Measurement of direct photons at forward rapidities in p-A collisions at LHC with ALICE

a probe for nuclear PDFs and saturation

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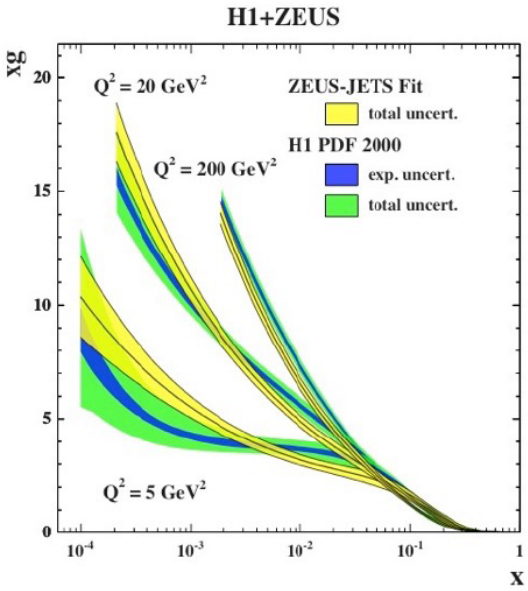
1. Low-x physics and gluon saturation in p/d+A
   - results from RHIC and LHC
2. Direct Photons
3. FoCal - an ALICE Upgrade Proposal
   - performance studies
   - detector R&D

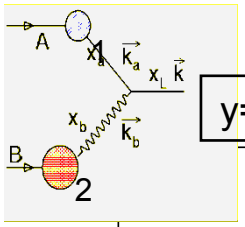
ALICE

Experimental results from RHIC and LHC

- **Gluon saturation**
  From DIS, HERA:
  gluon density increases
  rapidly at low x
  → problems with unitarity
  (finite cross sections)

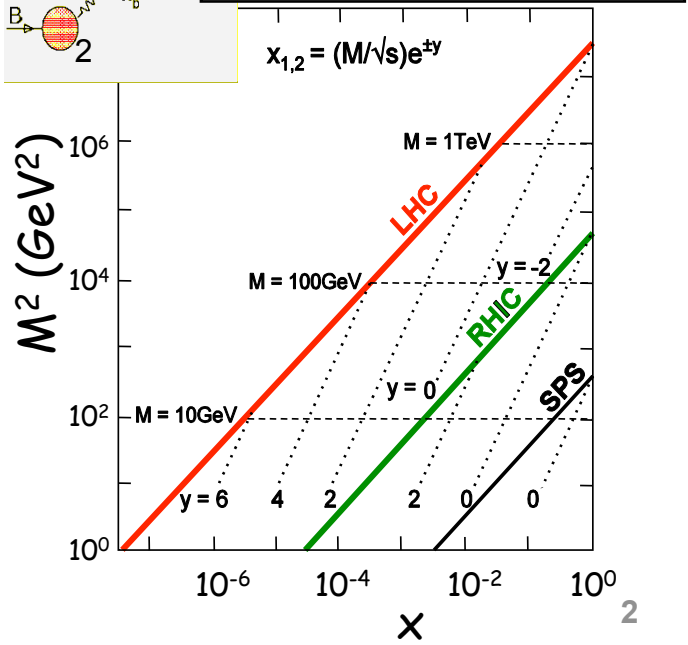


Kinematics



2→1 process

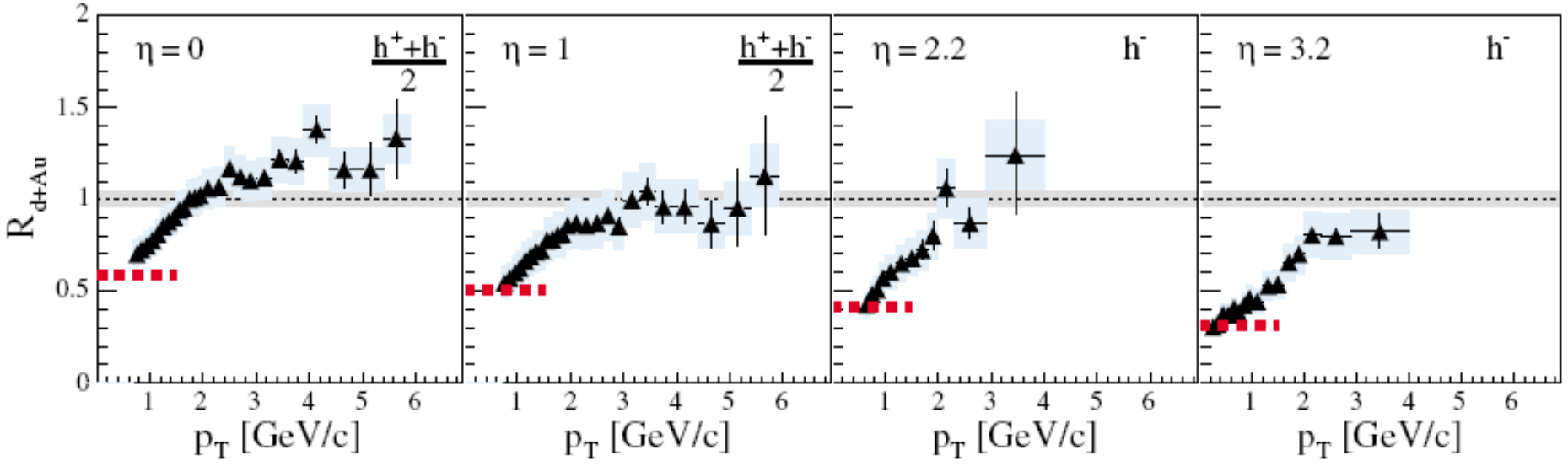
y=rapidity of (x_L, k) system



- **Particle production in nuclear collision at forward rapidities**
  Observation:
  suppression of hadron production
  in d+Au / p+Pb as compared
  to p+p
  → nuclear modification factor

Charged hadrons – R_{dAu} at different pseudorapidities (RHIC)

BRAHMS: PRL **93,** 242303 (2004)



$$R_{dAu} = \frac{1}{\langle N_{coll} \rangle} \frac{d^2N^{d+Au}/dp_T d\eta}{d^2N^{pp}_{inel}/dp_T d\eta}$$

where $\langle N_{coll} \rangle = 7.2 \pm 0.3$

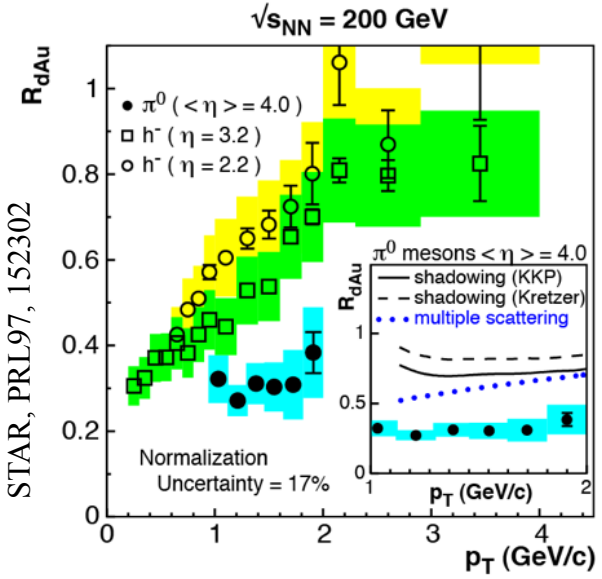
- **Clear suppression as η changes from 0 to 3.2**
- **CGC model describes R_{dAu} and R_{CP}**

D. Kharzeev, Y.V. Kovchegov, K. Tuchin, hep-ph/0405045 (2004); Phys.Lett. B599 (2004) 23-31

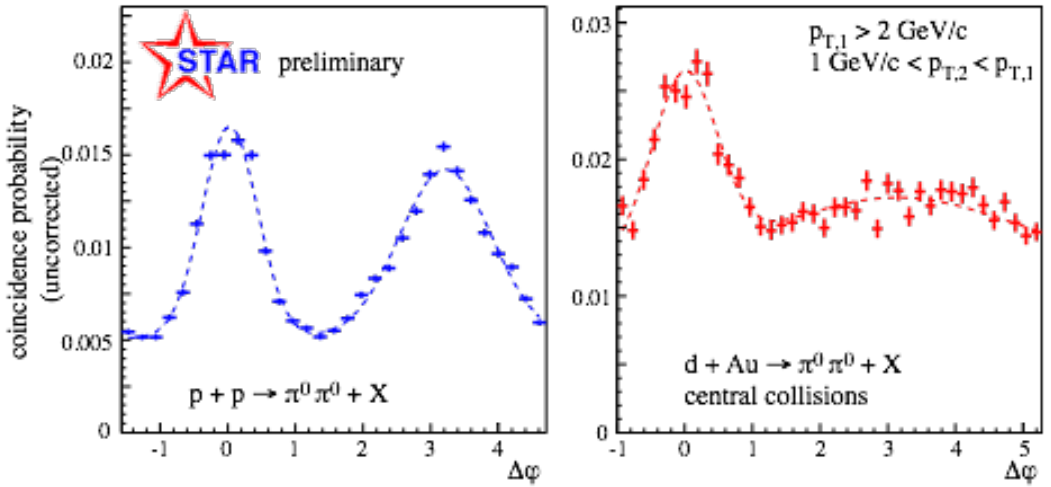
Experimental results from RHIC

Results from STAR

NMF



di-hadron correlations
(forward-forward correlations)

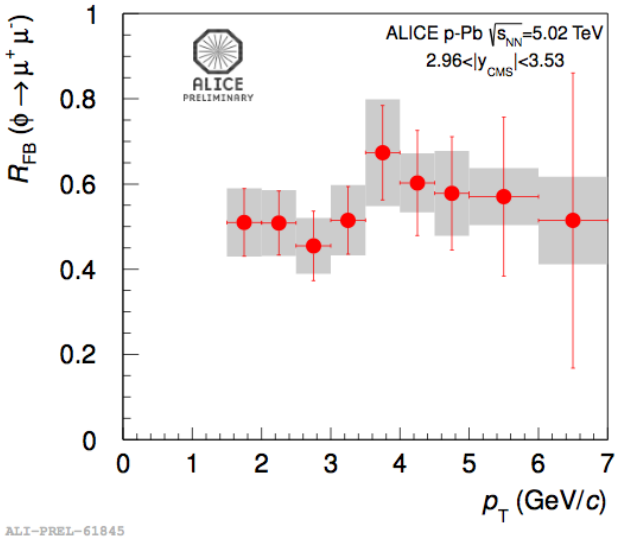


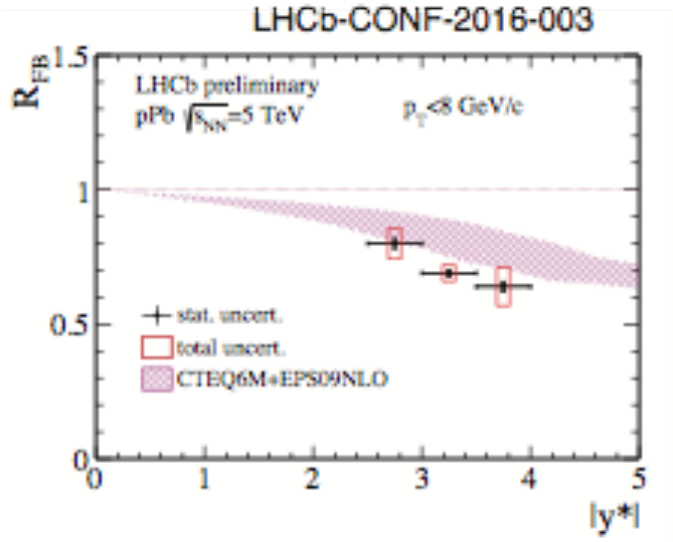
broadening/suppression of away-side peak in dAu

strong suppression of hadron yield

- qualitatively consistent with CGC expectations
- however, many open questions/alternative interpretations:
  e.g. effects of multiple interactions, beam energy loss, kinematic limits…

Results from p-Pb at LHC (1)





forward/backward ratio R_{FB}

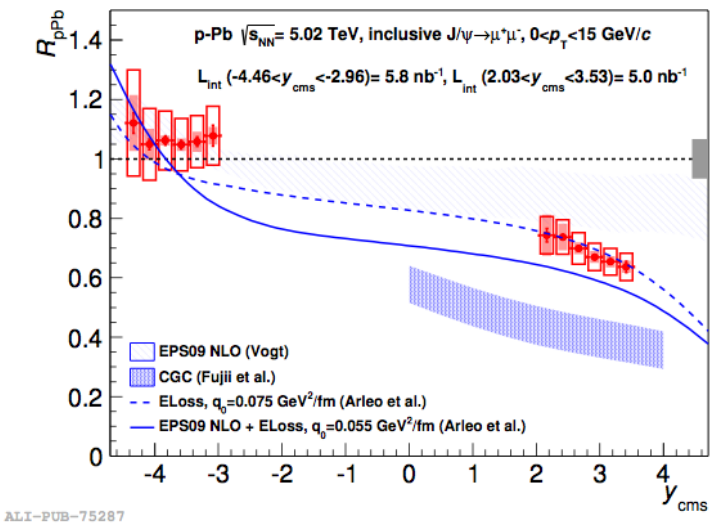
$$R_{FB} = \frac{dN/dp_T(\mathrm{p-going})}{dN/dp_T(\mathrm{Pb-going})}$$

for Φ-mesons in ALICE (dimuons)
and for open charm in LHCb

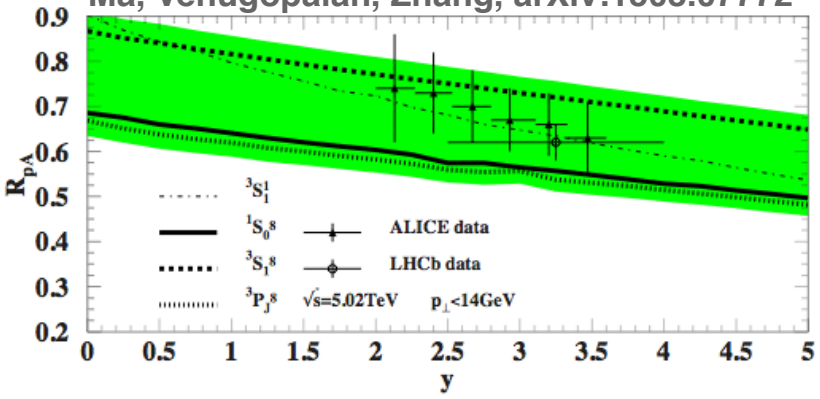
- **Φ strongly suppressed at forward rapidity**
  - interpretation unclear
- **prompt D^0 suppressed**
  - comparison with shadowing (EPS09): consistent, but data slightly more suppressed

Results from p-Pb at LHC (2)

ALICE, JHEP02 (2014) 073



Ma, Venugopalan, Zhang, arXiv:1503.07772



nuclear modification factor R_{pPb} for charmonium

- **J/ψ suppressed at forward rapidity**
  - consistent with shadowing (EPS09)
  - not described by a specific CGC calculation

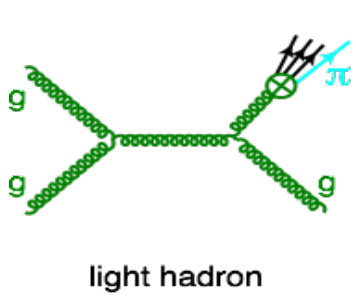
- **More recent CGC calculation compatible with observed J/Ψ**

→ inconclusive

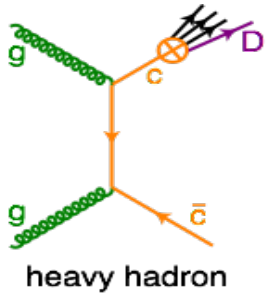
$$R_{pA} = \frac{dN/dp_T(pA)}{< N_{coll}(pA) > dN/dp_T(pp)}$$

A probe for gluon density – direct photons

- **Hadronic observables**
  - interpretation inconclusive

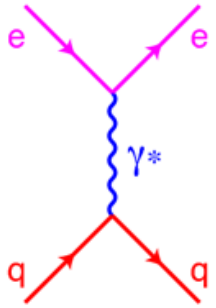


light hadron

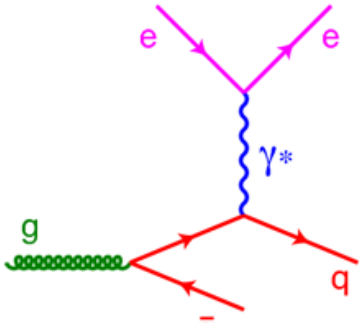


heavy hadron

- **Electromagnetic probes**
  - Deep-Inelastic Scattering (DIS)
    - » classical PDF method
    - » not sensitive to gluons at LO
    - » gluons from NLO

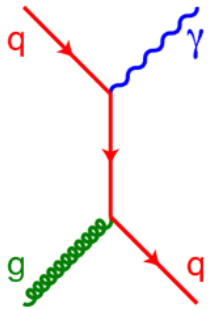


DIS (LO)



DIS (NLO)

  - Photon production in hadronic collisions
    - » sensitive to gluons at LO



direct-γ, Compton (LO)

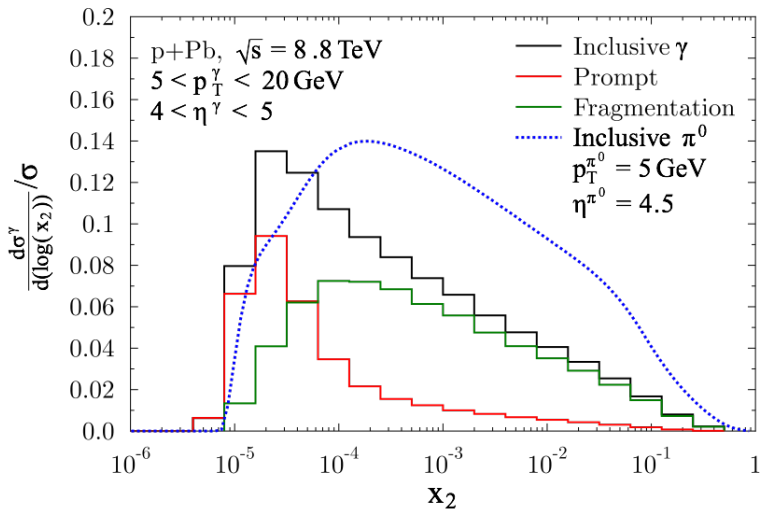
Direct photons - nPDF vs CGC

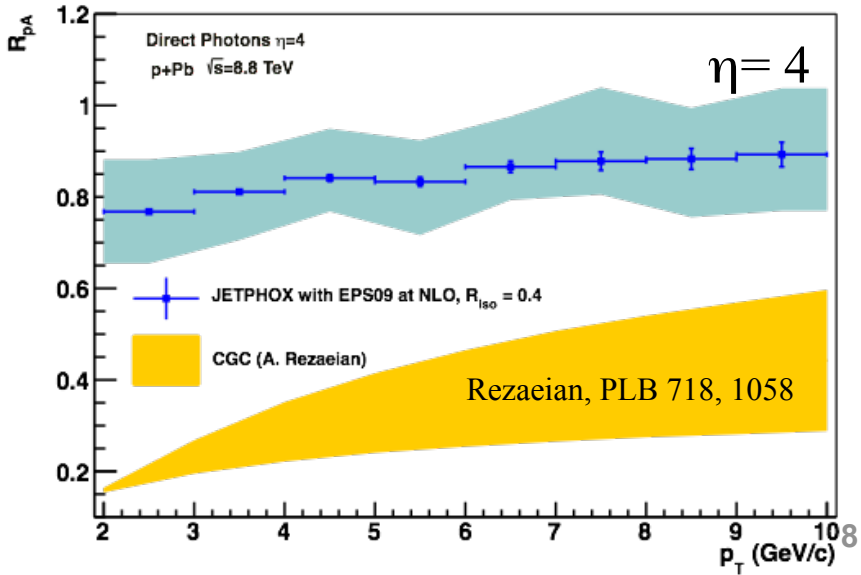
- **Direct photons**
  - large cross section
  - sensitive to small x at forward rapidity:
    $x \approx 10^{-5}$ at η=4-5
    (narrow peak, however with a sizeable tail)

- **Two scenarios for forward γ production in p +A at LHC**
  - normal nuclear effects
    NLO and LO nPDFs
  - saturation/CGC

→ **strong suppression in direct γ R_{pA}**
  - clean signal for isolated photons
  - signal expected at forward η, low-intermediate p_T

NLO pQCD calculations with shadowing (EPS09)
Helenius, Eskola, Paukkunen, arXiv:1406.1689

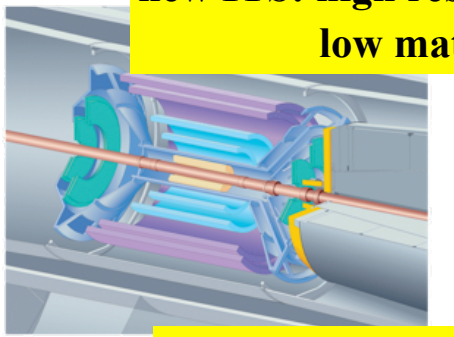




ALICE detector & upgrades

TPC: new GEM readout chambers, continuous readout

new ITS: high resolution, low material budget



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

MFT: secondary vertexing for muons

FoCal project

new beam pipe: smaller diameter

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

planned for installation in LS2 (2019), Letter of Intent: CERN-LHCC-2012-012

Proposed for LS3 upgrade (under internal discussion)

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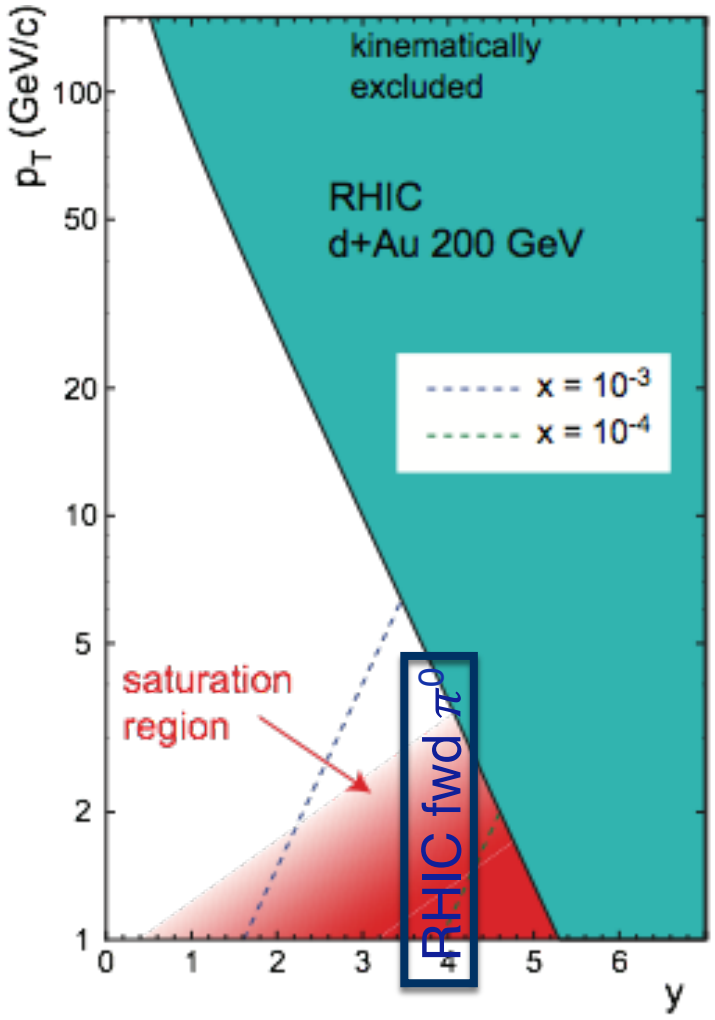
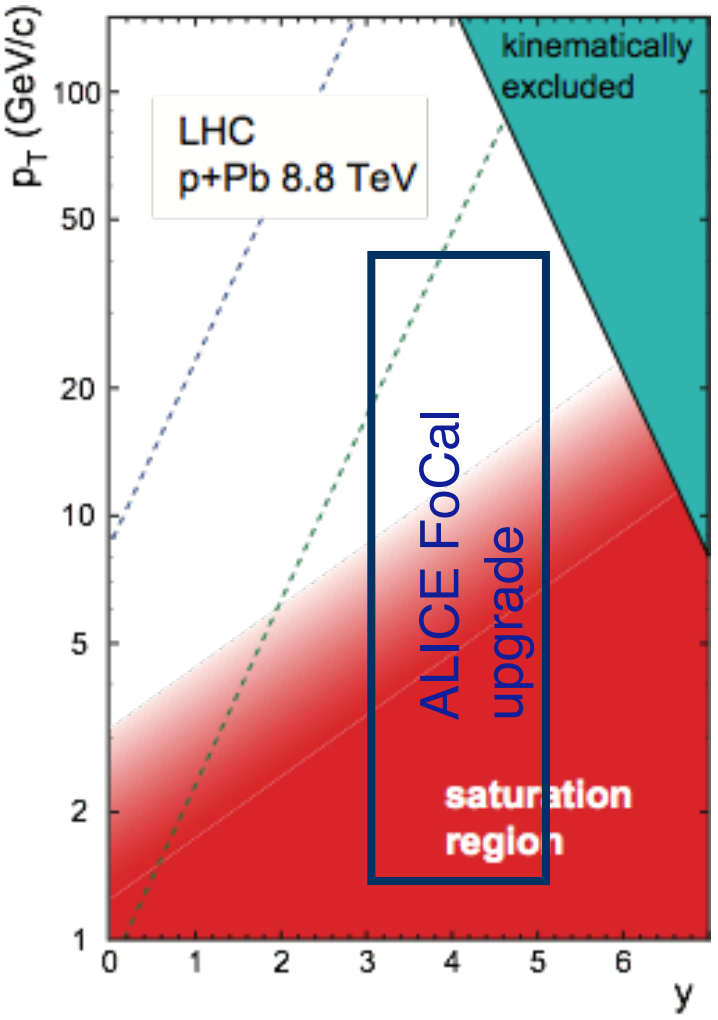
Forward measurements: RHIC vs LHC



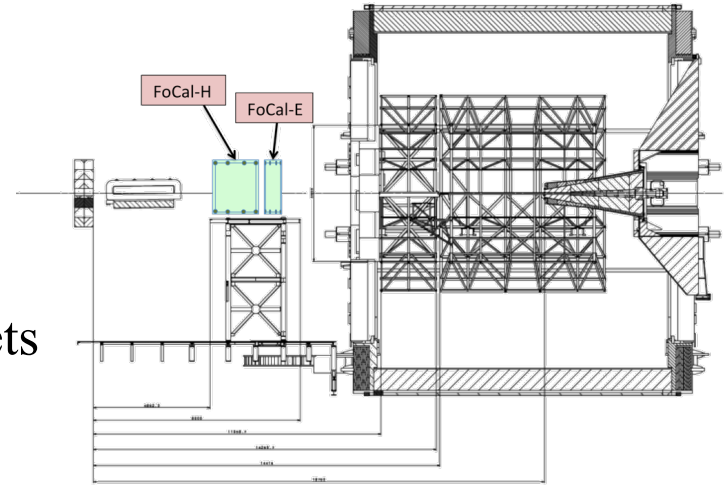
RHIC: low p_T,
kinematic limit at $p_T \approx 5$ GeV



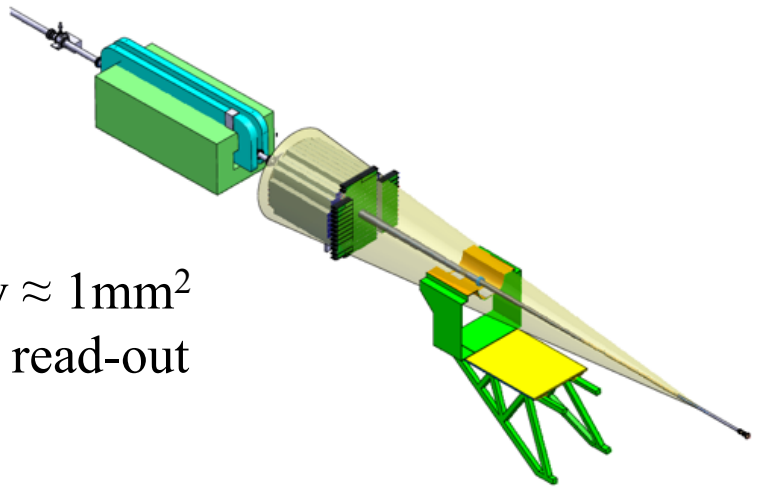
LHC: $x = 10^{-4}$-10^{-5} accessible
with $p_T \approx Q \approx 3$-5 GeV

FoCal in ALICE

- **FoCal-E**
  high-granularity Si-W calorimeter for direct (isolated) γ, e^+e^- (J/ψ) and π^0
- **FoCal-H**
  hadronic calorimeter for photon isolation and jets



- **location**
  $z \approx 7$m (outside magnet) $\rightarrow$ $3.3 < \eta < 5.3$
- **main challenge**
  separate γ/π^0 at high energy
- **technology**
  - Si-W calorimeter, effective granularity $\approx 1\text{mm}^2$
  - small Molière radius, high-granularity read-out



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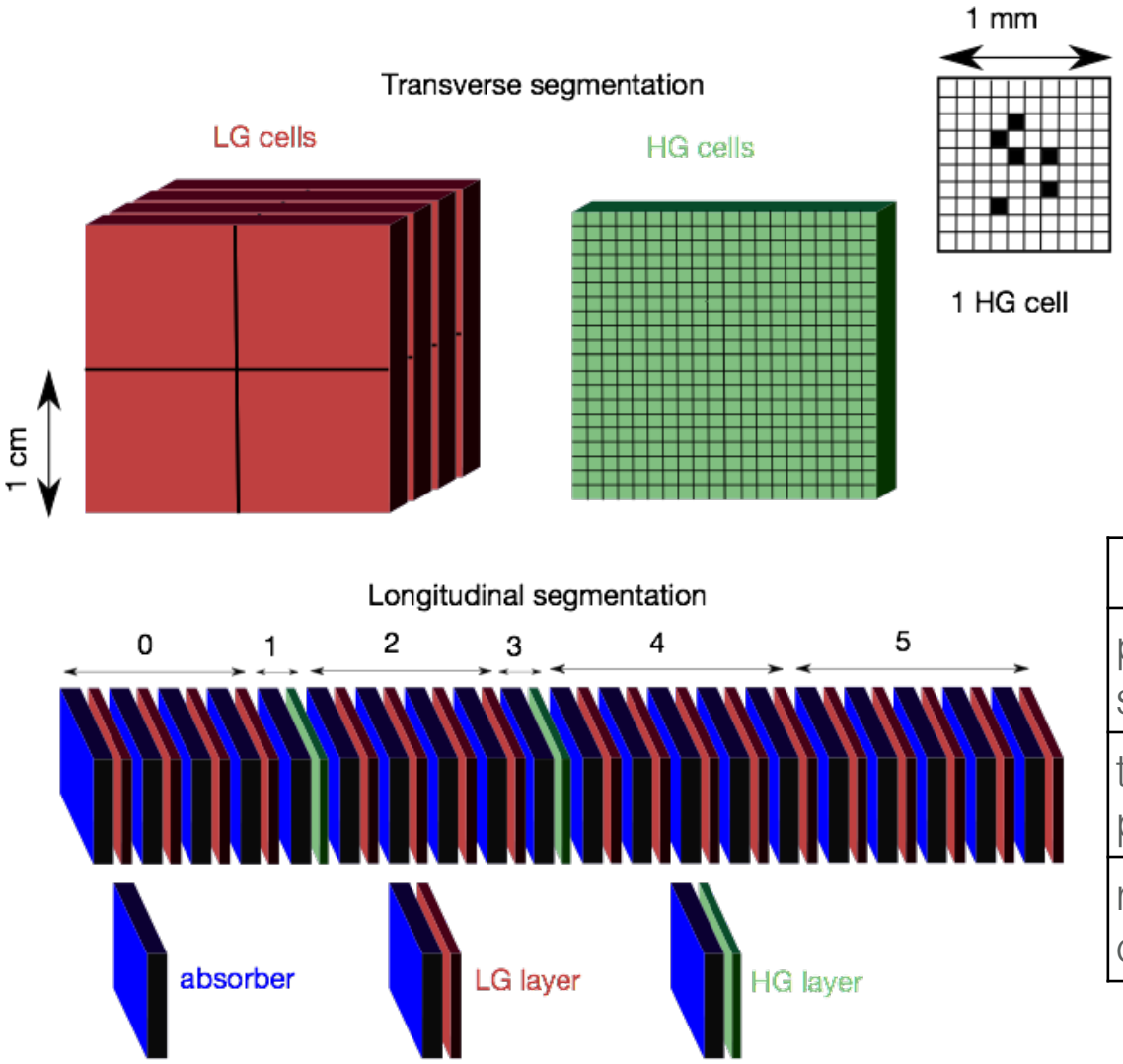
FoCal strawman design



studied in performance simulations:

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

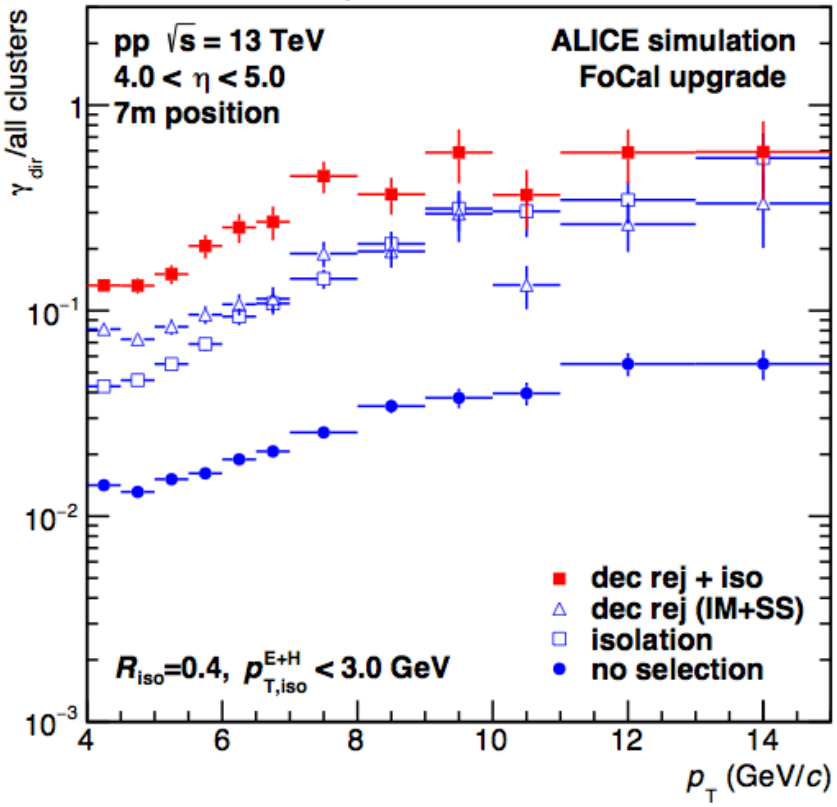
- low granularity (LG), Si-pads
- high granularity (HG), pixels (e.g. CMOS-MAPS)

	LG	HG
pixel/pad size	≈ 1 cm^2	≈ 30x30 μm^2
total # pixels/pads	≈ 2.5 x 10^5	≈ 2.5 x 10^9
readout channels	≈ 5 x 10^4	≈ 2 x 10^6

assuming ≈ 1m^2 detector surface

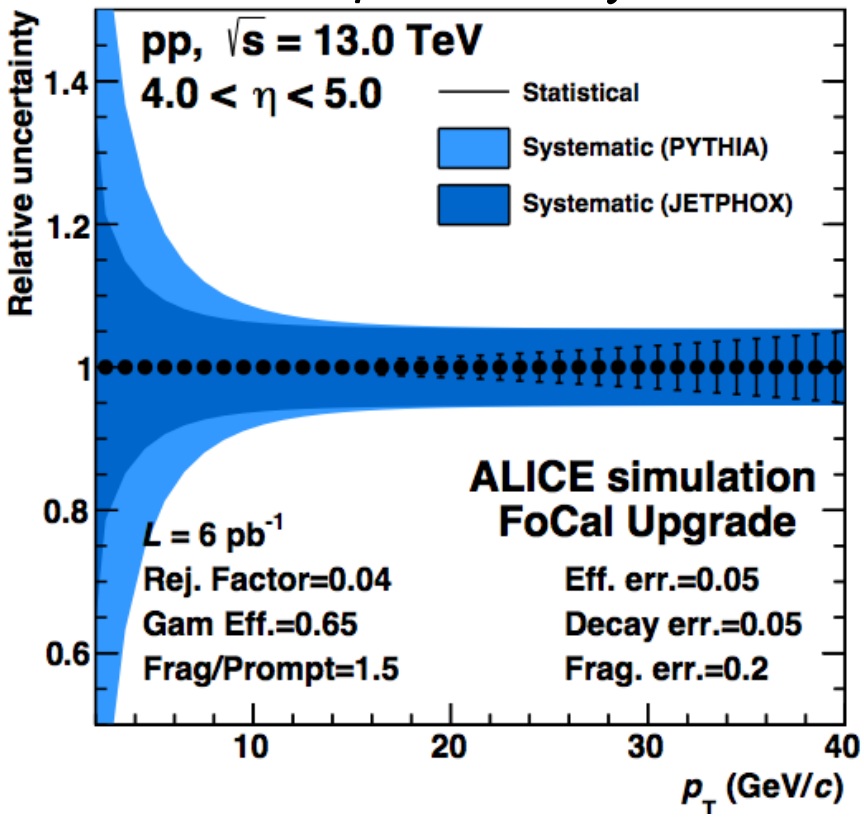
Direct-γ / decay-γ separation in pp

Direct γ/all cluster ratio



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

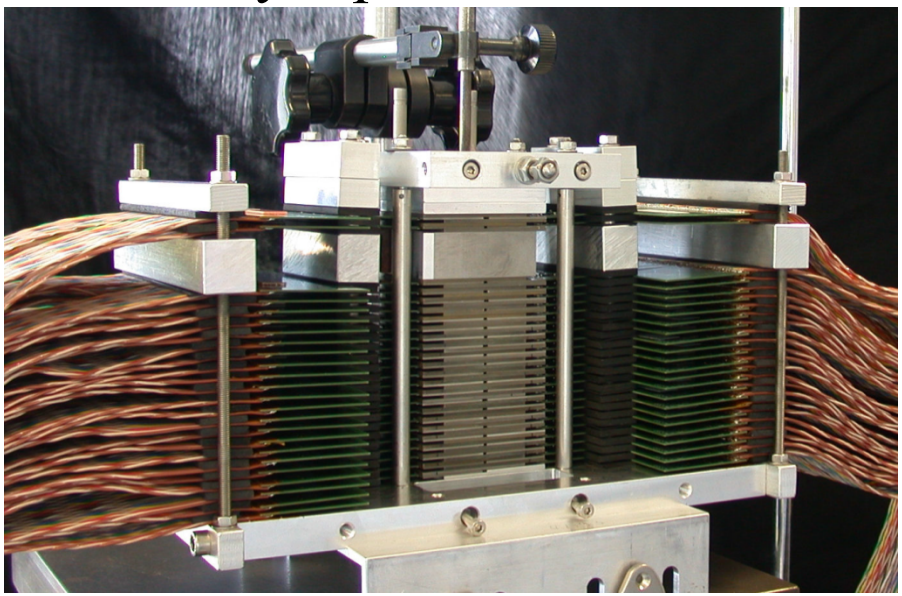
Direct γ uncertainty

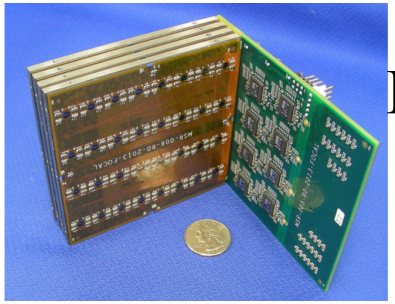


20-40% uncertainty at p_T = 4 GeV/c, decreases with increasing p_T

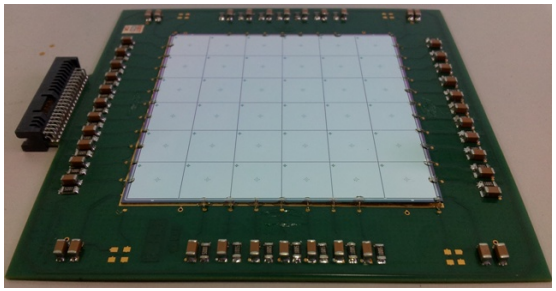
FoCal R&D: Si-W pixel and pad readout

20 layer pixel detector





Pad layer integration

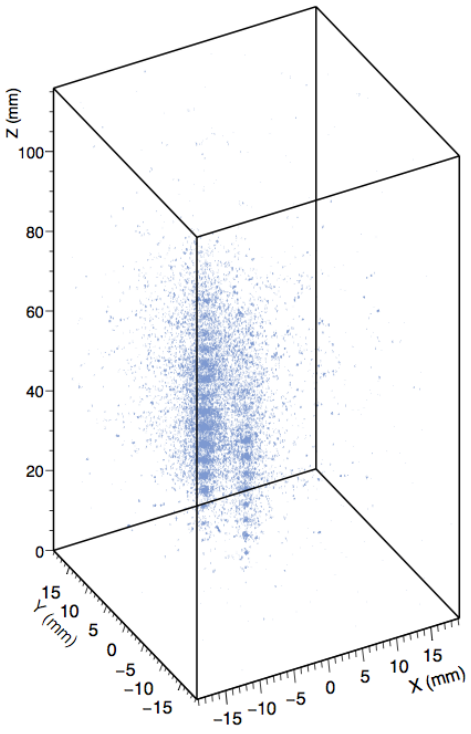


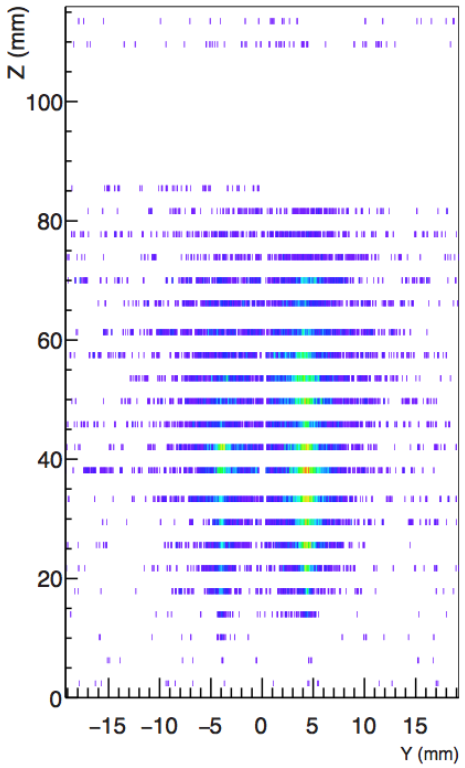
- **Several groups involved**
  - full prototype with pixel detectors CMOS (MIMOSA) 39M pixels, 30μm pitch
  - use synergy with R&D for ALICE ITS upgrade (ALPIDE)
  - full prototype with pad readout
- **Performed systematic tests**
  - test beam data from 2 to 250 GeV/c (DESY, CERN PS & SPS)
  - cosmic muons

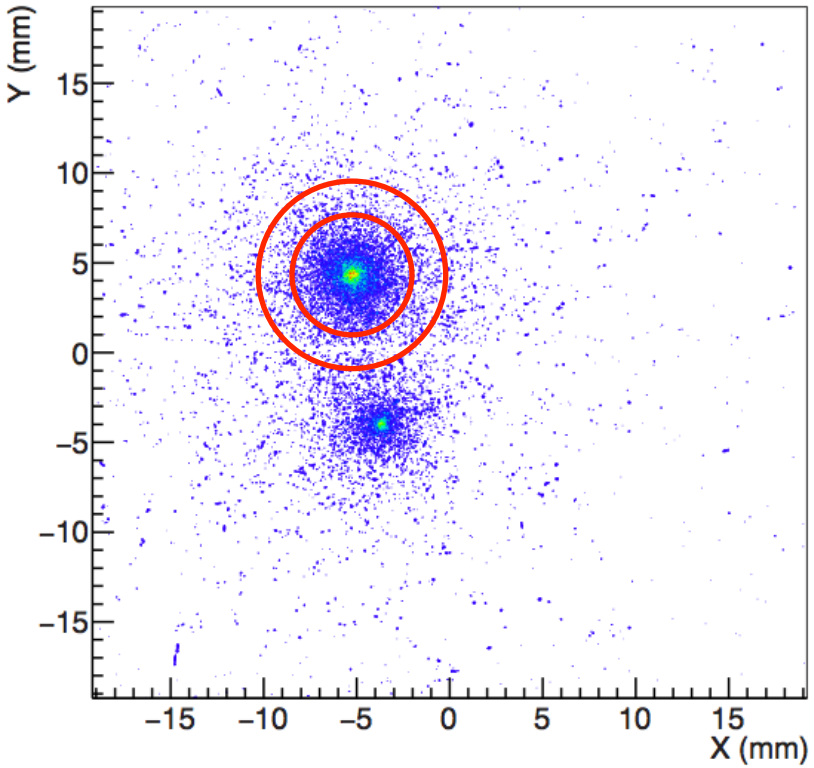
ALICE

R&D results - two shower separation

display of single event (with pile-up) from 244 GeV/c SPS mixed beam





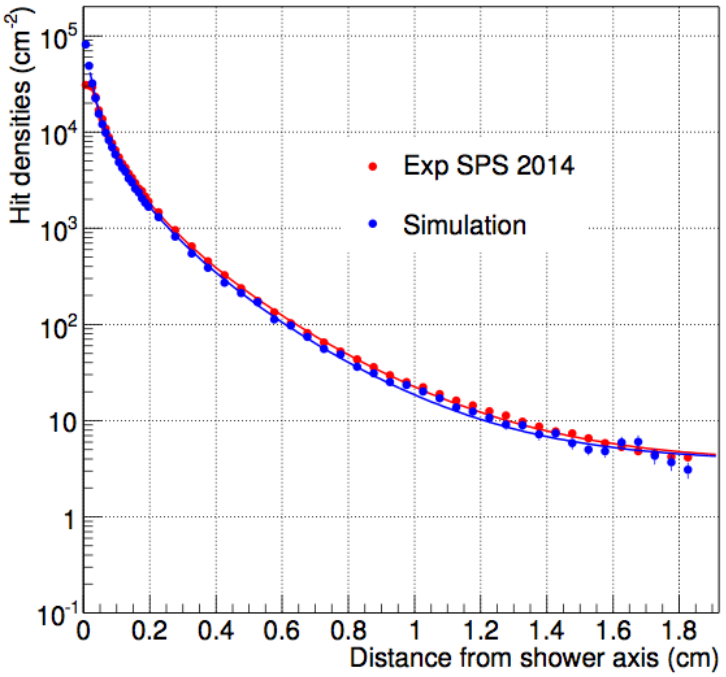


evaluate separation capability: core energy

- calculate shower energy in cylinder of finite radius
- study as function of radius

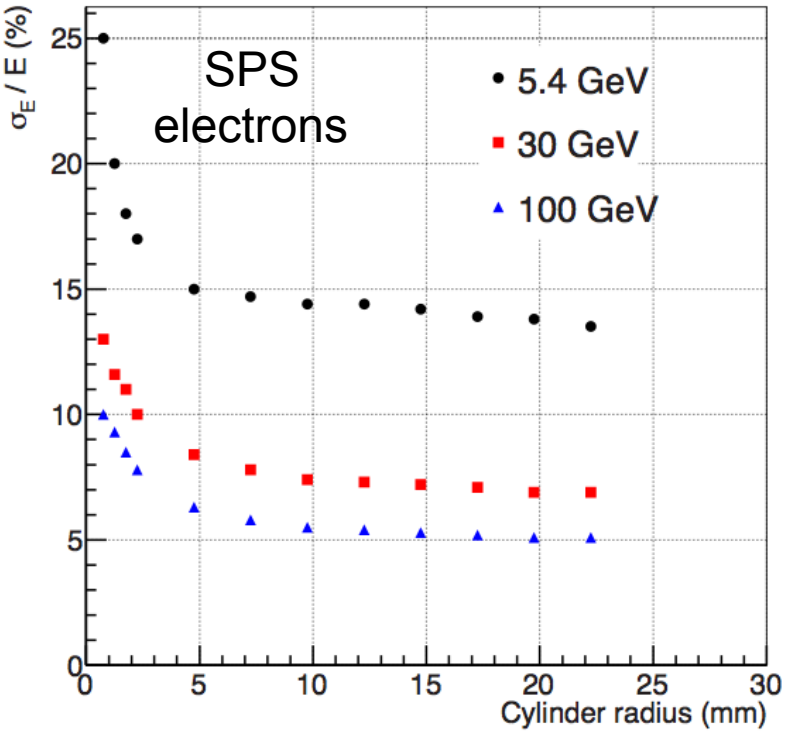
R&D results: lateral profile and core energy

lateral profiles for 50 GeV/c electrons - comparison to GEANT4



- extremely good spatial resolution $R_{Moliere} \approx 11$mm (estimated from cumulative distributions)
- good agreement with simulations using GEANT4 + charge diffusion

energy resolution



- reasonable energy resolution of pixel calorimeter
- response and resolution for core energy hardly affected down to r = 5mm

Summary

- LHC forward measurements provide unique opportunity for low-x physics
- ALICE experiment has open space to instrument forward rapidities
- FoCal detector in ALICE – upgrade proposal for LS3
  - opportunity for forward direct photon measurement
  - particle density/kinematics require extremely high granularity: feasible with SiW pixel calorimeter
  - rich physics program
    - » other observables: π^0, e^+e^- (J/ψ), jets
    - » p+Pb: gluon density, ridge
    - » Pb+Pb: medium effects

ALICE