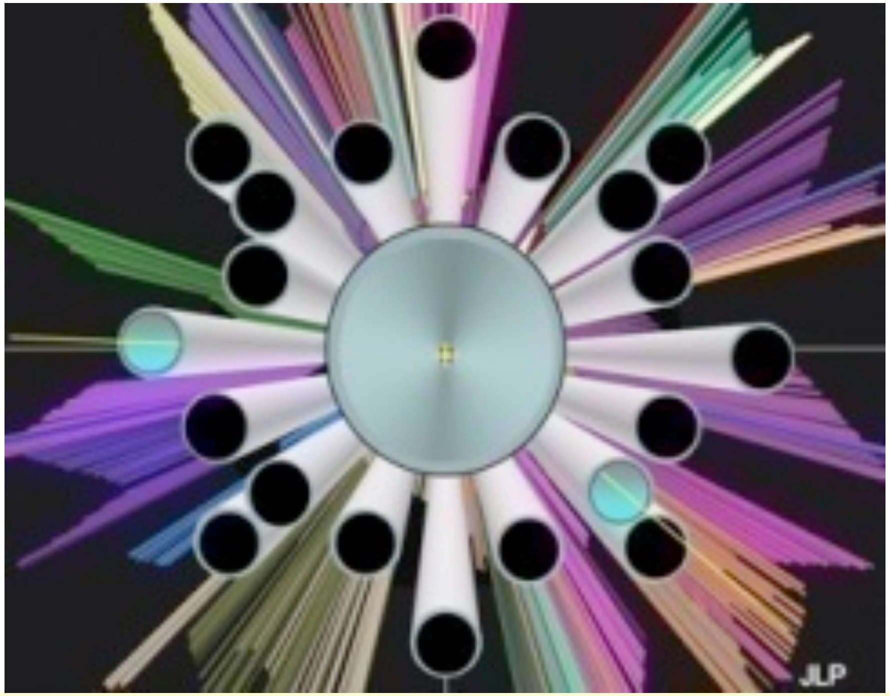


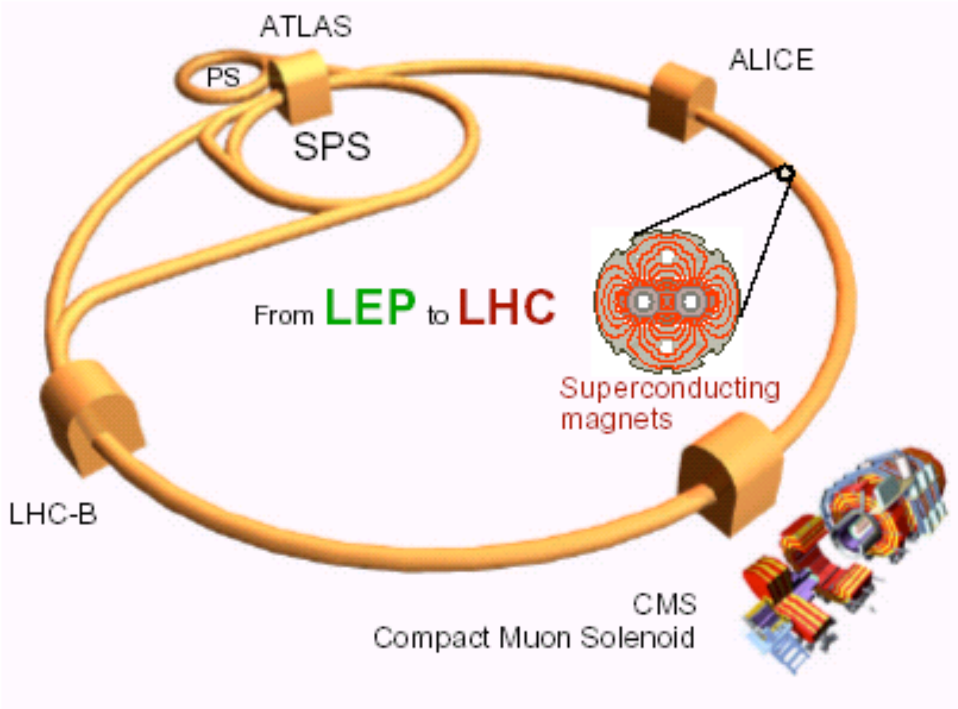
A Cherenkov Detector for Monitoring ATLAS Luminosity

A. Sbrizzi
On behalf of the ATLAS luminosity and forward detectors group

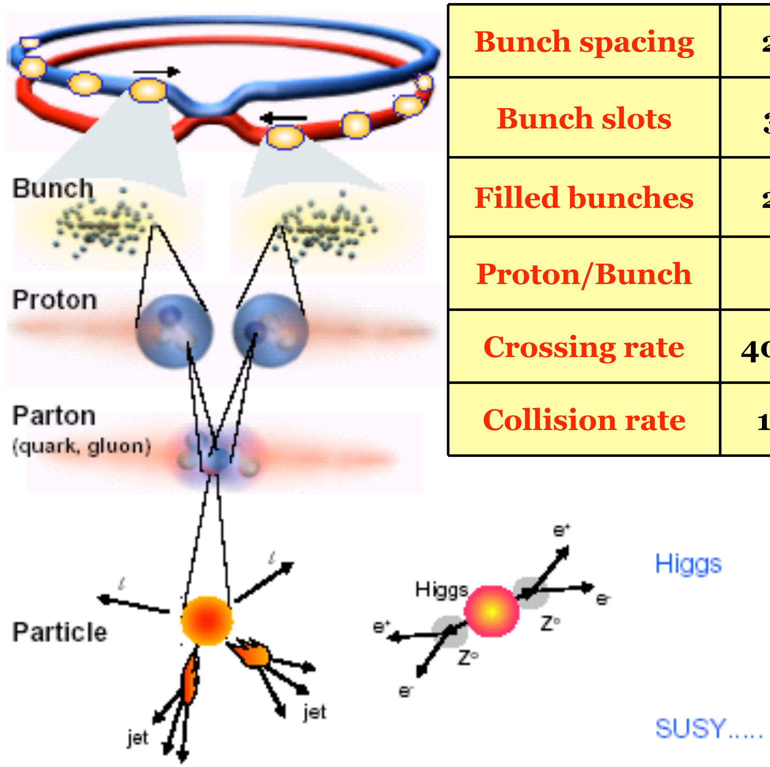
Outline

- Concept of Luminosity
- The LUCID Detector
- LUCID performance in 2009/2010
- Future Prospects

LHC: a pp collider at 7 TeV



Beams	Energy	Luminosity
p-p	7 TeV	10^{34} cm^{-2}s^{-1}
^{208}Pb-^{208}Pb	1148 TeV	10^{27} cm^{-2}s^{-1}



Bunch spacing	25 ns
Bunch slots	3564
Filled bunches	2808
Proton/Bunch	10^{11}
Crossing rate	40 MHz
Collision rate	1 GHz

Selection of 1 in 10,000,000,000,000

To observe rare processes (Higgs), high luminosity needed (LHC design: 10^{34} cm^{-2}s^{-1}).

Concept of Luminosity

Luminosity (L) relates physics process rates ($\propto \mu_{BX}$) to their cross sections (σ).

$$L = 40\ \text{MHz}\ \frac{N_{BX}}{3564}\frac{\mu_{BX}}{\sigma}$$

Physics definition

$$L = 40\ \text{MHz}\ \frac{N_{BX}}{3564}\frac{N^2_{protons/BX}}{4\pi\sigma_x\sigma_y}$$

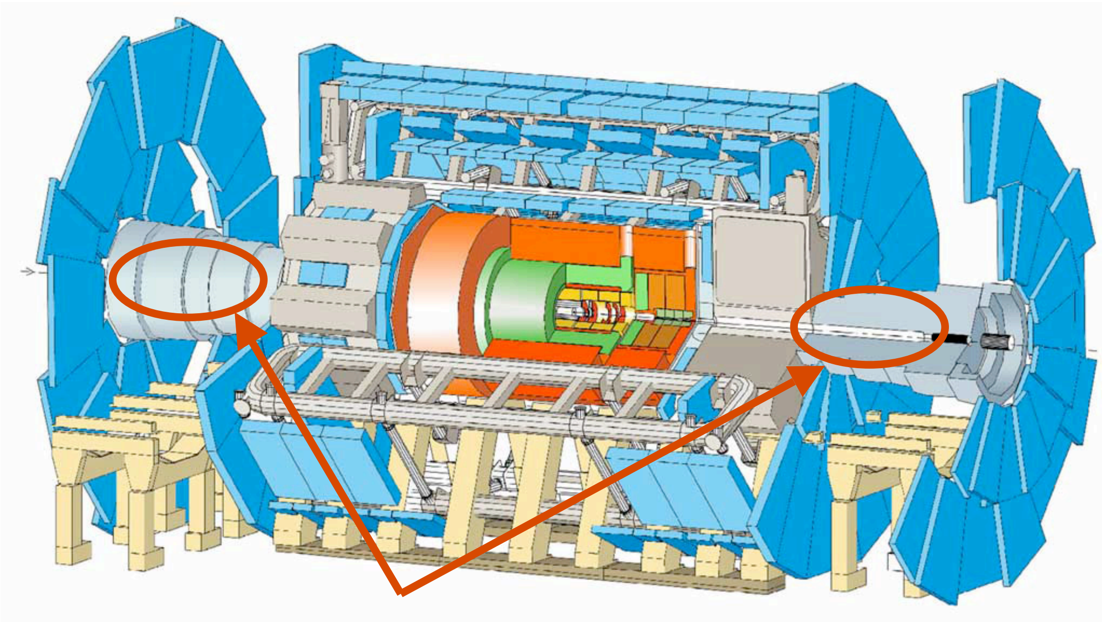
Dependence on “beam parameters”

N_{BX}	Number of filled bunches
μ_{BX}	Mean number of interactions per bunch crossing
$N_{protons/BX}$	Number of protons per bunch crossing
σ_x, σ_y	Beam width in x and y

- Absolute luminosity is measured in “dedicated runs” with a “beam separation scan” with an accuracy of 10%, the largest contribution coming from the number of protons. Later on, it will be more precisely measured from *elastic pp collisions* (<3%).

- In “physics runs”, luminosity is measured with relative monitors. LUCID is sensitive to *inelastic pp* collisions: $\sigma_{phojet} = 84.5$ mb $\rightarrow \mu_{BX} \sim 25$ at 10^{34} cm^{-2}s^{-1}.

LUCID: the ATLAS luminosity monitor



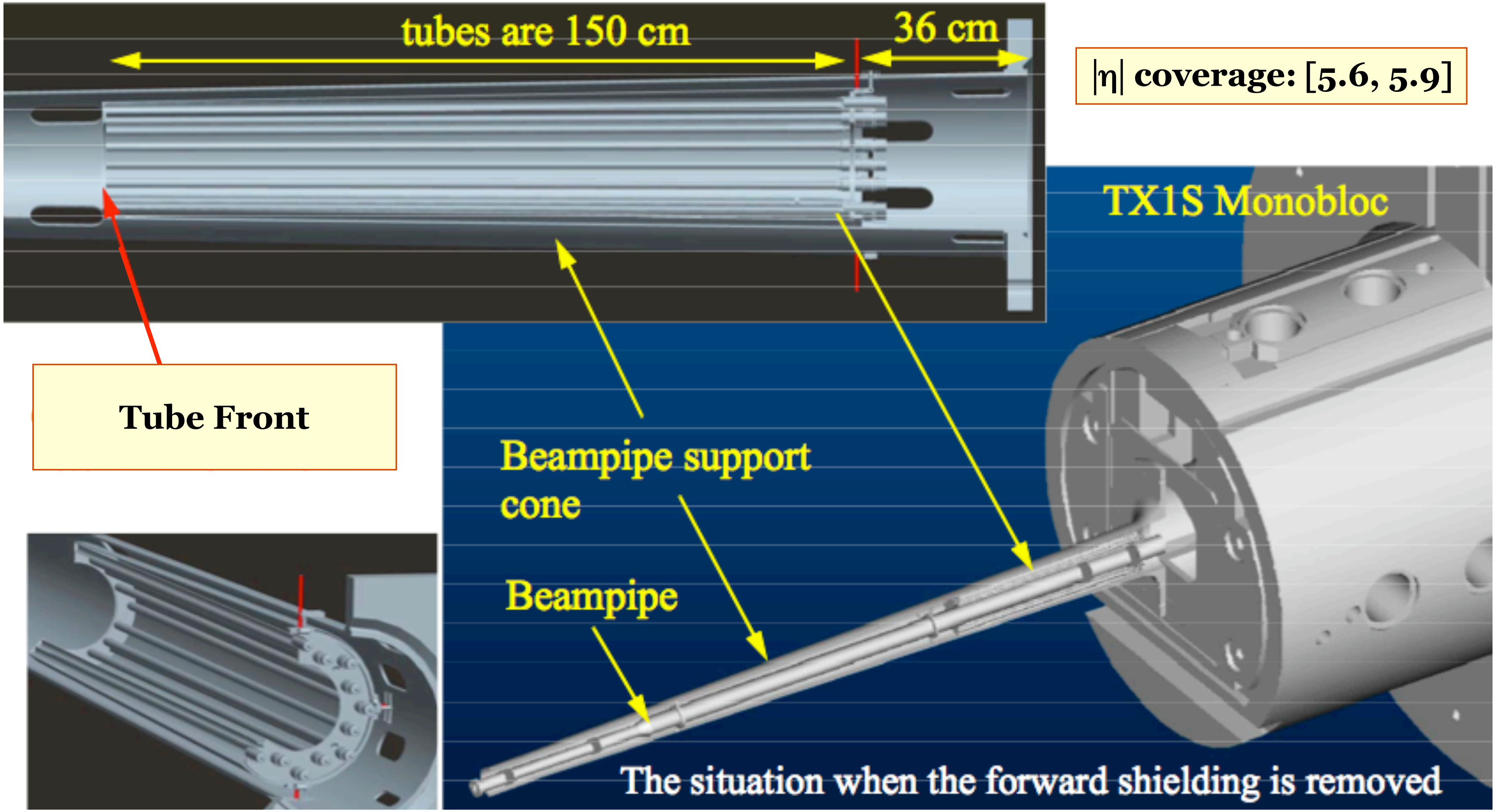
Location of LUCID modules inside ATLAS

- The two LUCID detector modules are located in the forward ATLAS region at 17 m from the IP
- LUCID detects charged particles pointing to the primary *pp* collision
- LUCID is designed to measure the luminosity up to $L = 4\times10^{33}$ $cm^{-2}s^{-1}$

Technical challenge: locate the detector in a high radiation area
7 Mrad/year @ highest luminosity (10^{34} $cm^{-2}s^{-1}$)

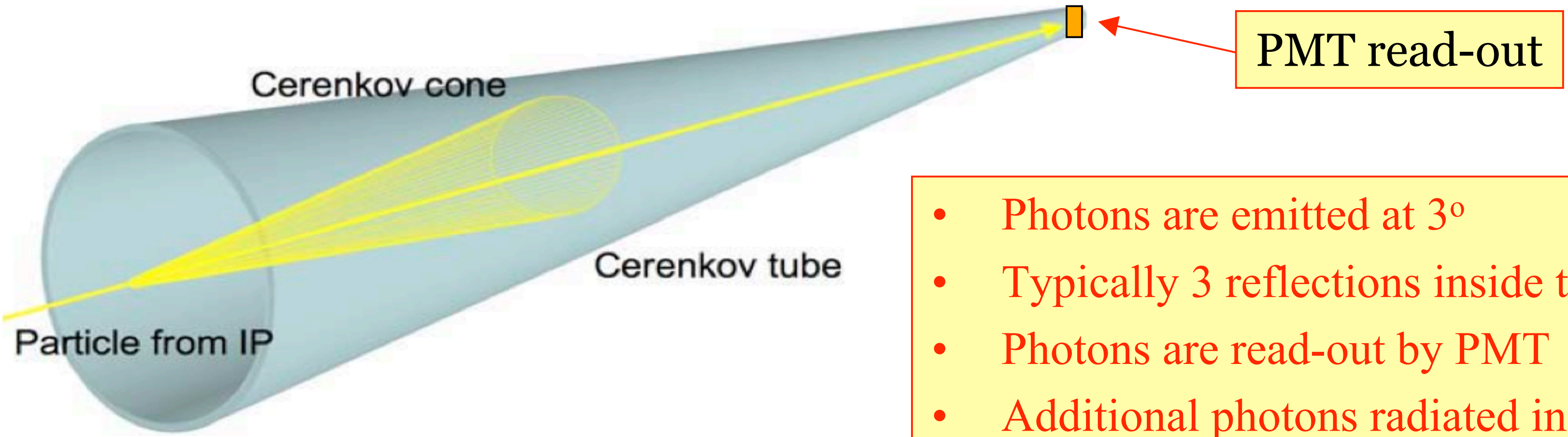
LUminosity measurement with a Cherenkov Integrating Detector

|η| coverage: [5.6, 5.9]



Array of mechanically polished Aluminum tubes filled with a Cherenkov gas (C_4F_{10}).
C_4F_{10} pressure at 1.1 bar (Leak <20 mbar/day/module).

LUCID detector principle

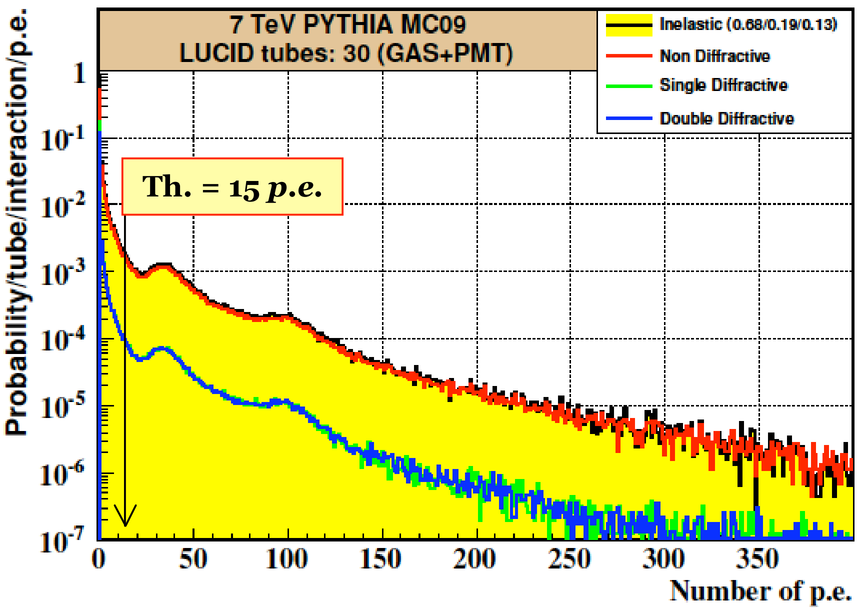


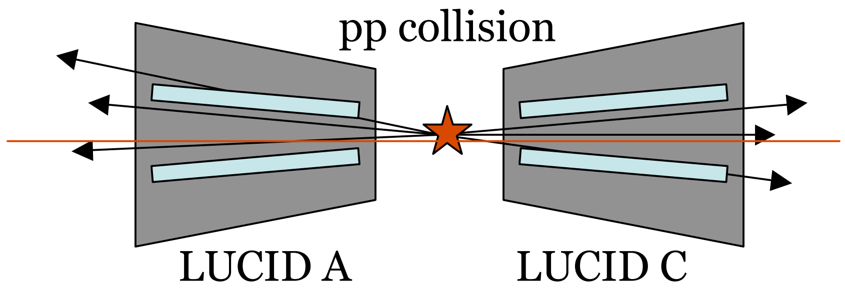
- Photons are emitted at 3°
- Typically 3 reflections inside the tubes
- Photons are read-out by PMT
- Additional photons radiated inside PMT

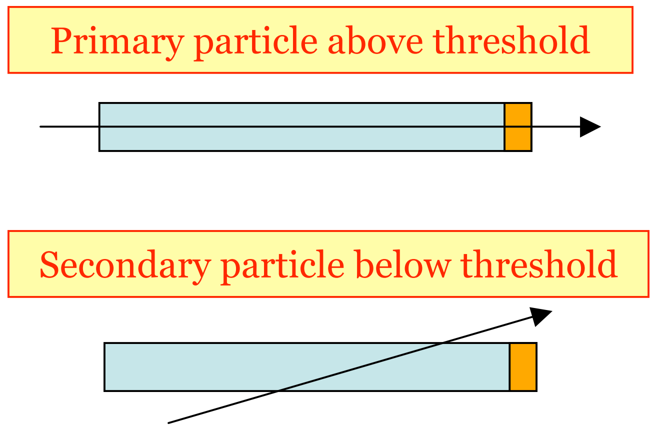
- Background suppression:
  - Cherenkov threshold: 10 MeV for e^- and 2.8 GeV for π, in the gas.
  - Geometry: tubes are pointing to the *pp* interaction region.

- The fast response (few ns) allows for single bunch crossing detection.
  - Increase the accuracy of the luminosity measurement.

Simulation of LUCID response to pp collisions







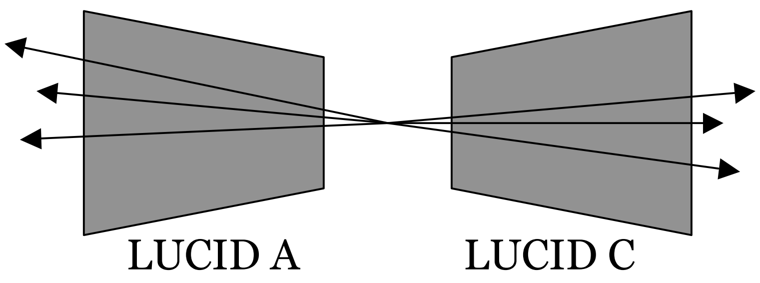
- A hit is defined with a threshold of 15 *p.e.*
- Particles below threshold cross only partially a tube.
- Maximum number of hits: 30 (saturation).

Definition of detected interaction

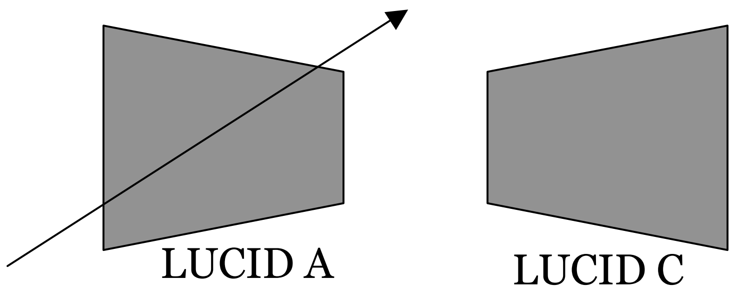
Single side mode (OR)	at least 1 hit in a module
Coincidence mode (AND)	at least 1 hit in both modules

The presence of hits in the detector might be due particles crossing the detector and "not directly related" to the primary *pp* collisions

Primary collision



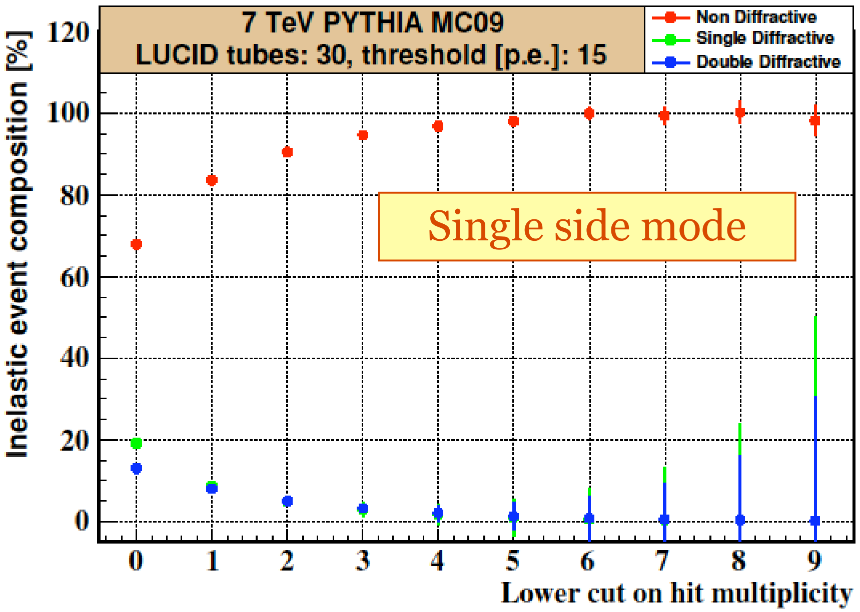
Accelerator Background event

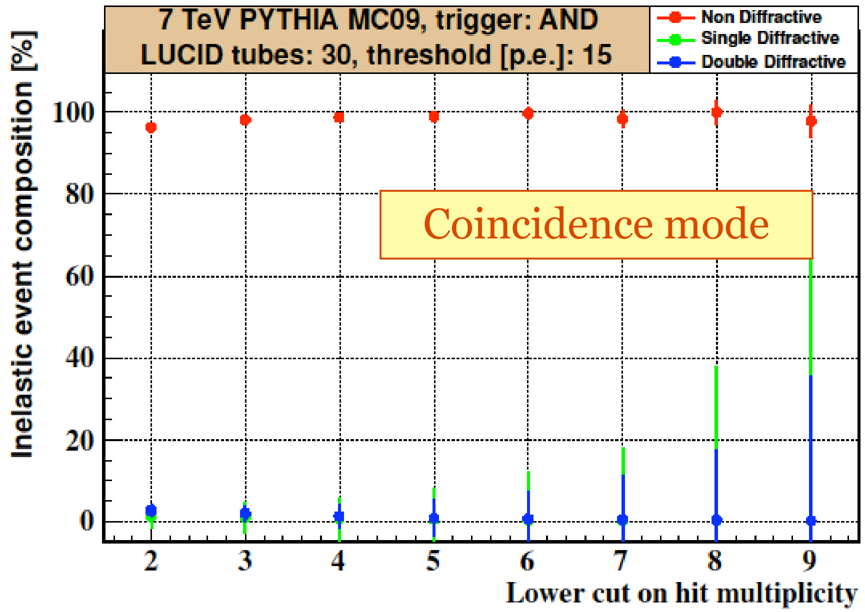


The coincidence method suppresses "accelerator background".

Effect of coincidence in physics

The inelastic event is made of 3 components: non-diffractive, single and double-diffractive.





Process	σ [mb] at 7 TeV
Non Diffractive	48.44
Single Diffractive	13.68
Double Diffractive	9.26

By requiring at least one hit in coincidence mode, non-diffractive events become dominant (> 95%).

Measurement of μ_{BX}

Event counting (μ < 0.01)

$$\mu_{BX} = \frac{P_{hits/BX}}{\varepsilon_{pp}}$$

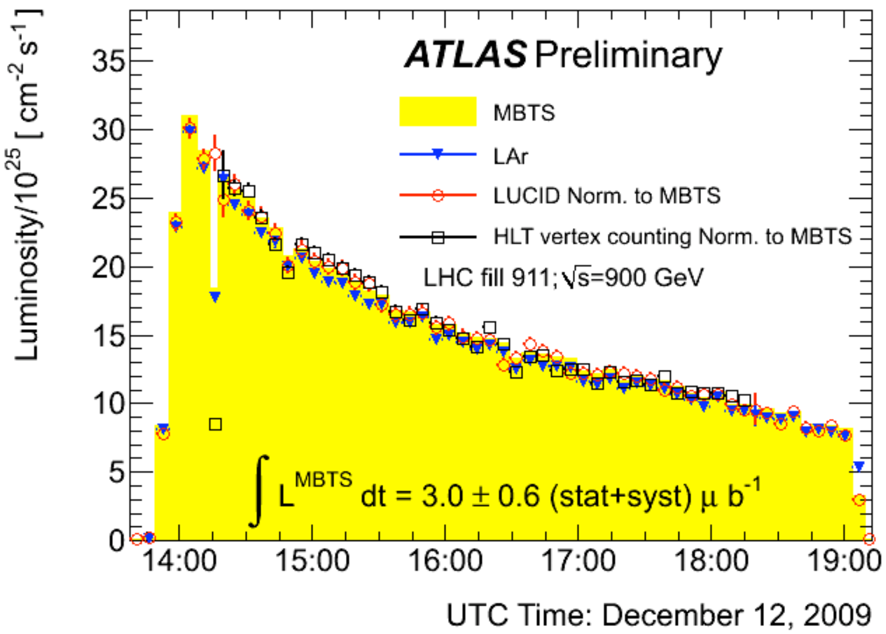
Hit counting (μ < 0.01)

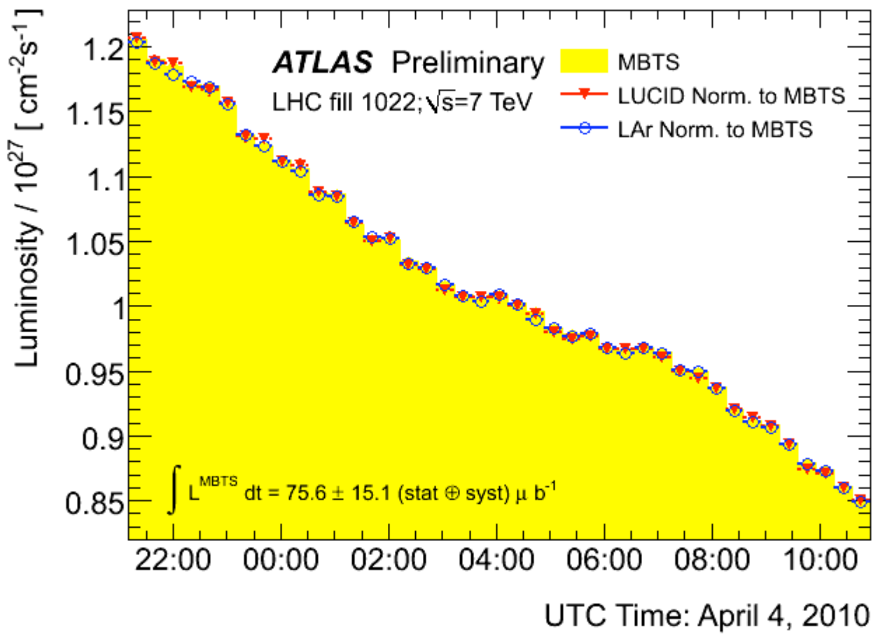
$$\mu_{BX} = \frac{N_{hits/BX}}{N_{hits/pp}}$$

$P_{hits/BX}$	Mean number of events detected per bunch crossing
ε_{pp}	LUCID efficiency to detect a *pp* interaction
$N_{hits/BX}$	Mean number of hits per bunch crossing
$N_{hits/pp}$	Mean number of hits per pp interaction

Simple linear formula is valid for μ < 0.01 (first LHC data).
For larger values the relation is not linear (need corrections).

Luminosity measurement 2009/2010



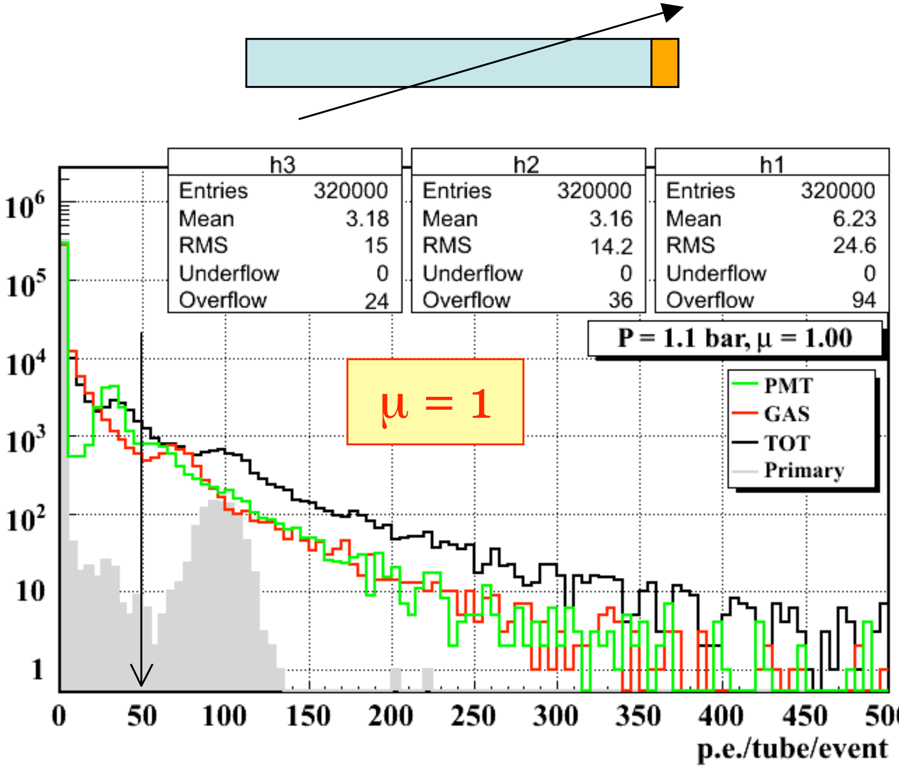


- Good agreement between luminosity measurement provided by different detectors.
  - LUCID (16+16 cherenkov tube covering $5.6 < |\eta| < 5.9$)
  - Minimum Bias Trigger Scintillators (16+16 scintillators covering $2.1 < |\eta| < 3.8$)
  - Liquid Argon (Electromagnetic and Hadronic calorimeter covering $|\eta| < 4.9$)
- LUCID feature: high stability, low background (cosmics/noise < 3%, beam related < 0.1%)
- In addition, LUCID provides luminosity also when ATLAS is down.

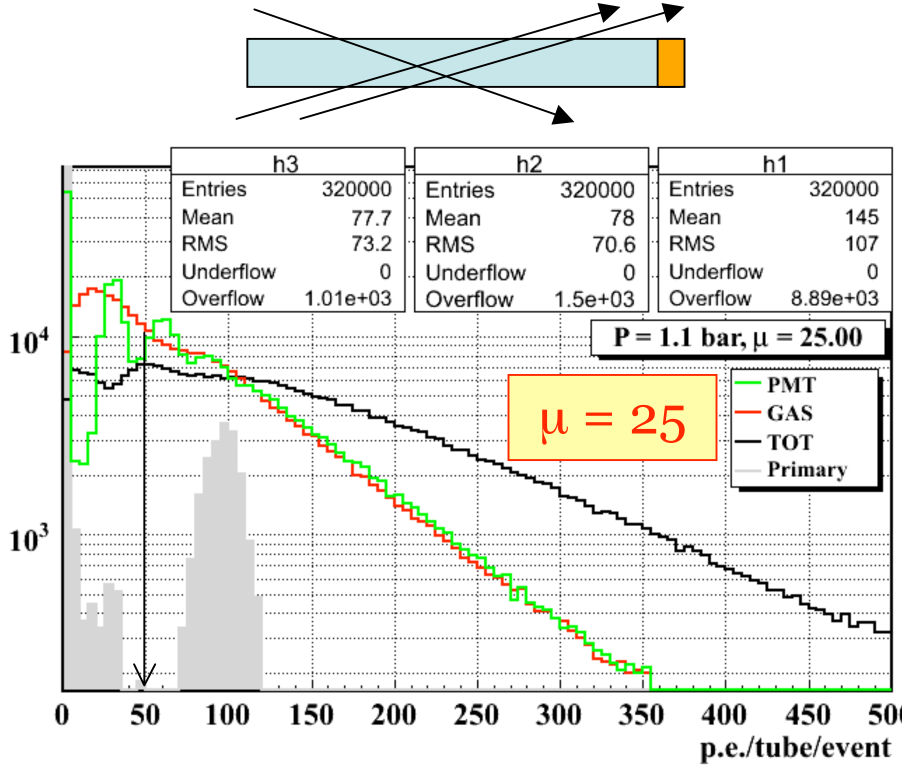
Integrated luminosity up to now: 10 nb^{-1}

Going towards high μ: Migration effect

Secondary below threshold (40 *p.e.*)

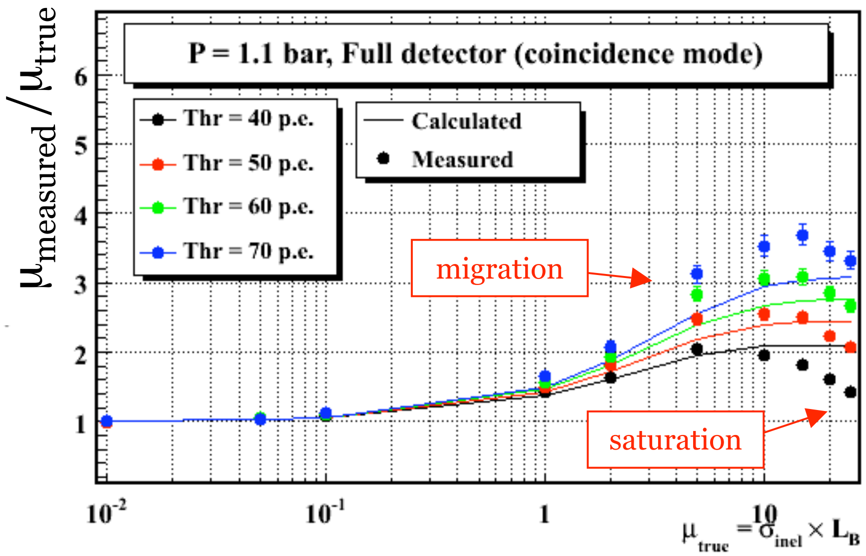


Secondaries above threshold (40+40= 80 *p.e.*)



- The spectrum get flattened when μ increases (>1 particle through the same tube)
- This effect is called "migration" of secondary particles above threshold

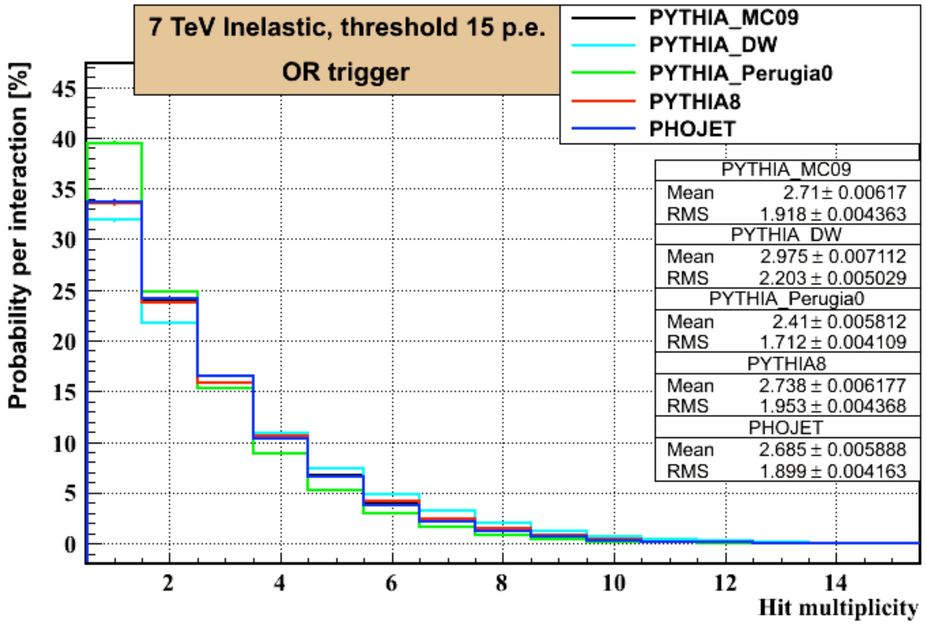
Going towards high μ: Non linearity

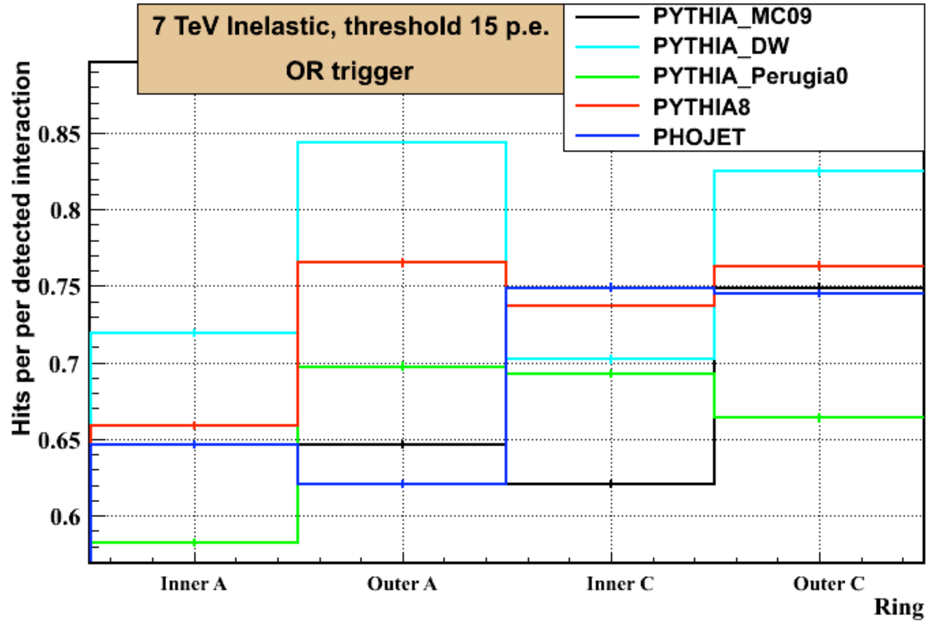


- Relation between μ_{meas} and μ_{true} is not linear at high luminosity
- Underestimate of μ is due to "saturation effect"
- Overestimate of μ at intermediate values is due to "migration effect"
- In addition, coincidence mode suffers of non- linear effects due to combinatorial and Poisson statistics, which can be calculated (solid line)
- Deviation from prediction: 10% @ μ = 10, when threshold is 50 *p.e.*

A MC based fit can be performed to provide the relation between μ_{meas} and μ_{true}

MC tuning: hit distributions





- Significant differences among models (especially in η).
  - η dependence also affected by 2 dead tubes.
- Possibility to constraint the MC at large pseudo-rapidity
  - Interesting because not many data available from past experiments.
- Before that, careful evaluation of systematic uncertainties
  - Effect of tube by tube variation.
  - Production of secondary particles in the beam pipe.

Conclusions

- Performance of measurement of luminosity with LUCID
  - High stability
  - Small background (< 3 %)
  - Total uncertainty smaller than 10% (with a calibration based on VdM scan)

- Plan for next 2 years: reach an integrated luminosity of 1 fb^{-1}.

- Going towards high luminosity:
  - Background goes down with luminosity. Anyway, possible accelerator related background" can be suppressed requiring hit coincidences.
  - "Coincidence effects" and "Detector related" effects (migration and saturation) are taken into account with a global fit to the Monte Carlo simulated events.
  - Other methods are currently under study fully based on data.

- Possibility to tune MC models by looking at hit distributions
  - Interesting for lack of data at high pseudo-rapidity from past experiments.

Backup slides

Efficiency table

Pythia cross sections are larger than Phojet ones and acceptance is smaller

Generator	ε^{OR}	ε^{AND}	N^{OR}_{hits}	N^{AND}_{hits}
PYTHIA MC09	0.6442 ± 0.0012	0.2171 ± 0.0011	1.7460 ± 0.0052	0.9200 ± 0.0051
PYTHIA DW	0.6398 ± 0.0012	0.2347 ± 0.0011	1.9070 ± 0.0059	1.1010 ± 0.0059
PYTHIA Perugia0	0.5785 ± 0.0013	0.1564 ± 0.0009	1.3940 ± 0.0046	0.6142 ± 0.0042
PYTHIA8	0.6665 ± 0.0012	0.2155 ± 0.0011	1.8260 ± 0.0053	0.9324 ± 0.0052
PHOJET	0.6938 ± 0.0012	0.2157 ± 0.0011	1.8640 ± 0.0052	0.9028 ± 0.0051

Table 1: LUCID efficiency and average number of hits per interaction for different MC generators of *pp* inelastic collisions at $\sqrt{s} = 7$ TeV and a full ATLAS detector simulation.

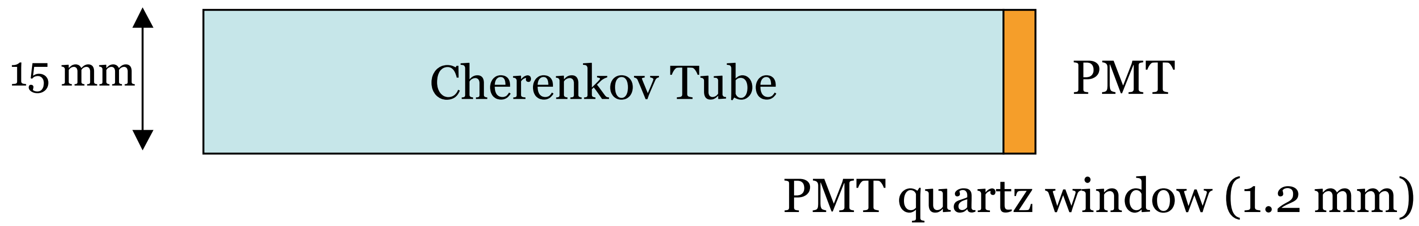
Energy	Threshold [p.e.]	$\Delta\varepsilon^{OR}$ [%]	$\Delta\varepsilon^{AND}$ [%]	ΔN^{OR}_{hits} [%]	ΔN^{AND}_{hits} [%]
7 TeV	10	5.3710	15.2464	17.0103	25.2174
7 TeV	11	4.0981	11.4694	12.7148	18.6957
7 TeV	12	2.9494	8.1069	8.8774	13.1522
7 TeV	13	1.9249	5.1129	5.6128	8.0978
7 TeV	14	0.8848	2.3952	2.6346	3.8478
7 TeV	15	0.0000	0.0000	0.0000	0.0000
7 TeV	16	-0.8538	-2.2570	-2.2910	-3.3696
7 TeV	17	-1.5989	-4.5601	-4.5246	-6.6630
7 TeV	18	-2.3595	-6.3565	-6.4147	-9.2500
7 TeV	19	-3.0891	-8.3372	-8.3047	-12.1087

Table 1: Variation of LUCID efficiency and average number of hits per interaction for *pp* inelastic collisions generated with PYTHIA MC09 and passed through a full ATLAS detector simulation.

LUCID read-out scheme

2×16 tubes are directly coupled to Photo-Multiplier Tubes (PMT).

PMT must be radiation hard.

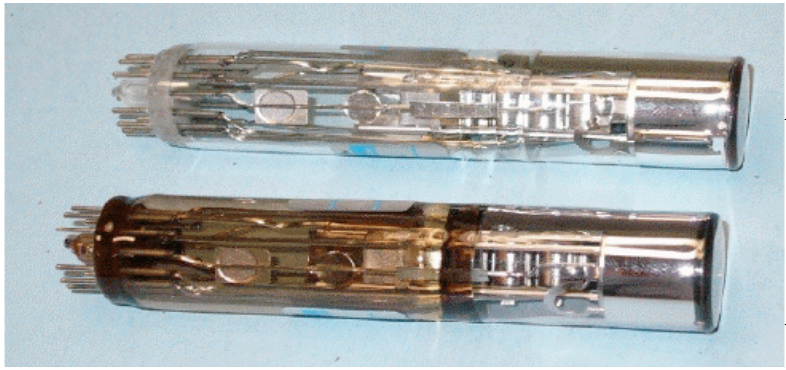


2×4 tubes are coupled to multi-anode PMT via Winston Cones and optical fibers.

Better for high luminosity runs (MAPMT not exposed to high radiation doses).

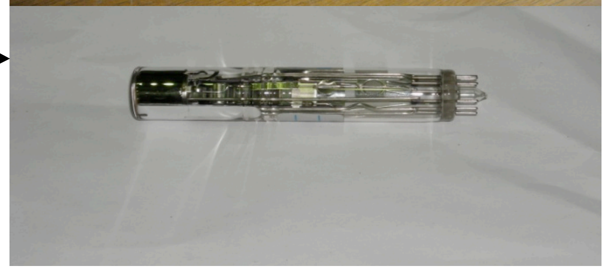
Radiation hardness test

γ: ^{60}Co, E = 1.22 MeV ***Dose = 20±1* Mrad** ***30 years of LHC in phase I***	***n: ENEA-Casaccia reactor*** ***E = 100 KeV*** ***Dose = 10 years of LHC in phase I***



Before

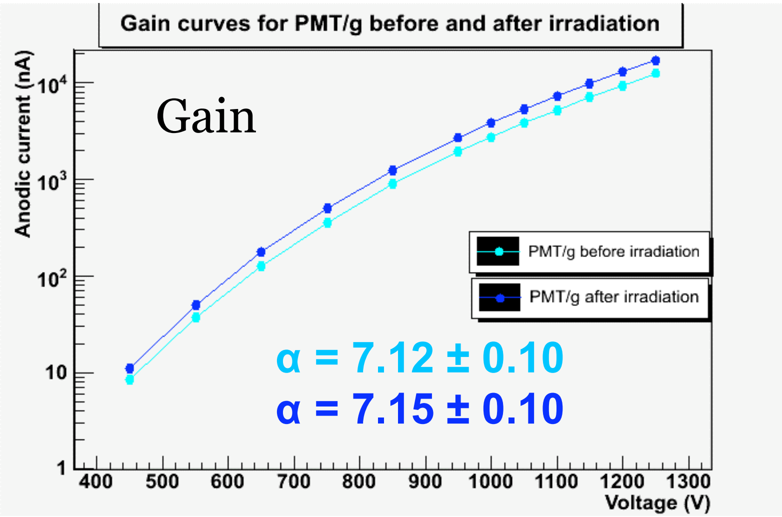
After

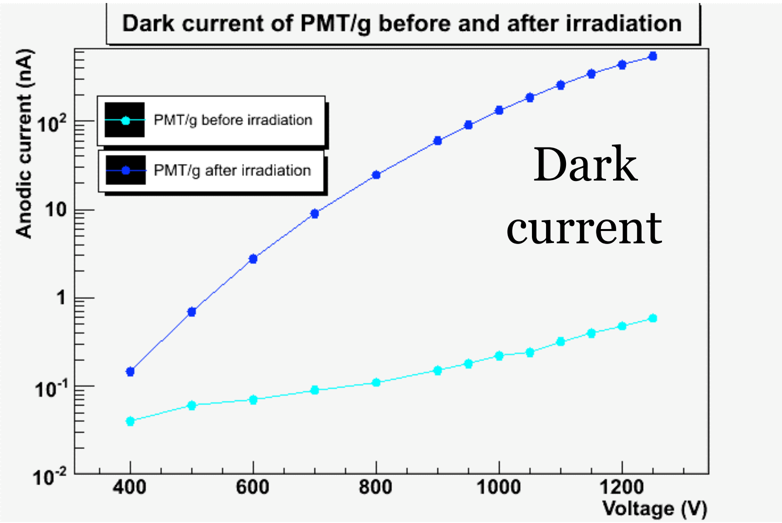


No visible damage to metal and quartz.
Glass opacity increased.

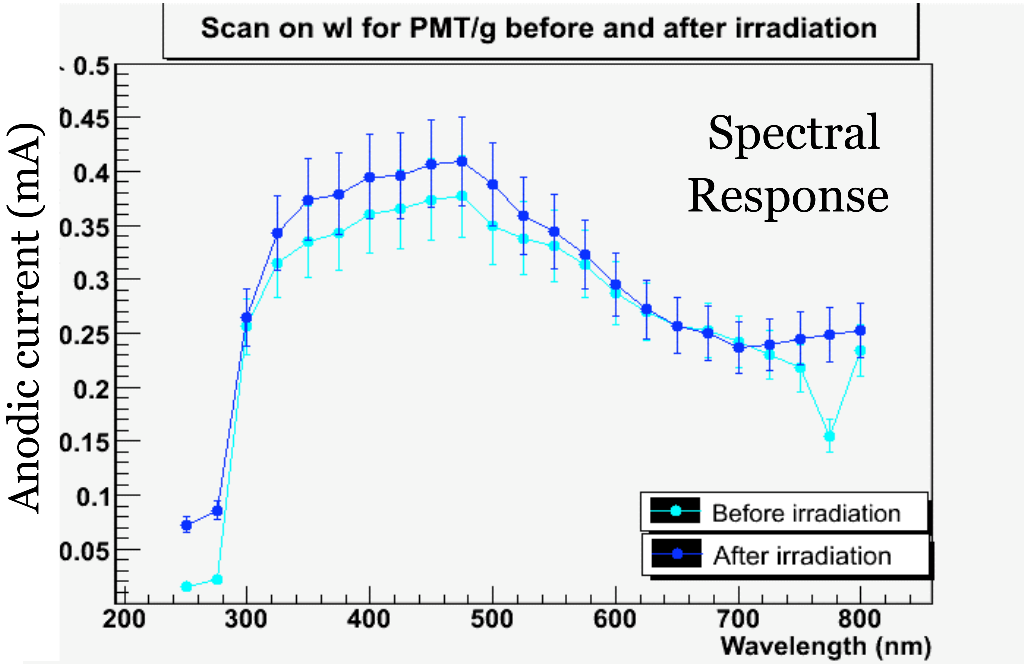
No visile damage to matal, glass and quartz

Radiation hardness



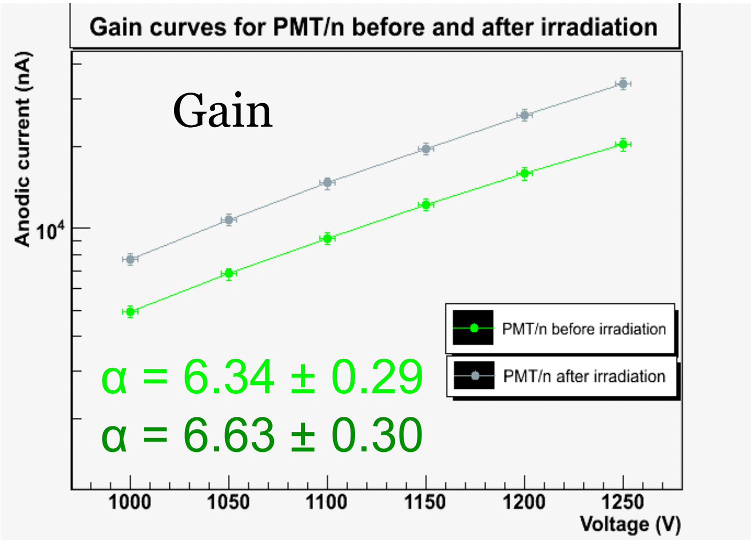


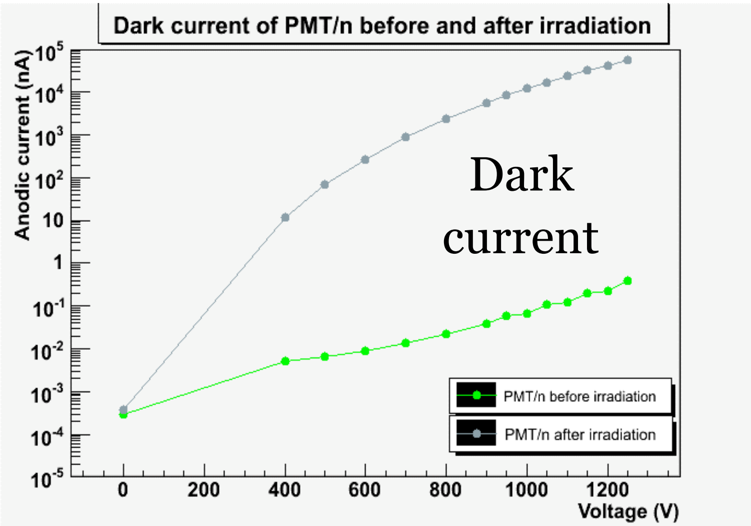
γ: ^{60}Co, E = 1.22 MeV
Dose = 20±1 Mrad
30 years of LHC in phase I



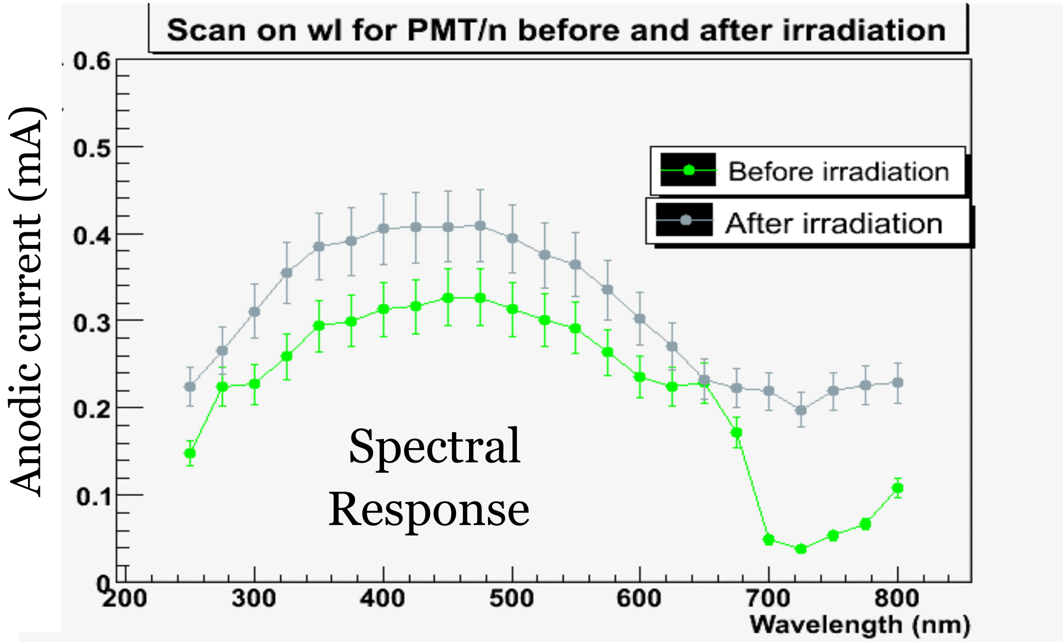
No relevant effects for phase I

Radiation hardness





n: ENEA-Casaccia reactor
E = 100 KeV
Dose = 10 years of LHC in phase I



No relevant effects for phase I