Deep subthreshold production of muon pairs and vector mesons: J/Psi, etc. at NICA energies

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Outline:

- **Nuclear structure functions at large X and cumulative processes**

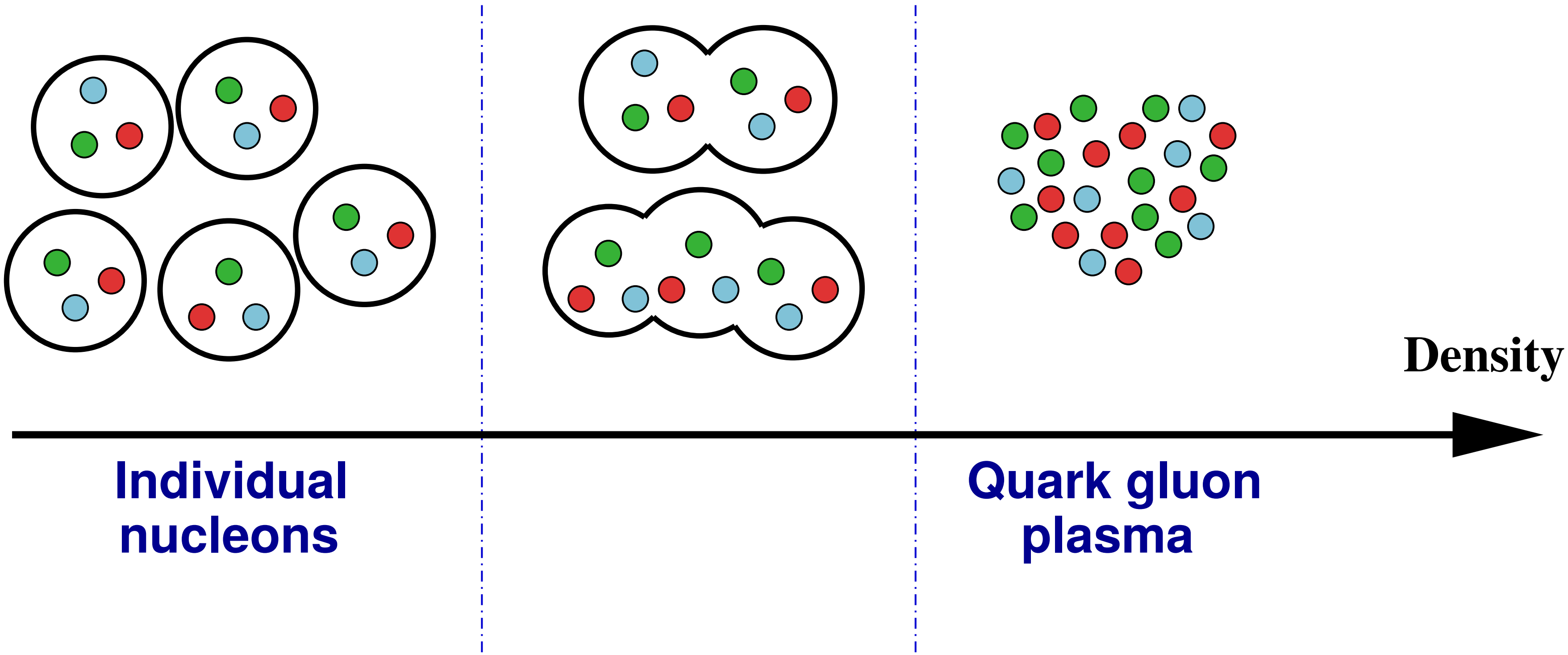
- **Flucton model: hard nuclear quark sea at large X**

- **Proposal for FIxed Target at NICA EXperiment (FITNEX)**

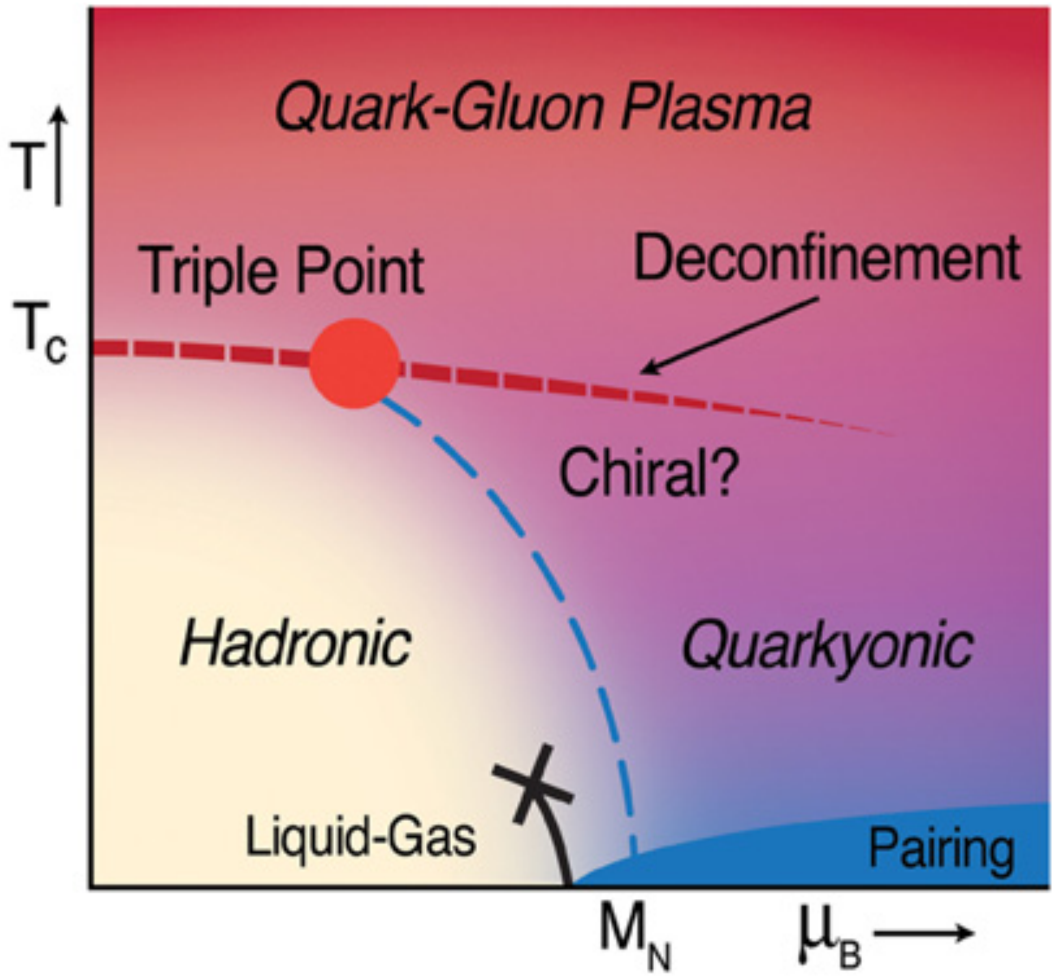
- **Summary**

Motivation: Dense Nuclear Matter

Hot and Cold Dense Nuclear Matter



Cold Superdense Baryon Matter



L.McLerran & L.McLerran & R. Pisarski (2007)
V. Braguta et al. (2016), ...

Cumulative Processes: definition

Cold models -> definition:

- Nuclear processes beyond one free-nucleon kinematics
- scaling property

->

Cumulative processes:

scaling nuclear processes with X > 1

GLAPD-evolution (RG-evolution) and Hard Factorization: Nuclear structure functions

A.Efremov (1985-87)

$$F_A(n,Q^2) = \int\limits_C^1 x_A^{n-1} F_A(x,Q^2)dx_A = \sum C_\alpha \left(n, \frac{Q^2}{\mu^2}, \alpha(\mu^2)\right) f_{\alpha/A}(n,\mu^2) + O\left(\frac{1}{Q^2}\right)$$

$$f(n) = \int_0^1 dx\, dx^{n-1} f(x);$$

$$\frac{d\, f_{a/A}(n,\mu^2)}{d\ln\mu^2} = \sum_b \gamma_{ab}\Big(n, \alpha(\mu^2)\Big) f_{b/A}(n,\mu^2)\,;$$

$$\mu^2 = Q^2;$$

$$V_a = q_a - \bar{q}_a\,, \quad f_1 = q^s(n,Q^2) = \sum_a (q_a + \bar{q}_a), \quad f_2 = G(n,Q^2);$$

$$\frac{dV_\alpha(n,Q^2)}{d\ln Q^2} = \gamma_{qq}^{NS}\Big(n, \alpha(Q^2)\Big) V_\alpha(n,Q^2);$$

$$\frac{df_i(n,Q^2)}{d\ln Q^2} = \gamma_{ik}^{S}\Big(n, \alpha(Q^2)\Big) f_k(n,G^2)\,, \quad i,k = 1.2$$

Nuclear structure functions:
GLAPD-evolution (RG-evolution) equations

A.Efremov (1985-87), A. Efremov et al. (88)

$$\begin{cases} V_A(n,Q^2) = T^{NS}(n)\cdot V_N(n,Q^2) \\ S_A(n,Q^2) = T^{S}(n)\cdot S_N(n,Q^2) \\ G_A(n,Q^2) = T^{S}(n)\cdot G_N(n,Q^2) \end{cases} = \begin{cases} V_A(x,Q^2) = \int\limits_0^A T^{NS}(y) V\left(\frac{x}{y},Q^2\right)dy \\ S_A(x,Q^2) = \int\limits_0^A T^{S}(y) S_N\left(\frac{x}{y},Q^2\right)dy \\ G(x,Q^2) = \int\limits_0^A T^{S}(y) S_N\left(\frac{x}{y},Q^2\right)dy \end{cases}$$

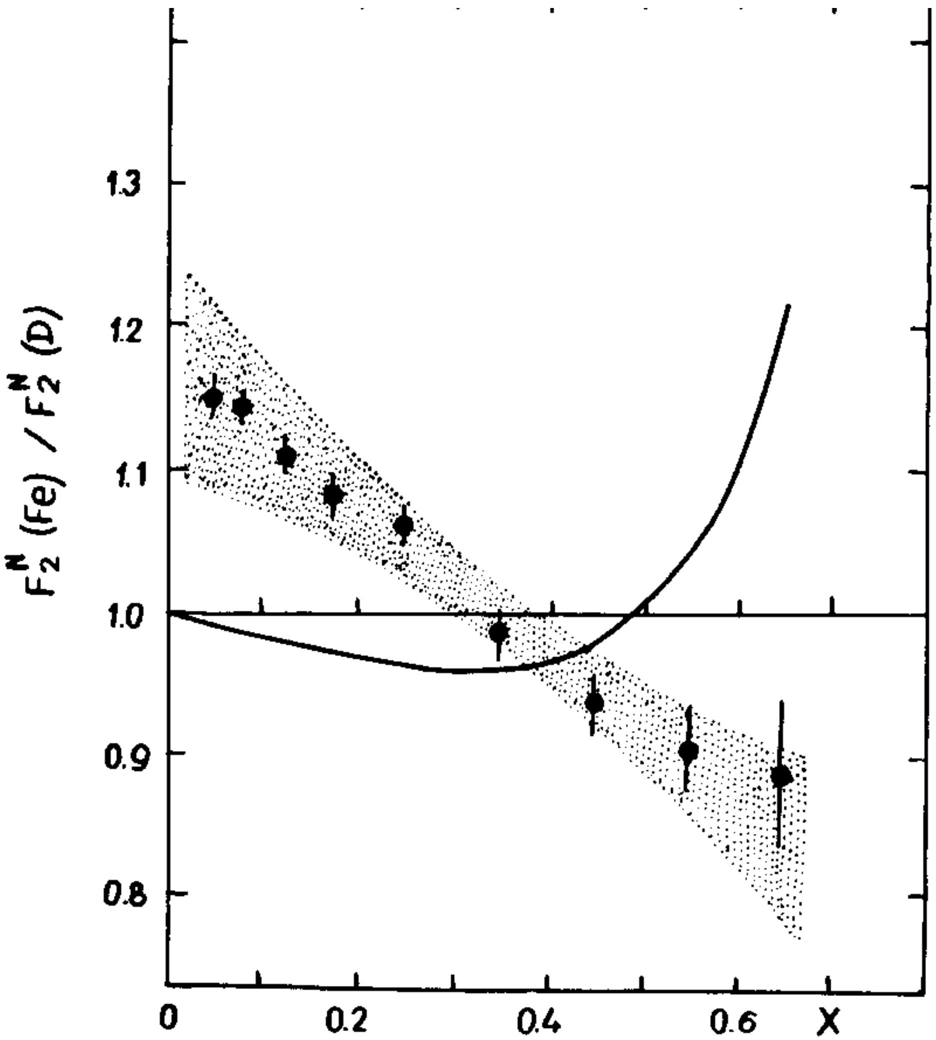
$$\frac{\langle x_q \rangle_A}{\langle x_q \rangle_N} = \frac{\langle x_g \rangle_A}{\langle x_g \rangle_N} = 1$$

Two basic sum rules for PDFs:

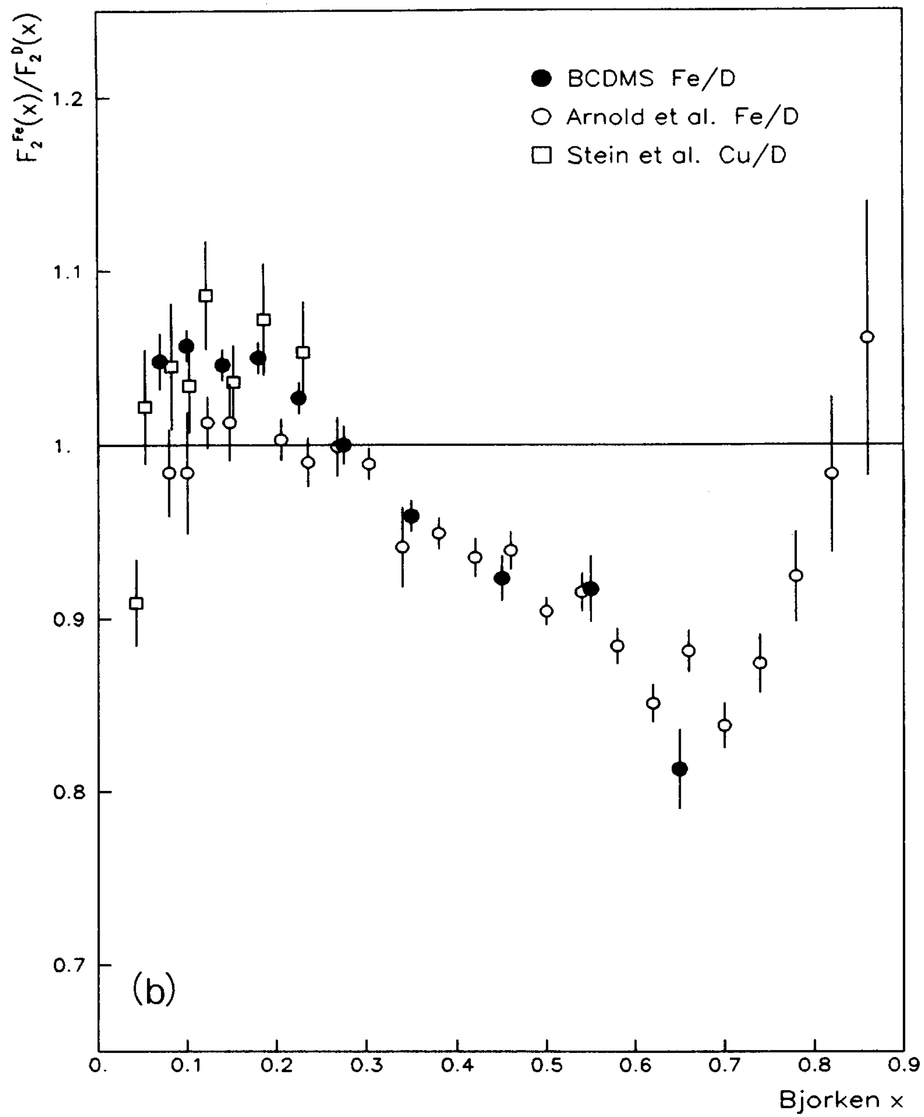
1. **Momentum conservation**
2. **Baryon number conservation**

Nuclear PDF cannot be a convolution of free nucleon PDF?

EMC-ratio for nuclear structure functions



EMC Coll. (1983)



BCDMS Coll. (1987)
SLAC (1987)

Nuclear structure functions: effective nucleon distribution

A.Efremov, A. Kaidalov, V.Kim, G.Lykasov, N. Slavin (1988)

tio (Singlet):

$$< T_A^S > -1 = \Delta_A > 0 \qquad \int_0^A d\alpha \left[T_A^S(\alpha) - T_A^{NS}(\alpha)\right] = \Delta_A > 0$$

xF_3-ratio (NonSinglet):

$$1 - < \alpha T_A^{NS} > = \delta_A > 0 \qquad \int_0^A d\alpha\, \alpha \left[T_A^S(\alpha) - T_A^{NS}(\alpha)\right] = \delta_A > 0$$

$$\delta_A \simeq \Delta_A \qquad \text{(more exactly } \tfrac{2}{3}\Delta_A)$$

$$R_2(x \simeq 0) = \int_0^A d\alpha\, T_A^S(\alpha) = 1 + \Delta_A > 1$$

$$O_A(x, Q^2) \equiv \Sigma_A - V_A$$

$$= \int_x^A d\alpha\, T_A^{NS}(\alpha) O_N\left(\frac{x}{\alpha}, Q^2\right) + \int_x^A d\alpha\, \left[T_A^S(\alpha) - T_A^{NS}(\alpha)\right] \Sigma_N\left(\frac{x}{\alpha}, Q^2\right)$$

$$O'_A \simeq \Delta_A \cdot T_A^{NS} \otimes V_N$$

Δ_A ~ few percents

Nuclear structure functions: extra hard nuclear sea

A.Efremov, A. Kaidalov, V.Kim, G.Lykasov, N.Slavin (1988)

Extra quark sea distribution in nucleus
is due to momentum "repumping"
from valence quarks to sea quarks and gluons

Extra quark sea distribution in nucleus
is hard as valence quark distribution (!):

$$O'_A \;\simeq\; \Delta_A \cdot T_A^{NS} \otimes V_N$$

Δ_A ~ few percents

Nuclear structure functions at large X: multiquark fluctons for cumulative processes

Quark "fluctons":

A.Efremov (76), V.Lukyanov, A.Titov, V.Burov (77)

$$F_A(y) = \Sigma_{k=1}^{A} P_k F_k(y)$$

$$F_k(y) = C_k\, y^{A_k} \, (k-y)^{B_k}$$

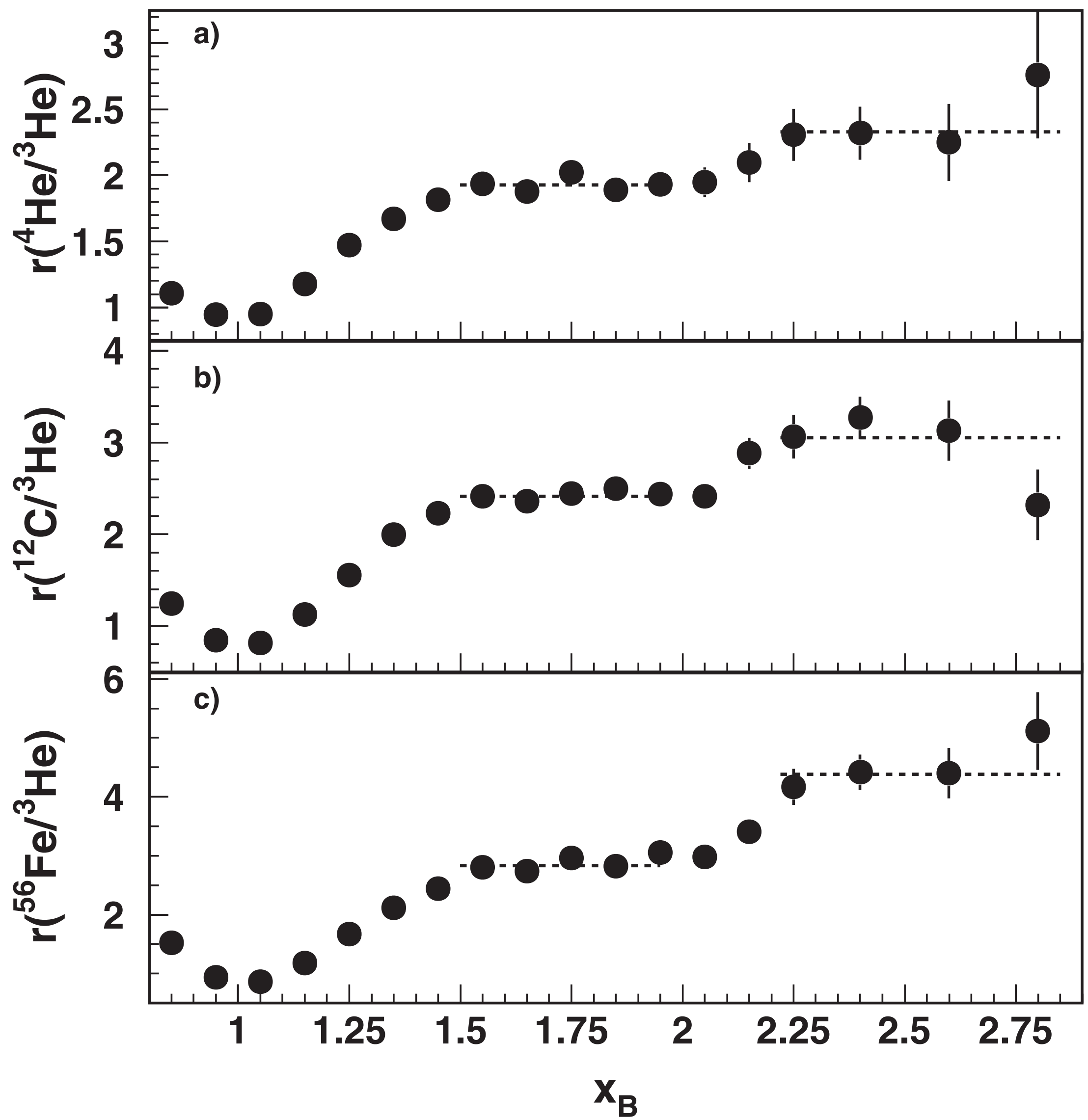
A. Kaidalov, A.Efremov, V.Kim, G.Lykasov, N.Slavin (1988)

- Hard quark sea at X > 1: $S_A(x) \sim S_N(x) + \Delta_A V_A(x)$

- Flucton fragmentation based on quark-gluon strings model

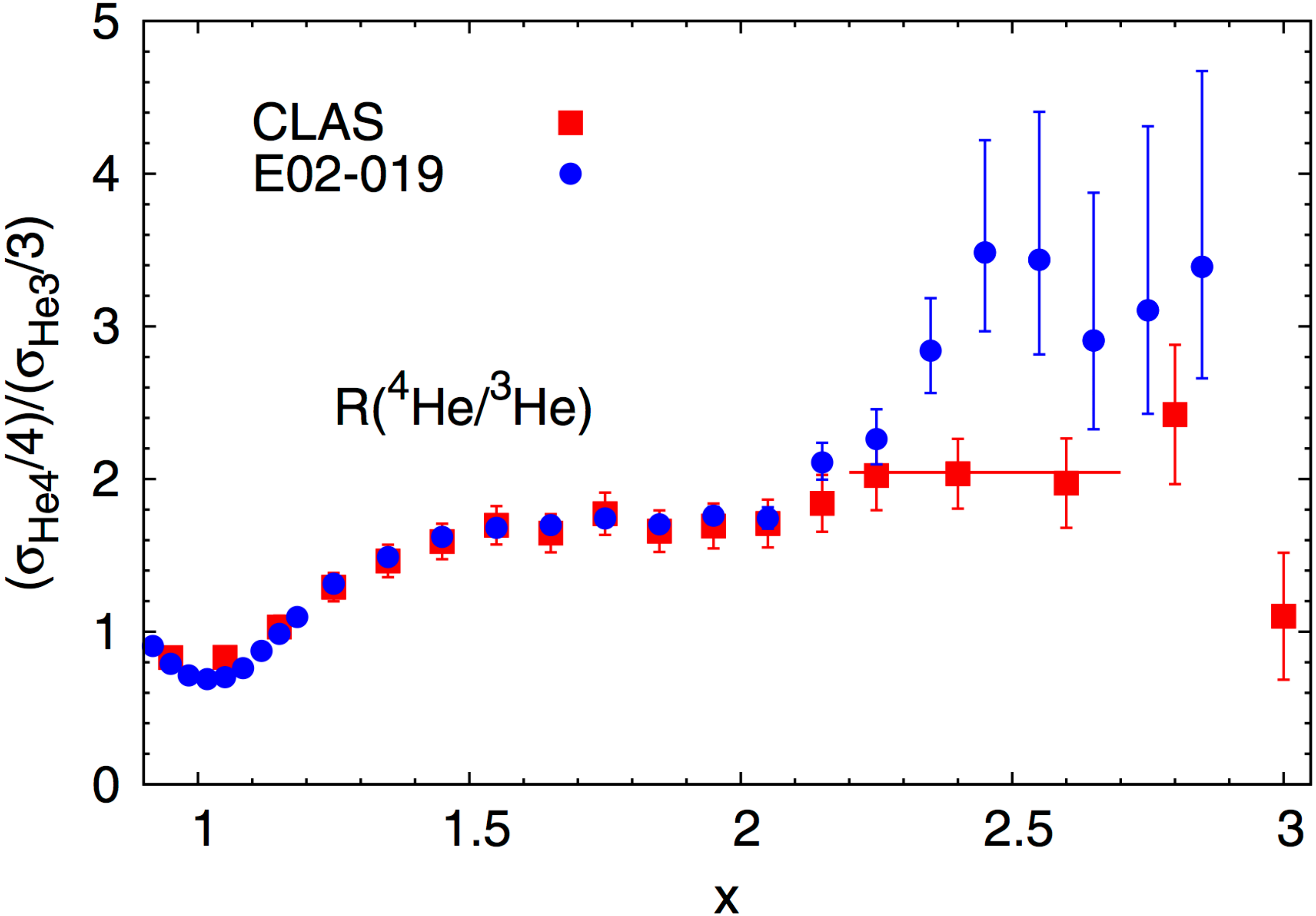
Nuclear structure functions at large X
in LO and NLO with TMC and higher twists
VK (1991, 2017)

Nuclear structure function ratio in lepton DIS at X > 1



JLAB CLAS Coll., K. Egiyan (06)

Nuclear structure function in lepton DIS at X > 1



JLAB E02-019 (2012), <Q2> = 2.9 GeV²
JLAB CLAS (2006) – no IS corrections, <Q2> = 1.6 GeV²

Nuclear structure functions: extra hard nuclear sea

A.Efremov, A. Kaidalov, V.Kim, G.Lykasov, N. Slavin (1988)

Extra quark sea distribution in nucleus is hard as valence quark distribution:

$$O'_A \simeq \Delta_A \cdot T_A^{NS} \otimes V_N$$

The nuclear extra quark sea distribution is small at x < 1,
but it is dominant at x > 1 !

Hard probe cumulative processes:
at high pT processes and heavy quarks production

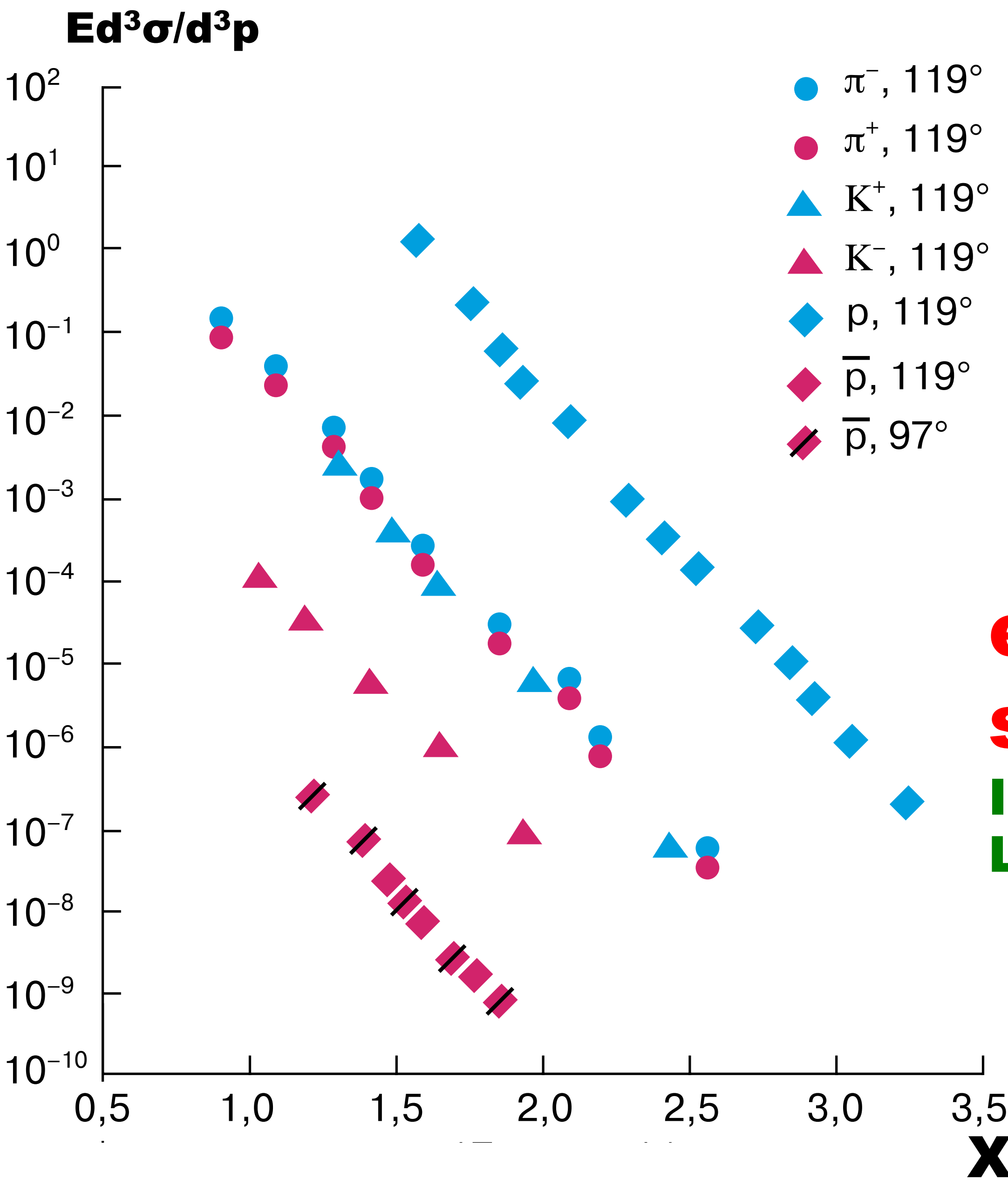
Cumulative high-pT processes in pA:

A.Efremov (76-78)
A.Efremov, V.K., G.Lykasov (1986) quark rescattering included
V.Burov, L.Kaptar, A.Titov (1986)

Cumulative MMT-DY pairs and J/Psi production in pA

N.Zotov, V. Saleev (90-91)

Cumulative proceess: superscaling !



A.Efremov, A.Kaidalov, VK, G.Lykasov, N.Slavin (1988)

prediction for pure "sea" particles:

K^-

antiproton

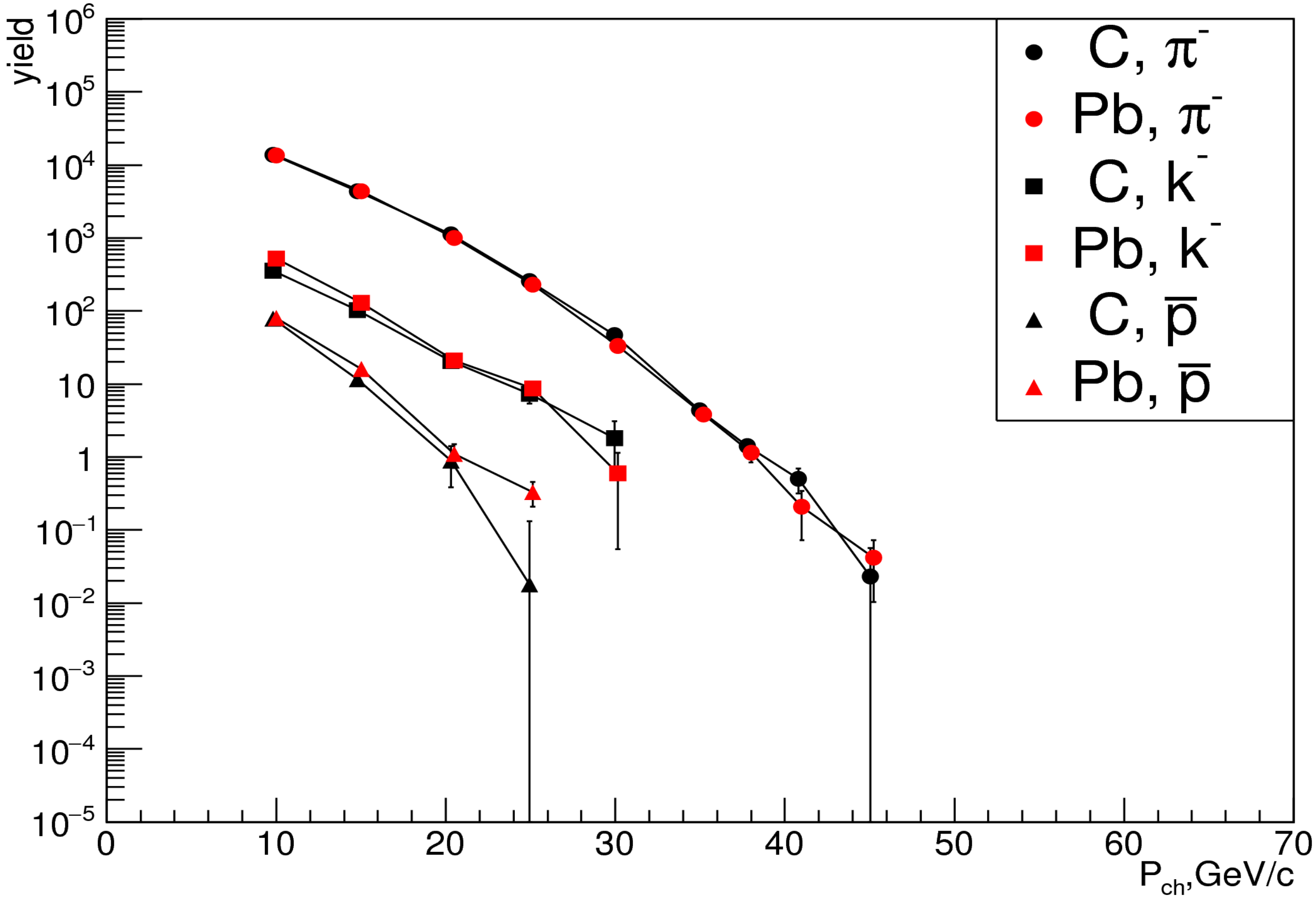
equal slopes: superscaling!

ITEP data:
Leksin et al. (1989)

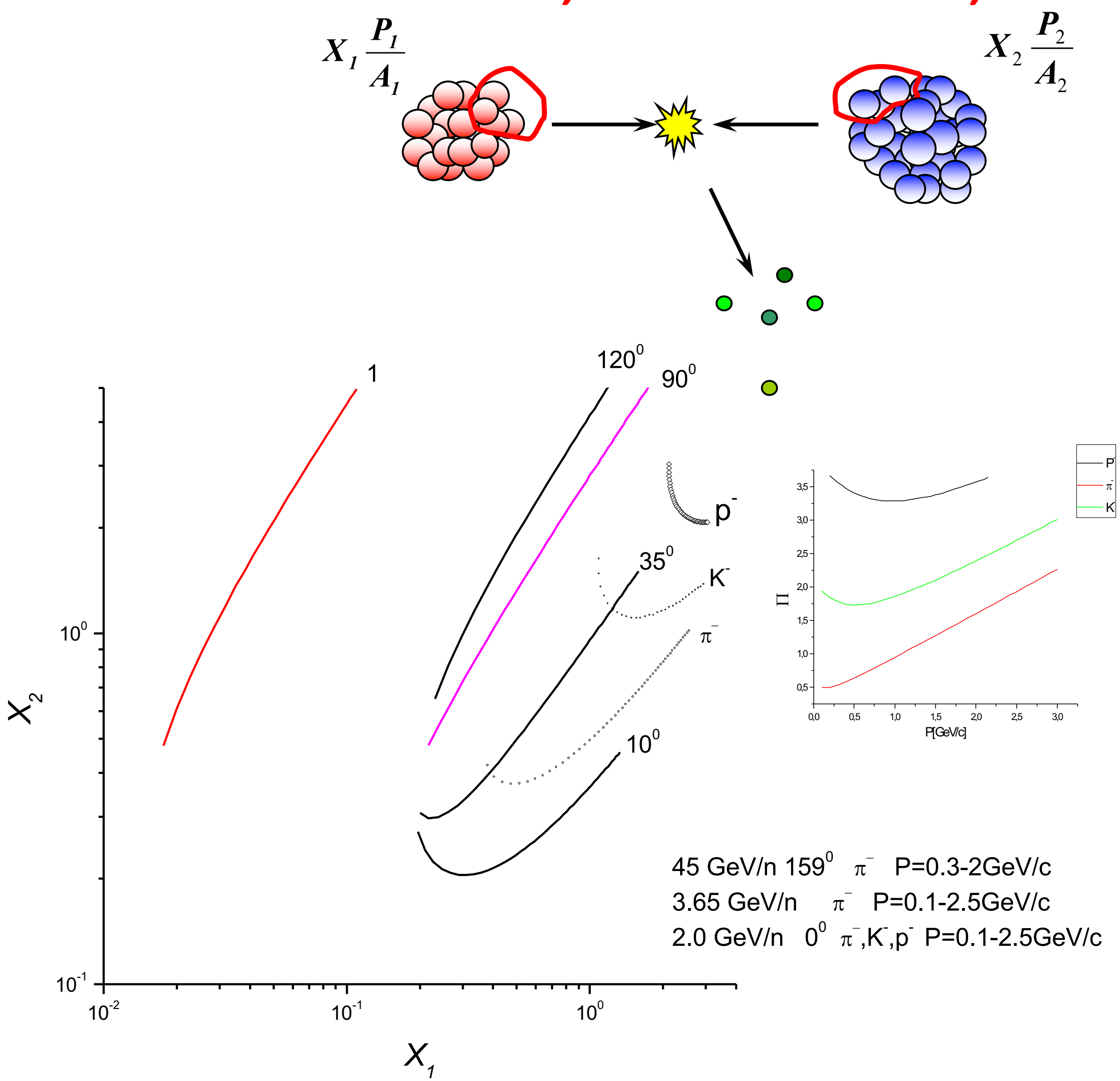
Cumulative processes (direct nucleus fragmentation): Carbon beam @ NRC KI - IHEP (Protvino)

beam: C^{12} 20 GeV/N forward fragmentation
fixed targets: C^{12}, Pb^{207}

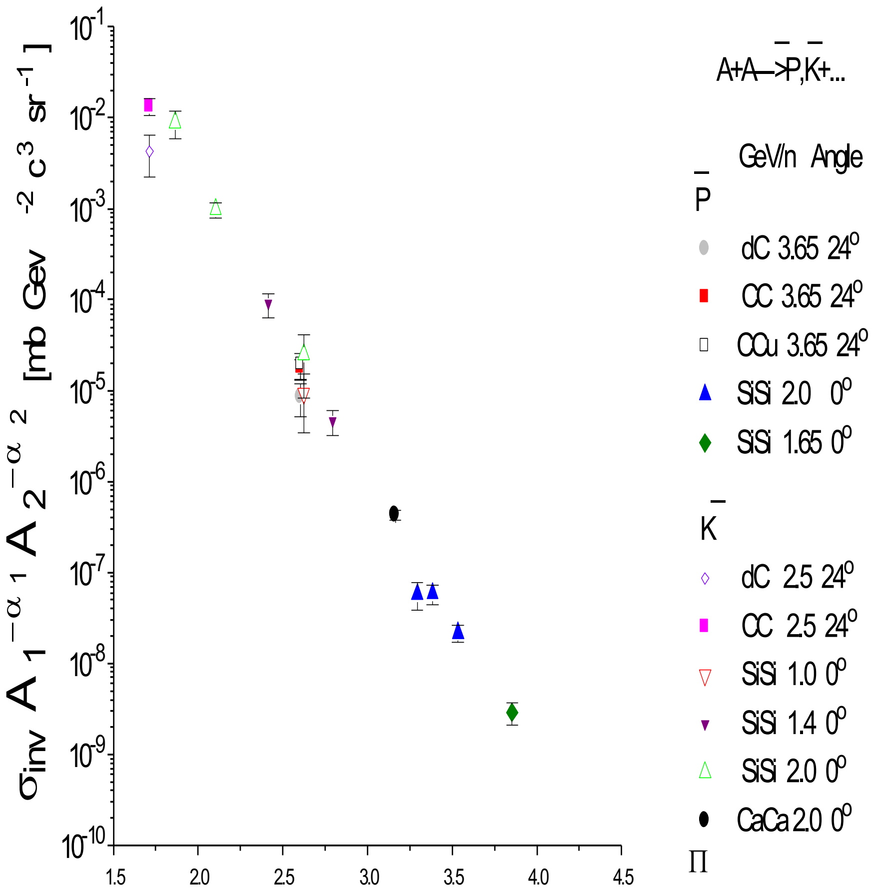
FODS-2, Bogolyubsky et al. (2017)

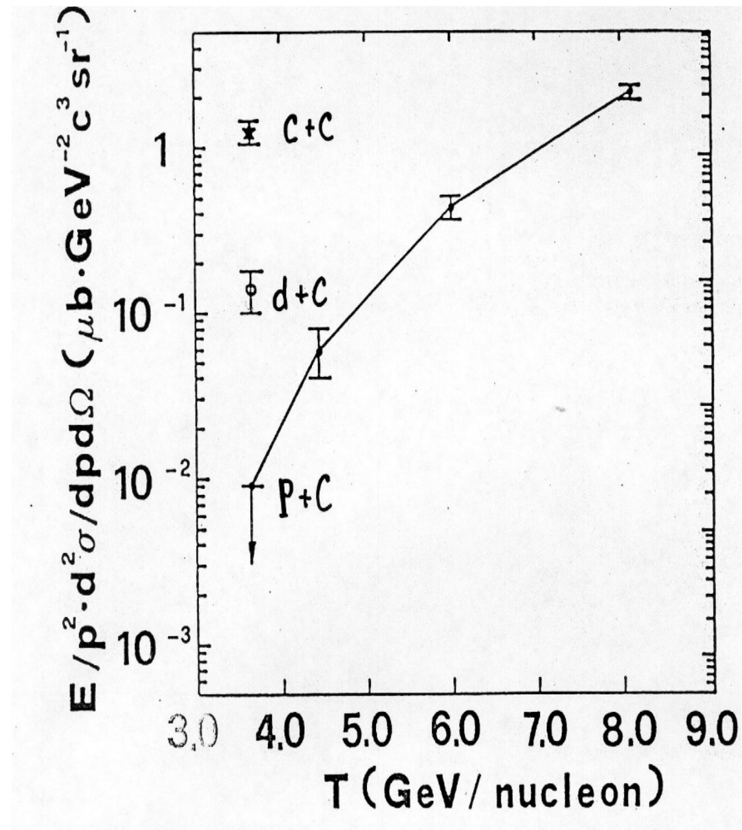


Double cumulative processes KASPIY, MARUSYA, etc.



Double cumulative deep subthreshold antimatter production





J.Carroll Nucl. Phys. A488 (1989) 2192.
A.Shor et al. Phys. Rev. Lett. 62 (1989) 2192.
A.A.Baldin et al. Nucl. Phys., A519 (1990) 407.
A.A.Baldin et al. Rapid Communications JINR, 3-92 (1992) 20.

J/ψ and MMT-DT muon pair production

At large X quark-antiquark subprocess is dominant:

nuclear sea at large X can be tested

$$\frac{d\sigma_h}{dm^2\,dy}(\mathrm{pt}\to c\bar{c};m^2)=\frac{1}{s}H_{\mathrm{pt}}(x_p,x_t;m^2) \qquad m^2=x_p x_t s=\tau^2 s.$$

$$H_{\mathrm{pt}}(x_p,x_t;m^2)=G_p(x_p)G_t(x_t)\sigma(gg\to c\bar{c};m^2)$$

$$+\sum_{i=u,d,s}\left(q_{pi}(x_p)\bar{q}_{ti}(x_t)+\bar{q}_{pi}(x_p)q_{ti}(x_t)\right)\sigma(q\bar{q}\to c\bar{c};m^2)$$

- Heavy quark mass or large muon pair mass ensures quark-gluon degrees of freedom

- Large x production comes from quark-antiquark annihilation

Nuclear structure functions: extra hard nuclear sea

VK et al, in progress

Extra quark sea distribution in nucleus is hard as valence quark distribution:

$$O'_A \simeq \Delta_A \cdot T_A^{NS} \otimes V_N$$

Δ_A ~ few percents

Qualitative Predictions:

1. **Cumulative 'sea' hadron production K- and antiprotons is hard as the 'valence' hadrons**

2. **JLAB PDF ratio should be qualitatively the same for nuclear antiquark PDF at X > 1**

3. **Matveev-Muradyan-Tavkhelidze-Drell-Yan (MMT-DY) lepton pair and j/Psi production at X > 1 is enhanced to compare SRC**

J/ψ production in AA-collsions

J/Psi suppression in central AA-collisions
T.Matsui & H.Satz (1986)

J/Psi suppression in central AA-collisions due to fluctons
A.Efremov & V.K., S.Shmakov, V.Uzhinsky (1989)

FITNEX: Deep subthreshold J/Psi-production in AA-collisions

- ■ Nuclear PDFs with multiquark fluctons constrained by
- - QCD factorization and GLAPD evolution equations
- - EMC effect
- - Cumulative processes with K-, antiproton production at X > 1

-> hard nuclear antiquark sea at X > 1

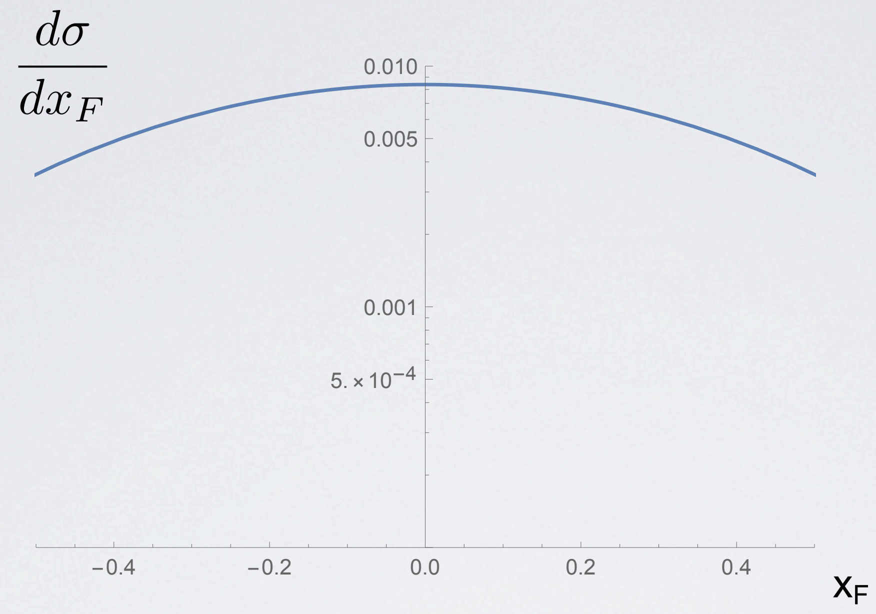
■ The hard nuclear antiquark sea at X > 1 can be tested by deep subthreshold MMT-DY lepton pair and J/Psi production at X > 1 with the proposed Fixed Target at NICA Experiment (FITNEX)

FITNEX: Deep subthreshold J/Psi-production in AA-collisions

- **The hard nuclear antiquark sea at X > 1 can be tested by deep subthreshold MMT-DY lepton pair and J/Psi production at X > 1 with the proposed Fixed Target at NICA Experiment (FITNEX)**

NICA fixed target: beam dump with heavy ion beam:

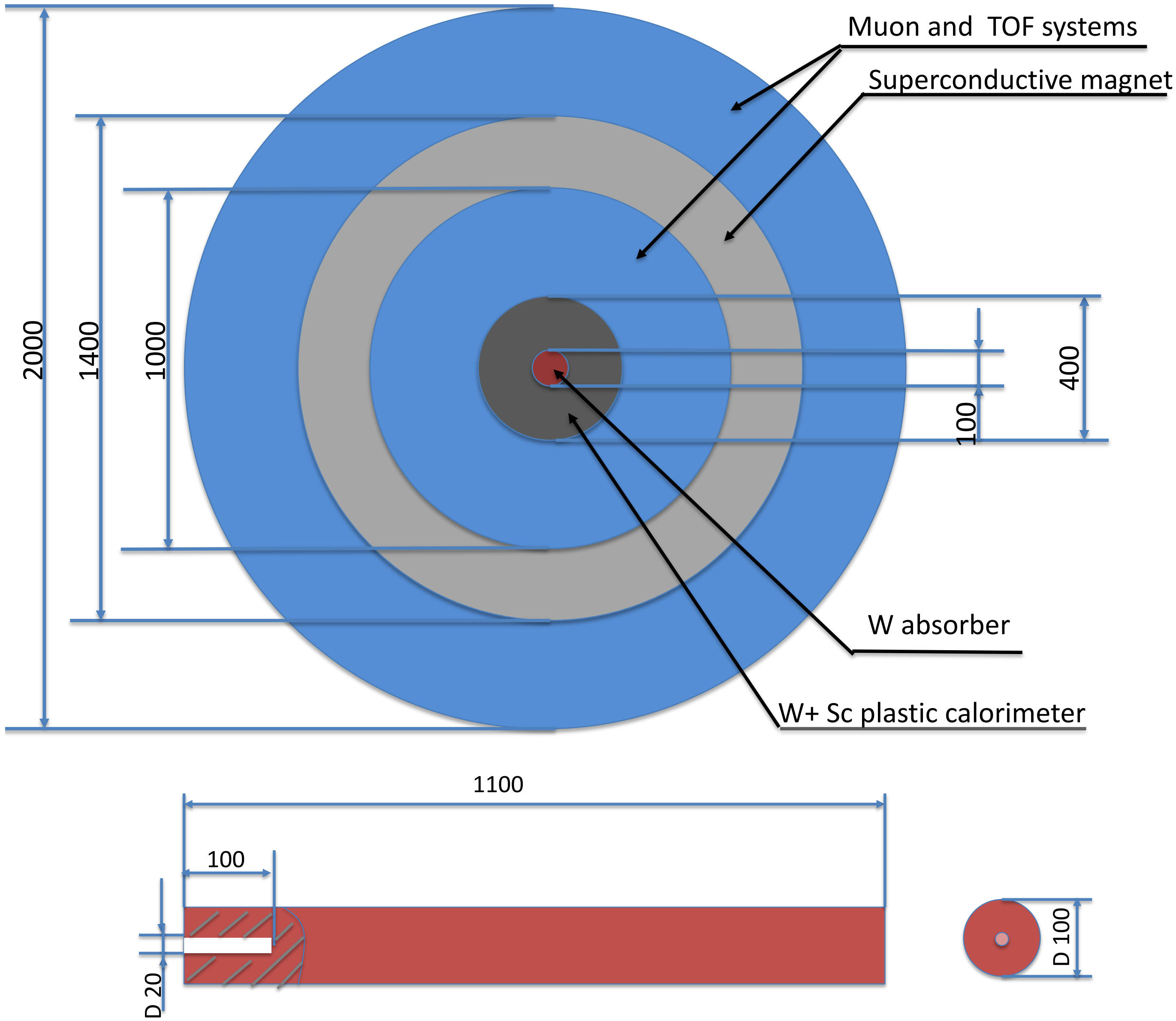
Au+W -> J/ψ X -> $\mu^+\mu^-$ X



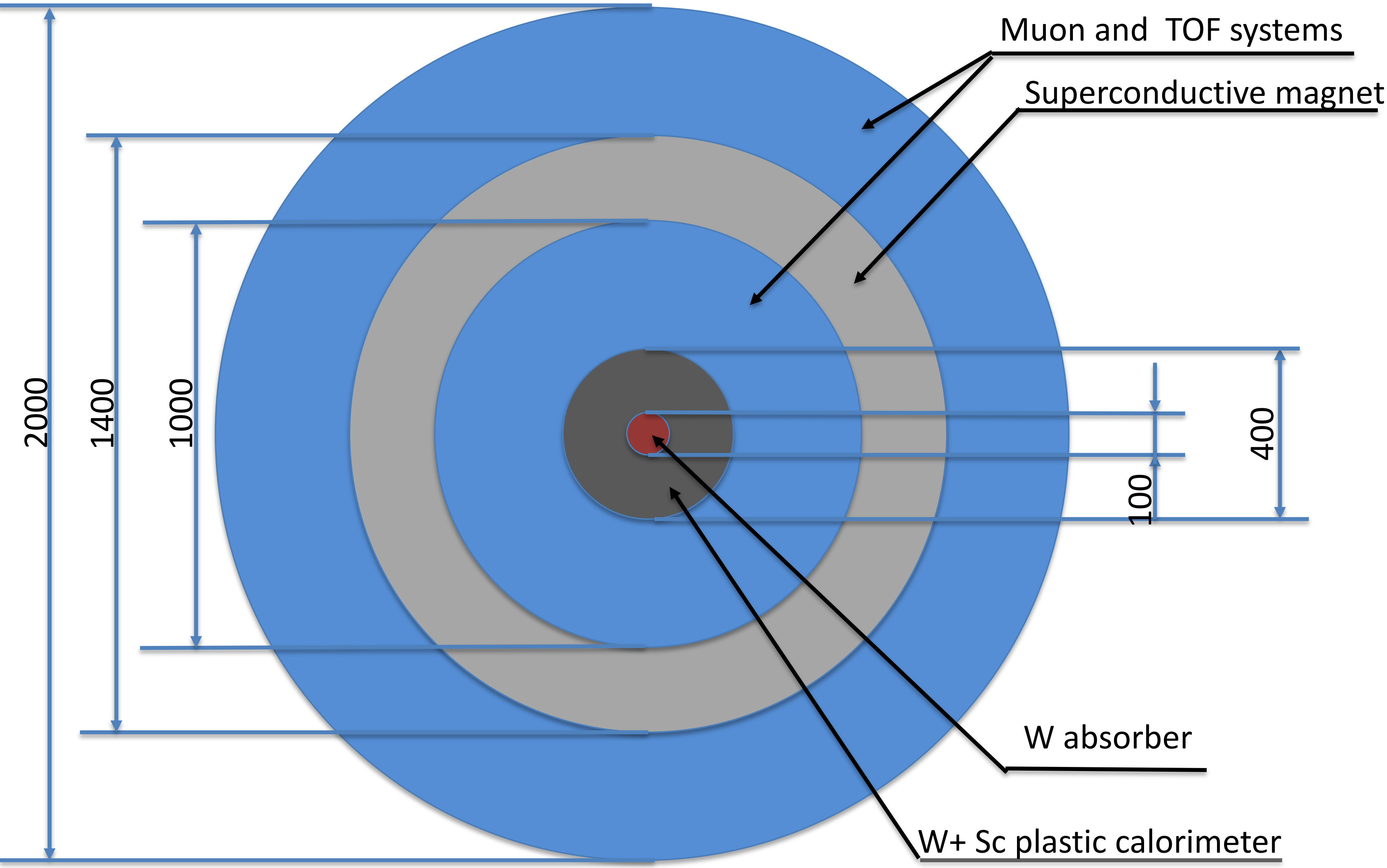
$$\frac{Ed^3\sigma}{d^3p\bot} = \frac{d}{p_\perp d\varphi}\left(\frac{d^2\sigma}{dx_F dp_\perp}\right)$$

$$\text{Au+W} \to J/\Psi + X \quad \text{Au: } 4 \text{ GeV/N } (\sqrt{s_{NN}} = 3.041 \text{ GeV}) \quad E^L_{NNth} = 11.3 \text{ GeV}$$

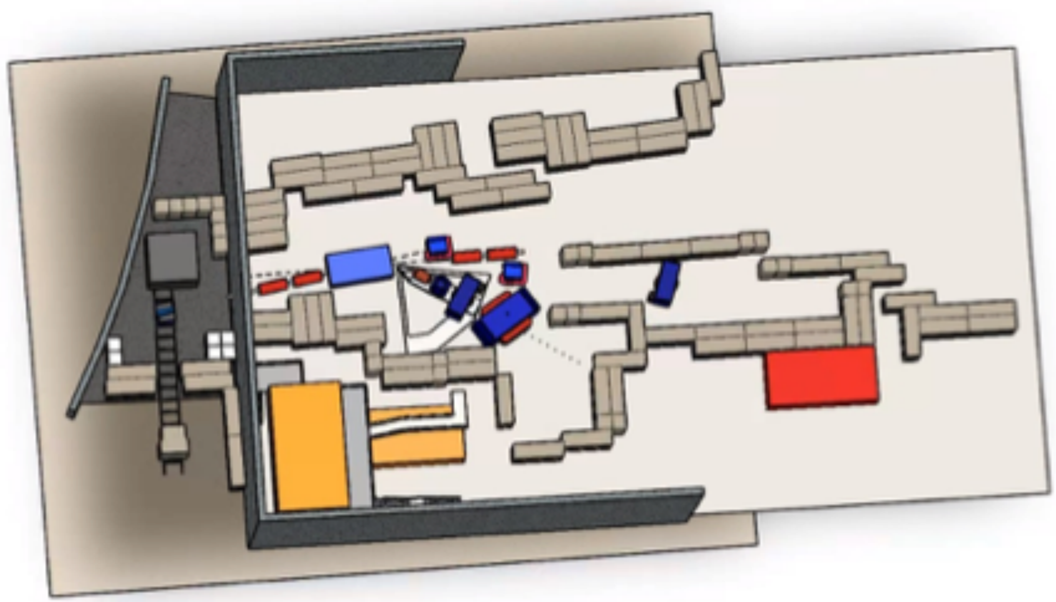
Proposal for FIxed Target at NICA Experiment (FITNEX)
A+A -> J/ψ X -> $\mu^+\mu^-$ X



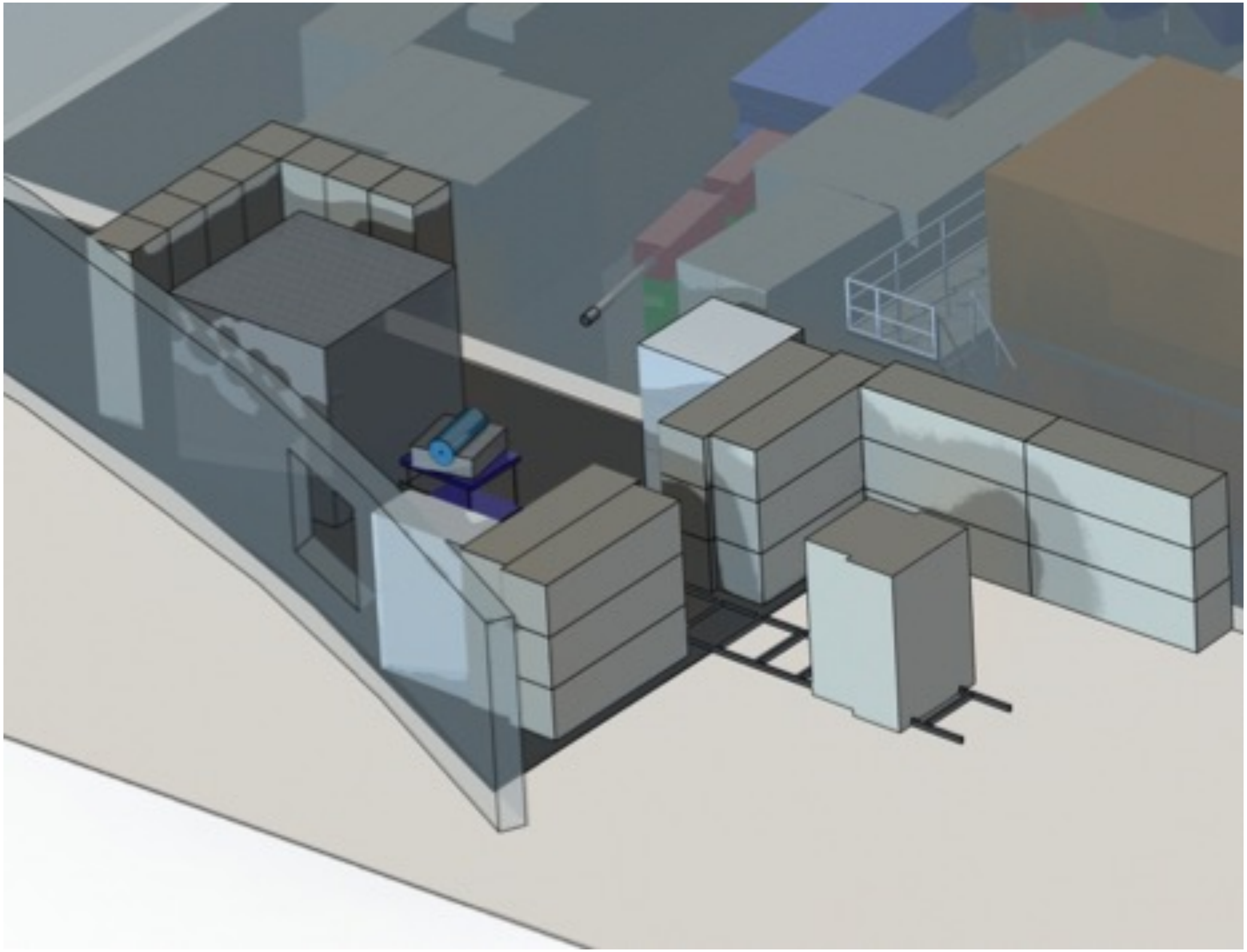
Very preliminary!!! Detector.
Compact muon spectrometer & active beam dump.



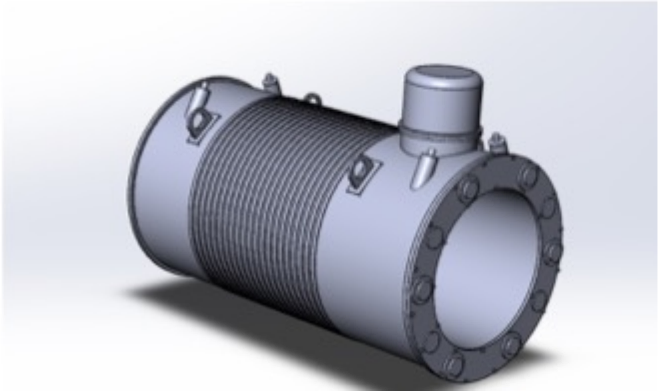
Possible FITNEX location layout



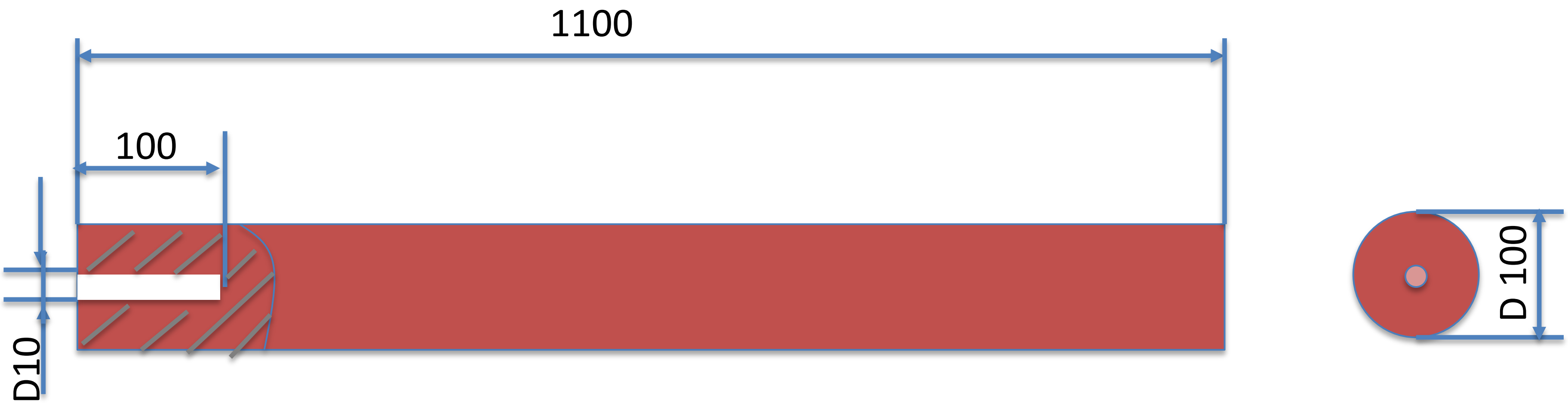
Possible FITNEX location layout



FITNEX Superconductive Solenoid



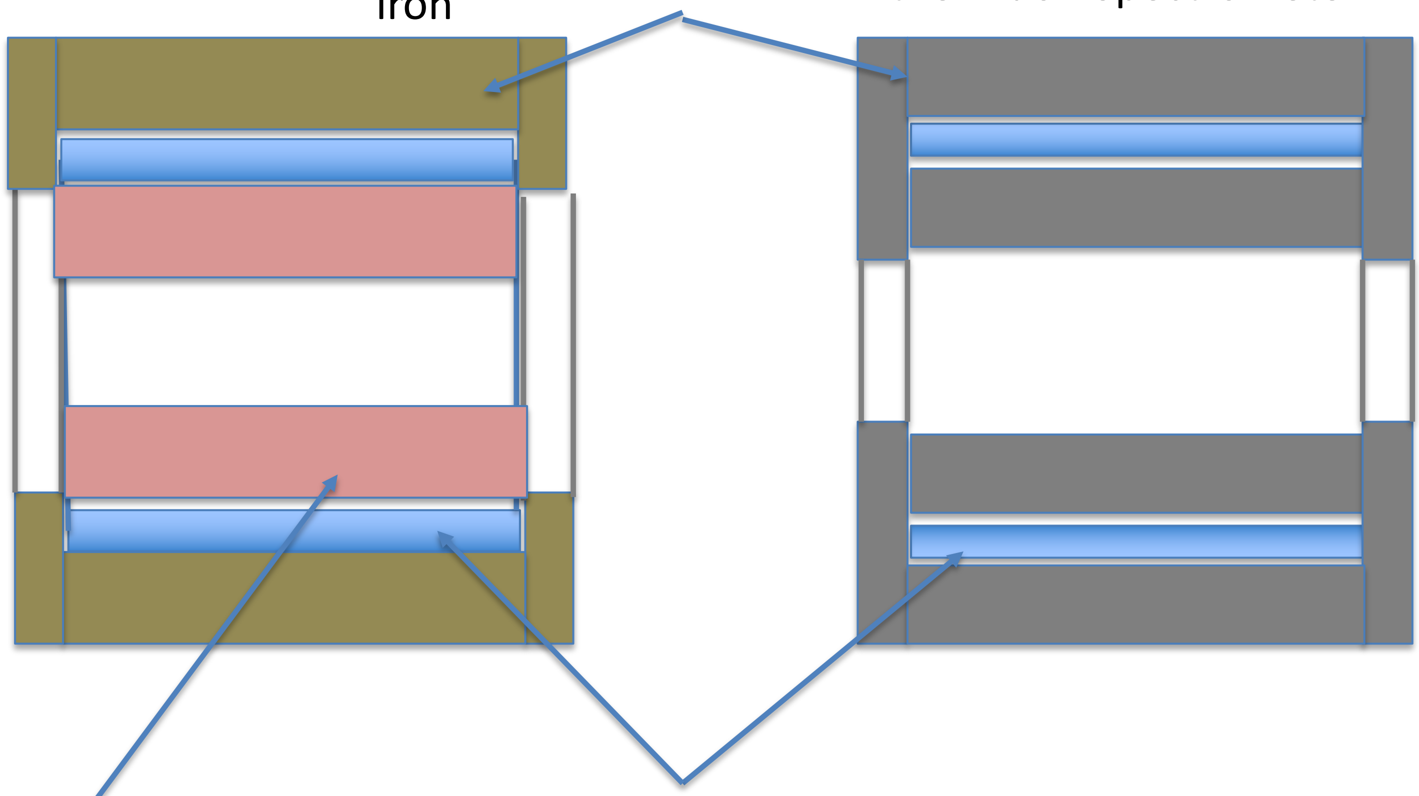
Tungsten beam dump
Very preliminary!



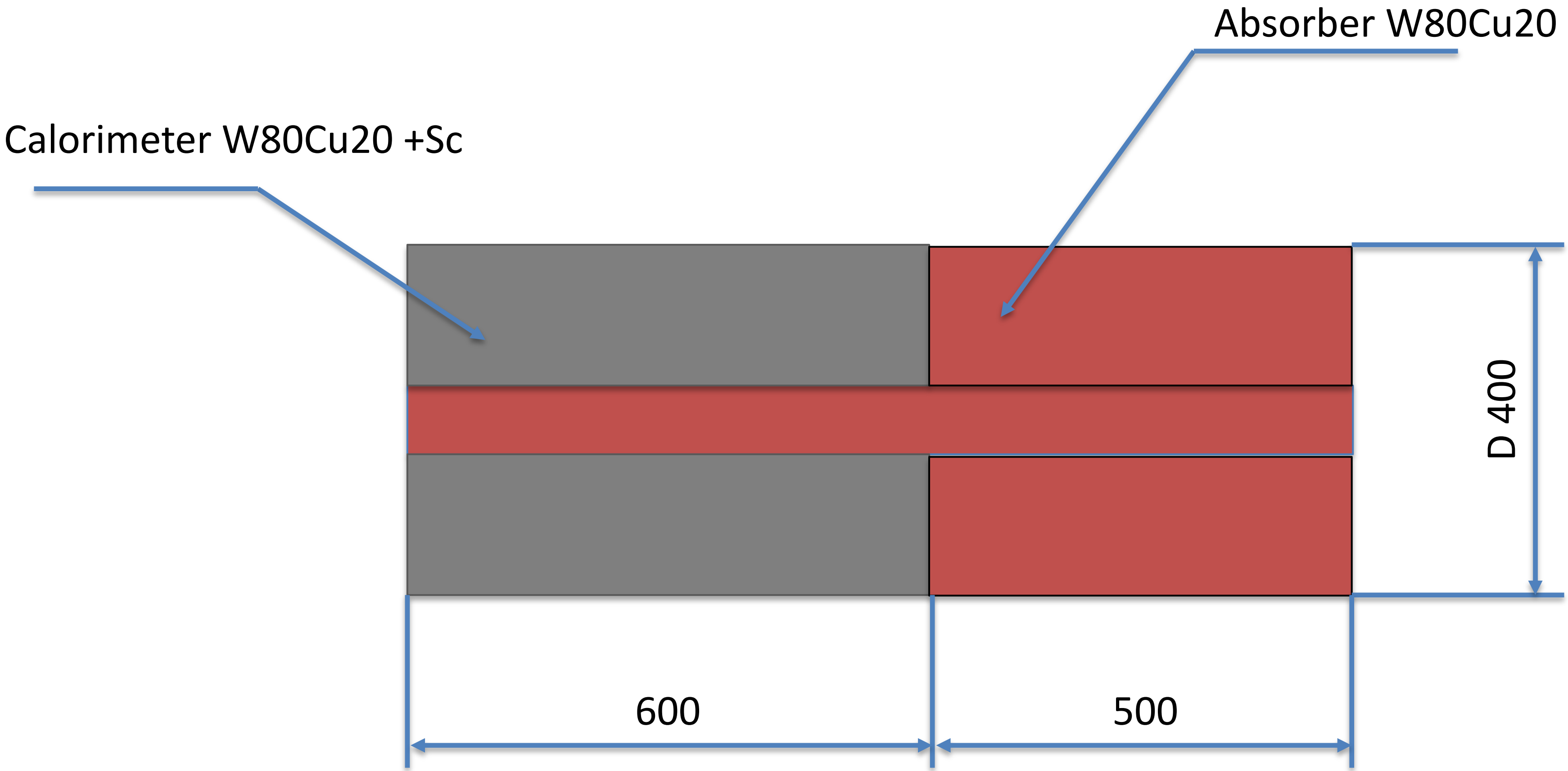
Very preliminary! Muon spectrometer.

- The spectrometer is placed around the superconductive magnet. There could be 2 options: magnetic field is concentrated in the muon spectrometer; solenoidal magnetic field distributed uniformly inside the magnet, external part of the spectrometer is combined with return yoke.
- The spectrometer should have TOF subsystem, we suppose that one layer of TOF system will be inside the magnet, the second is outside magnet. TOF could consists from Sc. Pads with SiPMs.
- MDT (monitored drift tubes with 10-30 mm diameter) could be a muon detector.
- Straw tubes could be used inside the magnet.

Very preliminary! Muon Spectrometer and Magnet.



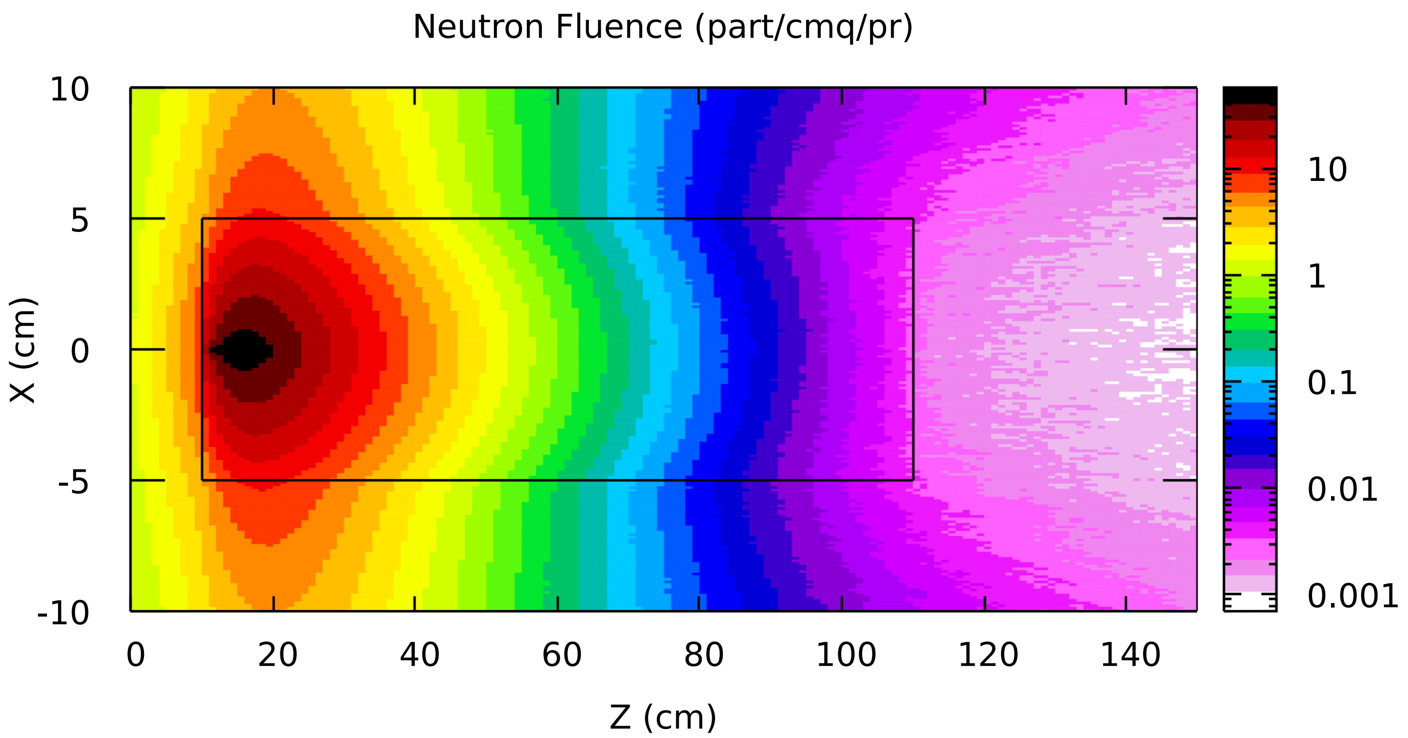
Very preliminary!!! Detector. Calorimeter for central interactions selection.



The calorimeter should be optimized for about 100 GeV energy deposition in the calorimeter from central events and about “0” GeV for peripheral events. Calorimeter: 5mm W80Cu20+ 5 mm Sc. Plastic+WLS fibers. The calorimeter thickness is 150 mm. Energy resolution is about 60%/√E.

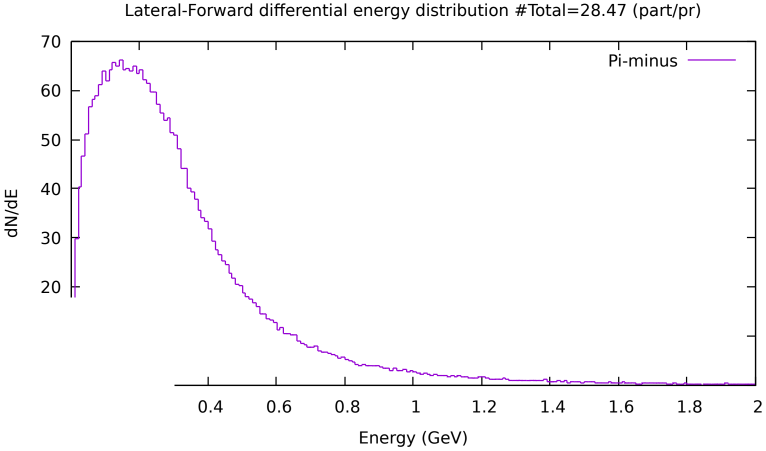
Some preliminary simulations with FLUKA. Au beam 4 GeV/c/nucleon

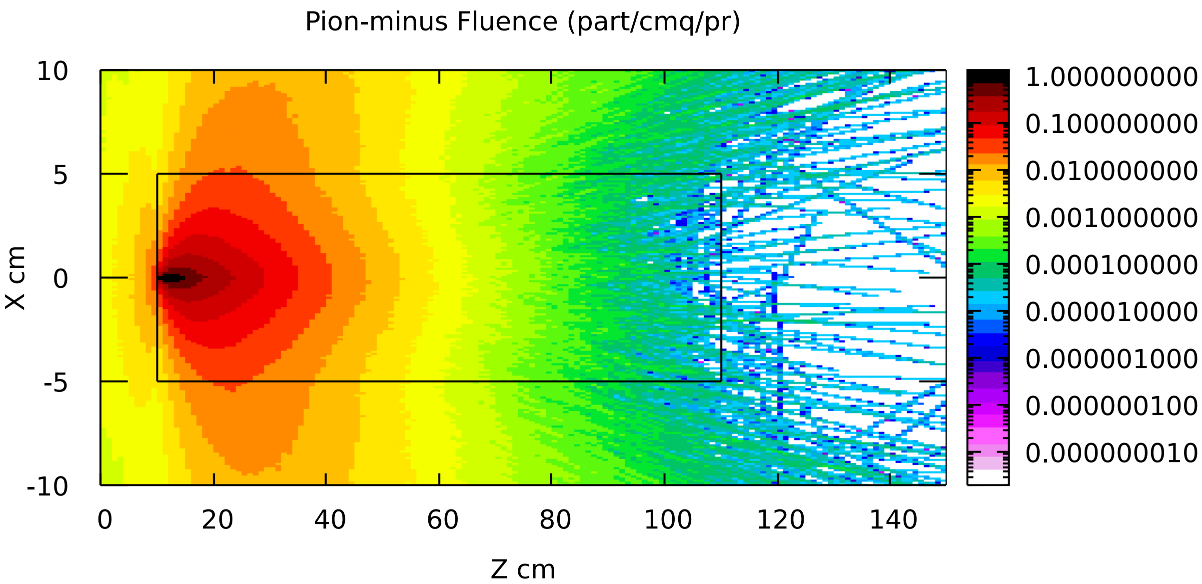
- Beam dump without the hole.



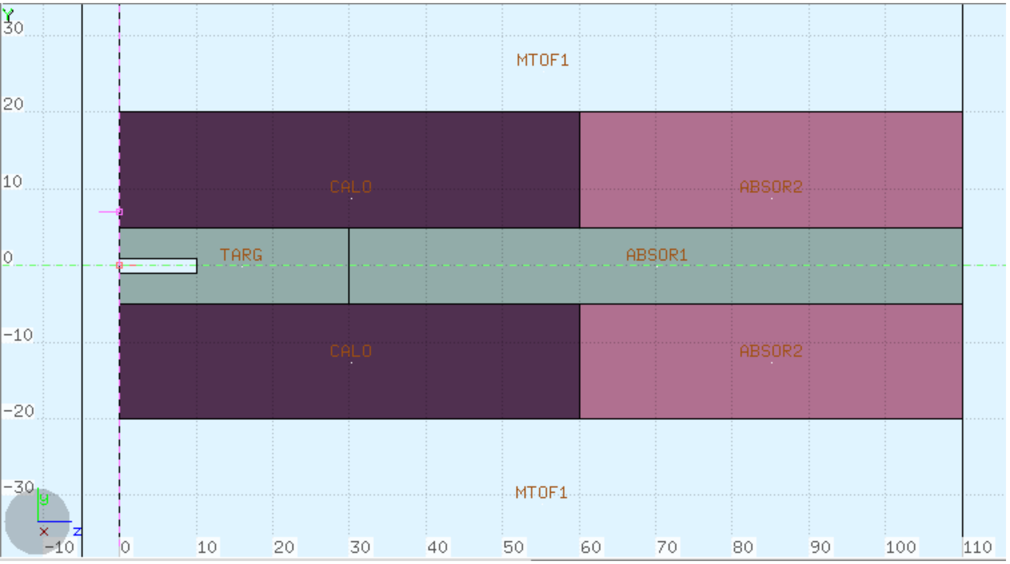
Some preliminary simulations with FLUKA. Au beam 4 GeV/c/nucleon

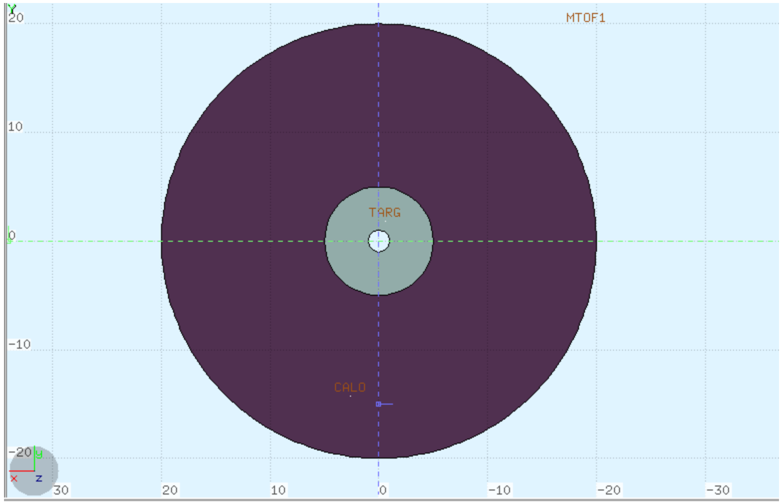
- Beam dump without the hole





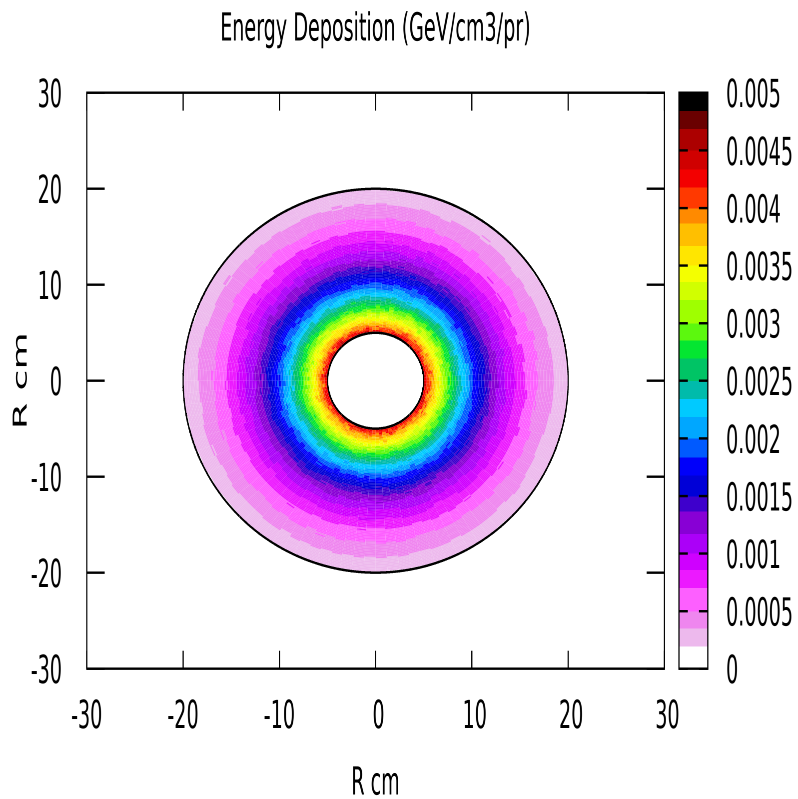
Modified beam dump with calorimeter.

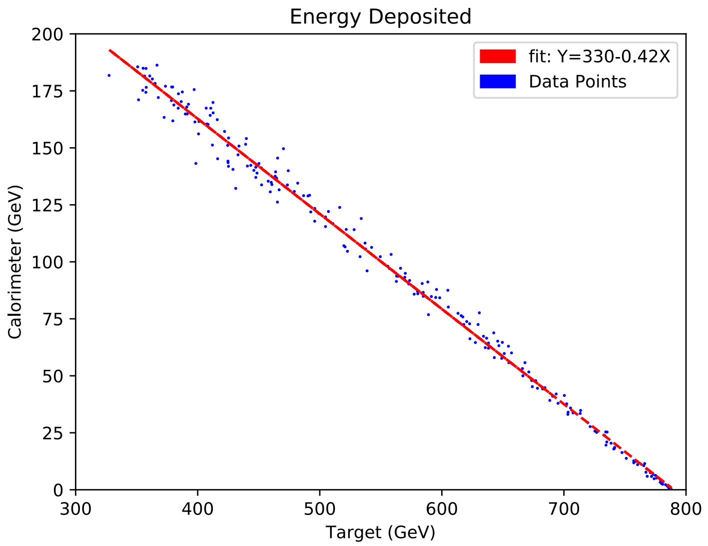


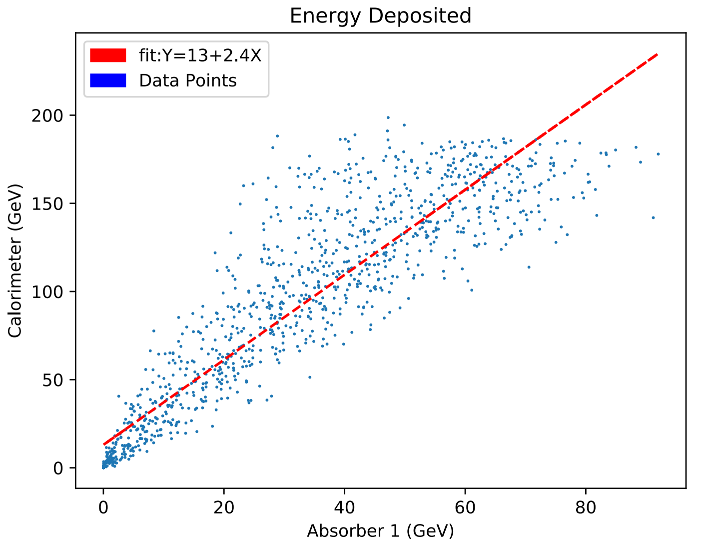


Some preliminary simulations with FLUKA. Au beam 4 GeV/c/nucleon

- Modified beam dump







Deep subthreshold production at NICA:
Testing the Hard antiquark sea in nuclei
Cold Dense Nuclear Matter?

Cumulative hadroproduction at NICA can be studied at BM@N and SPD

Usual main obstacles, which can be avoided with FITNEX:
- **small cross sections**
- **huge combinatorial background from high multiplicities**

Fixed Target at NICA Experiment with muon pairs from deep subthreshold MMT-DY and J/Psi production:

Beam dump -> higher rate at smaller background

Expected rates: ~ hundred muon pairs per hour at 10^6/s

Au+W-> $\mu^+\mu^-$ X   4 GeV/n

Au+W -> J/ψ X -> $\mu^+\mu^-$ X

Summary

- The hard nuclear antiquark sea at X > 1 can be tested by deep subthreshold MMT-DY lepton pair and J/Psi production at X > 1 with the proposed Fixed Target at NICA Experiment (FITNEX)

- The proposed FITNEX-SPD experiment can be:

  - an extension of the pioneering works at JINR on cumulation production for new region and new processes

  - a substantial addition to the NICA experiments

  - a natural extension of SPD to fixed target studies

Nuclear hard antiquark sea: key features

- ■ **Nuclear PDFs with multiquark fluctons constrained by**
- **- factorization and GLAPD evolution equations:**
- **- EMC effect**
- **- Cumulative processes with K-, antiproton production X > 1**

■ **Cold Dense Nuclear Matter study**

- **with nuclear structure functions at X > 1:**
  hard (anti)quark sea at X > 1

- **- deep subthreshold MMT-DY lepton pair and J/Psi production X > 1**
- **- CP-violating observables**

- ■ **FluctON model and Cold Dense Nuclear Matter:**
- **phase transition?**
- **chemical potential?**
- **isoscalar dominance?**
- **quarkyonic phase?**