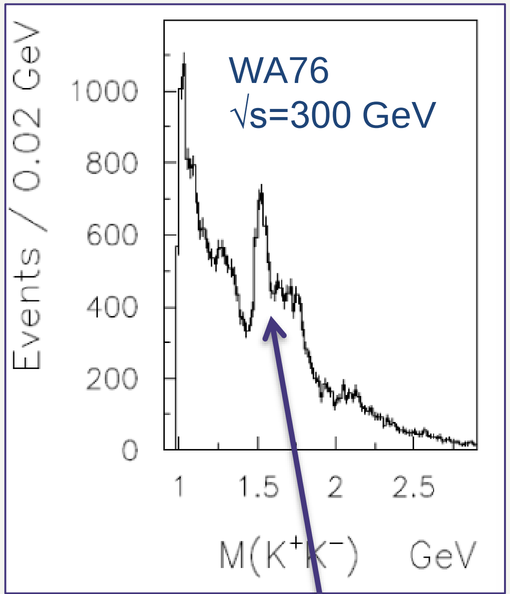
Poster: ICFA School https://indico.cern.ch/event/630418/



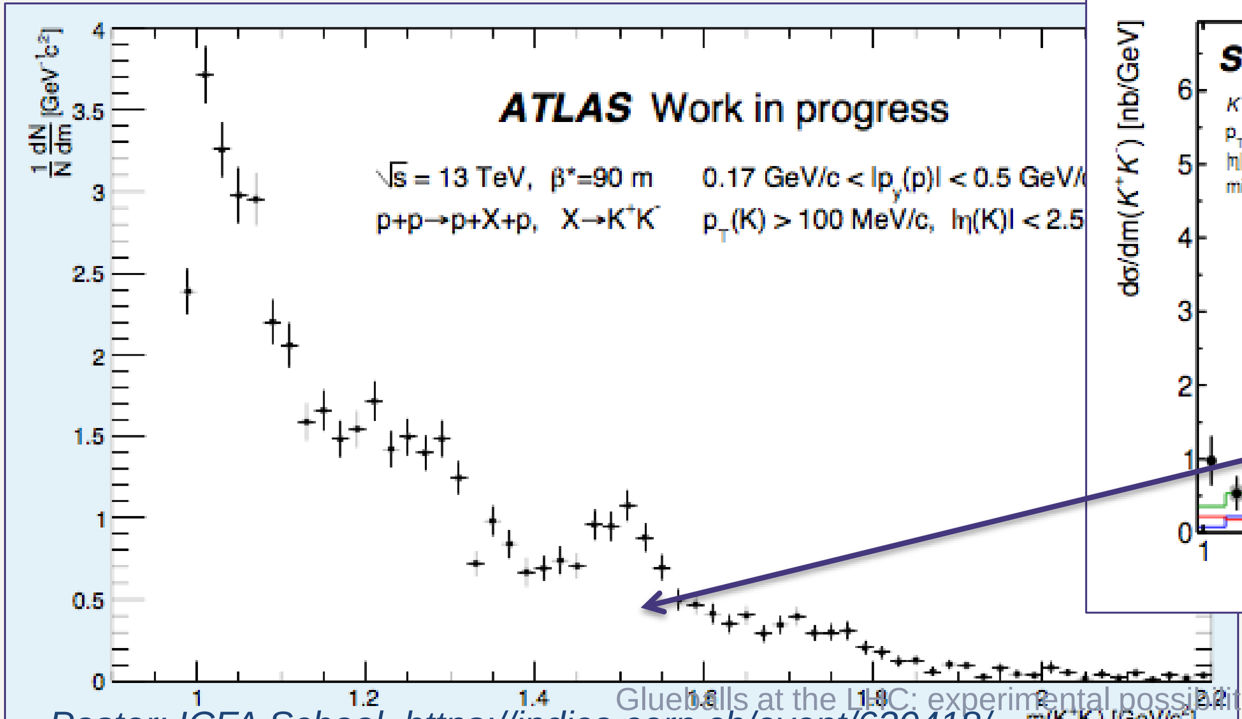
LHC sees similar structures. Very sensitive to kinematic requirements.
ATLAS results with proton-taggers eagerly anticipated.

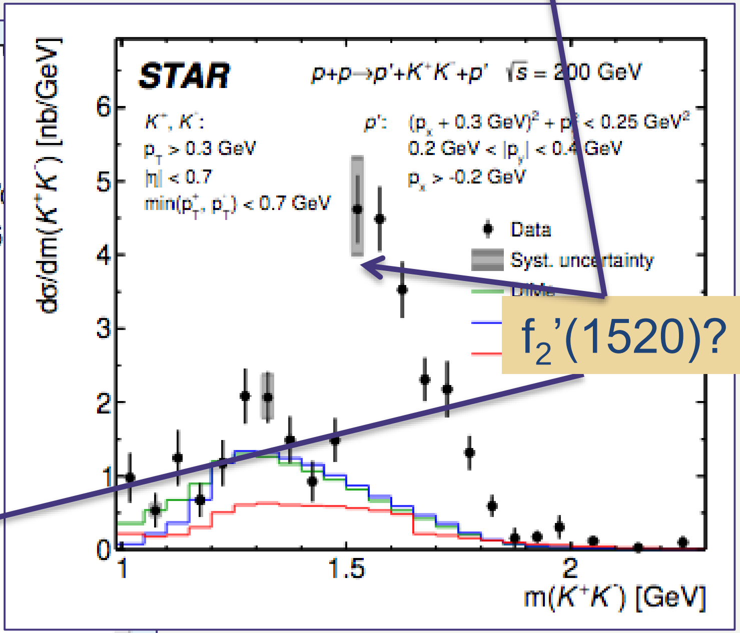
K^+K^- final state

Qualitatively similar.
Detail depends on experimental configuration



T. A. Armstrong et al., Z.Phys.C 51 (1991) 351-364





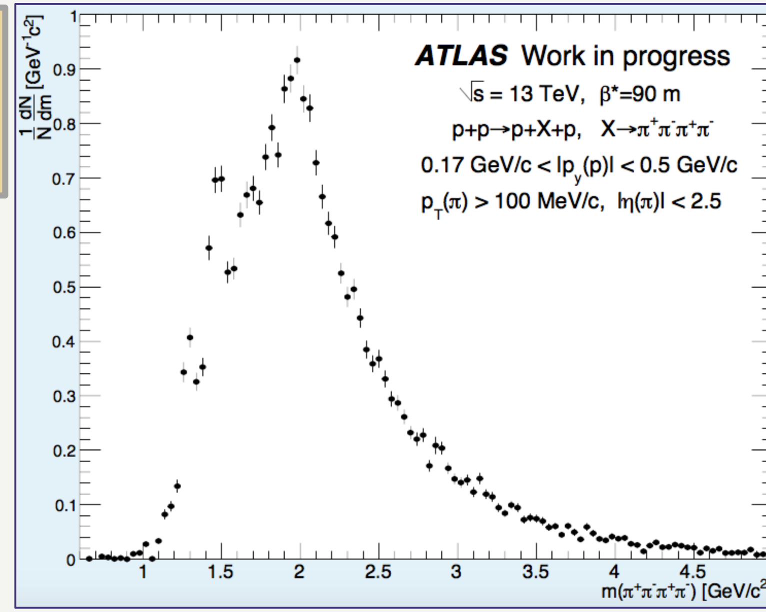
$f_2'(1520)$?

STAR collab., JHEP 07 (2020) 07, 178

Poster: ICFA School https://indico.cern.ch/event/630418/

Glueballs in ρρ / VV?

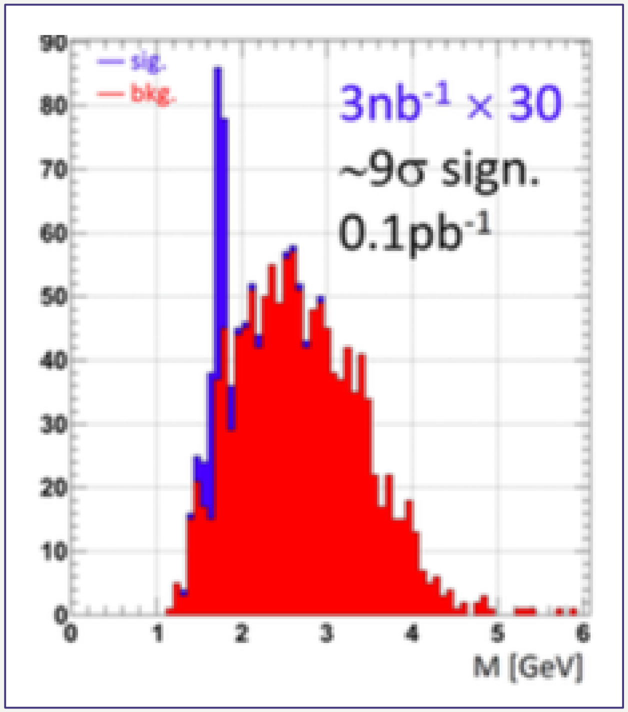
Simply reconstructed signals of 4π / 4K



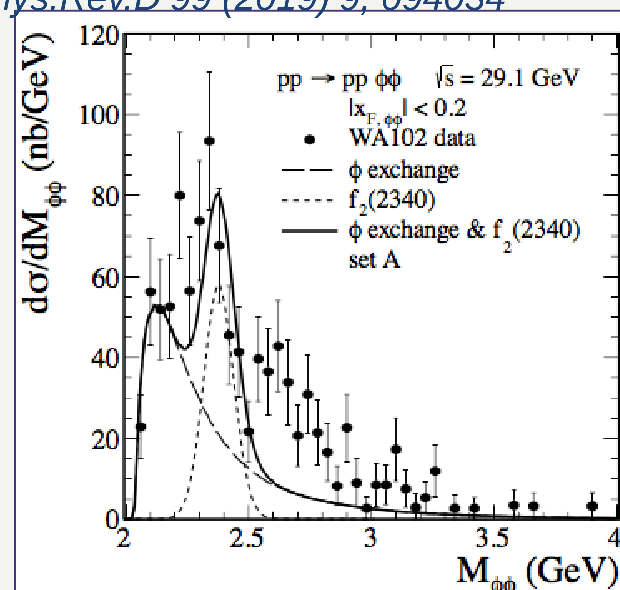
P. Lebiedowicz, O. Nachtmann, A. Szczurek
Phys.Rev.D 99 (2019) 9, 094034

Poster: ICFA School
https://indico.cern.ch/event/630418/

CERN-PH-LPCC-2015-001



Simulated f_0(1710)->ρρ signal in CMS-Totem



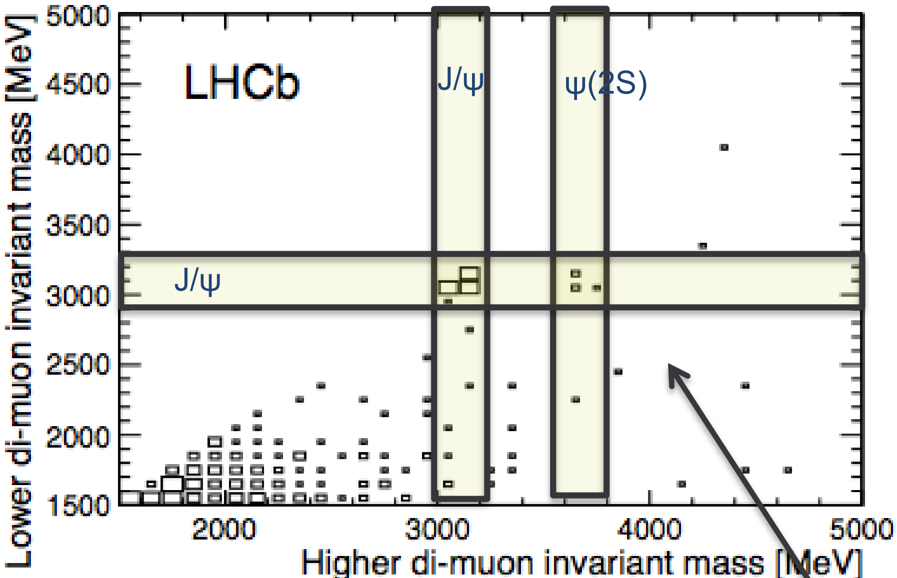
Model with f2(2340) + continuum that fits WA102 KKKK data

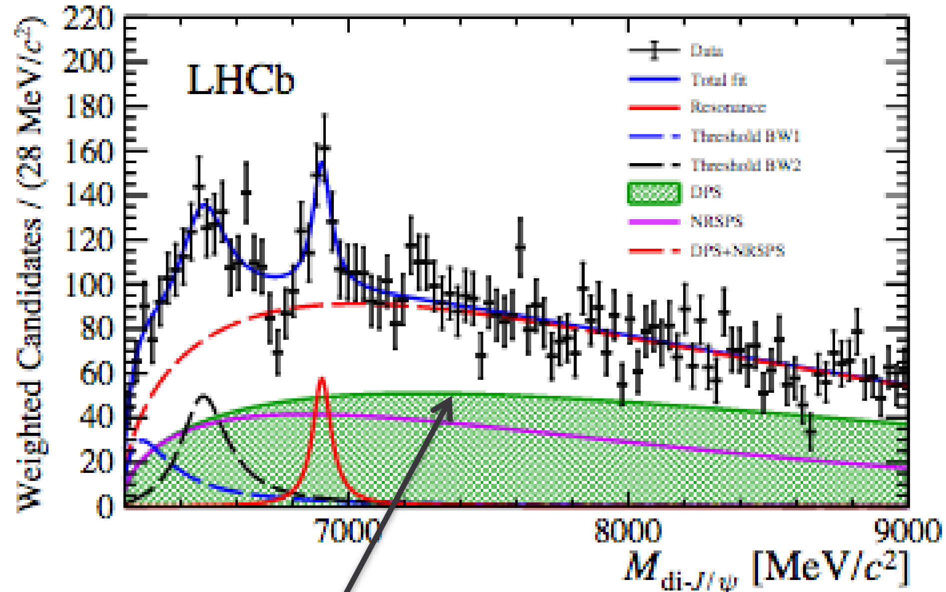
Such signals are also candidates for tetraquark, hybrid and molecular states

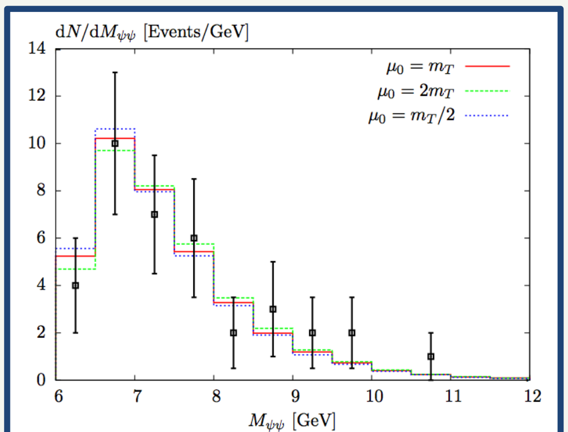
J/ψJ/ψ: search for exotica

LHCb collab., JPG 41 (2014) 115002

LHCb collab., arXiv: 2006.16957







EXCLUSIVE

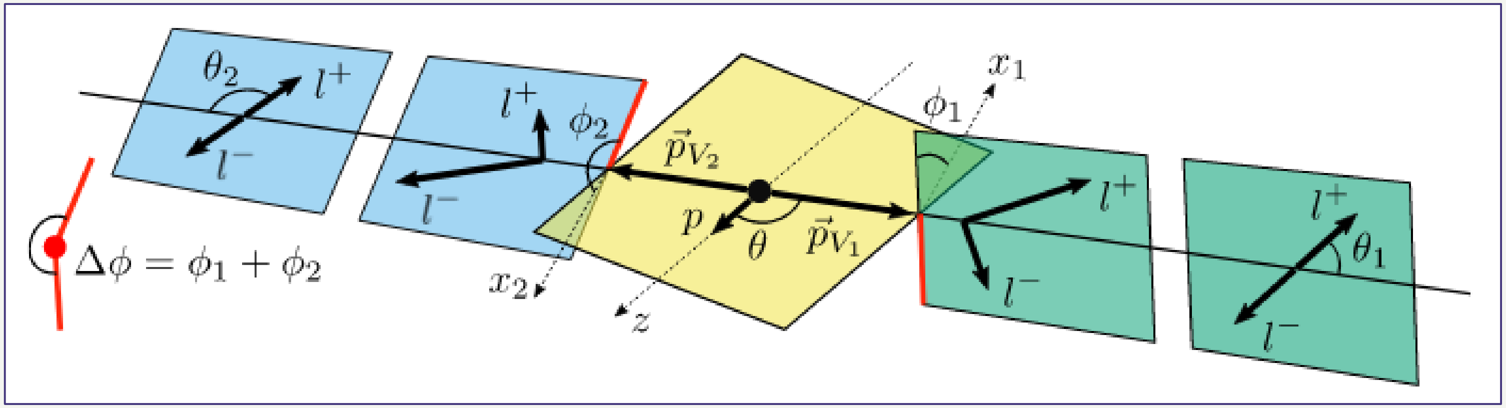
INCLUSIVE

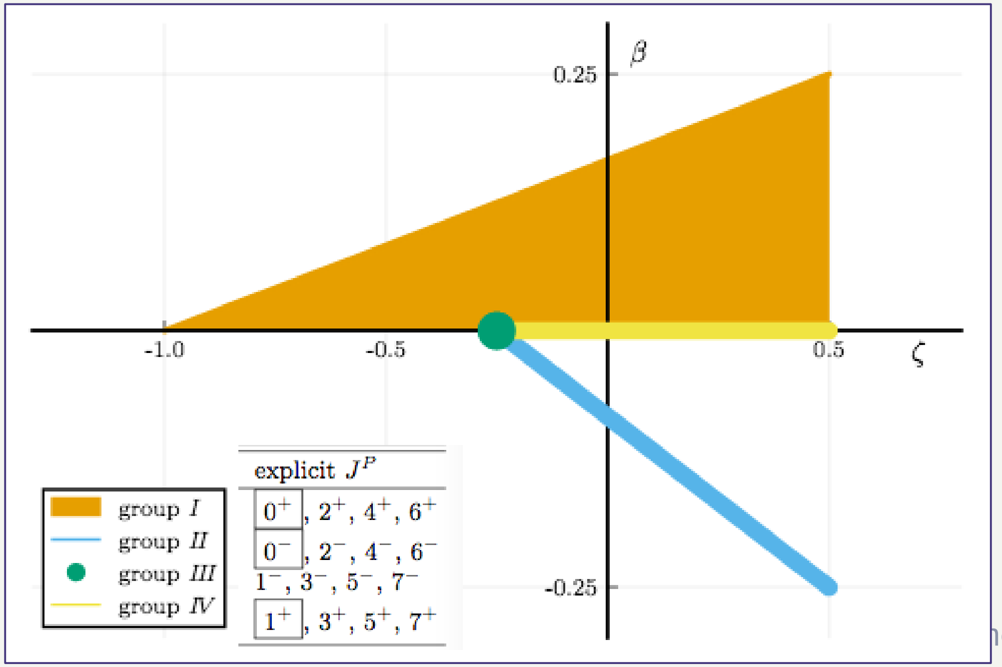
L A Harland-Lang, V A Khoze and M G Ryskin

J.Phys.G 42 (2015) 5, 055001

Angular analysis to extract J^P

M. Mikhasenko. L. An, R. McNulty, arXiv:2007.05501

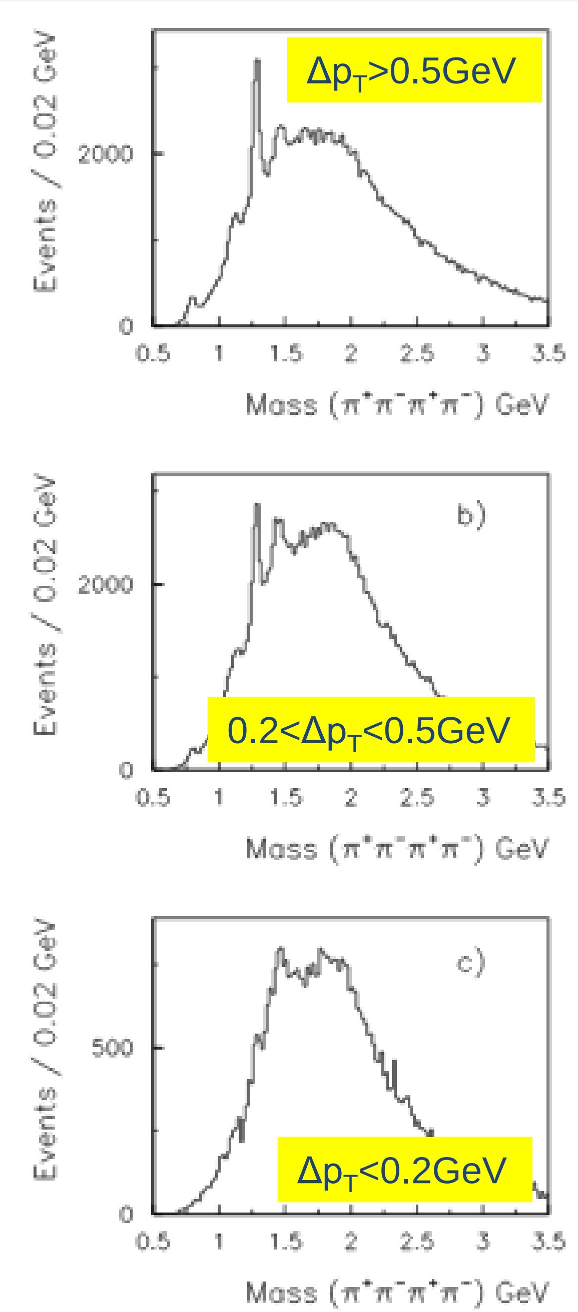




$$1+\beta\cos\Delta\phi$$

$$1+\frac{\zeta}{2}(3\cos^2\theta - 1)$$

Measurement of two angles can quickly show which J^P are inconsistent



Distinguishing glueballs from mesons

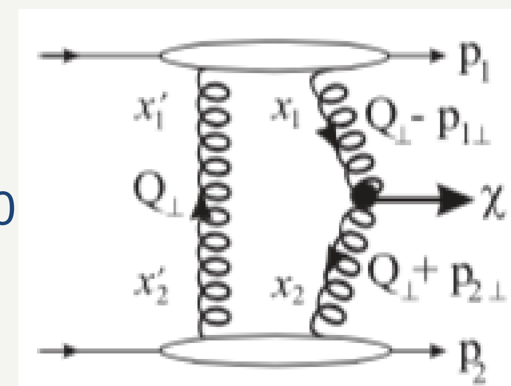
F.Close, A.Kirk, Phys.Lett.B397:333-338,1997

$\Delta p_T = p_T^{proton1} - p_T^{proton2}$

$q\bar{q}$ states relatively suppressed as $\Delta p_T \to 0$?

$f_1(1285)$ suppressed compared to $f_0(1500)$

However, there are also spin arguments.
As t->0, mesons produced in $J_z=0$ 1++ and 2++ amplitudes vanish.
(see also Landau-Yang theorem)

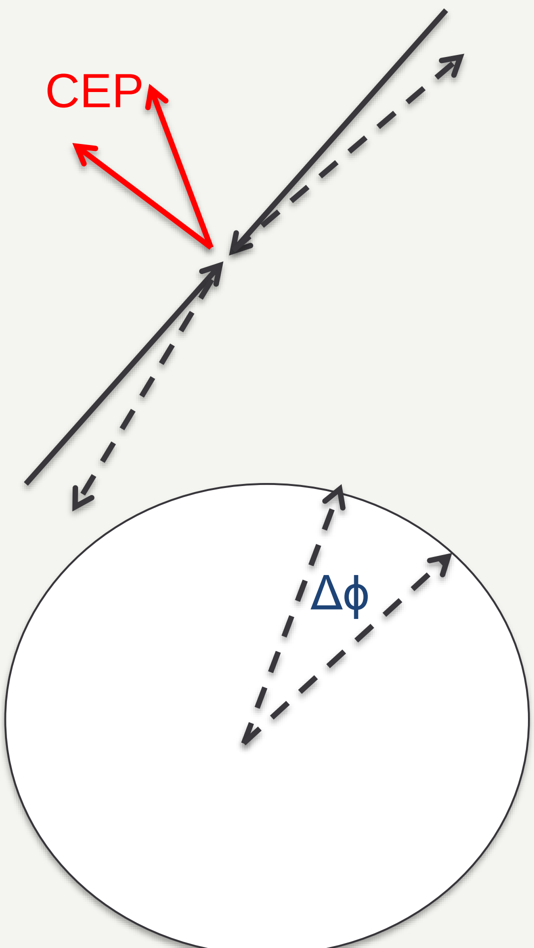


V. Khoze, A.D. Martin, M.G. Ryskin, Eur. Phys. J. C 19, 477 (2001)
F. Yuan Phys.Lett. B510 (2001) 155-160

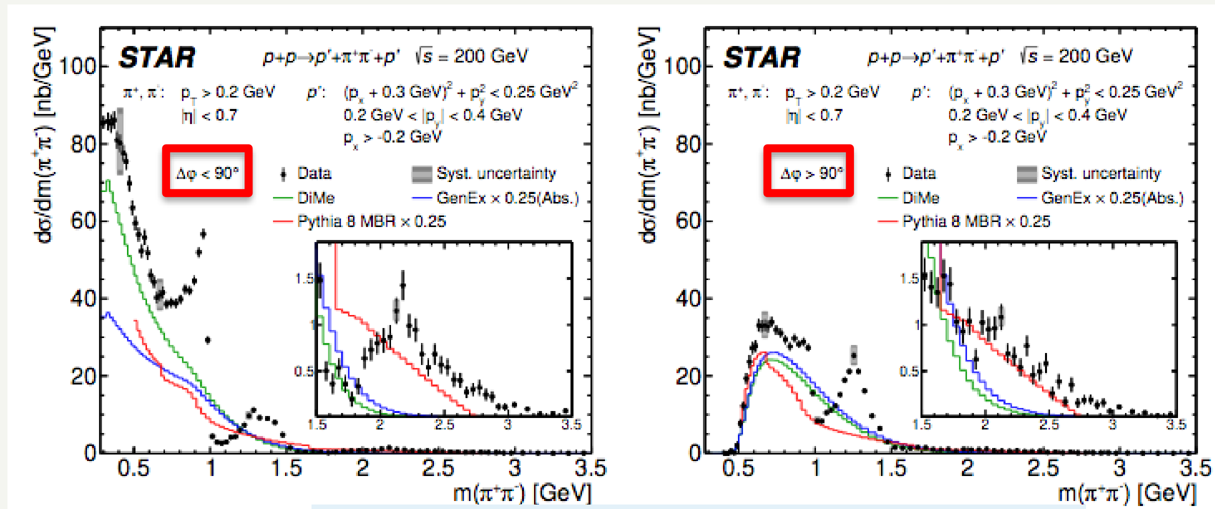
Glueball filter?

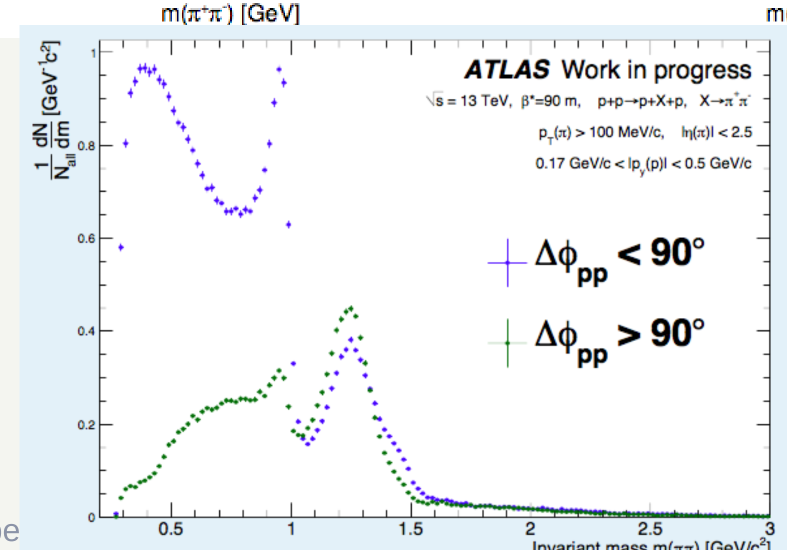
F. Close, A. Kirk, Phys.Lett.B397:333-338,1997

> We shall suggest that it is driven primarily by the variable $dP_T \equiv |\vec{p}_T^{\,\prime} - \vec{q}_T^{\,\prime}|$ and that gg configurations are enhanced in kinematic configurations where the gluons can flow "directly" into the final state with only small momentum transfer, in particular when $dP_T \to 0$.



STAR collab., JHEP 07 (2020) 07, 178





Poster: ICFA School https://indico.cern.ch/event/630418/

Conclusions

- LHC is a multi-gluon collider
- Clean reconstruction of final state
- Angular analyses possible
- Reconstruction of outgoing protons possible for subset of data
- Enormous statistics
- Where should we look for an unambiguous glueball determination?