Prototype Studies for a Forward EM Calorimeter in ALICE

T. Peitzmann, Utrecht University
for the ALICE-FoCal Collaboration

ALICE

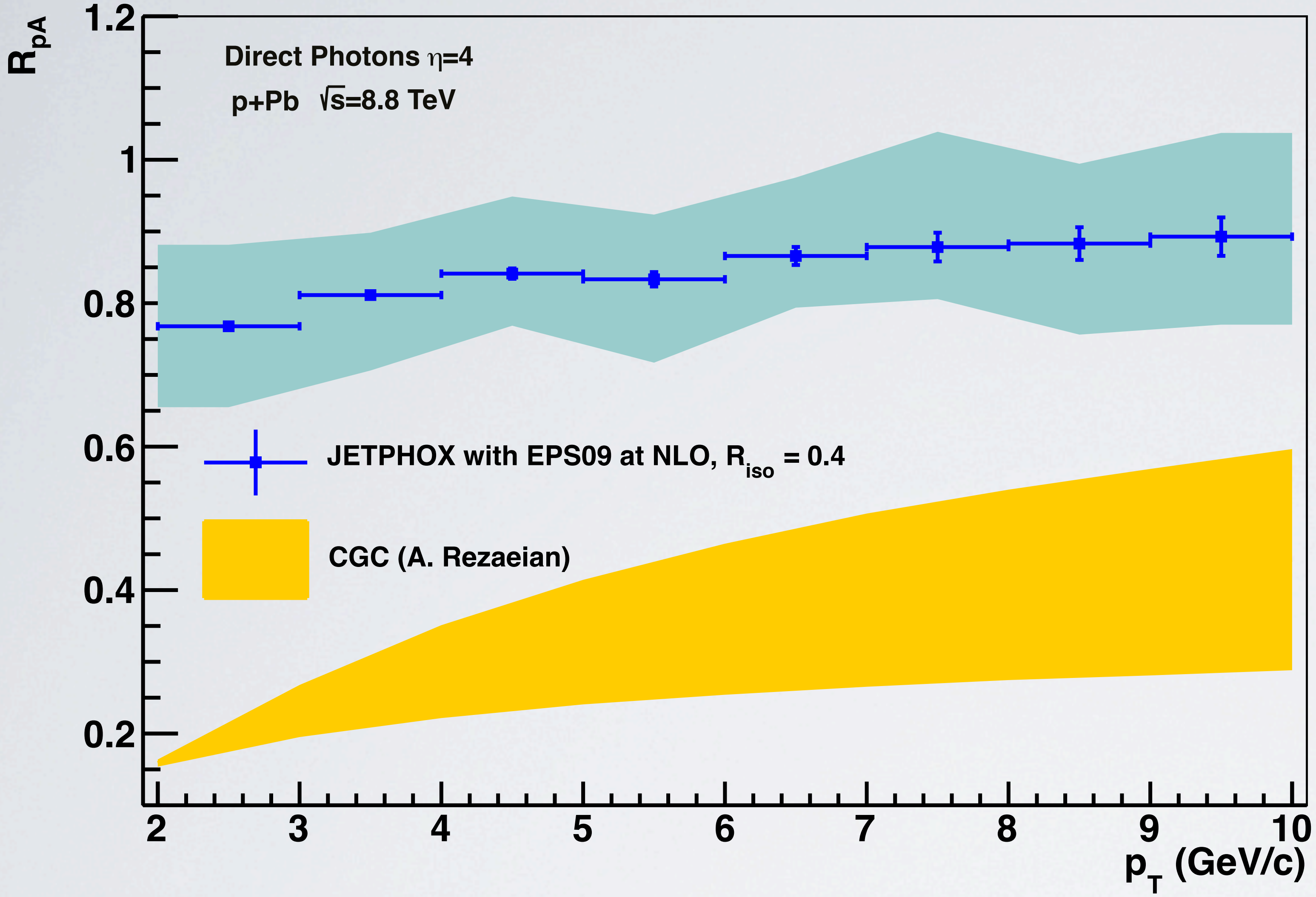
Universiteit Utrecht

NIKHEF

Outline

- Physics motivation
- ALICE FoCal detector
  - Strawman design and performance
- Pixel calorimeter prototype: first results
- Summary

nPDF/DGLAP vs CGC

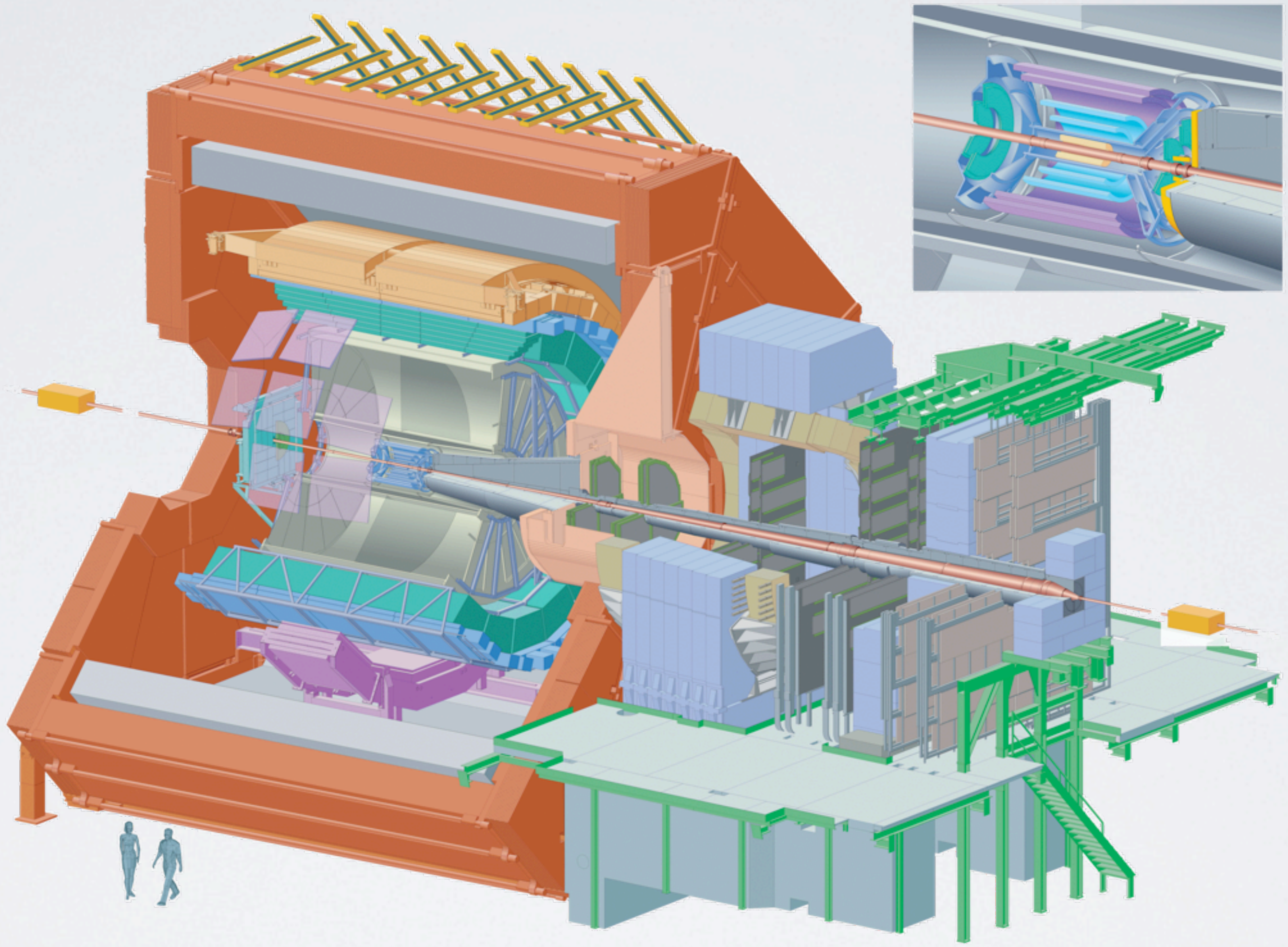


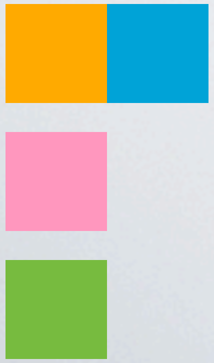
two scenarios for forward γ production in p+A at LHC:

- normal nuclear effects
  linear evolution, shadowing
- saturation/CGC
  running coupling BK evolution

- strong suppression in direct γ R_{pA}
- signals expected at forward η, low-intermediate p_T
  - transition expected - where?

ALICE Detector Upgrades





approved by LHCC

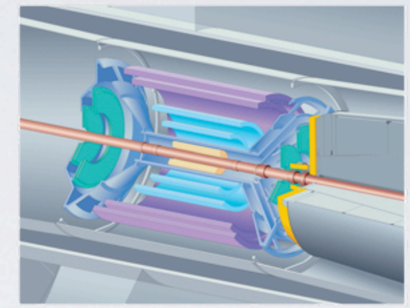
to be submitted to LHCC

under internal review

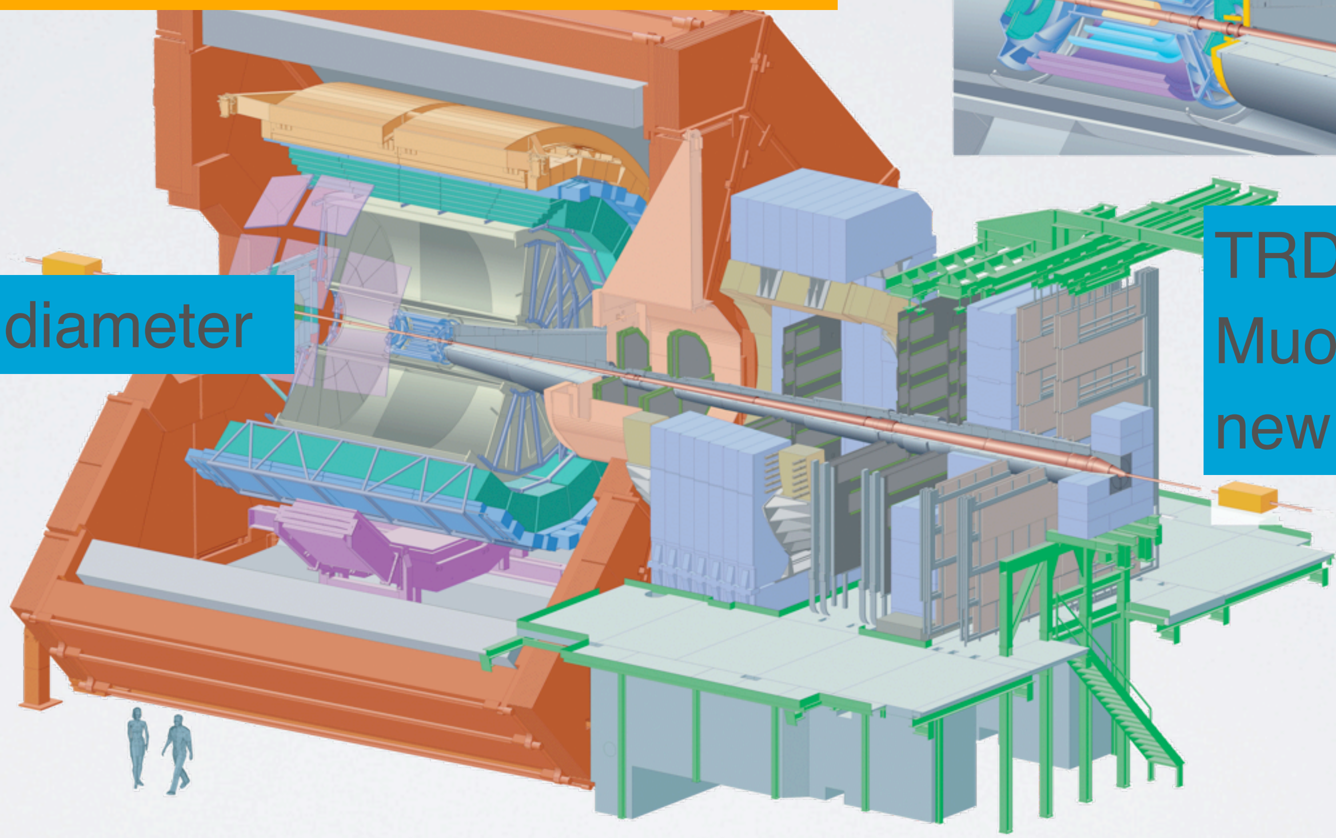
ALICE Detector Upgrades

EMCal: extension by DCAL (LS1)

new ITS: high resolution,
low material budget



TPC: new GEM readout chambers,
pipelined readout



new beam pipe: smaller diameter

TRD, TOF, PHOS, EMCal,
Muon spectrometer:
new readout electronics

Upgrade of forward/
trigger detectors
(ZDC, VZERO, T0)

approved by LHCC

to be submitted to LHCC

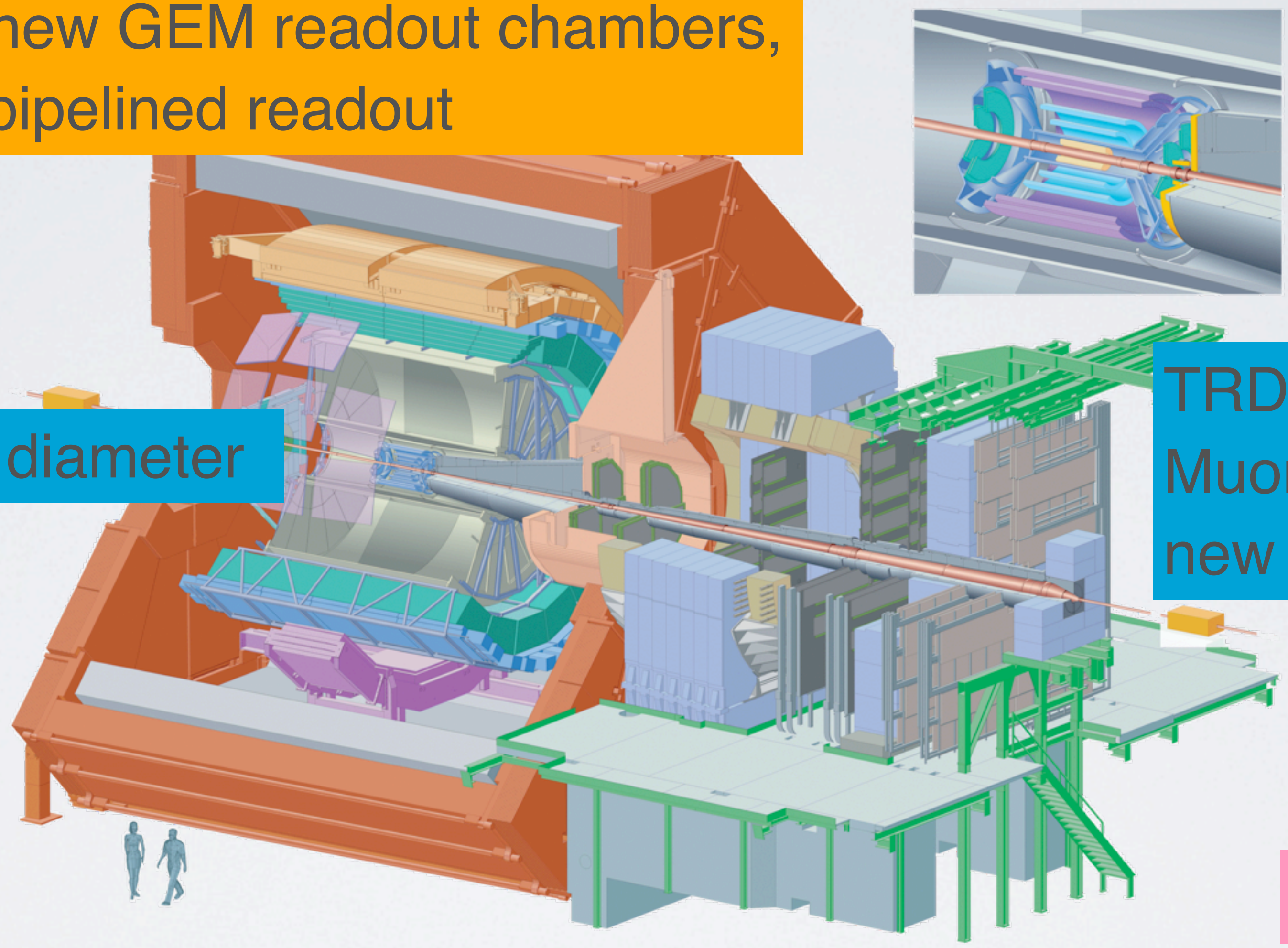
under internal review

ALICE Detector Upgrades

EMCal: extension by DCAL (LS1)

new ITS: high resolution,
low material budget

TPC: new GEM readout chambers,
pipelined readout



new beam pipe: smaller diameter

TRD, TOF, PHOS, EMCal,
Muon spectrometer:
new readout electronics

Upgrade of forward/
trigger detectors
(ZDC, VZERO, T0)

MFT project

approved by LHCC

to be submitted to LHCC

under internal review

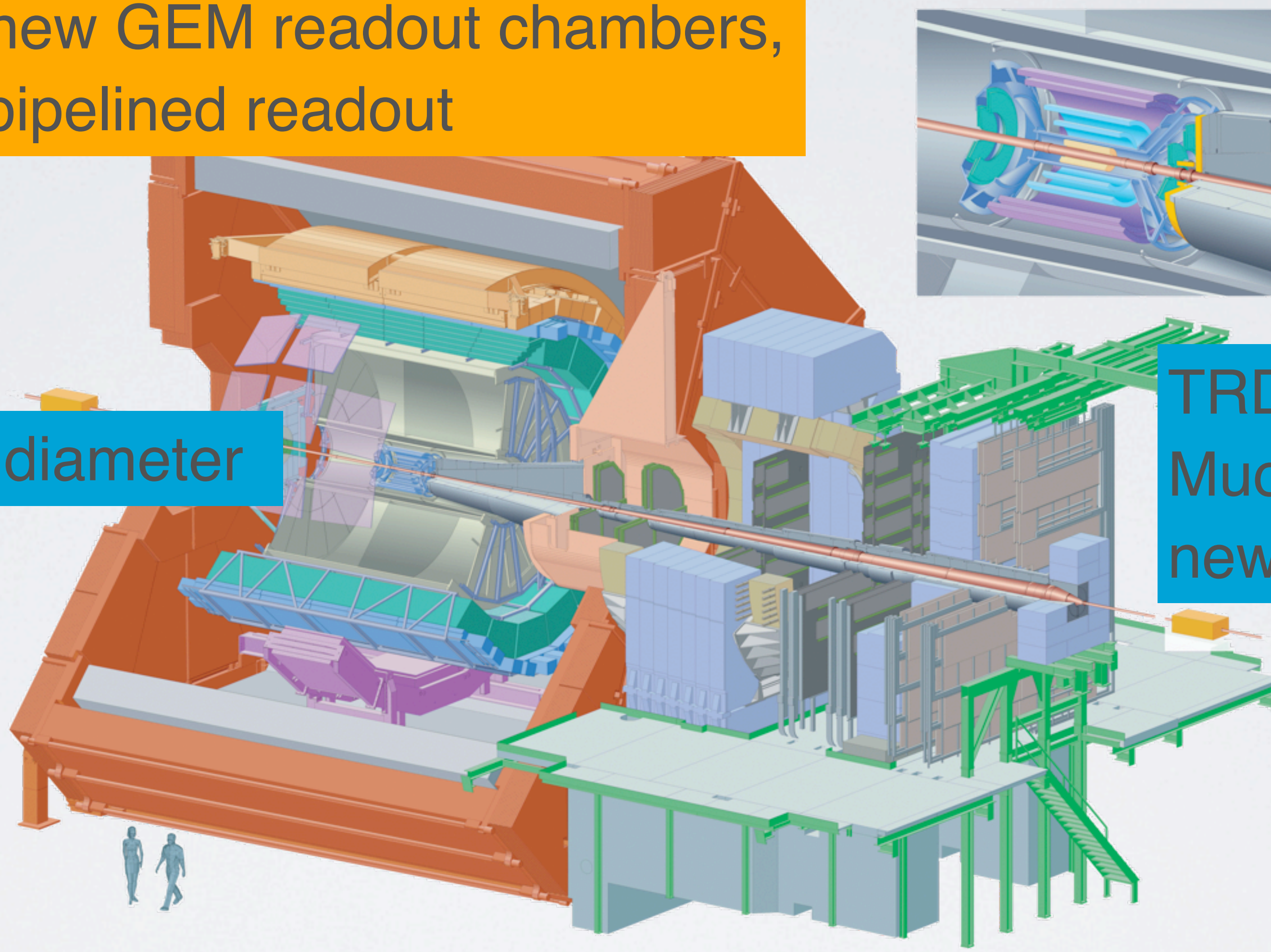
ALICE Detector Upgrades

EMCal: extension by DCAL (LS1)

new ITS: high resolution,
low material budget

TPC: new GEM readout chambers,
pipelined readout

FoCal project



new beam pipe: smaller diameter

TRD, TOF, PHOS, EMCal,
Muon spectrometer:
new readout electronics

Upgrade of forward/
trigger detectors
(ZDC, VZERO, T0)

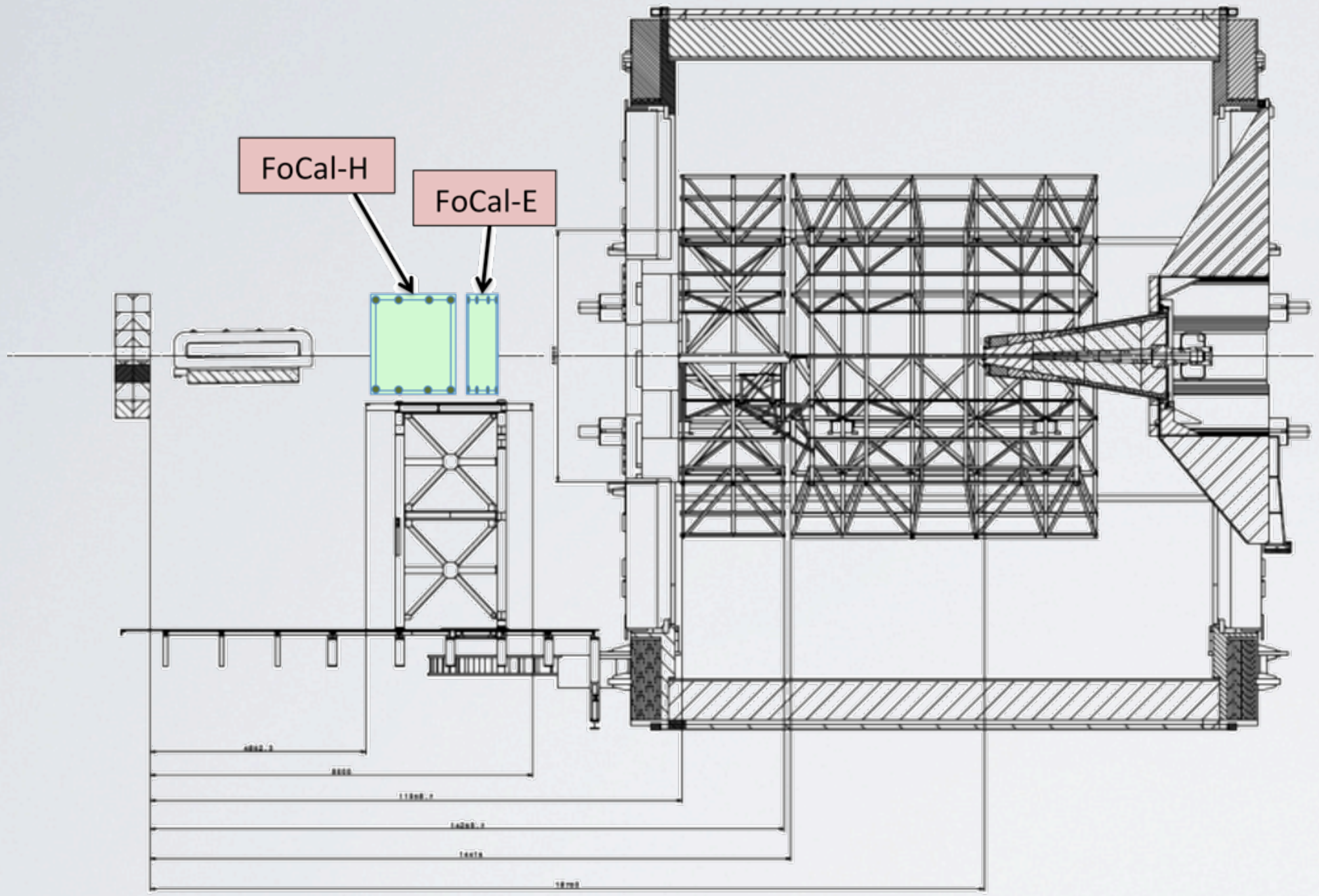
MFT project

approved by LHCC

to be submitted to LHCC

under internal review

FoCal in ALICE



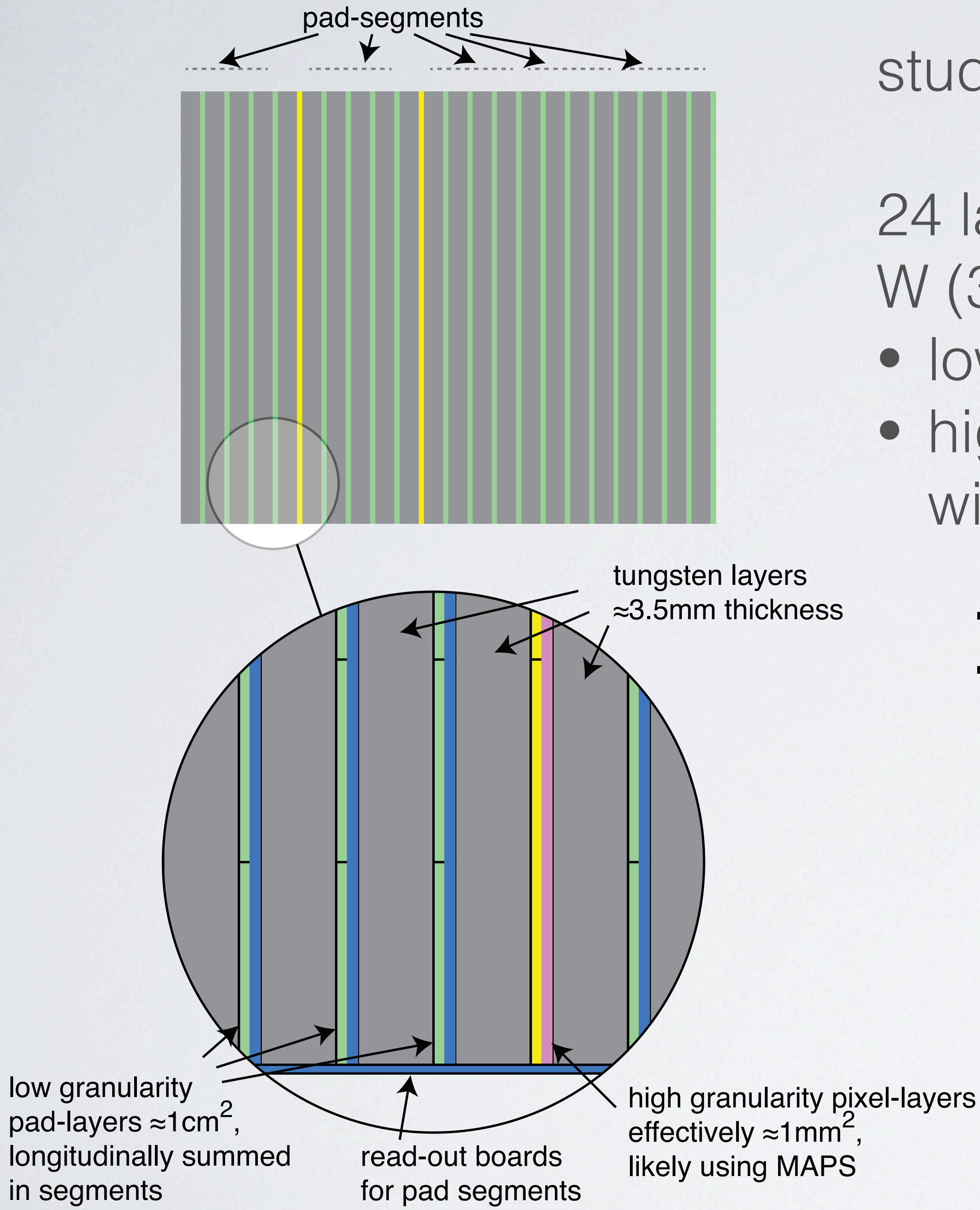
electromagnetic calorimeter for γ and π^0 measurement

two scenarios:

- at $z \approx 8$m (outside magnet)
  $3.3 < \eta < 5.3$
  (space to add hadr. calorimeter)
- at $z \approx 3.6$m (current PMD)
  $2.5 < \eta < 4.5$

- main challenge: separate γ/π^0 at high energy
- need small Molière radius, high-granularity read-out
  - Si-W calorimeter, granularity ≈ $1mm^2$

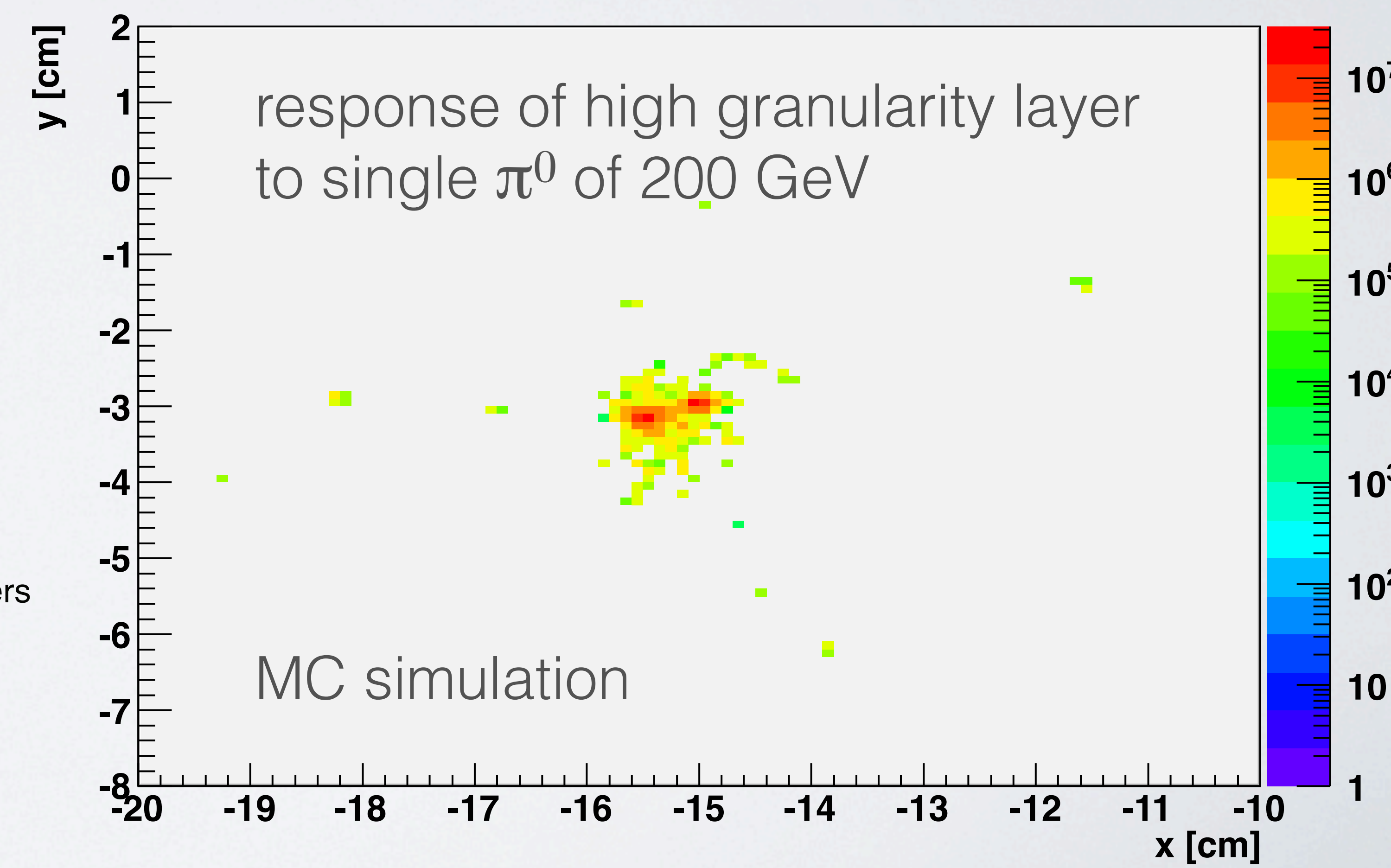
Strawman Design



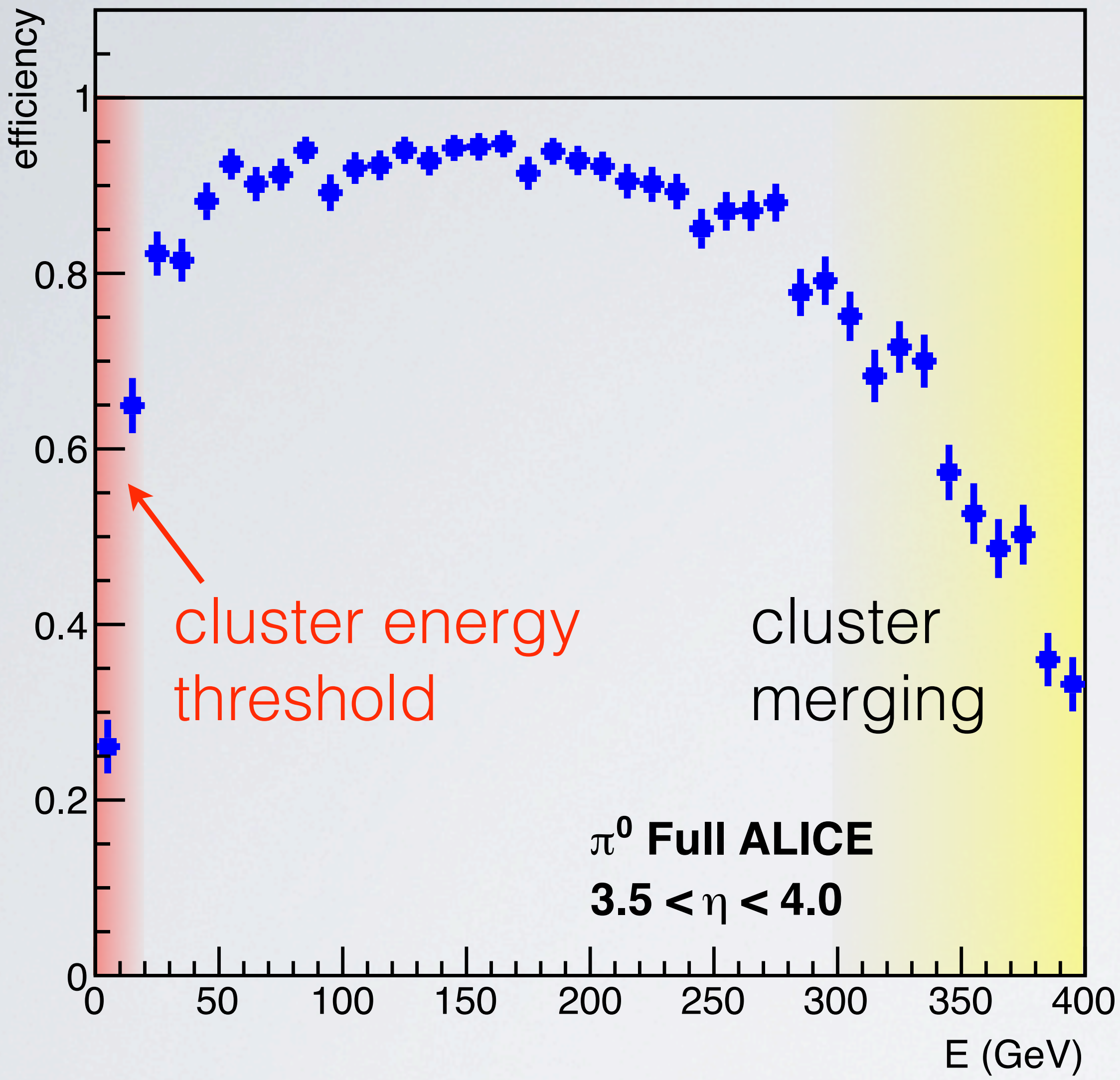
studied in performance simulations:

24 layers:
W (3.5mm ≈ 1 X_0) + Si-sensors (2 types)

- low granularity (LGL, ≈ 1 cm^2), Si-pads
- high granularity (HGL, ≈ 1 mm^2), obtained with pixels (e.g. CMOS-MAPS)

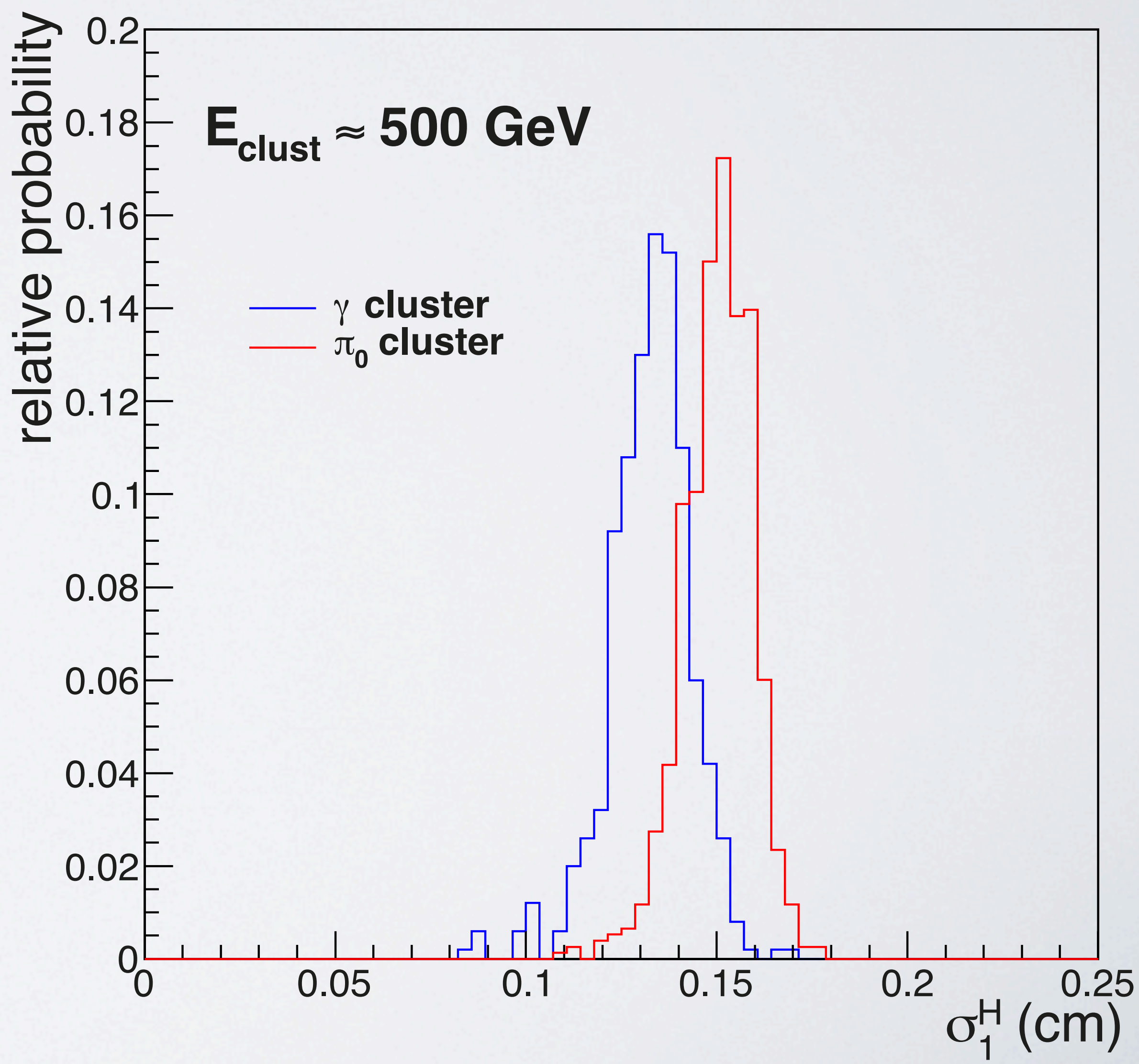


π^0 Efficiency



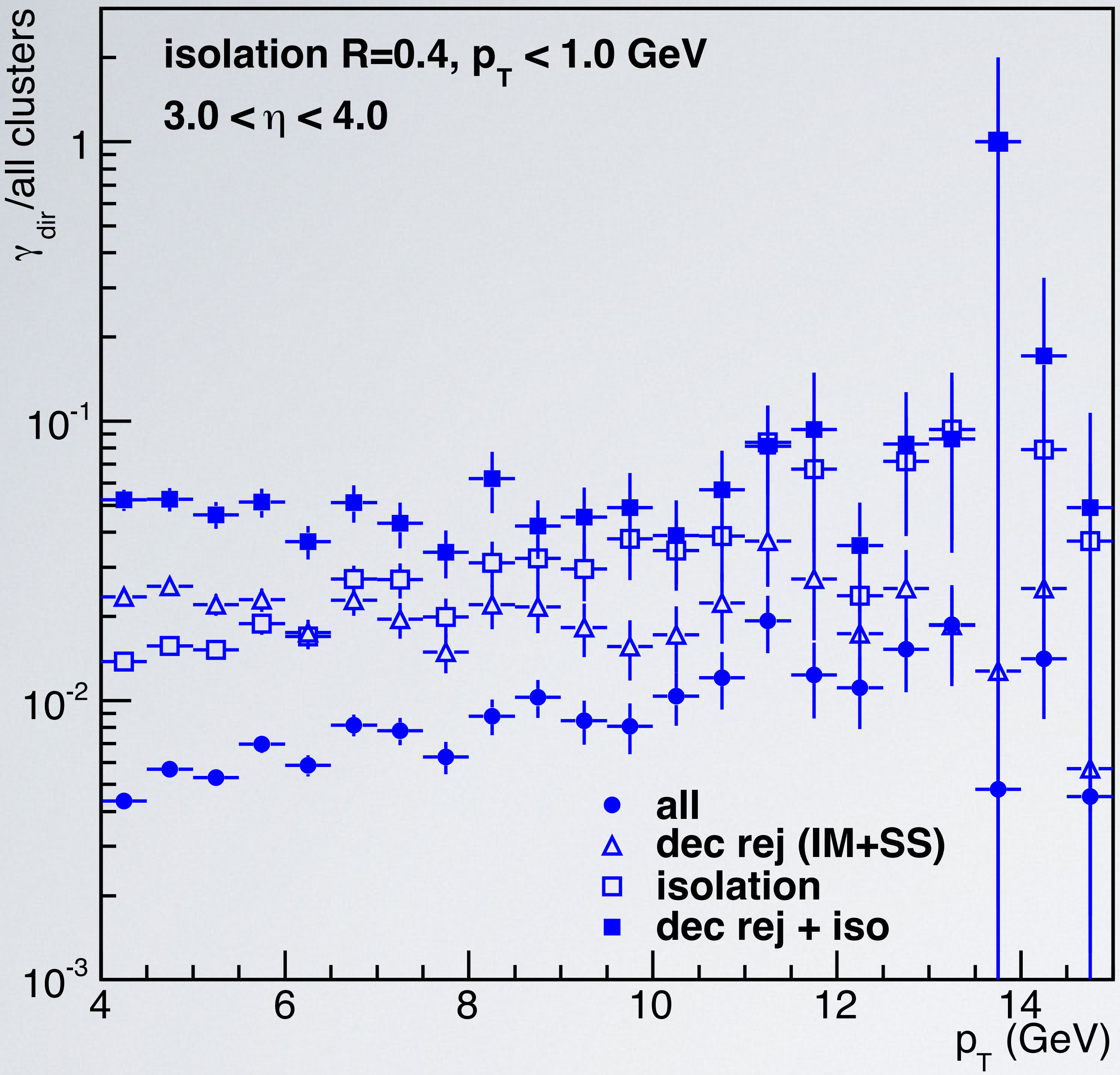
single particle simulation in full ALICE setup, good efficiency up to $E \approx 300$ GeV ($p_T \approx 10$ GeV/c)

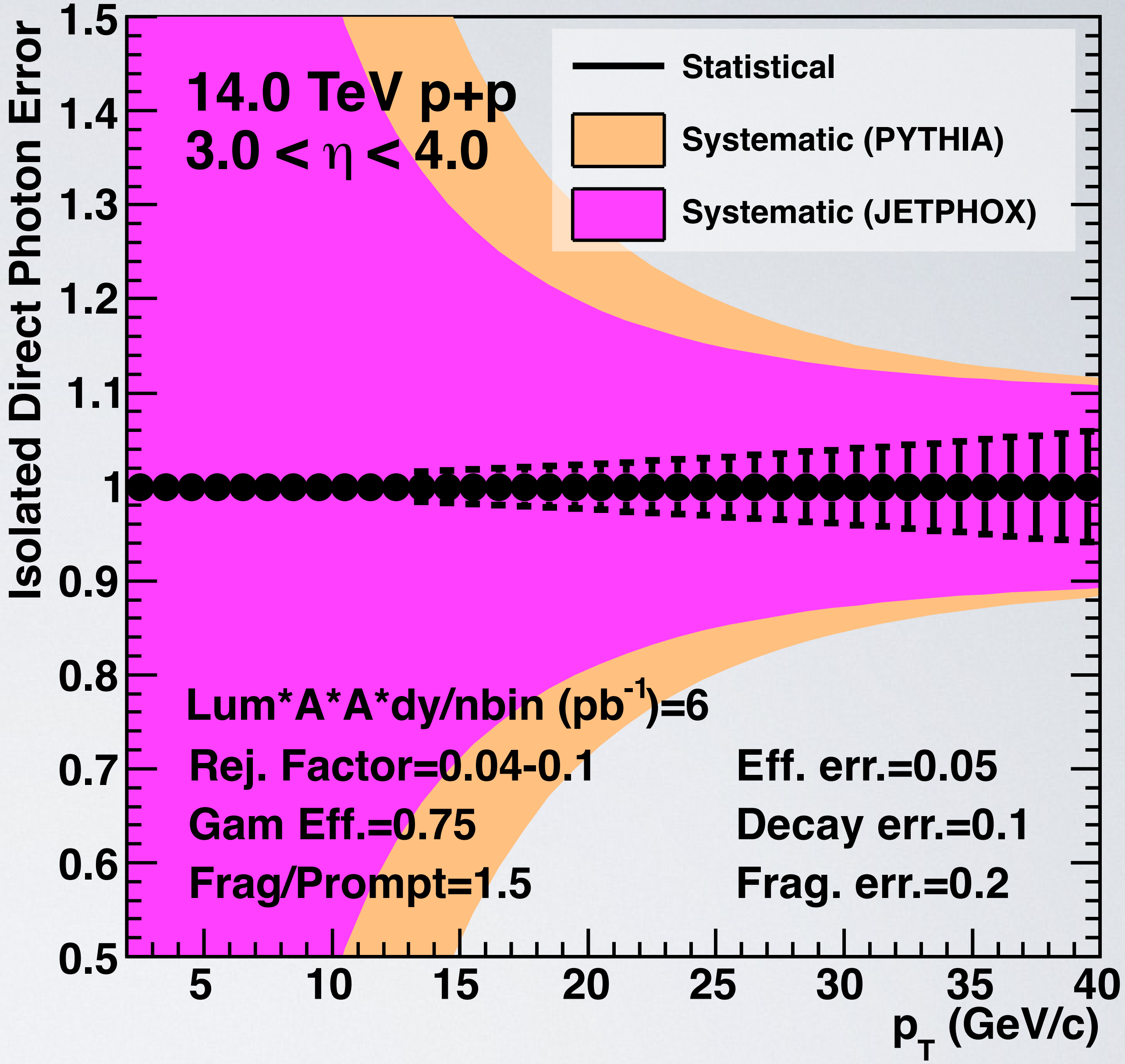
can still be improved by shower shape analysis in HGL



expect good discrimination from HGL info up to $E \approx 500$ GeV

Direct γ - Low Granularity



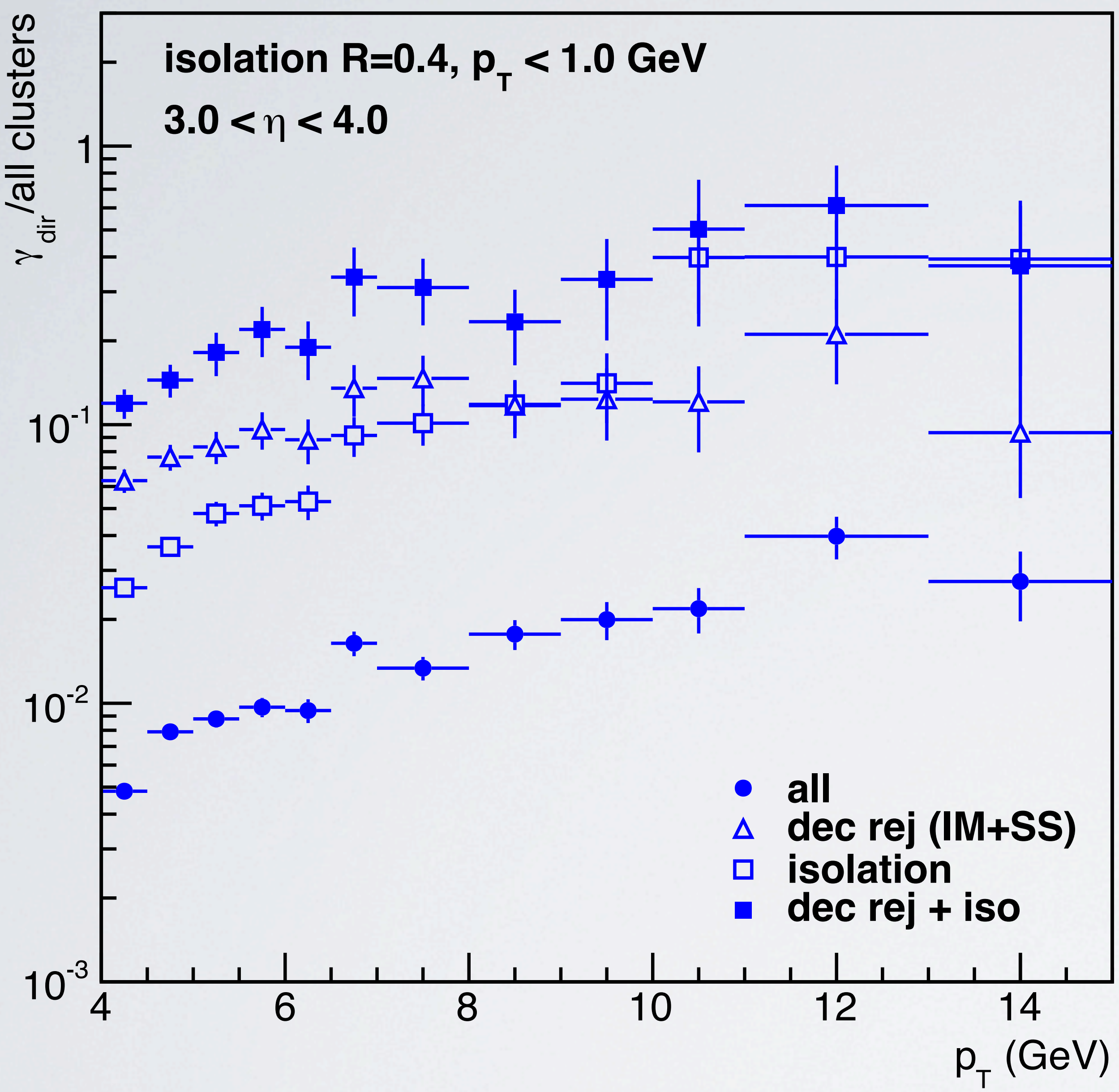


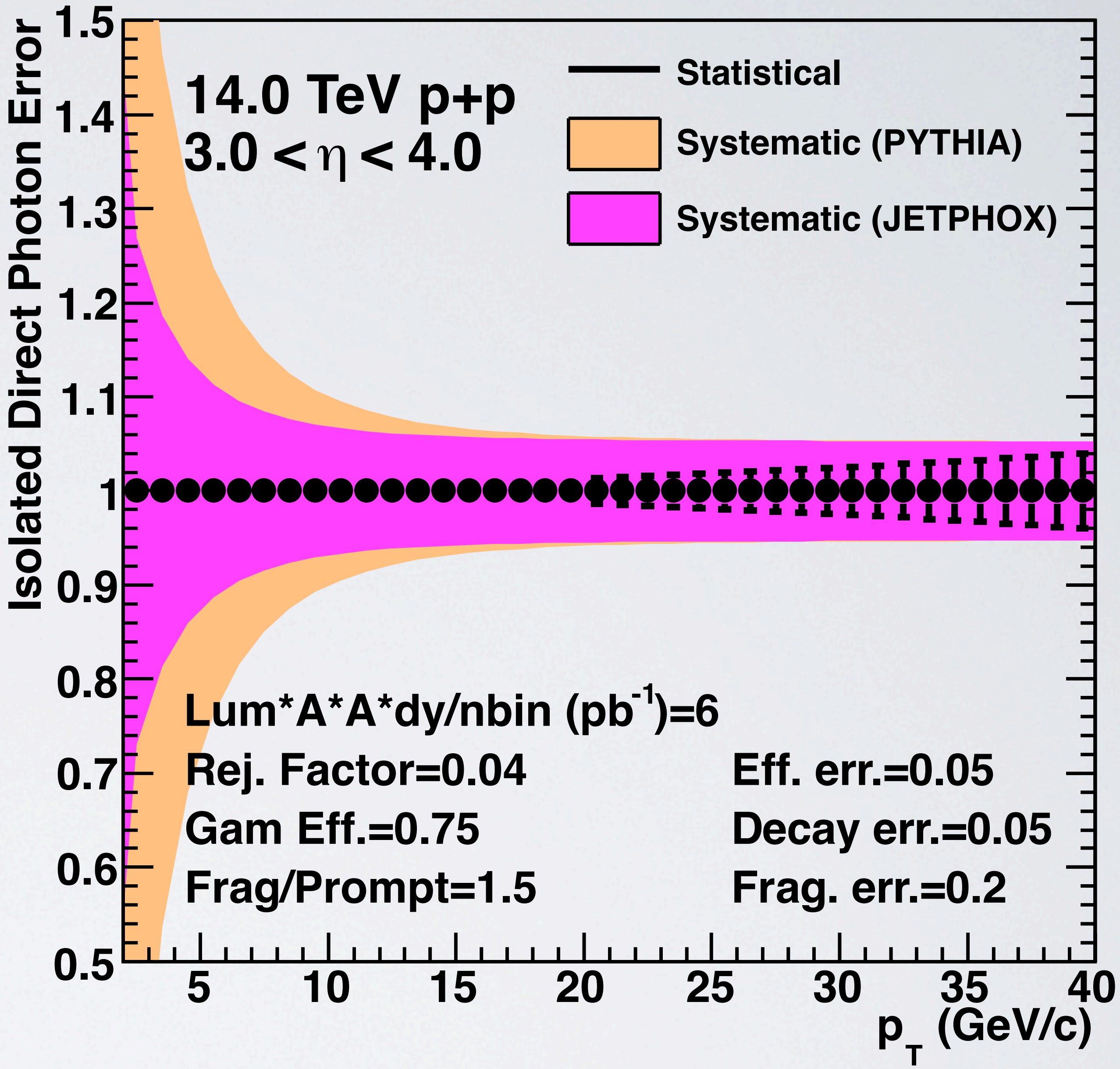
- low granularity (1cm^2) does not allow efficient decay rejection
- direct photon/all ≈ 0.05 for all p_T

significant measurement not possible at low p_T

NB: conditions similar to LHCb

Direct γ - High Granularity



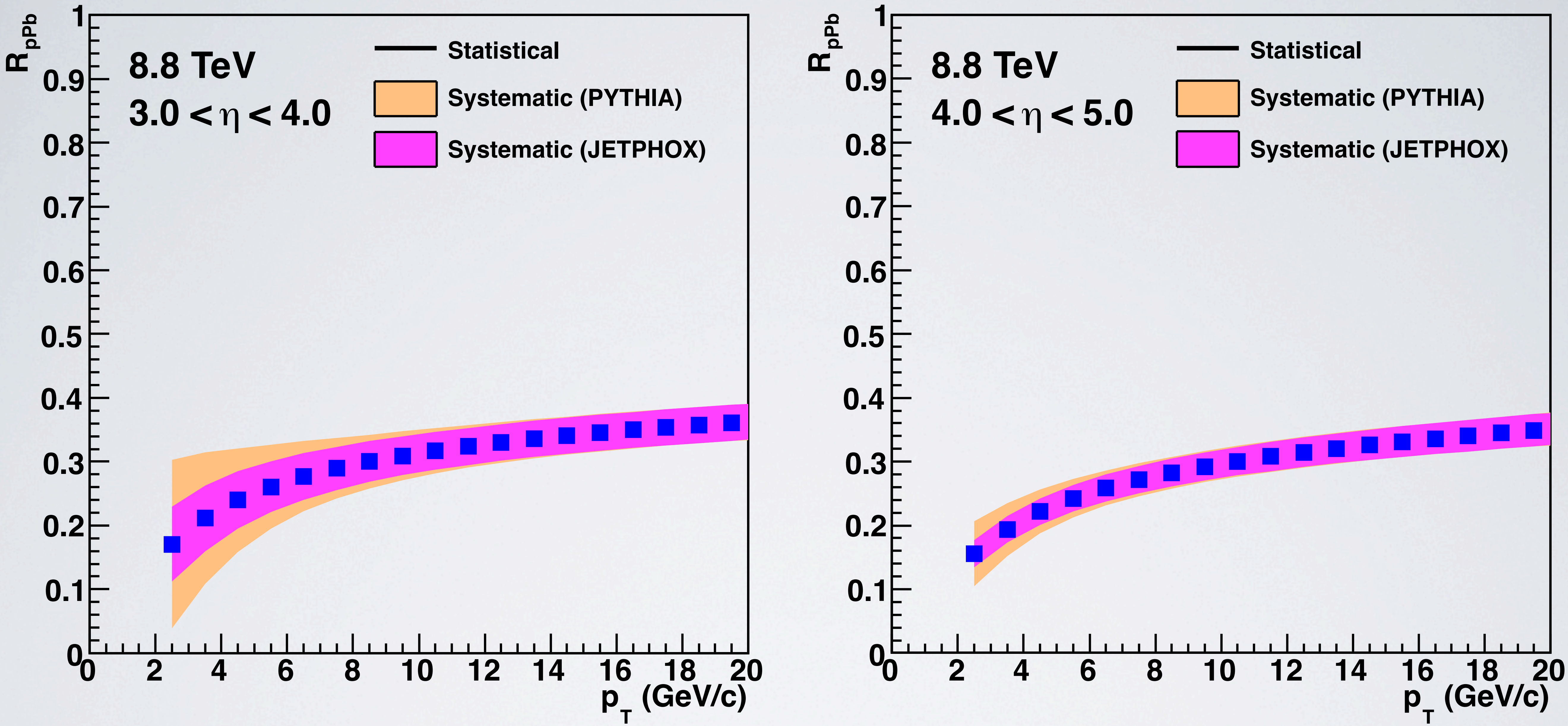


direct photon/all > 0.1
for p_T > 4 GeV/c

20-40% uncertainty
at p_T = 4 GeV/c
decreases with increasing p_T

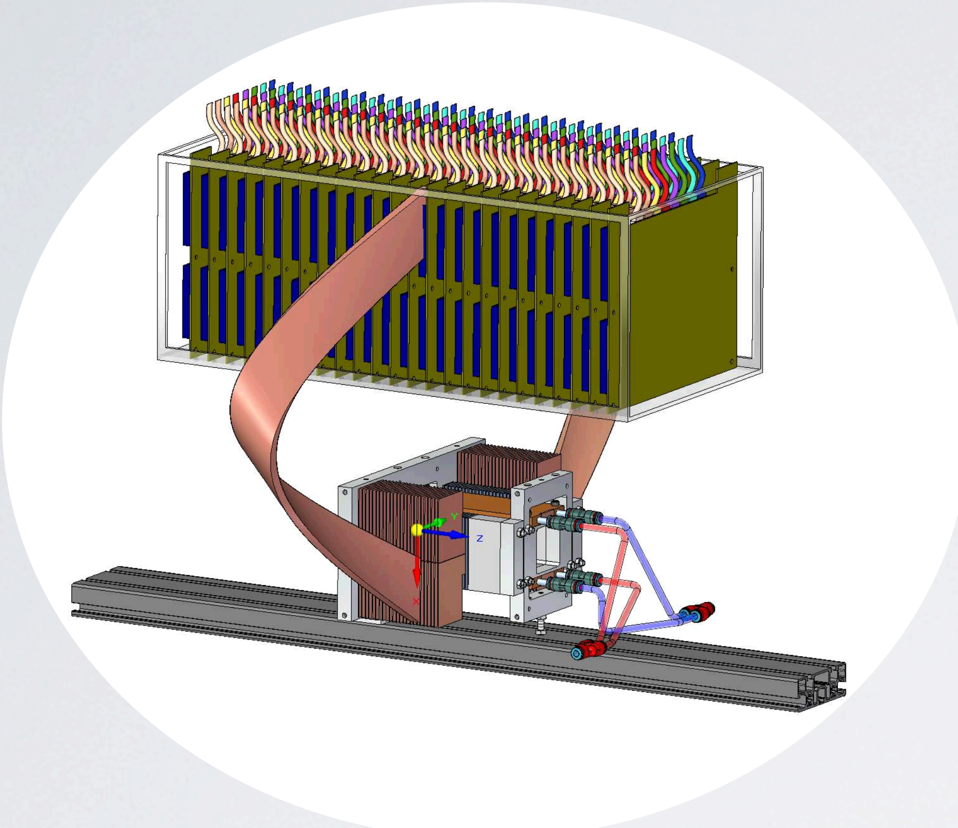
high granularity enables low p_T direct photon measurement

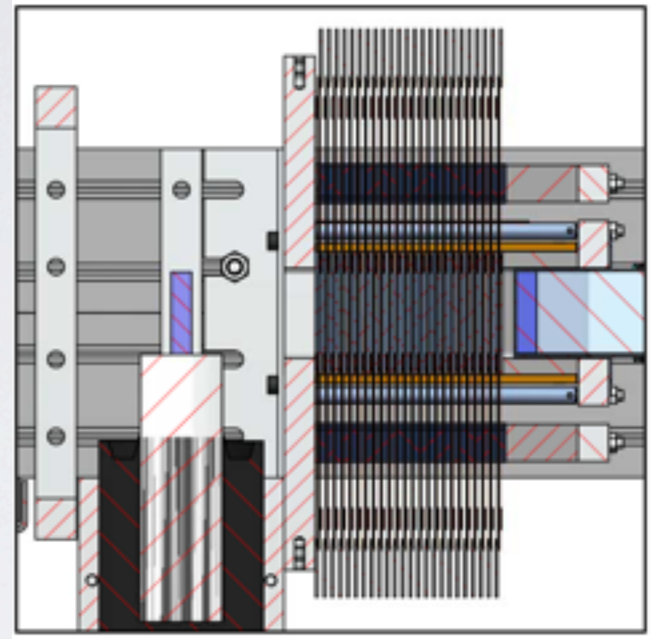
Performance in R_{pPb}

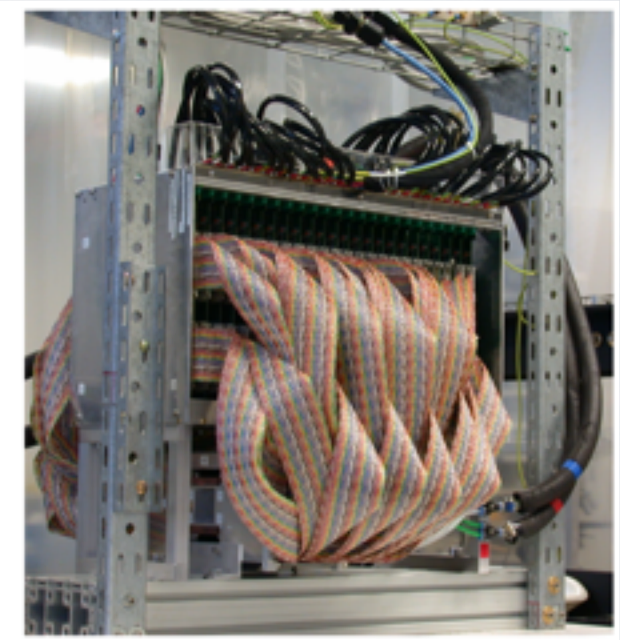


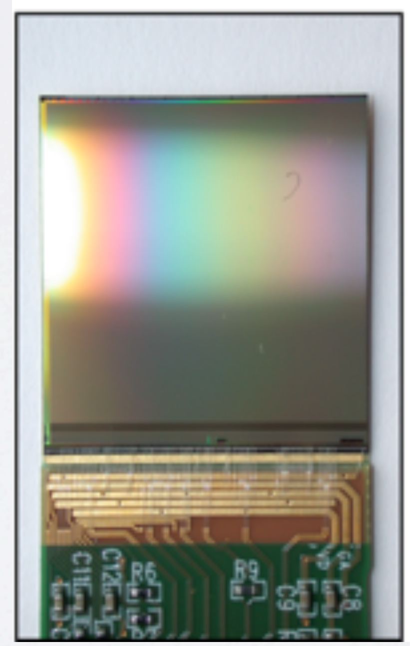
- expect significant constraint on direct photon R_{pPb}
  - confirm or refute CGC effects, constrain nPDF

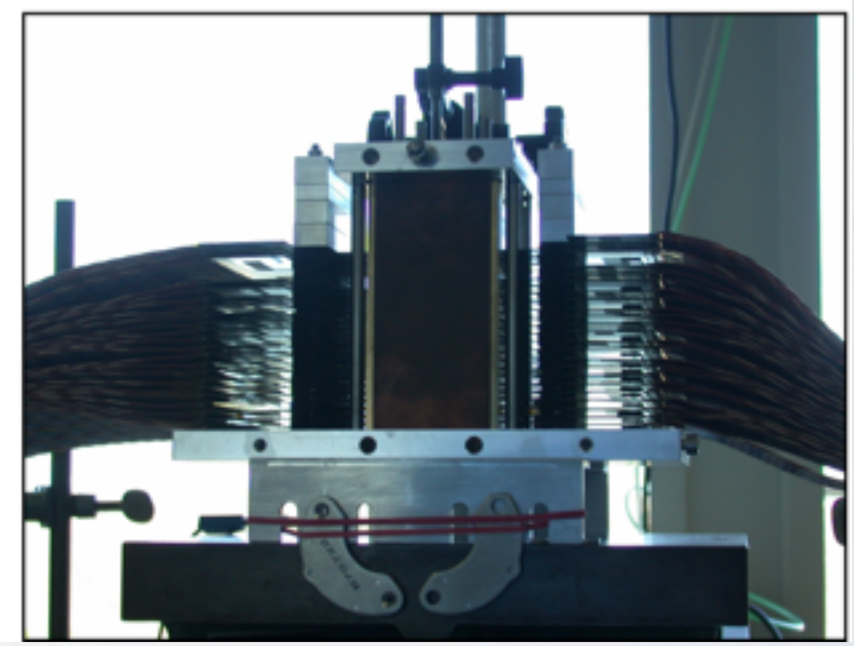
Pixel Calorimeter Prototype









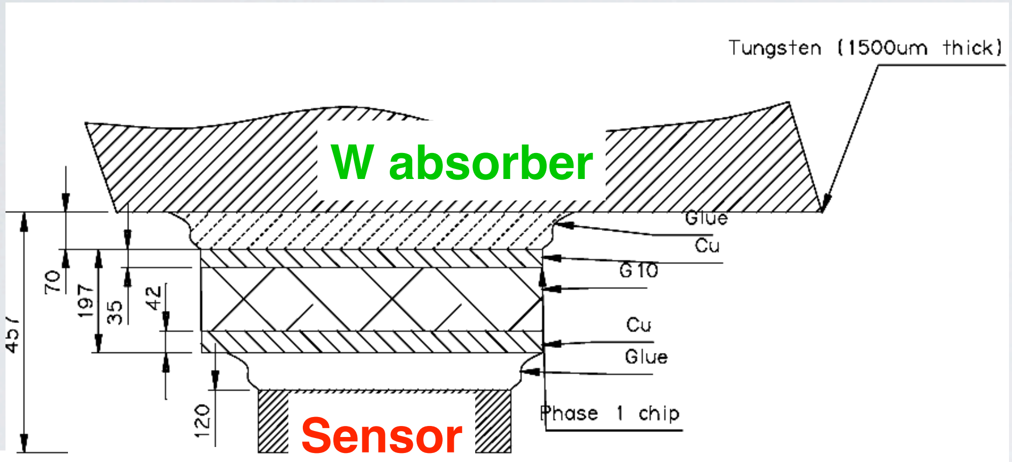


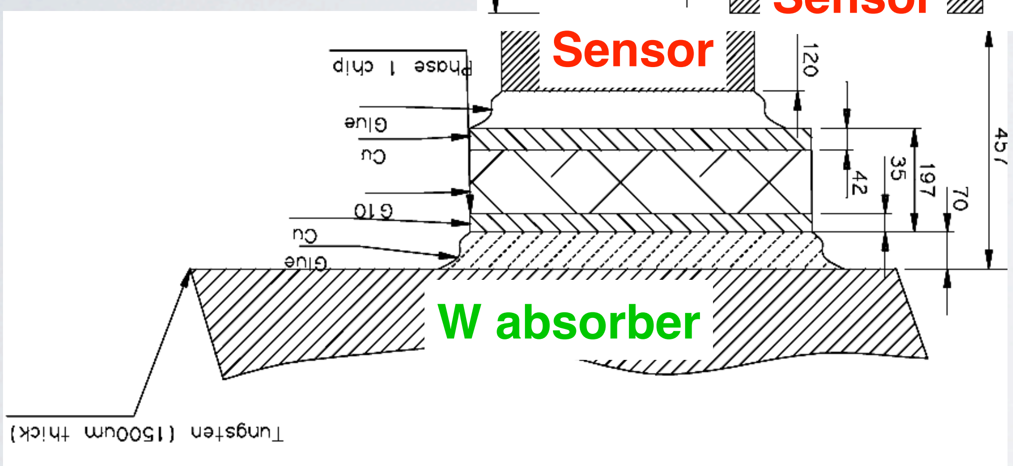
R&D (Utrecht/Nikhef, Bergen):
full MAPS prototype
24 layers

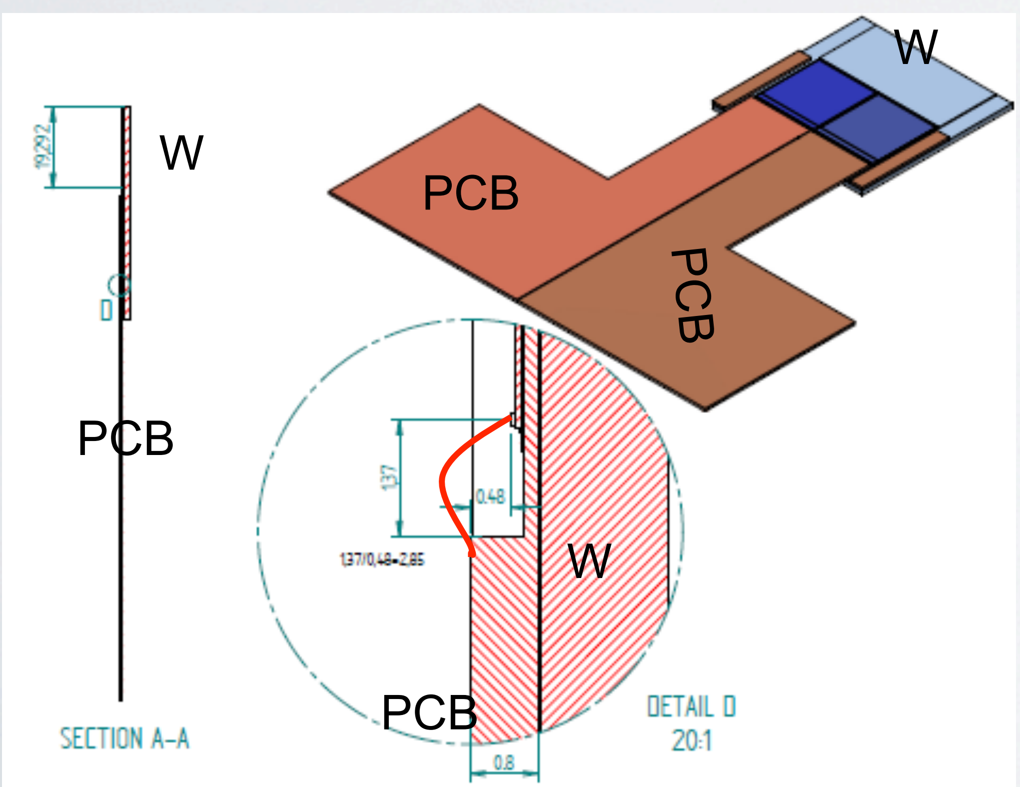
- 3mm W
- 1mm sensor layer
  - 120µm sensor (2x2 chips) + PCB, glue, air, ...
- 39 M pixels in 4x4x10 cm^3 !

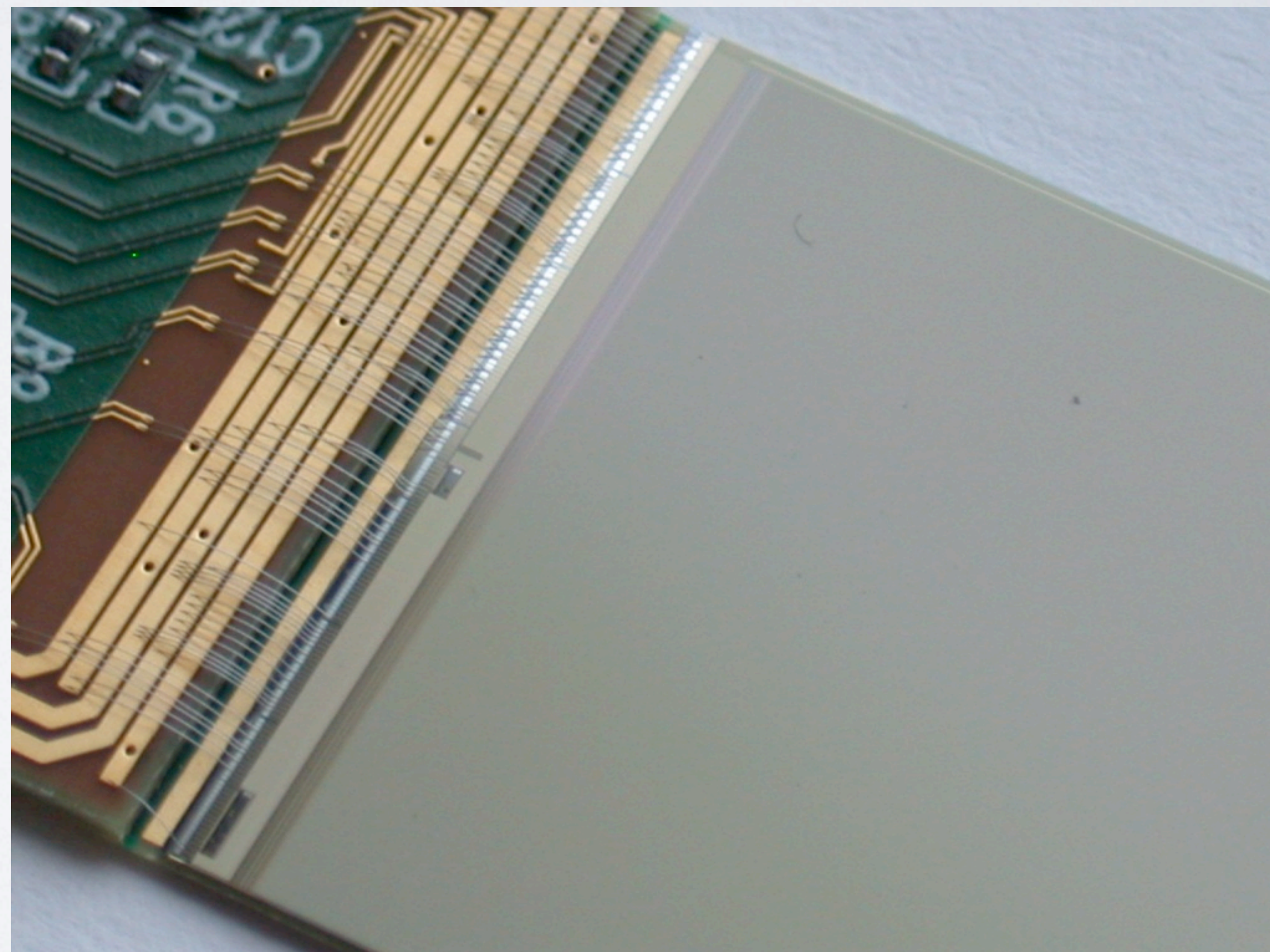
other R&D with prototypes ongoing at Tokyo, ORNL, Kolkata, Prague, ...

Prototype Details

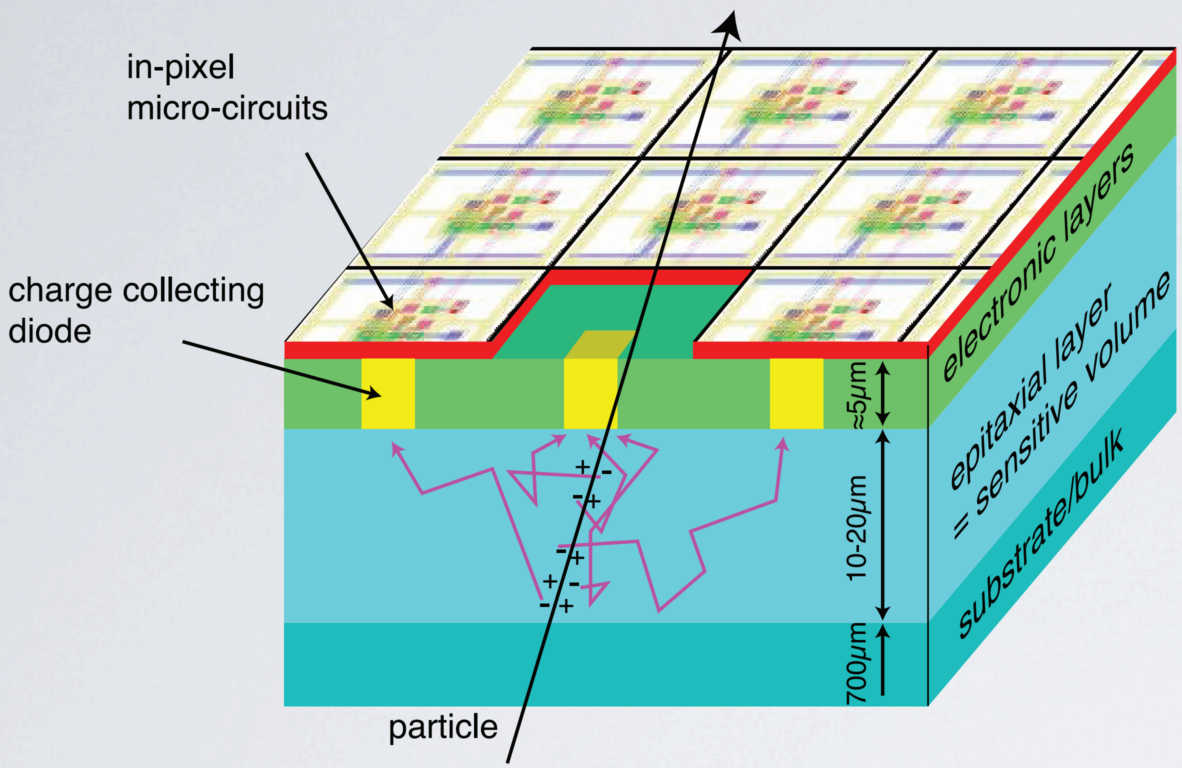


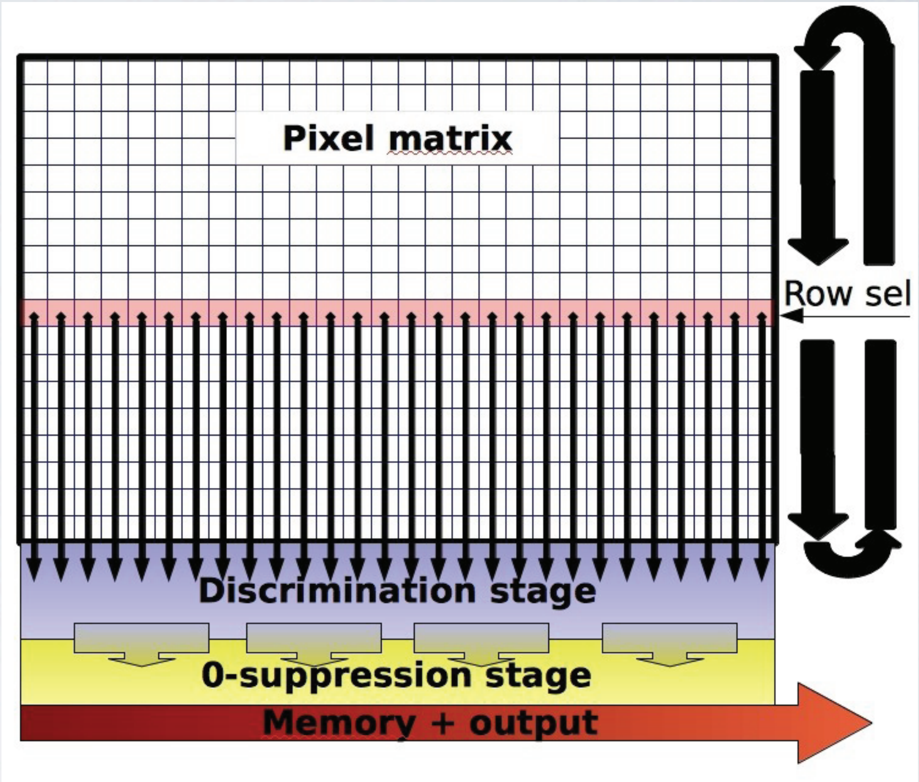






CMOS Sensor

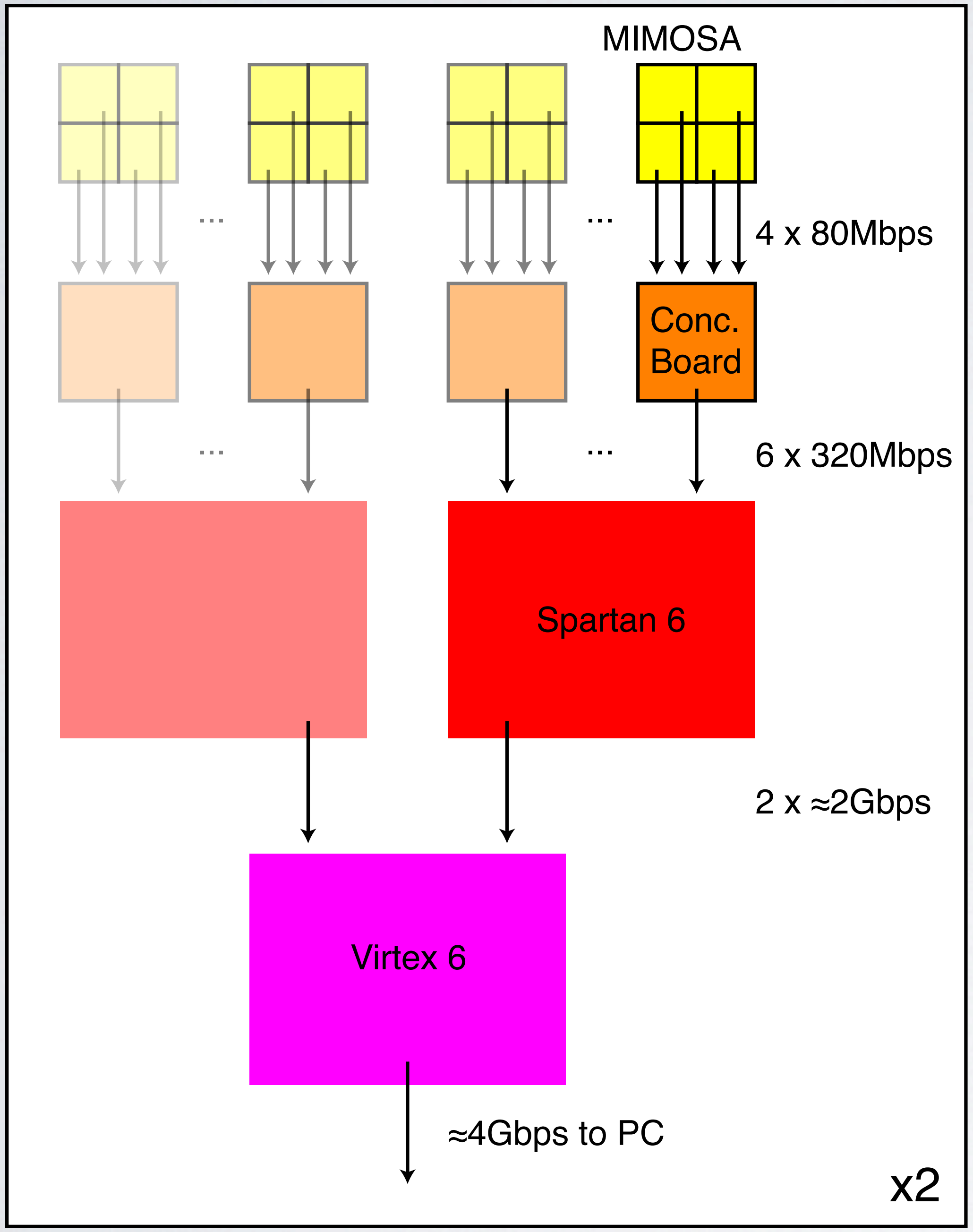




- Monolithic Active Pixel Sensors: Mimosa (IPHC Strasbourg)
  - here: MIMOSA23 (PHASE 2)
- rolling shutter: 640 μs total RO time
- digital readout
  - likely algorithm for real detector: on-chip hit count in macro pixel of 1 mm^2, for 30 μm pixels equivalent to 10bit analog value

chip size	19.5 x 21 mm^2
active area	19.2 x 19.2 mm^2
pixels	640 x 640
pitch	30 x 30 μm

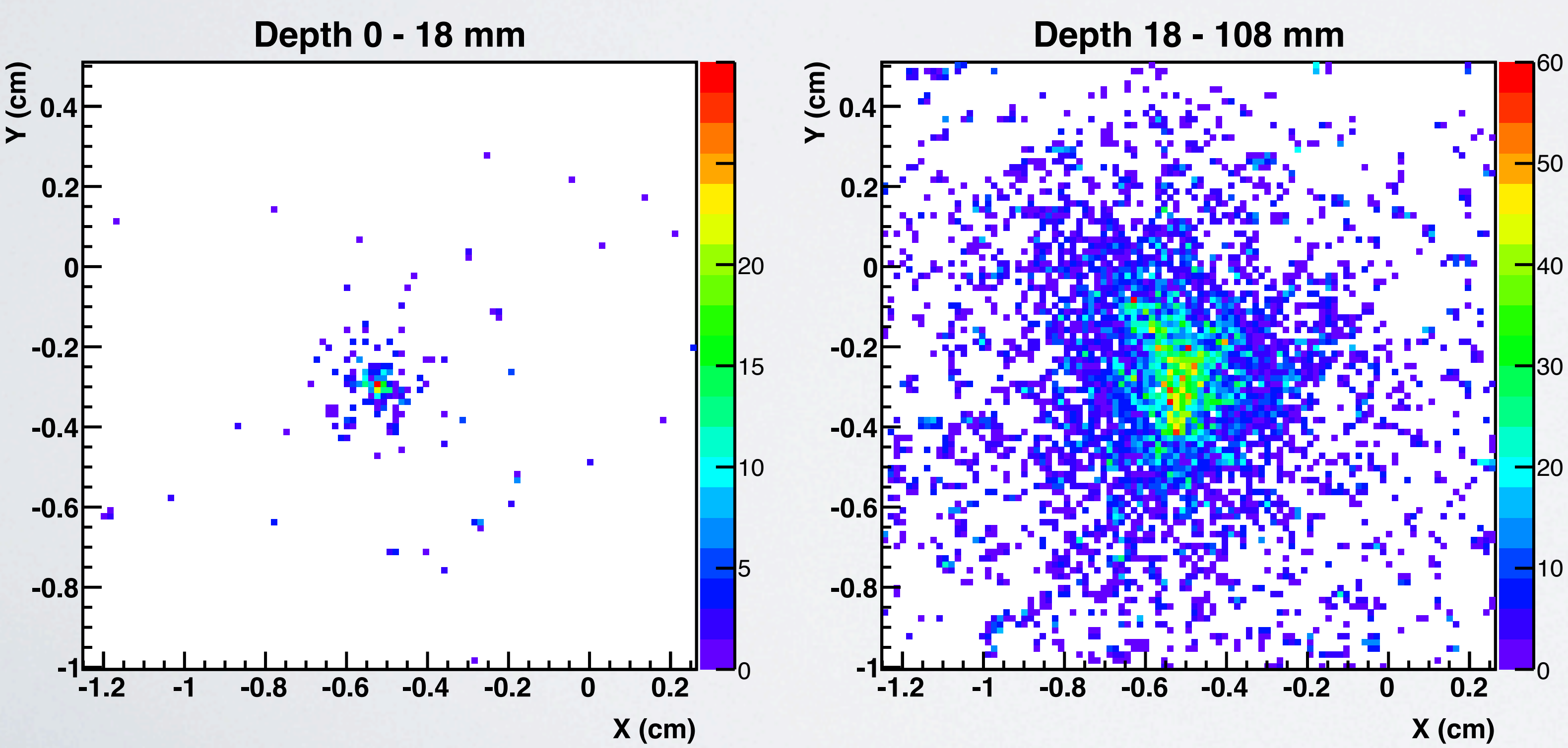
CMOS Sensor Readout



- full frame readout of prototype
  - no zero suppression
- low rate detector, but high data volume!
  - 39.3 Mbit x 1.6 kHz ≈ 8 GB/s
  - data transfer limits data taking also in test beams
- no model for real detector:
  - need faster sensor (avoid pile-up) and intelligent data reduction algorithms

Test Beams

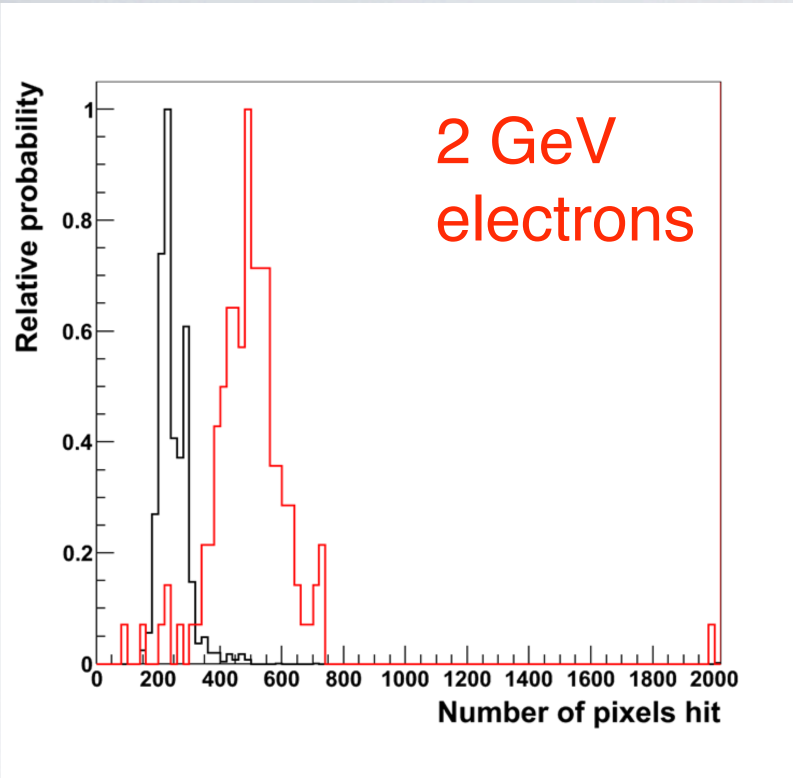
beam	6	# of triggers
DESY (electrons)	2, 5	88k
PS (mixed)	2, 3, 5, 6, 8	1.1M
SPS (mixed)	30, 50, 100, 150, 200, 250	290k

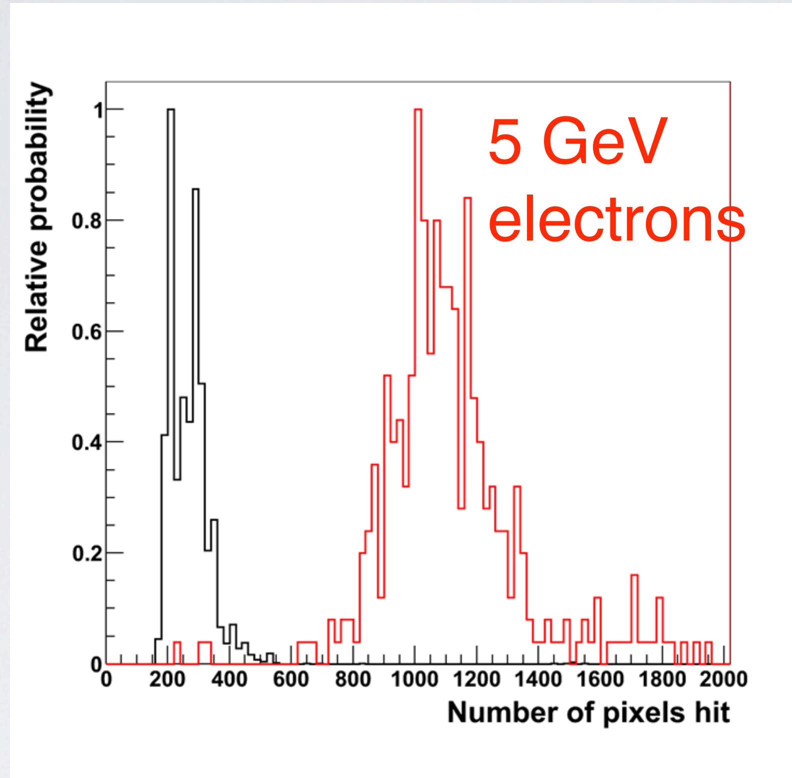


single electron (200 GeV)

analysis ongoing:
final calibration, alignment etc.
not yet done

Preliminary Results

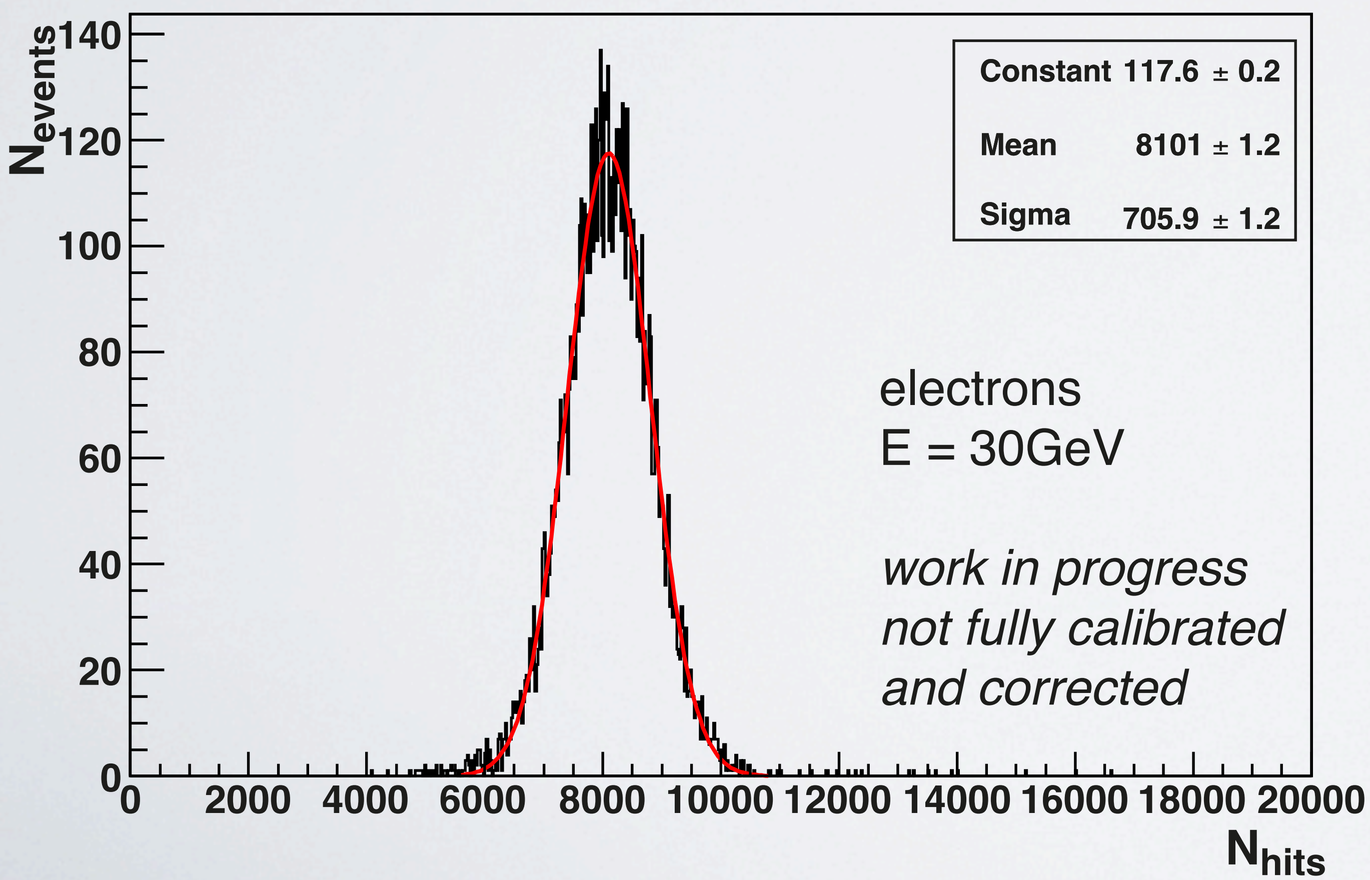




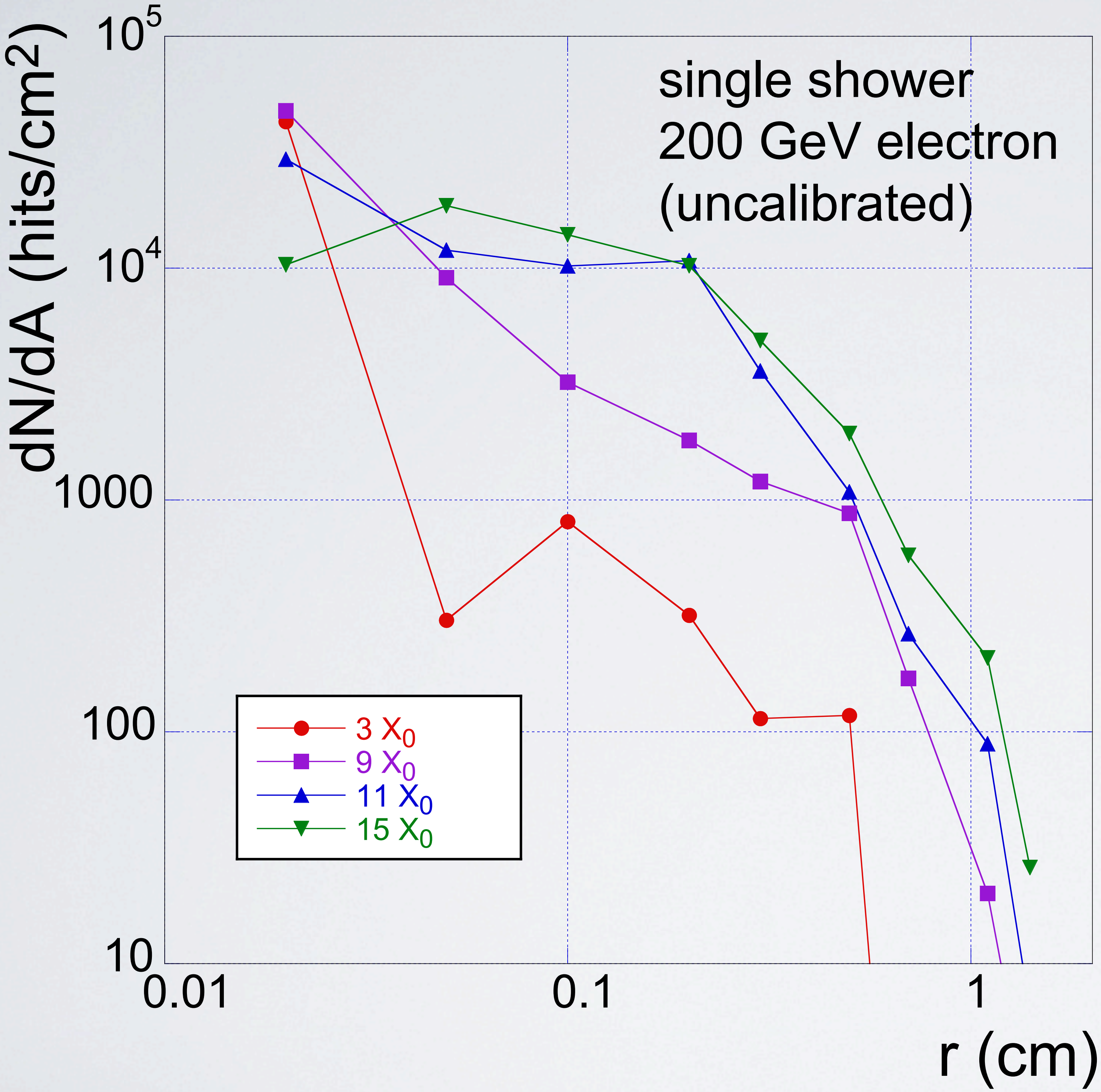
raw hit counts:
reasonable linearity and energy resolution

current resolution ≈2x ideal value from simulation

- more corrections under way
  - calibration (what level?)
  - alignment
  - dead chips/channels
  - particle ID
- energy resolution of fine layers does not limit full resolution of calorimeter



Shower Profiles



high granularity allows detailed measurements of shower distribution below the mm scale

narrow shower in front layers, significantly broadening during shower development

systematic studies require precise alignment

work in progress

Summary

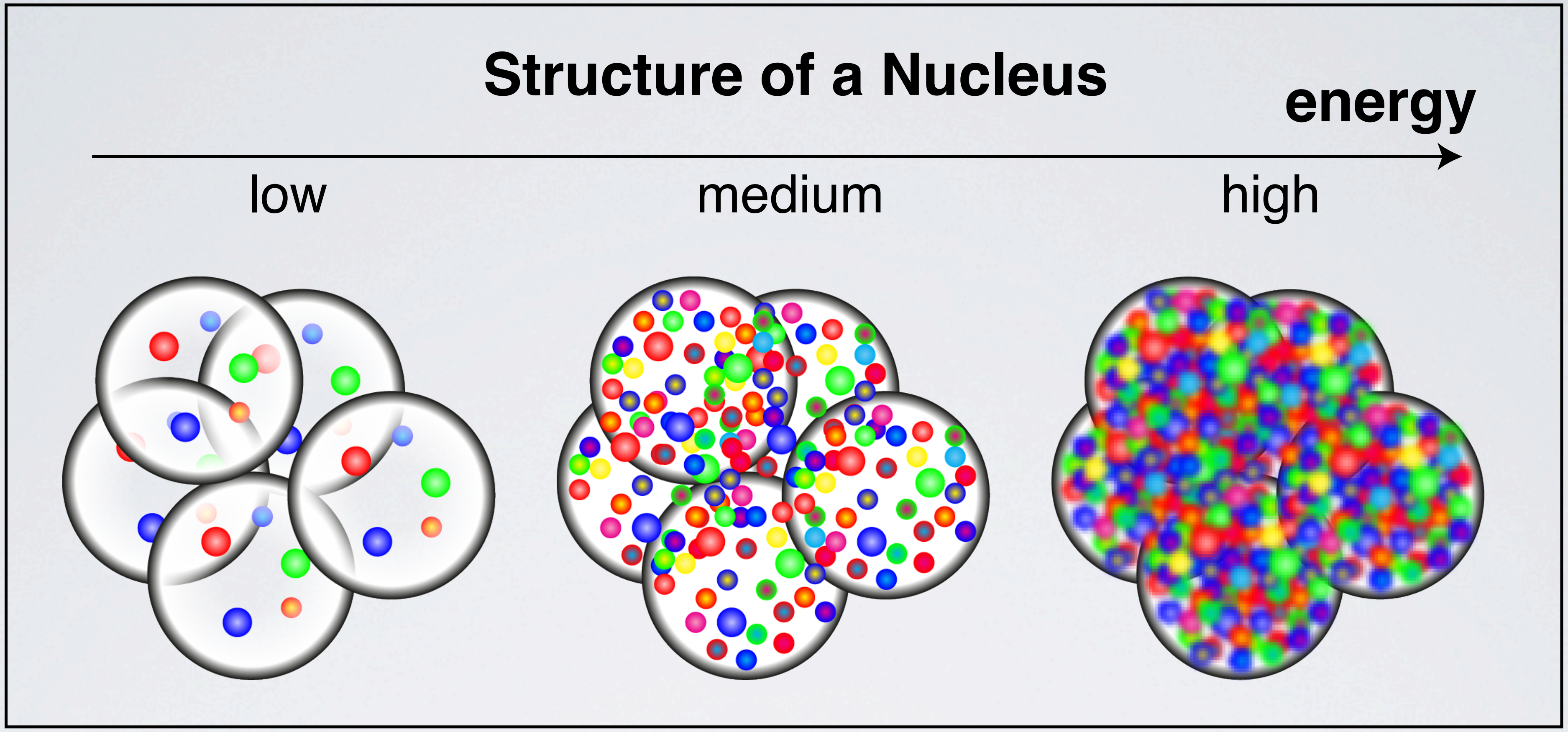
- Forward calorimeter (FoCal) in ALICE would enable unique measurements to constrain small-x gluon distribution
  - More physics with photons, pions and jets ...
  - *Still requires approval*
- Key property: high granularity
- SiW pixel calorimeter prototype
  - Proof of principle for digital calorimetry
  - Unprecedented shower shape studies possible

The ALICE-FoCal Collaboration

- – University of São Paulo
- – Czech Technical Institute, Prague
- – University of Jyväskylä
- – VECC, Kalkota
- – Bhabha Atomic Research Center (BARC), Mumbai
- – Tsukuba University
- – University of Tokyo (CNS)
- – Nikhef/Utrecht University
- – Bergen Univ
- – LLNL
- – ORNL
- – University of Tennessee
- – Wayne State University

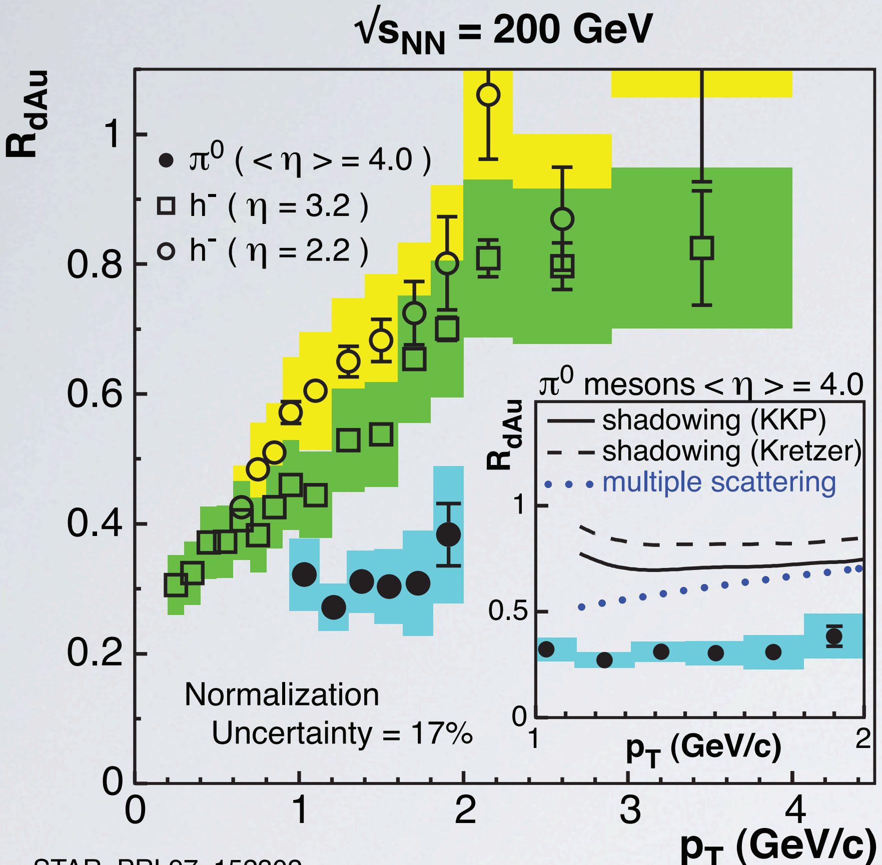
Backup Slides

Color Glass Condensate



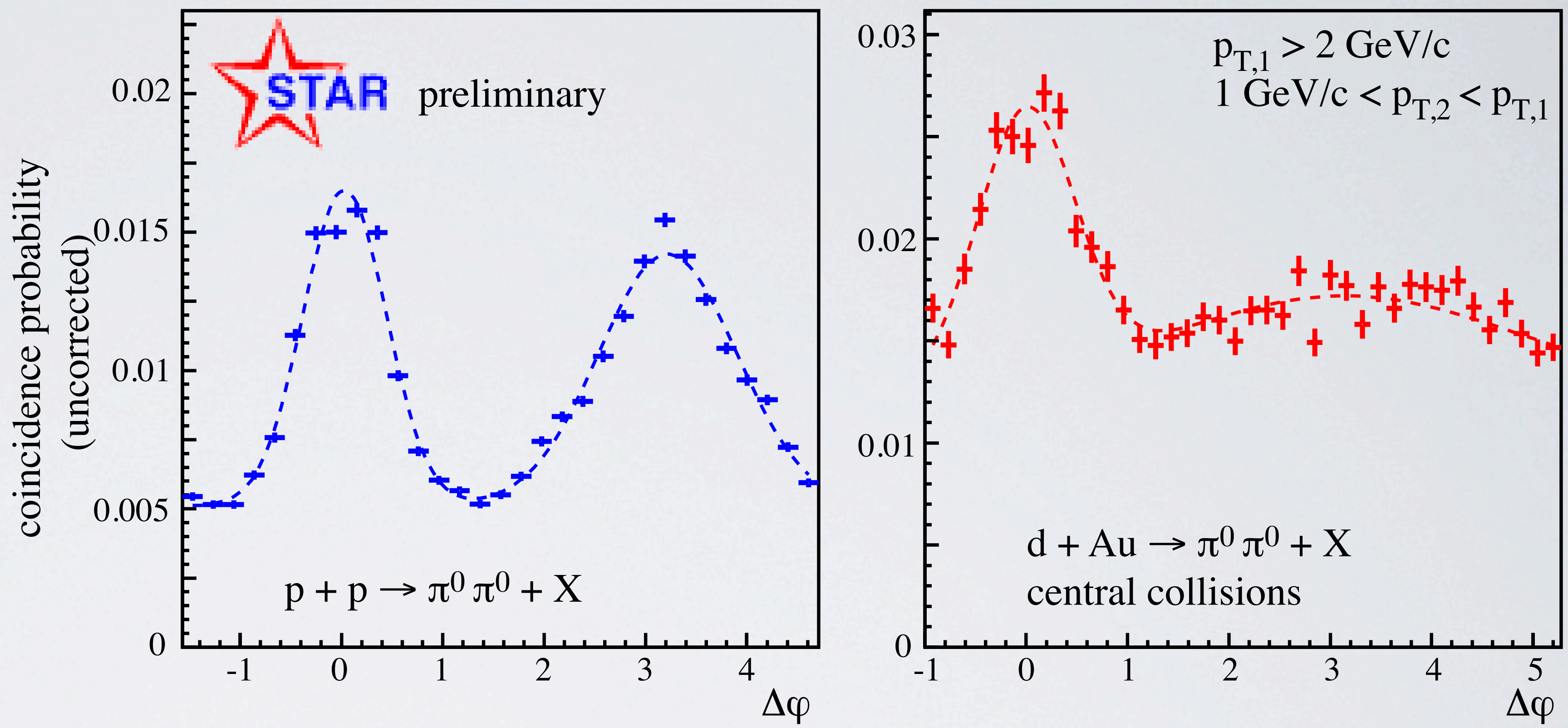
- low-x, low Q^2: high gluon occupation number, strong fields
  - classical color fields, theoretically calculable (JIMWLK)
- new phenomena: yield suppression, monojets
  - enhanced in nuclei (stronger color field compared to proton)

Indications from RHIC



STAR, PRL97, 152302

STAR, Braidot, Ogawa et al.

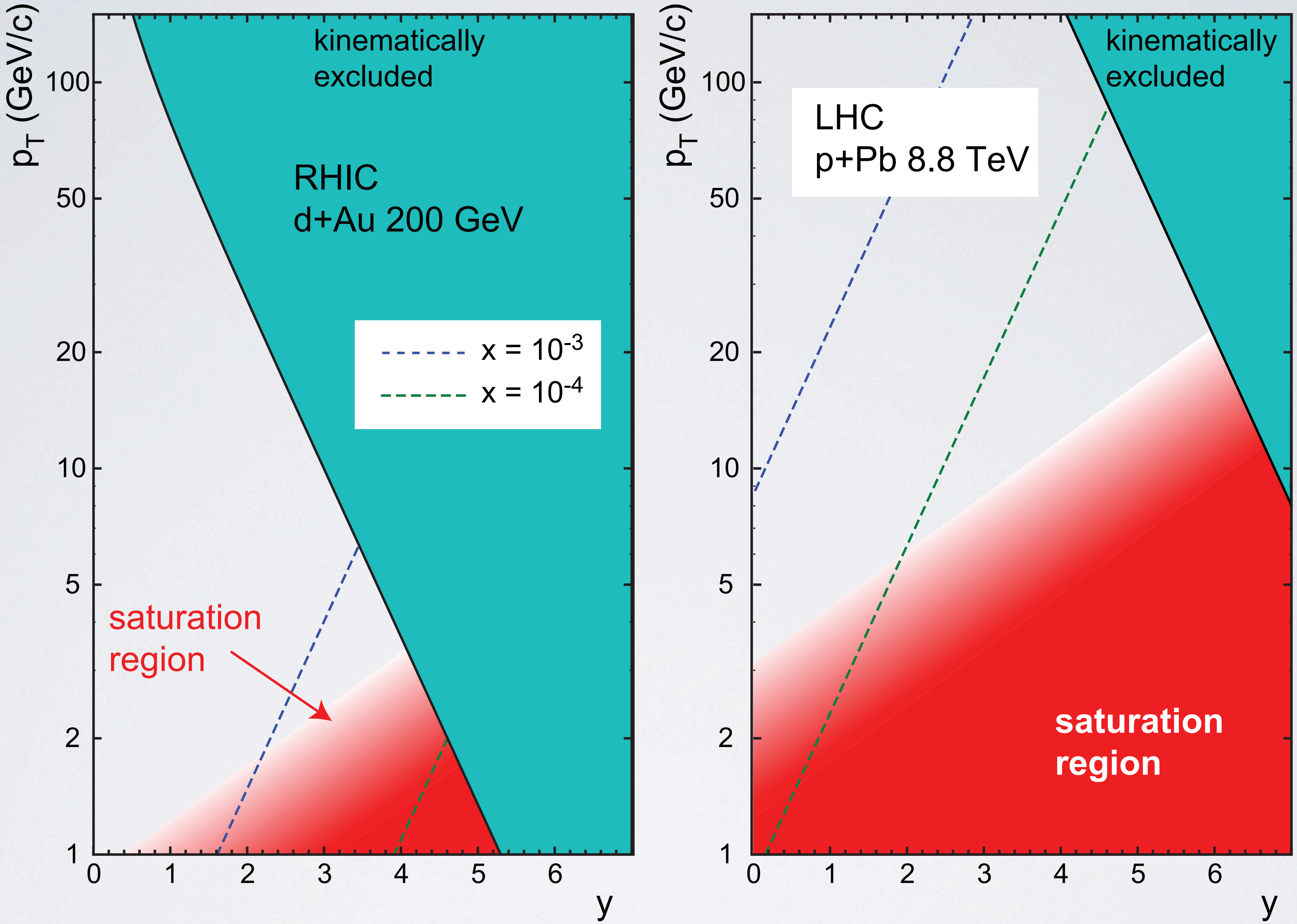


R_{dA}: strong suppression of hadron yield at forward rapidity

di-hadron correlations: broadening/suppression of away-side peak in dAu

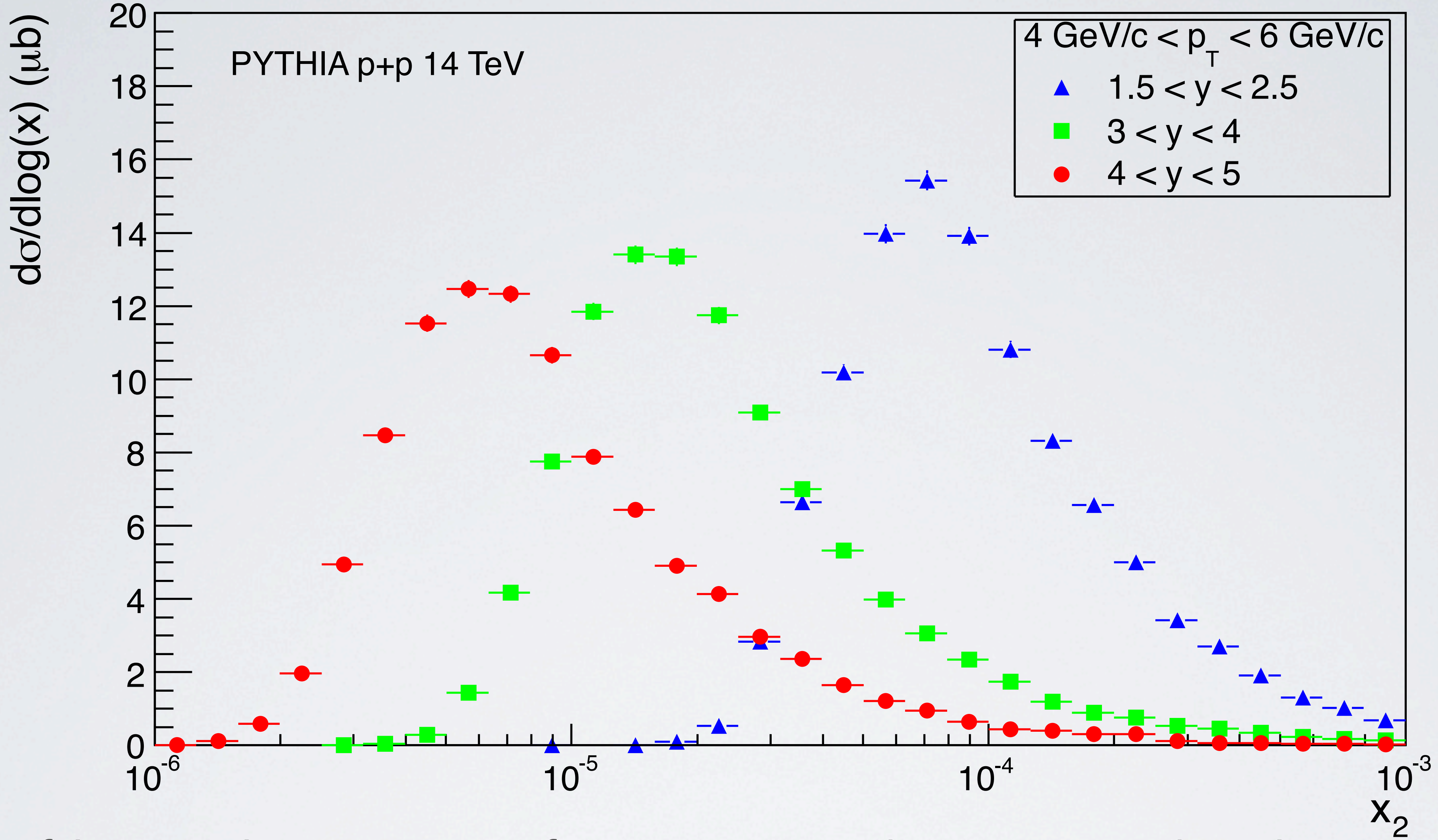
- qualitatively consistent with CGC, but ...
  - very low p_T, hadron observable (final state interactions)!
- extend p_T and y range (not possible at RHIC)
- measure prompt photons

LHC vs RHIC



- Q_{sat} larger: saturation in perturbative regime?
- larger energy: lower x at same rapidity, not constrained by kinematic limit

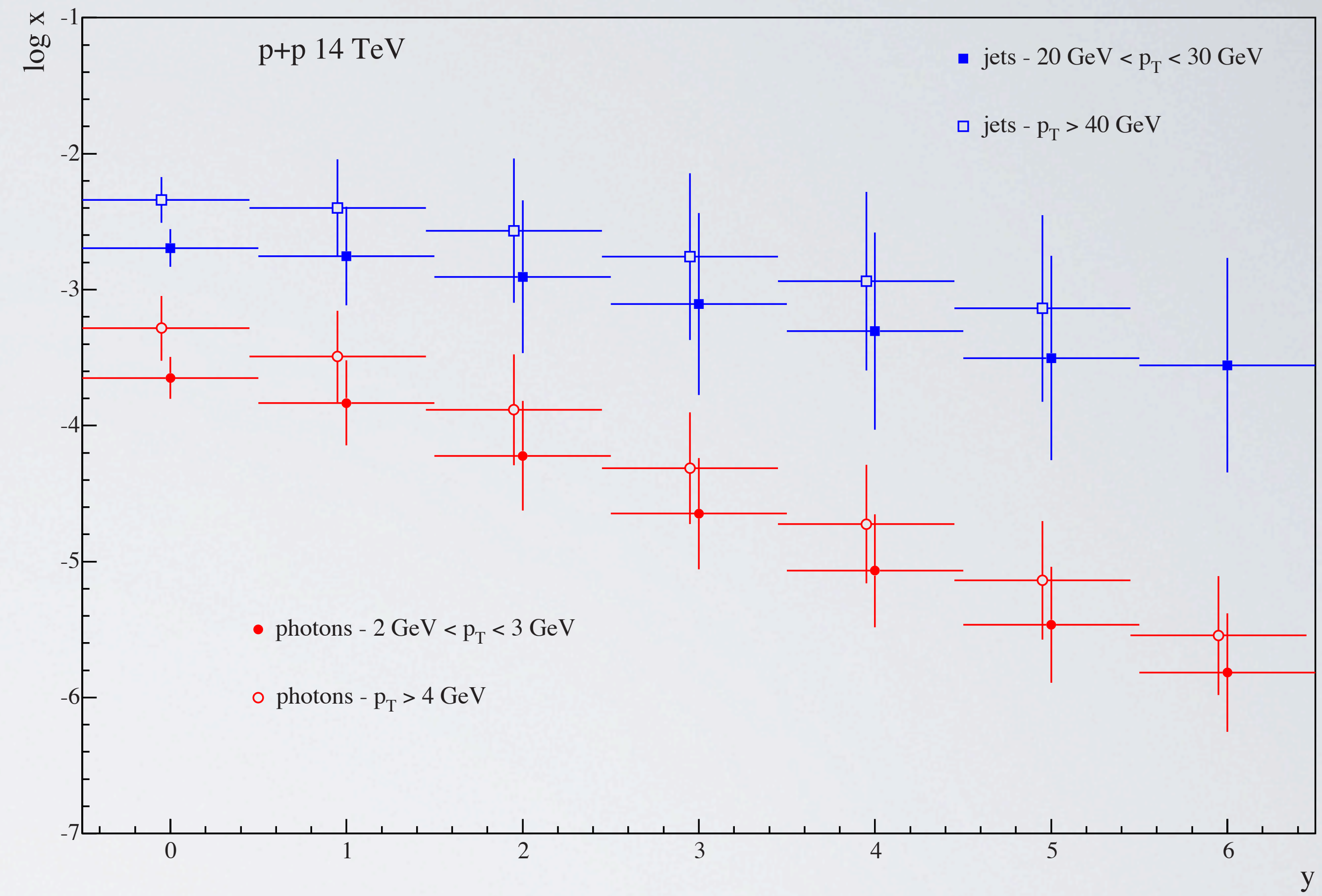
x-Reach with Direct Photons



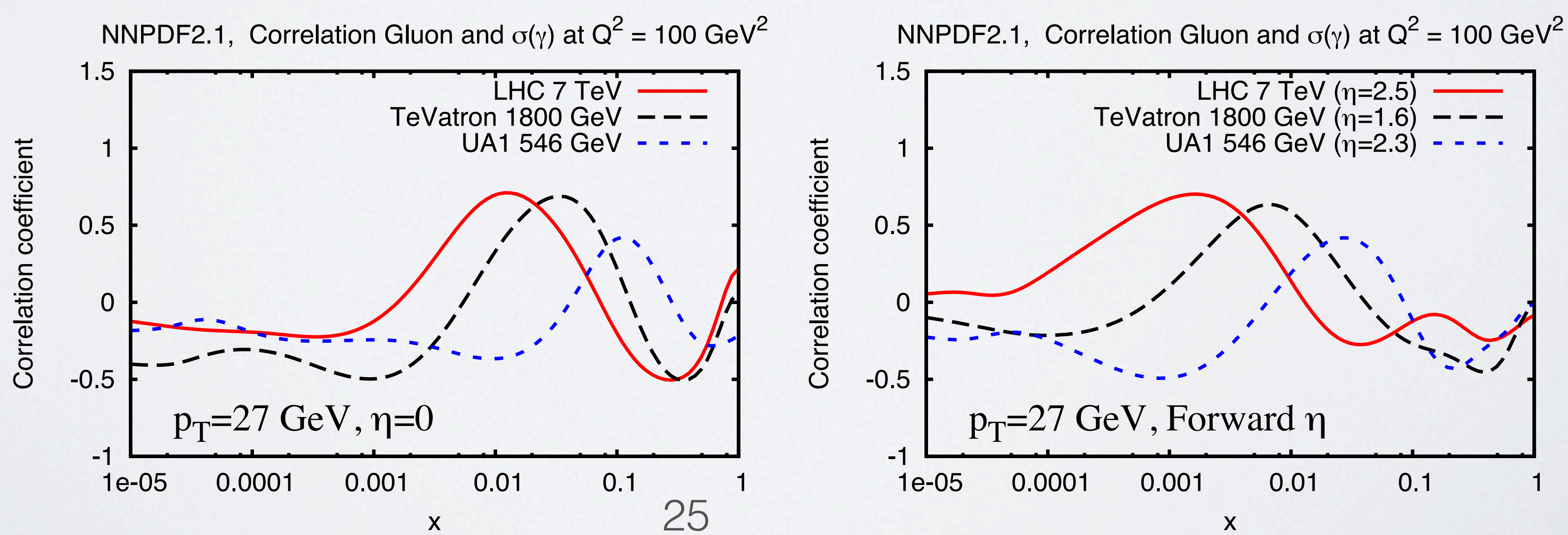
- x of incoming parton for prompt photon production with $p_T > 4$ GeV/c
- changes with NLO effects to be checked
  - should be small for isolated photons

Kinematic Constraints

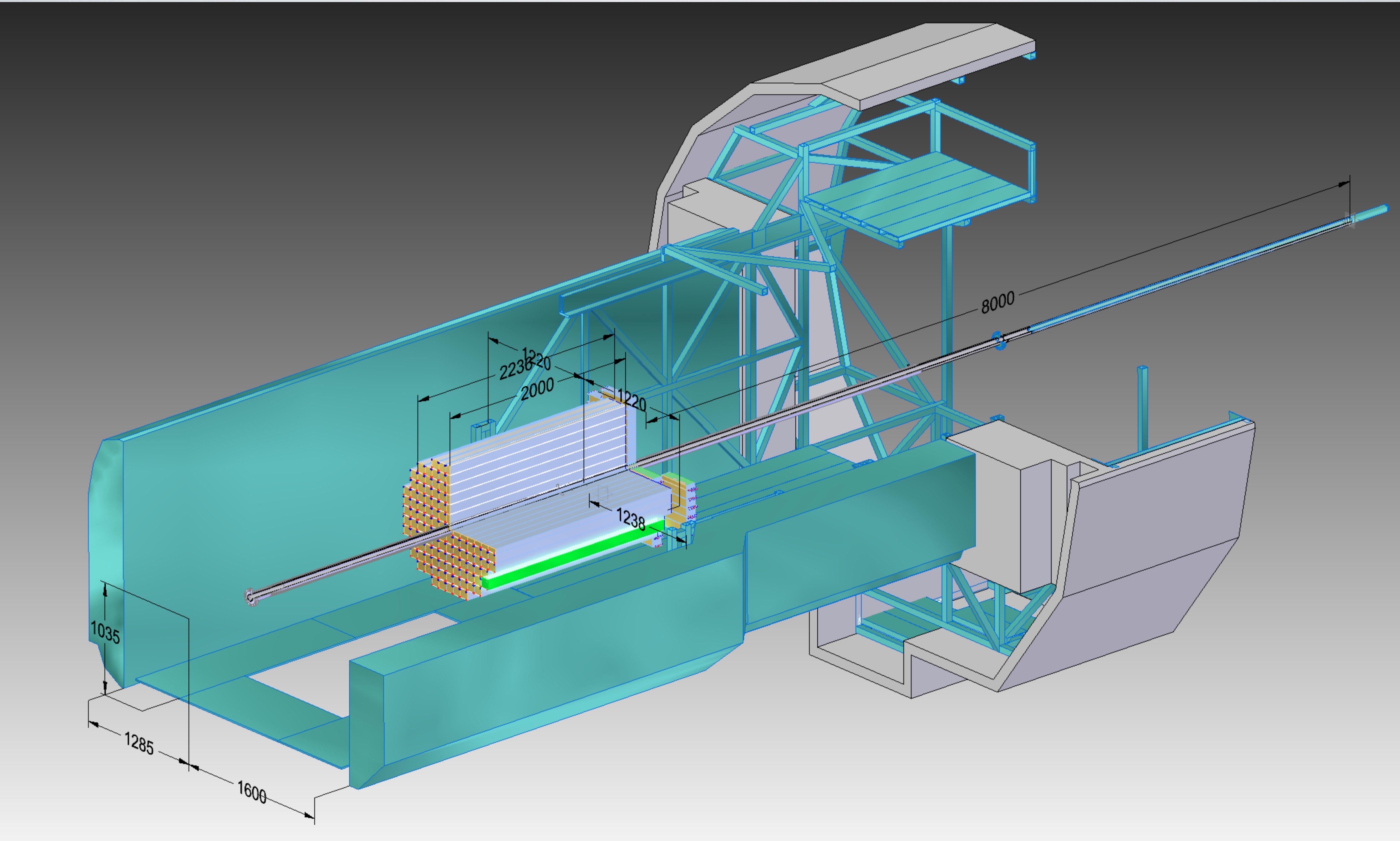
- large y prompt photons effective to constrain kinematics to low x
  - obvious in LO (PYTHIA)
- NLO studies in JETPHOX:
  - indicate clear sensitivity of isolated photons, dedicated calculations under way



from D. d'Enterria and J. Rojo, arXiv:1202.1762



FoCal in ALICE

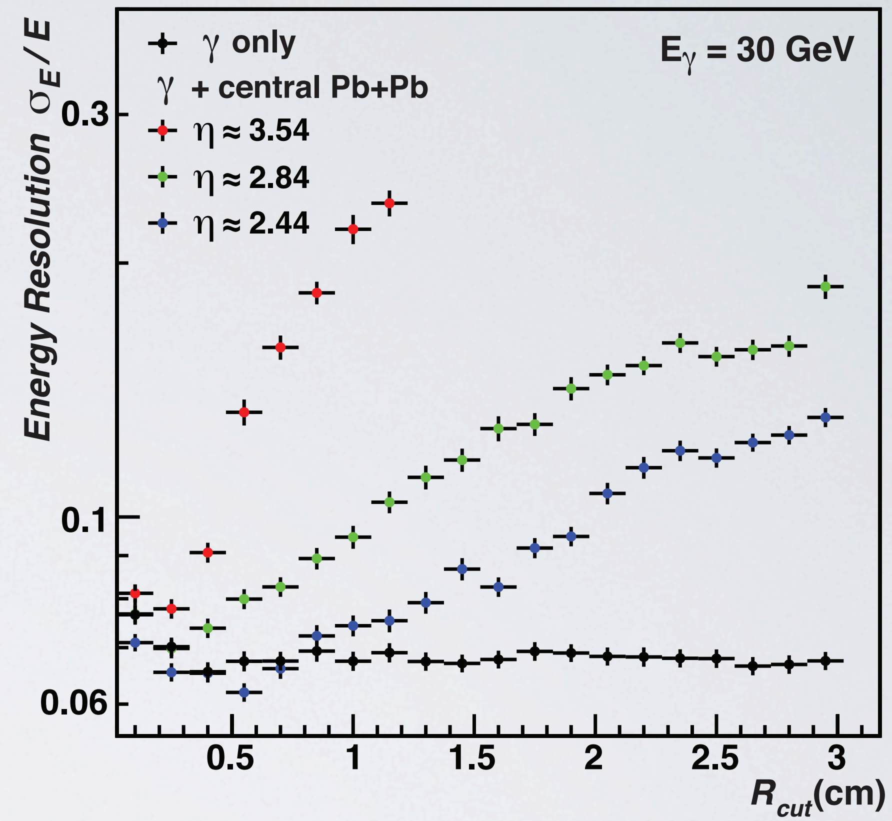


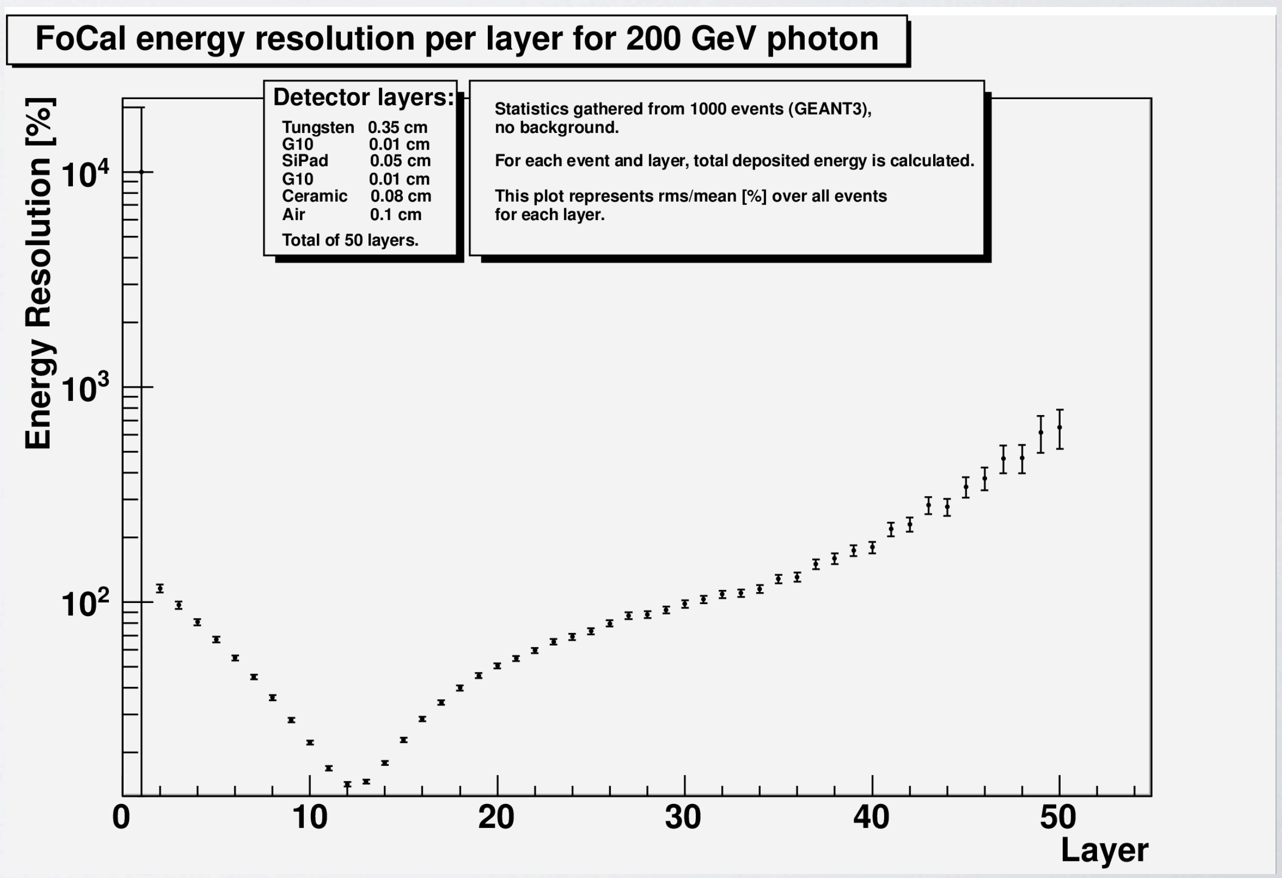
FoCal Physics Program

- p+Pb: saturation/CGC effects
  - forward direct γ spectra, γ-hadron/jet correlations (unique!)
  - π^0 spectra, π^0-π^0 correlations, possibly jets (had. calorimeter!)
- p+p: reference measurements
  - constraints on PDFs?
- Pb+Pb: QGP studies
  - extend acceptance for γ-hadron/jet, π^0-π^0 correlations
  - π^0 R_{AA} forward
    - longitudinal density profile, compare to forward J/ψ
  - event plane determination, ...

Detector Design Issues

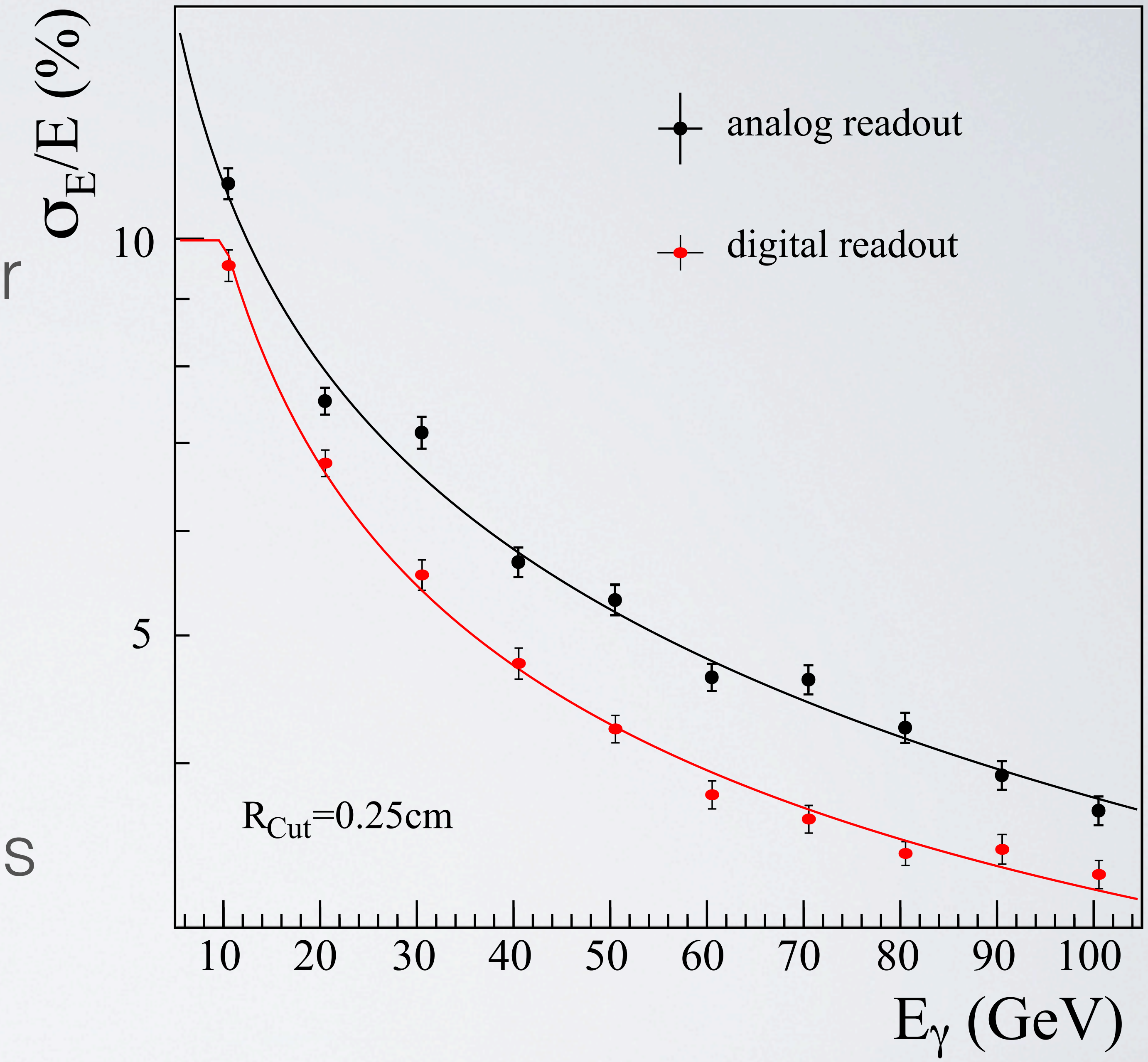
- energy measurement from small transverse area possible
- longitudinal segmentation?
  - obtain good energy estimate from few layers?
  - resolution from **single layer** < 20% for high energy
- optimize granularity per layer
  - studies ongoing
- need to check GEANT!



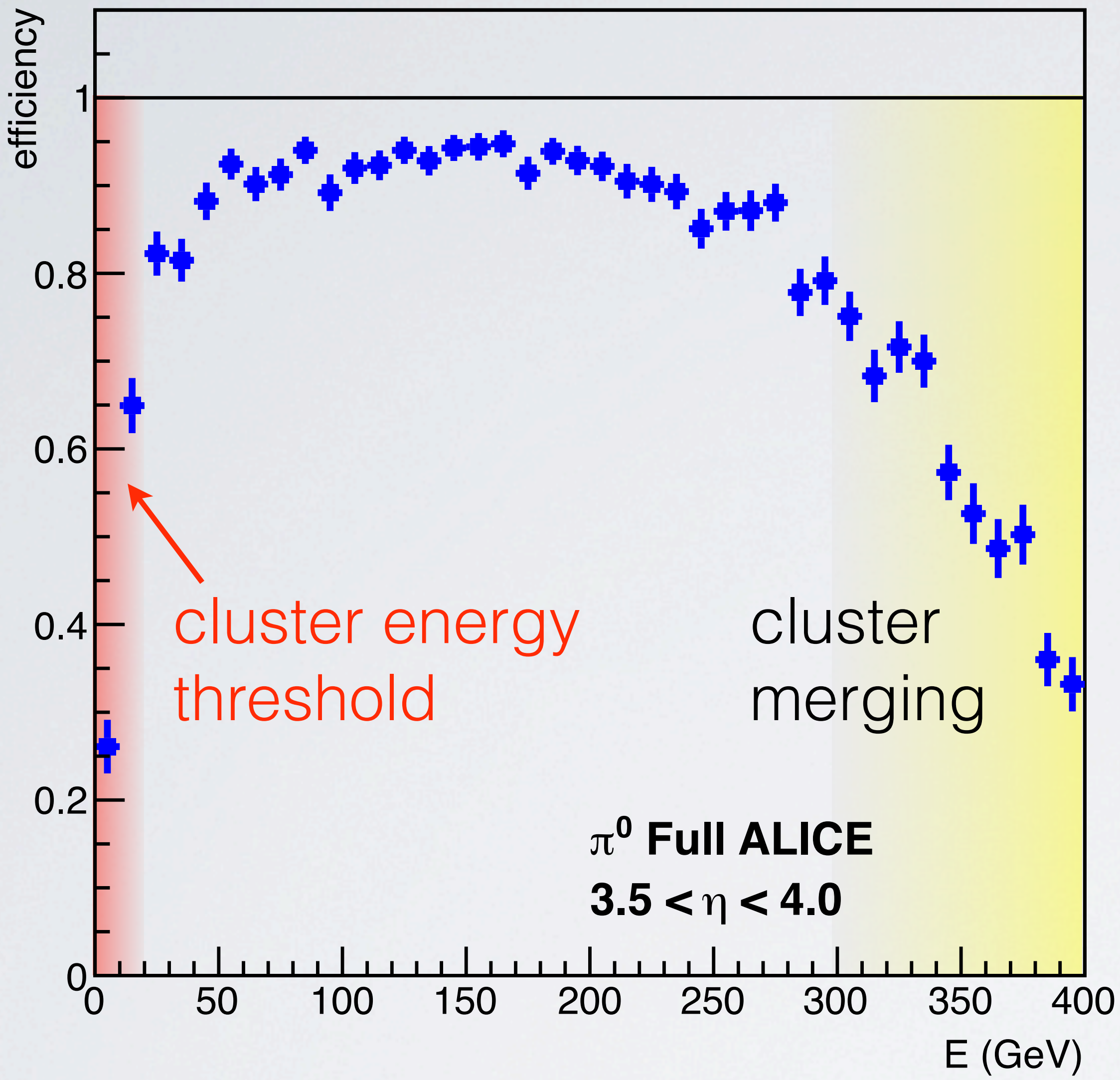


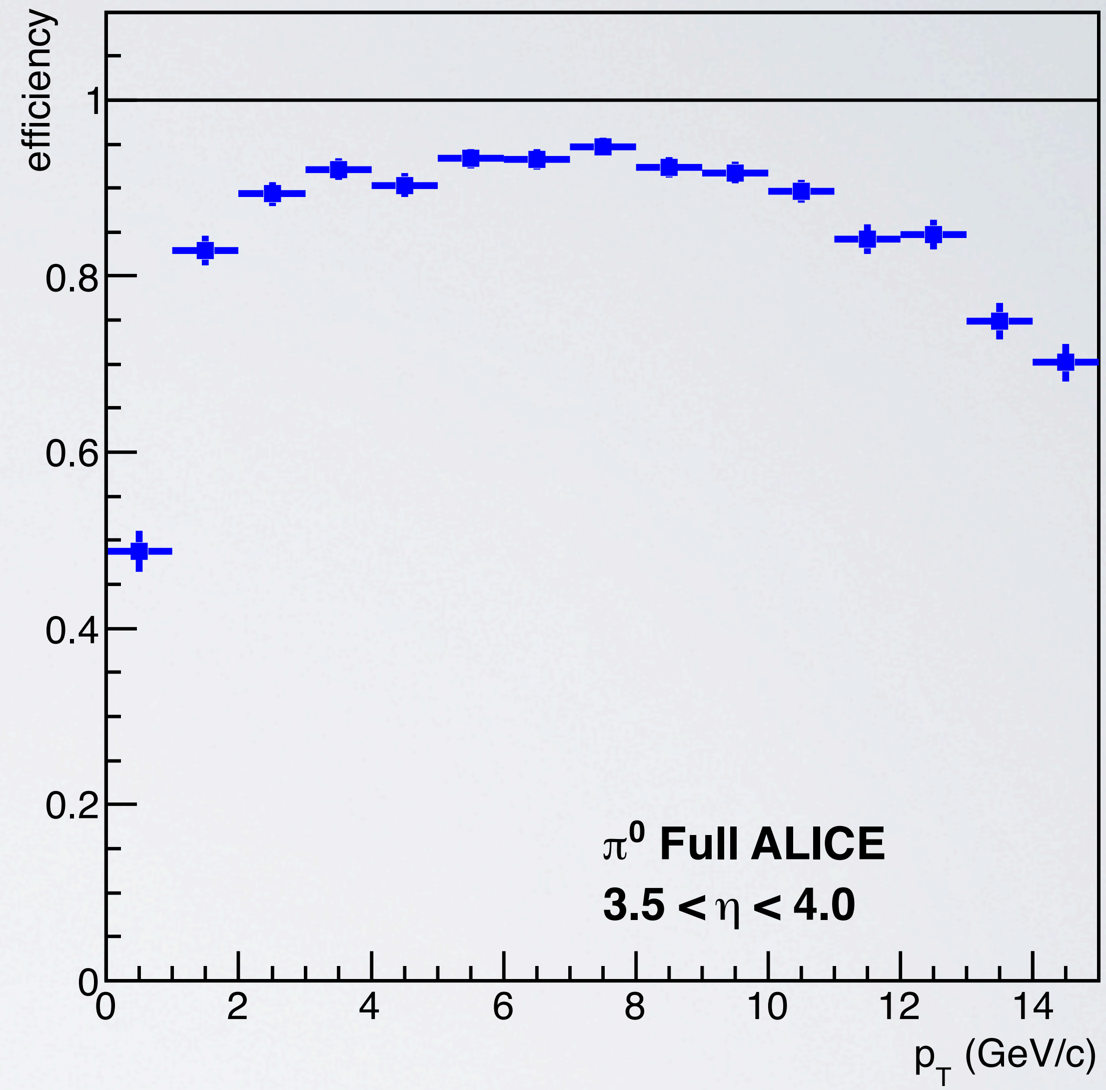
Digital Calorimetry

- FoCal with 50x50 μm^2 pixels
- compare
  - sum of analog signals from energy deposit in active layer
  - number of pixels above threshold
- better resolution for digital pixel readout
  - already seen in earlier studies
  - can work when multi-hit probability of pixels low
  - can we trust GEANT here?



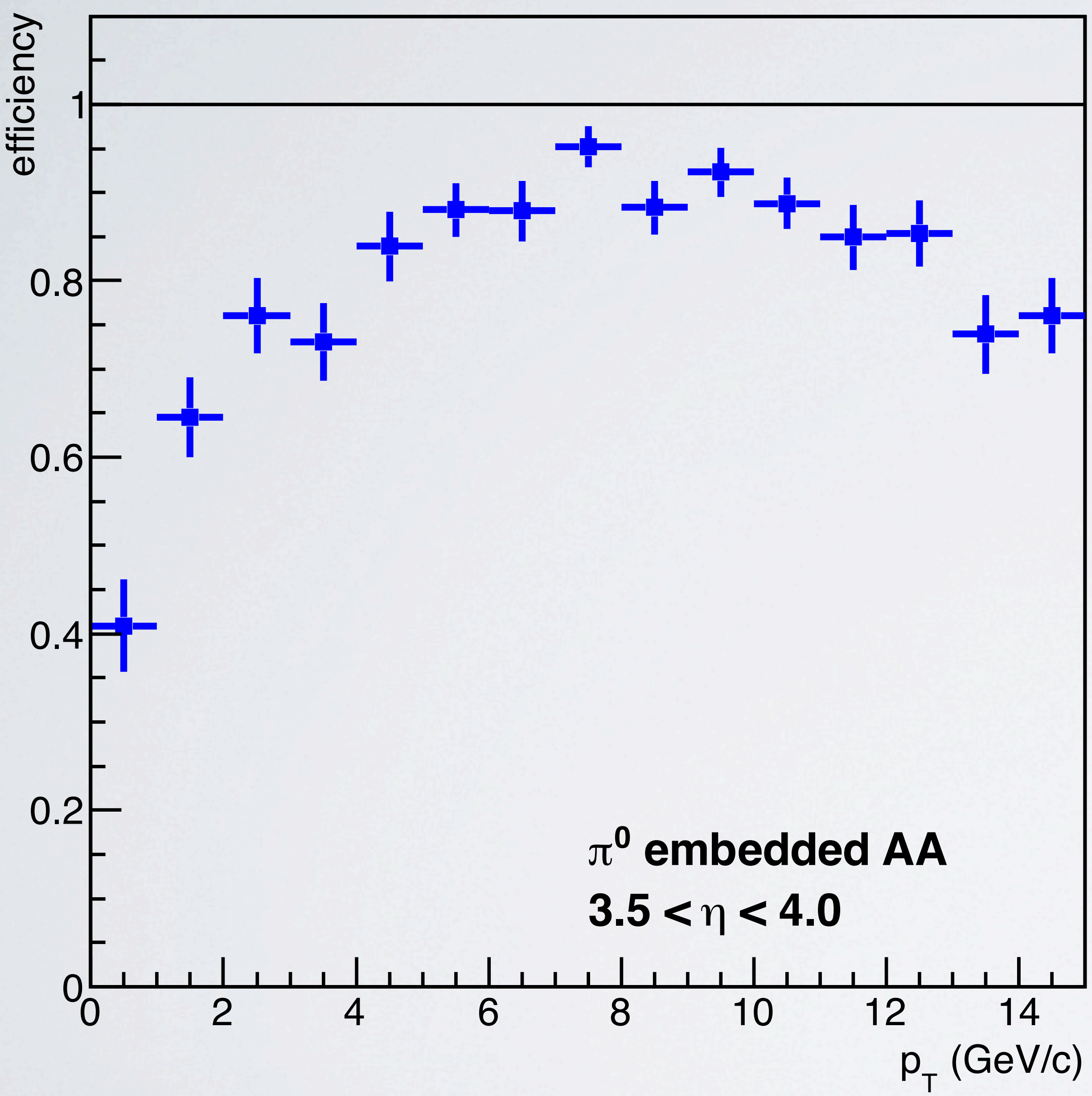
π^0 Efficiency





- results of single particle simulations using full ALICE setup
- excellent π^0 efficiency for $20 < E < 300$ GeV, $2 < p_T < 10$ GeV/c

Performance in Pb+Pb



performance in π^0 measurement:

- good efficiency
- expect larger uncertainty than in pp

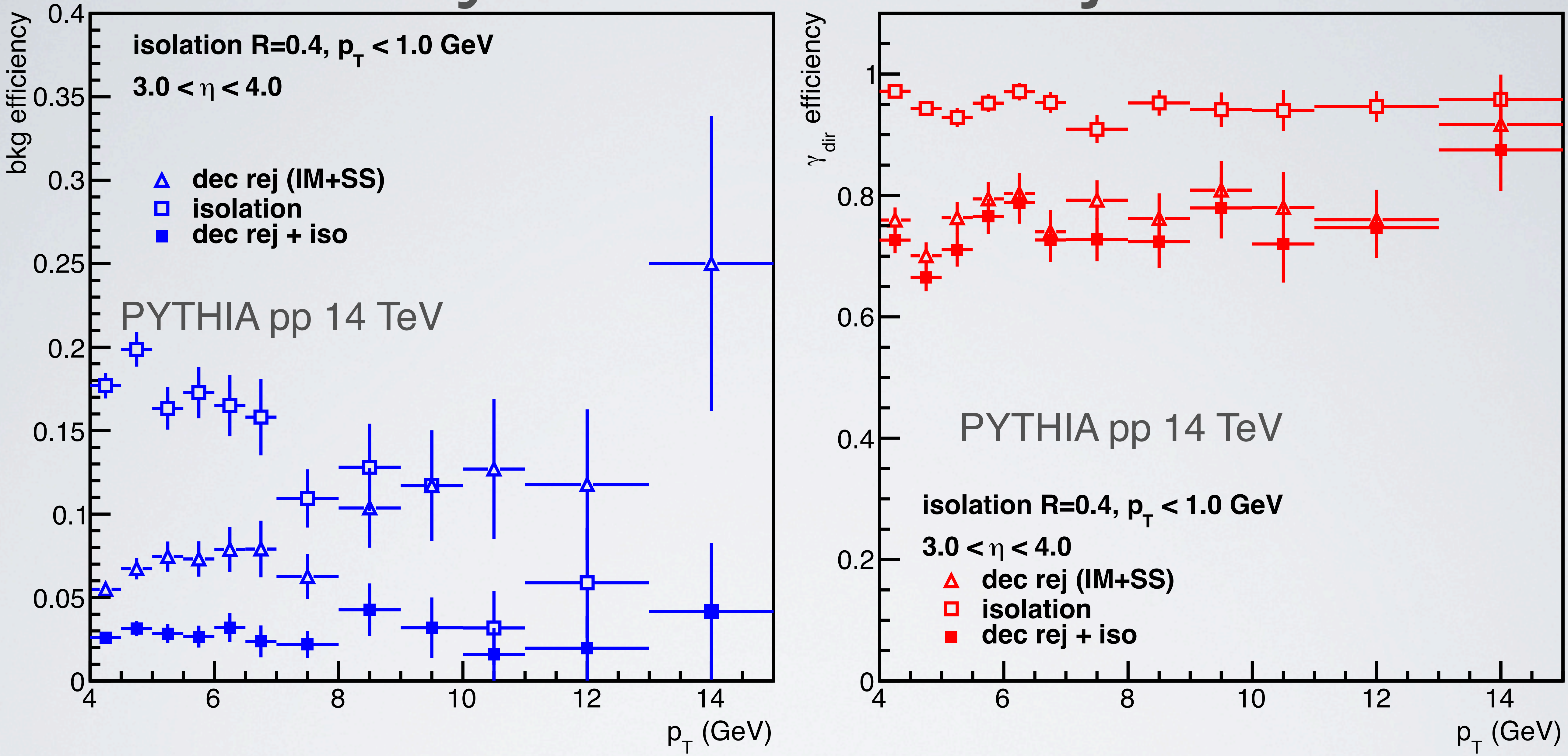
enables π^0 R_{AA} for $7 < p_T < 20$ GeV/c allows study of parton energy loss, medium density vs. η

also other observables, but significant thresholds due to underlying event bkg

- di-hadron correlations
- jet spectra, R_{AA}, di-jet correlations for $p_T > 20$ GeV/c
- direct photons in limited p_T range (tbc)

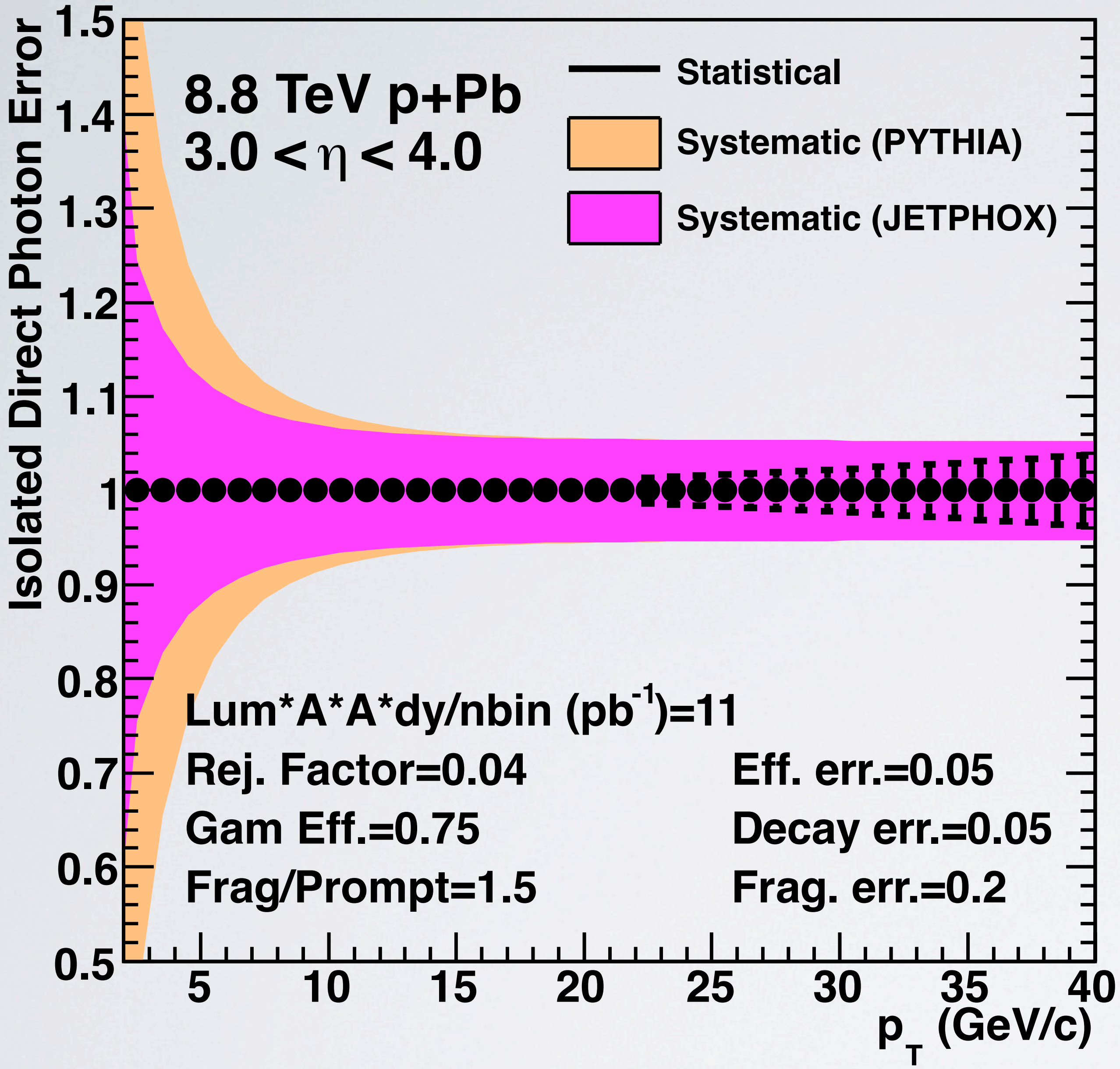
work in progress!

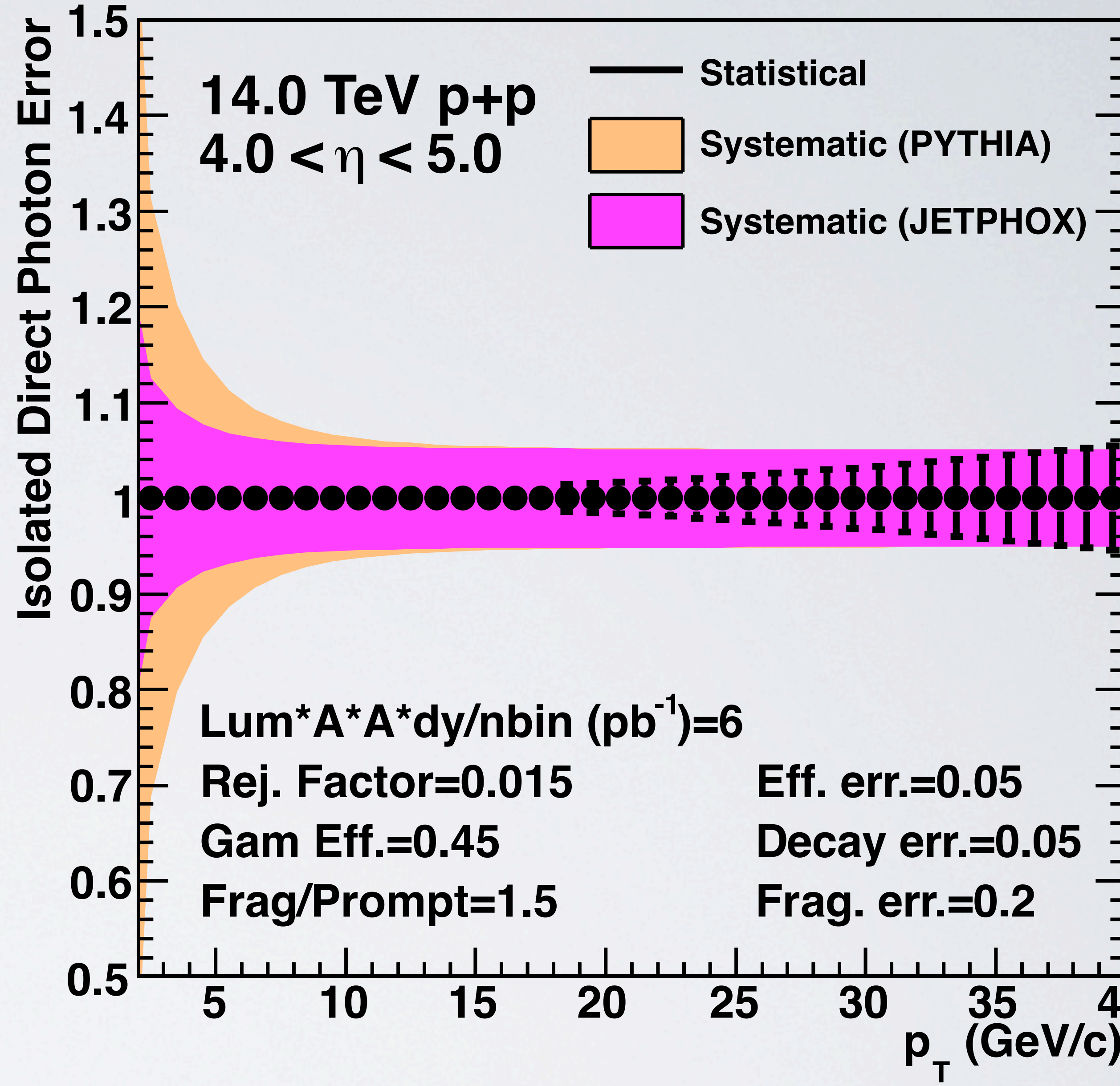
Decay Photon Rejection



- combined rejection (invariant mass + shower shape, isolation)
- rejection factor ≈30, direct photon efficiency ≈75%
  - largely p_T-independent

More Performance ...





better performance for 8.8 TeV (pA equivalent to pp)

better performance for larger η (only possible for z=8m, requires more integration work)

CMOS Sensor Readout