THE ATLAS FORWARD DETECTORS AND THEIR PHYSICS POTENTIAL

Benedetto Giacobbe on behalf of the ATLAS collaboration

WORKSHOP ON HIGH ENERGY PHOTON COLLISIONS AT THE LHC
CERN, 21-25 April 2008

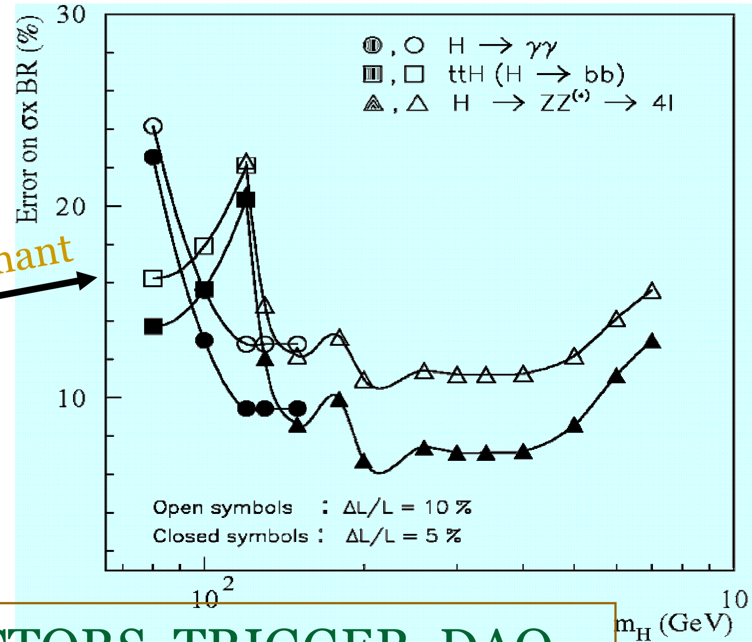
outline

- no $\mathcal{L}$uminosity, less physics …
- the ATLAS **F**orward **D**etectors
- luminosity measurements
- physics with **FD**: σ_{tot}
- **FD** upgrades
- extended physics program with **FD**
- summary

relative and absolute luminosity

- Absolute luminosity:
  - measure cross sections for standard physics
  - measure Higgs production cross section
  - observe deviations from SM and New Physics

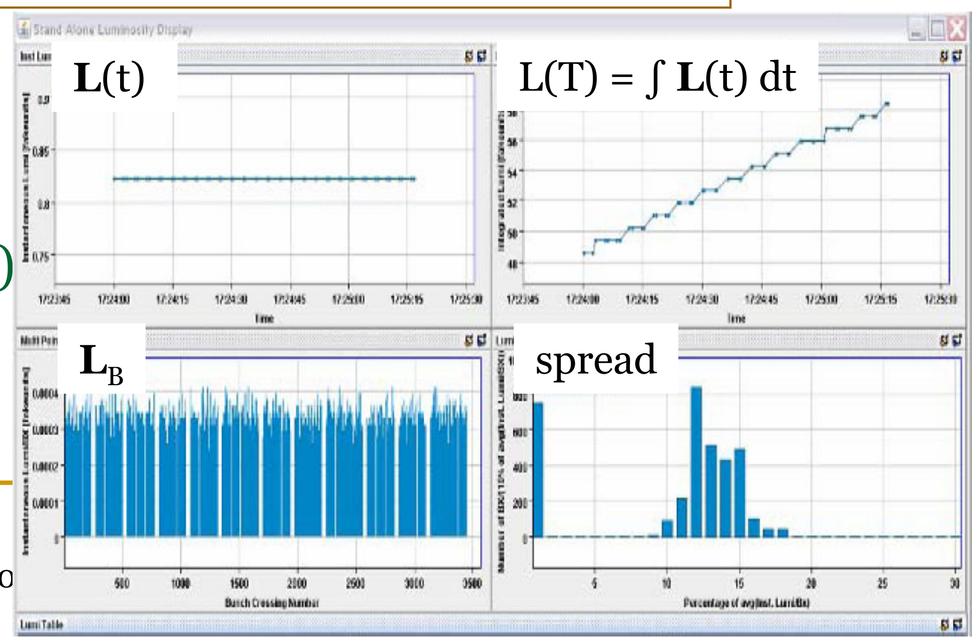
Lumi uncertainty dominant



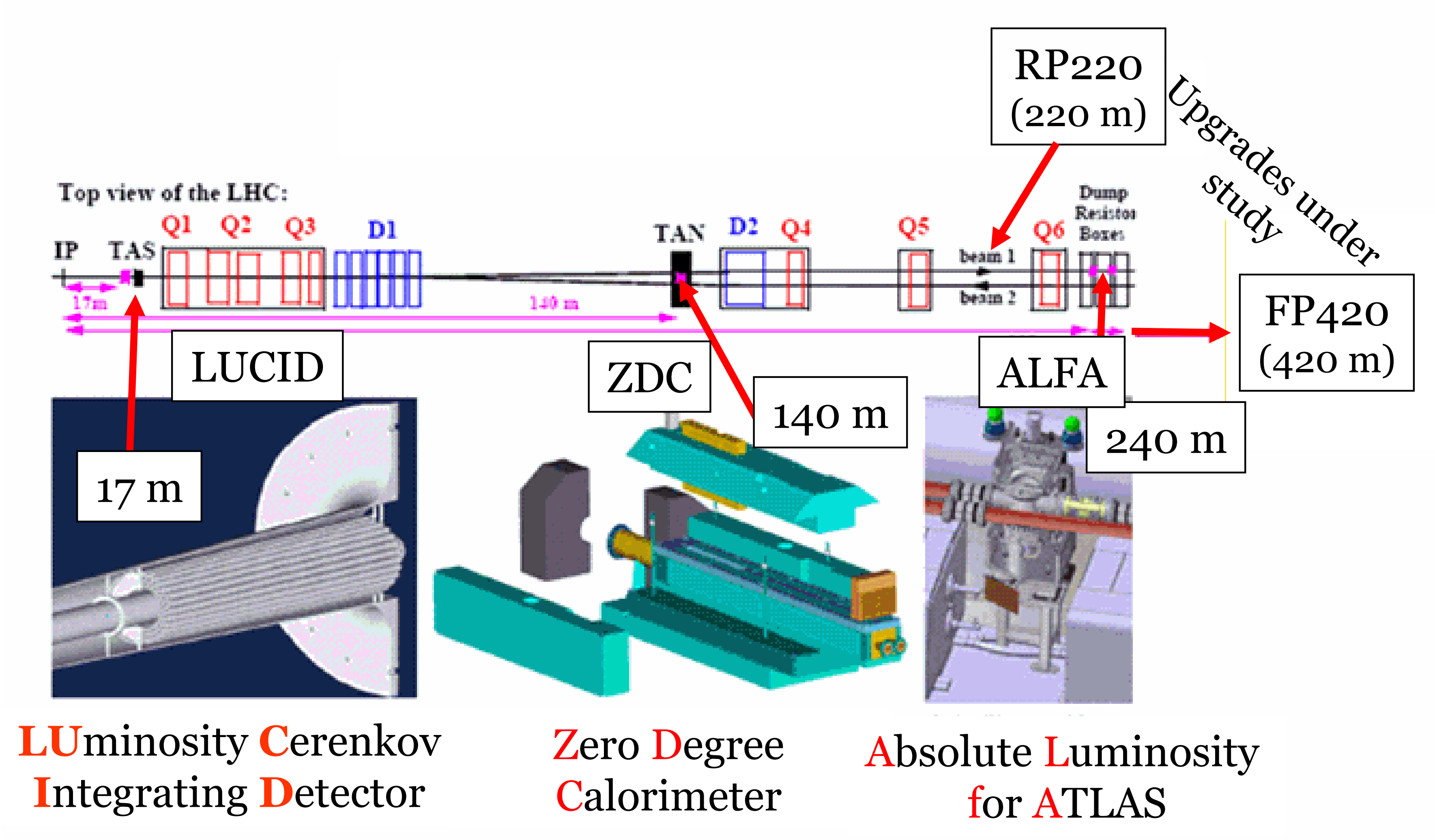
- Requirements:
  - ultimate precision at the 2-3% level
    - different methods needed for cross check
    - minimize systematics

COMBINED EFFORT FROM DIFFERENT DETECTORS, TRIGGER, DAQ..

- Relative luminosity:
  - beam stability
  - beam degradation (efficient use of trigger)
  - evaluate trigger & DAQ dead-times
  - determine beam background



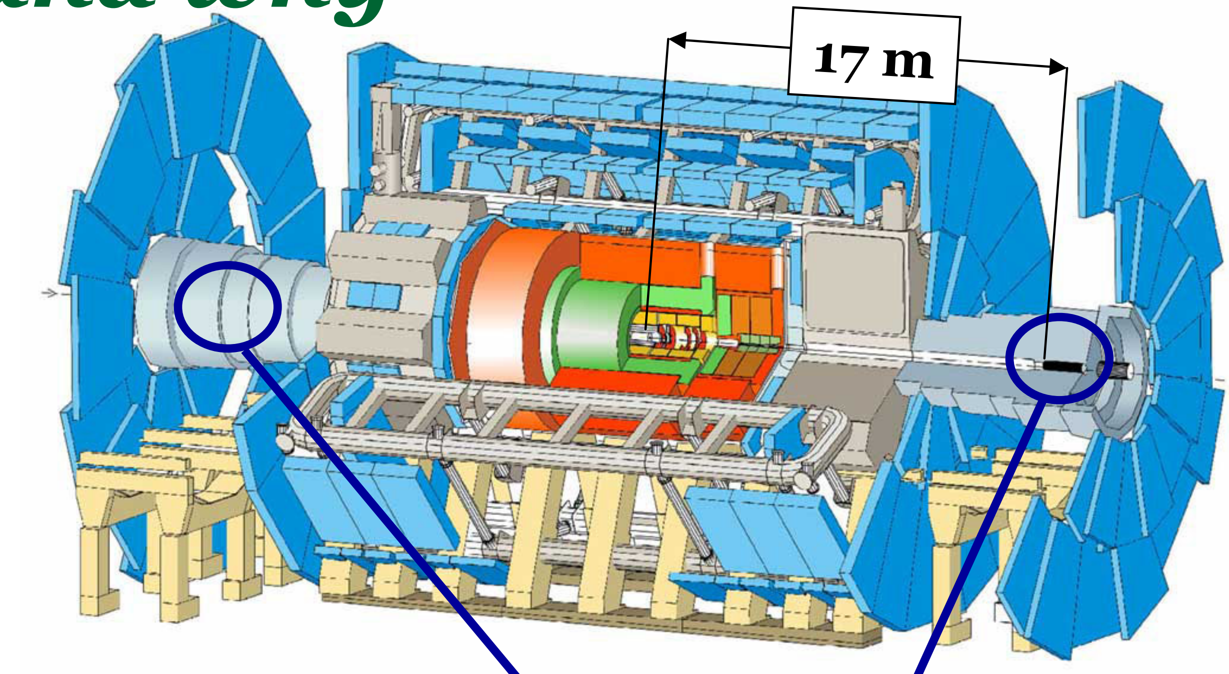
the ATLAS Forward Detectors



LUCID: where and why

- Monitor instant. $\mathscr{L}$:
  - BC-to-BC structure
  - beam degradation
  - indep. of LVL1 trigger
  - indep. of TDAQ

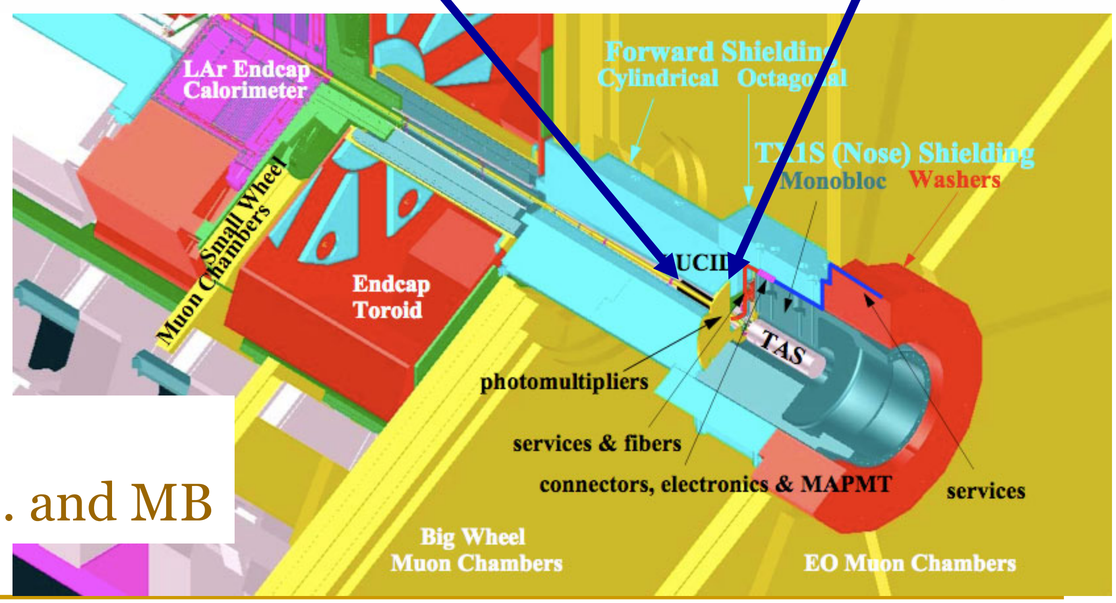
⇒ Requirements:
  - relative $\mathscr{L}$ sufficient
  - fast response (single BC)
  - online monitoring



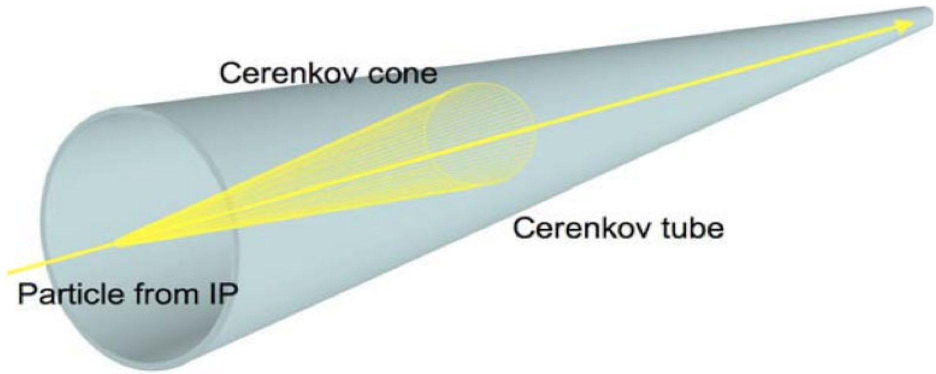
- Measure absolute $\mathscr{L}$:
  - Needed for phys. analysis

⇒ Requirements:
  - calibration needed
  - final precision ~ 2-3%

- Physics capability:
  - provide trigger for Forw.Phys. and MB



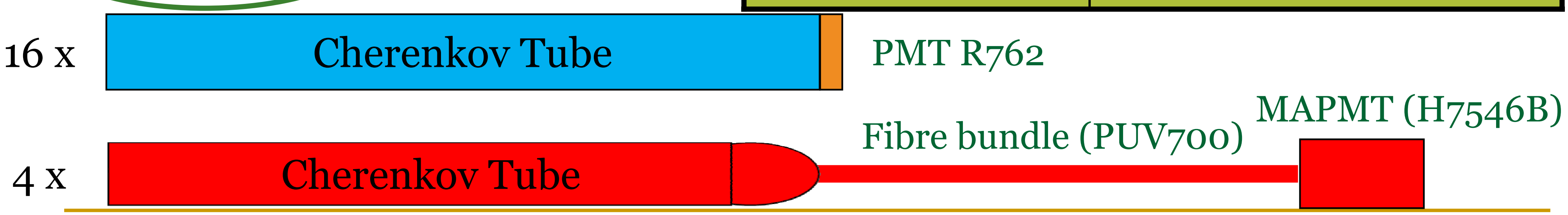
LUCID principle



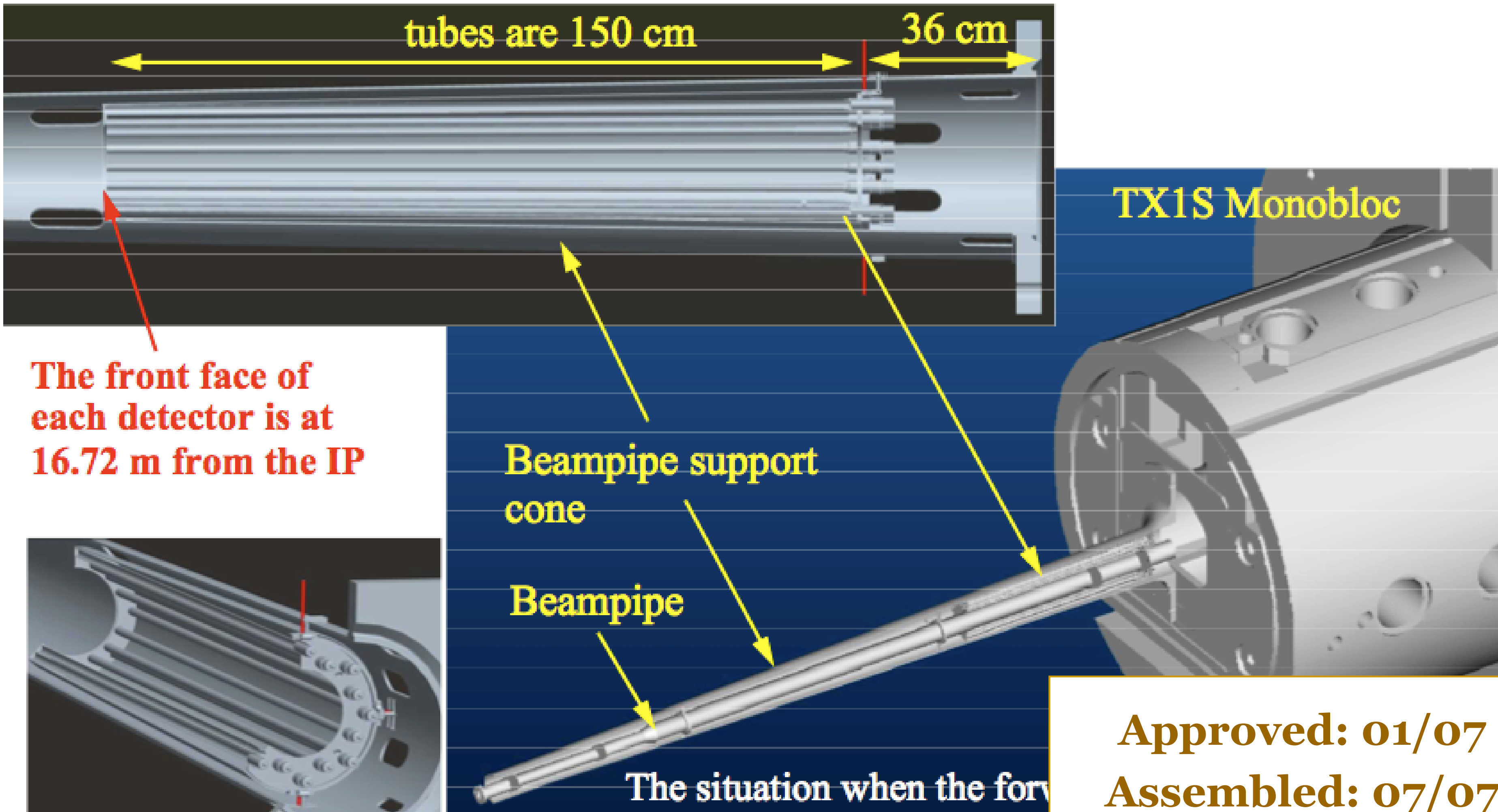
Projective geometry of tubes to IP

Main parameters per module	
η coverage	±[5.6, 6.0]
N. Tubes	20
Material	Mechanic. polished Al
Gas	C_4F_{10}
Pressure	1.2-1.5 bar
Cherenkov angle	3^o
<N. reflections>	3
Ch. threshold	e^-: 10 MeV p: 2.8 GeV
Signal duration	Few *ns*
Read-out	16 PMTs + 4 fibres
Expected dose	7 Mrad/y @ 10^{34} $cm^{-2}s^{-1}$

Phase I
(L < 10^{33} cm^{-2} s^{-1})

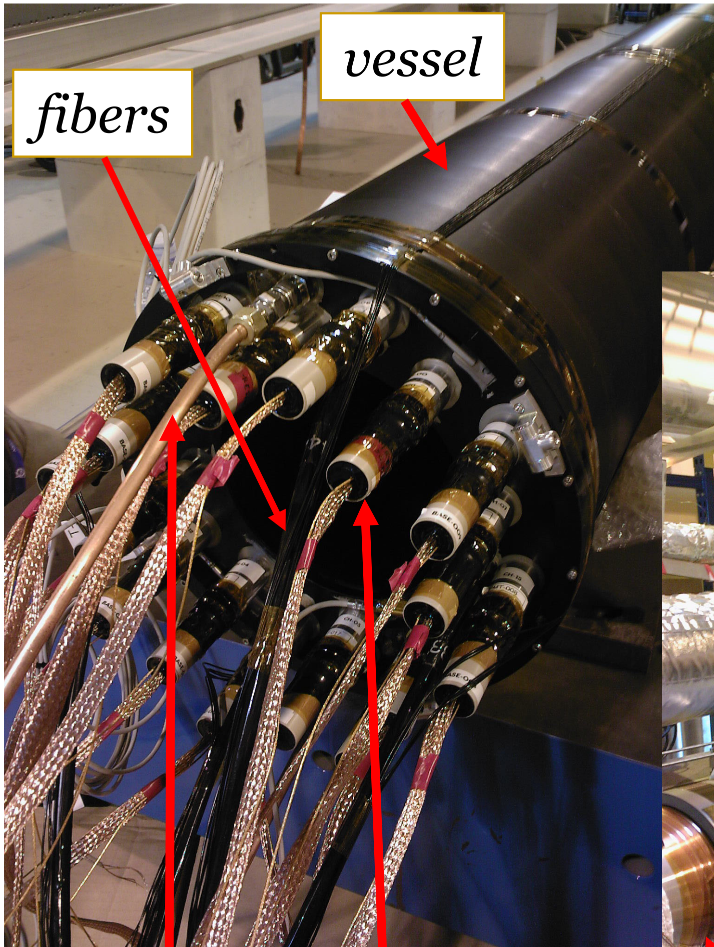


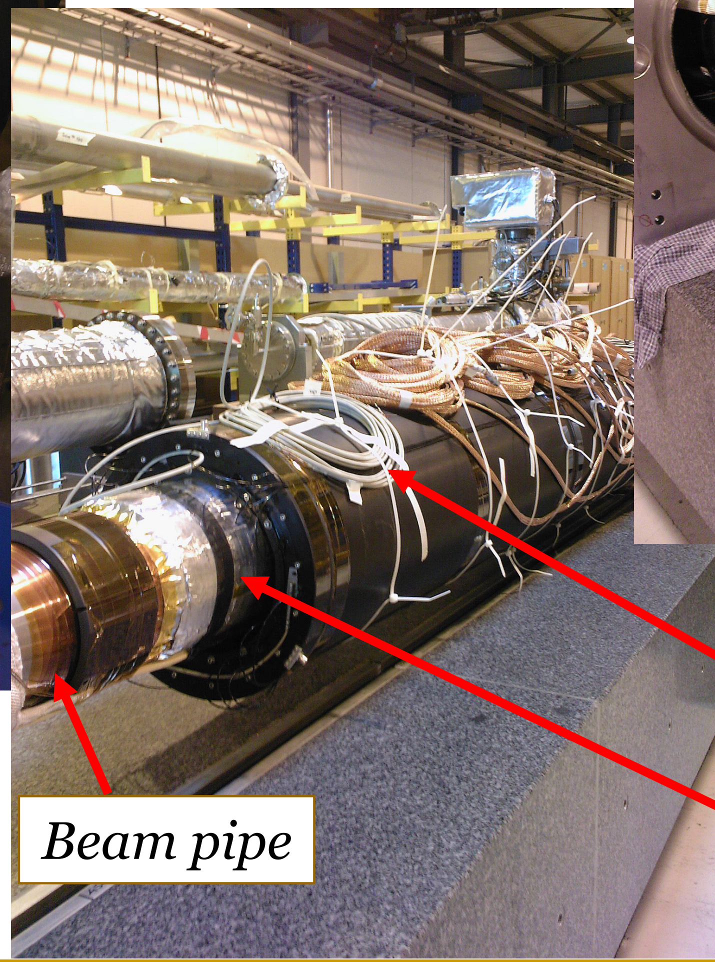
LUCID design for phase I

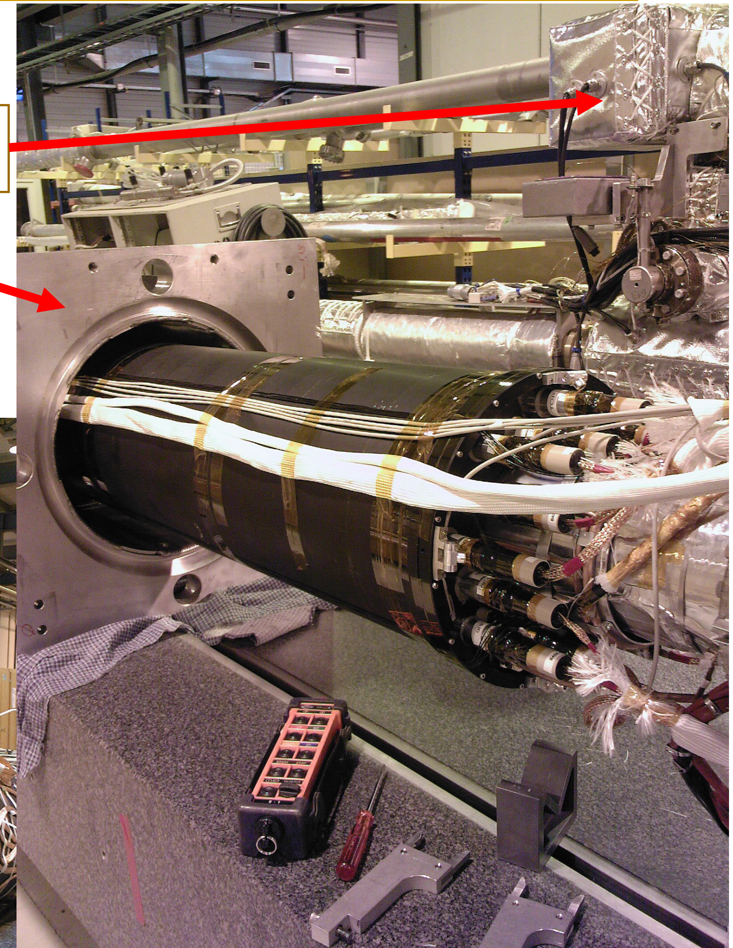


Approved: 01/07
Assembled: 07/07
Mounted: 03/08
In cavern: 05/08

LUCID status



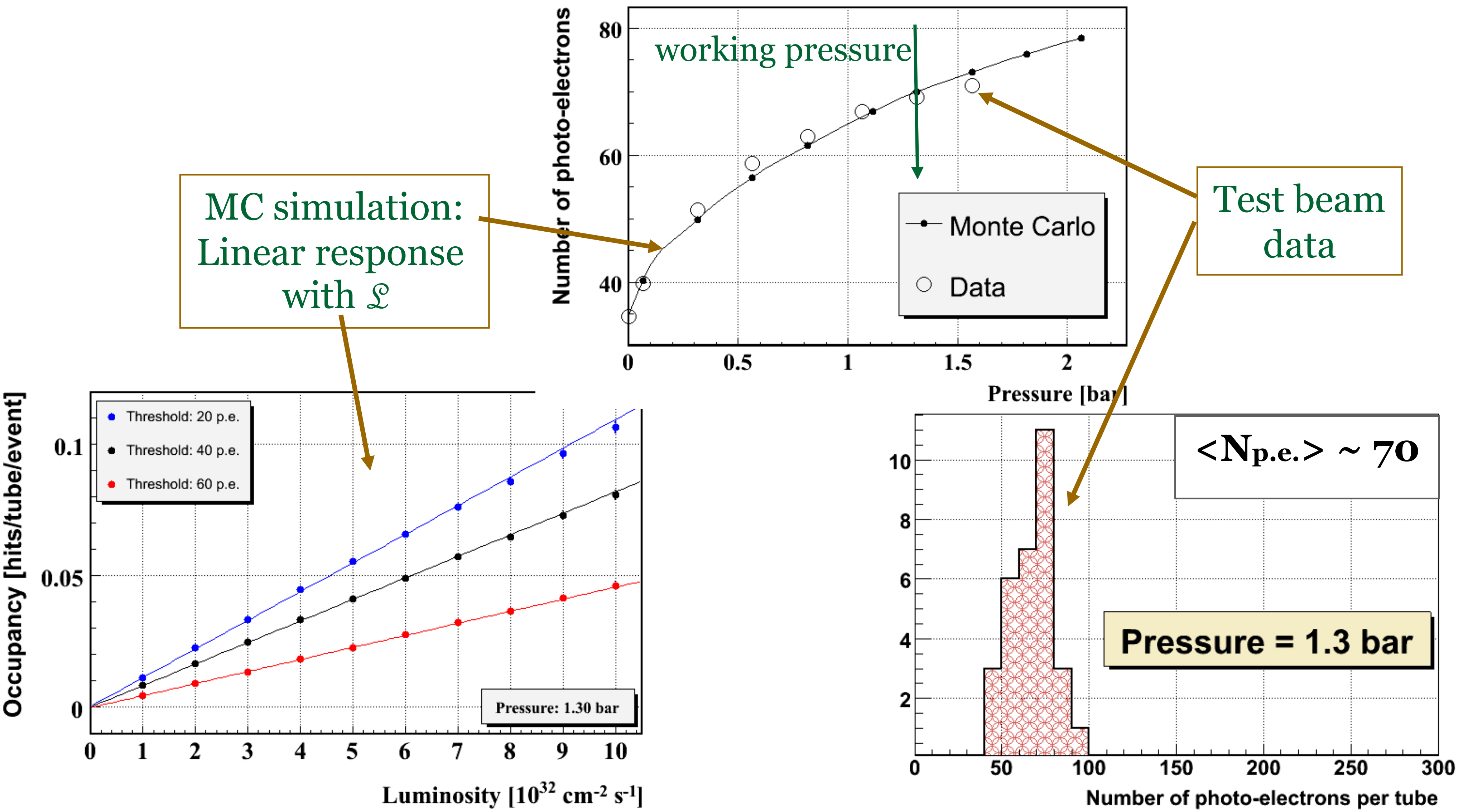




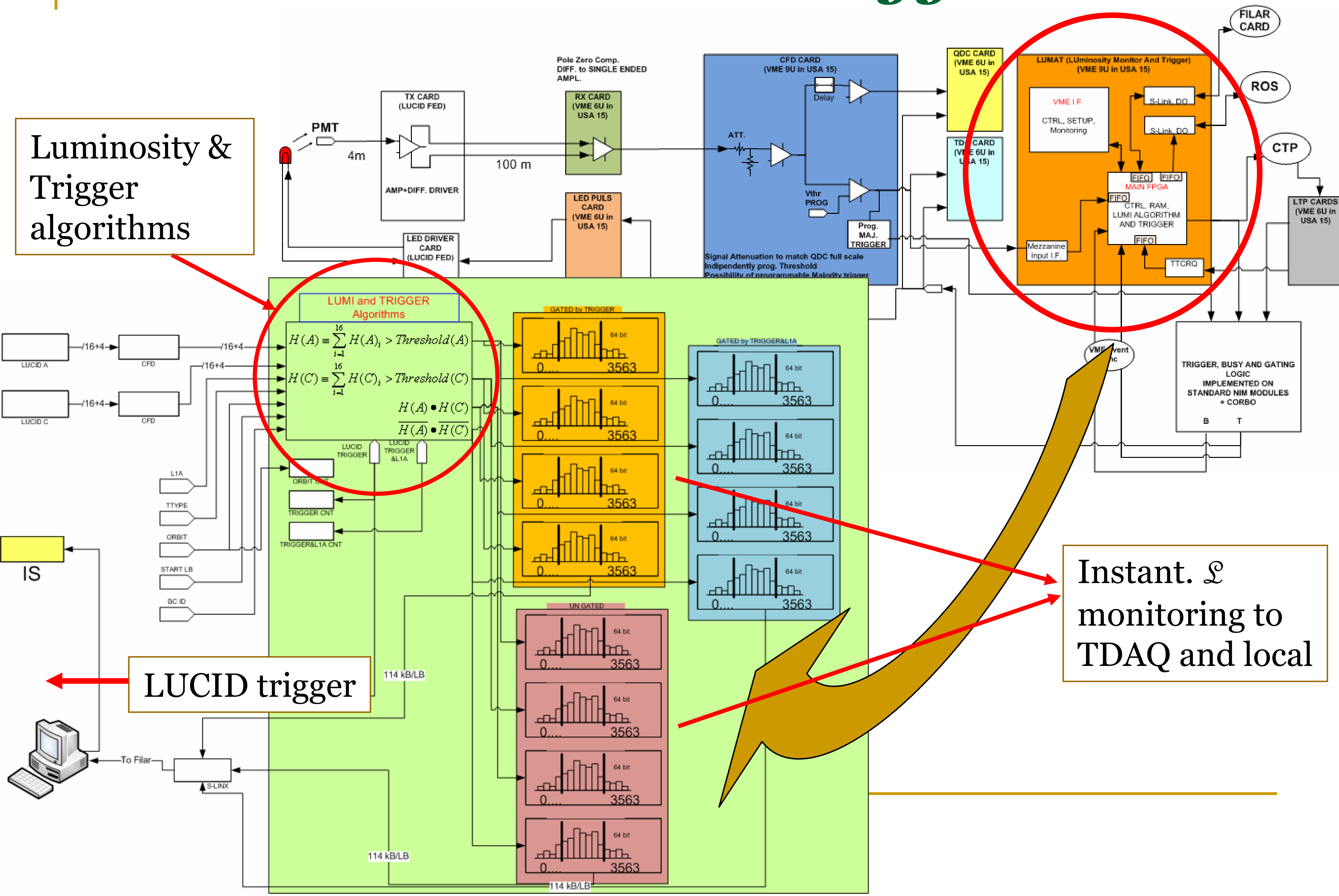
Ready to be mounted in the final position !

LUCID test beam & simulation

LUCID has been tested and calibrated with a beam of 180 GeV pions (SPS H8)

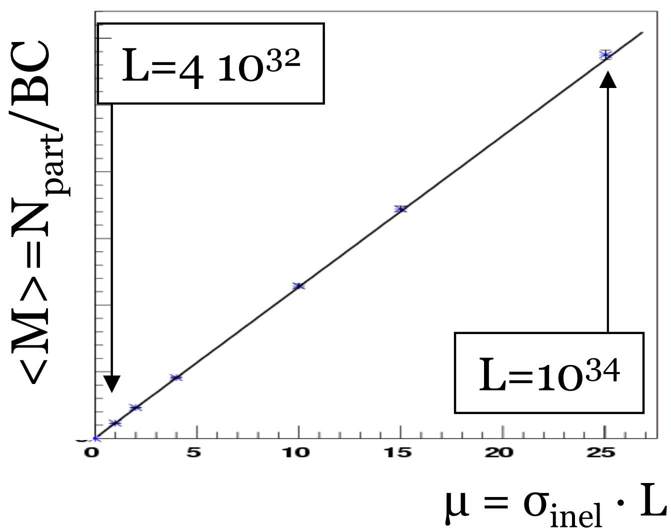


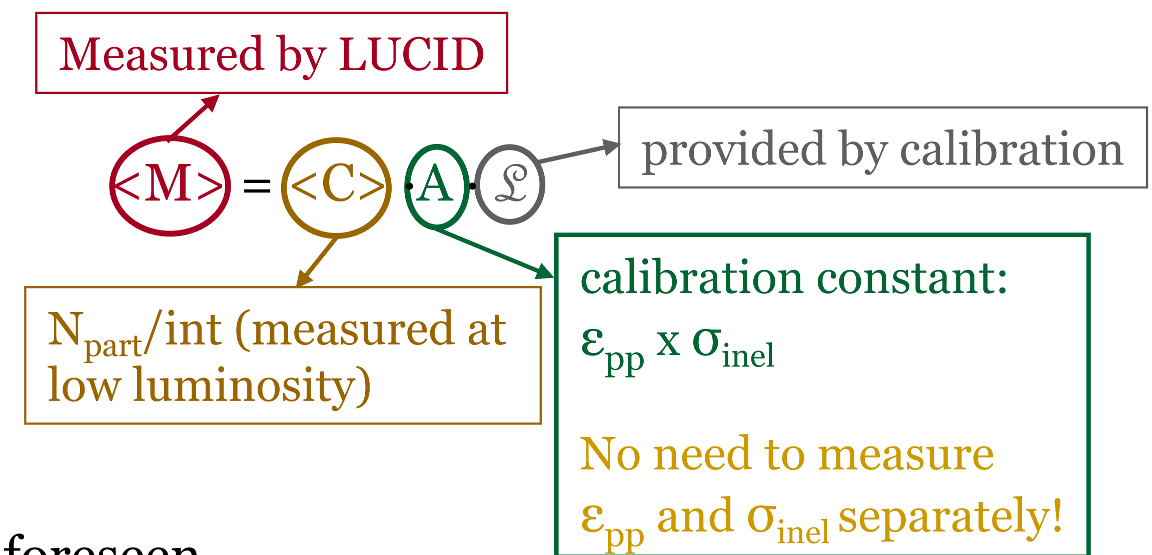
LUCID electronics and trigger



LUCID calibration

- Relative ℒ provided by LUCID from t=0
  - monitor beam stability and structure
  - allow fast reaction to LHC in case of problems
- Absolute ℒ needs calibration:





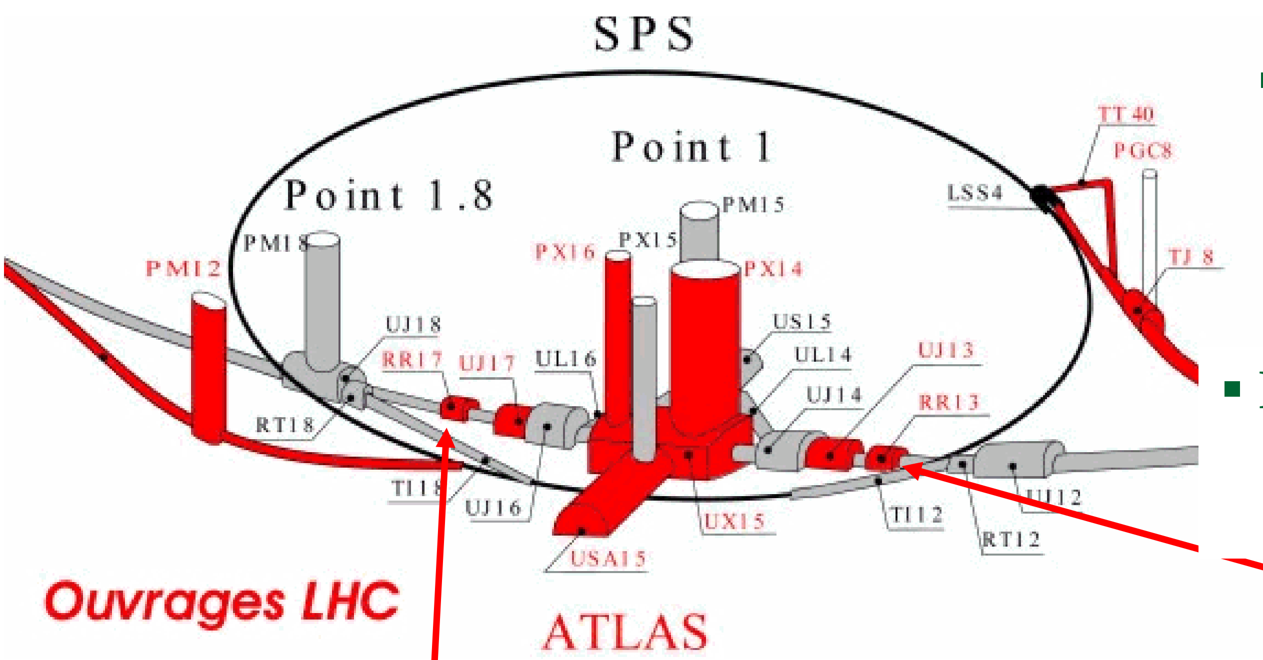
  - Different calibration methods foreseen
    - Beam parameters (~10% precision)
    - Physics channels (W, Z) (5-10% precision)
    - ALFA detector (from ~2010) (2-3% precision)

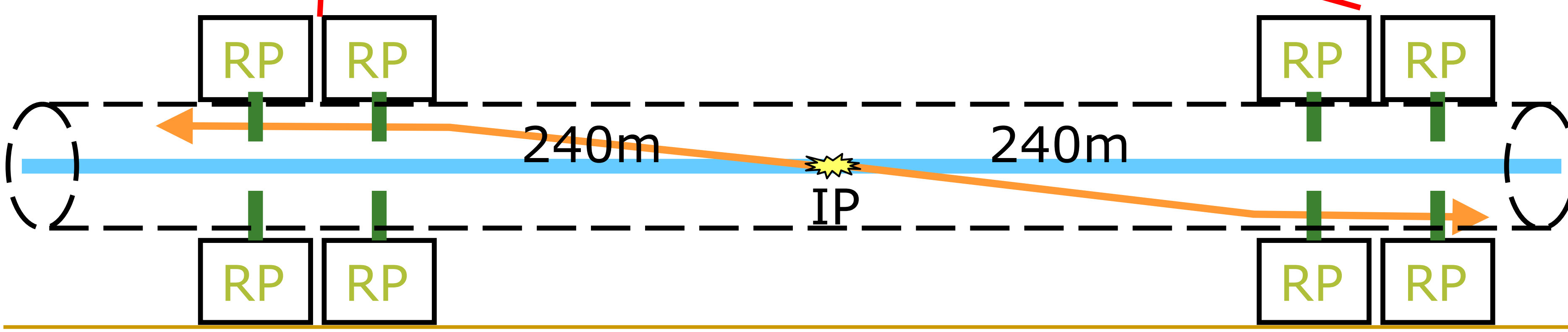
LUCID: absolute $\mathcal{L}$ determination

- Two methods foreseen depending on LHC operation:
  - only @ low luminosity: zero counting
  - low and high luminosity: hit or particle counting
- zero counting method: $n_{pp}/n_{BC} = 1 - \exp(-A\cdot \mathcal{L})$, $A = \varepsilon_{pp}\ \sigma_{inel}$
  - A from calibration
  - no need for particle counting capabilities
  - ☺ linear at low luminosity ($n_{pp}/n_{BC} \sim A\cdot \mathcal{L}$) but ☹ not at high luminosity
  - Can be spoiled by pile up
- Particle counting method: $\mathcal{L} = \langle M\rangle / (\langle C\rangle \cdot A)$, $A = \varepsilon_{pp}\ \sigma_{inel}$
  - A from calibration
  - Need for particle counting capabilities
  - Linear relation between <M> and $\mathcal{L}$
  - Suitable at both low and high luminosity

ALFA where and why

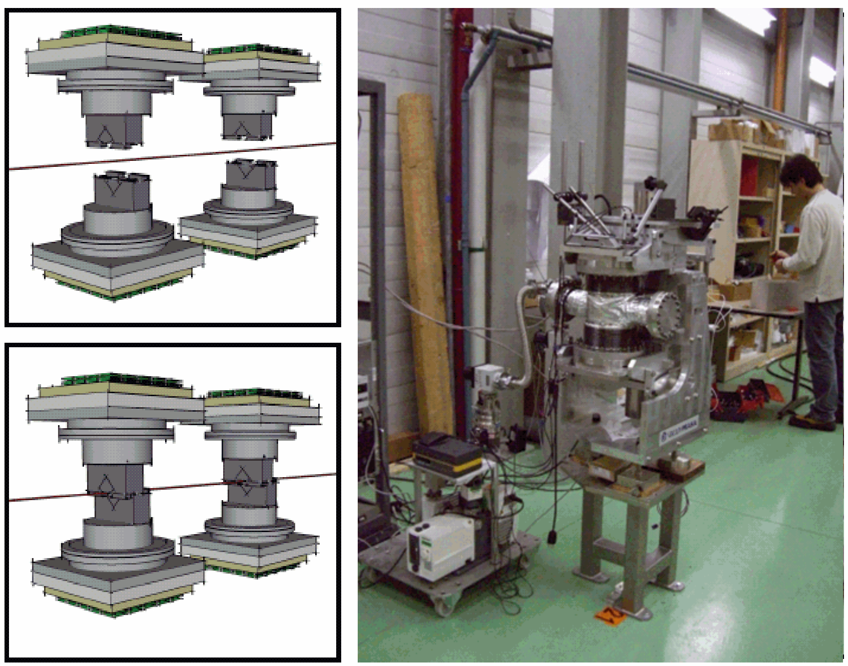
- Determine absolute $\mathcal{L}$ with elastic proton scattering:
  - Coulomb normalisation
  - Optical theorem
  - calibrate LUCID
- Requirements:
  - cover down to $\theta \sim 3\ \mu$rad
  - use modified beam optics
  - high spatial resolution
- Physics goals:
  - measure σ_{tot}
  - tag protons (Single Diff. Ph.)





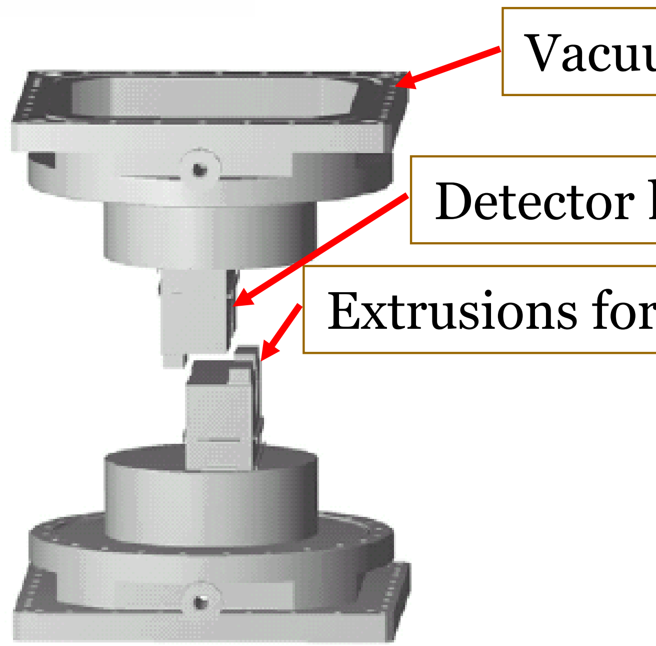
ALFA Roman Pots concept

Extracted position



Working position

Roman Pot unit




ATLAS

ATLAS Forward Detectors for Measurement of Elastic Scattering and Luminosity

ATLAS Collaboration

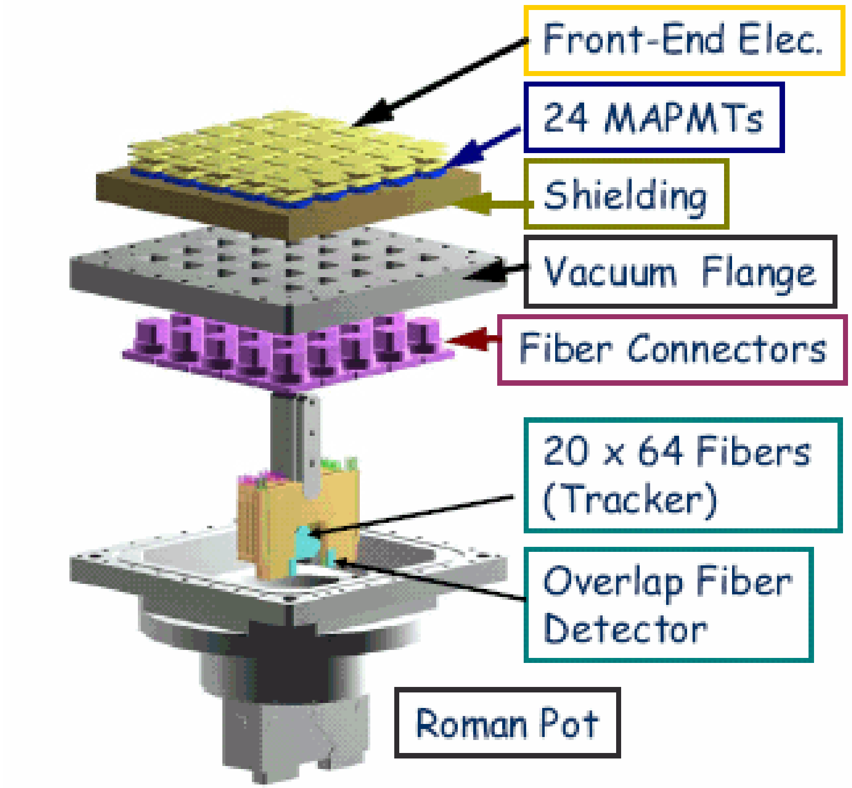
Technical Design Report

Approved by ATLAS
Presented to LHCC

- Proven techique for approaching very close to beam (10σ ~ 1 mm)
- 2 units 4 m apart in each side of IP ⇒ 8 independent pots
- Thin windows to approach active detector close to beam and minimize material
- precise positioning given by Overlap Detectors

STRINGENT LIMITS IMPOSED BY LHC CONSTRAINTS

ALFA detectors



- OD: scintillating fibres
  - measure vertical coord. only
  - detect beam halo
  - each made of 3 planes of 30 fibres

- Requirements:
  - measure |t| ~ 6 ·10^{-4} (θ~3 μrad)
  - $\sigma_{xy} << \sigma_{beam}$ (~ 130 μm) ⇒ 30 μm
  - radiation ≤ 100 Gy/yr
  - time resolution ~ 5 ns
  - top/bottom alignm. ~ 10 μm
  - vacuum tight

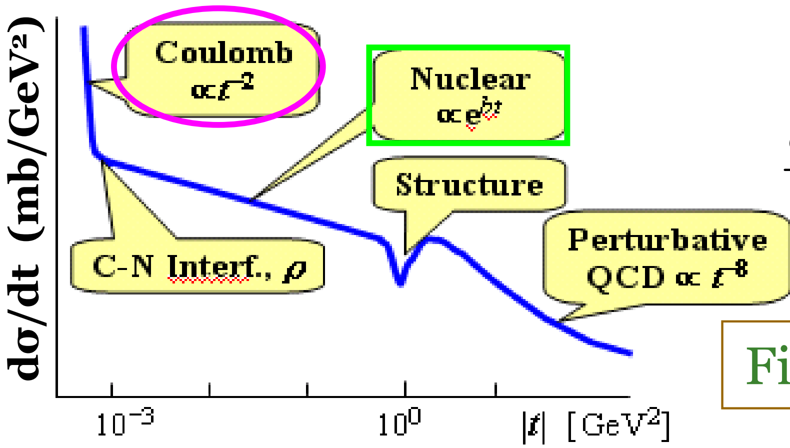
- Solution: scintillating fibres detector
  - edgeless (~ 10 μm)
  - 10 x 64 U + 10 x 64V fibres @ 90°
  - planes staggered by 70.7 μm
  - fibre eff. pitch 50μm (σxy ~ 20 μm)
  - MAPMT read out fibres
  - FE mounted directly on top of pot

Plastic scintillators cover active fibers area and provide local trigger

Goal: detector ready in ~ 1 year from now

absolute luminosity & σ_{tot}

- Elastic scattering in CNI region: $L \sim 10^{27}\ cm^{-2}s^{-1}$, large β^* optics (beam div.~0.2μrad)



$$\left.\frac{dN}{dt}\right|_{t=CNI} = L\pi\left|f_C + f_N\right|^2 \approx L\pi\left|-\frac{2\alpha_{EM}}{|t|} + \frac{\sigma_{tot}}{4\pi}(i+\rho)e^{-\frac{b|t|}{2}}\right|^2$$

Fit of data ➡ σ_{tot}, L, ρ, b ($\Delta L/L \sim 3\%$)

- optical theorem as complementary solution

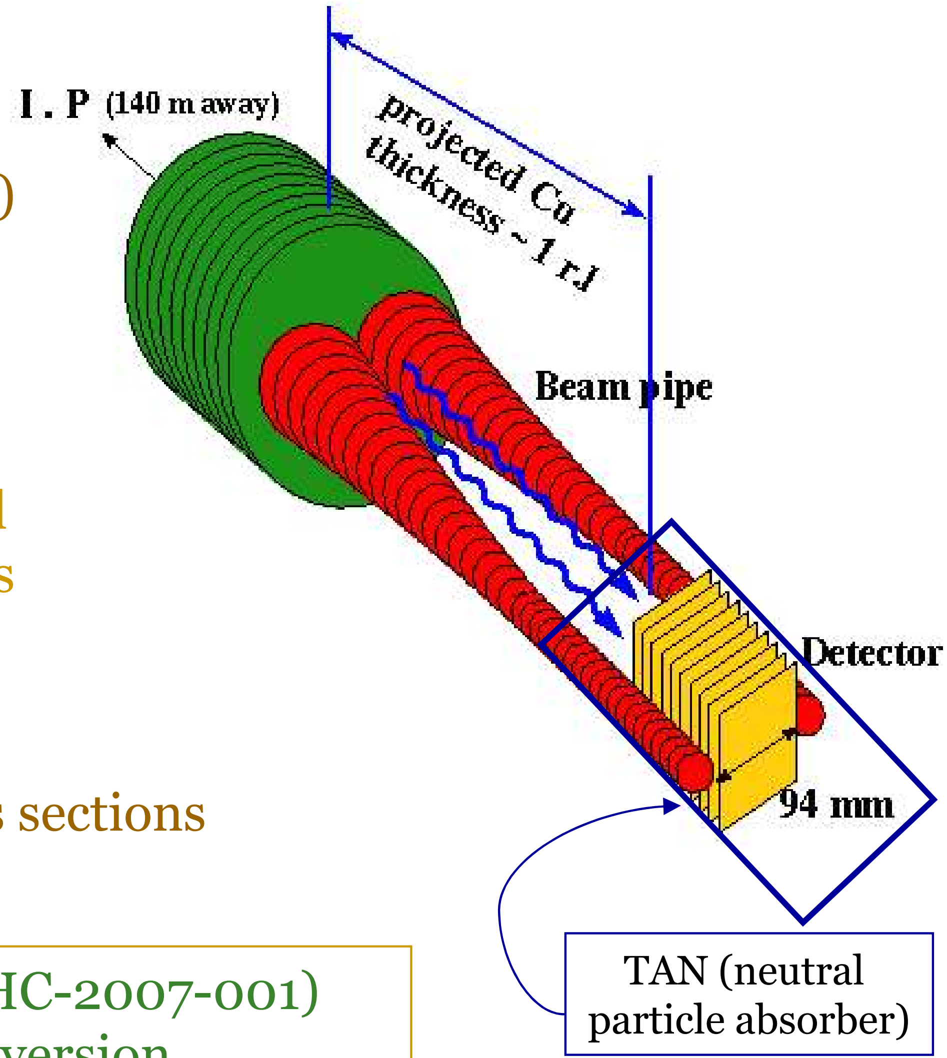
$$\begin{cases} L = \dfrac{(1+\rho^2)}{16\pi}\dfrac{N_{tot}^2}{\left.\frac{dN_{el}}{dt}\right|_{t=0}} \\ \sigma_{tot} = \dfrac{N_{tot}}{L} \end{cases}$$

N_{tot}, $dN_{el}/dt\,|_{t=0}$ ➡ L & σ_{tot}
☹ need MC for η extrapolation
😐 ρ shouldn't be a problem

- Provide high precision (2-3%) LUCID calibration

ZDC where and why

- Requirements:
  - measure neutral particles at 0° (n, γ, π^0)
    - both EM and HAD sections
  - beam monitoring and tuning
    - crossing angle
    - IP position
    - lumi monitor at the single BC level
    - tune LHC parameters in first times
  - radiation hard

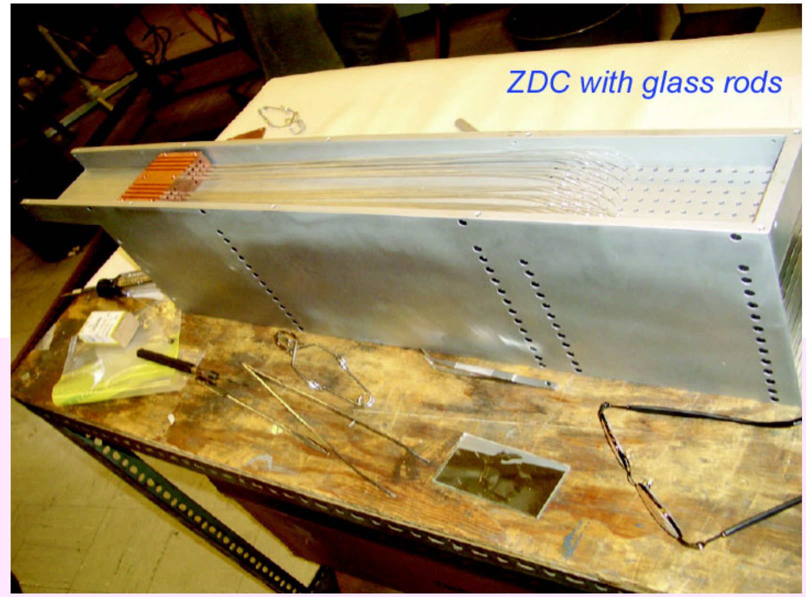


- Physics program:
  - pp physics: very forward (η>8.3) cross sections
  - Heavy Ions: event centrality, trigger

LOI presented in January 2007 (CERN-LHC-2007-001)
Status: installed both arms in a simplified version
system and electronics ready for first protons

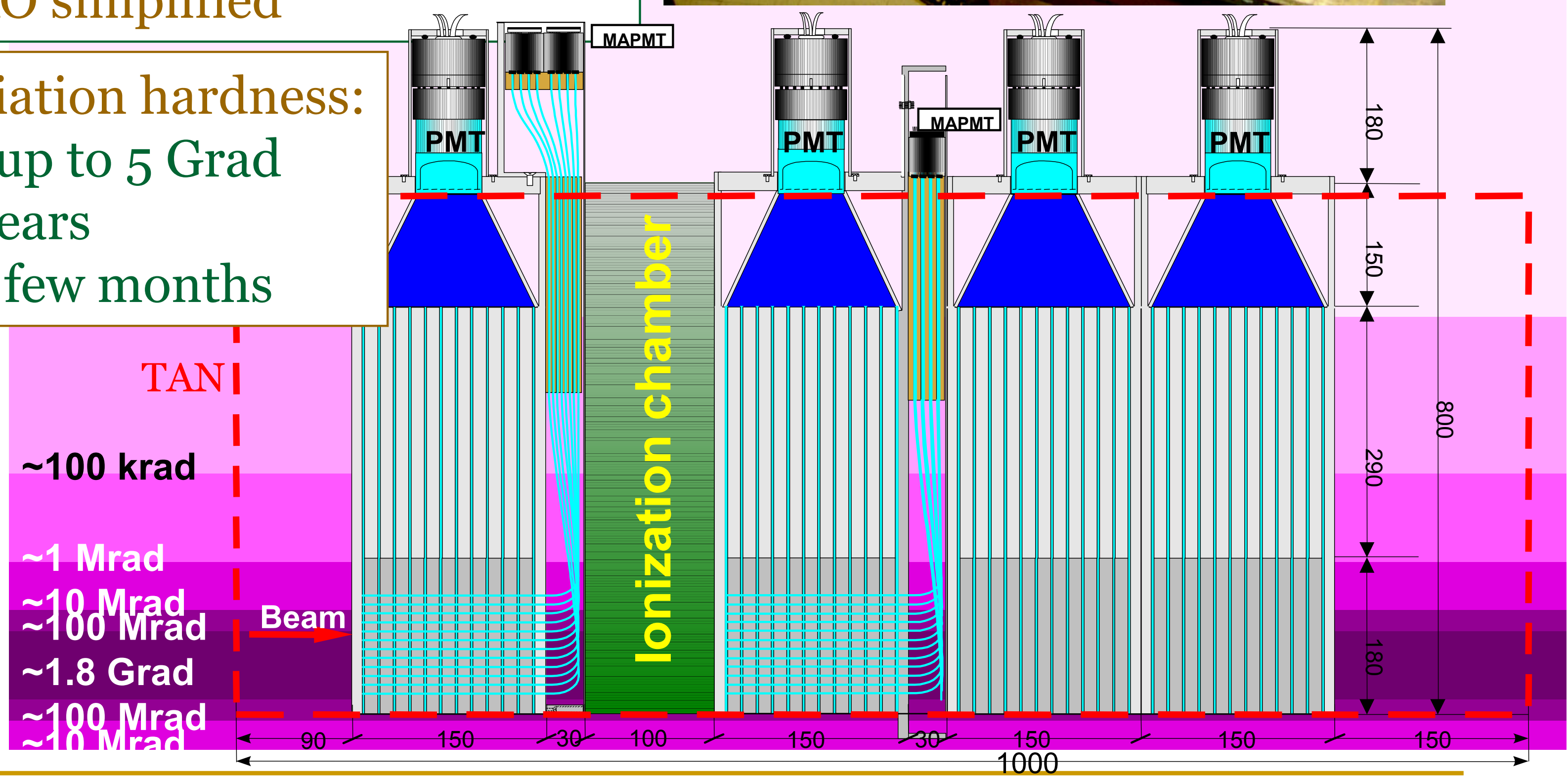
ZDC

- 1 EM ($29X_0$) + 3 HAD ($1.14\ \lambda_{int}$) modules/arm
- 11 W plates / module
- 1 mm quarz rods // to beam (E, x/y meas.) Cherenkov light read out by MAPMT
- 1.5 mm quarz strips (E meas.) ⊥ to beam read out by PM
- in HAD modules RO simplified



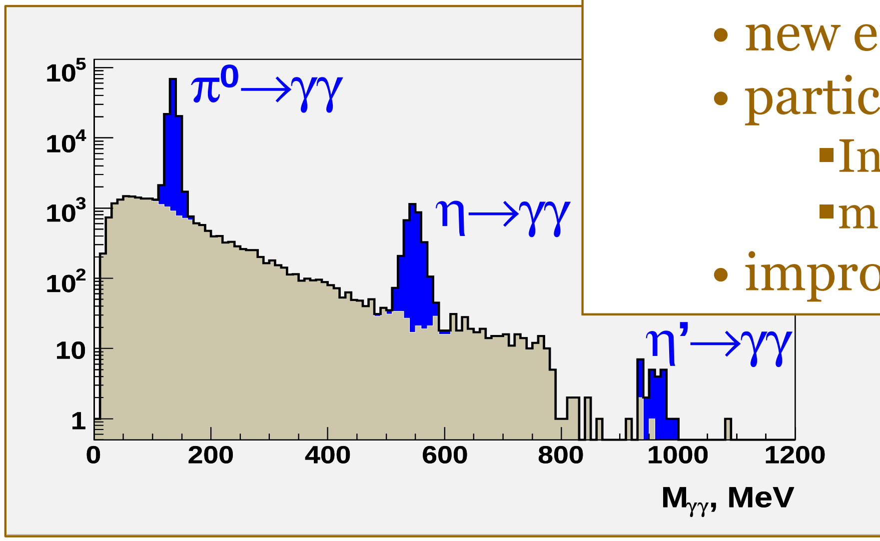
measured quarz radiation hardness:

- small degradation up to 5 Grad
- at 10^{33} ok for few years
- at 10^{34} will survive few months

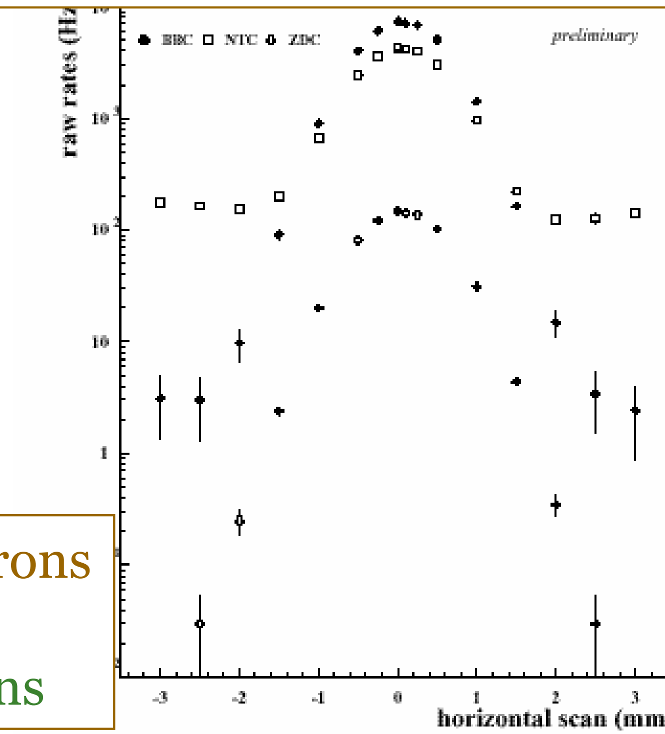


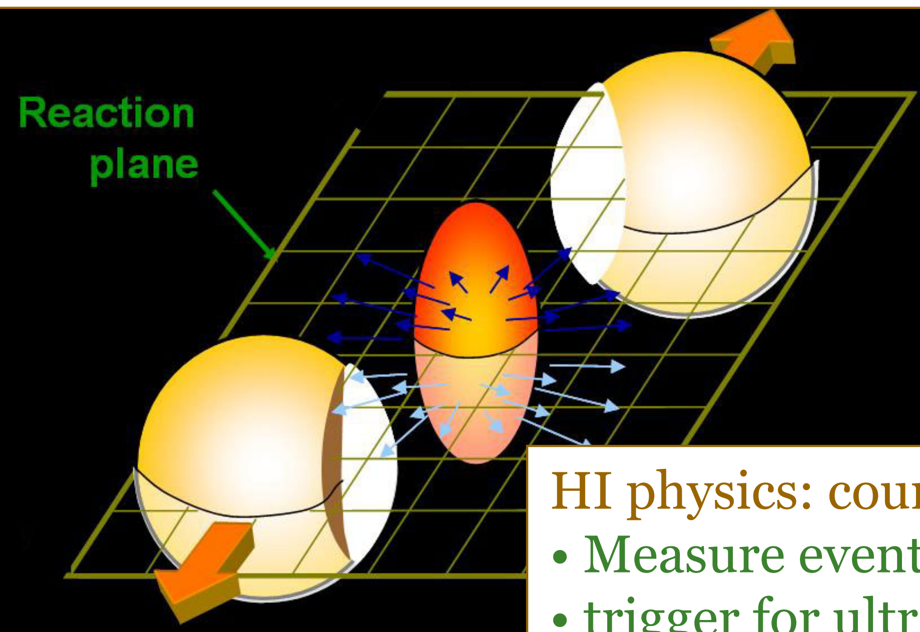
physics with ZDC: pp & heavy ions

pp: very forward cross sections:
- new energy range explored
- particle production:
  - Input for high energy cosmic rays (E_{lab}= 10^{17} eV, high stat.)
  - modeling air showers from protons
- improve hermeticity (double diffraction)



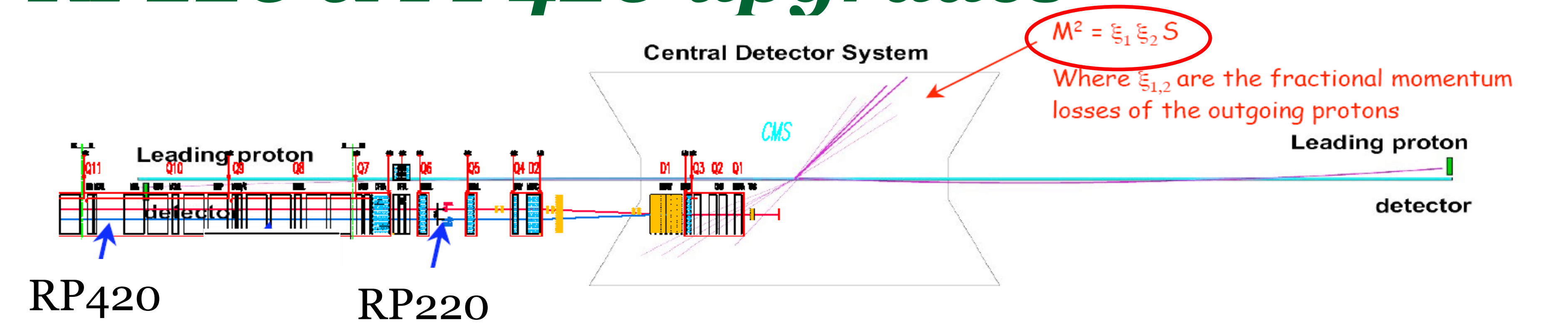
Van der Meer scan as a clean method for beam monitoring.



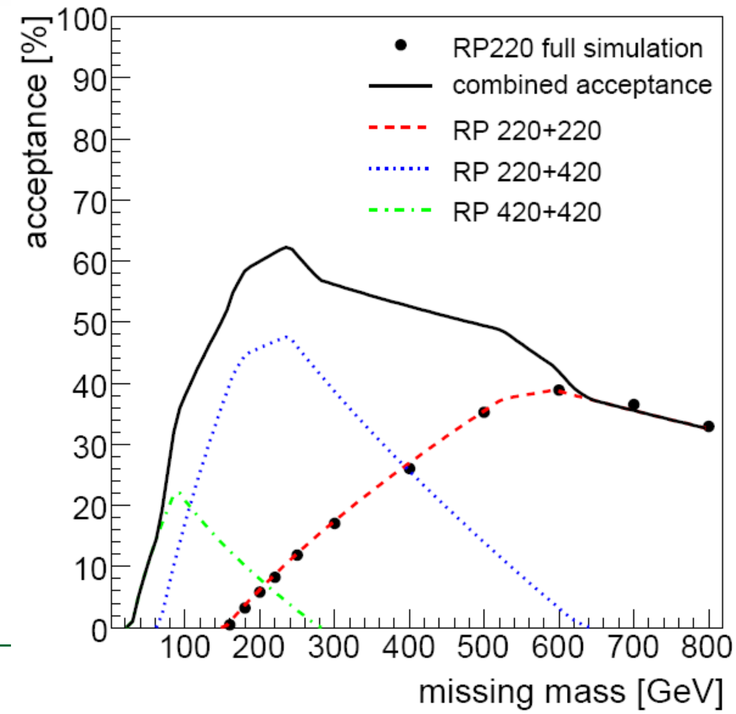


HI physics: count spectator neutrons
- Measure event centrality
- trigger for ultra-periph. collisions

RP220 & FP420 upgrades



- At nominal LHC running conditions:
  ~220m: 0.02 < ξ< 0.2
  ~420m: 0.002 < ξ < 0.02 (M>~30 GeV)



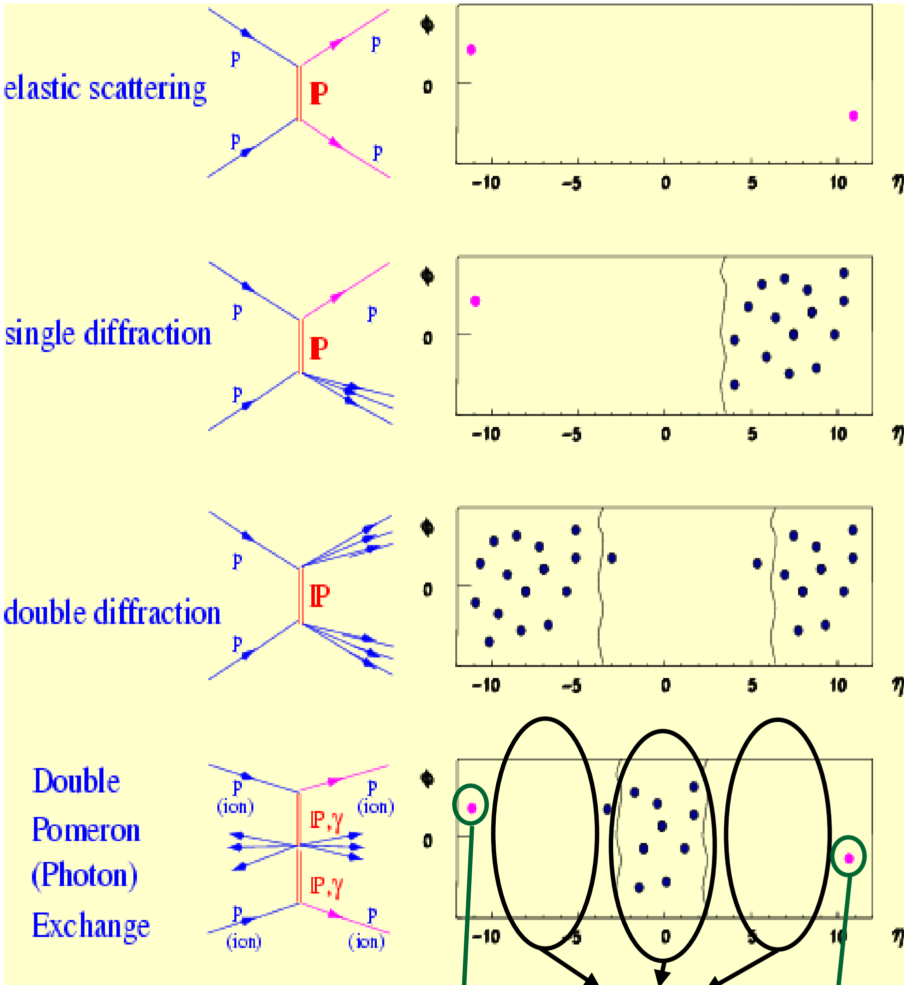
See talk by A. de Roeck

- Requirements:
  - Close to the beam => edgeless detectors
  - High lumi operation => radiation hard
  - Few μm - 1 μrad precision
  - Suppress pile-up => add fast timing det.

- Status of projects:
  - R&D advanced: conclusions ready and submitted by end 2008 for final decision
  - test beam campaign organised

diffractive physics

See talk by M. Tasevski



Total and elastic cross sections: precision of O(%)
- **ALFA**

Soft diffraction: RP220 & FP420
- sizeable fraction of inelastic cross section
- understand inclusive diffraction mechanisms
- study gluon content of the proton
- W, Z, Upsilon diffractive production

hard diffraction:
- Exclusive Higgs production (possible discovery channel in MSSM: 0^{++} & mass resolution ~ GeV!)
- gluon factory, exotics, anomalous W/Z prod.

Rapidity gap trigger **(Central Det., LUCID, ZDC, RP220) -** ☹ pile-up

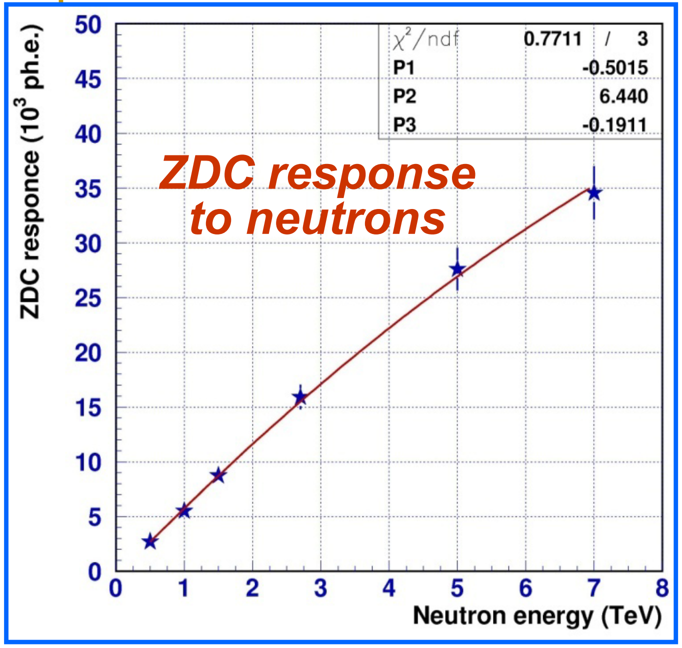
Proton tagging **(RP220 & FP420)**

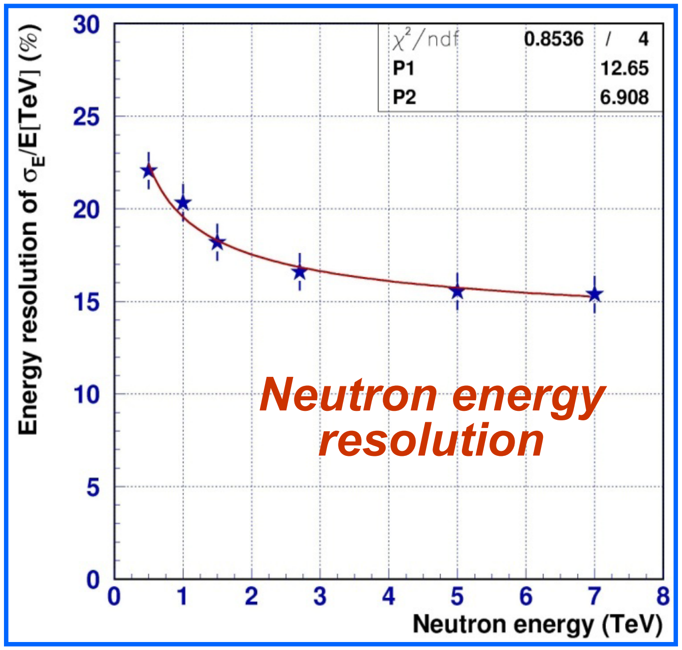
conclusions

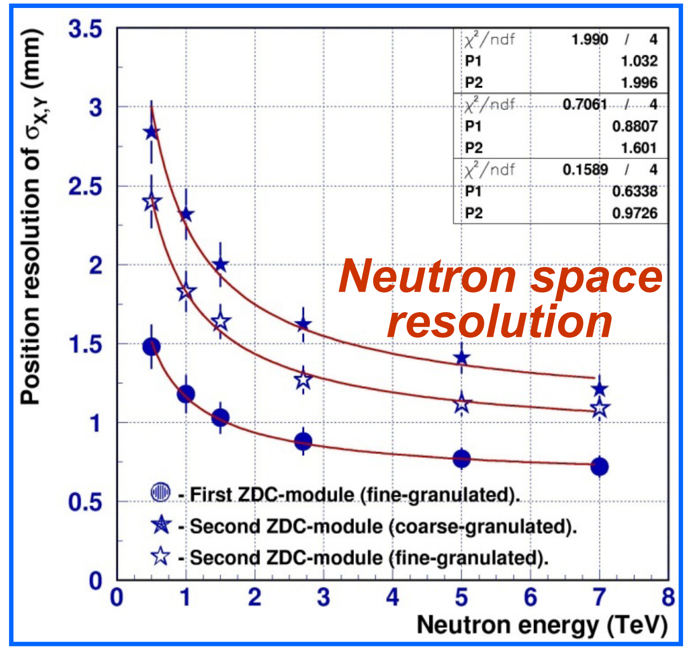
- **ATLAS Forward Detectors will allow $\mathcal{L}$ determination at 2-3% level, monitor beam conditions down to the BC scale and measure σ_{tot}**
  - **LUCID and ZDC installed and ready for beam**
  - **ALFA ready in ~ 1 year**
- **RP220-FP420 upgrade of ATLAS under study**
  - **R&D advanced. Conclusions ready and submitted by end 2008 for final decision.**
- **forward physics program extension foreseen**
  - **wide diffractive physics program possible**
  - **can prove to be a key field for new physics**

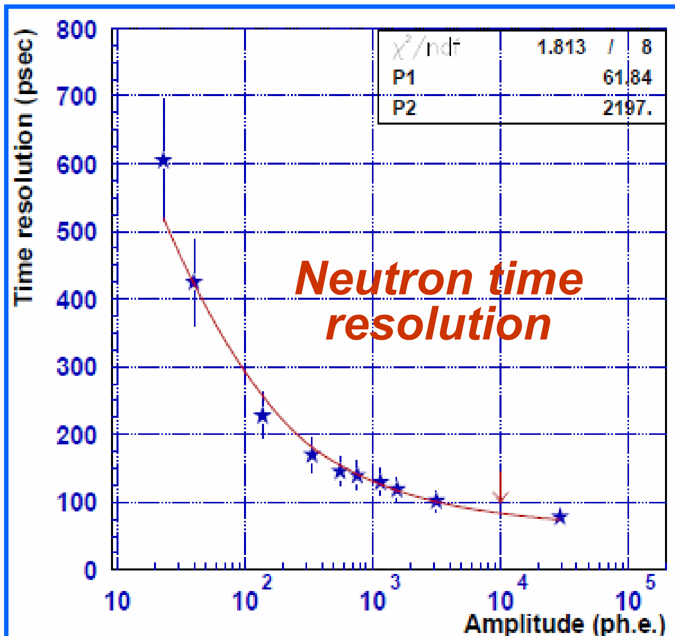
Backup slides

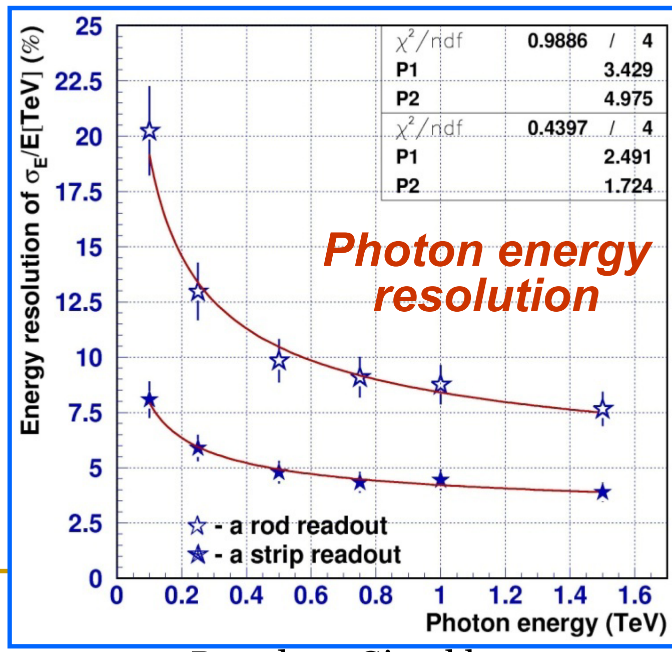
ZDC time, space and energy resolution (average over active area)

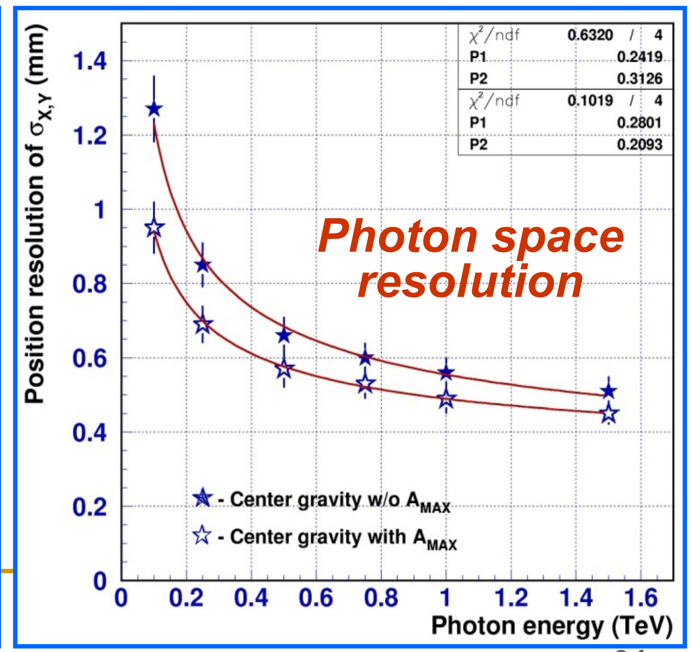












ATLAS Detectors for Luminosity Determination and Forward Physics

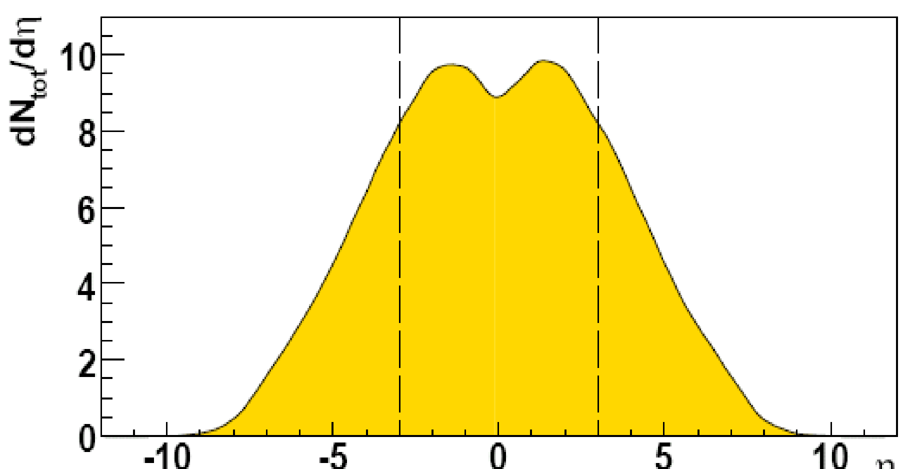
Baseline ATLAS detector covers $-5 < \eta < 5$

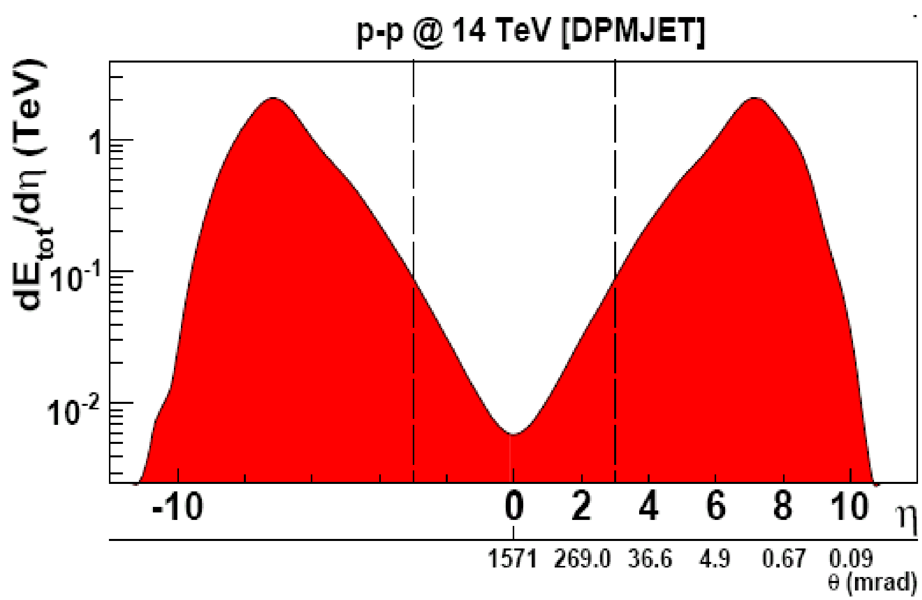
Tracking $-2.5 < \eta < 2.5$

However $\eta_{max} \sim \ln s/m_p \sim 9.5$

Large region in rapidity not covered

(Angles from 0.8 degree to 0 degrees)





Trigger conditions

- For the special run (~100 hrs, L=1027cm-2s-1)

- 1. ALFA trigger
  - coincidence signal left-right arm (elastic trigger)
  - each arm must have a coincidence between 2 stations
  - rate about 30 Hz

- 2. LUCID trigger
  - coincidence left-right arm (luminosity monitoring)
  - single arm signal: one track in one tube

- 3. ZDC trigger
  - single arm signal: energy deposit > 1 TeV (neutrons)

- 4. Single diffraction trigger
  - ALFA.AND.(LUCID.OR.ZDC)
  - central ATLAS detector not considered for now (MBTS good candidate)

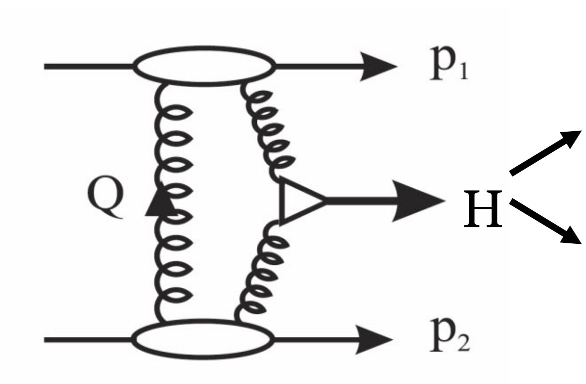
Single diffraction: trigger conditions

Efficiency [%]	Pythia	Phojet
Preselection		
ξ<0.2	97.1	94.8
ZDC [E>1 TeV]	51.5	38.7
LUCID [1 track]	45.1	57.3
[Central ATLAS E> 100 GeV]	24.9	38.7
Total preselection	75	74
RP selection		
ALFA **(Relative to preselection)**	60.1	54.2
Total acceptance	44.9	40.1

Exclusive Higgs production

Generator studies with detector cuts

Standard Model Higgs



b jets : M_H = 120 GeV s = 2 fb (uncertainty factor ~ 2.5)

M_H = 140 GeV s = 0.7 fb

M_H = 120 GeV : 11 signal / O(10) background in 30 fb^{-1}

hep-ph/0207042 with detector cuts

WW^* : M_H = 120 GeV s = 0.4 fb

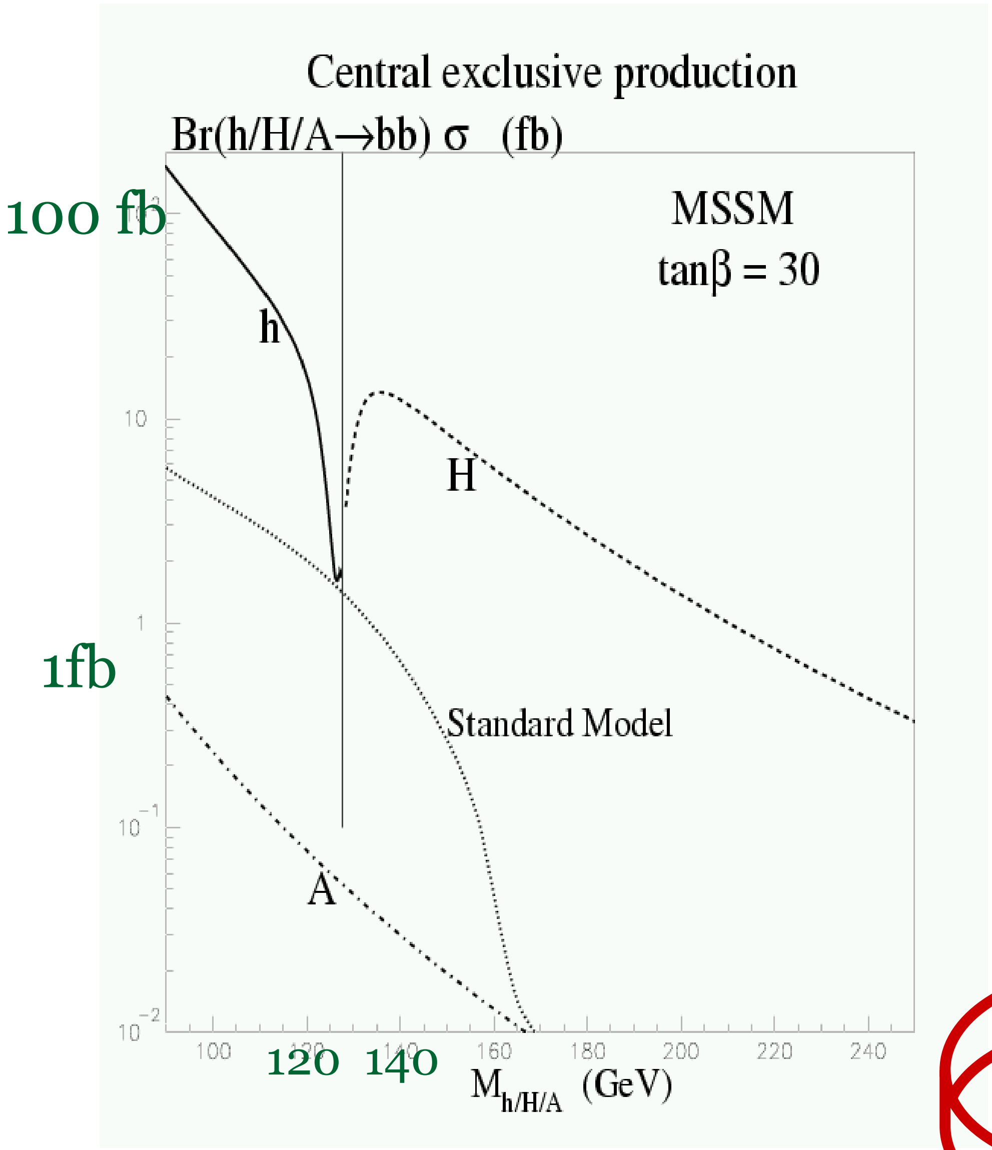
M_H = 140 GeV s = 1 fb

M_H = 140 GeV : 8 signal / O(3) background in 30 fb^{-1}

hep-ph/0505240 with detector cuts

- The b jet channel is possible, with a good understanding of detectors and clever level 1 trigger (need trigger from the central detector at Level-1, possibly with O(10) KHz rate)
- The WW^* (ZZ^*) channel is extremely promising : no trigger problems, better mass resolution at higher masses (even in leptonic / semi-leptonic channel)

Higgs Studies



Cross section factor
> 10 larger in MSSM
(high tanβ)
⇒ Few 100 events with
~ 10 background events
for 30 fb^{-1}

Kaidalov et al.,
hep-ph/0307064

⇒Study correlations between the outgoing protons to analyse the spin-parity structure of the produced boson

A way to get information on the spin of the Higgs
⇒ADDED VALUE TO LHC