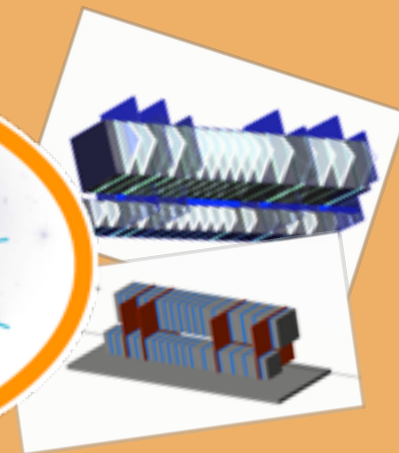
IFAE 2010
Roma 7 – 9 Aprile, 2010

The LHCf experiment at LHC

Alessia Tricomi
University and INFN Catania
on behalf of the LHCf Collaboration

- The LHCf detector
- Experiment goals
- Physics performance
- 900 GeV preliminary results
- A first look @ 7 TeV data



What is LHCf?

The Detectors

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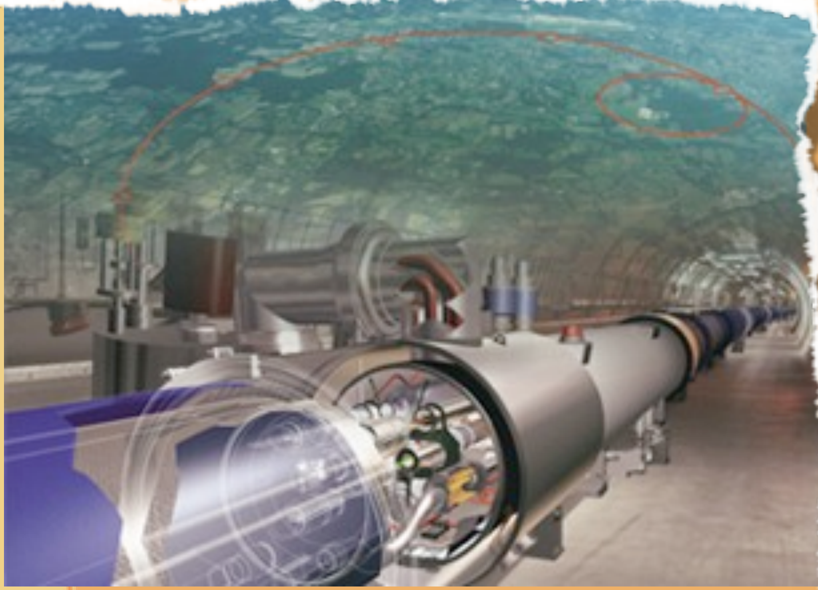
LHCf: an Astroparticle Experiment at LHC



7 TeV + 7 TeV proton collisions at LHC correspond to $E_{LAB} = 10^{17}$ eV

- LHCf is the smallest of the six LHC experiments and is a fully dedicated collider experiment for HECR Physics
- LHCf will use LHC data to calibrate the hadronic interaction models used in Monte Carlo simulations of atmospheric showers
- Two independent electromagnetic calorimeters equipped with position sensitive layers, on both sides of IP1 will measure energy and position for $|\eta|>8$ of γ from π^0 decays and neutrons produced in pp interaction at LHC

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Experimental set-up

Detector I

Tungsten

Scintillator

Scintillating fibers

INTERACTION POINT

IP1 (ATLAS)

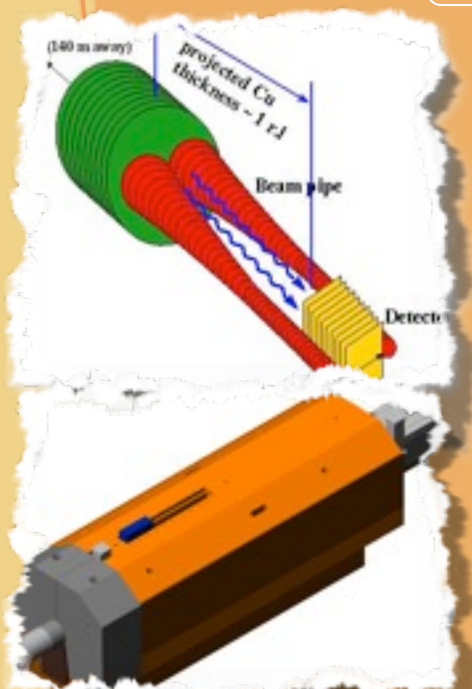
Detector II

Tungsten

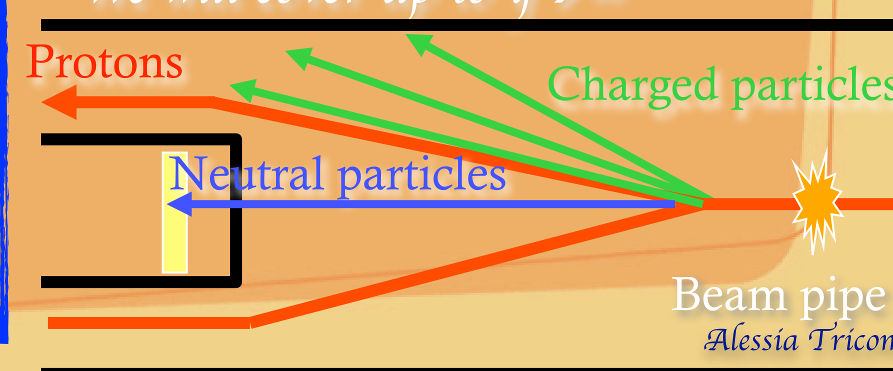
Scintillator

Silicon μ strips

Detectors installed in the TAN region, 140 m away from the Interaction Point 1



- Here the beam pipe splits in 2 separate tubes.
- Charged particle are swept away by magnets
- We will cover up to $y \rightarrow \infty$



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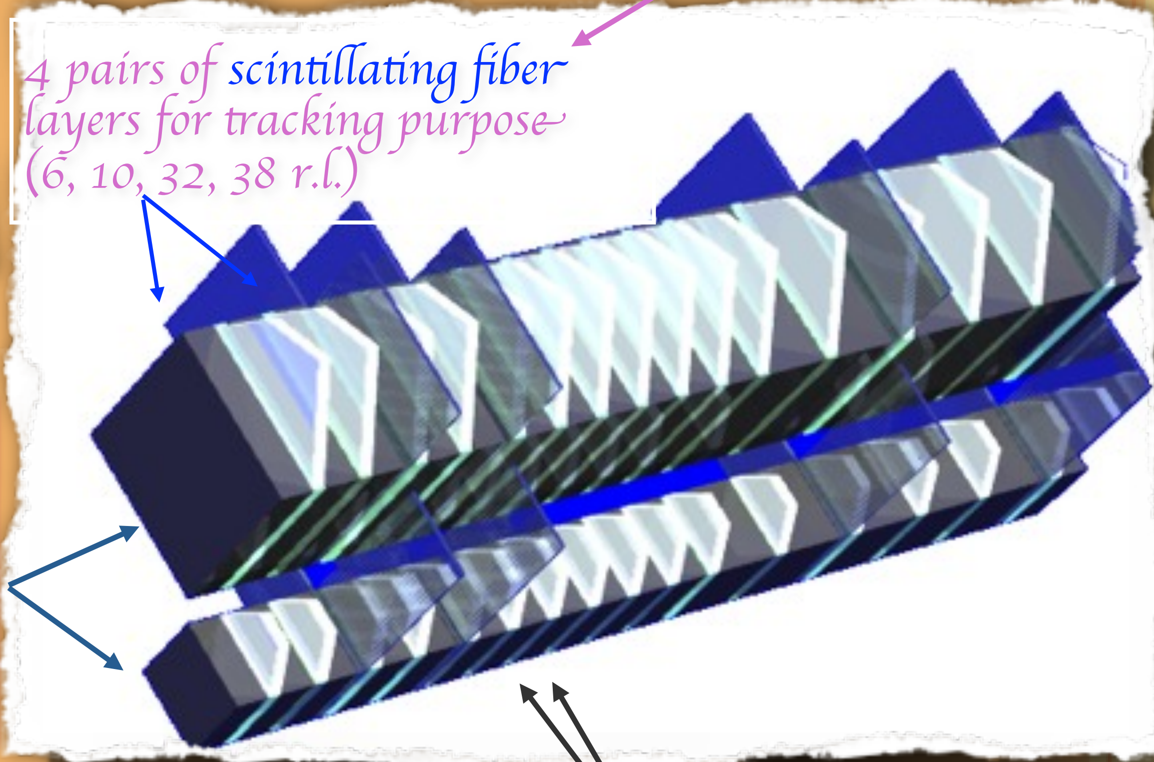
Detector #1

2 towers 24 cm long stacked vertically with 5 mm gap

Lower: 2 cm x 2 cm area

Upper: 4 cm x 4 cm area

Impact point (η)



Absorber

22 tungsten layers
7mm – 14 mm thick
(W: X_0 = 3.5mm, R_M= 9mm)

Energy

16 scintillator layers (3 mm thick)

Trigger and energy profile measurements

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Detector # 2

2 towers 24 cm long stacked on their edges and offset from one another

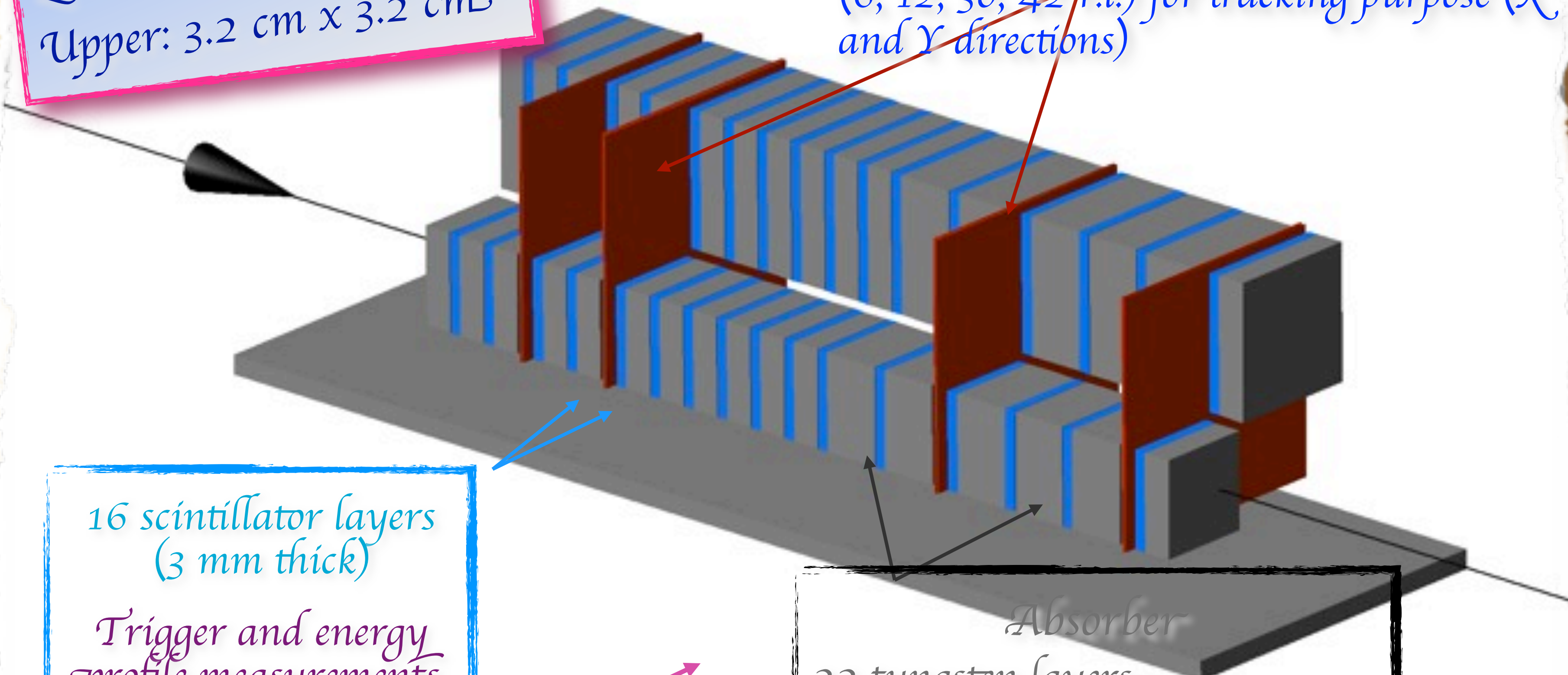
Lower: 2.5 cm x 2.5 cm

Upper: 3.2 cm x 3.2 cm

Impact point (η)

We used LHC style electronics and readout

4 pairs of silicon micro-strip layers (6, 12, 30, 42 r.l.) for tracking purpose (X and Y directions)



16 scintillator layers (3 mm thick)

Trigger and energy profile measurements

Energy

Absorber

22 tungsten layers
7mm – 14 mm thick (2-4 r.l.)
(W: X_0 = 3.5mm, R_M = 9mm)

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Double ARM Detectors

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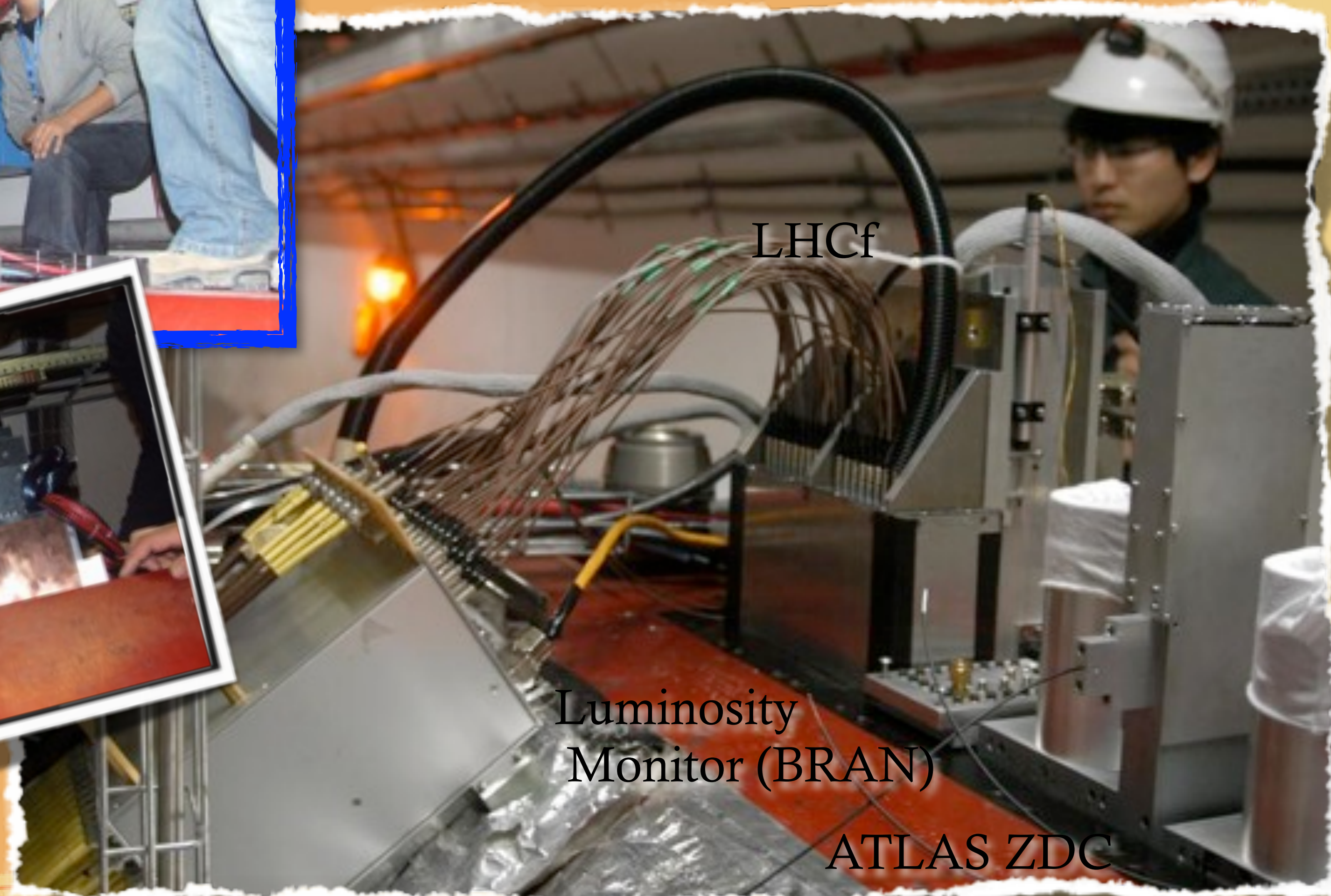
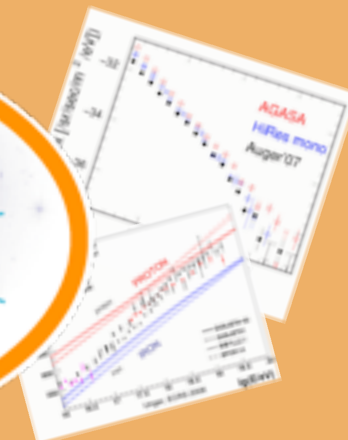
Detectors in place

Installation performed in two phases:

1. Pre-Installation (Jan/Apr 2007)
   Baking out of the beam pipe (200 °C)
2. Final Installation (Jan 2008)





Why LHCf?

Physics Motivations

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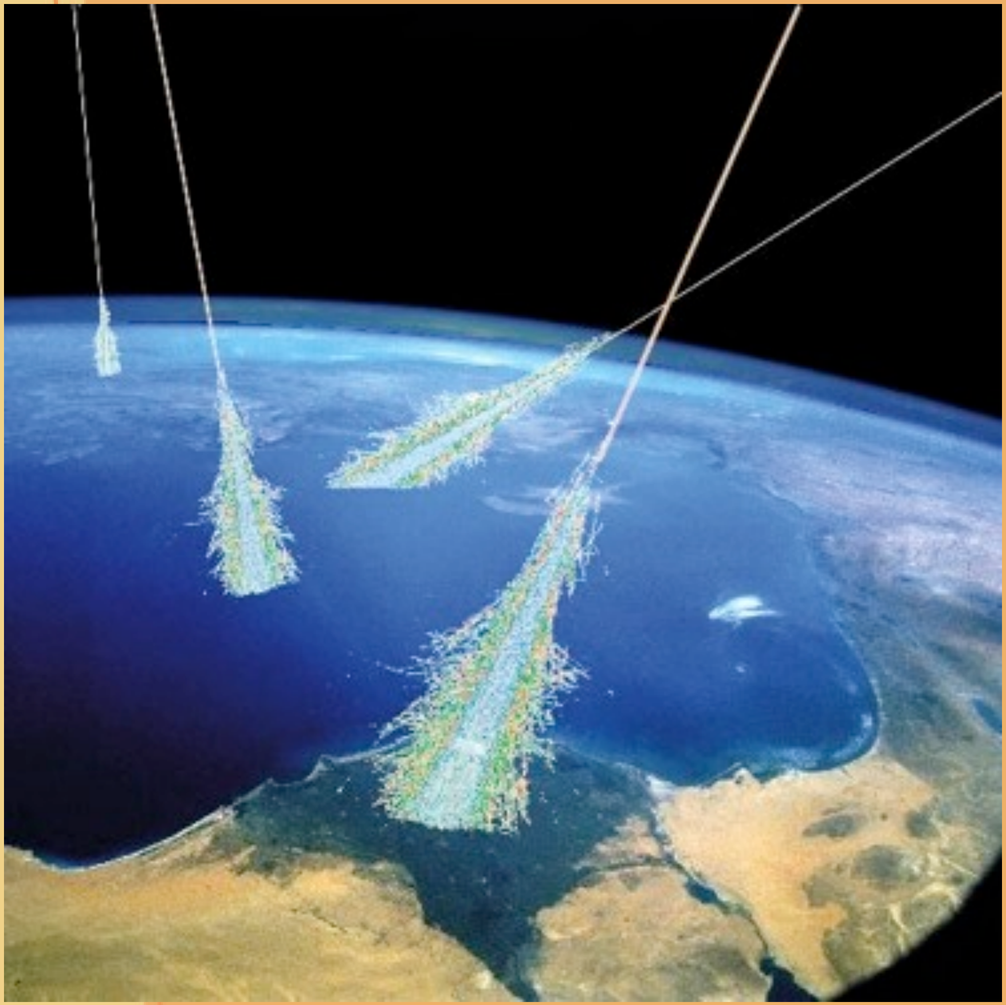
Ultra High Energy Cosmic Rays



Experimental observations: at E>100 TeV only EAS
(shower of secondary particles)
- lateral distribution
- longitudinal distribution
- particle type
- arrival direction

Astrophysical parameters:
(primary particles)
- spectrum
- composition
- source distribution
- origin and propagation

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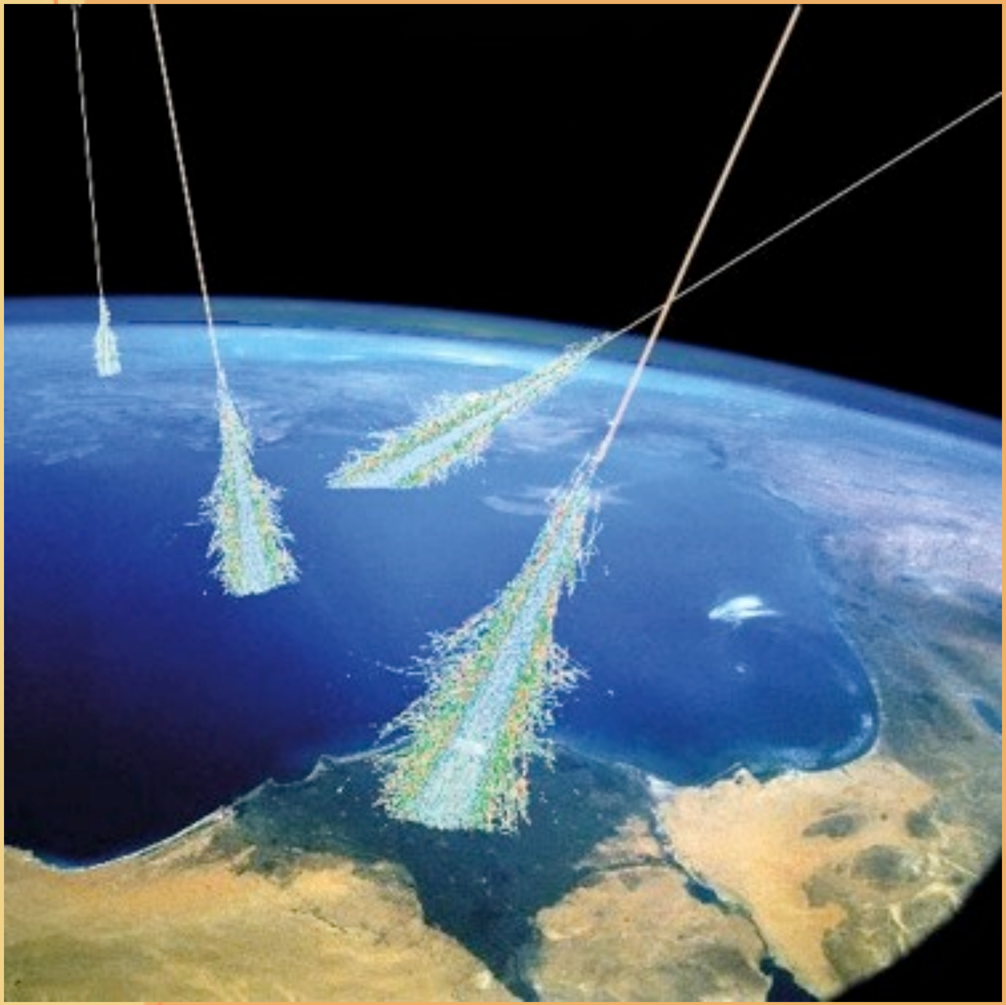
Ultra High Energy Cosmic Rays



Experimental observations: at E>100 TeV only EAS
(shower of secondary particles)
- lateral distribution
- longitudinal distribution
- particle type
- arrival direction

Air shower development
(particle interaction in the atmosphere)

Astrophysical parameters:
(primary particles)
- spectrum
- composition
- source distribution
- origin and propagation

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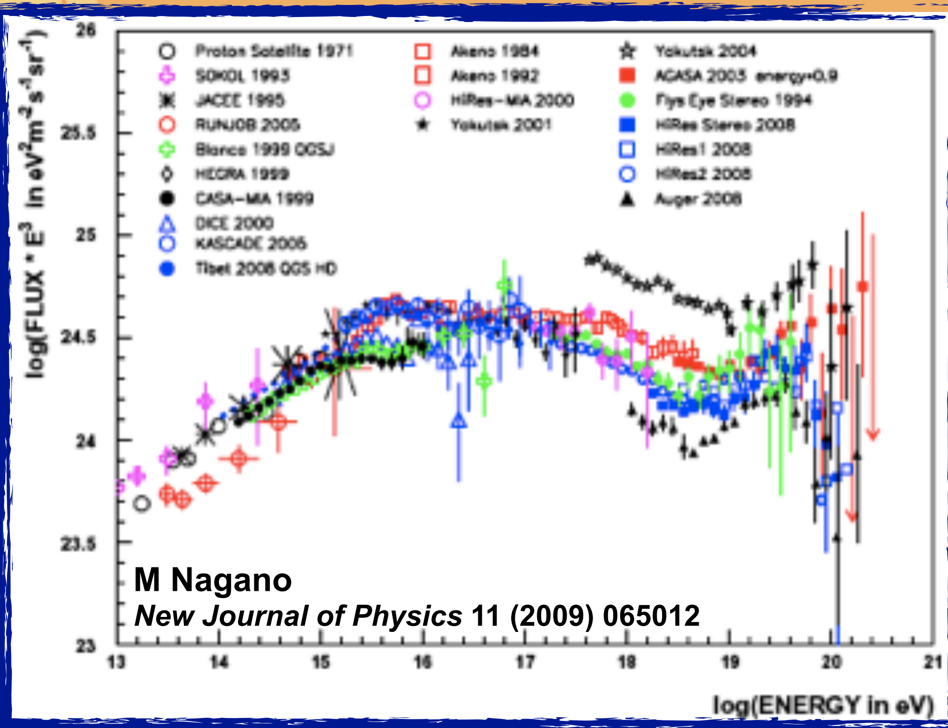
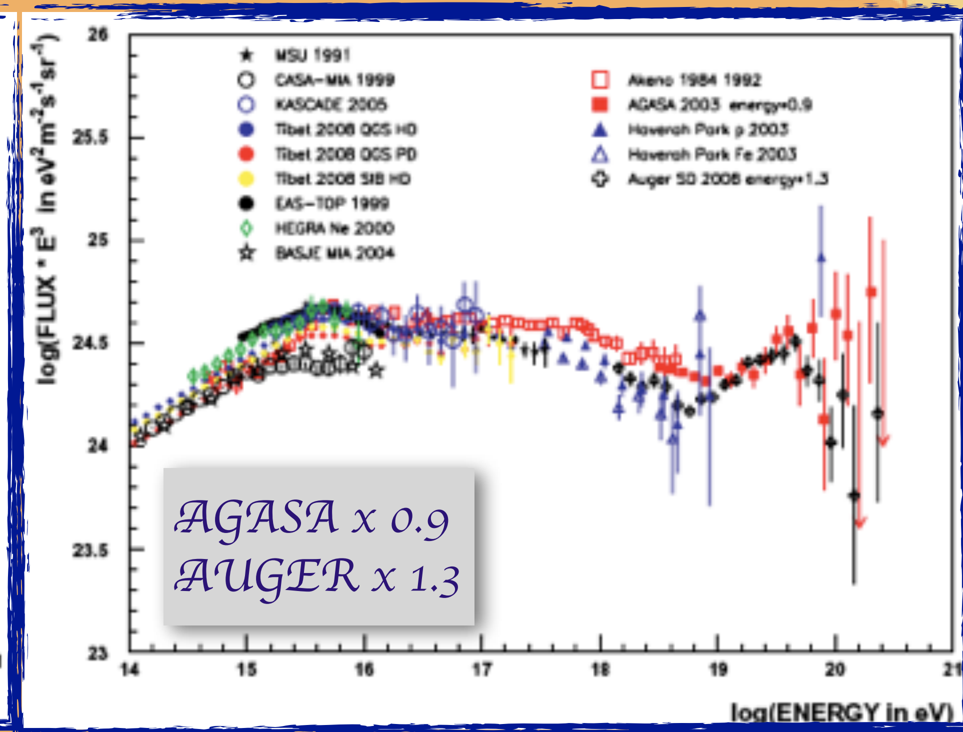
Cosmic Ray Energy Spectra





Difference in the energy scale between different experiments???

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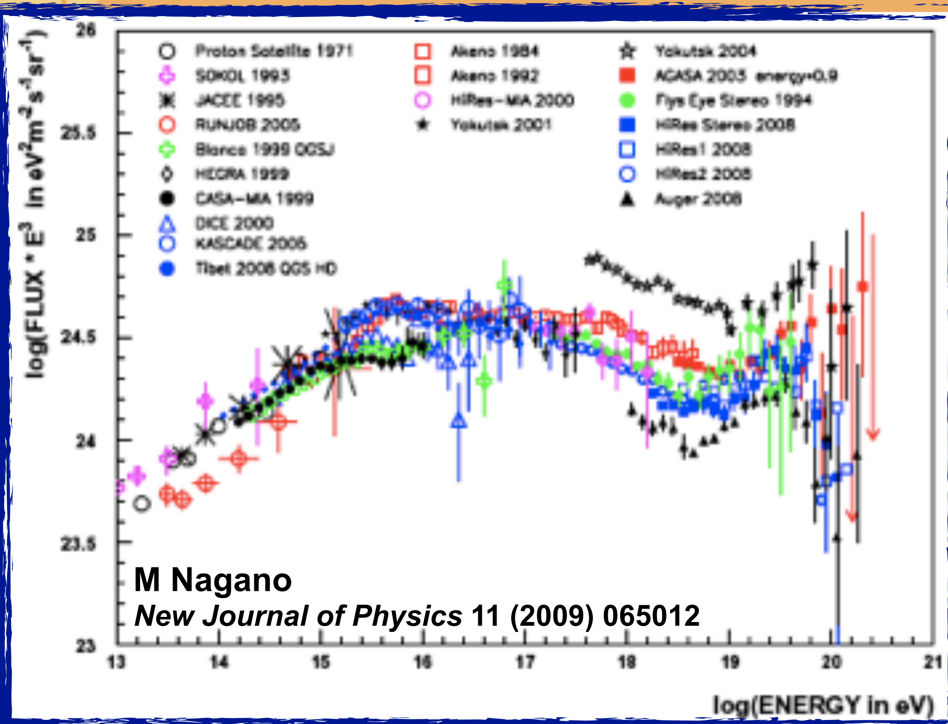
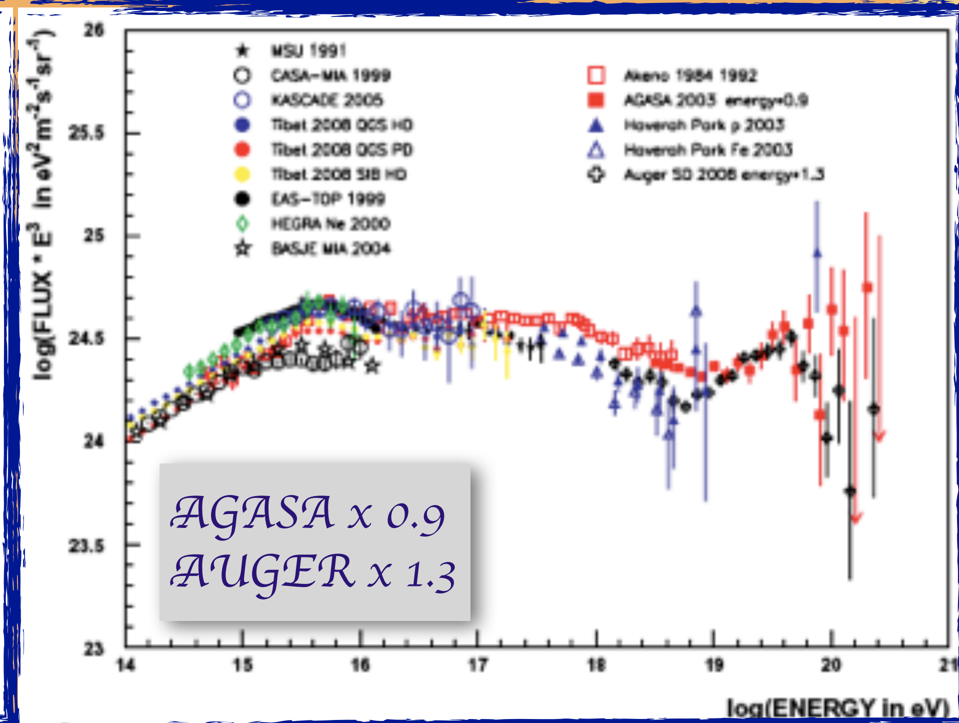
Cosmic Ray Energy Spectra





AGASA Systematics
Total ±18%
Hadron interaction
(QGSJET, SIBYLL) ~10%
(Takeda et al., 2003)

Difference in the energy scale between different experiments???

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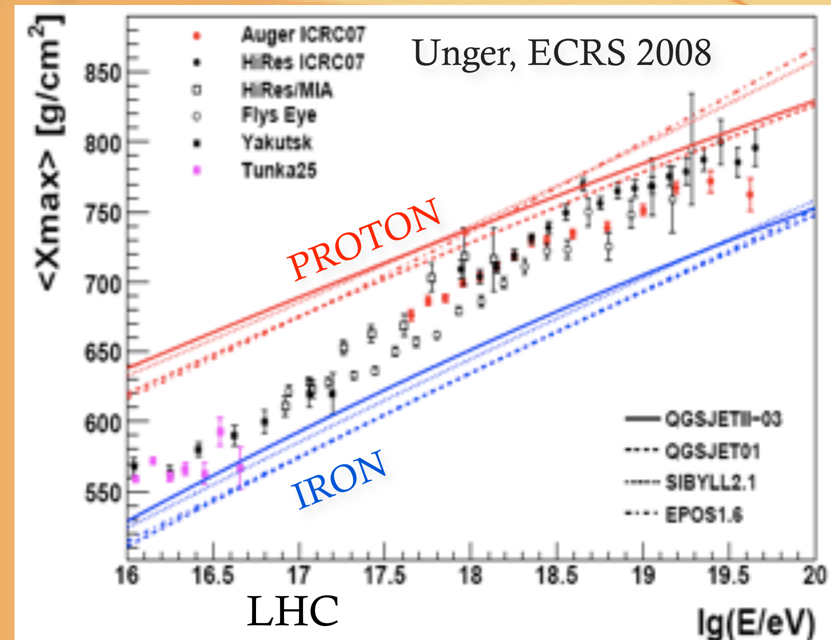
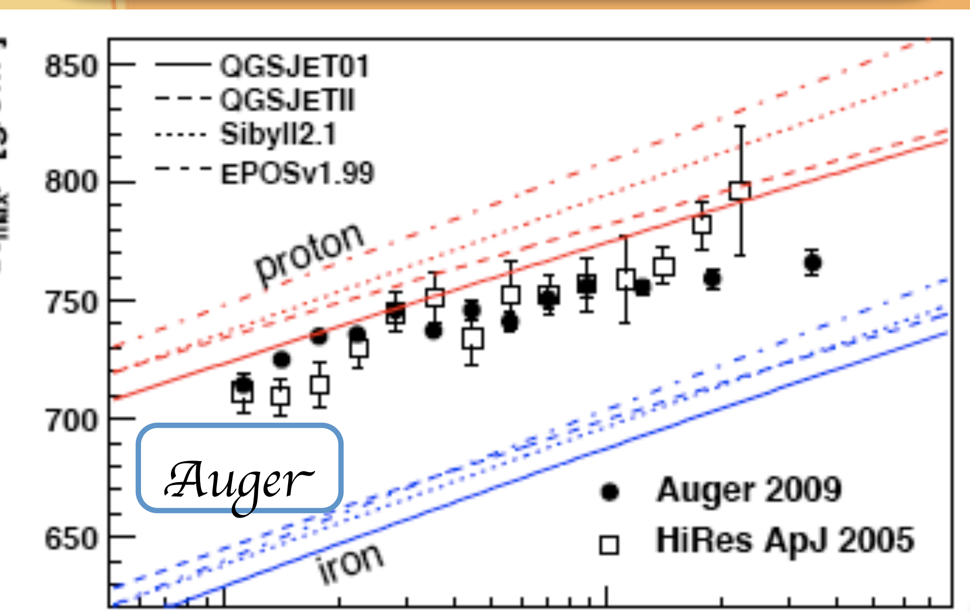
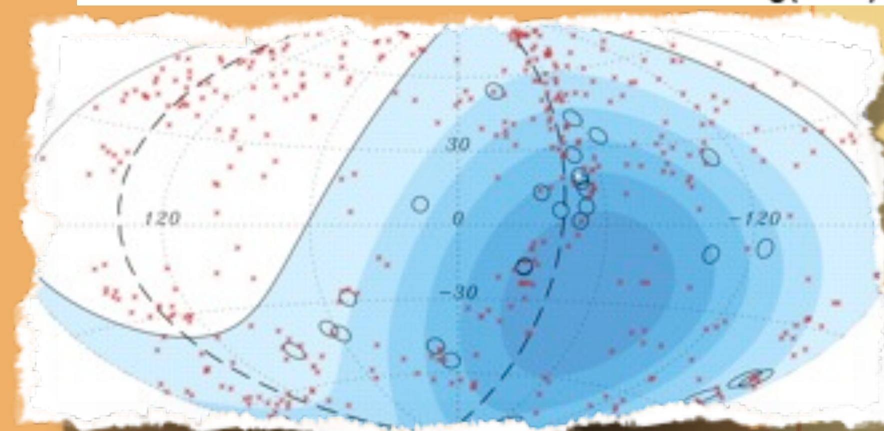
HECR composition

The depth of the maximum of the shower X_{max} in the atmosphere depends on energy and type of the primary particle

Different hadronic interaction models give different answers about the composition of HECR .







X_{max} measurements favours heavier composition as the energy increases

Anisotropy would favour proton primaries (AGN correlation still valid?)

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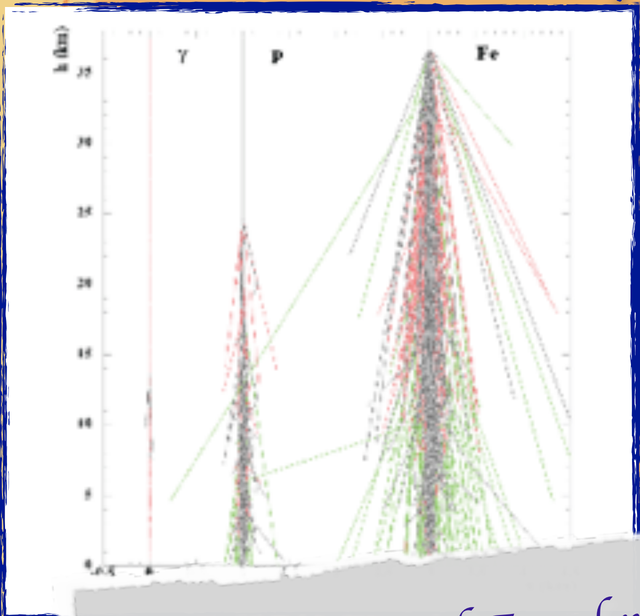
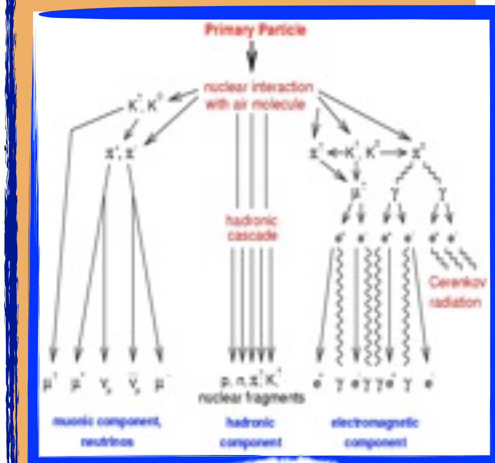
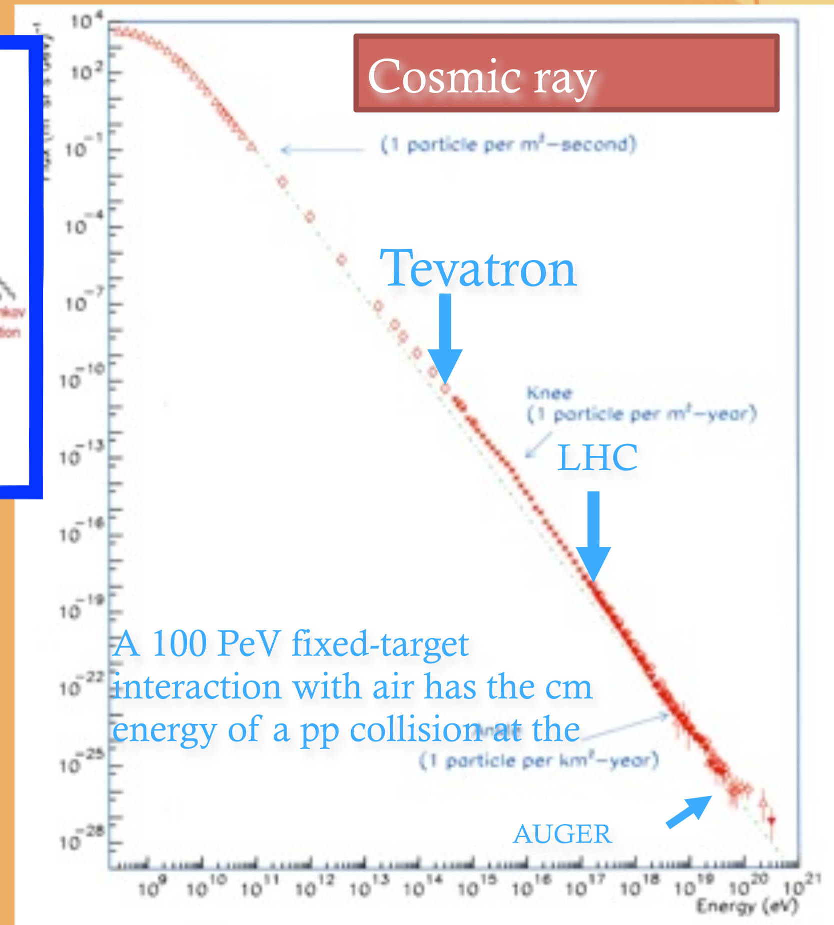
Development of atmospheric showers







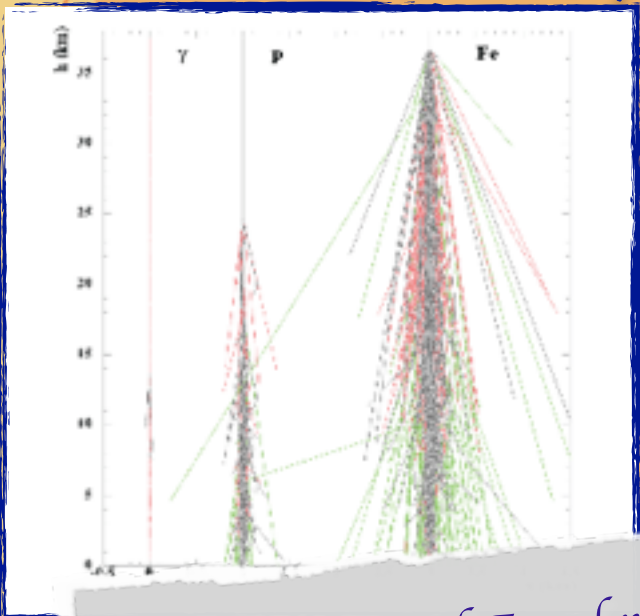
Determination of E and mass of CRs depends on description of primary UHE QCD (p+N,O-Fe+N,O) interaction

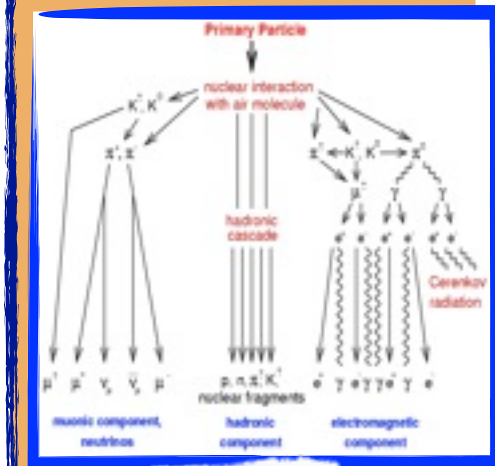
Hadronic MC's need tuning with data

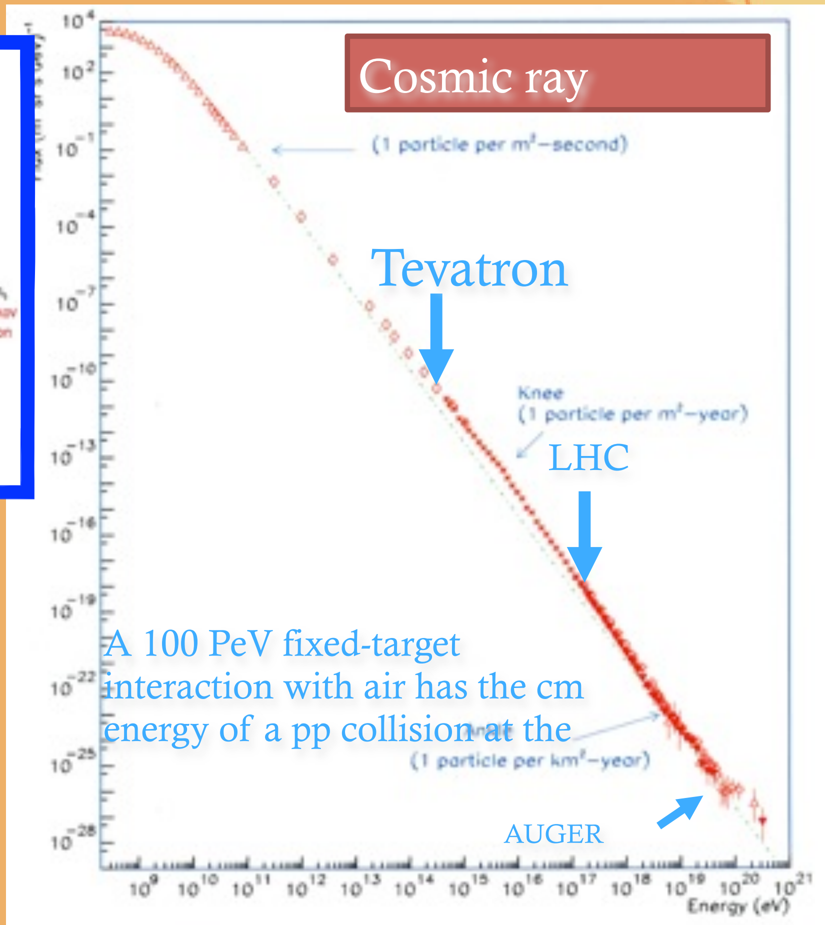
The dominant contribution to the energy flux is in the very forward region ($\theta \approx 0$)

In this forward region the highest energy available measurements of π^0 cross section done by UA7 ($E=10^{14}$ eV, $y= 5\div7$)

Development of atmospheric showers







A 100 PeV fixed-target interaction with air has the cm energy of a pp collision at the

Determination of E and mass of CRs depends on description of primary UHE QCD (p+N,O-Fe+N,O) interaction

Hadronic MC's need tuning with data

The dominant contribution to the energy flux is in the very forward region ($\theta \approx 0$)

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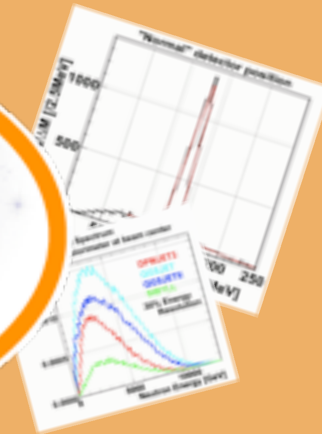
LHCf: use LHC
$\sqrt{s} = 14$ TeV $\Rightarrow E_{lab}=10^{17}$ eV
to calibrate MCs



How LHCf can calibrate MC?

Physics Performance

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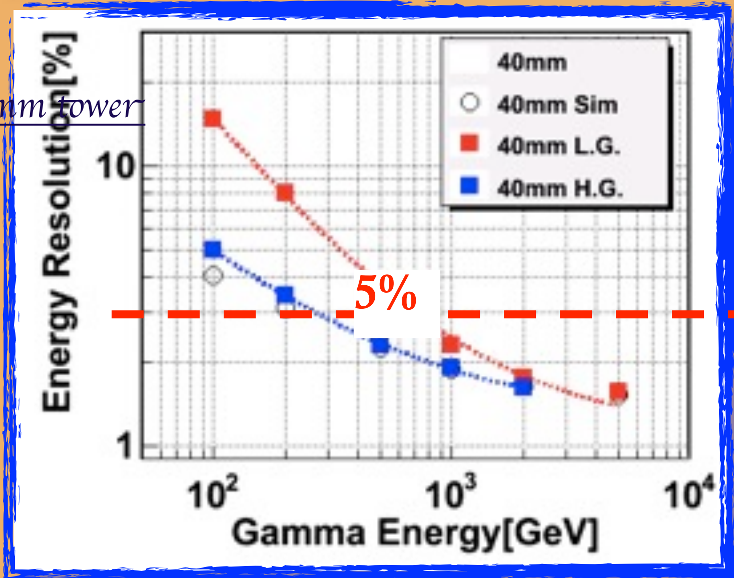
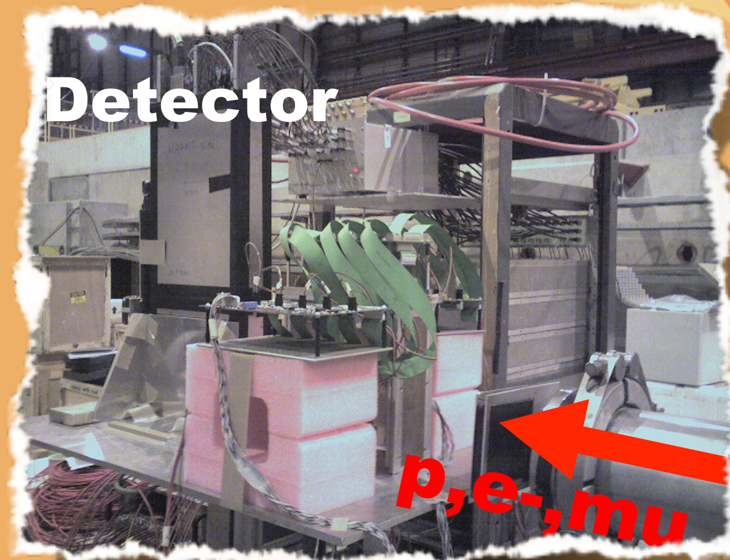
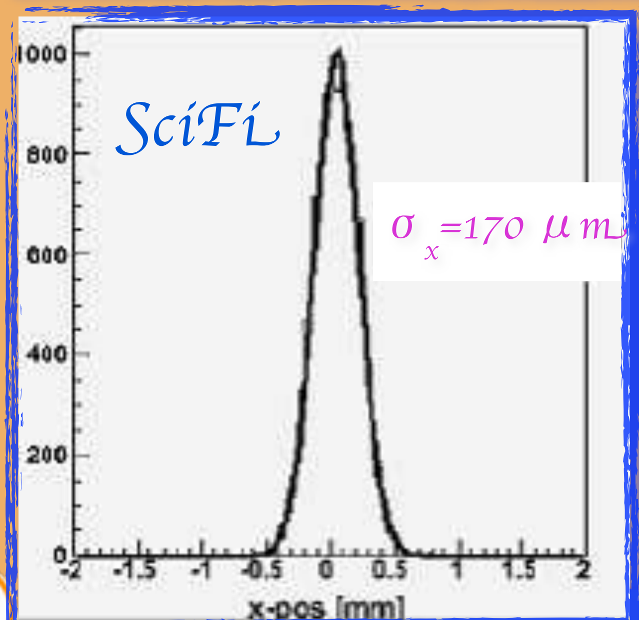
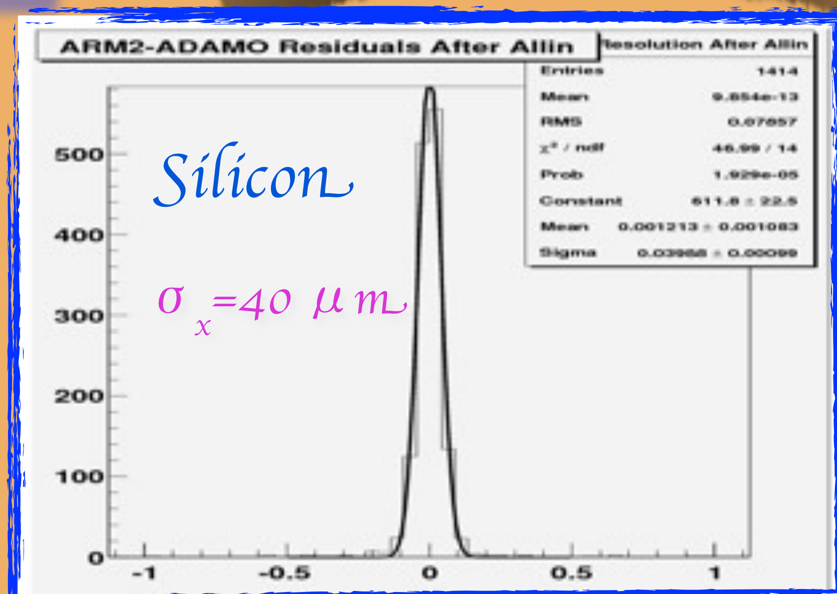
Physics Performances: Energy and position resolution

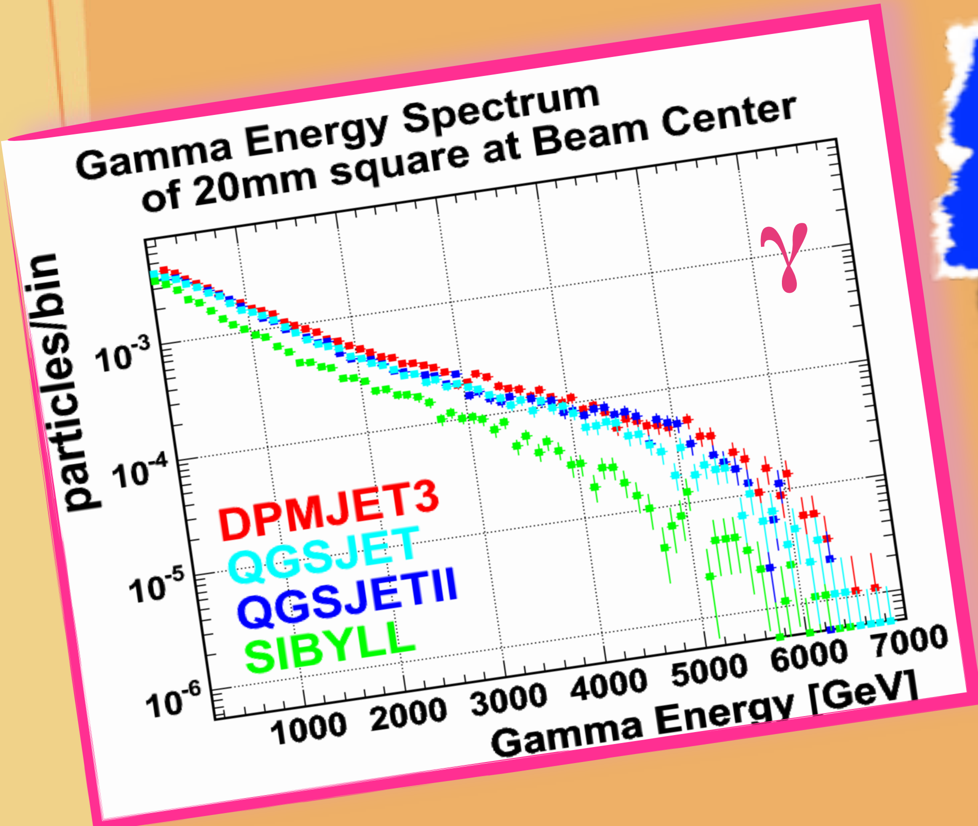




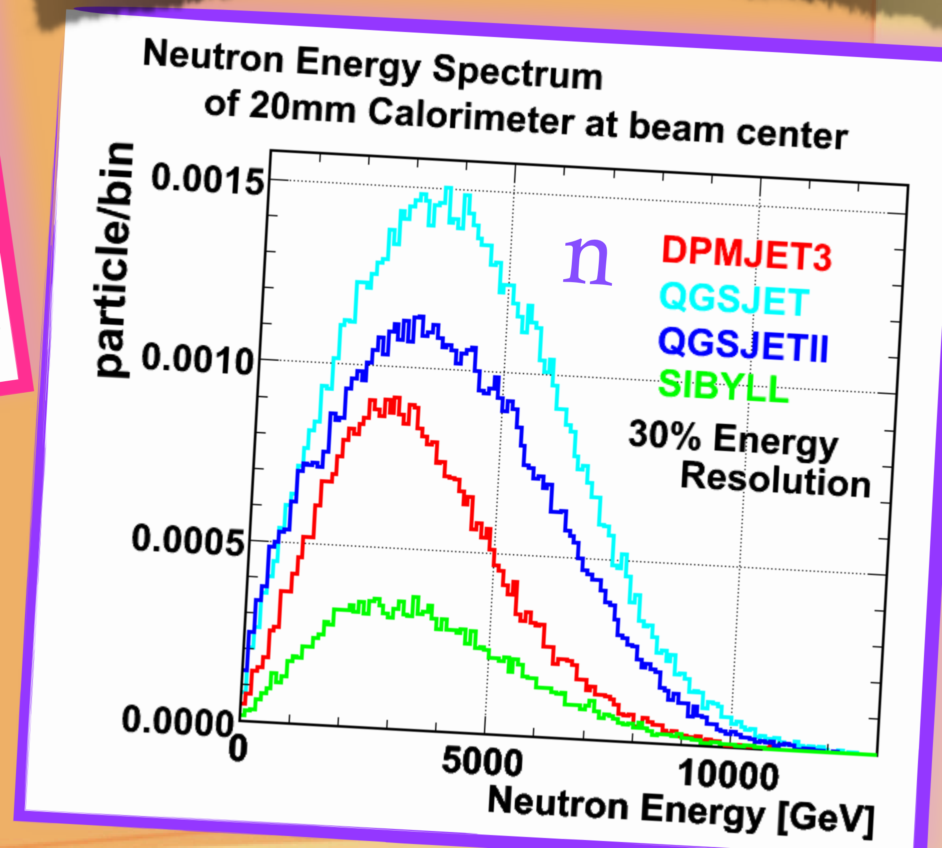




LHCf : Monte Carlo discrimination @ 14 TeV



10^6 collisions
↔ 2min. exposure @ $10^{29}cm^{-2}s^{-1}$



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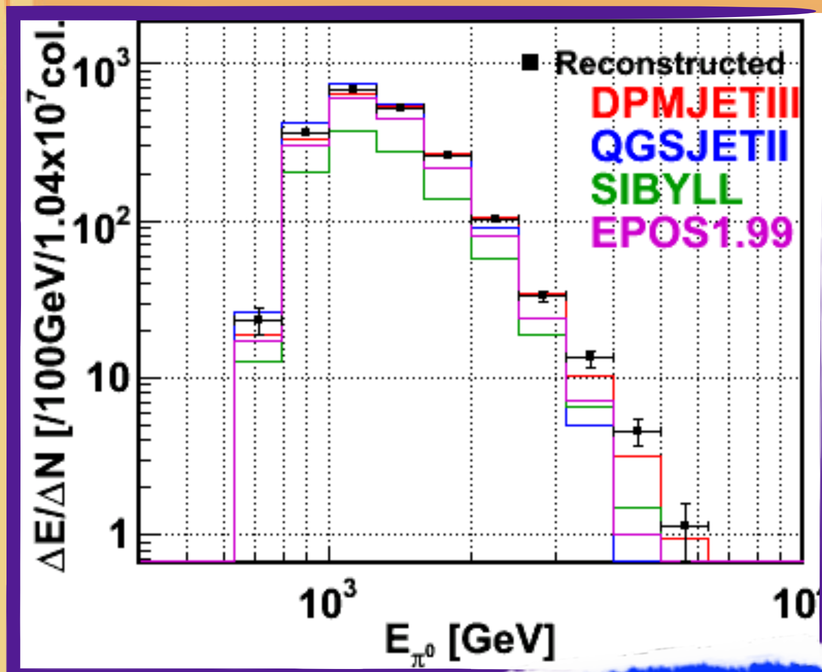
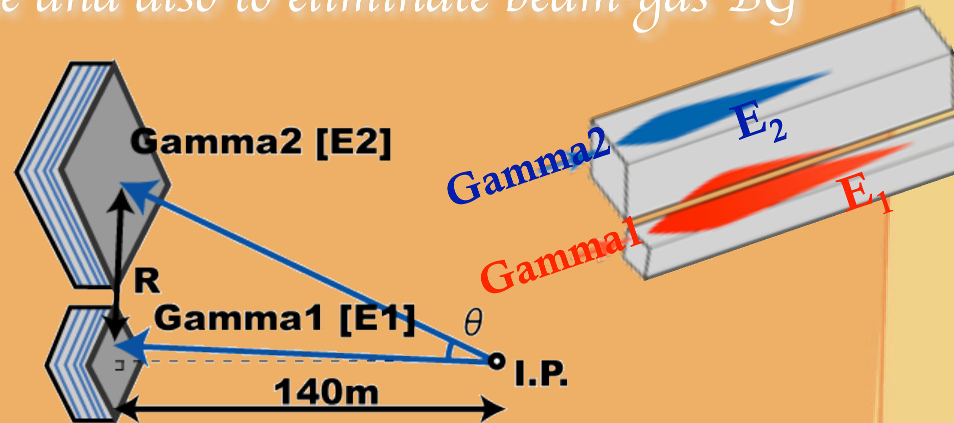
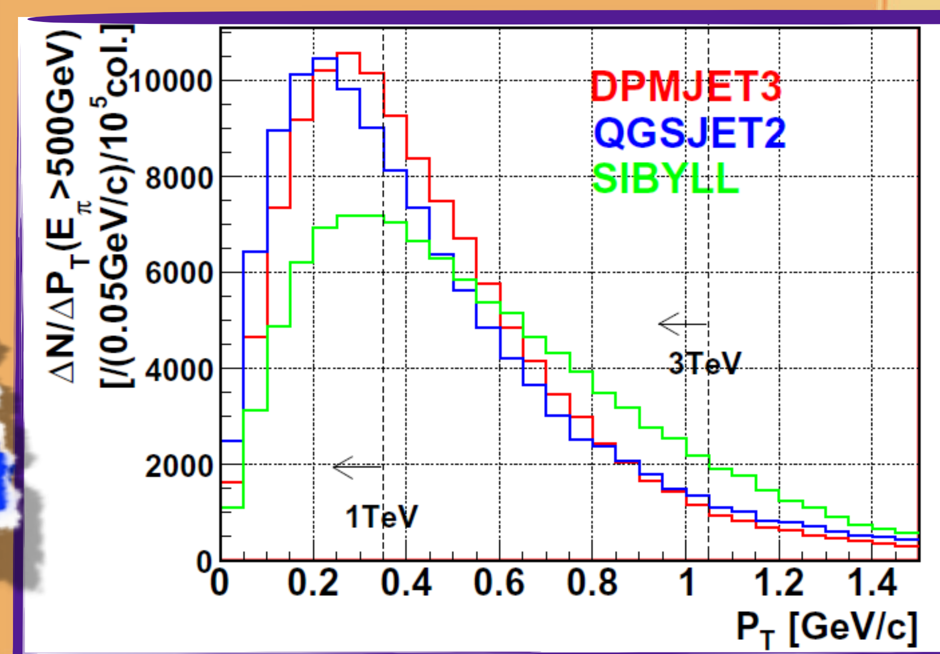
Monte Carlo discrimination @ 14 TeV

π^0 produced at collision can be extracted by using gamma pair events
Powerful tool to calibrate the energy scale and also to eliminate beam-gas BG







10^7 collisions
↔ 20min. exposure @ $10^{29} cm^{-2} s^{-1}$

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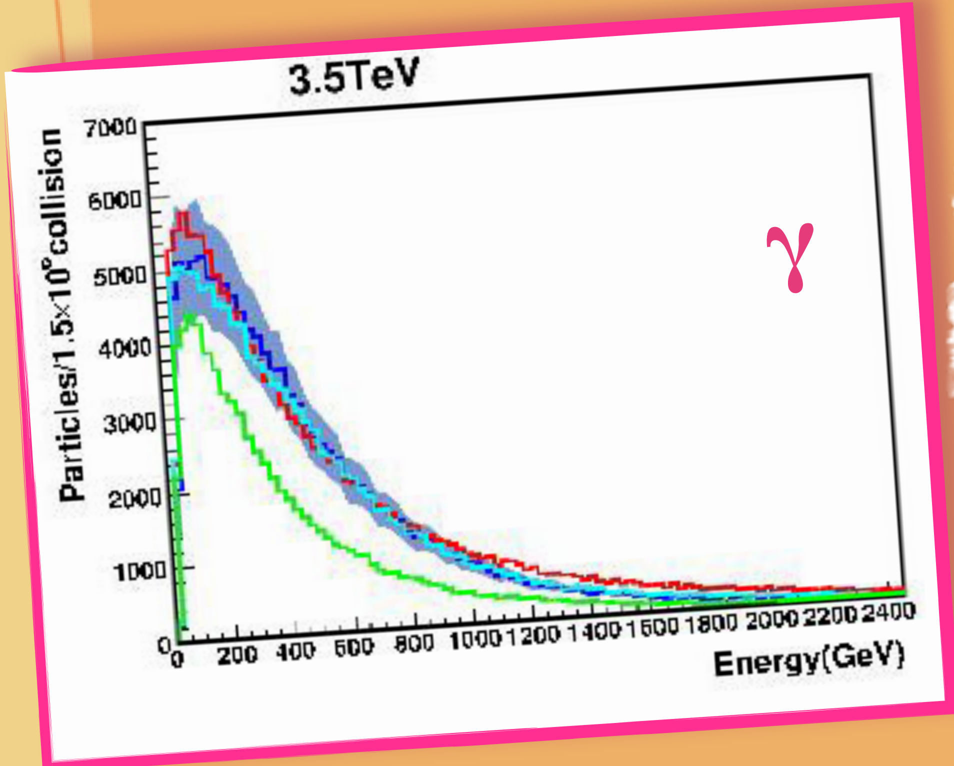
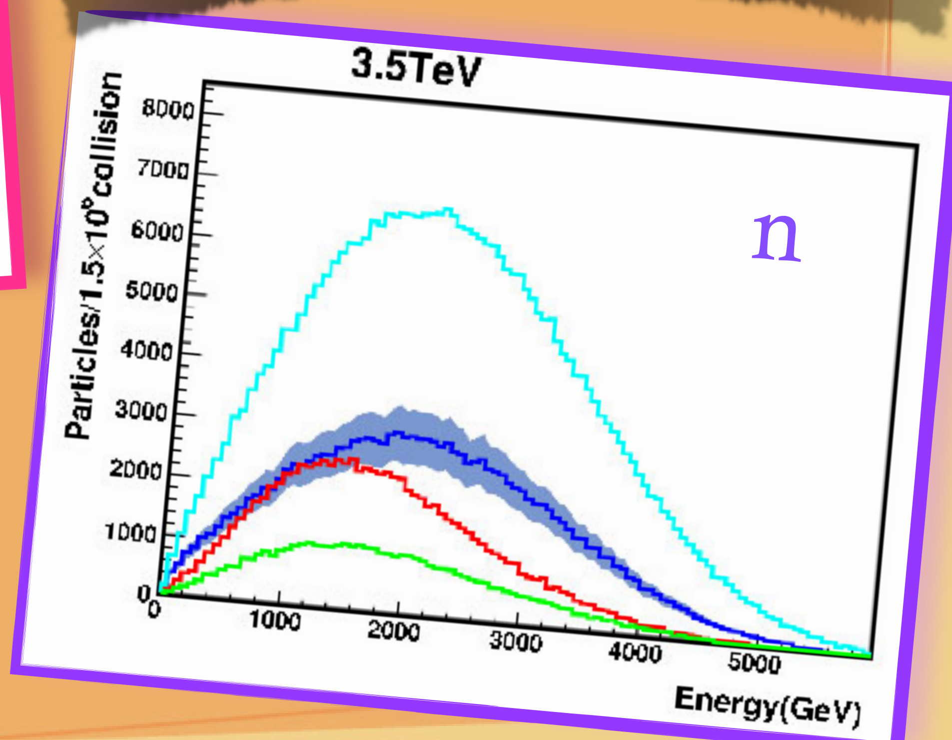
LHCf : Monte Carlo discrimination @ 7 TeV



p-p collisions
3.5 TeV+3.5 TeV

DPMJET3
QGSJET2
QGSJET1
SIBYLL



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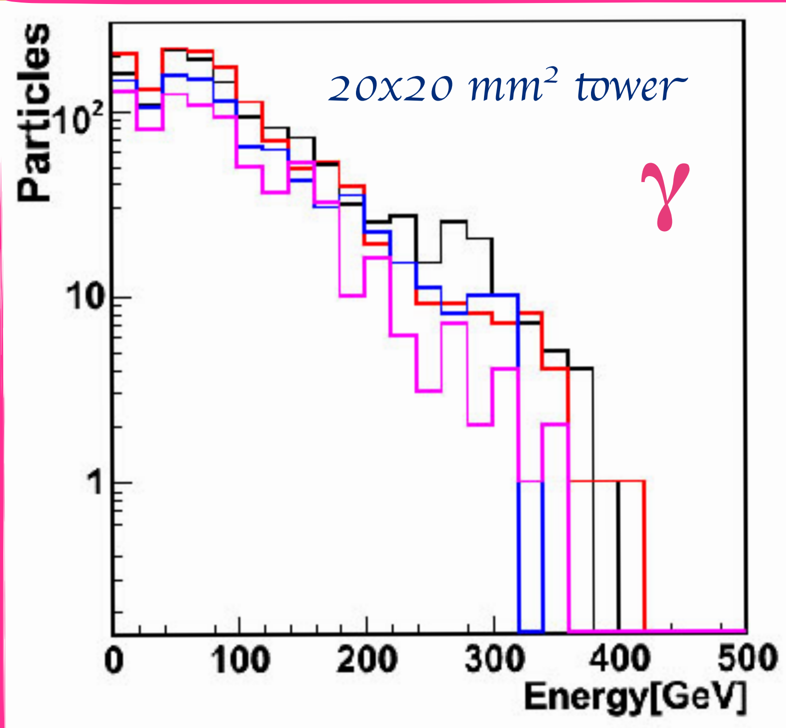
LHCf : Monte Carlo discrimination @ 900 GeV



10^7 collisions p-p collisions

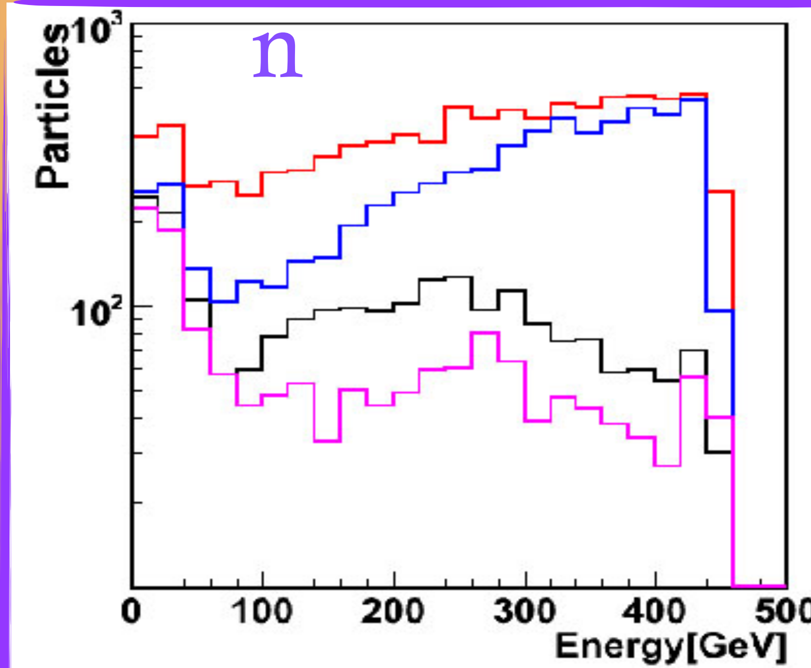
450 GeV+450 GeV

DPMJET3

QGSJET2

QGSJET1

SYBILL



Energy resolution is not taken account

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LHCf Data

Data taking & Analysis

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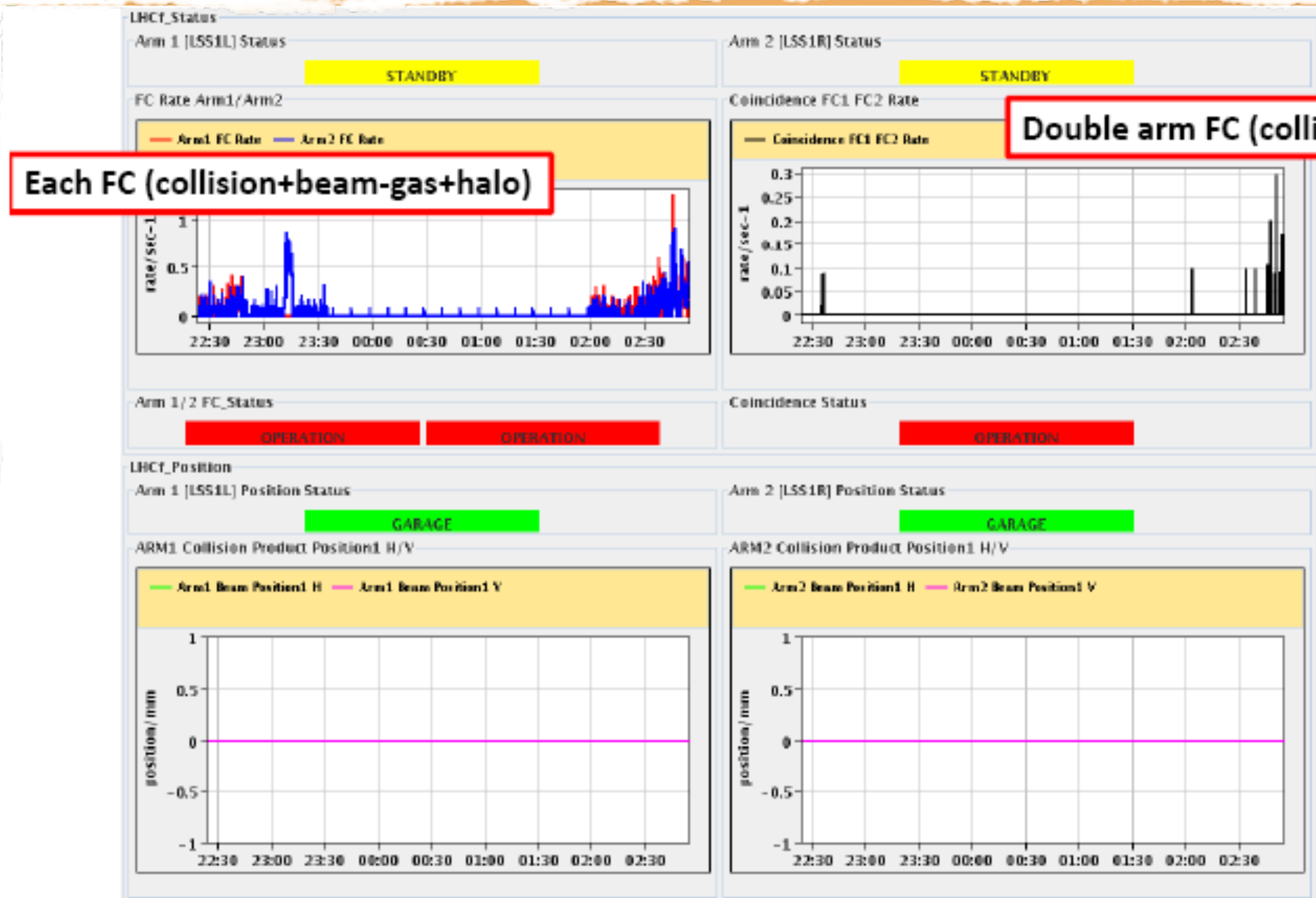
LHCf Control Room

The LHCf control room has been prepared and fully equipped in the Atlas area

Not really suited for media events but...

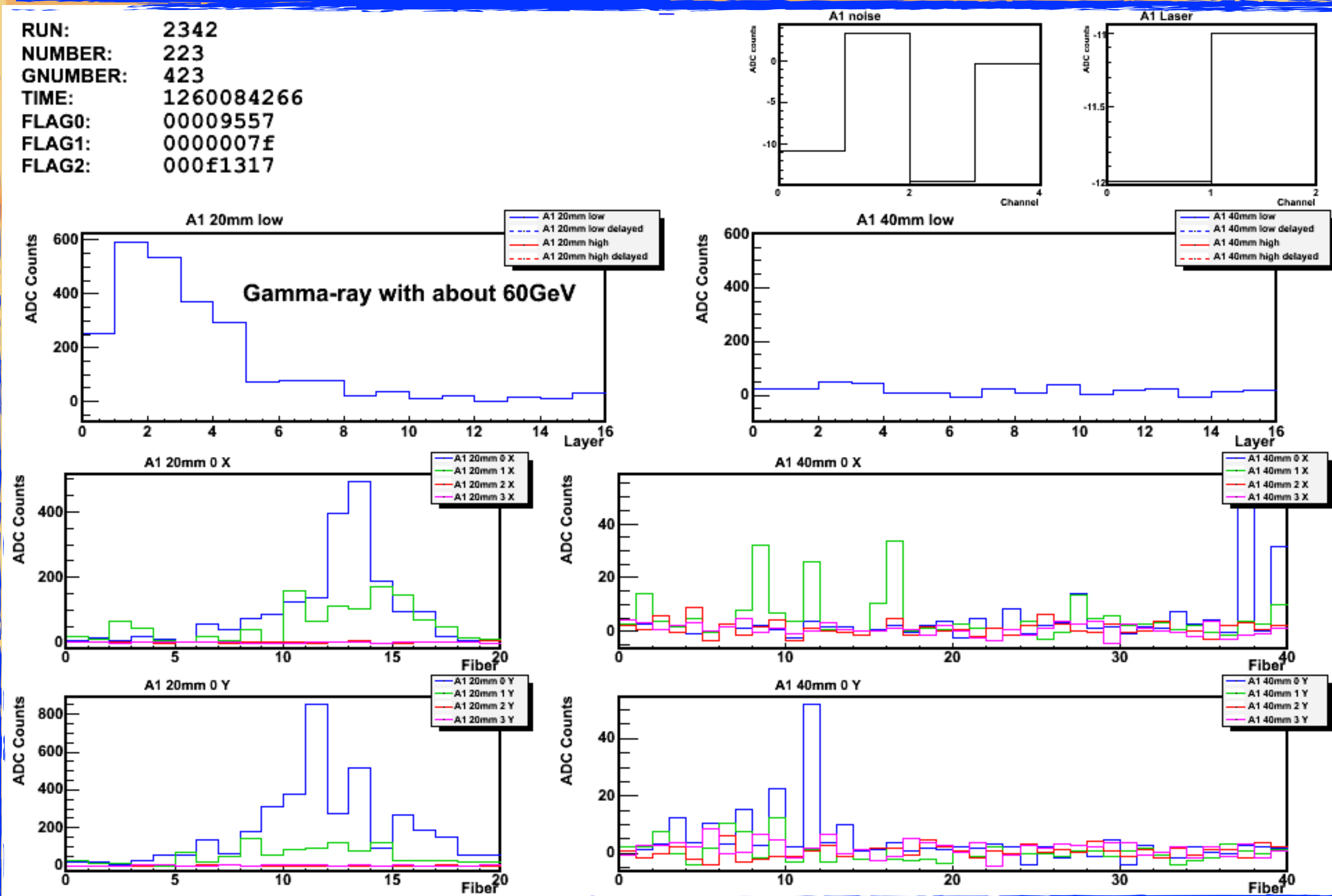
LHCf page on VISTAR



900 GeV Data Taking & Analysis

- Extremely useful period to test all the system
  - Detectors runned smoothly
- Only 6000 shower events on disk ($\approx$ 9.28 μb^{-1})
  - Neutral particle flux in LHCf region scale as E^2 (reduction factor $\approx 2.10^3$)
  - No π^0 reconstructed in LHCf ($E_{cm}^{thr} \approx 2$ TeV)
  - Luminosity 10^{26} $cm^{-2}s^{-1}$
- Big effort to understand the LHC beam (DIP signals)
  - Intensity bunch by bunch
  - Not colliding bunches vs colliding bunches to estimate Beam Gas rate
  - Timing of the bunches
- Quite few problems found during the analysis
  - Timing problems in Atlas (BPTX not synchronised)
  - Displaced bunches
  - Missing DIP information

ARM1 γ event @ 900 GeV



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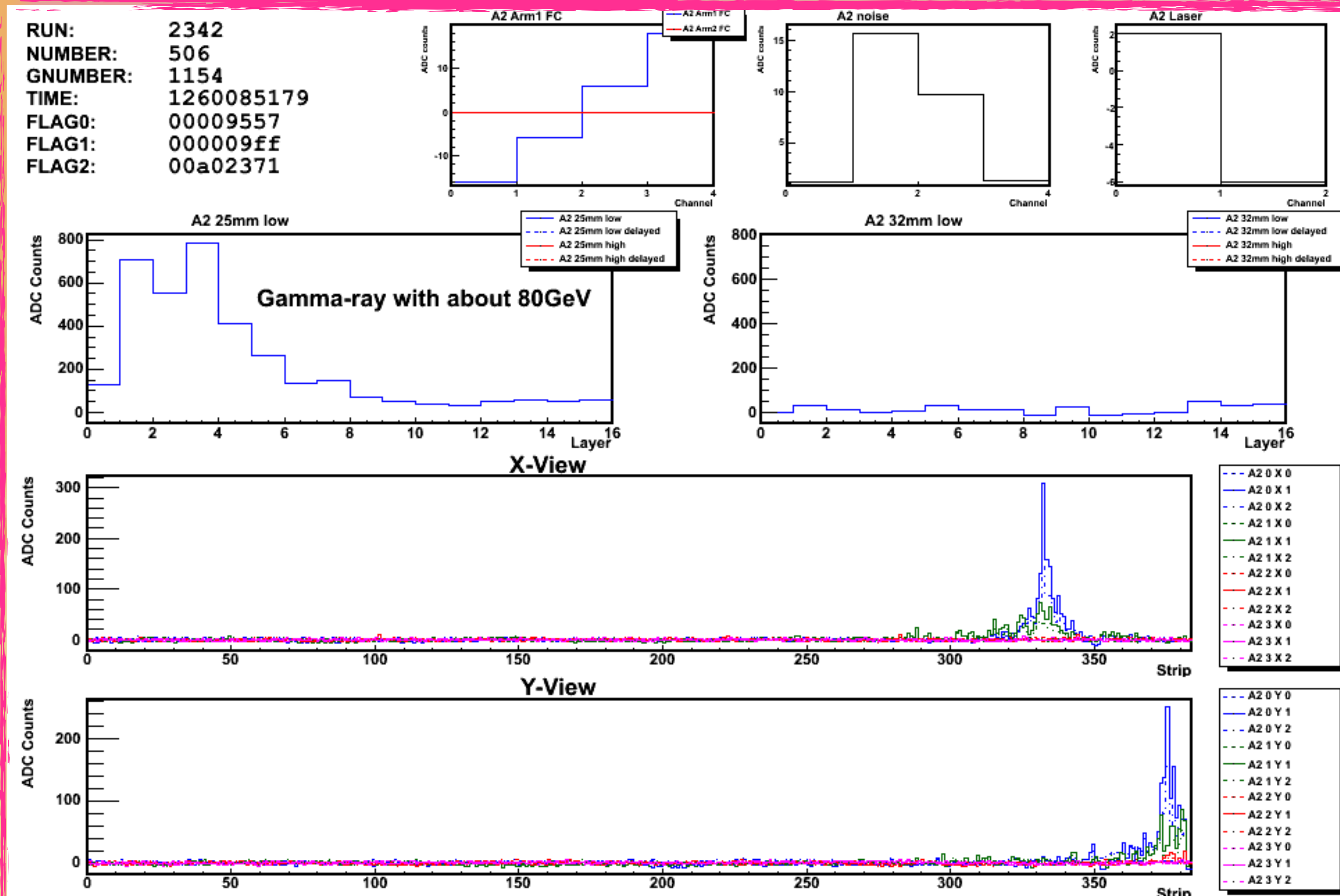
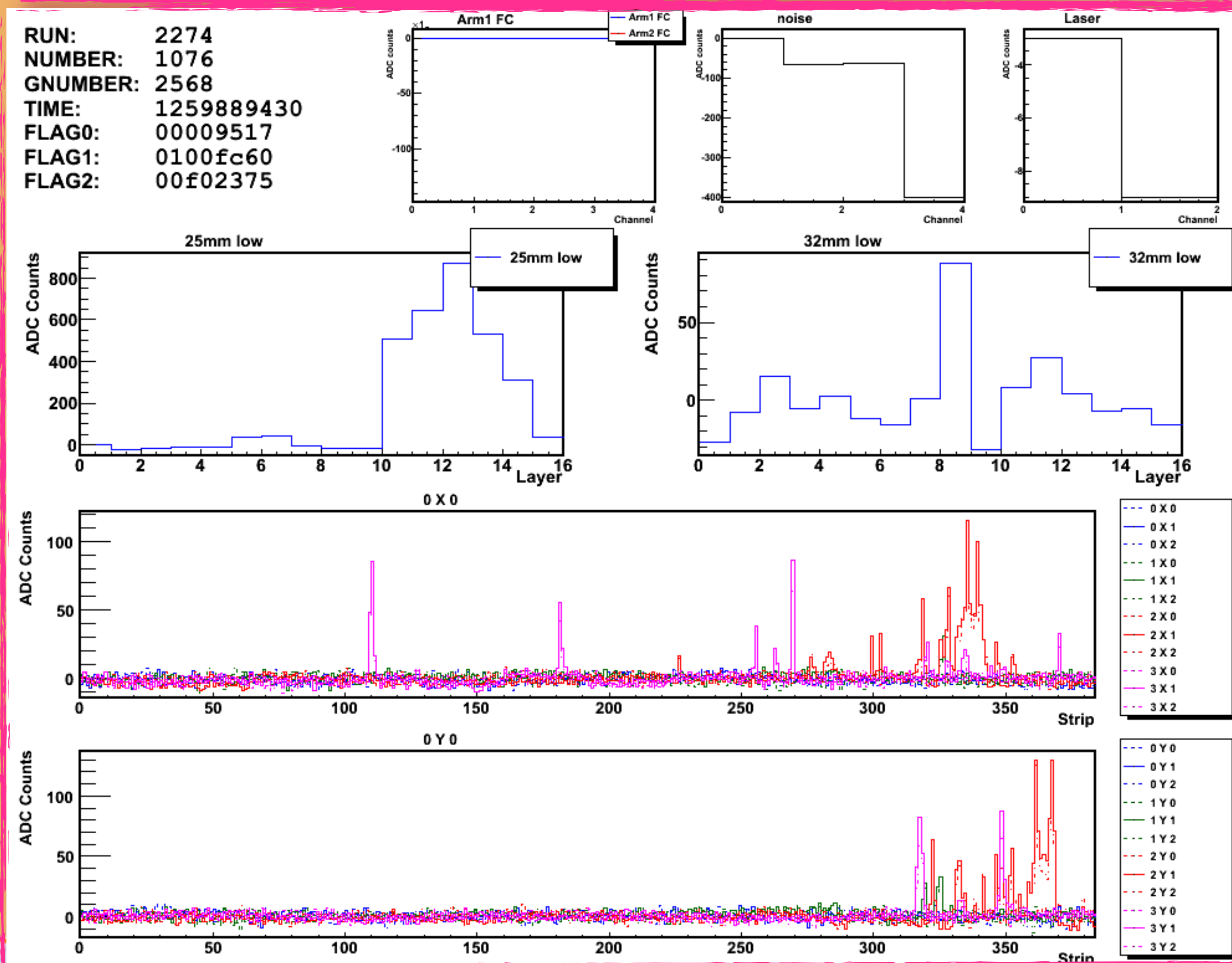
ARM2 γ event @ 900 GeV



ARM2 neutron event @ 900 GeV



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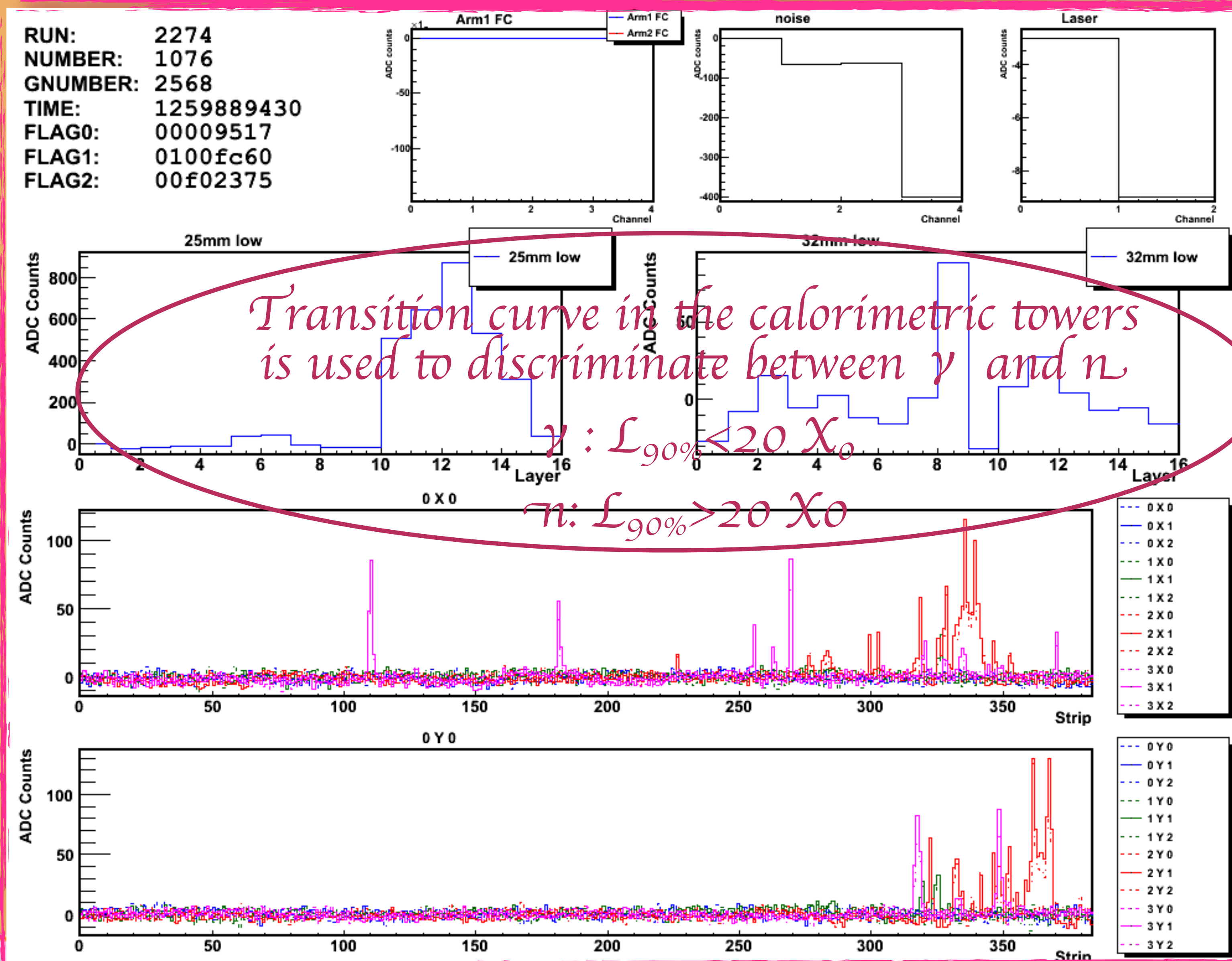
ARM2 neutron event @ 900 GeV



Transition curve in the calorimetric towers is used to discriminate between γ and n

γ : $L_{90\%} < 20\ X_0$

n: $L_{90\%} > 20\ X_0$

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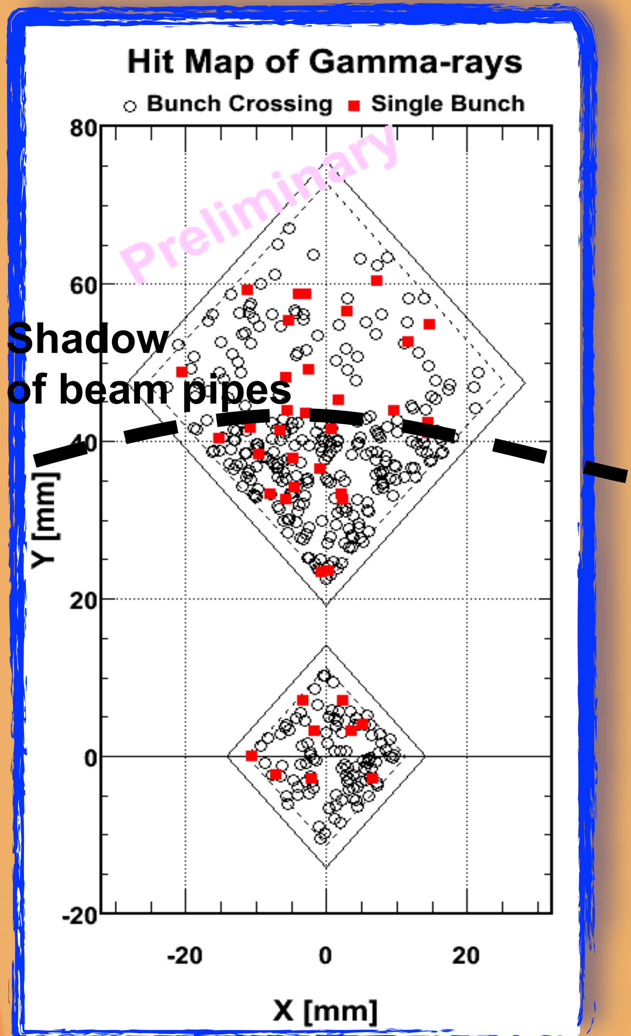
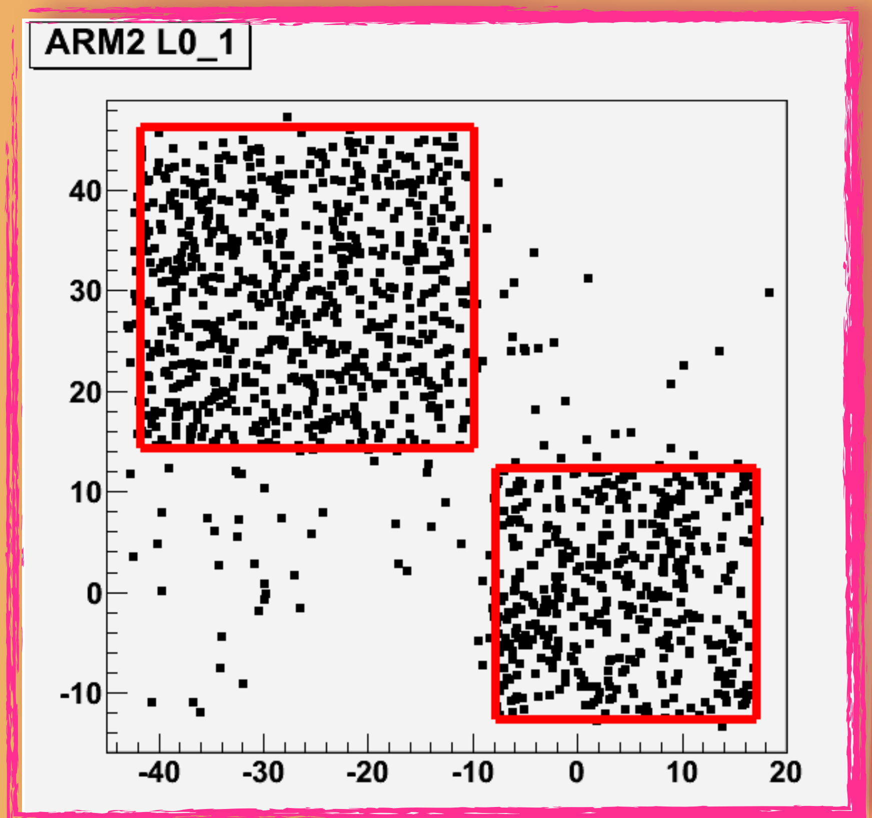
900 GeV Hit Map on ARM1 & ARM2





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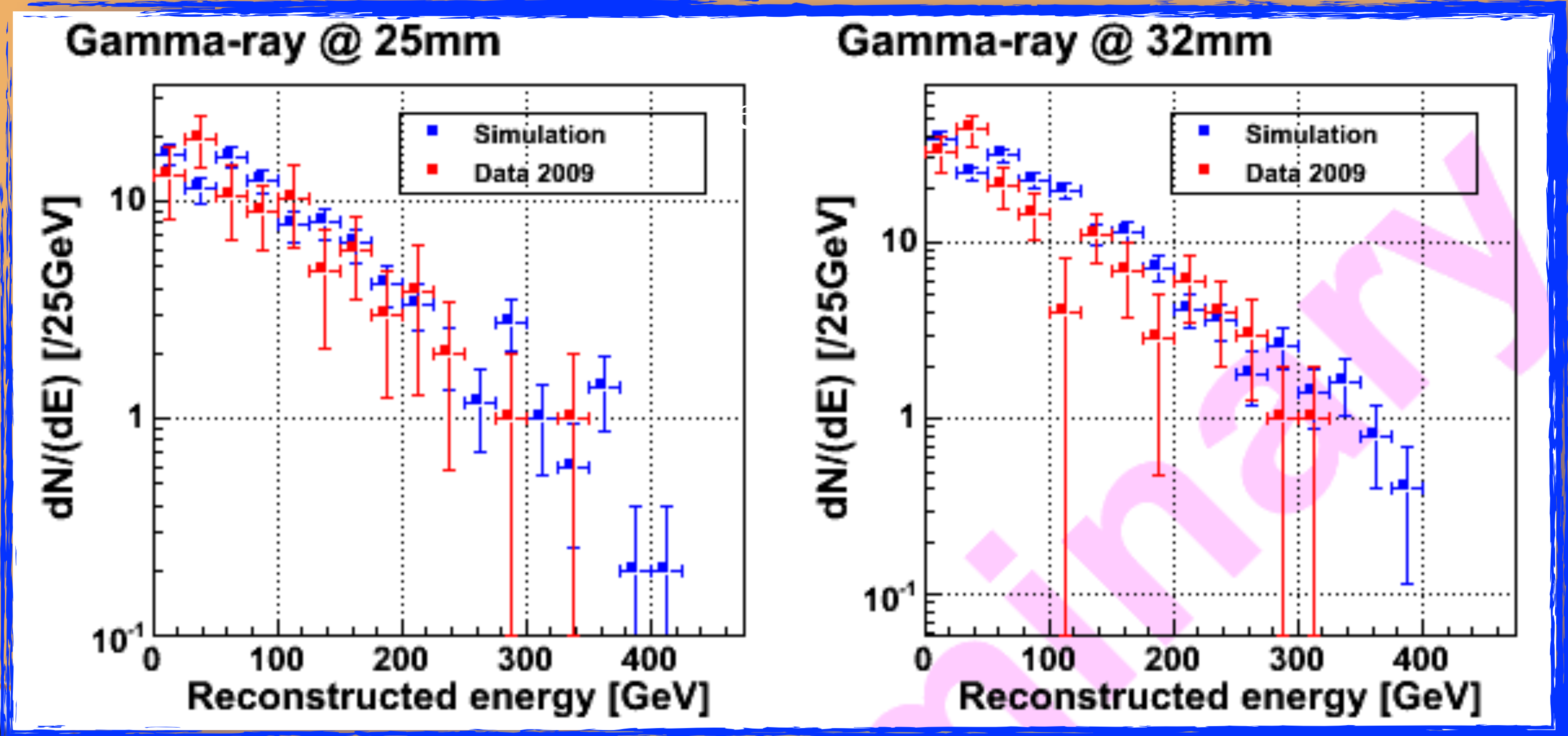
Preliminary 900 GeV results: ARM2 γ spectra

- Energy cut:
  - Integral energy deposit in one tower > 400 MIPS (10 GeV γ energy deposit)
- Fiducial volume cut for γ:
  - 2 mm inside from the tower edges.
- PID Cut:
  - Gamma-rays: L90 < 20 r.l.
  - Hadrons: L90 > 20 r.l

Very simple selection



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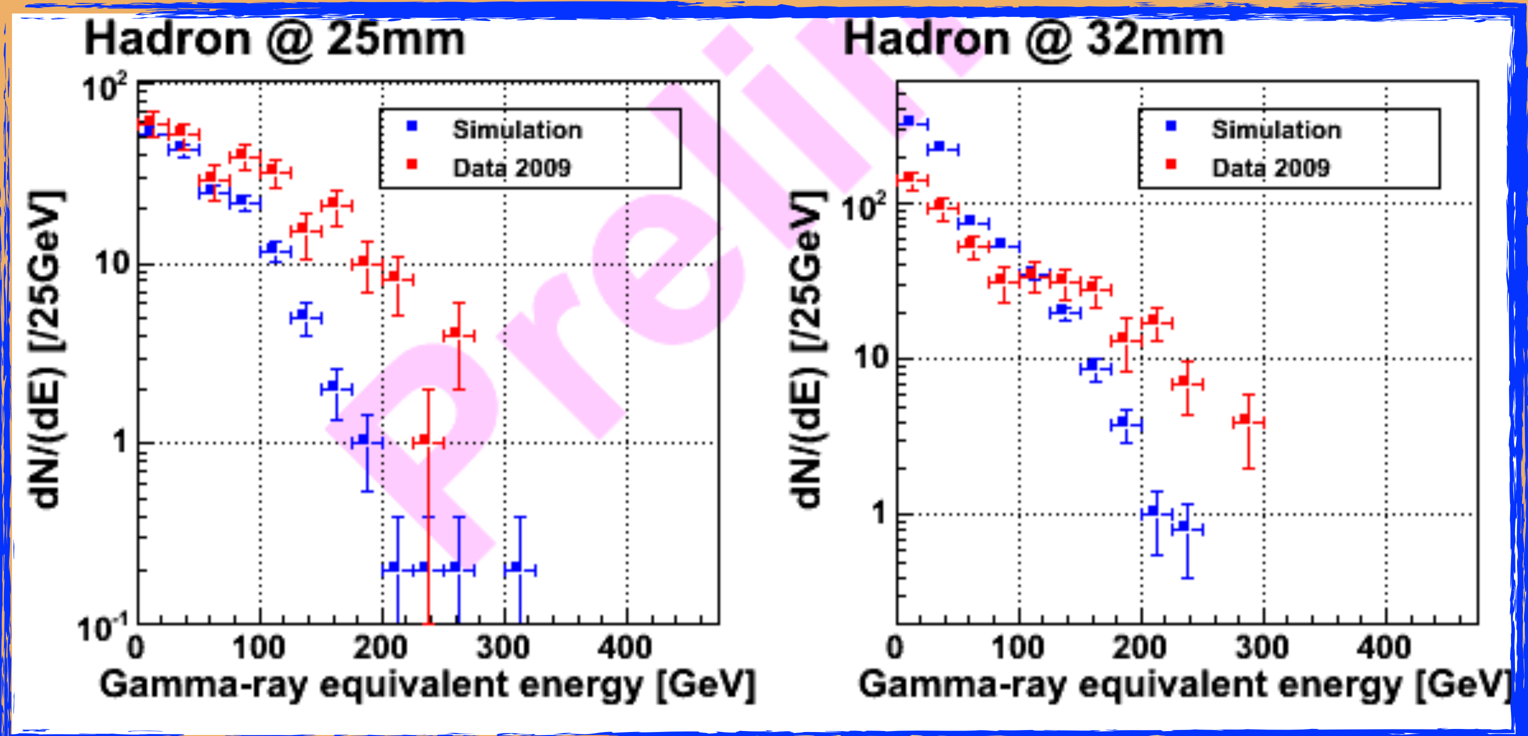

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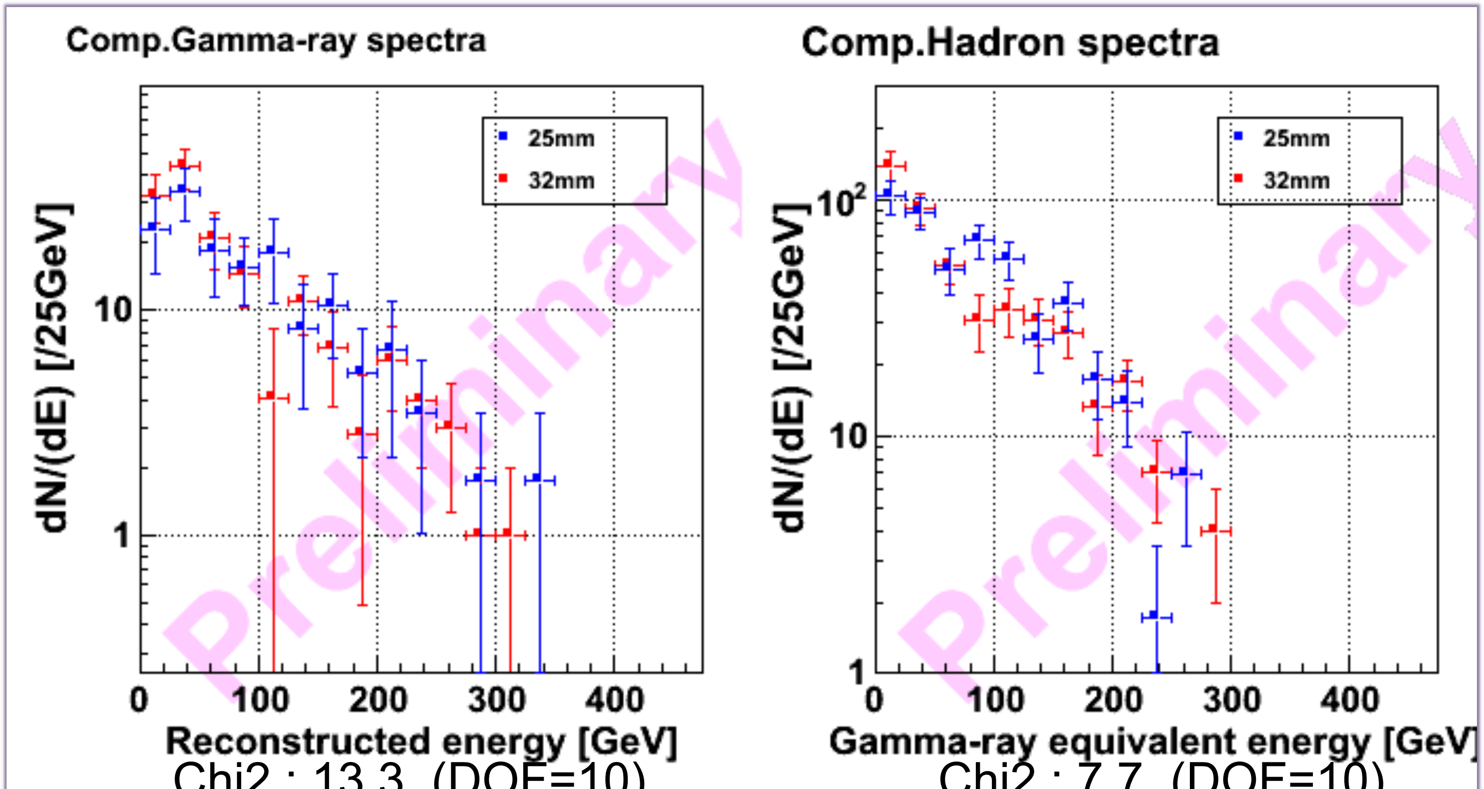
ARM2 900 GeV Results: two tower results



The spectra of 32 mm are normalised by the relative acceptance (factor 1.77)
No significant difference between 25mm and 32mm spectra.
It is consistent with the expectation by simulation:
Flat distributions at 900 GeV

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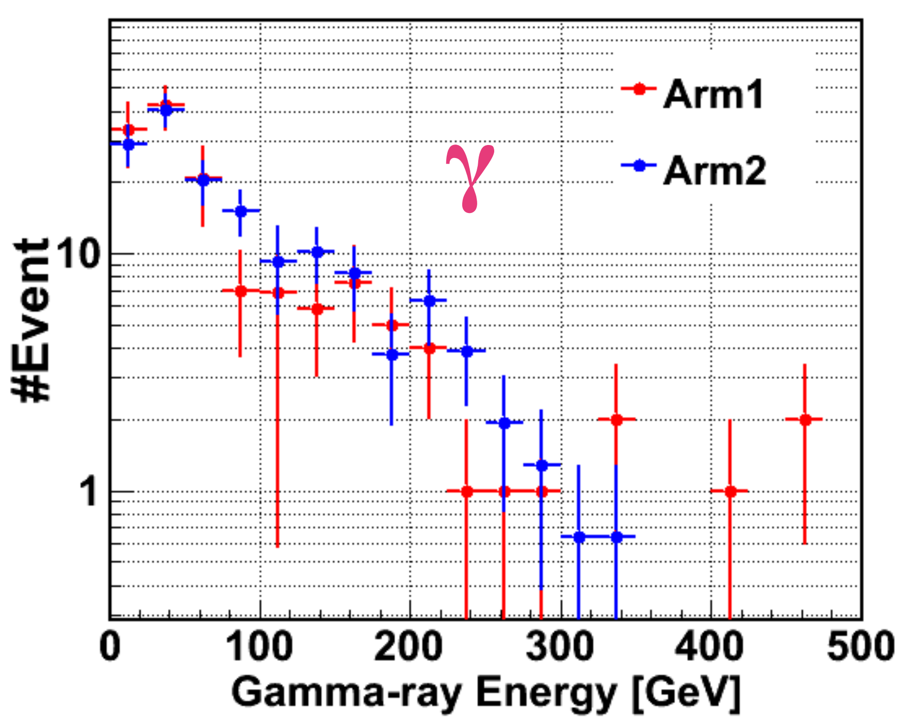
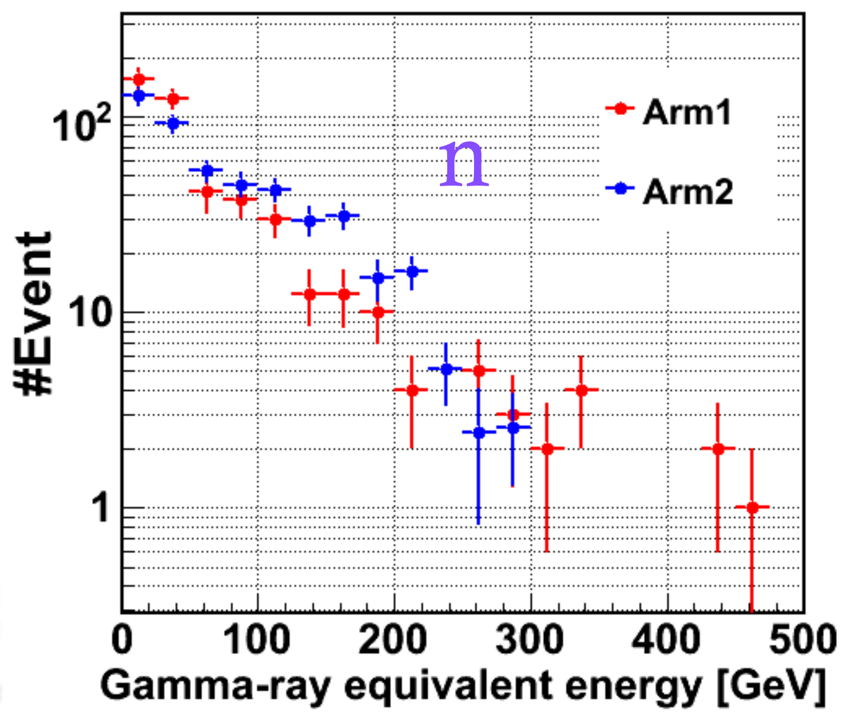
ARM1 vs ARM2 900 GeV results





ARM1/ARM2 normalised according to the ratio of fiducial volume surfaces

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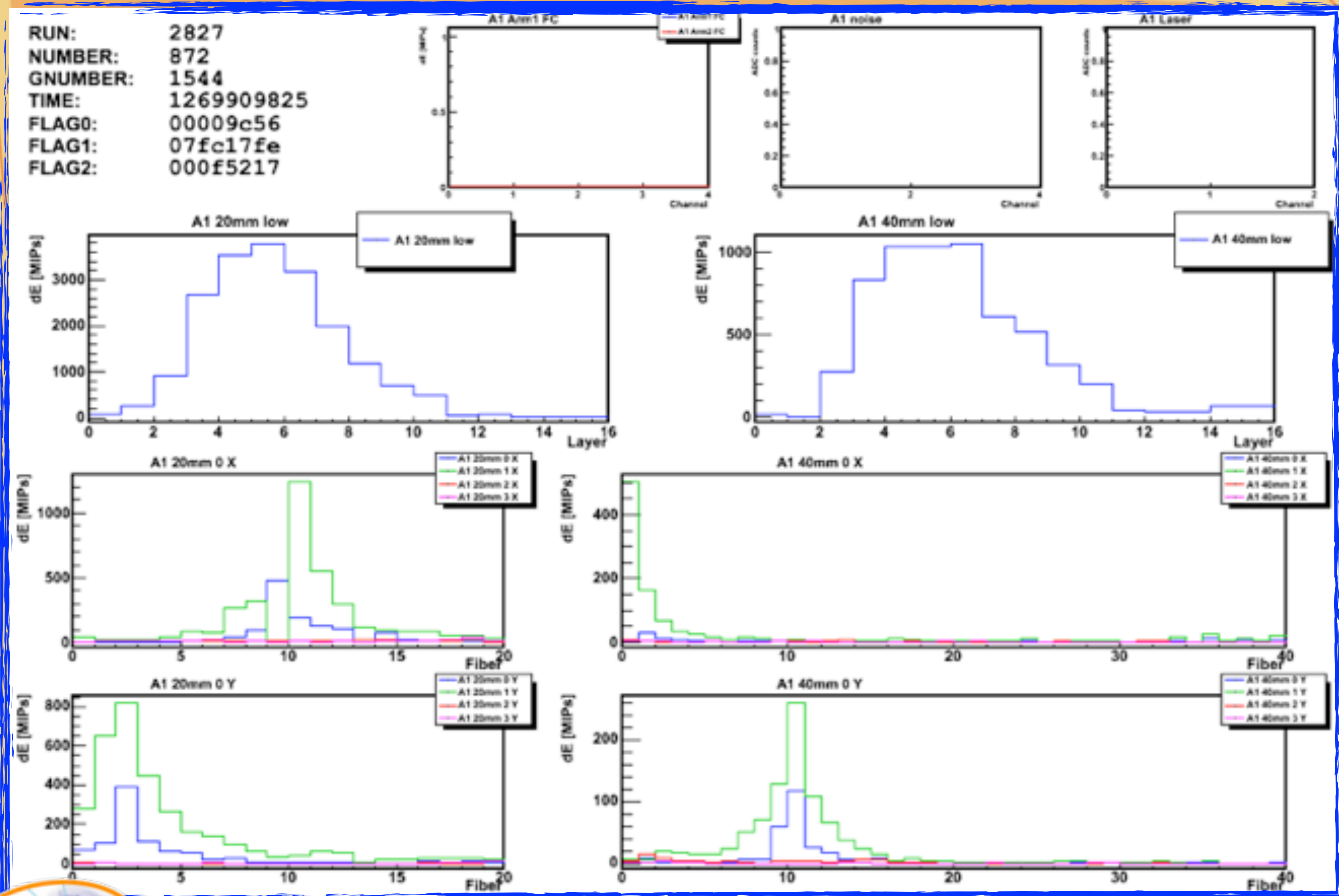
ARM1 γ event @ 7 TeV



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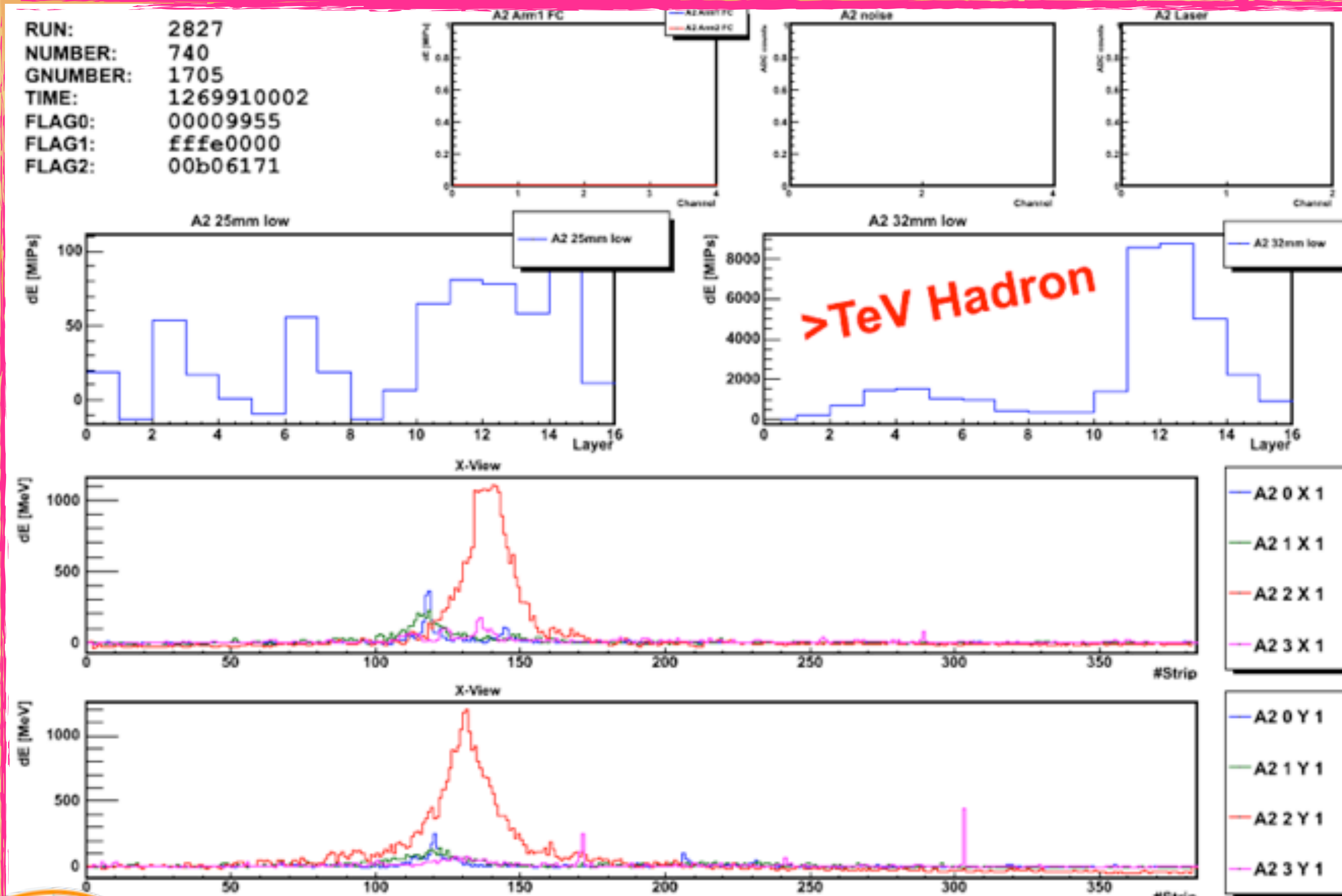
ARM2 hadron event @ 7 TeV



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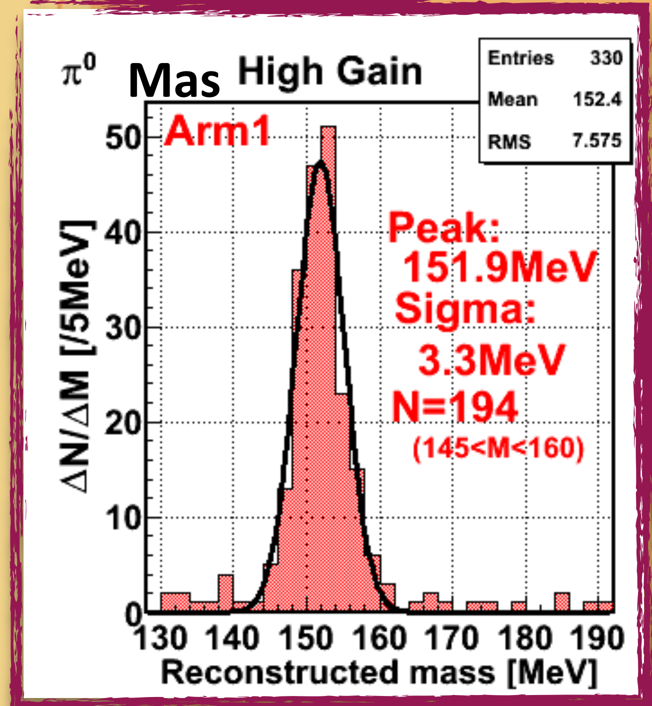
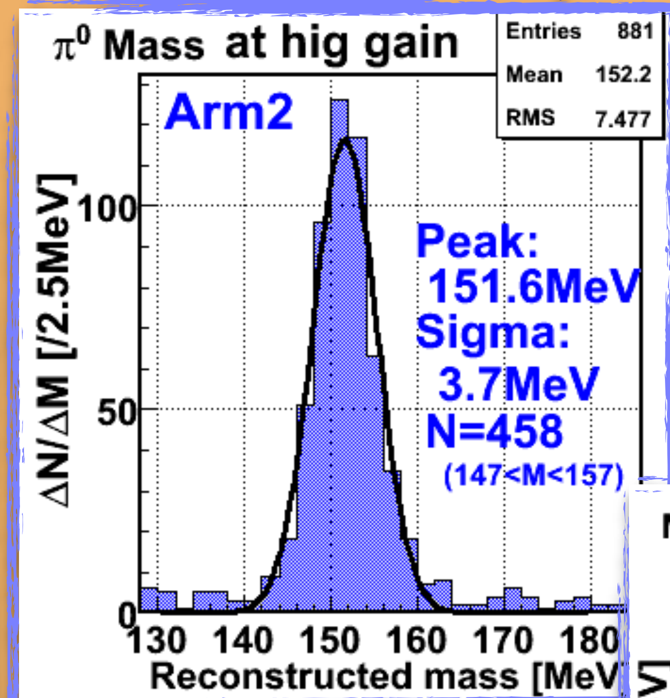
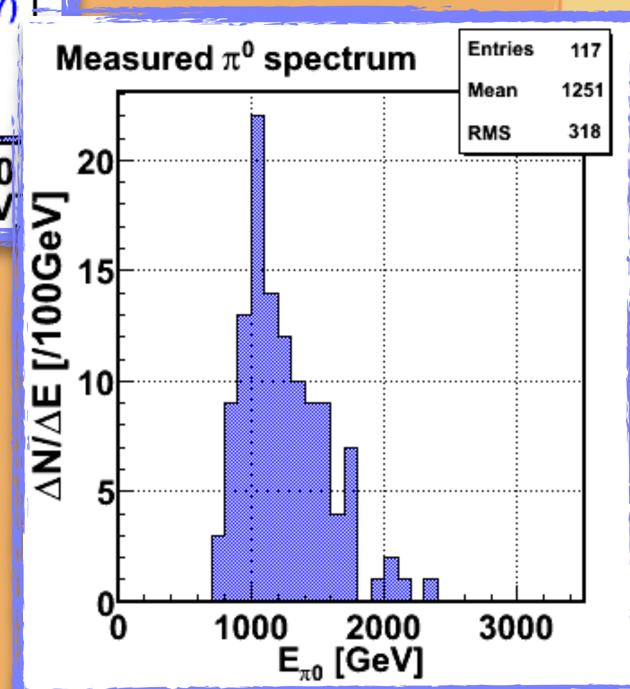
π^0 @ 7 TeV: more than preliminary...







Sigma/√N = 0.24MeV

0.24/151.9 = 0.16%

Sigma/√N = 0.17MeV

0.17/151.6 = 0.11%

Correction of shower leak-in is not taken account
Energy calibration to be checked

LHCf: conclusions and plans

- First data analysis is on going but preliminary results show already interesting features
  - Good agreement between Data and MC for γ both for ARM1 and ARM2
  - Some discrepancy for hadrons ⇒ Still to be investigated
  - γ and n spectra are practically flat at 900 GeV
  - Very nice agreement between ARM1 and ARM2 data!
  - π^0 peak shift at 7 TeV to be understood
- We plan to take data again at 900 GeV and 7 TeV up to 2 pb^{-1} of integrated luminosity then LHCf will go out for upgrade and come back at the next LHC energy step
- LHCf experiment will certainly provide crucial calibration of hadron interaction for CR study with the actual and forthcoming data

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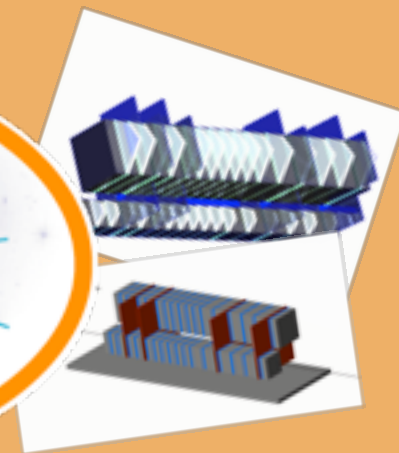

Back up slides

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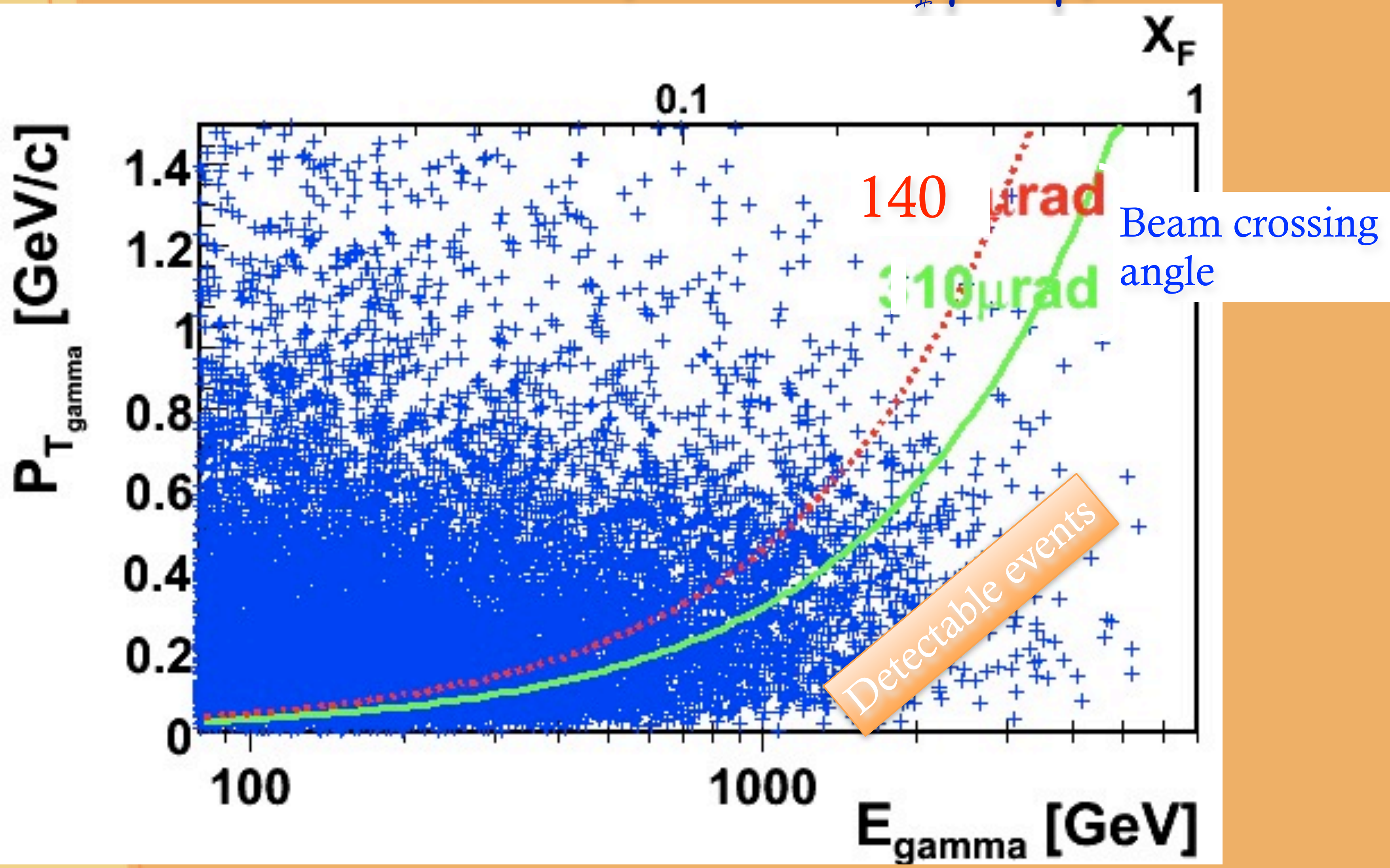
LHCf: acceptance on $P_{T\gamma}$-E_γ plane



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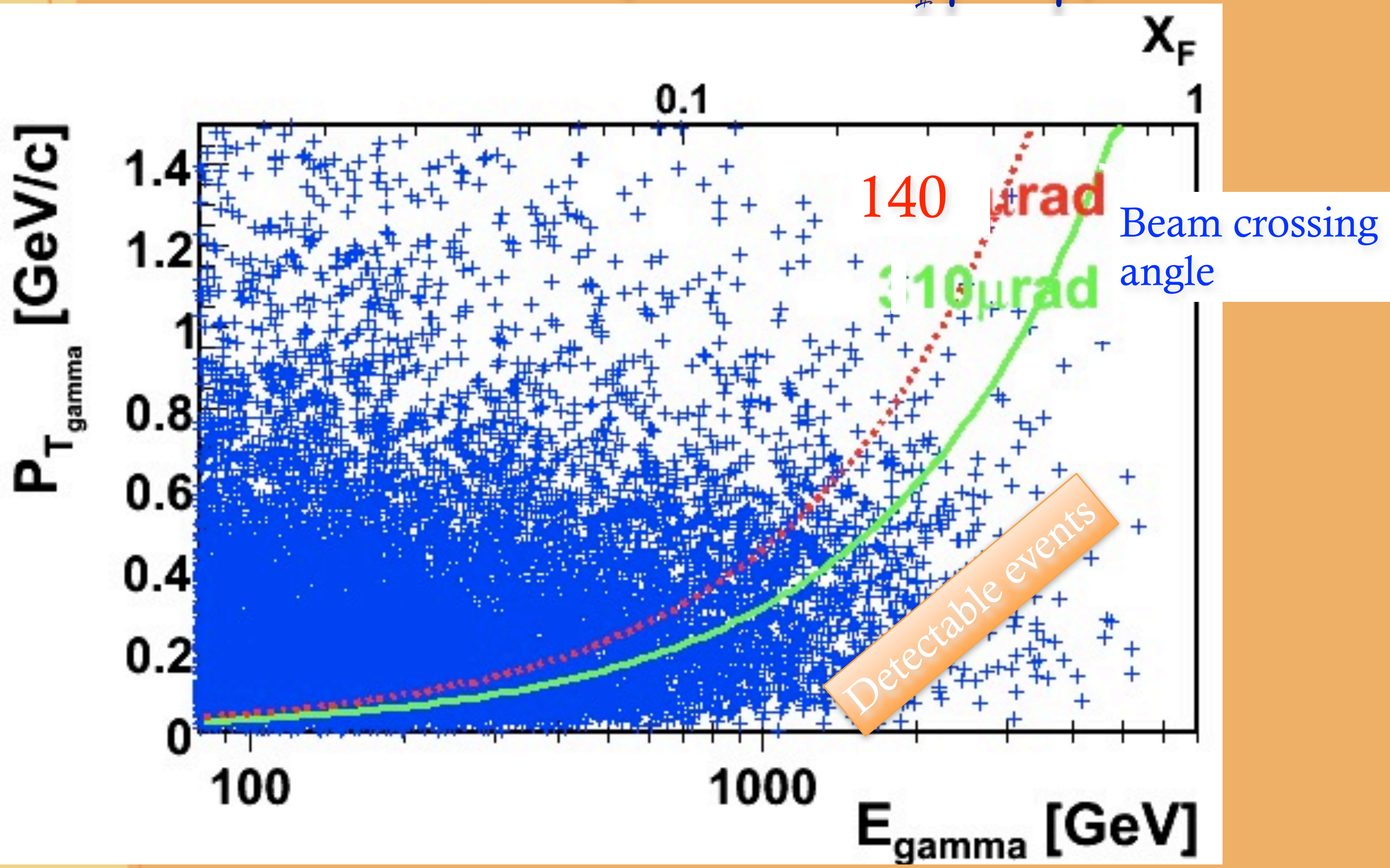
LHCf: acceptance on $P_{T\gamma}$-E_γ plane



A vertical beam crossing angle > 0 will increase the acceptance of LHCf

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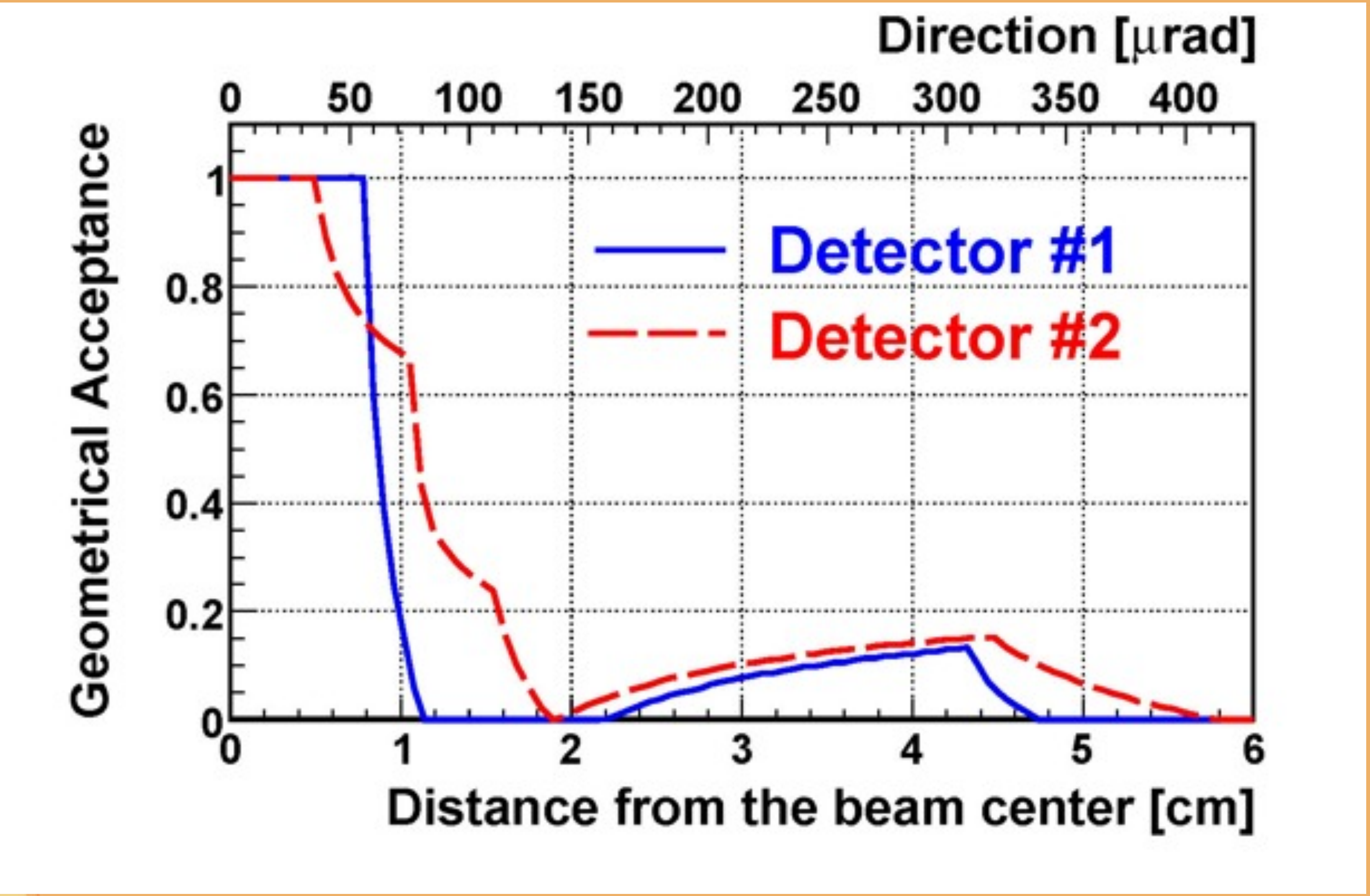
LHCf single γ geometrical acceptance



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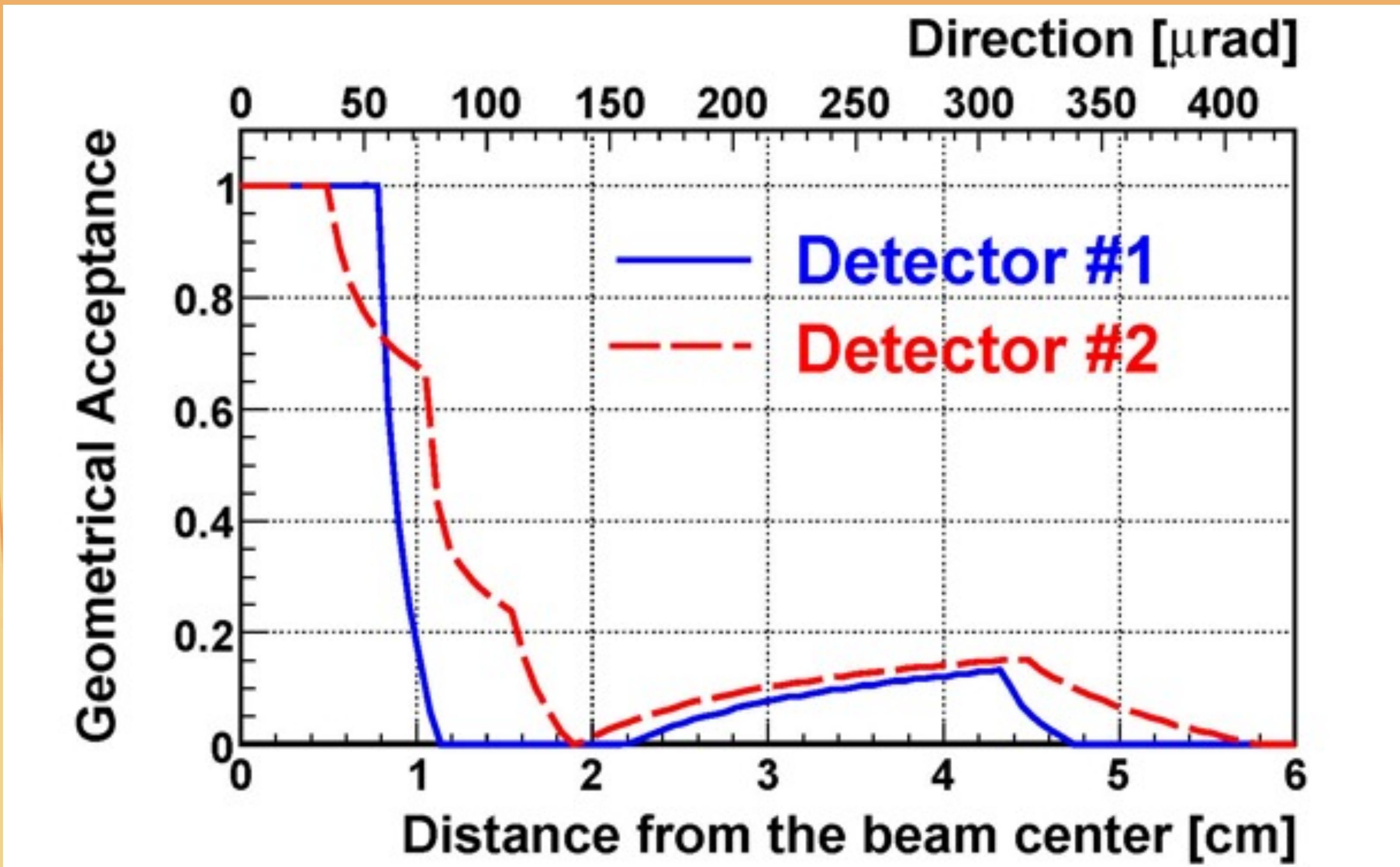
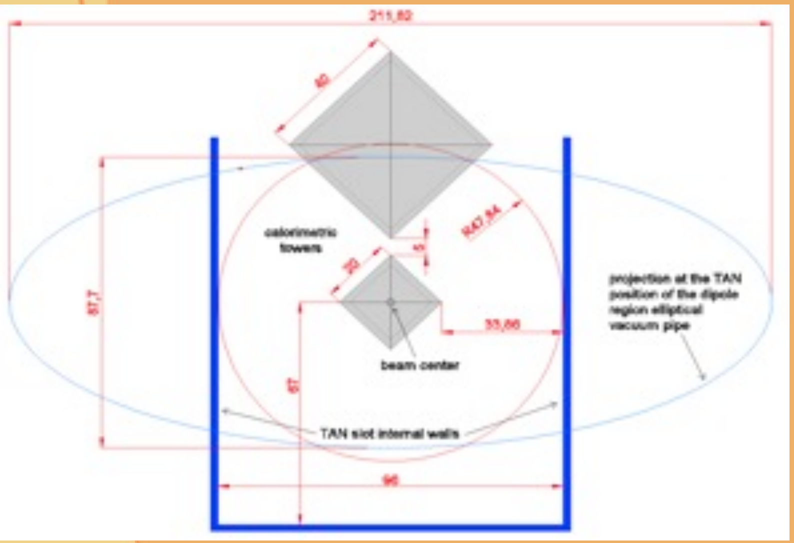
LHCf single γ geometrical acceptance

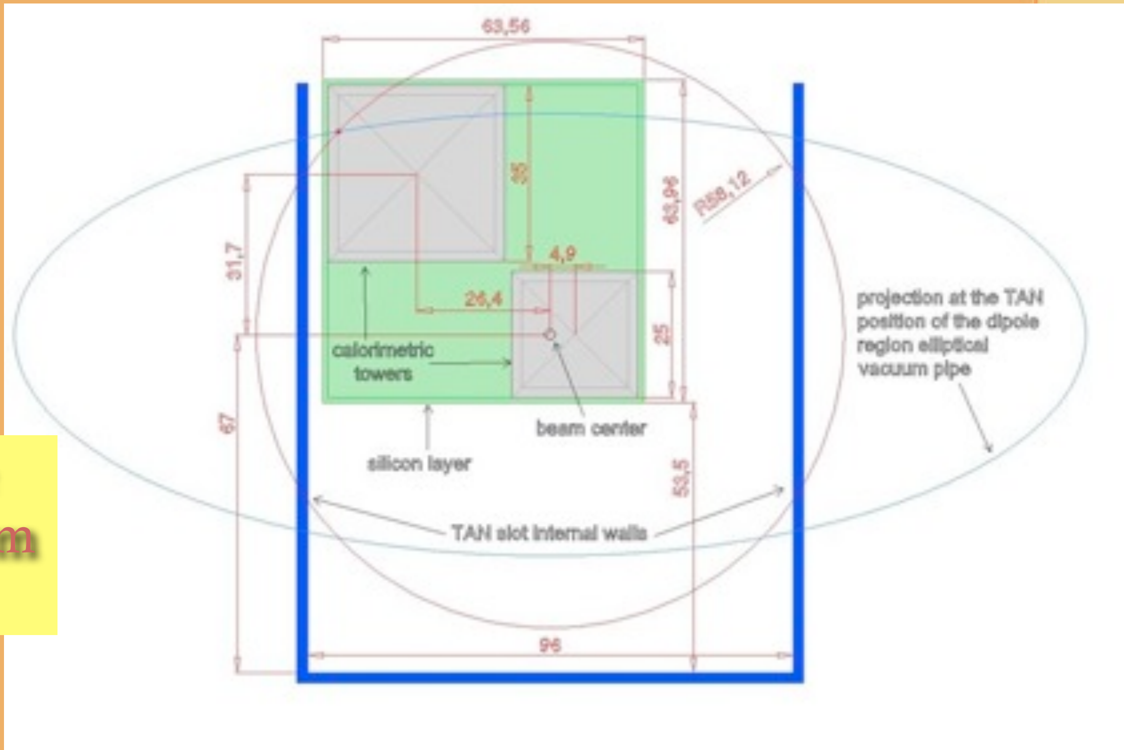


Some runs with LHCf vertically shifted few cm will allow to cover the whole kinematical range

Transverse projection in TAN slot

ARM1: Maximisation of the acceptance for vertical beam displacement (crossing angle>0)





ARM2: Maximisation of the acceptance in R (distance from beam centre)

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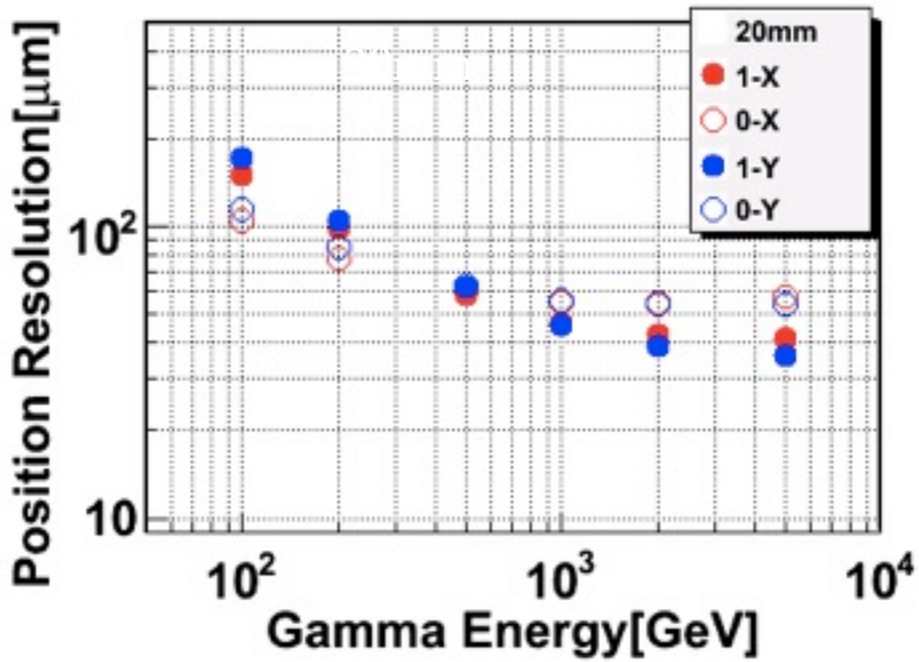
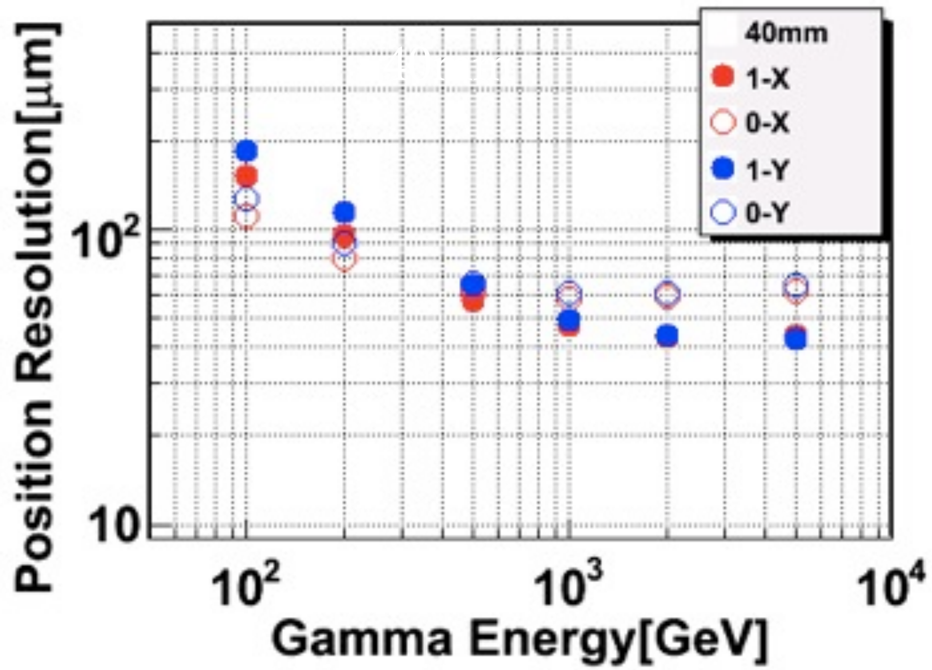
Position resolution for γs





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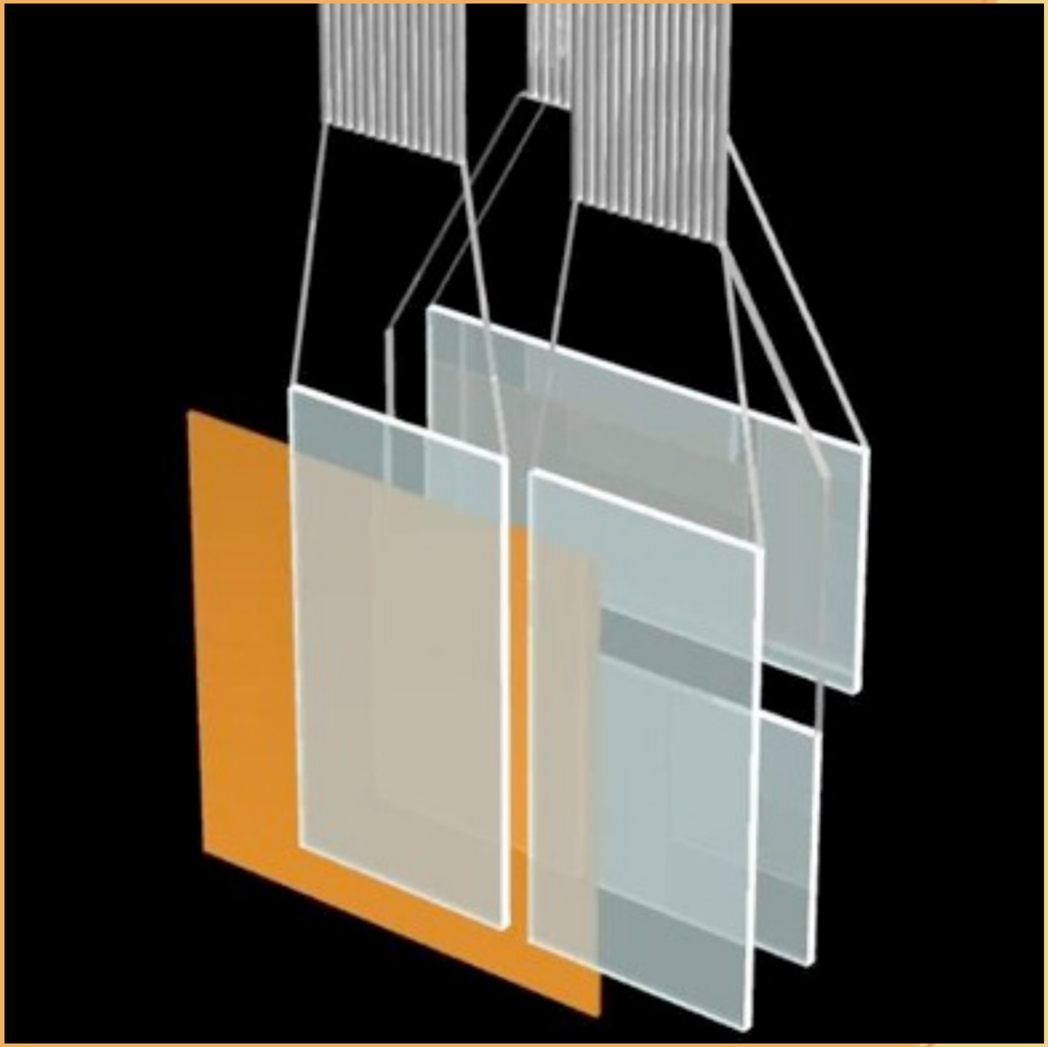
Front Counter

- 2 fixed Front Counters installed in front of Arm1 and Arm2
- They will not move with Arm1 and Arm2
- They are segmented in 2 x and 2 y slices
- Very useful to check the beam quality and hence decide to move Arm1 and Arm2 in the operating



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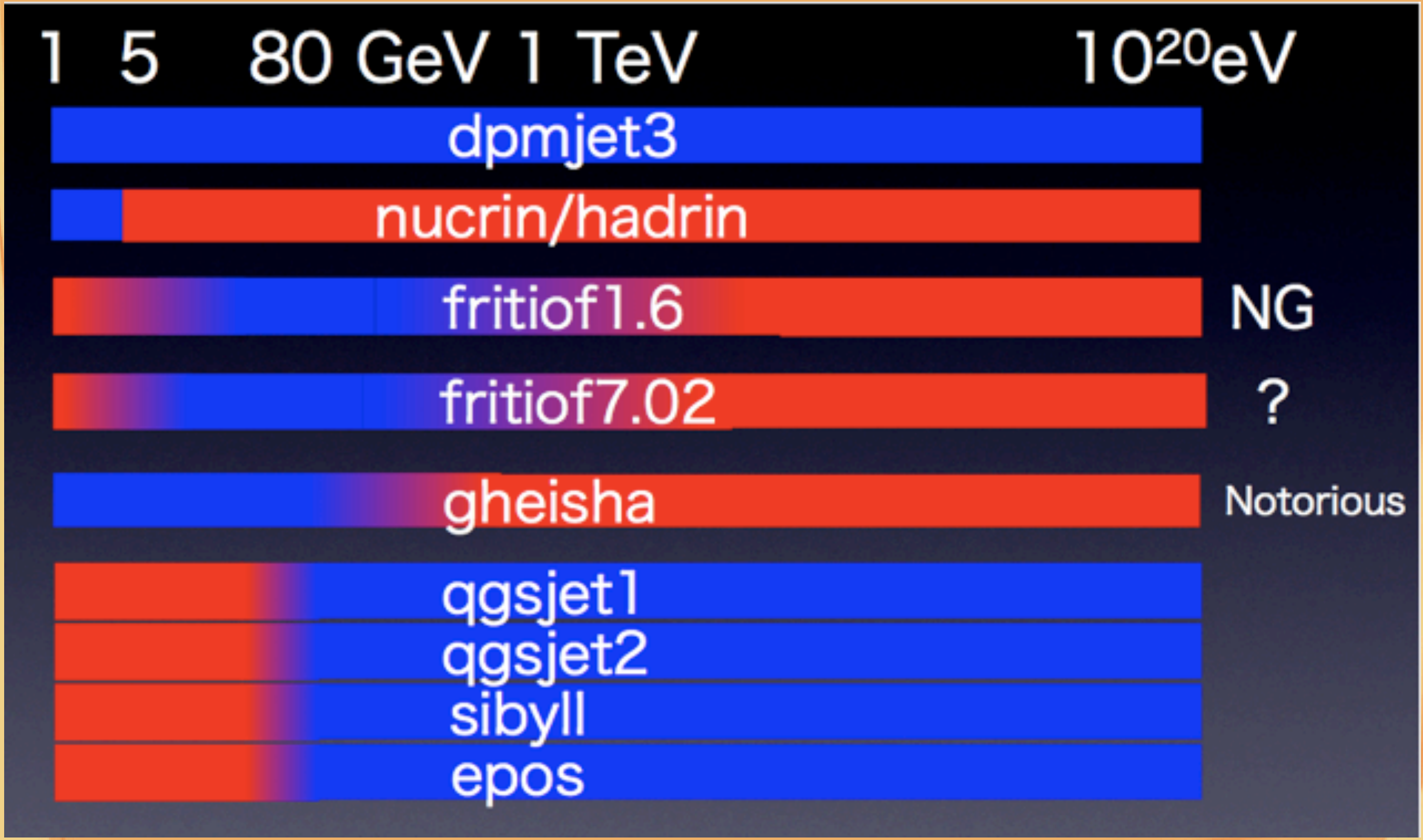
Monte Carlo Code comparison



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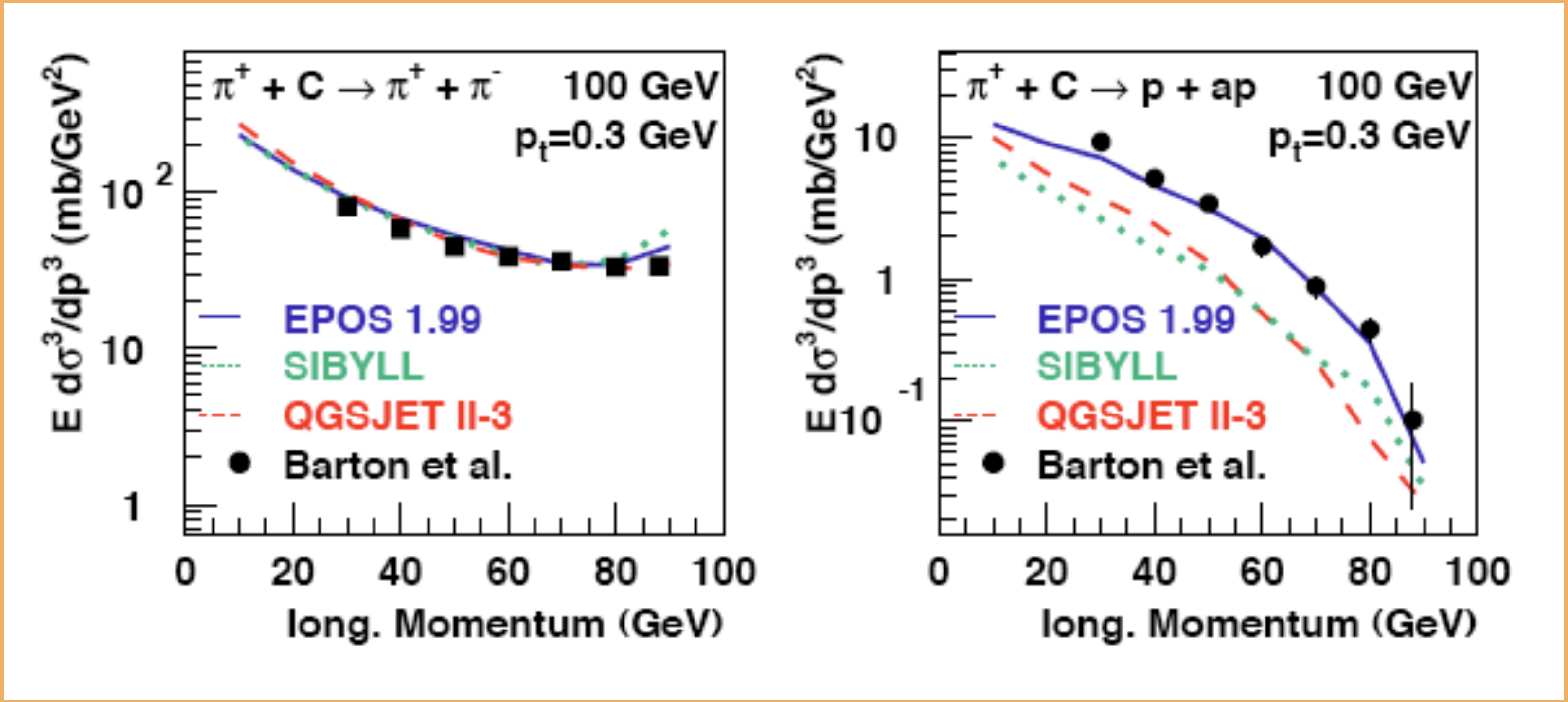
Monte Carlo Code comparison



Similar behaviour for pions but not for baryons

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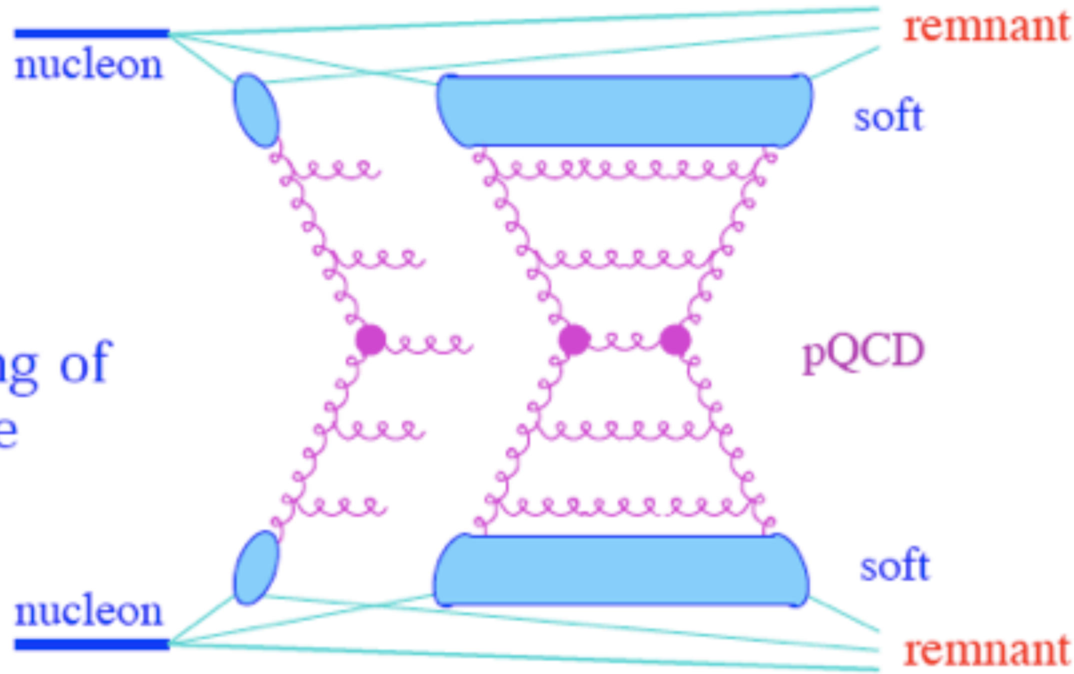
Physics of Monte Carlo

EPOS, QGSJET

Multiple scattering of Gribov-Regge type



- ☐ Semihard "Pomerons" : soft - pQCD - soft
- ☐ Remnants
- ☐ Partonic final state => strings

K. Werner, EDS09, CERN

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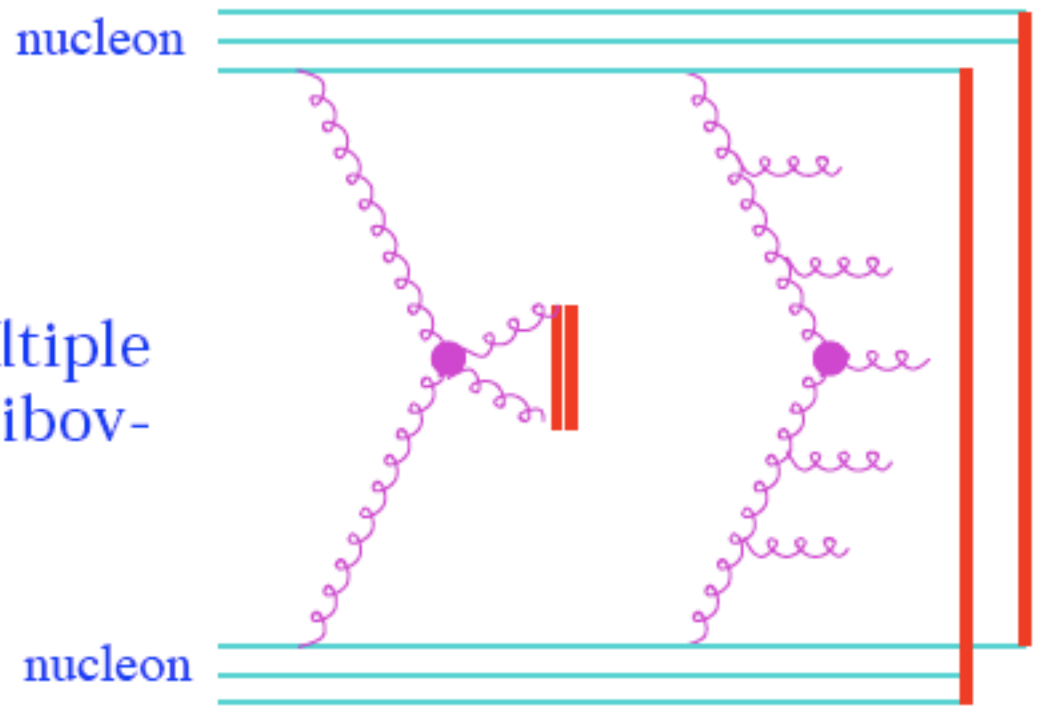
Physics of Monte Carlo

SIBYLL

as well multiple scattering of Gribov-Regge type



- ☐ no Remnants
- ☐ "main" scattering => qq-q strings
- ☐ further scatterings => strings between gluon pairs

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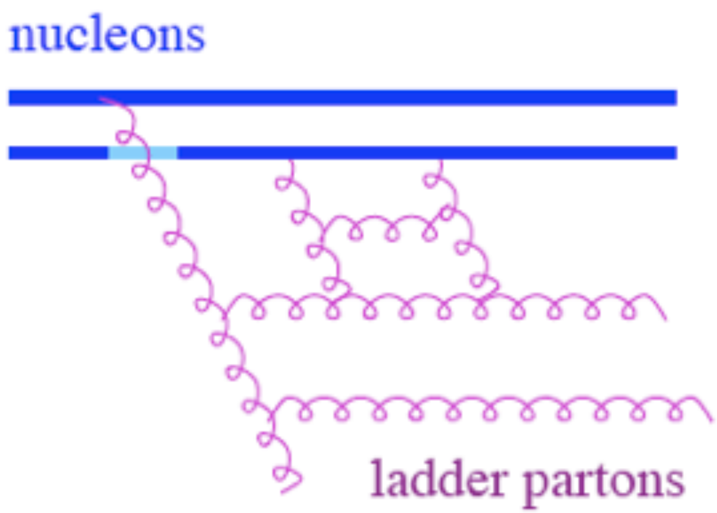
Nonlinear effects in EPOS

K. Werner, EDS09, CERN

To include rescatterings of partons,
fit parton-ladder[1] as $\alpha\,(x^+)^\beta (x^-)^\beta$ [2], modify as

$$\alpha\,(x^+)^\beta (x^-)^{\beta+\varepsilon},$$



Effect can be summarized by a simple positive exponent ε

(dep on $\log s$ and N_{particip}, incorporating saturation)

[1] imaginary part of the corresponding amplitude in b−space
[2] x^+, x^-: light cone momentum fractions of the first ladder partons

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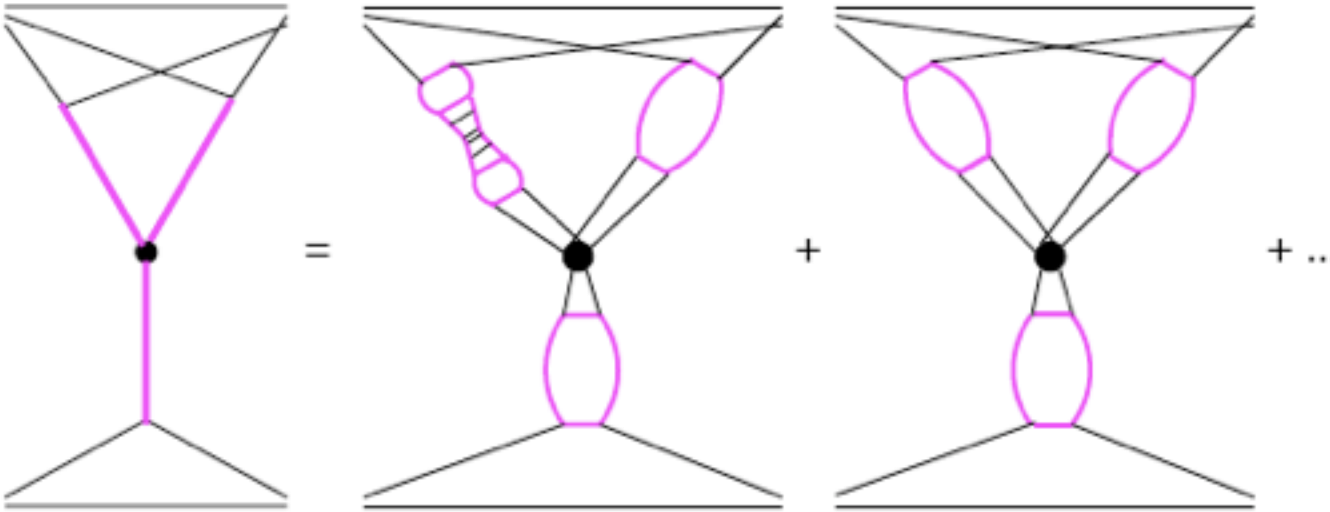
Nonlinear effects in QGSJET

Pomeron-Pomeron coupling



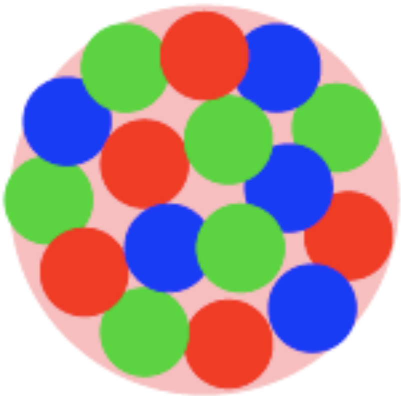
- ☐ Summing all orders
- ☐ No energy conservation
- ☐ (in EPOS full energy conservation, but effective treatment of nonlinear effects)

K. Werner, EDS09, CERN

Physics of Monte Carlo

Nonlinear effects in SIBYLL

Saturation scale obtained from



$$\frac{\alpha_s N_c}{Q^2} \times \frac{1}{N_c^2 - 1} \frac{xG}{\pi R^2} = 1$$

☐ Used as cutoff

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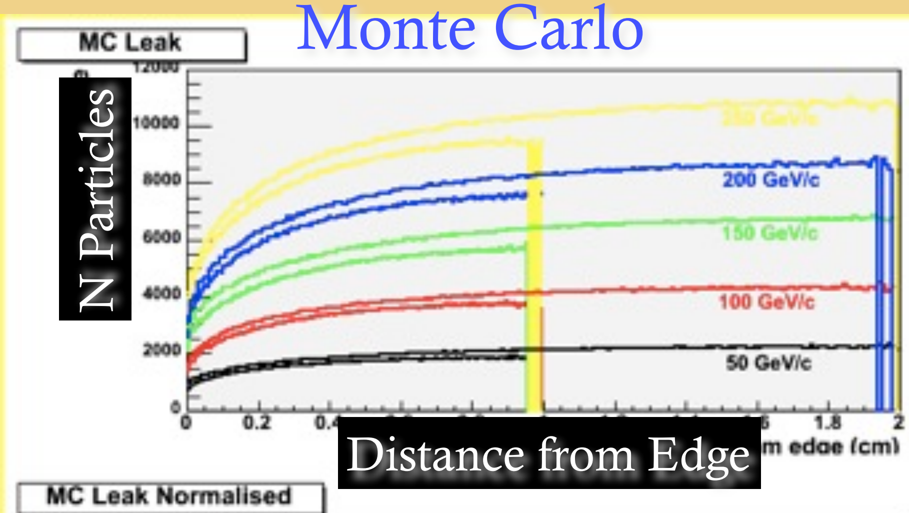
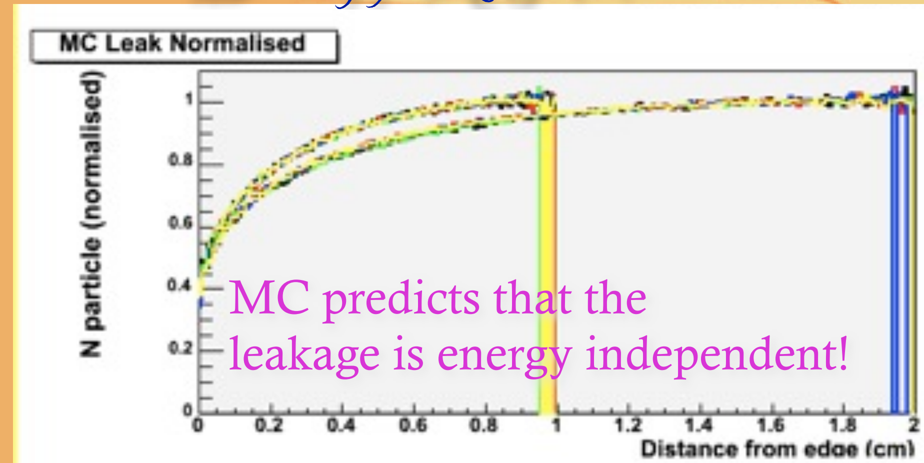
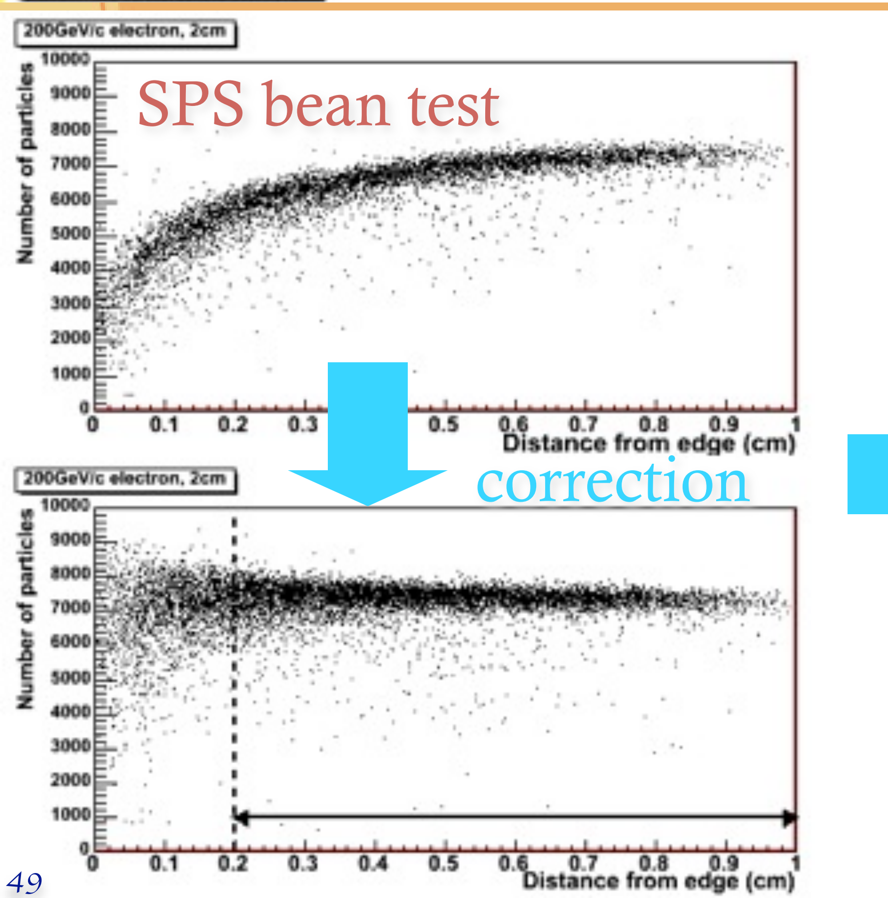
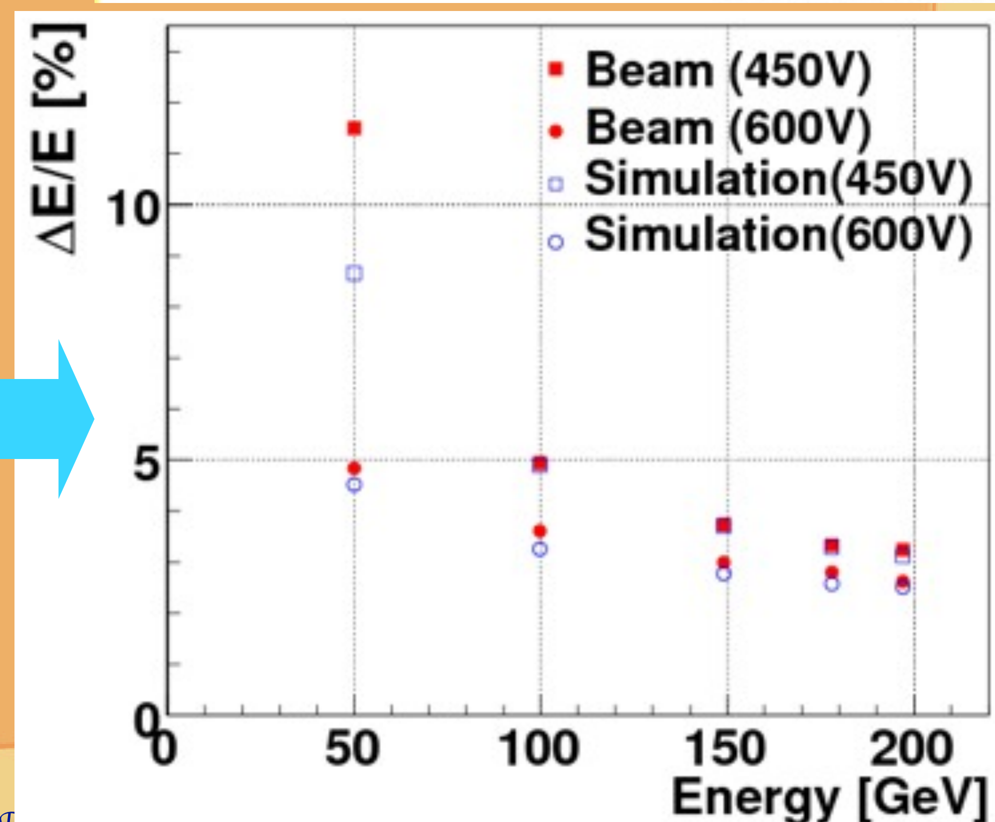
Energy Resolution





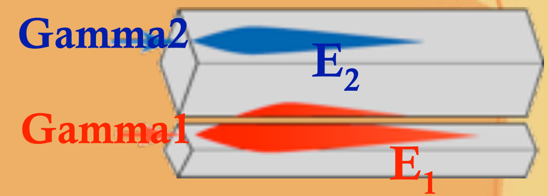


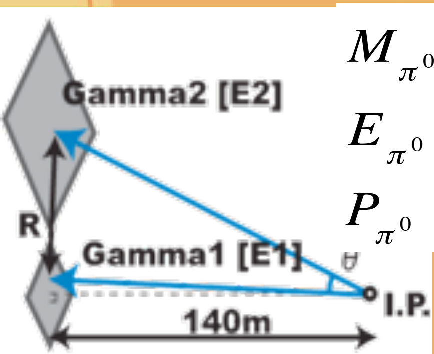


π^0 spectra

π^0 produced at collision can be extracted by using gamma pair events

Powerful tool to calibrate the energy scale and also to eliminate beam-gas BG

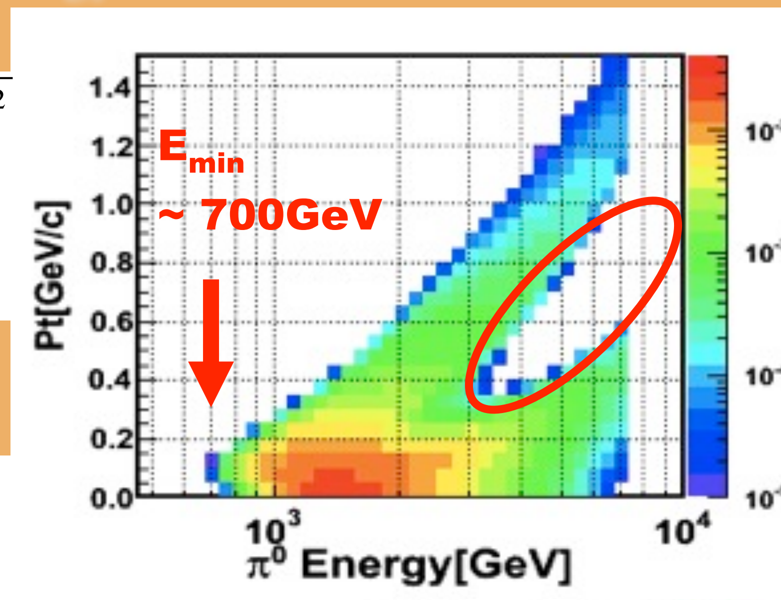




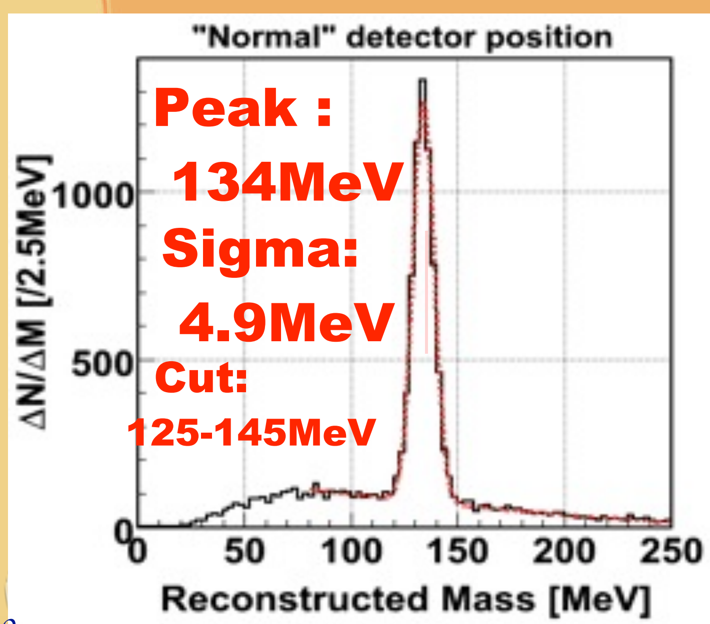
$$M_{\pi^0} = \sqrt{E_{\gamma 1} E_{\gamma 2} \theta^2}$$

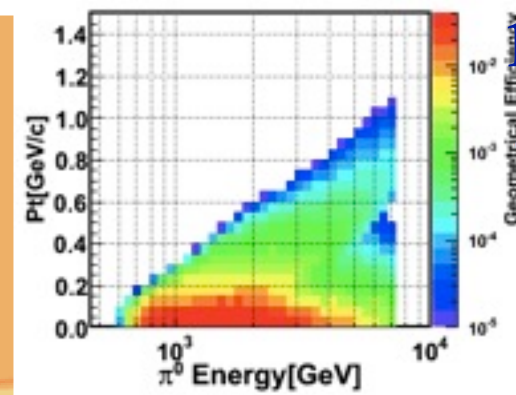
$$E_{\pi^0} = E_{\gamma 1} + E_{\gamma 2}$$

$$P_{\pi^0} = P_{\gamma 1} + P_{\gamma 2}$$

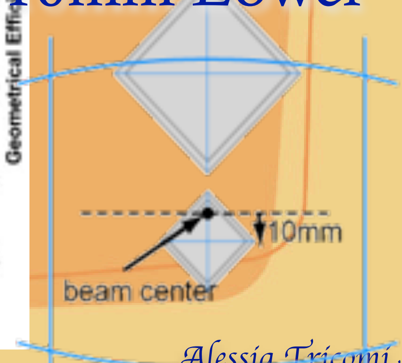


Geometrical Acceptance





10mm Lower



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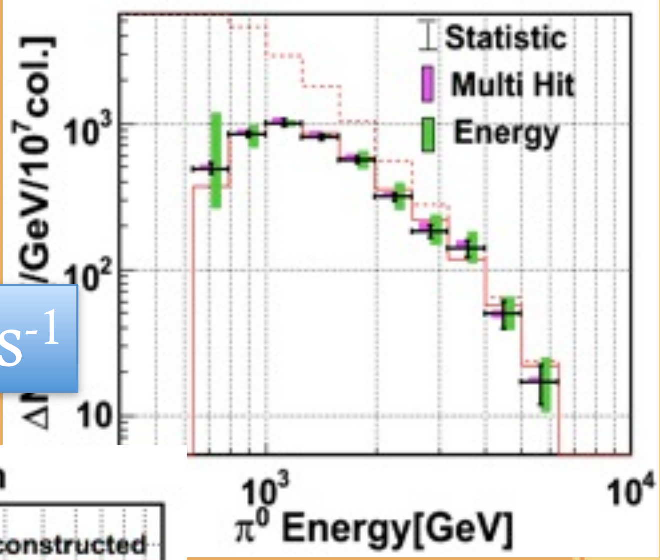
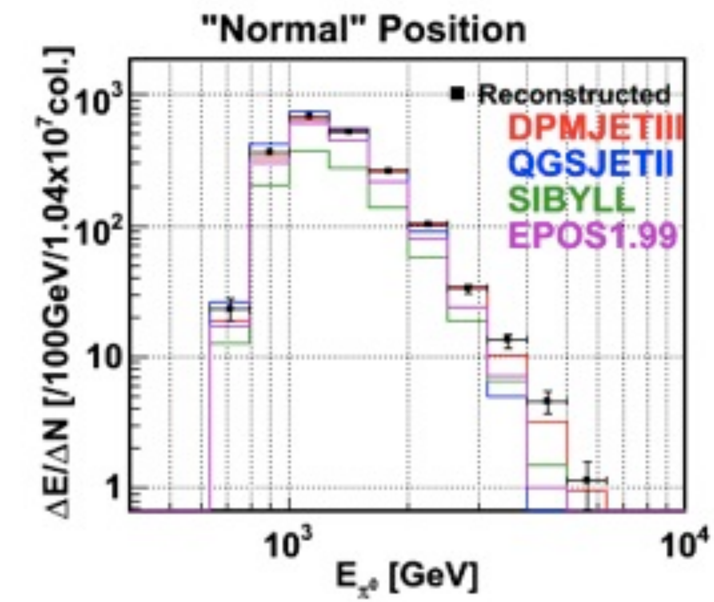
π^0 spectra and model discrimination

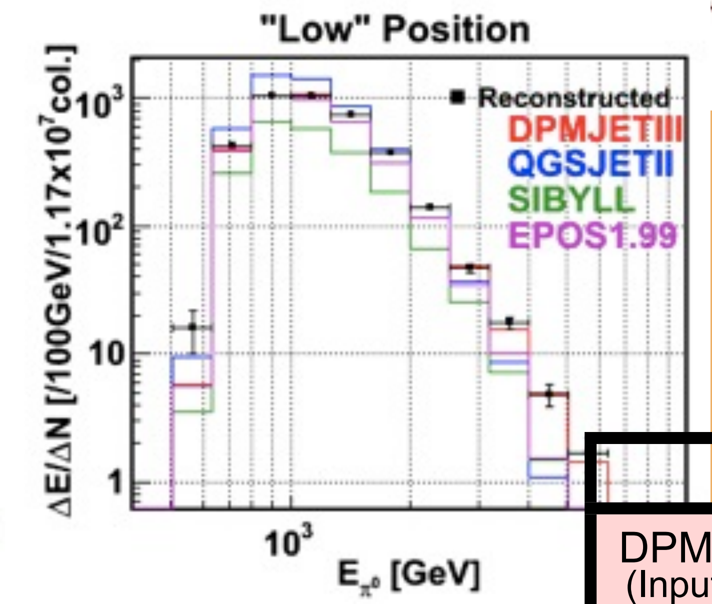
✓ Reconstructed spectrum in good agreement with the original π^0 production spectrum (DPMJETIII)

✓ Systematic errors mainly due to the uncertainty of the absolute energy scale of the calorimeters. ±5% uncertainty were conservatively assumed

20 min @ 10^{29} cm^{-2}s^{-1}







	χ^2	Prob.
DPMJET-III (Input to MC sim.)	11.5	0.83
QGSJET-II	224.9	$<10^{-20}$
SIBYLL	49.1	6×10^{-5}
EPOS1.99	68.2	3×10^{-8}

$$\chi^2(\alpha,\beta_{20},\beta_{40}) = \sum_i \frac{(\alpha N_i(\beta_{20},\beta_{40}) - M_i)^2}{(\sigma_{N_i})^2 + (\sigma_{M_i})^2}$$

N_i: # reconstructed events in the i-th bin

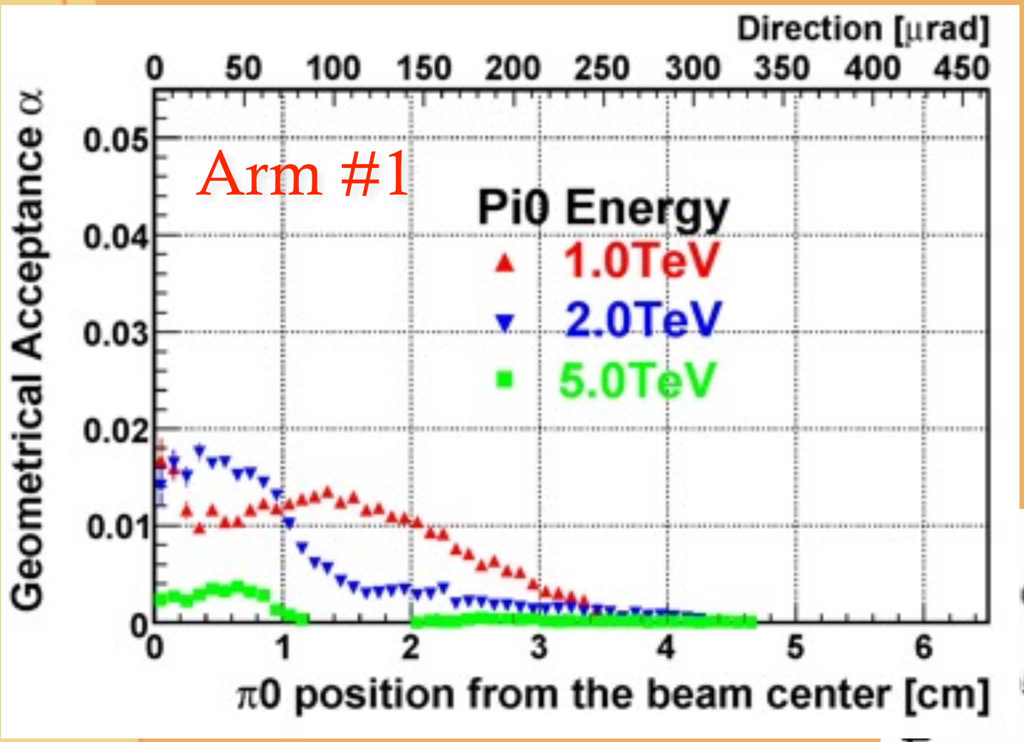
M_i: # events in model spectrum

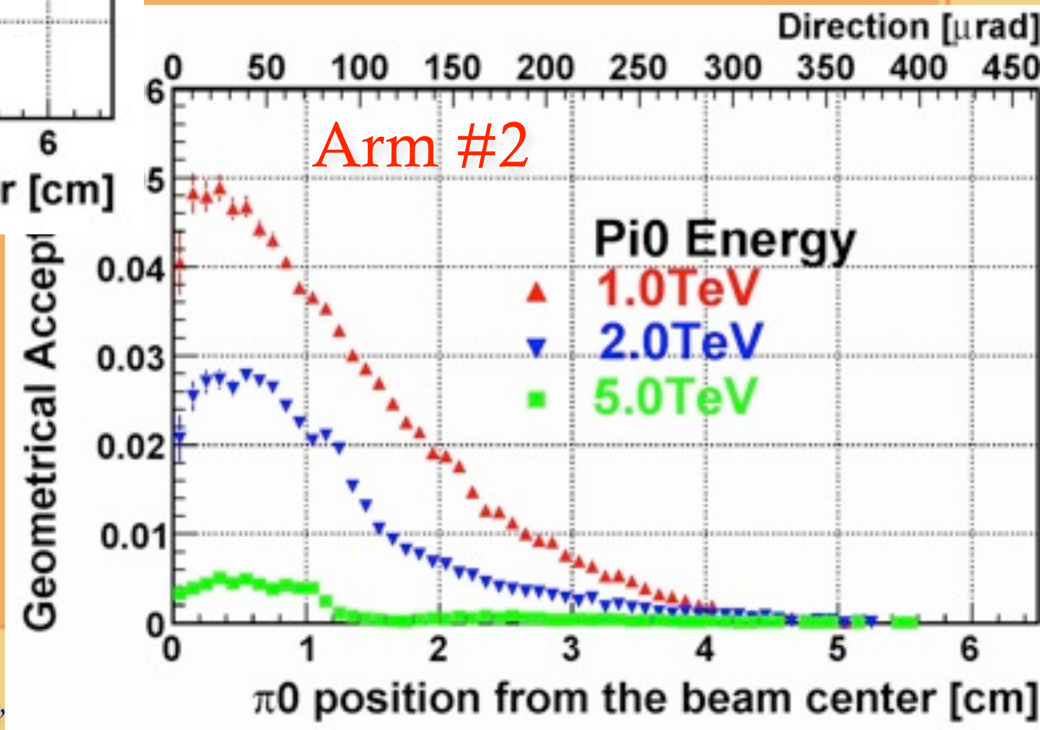
$\sigma_{N,M}$: statistical error

α: Normalisation parameter

$\beta_{20,40}$: Energy scale for 20mm and 40mm

LHCf performances: π^0 geometrical acceptance





γ rate

	20mm x 20mm	40mm x 40mm
1. Sum E > 100GeV	0.0674	0.0465
2. One Gamma Incident	0.0478	0.0353
3. One Hadron Incident	0.0146	0.0052
4. One Gamma in fiducial	0.0297	0.0272
5. One Neutron in fiducial	0.0006	0.0001

Table 3: Event rate of single γ's and hadrons per inelastic collision for the Detector #1. Here the 2cm×2cm tower is at the center of beam-pipe and without beam crossing angle..

	20mm × 20mm	40mm × 40mm
1. Sum E > 100GeV	0.0674	0.0869
2. One Gamma Incident	0.0478	0.0623
3. One Hadron Incident	0.0145	0.0081
4. One Gamma in fiducial	0.0297	0.0511
5. One Neutron in fiducial	0.0006	0.0002

Table 4: Event rate of single γ's and hadrons per inelastic collision for the Detector #1. Here the 2cm×2cm tower is at the center of the neutral particle flux and with beam crossing angle of 140μrad.

	20mm × 20mm	40mm × 40mm
1. Sum E > 100GeV	0.0949	0.0721
2. One Gamma Incident	0.0654	0.0528
3. One Hadron Incident	0.0198	0.0078
4. One Gamma in fiducial	0.0445	0.0427
5. One Neutron in fiducial	0.0009	0.0002

Table 5: Event rate of single γ's and hadrons per inelastic collision for the Detector #2. Here the detector is at default position and without beam crossing angle.

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π^0 rate

1. One Particle Incident on each Calorimeter	0.0040
2. Gamma Incident on each Calorimeter	0.0032
3. Invariant mass cut (125 MeV $< M_{\gamma\gamma} <$ 145MeV)	0.0007

Table 6: Event rate of π^0 production per inelastic collision for Detector #1. Here the 2cm$\times$2cm calorimeter is at the center of beam-pipe and the beam crossing angle is zero.

1. One Particle Incident on each Calorimeter	0.0066
2. Gamma Incident on each Calorimeter	0.0052
3. Invariant mass cut (125 MeV $< M_{\gamma\gamma} <$ 145MeV)	0.0011

Table 7: Event rate of π^0 production per inelastic collision for Detector #1. Here the 2cm$\times$2cm tower is at the center of the neutral particle flux and te beam crossing angle is 140μrad.

1. One Particle Incident on each Calorimeter	0.0080
2. Gamma Incident on each Calorimeter	0.0063
3. Invariant mass cut (125 MeV $< M_{\gamma\gamma} <$ 145MeV)	0.0015

Table 8: Event rate of π^0 production per inelastic collision for Detector #2. Here the 2.5cm$\times$2.5cm calorimeter is at the center of neutral particle flux and the beam crossing angle is 0μrad.

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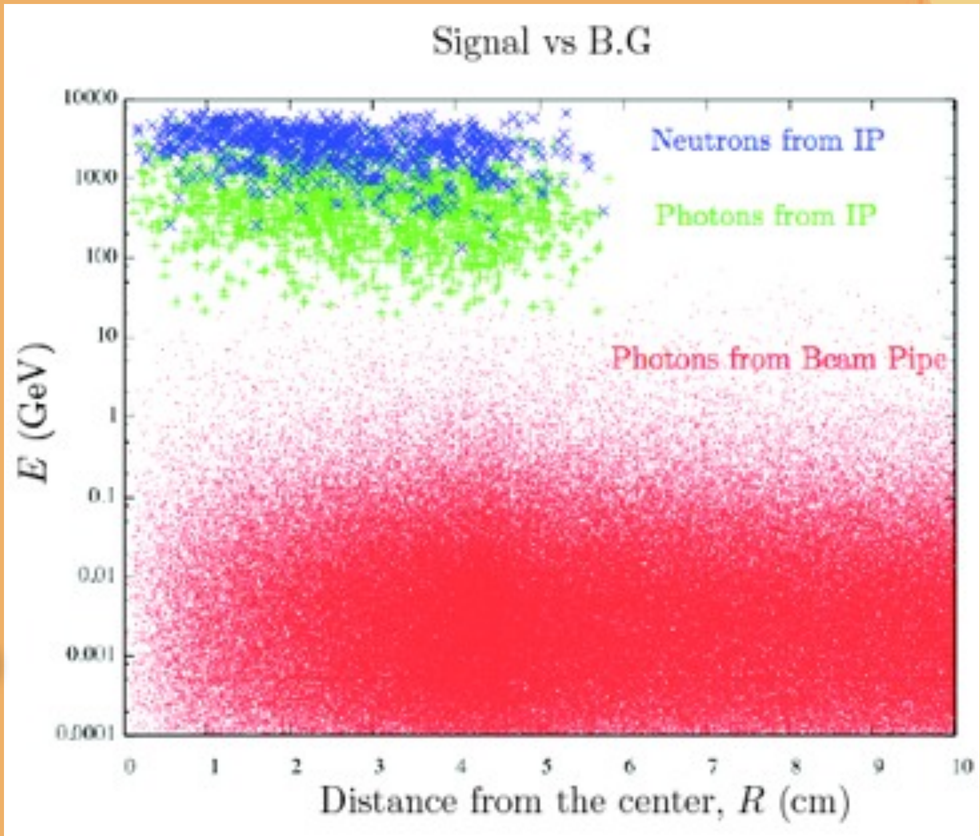
Estimate of the background

- beam-beam pipe
  - → E $_\gamma$(signal) > 200 GeV, OK
    background < 1%
- beam-gas
  - → It depends on the beam condition
    background < 1% (under 10^{-10} Torr)
- beam halo-beam pipe
  - → It has been newly estimated from the beam loss rate
    Background < 10% (conservative value)



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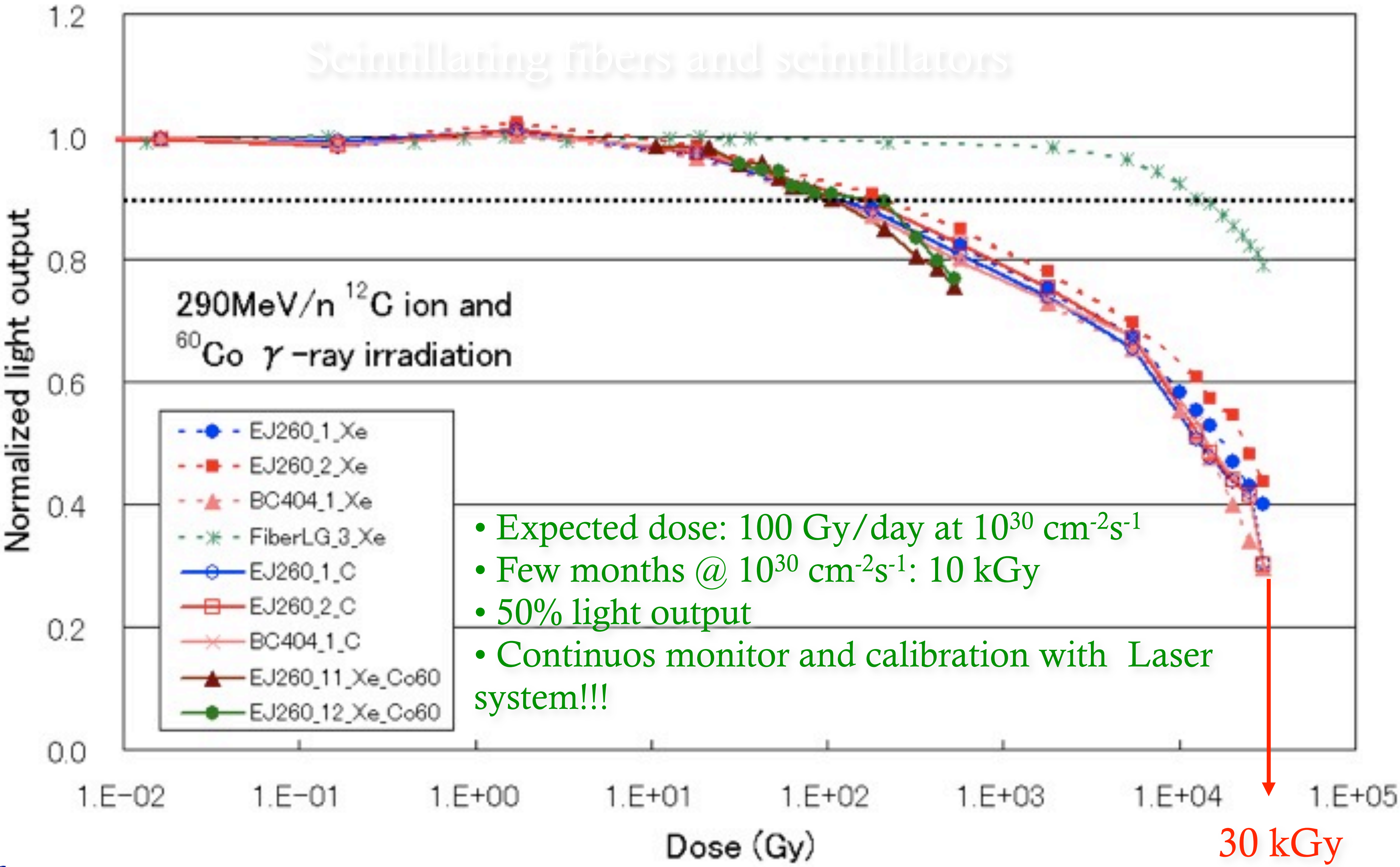
Radiation Damage Studies

Scintillating fibers and scintillators



- Expected dose: 100 Gy/day at 10^{30} $cm^{-2}s^{-1}$
- Few months @ 10^{30} $cm^{-2}s^{-1}$: 10 kGy
- 50% light output
- Continuos monitor and calibration with Laser system!!!

30 kGy