

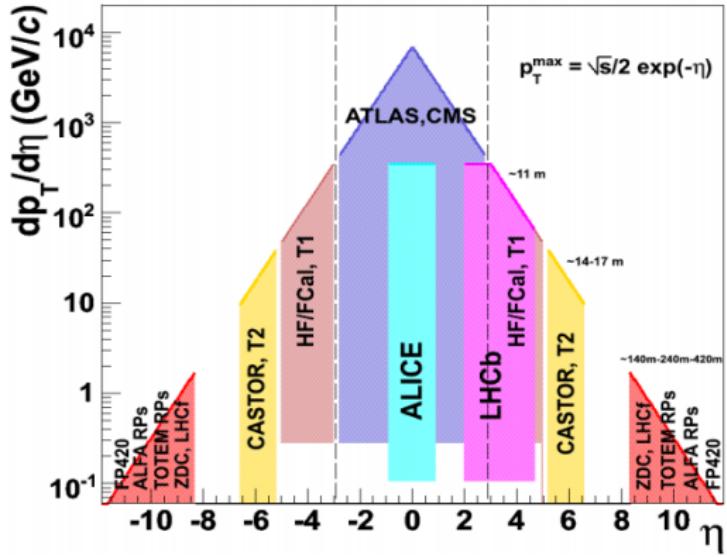
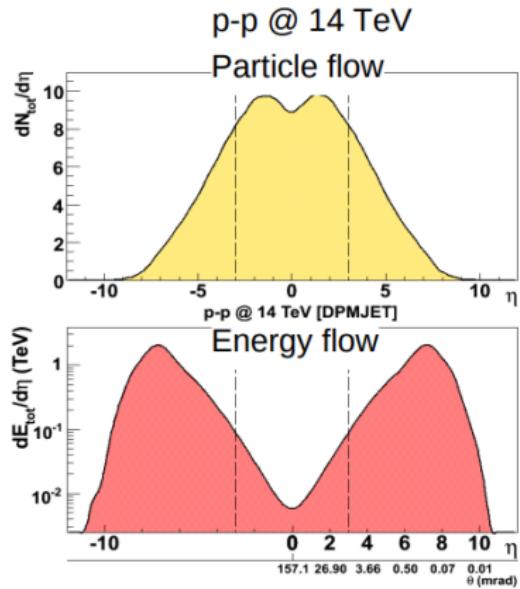
Particle Physics for Specialists

Forward Physics

Rafał Staszewski

27 January 2022

Introduction



David d'Enterria, arXiv:0708.0551

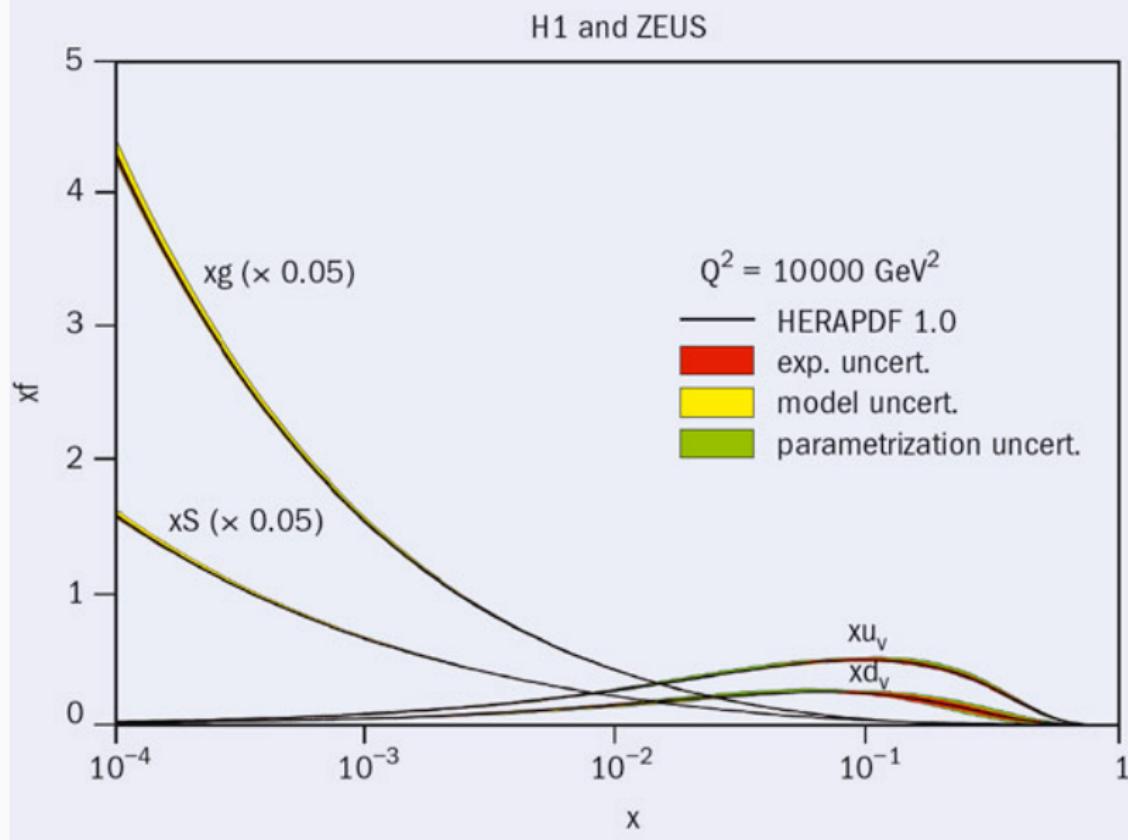
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Physics of low x

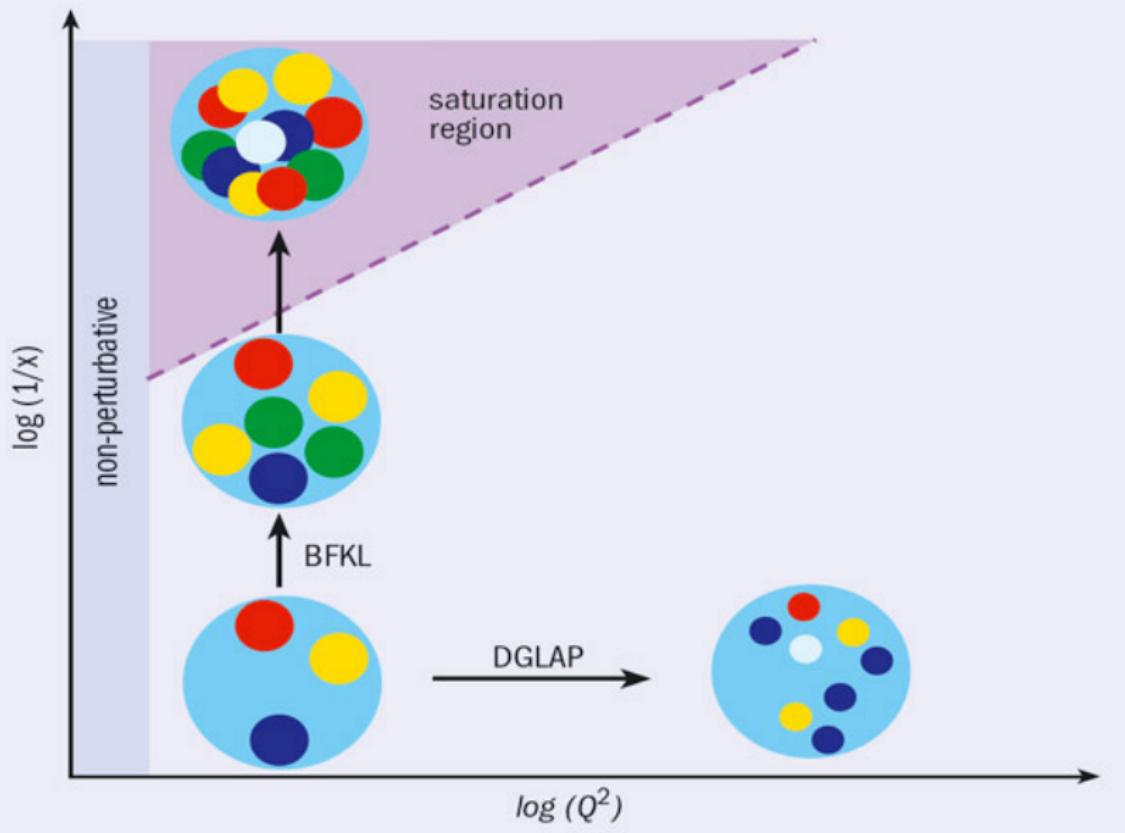
Diffraction

Photon-induced processes

Gluons at low x



Saturation



Underlying event

- Complex structure of hadron-hadron interaction
- Underlying event – activity in addition to the hard interaction:
 - initial state radiation
 - final state radiation
 - multiple parton interaction
 - colour reconnections with beam remnants
- Non-perturbative effects
- No clear soft/hard separation
- Phenomenological model in MC generators
- A need for tuning to experimental data

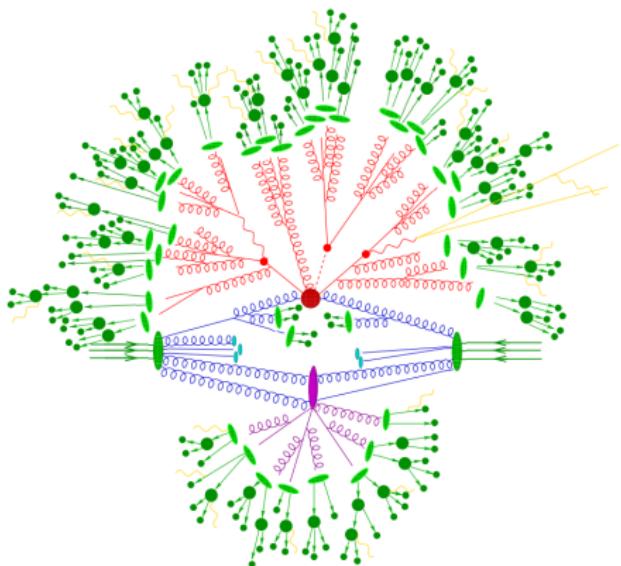
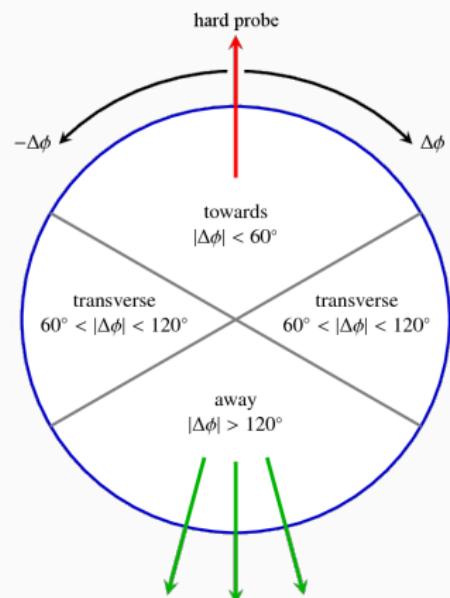


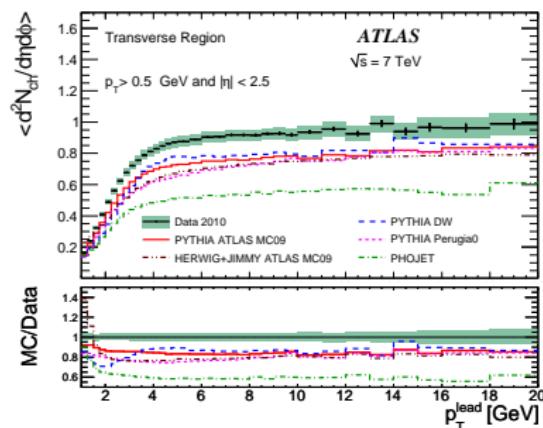
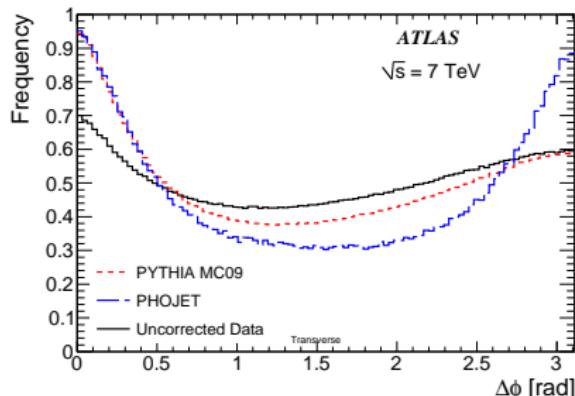
Figure from [arXiv:1411.4085]

Principle of the measurements

- Regions in ϕ defined w.r.t.
the direction of the hard object
- Transverse region – sensitive to UE
- Two transverse regions \rightarrow trans-min
and trans-max
(distinguished on the event-by-event
basis according to $\sum p_T$)
- UE observables:
 - $N_{\text{ch}}/\delta\eta\delta\phi$
 - $\sum p_T/\delta\eta\delta\phi$
 - Mean p_T



Results from inclusive pp interactions



- $\Delta\phi$ distribution initially not well described by MC
- Flattening of p_T dependence: entering dense region in proton

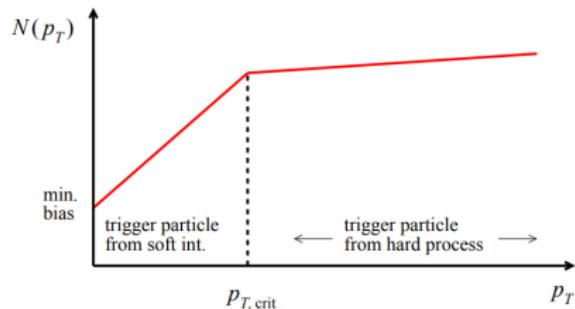


FIG. 6. Schematic illustration of the expected dependence of the transverse multiplicity, $N(p_T)$, on the p_T of the trigger.

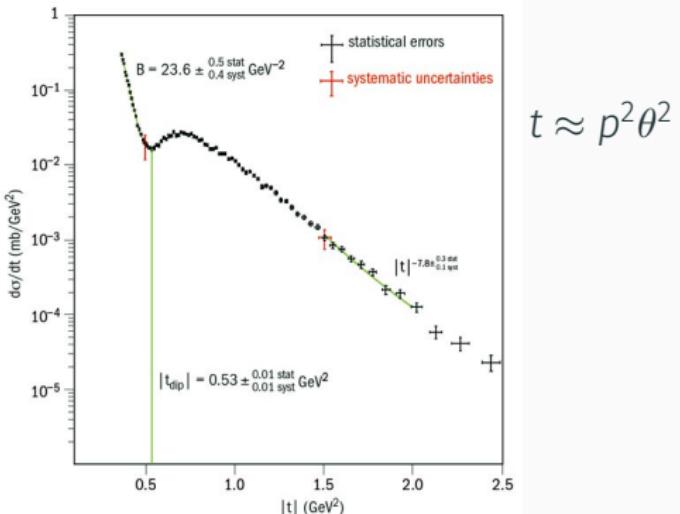
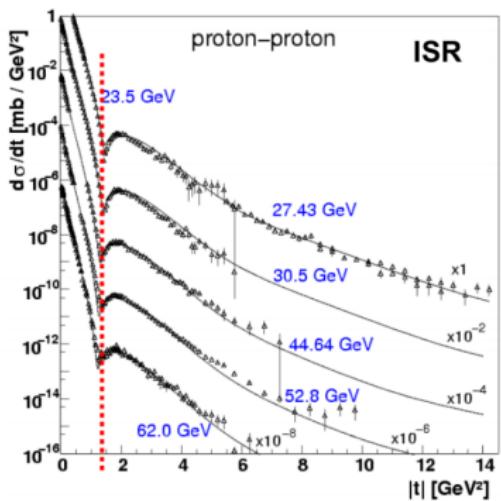
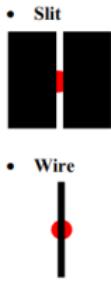
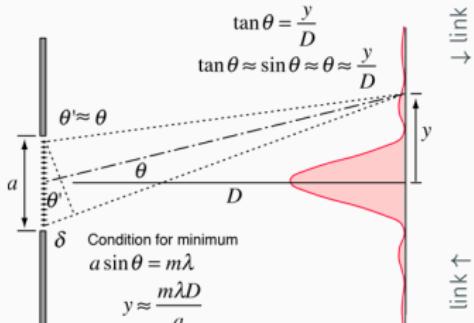
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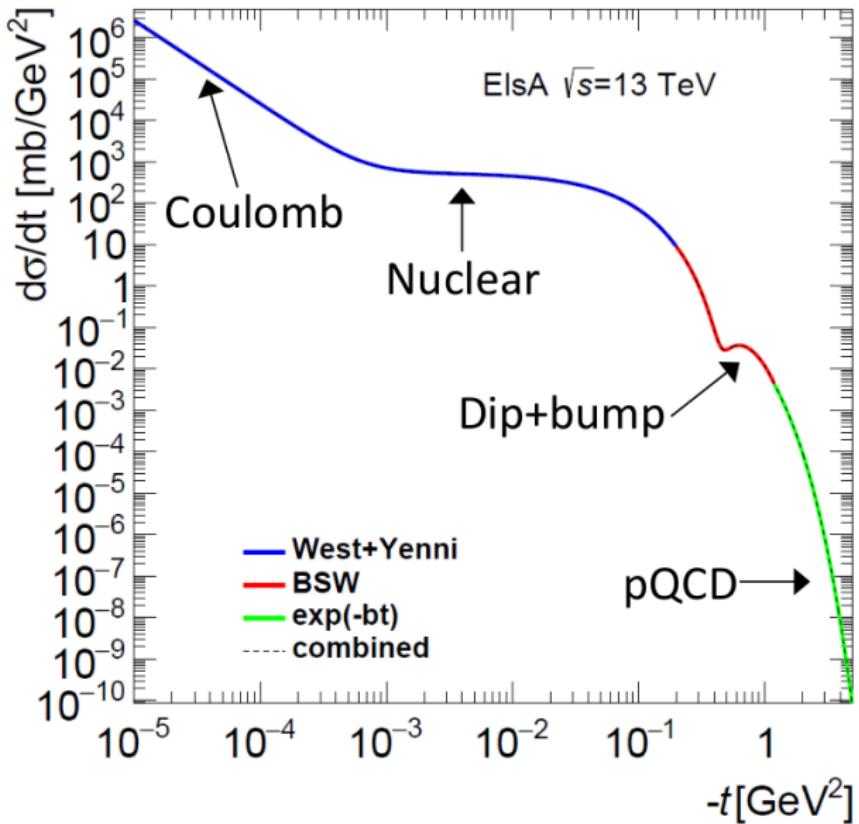
Diffraction

Photon-induced processes

Diffractive in particle physics



Physics of elastic scattering



Scattering angle vs impact parameters

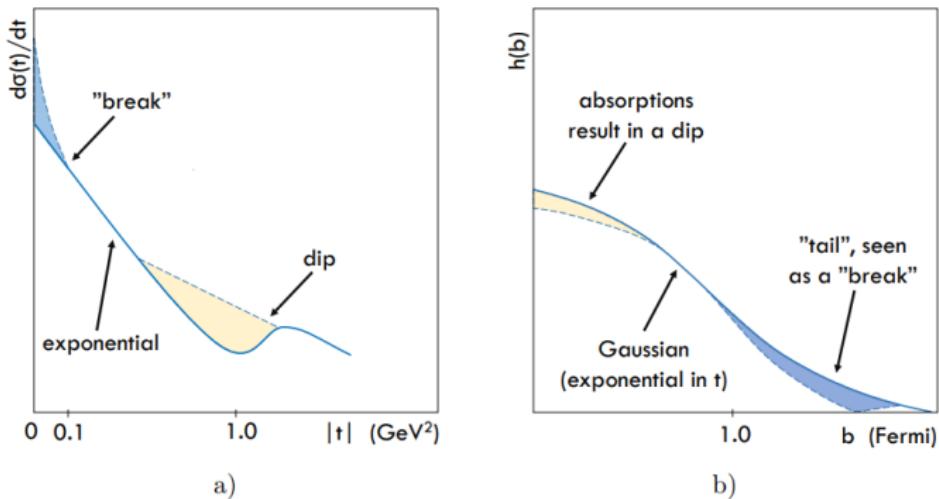


Figure 1: Schematic (qualitative) view of the "break", followed by the diffraction minimum ("dip"), shown both as function in t and its Fourier transform (impact parameter representation), in b . While the "break" reflects the presence of the pion "atmosphere" (clouding) around the nucleon at peripheral values of b , the dip results from absorption corrections, suppressing the impact parameter amplitude at small b .

Proton hollowness

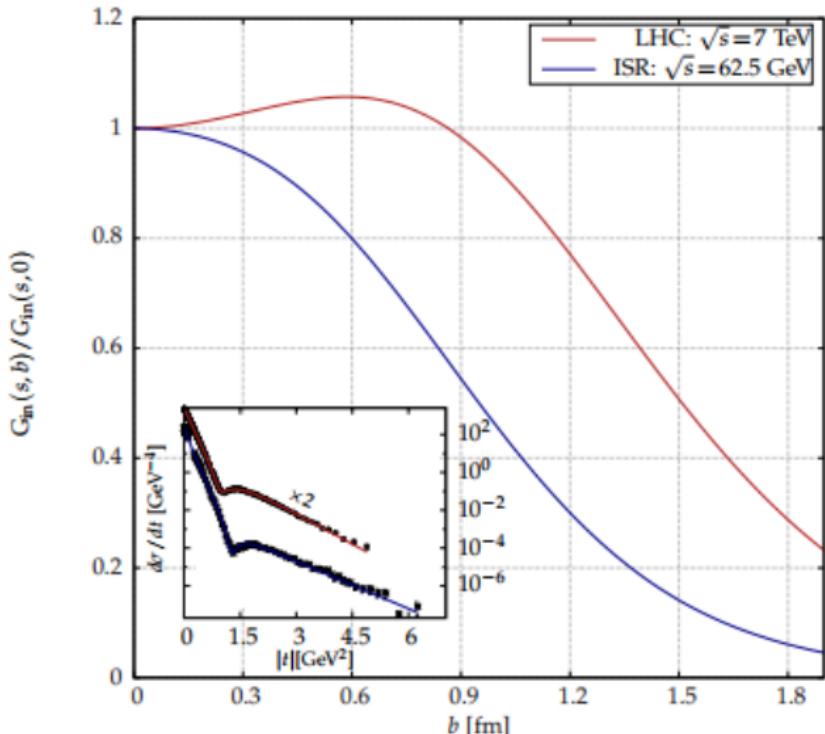


FIG. 1: Normalised inelasticity density, G_{in} , for LHC and ISR energies as a function of the impact parameter. Sub-pannel: fits to $d\sigma_{\text{el}}/dt$ data.

Optical theorem

S matrix and the Optical Theorem

$$\sum_n P(i \rightarrow n) = 1 = \sum_n |\langle n | S | i \rangle|^2 = \sum_n \langle i | S^\dagger | n \rangle \langle n | S | i \rangle = \langle i | S^\dagger S | i \rangle = 1$$

true for any $|i\rangle$, so $S^\dagger S = I$. Introduce trans matrix T : $S = I + iT$

$$(I - iT^\dagger)(I + iT) = I$$

$$i(T^\dagger - T) = T^\dagger T$$

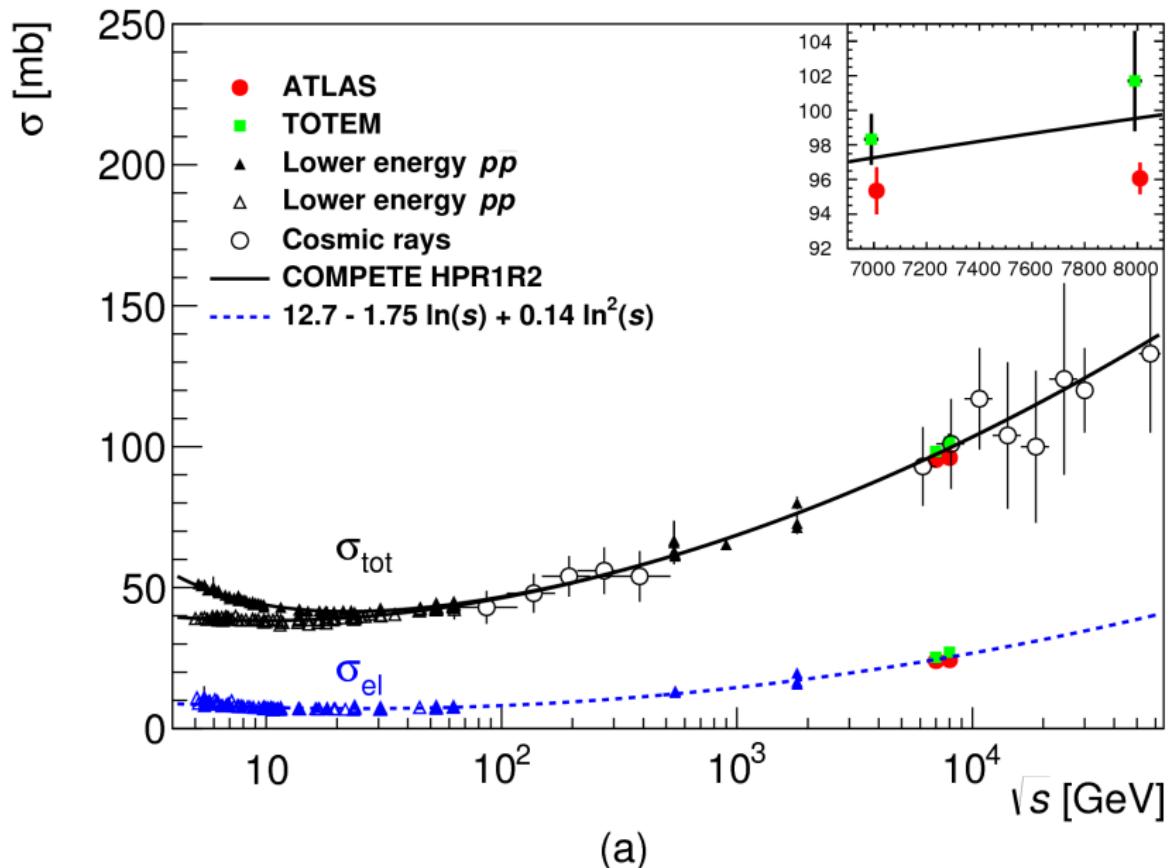
$$i\langle f | T^\dagger - T | i \rangle = \sum_n \langle f | T^\dagger | n \rangle \langle n | T | i \rangle$$

$$2 \operatorname{Im} T(i \rightarrow f) = \sum_n \langle n | T^* | f \rangle \langle n | T | i \rangle$$

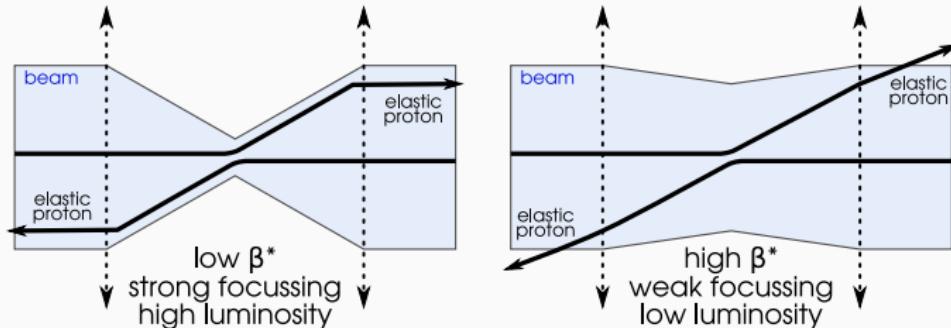
put $f = i$, forward elastic scatt. \rightarrow Optical theorem

$$2 \operatorname{Im} T_{\text{el}}(t=0) = \sum_n |T(i \rightarrow n)|^2 = \sigma_{\text{tot}}$$

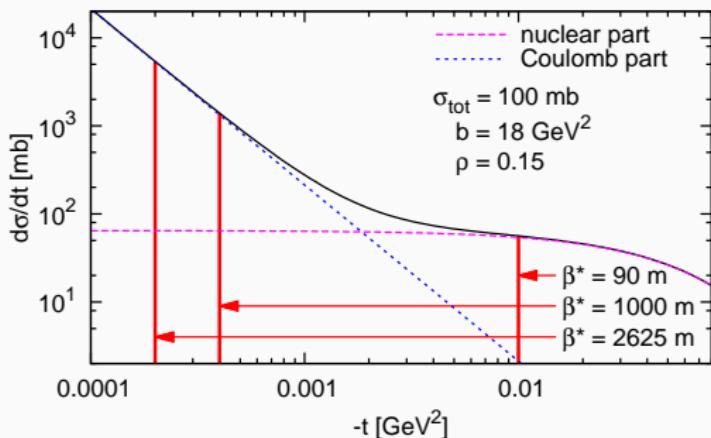
Total cross section



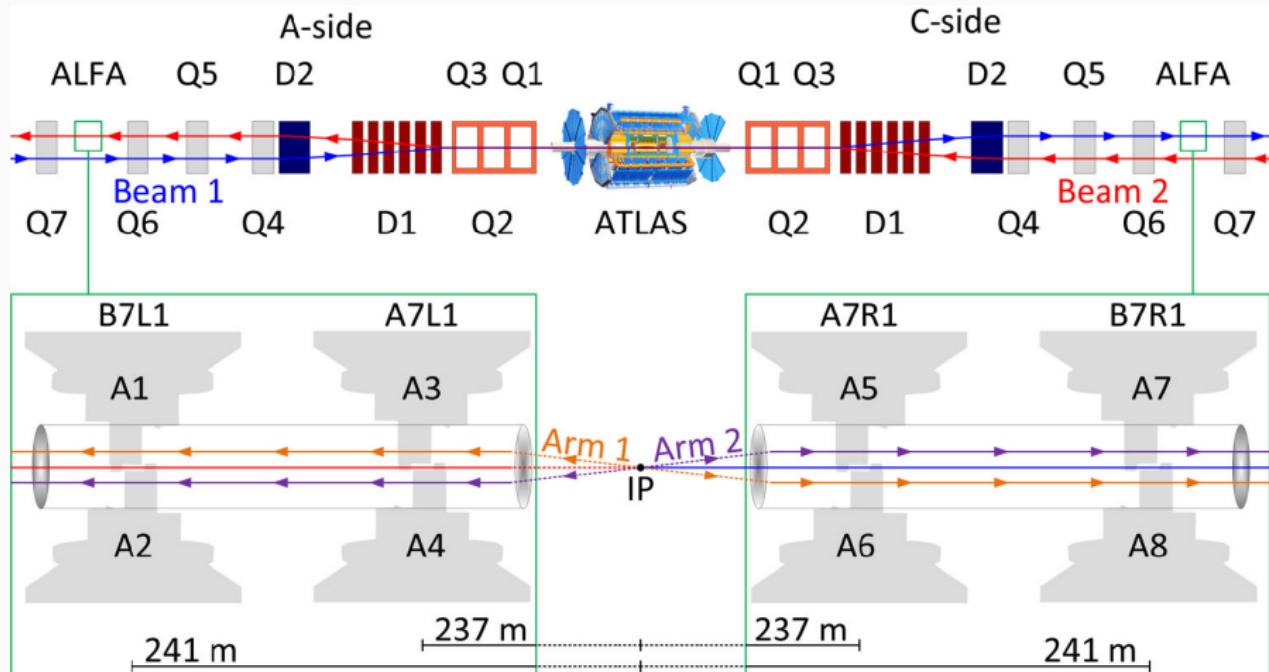
High- β optics



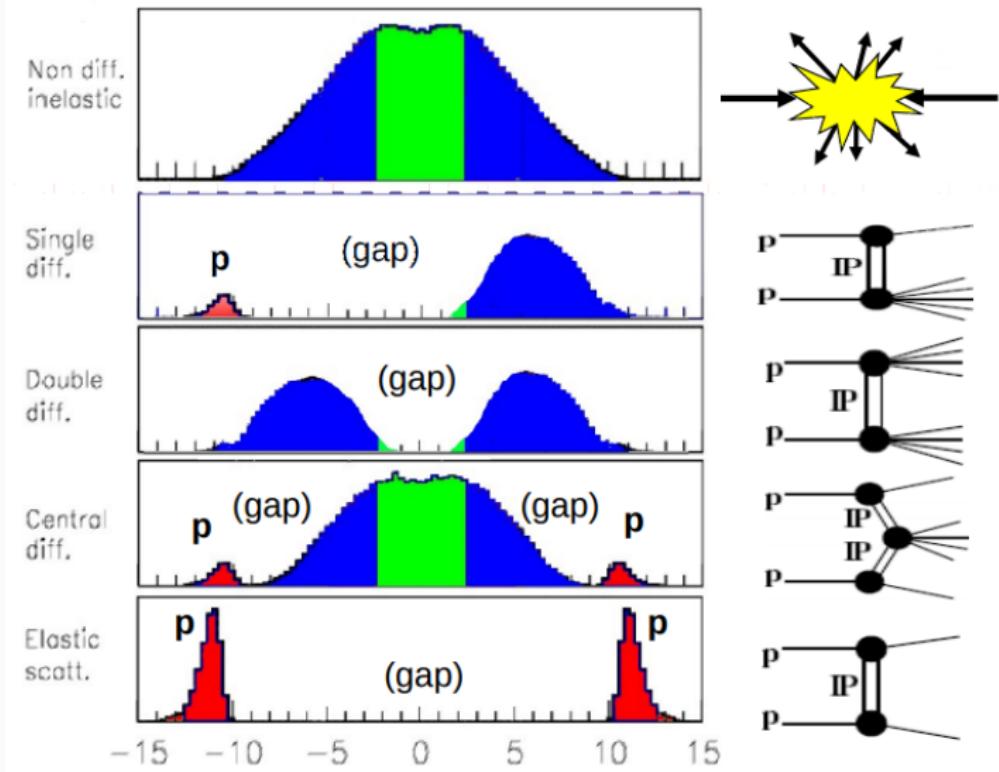
Elastic cross-section



ALFA Detectors



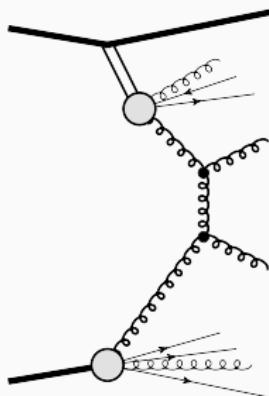
Diffractive processes



Hard diffraction

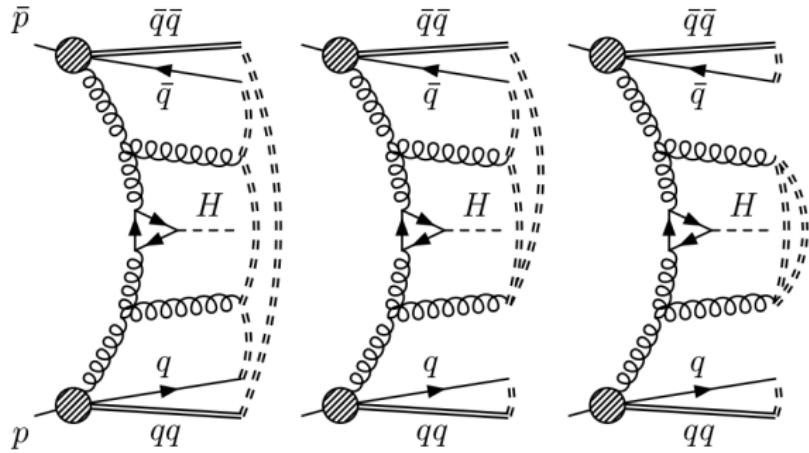
Resolved pomeron

- Ingelman-Schlein model
- pomeron has partonic structure

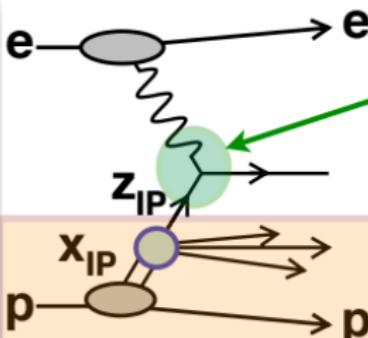


Soft colour interactions

- QCD-inspired model
- additional gluon exchanges screen the color flow



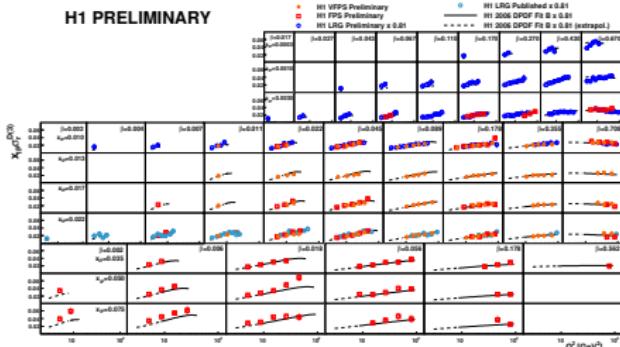
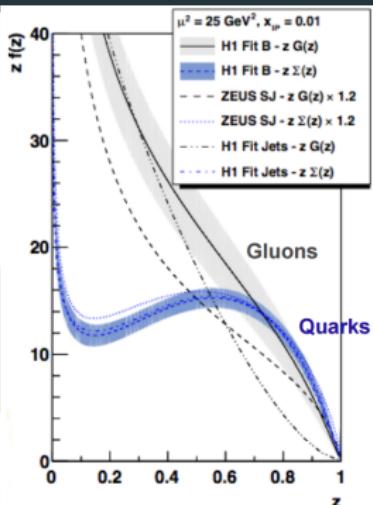
HERA: Diffractive PDFs



- ▶ hard scattering matrix element
- ▶ process dependent

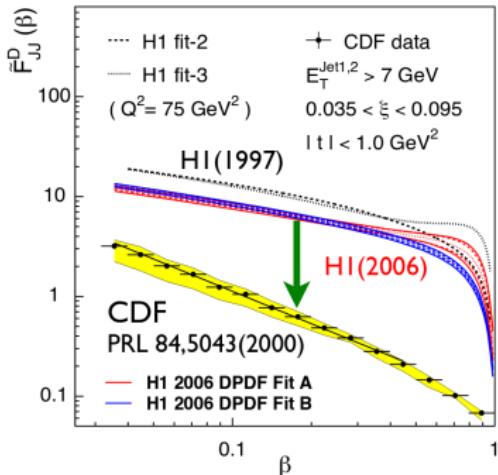
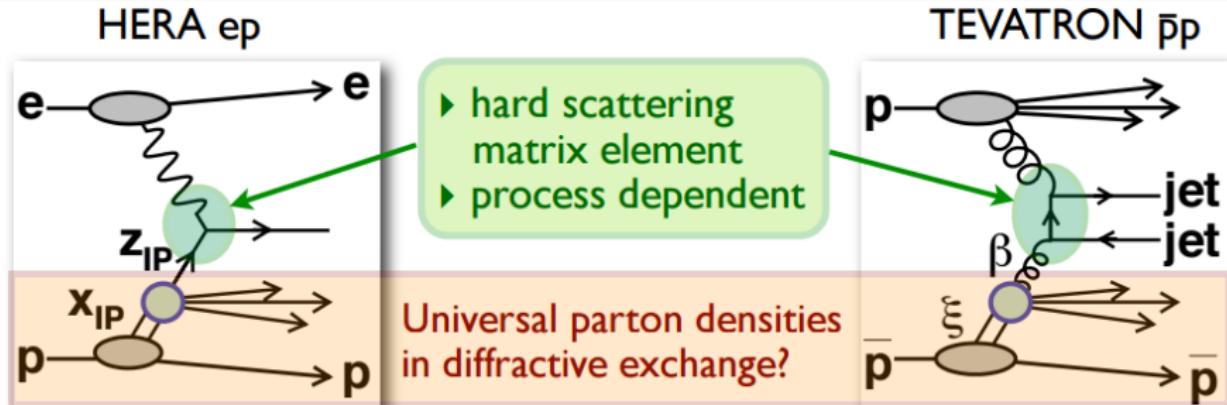
Universal parton densities
in diffractive exchange

Proved by J. Collins PRD 57,3051(1998)



- QCD fits
- dominated by gluons

Factorisation breaking



- Hard diffractive events rarer than naive extrapolations from HERA
- Suppression factor: gap survival probability
- Origin: additional interactions
- Confirmed in many processes

Contents

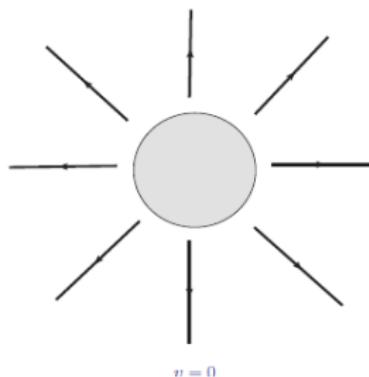
Physics of low x

Diffraction

Photon-induced processes

Equivalent photons

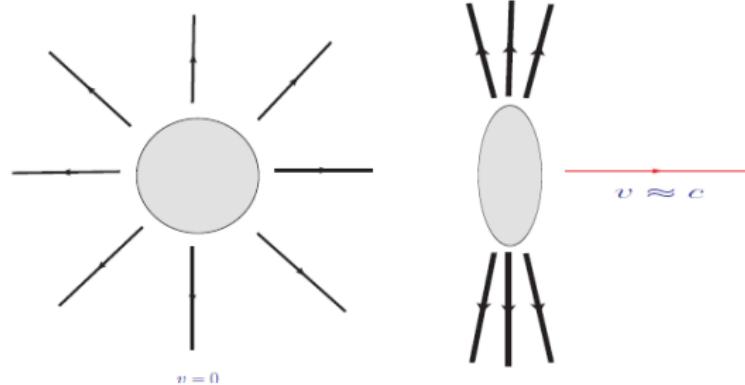
- Consider a charged nucleus at rest. The associated electromagnetic field can be represented by:



(slides from Victor Gonçalves)

Equivalent photons

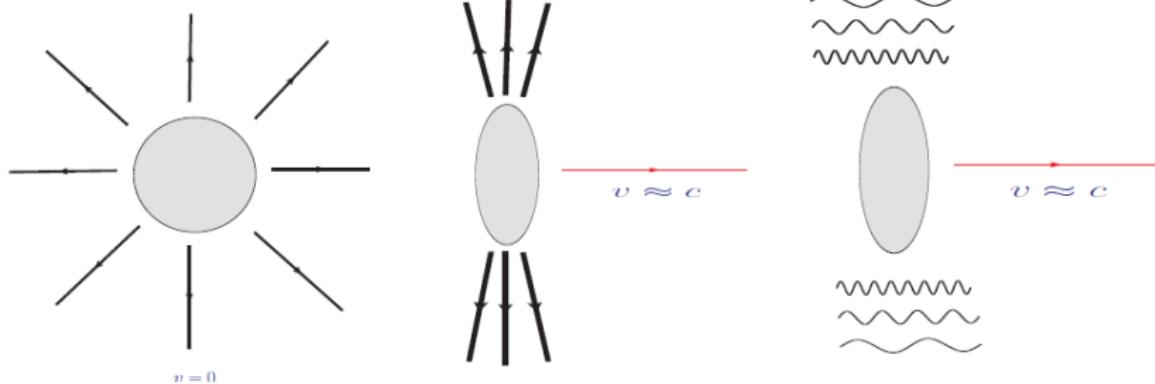
- As a charged nucleus moves with nearly the speed of light, the electromagnetic field becomes transverse to its velocity.



(slides from Victor Gonçalves)

Equivalent photons

- 💡 Since the electric and magnetic field associated to the nucleus take on the same absolute value, this transverse electromagnetic field can be simulated by an equivalent swarm of photons ^a.

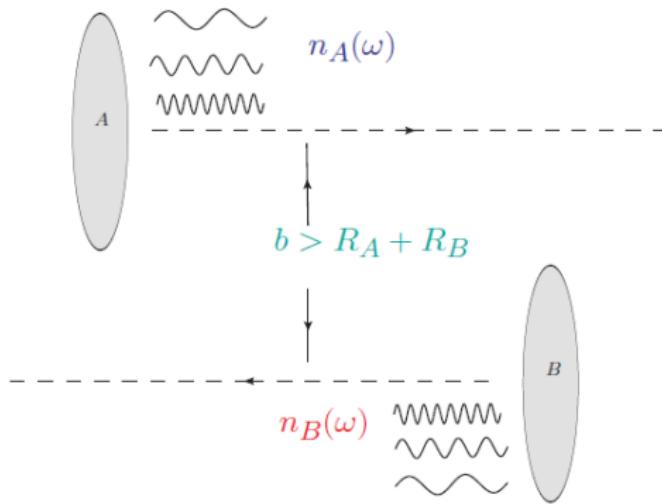


^aE. Fermi (1924), E. J. Williams (1933), C. F. Von Weizacker (1934)

(slides from Victor Gonçalves)

Equivalent photons

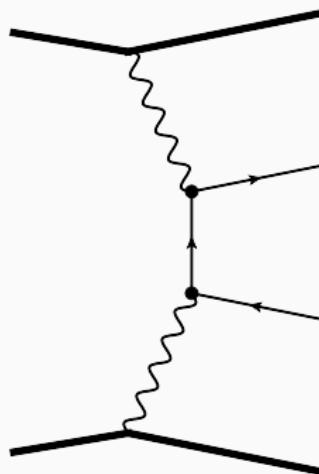
- Thus the collision of two charged nuclei at large impact parameter can be described as the collision of two equivalent swarms of photons.



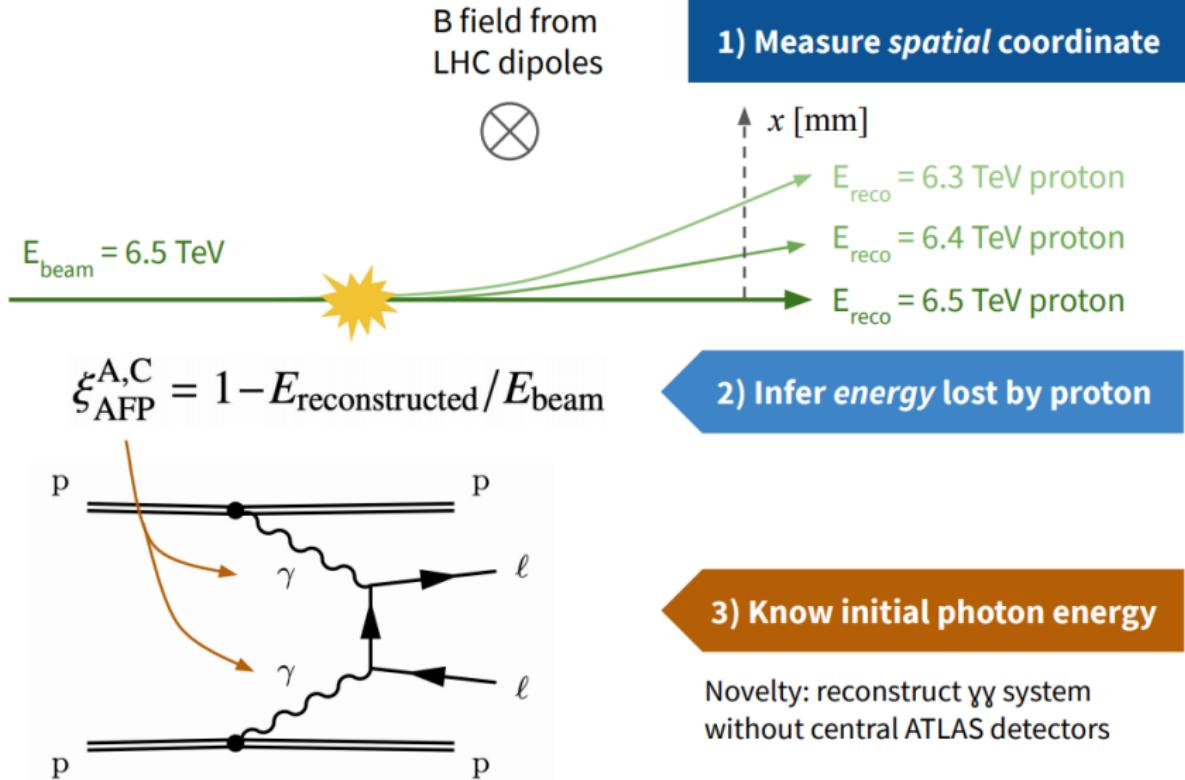
(slides from Victor Gonçalves)

Two-photon processes

- Two-photon processes can be computed within QED
- Exclusive $\gamma\gamma \rightarrow ll$
 - Standard candle for photon-induced physics
 - Non-negligible background to Drell-Yan like reactions
- Test of SM γWW and $\gamma\gamma WW$ couplings

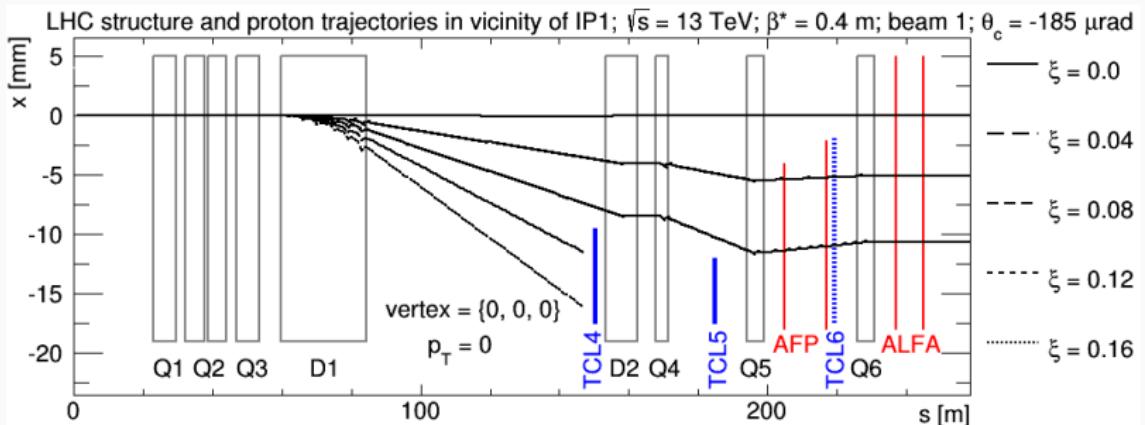
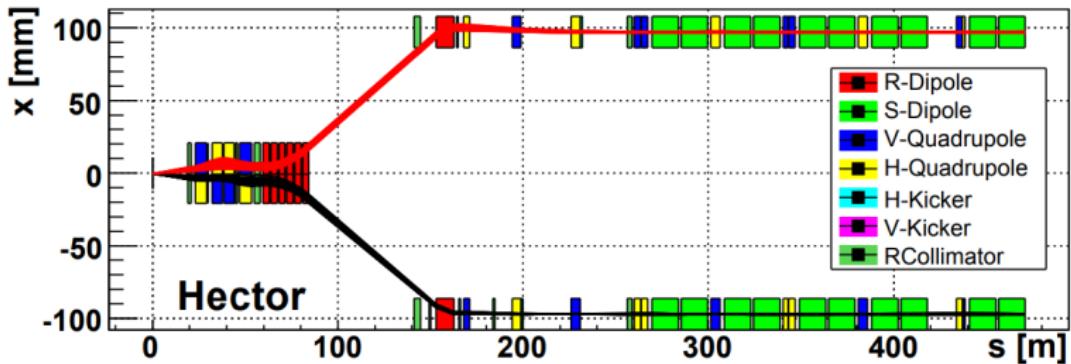


Forward proton spectrometer

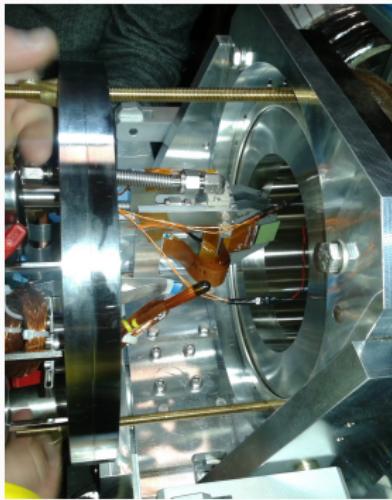
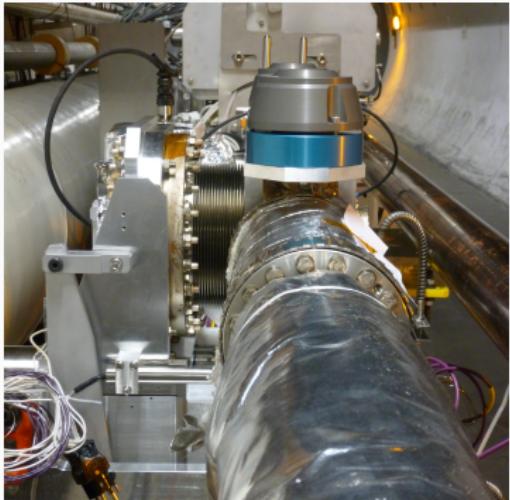


(drawing from Jesse Liu)

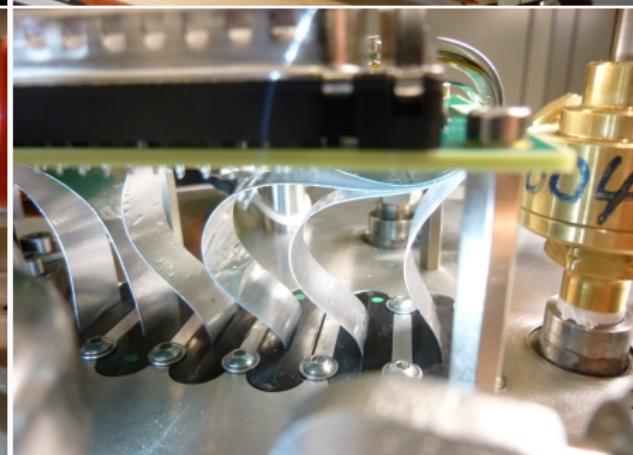
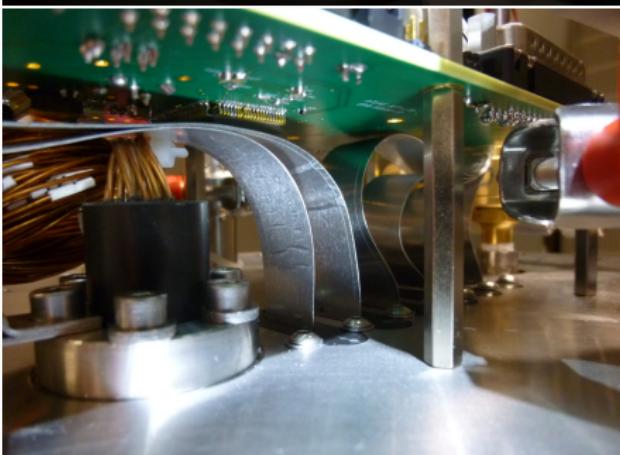
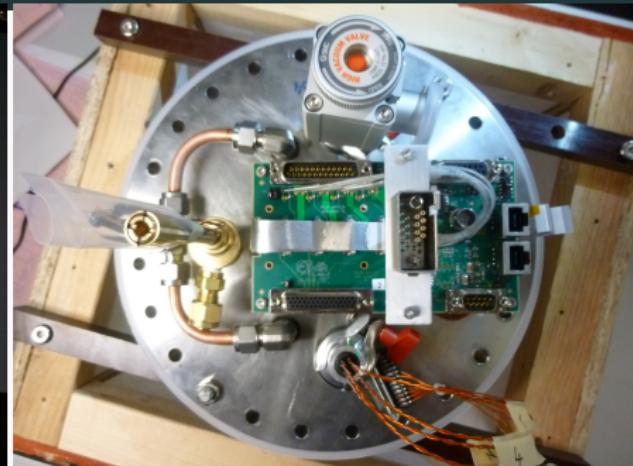
Trajectories of forward protons



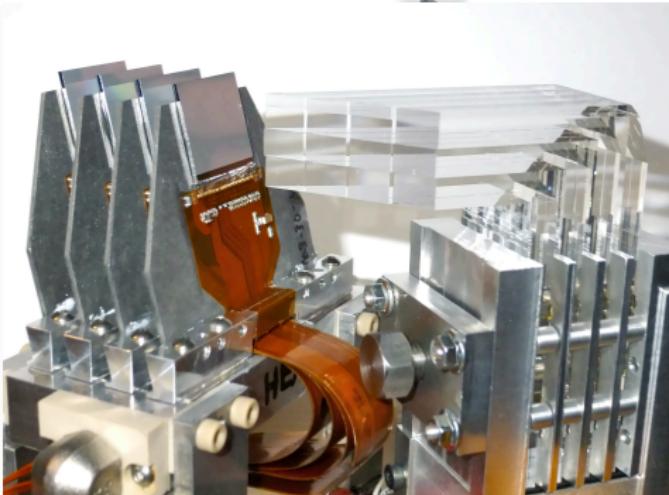
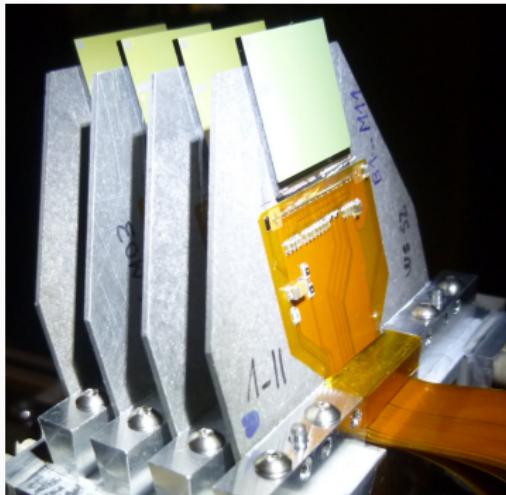
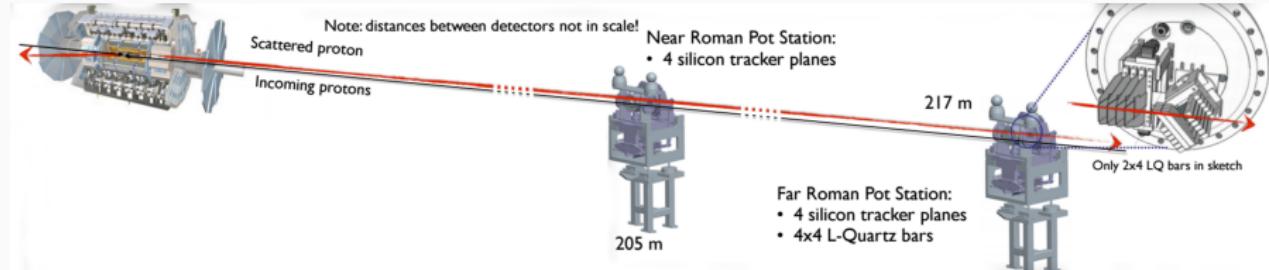
Roman pots



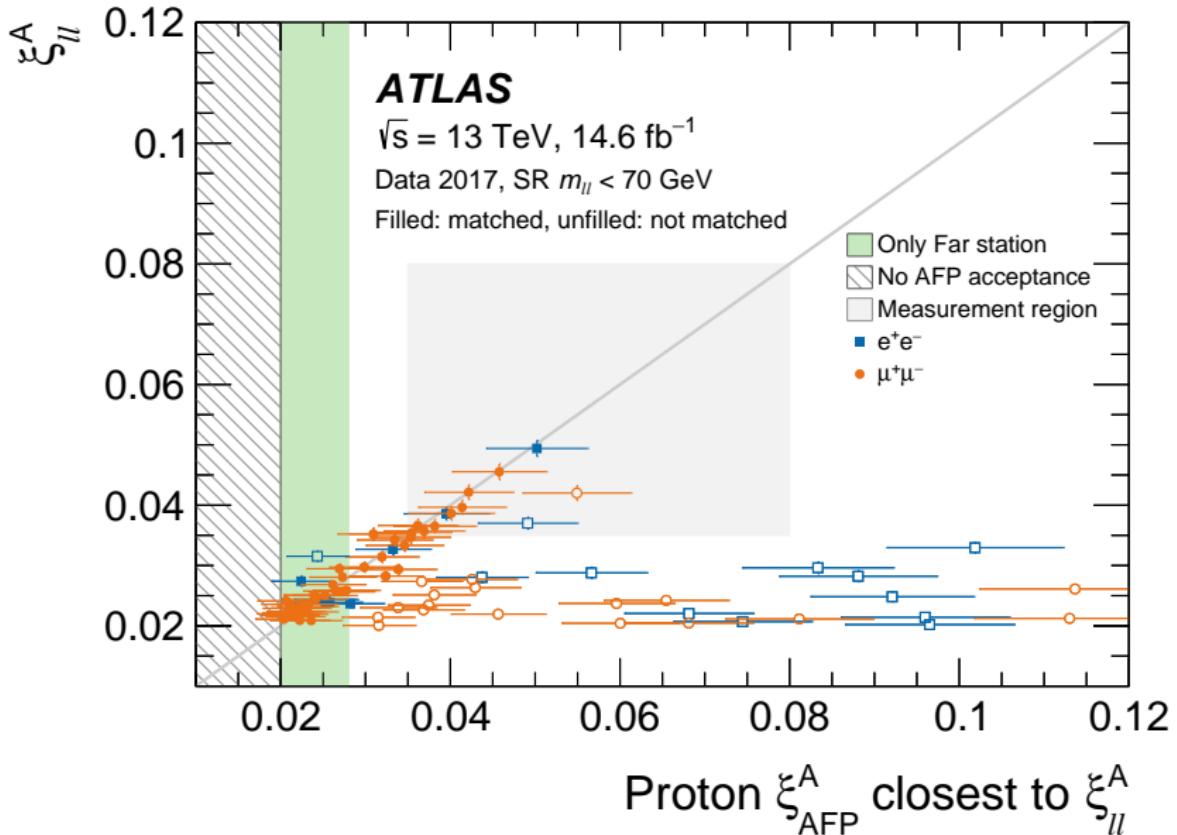
Feedthrough flange



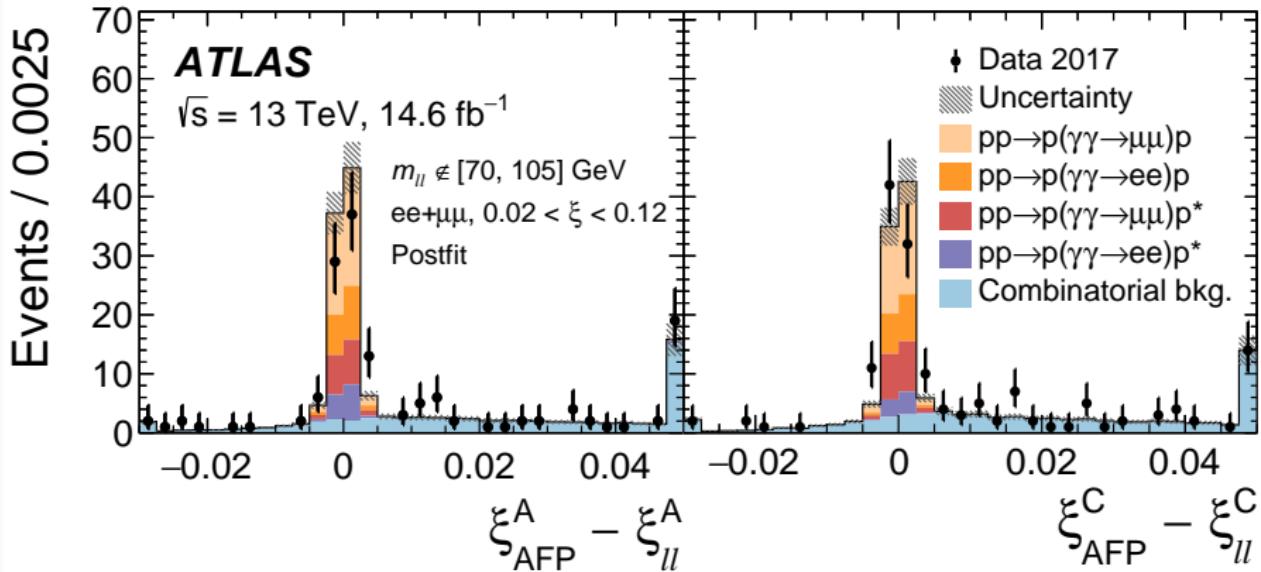
ATLAS Forward Proton detectors – one arm



Kinematic matching



Signal evidence



Summary

Forward physics

- physics between perturbative and non-perturbative QCD
- wide range of different topics
- standard and dedicated experimental methods