The ATLAS Experiment and Diffractive Physics

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(on behalf of the ATLAS Collaboration)

Outline:

I. Introduction: LHC and ATLAS

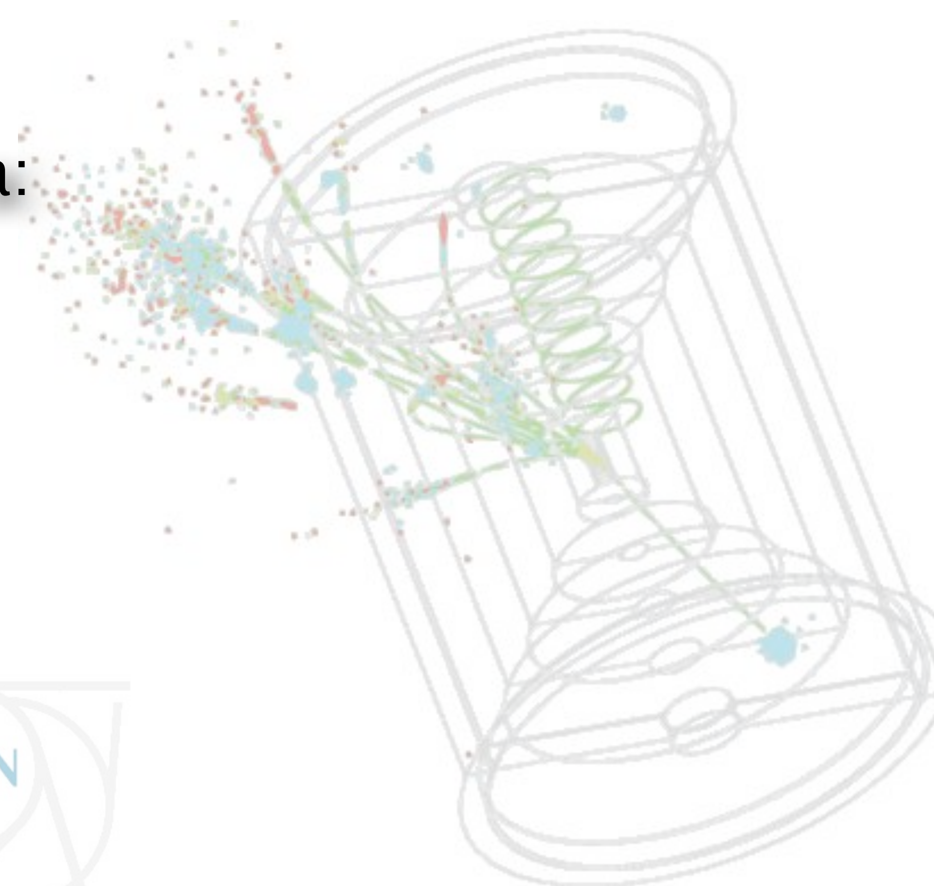
II. Forward Detectors

- a. MBTS
- b. LUCID
- c. ZDC
- d. ALFA

III. Diffractive Measurements with early data:

- a. Soft diffraction
- b. Gaps between jets
- c. CEP

IV. Summary



The Large Hadron Collider

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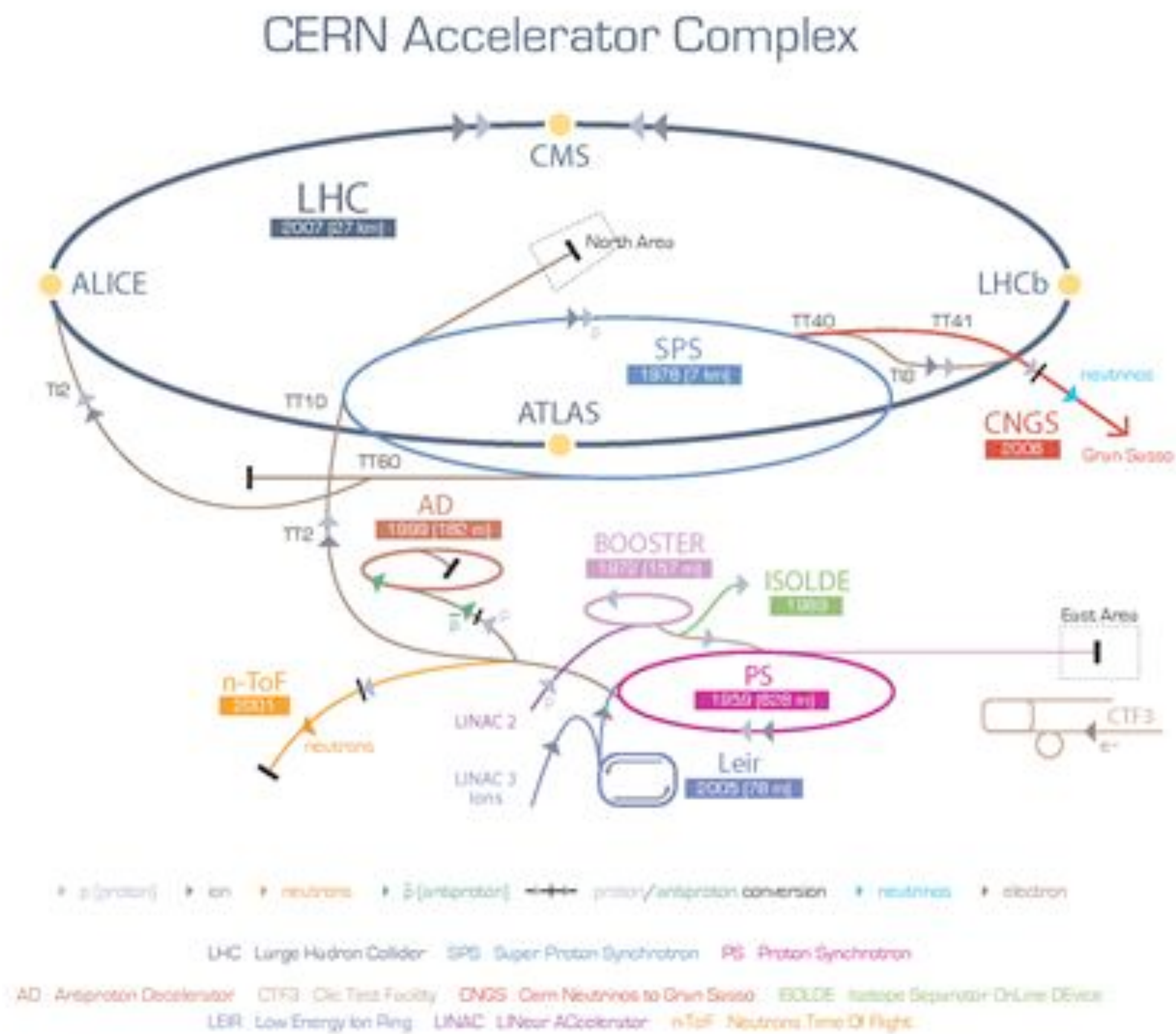
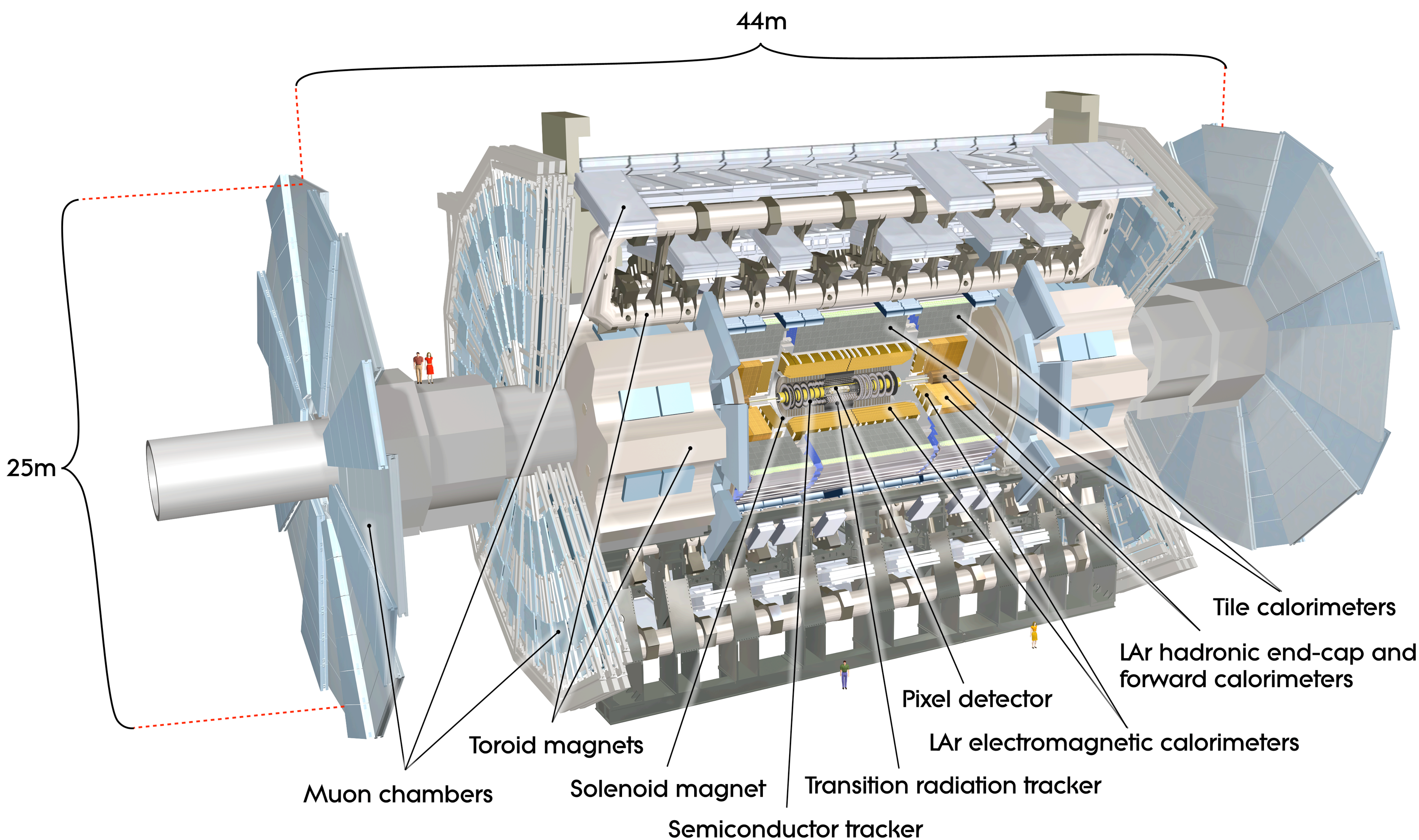


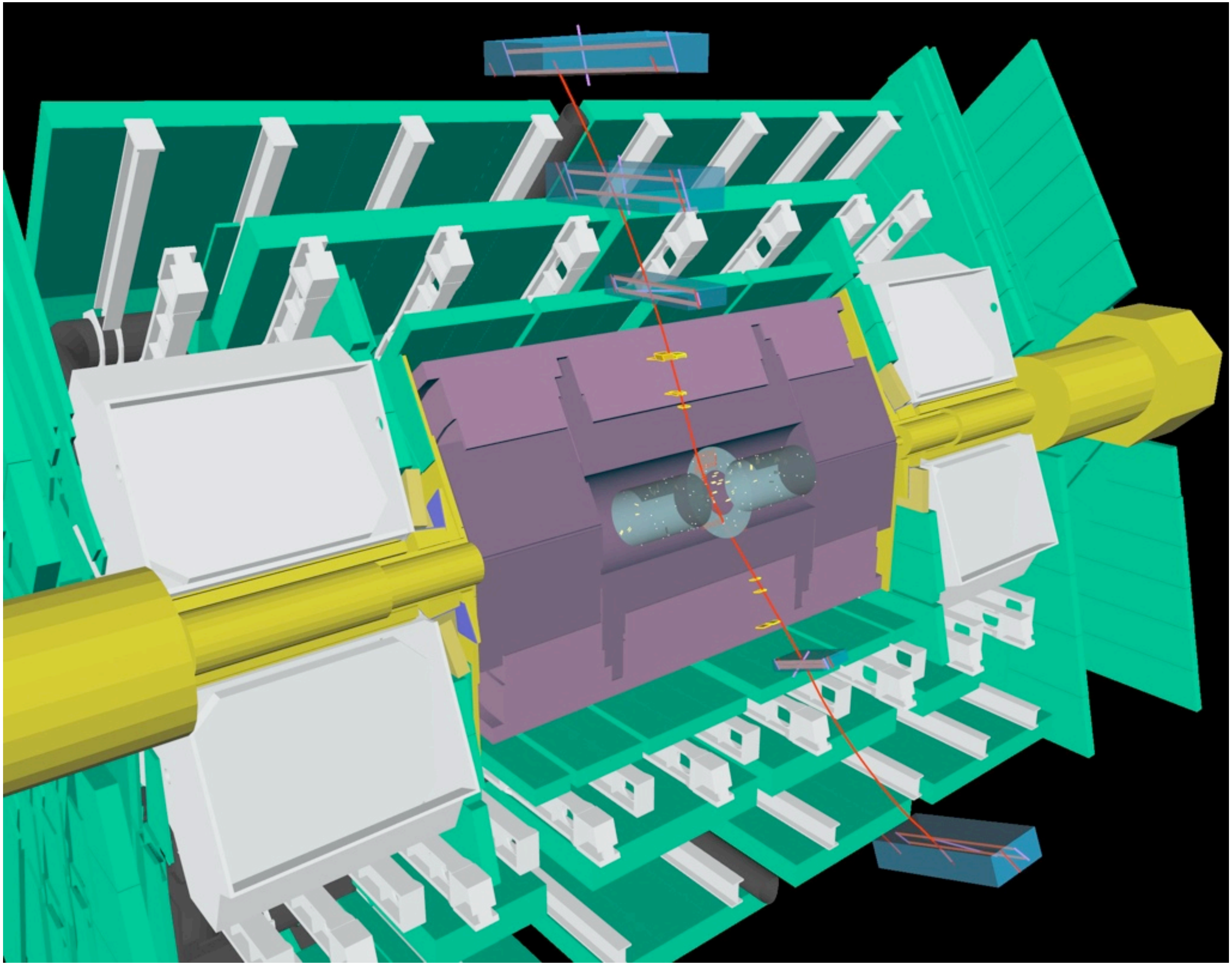
- p-p collisions at **$\sqrt{s}$=14TeV** (x7 wrt Tevatron)
- design luminosity **10^{34} cm^{-2}s^{-1}** (x100 wrt Tevatron)
- bunch crossing every 25 ns (**40 MHz**)
  - ~1fb^{-1}/year with L= 10^{32} cm^{-2}s^{-1}
  - ~10 fb^{-1}/year with L= 10^{33} cm^{-2}s^{-1}
- Current schedule:
  - Start-up in November 2009: pp collisions at $\sqrt{s}$=7TeV
  - **few months of physics runs at $\sqrt{s}$=7TeV in 2009/10**
    - **after collecting hundreds (?) of pb^{-1}, energy is expected to be raised up to $\sqrt{s}$=10TeV.**
    - **expect moderate pile-up early on.**

ATLAS: A Toroidal LHC ApparatuS



The ATLAS Collaboration,
G. Aad *et al.*, The ATLAS Experiment at the CERN Large Hadron Collider, JINST 3 (2008) S08003

Cosmic ray event detected by ATLAS (18th October 2008)



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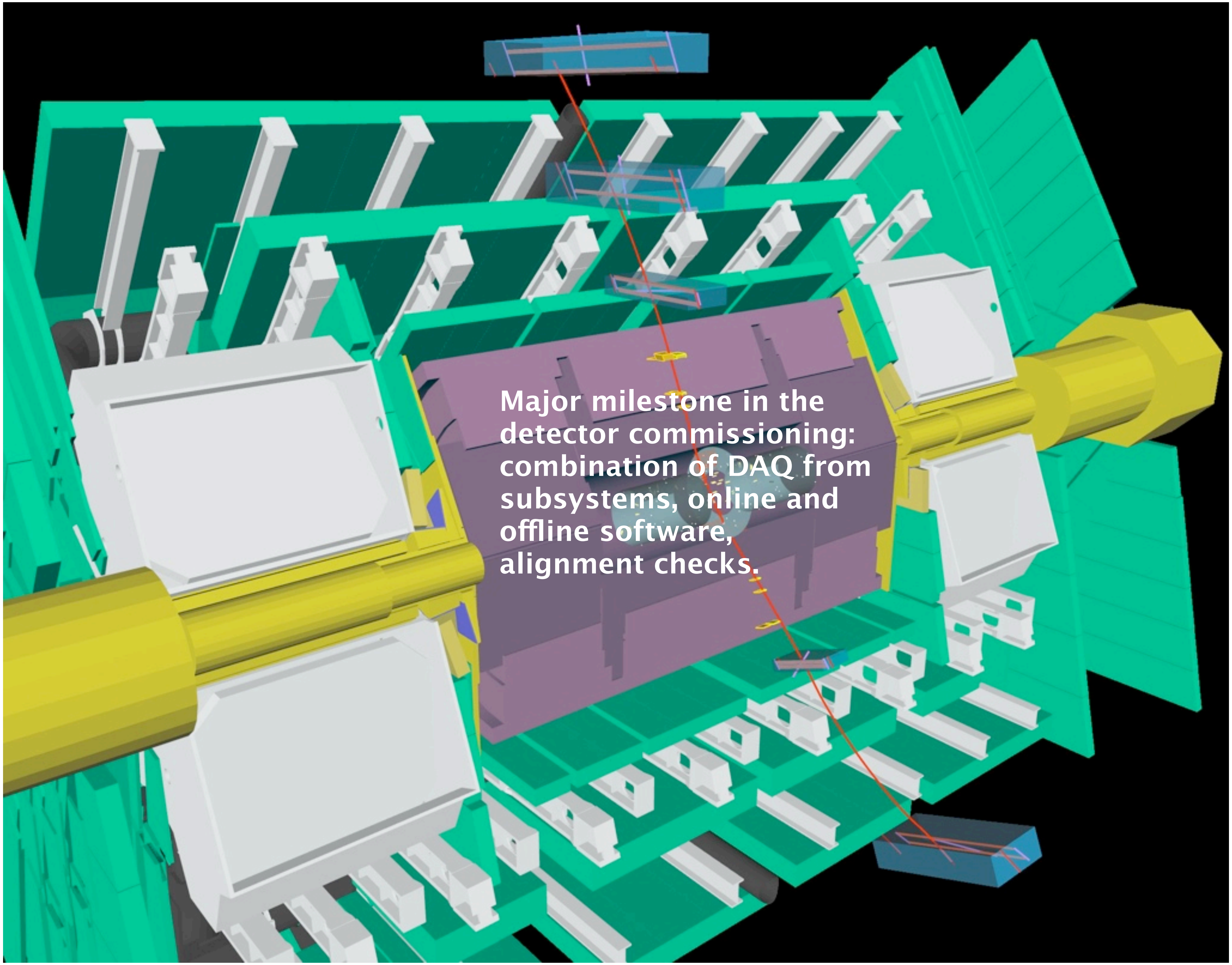

SM at the LHC: what can be done with early data?

- **Goals of SM physics studies with early data:**
  - Use W, Z and top to calibrate the detector & triggers.
  - Control **W**, **Z**, **top** and **QCD multi-jets** to properly estimate the background for physics beyond the SM
  - Improve current SM measurements to provide stringent consistency tests of the underlying theory.

few pb^{-1}
$L \sim 10^{30}$ to 10^{31} $cm^{-2}\ s^{-1}$

several fb^{-1}
$L \sim 10^{32}$ to 10^{33} $cm^{-2}\ s^{-1}$

SM at the LHC: what can be done with early data?

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☑ Extensive test beam characterization of prototypes and final modules. Also used for validation of G4 simulations.

☐ 'In situ' detector calibration:
- ☑ Cosmics runs;
- ☐ Single beam and beam gas runs during LHC commissioning;
- ☐ Calibration with physics processes;
  - – Procedure valid for all sub-detectors, ECAL, HCAL, inner trackers, Muon Chambers.

☐ Need to **"re-discover" the SM** at the LHC before claiming any discovery of new physics!

LHC Parton Kinematics

- Essentially all physics at LHC are connected to the interactions of quarks and gluons (small & large transferred momentum).

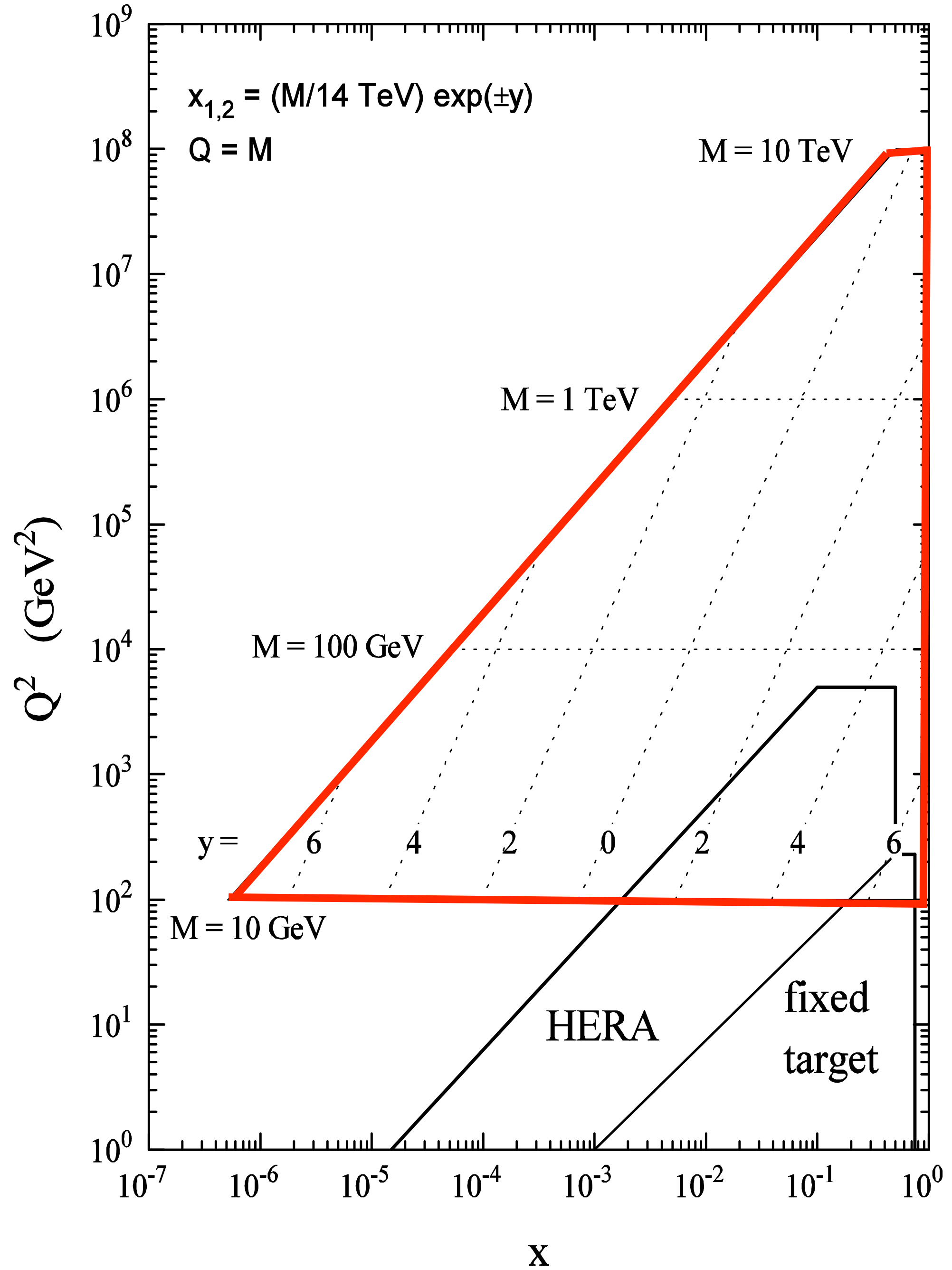
- Experience at the Tevatron is very useful, but scattering at the LHC is not necessarily just "rescaled" scattering at the Tevatron.

    - dominance of gluon on sea quark scattering;
    - large phase space for gluon emission and thus for the production of extra jets;
    - intensive QCD background!

- **This requires a solid understanding of QCD.**

- **Dijet production at large rapidity intervals will allow tests of BFKL predictions** *(low x processes)*.

- The kinematic acceptance of the LHC detectors allows a large range of **x** and **Q²** to be probed (ATLAS coverage: |y| < 5).

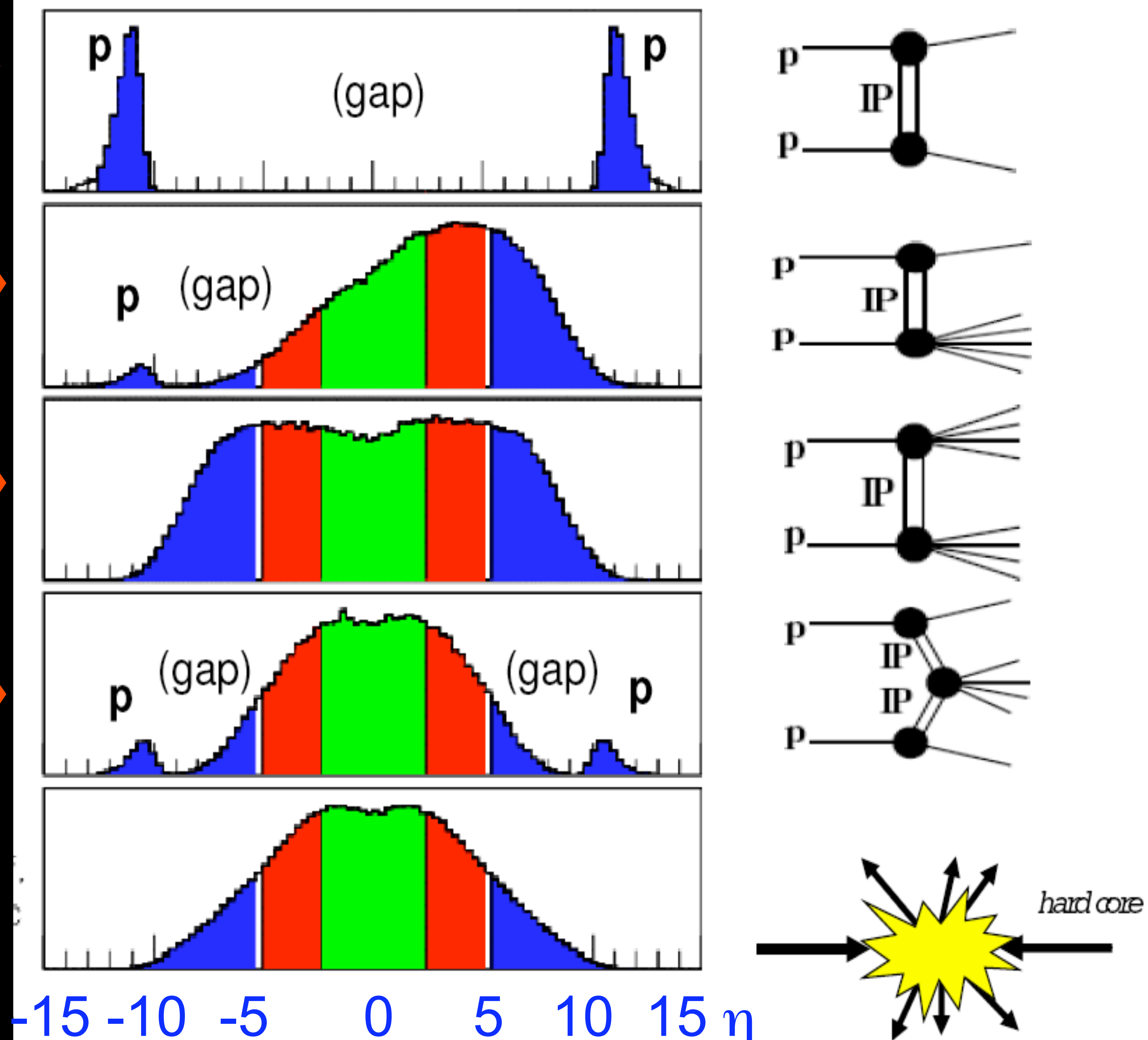


✱ **LHC will open up a wide range of x to be probed**

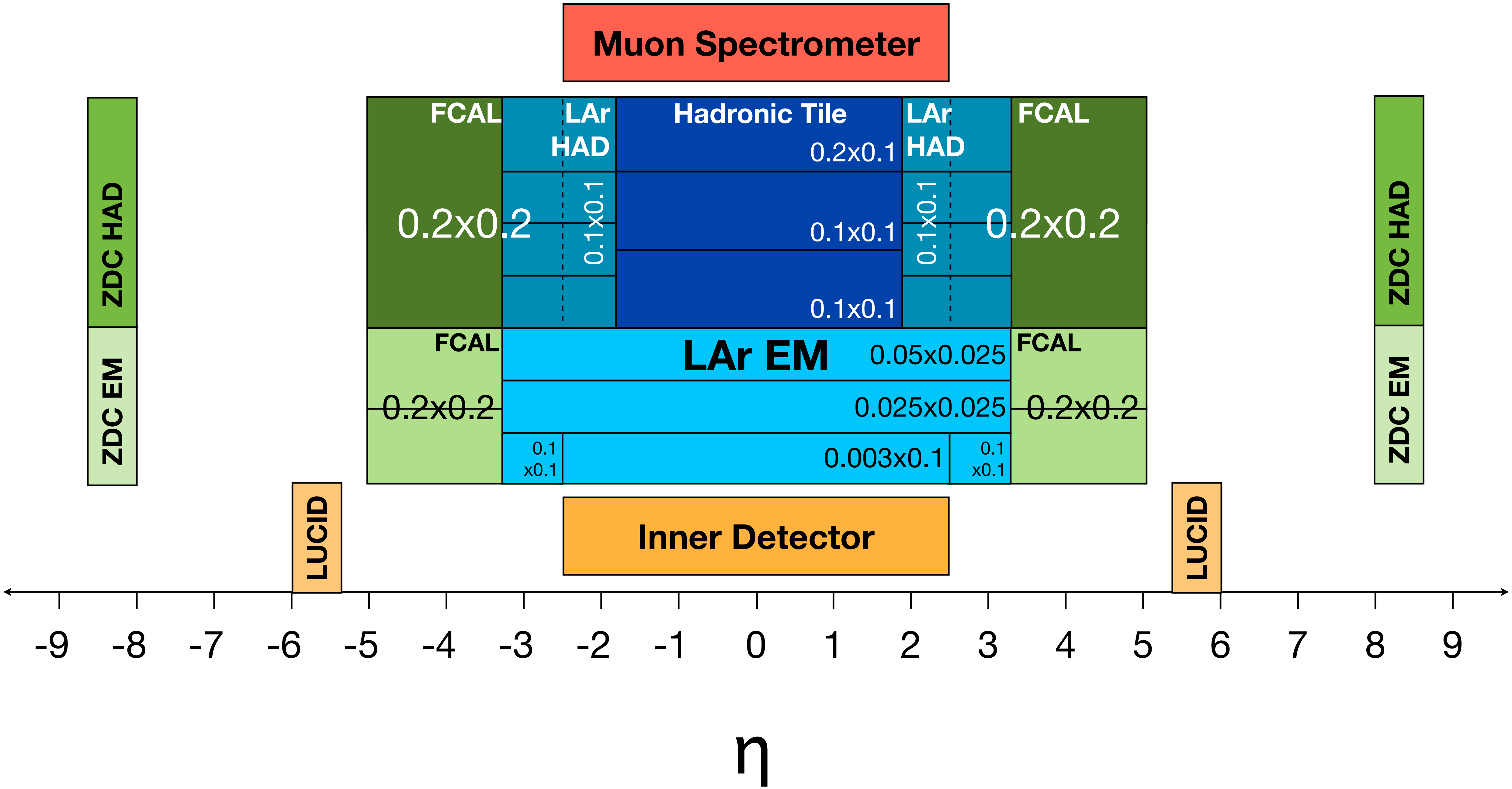
p-p collisions at the LHC

- Instrumentation of the forward region opens up a new window on QCD physics at the LHC.
  - diffractive & elastic collisions correspond to ~40% of the total p-p cross-section

- Elastic (25% of σ_{tot})
- Single diffractive (10% of σ_{tot})
- Double diffractive ($\sim 1\%$ if σ_{tot})
- Central diffractive DPE ($\sim 1\%$ if σ_{tot})
- Inelastic (non diffractive) (60% of σ_{tot})

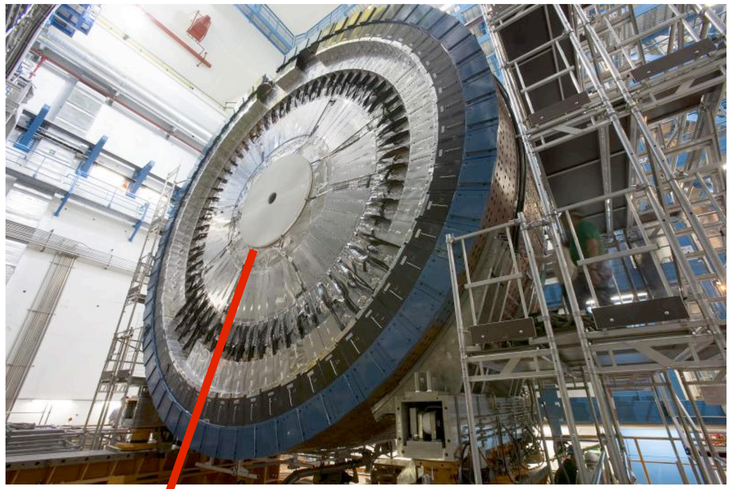


ATLAS: η coverage

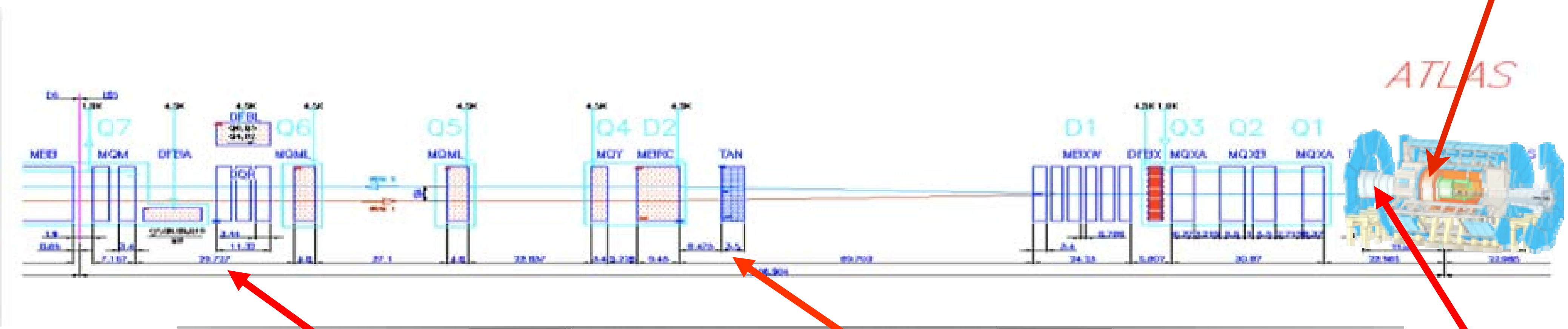


ATLAS Forward Detectors

Minimum Bias
Trigger Scintillator



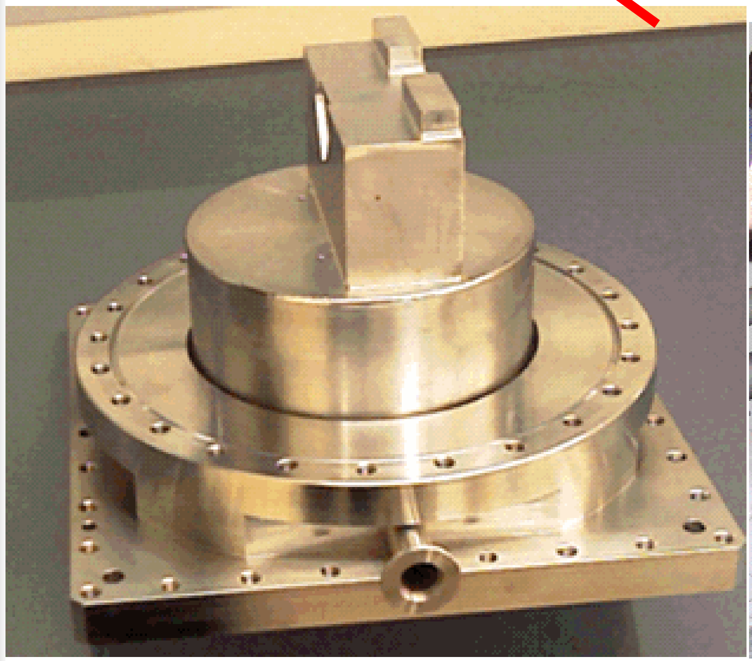
MBTS at 3.6 m

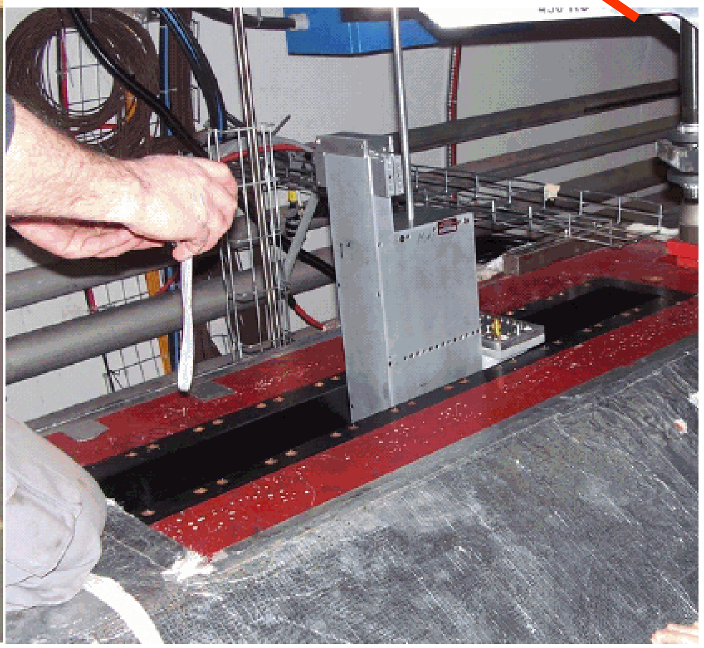


ALFA at 240 m

ZDC at 140 m

LUCID at 17 m





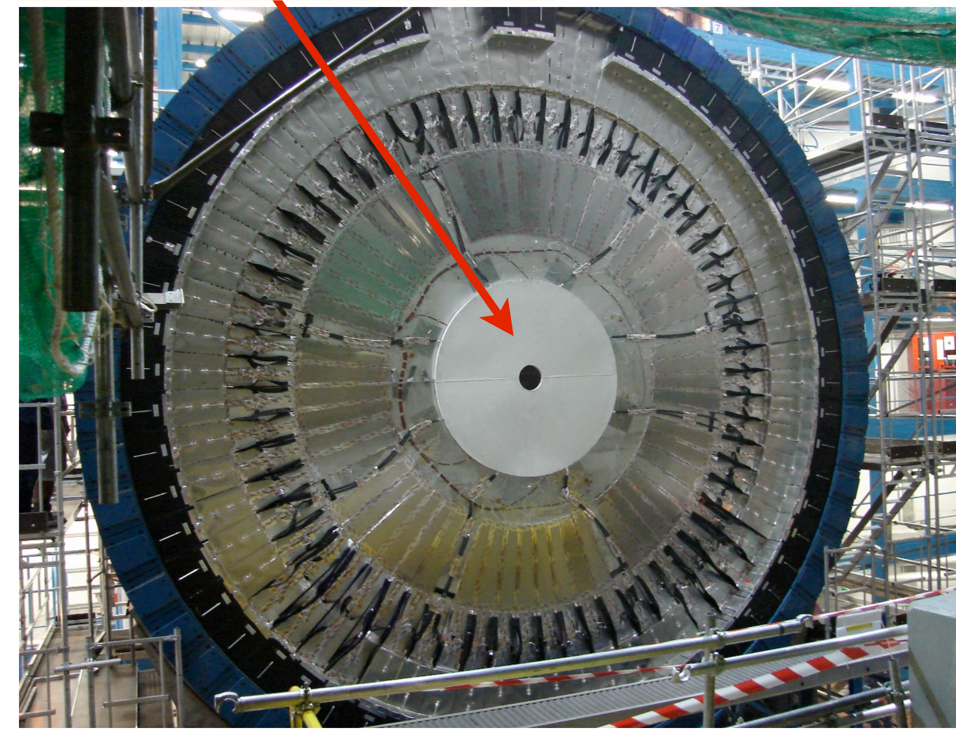
Absolute Luminosity
for ATLAS

Zero Degree
Calorimeter

Luminosity Cerenkov
Integrating Detector

MBTS

Minimum Bias Trigger Scintilators



- *Minimum Bias Trigger Scintilator* – *MBTS*

  - Trigger scintillation counters mounted on LAr endcap cryostats covering the radial dimension of the Inner Detector.

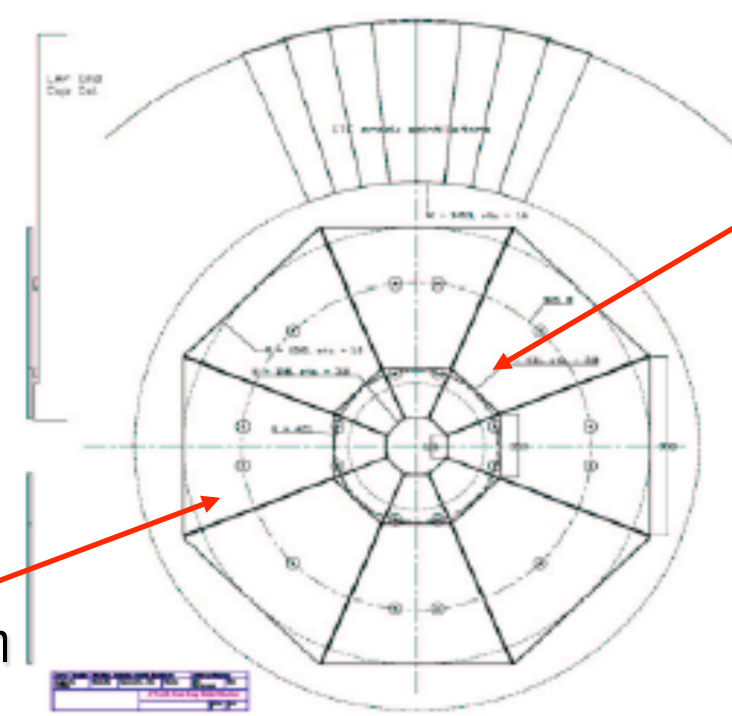
  - To be used for first beam (few months at low luminosity).

    – 2 segments in η;

    – 8 segments in φ on each side;

  - Counters will provide an effective “minimum bias” trigger. The MBTS will also be used to study topologies with η gaps.

inner η



outer η

MBTS

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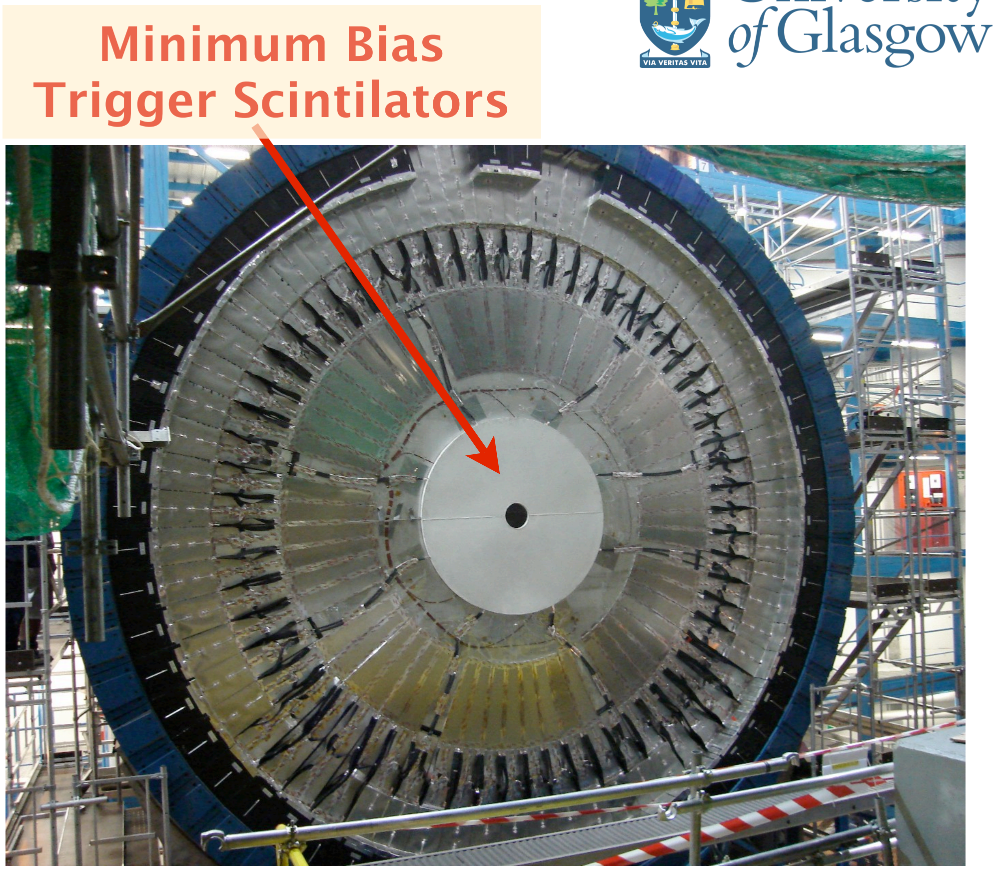
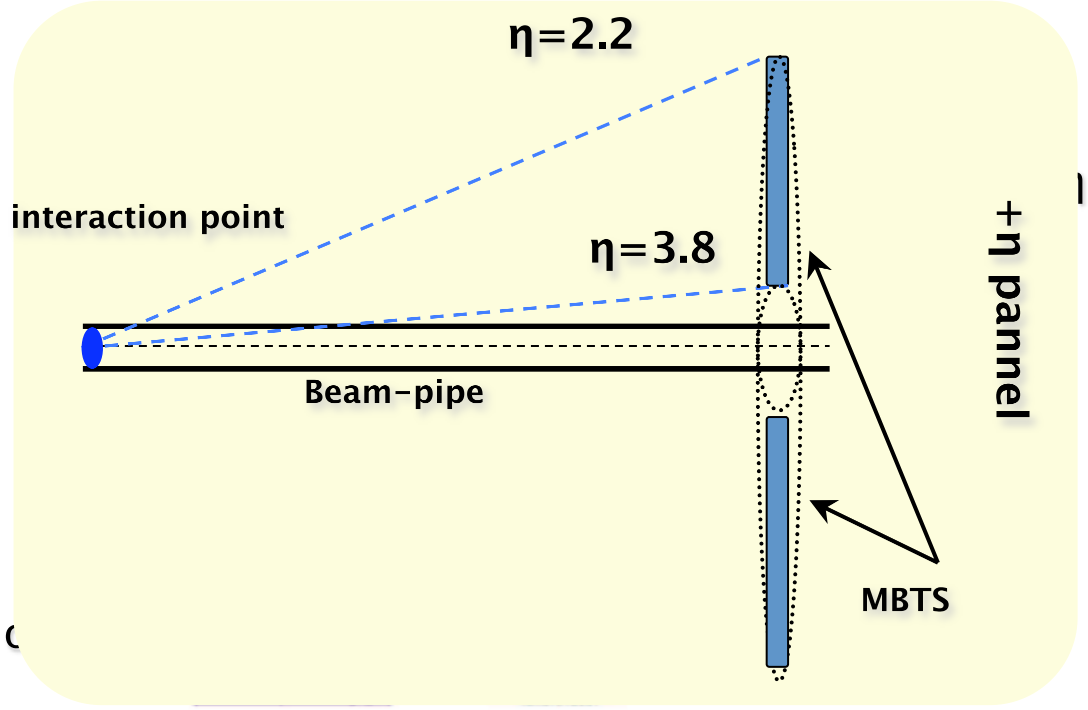
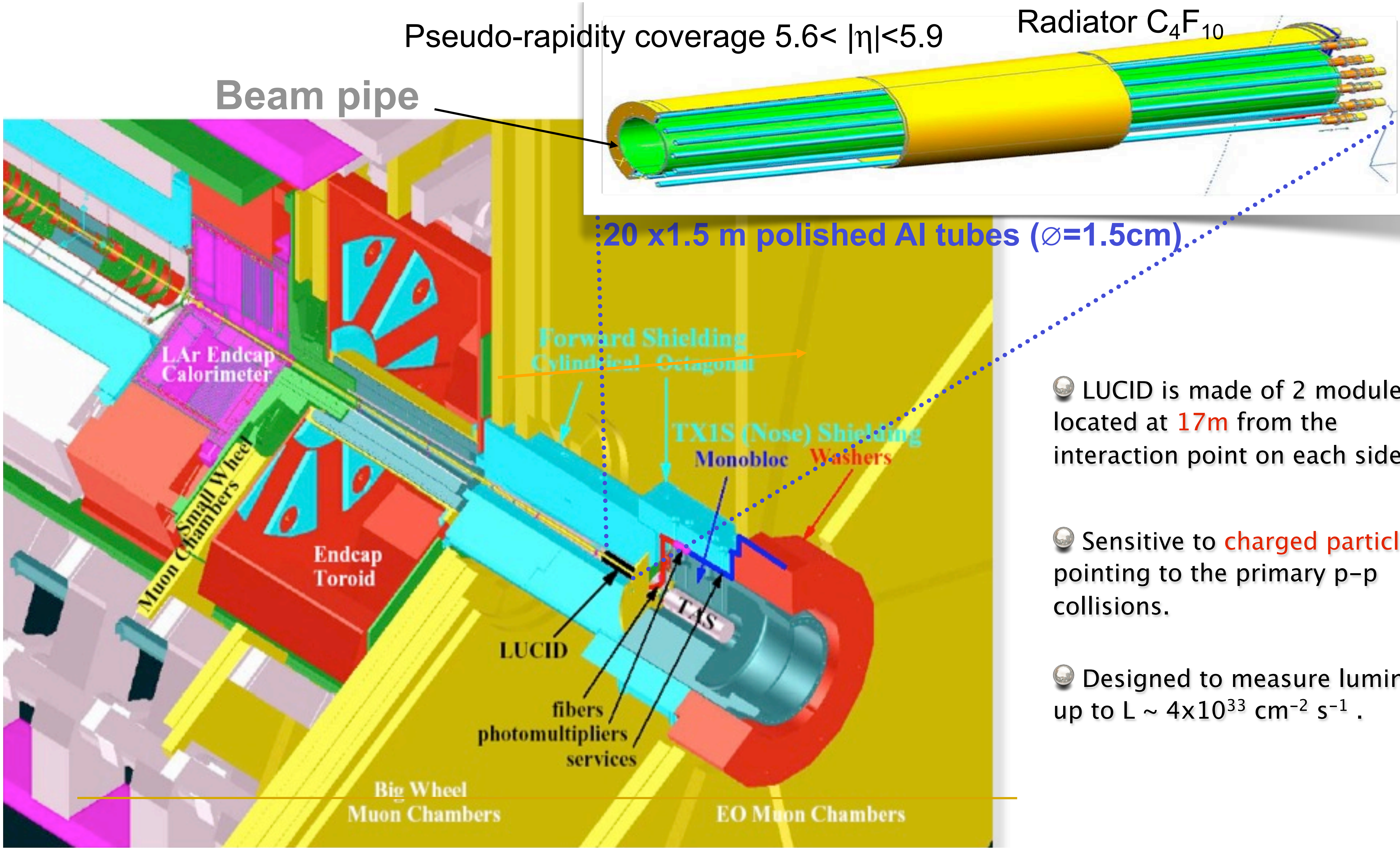


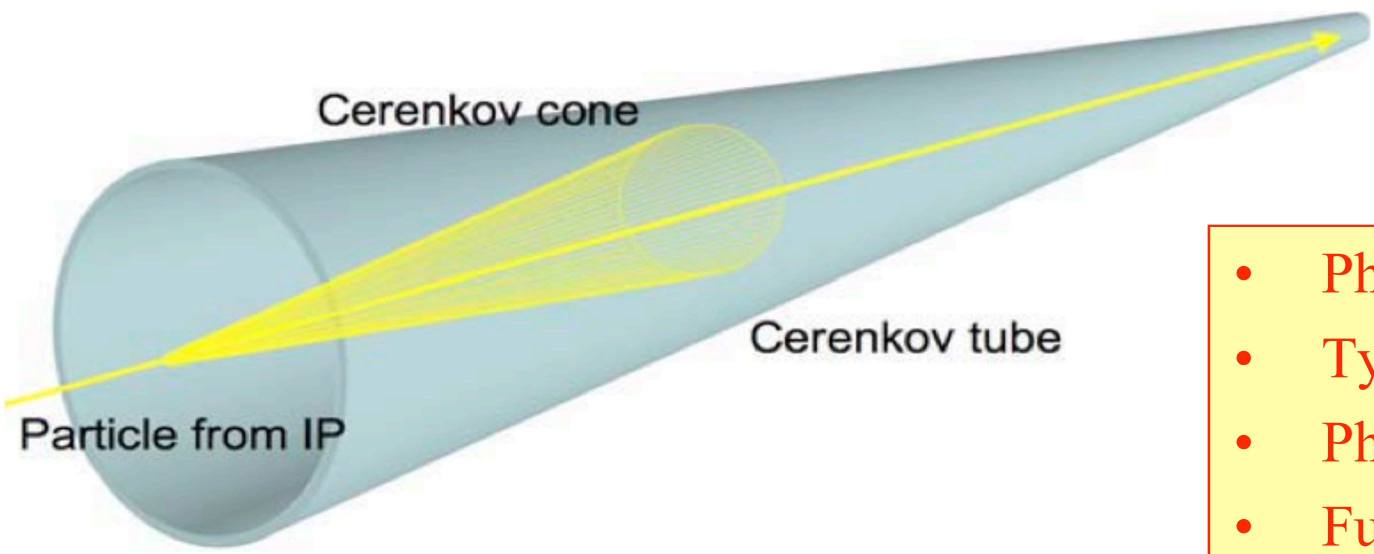


LUCID: Luminosity Monitor



- LUCID is made of 2 modules located at 17m from the interaction point on each side.
- Sensitive to charged particles pointing to the primary p-p collisions.
- Designed to measure luminosity up to L ~ $4x10^{33}$ cm^{-2} s^{-1} .

LUCID: Detector Principle

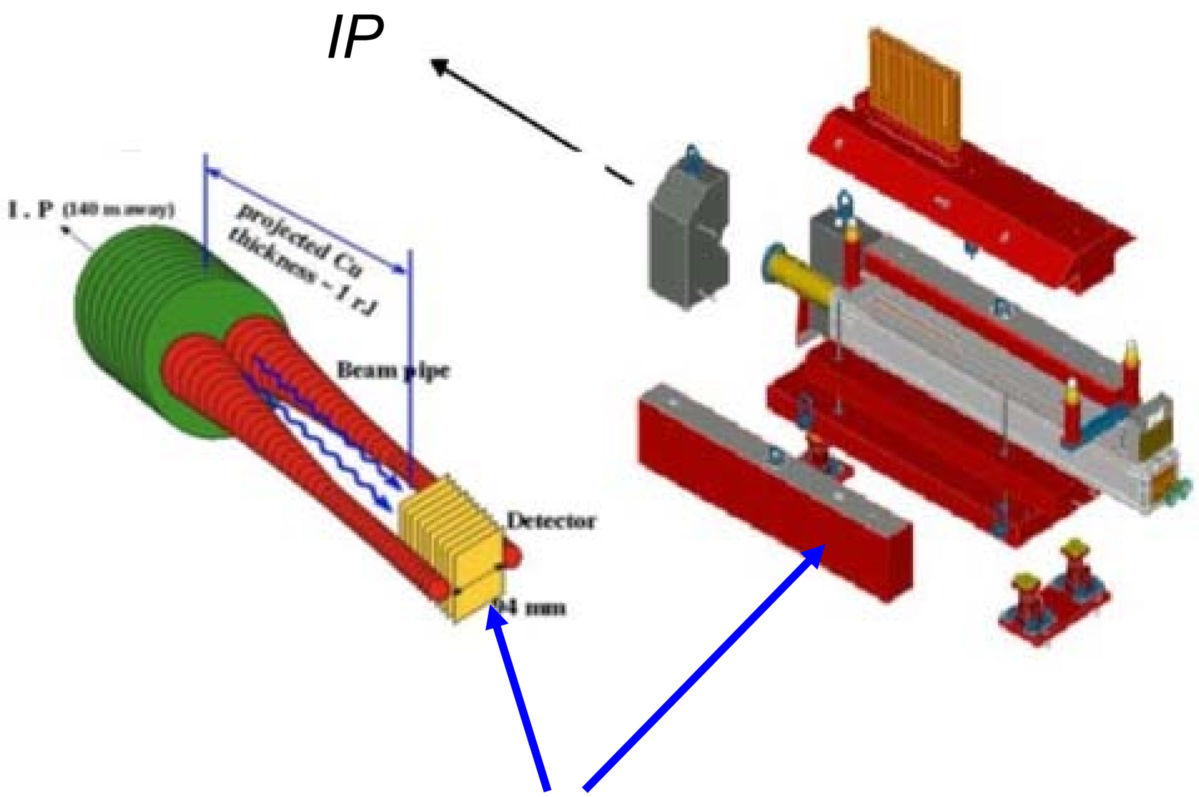


PMT read-out

- Photons are emitted at 3°
- Typically 3 reflections inside the tubes
- Photons are read-out by PMT
- Further photons radiated inside PMT

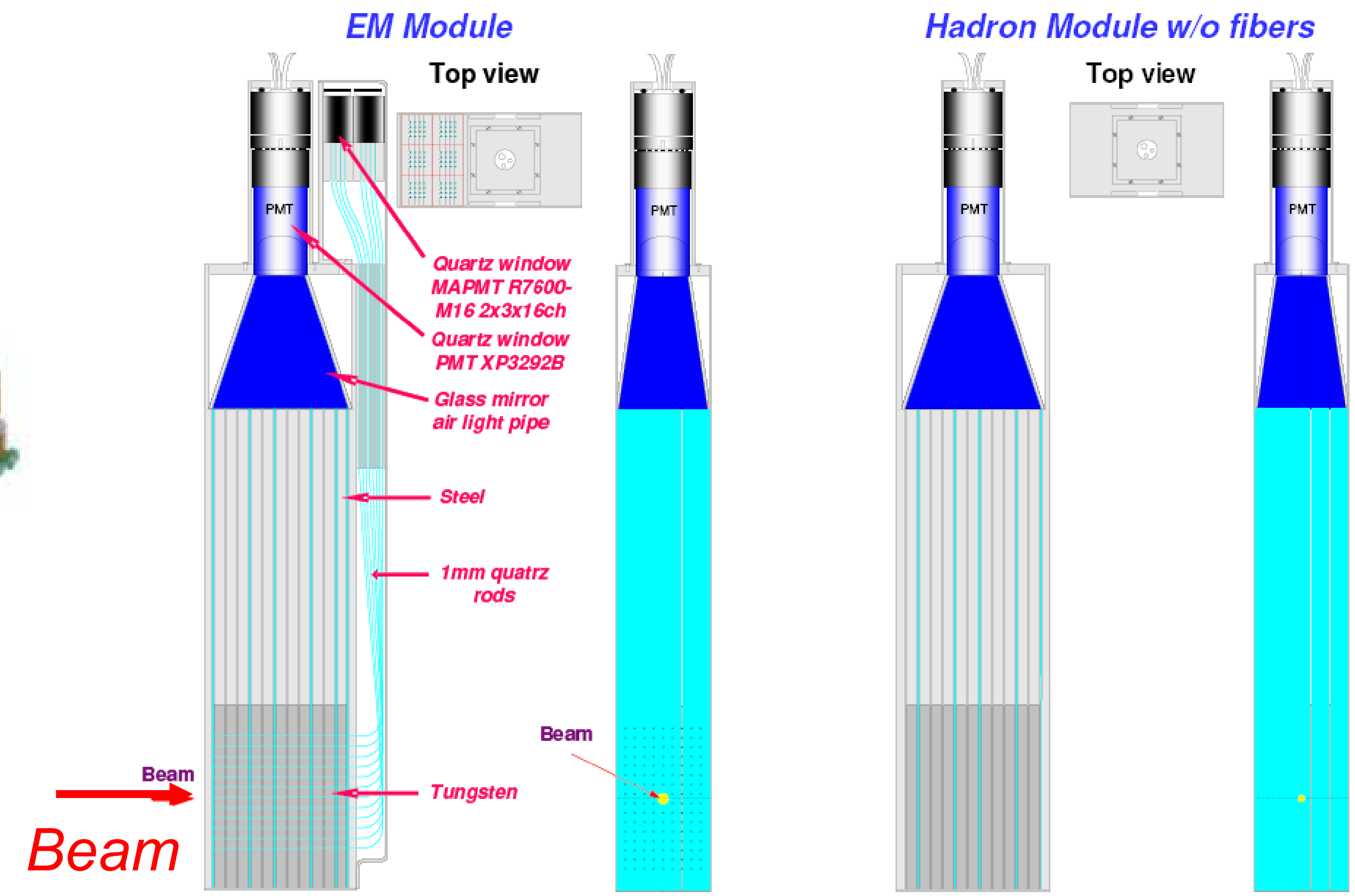
- Average number of tracks per tube per event proportional to luminosity.
- Monitor bunch by bunch stability. Measure relative luminosity.
- Calibration needed:
  - LHC machine parameters *(10-20%)*
  - Known reactions e.g. W, Z *(5-8%)*
  - ALFA calibration in special runs *(~2%)*

ZDC: Zero Degree Calorimeter



TAN housing beam pipe, and ZDC

(TAN: target absorber for neutrals)

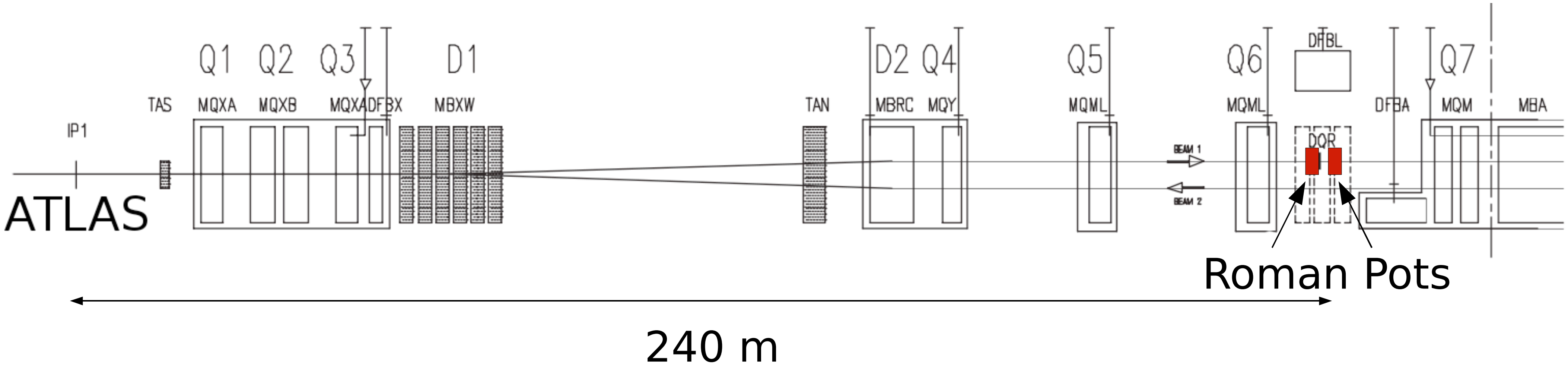


- The ZDC will measure production of neutral particles in the forward direction.
  - 1 EM and 3 hadronic calorimeters.
  - Tungsten/Quartz calorimeter covering |η|>8.3 for neutrals.
    - quartz strips for energy measurement.
    - horizontal rods for coordinate measurements

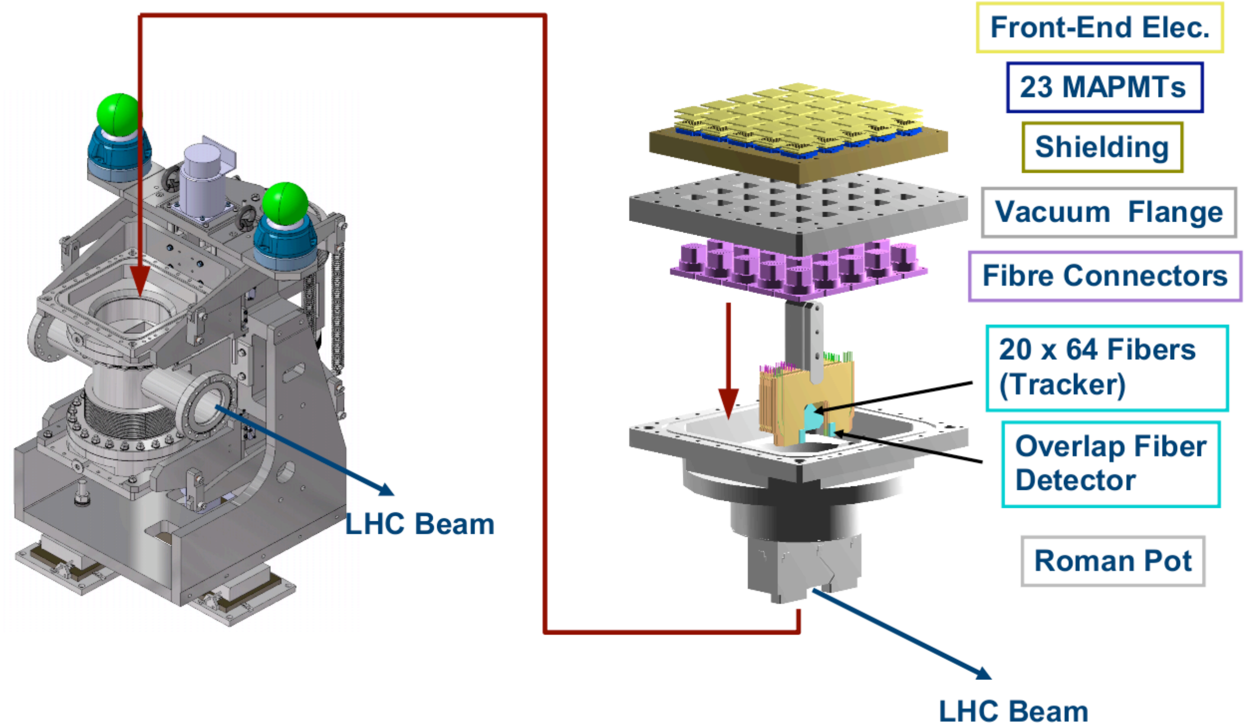
ZDC: Zero Degree Calorimeter

- Neutral particles at 0º :
  - Heavy Ion Physics: impact parameter (event centrality), luminosity, trigger input
  - p-p collisions: forward cross sections, trigger input
  - Accelerator tuning: Van der Meer scan, IP position, beam crossing angle

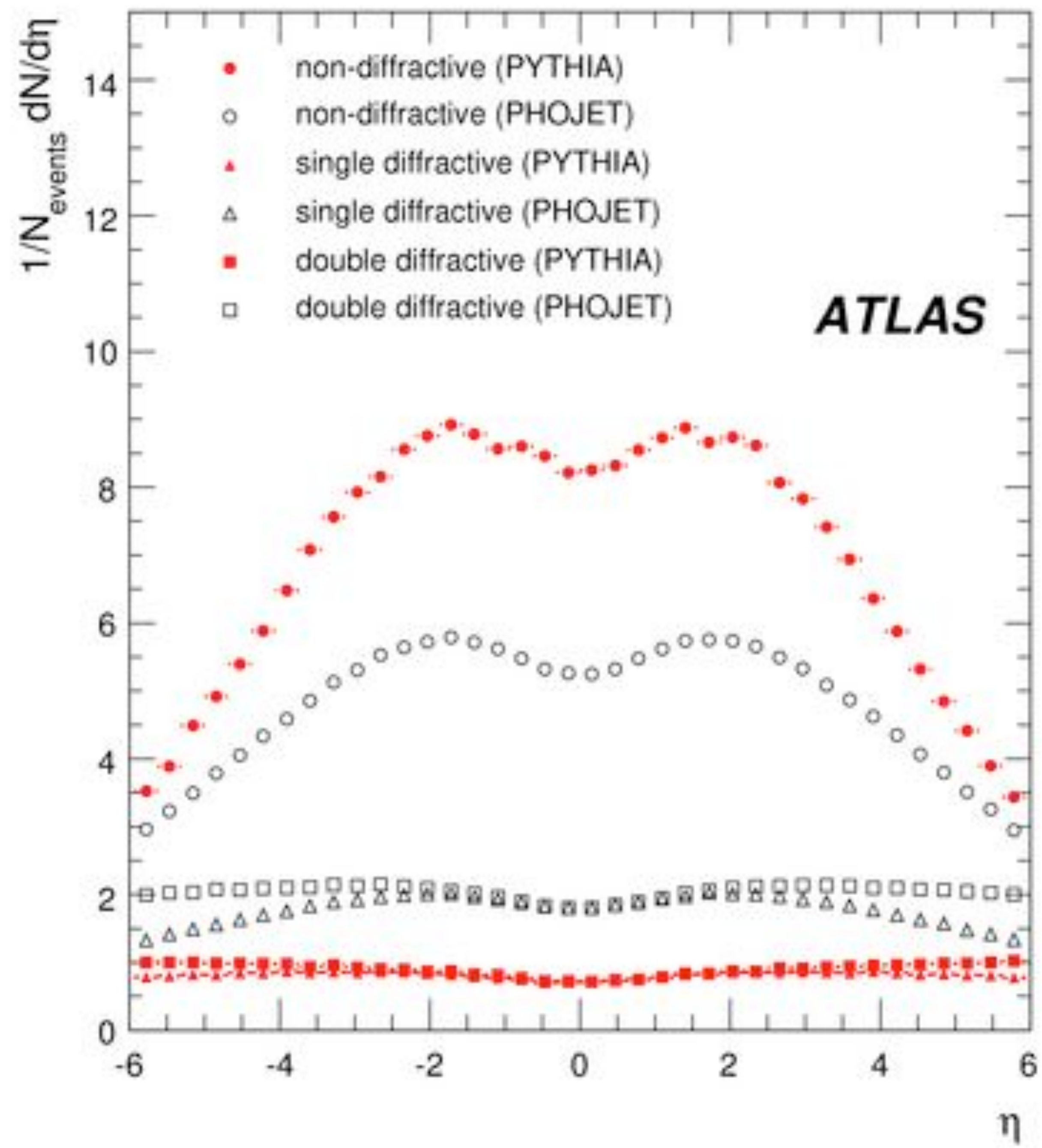
The ALFA Detector



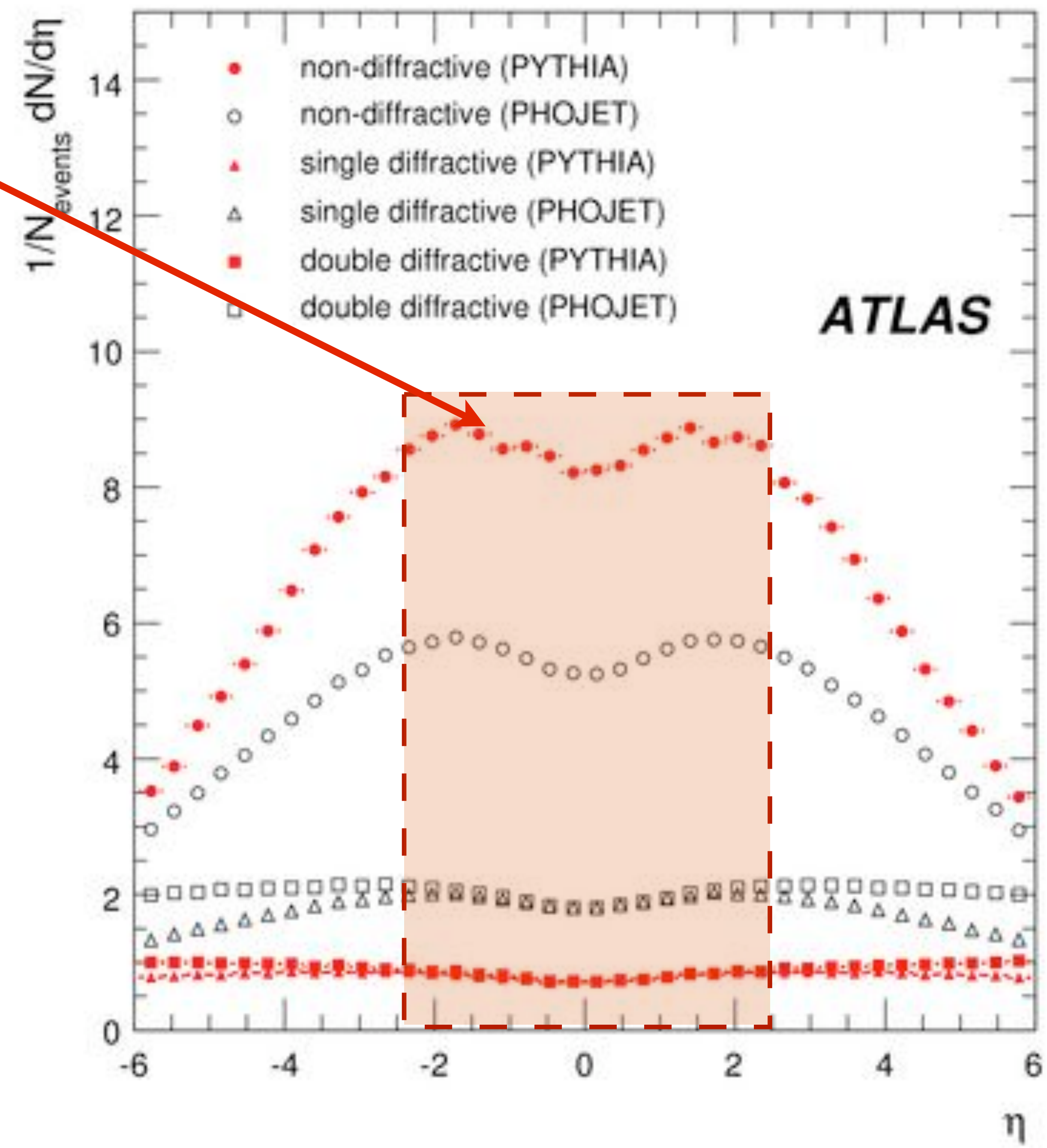
- *A*bsolute *L*uminosity *F*or *A*TLAS – *ALFA*
  - Two roman pot stations in the forward direction on each side of the interaction point of ATLAS.
  - Each station contains an upper and a lower detector.
    - each detector is made of a 20x64 scintillating fibers tracker



  - Measure elastic p-p scattering down to very small angles.
  - Need special runs: **high β*** and **low luminosity** (L ~10^{27} cm^{-2} s^{-1})

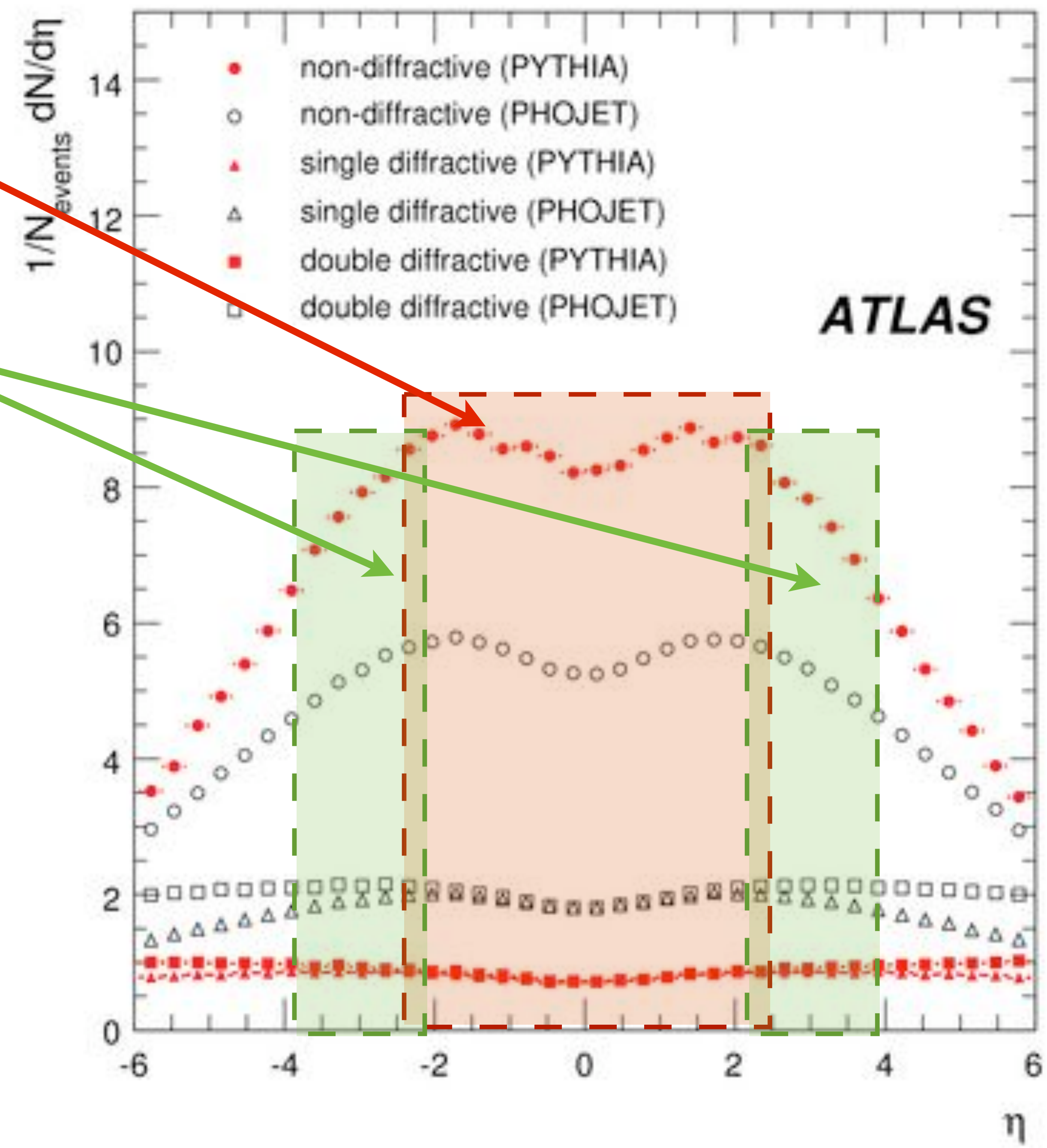

non-diffractive (PYTHIA)
non-diffractive (PHOJET)
single diffractive (PYTHIA)
single diffractive (PHOJET)
double diffractive (PYTHIA)
double diffractive (PHOJET)
ATLAS
$1/N_{events}\ dN/d\eta$
η
0
2
4
6
8
10
12
14
-6
-4
-2
0
2
4
6

Inner detector space points



Inner detector space points

Minimum bias trigger scintillators

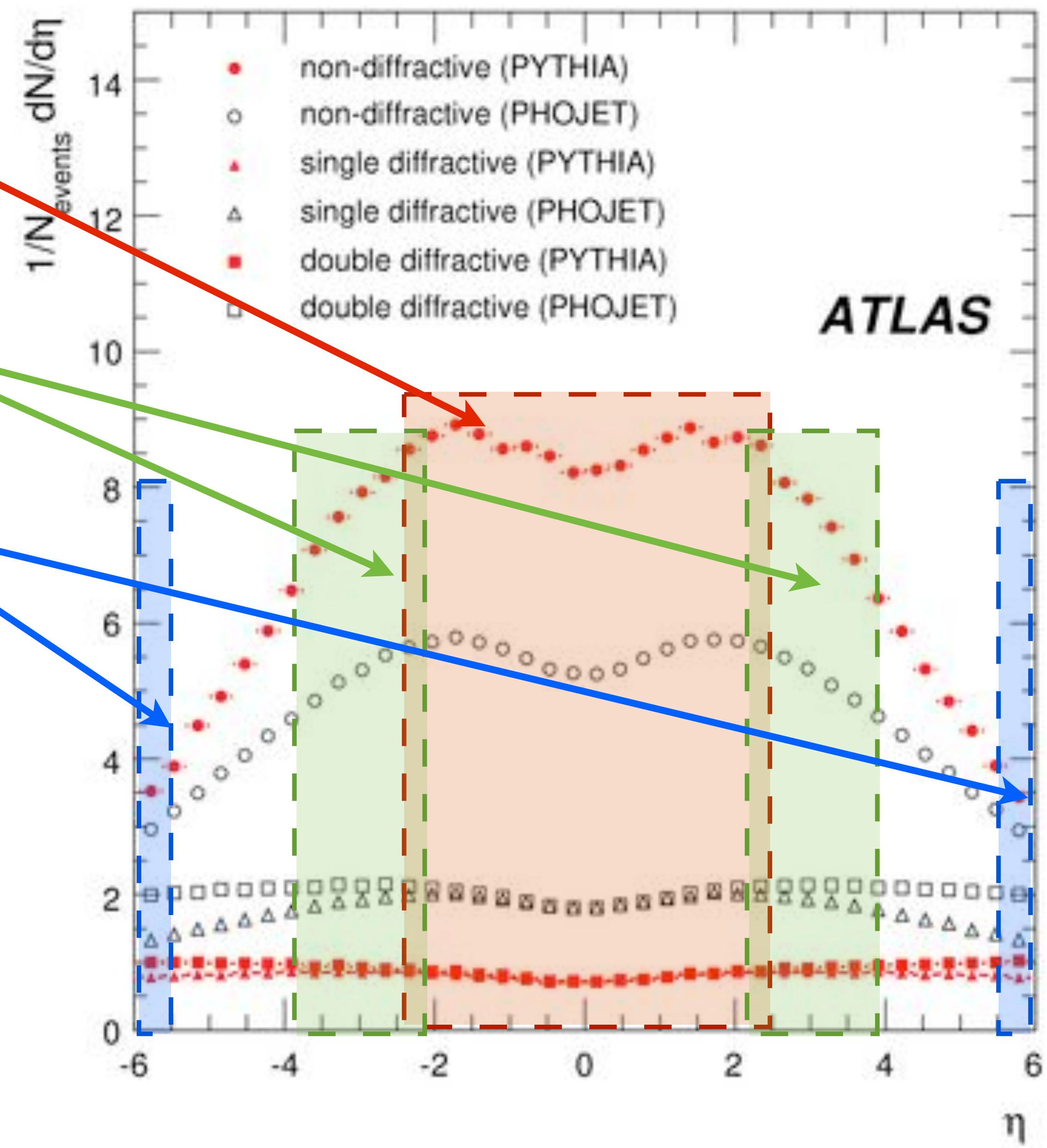


Inner detector space points

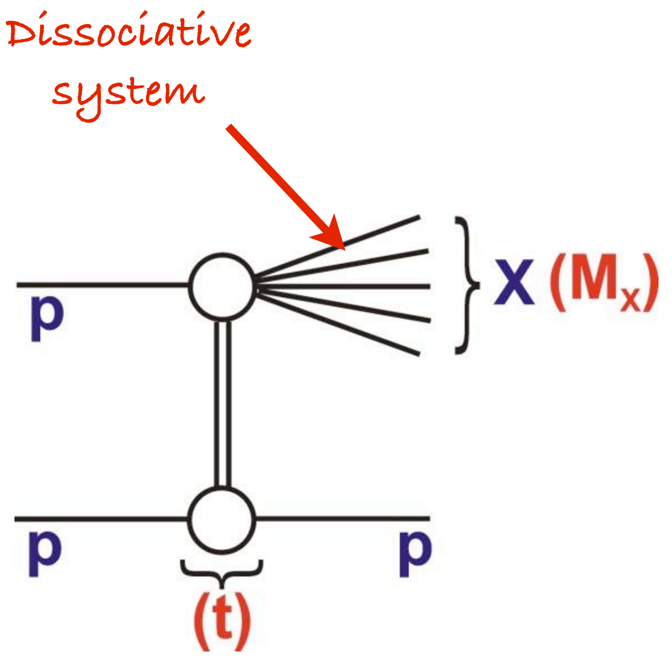
Minimum bias trigger scintillators

Cerenkov detector (LUCID)

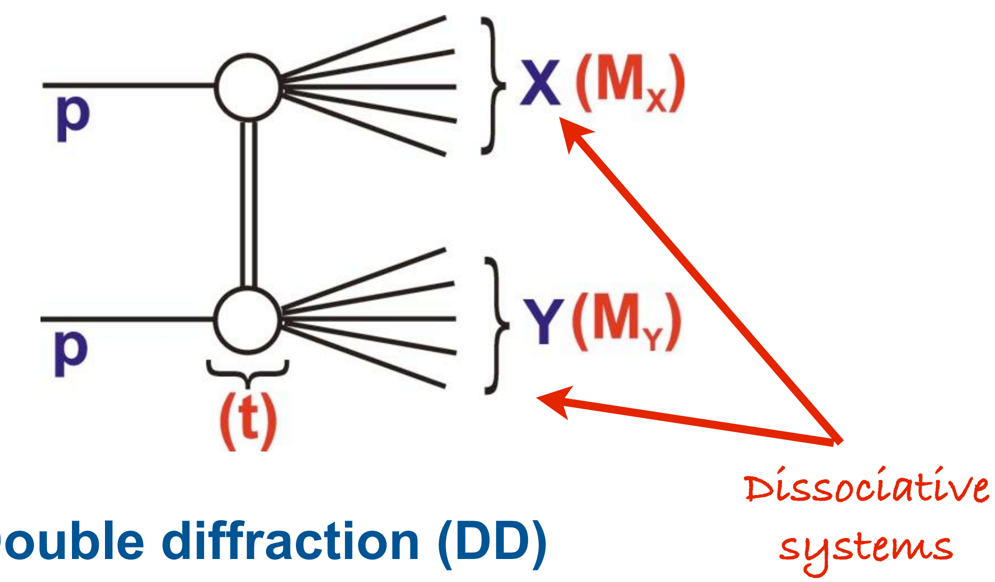
Zero degree calorimeter (ZDC)
8.3 → ∞



Soft Diffractive Events



Single diffraction (SD)



Double diffraction (DD)

- Single *(double)* diffraction is a low-t process in which a colour singlet, i.e. Pomeron, is exchanged between the two protons and one *(both)* of the protons breaks up into a dissociative system.
- Diffractive events can be tagged by identifying a rapidity gap between:
  - outgoing proton and dissociative system in SD, or
  - the two dissociative systems in DD.
  - Earliest experience in identifying gaps.

- The diffractive component of inelastic events is ~20% of the inelastic cross-section.
- Very attractive measurement for early data!
- Large model uncertainty - needs to be calibrated to LHC data.

Measuring Soft Diffractive Events with ATLAS

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- **High-η triggers (MBTS, LUCID, ZDC) are essential!**

- **Measuring soft diffraction:**

Approach 1:

- Identify the dissociated system using the Inner Detector, calorimeters, LUCID and the ZDC.

- Variable of interest: Invariant mass of dissociated system(s) M_X (M_X and M_Y for double-diffraction)

$$\xi = \frac{M_X^2}{s}$$

$$\frac{d\sigma}{dt}|_{M_X} \propto e^{bt}$$

$$b \sim b_0 + 2\alpha' ln\left(\frac{1}{\xi}\right)$$

- Preferably to be done during low luminosity runs.

- Model differences manifest as different fitted slopes, b.

- Characterization of SD & DD is fundamental for early minimum bias measurements and pile-up

- **Diffractive events have a very characteristic shape!**

Approach 2:

- Use ALFA RP detectors (special runs with **high-β*** and **low luminosity**)

- Tag the outgoing proton and measure f_L (fractional momentum loss) directly using:

$$f_L = 1 - \frac{|p'_z|}{|p_z|}$$

p_z and p'_z are the longitudinal momenta of the incoming and outgoing protons.

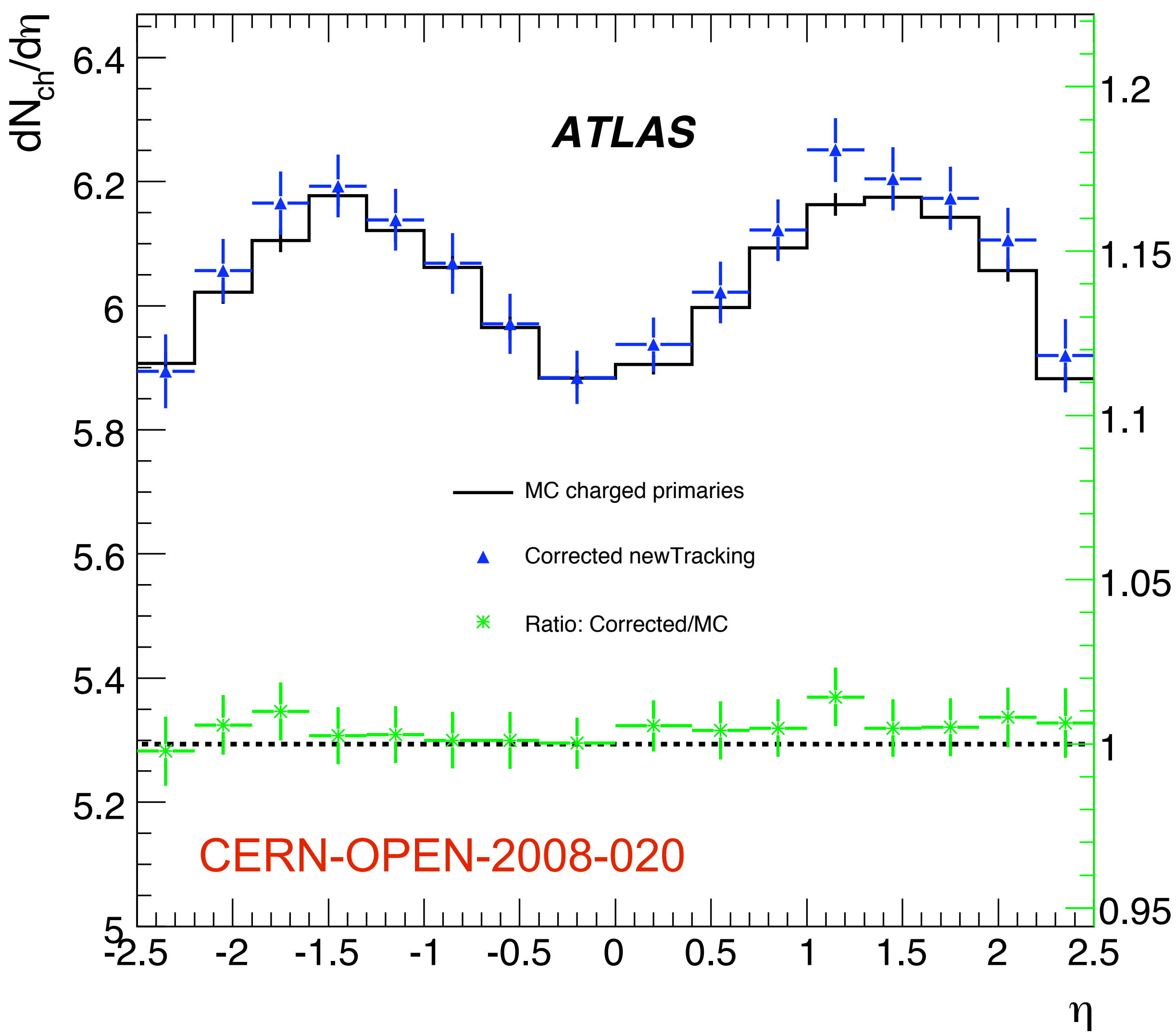
- ALFA will be able to measure f_L with an accuracy between 8% (for $f_L \sim 0.01$) and 2% (for $f_L \sim 0.1$)

- LUCID and ZDC will also be used to tag dissociative system(s) to separate the events from elastic scattering.

1.2 - 1.8M accepted events in 100h at 10^{27} cm^{-2} s^{-1} with overall acceptance of ~40-45%.

Reconstructing minimum bias events

MC charged primaries & track p_T > 150MeV



- Reconstructed distribution for non-single diffractive inelastic events (for p_T > 150MeV)
- This can be directly compared to previous measurements from UA5 and CDF for example.

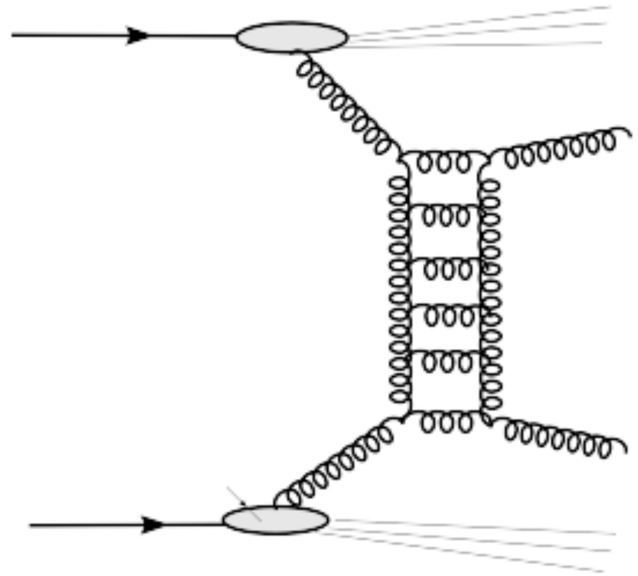
Summary of systematic uncertainties

Track selection cuts	2%
Mis-estimate of secondaries	1.5%
Vertex reconstruction	0.1%
Mis-alignment	6%
Beam-gas & pile-up	1%
Particle composition	2%
Diffractive cross-sections	4%
Total:	**8%**

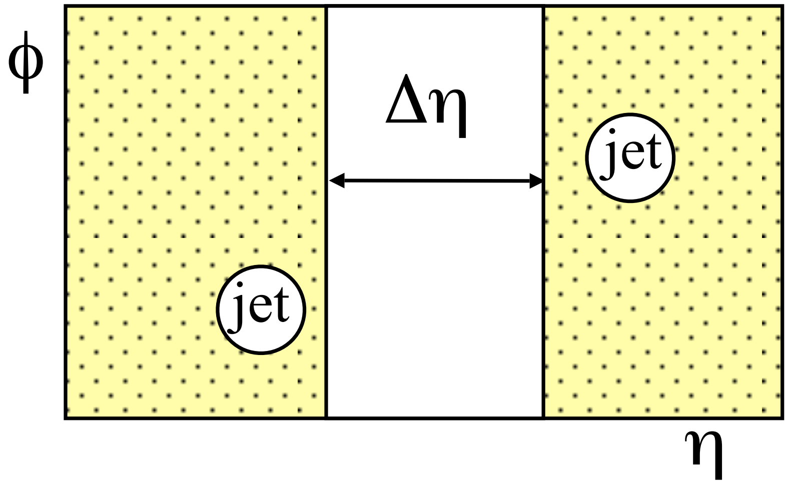
Corrections:
- Track-to-particle correction
- Vertex reconstruction correction
- Trigger bias

Colour singlet exchange: Gaps between jets

- Study the exchange of a colourless object between the protons
  - Lack of colour means reduced QCD radiation.



- Experimental signature for colour singlet exchange is a gap in the detector between the forward jets.
  - Events containing two jets separated by large rapidity interval containing little hadronic activity.
  - search through inclusive two-jet events for those that contain a rapidity gap between jets
  - determine nature of colour singlet exchange
  - colour singlet can be BFKL Pomeron

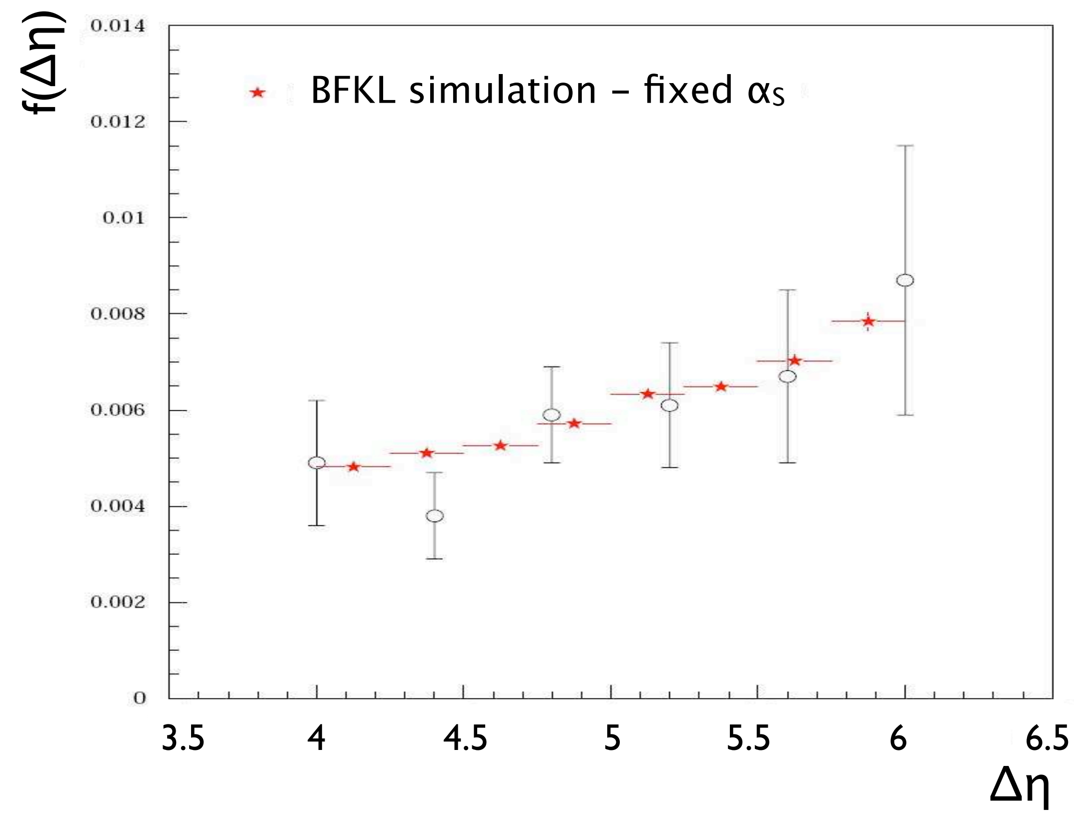


Jets separated by Δη

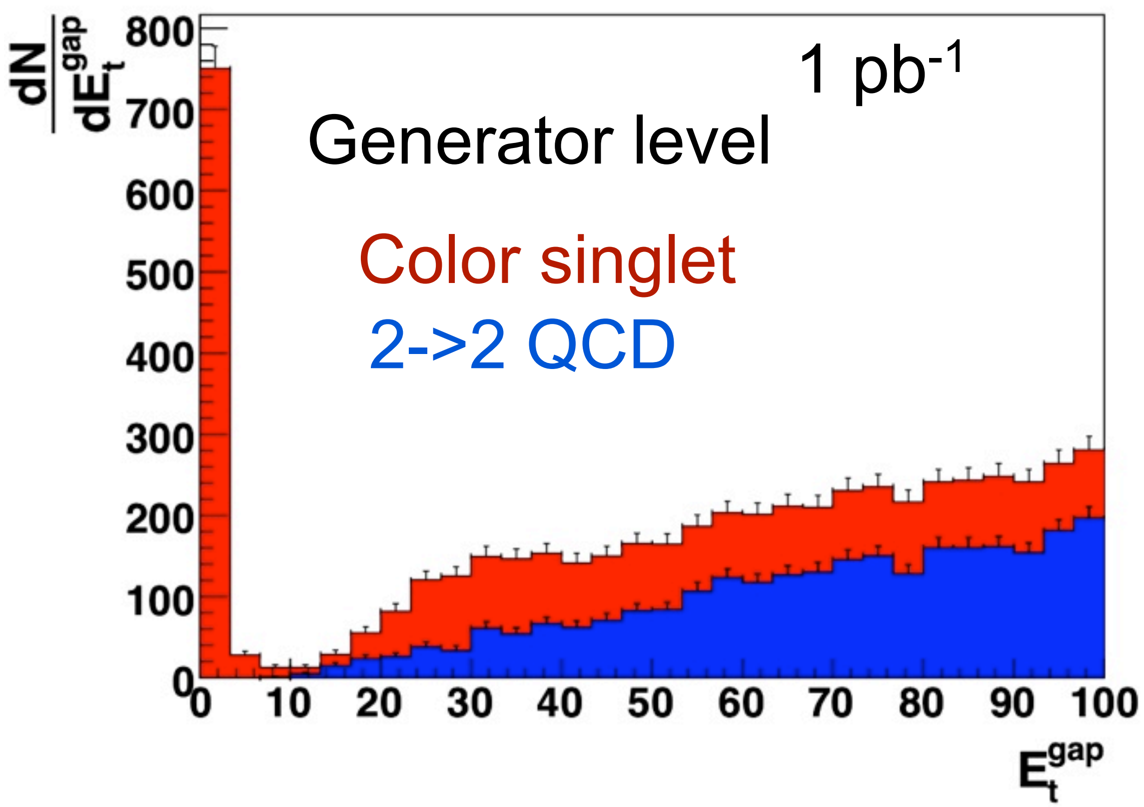
- Underlying event is dominating activity in the gap.
  - check for universality of the underlying event.
  - model calibration.

Gap fraction: fraction of events containing no radiation in the center of the detector.

Fraction of events with suppressed activity in the gap should rise with energy of jets and rapidity gap between jets.

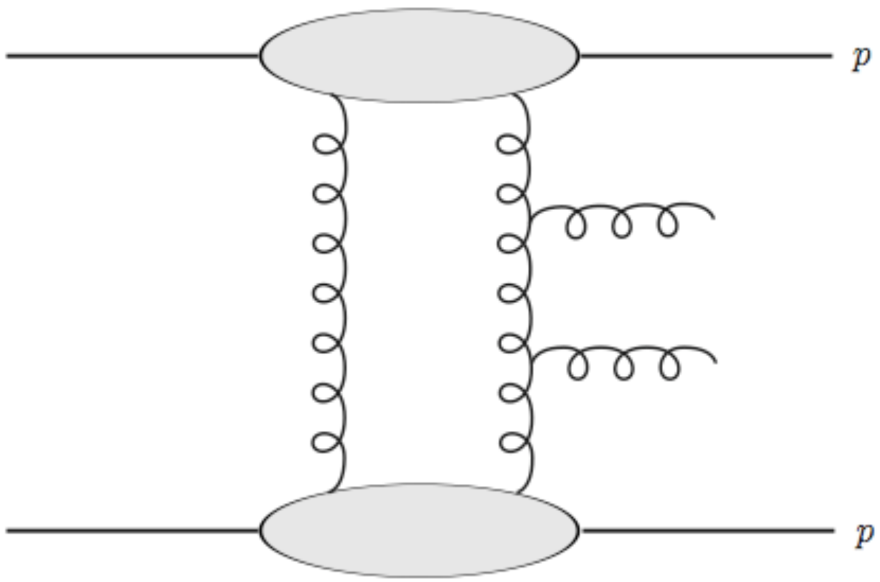


Gap fraction: comparison between D0 (open circles) and BFKL generated events – fixed αs (red circles)



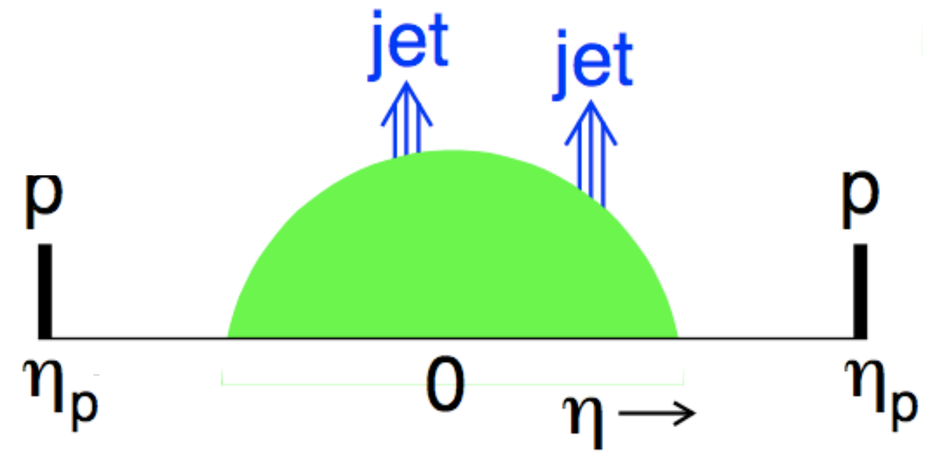
LHC prediction

Central exclusive dijet production



- Rapidity gaps *(no hadronic activity)* between central dijet system and outgoing protons.
  - – central system produced **exclusively**, i.e. suppression of radiation from incoming gluons.
  - – protons remain intact: no multiple parton interactions.

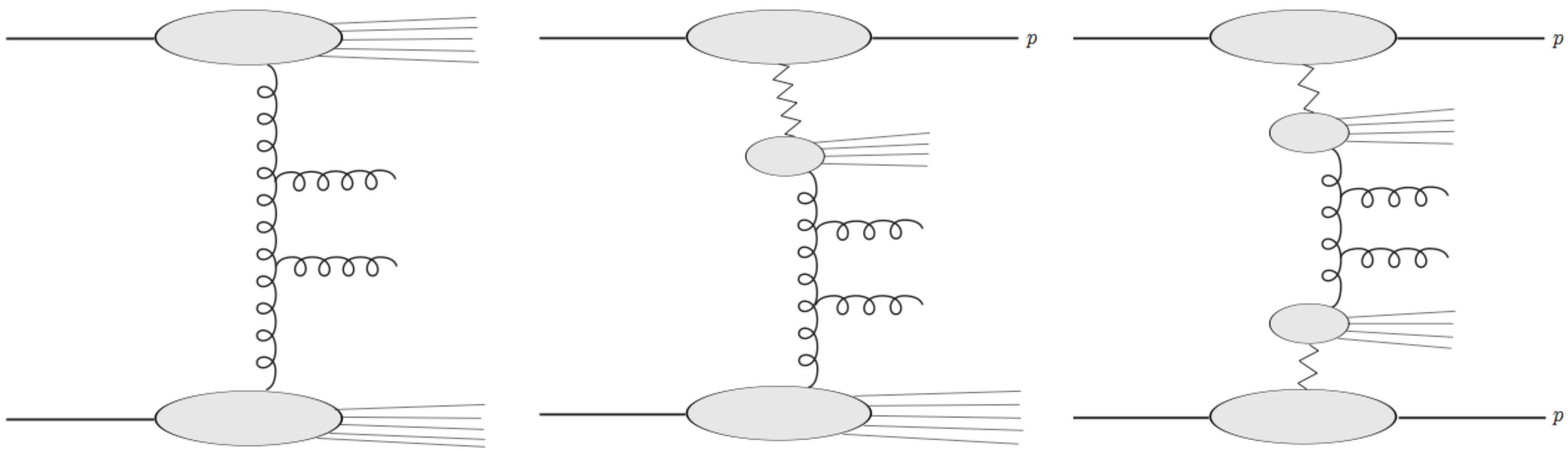
- Protons are scattered through very small angles, not detected by ATLAS.



- Early measurements will constrain theoretical uncertainty (factor of 2-3)
  - – Measure the exclusive dijet cross section as a function of E_T.

Central exclusive dijet production

- Background Processes:



Standard inclusive QCD dijet production

Single diffractive dijet production

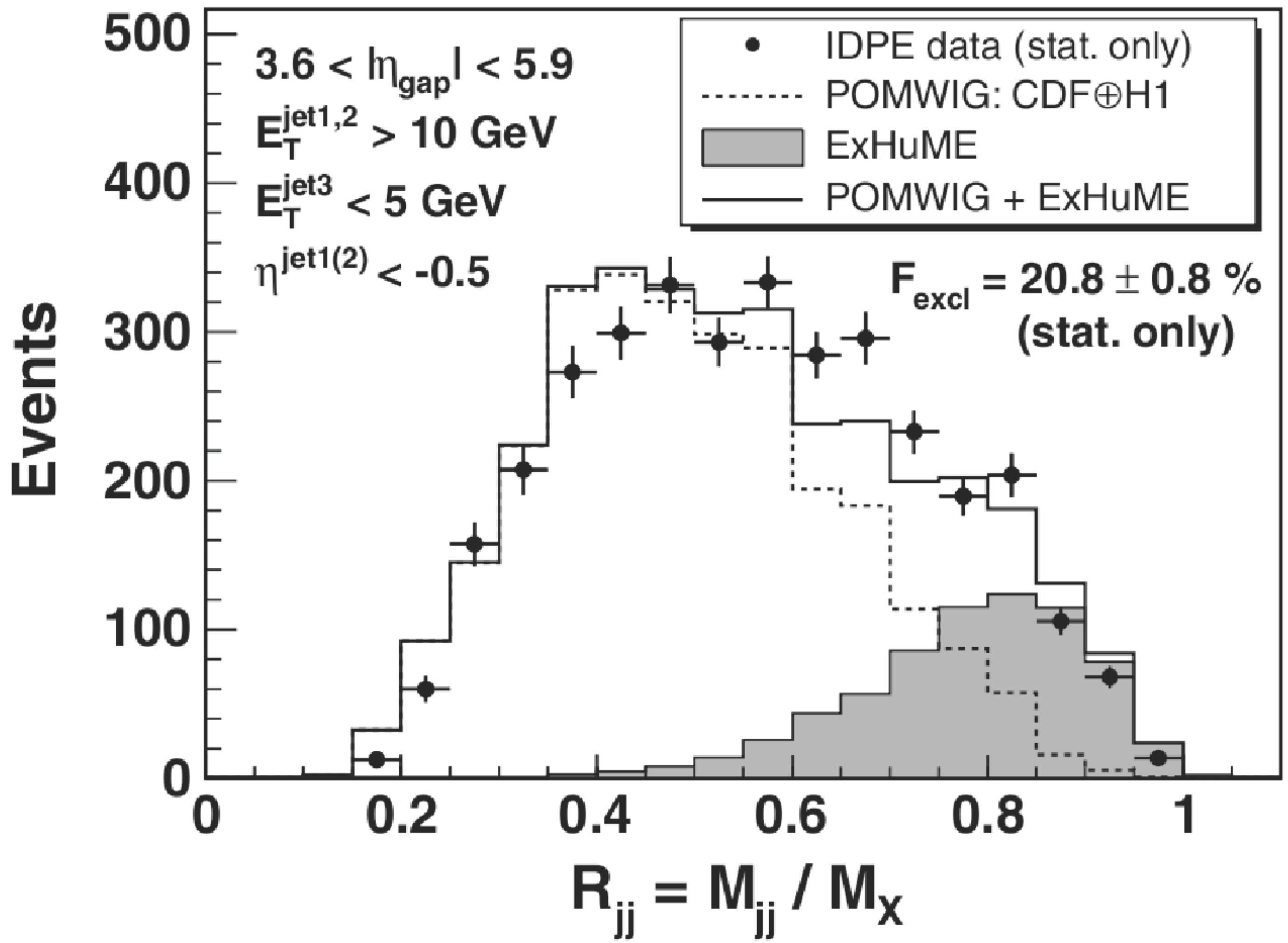
– one proton intact due to Pomeron exchange

– η gap between proton and Pomeron remnants

Dijet production by double Pomeron exchange

– both protons intact

– two η gaps



Exclusive dijets as observed by CDF

$$\xi_{1,2} = \frac{1}{\sqrt{s}} \sum_{clus} E_T^i \exp(\pm\eta_i)$$

$$x_{1,2} = \frac{1}{\sqrt{s}} \sum_{jets} E_T^i \exp(\pm\eta_i)$$

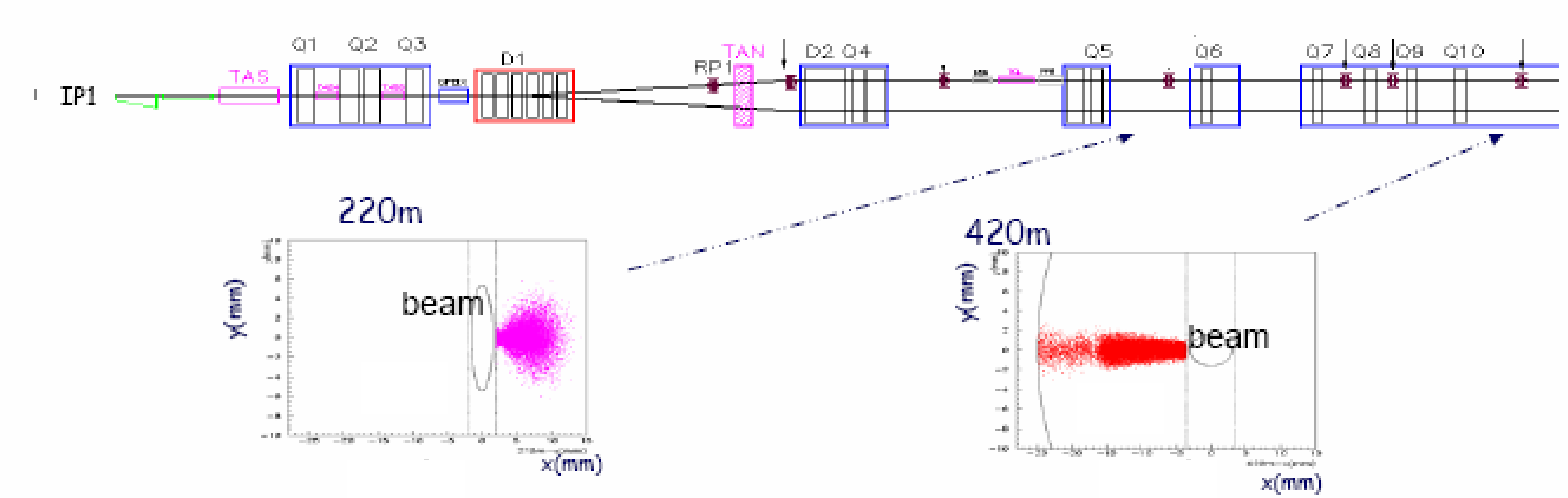
$$R_{jj} = \frac{M_{jj}}{M_{calo}} \simeq \sqrt{\frac{x_1 x_2}{\xi_1 \xi_2}}$$

- Observed by Tevatron: *Phys. Rev. D 77, 05, 2004.*
- $\sigma \sim O(10)$ pb at LHC energies.

Forward Physics and High Luminosity

- At high luminosity, pile-up events will fill in the gaps.

- However, ATLAS is planning to install new very forward proton detectors at ±220m and ±420m on each side of the IP to continue its forward physics programme.



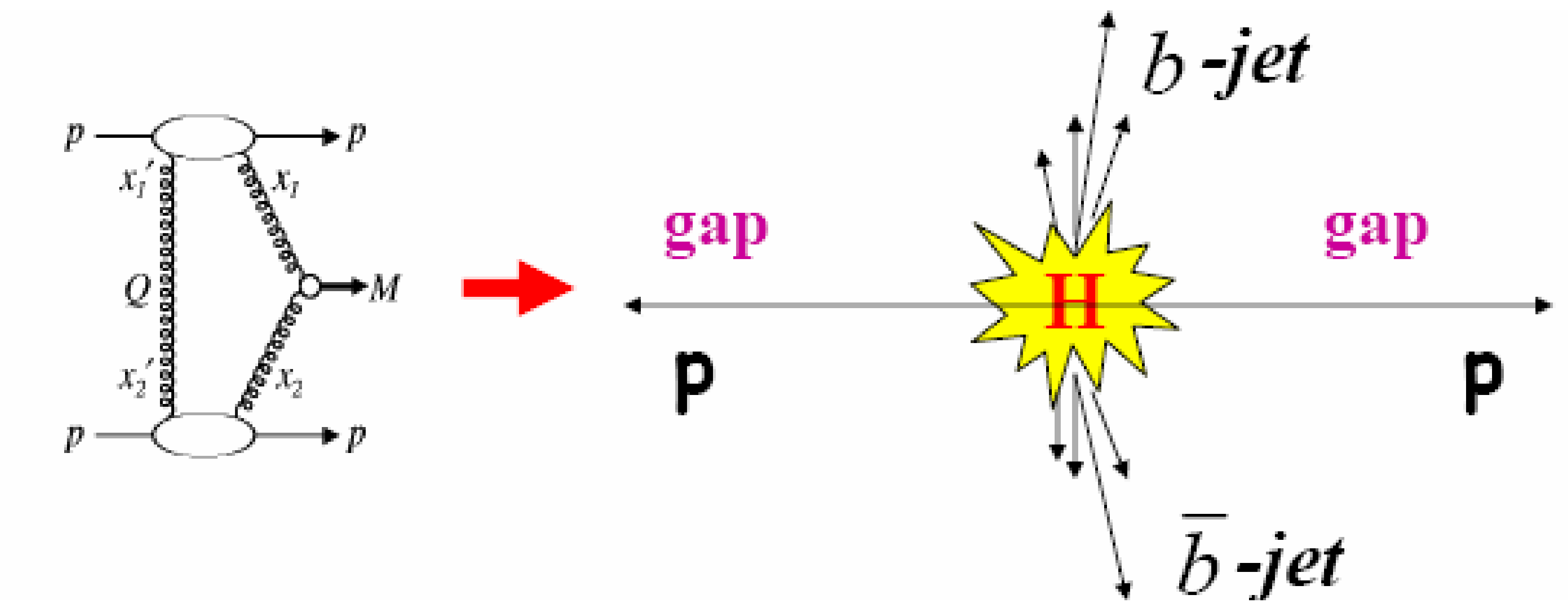
- Two stations installed to detect leading protons. Very challenging!

- Very precise ToF detectors used to differentiate the vertex of interest from pile-up events.

Forward Physics and High Luminosity

- Physics motivation (few examples):

  - CEP Higgs Physics



  - Photoproduction and photon−photon induced processes (e.g. W−pair production via the anomalous quartic gauge coupling γγWW)

Summary

- **The search for "New Physics" at the LHC will begin with the understanding the detector and the hadronic environment in LHC collisions.**
  - The Diffractive Physics measurements to be done with ATLAS will provide essential input for the understanding the LHC environment.

- **ATLAS is not only exceptionally well designed to find new physics (ie. Higgs and SUSY) but will also deliver very precise and detailed measurements of several diffractive topologies through its tracker and calorimeter and forward detectors.**
  - MBTS
  - LUCID
  - ZDC
  - ALFA

- **Diffractive studies (few examples with early data):**
  - Soft diffraction
  - Gaps between jets
  - CEP