LHCf status report

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on behalf of the LHCf collaboration

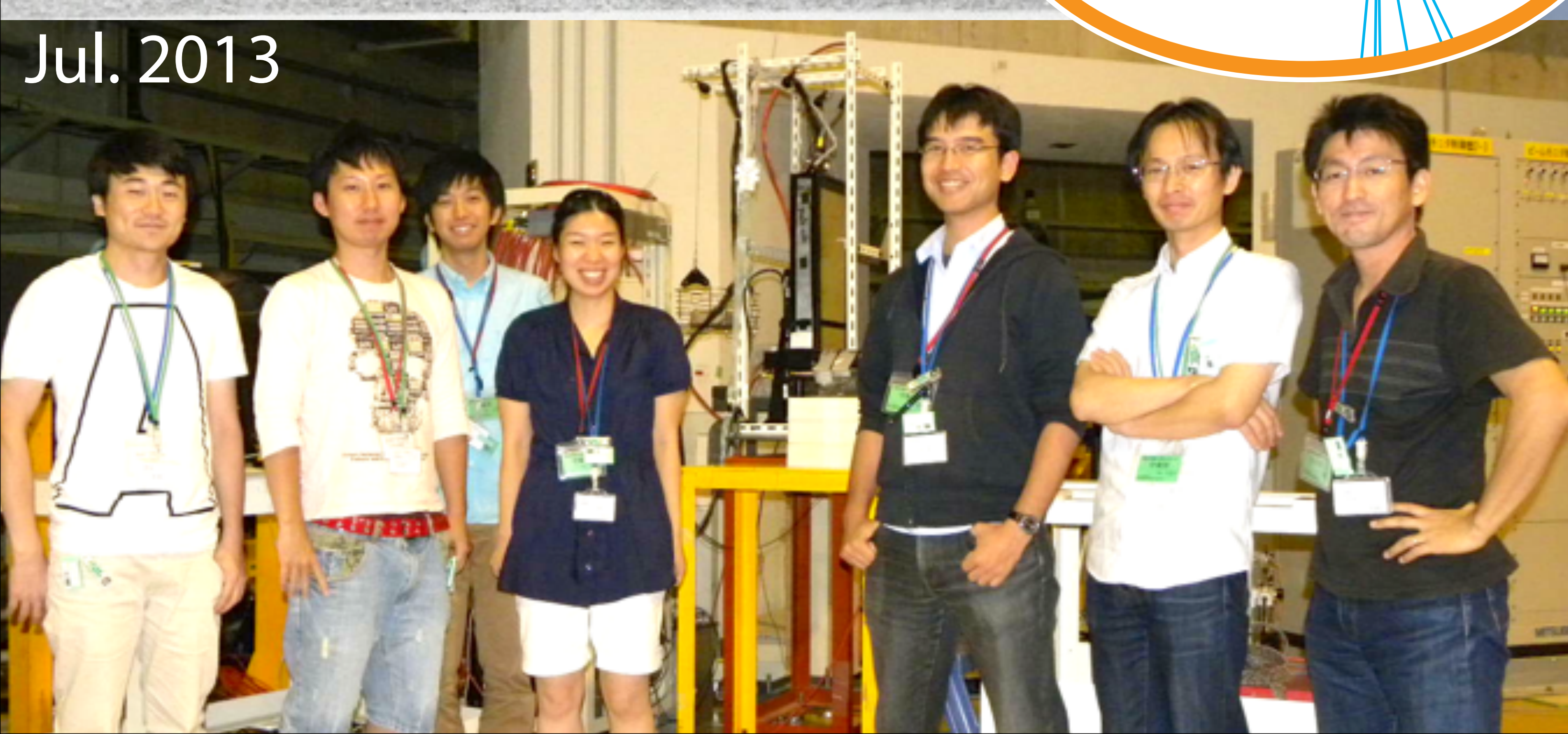
LHCC Open Session, CERN, March 5, 2014

Outline

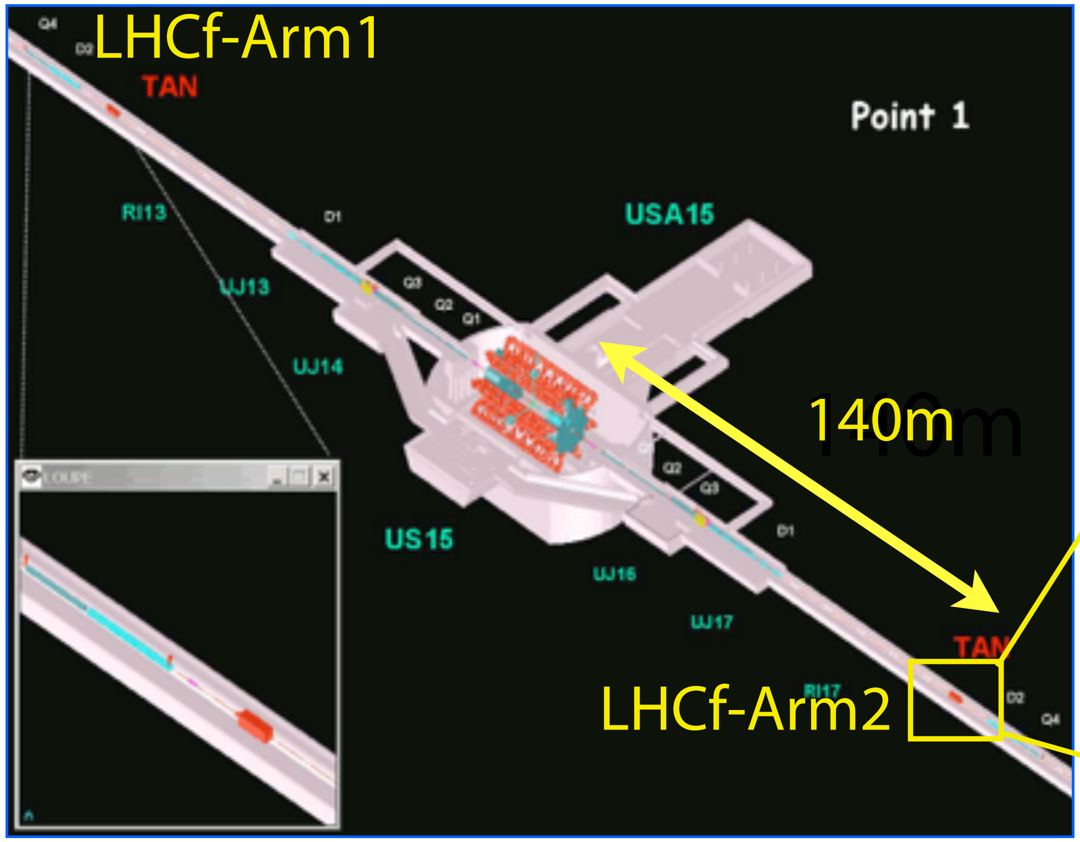
- Introduction and Physics motivation
- Recent physics results
  - Neutron energy spectra in p-p at 7 TeV
  - π^0 p_T spectra in p-Pb at 5.02 TeV
- Preparation towards the 13 TeV operation
- Summary

The LHCf collaboration

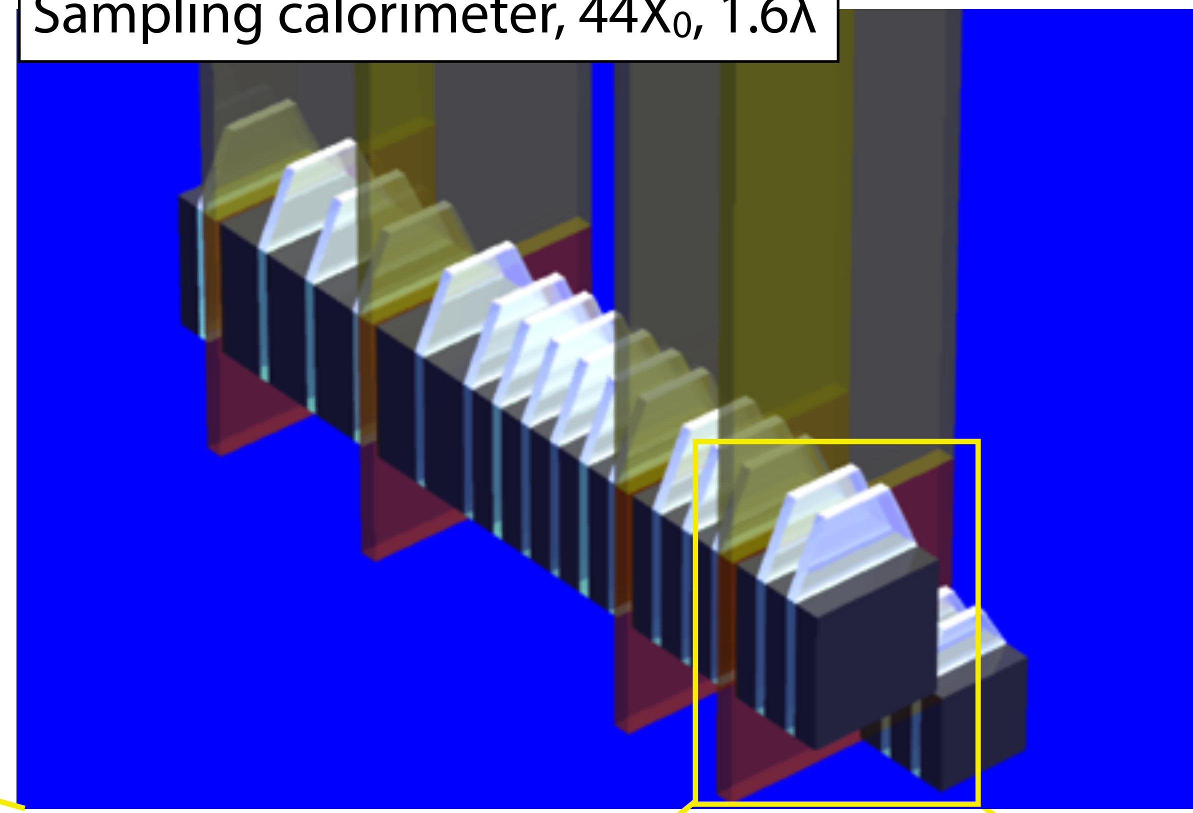
The LHCf collaboration involves ~30 members from 10 institutions.



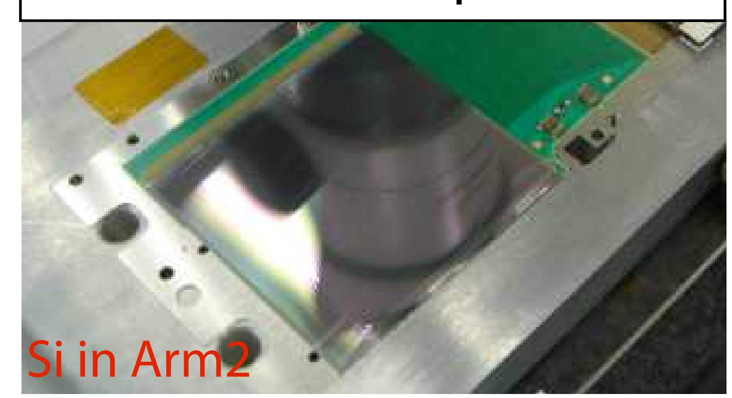
The LHCf detectors



10(W)cm x 10cm(H) x 30cm(D)
Sampling calorimeter, $44X_0$, 1.6λ

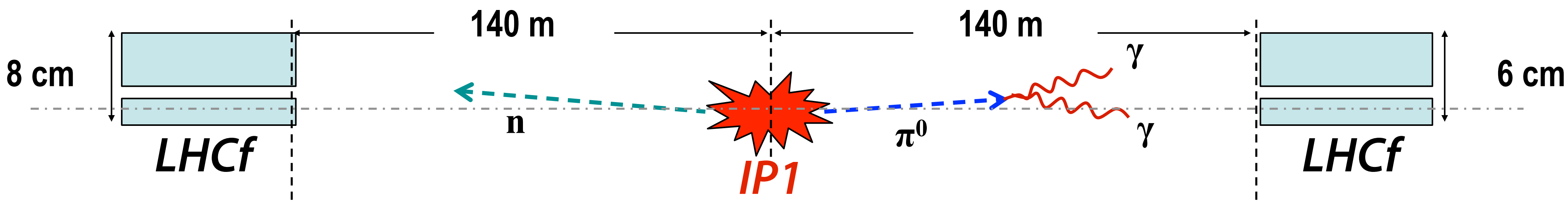


Position sensitive detector
Arm1 : Scintillation fibers
Arm2 : Silicon strip detector



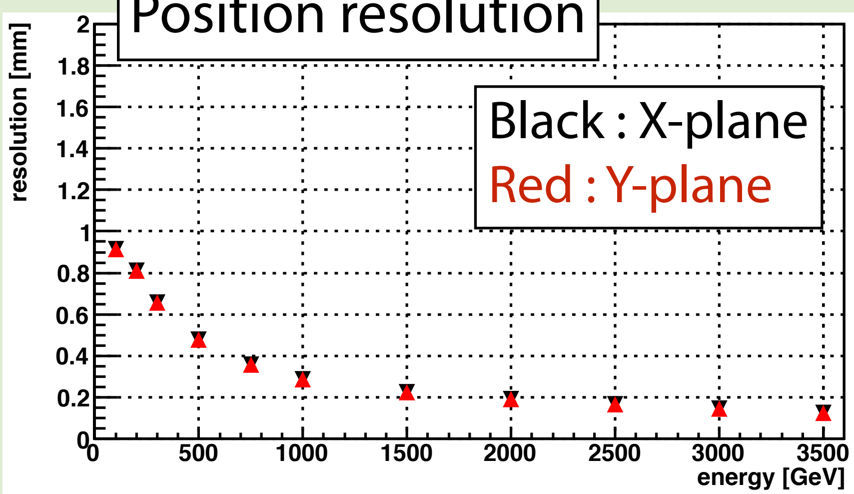
- Two independent detectors (Arm1 and Arm2) are located in TAN to measure the ***very forward particles***:
  - $\eta>8.7$ w/o crossing angle, >8.4 with crossing angle
  - $p_T<1.0$GeV at $\sqrt{s}$=7TeV.
- Sampling calorimeter + position sensitive detector.
- Charged particles are swept away due to the D1 magnet, so we can only observe neutral particles (photon and neutron).
- Same detectors have been used since 2009.

Detector performances

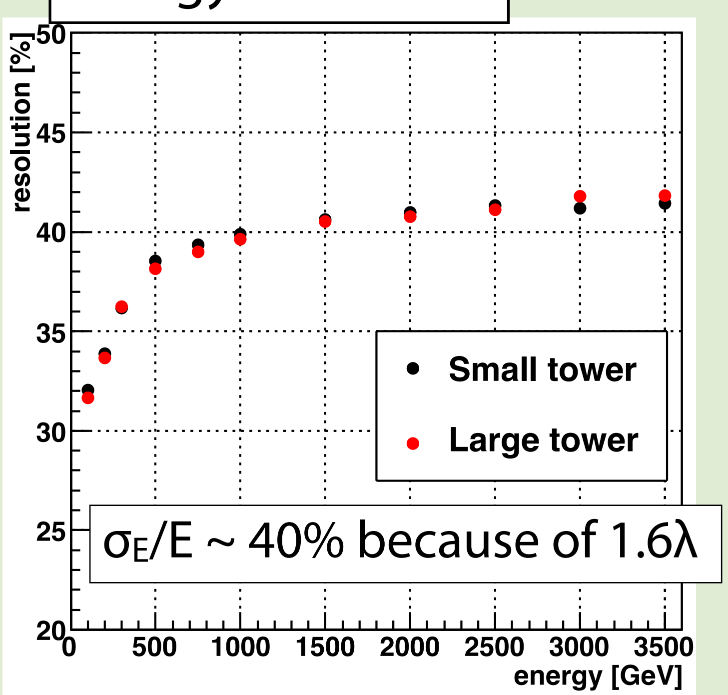


Hadronic shower (MC)

Position resolution



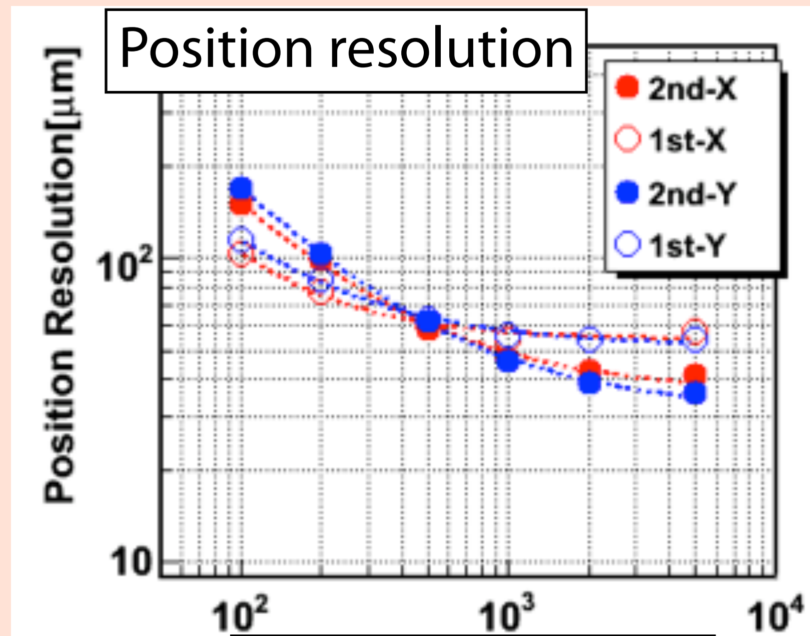
Energy resolution



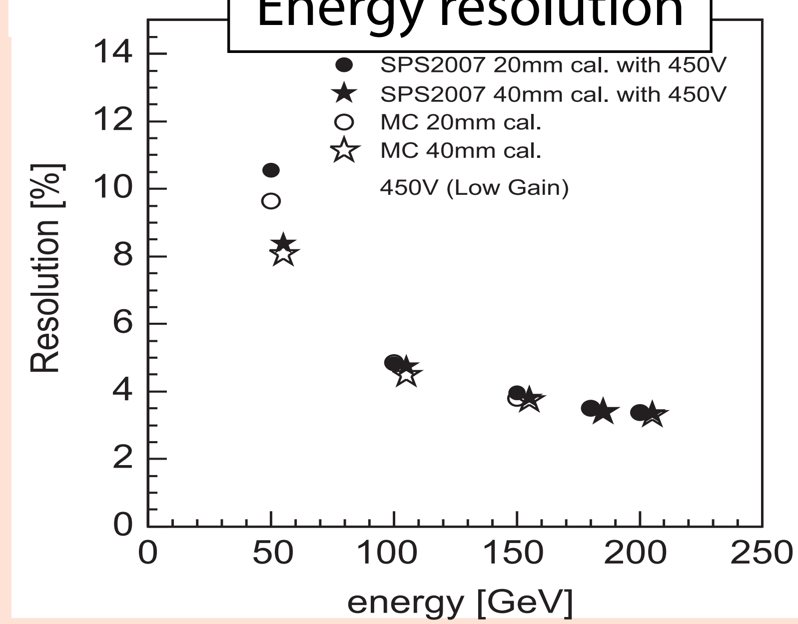
σ_E/E ~ 40% because of 1.6λ

EM shower (MC)

Position resolution

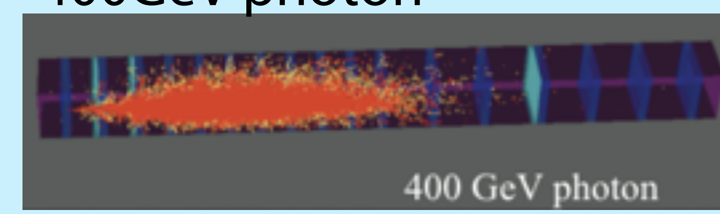


Energy resolution

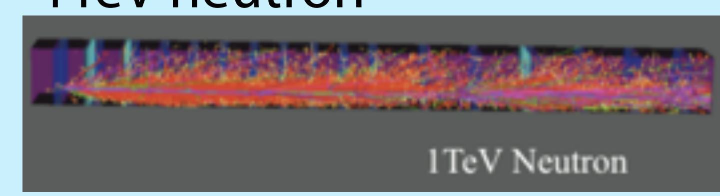


PID technique

400GeV photon

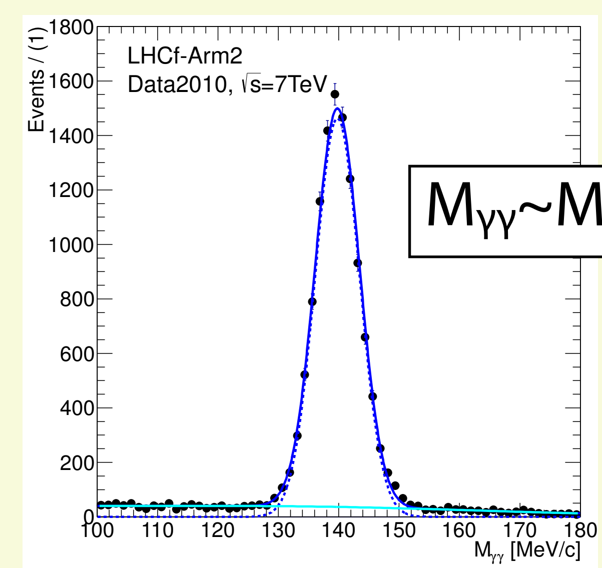


1TeV neutron



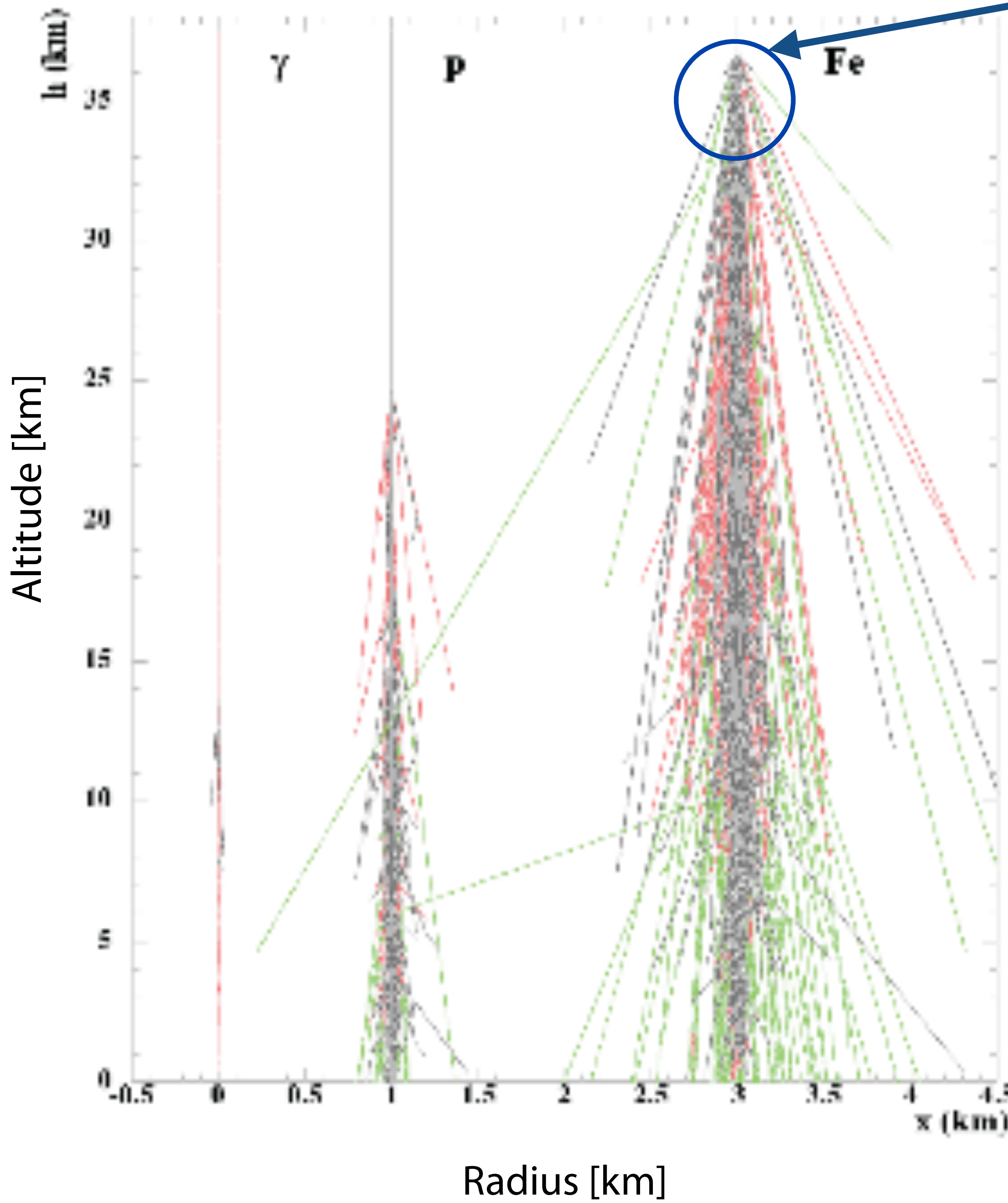
Identification of incoming particle by shower shape

π^0 reconstruction

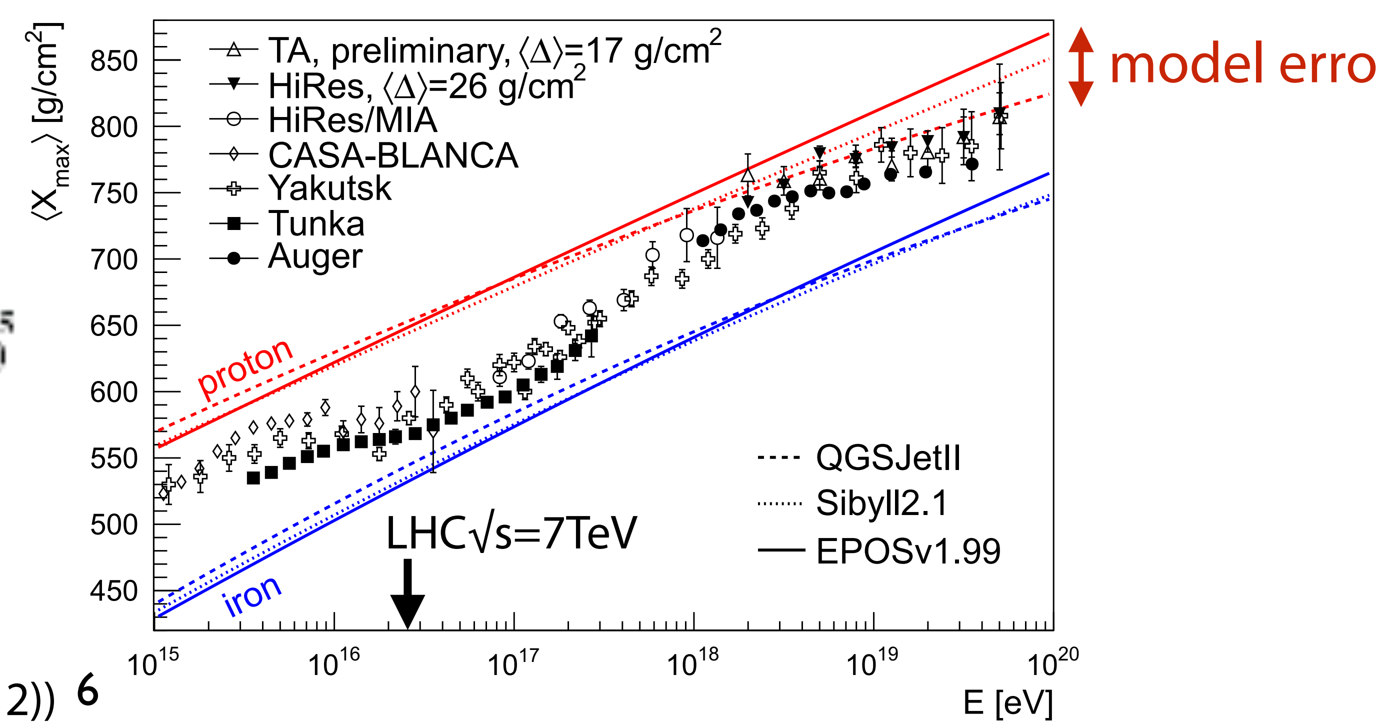


$M_{\gamma\gamma} \sim M_{\pi 0}$

Physics motivation (cosmic ray point of view)



1. **Inelastic cross section** (by TOTEM)
   large → rapid development
   small → deep penetrating
2. **Inelasticity $k = 1 - p_{lead}/p_{beam}$** — neutron (~leading baryon)
   large → rapid development
   small → deep penetrating
3. **Forward energy spectrum** — photon or π^0
   softer → rapid development
   harder → deep penetrating
4. **Nuclear effects** — p-Pb collisions
5. **Extrapolation to high energy** — many data points
   precise measurements in lower energies are crucial



(Kampert and Unger, Astropartphys. 35, 660, (2012))

Physics and test beam analysis at LHCf

	Photon (EM shower)	Neutron (hadron shower)	π (EM shower)
Test beam at SPS	NIM. A 671, 129–136 (2012)	arXiv:1312.5950 (accepted by JINST)	
p-p at 900GeV	Phys. Lett. B 715, 298-303 (2012)		
p-p at 7TeV	Phys. Lett. B 703, 128–134 (2011)	Today's report	Phys. Rev. D 86, 092001 (2012)
p-p at 2.76TeV			Today's report
p-Pb at 5.02TeV			Today's report

- LHC's analysis activity was so far directed to the EM shower events for its simplicity.
- We have extended the activity to neutron event analysis based on improved tools.
- Also we show the preliminary analysis results in p-Pb collisions.

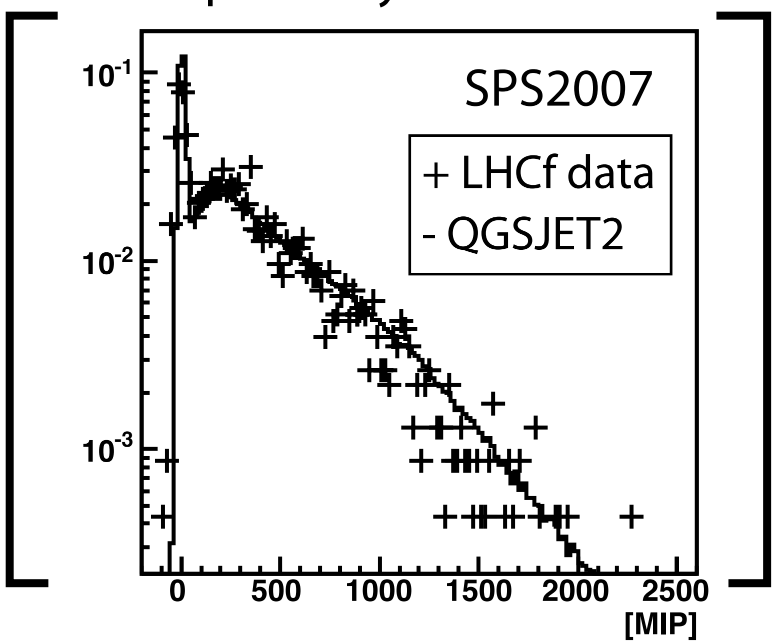
Analysis on the other parts are ongoing.

Neutron event reconstruction

Neutron energy reconstruction

example at layer8th

$$\sum_{l=2}^{15}$$



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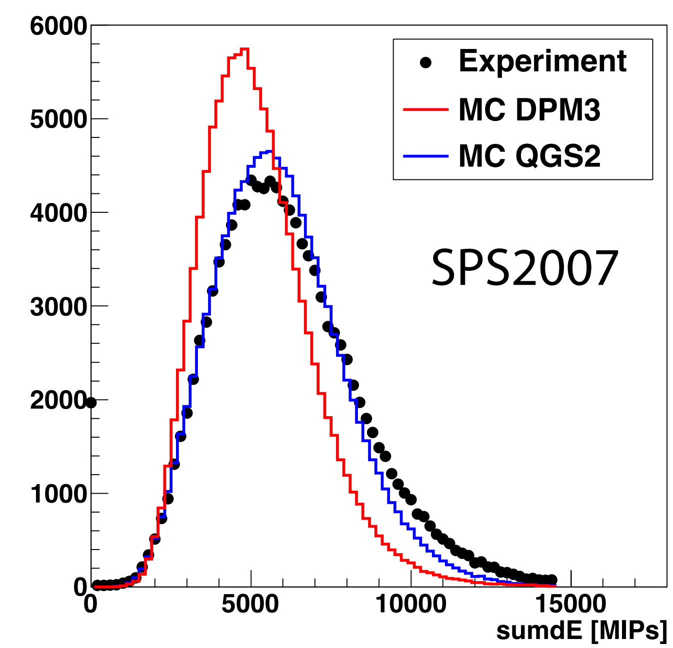
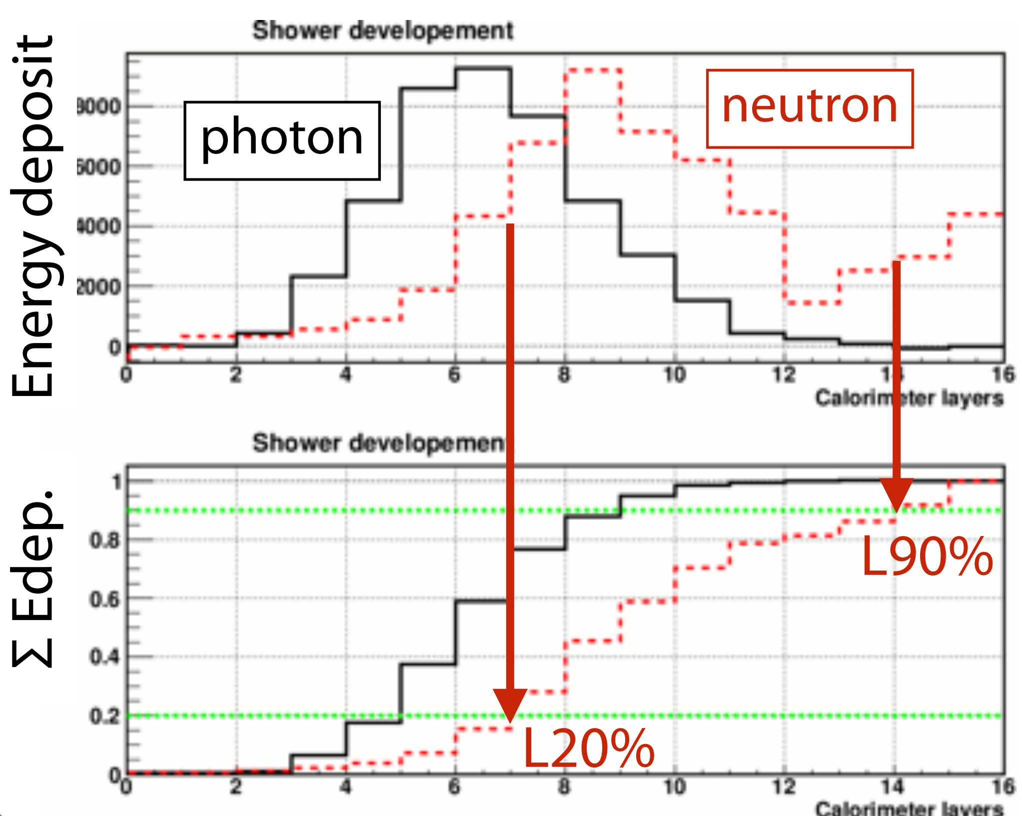
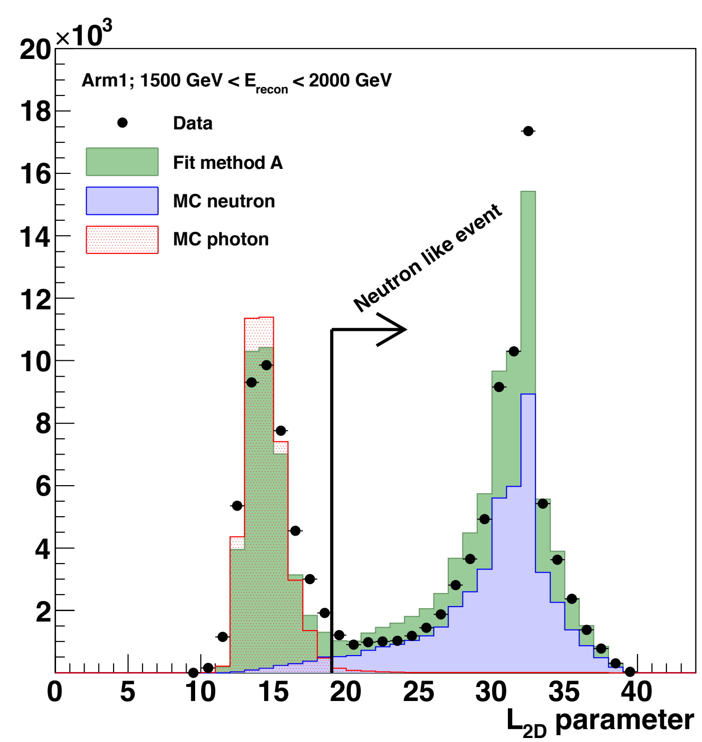


- Neutron energy is reconstructed by a sum of energy deposits.
- Detector simulation based on QGSJET2 for hadronic shower reproduces the test beam data better than that on DPMJET3.
- Difference between QGSJET2 and the test beam data is taken into account as a systematic error in the latter analysis.

Particle identification

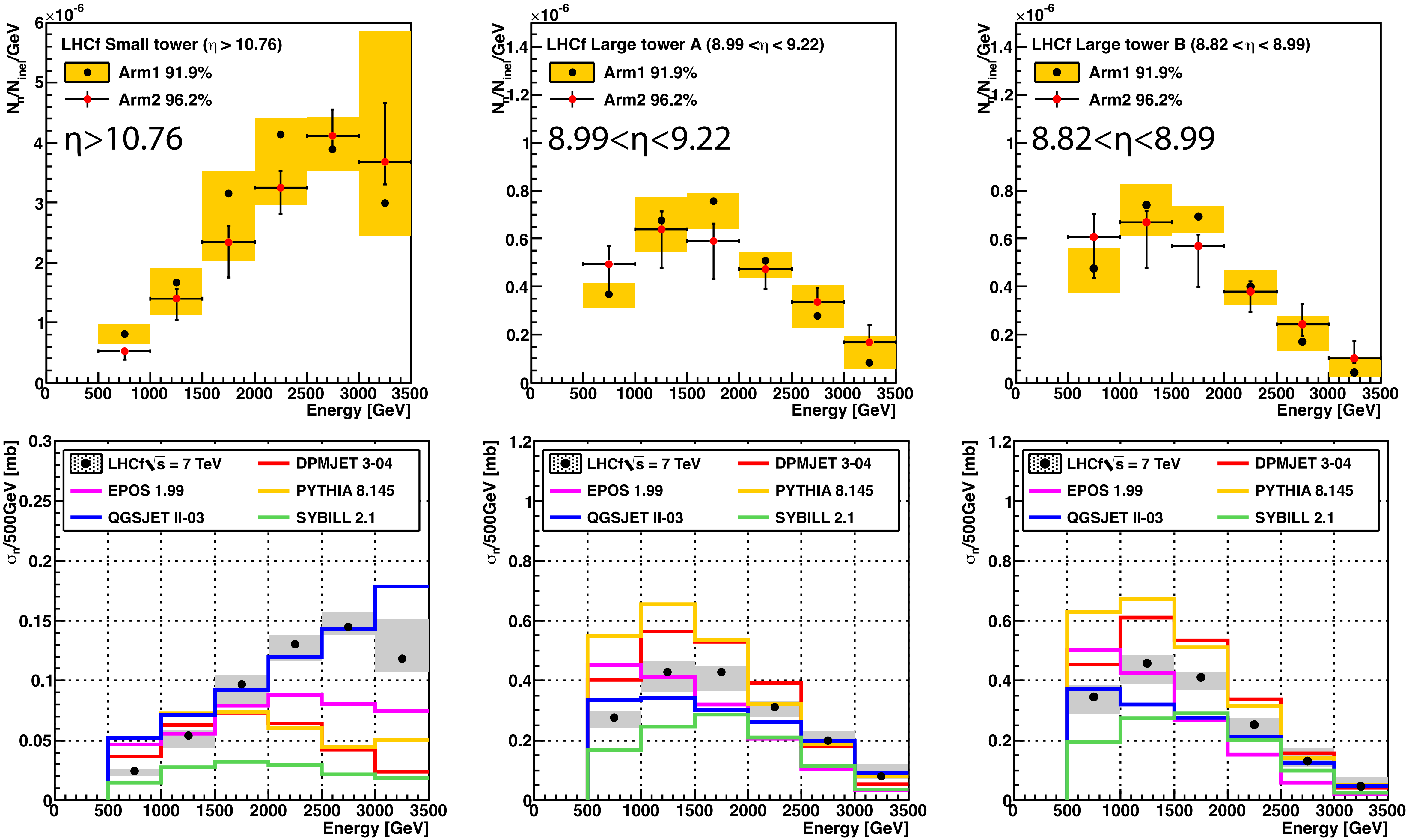




L_{2D} = L90%-0.25*L20%

- With two variables, L90% and L20%, PID performance is improved to reduce the photon contamination in neutron events.
- PID efficiency and purity are >90%.
- Energy spectra are corrected for PID inefficiency and BG contamination.

Neutron energy spectra in p-p collisions

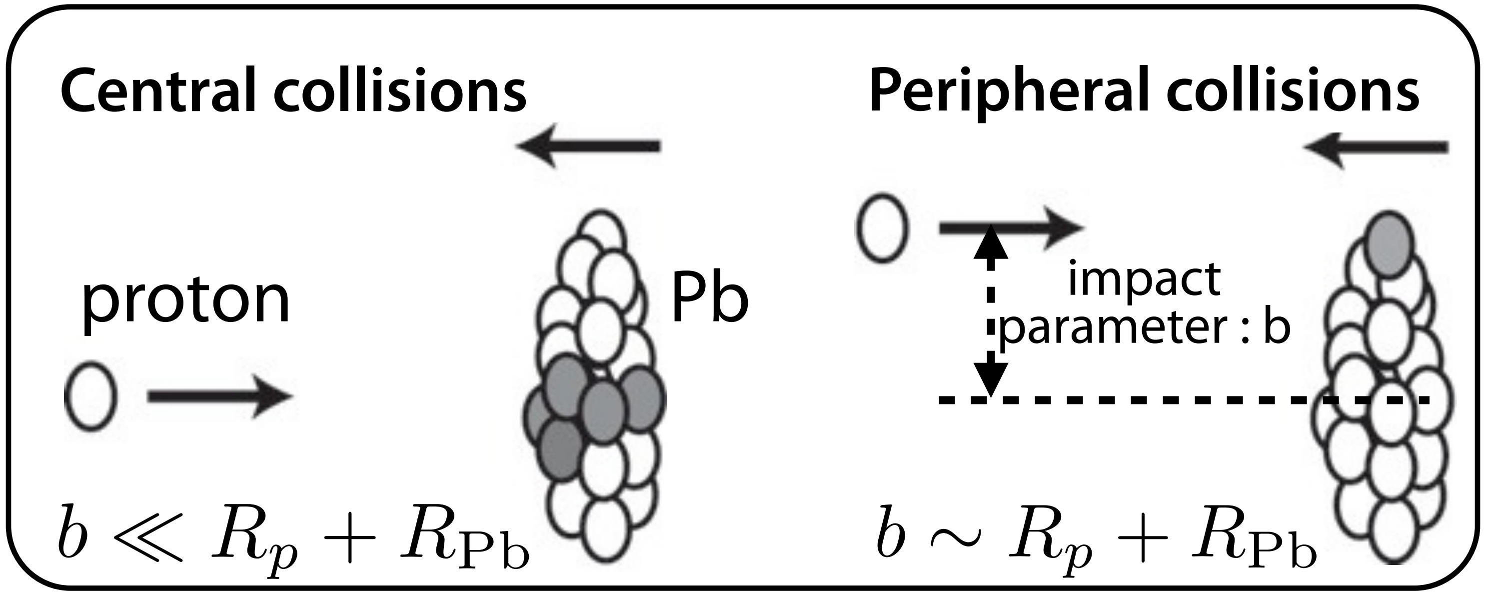


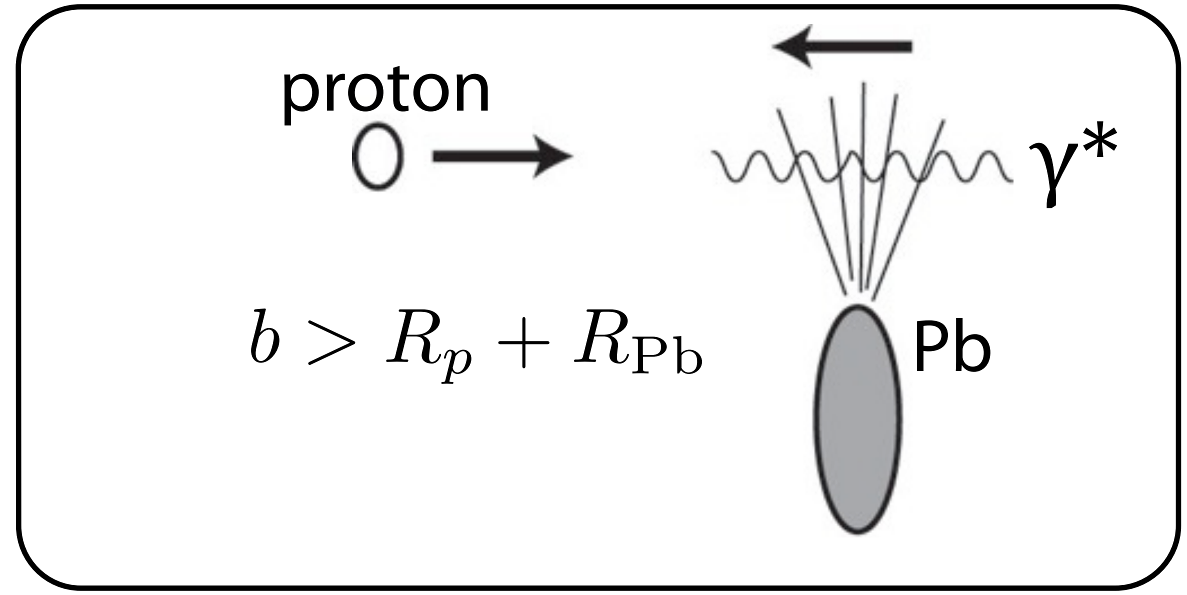
- LHCf Arm1 and Arm2 agree with each other within systematic error, in which the energy scale uncertainty dominates.
- In η>10.76 huge amount of neutron exists. Only QGSJET2 reproduces the LHCf result.
- In other rapidity regions, the LHCf results are enclosed by the variation of models.

π^0 event analysis in p-Pb collisions

(Soft) QCD :
central and peripheral collisions

Ultra peripheral collisions :
virtual photon from rel. Pb collides a proton.



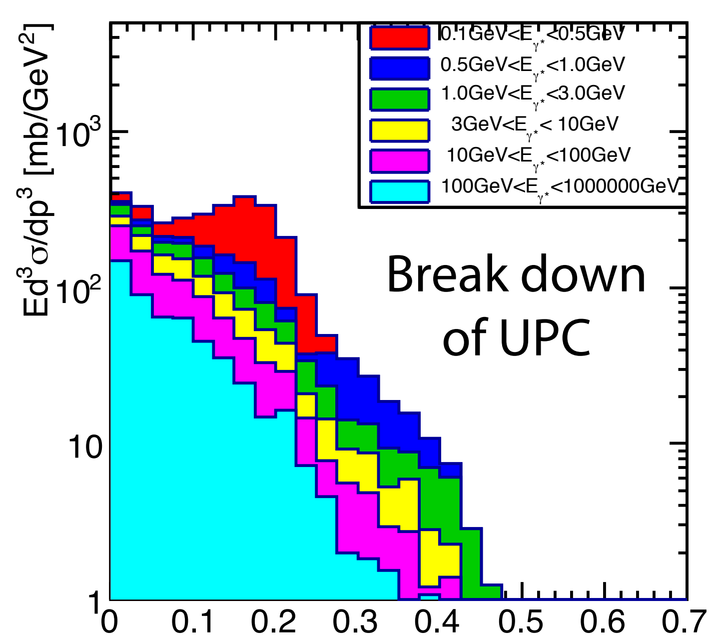


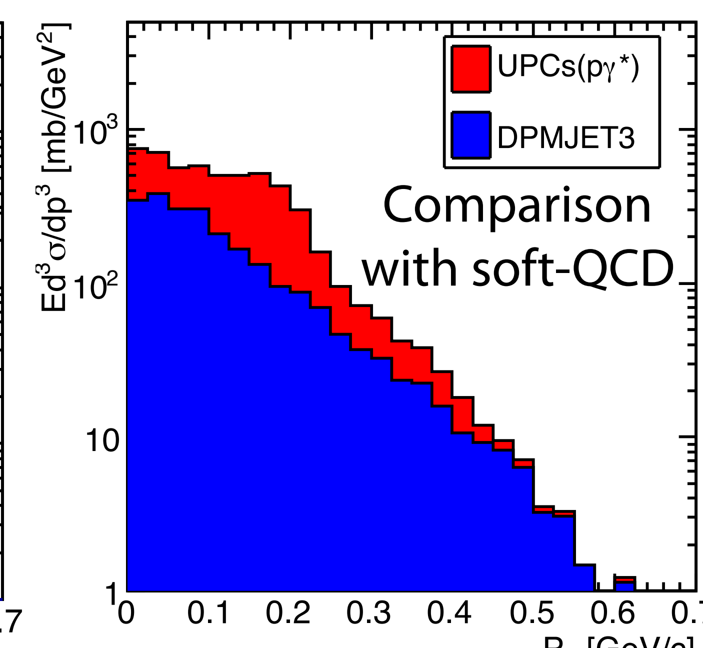
Momentum distribution of the UPC induced secondary particles is estimated as

1. energy distribution of virtual photons is estimated by the Weizsacker Williams approximation.
2. photon-proton collisions are simulated by the SOHIA model (E_γ > pion threshold).
3. produced mesons and baryons by γ-p collisions are boosted along the proton beam.

(1.–2.: proton rest frame)

Dominant channel to forward π^0 is
$\gamma + p \rightarrow \Delta(1232) \rightarrow p + \pi^0$
About half of the observed π^0 may originate in UPC, another half is from soft-QCD.

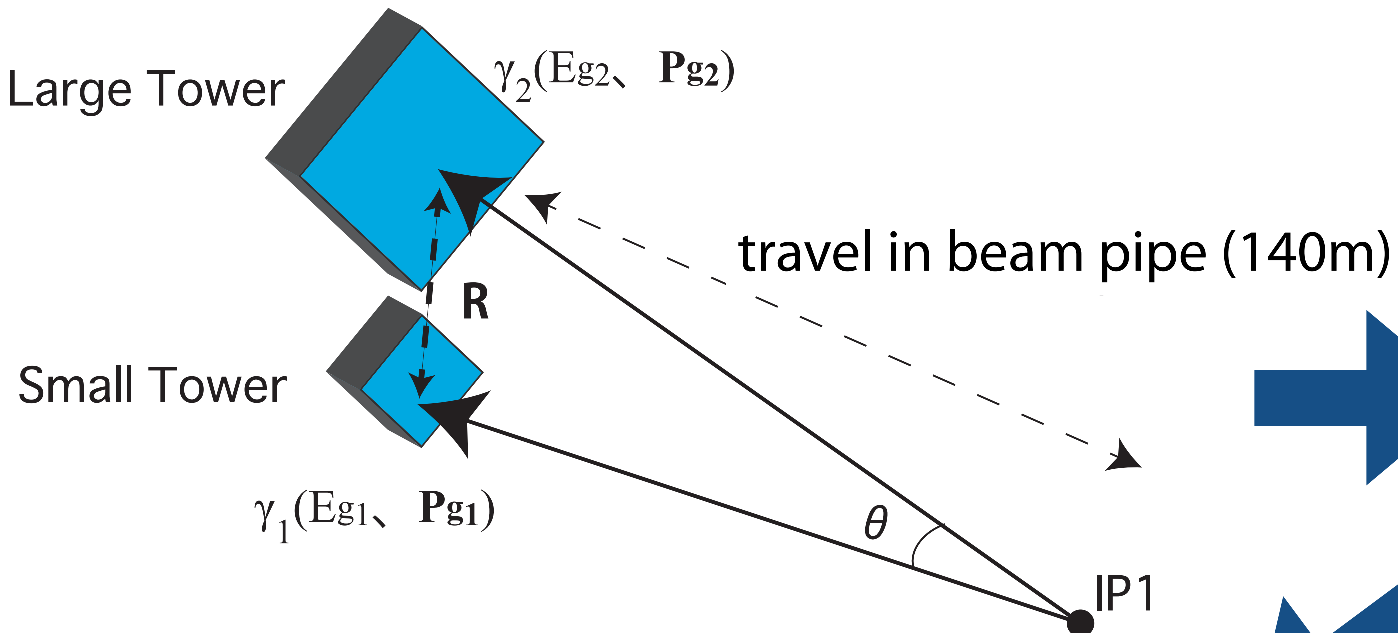




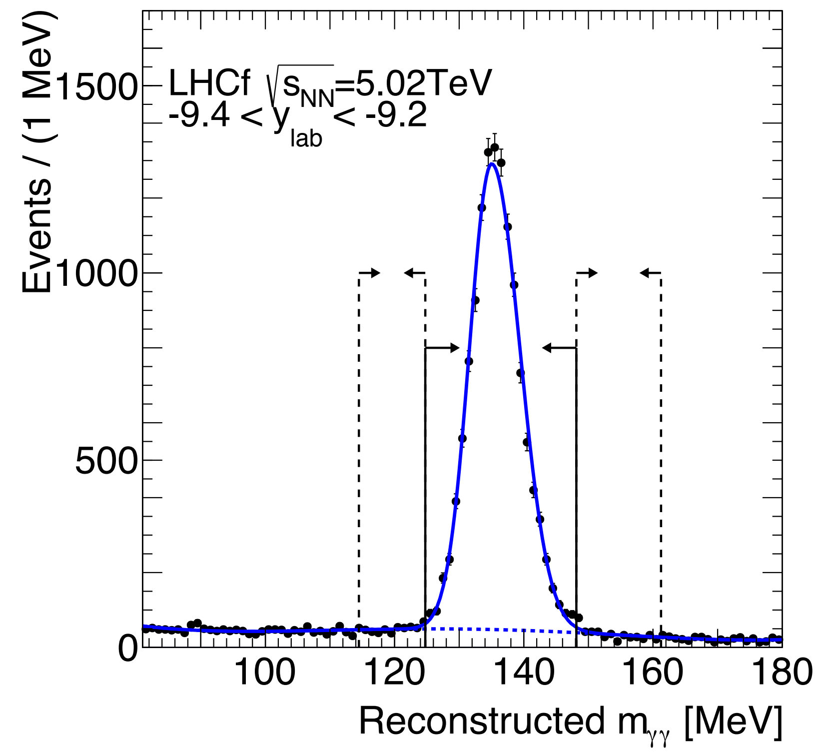
Preliminary

π^0 event reconstruction in p-Pb collisions

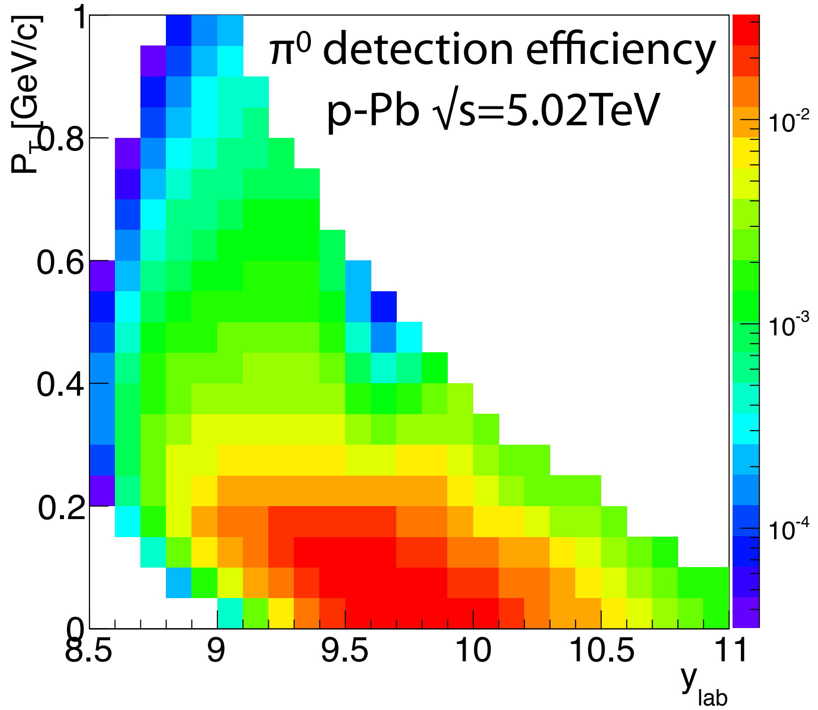
1. Search for two photons



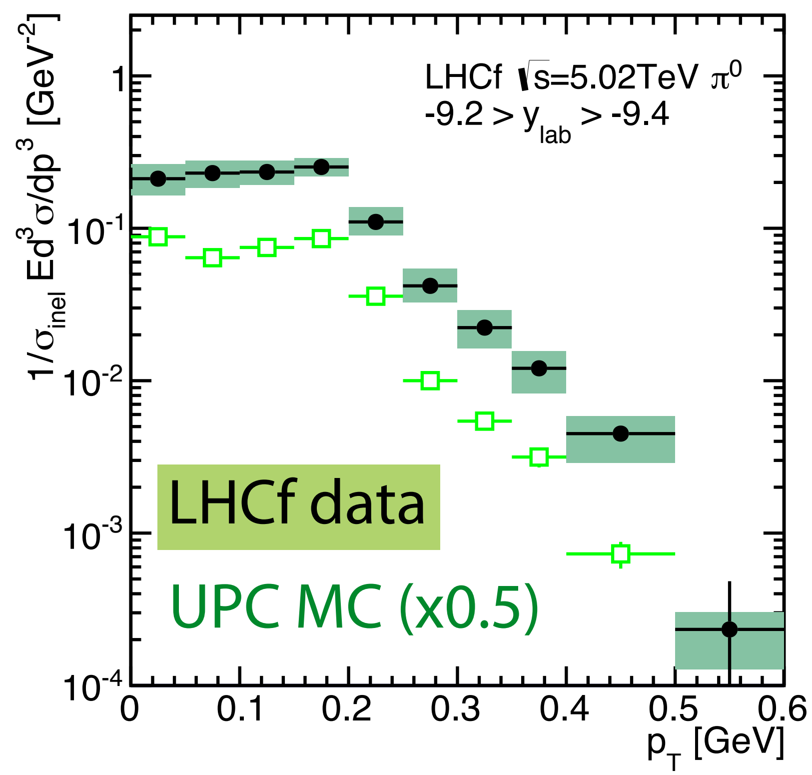
2. BG subtraction by sideband



3. Unfolding the smeared pT spectra and correction for geometrical inefficiency

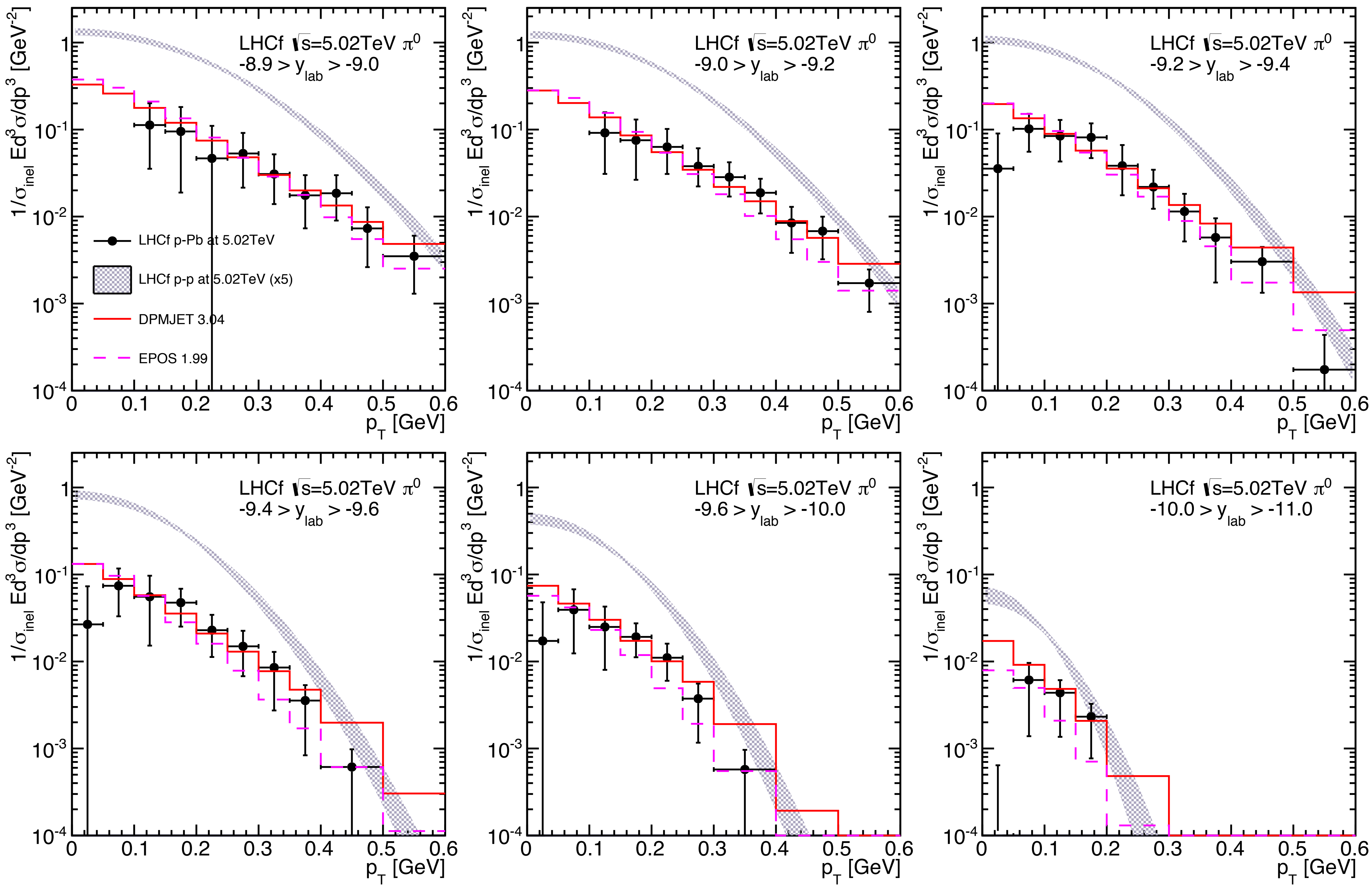


4. Subtraction of the UPC component



Preliminary

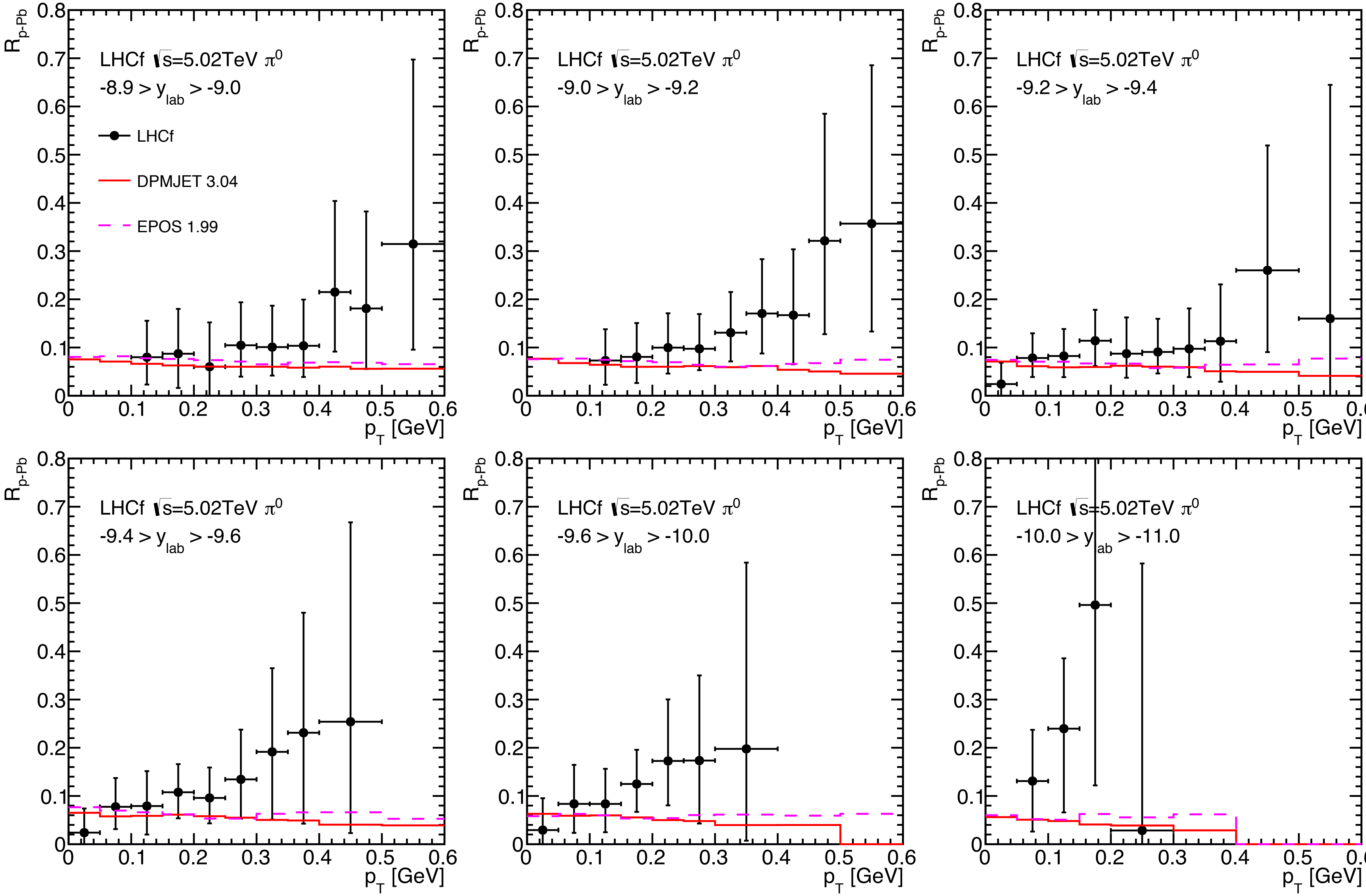
π^0 p_T spectra after the UPC subtraction



- The LHCf results in p-Pb (filled circles) show good agreement with DPMJET and EPOS. Note that UPC induced events are not involved in DPMJET and EPOS.
- The LHCf results in p-Pb are clearly harder than the LHCf results in p-p at 5.02TeV (shaded area) which are interpolated from the results at 2.76TeV and 7TeV.

Preliminary

Nuclear modification factor



$$R_{\mathrm{pPb}}(p_{\mathrm{T}}) \equiv \frac{d^2 N^{\mathrm{pPb}}_{\pi^0}/dy dp_{\mathrm{T}}}{\langle N_{\mathrm{coll}}\rangle d^2 N^{\mathrm{pp}}_{\pi^0}/dy dp_{\mathrm{T}}}$$

$\langle N_{coll} \rangle = 6.9$

- Both LHCf and MCs show strong suppression.
- But LHCf grows as increasing p_T, understood by the softer p_T spectra in p-p at 5TeV than those in p-Pb.

Towards the next operation at 13TeV

The LHCf detectors will be upgraded giving a priority to **high energy operation.**

1. Radiation damage will be more severe; $0.2 Gy/nb^{-1}$ at 7TeV → $2\text{-}3 Gy/nb^{-1}$ at 13TeV.
   - All of plastic scintillators were replaced with GSO scintillators in both Arm1 and Arm2. GSO scintillator can survive up to 10^6Gy.
   - Scintillation fibers (SciFi, position detector in Arm1) were replaced with GSO bars.
2. Old silicon detector would be saturated for >1.5TeV photon (Arm2).
   - New wire bonding scheme to avoid saturation effects, pulse height was reduced ~60%
   - Rearrangement of the Si detector position for effectively catching EM/hadon showers.

All parts except for new Si modules are ready and their properties were tested by the test beams at HIMAC (HI beam facility in Japan) and SPS.

p-p 7TeV

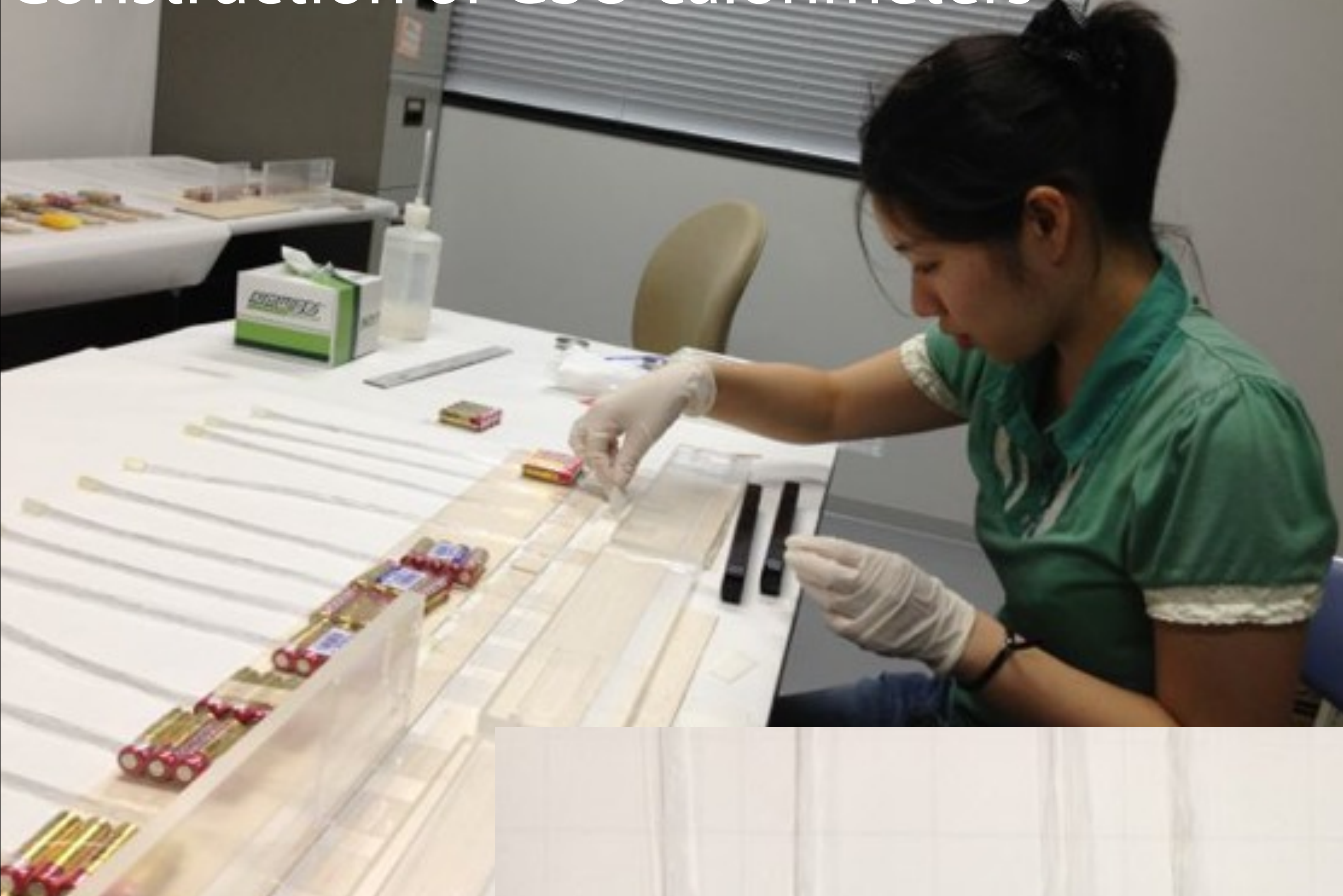
p-Pb 5.02TeV
p-p 2.76TeV

We are here

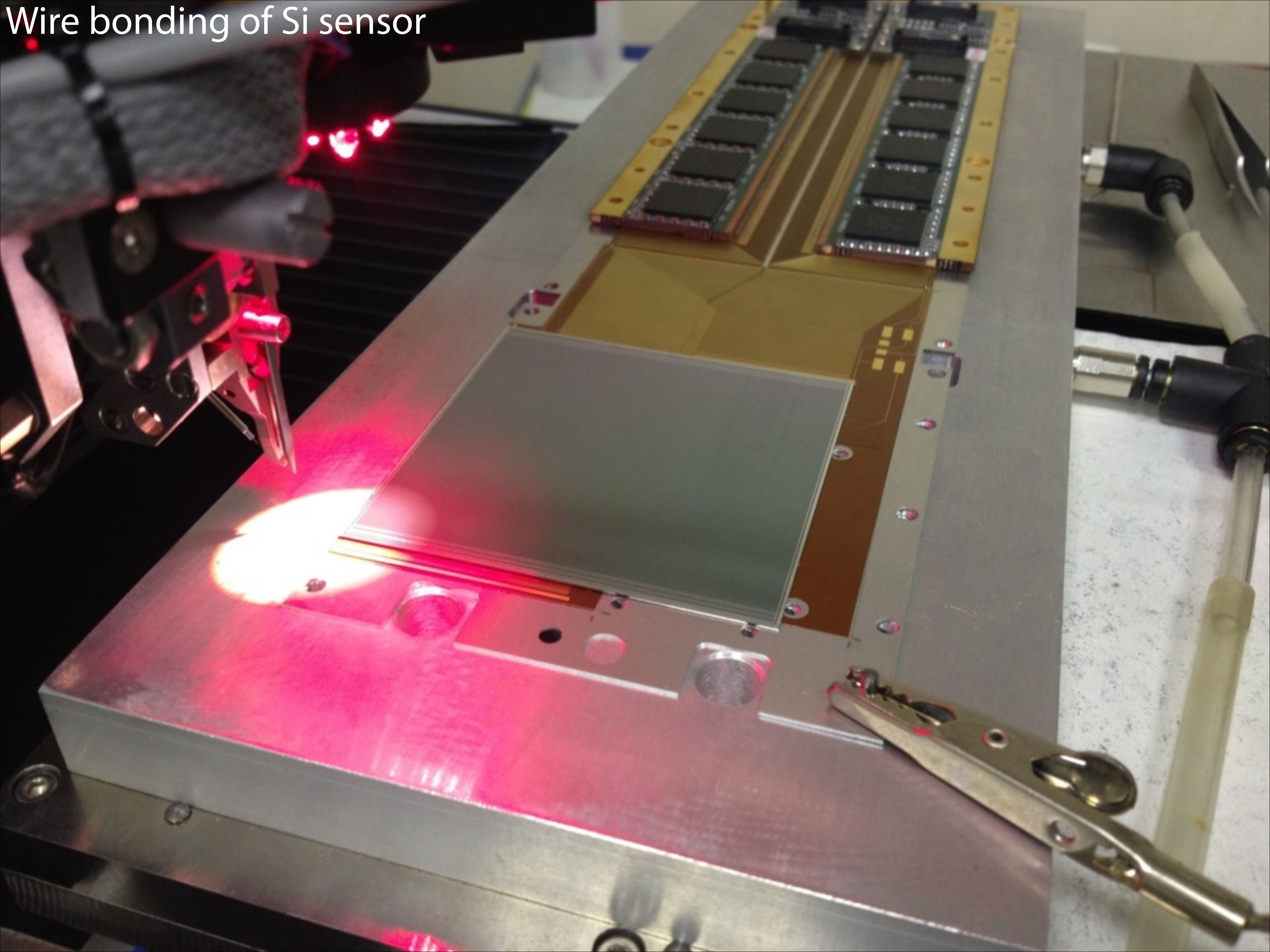
p-p 13TeV

	HIMAC Nov. 2011	HIMAC Jun. 2012	SPS Aug. 2012	HIMAC Jul. 2013	HIMAC Feb. 2014	LNS (Catania) Summer2014	SPS Oct. 2014
Arm1	GSO scinti.	GSO scinti. GSO bar (2/4)	GSO scinti. GSO bar (2/4)		GSO bar (4/4)		Full detector
Arm2		Old detector	Plastic scinti.	GSO scinti.		New Silicon	Full detector

Construction of GSO calorimeters



Wire bonding of Si sensor



Summary

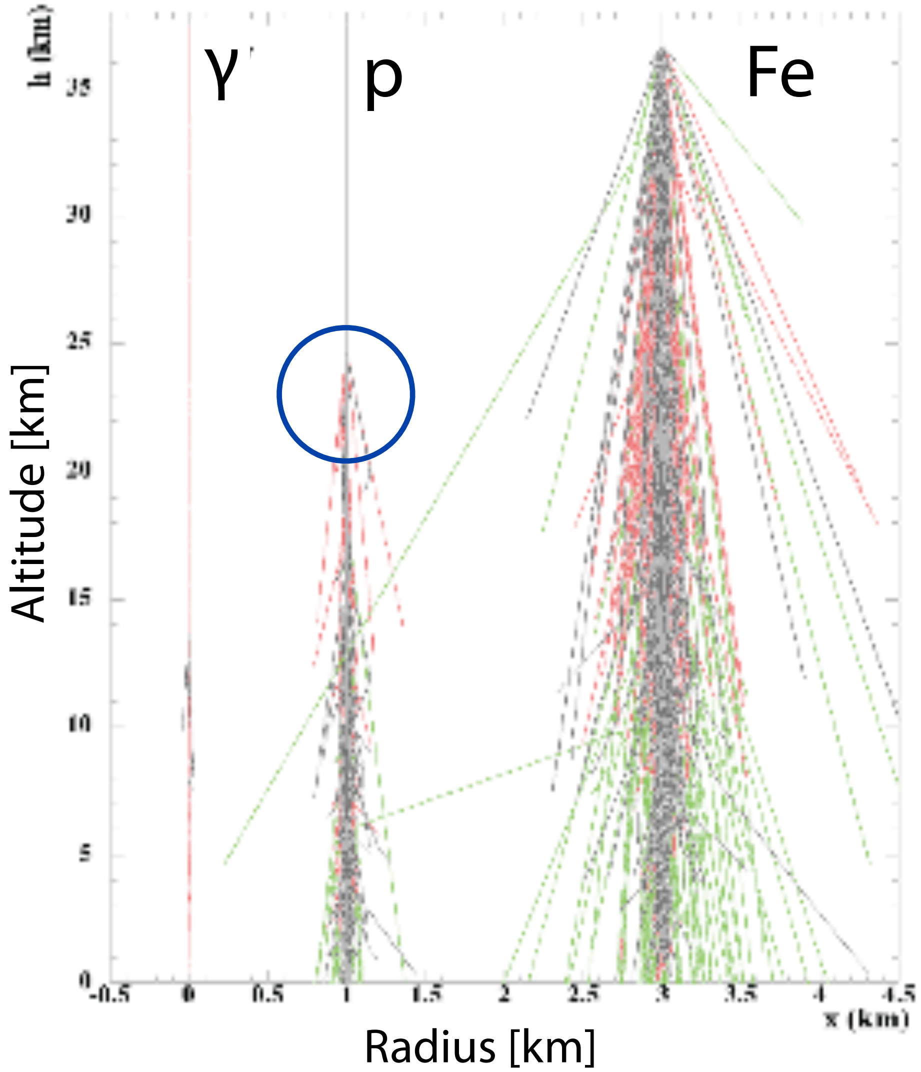
- Data analyses on many channels are ongoing.
  - Large yield of neutrons is recognized $\eta>10.76$.
  - Strong suppression of π^0 production is consistent with predictions.

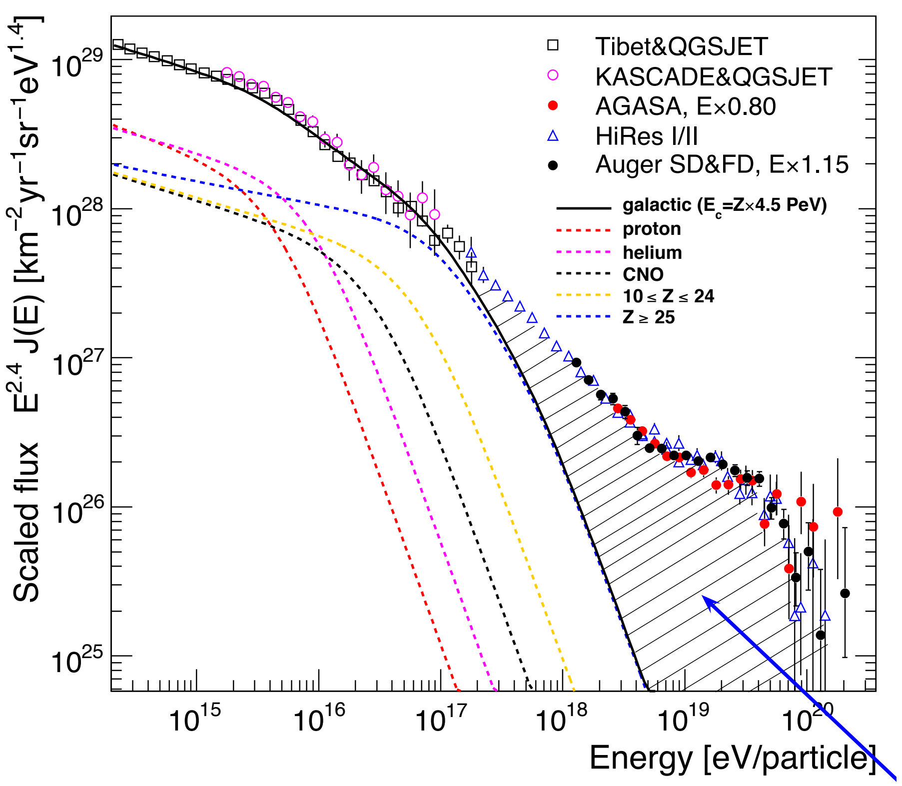
- Detector upgrade has been proceeded smoothly. We will have two beam tests at LNS-Catania for new Si modules and at SPS for the fully upgraded LHCf detectors.

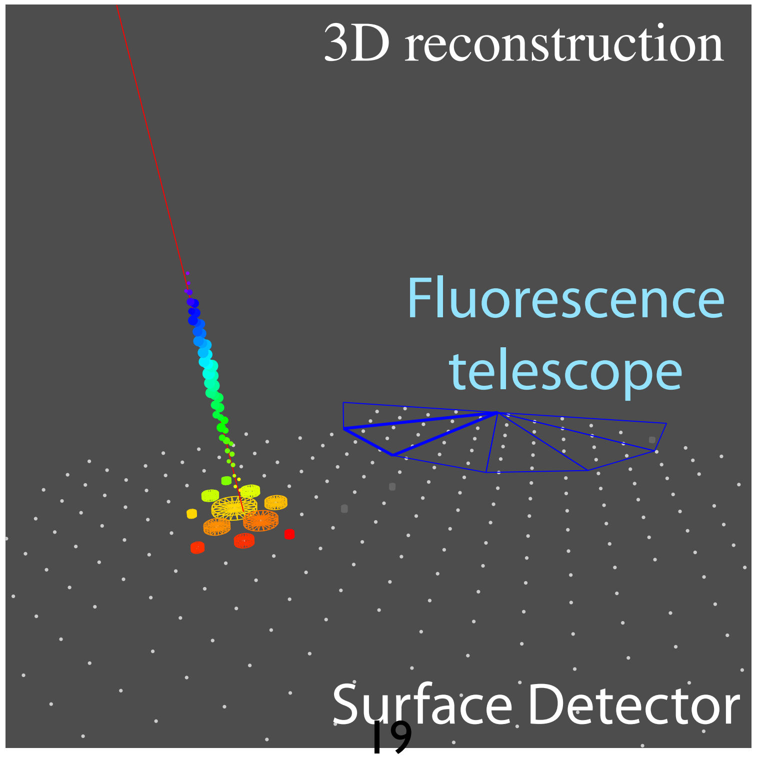
Backup

Measurement of cosmic rays

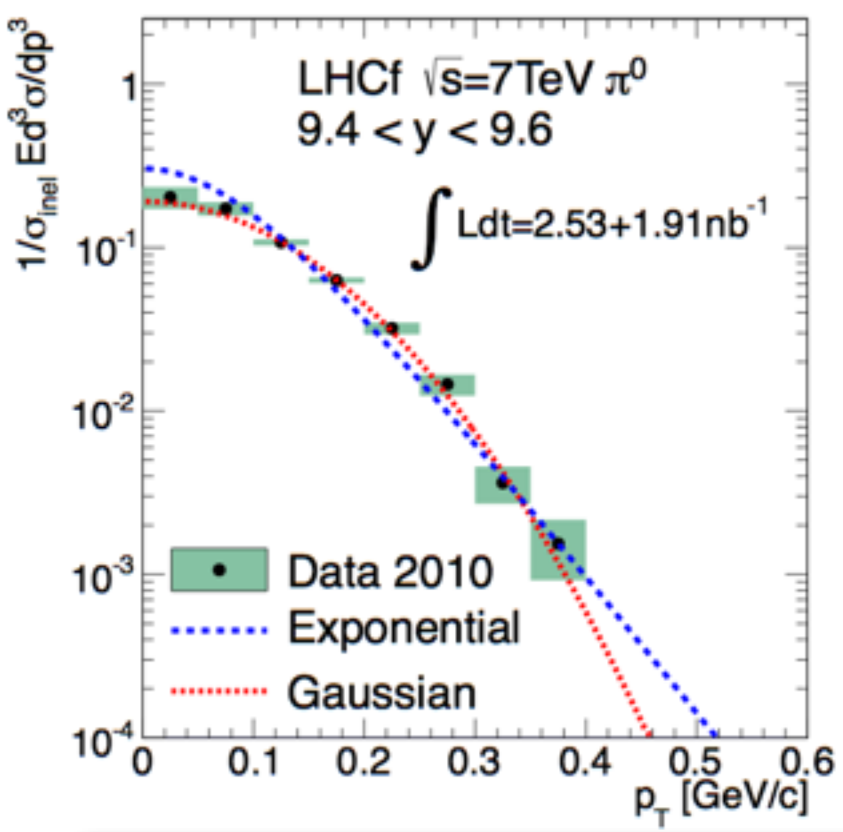
- Direct* measurement (e.g. ballon, AMS etc.) of cosmic rays is quite severe above $E_{lab}=10^{14}$eV.
- Instead, indirect measurement observing cascade showers of daughter particles (extensive air-shower, EAS) is the best way to increase statistics.
- Largest systematic uncertainty of indirect measurement is caused by a finite understanding of the hadronic interaction of cosmic ray in atmosphere (because very high energy and very forward).

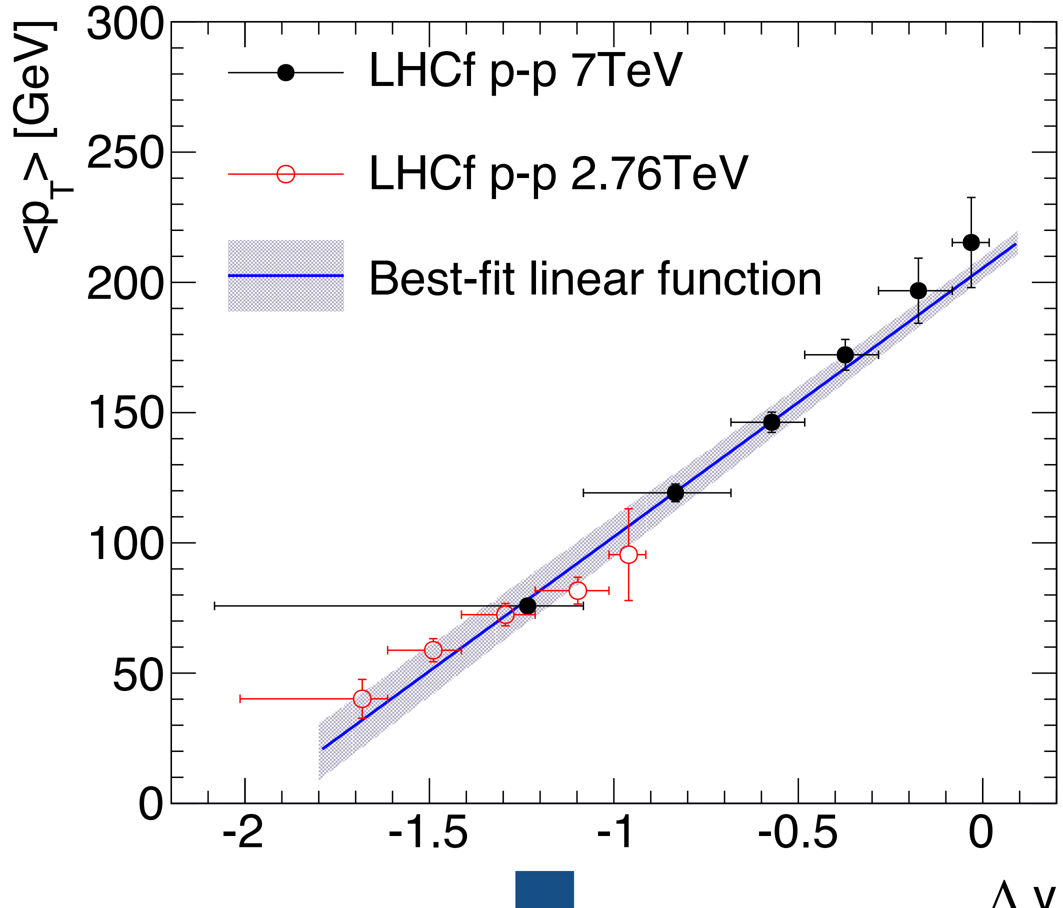






Derivation of p_T spectra in p-p at 5.02TeV





$$(\Delta y \equiv y_{\mathrm{beam}} - y)$$

1. Thermodynamics (Hagedron model)

$$\frac{1}{\sigma_{\mathrm{inel}}} E \frac{d^3\sigma}{dp^3} = A \cdot \exp(-\sqrt{{p_{\mathrm{T}}}^2 + m_{\pi^0}^2}/T)$$

$$\langle p_{\mathrm{T}} \rangle = \sqrt{\frac{\pi m_{\pi^0} T}{2}} \frac{K_2(m_{\pi^0}/T)}{K_{3/2}(m_{\pi^0}/T)}$$

2. Gauss distribution

$$\frac{1}{\sigma_{\mathrm{inel}}} E \frac{d^3\sigma}{dp^3} = A \cdot \frac{\exp(-p_{\mathrm{T}}^2/\sigma_{\mathrm{Gauss}}^2)}{\pi \sigma_{\mathrm{Gauss}}^2}$$

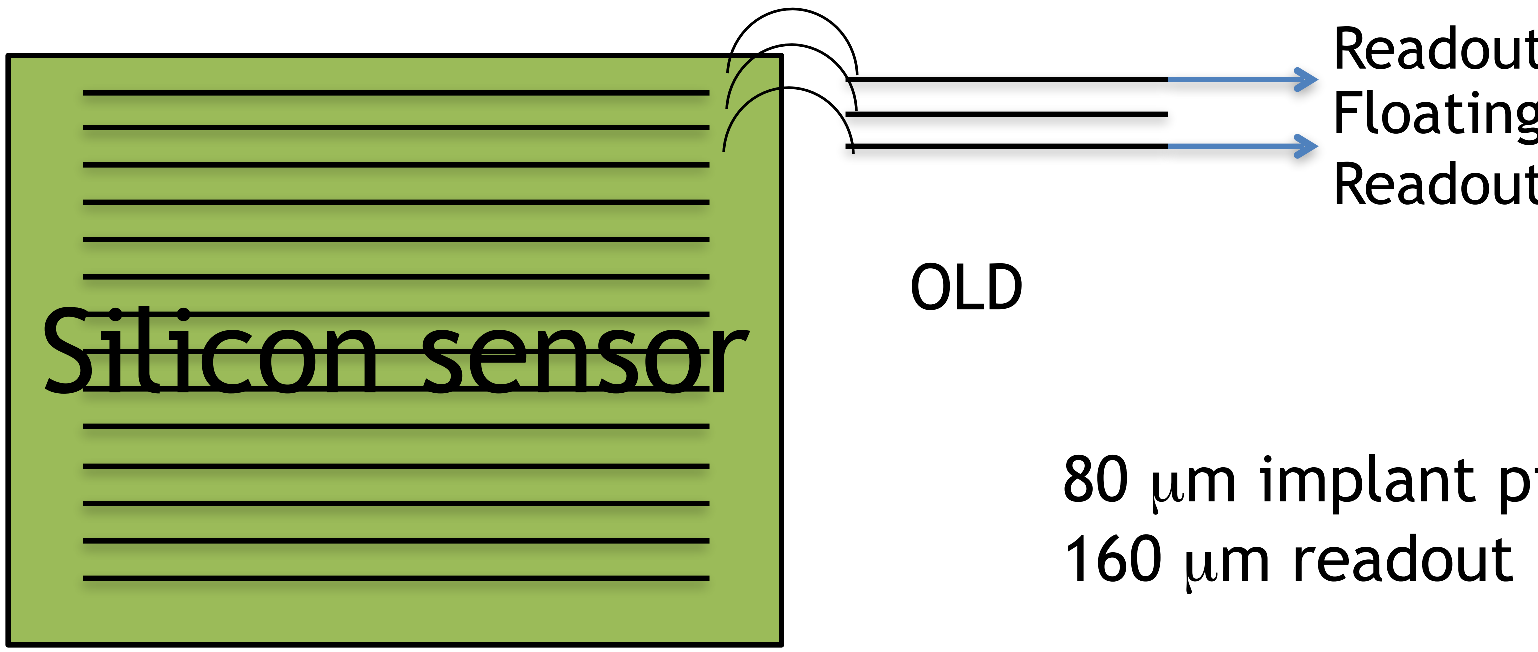
$$\langle p_{\mathrm{T}} \rangle = \frac{\sqrt{\pi}}{2} \sigma_{\mathrm{Gauss}}$$

$$\langle p_{\mathrm{T}} \rangle (y)|_{5.02\mathrm{TeV}} = 216.3 + 116.0(8.585 - y)\ [\mathrm{MeV}]$$

The pT spectra in "p-p at 5.02TeV" are obtained by the Gauss distribution with the above $<p_T>$.

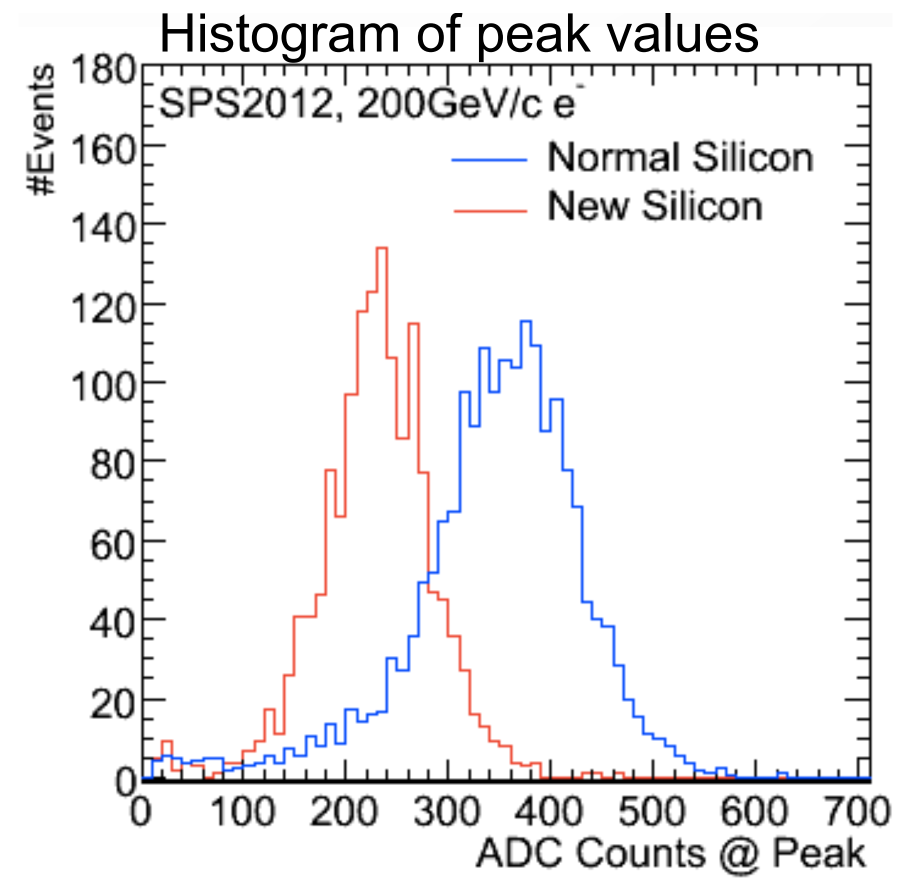
The idea for the new silicon planes

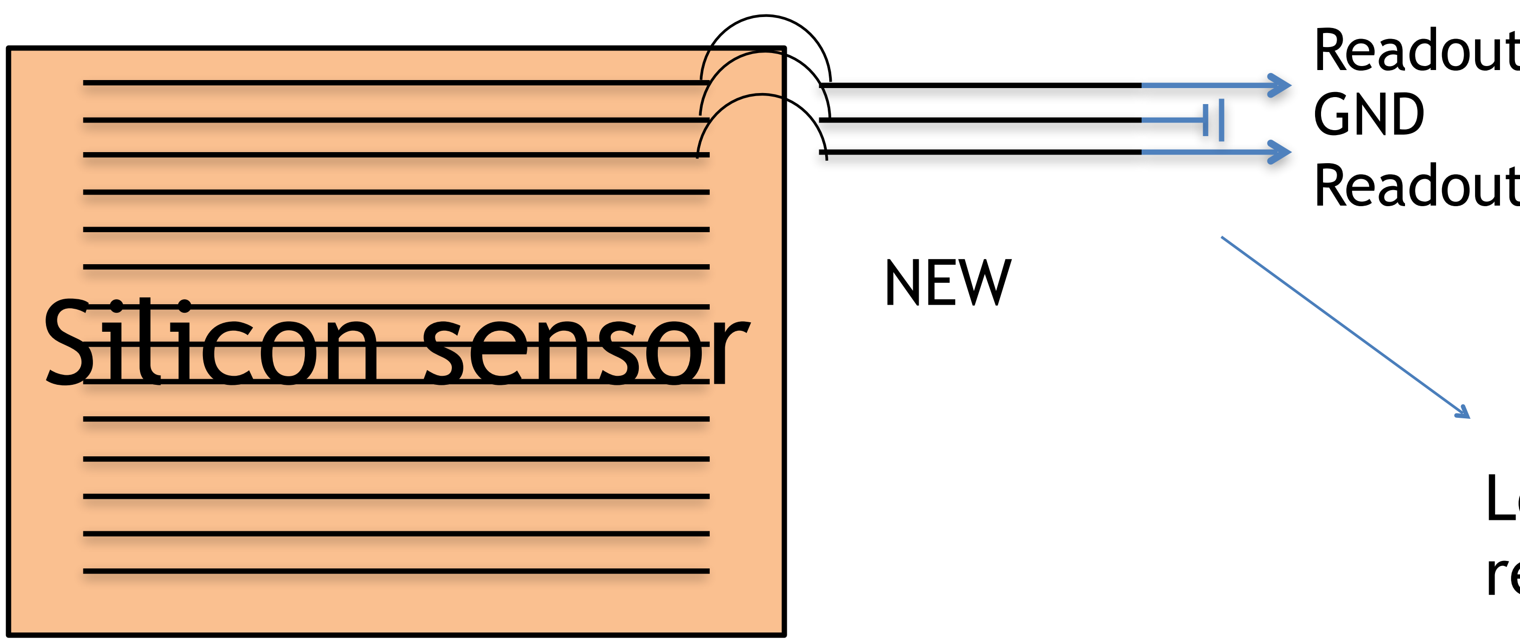
In the original scheme one strip over two was connected to the front-end electronics and the other strips were floating.



OLD

80 μm implant pitch
160 μm readout pitch



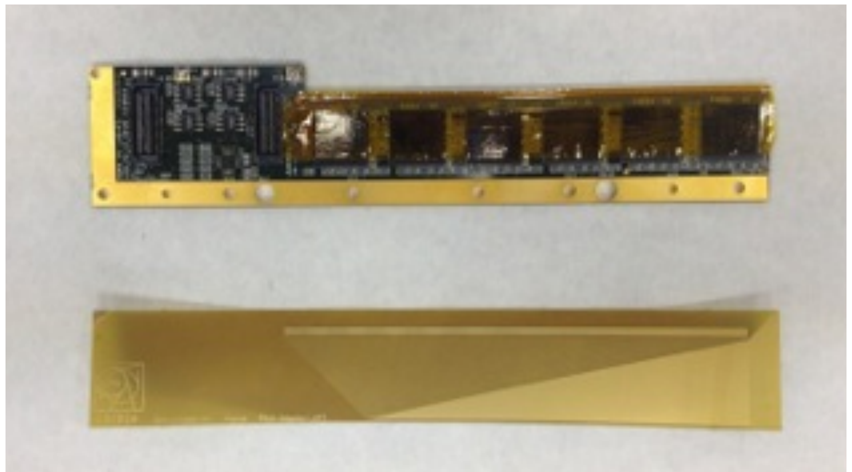


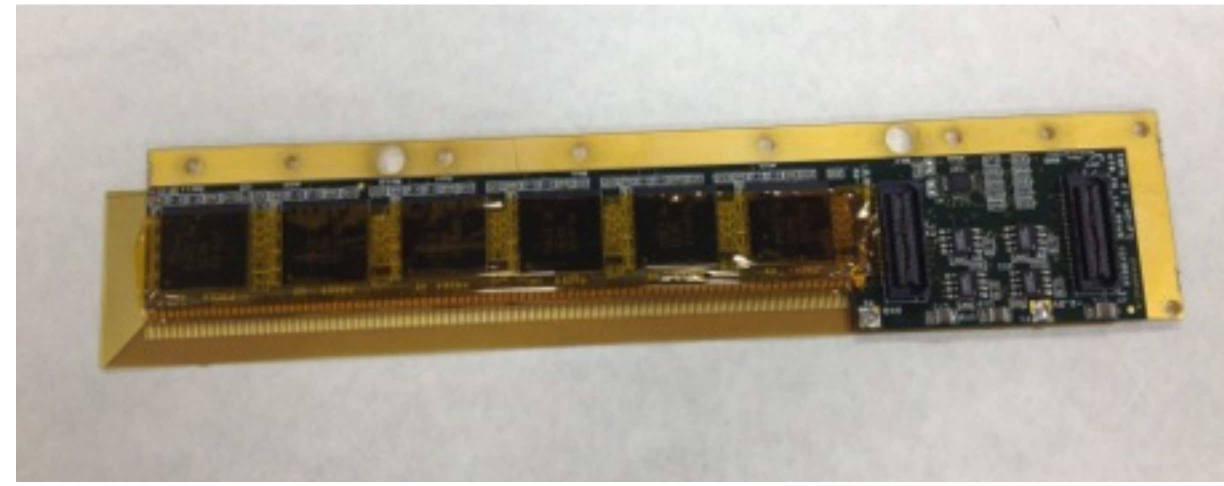
NEW

Loosing some part of the released energy

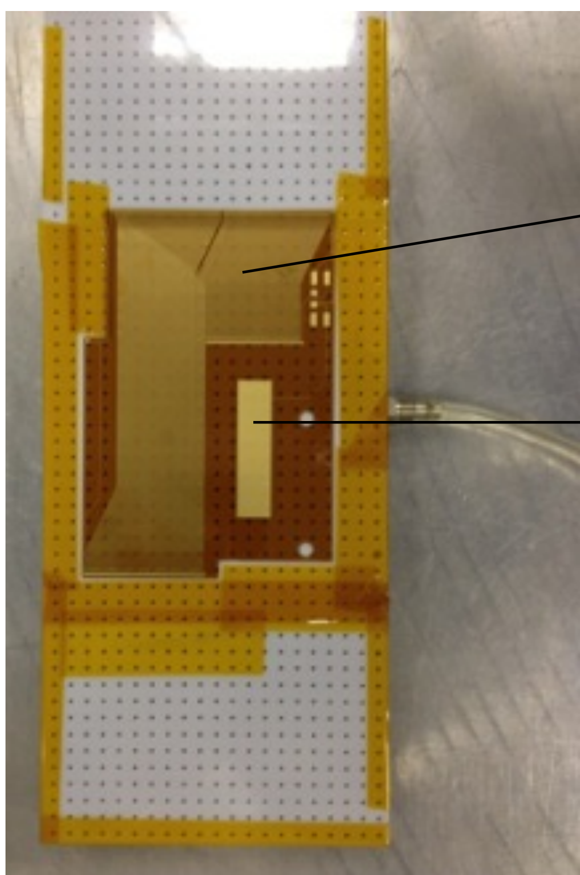
Assembling of new silicon planes

Gluing of **NEW** type hybrid circuits to old type kapton fanout



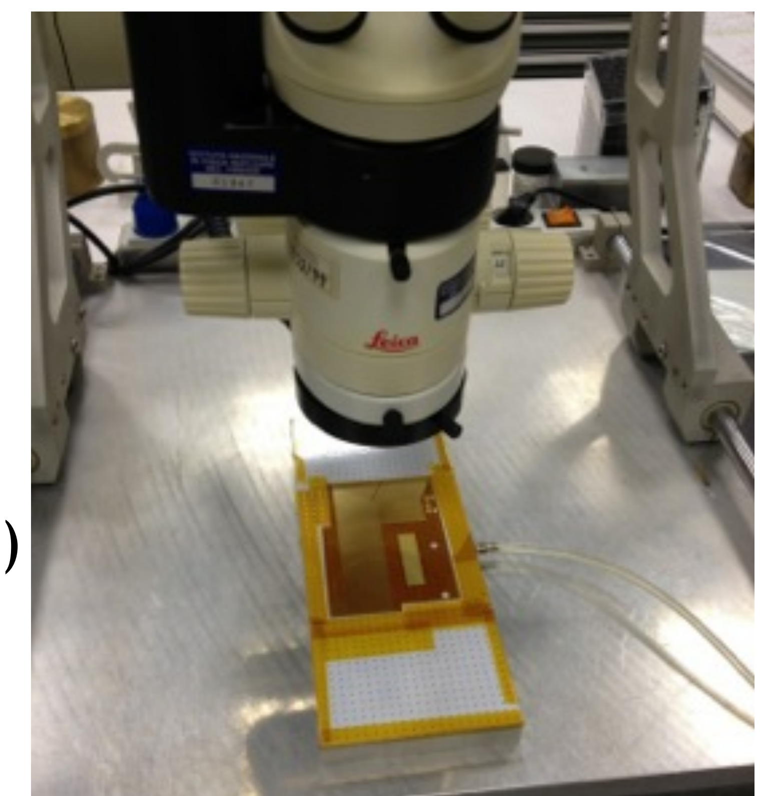


Gluing of silicon layers to the **NEW** kapton fanout (with GND pads for charge loss)

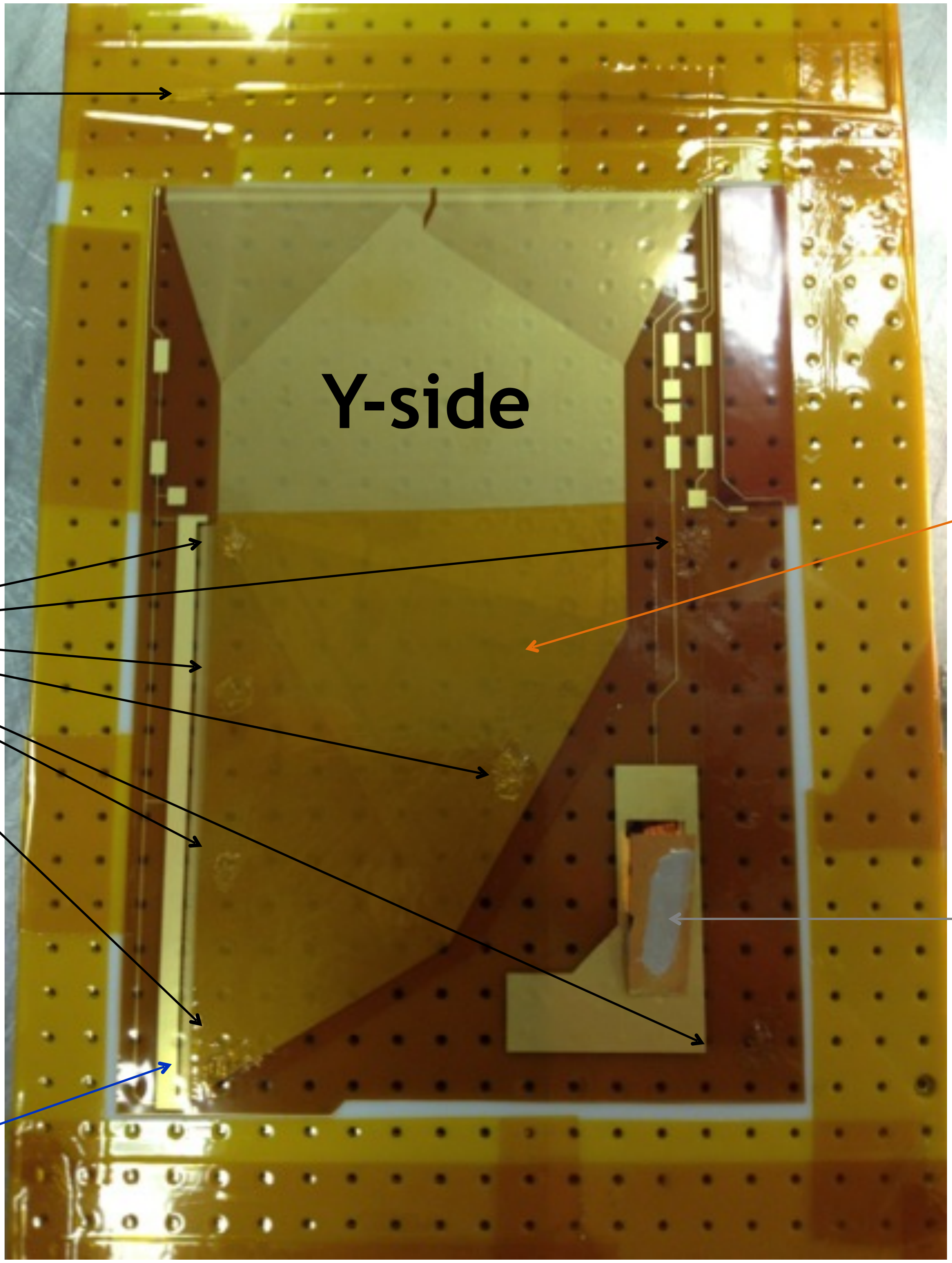


μ-strip fanout

Bias pad
(to be connected
to the silicon back-plane)



Glue deposition on the new kapton fanout cable



Plane with vacuum system

Thin layer of kapton tape for insulation

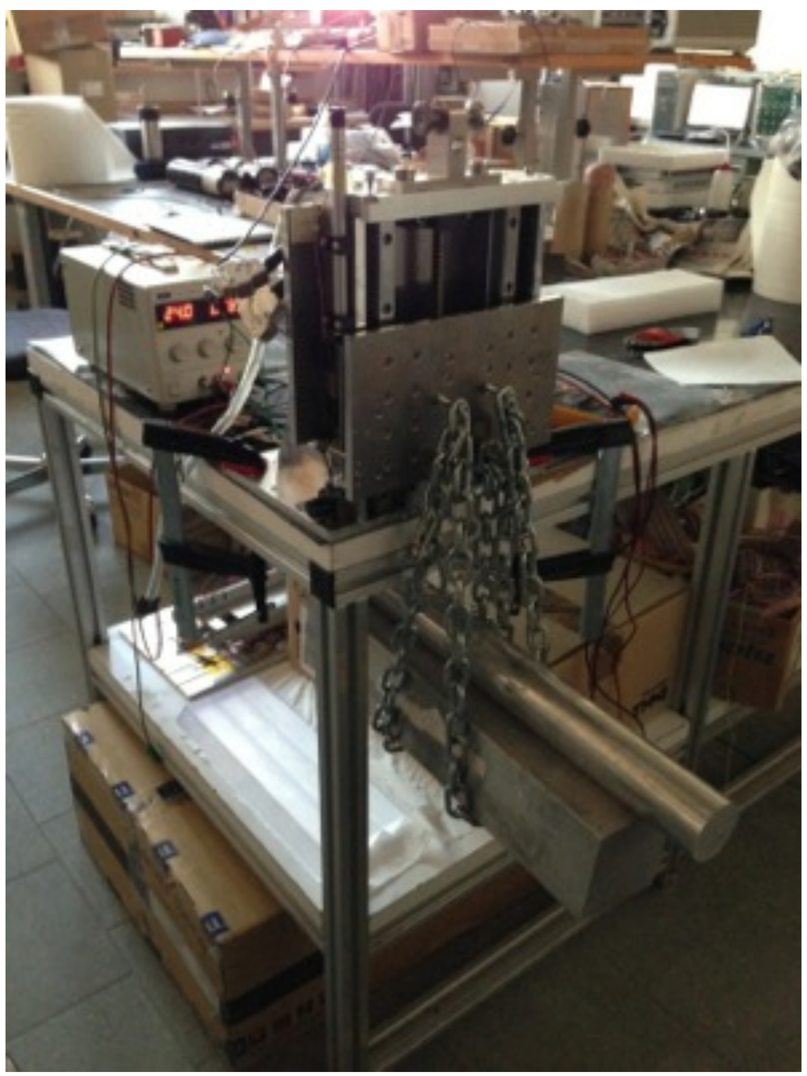
Thin layer of siliconic glue (not hard)

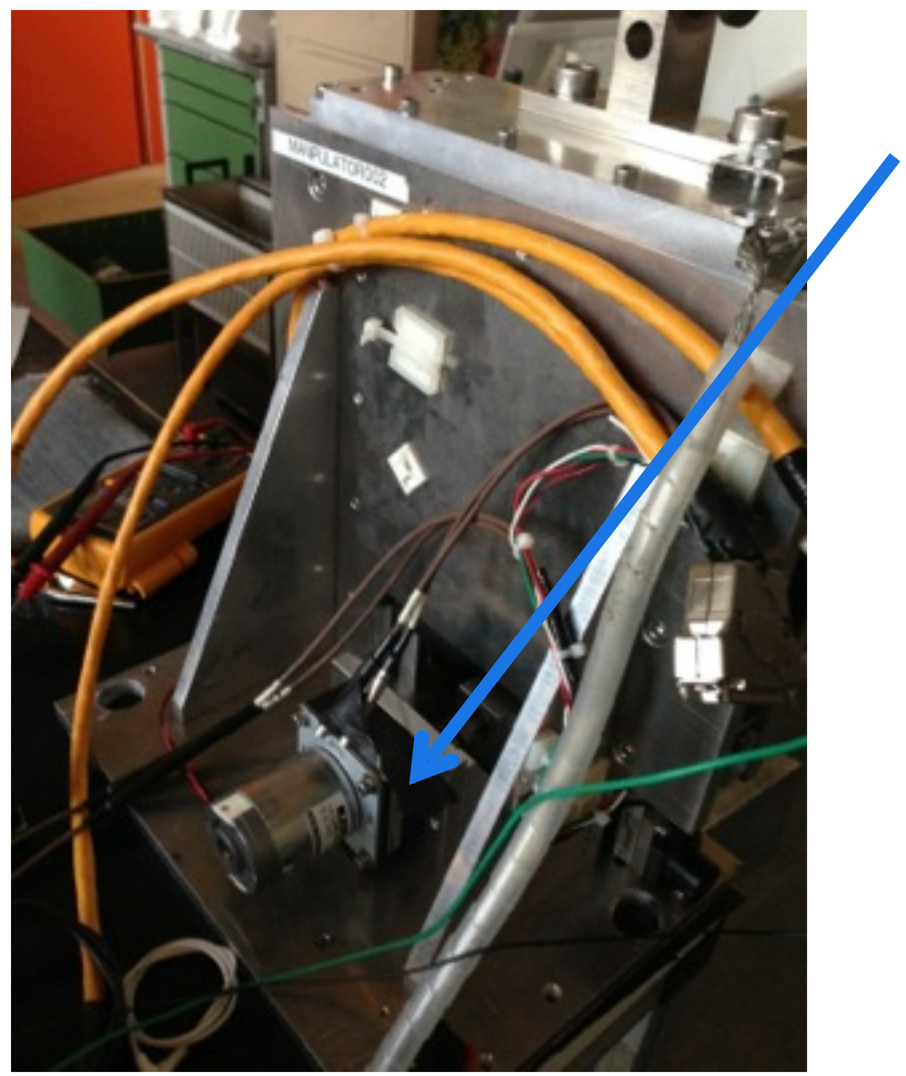
GND large pad

Electrically-conductive (Ag) glue deposited on a bent strip of golden kapton film for sensor biasing

Modification of the manipulators

Only one manipulator has been modified and tested.
The modification was necessary because the beam dumping procedure in 2013 went faster than in 2010. It lasted about 5 min. So the target of this modification was 5 min for 12 cm movement (from the operation position to the garage position it took about 12min before the modification)





Replacement of the gear box (decreased the gear ratio from 30 to 12.5)

Test with the weight corresponding to the LHCf detector was successful.

Final vertical speed:
12 cm / 4 min

Power consumption is well below the limits of the engine