MPD and BM@N detectors at NICA Prospects for the Polarization Effects Measurements

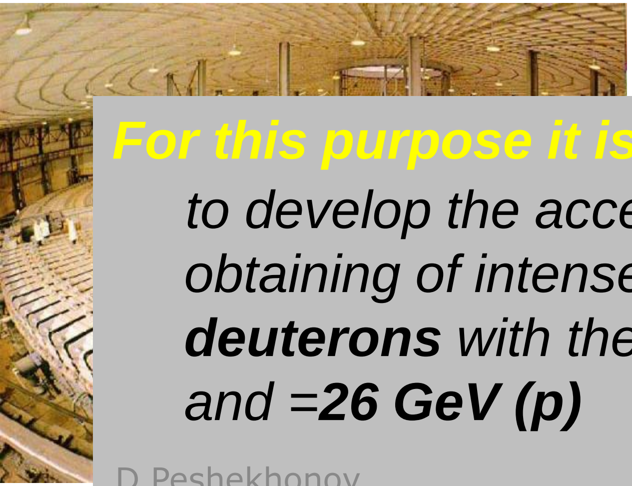
D.Peshekhonov JINR

From Synchrophasotron to heavy ion collider

1957 Synchrophasotron

10 GeV proton synchrotron

V. Veksler – author of the phase stability principle



1993 Nuclotron

Superconducting accelerator of heavy ions

A. Baldin

2019 NICA

Superconducting collider of heavy ions

Investigation of
- nuclear matter at extreme densities
- nucleon spin structure and polarized phenomena

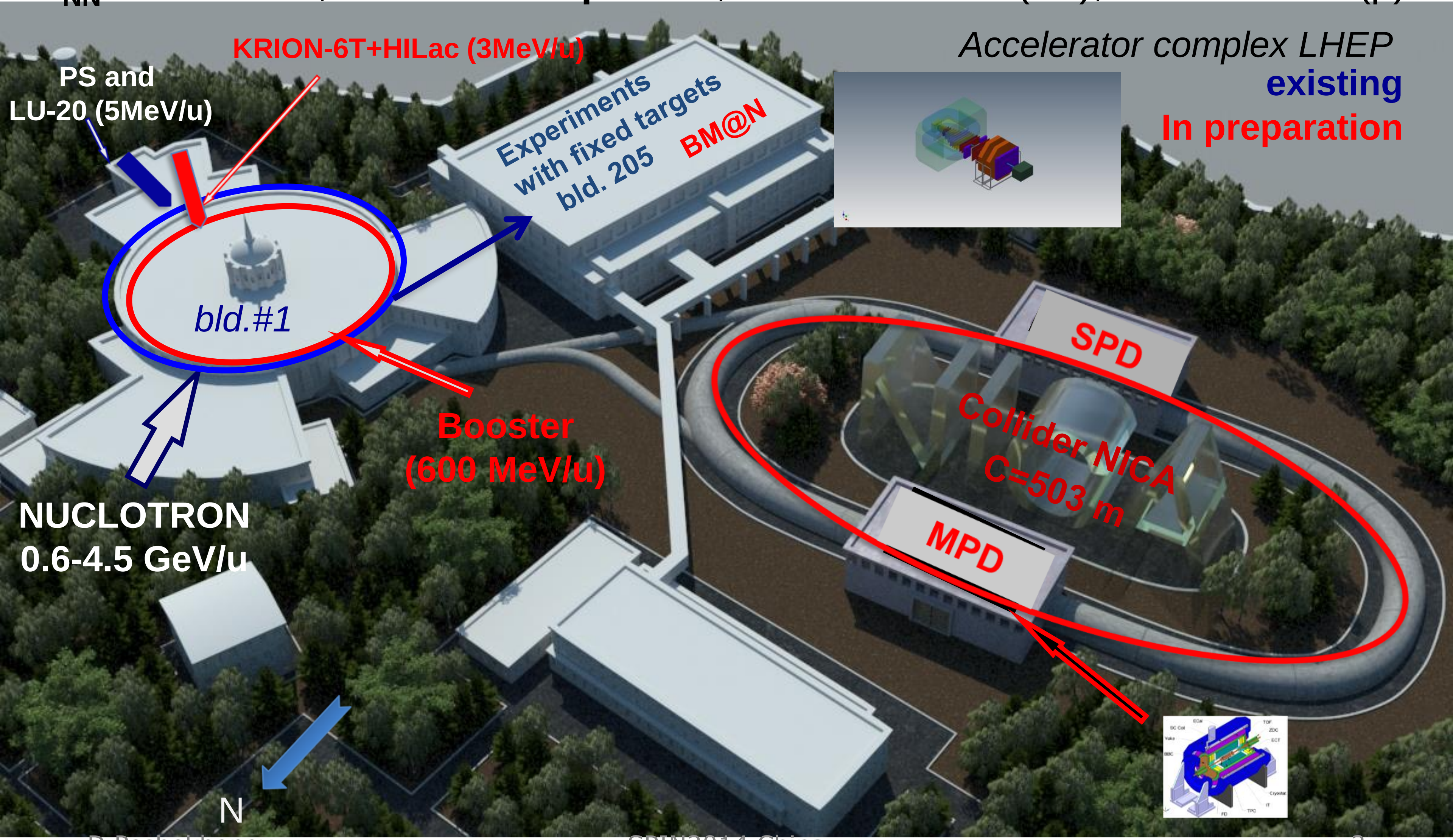
For this purpose it is necessary:

*to develop the accelerator complex at JINR, which will allow obtaining of intense beams from **p** to **Au** and polarized **protons** and **deuterons** with the maximum energy up to $\sqrt{S_{NN}}$= **11 GeV (Au^{79+})** and =**26 GeV (p)***

Complex NICA

Collider basic parameters:

$\sqrt{s_{NN}}$ = **4-11** GeV; ***beams****: from* **p** to **Au**; **L~10^{27}** $cm^{-2}\,c^{-1}$ (Au), ~**10^{32}** $cm^{-2}\,c^{-1}$ (p)



Civil Construction of NICA Complex

The whole Complex is split into several Objects:

- *MPD Hall* — *Dec. 2016*
- *SPD Hall* — *Jan. 2020 (?)*
- *West semi-ring* — *end of 2017*
- *East semi-ring* — *end of 2018*

- *Beam extraction*
- *Reconstruction of building #1*

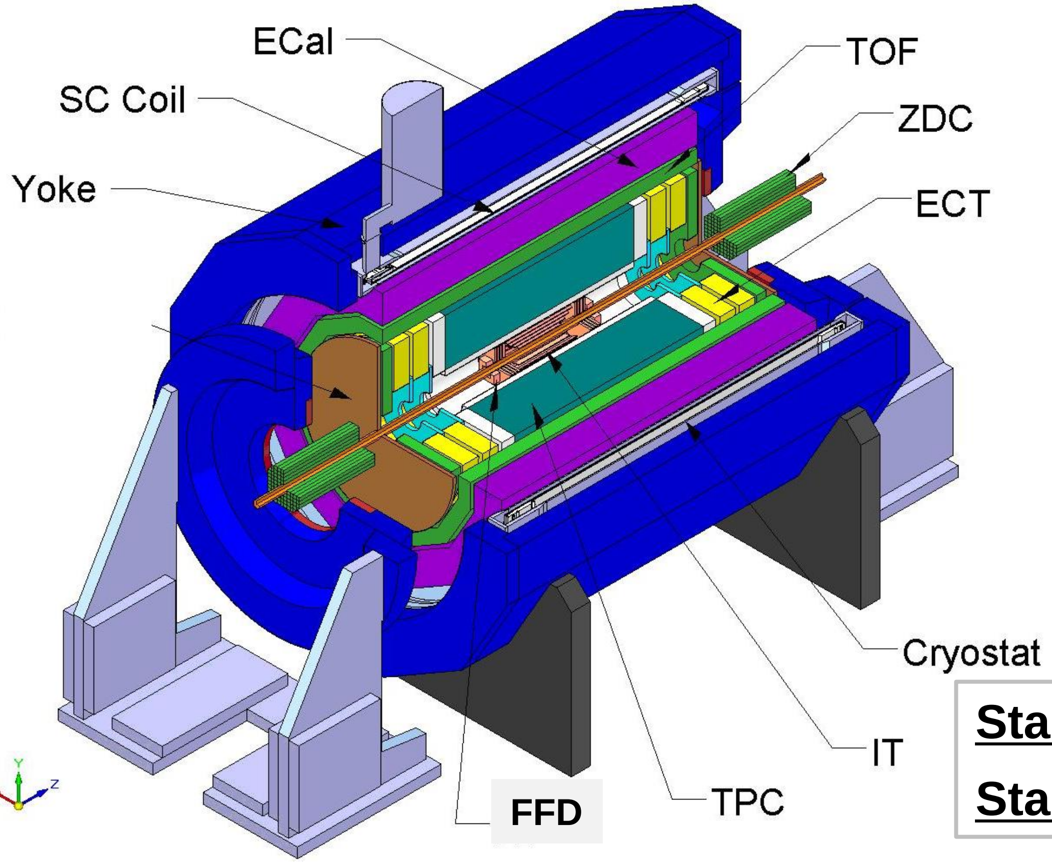
} *affect Nuclotron operation*

The schedule of object constructions should be coordinated with:

- *Nuclotron operation plans*
- *MPD magnet fabrication schedule*
- *Equipment installation plans*

MultiPurpose Detector (MPD)

MultiPurpose Detector (MPD)



9 m length, 6 m in diameter

Magnet: ***0.66 T superconducting solenoid***

Tracking: ***TPC, IT, ECT***

ParticleID: ***TOF, ECAL, TPC***

T0, Triggering: ***FFD***

Centrality, Event plane: ZDC

<u>Stage 1</u>: ***TPC, barrel (TOF, ECAL), ZDC, FFD***

<u>Stage 2</u>: ***<u>Endcaps</u> (tracker, TOF, ECAL) + IT***

MPD potential advantages:

- *Hermetic & homogenous acceptance (2π in azimuth), low material budget*
- *Good tracking performance and powerful PID (nuclei, hadrons, e, γ)*
- *High event rate capability and reliable event separation*

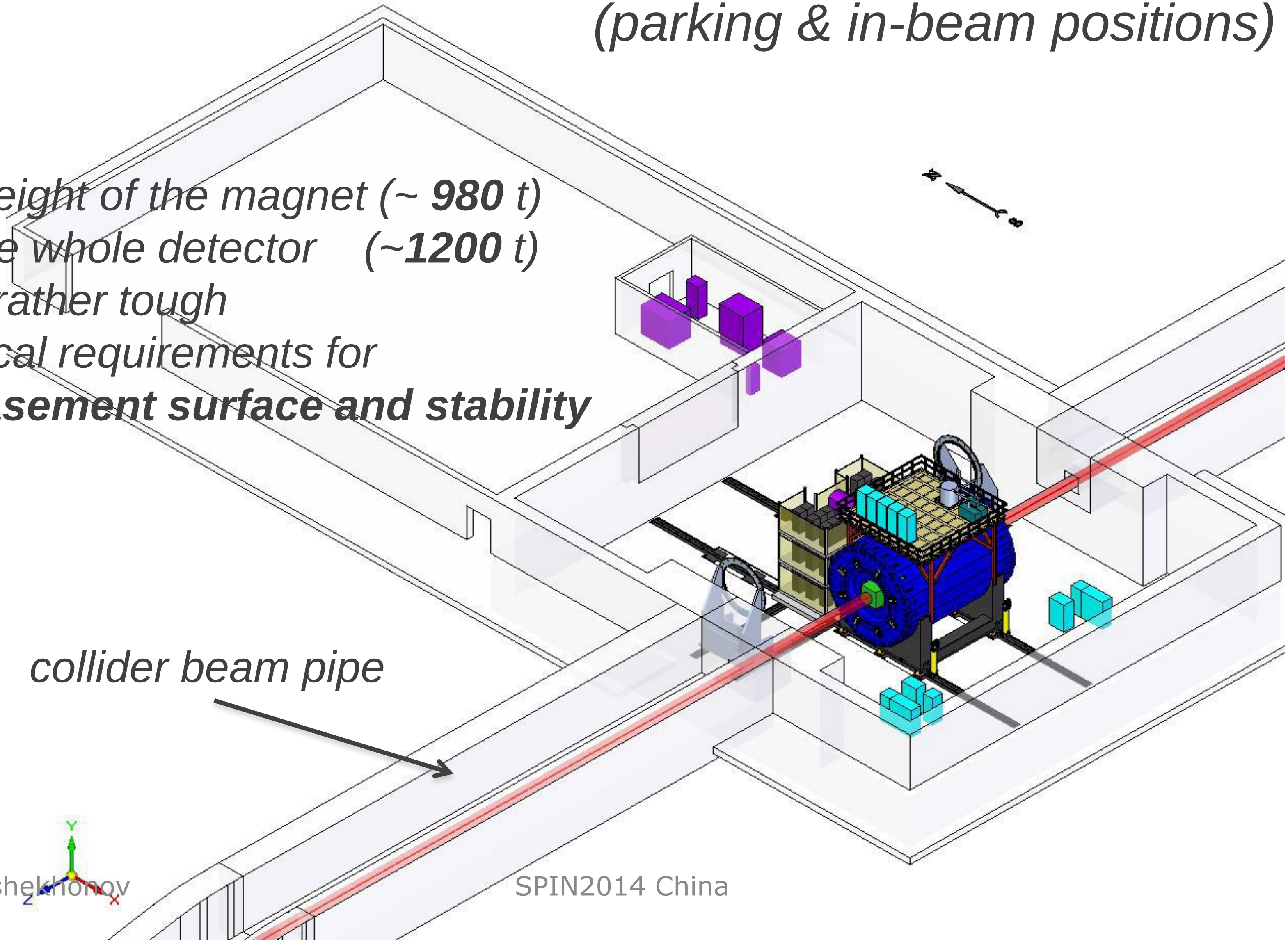
MPD status

1. **Magnet** – *survey for producers*
2. **Integration** – *project preparation*
3. **TOF, ECAL, ZDC** – *TDR preparation*
4. **FFD** – *fabrication stage*
5. **TPC**
   - *assembly area preparations*
   - *fabrication of basic elements*
   - *readout chambers – production + R&D (alternative)*
   - *FEE (ALTRO-based Front-End card prototype*
     - preproduction stage

The MPD Hall

push-pull scheme of MPD operation

(parking & in-beam positions)

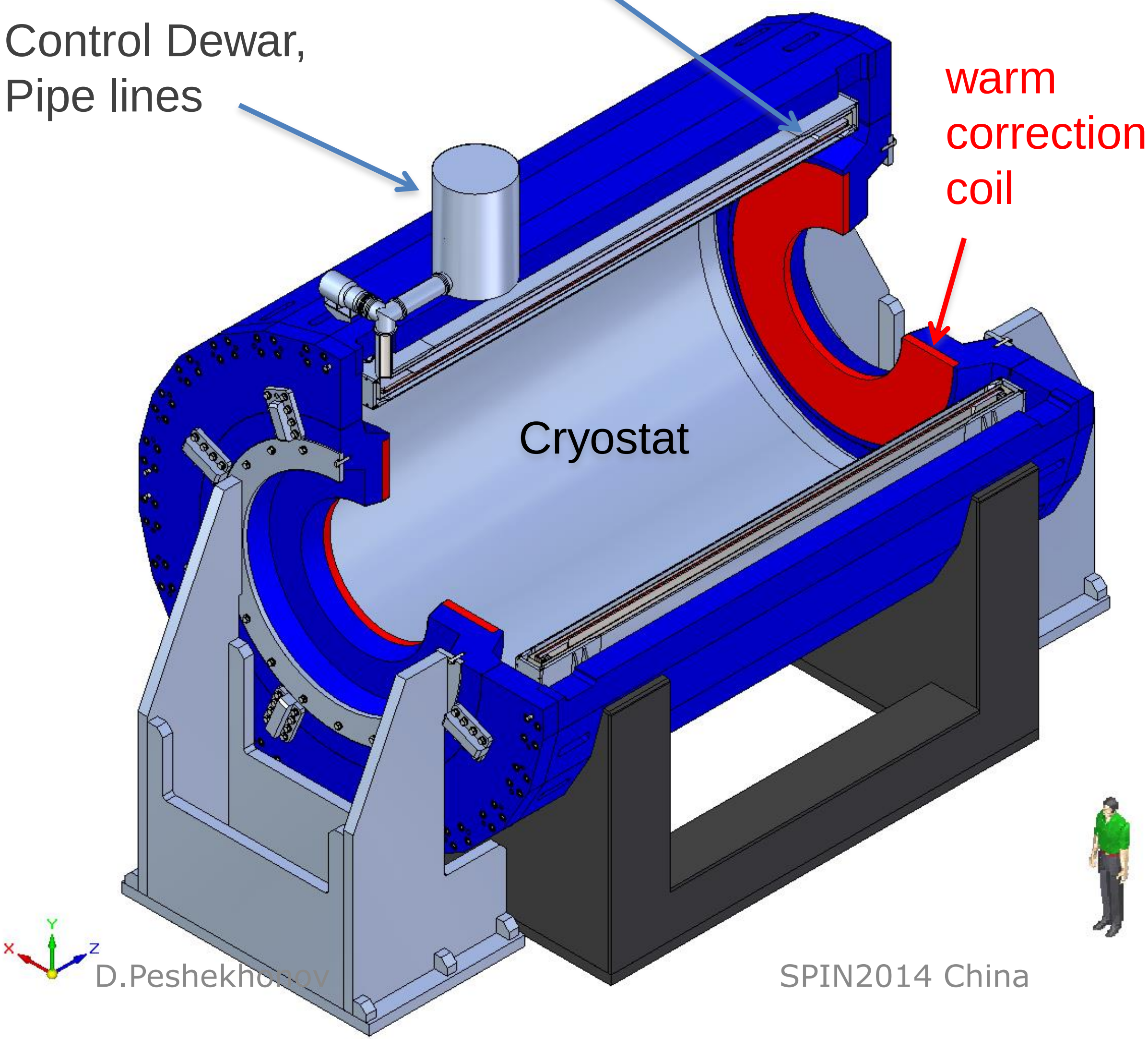


*The weight of the magnet (~ **980** t)*
*and the whole detector (~**1200** t)*
led to rather tough
technical requirements for
the basement surface and stability

collider beam pipe

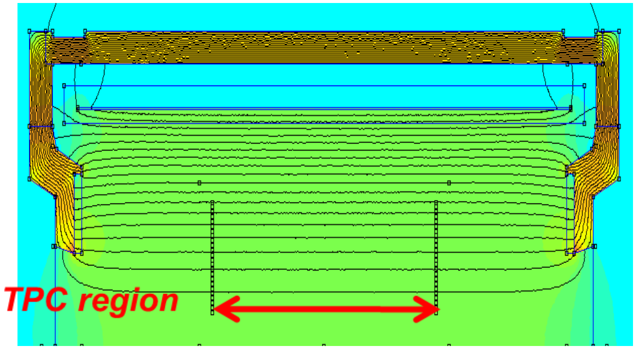
MPD Solenoid

B=0,66 T; level ~ 10^{-4} of magnetic field homogeneity



The 5 Packages:

1. Yoke + Poles, support structure
2. Cryostat vacuum system
3. Correction coils
4. Cryogenic System
5. Control System



Field simulation

MPD Solenoid

ASG Superconducting (Genova, Italy) -> CMS Solenoid

Three meetings at CERN with the CMS magnet team;

Two visits to ASG (Genova);

- *Production drawing preparation & adaptation - few monthes*
- *Production ~ 2 years*

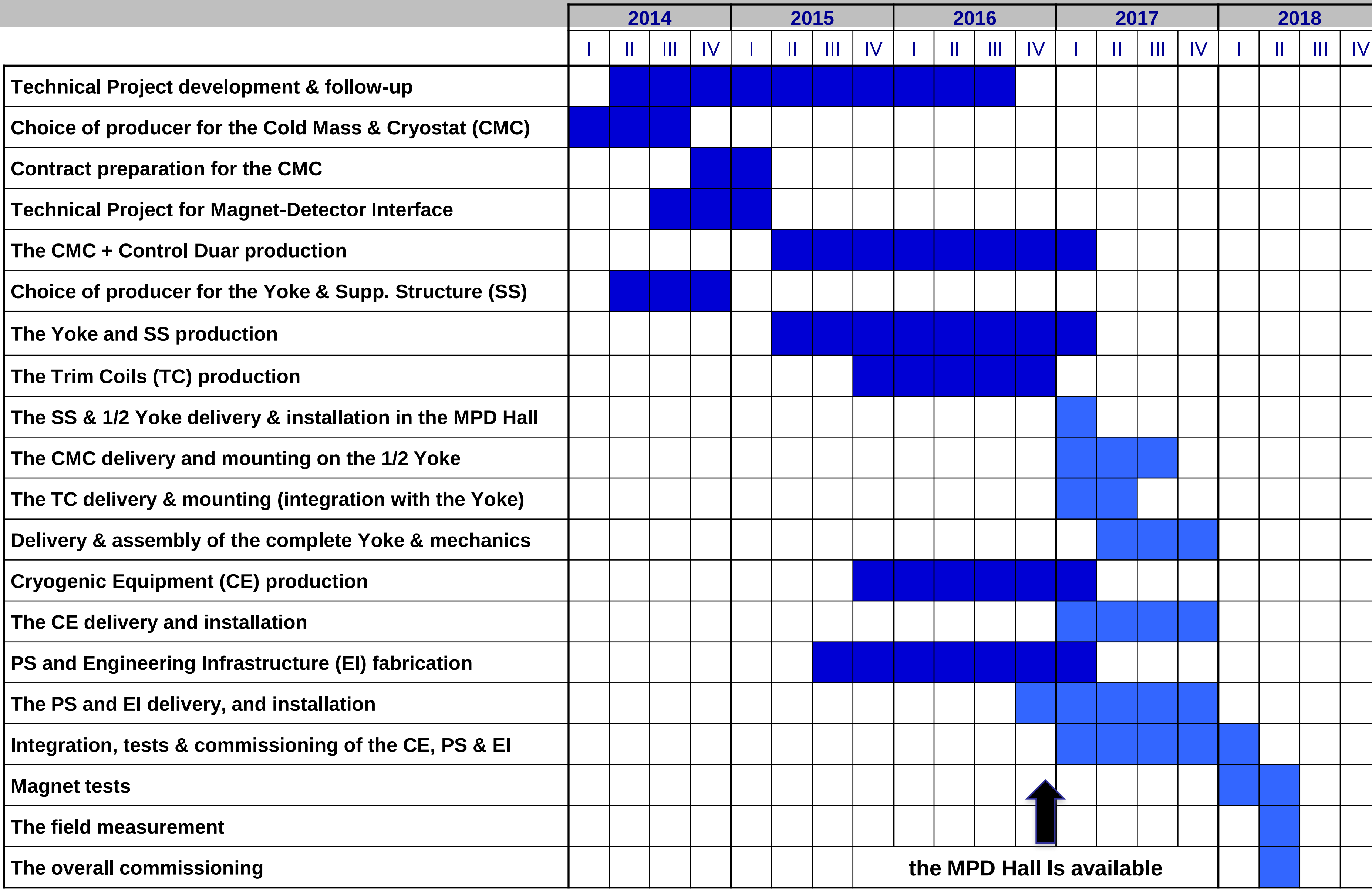
TOSHIBA (Japan) -> ATLAS Solenoid

Letter exchange with TOSHIBA
Consultancy with ATLAS representatives

Contracts for Magnet Packages:

- ✓ *selection of producers* *by November 2014*
- ✓ *contract preparation* *January 2015*

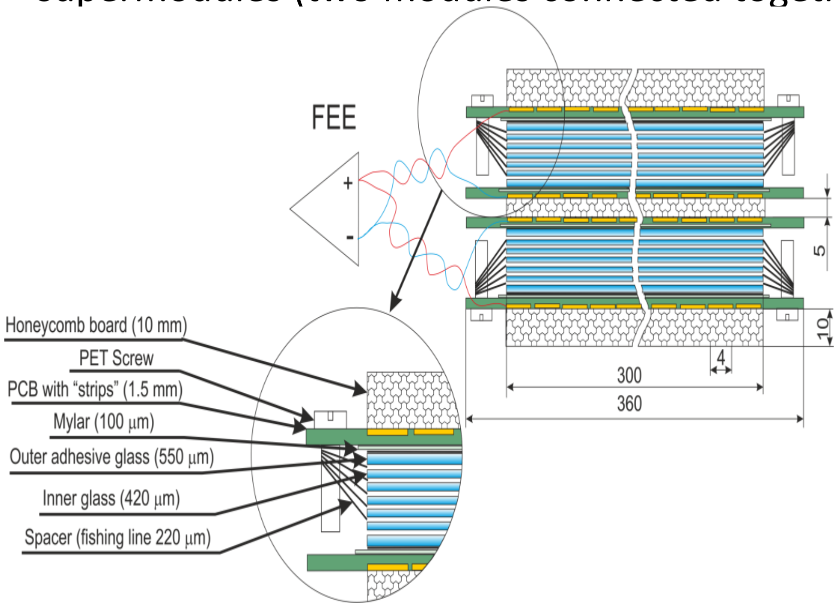
Schedule for MPD Magnet fabrication and put in operation

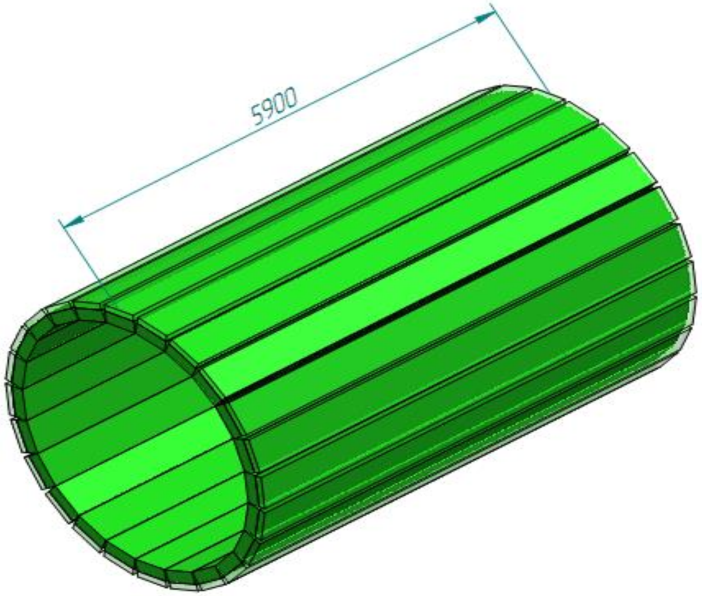


TOF Barrel Design

Active area of TOF barrel ~56 m^2
Number of channels 13824

The barrel of the TOF consist of 12 supermodules (two modules connected together)

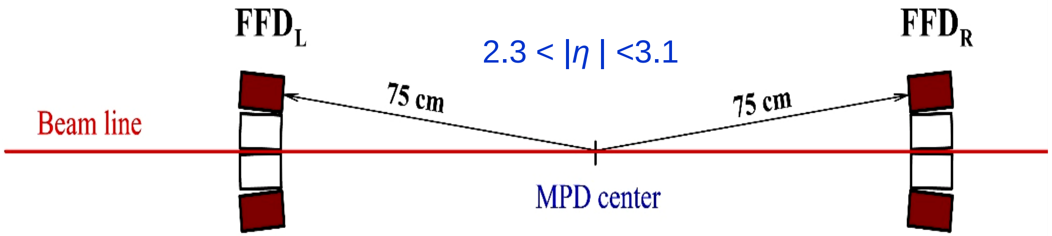




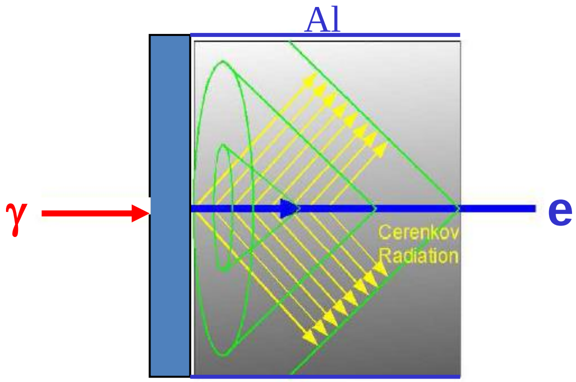
Number of gaps	2 stacks by 6 gaps
Width of gap	220 mkm
Sensitive area	300*600 mm^2
Inner/outer glass	550 mkm
Number of strips	48 strips by 5 mm width
Gas $C_2H_2F_4$, i-C_4H_{10}, SF_6	(90%/5%/5%)
Radiation length	2.09 g/cm^2

A full scale prototype of mRPC

FFD



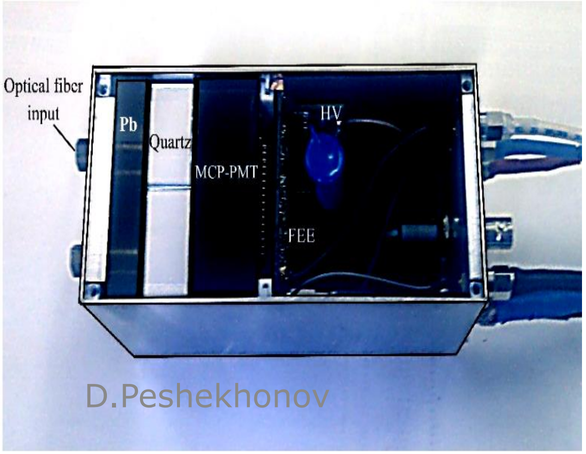
two-arm Cherenkov detector of high-energy photons



FFD goals:

1. Precise start signal for the TOF detector with $\sigma \leq 50$ ps
2. Pseudo-Vertex signal selecting collision in center of MPD

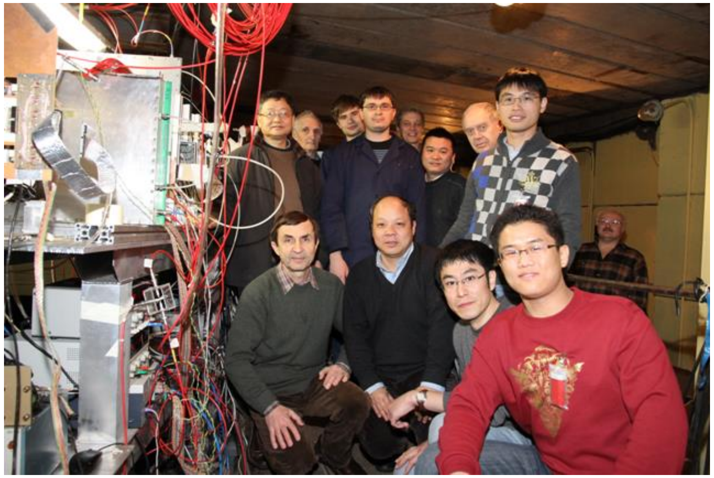
Concept of FFD is based on registration of high-energy photons from neutral pion decays



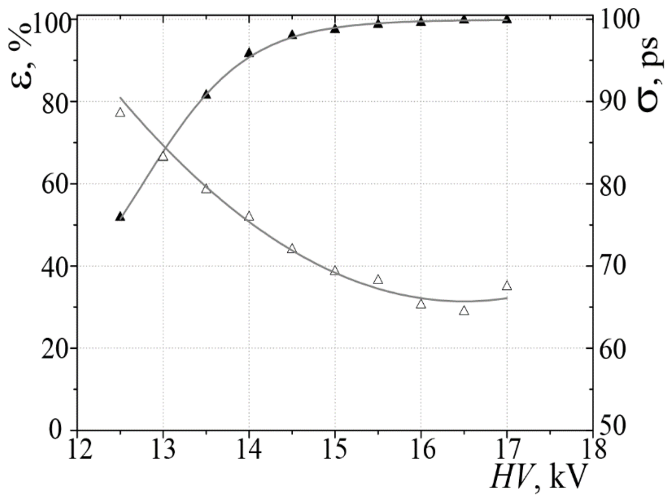
FFD Design

The high-energy photons are registered by their conversion to electrons inside a lead plate (1.5–2 X_0). The Cherenkov light, produced by the electrons in quartz radiator, is detected by MCP-PMT XP85012/A1-Q (Photonis).

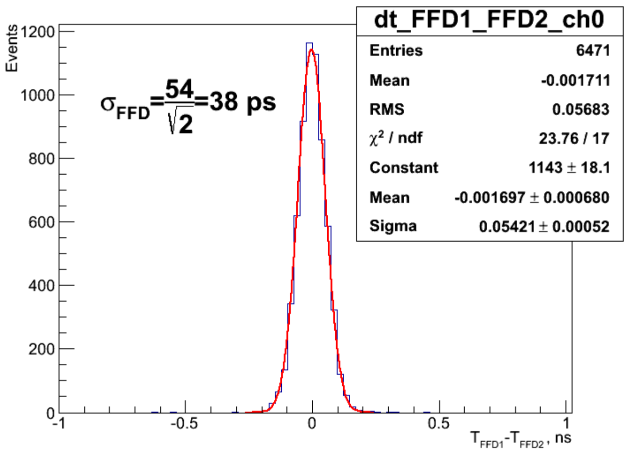
Results of beam tests on the Nuclotron

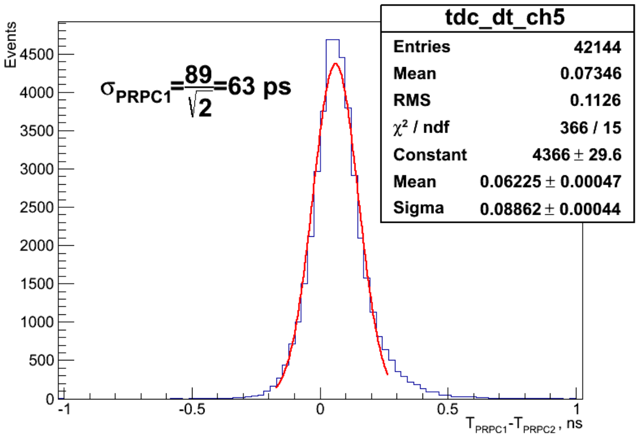


Cooperation with Hefei & Tsinghua Universities



Time resolution and efficiency of full scale prototype of the mRPCs.

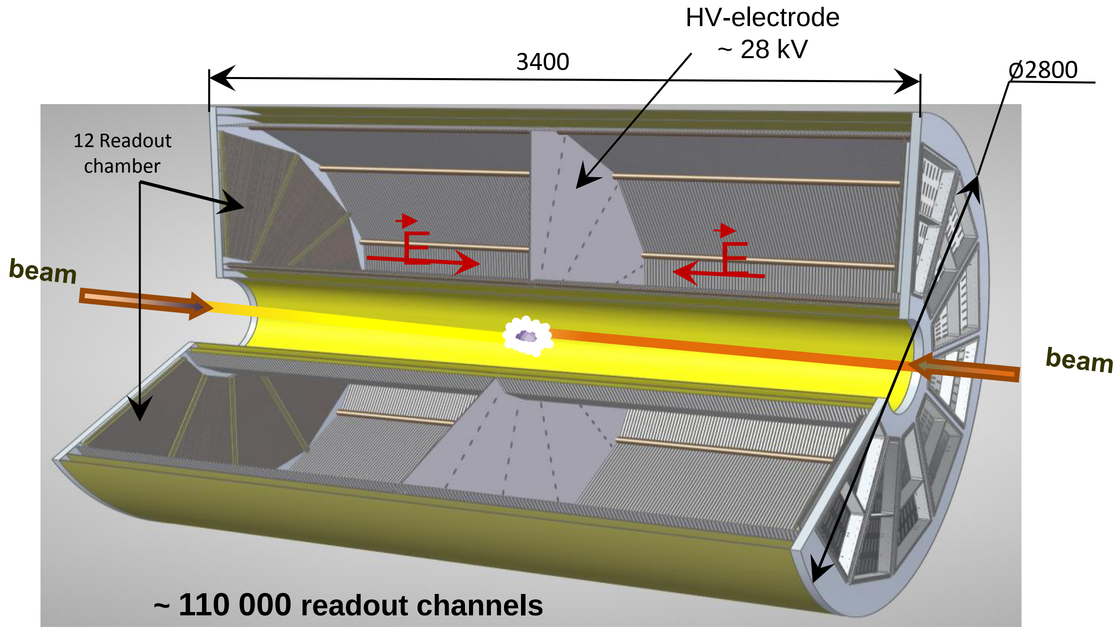




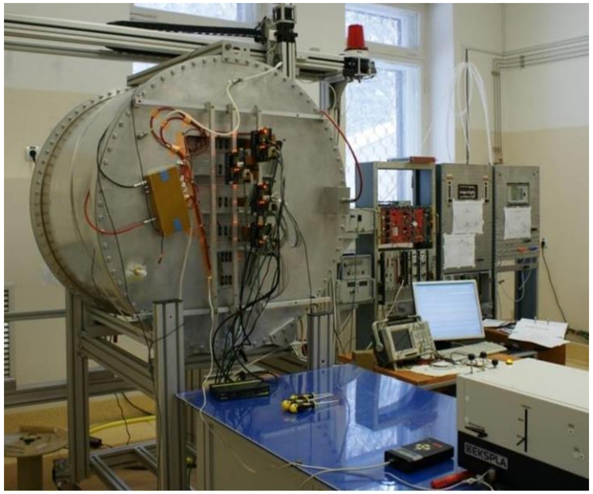
Time Projection Chamber

Physics requirements:

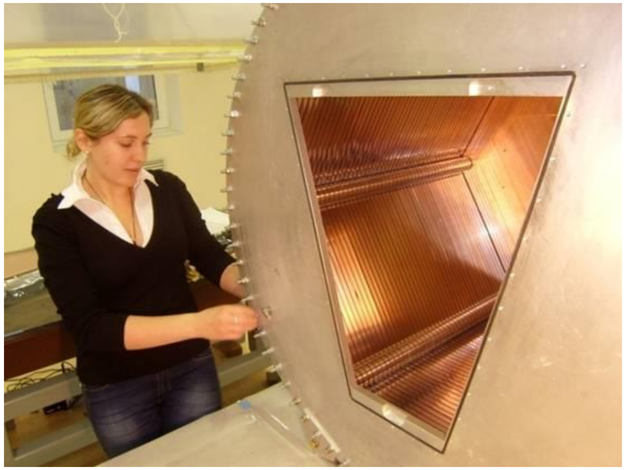
The overall acceptance on |η|~ 1.2
The momentum resolution ~ 3% in p_t interval from 0.1 to 1 GeV/c
Two-track resolution ~ 1 cm.
Charged particle multiplicity ~ 1000 in a central collisions
Hadron and lepton identification by dE/dx measurements with resolution better than 8%



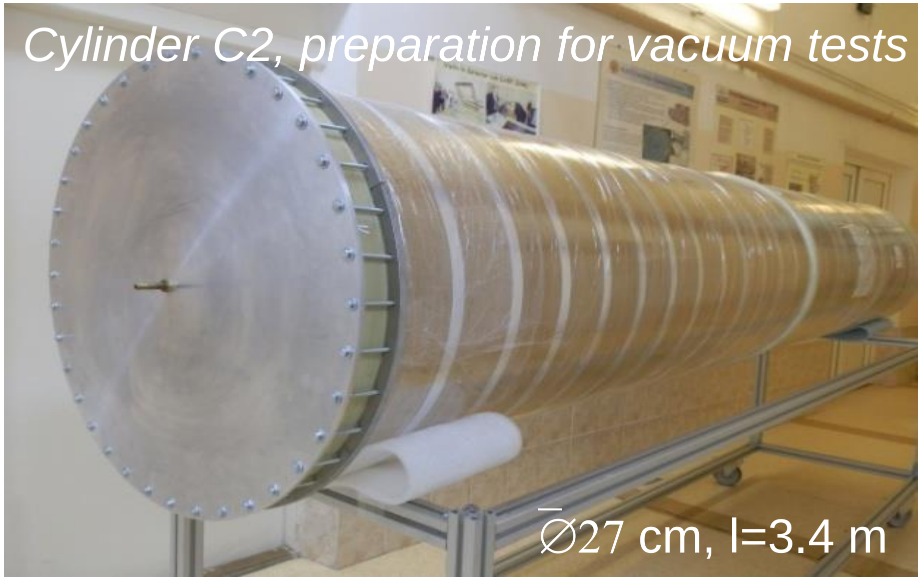
Sketch of TPC MPD

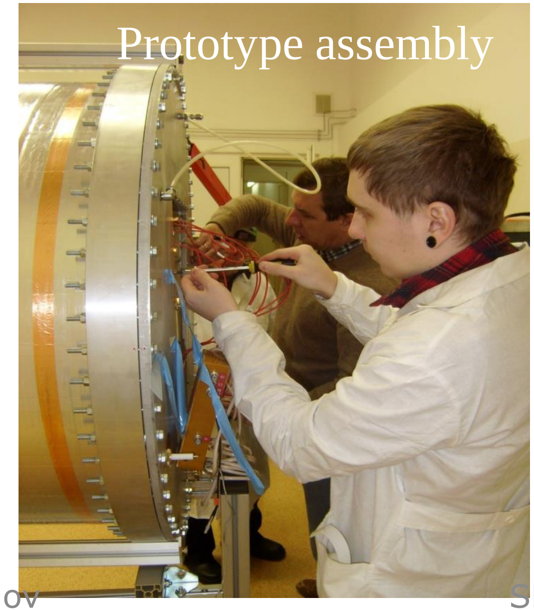


TPC Prototype



TPC - fabrication stage





FEC-64 prototype
(ALTERA FPGA, ALTRO, PASA chips)

ECAL – TDR in preparation

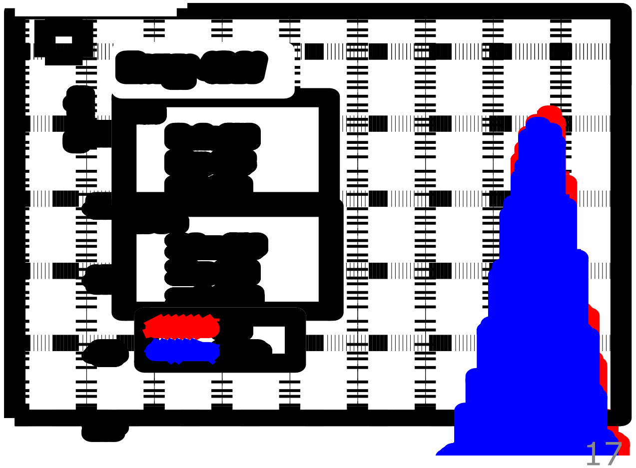
Preparation for tests with electron beams at DESY (December'13)

ECAL tests with *e*:

- performance study of two ECAL modules with *different WLS-fibers*
- Tests of the ECAL read-out electronics *(amplifiers and ADCs*)
- Energy scan (E_e = 1 - 6 GeV) *Analysis of the recorded data indicates good performance*

cosmic ray test

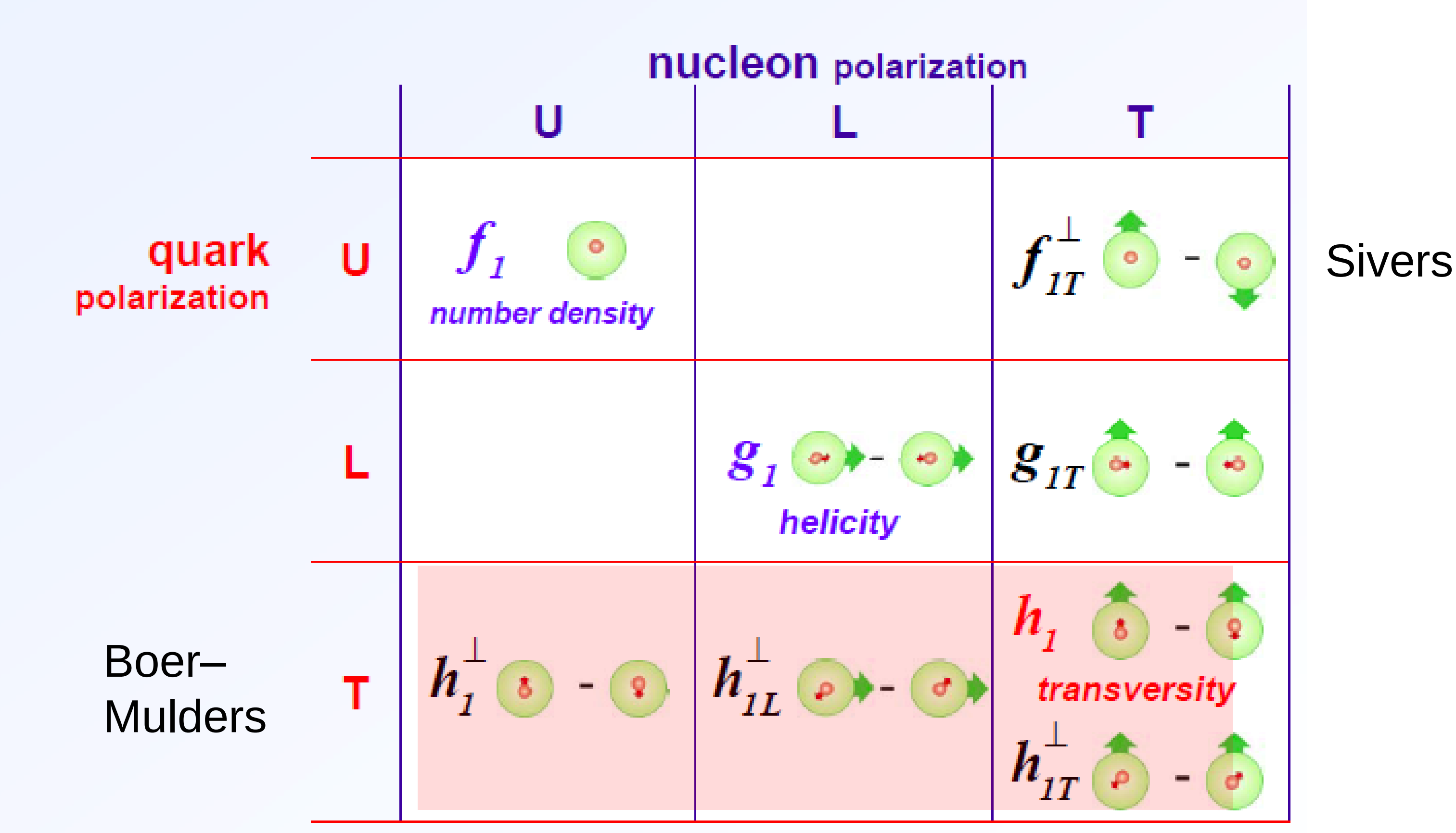
ECAL response to 4 GeV electrons



MPD with polarized beams

TMD parton distributions

- 8 intrinsic-transverse-momentum dependent PDFs at leading twist
- Azimuthal asymmetries with different angular modulations in the hadron and spin azimuthal angles, Φ_h and Φ_s
- Vanish upon integration over k_T except f_1, g_1, and h_1



Physics motivations

2.1. Nucleon spin structure studies using the Drell-Yan mechanism.

2.2. New nucleon PDFs and J/Ψ production mechanisms.

2.3. Direct photons.

2.4. Spin-dependent high-p_T reactions.

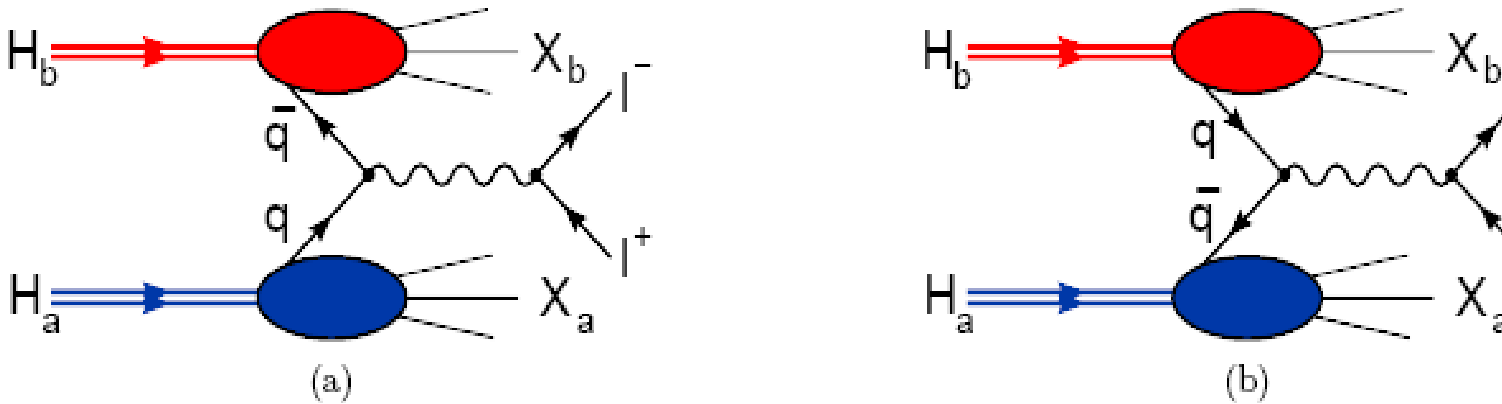
2.5. Spin-dependent effects in elastic *pp* and *dd* scattering.

2.6. Spin-dependent reactions in heavy ion collisions.

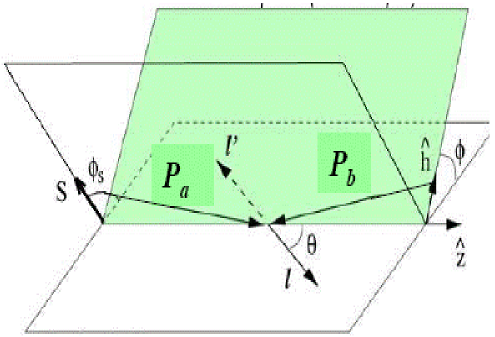
2.7. Future experiments on nucleon structure in the world.

Extraction of poor known or unknown PDFs with colliding proton and deuteron unpolarized, longitudinally & transversely polarized beams and asimmetries measuring

$$H_a(P_a, S_a) + H_b(P_b, S_b) \to l^-(l, \lambda) + l^+(l', \lambda') + X \,,$$



Asymmetries: A_{LU}, A_{UL}, A_{TU} , A_{UT}, A_{LL}, A_{TL}, A_{LT}, A_{TT}



$$A_{UU} \equiv \frac{\sigma^{00}}{\sigma^{00}_{\text{int}}} = \frac{1}{2\pi}(1 + D\cos 2\phi A^{\cos 2\phi}_{UU})$$

$$A_{LU} \equiv \frac{\sigma^{\rightarrow 0} - \sigma^{\leftarrow 0}}{\sigma^{\rightarrow 0}_{\text{int}} + \sigma^{\leftarrow 0}_{\text{int}}} = \frac{|S_{aL}|}{2\pi} D\sin 2\phi A^{\sin 2\phi}_{LU}$$

$$A_{UL} \equiv \frac{\sigma^{0\rightarrow} - \sigma^{0\leftarrow}}{\sigma^{0\rightarrow}_{\text{int}} + \sigma^{0\leftarrow}_{\text{int}}} = \frac{|S_{bL}|}{2\pi} D\sin 2\phi A^{\sin 2\phi}_{UL}$$

$$A_{TU} \equiv \frac{\sigma^{\uparrow 0} - \sigma^{\downarrow 0}}{\sigma^{\uparrow 0}_{\text{int}} + \sigma^{\downarrow 0}_{\text{int}}} = \frac{|\vec{S}_{aT}|}{2\pi}\left[A^{\sin(\phi-\phi_{S_a})}_{TU} \sin(\phi-\phi_{S_a}) + D\left(A^{\sin(3\phi-\phi_{S_a})}_{TU} \sin(3\phi-\phi_{S_a}) + A^{\sin(\phi+\phi_{S_a})}_{TU} \sin(\phi+\phi_{S_a}) \right)\right]$$

$$A_{UT} \equiv \frac{\sigma^{0\uparrow} - \sigma^{0\downarrow}}{\sigma^{0\uparrow}_{\text{int}} + \sigma^{0\downarrow}_{\text{int}}} = \frac{|\vec{S}_{bT}|}{2\pi}\left[A^{\sin(\phi-\phi_{S_b})}_{UT} \sin(\phi-\phi_{S_b}) + D\left(A^{\sin(3\phi-\phi_{S_b})}_{UT} \sin(3\phi-\phi_{S_b}) + A^{\sin(\phi+\phi_{S_b})}_{UT} \sin(\phi+\phi_{S_b}) \right)\right]$$

$$A_{LL} \equiv \frac{\sigma^{\rightarrow\rightarrow} + \sigma^{\leftarrow\leftarrow} - \sigma^{\rightarrow\leftarrow} - \sigma^{\leftarrow\rightarrow}}{\sigma^{\rightarrow\rightarrow}_{\text{int}} + \sigma^{\leftarrow\leftarrow}_{\text{int}} + \sigma^{\rightarrow\leftarrow}_{\text{int}} + \sigma^{\leftarrow\rightarrow}_{\text{int}}} = \frac{|S_{aL}S_{bL}|}{2\pi}\left(A^{1}_{LL} + DA^{\cos 2\phi}_{LL}\cos 2\phi \right)$$

$$A_{TL} \equiv \frac{\sigma^{\uparrow\rightarrow} + \sigma^{\downarrow\leftarrow} - \sigma^{\downarrow\rightarrow} - \sigma^{\uparrow\leftarrow}}{\sigma^{\uparrow\rightarrow}_{\text{int}} + \sigma^{\downarrow\leftarrow}_{\text{int}} + \sigma^{\downarrow\rightarrow}_{\text{int}} + \sigma^{\uparrow\leftarrow}_{\text{int}}} = \frac{|\vec{S}_{aT}|S_{bL}}{2\pi}\left[A^{\cos(\phi-\phi_{S_a})}_{TL}\cos(\phi-\phi_{S_a}) + D\begin{pmatrix} A^{\cos(3\phi-\phi_{S_a})}_{TL}\cos(3\phi-\phi_{S_a}) \\ +A^{\cos(\phi+\phi_{S_a})}_{TL}\cos(\phi+\phi_{S_a}) \end{pmatrix}\right]$$

$$A_{LT} \equiv \frac{\sigma^{\rightarrow\uparrow} + \sigma^{\leftarrow\downarrow} - \sigma^{\rightarrow\downarrow} - \sigma^{\leftarrow\uparrow}}{\sigma^{\rightarrow\uparrow}_{\text{int}} + \sigma^{\leftarrow\downarrow}_{\text{int}} + \sigma^{\rightarrow\downarrow}_{\text{int}} + \sigma^{\leftarrow\uparrow}_{\text{int}}} = \frac{S_{aL}|\vec{S}_{bT}|}{2\pi}\left[A^{\cos(\phi-\phi_{S_b})}_{LT}\cos(\phi-\phi_{S_b}) + D\begin{pmatrix} A^{\cos(3\phi-\phi_{S_b})}_{LT}\cos(3\phi-\phi_{S_b}) \\ +A^{\cos(\phi+\phi_{S_b})}_{LT}\cos(\phi+\phi_{S_b}) \end{pmatrix}\right]$$

$$A_{TT} \equiv \frac{\sigma^{\uparrow\uparrow} + \sigma^{\downarrow\downarrow} - \sigma^{\uparrow\downarrow} - \sigma^{\downarrow\uparrow}}{\sigma^{\uparrow\uparrow}_{\text{int}} + \sigma^{\downarrow\downarrow}_{\text{int}} + \sigma^{\uparrow\downarrow}_{\text{int}} + \sigma^{\downarrow\uparrow}_{\text{int}}} = \frac{|\vec{S}_{aT}||\vec{S}_{bT}|}{2\pi}\Big[A^{\cos(2\phi-\phi_{S_a}-\phi_{S_b})}_{TT}\cos(2\phi-\phi_{S_a}-\phi_{S_b}) + A^{\cos(\phi_{S_b}-\phi_{S_a})}_{TT}\cos(\phi_{S_b}-\phi_{S_a})$$

$$+D\Big(A^{\cos(\phi_{S_b}+\phi_{S_a})}_{TT}\cos(\phi_{S_a}+\phi_{S_b}) + A^{\cos(4\phi-\phi_{S_a}-\phi_{S_b})}_{TT}\cos(4\phi-\phi_{S_a}-\phi_{S_b})$$

$$+A^{\cos(2\phi-\phi_{S_a}+\phi_{S_b})}_{TT}\cos(2\phi-\phi_{S_a}+\phi_{S_b}) + A^{\cos(2\phi+\phi_{S_a}-\phi_{S_b})}_{TT}\cos(2\phi+\phi_{S_a}-\phi_{S_b})\Big)\Big]$$

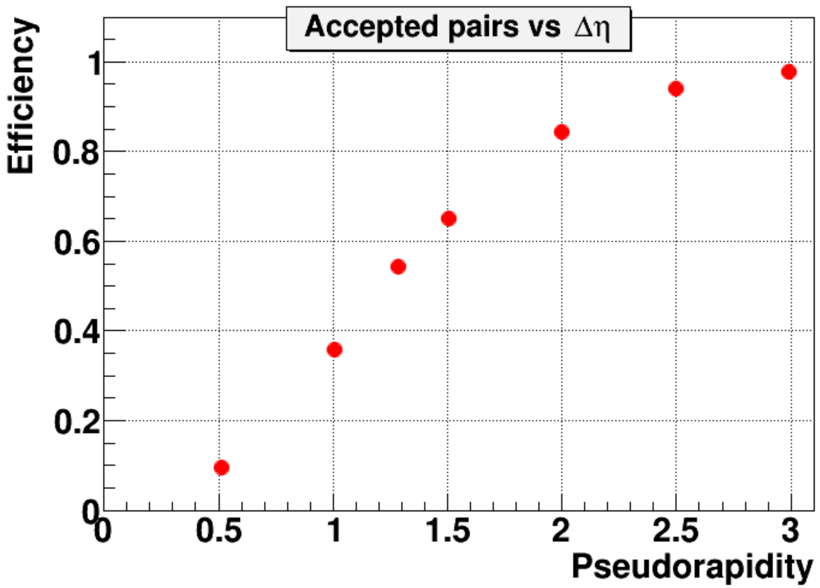
DY

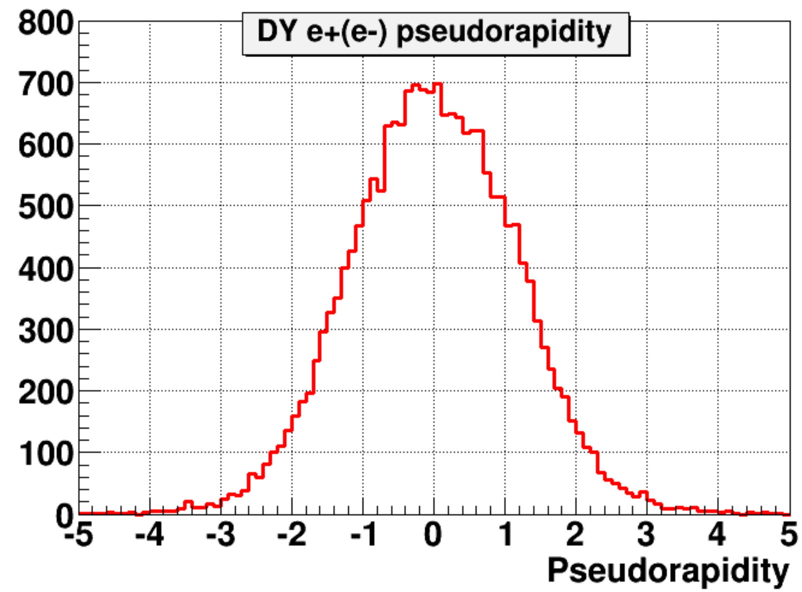
Estimations of DY total cross sections and numbers of events

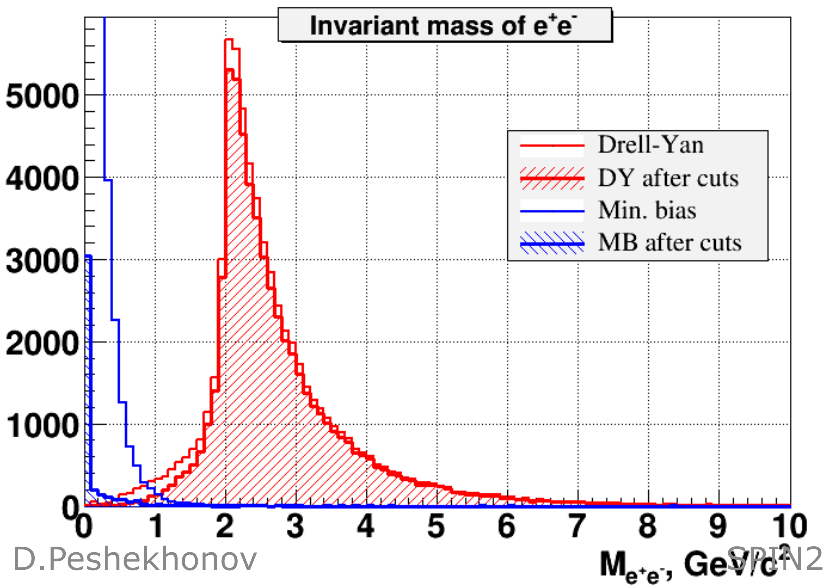
lower cut on Q, GeV	2.0	3.1	3.5	4.0
$\sqrt{s} = 20$ GeV ($L \simeq 0.5 \cdot 10^{32}$ cm^{-2}s^{-1})				
σ_{DY} total, nb	0.86	0.13	0.07	0.03
N events for a month, 10^3	120	18	9.7	4.6
$\sqrt{s} = 22$ GeV ($L \simeq 0.7 \cdot 10^{32}$ cm^{-2}s^{-1})				
σ_{DY} total, nb	1.01	0.16	0.09	0.05
N events for a month, 10^3	200	33	18	9.0
$\sqrt{s} = 24$ GeV ($L \simeq 1.0 \cdot 10^{32}$ cm^{-2}s^{-1})				
σ_{DY} total, nb	1.15	0.20	0.12	0.06
N events for a month, 10^3	300	52	30	15
$\sqrt{s} = 26$ GeV ($L \simeq 1.2 \cdot 10^{32}$ cm^{-2}s^{-1})				
σ_{DY} total, nb	1.30	0.24	0.14	0.07
N events for a month, 10^3	415	77	45	24

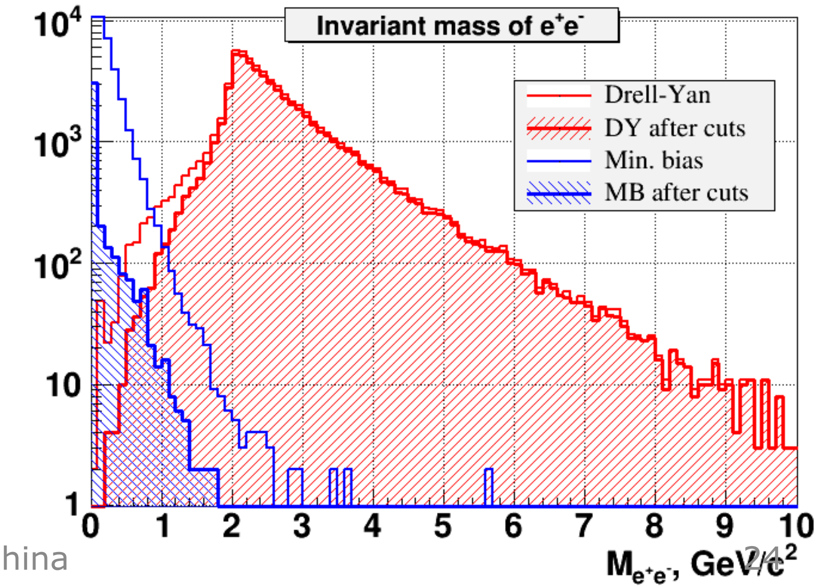
Possible DY statistics for NICA – p. 4

MPD simulation



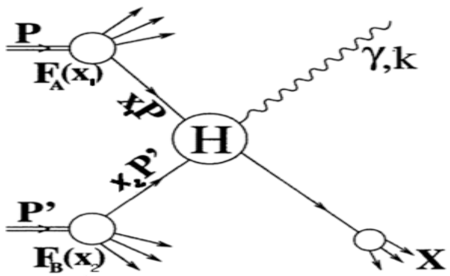






Direct photons

Direct photon productions in the non-polarized and polarized *pp (pd)* reactions provide information on the gluon distributions in nucleons



Vertex H corresponds to
q + qbar →γ+g or g+q→γ+q hard processes.

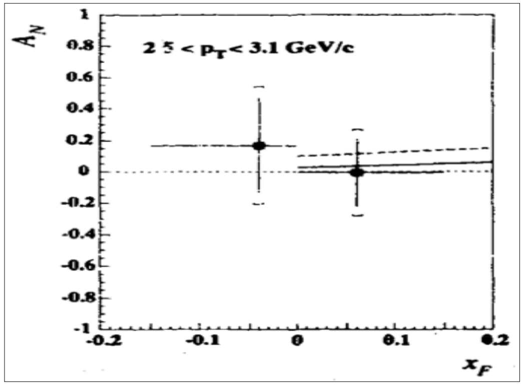
the polarized gluon distribution (Sivers gluon function) can be extracted from measurement of the transverse single spin asymmetry

$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

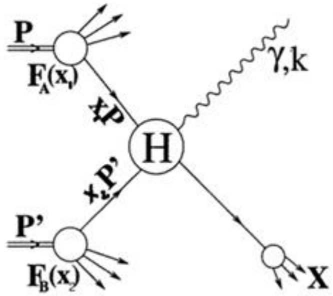
. It is of order few %.

Via double spin asymmetry A_{LL} one can measure a gluon polarization in the nucleon:

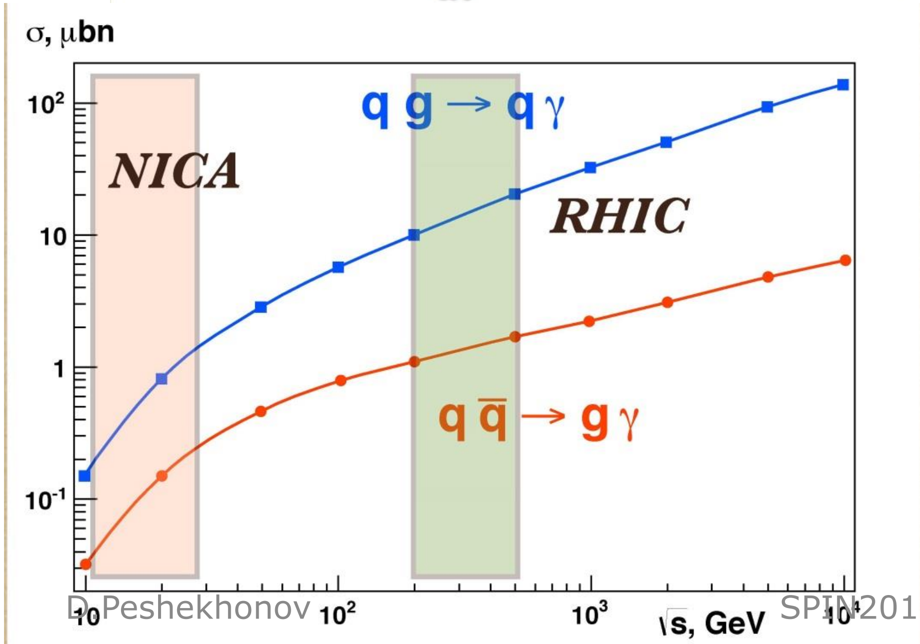
$$A_{LL} \approx \frac{\Delta g(x_1)}{g(x_1)} \cdot \left[\frac{\sum_q e_q^2 \left[\Delta q(x_2) + \Delta \bar{q}(x_2)\right]}{\sum_q e_q^2 \left[q(x_2) + \bar{q}(x_2)\right]} \right] \cdot \hat{a}_{LL}(gq \to \gamma q) + (1 \leftrightarrow 2),$$

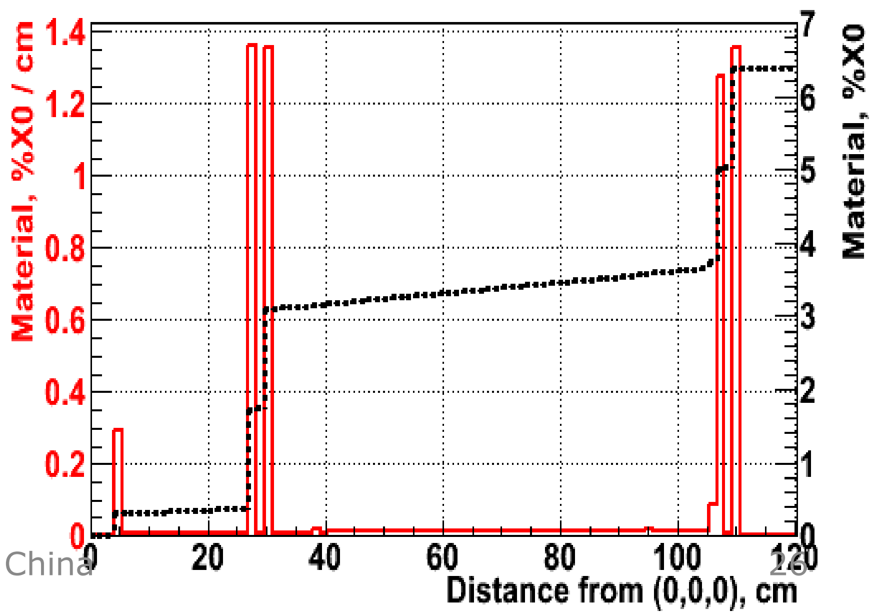


Direct photons at MPD



$$\sigma^{\uparrow} - \sigma^{\downarrow} = \sum_i \int_{x_{min}}^{1} dx_a \int d^2\mathbf{k}_{Ta} d^2\mathbf{k}_{Tb} \frac{x_a x_b}{x_a - (p_T/\sqrt{s})\, e^y} \left[q_i(x_a, \mathbf{k}_{Ta}) \Delta_N G(x_b, \mathbf{k}_{Tb}) \times \frac{d\hat{\sigma}}{d\hat{t}}(q_i G \to q_i \gamma) + G(x_a, \mathbf{k}_{Ta}) \Delta_N q_i(x_b, \mathbf{k}_{Tb}) \frac{d\hat{\sigma}}{d\hat{t}}(G q_i \to q_i \gamma) \right]$$



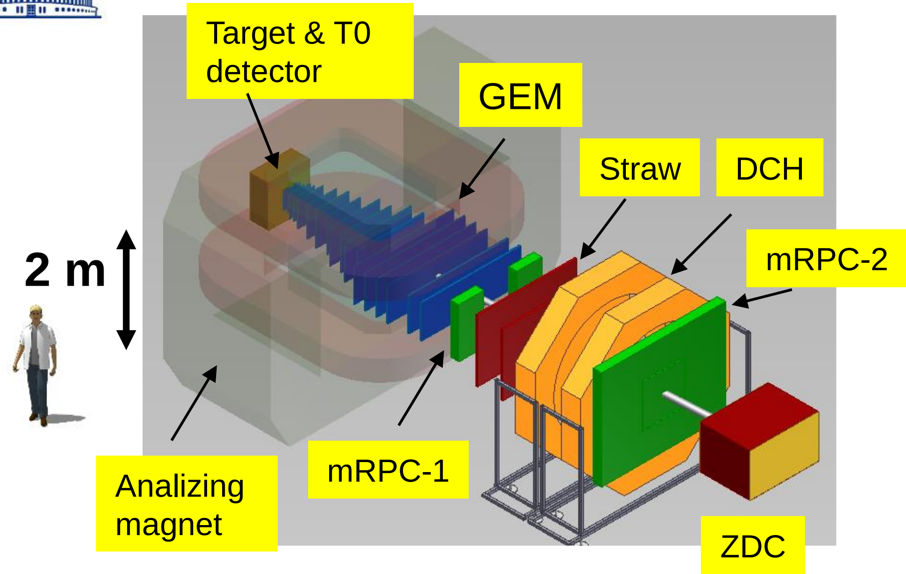


Estimations of direct photon production rates

$\sqrt{s}$=24 GeV $L = 1.0 \times 10^{32},\ cm^{-1}s^{-1}$	σ_{tot}, nbarn	$\sigma_{P_T>4\ GeV/c}$, nbarn	Events/year, 10^6	Events/year, 10^6 ($P_T > 4\ GeV/c$)
All processes	1290	42	3260	105
$qg \to q\gamma$	1080	33	2730	84
$q\bar{q} \to g\gamma$	210	9	530	21

$\sqrt{s}$=26 GeV $L = 1.2 \times 10^{32},\ cm^{-1}s^{-1}$	σ_{tot}, nbarn	$\sigma_{P_T>4\ GeV/c}$, nbarn	Events/year, 10^6	Events/year, 10^6 ($P_T > 4\ GeV/c$)
All processes	1440	48	4340	144
$qg \to q\gamma$	1220	38	3680	116
$q\bar{q} \to g\gamma$	240	10	660	28

BM@N setup



BM@N advantage: large aperture magnet (~1 m gap between poles)

→ fill aperture with coordinate detectors which sustain high multiplicities of particles

→ divide detectors for particle identification to "near to magnet" and "far from magnet" to measure particles with low as well as high momentum (p > 1-2 GeV/c)

→ fill distance between magnet and "far" detectors with coordinate detectors

- Central tracker (GEM) inside analyzing magnet to reconstruct AA interactions
- Outer tracker (DCH, Straw) behind magnet to link central tracks to ToF detectors
- ToF system based on mRPC and T0 detectors to identify hadrons and light nucleus
- ZDC calorimeter to measure centrality of AA collisions and form trigger
- Detectors to form T0, L1 centrality trigger and beam monitors
- Electromagnetic calorimeter for γ,e+e-

CONCLUSION REMARKS

1. The comprehensive program of the spin nucleon structure and other spin dependent reactions study can be realized at NICA using the polarized proton, deuteron and heavy ion beams and MPD detector.
2. Some spin dependent reactions can be studied with BM@N setup if polarized target will be added.

Thank you

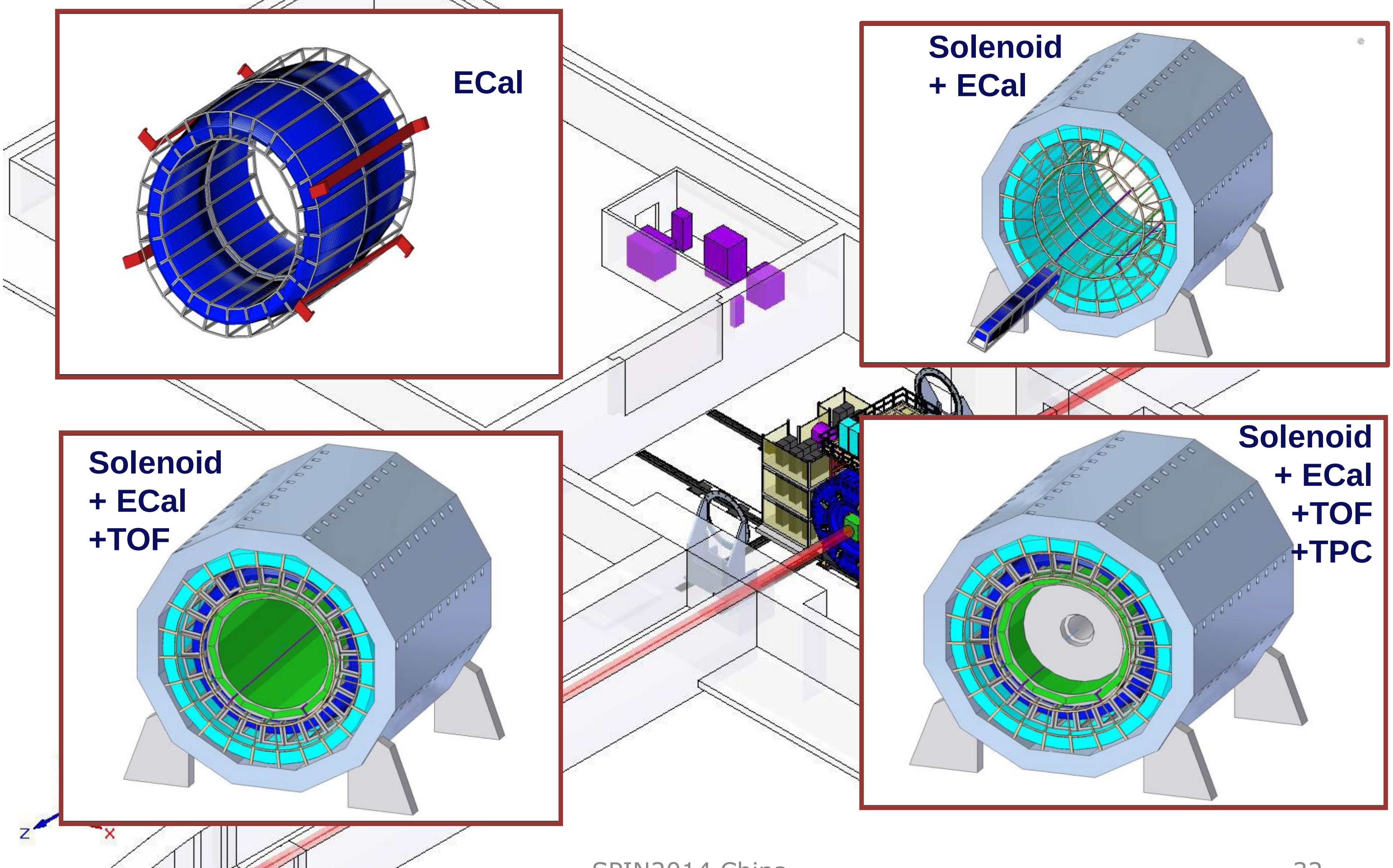
Straw wheels & Fast Forward Calorimeter

Straw: end-cup tracker
good spatial resolution & low material budget

FFD:
Trigger start-up, fast response (<40 psec)

Assembly & Integration

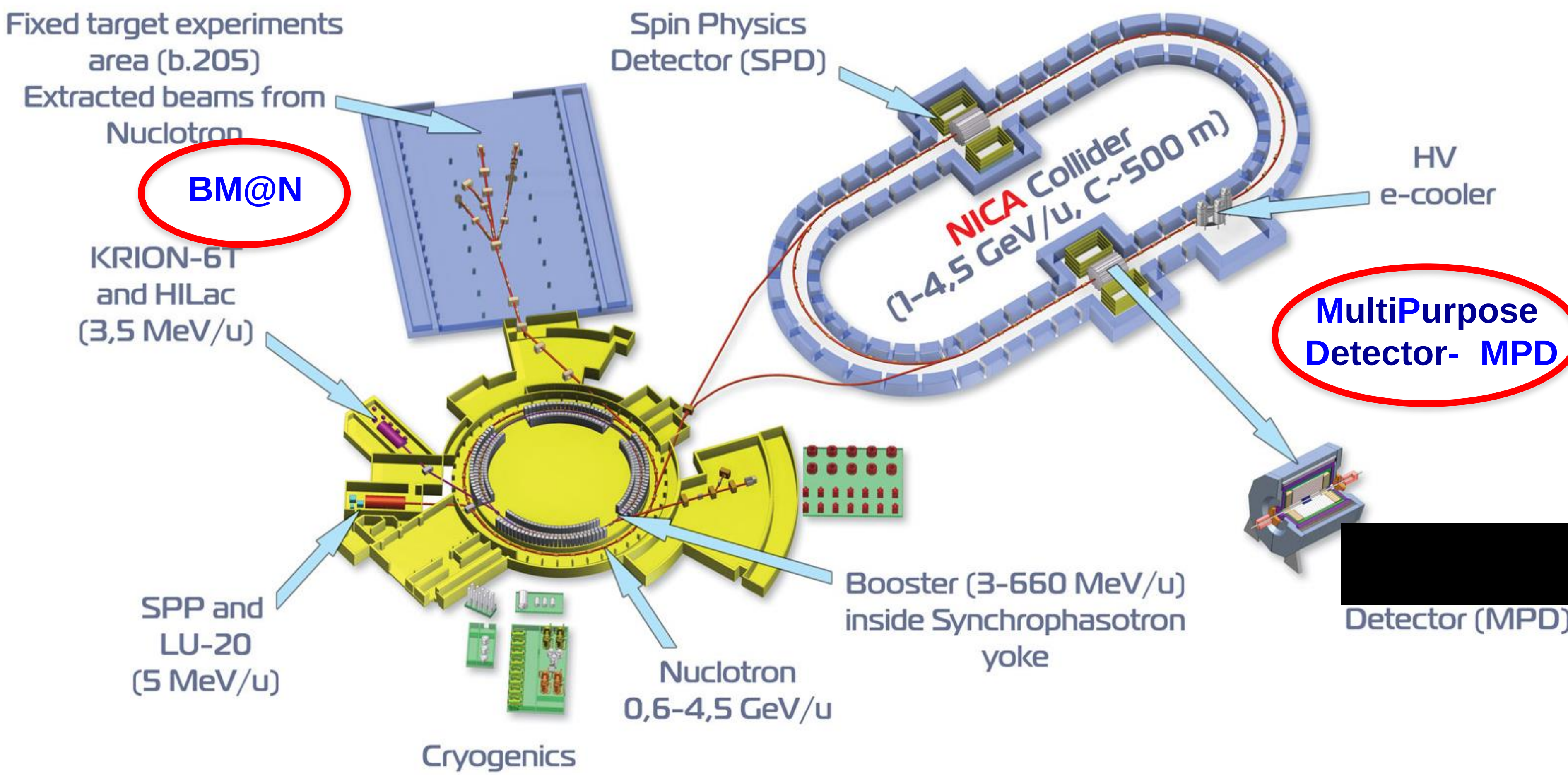
Project preparation



D.Peshekhonov

Superconducting accelerator complex NICA

(Nuclotron based Ion Collider fAcility)

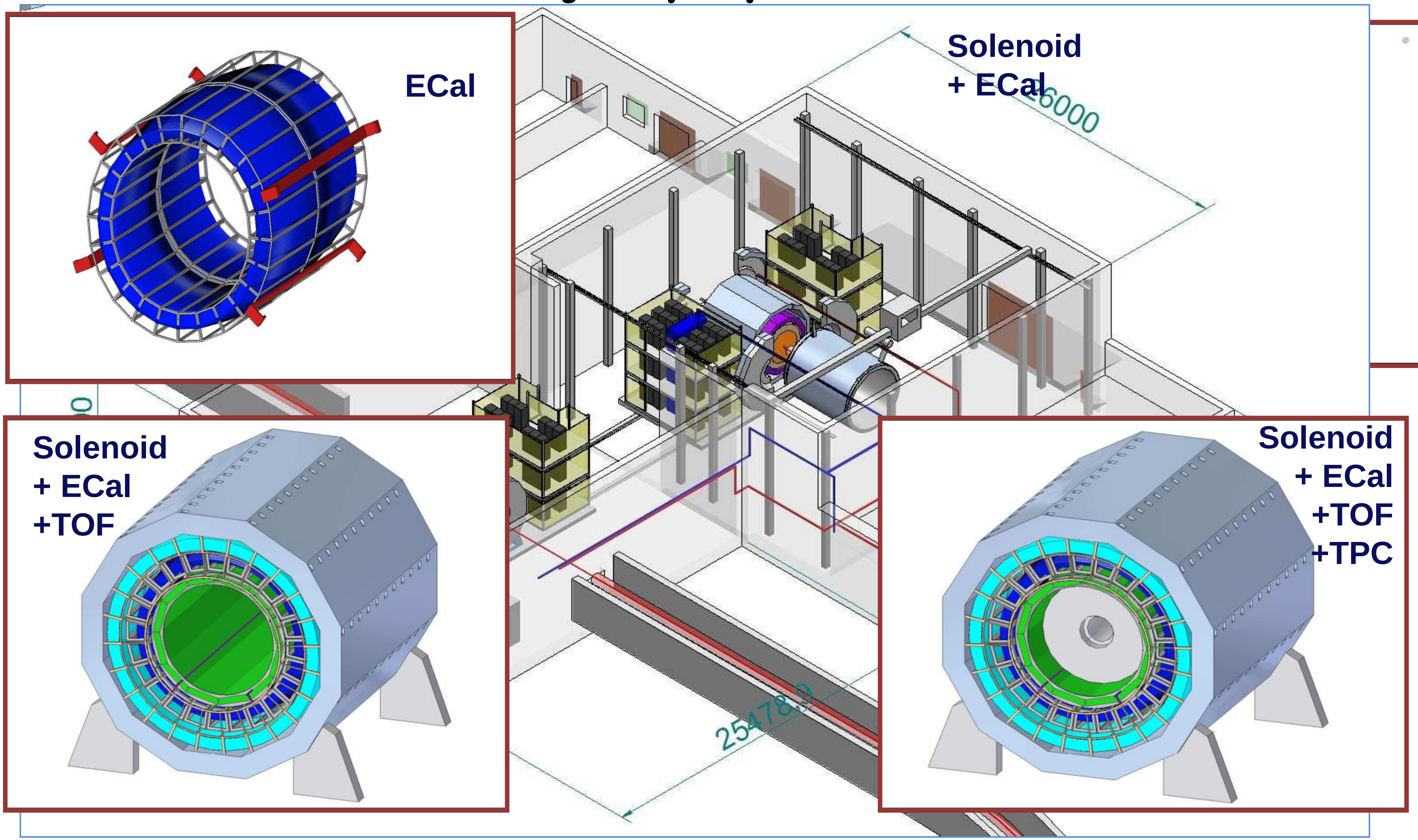


Требования к TPC

- ✓ Высокая эффективность регистрации треков в интервале псевдобыстрот $|\eta| \sim 1.2$;
- ✓ Двухтрековое разрешение ~ 1 см для разделения треков частиц;
- ✓ Для идентификации адронов и лептонов разрешение по dE/dx должно быть лучше 8%;
- ✓ Разрешение по импульсу заряженных частиц лучше 3% при поперечном импульсе до 1 ГэВ/c
  - ➢ Множественность вторичных частиц ~ 1000,
  - ➢ Частота столкновений 5 кГц.

Assembly & Integration

Project preparation



Drell-Yan with registration of electron pairs

Extraction of poor known or unknown PDFs with
proton and deuteron unpolarized, longitudinally/transversely polarized beams
With help of double and single asymmetries measurements

Extraction of unknown (poor known) parton distribution functions (PDFs):

$p(D)p(D) \to \gamma^* X \to l^+ l^- X$ **Boer-Mulders PDF**

$p^\uparrow(D^\uparrow)p(D) \to \gamma^* X \to l^+ l^- X$ **Sivers PDFs (Efremov,… PLB 612 (2005), PRD 73(2006));**

$p^\uparrow(D^\uparrow)p^\uparrow(D^\uparrow) \to \gamma^* X \to l^+ l^- X$ **Transversity PDF (Anselmino, Efremov, …)**

$p^\uparrow(D^\uparrow)p(D) \to \gamma^* X \to l^+ l^- X$

$p(D)p(D) \to \gamma^* X \to l^+ l^- X$

Transversity and first moment of Boer-Mulders PFDs (Sissakian, Shevchenko, Nagaytsev , Ivanov, PRD 72(2005), EPJ C46 ,2006 C59, 2009)

$p^\rightarrow(D^\rightarrow)p^\leftarrow(D^\leftarrow) \to \gamma^* X \to l^+ l^- X$ **Longitudinally polarized sea and strange PDFs and tenzor deuteron structure (Teryaev, …)**

Unpolarized beams

Process	Beams	Energy, GeV	L	To measure	Expected results
DY- J/ψ	pp	12x12	10^{32}	Asymmetry	Duality test
DY via e+e-	pp	12x12	10^{32}	Asymmetry	Boer-Mulders PDF
J/ψ via e+e-	pp	12x12	10^{32}	Cross sections	Model tests

Longitudinally polarized beams

Direct Photons	pp, dd	12x12, 6x6	10^{32}, 10^{31}	Asymmetry	ΔG/G
DY via e+e-	pp, dd	12x12, 6x6	10^{32}, 10^{31}	Asymmetry	Sea and strange PDFs, tenzor deuteron structure
DY+ hadron	pp	12x12	10^{32}	Asymmetry	
J/ψ via e+e-	pp, dd	12x12, 6x6	10^{32}, 10^{31}	Asymmetry	Model tests

Transversally polarized beams

Process	Beams	Energy, GeV	L	To measure	Expected results
DY- J/ψ	pp,	5-12, scan	10^{32}, 10^{31}	Asymmetry	Duality test
DY via e+e-	pp, dd, nucl	12x12,	10^{32}, 10^{31}	Asymmetries, cross section ratios	Transversity, Sivers, Pretzelority PDFs, sign(DY-SIDIS), EMC effect test
J/ψ via e+e-	pp,	12x12,	10^{32}, 10^{31}	Cross sections	Model tests
Direct Photons	pp,	12x12,	10^{32}, 10^{31}	Asymmetry	Gluon Sivers PDF