Fixed Metal Microstrip Target for the LHCb Experiment.

Physics and Techniques of Fixed Metal Target in the LHCb experiment

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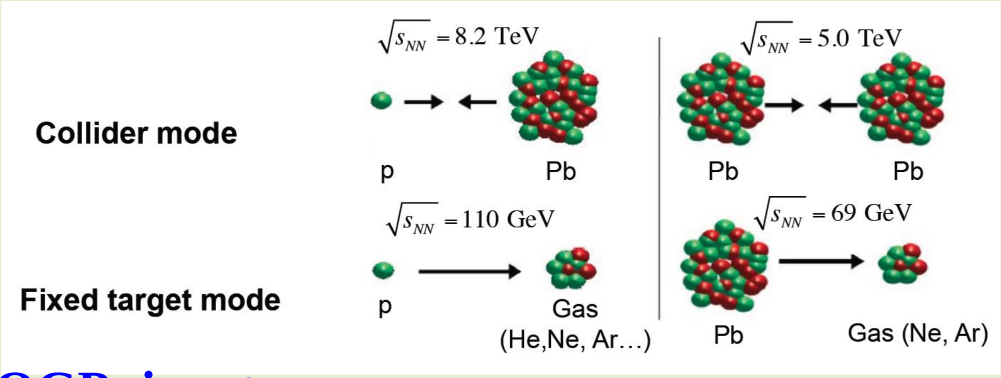
6th French-Ukrainian Workshop

on Intsrumentation Developments

(26-28)-Sep-2018

Heavy ion collisions studied by the LHCb detector

Physics Motivation



On the way to QGP signatures:

- **Study collisions at various center-of-mass energies and different beam-target system**
- **Compare quarkonium production in various collisions**
- **Compare data for prompt and non-prompt hadron production:**
  - **J/ψ from B -mesons is less affected than prompt J/ψ**

V.Pugatch 6th FU Workshop on
Instrmentation for HEP

$$R_{p\mathrm{Pb}}(y^*, p_\mathrm{T}, \sqrt{s_\mathrm{NN}}) \equiv \frac{1}{A}\frac{\mathrm{d}\sigma_{p\mathrm{Pb}}(y^*, p_\mathrm{T}, \sqrt{s_\mathrm{NN}})/(\mathrm{d}y^*\mathrm{d}p_\mathrm{T})}{\mathrm{d}\sigma_{pp}(y^*, p_\mathrm{T}, \sqrt{s_\mathrm{NN}})/(\mathrm{d}y^*\mathrm{d}p_\mathrm{T})}$$

Fixed Targets at LHC (operational and proposed).

- Physics Motivation
- Technical Realization

Gaseous Targets:

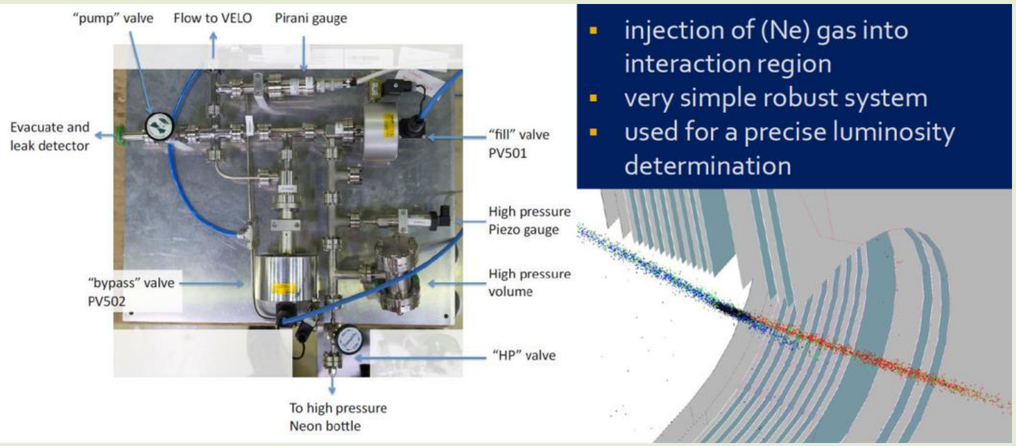
- SMOG (operational at LHCb)

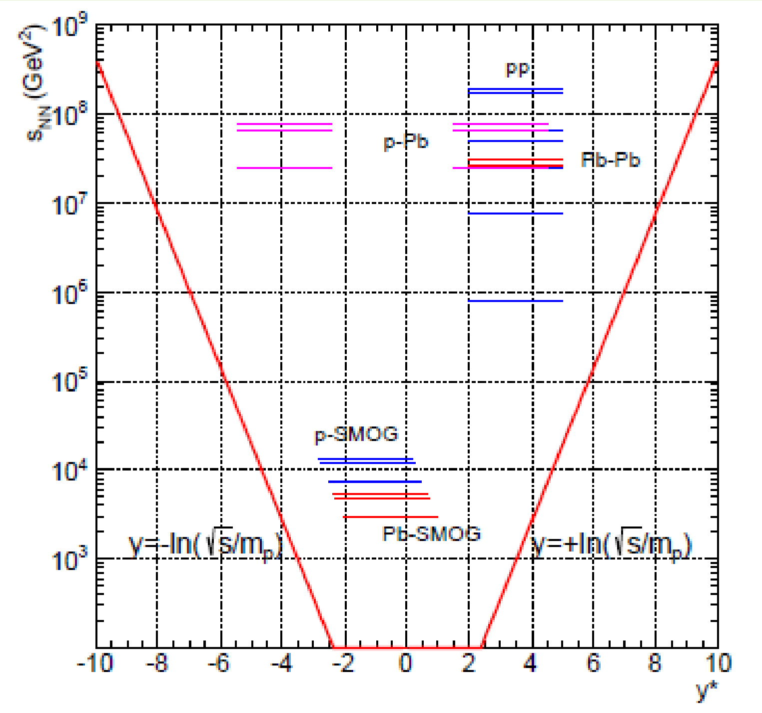
Solid Targets:

- AFTER (proposal)
- Bending Crystal (tests ongoing since many years)
- Microstrip Metal Detectors-Targets (Current presentation)

Heavy ion collisions at the LHCb experiment. Fixed Target mode.

LHCb is the only experiment at the LHC running in fixed-target mode, making use of unique gas-injection SMOG system.





Gas – He, Ne, Ar. JINST 9 (2014) P12005

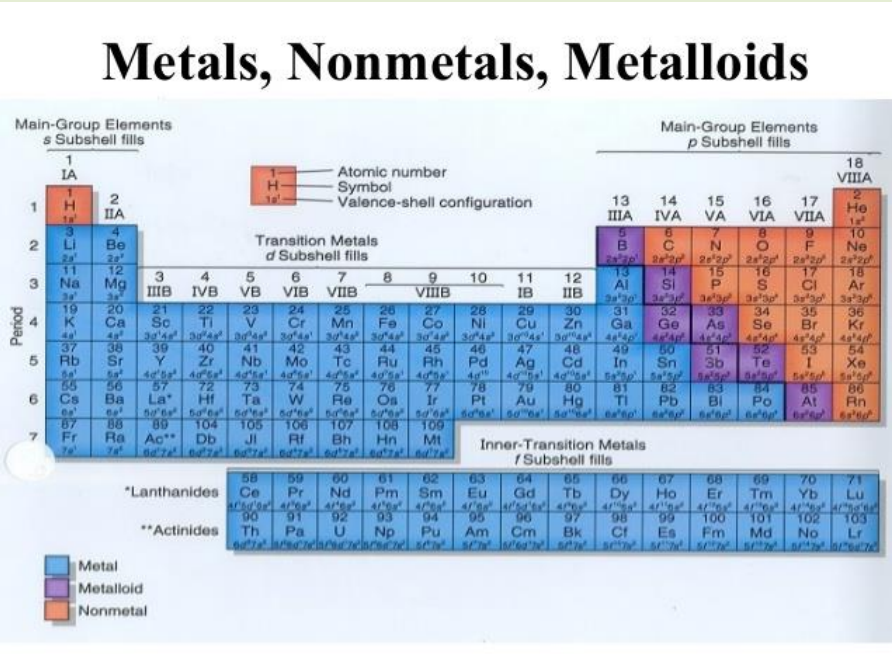
p-gas and Pb-gas interactions at the NN-cms energy of 70 - 110 GeV (-3.0 <y*<1.0)

***T* = 7TeV, Corresponding to $\sqrt{s_{NN}}$ = 114.6 GeV**

Bridging the gap between the SPS and RHIC/LHC energy scales

Extending range of nuclei and energies for heavy ions collisions at LHC

(proposal of metal micro-strip target LHC beam)



Immense variety of metal targets-nuclei (BLUE color in the table):

^{6,7}Li (1^+, $3/2^-$); ^{9}Be ($3/2^-$); ^{12,13}C ($1/2^-$, 0^+); ^{27}Al ($5/2^+$); $^{46-50}$Ti (0^+ - $7/2^-$); ^{56}Fe (0^+); ^{63,65}Cu ($3/2^-$); ^{116,117,118,119,120}Sn(0^+) … up to ^{252}Cf

Different ground state properties:

- **Isotopes**
- **Spin and parity**
- **Deformation**
- **Closed shells (magic nuclei)**
- **Neutron skin**
- **…**

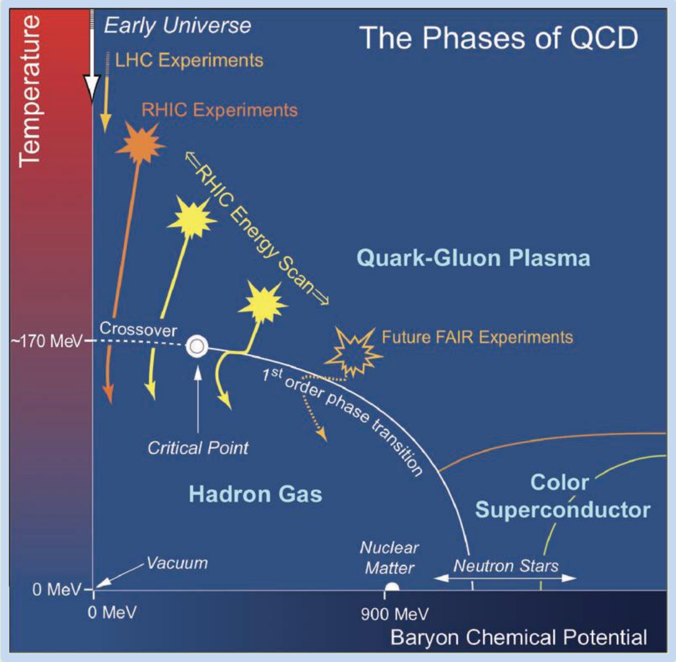
Nucleus-nucleus collisions studied in HEP:

p-p ; p – Pb; p –Au; p – Ne; p – He; d – Au; Pb – Pb; …

limited range for knowledge about an impact of the initial state on nucleus-nucleus collisions

Motivation for Solid Targets in the Beam Halo at LHCb

Experiment	Energy range (Au/Pb beams)	Reaction rates Hz
STAR@RHIC BNL	$\sqrt{s_{NN}}$ = 7 – 200 GeV	1 – 800 (limitation by luminosity)
NA61@SPS CERN	E_{kin}= 20 – 160 A GeV $\sqrt{s_{NN}}$= 6.4 – 17.4 GeV	80 (limitation by detector)
MPD@NICA Dubna	$\sqrt{s_{NN}}$= 4.0 – 11.0 GeV	~1000 (design luminosity of 10^{27} $cm^{-2}s^{-1}$ for heavy ions)
CBM@FAIR Darmstadt	E_{kin}= 2.0 – 35 A GeV $\sqrt{s_{NN}}$= 2.7 – 8.3 GeV	10^5 – 10^7 (limitation by detector)



Nu Xu (STAR Collaboration) QM2014)

QCD and nuclear PDFs studies at high x with a proton beam high-x studies for particle and astroparticle physics.
The very high luminosities, the access towards very low p_T and backward rapidities beyond that of RHIC experiments;

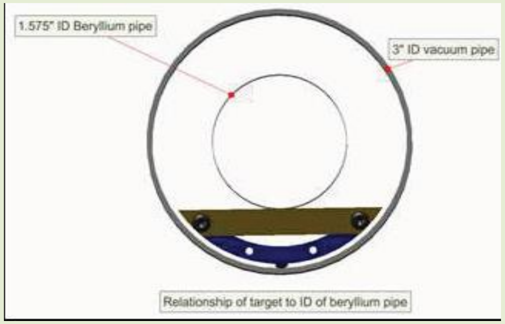
OPERATIONAL EXPERIENCE WITH AN INTERNAL HALO TARGET AT RHIC in 2016.

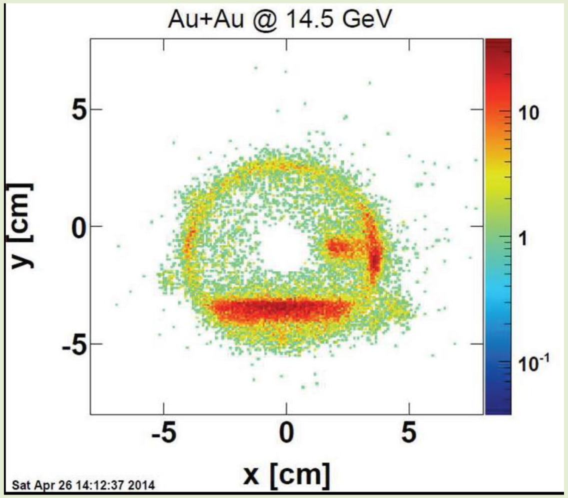
C. Montag, A thin (750 µm) gold foil was installed (upper figure).

The aperture of the target does not interfere with regular collider operations while it can intercept the beam halo in dedicated target mode.

With the detector beam pipe radius of 20 mm , a target aperture is of 16 mm. The target at s = −2.05 m intercepts the beam halo with a −10 mm orbit bump applied at the IP; the vertical β function at the IP is set to β∗ = 8 m.

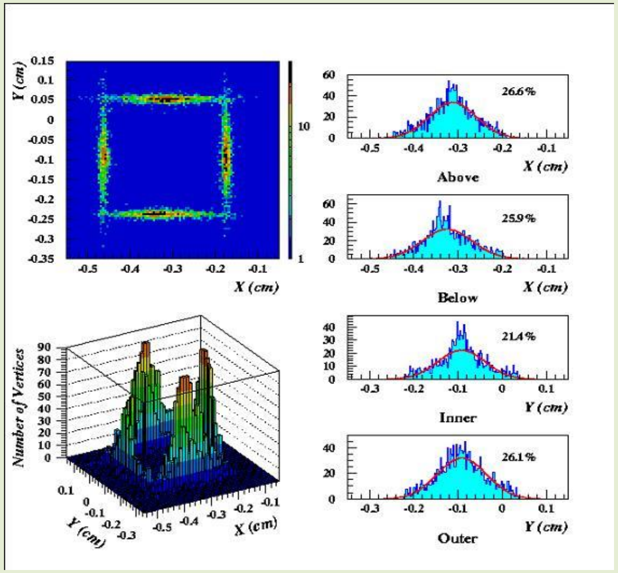
Run of half an hour,: one million beam-target Au-Au events at $\sqrt{s_{NN}}$ = 4.5 GeV/n that are currently being analyzed by the STAR collaboration. A vertex cut in the longitudinal vicinity of the target reveals the Au beam halo impinging on the target.



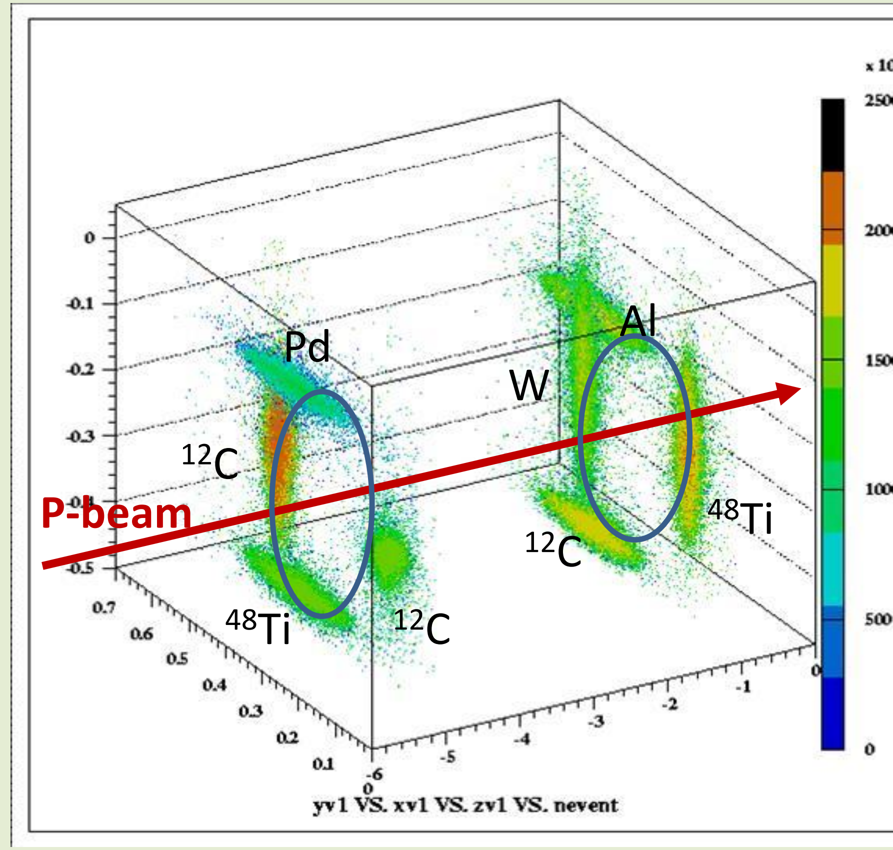


An image of the target from vertex cuts of collision events in the target vicinity

Predecessor …



Wire	Charge Integrators %	Vertices %
Above	26.06 ± 0.08	26.6 ± 0.7
Below	24.26 ± 0.10	25.9 ± 0.7
Inner	23.49 ± 0.06	21.4 ± 0.7
Outer	26.20 ± 0.07	26.1 ± 0.7



Four targets

Eight targets

Proof of the principle – **Vertices are equally distributed over inserted targets**.

8 targets simultaneously could be handled providing 40 MHz interaction rate

http://dx.doi.org/10.1063/1.1291460

Some beneficial features of the Metal micro-targets

- **Physics**
  - **Extension of the nuclei range for measuring known observables as well as searching for new ones, also at isotopically enriched targets**
  - **Impact of the individual nuclear properties (nuclear shell effects, spin, parity, deformation) on quark-gluon interactions and their hadronization, in particular via QGP stage.**
- **Technique:**
  - **Well localized interaction region (up to 10 μm) – high accuracy of vertexing, reduction of background etc.**
  - **Simultaneous data taking for many targets in a single run - errorless comparison of physical observables**
  - **Safe and reliable tuning/monitoring of the overall and partial luminosity**
  - **Robust and comparatively simple construction in terms of integration into UHV and RF environment of the LHC.**

Luminosity monitoring in metal targets

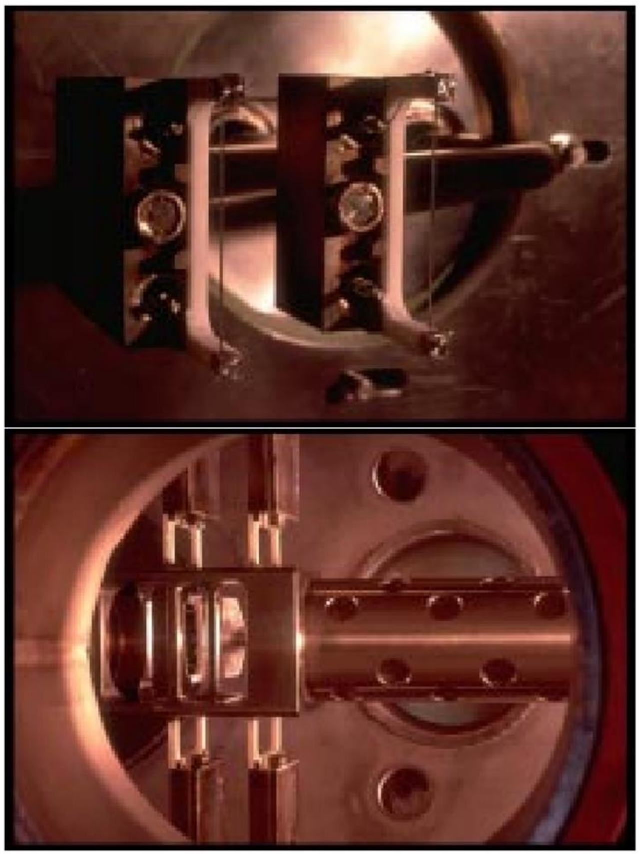
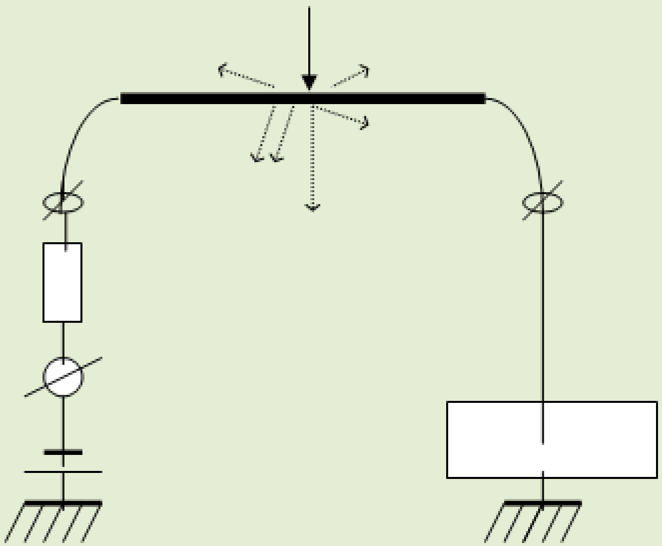


Figure 9: Targets mounted in the VDS vessel.

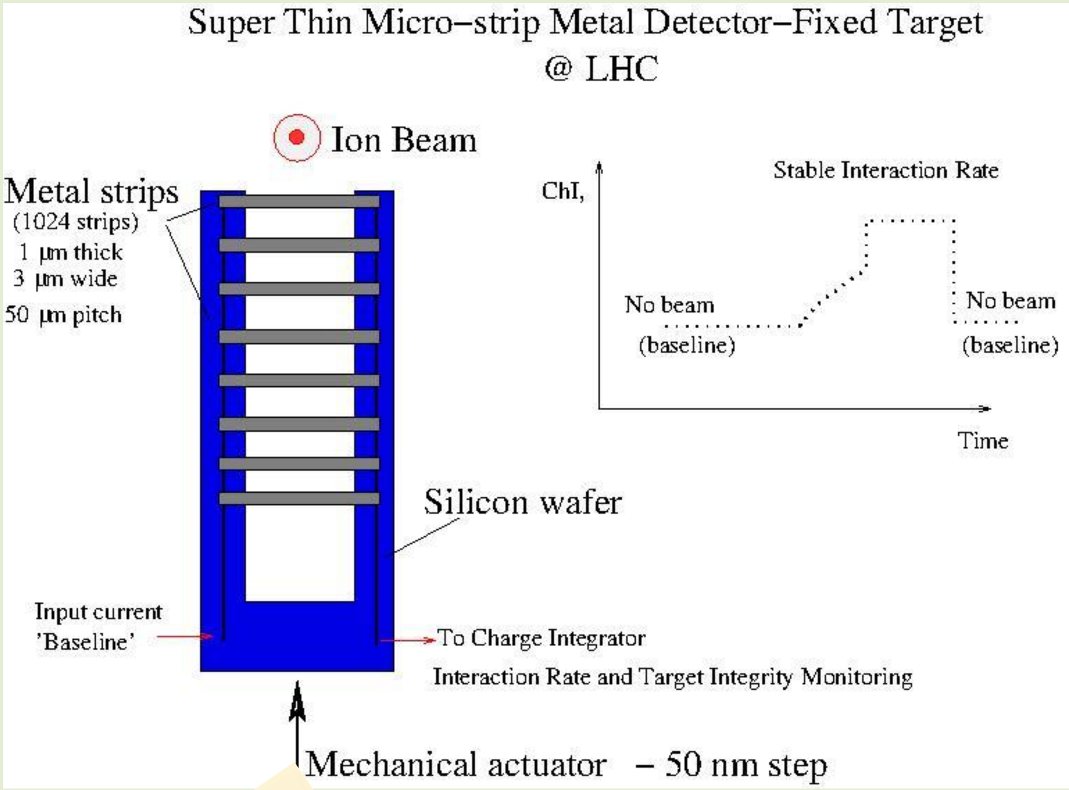


$$L^i = \frac{\alpha^i N_{BX}^{total}}{\sigma_{inel}^i} \lambda$$

λ - Average number of interactions per Bx (filled)

α^i *- partial contribution of the i- target*

Technical Realization of the Metal Microstrip Target-Detector



- Nano-technologies evolve fast
- – already nowadays- carbon nano-tubes,
- fullerene structures, graphenes, …
- May become a nano-wire target components.

LHCb Metal Micro Targets Steering (MTS)

There are two main characteristics of the MTS to be fulfilled:

1. **Stable Overall Interaction Rate (Luminosity) & Low background and safety of operation**
   - ➢ **- no harm to the LHC beam and detectors in the ring**

2. The steering has to provide fast beam finding, rate stabilization and emergency actions:

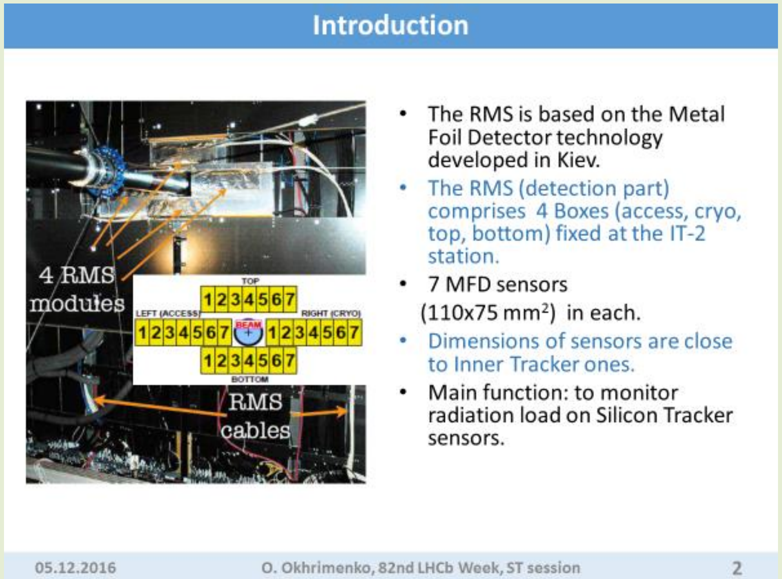
Overall Interaction Rate (Luminosity)

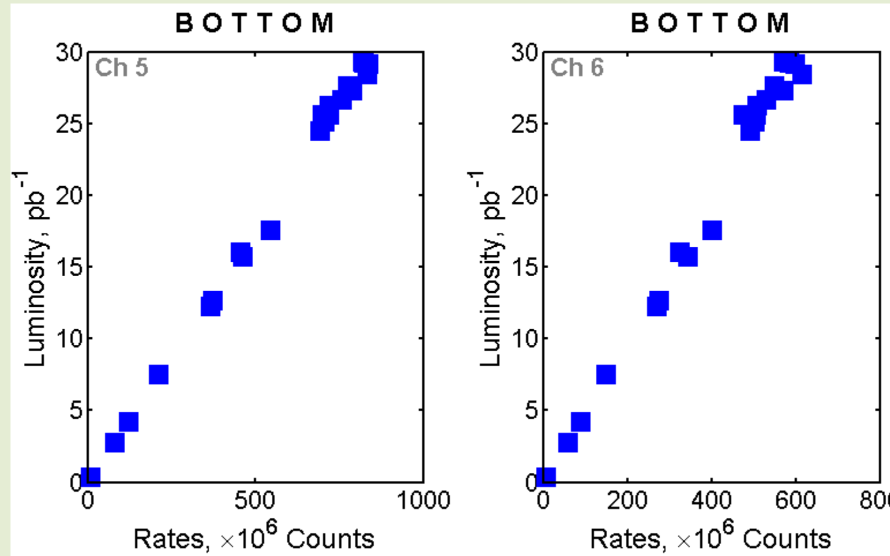
- ➢ **Radiation Monitoring System @ IT – the source of the data for general steering (the BLM and BCM data worthy to include for higher reliability)**

- ❑ **Charge integrated in a target**

- ❑ **Vertices reconstructed by the VELO (HLT-2)**

Metal Foil Detectors in RMS at Inner Tracker -
existing readout infrastructure for steering metal micro-targets





RMS design, construction, commissioning, running Radiation Monitoring System - i Collaboration with teams from MPIfK (Hd), Zurich University, LPHE (Lausanne), CERN (Richar Jacobson, Federico Alessio, Gloria Corti).

(see talk by O. Okhrimenko at this Workshop about RMS operation in 2018

Metal Micro-Targets in LHCb. Technical Realization.
Proposed location at VELO – (LS3)

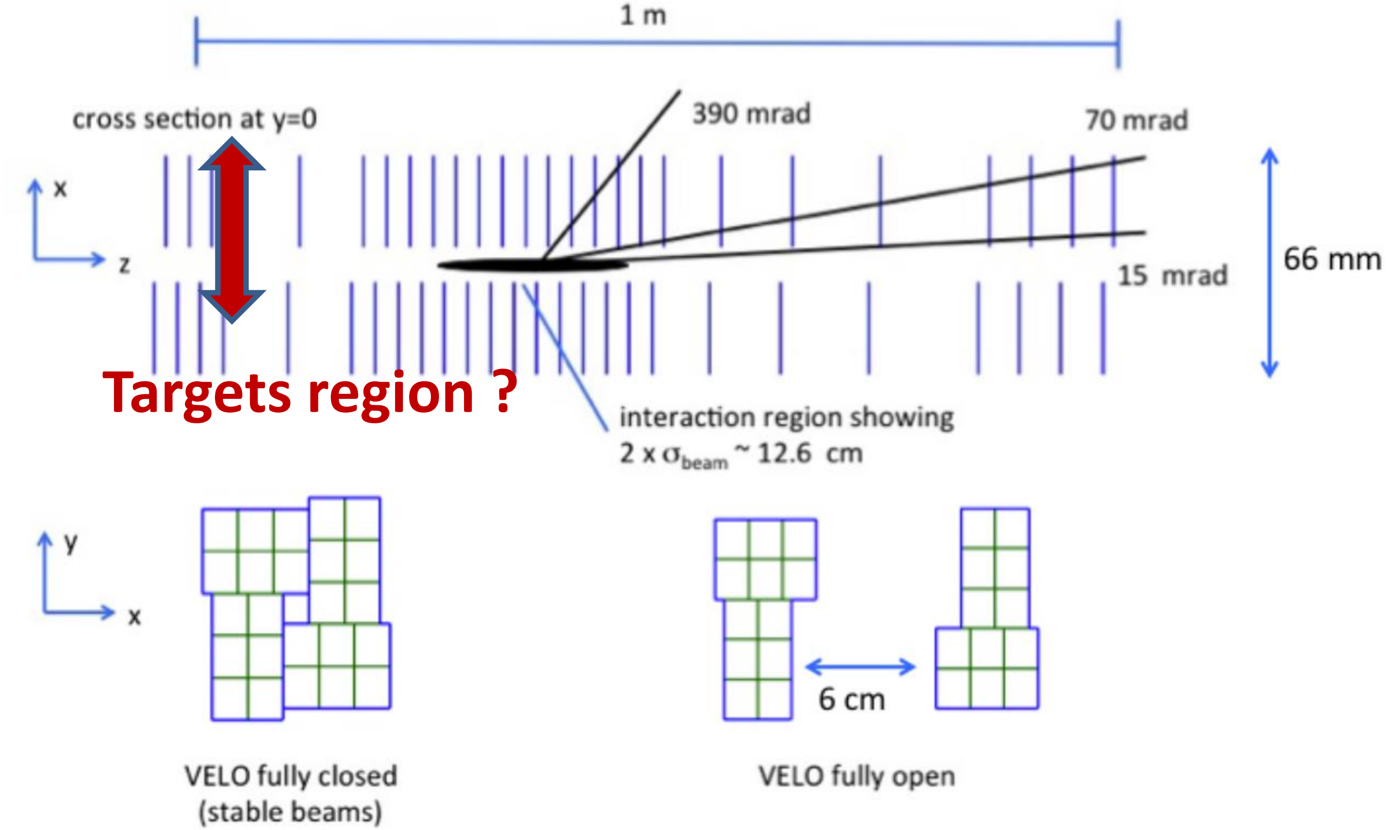
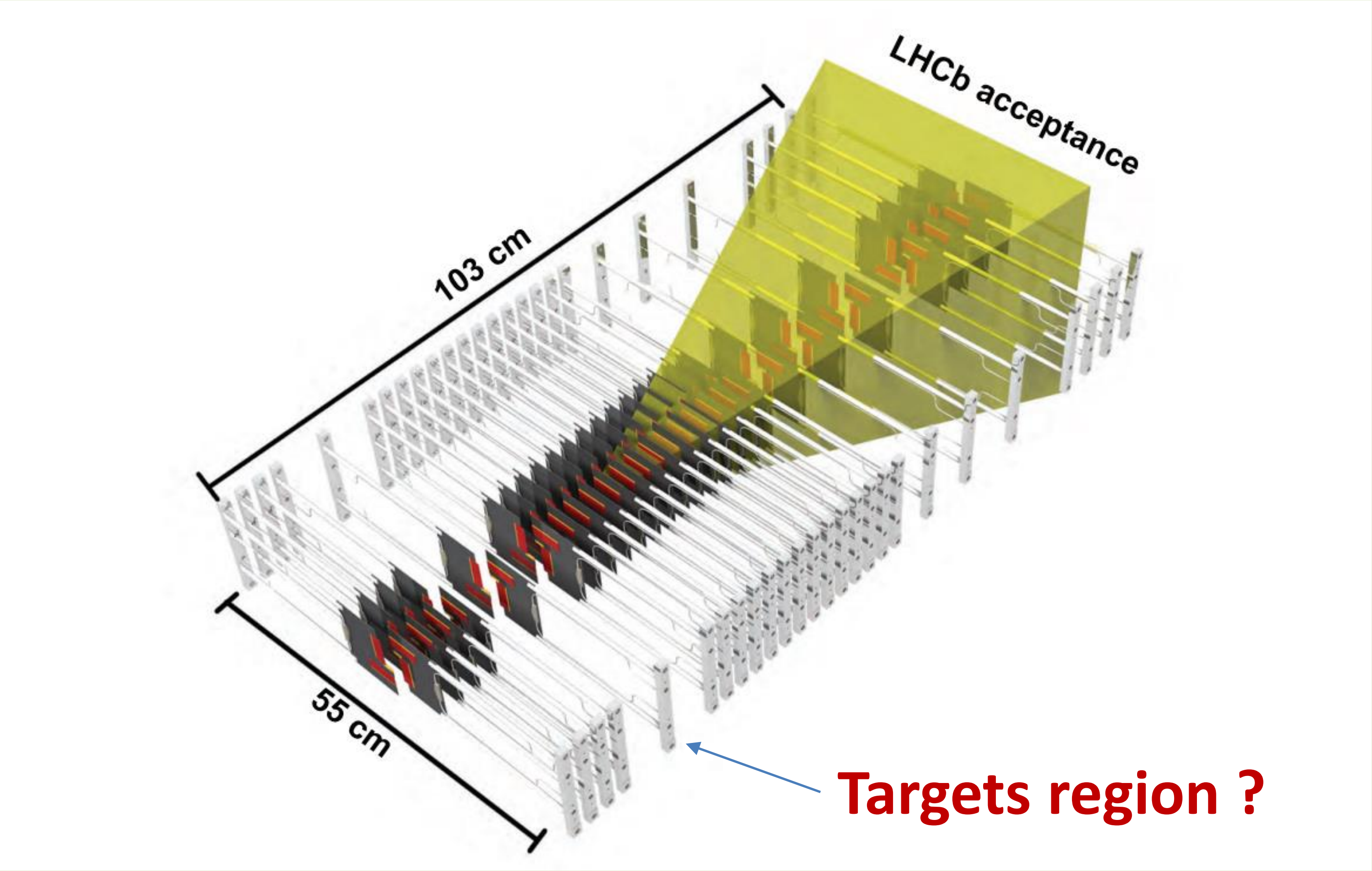
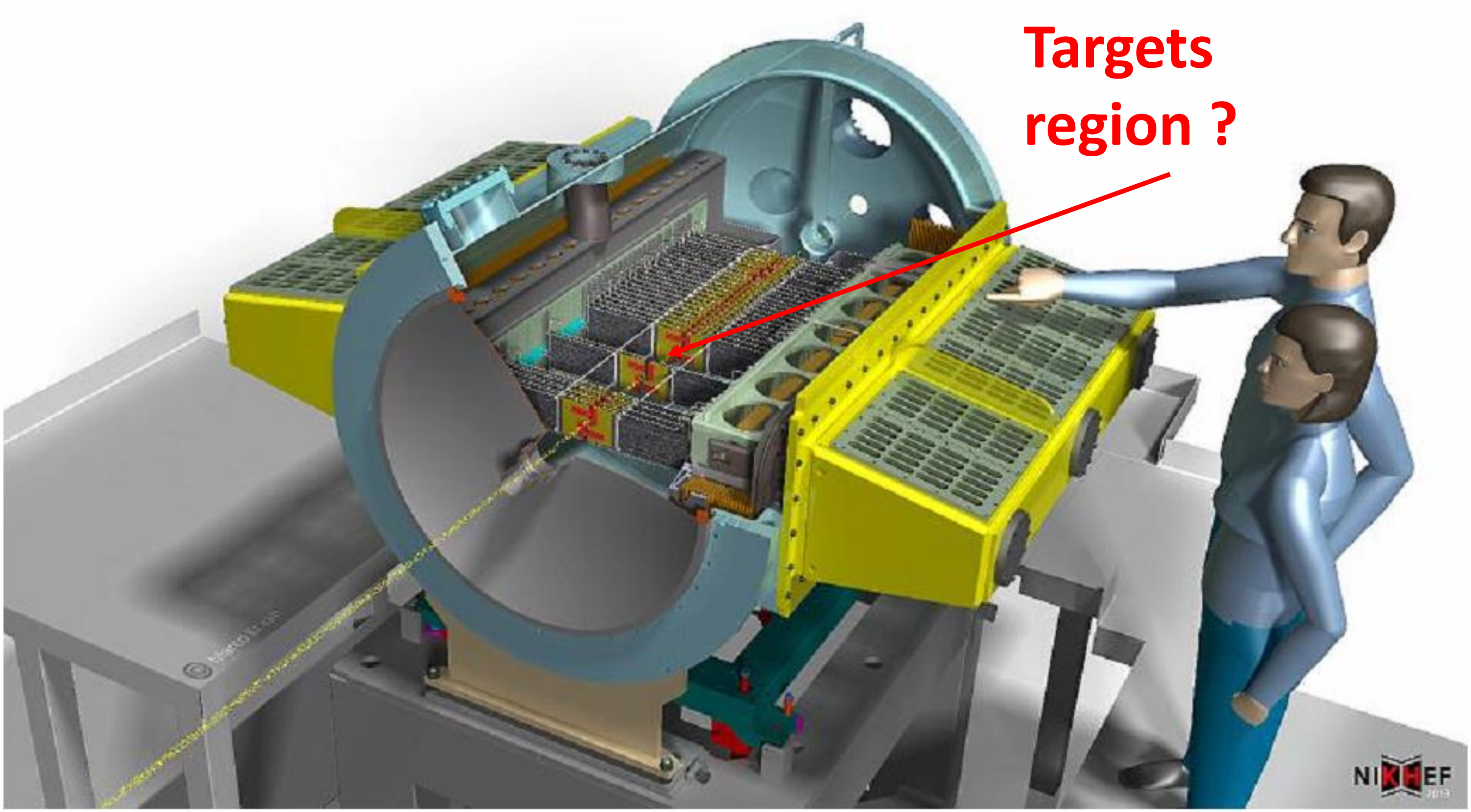


Figure 4: Schematic layout of the upgraded VELO.

VELO – VErtex Locator construction after upgrade



VELO – VErtex Locator construction after upgrade



Metal Micro Targets in LHCb. Technical Realization.

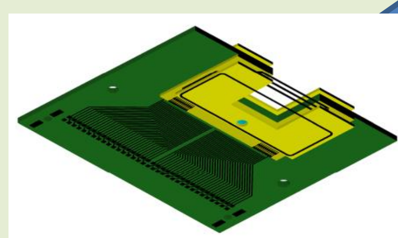
Phase -1. Feasibility studies.

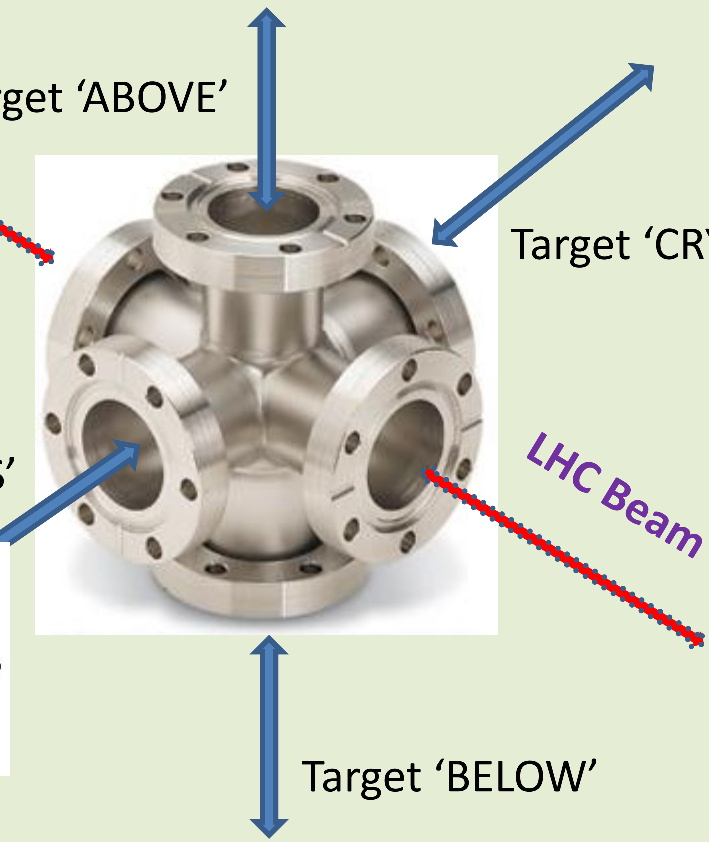
1st approach; Build Target section in the LHCb beam–pipe in a close vicinity to the VELO entrance.

- **Not accepted –safety issues**

ASA 6-Way Crosses (flat flanges)

https://www.leske … s/fittings_asa_crosses.
cfm?pgid=4way1





+ 2 UHV gate valve, Series 108, DN 100 (ID 4'') VAT Vakuumventile AG CH-9469 Haag, Schweiz

Beam Position Monitor + Target holder.

The targets should be inserted in the operating position after the tuning of the beam.

Technical Realization – 1st approach

- Some technical items:

LHC Ion Beam size (sigma) – 500 µm

Collimators @ 7-8 sigma

Wire-Target diameter : 25 – 50 µm

Wire –Target length: 10 -15 mm

UHV compatibility: < 10^{-9} Torr

Supporting frames – Si wafers

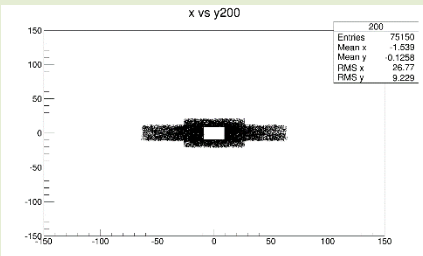
Signal output – micro-cables

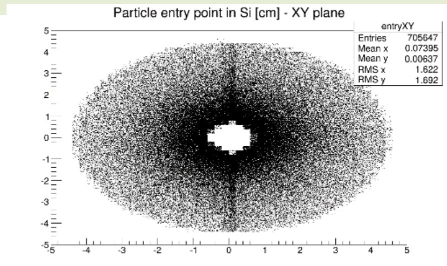
SEE – 'absorption' voltage – + 20 V

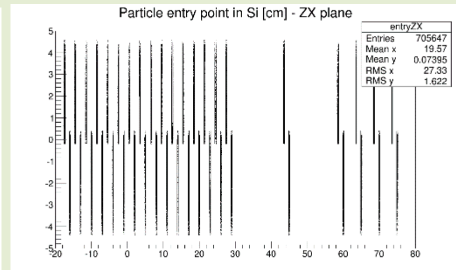
Step-by-Step Approach …

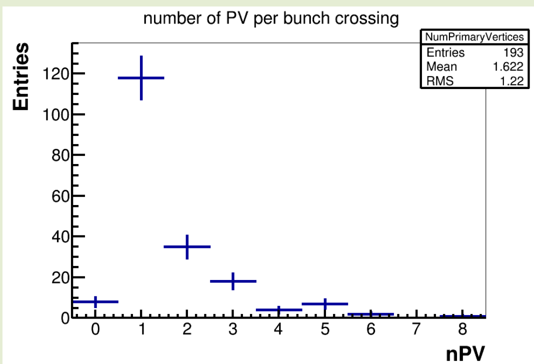
- Start discussions on safety issues from the point of view of affordable luminosities (from the LHC as well as from the detector side).
- Superthin Wire Targets, SWT-option (0.1 - 1 μm thickness). The related SWT-setup would be essentially different from other options
- Let us assume the affordable instantaneous luminosity of 10^28 cm^-2 s^-1 for the Pb(beam)-Ni(target) collisions. Inserting 1 mum thick (50 mum wide) Ni microstrip target into a Pb beam with 500 bunches (10^8 ions in each) at the distance of ~3 beam sigma (effective width of 200 mum) one would be close to the above mentioned luminosity.
- "Burning target" regime keeping in mind that target could also enter the beam core and might be melted. Even in such case the luminosity will not exceed limits for normal operation of detector as well as LHC magnets. After that the next strip of the target will arrive into the operational position in a beam to continue the experiment without interruption.
- Depending upon the test studies, one could evolve with the setup for real experiment.
- Your evaluation/criticism/proposals for developing SWT-project are welcome !

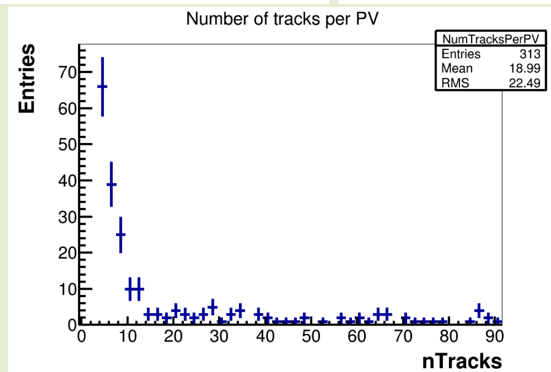
PbNi MC simulations











Beam parameters

#--Set the energy of the beams,

Gauss().BeamMomentum = 2510*SystemOfUnits.GeV

Gauss().B2Momentum = 0*SystemOfUnits.GeV

Gauss().B1Particle = 'Pb'

Gauss().B2Particle = 'Ni'

#--Set the average position of the IP: assume a perfectly centered beam in LHCb

Gauss().InteractionPosition = [
0.708*SystemOfUnits.mm,
0.069*SystemOfUnits.mm,
0.000*SystemOfUnits.mm]

#--Set the bunch RMS, this will be used for calculating the sigmaZ of the

Interaction Region. SigmaX and SigmaY are calculated from the beta* and

emittance

Gauss().BunchRMS = 72.0*SystemOfUnits.mm

Gauss().BeamHCrossingAngle = -0.318*SystemOfUnits.mrad

Gauss().BeamVCrossingAngle = 0.000*SystemOfUnits.mrad

Gauss().BeamLineAngles = [0.0, 0.0]

#--beta* and emittance (beta* is nomimally 3m and e_norm 2.5um,

adjusted to match sigmaX and sigmaY)

Gives \sigma_{x,y} = sqrt(beta* x emittance) = 0.0329 mm ~ 33 um

Gauss().BeamEmittance = 0.0034*SystemOfUnits.mm

Gauss().BeamBetaStar = 3.0*SystemOfUnits.m

Vertex smear SMOG

Generation("Generation").VertexSmearingTool = "FlatZSmearVertex"

Generation("Generation").addTool(FlatZSmearVertex)

Generation("Generation").FlatZSmearVertex.ZMin = -0.001

Generation("Generation").FlatZSmearVertex.ZMax = 0.001

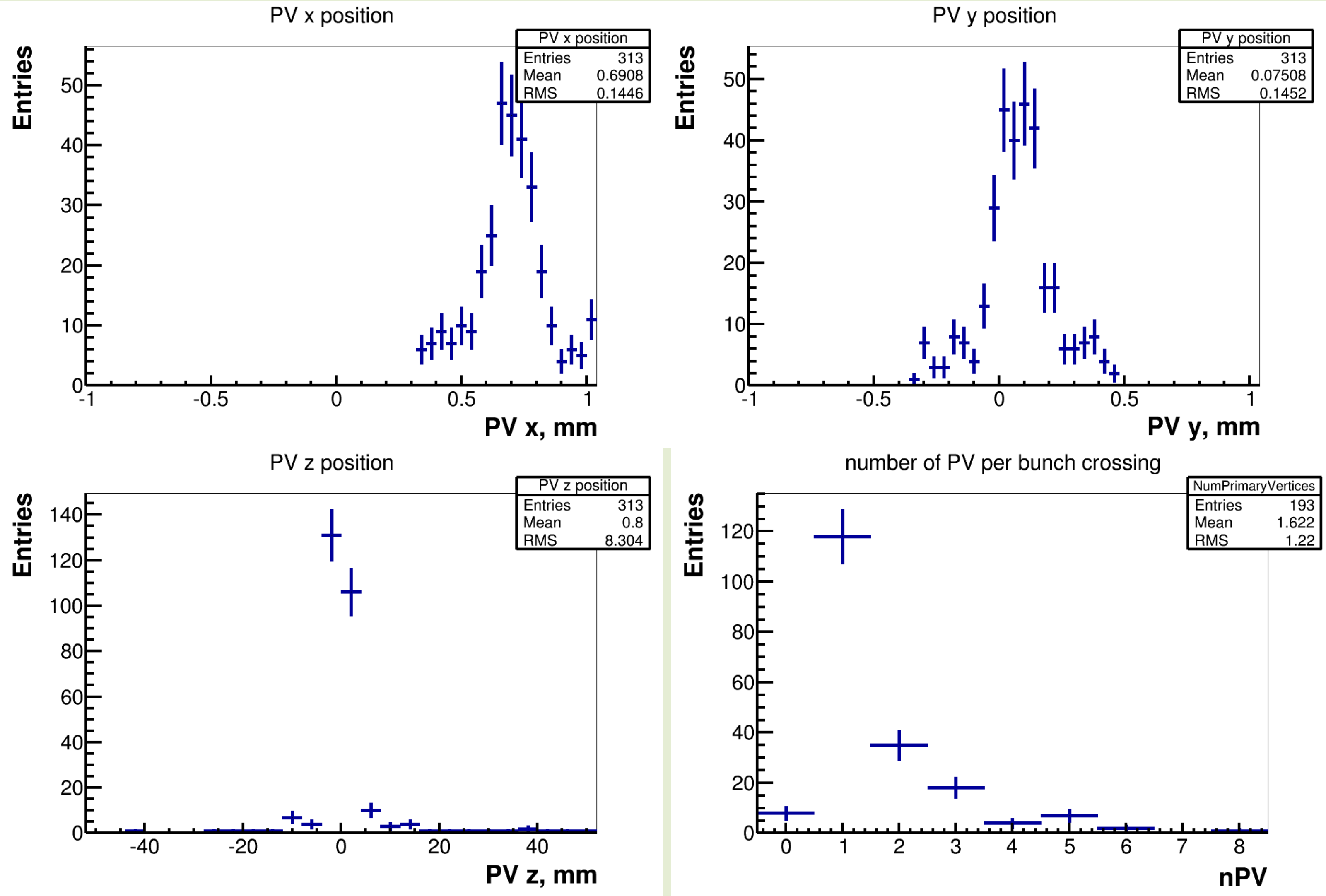
MC simulation train:

Gauss (Physics simulation, EPOS), **Bool** (digitalization),

Moore (L0 trigger), **Moore** (HLT trigger), **Brunel** (Reconstruction).

Generated 200 events

RESULTS of MC for Pb-Ni collisions



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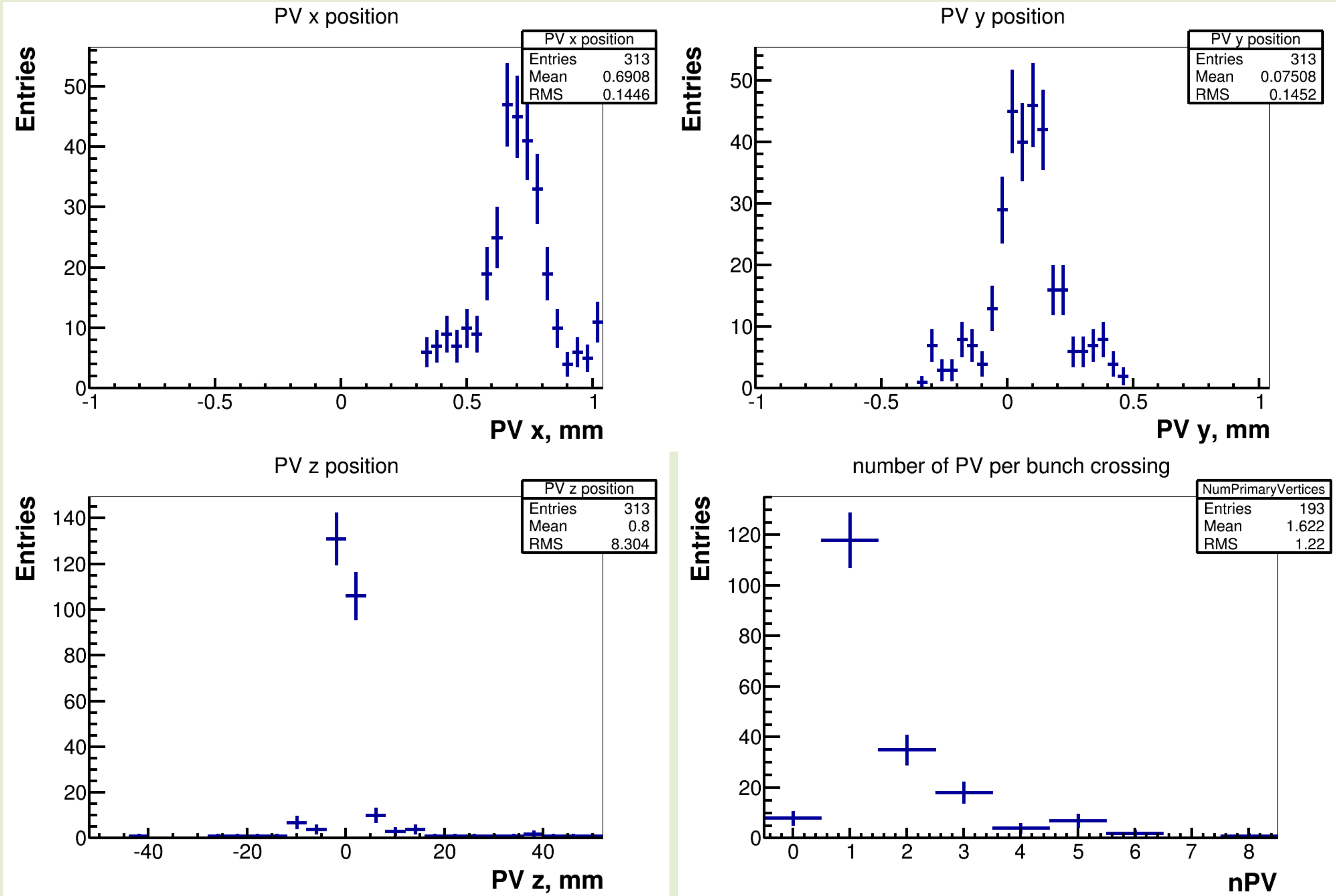

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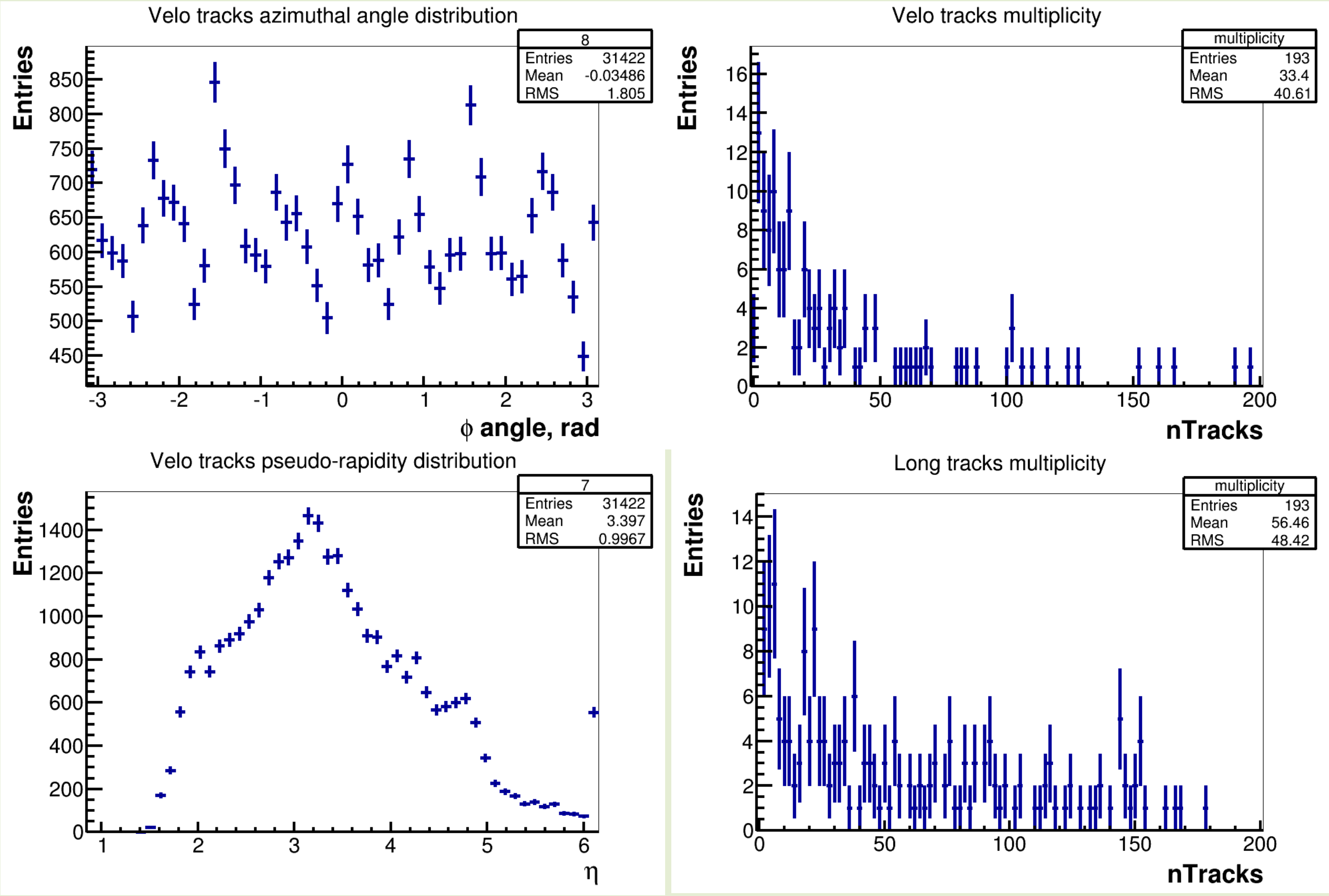

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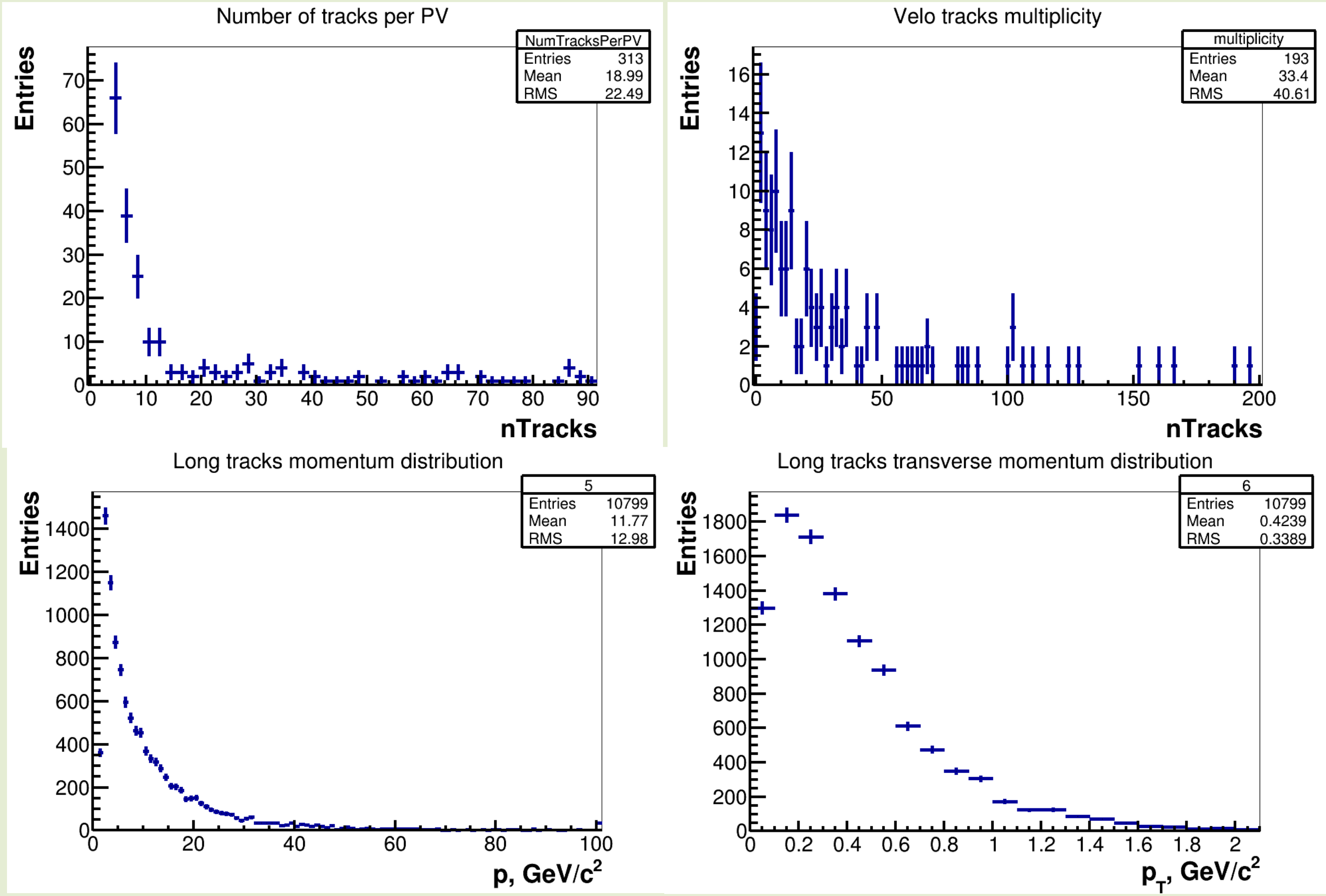
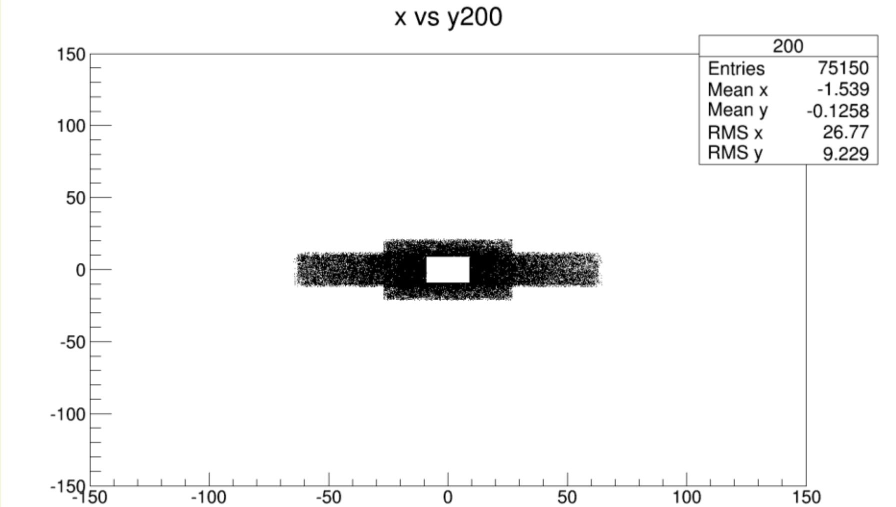
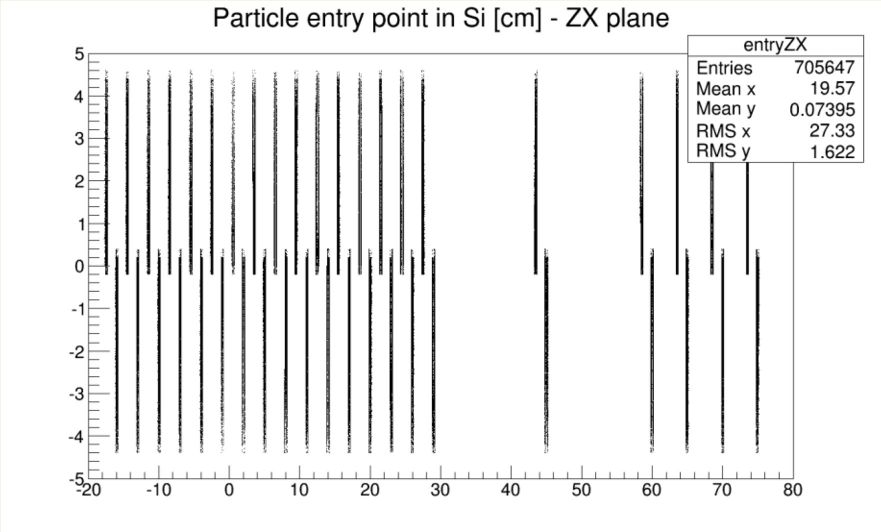
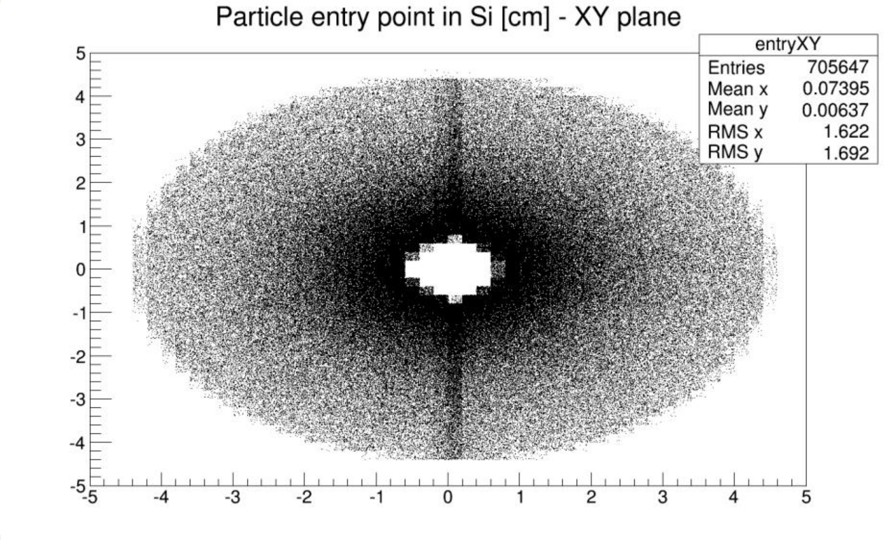


RESULTS of MC for Pb-Ni collisions

Hit maps for 50 events:
Right, top: IT-1 xy-plane
Right, bottom: Velo xy-plane
Left, bottom: Velo zx-plane







Quarkonium production measurements in Fixed Target

EPOS generator for PbAr (SMOG):

- Show the feasibility to reconstruct J/ψ and χc mesons

About 50,000 J/ψ and 1,000 χc (1P) candidates per year are expected in the LHCb kinematic region, assuming the luminosity of 0.7 nb^{-1} and a pressure of about 10^{-6} mbar.

The geometrical acceptance

for J/ψ production ~ 6 -8 %

At the RHIC, the production of J/ψ in p-p, d-Au, Au-Au, and Cu-Cu collisions (PHENIX at $\sqrt{s_{NN}}$ = 200 GeV

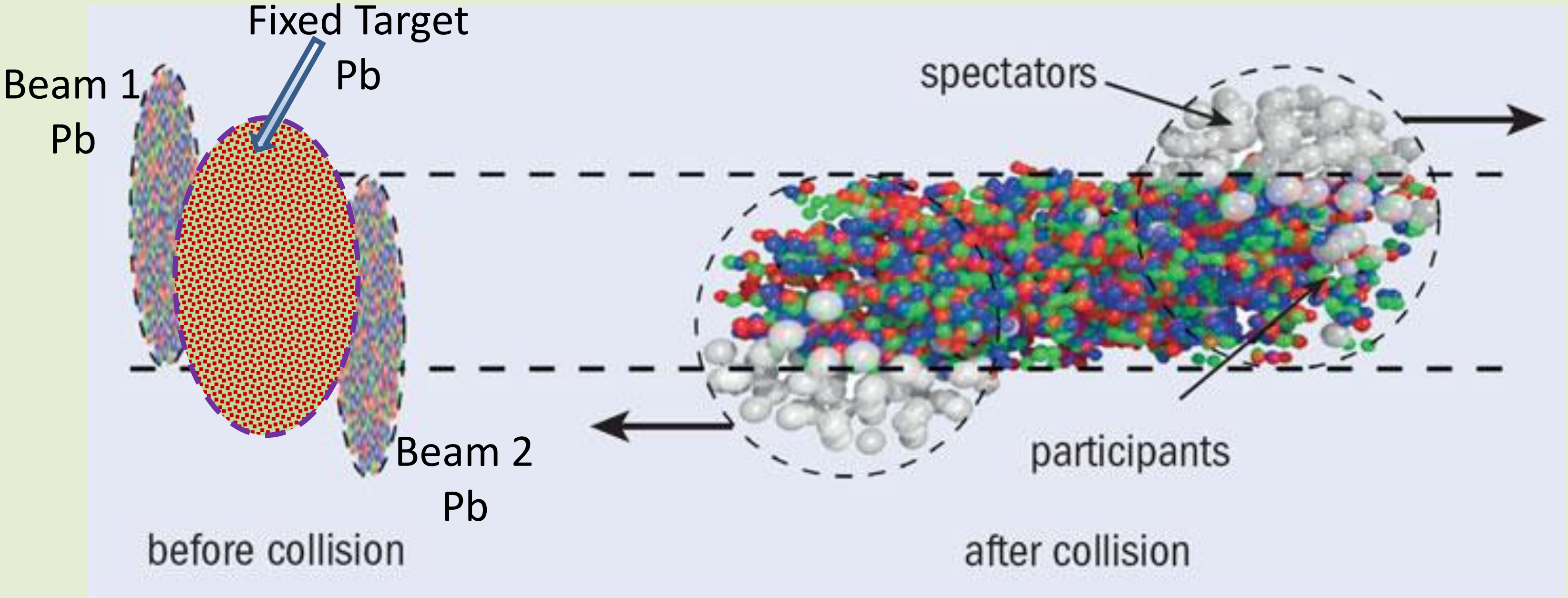
$$R_{AA} \equiv dN_{AA}/dy \,/\, (dN_{pp}/dy \cdot \langle N_{coll} \rangle)$$

The suppression of the J/ψ production in Au-Au collisions is considerably stronger at forward rapidity range 1.2 < $|y|$ < 2.2 than at midrapidity $|y|$ < 0.35.

Summary and Outlook

- **It is challenging project.**
- **Yet, it is not excluded!**
  - **even if the target will get status of the primary object for the LHC beam. One has to work out the safe mode of operation of the complex setup 'beam-target'.**
- **KINR group will contribute in designing, building and testing the SWT – setup at CERN.**
- **It was more than one time in the experimental physics - what looked impossible yesterday was solved today. And major sense in this activity is new physics events to discover in such targets.**

Un-known: Three-nuclei interaction
– two nuclei from LHC beams
and one from the Metal Microstrip Target



http://images.iop.org/objects/ccr/cern/53/4/18/CCfir5_04_13.jpg

Events with three Pb nuclei interaction !

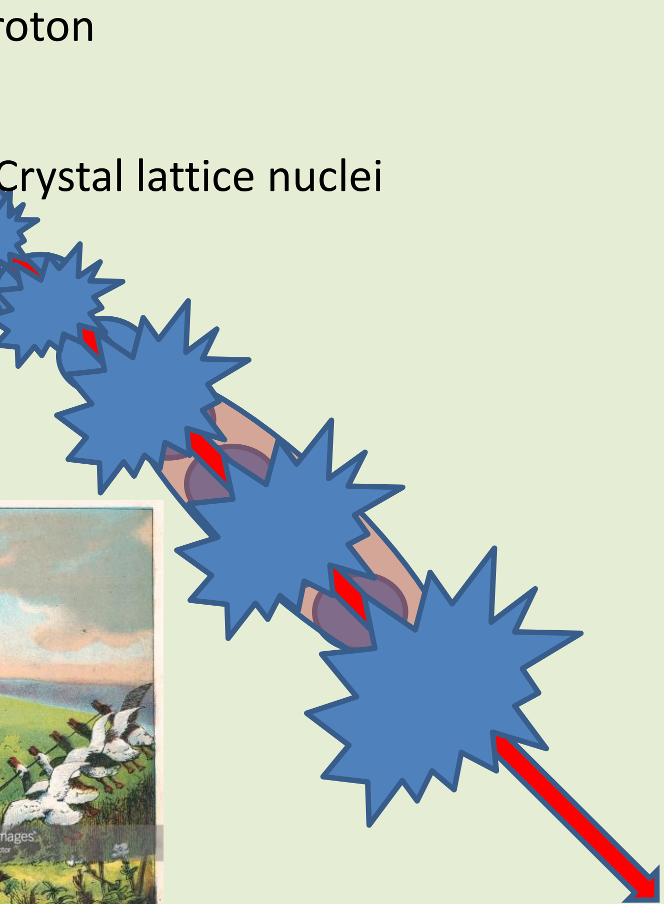
Never considered in earlier experiments:

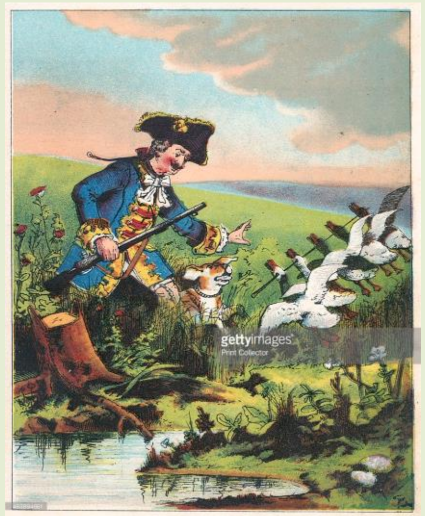
- Interesting phenomena – pairs of nucleons will interact at 0.1 or 5 TeV, and three-nucleons at … TeV …
- **What will be the Equation of State ? Which temperatures and densities of the hot matter might be ?**

Crystalline Targets

Crystall structure – alligned atoms&nuclei – sequential scattering of high energy nucleus:

- **Cascade of nuclear interactions – Multiplicity of event– 10^{5-8} - ?**
- **Fusion to super heavy nuclei ?**
  - **Mass-spectrometry, gamma-rays analysis after irradiation**
- **Neutron rich or even neutron nuclei production ?**
- **Scattering at excited short-lived nuclei - new RBF ?**
- **…**





Thank you for your attention!

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