Options for pA physics at the CMS site

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Abstract

Proton-nucleus collisions in the CMS detector present an opportunity to: test multiple scattering theories, elaborate on schemes of production mechanisms, study photon-Pomeron interactions, explore the structure of bound nucleons at small Bjorken-x, and to investigate parton propagation in nuclear matter. An improved understanding of these phenomena, guided by QCD, is very desirable; it is furthermore needed for a more reliable interpretation of Quark-Gluon-Plasma signatures and of cosmic ray data. The latter should be complemented by measurements with the CMS detector of the muon flux from rare cosmic air showers.

These topics are briefly outlined; a detailed assessement of experimental feasibility has still to be performed.

1   Introduction

Why would one bother to investigate p-nucleus (pA) collisions at very high energies, while the simpler pp interactions are either not understood sufficiently in the non-perturbative regime, or well matched by QCD predictions at large momentum transfer ?

The most naive reason is that - apart from limited expermental efforts with heavy targets and beam momenta $p_{Lab} = 800$ GeV/c [1], and with deuterons and alphas at a center-of-mass (cms) energy $\sqrt{s} = 63$ GeV [2] - most measurements have been performed at $p_{Lab} \leq 200$ GeV/c [2b,2c]. Hence, pA collisions at LHC near $\sqrt{s} = 9$ TeV [3] per nucleon would increase the energy scale for these interactions by more than a factor 230, a rather unprecedented jump, indeed. Extrapolations will become easier when based upon future pA experiments at RHIC ($\sqrt{s} \simeq 350$ GeV) [4].

Many of the following arguments for investigating pA collisions at the LHC depend on the fact that nuclei serve both as targets and detectors being made of a collection of nucleons with typical distances of the order of 1 fm in the nucleus rest frame, equivalent to a typical timescale of about $3 \cdot 10^{-22}$ sec. Very soft partons from all nucleons overlap, however, in Lorentz contracted nuclei. Their large density is expected to cause novel QCD effects replacing the known parton evolution scheme.

So far, the prominent features of pA interactions, such as total cross sections, elastic scattering, average multiplicities, and distributions of charged secondaries are conveniently described in the framework of Glauber theory of multiple scattering of hadrons [5], which is sketched in section II.

Predictions for collisions of heavy ions at, e.g., LHC are often made in this framework [5, 6], which holds also for the interpretation of cosmic ray data [7].

It may, however, turn out that one of the basic assumptions of this multiple scattering approach breaks down at very high energies. Therefore, basic features of pA collisions have to be determined experimentally in order to establish an improved theoretical framework. These questions, as well as the production of B-mesons and of top-quarks, Pomeron interactions, and the concept of "formation time" are addressed in section III.

The characteristics of rare "perturbative" processes in collisions involving hadrons depend on the structure functions of the colliding objects, which are, so far, not well understood theoretically. A wealth of data from deep inelastic lepton-nucleus scattering has revealed subtle nuclear effects [8]. Structure functions of nuclei can be derived at LHC most directly from measurements of yields of γ, J/Ψ, Y, W$^{\pm}$ and Z$^{\circ}$. Measurements of multiple production of heavy objects may give access to parton-parton correlations in nuclei. These aspects of the structure of bound nucleons and of nuclei are discussed in section IV.

Partons emerging from hard processes in pA collisions traverse the surrounding cold nuclear matter. The so-called "Cronin-effect", measured for single hadrons [9] and jets [10] at $p_{Lab} \leq 800$ GeV/c, signals parton multiple scattering [11] in the target nucleus. Systematic studies of whether these features persist at much higher energies should improve its theoretical understanding. This is particularly relevant, as QCD suggests differences of energy loss of partons in cold hadronic matter and in a hot, deconfined quark-gluon plasma (QGP) [12]. Section V is concerned with these topics.

Data to be obtained from pA collisions at LHC energies are not only interesting on their own, but serve also for improving on event generators for pA and heavy ion collisions. They are therefore crucial for calibrating quark-gluon plasma (QGP) searches at LHC as well as cosmic ray data at similar collision energies. In this context one may also envisage, as mentioned in section VI, dedicated measurements with the CMS detector of μ fluxes from cosmic air showers.

More speculative ideas, including those triggered by cosmic ray data, may be found in ref. [13], they are usually based upon very good acceptance in the fragmentation regions, and/or at rather small transverse momenta; these are kinematic regions not optimally covered by CMS.

Detailed experimental problems, such as triggering, data flow etc., are not addressed in the current context.

2   On the current understanding of pA data

2.1   Integrated cross sections and elastic scattering

Scattering of hadrons off nuclear targets at energies $\sqrt{s} \leq 63$ GeV is usually well described in the framework of multiple interactions[5], the main assumption being the one of independent small angle scatterings of the projectile hadron off individual target nucleons at frozen positions. This yields good agreement between data and predictions [14], as illustrated in

fig. 1a by measured and calculated differential cross sections for pd elastic coherent scattering at $\sqrt{s} = 63$ GeV; the individual contributions from single and double scattering, as well as from the deuteron s-wave (form factor S_s) and d-wave (form factor S_Q) are shown in fig. 1b. Application of the optical theorem leads to the following expression for the total cross section $\sigma_T(pd)$:

$$\sigma_T(pd) = \sigma_T(pn) + \sigma_T(pp) - \delta\sigma$$

Originally, $\delta\sigma$ was supposed to be a consequence of elastic double scattering of the incident hadron [5a]. More detailed theoretical work indicated, however, that there is a non-negligible contribution from inelastic intermediate states, where the object propagating from the first to the second target nucleon is not a hadron in its ground state. This demonstrates rather directly that nuclei may be used to analyse objects immediatly after emerging from a first interaction. The inelastic contribution grows with $\sqrt{s}$ [14] !

In the "large A" approximation of Glauber theory, the absorption cross section $\sigma_{abs}(pA)$, which corresonds to production of secondary particles, is given by [15]:

$$\sigma_{abs}(pA) = \pi R_p^2(\sqrt{s})A^{2/3} = \frac{1}{2}\sigma_T(pA)$$

where $R_p(\sqrt{s})$ in the proton radius extracted from pp collisions at a cms energy $\sqrt{s}$ using the relation [16]:

$$\sigma_T(pp) = 2\pi R_p^2(\sqrt{s})\Gamma_\circ(\sqrt{s})$$

Based on these relations one expects that, e.g. the ratio $\sigma_T(pA)/\sigma_T(pp) \approx A^{2/3}/\Gamma_\circ(\sqrt{s})$ decreases as function of $\sqrt{s}$ due to the proton opacity at its center, $\Gamma_\circ(\sqrt{s})$. It is measurable via the integrated elastic cross section, $\sigma_{el} : \sigma_{el}(pp)/\sigma_T(pp) = \dfrac{\Gamma_\circ(\sqrt{s})}{4}$ for a Gaussian proton density. The formula for $\sigma_{abs}(pA)$ reflects the fact that, even at rather low $\sqrt{s}$, a heavy target nucleus is "black", i.e. the nucleus absorbs the projectile by its surface. Available data, e.g. in fig. 2 [1], show that $\sigma_{abs}(pA) \approx A^{\alpha_\circ}$, with $\alpha_\circ \approx 0.71$, not too different from the value $\alpha_\circ = 2/3$ given above; actually, Glauber theory predicts that $\alpha_\circ > 2/3$ for rather small inelastic cross sections $\sigma_{inel}(pp)$ and/or lighter nuclei. Neither systematic measurements of the dependence of $\sigma_{abs}(pA)$ on both A and $\sqrt{s}$, nor a precise comparison to $\sigma_T(pp)$ or $\sigma_{inel}(pp)$ have been made so far at high energies.

In passing it should be added that, in the multiple scattering framework for heavy colliding ions A_1 and A_2, $\sigma_{abs}(A_1A_2) = \pi R_p^2(\sqrt{s})[A_1^{1/3}+A_2^{1/3}-\Delta]^2$ [15, 17] with an adjustable parameter $\Delta, \Delta \approx 1.2$, such that

$$\sigma_{abs}(AA) \approx \pi R_p^2(\sqrt{s})4A^{2/3} = \frac{1}{2}\sigma_T(AA)$$

As a consequence $\sigma_{abs}(pA)/\sigma_{abs}(AA) \approx \dfrac{1}{4}$ for heavy nuclei.

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2.2 Average multiplicities

Intuitively one would guess that the multiplicity $< n(pA) >$, i.e. the average number of secondary particles in pA collisions, is given by the average number, $\overline{\nu}_{pA}$, of collisions of the projectile in the nucleus, and by the multiplicity of nucleon-nucleon collisions, approximated by $< n(pp) >$:

$$< n(pA) >= \overline{\nu}_{pA} < n(pp) >$$

This relation is actually quite well borne out by the data taken at $p_{Lan} = 50 \div 200 \mathrm{GeV/c}$ [18]. However, $\overline{\nu}_{pA} \simeq A^{0.27}$, a weaker dependence on A than the Glauber prediction [15]:

$$\overline{\nu}_{pA} = \frac{A\sigma_T(pp)}{\sigma_T(pA)} \sim A^{1/3};$$

for AA collisions one has, also in the Glauber framework [15] :

$$\overline{\nu}_{AA} = \frac{A^2\sigma(pp)}{\sigma_T(AA)} \sim A^{4/3}$$

Nucleons are ejected from the target nucleus due to interactions of the projectile. Some of them can be detected as so-called "grey protons", i.e. recoiling protons with lab momenta above about 300 MeV/c. Thus the number "n_p" of grey protons per event is correlated with the number $\nu(n_p)$ of projectile interactions in this event. Fig. 3 [19] shows the multiplicity of pions, $< n_\pi >$, as function of $\nu(n_p)$ for various target nuclei and a proton beam of 200 GeV/c. One finds that, independently of A, the quantity $\nu(n_p)$, determines the final state multiplicity and is therefore something like a measure of the "centrality" of the collision. Of course, events with many projectile interactions are very rare, as illustrated by the data displayed in fig. 4 [20].

Most recently, experiment NA49 has installed an electronic detector for measuring grey particles [21]. The relative yields of strange and non-strange hadrons were then determined as function of n_p in pPb collisions at 158 GeV/c. One of the surprising and little understood findings is that the fraction of strange particles among the final state hadrons increases substantially with n_p [22]. This does not seem to be compatible with a simple Glauber scheme.

2.3 Inclusive spectra

A more detailed understanding of these multiple collision processes may be gained from inclusive differential cross sections; normalized to pp collisions, rapidity distributions of charged secondaries are displayed in fig. 5 as function of lab rapidity y for A = Xe and a proton beam of 200 GeV/c [23]. At the cms rapidity $y_{cms} = 0$, i.e. y $\approx$ 3, the ratio is close to $\overline{\nu}_{pA}$ as expected; there is a depletion beyond y $\approx$ 6, probably related to the energy loss of the projectile [24]. The very strong enhancement of particle production in pA collisions at y $\geq$ 2 is nevertheless surprising. Note, however, that the absolute number of secondaries in the range y < 2 is very small in case of pp collisions.

In order to find a simple, at least qualitative explanation of the measurements at y < 2, one may assume that the final state emerging from a hadron-hadron collision needs a certain formation time [25] to turn into hadrons. The minimum cms momentum (or the maximum rapidity y), at which hadrons begin to exist inside the nucleus, is given by the condition that the formation time in the lab, t_F, is smaller than the time needed to traverse the diameter, $2R_A$, of the target nucleus:

$$t_F = \gamma t_\circ \leq 2R_A,$$

from which follows that y < 2 for a formation time $t_0 = 1$ fm/c in the frame comoving with the hadronizing object. In case the quanta of this early final state are less efficient than hadrons in creating hadrons in subsequent collisions, it is only in this restricted kinematical range that many further hadrons are produced by reinteractions of secondary hadrons in the nucleus, a process often called "cascading".

An interesting aspect of this is that the formation times, $t_F(Q)$, of heavy quarks Q with mass m_Q may be shorter [25] than those of light quarks q for a given energy :

$$t_F(Q)/t_F(q) \approx \gamma_q/\gamma_Q \approx \frac{1}{m_Q}$$

The role of hadron formation time has also been addressed experimentally in deep inelastic scattering with modest effort: the number of hadrons carrying a fraction z_h of the momentum of the quark struck has been measured as function of the energy ν transferred [26]. As one may infer from fig. 6, hadrons with $z_h \geq 0.2$ from energetic quarks are nearly unaffected by the target nuclei - Cu and d in this case - as the quarks traverse the nucleus before hadronisation sets in, while leading hadrons from slower quarks are partially "absorbed" in the heavier nucleus.

One is thus lead to conclude that nuclei provide a testing ground for ideas on hadronization.

3 Measurement of characteristic features of pA interactions

3.1 Estimation of event rates, inclusive rates and event sizes

Extrapolation of fits to measurements of total cross sections for pp collisions (fig. 7, [27]) suggests that $\sigma_T(pp) \approx 100$ mb, $\sigma_T(pp) \approx 95$ mb, and $\sigma_T(pp) \approx 90$ mb at collision energies of 14 TeV, 9 TeV and 5.5 TeV, respectively. The latter values of the collision energies $\sqrt{s}_{A1A2}$ of two nuclei (A_1, Z_1) and (A_2, Z_2) follow from the relation $\sqrt{s}_{A1A2} = \sqrt{s}\sqrt{\frac{Z_1 Z_2}{A_1 A_2}}$, if the accelerator is tuned to a cms energy $\sqrt{s}$ for pp interactions. Based upon the formulae of section II.1, one arrives at $\sigma_T(pPb) \approx 3.3$ b and $\sigma_T(pCa) \approx 1.1$ b at 9 TeV and $\sigma_T(PbPb) \simeq 14$ b at $\sqrt{s} = 5.5$ GeV for $\Gamma_\circ(\sqrt{s}) = 1.0$. The expected luminosities, L, of table I [13],

which will be used from now on, yield than the following event rates $R = L \cdot \sigma_T$:

$$R \approx 3 \cdot 10^6 \text{sec}^{-1} \text{ for pPb collisions, and}$$

$$R \approx 10^7 \text{sec}^{-1} \text{ for pCa collisions, both at} \sqrt{s} = 9 \text{ TeV}.$$

This corresponds to the following relative event rates fo high luminosity runs with $L_{pp} = 10^{34} \text{ cm}^{-2} \text{ sec}^{-1}$ and $\Gamma_\circ (\sqrt{s}) = 1$:

$$\frac{\text{R(pPb/9 TeV)}}{\text{R(pp/14 TeV)}} \approx 3 \cdot 10^{-3},$$

$$\frac{\text{R(pCa/9 TeV)}}{\text{R(pp/14 TeV)}} \approx 10^{-2}, \text{and}$$

$$\frac{\text{R(pPb/9 TeV)}}{\text{R(PbPb/5.5 TeV)}} \approx 25.$$

Another important quantity for an experiment is the occupancy, essentially proportional to the expected event size. To a good approximation $\left.\frac{\text{dn}}{\text{dy}}\right|_0$ at $y_{cms}=0$ is proportional to $\overline{\nu}_{pA} \approx A^{1/3}$ (see section II.2) and to $\ell n \sqrt{s}$. One therefore concludes that the average event size for pPb (pCa) collisions at $\sqrt{s} = 9$ TeV is about equal to $\overline{\nu}_{pA} \cdot < n(pp/14 \text{ TeV})> \cdot \ell n \sqrt{s}/\ell n 14$, i.e. at most 5 (3) times larger than the average event size of pp collisions at 14 TeV. This is in qualitative agreement with simulations based upon the Glauber model in table II [3], where also the rapidity shifts Δy of the pA center-of-mass systems relative to that of pp collisions are given: $\Delta y = 0.5 \ell n \frac{Z_1 \cdot A_2}{Z_2 \cdot A_1}$. The event size may increase in addition by a factor of about 3 for very "central" pPb collisions (see section II.2). Typical event sizes for Pb Pb collisions at 5.5 TeV exceed those of pp collisions at 14 TeV by a factor of about 1000 [3], and those of pPb collisions at 9 TeV by a factor of about 160.

The inclusive rate $r(pA, \sqrt{s})$ for a detector acceptance covering full azimuth for a fixed rapidity range Δy is given by :

$$r(pA, \sqrt{s}) \approx 1/2 \cdot R(pA, \sqrt{s}) \cdot \frac{\Delta n}{\Delta y}(pA, \sqrt{s}), \text{as } \sigma_{\text{abs}}(pA)/\sigma_T(pA) = 1/2.$$

It follows that :

$$r(pA, \sqrt{s})/r(pp, 14\text{TeV}) \approx \left[\text{R}(pA, \sqrt{s})/\text{R}(pp, 14\text{TeV})\right] \cdot A^{1/3} \left[\ell n \sqrt{s}/\ell n 14\right]$$

$\approx 1,5 \cdot 10^{-2}$ (pPb) or $3 \cdot 10^{-2}$(pCa) at 9 TeV. Relative to AA interactions one has $r(pA, \sqrt{s})/r(AA, 5.5 \text{ TeV}) = [R(pA, \sqrt{s})/R(AA, 5.5\text{TeV})] \cdot A^{-1} [\ell n \sqrt{s}/\ell n 5.5]$, which is equal to 0.16 for $A = \text{Pb}$ and $\sqrt{s} = 9$ TeV.

While these estimates do not indicate any major problem for the CMS detector, the questions of triggers and data acquisition for processes with large cross sections deserve attention.

3.2 Experimental tests of the Glauber multiple scattering theory

Extrapolation of the measurement of $\sigma_T(\text{pp})$ in fig. 7 suggests a substantial rise up to about 100 mb at 14 TeV [27]. As stated in section II.1, $\sigma_T(\text{pp}) \sim R_p^2(\sqrt{s})$. Between $\sqrt{s} = 20$ GeV, where most of all pA data have been taken so far, and $\sqrt{s} = 14$ TeV, the effective proton radius may have increased by up to a factor of 1.5. It is therefore conceivable that, due to its size, a proton incident on a target nucleus interacts simultaneously with many nucleons. Thus, one of the key assumptions of Glauber multiple scattering theory does not hold any more. As a consequence, measurements of the differential cross section for elastic pA scattering, of the total cross section $\sigma_T(\text{pA})$, of the absorption cross section $\sigma_{abs}(\text{pA})$, and also of global features of invariant inclusive cross sections may hint at improvements of this theory (see e.g. ref. [28]).

3.2.1 Elastic pA scattering and total cross sections

Predictions for the differential cross sections for elastic and quasi-elastic (break-up of the nucleus without production of secondaries) pPb scattering are given in fig. 8 for $\sqrt{s} = 9$ TeV in the "large A" approximation [13]. For an optimal test of the theory, one should i) cover the t-range down to $|t| \geq 5 \cdot 10^{-3}$ (GeV/c)^2, and ii) be able to measure elastic and quasielastic collisions separately. At lower energies and/or for lighter nuclei the width of $\dfrac{d\sigma}{dt}$ increases due to smaller geometrical sizes of the scattering objects, such that it is easier experimentally to cover the necessary t-range. Extrapolation of the elastic differential cross sections to t = 0 then yields the total cross sections $\sigma_T(\text{pA})$ as function of $\sqrt{s}$ and A, allowing further tests of the theory. The large-A approximation to Glauber theory is very general and does thus not depend critically on its specific assumptions. Measurements with lighter nuclei, such as A = O, Ca, Ag in addition to Pb and p are therefore mandatory for a thorough study. In order to obtain a good overall picture, measurements with these nuclei should be performed at various energies, e.g. at $\sqrt{s} = 2$ (Tevatron), 5.5 (PbPb collisions at LHC), and 9 TeV.

It goes without saying, that an optimized detector is needed for a dedicated investigation of elastic and total cross sections for pA collisions, with a geometrical acceptance for the elastically scattered proton down to very small angles. Very good coverage for secondary hadrons ensures a precise measurement of the cross section for inelastic processes, as required for the determination of total cross sections independent of the knowledge of luminosity. It is therefore a fortunate coincidence that the TOTEM experiment [29] would like to share the CMS site; its main goal is a precise measurement of the elastic differential cross section, and therefore of the total cross section for pp collisions. At present it is not clear whether the kinematical range $|t| < 10^{-2}$ (GeV/c)^2 can be reached [29]; a measurement of $\sigma_{abs}(\text{pA})$ is then even more important (section II. 2.2). TOTEM also foresees an in-depth study of diffractive phenomena. As emphasized in ref. [13] an investigation of diffraction in pA collisions is very desireable.

For the separation of elastic coherent (pA $\rightarrow$ pA) and quasi-elastic contributions to elastic pA scattering one should be able to detect single nucleons ejected from the circu-

lating nuclei. It is conceivable to use a "0° calorimeter" of the type envisaged by ALICE [30] for this purpose (see section II.5).

3.2.2 Integrated cross section for the production of secondaries

There are no measurements of σ_{abs}(pA) for inelastic pA collisions at $p_{Lab} > 800$ GeV/c. Theoretical predictions can be derived in the Glauber framework as function of A, the expected energy dependence is related to the one of the elementary nucleon-nucleon interaction.

A measurement at LHC energies would require a rather complete geometrical acceptance up to very large cms rapidities. Again, use should be made of the TOTEM detector which covers rapidities $|y_{cms}| \geq 7$ in order to determine σ_T (pp) via the "luminosity independent" method [31], i.e. by recording the rate of inelastic pp collisions.

The choice of collision energies and of nuclei should be compatible with the one for elastic scattering. In particular, the usefulness of pN or pO collisions is to be emphasized here. These interactions at LHC energies are an important fraction of cosmic air showers at energies beyond the "knee" shown in fig. 9 [32]. Their relative contribution may change with energy. Thus, LHC data taken at well defined $\sqrt{s}$ and fixed A are very welcome to "calibrate" cosmic ray data.

An alternative method to determine σ_{abs}(pA) depends on measurements of the inclusive differential cross section $\dfrac{d\sigma}{dt}$ for protons at $|t| \geq 0.1$ $(\text{GeV/c})^2$, where inelastic production dominates elastic contributions [33].

3.2.3 Inclusive rapidity spectra

Typical inclusive rapidity distributions of negative particles from pAr and pXe collisions at $p_{Lab} = 200$ GeV/c are displayed in fig. 10 [34]; there are no data for heavy nuclei at higher energies. One concludes from fig. 10 that these measurements of non-identified secondaries are of rather modest precision, and that theoretical calculations, based upon a string model and including multiple interactions in the Glauber framework, are close to the data. It is, however, interesting to note that two-particle correlations in pBe interaction at $p_L = 200$ GeV/c are, so far, not matched by any model [35]. The experimental situation may soon improve substantially; experiment Na49 is expected to provide precise differential cross sections from pp and pPb interactions at 158 GeV/c [22], including a "centrality" dependence in case of pPb interactions. Nonetheless, the large energy gap up to LHC energies remains. At increasing energies, simple versions of string models may run into troubles, as strings may start overlapping. On the other hand, more and more partons would interact at rather large momentum transfer, giving rise to calculable perturbative parton cascades. Rather recent theoretical calculations of inclusive rapidity distributions for Pb collisions at LHC in the Glauber framework and from a Parton Cascade Model are shown in fig. 11 [36]; both predictions differ significantly. In the rapidity range $|y_{cms}| \geq 5$ relevant data can be obtained by CMS; for $7 \leq |y_{cms}| \leq 5$ the "inelastic" detector of TOTEM would be useful. For $|y_{cms}| \approx 7$ evidence for "nuclear" cascading may be found.

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A substantial reduction of particle production in the central region relative to Glauber predictions is also expected from Reggeon calculus [28]. In this theoretical framework the influence of nuclei on rapidity spectra and structure functions (see section IV) is closely related to diffraction and properties of the Pomeron (see section III.4).

To be more specific, what should be measured are the inclusive distribution dN/dy of charged secondaries, and the inclusive energy distribution dE/dy - including both the hadronic and el.-magn. component - with the nominal CMS magnetic field. As a non-negligible fraction of charged particles escape thus detection, a measurement of the inclusive pseudo-rapidity (η) distributions, dN/dη, for charged particles and of dE/dη should also be envisaged without magnetic field. The non-optimal position of tracking chambers in the case of no magnetic field might be (partially) compensated by the fact that one is dealing exclusively with straight tracks. A comparison of both data sets using event generators may improve the understanding of underlying dynamics substantially.

In addition, the feasability of measurements of inclusive production of strange particles at a reduced magnetic field of, e.g., 1 T should be investigated. Unexpected trends have been observed in pPb collisions at 158 GeV/c [22]; production of strange hadrons may signal the formation of a QGP [30] in PbPb collisions.

Like argued in previous sections data should be taken at $\sqrt{s} = 2$, 5.5 and 9 TeV, as well as for various nuclei, and, if possible, as function of the number of interacting nucleons determined by a 0° calorimeter (see section III.5). This would be close to what is currently being studied in considerable detail by Na49 [22].

As in the case of integrated cross sections, these measurements are relevant for understanding multiple production processes; an improved knowledge of pA production mechanisms is also essential for the interpretation of heavy ion collisions when searching for a QGP [37]. Last not least, these measurements serve again for calibrating cosmic ray data, even if the latter come predominantly - due to experimental procedures - from the fragmentation region.

3.3 Inclusive production of heavy quarks

Cosmic ray data indicate the existence of a threshold of heavy flavor production at very high energies [38]. It is intriguing to speculate that this might be a reflection of large densities of soft partons in high energy pA collisions (see section IV), which can be investigated at LHC. The inclusive rate of reconstructed B-mesons, or t-quarks, from pA collisions relative to the one in pp collisions is estimated on the basis of the formulae of section III.1. There may be a further enhancement factor (see section V) due to the "Cronin-effect" [9]. Differential cross sections from about 10^4 reconstructed B-decays ($B^\circ \rightarrow J/\Psi K_s^\circ$) [39] and t-decays [40] per month can be obtained from pPb or pCa interactions at 9 TeV ; $\sigma_{b\bar{b}} = 500\mu$b and $\sigma_{t\bar{t}} = 1$nb has been assumed for pp collisions. Much larger statistics is provided by semi-leptonic decays of b-quarks. Searching for a threshold implies obviously an energy scan, e.g. measurements at $\sqrt{s} = 2$, 5.5 and 9 TeV. Further interest in measuring b-quark yields in pA collisions is presented in section V.

Proton-Ca collisions at 9 TeV are equivalent to pp collisions at $\sqrt{s} = 14$ TeV and

L$_{pp} \geq 10^{32}$ cm^{-2} sec^{-1} as far as rates are concerned.

3.4 Photon-Pomeron interactions

Even if the concept of the Pomeron (P) has been introduced long ago, a profound inter-pretation of this object is still missing. This is why the Pomeron is currently being studied intensively in deep inelastic lepton-proton interactions [41]; at the HERA ep collider one relevant process is emission, by the incoming charged lepton, of a photon that interacts with a Pomeron coupled to the proton. In proton-proton collisions at $\sqrt{s}$= 63 GeV double Pomeron (PP) cross sections have been determined [42]; this process dominates over two-photon mechanisms due to the small el. magn. coupling constant. In heavy ion collisions at very high energies $\gamma\gamma$ processes are expected to occur much more frequently than PP interactions due to a factor Z^2 at each vertex instead of A$^{2/3}$ for each Pomeron [43].

One may therefore anticipate a relatively comfortable rate of γP interactions in pA collisions at LHC, with a Pomeron preferentially emitted by the proton, whereas the nucleus is the source of photons. Hopefully, competing mechanisms are negligible. Such a reaction is characterized kinematically by rather small momentum transfers between initial state and final state protons and nuclei, respectively, as well as by two large raidity gaps next to the outgoing fast hadrons. The γP interaction gives rise to particles or clusters of particles with limited invariant masses, produced close to y$_{cms} = 0$, but shifted systematically towards the rapidity of the nucleus. This feature is a consequence of the spectrum of emitted photons which is inversely proportional to the photon energy [43]. A non-Pomeron background to the γP process may be suppressed experimentally in collisions of heavy nuclei with deuterons acting as isospin filters.

Once theoretical predictions of cross sections and kinematics for these processes are available, an experimental feasibility study for CMS should be undertaken.

3.5 Calorimetry at 0°

In case of inelastic pA collisions it is important to determine the number "Π" of "target" nucleons involved, which are therefore recoiling with non-negligible transverse momentum. Equivalently, one can measure the number F of "spectator" nucleons non-affected and therefore retaining their incoming Fermi momenta. If F = A-Π nucleons recombine their Fermi-momenta in the final state to emerge as a nuclear fragment, A$_F$, the standard de-viation $\sigma_\perp$ of the distribution of the momenta of A$_F$, transverse to the direction of the incoming beam, is given by [44]:

$$\sigma_\perp \approx \frac{P_F}{\sqrt{5}}\sqrt{\frac{A_F(A - A_F)}{A - 1}} \approx 0(100\text{MeV/c});$$

P_F is the average Fermi momentum in a nucleus.

In coherent processes the outgoing nuclei stay in the beam pipe, as do nuclear fragments with Z/A $\approx$ 1/2. Non-interacting protons or neutrons leave the beam pipe as $\frac{Z}{A} = 1$, or 0,

respectively. Calorimeters measuring the total energy E° in a cone with an opening angle of the order of $\sigma_\perp/(\sqrt{s}/2)$ about the proton and neutron trajectories, yield therefore, to a good approximation, the number F of spectator nucleons provided that not many nuclear fragments A_F with $\dfrac{Z_F}{A_F} \approx \dfrac{1}{2}$ are produced.

This method of determining the centrality, or impact parameter, of a collision is particulary important for selecting candidate events for QGP searches in heavy ion collisions. In this context the experiment ALICE [30] has studied the feasibility of detecting the energy of spectators in two small cones using 2 appropriate calorimeters near each outgoing beam. They are placed at about 92 m from the interaction point; and have rather small transverse dimensions ($\leq (16cm)^2$, fig. 12).

It needs to be investigated whether one system of 2 radiation-hard calorimeters of this type can be integrated into the accelerator lattice at the "nucleus" side of CMS. Its use for tagging quasielastic pA scattering, for the suppression of eventaul background to γ-Pomeron events, and for selecting central pA collisions (see also sections IV and V) must be assessed.

4 Nuclear Structure Functions

Experiment shows that structure functions of bound nucleons differ from those of free nucleons [8]: at Bjorken - x ≥ 0.1 a relative depletion has been established relative to the case of free nucleons. There is abundant literature on the theoretical interpretation of this so-called "EMC-effect" [8]. A very simple argument emphasizes the main interest in this phenomenon in the framework of QCD: a nucleus A at high momentum p_A is Lorentz-contracted to a disc of thickness $\Delta z_A \approx 2R_A \dfrac{m_A}{p_A}$, where $R_A(m_A)$ is the radius (mass) of A. Soft partons are confined to a longitudinal dimension $\Delta z_S \approx (x(p_A/A))^{-1}$ by the uncertainty relation. For $\Delta z_s \leq \Delta z_A$, i.e. for $x \geq (2R_A m_A)^{-1} \approx 0.01$, all partons from all nucleons overlap in longitudinal space, with an individual transverse size of about 1 fm, or of the order of $\dfrac{1}{\sqrt{Q^2}}$ for momentum transfers $Q \geq Q_\circ$.

The number of partons, n_{part}, with x ≥ 0.01 per cross sectional area a of the nucleus A is given by $dn_{part} \approx A/A^{2/3} \approx A^{1/3}$ independent of $\sqrt{s}$. One may therefore anticipate a fast approach to saturation in pA collisions [45]; hence parton recombination processes may set in -a topical subject of current research at HERA [46]. This corresponds to novel QCD equations superseeding the known parton evolution, with non negligible effects e.g. on inclusive spectra (sections III.2.3 and III.3).

The A-dependence of structure functions is measurable, e.g., in the gluon mediated processes pp $\to$ gg $\to J/\Psi$, Y or via quark-antiquark fusion into Z° or W$^\pm$. Typical examples of measurements from J/Ψ production in pA collisions at various energies, and from lepton-anti-lepton pairs ($\ell\bar{\ell}$) in the Drell-Yan process pp $\to$ q$\bar{q}$ $\to \ell\bar{\ell}$ are shown in fig. 13 [8]. The relative yields from heavy nuclei signal directly a modification of the relevant structure frunctions by the nuclear environment. At $y_{cms} = 0$ there is the

kinematical relation between x and the mass, M of the produced particle : $x \approx \dfrac{M}{\sqrt{s}}$. The respective structure functions can therefore be investigated at $\sqrt{s} = 9$ TeV in the range $x \approx 10^{-2}(Z^{\circ}, W^{\pm})$, $x \approx 10^{-3}(Y)$, $x \approx 3 \cdot 10^{-4}(J/\Psi)$. In a similar way, direct photons at large p_T and $y_{cms} \approx 0$, produced in a quark-gluon fusion process, probe structure functions at $x \approx 2p_T/\sqrt{s}$. For reaching the range of $x << 10^{-4}$ good acceptance at very large rapidities would be needed [13].

Approximate event samples for 1 month of data taking at $\sqrt{s}=9$ TeV and a luminosity of 10^{30} cm^{-2} sec^{-1} can be scaled from calculated yields from PbPb collisions at $\sqrt{s} = 5.5$ TeV [36]:

$$
\begin{aligned}
\text{pBb} \quad &\rightarrow J/\Psi \quad :> 13000 \text{ ev.}, \\
&\rightarrow Y \quad :> 28000 \text{ ev.}, \\
&\rightarrow Z^{\circ} \quad :> 13000 \text{ ev.},
\end{aligned}
$$

these numbers must be multiplied by 2 for pCa collisions at a luminosity of 10^{31} cm^{-2} sec^{-1}.

Triggering on the centrality of those interactions may enhance states of even larger parton densities such that surprises are not excluded. This has not been attempted so far.

Differential cross sections for the above processes do not only depend on structure functions, but may also reveal details on multiple scattering of partons in the initial state [47], i.e. before parton fusion. The outgoing vector-meson resonances may furthermore be absorbed to some degree by the surrounding nuclear matter [48]; this should not be the case for production of lepton-antilepton $(\ell\bar{\ell})$ - pairs from Z° decays nor for photons, due to the weakness of el.-magn. forces.

Dedicated measurements along these lines should help interpreting data on parton-propagation both in cold hadronic matter (see section V), and in a hot, deconfined plasma [12].

Last, not least one may anticipate, that in pA collisions two partons of the incident proton undergo hard interactions with two partons from two nucleons of the nucleus. The signature is multiple production of energetic objects, such as jets [49], γ, J/Ψ, Y, Z$^{\circ}$, or W, eventually compensating their transverse momenta pairwise :

$$
\begin{aligned}
\text{pA} \quad &\rightarrow \quad J/\Psi + J/\Psi(+2\text{jets}) \\
&\rightarrow \quad Y + Y(+2\text{jets}) \\
&\rightarrow \quad Z^{\circ}/W + Z^{\circ}/WQ(+2\text{jets}) \\
&\quad \vdots \\
&\rightarrow \quad \gamma + 3\text{jets} \\
&\quad \vdots \\
&\rightarrow \quad 4\text{jets}
\end{aligned}
$$

A measurement of rates as function of A and of correlations among the pairs may

reflect correlations of partons inside nuclei. So far, no experiment was able to address this phenomenon; processes of this type should be more easily detectable at LHC energies.

5 Parton Propagation in Cold Hadronic Matter

5.1 Inclusive spectra

It came as a surprise to see, that in pA collisions at 200 GeV/c the differential cross section $\mathrm{E}\frac{\mathrm{d}\sigma}{\mathrm{d\overline{p}}}$(pA $\rightarrow$ hadron) was proportional to $\mathrm{A}^{\alpha(p_T)}$, with $\alpha(p_T)$ exceeding unity at $p_T \geq 2$ GeV/c; typical measurements of $\alpha(p_T)$ are shown in fig. 14 [9]. This so-called "Cronin-effect" found its likely explanation in terms of multiple parton scattering in the target nucleus [11], the hadron at high p_T being the leading fragment of a scattered parton [50]. One would expect that - in analogy to Glauber multiple scattering - the shape of the differential cross section of pA interactions depends on the differential cross section for pp collisions, and therefore on $\sqrt{s}$. However, an energy dependence of the Cronin-effect has so far not been measured with sufficient precision.

The theoretical interpretation of the Cronin-effect would imply that the differential cross section $E\frac{d\sigma}{d\overline{p}}$(pA $\rightarrow$ jet) was also proportional to $A^{\alpha(p_T)}$, with $\alpha(p_T) > 1$ for large transverse momenta p_T of hadron jets from scattered partons. Fig. 15 shows measurements of $\alpha(p_T)$ in pA collisions at 800 GeV/c [11]; the difference between both sets of numerical values of $\alpha(p_T)$ depends on the experimental definition of jets in pA collisions. One may conclude that the subject of parton propagation in cold nuclear matter is by far not exhausted, neither experimentally nor theoretically.

Comparisons of single pion and/or jet yields at rather large p_T from pA collisions at LHC with measured yields of J/Ψ, Y, W$^{\pm}$, as well as of $\gamma^{\star}/Z^{\circ} \rightarrow \ell\overline{\ell}$ should enable us to separate effects from structure functions and initial state multiple scattering from final state rescattering, especially of gluons which dominate inclusive single pion and jets rates in a range of $x \approx 2p_T/\sqrt{s} \geq 0.1$. The QCD mechanisms of energy loss of partons in nuclear matter are currently of considerable interest.

Another tool for the investigation of parton multiple scattering may turn out to be a measurement of Z$^{\circ}$ production with subsequent decay into a q$\overline{q}$ pair, background permitting. As the Z$^{\circ}$ lifetime is extremely short, i.e. about 10^{-25} s [51], it will be the (anti-)quark which reinteracts in the nucleus after evolving from a small color dipole for which the nucleus is supposed to be transparent. In case of reinteractions the ratio of the numbers of the decays Z$^{\circ} \rightarrow$ q$\overline{q} \rightarrow$ jet-jet and Z$^{\circ} \rightarrow \ell\overline{\ell}$ may depend on the measured value of p_T(Z). Due to the same reason the width of Z$^{\circ}$-bosons reconstructed from two jets may depend on A and p$_T$(Z) beyond instrumental effects.

For formation times, t$_F$, shorter than the time needed by a parton to traverse the nucleus, the internal structure of jets of hadrons from parton fragmentation could depend on A, a consequence of reinteracting hadrons. So far there are no sufficiently precise data on this subject.

Finally, it may be amusing to find an unusual trend of the relative yield of B-mesons to, e.g., pions as function of p_T and A. Pions at $p_T >> < p_T >$ are predominantly fragments of light quarks and gluons [50] with a rather long formation time, while the time to form B-mesons from b-quarks is expected to be very short (see section II.3). This is why B-mesons may have more time than pions to reinteract in the nucleus, giving rise to a stronger "Cronin-effect".

All these parton processes in cold hadronic matter should be understood before interpreting corresponding spectra fom AA collisions in terms of "jet quenching" in a QGP [15, 52].

5.2 Correlations

Measurements of correlations between two jets, j_1 and j_2, provide more detailed insight into the dynamics of final state partons in nuclear matter. Partons emerge from a hard interaction back-to-back in the plane transverse to the pA collisions axis, i.e. with an azimutal separation $\Delta\phi \approx 180°$; initial state (small) transverse momenta are neglected here. Both partons may reinteract or emit gluons subsequently such that the dispersion $\sigma(\Delta\phi)$ grows with increasing A. Experimentally, the azimuthal angles $\phi(j_{1,2})$ of both jets are taken for the azimuthal angles of both partons; the difference $\phi(j_1) - \phi(j_2)$ approximates then $\Delta\phi$. At $p_{Lab} = 800$ GeV/c this has been done as shown in fig. 16 [10]; one observes a widening of the measured distribution of $\Delta\phi$ with increasing A.

A quantitative analysis may become simpler if one of two jets was replaced by a photon or a Z° decaying into $\ell\bar{\ell}$, both of which are not affected by reinteractions in the nucleus. Replacing one of two jets by a Z° decaying into 2 jets tends to enhance the effect of final state interactions. Note that while 2-jet events are dominated by gluons in a large kinematic range of small to moderate transverse momenta/energies, jets recoiling against high p_T photons should be more often due to quarks.

A substantial improvement of the experimental situation should be attempted at LHC energies.

6 Cosmic rays

Interactions of protons with nuclei at $\sqrt{s} = 9$ TeV correspond to beam momenta of nearly 100 PeV/c incident on target nuclei at rest, thus to an energy range very important to cosmic ray physics (fig. 9) [32]. Extensive air showers (EAS) are predominantly induced by cosmic p, He and Fe (with energy dependent fractions) colliding with N and O in the atmosphere. As repeatedly stated in previous sections, these interactions should be studied for calibration purposes under the controlled conditions at LHC. The well-known ambiguity [53] between the chemical composition (i.e. A) of cosmic rays and the average inelasticity of their interactions in the atmosphere may thus be resolved. For experimental reasons, EAS experiments are particularly sensitive in the range of very large rapidities; therefore, any detector (e.g. TOTEM) completing the forward acceptance of CMS would be useful.

Measurements of total or inelastic cross sections, of inclusive fluxes of secondary particles and of transverse energy - even at more central rapidities -, as well as of inclusive yields of open heavy flavors for pO or pN collisions at $\sqrt{s} = 2$, 5.5, and 9 TeV are badly needed (not to forget FeO or FeN interactions at $\sqrt{s} \leq 5.5$ TeV).

Such a contribution of CMS to cosmic ray physics can be complemented by measurements of the μ component of EAS. Cosmo-ALEPH [54] with a sensitive area of about 16 m^2 (TPC) has given some characteristic numbers for μ with momenta above 70 GeV/c: the rate of μ from EAS is close to 0.4 $\mu(m^2$ sec$)^{-1}$; there is about one μ per m^2 for a typical shower. Two μ-showers are displayed in fig. 17 [54]. Using the whole CMS detector these numbers would translate into rates of more than to 80 μ/sec, and showers containing perhaps more than 4000 μ ! CMS provides good μ momentum measurement, μ identification and $\mu - \mu$ separation. The feasability of an independent trigger should be investigated, and a time stamp from the General Positioning System (GPS) would be valuable, in particular for correlation measurements with other (LHC) detectors. The total data taking time would easily exceed 10 years.

The CMS detector might be surrounded, up to a distance of about 1 km, by simple μ-stations of an area of 4 m^2 each, consisting of 2 layers of segmented scintillators. Thus, the centers of EAS can be determined more precisely. Coincidences over large distances have been found already by, e.g., ref. [55] and Cosmo-ALEPH [54].

Data from these stations can also be, due to their simplicity, made accessible via Internet, for example to highschools in the framework of an out-reach project.

7   Conclusions

Nuclei are attractive for at least two reasons: the internucleon distances of about 1 fm correspond to a timescale of about 10^{-22} sec., typical for strong interactions; they are also supposed to provide very high densities of soft partons. From p-nucleus interactions at high energies one may therefore extract better insight into many facets of the strong interaction in the framework of, or related to QCD. Even if this theory is unchallenged, it needs a more profound and complete understanding. The topics in the preceding sections have all been presented in this perspective: multiple scattering in the Glauber approach or its generalization, hadronisation, γ-Pomeron interactions, and, in particular, propagation of partons in extended nuclear matter and the structure of bound nucleons. Very soft partons may overlap strongly in Lorentz-contracted nuclei such that non-linear phenomena may occur which can no longer be described by current parton evolution schemes. CMS is able to contribute to an investigation of all that.

A compilation of desirable measurements is given in table III as function of $\sqrt{s}$, and of typical values of A. Some remarks concerning experimental aspects are added; especially mentioned is the interest in the set-up of TOTEM with its Roman pots and geometrical acceptance beyond $|y| = 5$, and in a dedicated small calorimeter ("ZDC") to determine the "centrality" of p-A collisions. Except for γ-Pomeron interactions and multiple hard parton collisions, for which cross sections are presently not known, typical time scales for

data taking per $\sqrt{s}-A$ combination are up to one day for the rather global measurements [29]; they are below one month-depending on the selected final state- for more differential cross sections of rarer rocesses. It is clear that much more detailed feasibility studies have to be performed in order to better assess experimental requirements, and to establish a well understood order of priorities.

Most of the relevant data are also badly needed for predictions of "standard" nuclear effects in high energy heavy-ion collisions; deviations from those extrapolations can then be taken as evidence for QGP formation.

Last, not least, p-nucleus collisions studied under the controlled conditions of accelerator experiments serve as a yard-stick for interpreting data from cosmic rays experiments, often at similar collision energies. The muon flux generated by cosmic rays in the atmosphere is also measurable with the CMS detector.

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Figures Captions

Fig. 1:   a) Differential cross section for elastic coherent pd scattering at $\sqrt{s} = 63$ GeV and a prediction from the extended Glauber model.
b) Calculation of the individual contributions to elastic coherent pd scattering at $p_{Lab} = 10$ GeV/c.

Fig. 2 :   Production cross sections from p-nucleus interactions at $p_{Lab} = 800$ GeV/c as function of A and a fit of the type A^{α}.

Fig. 3 :   Average multiplicity of negative particles from p-nucleus collisions at $p_{Lab} = 200$ GeV/c and theoretical predictions.

Fig. 4 :   Distributions of the number of "grey" tracks from $pA\ell$ and pAu collisions at p_{Lab} = 200 GeV/c and theoretical predictions.

Fig. 5 :   Ratio R(y) of track density $\rho_{Xe}(y)$ from pXe collisions and from pp collisions as functions of y for $p_{Lab} = 200$ GeV/c.

Fig. 6 :   Ratio of track density $dN/dz_h(z_h \geq 0.2)$ from μCu interactions and from μD_2 interactions as function of ν.

Fig. 7 :   Measured total cross sections for pp and $\overline{p}p$ interactions as function of $\sqrt{s}$ and fits based upon Regge theory.

Fig. 8 :   Predicted differential cross sections for elastic coherent and elastic incoherent (=quasielastic) pPb scattering as function of -t at LHC.

Fig. 9 :   Integral flux of cosmic rays as function of $\sqrt{s}$.

Fig. 10 :   Rapidity distributions of negative particles from pAr and pXe interactions at p_{Lab}= 200 GeV/c and theoretical predictions.

Fig. 11 :   Scaled particle density at LHC for 3 intervals of y = y_{cms} as function of A from Glauber and Parton Cascade Models.

Fig. 12 :   Layout of the ALICE 0° calorimeter.

Fig. 13 :   a) Ratio of the yields of Drell-Yan pairs from pCa and pd collisions as function of Bjorken-x.
b) Ratio of the number of vectormesons produced in πPt, πW, pPt, and pW interactions and in interactions with proton targets.

Fig. 14 :   The power α of the A dependence of the invariant differential cross section as function of transverse momentum for pA collisions at $p_{Lab} = 400$ GeV/c.

Fig. 15 :   The power α of the A dependence of jet yields as function of their transverse momenta from pA collisions at $p_{Lab} = 800$ GeV/c with (b) and without (a) subtracting an estimate of non-jet background.

Fig. 16 :   The number of pairs of jets as function of the difference $\Delta\phi$ in jet azimuth for pA collisions at $p_{Lab} = 800$ GeV/c.

Fig. 17 :   Displays of μ-showers in the Aleph detector.

Table I
Various parameters characterizing pA and AA' collisions at LHC

System	$\sqrt{s}$(TeV)	Central y	Multiplicity $|\eta| < 0.9$	σ_{inel} (barn)
PbPb	5.5	0.00	11,000	7.80
pp	14.0	0.00	11	0.07
pO	9.9	0.35	21	0.40
pCa	9.9	0.35	26	0.73
pPb	8.8	0.46	36	1.94
dO	7.0	0.00	29	0.68
dCa	7.0	0.00	36	1.10
dPb	6.2	0.12	50	2.62

Table II

Luminosities of ion collisions

Collision	Luminosity $(cm^{-2}s^{-1})$	Bunch spacing (ns)	Run time (s/year)	CM Energy (TeV)
pp	10^{29} - 10^{31}	25	10^7	14
PbPb	10^{26}	25,125	10^6	1148
CaCa	$4\ 10^{30}$	25	10^5 - 10^6	280
pPb	10^{30}	25,125	10^5	126
pCa	10^{31}	25	10^5	63

Table III

pA collisions : Selection of physics opportunities

HI : Heavy Ions; CR : Cosmic rays

Measurements	Main interest	Related to	$\sqrt{s}$[TeV]	A (indicative)	Additional exp. requirements
$\dfrac{d\sigma}{dt}, \sigma_{e\ell}, \sigma_T$	"Glauber"		0.2 /5.5/9	Pb, Ag, Ca, O/N	TOTEM
σ_{abs}	"Glauber"	HI, CR	0.2/5.5/9	Pb, Ag, Ca, O/N	TOTEM, $|\overline{B}| = 0$?
$\dfrac{d\sigma}{dy}(h^{\pm}), \dfrac{dE}{dy},$	"Glauber",	HI, CR	0.2 /5.5/9	Pb, Ag, Ca, O/N	TOTEM and/or ZDC beneficial
$\dfrac{d\sigma}{d\eta}(h^{\pm}), \dfrac{dE}{d\eta}$	hadroniz.				TOTEM and/or ZDC beneficial ; $|\overline{B}| = 0$?
$\dfrac{d\sigma}{dy}(V^0)$	hadroniz.	HI	0.2/5.5/9	Pb, Ag, Ca	TOTEM and ZDC beneficial ; $|\overline{B}| = 1$T ?
E $\dfrac{d\sigma}{dp}$(B,t)	prod. mech.	CR	5.5 /9	Pb, Ag, Ca, O/N	ZDC ?
$\sigma(\text{pA} \to \gamma\text{P} \to \text{hadrons})$	Pomeron		9	Pb, Ca	TOTEM and ZDC ?
E $\dfrac{d\sigma}{dp}(J/\Psi,\text{Y},\text{W},\text{Z},\gamma)$	structure function	HI	5.5 /9	Pb,Ag, Ca	ZDC beneficial
σ (double coll.)	parton corr.		9	Pb, Ca	ZDC ?
E $\dfrac{d\sigma}{dp}(h^{\pm}, \text{jet, Z}^\circ \to \text{q}\overline{\text{q}})$,	parton	HI	5.5 /9	Pb, Ag, Ca	ZDC ?
E $\dfrac{d\sigma}{dp}(2 \text{ jets, jet} + \gamma/ \text{ Z}^\circ)$	propagation				
Cosmic μ-fluxes	CR				μ-stations at large distances, GPS